The Future of Precipitation: Global and Regional

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Isla Victoria International Workshops
The Future of Water
May 12, 2008

Relative Change in Demand per Discharge

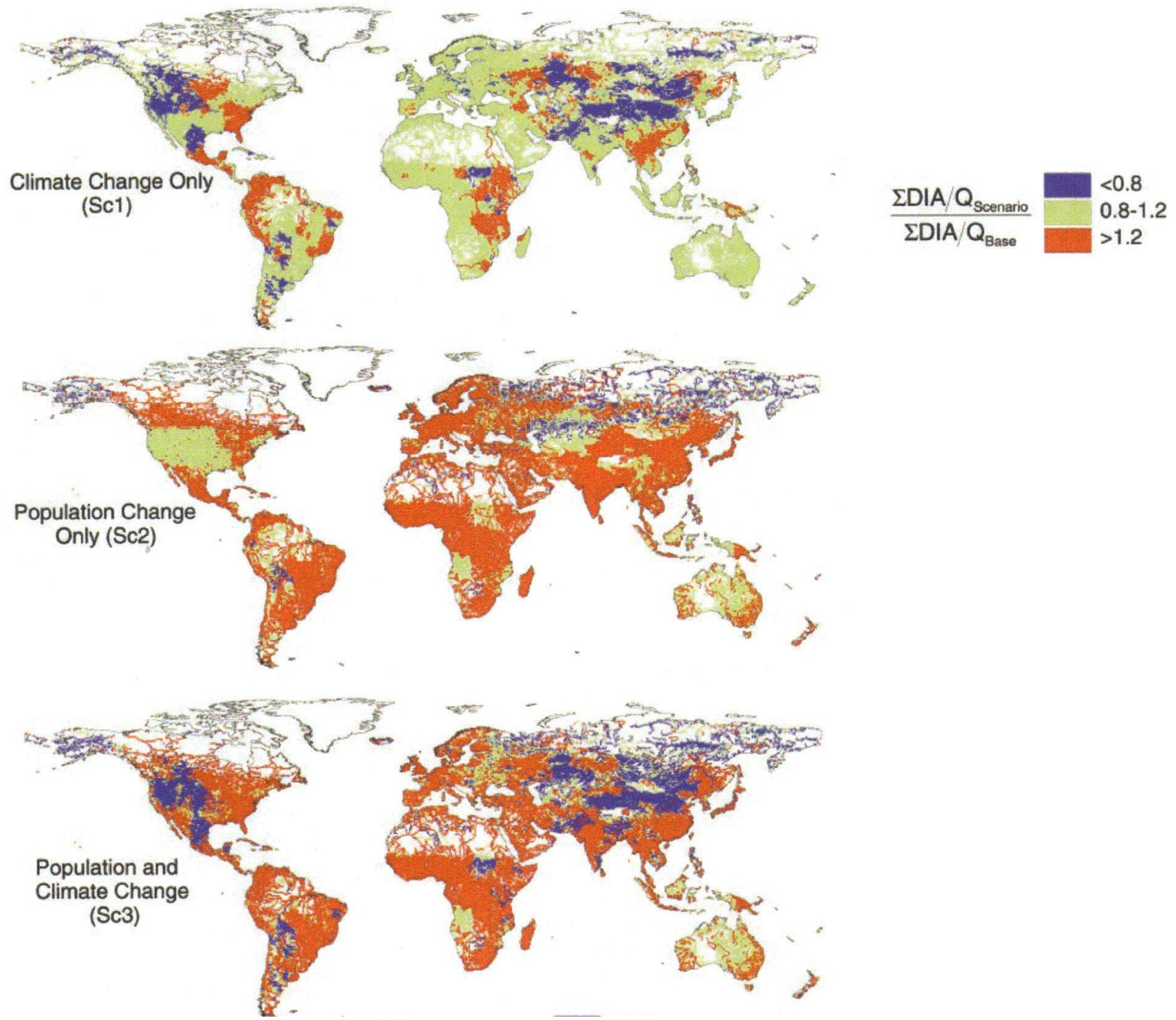
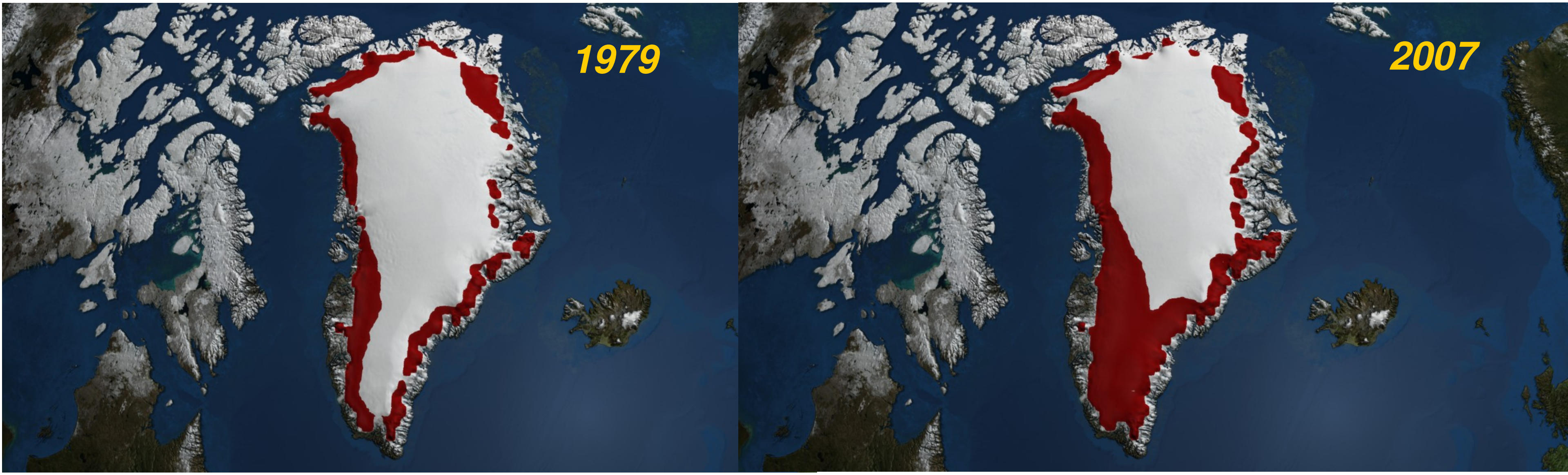


Fig. 3. Maps of the change in water reuse index ($\Sigma DIA/Q$) predicted by the CGCM1/WBM model configuration under Sc1 (climate change alone), Sc2 (population and economic development only), and Sc3 (both effects). Changes in the ratio of scenario-specific $\Sigma DIA/Q$ ($\Sigma DIA/Q_{Scenario}$) relative to contemporary ($\Sigma DIA/Q_{Base}$) conditions are shown. A threshold of $\pm 20\%$ is used to highlight areas of substantial change.

Global Water Resources: Vorosmarty et al: 2000 Science Vol 289

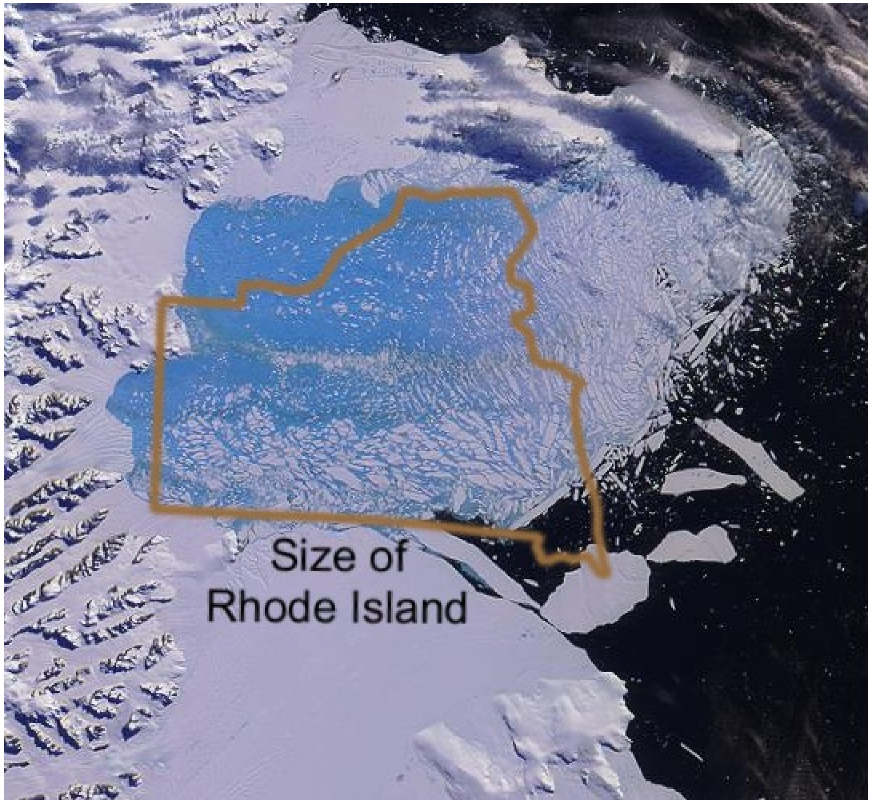
Let us see first what do we know about global warming:

Which signals are robust which ones les certain

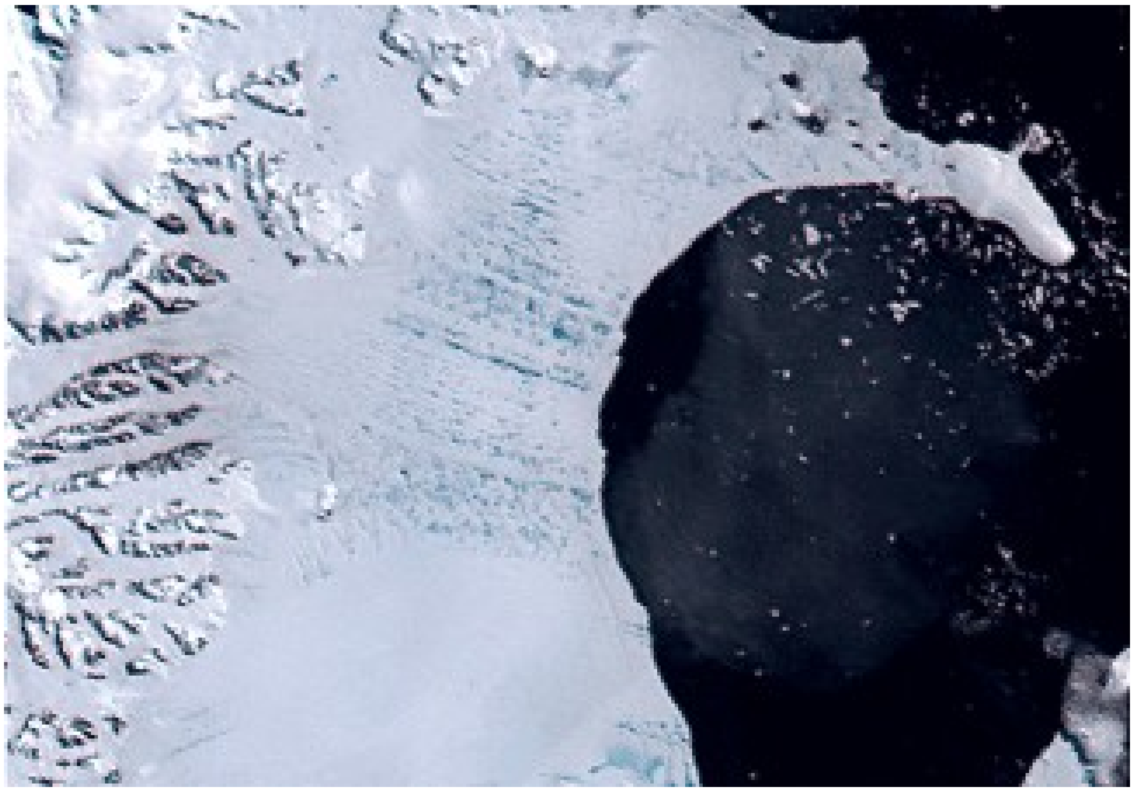


Surface melt extent

Collapse of Larsen B ice shelf in March 2002



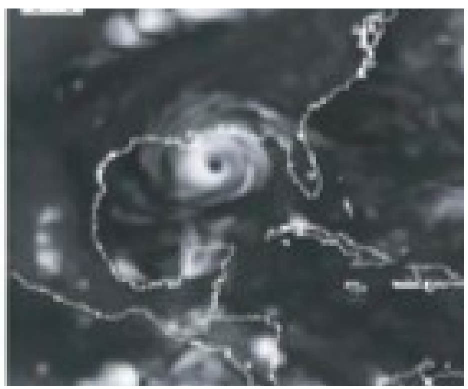
The ice desintegrated very fast



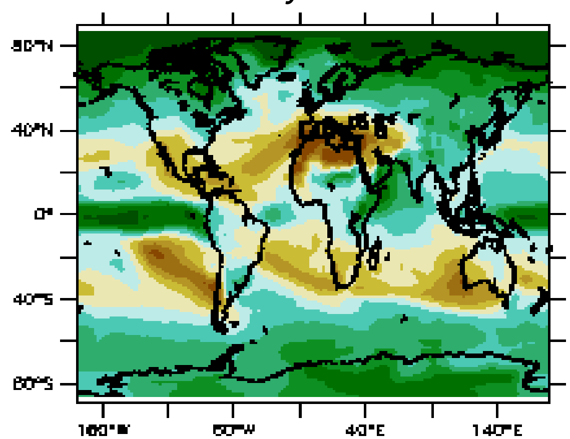
Collapse of Larsen B ice shelf in March 2002

Much of the results that I will show were the bases of last IPCC scientific assessment (4th scientific assessment 2007). Courtesy Isaac Held, Princeton,

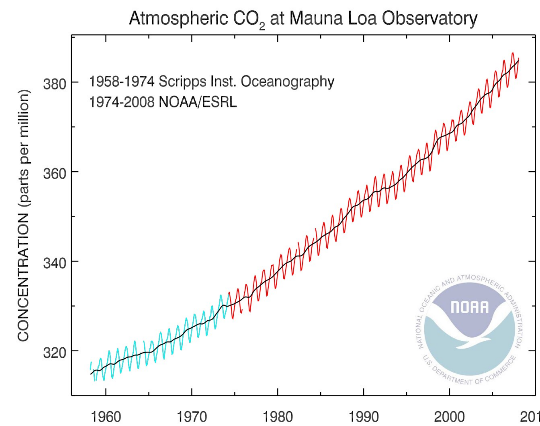
Katrina-like storm spontaneously generated in atmospheric model



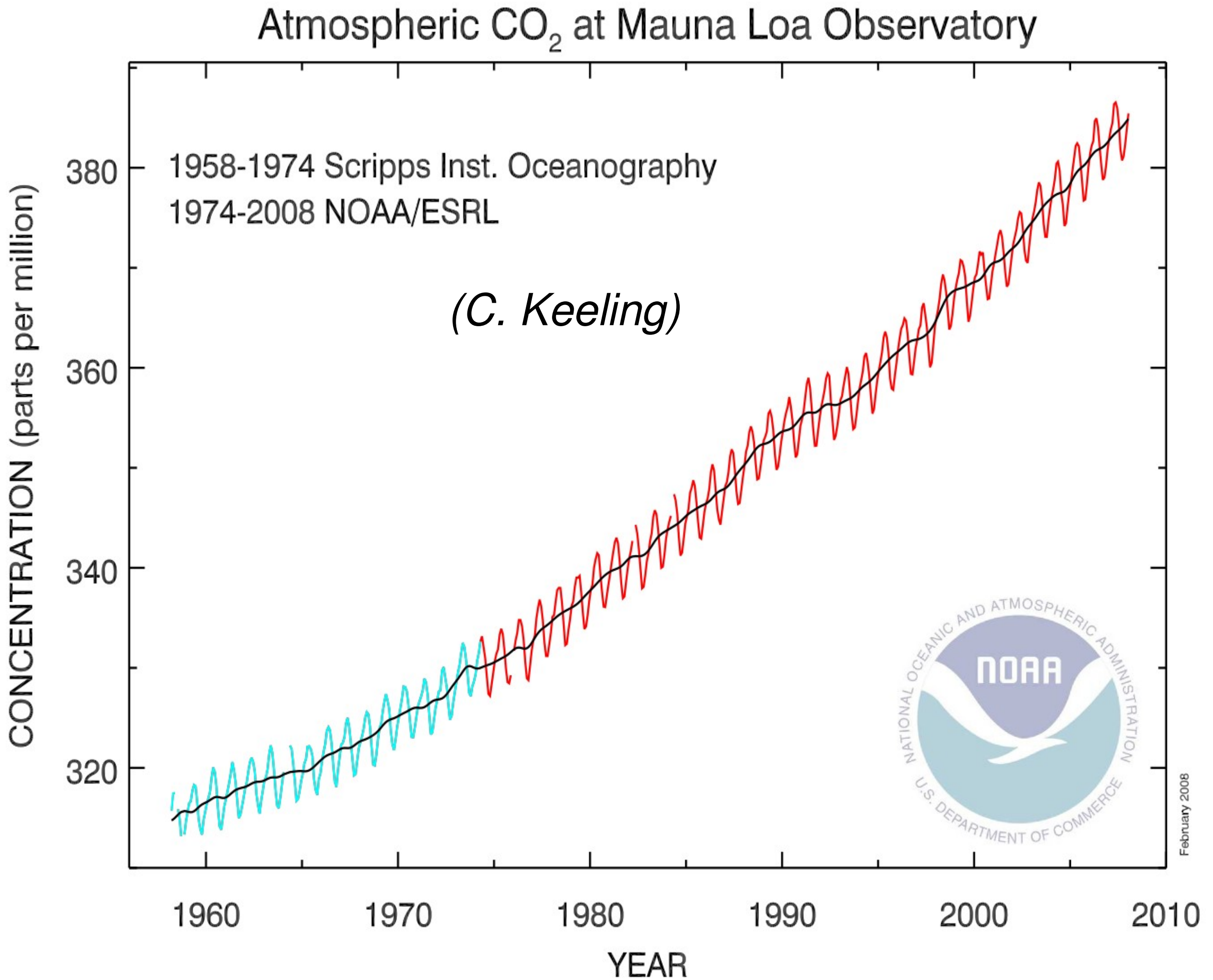
Regions projected to have more (green) and less (brown) precipitation In 21st century



