Climate Change Basics:
Science, Adaptation, & Mitigation with a Family Forest Perspective

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Outline

- What do we know, and how well (WG1)? Tree Studies
- What can we do? (Adapt (WG2), Mitigate (WG3), Both (Synergy!))
- What's the role of adaptation? What about managed adaptation?
- How much mitigation do we need? How do forests mitigate? How much can they do? At what cost?
- AFF Perspective: What research can help family forests adapt and mitigate profitably/sustainably?

Throughout, I will draw heavily on IPCC 2007: WG1, WG2, WG3, and Lessons Learned from AR4 (Doherty et al., 09) and Bierbaum's Pinchot Lecture

From Bierbaum ('09)

Climate Change: What do we know?

- **Past is not prologue…and the pace of change is quickening**
  - Infrastructure and natural resource management and planning based on the last 100 years of climate will be wrong
  - Design features of infrastructure and tolerances of species will be exceeded
- **Committed to further climate changes**
  - Adaptation is occurring, even if unplanned
- **Degree of warming matters**
  - Mitigation makes a difference
- **Its not just the averages that matter…**
  - Regional and local variances; seasonal changes; Extreme events
- **Need a Portfolio Approach**:
  - Adaptation and Mitigation—but there are interlinkages across the two!
- **Adaptive Management is needed**
  - In all sectors and regions
- **Investment is not commensurate with the urgency of the problem…**
  - Need integrative regional assessments involving stakeholders
  - Need prioritization of needs, not laundry lists
  - Need transformational not evolutionary change

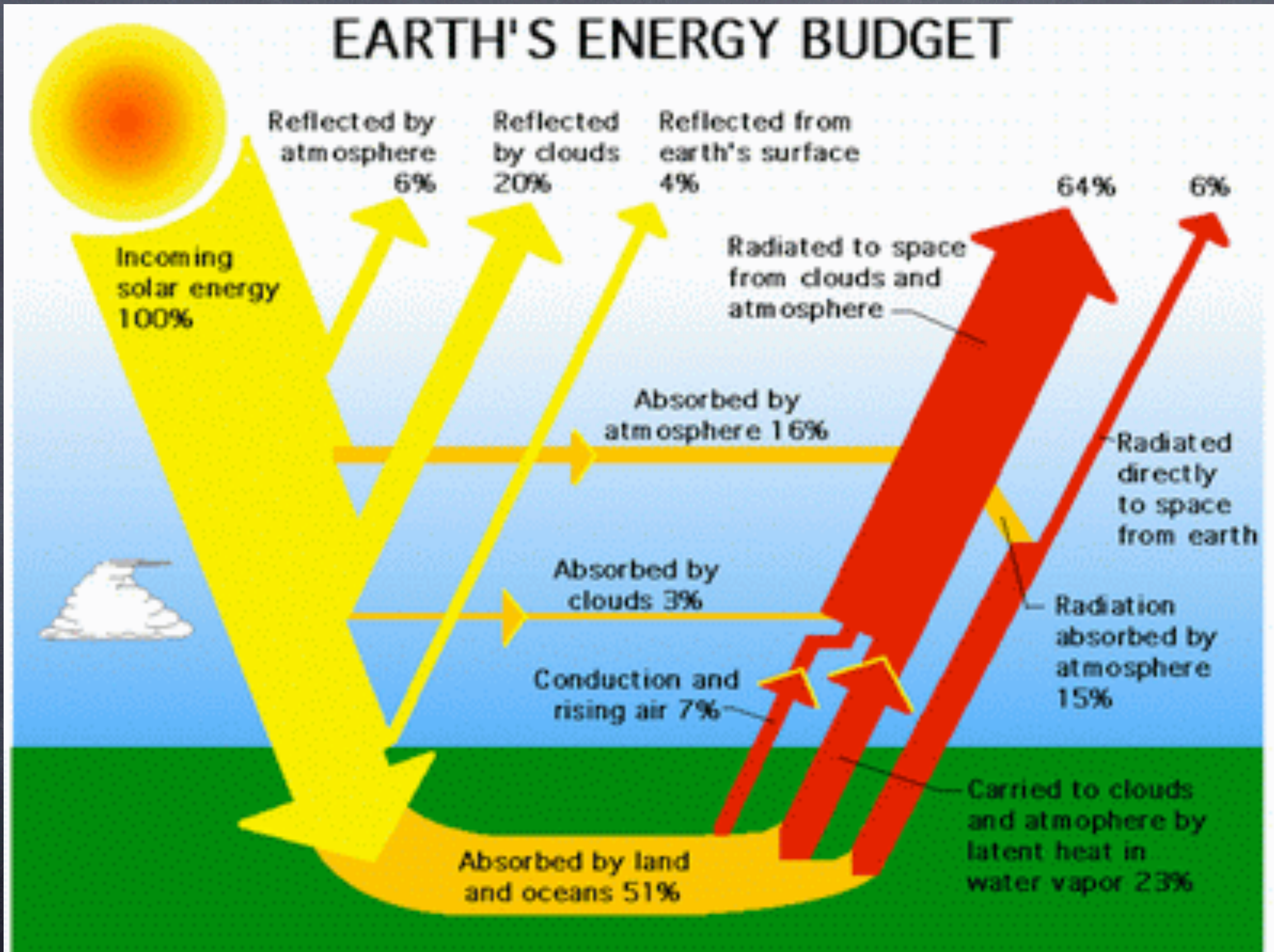
WGI: Physical Science

- Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years.

- The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture.

- The understanding of anthropogenic warming and cooling influences on climate has improved since the TAR, leading to very high confidence (9/10) that the global average 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

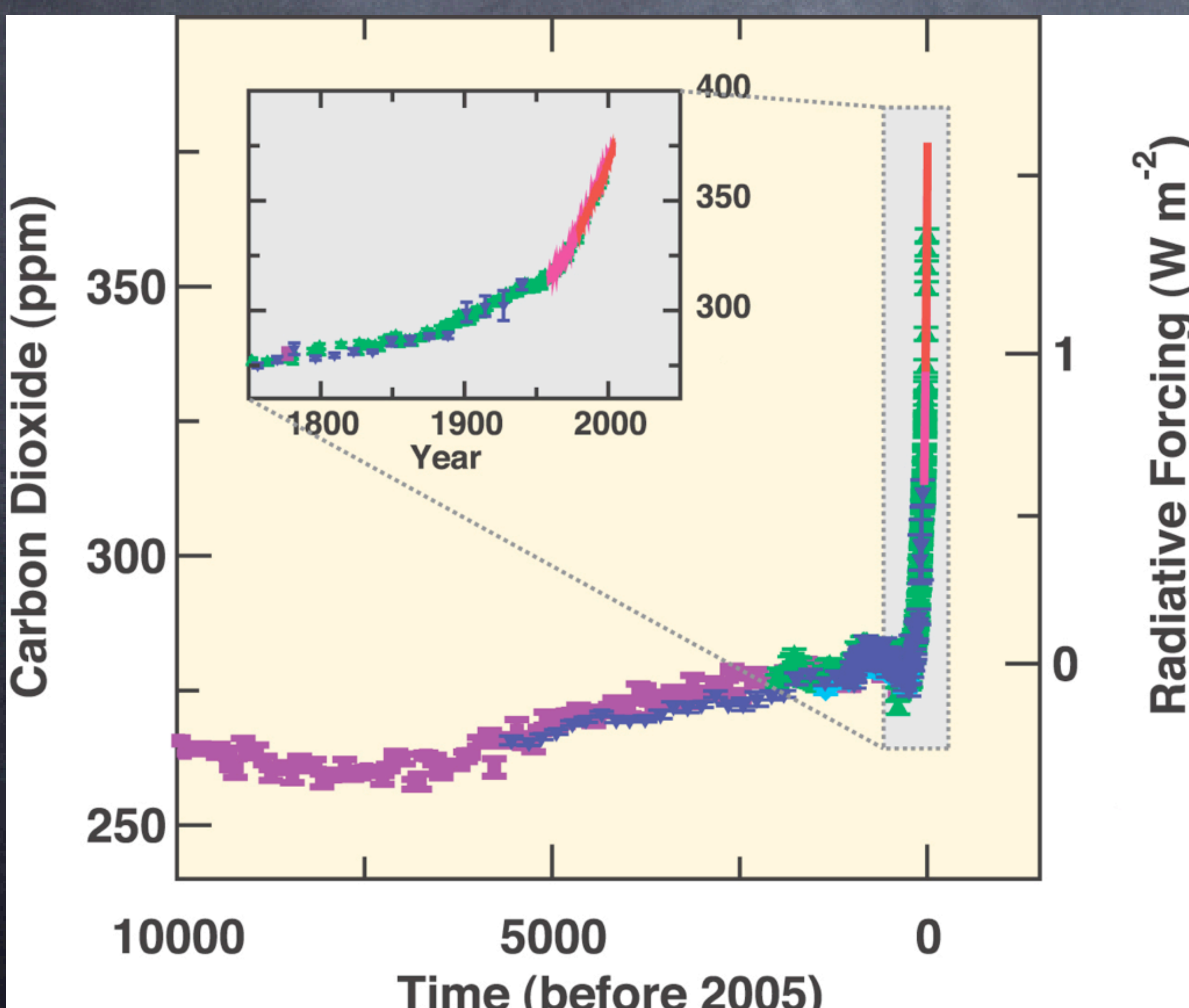
- Changes already observed to physical and biological systems are severe, and more are expected.

