Long Term Climate Change

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today

- Climate Change and Assessments
  - All about the IPCC
- Climate Modeling the Long Term
- Requirements for the IPCC 2007 Report
- Simulation Results
- Implications for Texas & the Southwest

Why should you believe the IPCC?

- Produced from an open and credible process
- Multiple layers of internal review
- 2001 report also was reviewed and endorsed by the National Academy
- 2001 report also endorsed by the AGU, AMS, AAAS, etc.

Could the IPCC be wrong?

- Recognize: the goal of the IPCC is not to reveal “truth,” but to summarize the peer-reviewed literature
- If the underlying science is wrong, then the assessment will also be wrong
- But the odds of the IPCC not accurately representing the views of the scientific community are basically nil

IPCC Fourth Assessment Report Findings:

- **The Earth has warmed about 0.74±0.2°C over the last 100 years**
- **Most of the warming of the last 50 years is very likely to be due to human activity**
- **Warming over the 21st century will be 1.8 to 4.0°C**
- **Impacts of this are possibly severe**

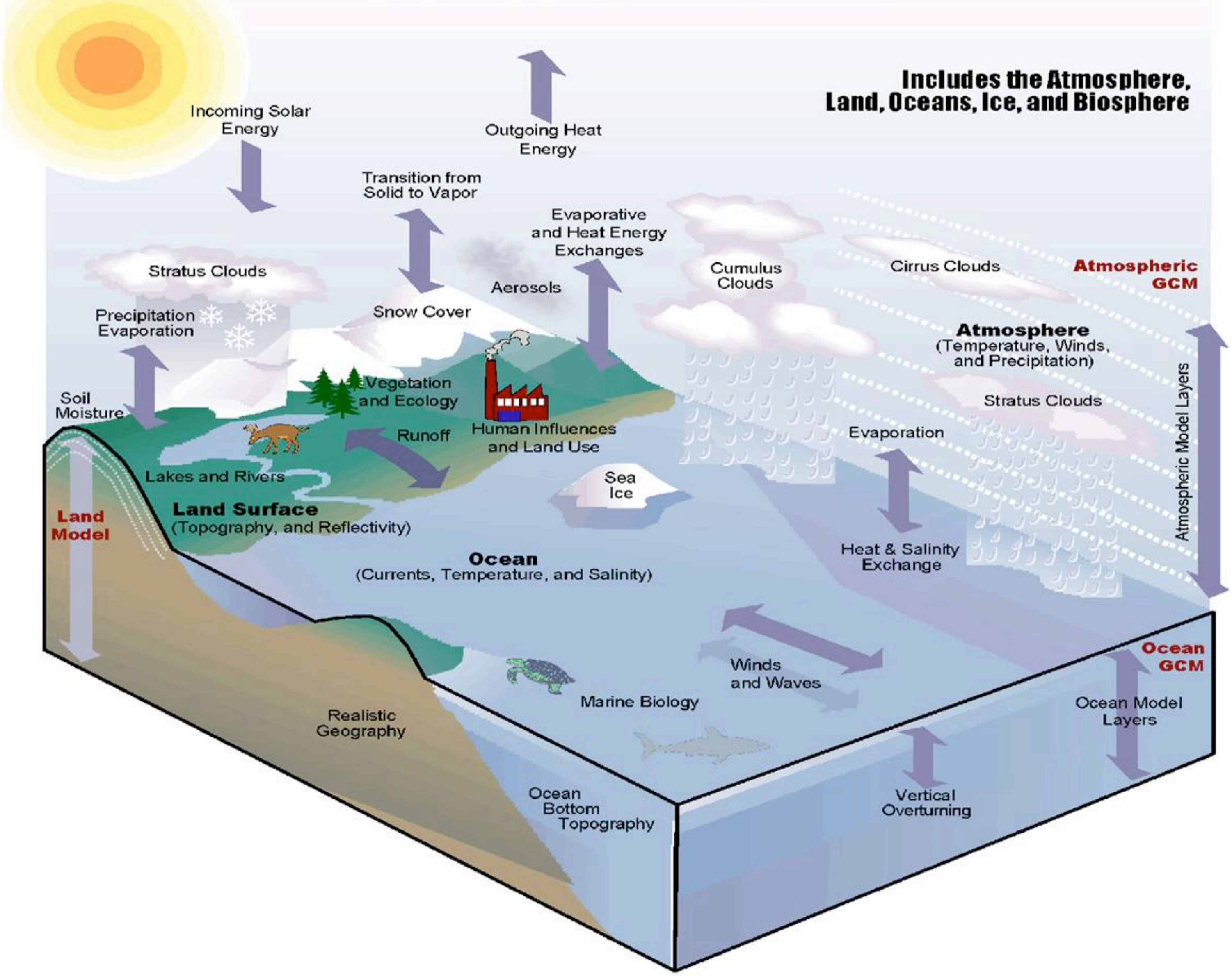
Now, About Climate Models

- It’s all about physics, numerical analysis, etc.
- Some history, progress in climate modeling
- What are the latest results?

Look Under the Hood of a Climate Model

- Physics of Atmospheric-Oceanic-Land System
- PD Equations: Conserve mass, energy, momentum, water.
- More physics: cloud, convection, ice, land surface, salinity, etc.

Modeling the Climate System



Includes the Atmosphere, Land, Oceans, Ice, and Biosphere

Washington & Parkinson (2005)

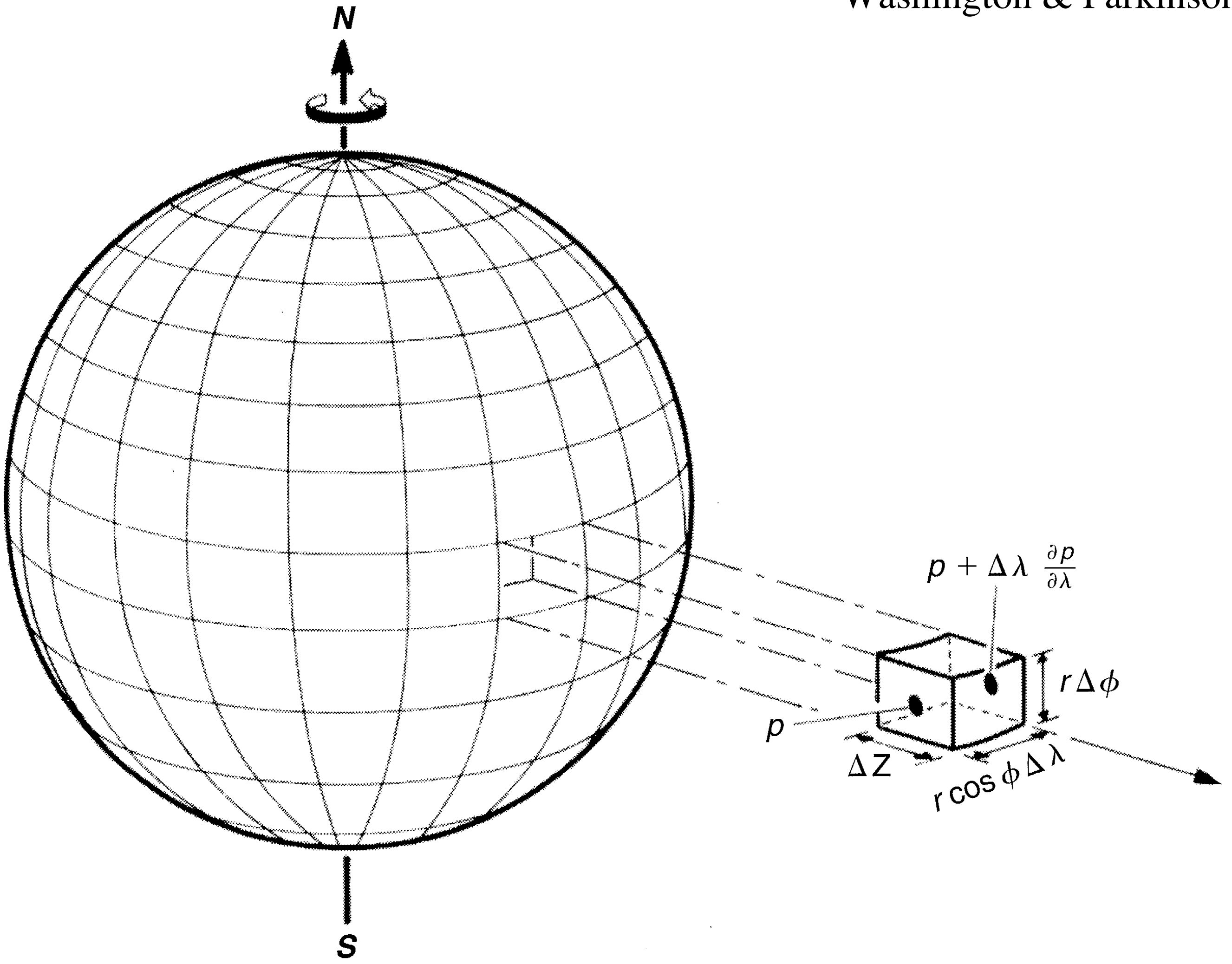


Figure 3.2 Schematic of pressure forces on an imaginary volume of air.

$$T(\vartheta,\varphi)=\sum_{\ell=0}^{L}\sum_{m=-\ell}^{l}T_{\ell}^{m}Y_{\ell}^{m}(\vartheta,\varphi)$$

