United Nations
Educational, Scientific and
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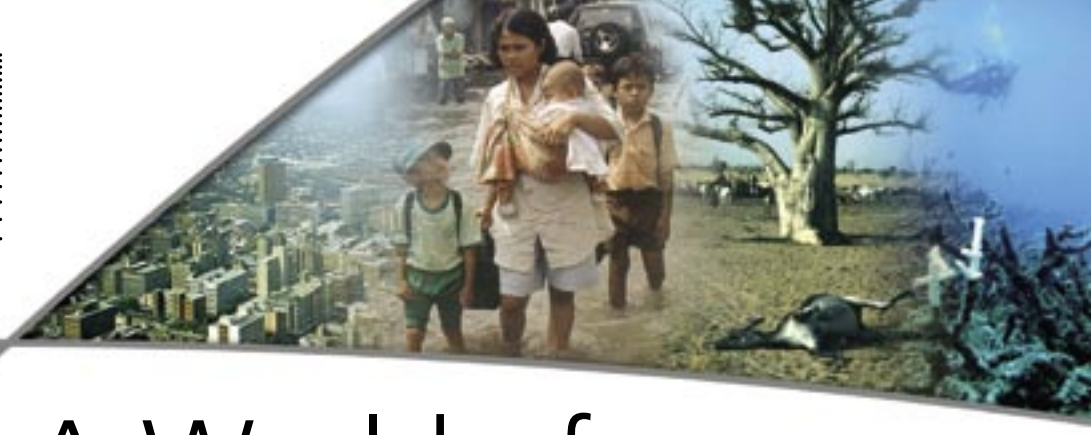

Retrospective on climate change

# A World of SCIENCE

Fifth anniversary issue

Natural Sciences
Quarterly Newsletter

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IN THIS ISSUE



EDITORIAL

## Damage control

Last February, the Intergovernmental Panel on Climate Change (IPCC) met at UNESCO to approve the scientific basis for its 2007 report on climate change. This report outlines the strongest case yet for a warming planet influenced largely by human activities.

'Warming of the climate system is unequivocal', notes the report approved by the world's governments. It predicts that global mean temperatures will rise by 1.8°–4.0°C this century, depending on which socio-economic scenario is followed. The report confirms that 'most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations' and that 'discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns.'

The International Polar Year launched last March will devote the next two years to monitoring one of the few remaining grey areas in the IPCC report, the polar regions. The report can predict sea-level rise of up to 60 cm by the end of the century, for example, but not the influence on sea-level rise of future changes in the dynamic ice flows in Greenland and Antarctica. The Polar Year will strive to fill some of the gaps in our understanding of these processes, an urgent task when you consider that the last time average polar temperatures were 3–5°C higher than today, some 125 000 years ago, the corresponding reduction in polar ice volume led to 4–6 m of sea-level rise.

Climate change is affecting not only our environment but also our way of life. Finding solutions to mitigate the negative impacts and adapt to a changing world – see the back page of this issue for a glimpse into the future – will require an approach that combines sound, unbiased science with social and cultural considerations. UNESCO offers a unique forum in this regard, bringing under one roof not only key disciplines for climate science such as geology, hydrology, ecology, oceanography, physics, chemistry and biology but also education, social and human sciences, and culture.

More than 30 UNESCO programmes address a range of climate-related issues, including glacier melt, biodiversity loss, sea-level rise, ocean acidification, carbon economics and sequestration, salt-water intrusion in coastal soils and groundwater, drought and flood management, renewable energy use, education for sustainable development, the effects of climate change on world heritage and biosphere reserves, and climate monitoring via global observing systems.

This anniversary issue of *A World of Science* is a compilation of climate-related articles published in the journal over the past five years. This retrospective has been put together to illustrate the role UNESCO has been playing – and must pursue – in helping countries to monitor, mitigate and adapt to climate change.

The debate about the human influence on climate is over. What the world needs now is damage control, via reductions in greenhouse gas emissions and adaptation strategies. If UNESCO does not take up these challenges, many of its programmes are in danger of becoming irrelevant.

*W. Erdelen*
*Assistant Director-General for Natural Sciences*

# UNESCO and **Johannesburg**

## Education for Sustainable Development Decade a 'tremendous challenge for UNESCO'

Arguably the most spectacular outcome of the World Summit on Sustainable Development (Johannesburg, South Africa, 26 August – 4 September 2002) for UNESCO is the recommendation to the United Nations General Assembly that 'it consider adopting a Decade of Education for Sustainable Development starting in 2005' (para. 117d, Plan of Implementation). The decision comes as welcome news to UNESCO, which first tabled the idea at the final preparatory meeting for the Summit in Bali (Indonesia) last May.

The next step is for the recommendation to be presented to the United Nations General Assembly in 2003 for adoption. UNESCO is preparing to take a leadership role in the Decade, in close association with a full range of partners from the inter- and non-governmental communities. The Decade 'represents a tremendous challenge for UNESCO', comments Andras Szollosi-Nagy, Deputy Assistant Director-General for Science at UNESCO.

***We are making great efforts to use satellite technologies and the Internet. Many people in Mongolia... would like the information and broadcasts emanating from the major developed countries to focus more on learning and education.***

President Bagabandi of Mongolia

As an early follow-up initiative to the Summit, UNESCO and the government of France are studying the feasibility of launching a virtual university on sustainable development at the University of Lyon in France.

### One billion promised access to sanitation by 2015

As expected, the global water crisis took priority at the Summit. Today, more than 1 billion people lack access to safe drinking water and more than 2.4 billion are without adequate sanitation. One of the most ambitious targets in the Plan of Implementation is that of halving the proportion of people without access to these basic requirements by 2015. Given the size of the challenge, UNESCO will most likely be maintaining 'water resources and supporting ecosystems' as the principal priority for natural sciences in 2004–2005.

The challenge is to improve water resources management and scientific understanding of the water cycle. The new UNESCO centres for water resource management and the UNESCO-IHE Institute for Water Education in Delft (Netherlands) provide a unique opportunity for UNESCO to demonstrate the practical significance of its science programmes in water resources.

UNESCO may also be asked by the World Water Forum in 2003 to expand its action. Preliminary results of the most extensive United Nations undertaking ever to assess the world's freshwater resources were presented to the Johannesburg Summit and will be published in the *World Water Development Report* due out in 2003. UNESCO is lead agency for the World Water Assessment Programme, which involves 24 United Nations agencies.

*Women carrying water in Antigua (Guatemala). Only 0.26% of the world's freshwater is stored in lakes and rivers. The remainder exists in the form of groundwater (30%) and ice and snow*

### Towards regular reporting on the marine environment

In the Plan of Implementation (para.34), the Intergovernmental Oceanographic Commission (IOC) received a clear confirmation of its current mandate to address the scientific uncertainties of climate and global change, and look more closely at new developments, especially in integrated coastal management. Through the IOC, UNESCO will be contributing towards establishing by 2004 a regular global reporting and assessment system on the state of the marine environment.

The IOC is a member of several Type 2 partnerships on oceans and coasts, including the 'African Process'.

One of the goals of the 2000 United Nations Millennium Declaration[1] is 'to integrate the principles

1. *www.developmentgoals.org/*

***Constructing the new paradigm*** [of sustainable development] ***is not about coining new terms – it is about action.***

Kader Asmal, Minister of Education, South Africa

of sustainable development into country policies and programmes and reverse the losses of environmental resources'. In the Plan of Implementation, governments commit themselves to achieving the Millennium goals and identify new targets. They undertake for example to restore fisheries to their maximum sustainable yields by 2015 and to establish a representative network of marine protected areas by 2012.

UNESCO will be participating actively in a Task Force on Water and Oceans established by the heads of all United Nations agencies under the chairmanship of the Secretary-General of the United Nations, to develop effective implementation plans to achieve the Millennium Goals.

### Reversing natural resources degradation

Governments undertake in the Plan of Implementation to reduce biodiversity loss by 2010 and to reverse the current trend towards natural resources degradation. Moreover, they commit themselves to improving developing countries' access to environmentally sound alternatives to ozone-depleting chemicals by the same date. They also invite the Global Environment Facility to consider including the United Nations Convention to Combat Desertification (UNCCD) as a focal area for funding.

***We must grasp the links between how different cultures shape the environment and vice versa.***

Koïchiro Matsuura, Director-General of UNESCO

It could be said of UNESCO's Man and the Biosphere (MAB) programme that it was fostering sustainable development long before the term was coined. For 30 years, MAB has been promoting through its biosphere reserves – which today number 408 in 94 countries – the sustainable use and conservation of biological diversity, while striving to improve the relationship between people and their environment (*see also page 12*).

The Plan of Implementation underscores the need to protect the rights of local and indigenous communities and to respect their traditional knowledge and resource management systems. Through the Local and Indigenous Knowledge Systems (LINKS) project, UNESCO is striking partnerships between indigenous people and scientists to bring traditional knowledge and world views into the biodiversity conservation process [2].

*2. Contact: d.nakashima@unesco.org*

### Summit innovates with 'Type 2' partnerships

The Summit produced three official documents: the Johannesburg Declaration on Sustainable Development and a Plan of Implementation (implemented by all governments and known as Type 1 outcomes) and, for the first time, the inclusion of partnership initiatives as an integral part of the Summit. These 'Type 2 partnerships' were agreed upon in Johannesburg only by those parties directly involved.

A number of Type 2 initiatives were made public in Johannesburg. For example, the USA announced it would be investing US$970 million over the next three years in water and sanitation projects, while the European Union introduced the 'Water and Life' initiative engaging partners to meet goals for water and sanitation primarily in Africa and Central Asia. By the end of the Summit, countries had pledged to replenish the Global Environment Facility with a total of US$3 billion.

A range of agreements were concluded by nine major electricity companies from G7 countries and the United Nations to facilitate technical cooperation for sustainable energy projects in developing countries. The European Union announced a US$700 million partnership initiative on energy and the USA that it would be investing up to US$43 million in 2003. The South African energy utility Eskom announced a partnership to extend modern energy services to neighbouring countries.

Some 20 Type 2 initiatives concluded in Johannesburg involve UNESCO. For examples, see the boxes on IGOS and GRASP.

### Summit produces 'collateral gains'

Independently of the formal Type 1 and Type 2 partnerships, there were distinct 'collateral gains' in Johannesburg. It was at the Summit that Russia pledged to ratify the Kyoto Protocol – foreseeing the reduction of greenhouse gas emissions to pre-1990 levels by 2012 –, a move which would enable the five-year agreement to enter into force. The Russian pledge was accompanied by Thailand's and China's announcements that they had ratified the Protocol and by Canada's pledge to submit the Protocol to Parliament for ratification before the end of the year.

Another 'collateral gain' was the pledge by individual countries in Johannesburg to increase official development assistance, which had fallen over the past decade from 0.33% of donor country GNP to 0.22% – far below the target of 0.7% agreed upon in Rio de Janeiro. This is all the more significant in that finance and trade issues represented much of the 25% of the Johannesburg documents still needing to be agreed upon when the Summit began on 26 August.

UNESCO would have liked to see the Summit place greater stress on respect for cultural diversity as an essential element of sustainable development but is nevertheless pleased that the level of awareness has been raised substantially.

### When small rhymes with vulnerable

Those who were in Johannesburg will recall the poignant appeal for help from the state of Tuvalu (26 km$^2$), a tiny group of atolls in the South Pacific with 12,000 inhabitants which is slowly sinking into the sea. According to a report published by the Intergovernmental Panel on Climate Change last year, sea level may rise 1 m over the next 50–100 years. The average altitude of Tuvalu is 1.5 m.

*A father with his children during a traditional dance ceremony in Vanuatu*

***No-one speaks out against biopiracy. Our resources are taken from us without any payment, in total disregard for the rights of local populations.***

Professor Catherine Odora-Hoppers, University of Pretoria, South Africa

UNESCO is giving a voice to small island states through its Small Islands Voice project launched in 2002. The Organization is pleased to see that the sustainable development of small island states was given importance in Johannesburg (*see also page 45*).

### Preparing for disaster

Another theme stressed in Johannesburg of obvious relevance for UNESCO is the development and strengthening of activities to improve natural disaster preparedness and response. As Summit follow-up, UNESCO will be targeting both natural and man-made hazards in megacities and rural areas. In addition to emergency relief and recovery, it will be engaging further in disaster prevention with vulnerable countries as a focus. Through joint international observation and research, countries will be familiarized with new techniques in surface-based monitoring and encouraged to use and disseminate satellite data.

Within an International Consortium on Landslides, UNESCO is launching a new International Programme on Landslides encompassing science, education and culture. Moreover, in the face of ever-increasing damage caused by flooding, the Council of UNESCO's International Hydrological Programme recently adopted a Resolution proposing the launch of a Joint UNESCO/WMO Programme on Floods.

### Renewable energy target wasn't to be

The Secretary-General of the United Nations, Kofi Annan, and the government of Brazil were among proponents of raising the market share of renewable energies to 10%. Solar energy may represent only 0.1% of today's energy demand, but it is also one of the world's fastest-growing renewable energy sources. The photovoltaic solar market for example is expanding by 15% annually, according to the Global Environment Facility, thanks largely to the lower costs made possible by research (*see also pages 23-27).*

## IGOS - or the new space race

The space race has entered a new phase. Today, it is fuelled by a far more critical goal than that of Cold War politics – the quest to understand the planet's life-support systems. There may be several global initiatives to observe the climate or the oceans but no single agency or organization can afford to implement one of these systems alone. This is where the Integrated Global Observing Strategy (IGOS) comes in.

An umbrella organization, IGOS is made up of 14 partners including UNESCO, the World Meteorological Organization (WMO) and the Committee on Earth Observation Satellites (CEOS), which represents 23 space agencies.

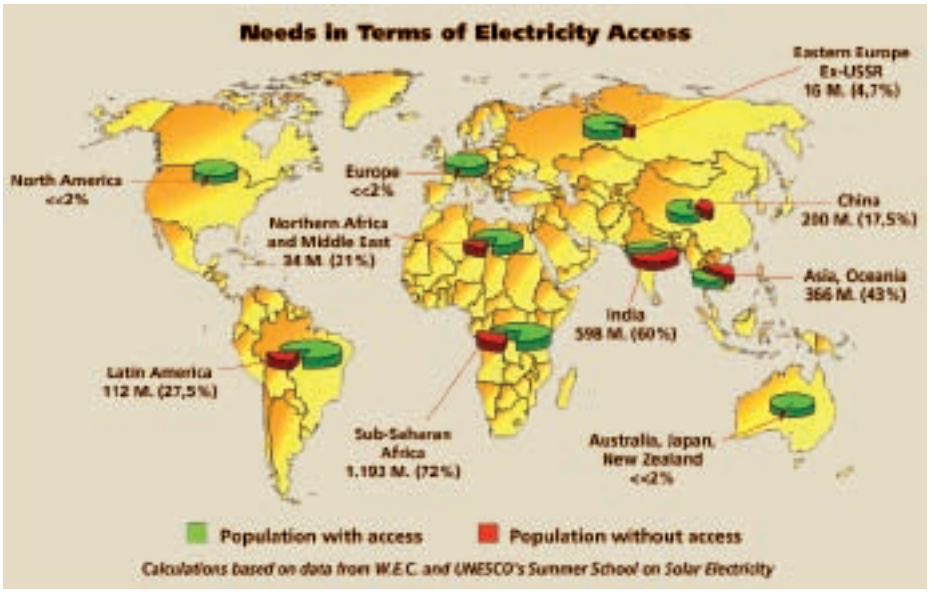
IGOS is weaving a global network to collect, compare and synthesize the data of the various satellites with land-based observations. The aim is to finalize the system within the next two years to prepare for the launch of a constellation of nine Global Precipitation Measurement satellites, which will be able to measure the rainfall at any spot on the globe every three hours.

IGOS is developing a similar strategy to study the impact of rising carbon dioxide emissions. Carbon dioxide is the most dangerous greenhouse gas because it can hang in the air for tens and even thousands of years, trapping heat in the atmosphere. To predict how atmospheric carbon dioxide levels and climate may change in the future, we must understand where and how it moves between the land, oceans and atmosphere in what is known as the global carbon cycle.

For further information on this Type 2 initiative, go to www.igospartners.org or contact r.missotten@unesco.org. *(see also p. 28)*

Although the hoped-for target is ultimately absent from the Plan of Implementation, governments do commit to increasing access to modern energy services to augment energy efficiency and to fostering the use of renewable energy. They also agree to phase out, where appropriate, energy subsidies.

Of great interest to UNESCO is the government commitment to supporting the NEPAD [3] objective of ensuring access to energy for at least 35% of the African population within 30 years. UNESCO launched the ten-year World Solar Programme in 1996 to help Africa in particular gain access to energy. The Programme includes the Global Renewable Energy Education and Training Programme (GREET). GREET is particularly active in sub-Saharan Africa, where 15% of the urban population and 92% of the rural population lack electricity (UNESCO data).




*UNESCO calculations of the world's renewable energy outlook (UNESCO exhibition at the Johannesburg Summit)*

***It is inhuman that developing countries must spend about half their budgets on international financial obligations. The resources should be made available for education and social programmes to ease the extreme poverty which is a major cause of environmental damage in developing countries.***

President Noboa
of Ecuador

* * *

UNESCO is in the process of putting together its own transdisciplinary action plan, involving its programmes not only in natural sciences but also in the social sciences, education, culture and communication. Of particular interest to UNESCO are the areas emphasized in Johannesburg of education for sustainable development, freshwater and the oceans, ecosystem management, renewable energy and the ethical dimensions of sustainable development.

UNESCO looks forward to working with its inter-governmental and non-governmental partners to implement follow-up to the World Summit on Sustainable Development.

Susan Schneegans[4]

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*3. New Partnership for Africa's Development: www.nepad.org*
*4. Editor*, A World of Science

## The Great Apes Survival Project (GRASP)

At current rates, the orang-utan may have disappeared from the world's forests within the next ten years. It is a voiceless victim of habitat destruction, including that caused by the fires which regularly ravage Borneo's forests, the orang-utan's primary habitat. And the orang-utan is not alone. Chimpanzees, gorillas and bonobos are also threatened with extinction. In Africa, poaching and armed conflict pose the greatest threat to their survival.

Faced with the urgency of saving *Homo sapiens sapiens*' closest relatives, UNESCO and the United Nations Environment Programme (UNEP) have launched the Great Apes Survival Project (GRASP) in partnership with a number of non-governmental organizations (NGOs) as a Type 2 initiative. Through GRASP, UNESCO is using its World Network of Biosphere Reserves and World Heritage Sites to help conserve the Great Ape habitats in Africa and Asia.

For further information on this Type 2 initiative, go to:
www.unesco.org/mab/grasp/home.sthml
or contact: s.mankoto@unesco.org

*'Boris', a chimpanzee in Chester Zoo (UK) drawn by Professor Aterini. His mother was shot in the wild when he was a baby*

# **The water crisis:** how has it come to this?

**Arguably the strongest message to emerge from the International Year of Freshwater is that the global water crisis will reach unprecedented levels in the years ahead if nothing is done to rectify the current 'inertia at the leadership level.'**

This is the sobering prediction of the *World Water Development Report – Water for People, Water for Life* published by UNESCO this year on behalf of 24 United Nations agencies. The report predicts 'growing per capita scarcity of water in many parts of the developing world' because of population growth, pollution and expected climate change.

Water supplies are falling while the demand per capita is dramatically growing at an unsustainable rate. Over the next 20 years, the average supply of water is expected to drop worldwide by one-third,' notes UNESCO Director-General Koïchiro Matsuura. 'No region will be spared from the impact of this crisis which touches every facet of life, from the health of children to the ability of nations to secure food for their citizens'.

So, how has it come to this? Simply because, despite widely available evidence of the crisis, political commitment to reverse these trends has been lacking. A string of international conferences over the past 25 years has focused on a great variety of water issues including ways to provide the basic water supply and sanitation services required in the years to come. Several targets have been set to improve water management but 'hardly any', says the report, 'have been met. Inertia at leadership level and a world population not fully aware of the scale of the problem means we fail to take the needed timely corrective actions'.

**Above:** *Boats stranded in what used to be a deep-water port in south-west Kazakhstan. The Aral Sea has shrunk to about half its original size and what remains is heavily polluted, an ecological disaster* (see also p.14)
**Opposite page:** *Cultivating plants in the desert*

### Many countries and territories already in crisis

The report ranks over 180 countries and territories in terms of the amount of renewable water resources available per capita, meaning all of the water circulating on the surface, in the soil or deeper underground (*see table for both ends of the scale*).

By the middle of this century, at worst 7 billion people in 60 countries will be faced with water scarcity and at best 2 billion in 48 countries, depending on factors like population growth and policy-making. Climate change will account for an estimated 20% of this increase in global water scarcity. Humid areas will probably see more rain, whereas precipitation is expected to decrease and become more erratic in many drought-prone regions and even some tropical and sub-tropical regions. Water quality too will worsen with rising pollution levels and water temperatures.

The water crisis 'is set to worsen despite continuing debate over the very existence of such a crisis'. One litre of wastewater pollutes about eight litres of freshwater. There is an estimated 12 000 $km^3$ of polluted water worldwide, which is more than the total amount contained in the world's ten largest river basins at any given moment. If pollution keeps pace with population growth, the world will effectively lose 18 000 $km^3$ of freshwater by 2050 – almost nine times the total amount countries currently use each year for irrigation, which is by far the largest consumer of the resource. Irrigation currently accounts for 70% of all water withdrawals worldwide.

Using treated wastewater could ease the water crisis. Farmers already use this resource for about 10% of irrigated land in developing countries and could use more (see overleaf *Tips for improving water availability*).

In terms of water quality, the poor continue to be the worst affected, 'with 50% of the population in developing countries exposed to polluted water sources.' Asian rivers are the most polluted in the world, with three times as many bacteria from human waste as the global average. Moreover, these rivers contain 20 times more lead than those of industrialized countries.

'The future of many parts of the world looks bleak,' says the report, in reference to projected population growth

which will continue to be a driving factor in the water crisis. Per capita water supplies decreased by a third between 1970 and 1990, according to the report. Even though birth rates are slowing down, the world's population should still reach about 9.3 billion by 2050.

'Water consumption has almost doubled in the last 50 years. Meanwhile, water quality continues to worsen […]. Every day, 6000 people, mostly children under the age of five, die from diarrhoeal diseases,' says the report. 'These statistics illustrate the enormity of the problems facing the world with respect to its water resources and the startling disparities that exist in its utilization.'

'Globally, the challenge lies in raising the political will to implement water-related commitments. Water professionals need a better understanding of the broader social, economic and political context, while politicians need to be better informed about water resource issues. Otherwise, water will continue to be an area for political rhetoric and lofty promises instead of sorely needed actions.'

**The two extremes in terms of water availabilty**

| The 20 water-richest countries and territories* (in $m^3$ per person per year) | |
|---|---|
| French Guiana | 812,121 |
| Iceland | 609,319 |
| Guyana | 316,689 |
| Suriname | 292,566 |
| Congo | 275, 679 |
| Papua New Guinea | 166,563 |
| Gabon | 133,333 |
| Solomon Islands | 100,000 |
| Canada | 94,353 |
| New Zealand | 86,554 |
| Norway | 85,478 |
| Belize | 82,102 |
| Liberia | 79,643 |
| Peru | 74,756 |
| Bolivia | 74,743 |
| Laos | 63,184 |
| Paraguay | 61,135 |
| Chile | 60,614 |
| Equatorial Guinea | 56,893 |
| Panama | 51,814 |

| The 20 water-poorest countries and territories (in $m^3$ per person per year) | |
|---|---|
| Kuwait | 10 |
| Gaza Strip | 52 |
| United Arab Emirates | 58 |
| Bahamas | 66 |
| Qatar | 94 |
| Maldives | 103 |
| Libyan Arab Jamahiriya | 113 |
| Saudi Arabia | 118 |
| Malta | 129 |
| Singapore | 149 |
| Jordan | 179 |
| Bahrain | 181 |
| Yemen | 223 |
| Israel | 276 |
| Barbados | 307 |
| Oman | 388 |
| Djibouti | 475 |
| Algeria | 478 |
| Tunisia | 482 |
| Burundi | 566 |

World Water Development Report – Water for People, Water for Life (2003)

** Excluding Greenland (10,767,857 $m^3$) and Alaska (1,563,168 $m^3$)*

## Health and economics

The overriding problem of the 21st century is that of water quality and management. 'More than 2.2 million people die each year from diseases related to contaminated drinking water and poor sanitation. Water vector-borne diseases also take a heavy toll: about one million people die from malaria each year and more than 200 million suffer from schistosomiasis. Yet these terrible losses, with the waste and suffering they represent, are preventable.'

The international community pledged through the UN Millennium Development Goals (2000) and at the World Summit on Sustainable Development (Johannesburg, 2002) to halve the proportion of people without access to safe drinking water and basic sanitation by 2015. To achieve these targets, an additional 1.5 billion people will require improved access to water supply (by 2015). This means providing services for another 100 million people each year (274,000/day) from 2000 to 2015.

'The challenge for sanitation is more daunting. An additional 1.9 billion people will need improved access, which means another 125 million each year (or 342 000/day) from 2000 to 2015. The report explains that cultural factors further complicate the logistic and financial difficulties in providing adequate sanitation.

Were current levels of investment to be maintained, all regions in the world could reach or come close to both goals, with the exception of sub-Saharan Africa. But 'in absolute terms, the investment needs of Asia outstrip those of Africa, Latin America and the Caribbean combined.' It is estimated that the first interventions would cost about US$ 12.6 billion.

Questions remain as to the source of this investment. 'Financing the Millennium Development Goals will probably be one of the most important challenges that the international community will have to face over the next 15 years'. The report outlines debates over water pricing and privatization.

© Yann Arthus-Bertrand/UNESCO

## Tips for improving water availability

Did you know that you can bolster nature's capacity for replenishing groundwater simply by letting water seep through a river bank? Or by injecting water underground through boreholes? These are two examples of tried and true methods which have demonstrated their sustainability over time.

The water injection method is currently used in major cities like Berlin (Germany) where two-thirds of drinking water is bank-infiltrated. And the same process utilized in Berlin* with state-of-the-art monitoring is commonly used in rural India and southern Africa. In these parts, hand-dug pits and dams are used to collect floodwater or seasonal river flow and store it safely from evaporation in the form of groundwater which can later be pumped for use. These simple, low-cost structures can ease water scarcity in arid areas of developing countries through the storage of infrequent excess water.

Soil acts as a natural filter of particles in water, breaking down impurities like pharmaceuticals. In addition to being purified during its passage through the soil, water also leaches beneficial nutrients, thereby improving its quality. Aquifers even have the capacity to inactivate harmful micro-organisms like viruses, a prowess which is the object of intensive research. Thanks to the natural biological, chemical and physical processes occurring underground, treated reclaimed wastewater can be used safely for mostly non-potable purposes, a great asset for arid zones in particular where water is scarce.

Within a project launched with its partners in 2002, the UNESCO-IHP has published a brochure on how to replenish groundwater, entitled *Managing Aquifer Recharge*: http://unesdoc.unesco.org/images/0012/001278/127843e.pdf

You will find details of methods employed specifically in the drier regions of the world in a booklet UNESCO is currently preparing with the International Association of Hydrogeologists on *Wise Strategies for Recharge Enhancement in Arid and Semi-arid Areas*. The booklet is available at: http://unesdoc.unesco.org/images/0014/001438/143819e.pdf

* *www.kompetenz-wasser.de*

'Although it is considered essential to involve the private sector in water resource management, it should be seen as a financial catalyst – not so much as a precondition – for project development […]. Control of the assets and the resource should remain in the hands of the government and users.'

Any privatization or water-pricing scheme must include mechanisms to protect the poor. 'A disturbing fact is that poor people with the most limited access to water supply have to pay significantly more for water.' In Delhi (India), for example, vendors charge the poor US$ 4.89 per $m^3$, whereas families with piped connections pay just US$ 0.01, according to a survey published in the report. In Vientiane (Lao PDR), vendors charge US$ 14.68 per $m^3$, compared to municipal tariffs of US$ 0.11.

**Hunger unlikely to be halved before 2030…**

About 25 000 people die every day from hunger. An estimated 815 million people suffer from malnutrition: 777 million in developing countries, 27 million in countries in transition and 11 million in industrialized countries. The absolute number of malnourished people is dropping at a much slower rate, despite the fact that 'food production is satisfying the market demand at historically low prices'.

The international community has pledged through the Millennium Development Goals to halve the proportion of people suffering from hunger by 2015. However, by factoring in a distinction between rain-fed and irrigated crops (a distinction not made in previous estimates), the report is able to present more precise projections concerning the water required to feed the world today and in the future: it concludes that the target may not be achieved before 2030. According to these new calculations, another 45 million ha will be irrigated by 2030 in 93 developing countries, where most of the population growth will take place. About 60% of all land that could be irrigated will be in use. This will require a 14% increase in irrigation water.

Of the 170 countries and territories surveyed, 20 are already using more than 40% of their renewable water resources for irrigation, 'a threshold used to flag the level at which countries are forced to make difficult choices between their agricultural and urban water supply sectors'. Most of these are Arab states. Another 16 countries use more than 20%, 'which can indicate impending water scarcity. By 2030, South Asia will have reached the 40% level on average and the Near East and North Africa not less than 58%.'

By contrast, sub-Saharan Africa, Latin America and East Asia are likely to remain far below the critical threshold. These regions will see the bulk of agricultural expansion in the next 30 years.

Pastures and crops take up 37% of the Earth's land area. Irrigation is extremely inefficient – close to 60% of the water used is wasted. This will only improve by an estimated total of 4%. Moreover, About 10% of the world's irrigated lands have been damaged by waterlogging and salinization because of poor drainage and irrigation practices. There is a tremendous need to improve the financing of better technology and to promote better management practices.

**…even though food security is growing**

On a more positive note, food security is improving globally. Per capita food consumption in developing countries rose from 2054 kcal per day in 1965 to 2681 kcal per day in 1998.

Average grain yields doubled between 1962 and 1996, from 1.4 to 2.8 tons/ha/crop. This means that less than half the amount of arable land is now required to grow the same amount of grain. 'By 2030, it is expected that 80% of the increase in crop production will come from higher yields, increased multiple cropping and shorter fallow periods.'

'Towards 2050, the world could enjoy access to food for all,' notes the report. 'The fact that 815 million are presently ravaged by chronic undernourishment is not due to a lack of capacity to produce the required food but to global and national social, economic and political contexts that permit, and sometimes cause, unacceptable levels of poverty to perpetuate.'

### We are nonchalantly destroying ecosystems

By 2025, it is predicted that water withdrawal will increase by 50% in developing countries and by 18% in developed countries.

The report describes a vicious circle unleashed by growing water demand. By depleting and polluting rivers, lakes and wetlands, we are destroying ecosystems which play an essential role in filtering and assuring freshwater resources. In the USA, 40% of water bodies assessed in 1998 were not deemed fit for recreational use due to nutrient, metal and agricultural pollution. Furthermore only five out of 55 rivers in Europe are considered pristine, according to the report and, in Asia, all rivers running through cities are badly polluted. Some 60% of the world's 227 largest rivers are severely fragmented by dams, diversions and canals leading to the degradation of ecosystems.

Turning to the animal life of inland waters, the report claims that 24% of mammals and 12% of birds are threatened with extinction. Only about 10% of the world's fish species, the majority from inland waters, have been studied in detail, yet one-third are at risk. Up to 80 known fish species have become extinct since the late 19th century.

### When cities become life-threatening

'When infrastructure and services are lacking, urban areas lacking water infrastructure are among the world's most life threatening environments'. According to a survey of 116 cities, urban areas in Africa are the worst served, with only 18% of households connected to sewers, followed by Asia where the connection rate is just over 40%.

'The poor of these cities are the first victims of sanitation-related disease, flooding and even a rising rate of water-borne disease like malaria, which is now among the main causes of illness and death in many urban areas'. In South Asia, for example, the *Anopheles stephensi* mosquito has actually adapted its breeding habits around the ubiquitous rooftop water storage tanks.

'From a public health perspective, it is better to provide a whole city's population with safe supplies to taps within 50 m of their home than to provide only the richest 20% of households with water piped to their home.'

