CPTEC
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Detecting and atributing causes of climate change, according to IPCC AR4 WG1-Chapter 9

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BRASIL UM PAÍS DE TODOS GOVERNO FEDERAL

PROBIO GEF

Basics

Distinguishing between the effects of external influences and internal climate variability requires careful comparison between observed changes and those that are expected to result from external forcing. These expectations are based on physical understanding of the climate system. Physical understanding is based on physical principles. This understanding can take the form of conceptual models or it might be quantified with climate models that are driven with physically based forcing histories. An array of climate models is used to quantify expectations in this way

The extent to which a model is able to reproduce key features of the climate system and its variations, for example the seasonal cycle, increases its credibility for simulating changes in climate.

‘Detection’ is the process of demonstrating that climate has changed in some defined statistical sense, without providing a reason for that change. Detection does not imply attribution of the detected change to the assumed cause.

‘Attribution’ of causes of climate change is the process of establishing the most likely causes for the detected change with some defined level of confidence

Both detection and attribution require knowledge of the internal climate variability on the time scales considered, usually decades or longer. However, these estimates are uncertain because the instrumental record is too short to give a well-constrained estimate of internal variability, and because of uncertainties in the forcings and the estimated responses. Thus, internal climate variability is usually estimated from long control simulations from coupled climate models

Understanding and Attributing Climate Change

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.

This is an advance since the TAR’s conclusion that “most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations”.

Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns

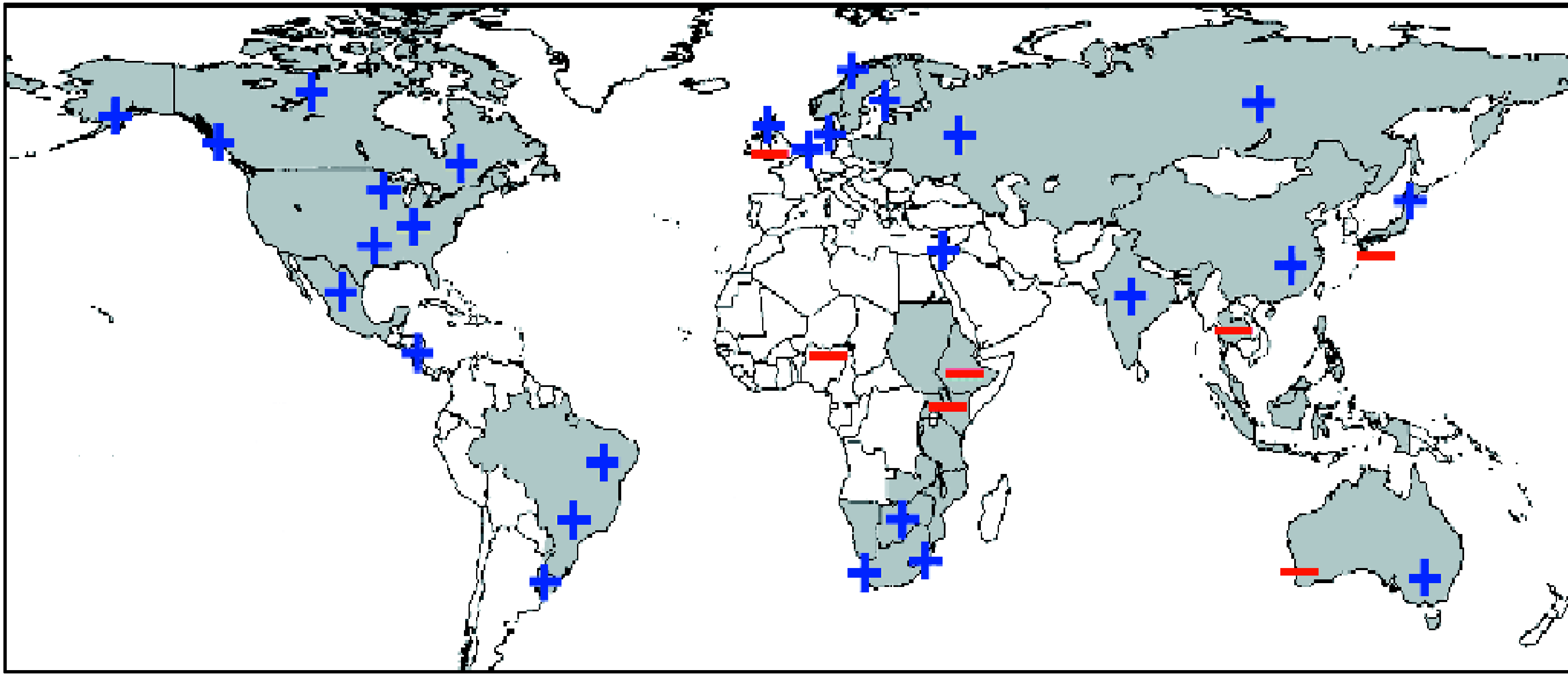
Changes in Precipitation, Increased Drought

- Significantly increased precipitation in eastern parts of North and South America, northern Europe and northern and central Asia.
- The frequency of heavy precipitation events has increased over most land areas - consistent with warming and increases of atmospheric water vapour
- Drying in the Sahel, the Mediterranean, southern Africa and parts of southern Asia.
- More intense and longer droughts observed since the 1970s, particularly in the tropics and subtropics.

Other changes in Extreme Events

- Widespread changes in extreme temperatures observed
- Cold days, cold nights and frost less frequent
- Hot days, hot nights, and heat waves more frequent
- Observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures

Proportion of heavy rainfalls: increasing in most land areas



Regions of disproportionate changes in heavy (95th) and very heavy (99th) precipitation

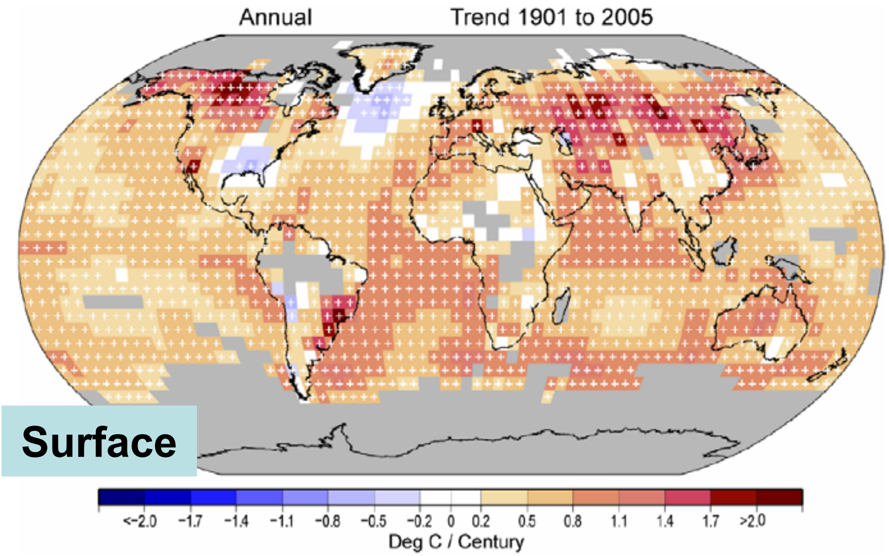
Human and natural drivers of climate change

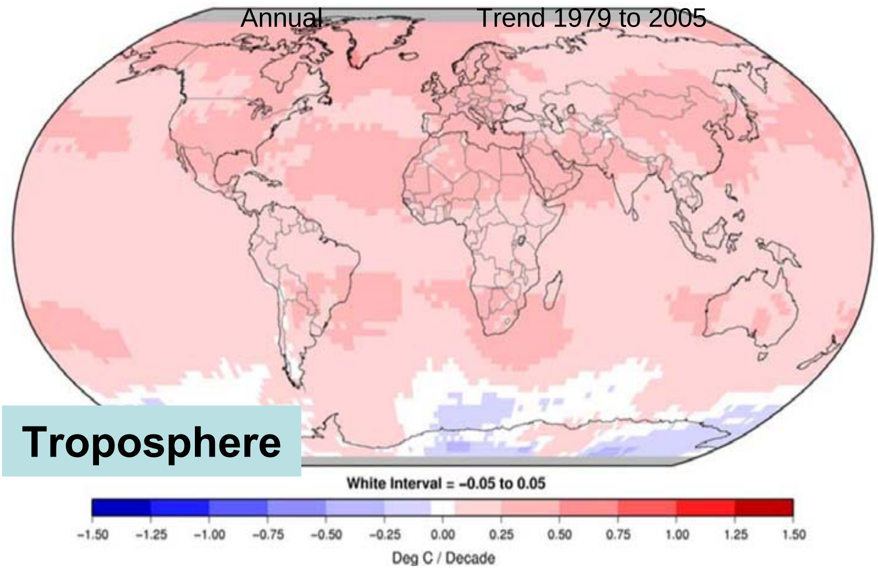
- Annual fossil CO_2 emissions increased from an average of 6.4 GtCper year in the 1990s, to 7.2 GtC per year in 2000-2005
- CO_2 radiative forcing increased by 20%from 1995 to 2005, the largest in any decade in at least the last 200 years
- Changes in solar irradiance since 1750 are exstimated to have caused a radiative forcing of +0.12 [+0.06 to +0.30] Wm^{-2}

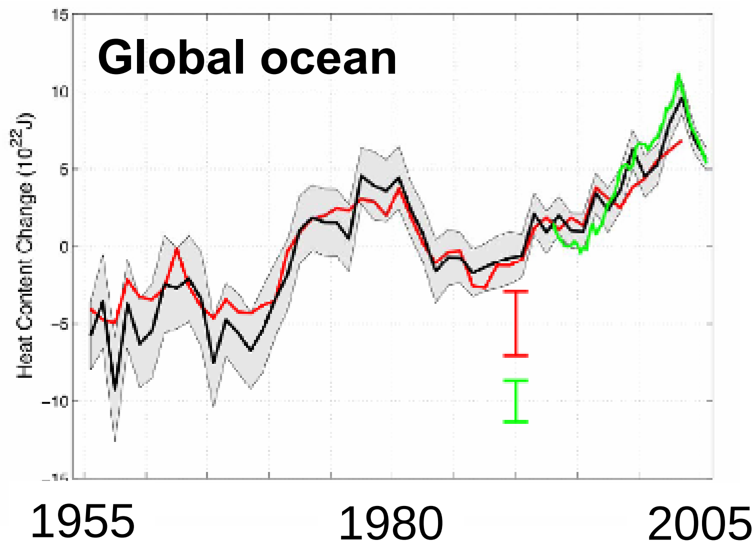
Human and Natural Drivers of Climate Change

The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report (TAR), leading to *very high confidence* that the globally averaged net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W m^{-2}.