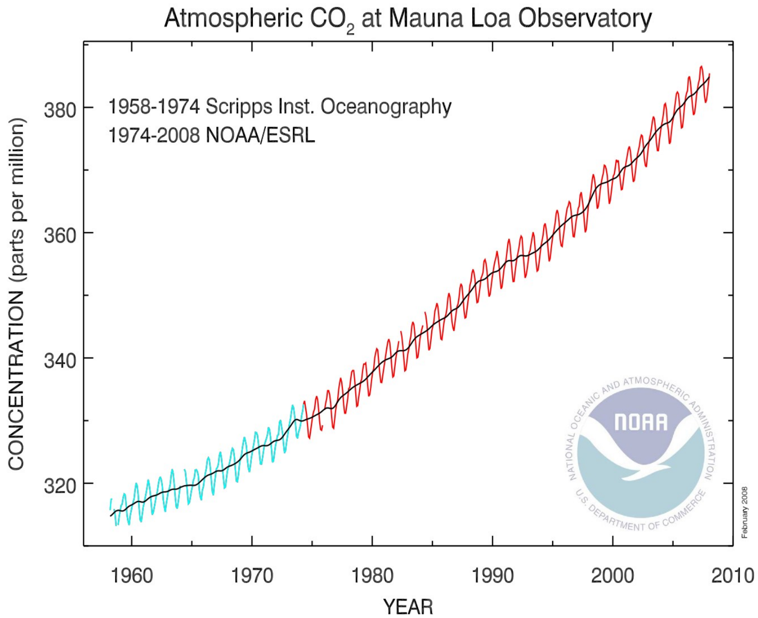
The Keeling curve



poorly understood ⟷ *well understood*



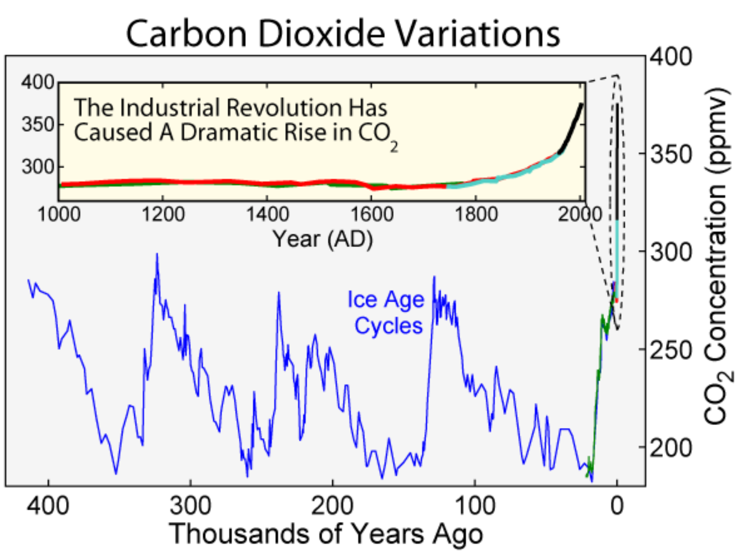
Courtesy Isaac Held, Princeton,



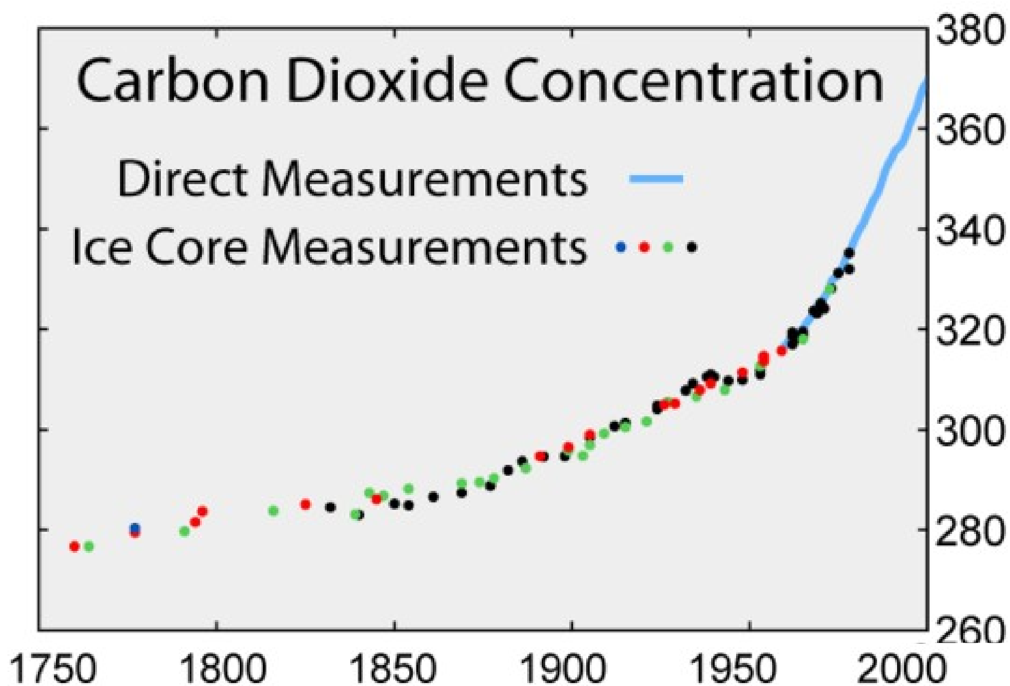
Courtesy Isaac Held, Princeton,

Ice cores + direct measurements provide a beautiful record of the history of atmospheric carbon dioxide

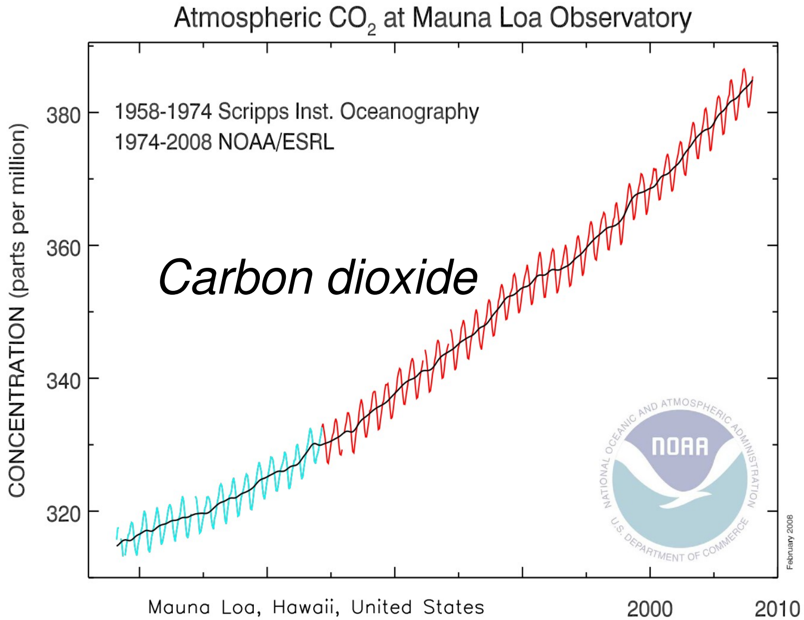
www globalwarmingart.com.

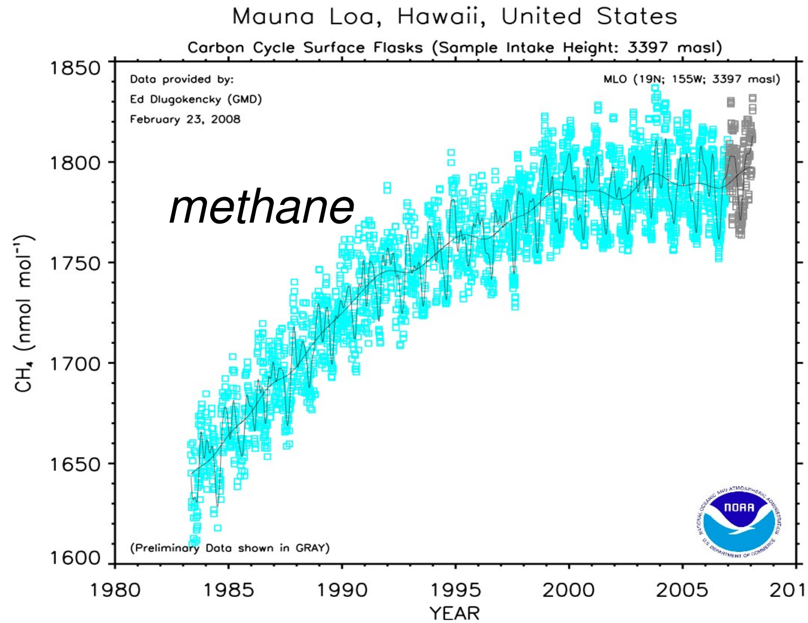


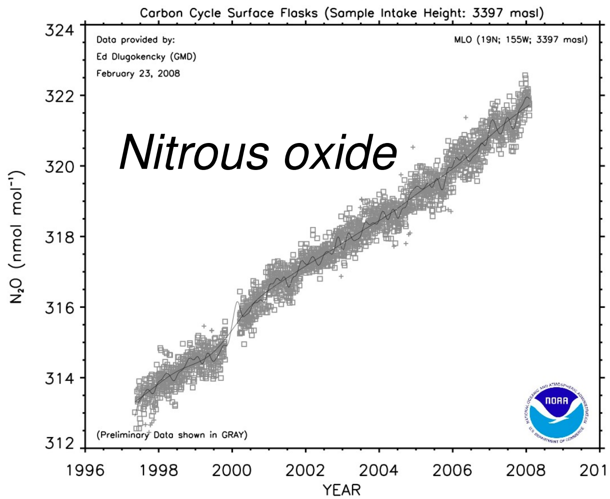
Jouzel, Lorius et al-- Vostok late 70's-80's

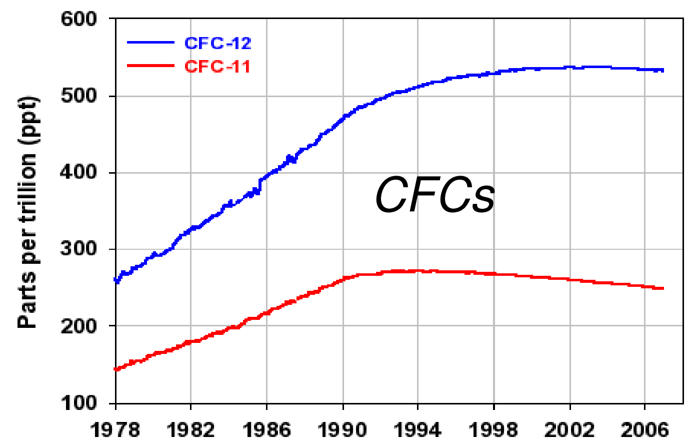


Etheridge, et al -- Law Dome 1990's





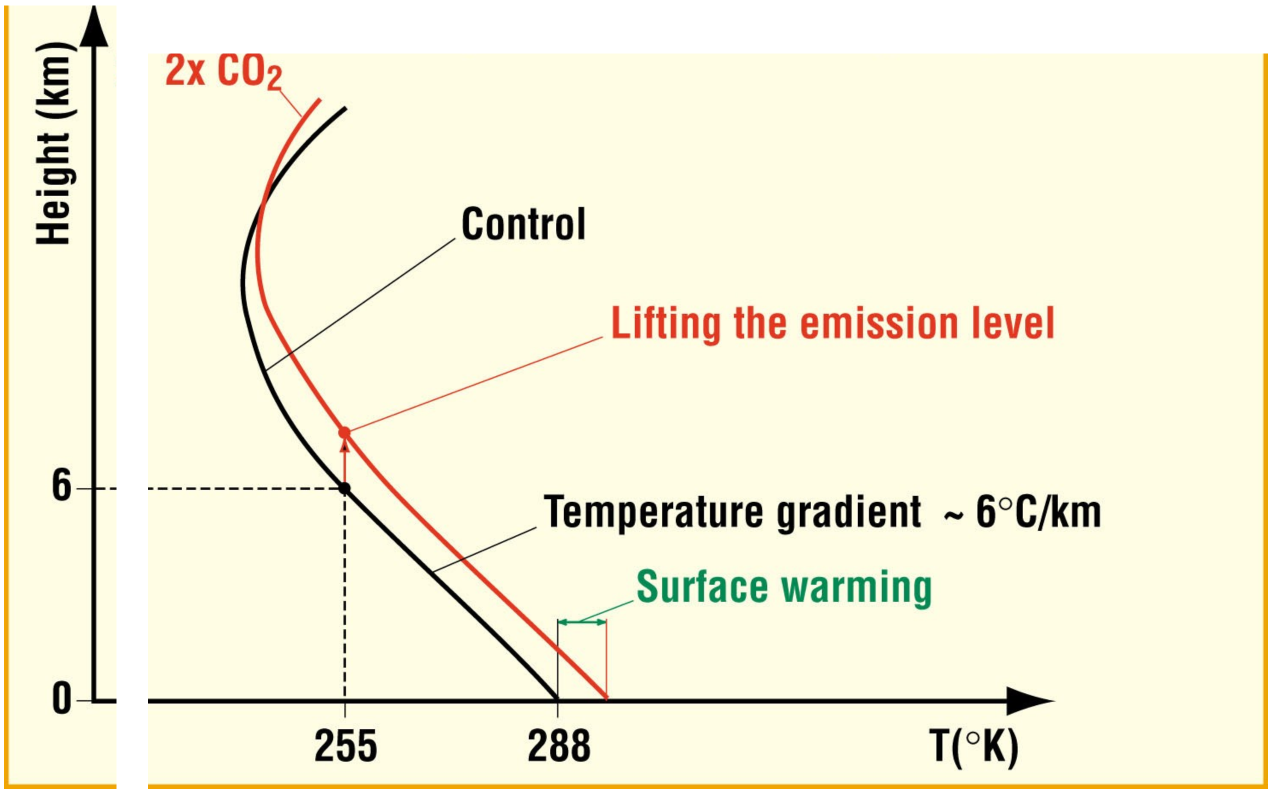




Methane and Nitrous Oxide: (1976) Wang, W.-C., et al
CFCs: (1975) V. Ramanathan

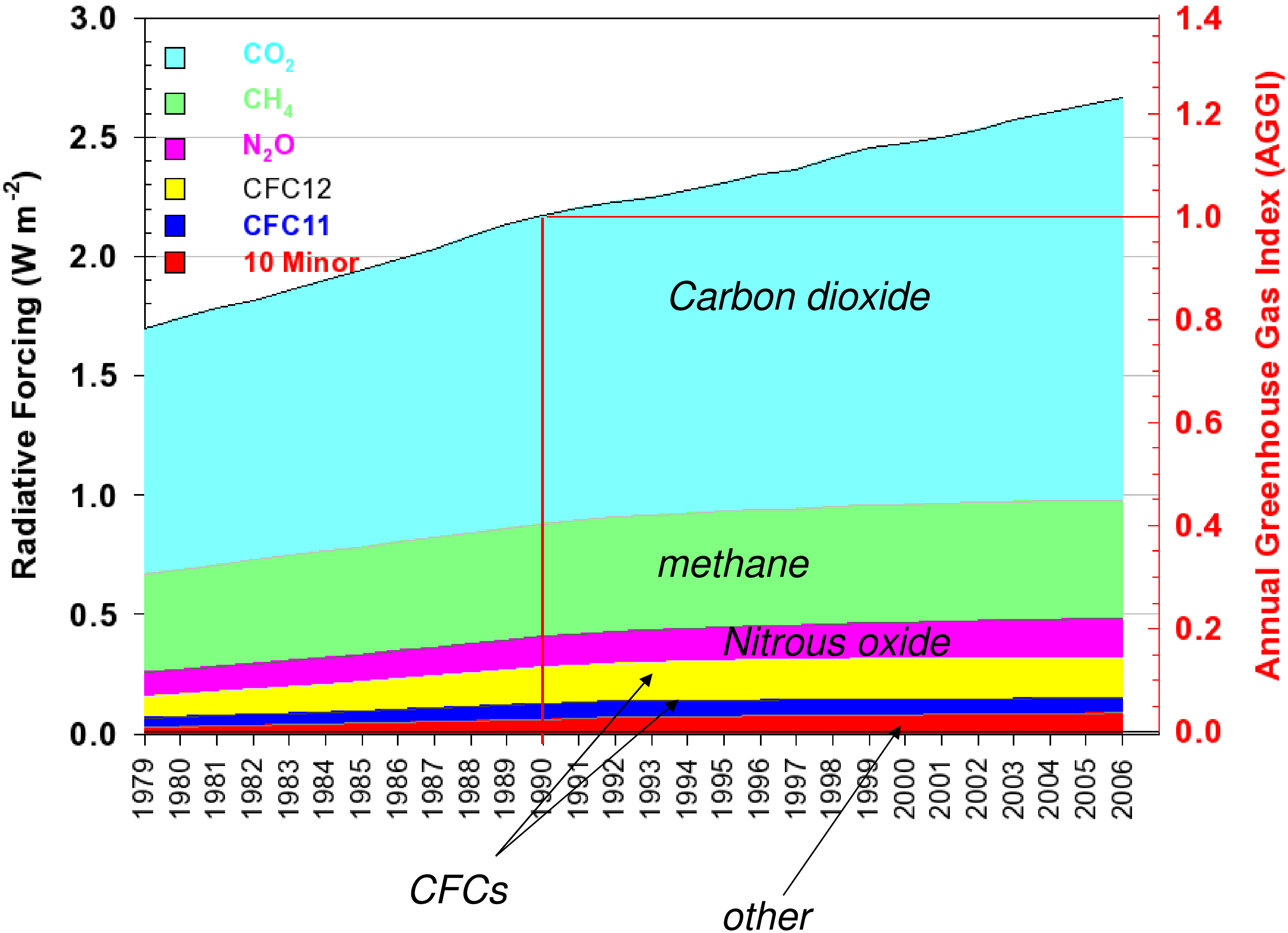
(1974) Molina-Rowland: catalytic destruction of ozone by chlorine;
(1985) Farman et al: ozone hole

Courtesy Isaac Held, Princeton,

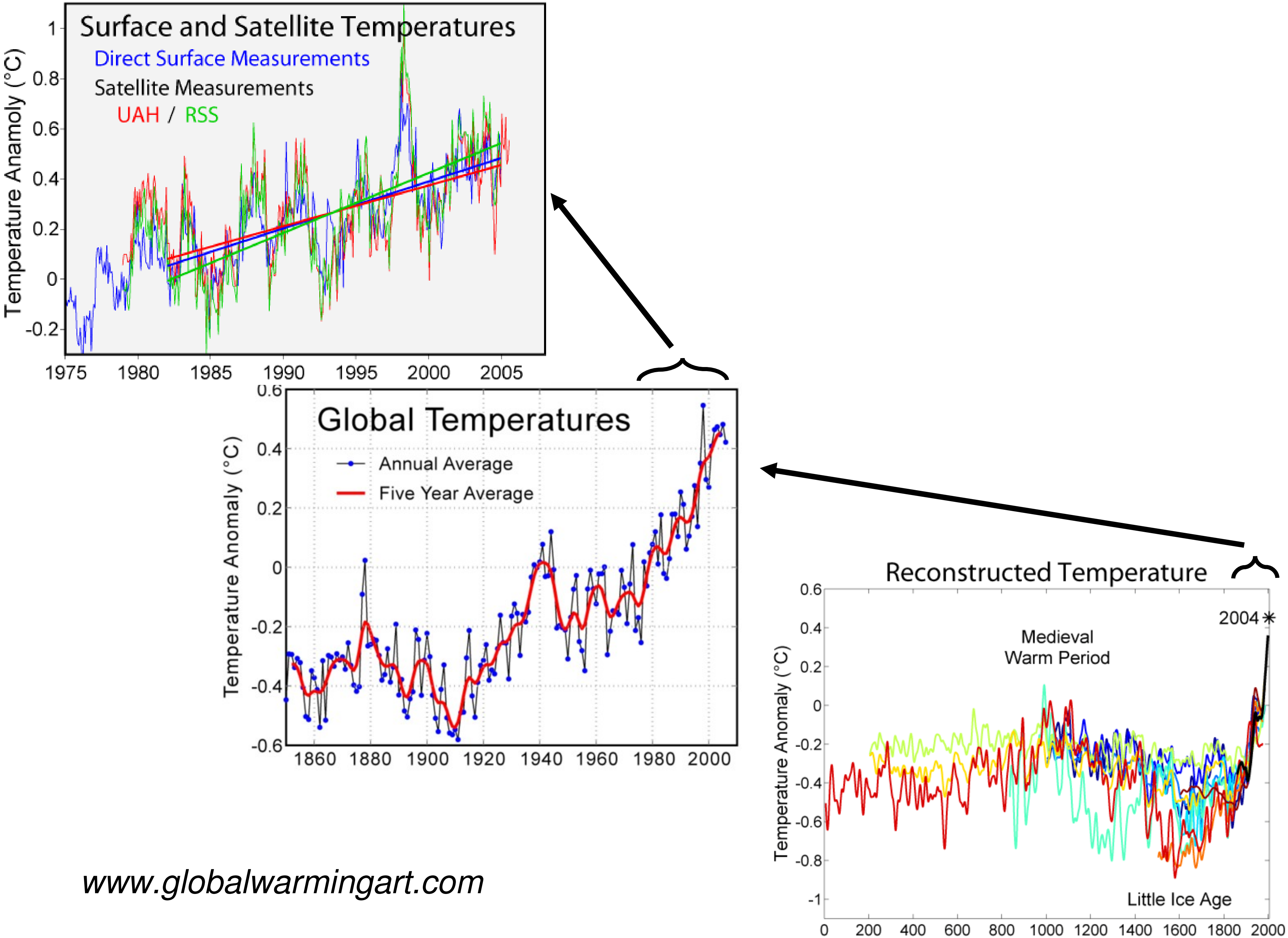


Courtesy Isaac Held, Princeton,

http://www.esrl.noaa.gov/gmd/aggi/



Courtesy Isaac Held, Princeton,



www.globalwarmingart.com

Was the 20th century warming

1) primarily forced by increasing greenhouse gases?

or,

2) primarily forced by something else?

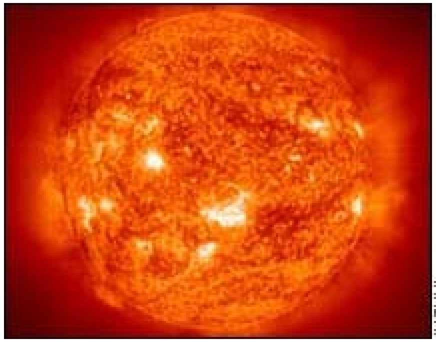
or,

3) primarily an internal fluctuation of the climate?

