An Overview of Tropical Prediction with NCEP's Global Weather and Climate Forecast Systems

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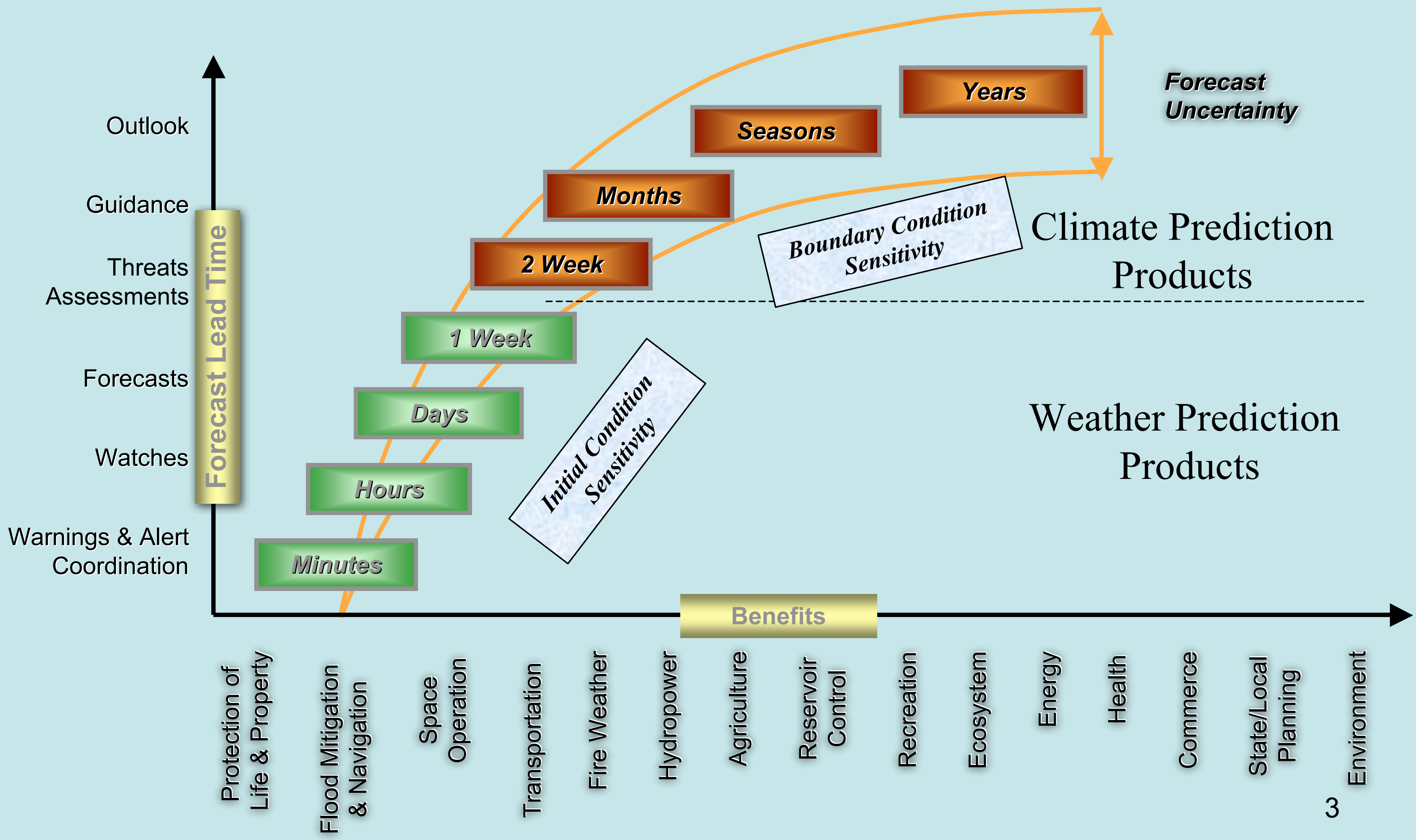
Soo-Hyun Yoo and Jae Schemm (NCEP/CPC)

Overview

- Introduction to NCEP's global forecast systems (current and ~2015)
- Weather → Climate strategy at NCEP
- Current Climate Forecast System (CFS)
- CFS performance
  - MJO
  - Diurnal convection (USA)
- Weather performance
  - Tropical cyclogenesis
  - Mesoscale (convective storm) experiments

NOAA Seamless Suite of Forecast Products Spanning Climate and Weather

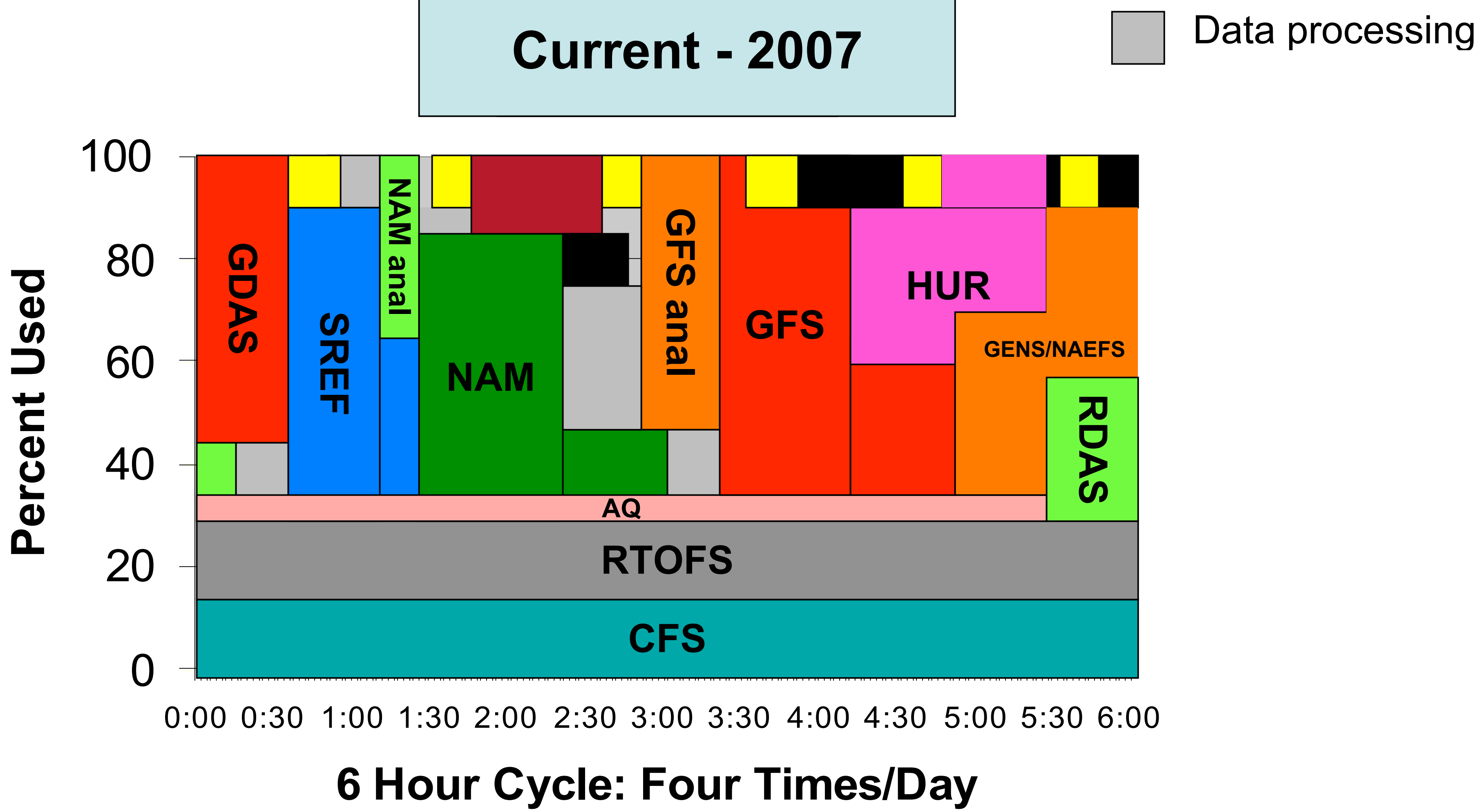


Mission Requirements & Forecast Suite Elements

Suite Elements	Global NWP	Reg. NWP	Fire Wx Rapid Update Hurricane	Air Quality	Global Ensembles	Regional Ensembles	Real Time Ocean	S/I Climate
NCEP	X	X	X	X	X	X	X	X
UKMO	X	X		X	X	X	X	X
ECMWF	X				X			X

NCEP Production Suite
Weather, Ocean, Land & Climate Forecast Systems

Current - 2007



NCEP Global Forecast Suite

CURRENT (2007)

Forecast Product	Number of members per refresh period	Runs/day	Membership refresh period	Horizontal Resolutio	Forecast Length	Initialization technique	Computing Resource ratio*
Daily-hires	1	4	daily	35 km	15 days	GSI	1.0
Weekly	80	80	daily	100	15 days	ET breeding	2.5
Monthly (Development)	56	8	weekly (7 days)	100	60 days	??	1.0
Seasonal	60	2	monthly	200	1 year	Lagged analysis 2x daily	0.44

FUTURE (2015)

- All forecasts will be **Atmosphere-Land-Ocean coupled**
- All systems are **ensemble-based** except daily, high-resolution run
- All forecasts **initialized with LDAS, GODAS, GSI** from GFS initial conditions
- Physics and dynamics packages may vary
  - Anticipated that the weekly forecast will have most rapid implementations and code changes, seasonal configuration may be one (or at most two) versions behind weekly

Future Computing Requirements

Forecast System	Current Horizontal Resolution	Current Vertical Resolution	Future Horizontal Resolution	Future Vertical Resolution	Other factors	Total Compute Factor	Years to Achieve at current constant funding
GFS & GDAS	**35**	**64**	**10**	**200**	**2x physics 10x 4D-Var**	**2680**	**23**
GENS	100	28	10	200		7143	26
NAM	12	60	2	100	2x physics	720	19
SREF	37	48	5	100		844	20
AQ	12	22	2	100	2x particulates 2x in NAM	3927	24
Fire Wx	8	60	1	100	125x fireline (7x nesting)	15360	28
Hurricane WRF	9	42	1	100	2x physics (6x nesting) 1.2 storm surge 1.5 6 storms 1.4 7dy fcsts 10x members	14580	28
CFS-Atm	**200**	**64**	**30**	**200**	**2x physics**	**1852**	**22**
CFS-Ocean	**100**	**40**	**10**	**60**		**1500**	**21**

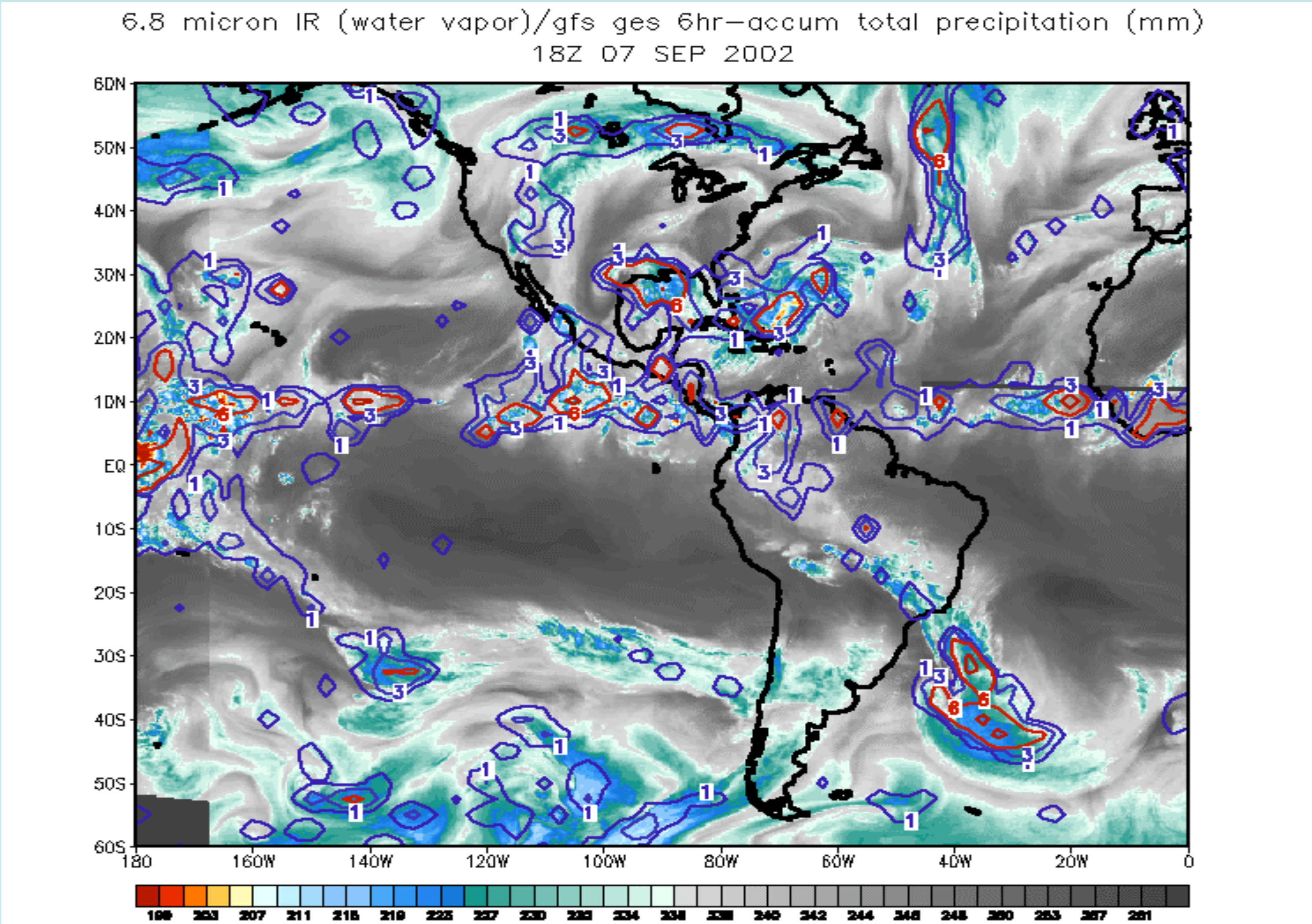
Weather → Climate (S/I) Strategy

- **NCEP Global Weather and Climate Forecast System**
  - GFS (atmospheric model) physical parameterizations
    - Simplified Arakawa-Schubert convection (Pan, 1991)
    - Non-local PBL (Pan & Hong, 1995)
    - **SW radiation (Chou, modifications by Y. Hou, 2001)**
    - **Prognostic cloud water (Moorthi, Hou & Zhao, 2001)**
    - LW radiation (GFDL, AER in operational wx model, 2003)
  - 64 vertical layers
  - Tested against observations daily
    - Easterly waves
    - MJO
    - Mid-latitude precipitation
    - Global cloudiness
  - GFDL MOM-3 ocean model
  - Coupled daily

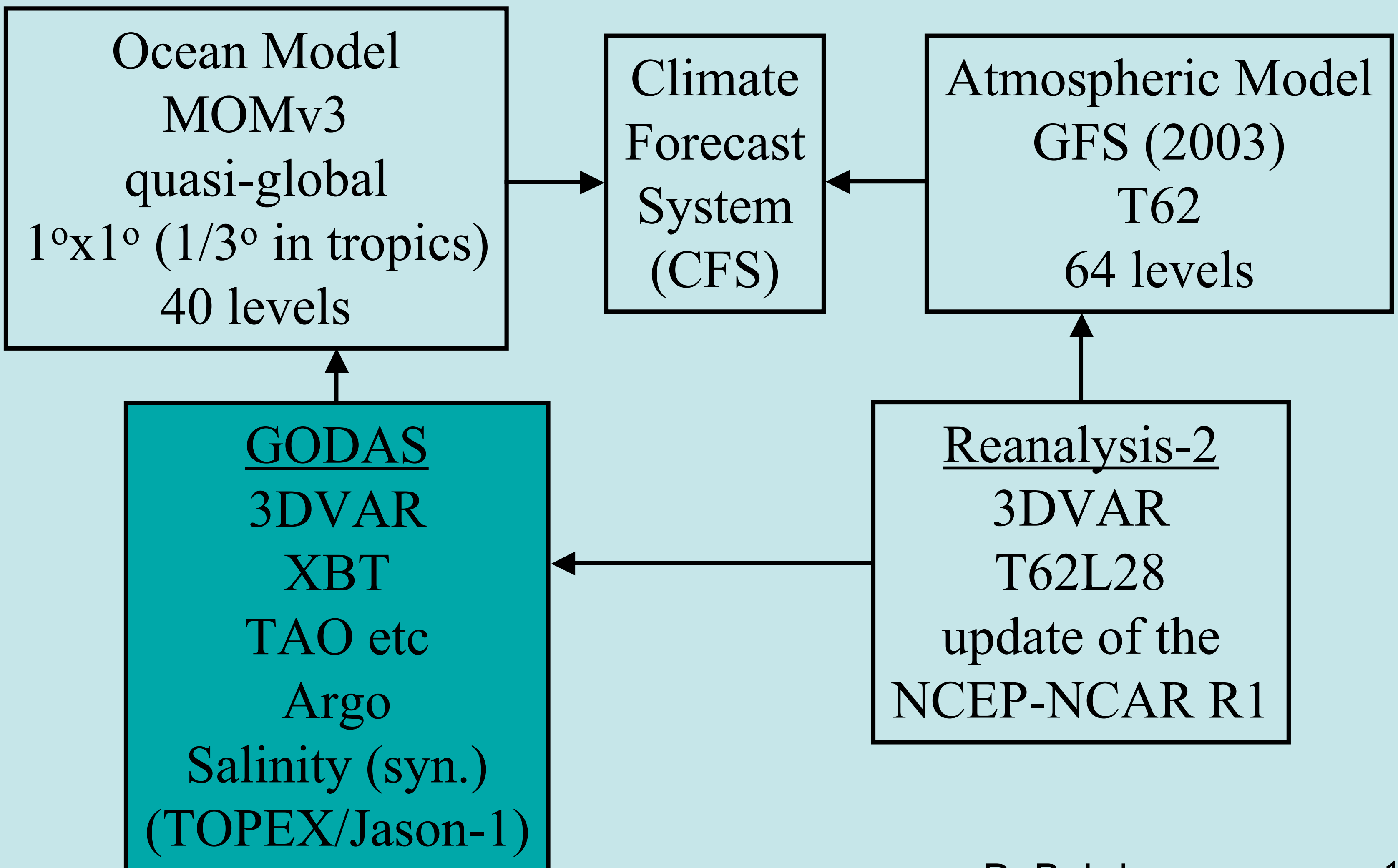
Tropical disturbances

- Since 1995, the GFS system started to produce easterly waves in the forecast and some of the easterly waves deepen into tropical storms
  - Cumulus parameterization (Kuo → SAS)
  - Non-local PBL
- Since 2001, the tropical cyclone genesis false alarm rate greatly diminished
  - Prognostic cloud water
  - Cumulus momentum mixing
- In longer forecasts, the GFS has a very active tropics