*In Haiti, a woman bathes her daughter in their courtyard*

The report outlines several reasons as to why cities and towns should take priority over rural areas when choices must be made. Firstly, the unit costs of the required infrastructure are lower because urban areas provide significant economies of scale and proximity. Secondly, many cities have a more prosperous economic base than rural areas, providing greater possibilities for raising revenues for water provision. Thirdly, 'urban areas concentrate not only people and enterprises but also their wastes.'

### Industrial countries produce 80% of hazardous wastes

Today, industry accounts for 22% of total water use in the world: 59% in high-income countries and 8% in low-income countries. The report predicts that this average will reach 24% by 2025 when industry will be using an estimated 1170 $km^3$/year of water. Every year, 300–500 million tons of heavy metals, solvents, toxic sludge and other wastes accumulate in water resources from industry. More than 80% of the world's hazardous waste is produced in the USA and other industrial countries.

### The pros and cons of tapping the hydropower potential

Hydropower is the most important and widely used renewable source of energy, providing about 19% of total electricity production. Industrialized countries are exploiting about 70% of their electricity potential, compared to 15% in developing countries. Canada is the largest producer, followed by the USA and Brazil. Untapped hydro-resources are still abundant in Latin America, India and China.

'By developing half of this potential, we could reduce greenhouse gas emissions by about 13%,' says the report. However, it also points to the many negative impacts of dam construction, including displacement of local populations and environmental damage (like loss of biodiversity and wetlands).

Amy Otchet

# Taking the **temperature of mountains**


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**Future climate warming is expected to be especially marked in colder environments, such as mountains and northern climes. For the past two years, 350 scientists participating in the European Union-funded Global Change in Mountain Regions (GLOCHAMORE) project involving UNESCO and the Swiss-based Mountain Research Initiative have been developing a network of sites in selected mountain biosphere reserves to observe and study over time the signs of global change in nature and their impact on the people who inhabit these regions. The project was coordinated by the University of Vienna (Austria) and comprised 14 partners from eight European countries, plus India. By the time the project wound up last October, some 28 biosphere reserves around the world had been identified and the foundations had been laid for the long-term study of change in these alpine monitoring sites.**

One-quarter of our globe's terrestrial surface is covered by mountain regions, which provide goods and services – such as the provision of clean freshwater – to more than half of humanity. Though rugged in appearance, mountains are actually highly susceptible to environmental degradation, as anyone knows who has seen the corrosive effects of strip-mining or clear-cut logging on mountain slopes. The main drivers of change in alpine environments are climate, land use and nitrogen deposits.


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## Climate change to create water shortages for millions dependent on glaciers

For millions of people in Asia and Latin America who rely on melting snow and glaciers for freshwater supplies, climate change will cause major shortages, says a research team led by Tim Barnett of the US-based Scripps Institute of Oceanography, in a paper published in *Nature* on 17 November.

In many parts of the world, glaciers are melting at an unprecedented rate. The area of Peru covered by glaciers has shrunk by 25% in the past 30 years. However, 'perhaps the most critical region in which vanishing glaciers will negatively affect water supply in the next few decades', say the authors, 'will be China and parts of Asia, including India, which together form the Himalaya–Hindu Kush region' populated by about 50–60% of the world's population.

The Himalaya–Hindu Kush region contains more ice than anywhere else on Earth, apart from the polar regions. The authors write that 'there is little doubt that the glaciers of the Himalaya-Hindu Kush region are melting and that the melting is accompanied by a long-term increase of near-surface air temperature'. After 25 years of study, the recently released *China Glacier Inventory* shows 'substantial melting of virtually all glaciers, with one of the most marked retreats in the last 13 years (750 m) of the glacier that acts as one of the major sources of the Yangtze River, the largest river in China,…' The authors add that the rate of melting seems to be accelerating.

'The hydrological cycle of the region is complicated by the Asian monsoon but there is little doubt that melting glaciers provide a key source of water for the region in the summer months: as much as 70% of the summer flow in the Ganges and 50–60% of the flow in other major rivers. In China, 23% of the population lives in the western regions, where glacial melt provides the principal dry season water source'.

The authors conclude that 'it appears that some areas of the most populated region on Earth are likely to "run out of water" during the dry season if the current warming and glacial melting trends continue for several more decades. This may be enough time for long-term planning to see just how the region can cope with this problem'.

*Source:* Nature *438, 303 (2005) and M. Shanahan for SciDev.net*



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*In the Cordillera Blanca mountain range in Latin America, the area covered by glaciers has shrunk markedly over the past 30 years. Seen here is rapidly retreating Yanamarey Glacier in the Huascarán Biosphere Reserve in Peru*

*Scientists can reconstruct climate history from sediment layers and ice cores. These scientists are studying mountain snow pack to reconstruct climate history in Glacier National Park in the State of Montana in the USA*

Mountain landscapes are among the most complex and fragile ecosystems on earth. Their mere verticality produces a huge range of habitats, whose composition varies dramatically with short changes in altitude. These differences can be obvious in the tropics or sub-tropics – such as the presence of palm trees at lower altitudes and glaciers at higher ones – or more subtle, such as the shifts in insect species as you move up a mountain slope.

Calculating and forecasting the effects of climate change on these environments encompasses a demanding range of scientific inquiry. This is why the scientists participating in the GLOCHAMORE project developed a research strategy encompassing such diverse areas as land-use changes, the cryosphere (permanent frozen landscapes, from the Greek word *Kruos* meaning cold) and snow-covered areas, hydrological systems, grasslands and tundra areas, forests and aquatic ecosystems, wildlife, alien plant and animal species and natural hazards (floods, fires, landslides, etc), to name but a few.

One of the recommendations made by scientists participating in GLOCHAMORE is for 'early warning' mechanisms to be developed to detect invaders and their environmental impact. As annual temperatures rise over the long-term due to global warming, for example, non-native plant, insect and animal species may more easily invade new ecosystems where there is often no check on their behaviour. This lack of "checks and balances" can play havoc with a mountain ecosystem's structure and function. Hostile bugs might attack the plants and grasses that anchor a slope's thin layer of topsoil, for example. Remove the anchor and you get severe erosion and landslides, with their cascading effect on local communities.

### A network of alpine observation posts

The GLOCHAMORE project set up a network of observation posts to monitor the effects of changes on the natural world but also on the people living in these colder climes. In the space of two years, the project has developed a plan for environmental and social monitoring in mountain regions that is helping to implement global change research strategies in selected UNESCO Biosphere Reserves (*see table overleaf*). There is no reason why the GLOCHAMORE research strategy could not be applied to other mountain biosphere reserves – there are over 150 in total – or to world heritage sites, such as Mount Kilimanjaro in the United Republic of Tanzania. Some alpine sites have even been accorded dual status, as in the case of Uvs Nuur Basin (Mongolia) and Mount Kenya, which are both biosphere reserves and world heritage sites. It so happens that the impact of climate change on world heritage sites will be the subject of a meeting taking place at UNESCO just two months from now, on 16 and 17 March.

## Tell-tale signs of climate change

In a survey conducted in 2004 within the GLOCHAMORE project, managers of mountain biosphere reserves reported on their experiences of global warming. High on the list of concerns was the economic impact of the changing natural environment. In the Kosciuszko Biosphere Reserve in Australia, for example, where four ski resorts bring the area an estimated A$190 million annually, the winter season is becoming shorter. In Changbaishan Biosphere Reserve in China, lesser snow cover is responsible for a drop in the quantity of water available to farmers for agriculture. In Mount Kenya Biosphere Reserve, flash floods and other hydrological hazards are silting waterworks and canals used for irrigation. Local communities are also suffering from water shortages, as in the Kruger to Canyons Biosphere Reserve in South Africa.

The greatest impact of climate warming observed in nature can be seen in vegetation. The Changbaishan Biosphere Reserve reported that 'the alpine *Betula ermannii* birch tree has moved upwards towards the tundra ecosystem over the past 20 years. Results show that, for other species, such as the *Larix olgensis* and *Abies nephrolepis*, there is an apparent increase in their biomass with climate warming'. In other words, these two plant species are proliferating as a result of the increase in temperature, a phenomenon which will eventually create an ecological imbalance.

The following is a non-exhaustive list of impacts associated with climate change in mountain biosphere reserves. Many of the signs of climate change below are interlinked, reflecting the fact that a single impact of climate change can set off chain reactions with both physical and social dimensions:

- Greater solar ultraviolet radiation
- Melting of glaciers (see box on facing page)
- Thawing of permafrost soils causing greater weathering (the breakdown of rocks and minerals on, or just below, the surface, caused by changes in temperature or humidity, etc.)
- As a result of greater weathering, dryer soils, subsidence, siltation, landslides caused by erosion, etc.
- More frequent storms, floods, landslides and avalanches of greater intensity
- Changes in the distribution and numbers of plant and animal species
- A longer growing period for vegetation, with the vegetation lines moving up the mountain
- Less rainfall and snowfall (precipitation)
- Drying out of the forest area due to the drop in precipitation
- A greater fire hazard due to the drying out of the forest area
- Greater competition for more limited natural resources among the human populations living in the lowlands.

*Sky Lake Meteorological Station at an altitude of 2600 m in Changbaishan Biosphere Reserve in China. Other research stations study hydrological factors and seismic and volcanic activity*

Over the past two years, GLOCHAMORE has defined indicators to detect and analyse signals of change in these high-altitude regions and to analyse direct cause–effect relationships in individual ecosystems using carefully chosen markers. These indicators have been ranked in terms of ease of application.

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*Crossing a river in Katunsky Biosphere Reserve in Altai, Russian Federation*

### Disturbing evidence of climate change

Glaciers, permafrost and alpine regions are all sensitive to changes in atmospheric temperature, so act as an indicator of global climate change. Warming during the 20th century has already had a pronounced effect on glacial and periglacial mountain belts. If this trend continues, experts predict smaller mountain glaciers could melt, areas of frozen ground (permafrost) could thaw and alpine regions could shrink.

Specifically, the network of selected biosphere reserves is observing cryospheric indicators, such as snow cover, glaciers, permafrost and solifluction (where freezing and thawing of the ground results in soil-surface slippage); high-mountain, freshwater ecosystems and watershed hydrology; and terrestrial ecosystems, especially mountain plant life and certain soil-dwelling animals. They have already uncovered disturbing evidence of climate change (*see box on page 11*).

## Living laboratories for sustainable development

UNESCO's mountain biosphere reserves were chosen as monitoring sites for the GLOCHAMORE project both because they offer a major advantage for global comparisons and because the 'biosphere concept' is particularly well adapted to integrated research observing change in both the natural and socio-economic environments.

This is because the biosphere concept acknowledges that people and nature cohabit and that conservation practices have to incorporate this reality. The biosphere reserve concept adopts a zoning approach: strictly protected core areas are surrounded by buffer zones where conservation is emphasized but where people also live and work; and the whole is encircled by a transition area promoting sustainable development.

It was the Brundtland Report, *Our Common Future*, which proposed a definition of sustainable development in 1987 that is now generally recognized as the standard:

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

The Brundtland report helped to trigger a wide range of initiatives by the United Nations, including the 'Earth Summits' in Rio (Brazil, 1992), which adopted *Agenda 21*, and in Johannesburg (South Africa, 2002), as well as the Framework Convention on Climate Change, to which the Kyoto Protocol was added in 1997 (*see p. 29*).

At the Earth Summit in Rio, the United Nations promoted UNESCO's wide network of biosphere reserves as 'living laboratories' for conservation efforts. The Rio Summit was the start of a growing awareness of the importance of mountains. A decade later, the United Nations would designate 2002 as the International Year of Mountains. UNESCO's main contribution to the Year would be the launch of the GLOCHAMORE project. Significantly, mountain-related research by the European Union has also gathered momentum in the past decade.

*On the International Year of Mountains, see*
A World of Science *1(2), January 2003*


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*People in the Sierra Nevada Biosphere Reserve in southern Spain live in close proximity to the mountain. The mountain serves as a source of revenue via tourism and recreational activities. A ski resort is situated in the buffer zone on the lower slopes*

### Ensuring the long-term viability of mountain monitoring

The choice of monitoring sites was not a random one. Sites were chosen in countries in such a way as to provide representative geographic coverage and different socio-economic backgrounds and cultures. Another criterion for selection was whether or not the site had the necessary infrastructure in place to partake in the project.

The studies undertaken at the chosen locations needed to integrate natural and societal factors, and therefore various scientific disciplines. 'Through monitoring, one can design a scheme to target indicators that are driven by human action and managers of mountain biosphere reserves can set threshold values, such as for sustainability for example, which can be met by management,' suggests the report of the project's first thematic meeting in Vienna in 2004. But a fully integrated study of the so-called 'nature–society system' entails finding common denominators and even coining a new language which practitioners of both the natural and social sciences can understand, the report concludes.

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*Glacier National Park in the USA*

| *The selected mountain biosphere reserves* | *Altitudinal range (m.a.s.l.)* |
|---|---|
| **Africa** | |
| Tassili N'Ajjer (Algeria) | 1 150 – 2 158 |
| Mount Kenya | 1 600 – 5 199 |
| Oasis du Sud (Morocco) | 680 – 4 071 |
| Kruger to Canyons (South Africa) | 200 – 2 050 |
| **Asia-Pacific** | |
| Kosciuszko (Australia) | 213 – 2 228 |
| Changbaishan (China) | 720 – 2 691 |
| Issyk-Kul (Kyrgyzstan) | 1 609 – 7 439 |
| Nanda Devi (India) | 1 800 – 7 817 |
| Uvs Nuur Basin (Mongolia) | 759 – 3 966 |
| Katunskiy (Russian Federation) | 765 – 4 506 |
| Sikhote-Alin (Russian Federation) | 0 – 1 600 |
| Teberda (Russian Federation) | 1 260 – 4 047 |
| **Europe** | |
| Gossenköllersee (Austria) | 2 413 – 2 828 |
| Gurgler Kamm (Austria) | 1 900 – 3 400 |
| Berchtesgaden Alps (Germany) | 471 – 2 713 |
| Sierra Nevada (Spain) | 400 – 3 482 |
| Lake Torne (Sweden) | 340 – 1 610 |
| Entlebuch (Switzerland) | 600 – 2 350 |
| Swiss National Park | 1 500 – 3 174 |
| **Latin America** | |
| Araucarias (Chile) | 800 – 3 124 |
| Torres del Paine (Chile) | 20 – 3 050 |
| Cinturón Andino (Colombia) | 1 700 – 5 750 |
| Huascarán (Peru) | 2 500 – 6 768 |
| **North America** | |
| Mount Arrowsmith (Canada) | 300 – 1 817 |
| Glacier National Park (USA) | 972 – 3 185 |
| Niwot Ridge (USA) | 2 866 – 3 780 |
| Denali (USA) | 122 – 6 194 |
| Olympic (USA) | 0 – 2 428 |

## The *Perth Declaration* moves mountains

During its two years of activity, GLOCHAMORE organized no less than five specialized international workshops. In general, these scientific workshops focused on the drivers of global change and the impact of those changes on ecosystems, ecosystem goods and services, regional economies, health and institutional arrangements. The proceedings of these workshops are compiled in a series of publications.

Scientists examined the most pressing aspects of climate change observed in mountain landscapes, such as sustainable land use and natural resource management, the monitoring of human activity linked to environmental changes and modelling to project the future effects of global warming in mountains.

The project culminated in an Open Science Conference on Global Change in Mountain Regions in Perth (Scotland) from 2 to 6 October. This meeting built on successful gatherings in Vienna (Austria) and l'Aquila (Italy) in 2004, in Granada (Spain) and Samedan (Switzerland) in 2005 and the project's kick-off meeting at the Entlebuch Biosphere Reserve (Switzerland) in November 2003.

The Open Science Conference brought together 250 delegates from 47 countries to review the project's work and define the path ahead. At the conference, scientists issued a clarion call – the *Perth Declaration* – to governments, funding agencies and private sector to support further research into the effects of climate change on mountain ecosystems and the sustainable management of mountain environments and adjacent lowland communities.

*Read the* Perth Declaration*: www.unesco.org/mab/mountains/news.htm; and the Proceedings of the GLOCHAMORE meetings: www.unesco.org/mab/mountains/publications.htm*

Managers of mountain biosphere reserves will be crucial to the long-term viability of mountain monitoring. They will serve as the custodians of the information and data collected by the body of both national and visiting scientists who, themselves, will come and go over the coming decade. By definition, monitoring climate change is a long-term undertaking that calls for comprehensive and constant *in situ* observation. The involvement of other stakeholders, such as local communities, will also be crucial to maintaining a viable 'observation post' for climate change.

*This article is the work of contributors from the GLOCHAMORE Consortium; for details: t.schaaf@unesco.org*

Igor Vasilievich Severskiy

# Glacier melt and poor policies behind Central Asia's water woes

**Last November, Igor Vasilievich Severskiy was one of 60 experts from 13 countries who called for a regional centre to be established on glacier research, at a workshop run by UNESCO and partners in Almaty (Kazakhstan). Prof. Severskiy heads the Laboratory of Glaciology at Kazakhstan's Institute of Geography, as well as Kazakhstan's National Committee within UNESCO's International Hydrological Programme. He explains why both scientists and policy-makers in Central Asia have a lot to gain from a regional centre on glacier research.**

## How fast are glaciers retreating in the mountain ranges of Central Asia?

Several studies presented to the international workshop I attended last November show that glaciers in the Central Asian mountain regions of Dzhunghar Alatau and Pamir-Alai are melting very rapidly. Between 1955 and 2000, they lost about 0.6–0.8% per year in surface area and 0.8–1% in volume. These figures leave no doubt that global warming is the main reason for deglaciation and shrinking snow and ice in Central Asia.

## Is glacier monitoring satisfactory in Central Asia?

There are too many gaps in monitoring. The November workshop acknowledged that the lack of a monitoring system in Central Asia is responsible for inadequate information on glacier mass dynamics. This is a critical problem in the region, since glaciers are key indicators of global climate change. There is practically no monitoring system, for instance, for snow cover in the high-mountain belt above 3000–3200 m, even though this is where about half of snow is concentrated, according to our research. It is this snow which is the main source of runoff in Central Asia. Most countries in the region do not even have regular monitoring of permafrost soils. This lack of factual information on processes and natural phenomena at high altitudes in cold mountain regions forces scientists to use secondary data, indirect methods and to make assumptions when constructing forecast models. This explains the lack of consensus among scientists on the impact of climate change on the region's water resources in general and glaciers in particular.

I believe this was why the workshop participants called for a regional centre on glacier research to be established in Central Asia under the auspices of UNESCO. The centre would promote and coordinate monitoring to improve scientific understanding of climate-driven changes in snow- and icepack in glaciers, in permafrost and in the flow system connecting melt water to rivers and lakes in the lowlands.

## Is it true that glaciers will disappear by mid-century?

There is tremendous concern in scientific literature that Central Asian glaciers may disappear by mid-century. Yet, our research pens a slightly more optimistic scenario. For example, glacier retreat in Northern Tien Shan reached a climax in the mid-1970s before slowing down in the early 1980s. A similar scenario has played out in the Gissar-Alai mountain range. To take another example, glacier upsurge has even been reported in the Central Karakoram mountains, where the glacier advanced by up to 2.5 km along the valleys between 1990 and 2000.

Long-term monitoring of the average annual temperature of permafrost near the mountain pass of Zhusalykezen (3400 m) in the Zailiyskiy Alatau mountain range (Northern Tien Shan) indicates a constant rise in temperature between 1974 and 1995. Thereafter, the temperature stabilized at around -0.2°C for more than a decade. Moreover, based on our analysis, which takes into account current global warming trends, the glacier area of the Balkhash Basin may shrink by about one-third but will not disappear completely.

These case studies show that glaciers in Central Asia may not disappear as rapidly as predicted. This said, we need updated monitoring systems to improve our understanding before venturing to make any forecast.

## Might glacier lakes turn into hazards by overflowing or bursting their banks?

Yes, that is quite a likely possibility. The hazard might be caused by glacier melt forming a new lake nearby by a swollen lake, or even by disturbances in the stability of loose soils. All three processes considerably increase the probability of mud flows.

## Is glacier melt to blame for the water shortages the lowlands are experiencing?

Water resources management in Central Asia is a critical problem, especially in the Aral Sea Basin. Melt water from

permanent snowfields and glaciers feeds the two main rivers flowing into the Aral Sea Basin, the Syrdarya and Amudarya. These rivers swell mostly in spring and during the thaw in summer.

As early as the beginning of the 1990s, 150% of the natural runoff from the Syrdarya River and 110% of runoff from the Amudarya River was being used up. You may be curious as to why the percentage exceeds 100; this is because the figures also incorporate return flows from agricultural lands.

It is an interesting fact that runoff from the main rivers has remained practically the same over the past 70–80 years. Despite the considerable shrinking of glacier area, water flow into the river system has not changed. Moreover, the cumulative amount of precipitation and maximal snow reserves has shown practically no change either over the same period. The reason for growing water shortages in the region is thus not a case of a drop in the supply of head water but rather of poor water management downstream.

## In what way is water being poorly managed?

Poor management of water in the region dates back to the 1960s, when the central Soviet authorities decided to divert unprecedented amounts from the Amudarya and Syrdarya Rivers to irrigate huge cotton plantations. As a result, water shortages in the Syrdarya River Basin rose steeply between 1960 and 1990. In parallel, farmers were encouraged to use more water and dangerous amounts of pesticide and fertilizer.

Yet, even in the 1960s, no more than 25% of the river's natural runoff reached the Aral Sea. This tells us that the human impact on the basin was perceptible long before the so-called "cotton" era. Irrigated farming was well-established in the region as early as the 1930s.

From 1970 to 1989, total water losses in the basin increased by 13.8–14.2 $km^3$/year. The climate was responsible for less than 5 $km^3$ of water loss each year (about 35% of the total), compared to 8–9 $km^3$ for economic activities. This loss was caused by fast-growing irrigated areas and evaporation loss from the many reservoirs constructed in the region. A further 6 $km^3$ was lost each year to evaporation from the Arnasaisk water storage reservoir alone. Currently, there are about 100 water reservoirs and 24 000 km of irrigated channels in the Aral Sea basin.

Water loss from the Priaralje irrigated area in Kazakhstan increased over the same period from 2.5 $km^3$ to 4.6 $km^3$ per year. Today, the Aral Sea is just one-quarter its size 50 years ago.

According to forecasts based on general atmospheric circulation models incorporating the most pessimistic climate scenario, water resources in the region may fall by 20–40% by mid-century.

However, as I said earlier, even as glaciers have retreated, annual runoff in terms of volume and yearly distribution has remained unchanged for several decades. This suggests the existence of a possible compensating mechanism, a hypothesis supported by recent research.

## What kind of 'compensating mechanism'?

With global warming, rising temperatures have caused underground ice – in the form of buried glaciers, rock-glaciers and ice accumulated in the permafrost layer – to thaw. This has contributed to the compensating mechanism. As a result, the supply of runoff to the river basin has remained unchanged.

## Surely, this compensatory mechanism will dry up once the permanent ice has completely melted?

We believe the compensatory mechanism will work for up to a century, despite glacier retreat. This is because the reserves of underground ice in the high mountains of Kazakhstan and the rest of Central Asia are equivalent to the icepack in present-day glaciers. Moreover, in the Chinese mountains, there is twice as much underground ice as ice storage in the surface glaciers. Another consideration is that underground ice melts at a much slower rate than ice in open glaciers.

Hence, we can predict that the ongoing retreat of glaciers will not cause runoff and water supplies to shrink in the region for a few decades yet. However, this optimistic vision needs additional verification, a task which will require monitoring and more scientific studies coordinated at both the regional and international levels. I believe the proposed regional centre on glacier research will help us to predict with greater accuracy the impact of climate change on glaciers and water supplies in the region.

## What can central and local governments do to prepare for future water shortages?

The question warrants serious thought. As a matter of fact, a great number of programmes and studies have already tackled these policy issues, including some global projects. Most of their recommendations concern improving the system for managing regional water resources. There have been recommendations, for instance, to substitute cotton and rice for less thirsty crops in irrigated farming, such as wheat and other cereals.

Unfortunately, in spite of the efforts by regional governments and the international community, the situation as regards regional water-sharing remains tense and is even deteriorating. New water reservoirs are still being constructed and irrigated areas continue to grow in the basin. In parallel, population growth remains high.

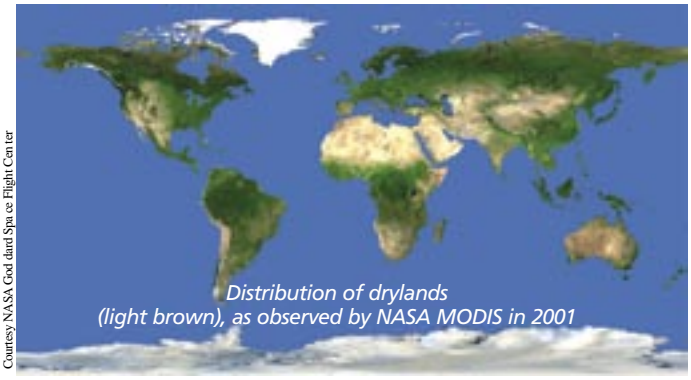
The situation is further aggravated by internal issues. For one thing, individual countries lack clearly defined water strategies. On top of that, there is no legislative basis for the transboundary management of shared water resources, nor any mutually acceptable criteria for transboundary water-sharing.

Interview by Anil Mishra

*For details (in Almaty): a.mishra@unesco.org*

# The future of **arid lands**

**Back in 1956, *The Future of Arid Lands*[5] predicted that drylands would receive renewed and sustained interest in coming decades. Drylands have been plagued by underinvestment ever since, regardless of the fact that advancing deserts continue to consume arable land at an alarming rate. Today, one-third of the Earth's surface is threatened by desertification and arable land is expected to shrink by two-thirds in Africa, one-third in Asia and one-fifth in Latin America by 2025 in relation to 1990.**



Courtesy NASA God dard Spa ce Flight Cen ter

*Distribution of drylands (light brown), as observed by NASA MODIS in 2001*

**A publication commissioned by UNESCO to mark the International Year of Deserts and Desertification, *The Future of Arid Lands – Revisited*, takes a critical look at the unintended consequences of past thinking on dryland ecosystems and the socio-economics of dryland development. What mistakes did we make and how can we learn from them? Due out in 2007, *The Future of Arid Lands – Revisited* argues for giving a new impetus to dryland research to fill the persistent gaps in our knowledge.**

Paradoxically, the dryland climate in the low latitudes has much to recommend it as a place to live and a place to grow crops: clear skies, warm temperatures and long growing seasons. The key to making the desert bloom has always been finding water. With water at such a premium in drylands, the pursuit of new sources has been intense and unrelenting.

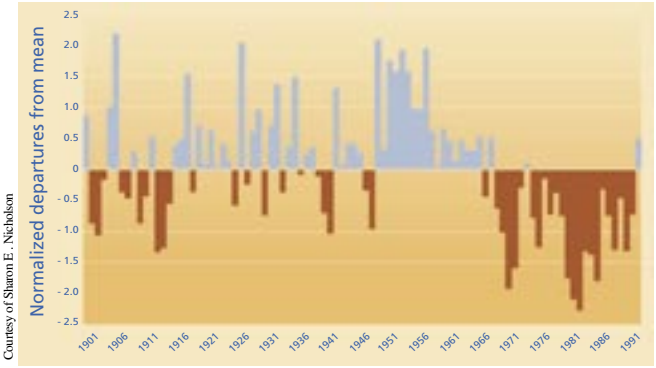
## Cloud seeding and other schemes

In the 1950s, there was a great belief in what future technology might deliver. The 1950s were the dawning of the era of large dam-building, whereas little attention was paid to groundwater as a major water resource. Water was to come from existing surface sources, from augmenting existing sources through cloud seeding (*see photo*) and other measures, or from 'new' water originating from untapped sources, such as the desalinization of brackish water and seawater.

The intervening years have seen much of what was discussed then play out. Inevitably, though, many things have happened that were not foreseen. The 1950s marked the beginning of a period of unanticipated growth in water consumption in the agricultural sector in particular that has continued until today. Perhaps as a consequence of this rapid growth in consumption, there have also been some fundamental changes in the general perception of water development. While cost–benefit analysis was, and is, done for most water development projects, the scope of what is included among both costs and benefits has been broadened significantly since then from strictly economic costs to incorporate environmental and social costs as well.

Despite the fact that groundwater was largely dismissed as a major option in 1956, exploitation of groundwater resources developed rapidly from the 1950s onward, with most development taking place between 1960 and 1980. This development was mostly concerned with immediate returns on investment and not sustainability. Now, as the value of water is increasingly realized, markets have emerged as a mechanism for addressing inequities in the distribution of water through its direct sale and through the trade of commodities that represent water, or "virtual water."


*Repeat satellite images of Almeria in southern Spain in January 1974 (left) and April 2000*




Courtesy of Sharon E. Nicholson

*Rainfall index showing standardized departures from mean annual rainfall compiled from meteorological stations in the West African Sahel between 1901 and 1994*

In considering water development and water use as a whole, the most fundamental difference between 1956 and today is that focus has shifted from developing new water supplies to a more comprehensive effort to manage all water from an integrated perspective, both on the supply and the demand sides, and from a quality point of view.

## Modifying the weather and climate change

In drylands, where rainfall is often scarce but always variable, there has been a keen interest in understanding and being able to predict this variability and in finding ways to 'make it rain' when natural rainfall is inadequate. By the time *The Future of Arid Lands* was published, techniques for modifying the weather, like cloud seeding, were just emerging. Significantly, these were paralleled by the beginnings of numerical weather modelling using computers. The general view held that modifying weather and climate was a promising and appropriate means of furthering societal and even military goals. It proved to be possible to induce rainfall in very restricted situations over small areas but this technique was of such limited and often unpredictable value that it was largely sidelined after a good deal of research. However, it is still routinely pursued in some areas with the hope of marginally increasing water supplies, such as in the Colorado River basin in the USA.

Some 50 years on, the optimism that once surrounded our emerging ability to control climate and create more favorable weather in the drylands has largely given way to concern about undesired human impacts on global climate, such as global warming. Scientific and political discourse that once focused on purposeful weather modification has been replaced by debate over strategies for mitigating the impacts of inadvertent climate change and adapting to its consequences. With the growing awareness of the connectedness of large-scale atmospheric, oceanic and terrestrial systems, the focus of scientific interest has shifted from local and regional impacts to changes on a global scale. Temperature increases threaten the modest water resources of drylands in several ways. Clearly, increases in evaporation rates as a function of higher temperatures not only threaten reserves stored in reservoirs and soils but also increase water demand by plants. A more ominous threat for many regions may be that, as minimum temperatures rise, lesser amounts of water will be stored in snowpack in the mountains surrounding many of the world's drylands.

## The balance of nature versus the flux of nature

Ecology, maybe more than any other discipline, can be taken as an example of how paradigms develop. The process is not necessarily chronological with a new paradigm replacing an older one. Rather, schools of thought, or paradigms, fall into and out of favour with communities of practice. In ecology, the two most prominent paradigms are represented by the equilibrium (balance of nature) and the non-equilibrium (flux of nature) models of ecosystem behavior.

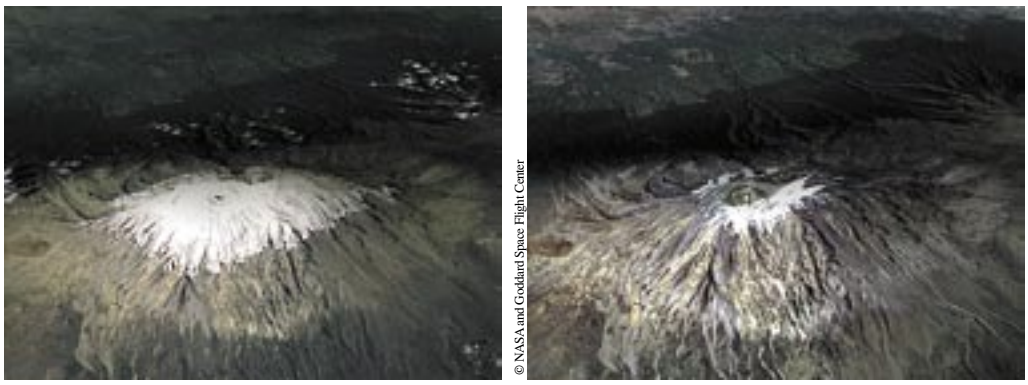
Ecological thinking in *The Future of Arid Lands* was dominated by the equilibrium paradigm, a model of ecological dynamics based on assumptions conceived in the context of northern temperate zones that had emerged early in the preceding century. Its validity as a framework for thinking about dryland environments was challenged almost from the very beginning, yet it came to dominate policy thinking for most of the 20th century. Today, though, dryland ecosystems are better described by non-equilibrium models, with disturbance, variability and unpredictability as accepted drivers. However, the equilibrium model persists institutionally and management in many drylands still follows an equilibrium approach.

