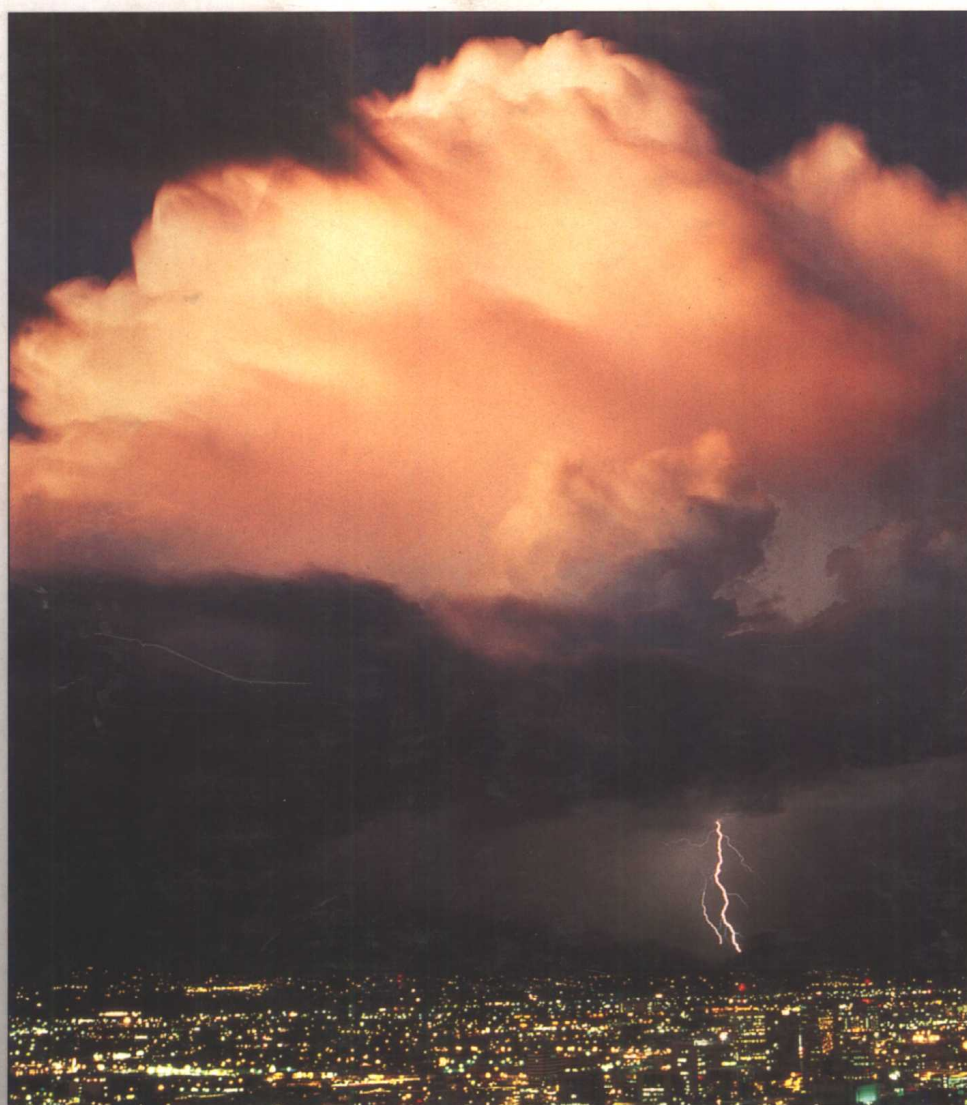


CLIMATE CHANGE 1995

The Science of Climate Change



Summary for Policymakers

*Approved by Working Group I of the IPCC and
accepted by the IPCC*

and

Technical Summary of the Working Group I Report

Accepted by the IPCC



WMO



UNEP

Part of the Working Group I contribution to the Second Assessment
Report of the Intergovernmental Panel on Climate Change

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Foreword

The Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization and the United Nations Environment Programme in 1988, in order to: (i) assess available scientific information on climate change, (ii) assess the environmental and socio-economic impacts of climate change, and (iii) formulate response strategies. The IPCC First Assessment Report was completed in August 1990 and served as the basis for negotiating the UN Framework Convention on Climate Change. The IPCC also completed its 1992 Supplement and "Climate Change 1994: Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios" to assist the Convention process further.

