NOAA Earth System
Research Laboratory

Blocking and the MJO in GEFS reforecasts: forecast skill and interactions

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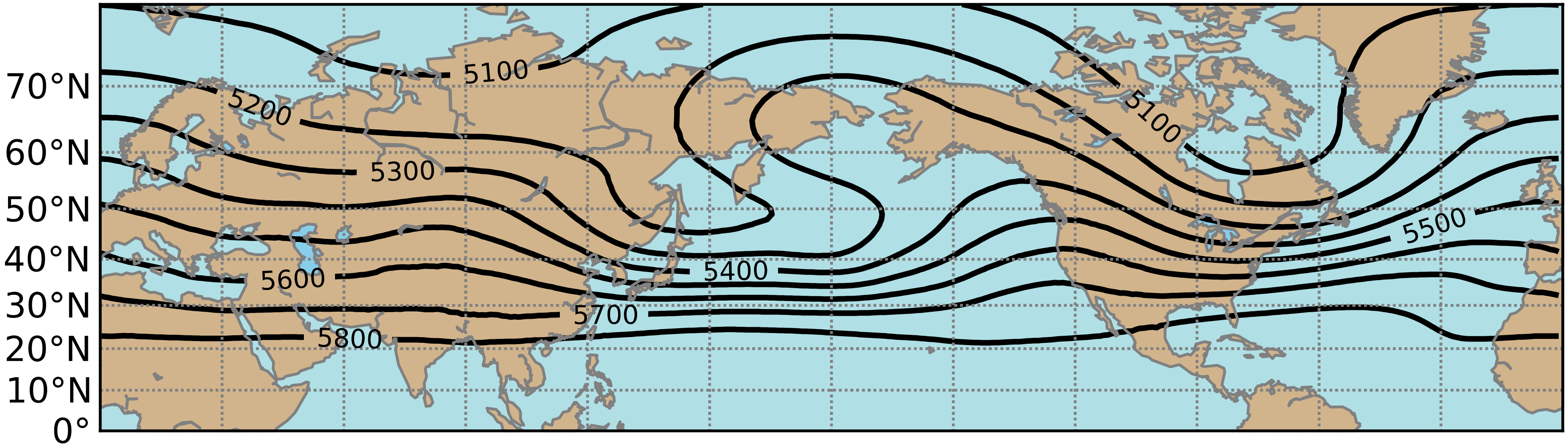
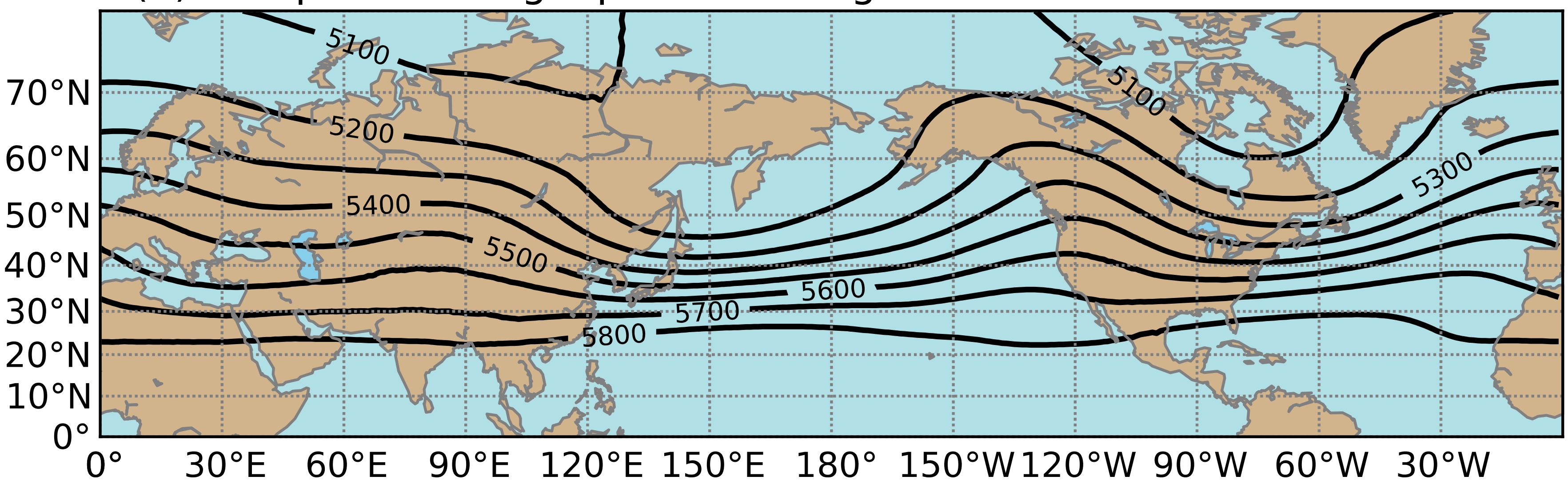
presentation to 37th Climate Diagnostics and Prediction Workshop, Ft. Collins, CO, October 2012

(a) Composite 500 hPa geopotential height under block at Lon = 180E



(b) Composite 500 geopotential height under no block at Lon = 180E



Dec-Jan-Feb 1985-2010 CFSR data. Blocks defined here by Tibaldi/Molteni algorithm.

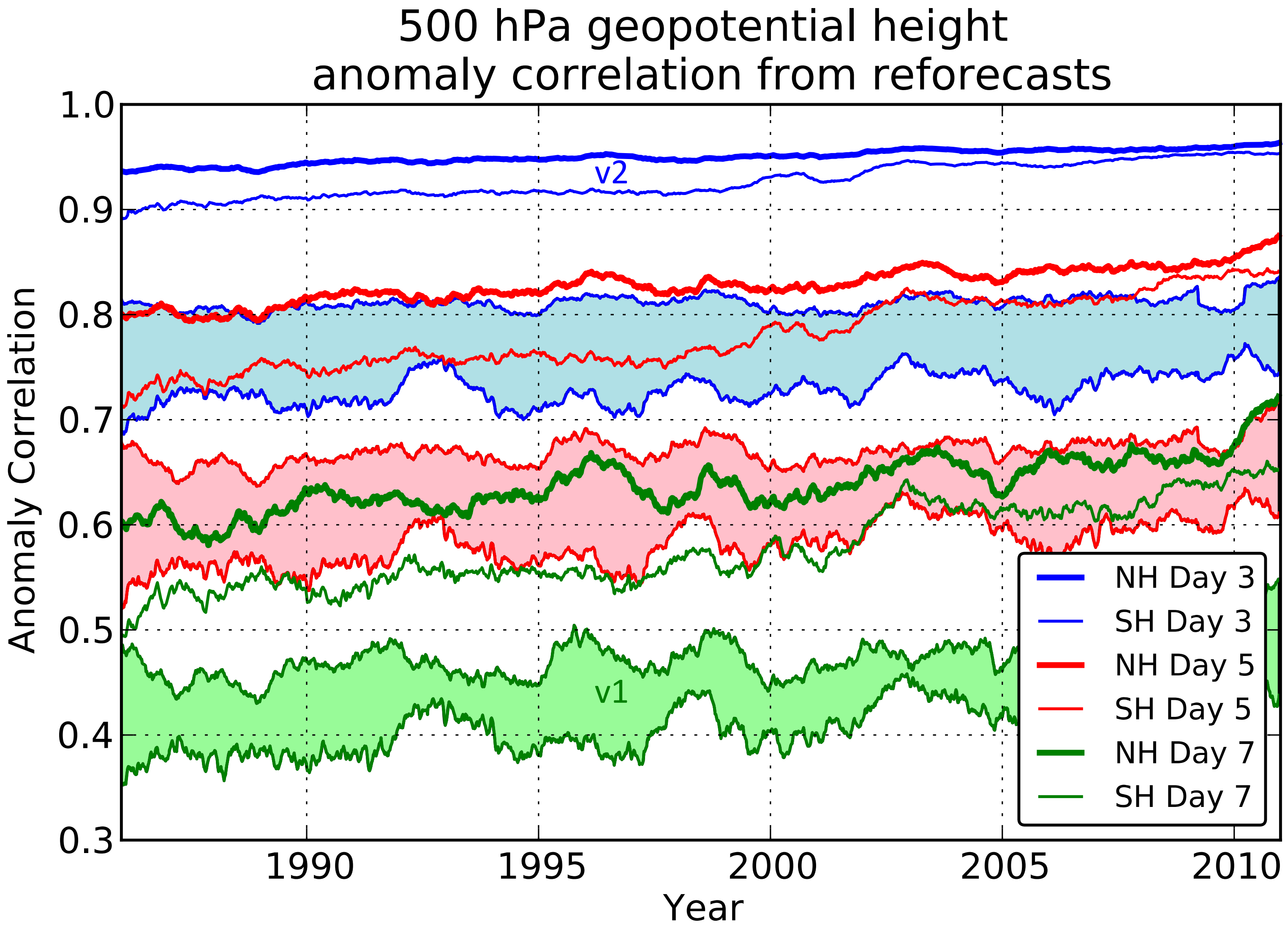
Questions

- How well are blocking and MJO predicted in GEFS?
- Is blocking frequency and skill related to MJO activity?
- Does GEFS predict interactions of blocking with MJO well?

(Interactions between these somewhat uncommon phenomena easier to diagnose if one has a large reforecast data set)

Data sets and methods

- GEFS Reforecast
  - Every day from 1985-present (through 2010 here).
  - 11 members, 1x daily (00 UTC). Forecasts to +16 days.
  - CFSR (prior to 2011), operational GSI (since 2011) + ensemble transform with rescaling (ETR) cycled initial conditions.
  - Model: 2012 GEFS configuration; T254L24 in week 1 (~40 km at 40°N), T190L24 in week 2.
  - Reforecast archive and documentation (incl. *BAMS* submitted article) at http://esrl.noaa.gov/psd/forecasts/reforecast2/
- MJO: RMM1 and RMM2 defined from CFSR reanalysis U850, U200, and OLR following standard Wheeler & Hendon algorithm.

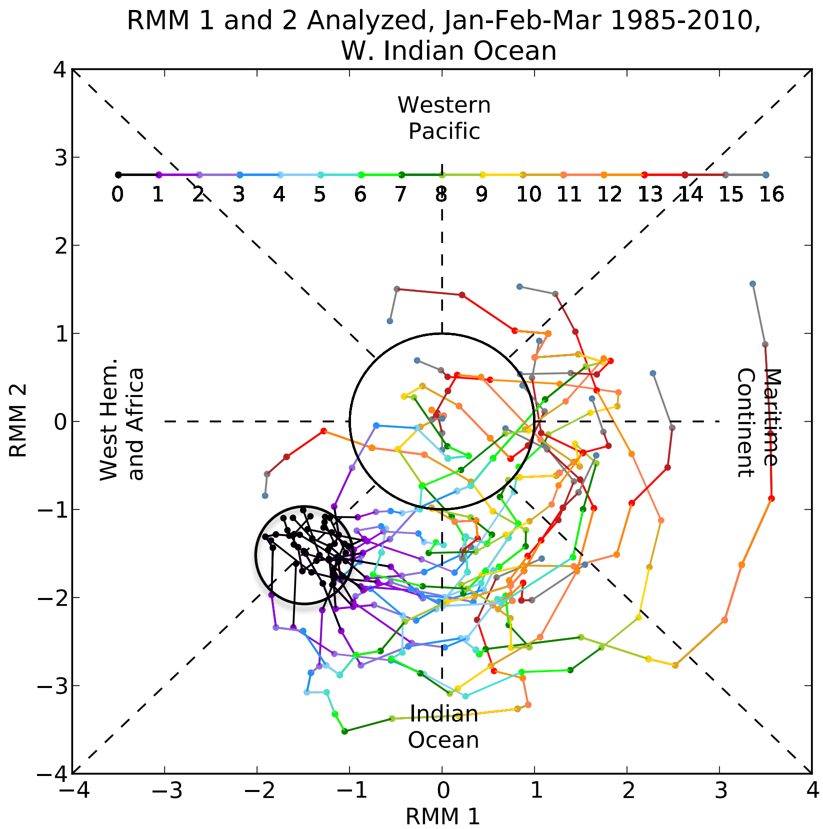


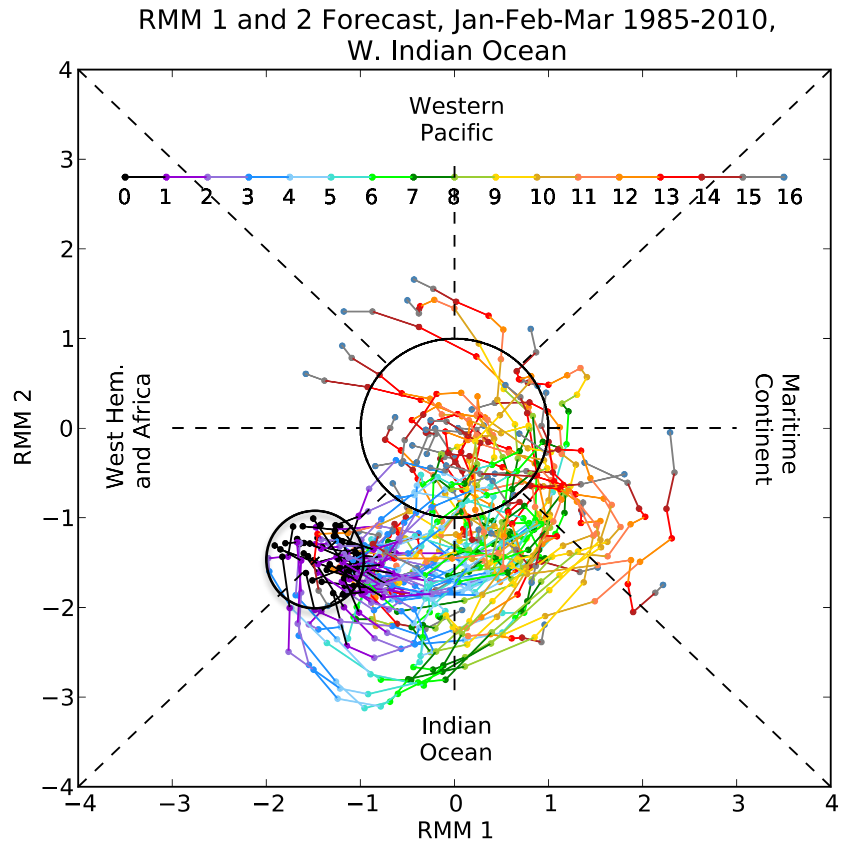
(1) CFSR initial conditions used in GEFS generally improve over the decades, leading to slight improvements in GEFS skill.

