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# Prediction of the Madden-Julian Oscillation and its impact on the European weather in the ECMWF monthly forecasts

Frédéric Vitart

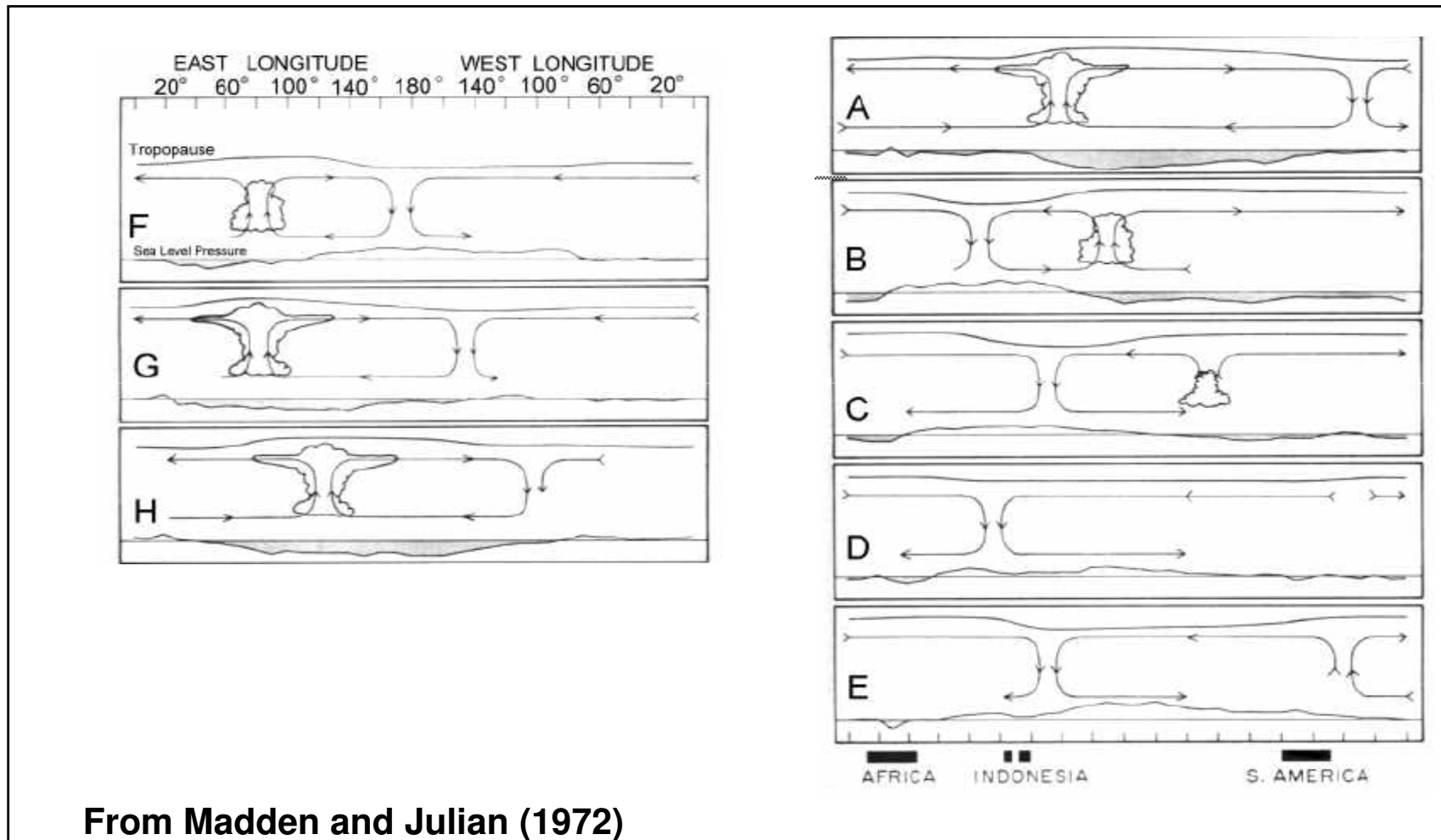
European Centre for Medium-Range Weather Forecasts

# Outline

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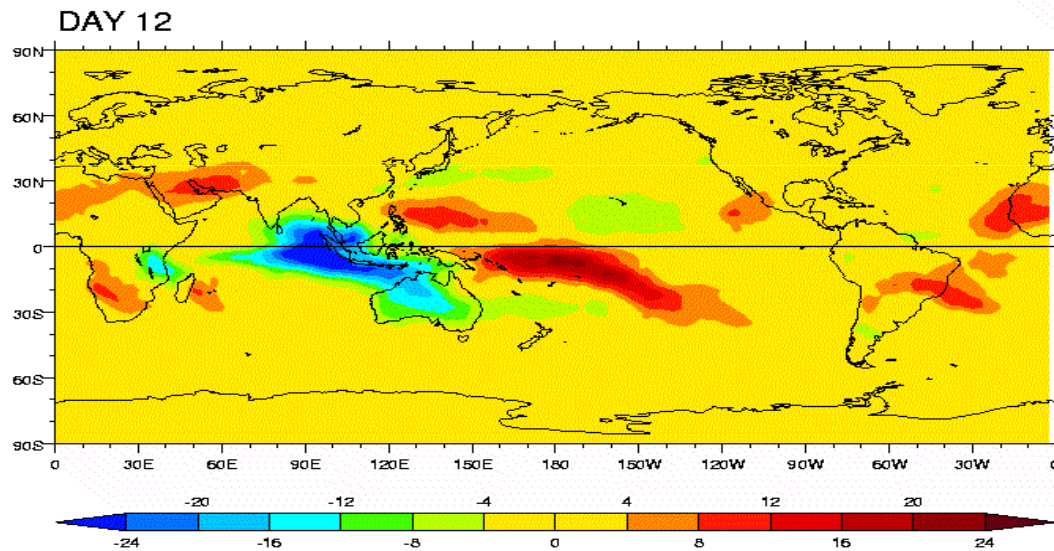
1. Introduction to the MJO and its impacts
2. MJO simulation in the ECMWF model
3. MJO teleconnections in the ECMWF forecast system
4. Impact of the Northern Extratropics on the MJO

# 1. The Madden-Julian Oscillation (MJO)

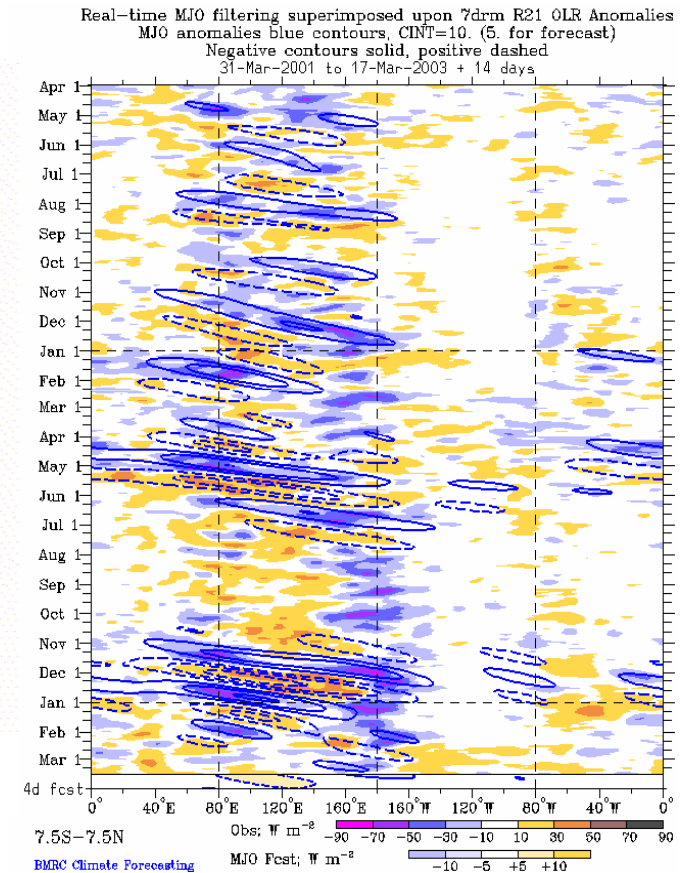


# 1. The Madden Julian Oscillation (MJO)

## MJO life cycle



(From NASA)



From

<http://www.bom.gov.au/bmrc/clf>

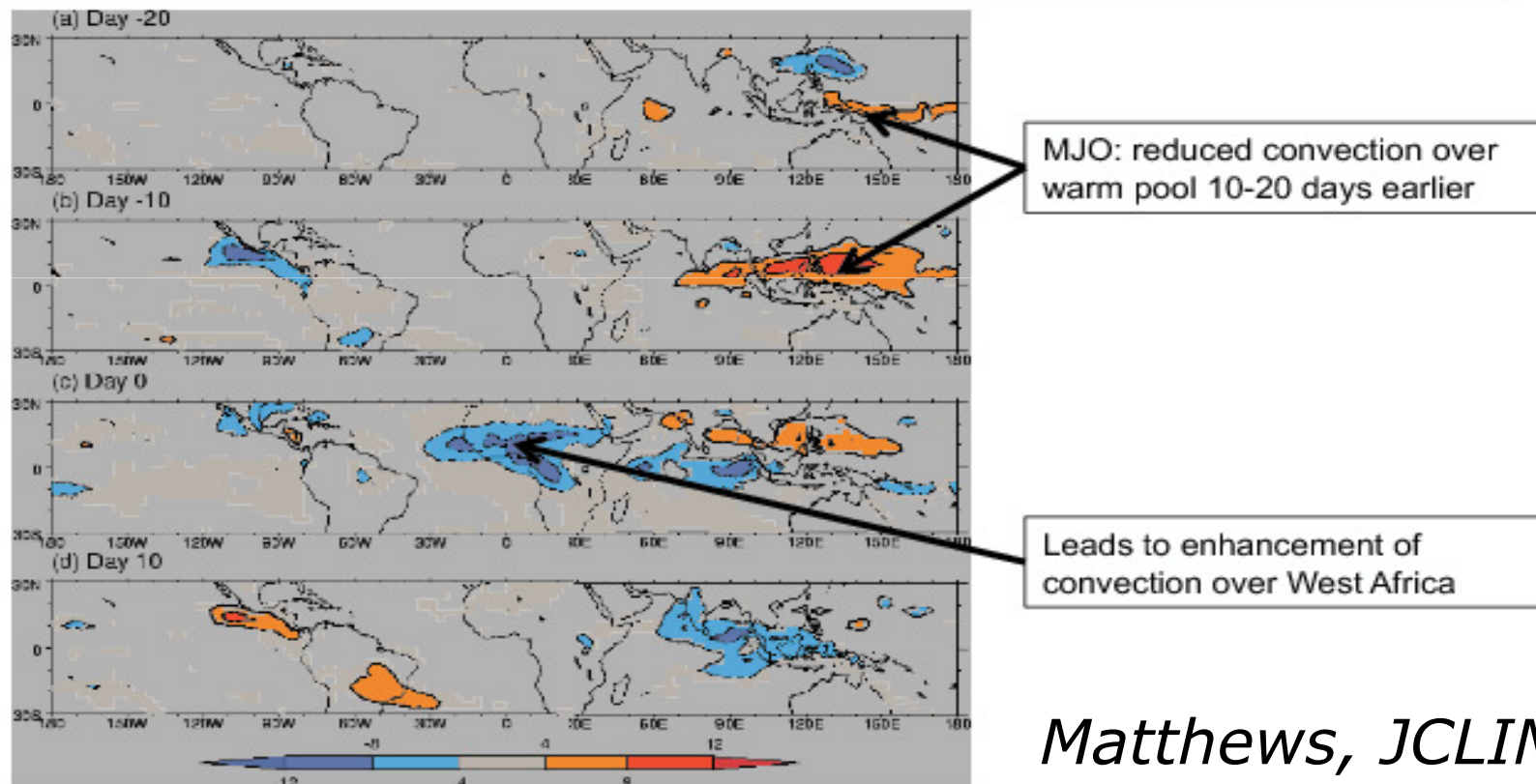
# ↪ 1. Why is the MJO so important?

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- Impact on the Indian (e.g. Yasunari 1979) and Australian summer monsoons (e.g. Hendon and Liebman (1990))
- Impact on ENSO (e.g. Kessler and McPhaden 1995)
- Impact on tropical storms (Nakazawa 1988; Maloney et al 2000; Mo 2000 ...)
- Impact on African summer rainfall
- Impact on Northern Hemisphere weather (Knutson and Weickmann 1986, Ferranti et al 1990, Matthews et al 2004, Lin et al 2009...)

# 1. Impact of MJO on African Summer precipitation

## Response of the West African monsoon to the MJO Observed OLR: JJAS

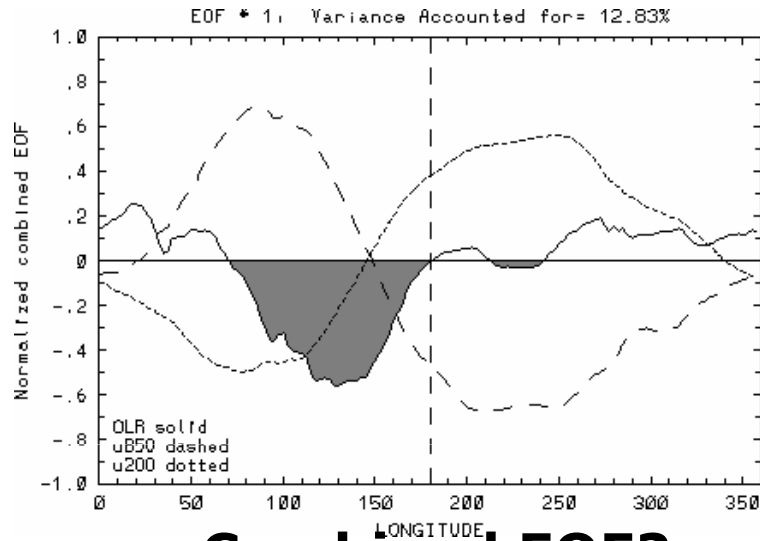


*Matthews, JCLIM 2004*

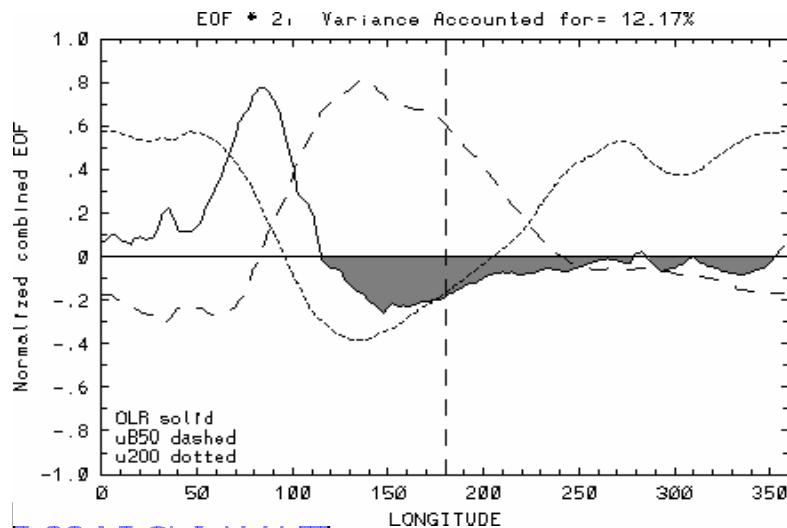
Matthews AJ, 2004: Intraseasonal variability over tropical Africa during northern summer. *J. Climate*, 17, 2427-2440

# 1. MJO Metrics: combined EOFs of U200, U850 and OLR

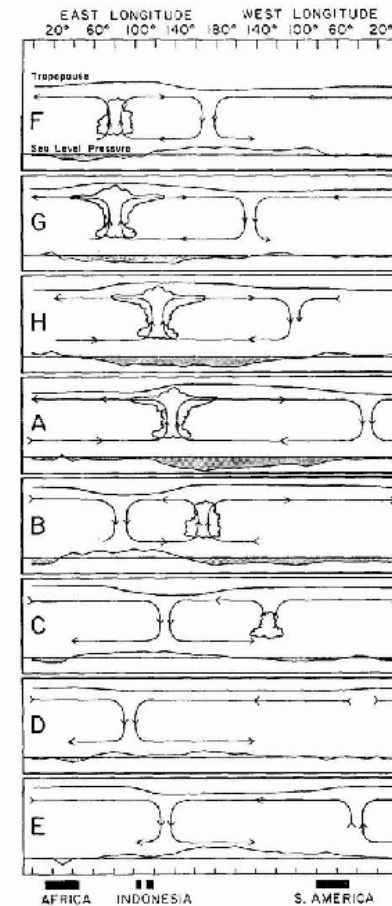
## Combined EOF1



## Combined EOF2



Madden and Julian's (1972) schematic



} Like negative EOF 2

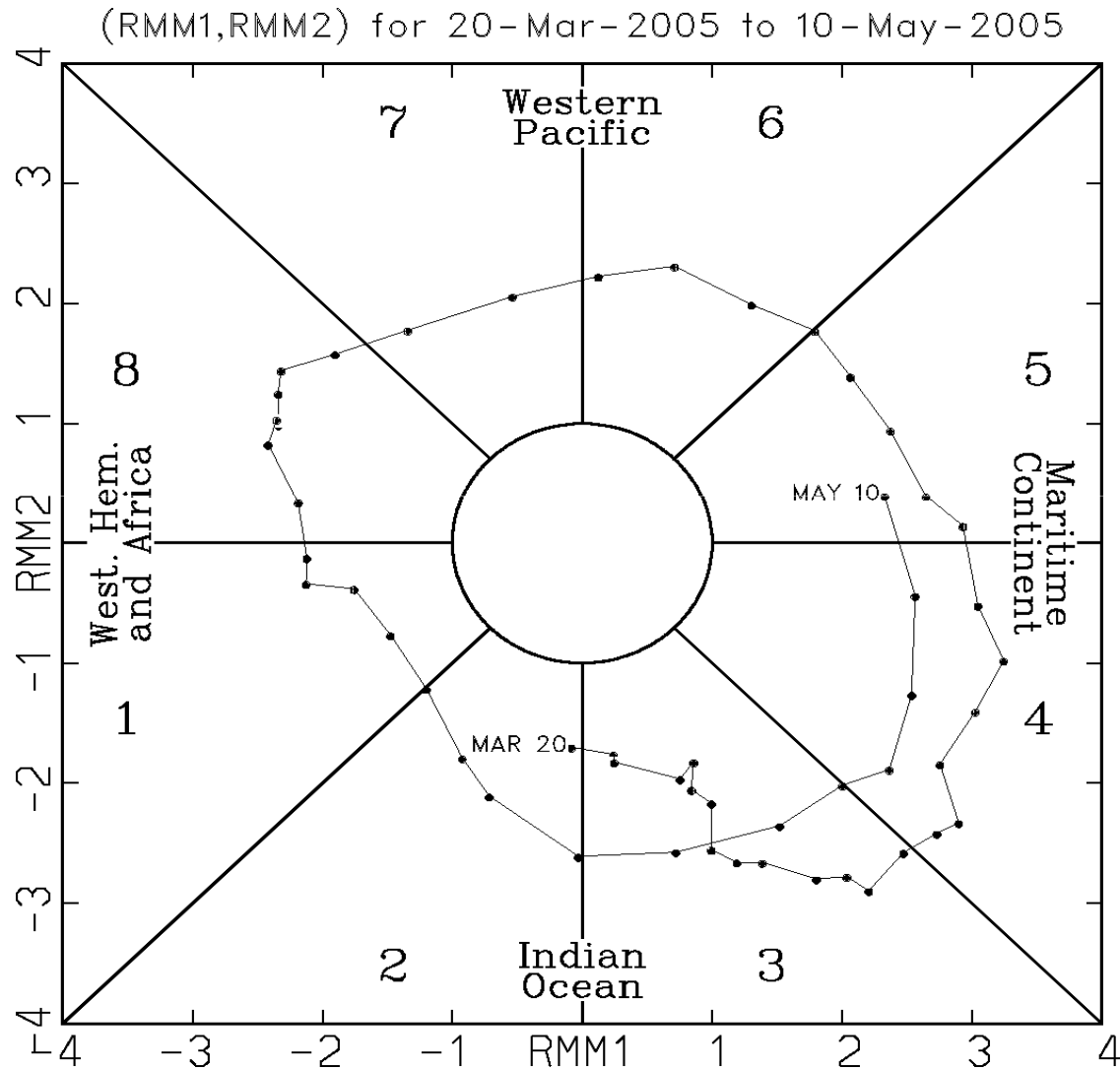
} Like positive EOF 1

} Like positive EOF 2

} Like negative EOF 1

*Wheeler and Hendon, MWR 2004*

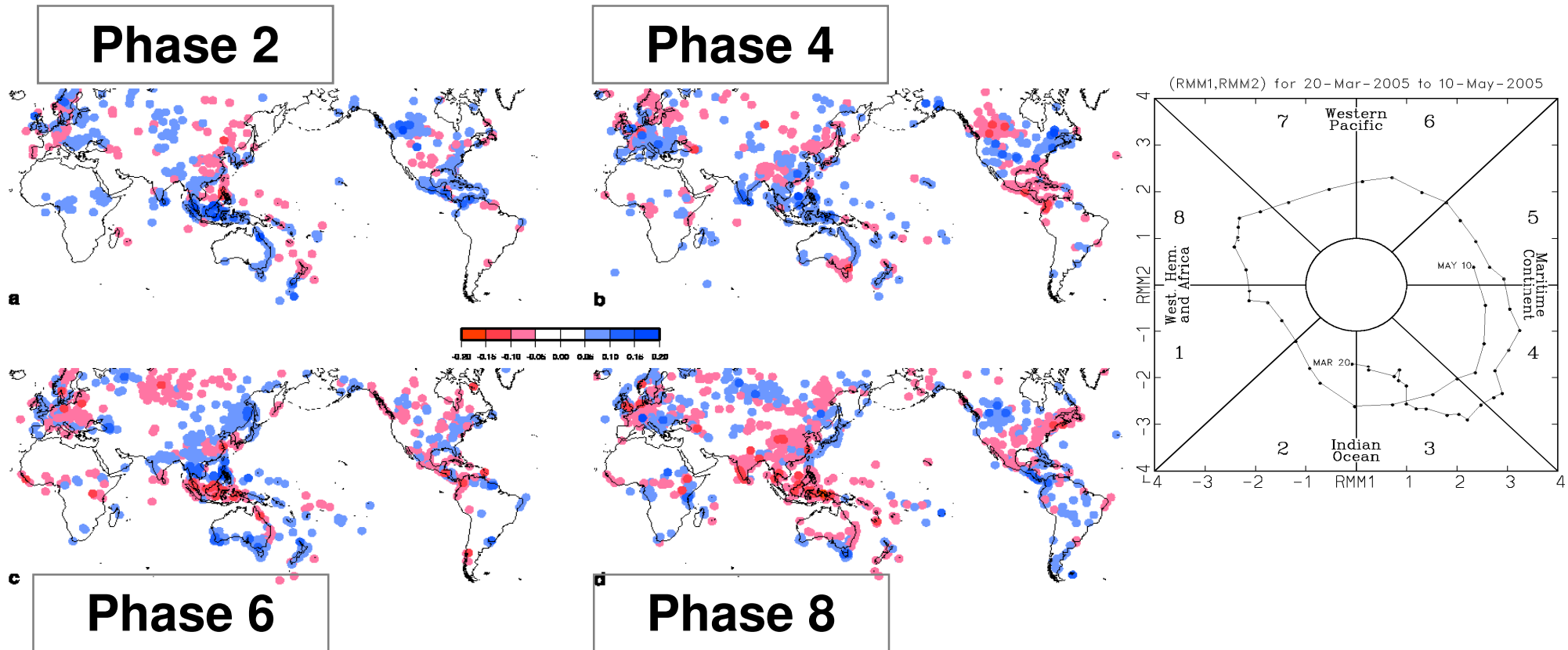
# 1. MJO Metrics: combined EOFs of U200,U850 and OLR