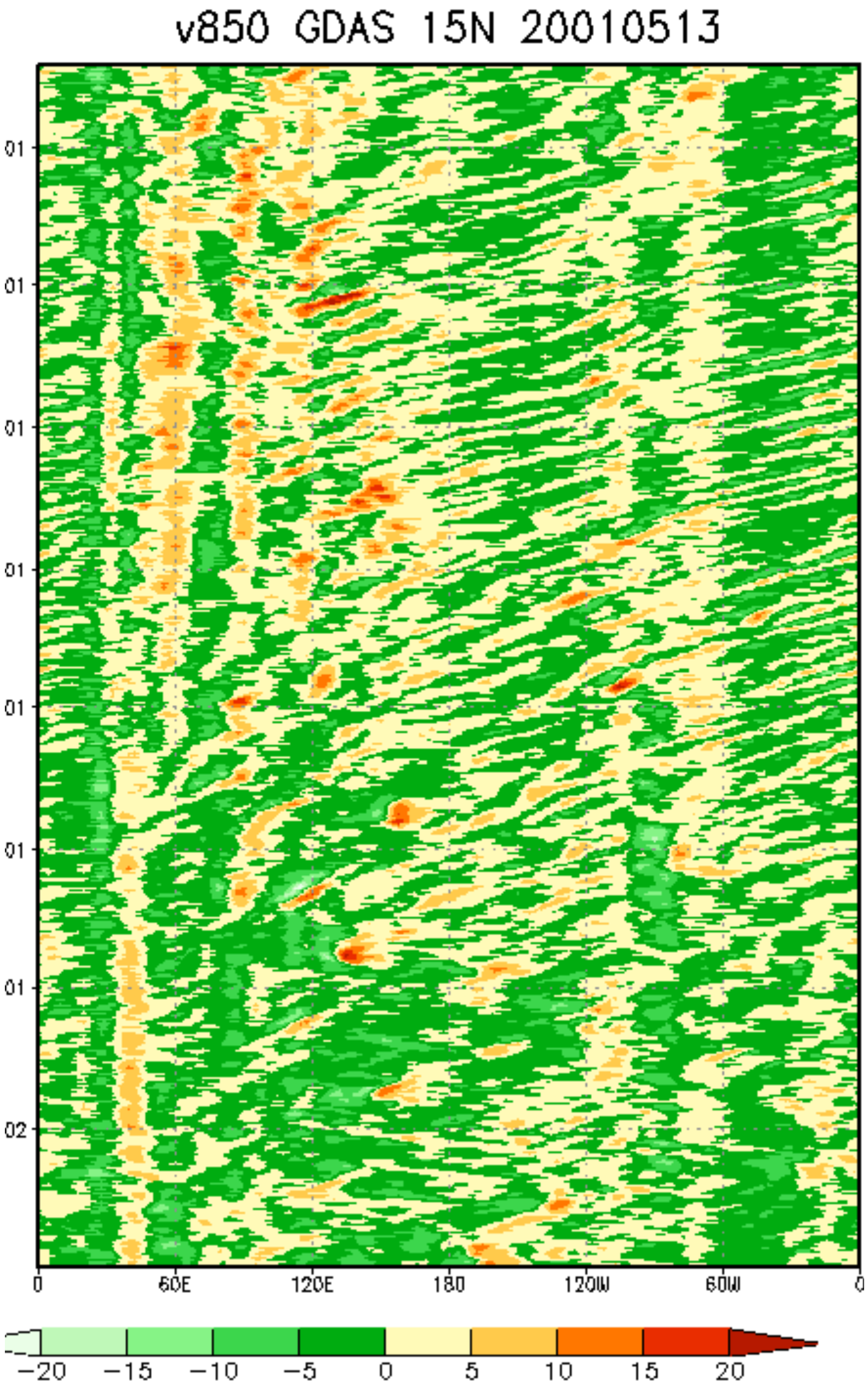
NCEP Global Forecast System
6 hr Forecast and WV Imagery

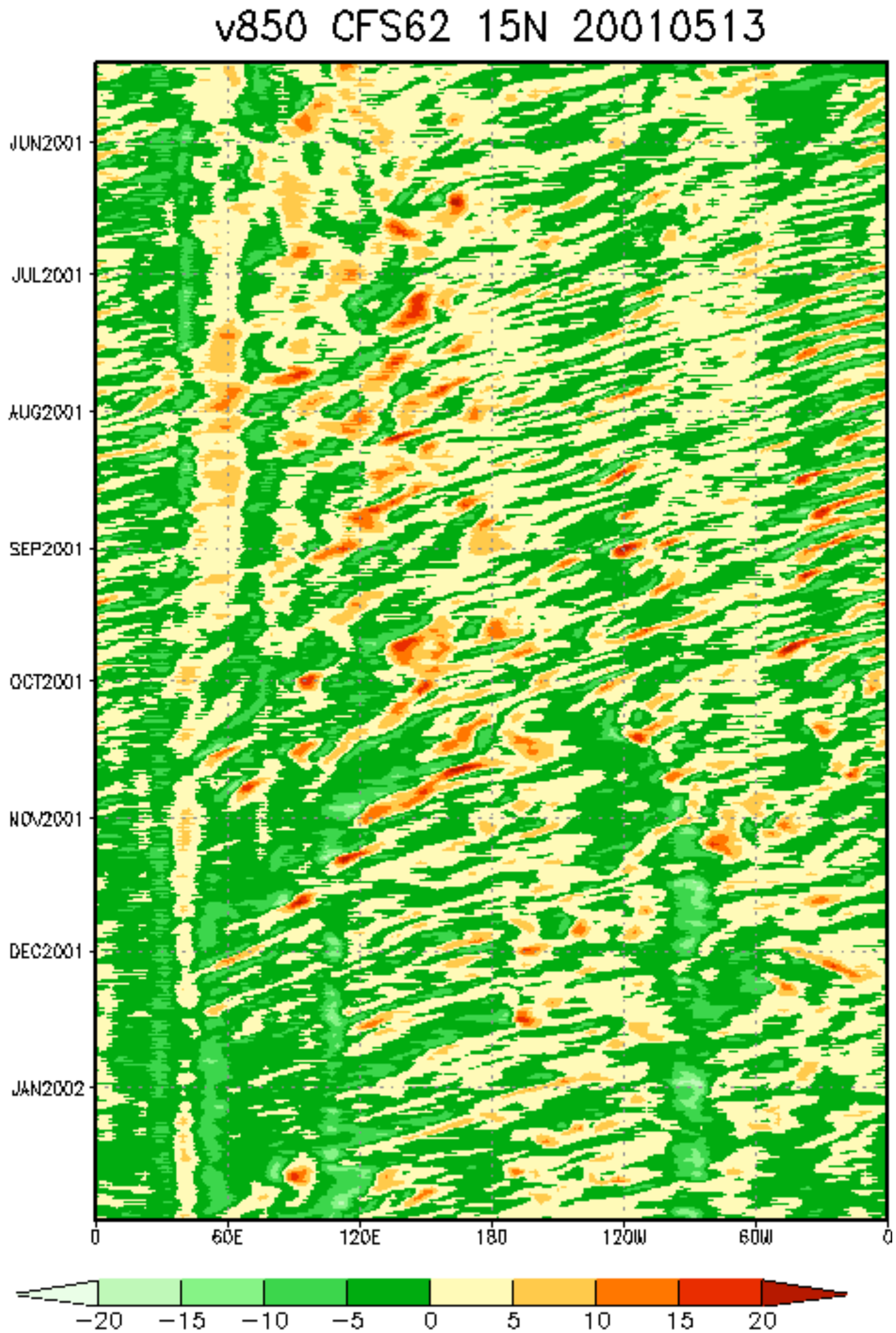


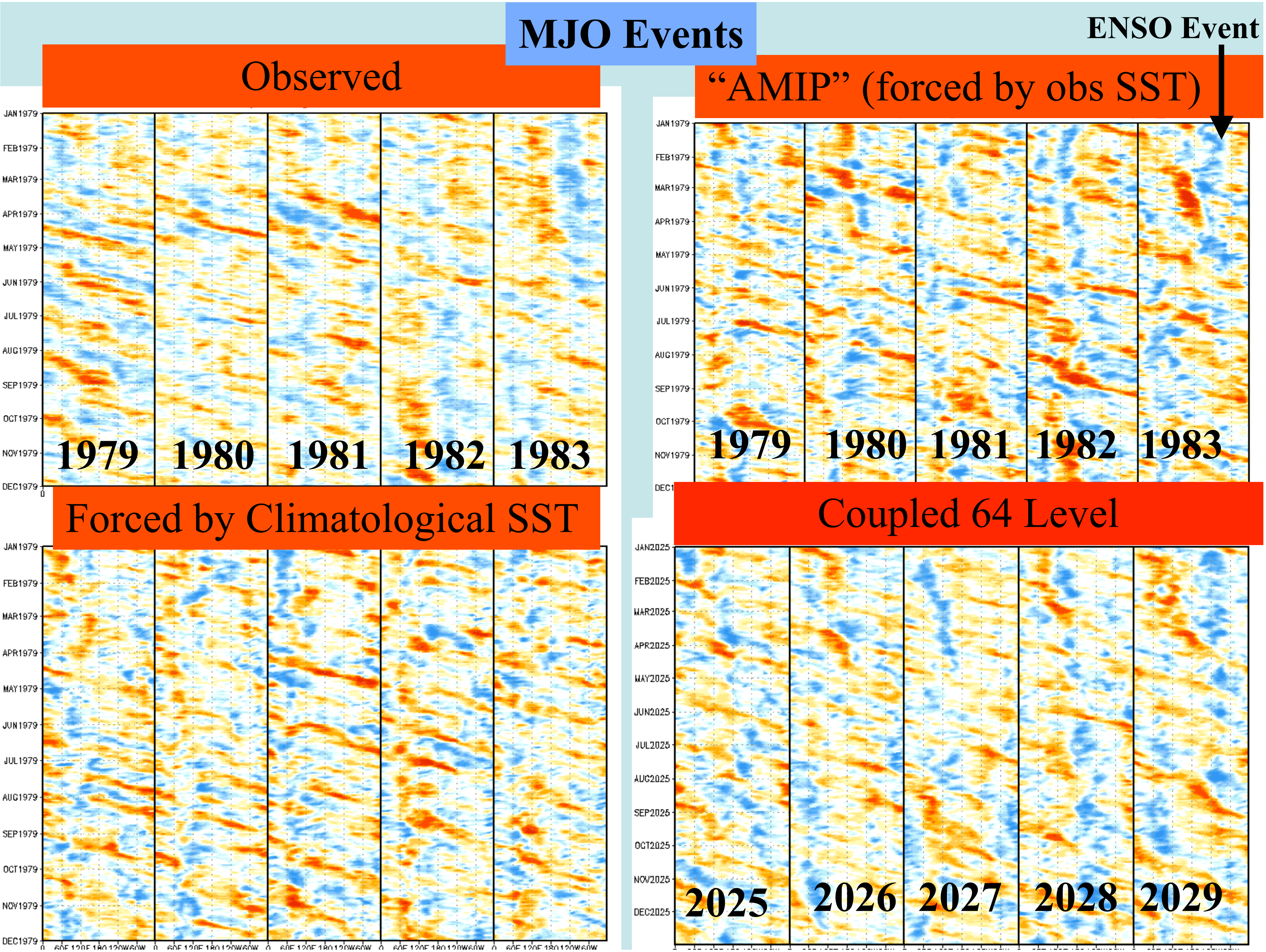
Seasonal to Interannual Prediction at NCEP



D. Behringer


v850 GDAS 15N 20010513
01
01
01
01
01
01
01
02
0
60E
120E
180
120W
60W
0
−20
−15
−10
−5
0
5
10
15
20

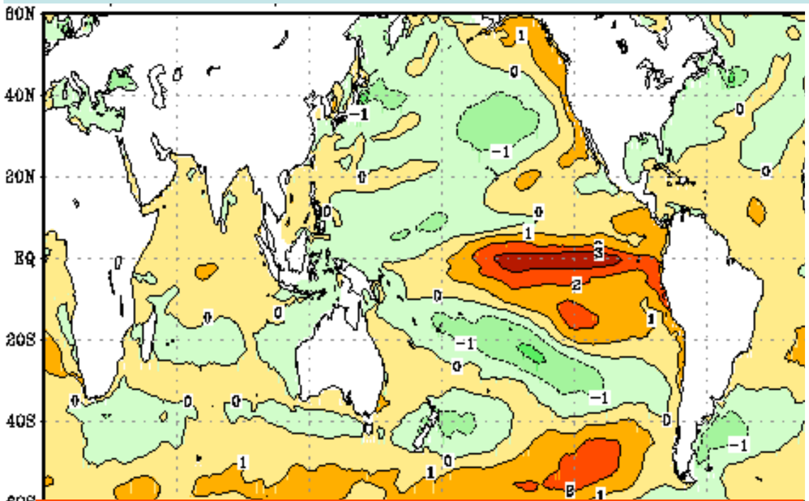

v850 CFS62 15N 20010513
JUN2001
JUL2001
AUG2001
SEP2001
OCT2001
NOV2001
DEC2001
JAN2002
0
60E
120E
180
120W
60W
0
−20
−15
−10
−5
0
5
10
15
20



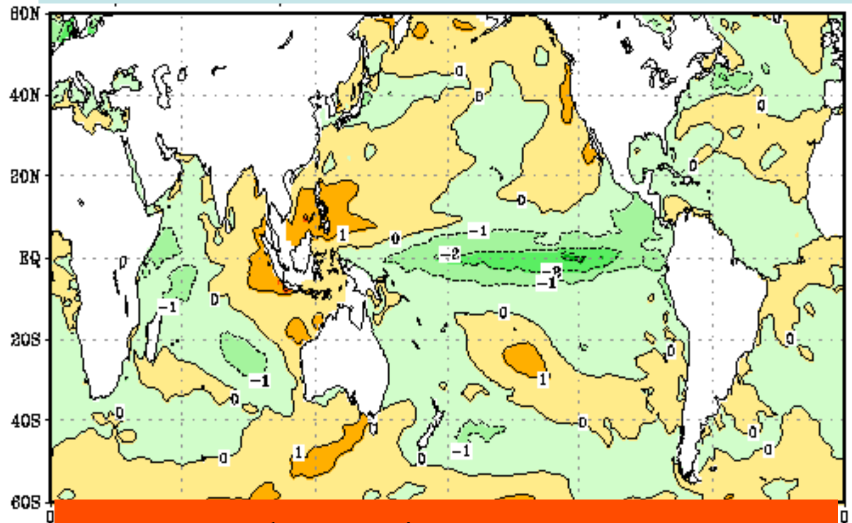
MJO Events
ENSO Event
Observed
1979
1980
1981
1982
1983
"AMIP" (forced by obs SST)
1979
1980
1981
1982
1983
Forced by Climatological SST
Coupled 64 Level
2025
2026
2027
2028
2029