(2) About a +2 day improvement relative to 1998 GEFS T62 reforecasts.

MJO diagnostics

MJO, analyzed and deterministic forecast, W. Indian Ocean



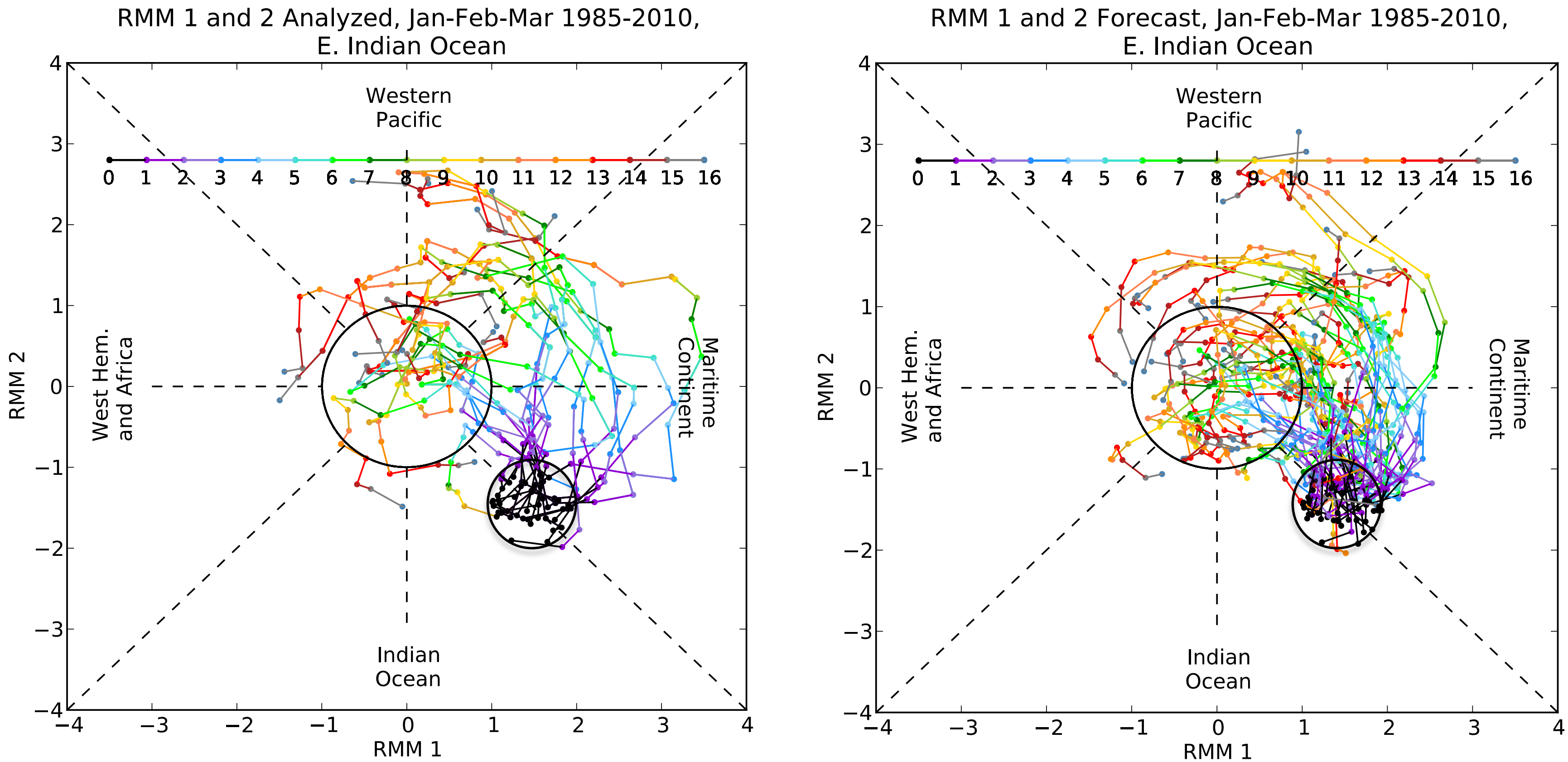


Let's examine a subset of cases that start off with initial conditions that have large negative RMM1 and 2, i.e., they suggest a relatively strong MJO emerging from African continent.

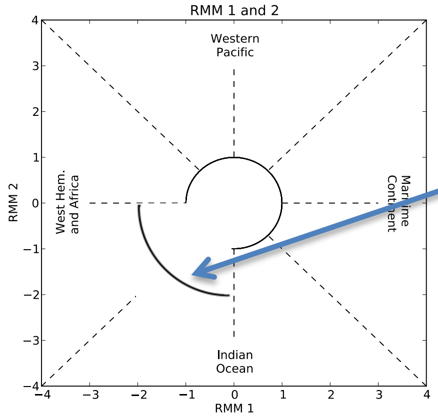
We have lots of cases of this afforded by multi-decadal reforecasts.

It appears that GEFS is too regular with the amplitude of its RMM1/RMM2 forecasts, while the analyzed evolution of amplitude is more scattered.

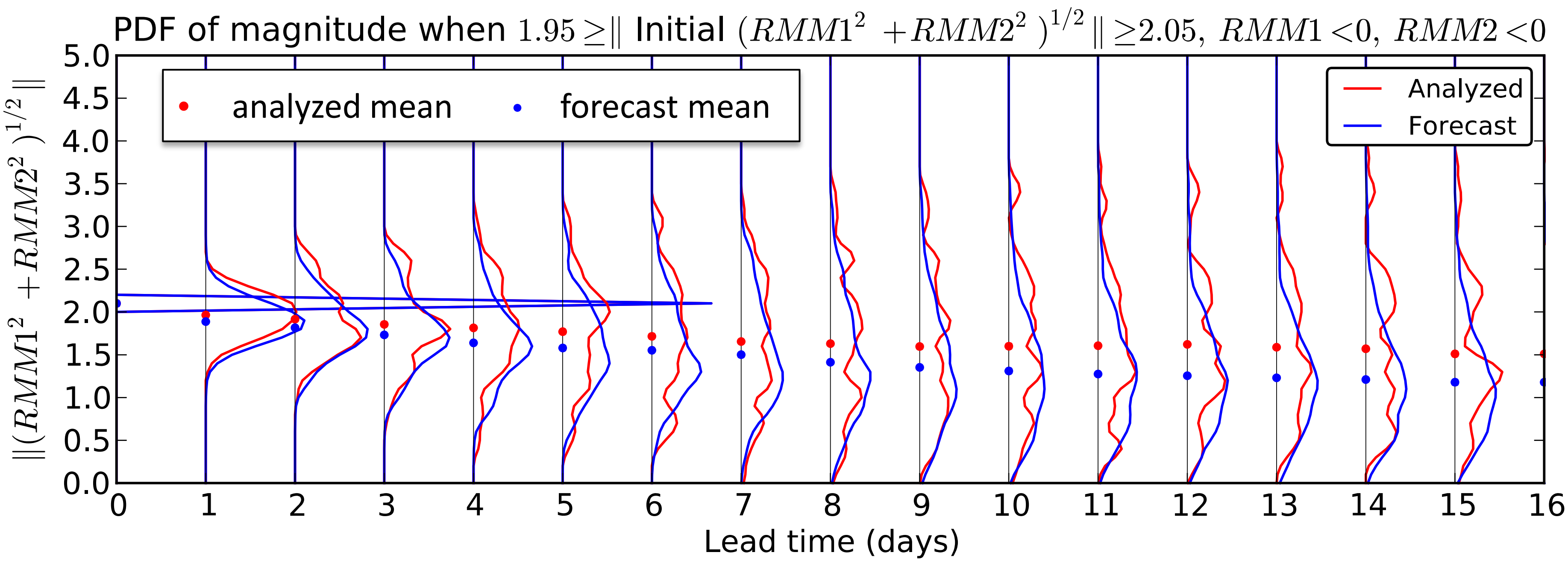
MJO, analyzed and deterministic forecast, E. Indian Ocean



Again, it appears that GEFS is too regular with its RMM1/RMM2 amplitude forecasts.

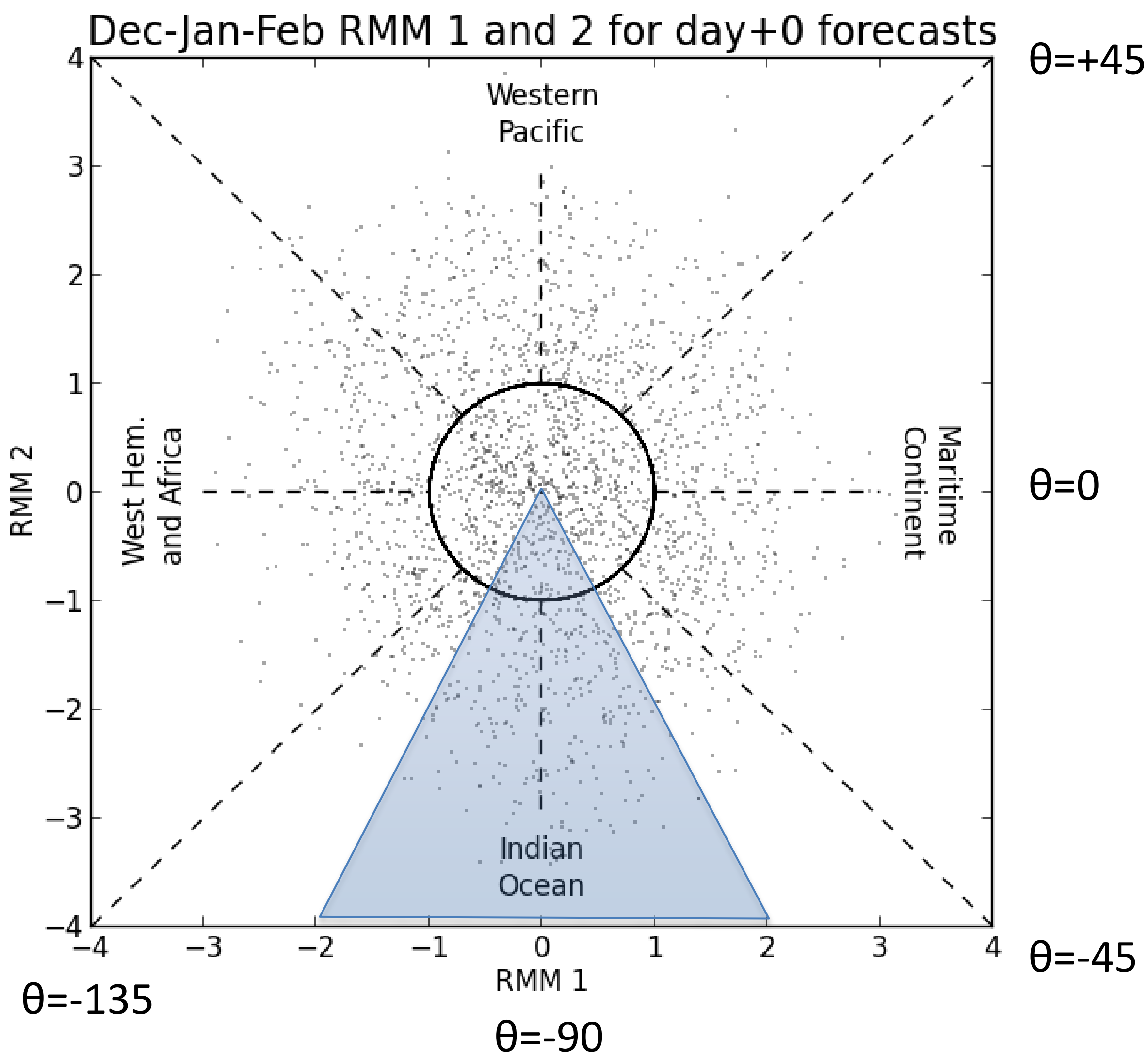


Find the initial-condition samples with analyzed magnitudes between 1.95 and 2.05 and RMM1 < 0, RMM2 < 0. Then follow **analyzed and forecast magnitude evolution** and plot pdf.