# 1. MJO and Precipitation

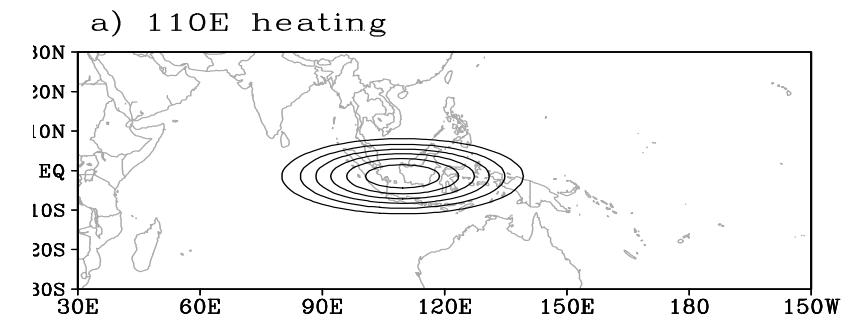
- Observational study (precipitation)



*Donald et al. (2006, GRL)*



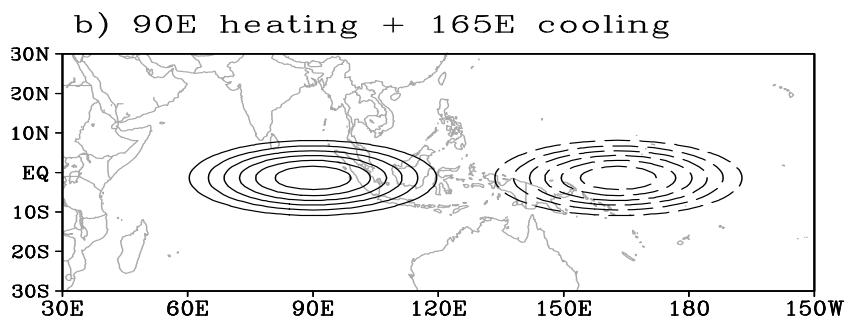
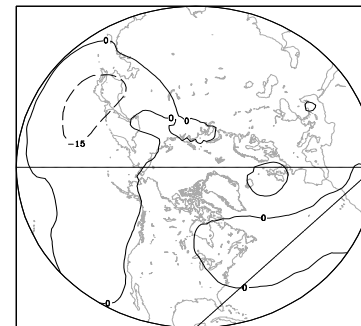
# 1. Impact of the MJO on Extratropics



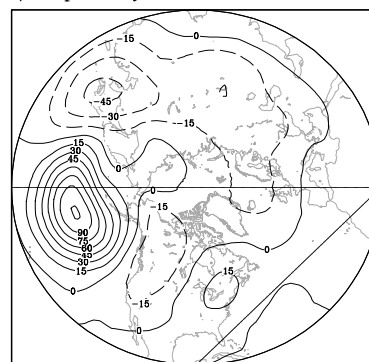
a) Exp1: days6-10



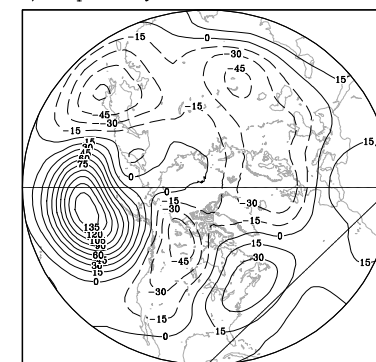
b) Exp1: days11-15



c) Exp2: days6-10



d) Exp2: days11-15



*Lin et al, MWR 2010*

See also

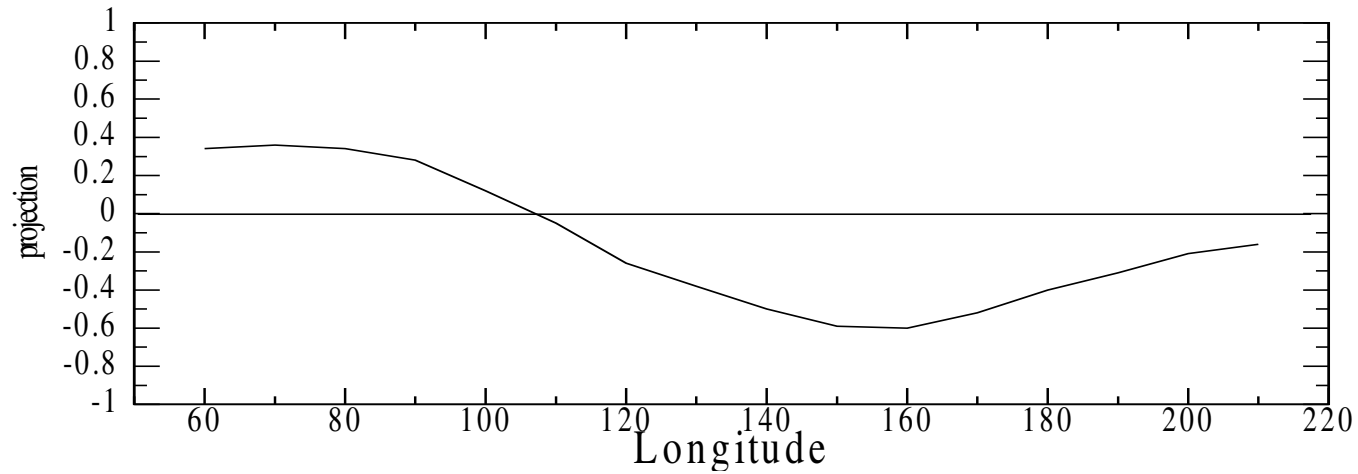
*Simmons et al JAS 1983*

*Ting and Sardeshmukh JAS 1993*



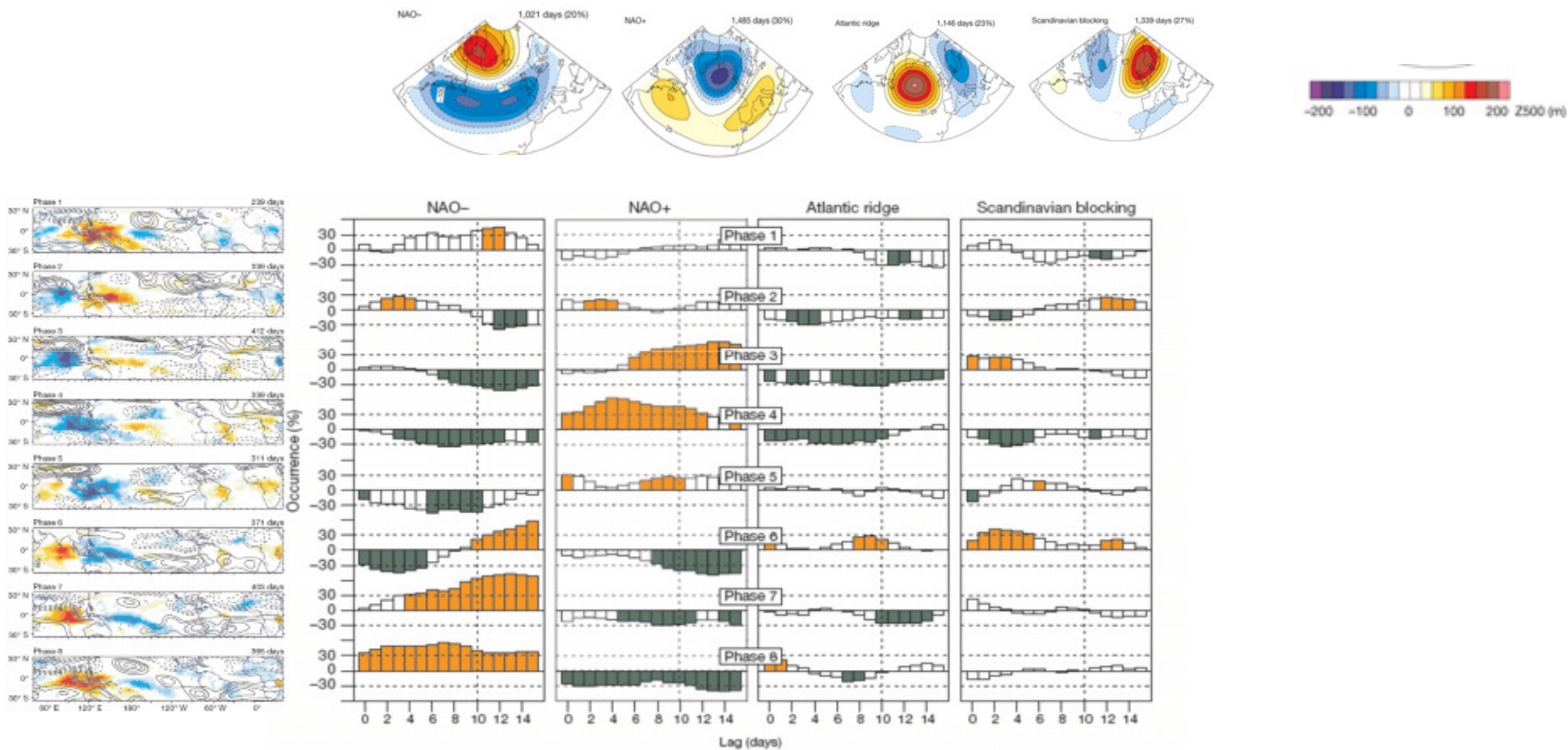
# 1. Impact of the MJO on Extratropics

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*Lin et al, MWR 2010*

# 1. Impact of the MJO on weather regimes



Cassou C, 2008: Intraseasonal interaction between the Madden-Julian Oscillation and the North Atlantic Oscillation. *Nature*, 455, 523-527.

Cassou (2008)



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## 2. Simulation of the Madden Julian Oscillation

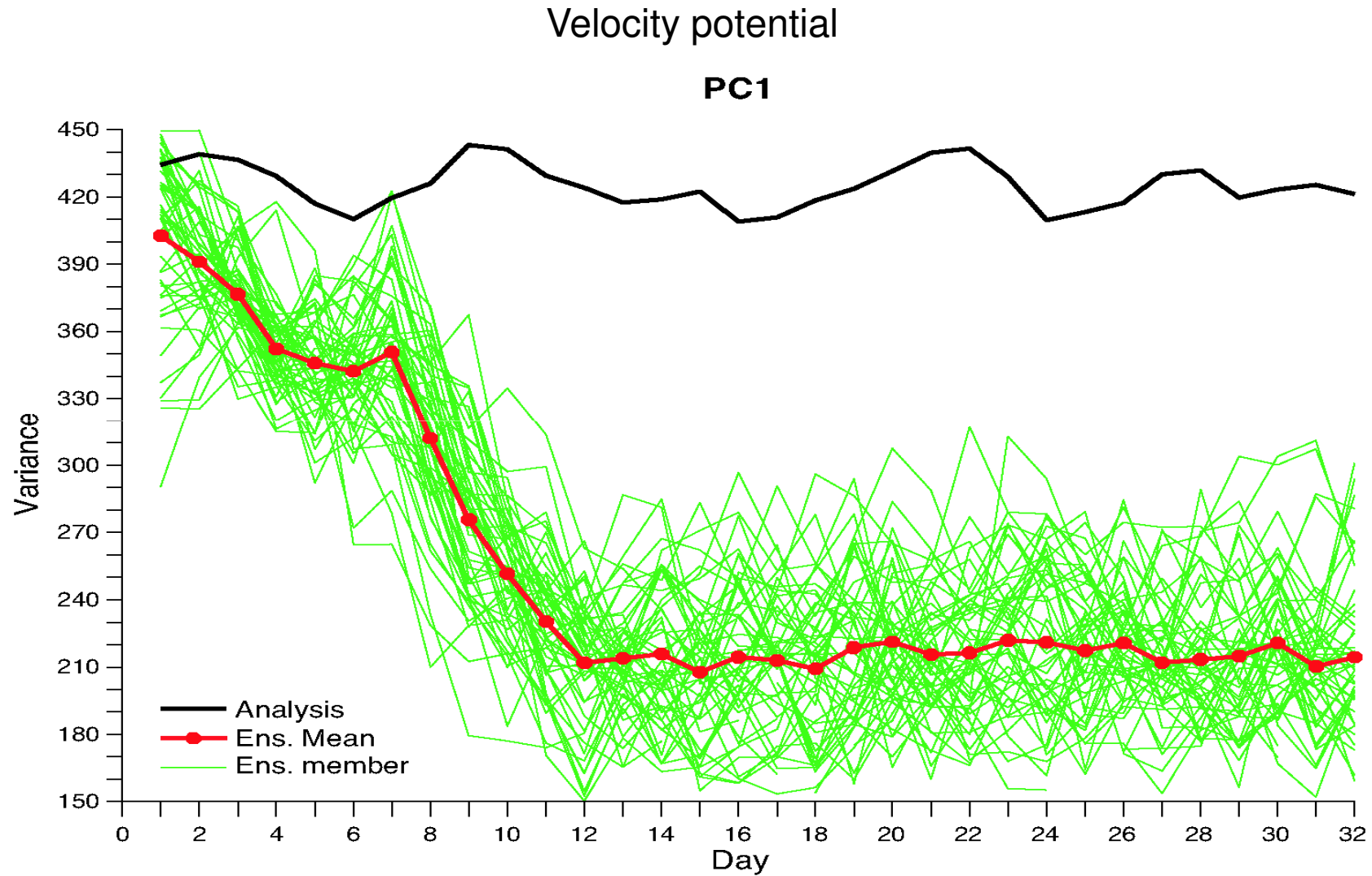
# Simulation of the MJO in climate models

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- ❑ Still a challenging task
- ❑ No satisfactory theory that everyone agrees
- ❑ Inadequate simulation in most GCMs (Slingo et al. 1996, Waliser et al. 2003 and Lin et al. 2006)



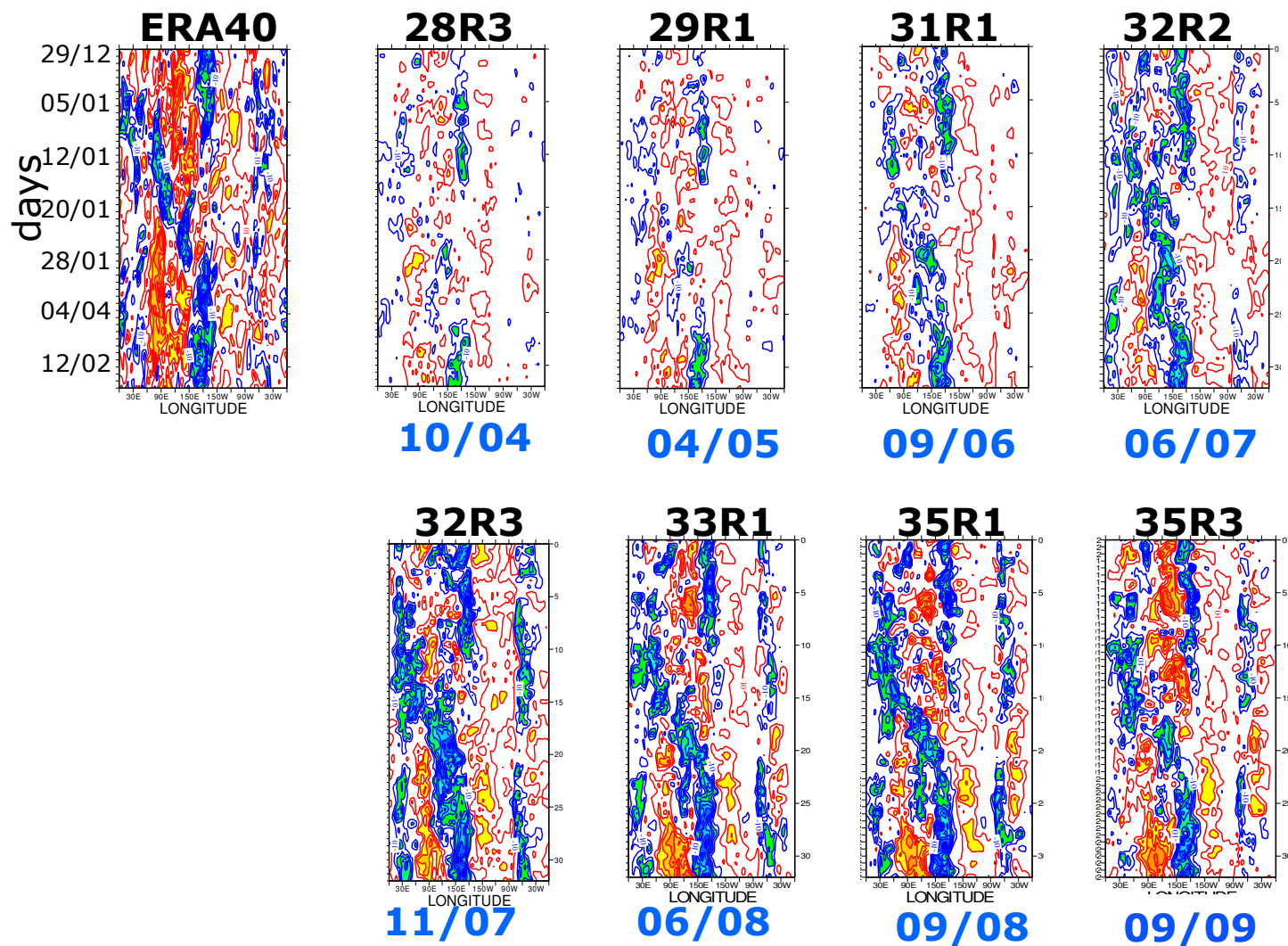
# Simulation of the MJO



*Vitart, 2003*



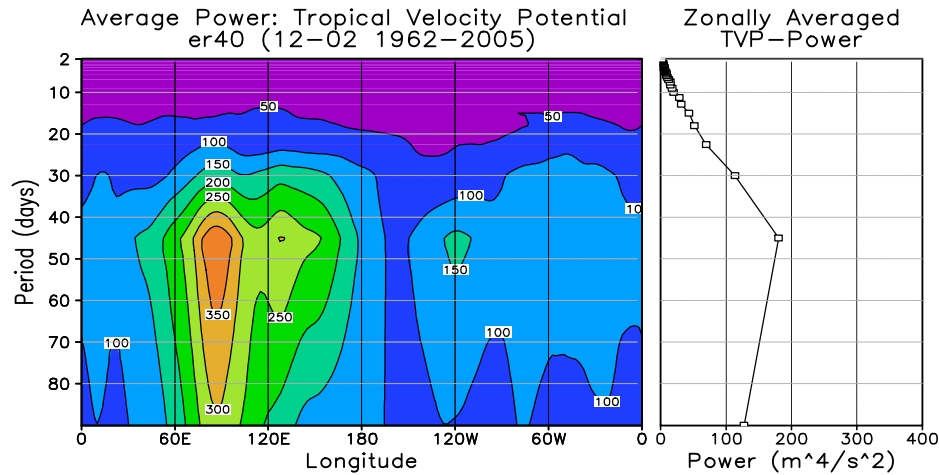
# OLR anomalies - Forecast range: day 15