The development of dryland ecology has further benefited from the emergence of, and advances, in complex systems science. Focus has now shifted from the study of individual components of dryland ecosystems – such as soil, water, vegetation and herbivores – to relationships and interactions among them.

## Plant and animal alternatives

The primary focus of *The Future of Arid Lands* was plant and animal agricultural production. Only a handful of strategies were envisioned for improving drylands agriculture:

*Cloud seeding in New Mexico (USA) undertaken by Project Cirrus (1947–1952). Cloud seeding attempts to induce precipitation (rain or snow) by dispersing tiny particles such as silver iodide and frozen $CO_2$ (dry ice) as condensation nuclei into the air. This stimulates the formation of water droplets or ice crystals in the cloud. While cloud seeding with dry ice required an aircraft as seeding platform, silver iodide could be vaporized from the ground and borne up by air currents (photo: mobile silver iodide smoker mounted on an Oldsmobile). Cloud seeding is effective in reducing cloud cover but its capacity to increase precipitation is controversial. How can one know, for example, how much precipitation would have fallen from a cloud had it not been seeded?*




*Repeat satellite images showing glacier retreat on Mount Kilimanjaro in the United Republic of Tanzania in 1993 (left) and in 2000. Last July, UNESCO's World Heritage Committee adopted a strategy for predicting and managing the effects of climate change on both natural and cultural sites, including Mount Kilimanjaro*

exploiting existing plant and animal resources; introducing crops and/or animals from other similar regions that might perform better than natives; or creating 'better' crops or animals through breeding or more advanced forms of genetic manipulation.

Some argued that larger animals were inherently more efficient than smaller breeds and favoured the camel as being 'ideal'; but the difficulty of expanding the market for camel products outside their traditional range was not discussed. It was generally agreed that more and better forage was the most critical element for livestock production. Thus, plant production became the primary focus both for rangelands and in agricultural fields.

Exotic plant species were seen as having great potential. A century or so of unwitting introductions had established that many plant species performed much better when introduced into areas outside their native range, particularly in areas with homologous climates. By 1956, there were programmes to reseed burned or degraded rangelands with exotic grasses.

Since then, exotic species use has been very controversial. In many areas, such as the Sonoran Desert of northern Mexico, large areas of native vegetation have been cleared and reseeded with exotic grasses (*see photo*). Many ranchers like their ability to colonize disturbed areas, outcompete native species and survive drought; they feel their land can now support more cattle. However, these very characteristics make these exotics undesirable in other parts of the region, where they are seen as a distinct hazard because they replace native species and introduce fire where it was previously unknown.

Many conventional crops are prodigious water users. There is a long history of seeking 'new' crops better adapted to arid conditions. Two different approaches to this search were discussed in 1956. One was to exploit native drylands plants with unique properties, like jojoba, a source of high-quality wax. The other was to selectively breed or engineer conventional crops for specific features, such as improved yield, drought tolerance, or disease resistance.

## The camel farm

Camels are often kept in excessive numbers in the open desert, putting a strain on desert vegetation. Camel farms may be the answer. By feeding camels farm-grown native desert plants, camel farms would enable the ecosystems of grazing rangelands to recover.

Camel farms could also reduce the amount of freshwater needed for milk production and save on electricity. Camel's milk does not need to be produced in an air-conditioned environment and a camel produces four times more milk per day (8 litres) in the open desert than a cow. (Cows can produce 25 litres of milk per day but only in an air-conditioned environment.) Producing native desert plants and halophytes as camel fodder would also use less freshwater than growing the *Alfa alfa* or Rhodes grass that camels currently eat.

One camel farm already exists in the United Arab Emirates, in Dubai. UNESCO's Doha office is developing a research project to study the pros and cons of establishing other camel farms.

Scientists working on the project will study such aspects as the nutritional and medicinal (dis)advantages of camel's milk versus cow's and goat's milk and the quantity of water needed to produce one litre of camel's milk in comparison to one litre of goat's and cow's milk. The project will also study public attitudes to camel milk.

Scientists will study whether camel fodder can reduce the production of freshwater-dependent Rhodes grass and *Alfa alfa* by using the full range of farm-produced native desert plants (*Cenchrus, Pennisetum, Panicum, Rhanterium*, etc.), which will also be studied to determine how each influences the taste of the milk.

They will also study the genetic variety of camels in different parts of arid lands to ascertain whether (and which) camels can be fed with indigenous or halophytic (salt-tolerant) plants and still produce milk that is of good quality and plentiful.


*Camels grazing rangelands in Qatar*

The availability of oil and water has changed the way of life of the Arab bedu in both desirable and undesirable ways. Camel farming could help not only to rehabilitate the desert they call home but also to pull them out of poverty.

*For details: b.boer@unesco.org*

## The green revolution

**Beginning in Mexico in the late 1940s, a host of advances were made in the development of improved crop varieties that were higher-yielding, more consistent in production and more resistant to pests. This led to the 'Green Revolution' in the 1960s, which helped to prevent famine in some parts of the developing world, including India. It did not benefit all people or all regions equally however. The Green Revolution has also drawn criticism for its focus on hybrid and genetically modified crops and the resulting loss of biodiversity, as well as for the health risks associated with the use of chemical pesticides.**

**In drylands, the first waves of the Green Revolution only reached areas that could be irrigated. Much of sub-Saharan Africa was largely bypassed. Part of this has been attributed to unreliable climate and lack of irrigation but also the inability of poor farmers to invest in the inputs, like fertilizers, that modern crop varieties demand. It has also been suggested that the late penetration of the Green Revolution into many of the world's drylands was due to a failure to invest in the exploration of local plant resources and establish appropriate local plant breeding programmes suited to marginal dryland environments.**

**Newer centres – such as the International Center for Agriculture in Dry Areas (ICARDA) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) – confronted these specific obstacles. In sub-Saharan Africa, improvements in crops like millet, sorghum and cassava began to produce results in the 1990s. However, the modest gains experienced in many dryland areas were offset by general decreases in major grain prices, placing many dryland farmers in a double bind. It has been argued that continued investment in research by the international community is the only way for these farmers to 'catch up' eventually.**

©ICRISAT

*Sorghum farmer in Burkina Faso*

By 1956, the work of the International Maize and Wheat Improvement Center (CIMMYT) had made Mexico self-sufficient in wheat production; this success spurred even greater interest in the genetic approach to increasing crop production (*see box above*).

Both these approaches have their limitations. During photosynthesis, plants take up $CO_2$ from, and give up water to, the atmosphere. This presents two constraints. Firstly, while plants can be engineered to be more water-efficient, there are fundamental limits to what can be achieved. Secondly, the adaptations many dryland plants have to reduce water loss also restrict their ability to take up $CO_2$: many desert plants are not particularly water-efficient.

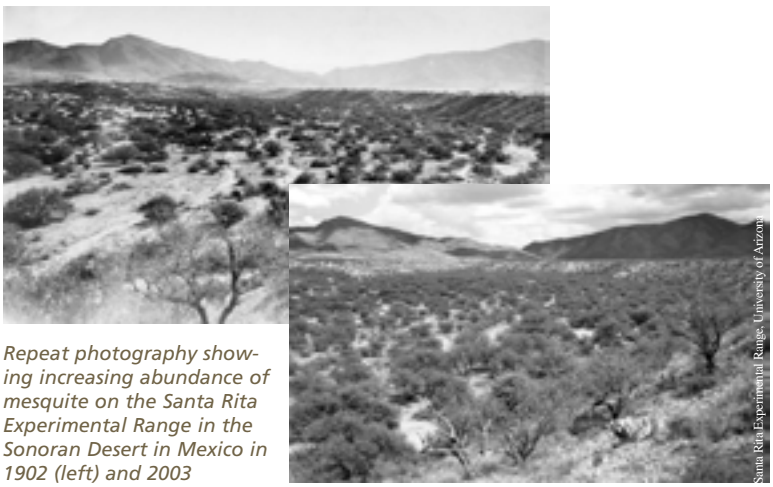
Furthermore, some dryland plants, such as jojoba, will not produce fruit during drought; if a crop is desired every year – something farmers expect – the plants must be irrigated often, thus negating some of their presumed drought-adapted advantage.

A third approach to using dryland plants was discussed in 1956 but has only really emerged over the past few decades. Dryland plants produce unique chemical compounds to deal with competition, heat, drought stress and predation. There are now programmes to discover and characterize compounds produced by dryland plants and associated microbes, to determine whether they have value for treating diseases such as cancer and HIV/AIDS.

Discussion in 1956 focused on identifying one crop, or some small suite of crops, that might transform dryland agriculture. Since then, research and development have come to focus not only on improving the plant and its environment through irrigation, fertilization and pest management but also on improving rural livelihoods and the physical, social and economic well-being of households and communities.

### Greening the desert

In 1956, the dominant strategy was to 'green the desert' by developing primarily surface water resources and extending large-scale irrigation systems to all lands that could be economically included. There was little concern with environmental and social impacts or water use efficiency. Maximizing the area under rainfed agricultural production was also a priority. However, it was understood that, because of climate variability, extending rainfed cropping into lands that had been previously devoted to grazing was risky. There was a great deal of concern in 1956 over possible negative impacts of traditional land use systems on drylands, particularly in developing countries. Livestock production, especially pastoralism, was clearly considered less desirable than cultivation and needed to be made more productive through the use of modern range management techniques. This, however, might involve 'improvement' by removing undesirable



Santa Rita Experimental Range, University of Arizon

*Repeat photography showing increasing abundance of mesquite on the Santa Rita Experimental Range in the Sonoran Desert in Mexico in 1902 (left) and 2003*

## Scientists pick priorities for curbing desertification

**Each year, US$2.4 billion is spent fighting land degradation in the world's drylands, a problem experts believe is likely to worsen. On 21 June, 400 scientists, experts and decision-makers from these regions identified research priorities in the Tunis Declaration. The Declaration was adopted at the close of a three-day meeting co-organized by UNESCO on The Future of Drylands, a landmark in the International Year of Deserts and Desertification. Areas of research singled out by the Declaration include: the interdependence and conservation of cultural and biological diversity, integrated management of water resources, the identification of sustainable livelihoods for the inhabitants of drylands, renewable energy suitable for dryland development, coping with and management of natural and man-made disasters and the costs related to inaction in fighting land degradation.**

*Read the* Tunis Declaration: *www.unesco.org/mab/ecosyst/futureDrylands.shtml*

Courtesy of Chris Reij

*Tourist accommodation in Dana Biosphere Reserve (Jordan) at dusk. Ecotourism is one of several income-generating activities being fostered by the Sustainable Management of Marginal Drylands (SUMAMAD) project run by UNESCOMAB and the UNU. Other activities in Dana Biosphere Reserve involve the production of olive oil soap and jewellery-making for women specifically. In parallel, the project is improving the way in which irrigation is managed*

vegetation through mechanical or chemical means and/or a reduction in stocking rates so that vegetation might recover. Either alternative was, and still is, expensive and probably not suited to developing countries.

Since then, strict distinctions among agricultural land uses have blurred. Agricultural research and development has focused increasingly on each use as one part of a larger system, thus exploiting synergies among these, such as agro-silvopastoralism. The value of land has also come to be determined by other considerations, including environmental, historical, social, cultural and spiritual values.

Attention has also been drawn to the negative consequences of some of the modern methods put in place decades earlier. The potential of salt accumulation in the soil was well recognized in the 1950s and the basic concepts of salinity management were known but solutions, such as drainage systems, were expensive. It was also believed that the process was easily reversed. Salinity management continues to be the main challenge facing irrigated agriculture. Furthermore, as concern grows over land degradation and desertification, large irrigation schemes are often viewed sceptically for their high financial, social and environmental costs and their potential to damage other sectors like fisheries, particularly in developing countries.

©Chris Reij

*Rainwater harvesting in Burkina Faso using lowcost hand-constructed structures*

Considerable progress has been made in increasing the efficiency of water use. Centre-pivot irrigation spread quickly from the 1960s onwards. In this system, sprinklers positioned on pipes rotate around fixed points (pivots) to irrigate circular fields. This technology allowed comparatively inexpensive irrigation virtually anywhere where water was available. It also allowed irrigation of a wide variety of terrains. Other advances have been made in conventional irrigation. On large scales, land levelling has greatly increased water use efficiency. On small scales, the development of small portable pumps has allowed many farmers to ensure production during dry spells and to increase the number of cropping seasons per year. Development of drip irrigation has also increased water use efficiency, particularly in developed countries.

More recently, micro-irrigation techniques, which involve drip irrigation using buckets and inexpensive tubing, offer multiple potential benefits for small farmers in developing countries in terms of increasing yields while decreasing water, fertilizer and labour requirements.

In developing countries, rainwater harvesting through low-cost hand-constructed water control structures (*see photo*) is also receiving renewed attention as a means of promoting local self-sufficiency, reducing poverty and increasing food security where irrigated agriculture is not feasible. Such solutions are seen as potentially more sustainable, being based on local technologies and materials and generally requiring little cash investment.

As our skill in near-future weather prediction improves, more adaptive management policies will probably be required. For example, if we can predict good or bad growing seasons six months into the future, mechanisms must be in

©UNESCO

*This plant in flower in Qatar is a* Limonium axillare, *also known as beach lavender. It has a high salinity tolerance, making it a 'halophyte'. Scientists are studying ways of breeding halophytes and turning certain halophytes into agricultural crops. UNESCO's Doha office supported the publication this year of* Biosaline Agriculture and Salinity Tolerance in Plants

place to advise and allow farmers and livestock operators to adjust their cropping or stocking strategies accordingly.

The primary objective in 1956 was to do 'better.' This implied more water and more agricultural production. Many development threads pursued after 1956 were clearly unsustainable, such as the exploitation of fossil groundwater in North America, North Africa and the Arabian Peninsula. Much of the improvement in system performance over the past 50 years may be technical, such as improved crop varieties but a great deal may also be related to policy, including trade, subsidies and tariffs.

### Why invest in drylands research?

**Firstly**, the problem described by Malthus[6] 200 years ago has not gone away. Over the next 40 years, the world's population will increase by 50% to 9 billion. Drylands constitute about 41% of the Earth's surface and will have to play a greater role in meeting these growing demands over the long term.

Most population growth will occur in developing countries, much of that in drylands and the bulk in urban areas. The challenge will be to develop safe, secure urban water supplies without causing undue harm to the agricultural sector – which would further encourage urban migration – or damaging the ability of the environment to provide goods and services for future generations. One opportunity is the reclamation and use of urban wastewater streams. Policy must acknowledge wastewater and stormwater as increasingly important resources.

**Secondly**, from a more immediate environmental perspective, it can be argued that significant parts of the world's drylands are the source of potentially serious global problems. Dust from the Saharo-Sahelian region of Africa and the drylands of central Asia is transported over continental scales and is of global concern. Dust from central Asia causes health concerns not only in China and Japan but also in North America. Dust from Africa may be contributing to the decline of coral reefs in the Caribbean.

## Quranic botanical gardens for the Arabian Peninsula

**Botanical gardens are lacking in the Arabian Peninsula, despite their obvious value for conserving plant species ex-situ and the centuries old Islamic tradition of botanical studies.**

**Together with a team of architects, botanists, engineers, phytochemists and Muslim scholars, UNESCO's Doha office has designed a project to create a network of botanical gardens which will pay tribute to ancient regional traditions and cultures. These botanical gardens will display living plants mentioned in the Holy Quran, such as date palms, pomegranates, figs and grapes. They will also exhibit plants of importance to Islam, such as the medicinal plants used by the Prophet Mohammed and cited in his Sayings.**

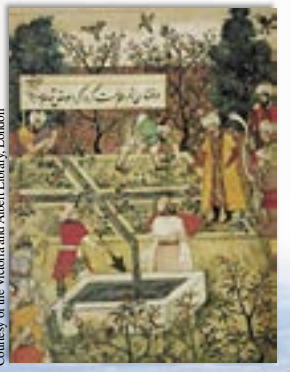
**The gardens will educate the public about the need to preserve biological diversity. The victim of habitat loss, oil spills and inadequate livestock management practices, the flora of the rapidly developing Arabian Peninsula is in dire need of better protection from human influences.**

**The plans for the botanical gardens will respect the two major landscaping concepts of the Islamic gardening cultures. The first is based on typical desert environments, such as the Arabian concepts of wadi, baadiya, raudhas, sandy area and oasis. The second is characterized by planned gardens, such as the Persian concepts of sunken flowerbeds, *gulistan* (flower garden), *bustan* (orchard) or the quadripartite *chahar bagh*.**

**The core of the gardens will feature an orderly display of plants arranged in four quarters and divided by water canals, with a water fountain or basin at its centre. The plan of this core will be enriched by sunken flowerbeds, an ingenious traditional system motivated by the need for irrigation to reduce soil evaporation and plant transpiration.**

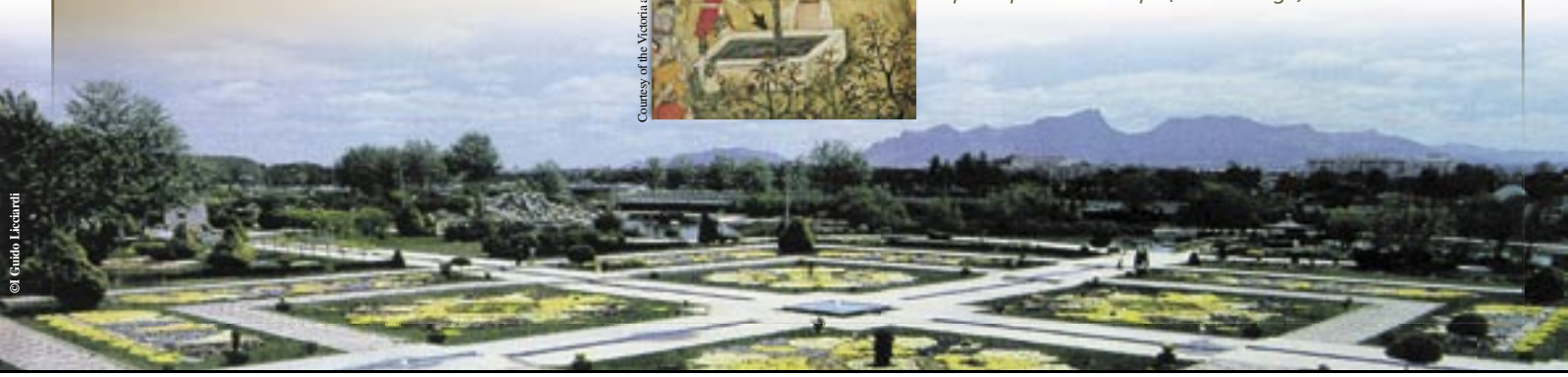
**Around the core, each garden will conserve plants from different regional ecosystems. It will grow plants found on the coast, in mountainous regions, sandy areas, gravel deserts, the *wadis*, oases and aquatic habitats, as well as agricultural plants and halophytes (salt-tolerant plants). The project will be implemented over the coming year. Funds in trust agreements and workplans for each of the gardens are currently being discussed with potential donors.**

*For details, contact in Doha: h.al-hammami@unesco.org*



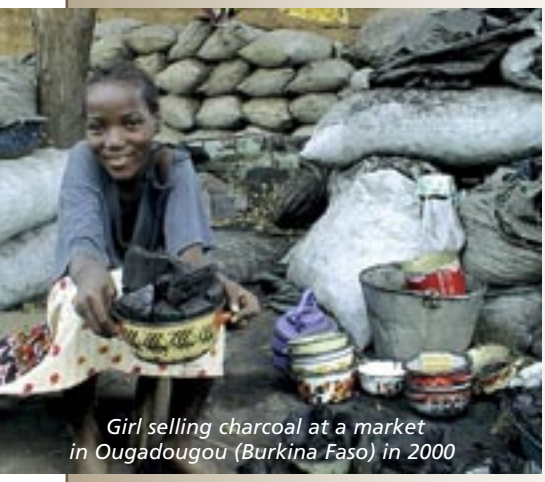
Courtesy of the Victoria and Albert Library, London

*(Left) The Emperor Babur supervising the construction of a garden illumination in the Baburname scroll (Below) Modern garden in Isfahan (Iran) based on the traditional quadripartite concept (*chahar bagh*)*



© Guido Licciardi

## Fighting desertification with solar power



*Girl selling charcoal at a market in Ougadougou (Burkina Faso) in 2000*

© B.benchikh/UNESCO

Firewood remains the main source of energy (80%) in sub-Saharan Africa, where it is used primarily for cooking, lighting and heating water. People used to collect deadwood but, with the decline in tree cover, they are now having to resort to living trees. This practice, combined with the pressures of population growth, slash and burn land-clearing for agriculture and recurrent drought, is decimating Africa's forests, 10% of which are expected to disappear within the next 20 years.

In the Sahelian zone, the wind easily erodes the soil today because there is little vegetation to anchor the soil. The Eden Foundation, a Swedish NGO active in Niger, has observed that sand dunes can even be found in villages 200 km south of the Sahara, not because they have blown in from the north but because they have formed locally from eroded soil in places where trees have been felled to make way for annual crops like millet. The Director of the Department of the Environment in Niger was cited by the Eden Foundation in 1992 as saying that '250 000 hectares (equivalent to an area the size of Luxembourg) are being lost each year in Niger through desertification'. The Director added that 'firewood destined for the town of Zinder is collected up to 200 km away.'

Pilot projects have been run in recent decades to heighten awareness of the benefits of substituting wood for sustainable forms of domestic energy. In Africa, UNESCO's Renewable Energy Programme is supporting pilot projects to create 'solar villages'. Last year, UNESCO helped the Governments of Burkina Faso and Mali to install solar electricity in public facilities in remote villages, including rural health care centres and maternity hospitals. Particularly needed in the maternity hospitals was solar water heating to improve hygiene and thereby protect mothers and their newborn babies from life-threatening infections.

*For details: o.benchikh@unesco.org*

*Women in Mauritania using a solar cooker outdoors. In harnessing the sun's energy to cook food, solar cookers do away with the need to burn wood. They also save lives; every year, thousands of women die from inhaling poisonous carbon monoxide fumes given off by wood-burning in poorly ventilated dwellings*

© B.benchikh/UNESCO

There is growing concern among researchers about potential effects of dryland dust on global climate as a result of reflection, scattering and absorption of solar radiation, and on cloud formation and precipitation.

**Thirdly**, from a global economic perspective, drylands have largely been marginalized. This is partly due to their physical isolation but is also a function of their lack of economic, political and social leverage within their respective countries. In some drylands that possess energy or other mineral resources necessary for global industry, this is not the case. In the future, due to their favourable location,climate,lack of competing land uses and correspondingly low land prices, drylands may also play a central role on the renewable energy stage as solar technology improves and costs decline. It is conceivable that drylands may enjoy other increasingly competitive advantages as suppliers of specialty crops or tourist destinations. Perhaps most importantly, it has now been shown that potential returns on investment in drylands are higher than in more humid areas.

**Lastly**, globalization is about more than just economics. There are issues of equity. Currently, 20% of the world's population consumes 85% of the world's resources. Many of the problems enumerated here are rooted, at least partially, in poverty. Between 1997 and 2020, a combination of poverty and a deteriorating environment are expected to drive 60 million people from the desertic areas of sub-Saharan Africa towards northern Africa and Europe. Both environmental sustainability and the eradication of extreme poverty and hunger are Millennium Development Goals.

Charles F. Hutchinson and Stefanie M. Herrmann[7]

5. *In 1956, the American Association for the Advancement of Science (AAAS) published* The Future of Arid Lands*. Edited by Gilbert White, it contains papers presented to international meetings of experts in New Mexico in 1955 to develop a research agenda on arid lands. The meetings were organized by the AAAS and sponsored by UNESCO with support from the Rockefeller Foundation*
6. *Thomas Robert Malthus was an English demographer and political economist best known for* An Essay on the Principle of Population *(1798). He predicted that population would outrun food supply on the basis of the idea that, if unchecked, population increases at a geometric rate (i.e. 2, 4, 8, 16, 32, etc.), whereas food supply grows at an arithmetic rate (i.e. 1, 2, 3, 4, etc.)*
7. *Both authors of* The Future of Arid lands – Revisited *are affiliated to the Office of Arid Land Studies at the University of Arizona (USA)*

# The **solar school**

**Alassane Agalassou is one of 26 technicians, engineers and project personnel designated by their governments or institutions to take part in this year's edition of UNESCO's annual summer school organized over a three-week period every July. This year's theme was Solar Electricity for Rural and Remote Areas. In tandem with a series of regional workshops, these annual 'schools' on solar electricity are helping to train skilled personnel, boost public awareness and promote relevant energy policies.**

© Osman Benchikh/UNESCO

*Electrical cabling of solar panels and the installation of solar systems by participants as part of practical field-work organized by UNESCO in Bamako (Mali) in 2003*

Over the past 15 years, over 500 trainees have 'graduated' from the summer school. They have gone on to become trainers themselves in more than 50 countries situated mainly in Africa but also in Europe and beyond, including Bolivia, Brazil, Canada, Colombia, Germany, Guatemala, Lebanon, Turkey and Vietnam.

Alassane Agalassou is employed by the Agency for the Development of Rural Electrification and Domestic Energy (AMADER) in Bamako (Mali) to give peri-urban and rural populations better access to modern electrical services, such as home lighting, refrigeration, television and radio. 'AMADER is facing the vital challenge of bringing modernity and hope to the majority of Malians through its decentralized electrification programme', Agalassou explains. 'You must understand that, in my country, only about 10% of the 11 million inhabitants live in communities with electricity'.

Agalassou intends to use his new knowledge of the economic and technological aspects of solar photovoltaic conversion to design and implement projects that will improve living conditions and health by making food production and conservation more efficient and more hygienic in a country where temperatures can soar into the forties.

The summer school targets men and women with technical or university training who are involved directly or indirectly in decentralized electrification using solar energy. The training programme covers both theoretical and applied aspects of solar energy conversion and is taught both by experts and by representatives of industry and specialized institutions.

Initially, the summer school included visits to research centres, industries and installations in France only. Since 1992, the financial and practical support of external partners has made it possible to venture as far afield as Belgium, Germany, Spain, Italy and Morocco for a series of technical visits which last a week on average. The remainder of the course is taught at UNESCO Headquarters in Paris.

© Osman Benchikh/UNESCO

*Participants learning to use sizing software to determine the exact energy needed for a given project, during a one-day practical session at this year's solar school*

*Practical training to assess solar radiation and simulate a solar installation. This session was organized at the CDER in Morocco during the 2001 summer school*

## What is solar energy?

Solar electricity is the result of the photo-electric (or photovoltaic) effect discovered in 1839 by the French physicist Edmond Becquerel. Photovoltaic cells convert the luminous energy of the sun into electricity. Most of the solar cells used are actually made of silicon.

Photovoltaic cells produce a voltage of approximately 0.6 volts (V) which is not dependent on the surface of the cell, unlike the electric current produced. To obtain a higher voltage, cells are linked up in a series to make a module which is the sum of the individual cells. The modules produce an unbroken current, the standard voltage for a commercialised module being 12 V. Depending on the installation needs, the modules can be connected in series to obtain a higher voltage. The most frequent voltages used in photovoltaic installations are 12 V, 24 V and 48 V. In general, the power produced by the modules is expressed in Watts (W), which corresponds to 10 W, 50 W, 75 W or 120 W for the commercialized ones.

In the early 1960s, solar conversion took off thanks to spatial applications. Since then, solar energy has expanded to include such applications as rural and decentralized electrification, water pumping and health and telecommunications; in other words, it goes everywhere the electricity network does not.

At isolated sites, the average cost of a complete solar installation (including batteries for storage) varies between 15 euros (excluding TVA) per Watt (for power of 1.5–2 kW) and 40 euros per Watt (for 200–400 W).



*Solar-powered refrigerator used to conserve vaccines in health-care centres in rural and isolated areas. This technology was one of the subjects of this year's solar school*

### Modules *à la carte*

The course is structured by modules to enable specialists from different fields to choose the lecture of interest to them *à la carte*. Decision-makers, energy managers and others are thus able to choose whether they participate in a specific aspect of practical work, in a technical visit or in a given roundtable discussion.

Mahamat Oumara from Tchad is grateful to have refined his knowledge of photovoltaic technologies. But for him, the contacts he has made through the summer school are equally valauble. His only regret is that, 'if we had better equipment in our own laboratories to test essential materials, we could do a better job of spreading the technology.'

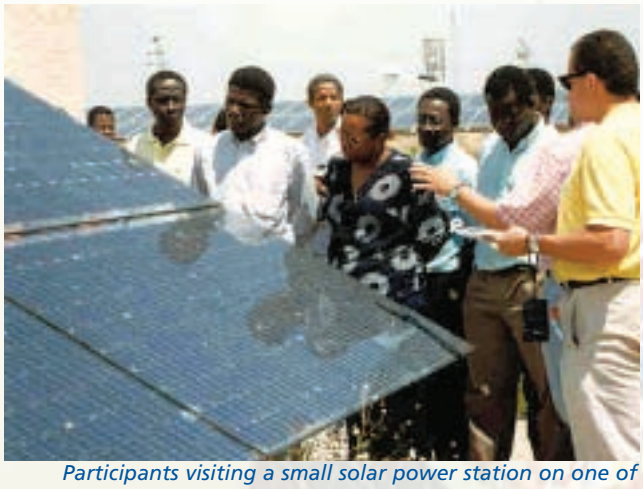
'One of the greatest obtacles to developing renewable energies in our countries', Oumara adds, 'is the dearth of relevant information at all levels. This affects not only decision-makers and users but also those engineers and technicians who lack the necessary know-how. The local rural population would benefit from well-trained project managers', he notes. 'Good project management extends a system's lifespan and leads to cost-savings, not to mention better use and maintenance of the systems once these are installed. Similarly, a good engineer will design a better project and thereby increase the chances of attracting funding. He or she will also tailor the system better to the needs of the end-user, which can translate into cost-savings for the rural population'.

### Demystifying solar energy

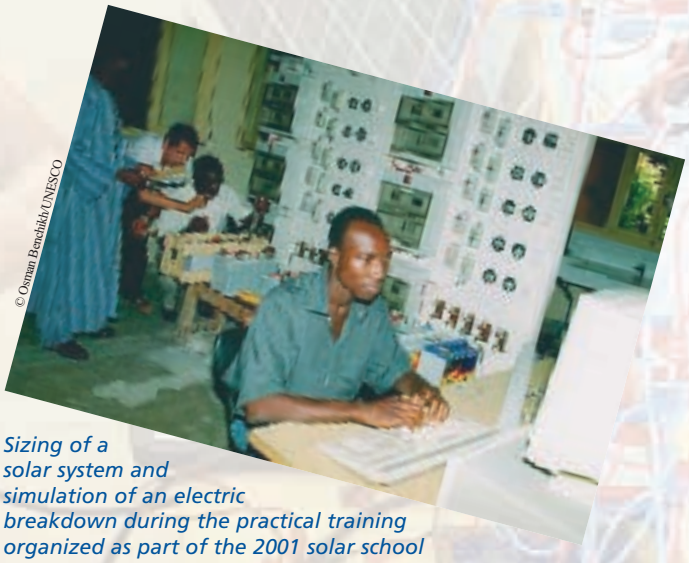
Along with three other French industrialists, René Desserrières of French Solar Manufacturers Photowatt has lectured at the school for the past three years. 'We always know about 20% of students,' he says 'which can make for animated discussions about existing installations and component parts between manufacturers and users, who really get down to the nitty-gritty.'

Desserrières explains that the summer school is an excellent complement to other training activities which are more closely linked to specific projects. 'The UNESCO course is given in another spirit,' he says. 'It aims at a higher level of engineer and technician. Despatched by their countries or a local or regional institution, these young people will eventually play an important role in designing and implementing rational energy policies, hopefully avoiding the errors of the past when it comes to planning and project management in particular. The summer school promotes a realistic approach which debunks the myths and demystifies solar energy'. He observes that, 'Both sides need to treat one another like partners. Some experts in developing countries regard us as nothing more than the suppliers of a technology they would like to see transferred without delay.'


