



# Enhanced Predictability During Extreme Winter Flow Regimes

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ECMWF UEF | 2016

Reading, UK

June 6 – 9, 2016

## Where does forecast verification occur today?

- Internal teams within NWP centers
- Media: TV broadcasters, print, web
- Social Media, Twitter / Facebook

## Who is doing model forecast verification?

- Trained forecasters, gov't & commercial
- Your neighbor

**High impact events**



## SCIENTIFIC METHOD / SCIENCE &amp; EXPLORATION

## Why European forecasters saw Sandy's path first

US weather model is good, but lags behind the best.

by Scott K. Johnson - Dec 26, 2012 1:30pm EST



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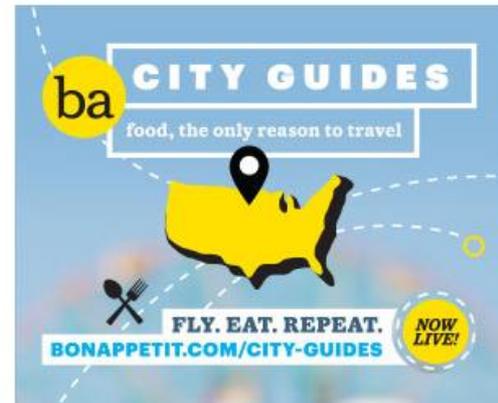
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Satellite image of Hurricane Sandy.

 NASA Earth Observatory


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## LATEST FROM ARS TECHNICA/UK



Labour backs “principle” of Tory government’s Investigatory Powers Bill



EU net neutrality draft guidelines split the crowd—public told to wade in



What a Brexit would mean for Europe’s television channels



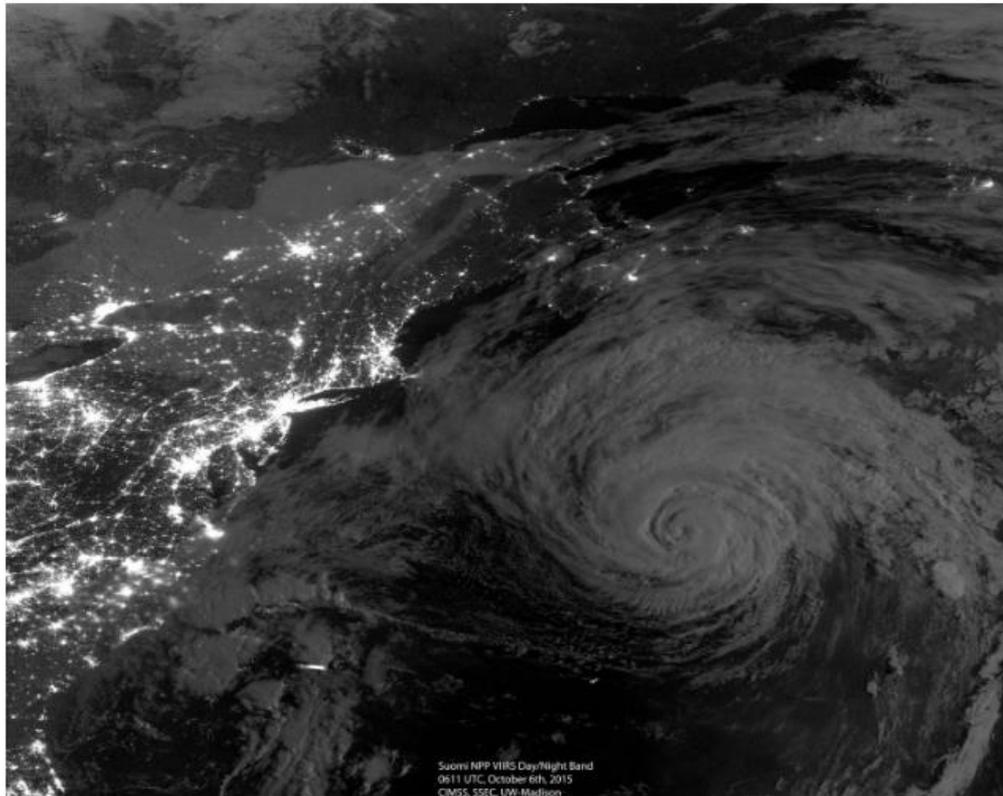
Google’s AlphaGo AI will play Go against humanity’s best



Capital Weather Gang

## What the European model ‘win’ over the American model in Joaquin means for weather forecasting

By Jason Samenow October 6, 2015



Suomi NPP VIIRS Day/Night Band  
0611 UTC, October 6th, 2015  
CIMSS, SSEC, UW-Madison

Hurricane Joaquin (Cooperative Institute for Meteorological Satellite Studies at the University of Wisconsin-Madison)

Last week, on the biggest of stages, a weather forecast model from Europe proved superior to the principal U.S. model in its prediction for a hurricane threatening the United States.

### Most Read

- 1 Traffic-weary homeowners and Waze are at war, again. Guess who's winning?
- 2 A six-month sentence in Stanford sexual assault case leads to a push to recall the judge
- 3 'I will not help you hide your money when you apply for financial aid' – and more straight talk from college admissions officers to parents
- 4 The 'heartbreaking' moment a dying mother begged her friend: 'Will you take my babies?'
- 5 'Which Way' is faster during SafeTrack's first surge – the Silver Line or one of the alternatives?

### At a Glance

Mon.	Tue.	Wed.
- / 87°	68° / 85° 30%	61° / 75°
Thu.	Fri.	Sat.
57° / 76°	58° / 78°	61° / 83° 20%

Forecast by National Weather Service

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## F Europeans shine in weather forecasting

David Kramer

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January 2016, page 22

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       (3)

The US global model lags the performance of two European competitors in predicting weather up to two weeks ahead.

GO TO SECTION... ▾

Although Hurricane Joaquin passed well off the US East Coast in October, the storm had a different kind of impact: bringing into focus the outstanding performance of one of numerous global weather prediction models. The European Centre for Medium-Range Weather Forecasts (ECMWF) was the world's only major forecast simulation to pinpoint the hurricane's track several days out. Others, including the US Global Forecast System (GFS), had charted a course for Joaquin that was hundreds of miles to the west and showed that it would make landfall along the mid-Atlantic coast.

The exceptional performance of the ECMWF model had also been seen in 2012 when it was the only one to predict the left hook that brought Hurricane Sandy ashore in New Jersey. Other models had Sandy staying well out to sea.



**Aerial view of the New Jersey coast** in the aftermath of Hurricane Sandy. The global weather model from the European Centre for Medium-Range Weather Forecasts was the only one to correctly predict that the storm would make landfall there.

US AIR FORCE

## INTRODUCING 41R2: MOST ACCURATE AND HIGHEST- EVER RESOLUTION IN GLOBAL NUMERICAL WEATHER PREDICTION.

10 MARCH 2016

### What has been announced today?

We're announcing a significant set of upgrades launched by the European Centre for Medium Range Weather Forecasts (ECMWF). The changes nearly halve the distance between global weather prediction points, substantially increasing the effective resolution of the forecast. As a result, ECMWF's numerical weather predictions, which are widely used by Europe's meteorological services, are more accurate, contain three times as much detail and can predict the weather up to half a day further ahead.

### Key messages

- Most accurate global weather predictions at record-breaking resolution.
- Number of grid points tripled to 900 million in the high-resolution forecast, evenly distributed around the globe.
- Gain in predictability of up to half a day at same level of quality.

$$3600x \ 1801y \ 137L = 888M$$

## Forecasts are about to get a lot more accurate: NOAA unveils new '4D' supercomputer model of the world's weather

- New model of global weather takes into account how weather systems evolve on a 3D spatial grid over time
- Dramatically improves accuracy of forecasts, and allows NOAA to see hourly forecasts for the next five days

By [MARK PRIGG FOR DAILYMAIL.COM](#) 

PUBLISHED: 16:22 EST, 12 May 2016 | UPDATED: 21:45 EST, 12 May 2016



National Oceanic and Atmospheric Administration  
U.S. Department of Commerce

[< NEWS & FEATURES](#)

## NOAA's premier forecast model goes 4-D

[Weather](#) | [supercomputers](#) | [modeling](#) | [GFS](#)

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May 11, 2016 — NOAA's powerful new supercomputers paved the way for another upgrade to the U.S. Global Forecast System (GFS), NOAA's primary model for weather prediction.



< NEWS & FEATURES

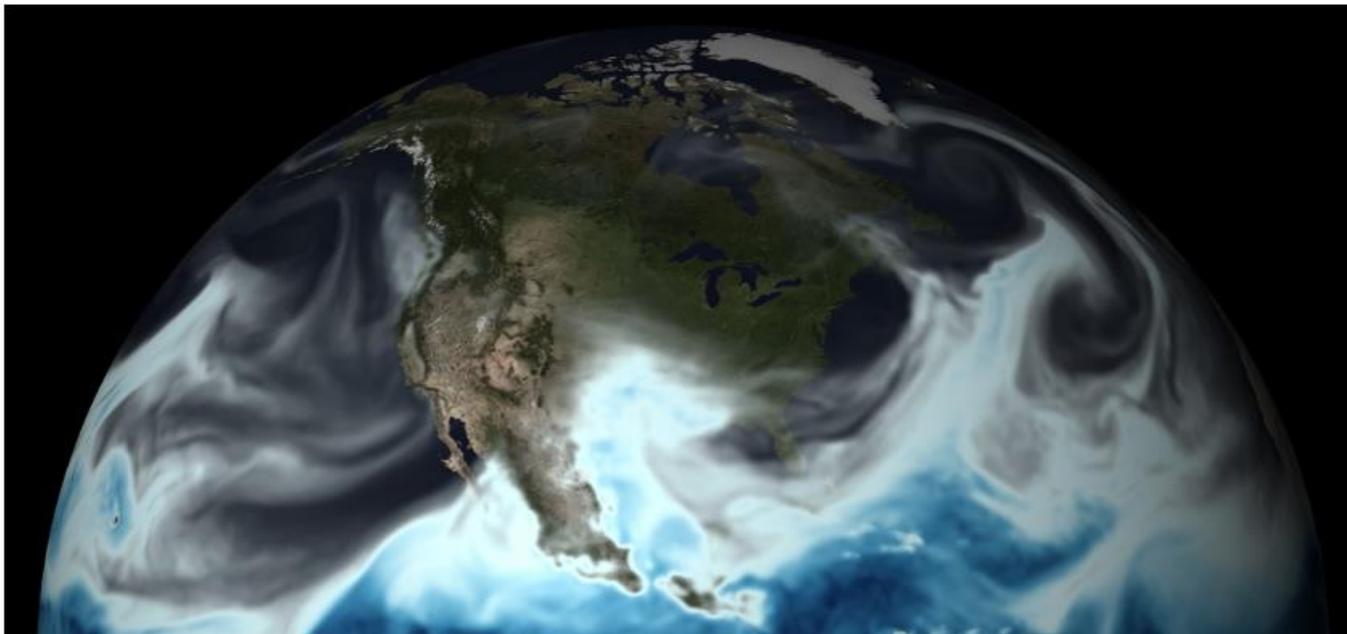
# NOAA's premier forecast model goes 4-D

Weather | supercomputers modeling GFS

SHARE



May 11, 2016 — NOAA's powerful new supercomputers paved the way for another upgrade to the U.S. Global Forecast System (GFS), NOAA's primary model for weather prediction.





## SCIENTIFIC METHOD / SCIENCE & EXPLORATION

# TV maker Panasonic says it has developed the world's best weather model

The company says it has beaten the GFS for a while and now equals the ECMWF.

by Eric Berger - Apr 6, 2016 11:36am EDT



65



# Comparison of Operational Suites



HRES Global model 0-10 days (2x)  
EPS Ensembles 0 -15 days, 46 days  
Seasonal 7-months (1 per mon)

GFS global model 0 -16 days (4x daily)  
GEFS ensembles 0-16 days (4x daily)  
NAM (12-km) 0-84 hours (4x), *NAM-RR*  
NAM 4-km Nest 0-60 hours (4x)  
RAP 12-km (24x)  
HRRR 3-km (24x), *HRRR-E*  
CFSv2 climate forecast 0-270 days (4x)  
HIRESW 4-km WRF-windows (2x)  
SREF ensemble 16-km (4x)  
RTMA/URMA analysis (24x)  
WW3 Wave model (4x)  
RTOFS global model (1x)  
NDFD 2.5 km (48x)  
National Water Model, Aerosols  
HWRF hurricane model (4x)  
WPC, SPC, NWS, NSIDC, OPC, Space ...