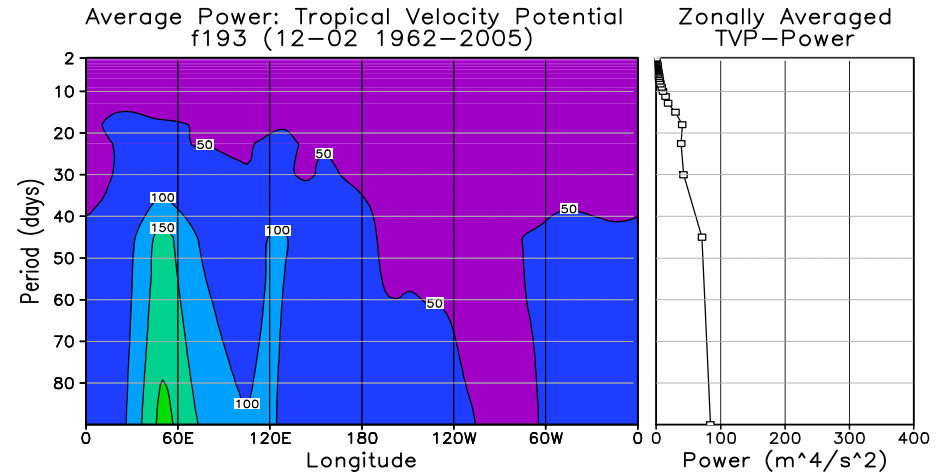


# MJO in 6-month integrations

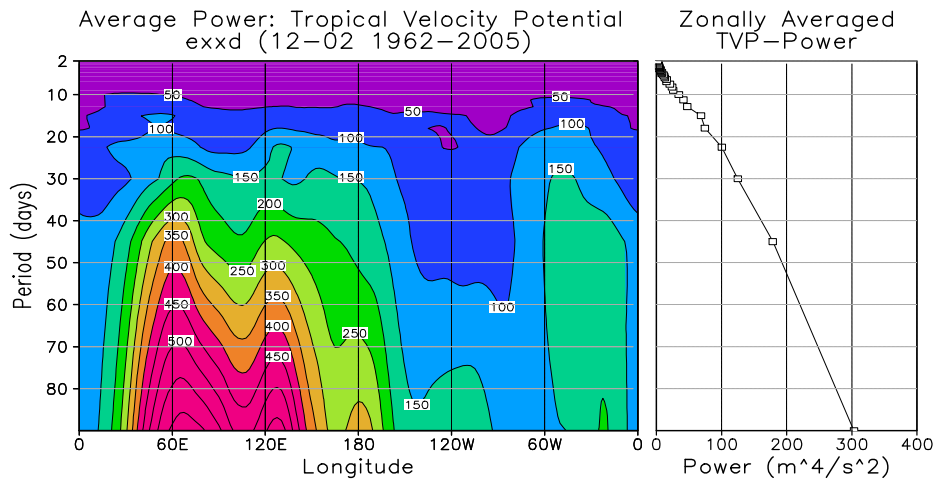
## ERA



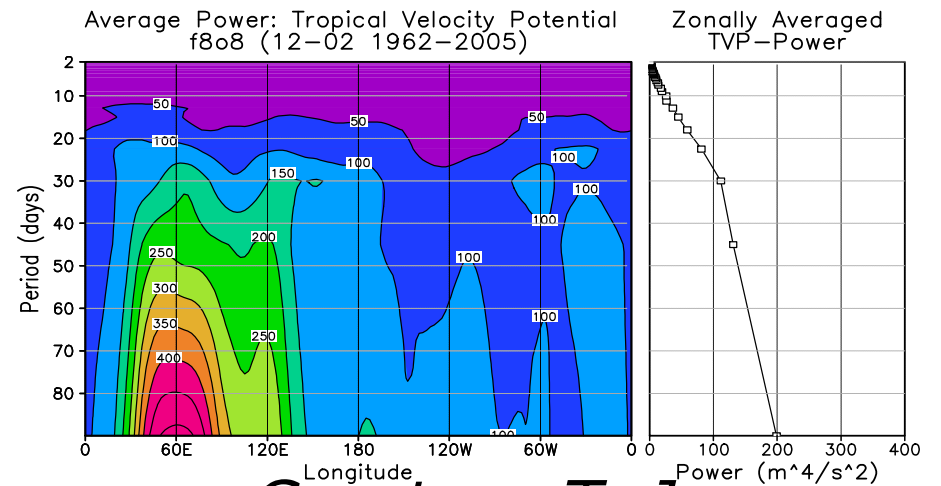
## 30R1



## 32R3



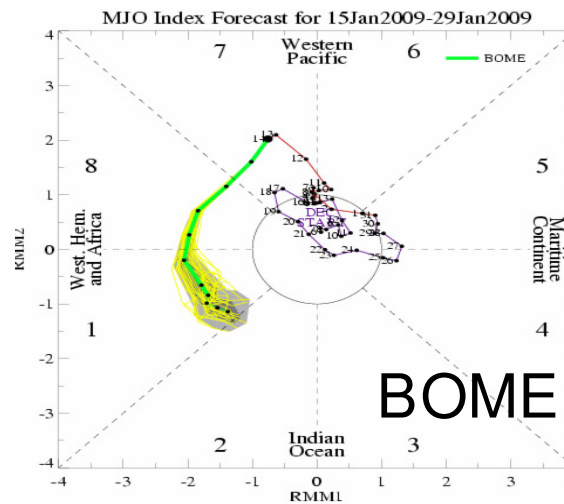
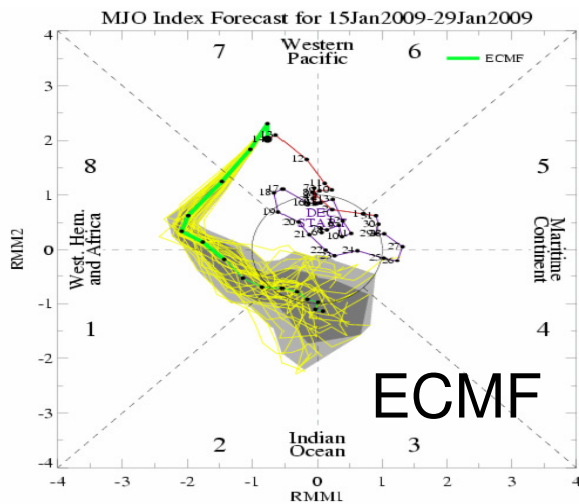
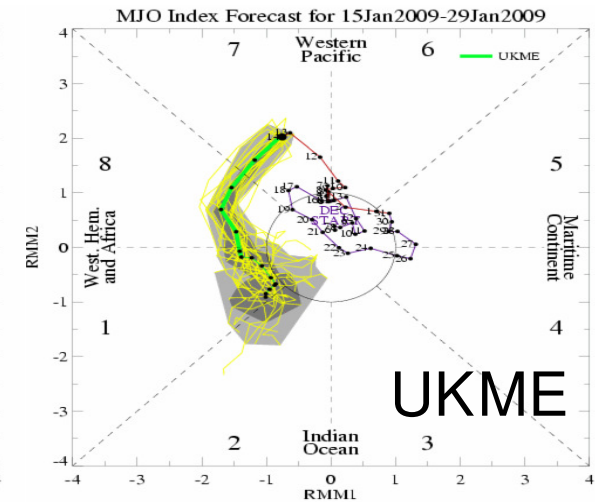
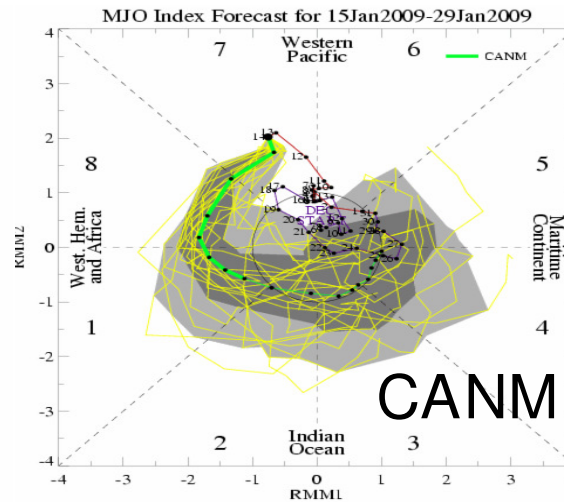
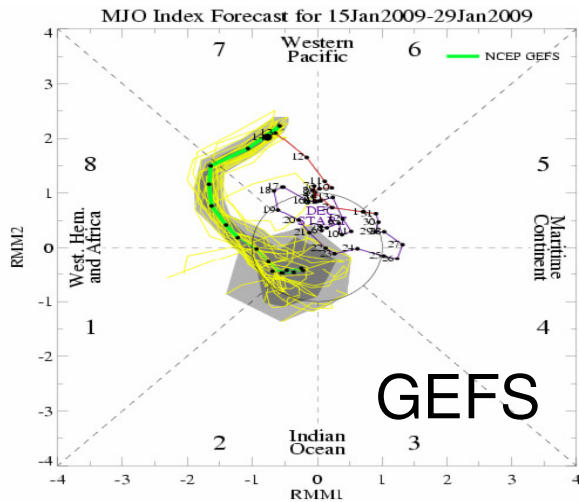
## 36R1



Courtesy T. Jung



# An example of 15-day MJO forecasts



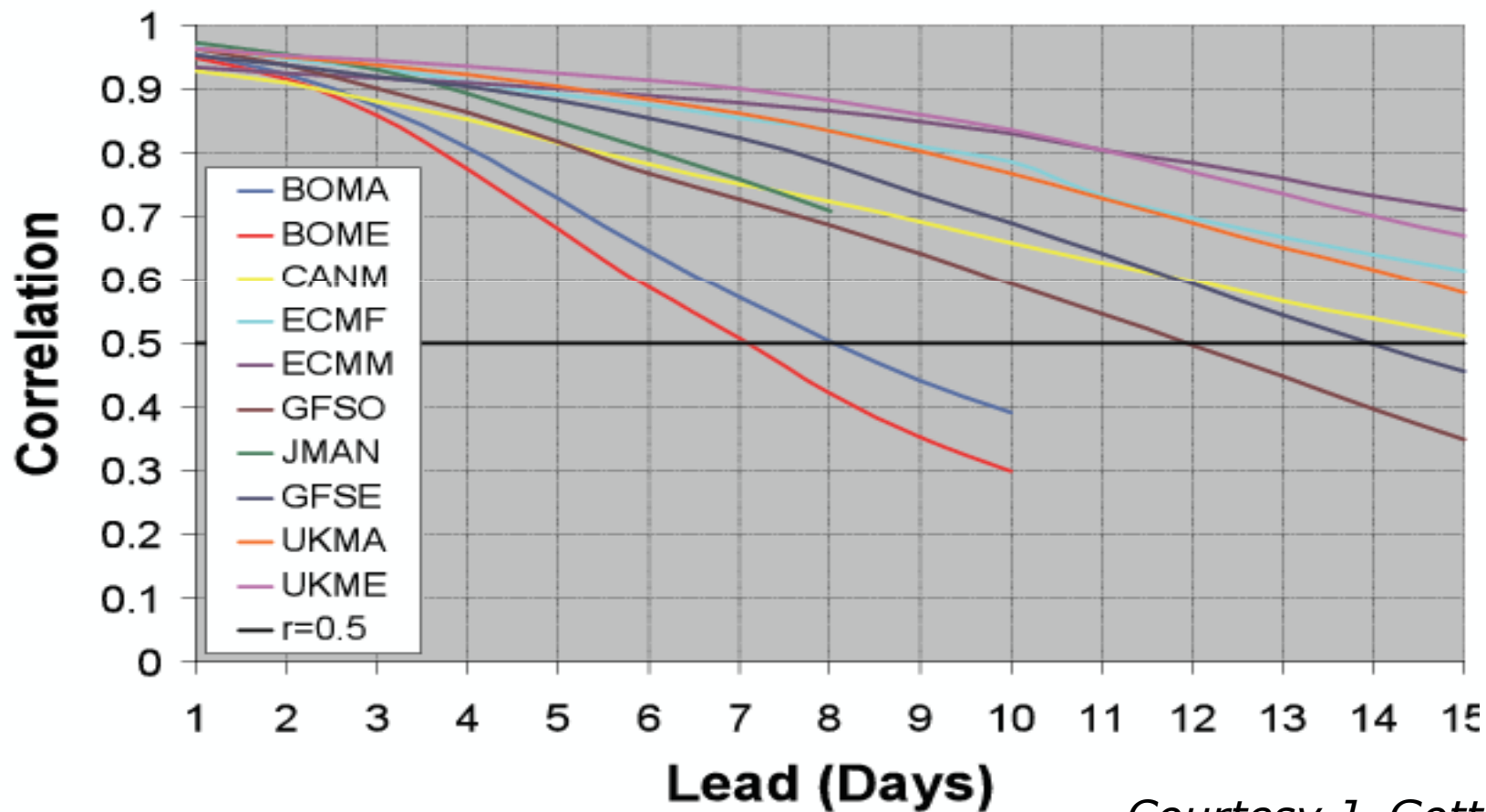
Differences in:

- (1) Ensemble spread
- (2) Propagation speed
- (3) Amplitude

**Courtesy J. Gottschalk**

# MJO forecast skill scores

## Preliminary Verification Bivariate Correlation for MJOTF Models



Courtesy J. Gottschalk



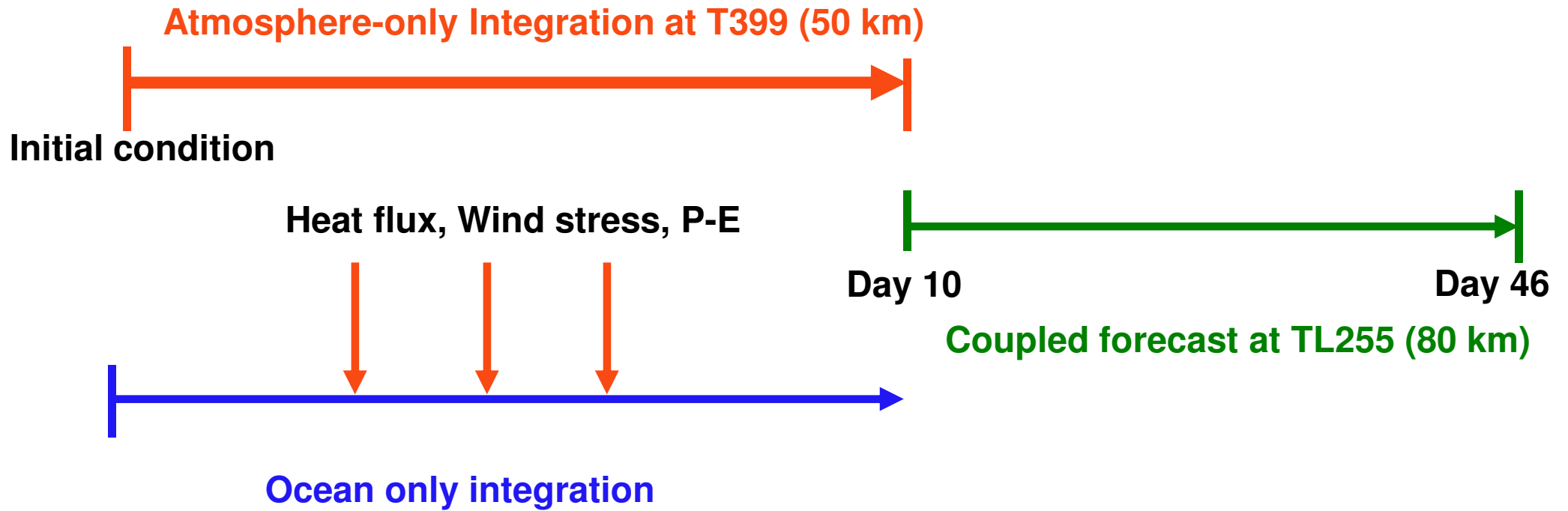
# Hindcast Experiment

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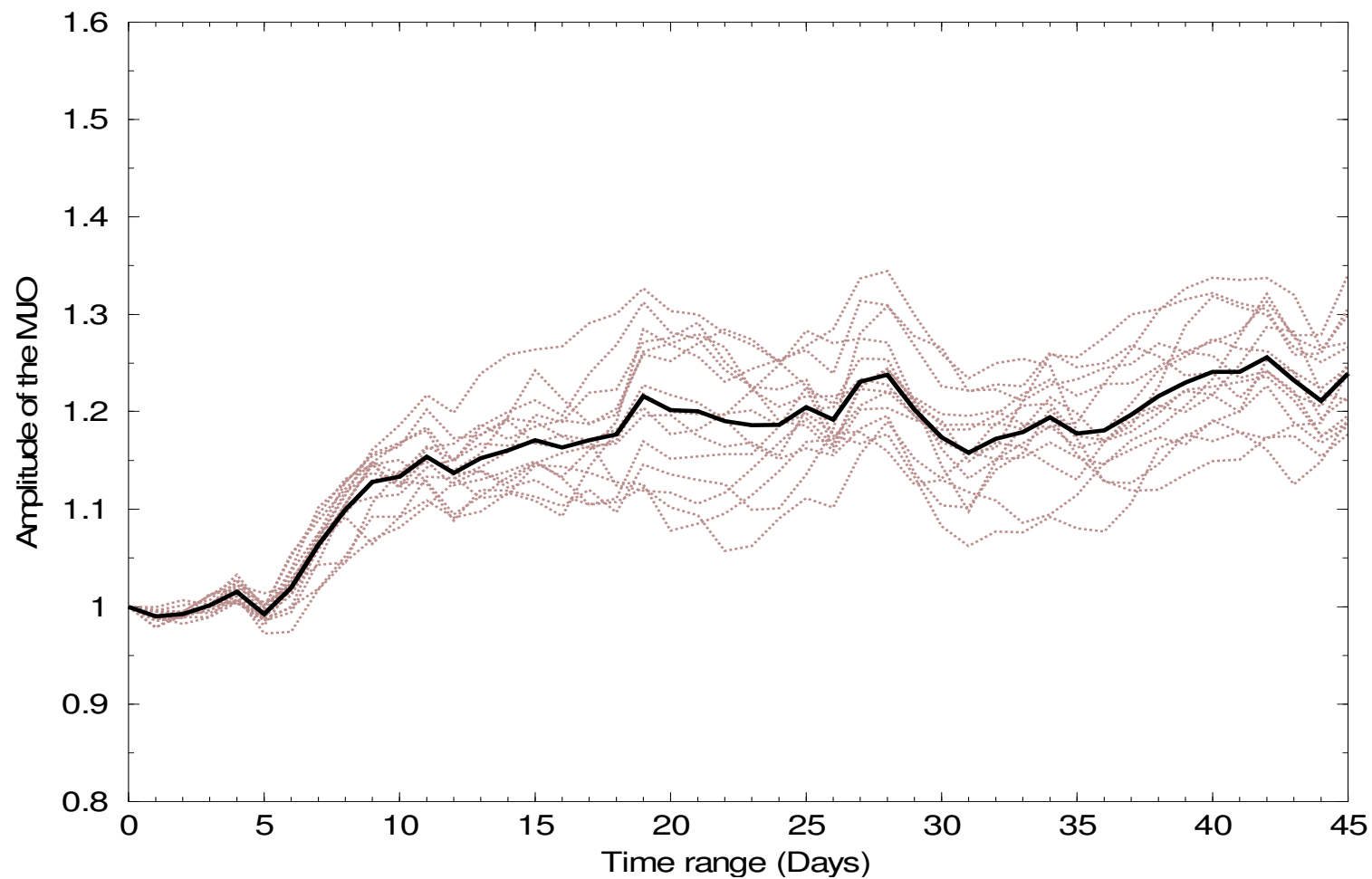
- 15-member ensemble forecasts starting on the 15<sup>th</sup> of each month from 1989 to 2008.
- 46-day integrations
- Cycle 32R3
- T399 (50 km) uncoupled till day 10 and T255 (80km) coupled after day 10



# Experimental setup



# Amplitude of the MJO

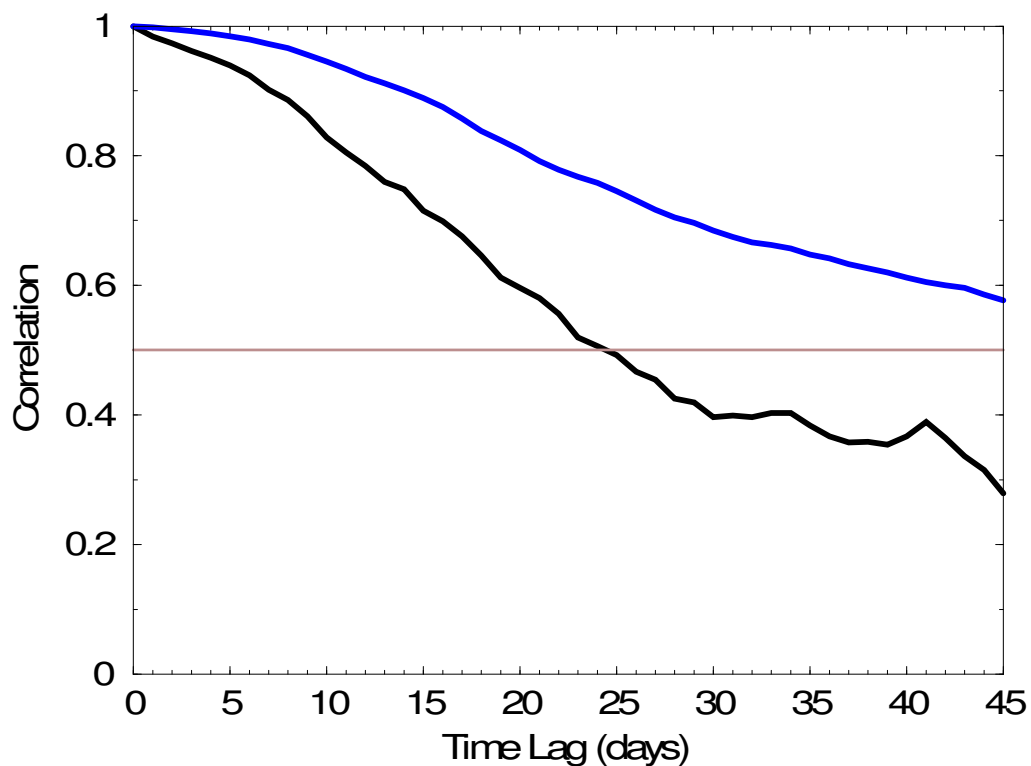


— Ensemble mean      — — — Individual ensemble members

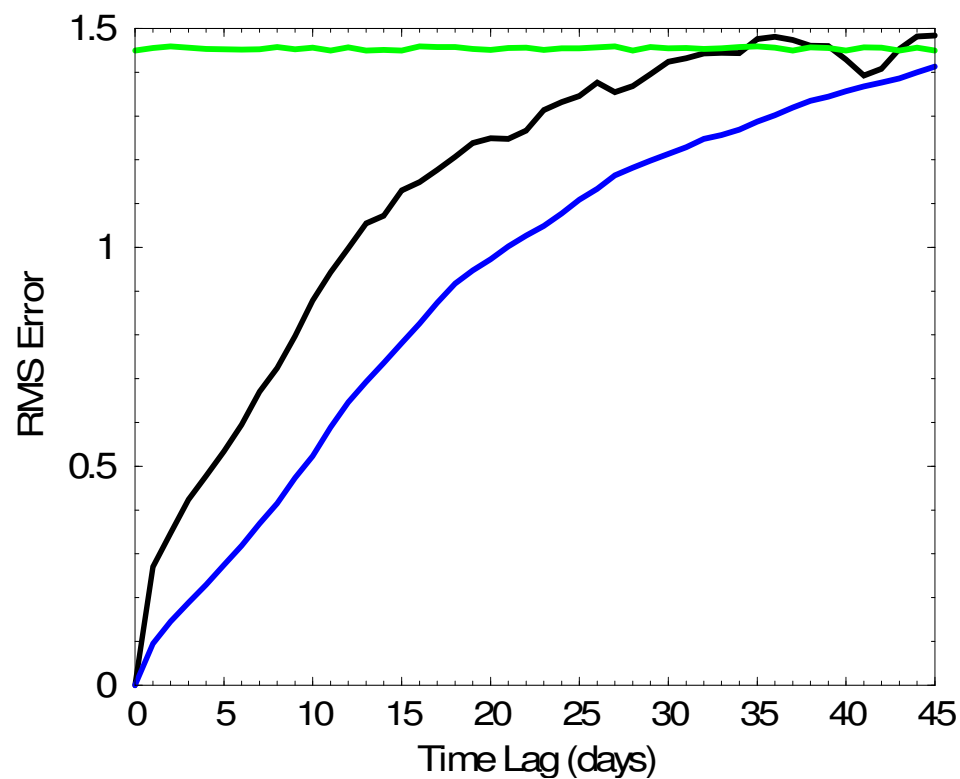


# MJO Skill scores

## Bivariate Correlation



## Bivariate RMS error



**— Ensemble mean/ reanalysis**

**— "Perfect Model"**

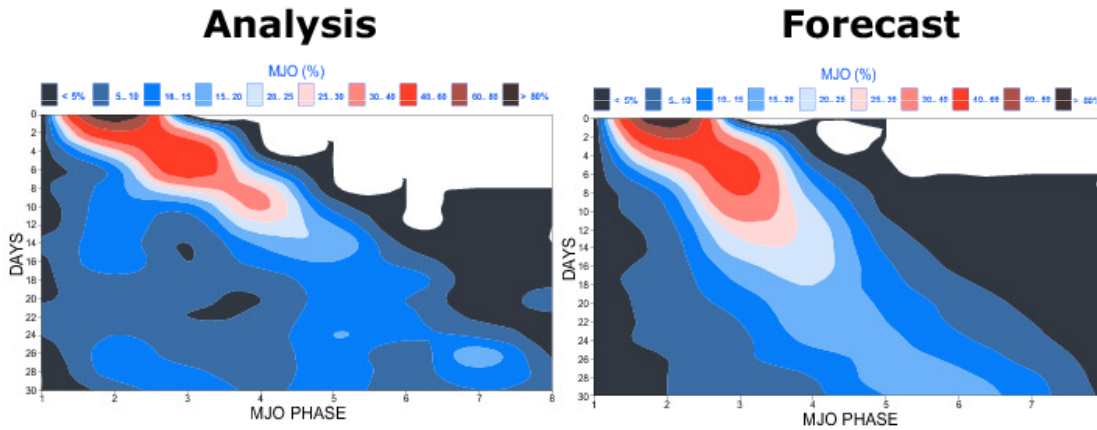
**— Ensemble mean/ reanalysis**

**— Ensemble Spread**

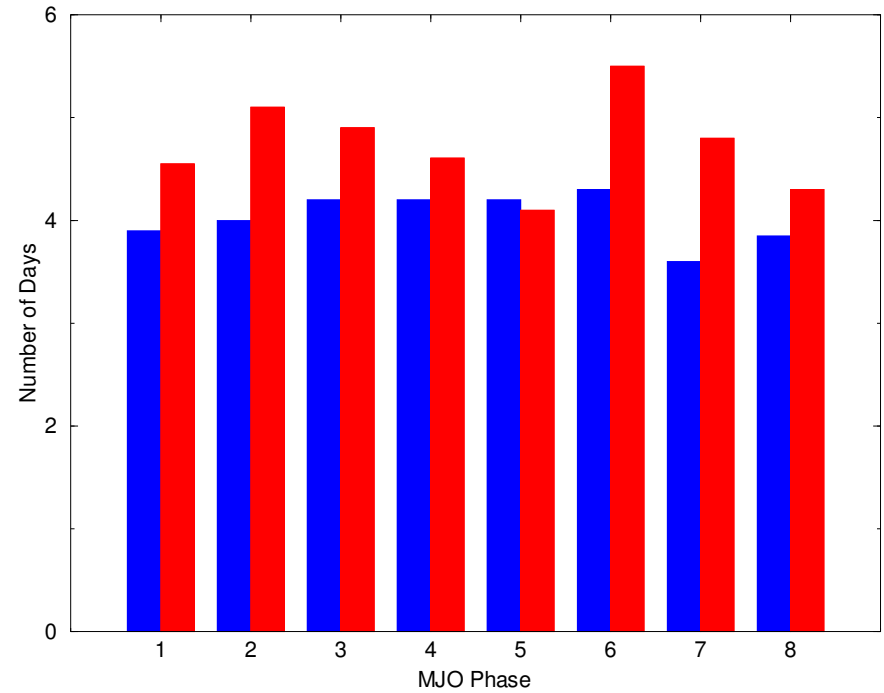
**— Climatology**

# MJO Propagation

MJO Propagation



Time spent in each phase of the MJO



**Model** **EI**



# MJO Propagation

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## Percentage of MJO events propagating from one phase to the next one

