Jun. 23, 2014, ICTP TTA-1, Trieste, Italy

Seamless Prediction of Weather and Climate from Days to Decades

Part I: Weather-Intraseasonal-Seasonal

Part II: Seasonal-Decadal and Climate Change

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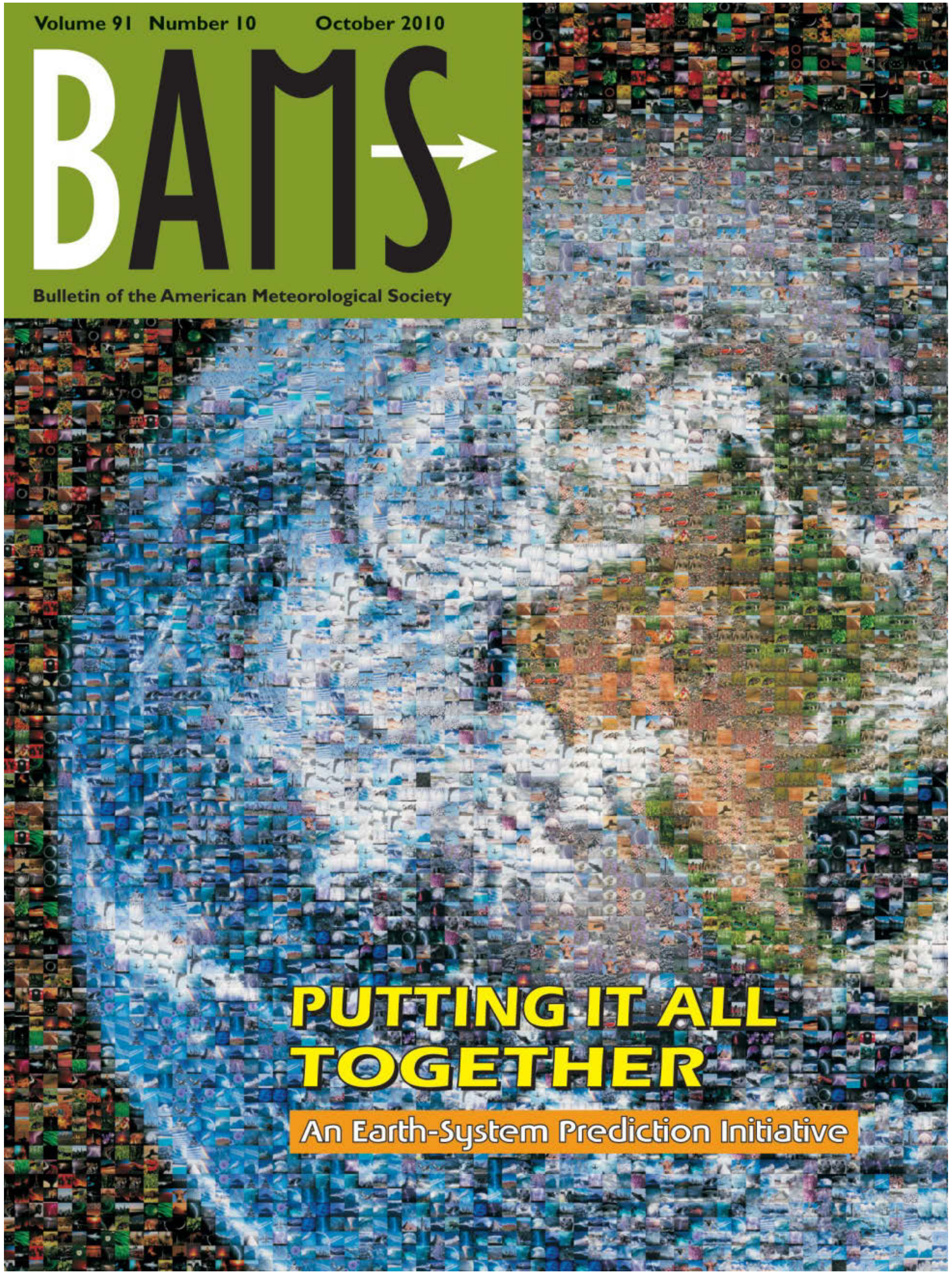
Seamless Prediction

- **Since climate in a region is an ensemble of weather events, understanding and prediction of regional climate variability and climate change, including changes in extreme events, will require a unified initial value approach that encompasses weather, blocking, intraseasonal oscillations, MJO, PNA, NAO, ENSO, PDO, THC, etc. and climate change, in a seamless framework.**



Brunet, G., et al, 2010: Collaboration of the Weather and Climate Communities to Advance Sub-Seasonal to Seasonal Prediction. *BAMS, Vol. 91, 1397-1406*

Shapiro, M., J. Shukla, et al, 2010: An Earth-System Prediction Initiative for the 21st Century. *BAMS, Vol.91, 1377-1388*

Shukla, J., T.N. Palmer, R. Hagedorn, B. Hoskins, J. Kinter, J. Marotzke, M. Miller, and J. Slingo, 2010: Towards a New Generation of World Climate Research and Computing Facilities. *BAMS, Vol.91, 1407-1412*

Shukla, J., R. Hagedorn, B. Hoskins, J. Kinter, J. Marotzke, M. Miller, T.N. Palmer, and J. Slingo, 2009: Revolution in climate Prediction is Both Necessary and Possible: A Declaration at the World Modelling Summit for Climate Prediction. *BAMS, Vol.90*, 16-19

An Earth system Prediction Initiative

The WCRP Strategic Framework 2005-15

Coordinated Observation and Prediction of the Earth System

(WCRP-COPES)

AIM

To facilitate analysis & prediction of Earth system variability & change for use in an increasing range of practical applications of direct relevance, benefit & value to society

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WCRP Strategic Framework (COPES)

Seamless Prediction Problem

1. **There is now a new perspective of a continuum of prediction problems**, with a blurring of the distinction between shorter-term predictions and longer-term climate projections. Increasingly, **decadal and century-long climate projection will become an initial-value problem** requiring knowledge of the current observed state of the atmosphere, the oceans, cryosphere, and land surface (including soil moisture, vegetation, etc.) in order to produce the best climate projections as well as state-of-the-art decadal and interannual predictions.

WCRP Strategic Framework (COPES)

Seamless Prediction Problem

2. **The shorter time-scales and weather are known to be important in influencing the longer-time-scale behaviour.** In addition, the regional impacts of longer-time-scale changes will be felt by society mainly through the resulting changes in the character of the shorter time-scales, including extreme events. In recognition of this, climate models are being run with the highest possible resolutions, resolutions that were employed in the best weather forecast models only a few years ago.

3. **Even though the prediction problem itself is seamless, the best practical approach to it may be described as unified**: models aimed at different time-scales and phenomena may have large commonality but place emphasis on different aspects of the system.

Coordination of WCRP Modeling Activities

Weather Prediction (1-10 days)	WGNE
Intra-Seasonal Prediction (1-30 days)	WGNE, TFSP, GMPP
Seasonal Prediction (1-100 days)	WGSIP, TFSP, GMPP, CliC, SPARC, WGOMD
Interannual Prediction (1-1,000 days)	WGSIP, TFSP, WGCM, WGOMD
Decadal Prediction (1-10,000 days)	WGCM, WGOMD
Climate Change Prediction (1-100,000 days)	WGCM

Seamless Prediction of Weather and Climate from Days to Decades

Part I: Weather-Intraseasonal-Seasonal

1. Introduction

2. Weather

3. Intraseasonal – Seasonal

4. Summary

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Patterns of Weather and Climate Variability

- **Tropics** — • **Organized convections, Hurricanes, Typhoons, Easterly waves, Monsoon depressions, Madden Julian "Oscillation" (MJO), QBO, Monsoons, ENSO, TBO, Droughts and floods, Hadley cell and Walker cell**
- **Extratropics** — • **Cyclones, Storms, Blocking, PNA, PDO, NAO, AMO, Ferrel cell**
- **Polar** — • **Arctic Oscillation (NAM), Antarctic Oscillation (SAM)**
- **Global** — • **Thermohaline circulation**

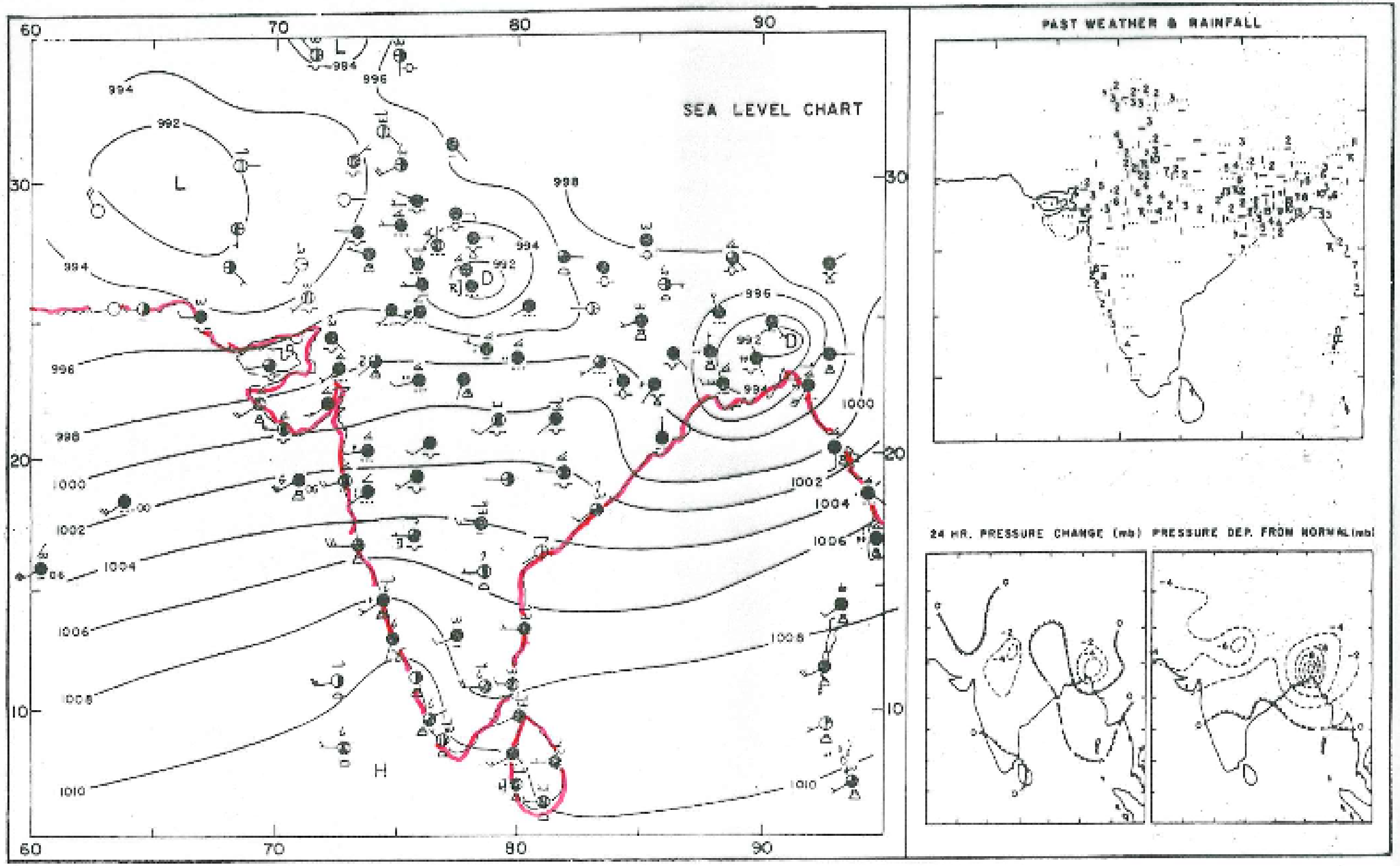
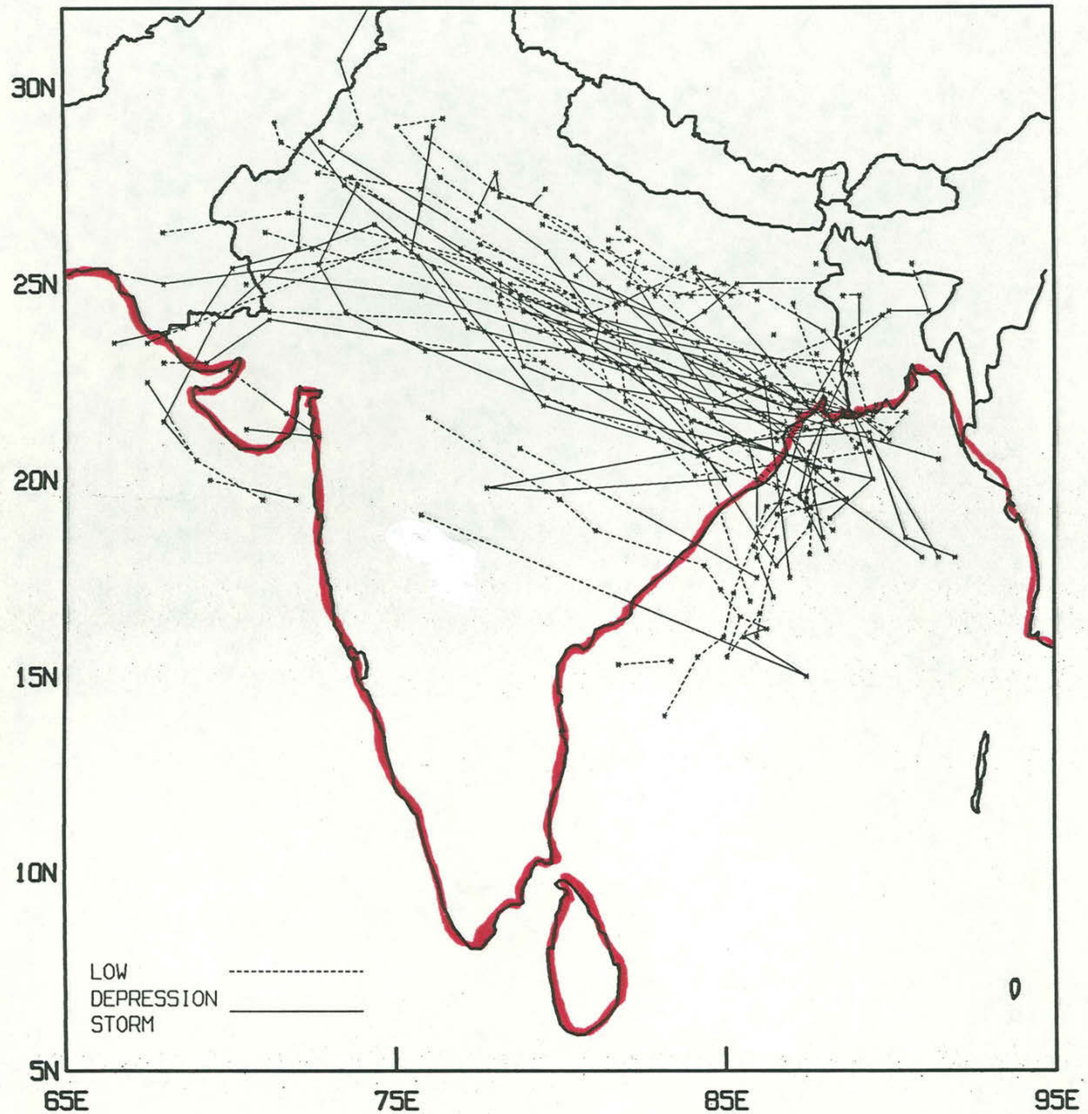