Claim: Our climate theories STRONGLY support 1)

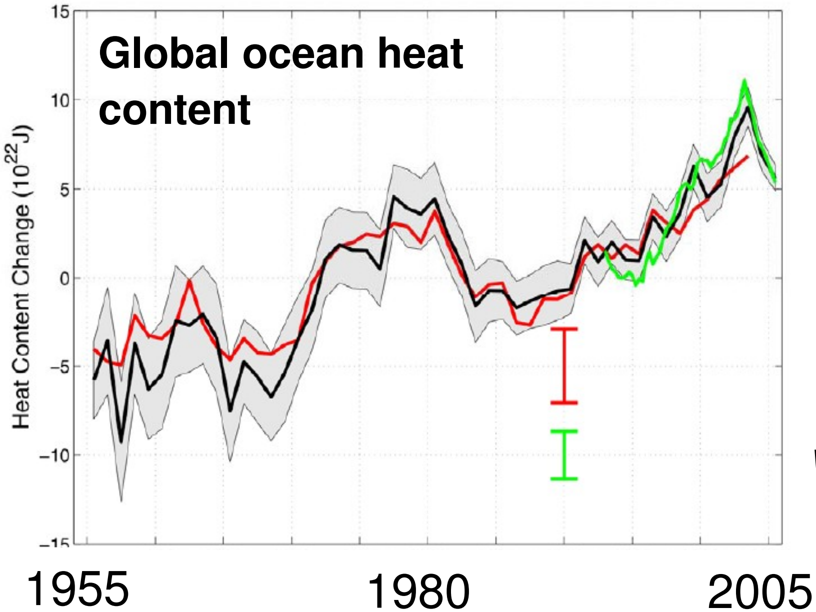
A central problem for the IPCC has been to evaluate this claim and communicate our level of confidence appropriately

Courtesy Isaac Held, Princeton,



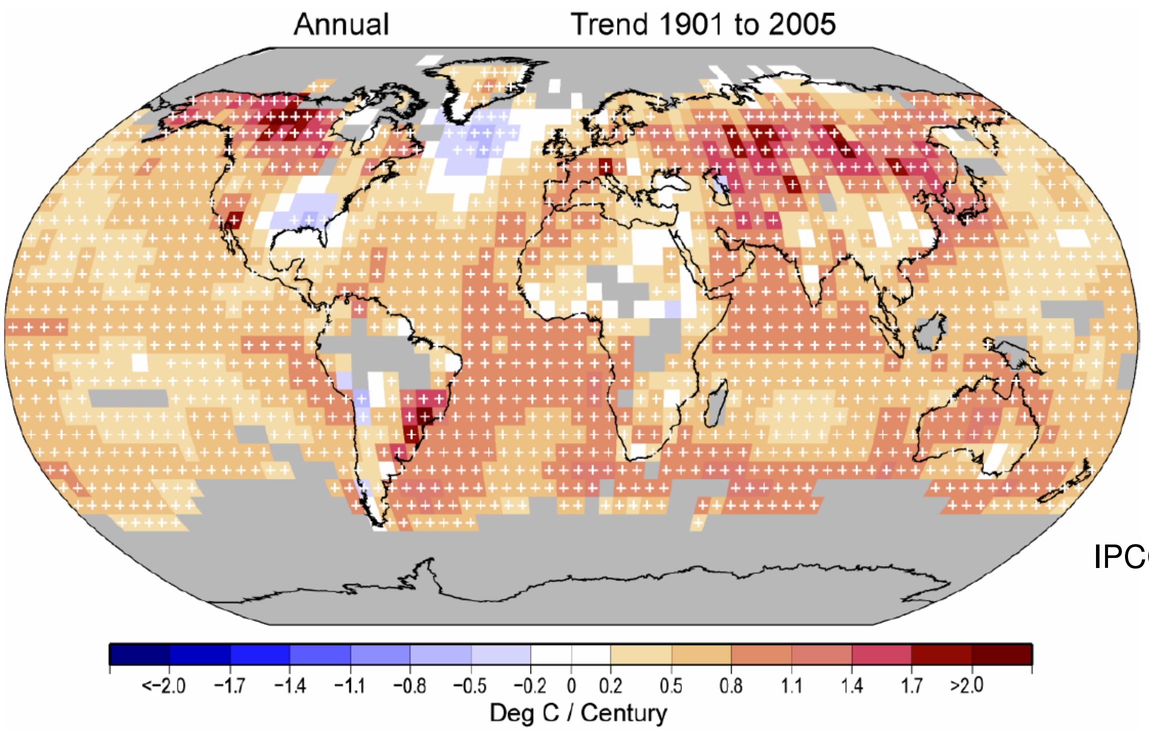
Lean, a research physicist in the Space Science Division of the Naval Research Laboratory in Washington, D.C., is an expert on solar radiation.

The general conclusion of their study is that the sun may have played a dominant role in pre-industrial climate change (from 1600 to 1800, for example) but it has not played a significant part in long-term climate change during the past few decades. It is furthermore unlikely that the sun accounted for more than half, at most, of climate change from 1900 to 1970. "A larger role for the sun in explaining the observed climate warming over the 20th century is inconsistent with direct measurements of solar output and with proxy evidence of solar variability during the pre-industrial era," said Lean in an abstract prepared for seminar attendees.



Energy is going into ocean
=>
More energy is entering the atmosphere from space than is going out

www.globalwarmingart.com

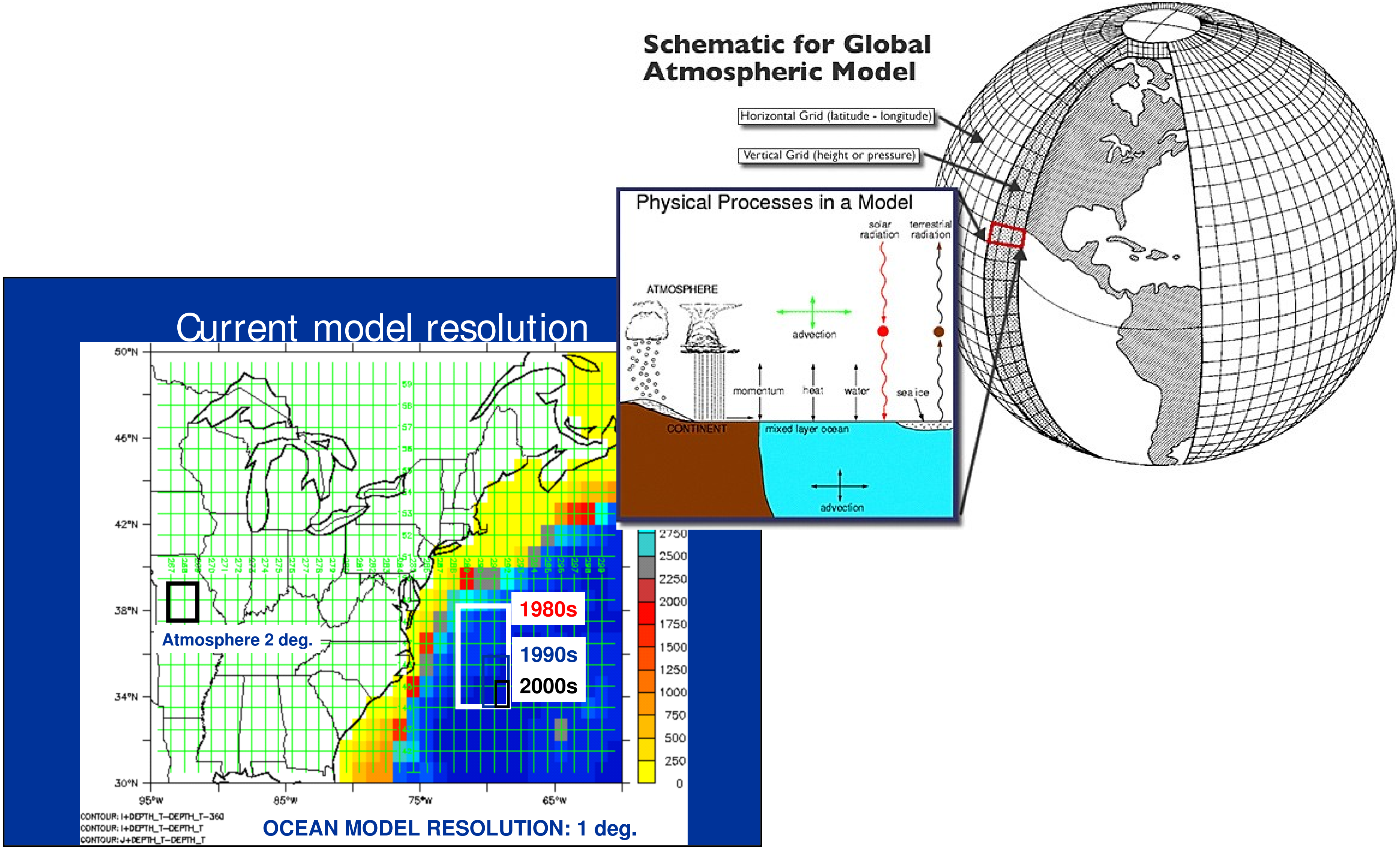


Almost all parts of the Earth's surface have warmed over the past 100 years

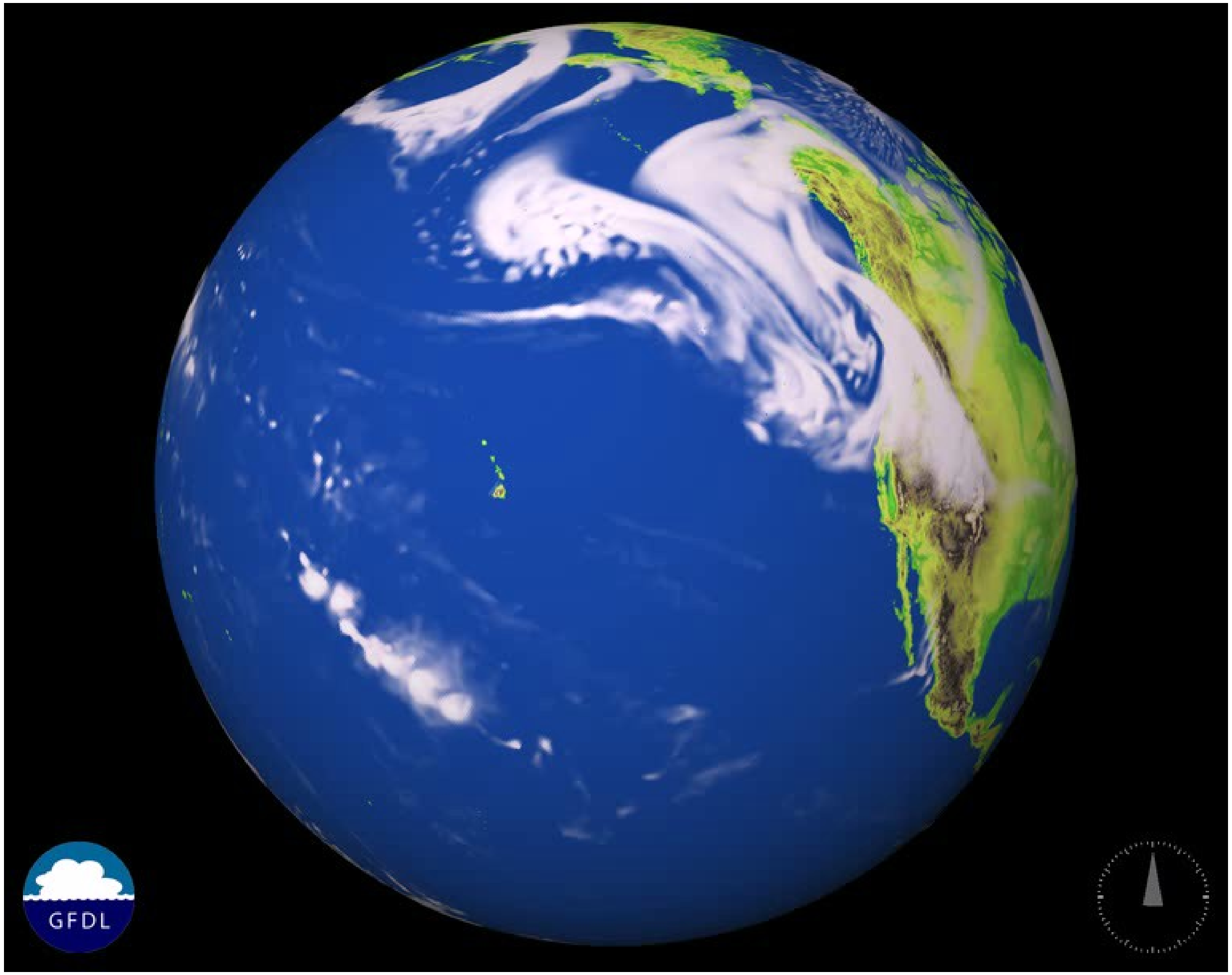
IPCC 4th Assessment Report.

Courtesy Isaac Held, Princeton,

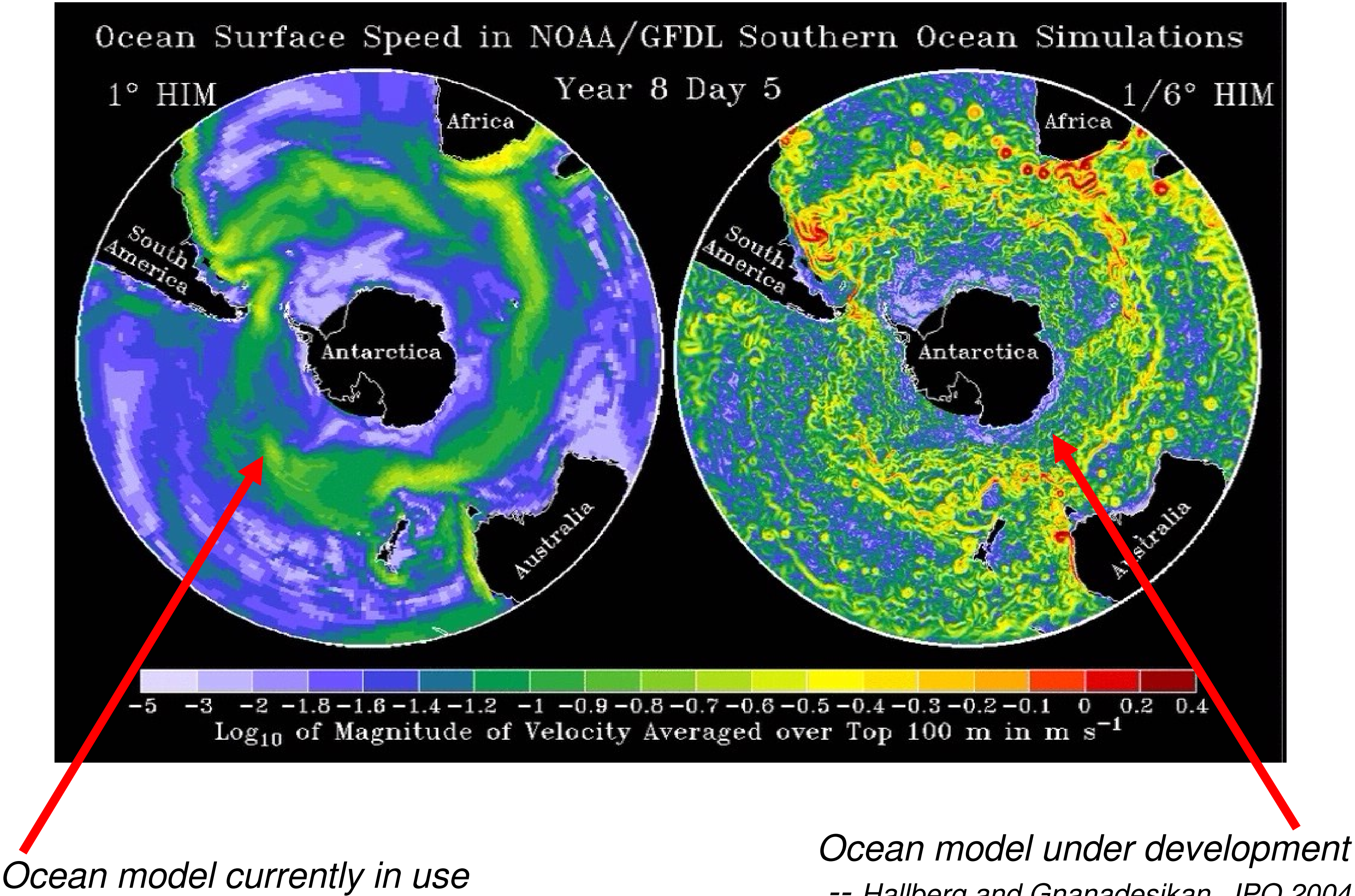
The components of an earth system model



Theories/models required to discuss future changes in climate



Orlanski, I., and C. Kerr, 2007: **Project TERRA: A glimpse into the future of weather and climate modeling.** In, *High resolution numerical modelling of the atmosphere and ocean, K. Hamilton & W. Ohfuchi, Editors. New York NY: Springer; 45-50.*



Simulation of Surface Currents

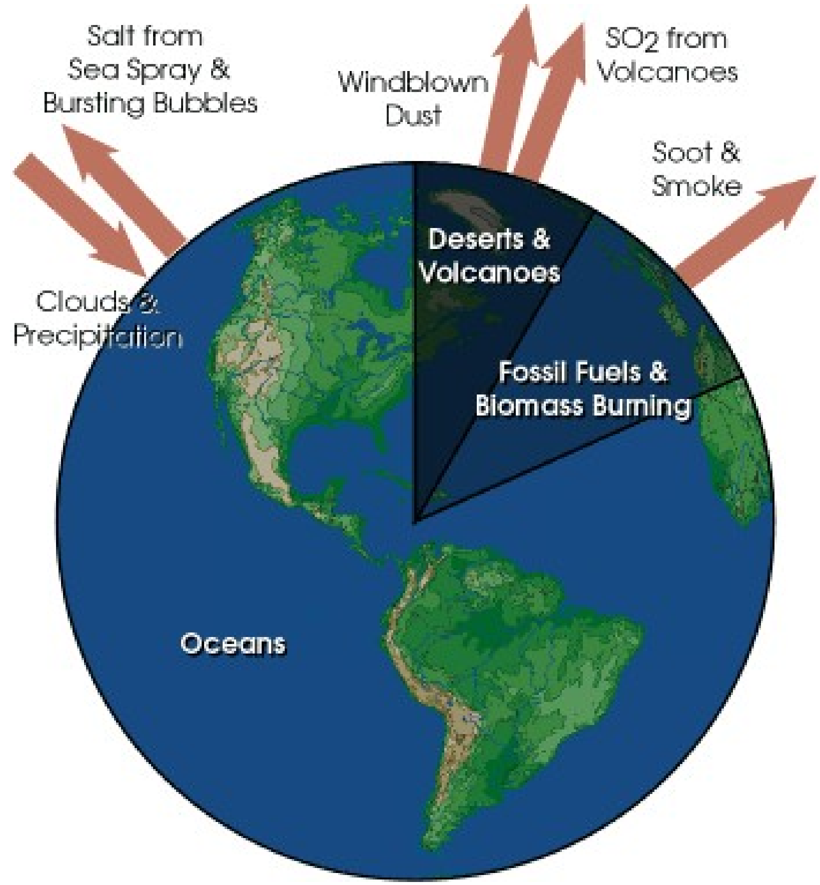
Climate sensitivity =
temperature change per unit change in radiative forcing

Nature has conspired to make the problem of constraining climate sensitivity very difficult:

- ***The uncertainty in aerosol forcing over the 20th century limits our ability to use 20th century warming to determine sensitivity empirically***

2) The difficulty in simulating clouds prevents us from developing a satisfying quantitative theory of climate sensitivity

Aerosol particles larger than about 1 micrometer in size are produced by windblown dust and sea salt from sea spray and bursting bubbles. Aerosols smaller than 1 micrometer are mostly formed by condensation processes such as conversion of sulfur dioxide (SO_2) gas (released from volcanic eruptions) to sulfate particles and by formation of soot and smoke during burning processes. After formation, the aerosols are mixed and transported by atmospheric motions and are primarily removed by cloud and precipitation processes.



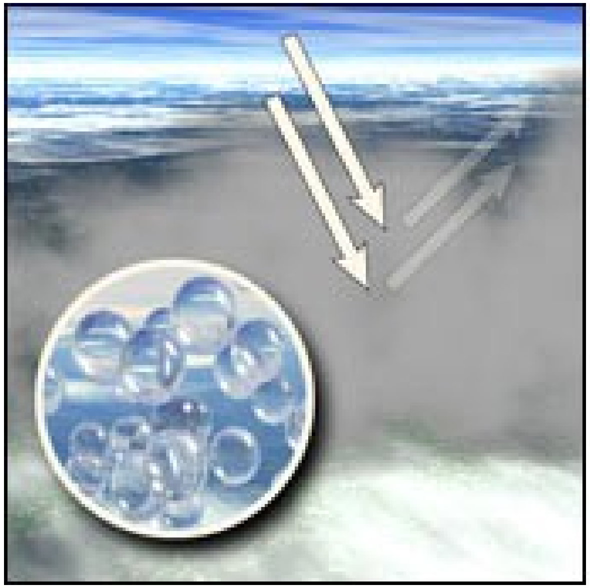
Aerosols affects climate in two ways: direct and indirect mechanisme.

direct forcing mechanism, aerosols reflect sunlight back to space, thus cooling the planet. (Sooty) aerosols from such processes as biomass burning absorb some of this solar energy leading to a local atmospheric heating.