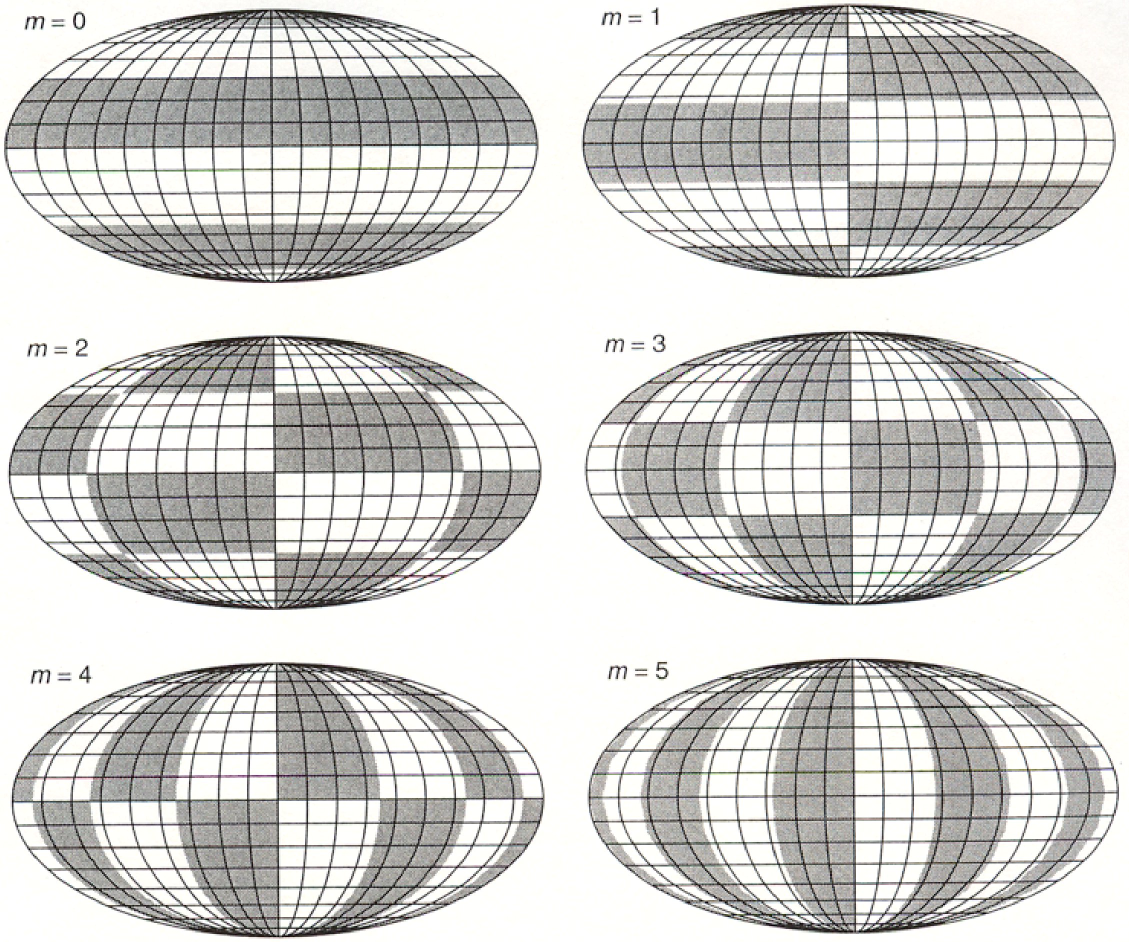
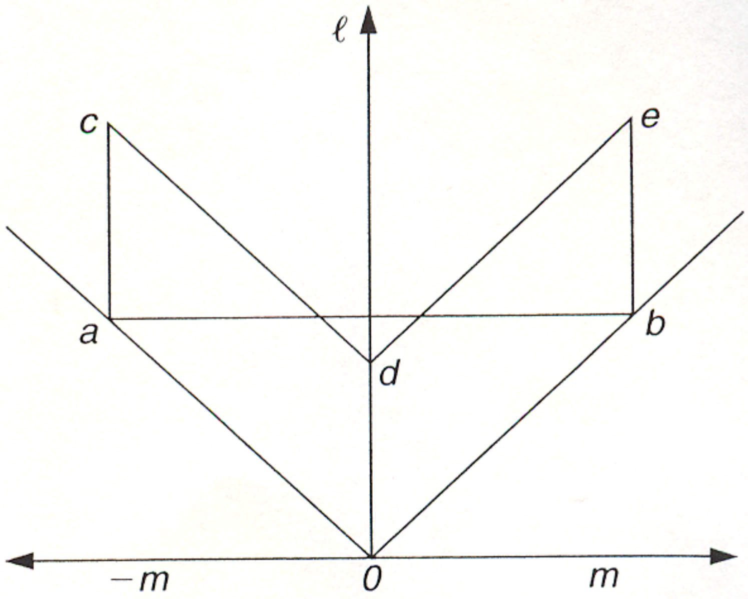
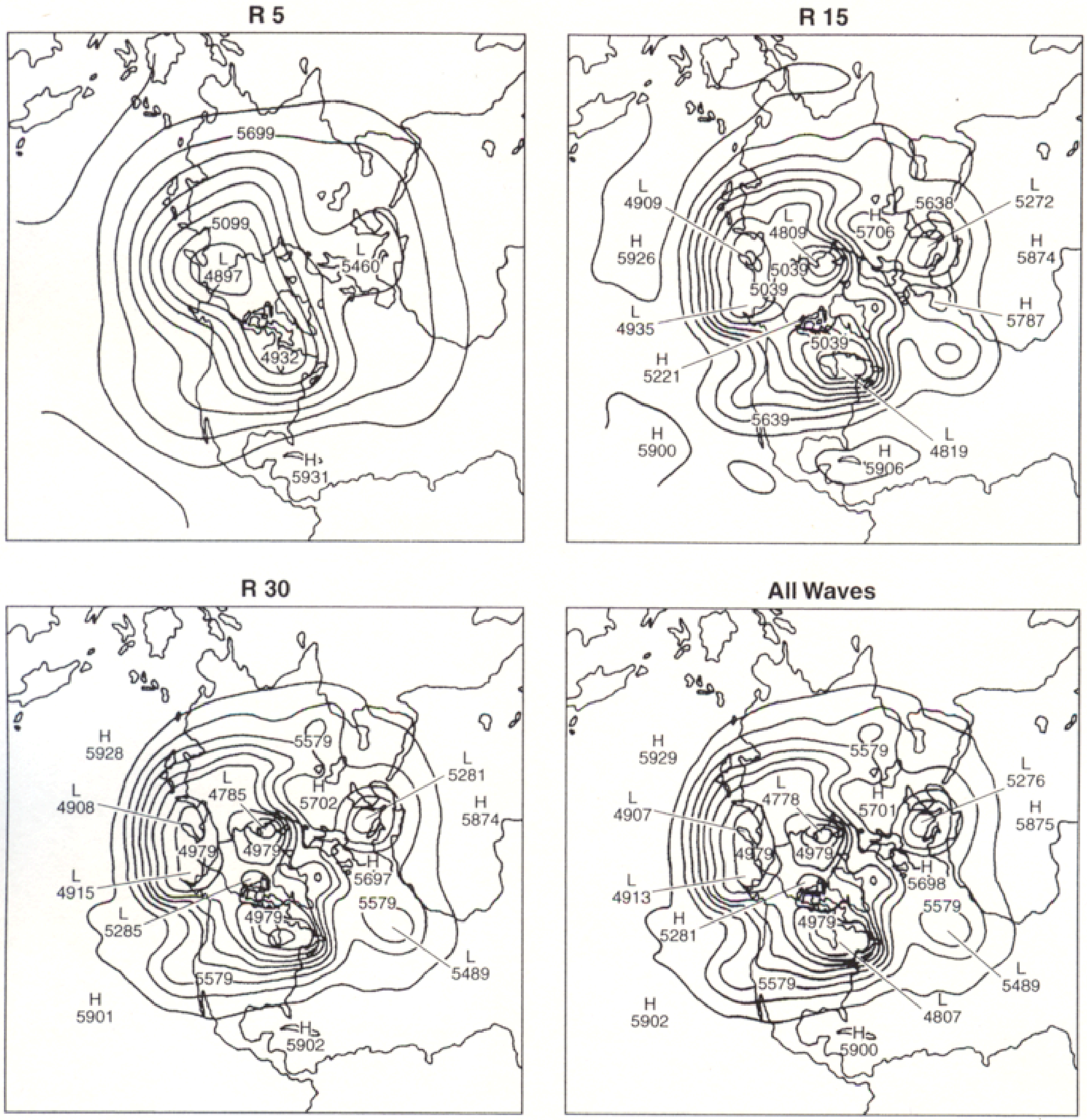


Figure 4.10 Alternating patterns of positives and negatives for spherical functions with $\ell = 5$ and $m = 0, 1, 2, 3, 4, 5$. (Redrawn from Baer 1972.)

Truncating Methods: R vs T

Figure 4.9 ℓ and m space showing two commonly used spectral truncations, triangular (0, a, b) and parallelogramic (a, c, d, e, b, 0).