Examples of ENSO events

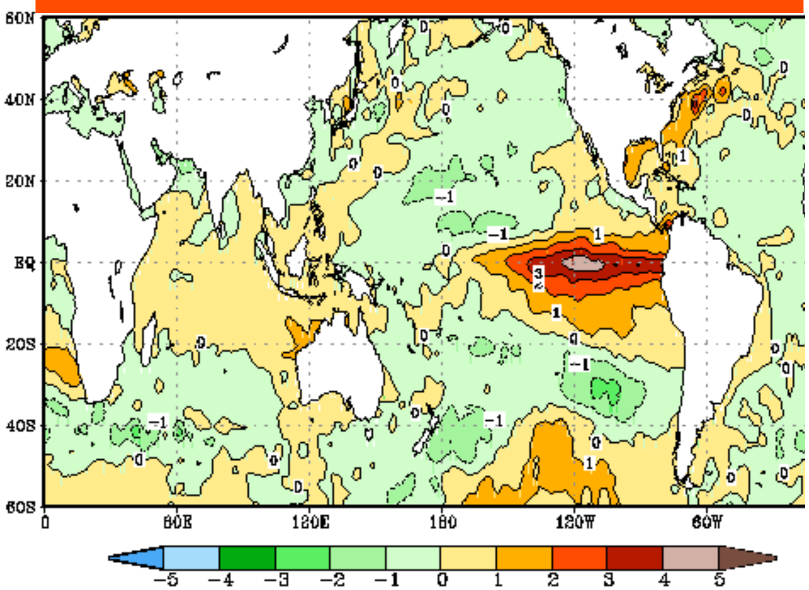
Simulated El Nino 2015-2016



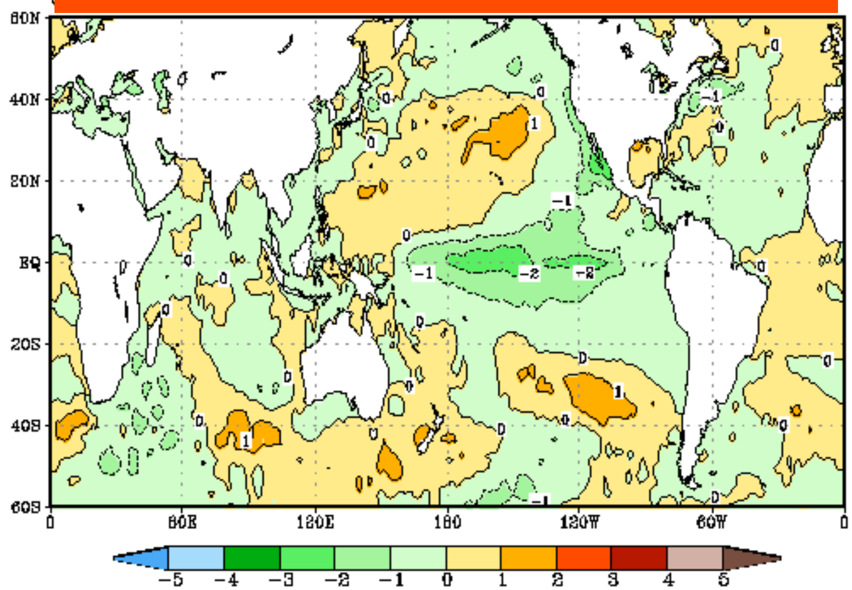
Simulated La Nina 2017-18



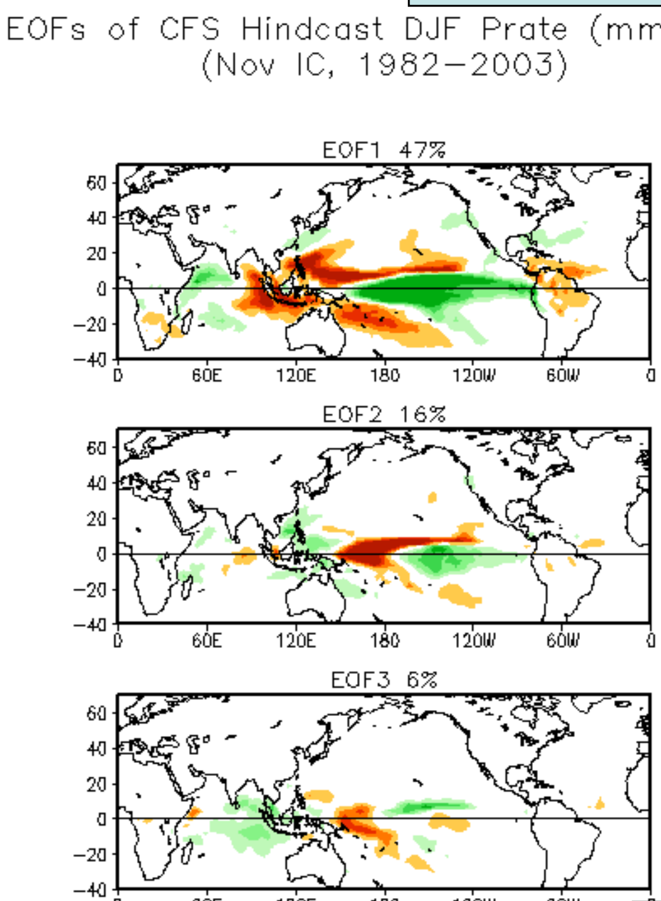
Real El Nino 1982-1983



Real La Nina 1988-1989



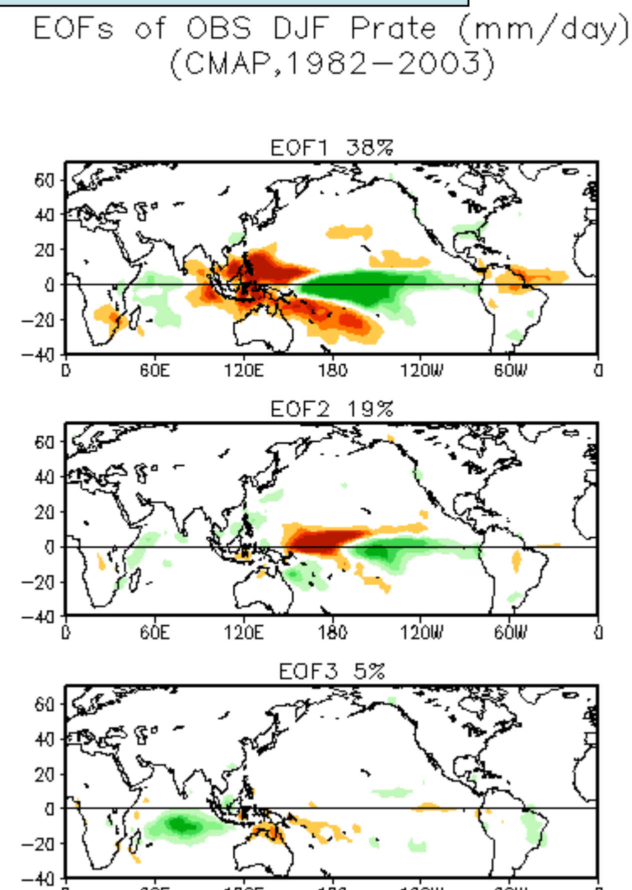
Tropical Precipitation Performance



AC=.86

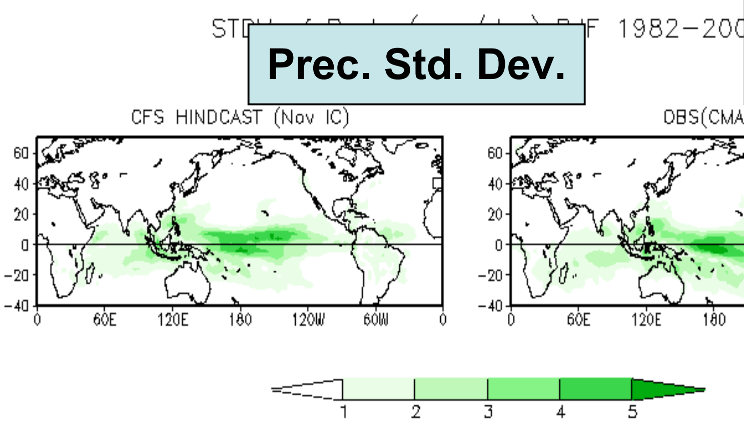
AC=.80

AC=.43

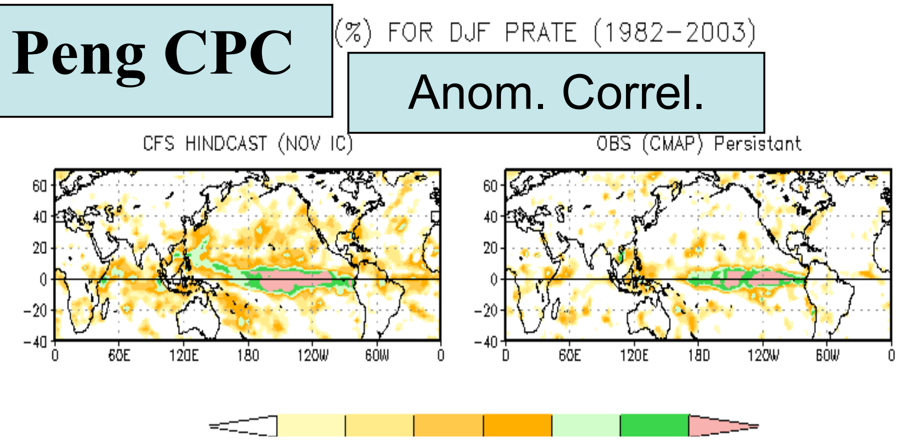


Peitao Peng CPC

Prec. Std. Dev.



Anom. Correl.

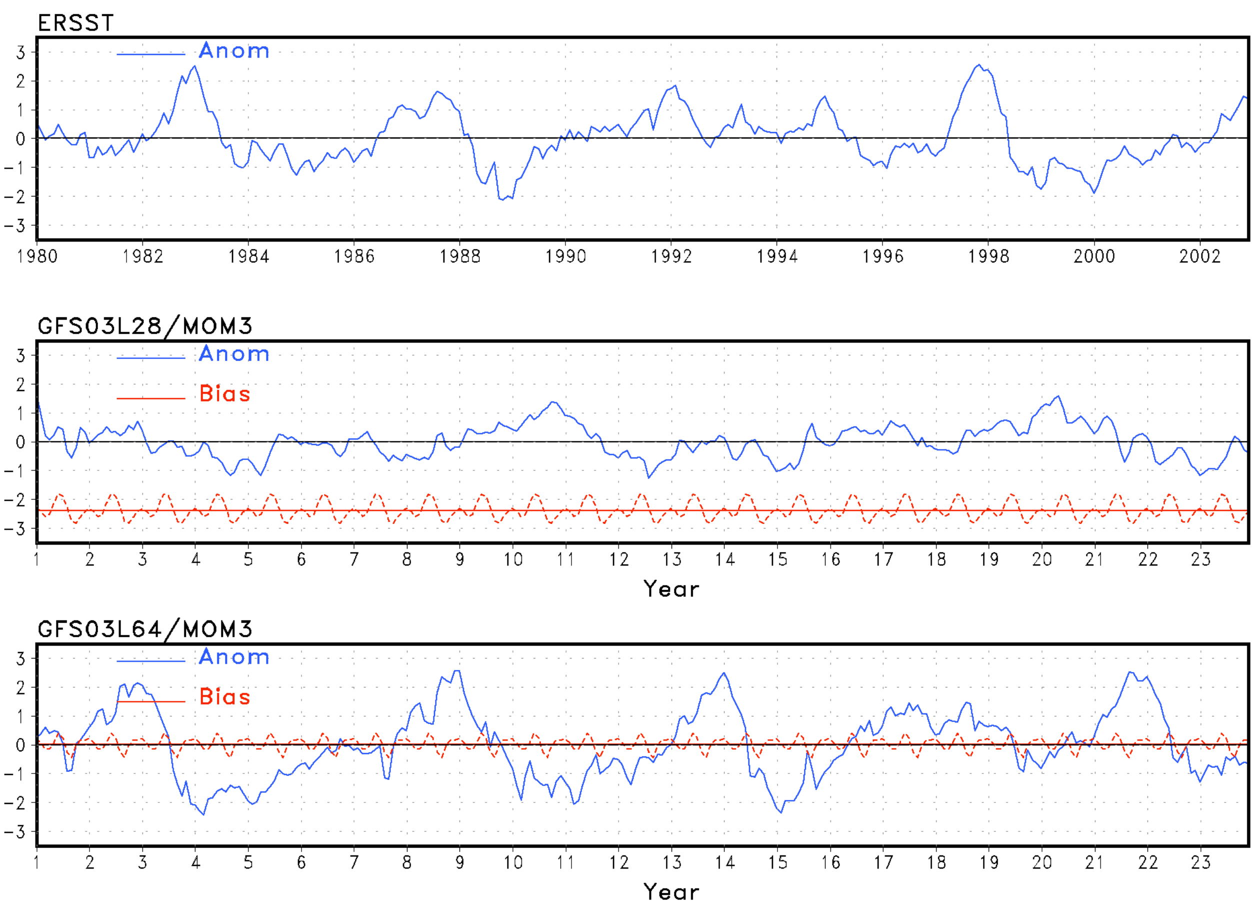


CFS (fully coupled) Simulations

64 Level (0.2 hPa) vs 28 Level (2.0 hPa) Atm.

ENSO SST cycles

Nino 3.4 SST Anomalies



Observed

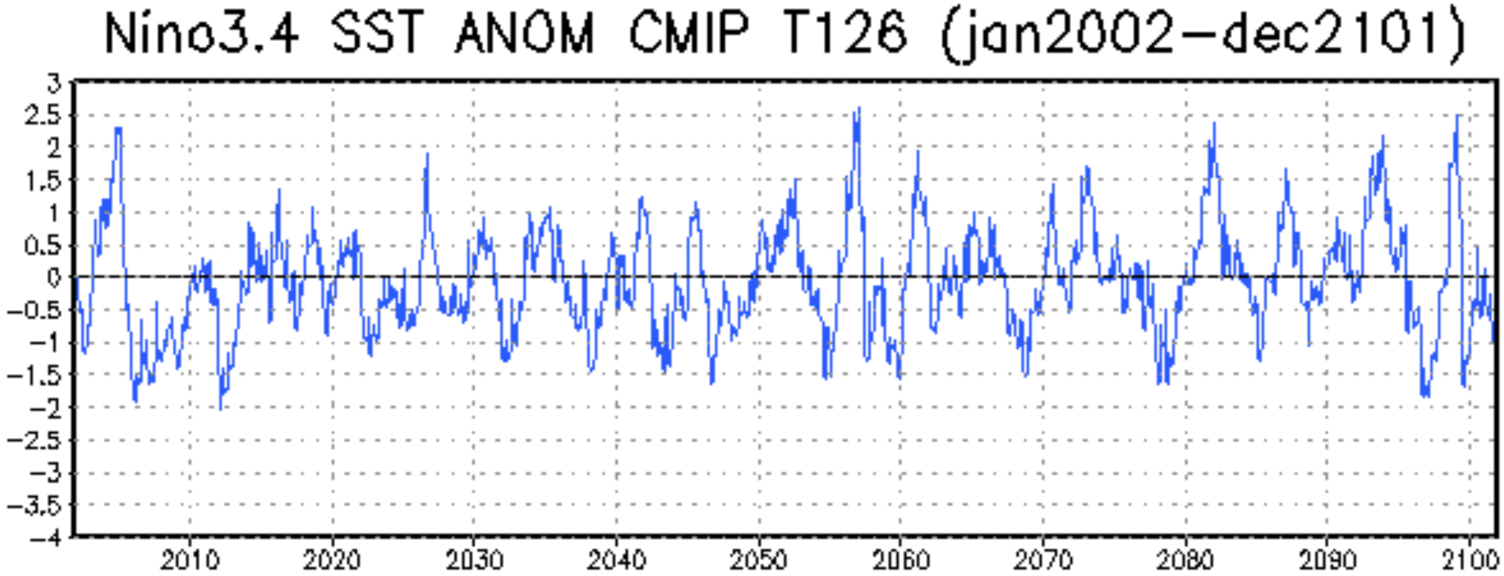
28 Level Atm

Coupled

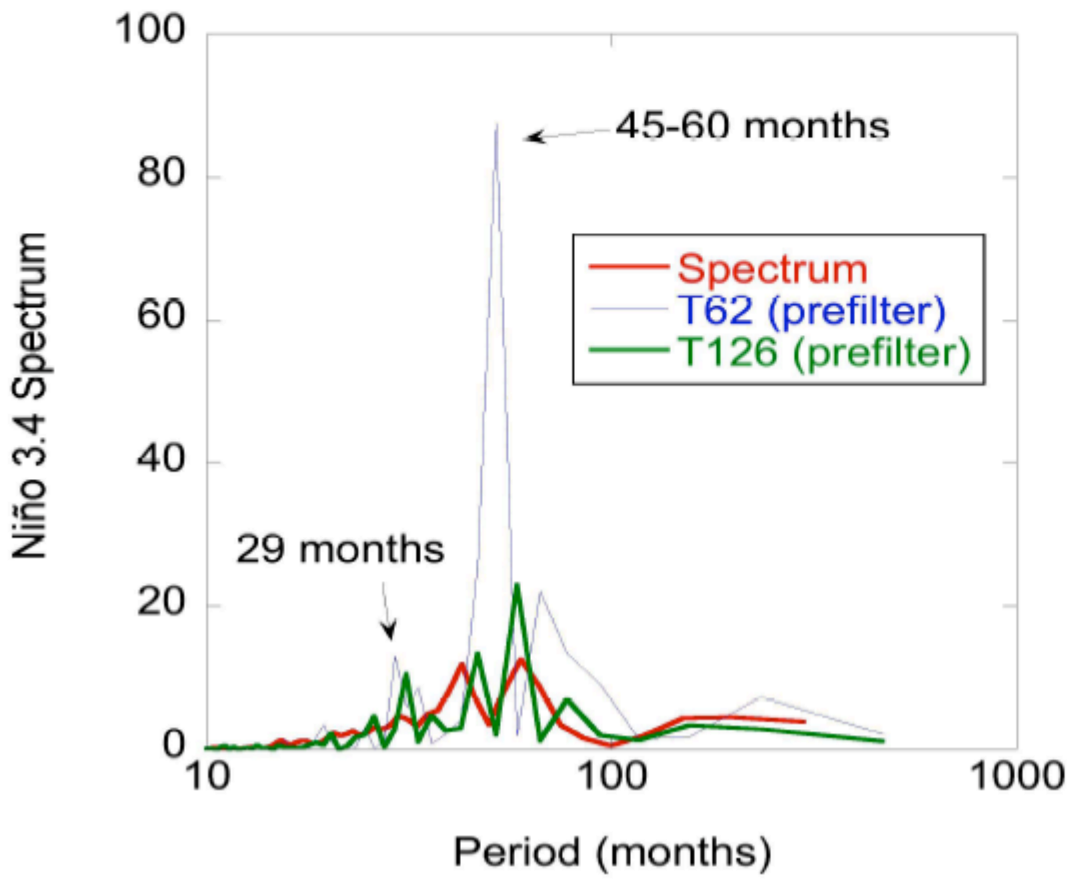
Red: monthly bias

64 Level Atm

CFS simulations using a T126 version of the model



Niño 3.4 spectra: Red: COADS. Blue: T62. Green: T126.



Conclusions: **The resolution of the atmospheric component of the model matters a lot! The T126 improves the El Niño spectrum**

Forecasting Tropical Intraseasonal oscillations with the CFS

Augustin Vintzileos and Hua-Lu Pan

UCAR and EMC/NCEP/NOAA

Part I: Hindcasts with the CFS126 version of operational seasonal Climate Forecast System

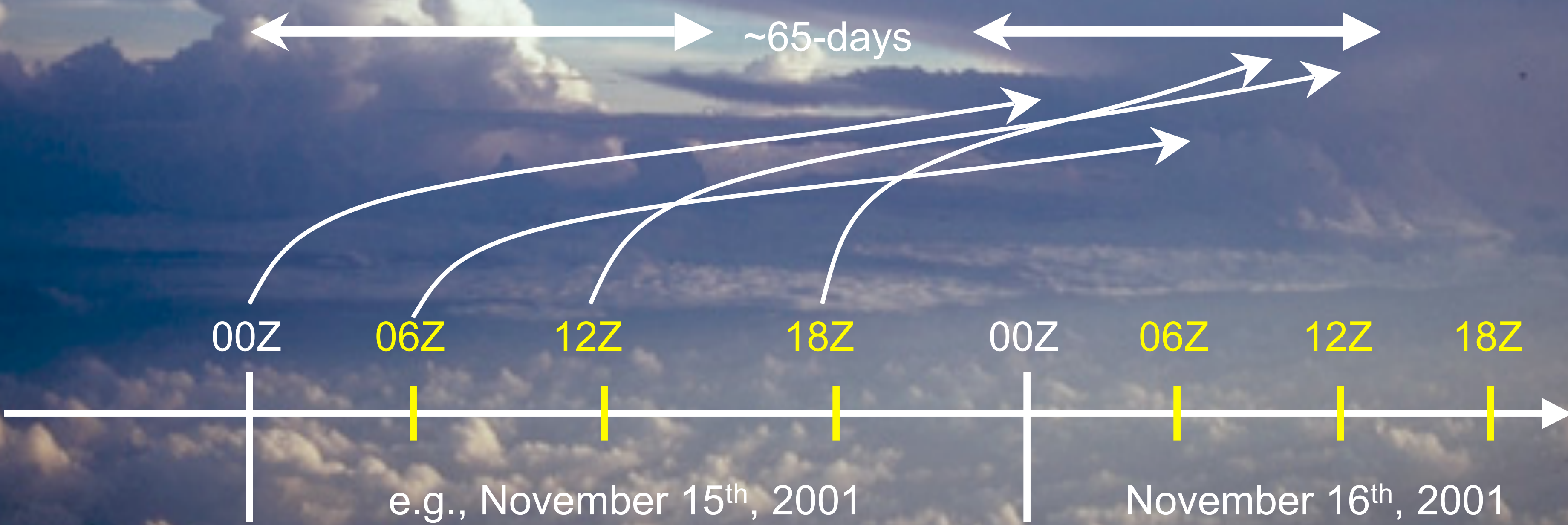
Retrospective forecast design:

May 7th to July 15th and November 7th to January 15th from 2000 to 2004.

4 forecasts each day.