In 1992, the Panel reorganised its Working Groups II and III and committed itself to complete a Second Assessment in 1995, not only updating the information on the same range of topics as in the First Assessment, but also including the new subject area of technical issues related to the economic aspects of climate change. We applaud the IPCC for producing its Second Assessment Report (SAR) as scheduled. We are convinced that the SAR, like the earlier IPCC Reports, will become a standard work of reference, widely used by policymakers, scientists and other experts.

This document, which contains the Summary for Policymakers and Technical Summary of the full Working Group I report, represents part of the Working Group I contribution to the SAR. It discusses the physical climate system, the factors that drive climate change, analyses of past climate, detection and attribution of a human influence on recent climate and projections of future climate change.

As usual in the IPCC, success in producing this document and the full report on which it is based has depended upon the enthusiasm and co-operation of numerous busy scientists and other experts world-wide. We are exceedingly pleased to note here the very special efforts made by the IPCC in ensuring the participation of scientists and other experts in its activities, in particular in the writing, reviewing, and revising of its reports. The scientists and experts from the developed, developing and transitional economy countries have given of their time very generously, and governments have supported them, in the enormous intellectual and

physical effort required, often going substantially beyond reasonable demands of duty. Without such conscientious and professional involvement, the IPCC would be greatly impoverished. We express to all these scientists and experts, and the governments who supported them, our sincere appreciation for their commitment.

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Secretary-General
World Meteorological Organization

Ms. E. Dowdeswell
Executive Director
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This document comprises both the Summary for Policymakers and the Technical Summary of the Working Group I (WGI) report. It represents, in conjunction with the 11 chapters of the underlying WGI report from which this material was drawn, the most comprehensive assessment of the science of climate change since WGI of the IPCC produced its first report *Climate Change: The IPCC Scientific Assessment* in 1990. It enlarges and updates information contained in that assessment and also in the interim reports produced by WGI in 1992 and 1994. The first IPCC Assessment Report of 1990 concluded that continued accumulation of anthropogenic greenhouse gases in the atmosphere would lead to climate change whose rate and magnitude were likely to have important impacts on natural and human systems. The IPCC Supplementary Report of 1992, timed to coincide with the final negotiations of the United Nations Framework Convention on Climate Change in Rio de Janeiro (June 1992), added new quantitative information on the climatic effects of aerosols but confirmed the essential conclusions of the 1990 assessment concerning our understanding of climate and the factors affecting it. The 1994 WGI report *Radiative Forcing of Climate Change* examined in depth the mechanisms that govern the relative importance of human and natural factors in giving rise to radiative forcing, the “driver” of climate change. The 1994 report incorporated further advances in the quantification of the climatic effects of aerosols, but it also found no reasons to alter in any fundamental way those conclusions of the 1990 report which it addressed.

We believe the essential message of this report continues to be that the basic understanding of climate change and the human role therein, as expressed in the 1990 report, still holds: carbon dioxide remains the most important contributor to anthropogenic forcing of climate change; projections of future global mean temperature change and sea level rise confirm the potential for human activities to alter the Earth’s climate to an extent unprecedented in human history; and the long time-scales governing both the accumulation of greenhouse gases in the atmosphere and the response of the climate system to those accumulations, means that many important aspects of climate change are effectively irreversible. Further, that observations suggest “a discernible

human influence on global climate”, one of the key findings of this report adds an important new dimension to the discussion of the climate change issue.

