Developing Physics-oriented Diagnostic Tools for Model Evaluation and Improvement

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Model Evaluation

- Evaluation of model forecasts is an indispensible component of the model development effort.
- Standard performance-oriented metrics, such as ACC and RMSE, are routinely used in operational centers for forecast verification. NCAR DTC also developed model evaluation tools (MET).
- Physics-oriented diagnostics focus on the critical processes or phenomena and, through evaluation of key variables, shed light on the deficiencies of the physical parameterization or other errors in a model.
- In brevity, physics-oriented evaluation not only provides information on how well a model performs but also on why a model may fail in a certain aspect.
- There is an increasing demand in recent years in the community to develop and adopt physics-oriented diagnostics

Over-arching Objective

- **Objective**: develop physics-oriented diagnostic tools to assist the development of the NOAA's Next Generation Global Prediction System (NGGPS) under the R2O Initiative
- **Expected outcome**: a suite of diagnostic tools with general applicability across models
- In-depth evaluation of model forecasts using physics-oriented metrics helps to "*improve the physical parameterizations to allow for efficient, accurate and more complete representations of physical processes and their interactions across scales*" and helps to "*achieve a world class global predication system*", which is highly relevant to the priority of the R2O initiative.

Outline of Physics-based Evaluations: Two levels of products

1. Level 1: Prominent Motion Systems
   - Tropical Cyclones (ongoing)
   - MJO (ongoing)
   - Blocking (to be developed)
   - Teleconnection (to be developed)
2. Level 2: Specific Physical Processes
   - Cumulus parameterization: CWV-precip relationship, Q1/Q2 diagnoses (ongoing)
   - Model representation of different cloud regimes (to be developed)

Two Phases

- Phase 1: The products will be developed and tested using the GEFS reforecasts.
- Phase 2: Products will be generalized to different models; an inter-model comparison will be carried out by taking advantage of the HIWPP project

Data: Global Ensemble Forecasting System Reforecast-2 (GEFS-R)

a) GEFS-R uses **a fixed version** (9.0.1) of the GEFS → useful information on the operational GEFS;

b) With the forecast lead up to 16 days

c) A multi-decadal reforecast database (**~ 30 years**) with larger sample size better evaluates model performance and predictability,

d) Ensemble forecasts make probabilistic forecast possible.

Data: GEFS-R

<table>
<tr><th>Dynamical model</th><th>Resolution</th><th>Ensembles</th></tr>
<tr><td><i>Week 1
(Day 0 - Day 7)</i></td><td><i>T254L42 (~ 40 km)
42 levels in vertical</i></td><td><i>1 control + 10
perturbed members</i></td></tr>
<tr><td><i>Week 2
(Day 8 - Day 16)</i></td><td><i>T190L42 (~ 54 km)
42 levels in vertical</i></td><td><i>1 control + 10
perturbed members</i></td></tr>
<tr><td colspan="3"><i>SST analysis: assimilates observations from past 7 days
SST forecast: damped with an e-folding time of 90 days</i></td></tr>
</table>

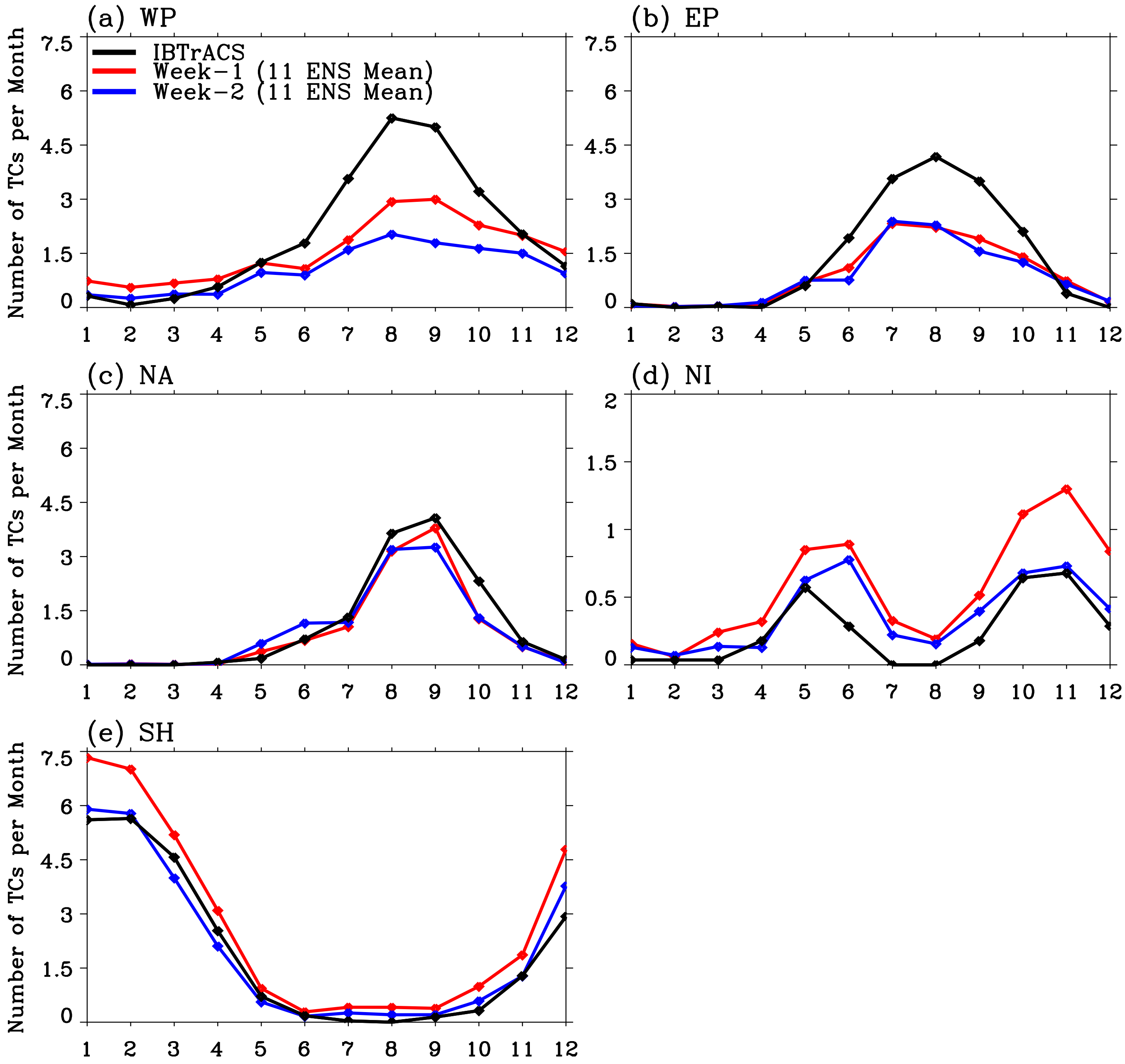
Time Period	*01 Jan – 31 Dec (1985 – 2012)*
Observation/Reanalysis	*IBTrACS , ERA-interim CMORPH, SSMI, etc.*
Region	*Global (5 basins)*

1.1 Tropical Cyclones

Detection of Model TCs

- **GFDL vortex tracker** *(Marchok 2002)*: 6-hourly TC tracks
- **Exclude:** i) short-lived TC (<= 48 h), ii) TC with maximum intensity <= 16.5 m s^{-1} (~ 32 knots), iii) genesis latitude higher than 40°, iv) warm core lasting >= 48 h during its lifetime
- Observation: IBTrACS data, 1985 - 2012
- Categorization of model TCs: hit, early genesis (EG), late genesis (LG), and false alarms

Seasonality of TC Genesis in Diff. Basins



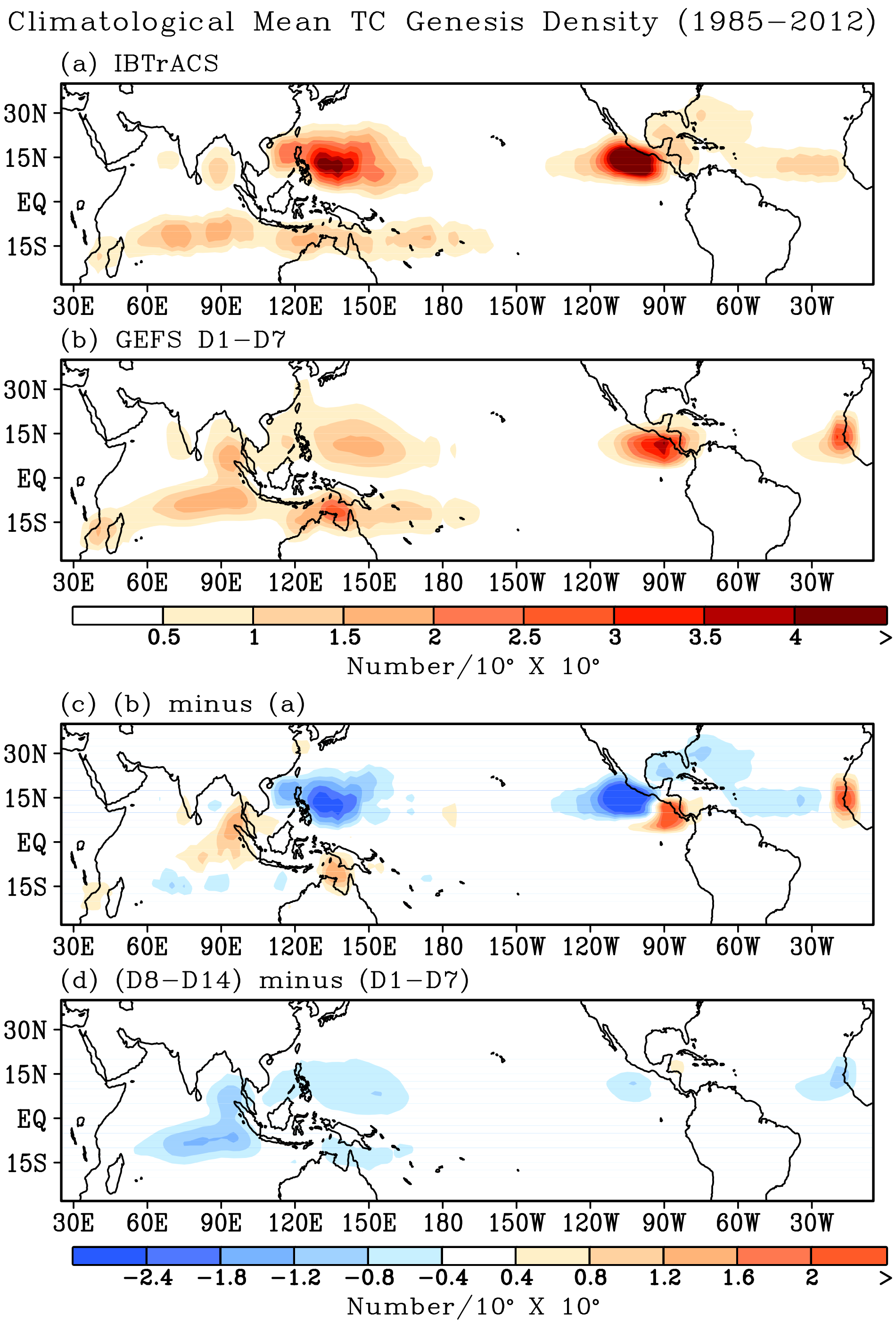
Genesis density function: 2D distribution of genesis frequency

IBTrACS

Week-1

“Week-1” - Obv

“Wk-2” –“Wk-1”


Climatological Mean TC Genesis Density (1985–2012)

(a) IBTrACS

(b) GEFS D1–D7

(c) (b) minus (a)

(d) (D8–D14) minus (D1–D7)

The TCG distribution in GEFS is broadly consistent with IBTrACS, but quantitative diff. are also evident.

