ESS@20 Symposium
National Academy of Sciences, June 22-24, 2009

Advances in Climate Prediction and Climate Model Validation from Space Observations

Jagadish Shukla
Department of Atmospheric, Oceanic and Earth Sciences (AOES)
George Mason University (GMU)
Center for Ocean-Land-Atmosphere studies (COLA)
Institute of Global Environment and Society (IGES)

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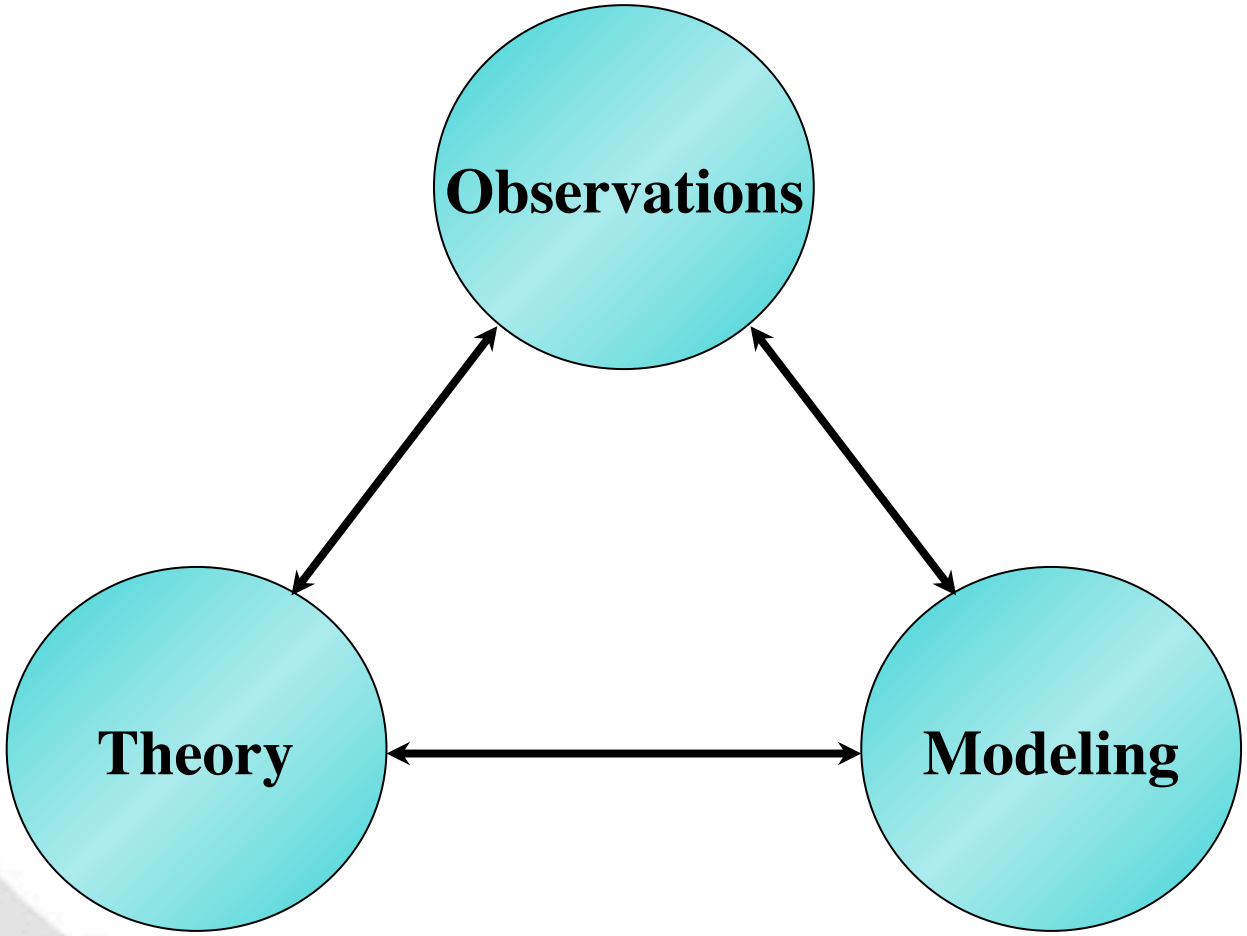
CREW Center for Research on Environment and Water
GEORGE MASON UNIVERSITY

Outline

- NASA/Space Observations Advance ESS
  - Weather Prediction
  - Climate Prediction
  - Climate Model Validation
- Challenges
  - Scientific
    - Observations/Data Assimilations
    - Modeling/Prediction
    - Data/Information Systems
  - Institutional
  - Multi-Agency (U.S./International)
- Summary/Suggestions

The "Charney" Diagram



Use of Incomplete Historical Data to Infer the Present States of the Atmosphere

J. Charney, M. Halem,
R. Jastrow, M. Cane

Thanks to:
M. Halem, A. Arking, M. Cane

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Use of Incomplete Historical Data to Infer the Present States of the Atmosphere

J. Charney, M. Halem and R. Jastrow

Journal of Atmospheric Science, 1969, pp1160-1163

Nimbus III launched on 13 April 1969 T(z) with SIRS

M. Tepper: First vertical profile of T from NOAA

Use of Incomplete Historical Data to Infer the Present States of the Atmosphere

J. Charney, M. Halem and R. Jastrow

Journal of Atmospheric Science, 1969, pp1160-1163

New UCLA Model: July, 1969
Submitted: August, 1969
Published: September, 1969
Editor of JAS: R. Jastrow (GISS)
Associate Editor: S. I. Rasool (GISS)

Department of Atmospheric Science

Colorado State University
Fort Collins, Colorado
80523

17 December 1974

17 December 1974

Professor Jule Charney
Department of Meteorology
Massachusettes Institute of Technology
Cambridge, Massachusettes 02139

Dear Dr. Charney,

At the request of Mr. William Bandeen, we are sending you color photographs of Nimbus-3 data, in which you are interested. We are also enclosing a copy of the paper which describes the data set in detail. As I discussed with you in Stockholm, we are very interested in your use of this data; please keep us informed.

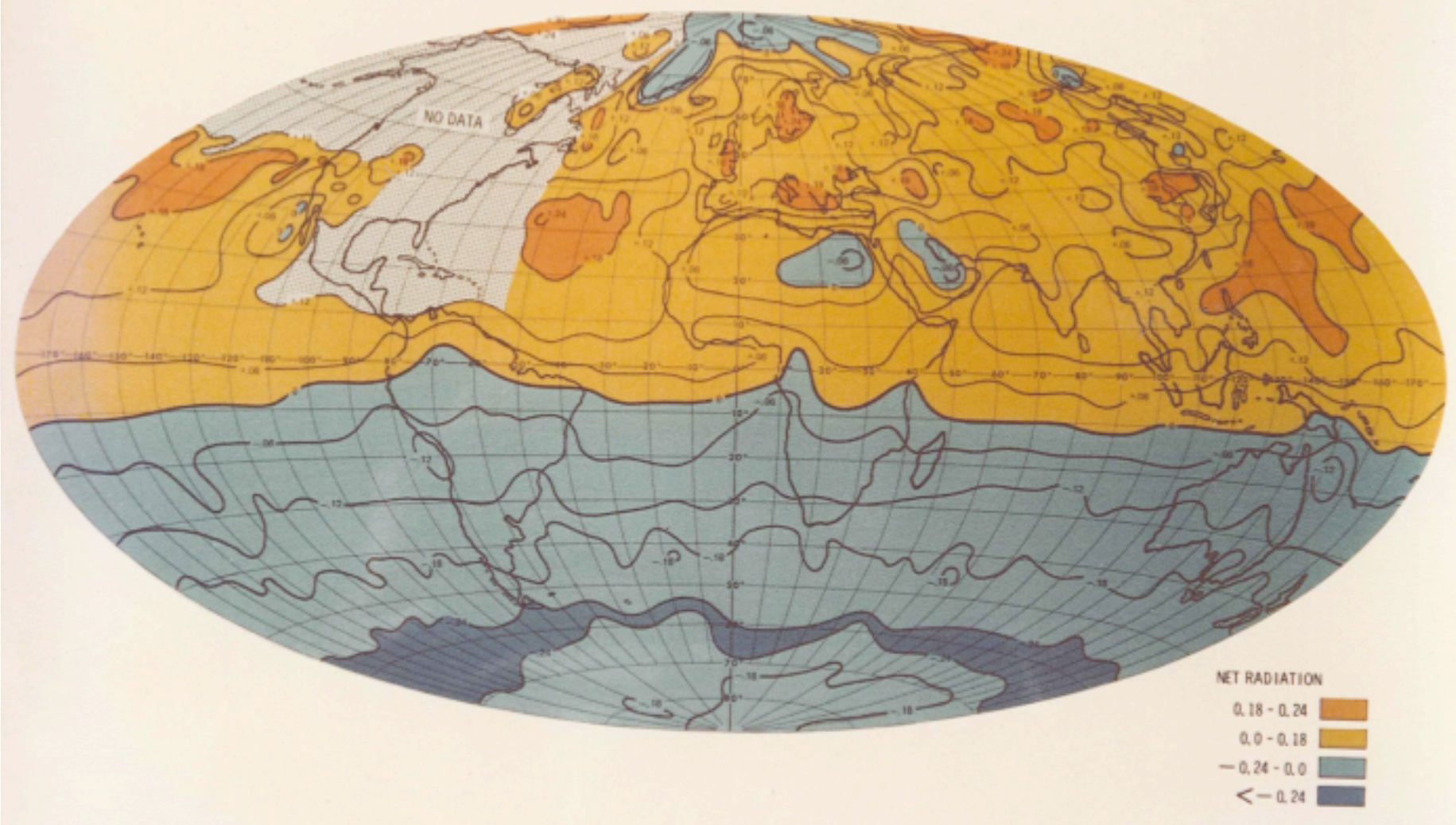
Best Regards,

Tom

Thomas H. Vonder Haar

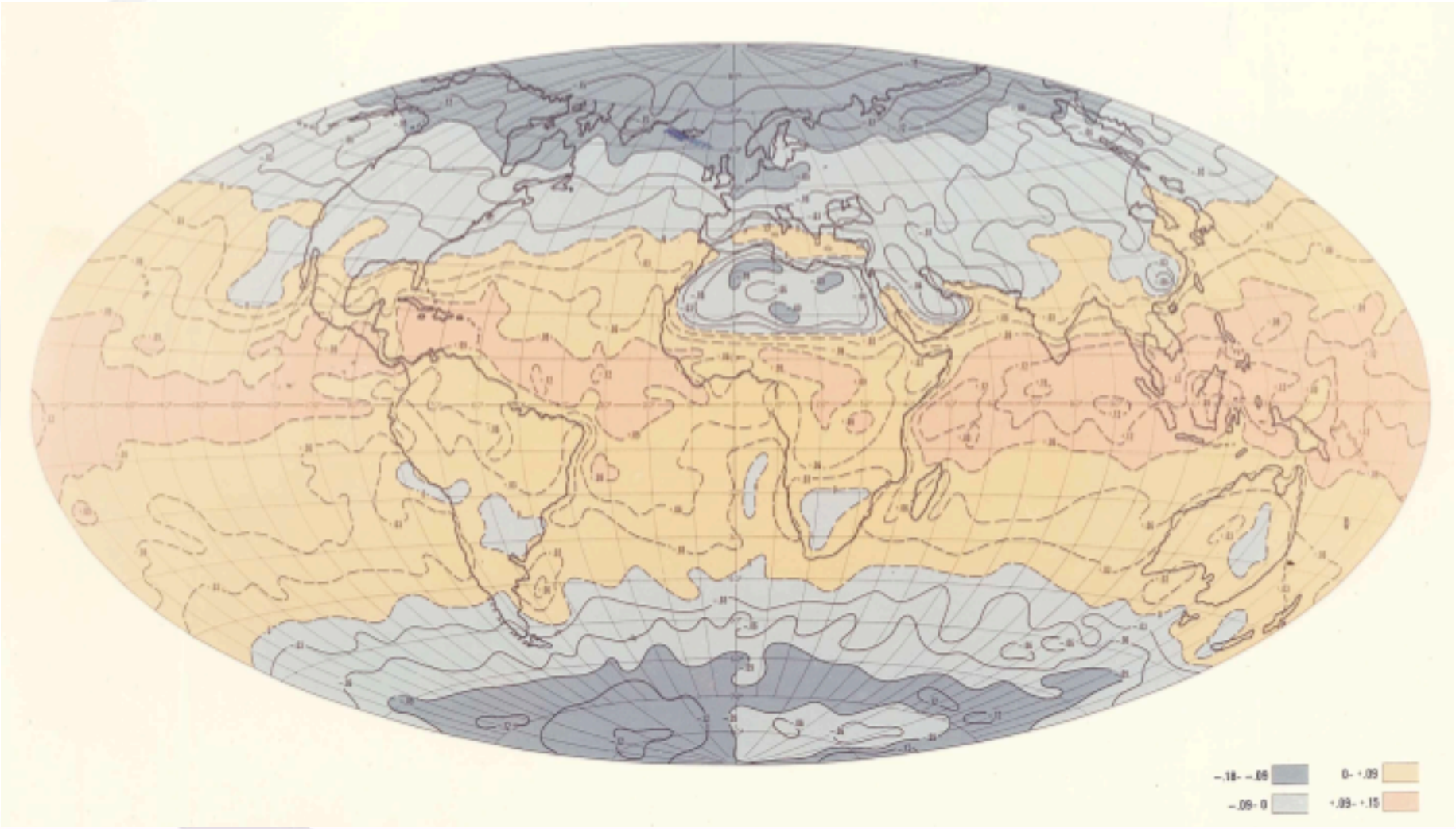
Net Radiation at the Top of the Atmosphere [Ly./min]

NIMBUS III 16-30 June 1969



Radiation Balance [cal cm^{-2}min^{-1}]

NIMBUS III : 1-15 May, 16-31 July, 3-17 October 1969, 21Jan-3Feb 1970



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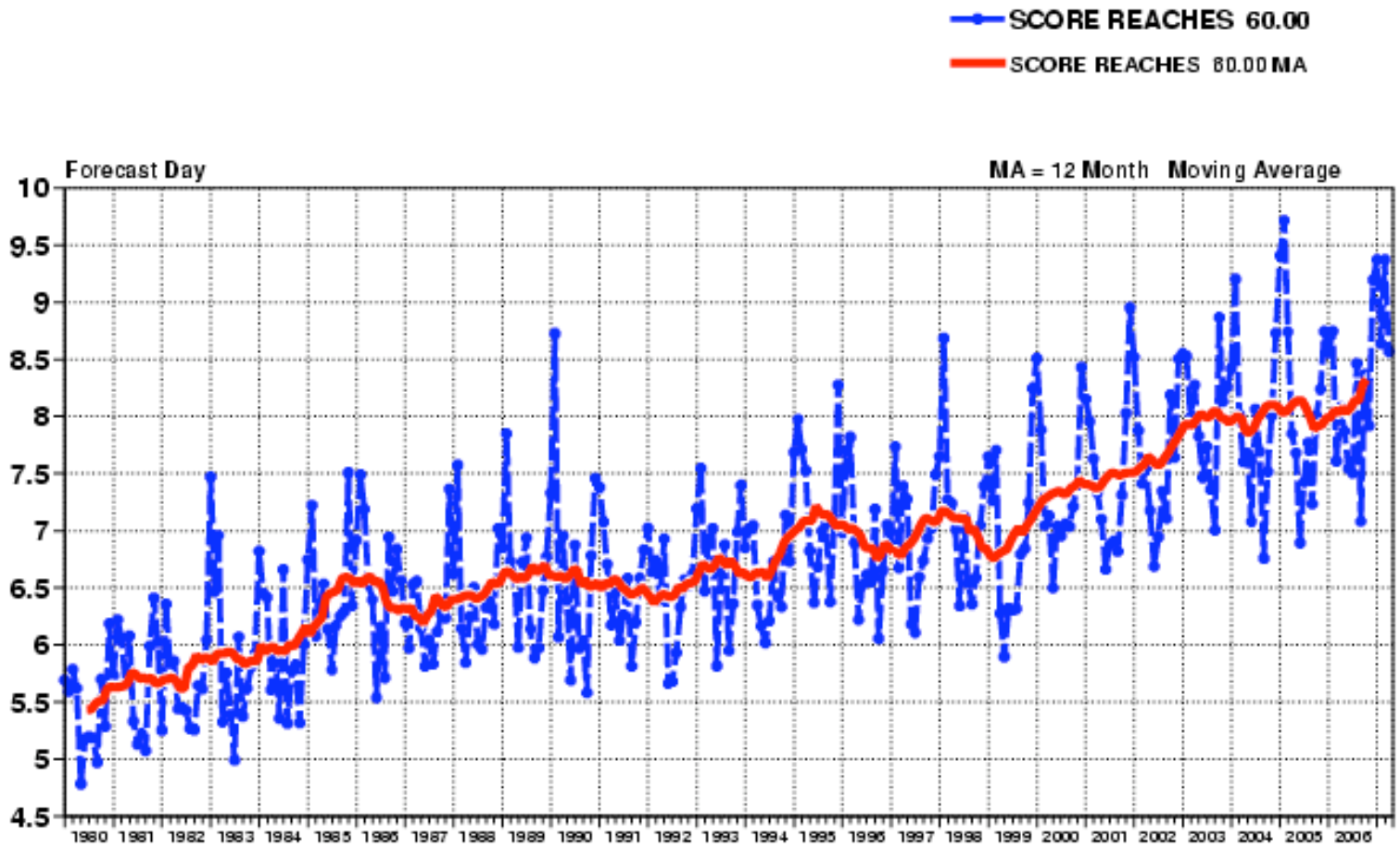
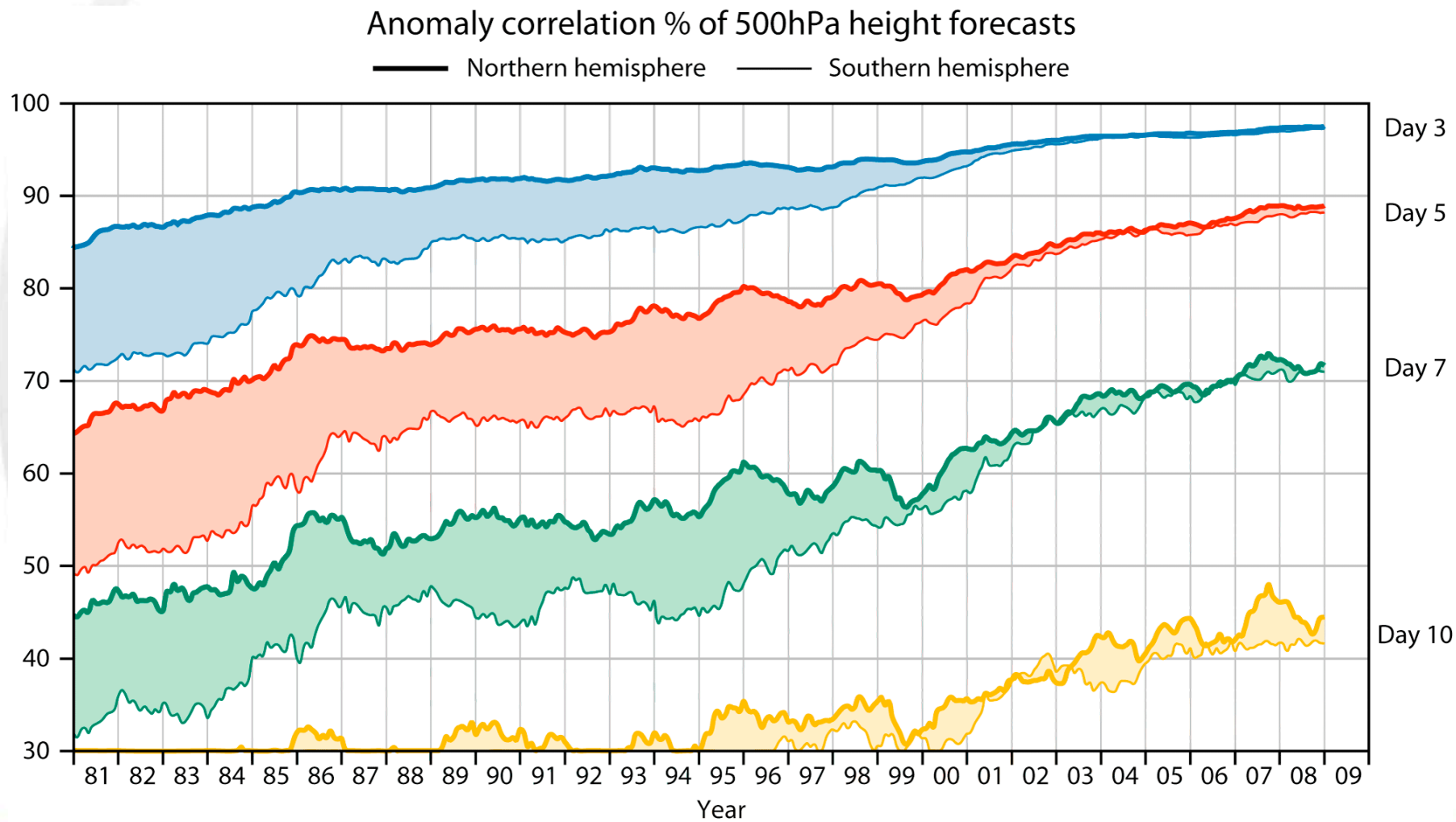
ERA Forecast Verification

Anomaly Correlation of 500 hPa GPH, 20-90N



Evolution of ECMWF scores comparison northern and southern hemispheres



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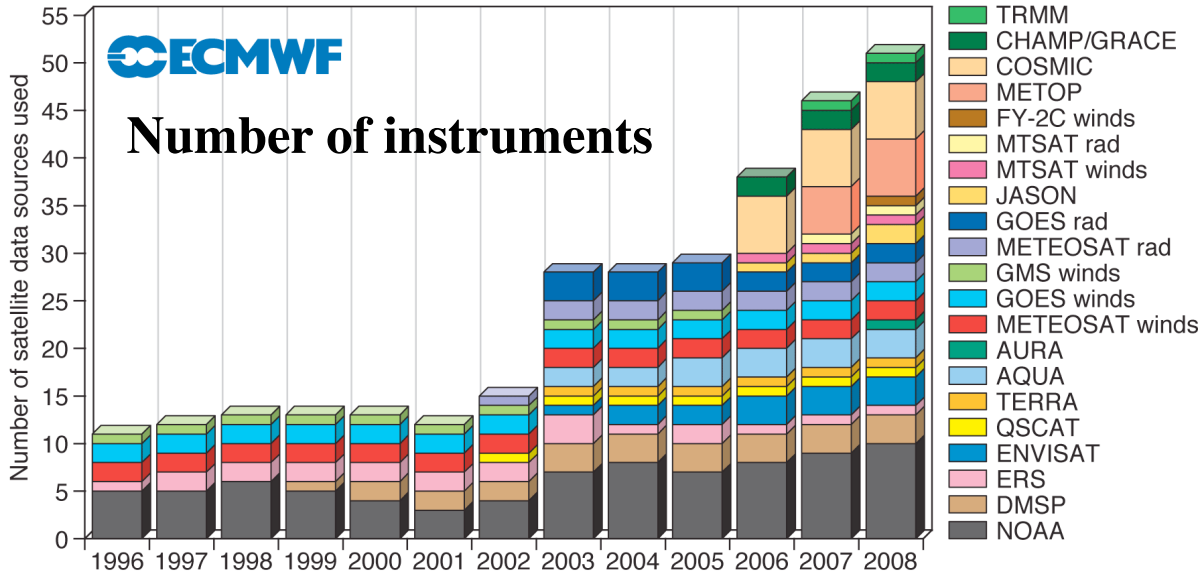
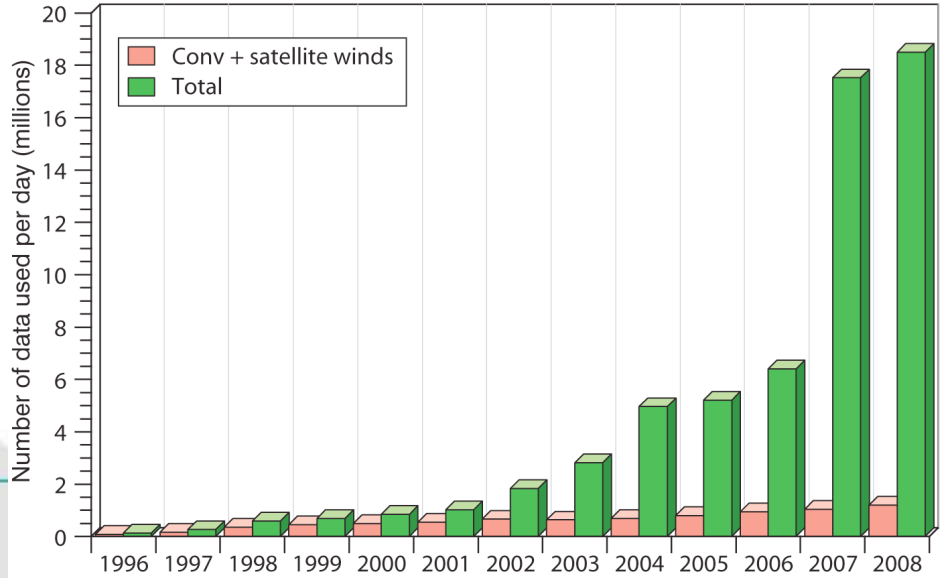
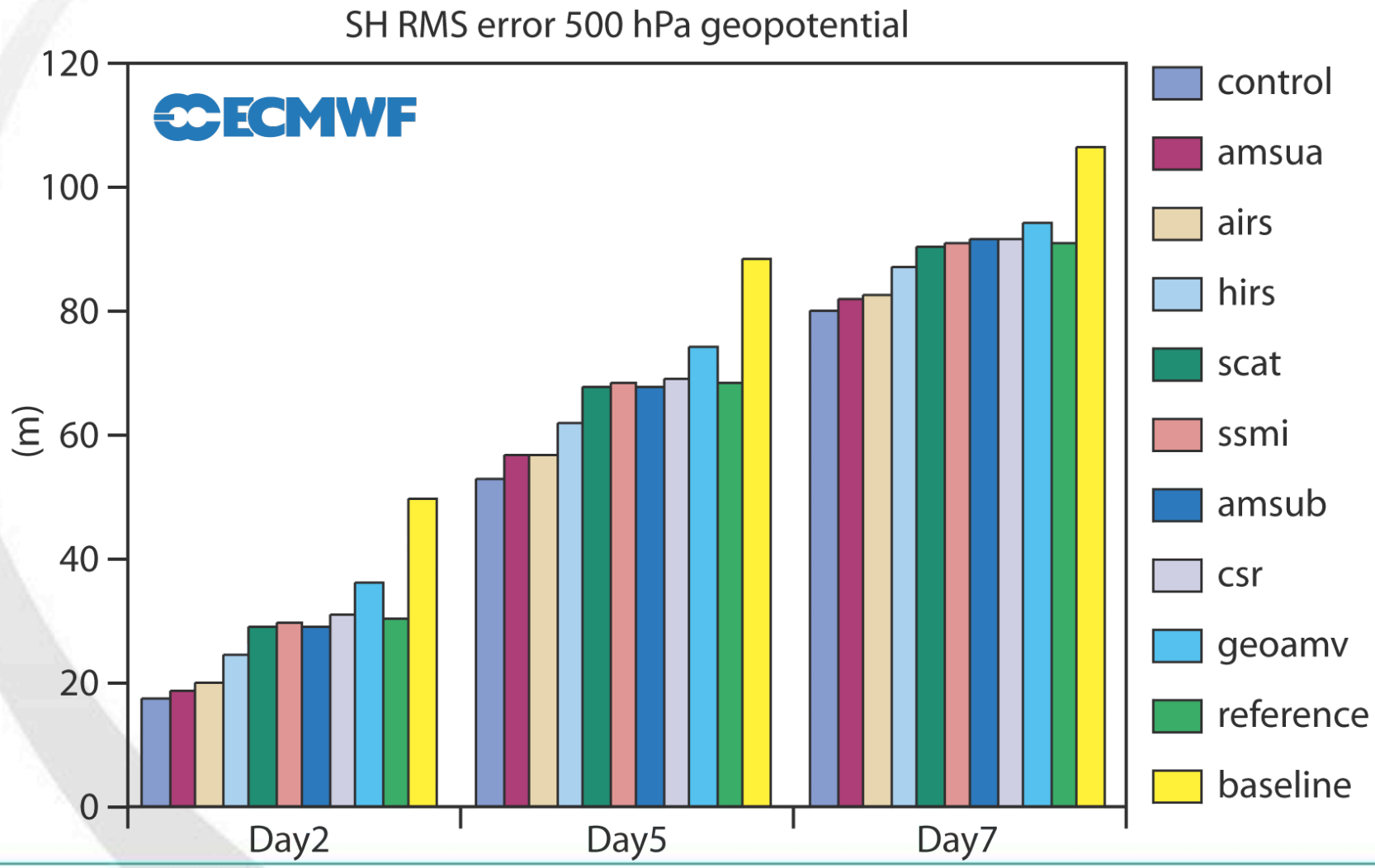
Satellite Data used by ECMWF





Evolution of the impact of the space component of the Global Observing System through Observing System Experiments



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Predictability of Monsoons

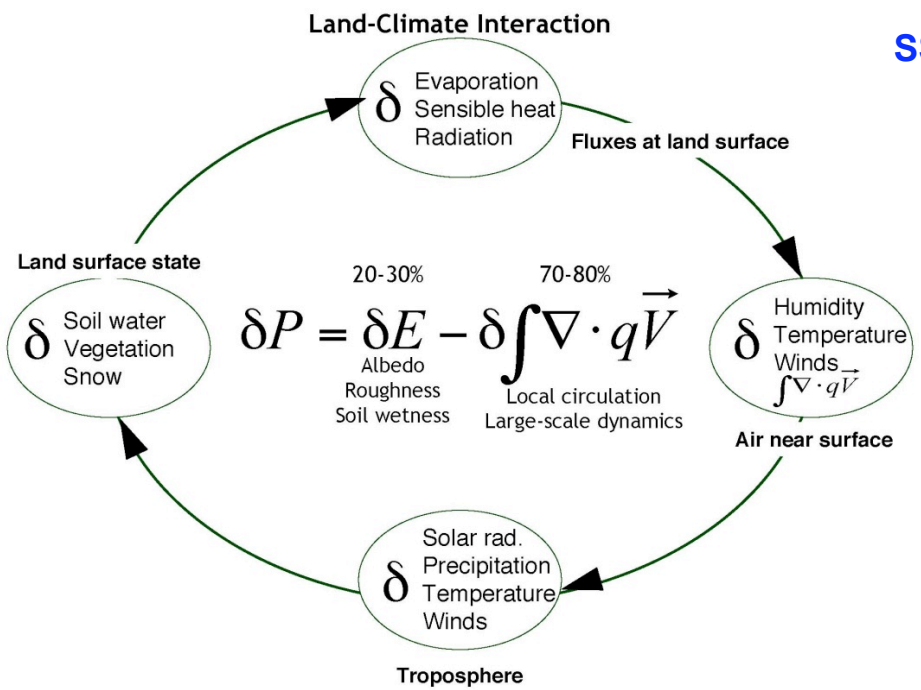
J. Charney & J. Shukla (1977, 1981)

Monson Dynamics, Cambridge University Press,
Editors: Sir Jame Lighthill and R. P. Pearce

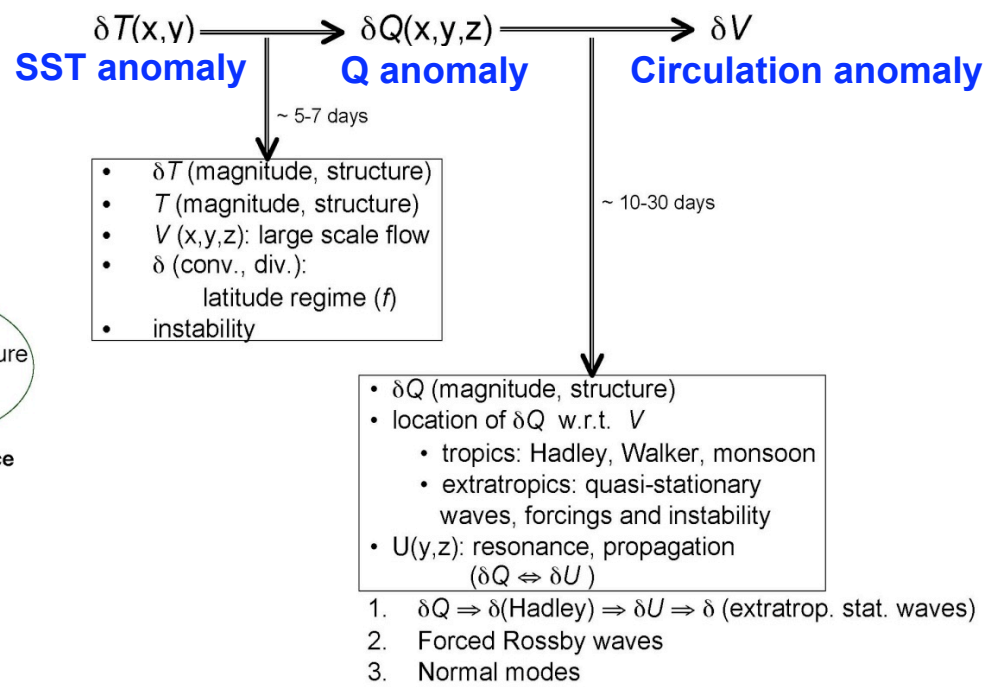
"Above all, we consider that attempts at longer-range prediction in low latitudes should concentrate first on the observation and prediction of fluctuations in such variables as sea-surface temperature, vegetative cover, albedo and ground moisture. Such observations can in principle be made from polar orbiting or geostationary satellites."