*Using a platform to simulate a solar system in 2002. This training platform was developed by UNESCO in collaboration with the French agency, ADEME*




*Participants visiting a small solar power station on one of several technical visits organized in Spain during the 2001 summer school on the same theme of 'solar electricity for rural and remote areas'*




*Sizing of a solar system and simulation of an electric breakdown during the practical training organized as part of the 2001 solar school*

For Desserrières, the manufacture of photovoltaic cells remains too sophisticated and costly to transfer. 'Nevertheless,' he relativises, 'developing countries can produce other components and, by developing solar electricity, reap 80% of the benefits, create jobs and improve the standard of living in their rural communities.'

Many regional institutions send engineers and technicians to UNESCO's summer school. These include the Centre for the Development of Renewable Energies (CDER) in Algiers (Algeria) and the National Centre for Scientific and Technical Research (CNRST) in Rabat (Morocco). 'For our higher level people,' says Abdelaziz Bennouna, head of the renewable energy laboratory at CNRST, 'the course is excellent from many points of view; it keeps us abreast of what is going on in the field, we meet key people, form contacts with top-level faculty members and, last but not least, meet specialists from other regions'.

## People are in the market for energy

Almost two billion people in rural Africa and elsewhere still lack access to basic electrical services. 'It is very sad to see, in this new millennium, most of the rural population in the developing world still using candles and petrol lamps', laments Bennouna. He regrets the lack of technological autonomy in even those countries which use and apply renewable energies on a massive scale. For Bennouna, 'solar cells and silicon are unfortunately not going to be produced and manufactured in the foreseeable future. The industrial process for solar cell production calls for high technological know-how and sophisticated technology that needs a large market to be profitable and economically viable. '

'This said', he adds, 'enormous progress has been made. In some countries today, solar system components are being locally manufactured, commercialized and even exported. In Morocco for instance, solar systems are sold in the market-place by local merchants along with fruit, spices and other goods. Mentalities have changed. People are now in the market for energy; they are purchasing their own 'solar kits' in much the same way they would buy a television set or refrigerator. This is one way in which solar technology is trickling down to the end-user and becoming a household name'.

Osman Benchikh

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# Osman Benchikh

## 'The age of renewables has now begun'

**With global oil consumption expected to rise by 2.5 million barrels a day this year, largely due to China's growing needs, and with oil production struggling to keep up with demand, last June's conference on renewable energies in Bonn could not have come at a better time.**

**In his opening remarks, German Federal Minister for the Environment Jürgen Trittin declared that 'the age of renewables has now begun'. Germany has been the undisputed world leader in wind energy since the early 1990s, solar energy being dominated by Japan. In Bonn, Germany reaffirmed its determination to help countries of the South adopt clean forms of energy by pledging to add a further US$500 million per year for five years in interest-free loans to the US$1 billion announced two years earlier at the World Summit on Sustainable Development – almost as much as the World Bank. This spectacular initiative is one of many commitments to renewable energy made in Bonn by individual countries, including the Philippines and China, evoked below.**

**But should we rejoice at a declaration adopted by 154 governments which contents itself with noting the targets individual countries have set themselves rather than fixing any financial targets of its own? Responsible for renewable energy at UNESCO, Osman Benchikh has his own views on the subject.**

**Neither the escalating price of oil[8], nor the problems linked to its geostrategic importance seems to have caused an 'electroshock' in the international community in Bonn. Does that make the conference only a semi-success?**

Bonn may yet prove to have been a milestone in the history of renewable energy. Representatives of 154 countries, including 120 Ministers and several Heads of State, sat down in Bonn to discuss renewable energy issues. In that sense, the conference did meet its objectives by raising public awareness. Bonn has shown that the international community is now seriously considering renewable energy as a rational and credible alternative. This growing awareness has led the international community, and the developed countries in particular, to make a firm commitment to renewable energy in recent years. In Europe, wind power grew by more than 35% annually between 1996 and 2003; last year, the photovoltaic sector grew by 33%. Today, the European renewable energy industry has a turnover of 10 billion euros and employs 200 000 people.

Osman Benchikh

It is true that the final outcome of the Bonn Conference – the political declaration – is weak. Concrete commitments are still missing and it sets no targets. I do believe, though, that the history of humanity is a fairly long process and that some countries are simply not yet ready to make a more ambitious commitment.

If I may go back for a moment to the World Summit on Sustainable Development, in order to set targets, the Summit identified five key areas for sustainable development: water, energy, health, agriculture and biodiversity. Two years on, what are we saying? That energy is a key component of development and that, if countries are serious about sustainable development, be they developing or developed, they have no choice but to consider renewable energy as an essential element of sustainable development. The very act of organizing this conference, which has drawn a massive participation by government representatives, makes it a success in my eyes.

**Could some of those countries which are not yet ready to commit be thinking of nuclear power as an alternative to oil?**

I don't think so. In any case, as much as 56% of oil is absorbed by transportation and you can't propel a plane with nuclear power – at least for the time being. Even if electric buses and cars do exist, they remain a rare sight because they can only operate over short distances.

Don't forget that the technology and use of nuclear energy call for know-how and capital that remain accessible to only a small number of industrialized countries.

8. *The price of oil had already climbed to over US$40 a barrel by the time the Bonn conference took place. By 20 August, it was nudging towards US$50, a 50% increase since the beginning of the year*

**Would you say that it was largely the developing countries which set an example in Bonn? I am thinking of China, which committed in Bonn to using renewable energy for 10% of its needs by 2010. China has of course also ratified the Kyoto Protocol.**

With a galloping economy, China needs to consume a lot of energy. It is indeed very significant that China should have committed to using renewable energy for 10% of its needs. After all, one in five human beings is Chinese.

In my opinion, we shouldn't link the development of renewable energy systematically to the Kyoto Protocol, even if it is true that mastering energy is the first step towards protecting the environment. If, for the developed countries, renewable energy represents an option for the future which will enable them to diversify their sources of energy, protect the environment and possibly avoid conflicts and tensions linked to the quest for energy, it remains only one of several options.

For the developing countries, on the other hand, it is their only option. That is a big difference. It is their only option at this time if they are to access a minimum of comfort and modernity. Thus, there is a 'converging antagonism' here, with North and South sharing complementary interests.

For the countries of the South, the environmental issue is important but I must stress that there are other priorities for these countries which are equally urgent, if not more so. Nothing is more urgent than giving a minimum of energy to those who have none at all and who unfortunately represent more than one-third of the world population.

**If renewable energy is so important for the South, why does the World Bank finance renewable energy 20 times less than gas, oil and coal?**

The World Bank is first and foremost a bank and a bank acts in its own interests. When making an investment, a bank will endeavour to ensure a return on that investment.

I don't think we should be guided by a purely economic approach. That eclipses any form of solidarity. I am pleased to see that the European Investment Bank has decided that half of the loans it issues between now and 2010 will go to renewable energy.

I should stress that the World Bank is increasingly financing renewable energy projects, further proof, if such were necessary, of the economic viability of renewable energy.

**For you, what is the 'ideal' threshold which rich and poor countries should target in terms of renewable energy use?**

I don't think there can be an identical threshold for all countries. Even if we confine ourselves to the developing countries, we have to distinguish between those which enjoy fairly good electrification and those which do not. For countries with a large population not connected to the electricity grid, renewable energy represents the most valid option today. African countries are a case in point. In Africa, *circa* 72% of the population lacks access to electricity. This proportion can only increase, given that the continent's population is growing faster than the grid's outreach. As I said, for those countries with a large population deprived of the grid, 40% electrification using renewable energy would be an appropriate threshold in my view.

In this connection, I should like to cite the example of the Government of the Philippines, if I may. The government has set itself the goal of raising the share of renewable energies in the total energy capacity by 100%, to 4 700 MW, or around 40% of national energy consumption, by 2013.

As for Europe, the target fixed in 2002 of doubling the share of renewable energies in the European Union energy sector to 12% by 2010 strikes me as a realistic objective. Towards 2050, I think renewable energies should represent a share of around 40% of the energy sector in the industrialized countries.

It could be useful to establish viable scenarios for the medium and long term for the optimum use of renewable energy. An independent group could reflect on the question, in order to define and propose the best energy future possible for our children and their children.

**Are you suggesting creating a panel on energy, in much the same way the UNDP and WMO set up the Intergovernmental Panel on Climate Change in 1998?**

UNESCO tabled just such a proposal in Bonn. The Organization joined the German Minister of Education and Research in organizing a Science Panel, which consisted of an entire day devoted to science, research, development and human resources. The proposal to create an expert panel to advise and orient States on energy figured among the day's conclusions.

The same Ministry has committed to financing a second UNESCO proposal for the setting-up of an 'open university' on renewable energy. This virtual university would function via existing centres in the North and South. As lead agency, UNESCO will be launching the initiative next year, hopefully with other partners.

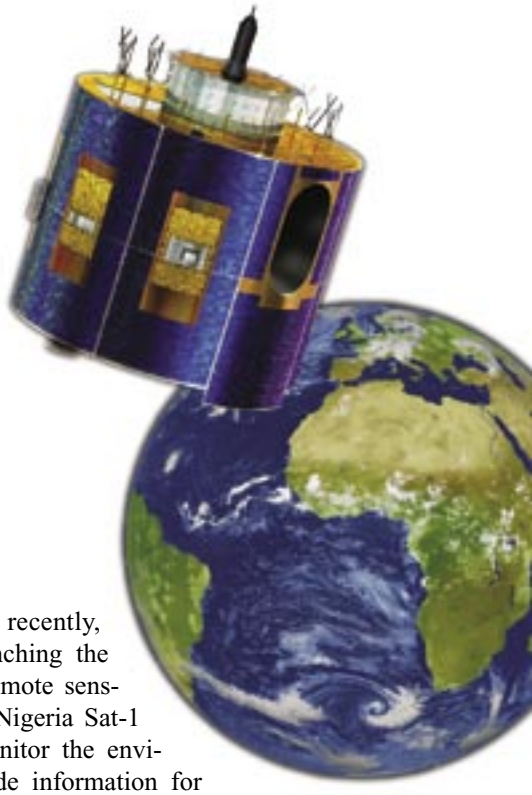
I am convinced that these twin initiatives will garner the support they need to get off the ground. During the current wave of consultations of the National Commissions for UNESCO conducted by the Director-General, the regions consulted thus far, namely Africa, Latin America and the Caribbean, and Asia and the Pacific, have all proposed that renewable energy be one of the priorities for the Organization's next Programme and Budget covering 2006–2007.

This leaning towards renewable energy is nothing new. Since its inception, UNESCO has been a pioneer in promoting and developing renewable energy. As far back as the 1950s, UNESCO advocated developing arid zones within a programme by the same name, through the use of renewable energy in general and wind and solar energy in particular.

Interview by Susan Schneegans

*For details of the Bonn conference: www.renewables2004.de*

# A system for **managing the planet** by 2015



**On 25 April 2004, the second Earth Observation Summit in Tokyo (Japan) moved a step closer to a global information system for 'managing the planet' with the adoption by Ministers of the *Framework* for a 10-year implementation plan. While not legally binding, the *Framework* represents a strong political commitment by 47 governments and the European Commission to putting in place comprehensive, co-ordinated and sustained observation of the Earth by 2015 within a Global Earth Observation System of Systems (GEOSS).**

On the face of it, this may seem like nothing new, since many international organizations and programmes are already working to sustain and improve co-ordination of Earth observation systems, such as within the Integrated Global Observing Strategy partnership. However, efforts have been hindered up to now by an ambivalent attitude on the part of governments. Even in the wealthiest countries, technical infrastructure has been eroding for want of a sustained commitment to Earth observation and space agencies have been feeling the pinch.

Times are changing. Governments are coming to appreciate the importance of Earth observation for planning sustainable development. This first became apparent at the World Summit on Sustainable Development in Johannesburg (South Africa) in 2002. The G8 meeting in France in June 2003 then went on to identify Earth observation as the highest scientific priority for the coming years. This in turn led to the first Earth Observation Summit in Washington (USA) the following month where 33 countries and the European Commission committed to preparing a 10-year implementation plan.

A technical Group on Earth Observations (GEO) was formed. Co-chaired by the USA, European Commission, Japan and South Africa, and joined by more than 21 international organizations including UNESCO and its Intergovernmental Oceanographic Commision (IOC), the GEO is to prepare the implementation plan. Now that the Framework has been approved, the next step will be for the GEO to translate this document into a detailed plan for presentation to the third Earth Observation Summit in February 2005.

GEOSS will build on existing systems, including those of individual nations, the joint Global Monitoring for Environment and Security of the European Union and European Space Agency, and initiatives within the United Nations system.

Half of the 47 governments at last April's Summit represented developing countries. This is logical because countries of diverse financial means have invested in Earth observation satellites, from the USA, Japan and France to India, China, Vietnam, Argentina, Brazil, Algeria, South Africa and, most recently, Nigeria. Since launching the Low Earth Orbit remote sensing micro-satellite Nigeria Sat-1 last October to monitor the environment and provide information for infrastructure development, Nigeria has been welcomed into the fold of the Disaster Monitoring Constellation grouping Algeria, China, the UK and Vietnam. Natural hazards being unpredictable phenomena, membership of the constellation multiplies each country's chances of being overflown by one of the five satellites at the 'right' moment and thereby of reducing reaction time.

It is also logical that countries which do not possess their own satellites should be part of GEOSS. For one thing, they are regularly overflown and remotely sensed by satellites yet currently have only limited access to the data collected, a situation obviously unsatisfactory for them but also for developed countries which themselves have a stake in making Earth observation more inclusive. If we are to understand the natural processes involved in such long-term phenomena as climate variability, desertification or natural hazards and improve prediction, this will demand comprehensive, sustained global observation both by satellites and *in situ* (on land and at sea) over several centuries. We know from instrumental records dating back to 1861, for example, that the increase in surface temperatures in the Northern Hemisphere during the 20th century surpassed that of any other century for at least 1000 years. But we are hampered in making a global assessment by the fact that insufficient records exist for the Southern Hemisphere.

'For GEOSS to achieve its objectives', Ambassador Ben Ngubane of South Africa told the April Summit, 'it is vital that membership include more representatives from developing countries [...] Integration of regional initiatives such as NEPAD into the development of GEOSS will be critical in this regard. It is ultimately essential for the GEO to interrogate and resolve issues such as the availability of Earth observation data to developing countries at minimum and affordable costs.'

### An information management system for our planet

Ben Ngubane was outlining South Africa's expectations of GEOSS on behalf of Phumzile Mlambo–Ngcuka, Minister of Arts, Culture, Science and Technology. 'Over the past 20 years', he noted, [...] 'we have made strides in establishing credible political structures to promote compliance with science-based global sustainable development criteria. This [...] is exemplified by the phenomenon of the 'ozone hole', where detection, an understanding of causality and an effective remedy mandated by international political structures were separated by little more than a decade[9]. What is missing then? To avoid our successes being limited to a series of *ad hoc* examples such as that of the ozone hole, we need what the business world calls a management information system, [...] founded on broad global benefit principles and monitored according to internationally accepted indicators amenable to reliable and affordable scientific measurement. Our vision for GEOSS is that it should be the information management system for our planet'.

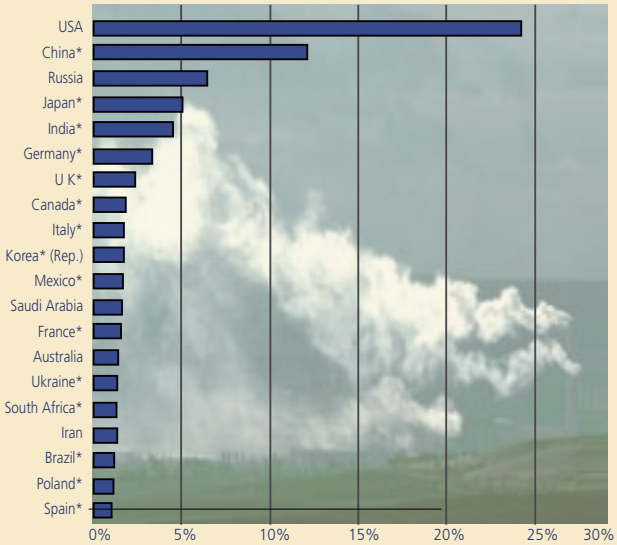
## The current status of the Kyoto Protocol

Negotiated by over 100 countries for more than a decade, the Kyoto Protocol calls for the 38 largest industrial nations to reduce their emissions of greenhouse gases to 5.2% below 1990 levels by 2012.

As of April 2004, 122 countries responsible for 44.2% of the world's $CO_2$ emissions had ratified the Kyoto Protocol, the most recent additions being Israel (March 2004) and Ukraine (April 2004). Since the Protocol must be ratified by countries representing 55% of world $CO_2$ emissions before it can come into force, the Protocol's successful implementation will depend upon the ratification by one or more of the 12 remaining Parties to the UN Framework Convention on Climate Change.

*For details of the Kyoto Protocol: http://unfcc.int*

The top 20 $CO_2$ emitters (2000)




Source:http://cdiac.esd.ornl.gov/trends/emis/graphics/top20_2000.gif

* has ratified the Kyoto Protocol
N.B. All but Iran and Saudi Arabia are parties to the UN Framework on Climate Change

### Furthering implementation of environmental treaty obligations

Besides improving understanding of dynamic Earth processes and enhancing prediction, the GEO has the stated ambition of furthering implementation of environmental treaty obligations. Examples in recent years are the Convention on Biological Diversity adopted at the Earth Summit in Rio in 1992, the Convention to Combat Desertification of 1994 or the Kyoto Protocol (*see box*).

As Eric Vindimian of the French Ministry of Ecology and Sustainable Development explains, 'the act of participating in the GEO does not imply a desire to ratify treaties. But the fact remains that the ambition of GEOSS is to develop tools which enable us to observe the planet and that these tools are designed to respond to the needs of the major users, in other words the governments; it is they who most need to know what state the planet is in, in order to sign and ratify international treaties. Even governments which have not ratified certain treaties are not averse to seeing GEOSS serve the implementation of international treaties. Obviously, the pressures on the environment are one parameter to observe and the manner in which the environment copes with these pressures is another.'

### The Integrated Global Observing Strategy

Since the end of the Cold War, space agencies have increasingly focused on environmental security by launching an expanding constellation of satellites equipped with optical, infrared and radar sensors to monitor the Earth. These satellites are often the only way to obtain suitable data to understand and predict both man-made and natural changes to the atmosphere, land and oceans.

However, satellites are an expensive business and global *in situ* observation hardly less so. In 2002, Tillman Mohr of the Committee on Earth Observation Satellites (CEOS) remarked that, 'there are several global initiatives to observe the climate or the oceans, for example, but no single agency or organization can afford to implement one of these systems alone.'

Cost-sharing was one consideration in the decision to launch the Integrated Global Observing Strategy (IGOS) four years ago. A second consideration was the growing realization that land, atmosphere and the oceans were not separate systems but interlocking parts of a single Earth system and that research programmes would only be effective if bridges were thrown between the different global initiatives.

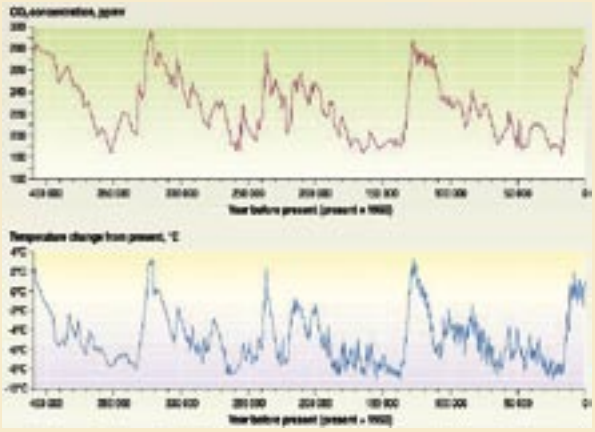
IGOS is made up of 14 partners, including CEO representing 23 space agencies, UNESCO, FAO, UNEP, WMO, the Global Terrestrial (GTOS), Ocean (GOOS) and Climate (GCOS) Observing Systems, ICSU, the World Climate Research Programme and International Geosphere–Biosphere Programme.

9. *Some 90% of ozone is found in the stratosphere (altitude of 11-30 km). At this height, ozone acts like a protective shield against UV radiation. The Montreal Protocol first reduced (1987) then banned (1992) chlorofluorocarbons in developed countries. The natural ozone production process should heal the ozone layer by 2050, although climate change could delay its recovery*

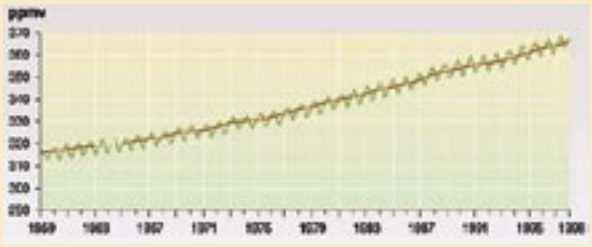
The *Framework* for the implementation plan of GEOSS recognizes the contribution of IGOS as one of a number of groups which have developed 'some important work and guidance for future action' in the area of co-operation in land, water, climate, ice and ocean observation'.

Among the anticipated socio-economic benefits listed by the *Framework* are reducing loss of life and property from natural and human-induced disasters, understanding environmental factors affecting human health and wellbeing, improving management of energy resources, understanding, predicting, mitigating and adapting to climate variability and change, improving water resource management and the protection of terrestrial, coastal and marine ecosystems, and biodiversity conservation. These are the very objectives of IGOS.

## $CO_2$ concentration in the atmosphere



*From the Vostok ice core. Note the correlation between change in temperature (bottom) and change in $CO_2$ concentrations (top) over the past 420 000 years. Each dip in the temperature curve corresponds to an ice age. The present $CO_2$ concentration (368 parts per million by volume (ppmv) in 2000) has not been exceeded during the past 420 000 years and likely not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20 000 years. The projected concentration of $CO_2$ in the year 2100 ranges from 540 ppmv to 950 ppmv. The variation results from uncertainties as to the persistence of present removal processes (carbon sinks) and the magnitude of the climate feedback on the terrestrial biosphere.*



*Before the industrial era (around 1750), atmospheric $CO_2$ concentration was 280±10 (ppmv) for several thousand years. It has risen continuously since then, reaching 368 ppm in 2000.*

### The IGOS 'theme teams'

Over the past four years, IGOS has identified several critical issues, including ocean observation needs and currents and climate change, the state of the world's water cycle, the global carbon cycle, atmospheric chemistry and geohazards such as volcanic eruptions and landslides. Scientists specializing in these areas have been working in committees to develop strategies in the form of reports, which begin by identifying the type and duration of satellite data which might fill the gaps in current knowledge.

So far, the IGOS partners have approved the strategies for five of the 'theme teams', as they are known. These concern the carbon cycle, water, the oceans, geohazards and the subtheme on coral reefs. The strategies for atmospheric chemistry and coastal observations are still under preparation.

Two further themes have been proposed, those of land cover and the cryosphere. Derived from the Greek word *kruos* meaning frost or icy cold, the cryosphere is the portion of the Earth's surface where water is found in a solid form, such as sea ice, freshwater ice, snow, glaciers and frozen ground (or permafrost). The land cover theme will focus on sustainable land use, natural ecosystems, soils, biodiversity and on monitoring changes in land cover.

### Life inside the greenhouse

There are already fairly regular and accurate measurements of air-pollution levels for many capitals but air pollution goes unmonitored in most of the world's cities, despite exponential growth in motor vehicle use in even the poorest countries. Air pollution being both a health issue and an environmenta issue, we need a better grasp of the ways in which different chemicals affect the atmosphere. Satellites may very well provide a global monitoring system for this purpose.

Unlike stratospheric ozone which is beneficial, ground-level ozone (up to an altitude of 11 km) is the primary constituent of city smog. Ozone is created by sunlight acting on nitrogen oxides and volatile organic compounds emitted by motor vehicles and stationary sources. These emissions can be carried hundreds of kilometres and result in high ozone concentrations over great distances. An Airtrends summary in 1995 by the US Environmental Protection Agency cited scientific evidence that 'exposure to ozone for six to seven hours, even at relatively low concentrations, significantly reduces lung function and induces respiratory inflammation in normal, healthy people during periods of moderate exercise. It can be accompanied by symptoms such as chest pain, coughing, nausea and pulmonary congestion.' The report estimated that 'ozone is responsible for approximately $1–2 billion of agricultural crop yield loss in the USA each year [...] and damages forest ecosystems in California and the eastern USA'.

Several reports published as recently as May 2004 note growing damage to health as a result of atmospheric pollution. One published by the French Environmental Health Agency (*Agence française de sécurité sanitaire environne-*

© UNESCO

*'Exposure to ozone for six to seven hours significantly reduces lung function and induces respiratory inflammation in normal, healthy people during periods of moderate exercise'*

*mentale*) estimates that atmospheric pollution is responsible for 6500–9500 deaths every year (out of a French population of 60 million), or 3–5% of deaths in the population aged over 30. Another report published by the Harvard Medical School in the USA and cited by the medical journal *The Lancet*, entitled *Inside the greenhouse: the impacts of $CO_2$ and climate change on public health in the inner city*, lays part of the blame for more widespread childhood asthma at the door of fossil-fuel combustion. Inner-city children are described as being most at risk, since diesel particles are highly effective at depositing pollen in immune cells in the lungs, even as higher $CO_2$ levels are stimulating plants to produce more pollen earlier in the year. In the USA, childhood asthma rose by 160% between 1980 and 1994; in Europe, one child in seven is thought to suffer from the affliction today.

## A decade of data just a drop in the bucket

The approved ocean theme report was published in January 2001. The adoption of this ocean programme led to an agreement between two research space agencies, NASA (USA) and the CNES (France), and two operational space agencies, NESOLS (USA) and EUMETSAT (Europe), to launch Jason-2 jointly in 2005. This satellite will follow in the footsteps of the Jason-1 and Topex/Poseidon, Franco-American satellites that revolutionized our understanding of oceanography.

Circling the Earth every 112 minutes, Topex/Poseidon (launched in 1992) was the first satellite capable of measuring the height of the height ocean surface with a precision of a few centimetres; this permitted scientists to infer the dynamics of the underlying ocean and temperature of sea waves, as well as related wind speed. This kind of data ables scientists to observe the major ocean currents that regulate our climate by shifting heat around the world. Topex/Poseidon has also provided an efficient method of monitoring the variation in global mean sea level in relation to global climate change.

The Topex/Poseidon mission was so successful that the USA and France launched a follow-up, Jason-1, in 2001. The satellite has been sending the most precise measurements of sea surface ever recorded, with an accuracy of 1cm. Jason-1 should be operating for about ten years.

Even so, a decade of data is just a drop in the bucket in scientific terms. 'We now know that events like El Niño and the North Atlantic Oscillation, an atmospheric see-saw driving winter storms west to east across the ocean, don't simply occur on a year-to-year basis but follow decadal cycles,' says Colin Summerhayes of the UNESCO-IOC. 'With longer-term data, weather forecasters might provide practical information for agricultural planning, especially in arid regions.'

## Plugging the holes in our knowledge of the water cycle

IGOS has produced a similar theme report on the world's water cycle. We take for granted the satellite images shown by weather forecasters on television, which have been around ever since a string of meteorological satellites followed the first US mission launched in 1960.

However, there are still gaping holes in scientists' understanding of the basic water cycle. Precipitation is notoriously difficult to evaluate; it has been estimated that only 1–4% of the globe's area is covered at any one time by rainfall. Moreover, the intensity of that rainfall can vary widely in a matter of minutes or even seconds. Scientists will soon have an unprecedented quantity and quality of water-related data thanks to a new generation of satellites: Terra and Aqua (USA) and Envisat (Europe).

IGOS is weaving a global network to collect, compare and synthesize the data of the various satellites with land-based observations. The aim is to finalize the system in time for what promises to be a technological milestone. In 2007, the USA and Japan will be launching a constellation of nine Global Precipitation Measurement satellites which will be able to measure the rainfall at any spot on the globe every three hours.

## Satellites alone won't provide all the answers

However, satellites alone cannot answer most of the critical questions facing scientists today. Satellites alone cannot measure the amount of CO2 absorbed by forests or the rate of coastal erosion. This is why IGOS is also developing strategies to integrate land- and space-based data. Satellite images of coastal erosion can transform the studies of a marine biologist.

© D.Roger/UNESCO

*Rice paddies in Indonesia. Feeding the world's growing population will demand greater agricultural productivity, a goal better information on the water cycle will help us to achieve*

## The eruption of the century

Courtesy of US Geological Survey

*Mount Pinatubo wakes from 400 years of slumber*

After lying dormant for four centuries, Mount Pinatubo in the Philippines erupted so violently in June 1991 that it spewed columns of more than 10 $km^3$ of pyroclastic debris and ash to an altitude of 40 km and flung a giant umbrella cloud containing 17 megatons of sulphur dioxide into the stratosphere. Volcanic ash hung in the air for months, some of it being scattered by the wind as far as Russia and North America.The eruption caused average temperatures in the Northern Hemisphere to fall by up to 0.6°C. The eruption buried more than 400 $km^2$ of countryside under hot ash flows and blanketed 7500 $km^2$ of the island of Luzon in ash. More than one million people were displaced and approximately 900 killed. Damage to property and infrastructure ran into hundreds of millions of dollars.

Courtesy of US Geological Survey

*The eruption blanketed the Philippine iland of Luzon in ash and turned day into night*

Courtesy of US Geological Survey

*Children on the roof of their school in Bamban in October 1991*

Volcanic activity is monitored regularly around the world. Computer-based data acquisition and processing have made great strides but not to the point of replacing the traditional cylindrical drum recorders you will still see at volcano observatories, where they record signals from seismometers that are strategically stationed around potentially active volcanoes.

At the same time, space agencies need information from the field to interpret the signals sent by satellites.

### Understanding the carbon cycle to predict climate change

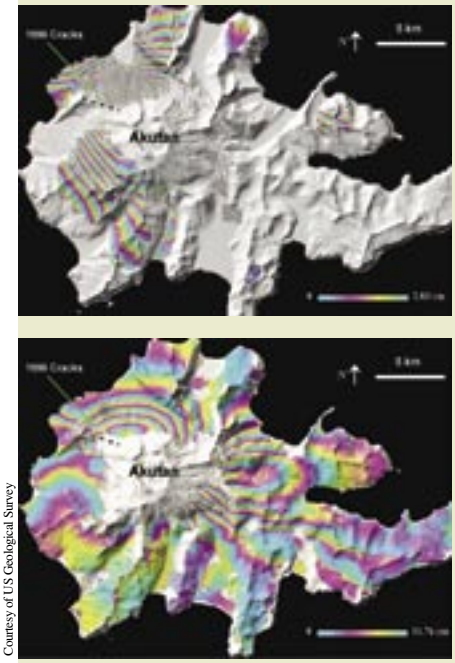
IGOS approved a strategy to study the impact of rising carbon dioxide $CO_2$ emissions in early 2004. $CO_2$ is responsible for more of the atmospheric warming than all other greenhouse gases combined, including methane, nitrous oxide and halocarbons. Part of the problem stems from the fact that $CO_2$ concentrations in the atmosphere take centuries to stabilize even after the level of emissions itself stabilizes. Concentrations of methane, on the other hand, a gas produced primarily by agricultural activity, waste disposal, coal mining and natural gas, will stabilize only decades after the level of emissions itself stabilizes.

To predict how atmospheric $CO_2$ levels and climate may change in the future, we must understand where and how $CO_2$ moves between the land, oceans and atmosphere in what is known as the global carbon cycle.