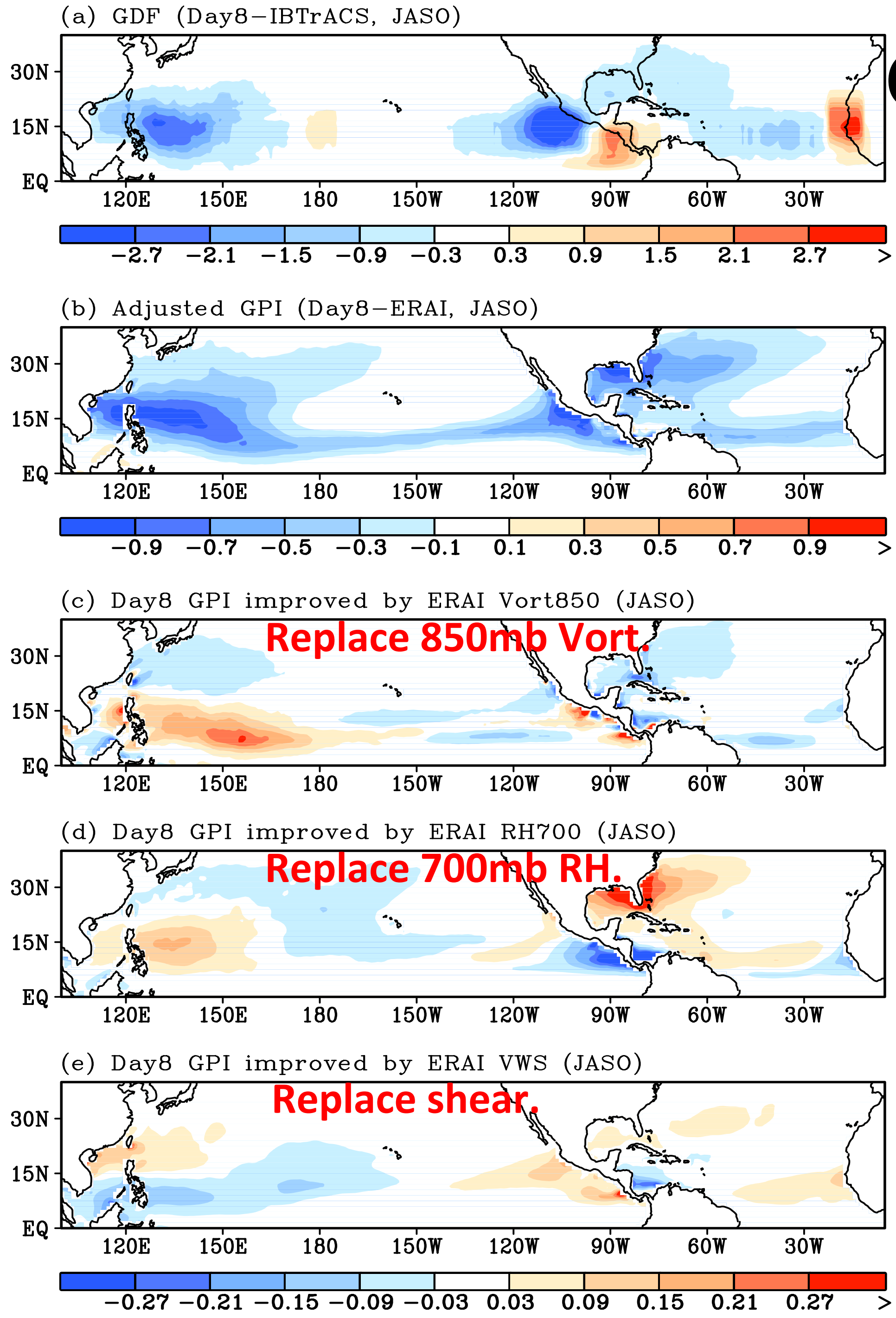
Unit:

# of TCs forming within a 10-degree box per year

Genesis Potential Index

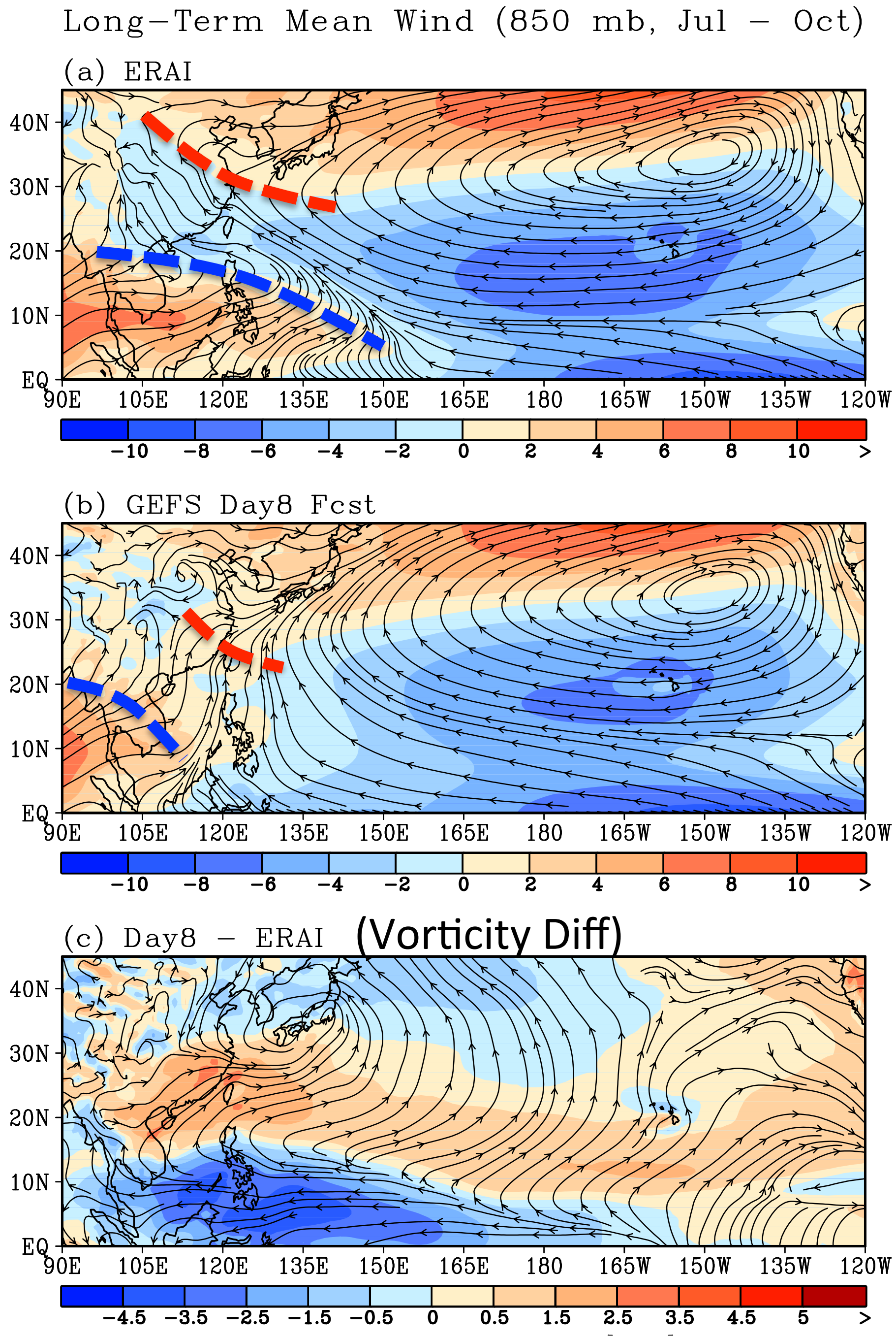
(Emanuel and Nolan 2004)

$$GP = |10^5\eta|^{\frac{3}{2}} \left(\frac{RH}{50}\right)^3 \left(\frac{PI}{70}\right)^3 (1+0.1VWS)^{-2}$$



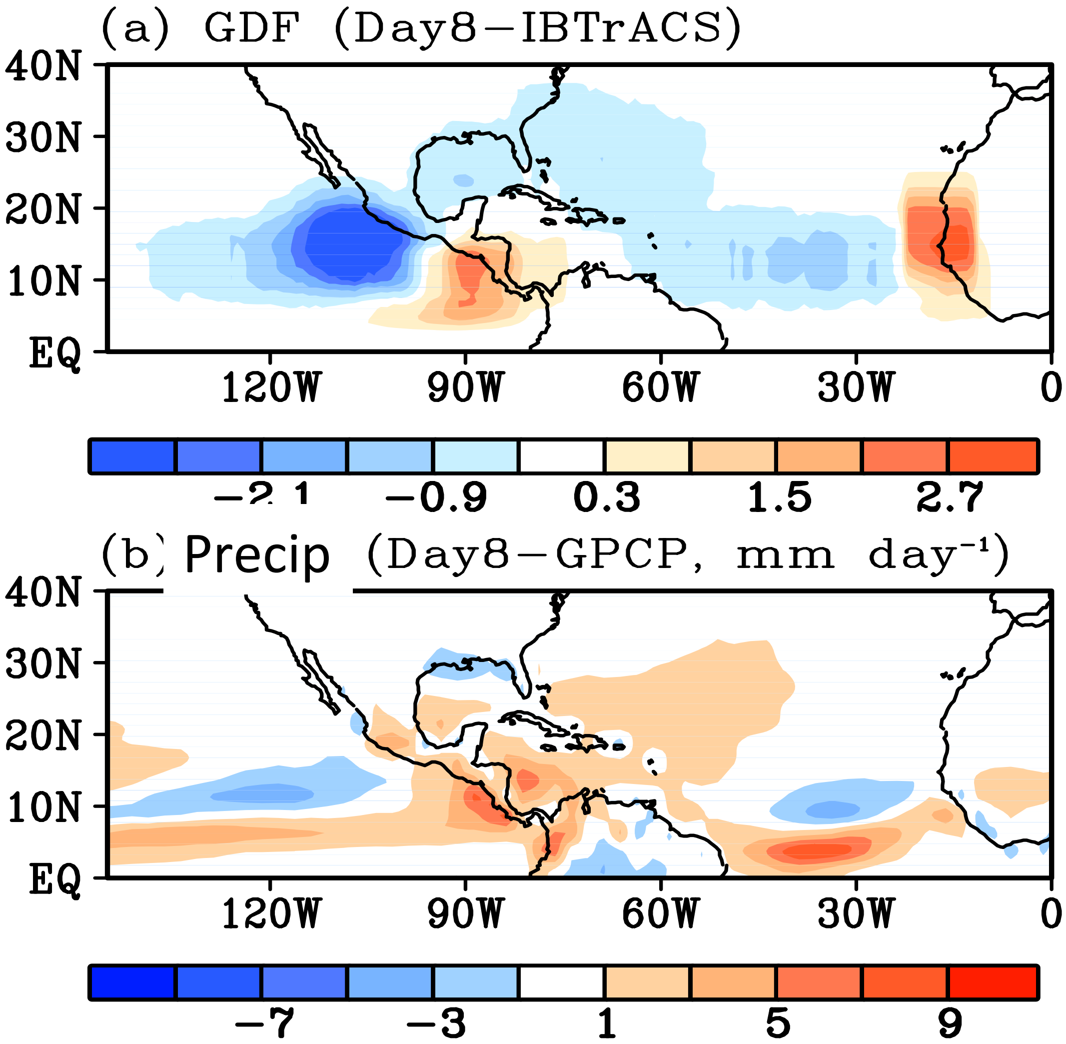
- 850 hPa vorticity, 700 hPa RH, VWS and PI.
- GPI is a function of the environmental conditions, can be used as a proxy for genesis probability.
- Comparison of GPI derived from GEFS-R and ERAI: How much can we attribute the errors in TCG to errors in the large-scale environment?