## Framework & Goals

- Use current NWP deterministic & ensemble systems to analyze large-scale flow patterns and relate to medium-range forecast skill “dropouts”
- Diagnose causes of low-predictability flow regimes including dropouts: inadequate observations, large analysis uncertainty, and/or model error growth
- Link to skill of Teleconnection Indices such as AO/NAO, EPO, WPO and PNA

## Definitions

- Forecast skill metrics: 5 or n-day 500 hPa geopotential anomaly correlation (NH: 20°-80°N),
- Forecast dropout: an individual or collection of several consecutive forecasts that have significantly lower 500 hPa geopotential anomaly correlation skill – compared to monthly/seasonal mean  
**(AC < 0.8)**
- Low-predictability regime: particular hemispheric-scale configuration of upper-level flow that leads to below average forecast skill

# Anomaly Correlation: Definition

$$ACC = \frac{\sum_{m=1}^M f'_m o'_m}{\left[ \sum_{m=1}^M (f'_m)^2 \sum_{m=1}^M (o'_m)^2 \right]^{1/2}}$$

500-hPa geopotential height  
Northern Hemisphere 20°-80° N

$$f'_m = f_m - c_m \quad \text{Forecast anomaly from climatology* at each grid point } (m)$$
$$o'_m = o_m - c_m \quad \text{Analysis anomaly}$$

- The AC is common forecast skill metric used by operational centers
- Forecasts with  $AC > 0.6$  are considered as providing potential positive skill
- Not perfect metric, but used in concert w/ e.g. mean squared error

\* ERA-Interim (reanalysis) 1981-2010 climatology



# Archive of Analysis and Forecast Fields

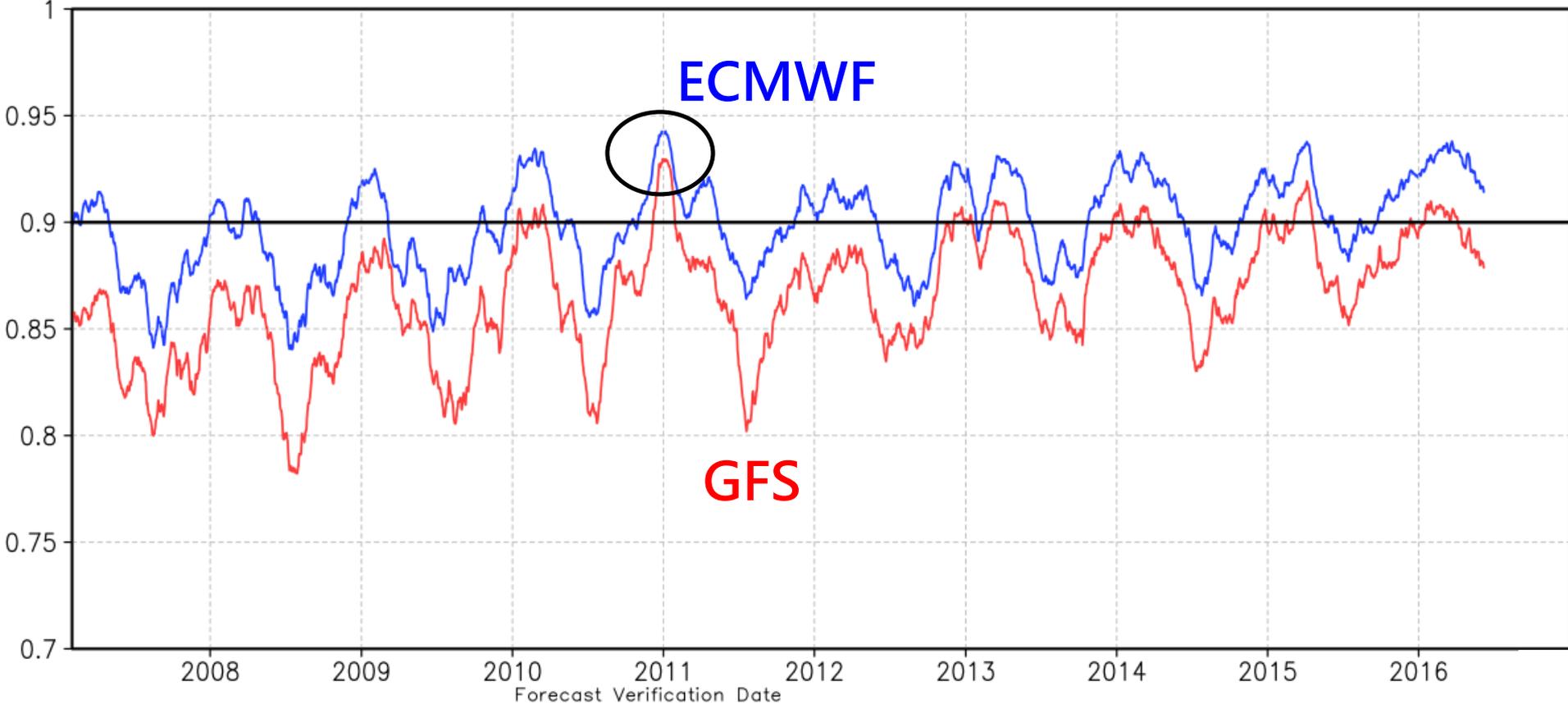
- Historical record of analysis and forecasts from current NWP deterministic and ensemble systems
- Key is archive and/or “real-time” access to forecast products
- Valuable resource includes the EPS Reforecasts / Hindcasts or any frozen forecast model for post-processing purposes e.g. EFI, M-Climate

<b>MODEL</b>	<b>TIME PERIOD</b>	<b>GRID/FIELDS</b>	<b>SOURCE</b>
<b>ECMWF</b> HRES & EPS	Oct 2006-present	T799-T1279L137 Tco1279L137 ~9/18 km	WeatherBELL ECMWF MARS
<b>NCEP GFS</b> GEFS	Feb 2004-present	T382-T574L64 T1534L64 0.25° - 0.5° - 1°	NOMADS/NCDC
<b>NAVY</b> NAVGEM	Jan 2004-present	T239-T319-T359 0.5°	NRL MONTEREY
*Forecasts verified against own analysis			



# Anomaly Correlation: Forecast skill

45-day Running Mean | 500 hPa NH Z [20°-80° N] Anomaly Correlation 5-day Forecast



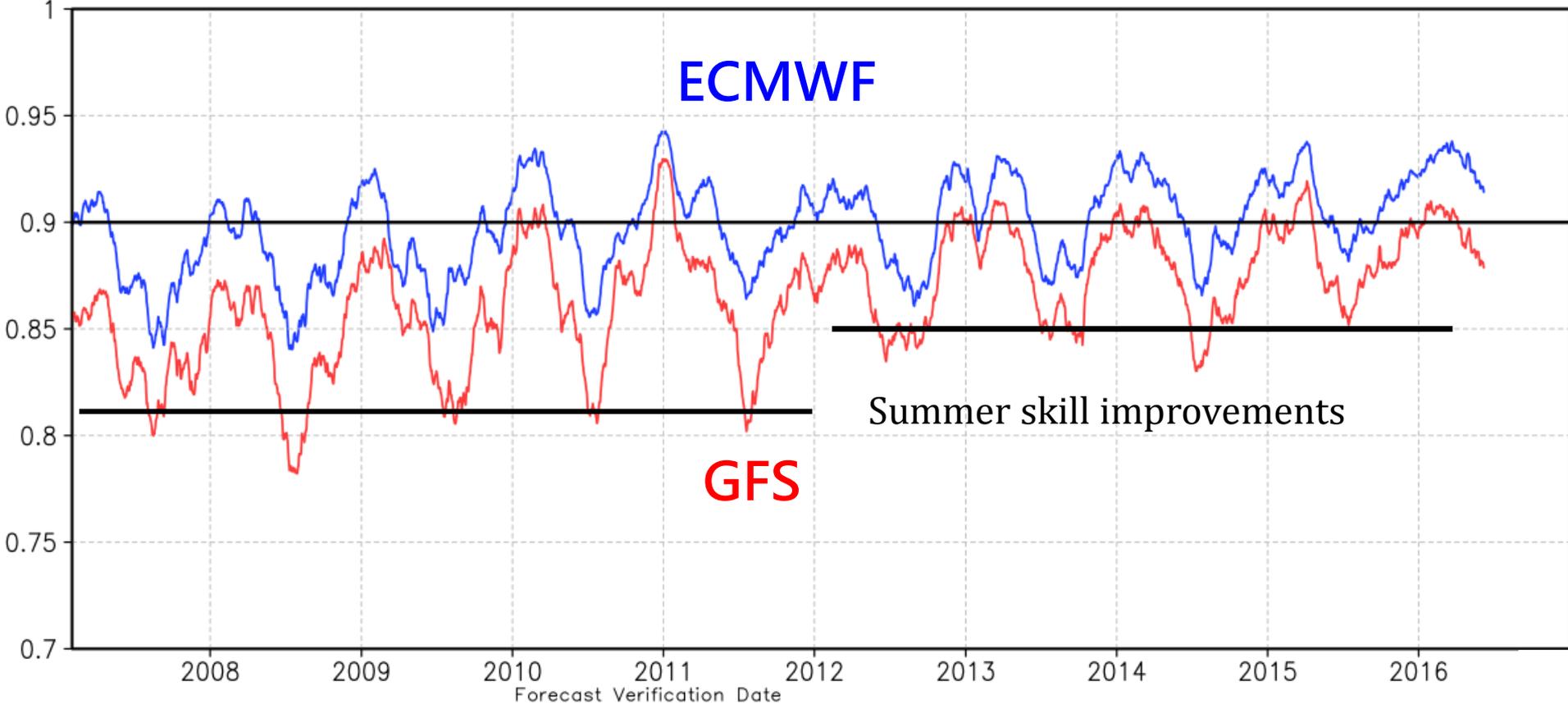
Seasonal AC scores are highly correlated  
NH Winter skill >> Summer Skill.

Both models showed record-high skill during winter 2010-2011



# Anomaly Correlation: Forecast skill

45-day Running Mean | 500 hPa NH Z [20°–80° N] Anomaly Correlation 5-day Forecast

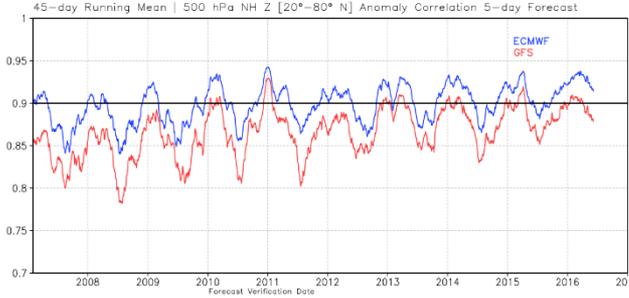


- Sustained improvement skill jumps mainly due to major model configuration changes:

Jan 26, 2010: ECMWF T799 → T1279      March 2016: 41r2

July 28, 2010: GFS T382 → T574 and physics major upgrade → T1534 → 4D-Hybrid EnVar      May 11, 2016

# Anomaly Correlation: Forecast skill



## 5-DAY NH Geopotential Height ECMWF vs GFS calendar year “Model Wars” in U.S.A. media

YEAR	GFS	ECMWF
2009	0.852	0.888
2010	0.872	0.904
2011	0.862	0.898
2012	0.871	0.900
2013	0.880	0.904
2014	0.875	0.905
2015	0.885	0.910
2016	YTD 0.894 12m 0.886	YTD 0.926 12m 0.915

NCEP May Upgrade:  
4D-Var Hybrid EnKF  
GFS gains have  
“leveled out”