An important political development since 1990 has been the entry into force of the UN Framework Convention on Climate Change (FCCC). IPCC is recognised as a prime source of scientific and technical information to the FCCC, and the underlying aim of this report is to provide objective information on which to base global climate change policies that will meet the ultimate aim of the FCCC – expressed in Article 2 of the Convention – of stabilisation of greenhouse gases at some level that has yet to be quantified but which is defined as one that will “prevent dangerous anthropogenic interference with the climate system”. Because the definition of “dangerous” will depend on value judgements as well as upon observable physical changes in the climate system, such policies will not rest on purely scientific grounds, and the companion IPCC reports by WGII on *Impacts, Adaptations and Mitigation of Climate Change*, and by WGIII on *Economic and Social Dimensions of Climate Change* provide some of the background information on which the wider debate will be based. Together the three WG reports establish a basis for an IPCC synthesis of information relevant to interpreting Article 2 of the FCCC. An important contribution of WGI to this synthesis has been an analysis of the emission pathways for carbon dioxide that would lead to a range of hypothetical stabilisation levels.

The Summary for Policymakers and Technical Summary were compiled between January and November 1995 by 78 lead authors from 20 countries with assistance from a few additional experts with experience of the science-policy interface. Formal review of the summaries by governments, non-governmental organisations (NGOs) and individual experts took place during May to July. Over 400 contributing authors from 26 countries submitted draft text and information to the lead authors and over 500 reviewers from 40 countries submitted valuable suggestions for improvement during the review process. The hundreds of comments received were carefully analysed and assimilated in a revised document that was distributed to countries and NGOs six weeks in advance of the fifth session of WGI in Madrid, 27-29 November 1995. It was at this session, where participants included 177 delegates

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from 96 countries, representatives from 14 NGOs and 28 lead authors, that the Summary for Policymakers was approved in detail and the underlying 11 chapters of the full WGI report accepted. The Technical Summary to the WGI report, and the report itself, were accepted at IPCC-XI in Rome, 11-15 December 1995.

We wish first of all to express our sincere appreciation to the lead authors whose expertise, diligence and patience have underpinned the successful completion of this effort, and to the many contributors and reviewers for their valuable and painstaking work. We are grateful to the governments of Sweden, UK and USA which hosted drafting sessions in their countries, and to the government of Spain which hosted the final session of Working Group I in Madrid at which the documents were accepted and approved. The IPCC Trust Fund, contributed to by many countries, supported the participation of many developing country scientists in the completion of this report. The WGI Technical Support Unit was funded by the UK government with assistance from the Netherlands, and we echo the appreciation expressed in the Foreword to the members of the Technical Support Unit.

Bert Bolin
IPCC chairman

John Houghton
Co-chair (UK) IPCC WGI

L. Gylvan Meira Filho
Co-chair (Brazil) IPCC WGI

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SUMMARY FOR POLICYMAKERS

This summary, approved in detail at the fifth session of IPCC Working Group I, (Madrid, 27-29 November 1995), represents the formally agreed statement of the IPCC concerning current understanding of the science of climate change.

Summary for Policymakers

Considerable progress has been made in the understanding of climate change¹ science since 1990 and new data and analyses have become available.

Greenhouse gas concentrations have continued to increase

Increases in greenhouse gas concentrations since pre-industrial times (i.e., since about 1750) have led to a positive *radiative forcing*² of climate, tending to warm the surface and to produce other changes of climate.

- The atmospheric concentrations of greenhouse gases, *inter alia* carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) have grown significantly: by about 30%, 145% and 15% respectively (values for 1992). These trends can be attributed largely to human activities, mostly fossil fuel use, land-use change and agriculture.
- The growth rates of CO₂, CH₄ and N₂O concentrations were low during the early 1990s. While this apparently natural variation is not yet fully explained, recent data indicate that the growth rates are currently comparable to those averaged over the 1980s.
- The direct radiative forcing of the long-lived greenhouse gases (2.45 Wm⁻²) is due primarily to increases in the concentrations of CO₂ (1.56 Wm⁻²), CH₄ (0.47 Wm⁻²) and N₂O (0.14 Wm⁻²) (values for 1992).
- Many greenhouse gases remain in the atmosphere for a long time (for CO₂ and N₂O, many decades to centuries), hence they affect radiative forcing on long time-scales.
- The direct radiative forcing due to the CFCs and HCFCs combined is 0.25 Wm⁻². However, their *net* radiative forcing is reduced by about 0.1 Wm⁻² because they have caused stratospheric ozone depletion which gives rise to a negative radiative forcing.
- Growth in the concentration of CFCs, but not HCFCs, has slowed to about zero. The concentrations of both CFCs and HCFCs, and their consequent ozone depletion, are expected to decrease substantially by 2050 through implementation of the Montreal Protocol and its Adjustments and Amendments.
- At present some long-lived greenhouse gases (particularly HFCs (a CFC substitute), PFCs and SF₆) contribute little to radiative forcing but their projected growth could contribute several per cent to radiative forcing during the 21st century.
- If carbon dioxide emissions were maintained at near current (1994) levels, they would lead to a nearly constant rate of increase in atmospheric concentrations for at least two centuries, reaching about 500 ppmv (approaching twice the pre-industrial concentration of 280 ppmv) by the end of the 21st century.