850 hPa Wind



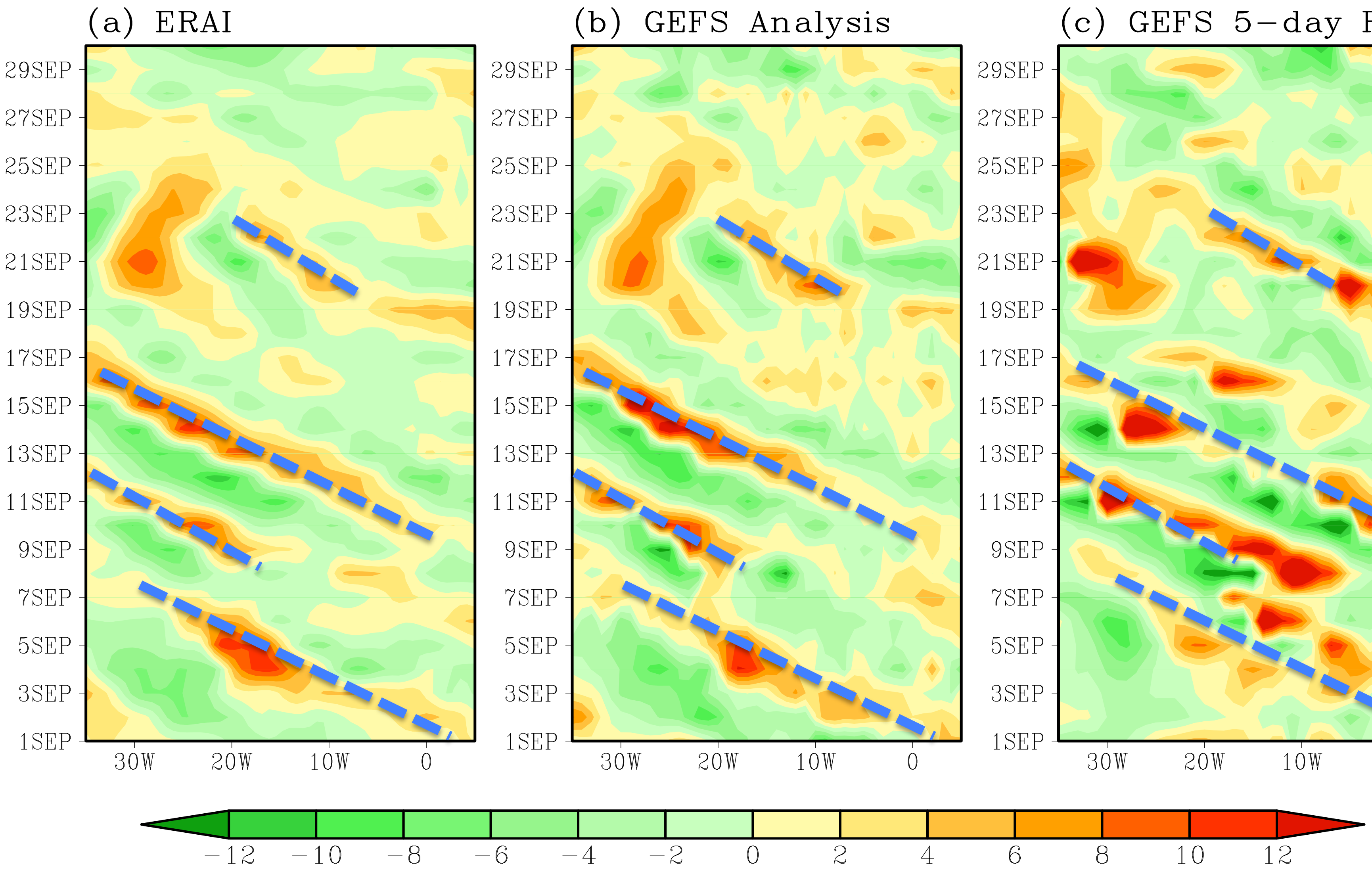
- The monsoon trough is too weak in GEFS, leading to a negative bias of relative vorticity and drier midlevel atmosphere over the western north Pacific.
- The weaker subtropical ridge near Japan contributes to a positive bias in extratropical cyclogenesis in that region (not shown).
- An improved mean state can improve TC forecasting.

East Pacific and Atlantic

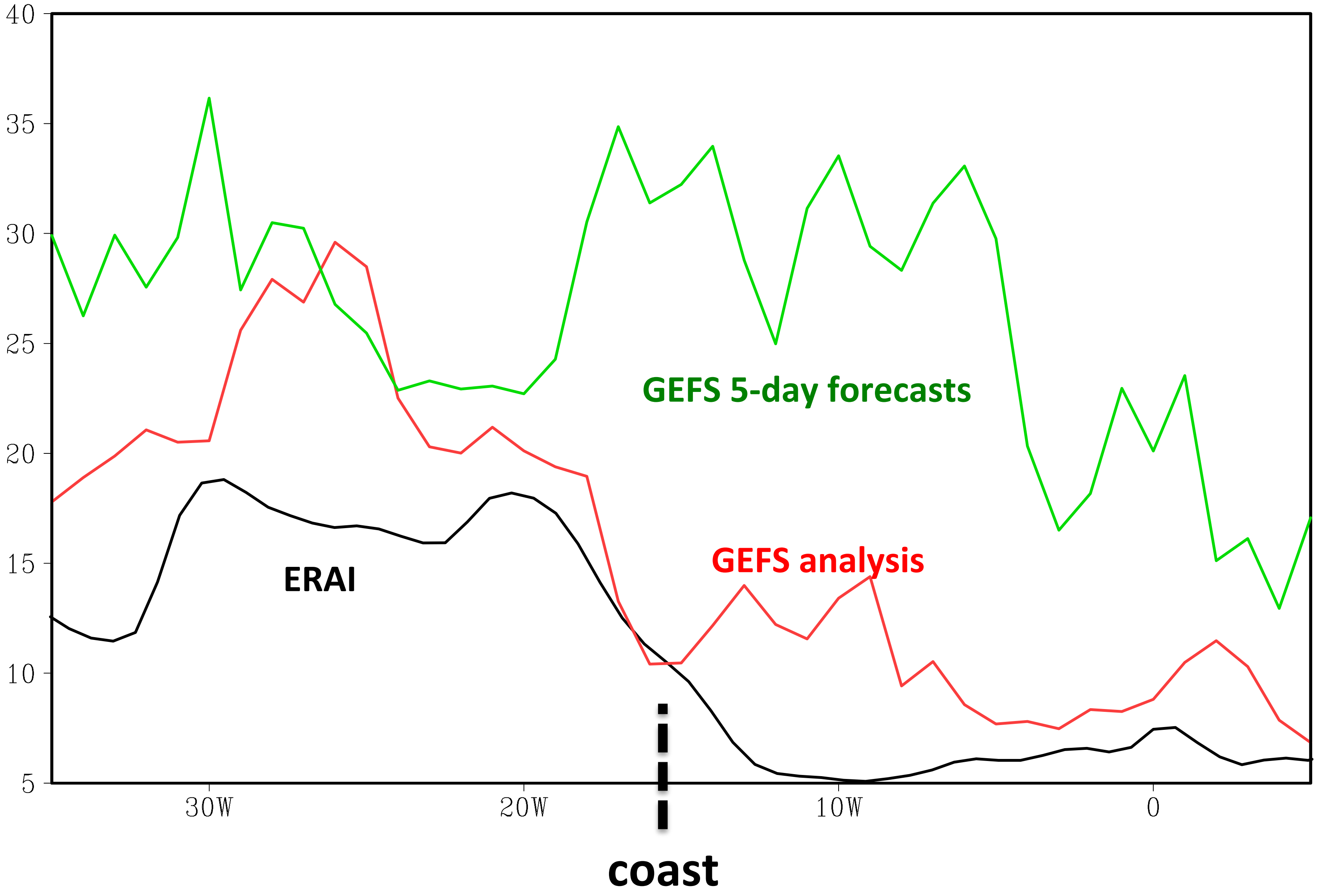


- The ITCZ is displaced southward over the E. Pac and the Atlantic.
- The tip of the ITCZ is most unstable for ITCZ breakdown.
- Precipitation is overpredicted over West Sahel.