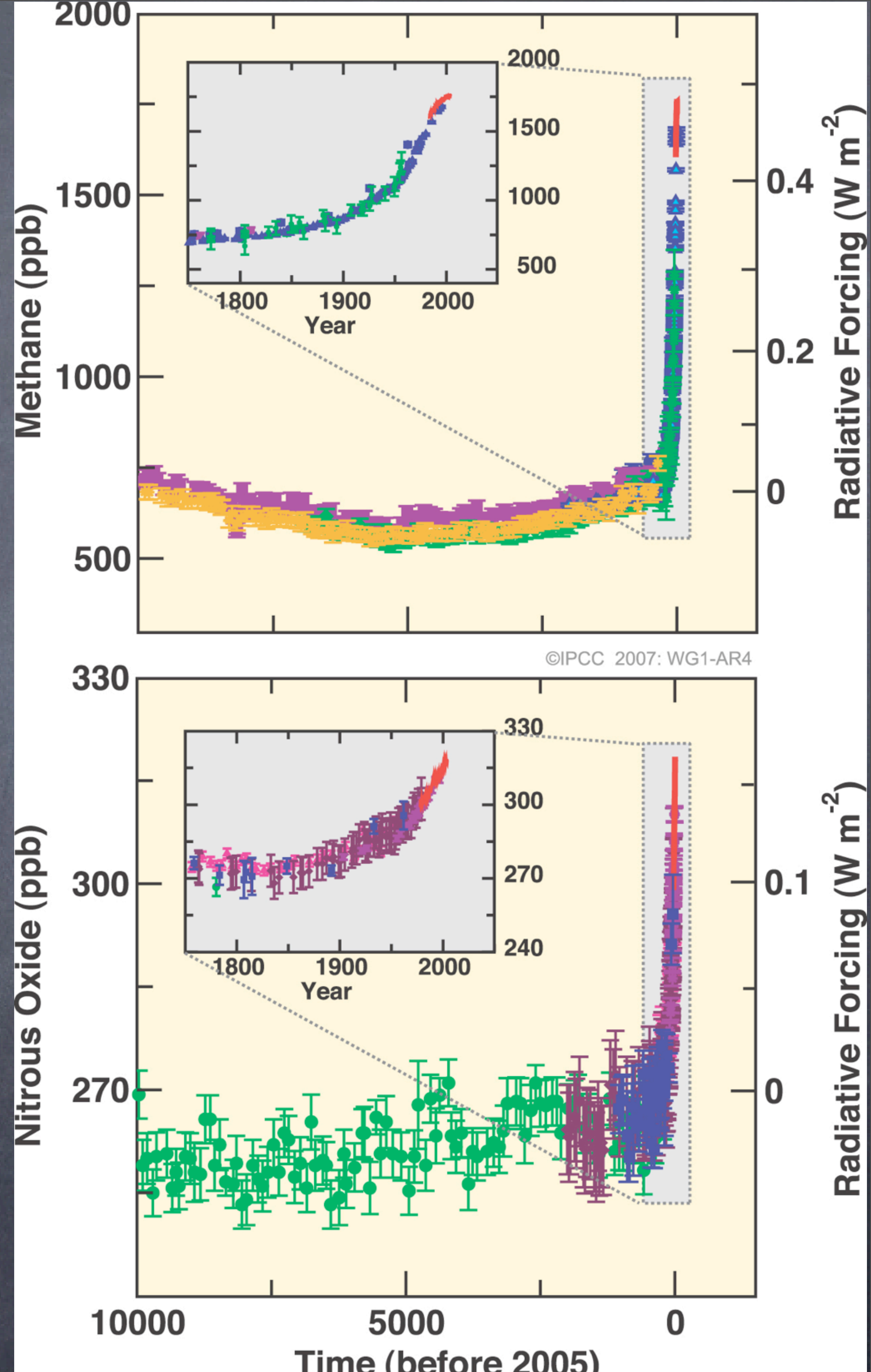

EARTH'S ENERGY BUDGET
Reflected by atmosphere 6%
Reflected by clouds 20%
Reflected from earth's surface 4%
64%
6%
Incoming solar energy 100%
Radiated to space from clouds and atmosphere
Absorbed by atmosphere 16%
Radiated directly to space from earth
Absorbed by clouds 3%
Radiation absorbed by atmosphere 15%
Conduction and rising air 7%
Carried to clouds and atmophere by latent heat in water vapor 23%
Absorbed by land and oceans 51%

Credit:NASA

10,000 yrs of Greenhouse Gas History

(Ice Cores, IPCC 07)





Going back even farther...

Ice cores from permanent ice pack (e.g., Antartica) allow us to see back more than one ice-age cycle.

The present GHG concentration in the atmosphere exceeds that over the past 650,000 yrs.

>10%/decade at present rates

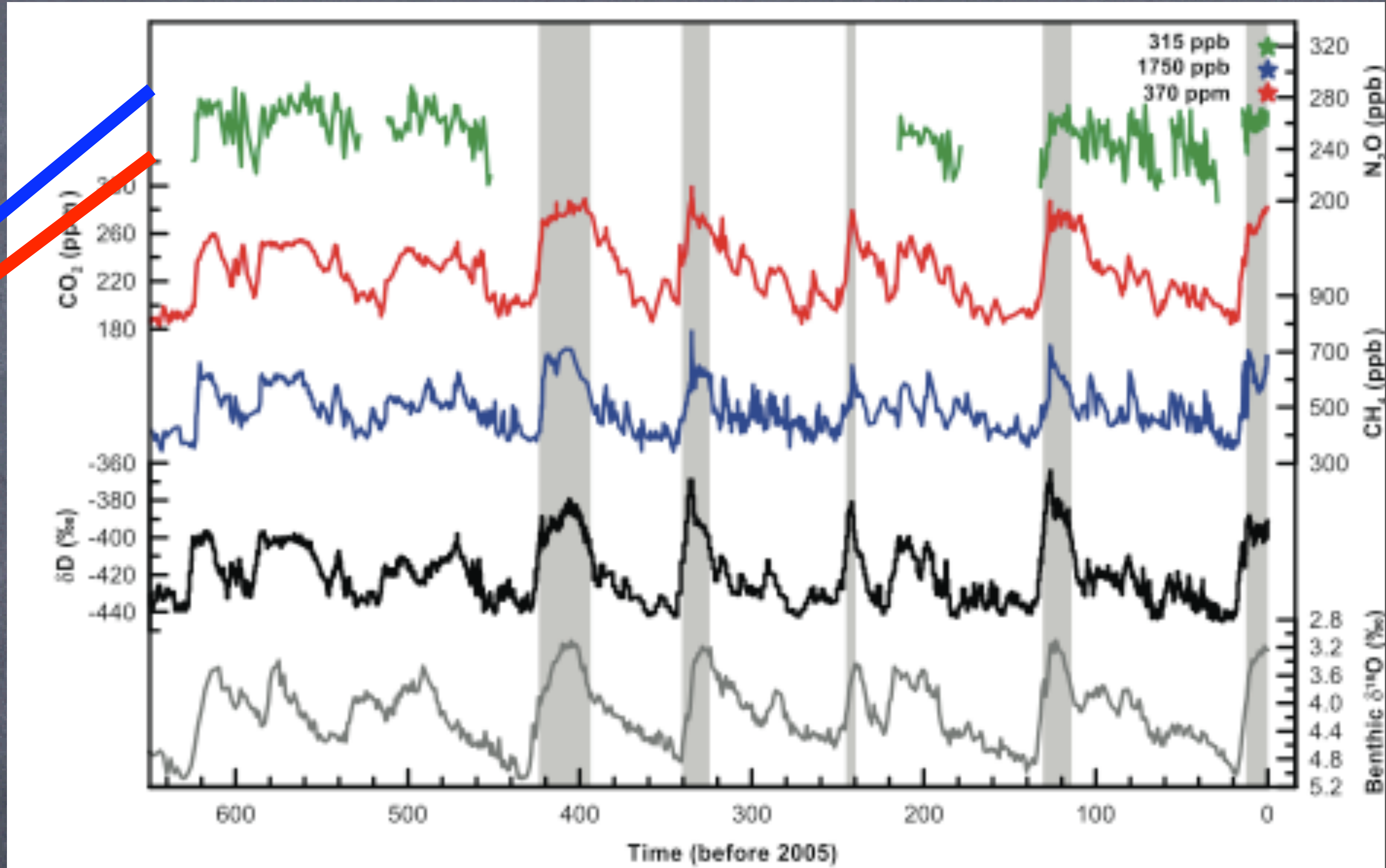
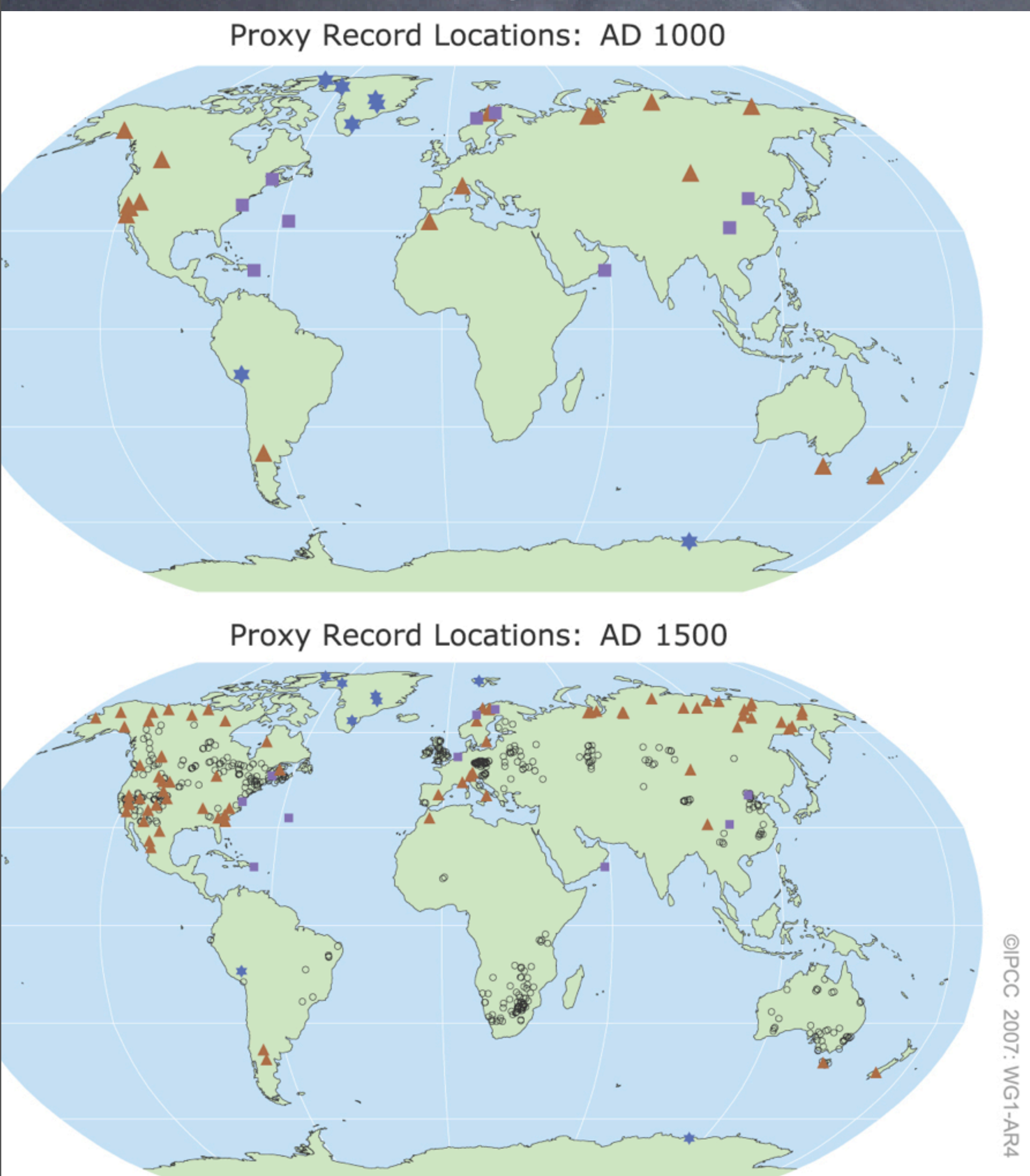


