The Rossby Wave Source Influence on the Predictability of the MJO Response: A New Pathway of the Influence of Mid-Latitude Transients?

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Intrinsic Predictability Limits arising from Indian Ocean MJO Heating: Effects on tropical and extratropical teleconnections

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Intrinsic Predictability Limits of the S2S Response to the MJO

Tropical heating in general is highly intermittent in space and time

This is true even *even within a single episode of the MJO*.

The precise evolution of the heating is therefore presumably not predictable on S2S time scales.

Goal: Study the limits on predictability that are imposed by our inability to predict the precise space-time evolution of the MJO tropical heating, even if we can predict its envelope.

Discussion today: What role does uncertainty in the Rossby wave source play in limiting extra-tropical predictability?

Role of the Rossby Wave Source in the Response to the MJO

Stationary wave theory was designed to explain the time mean extra-tropical response to a time mean forcing.

It is widely used to understand the extra-tropical response to the MJO.

This assumes that the MJO heating is quasi-stationary (for ~ 10-20 days?)

The Rossby wave source was developed to help understand the time mean, extra-tropical barotropic response to time mean upper-level tropical divergence (a proxy for tropical heating)

Here we try to understand the predictability of the Rossby Wave Source itself by considering its evolution in time.

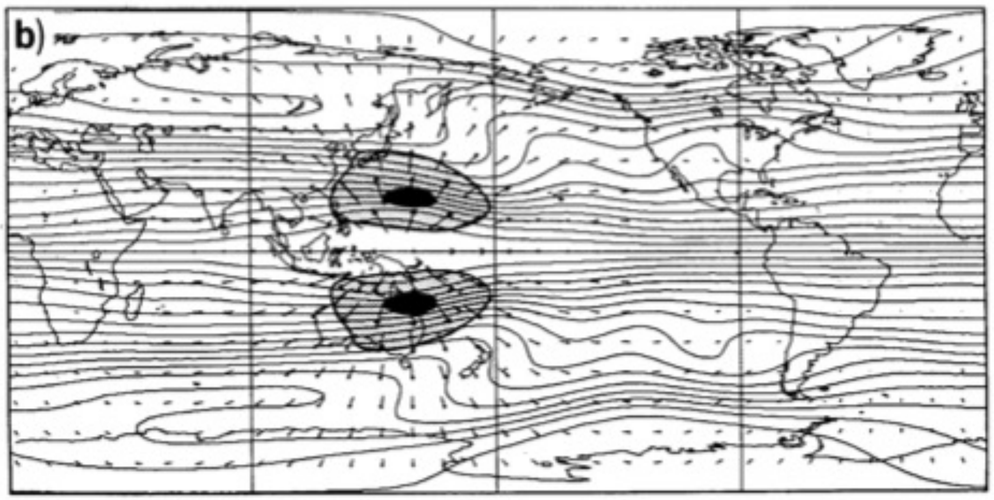


FIG. 2. (a) Rossby wave source S (shaded; units $10^{-11}\ s^{-2}$) on day 0. The steady divergent wind vectors and the initial absolute vorticity ($10^{-5}\ s^{-1}$) that determine this source are also shown. (b) as in (a) but on day 48 of the fully nonlinear integration. The largest divergent winds in the subtropics are about 5 m s^{-1}.

The Rossby Wave Source

Sardeshmukh and Hoskins (1988) pointed out that upper-level tropical divergence alone is not enough to force stationary waves in the extra-tropics if the divergence is located in background Easterlies (which it is for phase 3 of the MJO).

The Rossby Wave Source S includes all baroclinic forcing terms in the barotropic vorticity equation. It is maximum in the sub-tropics, with background westerlies. It can be thought of as forcing extra-tropical stationary waves .

$$S = -\vec{\nabla} \cdot (\vec{v}_\chi \zeta_a) = -D\zeta_a - \vec{v}_\chi \cdot \vec{\nabla}\zeta_a$$

$$S = S_{stretch} + S_{advect}$$

D = Divergence

ζ_a= Absolute Vorticity

$\vec{v}_\chi$= divergent component of wind

A Model Study (ECMWF's Integrated Forecast System – IFS Cycle 43r3)

Ensemble reforecasts from MJO initial conditions (61-days)

For each initial condition, the ensemble members differ from each other only because of perturbations introduced throughout the run in the tropical Indo-Pacific region. (*The initial conditions are NOT perturbed*)

The ensemble spread is entirely due to the uncertainty in the output of the physical parameterizations in the tropical Indo-Pacific region.