A bit more spreading out of the analyzed magnitudes relative to the forecast magnitudes in the first few days of the forecast.
Also, amplitude of forecast decreases more.

My method of quantifying MJO phase



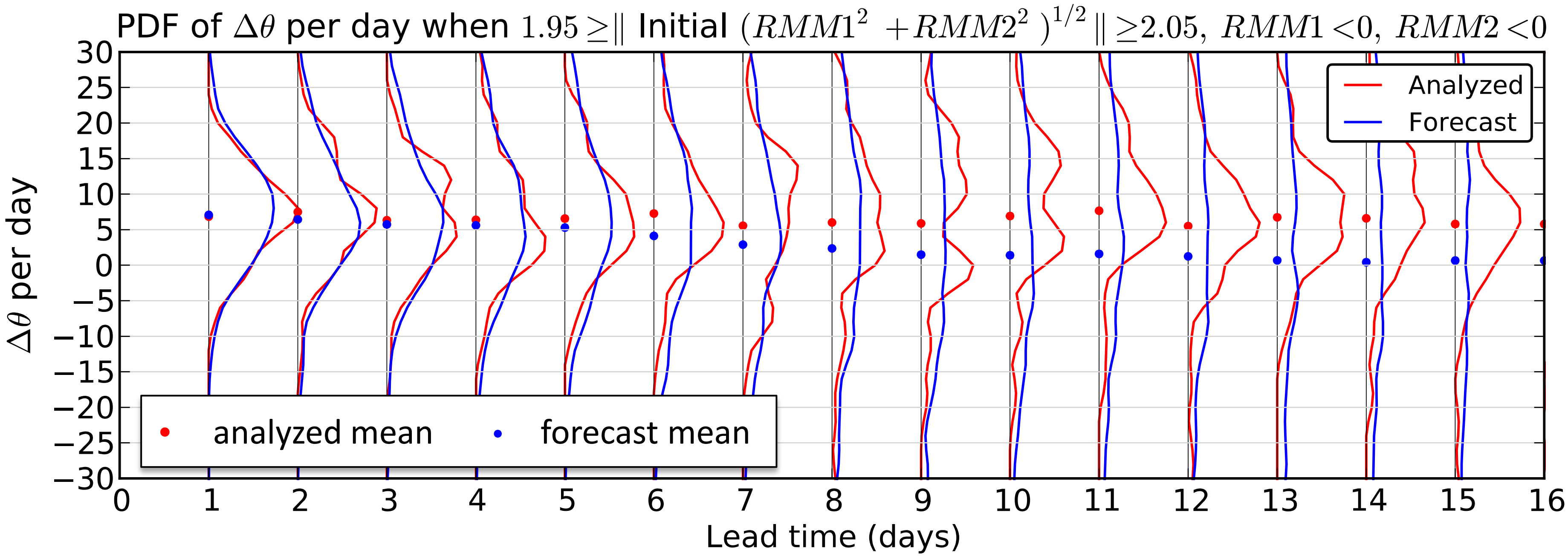
In subsequent plots you'll see I refer to the phase of MJO by its angle from x axis, a θ in conventional polar coordinates.

When examining statistics for $\theta=\theta_0$, I use RMM 1/2 samples with associated θ_0 +/- 22.5 degrees.

Example below for θ_0=-90 uses samples in blue cone.

A "strong" MJO is in the top 25% of RMM 1/2 amplitudes within the cone.

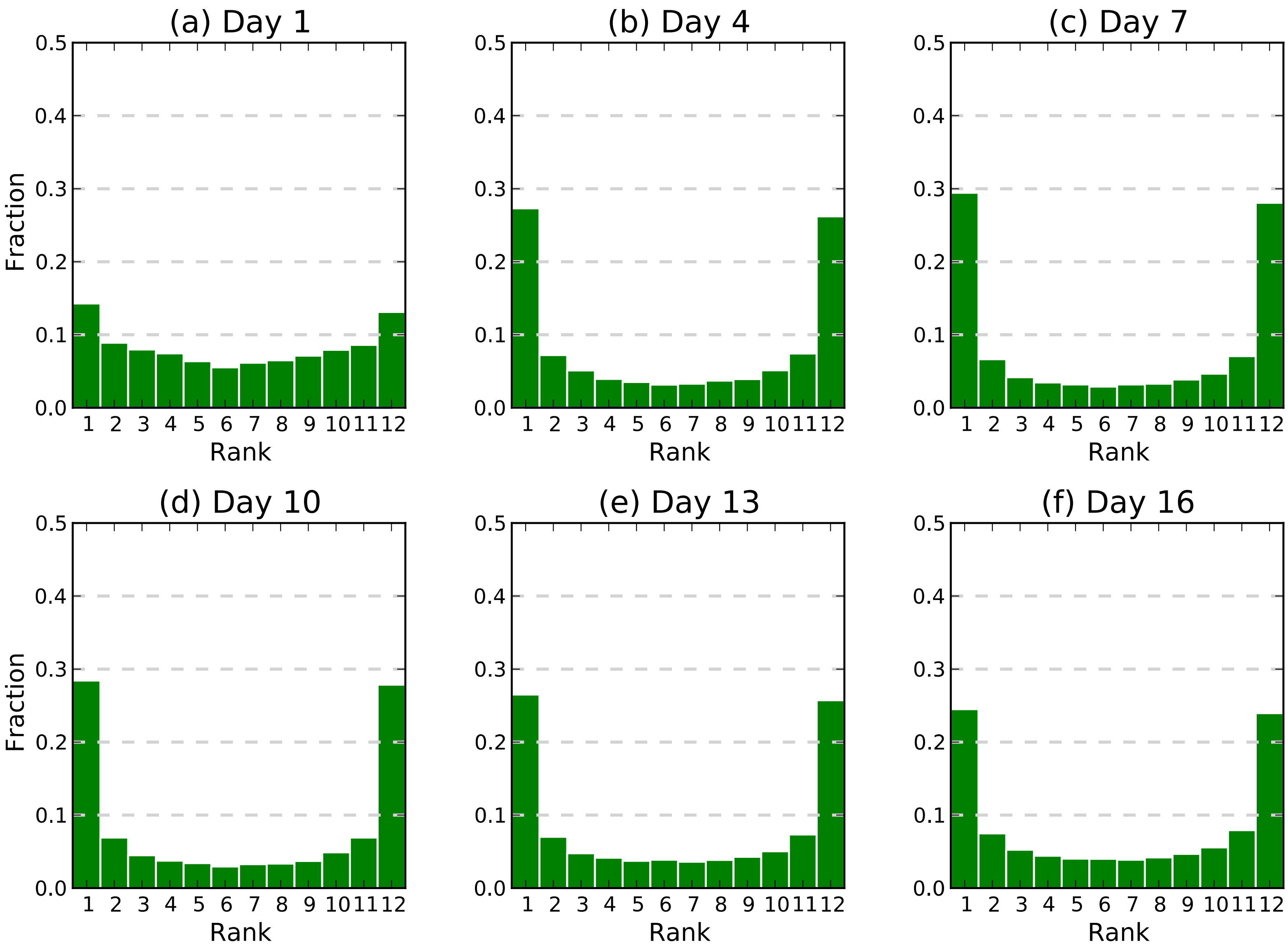
Find the initial-condition samples with analyzed magnitudes between 1.95 and 2.05 and RMM1 < 0, RMM2 < 0. Then follow analyzed and forecast **change in MJO phase** per day.



Observed MJO propagates in phase more regularly than forecast MJO, especially at longer forecast lead times.

Observed MJO retains ~ 7 degrees/day phase change. Forecast phase changes decrease to near zero with increasing lead time.

Rank histograms, RMM1 and RMM2 composited



Most under-spread and/or biased at the medium range.

MJO deterministic verification metrics

$$\mathrm{COR}(\tau) = \frac{\sum_{i=1}^{N} [a_{1i}(t)b_{1i}(t) + a_{2i}(t)b_{2i}(t)]}{\sqrt{\sum_{i=1}^{N} [a_{1i}^2(t) + a_{2i}^2(t)]}\sqrt{\sum_{i=1}^{N} [b_{1i}^2(t) + b_{2i}^2(t)]}},$$

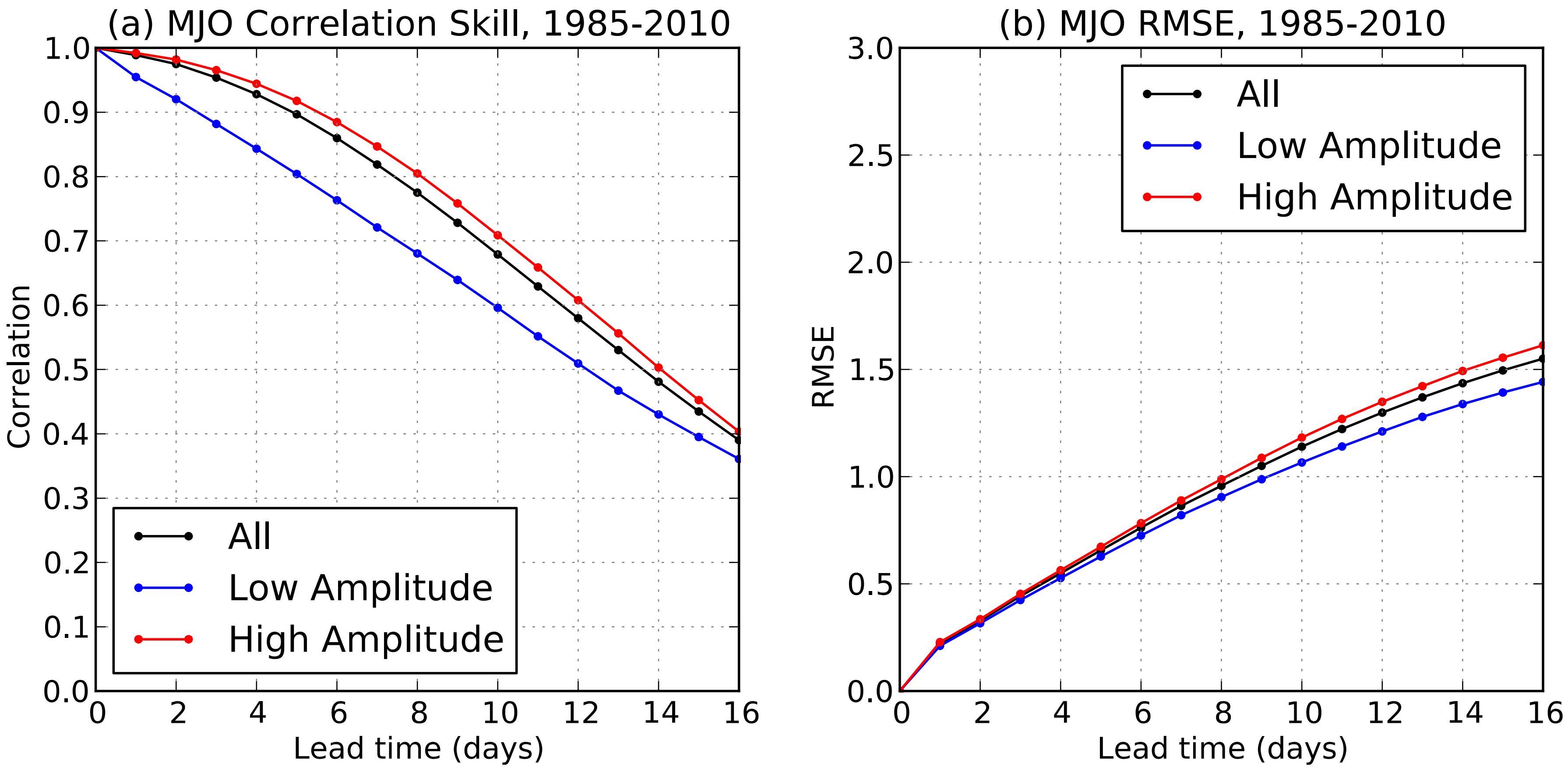
where $a_{1i}(t)$ and $a_{2i}(t)$ are the observed RMM1 and RMM2 at day t, and $b_{1i}(t)$ and $b_{2i}(t)$ are their respective forecasts, for the ith forecast with a τ-day lead. Here, N is the number of forecasts.