Observed widespread warming

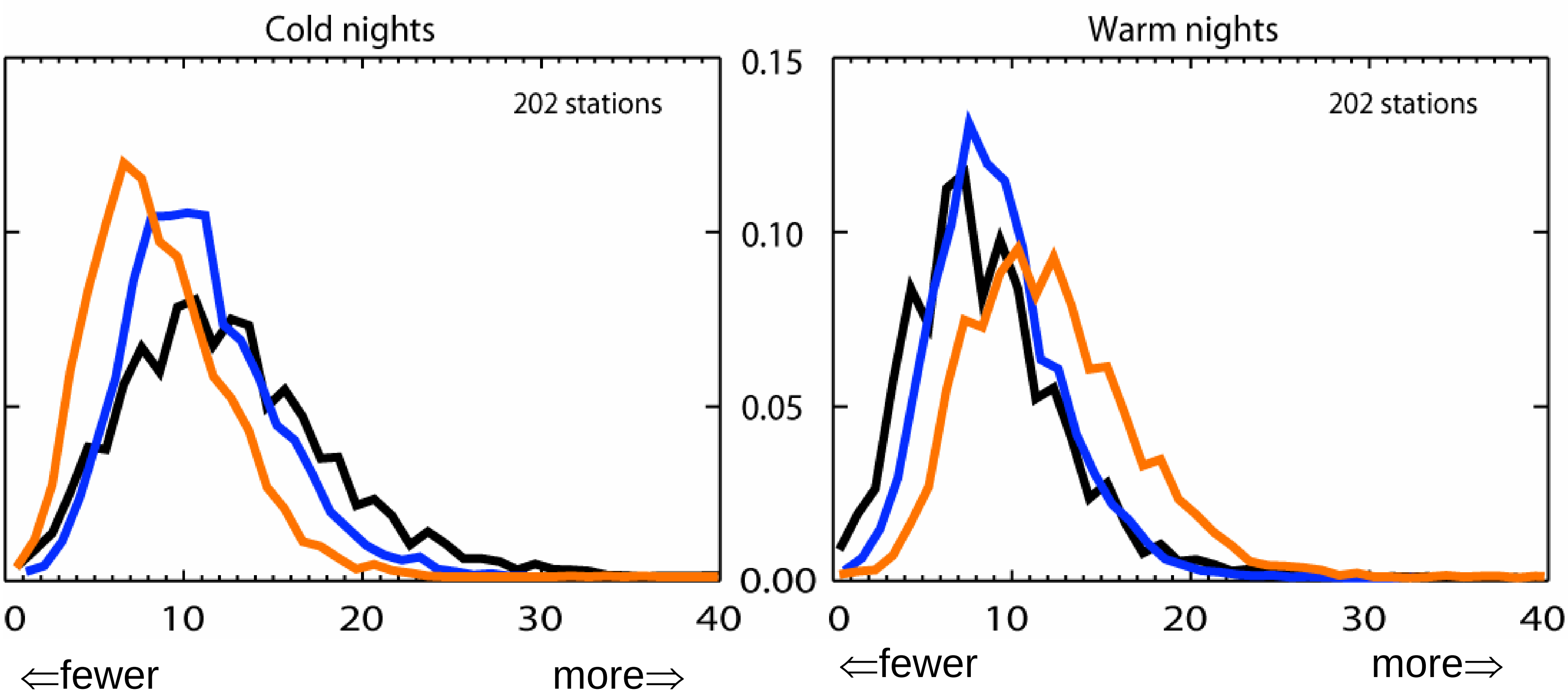






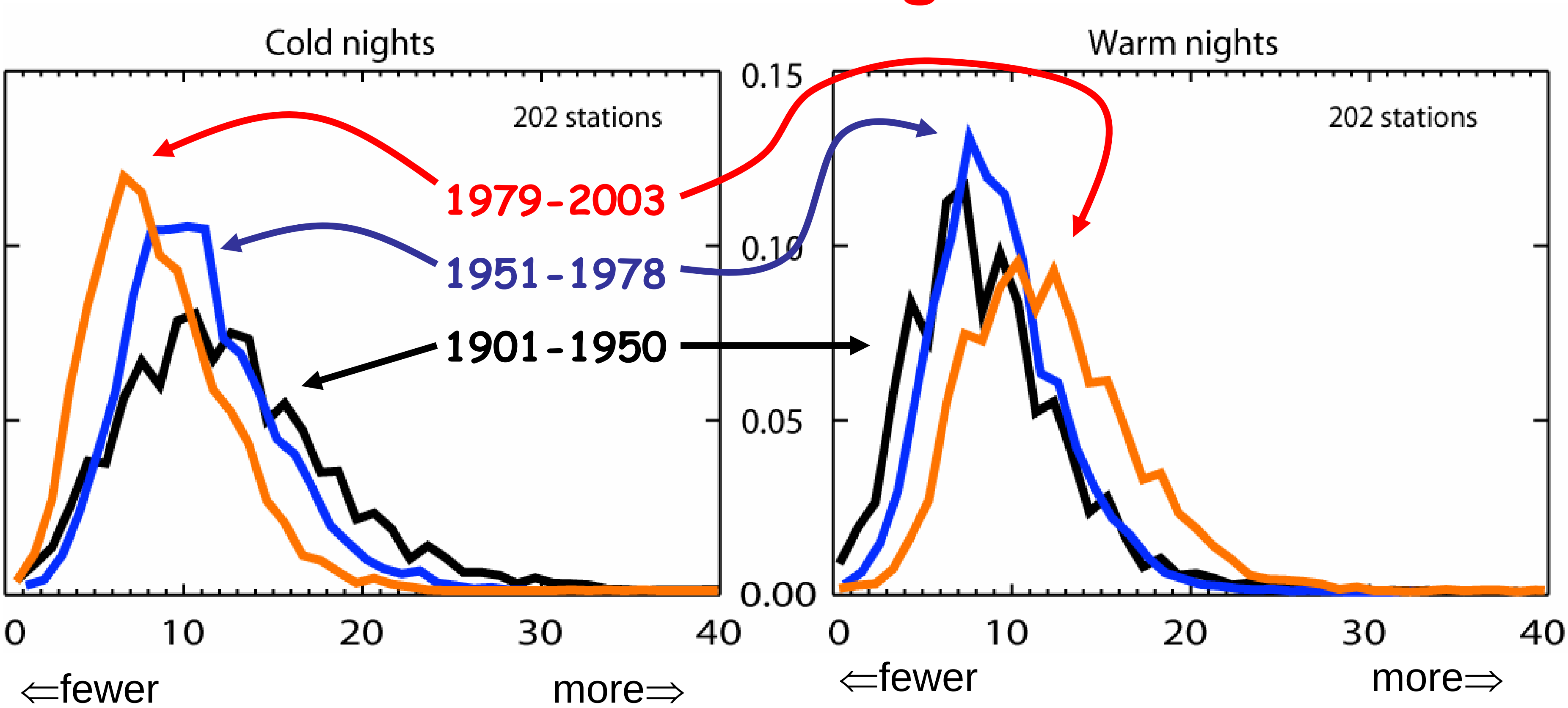
- extremely unlikely without external forcing
- very unlikely due to known natural causes alone

Cold nights decreasing; Warm nights are increasing



Frequency of occurrence of cold or warm temperatures for 202 global stations for 3 time periods:
1901 to 1950 (black), 1951 to 1978 (blue) and 1979 to 2003 (red).

Cold nights decreasing; Warm nights are increasing



Frequency of occurrence of cold or warm temperatures for 202 global stations for 3 time periods:
1901 to 1950 (black), 1951 to 1978 (blue) and 1979 to 2003 (red).

The uncertainty guidance provided for the Fourth Assessment Report draws, for the first time, a careful distinction between levels of confidence in scientific understanding and the likelihoods of specific results. This allows authors to express high confidence that an event is extremely unlikely (e.g., rolling a dice twice and getting a six both times), as well as high confidence that an event is about as likely as not (e.g., a tossed coin coming up heads). Confidence and likelihood as used here are distinct concepts but are often linked in practice.

The standard terms used to define levels of confidence in this report are as given in the IPCC Uncertainty Guidance Note, namely:

Confidence

Confidence Terminology	Degree of confidence in being correct
Very high confidence	At least 9 out of 10 chance
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 1 out of 10 chance

Note that 'low confidence' and 'very low confidence' are only used for areas of major concern and where a risk-based perspective is justified.

The standard terms used in this report to define the likelihood of an outcome or result where this can be estimated probabilistically are:

Likelihood

Likelihood Terminology	Likelihood of the occurrence/ outcome
Virtually certain	> 99% probability
Extremely likely	> 95% probability
Very likely	> 90% probability
Likely	> 66% probability
More likely than not	> 50% probability
About as likely as not	33 to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Extremely unlikely	< 5% probability
Exceptionally unlikely	< 1% probability

The terms 'extremely likely', 'extremely unlikely' and 'more likely than not' as defined above have been added to those given in the IPCC Uncertainty Guidance Note in order to provide a more specific assessment of aspects including attribution and radiative forcing.