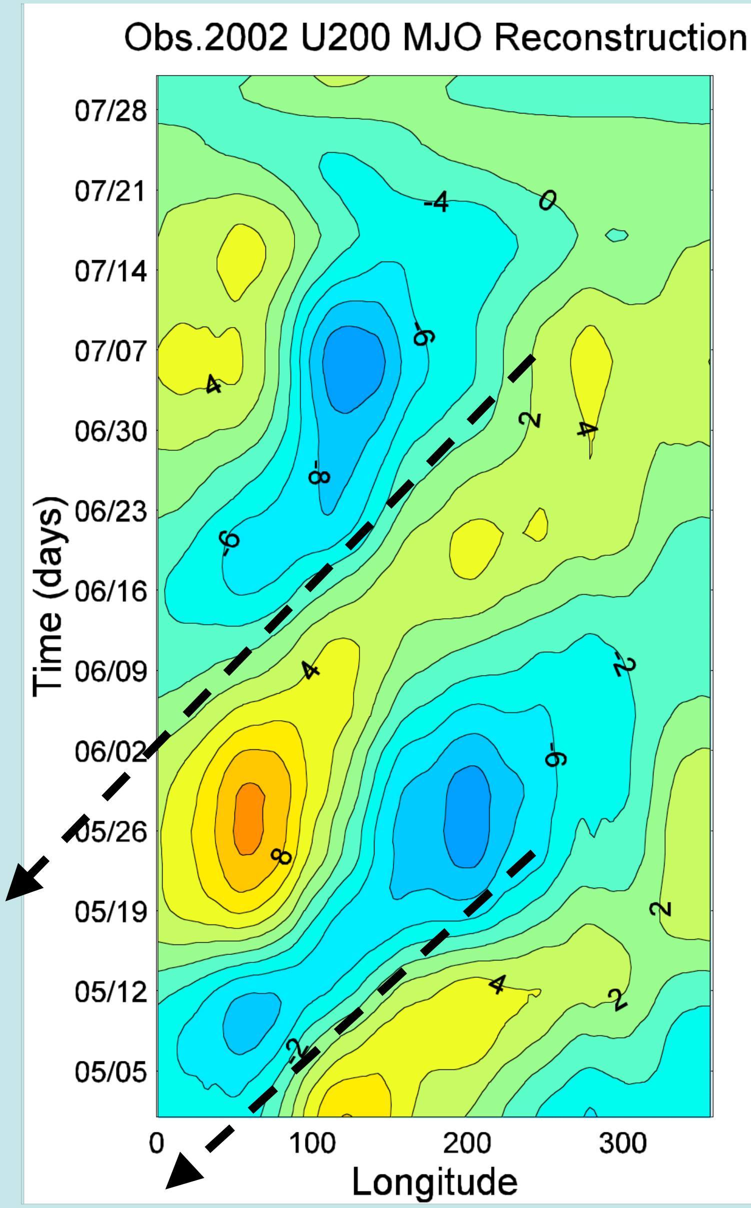
Forecast leads: day 1 to day 65

Verification:
Tropical Intraseasonal Oscillation index
- U200 averaged between 20S and 20N
- Projected to the <u>observed</u> EOF modes



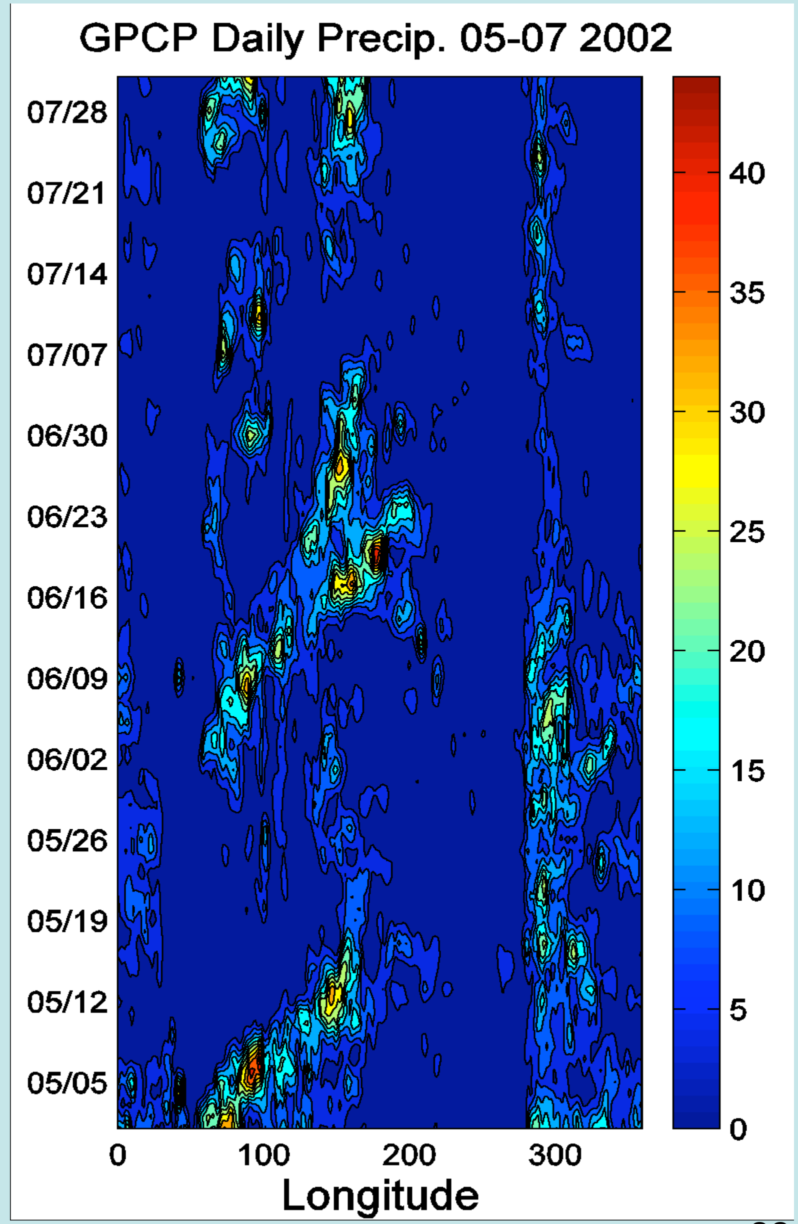
Initial conditions: ***Atmosphere, Land*: from Reanalysis 2, *Ocean*: from GODAS**

Reconstructed U200 vs. GPCP Precipitation, May – July, 2002



Upper level diverg ence

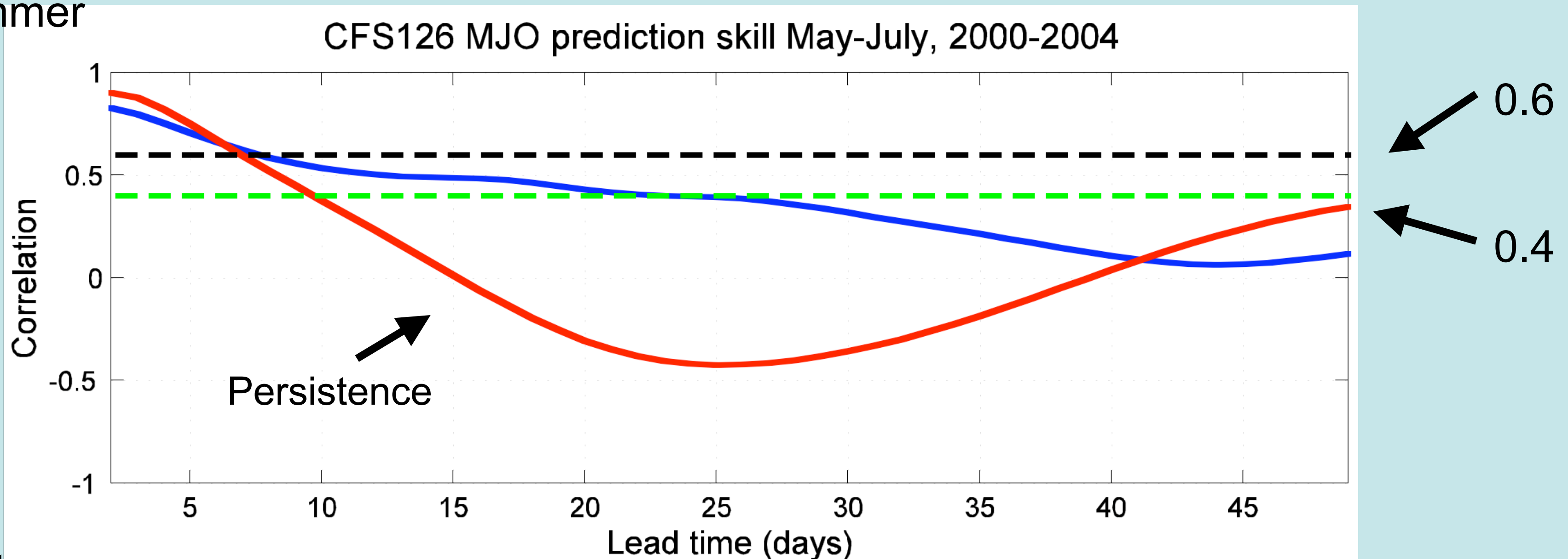
20S-20N averaged, filtered U200 anomaly field



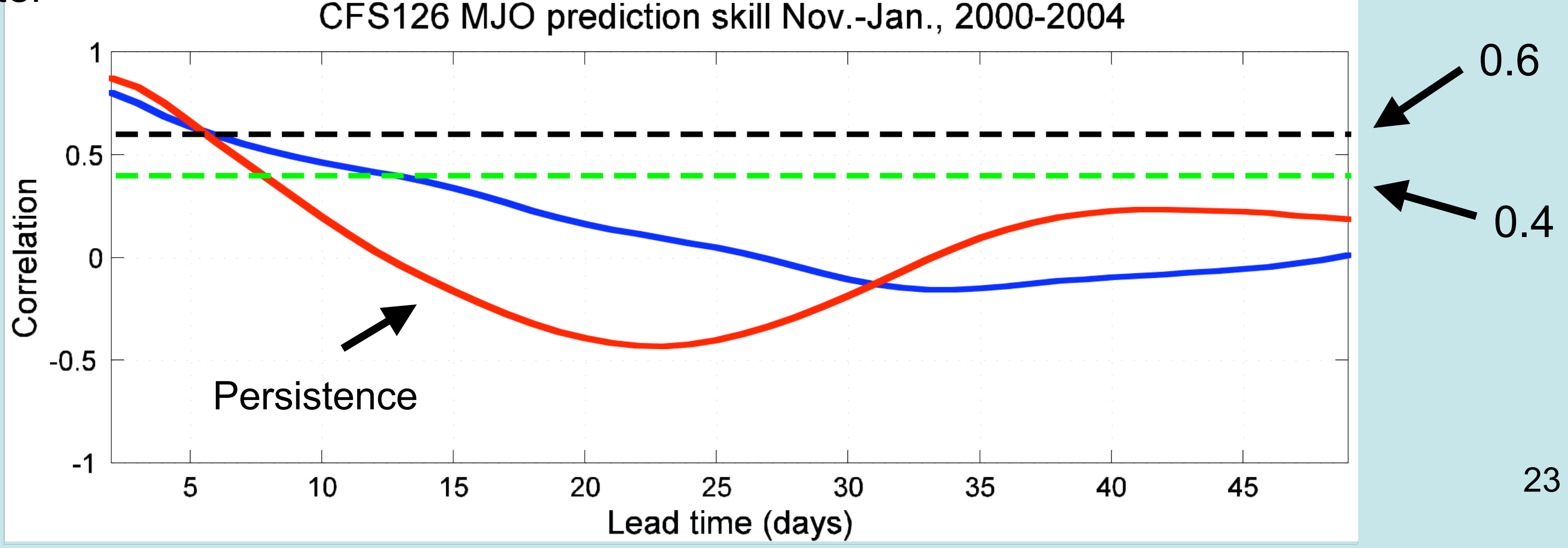
5S-5N averaged, total unfiltered precipitation field

Pattern correlation for 2000-2004

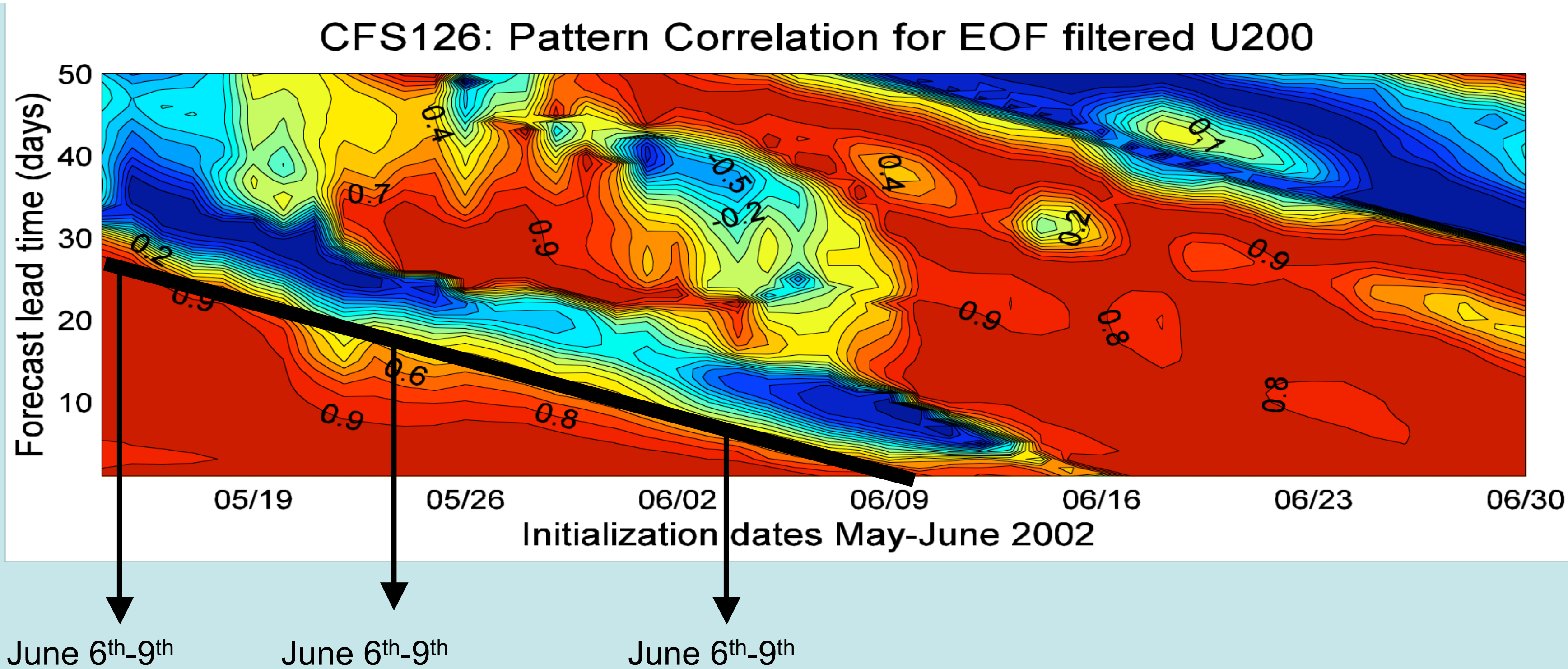
Summer



Winter



The Predictability Barrier



6-9 June: MJO maximum activity crosses “the Maritime Continent”

Part II: Impact of initial conditions and resolution

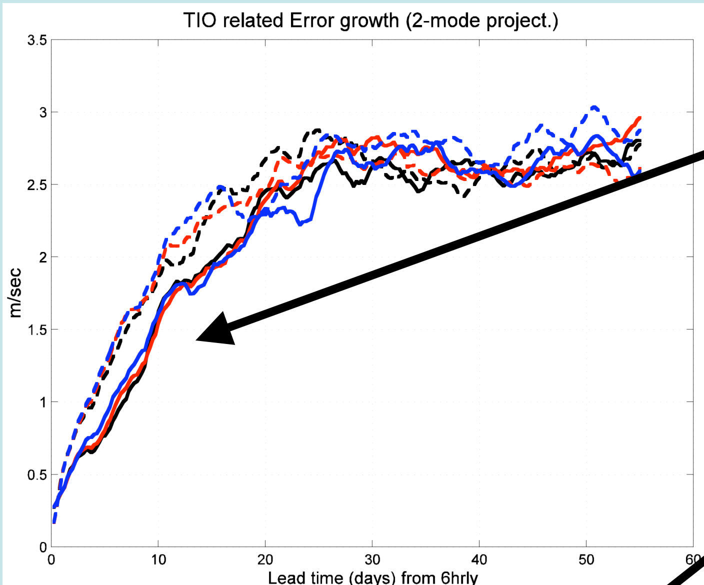
- Use the most recent version of GFS at T62, T126 and T254 and the standard MOM-3 ocean model initialized by GODAS

- Initialize with current GDAS and CDAS-2

- 60-day forecasts initialized every 5 days from May 23rd to August 11th from 2002 to 2006 a total of 105 hindcasts

- Use the same Tropical Intraseasonal Oscillation index: U200 averaged between 20S and 20N and projected to the observed EOF modes.

RMS Error Growth



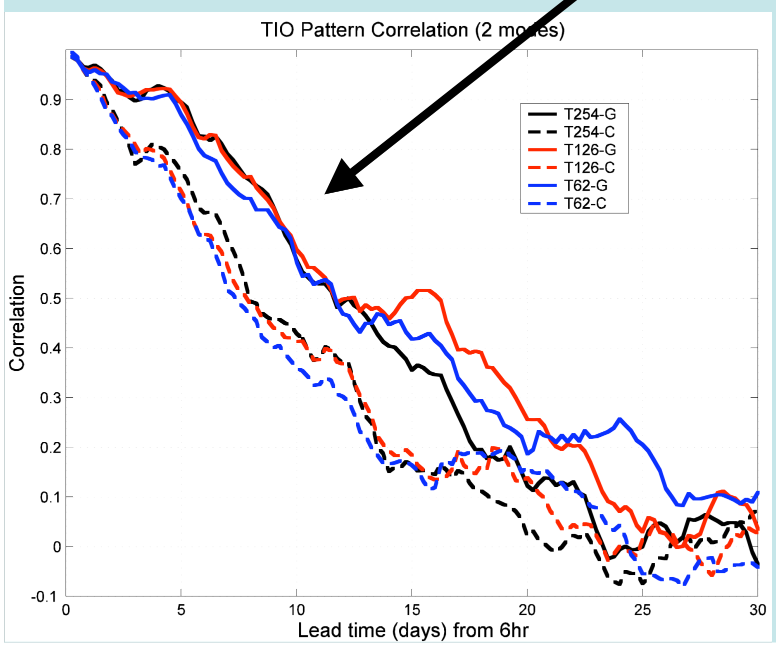
Resolution does not affect skill.

Forecasts initialized by GDAS are better (a gain of ~3-5 days).

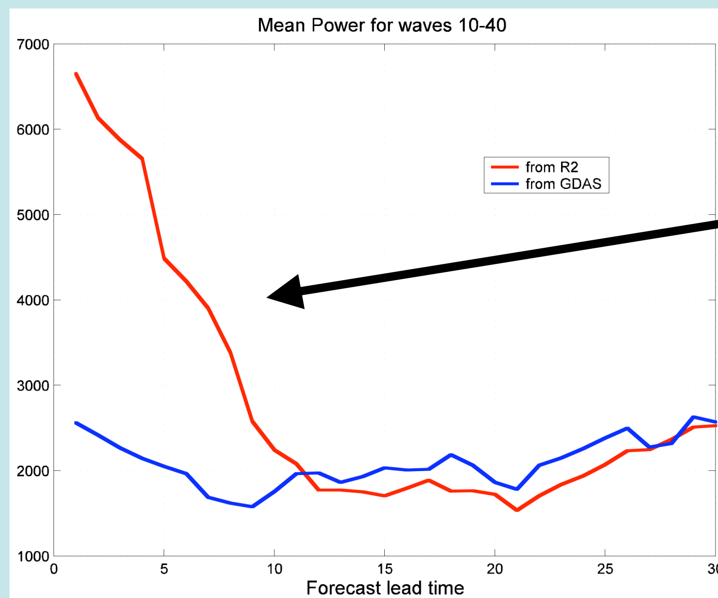
T254
T126
T62

GDAS
CDAS-2

Pattern Correlation



Time evolution of mean energy at wave numbers 10-40 when CFS is initialized by R2 (red) or by GDAS (blue).



drift

Conclusion

- Initializing with current GDAS clearly improves individual forecasts of the Tropical Intraseasonal Oscillation as defined by index by ~3-5 days.
  - May be due to better handling of the predictability barrier.