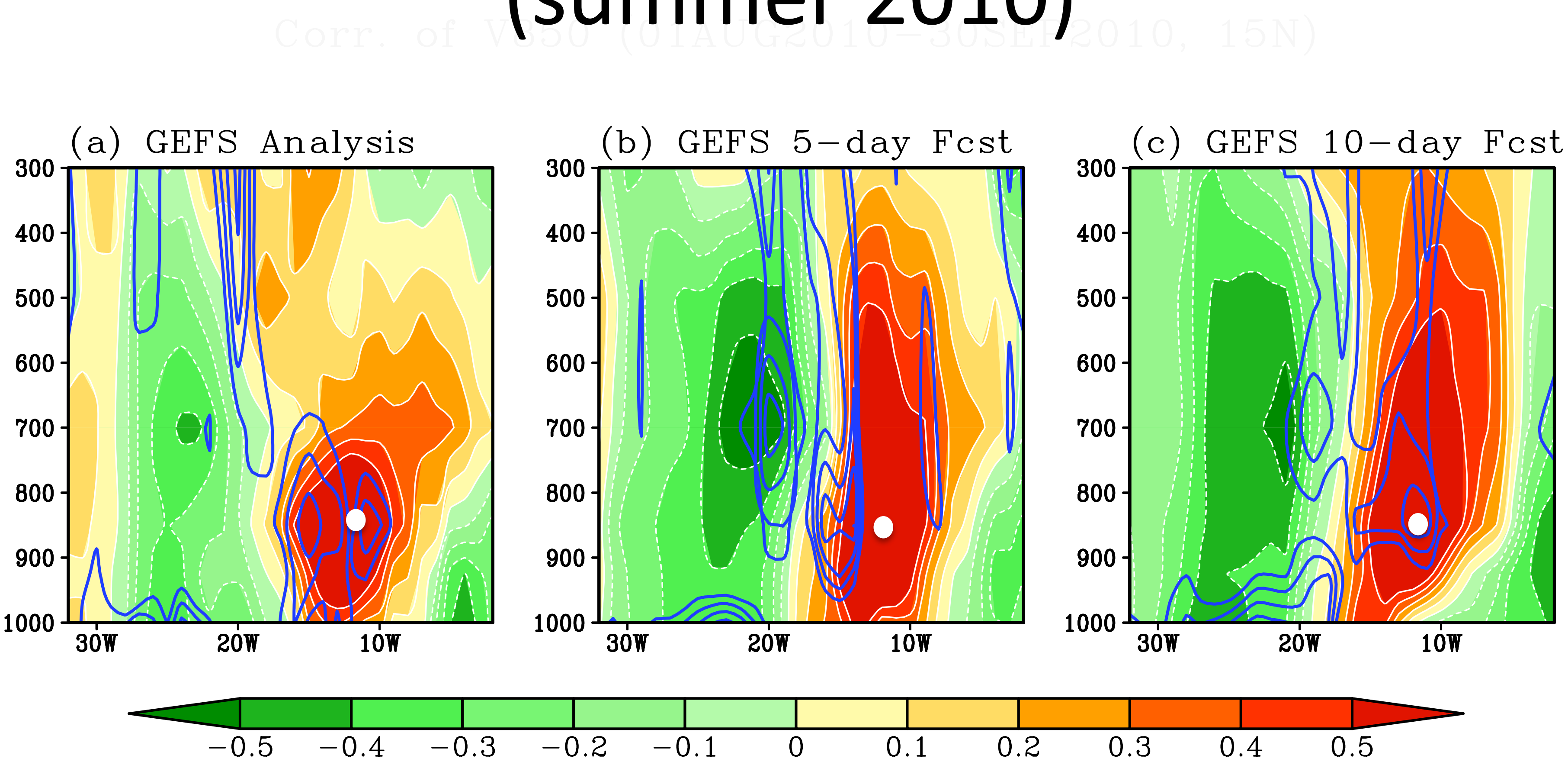
Hovmoller Diagram of V850 (15N, 2010)



Variance of V850 along 15N (summer 2010)



Vertical Cross Section of Correlation (summer 2010)



One-point correlation of V, with the reference point: 850 hPa, (15N, 12W)

Hyperactive convection over land leads to stronger AEWs of deeper vertical structure, and the early TC development (false alarms) off the coast.

1.2 MJO: boreal summer

Why are we interested in the MJO?

- The dominant mode of intraseasonal variability in the tropics, and plays a significant role in modulating the tropical weather and climate:
  - strong impacts on Asian and Australian monsoon and moderate impacts on the North American and South American monsoon (Lau and Chan 1986; Kiladis and Weickmann 1992; Mo 2000; Higgins et al. 2000)
  - plays an active role in the onset and development of ENSO (e.g., Zhang and Gottschalck 2002)
  - modulates tropical convection and tropical cyclone activity over the East Pacific and the Atlantic
  - has remote impacts in the extratropics and affects the midlatitude weather predictability (e.g., Liebmann and Hartmann 1984; Weickmann et al. 1985; Blade and Hartman 1995; Jones et al. 2004)
- An important source of predictability on the subseasonal scales.
- As a multi-scale process, it provides an ideal test bed to evaluate model physics across different spatio-temporal scales.
- MJO is stronger in boreal winter than in boreal summer.