	Phase 1-> 2	Phase 2-> 3	Phase 3 -> 4	Phase 4 -> 5	Phase 5 -> 6	Phase 6-> 7	Phase 7 -> 8	Phase 8 -> 1
OBS	71%	81%	81%	80%	86%	79%	68%	55%
Model	71%	81%	80%	71%	72%	78%	65%	87%

**Indian  
Ocean**

**Maritime  
Continent**

**West  
Pacific**



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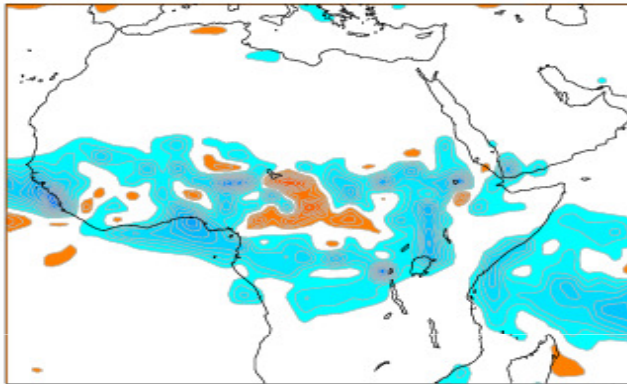
# Simulation of the MJO teleconnections