¹ Climate change in IPCC Working Group I usage refers to any change in climate over time whether due to natural variability or as a result of human activity. This differs from the usage in the Framework Convention on Climate Change where climate change refers to a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

² A simple measure of the importance of a potential climate change mechanism. Radiative forcing is the perturbation to the energy balance of the Earth-atmosphere system (in watts per square metre [Wm⁻²]).

- A range of carbon cycle models indicates that stabilisation of atmospheric CO₂ concentrations at 450, 650 or 1000 ppmv could be achieved only if global anthropogenic CO₂ emissions drop to 1990 levels by, respectively, approximately 40, 140 or 240 years from now, and drop substantially below 1990 levels subsequently.
- Any eventual stabilised concentration is governed more by the accumulated anthropogenic CO₂ emissions from now until the time of stabilisation, than by the way those emissions change over the period. This means that, for a given stabilised concentration value, higher emissions in early decades require lower emissions later on. Among the range of stabilisation cases studied, for stabilisation at 450, 650 or 1000 ppmv accumulated anthropogenic emissions over the period 1991 to 2100 are 630 GtC¹, 1030 GtC, and 1410 GtC respectively (\pm approximately 15% in each case). For comparison the corresponding accumulated emissions for IPCC IS92 emission scenarios range from 770 to 2190 GtC.
- Stabilisation of CH₄ and N₂O concentrations at today's levels would involve reductions in anthropogenic emissions of 8% and more than 50% respectively.
- There is evidence that tropospheric ozone concentrations in the Northern Hemisphere have increased since pre-industrial times because of human activity and that this has resulted in a positive radiative forcing. This forcing is not yet well characterised, but it is estimated to be about 0.4 Wm⁻² (15% of that from the long-lived greenhouse gases). However the observations of the most recent decade show that the upward trend has slowed significantly or stopped.

Anthropogenic aerosols tend to produce negative radiative forcings

- Tropospheric aerosols (microscopic airborne particles) resulting from combustion of fossil fuels, biomass burning and other sources have led to a negative direct forcing of about 0.5 Wm⁻², as a global average, and possibly also to a negative indirect forcing of a similar magnitude. While the negative forcing is focused in particular regions and subcontinental areas, it can have continental to hemispheric scale effects on climate patterns.
- Locally, the aerosol forcing can be large enough to more than offset the positive forcing due to greenhouse gases.
- In contrast to the long-lived greenhouse gases, anthropogenic aerosols are very short-lived in the atmosphere, hence their radiative forcing adjusts rapidly to increases or decreases in emissions.

Climate has changed over the past century

At any one location year-to-year variations in weather can be large, but analyses of meteorological and other data over large areas and over periods of decades or more have provided evidence for some important systematic changes.

- Global mean surface air temperature has increased by between about 0.3 and 0.6°C since the late 19th century; the additional data available since 1990 and the re-analyses since then have not significantly changed this range of estimated increase.
- Recent years have been among the warmest since 1860, i.e., in the period of instrumental record, despite the cooling effect of the 1991 Mt. Pinatubo volcanic eruption.

¹ 1 GtC = 1 billion (10⁹) tonnes of carbon.

