# Introduction to the Working Group II Fourth Assessment Report

## A. The Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization and the United Nations Environment Programme in 1988, in response to the widespread recognition that human-influenced emissions of greenhouse gases have the potential to alter the climate system. Its role is to provide an assessment of the understanding of all aspects of climate change.

At its first session, the IPCC was organised into three Working Groups. The current remits of the three Working Groups are for Working Group I to examine the scientific aspects of the climate system and climate change; Working Group II to address vulnerabilities to, impacts of and adaptations to climate change; and Working Group III to explore the options for mitigation of climate change. The three previous assessment reports were produced in 1990, 1996 and 2001.

## B. The Working Group II Fourth Assessment

The decision to produce a Fourth Assessment Report was taken by the 19th Session of the IPCC at Geneva in April 2002. The report was to be more focussed and shorter than before. The Working Group II contribution was to be finalised in mid-2007.

The IPCC Fourth Assessment is intended to be a balanced assessment of current knowledge. Its emphasis is on new knowledge acquired since the IPCC Third Assessment (2001). This required a survey of all published literature, including non-English language and 'grey' literature such as government and NGO reports.

Two meetings were held in 2003 to scope the Fourth Assessment, from which emerged the outline for the Working Group II Assessment submitted to IPCC Plenary 21 in November 2003 for approval and subsequent acceptance.

The Report has twenty chapters which together provide a comprehensive assessment of the climate change literature. These are shown in Table I.1. The opening chapter is on observed changes, and addresses the question of whether observed changes in the natural and managed environment are associated with anthropogenic climate change. Chapter 2 deals with the methods available for impacts analysis, and with the scenarios of future climate change which underpin these analyses. These are followed by the core chapters, which assess the literature on present day and future climate change impacts on systems, sectors and regions, vulnerabilities to these impacts, and strategies for adaptation. Chapters 17 and 18 consider possible responses through adaptation and the synergies with mitigation. The two final chapters look at key vulnerabilities, and the inter-relationships between climate change and sustainability.

Chapters 9 to 16 of the Working Group II Fourth Assessment consider regional climate change impacts. The definitions of these regions are shown in Table I.2.

**Table I.1.** *The chapters of the Working Group II contribution to the IPCC Fourth Assessment.*

**Section A. ASSESSMENT OF OBSERVED CHANGES**
1. Assessment of observed changes and responses in natural and managed systems

**Section B. ASSESSMENT OF FUTURE IMPACTS AND ADAPTATION: SYSTEMS AND SECTORS**
2. New assessment methods and the characterisation of future conditions
3. Freshwater resources and their management
4. Ecosystems, their properties, goods and services
5. Food, fibre and forest products
6. Coastal systems and low-lying areas
7. Industry, settlement and society
8. Human health

**Section C. ASSESSMENT OF FUTURE IMPACTS AND ADAPTATION: REGIONS**
9. Africa
10. Asia
11. Australia and New Zealand
12. Europe
13. Latin America
14. North America
15. Polar regions (Arctic and Antarctic)
16. Small islands

**Section D. ASSESSMENT OF RESPONSES TO IMPACTS**
17. Assessment of adaptation practices, options, constraints and capacity
18. Inter-relationships between adaptation and mitigation
19. Assessing key vulnerabilities and the risk from climate change
20. Perspectives on climate change and sustainability