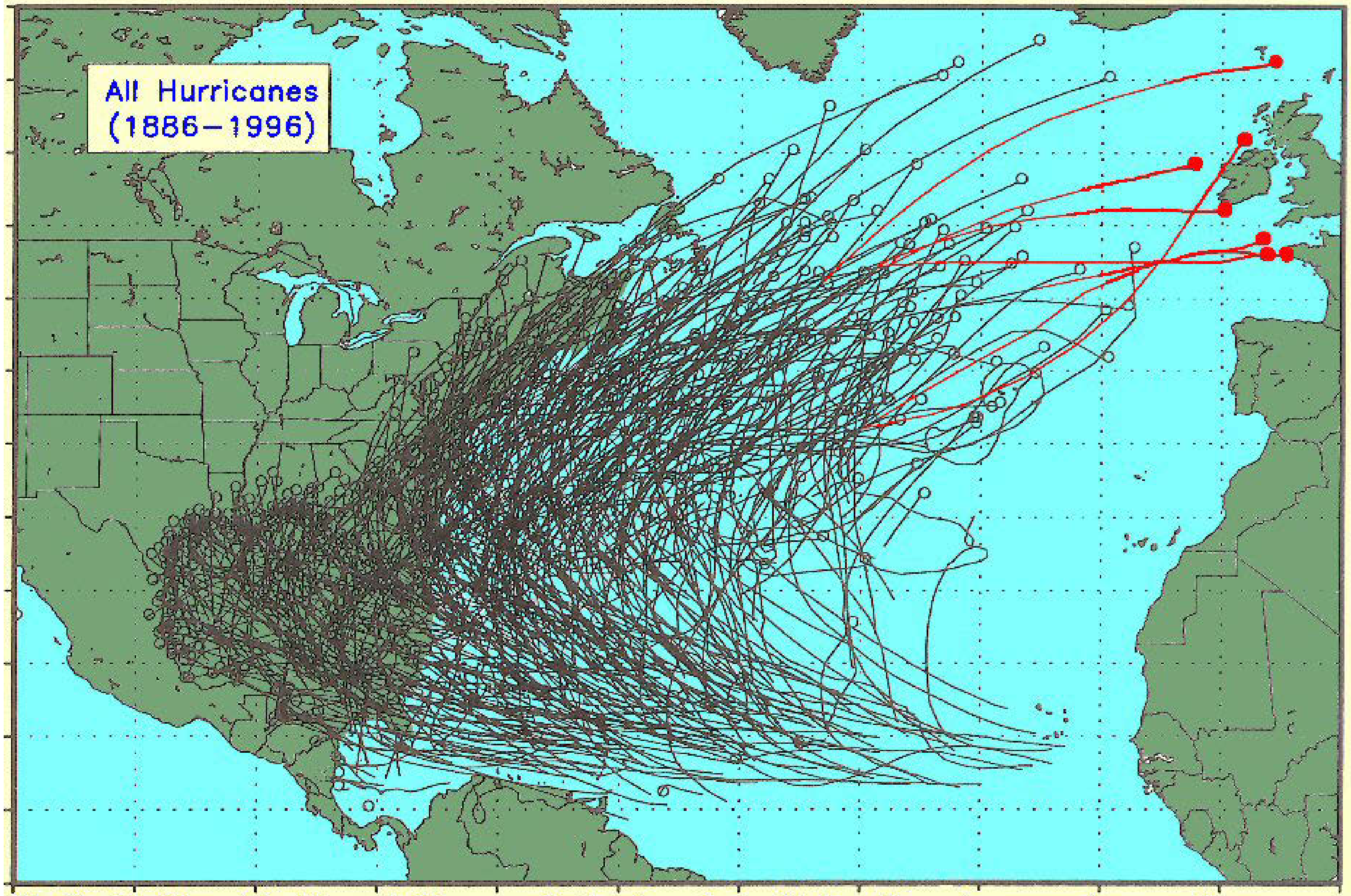
Fig.9.7(h) Synoptic charts 0300 GMT 10 July 1968.

FIVE HIGHEST MONSOON RAINFALL

1961.1917.1892.1956.1933



Atlantic Hurricanes Tracks (1886 – 1996)

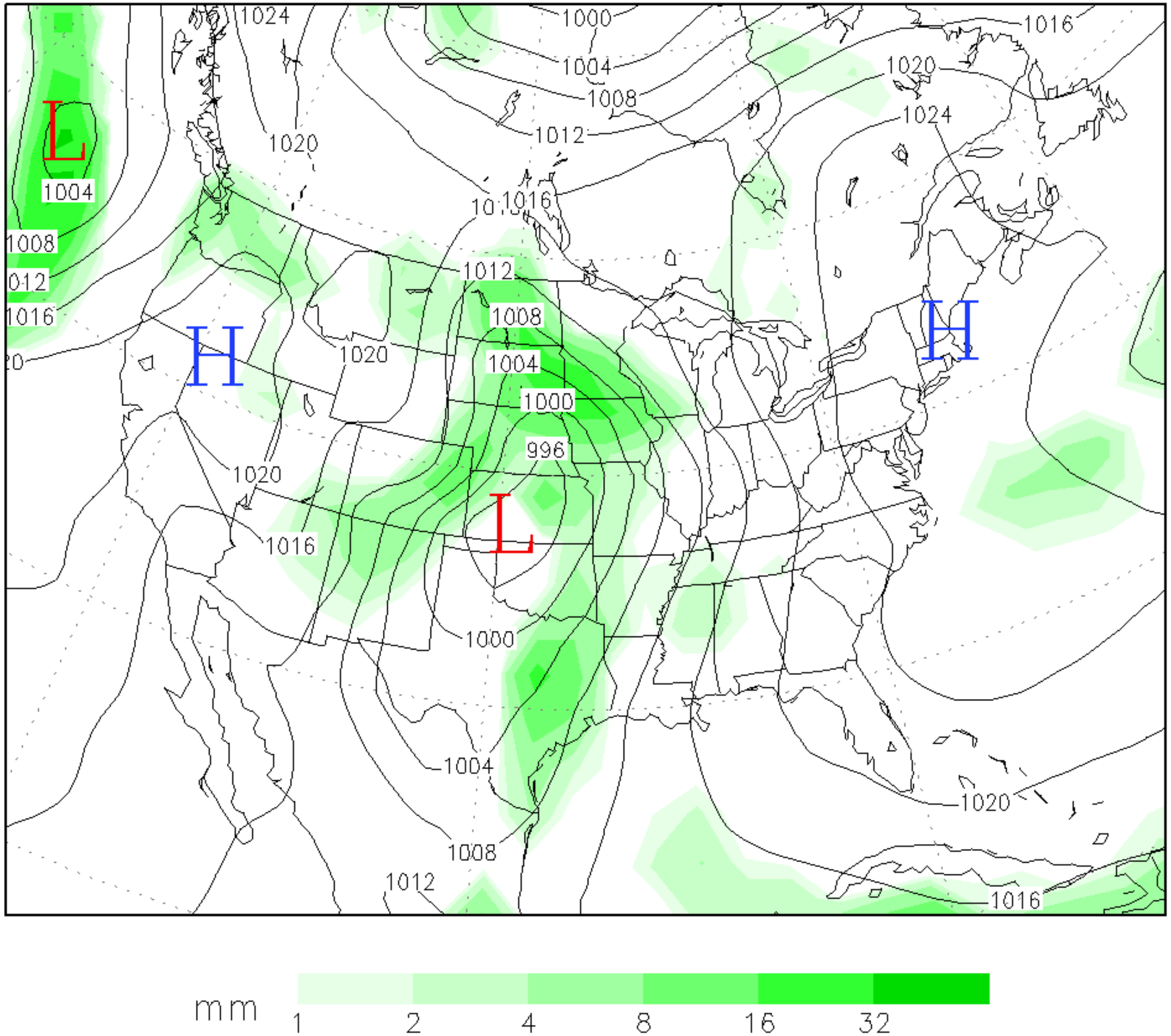


The English Channel is at the end of the range for hurricane tracks. Perhaps they only very rarely proceed into it without dissipation, but the sea may be in an overshoot area for exceptional hurricanes.

Modified after Elsner and Kara (1999). Ian West and Tonya West (c) 2005.

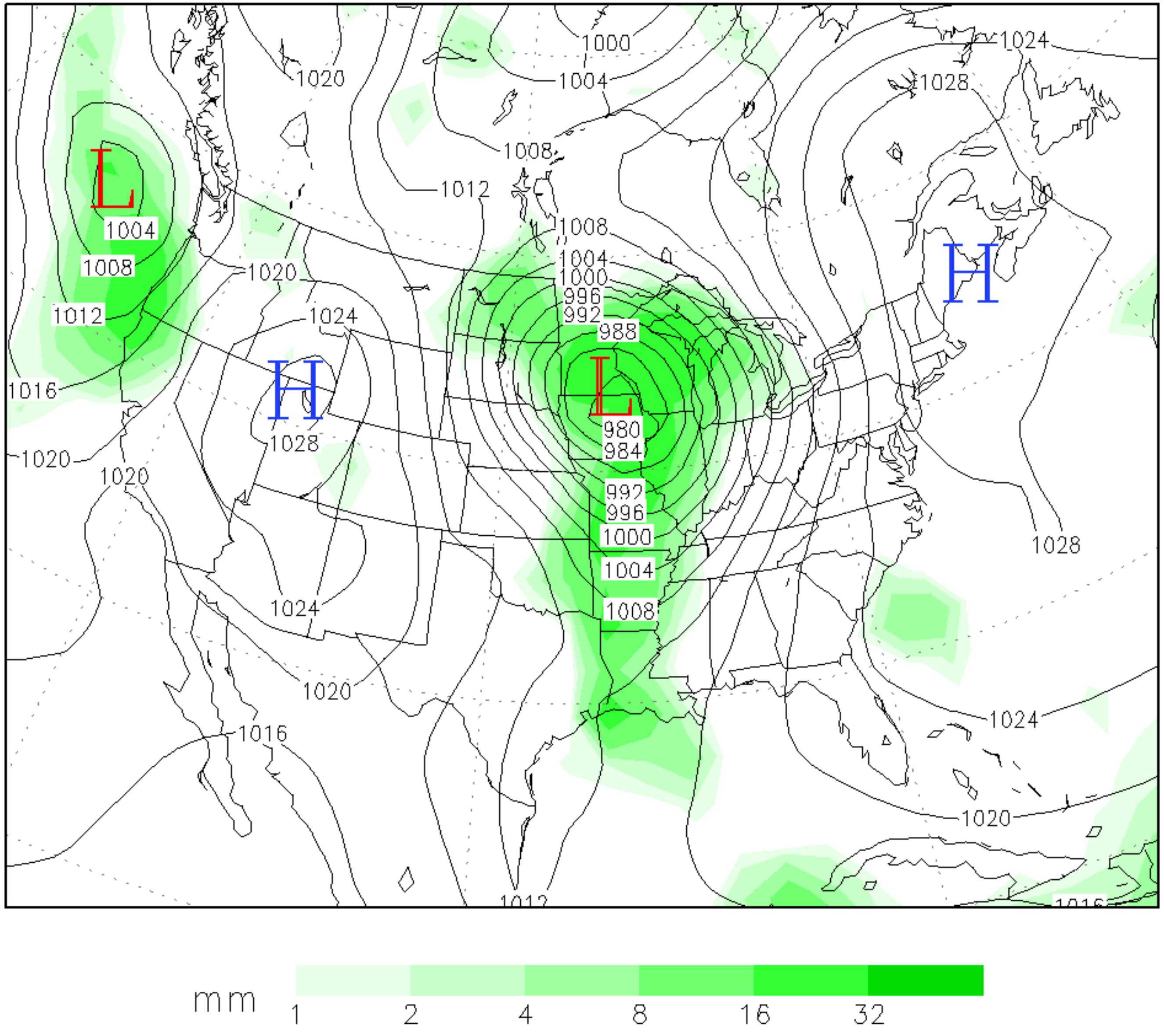
Sea Level Pressure (mb) & Precipitation Rate (mm/12Hr)