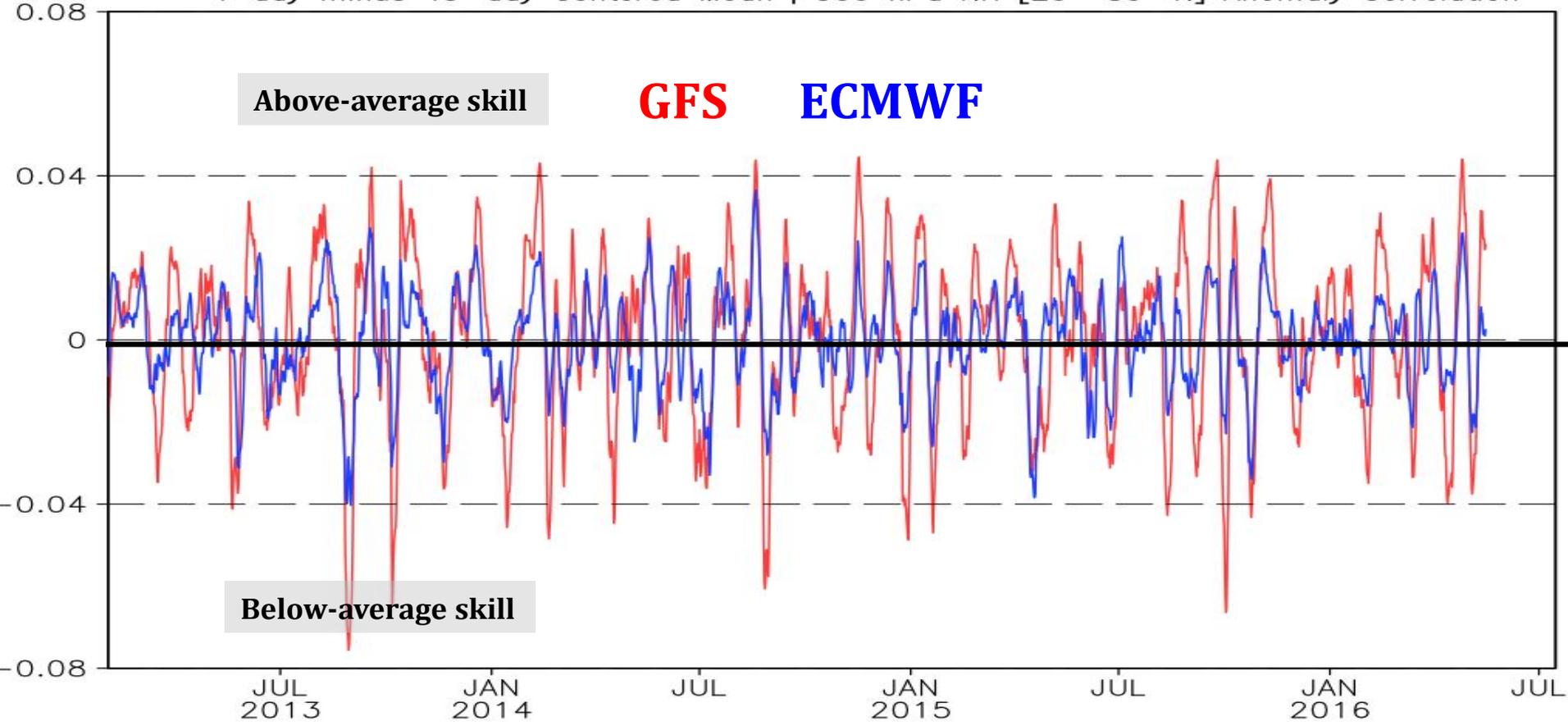
Cycle 42r1 significant  
Improvement  
  
“Gap widened” by 20%  
0.0025 → 0.03  
  
On pace for 0.92



# Predictive Skill Regimes

From N Hemi AC, ECMWF & GFS: Centered means of 45-days and 7-days are calculated  
The 7-day *minus* 45-day mean represents a seasonally adjusted measure of skill

7 day minus 45-day Centered Mean | 500 hPa NH [20°-80° N] Anomaly Correlation



**Models tend to have low and high skill on the same forecast(s)- but ECMWF skill drops off less than GFS**



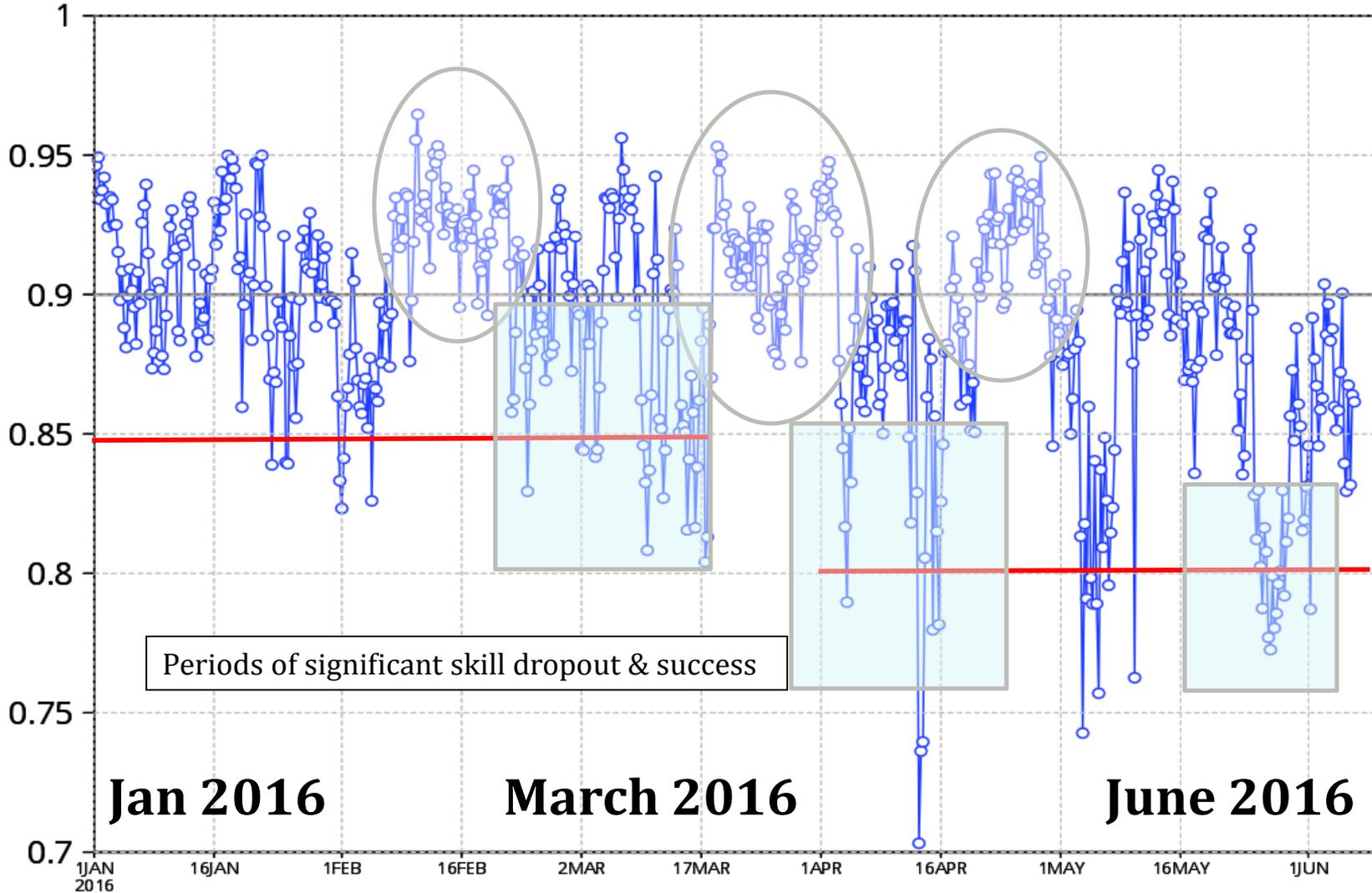
# Anomaly Correlation: GFS recent skill

NCEP GFS 500 hPa NH [20°-80° N] Anomaly Correlation | 5 day Forecasts [4x daily]

Last Verification Date: 18Z06Jun2016

Last 7-days: 0.859 | 30-days: 0.873

Last 365-days: 0.884



Last 40-scores  
Verf Time | AC

18Z06JUN	0.862
12Z06JUN	0.864
06Z06JUN	0.832
00Z06JUN	0.867
18Z05JUN	0.829
12Z05JUN	0.839
06Z05JUN	0.900
00Z05JUN	0.872
18Z04JUN	0.858
12Z04JUN	0.851
06Z04JUN	0.860
00Z04JUN	0.888
18Z03JUN	0.883
12Z03JUN	0.897
06Z03JUN	0.886
00Z03JUN	0.904
18Z02JUN	0.863
12Z02JUN	0.859
06Z02JUN	0.846
00Z02JUN	0.867
18Z01JUN	0.877
12Z01JUN	0.892
06Z01JUN	0.787
00Z01JUN	0.846
18Z31MAY	0.831
12Z31MAY	0.819
06Z31MAY	0.815
00Z31MAY	0.853
18Z30MAY	0.861
12Z30MAY	0.888
06Z30MAY	0.848
00Z30MAY	0.873
18Z29MAY	0.856
12Z29MAY	0.820
06Z29MAY	0.811
00Z29MAY	0.792
18Z28MAY	0.830
12Z28MAY	0.801
06Z28MAY	0.796
00Z28MAY	0.786
18Z27MAY	0.780

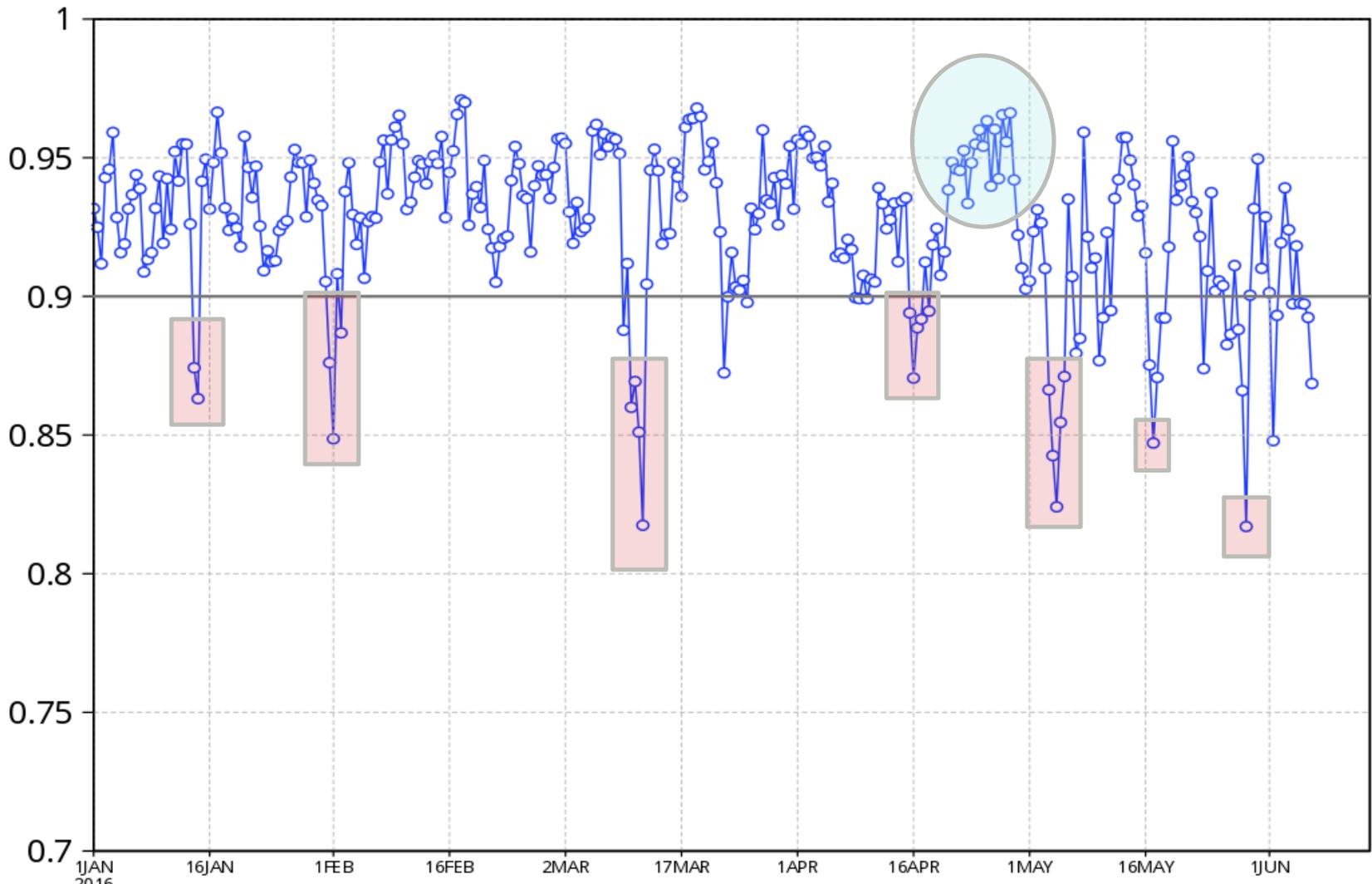


# Anomaly Correlation: HRES ECMWF 5-day

ECMWF 500 hPa NH [20°-80° N] Anomaly Correlation | 5 day Forecasts [2x daily]