Experimental Configuration

ECMWF IFS Cycle 43r3

Atmospheric Model Resolution: 36 km horiz. resolution – 91 levels up to 0.01 Pa

NEMO Ocean Model v3.4.1 (1/4 degree horiz. resolution)

INITIAL CONDITIONS (all having MJO phases 2 and 3 at initial time)

8 start dates for 1 Nov (different years), 5 start dates for 1 Jan (different years)

Reforecasts for 61 days, each with an ensemble of 51 members (so 663 reforecasts in total)

Perturbations: The ECMWF model incorporates stochastic perturbations to the tendencies produced by sub-grid scale processes *as an integral part of the model,* so the only change we have made is to limit the application of these perturbations to the tropical Indo-Pacific region

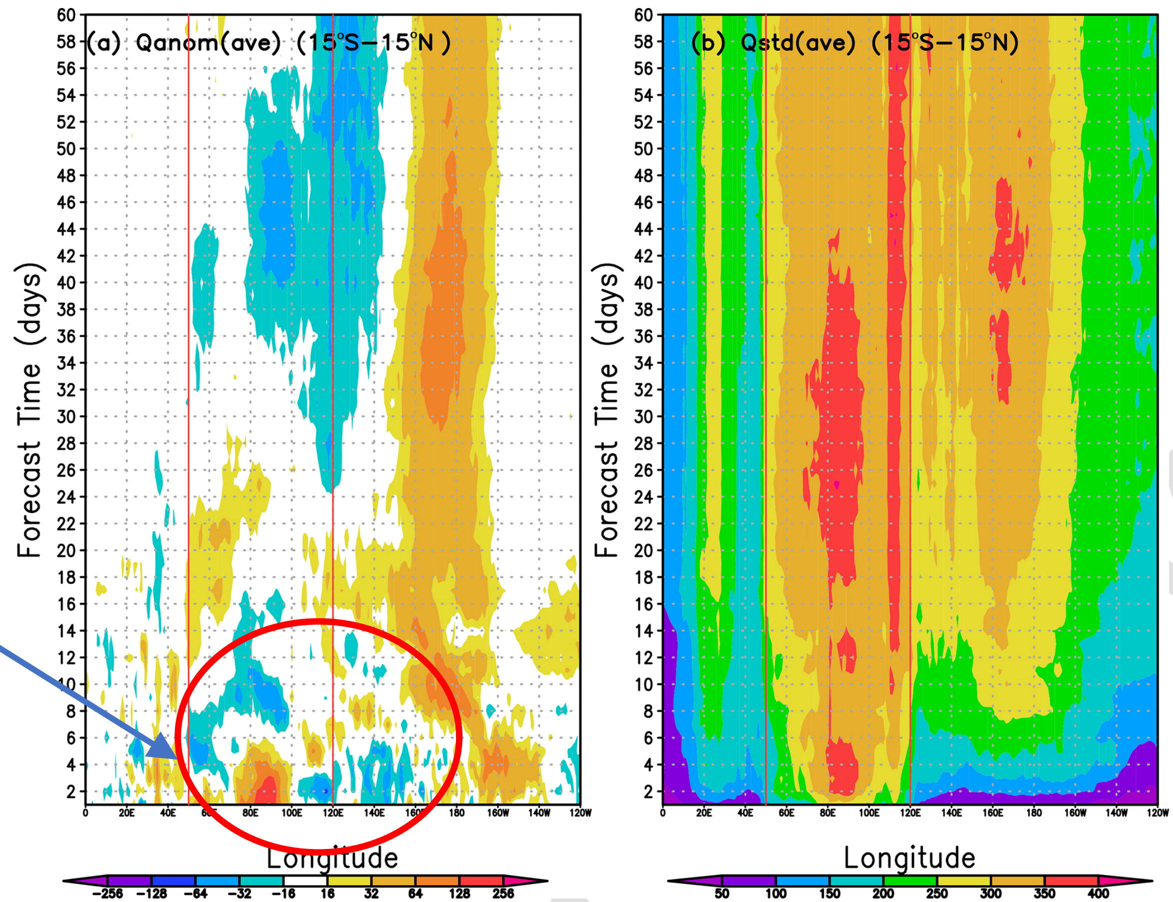
Table 1. Summary of the model runs performed for this study, for the November start dates (left) and the January start dates (right).