- Night-time temperatures over land have generally increased more than daytime temperatures.
- Regional changes are also evident. For example, the recent warming has been greatest over the mid-latitude continents in winter and spring, with a few areas of cooling, such as the North Atlantic Ocean. Precipitation has increased over land in high latitudes of the Northern Hemisphere, especially during the cold season.
- Global sea level has risen by between 10 and 25 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature.
- There are inadequate data to determine whether consistent global changes in climate variability or weather extremes have occurred over the 20th century. On regional scales there is clear evidence of changes in some extremes and climate variability indicators (e.g., fewer frosts in several widespread areas; an increase in the proportion of rainfall from extreme events over the contiguous states of the USA). Some of these changes have been toward greater variability; some have been toward lower variability.
- The 1990 to mid-1995 persistent warm-phase of the El Niño-Southern Oscillation (which causes droughts and floods in many areas) was unusual in the context of the last 120 years.

The balance of evidence suggests a discernible human influence on global climate

Any human-induced effect on climate will be superimposed on the background “noise” of natural climate variability, which results both from internal fluctuations and from external causes such as solar variability or volcanic eruptions. Detection and attribution studies attempt to distinguish between anthropogenic and natural influences. “Detection of change” is the process of demonstrating that an observed change in climate is highly unusual in a statistical sense, but does not provide a reason for the change. “Attribution” is the process of establishing cause and effect relations, including the testing of competing hypotheses.

Since the 1990 IPCC Report, considerable progress has been made in attempts to distinguish between natural and anthropogenic influences on climate. This progress has been achieved by including effects of sulphate aerosols in addition to greenhouse gases, thus leading to more realistic estimates of human-induced radiative forcing. These have then been used in climate models to provide more complete simulations of the human-induced climate-change “signal”. In addition, new simulations with coupled atmosphere-ocean models have provided important information about decade to century time-scale natural internal climate variability. A further major area of progress is the shift of focus from studies of global-mean changes to comparisons of modelled and observed spatial and temporal patterns of climate change.

The most important results related to the issues of detection and attribution are:

- The limited available evidence from proxy climate indicators suggests that the 20th century global mean temperature is at least as warm as any other century since at least 1400 AD. Data prior to 1400 are too sparse to allow the reliable estimation of global mean temperature.
- Assessments of the statistical significance of the observed global mean surface air temperature trend over the last century have used a variety of new estimates of natural internal and externally forced variability. These are derived from instrumental data, palaeodata, simple and complex climate models, and statistical models fitted to observations. Most of these studies have detected a significant change and show that the observed warming trend is unlikely to be entirely natural in origin.

- More convincing recent evidence for the attribution of a human effect on climate is emerging from pattern-based studies, in which the modelled climate response to combined forcing by greenhouse gases and anthropogenic sulphate aerosols is compared with observed geographical, seasonal and vertical patterns of atmospheric temperature change. These studies show that such pattern correspondences increase with time, as one would expect as an anthropogenic signal increases in strength. Furthermore, the probability is very low that these correspondences could occur by chance as a result of natural internal variability only. The vertical patterns of change are also inconsistent with those expected for solar and volcanic forcing.
- Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long-term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse gases and aerosols, and land surface changes. Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate.

Climate is expected to continue to change in the future

The IPCC has developed a range of scenarios, IS92a-f, of future greenhouse gas and aerosol precursor emissions based on assumptions concerning population and economic growth, land-use, technological changes, energy availability and fuel mix during the period 1990 to 2100. Through understanding of the global carbon cycle and of atmospheric chemistry, these emissions can be used to project atmospheric concentrations of greenhouse gases and aerosols and the perturbation of natural radiative forcing. Climate models can then be used to develop projections of future climate.