**Table I.2.** *Countries by region (see Chapters 9 to 16) for the Working Group II Fourth Assessment.*

| | | | |
|---|---|---|---|
| **Africa** | | | |
| Algeria | Angola | Benin | Botswana |
| Burkina Faso | Burundi | Cameroon | Central African Republic |
| Chad | Congo, Republic of | Congo, Democratic Rep. of | Côte d'Ivoire |
| Djibouti | Egypt | Equatorial Guinea | Eritrea |
| Ethiopia | Gabon | Ghana | Guinea |
| Guinea-Bissau | Kenya | Lesotho | Liberia |
| Libya | Madagascar | Malawi | Mali |
| Mauritania | Morocco | Mozambique | Namibia |
| Niger | Nigeria | Reunion | Rwanda |
| Senegal | Sierra Leone | Somalia | South Africa |
| Sudan | Swaziland | Tanzania | The Gambia |
| Togo | Tunisia | Uganda | Zambia |
| Zimbabwe | | | |
| **Asia** | | | |
| Afghanistan | Bahrain | Bangladesh | Bhutan |
| Brunei Darussalam | Cambodia | China | East Timor |
| India | Indonesia | Iran, Islamic Republic of | Iraq |
| Israel | Japan | Jordan | Kazakhstan |
| Korea, Dem. People's Rep. | Korea, Republic of | Kuwait | Kyrgyz Republic |
| Laos | Lebanon | Malaysia | Mongolia |
| Myanmar | Nepal | Oman | Pakistan |
| Papua New Guinea | Philippines | Qatar | Russia – East of the Urals |
| Saudi Arabia | Singapore | Sri Lanka | Syria |
| Tajikistan | Thailand | Turkey | Turkmenistan |
| United Arab Emirates | Uzbekistan | Vietnam | Yemen |
| **Australia and New Zealand** | | | |
| Australia | New Zealand | | |
| **Europe** | | | |
| Albania | Andorra | Armenia | Austria |
| Azerbaijan | Belarus | Belgium | Bosnia and Herzegovina |
| Bulgaria | Croatia | Czech Republic | Denmark |
| Estonia | Finland | France | Georgia |
| Germany | Greece | Hungary | Ireland |
| Italy | Latvia | Liechtenstein | Lithuania |
| Luxembourg | Macedonia | Moldova, Republic of | Monaco |
| Montenegro | Norway | Poland | Portugal |
| Romania | Russia – West of the Urals | San Marino | Serbia |
| Slovak Republic | Slovenia | Spain | Sweden |
| Switzerland | The Netherlands | Ukraine | United Kingdom |
| Vatican City, State of | | | |
| **Polar Regions** | | | |
| Antarctic | North of 60°N (including Greenland and Iceland) | | |
| **Latin America** | | | |
| Argentina | Belize | Bolivia | Brazil |
| Chile | Colombia | Costa Rica | Ecuador |
| El Salvador | French Guiana | Guatemala | Guyana |
| Honduras | Mexico | Nicaragua | Panama |
| Paraguay | Peru | Suriname | Uruguay |
| Venezuela | | | |
| **North America** | | | |
| Canada | United States of America | | |
| **Small islands:** non-autonomous small islands are also included in the assessment but are not listed here | | | |
| Antigua and Barbuda | Barbados | Cape Verde | Comoros |
| Cook Islands | Cuba | Cyprus | Dominica |
| Dominican Republic | Fed. States of Micronesia | Fiji | Grenada |
| Haiti | Jamaica | Kiribati | Maldives |
| Malta | Marshall Islands | Mauritius | Nauru |
| Palau | Saint Kitts and Nevis | Saint Lucia | Saint Vincent & Grenadines |
| Samoa | São Tomé & Príncipe | Seychelles | Solomon Islands |
| The Bahamas | Tonga | Trinidad and Tobago | Tuvalu |
| Vanuatu | | | |

## C. Cross-chapter case studies

Early in the writing of the Working Group II contribution to the Fourth Assessment, there emerged themes of environmental importance and widespread interest which are dealt with from different perspectives by several chapters. These themes have been gathered together into 'cross-chapter case studies', which appear in their entirety at the end of the volume and are included in the CD-ROM which accompanies this volume. A 'roadmap' in Table I.3 shows where the cross-chapter case study material appears in the individual chapters.

The four cross-chapter case studies are:

1. The impact of the European 2003 heatwave
2. Impacts of climate change on coral reefs
3. Megadeltas: their vulnerabilities to climate change
4. Indigenous knowledge for adaptation to climate change

## D. Regional and subject database of references

This Assessment is based on the review of a very large amount of literature for all parts of the world and for many subjects. For those interested in accessing this literature for a given region or subject, a regional and subject database of references is provided on the CD-ROM which accompanies this volume. The database contains in full all the references in this volume and can be viewed by region and subject.