- The most crucial point: **understand what happens when the enhanced convection phase of the TIO crosses the Maritime Continent**

- Ensemble forecast should increase the skill even more (as indicated by the skill of operational CFS-126)

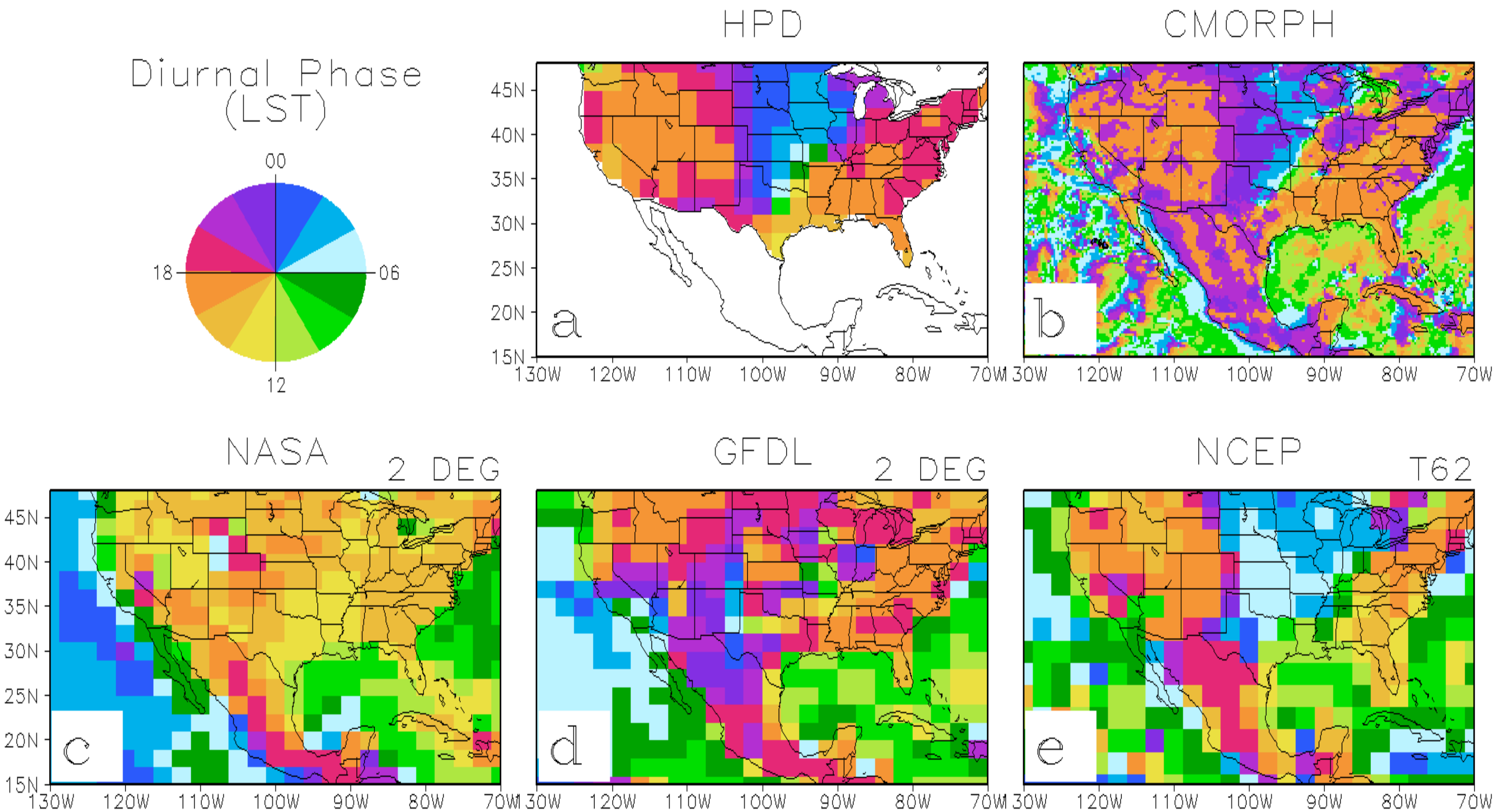
Diurnal Convection (Trigger function)

- Most mass-flux schemes use closure as trigger … Whenever the column is unstable ‘enough’, convection starts
  - Modifications to delay onset mostly use environmental conditions such as RH
- Mesoscale modelers look at parcel buoyancy when lifting a parcel through inversion

Trigger in the GFS

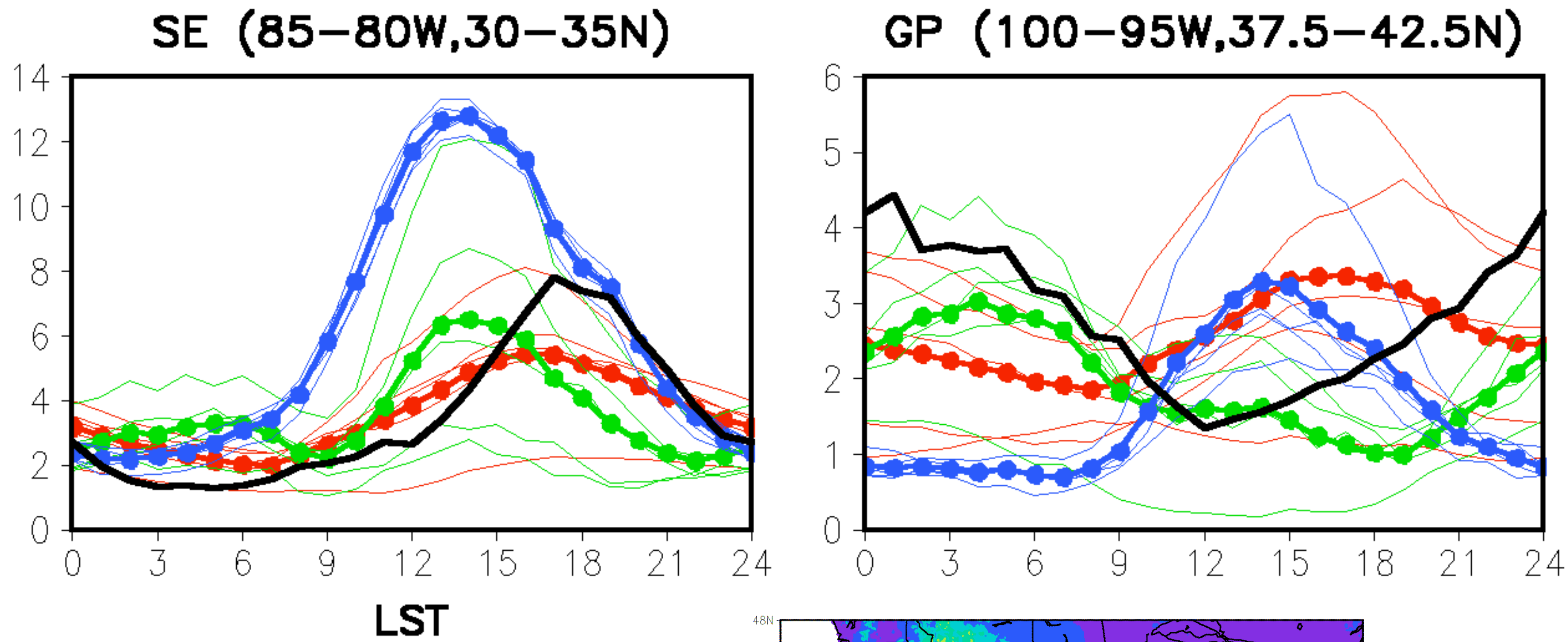
- GFS uses the parcel concept to check for level of free convection
  - Simplified trigger requires lifted parcel to have level of free convection within 150 hPa
  - Often delays the onset of convection

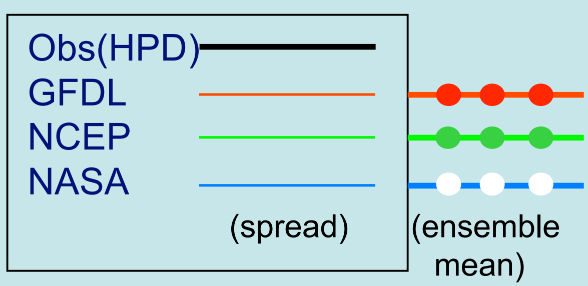
Phase (local time) of Maximum Precipitation (24-hour cycle)

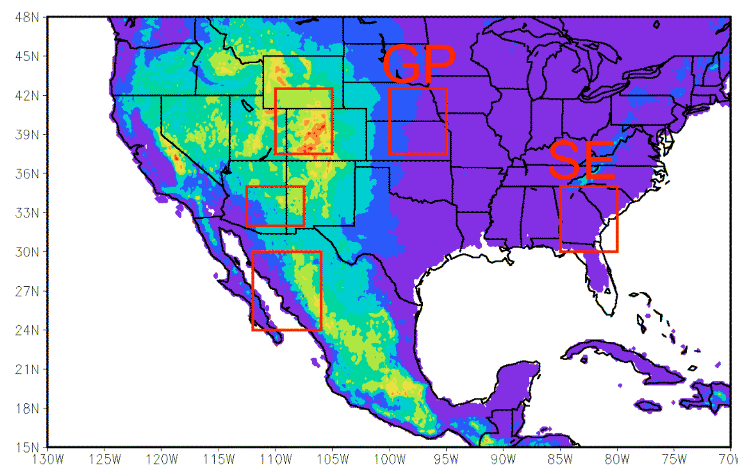


Five-member ensembles driven by Climatological SST forcing (1983-2002 avg)

Diurnal Cycle of Rainfall – Ensemble Mean and Spread





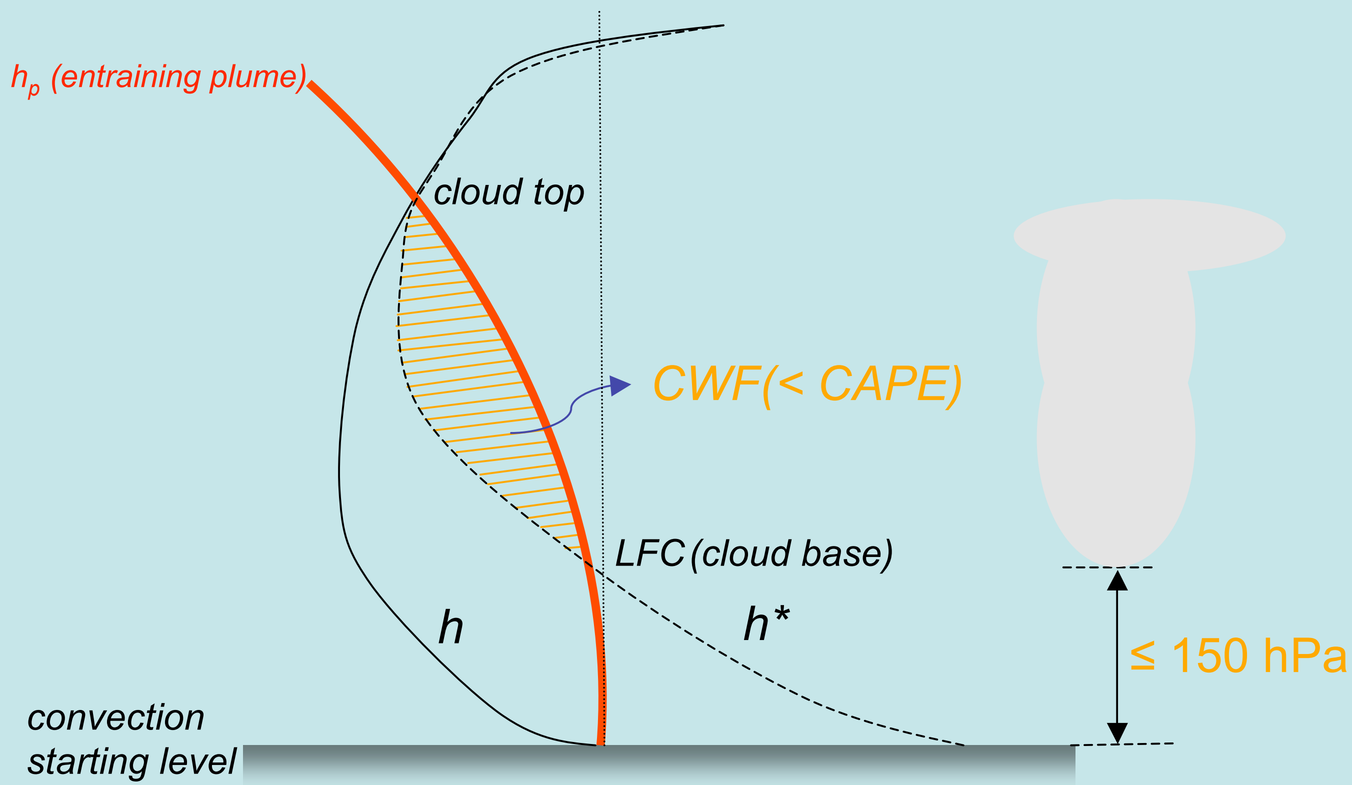


Convection Starting Level

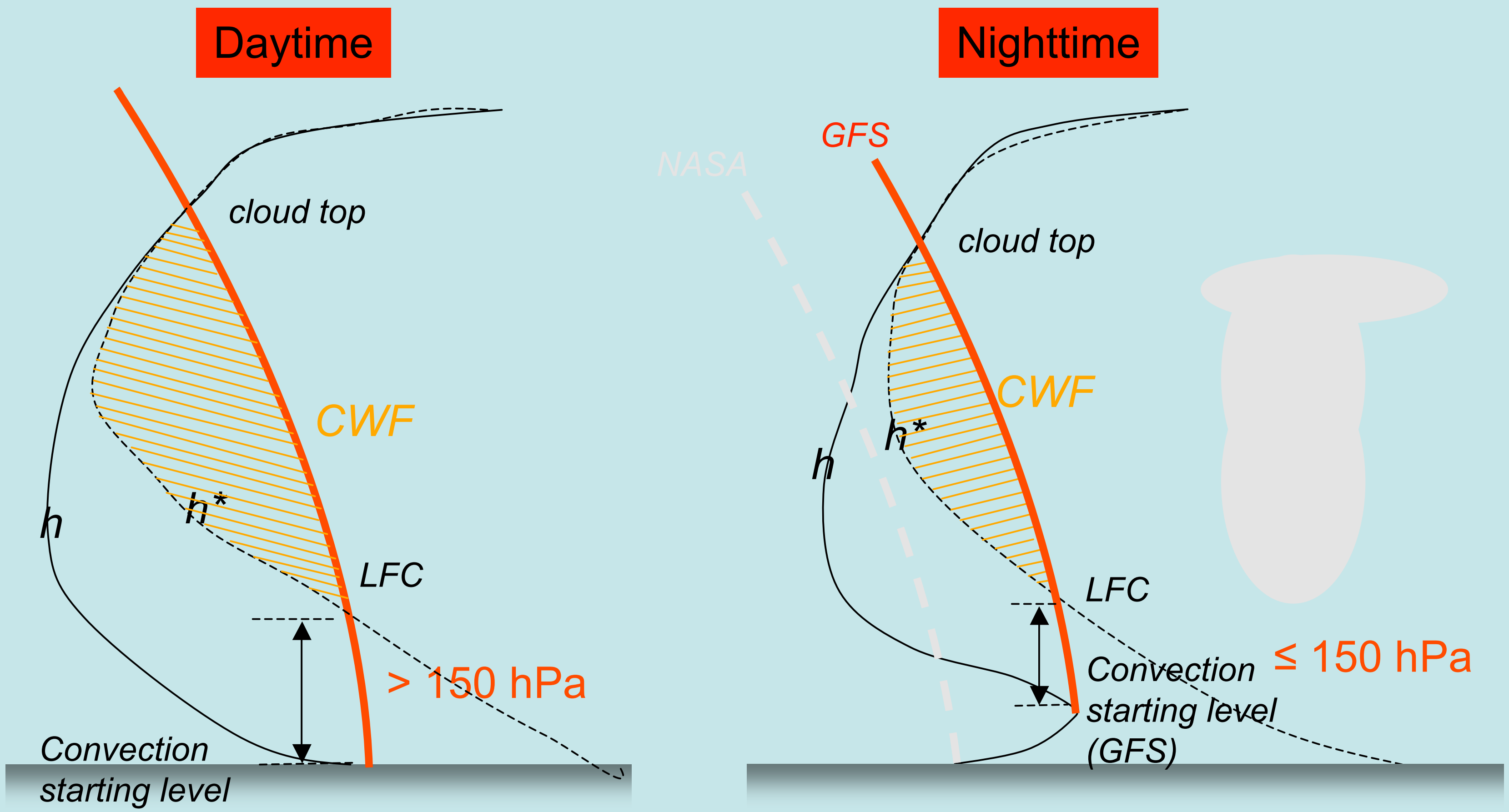
Defined as the level of maximum moist static energy (*h*)

The level of free convection (*LFC*) should be also defined for the deep convection – positive cloud work function (CWF)

LFC should be defined within the 150 hPa depth from the convection starting level (max h from ground)



GFS Nocturnal Precipitation Mechanism (Great Plains)



Bigger CWF but no convection trigger

Smaller CWF but trigger

Cumulus Momentum Mixing (CMM)

- Has a remarkable effect on tropical storm genesis
  - Without **CMM**
    - Most of the model’s tropical disturbances develop vorticity centers due mostly to grid-scale (“resolved”) heating.
    - Too many disturbances
    - Tuning and adding “moist adjustment” were not completely effective
  - With **CMM**
    - Parameterized convective heating is smaller
    - Most important, vortex development is restricted only to the ‘real’ storms

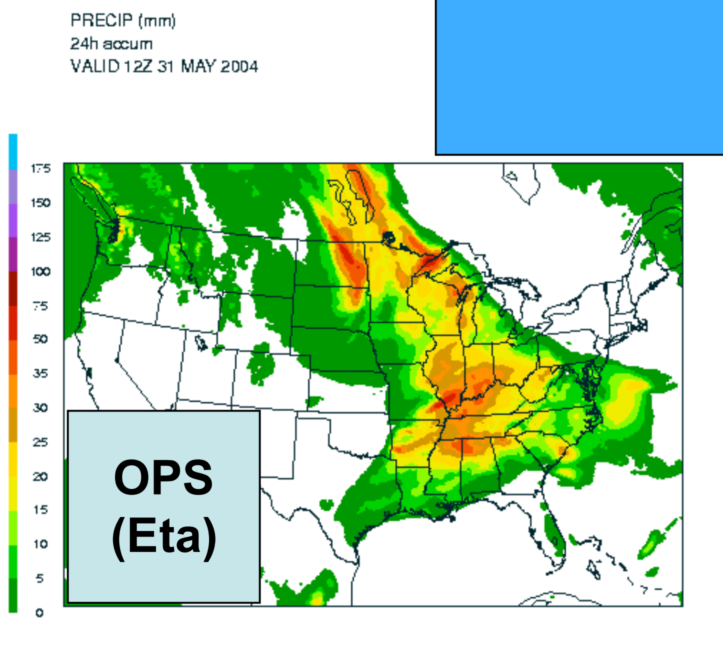
With CMM (cont)

