

Development and testing of a multi-model ensemble prediction system for sub- monthly forecasts

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International Research Institute
for Climate and Society
EARTH INSTITUTE | COLUMBIA UNIVERSITY

*NGGPS FFO PI Meeting
August 2-3, 2016 NCWCP, College Park, MD*



NGGPS Columbia University Summary



- **Major Accomplishment in FY16:**
 - Archived subset of S2S forecast/re-forecast database in IRI Data Library (ECMWF, NCEP, CMA model subsets).
 - Evaluated ECMWF and NCEP week 1–4 re-forecast performance in weekly-averaged precip, 500hPa geopotential and 2m temperature (anomaly correlation, RME error).
 - Developed extended logistic regression calibration of sub-seasonal precip forecasts for ECMWF, NCEP and CMA models, together with a multi-model combination.
- **Priority Focus for FY17**
 - Improving extended logistic regression model for week 3-4 precipitation forecasts.
 - Diagnostics of ECMWF vs NCEP performance differences over the U.S.
 - Tailoring post-processing codes for NCEP usage.
- **Key Issue**
 - Developing well-calibrated sub-seasonal (week 3-4) probabilistic forecasts over the U.S.

Objectives

- **Quantify the sub-monthly hindcast skill of the CFSv2 and selected other individual models over the U.S.** in terms of: gridded fields of precipitation and temperature, as well as atmospheric indices such as the NAO and PNA; lead time and averaging range, including weekly averages in weeks 2–4; deterministic and probabilistic forecast skill metrics; and diagnostics of predictability.
- **Develop MME methodology and evaluate the benefit of including an additional 1–3 models in a multi-model ensemble**, with focus over the U.S.
- **Improve physical understanding** of sub-monthly predictability over the U.S.
- **Establish the applicability of MME methods developed for weather/seasonal forecasts to the sub-monthly scale.**
- (Implement a real-time S2S MME at CPC, built using the most skillful and models that are available to CPC in real time.)

S2S Data @ IRIDL

IRI Data Library ECMWF S2S

Language: english

Description Expert Mode

SOURCES ECMWF S2S

ECMWF S2S

ECMWF S2S: Sub-seasonal to Seasonal P

Documents

[overview](#) an outline showing sub-dataset
[ECMWF](#) ECMWF S2S Wiki Page
[S2S Project](#) S2S Project Page

Datasets and Variables

[CMA](#) Beijing Climate Center (BCC) Climat
[ECMF](#) ECMWF Ensemble.
[NCEP](#) NCEP CFSv2 Ensemble.

Last updated: Tue, 15 Mar 2016 21:48:35 C

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IRI Wiki Pages | Climate / 2016 Workshop on Sub-Seasonal to sea... DLAAuth - Sign in

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IRI Data Library ECMWF S2S ECMF forecast control

Description Views Data Selection Data Files Data Tables Expert Mode

SOURCES ECMWF S2S ECMF forecast control

ECMWF S2S ECMF forecast control

forecast control from ECMWF S2S ECMF: ECMWF Ensemble.

Documents

[outline](#) an outline showing all sub-datasets and variables contained in this dataset

Datasets and Variables

10_m_above_ground	ECMWF S2S ECMF forecast control 10_m_above_ground[10u 10v]
Surface Air Temperature	ECMWF S2S ECMF forecast control 2t[X Y I LA S]
320_K_isentropic_level	ECMWF S2S ECMF forecast control 320_K_isentropic_level[pv]
Convective Available Potential Energy	ECMWF S2S ECMF forecast control cape[X Y I LA S]
mean_sea_level	ECMWF S2S ECMF forecast control mean_sea_level[msl]
pressure_level	ECMWF S2S ECMF forecast control pressure_level[q v w u gh]
surface	ECMWF S2S ECMF forecast control surface[tp]
top_of_atmosphere	ECMWF S2S ECMF forecast control top_of_atmosphere[ttr]

Independent Variables (Grids)