Observations of Global Boundary Conditions Enhance Dynamical Seasonal Prediction

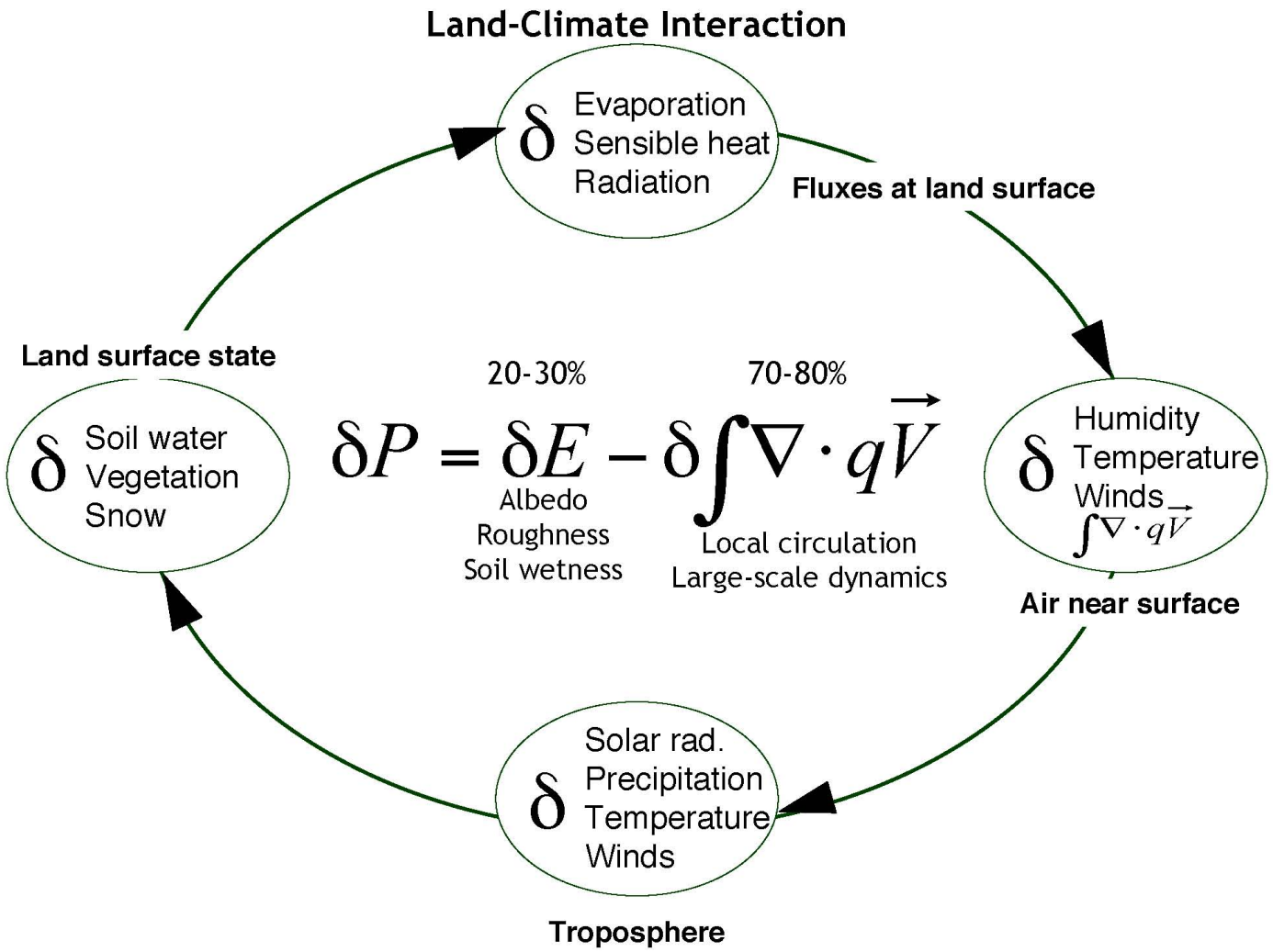
Influence of Land Surface



Influence of SST Anomalies



Land-Climate Interaction



Effects of SST Anomaly

$\delta T(x,y) \longrightarrow \delta Q(x,y,z) \longrightarrow \delta V$

SST anomaly — heating anomaly — circulation anomaly

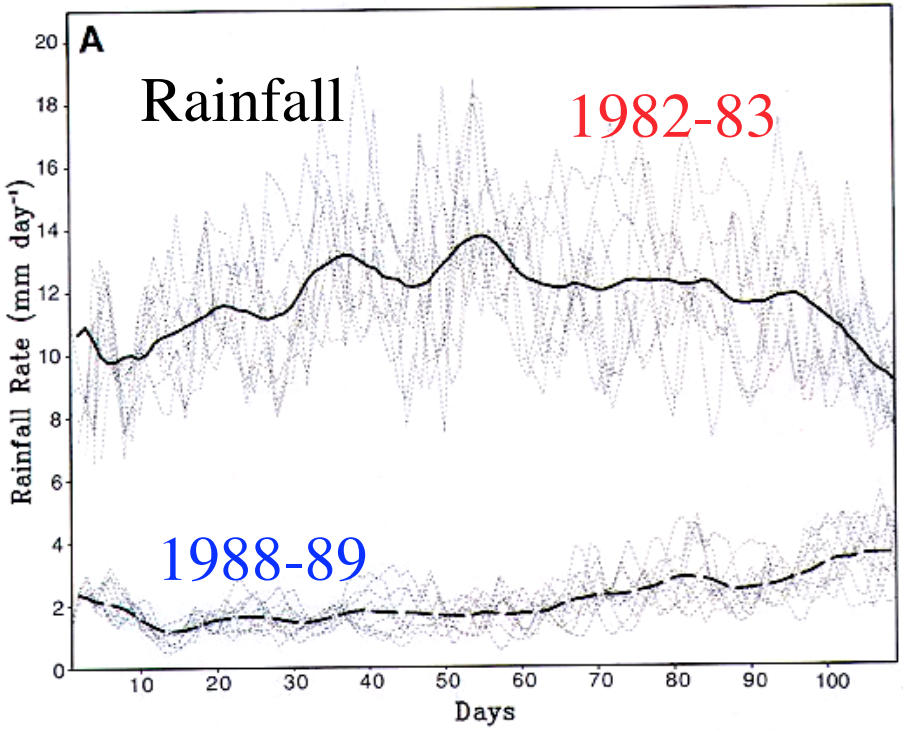
~ 5-7 days

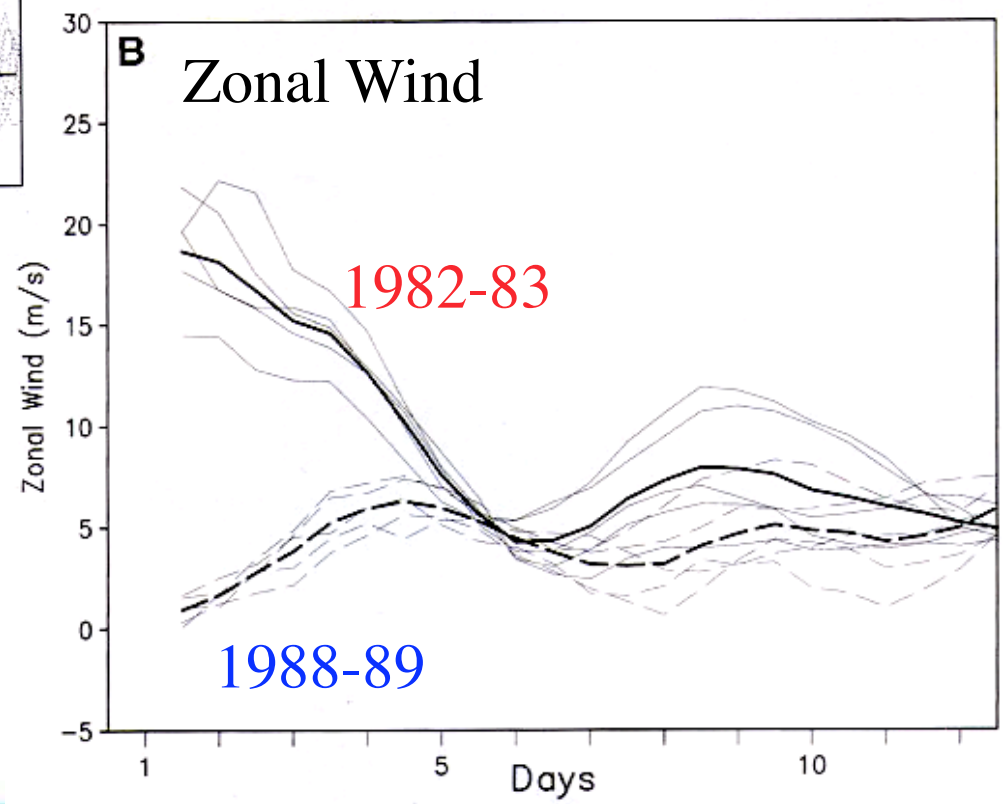
- δT (magnitude, structure)
- T (magnitude, structure)
- V (x,y,z): large scale flow
- δ (conv., div.):
  latitude regime (f)
- instability

~ 10-30 days

- δQ (magnitude, structure)
- location of δQ w.r.t. V
  - tropics: Hadley, Walker, monsoon
  - extratropics: quasi-stationary waves, forcings and instability
- U(y,z): resonance, propagation
  ($\delta Q \Leftrightarrow \delta U$)

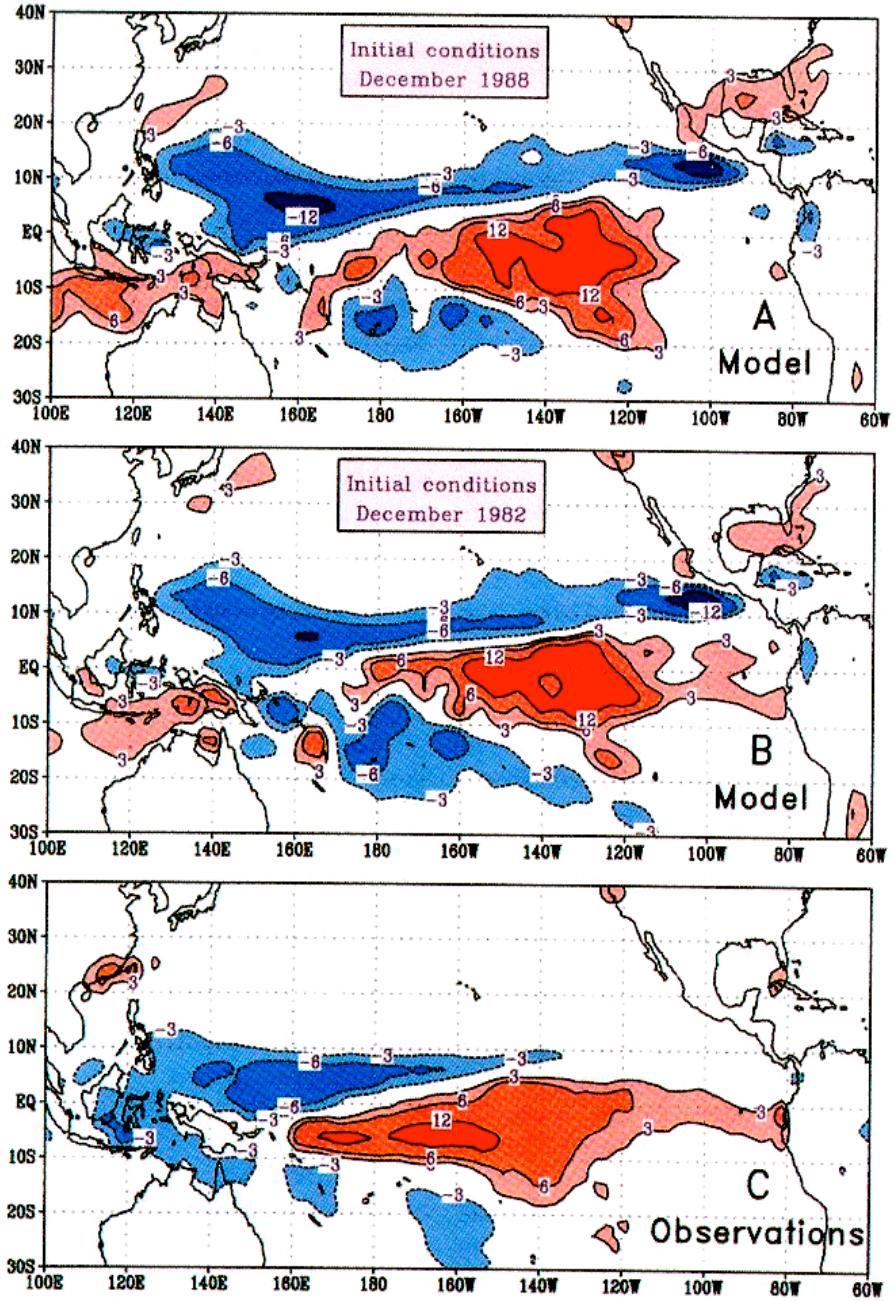
1. $\delta Q \Rightarrow \delta$(Hadley) $\Rightarrow \delta U \Rightarrow \delta$ (extratrop. stat. waves)
2. Forced Rossby waves
3. Normal modes





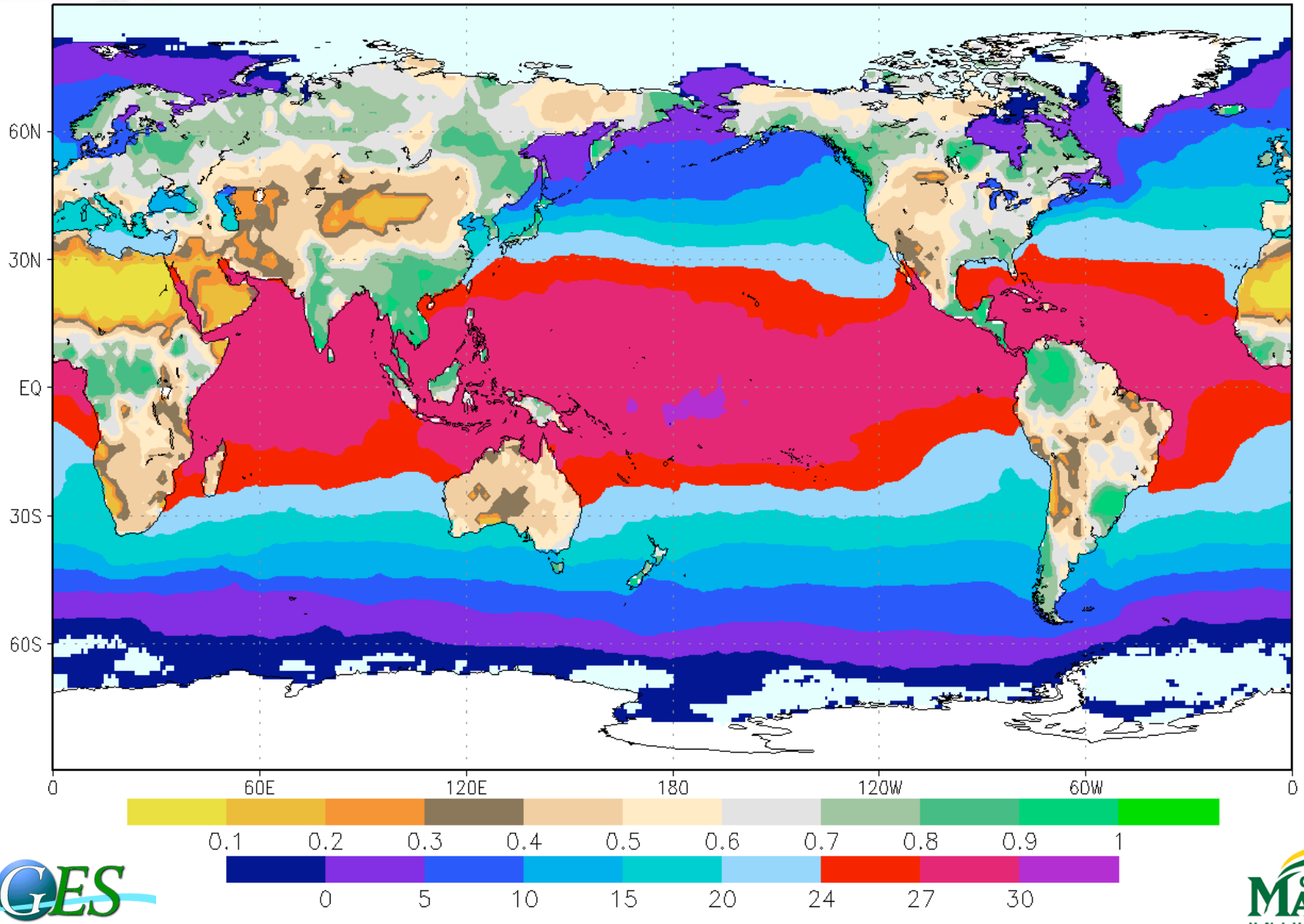
The atmosphere is so strongly forced by the underlying ocean that integrations with fairly large differences in the atmospheric initial conditions converge, when forced by the same SST (Shukla, 1982).

Rainfall Anomalies



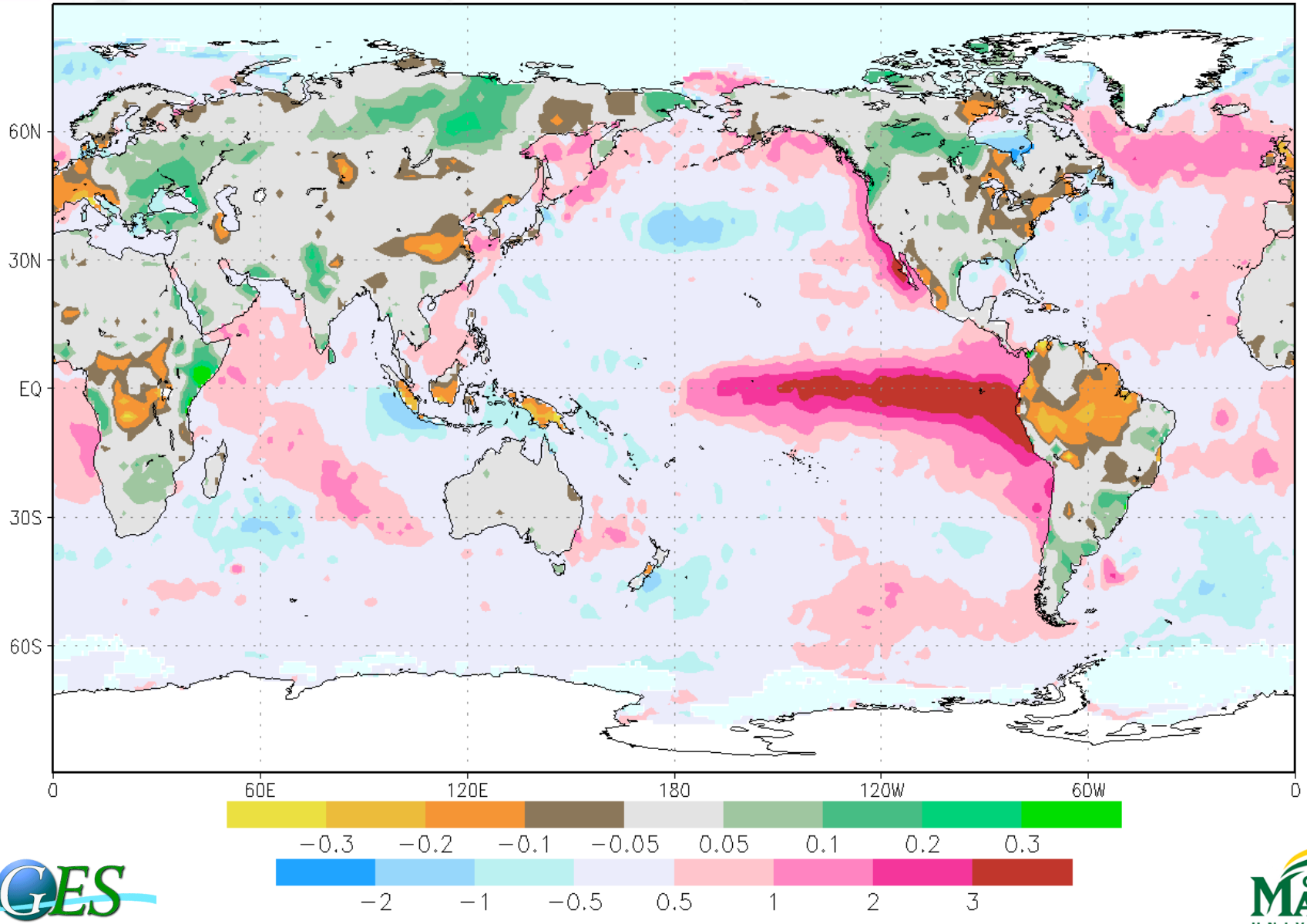
GOLD Soil Wetness (fraction) & HADISST SST (°C)

Total in November 1997



GOLD Soil Wetness (fraction) & HADISST SST (°C)

Anomalies (1979-99 mean) in November 1997



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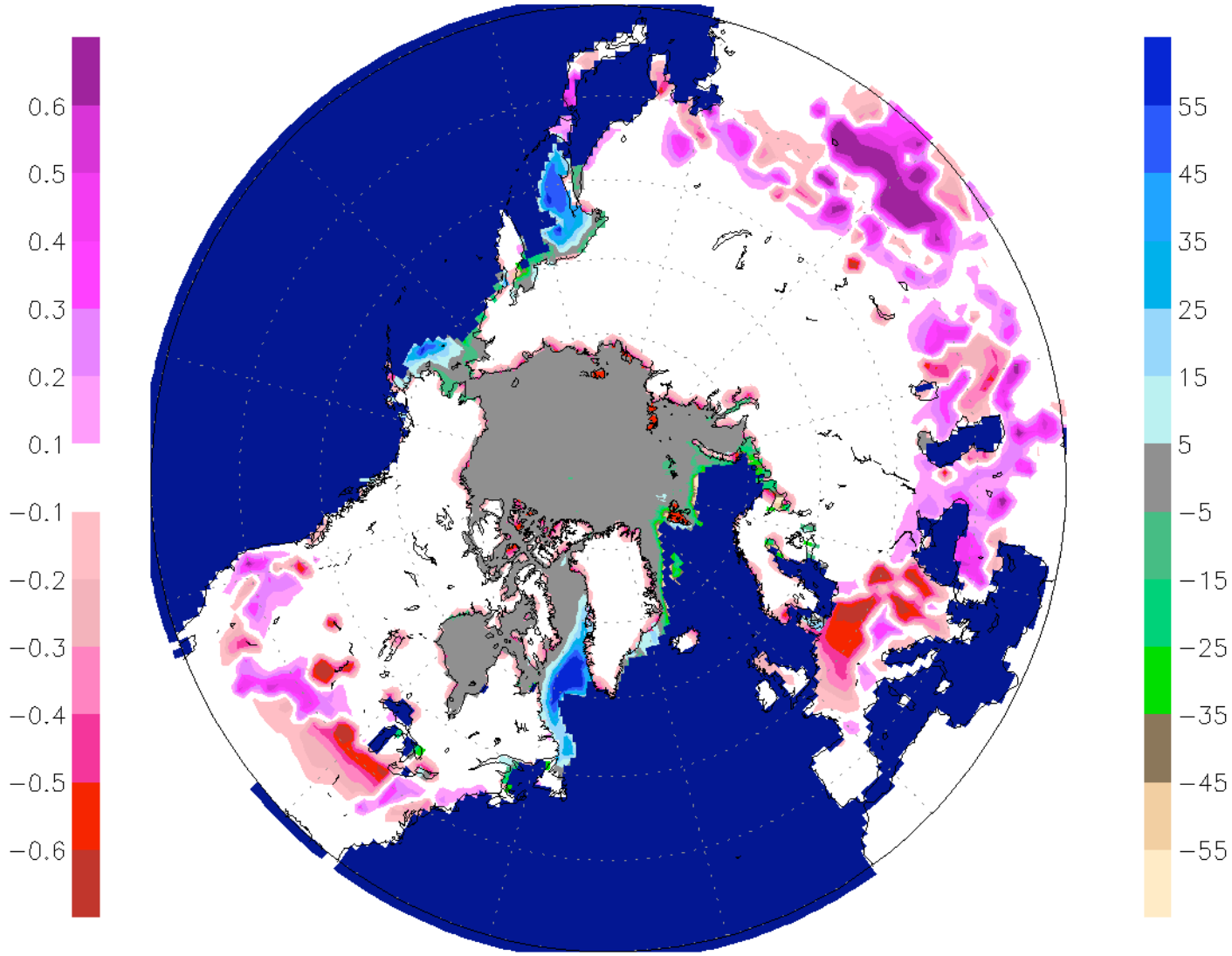
NESDIS Snow Cover Anomaly (Fraction) and HADISST Sea Ice Anomaly (%) for Jan 1983

(1966-1990 climatology)



Simulation of (Uncoupled) Boundary-Forced Response: Ocean, Land and Atmosphere

INFLUENCE OF OCEAN ON ATMOSPHERE

- Tropical Pacific SST
- Arabian Sea SST
- North Pacific SST
- Tropical Atlantic SST
- North Atlantic SST
- Sea Ice
- Global SST (MIPs)

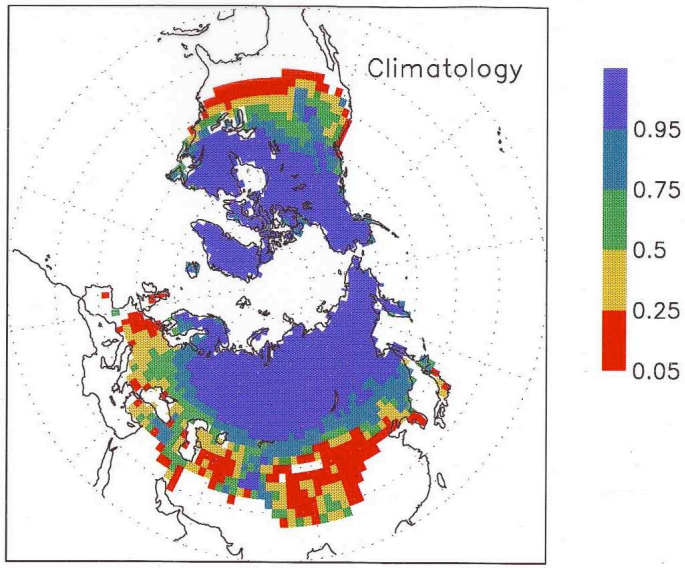
INFLUENCE OF LAND ON ATMOSPHERE

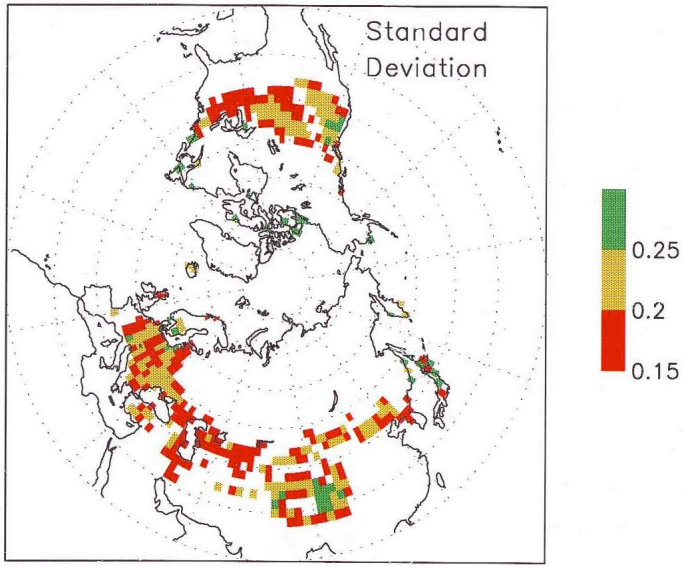
- Mountain / No-Mountain
- Forest / No-Forest (Deforestation)
- Surface Albedo (Desertification)
- Soil Wetness
- Surface Roughness
- Vegetation
- Snow Cover

(Thanks to COLA!)

Winter (DJFM) Snow Cover Frequency

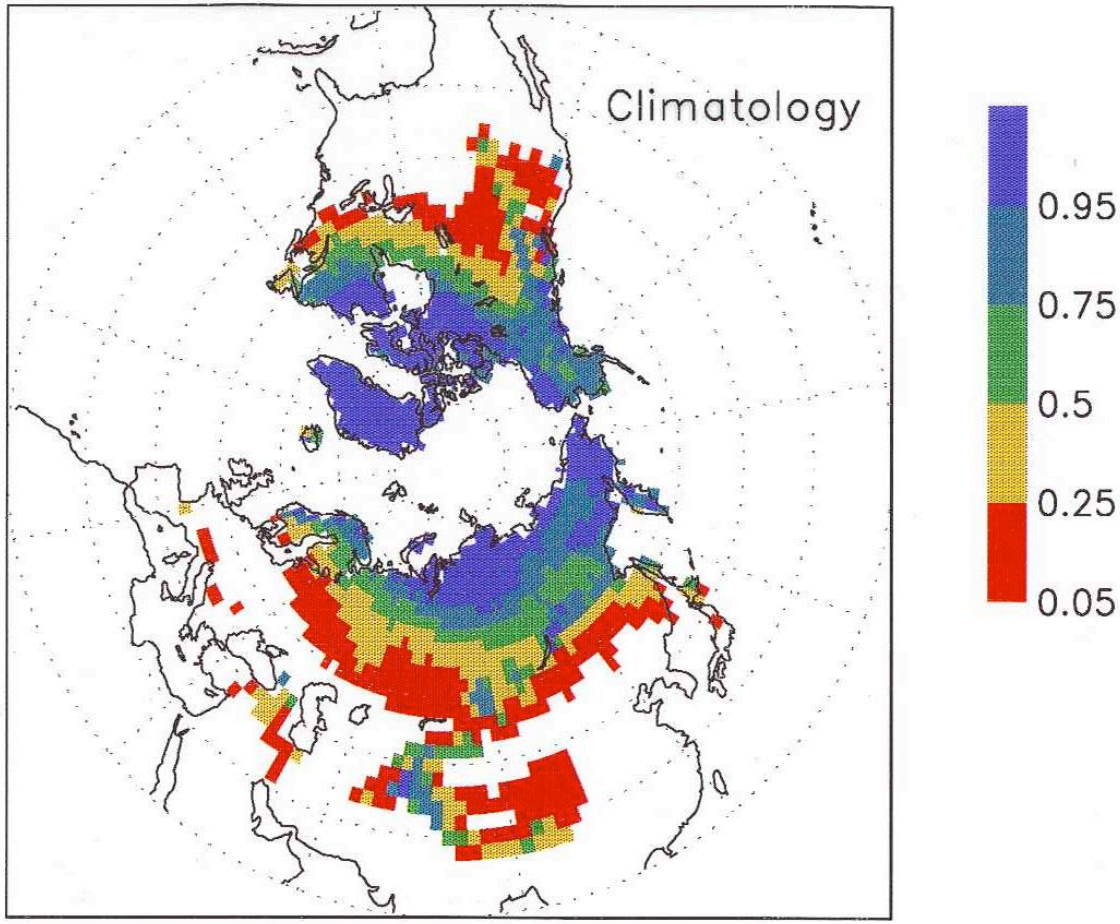
OBSERVED (NOAA)





Spring (AM) Snow Cover Frequency

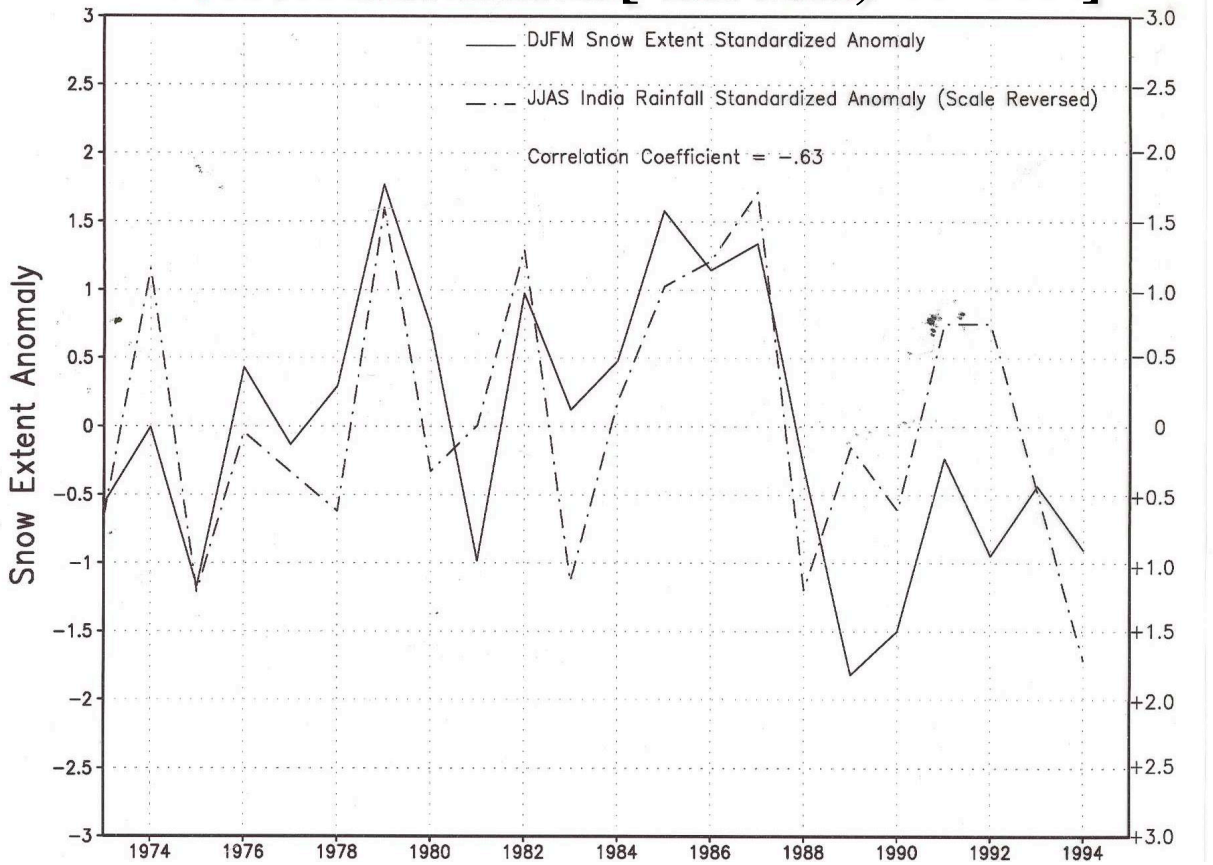
OBSERVED (NOAA)



"The excessive winter and spring snowfall in the Himalayas is prejudicial to the subsequent monsoon rain fall in India." **H.F. Blanford, 1882**

Snow Extent and Indian Rainfall (Bamzai 1997)

Western Eurasia [-10-30E; 40-60N]



"The excessive winter and spring snowfall in the Himalayas is prejudicial to the subsequent monsoon rain fall in India." **H.F. Blanford, 1882**

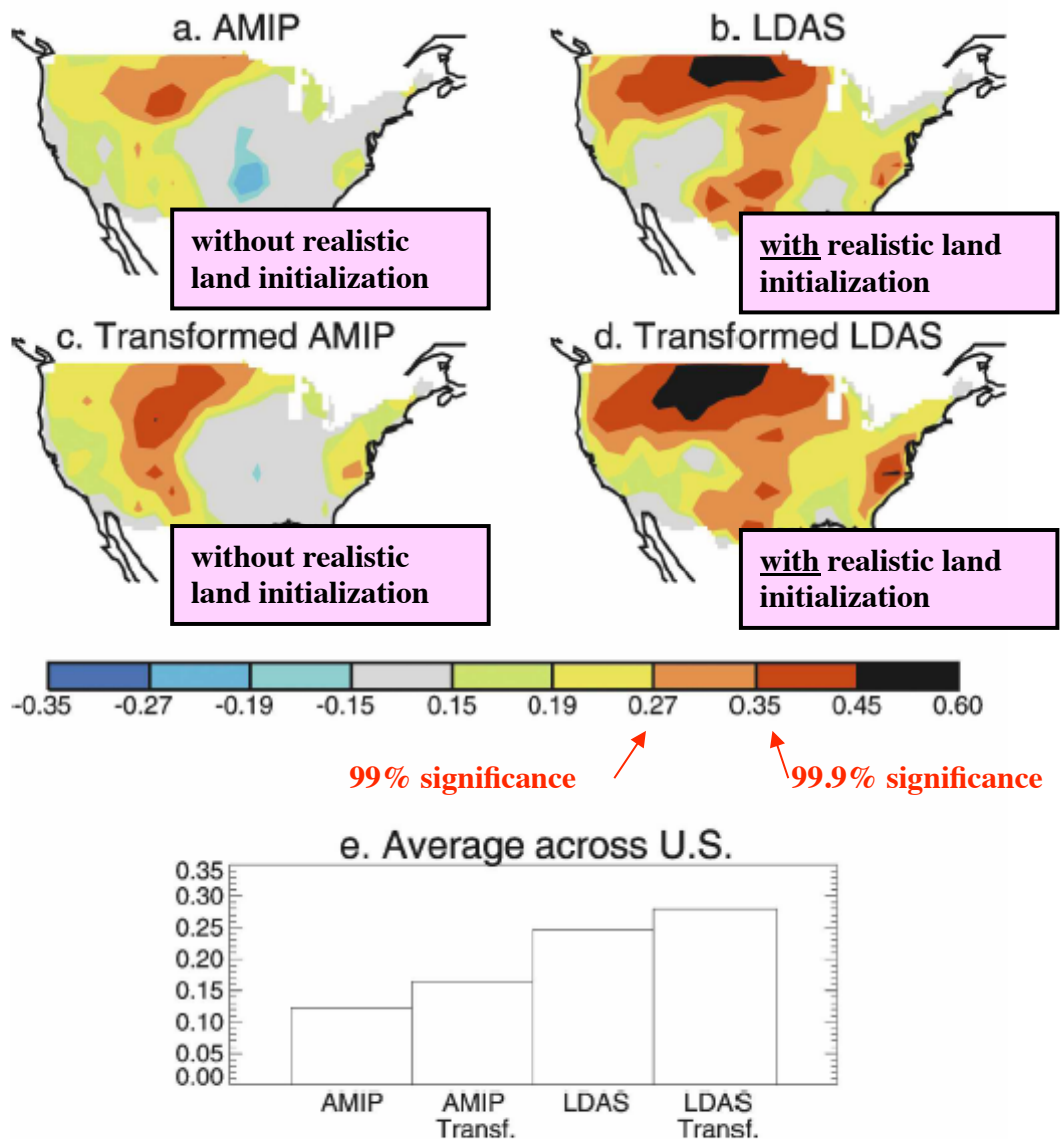
"These observations were later substantiated." **Walker, 1910**

Air temperature: Skill (r) of monthly forecasts

Skill scores derived from 75 independent 1-month warm-season forecasts.