R 5

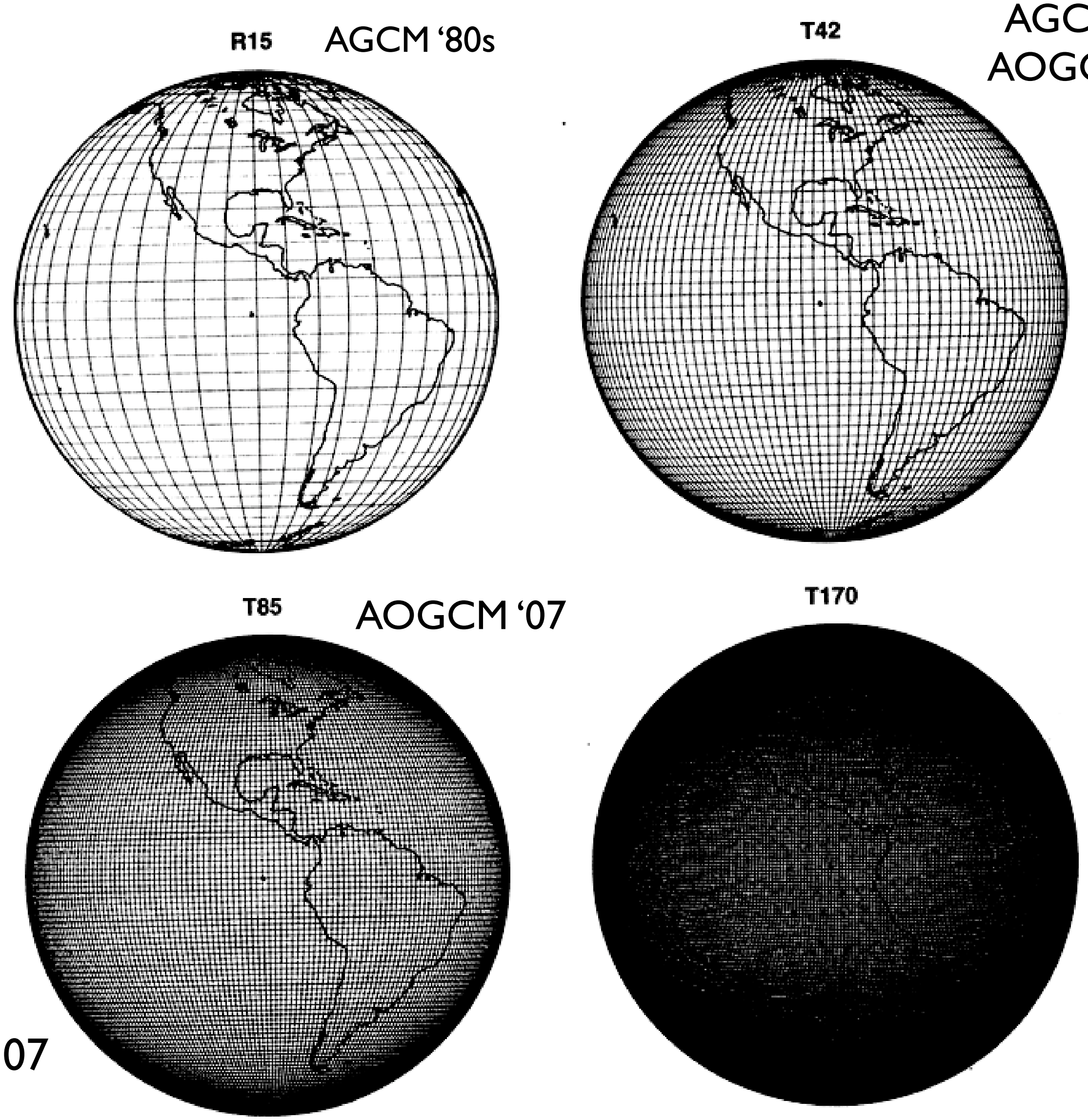
R 15

R 30

All Waves

Figure 4.11 Demonstration of the effects of various horizontal truncations of 500 mb patterns of geopotential height (*m*) of 2.5° latitude/longitude data: rhomboidal, R5, R15, and R30, and the original 2.5° data (All Waves). (Redrawn from David Baumhefner, personal communication, 1986.)

Equivalent Grids for Various Truncations



AGCM ‘80s

AGCM ‘90s
AOGCM ‘00s

AOGCM ‘07

IPCC 07

Figure 4.12 Gaussian and triangular grids on the globe for various resolutions: rhomboidal, R15, and triangular, T42, T85 and T170. (David Williamson, personal communication, 2002.)

Timeline of Climate Model Development

Mid-1960s	Mid 1970s-1980s	1990s	Present Day	2000-2010
Atmosphere/ Land Surface	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation	Atmosphere/ Land Surface/ Vegetation
Ocean	Ocean	Ocean	Ocean	Ocean
	Sea Ice	Sea Ice	Sea Ice	Sea Ice
	Coupled Climate Model	Coupled Climate Model	Coupled Climate Model	Coupled Climate Model
		Sulfate Aerosol	Sulfate Aerosol	Sulfate Aerosol
		Carbon Cycle	Carbon Cycle	Carbon Cycle
			Dust/Sea Spray/Carbon Aerosols	Dust/Sea Spray/Carbon Aerosols
			Interactive Vegetation	Interactive Vegetation
			Biogeochemical Cycles	Biogeochemical Cycles
				Ice Sheet

T42 Simulations

Precipitation
Distribution

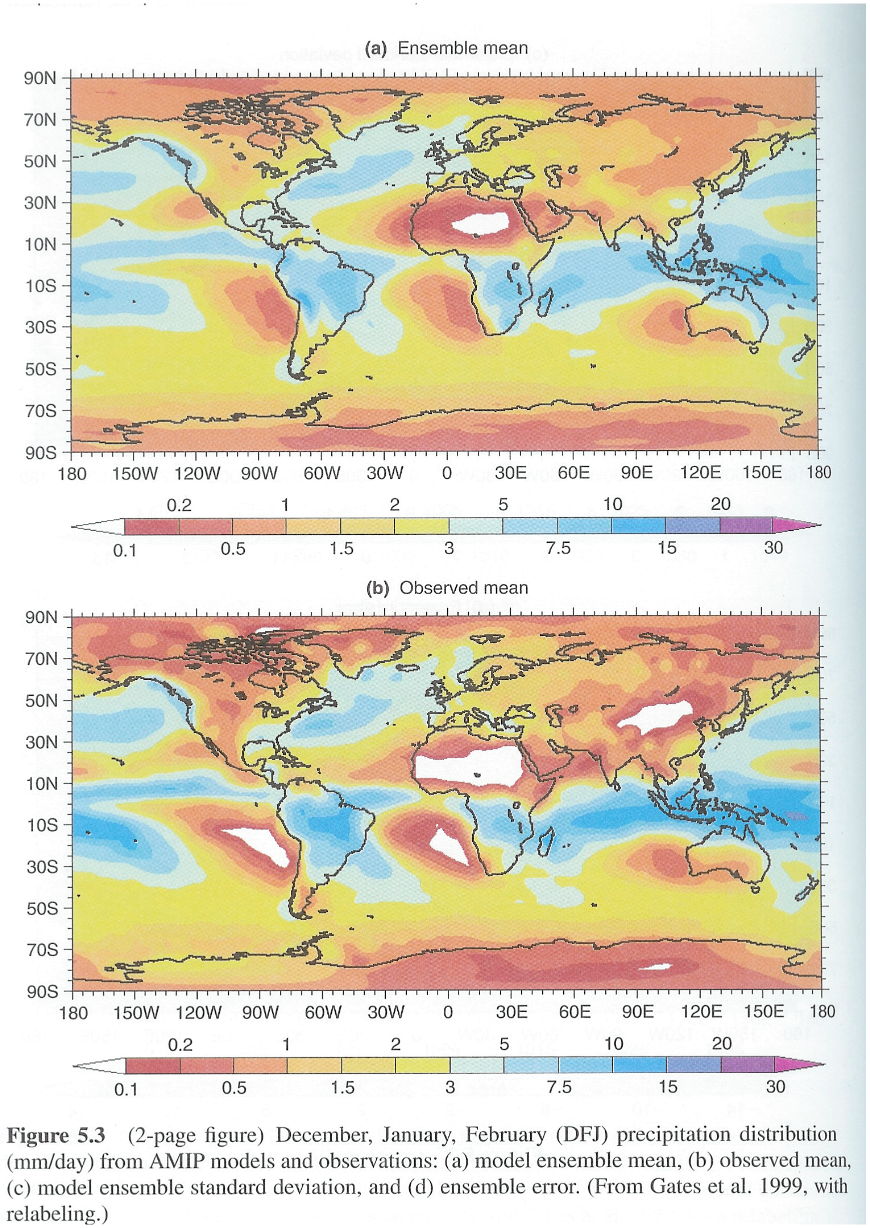


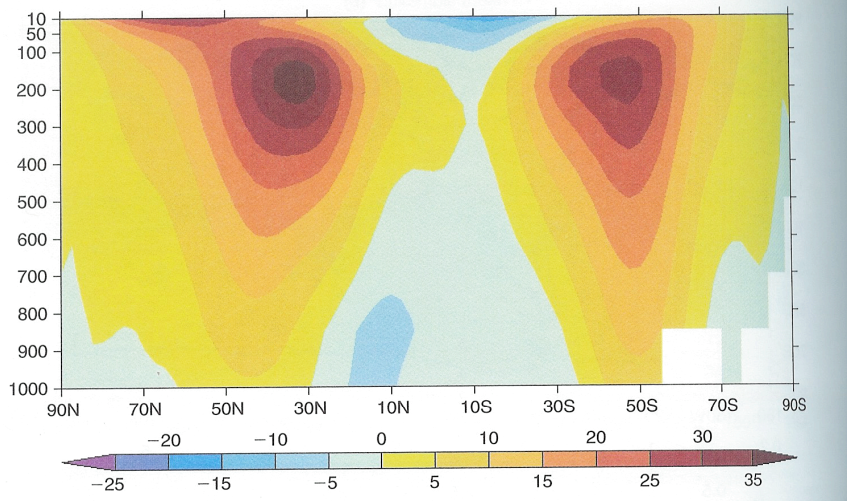
Figure 5.3 (2-page figure) December, January, February (DFJ) precipitation distribution (mm/day) from AMIP models and observations: (a) model ensemble mean, (b) observed mean, (c) model ensemble standard deviation, and (d) ensemble error. (From Gates et al. 1999, with relabeling.)