COR(τ) measures the skill in forecasting the phase of the MJO, which is insensitive to amplitude errors. COR(τ) is equivalent to a spatial pattern correlation between the observations and the forecasts when they are expressed by the two leading combined EOFs.

$$\mathrm{RMSE}(\tau) = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \{[a_{1i}(t) - b_{1i}(t)]^2 + [a_{2i}(t) - b_{2i}(t)]^2\}}.$$

from Lin et al., Nov 2008 *MWR*.

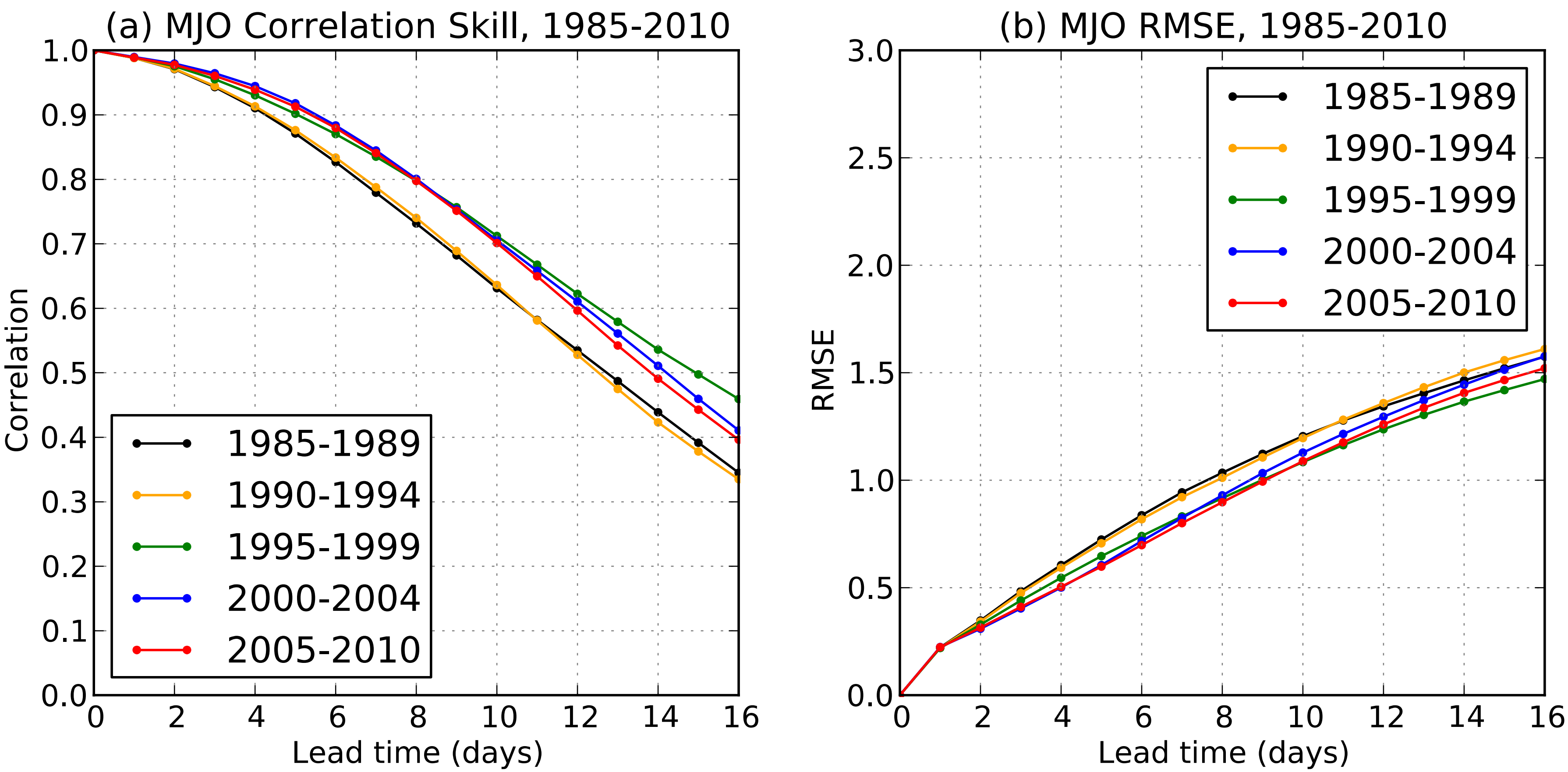
Bi-variate RMM1 and RMM2 correlation and RMSE



Low amplitude: $\sqrt{(RMM1^2+RMM2^2)} < 1$

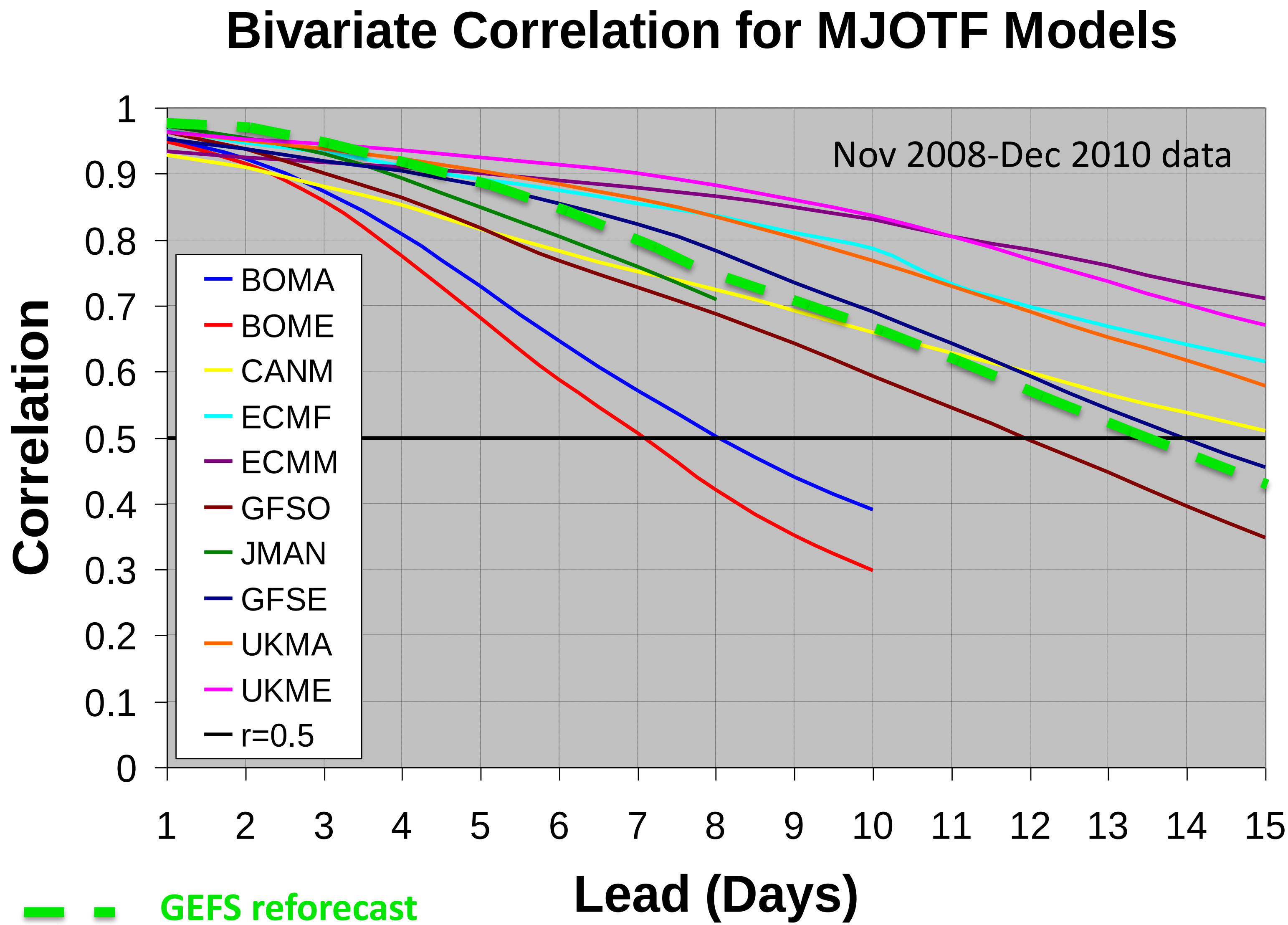
High amplitude: $\sqrt{(RMM1^2+RMM2^2)} \geq 1$

Bi-variate RMM1 and RMM2 correlation and RMSE by half decade



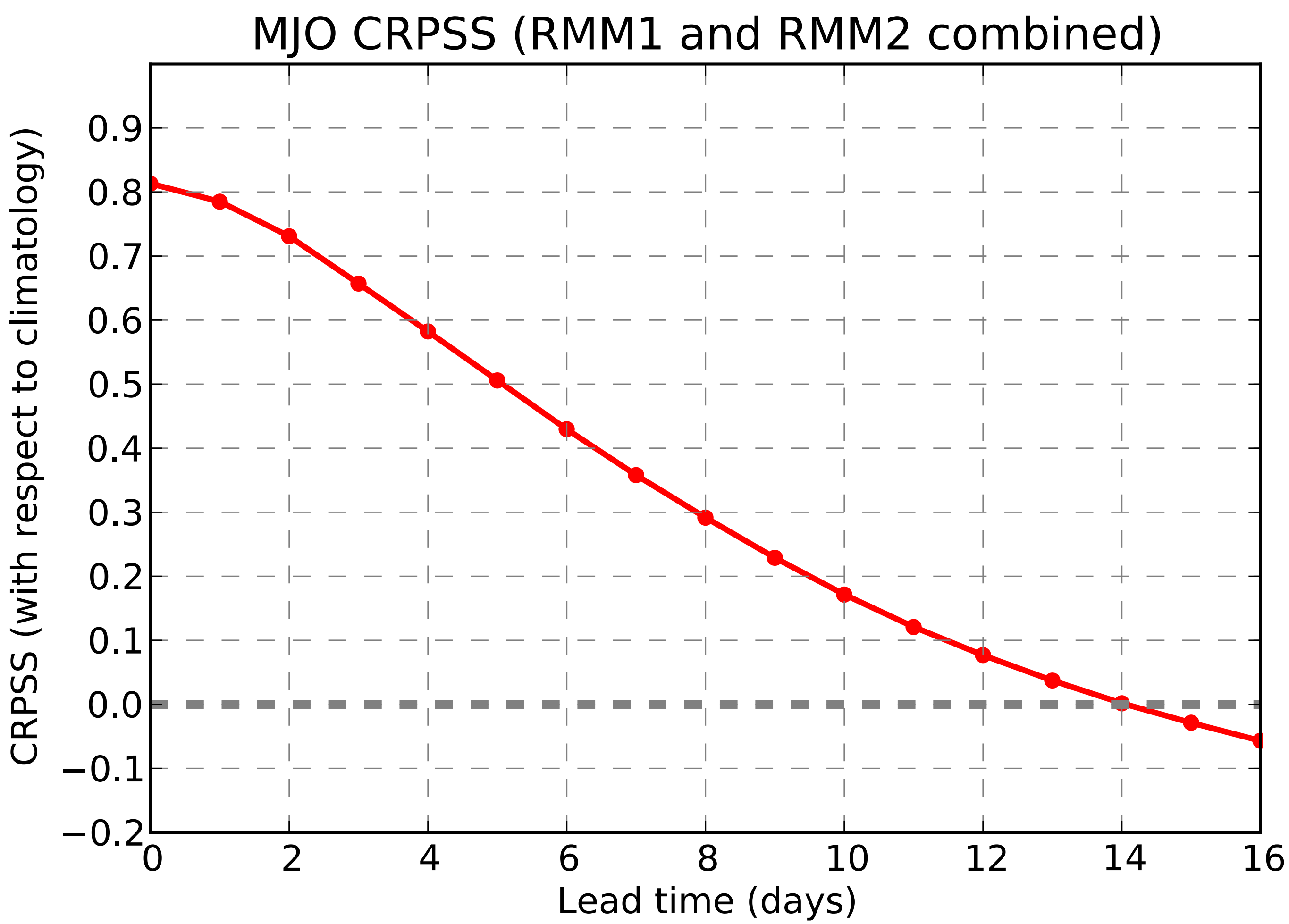
The first 10 years are much less skillful than the subsequent 16.