Start date	Ensemble size	Start date	Ensemble size
01 Nov 1986	50+1	01 Jan 1987	50+1
01 Nov 1987	50+1	01 Jan 1990	50+1
01 Nov 1990	50+1	01 Jan 1995	50+1
01 Nov 2001	50+1	01 Jan 2010	50+1
01 Nov 2002	50+1	01 Jan 2013	50+1
01 Nov 2004	50+1		
01 Nov 2011	50+1		
01 Nov 2015	50+1		
01 Nov 1981..2016	8+1	01 Jan 1981..2016	8+1

Daily Ensemble Mean of vertically integrated diabatic heating

Longitude Time Plot

MJO signal is apparent in the first 10 days



Daily Ensemble Spread of vertically integrated diabatic heating

Longitude Time Plot

Red dotted lines give the region of perturbations

Note large spread compared to signal

Figure 1. **(a)** Evolution of the daily mean, ensemble mean anomaly of diabatic heating anomaly Q (averaged 15° S–15° N) for days 1–60 of the 60 d experiments averaged over all experiments. **(b)** The evolution of the ensemble standard deviation of the daily mean heating (vertically integrated and averaged 15° S–15° N) averaged over all experiments. The abscissa gives the forecast time in days. The red lines indicate the range of longitudes over which the stochastic parametrization was applied. Units are watts per square meter ($W\,m^{-2}$).

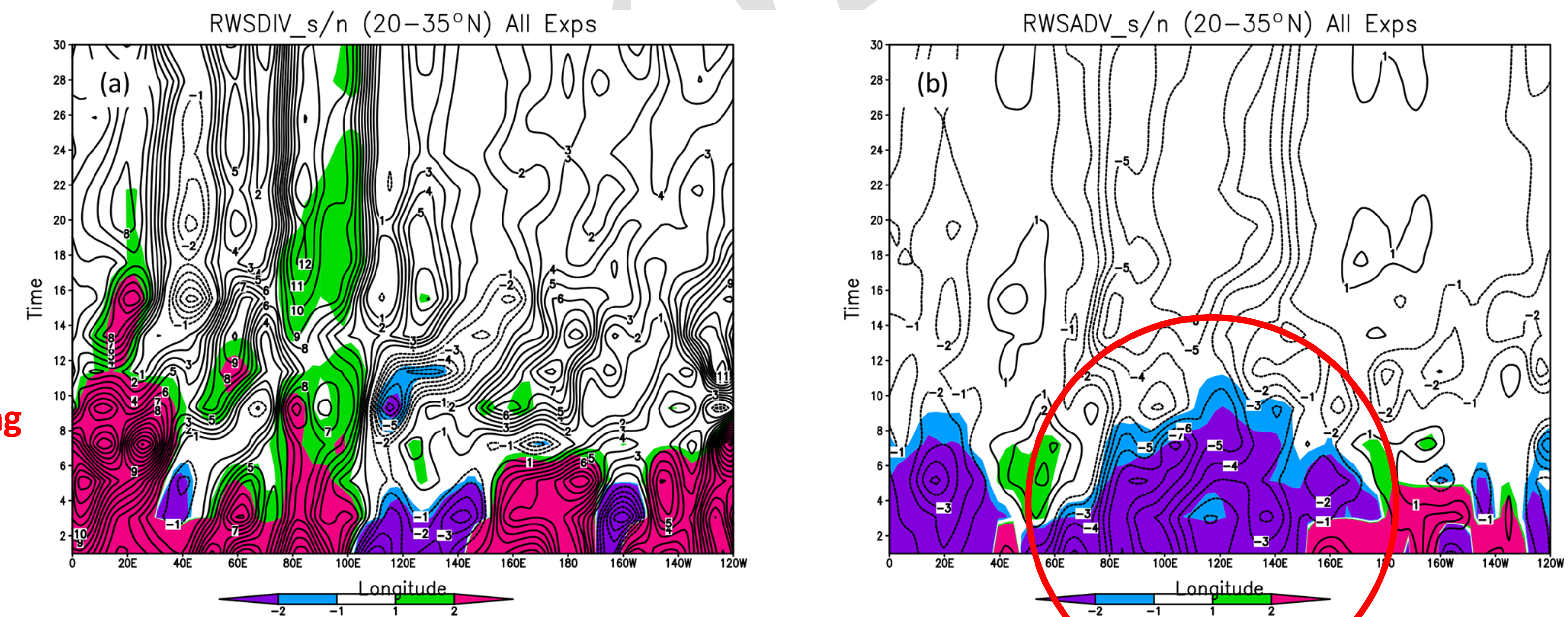
The Rossby wave source Signal

Evolution of the Two Rossby wave source components [averaged 20°N – 35°N]

Averaged over all ensemble members and experiments

Colors give ratio of ensemble mean to ensemble spread.