## E. Procedures followed in this Assessment by the authors, reviewers and participating governments

In total, the Working Group II Fourth Assessment involved 48 Coordinating Lead Authors (CLAs), 125 Lead Authors (LAs), and 45 Review Editors (REs), drawn from 70 countries. In addition, there were 183 Contributing Authors and 910 Expert Reviewers.

Each chapter in the Working Group II Fourth Assessment had a writing team of two to four CLAs and six to nine LAs. Led by the CLAs, it was the responsibility of this writing team to produce the drafts and finished version of the chapter. Where necessary, they could recruit Contributing Authors to assist in their task. Three drafts of each chapter were written prior to the production of the final version. Drafts were reviewed in two separate lines of review, by experts and by governments. It was the role of the REs (two to three per chapter) to ensure that the review comments were properly addressed by the authors.

The authors and REs were selected by the Working Group II Bureau from the lists of experts nominated by governments. Due regard was paid to the need to balance the writing team with proper representation from developing and developed countries, and Economies in Transition. In the review by experts, chapters were sent out to experts, including all those nominated by governments but not yet included in the assessment, together with scientists and researchers identified by the Working Group II Co-Chairs and Vice-Chairs from their knowledge of the literature and the global research community.

## F. Communication of uncertainty in the Working Group II Fourth Assessment

A set of terms to describe uncertainties in current knowledge is common to all parts of the IPCC Fourth Assessment, based on the *Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties*[1], produced by the IPCC in July 2005.

### *Description of confidence*

On the basis of a comprehensive reading of the literature and their expert judgement, authors have assigned a confidence level to the major statements in the Report on the basis of their assessment of current knowledge, as follows:

| *Terminology* | *Degree of confidence in being correct* |
|---|---|
| Very high confidence | At least 9 out of 10 chance of being correct |
| High confidence | About 8 out of 10 chance |
| Medium confidence | About 5 out of 10 chance |
| Low confidence | About 2 out of 10 chance |
| Very low confidence | Less than a 1 out of 10 chance |

### *Description of likelihood*

Likelihood refers to a probabilistic assessment of some well-defined outcome having occurred or occurring in the future, and may be based on quantitative analysis or an elicitation of expert views. In the Report, when authors evaluate the likelihood of certain outcomes, the associated meanings are:

| *Terminology* | *Likelihood of the occurrence/ outcome* |
|---|---|
| Virtually certain | >99% probability of occurrence |
| Very likely | 90 to 99% probability |
| Likely | 66 to 90% probability |
| About as likely as not | 33 to 66% probability |
| Unlikely | 10 to 33% probability |
| Very unlikely | 1 to 10% probability |
| Exceptionally unlikely | <1% probability |