Projections of Future Changes in Climate

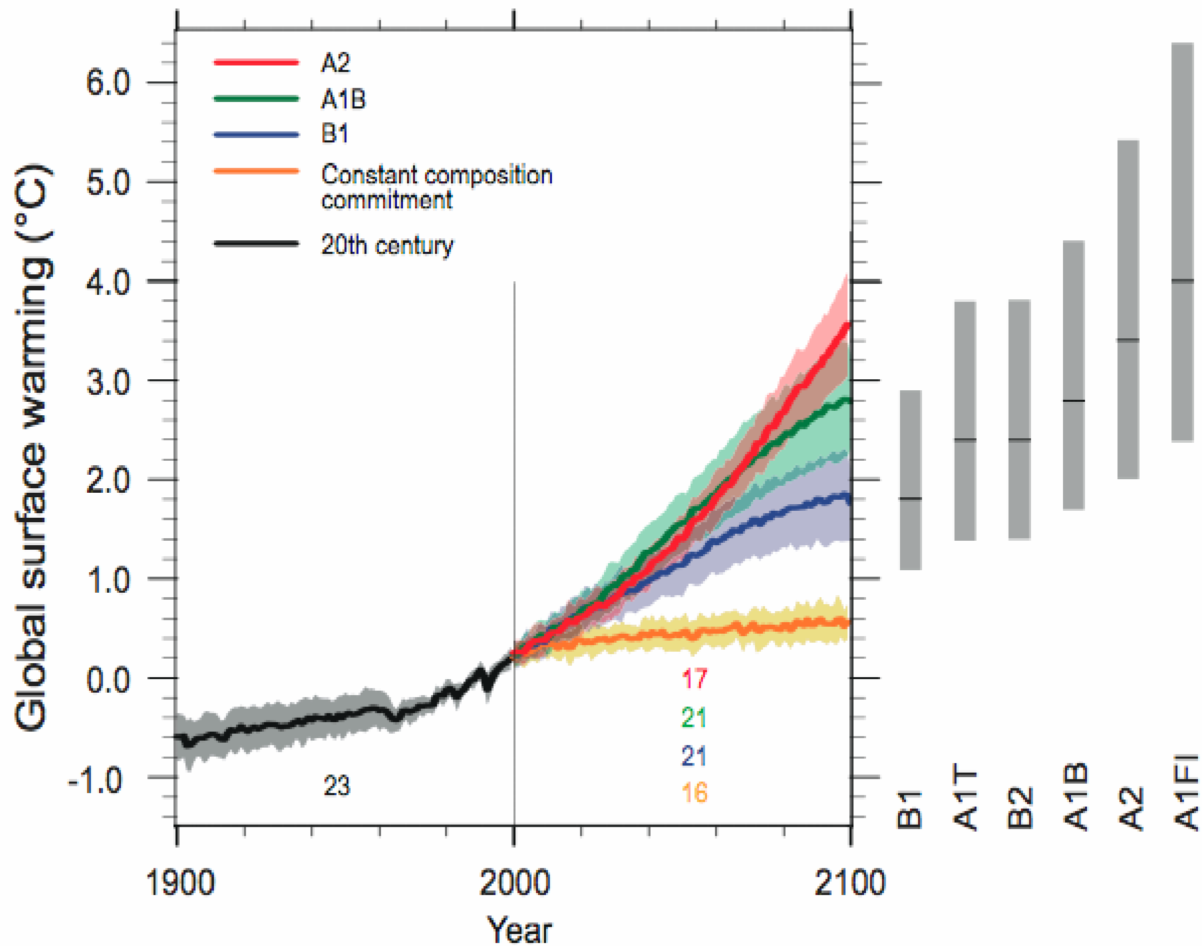
Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century.

- Best estimate and assessed likelihood range for future temperature projections for first time
- Broadly similar to the TAR but not directly comparable

Projections of Future Changes in Climate

Best estimate for low scenario (B1) is 1.8°C (*likely* range is 1.1°C to 2.9°C), and for high scenario (A1FI) is 4.0°C (*likely* range is 2.4°C to 6.4°C).

Broadly consistent with span quoted for SRES in TAR, but not directly comparable

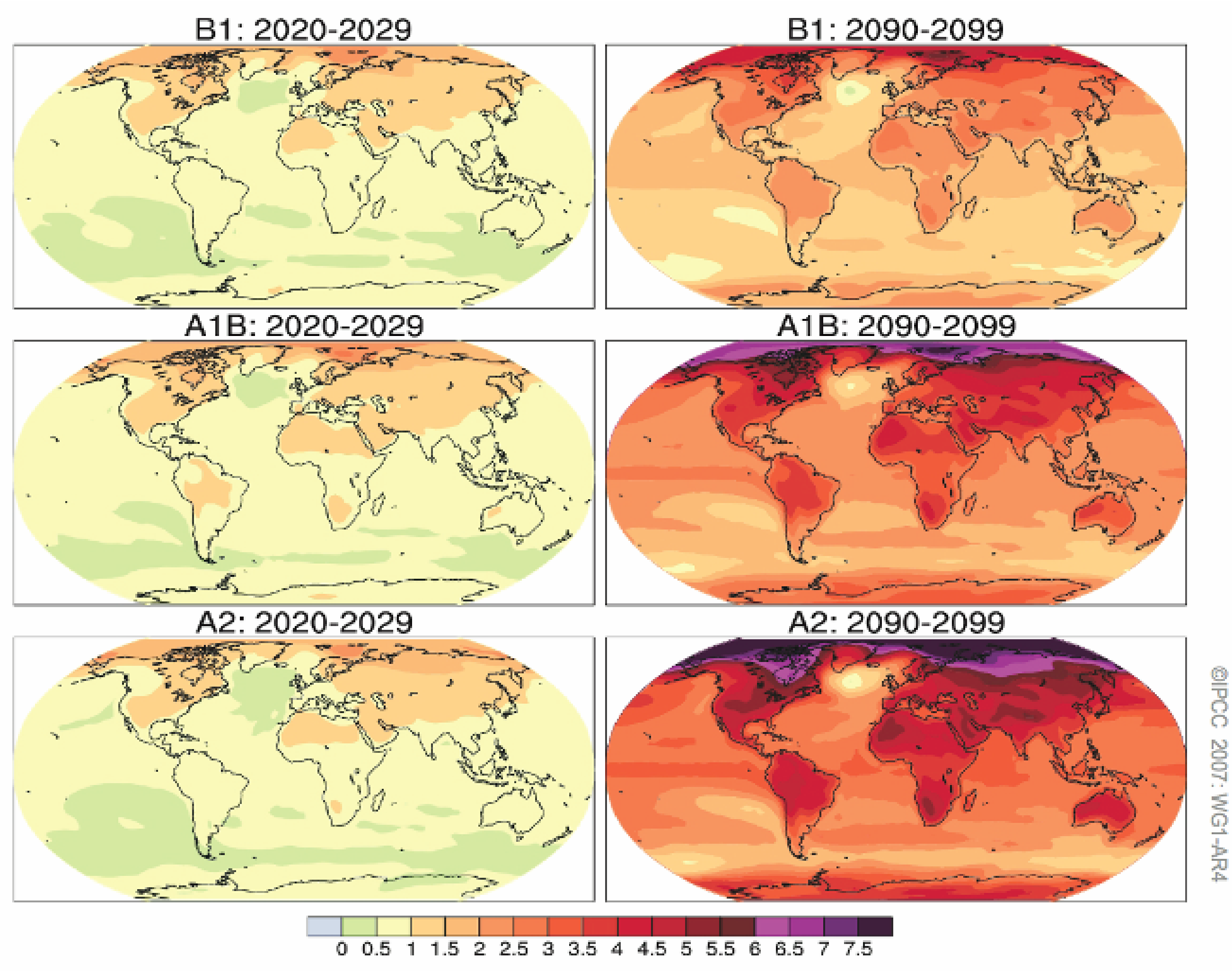


Projections of Future Changes in Climate

Projected warming in 21st century expected to be

greatest over land and at most high northern latitudes

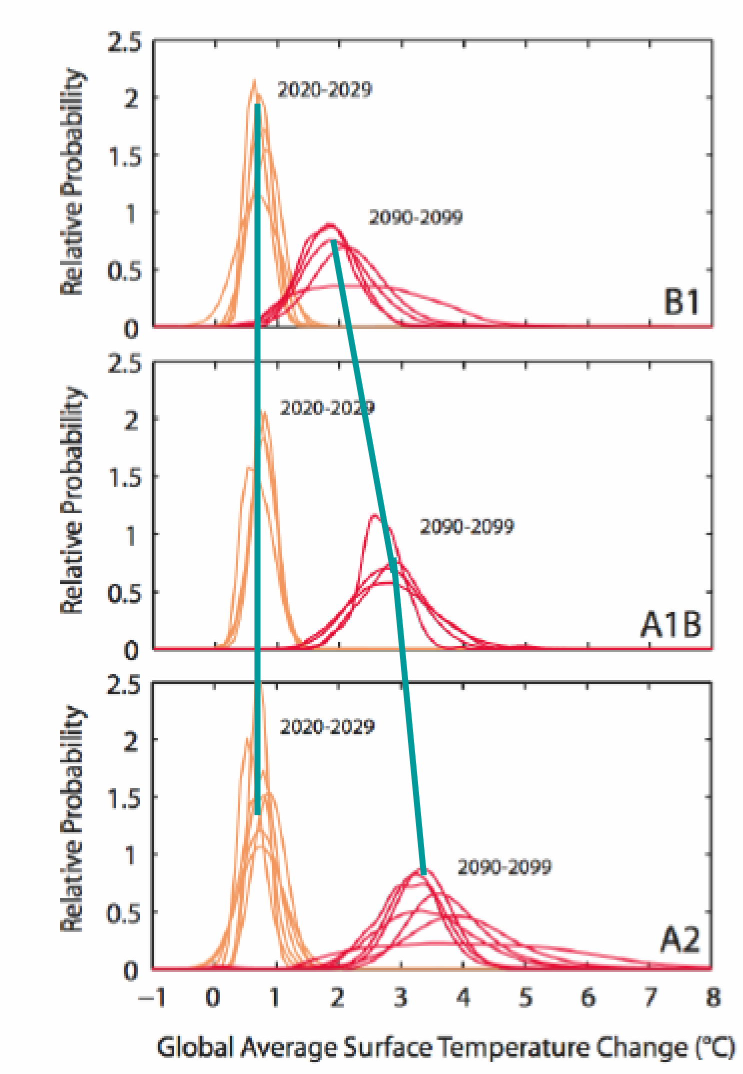
and least over the Southern Ocean and parts of the North Atlantic Ocean