Washington & Parkinson (2005)

T42 Simulations

Zonal Winds

(a) Ensemble mean



(b) Observed mean

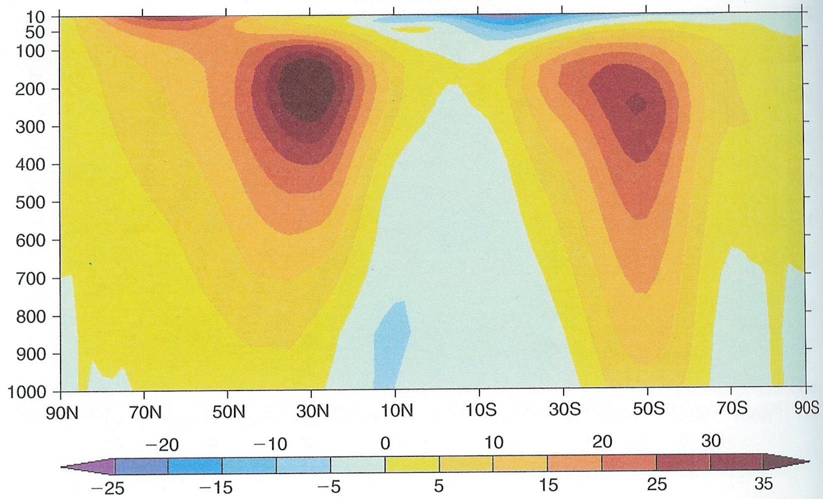
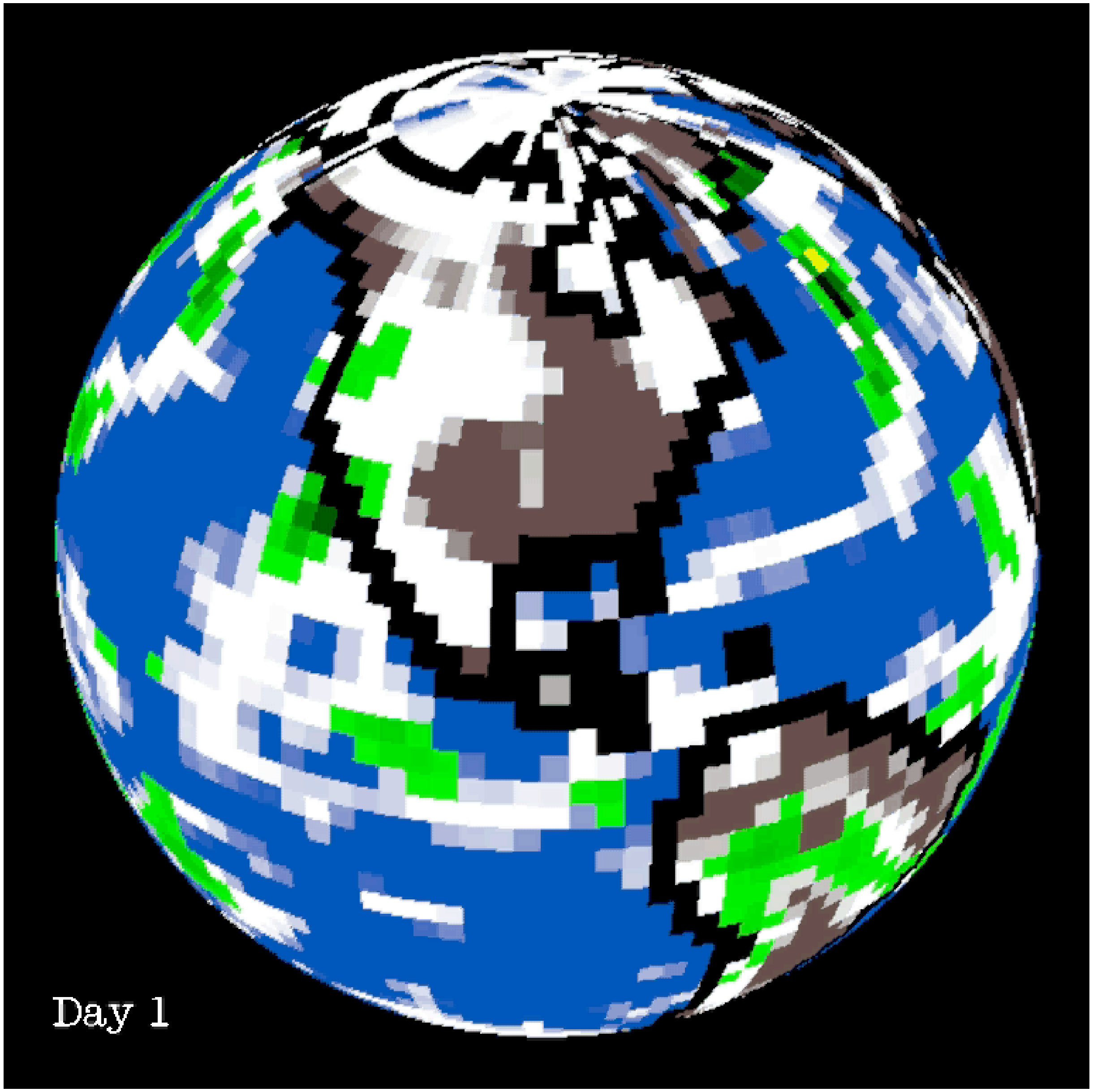


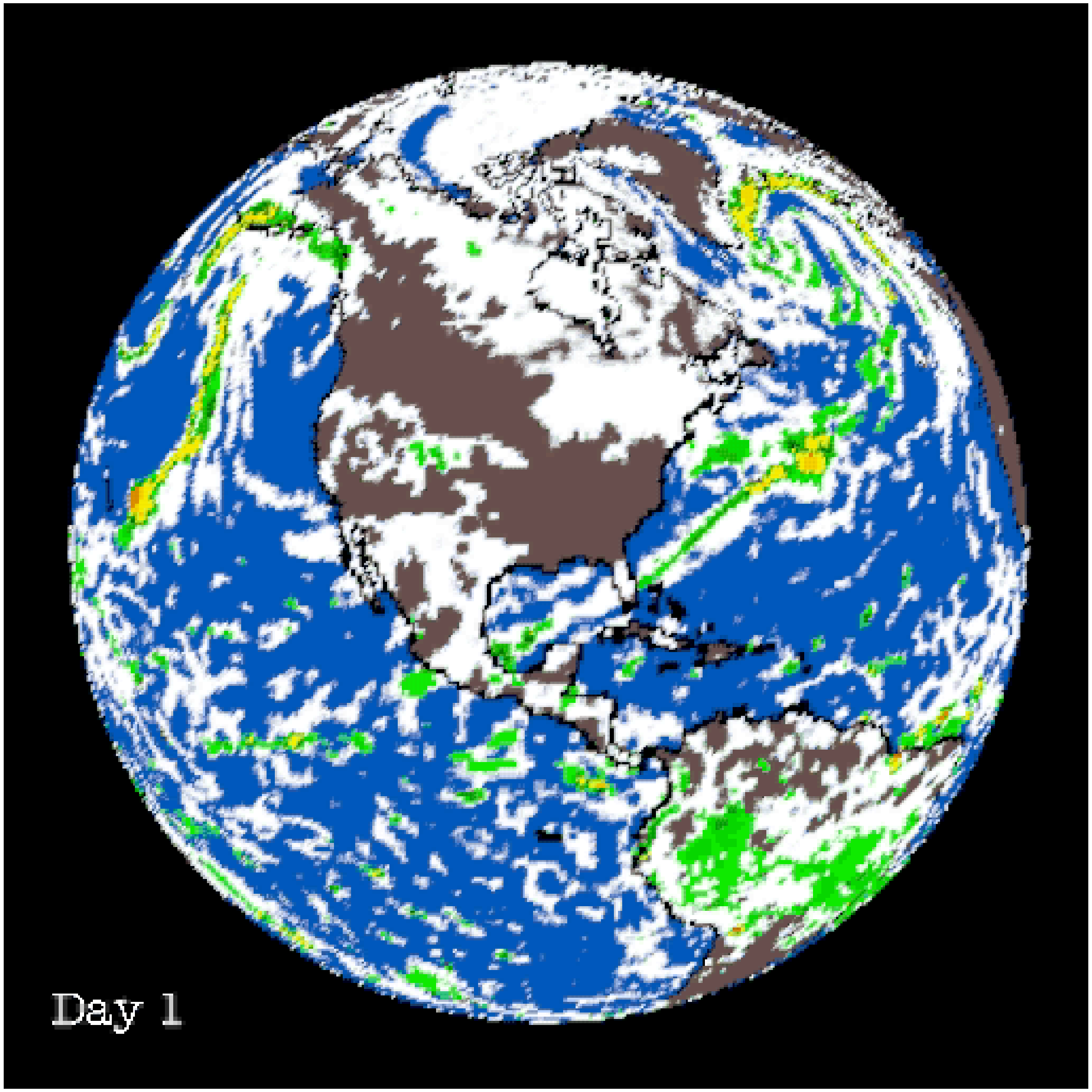
Figure 5.4 (2-page figure) December, January, February (DJF) zonal wind patterns (m s^{-1}) from AMIP models and observations: (a) ensemble mean, (b) observed zonal mean, (c) model ensemble standard deviation, and (d) ensemble error. (From Gates et al. 1999, with relabeling.)