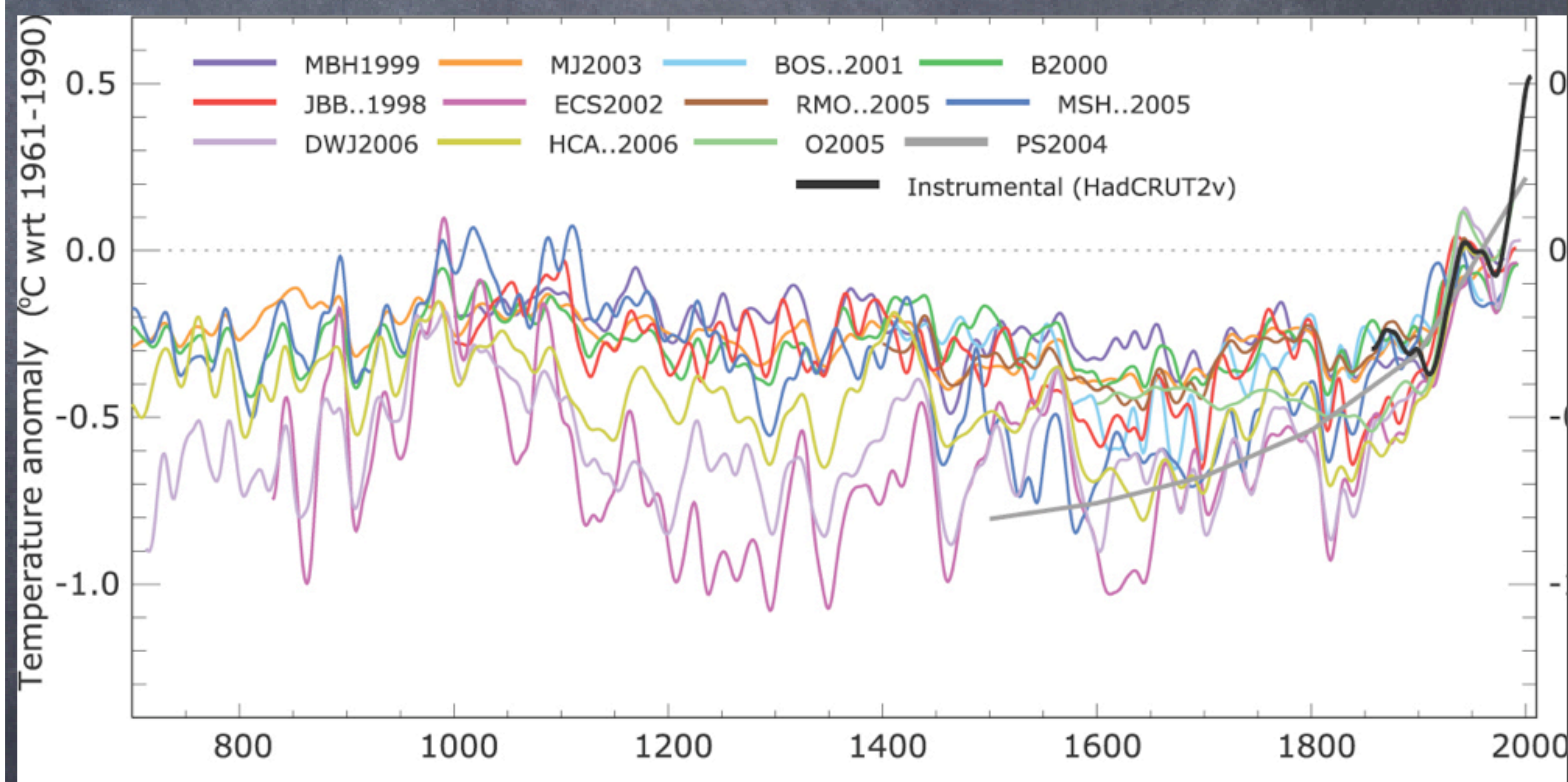
Figure 6.3. *Variations of deuterium (δD; black), a proxy for local temperature, and the atmospheric concentrations of the greenhouse gases CO_2 (red), CH_4 (blue), and ni oxide (N_2O; green) derived from air trapped within ice cores from Antarctica and from recent atmospheric measurements (Petit et al., 1999; Indermühle et al., 2000; EPICA munity members, 2004; Spahni et al., 2005; Siegenthaler et al., 2005a,b). The shading indicates the last interglacial warm periods. Interglacial periods also existed prior t ka, but these were apparently colder than the typical interglacials of the latest Quaternary. The length of the current interglacial is not unusual in the context of the last 65 The stack of 57 globally distributed benthic $\delta^{18}O$ marine records (dark grey), a proxy for global ice volume fluctuations (Lisiecki and Raymo, 2005), is displayed for compa with the ice core data. Downward trends in the benthic $\delta^{18}O$ curve reflect increasing ice volumes on land. Note that the shaded vertical bars are based on the ice core ag model (EPICA community members, 2004), and that the marine record is plotted on its original time scale based on tuning to the orbital parameters (Lisiecki and Raymo, The stars and labels indicate atmospheric concentrations at year 2000.*

Holocene Paleoclimate & Tree Rings

Triangles=Tree Record

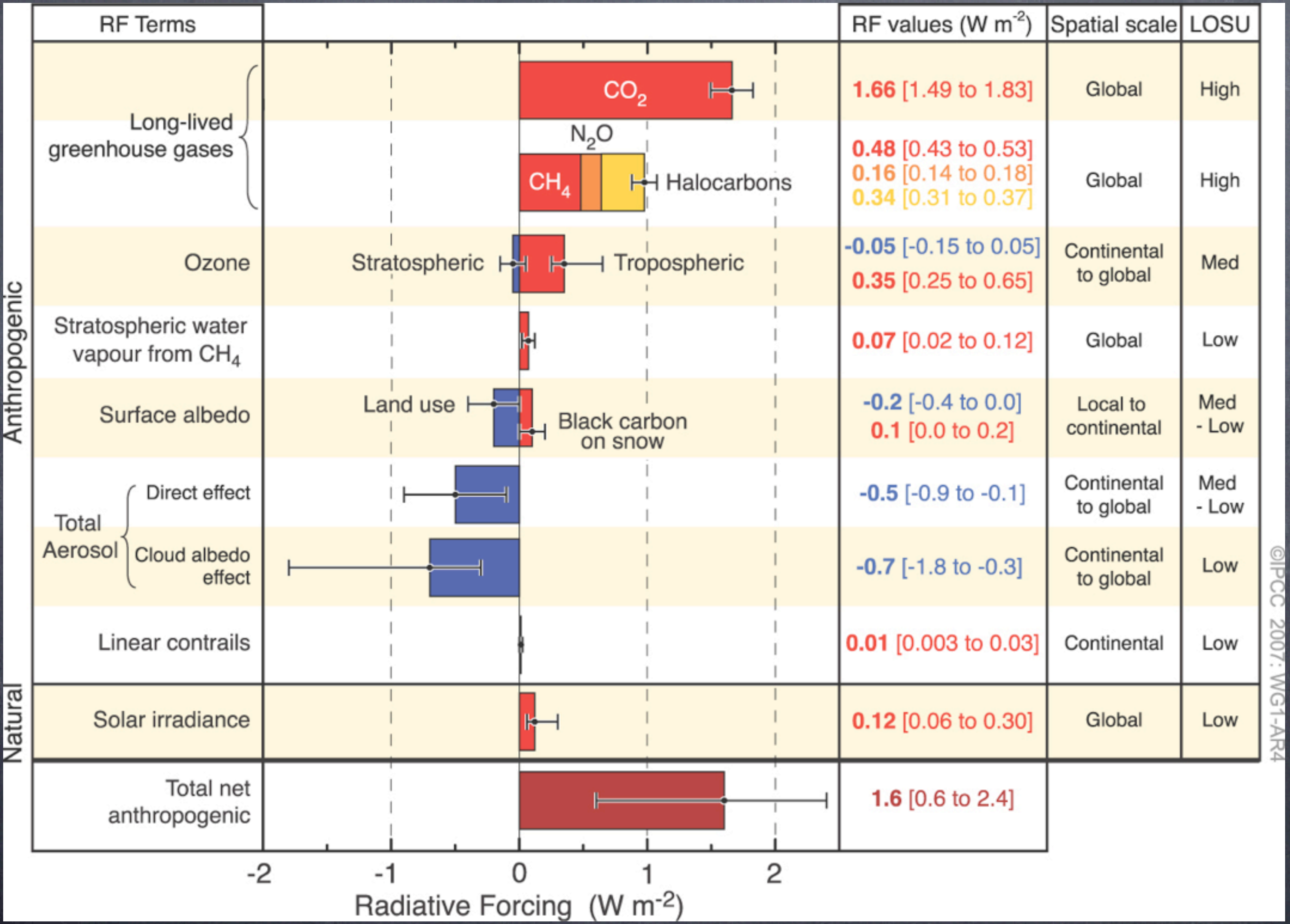
- Dating Accuracy diminishes with time--Tree Rings are often the most accurate (IPCC WGI)
- Networks of tree ring widths and densities can be used to infer climate patterns
- Temperature, moisture, solar variations, etc., detectable from tree records





Tree Rings show recent warming largest is 1000yr (IPCC 07)

Radiative Forcing Components



Cause is Radiative Imbalance, Anthropogenic Big.

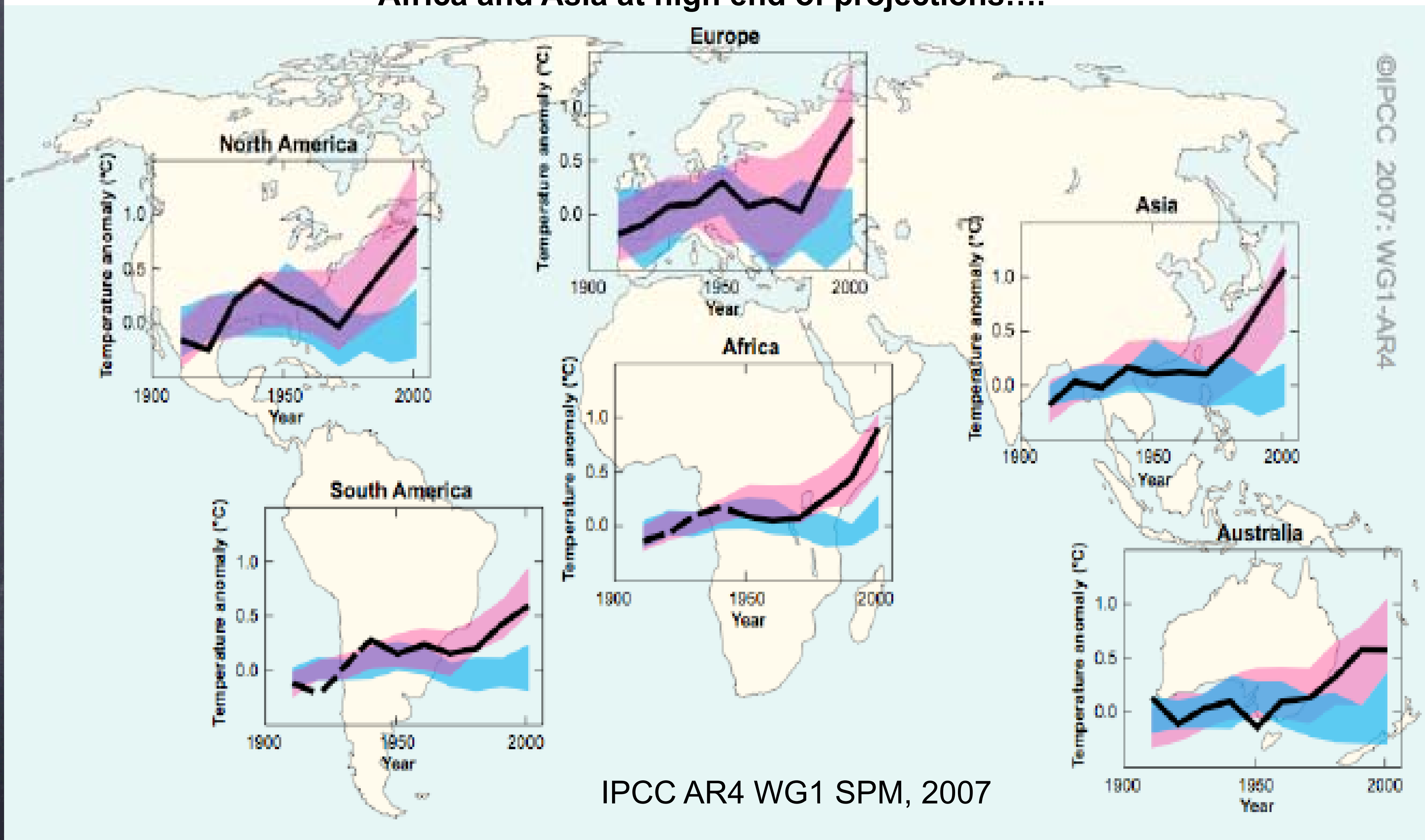
But, Feedbacks are Important!

- The most powerful greenhouse gas is water vapor (about 30 W/m^2).
- We do not directly control water vapor, but as the planet warms from other ghg, more water vapor builds up
- So, the primary climate effect is indirect--a small change to the part we dominate sets off changes in natural systems.

Computer models allow us to understand our impact.
Model uncertainty is large, but smaller than uncertainty about our actions (scenario forecasts)

Computer models match observed ΔT on all continents -

Africa and Asia at high end of projections….



Black lines are decadally averaged observations. Blue bands are computer models with natural forcings only. Pink bands are computer models with human + natural forcings.