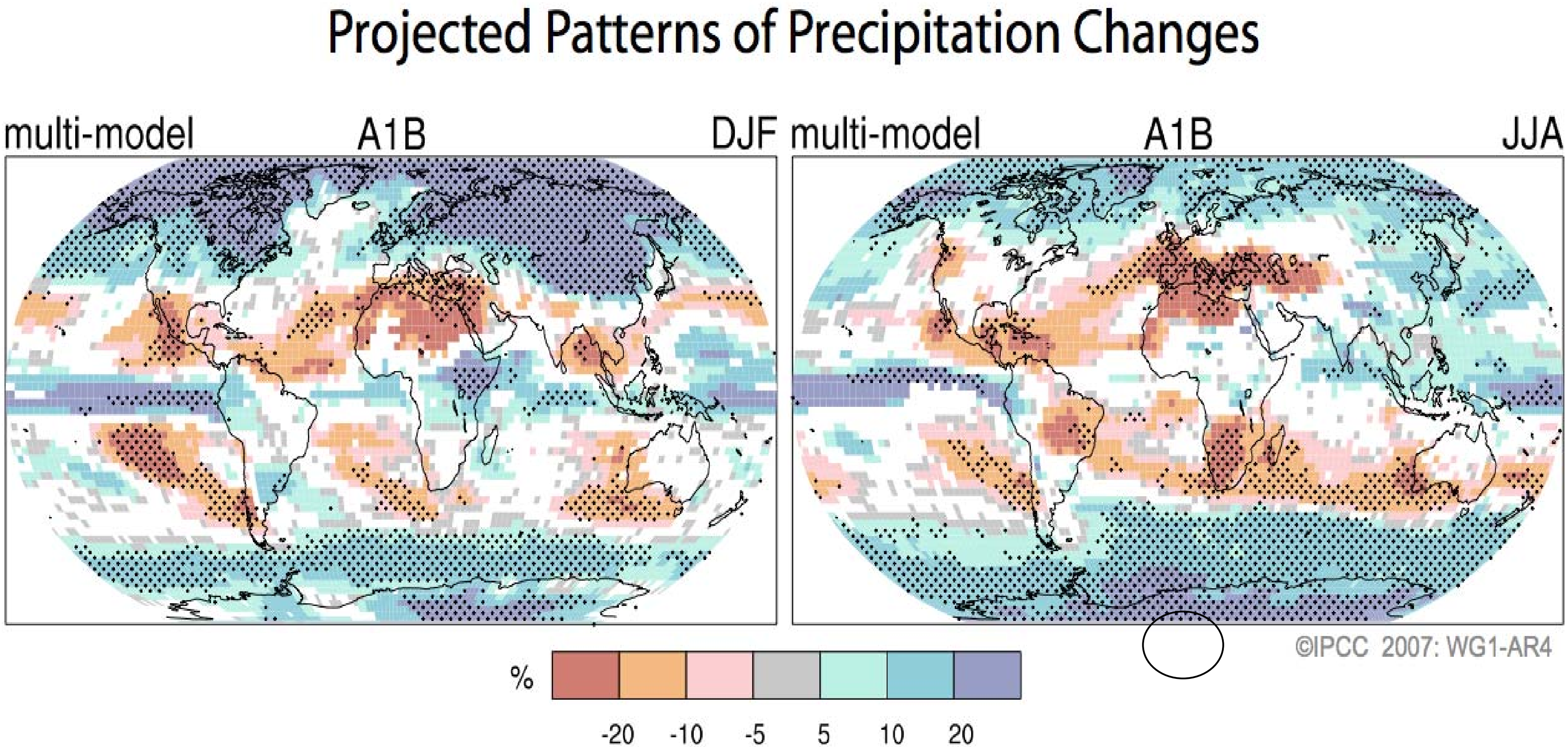
Projections of Future Changes in Climate

Near term projections insensitive to choice of scenario

Longer term projections depend on scenario and climate model sensitivities



Projections of Future Changes in Climate



Precipitation increases *very likely* in high latitudes

Decreases *likely* in most subtropical land regions

Dots show agreements between most of the models

Projections of Future Changes in Climate

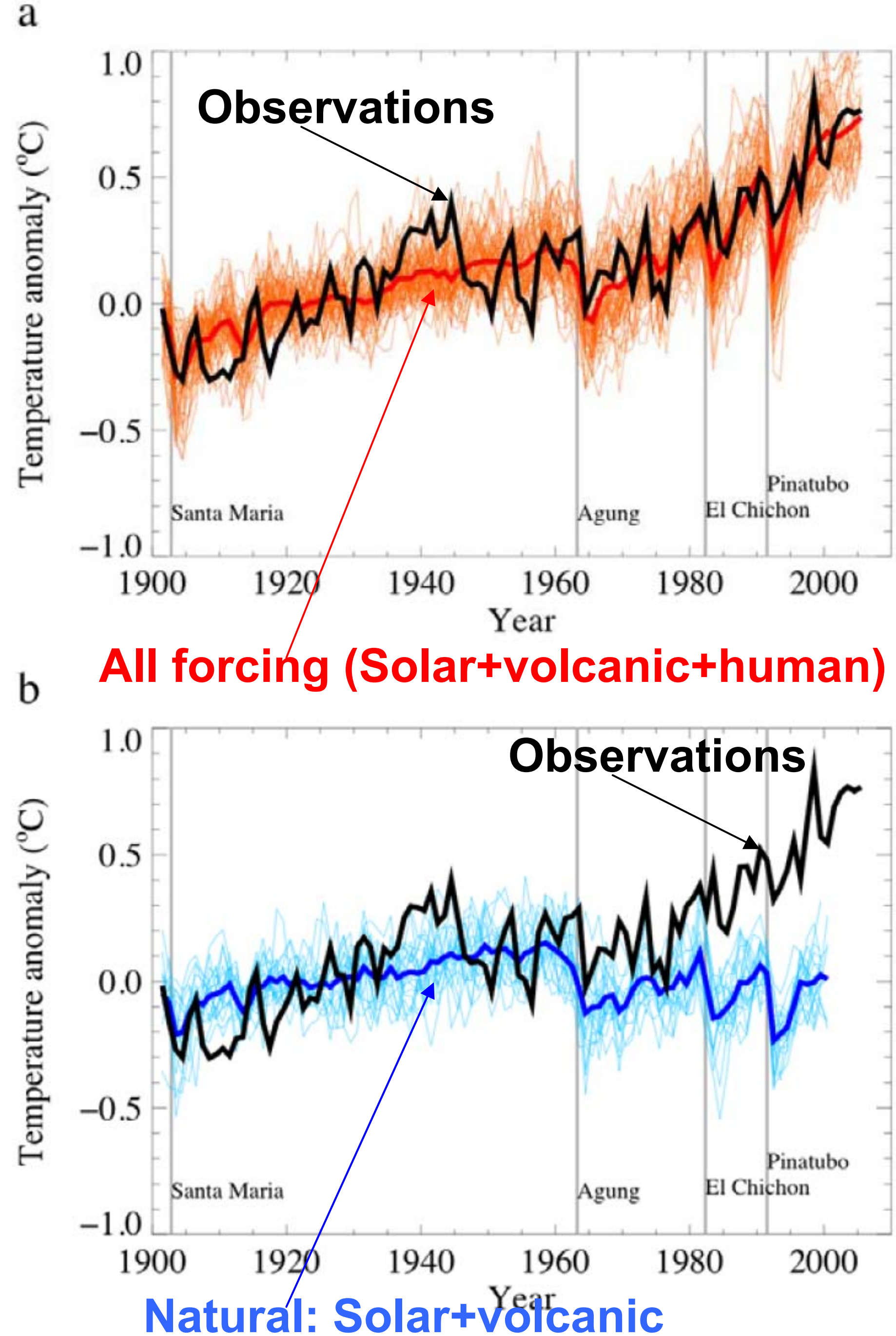
Simulations of global mean 20th-century temperature change that accounted for anthropogenic greenhouse gases and sulphate aerosols as well as solar and volcanic forcing were found to be generally consistent with observations.

In contrast, a limited number of simulations of the response to known natural forcings alone indicated that these may have contributed to the observed warming in the first half of the 20th century, but could not provide an adequate explanation of the warming in the second half of the 20th century, nor the observed changes in the vertical structure of the atmosphere.