Last Verification Date: 12Z06JUN2016

Last 7-days: 0.903 | 30-days: 0.911  
Last 365-days: 0.916



Last 40-scores  
Verf Time | AC

12Z06JUN	0.869
00Z06JUN	0.892
12Z05JUN	0.897
00Z05JUN	0.898
12Z04JUN	0.918
00Z04JUN	0.897
12Z03JUN	0.924
00Z03JUN	0.939
12Z02JUN	0.919
00Z02JUN	0.893
12Z01JUN	0.848
00Z01JUN	0.901
12Z31MAY	0.929
00Z31MAY	0.910
12Z30MAY	0.950
00Z30MAY	0.932
12Z29MAY	0.900
00Z29MAY	0.817
12Z28MAY	0.866
00Z28MAY	0.888
12Z27MAY	0.911
00Z27MAY	0.886
12Z26MAY	0.883
00Z26MAY	0.904
12Z25MAY	0.906
00Z25MAY	0.902
12Z24MAY	0.937
00Z24MAY	0.909
12Z23MAY	0.874
00Z23MAY	0.922
12Z22MAY	0.930
00Z22MAY	0.934
12Z21MAY	0.950
00Z21MAY	0.944
12Z20MAY	0.940
00Z20MAY	0.935
12Z19MAY	0.956
00Z19MAY	0.918
12Z18MAY	0.892
00Z18MAY	0.892
12Z17MAY	0.871

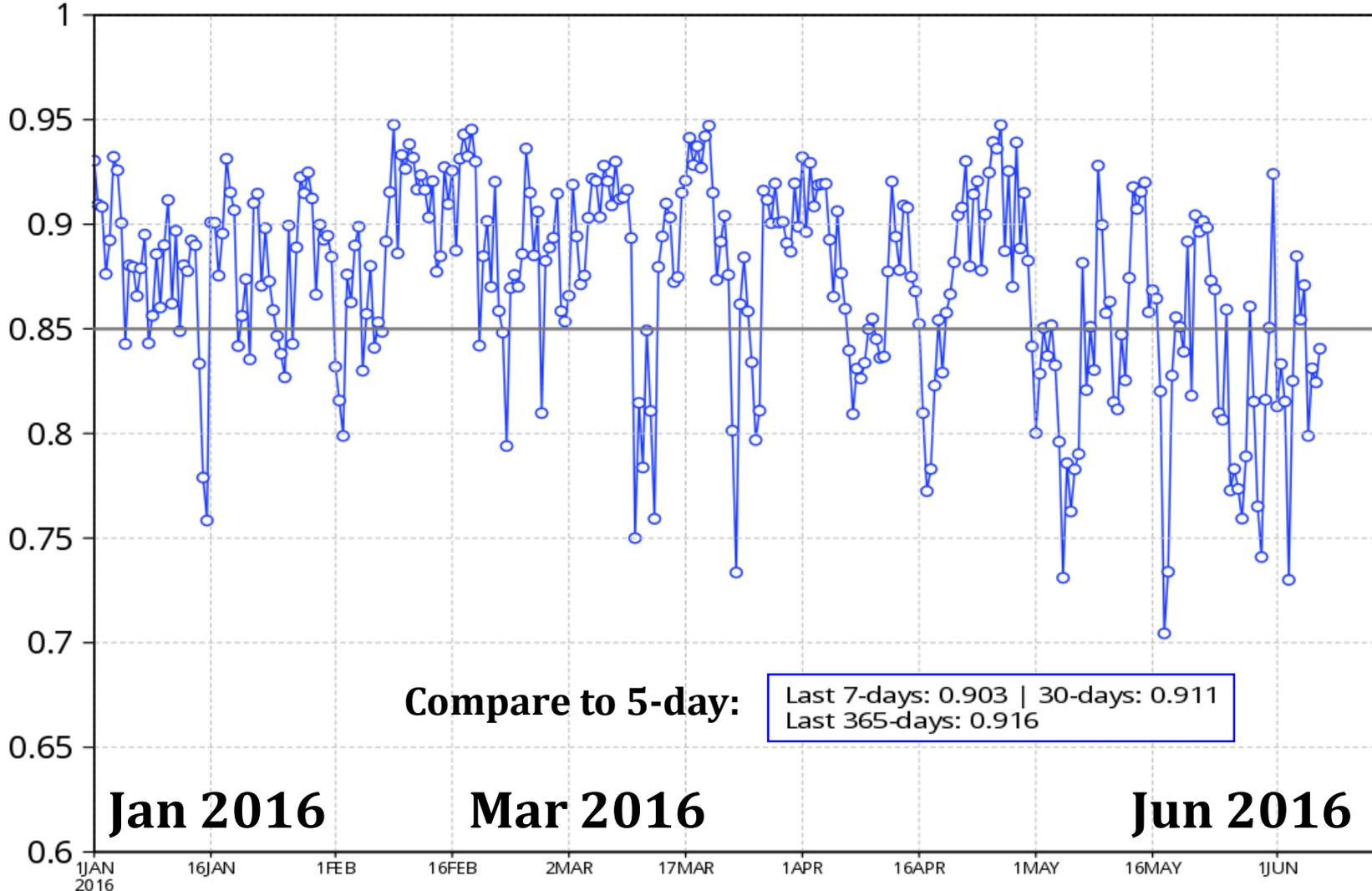


# Anomaly Correlation: ECMWF 6-day

ECMWF 500 hPa NH [20°-80° N] Anomaly Correlation | 6 day Forecasts [2x daily]

Last Verification Date: 12Z06JUN2016

Last 7-days: 0.835 | 30-days: 0.840 | 365-days: 0.854



Last 40-scores  
Verf Time | AC

- 12Z06JUN 0.841
- 00Z06JUN 0.824
- 12Z05JUN 0.831
- 00Z05JUN 0.799
- 12Z04JUN 0.871
- 00Z04JUN 0.854
- 12Z03JUN 0.885
- 00Z03JUN 0.825
- 12Z02JUN 0.730
- 00Z02JUN 0.815
- 12Z01JUN 0.833
- 00Z01JUN 0.813
- 12Z31MAY 0.924
- 00Z31MAY 0.851
- 12Z30MAY 0.816
- 00Z30MAY 0.741
- 12Z29MAY 0.765
- 00Z29MAY 0.815
- 12Z28MAY 0.861
- 00Z28MAY 0.789
- 12Z27MAY 0.759
- 00Z27MAY 0.774
- 12Z26MAY 0.783
- 00Z26MAY 0.773
- 12Z25MAY 0.859
- 00Z25MAY 0.807
- 12Z24MAY 0.810
- 00Z24MAY 0.869
- 12Z23MAY 0.873
- 00Z23MAY 0.898
- 12Z22MAY 0.902
- 00Z22MAY 0.896
- 12Z21MAY 0.904
- 00Z21MAY 0.818
- 12Z20MAY 0.892
- 00Z20MAY 0.839
- 12Z19MAY 0.851
- 00Z19MAY 0.856
- 12Z18MAY 0.828
- 00Z18MAY 0.734
- 12Z17MAY 0.704



# Anomaly Correlation: ECMWF 10d 2013-2014

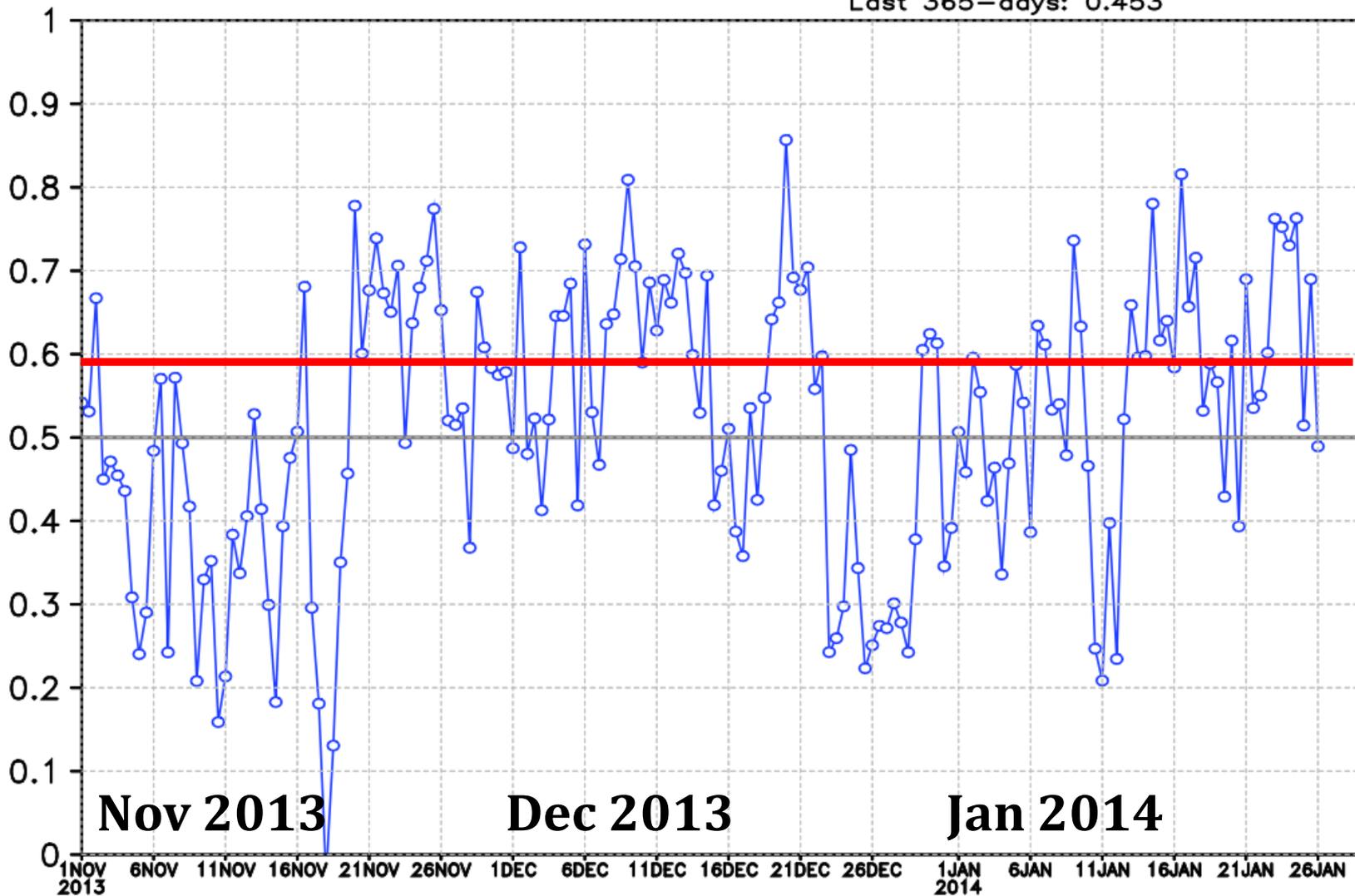
ECMWF 500 hPa NH [20°–80° N] Anomaly Correlation :|: 10-day Forecasts