Models still deficient

- Clouds & Aerosols
- Land Ice
- Ocean Eddies
- Seasonal/Diurnal Cycles
- Ecosystem Feedbacks
- AR5&6 models will improve all these

From Stine et al. '09

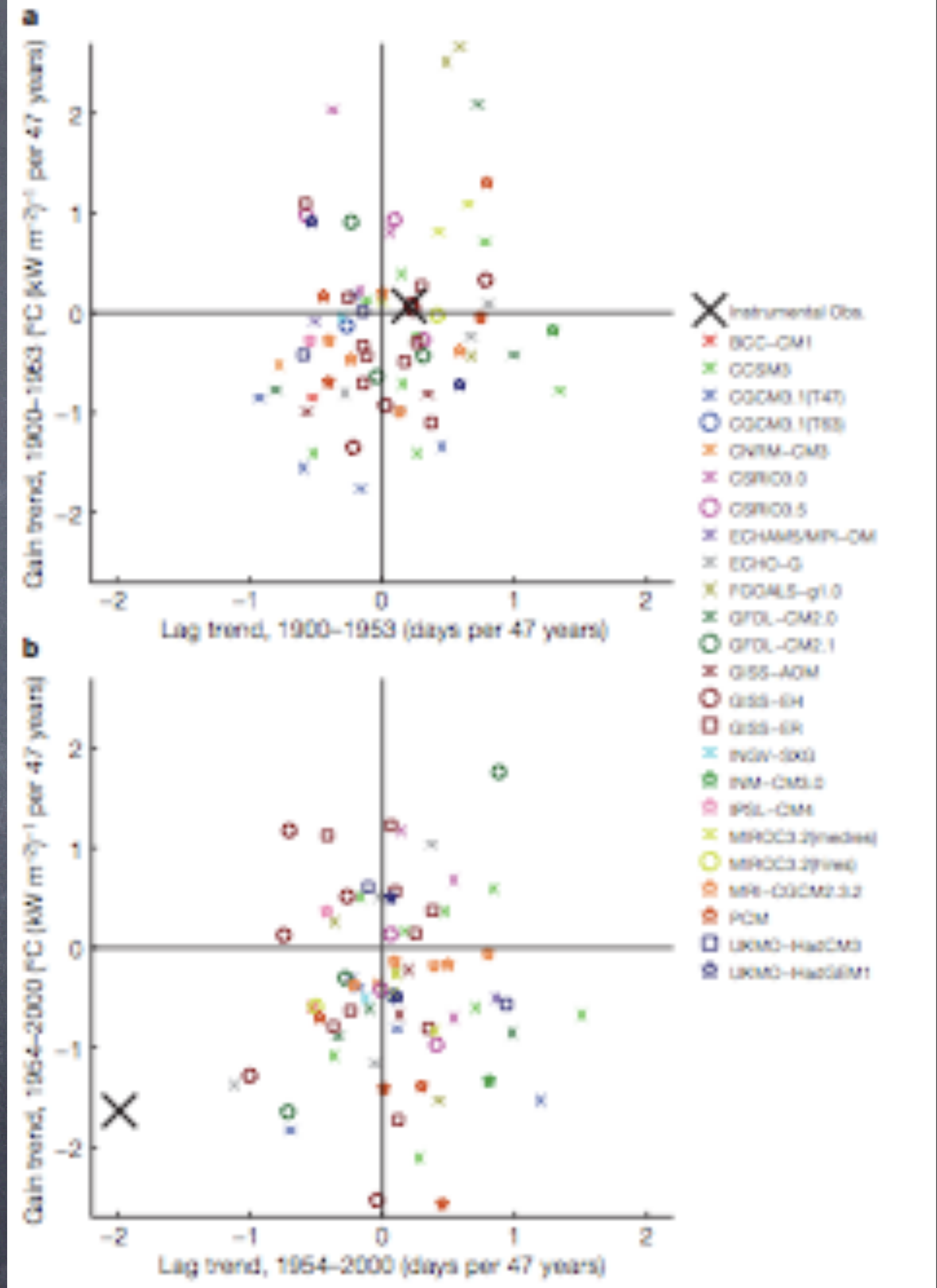
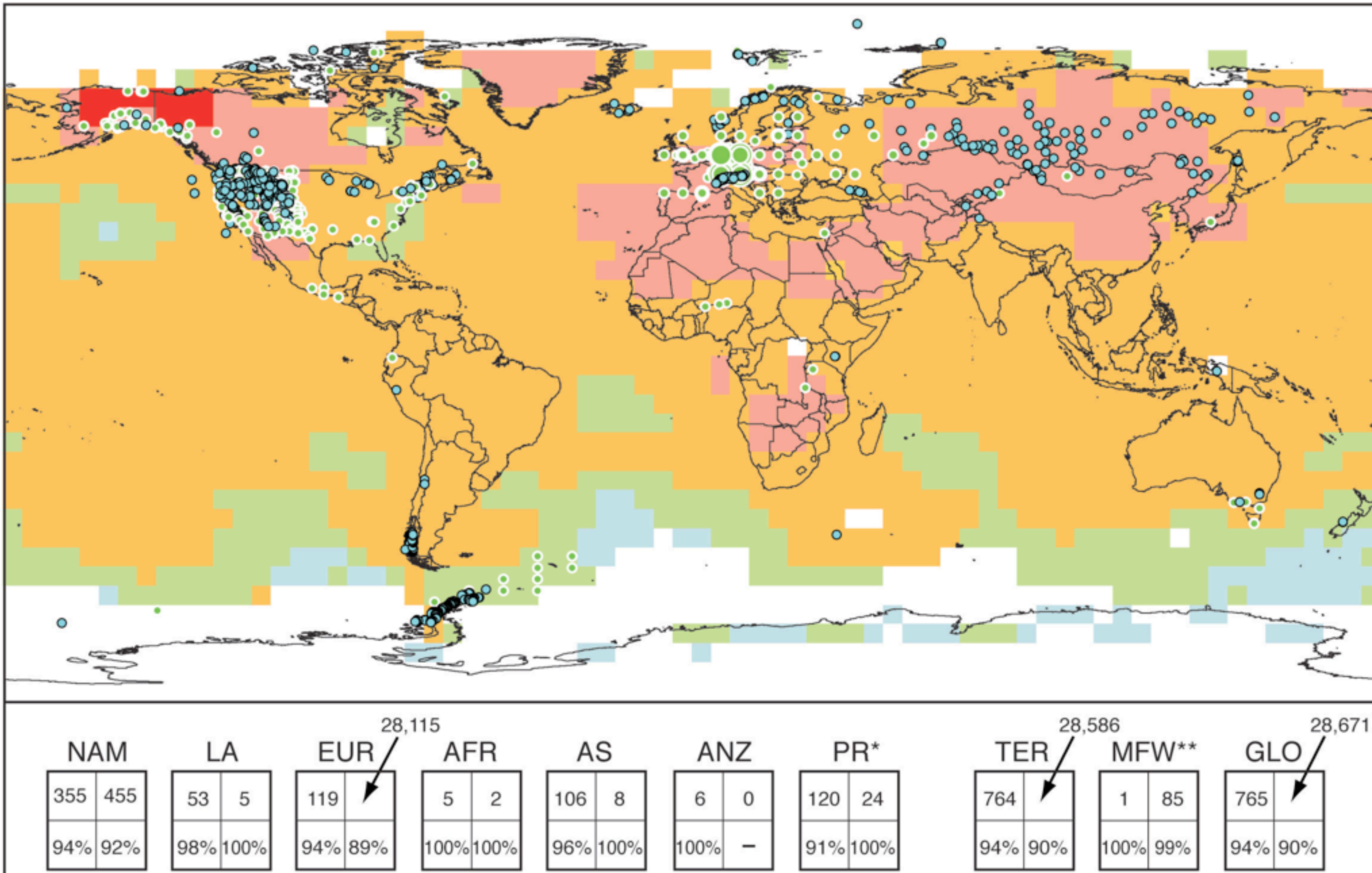


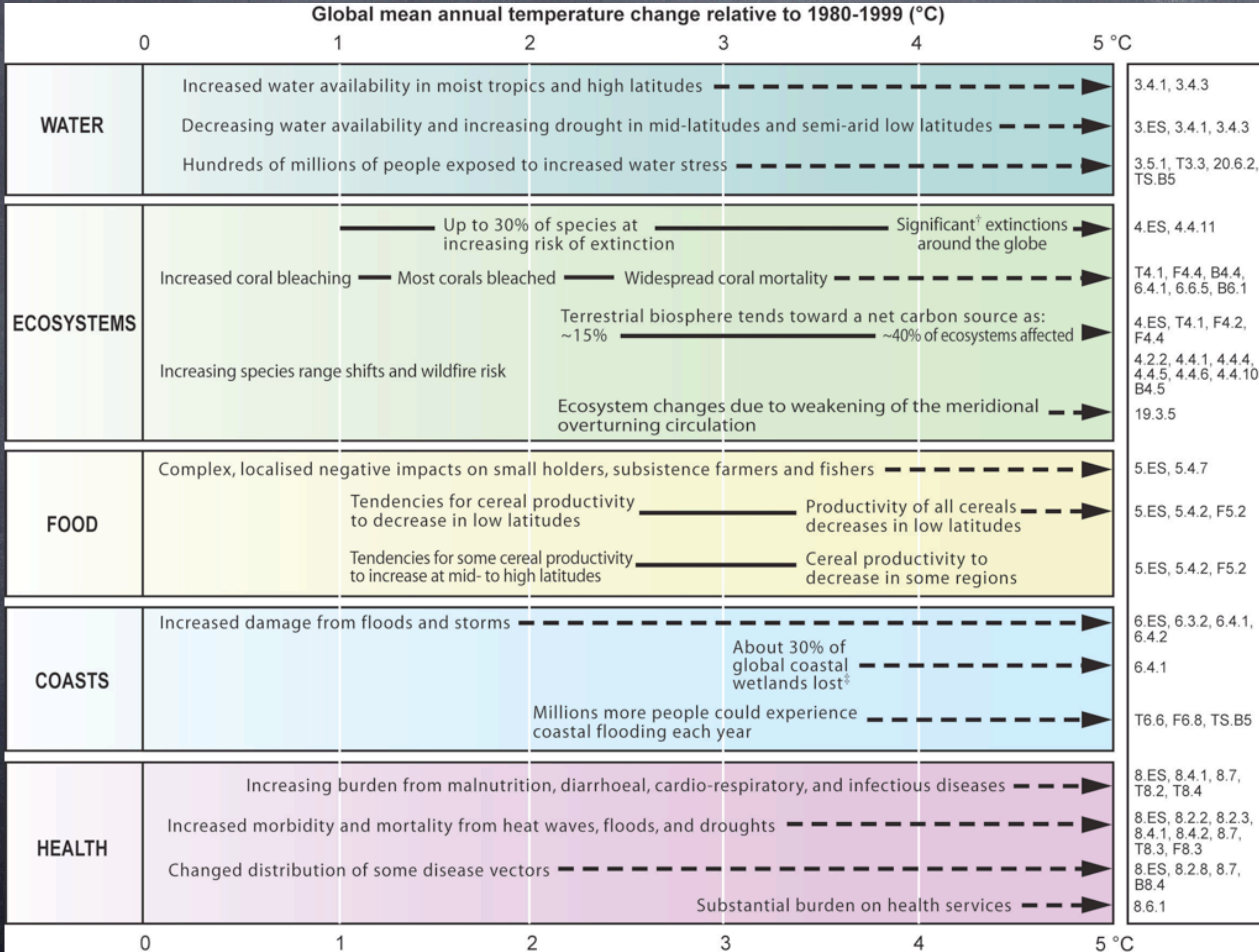
Figure 3 | Modelled and observed mean land trends. a, Observed

How bad is it now?

Changes in physical and biological systems and surface temperature 1970-2004



How bad will it be? Depends.