Variance of band-pass filtered U200

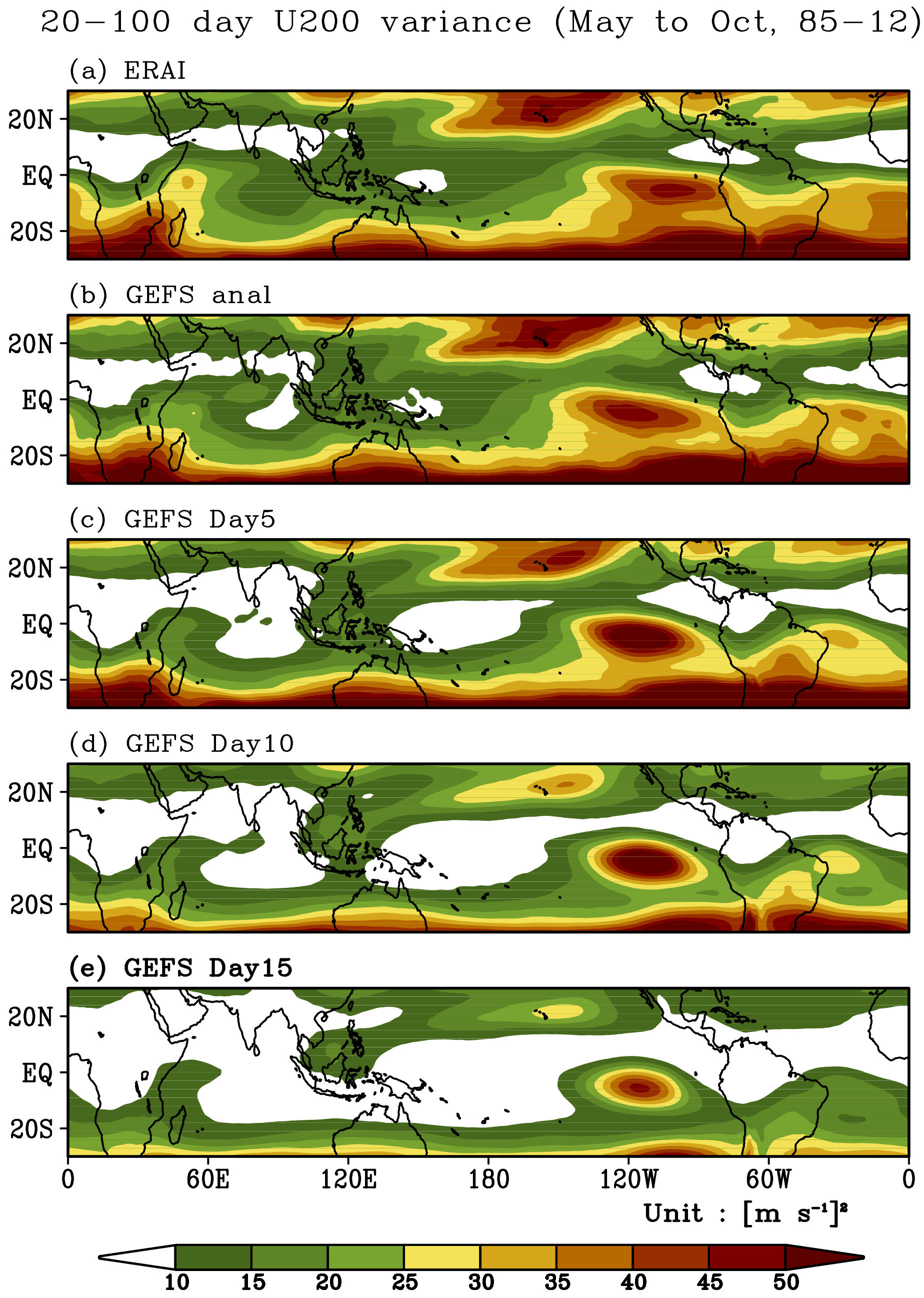
ERA-Interim

GEFS analysis

GEFS 5-day fcst

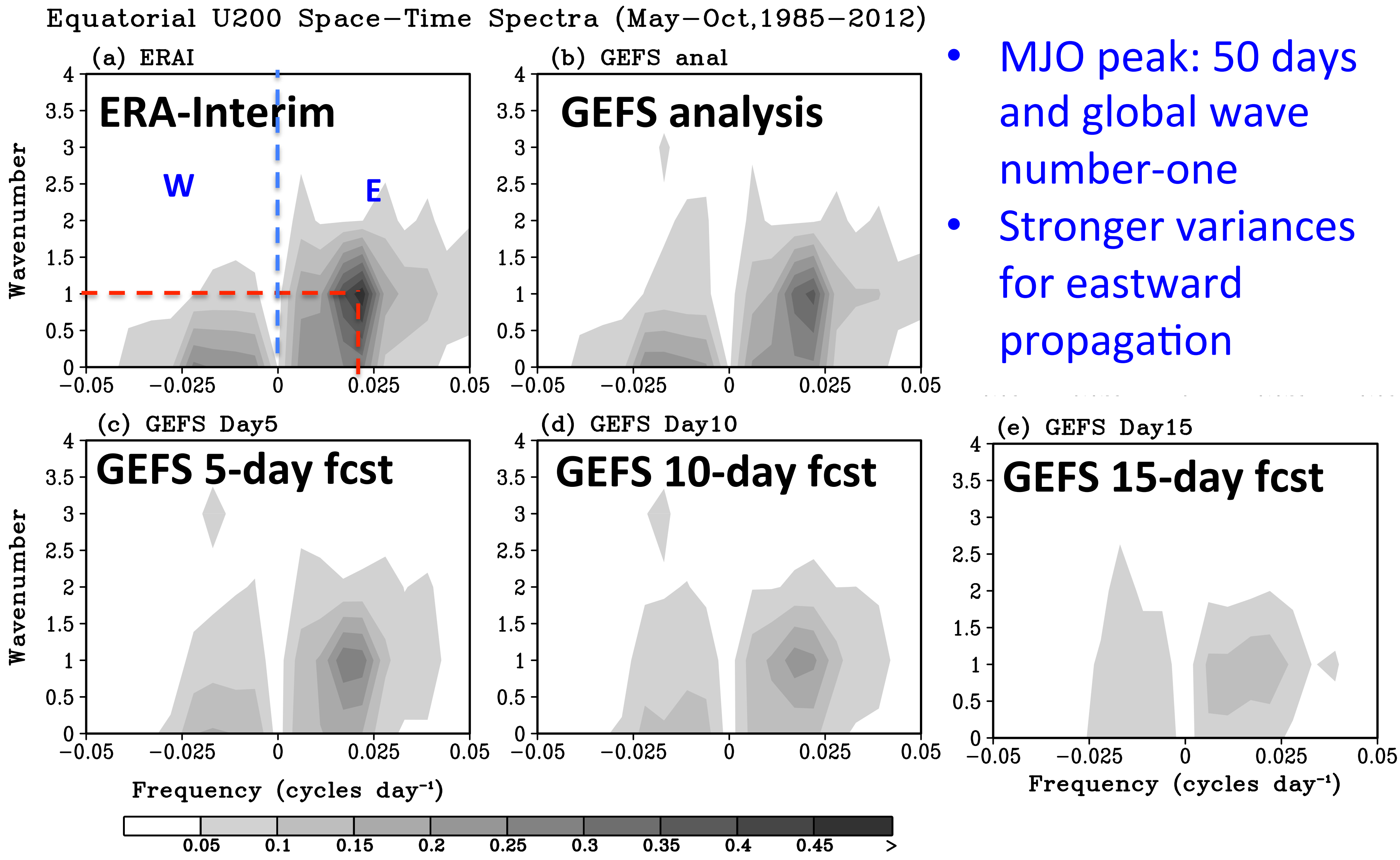
GEFS 10-day fcst

GEFS 15-day fcst



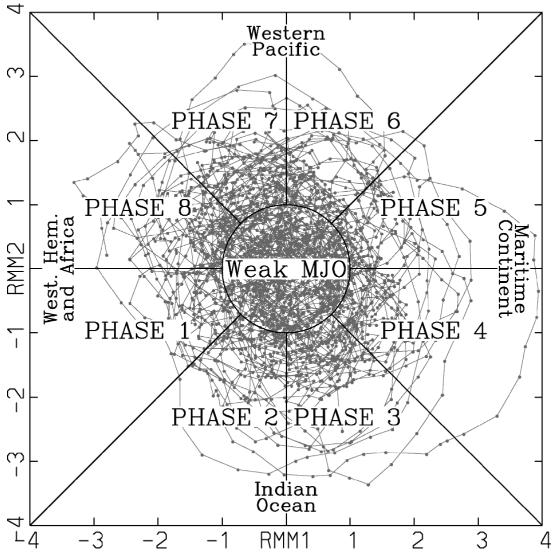
Wavenumber-frequency Diagram

Equatorial U200 Space−Time Spectra (May−Oct,1985−2012)

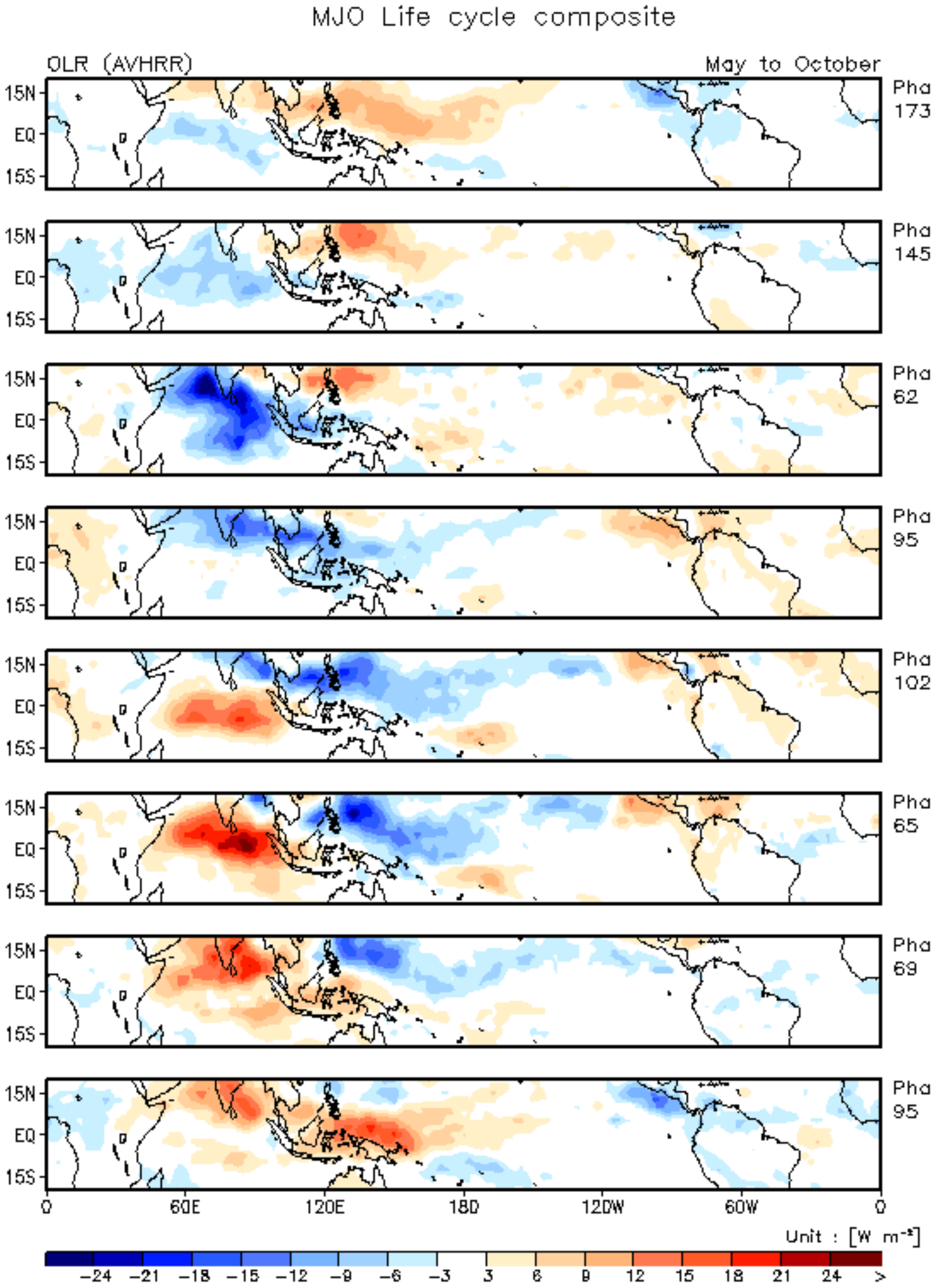


- MJO peak: 50 days and global wave number-one
- Stronger variances for eastward propagation