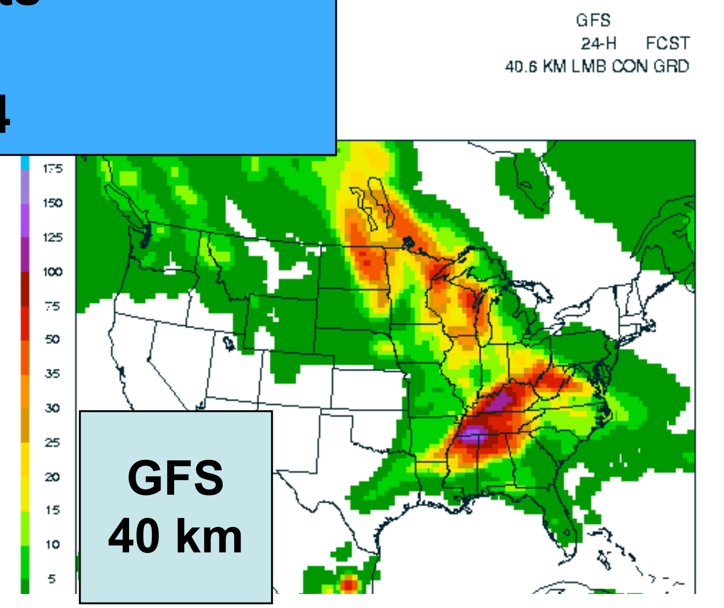
- Leads to weaker storms
  - Vorticity
  - Sea-level pressure
  - Since the model tropics selects the real storms, hurricane track prediction in global model is improved (even possible)
- In-cloud parcel momentum is not conserved
  - Pressure gradient term must be parameterized
  - Further study with cloud-resolving models may help
- Impacts mid-latitude MCC evolution in coarse-grid models
- Further study with cloud-resolving models may be helpful
  - Parameterizing pressure gradient term
  - Closer look at momentum budgets

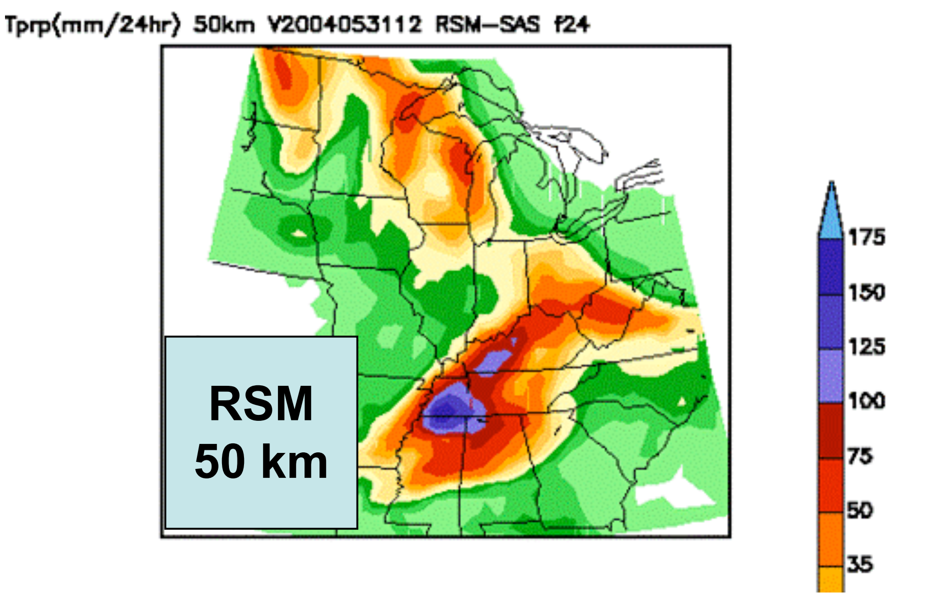
Mesoscale modeling

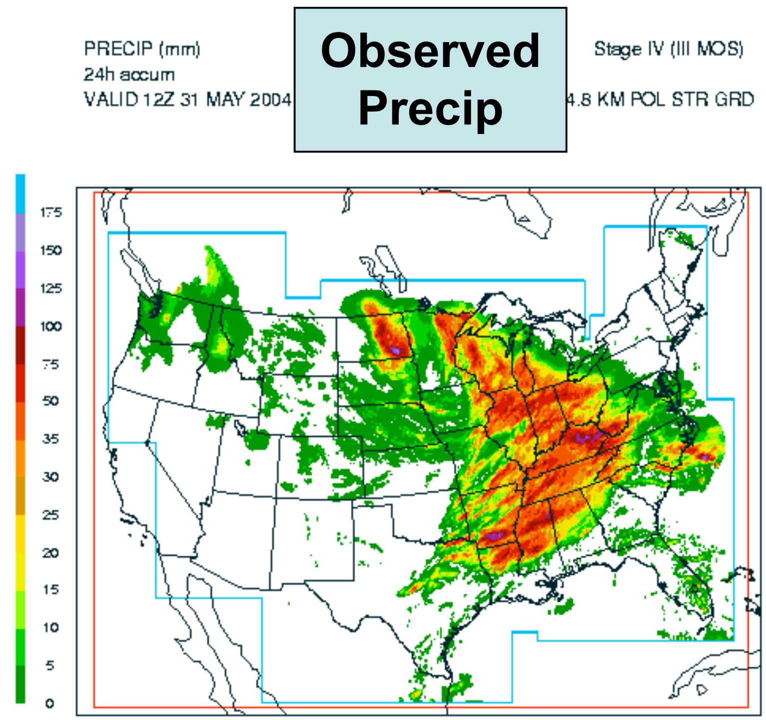
- How does parameterized convection (and for that matter turbulence) work when the resolution goes from 40 km to 4 km?
  - The “convergence” problem for convective parameterization (Arakawa)
  - With the GFS trigger
    - Air column in disturbed regions becomes very moist
    - CAPE is reduced
    - I.e. moist adiabat is approached
    - Parameterized convection plays a diminishing role
    - Grid-scale convection “takes over”
- Convective momentum mixing continues to exert influence on the intensity of the tropical storms

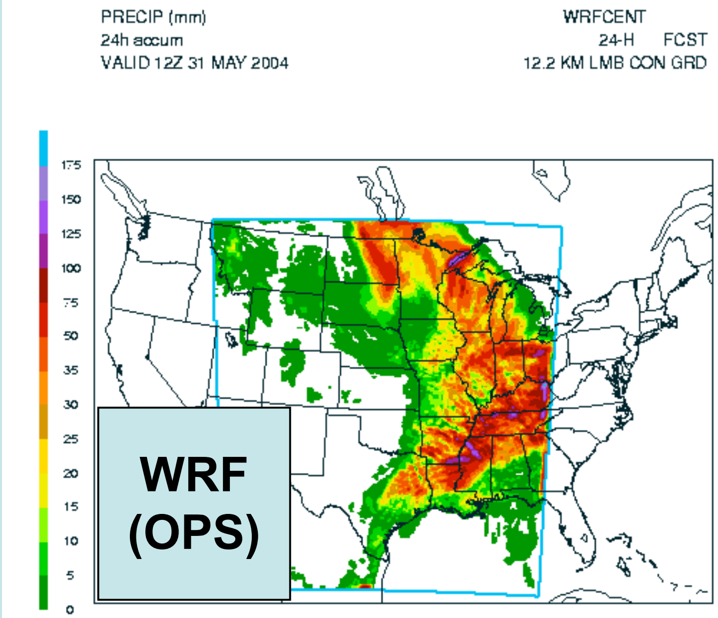
24 h Forecasts
12 UTC
31 May 2004

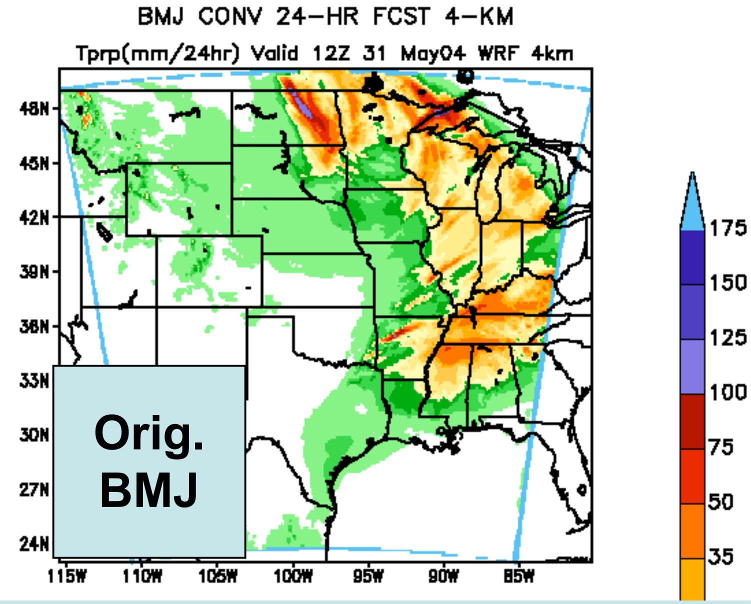


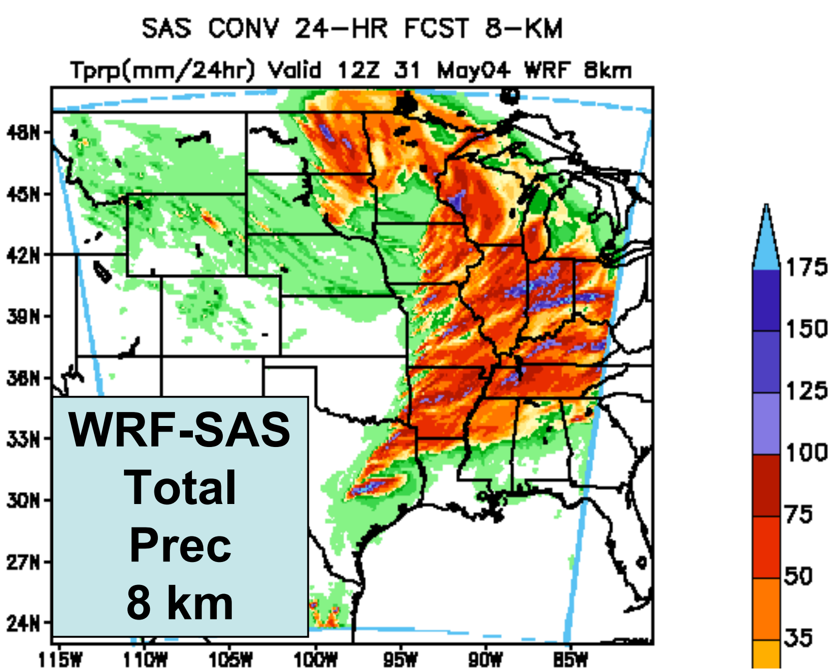


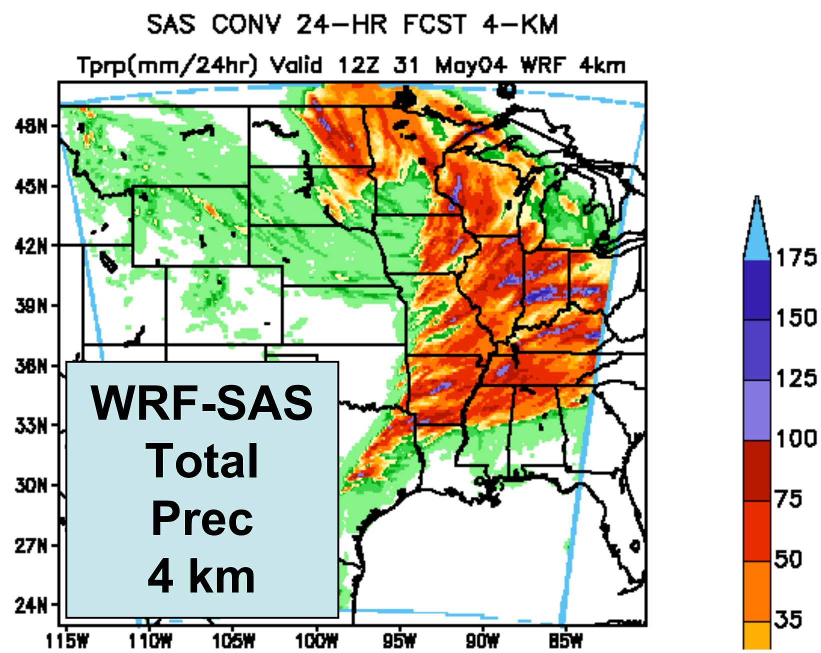


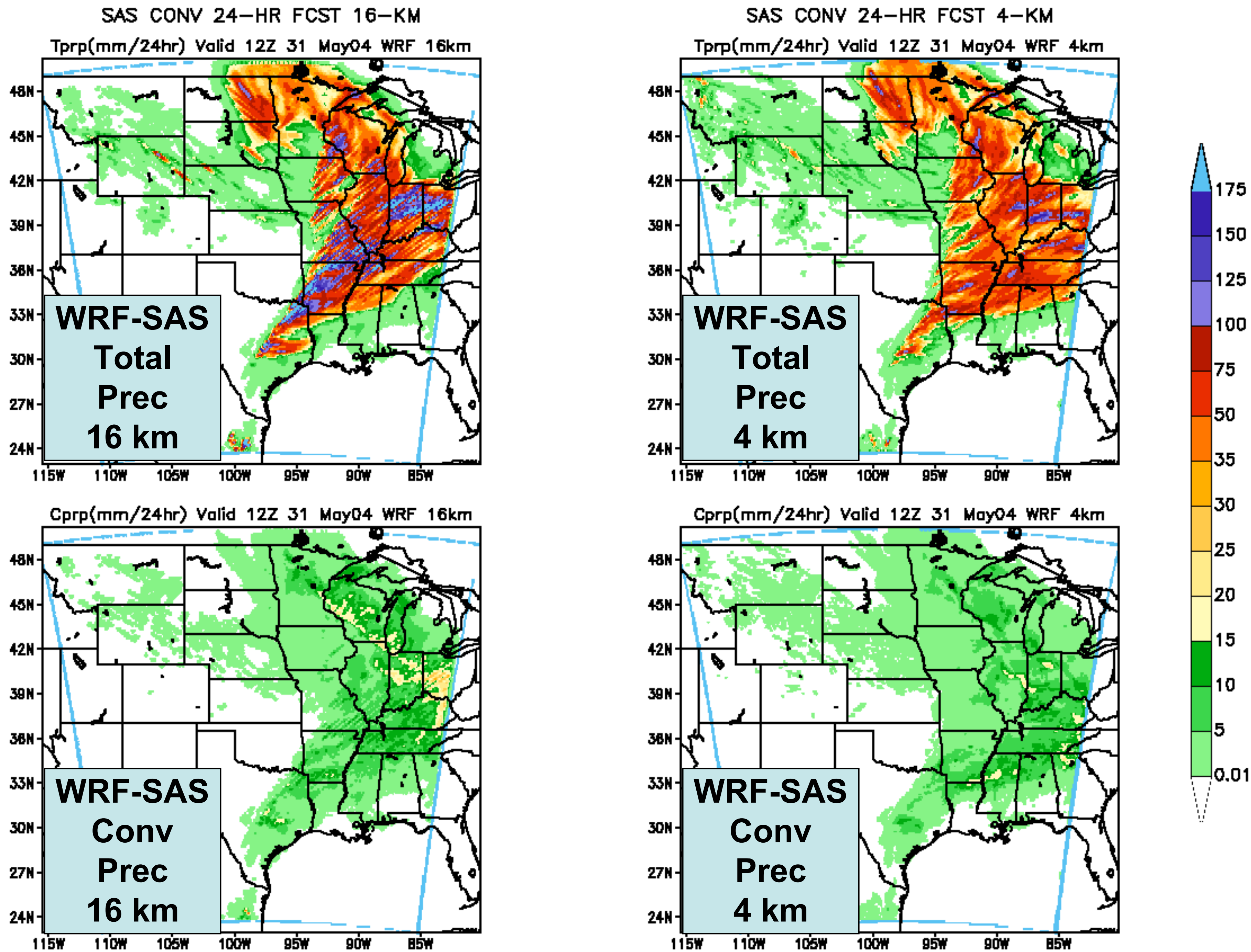



PRECIP (mm)
24h accum
VALID 12Z 31 MAY 2004
WRFCENT
24-H FCST
12.2 KM LMB CON GRD
WRF (OPS)

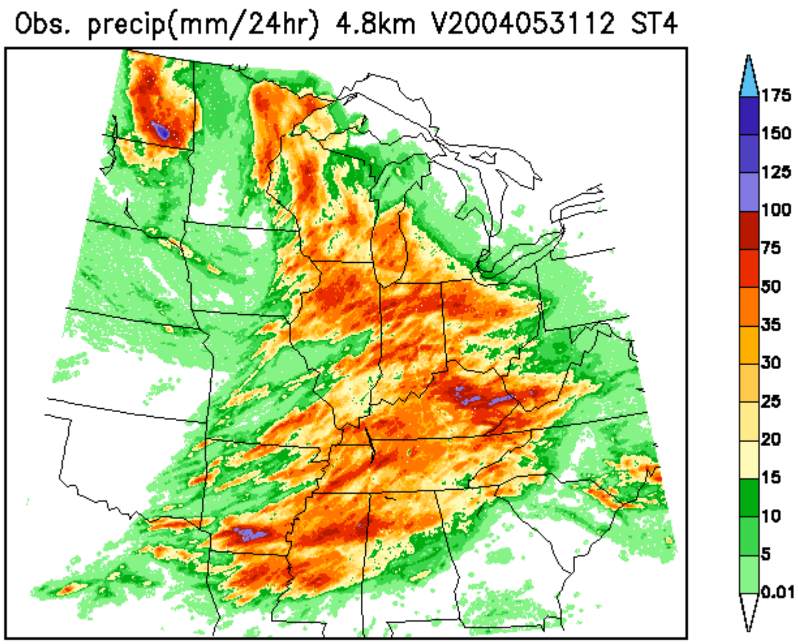

BMJ CONV 24-HR FCST 4-KM
Tprp(mm/24hr) Valid 12Z 31 May04 WRF 4km
Orig. BMJ

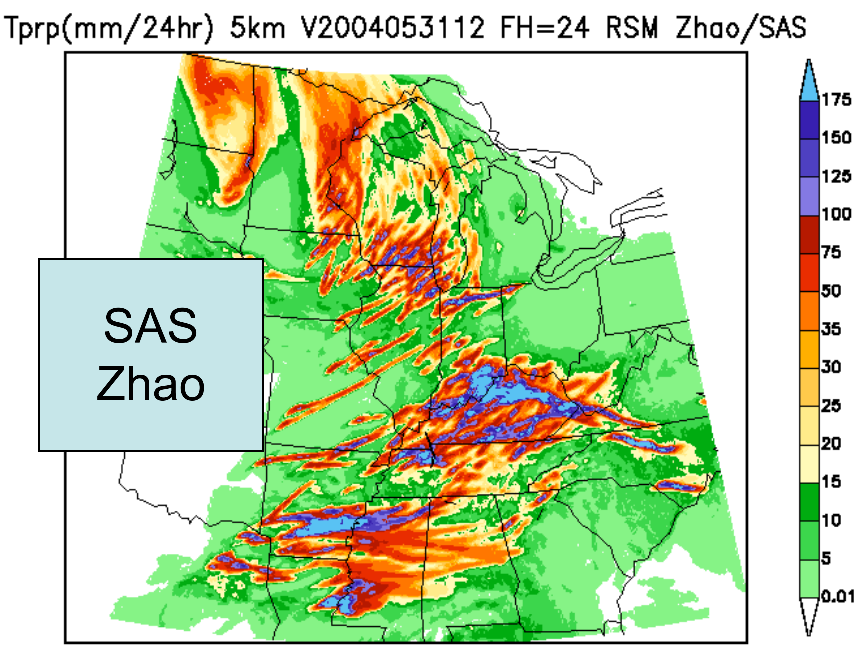

SAS CONV 24-HR FCST 8-KM
Tprp(mm/24hr) Valid 12Z 31 May04 WRF 8km
WRF-SAS Total Prec 8 km