All forecasts used well-predicted SSTs but unrealistic atmospheric initial conditions.

Transformed forecasts: Use of semi-empirical observations-based forecast adjustment



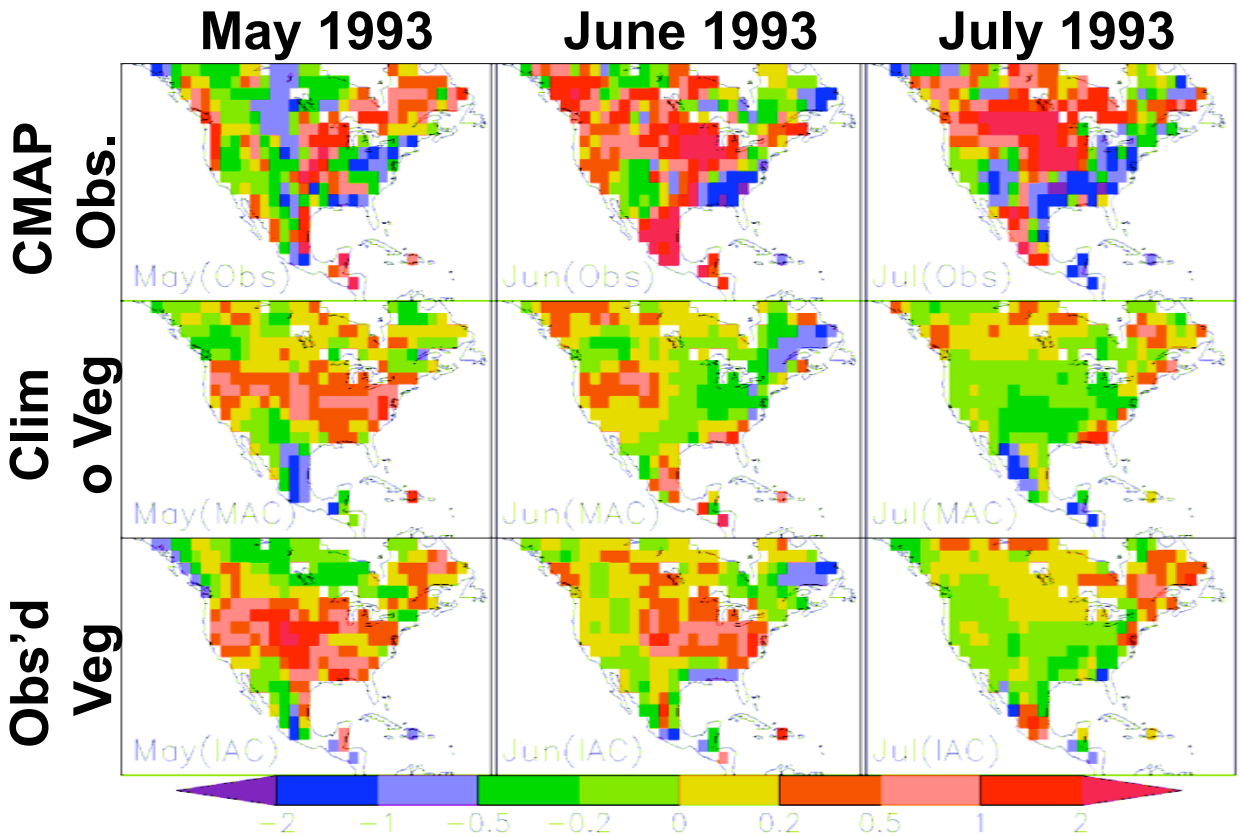
Koster et al., J. Hydromet., 5, 1049-1063, 20
Koster et al., Mon. Wea. Rev., 136, 1923-1939, 2008.

Interannual Vegetation Variations Impact Hindcasts

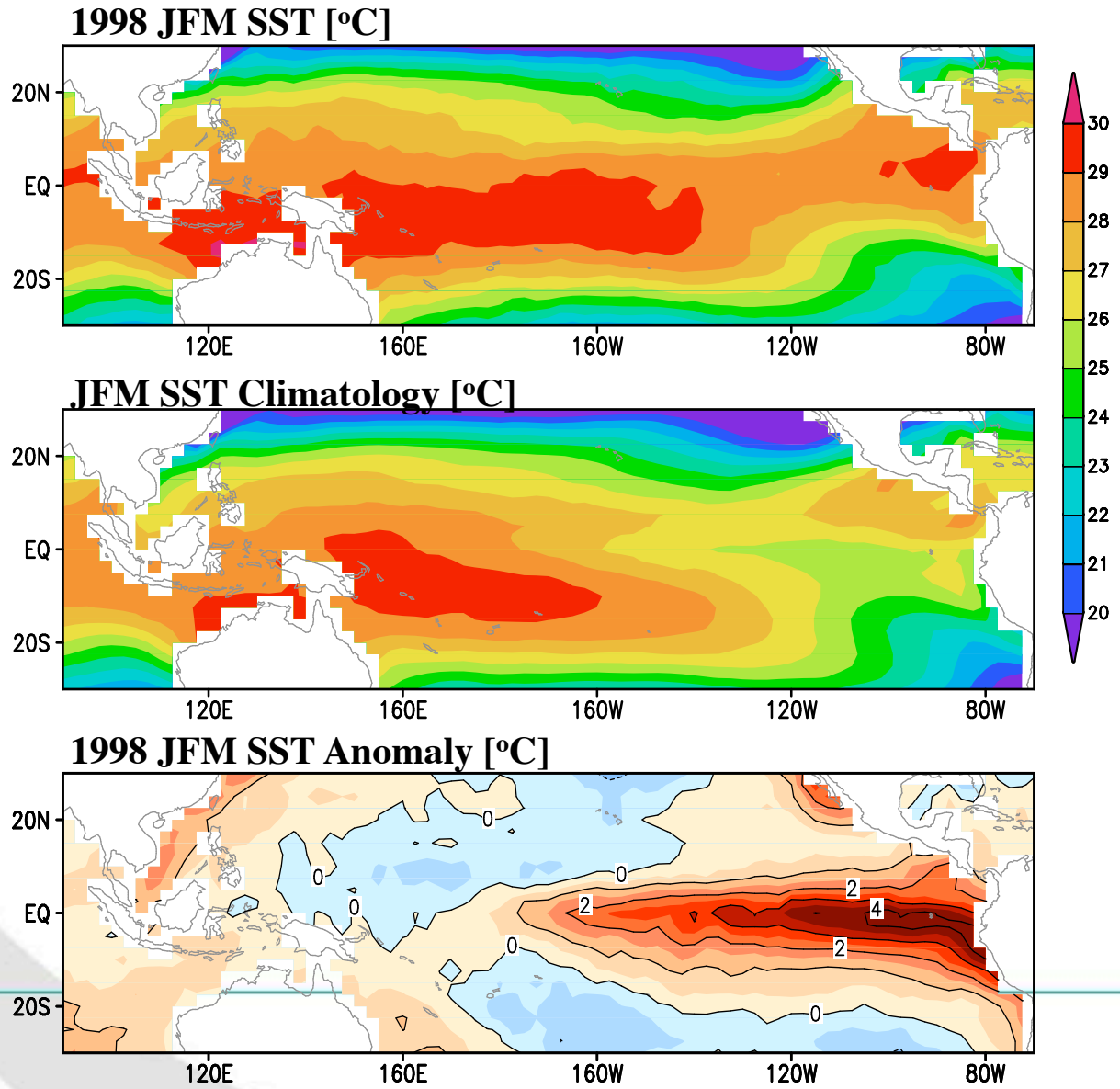
When regional vegetation anomalies are large, they improve prediction of monthly-seasonal precipitation in 1/3 of cases. Half of cases show no change, and 1/6 are worse (1986-1995 period, all areas of globe).

Gao, X., P. A. Dirmeyer, Z. Guo, and M. Zhao, 2008: J. Hydrometeor., 9, 348-366

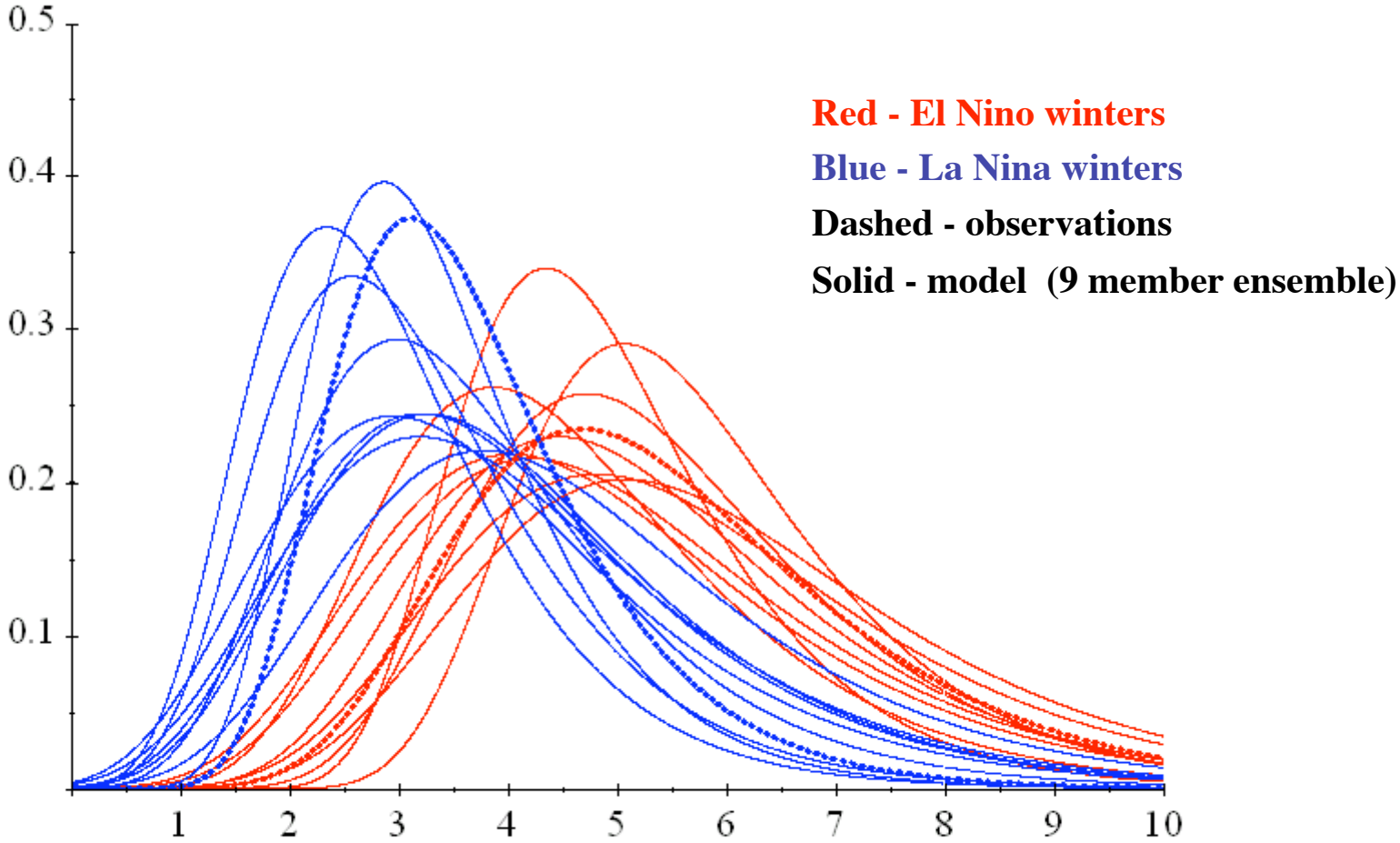
Precipitation Anomalies (mm/d)



El Nino/Southern Oscillation



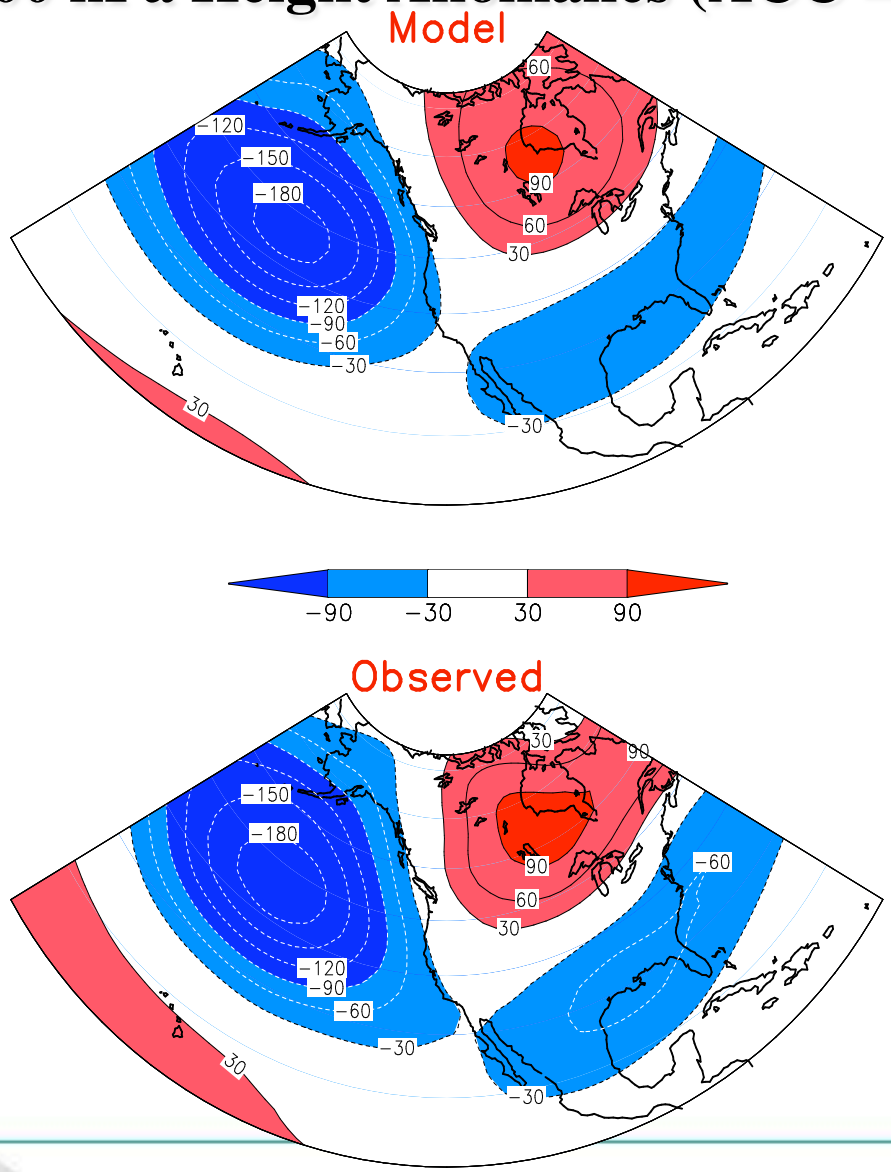
Probability Density Function of Extreme Winter Storms in Southeastern US (DJF 1949-1998)



Maximum value of the intensity of storms affecting the southeastern United States (storms are identified from an EOF analysis of daily precipitation). Values are the principal components scaled so that the model and observed EOFs have the same total variance. Units are arbitrary. The PDFs are the fits to a Gumbel Distribution. ***(Schubert et al., GMAO)***

Model Simulation of ENSO Effects

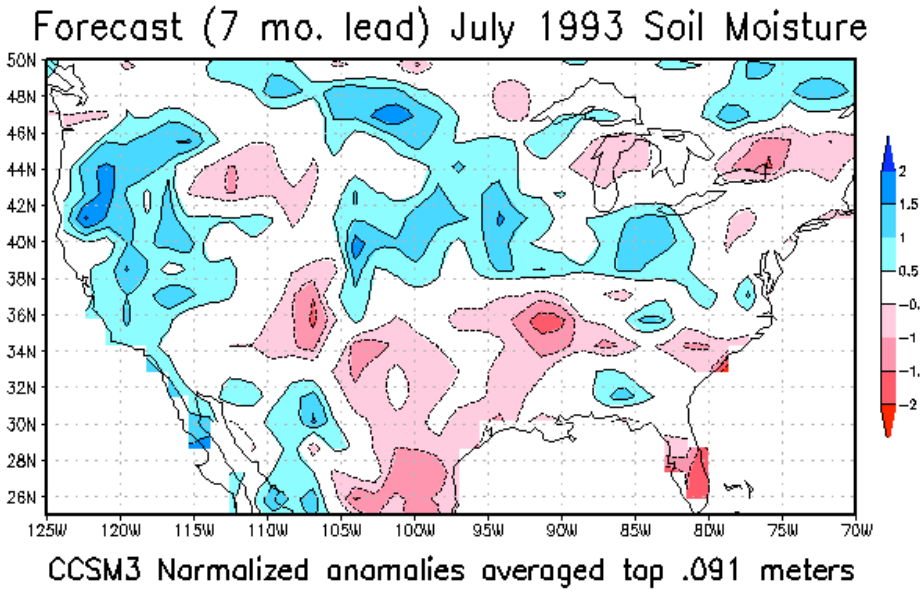
500 hPa Height Anomalies (ACC = 0.98)

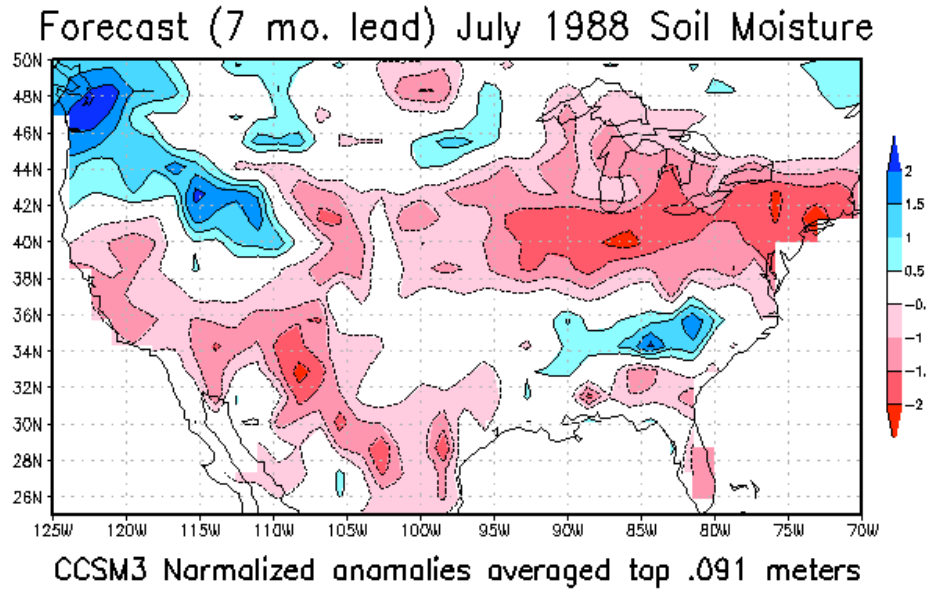


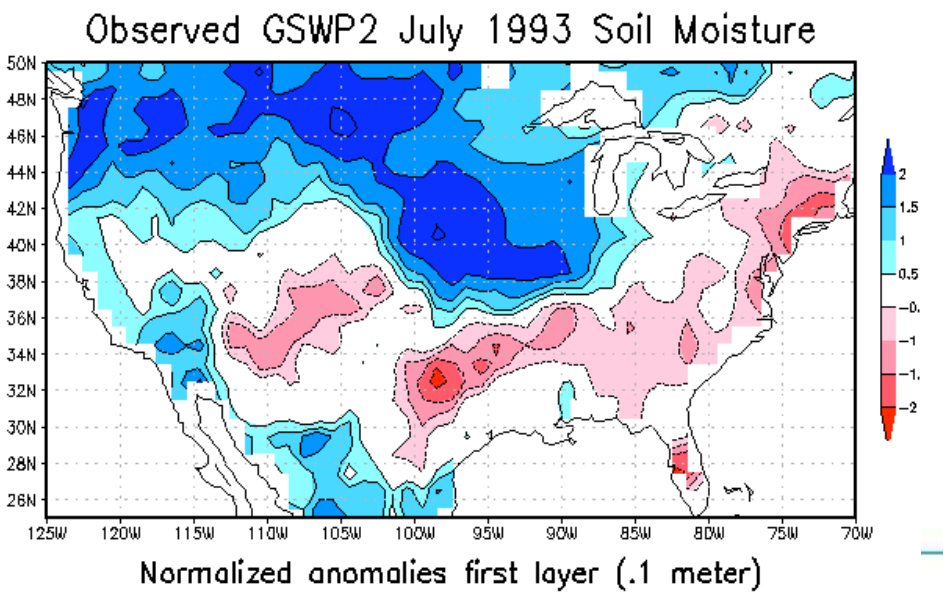
Vintage 2000 AGCM

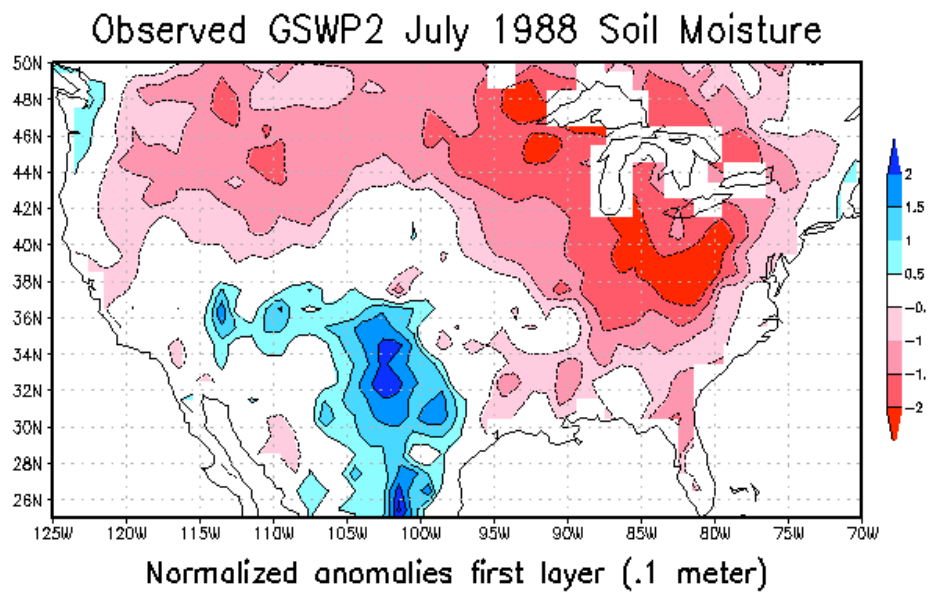
NINO3 Warm(83,87,92) – Cold(85,89)

CCSM Re-Forecasts with Land ICs









Courtesy of Dan Paolino

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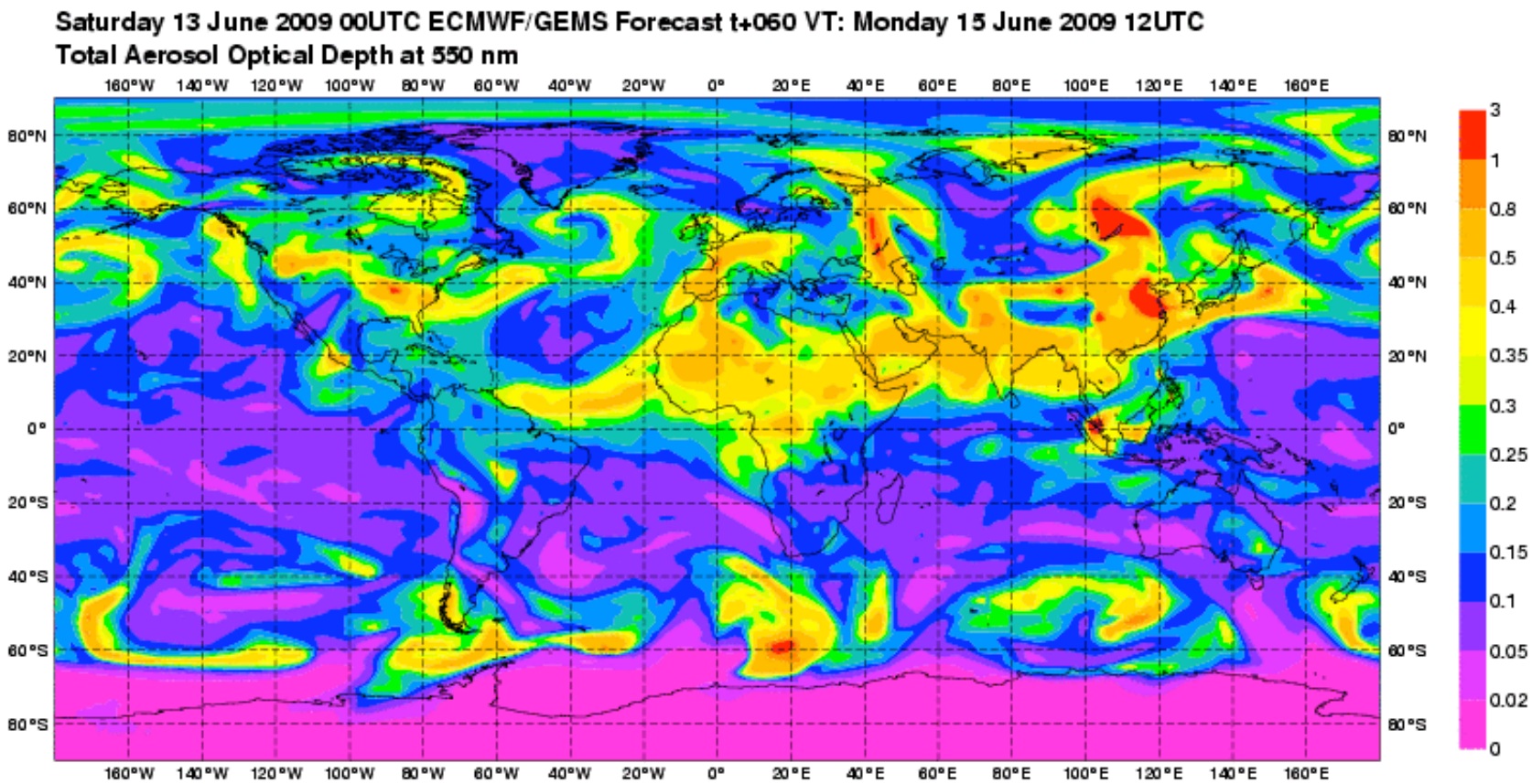
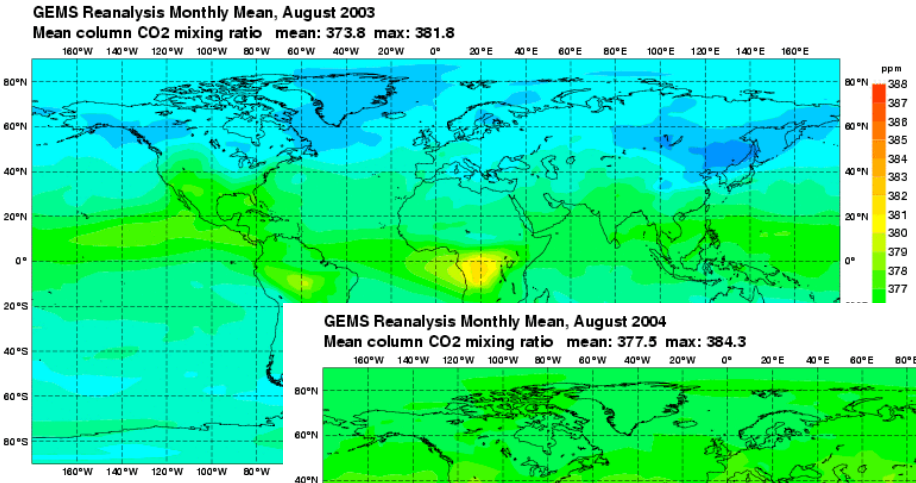
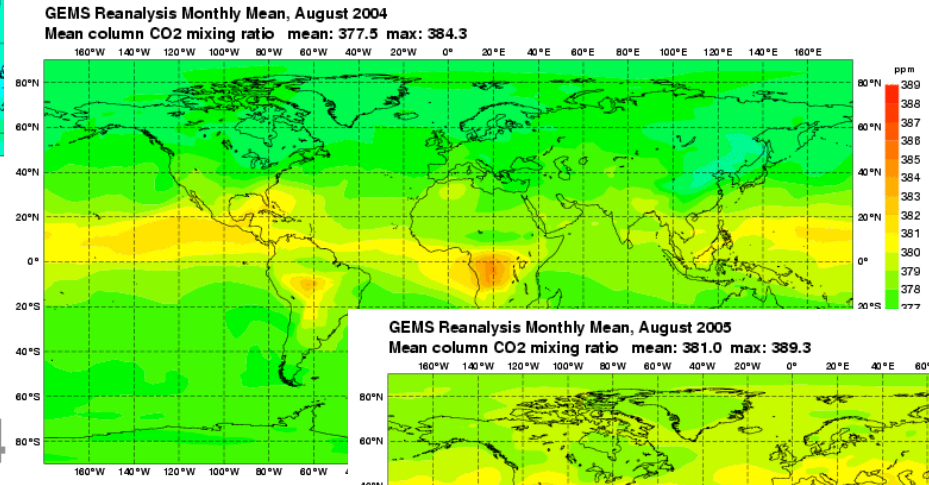
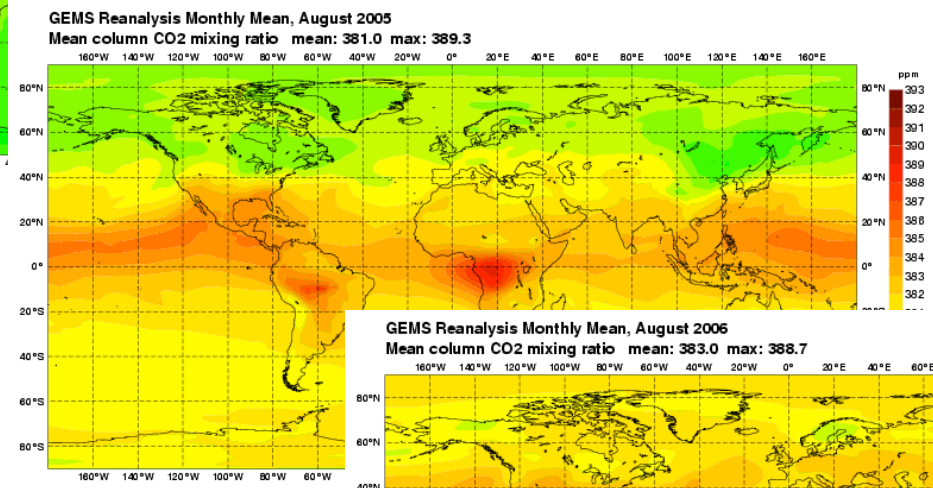
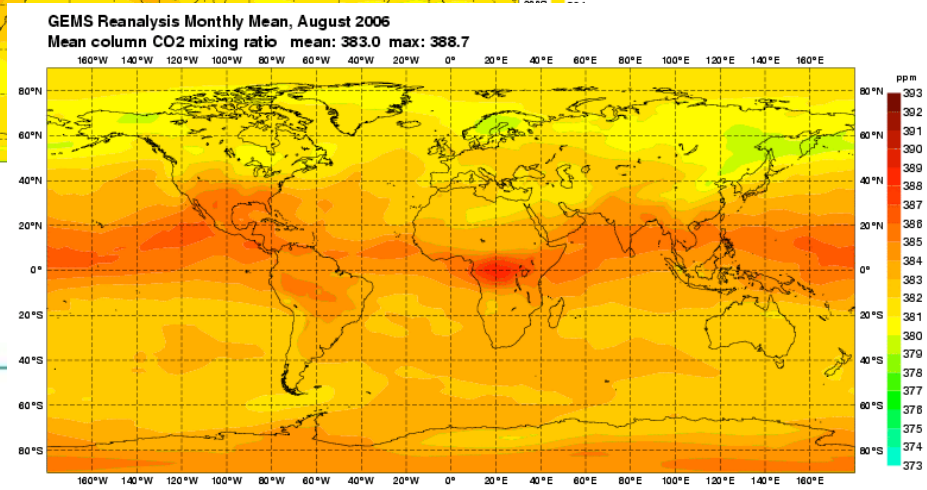
An example of pre-operational forecast from GEMS: Aerosol optical depth with MODIS data assimilation











2003

2004

2005

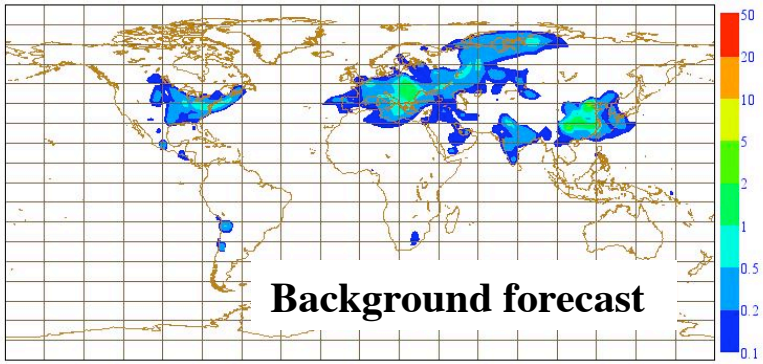
2006

The European GEMS project provided a 5-year CO_2 reanalysis based on AIRS observations.

The follow-on MACC project will also assimilate IASI, GOSAT, and other new instruments.