Lead (forecast_period)	grid: /L (days) ordered (0.0 days) to (46.0 days) by 1.0 N= 47
Lead (forecast_period)	grid: /LA (days) ordered (0.5 days) to (45.5 days) by 1.0 N= 4
Pressure level (air_pressure)	grid: /P (mb) ordered [(850)] :grid
Pressure level (air_pressure)	grid: /P (mb) ordered [(850) (500) (200)] :grid
Pressure level (air_pressure)	grid: /P (mb) ordered [(500)] :grid
Pressure level (air_pressure)	grid: /P (mb) ordered [(850)] :grid
forecast start time (forecast_reference_time)	grid: /S (days since 1960-01-01) ordered (0000 1 Jun 2015) 1
longitude (longitude)	grid: /X (degree_east) periodic (0) to (1.5W) by 1.5 N= 240 pt
latitude (latitude)	grid: /Y (degree_north) ordered (90N) to (90S) by 1.5 N= 121

served from IRI/LDEO Climate Data Library

IRI Data Library ECMWF S2S ECMF reforecast perturbed

Description Views Data Selection Data Files Data Tables Expert Mode

SOURCES ECMWF S2S ECMF reforecast perturbed

ECMWF S2S ECMF reforecast perturbed

reforecast perturbed from ECMWF S2S ECMF: ECMWF Ensemble.

Documents

[outline](#) an outline showing all sub-datasets and variables contained in this dataset

Datasets and Variables

10_m_above_ground	ECMWF S2S ECMF reforecast perturbed 10_m_above_ground[10u 10v]
Surface Air Temperature	ECMWF S2S ECMF reforecast perturbed 2t[X Y I M LA S hdate]
320_K_isentropic_level	ECMWF S2S ECMF reforecast perturbed 320_K_isentropic_level[pv]
Convective Available Potential Energy	ECMWF S2S ECMF reforecast perturbed cape[X Y I M LA S hdate]
mean_sea_level	ECMWF S2S ECMF reforecast perturbed mean_sea_level[msl]
pressure_level	ECMWF S2S ECMF reforecast perturbed pressure_level[q v gh u w]
surface	ECMWF S2S ECMF reforecast perturbed surface[tp]
top_of_atmosphere	ECMWF S2S ECMF reforecast perturbed top_of_atmosphere[ttr]

Independent Variables (Grids)