00Z Tue 10 Nov 1998



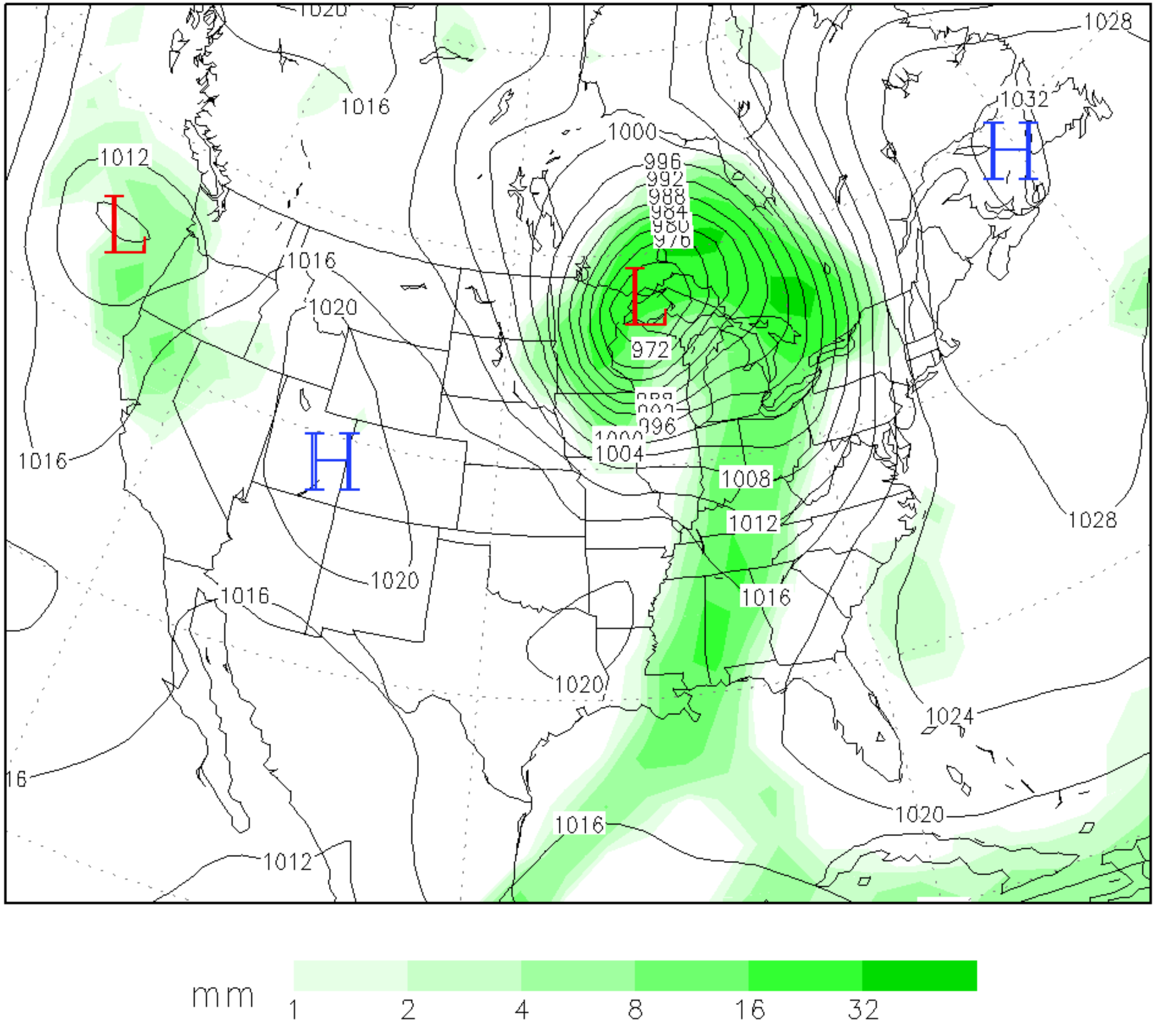
Sea Level Pressure (mb) & Precipitation Rate (mm/12Hr)

12Z Tue 10 Nov 1998



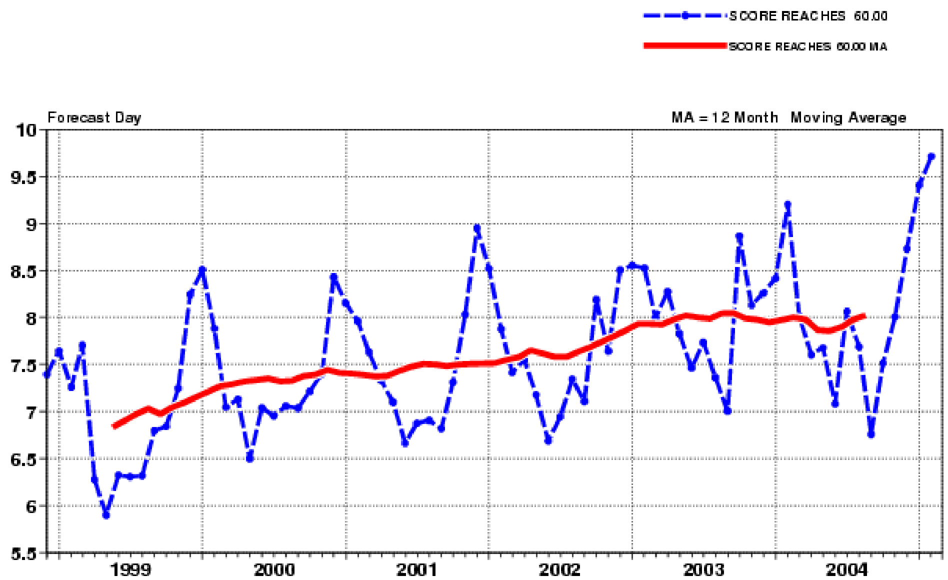
Sea Level Pressure (mb) & Precipitation Rate (mm/12Hr)

00Z Wed 11 Nov 1998

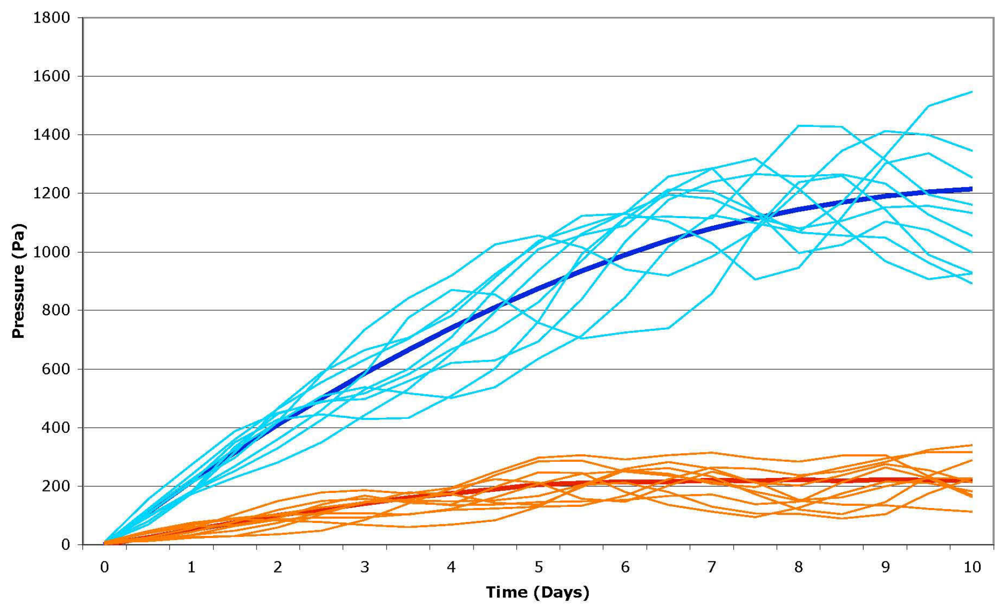


ERA Forecast Verification

Anomaly Correlation of 500 hPa GPH, 20-90N



Schematic Error Growth
for the Tropics (Red) & Midlatitude (Blue)



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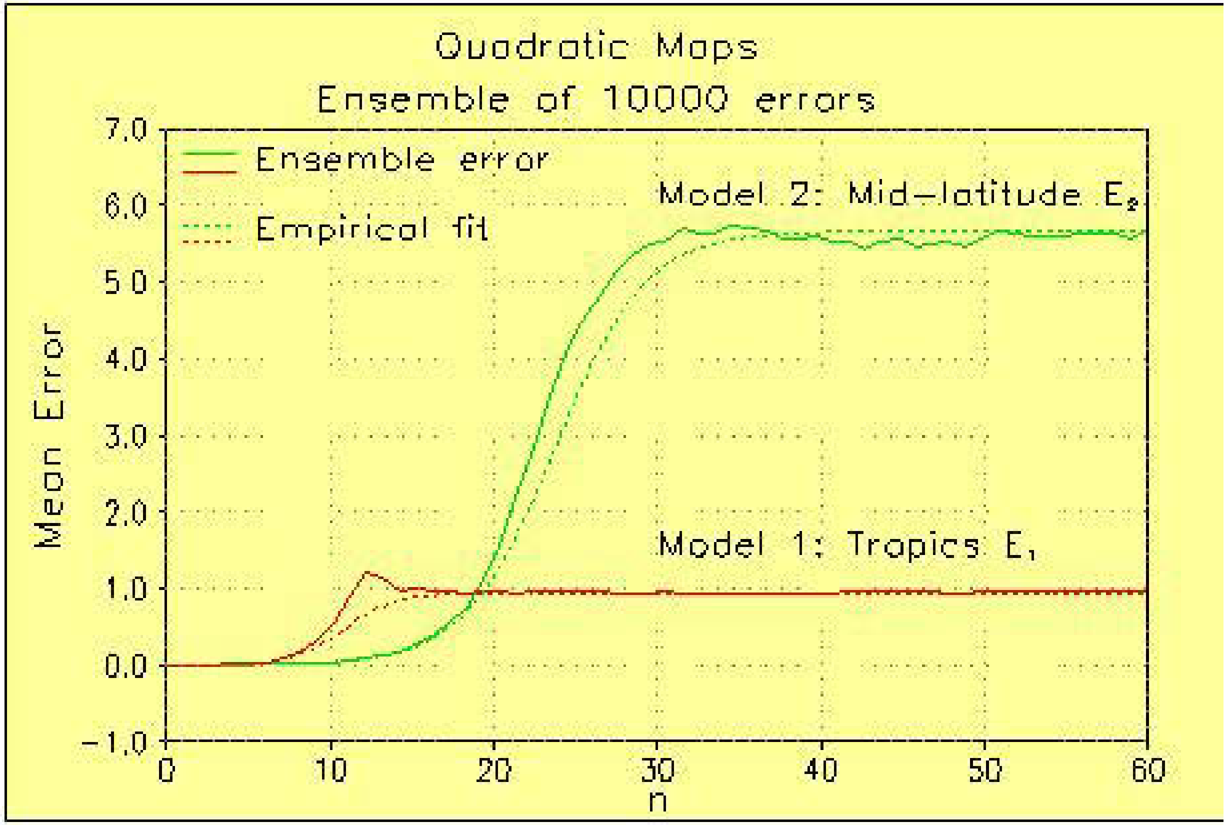
Growth of Random Errors in the simple model of Tropics and midlatitudes

Model 1: $X_{n+1} = X_n^2 - a$ (Tropics) $a = 1.98$

Model 2: $Y_{n+1} = 0.1Y_n^2 - 10b$ (Mid-latitude) $b = 1.60$

An ensemble of 10000 initial random errors was allowed to evolve for each model.



Empirical fit for Error growth

$$\frac{dE_1}{dt} = \lambda_1 E_1 - s_1 E_1^2$$

$$\frac{dE_2}{dt} = \lambda_2 E_2 - s_2 E_2^2$$

$$\lambda_1 > \lambda_2$$

$$\lambda_1 = 0.63$$

$$\lambda_2 = 0.37$$

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The Knife's Edge

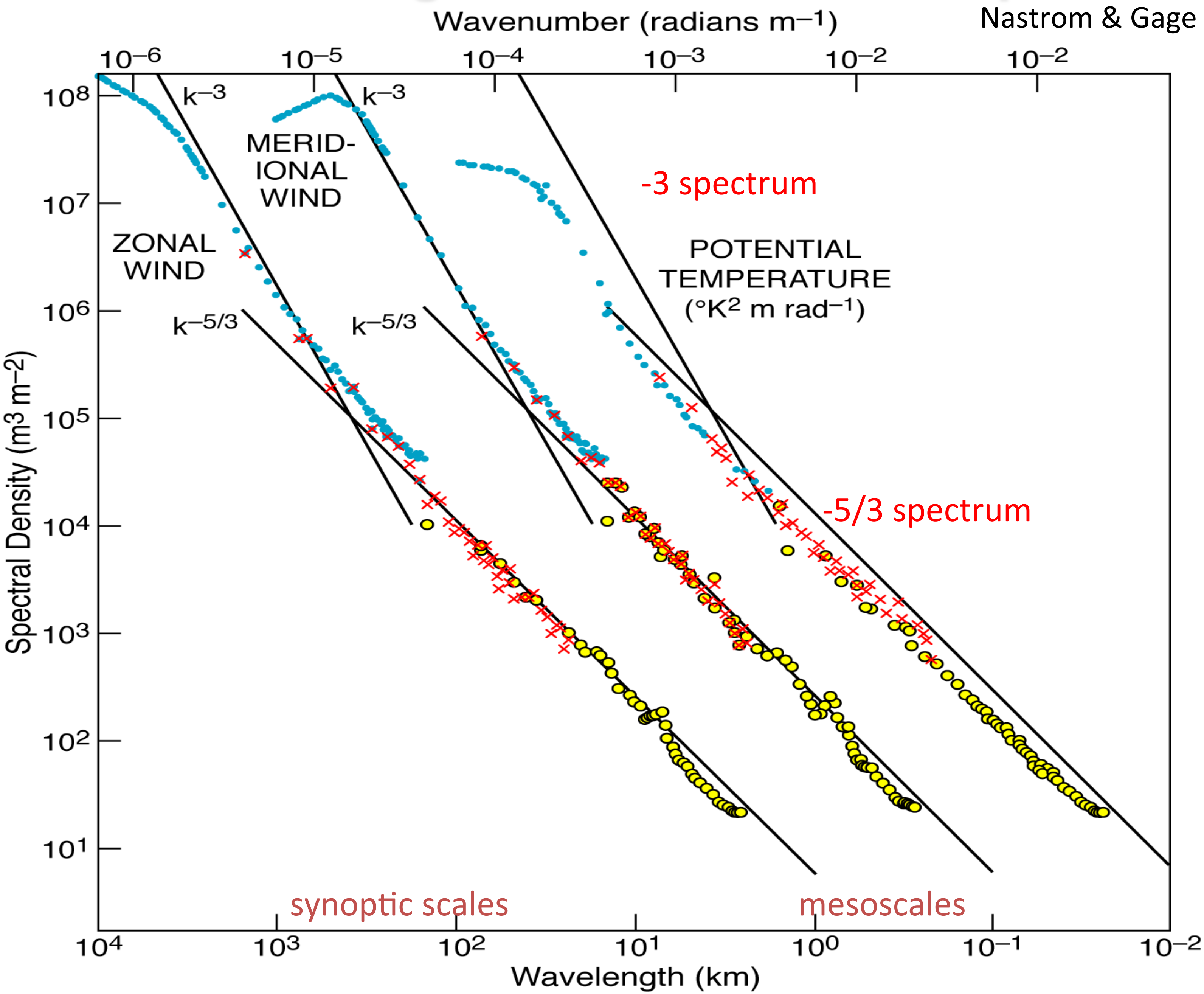
"…if the energy per unit wave number obeys a minus-three or higher negative power law, … the series for [the range of predictability] would fail to converge."

Translation: Range of Predictability can be increased indefinitely by reducing initial observation error.

-Lorenz, 1969: The predictability of a flow which possesses many scales of motion. Tellus, pg. 304.