Comparing against MJO task force data…



c/o Jon Gottschalk

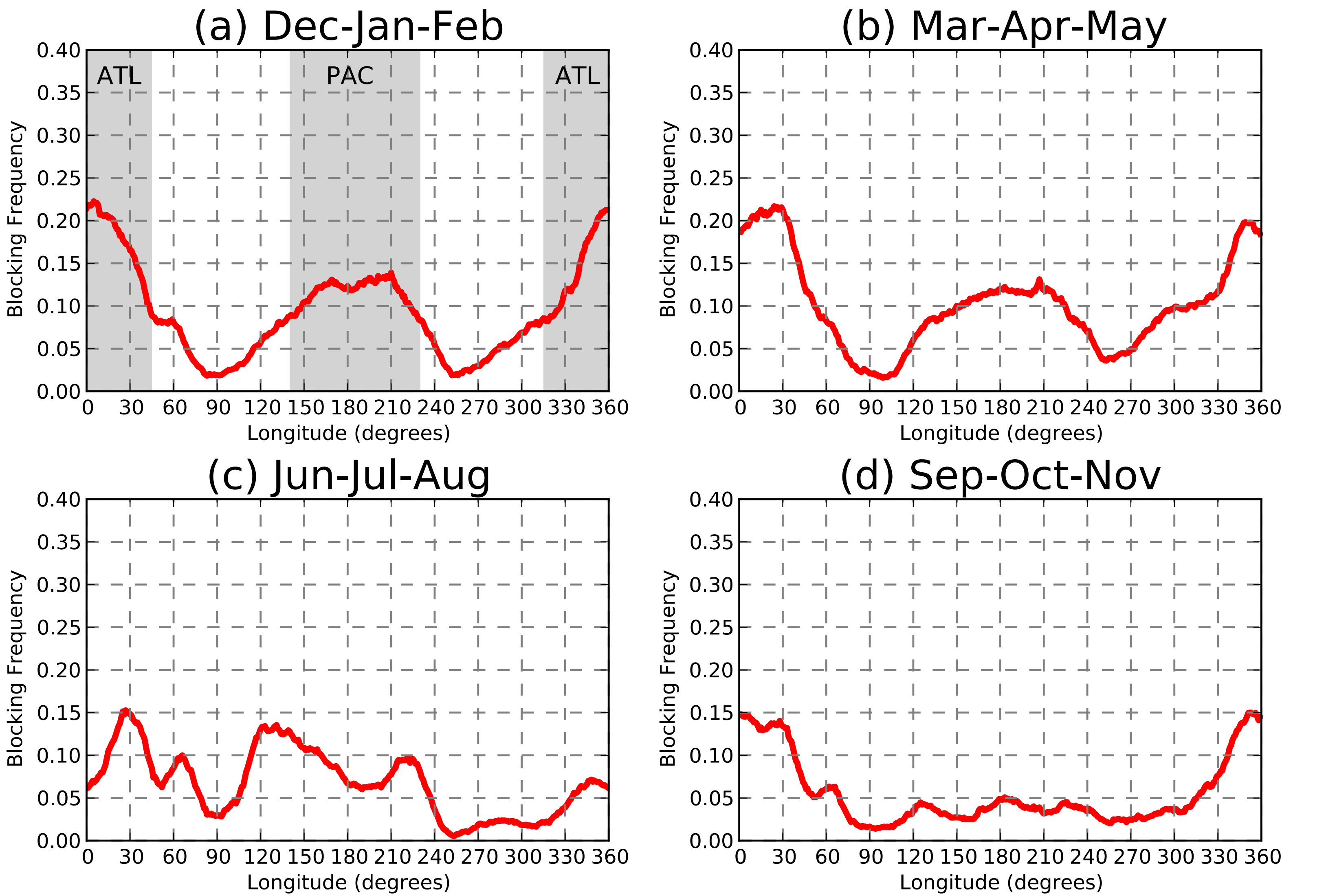
Probabilistic forecast verification: CRPSS



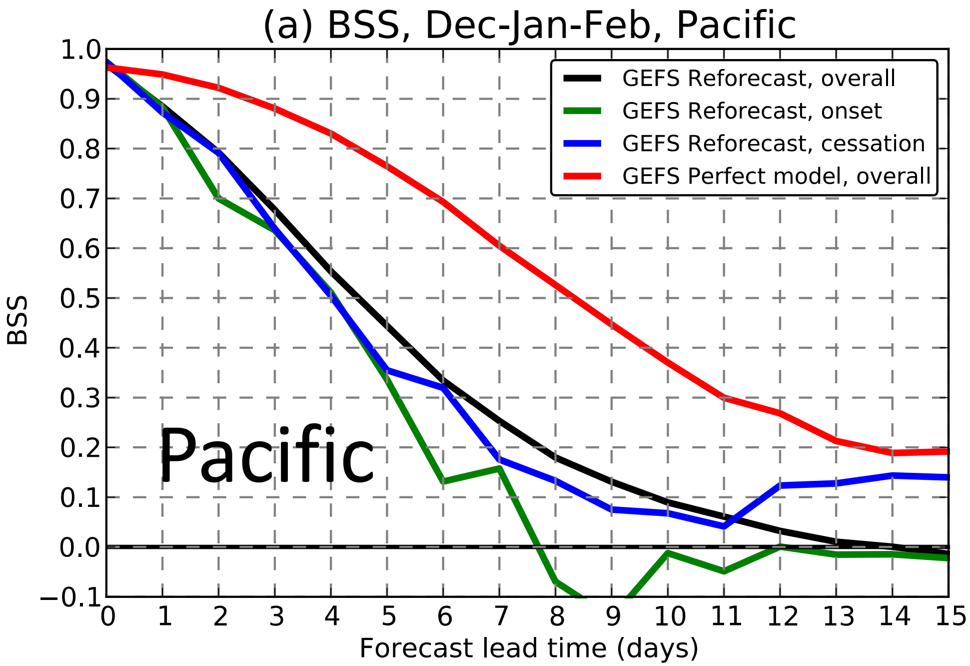
Method for computing CRPSS discussed in supplementary slides. Reference is climatology. A tougher reference like lagged persistence (slides 7-8) would show the forecasts have a much quicker loss of skill.

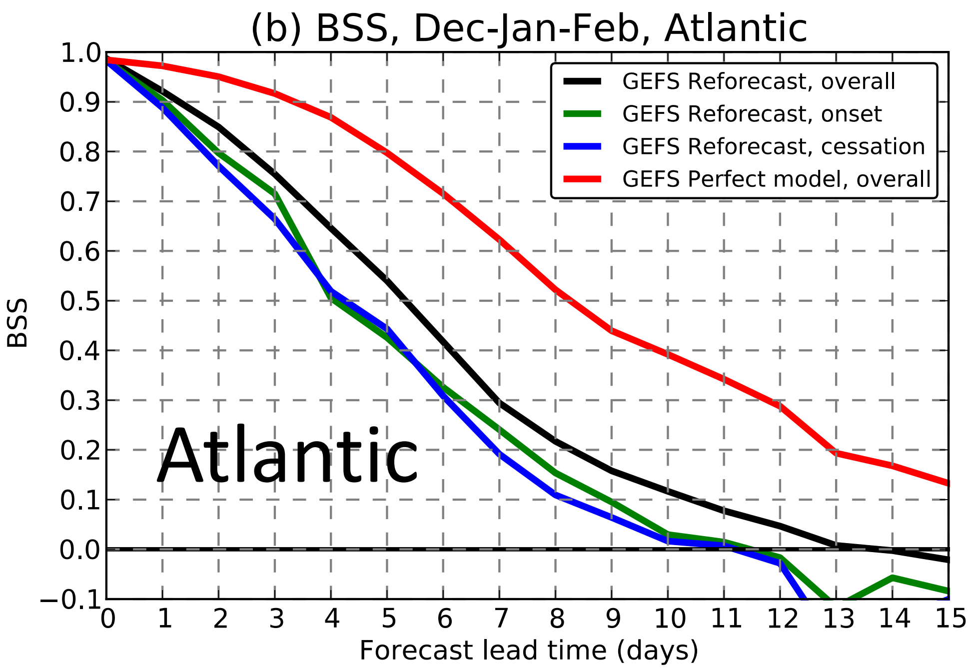
Northern Hemisphere atmospheric blocking

N Hem. blocking: more common in winter, spring



Blocking as defined in Tibaldi and Molteni (1990) using Z500. Hereafter, let's focus on Dec-Jan-Feb. Grey bands defines Euro/Atlantic and Pacific blocking sectors in subsequent plots.





NH blocking skill in GEFS reforecasts

BSS (Brier skill score) as defined in supplementary slides.

Perfect model uses one member of ensemble as surrogate for analyzed.

Real model: skill in blocking to ~12 days

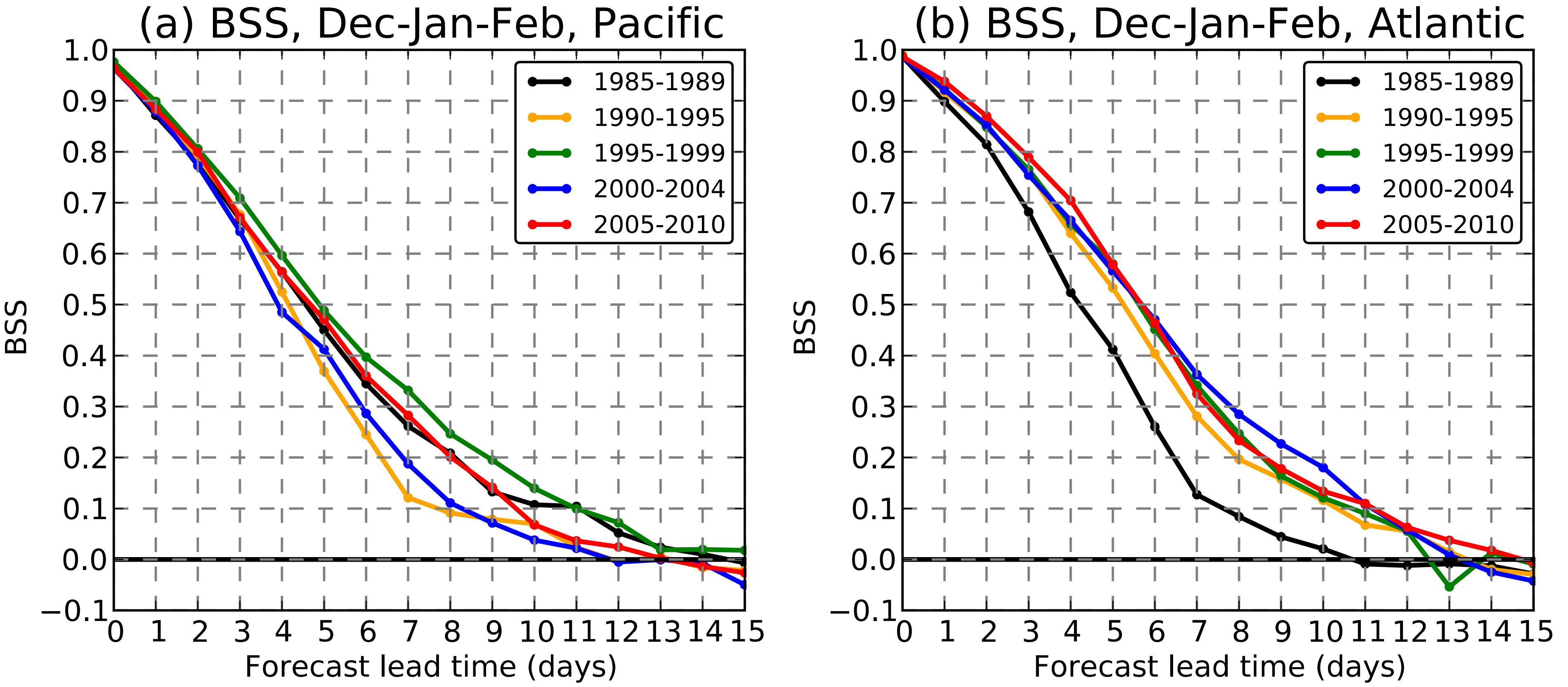
Perfect model: ~ 3-4 days longer skill.

Onset: date when there are more than 10 subsequent days where at least 20 degrees of longitude in a sector are blocked.