Attribution

Changes are observed consistent with

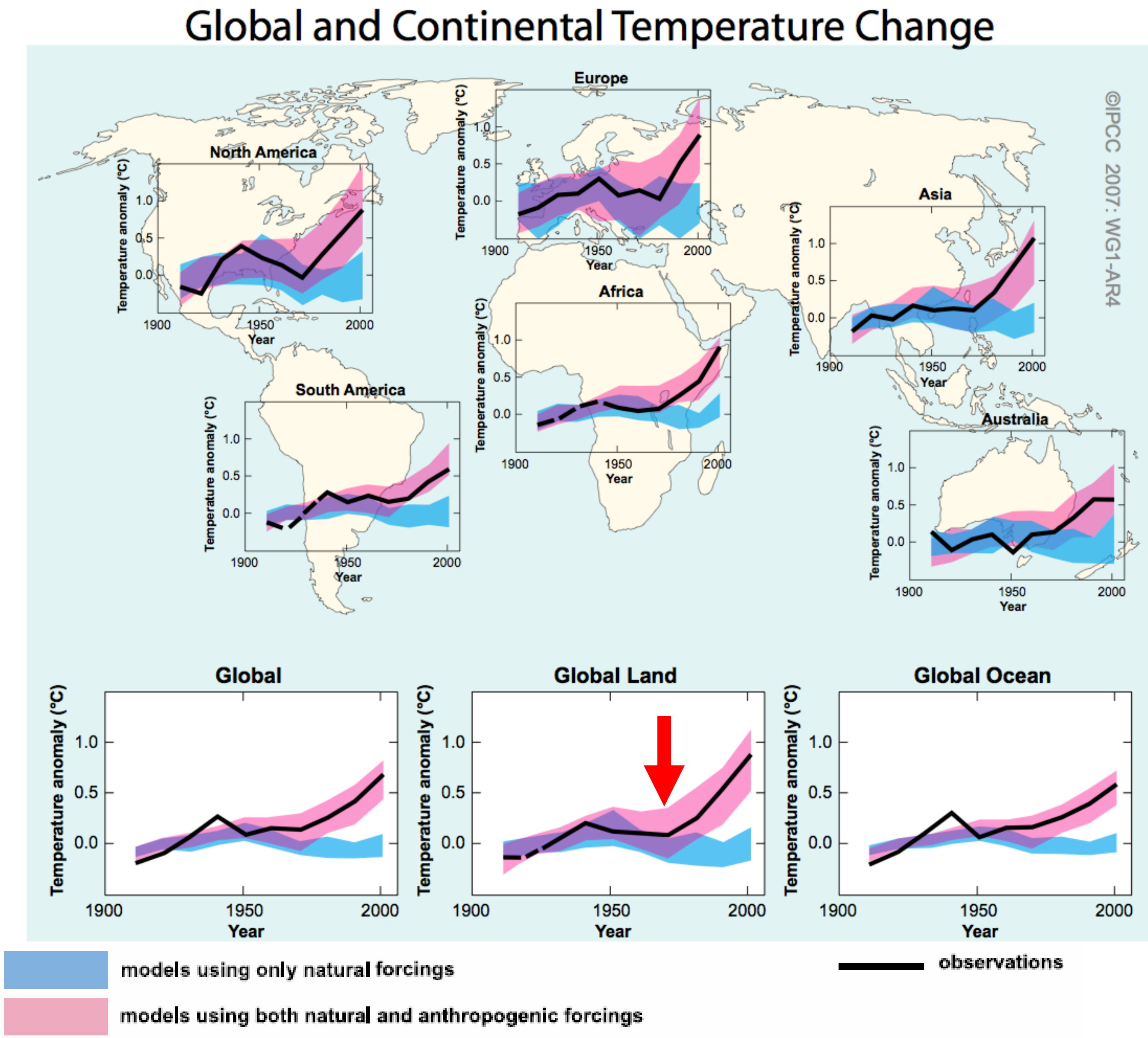
- ☑ expected responses to forcings
- ☒ inconsistent with alternative explanations (natural climate variability alone)



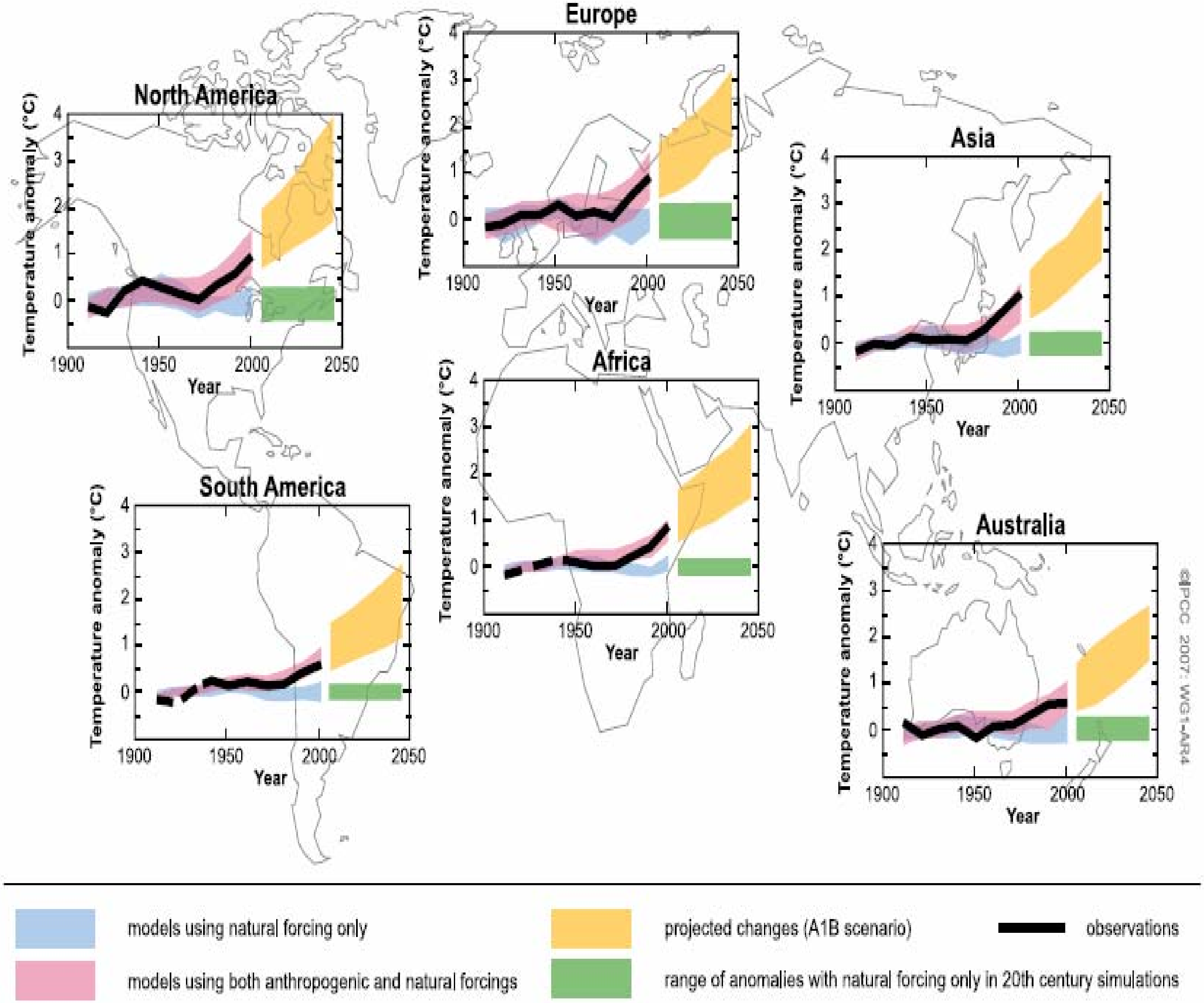
Understanding and Attributing Climate Change (XX Century)

Continental warming

likely shows a significant anthropogenic contribution over the past 50 years



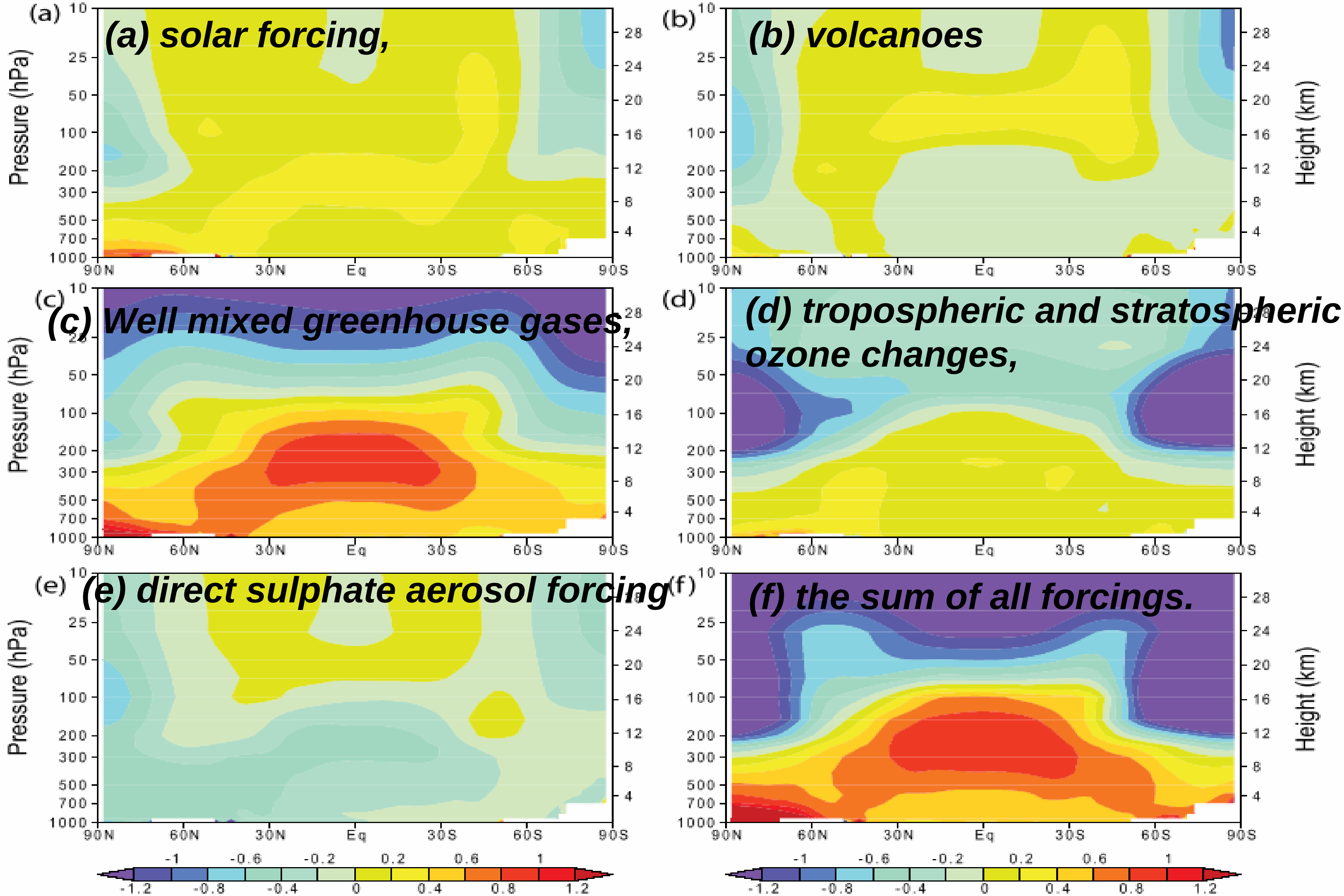
Understanding and Attributing Climate Change (XX-XXI Century)