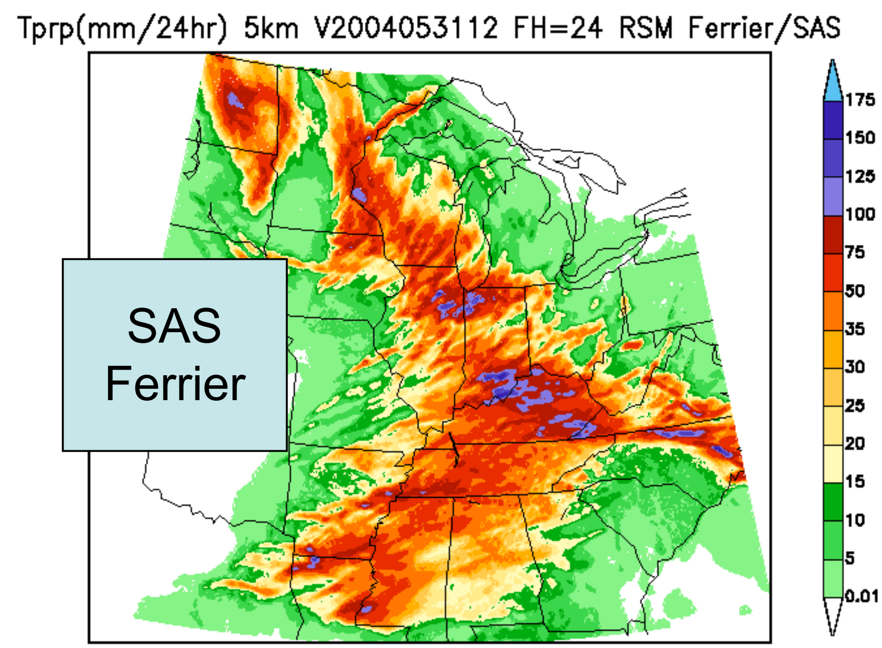

SAS CONV 24-HR FCST 4-KM
Tprp(mm/24hr) Valid 12Z 31 May04 WRF 4km
WRF-SAS Total Prec 4 km


SAS CONV 24-HR FCST 16-KM
Tprp(mm/24hr) Valid 12Z 31 May04 WRF 16km
WRF-SAS Total Prec 16 km
SAS CONV 24-HR FCST 4-KM
Tprp(mm/24hr) Valid 12Z 31 May04 WRF 4km
WRF-SAS Total Prec 4 km
Cprp(mm/24hr) Valid 12Z 31 May04 WRF 16km
WRF-SAS Conv Prec 16 km
Cprp(mm/24hr) Valid 12Z 31 May04 WRF 4km
WRF-SAS Conv Prec 4 km
175 150 125 100 75 50 35 30 25 20 15 10 5 0.01
48N 45N 42N 39N 36N 33N 30N 27N 24N
115W 110W 105W 100W 95W 90W 85W

Impact Of Microphysics 5 km (RSM)







Concluding Remarks

- NCEP's mission covers global to sub-10 km scales, hours to 1 year
  - Requires convective parameterization for foreseeable future
  - Consistent forecasts required across all time and space scales
- Successful CFS (climate) and GFS (weather) indicates physical parameterizations are working well together
  - All ingredients are important: convection, PBL, radiation, microphysics, land surface, ocean
- Contribution of parameterized convection important until sub-4 km resolution is reached
- Replacement of parameterized systems in operations by explicit convection may take ~20 years at current rate of computing growth

Concluding Remarks (cont)

- Research areas for improvements
  - Convective trigger (+PBL)
  - Convective momentum transport
  - Refining physical basis for closure and cloud model on various spatial scales (e.g. diagnose fractional area coverage)
  - Interaction with radiation and microphysics

- Approach must be physically-based
  - Keep in mind the convergence problem (Arakawa) as a guiding principle
  - Using limited area forecast models can be useful
  - Testing in seasonal climate applications can be at 20-50 km resolution in the future

- NCEP can contribute
  - With its current parameterization suite as a control
  - By testing new candidate parameterizations (given sufficient resources)
  - Its talent and experience in numerical weather and climate prediction

A. Arakawa
"The Cumulus Parameterization Problem:
Past Confusions, Current Frustrations and Future Excitements"
Seminar at the Laboratory for Atmospheres
NASA Goddard Space Flight Center
May 20, 2004

THE CONVERGENCE PROBLEM FOR MODEL PHYSICS

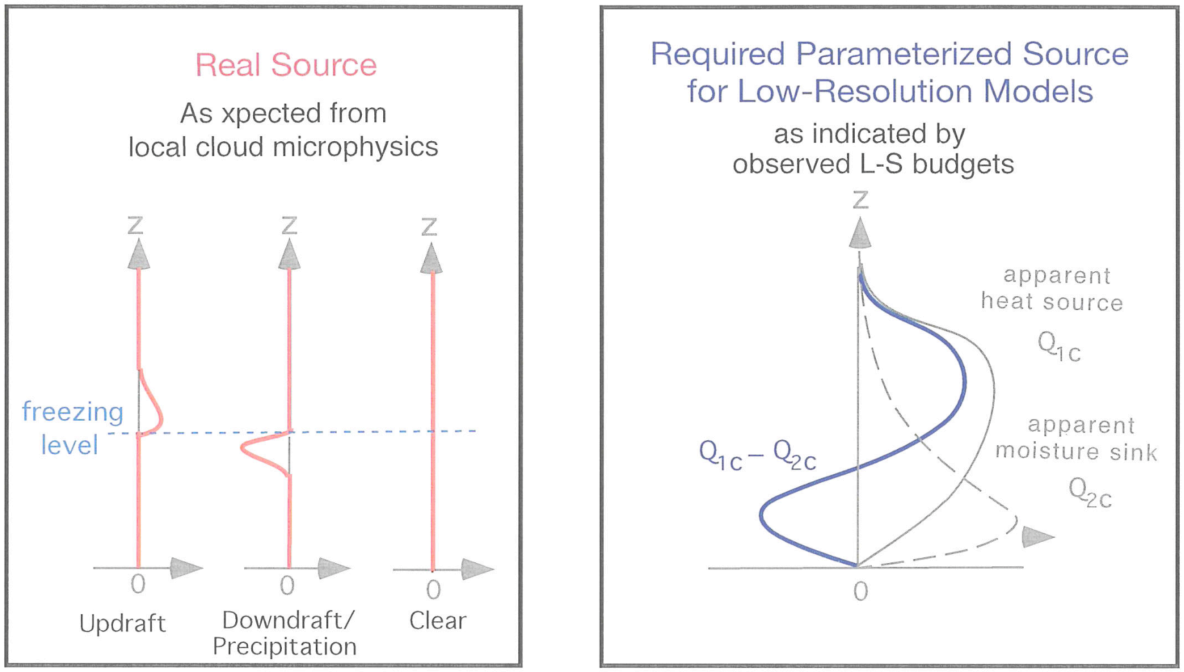
Justification of a discrete model relies on the hope that its solution converges to the solution of the original system as the resolution is refined.

The convergence problem for model physics is different from the standard convergence problem in numerical analysis:

the governing equation is modified rather than approximated.

"Theoretical Expectations"

TYPICAL VERTICAL PROFILES OF MOIST STATIC ENERGY SOURCE
DUE TO CONVECTIVE CLOUD PROCESS

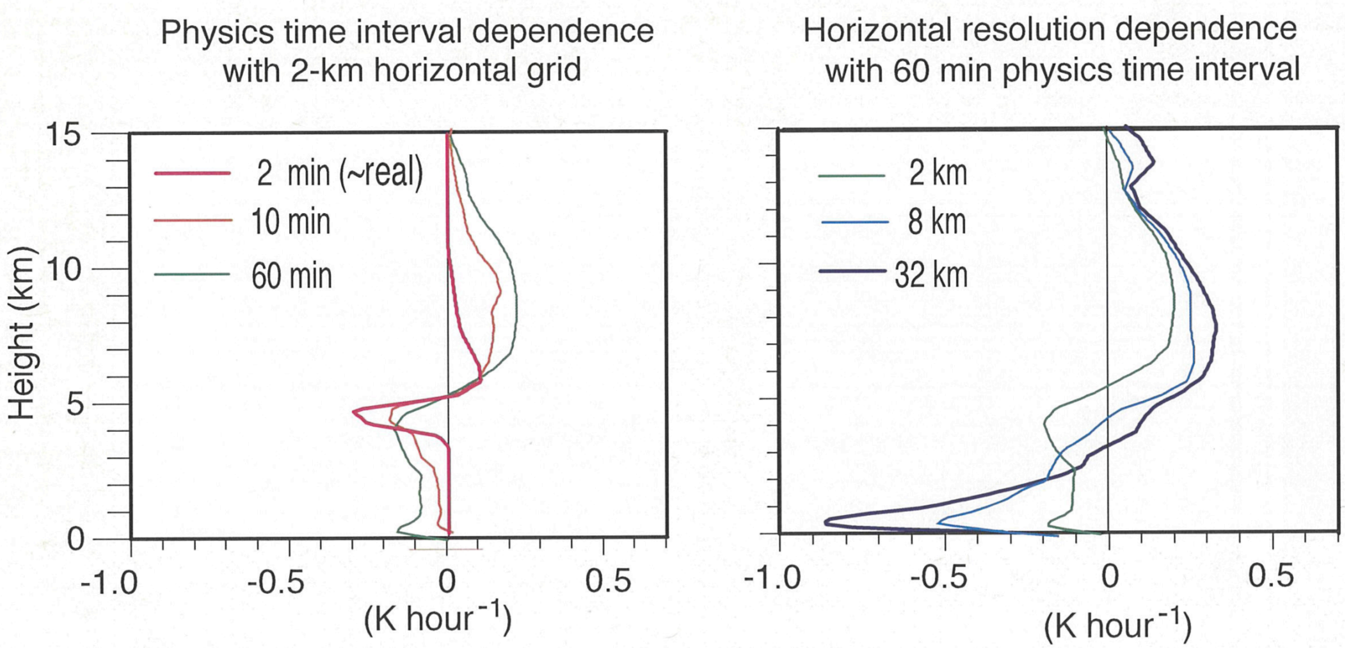


Any space/time/ensemble averages of the profiles in the left panel do NOT give the profile in the right panel.

Cloud Resolving Model Results

Domain/ensemble average profiles of required cloud-microphysical source for moist static energy diagnosed from cloud-system resolving model experiments

(from Jung and Arakawa, *JAS*, 2004)



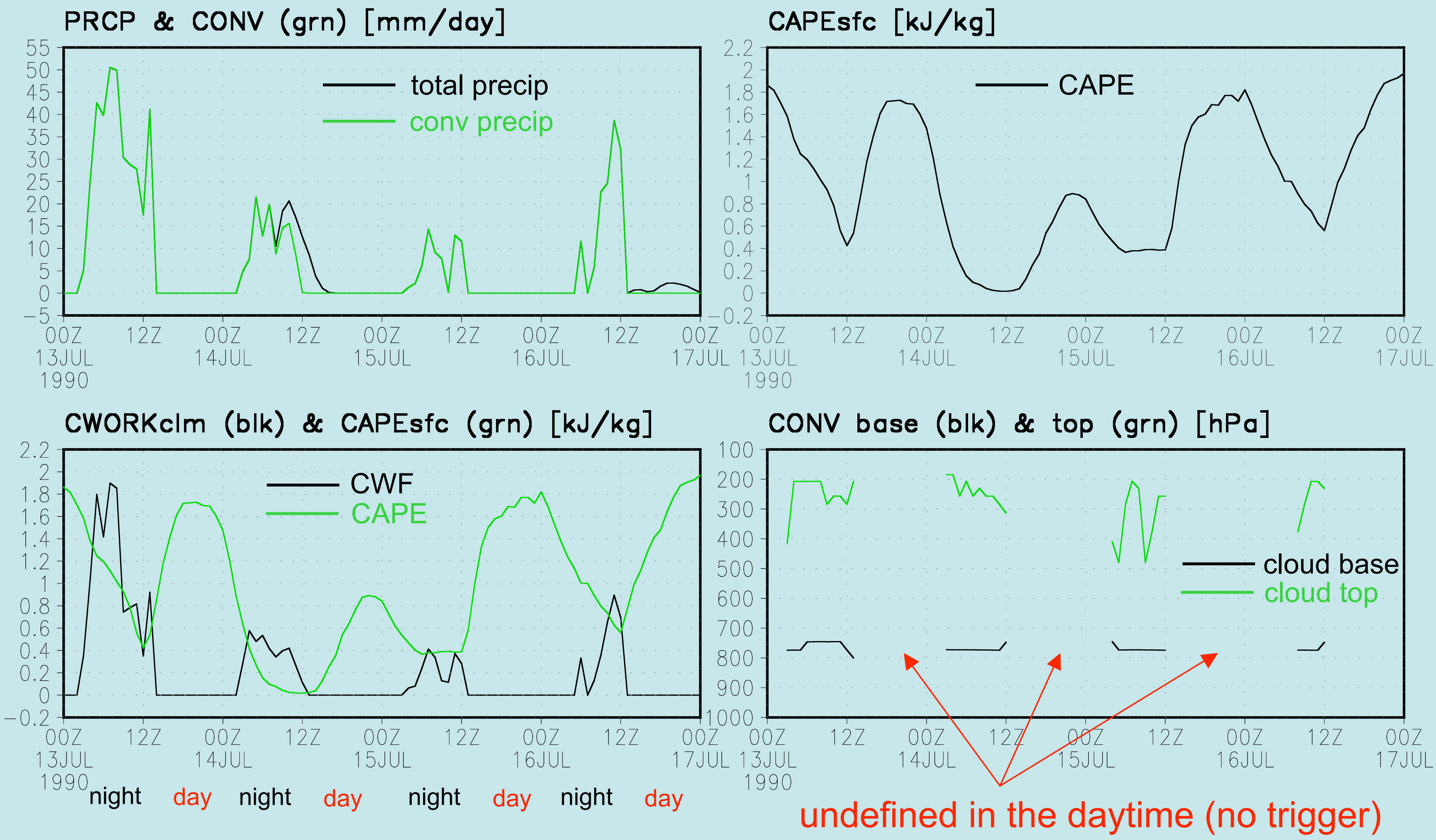
- *A parameterizatin must produce this kind of scale dependency.*
- *Otherwise, the model does not converge to (an ensemble-averaged) cloud-system model*

NCEP's CFS Components for S/I Climate

- T62/64-layer version of the current NCEP **GFS** (**G**lobal **F**orecast **S**ystem) weather model
- GFDL Modular Ocean Model, version 3 (MOM-3)
- Global Ocean Data Assimilation (GODAS)
- Direct coupling (no flux correction)

GFS Simulations at Great Plains

Control Run, ens1, -90W, 35N, Case study(00z Jul 13- 00z Jul 17)



Definition of a simple MJO index:

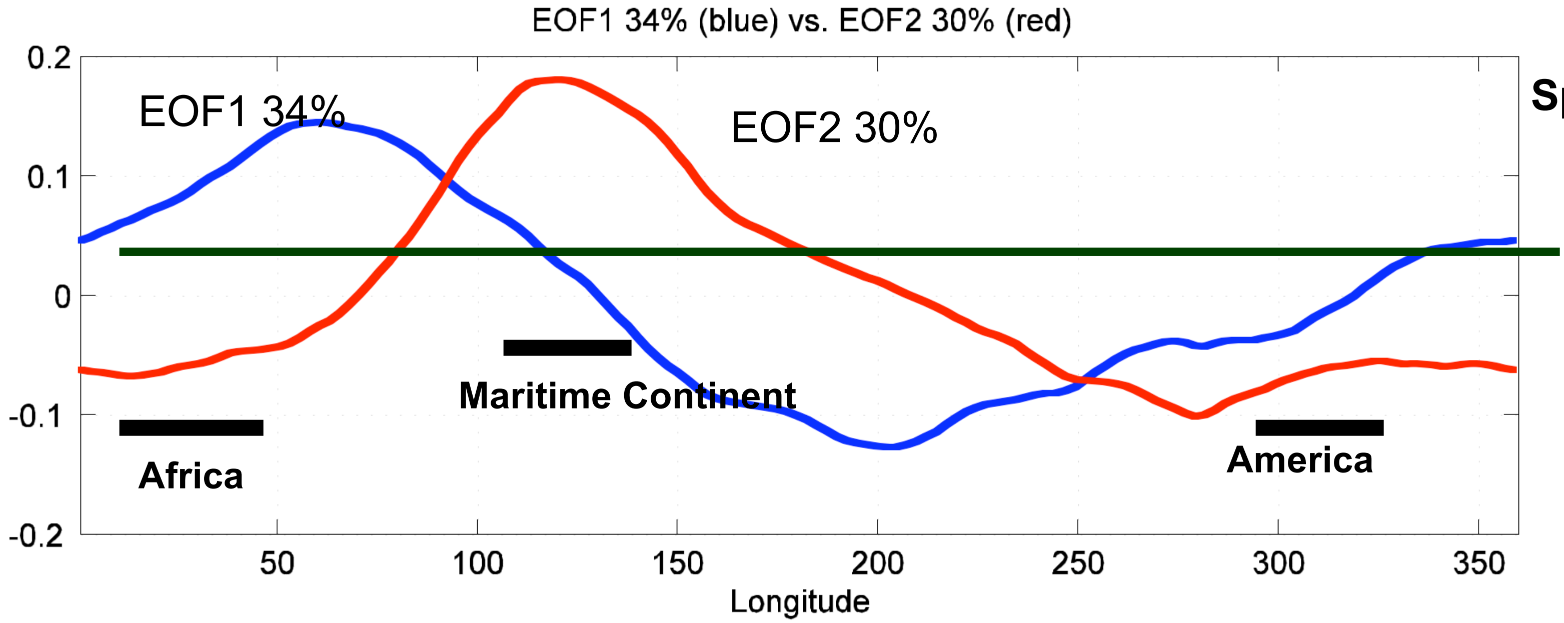
<u>Constraints</u>:

We have a relatively short re-forecast period (2000-2004) and we need to remove systematic biases and drifts of the model computed over this period.