The "Knife's Edge" – The Observed Spectrum

Nastrom & Gage 1985

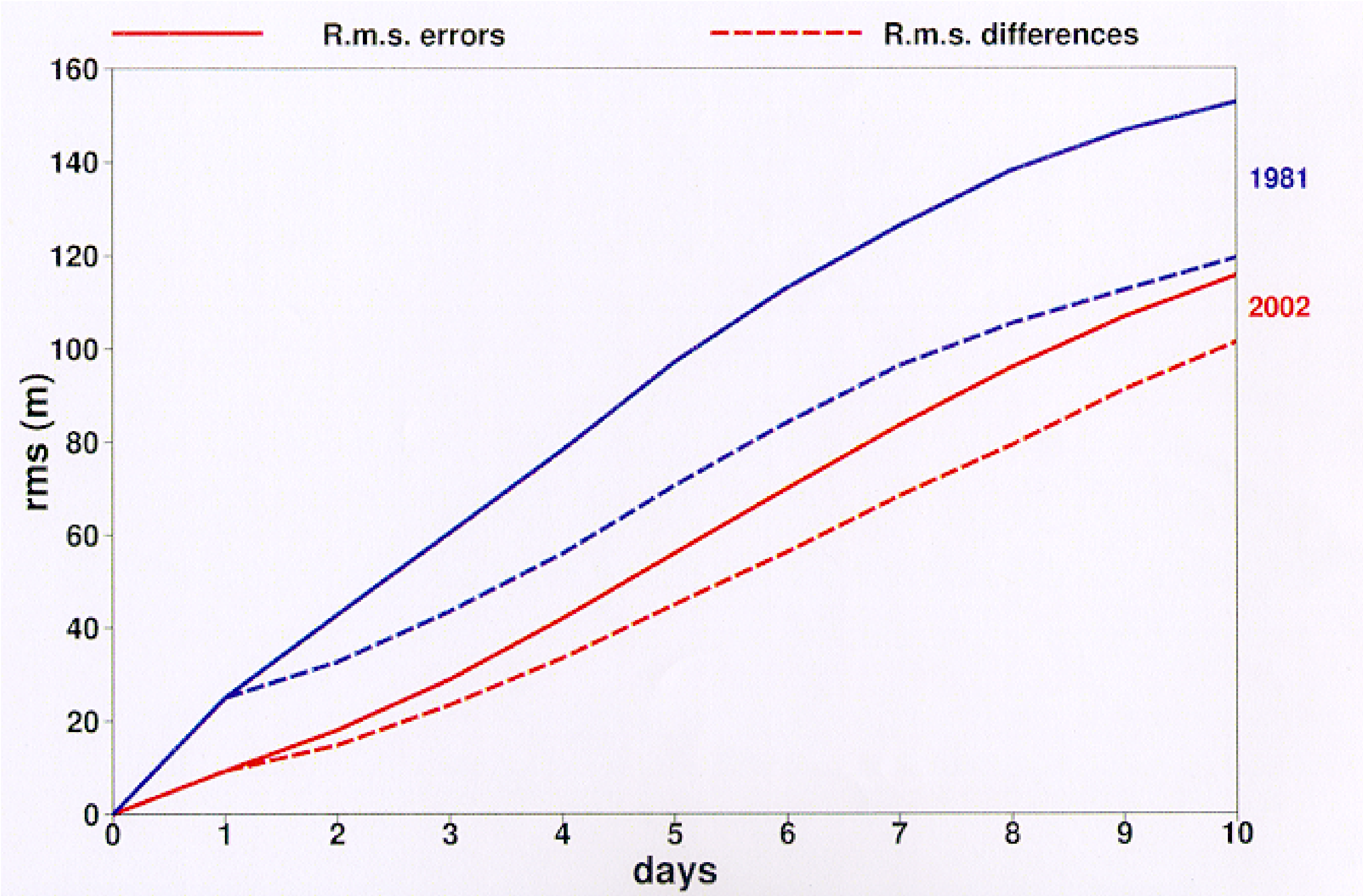


Does the Observed -5/3 Spectrum Imply that the Range of Predictability Cannot be Lengthened by Reducing Initial Error?

- The eddies associated with the observed -5/3 spectrum do not interact with the large scale

RMS Error and Differences between Successive Forecasts

Northern Hemisphere 500 hPa Height in Winter

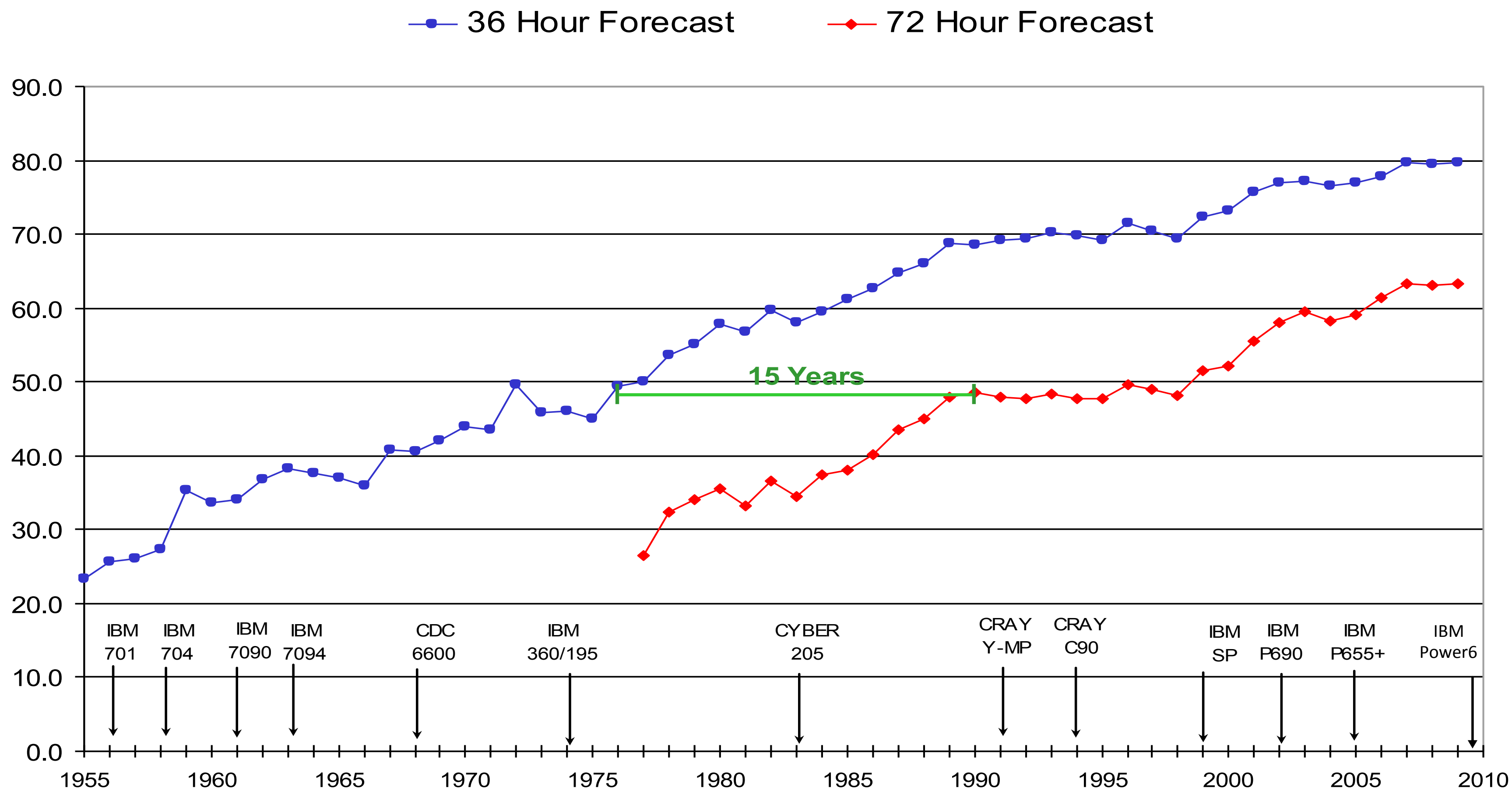


Current Limits of Predictability, A. Hollingsworth, Savannah, Feb 2003

NCEP Operational Forecast Skill

36 and 72 Hour Forecasts @ 500 MB over North America

[100 * (1-S1/70) Method]



NCEP Central Operations/SIB January 2010

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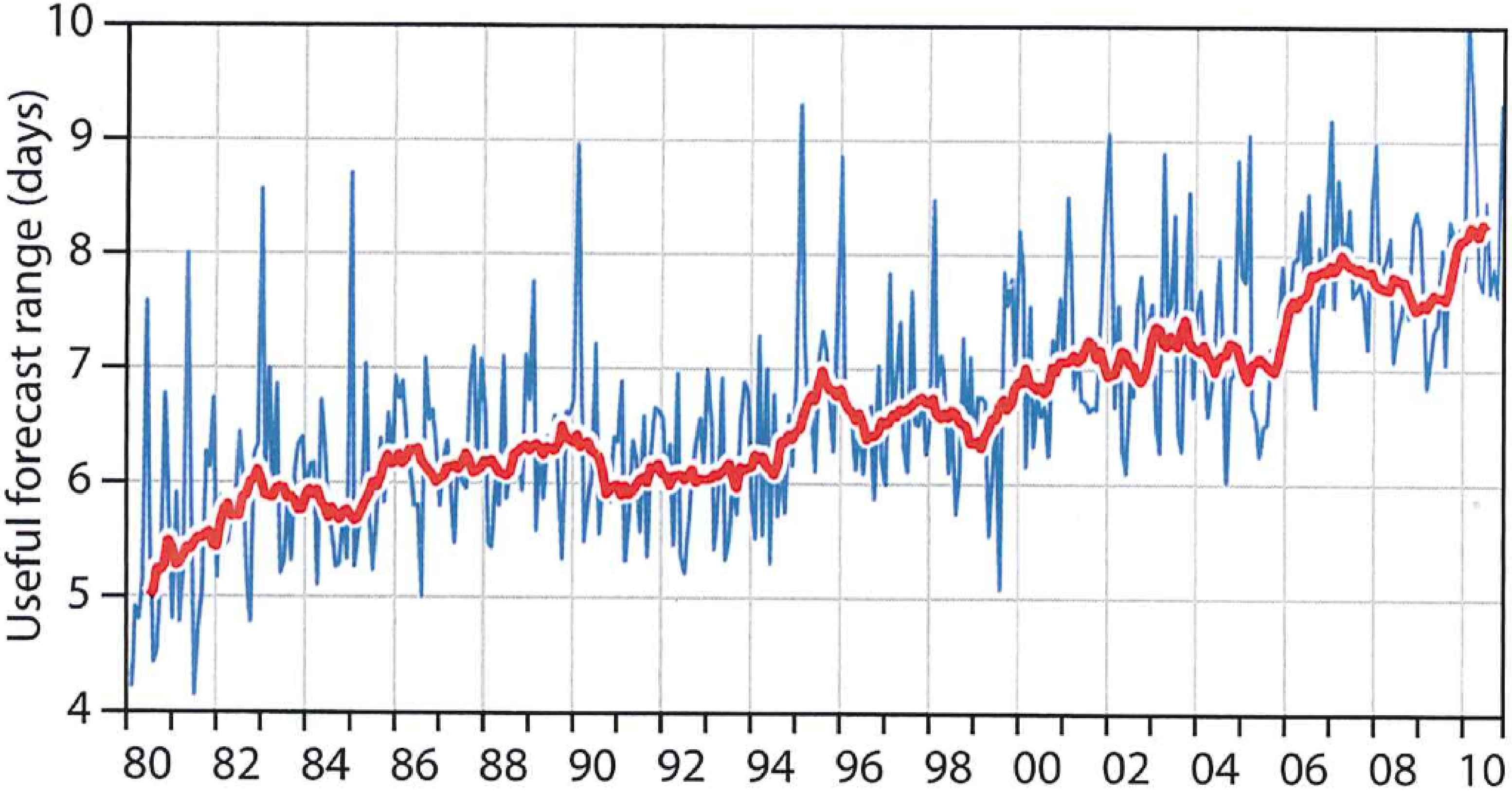
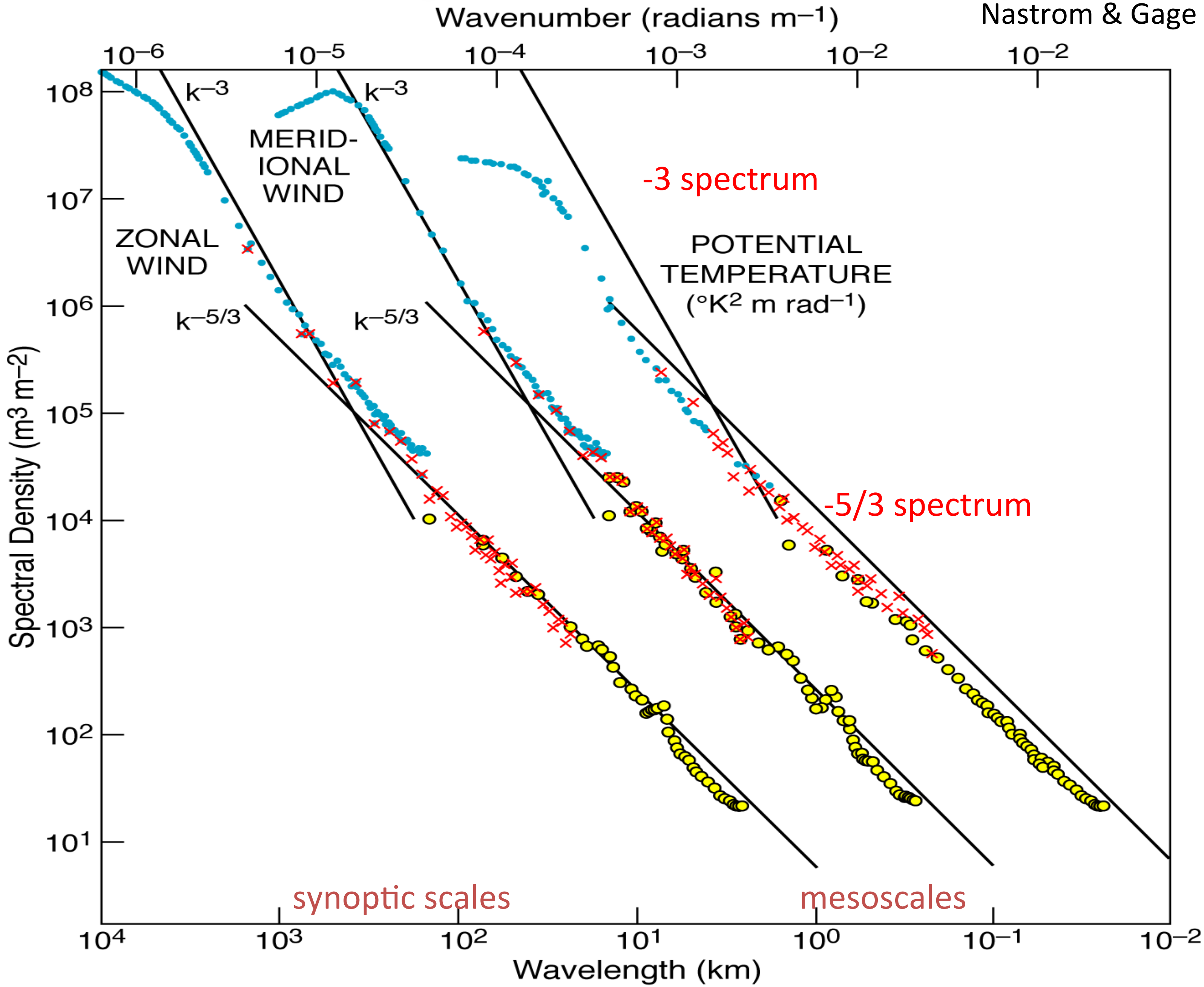
ECMWF: Useful forecast range (days) for Europe (1980 – 2010)



Record performance of the deterministic forecasting system. *The useful range of the deterministic forecasts for Europe reached its highest ever monthly value in February 2010. Overall the performance has been consistently good during 2010. The useful forecast range is determined by the time at which the anomaly correlation for 500 hPa height operational forecasts at 12 UTC reached 60%.*

The "Knife's Edge" – The Observed Spectrum

Nastrom & Gage 1985



Interim Summary (NWP)

- In spite of the $k^{-5/3}$ spectrum, and,
- Despite 40 years of research, we still cannot definitively state whether the range of predictability cannot be increased by reducing the initial error.