Last Verification Date: 00Z05FEB2014

Skill Avg Since May 1, 2013: 0.516

Last 7-days: 0.621 :|: 30-days: 0.542

Last 365-days: 0.453



Last 40-score  
Init Time | AC

00Z26JAN	0.489
12Z25JAN	0.690
00Z25JAN	0.514
12Z24JAN	0.763
00Z24JAN	0.730
12Z23JAN	0.752
00Z23JAN	0.762
12Z22JAN	0.601
00Z22JAN	0.550
12Z21JAN	0.535
00Z21JAN	0.690
12Z20JAN	0.393
00Z20JAN	0.616
12Z19JAN	0.429
00Z19JAN	0.566
12Z18JAN	0.589
00Z18JAN	0.532
12Z17JAN	0.716
00Z17JAN	0.657
12Z16JAN	0.816
00Z16JAN	0.584
12Z15JAN	0.640
00Z15JAN	0.616
12Z14JAN	0.780
00Z14JAN	0.598
12Z13JAN	0.596
00Z13JAN	0.659
12Z12JAN	0.522
00Z12JAN	0.234
12Z11JAN	0.397
00Z11JAN	0.209
12Z10JAN	0.247
00Z10JAN	0.466
12Z09JAN	0.633
00Z09JAN	0.736
12Z08JAN	0.479
00Z08JAN	0.540
12Z07JAN	0.533
00Z07JAN	0.611
12Z06JAN	0.634
00Z06JAN	0.386

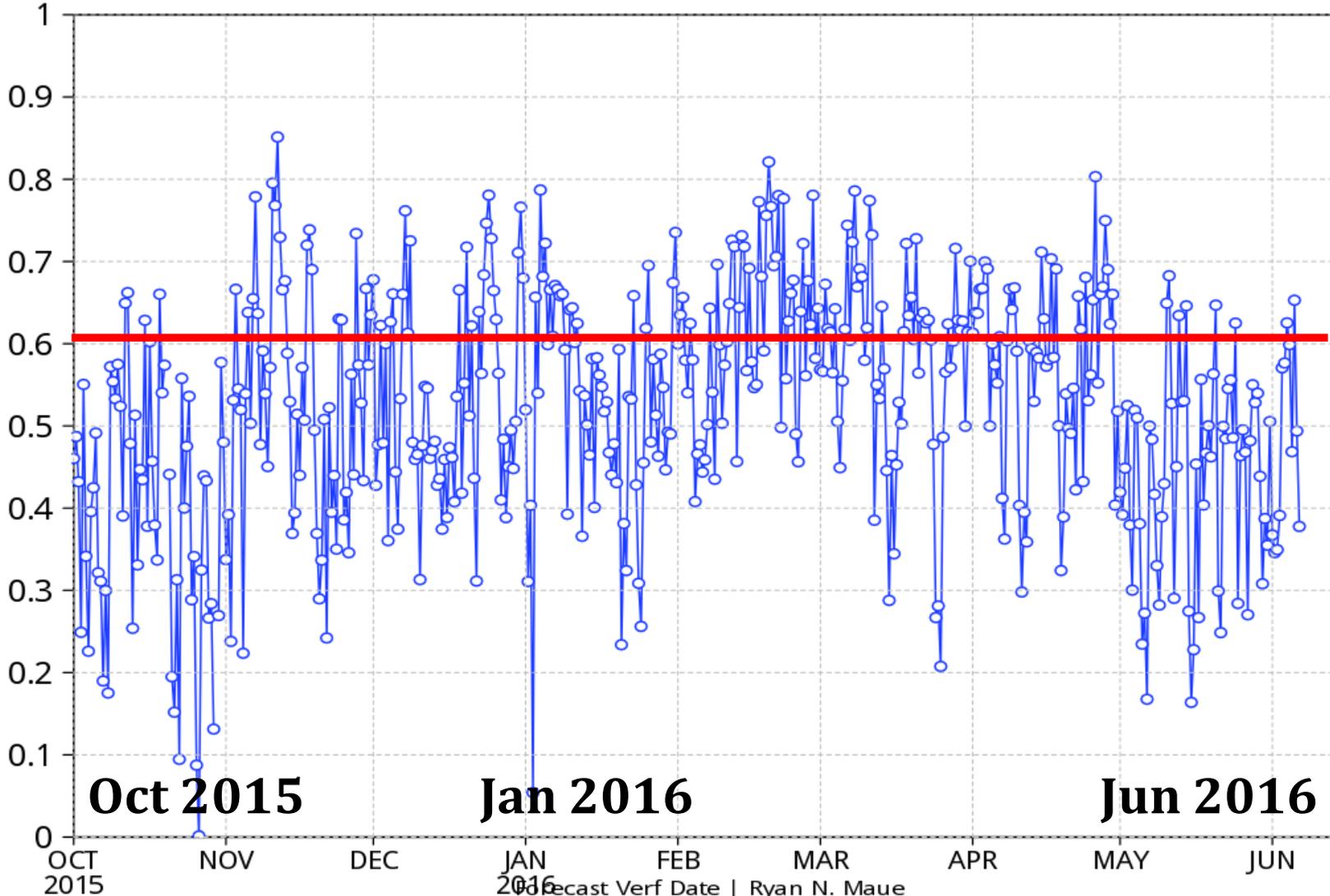


# Anomaly Correlation: ECMWF 10d 2015-2016

ECMWF 500 hPa NH [20°-80° N] Anomaly Correlation :|: 240-hour Forecasts

Last Verification Date: 12Z06JUN2016

Last 7-days: 0.477 :|: 30-days: 0.457 :|: 365-days: 0.495

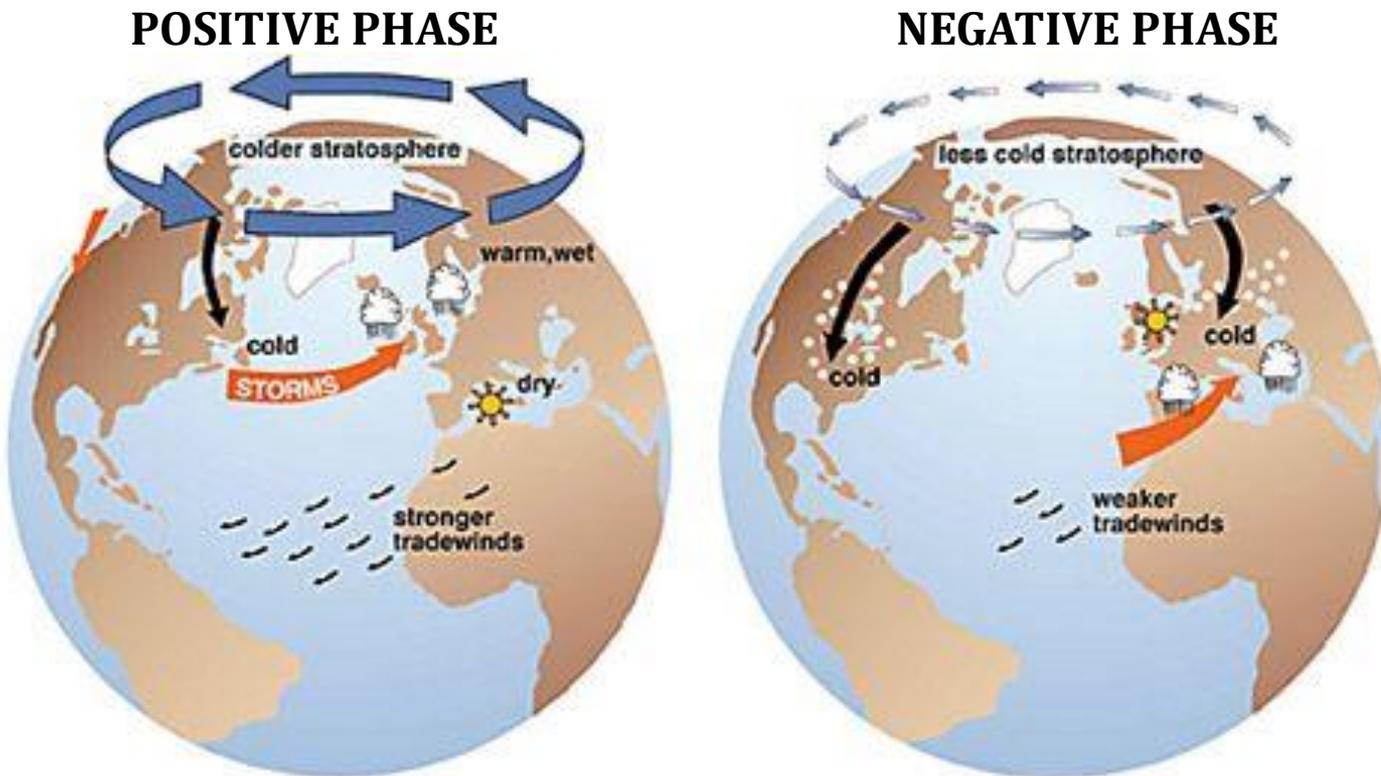


Last 40-scores  
Verf Time | AC

12Z06JUN	0.378
00Z06JUN	0.494
12Z05JUN	0.653
00Z05JUN	0.469
12Z04JUN	0.599
00Z04JUN	0.625
12Z03JUN	0.577
00Z03JUN	0.571
12Z02JUN	0.391
00Z02JUN	0.350
12Z01JUN	0.346
00Z01JUN	0.367
12Z31MAY	0.505
00Z31MAY	0.355
12Z30MAY	0.387
00Z30MAY	0.308
12Z29MAY	0.439
00Z29MAY	0.540
12Z28MAY	0.528
00Z28MAY	0.550
12Z27MAY	0.482
00Z27MAY	0.270
12Z26MAY	0.468
00Z26MAY	0.495
12Z25MAY	0.464
00Z25MAY	0.284
12Z24MAY	0.625
00Z24MAY	0.486
12Z23MAY	0.556
00Z23MAY	0.545
12Z22MAY	0.485
00Z22MAY	0.499
12Z21MAY	0.249
00Z21MAY	0.299
12Z20MAY	0.647
00Z20MAY	0.563
12Z19MAY	0.462
00Z19MAY	0.500
12Z18MAY	0.467
00Z18MAY	0.404
12Z17MAY	0.557

# Example: Arctic Oscillation

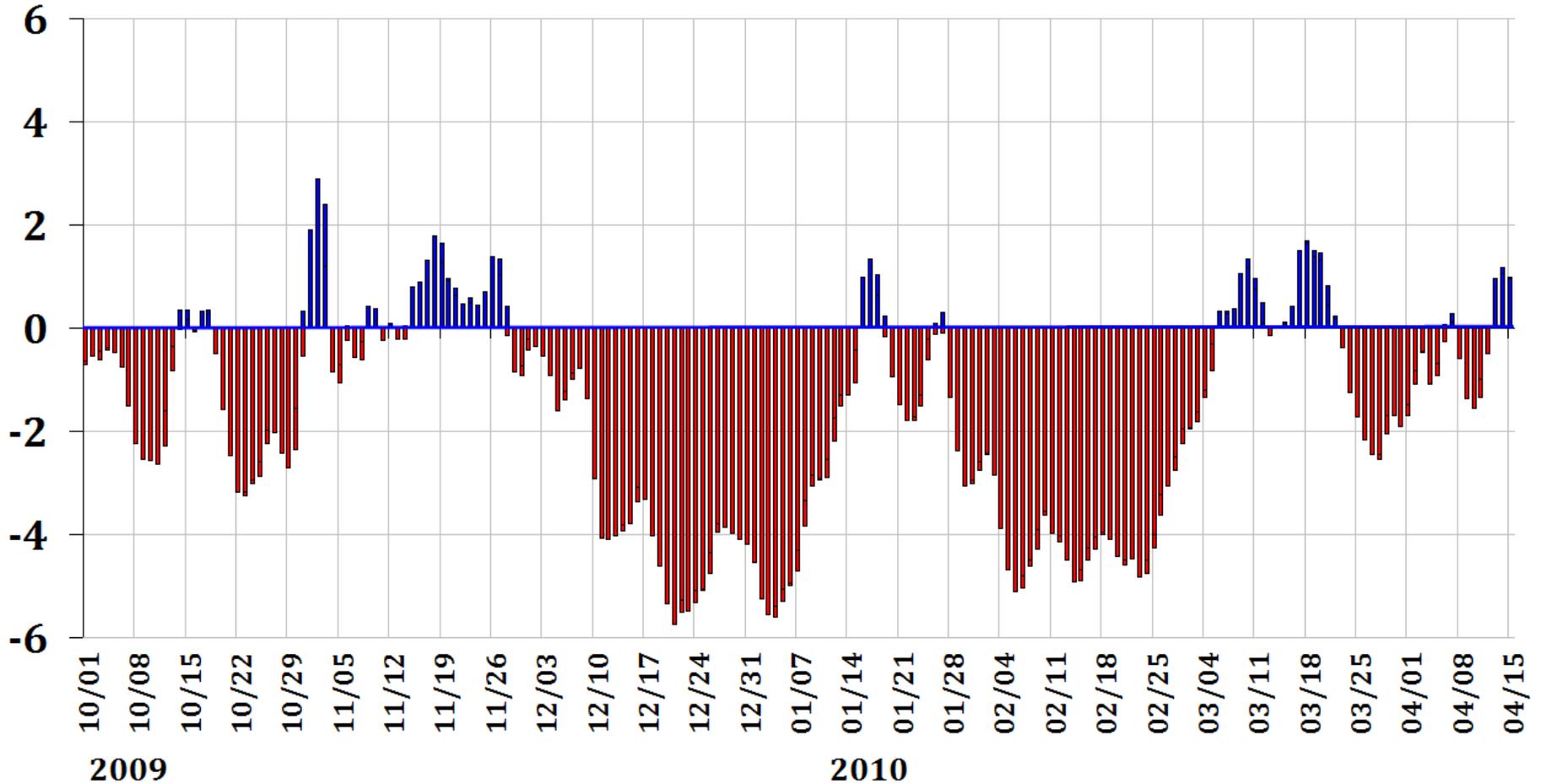
- AO is the first EOF of sea-level pressure (1000 hPa geopotential height) variations north of 20°N latitude
- How do NWP systems perform during the + and - phase of the AO, as well as through *transitions* [e.g. Archambault et al. 2010] – during the Northern Hemisphere cold season?





