The Experimental MJO Prediction Project

Duane Waliser[1], Klaus Weickmann, Randy Dole, Siegfried Schubert, Oscar Alves, Charles Jones, Matthew Newman, Hua-Lu Pan, Andres Roubicek, Suranjana Saha, Cathy Smith, Huug van den Dool, Frederic Vitart, Matthew Wheeler, Jeffrey Whitaker

Submitted to "Inbox" of the
Bulletin of the Meteorological Society January 2005
With Revisions July and November 2005

Weather prediction is typically concerned with lead times of hours to days, while seasonal-to-interannual climate prediction is concerned with lead times of months to seasons. Recently, there has been growing interest in subseasonal forecasts; those that have lead times on the order of weeks (e.g., Schubert et al. 2002; Waliser et al. 2003; Waliser et al. 2005). The basis for developing and exploiting "subseasonal" predictions largely resides with phenomena such as the Pacific North American pattern, the North Atlantic Oscillation, the Madden-Julian Oscillation (MJO), mid-latitude blocking, and the memory associated with soil moisture, as well as modeling techniques that rely on both initial conditions and slowly varying boundary conditions (e.g., tropical Pacific SST). An outgrowth of this interest has been the development of an Experimental MJO Prediction Project (EMPP). The project provides real-time weather and climate information and predictions for a variety of applications, broadly encompassing the subseasonal weather-climate connection. The focus is on the MJO because it represents a repeatable, low frequency phenomenon. MJO's importance among the subseasonal phenomena is very similar to that of El Nino Southern Oscillation (ENSO) among the interannual. This note describes the history and objectives of EMPP, its status, capabilities, and plans.

One of the fundamental components in the development of this project was the recent activity in empirical prediction of the MJO. This not only indicated a strong interest in the problem but also resulted in schemes that provided potential skill with lead times of 2-4 weeks. More formally the project arose from two parallel developments. The first was the NASA-sponsored 1st subseasonal workshop in April 2002, which recognized the importance of the MJO to potential skill in subseasonal predictions (Schubert et al. 2002). The second ensued from the US CLIVAR Asian-Australian Monsoon Working Group (AAMWG), which recommended the development of an experimental MJO prediction program due to the significant influence that the MJO has on the Asian-Australian monsoons.

An E-mail discussion among MJO forecast enthusiasts during the summer and fall of 2002 developed the framework for such a program. The program needed the technical and electronic management of a host, however--one with expertise in subseasonal phenomena and forecasting. Fortunately, the Climate Diagnostics Center of NOAA offered to host the project. Project organizers wrote to a number of forecast agencies, modeling centers and empirical MJO modelers inviting them to participate in the program. The overwhelming majority accepted the invitation, and the program proceeded to define its objectives and develop a framework for both science and logistics. These aspects were finalized at a meeting during the US CLIVAR / NASA – sponsored 2nd subseasonal workshop in June 2003.

[1] Corresponding author: duane.waliser@jpl.nasa.gov

Objectives

The overarching target of the project is the delivery of skillful predictions, with lead times of 1-4 weeks, of the tropical intraseasonal variability (namely the MJO), with an eye towards improving predictions of regimes and processes influenced by this variability. We recognize that the state of the MJO and its evolution is crucially important for the prediction of tropical variability at these lead times. In addition, skillful prediction of the MJO seems to be somewhat, or at least intermittently, important for extratropical weather forecasts at lead times of 1 to 2 weeks. At lead times of 3 to 4 weeks, the MJO may provide some forecast skill for predicting regime changes in the extratropical flow. In both the tropical and extra-tropical cases, skillful MJO forecasts could lead to useful predictive information on the probability of extreme events (e.g., U.S. West Coast storms and tropical cyclones). At lead times longer than 4 weeks, there is little expectation that the deterministic aspects of MJO forecasts will be of much use. At these and longer lead times, the importance of initial condition information starts to give way to the importance of boundary condition information, such as tropical SSTs (e.g., phase of ENSO). This indicates that the utility of the MJO forecasts at these longer leads may stem mainly from information regarding the predominant location of MJO activity which has been shown to be influenced by El Nino and La Nina SST anomalies. Such relationships could be exploited to anticipate the level of subseasonal activity in a given season and region of the Tropics.

Once it can be established that useful forecast skill can be derived from the contributing models, whether empirical or dynamical, EMPP will collaborate with forecast agencies by contributing this forecast utility to their activities focused on week 2 and monthly predictions. In addition, the forecast and diagnostic information provided by the EMPP will make it easier to routinely diagnose and explain subseasonal weather anomalies. Finally, apart from its prediction purposes, EMPP is intended to be a basis for model comparisons. This includes using the forecasts and biases in model error growth or MJO signal to learn more about, and possibly rectify, model shortcomings associated with the MJO.

Since the web page became active in November 2003, the project has been improving data transfer, pre- and post-processing of forecasts, web page design, graphical delivery, and other issues. The web site (www.cdc.noaa.gov/MJO) includes a project history, a primer on the MJO, a multi-time scale synoptic model based on the MJO, as well as a description of the forecasting and project framework and of course the forecasts and validation analyses. The website came online just in time for a moderately active MJO season (December 2003-March 2004). By October 2004, forecasts from nine prediction systems - three GCM ensembles, one coupled GCM and five statistical models - were being displayed (see Table 1).

Subseasonal Predictions

In order to retain flexibility for future applications, contributed forecasts are expected to have daily resolution, consist of global 2.5x2.5 degree grids and be updated daily or at least weekly. These subseasonal predictions are displayed in a common graphical format so synoptic features and weather patterns can be easily compared. A real-time report synthesizes the forecast fields and discusses the dynamics of recent subseasonal climate anomalies.

To provide a focus, two different types of forecasts are emphasized: 1) the phase and amplitude of the MJO and 2) the circulation variability in the Pacific/Americas (P/A) region.