The observed monsoon intraseasonal variability over the Asia-Pacific

Thanks to: Ravi P. Shukla, Jieshun Zhu, James L. Kinter, Wallace, Angel Adames

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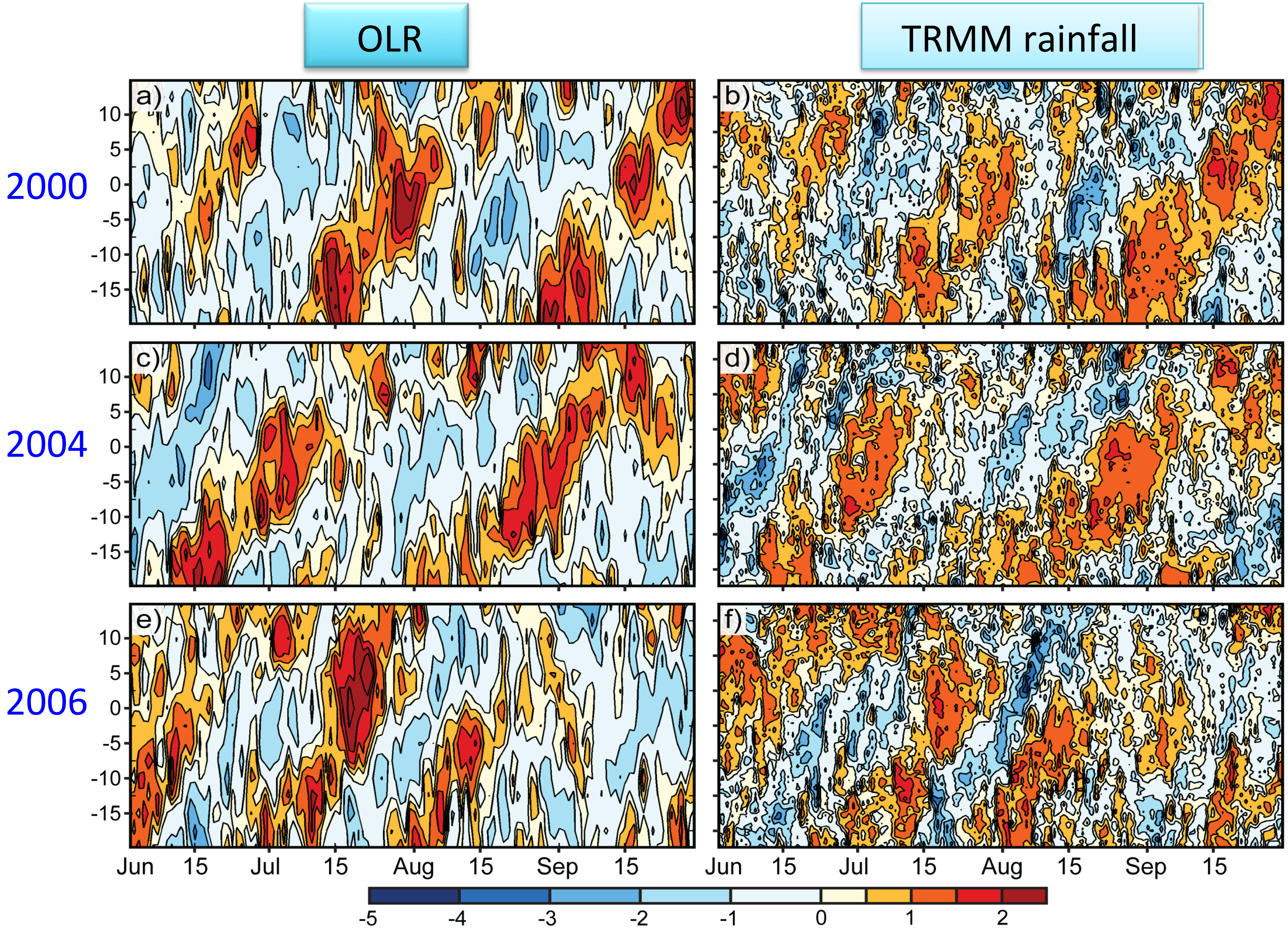
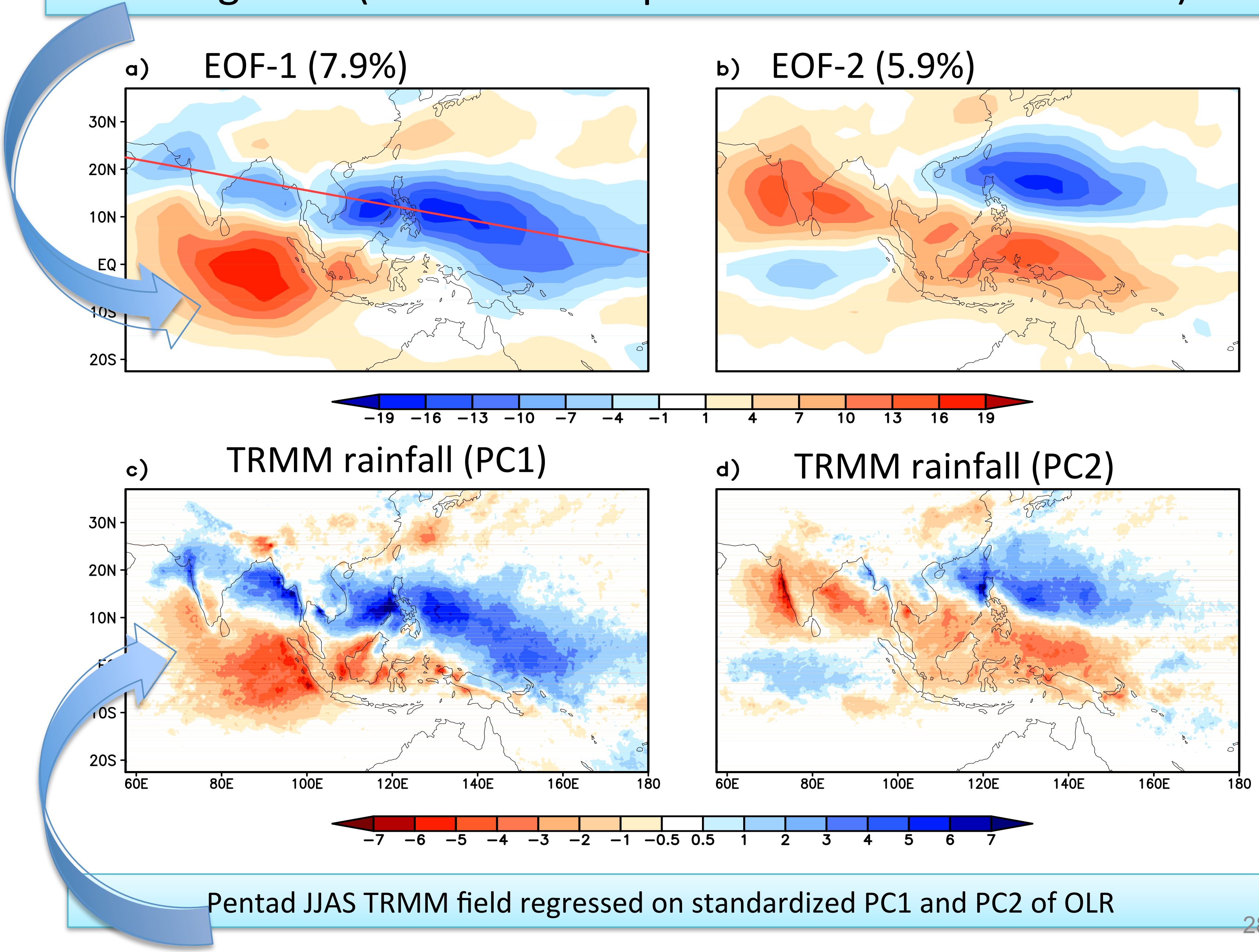
Time-Latitude section of daily JJAS OLR and TRMM Rainfall

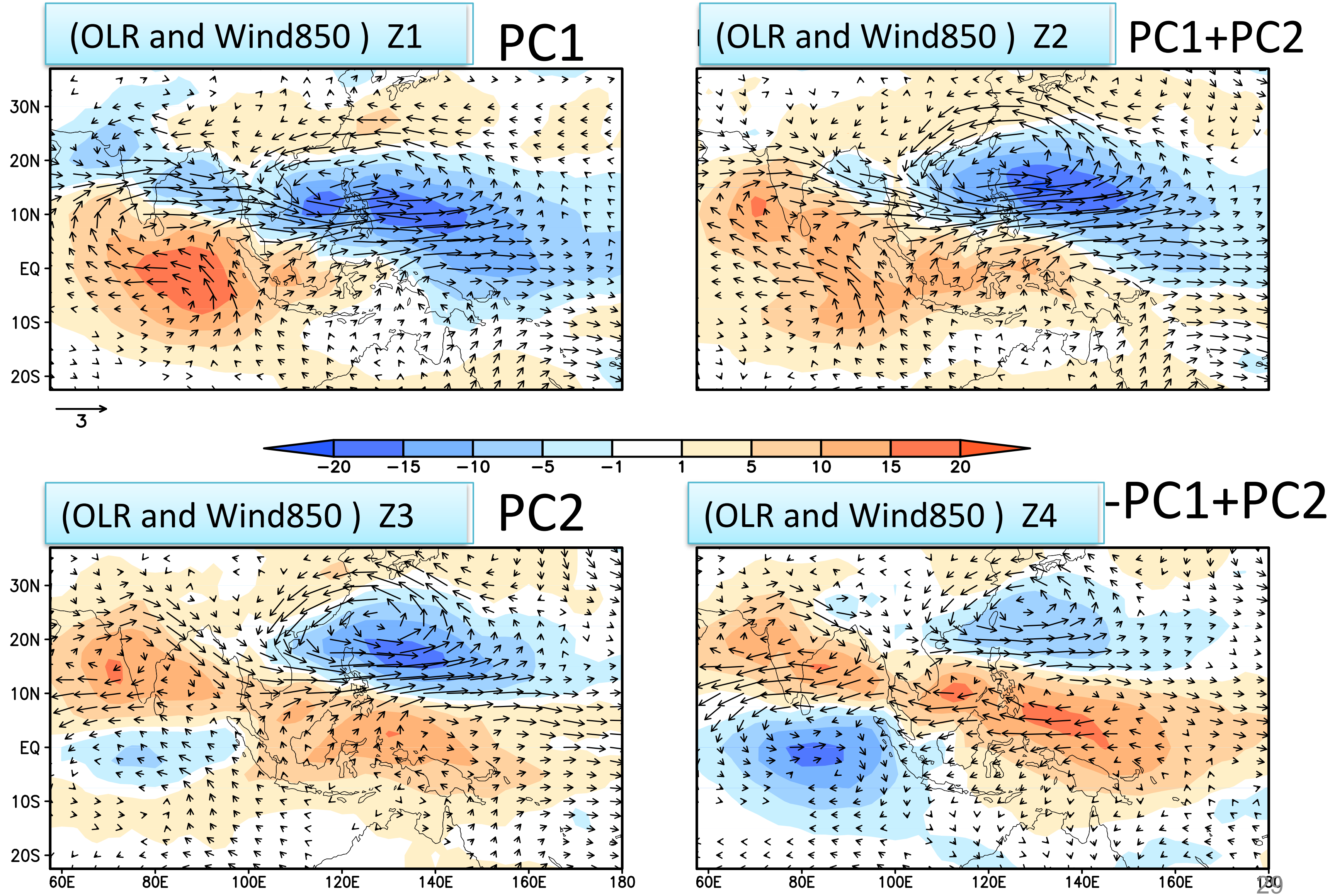


Leading EOFs (OLR based on pentad data for JJAS Season)



Pentad JJAS TRMM field regressed on standardized PC1 and PC2 of OLR

Projection of OLR (colored shading) and 850 hPa wind vectors upon standardized linear combinations of PC1 and PC2 of pentad-mean JJAS OLR: (*a*) PC1; (*b*) PC1 + PC2; (c) PC2; (*d*) –PC1 + PC2.