Washington & Parkinson (2005)

Look at a Couple of 10 day Simulations

T42





T239 Resolution
(Weather Forecasting Resolution)

Now, a little about TX and the SW

- Hadley Circulation and its expansion
- New paper to appear in *Science*
  - Future climate of the US SW
- Low frequency variability differences

Washington & Parkinson (2005)

Hadley Cell

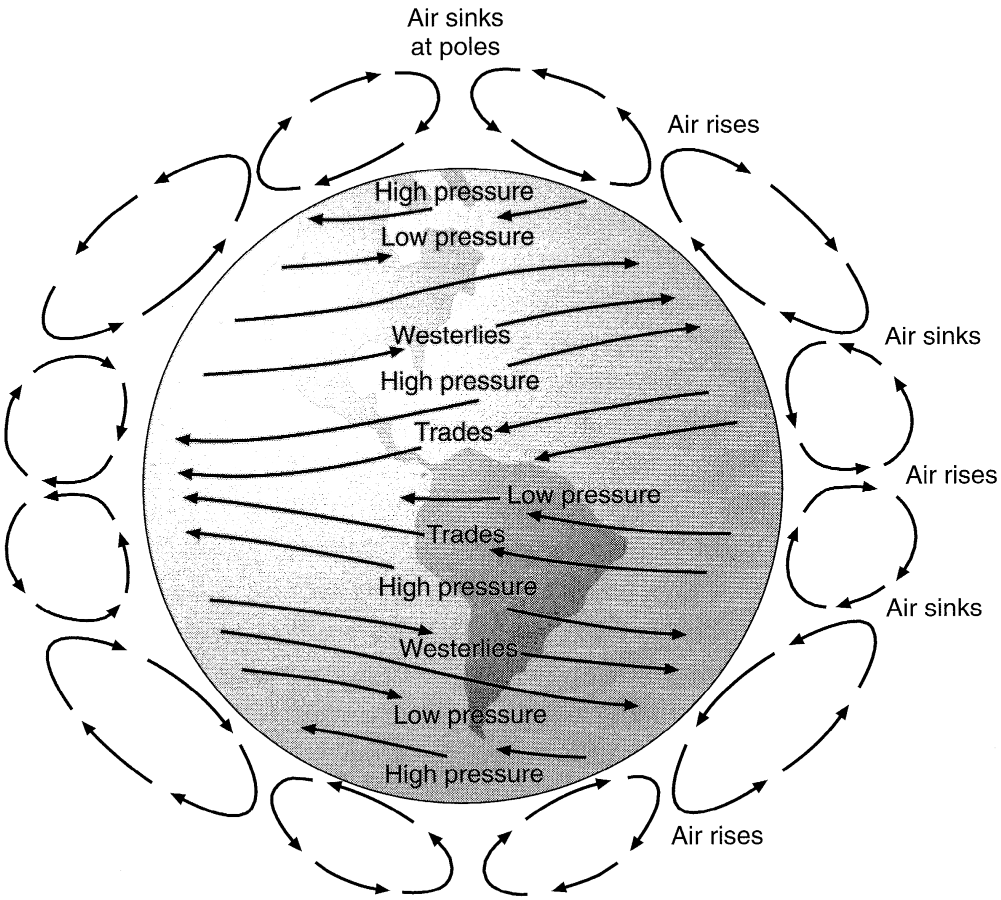


Figure 2.6 Schematic of the Earth's generalized, large-scale cross-sectional and low-level circulation patterns. (From Battan 1979, with relabeling.)

GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L06805, doi:10.1029/2006GL028443, 2007

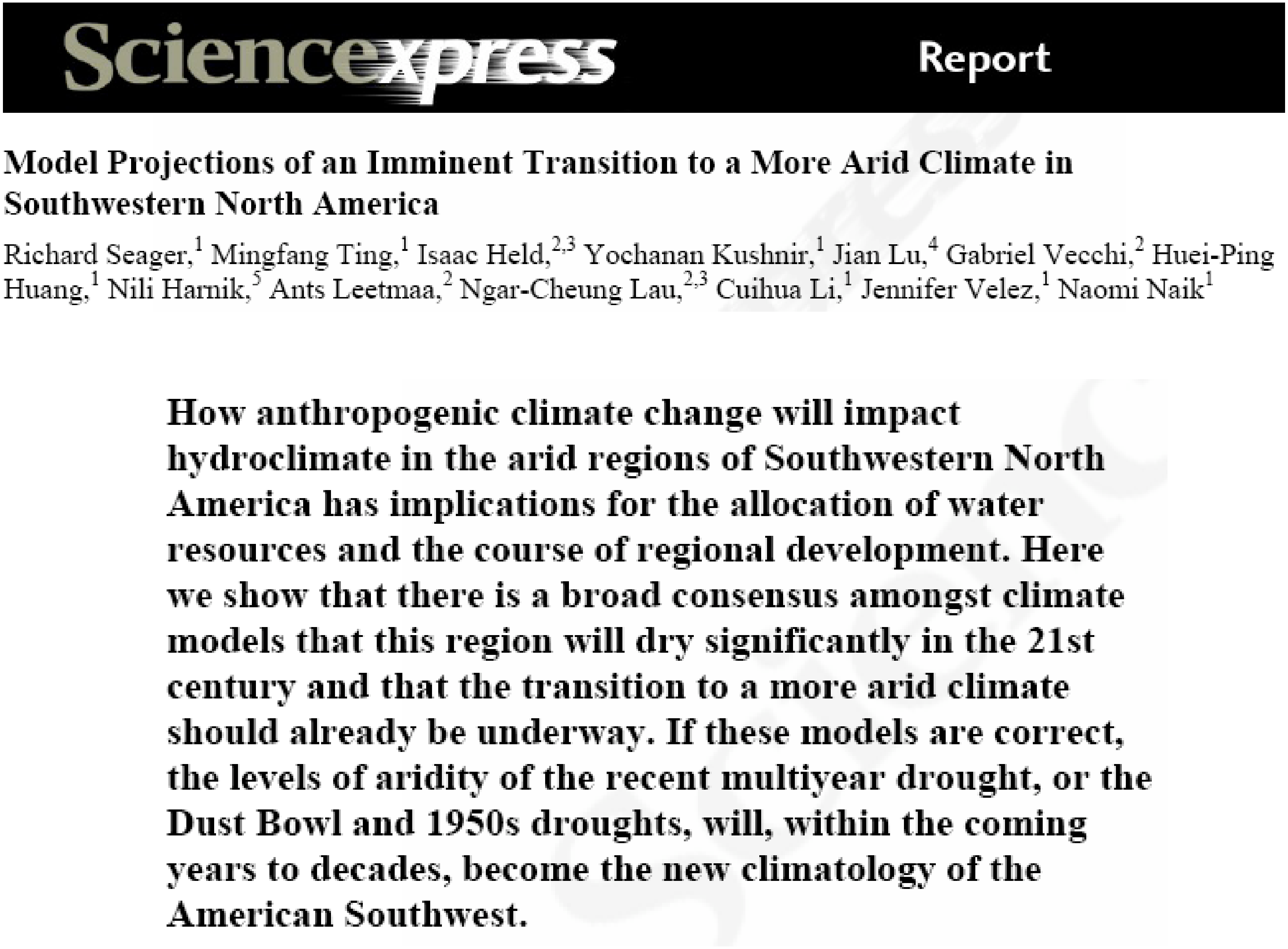
Click Here for Full Article

Expansion of the Hadley cell under global warming

Jian Lu,[1,2] Gabriel A. Vecchi,[3] and Thomas Reichler[4]

Received 11 October 2006; revised 9 February 2007; accepted 21 February 2007; published 24 March 2007.

[1] A consistent weakening and poleward expansion of the Hadley circulation is diagnosed in the climate change simulations of the IPCC AR4 project. Associated with this widening is a poleward expansion of the subtropical dry zone. Simple scaling analysis supports the notion that the poleward extent of the Hadley cell is set by the location where the thermally driven jet first becomes baroclinically unstable. The expansion of the Hadley cell is caused by an increase in the subtropical static stability, which pushes poleward the baroclinic instability zone and hence the outer boundary of the Hadley cell. **Citation:** Lu, J., G. A. Vecchi, and T. Reichler (2007), Expansion of the Hadley cell under global warming, *Geophys. Res. Lett.*, *34*, L06805, doi:10.1029/2006GL028443.