*(Vitart and Molteni MWR 2010)*

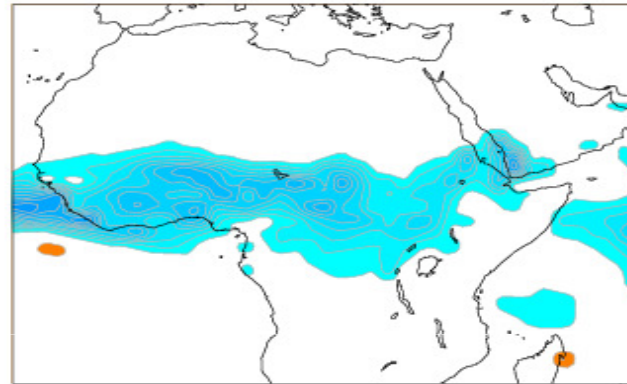
# ↻ Impact on precipitation over Africa

**JJA**

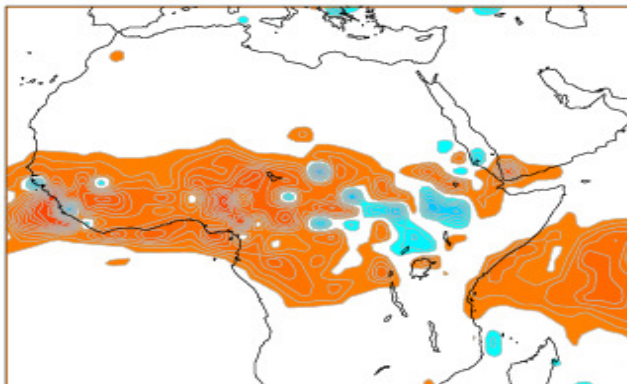
a) ERA Phase 2



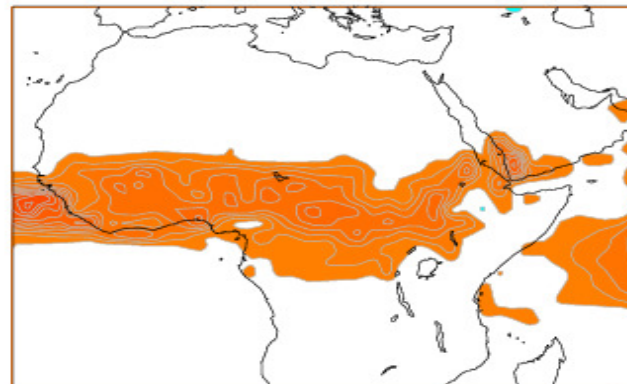
b) EPS Phase 2



c) ERA Phase 6



d) EPS Phase 6

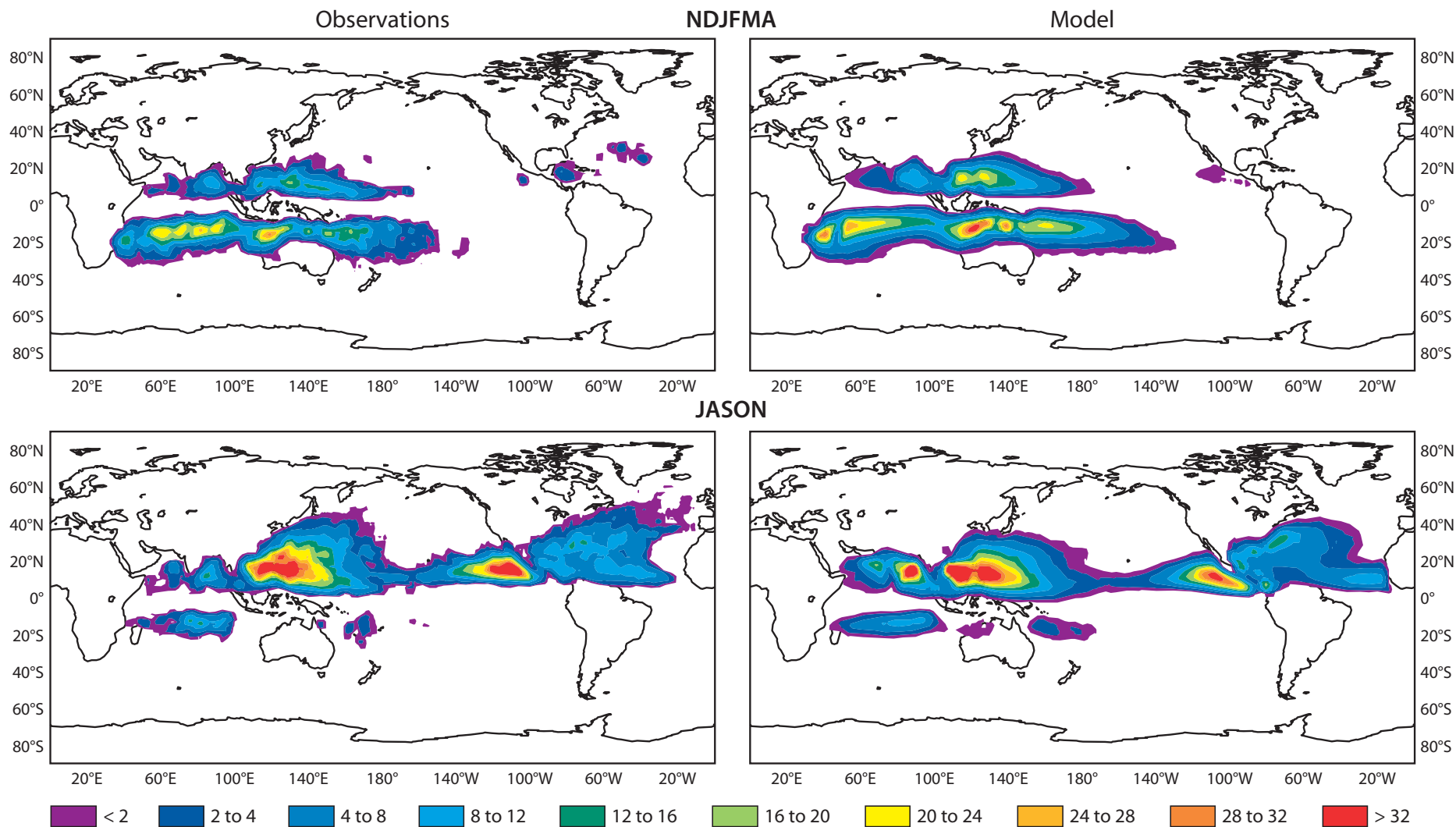


Interval = 0.2 mm/day



# Tropical Cyclone Density climatology

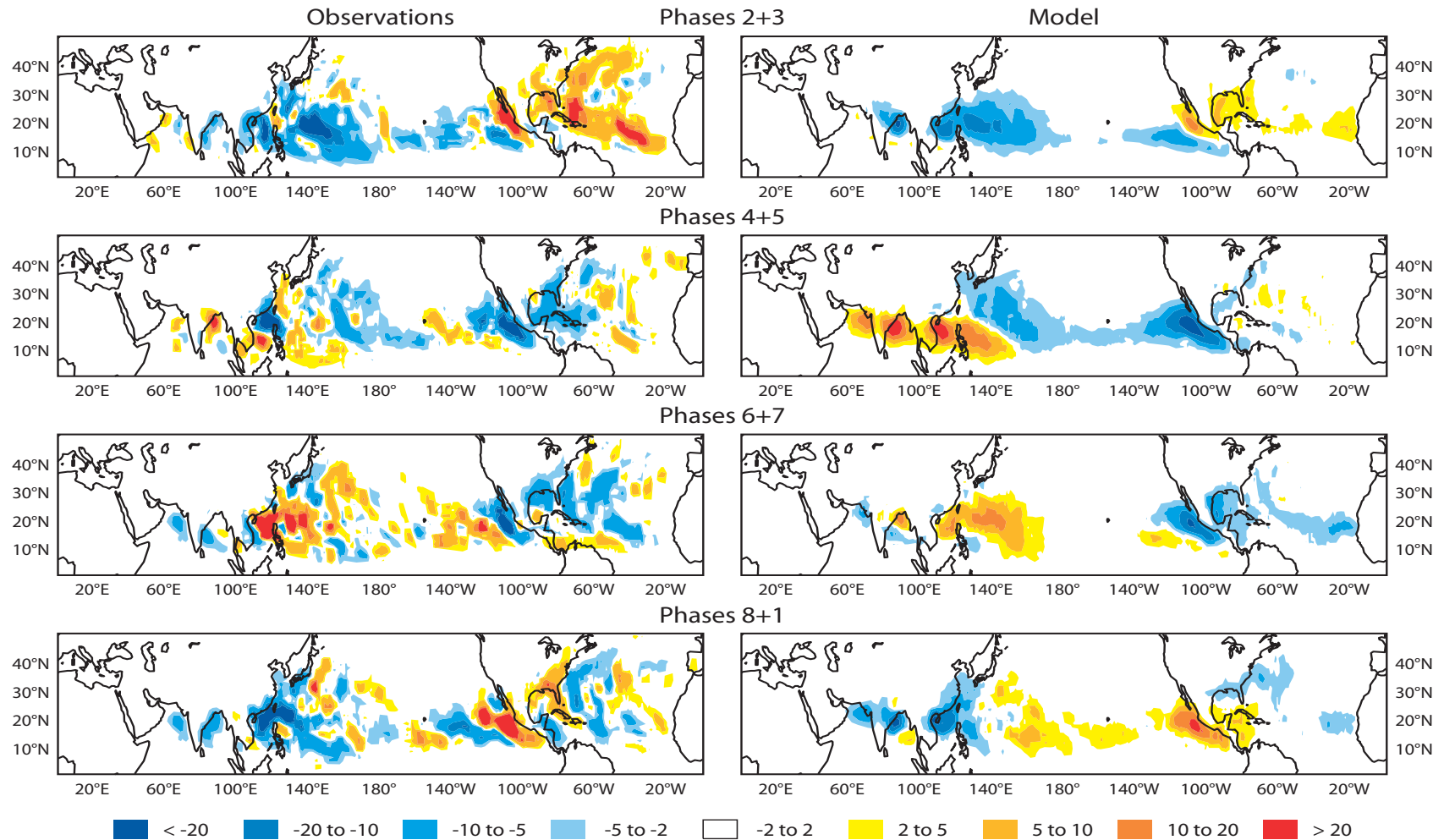
## 1989-2008



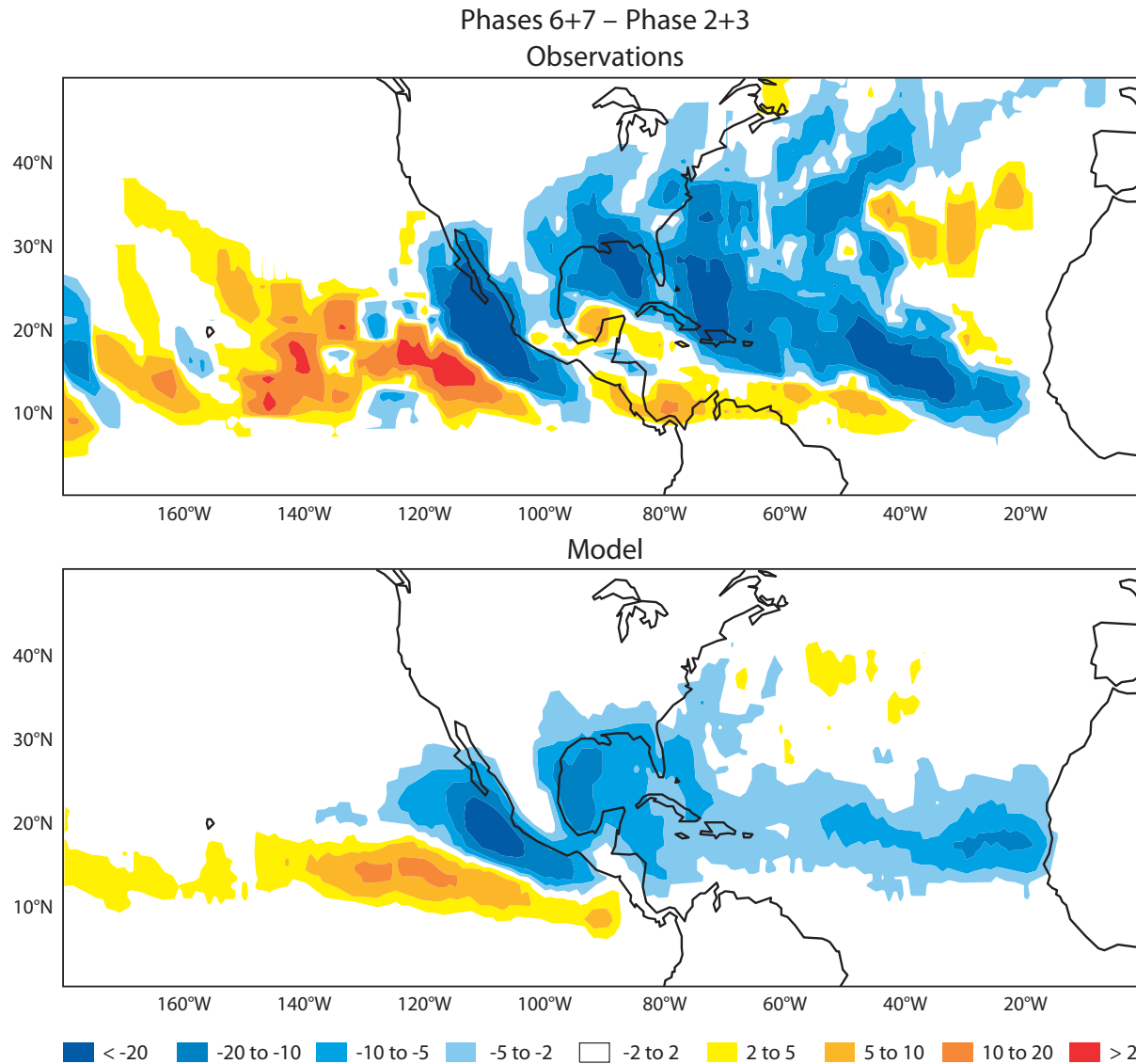


# Impact of the MJO on tropical Storm Activity

## JJA



# Impact of the MJO on tropical Storm Activity - ASO

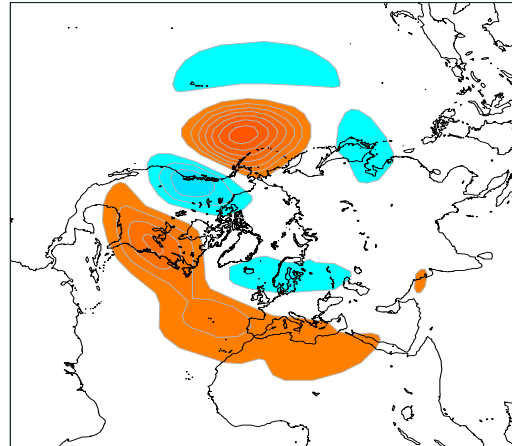


*Vitart, GRL 2009*

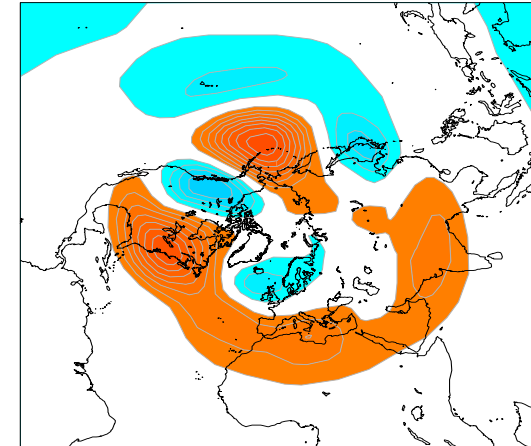
# Impact on Z500 – NDJFM 1989-2008

## Hindcasts- Composites Phase 3

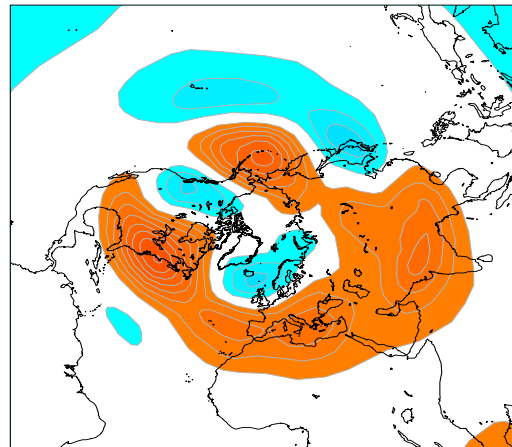
a) Day1-5 - Day-4.0



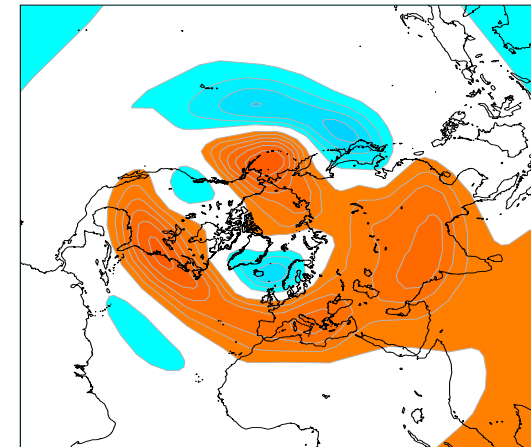
b) Day6-10 - Day-4.0



c) Day11-15 - Day-4.0



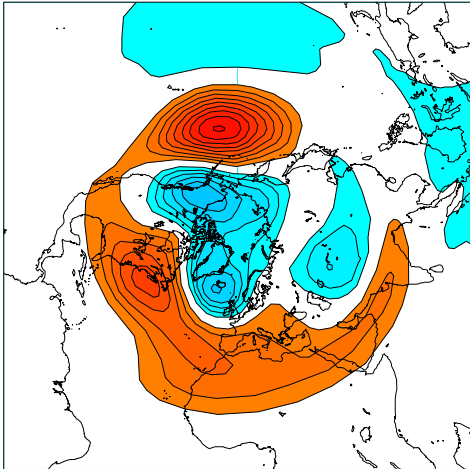
d) Day16-20 - Day-4.0



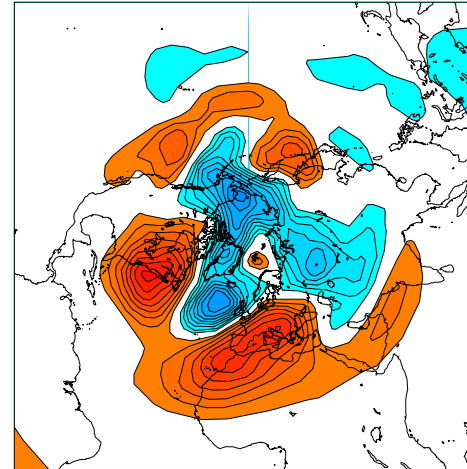
Interval = 5 metres

# Impact on Z500 – NDJFM 1989-2008

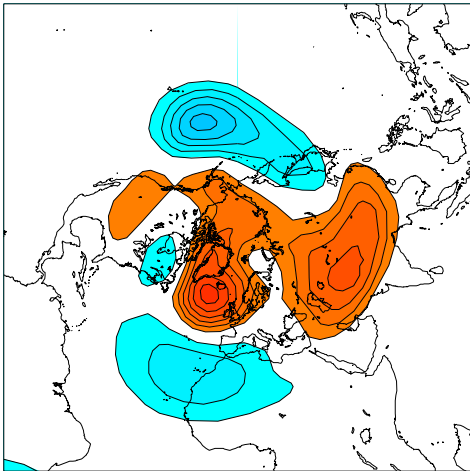
MODEL Phase 3 + 10 days



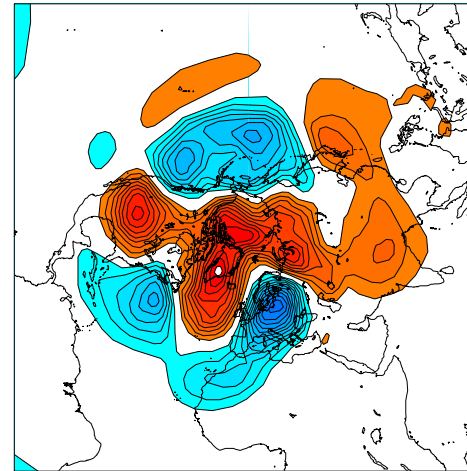
ERA Phase 3 + 10 days



MODEL Phase 6 + 10 days



ERA Phase 6 + 10 days

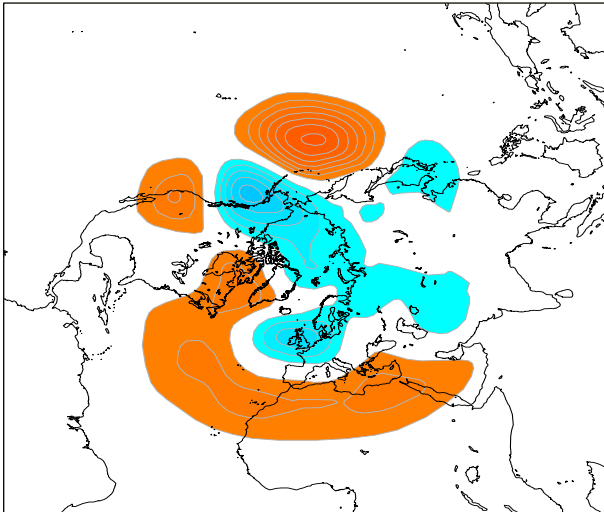


Interval = 5 metres

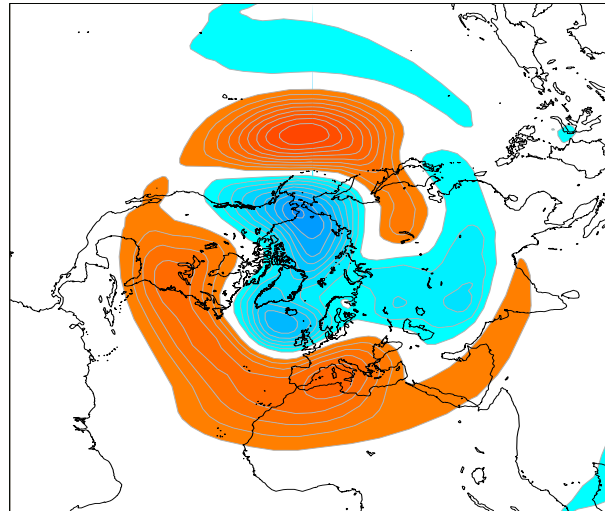


# Impact of MJO on Z500 anomalies

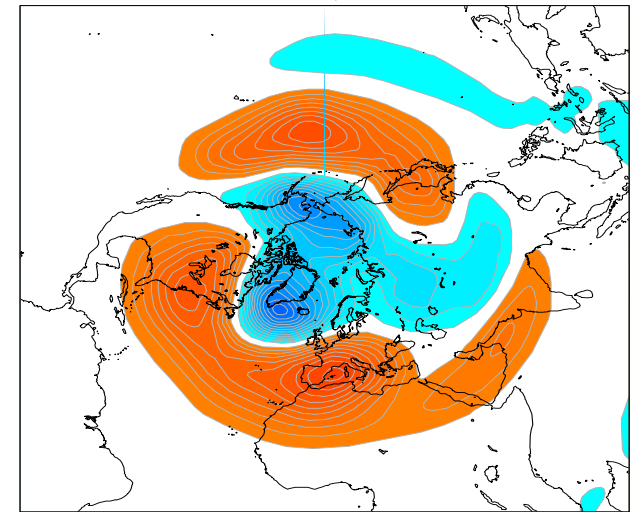
**1 std < AMP < 1.5 std**



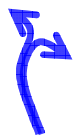
**1.5 std < AMP < 2 std**



**AMP > 2 std**

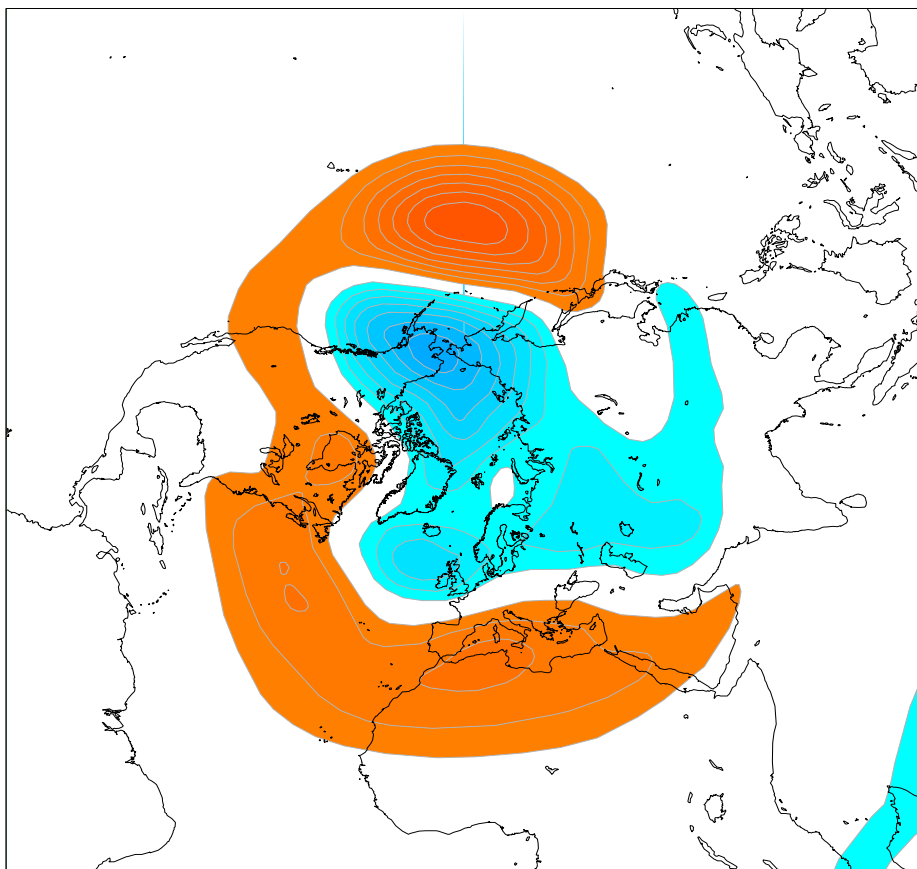


Interval = 5 metres

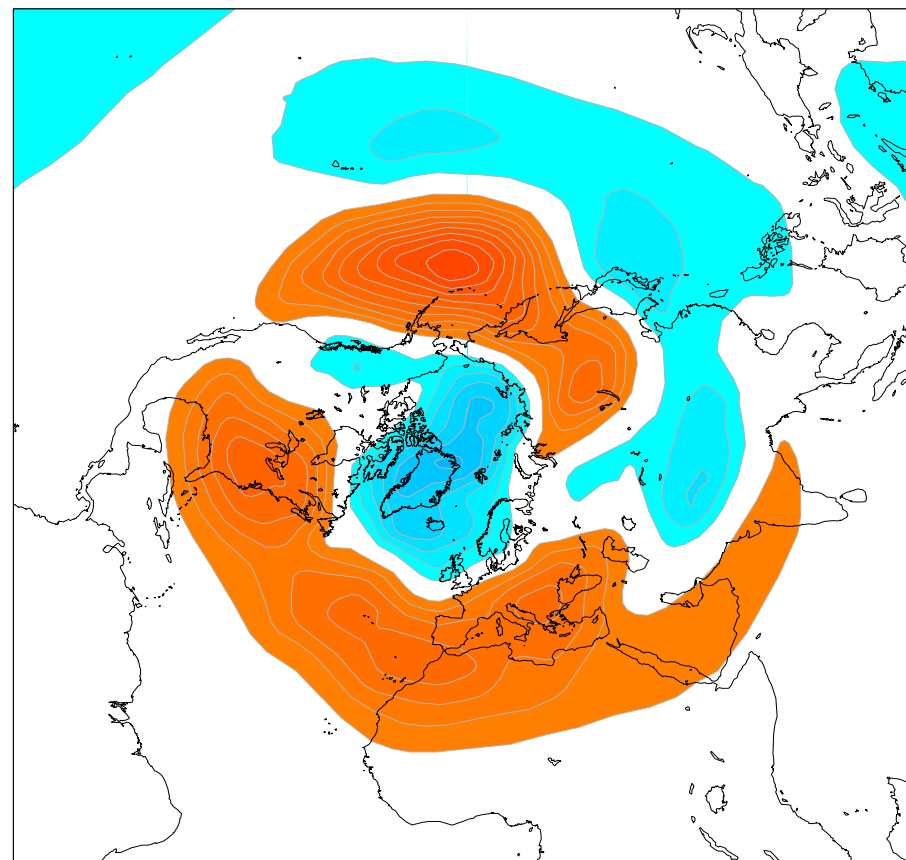


# Impact of MJO propagation speed

## Slow MJO

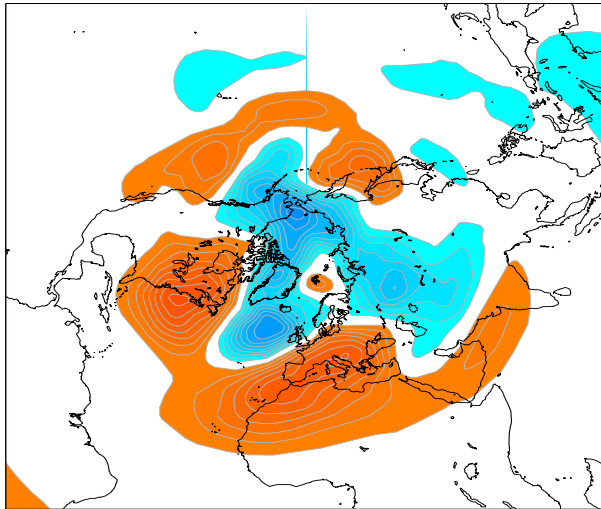


## Fast MJO

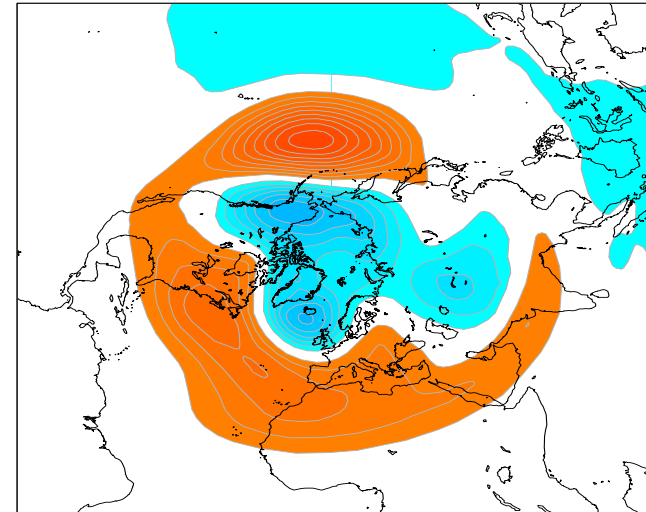


# Impact of MJO on Z500 anomalies

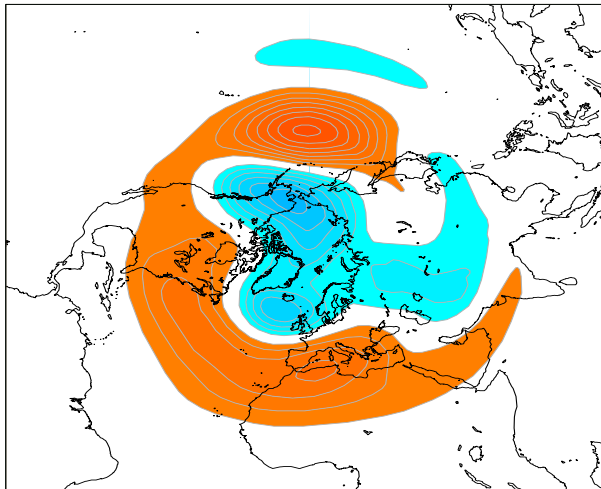
**ERA  
Interim**



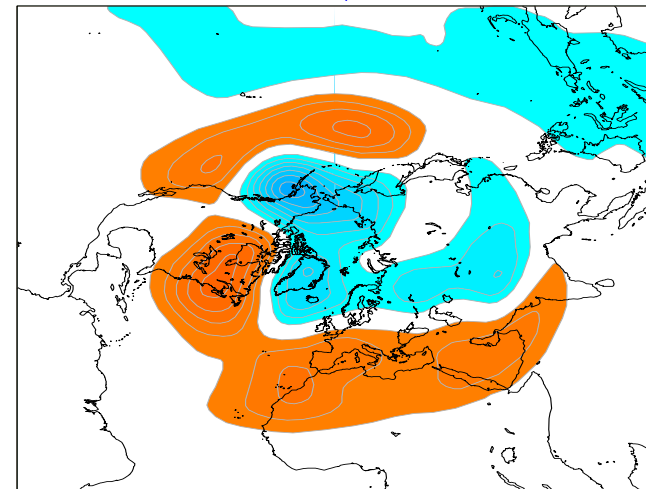
**32R3**



**36R1**

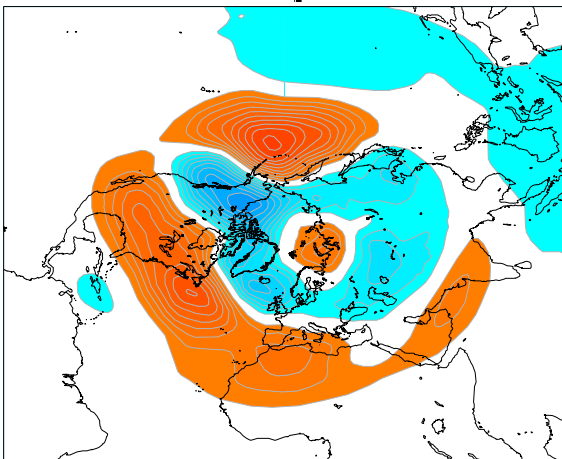


**36R1  
+relax**

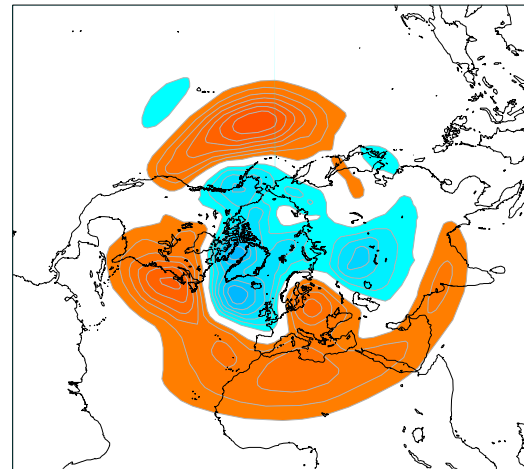


# Impact on Z500

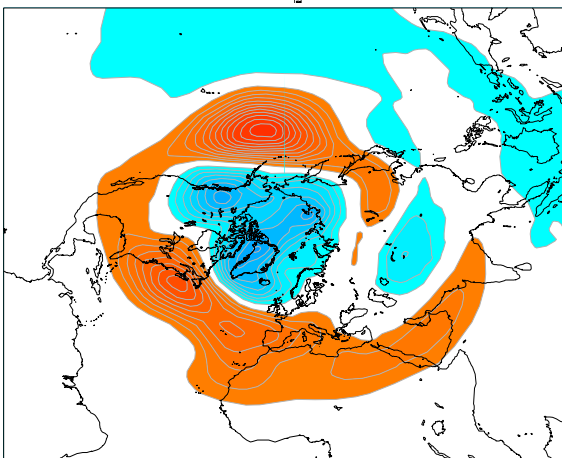
PERT 0+1



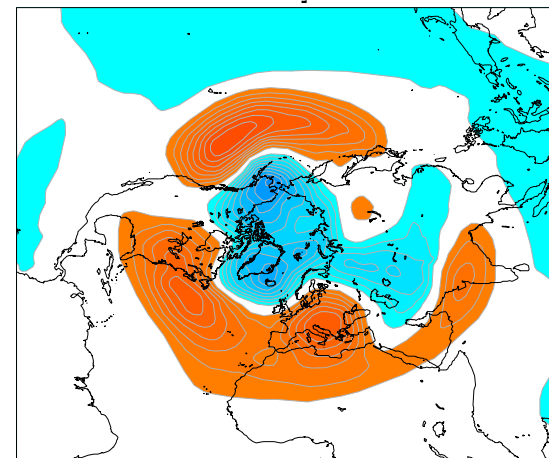
PERT 2+3



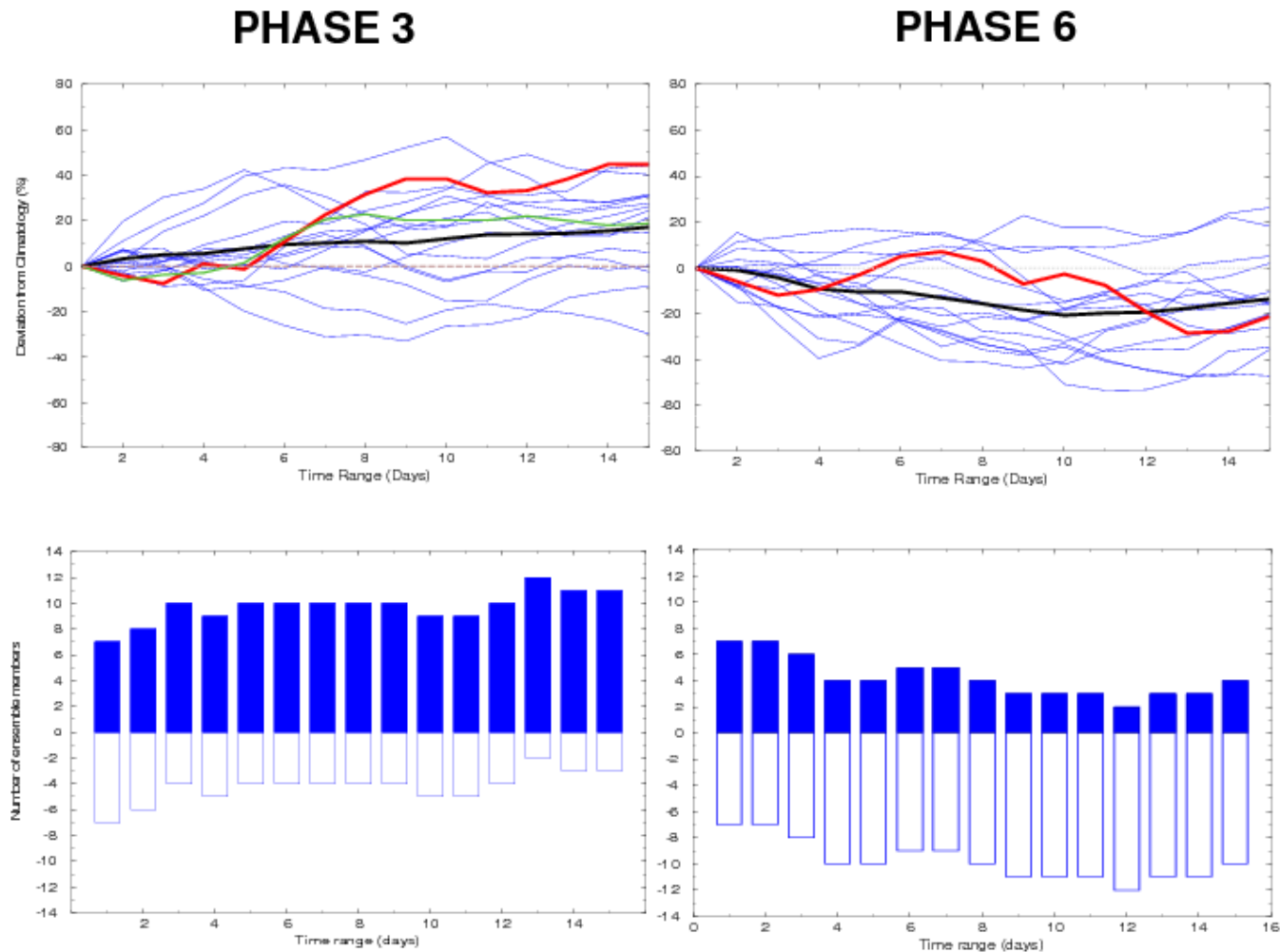
PERT 13 + 14



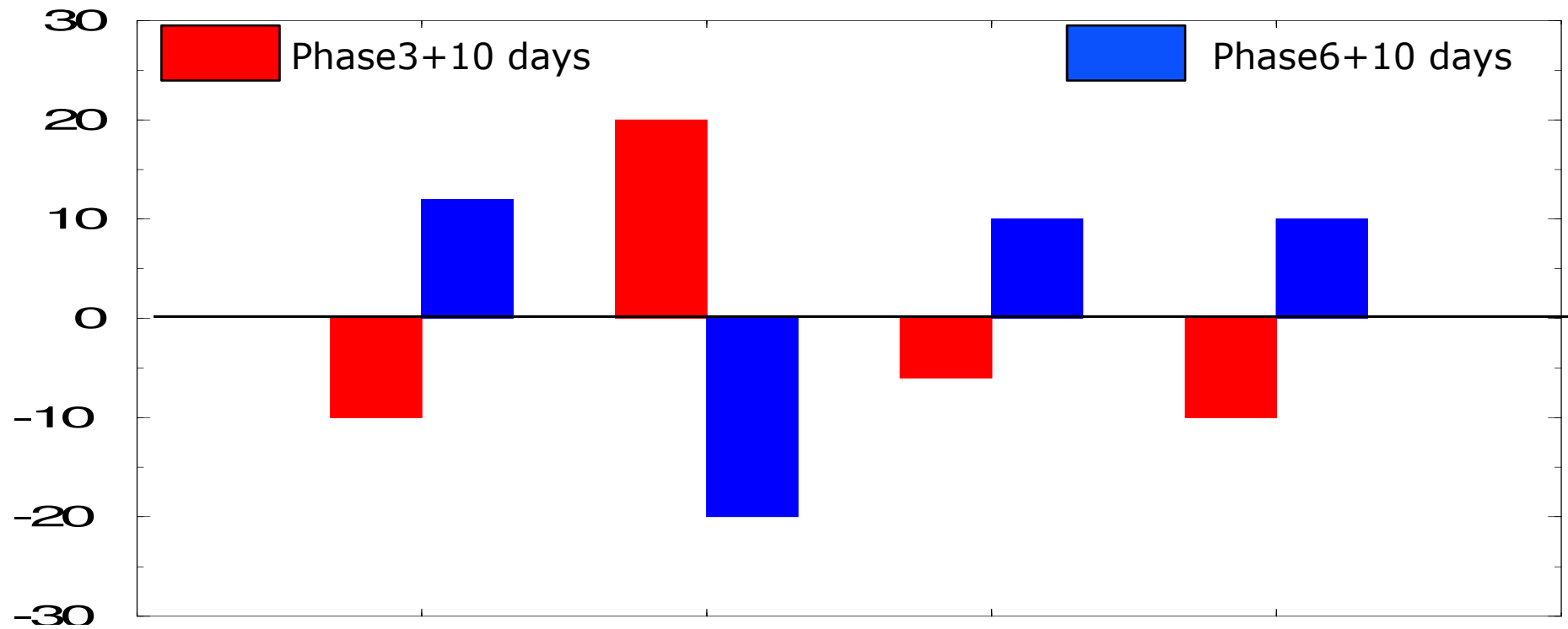
PERT 7+8



# Weather Regimes : Impact of MJO on NAO+



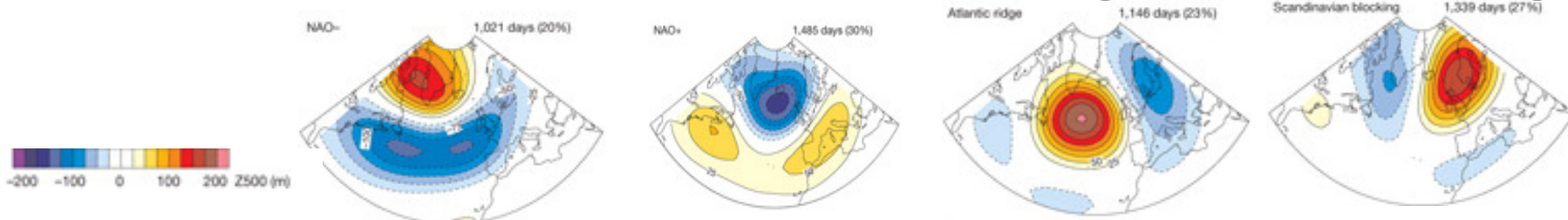
# Impact on weather regimes in hindcasts



**NAO-**

**NAO+**

**Atlantic ridge  
Scandinavian  
blocking**



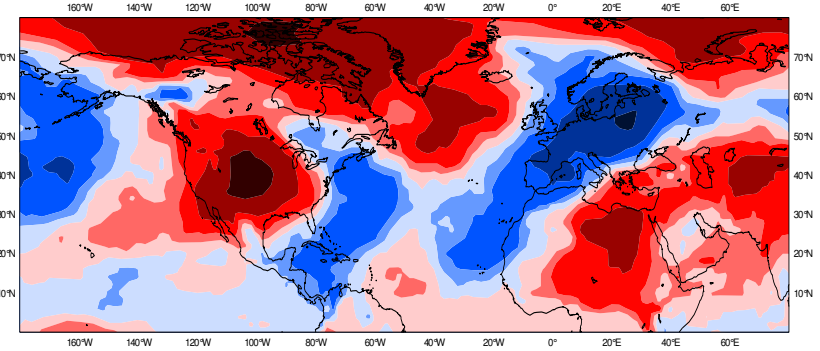
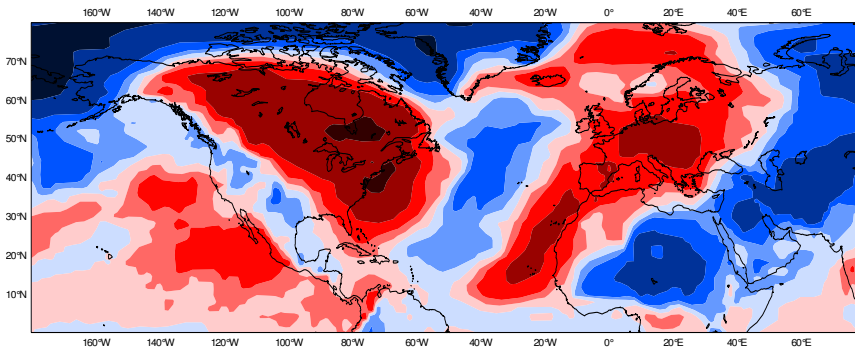