Composites based on the Real-time Multivariate MJO (RMM) Index: NOAA OLR



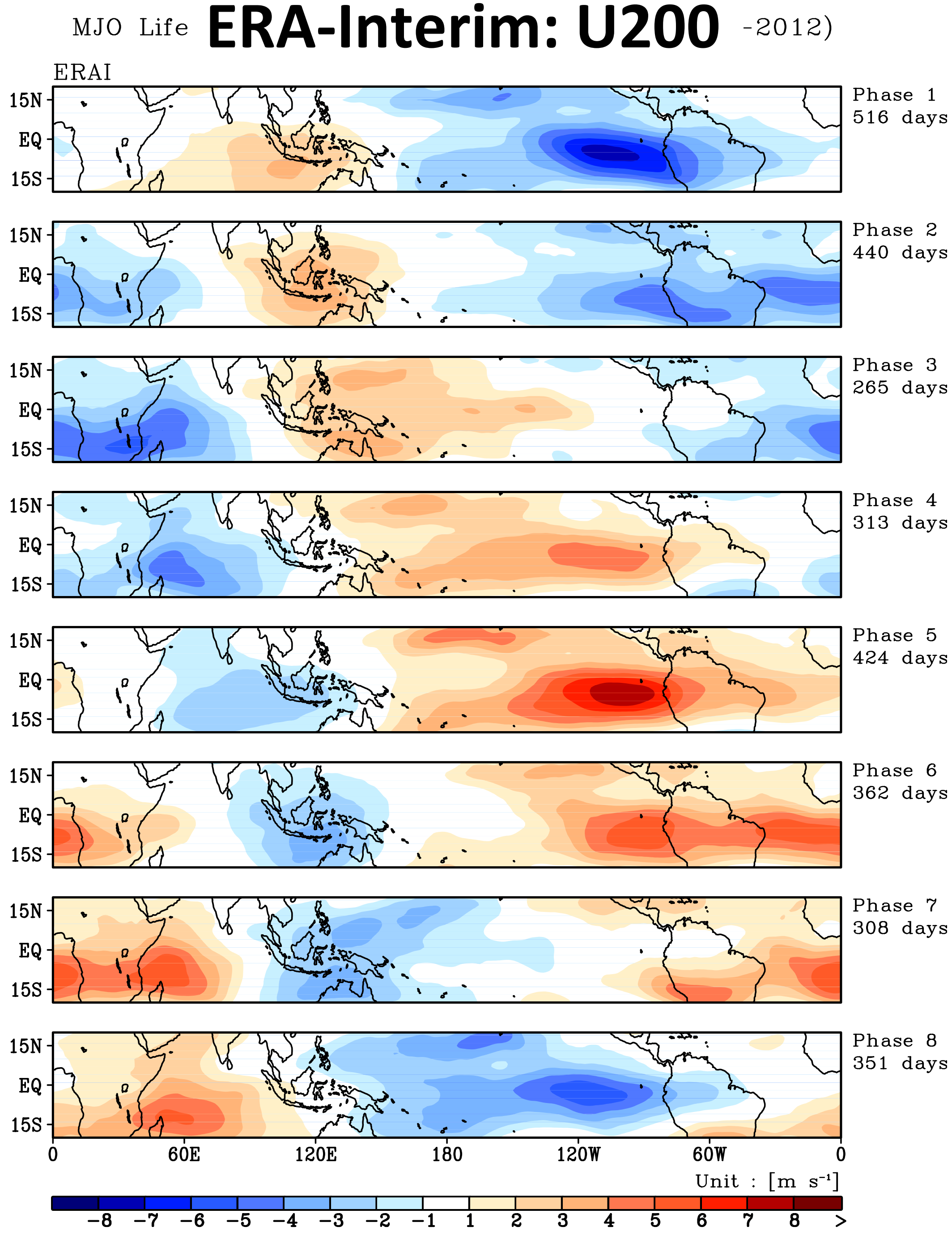
Wheeler and Hendon 2004



Phase 1

Phase 8

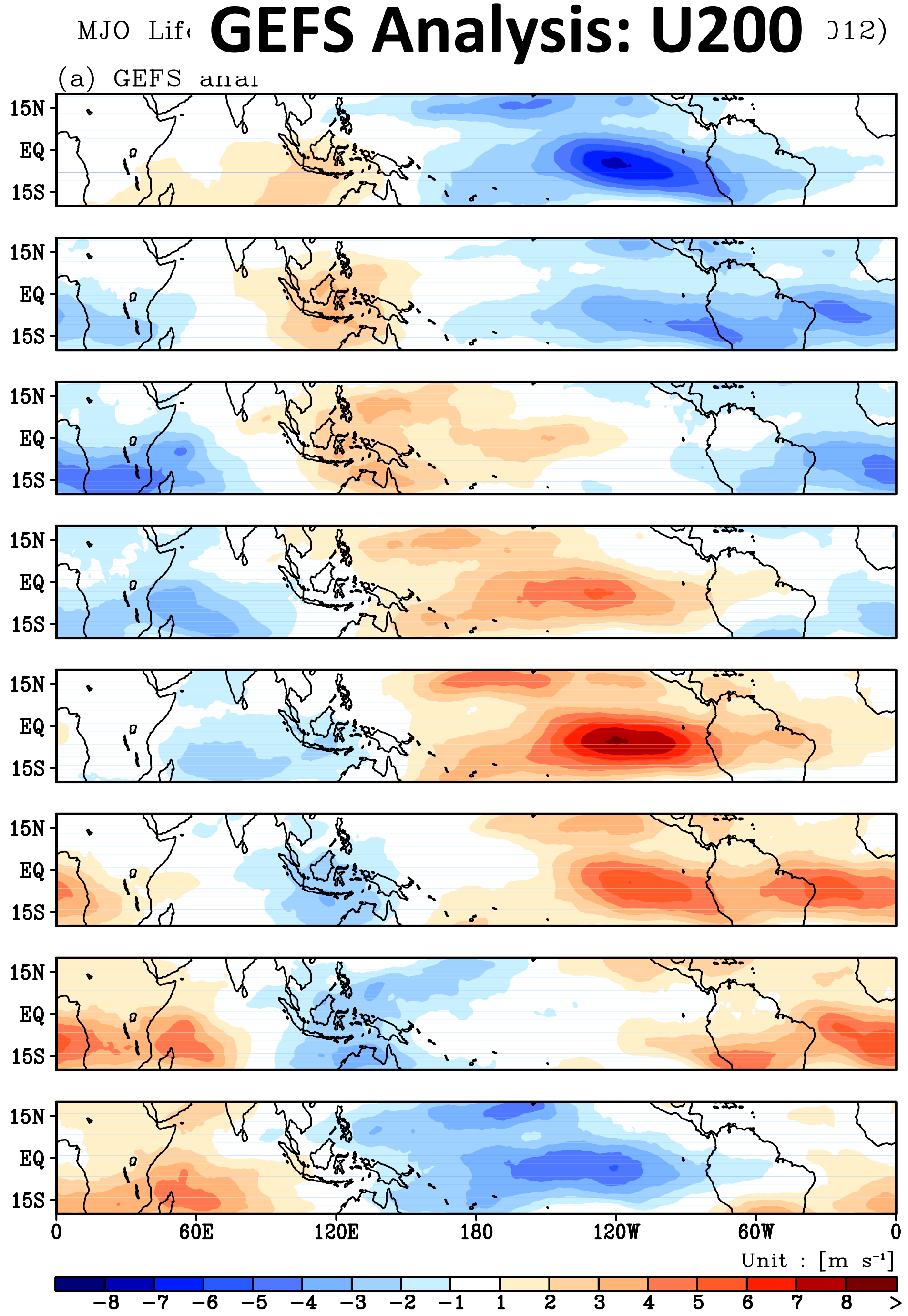
ERA-Interim: U200



Phase 1

Phase 8

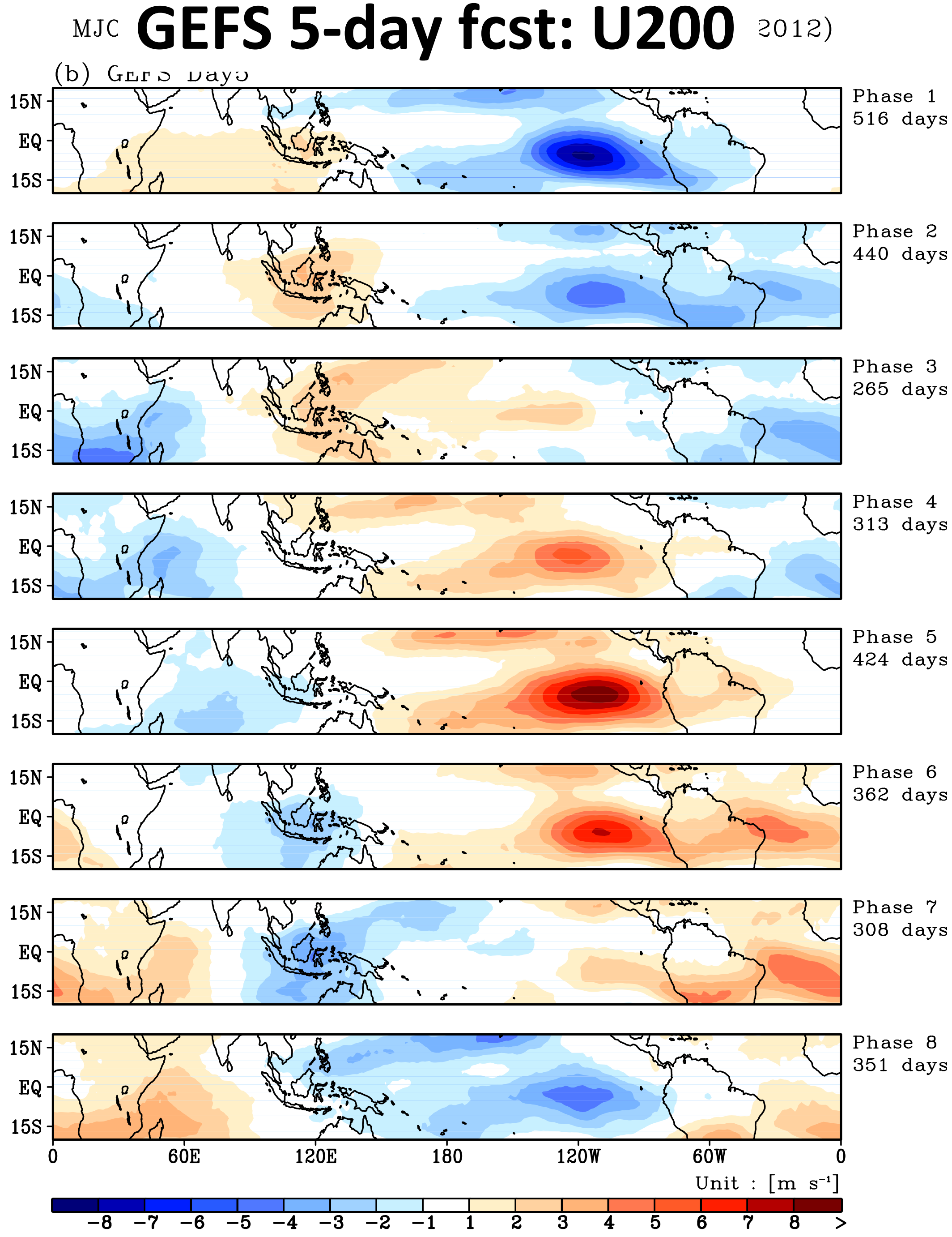
GEFS Analysis: U200



Phase 1

Phase 8

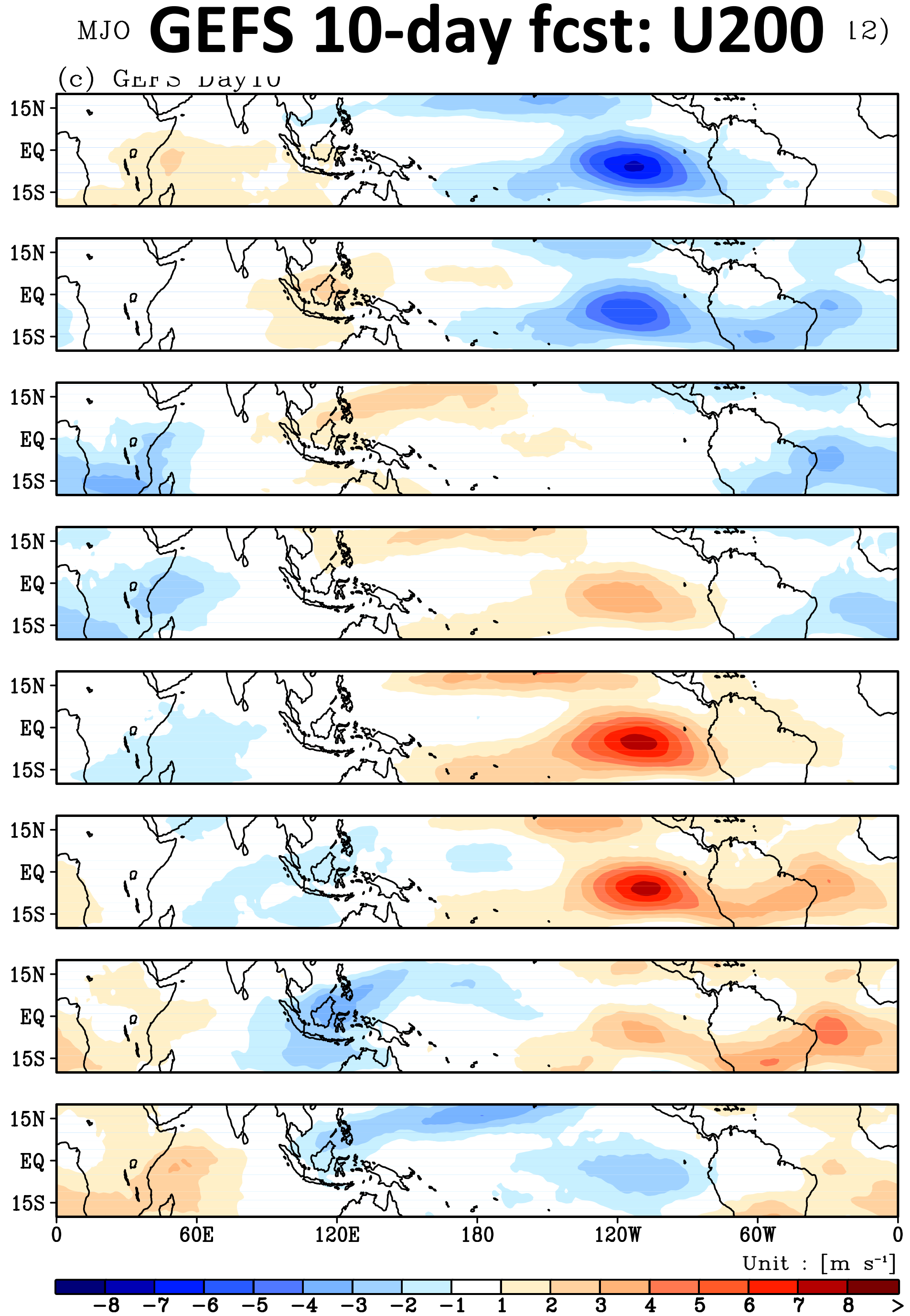
GEFS 5-day fcst: U200



Phase 1

Phase 8

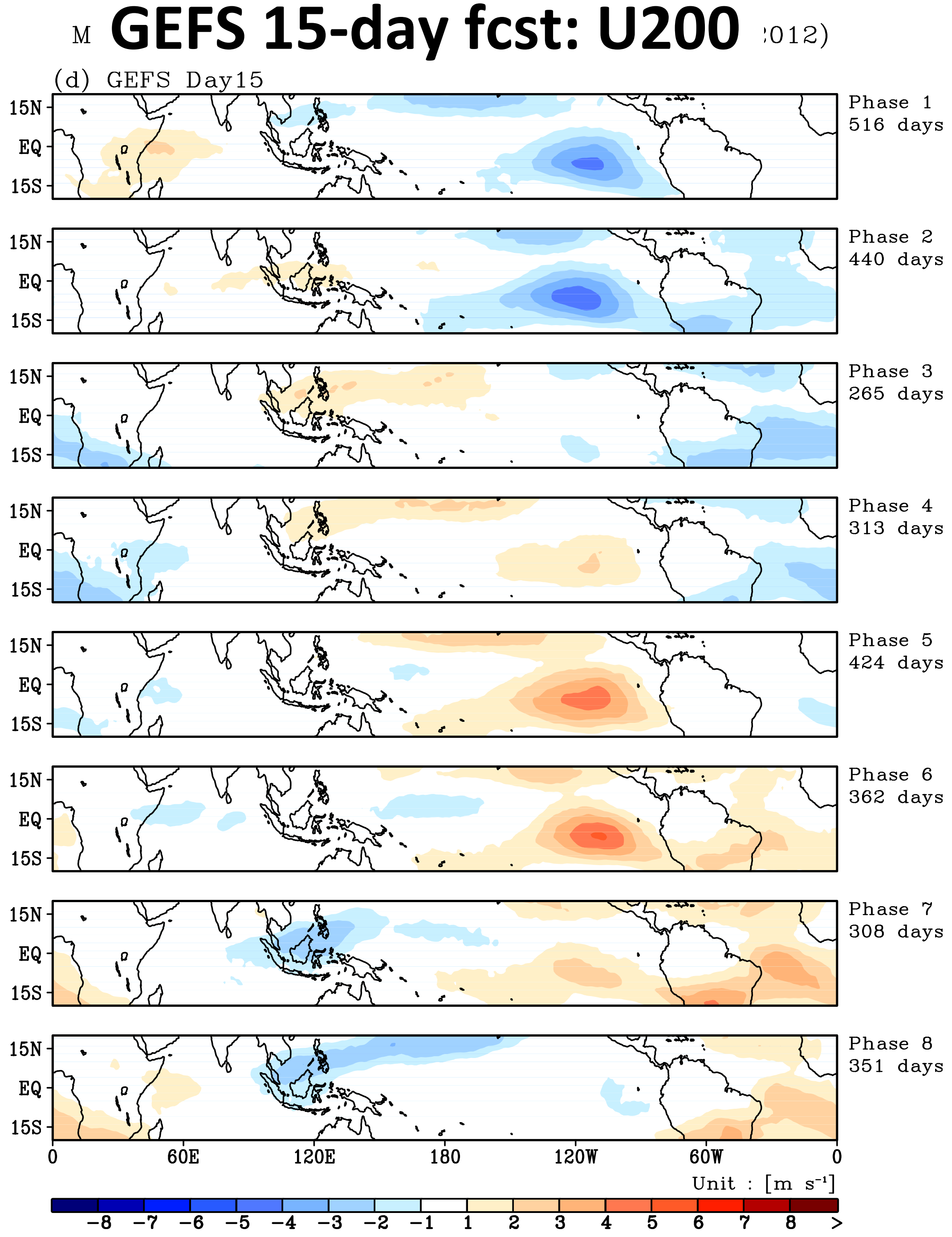
GEFS 10-day fcst: U200



Phase 1

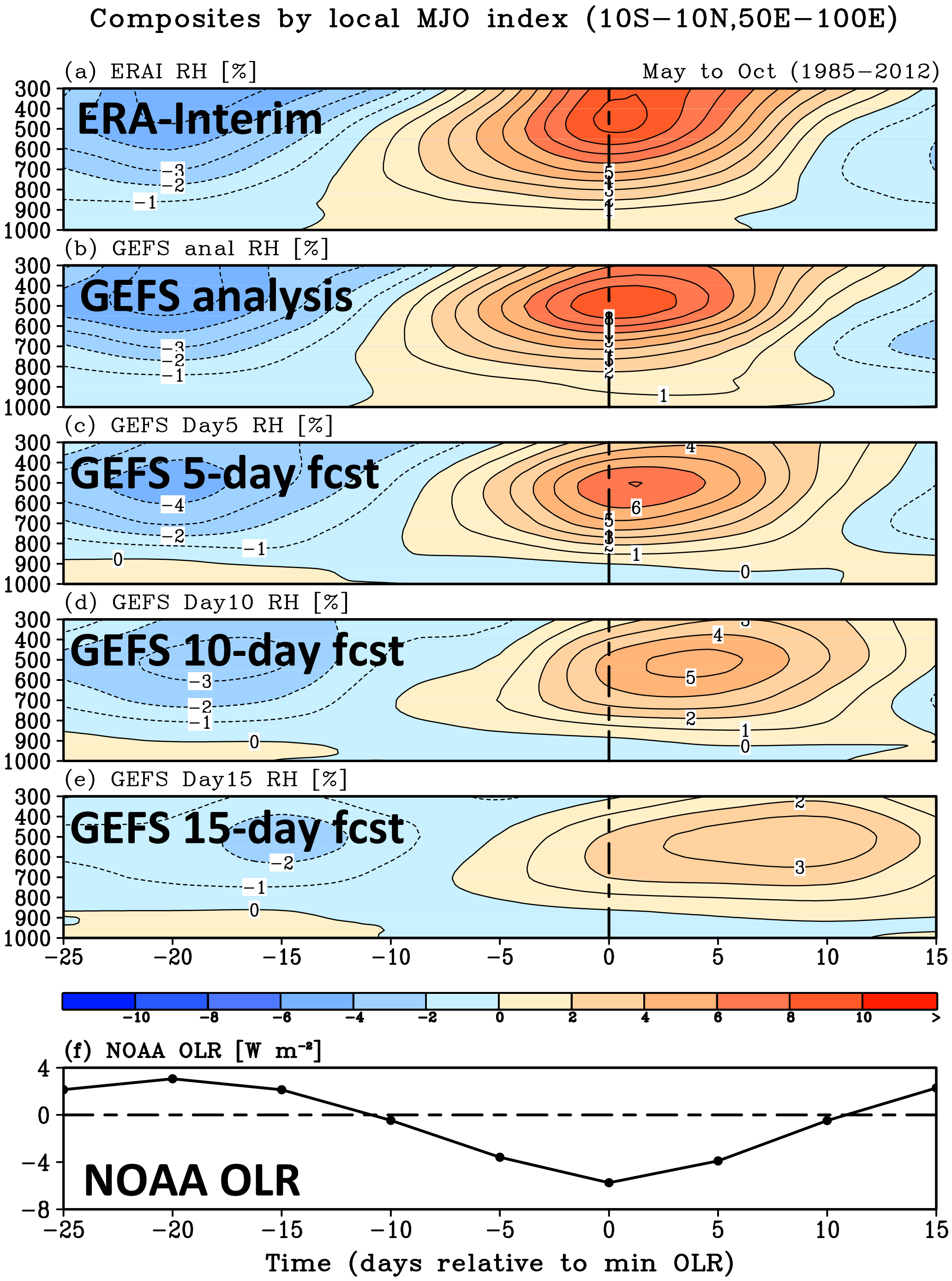
Phase 8

GEFS 15-day fcst: U200



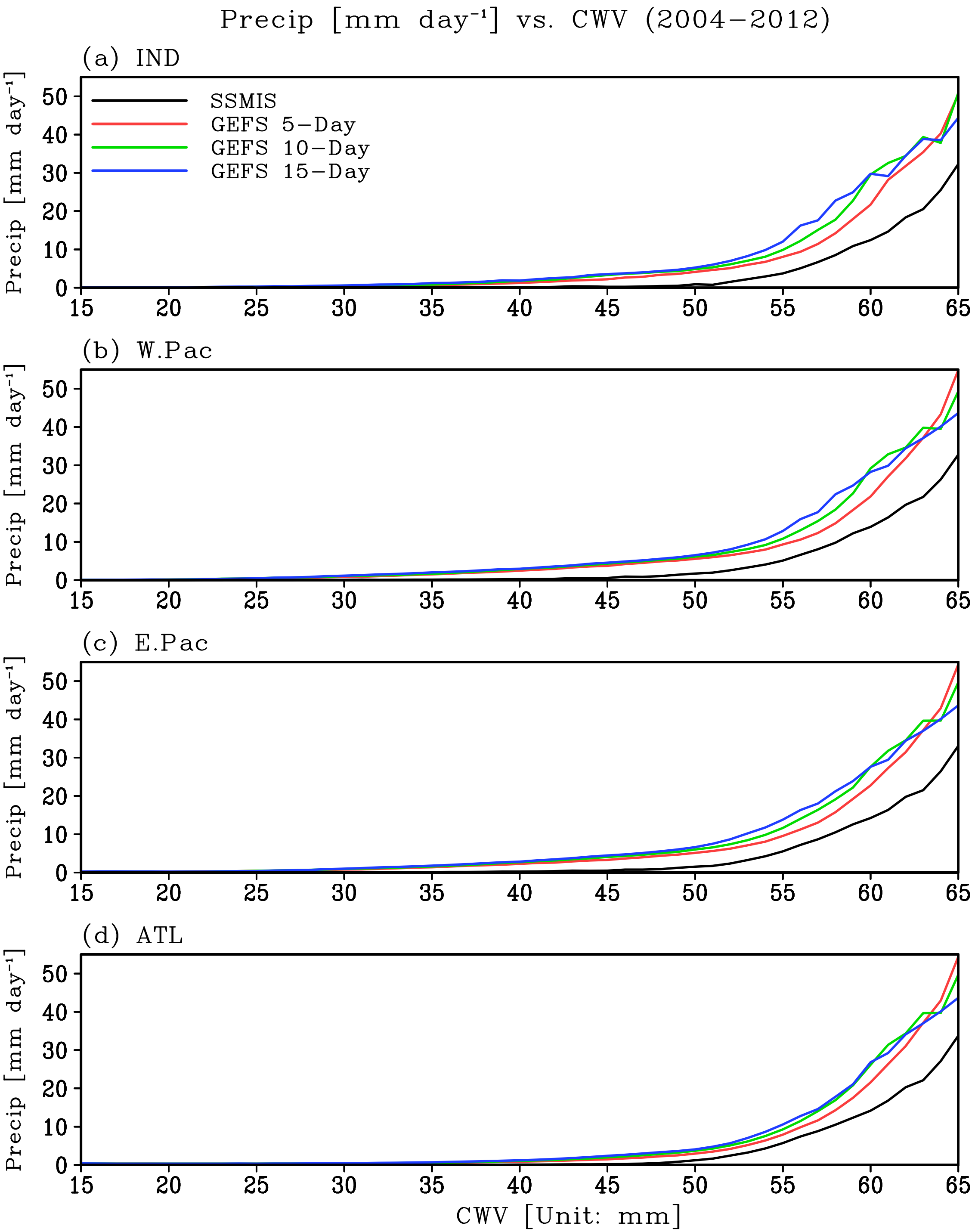
Phase 1

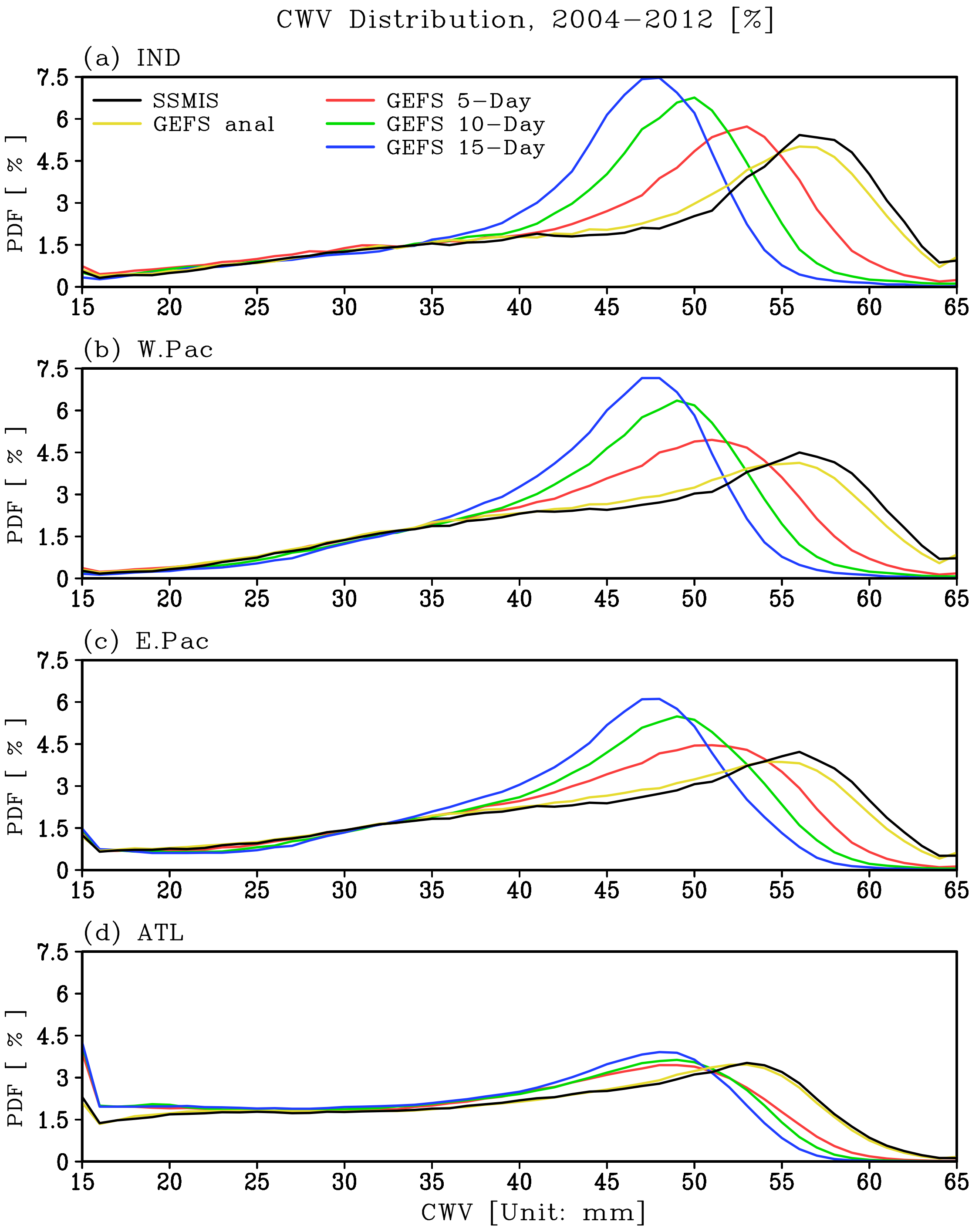
Phase 8

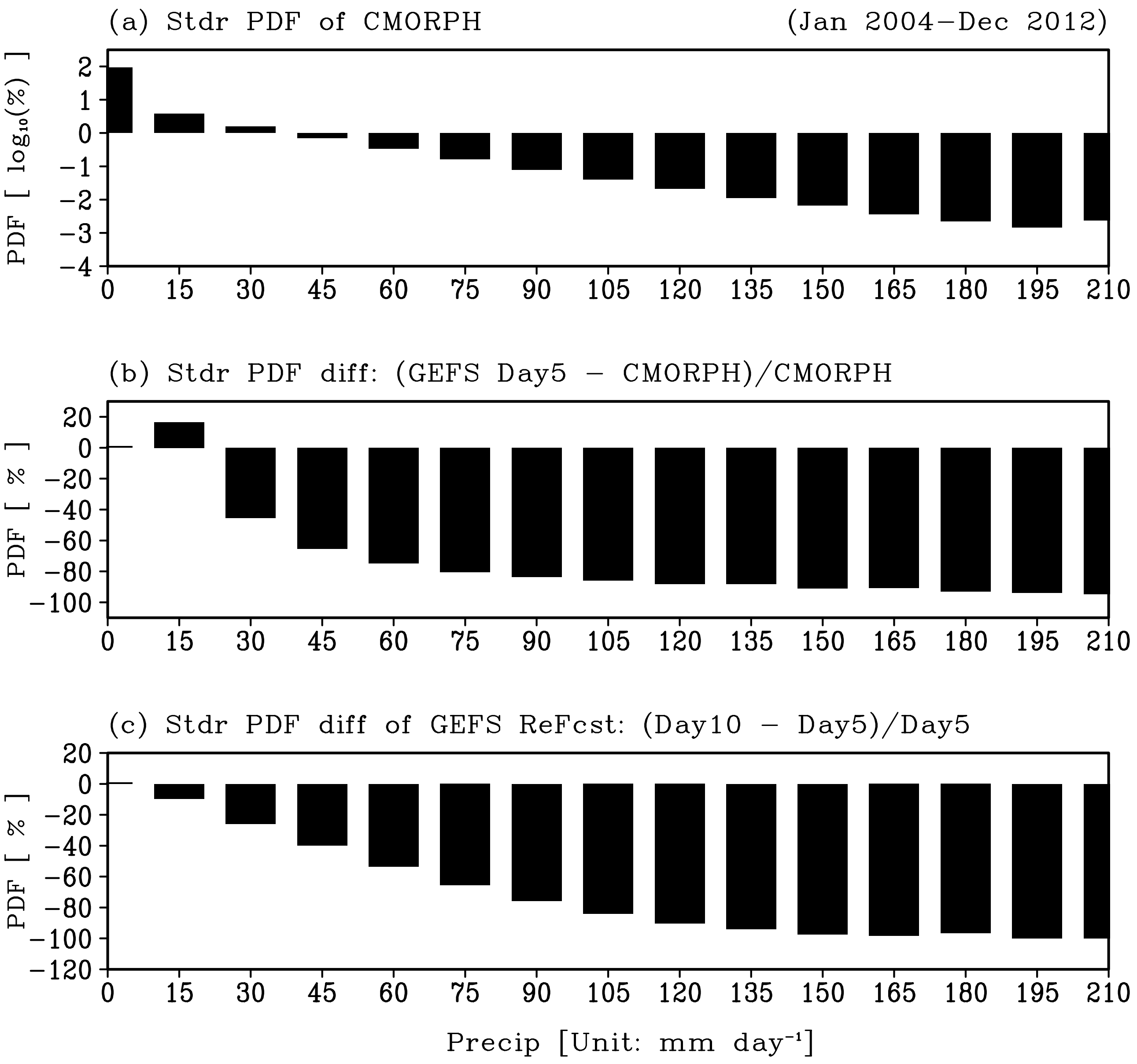


- A local MJO index was defined based on the band-pass filtered OLR.
- The magnitude of the RH anomalies weakens with the lead time.
- Are cumulus congestus and startiform precip. under-predicted in GEFS-R?

2. Precipitation Processes


Precip [mm day⁻¹] vs. CWV (2004–2012)
(a) IND
(b) W.Pac
(c) E.Pac
(d) ATL
SSMIS
GEFS 5–Day