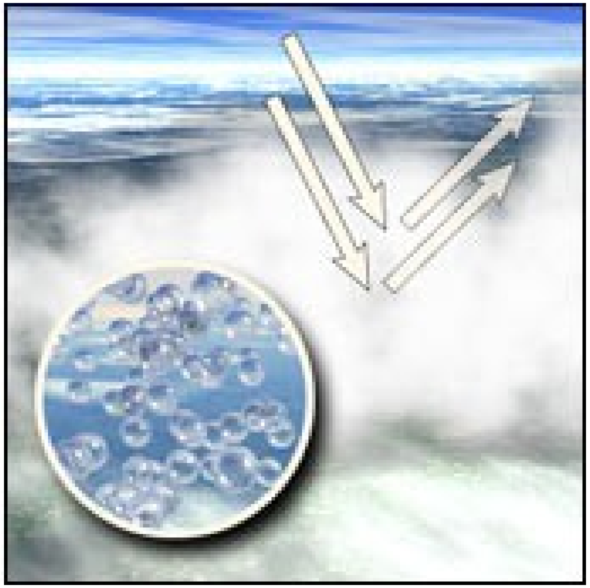
The indirect effect involves aerosol particles acting as (additional) cloud condensation nuclei, spreading the cloud's liquid water over more, smaller, droplets.

Effects of Aerosol on Clouds

Clouds with low aerosol concentration and a few large droplets do not scatter light well, and allow much of the Sun's light to pass through and reach the surface.

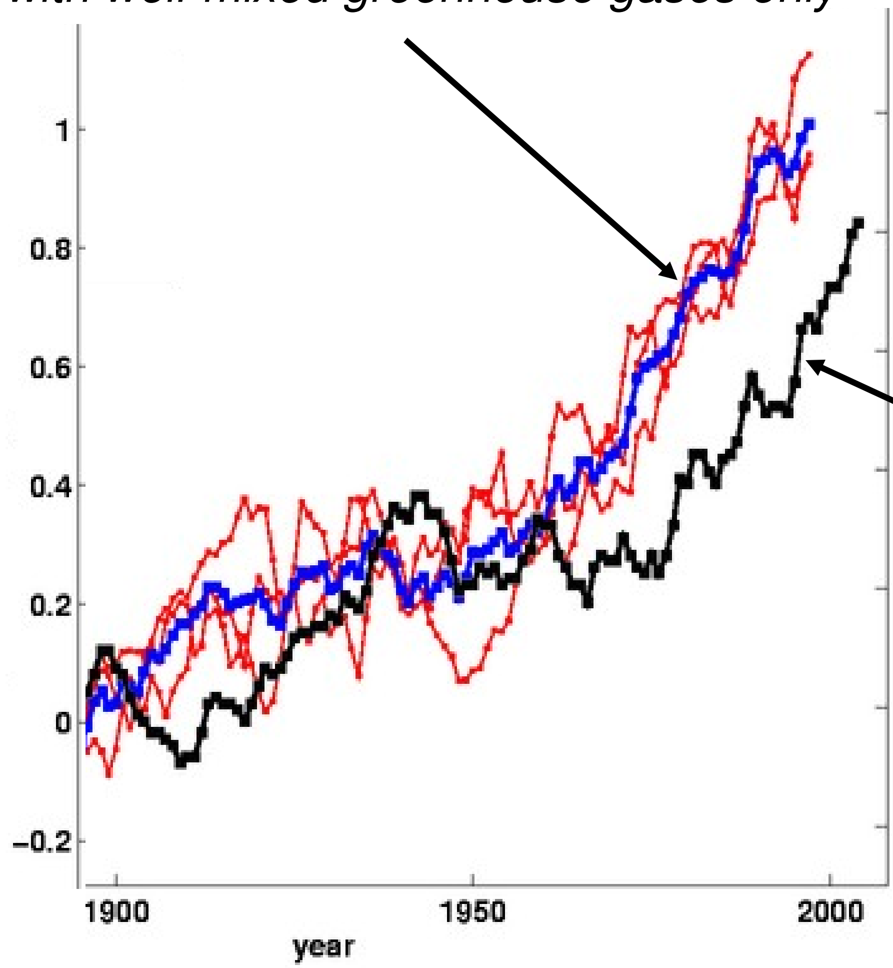


The high aerosol concentrations in these clouds provide the nucleation points necessary for the formation of many small liquid water droplets. Up to 90% of visible radiation (light) is reflected back to space by such clouds without reaching Earth's surface.



GFDL's CM2.1 with well-mixed greenhouse gases only

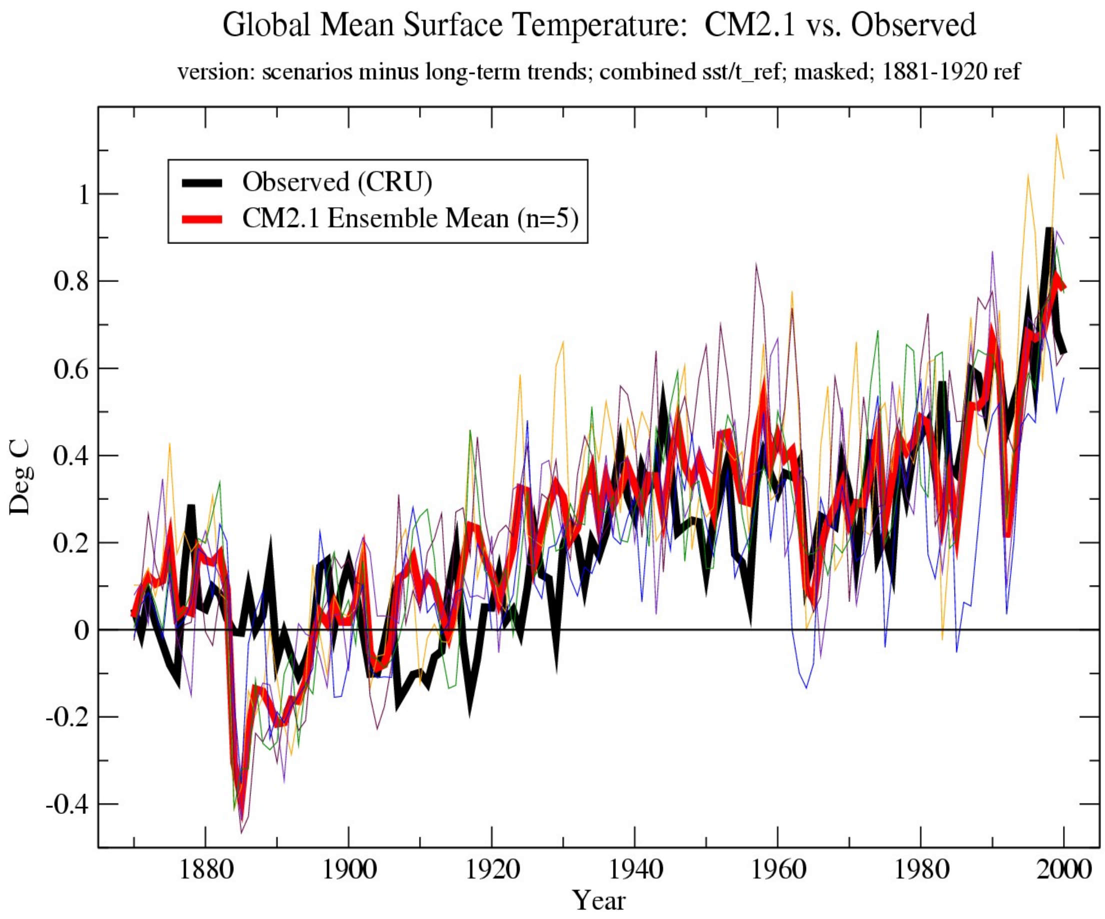
Global mean temperature change



Observations (GISS)

"It is likely that increases in greenhouse gas concentrations alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place." (AR4 WG1 SPM).

Courtesy Isaac Held, Princeton,



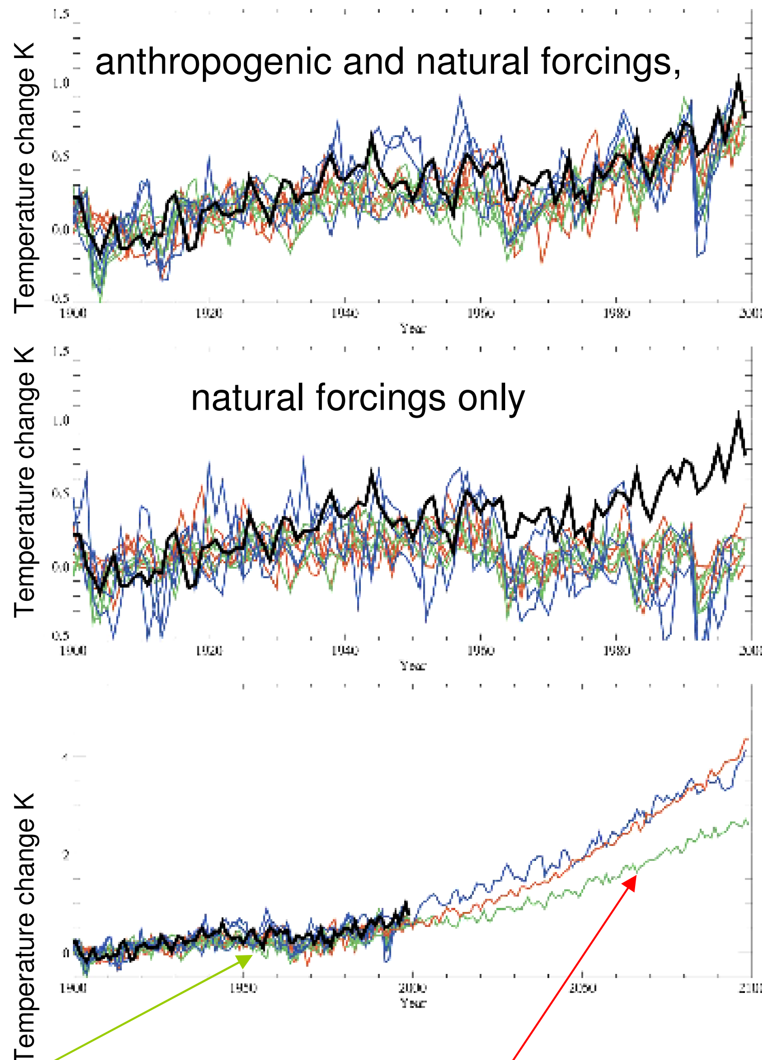
(GFDL CM2.1 -- Includes estimates of volcanic and anthropogenic aerosols, as well as estimates of variations in solar irradiance)

Models can produce very good fits by including aerosol effects,
but models with
stronger aerosol forcing and higher climate sensitivity
are also viable (and vice-versa)

Courtesy Isaac Held, Princeton,

Global mean temperatures from observations (black lines), and simulations of the HadCM3 (red), PCM (green), and GFDL R30 (blue) models.

HadCM3: Hadley Center, Reading, UK.
PCM: Consortium of centers, Los Alamos, USA.
GFDL R30: Geophysical Fluid Dynamic Laboratory/NOAA, Princeton, USA.

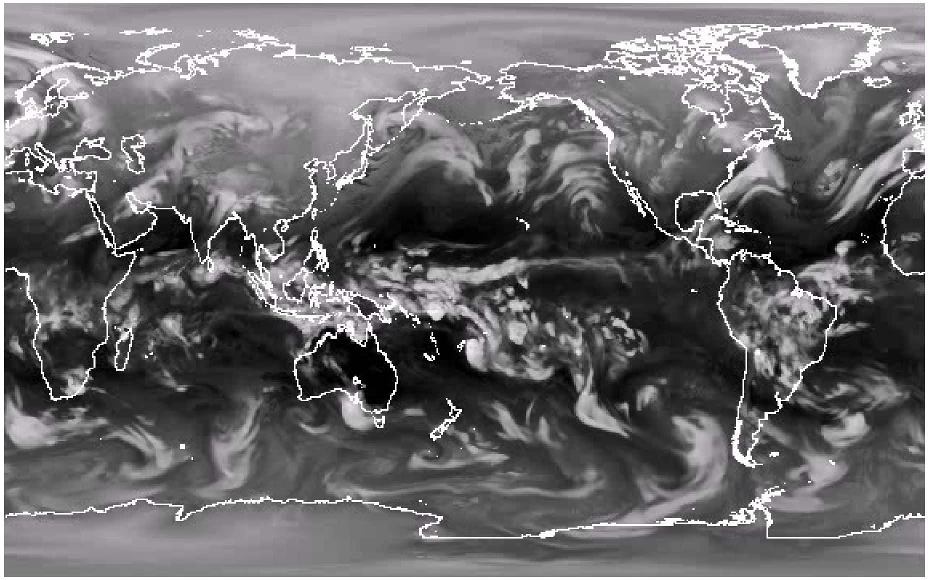


both anthropogenic and natural forcings to 2000 followed by anthropogenic forcings to 2100 according to the SRES A2 scenario.

Observational Constraints on Past Attributable Warming and Predictions of Future Global Warming Stott 2006, J. Clim.

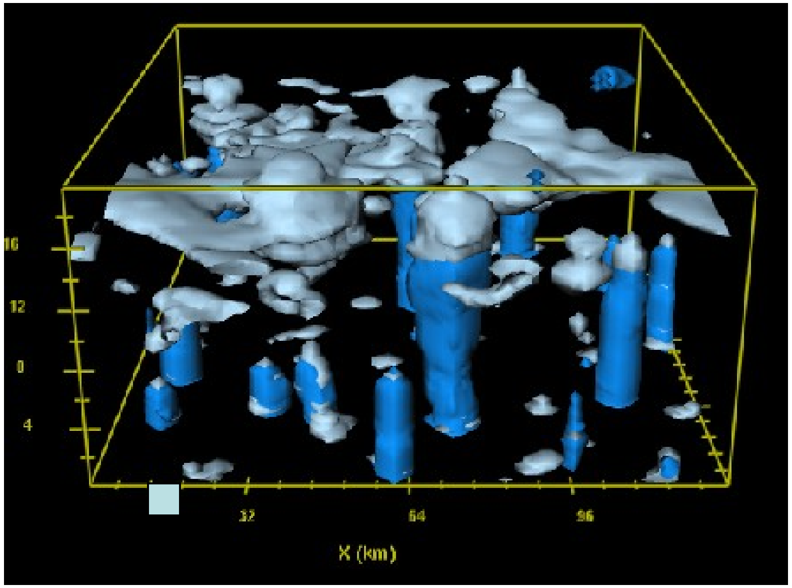
The issue of clouds

Model simulated clouds (actually infrared radiation escaping to space)



Courtesy Isaac Held, Princeton,

Clouds (especially in the tropics) are influenced by small scales in the atmospheric circulation