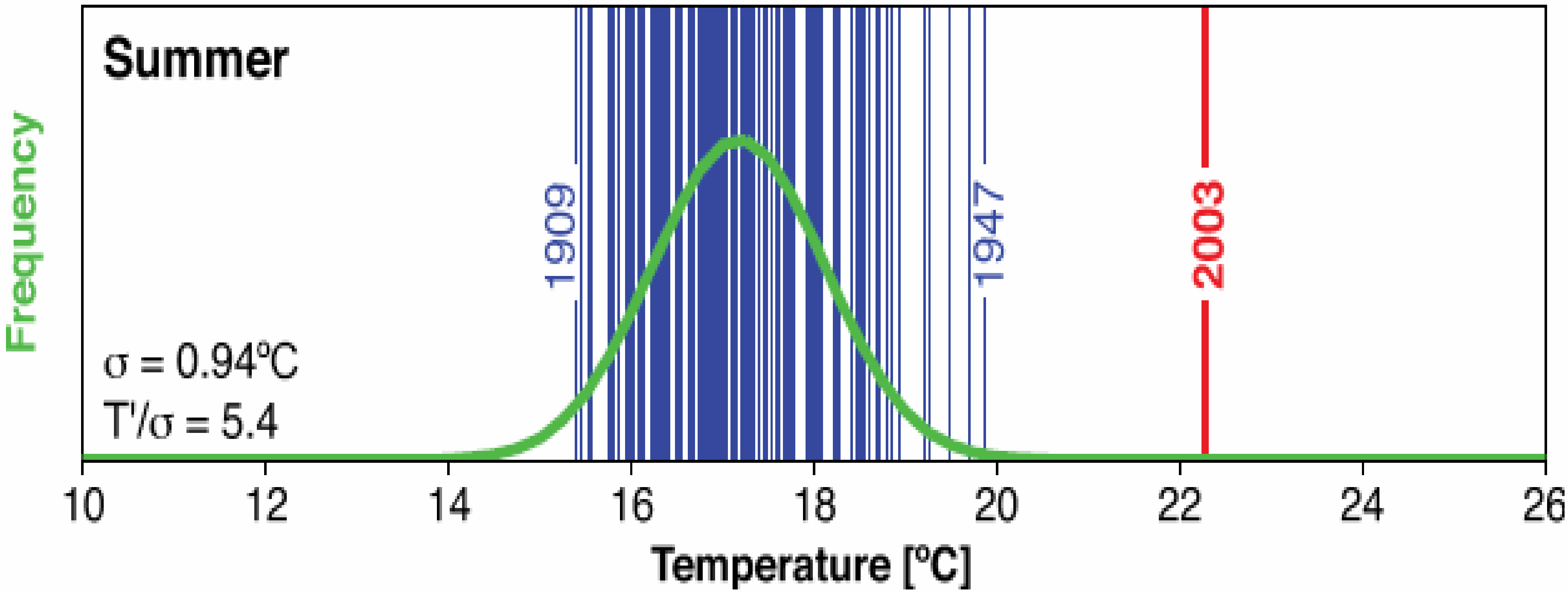
Decadal mean continental surface temperature anomalies (°C) in observations and simulations for the period 1906 to 2005 and in projections for 2001 to 2050. The yellow shading represents the 5th to 95th percentile range of projected changes according to the SRES A1B emissions scenario. The green bar denotes the 5th to 95th percentile range of decadal mean anomalies from the 20th-century simulations with only natural forcings

Projections of Future Changes in Climate

There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation, and some aspects of extremes and of ice.



Zonal mean atmospheric temperature change from 1890 to 1999 (°C per century) as simulated by the PCM model from, Plot is from 1,000 hPa to 10 hPa (shown on left scale) and from 0 km to 30 km (Santer et al. 2003a).

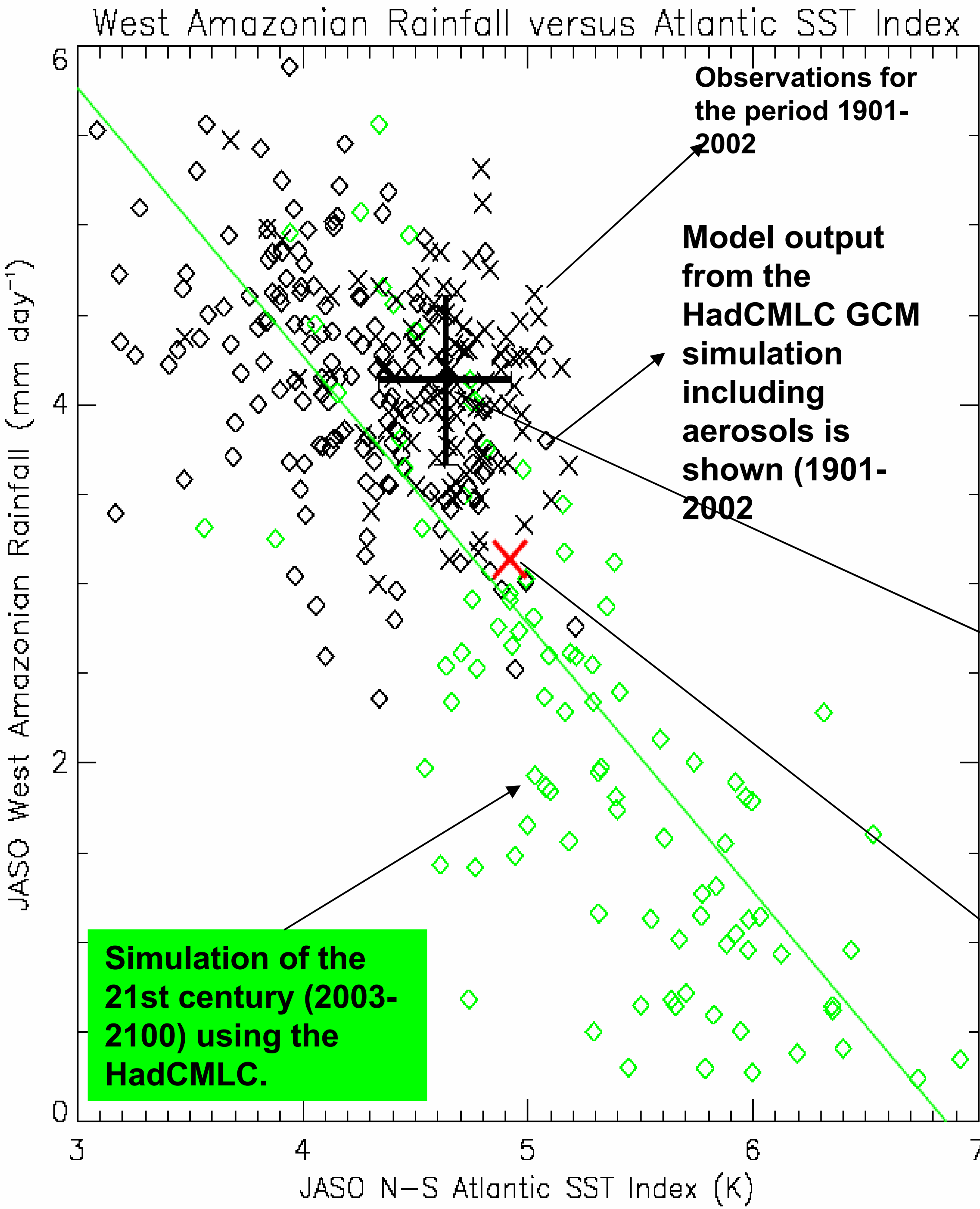


Europe heat wave of 2003:

Summer temperatures in Switzerland from 1864 to 2003 are, on average, about 17°C, as shown by the green curve. During the extremely hot summer of 2003, average temperatures exceeded 22°C, as indicated by the red bar (a vertical line is shown for each year in the 137-year record). The years 1909, 1947 and 2003 are labelled because they represent extreme years in the record. The values in the lower left corner indicate the standard deviation (σ) and the 2003 anomaly

Drought of Amazonia 2005:

Relationship between July-October anomalies in rainfall in Western Amazonia and in the Index of the north-south SST gradient across the tropical Atlantic ocean (Cox et al. 2007)



Mean and STDV of the drought of 2005 from observations

Mean and STDV estimated values for the 2005 Amazon drought from the HadCMLC

Result	Region	Likelihood	Factors contributing to likelihood assessment
Surface temperature			
Warming during the past half century cannot be explained without external radiative forcing	Global	Extremely likely (>95%)	Anthropogenic change has been detected in surface temperature with very high significance levels (less than 1% error probability). This conclusion is strengthened by detection of anthropogenic change in the upper ocean with high significance level. Upper ocean warming argues against the surface warming being due to natural internal processes. Observed change is very large relative to climate-model simulated internal variability. Surface temperature variability simulated by models is consistent with variability estimated from instrumental and palaeorecords. Main uncertainty from forcing and internal variability estimates (Sections 9.4.1.2, 9.4.1.4, 9.5.1.1, 9.3.3.2, 9.7).
Warming during the past half century is not solely due to known natural causes	Global	Very Likely	This warming took place at a time when non-anthropogenic external factors would likely have produced cooling. The combined effect of known sources of forcing would have been extremely likely to produce a warming. No climate model that has used natural forcing only has reproduced the observed global warming trend over the 2nd half of the 20th century. Main uncertainties arise from forcing, including solar, model-simulated responses and internal variability estimates (Sections 2.9.2, 9.2.1, 9.4.1.2, 9.4.1.4; Figures 9.5, 9.6, 9.9).
Greenhouse gas forcing has been the dominant cause of the observed global warming over the last 50 years.	Global	Very likely	All multi-signal detection and attribution studies attribute more warming to greenhouse gas forcing than to a combination of all other sources considered, including internal variability, with a very high significance. This conclusion accounts for observational, model and forcing uncertainty, and the possibility that the response to solar forcing could be underestimated by models. Main uncertainty from forcing and internal variability estimates (Section 9.4.1.4; Figure 9.9).