Stretching Term



Advection Term shows more consistent propagation

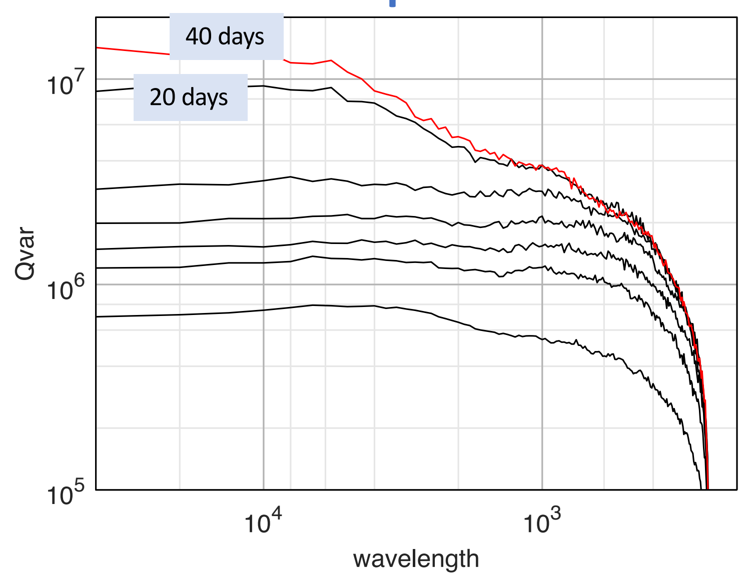
Figure A2. Evolution of the two components of the Rossby wave source (S): **(a)** the stretching term and **(b)** the advection term (as in Eq. 1), averaged over all experiments. The terms were computed at the equivalent of T21 triangular spectral truncation (see text for details). S was averaged between 20 and 35° N. The color scale gives the ratio of the ensemble mean to ensemble spread. The units of the RWS are meters per second ($\mathrm{m\,s^{-1}}$).

Error Spectra of Tropical Heating

-- nearly white (flat spectrum) initially associated with localized heating error

-- Errors at largest scales grow most slowly. Even after 40 days the largest scales have not saturated.

-- some expectation that mid-latitude response most sensitive to largest scales of heating)



Zonal wavenumber spectra of error variance in mid-level tropical diabatic heating Q_{mid}* (avg 15S-15N). Black lines give error of 2-day averaged Q_{mid} for 1-2 days, 3-4 days, 5-6 days, 9-10 days, 19-20 days and 39-40 days. Red line gives error for days 59-60.