Currently five models[2] more or less explicitly forecast the state and evolution of the MJO, as measured by either tropical outgoing longwave radiation (OLR) or diabatic heating. The other models are primarily general circulation models (GCMs) or coupled prediction models and require post-processing of the forecasts in order to extract the MJO signal. A goal for the website is to use two-dimensional phase diagrams of the state and evolution of the MJO for both GCM and statistical model predictions. The MJO phase can then be used to help predict any number of variables or conditions (e.g., extreme precipitation over Australia and flooding in the Pacific Northwest).

The second type of forecast is of circulation anomalies in the P/A region, which is downstream of the evolving convection of the MJO. The impacts there should be large because of Rossby wave dispersion emanating from the convection anomalies. Coherent tropical-extratropical interactions and hemispheric-symmetry in Rossby wave trains are prevalent in the region. The focus for this forecast type is on "regime" transitions over the P/A region and the extent to which they are associated with tropical forcing. The GCM forecast skill during transitions in the circulation will be studied (e.g., Weickmann and Berry, 2006) as part of the project and will connect with similar studies on hindcast model data sets that are part of a larger community effort to assess subseasonal predictability. (Waliser et al. 2003)

A linear inverse model developed by Winkler et al. for weekly averages will serve the project as a skill standard for predictions of both the MJO and subseasonal variability in general. It has been used in real time during two northern winters (1999-2000, 2000-2001) and proven to be a useful diagnostic tool. Forecast skill is derived from the MJO, the PNA and El Nino and the forecast skill can be predicted at the initial time as part of the model dynamics. (Newman et al., 2003).

Weather-climate discussions

A weather-climate discussion posted on the project Web site highlights current subseasonal anomalies and physical processes for possible attribution, and evaluates the predictions posted on the website. In addition, a subseasonal synoptic model (Weickmann and Berry, 2006) is used to facilitate diagnosis, prediction and attribution. The model consists of fast (synoptic-scale energy dispersion), medium (teleconnections), and slow (MJO) time scale phenomena and their interactions in space and time.

The synoptic model consists of four stages that depict the growth, movement, and decay of multiple time scale subseasonal phenomena during a MJO. The model is a subseasonal analogue to the well known synoptic models of the extratropical cyclone and its life cycle. A primary goal of the development and application of this model is to understand the dynamical-physical processes that give rise to current circulation and weather patterns and to use this information to evaluate predictions from statistical and general circulation models. While the focus is on the MJO, transient continental-scale mountain effects and hemispheric-scale wave energy dispersion are also considered.

Example Forecast Products

The forecast products available include: 1) spatial weekly means of five different variables, 2) time-longitude Hovmoller diagrams depicting a sequence of forecasts valid at a selected lead time, and 3) forecast verifications using spatial anomaly correlations. The Hovmoller diagrams provide a history of the forecasts and are useful for spotting systematic model

---

[2] multivariate regression model, CDC experimental ensemble mean, lag regression model, coherent OLR modes model, NCEP ensemble mean

errors or differences in climatology. They can also be verified by superimposing an observed field. A more conventional verification statistic is provided by the anomaly correlation.

Fig. 2 shows week 2 predictions of precipitation and outgoing longwave radiation. The LIM model when implemented will predict tropical diabatic heating. The diversity of variables presents a challenge but the similarity of large-scale patterns can be assessed subjectively. In this particular example, the two model forecasts exhibit rather poor agreement between themselves. Additionally not all model forecasts are up-to-date and valid at the same time. Efforts are underway to rectify such inconsistencies. Other variables available in a similar format as either means or anomalies include 500 hPa height, 200 hPa streamfunction, and 200 hPa velocity potential. The initial focus is on global anomaly fields but eventually regional plots will be added, especially in the tropics where the MJO is active. Not all models predict all fields, although in principle they could. Velocity potential is the most commonly predicted variable but the vertical levels available are not the same. The project is striving to provide as much uniformity as possible of products across the models to facilitate interpretation and model forecast intercomparison.

Fig. 3 shows a time-longitude Hovmoller diagram for tropical precipitation anomalies based on 12-hour forecasts from the operational NCEP ensemble. The contours superimposed depict convectively coupled tropical modes including the MJO and are obtained using space-time filtering applied to outgoing longwave radiation data (for more on this technique, see the *Journal of Atmospheric Science* article by Wheeler and Kiladis). Subjectively, the 12-hour predicted precipitation and the MJO envelope correspond fairly well, especially for the operational NCEP ensemble. The initial conditions generate realistic precipitation forecasts at least for very short leads. Figures 4a and 4b show week 2 forecasts from the NCEP GFS and the circ-1998 MRF ensemble (hereafter CDC ensemble), both of which exhibit poor skill for this case. There is slight skill relative to the Wheeler and Kiladis coherent modes for the NCEP GFS whereas the CDC ensemble responds mainly to the warm SSTA. Quantitative verifications to be discussed below confirm the low skill.

Another difference between Figure 4a and 4b is caused by using a consistent model climatology when computing anomalies for the CDC ensemble but an inconsistent reanalysis climatology when computing the GFS ensemble anomalies. Using the NCEP reanalysis precipitation climatology for the latter leaves a residual that is similar in magnitude to the actual anomalies (e.g., along 60_{o}W). The reanalysis climatology has much more precipitation over the eastern hemisphere warm pool and much less over the western hemisphere ITCZs than the (apparent) GFS precipitation climatology. This illustrates problems that can be encountered when computing anomalies without a lead-dependent climatology for each model.

Forecast Verifications

The website includes simple verification statistics for some of the models using spatial anomaly correlations. In all cases, the verification field is the NCEP reanalysis, and, except for the CDC ensemble, the reanalysis climatology is used to compute anomalies. For the CDC ensemble, a lead-dependent model climatology is available. The ensemble mean forecast for day 11 is verified against the total daily anomaly from the reanalysis. Since daily data is being verified, the correlations are relatively low.