Increases in greenhouse gas concentrations alone would have caused more warming than observed over the last 50 years because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place.	Global	Likely	Estimates from different analyses using different models show consistently more warming than observed over the last 50 years at the 5% significance level. However, separation of the response to non-greenhouse gas (particularly aerosol) forcing from greenhouse gas forcing varies between models (Section 9.4.1.4; Figure 9.9).
There has been a substantial anthropogenic contribution to surface temperature increases in every continent except Antarctica since the middle of the 20th century	Africa, Asia, Australia, Europe, North America and South America	Likely	Anthropogenic change has been estimated using detection and attribution methods on every individual continent (except Antarctica). Greater variability compared to other continental regions makes detection more marginal in Europe. No climate model that used natural forcing only reproduced the observed continental mean warming trend over the second half of the 20th century. Uncertainties arise because sampling effects result in lower signal-to-noise ratio at continental than at global scales. Separation of the response to different forcings is more difficult at these spatial scales (Section 9.4.2; FAQ 9.2, Figure 1).

Early 20th-century warming is due in part to external forcing.	Global	Very Likely	A number of studies detect the influence of external forcings on early 20th-century warming, including a warming from anthropogenic forcing. Both natural forcing and response are uncertain, and different studies find different forcings dominant. Some studies indicate that internal variability could have made a large contribution to early 20th-century warming. Some observational uncertainty in early 20th-century trend (Sections 9.3.3.2, 9.4.1.4; Figures 9.4, 9.5).

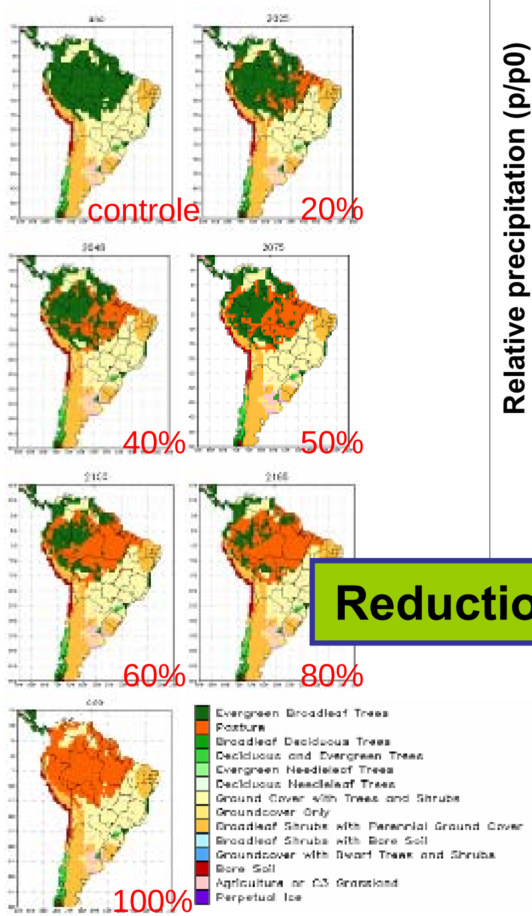
Pre-industrial temperatures were influenced by natural external forcing (period studied is past 7 centuries)	NH (mostly extratropics)	Very Likely	Detection studies indicate that external forcing explains a substantial fraction of inter-decadal variability in NH temperature reconstructions. Simulations in response to estimates of pre-industrial forcing reproduce broad features of reconstructions. Substantial uncertainties in reconstructions and past forcings are unlikely to lead to a spurious agreement between temperature reconstructions and forcing reconstructions as they are derived from independent proxies (Section 9.3.3; Figures 9.4, 6.13).
Temperature extremes have changed due to anthropogenic forcing	NH land areas and Australia combined.	Likely	A range of observational evidence indicates that temperature extremes are changing. An anthropogenic influence on the temperatures of the 1, 5, 10 and 30 warmest nights, coldest days and coldest nights annually has been formally detected and attributed in one study, but observed change in the temperature of the warmest day annually is inconsistent with simulated change. The detection of changes in temperature extremes is supported by other comparisons between models and observations. Model uncertainties in changes in temperature extremes are greater than for mean temperatures and there is limited observational coverage and substantial observational uncertainty (Section 9.4.3).

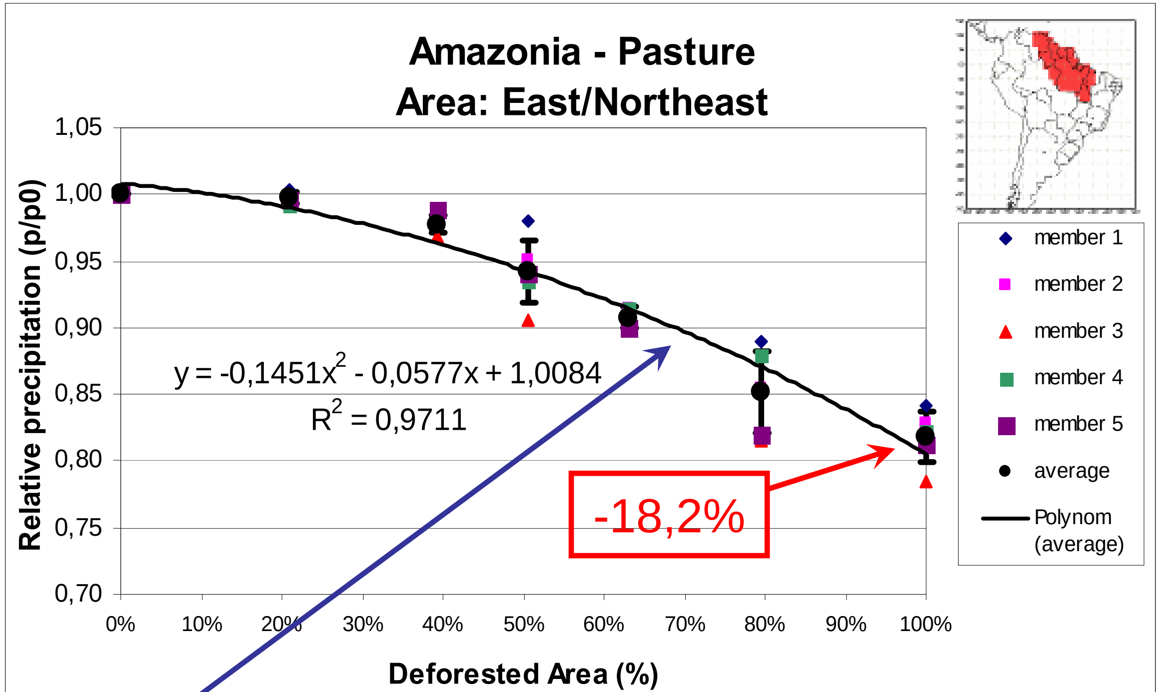
Anthropogenic forcing contributed to sea level rise during the latter half 20th century	Global	Very likely	Natural factors alone do not satisfactorily explain either the observed thermal expansion of the ocean or the observed sea level rise. Models including anthropogenic and natural forcing simulate the observed thermal expansion since 1961 reasonably well. Anthropogenic forcing dominates the surface temperature change simulated by models, and has likely contributed to the observed warming of the upper ocean and widespread glacier retreat. It is very unlikely that the warming during the past half century is due only to known natural causes. It is therefore very likely that anthropogenic forcing contributed to sea level rise associated with ocean thermal expansion and glacier retreat. However, it remains difficult to estimate the anthropogenic contribution to sea level rise because suitable studies quantifying the anthropogenic contribution to sea level rise and glacier retreat are not available, and because the observed sea level rise budget is not closed (Table 9.2; Section 9.5.2).

Anthropogenic forcing contributed to the increase in frequency of the most intense tropical cyclones since the 1970s	Tropical regions	More likely than not (>50%)	Recent observational evidence suggests an increase in frequency of intense storms. Increase in intensity is consistent with theoretical expectations. Large uncertainties due to models and observations. Modelling studies generally indicate a reduced frequency of tropical cyclones in response to enhanced greenhouse gas forcing, but an increase in the intensity of the most intense cyclones. Observational evidence, which is affected by substantial inhomogeneities in tropical cyclone data sets for which corrections have been attempted, suggests that increases in cyclone intensity since the 1970s are associated with SST and atmospheric water vapour increases (Section 3.8.3, Box 3.5 and Section 9.5.2.6).
Volcanic forcing influences total rainfall	Global land areas	More likely than not (>50%)	Model response detectable in observations for some models and result supported by theoretical understanding. However, uncertainties in models, forcings and observations. Limited observational sampling, particularly in the SH (Section 9.5.4.2; Figure 9.18).
Increases in heavy rainfall are consistent with anthropogenic forcing during latter half 20th century	Global land areas (limited sampling)	More likely than not (>50%)	Observed increases in heavy precipitation appear to be consistent with expectations of response to anthropogenic forcing. Models may not represent heavy rainfall well; observations suffer from sampling inadequacies (Section 9.5.4.2).
Increased risk of drought due to anthropogenic forcing during latter half 20th century	Global land areas	More likely than not (>50%)	One detection study has identified an anthropogenic fingerprint in a global Palmer Drought Severity Index data set with high significance, but the simulated response to anthropogenic and natural forcing combined is weaker than observed, and the model appears to have less inter-decadal variability than observed. Studies of some regions indicate that droughts in those regions are linked either to SST changes that, in some instances, may be linked to anthropogenic aerosol forcing (e.g., Sahel) or to a circulation response to anthropogenic forcing (e.g., southwest Australia). Models, observations and forcing all contribute uncertainty (Section 9.5.3.2).

1• Simulations of the effects of land use changes in eastern Amazonia (Sampaio et al. 2007)

PROJECTED SCENARIOS





Reduction of rainfall due to deforestation !