Q_{mid} is heating averaged between 850 and 400 hPa

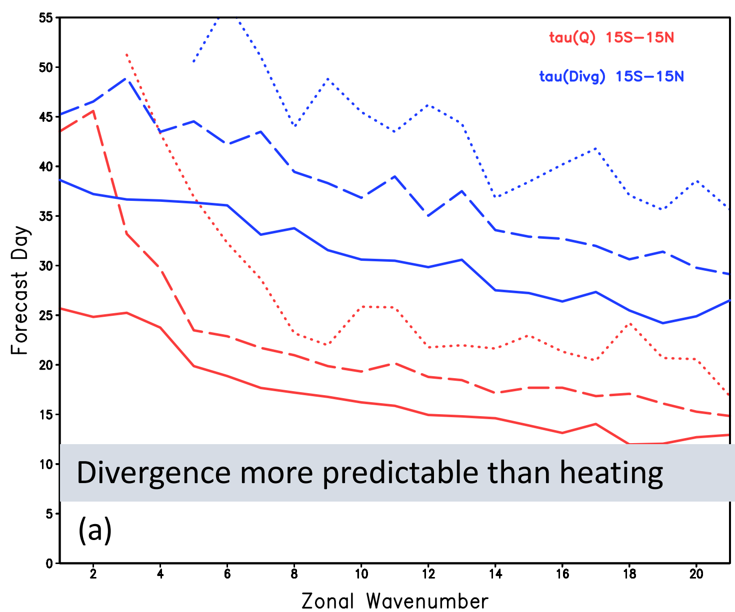
Predictability Times

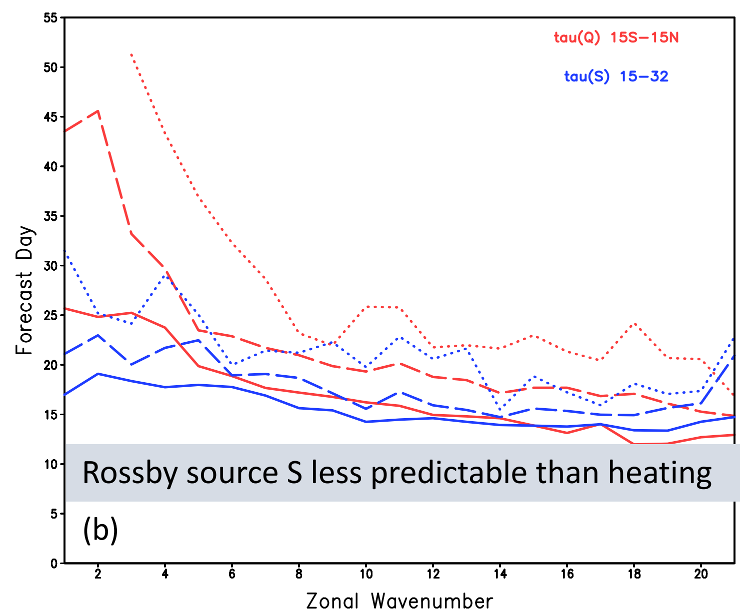
Times at which error variance reaches a certain fraction of saturation as a function of zonal wavenumber

solid lines : error variance reaches 50% of saturation

dashed lines: error variance reaches 70% of saturation

dotted lines: error variance reaches 90% of saturation





Predictability Times for Heating