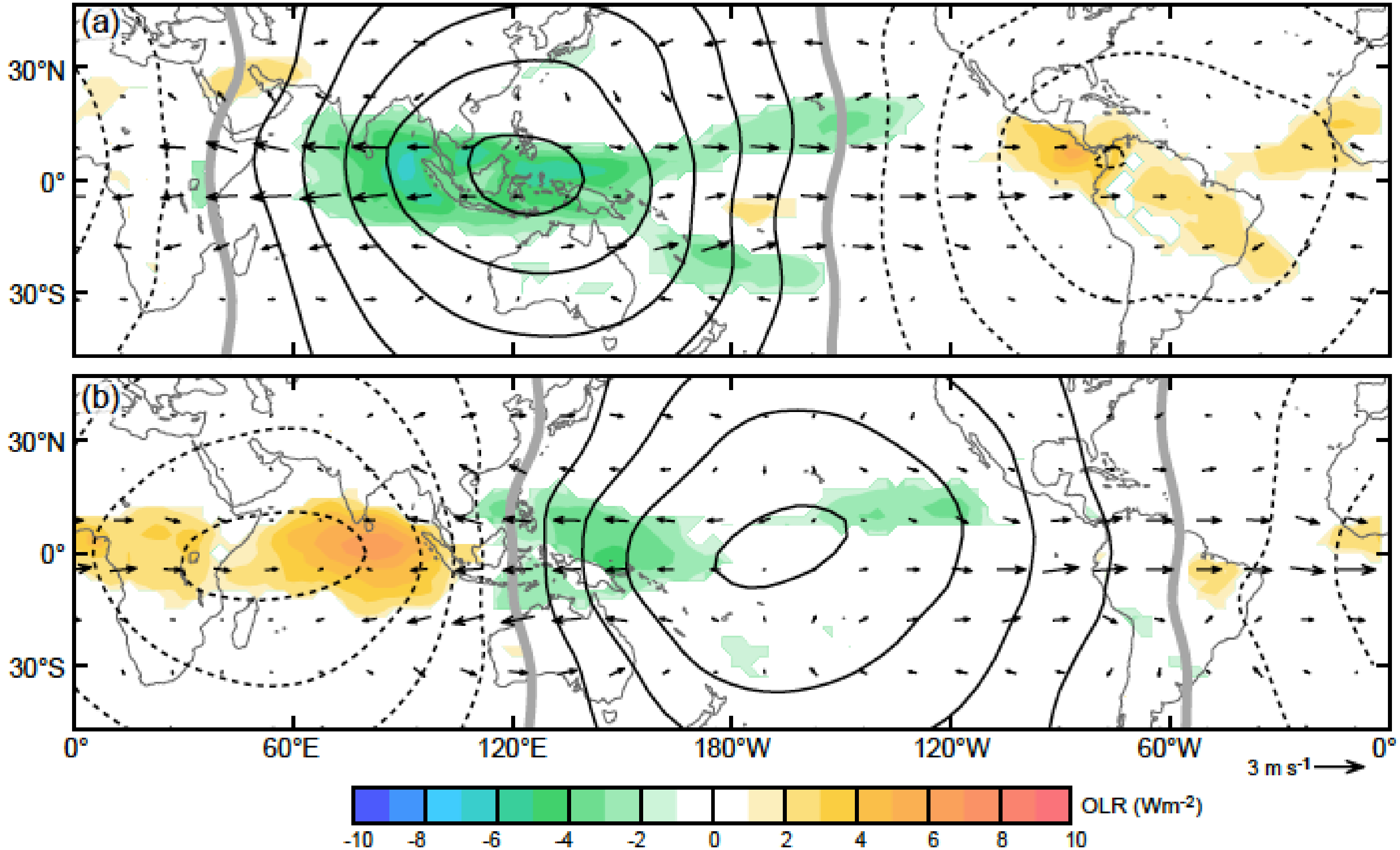


Data

- ERA – Interim pressure level fields
  - 1979-2011 four times daily (33 years)
  - 1.5° x 1.5° resolution

- NOAA OLR
  - 1979-2011 daily
  - 2.5° x 2.5° resolution

EOFs 1 and 2 of 850 minus 150 hPa Velocity Potential, its regression with OLR (color), and total 150hPa Wind Vectors (arrows) for 12 calendar months

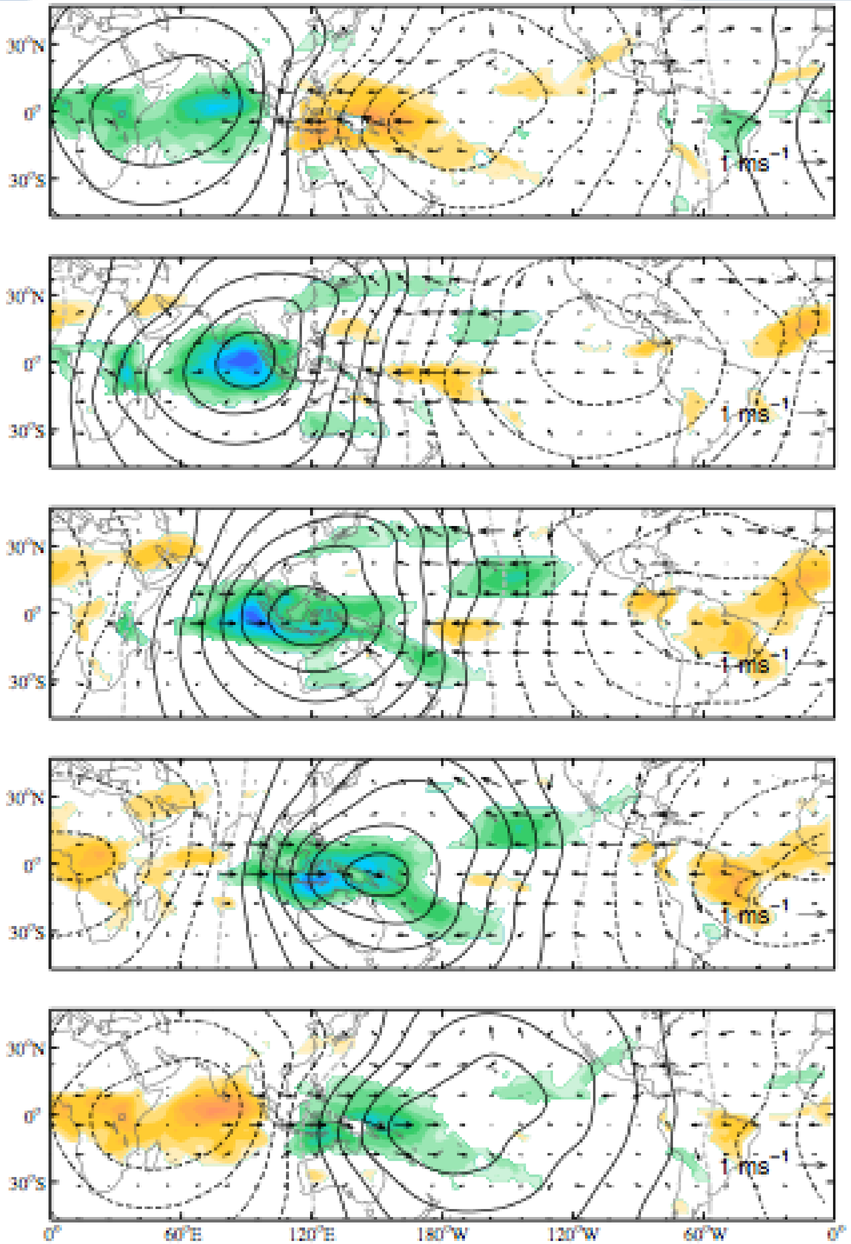


Contour interval $0.75 \times 10^6\ m^2\ s^{-1}$

29%

26%

MJO phases with 150-850 hPa χ



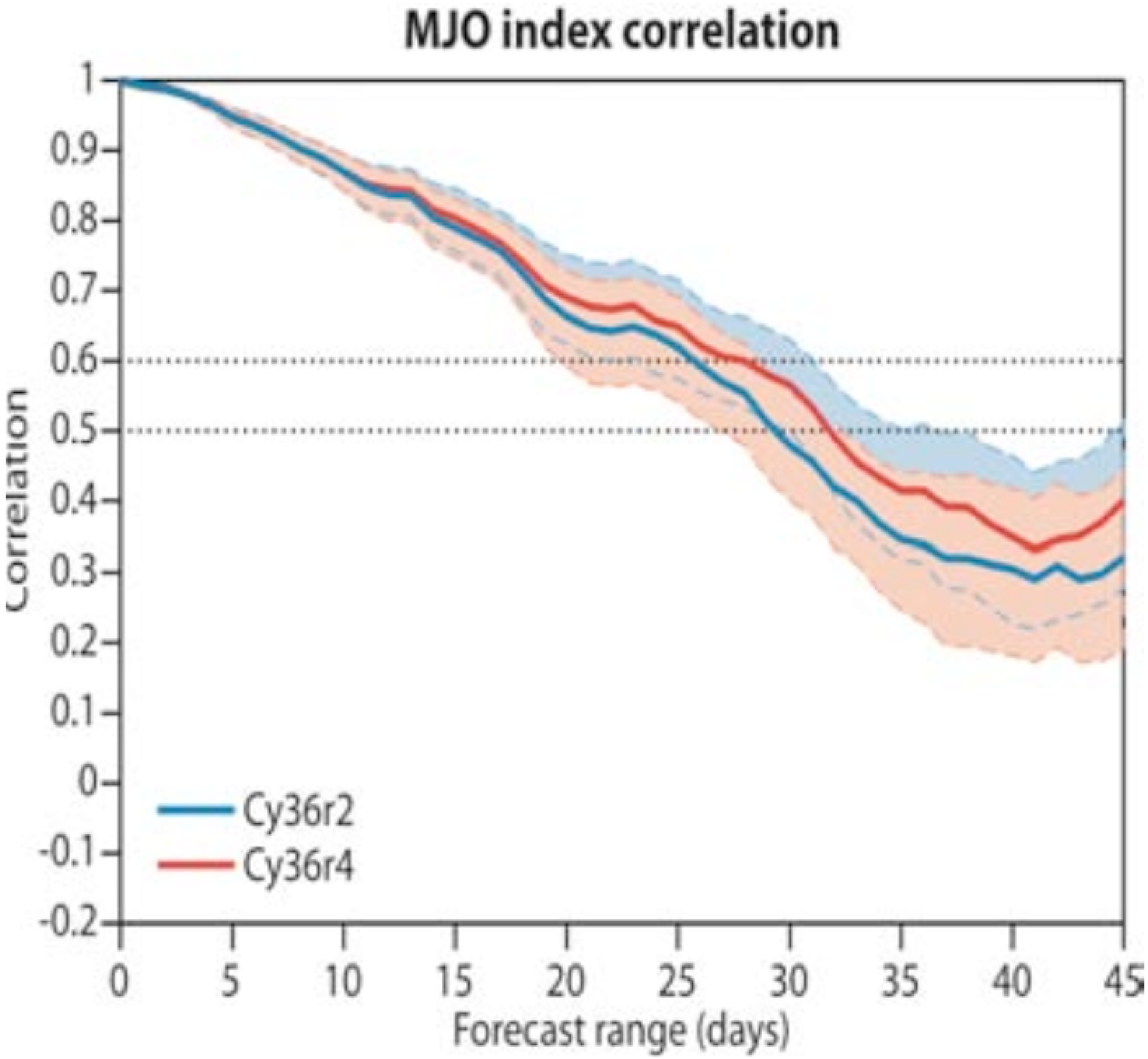
Phase 2 -> - PC2

Phase 3 -> PC1 - PC2

Phase 4 -> PC1

Phase 5 -> PC1 + PC2

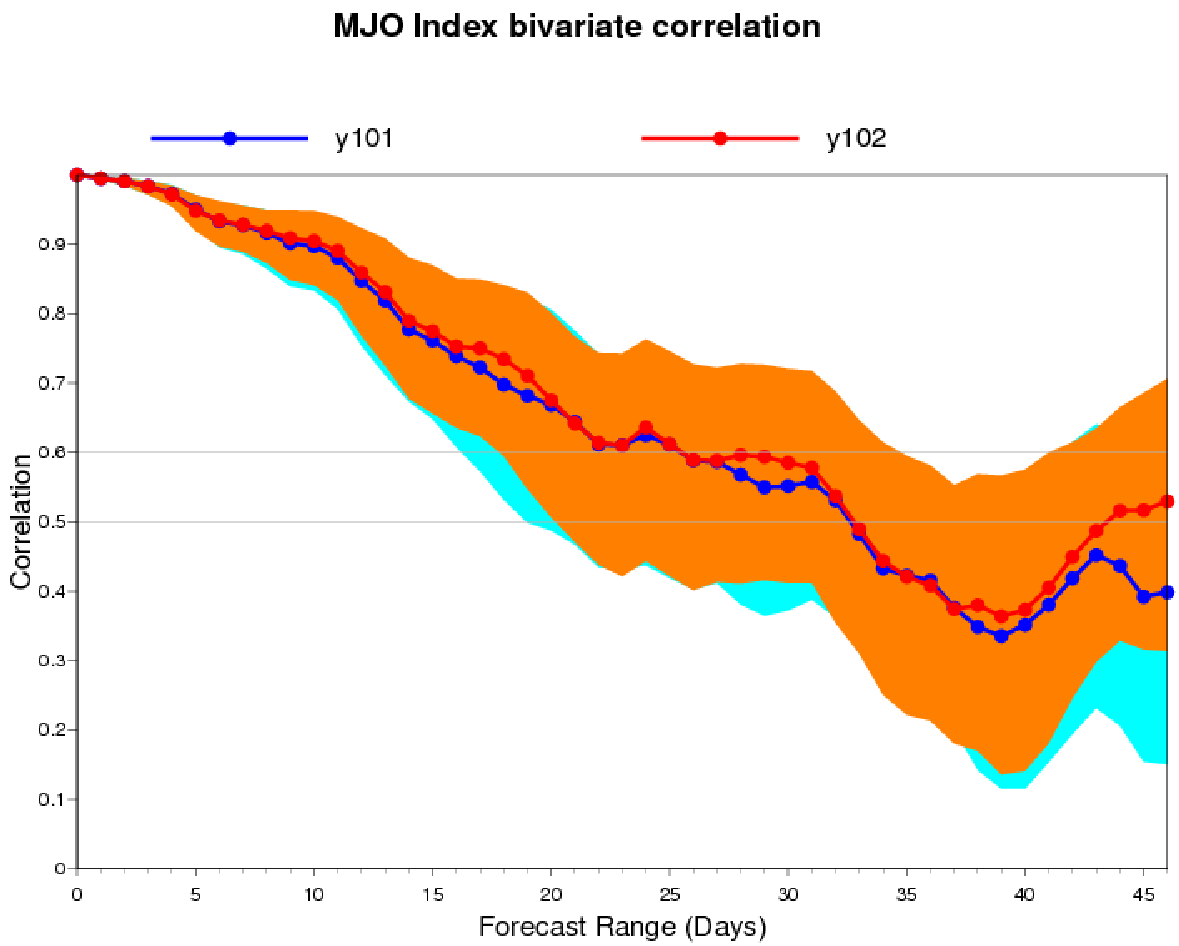
Phase 6 -> PC2



MJO

Bivariate Correlation between ECMWF Ensemble Mean Forecast and Observations Based on 80 Dates (1st Feb, May, Aug, Nov, 1989-2008)