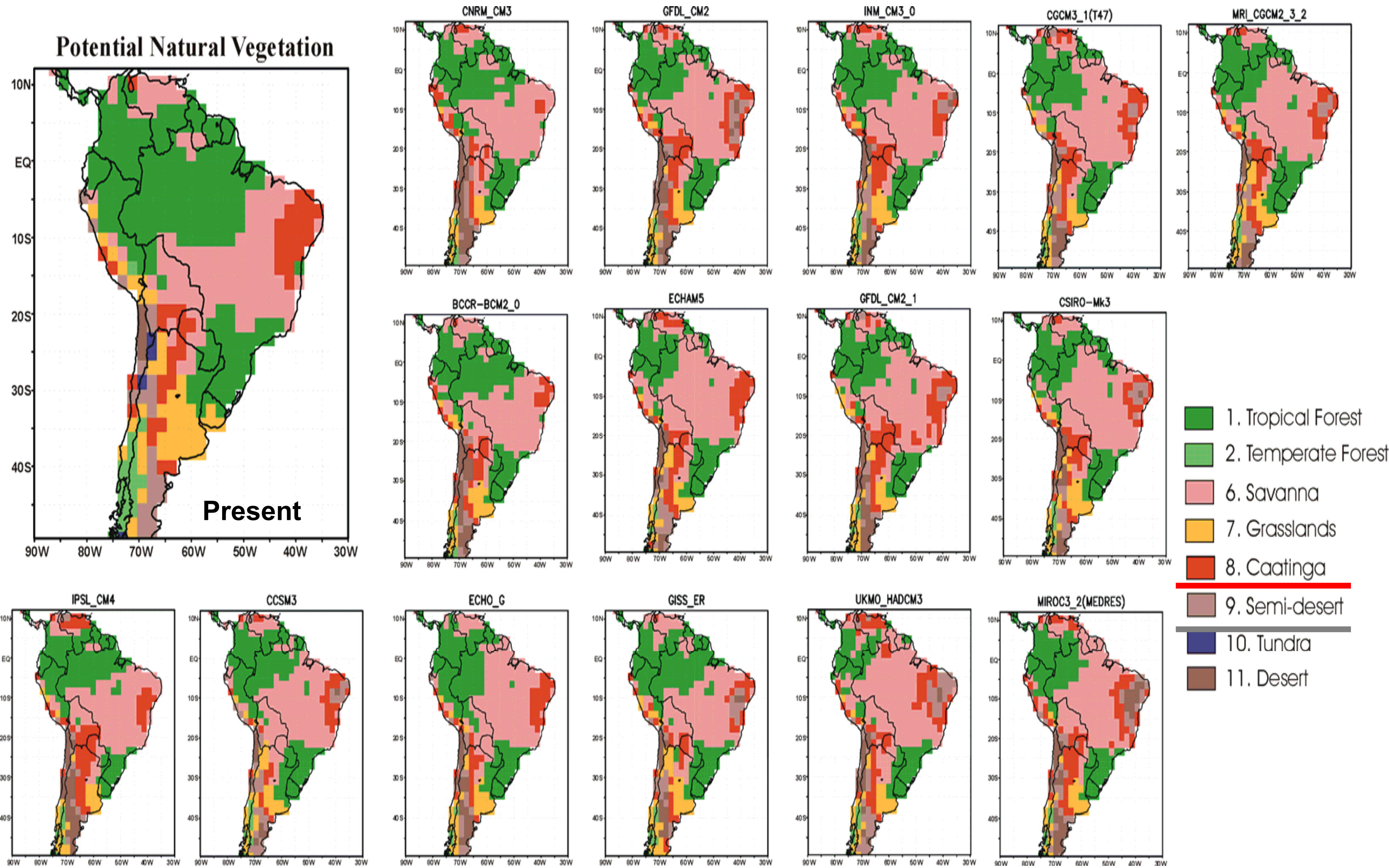
Relative Precipitation

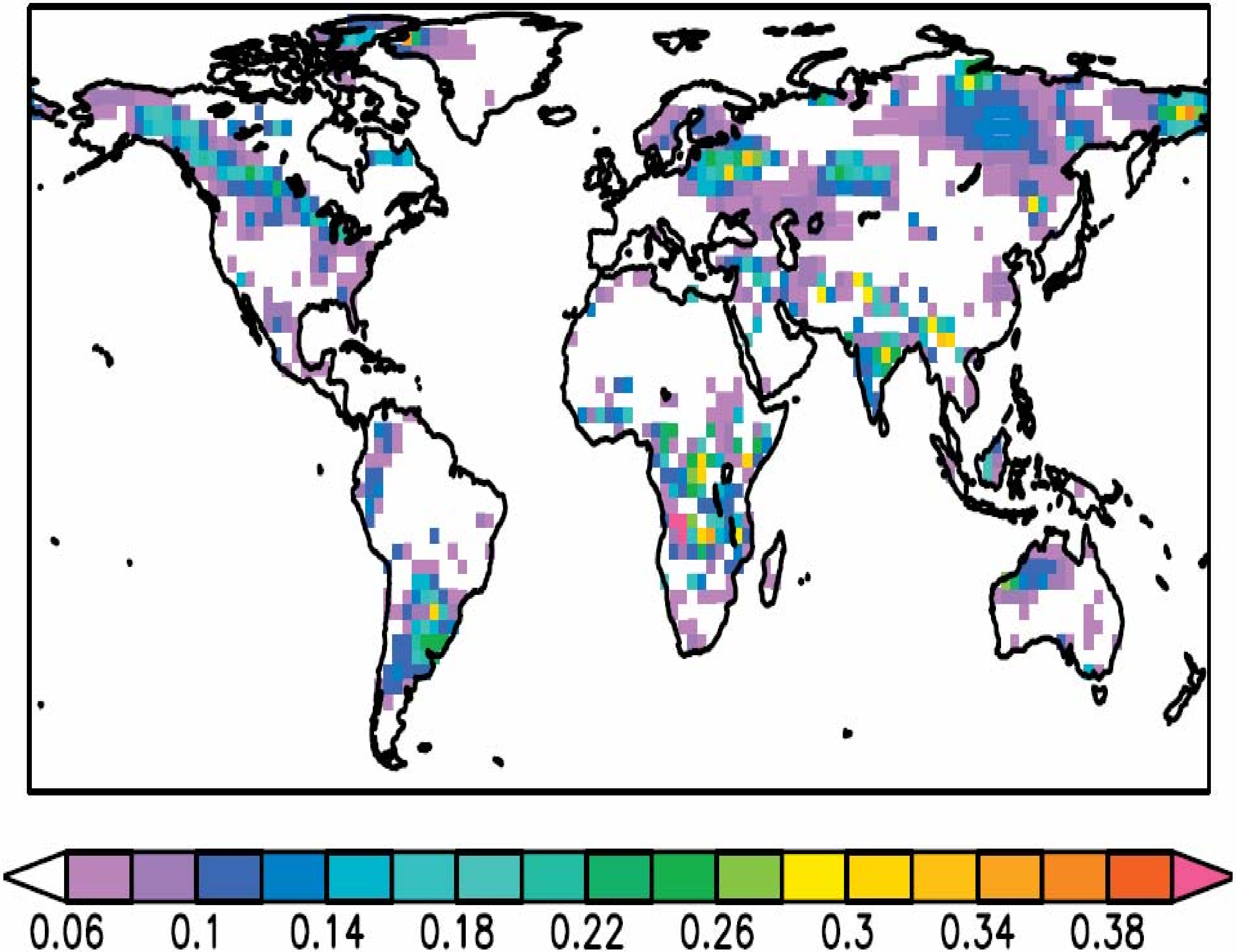
	All Pasture
JJA	-27,5%
SON	-28,1%

Large reduction of precipitation during the low rainfall season

Sampaio et al. (2007)

Natural vegetation projected by the CPTEC PVM in South America for 2100, using the A2 IPCC AR4 global climate change projections from 15 AGCMs (Salazar et al. 2007)





"The impacts of land use change on climate are expected to be locally significant in some regions, but are small at the global scale in comparison with greenhouse gas warming" (IPCC WG1-TS).

Ratio of the magnitude of the near surface temperature response to land cover change over the magnitude of the response to GHGs (Land use/GHG) concentrations increase, for the B2 scenarios (Voldoire 2006)

There are numerous sources of uncertainty on global and regional climate change projections in any other region of the planet.

Land use/cover change is an important forcing that is inherently regional in scope.

The other major component of uncertainty is the responses and feedbacks of the climate system to emissions as represented in climate models.

These uncertainties are related to the model representation of the conversion of the emissions into concentrations of radiatively active species (i.e., via atmospheric chemistry and carbon-cycle models) and the subsequent response of the physical climate system.

In turn, the latter uncertainties result from the representation of resolved processes (e.g., moisture advection), the parameterizations of sub-grid-scale processes (e.g., clouds, precipitation), feedback mechanisms on the global and regional scale (e.g., changes in land-use/cover affecting the atmosphere, the role of aerosols on the rainy season in Amazonia) and so on.

The long-term variations of models´ skill represent an additional source of uncertainty, and indicate that the regional reliability of long climate model runs may depend on the time slice in which the output of the model is analyzed.

Summary:

Human-induced warming of the climate system widespread.

Anthropogenic warming of the climate system can be detected in temperature observations taken at the surface, in the troposphere and in the oceans.

It is *extremely unlikely* (<5%) that the global pattern of warming during the past half century can be explained without external forcing, and *very unlikely* that it is due to known natural external causes alone.

Greenhouse gas forcing has *very likely* caused most of the observed global warming over the last 50 years.

- It is *likely* that there has been a substantial anthropogenic contribution to surface temperature increases in every continent except Antarctica since the middle of the 20th century.

- Surface temperature extremes have *likely* been affected by anthropogenic forcing.

- There is evidence of anthropogenic influence in other parts of the climate system.

- Analyses of palaeoclimate data have increased confidence in the role of external influences on climate.

- Overall consistency of evidence.

- Remaining uncertainties

Remaining uncertainties

Further improvements in models and analysis techniques have led to increased confidence in the understanding of the influence of external forcing on climate since the TAR. However, estimates of some radiative forcings remain uncertain, including aerosol forcing and inter-decadal variations in solar forcing.

Better understanding of instrumental and proxy climate records, and climate model improvements, have increased confidence in climate model-simulated internal variability. However, uncertainties remain. For example, there are apparent discrepancies between estimates of ocean heat content variability from models and observations. Uncertainties in the radiosonde and satellite records still affect confidence in estimates of the anthropogenic contribution to tropospheric temperature change.

Incomplete global data sets and remaining model uncertainties still restrict understanding of changes in extremes and attribution of changes to causes, although understanding of changes in the intensity, frequency and risk of extremes has improved.