[1] http://www.ipcc.ch/activity/uncertaintyguidancenote.pdf

**Table I.3.** *Cross-chapter Case Studies: location in text.*

| Topic: | Chapter: | Location in chapter: |
|---|---|---|
| **The impact of the European 2003 heatwave** | | |
| **Scene-setting and overview** | | |
| The European heatwave of 2003 | Chapter 12 | 12.6.1 |
| **Impacts on sectors** | | |
| Ecological impacts of the European heatwave 2003 | Chapter 4 | Box 4.1 |
| European heatwave impact on the agricultural sector | Chapter 5 | Box 5.1 |
| Industry, settlement and society: impacts of the 2003 heatwave in Europe | Chapter 7 | Box 7.1 |
| The European heatwave 2003: health impacts and adaptation | Chapter 8 | Box 8.1 |
| **Impacts of climate change on coral reefs** | | |
| **Present-day changes in coral reefs** | | |
| Observed changes in coral reefs | Chapter 1 | Section 1.3.4.1 |
| Environmental thresholds and observed coral bleaching | Chapter 6 | Box 6.1 |
| **Future impacts on coral reefs** | | |
| Are coral reefs endangered by climate change? | Chapter 4 | Box 4.4 |
| Impacts on coral reefs | Chapter 6 | Section 6.4.1.5 |
| Climate change and the Great Barrier Reef | Chapter 11 | Box 11.3 |
| Impact of coral mortality on reef fisheries | Chapter 5 | Box 5.4 |
| **Multiple stresses on coral reefs** | | |
| Non-climate-change threats to coral reefs of small islands | Chapter 16 | Box 16.2 |
| **Megadeltas: their vulnerabilities to climate change** | | |
| **Introduction** | | |
| Deltas and megadeltas: hotspots for vulnerability | Chapter 6 | Box 6.3 |
| **Megadeltas in Asia** | | |
| Megadeltas in Asia | Chapter 10 | Section 10.6.1, Table 10.10 |
| Climate change and the fisheries of the lower Mekong – an example of multiple stresses on a megadelta fisheries system due to human activity | Chapter 5 | Box 5.3 |
| **Megadeltas in the Arctic** | | |
| Arctic megadeltas | Chapter 15 | Section 15.6.2 |
| **Case study of Hurricane Katrina** | | |
| Hurricane Katrina and coastal ecosystem services in the Mississippi delta | Chapter 6 | Box 6.4 |
| Vulnerabilities to extreme weather events in megadeltas in a context of multiple stresses: the case of Hurricane Katrina | Chapter 7 | Box 7.4 |
| **Indigenous knowledge for adaptation to climate change** | | |
| **Overview** | | |
| Role of local and indigenous knowledge in adaptation and sustainability research | Chapter 20 | Box 20.1 |
| **Case studies** | | |
| Adaptation capacity of the South American highlands´ pre-Colombian communities | Chapter 13 | Box 13.2 |
| African indigenous knowledge systems | Chapter 9 | Section 9.6.2 |
| Traditional knowledge for adaptation among Arctic peoples | Chapter 15 | Section 15.6.1 |
| Adaptation to health impacts of climate change among indigenous populations | Chapter 8 | Box 8.6 |

## G. Definitions of key terms

*Climate change* in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where *climate change* refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

*Adaptation* is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

*Vulnerability* is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. *Vulnerability* is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system.

## Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

# Summary for Policymakers

*This summary, approved in detail at the Eighth Session of IPCC Working Group II (Brussels, Belgium, 2-5 April 2007), represents the formally agreed statement of the IPCC concerning the sensitivity, adaptive capacity and vulnerability of natural and human systems to climate change, and the potential consequences of climate change.*

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## A. Introduction

This Summary sets out the key policy-relevant findings of the Fourth Assessment of Working Group II of the Intergovernmental Panel on Climate Change (IPCC).

The Assessment is of current scientific understanding of the impacts of climate change on natural, managed and human systems, the capacity of these systems to adapt and their vulnerability.[1] It builds upon past IPCC assessments and incorporates new knowledge gained since the Third Assessment.

Statements in this Summary are based on chapters in the Assessment and principal sources are given at the end of each paragraph.[2]

## B. Current knowledge about observed impacts of climate change on the natural and human environment

A full consideration of observed climate change is provided in the Working Group I Fourth Assessment. This part of the Working Group II Summary concerns the relationship between observed climate change and recent observed changes in the natural and human environment.

The statements presented here are based largely on data sets that cover the period since 1970. The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly since the Third Assessment in 2001. The quality of the data sets has also improved. There is, however, a notable lack of geographical balance in the data and literature on observed changes, with marked scarcity in developing countries.

Recent studies have allowed a broader and more confident assessment of the relationship between observed warming and impacts than was made in the Third Assessment. That Assessment concluded that "there is high confidence[3] that recent regional changes in temperature have had discernible impacts on many physical and biological systems".

From the current Assessment we conclude the following.

**Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.**

With regard to changes in snow, ice and frozen ground (including permafrost),[4] there is high confidence that natural systems are affected. Examples are:

- enlargement and increased numbers of glacial lakes [1.3];
- increasing ground instability in permafrost regions, and rock avalanches in mountain regions [1.3];
- changes in some Arctic and Antarctic ecosystems, including those in sea-ice biomes, and also predators high in the food chain [1.3, 4.4, 15.4].

Based on growing evidence, there is high confidence that the following effects on hydrological systems are occurring:

- increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers [1.3];
- warming of lakes and rivers in many regions, with effects on thermal structure and water quality [1.3].

There is very high confidence, based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems, including such changes as:

- earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying [1.3];
- poleward and upward shifts in ranges in plant and animal species [1.3, 8.2, 14.2].