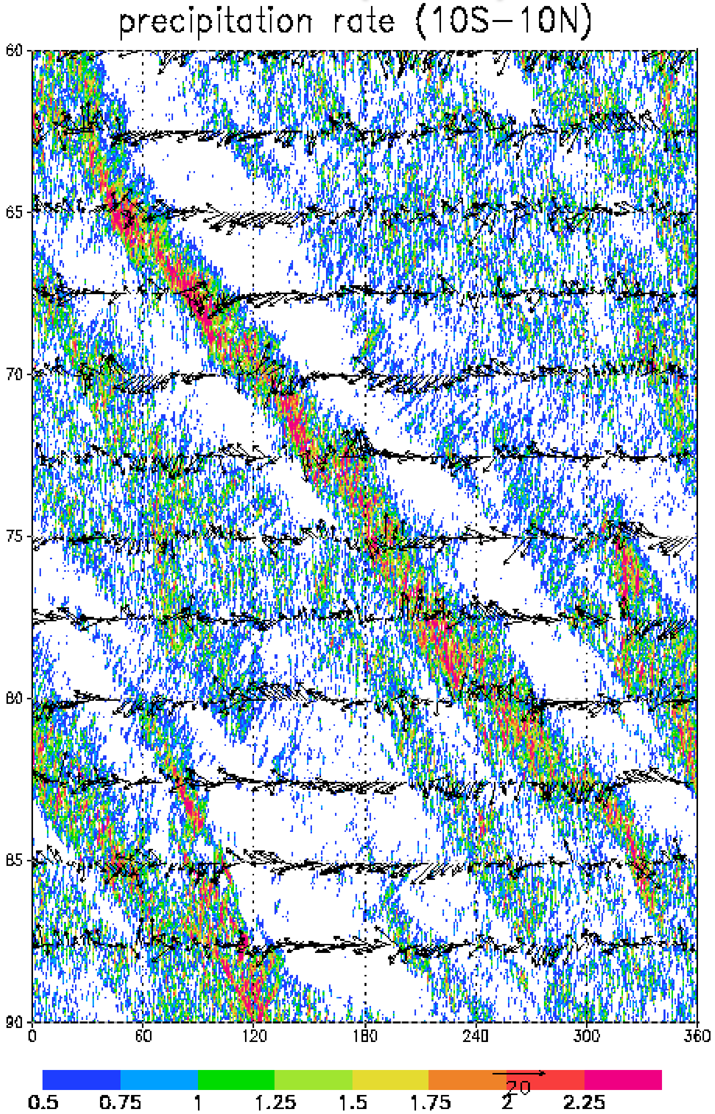
Impact of Resolution on MJO Predictability



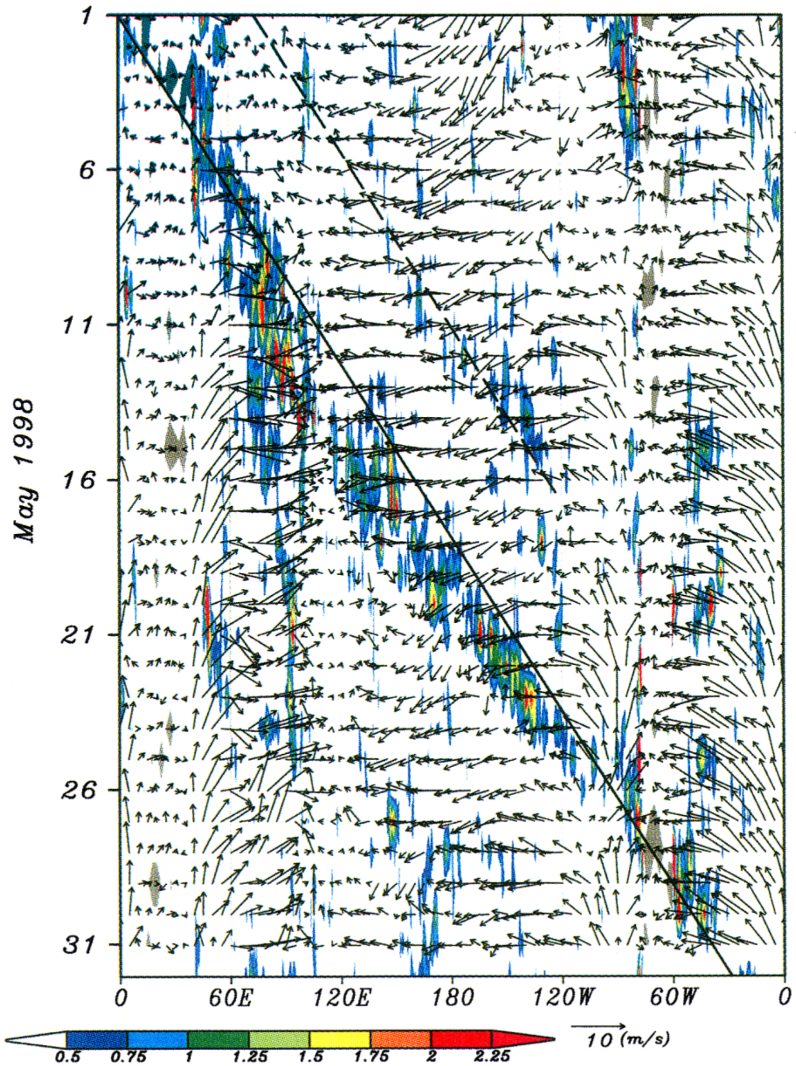
November IC
(1980 – 2000)

Blue: T319
Red: T639

NICAM (7-km)



Obs. (Takayabu et al. 1999)



Matsuno (AMS, 2007)

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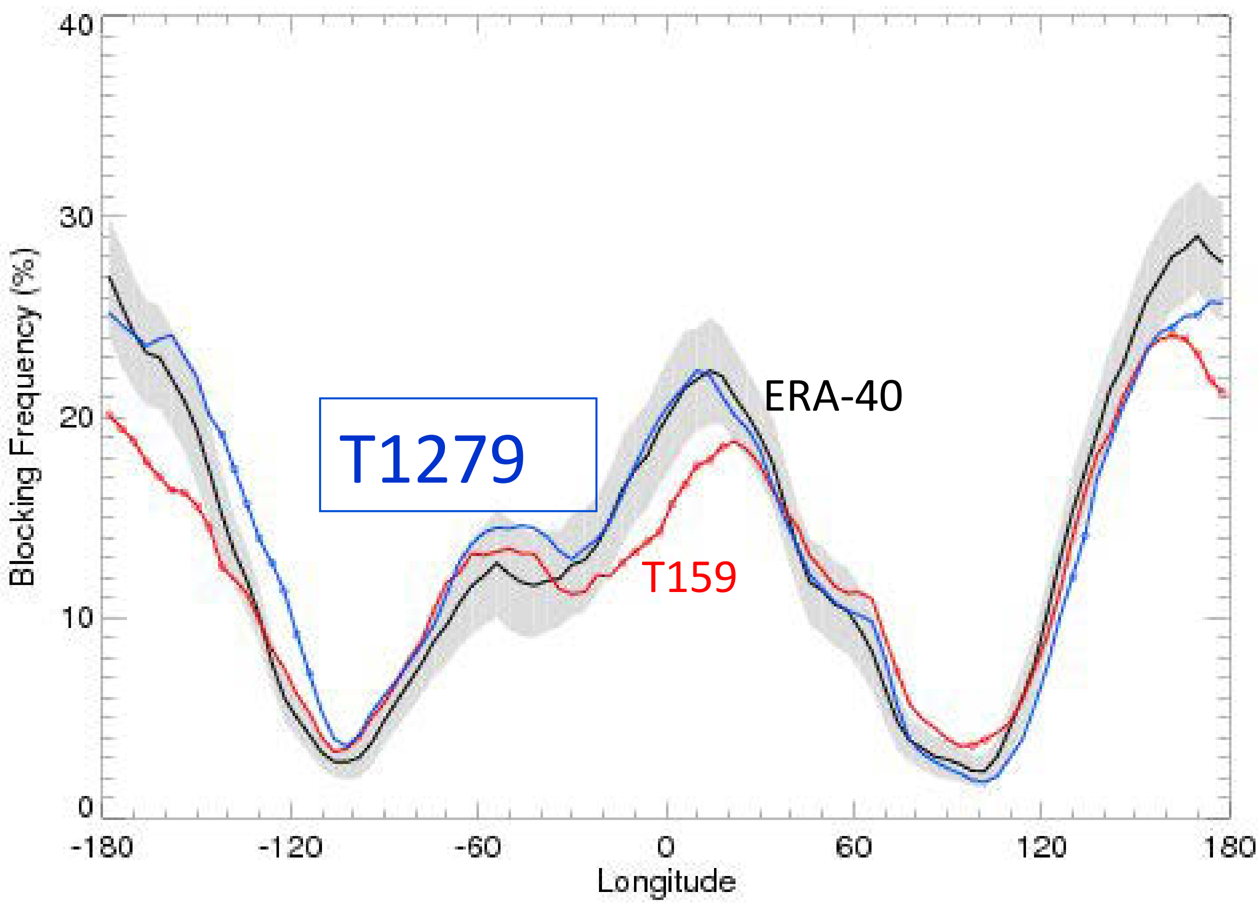
Blocking Frequency

Black: Reanalysis (ERA); Red: T 159; Blue: T 1279 (ECMWF)

(Higher Resolution Model Improves Simulation of Blocking Frequency)



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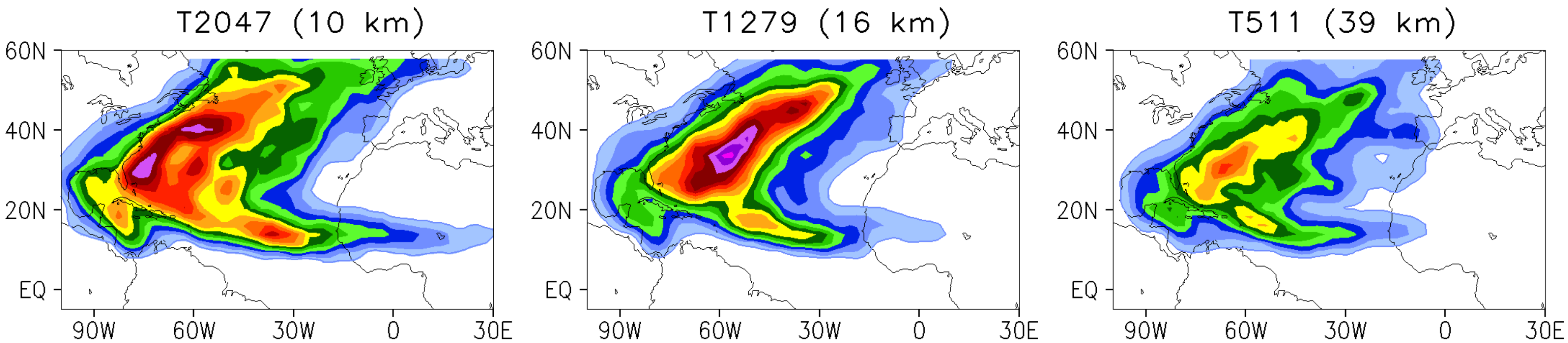
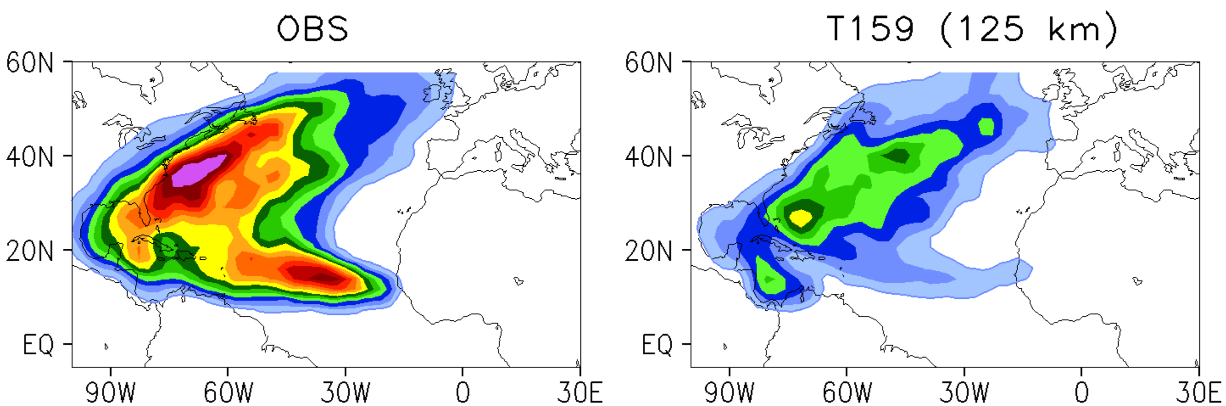
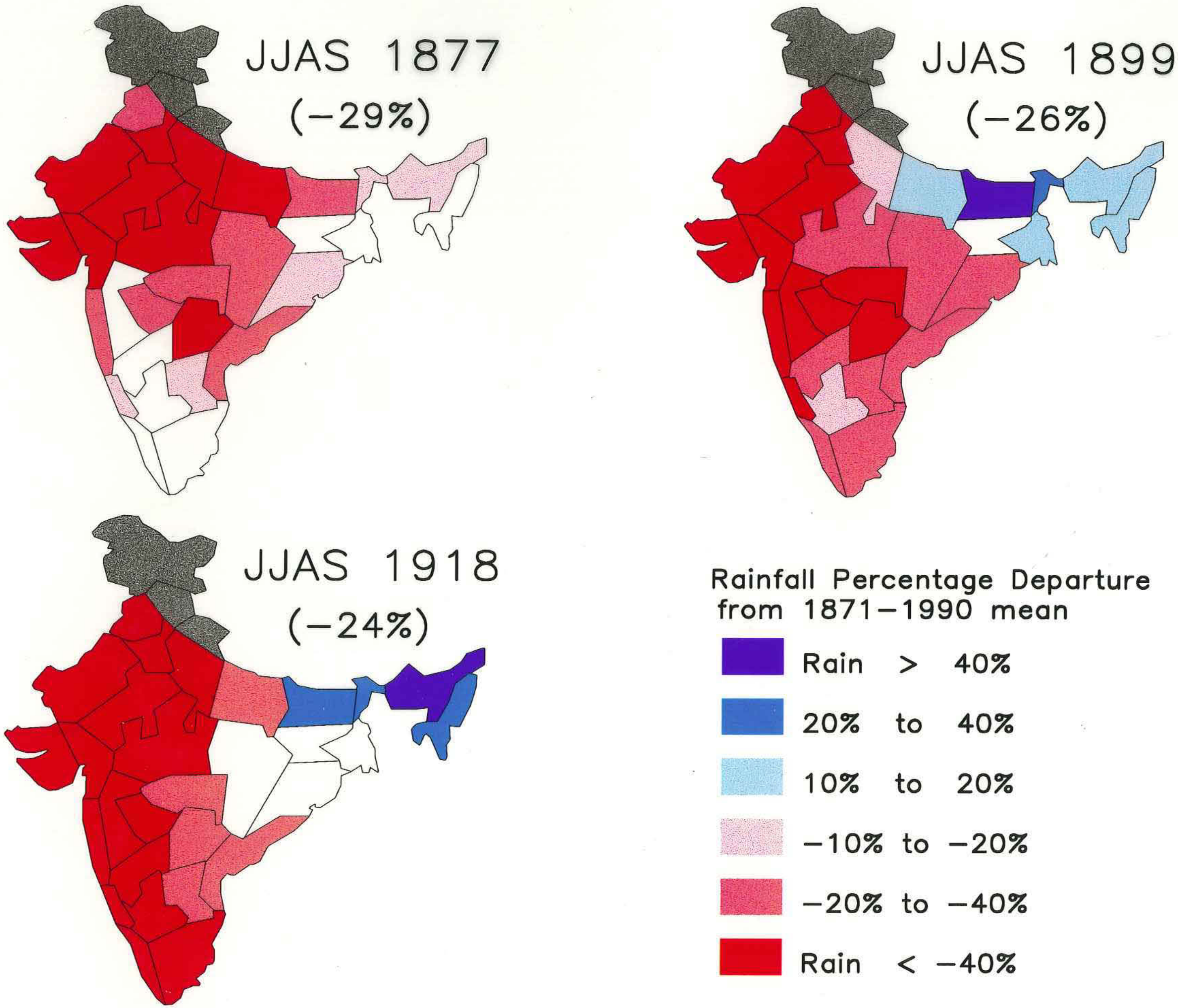
Tropical Cyclone Density Depends on Resolution