Fig. 5 shows verifications of tropical velocity potential for four of the forecast models. On average the correlation is about 0.3 but there are large swings in the coefficients especially for the statistical models. The time variations do not appear simply related to the phase of the MJO. As expected, the skill is lower for GCM precipitation forecasts, about 0.1 over the warm pool region (not shown). These preliminary assessments of day 11 forecast skill for the period of record are sobering and leave much room for improvement. An experimental program such as the one discussed here should help facilitate these improvements.

Summary and Plans

The project plans to archive the forecasts so that diagnostic case studies can be performed. Currently, only the previous month is available pending acquisition of additional computer hardware. Apart from this, other implementation issues concern how to deal with forecast models that have yet or routinely do not have a lead-dependent forecast climatology which is necessary to remove a model's systematic biases, the degree that coupled models and ensembles need to be or can be incorporated into the project, and the manner the MJO signal(s) are to be consistently extracted from the heterogeneous set of models (e.g., empirical and numerical).

Finally, the format, content and length of the weather-climate discussions are still undergoing experimentation. There were some outstanding examples of MJO activity and tropical-extratropical interaction presented in the fifteen weather-climate discussions posted to the website thus far. However, to date, the initiation and completion of these discussions has tended to be driven by available time, resources and current state of MJO activity. Ideally these should be issued weekly and contain a section that explicitly summarizes the various predictions of the MJO; we hope to achieve this during the 2006/7 northern hemisphere winter season.

In summary, we hope this project will allow the community to take advantage of the potential skill in forecasting the MJO that is present now, and that will hopefully increase in the near future, as well as lend a modeling resource to those trying to remedy MJO simulation problems or diagnose interactions between the MJO and other aspects of weather and subseasonal variability (e.g., PNA, NAO). We would welcome any commentary, suggestions, or additional contributions. We are proposing the establishment of a US CLIVAR Subseasonal Working Group to, in part, focus on MJO modeling and forecasting issues. Plans are also underway for a third workshop in 2006 to consider refinements to the project and web site, new focus areas, how to implement additional validation analyses, as well promote better connections to the operational forecasting communities.

Acknowledgements

We would like to thank the NOAA-CIRES Climate Diagnostics Center for providing support to host the project's web site, NASA and US-CLIVAR for supporting the first two subseasonal workshops, the participants of these two workshops for helping to articulate the framework for, and benefits of, such a project, as well as the participants and their countries for providing the included forecast products. Support for D. Waliser was provided by the Human Resources Development Fund at the Jet Propulsion Laboratory, the National Oceanographic and Atmospheric Administration under grant NA16GP2021 and the National Science Foundation under grant ATM-0094416. The research at the Jet Propulsion Laboratory (JPL), California Institute of Technology was performed under contracts with the National Aeronautics and Space Administration. C. Jones thanks the National Science Foundation (ATM-0094387) and NOAA Office of Global Programs CLIVAR-Pacific Program (NA16GP1019) for support.

References

Newman M., P.D. Sardeshmukh, C.R. Winkler and J.S. Whitaker, 2003: A study of subseasonal predictability. Mon. Wea. Rev., 131, 1715-1732.

Schubert, S., R. Dole, H. van den Dool, M. Suarez and D.Waliser, 2002: Proceedings from a Workshop on "Prospects for Improved forecasts of Weather and Short-term Climate Variability on Subseasonal (2 week to 2 month) Time Scales", 16-18 April 2002, Mitchellville, MD, NASA/TM 2002-104606, vol. 23, 171 pp.

Waliser, D., S. Schubert, A. Kumar, K. Weickmann and R. Dole, 2003: Proceedings from a workshop on "Modeling, Simulation and Forecasting of Subseasonal Variability", 4-5 June 2003, University of Maryland, College Park, Maryland, NASA/CP 2003-104606, vol. 25, 62 pp.

Waliser, D. E., 2005: Predictability and Forecasting. "Intraseasonal Variability of the Atmosphere-Ocean Climate System" W. K. M. Lau and D. E. Waliser, Eds., Springer, Heidelberg, Germany, 474.

Wheeler, M. C. and H. H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. Monthly Weather Review, 132, 1917-1932.

Wheeler, M.C. and G.N. Kiladis, 1999: Convectively coupled equatorial waves: Analysis of clouds and temperature in the wavenumber-frequency domain. J. Atmos. Sci., 56, 374-399.

Winkler, C.R., M. Newman, and P.D. Sardeshmukh, 2001: A linear model of wintertime low-frequency variability: Part I: Formulation and forecast skill. J. Climate, 14, 4474-4494.

Weickmann, K.M., and E.B. Berry, 2006: A synoptic model of subseasonal variability. Mon. Wea. Rev., submitted.

Figure Captions

Fig. 1. The homepage for the MJO Experimental Prediction Website

Fig. 2. An example of week 2 forecasts from the experimental website. They include a) ensemble precipitation anomalies from a circa-1998 version of the MRF, and b) outgoing longwave radiation anomalies from the Wheeler and Hendon statistical model.

Fig. 3. 12-hour forecasts of precipitation anomaly for the NCEP GFS ensemble shown in timelongitude format. Data are averaged between 7.5N – 7.5S. The contours represent observed coherent OLR modes (Wheeler and Kiladis, 1999) based on the outgoing longwave radiation anomalies. Good correspondence can be seen between the initial model predictions of precipitation and the envelope of the MJO (blue contours).

Fig. 4. Same as Fig. 3 except for week 2 predictions of equatorial precipitation from the a) NCEP GFS ensemble and the b) MRF ensemble. Poor correspondence is seen between the MJO envelope (contours) and the precipitation predictions. In a), the differences in the climatology between the GFS and the NCEP reanalysis dominates; in b) where a consistent circa-1998 MRF climatology is used, the model is primarily reacting to persistent SST anomalies.