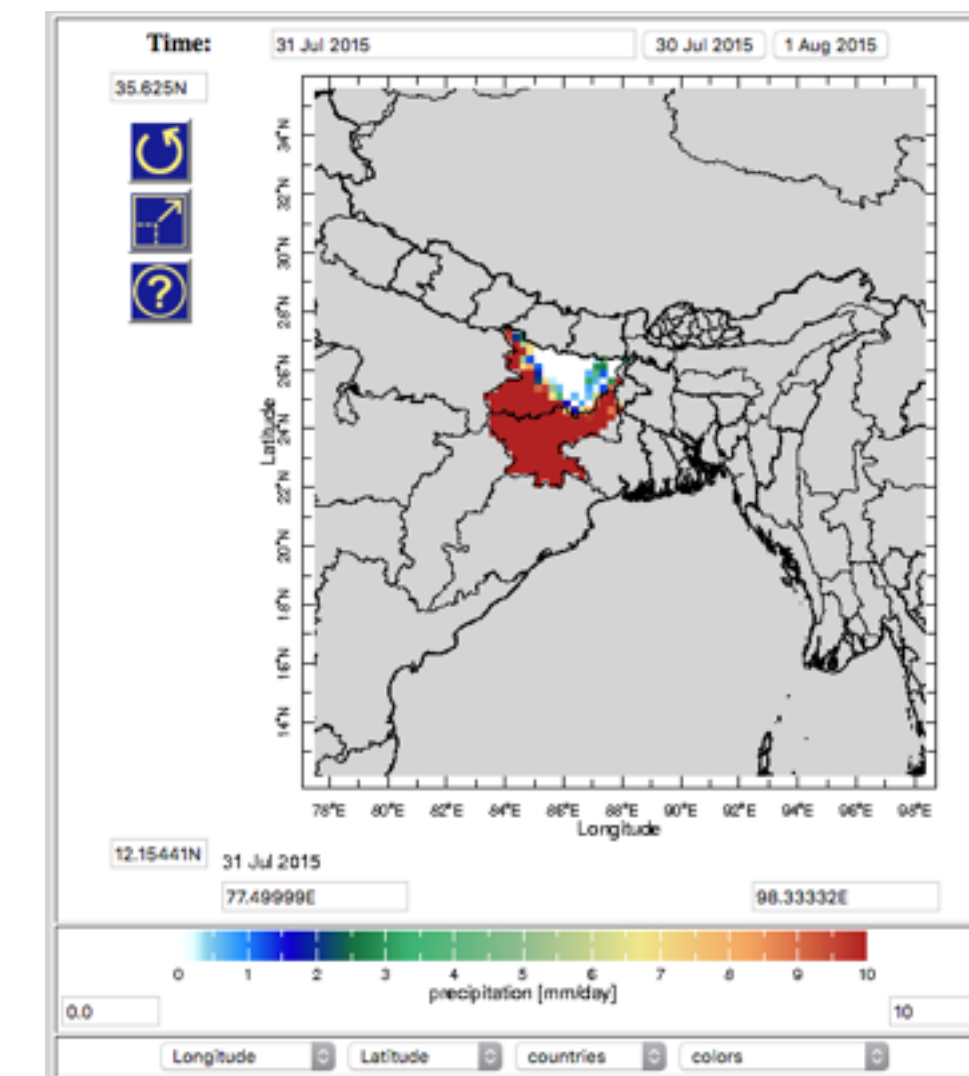
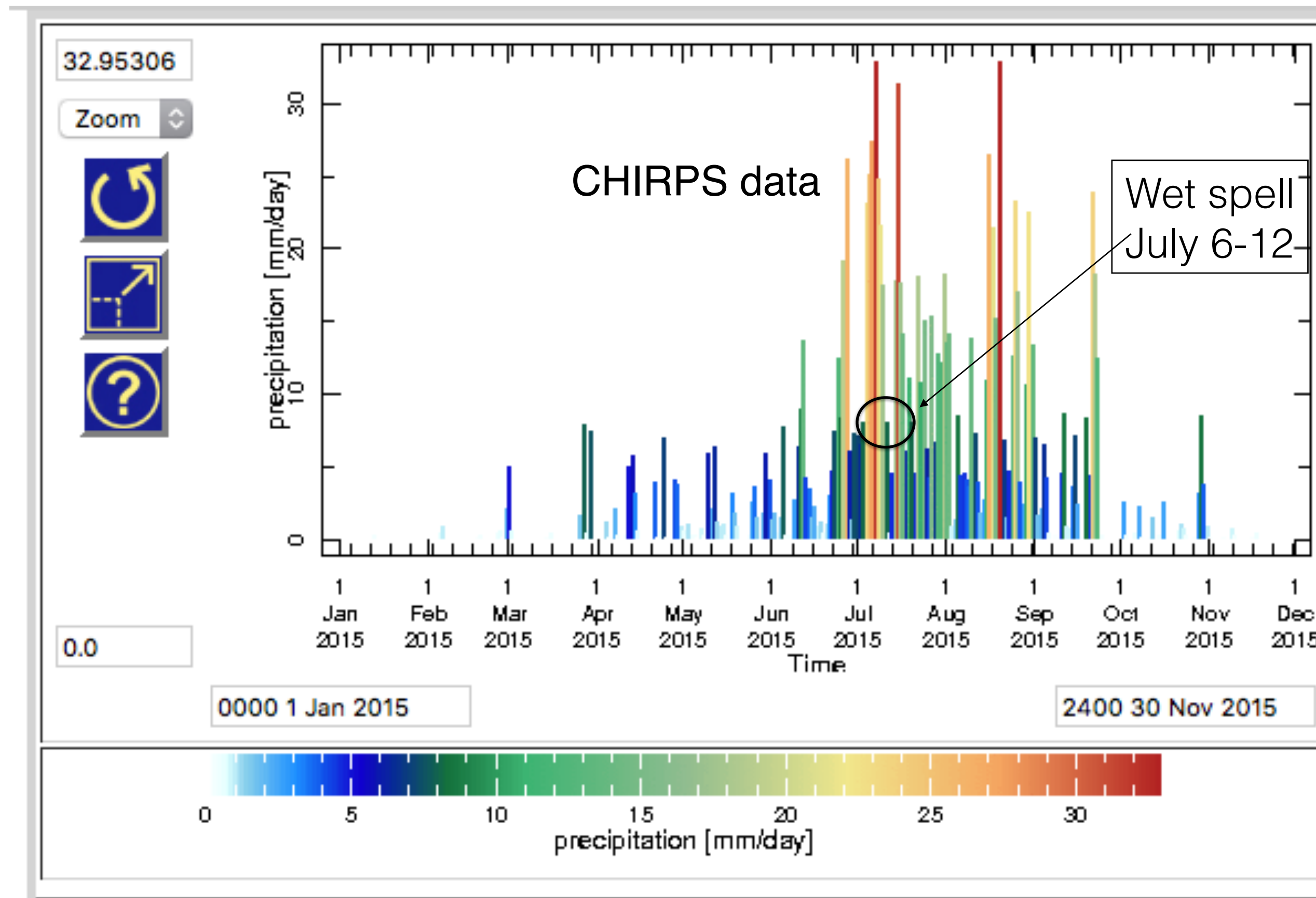
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Lead (forecast_period)	grid: /LA (days) ordered (0.5 days) to (45.5 days) by 1.0 N= 46 pts :grid
Ensemble Member (realization)	grid: /M (unitless) ordered (1.0) to (10.0) by 1.0 N= 10 pts :grid
Ensemble Member (realization)	grid: /M (unitless) ordered (1.0) to (10.0) by 1.0 N= 10 pts :grid
Pressure level (air_pressure)	grid: /P (mb) ordered [(850)] :grid
Pressure level (air_pressure)	grid: /P (mb) ordered [(850) (500) (200)] :grid
Pressure level (air_pressure)	grid: /P (mb) ordered [(500)] :grid
Pressure level (air_pressure)	grid: /P (mb) ordered [(850)] :grid
forecast start time (forecast_reference_time)	grid: /S (days since 1960-01-01) ordered (0000 1 Jun 2015) to (0000 16 Jun 2016) by 1.0 N= 382 pts :grid
longitude (longitude)	grid: /X (degree_east) periodic (0) to (1.5W) by 1.5 N= 240 pts :grid
latitude (latitude)	grid: /Y (degree_north) ordered (90N) to (90S) by 1.5 N= 121 pts :grid