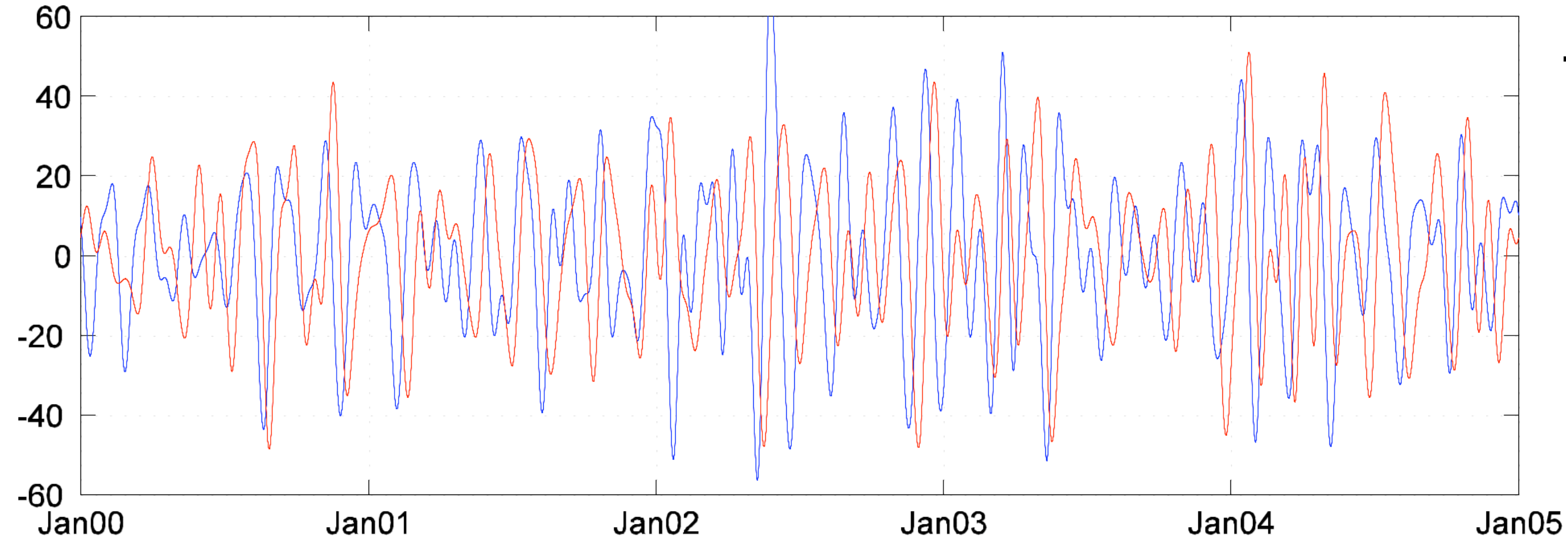
Therefore, we must exclude indexes based on precipitation, OLR and other variables that present high frequency behavior.

- Use Zonal Wind at 200HPa from 2000 to 2004 (Reanalysis).
- Average 20ºS - 20ºN
- Band pass 20-90 days
- EOF analysis. Forecasts will be projected to these modes.

EOF analysis of U at 200 hPa from 2000 to 2004



Spatial Patterns

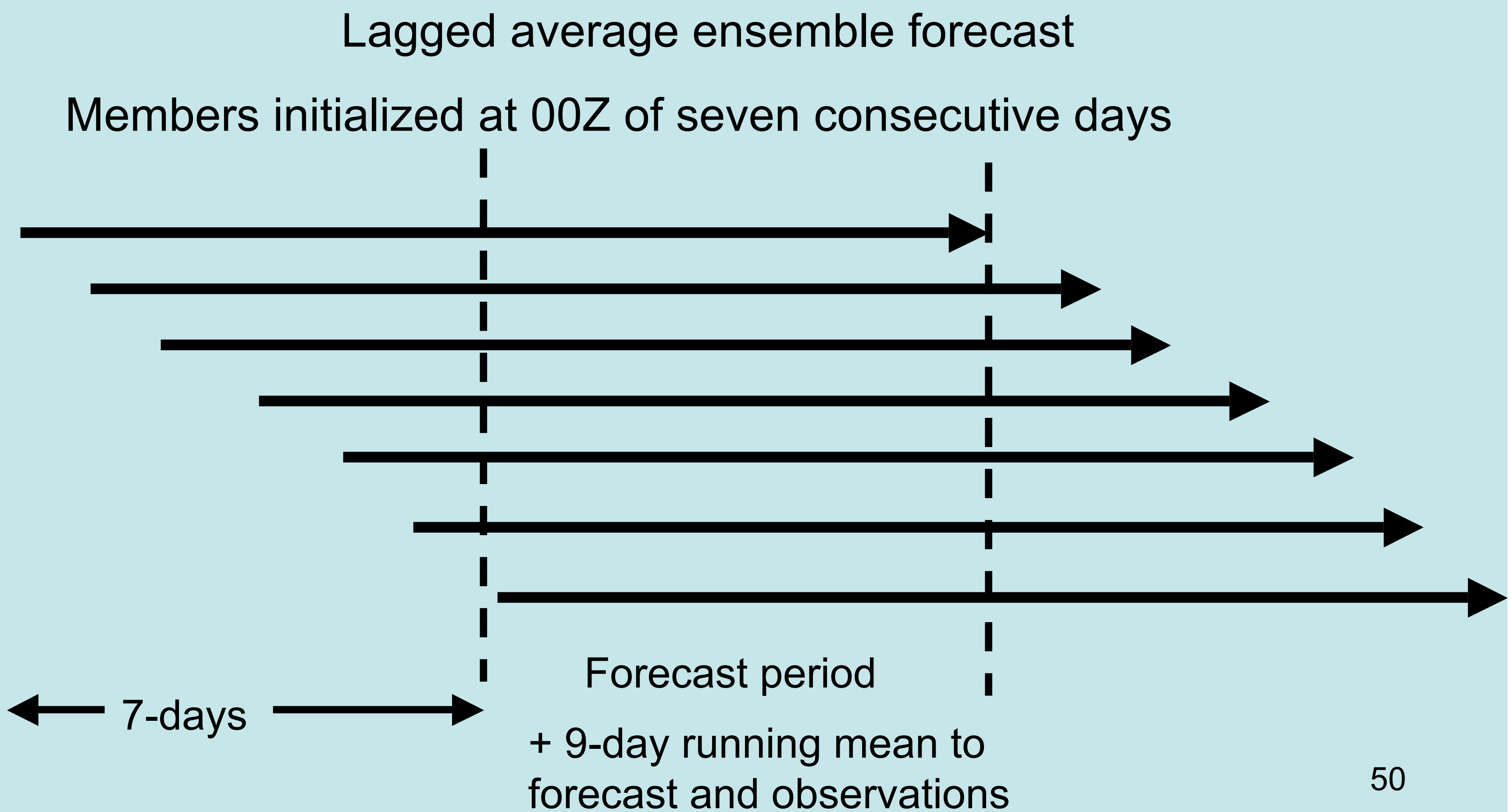


Time Patterns

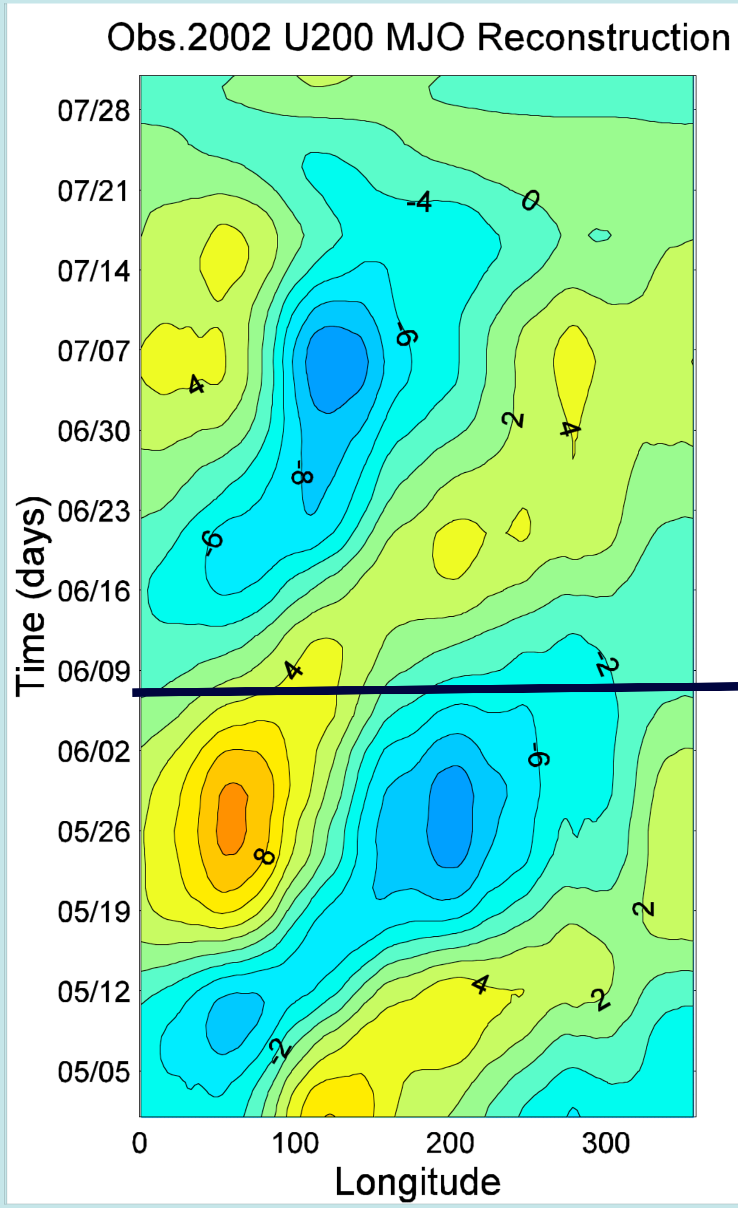
Lagged correlation of R=0.75 at 10 days

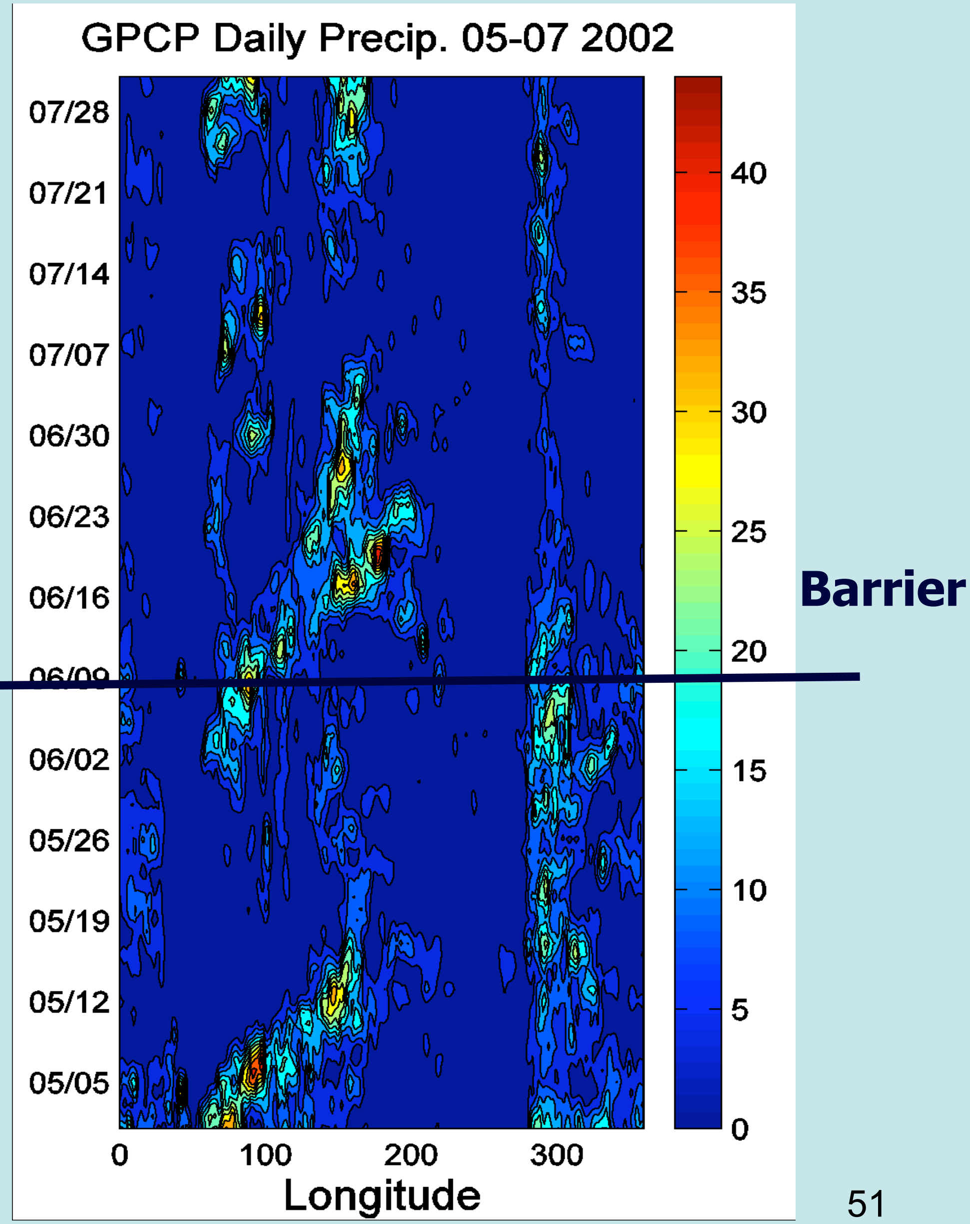
A wave at T=40 days

Forecast Skill based on pattern correlation



The Predictability Barrier

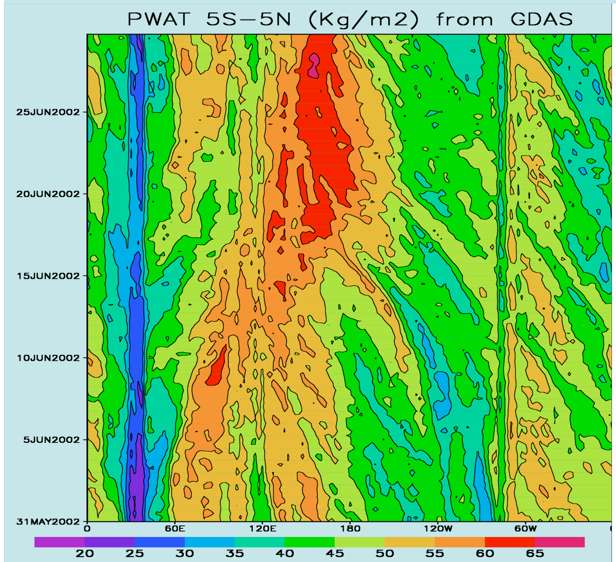




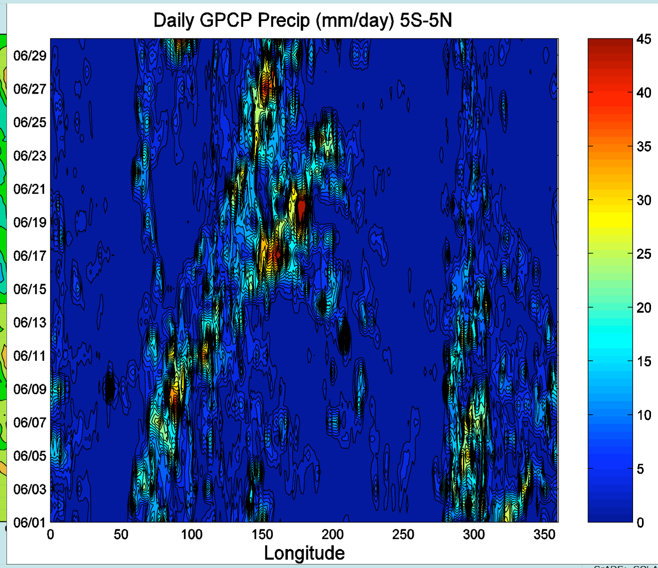
20S-20N averaged, filtered U200 field

5S-5N averaged, total unfiltered precipitation field

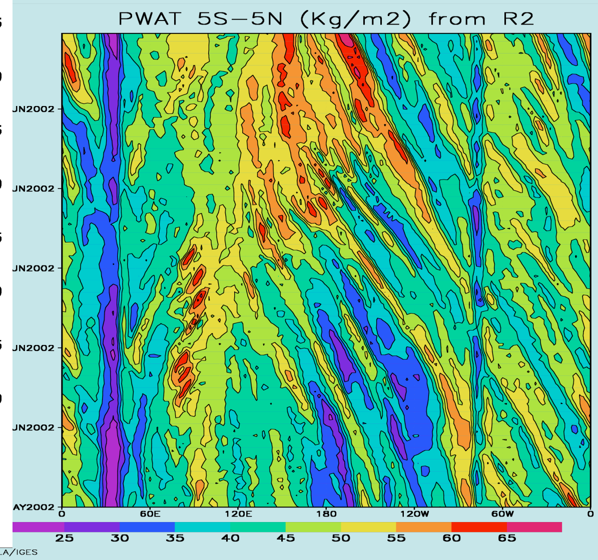
GDAS *vs. GPCP vs.* Reanalysis-2 for June 2002



GDAS Precipitable Water

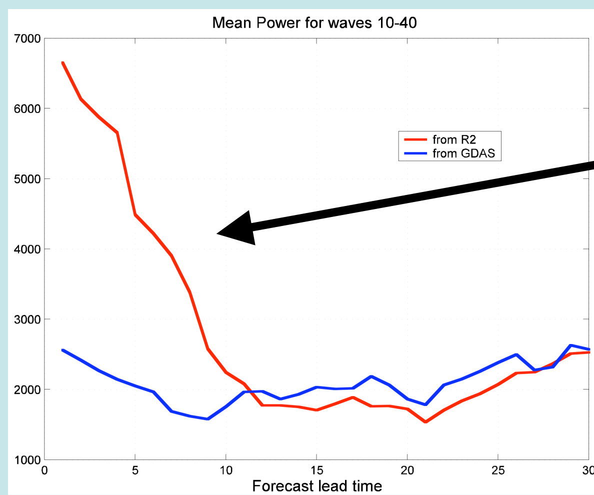


GPCP Precipitation



Reanalysis 2 Precipitable Water

Time evolution of mean energy at wave numbers 10-40 when CFS is initialized by R2 (red) or by GDAS (blue).



drift