# Arctic Oscillation

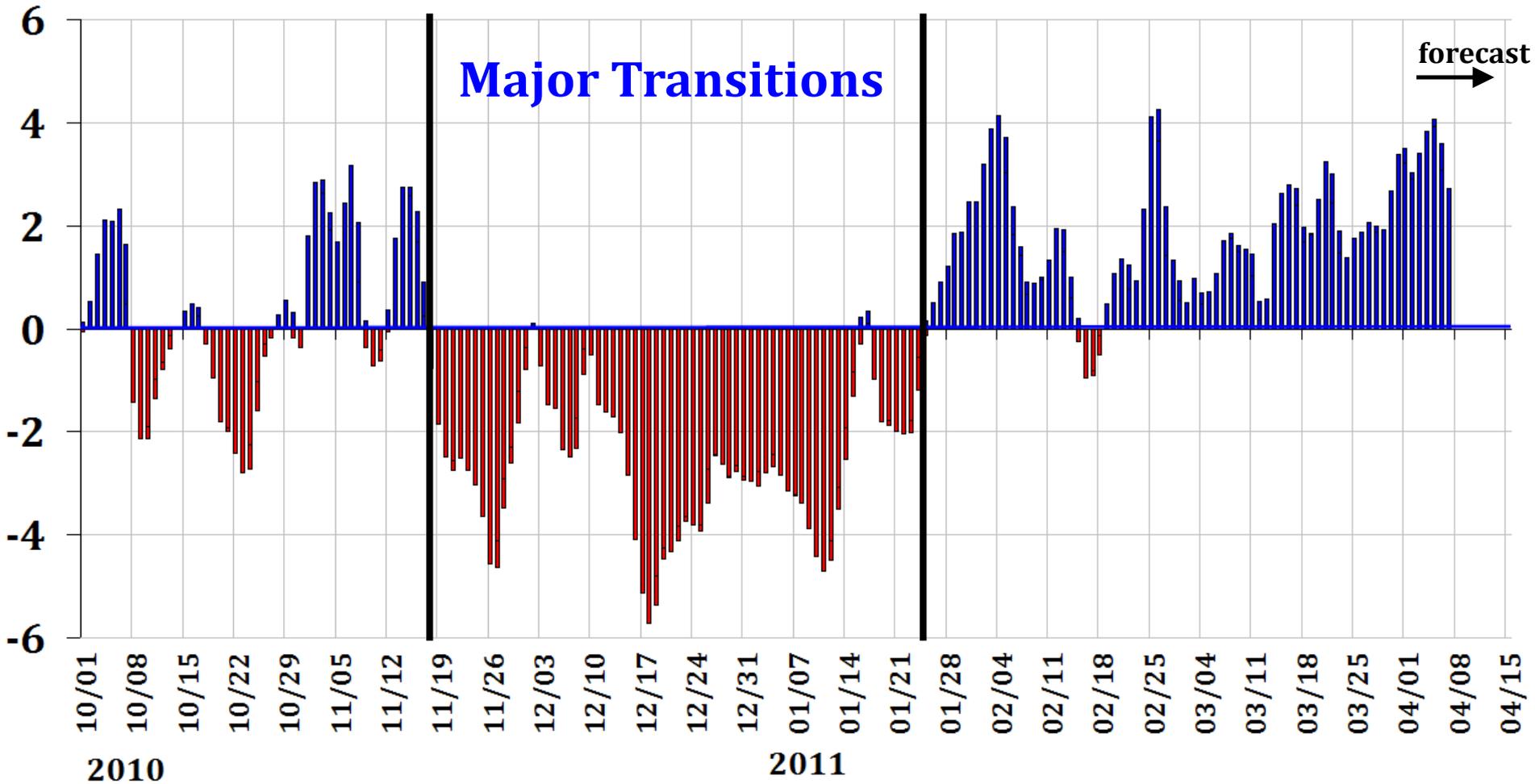
**Winter 2009 - 2010**  
Sustained Negative AO



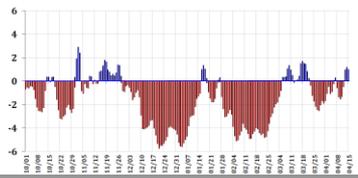
# Arctic Oscillation

## Winter 2010 - 2011

November - January Negative AO, followed by strong Positive



# Arctic Oscillation

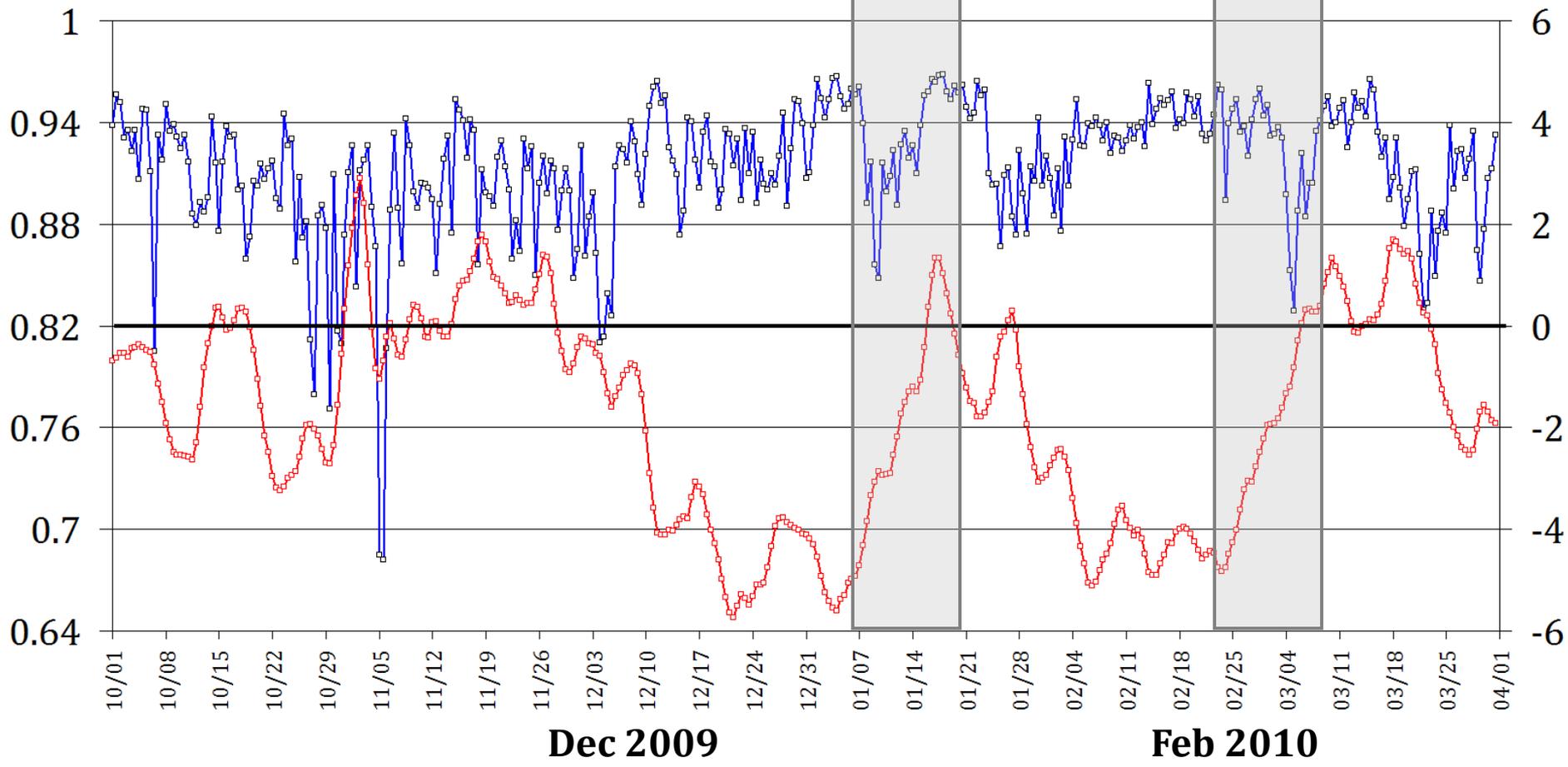


## ECMWF – Winter 2009 – 2010

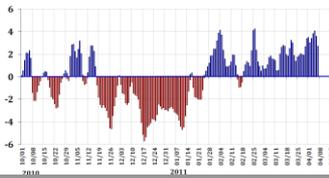
500 hPa NH Anomaly Correlation ——— (blue line)  
Arctic Oscillation Index ——— (red line)