Fig. 5. The pattern correlation between day 11 predictions of the tropical velocity potential anomaly and the NCEP reanalysis "observed" anomaly for predictions made during 2004.

Table 1

Contact	Email	Affiliation	Type of Forecasts
Matthew Wheeler	m.wheeler@bom.gov.au	BMRC, Melbourme Australia	Mulitple Linear Regression
Matthew Newman	matt.newman@noaa.gov	NOAA-CIRES CDC	Linear Inverse Model
Huug van den Dool/Hua-Lu Pan/Suranjana Saha	vandendool@ncep.noaa.gov	NCEP/CPC	NCEP GFS Ensemble GCM
Jeffrey Whitaker	Jeffrey.Whitaker@noaa.gov	NOAA-CIRES CDC	Circa-1998 MRF Ensemble GCM
Oscar Alves	O.Alves@bom.gov.au	BMRC, Melbourme Australia	BOM POAMA Ocean-Atmosphere Coupled Model
Matthew Wheeler	m.wheeler@bom.gov.au klaus.weickmann@noaa.gov	BMRC, Melbourme Australia	Extrapolation of space-time filter of tropical OLR
Charles Jones	cjones@icess.ucsb.edu	UCSB	Regression model using filtered EOFs
Huug van den Dool	vandendool@ncep.noaa.gov	NCEP/CPC	Empirical wave propagation model
Frederic Vitart	Frederic.Vitart@ecmwf.int	ECMWF	ECMWF ensemble GCM

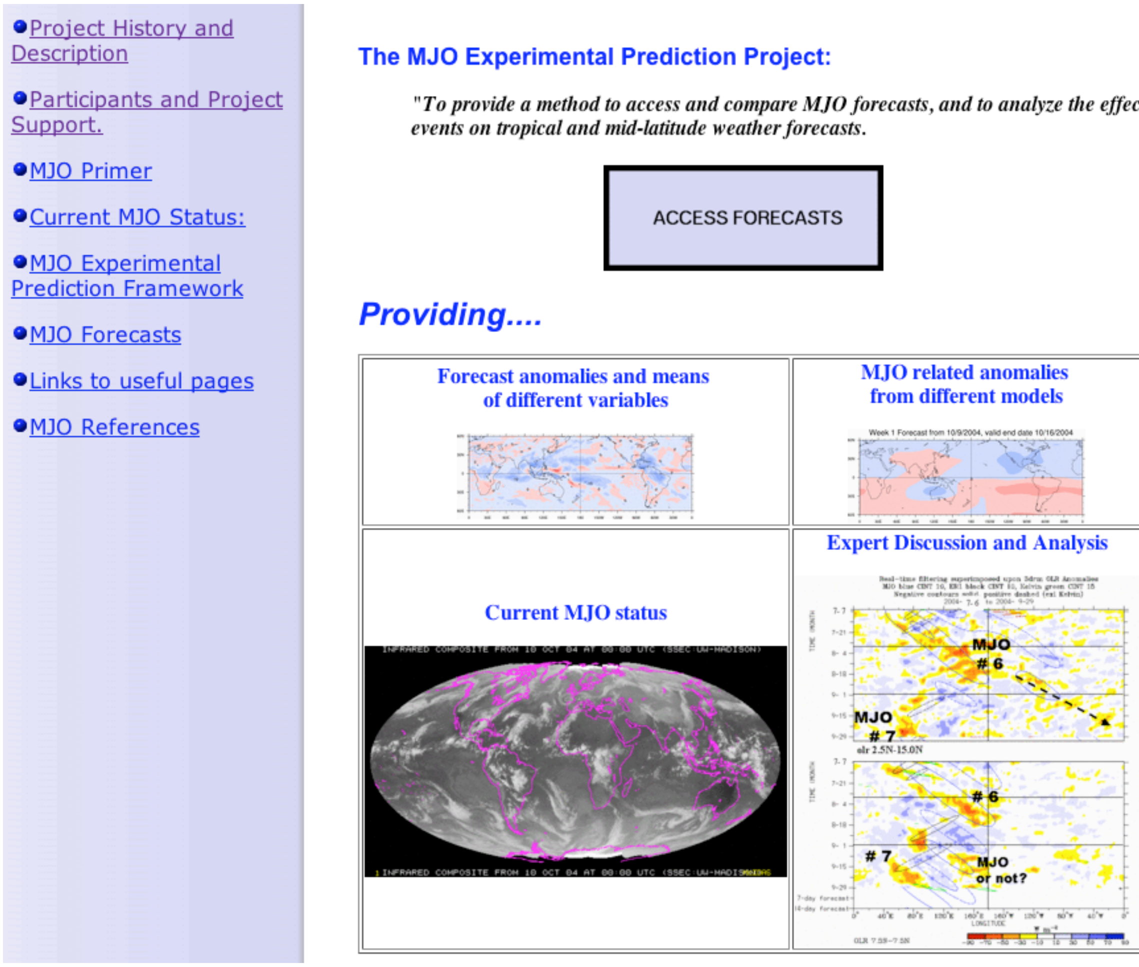

Project History and Description
Participants and Project Support.
MJO Primer
Current MJO Status:
MJO Experimental Prediction Framework
MJO Forecasts
Links to useful pages
MJO References
The MJO Experimental Prediction Project:
"To provide a method to access and compare MJO forecasts, and to analyze the effects of MJO events on tropical and mid-latitude weather forecasts.
ACCESS FORECASTS
Providing....
Forecast anomalies and means of different variables
MJO related anomalies from different models
Week 1 Forecast from 10/9/2004, valid end date 10/16/2004
Current MJO status
INFRARED COMPOSITE FROM 10 OCT 04 AT 00:00 UTC (SSEC:UW-MADISON)
Expert Discussion and Analysis
MJO
6
MJO
7
olr 2.5N-15.0N
6
7
MJO
or not?