Within this cycle, the oceans will ultimately absorb approximately 90% of the anthropogenic $CO_2$ emitted to the atmosphere. However, the rate of absorption by the ocean's surface waters and its transport into the deep ocean, where it is out of contact with the atmosphere for thousands of years, is much slower than the rate of $CO_2$ emissions to the atmosphere. This leads to a build-up of $CO_2$ in the atmosphere. At present, the oceans are absorbing about 30% of fossil fuel carbon but understanding how this process works and may work in the future under a changed environment is problematic. The ocean removes $CO_2$ from the atmosphere in two ways. Microscopic plants, known as phytoplankton, convert $CO_2$ to organic matter by photosynthesis; this carbon is then transported into the deep ocean when the plants die and sink in a process called the 'biological pump'. Another mechanism, the 'solubility pump', results from the fact that $CO_2$ from the atmosphere is soluble in seawater. When surface seawater is cooled in the high latitudes, it becomes very dense and sinks to the deep ocean, carrying this dissolved $CO_2$ with it. The net ocean uptake of anthropogenic $CO_2$ appears to be controlled over long time-scales by ocean physics, specifically the transport of these surface waters saturated with $CO_2$ to the deep ocean. However, in many regions and over shorter time-scales, the biological pump can have a stronger control on the distribution of $CO_2$ in the oceans.

Through measurements of carbon in surface and deep waters and an understanding of the physical circulation of the ocean, scientists can begin to understand where, how and how quickly the ocean is removing $CO_2$ from the atmosphere. These measurements are made through a combination of samples taken on board research vessels or specially equipped commercial vessels and by using scientific buoys. By studying satellite images of ocean colour, scientists can gauge phytoplankton levels globally and begin to understand the processes controlling the spatial and geographic variability of the growth patterns. It is essential to combine these observations to develop models on how the

## A satellite study




Courtesy of US Geological Survey

These two interferograms show Akutan Volcano on a remote island in the Aleutians in Alaska (USA). In 1996, an intense earthquake swarm shook the sparsely populated island. Fearing the dormant volcano might erupt (which it did not), scientists used two pairs of satellite images produced from radar of different wavelengths to measure changes in the volcano's topography.

The C-band interferogram (top) on the shorter wavelength was constructed on the basis of images taken by a sensor onboard the European Space Agency's ERS satellite; the L-band interferogram (bottom) stems from the Japanese J-ERS satellite. To calculate an interferogram, you need a minimum of one pair of images of the same target taken at different times. Current satellites measure the same target about once a month. One image is then superimposed on the other to show where changes have occurred. The pairs of images used to produce the interferograms on the left reveal a deformation in the surface of the volcano caused by the intrusion of magma, which moved from under the volcano's summit to the east. This deformation has been 'captured' because one image was taken before the intrusion and the other afterwards.

C-band may be more sensitive to smaller deformations than L-band but it is not suited to monitoring deformations that displace the target more than a few centimetres between two observations.

The presence of vegetation and cloud variations alter the path followed by the wavelength. As most natural surfaces are not solid rock but include soils, rubble and so on (as in the case of this island), the longer L-band radar would appear to be much more useful than C-band for geohazards monitoring, even in the absence of vegetation.

No L-band missions are being flown at the moment, so observations like the one shown in the bottom picture are no longer possible. The Japanese Space Agency is, however, scheduled to send the (L-band) ALOS satellite into orbit. Several other satellites are flying with C-band interferometric capabilities: the Canadian RadarSat, the European ERS-2 and Envisat.

carbon absorbed and released by the ocean interacts with the atmosphere and land (*see also page 41*).

'Today, there are several models but the results they give can vary by as much as 50%', notes Philippe Ciais of the French Atomic Energy Commission, leader of the IGOS strategy for the carbon cycle. 'These models will probably improve. But if we don't improve our current observations, we won't have a reference point to measure the extent to which the carbon cycle has changed between now and the next decade.'

### Taking the measure of geohazards

The geohazards strategy was published in April 2004 by the three leaders of the theme team, the British Geological Survey, European Space Agency and UNESCO.

Every year, volcanic eruptions, earthquakes and landslides claim thousands of lives, injure thousands more, devastate peoples' homes and destroy livelihoods. The cost in terms of damaged infrastructure runs into the billions in any currency, a cost pushed higher still by insurance premiums. Geohazards affect rich and poor alike but have a disproportionate impact on the developing world. As the human population increases, more and more people are living in hazardous areas, causing this impact to grow at an unsustainable rate.

Citizens need to know a hazard's location, timing, extent, likely behaviour and duration. It is not yet possible to give firm answers to any of these questions. This is because of critical gaps in topographic data, hazard inventories and geoscience maps, insufficient coverage of local GPS and seismic networks, inadequate geohazards models and a lack of continuity in C-band – and especially L-Band – radar interferometry (*see box*).

The goal over the next decade is to fill these gaps by integrating disparate geohazards research into global operational systems. This should enable the geohazards community to improve mapping, monitoring, forecasting, mitigation and preparedness, and thereby provide the agencies involved in disaster management with critical information. The strategy will fill key gaps in long-term observations and bridge issues not covered by the disaster response system set up under the international Charter on Space and Major Disaster or the UN Action Team on Disaster Management.

### Into the political arena

Over the next decade, the IGOS partnership will bring us a more thorough understanding of how the planet's life support systems function and interact. In so doing, IGOS will be fashioning the tools decision-makers will need to plan sustainable development.

The ten-year Earth observation summit process brings the work of IGOS into the political arena. These parallel processes hold the promise of a potent cocktail blending scientific rigour and political commitment. The summit next February should design the architecture of an Earth observation system which will revolutionize the way we manage the planet.

Susan Schneegans, Amy Otchet,
Robert Missotten[10] and Maria Hood[11]

*To read the theme reports: www.igospartners.org*

*10. UNESCO Programme Specialist in geological sciences*
*11. UNESCO Programme Specialist in marine Sciences*

# Watching the oceans for signs of climate change


© Jerzy Smykla

*Summertime sea ice (here) may become a much rarer sight in the future*

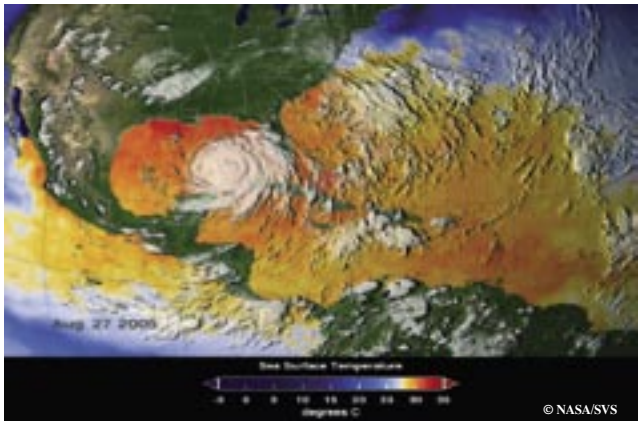
**The International Year of Physics will also enter the record books as one of climate extremes. The year 2005 saw the most hurricanes ever in the Atlantic sector, including one with the lowest surface pressure ever recorded, which left thousands of dead in their wake in North and Central America. In the Arctic Ocean, northern summertime sea ice cover was a record low and rainfall in the Indian state of Maharashtra during the monsoon a record high. The Amazon forest, source of the world's strongest-flowing river, is experiencing its worst drought in recorded history. The five warmest years on record are now 1998, 2002, 2003, 2004 and 2005. All of these climate events have a link to the ocean.**

**It is scientifically impossible to link any one extreme event to global climate change but the ongoing trend confirms that global change is under way. The Intergovernmental Panel on Climate Change (IPCC), which is charged with assessing climate research, stated in 2001 that 'the balance of evidence' suggested a human influence on climate. Recent scientific studies, which will feed into the Panel's next report in 2007 (*see back page*), reinforce this evidence, key pieces of which come from the oceans.**

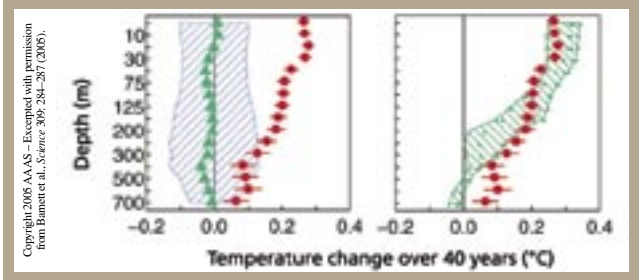
The oceans cover more than 70% of the globe. A major part of the climate system, they interact with the atmosphere and land. In the climate system, the oceans are unique for their high capacity to store heat: compared to air, seawater absorbs four times as much energy per kilogram in heating up one degree Celsius – and water is about 800 times denser than air at the surface. The heat energy contained in the top 3 m of the oceans is therefore equivalent to that contained in the entire atmosphere. This makes the oceans a key pathway for the transport of heat in the climate system.

Observations of the subsurface ocean have a fairly short history, beginning only in earnest after the Second World War and being concentrated in zones of high shipping traffic like the North Atlantic. But this history is now long enough to calculate trends in subsurface temperatures over vast expanses of ocean with a reasonable degree of scientific confidence.

The subsurface ocean is a good place to look for clear evidence of human-induced climate change. A change in the forcing of the climate system, such as that introduced by greenhouse gasses, forces the entire climate system to find a new balance, with a warmer Earth radiating more heat to space to compensate. The oceans are the major absorber of this extra heat. Since the subsurface oceans are less 'noisy' than the surface, which is affected by weather and the seasons, they have the clearest signals of long-term changes in the climate.




*Warm ocean waters fuel hurricanes and the waters were unusually warm in the tropical Atlantic in 2005. Hurricane Katrina is shown here, on 27 August 2005, in a satellite cloud image super-imposed on a map of the sea surface temperature*



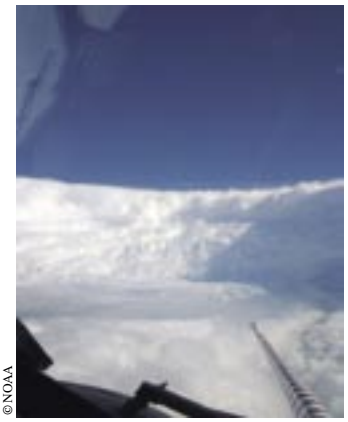

*The panel on the left shows the average (green triangles) and range (blue hatching) of climate models reproducing natural climate variability over hundreds of years without inclusion of the human effect. The panel on the right shows the variability of a climate model run with the full history of human input of greenhouse gases (green hatching and dots); the red dots in each panel are averages over the North Atlantic of changes in ocean temperature over the past 40 years. The surface waters have warmed the most, by about 0.25°C. The panel on the right is a far better match to the observations than the panel on the left and excellent evidence of human influence on climate*

## Conclusive evidence from the oceans

In an article published in *Science* in July 2005, Tim Barnett and his colleagues showed that the observed patterns of ocean warming over the past 40 years could not be explained by natural variability but instead were a good match with the climate predictions incorporating the human effect on climate (*see figure*), findings which disagree with measurements taken elsewhere.

The study has helped to boost scientific confidence in the ability of modern land–ocean–atmosphere climate models to simulate climate change. In large part, the scientific debate over whether human activity has provoked climate change is over. Exactly how it will change remains a question.

Even if the human emissions of greenhouse gases were to stop today, the global climate would keep changing for decades to come, due to the level of greenhouse gases currently in the atmosphere and the thermal inertia of the climate system. The climate will stabilize again only when the Earth heats up enough or greenhouse gases get absorbed into other parts of the climate system. The oceans have absorbed about 50% of historical greenhouse gas production, with potentially dramatic effects on ocean ecosystems (see *page 41*).



© NOAA

*Too close for comfort. This view from the cockpit of the ring of thunderstorms surrounding the eye of Hurricane Katrina (known as an eyewall) was captured aboard a NOAA hurricane hunter aircraft a day before the powerful storm came crashing ashore. The heaviest rain and strongest winds are found in the eyewall, whose energy comes from heat from the ocean*

## Climate impacts driven from the ocean

Since the oceans are a major reservoir of heat in the climate system, prediction of short-term climate variations – those felt over days or months – is highly dependent on the interaction between the ocean and atmosphere. The climate records achieved this year are best understood using models that include the physics of ocean circulation. It is the extremes in rainfall and temperature which most affect humans, provoking floods, landslides, drought and shifts in the seasons which affect food production and tourism.

## A record-breaking hurricane season

Unusually warm ocean conditions in the tropical Atlantic in 2005 contributed to the strength of hurricanes during the hurricane season, the most damaging season in recorded history. Hurricane Katrina last August devastated the US Gulf Coast (*see images*). Rainfall associated with Hurricane Stan in early October triggered severe flooding and landslides that killed up to 2000 people in Guatemala and other countries in Central America. Seven of the 14 hurricanes that formed were major and three were of the highest strength[12]. Meteorologists ran out of names for Atlantic hurricanes for the first time, resorting to the Greek alphabet and ending with Hurricane Epsilon.

© K. Niemi/US XCoast Guard Digital

*The fierce winds and extreme low pressure of Hurricane Katrina forced enormous storm surges, flooding a territory half the size of France. They breached a number of the levees protecting the coastal city of New Orleans, built mostly below sea level. Over 1 million people had to be evacuated, like the children in this photo, and more than 1200 people lost their lives. It is estimated that reconstruction will cost the USA over US$100 billion.*

The strong winds of a hurricane evaporate enormous quantities of water vapour from the ocean surface. The evaporation is strongest over ocean water with the greatest heat reserves. Climate change models incorporating hurricanes show an increase in the intensity of hurricanes – but not in their number – as the oceans warm. The debate is still ongoing as to whether the current warming of the tropical Atlantic is due to climate change or natural variability but global warming has already led to an increase in ocean temperatures.

## A parched Amazon

While Central and North America flooded, the Amazon forest was experiencing its worst-ever recorded drought. Lakes and lagoons have dried up, river channels are no longer navigable, farming and fishing have been disrupted, the delicate tropical rain forests are burning, and stagnant water left

© Ana Cristina Vieira Folha

*A dry mangrove swamp in Bragança, Brazil, in early 2005. The Amazon is experiencing severe drought, also due to the warm tropical Atlantic*

*12. Category Five, with winds in excess of 249 km/hr*

## The ocean conveyor belt

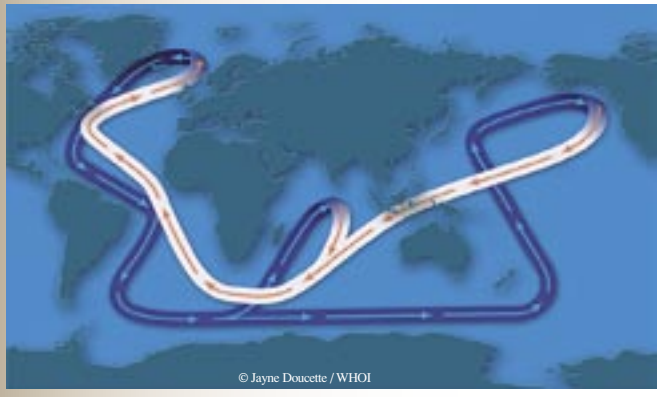
The average temperature between the equator and the poles differs because of the tilt of the Earth's surface relative to the sun. However, this difference is much weaker than one would expect. This is because the oceans and atmosphere carry heat to the poles, ensuring a more comfortable balance (for humans at least), by cooling temperatures at the equator and warming them at the poles.

The ocean transports about half of this heat via shallow and deep currents collectively known as the ocean conveyor belt (thermohaline circulation, see figure). One of the busiest ocean highways is the wind-driven Gulf Stream and North Atlantic Current, which warms Europe to its east. These surface currents transport tens of millions of cubic metres of warm tropical water northwards every second. Since mid-latitude weather systems generally move from west to east, New York in the USA is cooler than Naples in Italy, even though they are the same distance from the equator.

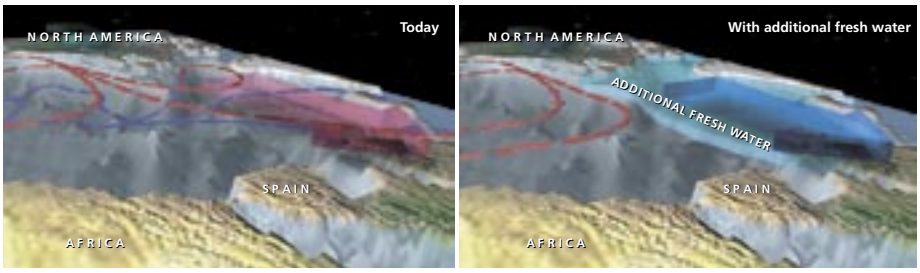
Evaporation to the atmosphere leaves behind saltier and cooler (and therefore denser) water. The waters below the upper layer everywhere in the world are filled with the densest cold and salty waters, formed mostly in the polar North Atlantic by extreme winter evaporation and heat loss; most of the sub-surface ocean is just a few degrees above freezing.

Carried in deep southward flows away from its source and, eventually, over thousands of years, spreading to the other oceans, the wind and tides bring this deep water back to the surface. There it is warmed by the sun and freshened by rain. Eventually, the water heads back to the poles again in the surface ocean to repeat the cycle.

Climate models with scenarios of human-induced change nearly all show that the ocean conveyor belt will slow down as the climate warms.




*The path followed by the ocean conveyor belt*




*Left: the warm surface water of the North Atlantic flows northward (red lines), replacing the southbound flow of cold, deep water (blue lines). This transports heat northward, warming the winds blowing eastward over Europe (large red arrow). A large addition of freshwater from melting land ice (right) would prevent seawater from sinking in the North Atlantic. The northward oceanic heat transfer could then stop, making the winds blowing over Europe much cooler, despite global warming (large blue arrow)*

in riverbeds is causing disease-carrying mosquitoes to proliferate. The same warming of the tropical Atlantic is thought to be to blame, as greater evaporation and rising air over the ocean has forced the air to descend over the Amazon, displacing the rains.

### Monsoons driven by ocean heat

A similar balance of ocean and land evaporation drives the monsoon, a periodic wind which can be likened to a very strong sea breeze. The strongest of the monsoons occurs over the northern Indian Ocean, with the winds blowing from the southwest during one half of the year and from the northeast during the other half.

Tropical monsoon rainfall is driven by the difference in the heat capacity of the oceans and land. In summer under strong sunshine, the temperature on land rises much more quickly than the temperature at the sea surface. The warm air over land rises, drawing moist air from over the oceans inland and feeding strong rainfall. Both the amount of heat stored in the ocean and the difference in temperature between ocean and land affect the intensity of monsoons.

### Melting ice and rising seas

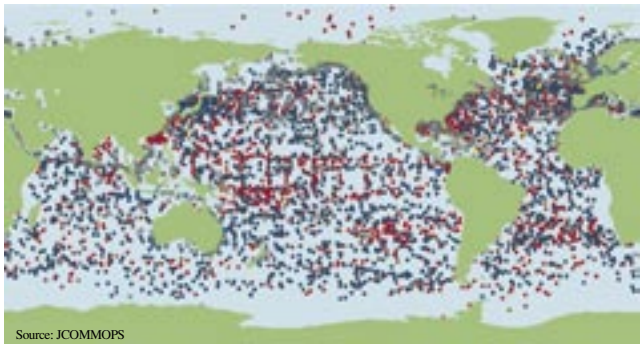
The oceans are of course central to sea-level rise caused both by the expansion of warming oceans and the melting of glaciers (*see box, p. 10*) and ice caps. The global average sea level has been increasing by about 2 mm per year. But the increase is not entirely uniform; as the climate changes, the average winds and ocean circulation have also changed, creating localized changes in sea level.

How will things change in the future? Will there be stronger hurricanes across the tropics? How likely is it that Europe will cool? Will disappearing sea ice finally open the fabled Northwest Passage to shipping? Will Tuvalu disappear beneath the waves? Will the mighty Amazon be reduced to a trickle? And could the climate change suddenly? (*see box on facing page*)

### The World Climate Research Programme

The Intergovernmental Oceanographic Commission (IOC) of UNESCO, along with its partners the World Meteorological Organization (WMO) and the International Council for Science (ICSU), sponsors a World Climate Research Programme (WCRP) that tries to answer these questions. Its major goal is to determine both the limits of predictability of the climate system and the human influence on climate.

Published articles stemming from climate research within the WCRP make the main contribution to the body of knowledge periodically assessed by the IPCC.




*Towards global coverage:* in situ *platforms observing the ocean in October 2005, which produce data available in real time. These data come mainly from Argo floats (dark blue), ships of opportunity (light grey, light blue and yellow), fixed moorings and drifting buoys (red). The seasonally ice-covered oceans pose technical problems that are yet to be surmounted*

One continuing difficulty for scientists is how to separate human-induced climate change from natural climate variability. In fact, climate variability itself appears to be changing, with more extreme swings outside the realm of 'normal' weather. This in itself is an indication of climate change. The WCRP's Climate Variability and Predictability project is helping us to better predict and model the extremes in climate, on time scales ranging from days to months to years ahead.

© J.C. Miranda/Rediff.com

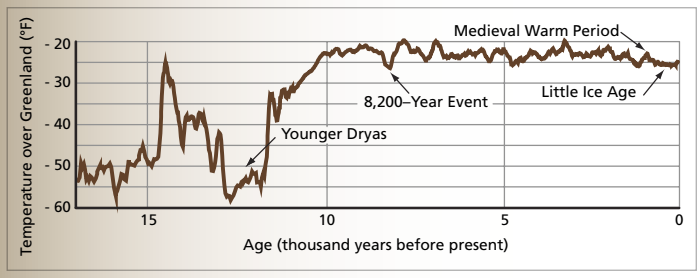
*The aftermath of severe monsoon flooding in Mumbai, India, on 26 July 2005, when 1 m of rain fell in less than 24 hours, almost doubling the city's previous record. The resulting flooding and landslides took more than 1000 lives. The strength of the monsoon is dependent on the ocean heat content in the Indian Ocean, along with other factors like the phase of El Niño in the Pacific*

## Could the climate change suddenly?

Studies of past climate from fossils and ice cores show that the climate system has made sudden jumps in the past.

The most recent climate jump occurred at the end of the last ice age, about 12 000 years ago, as humans were settling the American continent and, elsewhere, first began to farm. The melting North American ice sheets suddenly released a large amount of fresh water into the North Atlantic. Fresh water is less dense than salt water, so the normal formation of deep water in the polar North Atlantic stopped abruptly (see *The ocean conveyor belt*). The consequence was the collapse of the thermohaline circulation, causing average temperatures in the North Atlantic region to plummet by 5°C in less than a decade.

Some scientists fear that the melting of the Greenland ice cap could lead to a similar freshening of the North Atlantic and a climate jump. A great exaggeration of that scenario was recently at the heart of a Hollywood disaster film. What then is the threshold for abrupt climate change? Our present-day climate models are not yet skilled enough to tell us. But the consequences of a sudden jump in climate to ecosystems and to human society would most likely be catastrophic.




© R.B. Alley and WHOI

*Ice cores extracted from the 3km-thick Greenland ice sheet show several sudden shifts in climate in the past, within periods as short as a decade. Most dramatic was the Younger Dryas period, when average temperatures in the North Atlantic region dropped abruptly and remained cold for 1300 years before rapidly warming again*[13]

There are already signs of a slowdown in part of the ocean conveyor. Only last month, scientists revealed that the deep southward flow of cool water in the North Atlantic, measured by five expeditions over five decades, had dropped by 30% between 1957 and 2004[14]. Should we put this down to a cycle of natural variability, or is this drop indicative of a longer-term change in the ocean conveyor? Only time – coupled with sustained observation – will tell.

*13. All the figures from the Woods Hole Oceanographic Institution are reproduced, with kind permission, from the brochure* Abrupt climate change: should we be worried?, *put together for the Davos Economic Forum in Switzerland in 2003: www.whoi.edu/institutes/occi/currenttopics/ct_abruptclimate.htm*

*14. These findings were published by Harry Bryden and colleagues in the 1 December 2005 issue of* Nature

## Give and take: competing climate feedbacks

Scientists who grapple with trying to understand the complex climate system have found a simple way to describe the patterns of interaction that they observe: as feedbacks. Feedbacks can either reinforce the current state of the climate system or lead it to run away.

An example of a stabilizing feedback (called a negative feedback) is the interaction between solar radiation, the sea surface temperature, and clouds in the tropics. The ocean warms from solar heating, warming and humidifying the atmosphere above. The strong winds of a hurricane evaporate enormous quantities of water vapour from the ocean surface. Energy from the latent heat released when this vapour then condenses into raindrops is injected into the storm, further increasing its strength. These clouds shield the ocean surface, which cools. In this way, the climate system creates a natural barrier to endless heating of the ocean. The opposite is also true: cooler oceans mean fewer clouds and more solar radiation reaching the surface. A negative feedback moves things towards an equilibrium.

*Convective clouds in the tropics cast shadows over the warm ocean below*

An example of a runaway feedback (called a positive feedback) is the interaction between solar radiation and ice in the polar regions. Ice is a very efficient reflector of sunlight, bouncing a significant fraction of its energy back into space. If the ice melts and is replaced by darker ocean or land surfaces, less sunlight is reflected, heating the surface. The heating will further melt ice. It is this which makes the polar regions particularly sensitive to climate change.

The balance of feedbacks, and whether a positive feedback can temporarily gain the upper hand over the stabilizing negative feedbacks, describes the evolution and natural variability of the climate.

The best-known interaction of climate feedbacks involving the ocean is El Niño, a temporary shift of the warmest waters in the tropical Pacific towards the east, with patterns of atmospheric uplift and rainfall following, bringing drought to Indonesia and Australia, excessive rainfall to Peru and Ecuador, and changed storm patterns over much of the globe.

Will El Niño change as the global climate changes? Many scientists believe it will or that it already has but predicting El Niños remains a difficult task.

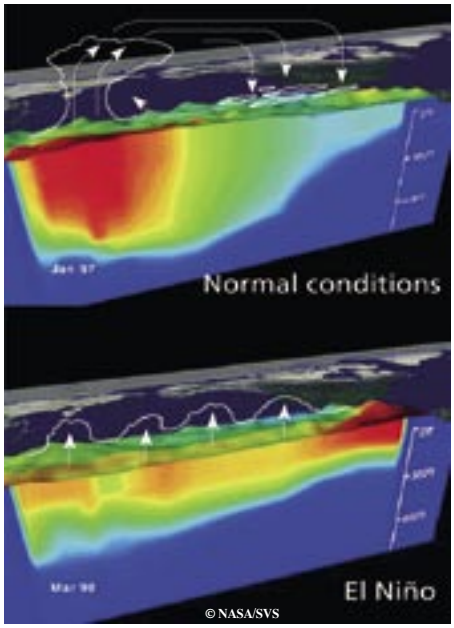
© ESA

*Satellites provide global coverage of the oceans and are a key element of GOOS. This is an artist's impression of the European SMOS satellite, which will measure surface salinity from 2007 onwards*

### Observing the oceans to understand them

The IOC of UNESCO and its flagship programme, the Global Ocean Observing System (GOOS), make up the UN arm responsible for sustained global ocean observations. An IOC group of experts, the Ocean Observations Panel for Climate (OOPC), helps to define the standards and goals of the global climate component of GOOS and the tools for monitoring and evaluating the system.

Through a joint technical commission with the WMO for oceanography and marine meteorology (JCOMM), the IOC is also actively coordinating these global networks through an *in situ* (in the water) platform support centre (JCOMMOPS) located in Toulouse, France, which continually monitors the thousands of floats, ships and fixed moorings transmitting oceanographic data.




*A slice of temperatures the Pacific ocean, cut east–west at the equator and looking northwards, as visualized from the tropical array of fixed moorings in the Pacific. Normally, air rises over a pool of the warmest water in the western Pacific (top image), drawing the surface winds from the east that maintain this warm pool by piling up warm water. During an El Niño event (bottom image), something weakens the surface winds, which allows the warm water to slump eastward. The centres of rising air follow eastward, further weakening the surface wind and allowing the warm water to slump further, a positive feedback. The result is a change in the tropical Pacific on the ocean side and global changes in the atmospheric circulation*

### Satellites: scratching the surface

Ocean satellite missions have revolutionized oceanography; they are critical for global coverage of surface temperature, ocean eddies (the sea's weather systems), surface wind and ocean colour as an indicator of biological activity.

The oceans pose a serious impediment to satellite observations however. As the conductivity of salt water makes them almost impervious to electromagnetic radiation, only the skin of the ocean is visible from space. To observe the global oceans fully, measurements need to be taken in the oceans themselves, from different types of autonomous platforms and research ships.


*An Argo profiling float being deployed from the Canadian coast guard ship John P. Tully in the Gulf of Alaska*

### Robotic sentinels of the deep

The most rapidly growing of these *in situ* networks is the Argo profiling float network. Argo floats are robotic, self-contained oceanographic measuring devices that park in the deep ocean, 2 km below the surface. Changing their buoyancy once every 10 days by shifting oil out to an external bladder, they rise to the surface. On the way up, they collect information on temperature and salinity (some also measure oxygen), which they then transmit by satellite at the surface.

By the end of 2005, the four-year old Argo project had seeded the oceans with more than 2000 floats, two-thirds of its way to its initial goal of 3000 floats, roughly one per every 100 000 km$^2$. When the batteries fail after about four years, the floats cannot rise to the surface. Most will eventually sink to the bottom. Argo floats are widely distributed in the world's oceans, thanks to the coordinated efforts of more than 20 participating countries. In some areas, the floats are now returning more information on the subsurface ocean in one year than can be found in the entire historical database before Argo.

### A modern message in a bottle

Inspired by shipwreck survivors who sometimes cast messages sealed in a bottle to the waves, US scientist and statesman Benjamin Franklin used message-carrying bottles in the mid-1700s to compile an atlas of currents off the east coast of North America.


*One of 70 fixed moorings in the tropical Pacific which monitor and forecast El Niño events within the global ocean observing system. The last El Niño event occurred in 2002–2003*

In 1929, German scientists released a message that could be read without breaking the bottle in the South Indian Ocean. It was read and re-released a number of times. Caught up in the strong circumpolar current, it had travelled more than 25 000 km by 1935.

Today, a modern equivalent of these messages in a bottle – surface drifting buoys – ply the surface currents of the world, transmitting their electronic reports of surface temperature, currents and often barometric pressure. These buoys provide a ground truth for satellite estimates of the sea surface temperature and are the best witnesses of ocean surface currents, themselves driven by winds and ocean eddies. They also improve weather forecasts by reporting on the surface pressure.

The scientific goal set by OOPC for the surface drifting buoy network was to have one in every 300 000 km$^2$ box of ocean, or 1250 in total. That goal was reached in September 2005, when Global Drifter 1250 was launched at a special ceremony held in conjunction with the Second Session of JCOMM in Halifax, Canada. It is the first of the *in situ* global ocean observing networks to reach the goal it was designed for, a major milestone.

But scientists can't just declare victory and go home; the drifting buoy network needs constant replenishing as floats fail and drift out of regions of current divergence. Moreover, the planned global *in situ* ocean observation network of floats, profilers, moorings, sea level gauges and volunteer and research ships is currently only about 55% complete.


*A message in a bottle: Global Drifter 1250, symbolically completing the first component of GOOS, is deployed in September 2005 in Canadian waters*


*A training course in ocean data management at the IOC's International Oceanographic Data and Information Exchange (IODE) programme office in Oostende, Belgium. These courses build countries' capacities to participate in, and benefit from, ocean observing systems*

### Scientists hitch a ride on the oceans

The M/V Skogafoss, a 100 m-long container freighter, sets sail monthly from the port of Reykjavik, in Iceland, carrying containers full of frozen fish to North America. It returns two weeks later, repeating this voyage year in and year out. It navigates the most northerly regular ship route in the North Atlantic, dodging icebergs flowing southward in the Labrador Current well into spring.

The Skogafoss is also a volunteer observing ship. It regularly launches radiosondes (atmospheric profilers) from an automated laboratory mounted on a rear deck. It has automatic systems recording surface meteorology and sea surface temperature, as well as atmosphere and ocean carbon measurements. Once every few hours, the officer on duty steps out onto one of the bridge wings, loads an expendable bathythermograph (XBT) into a launcher and pulls the trigger. The XBT drops into the ocean and measures a profile of temperature, sending back its data on an unspooling length of copper wire thinner than a human hair. These observations are a key part of the global system and are coordinated through JCOMM's Ship Observations Team. The captain and the shipping company provide their services for free, volunteering their time and space aboard the ship.

This is a real boon for scientists, as a modern research vessel is extremely expensive to run. Paying for fuel, maintenance, three round-the-clock shifts of officers, engineers and sailors adds up, to the tune of US$ 20 000–50 000 per day. These volunteer ships of opportunity are also a major deployer of Argo and surface drifting floats, filling holes in the observational network as they open up.