- The increasing realism of simulations of current and past climate by coupled atmosphere-ocean climate models has increased our confidence in their use for projection of future climate change. Important uncertainties remain, but these have been taken into account in the full range of projections of global mean temperature and sea level change.
- For the mid-range IPCC emission scenario, IS92a, assuming the “best estimate” value of climate sensitivity¹ and including the effects of future increases in aerosol, models project an increase in global mean surface air temperature relative to 1990 of about 2°C by 2100. This estimate is approximately one third lower than the “best estimate” in 1990. This is due primarily to lower emission scenarios (particularly for CO₂ and the CFCs), the inclusion of the cooling effect of sulphate aerosols, and improvements in the treatment of the carbon cycle. Combining the lowest IPCC emission scenario (IS92c) with a “low” value of climate sensitivity and including the effects of future changes in aerosol concentrations leads to a projected increase of about 1°C by 2100. The corresponding projection for the highest IPCC scenario (IS92e) combined with a “high” value of climate sensitivity gives a warming of about 3.5°C. In all cases the average rate of warming would probably be greater than any seen in the last 10,000 years, but the actual annual to decadal changes would include considerable natural variability. Regional temperature changes could differ substantially from the global mean value. Because of the thermal inertia of the oceans, only 50-90% of the eventual equilibrium temperature change would have been realised by 2100 and temperature would continue to increase beyond 2100, even if concentrations of greenhouse gases were stabilised by that time.

¹ In IPCC reports, climate sensitivity usually refers to the long term (equilibrium) change in global mean surface temperature following a doubling of atmospheric equivalent CO₂ concentration. More generally, it refers to the equilibrium change in surface air temperature following a unit change in radiative forcing (°C/Wm⁻²).

- Average sea level is expected to rise as a result of thermal expansion of the oceans and melting of glaciers and ice-sheets. For the IS92a scenario, assuming the “best estimate” values of climate sensitivity and of ice melt sensitivity to warming, and including the effects of future changes in aerosol, models project an increase in sea level of about 50 cm from the present to 2100. This estimate is approximately 25% lower than the “best estimate” in 1990 due to the lower temperature projection, but also reflecting improvements in the climate and ice melt models. Combining the lowest emission scenario (IS92c) with the “low” climate and ice melt sensitivities and including aerosol effects gives a projected sea level rise of about 15 cm from the present to 2100. The corresponding projection for the highest emission scenario (IS92e) combined with “high” climate and ice-melt sensitivities gives a sea level rise of about 95 cm from the present to 2100. Sea level would continue to rise at a similar rate in future centuries beyond 2100, even if concentrations of greenhouse gases were stabilised by that time, and would continue to do so even beyond the time of stabilisation of global mean temperature. Regional sea level changes may differ from the global mean value owing to land movement and ocean current changes.
- Confidence is higher in the hemispheric-to-continental scale projections of coupled atmosphere-ocean climate models than in the regional projections, where confidence remains low. There is more confidence in temperature projections than hydrological changes.
- All model simulations, whether they were forced with increased concentrations of greenhouse gases and aerosols or with increased concentrations of greenhouse gases alone, show the following features: greater surface warming of the land than of the sea in winter; a maximum surface warming in high northern latitudes in winter, little surface warming over the Arctic in summer; an enhanced global mean hydrological cycle, and increased precipitation and soil moisture in high latitudes in winter. All these changes are associated with identifiable physical mechanisms.
- In addition, most simulations show a reduction in the strength of the North Atlantic thermohaline circulation and a widespread reduction in diurnal range of temperature. These features too can be explained in terms of identifiable physical mechanisms.
- The direct and indirect effects of anthropogenic aerosols have an important effect on the projections. Generally, the magnitudes of the temperature and precipitation changes are smaller when aerosol effects are represented, especially in northern mid-latitudes. Note that the cooling effect of aerosols is not a simple offset to the warming effect of greenhouse gases, but significantly affects some of the continental scale patterns of climate change, most noticeably in the summer hemisphere. For example, models that consider only the effects of greenhouse gases generally project an increase in precipitation and soil moisture in the Asian summer monsoon region, whereas models that include, in addition, some of the effects of aerosols suggest that monsoon precipitation may decrease. The spatial and temporal distribution of aerosols greatly influence regional projections, which are therefore more uncertain.
- A general warming is expected to lead to an increase in the occurrence of extremely hot days and a decrease in the occurrence of extremely cold days.
- Warmer temperatures will lead to a more vigorous hydrological cycle; this translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. Several models indicate an increase in precipitation intensity, suggesting a possibility for more extreme rainfall events. Knowledge is currently insufficient to say whether there will be any changes in the occurrence or geographical distribution of severe storms, e.g., tropical cyclones.