Predictability Times for 200 hPa divergence

both averaged 15S – 15N

Predictability Times for Heating

Predictability Times for S (Rossby Wave Source)

Rossby Wave Source averaged 15N – 32N

Comparison of Predictability Times for the Largest Scales

-- Tropical upper-level divergence is more predictable than heating. The divergence in some sense integrates over details of the heating

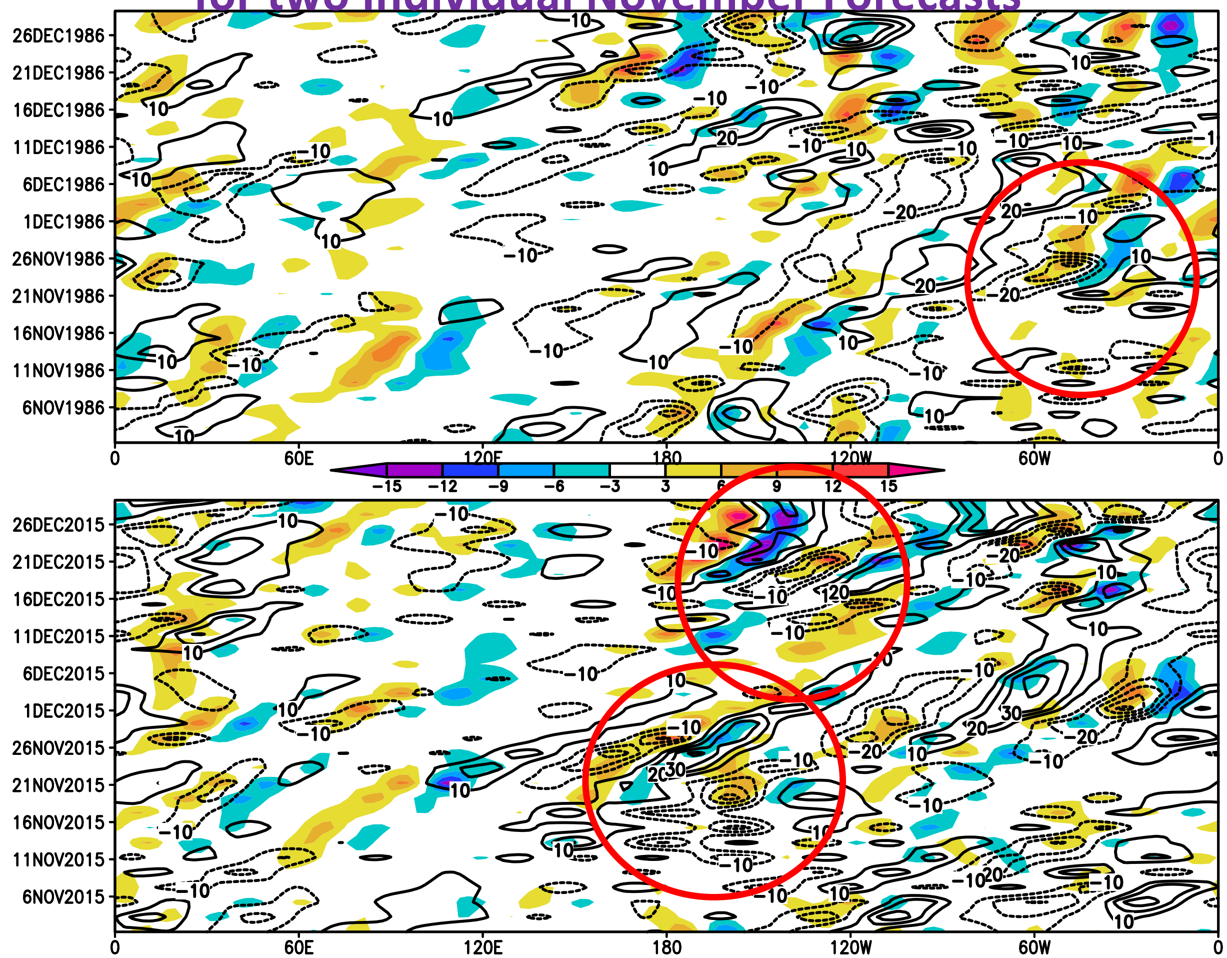
-- Subtropical Rossby Wave Source is less predictable than the heating !!