### Global information for local decisions

The global component of GOOS was designed for climate monitoring, forecasting and research but it also helps to improve weather and marine prediction. Ocean data (now coming from nearly 70 countries) is managed and disseminated globally in a coordinated fashion and turned into ocean and climate models and other products. The IOC has also taken on a strong role in the coordination of global ocean natural hazard warnings, in particular as regards tsunamis. The observing platforms that feed into the warning systems are often the same: moored buoys and tide gauges are used in both the climate and tsunami observing systems. The IOC is working to maximize the synergies between the two systems.

Raw ocean data are of interest to scientists but may be incomprehensible to government officials and other decision-makers responsible for addressing climate change, managing fisheries or sailing safely. GOOS and the WCRP are working to develop ocean and climate models that can provide more targeted information for decision-making.

### Long-term foresight in short supply

The global oceans that cover such a large portion of our Earth belong to all nations collectively – but very few people live on the oceans. Whereas nearly every country, rich or poor, has a national meteorological agency charged with observing and forecasting the atmosphere, very few have national oceanography agencies with a mandate to observe the oceans and even fewer a mandate to observe the global ocean.

The ocean observing network has been built on the sustained work of research oceanographers. But this poses its own problems; for example, subsurface current meters have been monitoring part of the thermohaline circulation in the Atlantic (see *The ocean conveyor belt*) for over a decade but a number will not be renewed because the national research agencies are keen to fund something new. There is no-one however to fill the gap once this monitoring ceases.

This lack of commitment by the world's governments to sustained observations of the oceans is shortsighted. In the face of slow political action to change mounting human production of greenhouse gases, it is clear that climate will continue to change and that this change may even accelerate.

Scientific observations and research are needed to help us understand how regional climate will change, to improve predictions about shorter-term changes in the local climate, to improve our poor understanding of how ocean chemistry and ecosystems may change and to equip governments and citizens of the world with better knowledge to help them in making decisions about the future.

Humans have generated an unprecedented perturbation in the Earth's climate. In facing the consequences, we need to be as informed as possible.

Albert Fischer[15]

*For details: http://ioc.unesco.org/iocweb/climate-Change; a.fischer@unesco.org*

*15. UNESCO–IOC Programme Specialist and physical oceanographer*

# **A carbon sink** that can no longer cope?

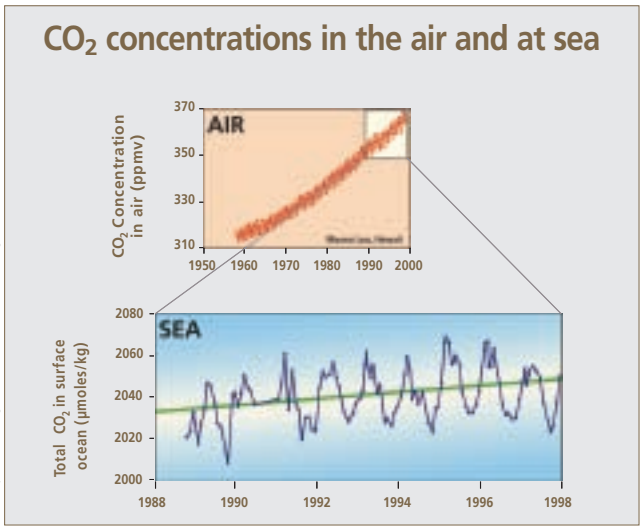
**The oceans provide us with a valuable service by absorbing half of the carbon dioxide ($CO_2$) emitted by the burning of fossil fuels, thereby reducing the impact of this greenhouse gas on climate. A symposium held at UNESCO in May[16] has concluded, however, that we may soon pay a very high price for this service.**

**When, last May, over 100 of the world's leading ocean carbon scientists from different branches of marine biology and chemistry pieced together some of the best scientific information available, the results were alarming. The compiled research suggests that the increasing acidity of the ocean could seriously harm corals and other calcifying organisms, such as shellfish and some phytoplankton, the base of the marine food chain. If this food chain becomes disrupted, it could lead to the collapse of fisheries industries in many parts of the world, as well as of the billion dollar tourism industry that surrounds healthy coral reefs. These changes may also alter the ocean's ability to absorb fossil-fuel $CO_2$ in ways that are not yet fully understood.**

The May meeting went on to fix urgent research priorities to probe the possible consequences of an acidifying ocean on marine ecosystems and assess the safety of proposed geo-engineering strategies for mitigating the impact on climate by storing excess $CO_2$ in the deep ocean.

## How the carbon–climate connection was made

In the mid-1800s, the hot topic in the scientific world was the ice ages, a new hypothesis that much of the northern land masses had been covered in thick layers of ice tens of thousands of years previously. In investigating how the climate of the planet could change so dramatically, scientists discovered that certain gases in the Earth's atmosphere trap heat from the sun. Calculations showed that the conditions experienced during the ice ages could be brought on by halving the abundance of $CO_2$ in the atmosphere. But what natural processes might cause such large changes in concentrations of $CO_2$? This question launched one of the most challenging – and enduring – investigations of earth science: that of understanding the global carbon cycle.




Courtesy C.D. Keeling and N. Bates, U.S. JGOFS Program.

*Increases in atmospheric and oceanic CO2 levels. The dips in the sea curve correspond to seasonal variation*

At the beginning of the industrial revolution in the mid-eighteenth century, human activities like the burning of fossil fuels began adding $CO_2$ to the atmosphere but the amounts were small when compared with the amount of $CO_2$ naturally present in the atmosphere. Early concerns about the long-term build up of this $CO_2$ in the atmosphere were not taken seriously because most scientists at the time believed that the oceans would naturally absorb 90% of the industrially produced $CO_2$ emitted to the atmosphere.

In the late 1950s, geochemists Roger Revelle (the founder of UNESCO's Intergovernmental Oceanographic Commission, IOC) and Hans Suess sounded the alarm. Their calculations showed that ocean uptake of $CO_2$ was much slower than originally thought and that the oceans could absorb no more than 50% of the $CO_2$ being emitted annually by fossil-fuel burning. The remainder, they warned, would build up in the atmosphere, where it would increase the atmosphere's ability to trap heat, producing a 'greenhouse effect'. In 1958, Charles David Keeling began taking the first high-quality measurements of atmospheric $CO_2$ at the Mauna Loa Observatory in Hawaii (USA); he would soon give the world proof of the steady climb in the concentration of $CO_2$ in the atmosphere. Twenty-five years later, measurements of ocean $CO_2$ began, in turn, at the Bermuda Atlantic Time Series Station, documenting the slow penetration of this excess $CO_2$ into the surface oceans.

## Solving the riddle of the missing carbon sink

Of the fossil-fuel $CO_2$ emitted globally, only half has accumulated in the atmosphere. The fate of the other half has prompted a decades-long search for the 'missing carbon sink'. The two possible sinks for this $CO_2$ are the terrestrial biosphere (e.g. via photosynthesis) and the ocean. The ocean represents the largest natural stockpile

*16. The Ocean in a High $CO_2$ World. International Science Symposium sponsored by the Scientific Committee on Oceanic Research and UNESCO's Intergovernmental Oceanographic Commission (IOC)*

of carbon and has a dynamic interaction with the atmosphere over 70% of the planet's surface. The only direct method of calculating the amount of $CO_2$ absorbed by the ocean is through direct measurements on a global scale. From 1990 to 1998, a multinational research programme called the World Ocean Circulation Experiment/Joint Global Ocean Flux Study amassed data from nearly 10 000 stations around the world's oceans from 95 separate expeditions and produced the first global survey of carbon distribution in the ocean.

Recent results from the global survey have solved the mystery of the missing carbon sink: the data show that the oceans have taken up approximately 118 billion tons of the $CO_2$ emitted since 1800, roughly 48% of the total; currently, some 20–25 million tons of $CO_2$ are being added to the oceans daily, calculates the study, which was published in *Science* in July[17]. Without the ocean sink, atmospheric $CO_2$ would be much higher and its climatic impacts more severe[18]. But scientists are now faced with a new question, 'Will the oceans continue to take up almost half of the $CO_2$ emitted to the atmosphere, even in a warmer climate with changed ocean mixing patterns?' A second global survey and several international research programmes were launched in 2003 to find out.

***The oceans have taken up 118 billion tons of the $CO_2$ emitted since 1800; currently, 20–25 million tons of $CO_2$ are being added to the oceans daily***

## Acid ocean?

A second and perhaps more pressing question is, 'How are these higher levels of ocean $CO_2$ going to affect ocean ecosystems?' Today, there is growing concern that this natural service provided by the oceans may have a steep ecological cost, the acidification of the oceans.

As $CO_2$ dissolves in seawater, the pH of the water decreases, making it more acidic. Since the beginning of the industrial revolution, the pH has dropped globally by 0.12 pH units[19].

Photos courtesy of Professor Ulf Riebesell, Leibniz-Institut für Meereswissen-schaften, IFM-GEOMAR

*Experiments in a floating corral (or mesocosm) in this Norwegian fjord help to understand how marine ecosystems will behave in a more acidic environment*

While these pH levels are not particularly alarming, the rate of change and the downward trend is cause for concern. To the best of our knowledge, the oceans have never experienced such a rapid acidification. By the end of this century, if concentrations in the atmosphere continue to rise exponentially, we may expect to see changes in pH that are three times greater and 100 times faster than those experienced during the transitions from glacial to interglacial periods. Such large changes in ocean pH have probably not been experienced on the planet for the past 21 million years.

***By the end of this century, changes in pH may be three times greater and 100 times faster than during the transitions from glacial to inter-glacial periods.***

## Marine ecosystems under threat

Corals, calcareous phytoplankton, mussels, snails, sea urchins and other marine organisms use calcium carbonate ($CaCO_3$) in seawater to construct their shells or skeletons. As the pH decreases, such as when water is more acidic, it becomes more difficult for organisms to secrete $CaCO_3$ to form their skeletal material. It is this effect that has marine scientists concerned: since the oceans have never experienced such a rapid acidification, it is not clear how ocean chemistry will change or how ecosystems will adapt.

The penetration of $CO_2$ into the ocean occurs very slowly but scientists can accelerate this process in the laboratory or in field experiments to study the effects that increasing $CO_2$ may have on marine ecosystems in the coming decades. One method is to set up floating corrals (mesocosms) in the ocean that encircle natural populations of phytoplankton and to manipulate the $CO_2$ concentration in the air above the corral to study the effects of varying levels of $CO_2$ on the ecosystem. Since the lifespan of phytoplankton is of the order of one week, scientists can observe the effects on many generations over a short period of time.

From laboratory and mesocosm experiments conducted to date, almost all calcifying organisms have shown decreased calcification in more acidic environments. This is true for both the smallest single-celled organisms and for reef-building corals. Under such conditions, calcareous phyto-plankton, which constitutes part of the basis of the marine food chain, will form thinner skeletons and thus experience difficulties in growth and reproduction. This, in turn, may have profound effects on the marine food web, causing shifts in fish population size or geographic location.

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*17. Sabine et al. (2004) The Oceanic Sink for Anthropogenic $CO_2$,* Science, **305**, *367–371*

*18. The cost of avoiding $CO_2$ emissions is currently US$40–60 per ton of $CO_2$ (International Energy Agency Greenhouse Gas Research and Development Programme). By absorbing 118 billion tons of fossil fuel since the beginning of the industrial revolution, the ocean has provided a natural ecosystem service of the order of US$6 trillion*

*19. The lower the pH, the more acidic the solution. Natural seawater has a range of 7.7–8.2 pH units*

Coral reefs face two challenges from increasing atmospheric $CO_2$. Firstly, higher $CO_2$ concentrations in the atmosphere are linked to warmer global temperatures, which in turn lead to warmer water temperatures. Corals are very sensitive to temperature change: a 1–2º C change in local temperature above their normal summer maximum can lead to a phenomenon called 'bleaching', whereby the corals expel their vital algal symbionts (algae which live in symbiosis with the coral), leaving the coral tissues translucent. In 1998, a single bleaching event led to the loss of almost 20% of the world's living coral. Corals can recover from these events but repeated episodes are likely to weaken the coral ecosystem, making them more susceptible to disease and causing a loss of biodiversity. The second challenge faced by corals is the increasing acidity of the water caused by higher $CO_2$ concentrations. Lowered calcification rates affect the reef's ability to grow its carbonate skeleton, leading to slower growth of the reef and a more fragile structural support, which makes the reef more vulnerable to erosion. By the middle of this century, the estimated reduction in calcification rates may lead to a situation where we are losing more reef area to erosion than can be rebuilt through new calcification.

***Invertebrates and even some fish may be affected by lower pH environments, leading to lowered resistance, metabolic depression, behavioural depression affecting physical activity and reproduction, and asphyxiation.***

Higher marine life forms, such as invertebrates and even some fish, may be affected by lower pH environments through acidosis (an increase in carbonic acid in body fluids) leading to lowered resistance, metabolic depression, behavioural depression affecting physical activity and reproduction, and asphyxiation.

While these projections of our future oceans may seem like doomsday scenarios, we will probably never see dramatic, rapid changes. Instead, there will be slow, progressive shifts in the equilibrium conditions of marine ecosystems over many decades. Scientists will be watching for indications that these ecosystem changes are occurring.

## Dodging the impacts

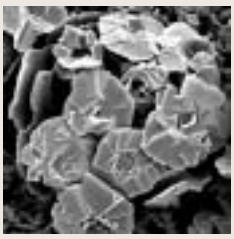
Many scientists believe that stabilizing atmospheric $CO_2$ concentration at 550 parts per million (ppm) may avoid the worst impacts on climate. Atmospheric concentration of $CO_2$ is currently ~380 parts per million (ppm) and, if no precautionary action is taken, is expected to reach 550 ppm by the middle of this century. Stabilizing $CO_2$ at 550 ppm will be a global challenge on an unprecedented scale. According to the Intergovernmental Panel on Climate Change (IPCC), the most authoritative source for scientific assessments of climate change, this may not be achieved through emissions reductions alone but rather through a carefully crafted portfolio of actions that also includes investments to develop low-cost, low-carbon or no-carbon energy sources, improvements in energy efficiency and carbon management options. The latter include storing carbon in the terrestrial biosphere (e.g. planting trees, limiting deforestation), or capturing the $CO_2$ emitted from an industrial source and storing it in geological formations or in the deep ocean. The IPCC is currently assessing these options for their feasibility, efficacy and safety, and calling for more research wherever information is insufficient to make a sound policy decision.

Scientists participating in the UNESCO symposium were asked to examine the issue of the potential efficiency and ecological impacts of using the ocean purposefully to store atmospheric $CO_2$. Much relevant research has been conducted in the past decade but the potential effectiveness and risks of ocean carbon sequestration have been neither thoroughly discussed nor assessed. Moreover, the science itself has become trapped in a tug of war between environmental groups and commercial entrepreneurs seeking financial compensation for artificially sequestering carbon in the ocean. Frustrated scientists have asked the IOC to provide a safe-haven

## How does phytoplankton react to high levels of $CO_2$ ?

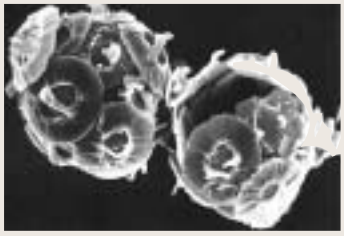
*Today's world ($pCO_2$: 280–380 ppm)*

*High $CO_2$ world ($pCO_2$: 580–720 ppm)*



*Scanning electron microscopy photographs of two calcifying phyto-plankton under $pCO_2$ conditions of today ($pCO_2$ from 280 ppm to 380 ppm) and under the high $CO_2$ conditions expected by the end of this century. Experimental results show that increased $CO_2$ con-centrations lead to malformations of calcium carbonate shells*

*Calcidiscus leptoporus*



*Gephyrocapsa oceanica*

Photos courtesy of Professor Ulf Riebesell, Leibniz-Institut für Meereswissen-schaften, IFM-GEOMAR. Adapted and reprinted with permission of Nature (www.nature.com): Riebesell et al. (2000) Reduced calcification of marine phytoplankton in response to increased atmospheric CO2 Nature 407, 364-367.

Photos courtesy of Dr Ove Hoegh-Guldberg, Centre for Marine Studies, University of Queensland, Australia

*Increasing $CO_2$ and sea temperatures can rapidly change coral reefs from healthy ecosystems into virtual graveyards of bleached and decaying coral*

for scientific discussions, free from the influences of special interest groups.

## Storage strategies and research requirements

Debate centres on two methods of using the ocean to store excess $CO_2$. One strategy is to induce and enhance artificially the growth of carbon-fixing plants in the surface ocean. When these organisms die, they sink to the deep ocean, carrying the carbon with them. In many regions, phytoplankton growth is limited by lack of an essential micro-nutrient, iron. Over the past decade, eight small-scale experiments have shown that introducing iron to iron-poor regions can stimulate phytoplankton growth to 20–30 times the natural rate.

Symposium participants agreed that iron fertilization experiments have been, and will continue to be, important for understanding the links between marine ecosystems and the global carbon cycle. However, all available research indicates that iron fertilization would be a very inefficient method for sequestering atmospheric $CO_2$, both from the viewpoint of the limited amount of carbon that could be sequestered by this method and the likelihood that, even if iron limitations were eliminated, other nutrients and environmental factors would eventually limit growth.

Another method of ocean carbon sequestration is to capture $CO_2$ from industrial sources, compress it into a liquid and store it in natural reservoirs out of contact with the atmosphere, such as deep geological formations or the deep ocean. Many important questions remain about the efficiency and impacts of injecting liquid $CO_2$ into the deep ocean and experimental data are extremely limited. The efficiency of this method would depend on the location and depth of the injection, since the goal is to keep the injected $CO_2$ out of contact with the atmosphere for as long as possible, while minimizing environmental damage around the area of the injection. Reproducing the temperature, pressure and the biological communities found in the deep ocean in a laboratory is extremely difficult. Carrying out small-scale experiments *in situ* in the deep ocean is no simple matter either, often requiring the use of deep-sea remotely operated vehicles or special instruments that must be lowered to great depths from a research vessel.

To further complicate matters, several attempts to perform experiments *in situ* have been blocked by environmental groups over concerns that these experiments represent the first step towards industrial-scale dumping. This has been a very divisive issue within the scientific community itself, with many strongly opposed to ocean carbon sequestration, even to the extent of suggesting that the community should not pursue research on the subject.

Unfortunately, because of the ocean's large natural capacity to store $CO_2$, ocean carbon sequestration will continue to interest commercial companies, some of whom may attempt to promote this technique without regard for potential environmental impacts. Symposium participants agreed that, even in the face of strong ethical opposition, investigations into the technical and economic feasibility of implementing this mitigation strategy are likely to continue. The international scientific community must be ready to respond accurately and without bias to questions of potential environmental impacts, long-term efficiency or benefits of this technique, weighing ocean carbon sequestration against other options and the critical need to stabilize atmospheric $CO_2$ at a concentration that will avoid the majority of impacts on human life and welfare.

## Keeping watch

The ultimate objective of the UN Framework Convention on Climate Change is 'to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.' Whereas 'dangerous anthropogenic interference with climate' has been widely discussed, no such debate has taken place over acceptable oceanic $CO_2$ levels. As a result, there are no standards to apply to judge what oceanic $CO_2$ levels should be considered tolerable for marine life or how proposed carbon management strategies might moderate or exacerbate effects on ocean chemistry and biology.

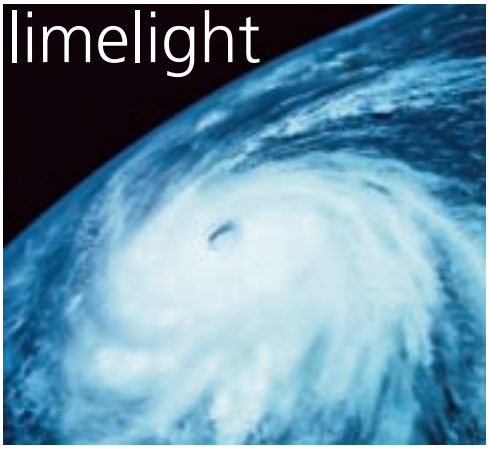
The IOC will maintain its Watching Brief on ocean carbon sequestration science and will continue to bring together the international and intergovernmental scientific community to develop unbiased policy-relevant scientific information for use by scientists, policy makers and the general public.

Maria Hood[20]

*Read the report of the symposium and the IOC Watching Brief :http://ioc.unesco.org/iocweb/co2panel/*

*20. UNESCO Programme Specialist in marine sciences*

# **Small islands** step into the limelight



© Stockbyte

**If ever there was a way to draw the world's attention to the specific needs of small islands, Cyclone Heta was it. The cyclone bulldozed its way through the Pacific in the early days of 2004, sparing only Tokelau and Wallis & Futuna which had the good fortune to be situated where the cyclone formed. Five other islands were not so lucky. Heta wreaked severe damage in American Samoa, the Cook Islands, Niue, Samoa and Tonga.**

**Niue was worst hit. A single island state of only 250 km$^2$ with a resident population of 2100, Niue could only watch as the cyclone laid waste to its recent development efforts. Heta's 300 km per hour winds, unprecedented in Niue's history, ripped away all the island's satellite communications equipment; however, due to the efforts of local volunteers, Internet services were operational only 10 days later.**

**While the future of Niue and the Niuean people continues to be debated – predominately by non-Niueans – the locals have quietly set about rebuilding their island, a testimony to the fortitude and resilience of islanders across the globe.**

## Hazardous territory

More than half of the 25 most disaster-prone countries are Small Island Developing States (SIDS), vulnerable as these are to volcanic eruptions, earthquakes, tsunamis, landslides, floods, hurricanes and cyclones. For the past 40 years, UNESCO has focused on identifying areas subject to natural hazards, improving risk assessment methods and encouraging preparedness for hazardous events. Work in the Pacific includes support to community-driven natural disaster/hazard mitigation in Tonga, Vanuatu and elsewhere, in collaboration with Massey University in New Zealand and other partners. UNESCO's Intergovernmental Oceanographic Commission (IOC) has provided support for many years to the Tsunami Warning System in the Pacific, which includes disseminating tsunami watches, warnings and advisory bulletins throughout the region.

For the past 10–15 years in the Caribbean, within UNESCO's Coastal and Beach Stability in the Lesser Antilles project, coastal planners, governments and NGOs have been monitoring beaches and coastlines to determine wise developmental practices. Also in the Caribbean, a number of collaborative activities have been undertaken on educational and communication aspects of disaster mitigation, such as a disaster preparedness manual for Caribbean schools through a joint initiative with the Caribbean Disaster Emergency Response Agency.

## Harnessing natural forces

The development of alternative energy systems is a crucial issue for many small islands. UNESCO's long-standing work on harnessing clean energy sources was boosted in the 1990s by the World Solar Summit process (1993–1995) and subsequently through the Organization's contribution to the UN World Solar Programme (1996–2005). Capacity-building aspects include the Global Renewable Energy and Training Programme (GREET) and a series of learning materials on new and renewable energies. Toolkits have recently been published on such topics as solar photovoltaic systems and geothermal energy, with a set of video materials (*see Rays of Hope overleaf)* tracing the history of, and prospects for, renewable energy in the Pacific.

*Pinney's Beach on Nevis in the Caribbean before Hurricane Luis struck in August 1995*

© G. Cambers

*The same section of Pinney's Beach in October 1995, two months after the passage of Hurricane Luis*

An ongoing UNESCO–UNDP initiative provides support to a range of regional and national Pacific sustainable energy projects, such as a national energy policy and strategic action plan for Tokelau, options for 24-hour power for Apolima Island (Samoa), increased use of renewable energies in the Cook Islands and training in photovoltaic solar home systems.

### Rising seas

Since the 1994 Barbados Conference (*see page 49*), the Intergovernmental Panel on Climate Change has refined its projections of the impact of climate change on SIDS. This has prompted island nations to assess their needs in terms of resources, training and financial support. Faced with sea-level rise of up to 1 m by the end of the next century, many have drawn up plans to protect their coastlines, such as through the construction of dykes. The densely populated Maldives is even constructing an artificial island for some of its citizens, while Tuvalu and Kiribati in the Pacific are exploring options for the relocation of their entire populations to Australia, New Zealand and elsewhere within the next 50 years.

A major UNESCO contribution to issues related to rising sea levels is the Global Ocean Observing System (GOOS), a collaborative international effort led by the IOC. GOOS is a global network of ships, buoys (*see page 34),* subsurface floats, tide gauges and satellites that collect real-time data on the physical state and biogeochemical profile of the world's oceans. This includes subsystems for data and information management for a variety of purposes, such as measurements and forecasts of changes in water level, the position and strengths of currents, sea-ice measurements and coverage, maps and forecasts of harmful algal blooms and vulnerability assessments of fish stocks and farms.

©Gloria McConnaghy

*'Solar panels are made up of many individual cells connected in series. A panel of 34 cells (insert) is for 12 V systems. The larger the panel, the greater the electrical energy produced. For best results, there should be no shade on a solar panel between 9 am and 3 pm. Even if only one cell is shaded, the output can be cut by half or more.' Taken from UNESCO (2003)* Solar Photovoltaic Systems Technical Training Manual. *The toolkit is based on experience gained in the Pacific, where scattered island communities have pioneered the field testing of solar photovoltaics and rural electrification*

## Rays of Hope

The '*Rays of Hope*' video and booklet highlight the importance of renewable energy in the Pacific, environmental concerns, energy dependence and types of renewable energy. Interviews and project insights from several countries are featured:

In **Kiribati**, solar panels power rural health centres and remote radio-telephone sites.

In **Fiji**, a village co-operative runs a small-scale hydro-electric project providing electricity for over 200 homes in a settlement deep in the interior of the main island.

In **Samoa**, a medium-scale hydro-project in Afalilo has reversed the proportions of hydropower and diesel feeding a hydro-electric power plant, with 80% of energy henceforth coming from hydropower and 20% from diesel.

In **Vanuatu**, coconut oil is being used as fuel for buses, taxis and other vehicles; it is also being used in generators that power a project in hydroponics (plant-growing in a medium other than soil).

*'Rays of Hope' is an initiative of UNESCO's Engineering Programme: t.marjoram@unesco.org; to order a copy: www.unesco.org/publishing.*

### It's a question of 'fresh' water

With their small size and particular geological, topographical and climatic conditions, many SIDS face hurdles when it comes to accessing and managing freshwater of suitable quality and quantity. UNESCO contributes to sustainable water management through the International Hydrological Programme (IHP) and UN World Water Assessment Programme, as well through the Man and the Biosphere (MAB) Programme. Under the aegis of the IHP Pacific Working Group, past and ongoing studies have been focusing on catchments and communities (*see The drama of rivers overleaf*), atoll groundwater recharge and groundwater pollution, among others.

### The flywheel of evolution

Small islands have long played an important role in scientific studies on the genetic diversity and evolution of living beings. As David Quammen in *The Song of the Dodo*[21] puts it, 'geographical isolation is the flywheel of evolution'. A century-and-a half ago, observations on the Galapagos Islands were critical in shaping Charles Darwin's revolutionary *Theory on the Origin of Species by Means of Natural Selection*. At about the same time, the islands in the Malay Archipelago proved essential for refining Alfred Wallace's thoughts on natural law.

However, biological diversity on many small islands is coming under increasing threat through the introduction of exotic species, development of tourism infrastructure, inadequate waste disposal, excessive harvesting of particular biotic groups, such as corals, and so on.

*21.Quammen, D. The Song of the Dodo. Island Biogeography in an Age of Extinction. Simon & Schuster, New York, 1997, p 128*

UNESCO's concern for biological diversity is rooted in two complementary international initiatives. The first is the Convention for the Protection of the World's Natural and Cultural Heritage, a binding legal instrument that focuses on unique sites of outstanding and universal value. The World Heritage List includes: the Aldabra Atoll (Seychelles), East Rennell (Solomon Islands), Mornes Trois Pitons National Park (Dominica), Cocos Island (Costa Rica), two sites in Cuba and the Galapagos National Park and Marine Reserve (Ecuador). The second initiative is the World Network of Biosphere Reserves within the MAB Programme; these sites are exemplary in exploring approaches to sustainable development with the involvement of local people. The list currently comprises 440 sites in 97 countries and territories, including Cuba, Dominica, Mauritius and the US Virgin Islands.

## A cultural melting pot

The perception of small island communities as historically remote and isolated is erroneous. In fact, the history of the islands testifies to the great cultural interaction and mixing that they have offered humanity. Indeed, it may be much more appropriate to understand islands as 'cultural crossroads'.

Unlike earlier theories, which imagined people 'drifting' on large rafts at the whim of the ocean currents, we now know that the first settlers were moving deliberately and

## The world's small island nations

| | | Population (2003) | Terrain | Coast-line (km) | Land area ($km^2$) | Renewable water/ capita/year ($m^3$) | Adult HIV/AIDS 2001[c] (%) |
|---|---|---|---|---|---|---|---|
| **Atlantic Ocean** | Cape Verde | 412,137 | rugged, rocky, volcanic | 965 | 4,033 | 703 | 0.04 |
| | Sao Tome & Principe | 175,883 | volcanic, mountainous | 209 | 1,001 | 15,797 | – |
| **Indian Ocean** | Comoros | 632,948 | volcanic islands | 340 | 2,170 | 1,700 | 0.1 |
| | Maldives | 329,684 | flat | 644 | 300 | 103 | 0.1 |
| | Mauritius | 1,210,447 | small coastal plain, central plateau | 177 | 2,030 | 1,904 | 0.1 |
| | Seychelles | 80,469 | narrow coastal strip, coral, flat | 491 | 455 | – | – |
| **Gulf** | Bahrain[a] | 667,238 | low desert plain, low central escarpment | | 665 | 181 | 0.3 |
| **Pacific Ocean** | Cook Islands | 21,608 | low coral atolls, volcanic, hilly | 120 | 240 | – | – |
| | Fiji | 868,531 | mountainous of volcanic origin, coral atolls | 1,129 | 18,270 | 35,074 | 0.1 |
| | Kiribati | 98,549 | low-lying coral atolls | 1,143 | 811 | – | – |
| | Marshall Islands | 56,429 | low coral limestone and sand islands | 370 | 181 | – | – |
| | Micronesia | 108,143 | low coral atolls, volcanic, mountainous | 6,112 | 702 | – | – |
| | Nauru | 12,570 | sandy beach, coral reefs, phosphate plateau | 30 | 21 | – | – |
| | Niue | 2,145 | limestone cliffs, central plateau | 64 | 260 | – | – |
| | Palau | 19,717 | low coral islands, mountainous main island | 1,519 | 458 | – | – |
| | Papua New Guinea | 5,295,816 | coastal lowlands, mountains | 5,152 | 452,860 | 166,563 | 0.7 |
| | Samoa | 178,173 | narrow coastal plains, interior: mountains | 403 | 2,934 | – | – |
| | Solomon Islands | 509,190 | low coral atolls, rugged mountains | 5,313 | 27,540 | 100,000 | – |
| | Tokelau[a,b] | 1,418 | atolls | – | 10 | – | – |
| | Tonga | 108,141 | coral formation, volcanic | 419 | 718 | – | – |
| | Tuvalu | 11,305 | low-lying and narrow coral atolls | 24 | 26 | – | – |
| | Vanuatu | 199,414 | narrow coastal plains, mountains of volcanic origin | 2,528 | 12,200 | – | – |
| **Mediterranean Sea** | Cyprus | 771,657 | plains, mountains | 648 | 9,240 | 995 | 0.3 |
| | Malta | 400,420 | low, flat plains, coastal cliffs | 140 | 316 | 129 | 0.1 |
| **Caribbean Sea** | Antigua & Barbuda | 67,897 | low-lying limestone and coral islands | 153 | 443 | 800 | – |
| | Aruba[b] | 70,844 | flat, some hills, scant vegetation | – | 193 | – | – |
| | Bahamas | 297,477 | long, flat, coral formations | 3,542 | 10,070 | 66 | 3.5 |
| | Barbados | 277,264 | flat, central highland | 97 | 431 | 307 | 1.2 |
| | Cuba | 11,263,429 | terraced plains, small hills, mountains | 5,746 | 110,860 | 3,404 | <0.1 |
| | Dominica | 69,655 | rugged mountains of volcanic origin | 148 | 754 | – | – |
| | Dominican Republic[a] | 8,715,602 | rugged highlands and mountains | – | 48,380 | 2,507 | 2.5 |
| | Grenada | 89,258 | volcanic in origin, central mountains | 121 | 344 | | – |
| | Haiti[c] | 7,527,817 | rugged, mountainous | – | 27,560 | 1,723 | 6.1 |
| | Jamaica | 2,695,867 | narrow coastal plains, mountains | 1,022 | 10,831 | 3,651 | 1.2 |
| | Netherlands Antilles[a,b] | 216,226 | hilly, volcanic interiors | 364 | 960 | – | – |
| | St Kitts & Nevis | 38,763 | volcanic, mountainous interiors | 135 | 261 | 621 | – |
| | St Lucia | 162,157 | volcanic, mountainous with broad valleys | 158 | 606 | – | – |
| | St Vincent & Grenadines | 116,812 | volcanic, mountainous | 84 | 389 | – | – |
| | Trinidad & Tobago | 1,104,209 | flat, hilly, mountainous | – | 5,128 | 2,968 | 2.5 |
| | US Virgin Islands[a,b] | 124,778 | hilly, rugged, mountainous | 188 | 349 | – | – |
| **South China Sea** | Singapore | 4,608,595 | lowland, undulating central plateau | 193 | 683 | 149 | 0.2 |

[a] *Not a member of the Alliance of Small Island States (the Netherlands Antilles and US Virgin Islands are however observers);* [b] *Non-self governing;*
[c] *Population estimates for Haïti explicitly take into account the effects of excess mortality due to AIDS;* [d] *Estimate*

Source: www.un.org/esa/sustdev/sids/sidslist.htm; population data for 2003, HIV/AIDS and land area data: CIA Factbook : www.cia.gov/cia/publications/factbook; freshwater data: UN (2003) *World Water Development Report. Water for People, Water for Life* (Table 4.2). UNESCO Publishing, Paris

## The drama of rivers

For the past three years in the Epule community in Vanuatu, there has been a ban on fishing in the local river and on some of the associated reefs. This has met with resistance from the locals even though they have long suspected that their river was being polluted by logging, farming and a growing village population. The village chief hopes the locals will ultimately come to accept the ban.