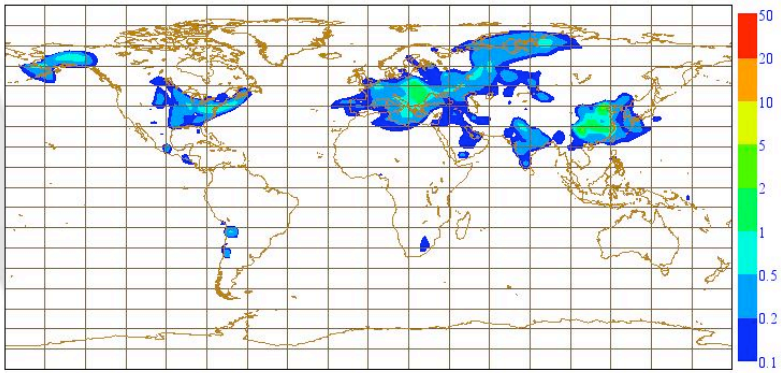
Monthly mean column-averaged CO_2 for August

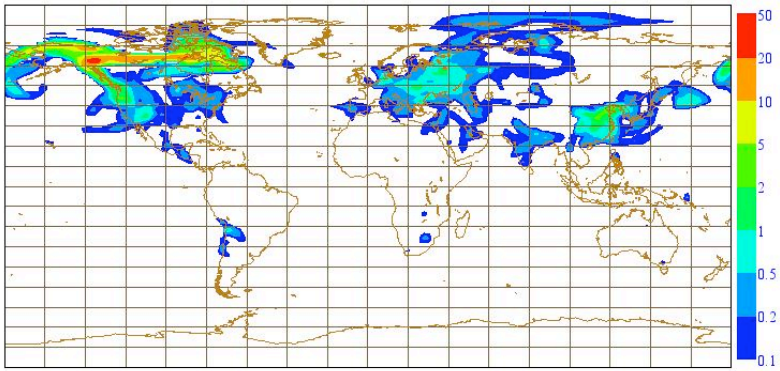
SO2 assimilation in GEMS at ECMWF
Mount Redoubt eruption in Alaska



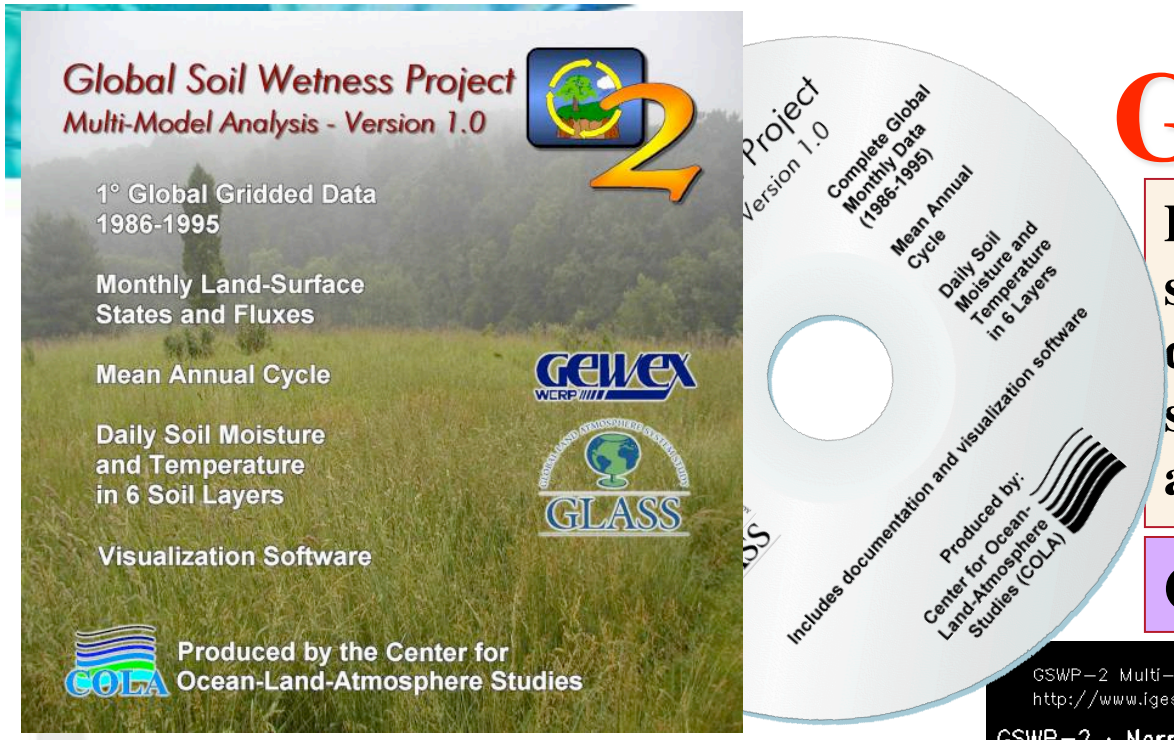
23 March, 00UTC

25 March, 12 UTC





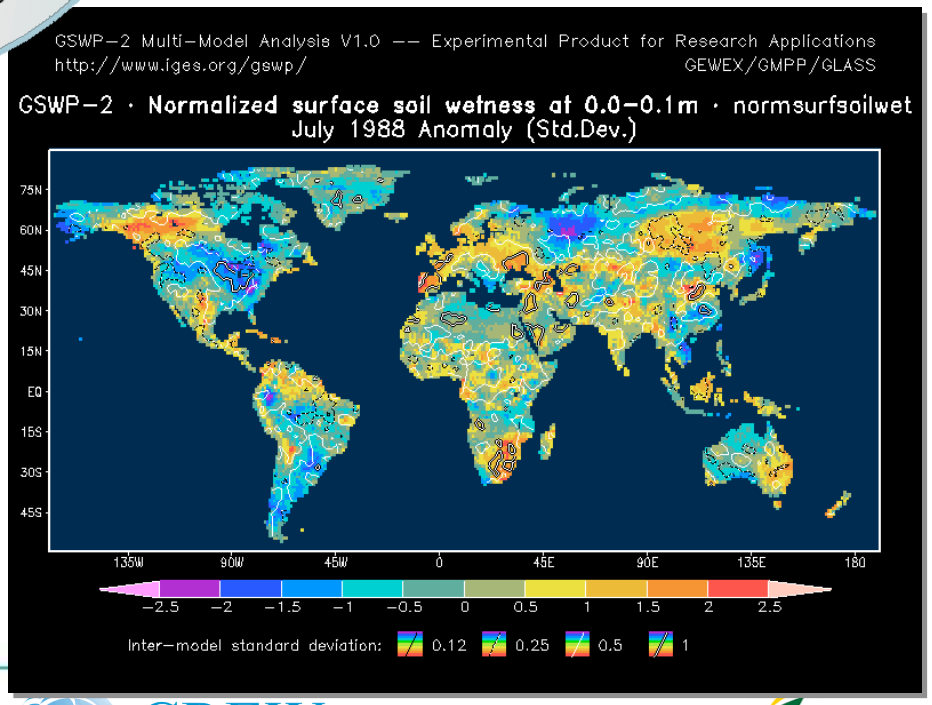
Analyses with ESA/SCIAMACHY SO2 retrievals



GSWP-2

DVD with 10yr global 1° land-surface data sets for 50 different variables, including soil moisture and temperature at 6 levels.

October 2006 BAMS



- Includes documentation, data (NetCDF monthly and climatological; daily for soil moisture and temperature only), sample images, and GrADS software.
- Monthly data include inter-model standard deviation as well as multi-model mean.
- Complete daily data online (see: www.iges.org/gswp/).

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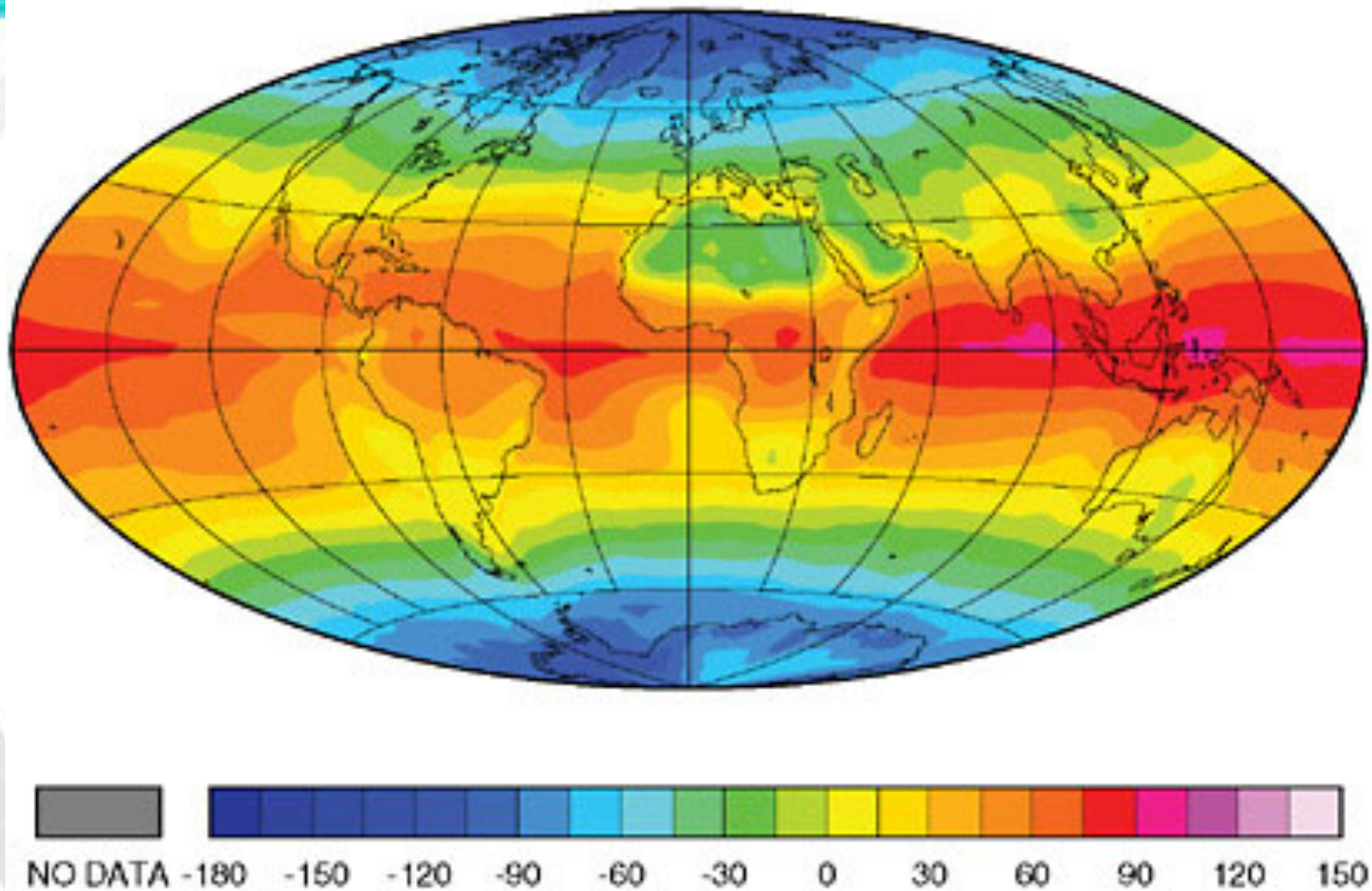
George Mason University

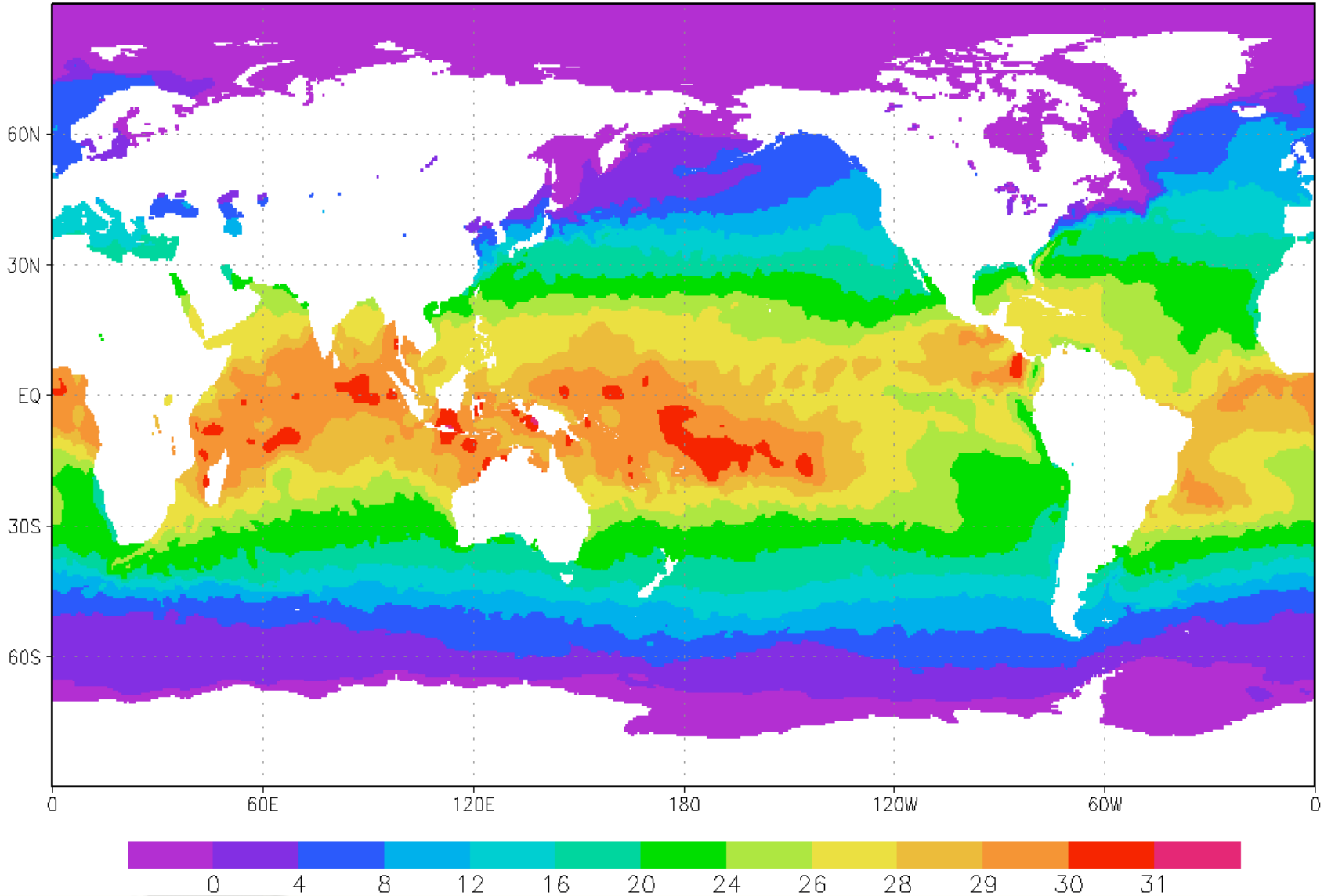
Net Radiation (1985-86)



Net annual imbalance between incoming solar radiation and outgoing long wave radiation (ERBE data). Positive values indicate downward flux.

Real Time Global 1/2° Daily SST Analysis

for 13 March 2003



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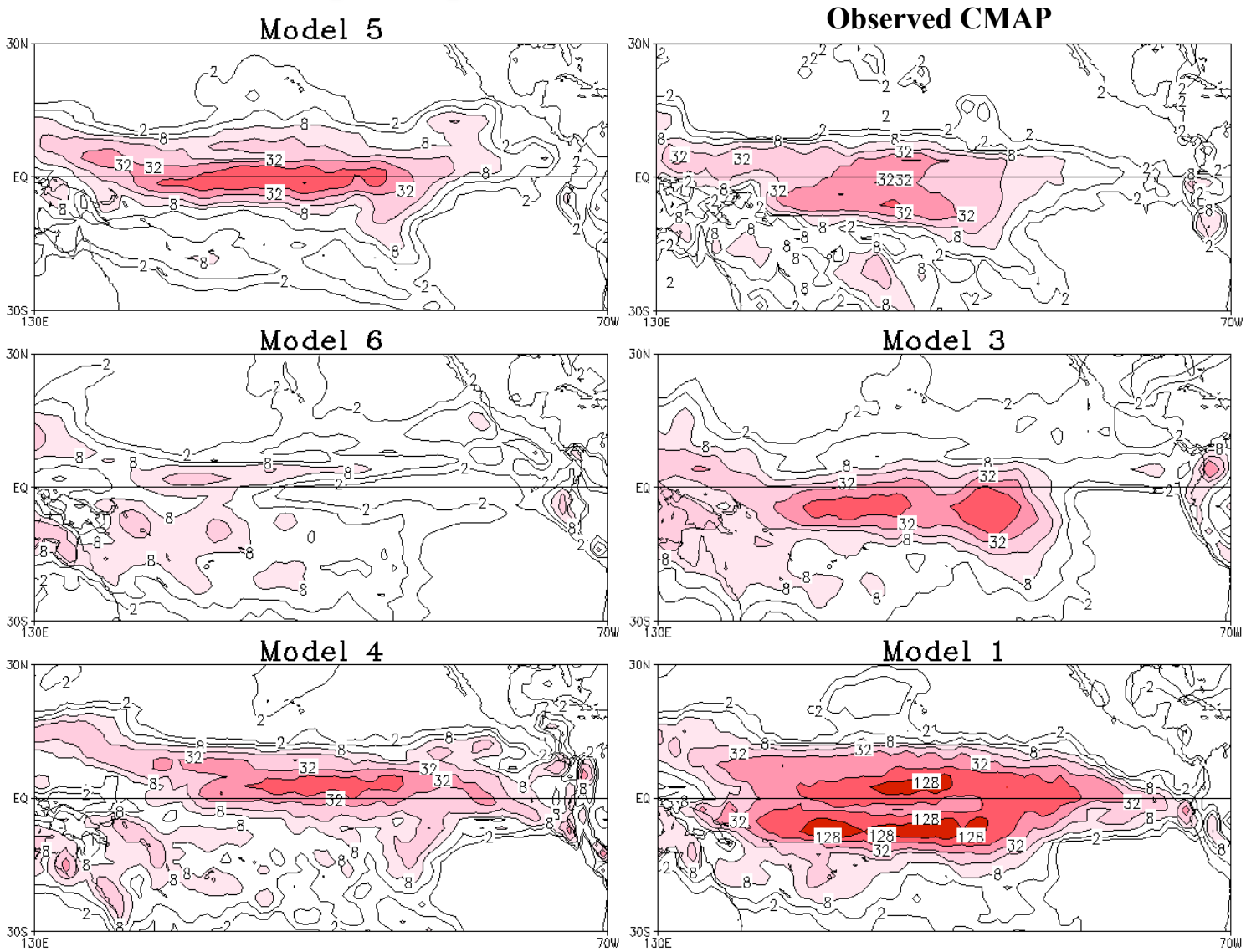
Boreal Winter (DJF) Rainfall Variance in AGCMs



(mm^2)

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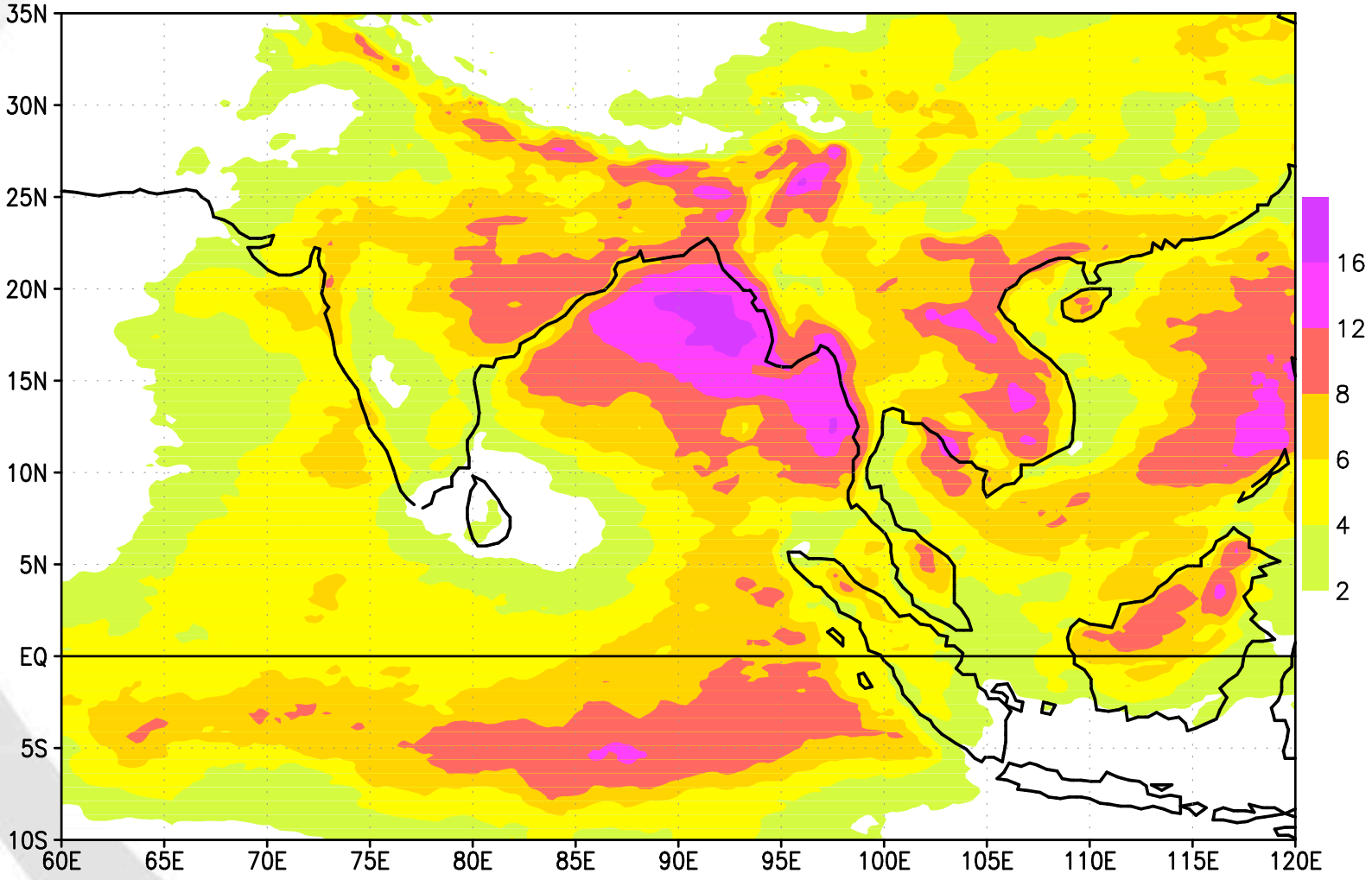
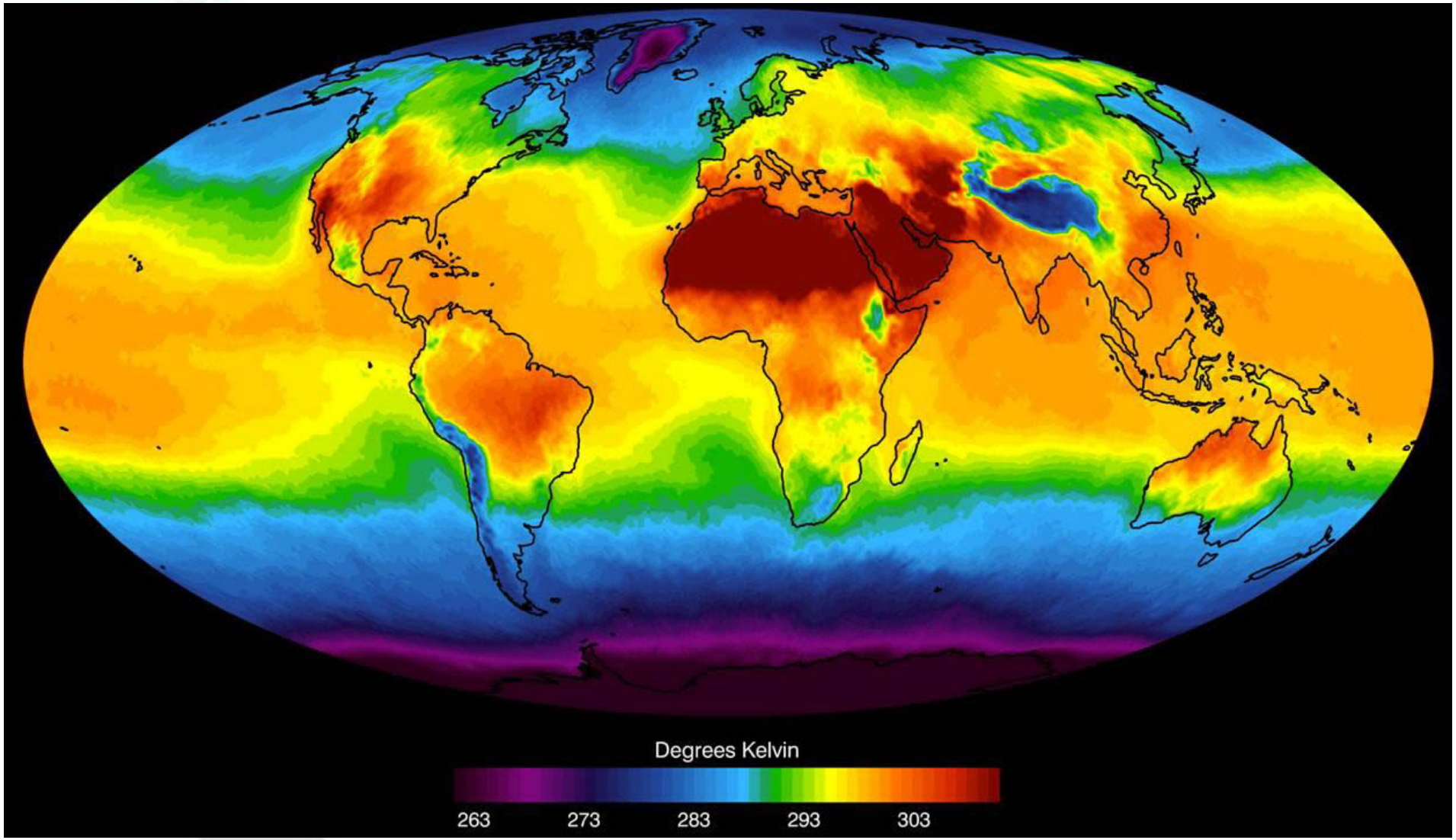
Observed Summer (JJAS) Precipitation (mm/day) from Satellite (2003-2006)



Mean Surface Air Temperature

AIRS data July 2003



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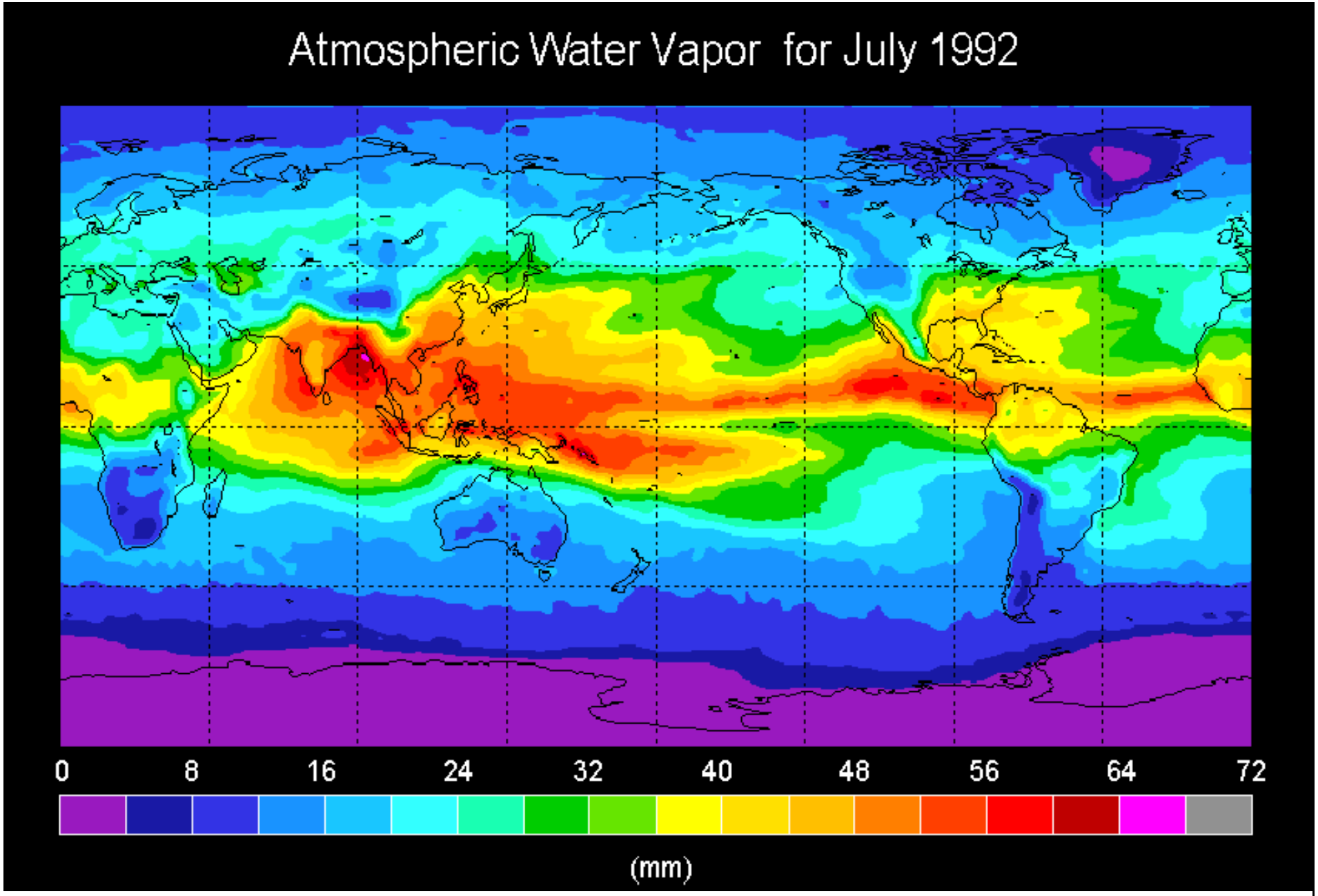
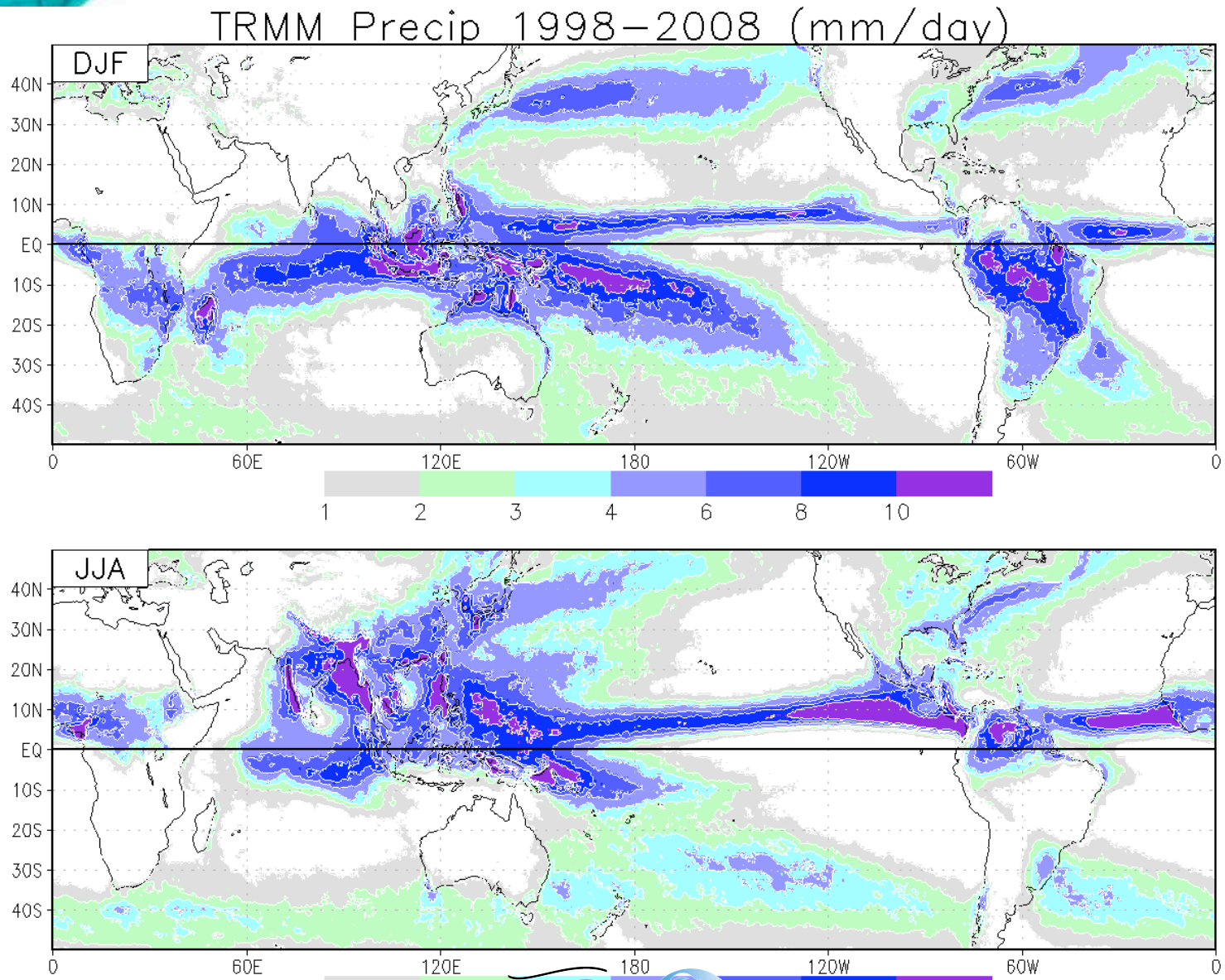


The NASA Water Vapor Project (NVAP) total column (integrated) water vapor data sets comprise a combination of radiosonde observations, Television and Infrared Operational Satellite (TIROS) Operational Vertical Sounders (TOVS), and Special Sensor Microwave/Imager (SSM/I) data sets.

Climatology of TRMM Precipitation (1998-2008)



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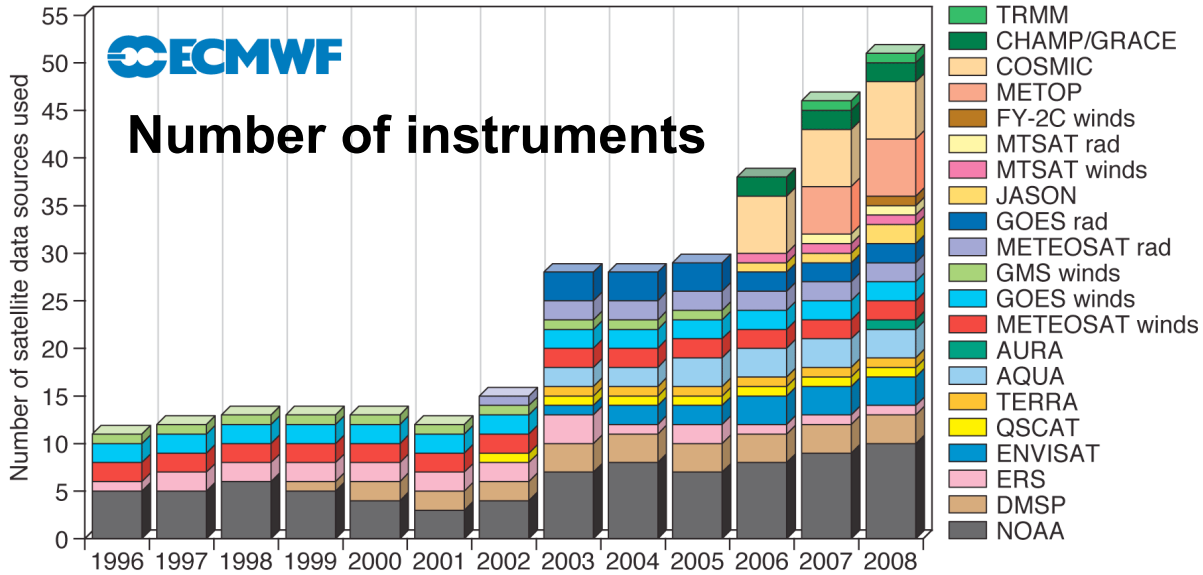
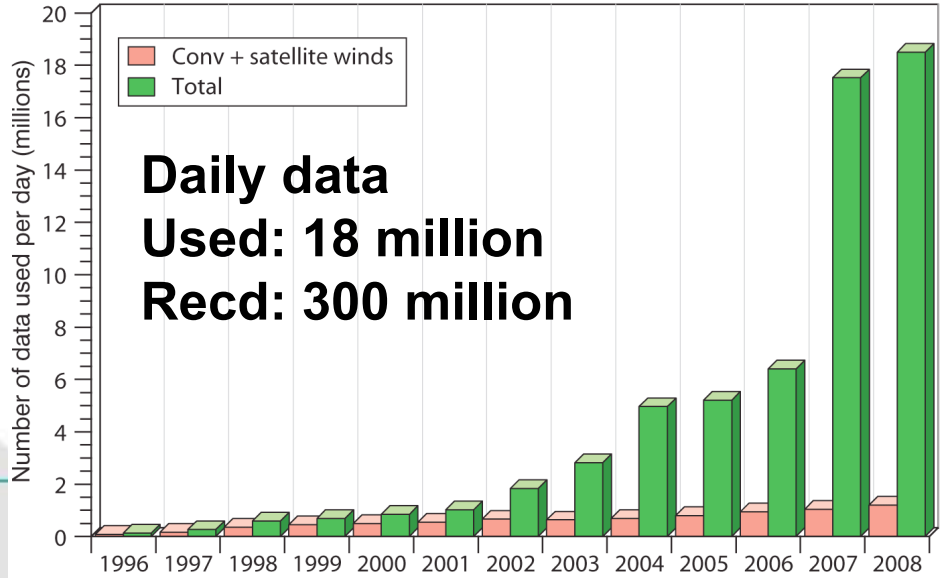
Outline

- NASA/Space Observations Advance ESS
  - Weather Prediction
  - Climate Prediction
  - Climate Model Validation
- Challenges
  - Scientific
    - Observations/Data Assimilations
    - Modeling/Prediction
    - Data/Information Systems
  - Institutional
  - Multi-Agency (U.S./International)
- Summary/Suggestions

Satellite Data used by ECMWF





Commentary

ECMWF is utilizing less than 10% of daily satellite data (18 million out of 300 million) because insufficient computer power and scientific staff. Each instrument's data assimilation requires unique and additional work.