-- What is limiting this predictability?

Comparison of Rossby Wave Source Colors with Storm Tracks (Contours) for two Individual November Forecasts

*Storm Track indicator is deviation of meridional wind v from its 60-day time average [40N – 50N]

Rossby Wave Source averaged [20N – 35N]

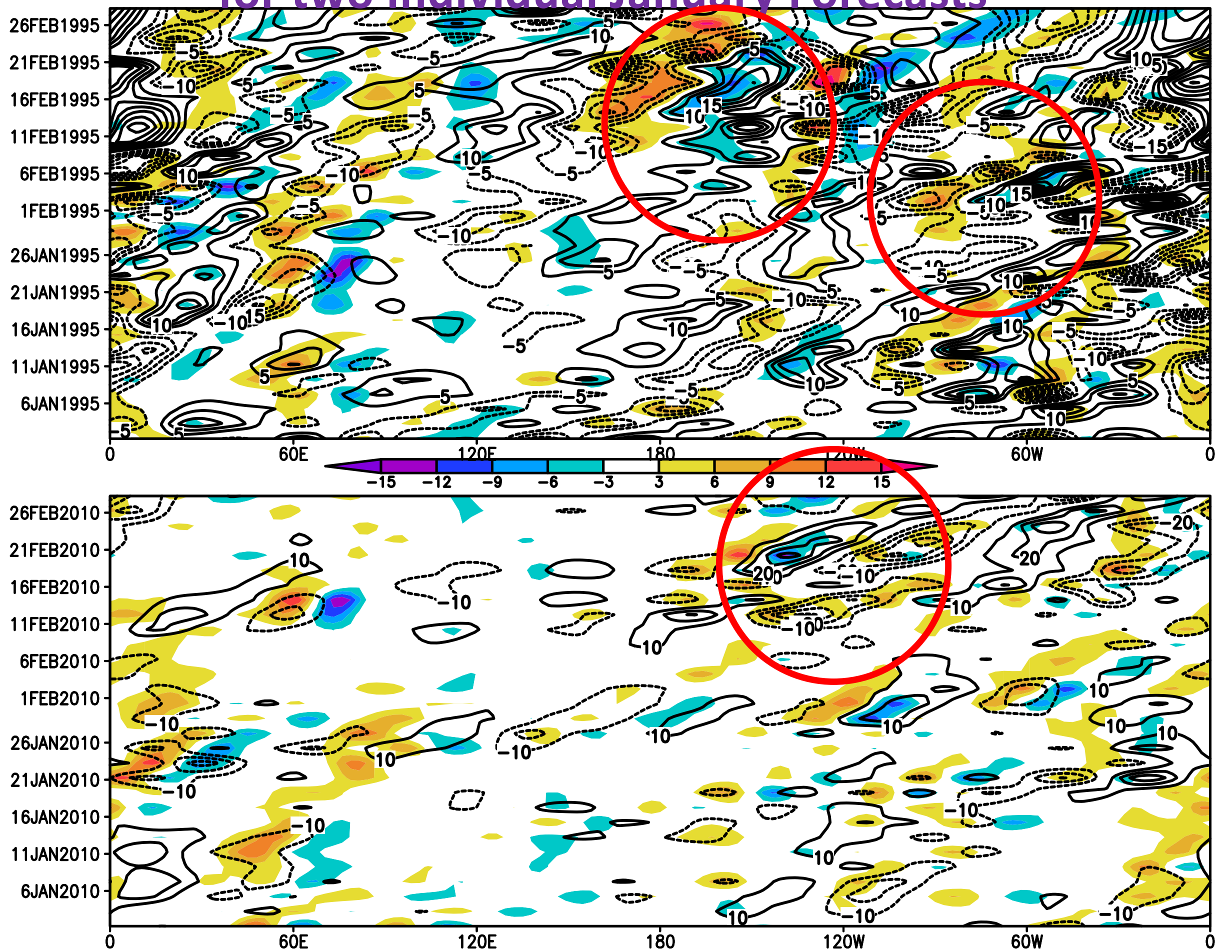


Note periods for which the RWS follows the storm tracks !!!

Comparison of Rossby Wave Source Colors with Storm Tracks (Contours) for two Individual January Forecasts

*Storm Track indicator is deviation of meridional wind v from its 60-day time average [40N – 50N]

Rossby Wave Source averaged [20N – 35N]



Note periods for which the RWS follows the storm tracks !!!

Comparison of Rossby Wave Source with Storm Tracks
Tentative Conclusions

-- The evolution of the synoptic systems in mid-latitudes seems to (at times) dominate the evolution of the Rossby Wave Source

-- Mechanism likely effect of upper-level divergence and strong divergent outflow associated with strong storms influencing the Rossby wave source

-- This is an alternative way to understand the role of transient eddies (the “noise”) in limiting our predictability of the MJO response in the extra-tropics.