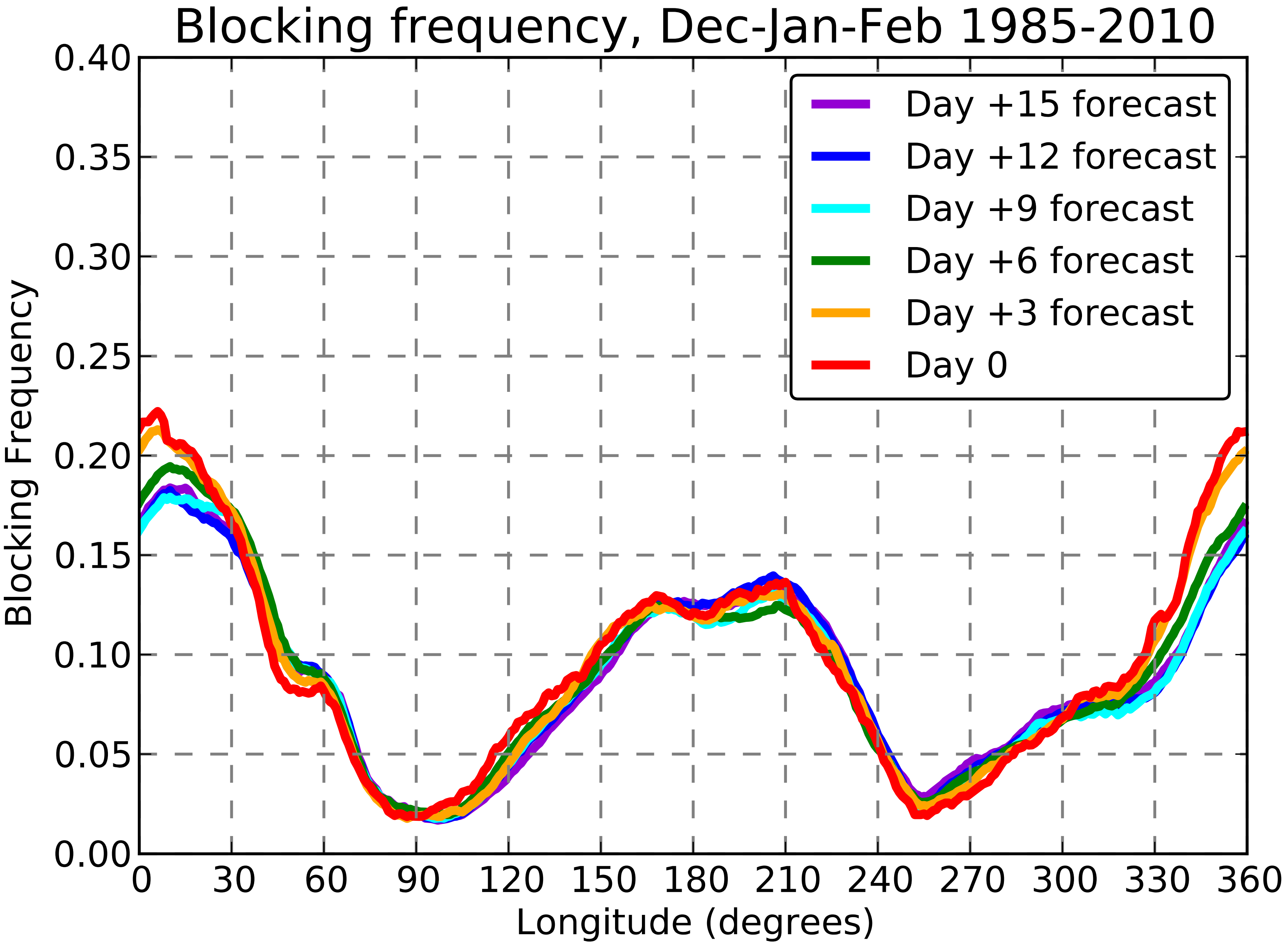
Cessation: date of end of that period.

Statistics include onset and previous 3 days, cessation and previous 3 days.

GEFS blocking skill by half decade

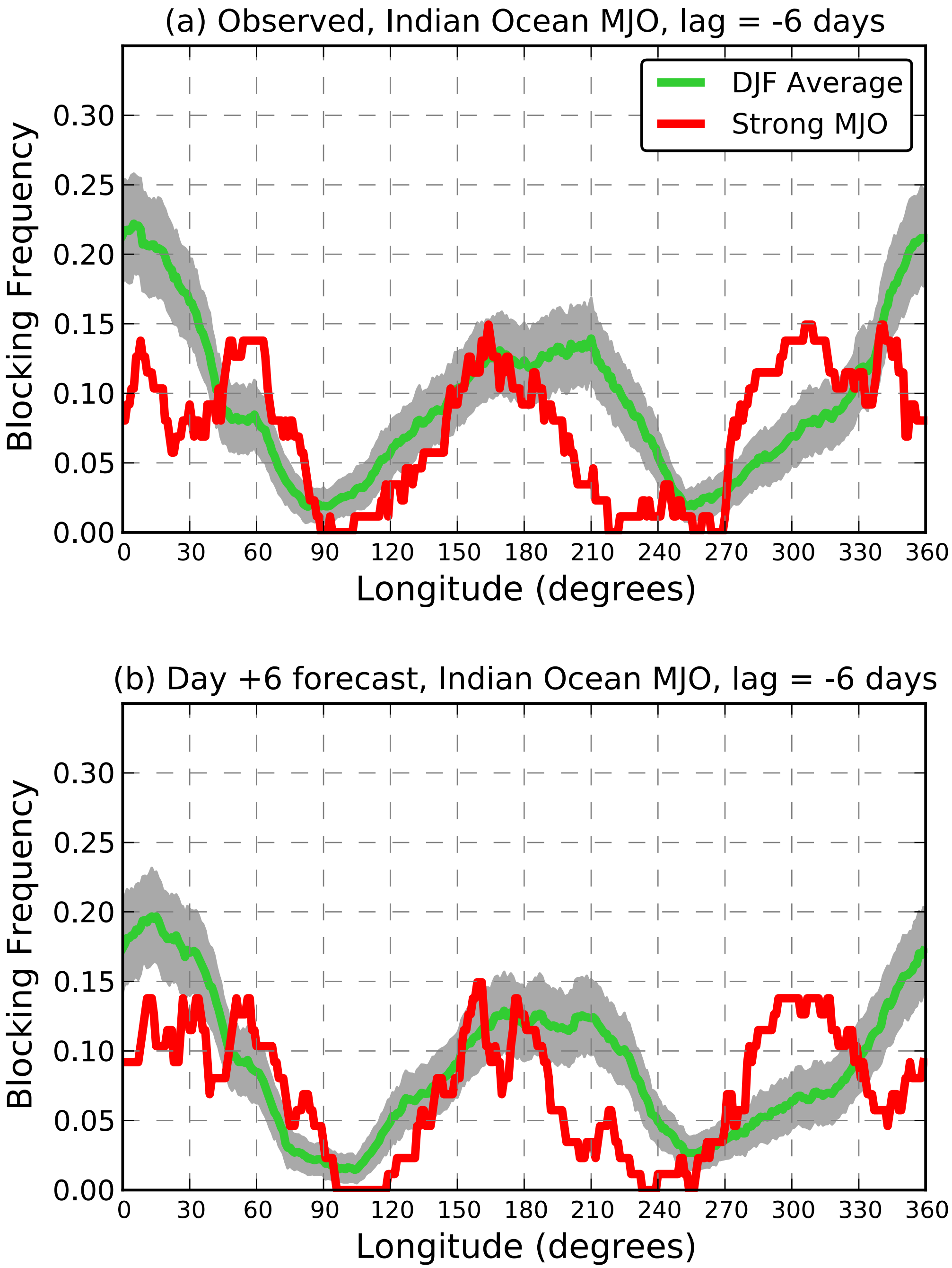


Decreased Atlantic sector skill in 1985-1989 period stands out.