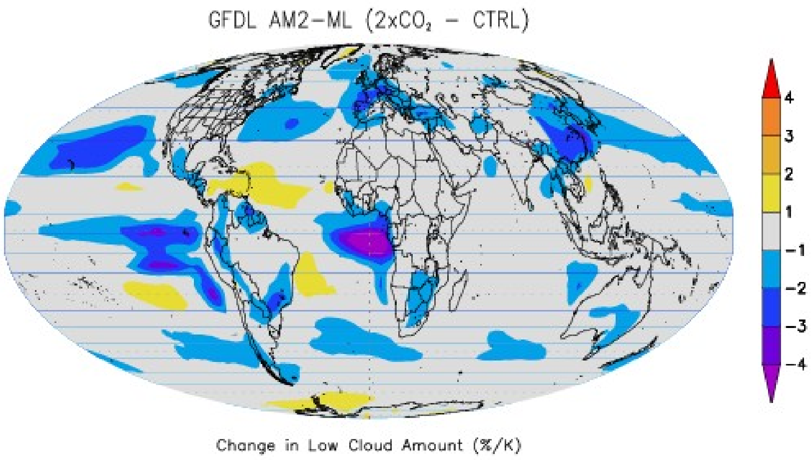


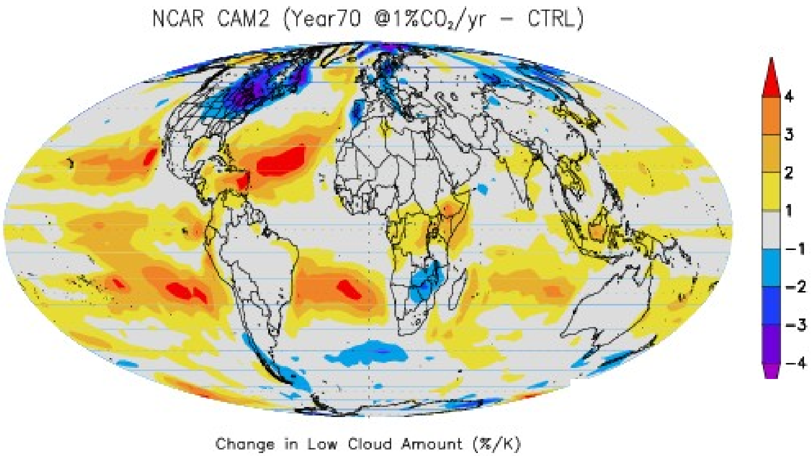
100kms

simulation of a 100km x 100km area of the tropics

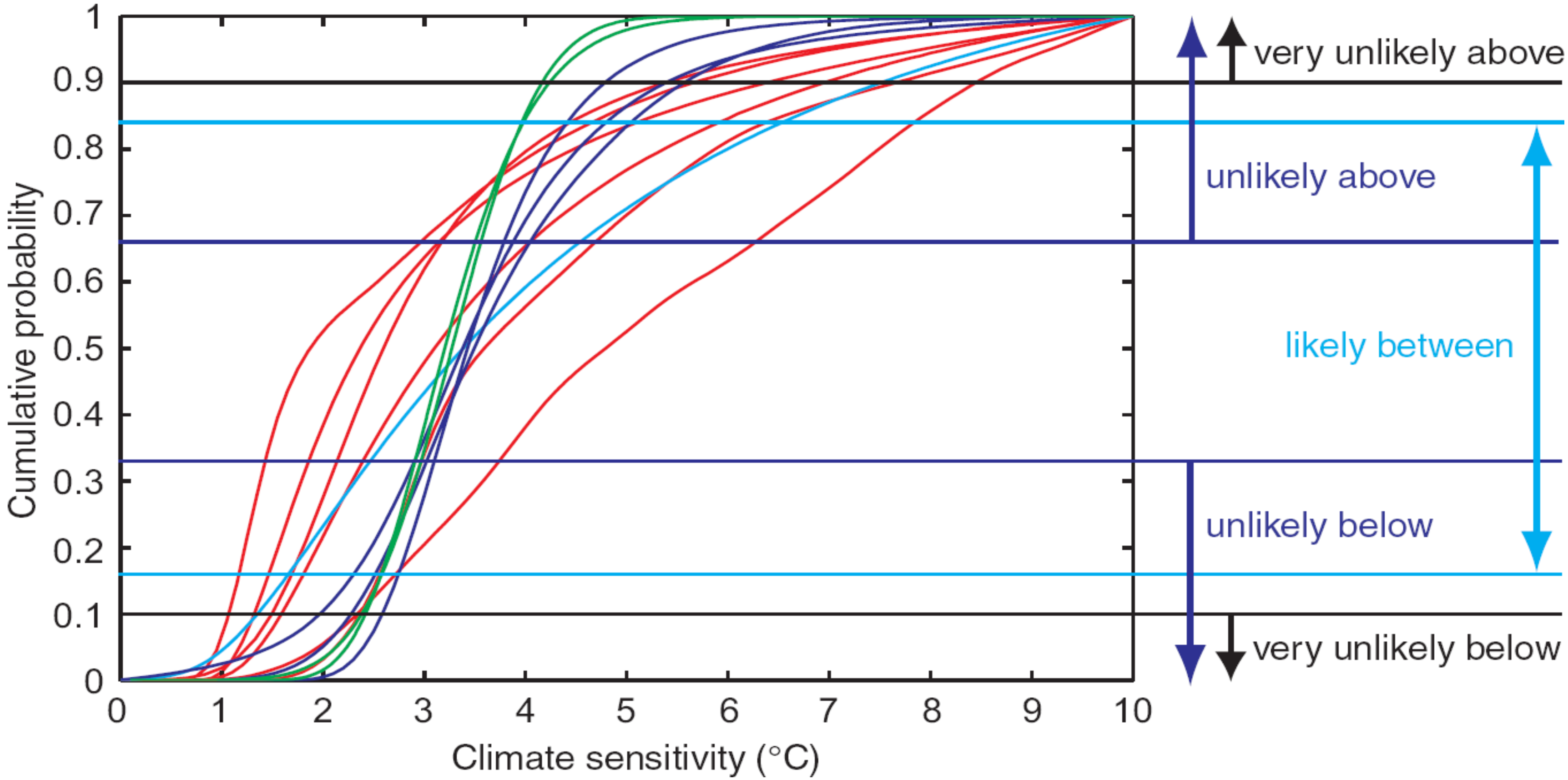
Courtesy Isaac Held, Princeton,

Change in Low Cloud Amount (%/K) GFDL and NCAR/CAM models



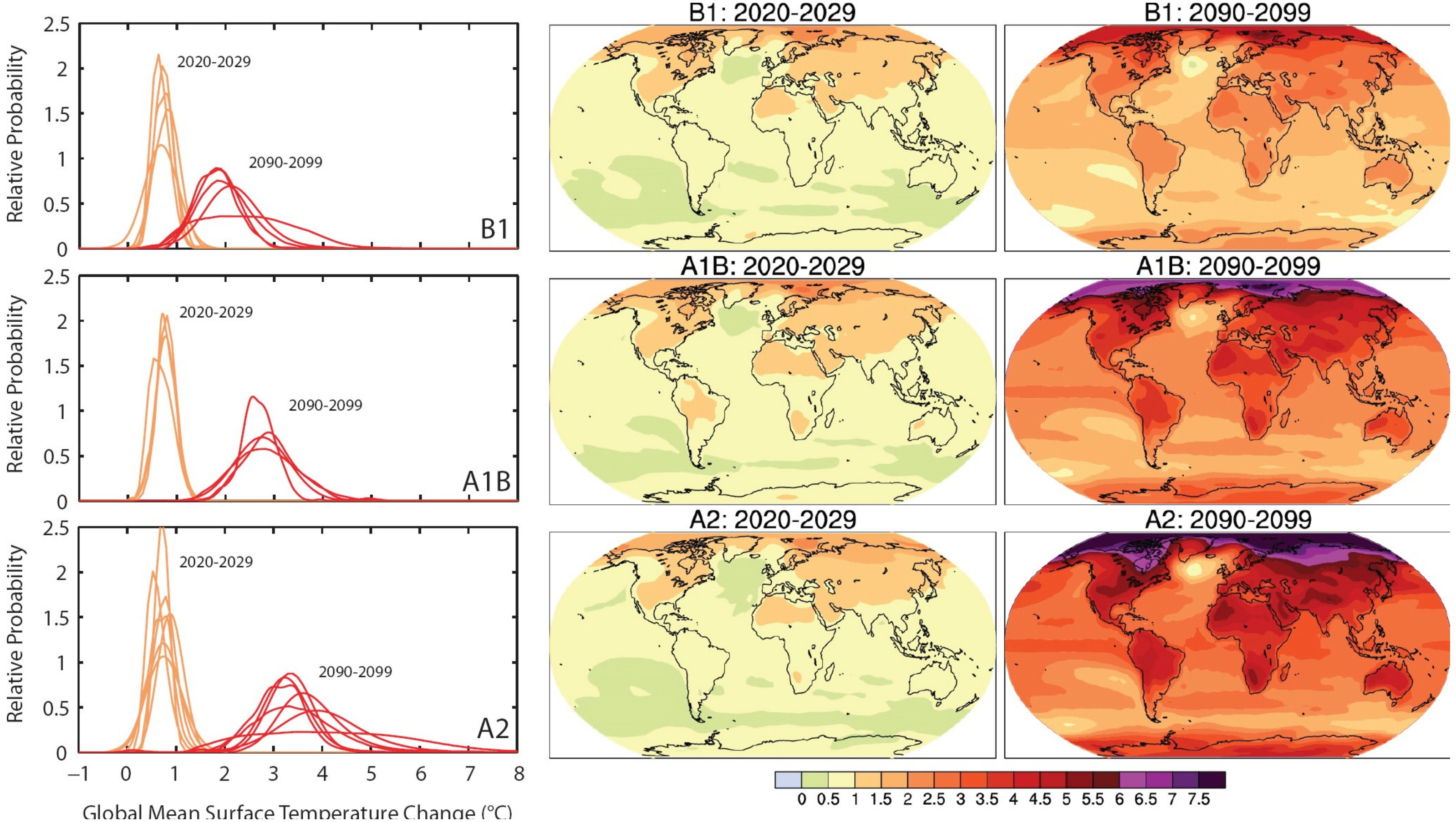


Courtesy of Brian Soden



Various estimates of climate sensitivity
(global mean warming for doubling carbon dioxide)
(from IPCC AR4 WG1)

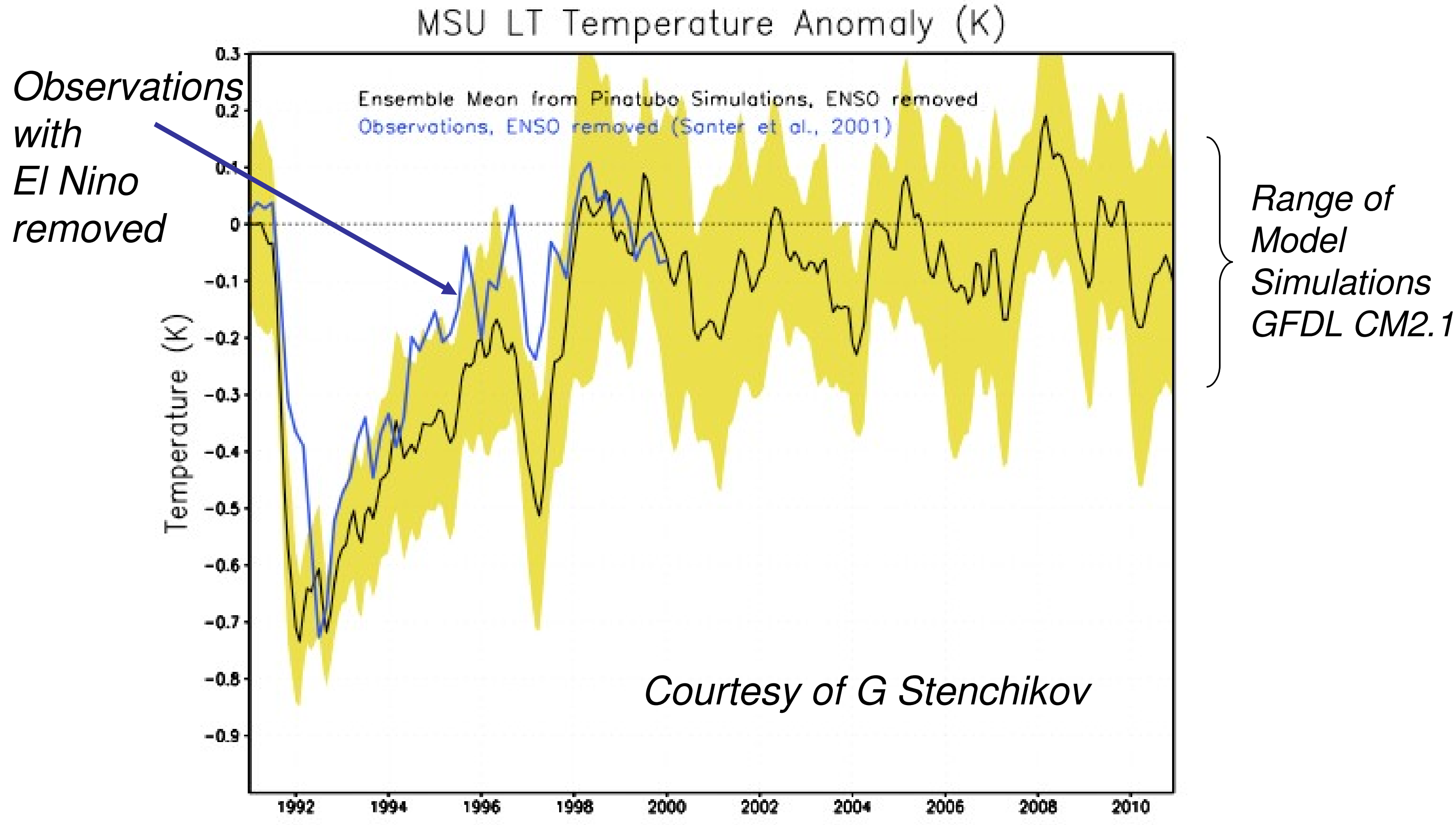
Courtesy Isaac Held, Princeton,



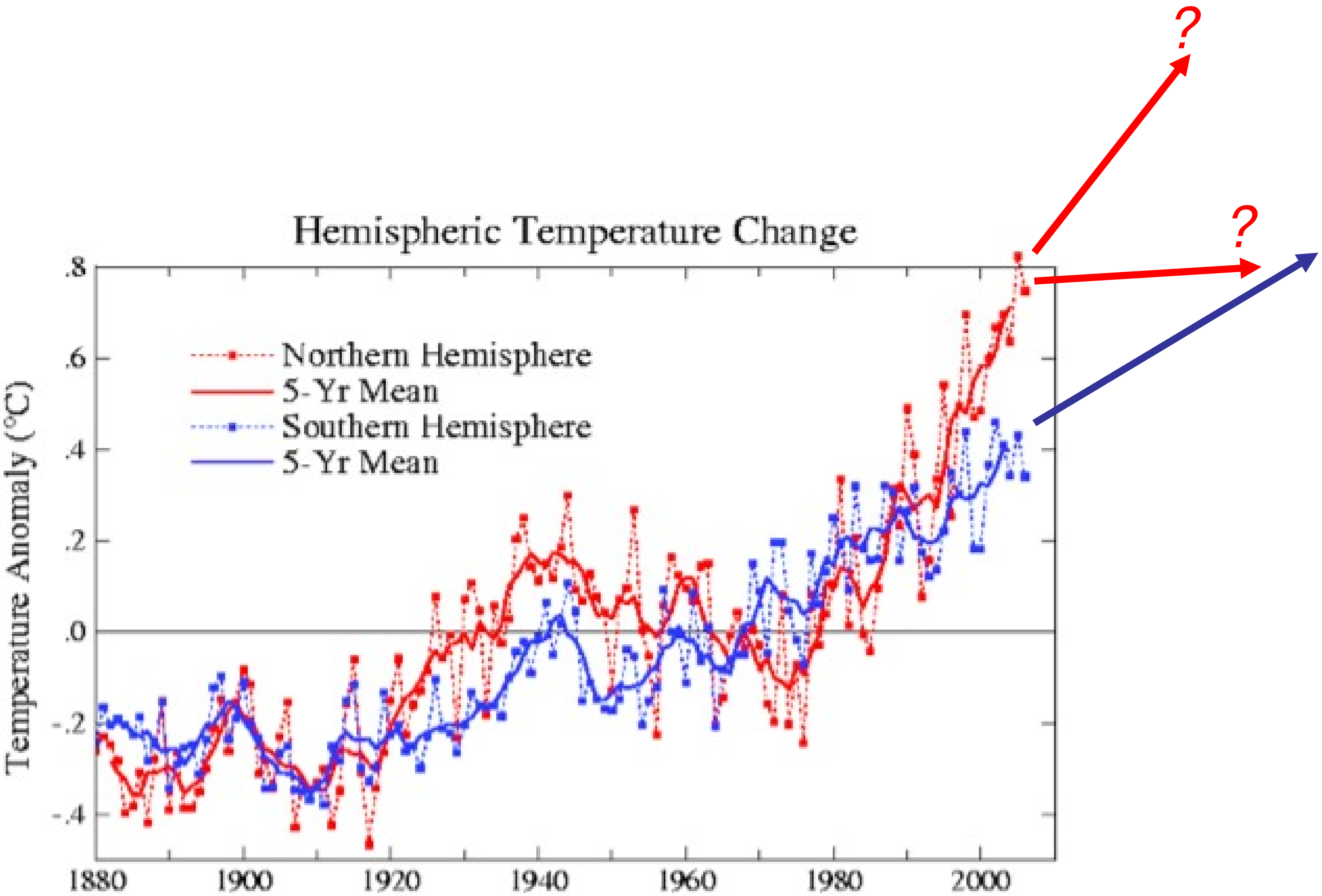
IPCC AR4 WG1 Summary for Policymakers

Courtesy Isaac Held, Princeton,

Global mean cooling due to Pinatubo volcanic eruption



Relaxation time after abrupt cooling contains information on climate sensitivity



Hemispheric Temperature Change
Northern Hemisphere
5-Yr Mean
Southern Hemisphere
5-Yr Mean
Temperature Anomaly (°C)
.8
.6
.4
.2
.0
-.2
-.4
1880
1900
1920
1940
1960
1980
2000
?
?

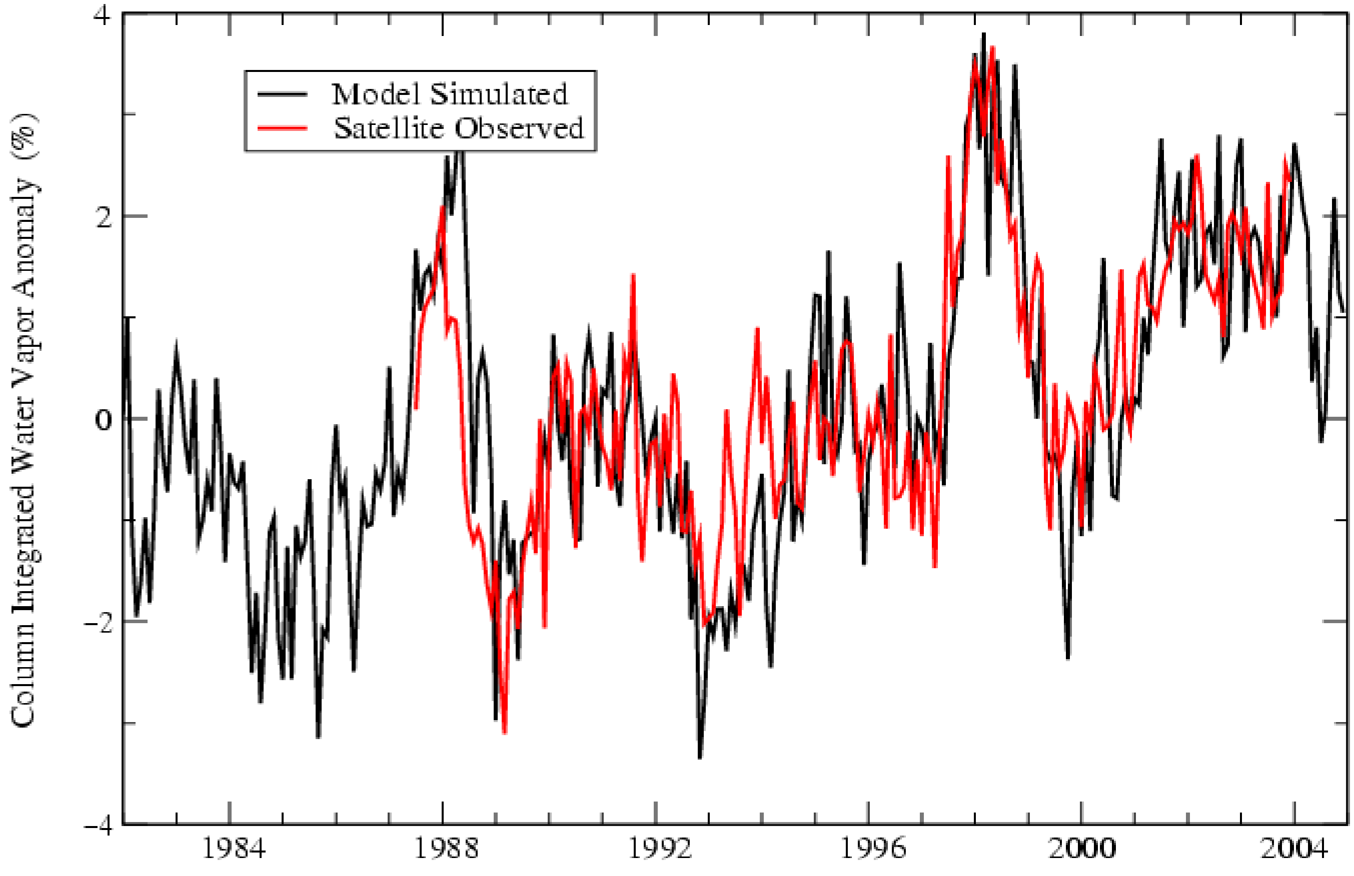
3 aspects of the global response of the hydrological cycle to warming

"the dry get drier and the wet get wetter"

the semi-arid subtropics expand polewards

the tropical rain belts move towards the hemisphere that warms the fastest

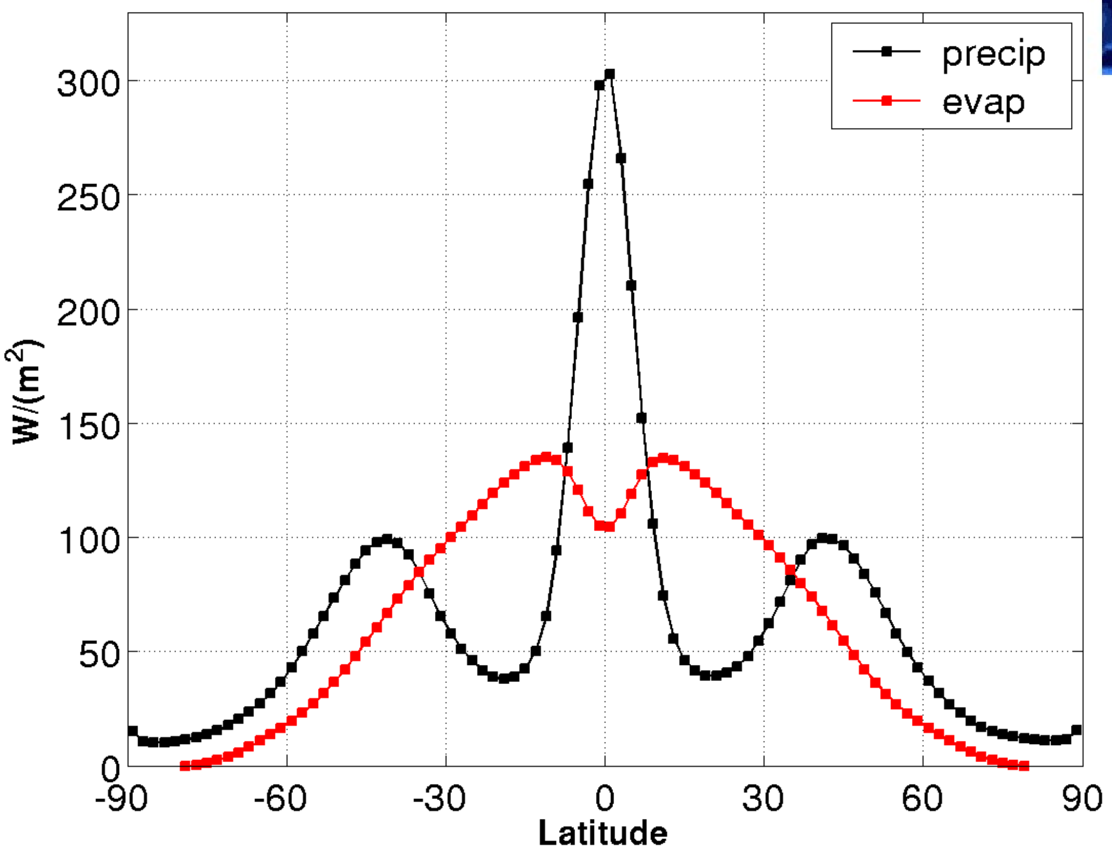
Total Column Water Vapor Anomalies (1987-2004)



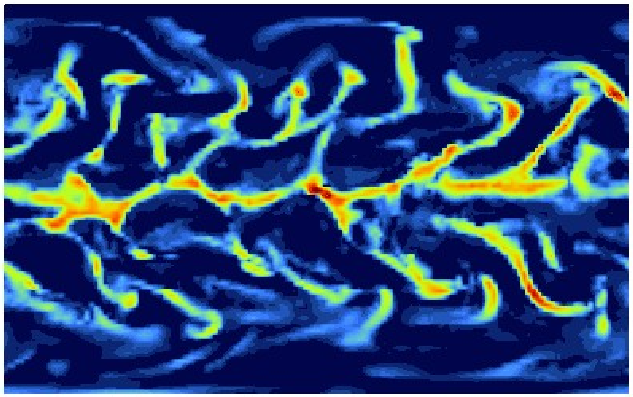
We have high confidence in the model projections of increased water vapor.