AC

AO



# Arctic Oscillation

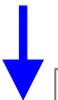


## ECMWF – Winter 2010 – 2011

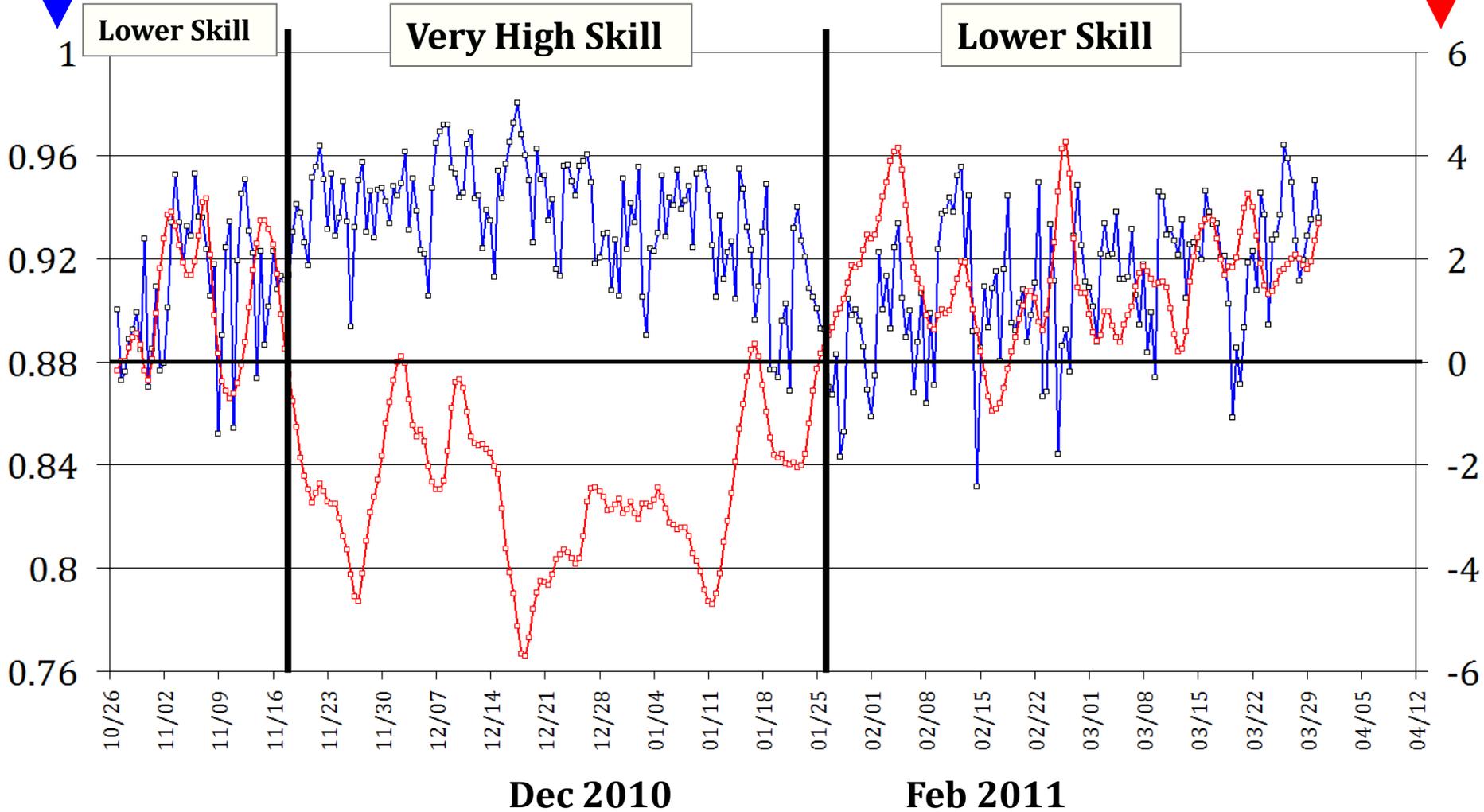
500 hPa NH Anomaly Correlation

Arctic Oscillation Index

AC



AO



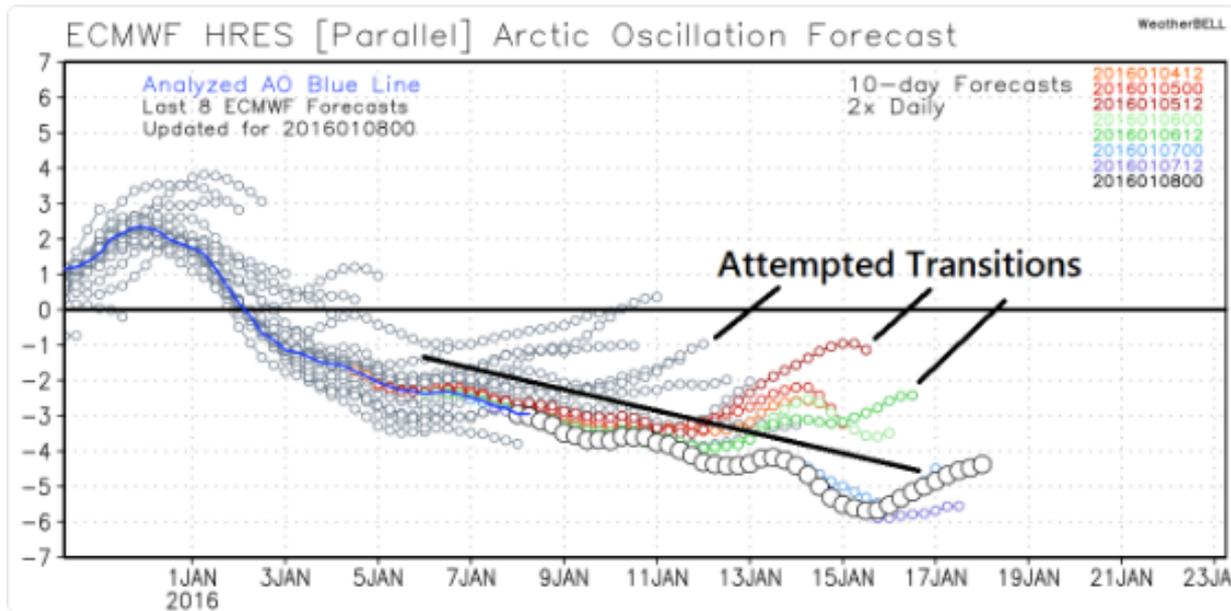
# Visualizing Arctic Oscillation Forecast Index



Ryan Maue  
@RyanMaue

January 8, 2016

Visualize bias in global model using indices like AO ... EC parallel tried hard in medium range to be less negative