Figure 1

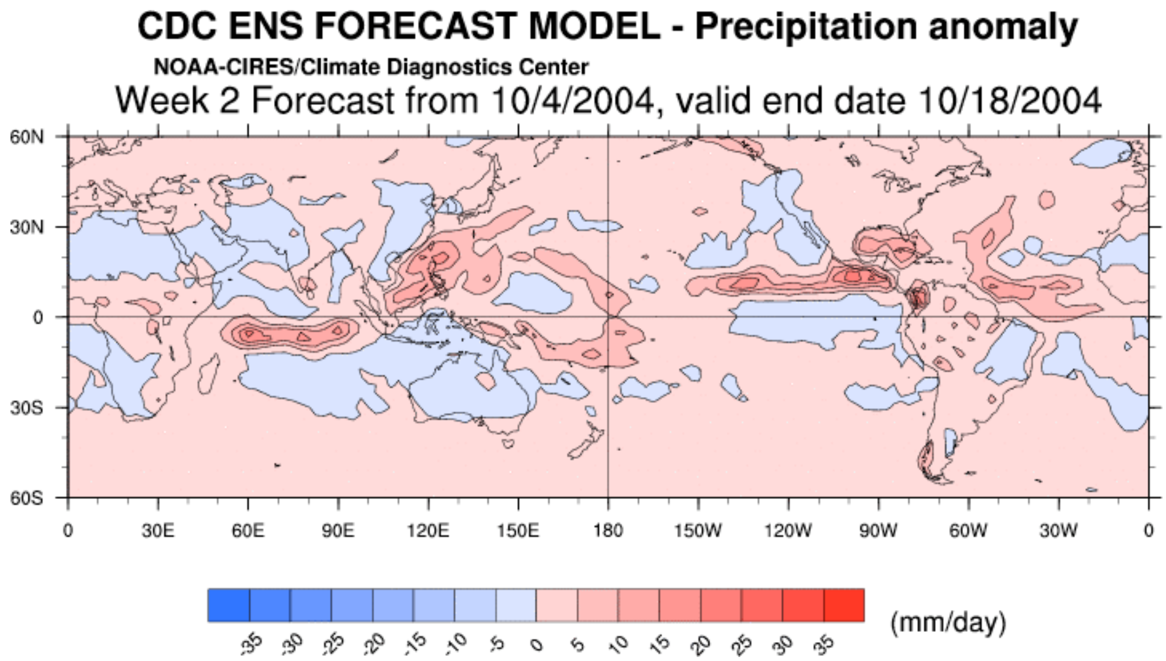


Figure 2

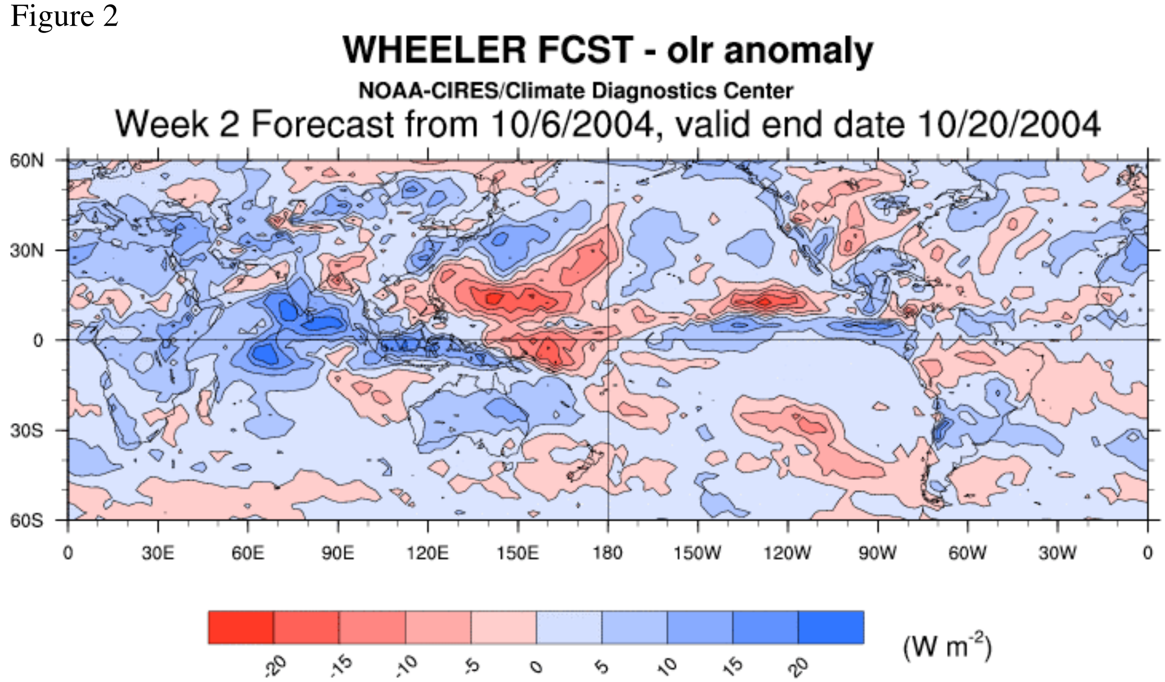
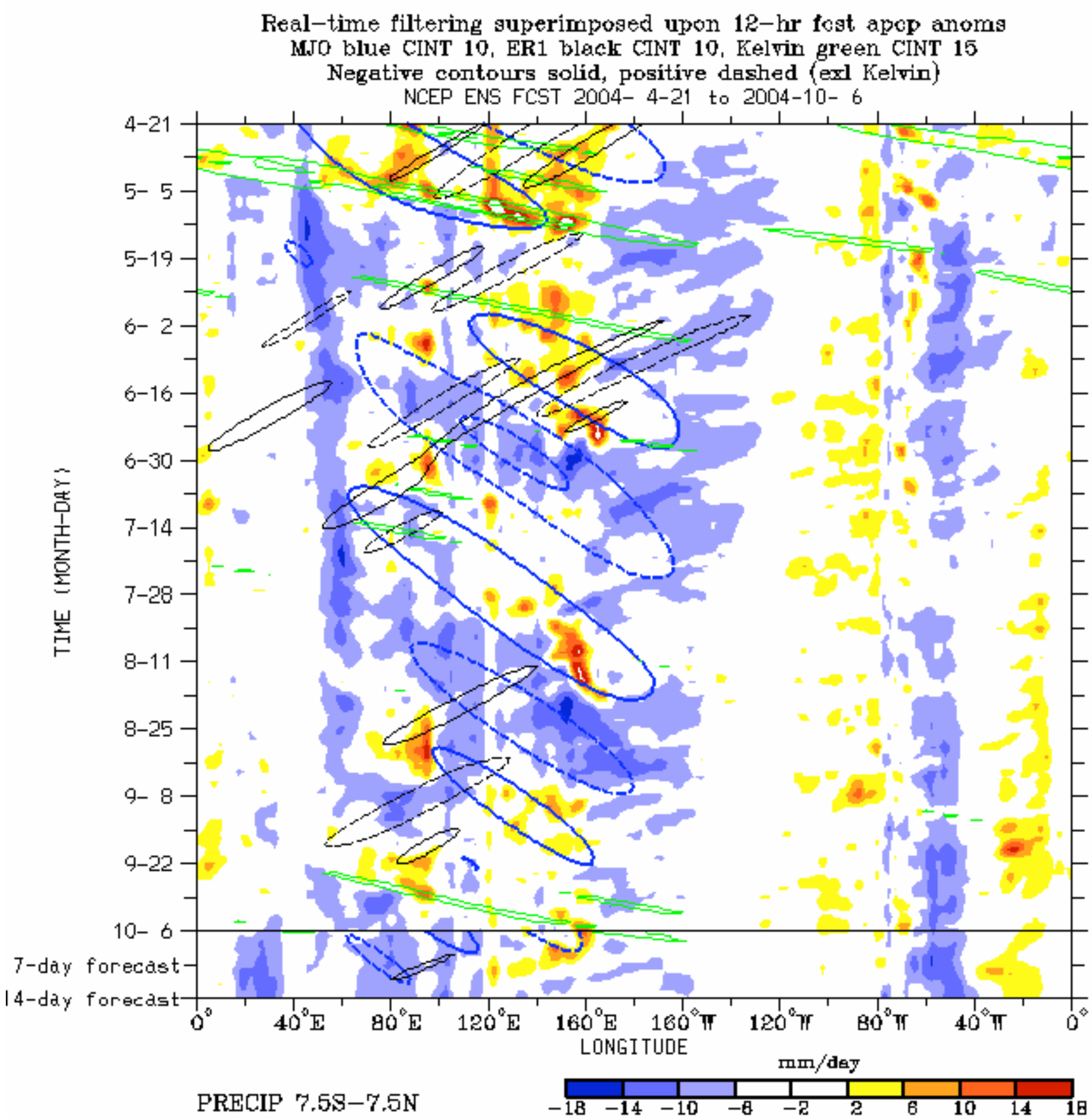