# T850 anomalies – NDJFM 1989-2008

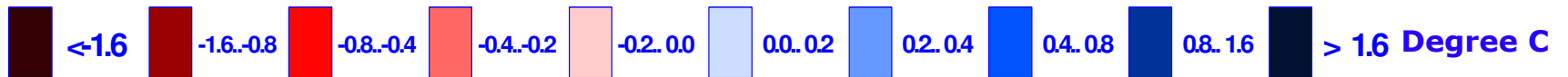
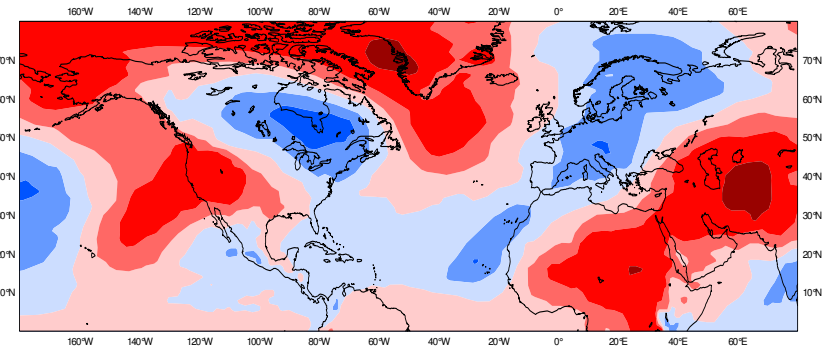
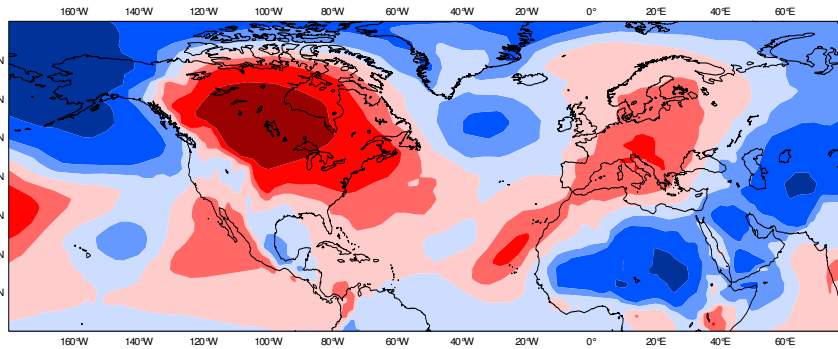
## Phase 3 + 10 days

## Phase 6 + 10 days

**ERA**



**MODEL**

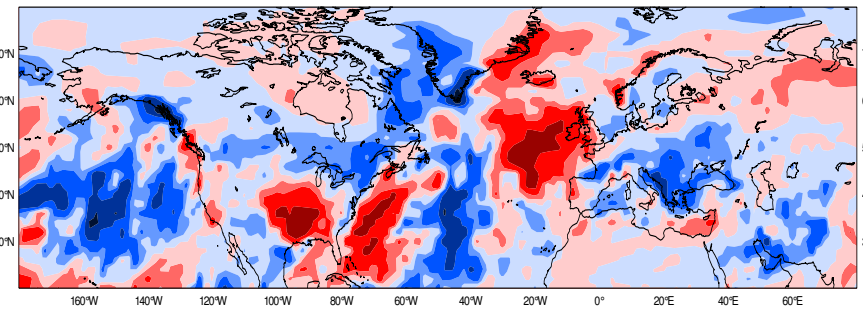
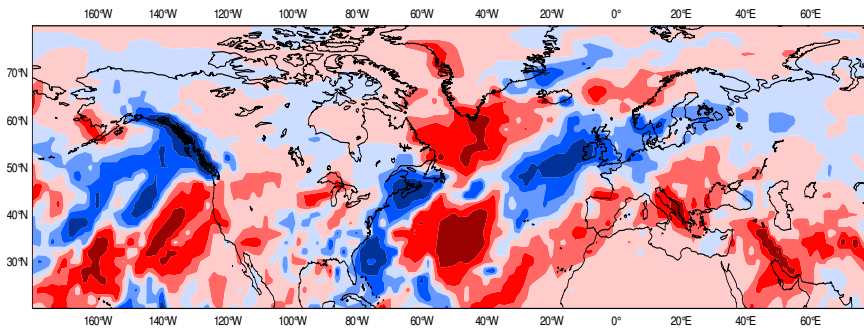


# Precipitation anomalies – NDJFM 1989-2008

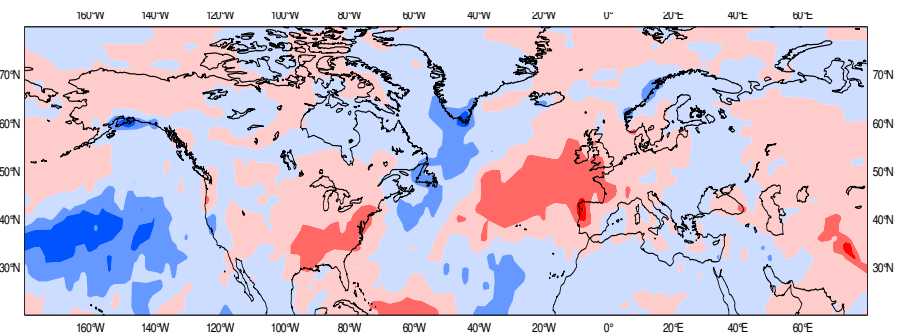
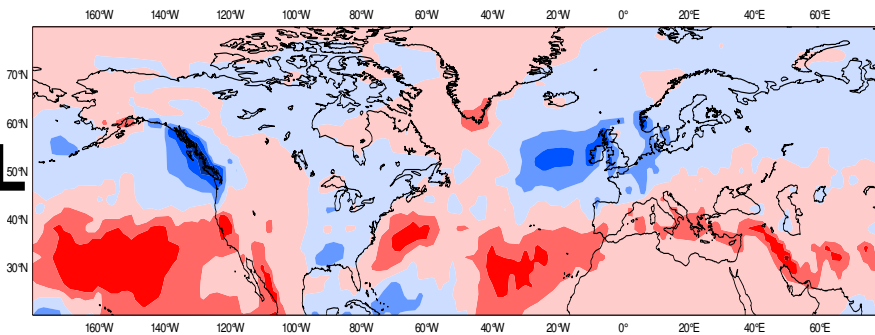
## Phase 3 + 10 days

## Phase 6 + 10 days

**ERA**



**MODEL**







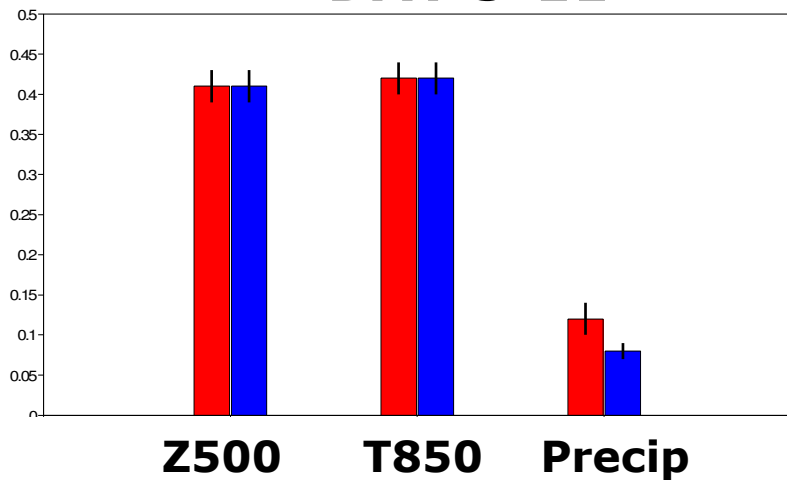
---

# 3. Impact on Forecast Scores

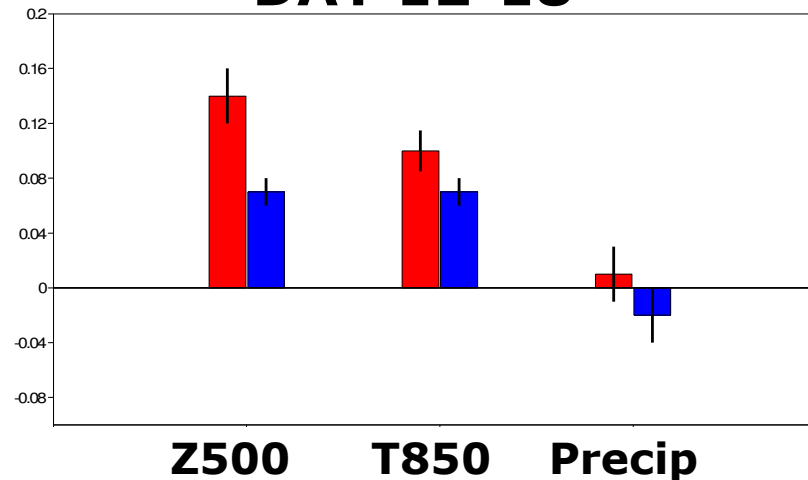


# Impact of the MJO on Brier Skill Scores NDJFMA 1989-2008- N. Extratropics

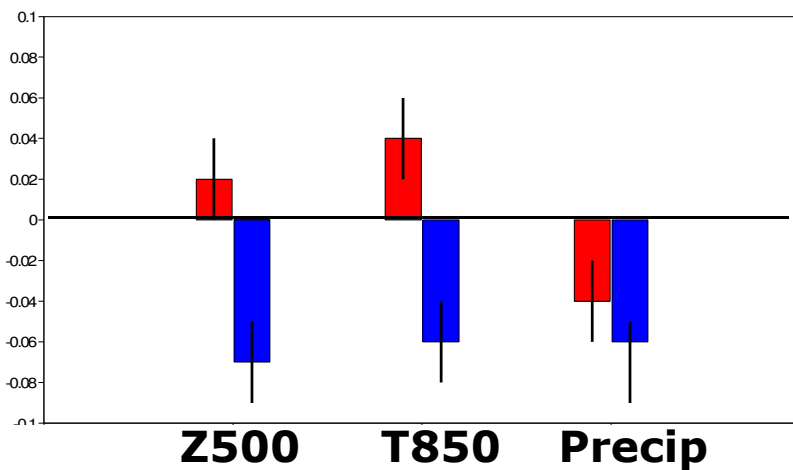
## DAY 5-11



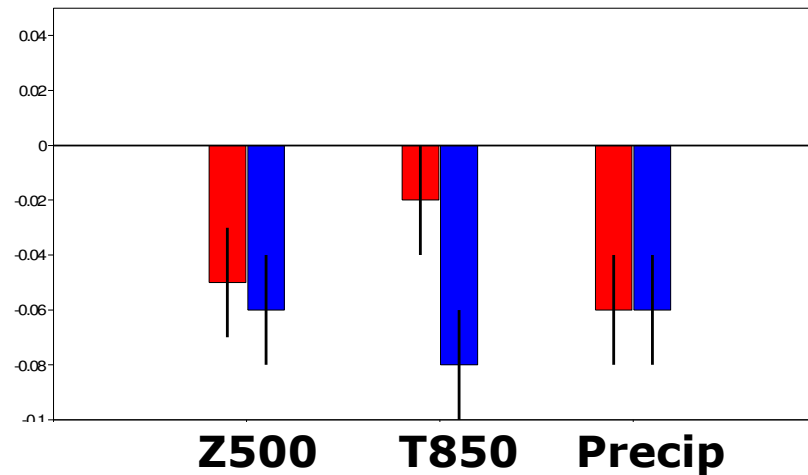
## DAY 12-18



## DAY 19-25



## DAY 26-32

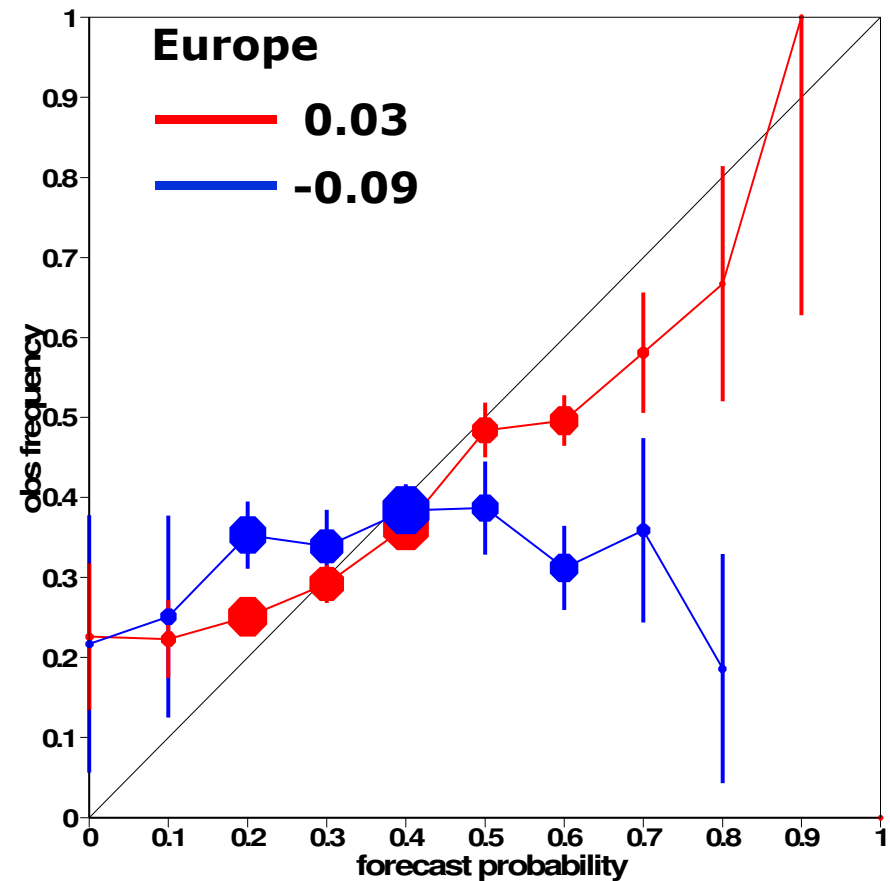
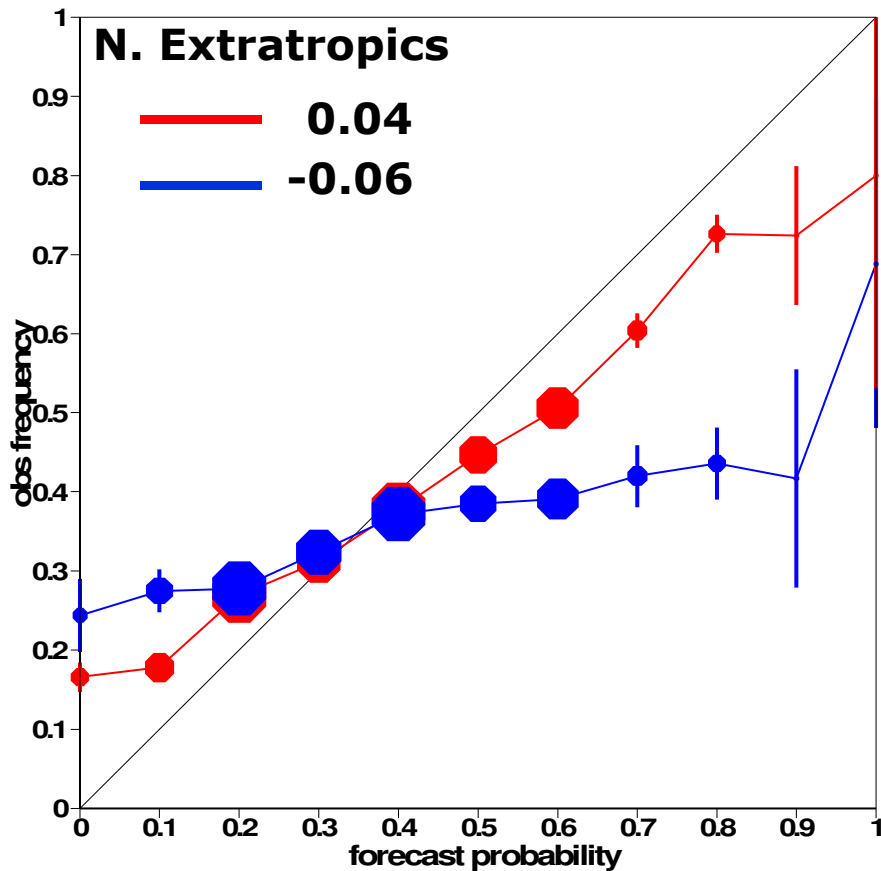


**■ MJO in IC**

**■ NO MJO in IC**

# Probabilistic skill scores – NDJFMA 1989-2008

## Reliability Diagram Probability of 2-m temperature in the upper tercile Day 19-25



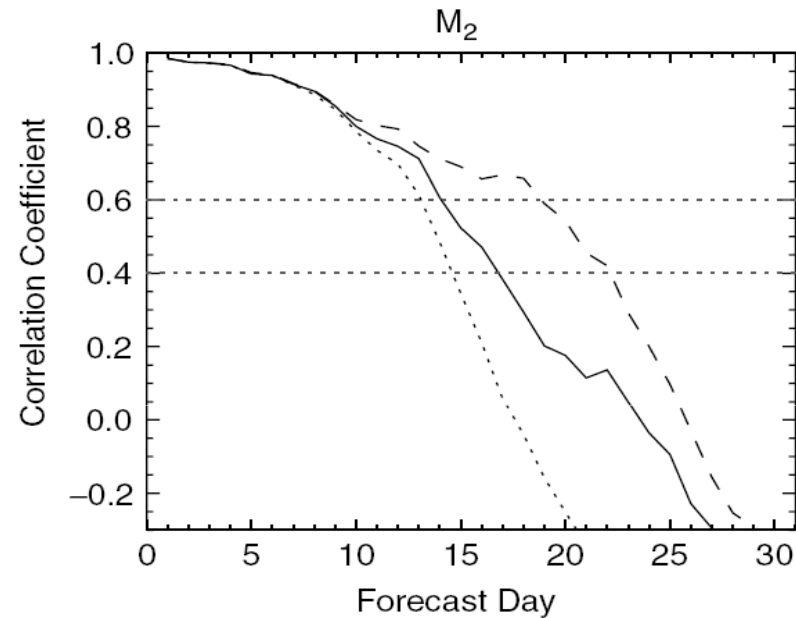
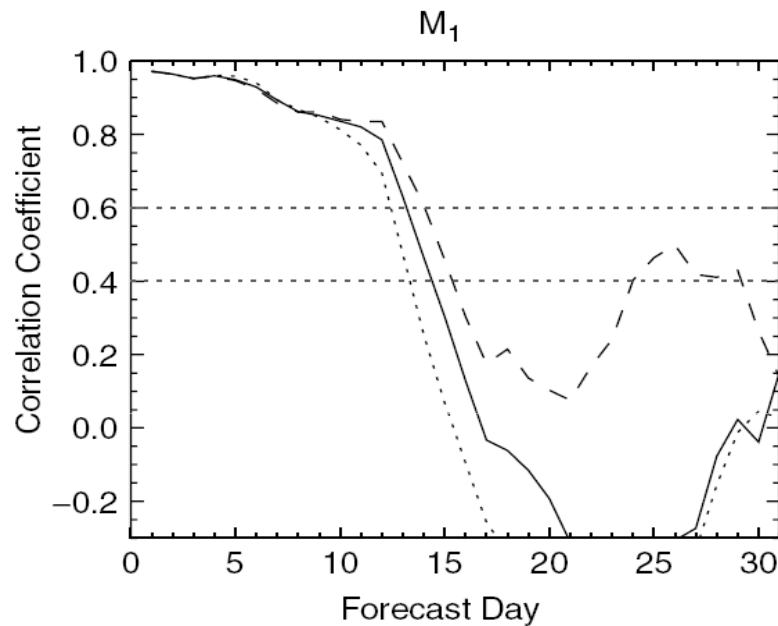
— MJO in IC — NO MJO in IC

# Simulation of the MJO in climate models

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- Horizontal resolution: not important
- Vertical resolution: positive impact
- Air-sea coupling: Positive impact but not crucial
- Convection scheme: crucial

# Improvement of MJO Skill with Ocean Coupling

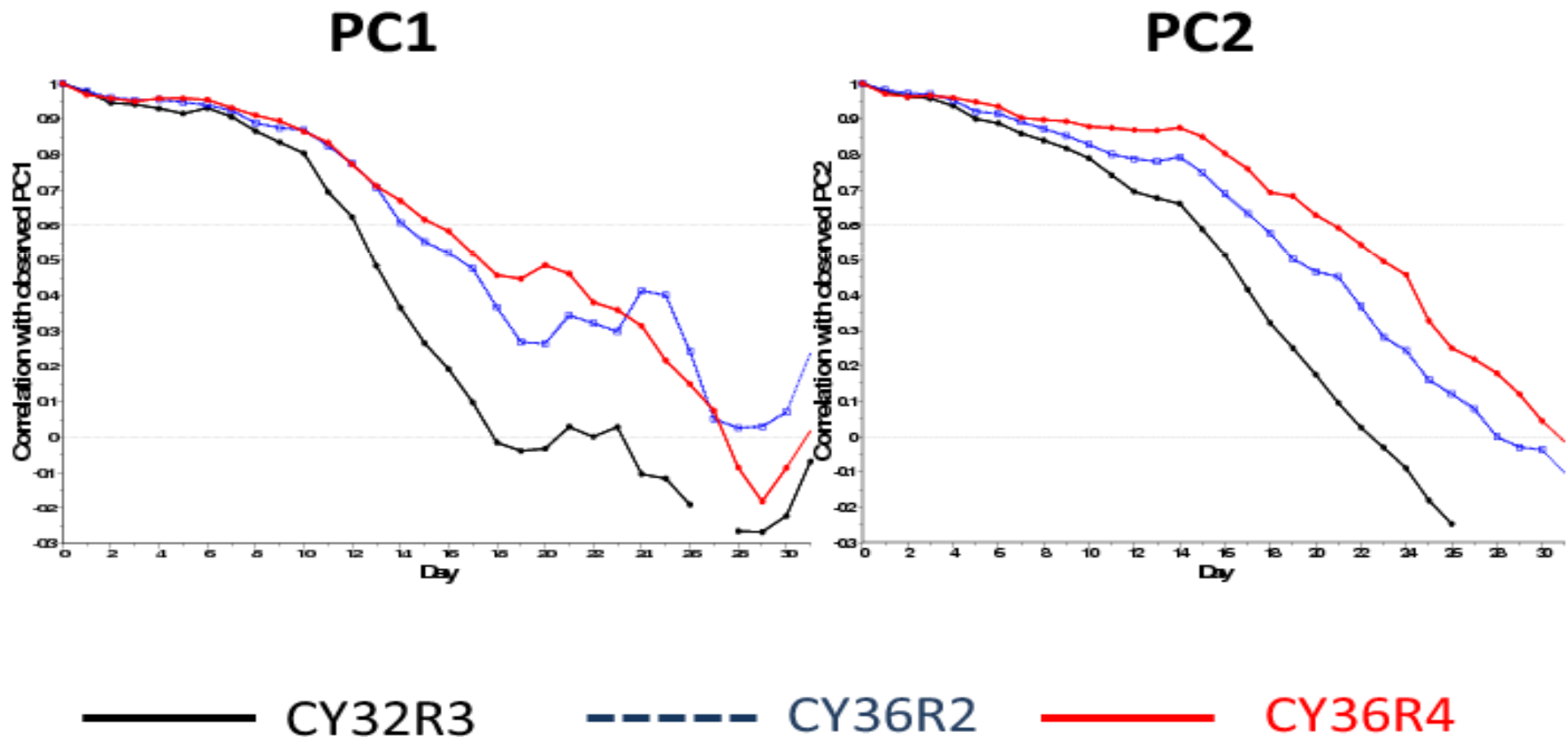


**CONT : solid line**  
**ML : dashed line**  
**PERS : dotted line**

Woolnough et al. (2007, QJRMS)