Model has coarse resolution compared to satellite data.

Outline

- NASA/Space Observations Advance ESS
  - Weather Prediction
  - Climate Prediction
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- Challenges
  - Scientific
    - Observations/Data Assimilations
    - Modeling/Prediction
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  - Institutional
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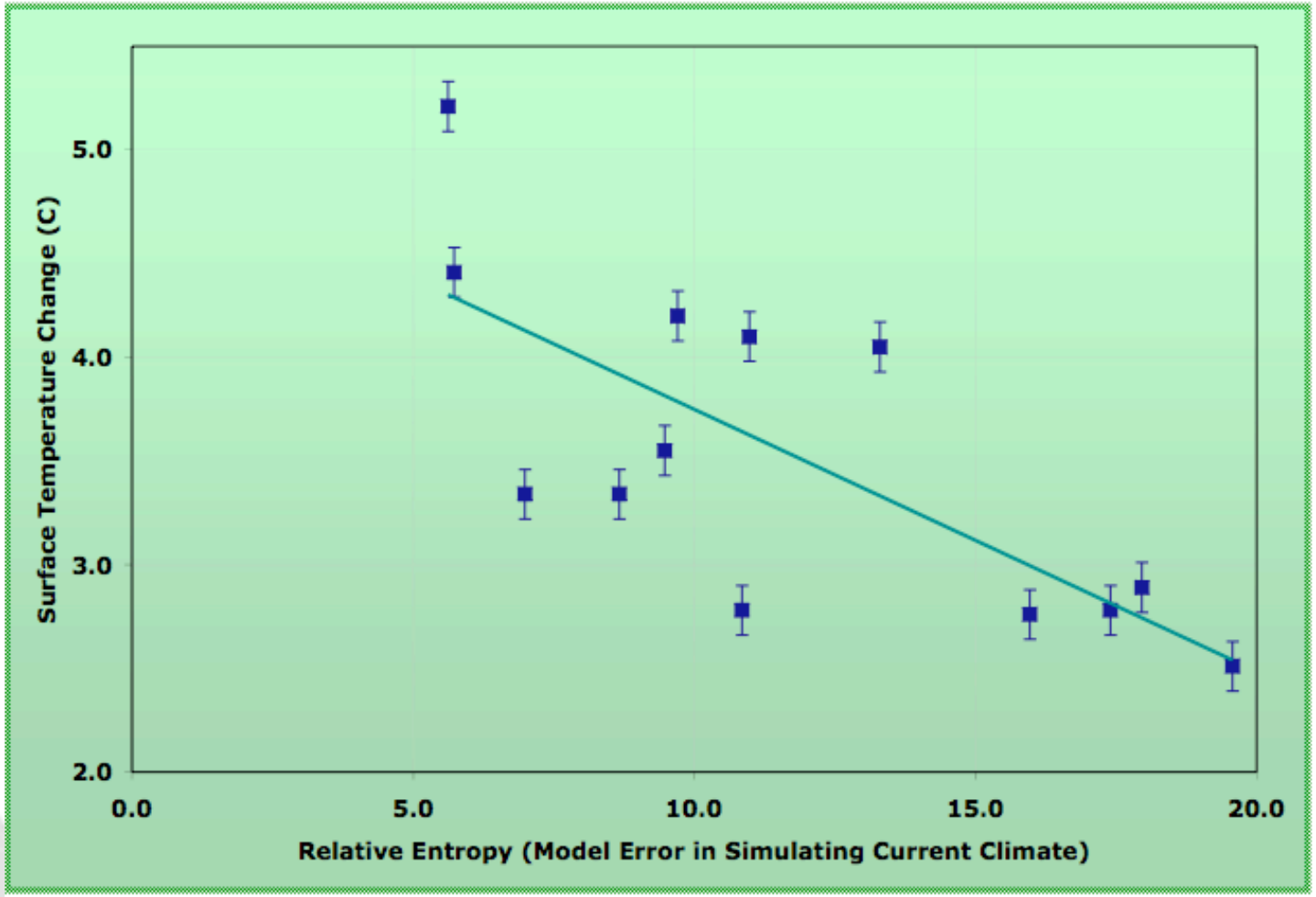
- Summary/Suggestions

Climate Model Fidelity and Projections of Climate Change

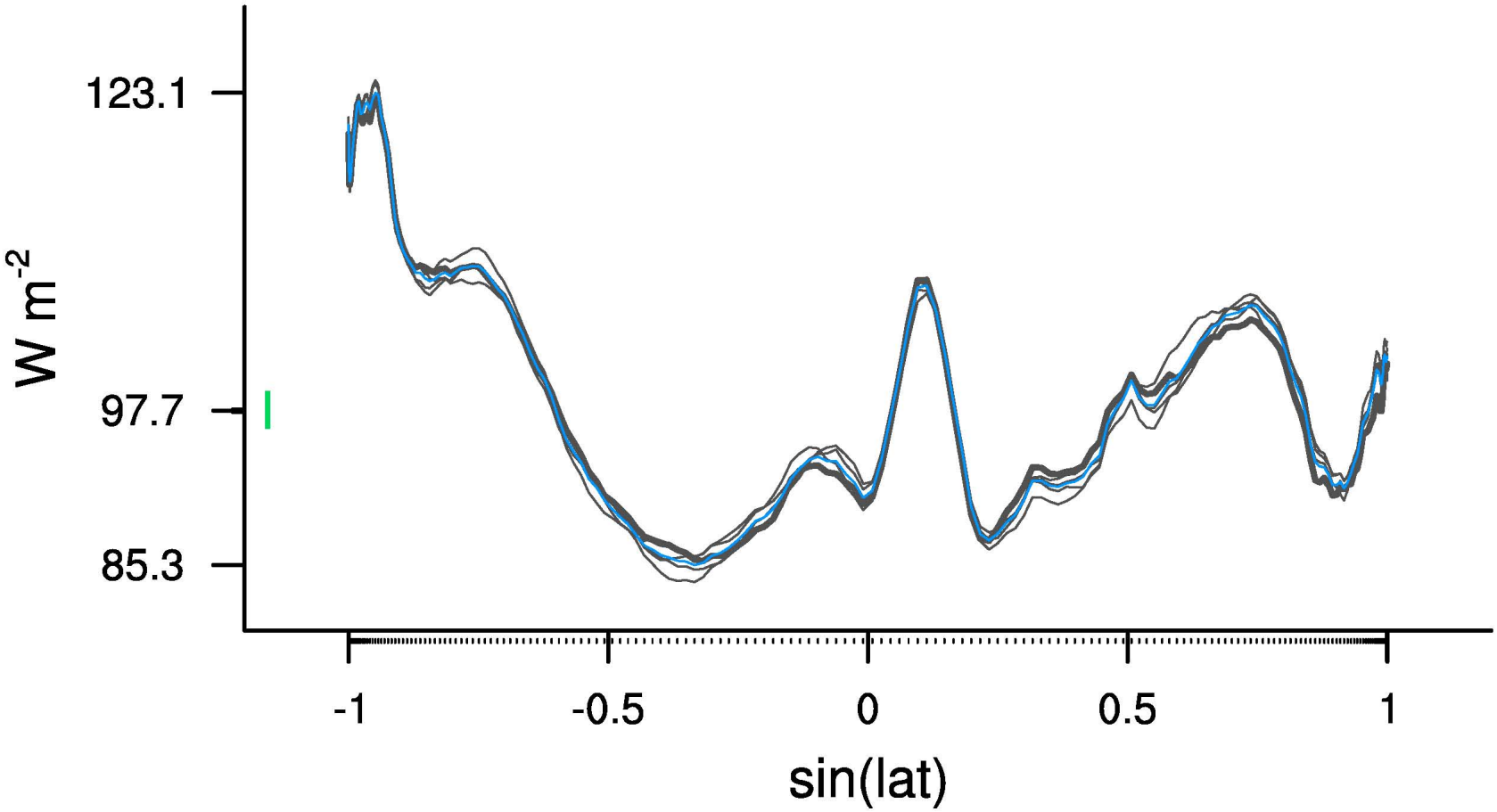
J. Shukla, T. DelSole, M. Fennessy, J. Kinter and D. Paolino

Geophys. Research Letters, 33, doi10.1029/2005GL025579, 2006

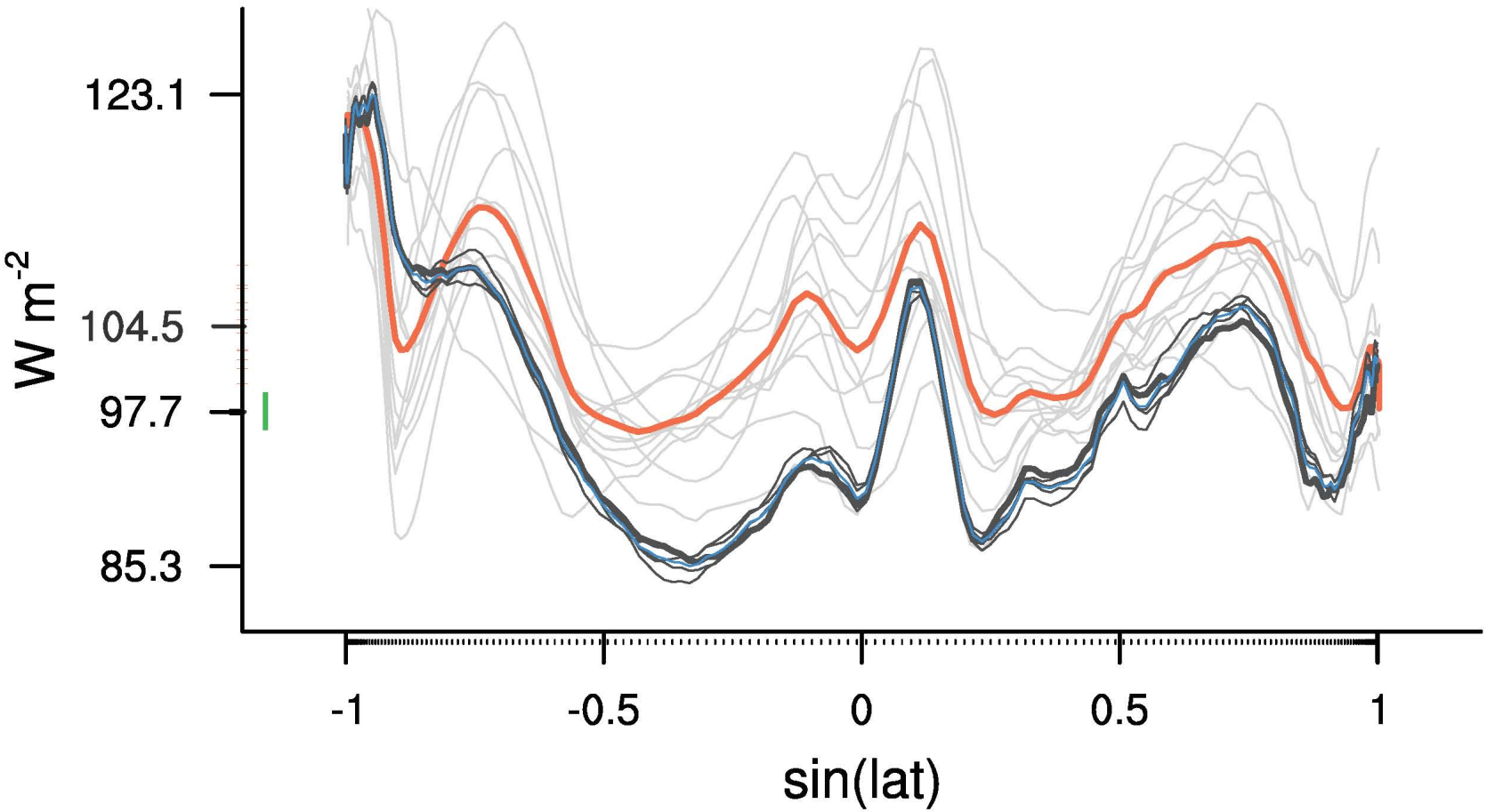


Model sensitivity versus model relative entropy for 13 IPCC AR4 models. Sensitivity is defined as the surface air temperature change over land at the time of doubling of CO_2. Relative entropy is proportional to the model error in simulating current climate. Estimates of the uncertainty in the sensitivity (based on the average standard deviation among ensemble members for those models for which multiple realizations are available) are shown as vertical error bars. The line is a least-squares fit to the values.

Annually & Zonally Averaged Reflected SW Radiation



Annually & Zonally Averaged SW Radiation (AR4)



- 101-106 W/m2 (Wild et al., survey)
- 107 W/m2 (Trenberth and Kiehl (ERBE)
- 101 W/m2 (CERES)

Fundamental barriers to advancing weather and climate diagnosis and prediction on timescales from days to years are (partly) (almost entirely?) attributable to gaps in knowledge and the limited capability of contemporary operational and research numerical prediction systems to represent precipitating convection and its multi-scale organization, particularly in the tropics.

(Moncrieff, Shapiro, Slingo, Molteni, 2007)

WMS takes place at ECMWF (6-9 May 2008). Nearly 150 participants from all modelling centers of the world.

They say they want a revolution

Climate scientists call for major new modelling facility.

Climatologists have called for massive investment in computer and research resources to help revolutionize modelling capabilities. The eventual aim is to provid predictions that are as weather forecasts.

At the end of a four-day at the European Centre Weather Forecasts in Rea made the case for a clim on the scale of the Hum key component of this cost something up to, lars, would be a world cl research facility with co

— to speeds in the hundreds of petaflops — would allow modellers to study simulations at the kilometre scale, enabling better predictions

Article in Nature, May 2008

Researchers from around the world gathered in Reading, UK, for the summit.

ECMWF

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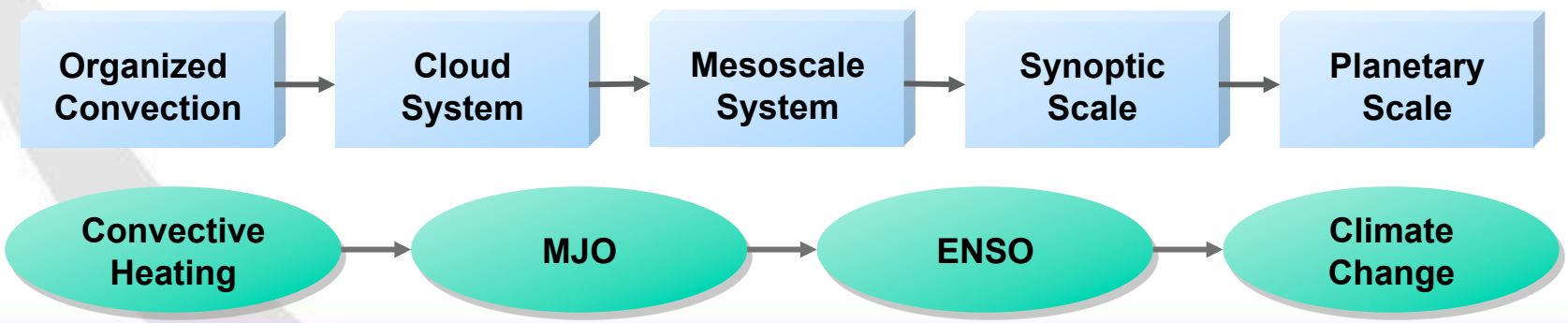
A Billion Dollar Conjecture

- The largest obstacles in realizing the potential predictability of weather and climate are inaccurate models and insufficient observations, rather than an intrinsic limit of predictability.
  - In the last 30 years, most improvements in weather forecast skill have arisen due to improvements in models and assimilation techniques
- The next big challenge is to build a hypothetical "perfect" model which can replicate the statistical properties of past observed climate (means, variances, covariances and patterns of covariability), and use this model to estimate the limits of weather and climate predictability
  - The model must represent ALL relevant phenomena, including ocean, atmosphere, and land surface processes and the interactions among them

Seamless Prediction of Weather and Climate

From Cyclone Resolving Global Models to Cloud System Resolving Global Models

1. Planetary Scale Resolving Models (1970~): Δx~500Km
2. Cyclone Resolving Models (1980~): Δx~100-300Km
3. Mesoscale Resolving Models (1990~): Δx~10-30Km
4. Cloud System Resolving Models (2000 ~): Δx~3-5Km♪



Revolution in Climate Prediction is Possible and Necessary

Coupled Ocean-Land-Atmosphere Model ~2015

Assumption:
Computing power enhancement by a factor of 10^6

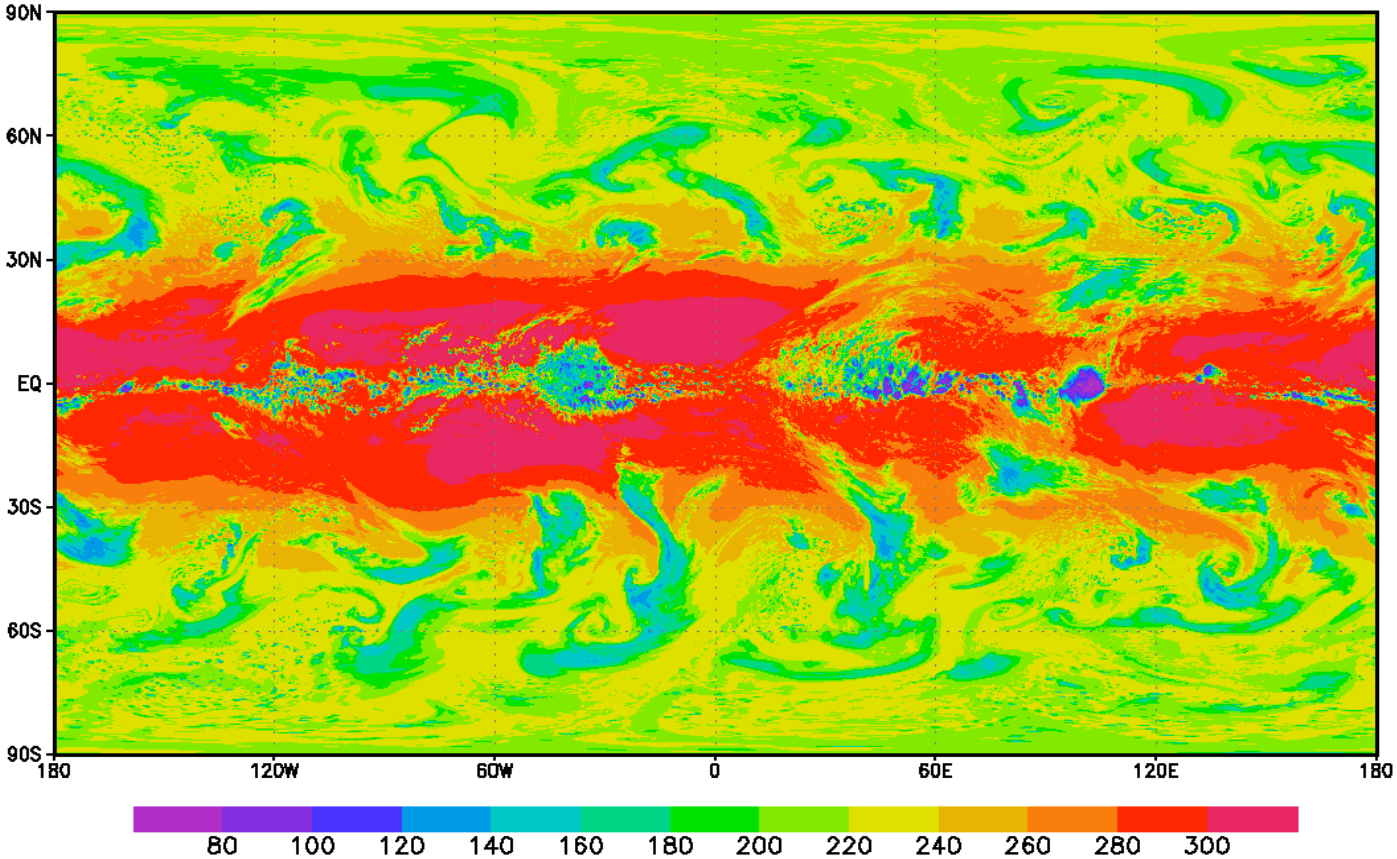
~1 km x ~1 km (cloud-resolving)
100 levels
(Unstructured, adaptive grids)

~100 m
10 levels
Landscape-resolving

~10 km x ~10 km (eddy-resolving)
100 levels
(Unstructured, adaptive grids)

- **Improved understanding of the coupled O-A-B-C-S interactions**
- **Data assimilation & initialization of coupled O-A-B-C-S system**

Closest attempt to global cloud resolving model so far …

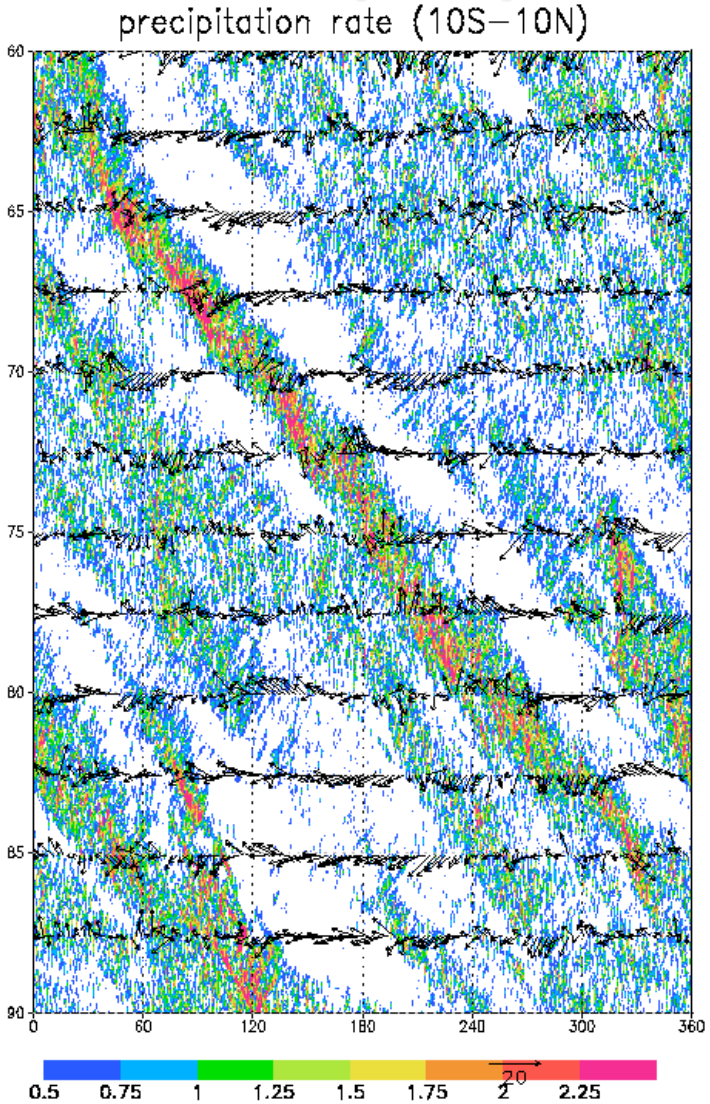


Running on Earth Simulator

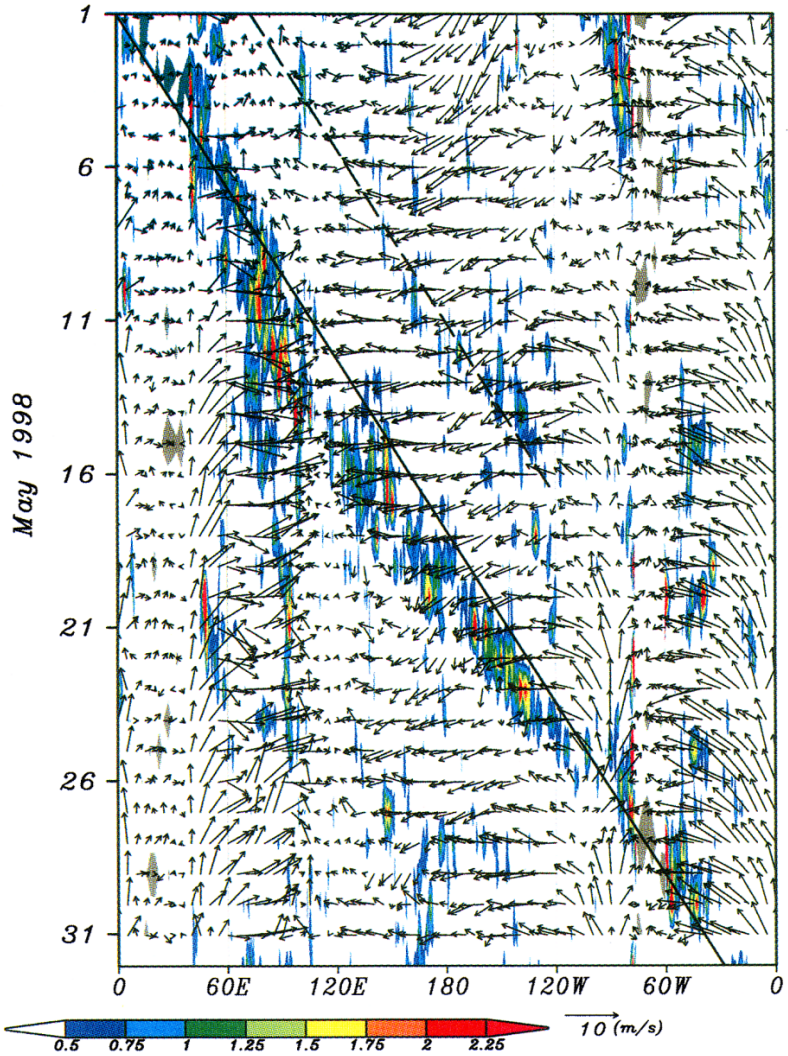
- **Ocean-covered Earth**
- **Geodesic grid**
- **3.5 km cell size, ~10^7 columns**
- **54 layers, top at 40 km**
- **15-second time step**
- **~ 1 TF-day per simulated day**

*Masaki Satoh, Hirofumi Tomita, Hiroaki Miura, Shinichi Iga and Tomoe Nasuno, 2005: J. Earth Simulator, **3**, 1-9.*

NICAM (7-km)

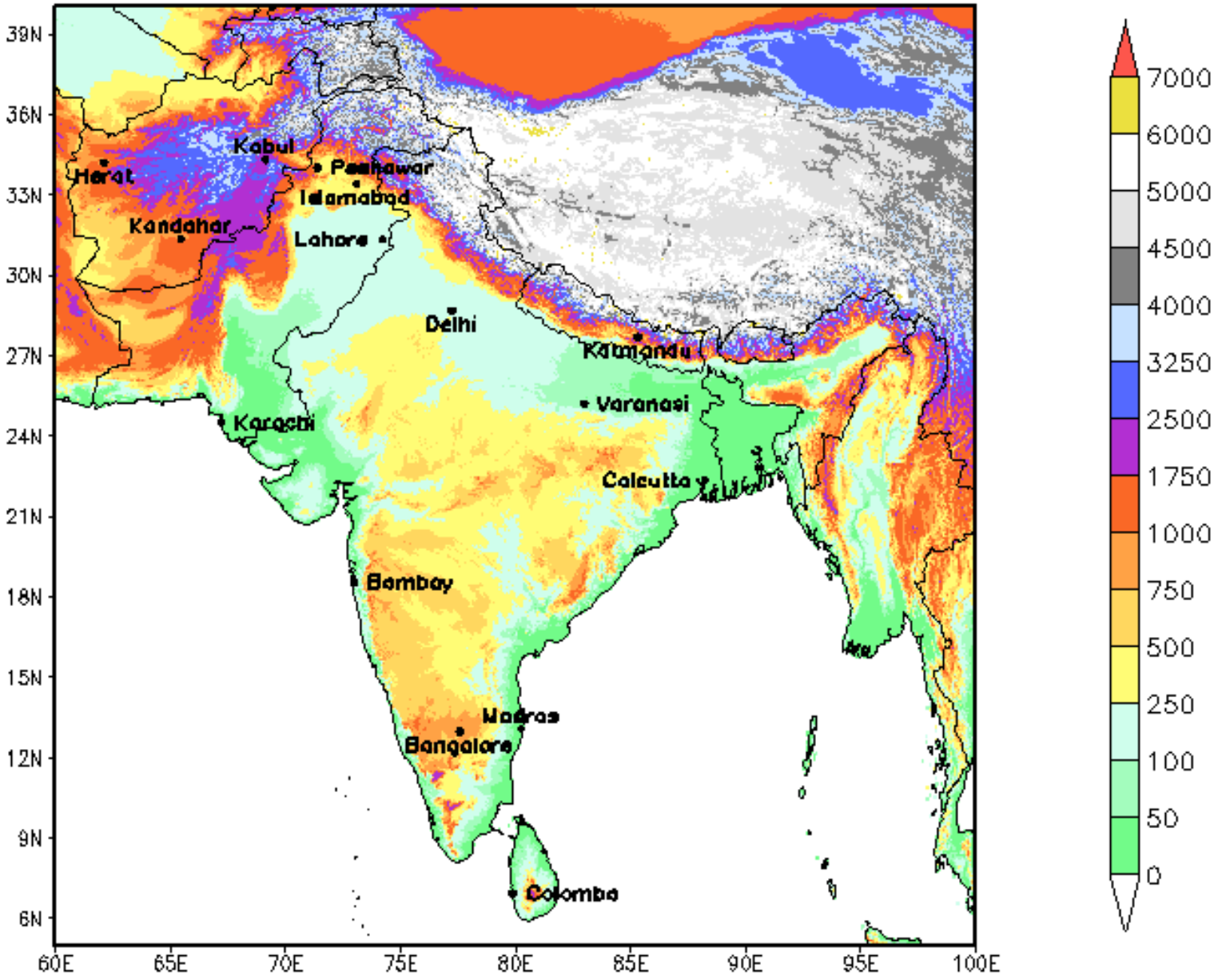


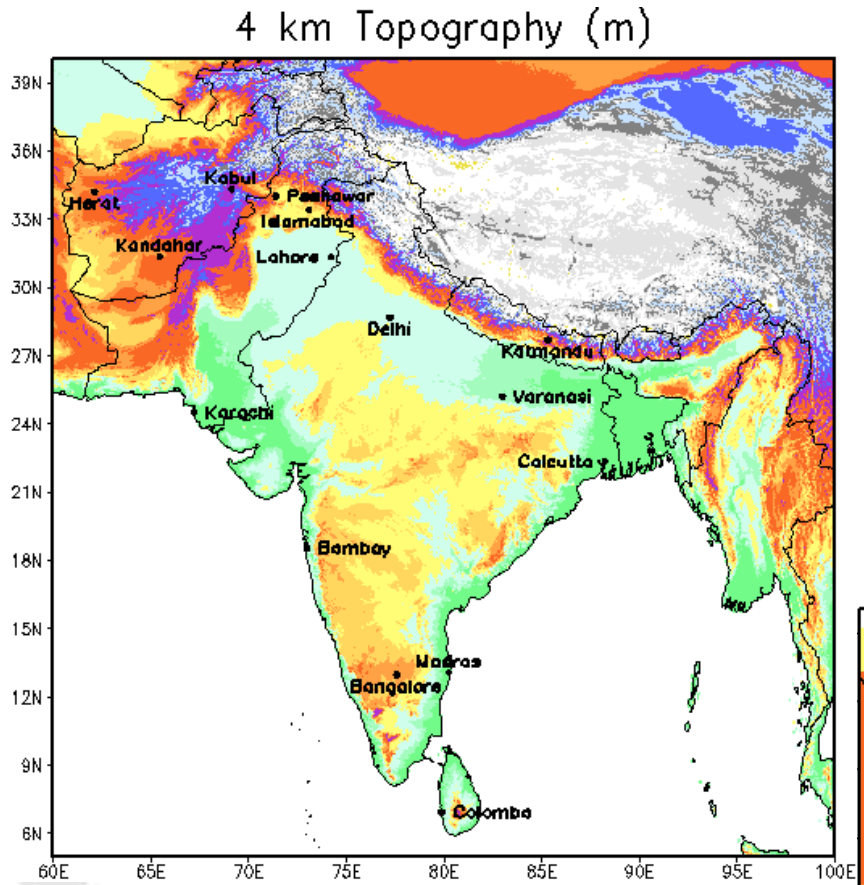
Obs. (Takayabu et al. 1999)

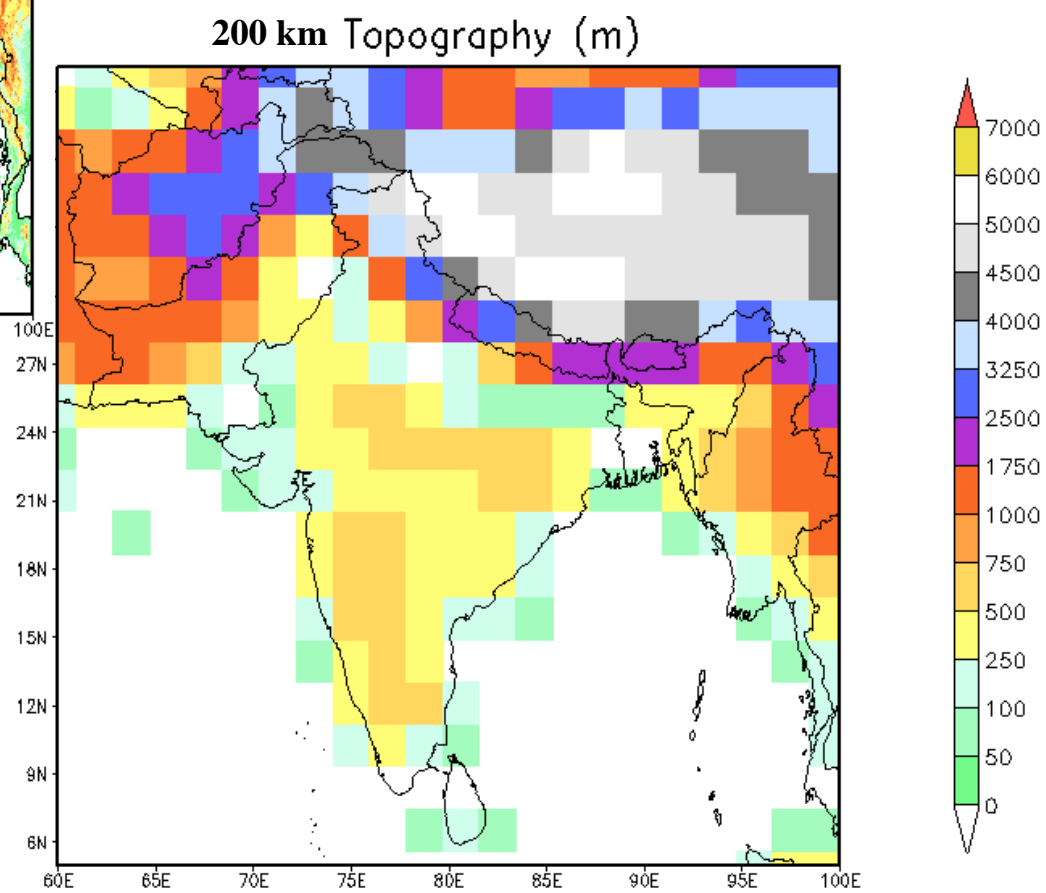


Matsuno (AMS, 2007)