Figure 2 continued



Real-time filtering superimposed upon 12-hr fcst apcp anoms
MJO blue CINT 10, ER1 black CINT 10, Kelvin green CINT 15
Negative contours solid, positive dashed (exl Kelvin)
NCEP ENS FCST 2004- 4-21 to 2004-10- 6
TIME (MONTH-DAY)
4-21
5- 5
5-19
6- 2
6-16
6-30
7-14
7-28
8-11
8-25
9- 8
9-22
10- 6
7-day forecast
14-day forecast
0°
40°E
80°E
120°E
160°E
160°W
120°W
80°W
40°W
0°
LONGITUDE
mm/day
PRECIP 7.5S-7.5N
-18
-14
-10
-6
-2
2
6
10
14
18

Figure 3

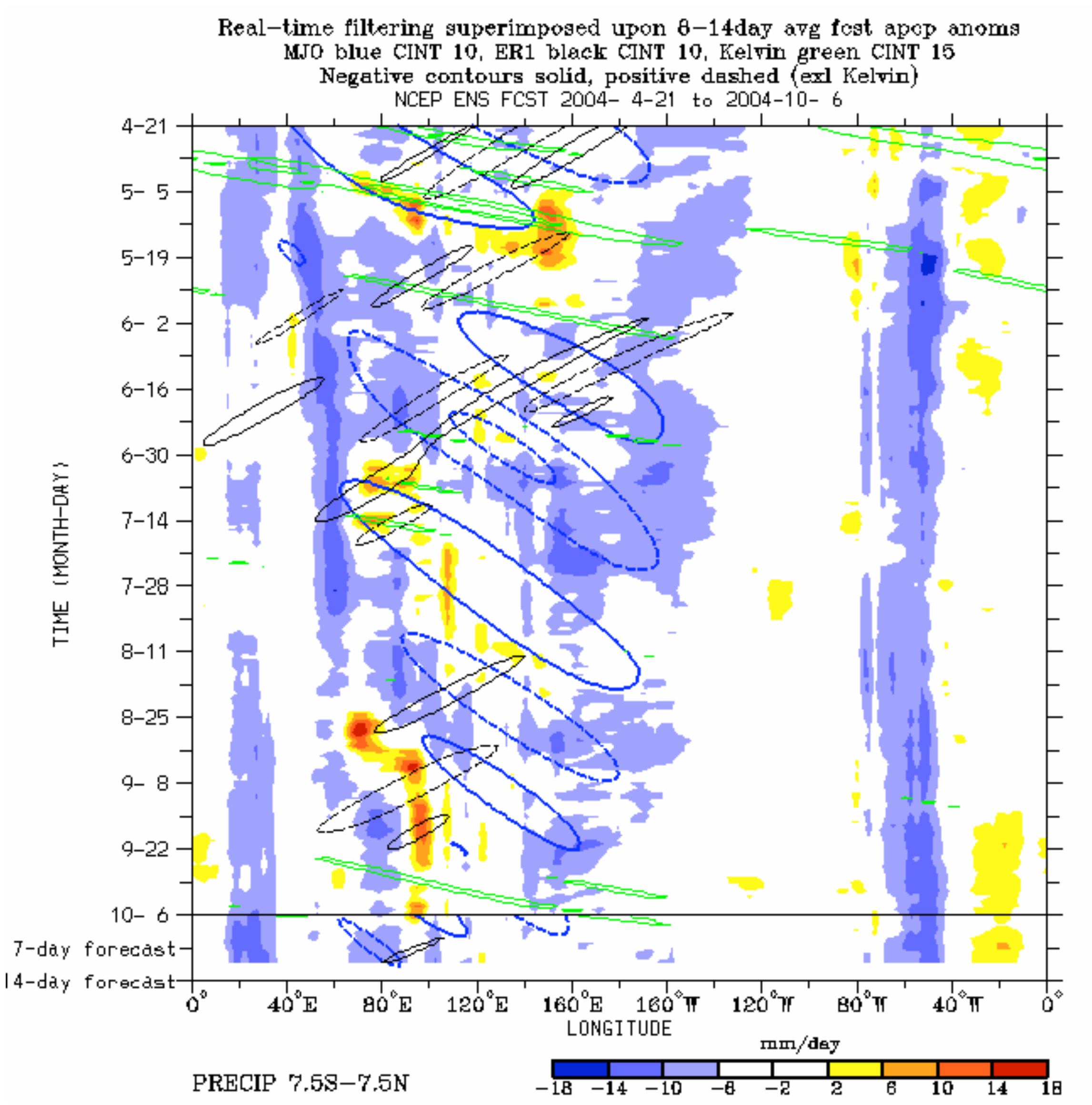

Real-time filtering superimposed upon 8-14day avg fcst apcp anoms
MJO blue CINT 10, ER1 black CINT 10, Kelvin green CINT 15
Negative contours solid, positive dashed (exl Kelvin)
NCEP ENS FCST 2004- 4-21 to 2004-10- 6
TIME (MONTH-DAY)
4-21
5- 5
5-19
6- 2
6-16
6-30
7-14
7-28
8-11
8-25
9- 8
9-22
10- 6
7-day forecast
14-day forecast
0°
40°E
80°E
120°E
160°E
160°W
120°W
80°W
40°W
0°
LONGITUDE
mm/day
-18 -14 -10 -6 -2 2 6 10 14 18
PRECIP 7.5S-7.5N