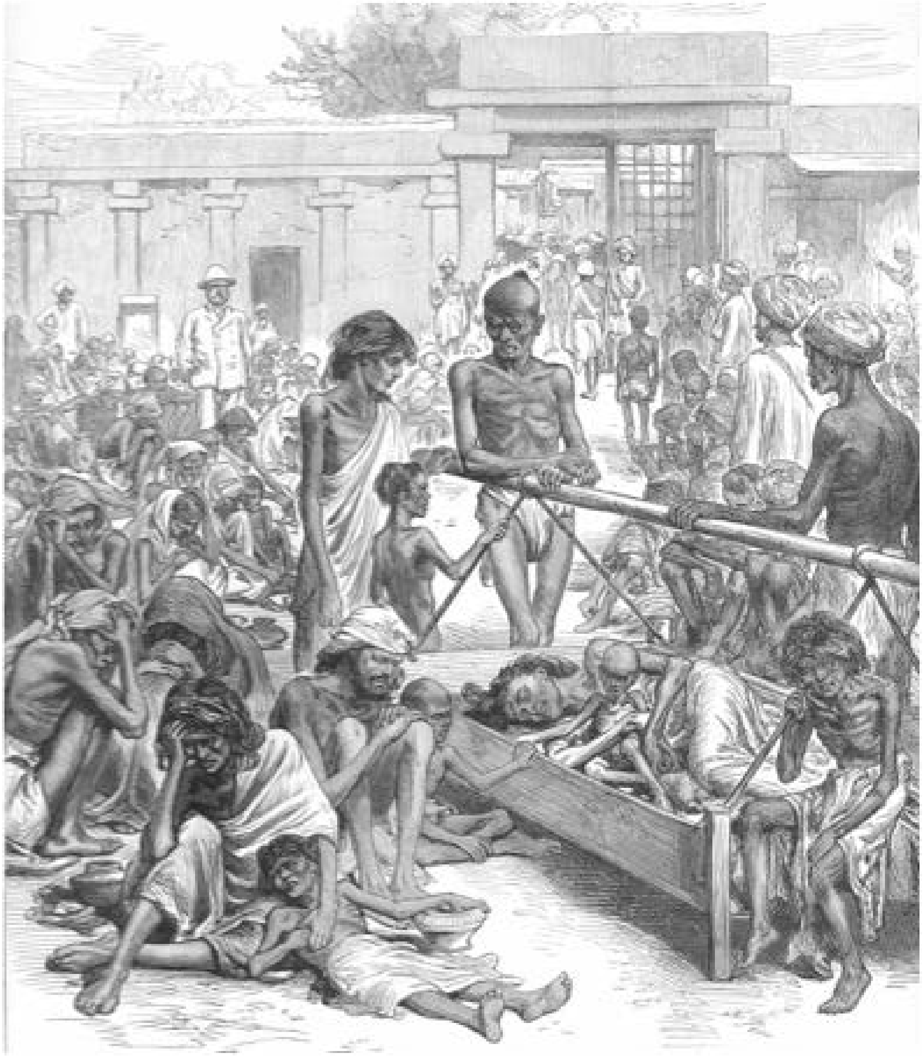


North Atlantic track densities as number density per season per unit area equivalent to a 5° spherical cap for IBTrACS (OBS) and IFS simulations, May-November season of 1990-2008.

Julia V. Manganello and Co-authors, 2012: “Tropical Cyclone Climatology in a 10-km Global Atmospheric GCM: Toward Weather-Resolving Climate Modeling”. *J. Climate*, in print.


JJAS 1877
(−29%)
JJAS 1899
(−26%)
JJAS 1918
(−24%)
Rainfall Percentage Departure from 1871−1990 mean
Rain > 40%
20% to 40%
10% to 20%
−10% to −20%
−20% to −40%
Rain < −40%

Great Famine of 1876-78 (India)



Great Famine of 1876-78 (India)

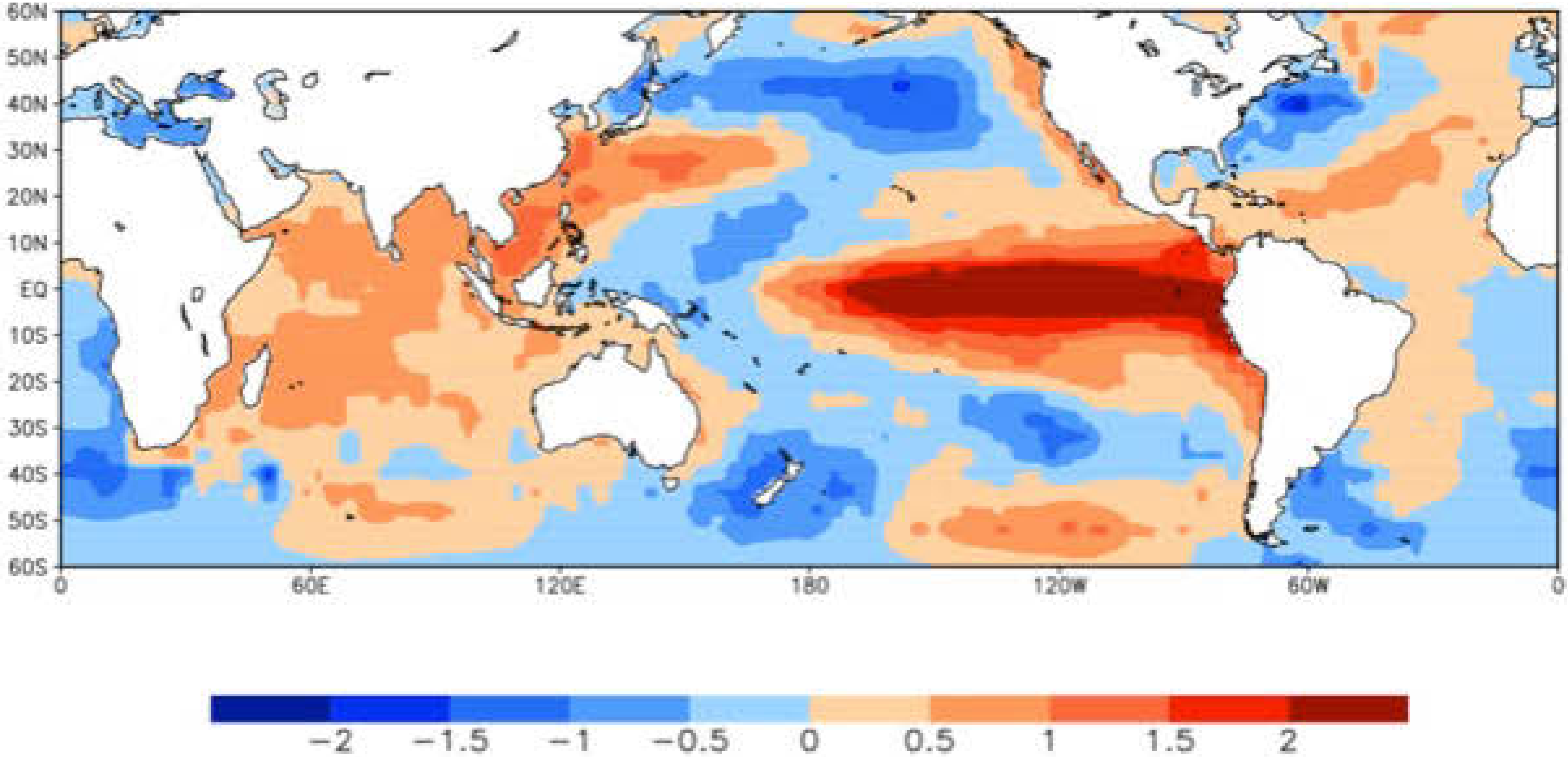
All India Monsoon Rainfall:	-29%
Drought Area:	670,000 km^2
Estimated Deaths (Wikipedia):	5.5 – 8.2 million
Governance:	British Rule

(Lord Lytton exported food from India to England)

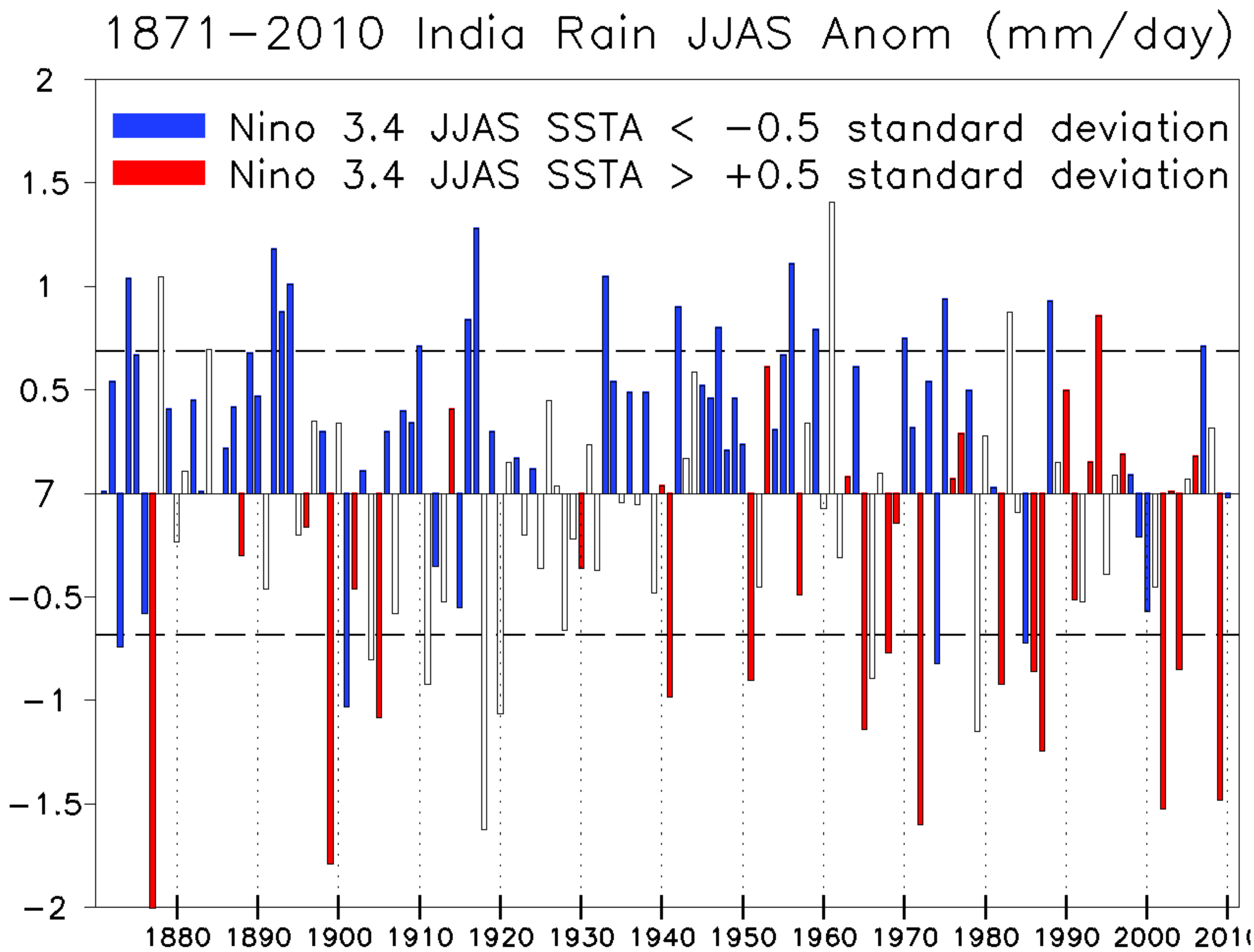
About 13 million people died in China

Late Victorian Holocausts (2001) by Mike Davis
El Nino Famines and the Making of the Third World

SST Anomaly (°C) for DJF 1877



Courtesy of Lakshmi Krishnamurti


1871–2010 India Rain JJAS Anom (mm/day)
Nino 3.4 JJAS SSTA < −0.5 standard deviation
Nino 3.4 JJAS SSTA > +0.5 standard deviation
2
1.5
1
0.5
7
−0.5
−1
−1.5
−2
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
201

Summary (1)

- In spite of the k $^{-5/3}$ spectrum, NWP history (~40 years) suggests: Higher resolution models, improved physical parameterizations, and data assimilation techniques reduced initial errors, and increased the range of predictability.

- Because of a lack of suitable computing and modeling infrastructure (dedicated powerful computers and critical mass of scientists) we are unable to derive the benefits of expensive space and in-situ observing systems, and apply the scientific and technological advances for accurate and reliable regional climate prediction.

Summary (2)

- **Dynamical weather prediction is challenging**: progress takes place slowly and through a great deal of hard work that is not necessarily scientifically stimulating, performed in an environment that is characterized by frequent setbacks and constant criticism by a wide range of consumers and clients

- Nevertheless, scientists worldwide have made tremendous progress in improving the skill of weather forecasts by **advances in data assimilation, improved parameterizations, improvements in numerical techniques and increases in model resolution and computing power**

THANK YOU!

ANY QUESTIONS?

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