Held and Soden J.Clim. 2006

Precipitation and evaporation
"Aqua_planet" climate model
(no seasons, no land surface)

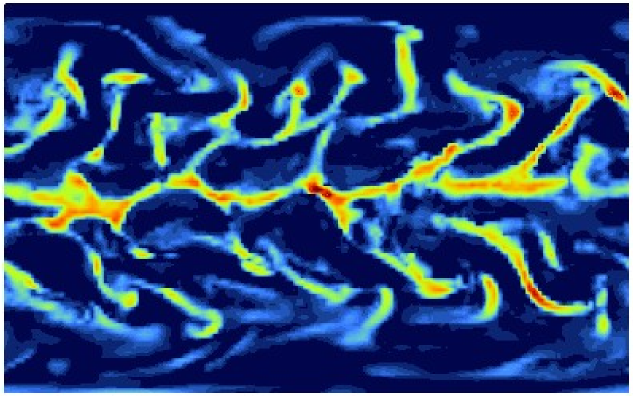


Time means

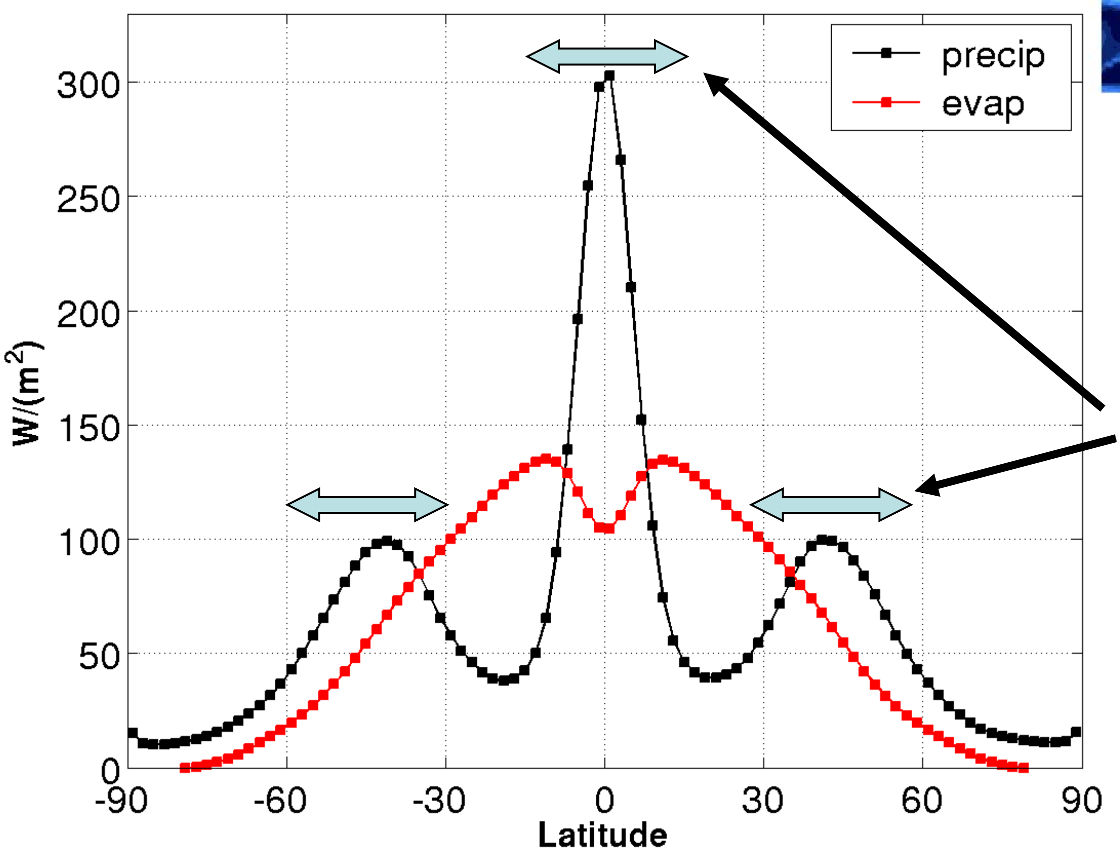


Instantaneous precip (lat,lon)

Precipitation and evaporation
"Aqua_planet" climate model
(no seasons, no land surface)

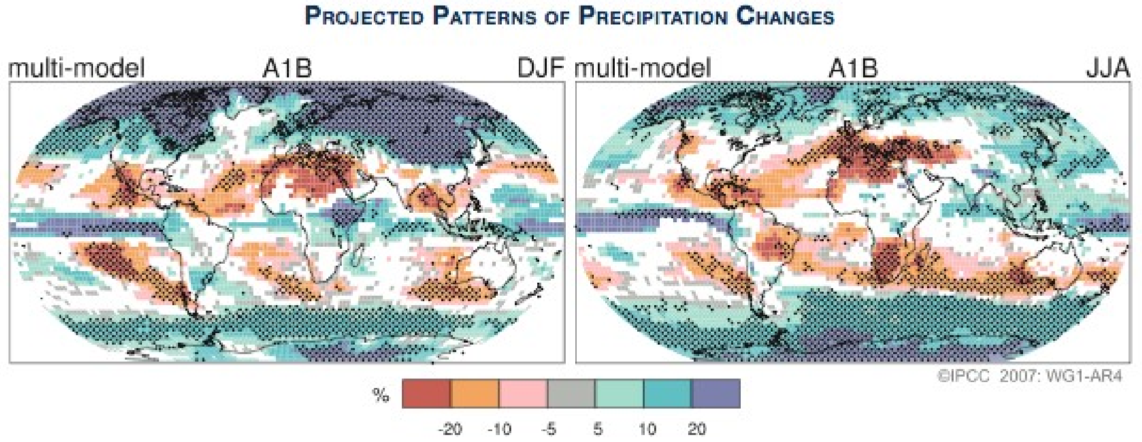


Instantaneous precip (lat,lon)

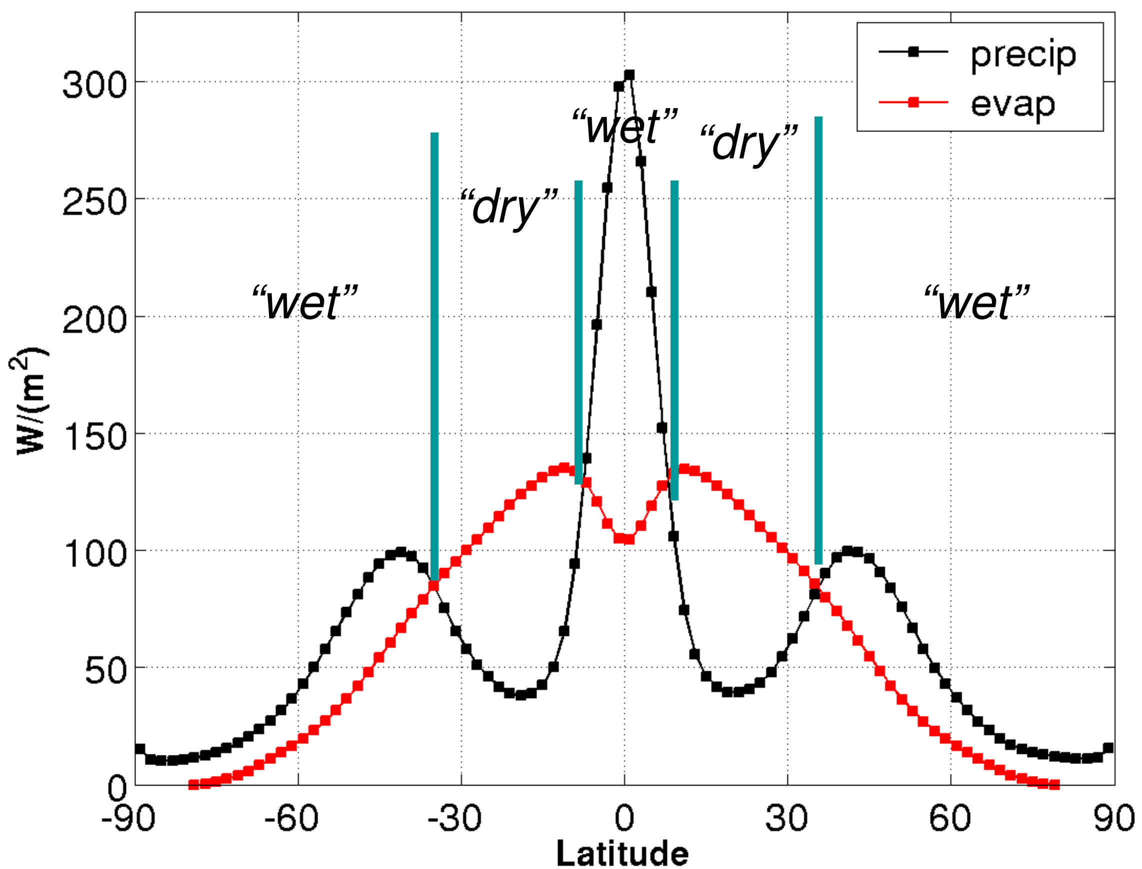


Precipitation moves
north and south with the seasons

Time means



Projected Patterns of Precipitation Changes
multi-model A1B DJF
multi-model A1B JJA
©IPCC 2007: WG1-AR4
%
-20 -10 -5 5 10 20



precip
evap
"wet"
"dry"
"wet"
"dry"
"wet"
"wet"
W/(m2)
300
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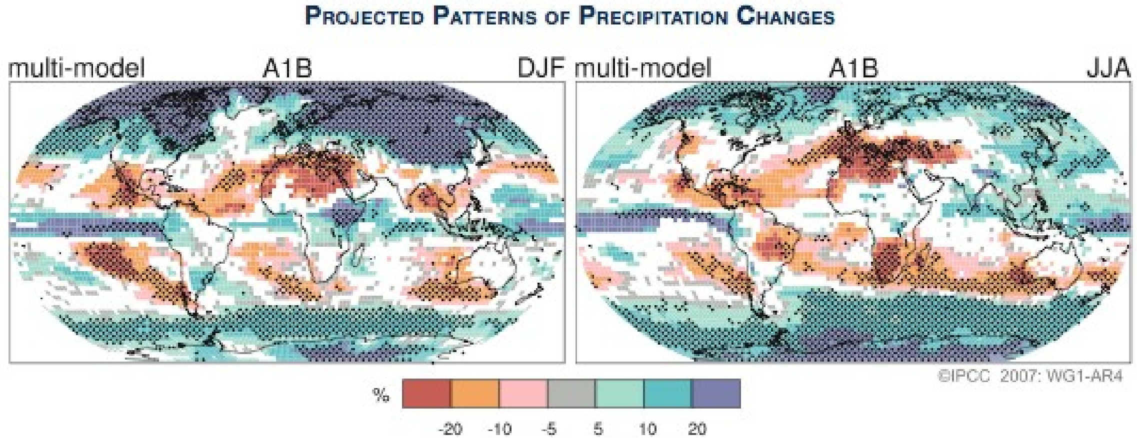
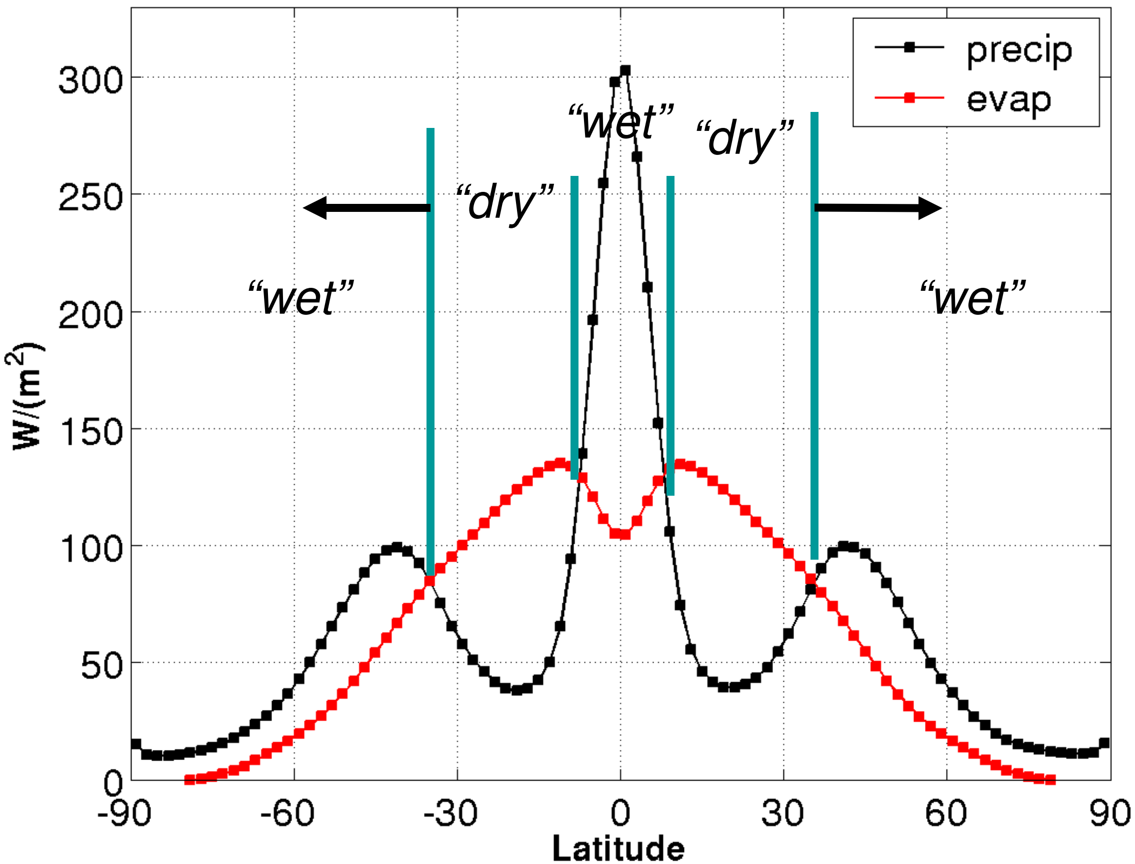
150
100
50
0
-90 -60 -30 0 30 60 90
Latitude

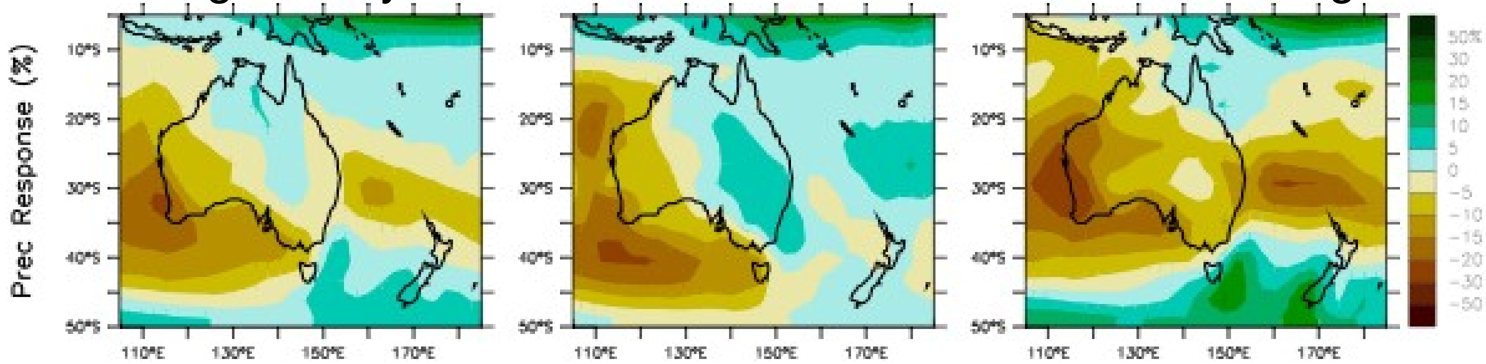

PROJECTED PATTERNS OF PRECIPITATION CHANGES
multi-model
A1B
DJF
multi-model
A1B
JJA
©IPCC 2007: WG1-AR4
%
-20
-10
-5
5
10
20

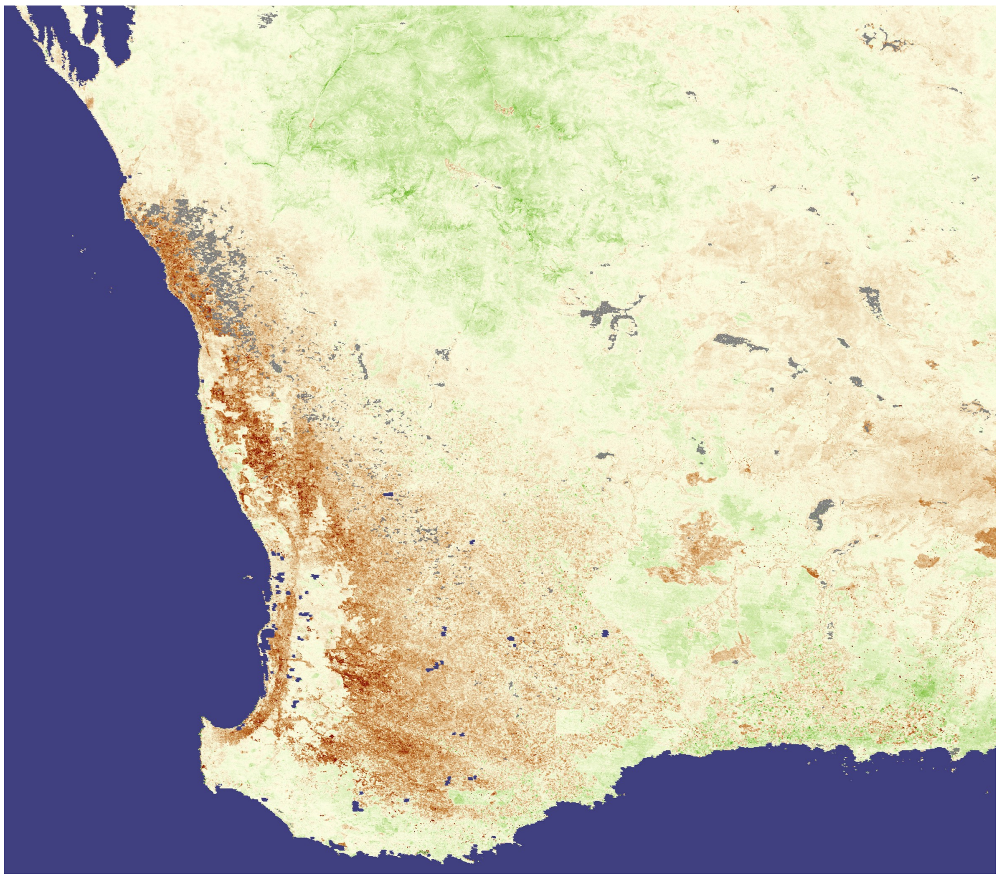

precip
evap
"wet"
"dry"
"dry"
"wet"
"wet"
W/(m^2)
300
250
200
150
100
50
0
-90
-60
-30
0
30
60
90
Latitude

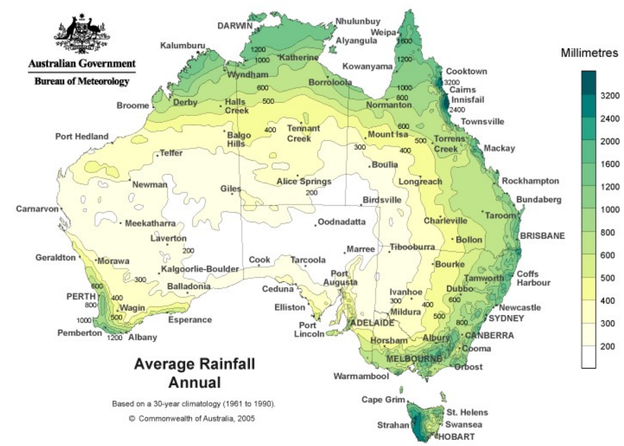
Regional impact of Precipitation: Present and Future.

Impact over Australia

Average over year | Dec-Jan-Feb | June-Jul-Aug







NDVI vegetation index
Anomaly in June 2006
(J. Allan – NASA Earth Observatory)

2006 Drought Headlines

News

Australia's drought may stay for keeps

By Benjamin Lester

Cosmos Online

....

Experts cited climate change as a factor contributing to the increasing uncertainty in Australian weather.

"It's a combination of short El Nino drought and longer-term decreasing rainfall," said Michael Coughlan, of the Australian Bureau of Meteorology.