WGII, Adaptation: Managed Forest Adaptation

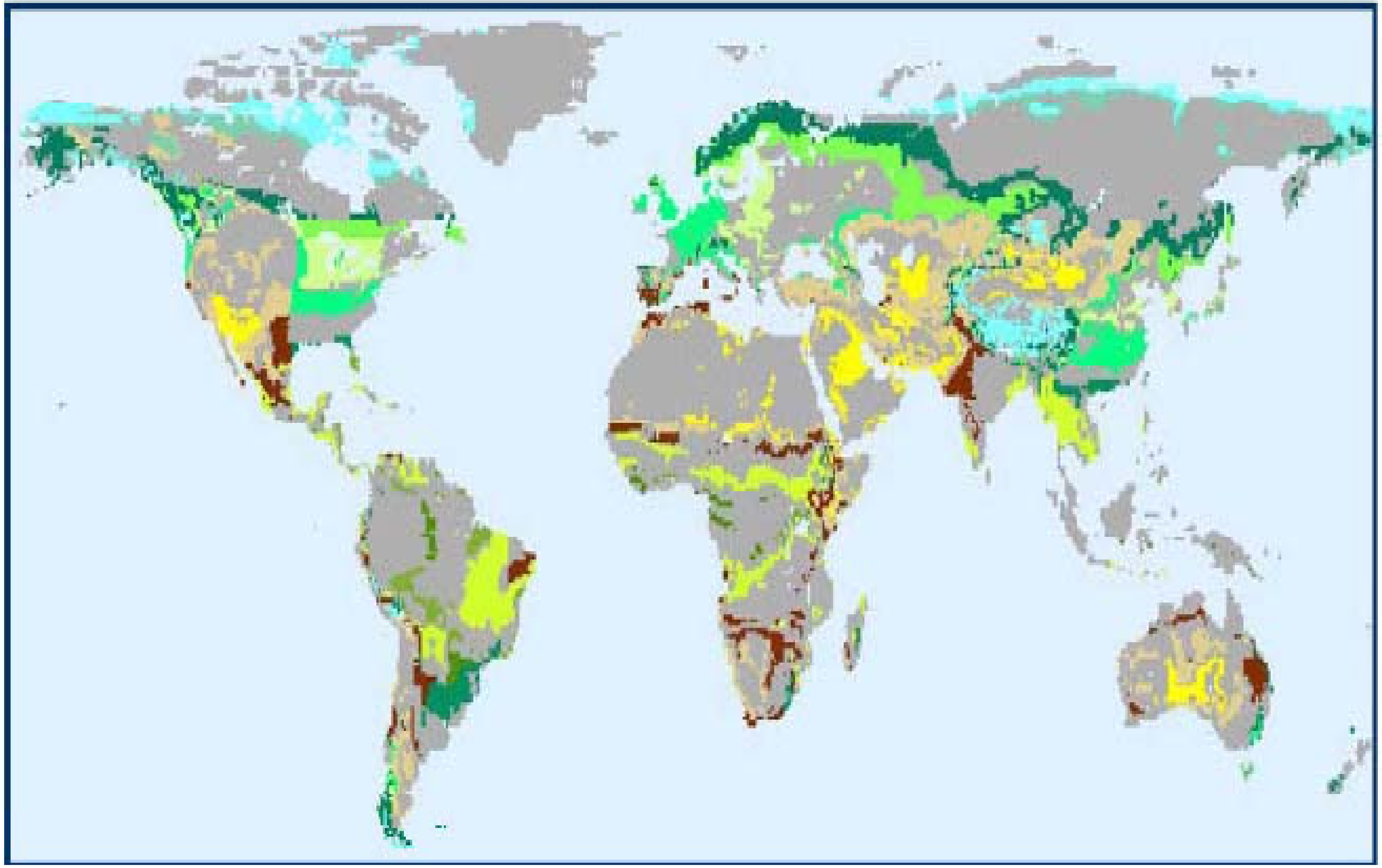
- Some climate change is unavoidable, so what should we do to adapt and prepare?
- Temperature Change
- Hydrological Change
- Forest fires, etc.

Managed Adaptation & Relocation

- Hoegh-Guldberg et al, Science 2008.

Managed Adaptation & Relocation

Where we're headed: ecosystem shifts



Shifts in ecosystems for a 3 degree C increase.

green=forests; brown = grasslands; yellow=deserts

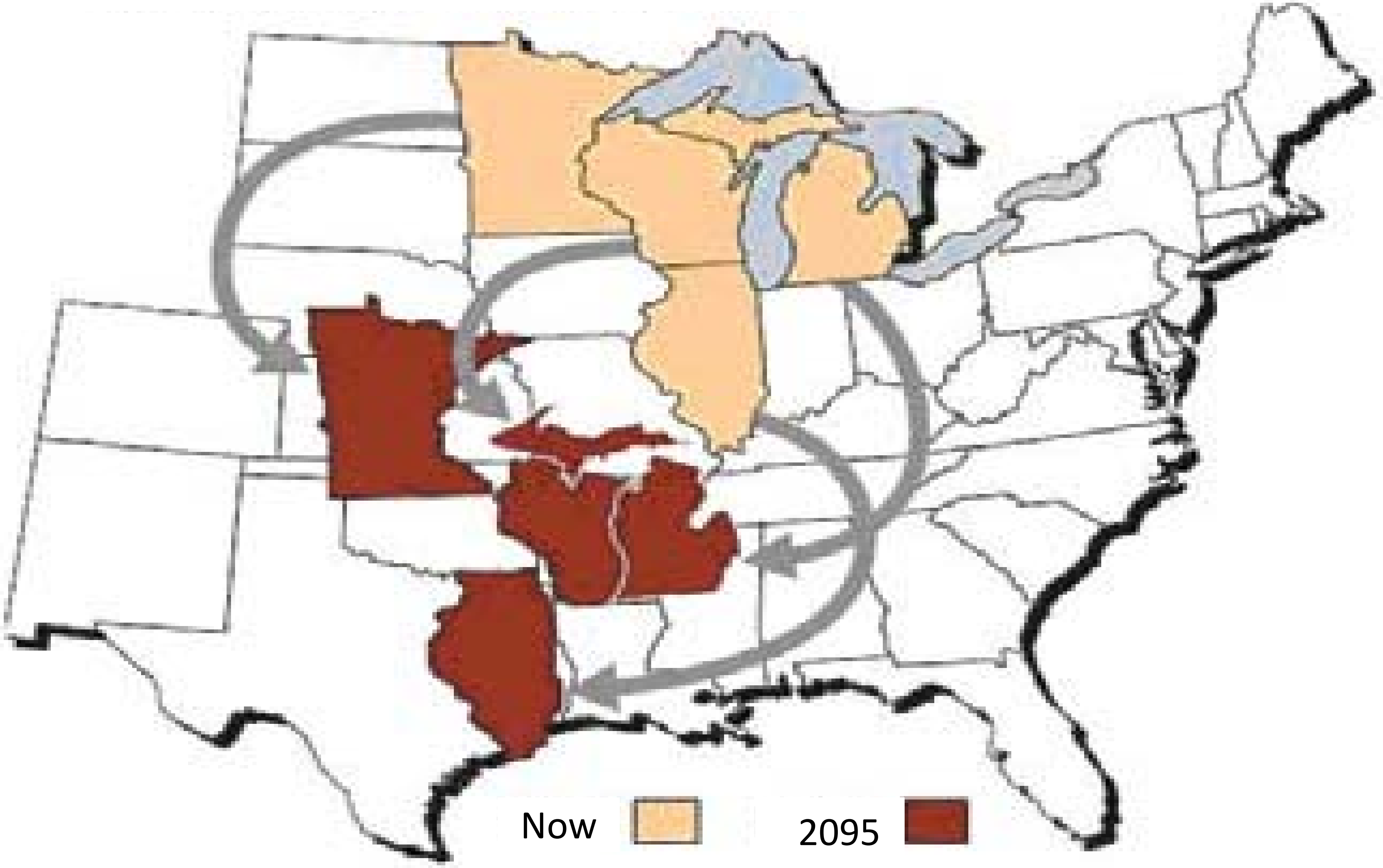
Source: Leemans and Eickhout, Global Environmental Change, 2004

Managed Adaptation & Relocation

Roughly 2 timber generations away, need to change species when replanting soon!

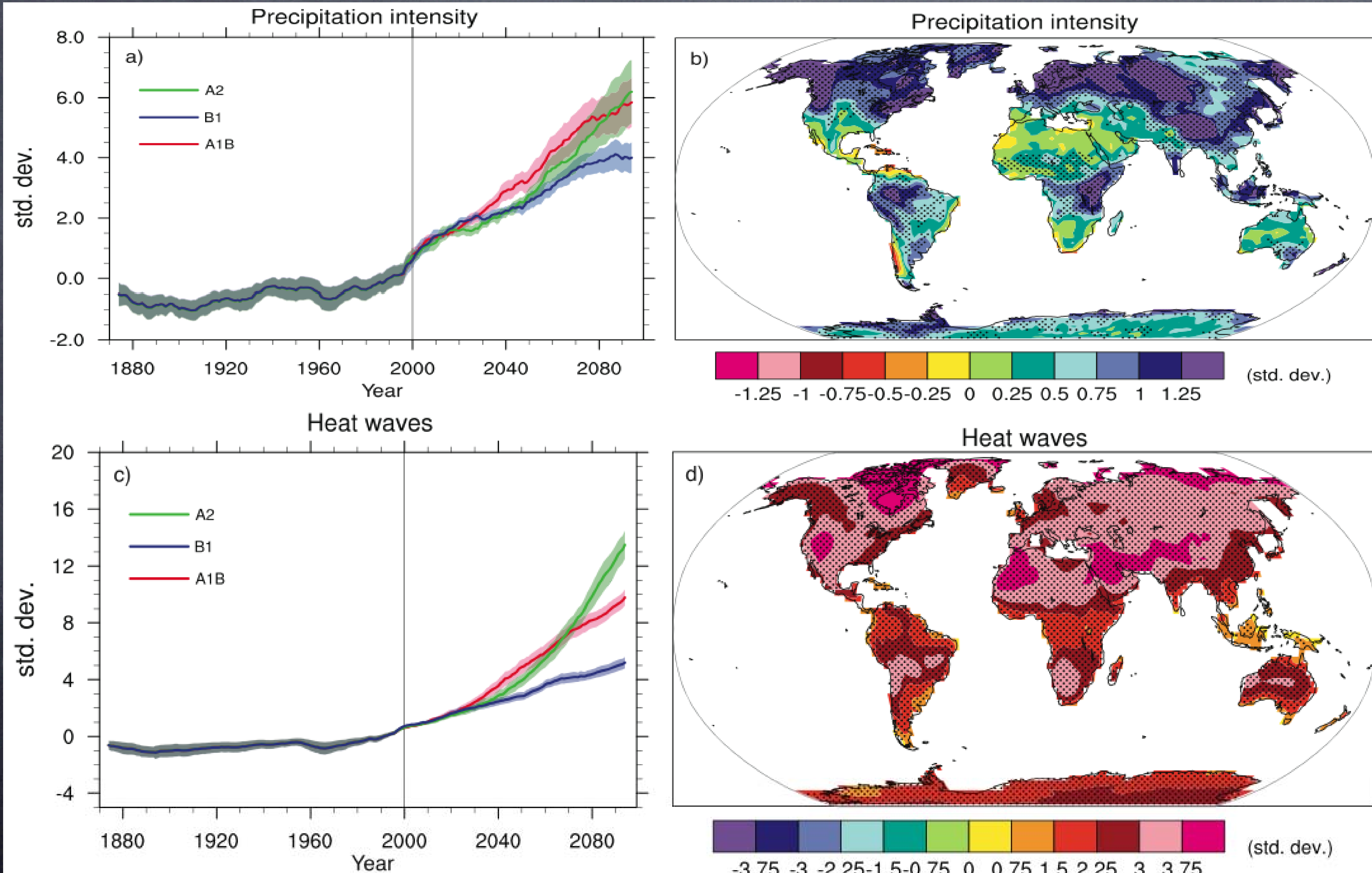
Climate on the Move:

Changing summers in the Midwest



U.S. Climate Change Science Program Draft Unified Synthesis Product Report, NOAA 2008.

Managed Adaptation & Relocation: Need more extreme-resilience, too.