Sciencexpress Report

Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America

Richard Seager,[1] Mingfang Ting,[1] Isaac Held,[2,3] Yochanan Kushnir,[1] Jian Lu,[4] Gabriel Vecchi,[2] Huei-Ping Huang,[1] Nili Harnik,[5] Ants Leetmaa,[2] Ngar-Cheung Lau,[2,3] Cuihua Li,[1] Jennifer Velez,[1] Naomi Naik[1]

How anthropogenic climate change will impact hydroclimate in the arid regions of Southwestern North America has implications for the allocation of water resources and the course of regional development. Here we show that there is a broad consensus amongst climate models that this region will dry significantly in the 21st century and that the transition to a more arid climate should already be underway. If these models are correct, the levels of aridity of the recent multiyear drought, or the Dust Bowl and 1950s droughts, will, within the coming years to decades, become the new climatology of the American Southwest.

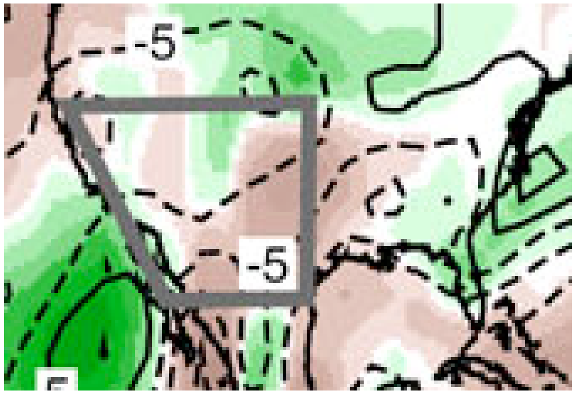
From the *Science* paper, Seager et al. (to appear):

In the multi-model ensemble mean there is a transition to a sustained drier climate that begins in the late 20th and early 21st centuries. In the ensemble mean both *P* and *E* decrease but the former by a larger amount. *P*–*E* primarily reduces in winter when *P* reduces and *E* is unchanged or modestly increased while in summer both *P* and *E* decrease (not shown).

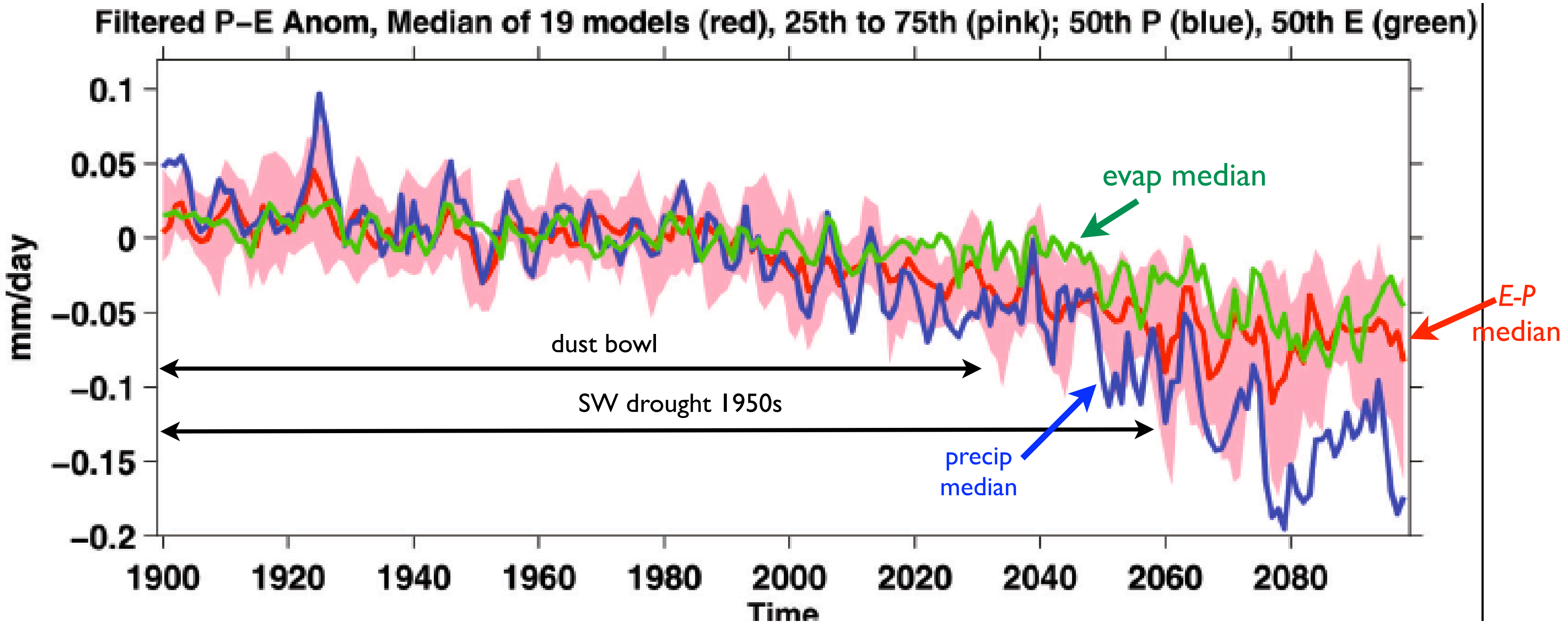
The annual mean reduction in *P* for this region, calculated from rain gauge data within the Global Historical Climatology Network, was 0.09 mm/day between 1932 and 1939 (the Dust Bowl drought) and 0.13 mm/day between 1948 and 1957 (the 1950s Southwest drought: *Drought of Record.*).

The ensemble
median reduction in *P* that drives the reduction in *P*–*E* reaches 0.1 mm/day in mid-century and one quarter of the models reach this in the early part of the current century.

‘Sinking Air Contribution’