Australia's Drought Could be Worst in 1,000 Years

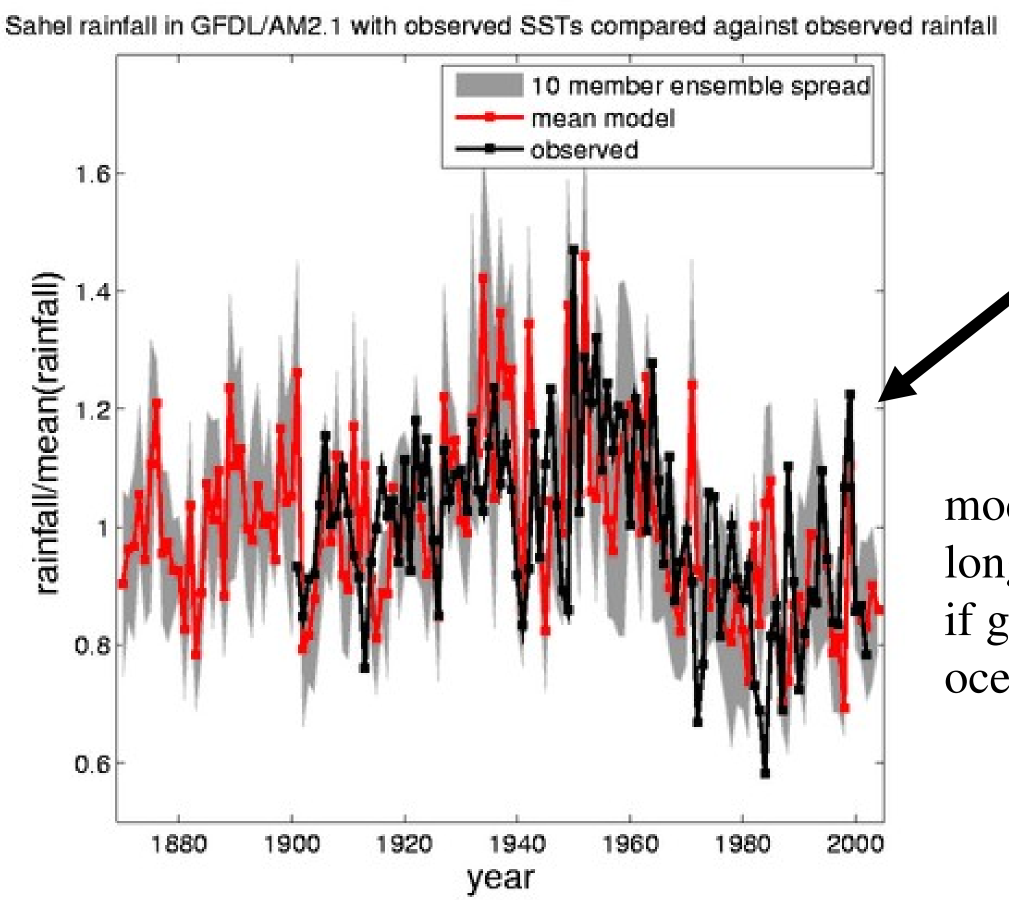
Australia's Drought Natural, Researcher Says

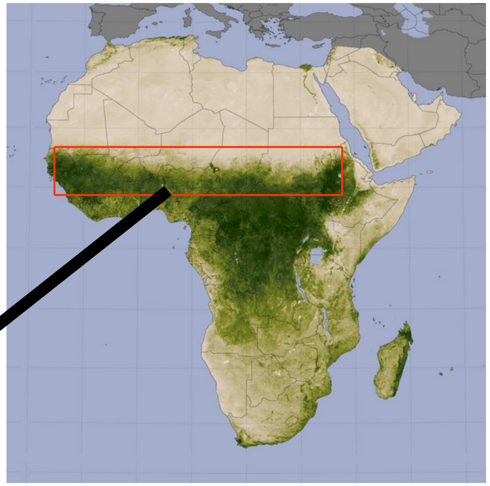
Precipitation over Africa

African drought

The Sahel drought of the 1970's and 1980's was NOT primarily due to "desertification"

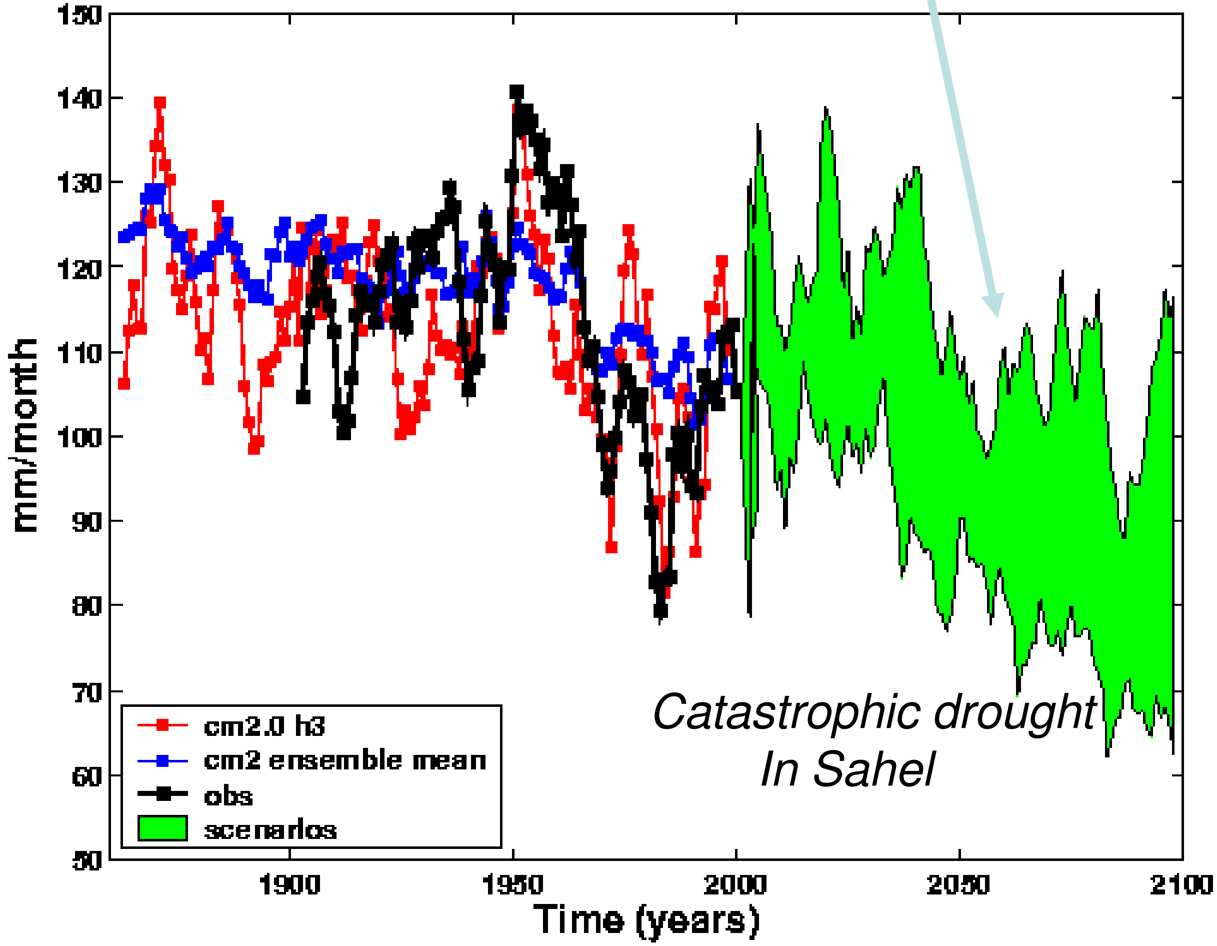
It was, rather, the response to changing ocean temperatures!





models can simulate the observed long term variations in *Sahel* rainfall if given the observed ocean surface temperatures

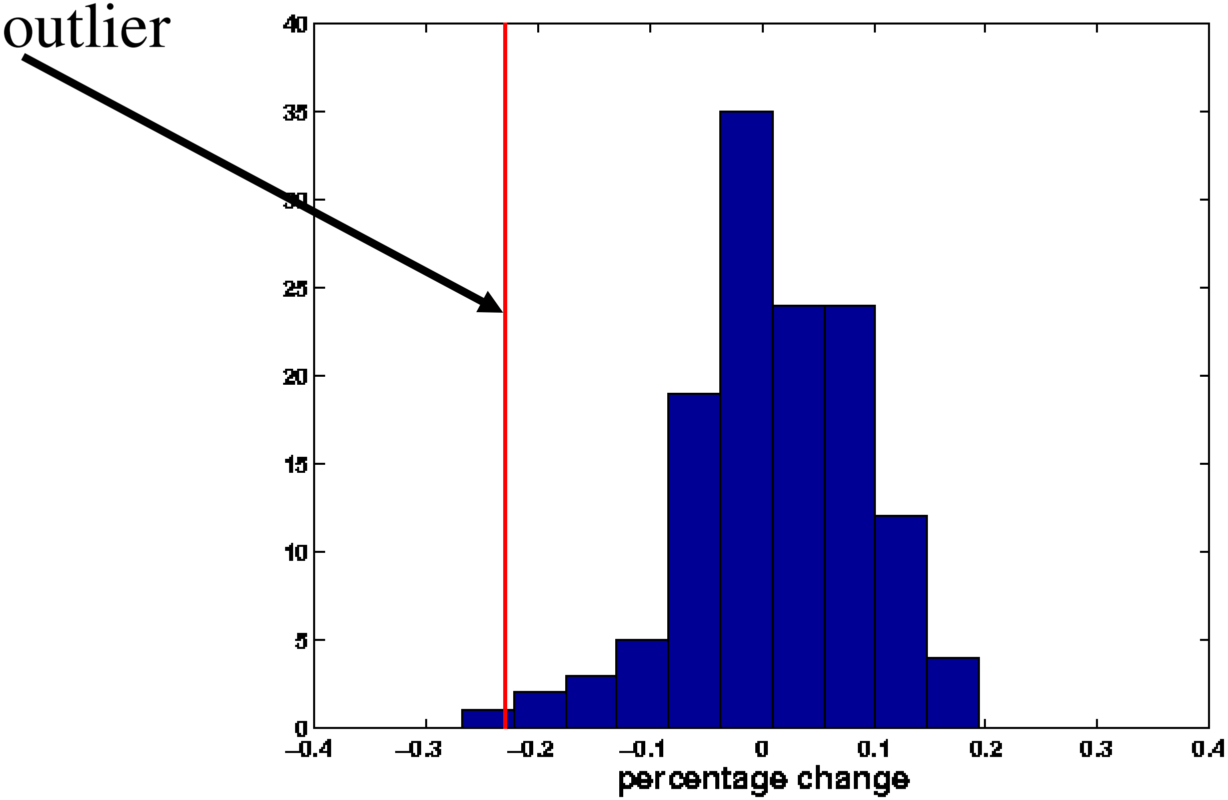
Response of GFDL/CM2.1 to range of SRES scenarios (B1/A1B/A2)



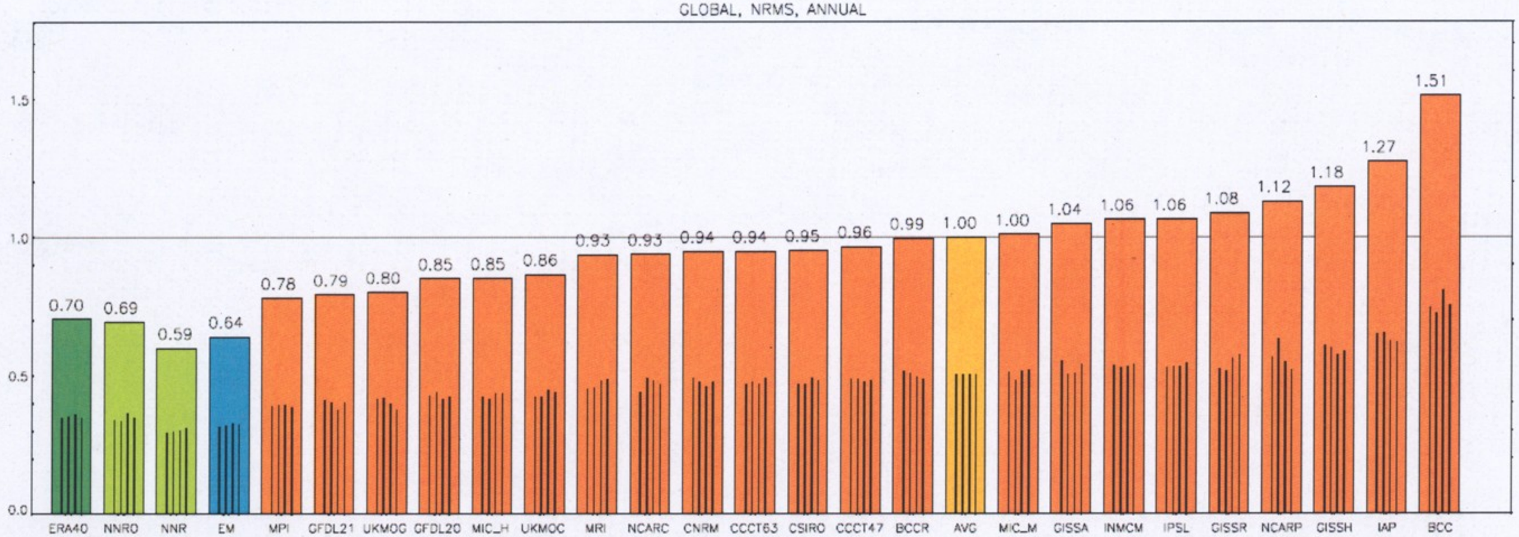
129 different models:
(courtesy of Matthew Collins, Hadley Center)

histogram of % Sahel rainfall response to 2xCO2

GFDL/CM2.1
is an outlier



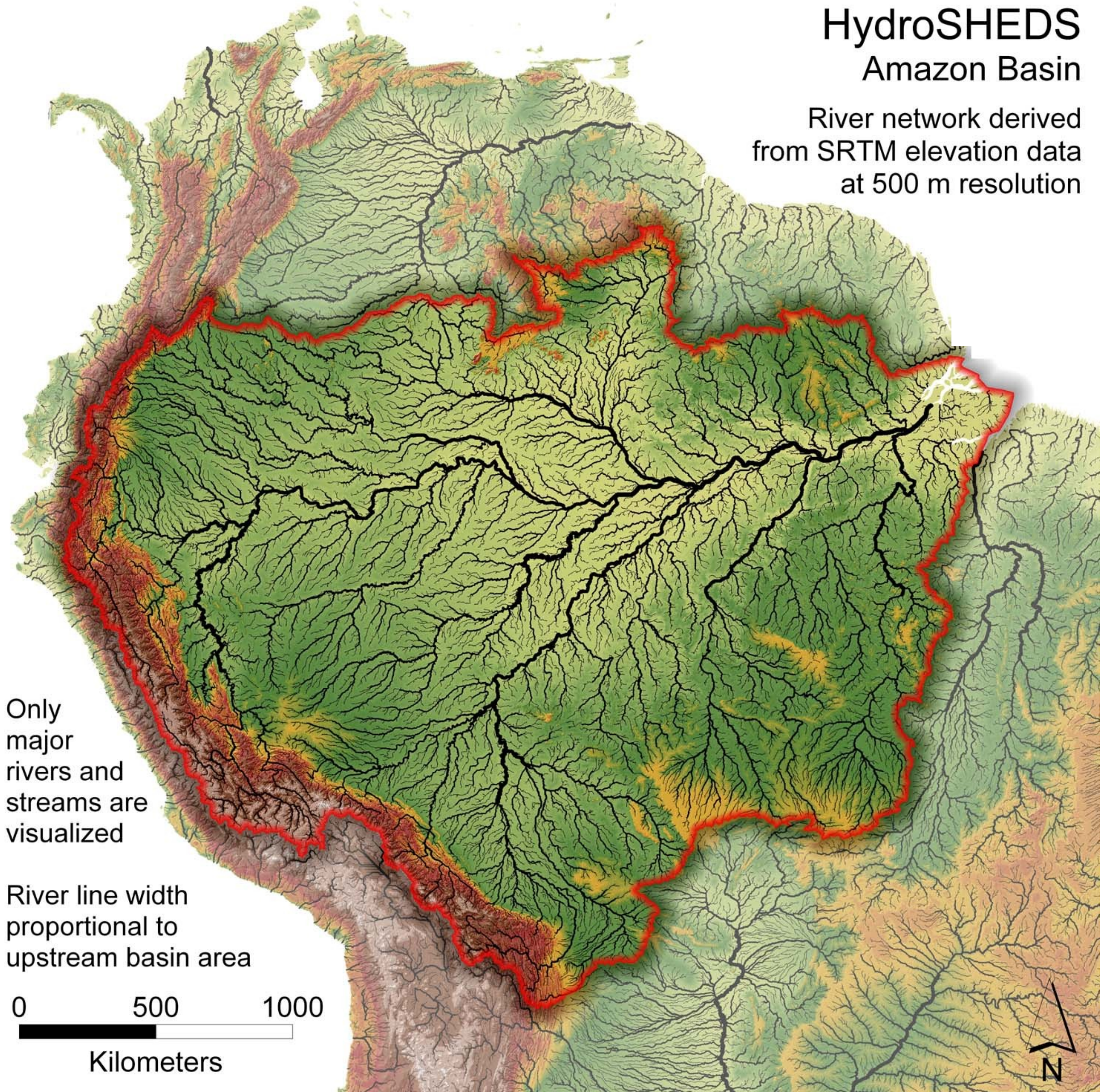
- overall performance in simulating global climatological fields (1979-1999)
- 4 seasons individually (black sticks) and mean over seasons (bars)
- based on normalized RMS error between model and observations
- 31 observational variables (ERA40 if no observations available)
- renormalized: index of 1 corresponds to average over all participating IPCC models



ERA40: ERA40 reanalysis compared against observations
NNRO: NCEP/NCAR reanalysis compared against observations
NNR: NCEP/NCAR reanalysis compared against observations or ERA40 (if no observations available)
EM: Ensemble mean over all models

reference: Kim, J., and T. Reichler (2005): A Performance Index for the Evaluation of Coupled Climate Models, AGU fall meeting, Global Environmental Change session, December 2005.

Some issues with the precipitation over South America


HydroSHEDS
Amazon Basin
River network derived
from SRTM elevation data
at 500 m resolution
Only
major
rivers and
streams are
visualized
River line width
proportional to
upstream basin area
0
500
1000
Kilometers
N

Amazon*

Total area: 5,866,100 km²

Countries	Area of Basin in Country km²	%
Brazil	3,672,600	62.61
Peru	974,600	16.61
Bolivia	684,400	11.67
Colombia	353,000	6.02
Ecuador	137,800	2.35
Venezuela	38,500	0.66
Guyana	5,200	0.09
Suriname	20	0.00

La Plata*

Total area: 2,954,500 km²

Countries	Area of Basin in Country km²	%
Brazil	1,379,300	46.69
Argentina	817,900	27.68
Paraguay	400,100	13.54
Bolivia	245,100	8.30
Uruguay	111,600	3.78

Main features of La Plata Basin

Description:

ApproximateExtension:

- ~ 3.200.000 km2

5 countries

- Argentina
- Bolivia
- Brasil
- Paraguay
- Uruguay

Main Rivers:

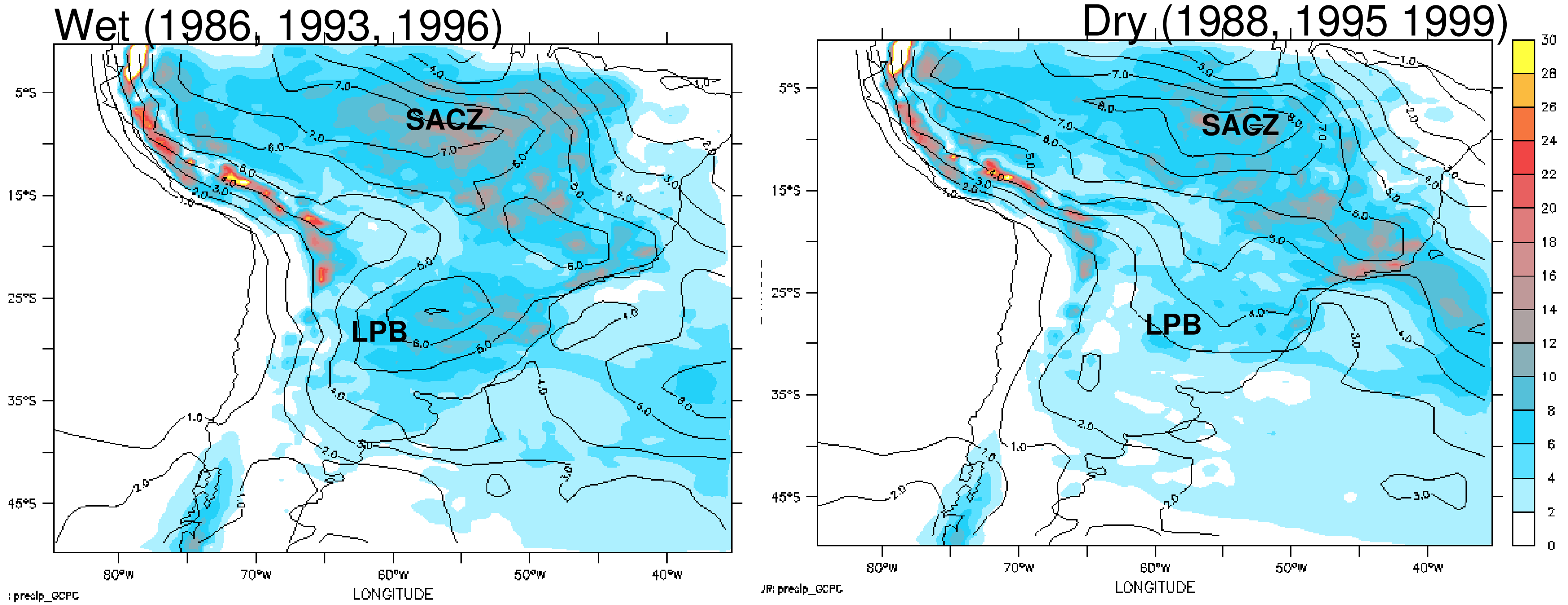
- Paraná, Paraguay, Uruguay, Iguazú, Pilcomayo y Bermejo.