The desire to impress upon the local ni-Vanuatu people that the ultimate responsibility for the management of water resources lay with them inspired the IHP to join forces recently with the local theatre groups Haulua and Won Smol Bag (bislama for 'one small bag'). The theatre groups put on plays for the local communities highlighting types of behaviour which are harmful to the river and contrary to laws and codes of practice within Vanuatu, such as logging within 50 m of a river.

The script for the *River Play* was developed in close collaboration with the Department of Geology, Mines and Water Resources. The performances were well received by village audiences at a number of locations. Most importantly, during the lively discussions which followed each performance, many villagers offered to participate in prevention and restoration activities, such as tree-planting along streams and rivers, or the monitoring of catchments.

*For further information on the IHP's Catchments and Communities project: www.unesco.org/water*

knowingly amongst the vast body of water that is the Pacific Ocean. Those 'bits' of land in the sea, the islands, were their meeting points, their 'crossroads'. With this understanding, UNESCO launched 'Vaka Moana: the Ocean Roads' under the auspices of the World Decade of Cultural Development, with the intention of reinforcing linkages between Pacific peoples through a better knowledge of their common historical links and dependence on the ocean, and the promotion of all forms of art which have the common theme of the sea.

### Promoting cultural heritage

In terms of the conservation of cultural heritage, more important perhaps to many SIDS than tangible properties and sites is what is known as 'intangible cultural heritage'. This embraces all forms of traditional and popular or folk culture originating in a given community transmitted orally or by gesture, including customs, languages, music, dance, rituals, festivities, traditional medicine and pharmacopoeia.

Several UNESCO cross-cutting activities are underway in island settings on the use of cultural assets for raising living standards and preserving cultural heritage. These schemes include the promotion in the Pacific region of traditional crafts as a way to open up job opportunities for the poorest youth. In the Caribbean, the YouthPATH initiative seeks to involve rural youth in natural and cultural heritage tourism and other income-generating initiatives. Activities focus on such attractions as a nesting turtle site, a former slave village, a fishing–whaling settlement. Underpinning the whole regional project is the notion of the Caribbean Sea as a connective link between island cultures, in temporal as well as spatial terms.

### Transmission of traditional knowledge

Local and indigenous knowledge is another dimension of cultural diversity that takes on special significance in small island situations. Traditional marine resource management in the Pacific has been the focus of several UNESCO events since the 1980s. In recent years, UNESCO work on local knowledge has been boosted through discussions on 'science and other systems of knowledge' linked to the UNESCO–ICSU World Conference on Science (Budapest, June 1999).

One significant outcome has been the launching of the project on Local and Indigenous Knowledge Systems in a Global Society (LINKS). In mid-2004, LINKS will be releasing a CD-ROM on traditional navigation in the Pacific, which will serve primarily as an educational tool for schools highlighting to students the significance of stick charts for teaching swell patterns, stone circles for illustrating star compasses and other indigenous knowledge practices. LINKS is also working through a Vanuatu-based project to encourage primary and secondary pupils to incorporate indigenous knowledge within their own communities and schools.

© UNESCO/Christopher Mercier

*Traditional navigation in the Pacific; foliage in the boat rigging provides a simple means of following subtle changes in the direction and strength of the wind*

### The fight against HIV/AIDS

Being a dynamic cultural crossroad can also negatively impact upon a country's aspirations. One serious concern in this regard is HIV/AIDS. Studies, especially those in the Caribbean, have underlined the cultural dimension in the prevention of HIV/AIDS and in caring for its victims, as well as the critical role of education in limiting the spread and impact of the epidemic. Multidisciplinary cooperation and broad partnerships are crucial for the prevention of HIV/AIDS, as are innovative uses of media and communication tools in building targeted public awareness and fostering behaviour change, particularly among youth.

## 'Front-line zones' on the road to Mauritius

*'The world's small island developing states are front-line zones where, in concentrated form, many of the main problems of environment and development are unfolding'.*

**United Nations Secretary-General, Kofi Annan, New York, September 1999**

**Rio**, June 1992. The international community at the Earth Summit recognized that small islands are 'a special case for environment and development'. This understanding paved the way for small island developing states to come together as a group to discuss their specific concerns.

**Barbados**, April – May 1994, 'Small Islands: Big Issues'. The Global Conference on the Sustainable Development of Small Island Developing States. The *Agenda 21* adopted at Rio spawned the Barbados Programme of Action (BPoA). BPoA lists 15 priority areas for specific action, including climate change and sea-level rise; natural and environmental disasters; waste management; coastal and marine resources; and tourism.

**Johannesburg**, September 2002. The World Summit on Sustainable Development reaffirmed that SIDS are a special case in terms of both environment and development. Among the recommended follow-up actions, the Johannesburg summit called for a full and comprehensive review of the BPoA.

**Mauritius**, 10–14 January, 'Small Islands, Big Stakes'. As decided by the UN General Assembly, a full and comprehensive 10-year review of the implementation of the BPoA will be undertaken and emerging issues will be identified for follow-up.

*For further information on UNESCO's contribution to BPoA:* www.portal.unesco.org/islandsBplus10; on the SIDS Network and the Alliance of Small Island States: www.sidsnet.org/aosis

In the Caribbean, UNESCO is working with a range of partners to encourage effective policies and practices for HIV/AIDS mitigation and prevention within formal and non-formal education. One example is a pilot project in Jamaica involving UNESCO, the Ministry of Education and other educational institutions in the country[22].

## Sustainable development can never be realized without youth

Immediately prior to, and during, the international BPoA review meeting in Mauritius in January 2005, young islanders from all SIDS will meet to discuss their concerns about small island living, share experiences, promote cultural under-standing, participate in debates and side-events and present their outcomes to the main meeting. This initiative, dubbed 'Youth Visioning for Island Living', while proposed by the Ministry of Education and Scientific Research of Mauritius, is being facilitated initially by UNESCO as a joint effort between its Coastal Regions and Small Islands Platform and its Section for Youth, and supported by a variety of national, regional and inter-regional organizations and donors.

*Go to: www.unesco.org/csi/smis/siv/vision-action.htm*

### Connecting islands to the global community

With limited numbers of tertiary institutes based in small islands – thereby exacerbating island 'brain drain' – one of the burgeoning areas of higher education is expected to be distance learning modules and programmes through greater application of ICTs. In a similar way, Community Multi-media Centres (CMCs) encourage community empowerment and address the digital divide by combining community broadcasting with Internet and related technologies. The aim is to transform existing community radio stations into CMCs, complete with PCs, faxes, telephones, and email and Internet services. Initial participants include radio stations in Barbados, Cuba, Jamaica, and Trinidad & Tobago.

Small Islands Voice (SIV[23]) is an inter-regional initiative in the Caribbean Sea and Indian and Pacific island regions. It uses ICTs and existing media to encourage general public discussion and involvement in sustainable development activities at a local level. Young islanders are also assured their 'space to speak' via the SIV Internet youth forum[24], which has generated debate on diverse subjects ranging from whaling and asbestos in schools to recycling and growing levels of gang violence.

© UNESCO/Herman Belmar

*Bequia Community High School in St Vincent & the Grenadines, contributing online to the Small Islands Voice youth Internet forum*

Implementation of the UN Barbados Programme of Action has had mixed results. Many living in small islands have no knowledge of the BPoA and how it relates to their everyday life. However, various initiatives have been improving life in SIDS. These include the Alliance of Small Island States and the UN-based information network, SIDSNET. Along with sister agencies, UNESCO is contributing to the overall goal of sustainable island development, in the belief that these island states are not 'islands in a far sea' but 'a sea of islands'[25].

Claire Green[26] and Malcom Hadley[27]

22. *UNESCO's International Institute of Educational Planning and the University of the West Indies, 2003; and the* Regional Strategy on Education and HIV/AIDS for the Caribbean, *UNESCO Kingston and IIEP*
23. *www.smallislandsvoice.org*
24. *www.sivyouth.org – username: view; password: only*
25. *Hau'ofa, E. (1993)* Our Sea of Islands. *In: A New Oceania. Rediscovering Our Sea of Islands. University of the South Pacific, Fiji, and Beake House, p. 7*
26. *UNESCO Coastal Regions and Small Islands platform: www.unesco.org/csi*
27. *Former Editor,* Nature and Resources *(UNESCO quarterly)*

# Saviours from space for **Siberia's frozen tombs**


*A very fine feline image made of wood and covered in gold leaf, as found in a grave in Berel in east Kazakhstan. In the background, you can see a perfectly preserved horse's hoof, complete with skin and hair. The bodies of horses were not mummified, so their internal organs remain. The content of a horse's stomach can tell us a lot about vegetation, climate etc.*

**Hundreds of frozen tombs lie scattered across the Altai mountains straddling Russia, Kazakhstan, Mongolia and China. A major archaeological find dating back to the 1920s, these tombs belong to the lost Scythian culture which flourished 2500 years ago. Inside the tombs lie bodies which have often been so well preserved in the frozen ground that even the tattoos on their skin remain intact.**

**Grave robbers and fortune hunters have been the tombs' traditional enemies but, today, a new threat hangs over them. Climate change is causing the permafrost in this part of Siberia to thaw. In a race against time, UNESCO and the University of Ghent in Belgium are helping teams in Russia and Kazakhstan to pinpoint the location of the remaining tombs from space, to help local conservationists protect them.**

For thousands of years, the Altai Mountains have been an important passage between the Mongolian and Kazakh steppes. The area is a rich source of archaeological information on commercial routes and other exchanges between populations. The Silk Road lies nearby and, buried in the graves of the Scythians, one can find Chinese vases, Persian carpets, Indian silks...

The term 'Scythian' is a generic term for the various populations which inhabited the Eurasian Steppe during the Iron Age and thus does not cover a single civilization. The Scythian economy was based on a semi-nomadic way of life.


*View of a coffin and sarcophagus in Berel in 2000 before they were hoisted out of the grave by the teams of Zeinolla Samashev from the Kazakh Institute of Archaeology and Henri-Paul Francfort from the* Centre national de recherche scientifique *(CNRS) in France. Once removed from its resting place, the wooden tomb was treated immediately with chemicals to prevent it from disintegrating after being exposed to the air and dryness. Wood samples were also taken for the purpose of dating the find. This is done by comparing the growth rings on the timber*

People moved about with the seasons, taking their herds of horses, yaks, sheep and goats with them and always returning to home base in the summer. This way of life has partly survived until today. As a result, no large villages or cities have ever been built and ancient settlements are a rare find. The primary source of archaeological information about the Scythians thus comes from the burial mounds, or *kurgans*.

## Buried with gold and horses

The Scythians were skilled warriors on horseback. Masters of horse breeding, they were traders but also feared for their raids on neighbouring territories. Some of these raids took them as far afield as Babylon or Eastern Europe.

The horses followed the Scythians into their tombs. The bodies of sacrificed horses have been found in the graves, together with artefacts and utensils made of wood, leather, cloth, silk, metal and gold. The ornaments are exquisitely made and in many cases exceptionally well-preserved.

Many of the tombs are buried in permafrost, which maintains temperatures at between 0°C and -20°C. As the Scythian populations inhabited the entire Eurasian Steppe stretching from the Black Sea to Mongolia, the frozen tombs are a unique source of information about one of the most intriguing cultures of their time.

## The Open Initiative

The Open Initiative was launched by UNESCO and the European Space Agency in 2001 to support the World Heritage Convention and the World Network of Biosphere Reserves. Its main objective is to develop cooperation among space agencies, research institutes, academies of science and universities, NGOs and the private sector, in order to protect natural and cultural sites in developing countries.

These sites face a variety of potential and very real threats, such as uncontrolled agricultural expansion, deforestation, urban sprawl, armed conflict, poaching, natural catastrophes, climate change and ecologically damaging tourism. Developing countries often lack accurate cartography to manage and protect these sites effectively. Satellite imagery can bridge this gap.

As its contribution to the Open Initiative, UNESCO has set up a Remote Sensing Programme headed by Mario Hernandez. In close partnership with the country responsible for a given site, the Programme defines the overall requirements, brings on board the specialized partners who will be implementing the project and secures the requisite funding. The Programme also coordinates the training of the local staff who will be handling all the information derived from the satellite images at the end of the project.

Besides the Altai project, the Open Initiative is currently surveying the Iguazu Falls in Argentina, the ancient Machu Pichu site in Peru and vestiges of the Mayan civilization in Guatemala. It is also using satellite imagery to observe and safeguard the archaeological site of Uruk-Warka in southern Iraq. A sixth project was completed in 2003; it consisted in providing the Democratic Republic of Congo, Rwanda and Uganda with their first accurate maps of inaccessible mountain gorilla terrain, as part of efforts to save the last 650 or so mountain gorillas.

The Open Initiative has now attracted a large number of space agencies.

*For details:*
*www.unesco.org/science/remotesensing*

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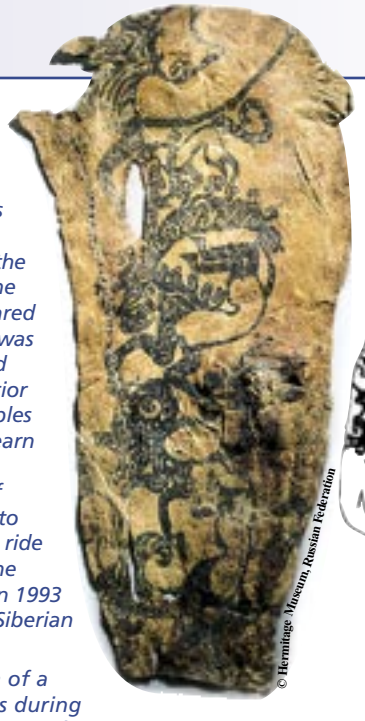


© Hermitage Museum, Russian Federation

*Left: This 'Ice Maiden' was discovered on the Ukok Plateau in the Altai Mountains, which lies about 2500 m above sea level. She lived at the time of the Pazyryk culture (Scythians) of the late 5th century BP and was aged about 25 years when she died. She is also known as the Ukok Princess because of the finery found in her tomb and the fact that she was the sole occupant – a woman usually shared her tomb with a man. Her mummified body was also tattooed and weaponry had been placed in her grave, giving rise to the idea of a warrior princess or even Amazone. By analysing samples of her hair and skin, geneticists are able to learn more about the ethnic origins of the Pazyryk population. Chemical and physical analysis of her bones and soft tissue provides insights into her nutrition, health and way of life. Did she ride horseback, for instance? What diseases did she suffer from? The Ice Maiden was excavated in 1993 by archaeologist Natalia Polosmak from the Siberian Branch of the Russian Academy of Sciences*

*On the right, a segment of the right arm of a Scythian man buried in the Altai Mountains during the same period as the Ice Maiden. The site was first excavated by Russian archaeologist Mikhail Gryaznov in 1929. The drawing on the far right shows the location of all the tattoos on the man's body. The tattoos represent animals and mythical creatures*

### No detailed maps of the Altai

Ghent University and Gorno-Altaisk State University have been conducting joint research in the Altai Mountains since 1995. Their research has focused both on excavating burial mounds and on thorough surveys of other archaeological heritage in the mountains. In 2003 and 2004, the research team studied the organization of ritual and funerary sites in the Altai landscape through time (diachronically).

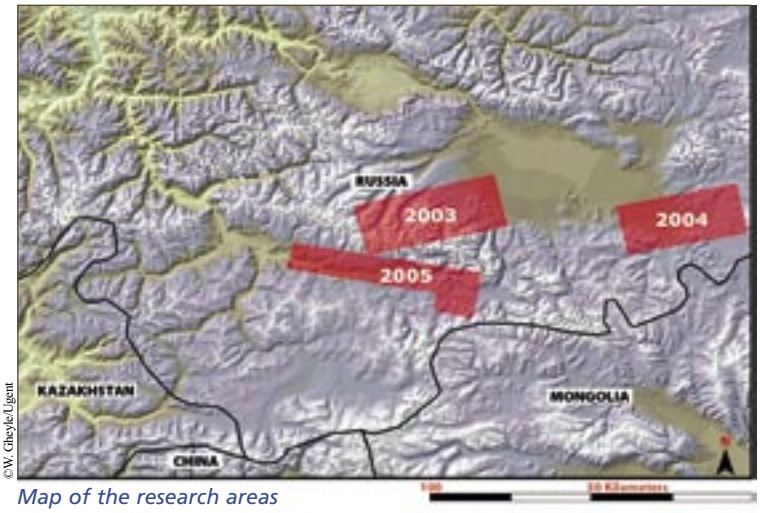
As this surveying work was hindered by the lack of detailed maps of the Altai Mountains, satellite images were used to make detailed topographic maps as background to the archaeological information.

### A fresh start

In past decades, a horde of national and international research teams have flocked to the Altai Mountains. They have excavated dozens of *kurgans* in China, Kazakhstan, Mongolia and Russia. Unfortunately, some of these teams have limited their research to the isolated excavation of a single promising burial mound, with no thought for placing the monuments in their cultural context or studying

the position of the sites in the landscape as a whole. Moreover, attempts have been made in the past to come up with protection measures and conservation management plans for the *kurgans* but none of these has ever got far beyond the drawing board.

The project put together by Ghent University with the support of UNESCO and a generous contribution of €330,000 from the Flemish Community of Belgium now fills this gap. The project sets out to inventory all the frozen tombs in the Altai Mountains, together with other archaeological heritage, over a two-year period beginning in 2005. To do this, the University of Ghent is deriving maps from satellite imagery that show the detailed topography of the region and the resting place of each *kurgan*. In parallel, the project is assessing climate change in the Altai and analysing the threats which climate change poses to the frozen tombs.




©W. Gheyle/Ugent

*Map of the research areas covered in 2003, 2004 and 2005. This map was made using RADAR images from the Shuttle Radar Topography Mission*

## Of robbers and roads

For many of the tombs alas, help will come too late. They have been destroyed by grave robbers and fortune hunters, some many centuries ago, others only recently. As a deterrent, the Russian government now demands a research permit before a *kurgan* can be excavated.

Other tombs have escaped the robbers, only to have their long sleep disturbed by roadworks. The construction of roads is gradually opening up this formerly inaccessible territory. When they were in Dzhazator in 2005, for example, the team from Ghent saw several sites that had been disturbed by roadworks.

In this case, however, something can be done to protect the tombs. Having a detailed inventory of the location of all the archaeological monuments in the area will help local authorities plan infrastructure development, such as the path a pipeline should follow. The inventory will also prove invaluable to the authorities in regulating emerging tourist activities, such as rafting, alpinism or camping, and in building awareness of the need to preserve the *kurgans*.


©S. Marchenko/Alaska Fairbanks University

*Here, a photo of Tuyuksu Glacier in Northern Tien Shan in July 1997. The glacier has retreated 362 m since 1955. No complete map showing the retreat of permafrost in the Altai mountains over time has ever been made, although the International Permafrost Association is looking for funding to monitor and map the permafrost of the entire Altai mountain range*

## A more insidious threat

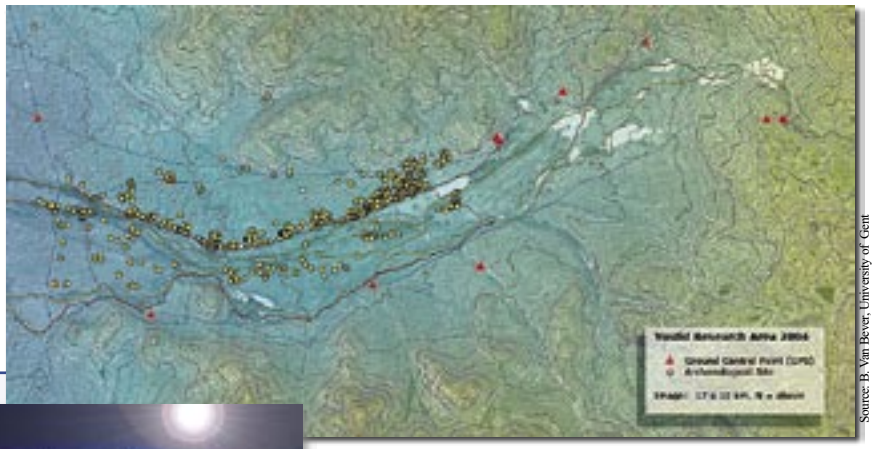
The other threat to the frozen tombs is weather-related. As the Altai Mountains are situated on the border of the vast permafrost zone covering much of Siberia, permafrost in the Altai is very vulnerable to climate change. With the permafrost that preserves the *kurgans* now gradually thawing, the frozen tombs and their precious contents will soon no longer be packed in the ice that has preserved them for so long. Measurements taken at weather stations, borehole monitoring and research on glaciers all indicate that the climate in the Altai is changing considerably. Permafrost in the region could disappear completely by the middle of this century. After 2500 years of perfect conservation, the remaining *kurgans* and the insights they provide into the ancient nomad Scythian culture could be lost for ever.

©H.-P. Francfort/CNRS

*This ornament resembling a reindeer was found on a horse harness in Berel. All the ornaments preserved in permafrost for centuries must be treated with chemicals immediately after being recovered, or they will crumble with exposure to the air. It would thus be pointless for modern-day grave robbers to steal the artefacts, as they would walk away empty-handed*

### Satellites to the rescue

Within its 'Open Initiative', UNESCO has brought in additional expertise to complement that of the University of Ghent in remote sensing (*see box p. 51*). It was UNESCO, for instance, which brought in the Jet Propulsion Laboratory, a research centre of the US National Aeronautics and Space Agency (NASA), to provide the University of Ghent with ASTER satellite images to monitor the status of the glaciers in the Altai Mountains (see *A beginner's guide to remote sensing*). The glaciers will need to be monitored continuously over several decades to determine which of them are retreating or advancing, a clear sign of climate change. Indirectly, this may provide insights into the rate at which permafrost is thawing. Armed with this information, local conservationists will be able to establish priorities for preserving each of the tombs. They will be able to determine, for example, which tombs lie in the areas where the permafrost is thawing fastest.



Source: B. Van Bever, University of Gent

The *kurgans* are literally packed in ice. After burial, each tomb was covered with stones which formed a permeable mound. Rainfall was able to penetrate the tomb where it froze. Over time, this process created an iceblock which preserved the tomb and its entire contents. As modern approaches to archaeology seek to avoid excavating tombs, scientists are studying ways of preserving the tombs *in situ*, such as by creating a system of 'air conditioning' that would keep the tombs frozen.

Thanks to data from the CORONA reconnaissance satellite and the precise measurements taken using a Global Positioning System (GPS) receiver, the problem of the lack of detailed maps has been overcome. The CORONA satellite provides ground resolution of 1.8 m, which is good enough for the purposes of topographical mapping. It is also detailed enough to detect most archaeological structures more than 2–3 m in diameter, such as *kurgans* and other funerary or ritual monuments (see *A beginner's guide to remote sensing*).

During the survey campaigns of 2003 and 2004, the University of Ghent was able to generate detailed topo-graphic maps and height models (3D models) derived from CORONA satellite imagery of a total surface area of 600 km$^2$. It is possible to obtain a height model by combining two images of the same area using

## A beginner's guide to remote sensing

© NASA

*View of the Terra satellite platform launched in 1999 as part of NASA's Earth Observing System*

Remote sensing is the science of deriving information about the Earth from images acquired at a distance. The most common forms of remote sensing are aerial photography and satellite imagery.

Remote sensing makes such extensive use of photogrammetry that it can become difficult to separate the two terms. Photograms may come in the shape of photographs or imagery stored electronically on tape or on disk; they may be video images or images taken using CCD cameras and other radiation sensors like scanners.

Satellite-based remote sensing usually targets the Earth's surface, changes in land cover, the oceans, snow and ice but it does also observe other areas, such as the atmosphere, the climate and recently even Mars and outer space.

Satellites may point to a fixed point on the Earth when they are in a geostationary orbit, as in the case of meteorological satellites, or they may cover almost the entire planet, as when they fly on an almost polar orbit. Each satellite 'scans' the Earth, capturing digital information that is transmitted to stations on the ground.

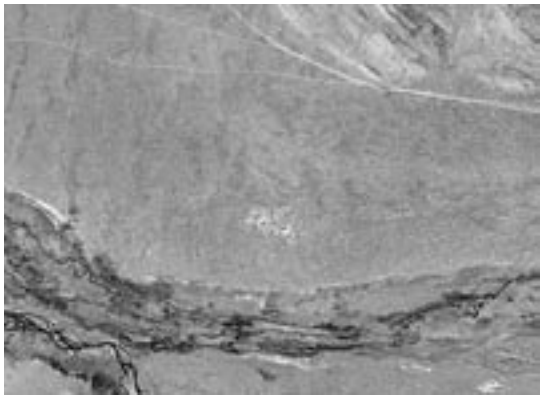
The following remote sensors are cited on these pages:

**ASTER** stands for Advanced Spaceborne Thermal Emission and Reflection Radiometer. ASTER is an imaging instrument flying on the Terra platform. ASTER is being used to obtain detailed maps of land surface temperature, reflectance and elevation. The thermal bands of ASTER's digital sensors are able to give an overview of ground temperatures on a large scale.

**CORONA** is a satellite which dates back to the 1960s and is no longer operational. It was originally a 'spying eye' of the American military. In line with US policy, which makes it possible to release selected military information into the public domain after a time, the images recorded by CORONA were released in 1996 and 2002. CORONA orbited the Earth at an altitude of 160–200 km, depending on the mission.

**Landsat** crosses the Equator from North to South at an altitude of 705 km. This satellite operates on a repetitive 16-day cycle and completes just over 14 orbits of the Earth a day at a speed of 7.5 km per second. Landsat 7 was launched at the same time as Terra, 27 years after NASA launched the first Landsat spacecraft within its Earth Observing System. The aim is to produce an uninterrupted record of the Earth's land surface for scientists and engineers working for state or local governments, agribusiness, the military, in commercial fields, academia or global change research and so on. Recently, Landsat 7 has been failing.

photo-grammetric computer software (see *A beginner's guide to remote sensing*). This enabled the Ghent team to document over 3000 archaeological monuments. The data were all fed into a database linked up to a Geographical Information System (GIS). The latter is a computer application which stores, views and analyses maps and other geographical information. Although the database and GIS are being used for research purposes, the database will also be offered to the Russian conservationists to help them manage development of the area and above all protect its archaeological heritage.



©W. Gheyle/Ugent

*Left: Satellite image taken in 1969 from a height of more than 150 km showing four Scythian burial sites. Note the parallel alignments of small dots, starting from the river bank, representing burial mounds in Yustid Valley. The sites were excavated by V. D. Kubarev in the 1980s and documented by the Ghent team in 2004. Right: Photo taken from a hilltop of aligned Scythian burial mounds*

Since 2005, the University of Ghent has been carrying out a thorough inventory of the archaeological heritage of parts of the Russian and Kazakh Altai Mountains using satellite imagery, in partnership with Gorno-Altaisk State University and the Margulan Institute of Archaeology in Almaty. Satellite images are being used to create a cartographical archaeological inventory that fuses traditional field work, satellite image interpretation and GPS.

Dzhazator Valley in the south of the Altai Republic of the Russian Federation was chosen for the first mapping campaign from 8 July to 18 August last year. Over this six-week period, 1687 different archaeological structures were located and described. These structures were spread over 192 sites and an area of 284 km². The entire Dzhazator Valley was mapped in detail using CORONA satellite images. Part of the expedition focused on defining good ground control points for Aster and Landsat satellite images. These ground control points are being used to georeference the satellite images and produce height models and orthophotographs. The latter are aerial photographs which remove the distortions of points on the ground caused by relief, tilt and perspective.

©W. Gheyle/Ugent

*Archaeologist Kaatje De Langhe and geographer Matthijs Vanommeslaeghe are standing on a well-preserved burial mound, typical of a Scythian* kurgan *in its undisturbed state. Here, they are measuring the location of this burial mound using a complex Global Positioning System (GPS) receiver during the 2005 campaign*

## This is only the beginning

The project will need to extend over Russia's border into the neighbouring countries of Kazakhstan, China and Mongolia to map the archaeological heritage and monitor climate change throughout the Altai Mountains. This year, the University of Ghent is surveying the Valley of Kara-Kaba in east Kazakhstan and studying the effects of climate change on glaciers, together with the Margulan Institute of Archaeology of Almaty and geocryologist Sergei Marchenko from the International Permafrost Association. For this segment of the project, UNESCO will be bringing on board another Open Initiative partner, the Chinese Academy of Sciences.

Given the need for uninterrupted monitoring of climate change over long periods of time, this will be only the beginning...