GEFS 10–Day
GEFS 15–Day
Precip [mm day⁻¹]
0
10
20
30
40
50
15
20
25
30
35
40
45
50
55
60
65
CWV [Unit: mm]


CWV Distribution, 2004–2012 [%]
(a) IND
(b) W.Pac
(c) E.Pac
(d) ATL
SSMIS
GEFS anal
GEFS 5–Day
GEFS 10–Day
GEFS 15–Day
PDF [%]
0
1.5
3
4.5
6
7.5
15
20
25
30
35
40
45
50
55
60
65
CWV [Unit: mm]



Precipitation >= 30 mm day^{-1} is under-predicted in GEFS-R

The negative biases increase with the forecast lead time.

Summary of Preliminary Analyses

- GEFS captures the seasonality of TC activity reasonably well, but large errors are found in the spatial distribution of TC genesis.
- Biases in TC genesis can be attributed to the mean state errors over the West and East Pacific, such as the weaker monsoon trough and subtropical ridge, and the southward displaced ITCZ.
- High FAR near the West African coast can be attributed to the hyperactive convection and the resultant strong AEWs in GEFS.
- **Better prediction of the large-scale circulation and synoptic-scale waves can help improve TC forecasts.**
- MJO signals weaken quickly with increasing forecast lead time; the pre-moistening of the lower and middle troposphere was not well captured by the GEFS reforecasts.
- Significant dry bias in CWV was found in GEFS-R, and moderate to heavy precipitation was under-predicted in GEFS-R.

Work Plan: Physics-based Evaluations

1. Prominent Motion Systems
   - Blocking
     - Frequency of occurrence; extreme weather events; predictability
   - Teleconnection
     - Remote impacts of low-frequency perturbations
2. Specific Physical Processes
   - Q1/Q2 diagnoses
     - Shallow and deep heating modes; distribution and impacts
   - Model representation of different cloud regimes
     - Evaluated against satellite data; employ satellite simulators
   - Sensitivity tests on model physics and resolution

Two Phases

- Phase 1: The products will be developed and tested using the GEFS reforecasts.
- Phase 2:
  - Generalize the products for other models;
  - Carry out an inter-model comparison using the HIWPP data.

END OF PRESENTATION