WGII: Adapting Forests

Food, fibre and forest products

Crop productivity is projected to increase slightly at mid- to high latitudes for local mean temperature increases of up to 1-3°C depending on the crop, and then decrease beyond that in some regions. * D [5.4]

At lower latitudes, especially seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1-2°C), which would increase the risk of hunger. * D [5.4]

Globally, the potential for food production is projected to increase with increases in local average temperature over a range of 1-3°C, but above this it is projected to decrease. * D [5.4, 5.6]

Increases in the frequency of droughts and floods are projected to affect local crop production negatively, especially in subsistence sectors at low latitudes. ** D [5.4, 5.ES]

Adaptations such as altered cultivars and planting times allow low- and mid- to high-latitude cereal yields to be maintained at or above baseline yields for modest warming. * N [5.5]

Globally, commercial timber productivity rises modestly with climate change in the short- to medium-term, with large regional variability around the global trend. * D [5.4]

Regional changes in the distribution and production of particular fish species are expected due to continued warming, with adverse effects projected for aquaculture and fisheries. ** D [5.4]

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];

Planting times, species can help adapt.

Impacts and choices are highly regional.

WGII: Regional Forests

Amazon: Droughts change Forest to Savanna

By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America. ** D [13.4]

Australia: Droughts and heat waves

Production from agriculture and forestry by 2030 is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in western and southern areas and close to major rivers due to a longer growing season, less frost and increased rainfall. ** N [11.4]

Central Europe: Droughts and heat waves

In Central and Eastern Europe, summer precipitation is projected to decrease, causing higher water stress. Health risks due to heatwaves are projected to increase. Forest productivity is expected to decline and the frequency of peatland fires to increase. ** D [12.4]

N. Europe: may benefit

In Northern Europe, climate change is initially projected to bring mixed effects, including some benefits such as reduced demand for heating, increased crop yields and increased forest growth. However, as climate change continues, its negative impacts (including more frequent winter floods, endangered ecosystems and increasing ground instability) are likely to outweigh its benefits. ** D [12.4]

WGII: N. American Forests

West: Overstressed Water, increased Pests & Fires

North America

Warming in western mountains is projected to cause decreased snowpack, more winter flooding, and reduced summer flows, exacerbating competition for over-allocated water resources. *** D [14.4, B14.2]

Disturbances from pests, diseases and fire are projected to have increasing impacts on forests, with an extended period of high fire risk and large increases in area burned. *** N [14.4, B14.1]

Moderate climate change in the early decades of the century is projected to increase aggregate yields of rain-fed agriculture by 5-20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilised water resources. ** D [14.4]

East: changes to water, species, but overall may be beneficial.

North: changes to water, but longer growing overall may be beneficial.

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems [4.4, 5.4]	Water resources [3.4]	Human health [8.2, 8.4]	Industry, settlement and society [7.4]
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	Virtually certain[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snow melt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g., algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially-isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	Likely	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortages for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	Likely	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers, potential for population migrations, loss of property
Increased incidence of extreme high sea level (excludes tsunamis)[c]	Likely[d]	Salinisation of irrigation water, estuaries and freshwater systems	Decreased freshwater availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

WGIII, Mitigation: Role of Forests

- Carbon Sink/Source by Afforestation/ Deforestation. Biomass burning!
- Aerosols & Air Quality Impact
- Albedo, Permafrost, etc.

PERSPECTIVE

Managing Forests for Climate Change Mitigation

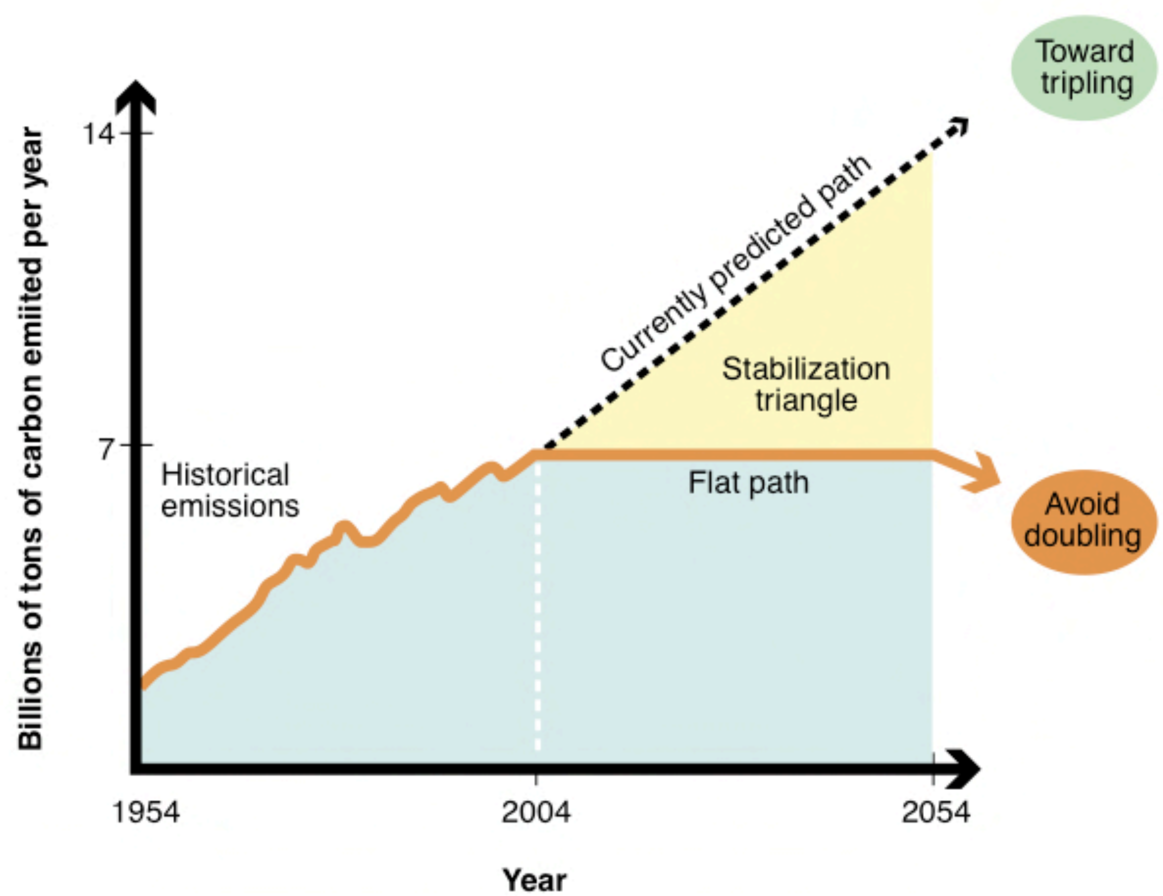
Josep G. Canadell* and Michael R. Raupach

Forests currently absorb billions of tons of CO_2 globally every year, an economic subsidy worth hundreds of billions of dollars if an equivalent sink had to be created in other ways. Concerns about the permanency of forest carbon stocks, difficulties in quantifying stock changes, and the threat of environmental and socioeconomic impacts of large-scale reforestation programs have limited the uptake of forestry activities in climate policies. With political will and the involvement of tropical regions, forests can contribute to climate change protection through carbon sequestration as well as offering economic, environmental, and sociocultural benefits. A key opportunity in tropical regions is the reduction of carbon emissions from deforestation and degradation.

13th June, 2008

How Much Mitigation Needed?
7 "Wedges"=7 GtC/yr

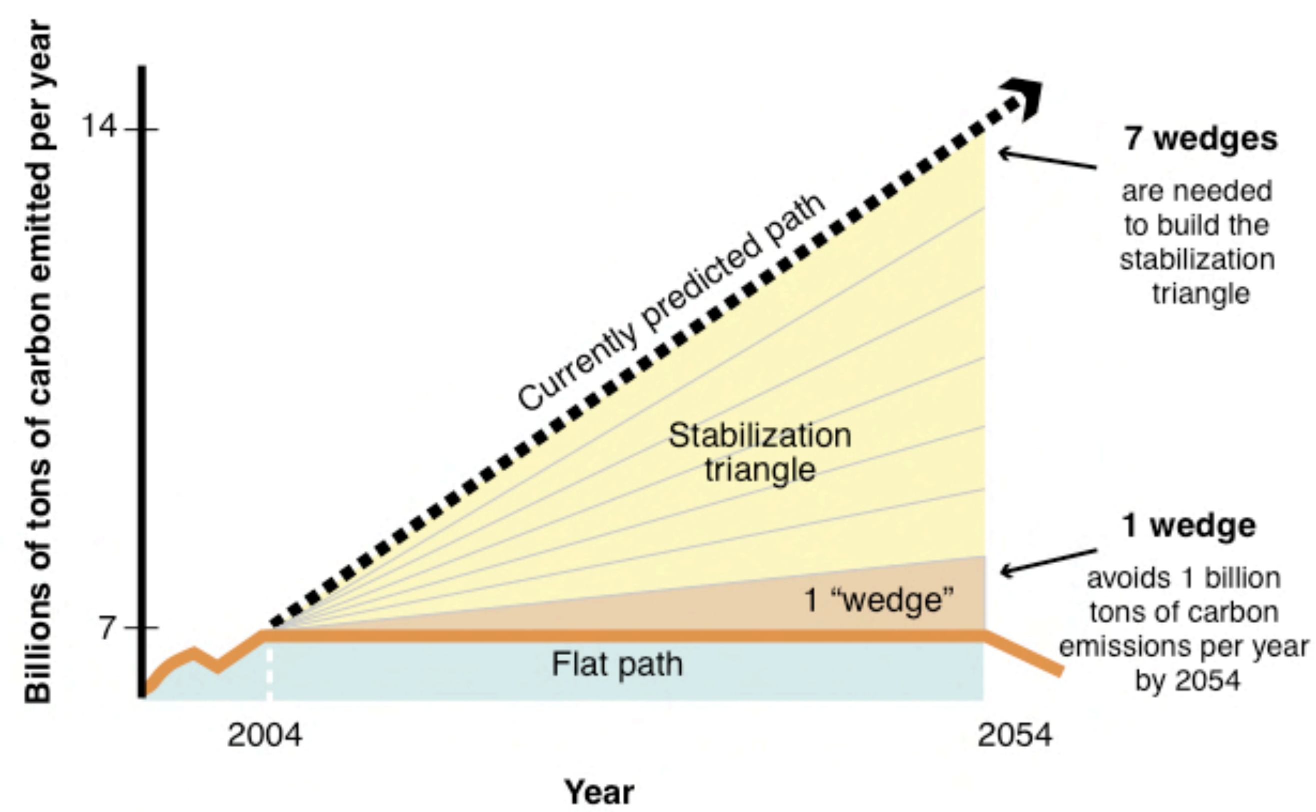
Figure 1a. Historical carbon emissions with two potential pathways for the future



NOTE: Our currently predicted path (dotted black line) will probably lead to at least a tripling of atmospheric carbon dioxide (CO_2) relative to its preindustrial concentration, while keeping emissions flat (solid line) would put us on track to avoid a doubling of CO_2.

SOURCE: R. Socolow, R. Hotinski, J. B. Greenblatt, and S. Pacala.