Based on satellite observations since the early 1980s, there is high confidence that there has been a trend in many regions towards earlier 'greening'[5] of vegetation in the spring linked to longer thermal growing seasons due to recent warming [1.3, 14.2].

There is high confidence, based on substantial new evidence, that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation [1.3]. These include:

- shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans [1.3];
- increases in algal and zooplankton abundance in high-latitude and high-altitude lakes [1.3];
- range changes and earlier migrations of fish in rivers [1.3].

[1] For definitions, see Endbox 1.
[2] Sources to statements are given in square brackets. For example, [3.3] refers to Chapter 3, Section 3. In the sourcing, F = Figure, T = Table, B = Box and ES = Executive Summary.
[3] See Endbox 2.
[4] See Working Group I Fourth Assessment.
[5] Measured by the Normalised Difference Vegetation Index, which is a relative measure of the amount of green vegetation in an area based on satellite images.

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic, with an average decrease in pH of 0.1 units [IPCC Working Group I Fourth Assessment]. However, the effects of observed ocean acidification on the marine biosphere are as yet undocumented [1.3].

**A global assessment of data since 1970 has shown it is likely[6] that anthropogenic warming has had a discernible influence on many physical and biological systems.**

Much more evidence has accumulated over the past five years to indicate that changes in many physical and biological systems are linked to anthropogenic warming. There are four sets of evidence which, taken together, support this conclusion:

1. The Working Group I Fourth Assessment concluded that most of the observed increase in the globally averaged temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.

2. Of the more than 29,000 observational data series,[7] from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (Figure SPM.1) [1.4].

3. A global synthesis of studies in this Assessment strongly demonstrates that the spatial agreement between regions of significant warming across the globe and the locations of significant observed changes in many systems consistent with warming is very unlikely to be due solely to natural variability of temperatures or natural variability of the systems (Figure SPM.1) [1.4].

4. Finally, there have been several modelling studies that have linked responses in some physical and biological systems to anthropogenic warming by comparing observed responses in these systems with modelled responses in which the natural forcings (solar activity and volcanoes) and anthropogenic forcings (greenhouse gases and aerosols) are explicitly separated. Models with combined natural and anthropogenic forcings simulate observed responses significantly better than models with natural forcing only [1.4].

Limitations and gaps prevent more complete attribution of the causes of observed system responses to anthropogenic warming. First, the available analyses are limited in the number of systems and locations considered. Second, natural temperature variability is larger at the regional than at the global scale, thus affecting identification of changes due to external forcing. Finally, at the regional scale other factors (such as land-use change, pollution, and invasive species) are influential [1.4].

Nevertheless, the consistency between observed and modelled changes in several studies and the spatial agreement between significant regional warming and consistent impacts at the global scale is sufficient to conclude with high confidence that anthropogenic warming over the last three decades has had a discernible influence on many physical and biological systems [1.4].

**Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers.**

Effects of temperature increases have been documented in the following (medium confidence):

- effects on agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbance regimes of forests due to fires and pests [1.3];
- some aspects of human health, such as heat-related mortality in Europe, infectious disease vectors in some areas, and allergenic pollen in Northern Hemisphere high and mid-latitudes [1.3, 8.2, 8.ES];
- some human activities in the Arctic (e.g., hunting and travel over snow and ice) and in lower-elevation alpine areas (such as mountain sports) [1.3].

Recent climate changes and climate variations are beginning to have effects on many other natural and human systems. However, based on the published literature, the impacts have not yet become established trends. Examples include:

- Settlements in mountain regions are at enhanced risk of glacier lake outburst floods caused by melting glaciers. Governmental institutions in some places have begun to respond by building dams and drainage works [1.3].

- In the Sahelian region of Africa, warmer and drier conditions have led to a reduced length of growing season with detrimental effects on crops. In southern Africa, longer dry seasons and more uncertain rainfall are prompting adaptation measures [1.3].

- Sea-level rise and human development are together contributing to losses of coastal wetlands and mangroves and increasing damage from coastal flooding in many areas [1.3].

[6] See Endbox 2.
[7] A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies.