Under-forecasting of Atlantic block frequency after day +3

MJO – blocking interactions

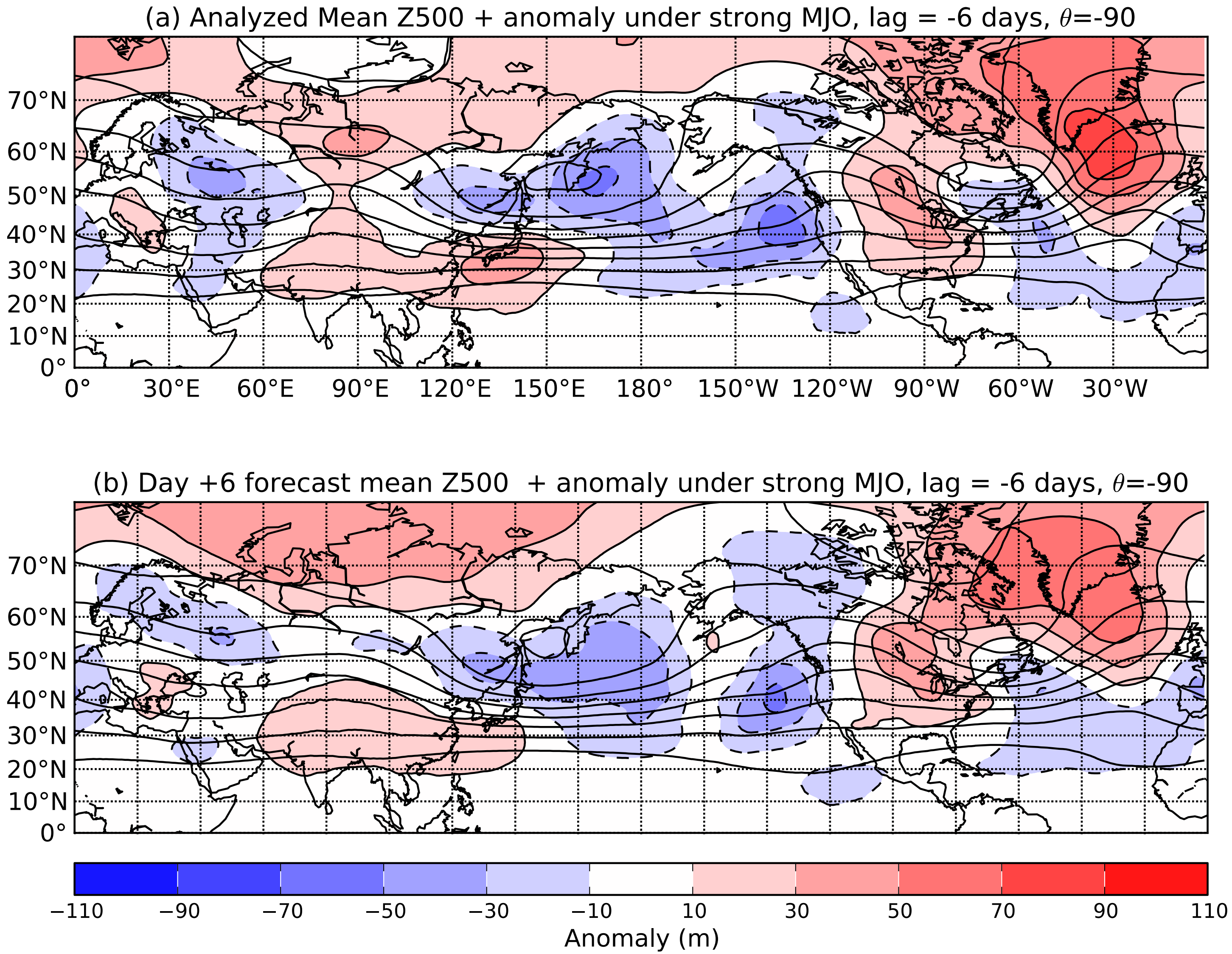


Change in blocking frequency under strong Indian Ocean MJO

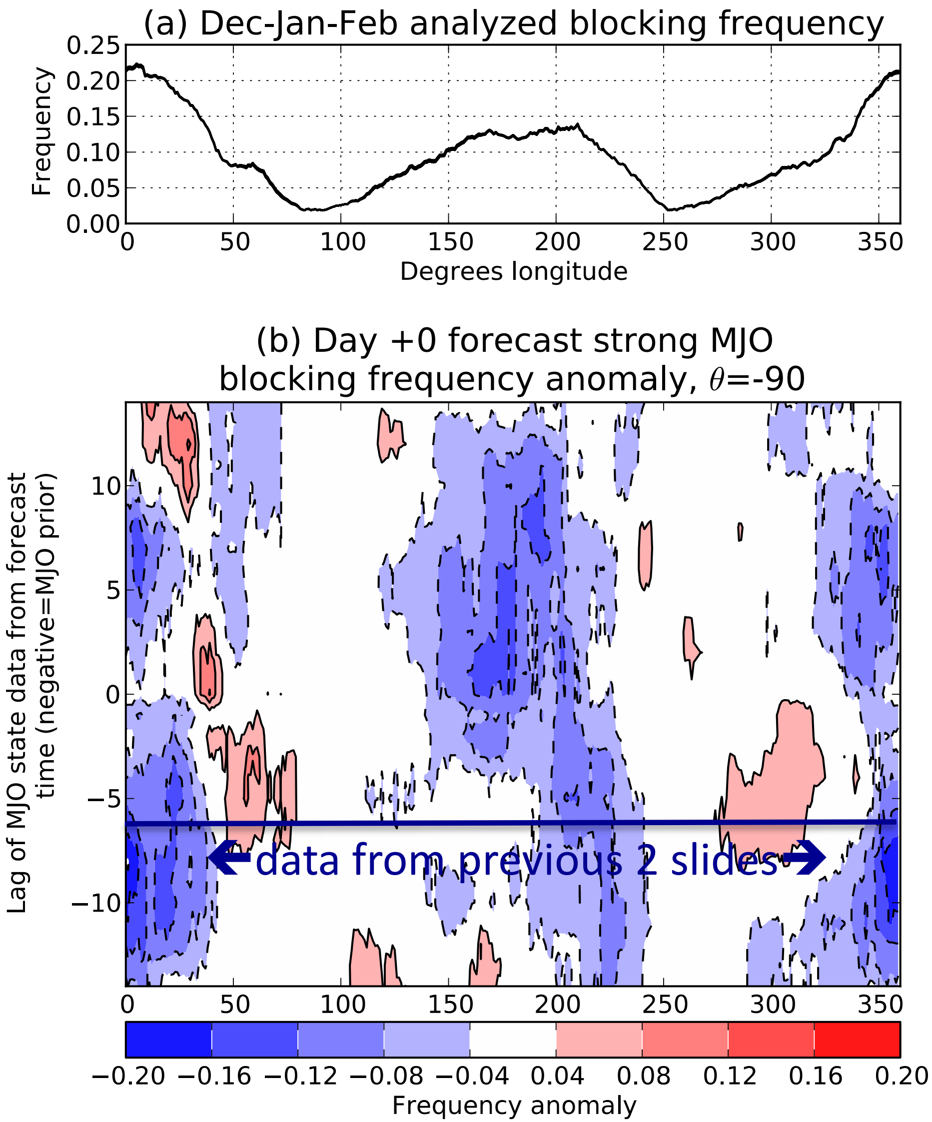
Shaded areas are confidence 5/95% confidence intervals.

Suppression of blocking frequency in the east Pacific and Atlantic under strong MJO. Day +6 GEFS nicely replicates this suppression.

Z500 anomalies under strong (6-day lagged) Indian Ocean MJO



How does (observed) blocking frequency change according to the lag time of the MJO?



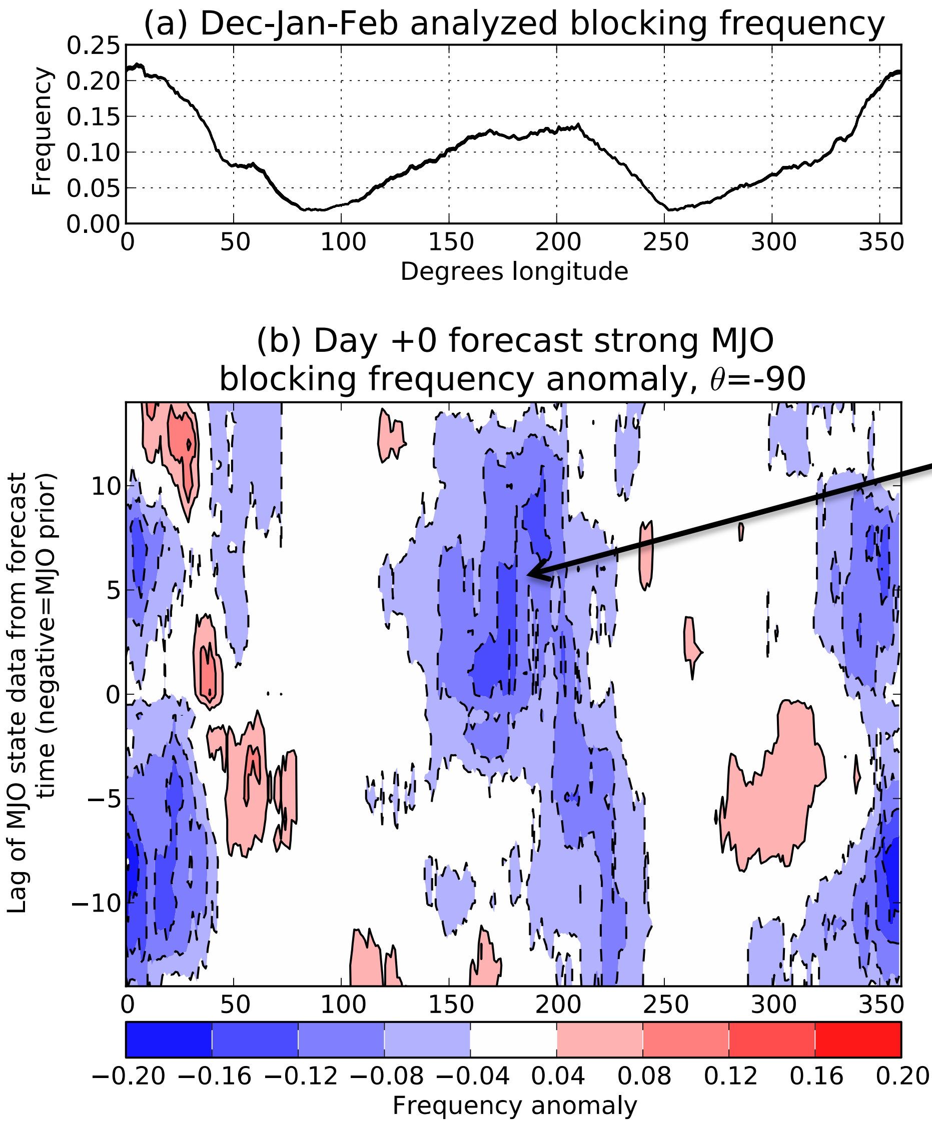
Top panel is unconditional DJF blocking frequency, for reference. Bottom panel is difference in strong MJO blocking frequency from unconditional DJF average as a function of latitude and time lag of MJO data relative to blocking data. Blue = less blocks.

Here, θ= -90, i.e., ~ Indian Ocean MJO.

Here, n-day negative lag means the MJO data was preceding the blocking calculation by n days.

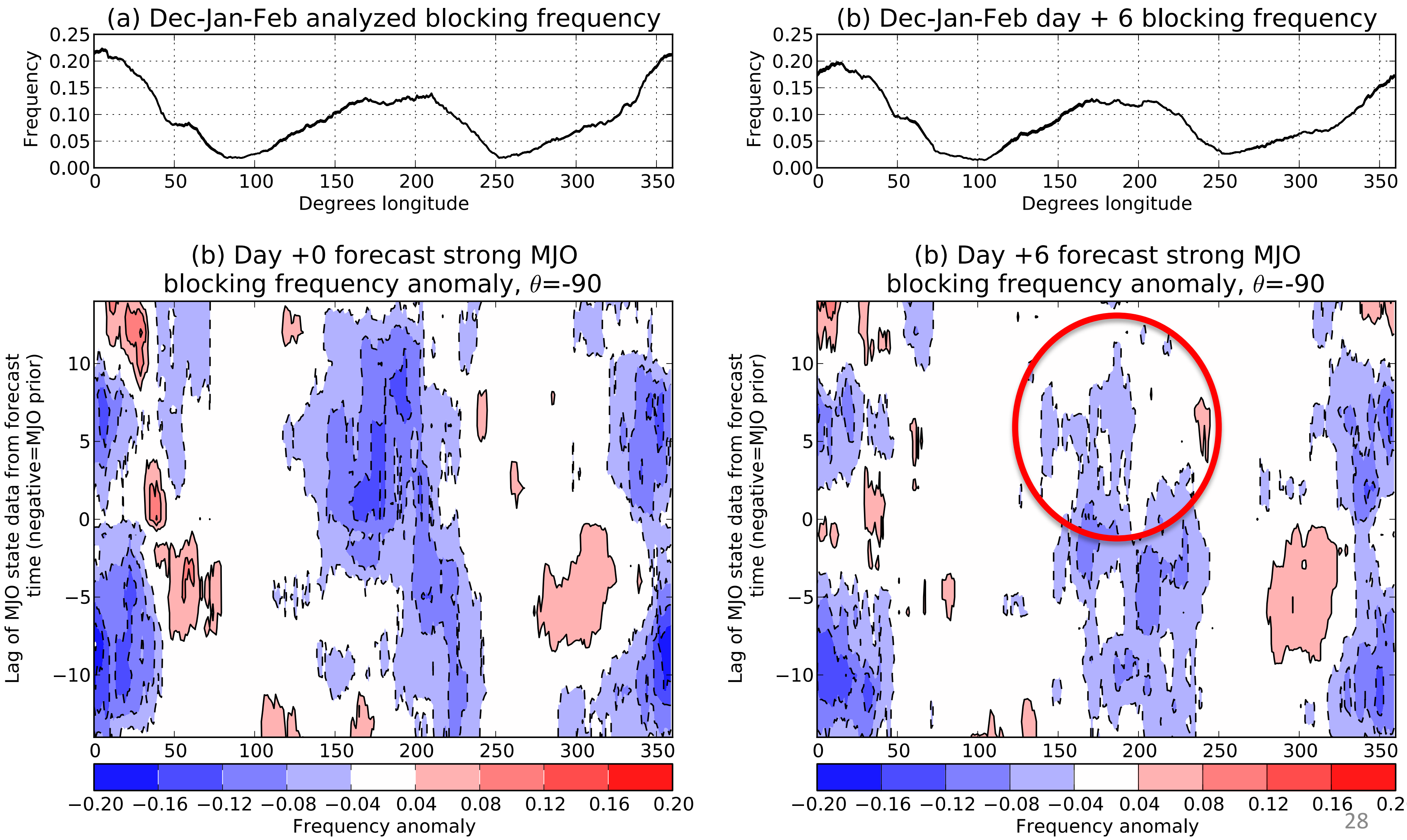
Again, note strong suppression of blocking in Pacific both prior to and subsequent to strong Indian Ocean MJO. Very strong suppression of Atlantic block subsequent to Indian Ocean MJO.

How does (observed) blocking frequency change according to the lag time of the MJO?

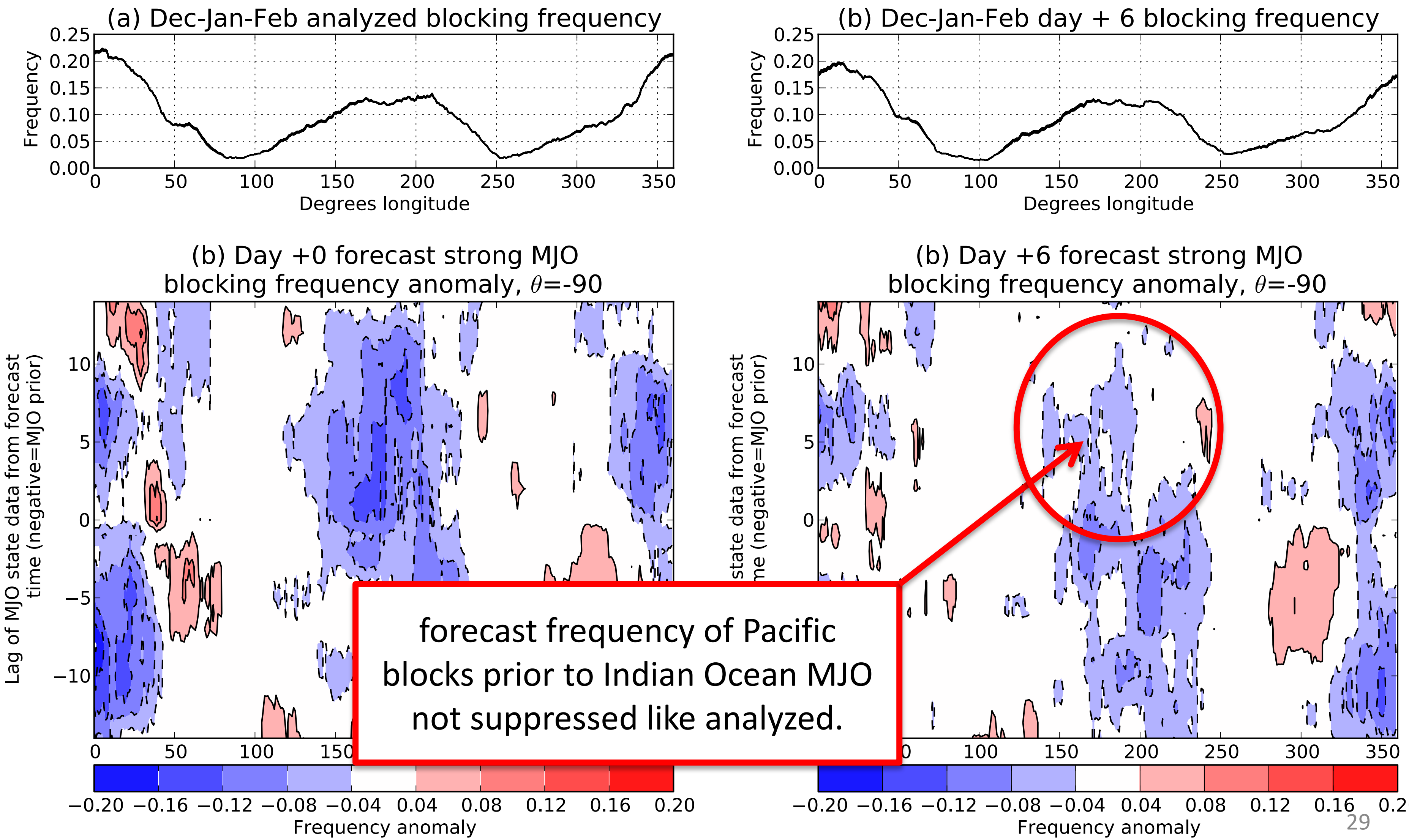


What the heck is happening here? 3-10 days prior to active MJOs in the Indian Ocean, there is a strong suppression of blocking in the Pacific, apparently.