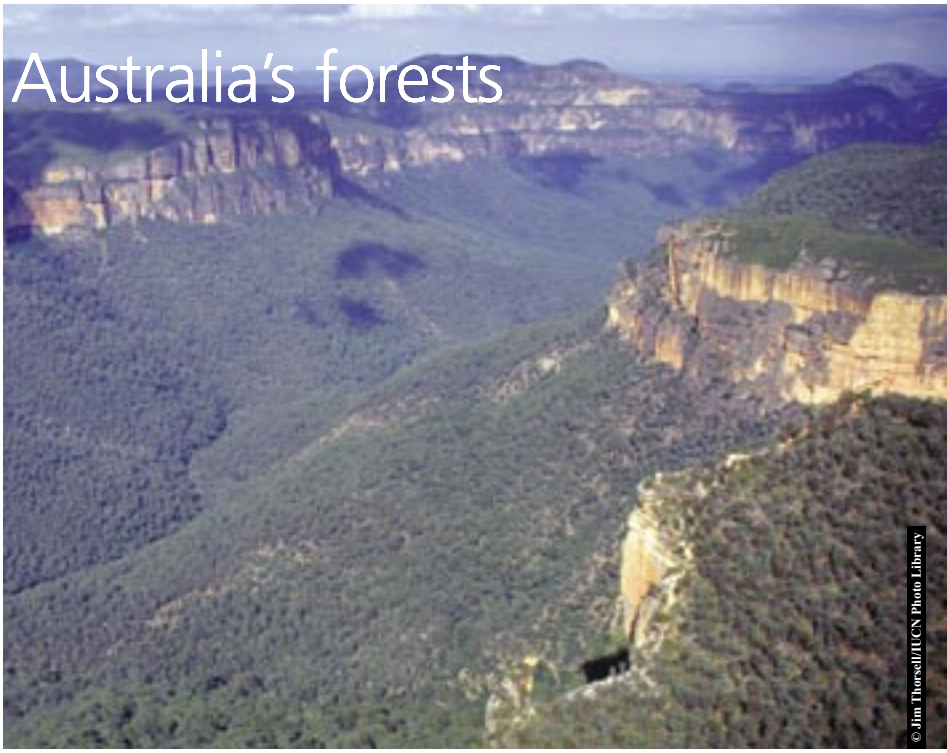
Wouter Gheyle with the collaboration of
Jean Bourgeois, Jessica Bunning and Mario Hernandez[28]

*For details: AltaiMountains@Ugent.be; www.archaeology.ugent.be/altai/; www.altai-republic.ru/; Ma.Hernandez@unesco.org; http://whc.unesco.org/; www.unesco.org/science/remotesensing*

*28. Jean Bourgeois is full professor and Wouter Gheyle is a scientific researcher at the Department of Archaeology and Ancient History of Europe at Ghent University in Belgium. Mario Hernandez is Head of UNESCO's Remote Sensing Programme and Jessica Bunning is a Programme Assistant at UNESCO*

# The heat is on for Australia's forests

**Australia is currently in the throes of its worst drought in living memory, with all but the far northwest affected. Between 1910 and 1999, the country saw an average increase in temperature of 0.7°C, most of which occurred after 1950. Projections by the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) based on climate models indicate an increase in average annual temperatures ranging from 0.4°C to 2.0°C by 2030 and as much as 1.0°C to 6.0°C by 2070. Evaluating future trends in rainfall remains more difficult. This change in climate regime raises a special concern for forests, where the impact of higher temperatures could heighten the risk of more frequent, intense and destructive wildfires, and decimate biodiversity.**




*The Greater Blue Mountains Area owes its blue haze to the highly flammable eucalyptus oil released into the atmosphere in response to heat. More than 100 eucalypt taxa have been recorded here*

**The Greater Blue Mountains and The Wet Tropics of Queensland are two of the sites profiled in *Case Studies on Climate Change and World Heritage*, published by UNESCO's World Heritage Centre in April. Separated by over 2700 km, these two Australian sites are poles apart in many ways: the former ecosystem is made up of temperate eucalypt forests, the latter of tropical rainforests and mangroves. Yet both will be highly vulnerable to Australia's warmer and drier climate in the 21st century.**

In 2003, Lesley Hughes from Sydney's Macquarie University argued that it was difficult to plot the impact of climate change in Australia on the broad range of species, due to the lack of sufficient baseline data from which to work. Studies carried out since however on vulnerable alpine and forest ecosystems point to a significant reduction in the numbers of many species and the probable extinction of some.

Perhaps the most vulnerable vertebrate species is the Mountain Pygmy Possum (*Burramys parvus*), whose life cycle requires sustained alpine snow cover. It is estimated that a 1°C rise in temperature would eliminate its bioclimate and a 2°C increase would eliminate the bioclimate of five other alpine species. Given that migration to an environment that has more snow cover is not an option, it is likely that such species will be driven to extinction.

In drier woodland ecosystems of Western Australia, a 0.5°C increase in temperature would reduce the habitat of all frogs and mammals by 28% and a 1°C increase would see the shrub species *Dryandra* become extinct or shrink to small pockets. Again, with only a 1°C increase in temperature, Hilbert *et al*[29] estimate that highland rainforest will decrease by around 50%. This is critical, given the importance of these ecosystems for many of the country's endemic vertebrates.

Moreover, the fragmentation of habitat associated with small protected areas like World Heritage sites often provides limited opportunities for migration to more compatible environments.



*The Greater Blue Mountains World Heritage Area is home to the endangered Brush-tailed rock wallaby (left) and Tiger Quoll (right). Their habitats and life-support systems could be profoundly impacted upon by climate change and the increased frequency and intensity of forest fires*

## One of the world's most fire-dependent forests

The eucalypt forests of Australia, including those of the Greater Blue Mountains in the southeastern state of New South Wales (*see map overleaf*), are among the most fire-dependent forest ecosystems in the world.

**Significant loss of biodiversity is projected to occur by 2020 in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics. Other sites at risk include the Kakadu wetlands, southwest Australia, sub-Antarctic islands and the alpine areas.**

**IPCC (2007)[30]**

The Greater Blue Mountains World Heritage Area consists of over 1 million ha of sandstone plateaux, escarpments and gorges covered largely by temperate eucalypt forests. Comprised of eight protected areas, the site was inscribed on the World Heritage List in 2000 for its representation of the evolutionary adaptation and diversification of eucalypts in post-Gondwana isolation on the Australian continent *(see box)*.

Another justification for the site's inscription on the World Heritage List is that it hosts 120 rare or threatened species, including 114 endemic taxa and evolutionary relict species like the Wollemi pine, which have persisted in highly restricted microsites.

## Eucalyptus oil highly flammable

The blue haze of the Greater Blue Mountain Area, from which it derives its name, is caused by the highly flammable eucalyptus oil being released into the atmosphere in response to heat. Many species of eucalypt, banksias and other native flora have become so adapted to fire that they only release their seeds after burning has taken place, the ash compensating for the often nutrient-poor soils.

There is usually a high rate of regrowth of eucalypts and banksias within the first three years following a major fire. However, a second hot fire, during that stage in the regeneration process, can lead to severe stress and a loss of species diversity by killing plants before they have matured sufficiently to produce seeds.

Consequently, if the interval of intense bush fires moves from long cycles of 10–20 years to below 6 years, there will be a significant decline in the diversity of the major eucalypt species and other flora of the region, a change that would have serious consequences for the ecosystem integrity of the area.

## Studying fire behaviour

Several strategies are being developed to protect the Greater Blue Mountains from the adverse impact of wildfires in the context of a changing climate. The first is to implement more informed policies through greater research into fire behaviour and its ecological impact, especially following the terribly destructive fires of 2002 that led to the establishment of a Bushfire Cooperative Research Centre in December 2003.

The second strategy concerns the use of controlled or mosaic burning to limit the risk of intense and ecologically destructive fires, appropriately designed to take into account the specific ecosystems involved. As the Greater Blue Mountains border the rapidly expanding suburban boundaries of Sydney – Australia's largest city with a population of 4.3 million – there is a real risk of conflicting policy priorities between the protection of urban property and biodiversity conservation.

## The gradual emergence of fire-adapted species

In Australian ecosystems, like others that have evolved in relation to 'Mediterranean type' climatic conditions, fire has been the selective mechanism over a very long time-frame. However, in Australia, fire became a more important factor around 100 000 years ago, with the drying of the environment at the end of a major ice age.

This resulted in the decline of the country's megafauna (large animal species) and the emergence of more fire-adapted species. Fire was to become an even more significant feature of the landscape with the arrival of the first Aboriginal inhabitants around 60 000 years ago, who used fire to manage the landscape.

These two factors meant that the fire-sensitive species, such as beeches, pines, tree ferns and sheoaks, along with wet rainforest species, gave way to the more fire-dependent eucalypts and banksias. This was also associated with the emergence of sclerophyll forests[31] and greater erosion of topsoil leading to the silting of coastal regions and the emergence of mangroves. For the Aboriginal population, the use of 'fire stick farming' to manage and clear the landscape was both a means of preventing extremely destructive fires and controlling the movement of game. Such cultural practices as mosaic burning over many thousands of years were to shape profoundly the Australian landscape.

**As a result of reduced precipitation and increased evaporation, water-security problems are projected to intensify by 2030 in southern and eastern Australia.**

**IPCC (2007)**

## Rising temperatures could force species up the mountain

Rising temperatures may threaten flora and fauna in the very limited parts of the Greater Blue Mountains that are wetter and at a higher altitude, by forcing species to move up the mountains and reducing the availability of water. Yet one of the attributes of the site relevant to its listing under natural criteria is the vari-

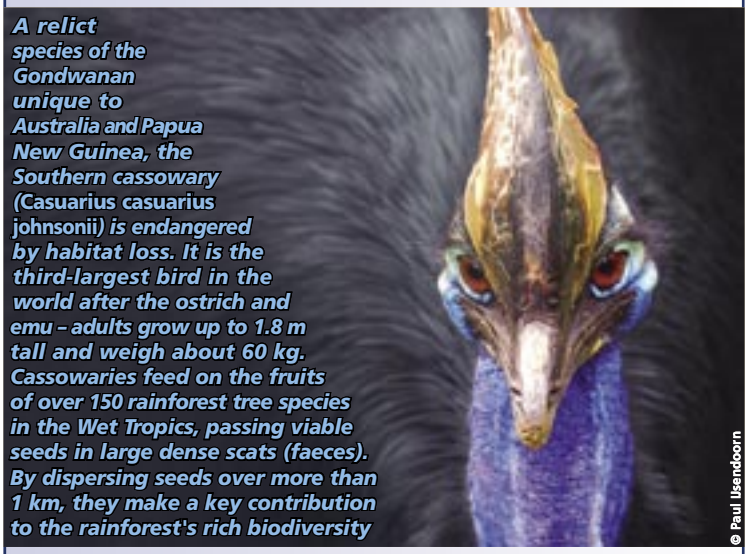

*Two red-barked snow gums (*Eucalyptus pauciflora*). Unique to Australia's southeastern alpine regions, snow gums are especially threatened by climate change*

## The Wet Tropics: a biodiversity hotspot

A second case study in Australia concerns The Wet Tropics of Queensland World Heritage Area, which stretches along the northeastern coast of Australia for some 450 km (*see map*). It is made up of tropical lowland and upland rainforests and thickets, vegetation complexes, mangroves and sclerophyll forests and woodlands. These ecosystems host a particularly extensive and diverse array of plant and animal species, including a high proportion considered as endemic, evolutionarily significant, rare or threatened (*see box*). It was these features which justified its inscription on the World Heritage List in 1988.

This remarkable ecosystem is threatened by rapid changes in temperature and rainfall, as many species in this area are unable to keep pace with rapid climate change.

For about half of the species modelled, a warming of 3.5 °C – corresponding to the average projected scenario – may lead to the total loss of their core environment; for the remaining species, range sizes are likely to be reduced on average to 11% of the current area. Even a 1°C increase in mean air temperature will lead to a significant decline in range size for almost every endemic vertebrate in the Wet Tropics of Queensland.




***A relict species of the Gondwanan unique to Australia and Papua New Guinea, the Southern cassowary (Casuarius casuarius johnsonii) is endangered by habitat loss. It is the third-largest bird in the world after the ostrich and emu – adults grow up to 1.8 m tall and weigh about 60 kg. Cassowaries feed on the fruits of over 150 rainforest tree species in the Wet Tropics, passing viable seeds in large dense scats (faeces). By dispersing seeds over more than 1 km, they make a key contribution to the rainforest's rich biodiversity***

Vertebrates living in these isolated tropical mountain rainforests may become trapped with nowhere to go, in response to the projected changes in climate. Many species could be lost in the Wet Tropics of Queensland within the next 50–100 years, including a number of frogs, mammals, birds and skinks. The extent of biodiversity loss will depend on the rate and timing of climate change.

Australia's Marine and Tropical Scientific Research Facility is conducting research to formulate feasible, proactive management initiatives on a regional scale in response to projected climate change. This research programme, which benefits from substantial funding from the Australian government, will refine present climate change models and scenarios to verify which species and ecological communities are most at risk, the long-term effects of these threats and their geographical distribution, how climate change might interact with other threats such as clearing, fragmentation, fire, weeds and feral animals; and whether, or where, some areas may provide continued habitat, or new areas of habitat, in the future.

Concerning the Wet Tropics World Heritage Area specifically, the James Cook University in Townsville, Queensland, has established a Centre for Tropical Biodiversity and Climate Change Research that will focus its efforts on the impact of climate change on the biota of the Wet Tropics of Queensland.

ability of vegetation in response to decreasing temperature across an altitude range of 100 m to 1400 m.

For example, the upland swamps of the Greater Blue Mountains contain some unique species that are adapted to seasonally waterlogged soils. These species are at risk of being displaced by species tolerant of drier soils. Upland swamps also provide habitat for the endangered skink *Elamprus leuraensis* and the Giant Dragonfly. Their ability to retain and slowly release water also contributes to the survival of threatened plants, such as *Microstrobus fitzgeraldii* and *Epacris hamiltonii*, which have adapted to permanently moist habitats. Swamps currently at the lower end of the suitable rainfall spectrum would be most vulnerable to contraction due to changes in rainfall and/or evaporation associated with climate change.

### Evidence of climate change still anecdotal

Much of the evidence of the impact of climate change on the ecosystems of the Greater Blue Mountains is anecdotal for the moment and has not been supported by adequate, systematic research. It is reported for example that at least one eucalypt species, *Eucalyptus corpulens*, related to the Snow Gums of the alpine regions, no longer grows in the Blue Mountains region. Some horticulturists and botanists attribute this to climate change.

There is also evidence of a lasting impact of the intense bush fires of 2002–2003, where normal regrowth of eucalypts has not occurred in the upper Greater Blue Mountains region.

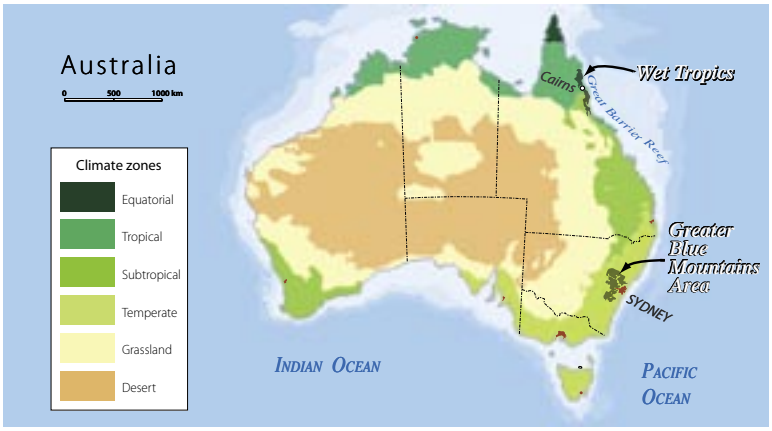
**Production from agriculture and forestry by 2030 is projected to decline over much of southern and eastern Australia ... due to increased drought and fire.**

**IPCC (2007)**

The spread of the soil pathogen *Phytophthora* is having a serious impact on a number of plant species in the mountains. Plant stress due to drought, erosion and the movement of soil due to extreme weather are believed to be some of the causes for its spread and impact on many vulnerable plant communities. There is evidence of greater long-term stress on hanging swamps[32] and the invertebrate species that depend upon these swamps, due to hotter and drier conditions. However, it is difficult to substantiate the claim that climate change is the cause, due to the lack of adequate research.

### A better understanding for better protection

Several research projects into the impact of climate change on the Greater Blue Mountains are being conducted under the auspices of the Australian Greenhouse Office, the New South Wales Department of Environment and Conservation and the Blue Mountains World Heritage Institute. The topics under study include the impact of climate change on biodiversity and ecosystem functions (terrestrial and aquatic), synergistic effects on other threats like invasive species and risks posed by bushfires to people and property.





*The Strangler Fig (*Ficus virens*) is one of the largest trees in tropical north Queensland. It germinates atop another tree, its seeds often being dispersed by birds. As it grows, it drops its roots until it "strangles" its host. This adaptation gives the Strangler Fig a distinctive height advantage in the competition for sunlight, which can only be reached by growing above the dense tree canopy*

With other partners, the Blue Mountains World Heritage Institute is undertaking a three-year research project between 2007 and 2010 to assess a range to threats to the region's ecosystems, including climate change.

The Institute is also establishing collaborative research programmes with other research institutes in France and the USA to share research and techniques for addressing extreme weather conditions, more frequent drought, greater fire risk and other impacts of climate change.

If the time-frames of the present climate change models are correct, we have very little time left to develop and test mitigation strategies for conserving both natural and cultural World Heritage sites. It is imperative that international agencies encourage developed countries with research capacity to engage in appropriate local and collaborative international research to support mitigation strategies as soon as possible. The window of opportunity may be smaller then we think.

*The Wet Tropics is home to Lumholtz's Tree-kangaroo (*Dendrolagus lumholtzi*), which stands less than 60 cm tall. A nocturnal, solitary animal, it spends most of its time in the tree canopy feeding on leaves and fruits.*


29. *Hilbert, D. et al. (2001) Sensitivity of tropical forests to climatic change in the humid tropics of north Queensland.* Australian Ecology *26: 590–603*

30. *IPCC (2007)* Impacts, Adaptation and vulnerability. *Executive Summary for Policy-makers. WGII Fourth Assessment report. April. Lesley Hughes, cited in this article, was the lead author of the chapter on Australia and New Zealand and a contributing author to the chapter on ecosystems: www.ipcc.ch*

31. *The leaves on plants in sclerophyll forests contain a lot of woody tissue, making the build-up of top soil very slow*

32. *A shallow swamp with a wealth of plant life. Constant saturation creates anaerobic (oxygen-starved) conditions in the soil, inhibiting the decomposition of dead plant material, which accumulates as peat. Peat acts as a sponge, retaining rainwater for later slow release*

33. *Author of a case study on the Greater Blue Mountains World Heritage site, an abridged version of which was published in* Case Studies on Climate Change and World Heritage, *Blue Mountains World Heritage Institute: j.merson@bmwhi.org.au*

## Nothing is a substitute for tackling $CO_2$ emissions

While there are now better methods for fighting bushfires and managing some of their more damaging impacts, this is not going to be a substitute for addressing the underlying problem of $CO_2$ emissions. What is needed is much greater public awareness of the real costs to present and future generations of the loss of biodiversity and ecosystem services that are presently taken for granted.

John Merson[33]

*Read:* Case Studies on Climate Change and World Heritage*:*
*http://whc.unesco.org/en/othermaterials/*

## A long evolution in isolation

The Wet Tropics region is home to about one-third of Australia's 315 mammal species, including unique green possums, fierce marsupial cats, kangaroos that climb trees and rare bats. As well as relatively common Australian mammals like the platypus and wallaby, the Wet Tropics is home to 13 mammal species found nowhere else in the world. All but two – the endangered Tropical Bettong (*Bettongia tropica*), and the Mahogany Glider (*Petaurus gracilis*), a possum – are rainforest dwellers. These include two tree-kangaroos (*see photo*), a rat-kangaroo, four ringtail possums and a melomys (native rat).

Some of the Wet Tropics rainforest species have close relatives in New Guinea and Southeast Asia. When Australia became isolated after the break-up of the supercontinent of Gondwana [Ed: Australia separated from Antarctica about 67 million years ago], it drifted northward. About 15 million years ago, it bumped into the Asian continental plate. This collision allowed an exchange to take place between two sets of animals and plants which had evolved in isolation. Asian flora and fauna, including many placental rats, moved into Australia. At the same time, Australian species moved north. Many of them colonized New Guinea, a new high altitude land mass created by the 'bow wave' of Australia's northerly drift. As a result, some of the unusual mammals of the Wet Tropics also live with Australia's northern neighbours, including the Long-tailed Pygmy Possum in Papua New Guinea and the tiny Tube-nosed Insectivorous Bat (weighing just 8 g) in Southeast Asia.

Source: Wet Tropics Management Authority: www.wettropics.gov.au/pa/pa_mam_info.html

## ENCYCLOPEDIA

### Encyclopedia of Life Support Systems

*Online encyclopedia launched by UNESCO in 2002 with sponsorship by EOLSS Publishers in the UK. Equivalent to 200 printed volumes, with contributions from thousands of scholars in over 100 countries. Internet-based and regularly updated, with free e-subscription for universities in least developed countries. Exists in English only.*

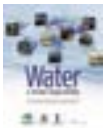
Over 2300 articles focus on climate change-related issues, including the economics of potential climate change, the cost of response strategies, the effect of global warming on: forests, biodiversity, agriculture, water management, sea-level rise; the impact on fisheries of melting polar ice caps, etc. To register for free access: www.eolss.net/eolss_subuldc.aspx; for details: unesco-eolss@unesco.org

## BOOKS

### Case studies on Climate Change and World Heritage

*Produced by UNESCO World Heritage Centre (2007). Exists in English only, 80 pages.*

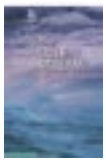
Features 26 case studies of natural and cultural sites inscribed on UNESCO's World Heritage List which are threatened by climate change. These case studies are representative of the dangers faced by the 830 sites inscribed on the List. Download: http://whc.unesco.org/en/othermaterials/




### Water: a Shared Responsibility

*2nd World Water Development Report. UNESCO Publishing and Berghahn Books. Published within World Water Assessment Programme hosted by UNESCO and involving 24 UN agencies (2006). ISBN: 92-3-104006-5, 56.00 €. As a CD-ROM: 36.00 €. Exists in English and Spanish.*

Discusses, inter alia, the effect of climate change on water resources and food production, and climate change and atmospheric pollution. Argues for integrating hydropower and other forms of sustainable energy production to reduce dependence on fossil fuel power stations, emissions from which exacerbate the problems of climate variability and change. Download full report: www.unesco.org/water/wwap



### The Gulf Stream

*By Bruno Voituriez. UNESCO-IOC Ocean Forum Series. UNESCO Publishing (2006). ISBN: 92-3-203995-8, 18.00 €. Exists in English, French and Spanish, 210 pages.*

What is the Gulf Stream? Relates the scientific discovery of the Gulf Stream, the phenomena behind it, its role in determining climate and its impact on marine ecosystems in the North Atlantic.

Coming soon

### The Future of Arid Lands – Revisited

*Commissioned by UNESCO-MAB. Charles F. Hutchinson and Stefanie M. Herrmann from the University of Arizona (USA) discuss the state of scientific knowledge on dryland ecosystems some fifty years after the The Future of Arid Lands, edited by Gilbert F. White. Due out in November 2007. For details, go to page 16 or to: www.unesco.org/mab/ecosyst/drylands/Pub.shtml; or write to: t.schaaf@unesco.org*

Coming soon

### Groundwater and Climate Change

*Compilation of case studies from around the world. Due out in early 2008, prior to a conference on Groundwater and Climate in Africa co-organized by UNESCO-IHP, IAHS and IAH in Kampala (Uganda) from 25 to 28 June 2008. For details: a.aureli@unesco.org*

## BOOKLETS

### Policy Briefs

*Series of six-page booklets launched in 2006 by UNESCO- MAB and ICSU's Scientific Committee on Problems of the Environment (SCOPE), English only.*

Several booklets in this new series address climate-change related issues, including *The Carbon Cycle* and *Human Alteration of the Nitrogen Cycle – Threats, Benefits and Opportunities*. Published in May 2007, the latter explains that 'over a 100-year period, $N_2O$ has a global warming potential 296 times larger than an equal mass of $CO_2$; it also contributes to stratospheric ozone depletion.' Download: www.unesco.org/mab/biodiv/biodivSC.shtml#assessments

### GRAPHIC

*Project presentation booklet by UNESCO-IHP (2006). Exists in English only, 20 pages.*

Introduces Groundwater Resources Assessment under the Pressures of Humanity and Climate Change (GRAPHIC), a project launched by the UNESCO-IHP in 2004 which will continue until at least 2013. Examines the impact of climate change on groundwater resources around the world and policy and management issues. Describes the different methods for assessing the impact over time. Download: http://unesdoc.unesco.org/images/0015/001507/150730E.pdf

### Science in Africa

***UNESCO's contribution to Africa's Plan for S&T to 2010***

*Division for Science Policy and Sustainable Development (2007). Exists in English and French, 32 pages.*

In tackling such problems as biodiversity loss, poor access to energy, desertification and food and water insecurity, Africa is conscious that the success of many of its programmes will depend upon its capacity to adapt to climate change and climate variability. Distributed by UNESCO to Heads of State and Government at the African Union Summit in January 2007. Download: www.unesco.org/science/science_africa.shtml or request a copy from: s.schneegans@unesco.org; a.candau@unesco.org

### Island Agenda 2004+

***Coping with change and sustaining diversities in small islands***

*Booklet produced by UNESCO's Coastal Regions and Small Islands Platform (2004). Exists in English and French, 48 pages.*

In 1989, the Alliance of Small Island States adopted the Malé Declaration proclaiming that 'sea-level rise threatens the very survival of some small island states' and pressing the international community to take effective measures to reduce the greenhouse effect. Describes UNESCO's role today in helping small island states cope with climate change and embrace sustainable development. Distributed at the Barbados +10 conference in Mauritius in January 2005 (*see also p.45*). Download: www.unesco.org/csi/B10/mim.htm

## FOR SCHOOLS

### Explaining the Climate

*By Guy Jacques.UNESCO Publishing/ Nouvelle Arche de Noé Publishing (2005). ISBN: 92-3-203990-7, 6.00 €. Exists in English, French and Spanish, 48 pages.*

Introduces climatology to younger readers keen to learn how the climate will affect their future. All topics are dealt with in an easily understandable manner, from the effects of latitude to those of altitude, from the history of climates to the geography of great climatic regions, and from meteorologists' instruments to the Kyoto Protocol.

### Explaining the Earth

*By Philippe Bouysse. Produced by UNESCO-IGCP. Discovering the World series. UNESCO Publishing/Nané Publishing (2006). ISBN: 978-92-3-104015-3. Exists in English and French, 8.00 €, 48 pages.*

Targets 11-16 years-olds. Presents basic aspects of the Earth sciences: our planet's place in the Universe and in our Solar System, the structure of the Earth, plate tectonics, the role of the atmosphere and hydrosphere, the formation of reliefs, the ice ages and natural hazards.

### Tell me about the Oceans

*By Patricia Chairopoulos. Discovering the World series. UNESCO Publishing (2003). ISBN: 978-92-3-103872-3. Exists in Arabic, English, French and Spanish, 4.60 €, 48 pages.*

Describes the beginnings of the world's oceans, their role in regulating world climate and the rich resources within.

### Educational Kit on Desertification

*Produced by UNESCO-MAB in collaboration with the UN Convention to Combat Desertification. Distributed to schools in least developed countries since 2003 and on sale since 2004. UNESCO Publishing. 30.00 €. ISBN: 92-3- 103892-3. Exists in Arabic, Chinese, English, French, German, Hindi, Mongol, Russian and Spanish.*

Targets primary school teachers and their pupils aged 10-12 years in desertification-affected countries. Each kit comprises a teacher's guide, case studies and three copies of the comic book, The School where the Magic Tree grows and a poster. For details: www.unesco.org/mab/ecosyst/drylands.shtml

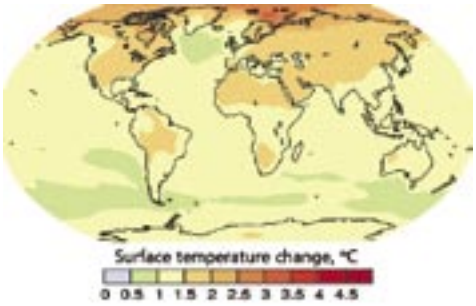
### Teaching Resource Kit for Dryland Countries

*Produced by UNESCO-MAB. Targets primary and secondary school teachers worldwide. Based on an innovative approach appealing to the creativity and artistic sensibilities of pupils aged 6-15 approximately (2007). A sample of the kit is available in English and French:*
www.unesco.org/mab/ecosyst/drylands/docs/kitArt_E.pdf

# A glimpse into **the future**

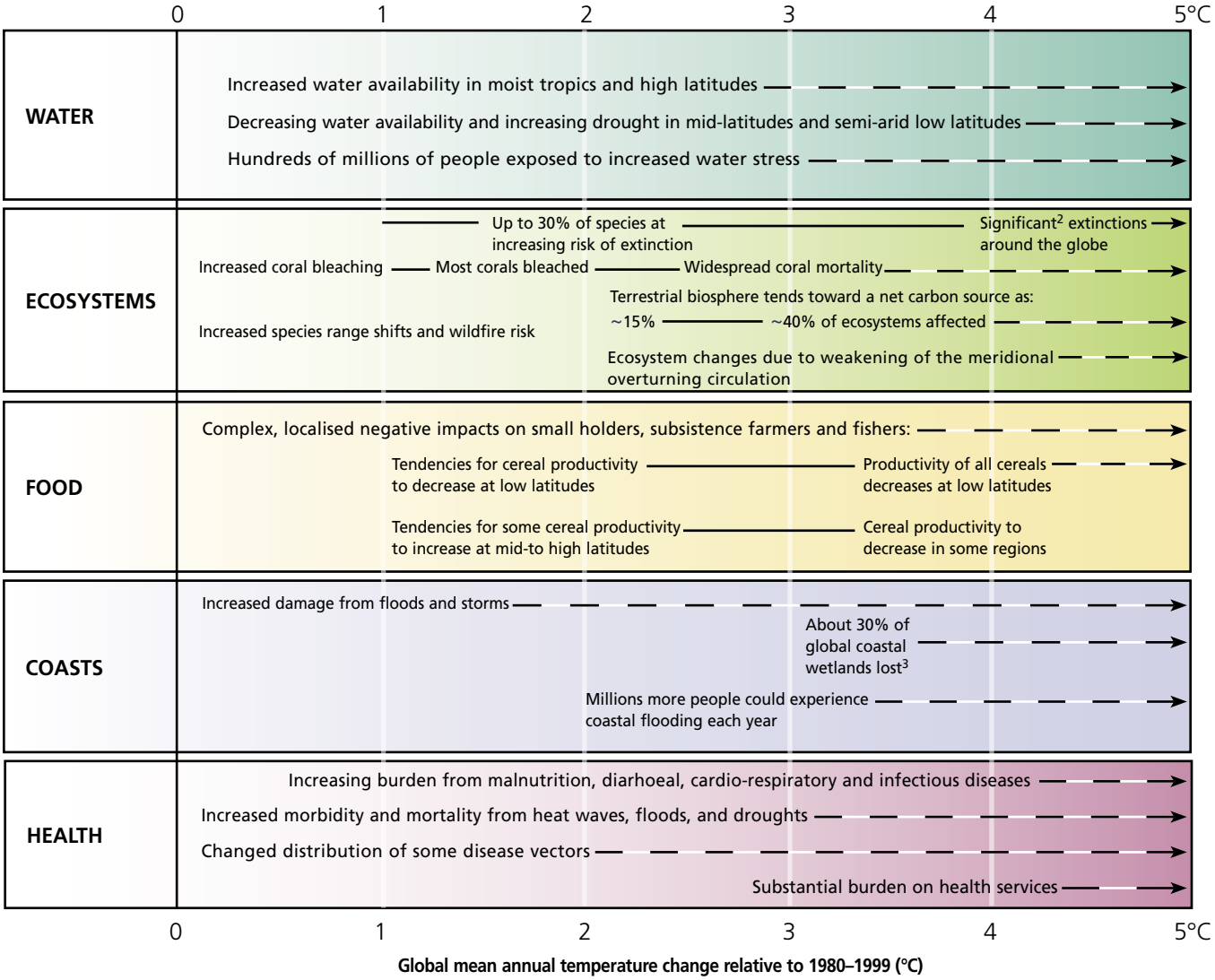
## Forecasts by the Intergovernmental Panel on Climate Change (2007)

***Right**: Seen here is the projected rise in global temperatures to 2020-2029 for the IPCC's middle-of-the-road scenario A1B (2.8°C temp. rise, $CO_2$ concentration of 850 ppm). Under this scenario, the world pursues rapid economic growth, global population peaks mid-century before declining, new and more efficient technologies are rapidly introduced and there is a balance across all sources of energy (fossil and non-fossil). The highest scenario (4°C temp. rise, $CO_2$ of 1550 ppm) is identical to A1B except in that it is fossil-fuel intensive. Were concentrations of $CO_2$ to be held constant at 2000 levels, global warming to 2100 would be limited to 0.6°.*




Source: IPCC (2007) *Climate Change 2007 – the Physical Science Basis.* Summary for Policymakers. 4th Assessment Report. Working Group I. February.

### Key impacts to 2100 of projected increases in mean global temperature[1]




1 Impacts will vary according to the extent of adaptation, rate of temperature change and socio-economic pathway taken.
2 Significant is defined here as more than 40%.
3 Based on average rate of sea-level rise of 4.2 mm/year from 2000 to 2080.
NOTE: Entries are placed so that the left-hand side of text indicates the approximate onset of a given impact. Confidence levels for all statements are high.

Source: IPCC (2007) *Impacts, Adaptation and Vulnerability*. Summary for Policymakers. 4th Assessment Report. Working Group II. April.

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