# MJO forecast skill scores

Serial Experiment 19921215-19930131





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## 4. Impact on Northern Extratropics on MJO Forecast Scores

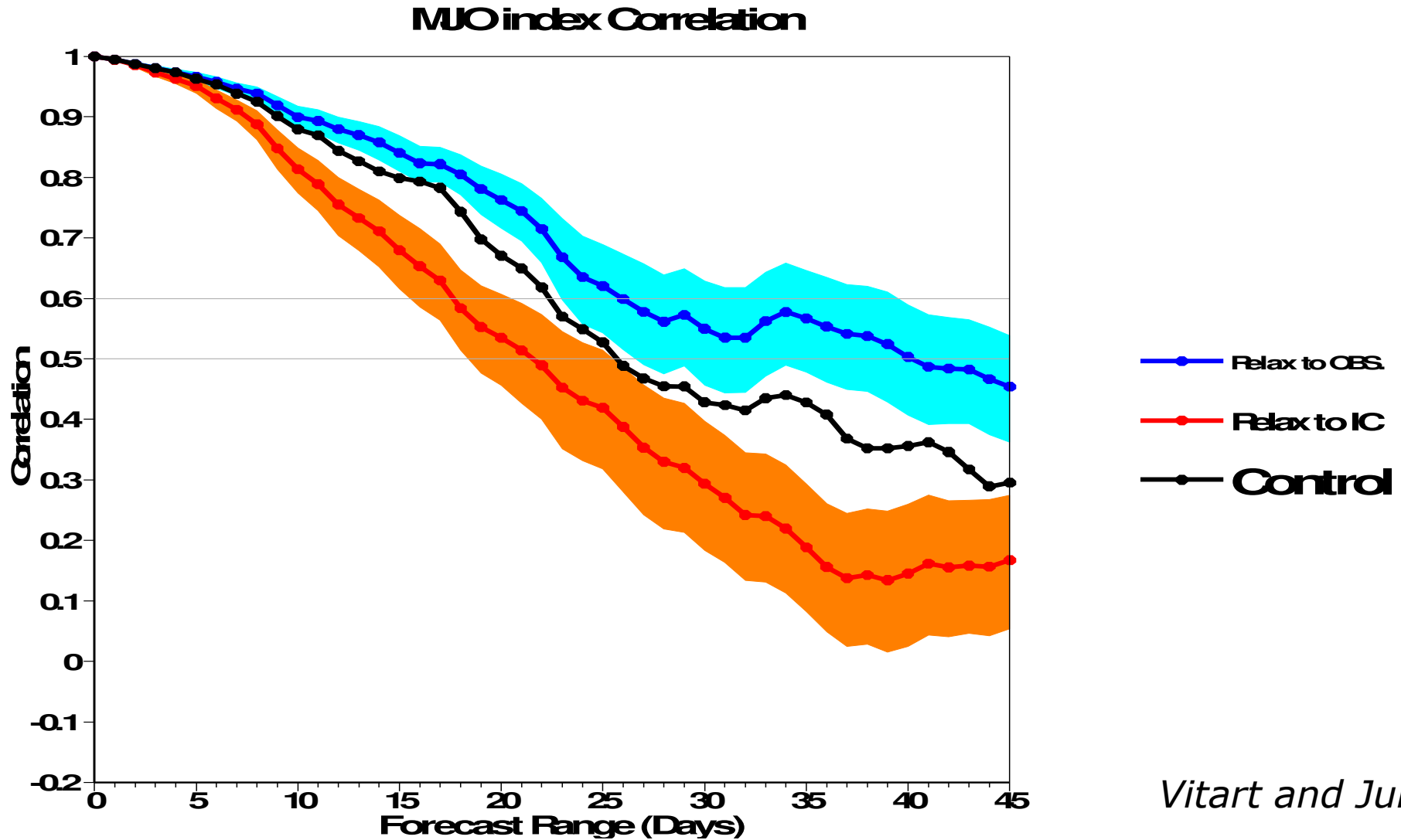
# Theories for the onset of an MJO event

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- ❑ **Local recharge/discharge processes** ( e.g. Hendon 1988, Blade and Hartmann 1993, Hu and Randall 1994...)
- ❑ **Upstream effects of circumnavigating waves** ( e.g. Knutson et al 1986, Knutson and Weickmann 1987, Lau and Peng 1987)
- ❑ **Stochastic forcing** (Wilson and Mak 1984, Neelin and Yu 1994, Yu and Neelin 1994)
- ❑ **Extratropical influences** (e.g. Lau and Peng 1987, Hsu et al 1990, Lin et al 2007, Ray et al 2010, Wedi and Smolarkiewicz 2010..)



# Impact of N. Extratropics on MJO forecast skill



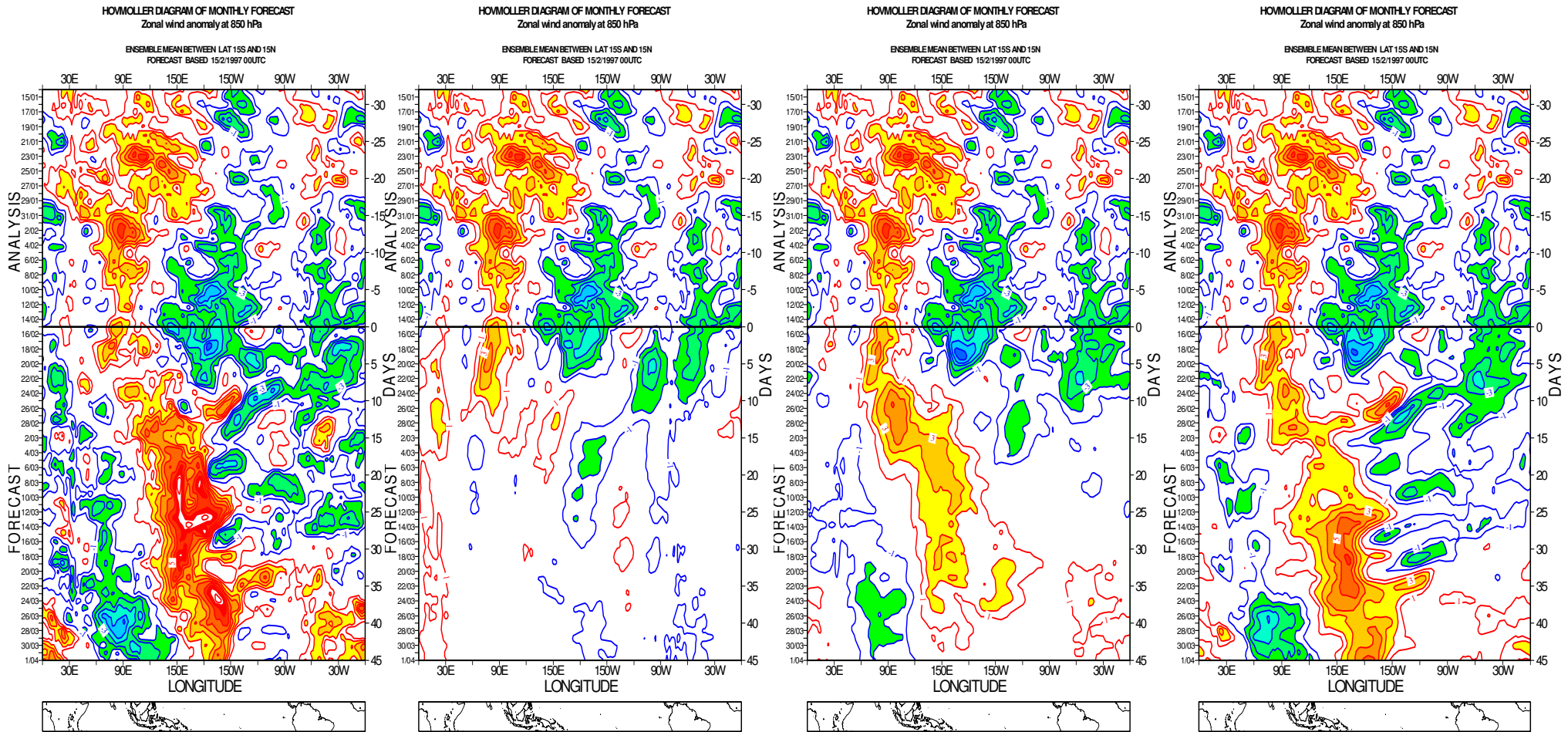


# March 1997 Westerly Wind Burst -U850

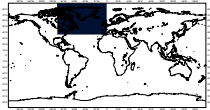
## Obs. Relaxed to Initial Conditions

## Control

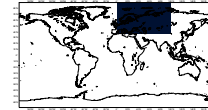
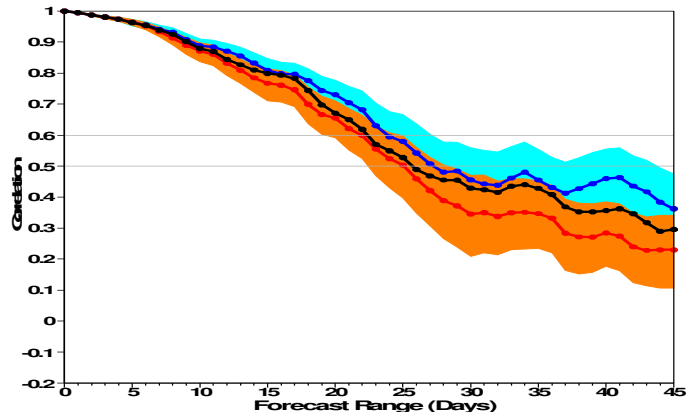
## Relaxed to Observations



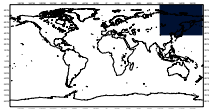
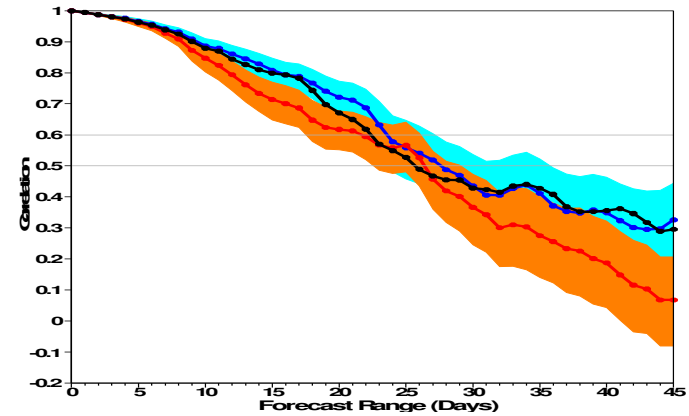
# Impact of N. Extratropics on MJO forecast skill



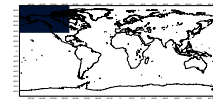
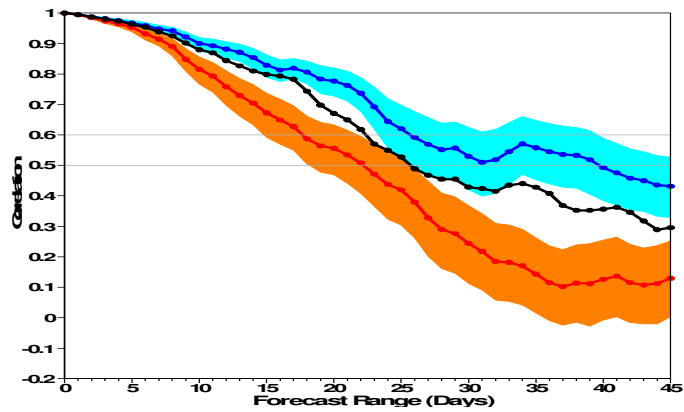
**North Atlantic**



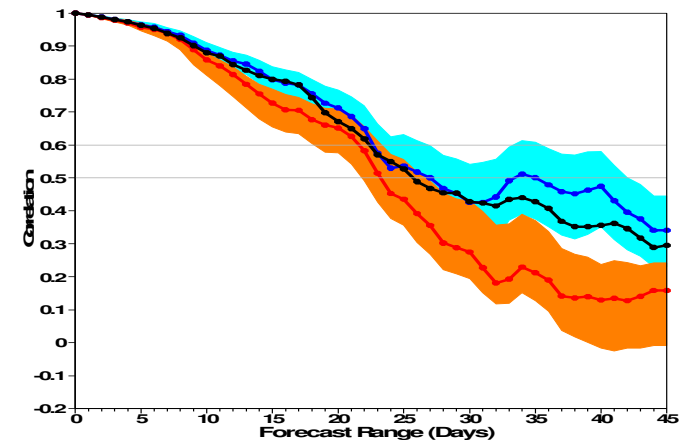
**Eurasia**



**West Pacific**



**East Pacific**



# Conclusions

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- Observed studies have shown that the MJO has a significant impact on the European weather through its impact on the NAO.
- The ECMWF forecast system has skill to predict the evolution of the MJO up to about day 20.
- The ECMWF model simulates reasonably well the teleconnection patterns over Europe and Atlantic, but with a weaker amplitude than in ERA Interim. The MJO impacts the forecast skill scores over Europe.
- The Northern Extratropics have a significant impact on the MJO forecast skill scores in the model integrations.



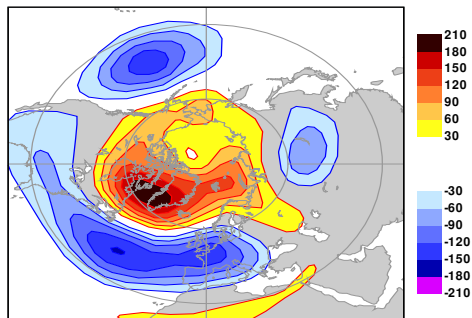
---

# Winter 2009/10

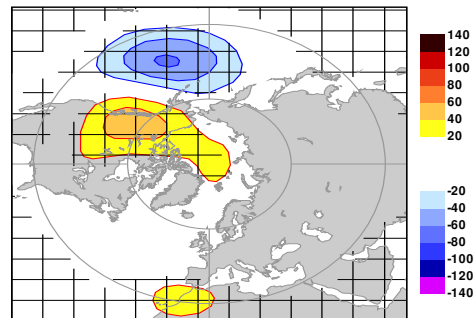


# 1<sup>st</sup> Nov seasonal forecasts DJF

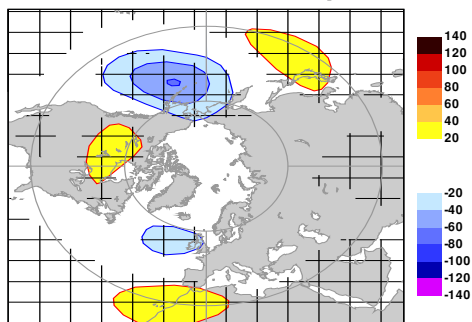
(a) Observed



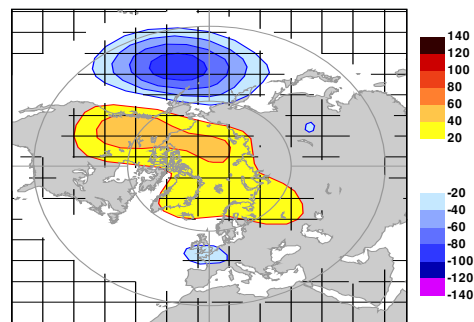
(b) CNT Ensemble (Uncoupled)



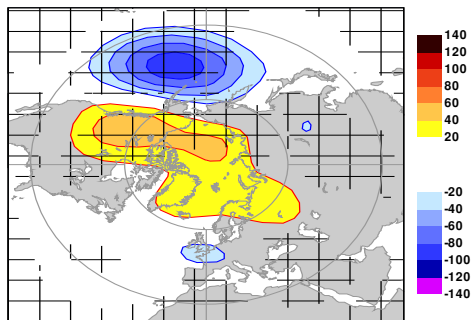
(c) CNT Ensemble (Coupled)