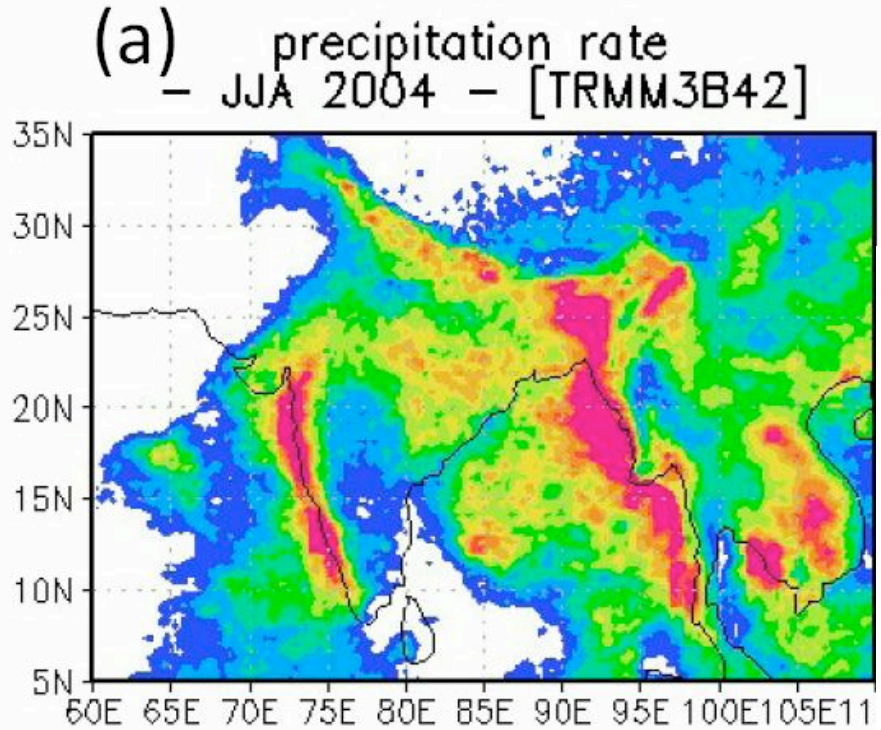
4 km Topography (m)



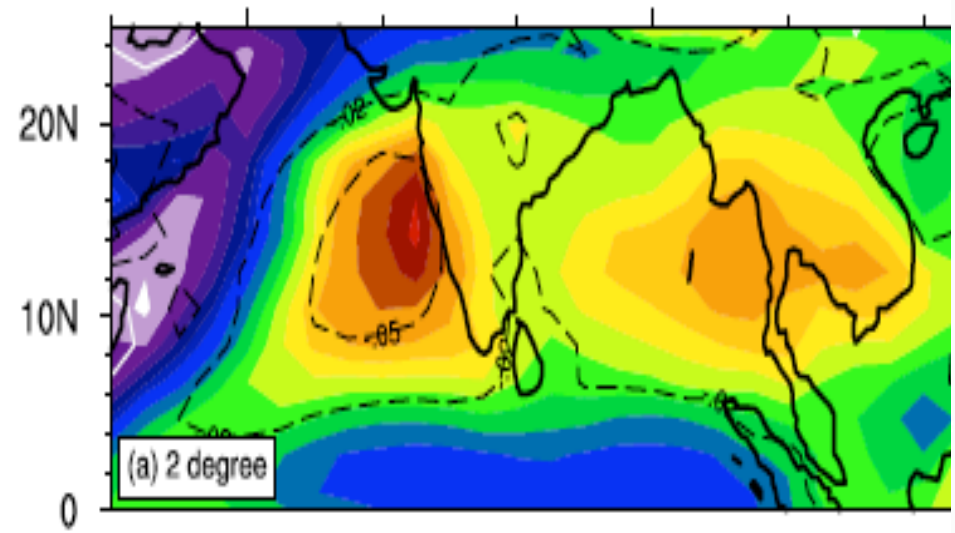

4 km Topography (m)
Kabul
Peshawar
Herat
Islamabad
Kandahar
Lahore
Delhi
Kathmandu
Varanasi
Karachi
Calcutta
Bombay
Madras
Bangalore
Colombo
39N
36N
33N
30N
27N
24N
21N
18N
15N
12N
9N
6N
60E
65E
70E
75E
80E
85E
90E
95E
100E

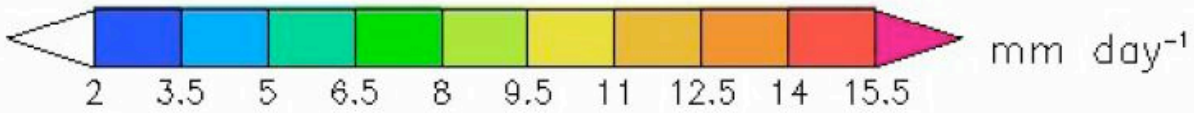

200 km Topography (m)
27N
24N
21N
18N
15N
12N
9N
6N
60E
65E
70E
75E
80E
85E
90E
95E
100E
7000
6000
5000
4500
4000
3250
2500
1750
1000
750
500
250
100
50
0

Monsoon Rainfall in Low Resolution Model

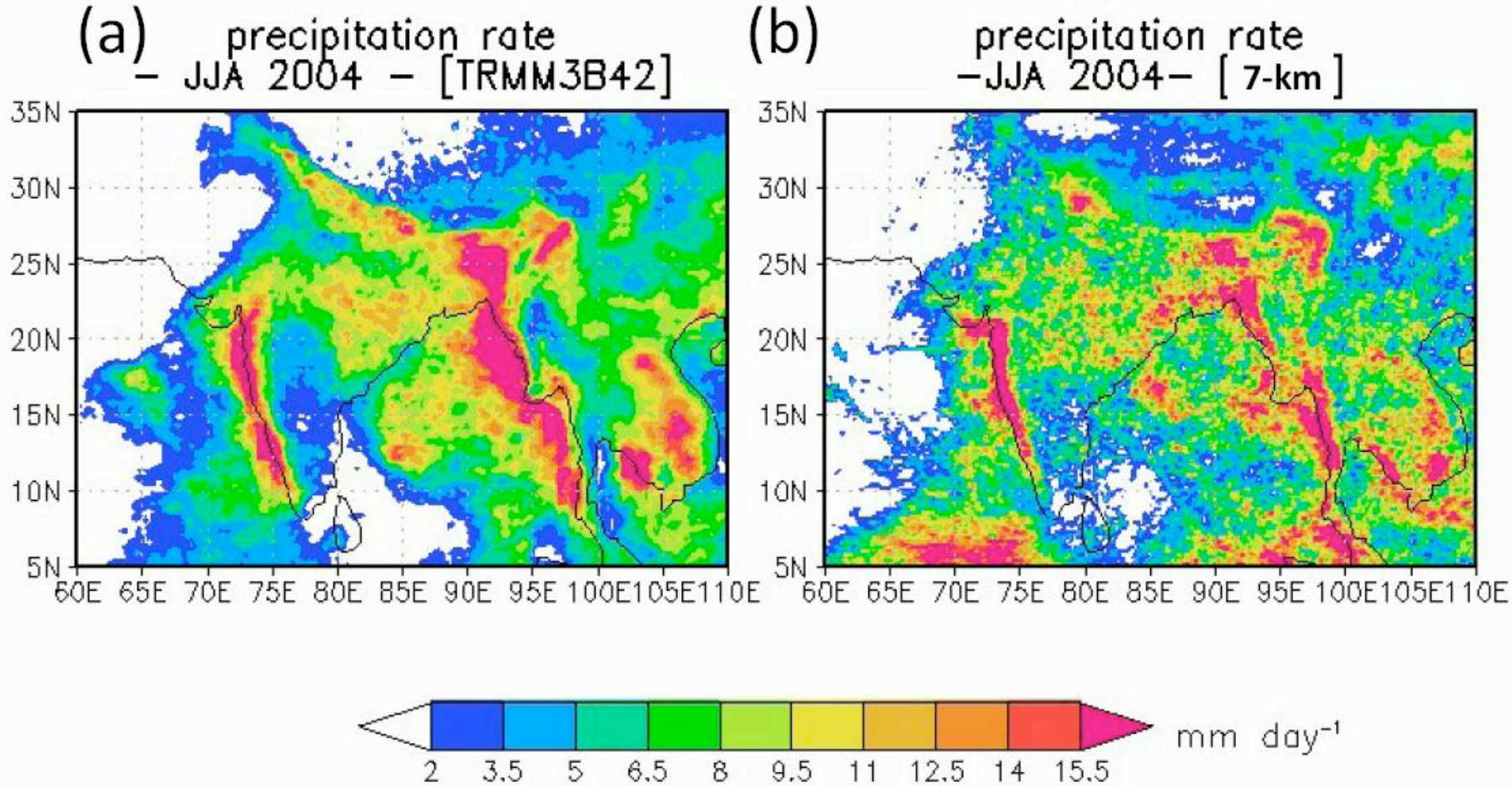


(b) Coupled model (2 degree)
- Climatology -



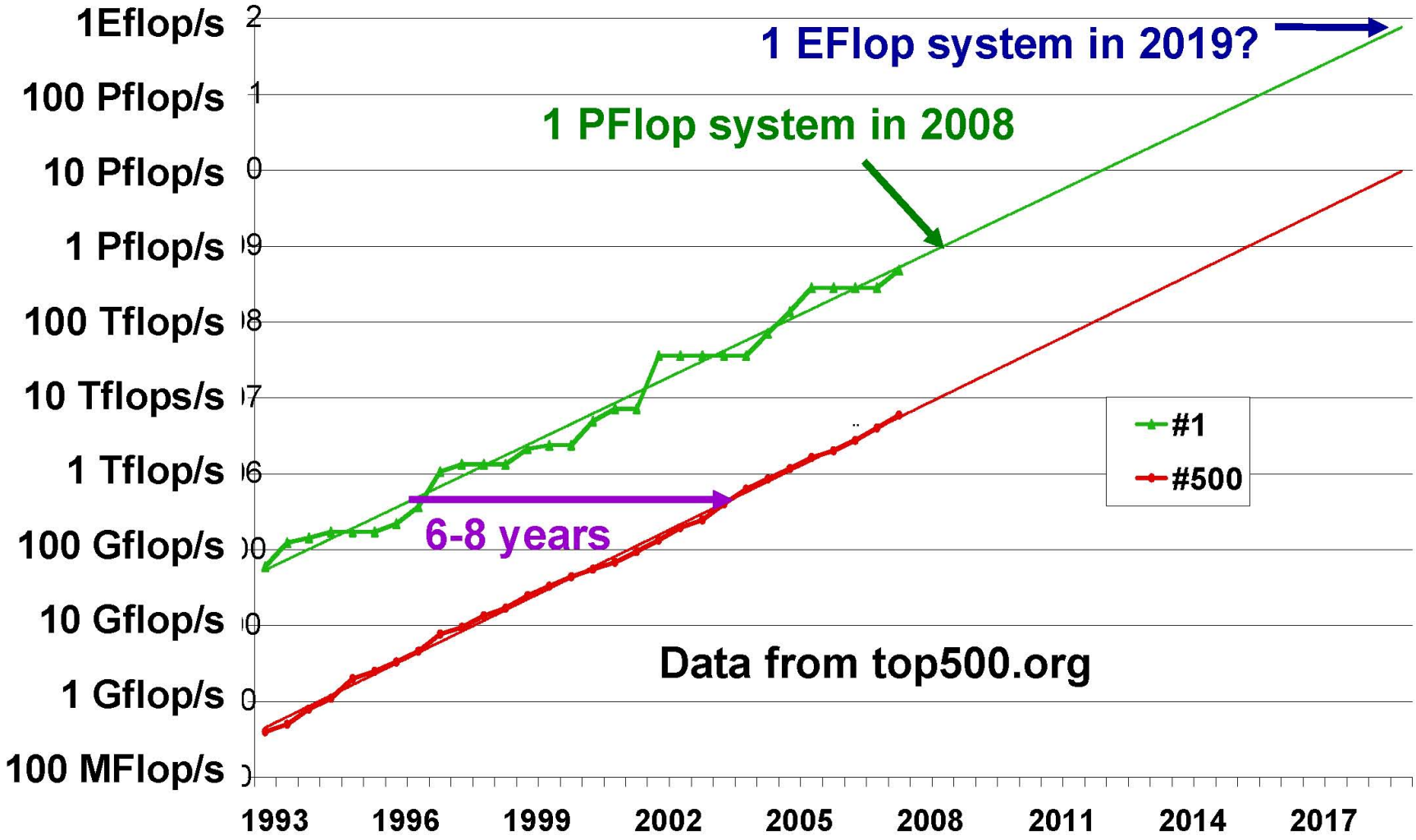


Monsoon Rainfall in High Resolution Model



***Oouchi et al. 2009*: (a) Observed and (b) simulated precipitation rate over the Indo-China monsoon region as June-July-August average (in units of mm day -1). The observed precipitation is from TRMM_3B42, and the simulation is for 7km-mesh run.**

Petaflop with ~1M Cores by 2008



Slide source Horst Simon, LBNL

Computing Capability & Model Grid Size (~km)

Peak Rate:	10 TFLOPS	100 TFLOPS	1 PFLOPS	10 PFLOPS	100 PFLOPS
Cores	1,400 (2006)	12,000 (2008)	80-100,000 (2009)	300-800,000 (2011)	6,000,000? (20xx?)
Global NWP[0]: 5-10 days/hr	18 - 29	9 - 14	4 - 6	2 - 3	1 - 2
Seasonal[1]: 50-100 days/day	17 - 28	8 - 13	4 - 6	2 - 3	1 - 2
Decadal[1]: 5-10 yrs/day	57 - 91	27 - 42	12 - 20	6 - 9	3 - 4
Climate Change[2]: 20-50 yrs/day	120 - 200	57 - 91	27 - 42	12 - 20	6 - 9

Range: Assumed efficiency of 10-40%
0 - Atmospheric General Circulation Model (AGCM; 100 levels)
1 - Coupled Ocean-Atmosphere-Land Model (CGCM; ~ 2X AGCM computation with 100-level OGCM)
2 - Earth System Model (with biogeochemical cycles) (ESM; ~ 2X CGCM computation)

* Core counts above $O(10^4)$ are unprecedented for weather or climate codes, so the last 3 columns require getting 3 orders of magnitude in scalable parallelization (scalar processors assumed; vector processors would have lower processor counts)

Thanks to Jim Abeles (IBM)

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International Research and Computational Facility to Revolutionize Climate Prediction

Examples of International Collaboration

- **CERN: European Organization for Nuclear Research**
  (Geneva, Switzerland)

- **ITER: International Thermonuclear Experimental Reactor**
  (Gadarache, France)

- **ISS: International Space Station**
  (somewhere in sky..)

WHAT ABOUT CLIMATE PREDICTION?

International Research and Computational Facility to Revolutionize Climate Prediction

1. Computational Requirement:

- Sustained Capability of 2 Petaflops by 2011
- Sustained Capability of 10 Petaflops by 2015

Earth Simulator (sustained 7.5 Teraflops) takes 6 hours for 1 day forecast using 3.5 km global atmosphere model; ECMWF (sustained 2 Teraflops) takes 20 minutes for 10 day forecast using 24 km global model

2. Scientific Staff Requirement:

- Team of 200 scientists to develop next generation climate model
- Distributed team of 500 scientists (diagnostics, experiments)

A computing capability of sustained 2 Petaflops will enable 100 years of integration of coupled ocean-atmosphere model of 5 km resolution in 1 month of real time

Summary

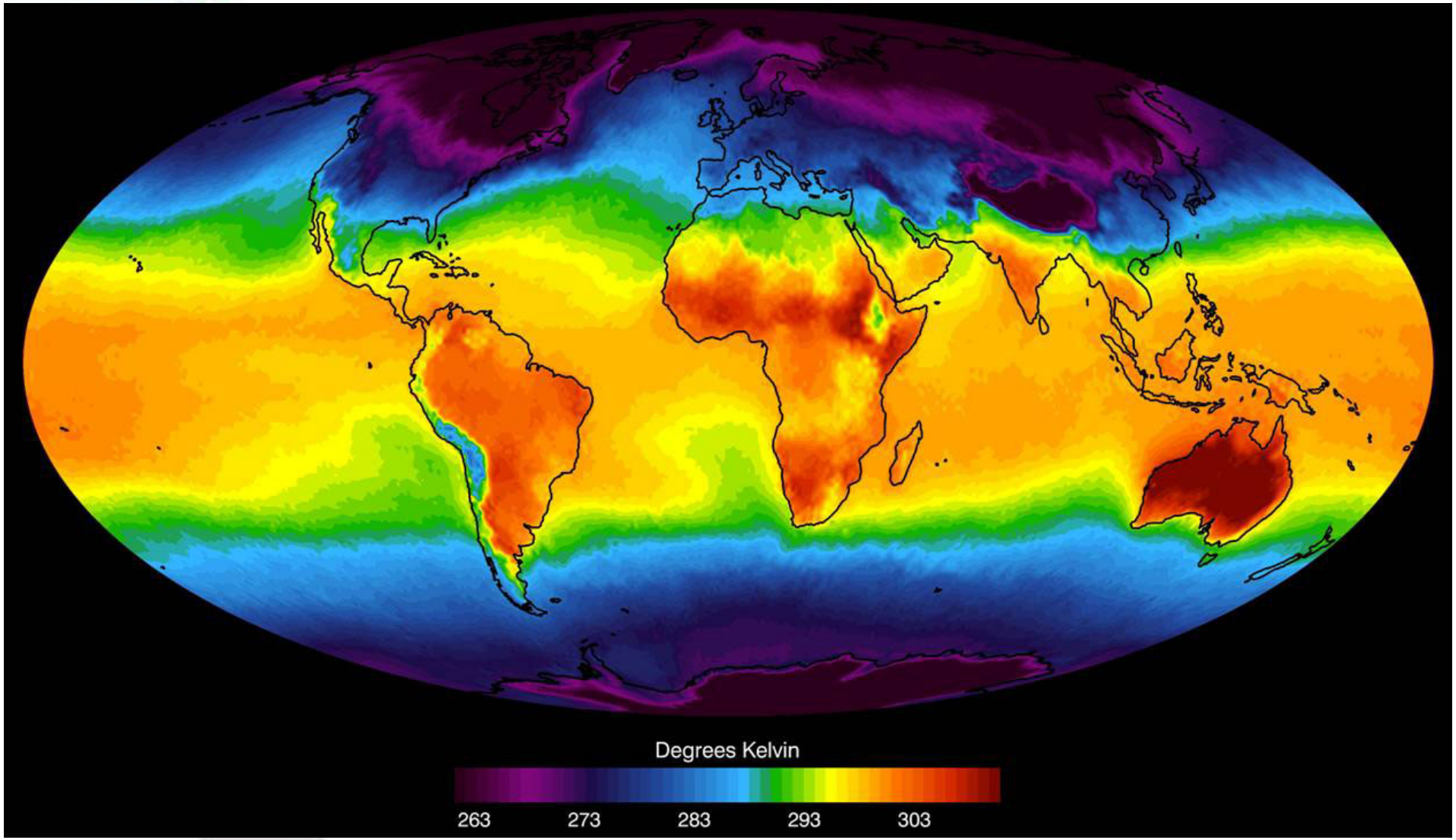
1. Space observations have made significant improvements in NWP in the southern hemisphere.
2. Space observations of global boundary conditions provided scientific foundation for dynamical seasonal prediction.
3. Models that better simulate the present climate have higher skill in seasonal prediction, and produce larger global warming for the 21st century.
4. Weather (and especially climate) models have far less resolution than space observations.
5. Due to lack of powerful computers and sufficient scientific staff only 1-10% of satellite data is being used for routine prediction of weather and climate.

THANK YOU!

ANY QUESTIONS?

Mean Surface Air Temperature

AIRS data January 2003



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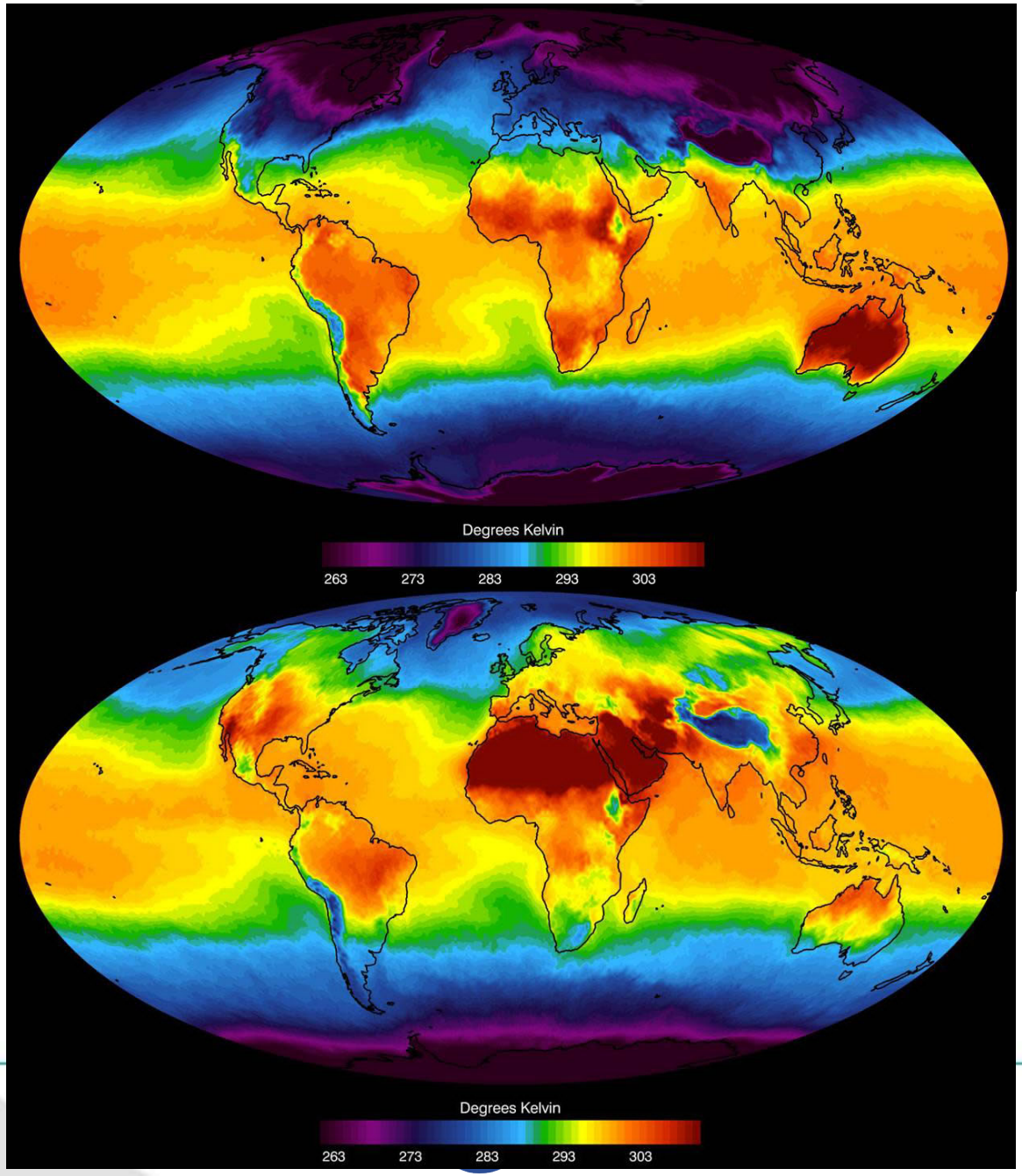
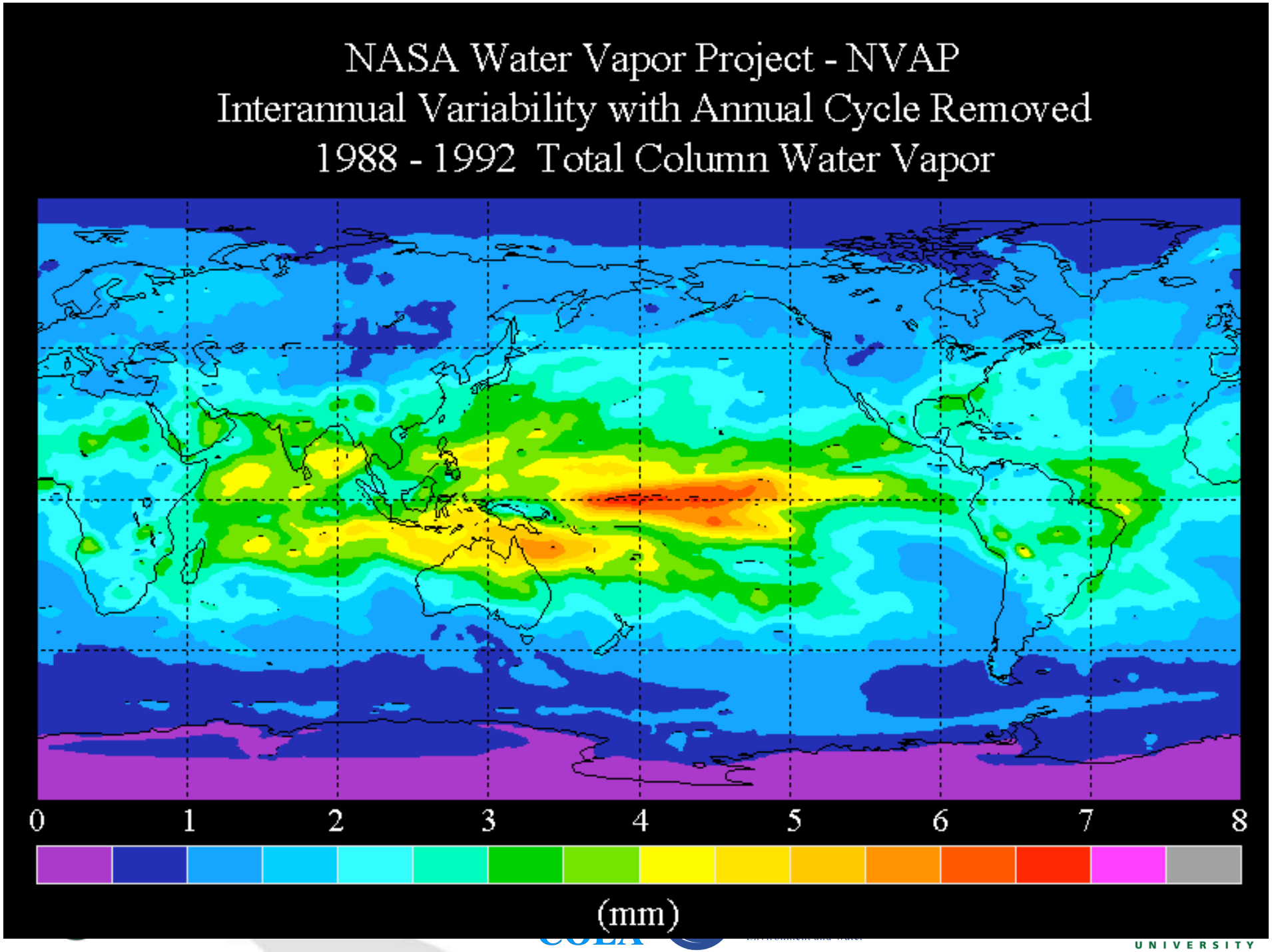
Mean Surface Air Temperature

Jan 2003

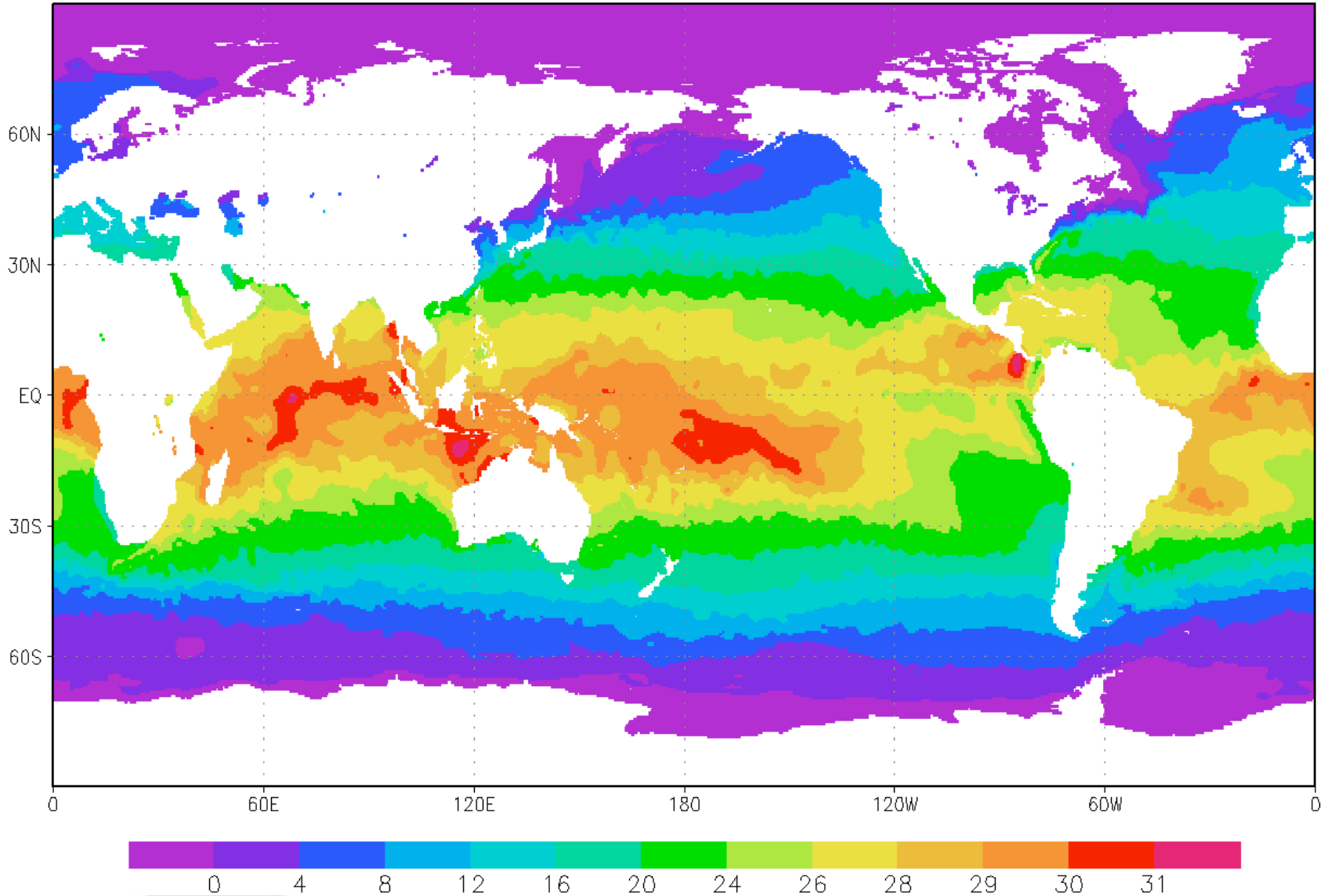
July 2003




NASA Water Vapor Project - NVAP
Interannual Variability with Annual Cycle Removed
1988 - 1992 Total Column Water Vapor
0
1
2
3
4
5
6
7
8
(mm)

Real Time Global 1/2o Daily SST Analysis

for 14 March 2003



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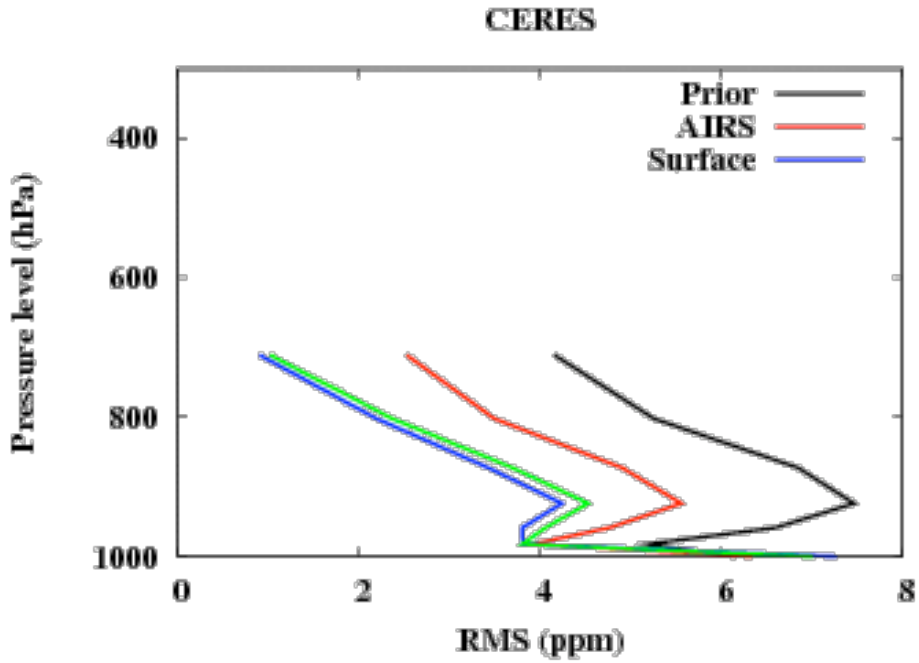
Validation with CERES campaign (C. Gerbig)

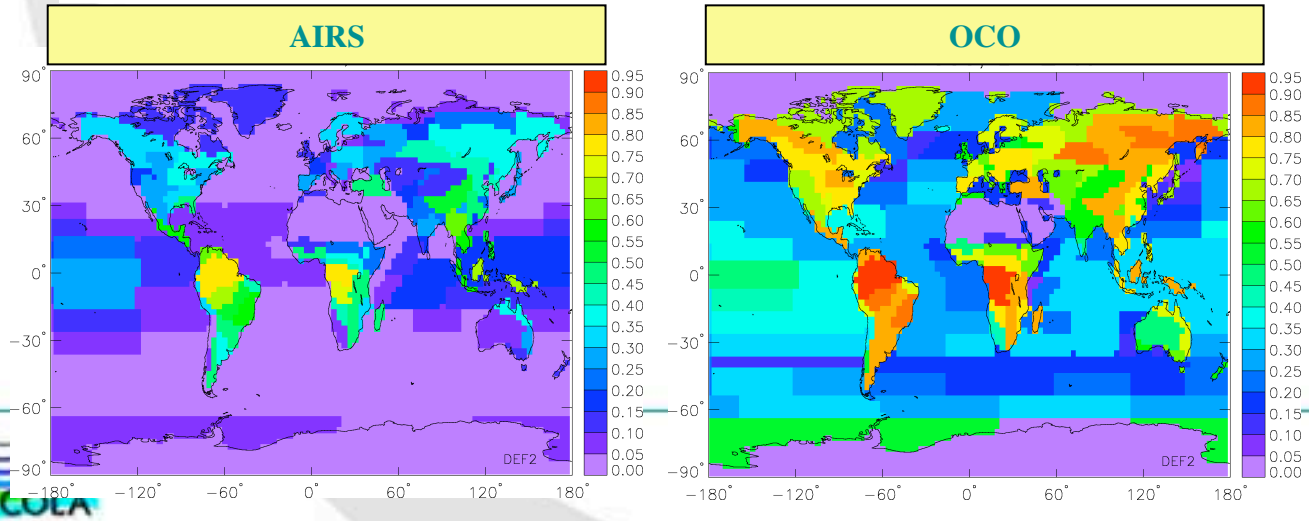
GEOmon
Global Earth Observation and Monitoring

Surface flask observations provid by T. Conway (NOA/ ESRL)



The flux inversion using the AIRS assimilation as input improves the surface fluxes, although not as much as the surface flask network.

Flux error simulations provided by Katja Hungershoefer (LSCE)



Flux error reduction (red is better) from an OCO-like sounder will be much larger than for AIRS, as illustrated by this

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The 60's Inspiration for GARP

- From address before the General Assembly of the U N

  President John F. Kennedy, September 25, 1961

  " As we extend the rule of law on earth, so must we also extend it to man's new domain--outer space.