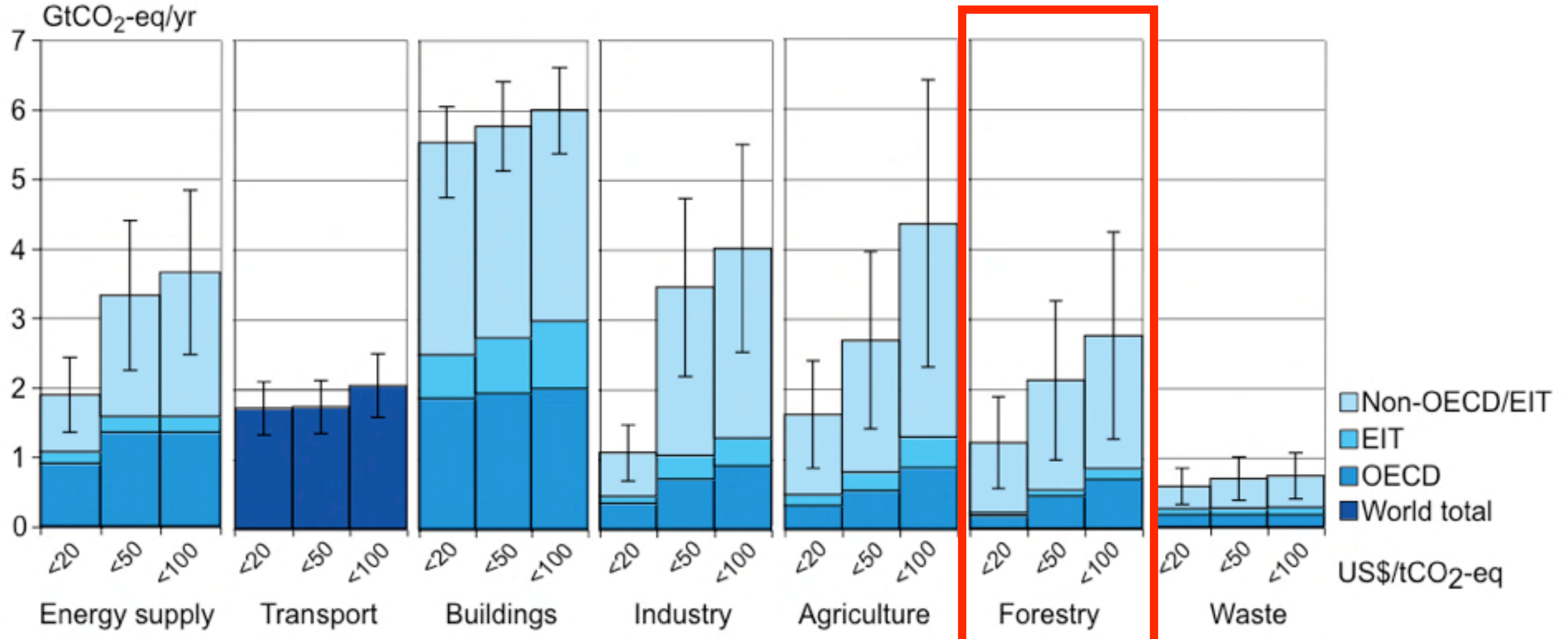
Figure 1b. Stabilization wedges



NOTE: The stabilization triangle in Figure 1a can be divided into seven equal "wedges" that represent activities capable of reducing one billion tons of carbon per year by 2054.

SOURCE: R. Socolow, R. Hotinski, J. B. Greenblatt, and S. Pacala.

Forests as Mitigation:
2 Wedges at < $100/ton?



(potential at <US$100/ tCO_2-eq: 2.4 - 4.7 Gt CO_2-eq/yr)	*(potential at <US$100/ tCO_2-eq: 1.6 - 2.5 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 5.3 -6.7 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 2.5 - 5.5 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 2.3 -6.4 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 1.3 - 4.2 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 0.4 - 1 Gt CO_2-eq/yr)*

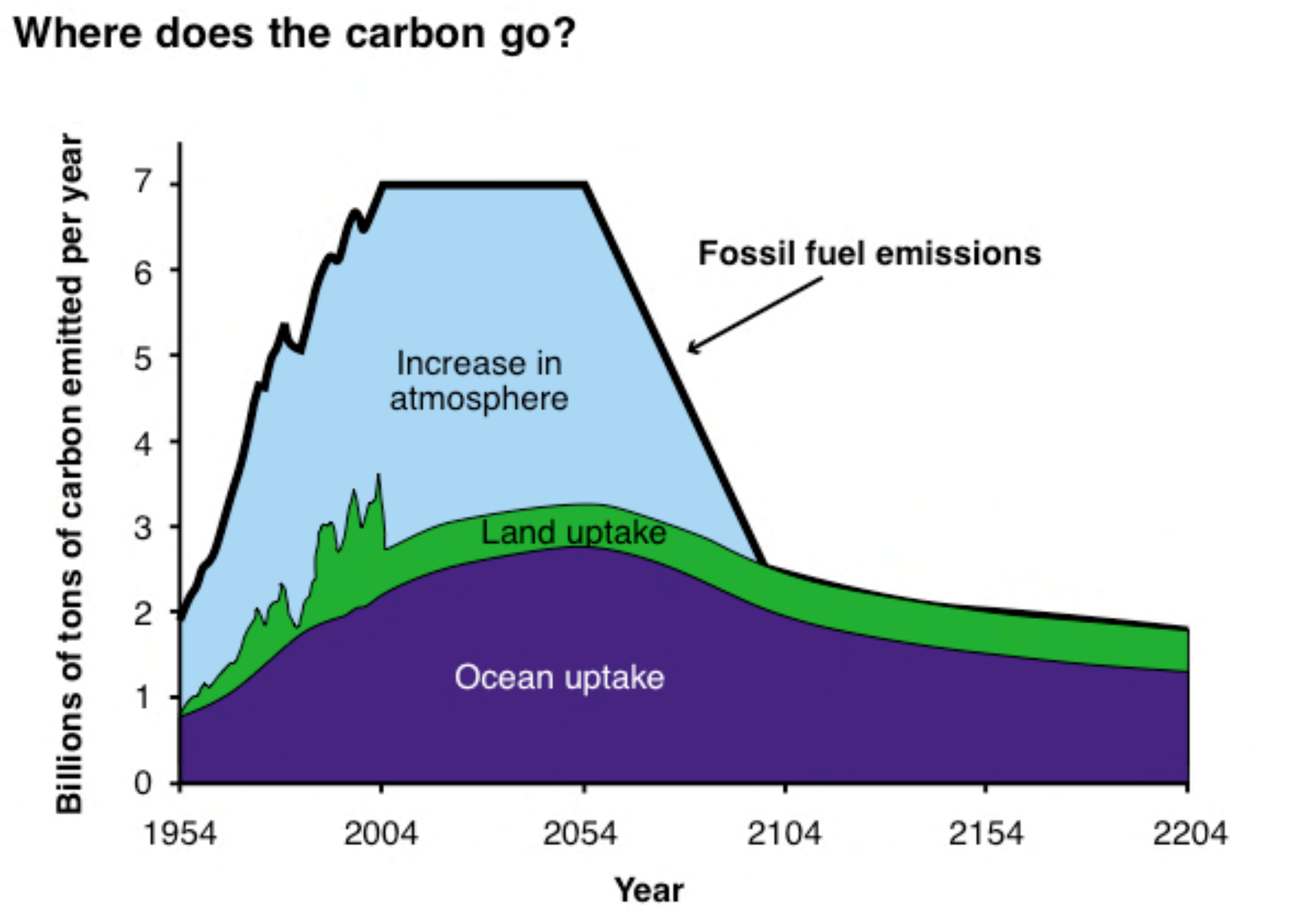
Figure SPM.6: *Estimated sectoral economic potential for global mitigation for different regions as a function of carbon price in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments. A full explanation of the derivation of this figure is found in Section 11.3.*

To stabilize:

Crucial transient uptake by land.

Permanent uptake, too.

Afforestation helps transient uptake.



NOTE: Shown are total fossil fuel emissions (thick black line), atmospheric increase (light blue), land uptake (green), and ocean uptake (dark blue). The atmospheric increase is the difference between fossil-fuel emissions and ocean and land sinks. The ocean sink is calculated with a simple model (see source below), and the land sink is held constant after 2004 at 0.5 billion tons of carbon per year. Fossil-fuel emissions are prescribed by a 500 parts per million stabilization path with the following four components: 1954–2004: historical emissions; 2004–2054: flat path emissions, as in Figures 1a and 1b; 2054–2104: linear descent to stabilization; after 2104: stabilization. "Stabilization" means there is no further build-up of CO_2 in the atmosphere, because emissions are balanced by land and ocean sinks.

SOURCE: R. Socolow, R. Hotinski, J. B. Greenblatt, and S. Pacala. The ocean sink is calculated using a model described in U. Siegenthaler and F. Joos, "Use of a Simple Model for Studying Oceanic Tracer Distributions and the Global Carbon Cycle," *Tellus* 44B (1992): 186–207.

Aerosols & Air Quality

- "The American Petroleum Institute filed suit against the EPA [and] charged that the agency was suppressing a scientific study for fear it might be misinterpreted... The suppressed study reveals that 80 percent of air pollution comes not from chimneys and auto exhaust pipes, but from plants and trees." Presidential candidate Ronald Reagan, in 1979.
- "Trees cause more pollution than automobiles do." -- Ronald Reagan, 1981

Aerosols

Aerosol chemical processes in the environment By Květoslav Spurný, Dieter Hochrainer

AEROSOLS IN THE FOREST ATMOSPHERE

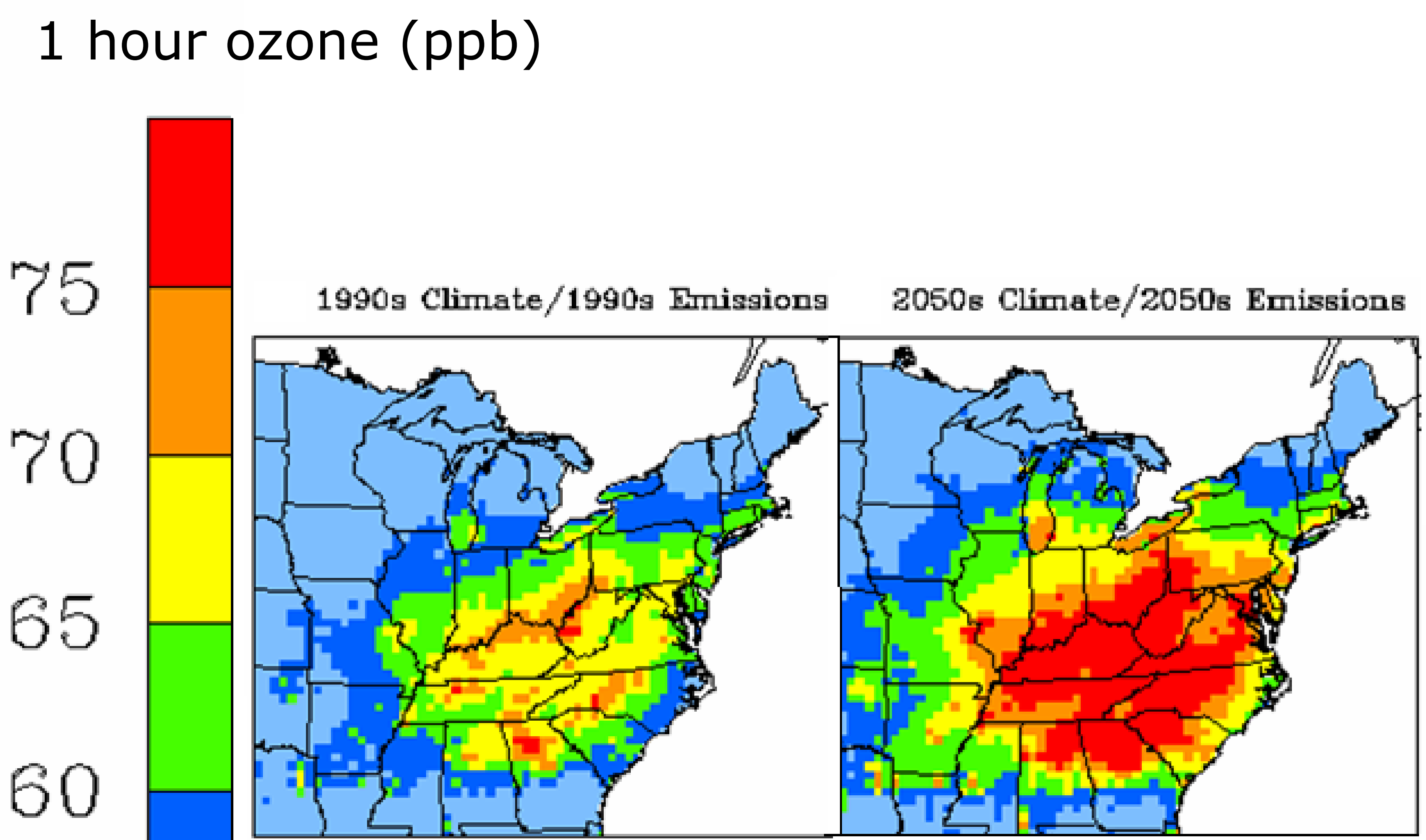
Several air pollutants, including inorganic and organic aerosols, are involved in the observed deterioration and decline of forests in Europe and North America.[60-65] The aerosols in the atmospheric environment of the forest are mainly imported into the forest areas from different industrial and automobile traffic emission sources. However, they are also produced or modified by the vegetation inside the forest atmosphere.