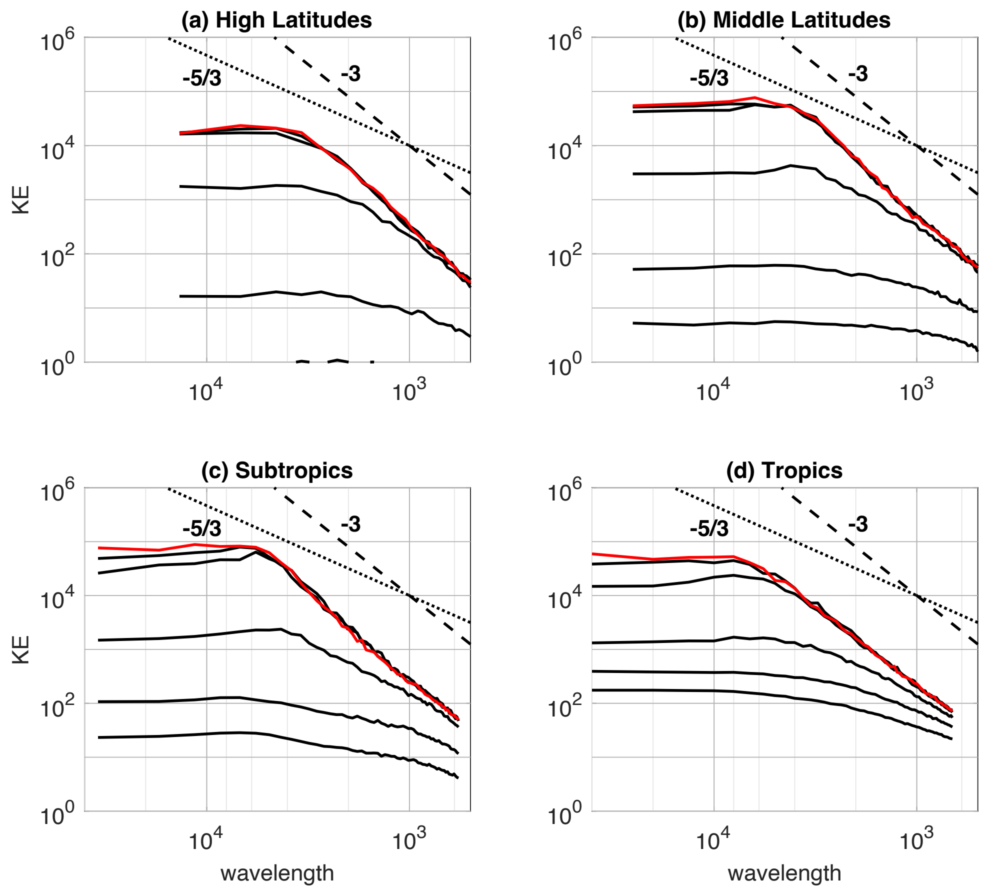
Current and Future Work

-- More systematically determine the relationship between the Rossby Wave Source signal and noise to storm track influence

-- Case studies to identify the precise mechanism.

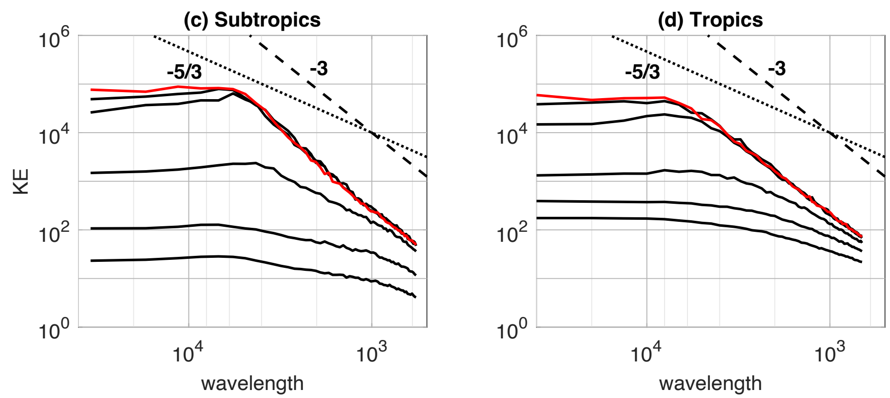
Error variance of 300 hPa kinetic energy for forecast days 3, 5, 10, 20, 30 and **60**

(a) High Latitudes 65N-75N
(b) Middle Latitudes 45-55N
(c) Subtropics 25-35N
(d) Tropics 15S – 15N



Spread of error from tropics to higher latitudes:

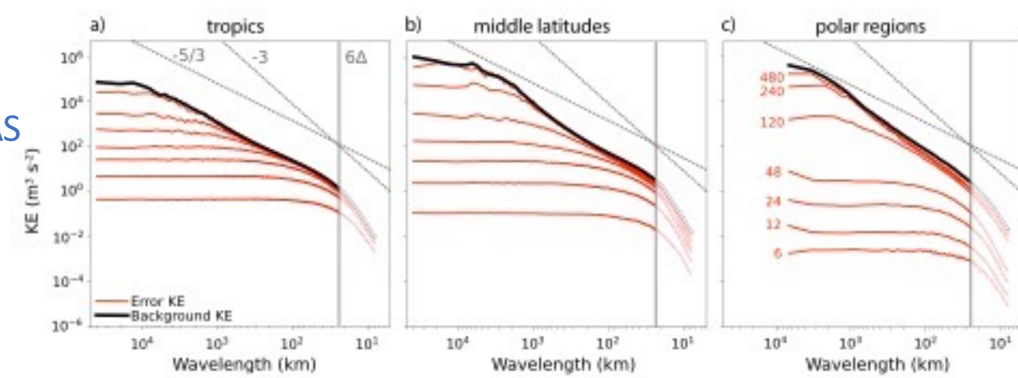
For any fixed forecast range, the error decreases as you move away from the tropics



TROPICS ECMWF

Tropical spectra:
~ k^{-3} dependence for ECMWF
~ $k^{-5/3}$ dependence for MPAS

TROPICS MPAS



~$k^{-5/3}$ characteristic of convection, divergent modes, gravity waves

FIG. 5. Background KE spectra (black) and error KE spectra (red), vertically averaged over the (a) tropics, (b) middle latitudes, and (c) polar regions. Error spectra are valid at 6, 12, 24, 48, 120, 240, and 480 h, as indicated by the red numbers in (c). Background spectra are

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MPAS 4 km resolution

Atmospheric Predictability of the Tropics, Middle Latitudes, and Polar Regions Explored through Global Storm-Resolving Simulations

FALKO JUDT