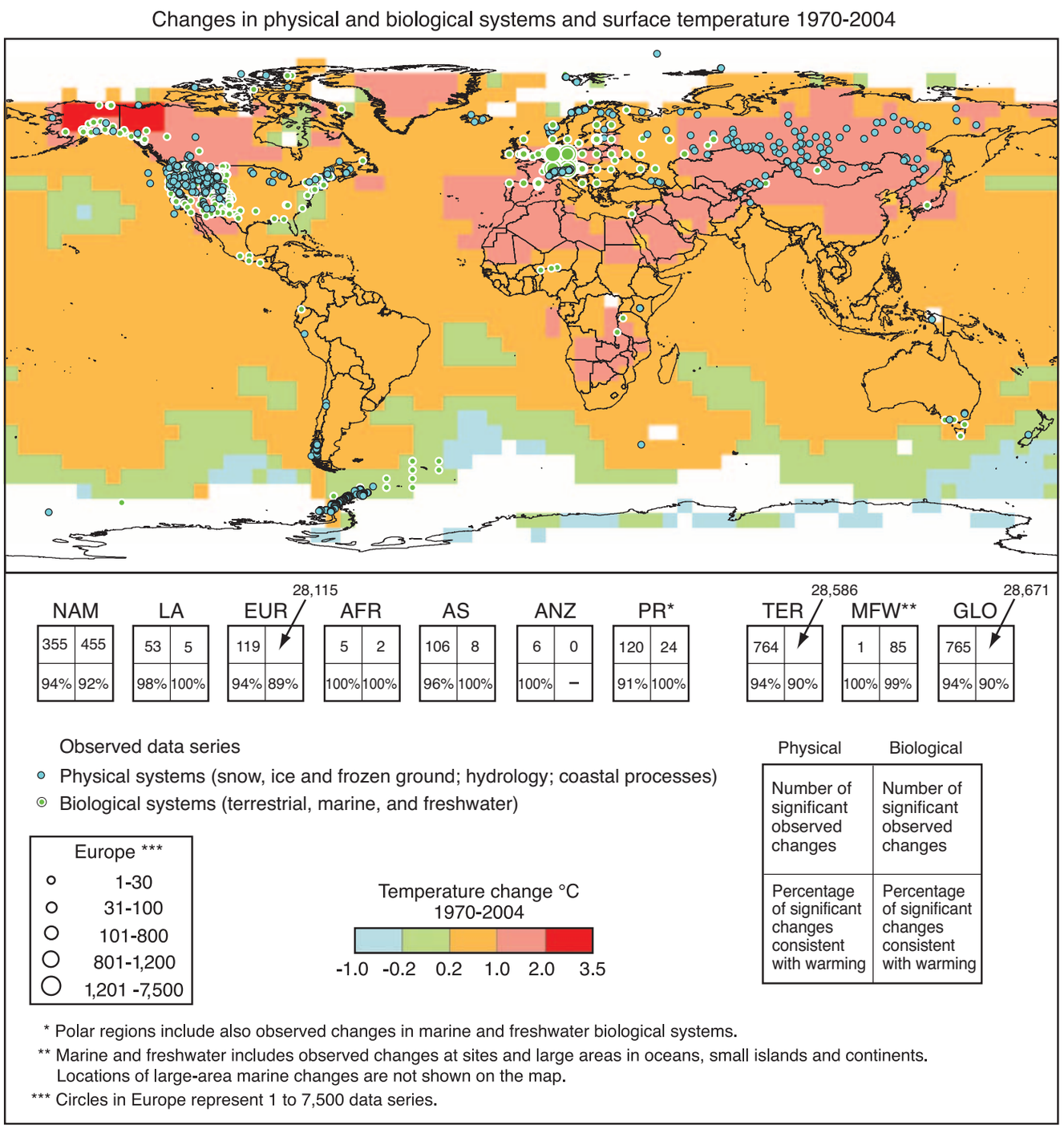


**Figure SPM.1.** *Locations of significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which about 70 are new since the Third Assessment) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 x 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, …, PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFW) systems. Locations of large-area marine changes are not shown on the map. [Working Group II Fourth Assessment F1.8, F1.9; Working Group I Fourth Assessment F3.9b].*