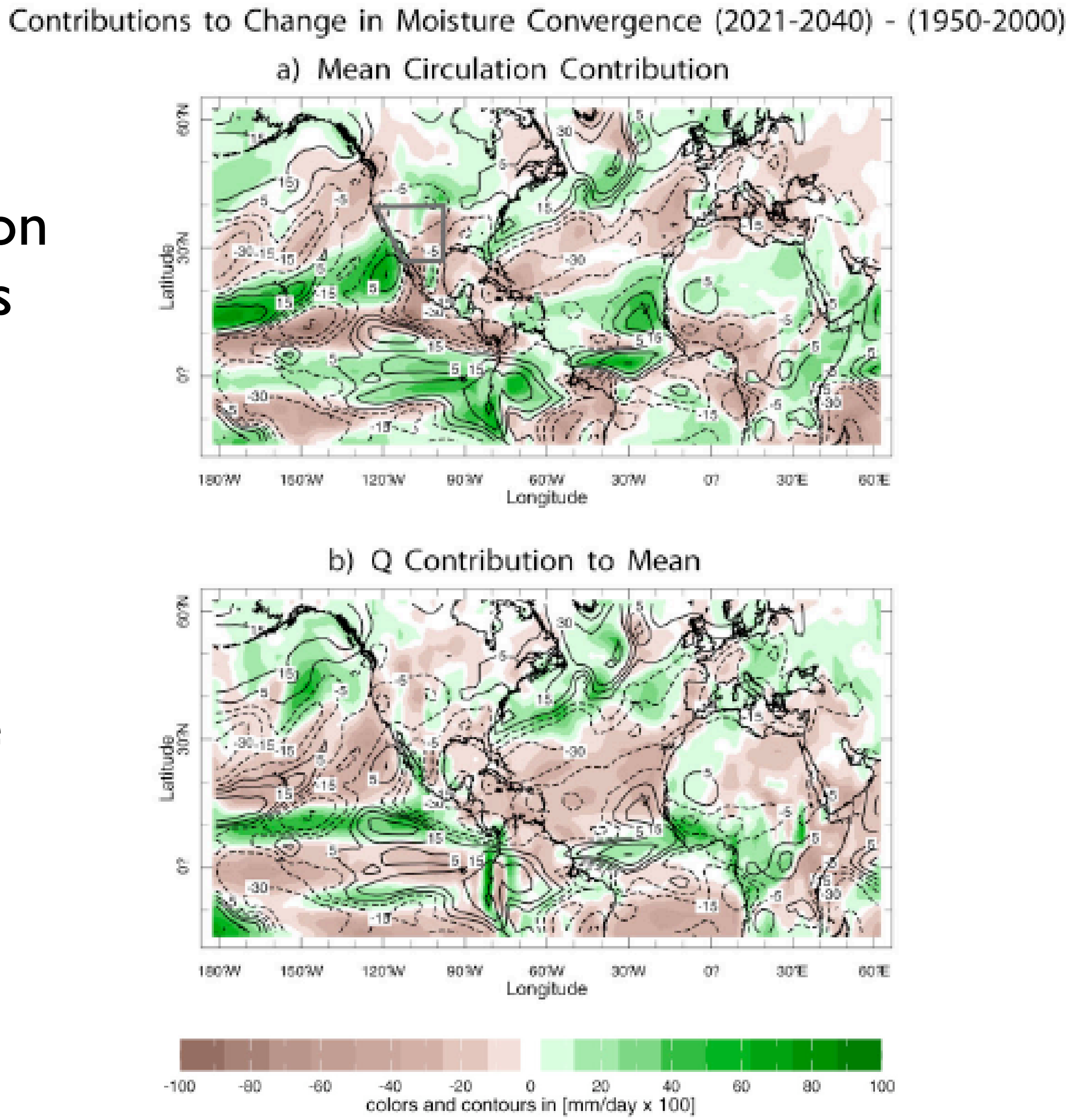
SW Region Analyzed



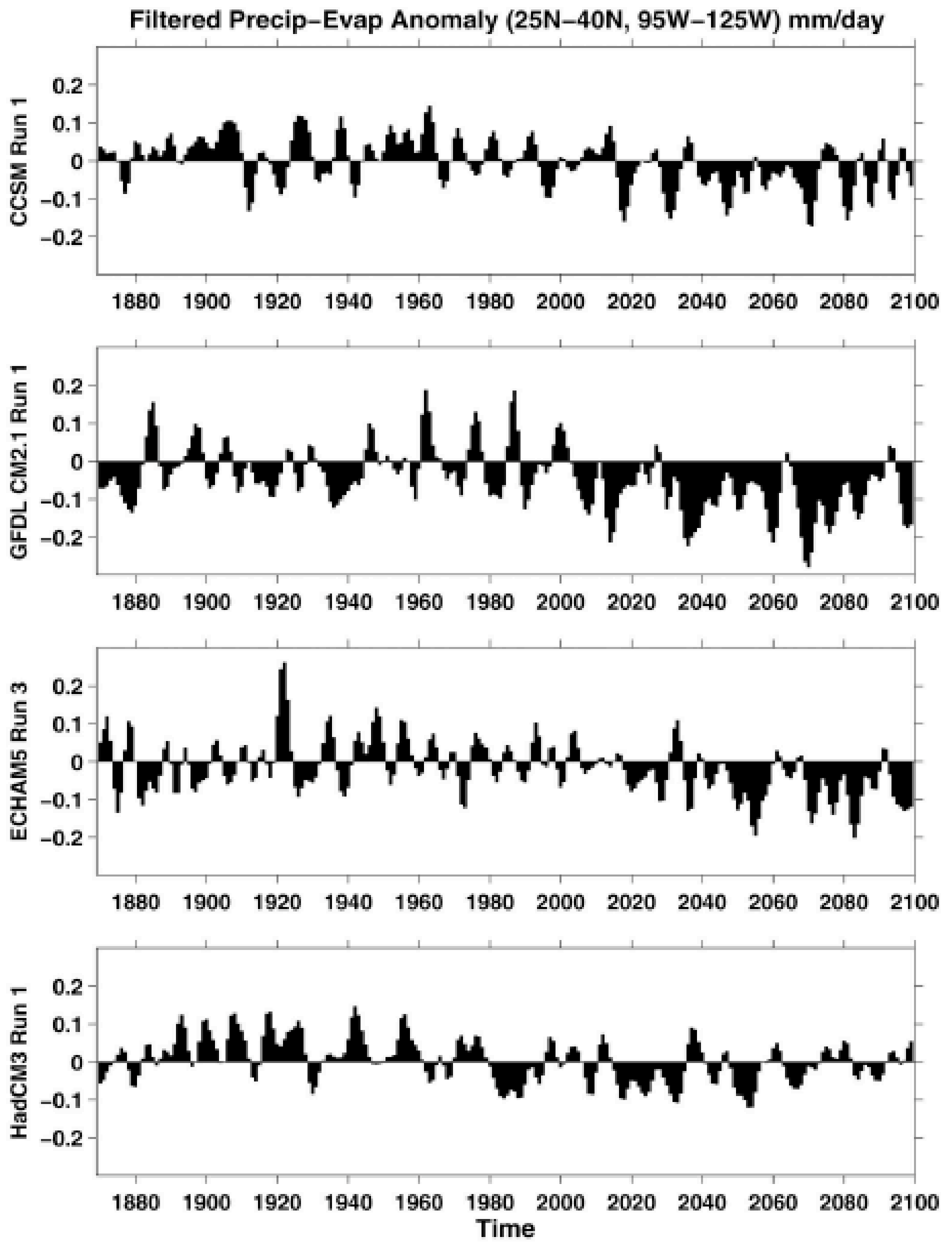
Modeled changes in annual mean precipitation minus evaporation over the American Southwest (125∘W −95∘W, 25∘N−40∘N, land areas only) averaged over ensemble members for each of the 19 models. The historical period used known and estimated climate forcings and the projections used the SResA1B emissions scenario. Shown are the median (red line) and 25th and 75th percentiles (pink shading) of the *P*−*E* distribution amongst the 19 models, and the ensemble medians of *P* (blue line) and *E* (green line) for the period common to all models (1900 to 2098). Anomalies for each model are relative to that model's climatology for 1950–2000. Results have been six year low pass Butterworth filtered to emphasize low frequency variability that is of most consequence for water resources. Units are in mm/ day. The model ensemble mean *P*−*E* in this region is around 0.3 mm/day.