  To this end,.… We shall propose further cooperative efforts between all nations in weather prediction and eventually in weather control. We shall propose, finally, a global system of communications satellites linking the whole world in telegraph and telephone and radio and television."
- WMO formally establishes GARP in 1967. B. Bolin Dir.
- NAS Report: Plan for US participation in GARP,1969

The 70's

- Simulation studies related to GARP show feasibility of observing system to improve weather forecasts. (BAMS 1970)
- FGGE: First GARP Global Experiment launched Jan. 1979

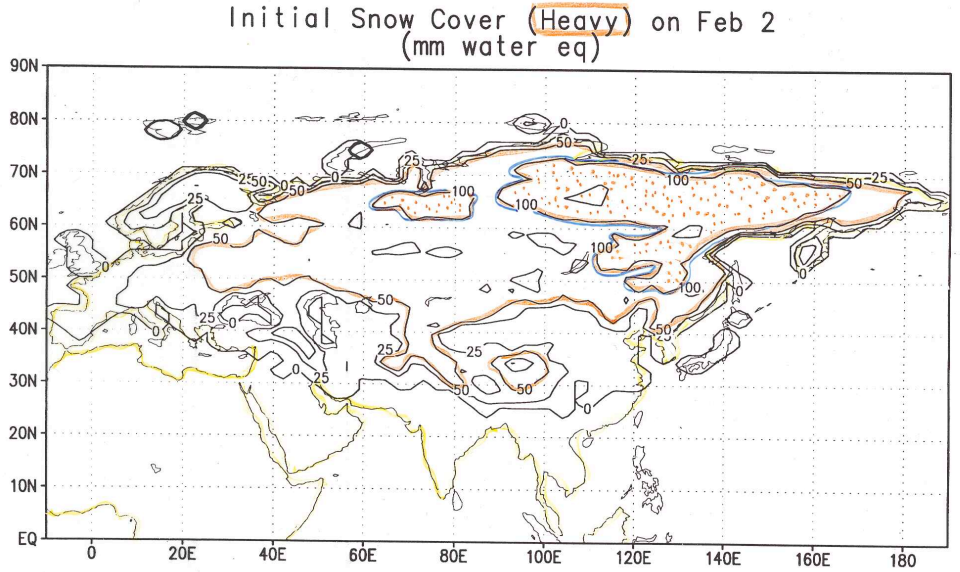
Colloquium in Bld'g 3 1978

- Prof. Jules Charney: Dynamic meteorology icon

Conclusion

- "….When we think of NASA, we think of Space Rockets, Astronauts, Robots, but the real future of NASA lies in Information Technology. "

Administrator Dan Goldin



Heavy Snow

Fig. 1a

Light Snow

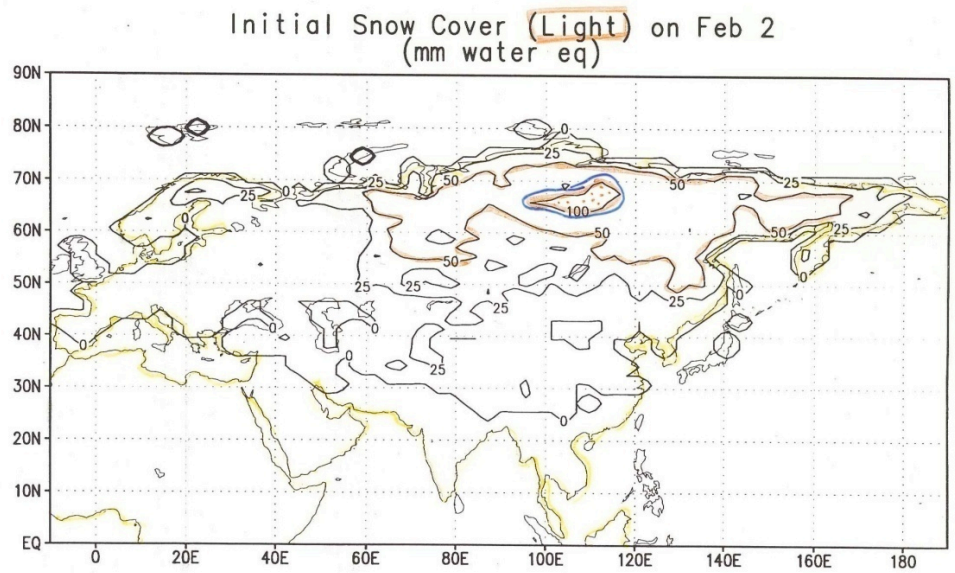


Fig. 1b

Model Simulation of Snow Effect on Monsoon Rainfall

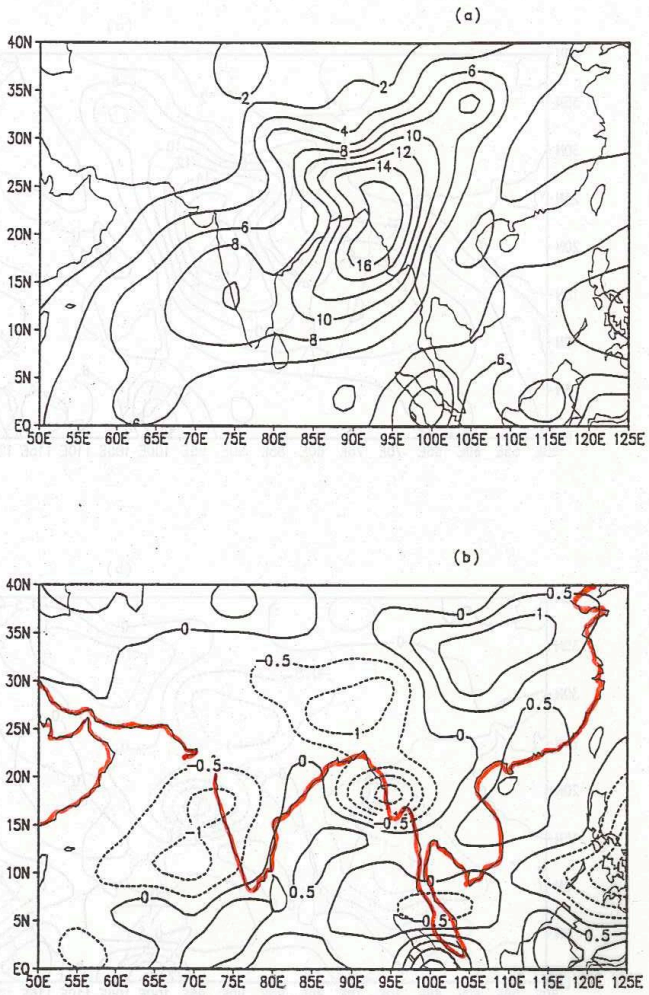


Figure 4.3.1.4 JJAS Precipitation (mm/day). (a) for LSE and (b) for HSE-LSE difference.

Mean Monsoon Rainfall

Rainfall Change due to Snow Anomalies

Zhou et al. 1994

Nimbus 2/3 provides first annual net radiation budget: Raschke , Bandeen and Van Der Haar

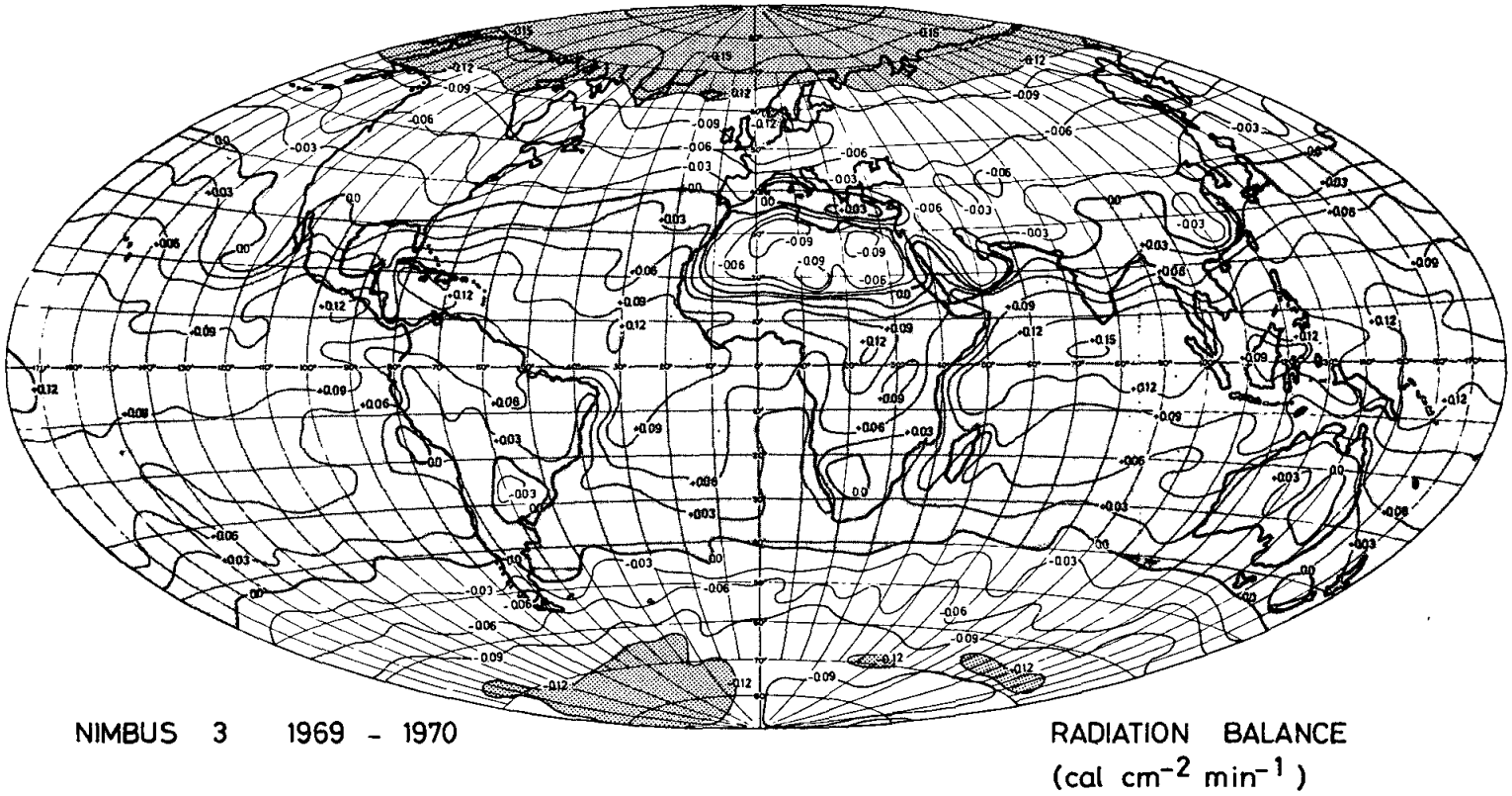
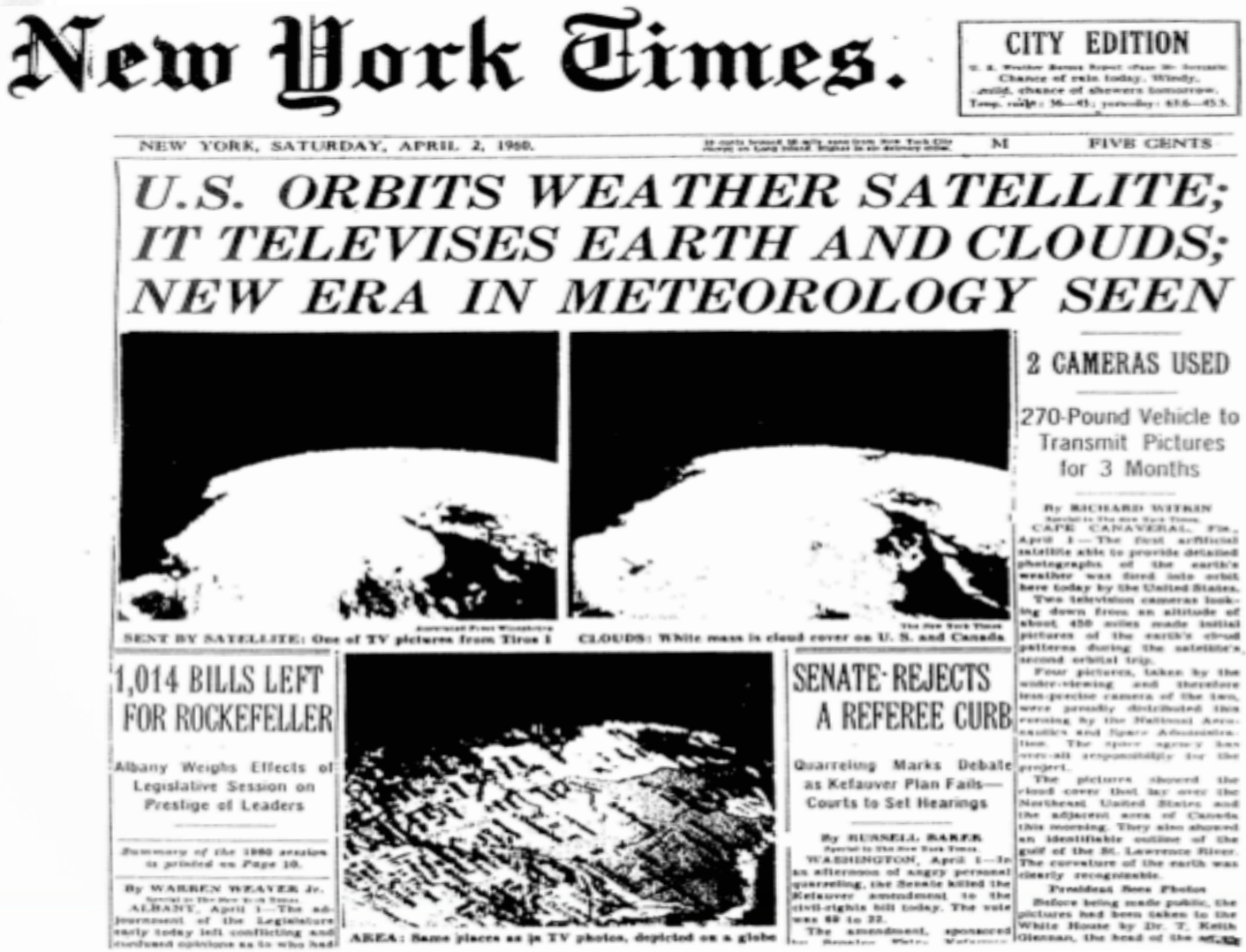


FIG. 17. Annual radiation balance of the earth-atmosphere system.

TIROS 1 April, 1, 1960 showing clouds over the N.E. of US and the curvature of the Earth



New York Times.

CITY EDITION

NEW YORK, SATURDAY, APRIL 2, 1960. M FIVE CENTS

U.S. ORBITS WEATHER SATELLITE; IT TELEVISES EARTH AND CLOUDS; NEW ERA IN METEOROLOGY SEEN

SENT BY SATELLITE: One of TV pictures from Tiros I

CLOUDS: White mass is cloud cover on U. S. and Canada

2 CAMERAS USED

270-Pound Vehicle to Transmit Pictures for 3 Months

By RICHARD WITKIN

CAPE CANAVERAL, Fla., April 1—The first artificial satellite able to provide detailed photographs of the earth's weather was fired into orbit here today by the United States.

Two television cameras looking down from an altitude of about 450 miles made initial pictures of the earth's cloud patterns during the satellite's second orbital trip.

Four pictures, taken by the under-viewing and therefore less-precise camera of the two, were proudly distributed this evening by the National Aeronautics and Space Administration. The space agency has over-all responsibility for the project.

The pictures showed the cloud cover that lay over the Northeast United States and the adjacent area of Canada this morning. They also showed an identifiable outline of the gulf of the St. Lawrence River. The curvature of the earth was clearly recognizable.

President Sees Photos

Before being made public, the pictures had been taken to the White House by Dr. T. Keith Glennan, the head of the

1,014 BILLS LEFT FOR ROCKEFELLER

Albany Weighs Effects of Legislative Session on Prestige of Leaders

Summary of the 1960 session is printed on Page 10.

By WARREN WEAVER Jr.

ALBANY, April 1—The adjournment of the Legislature early today left conflicting and confused opinions as to who had

AREA: Same places as in TV photos, depicted on a globe

SENATE REJECTS A REFEREE CURB

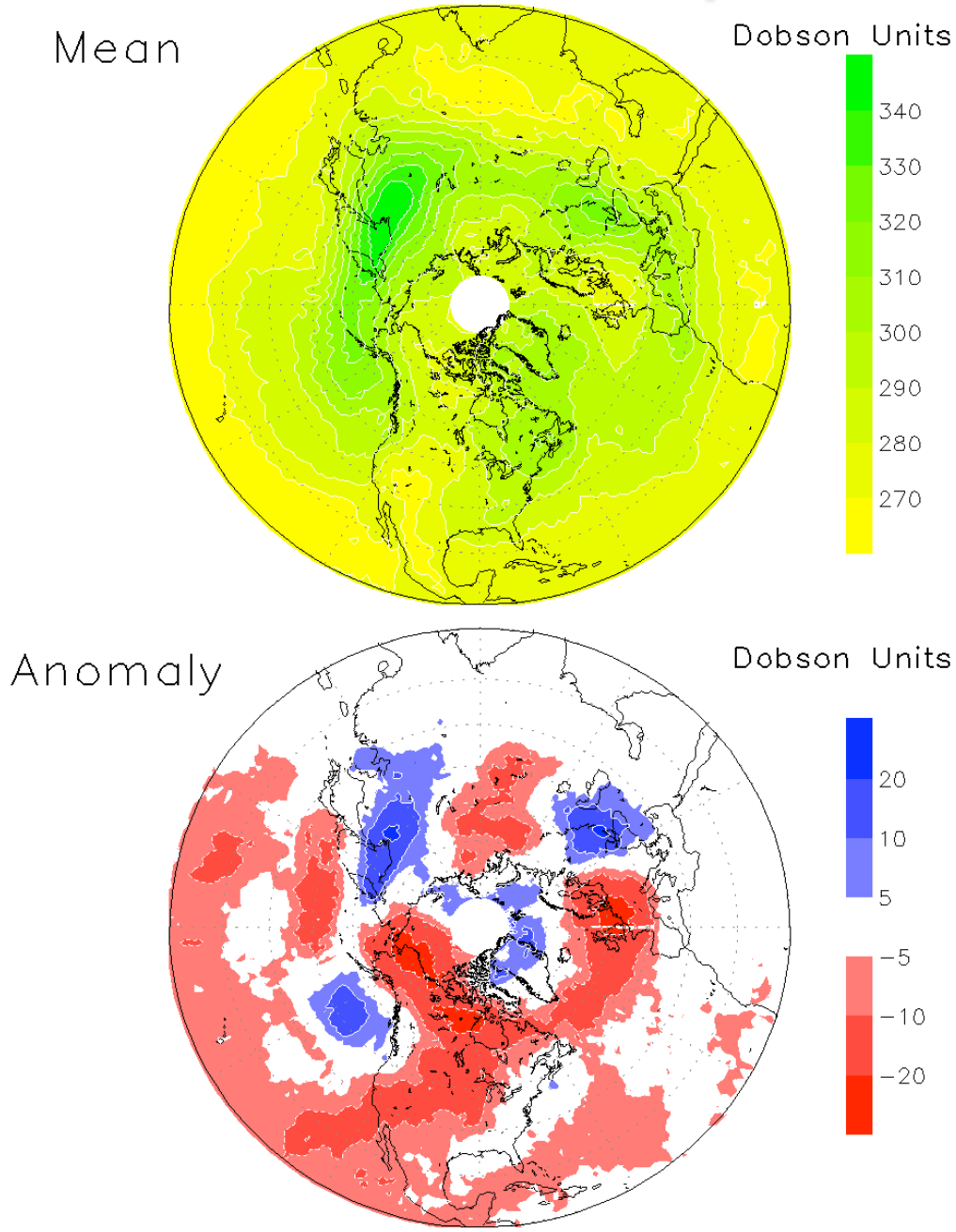
Quarreling Marks Debate as Kefauver Plan Fails—Courts to Set Hearings

By RUSSELL BAKER

WASHINGTON, April 1—In an afternoon of angry personal quarreling, the Senate killed the Kefauver amendment to the civil-rights bill today. The vote was 49 to 32.

The amendment, sponsored

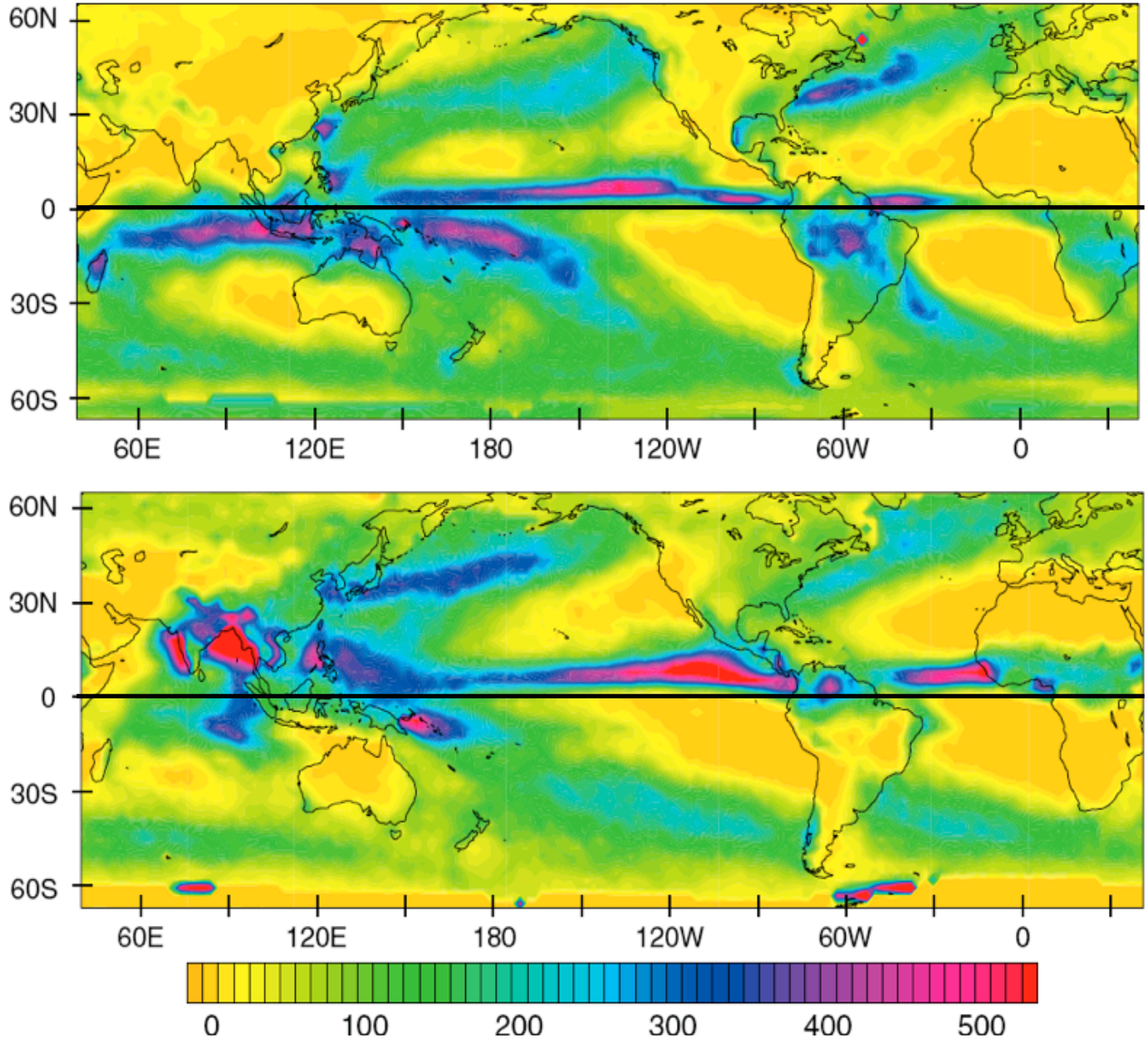
TOMS Ozone for Sep1997



Climatology of Precipitation

DJF

Annual mean rainfall based on station data over land and infrared satellite imagery over the sea.



Reprint Series
19 March 1982, Volume 215, pp. 1498–1501

SCIENCE

Influence of Land-Surface Evapotranspiration on the Earth's Climate

J. Shukla and Y. Mintz

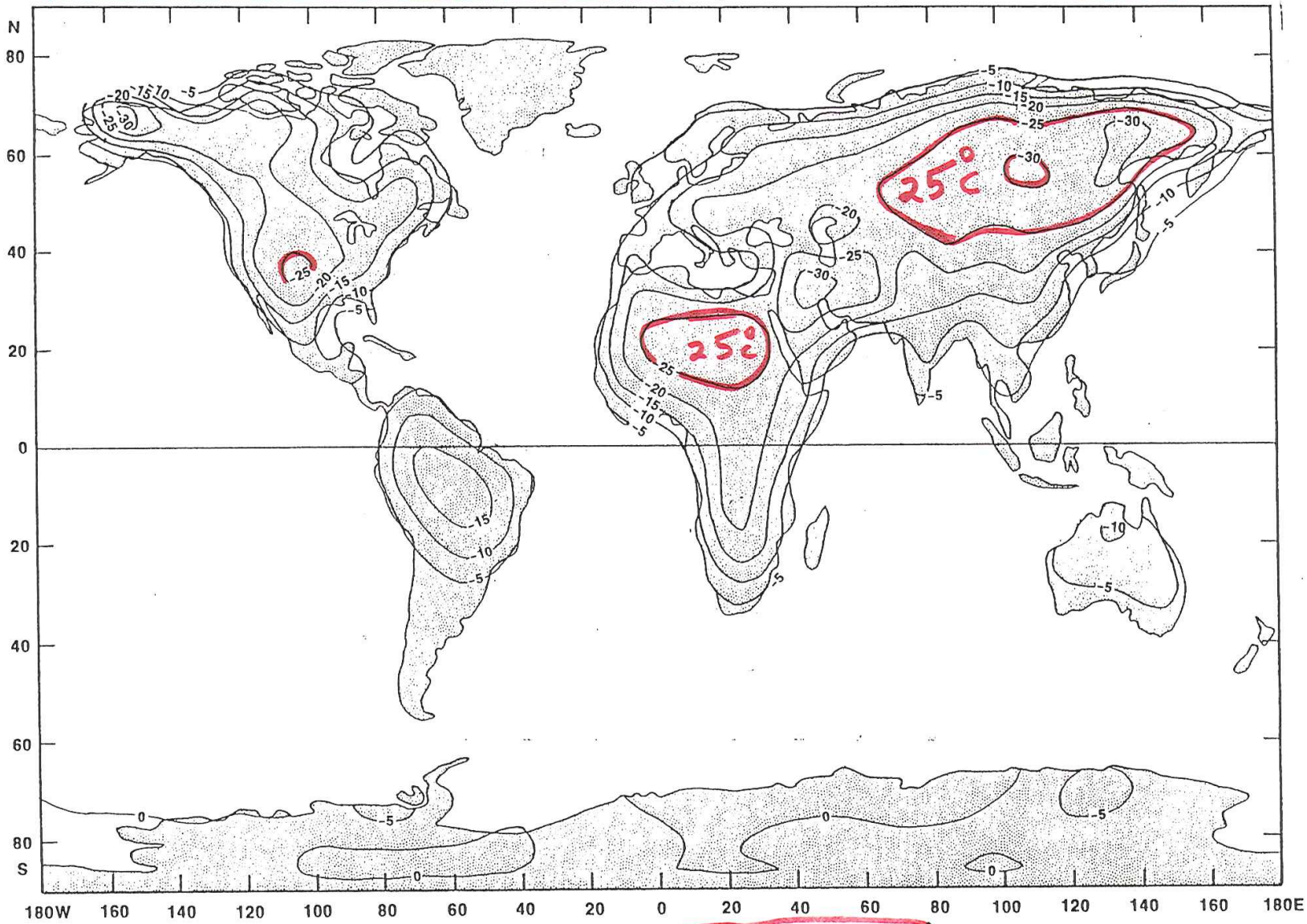
Global Land: $\beta = 0$; $E = 0$; "DRY" SOIL

" $\beta = 1$; $E = E_p$ "WET" SOIL

$$E = \beta E_p$$

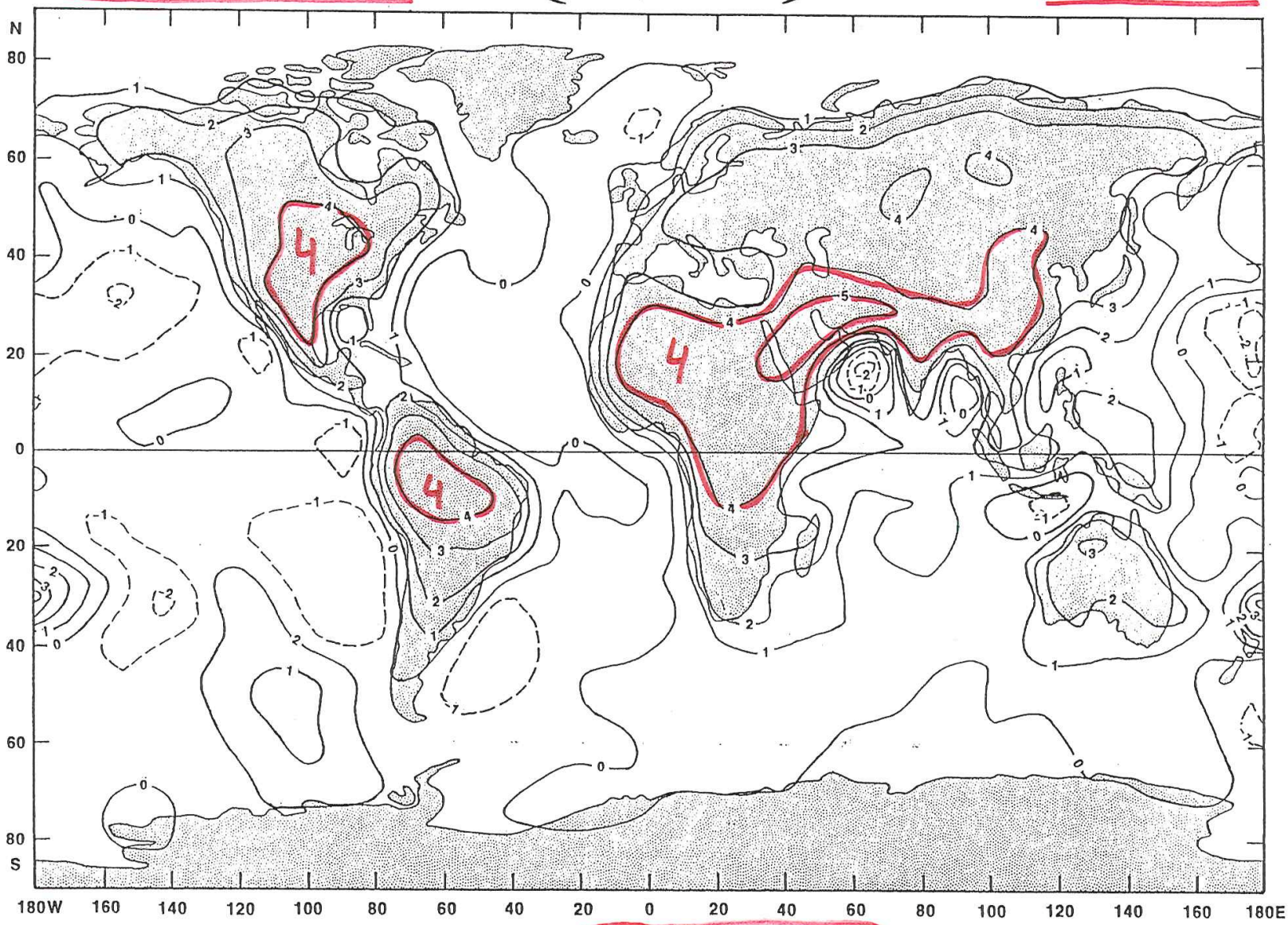
Copyright © 1982 by the American Association for the Advancement of Science

GROUND TEMPERATURE (Difference) JULY DEG K



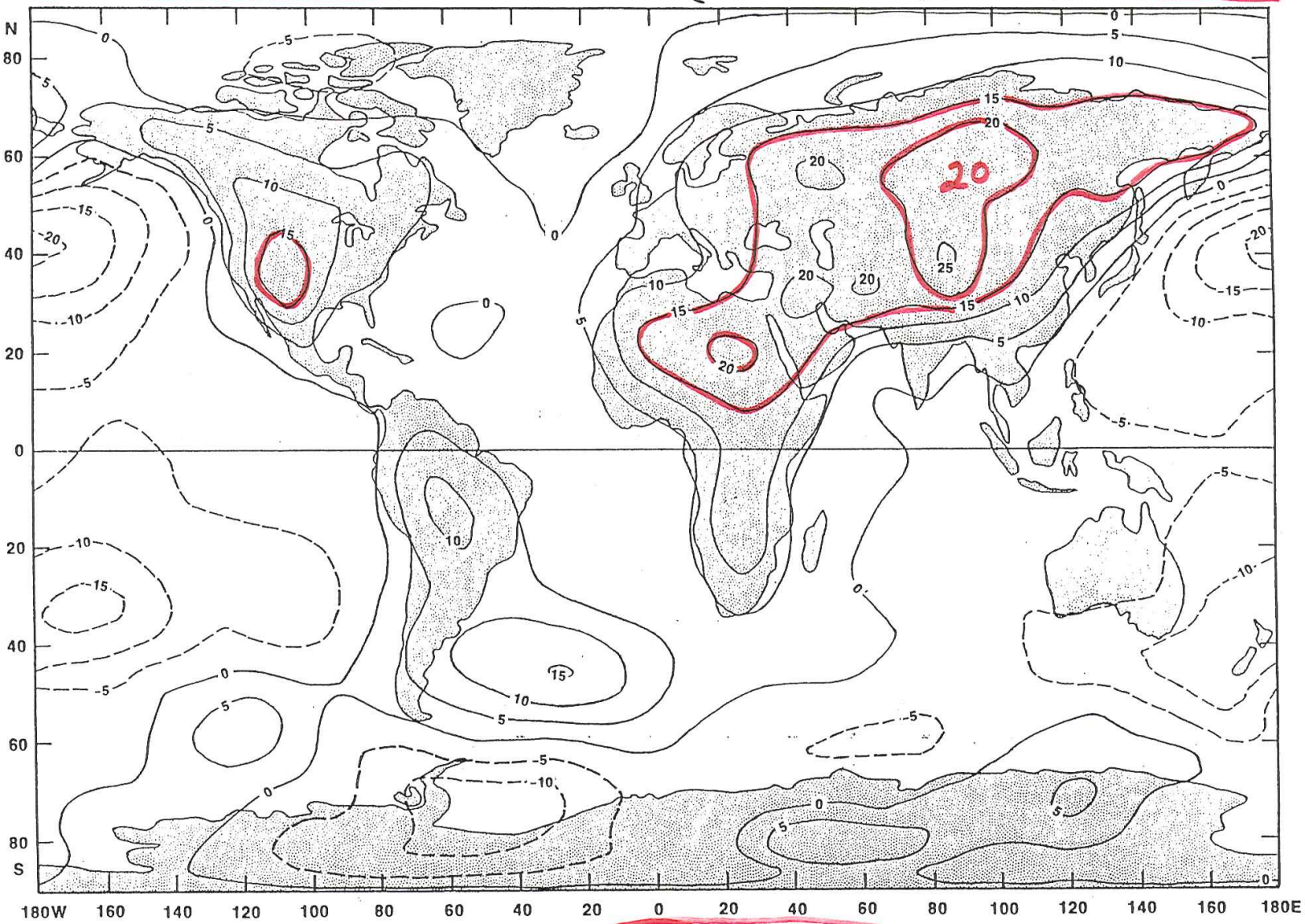
WET– DRY

EVAPORATION (Difference) JULY MM/DAY



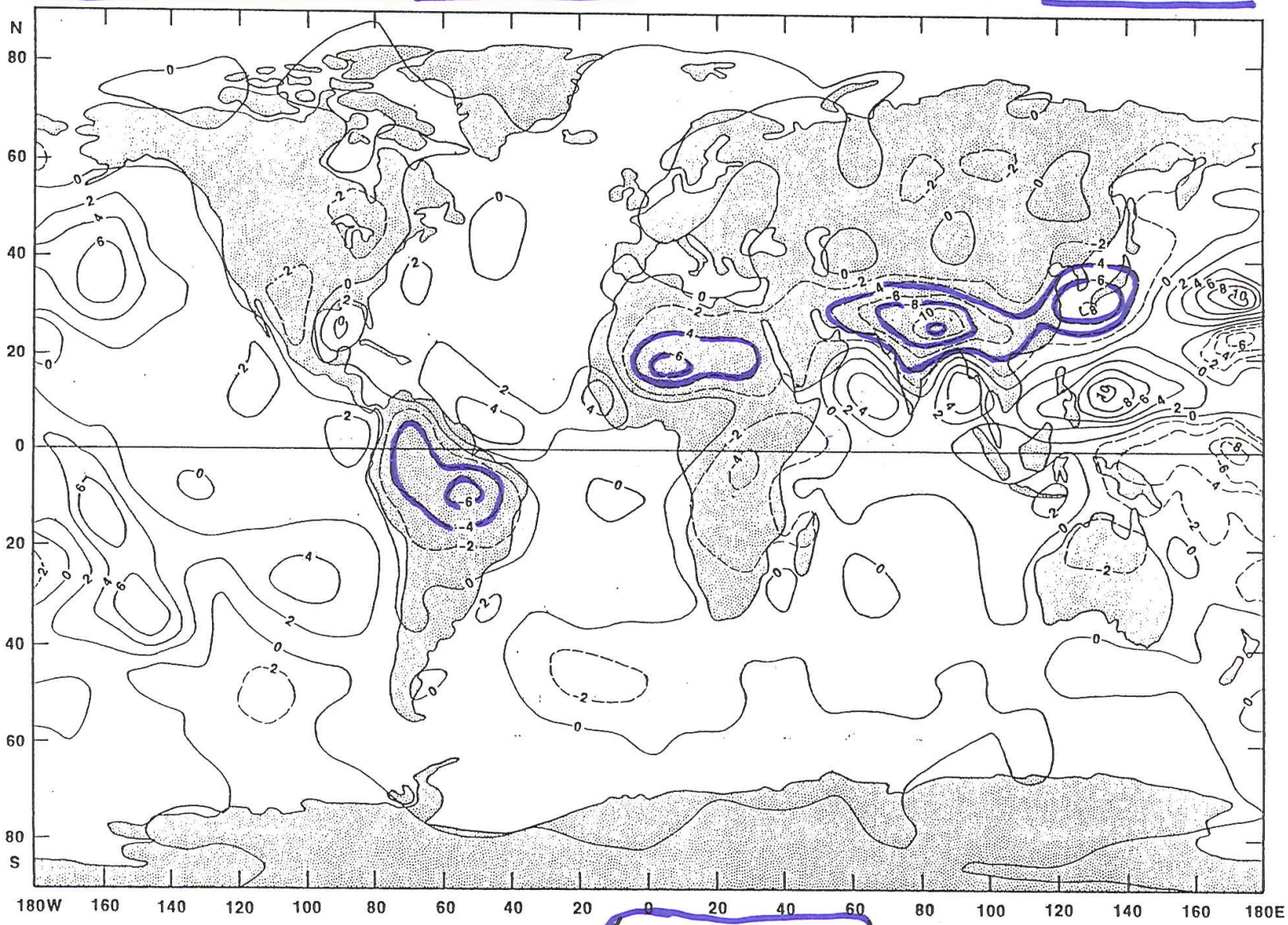
WET – DRY

SEA LEVEL PRESSURE (Difference) JULY (mb)