Figure 4a

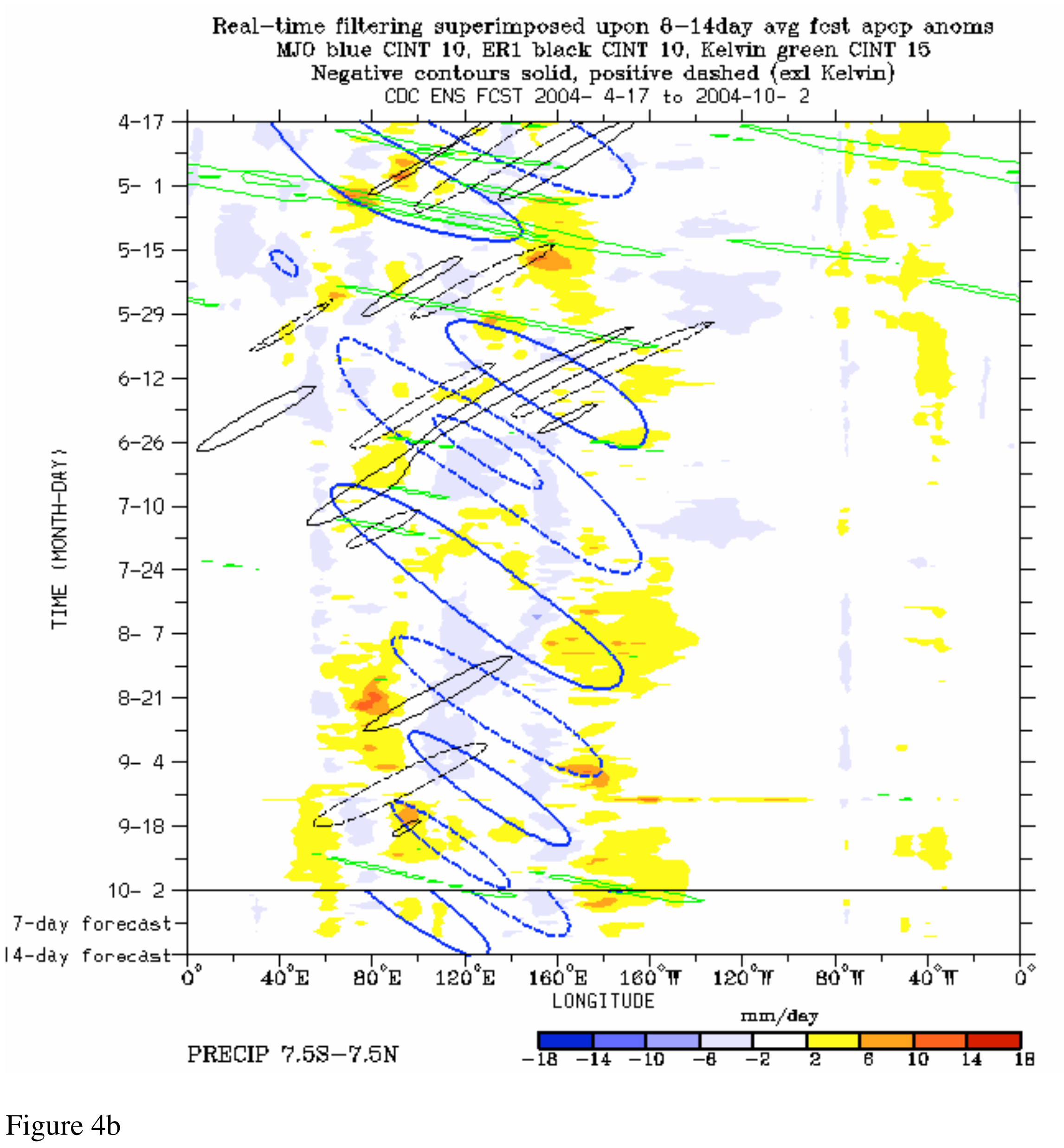

Real-time filtering superimposed upon 8-14day avg fcst apcp anoms
MJO blue CINT 10, ER1 black CINT 10, Kelvin green CINT 15
Negative contours solid, positive dashed (exl Kelvin)
CDC ENS FCST 2004- 4-17 to 2004-10- 2
TIME (MONTH-DAY)
4-17
5- 1
5-15
5-29
6-12
6-26
7-10
7-24
8- 7
8-21
9- 4
9-18
10- 2
7-day forecast
14-day forecast
0°
40°E
80°E
120°E
160°E
160°W
120°W
80°W
40°W
0°
LONGITUDE
mm/day
PRECIP 7.5S-7.5N
-18 -14 -10 -6 -2 2 6 10 14 18

Figure 4b