Economic Relevance:

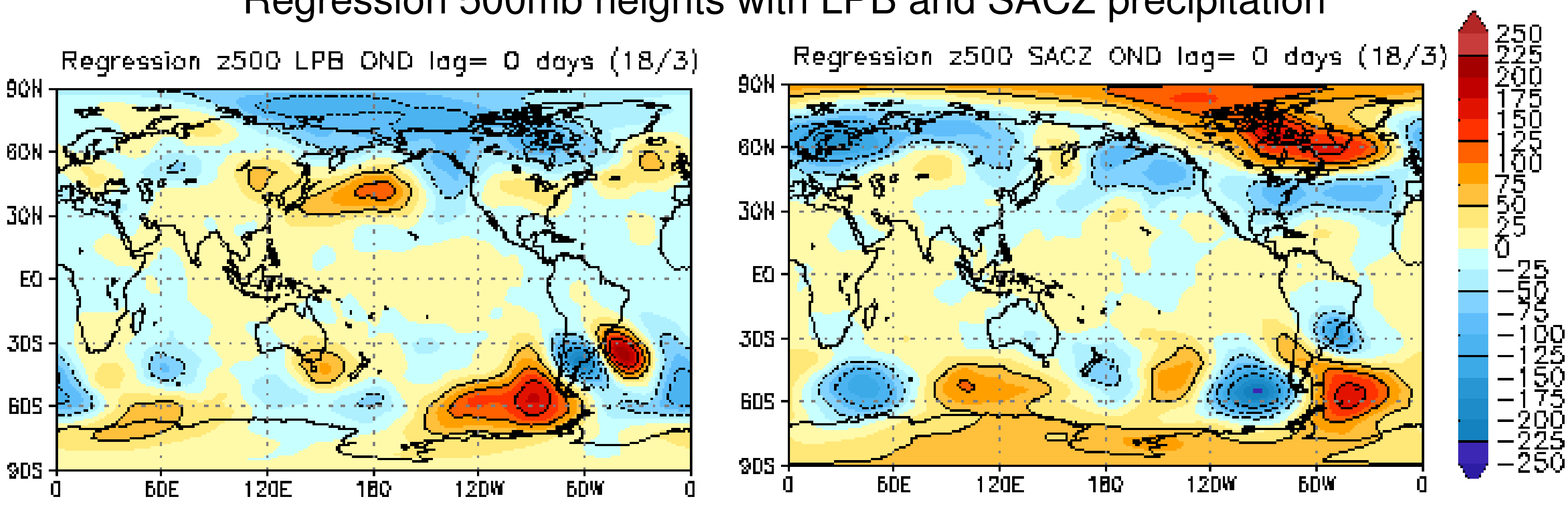
Highly populated:

- ~ 100.000.000 people
- Produces the 70% of the global production of the 5 countries.
- More than 40 hydroelectric centrals that satisfy the 60% of the power demand of the region.
- Is partially navigable by barges and ships.
- An Hydroway is under implementation now.

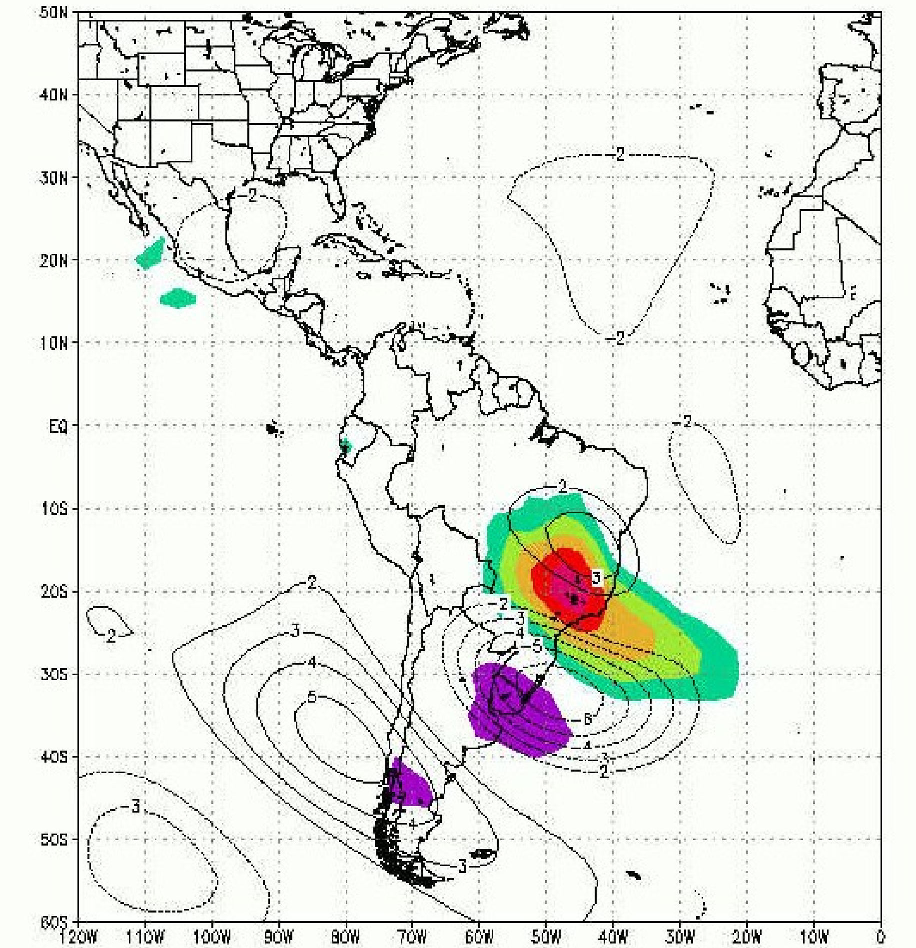
Precipitation (mm/day) Oct-Dec Simulations Zetac model



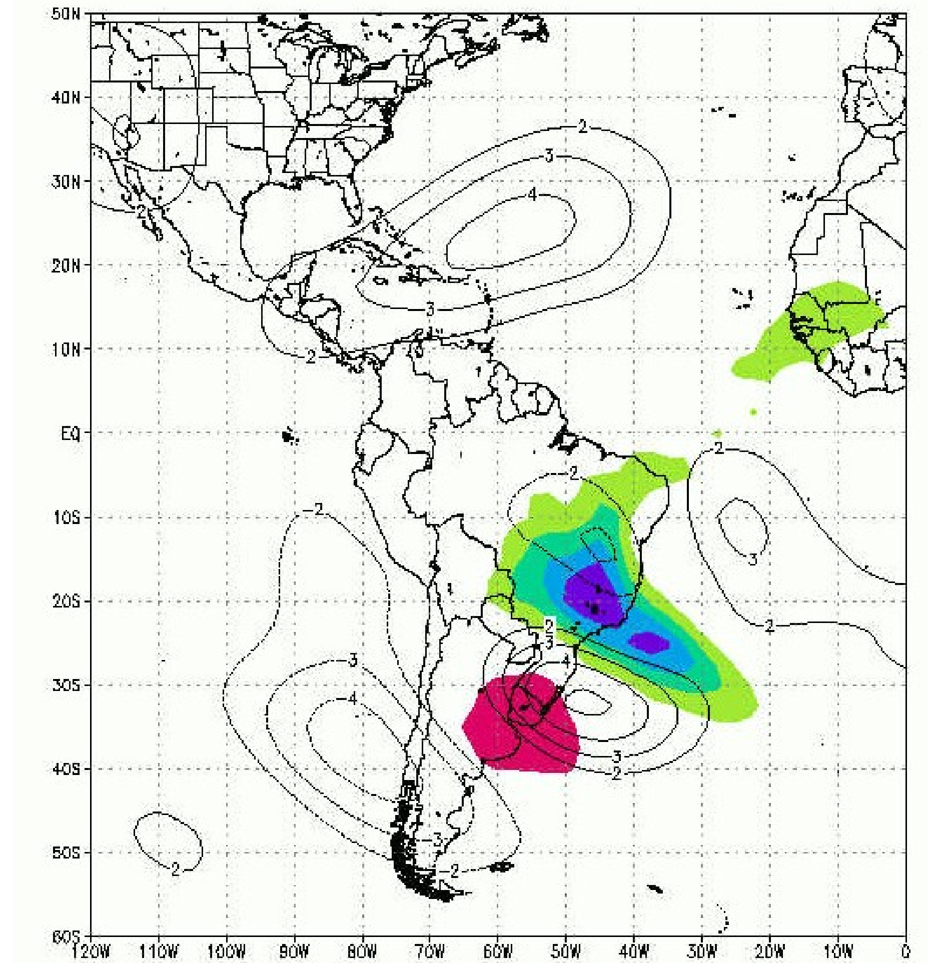
Regression 500mb heights with LPB and SACZ precipitation



Dominant periods of variability are found: 36-40 day (MJO) and a 22-28 day mode, The figures show OLR and 200 HPa streamfunction anomalies.



The 22-28 day mode



Linkages between thee Americas when the 22day and 40 day modes overlap.

Paegle et al (1999)

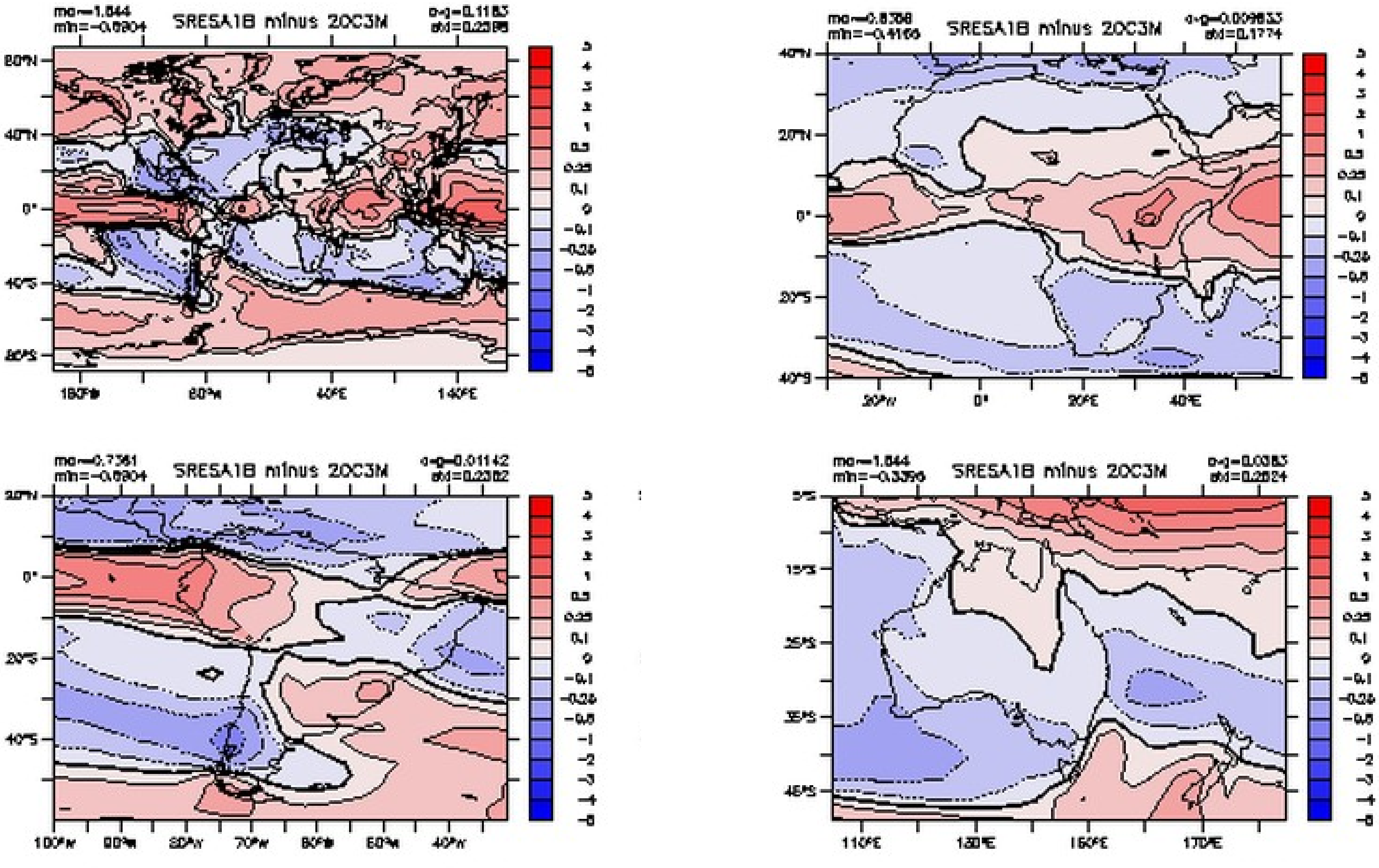
Preliminary Conclusions:

There is a see-saw pattern of precipitation between the Amazon and south of it.

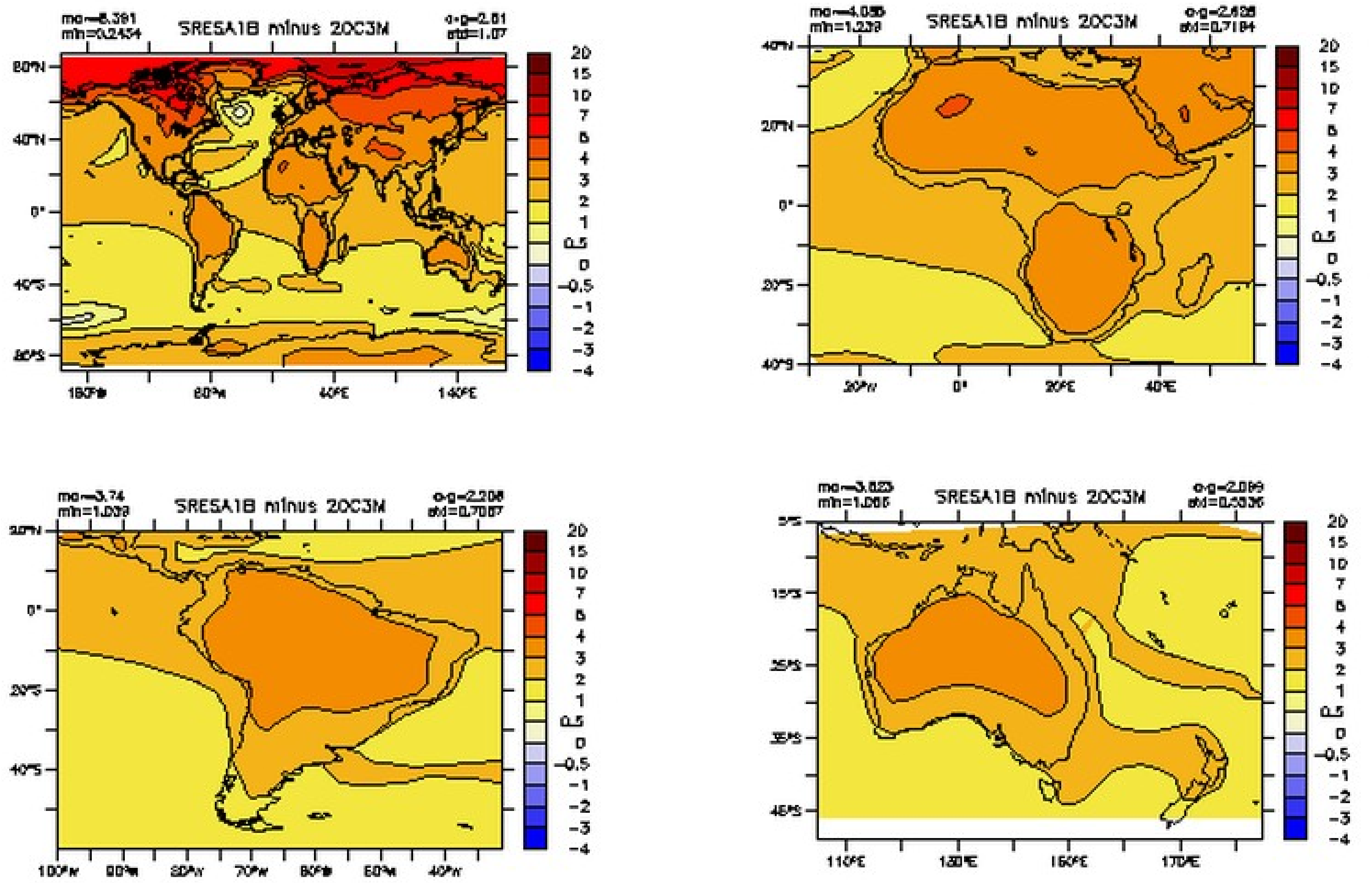
There is an interplay between a “high” south east of Brazil and “lows” entering from the south of Argentina. The “high” flux moisture to west of the LPB region, and the frontal system when enters from the south pushes the “high” further east and flux moisture to the northern regions of the subtropics displacing the precipitation further equatorward. These is the basic of the See-Saw pattern.

Is possible that if the storm tracks move poleward due to climate warming influence, the see-saw pattern of precipitation would change.

Annual Precipitaton anomaly (mm/day) SRESA 1B – 20C climate



Annual Temperature anomaly (C) SRESA 1B – 20C climate



Final Remarks:

the dry get drier and the wet get wetter"

the semi-arid subtropics expand polewards

the tropical rain belts move towards
the hemisphere that warms the fastest

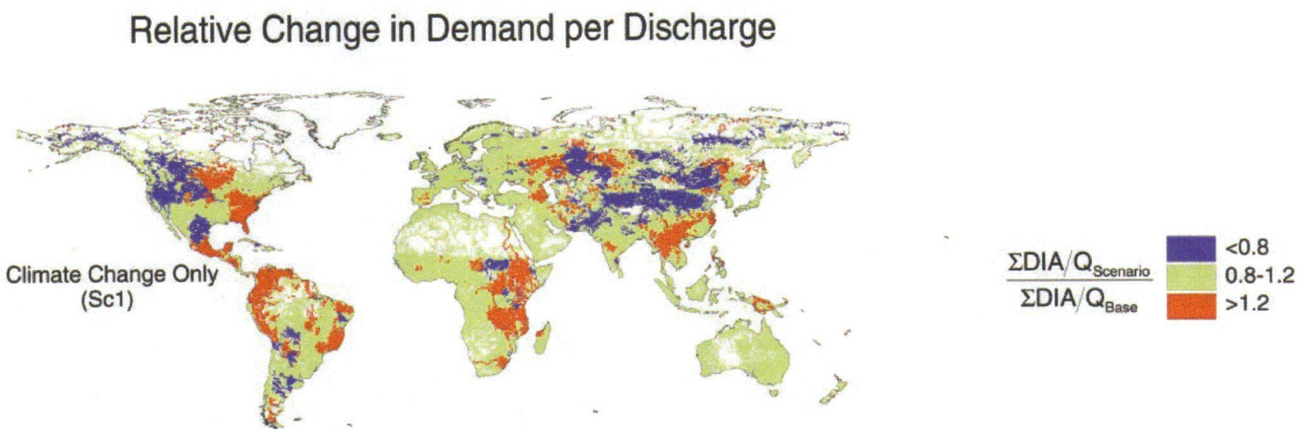


Fig from: Global Water Resources: Vorosmarty et al: 2000 Science Vol 289

Is it possible that with the new results of the IPCC 4th scientific assessment the stress shown on this figure underestimate the climate change scenario for the subtropical regions.?