Precipitation decreases

Moisture diverges

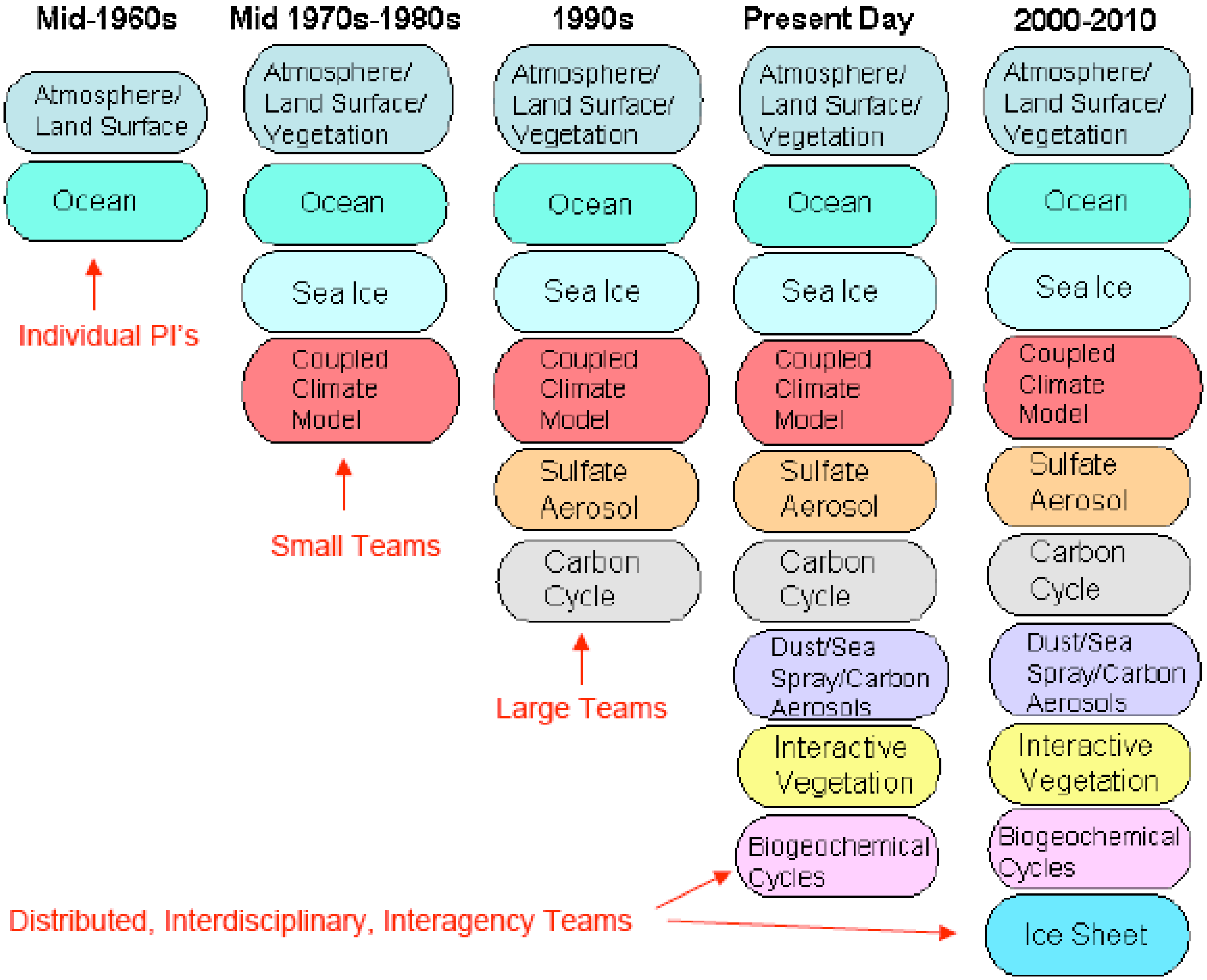


Comparing four model runs



More About Models

Timeline of Model Development



Mid-1960s

Atmosphere/ Land Surface

Ocean

Individual PI's

Mid 1970s-1980s

Atmosphere/ Land Surface/ Vegetation

Ocean

Sea Ice

Coupled Climate Model

Small Teams

1990s

Atmosphere/ Land Surface/ Vegetation

Ocean

Sea Ice

Coupled Climate Model

Sulfate Aerosol

Carbon Cycle

Large Teams

Present Day

Atmosphere/ Land Surface/ Vegetation

Ocean

Sea Ice

Coupled Climate Model

Sulfate Aerosol

Carbon Cycle

Dust/Sea Spray/Carbon Aerosols

Interactive Vegetation

Biogeochemical Cycles

2000-2010

Atmosphere/ Land Surface/ Vegetation

Ocean

Sea Ice

Coupled Climate Model

Sulfate Aerosol

Carbon Cycle

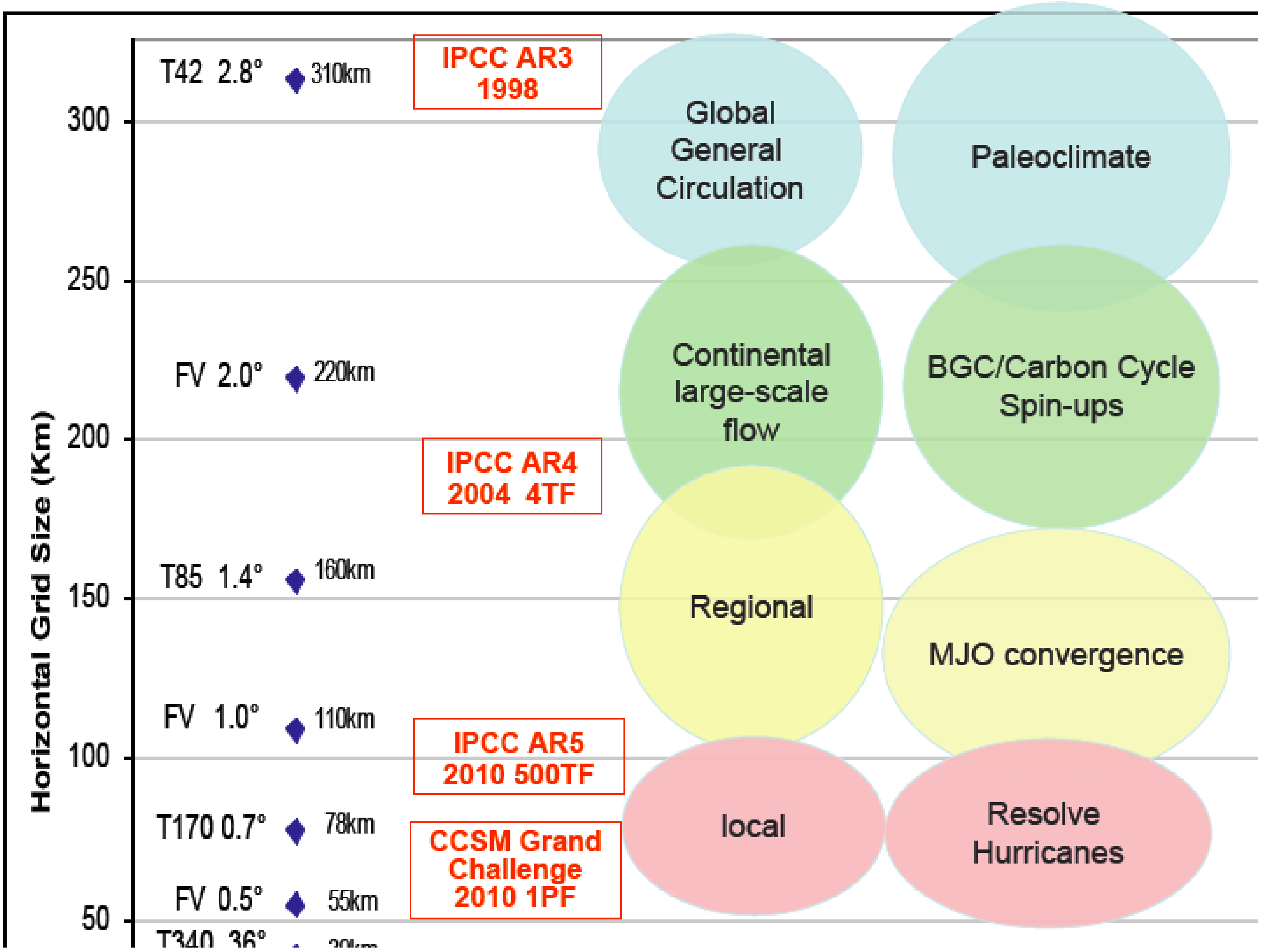
Dust/Sea Spray/Carbon Aerosols

Interactive Vegetation

Biogeochemical Cycles

Ice Sheet

Distributed, Interdisciplinary, Interagency Teams


Horizontal Grid Size (Km)
300
250
200
150
100
50
T42 2.8°
310km
FV 2.0°
220km
T85 1.4°
160km
FV 1.0°
110km
T170 0.7°
78km
FV 0.5°
55km
T340 36°
IPCC AR3 1998
IPCC AR4 2004 4TF
IPCC AR5 2010 500TF
CCSM Grand Challenge 2010 1PF
Global General Circulation
Paleoclimate
Continental large-scale flow
BGC/Carbon Cycle Spin-ups
Regional
MJO convergence
local
Resolve Hurricanes

Some Details of IPCC Runs

Kinds of codes:
- US Machines: Parallel hybrid MPI/OpenMP, hybrid scalar
- Japanese: vector

Computational Resources
- NCAR: IBM SP Power 4 (192 PEs)
- ORNL: IPM SP Power 4 (192 PEs)
- NERSC: RS/6000 Power 3 (112 PEs)
- Japan Earth Simulator: NEC SX-6

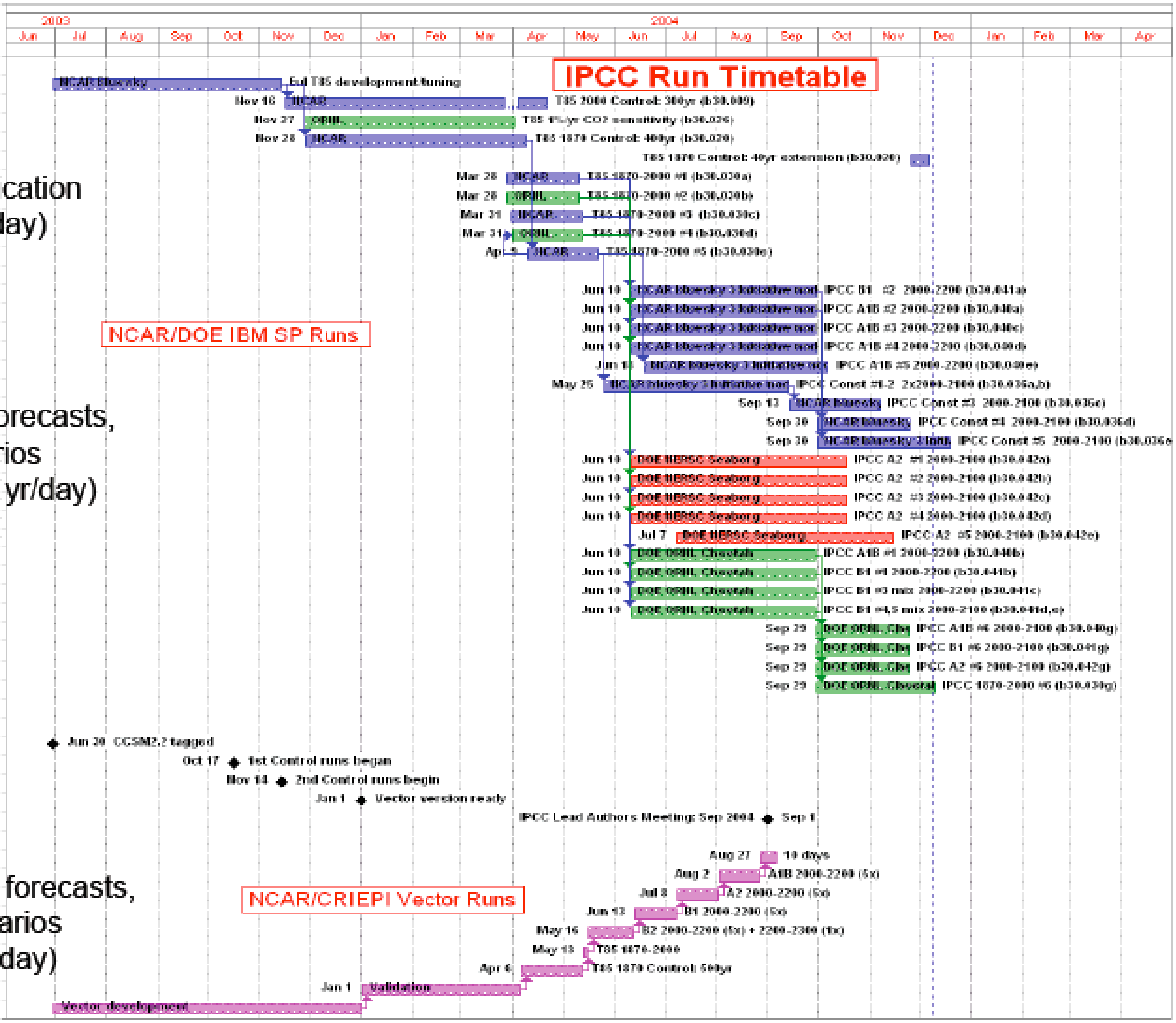
Data File Sizes:
- 10 GB (91 files) per simulated year
- 11,000 years in total
- ~ 110 TB data generated

IPCC Run Timetable

Control/verification
(T85,3-5 yr/day)

2000-2100 forecasts,
IPCC scenarios
(T85, 0.75-2 yr/day)

2000-2100 forecasts,
IPCC scenarios
(T85,40 yr/day)



Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) Simulations

- NCAR Community Climate System Model (CCSM-3).
- Open Source
- 8-member ensembles
- 11,000 model years simulated
- “T85” - high resolution
- ~1 quadrillion operations/simulated year
- Rate of simulation: 3.5 sim. years/day
- Data volume for IPCC: ~110 TB
- Development effort: ~1 person-century