The forest smog periods are well-known. These are formed in the forest atmosphere by chemical and photochemical, as well as by gas-to-particle conversion, processes.[63] These aerosols — organic as well as inorganic, solid as well as liquid — are then deposited on tree leaves and needles by means of different separation mechanisms. The forest is very effective at filtering particles out of the atmosphere.[64] The physical and chemical interactions with the leaf and needle surfaces and cells are responsible for their different phytotoxic effects. Air pollutants, both gaseous and particulates, produce harmful effects on plants. The stomates are major portal entries for these pollutants. Deposited aerosol particles block the stomates and/or, after dissolution or evaporation, diffuse into plants through them. Figure 1.10 illustrates the stomates (ST) and deposited particles on spruce needles sampled in a declined forest. Changes in the physiological and biochemical parameters of the plant cell are a possible explanation for current forest diseases.

"Forest Aerosol"

Qualitatively, inorganic aerosols in the forest atmosphere differ very little from urban aerosols. The local emission sources of inorganic particulates or of their precursors in a forested area are limited. The majority of inorganic particulates are imported into the forest atmosphere from urban and industrial anthropogenic sources and are therefore already altered. Particulates of PM-2.5 constitute the most important fraction of this aerosol type. Sulfate and ammonium, especially ammonium acid sulfates, account for more than 50% of the fine-fraction mass. The acidity of a forest aerosol is higher — often much higher — than the acidity of the aerosol in urban areas. The fine aerosol fraction contains the majority of nitrates, organic and inorganic carbon, and trace metals. On needles and leaves, deposited trace metals are involved in microbial metabolism. The capacity of foliage

Linkage Between Climate and Air Quality

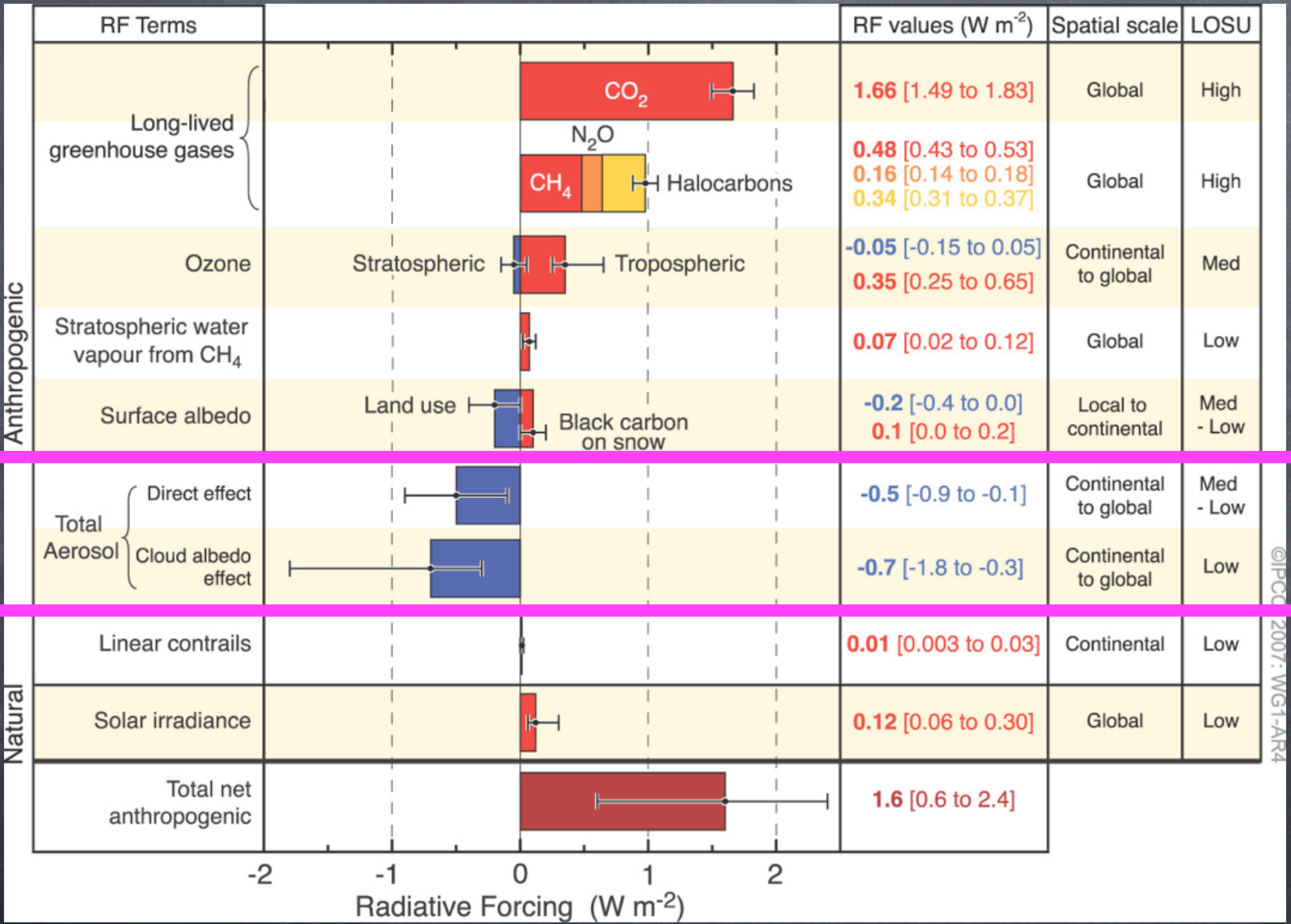


Impact on
Ozone Formation
of
Changes in Climate
vs.
Changes in
Emissions

New York Climate & Health Project

Understanding changes in air and forests' role/response is an important adaptation/mitigation consideration

Radiative Forcing Components



Much of the total uncertainty is due to aerosols.

Albedo, Permafrost, etc.

- Some carbon storage in forests may be offset in radiation balance by changes to albedo (snow->forest in particular). However, in most locations net gains outweigh losses.
- Huge amounts of carbon & methane may be released by melting permafrost (and other soil changes). The role of forests, afforestation, etc. in this process is important to understand.

What Research to Support? (Broad Federal Agenda)

Restructuring Federal Climate Research to Meet the Challenges of Climate Change

released 2/25/09

- Restructure the program around integrated scientific-societal issues
- Establish a US climate observing system with physical, biological, and social observations
- Support a new generation of coupled Earth-system models
- Strengthen research on adaptation, mitigation, and vulnerability
- Initiate a national assessment process with broad stakeholder participation
- Coordinate federal efforts to provide climate services routinely to decision makers

From Bierbaum '09

What Research to Support? (Some Gaps Persist)

From Bierbaum '09

NRC Report on CCSP* (9/12/07)

- Understanding and predicting physical climate change is progressing well
- Declining observing capability
- Inadequate human dimensions funding:
  - $30 million; lack of collaboration
- Inadequate progress
  - in assessing impacts on human well being and vulnerabilities
  - in providing knowledge to support decision making and risk analyses
  - in communicating results and engaging stakeholders in a two-way dialogue

**Evaluating Progress of the US CCSP Program: Methods & Preliminary Results*

What Research to Support? (May be some federal $$ forthcoming)

CLIMATE SECURITY ACT
(Lieberman-Warner Bill)

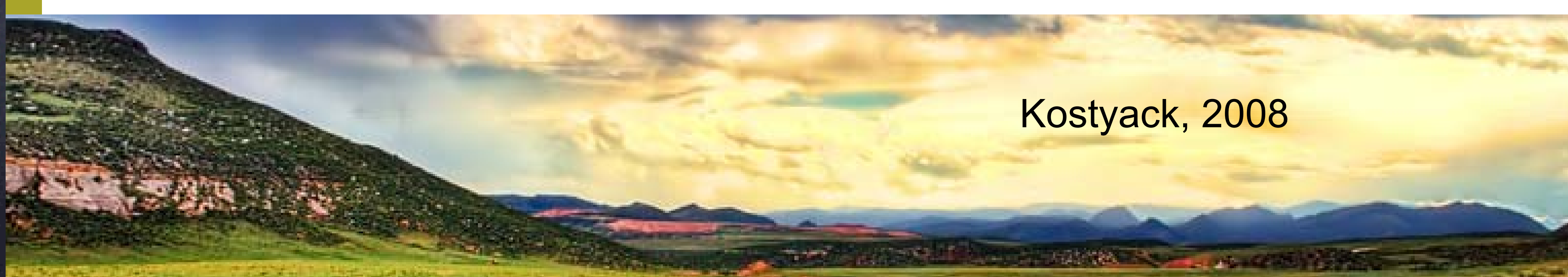
- 2 Percent Annual Reductions in GHGs

- Investment in U.S. Forests and Soils

  Sequestration: ***$115B Through 2030***

- Investment in U.S. Natural Resources

  Adaptation: ***$137B Through 2030***



Kostyack, 2008

From Bierbaum '09

LESSONS LEARNED FROM IPCC AR4

Scientific Developments Needed To Understand, Predict, And Respond To Climate Change

BY SARAH J. DOHERTY, STEPHAN BOJINSKI, ANN HENDERSON-SELLERS, KEVIN NOONE, DAVID GOODRICH, NATHANIEL L. BINDOFF, JOHN A. CHURCH, KATHY A. HIBBARD, THOMAS R. KARL, LUCKA KAJFEZ-BOGATAJ, AMANDA H. LYNCH, DAVID E. PARKER, I. COLIN PRENTICE, VENKATACHALAM RAMASWAMY, ROGER W. SAUNDERS, MARK STAFFORD SMITH, KONRAD STEFFEN, THOMAS F. STOCKER, PETER W. THORNE, KEVIN E. TRENBERTH, MICHEL M. VERSTRAETE, AND FRANCIS W. ZWIERS

Two fundamental classes of recommendations emerged from this process as follows:

1) **Improved process-level understanding, climate models, observations of climate-relevant parameters and climate monitoring systems are needed in specific areas.**
2) **Because some degree of climate change is virtually certain (IPCC 2007a), additional efforts are needed to make climate information more relevant to decisions concerning impacts, adaptation and mitigation.**

LESSONS LEARNED FROM IPCC AR4

Scientific Developments Needed To Understand, Predict, And Respond To Climate Change

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- #1: Improved Climate Modeling (including Land!)
- #2: 10-30yr Forecasts (will benefit forestry if metrics in place)
- #3: Regional Forecasts (will benefit forestry if metrics in place)
- #5: Regional impacts of sensitive systems needed
- #6: A systematic approach to vulnerability needed (incl. forests)
- #7: Scenarios for land use needed (incl. forest changes)
- #8: Observations of hydrology changes (forest role and impact)
- #10: Carbon cycle observations (forest role and impact)
- #11: Aerosols (Forest role and impact)

My Suggested AFF Priorities

- AFF should support research into the role family forests can play in mitigation
- AFF should support afforestation and reduced deforestation
- AFF should support research into adaptation strategies as applied to family forests
- AFF should support research that clarifies the information needed by family forests, so that basic research gives answers (metrics).
- For impact beyond family forests, AFF should encourage research projects that will inform or be useful as IPCC-class studies