WET – DRY

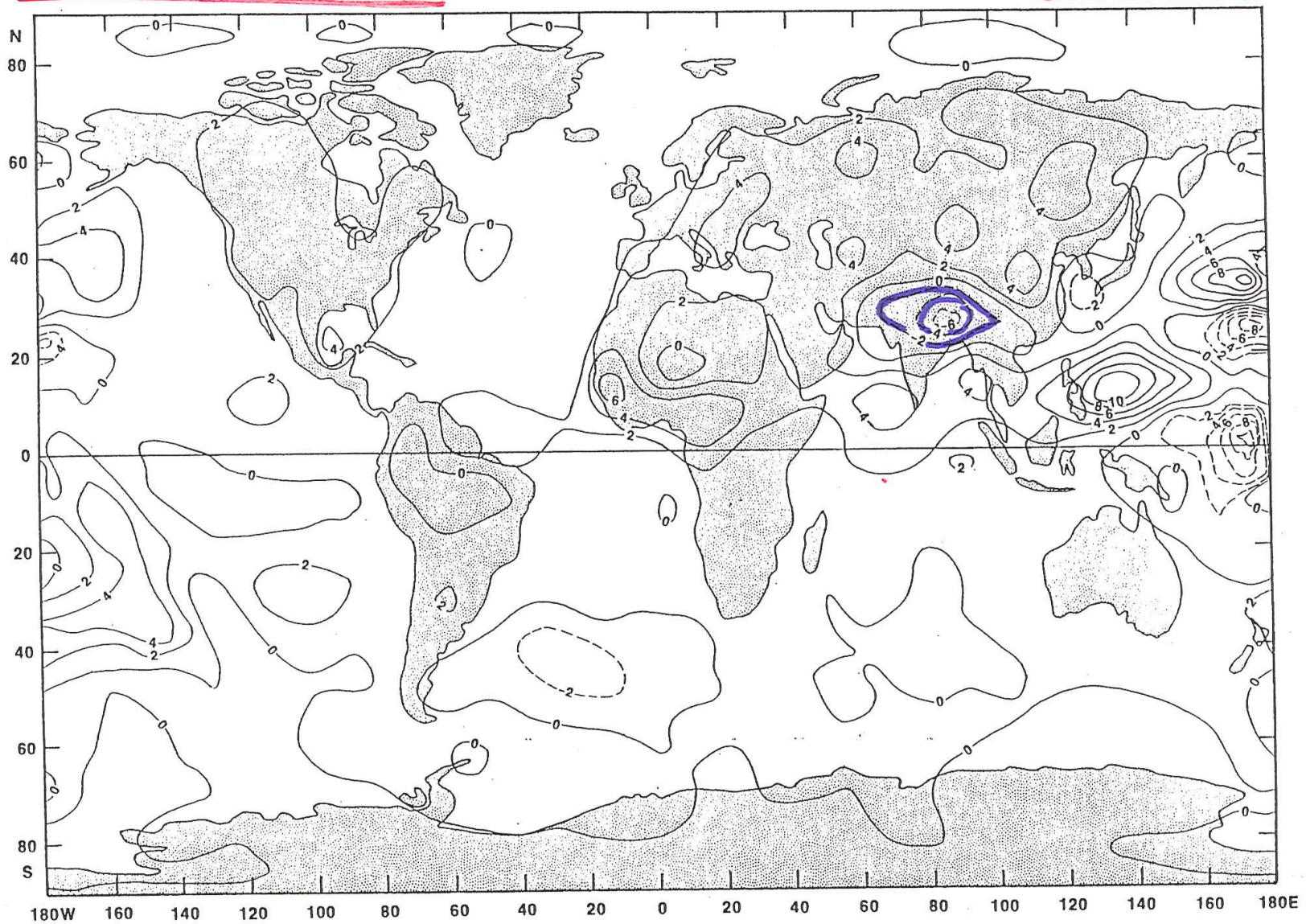
VERT. INT. MOIST. FLUX. CONV. Difference JULY MM/DAY



WET–DRY

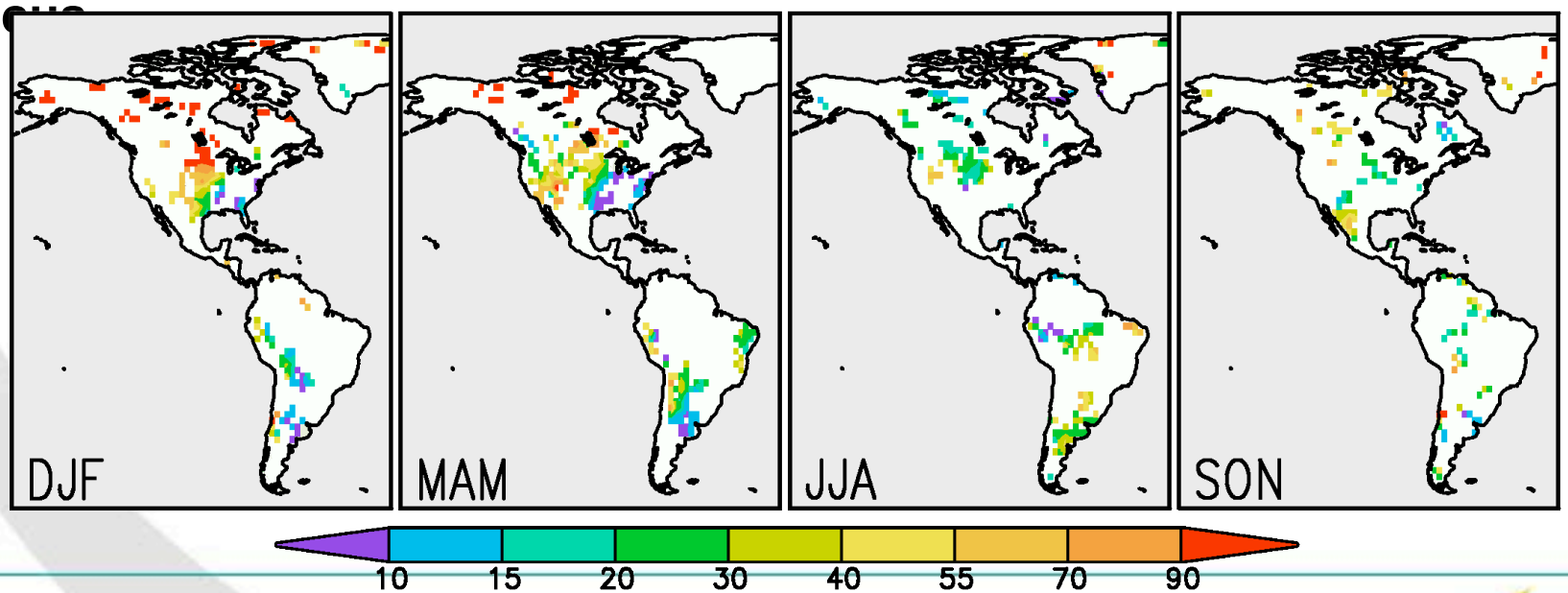
PRECIPITATION

JULY MM/DAY



Predictability over Land from Soil Moisture and Feedbacks

- Red in north in winter = frozen soil. Not “true” predictability.
- Any yellow-orange colors mean memory of one month or longer.
- Even blue-green areas may have extra harvestable predictability on sub-seasonal (beyond deterministic) time scales based on knowledge of land state (ICs for forecasts).
- Studies like this suggest **where observational networks should focus**



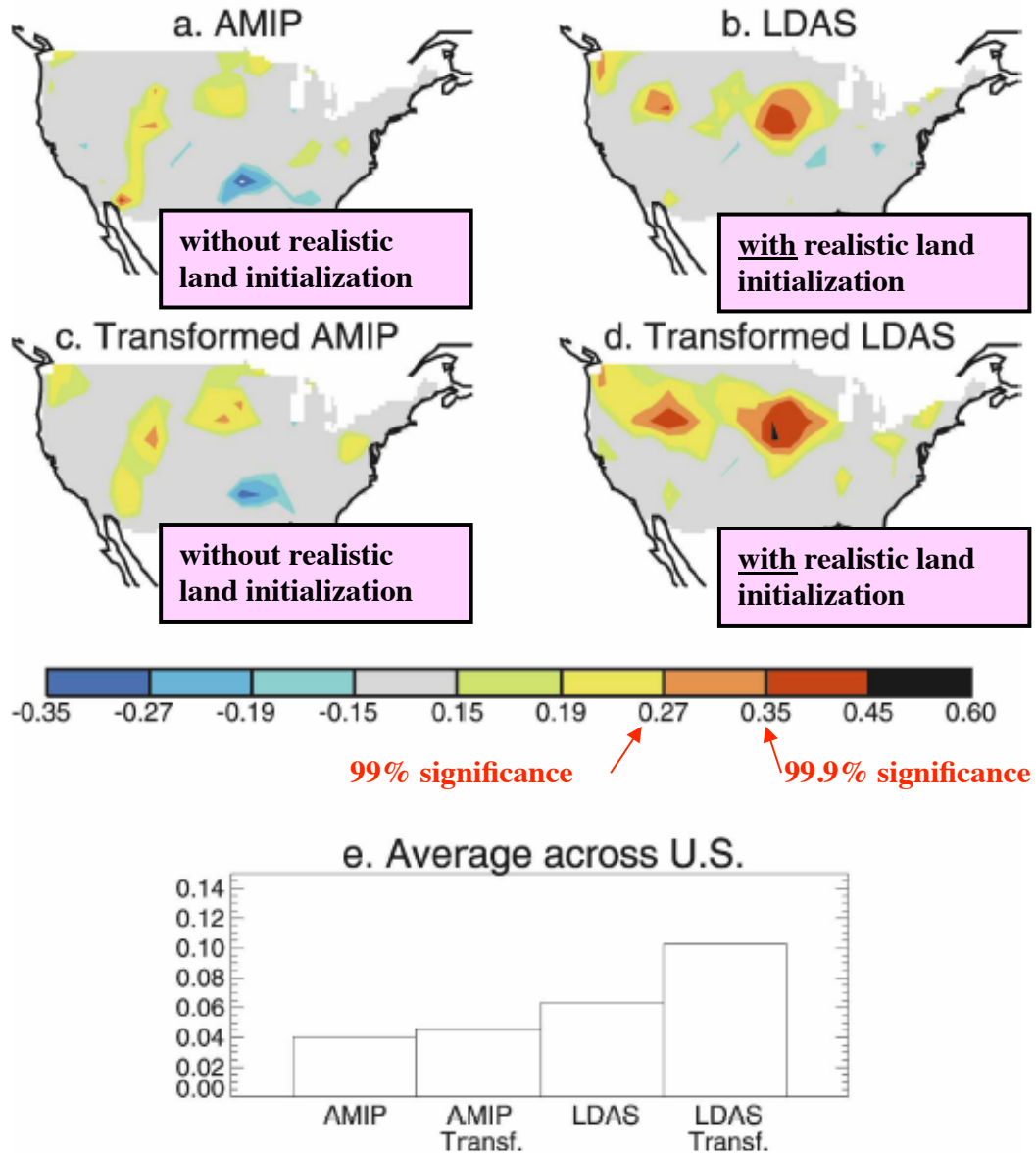
Dirmeyer, P. A., C. A. Schlosser, and K. L. Brubaker, 2009: *J. Hydrometeor*. 10, 278–288.

Precipitation: Skill (r) of monthly forecasts

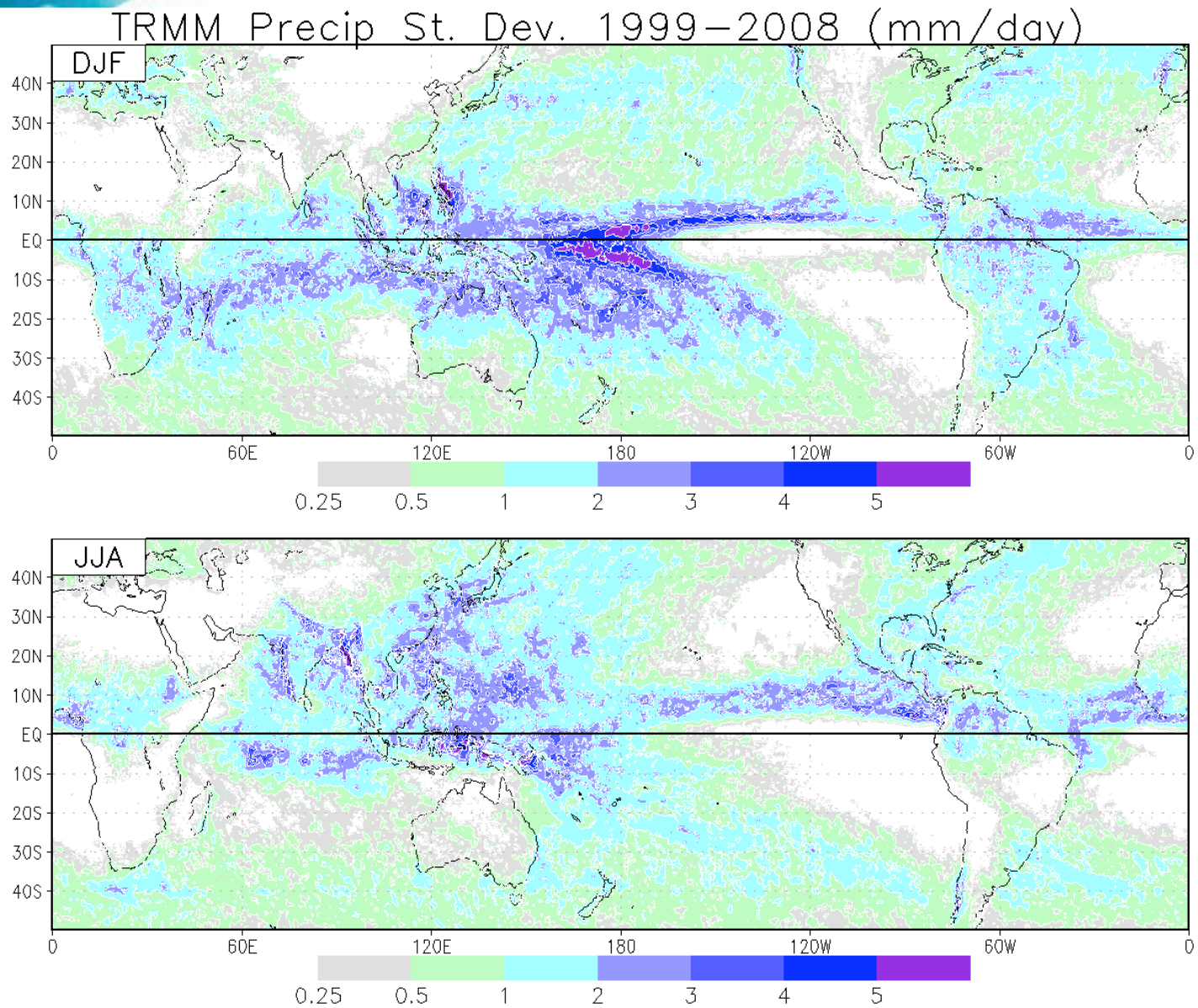
Skill scores derived from 75 independent 1-month warm-season forecasts.

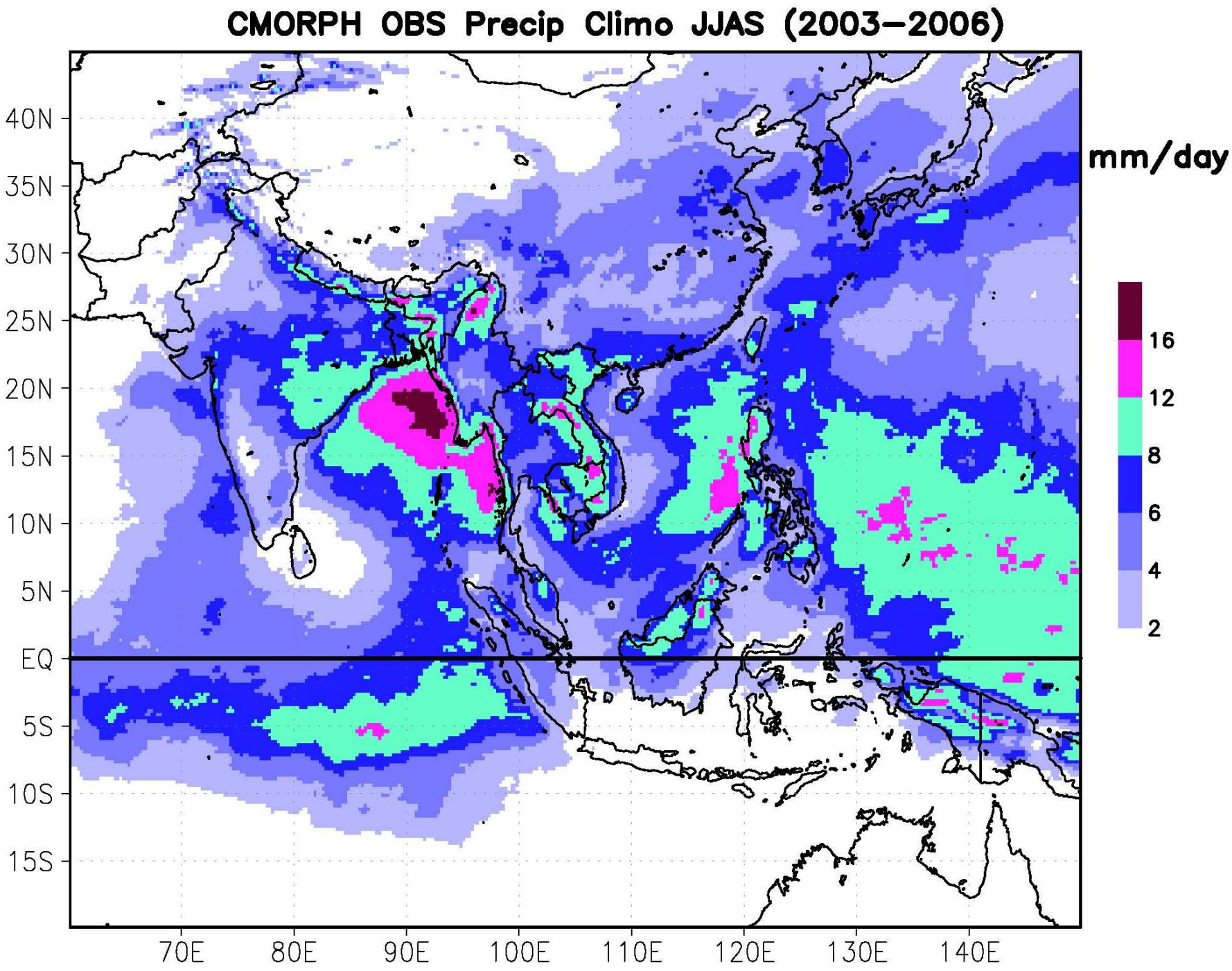
All forecasts used well-predicted SSTs but unrealistic atmospheric initial conditions.

Transformed forecasts: Use of semi-empirical observations-based forecast adjustment



Koster et al., J. Hydromet., 5, 1049-1063, 2004.
Koster et al., Mon. Wea. Rev., 136, 1923-1939, 2008.


TRMM Precip St. Dev. 1999–2008 (mm/day)
DJF
JJA
40N
30N
20N
10N
EQ
10S
20S
30S
40S
0
60E
120E
180
120W
60W
0
0.25
0.5
1
2
3
4
5


CMORPH OBS Precip Climo JJAS (2003–2006)
mm/day
16
12
8
6
4
2
40N
35N
30N
25N
20N
15N
10N
5N
EQ
5S
10S
15S
70E
80E
90E
100E
110E
120E
130E
140E

US Global Atmospheric Research Program Plan (NAS)
Chairperson, Prof. Jules Charney MIT

- Program for Global Observing System

  The system will be an international undertaking. US is and will continue to contribute many of the components of the system. In addition, we propose the US undertake two programs to assist the WMO in adopting a precise date for the First Global Experiment and the configuration of sensors.

First , conduct a series of Observing Systems Simulation Experiments consisting of computer evaluations of various alternative system components for the purpose of ascertaining forecast performance of alternative systems taking into account continuous assimilation of data inhomogeneous in space and time.

Second, conduct a Global Observing System Pacific Test, suggested for about 1973 to observe and analyze simultaneous operation of a number of key elements of the global system over a limited portion of the Earth.

Real time Data Systems Test 1976

Nimbus 6 Instruments Payload: June 1975

- ERBS (Earth Radiation Budget Sensor)
- ESMR (Electrically Scanning Microwave Radiometer) GSFC
- HIRS (High-Resolution Infrared Radiation Sounder)NESDIS
- LRIR (Limb Radiance Inversion Radiometer) NCAR
- PMR (Pressure Modulated Radiometer)
- SCAMS (Scanning Microwave Spectrometer)MIT
- T+DRE (Tracking and Data Relay Experiment)
- THIR (Temperature-Humidity Infrared Radiometer)
- TWERLE (Tropical Wind Energy Conversion and Reference Level Experiment) NCAR

NOAA/NMC provides data assimilation and global forecast

U/WISC provides McIDAS cloud tracked winds LeRC transmits A/C winds

GISS processes sounding temperatures transmitted from GSFC in real time

The 90's

- HST,ROSAT, UARS,TOMS, TRMM, Seawiffs
- HPCC Grand Challenge Teams and Earth Science Modeling Framework (ESMF)
- Beowulf Clusters 1994 Open S/W linux
- EOSDIS v0 and Seawifs processing systems, RACs
- COBE Processing (Lifting the veil of god)
- Scientific Visualization Studio
- A. Diaz recognizes IS&T by establishing Ass't Director of Information Science and CIO at Center level and approves IS&T colloquium and Excellence in IS&T award in Nov. 1999.

Ensemble Calculations for Seasonal Forecasting

Max Suarez/GSFC, NASA Seasonal to Interannual Prediction Project (NSIPP)
http://nsipp.gsfc.nasa.gov/

Goal: Establish the degree to which clusters of PC's may reduce the cost of ensemble forecasting

For the NSIPP atmospheric model, a cluster of commodity PC's provides performance similar to commercial products, but at significantly lower cost.

Computation of one simulated day using a 288x180x22 grid run on 32 processors of:

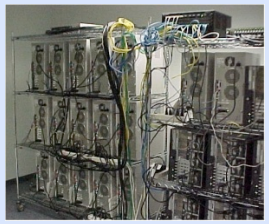
Cray T3E-600

Requires:
20 minutes

Origin

10 minutes

theHive (Linux cluster of PCs)



29 minutes

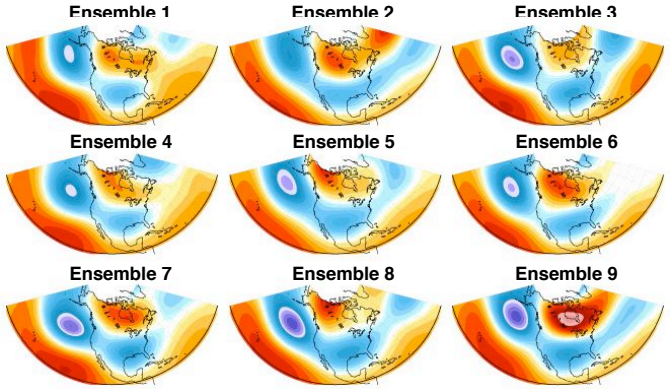
The 32 processor Linux cluster cost $120K in mid 1999, making it roughly 3 times more cost effective than the Origin.

The PC cluster approach is now commercially offered. It allows the latest PC chips to be made available in the computing center for high end applications as soon as they are available to the public.

Creation of the Linux cluster: John Dorband/GSFC
Porting to the Linux cluster: Tom Clune/SGI
Porting to the Origin: Jim Abeles/SGI, Tom Clune/SGI
Timing on the T3E: Max Suarez/GSFC

Since ensemble members are independent they can be run in parallel. 18 runs, using 32 processors each, would efficiently utilize 576 processors. Such work can be done cost effectively on 18 small clusters, reserving large, tightly coupled supercomputers, such as the T3E, for tasks in which independent calculations cannot be so readily organized.

Results produced by NSIPP atmospheric model
Forecast anomalies of the upper level flow of the 1983 El Nino event.



The panels show nine realizations taken at random from an 18-member ensemble forecast. Anomalies over North America are very similar in all members. Over the North Atlantic, however, there is considerable random variability. Ensemble forecasts are required to distinguish between these situations.

The 60's:

- TIROS 1,2,3,…7, Nimbus 2,3, Explorers14-41, ATS 1-5
- President Eisenhower views 1st successful weather satellite images from TIROS 1 in April, 1960
- GISS moved to NY in 1961 adjacent to Columbia Univ. in the Interchurch Center with Robert Jastrow as Director
- President Kennedy proposes to UN an international weather program, Sept 1961
- First map of global net radiation from TIROS 2/3 by I. Rasool and Cloud distributions by A. Arking , both 1964
- GSFC/GISS procures their 1st supercomputer; IBM 360/95s
- First IR sounding profile from Nimbus 3, April14, 1969 leading to 1st GCM model study to assimilate global sounding profiles. Charney, et. al., 1969

“The excessive winter and spring snowfall in the Himalayas is prejudicial to the subsequent monsoon rain fall in India.”

H.F. Blanford, 1882

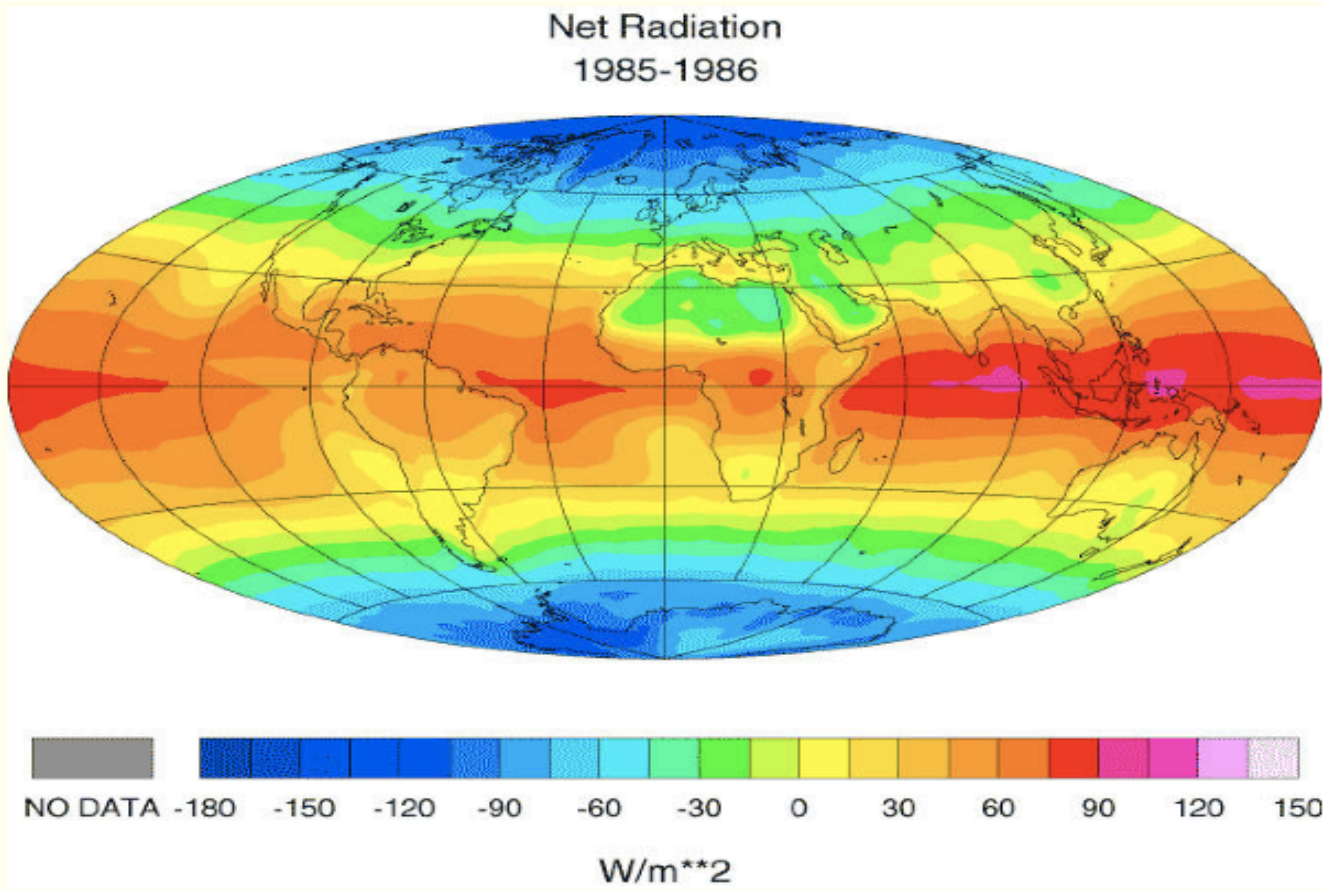
“These observations were later substantiated.”

Walker, 1910

“Snowfall has lost its power.”

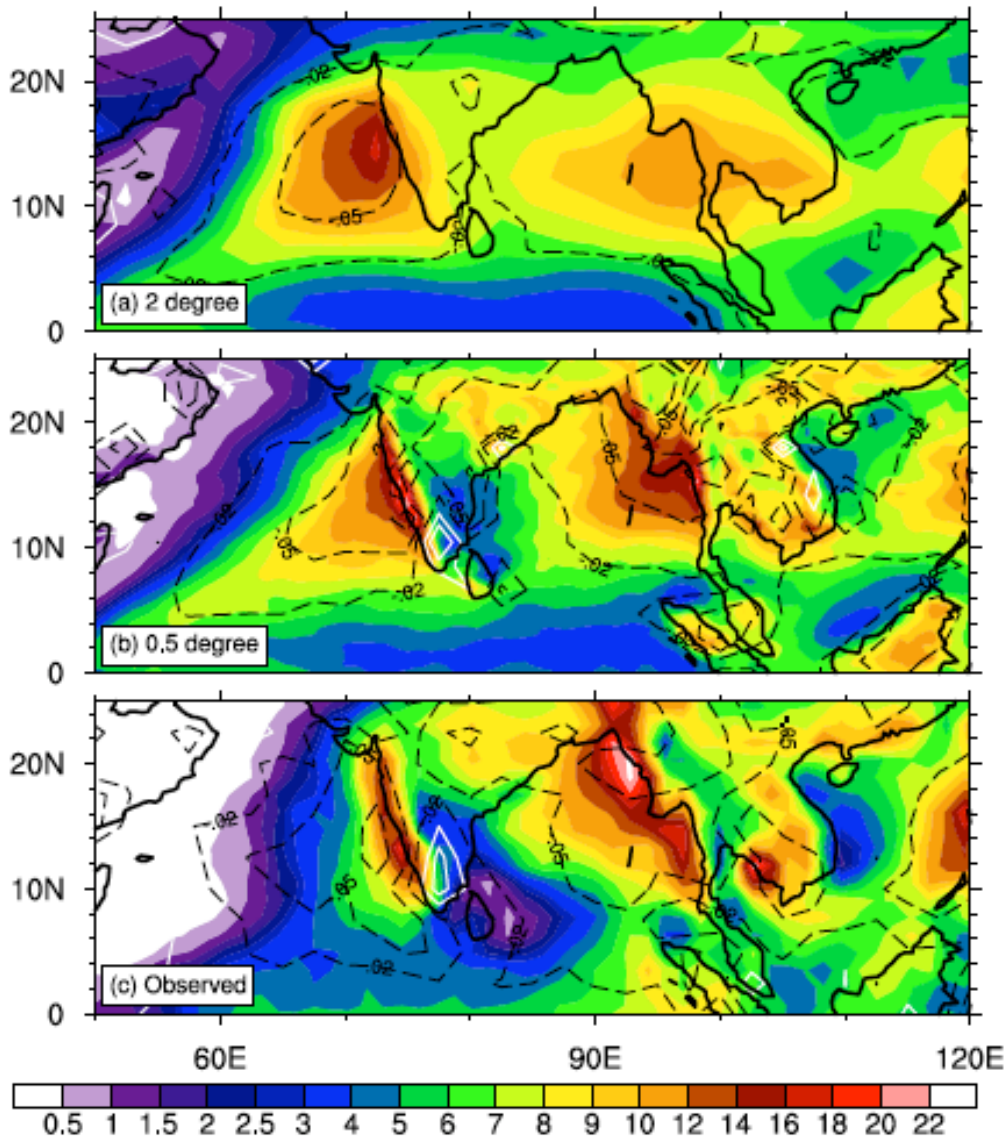
I.M.D., 1960

Energy Balance at Top of Atmosphere



- Net annual imbalance between incoming solar radiation and outgoing long wave radiation (ERBE data). Positive values indicate downward flux.

CCSM 3.5 @ 2.0° and 0.5° Resolutions: Asian Monsoon Rainfall Climatology



June - August rainfall (mm d^{-1}; colors) and ω_{700} (Pa s-1; contours) from 1980-2030 simulations (a & b) and observations (TRMM for rainfall and ERA40 for ω_{700})

Courtesy of Peter Gent