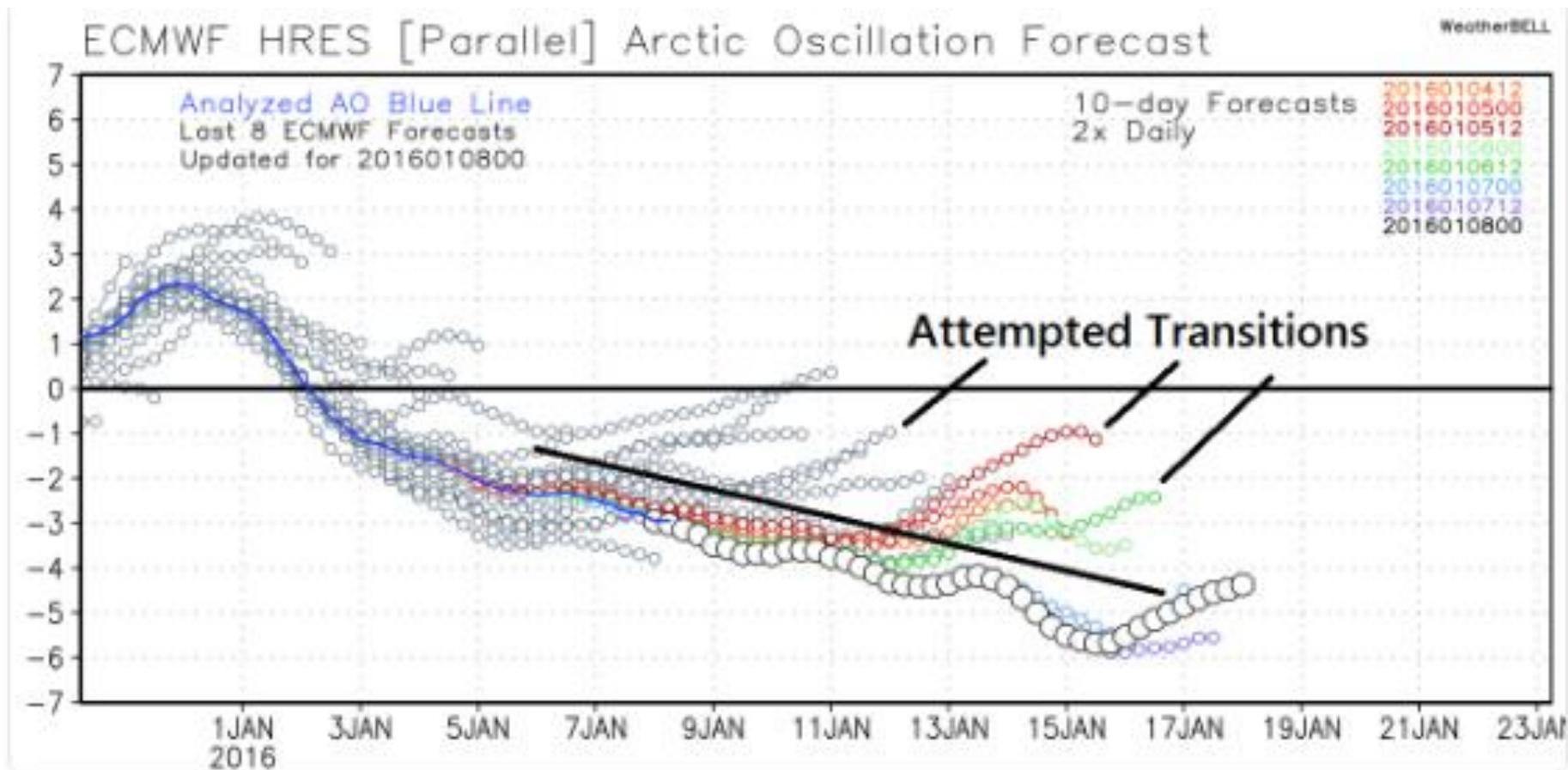


RETWEETS 13  
LIKES 15



10:56 AM - 8 Jan 2016

# Visualizing Arctic Oscillation Forecast Index

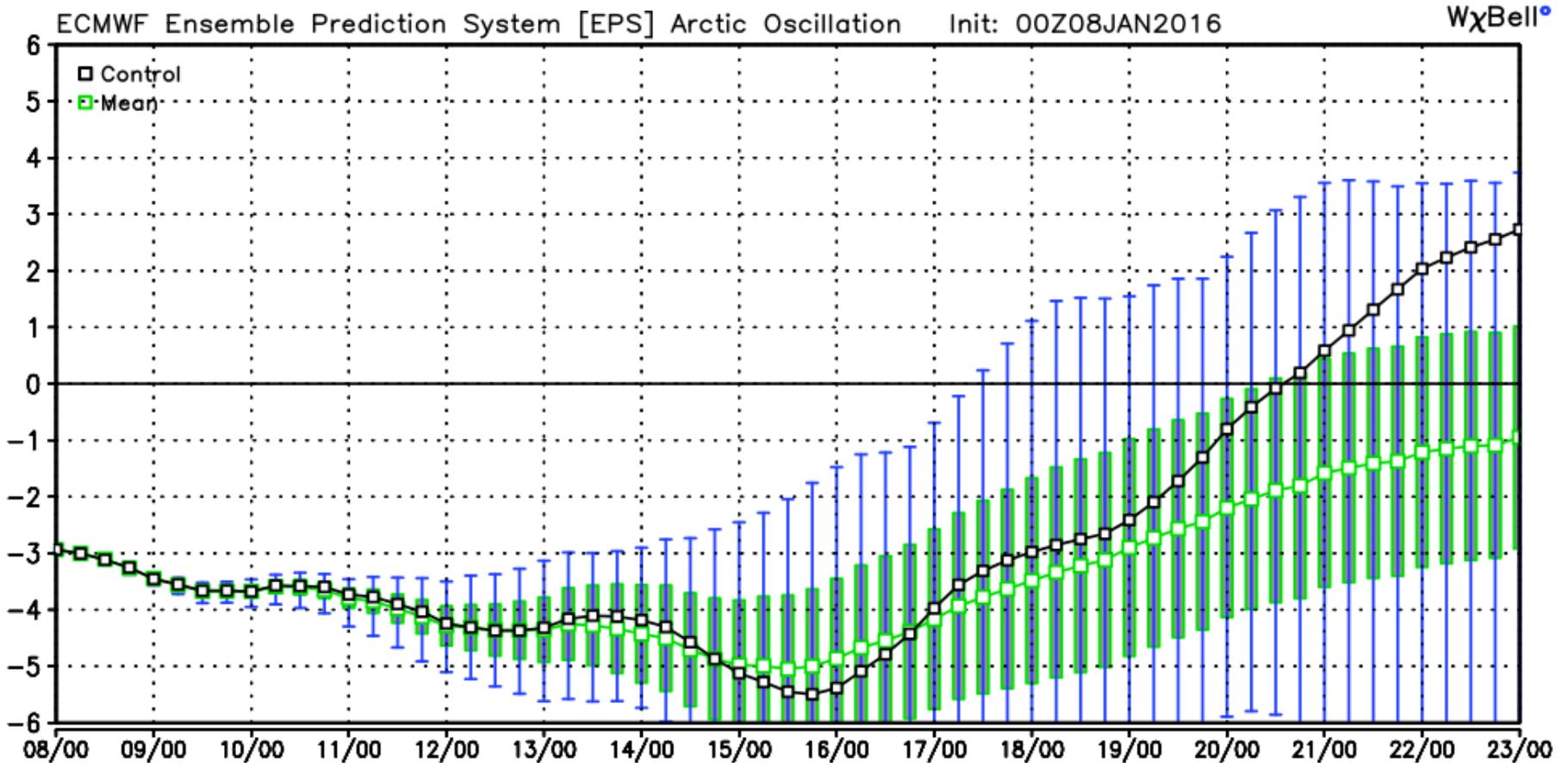


## Bubbles

Analyzed AO, 10-day forecast bubbles

INIT: January 8, 2016 00z  
HRES 41r2

# Visualizing Arctic Oscillation Forecast Index

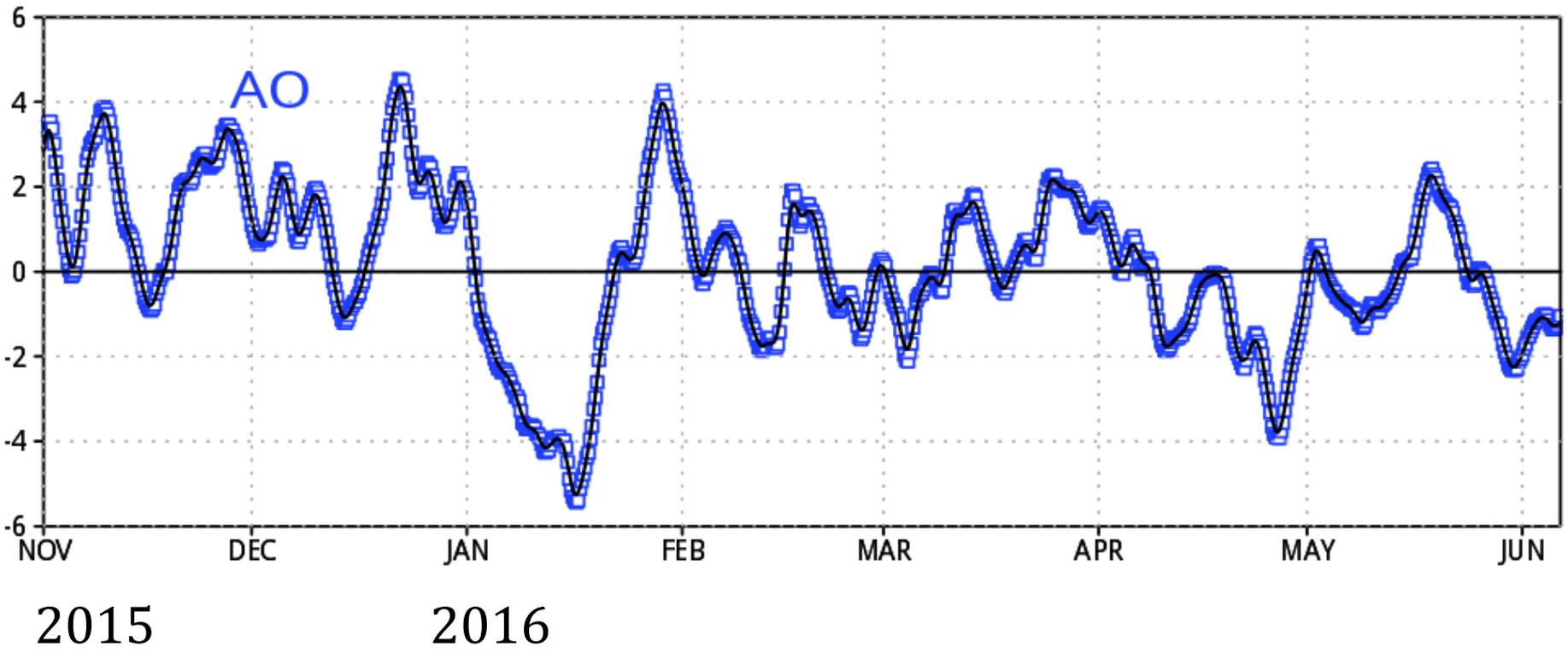


## Box & Whisker

Forecast AO, 15-day EPS forecast, ensemble mean & distribution + control



# Visualizing Arctic Oscillation Forecast Index

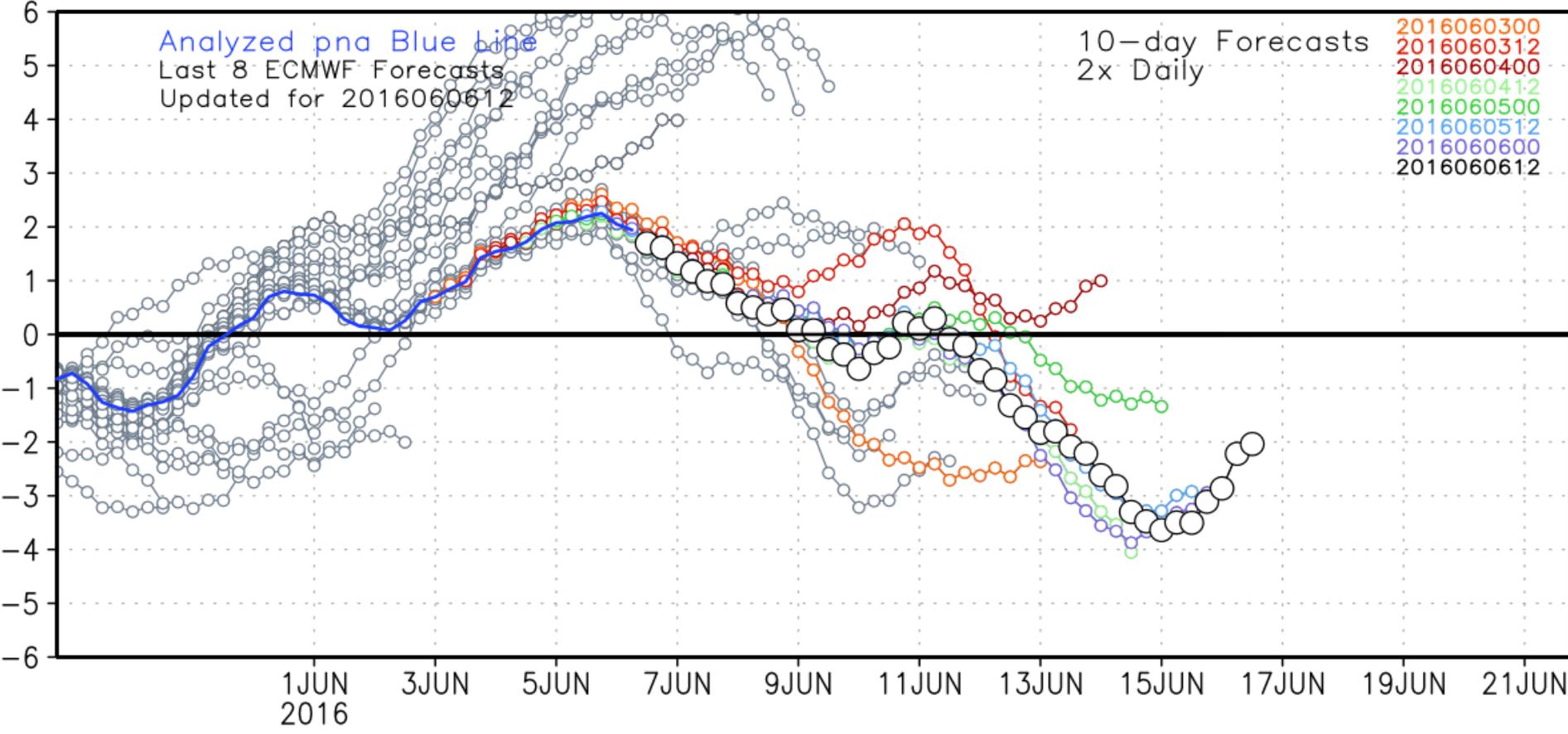




# Visualizing PNA Forecast Index

ECMWF Deterministic Pacific-North American Pattern Forecast

WeatherBELL



# Summary and Future Directions

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- A decade archive of high-resolution operational center deterministic forecasts has been developed to study “dropouts” in medium-range forecast skill
- The models tend to “dropout” during the same forecasts, in “lower-predictability” flow regimes
- The Arctic Oscillation (AO) index is (to some extent) anti-correlated with medium-range forecast skill, as measured by the 5-day anomaly correlation of 500mb height
- Value of frozen model w/many years of data ( $\sim 20$ ) to evaluate model performance during particular large-scale flow regimes
- Value of multi-model & ensemble **forecast-forecast** correlations for medium-range extreme events



# Acknowledgements

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WeatherBELL Analytics [2012-present]

**Data:** ECMWF, NCEP/NOMADS, NRL-Monterey

NRC Postdoc at NRL Monterey [2010-2012]

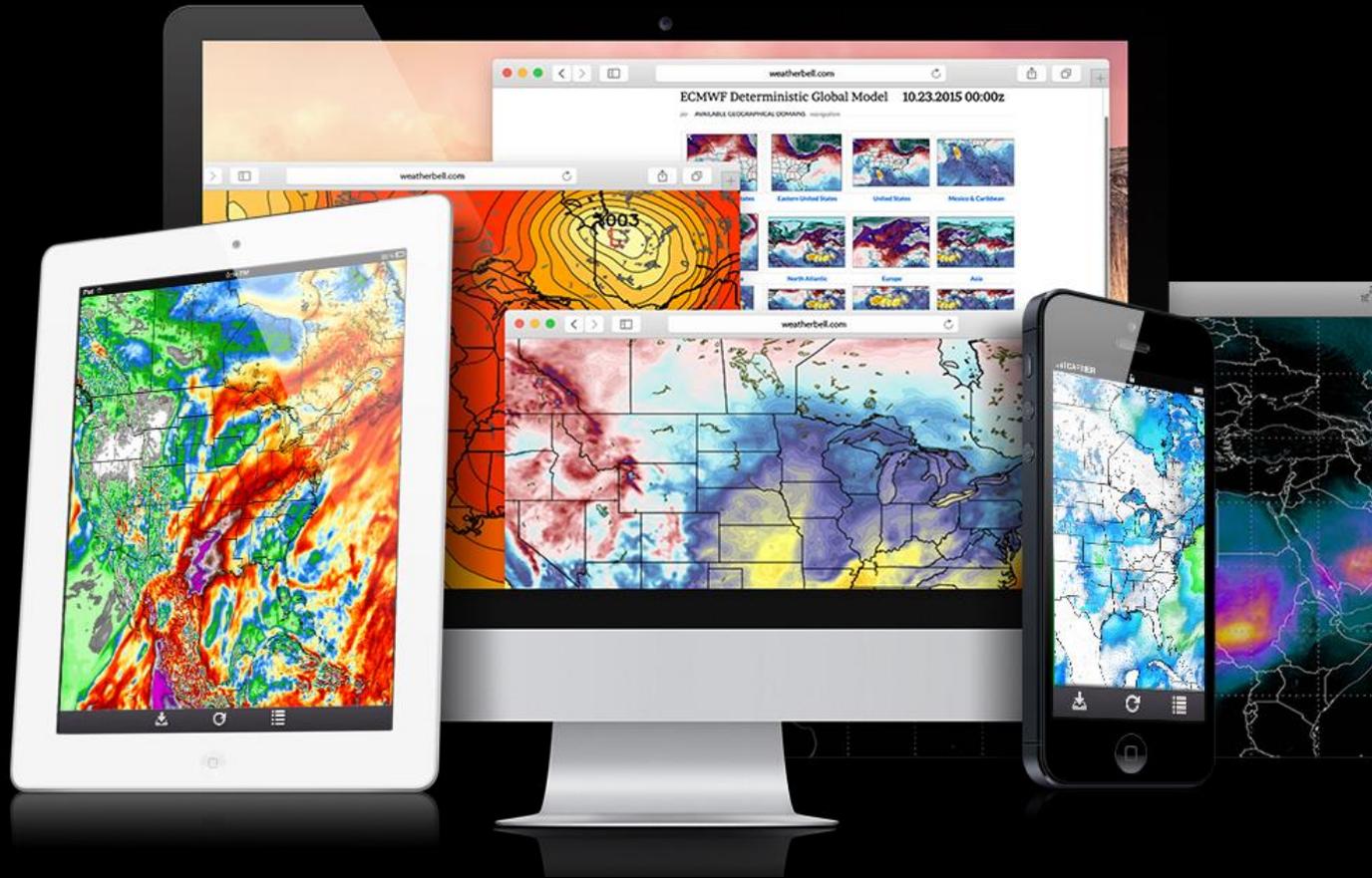
advisor: Dr. Rolf H. Langland

Updated research work based on Langland and Maue (*Tellus A*, 2012):  
Recent Northern Hemisphere mid-latitude medium-range deterministic forecast skill

**Appreciation and Thanks to Dr. Ghelli and ECMWF!**



# WeatherBELL Models



<http://models.weatherbell.com>