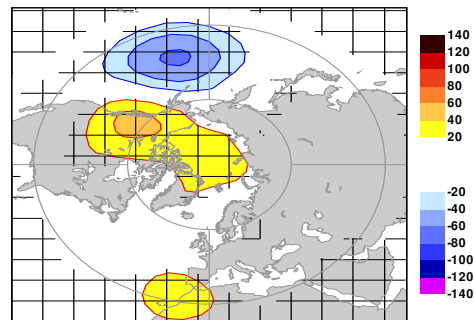
(d) TROP Ensemble



(e) EAWNP Ensemble



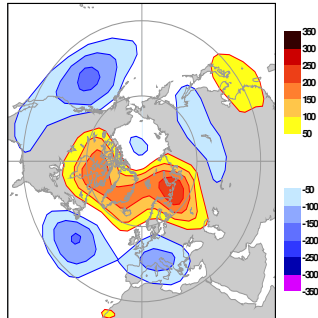
(f) NH-S Ensemble



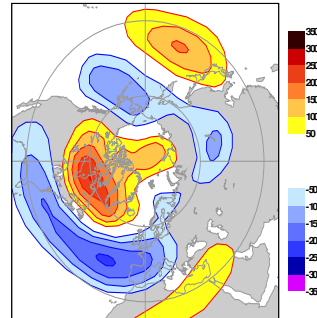


# Monthly Forecasts – Day 18-32

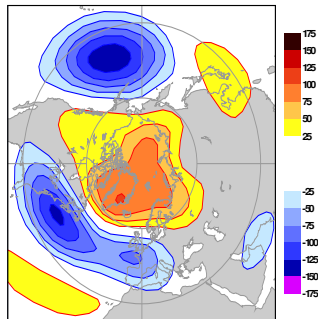
(a) Reanalysis: 20100114



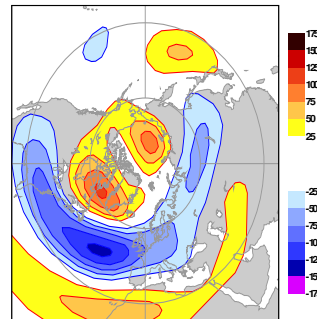
(d) Reanalysis: 20100211



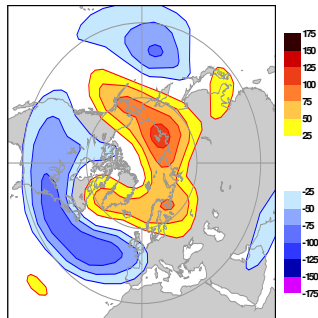
(b) Control: 20100114



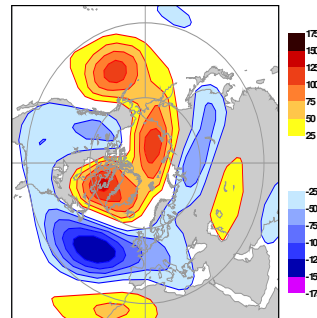
(e) Control: 20100211



(c) Experiment: 20100114

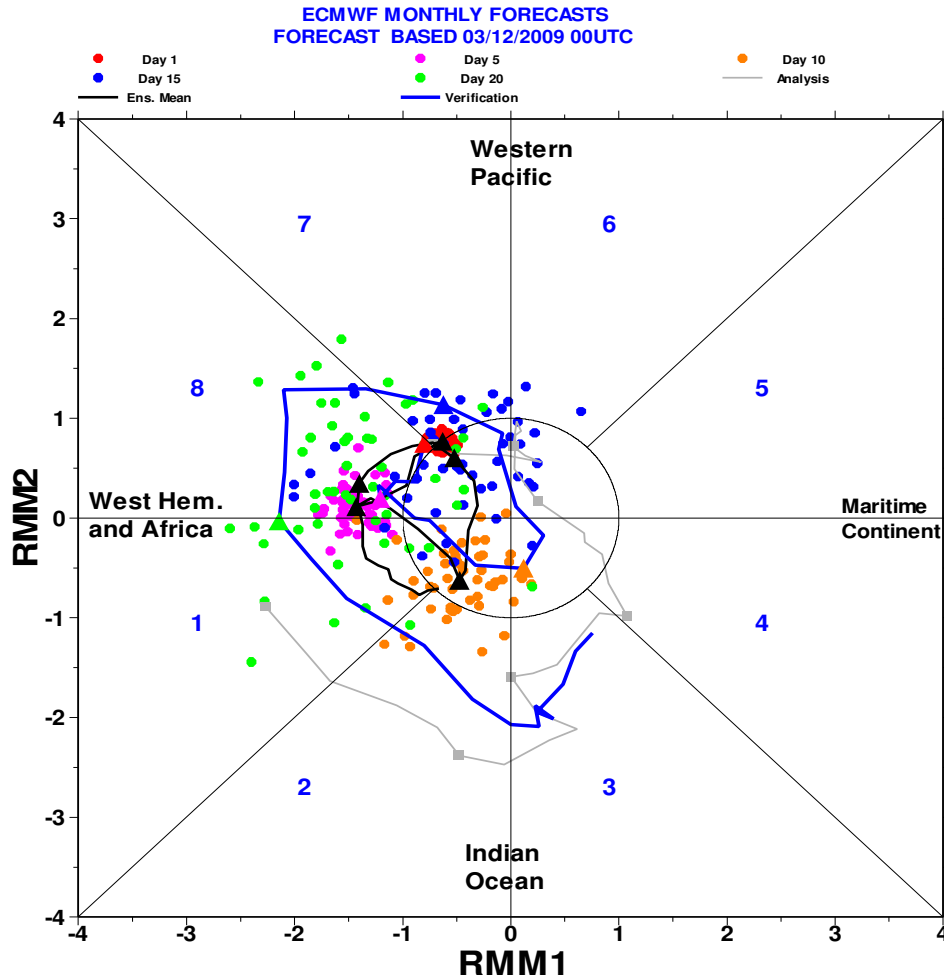


(f) Experiment: 20100211

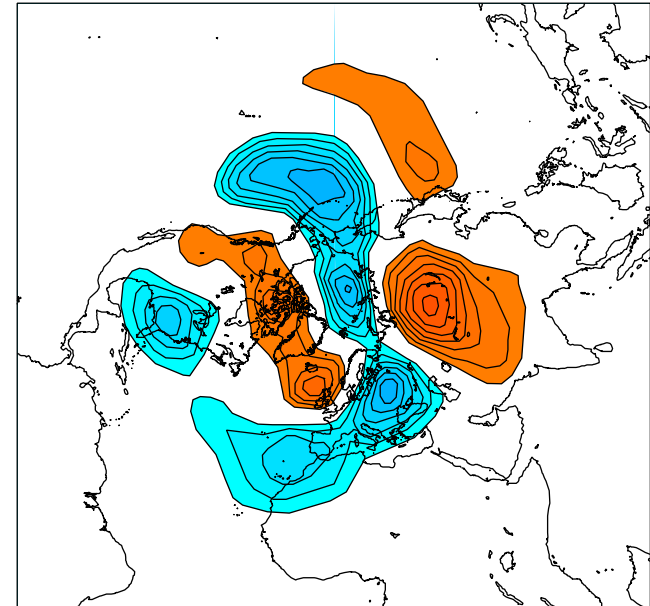




# 03/12/2009 Monthly Forecast



ERA Int. Phase 81



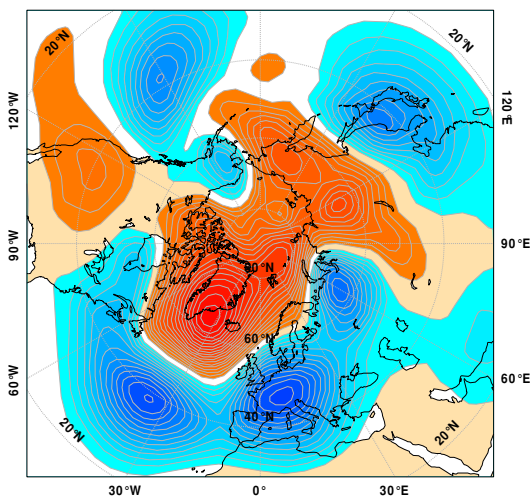




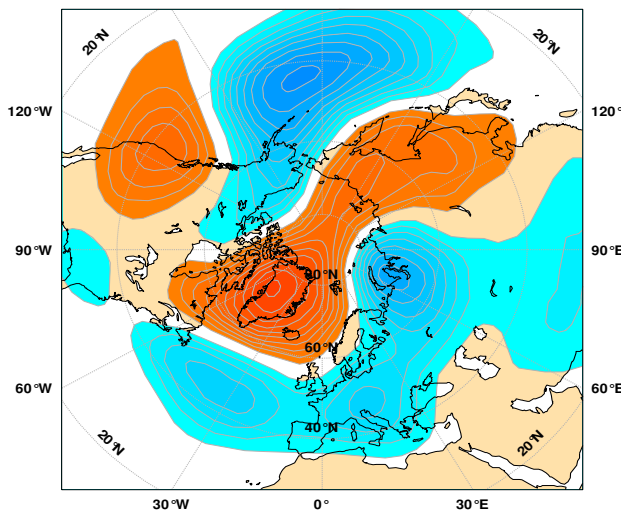
## Verification

## 10 good MJO forecasts 10 bad MJO forecasts

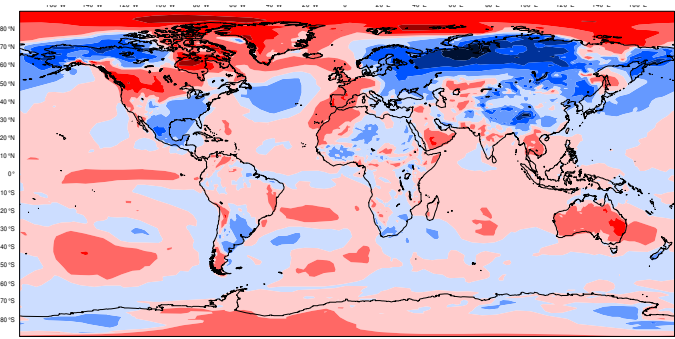
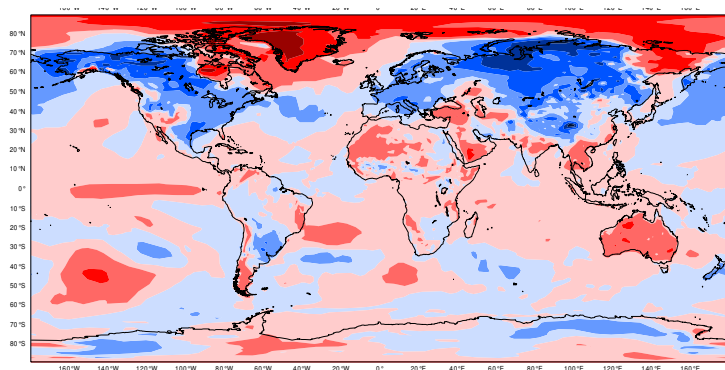
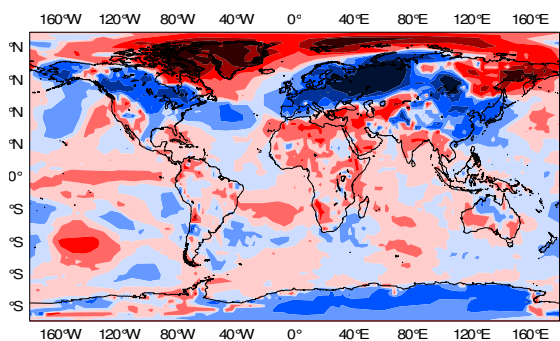
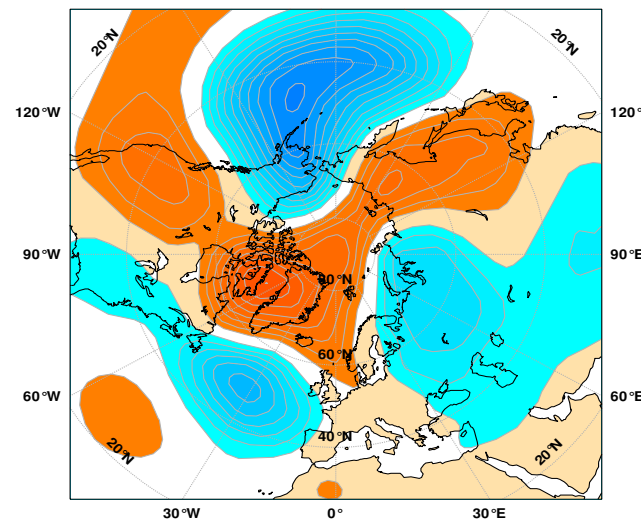
Observed anomaly: Mon 20091214- Sun 20091220



Day 12-18: Mon 20091214- Sun 20091220

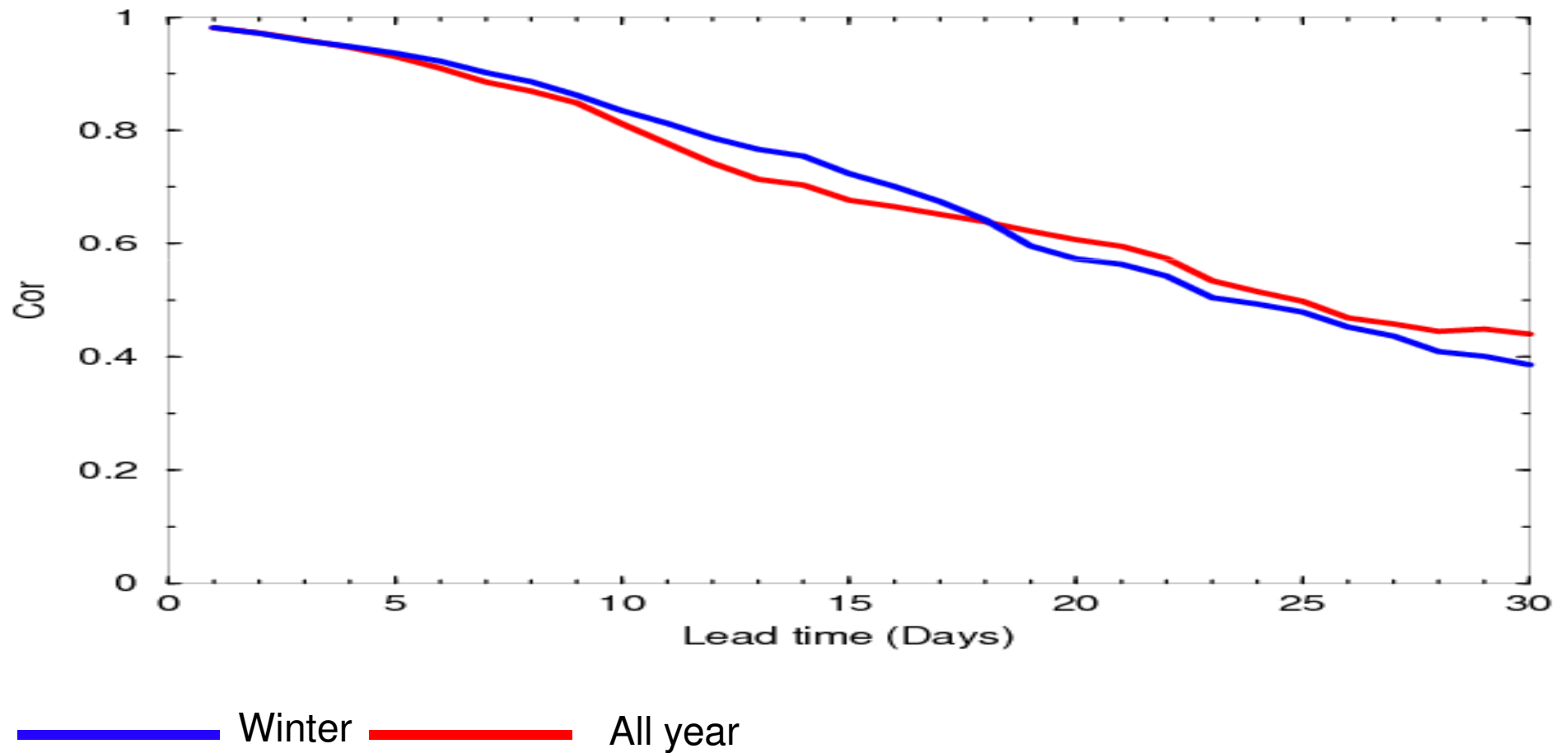


Day 12-18: Mon 20091214- Sun 20091220



# MJO Skill

## Correlation with reanalysis



## Preliminary Verification

$$COR(\tau) = \frac{\sum_{t=1}^N [a_1(t)b_1(t, \tau) + a_2(t)b_2(t, \tau)]}{\sqrt{\sum_{t=1}^N [a_1^2(t) + a_2^2(t)]} \sqrt{\sum_{t=1}^N [b_1^2(t, \tau) + b_2^2(t, \tau)]}}$$

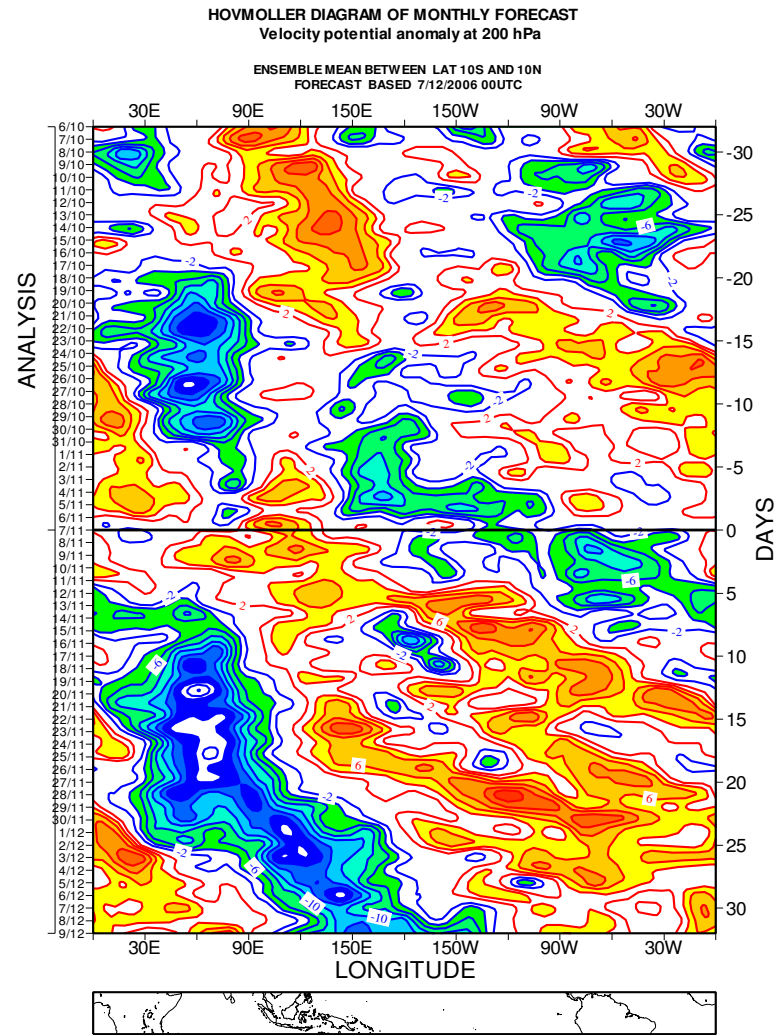
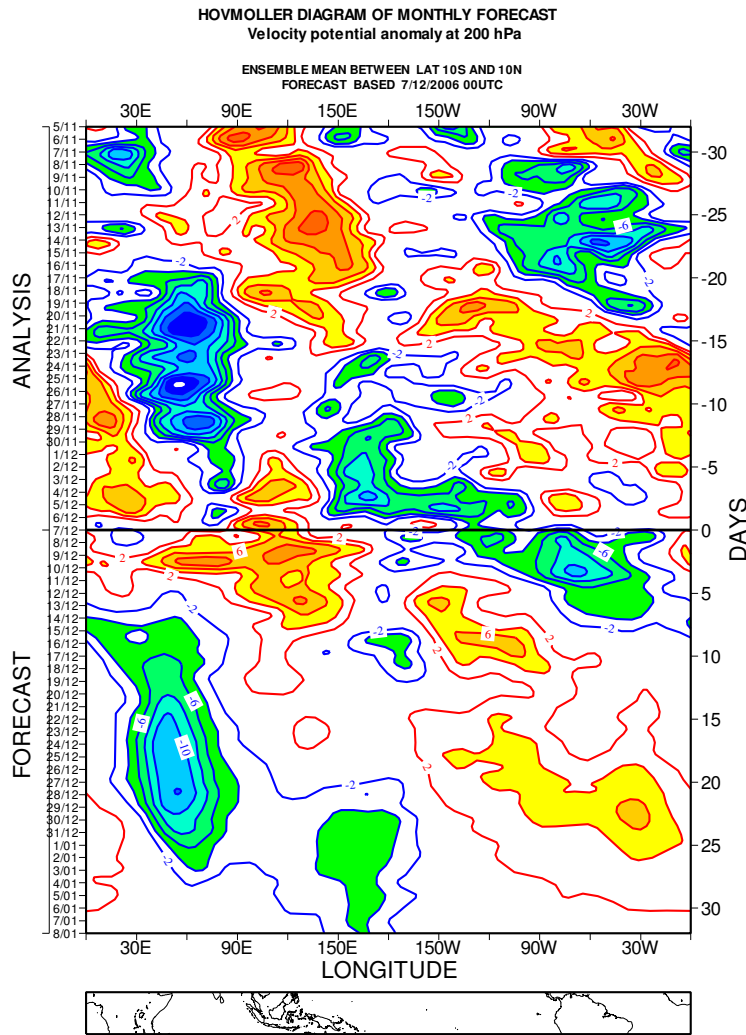
$$RMSE(\tau) = \sqrt{\frac{1}{N} \sum_{t=1}^N [a_1(t) - b_1(t, \tau)]^2 + [a_2(t) - b_2(t, \tau)]^2}$$

- November 2008 – May 2010 time period
- Some forecast data is missing, but not much
- Calculate using NCEP Reanalysis first as one benchmark (shown here)
- Calculate using a “multi-model analysis” for the final measure (ongoing)
- Stratification by MJO phase, season as additional data is obtained



# Prediction of the Madden Julian Oscillation (MJO)

## Monthly Forecast starting on 7 December 2007





## Center Data Specifics

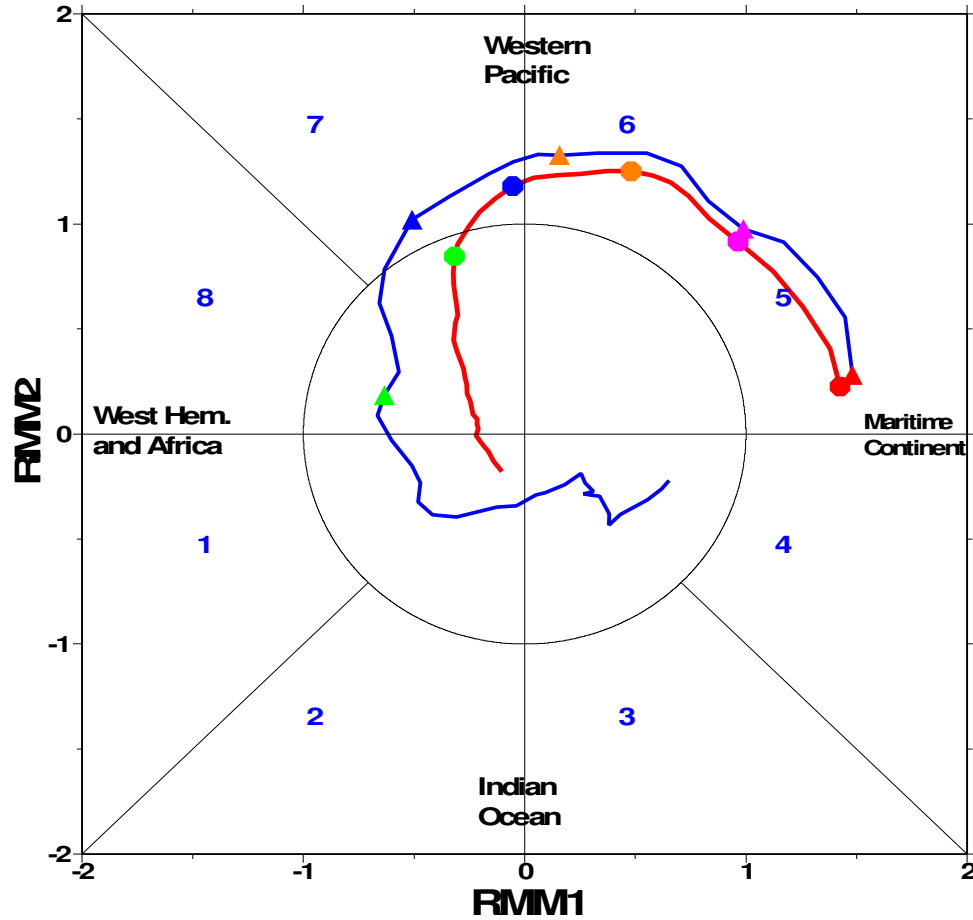
Center	Model	Data Stream ID	Ensemble Members	Forecasts Start	Length (Days)	Realtime Data FTP	Version 1 Plots	Model Climatology
NCEP	GFS EPS T126 <sup>1</sup>	NCPE	21	Nov 2007	15	----	Yes	No
NCEP	GFS T382 <sup>1</sup>	NCPO	1	Jan 2008	15	----	Yes	No
NCEP	CFS T62 <sup>1</sup>	NCFS	4	Jan 2007	40	----	Yes	Yes
CMC	GEMDM 400x200 <sup>2</sup>	CANM	20	Jun 2008	16	Yes	Yes	No
UKMO	MOGREPS <sup>3</sup>	UKMA	1	Oct 2007	15	Yes	Yes	No
UKMO	MOGREPS <sup>3</sup>	UKME	23	Oct 2007	15	Yes	Yes	No
ABOM	GASP T239 <sup>4</sup>	BOMA	1	Jun 2008	10	Yes	Yes	No
ABOM	GASP EPS T119 <sup>4</sup>	BOME	32	Aug 2008	10	Yes	Yes	No
ABOM	POAMA1 SFT47 <sup>5</sup>	HOVC	1	Jan 2008	40	Yes	Yes	No
ABOM	POAMA1 ST47 <sup>5</sup>	BOMH	1		40	No	No	Yes
ECMWF	VAREPS T299/T255 <sup>6</sup>	ECMF	51	Jun 2008	15	Yes	Yes	No
ECMWF	VAREPS T299/T255 <sup>6</sup>	ECMM	51	Jun 2008	15	Yes	Yes	Yes
ECMWF	SFSv3 T159 <sup>7</sup>	EMON	51 (W)	Jun 2008	32	Yes	Yes	No
ECMWF	SFSv3 T159 <sup>7</sup>	EMOM	51 (W)	Jun 2008	32	Yes	Yes	Yes
JMA	GSM WEPS T319 <sup>8</sup>	JMAN	51	Nov 2008	9	Yes	Yes	No
CPTC	GWEFS T126 <sup>9</sup>	CPTC	15	Feb 2009	15	Yes	No	No
IMD	NCMRWF T254 <sup>8</sup>	IMDO	1	Jun 2009	7	Yes	Yes	No
IMD	NCMRWF EPS T80 <sup>8</sup>	IMDE	8	----	7	No	No	No
FNMOG	NOGAPS T119 <sup>9</sup>	NGAP	10	----	10	No	No	No
TCWB	CWB EPS T119 <sup>6</sup>	TCWB	1	Oct 2009	40	Yes	Yes	No

- Multiple contributions for several centers
- High-resolution operational run data as well as data from ensemble prediction systems
- Varying forecast duration

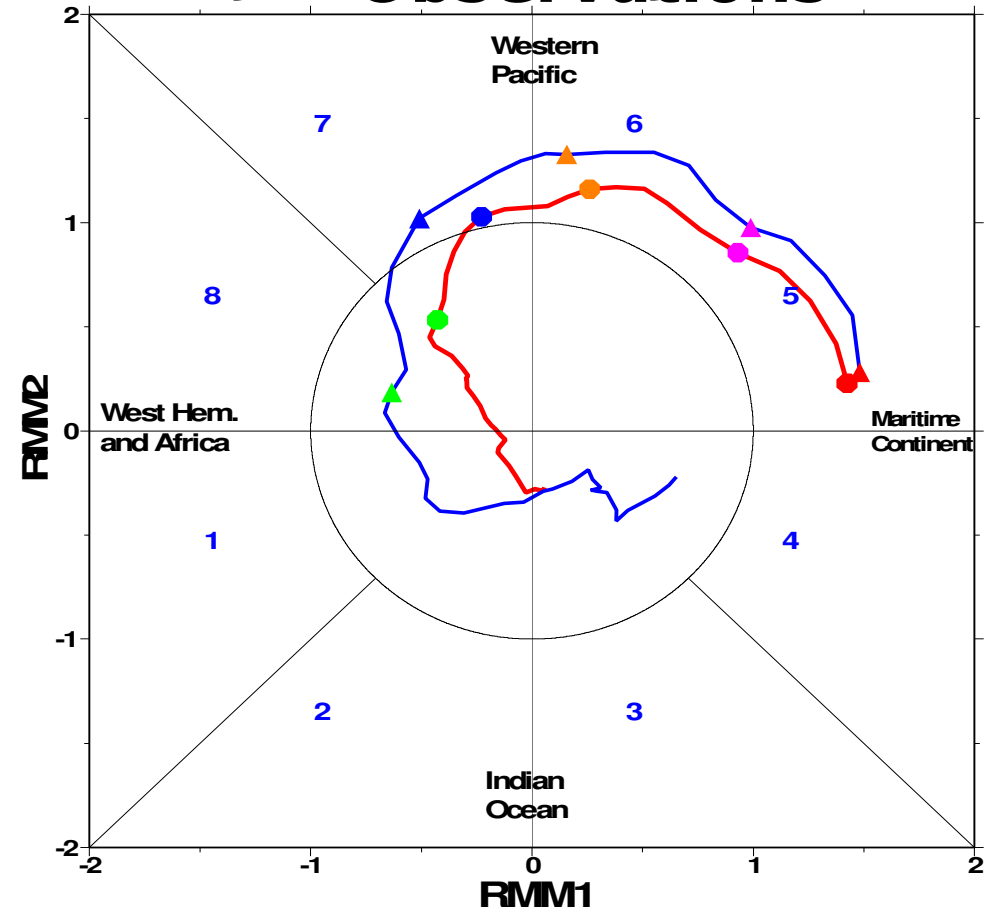


# COMPOSITE PHASE 4+5

## Relaxed to Initial Conditions



## Relaxed to Observations





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## Recent or planned changes to the ECMWF physical parametrizations

- Improved treatment of ice sedimentation, auto-conversion to snow in cloud scheme and super-saturation with respect to ice (CY31R1)
- **RRTM-SW + McICA**
- **MODIS albedo + revised cloud optical properties (CY32R2)**
- **New formulation of convective entrainment**
- **Variable relaxation timescale for closure**
- **Reduction in background free atmosphere vertical diffusion (CY32R3)**



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## Convection changes to operational massflux scheme

### **New formulation of convective entrainment:**

Previously linked to moisture convergence

- Now more dependent on the relative dryness of the environment

### **New formulation of relaxation timescale used in massflux closure:**

Previously only varied with horizontal resolution – Now a variable that is dependent on the convective turnover timescale i.e. variable in both space and time also

**Impact of these changes is large including a major increase in tropical variability**



# Average tropical cloud profiles

In the Tropics now a tri-modal cloud distribution becomes apparent, with a strong increase in mid-level clouds. CloudSat data will be used to verify these results.