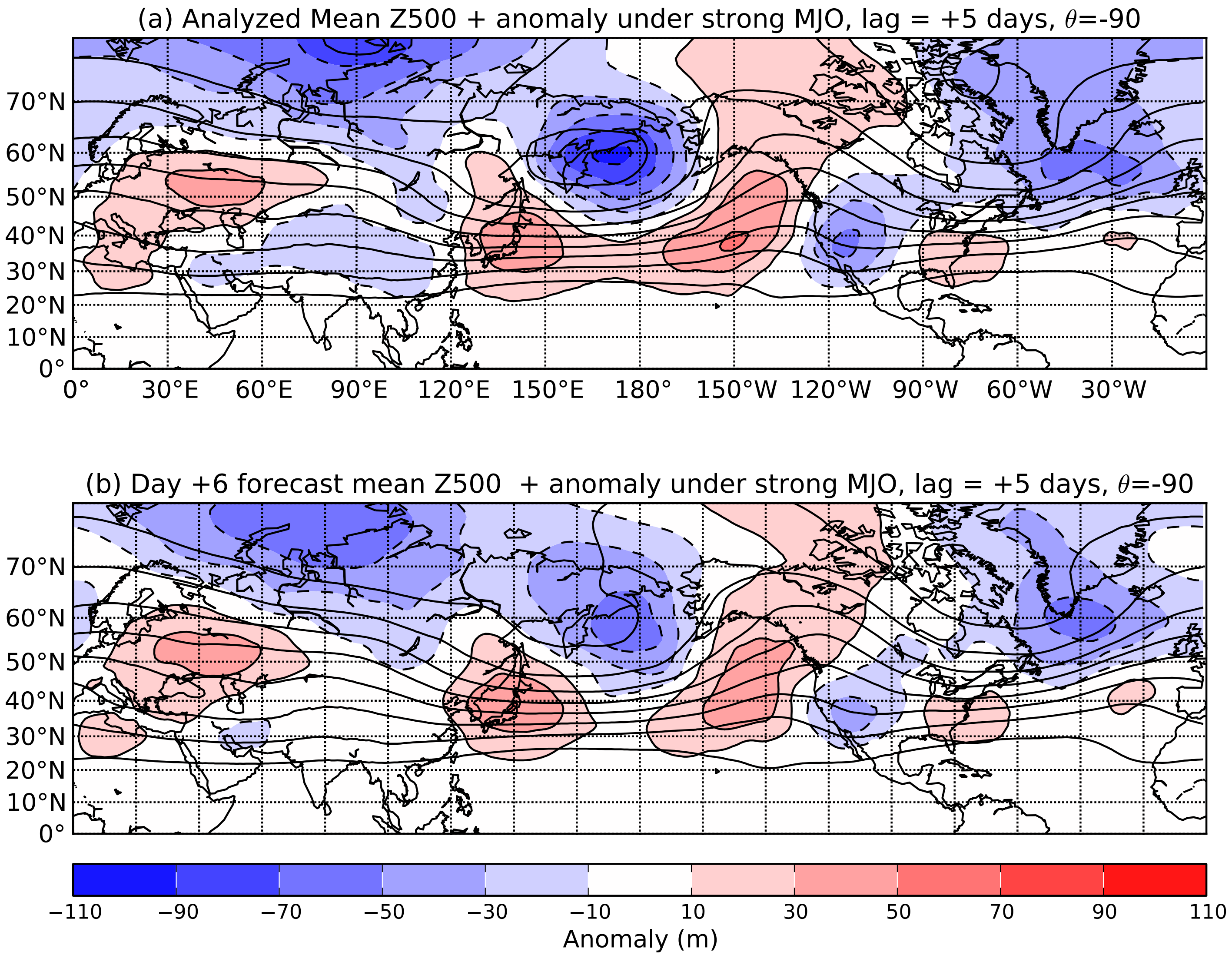
Observed and forecast blocking frequency change according to the lag time of the MJO



Observed and forecast blocking frequency change according to the lag time of the MJO



Flow anomalies associated with suppressed Pacific blocking 5 days prior to active Indian Ocean MJO



Conclusions

- MJO:
  - Forecasts decrease in amplitude, slow down relative to analyzed.
  - Ensemble forecasts under-dispersed/biased.
  - Some skill, though, especially for high amplitude MJOs
- Blocking:
  - Some skill, but much less than perfect model.
  - Reasonable replication of blocking climatological frequencies in forecasts.
- Blocking and MJO
  - Blocking frequency decreased under active Indian-Ocean MJO
- Acknowledgments: George Kiladis, Steve Colucci, Klaus Weickmann, Jeff Whitaker.

Define BSS for evaluating blocking skill

- The blocking Brier Skill score is calculated after summing forecast and climatological Brier scores over the relevant longitudes in either the Pacific or Atlantic basins, respectively, then averaged. For example (Pac):

$$BSS = 1.0 - \frac{BS_{forecast}}{BS_{climo}}$$

$$BS_{forecast} = \sum_{l_p=1}^{nlons} \sum_{i=1}^{ndates} \left(p_i^{forecast}\left(l_p\right) - o_i\left(l_p\right)\right)^2$$

$$BS_{climo} = \sum_{l_p=1}^{nlons} \sum_{i=1}^{ndates} \left(p_i^{climo}\left(l_p\right) - o_i\left(l_p\right)\right)^2$$

$$o_i\left(l_p\right) = \left\{ \begin{array}{cc} 1 & if\ blocked \\ 0 & if\ unblocked \end{array} \right\}$$

$$p_i^{forecast}\left(l_p\right) = ensemble - based\ probability\ of\ block\ for\ this\ longitude$$

$$p_i^{climo}\left(l_p\right) = climatological\ probability\ of\ block\ for\ this\ longitude$$

Computing the CRPSS of GEFS RMM1 and RMM2 forecasts

- CRPSS = 1 – CRPS(forecast) / CRPS(climatology)

$$CRPS(forecast) = \sum_{i=1}^{ndates} \sum_{j=1}^{ncats} \frac{1}{ncats} \left(\Phi_{forecast}\left(i, x(j)\right) - \Phi_{analyzed}\left(i, x(j)\right) \right)^2$$

$$CRPS(climo) = \sum_{i=1}^{ndates} \sum_{j=1}^{ncats} \frac{1}{ncats} \left(\Phi_{climo}\left(i, x(j)\right) - \Phi_{analyzed}\left(i, x(j)\right) \right)^2$$

$$x(1) = -5.0, \quad x(2) = -4.9, \quad \ldots, \quad x(ncats) = +5.0$$

$$\Phi(\cdot) = \textit{cumulative distribution function for either RMM1 or RMM2}$$

- $\Phi(\cdot)$ estimated from normal distribution fit to sample mean and standard deviation.

Blocking computation method: follows Tibaldi and Molteni, 1990 *Tellus*

(1950). The procedure we have applied is as follows: the 500 hPa field is firstly evaluated on a 4° by 4° regular latitude–longitude grid covering the Northern Hemisphere. Then the geopotential height gradients GHGS and GHGN (referring to middle and high latitudes respectively) are computed for each longitude point of the grid:

$$\mathrm{GHGS} = \frac{Z(\phi_o) - Z(\phi_s)}{(\phi_o - \phi_s)},$$

$$\mathrm{GHGN} = \frac{Z(\phi_n) - Z(\phi_o)}{(\phi_n - \phi_o)},$$

where

$$\phi_n = 80^\circ\mathrm{N} + \Delta,$$
$$\phi_o = 60^\circ\mathrm{N} + \Delta,$$
$$\phi_s = 40^\circ\mathrm{N} + \Delta,$$
$$\Delta = -4^\circ, 0^\circ \text{ or } 4^\circ.$$

A given longitude is then defined as "blocked" at a specific instant in time if the following conditions are satisfied for at least one value of Δ:

(1) $\mathrm{GHGS} > 0$,

(2) $\mathrm{GHGN} < -10$ m/deg lat.

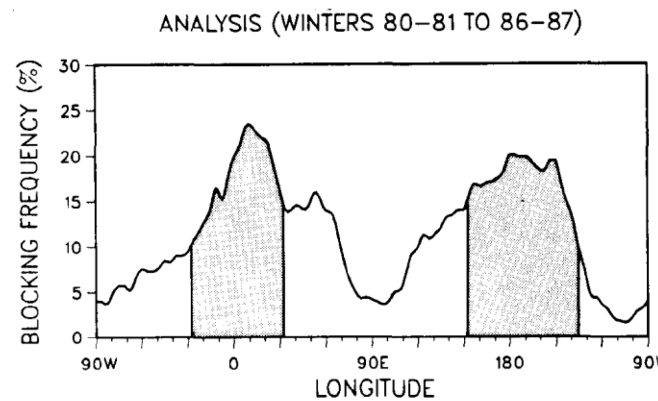


Fig. 1. Percentage frequency of blocking (objectively defined in Section 2) as a function of longitude and computed on all ECMWF daily objective analyses of our database.

There are alternatives, such as PV-based index by Pelly and Hoskins. While these may have some advantages, this old standard used hereafter.

MJO task force data

Center	Model	Data Stream ID	Ensemble Members	Forecasts Start	Length (Days)	Realtime Data FTP	Version 1 Plots	Model Climatology
NCEP	GFS EPS T126[1]	NCPE	21	Nov 2007	15	-----	Yes	No
NCEP	GFS T382[1]	NCPO	1	Jan 2008	15	-----	Yes	No
NCEP	CFS T62[1]	NCFS	4	Jan 2007	40	-----	Yes	Yes
CMC	GEMDM_400x200[2]	CANM	20	Jun 2008	16	Yes	Yes	No
UKMO	MOGREPS[3]	UKMA	1	Oct 2007	15	Yes	Yes	No
UKMO	MOGREPS[3]	UKME	23	Oct 2007	15	Yes	Yes	No
ABOM	GASP T239[4]	BOMA	1	Jan 2008	10	Yes	Yes	No
ABOM	GASP EPS T119[4]	BOME	32	Aug 2008	10	Yes	Yes	No
ABOM	POAMA1.5bT47[4]	BOMC	1	Jan 2008	40	Yes	Yes	No
ABOM	POAMA1.5T47[4]	BOMH	1	Jan 2008	40	Yes	No	Yes
ECMWF	VAREPS T299/T255[*]	ECMF	51	Jun 2008	15	Yes	Yes	No
ECMWF	VAREPS T299/T255[*]	ECMM	51	Jun 2008	15	Yes	Yes	Yes
ECMWF	SFSv3 T159[*]	EMON	51 (W)	Jun 2008	32	Yes	Yes	No
ECMWF	SFSv3 T159[*]	EMOM	51 (W)	Jun 2008	32	Yes	Yes	Yes
JMA	GSM WEPS T319[6]	JMAN	51	Nov 2008	9	Yes	Yes	No
CPTEC	GWEFS T126[7]	CPTC	15	Feb 2009	15	Yes	Yes	No
IMD	NCMRWF T254[8]	IMDO	1	Jun 2009	7	Yes	Yes	No
IMD	NCMRWF EPS T80[8]	IMDE	8	------	7	No	No	No
FNMOC	NOGAPS T119[9]	NGAP	10	------	10	No	No	No
TCWB	CWB EPS T119^	TCWB	1	Oct 2009	40	Yes	Yes	No