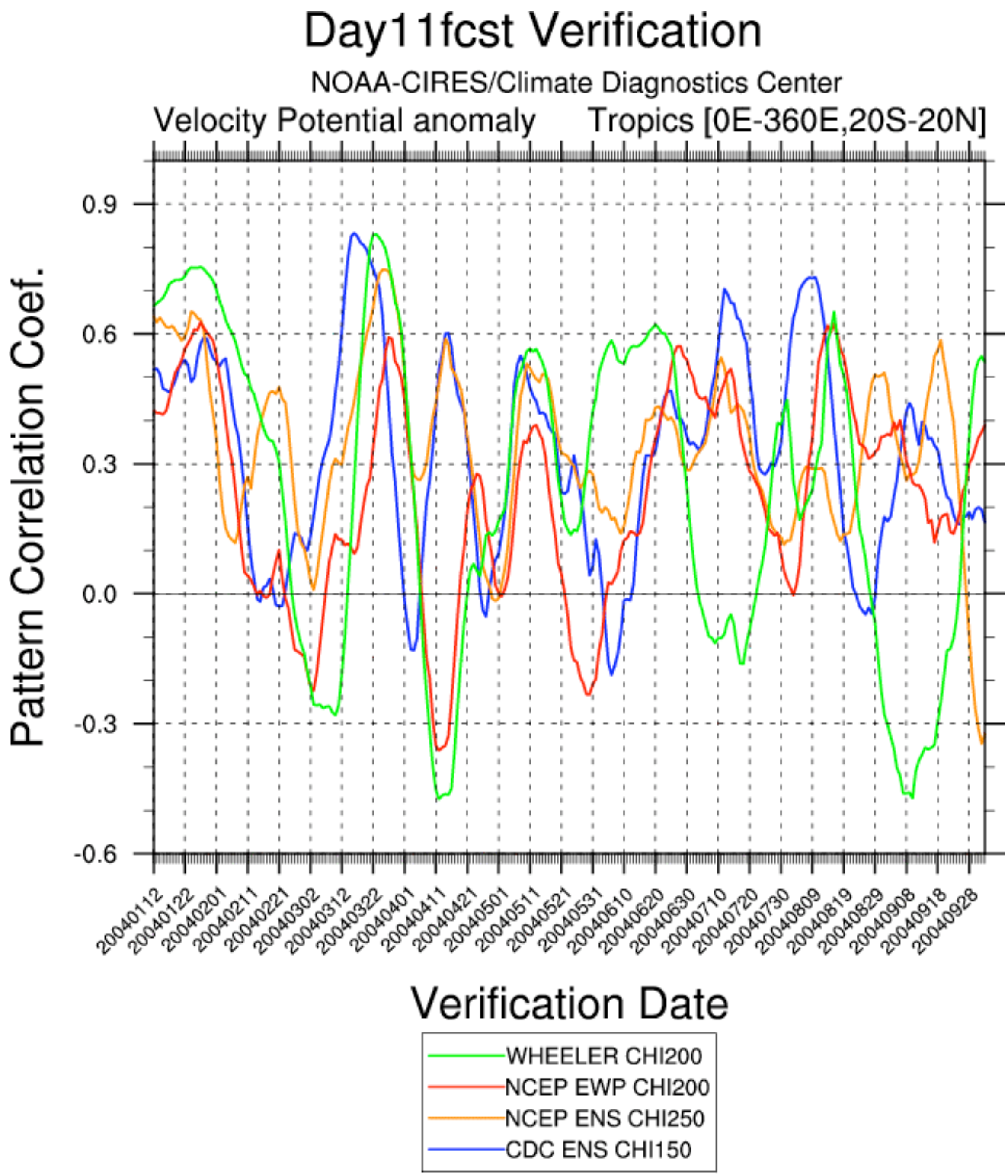

Day11fcst Verification
NOAA-CIRES/Climate Diagnostics Center
Velocity Potential anomaly
Tropics [0E-360E,20S-20N]
Pattern Correlation Coef.
0.9
0.6
0.3
0.0
-0.3
-0.6
20040112
20040122
20040201
20040211
20040221
20040302
20040312
20040322
20040401
20040411
20040421
20040501
20040511
20040521
20040531
20040610
20040620
20040630
20040710
20040720
20040730
20040809
20040819
20040829
20040908
20040918
20040928
Verification Date
WHEELER CHI200
NCEP EWP CHI200
NCEP ENS CHI250
CDC ENS CHI150

Figure 5