Last updated: Fri, 17 Jun 2016 14:53:52 GMT



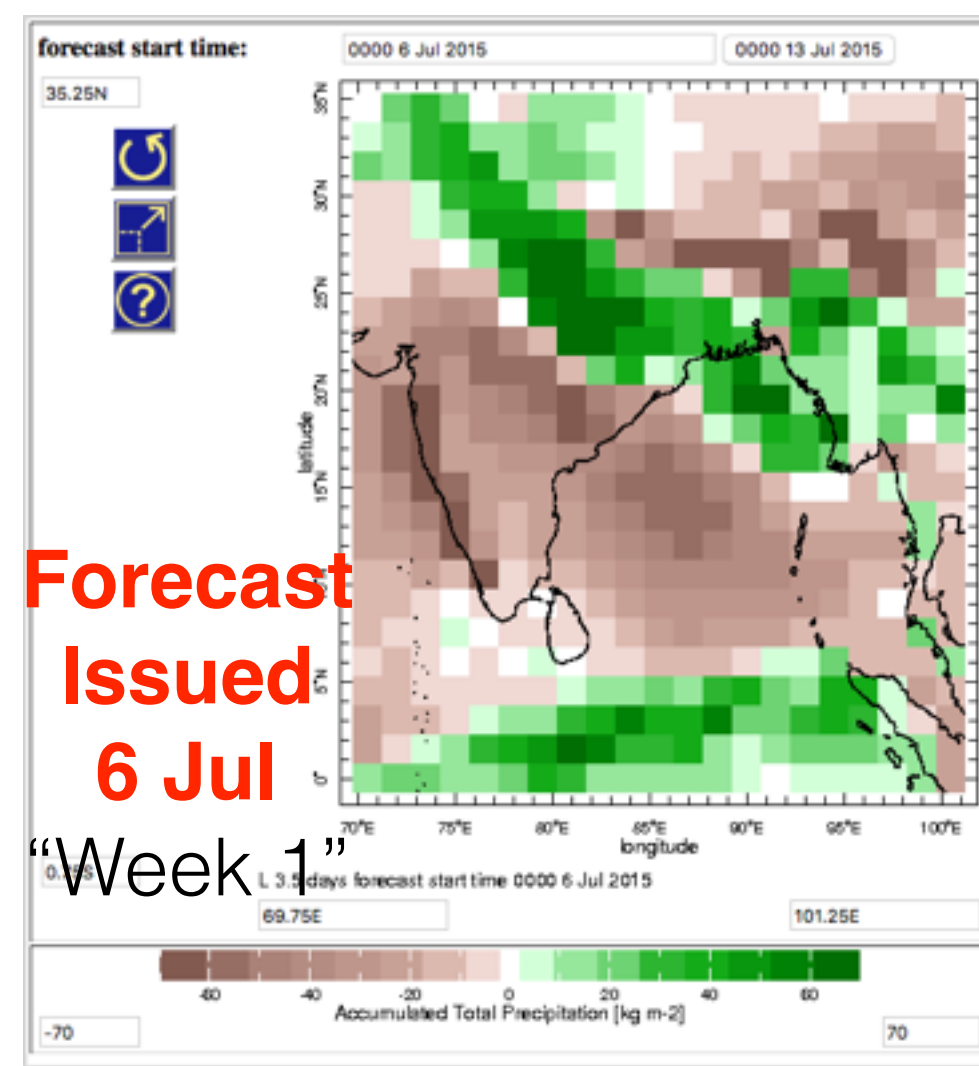
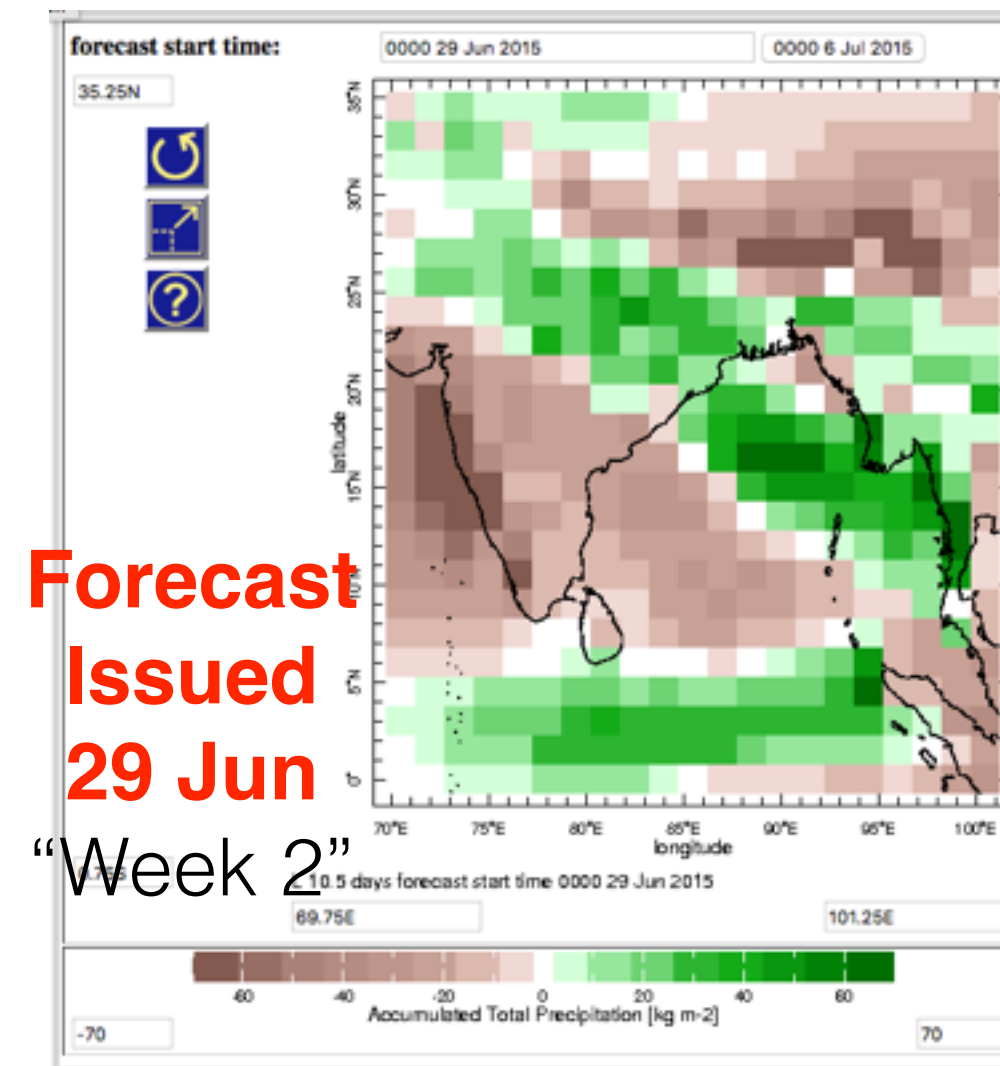
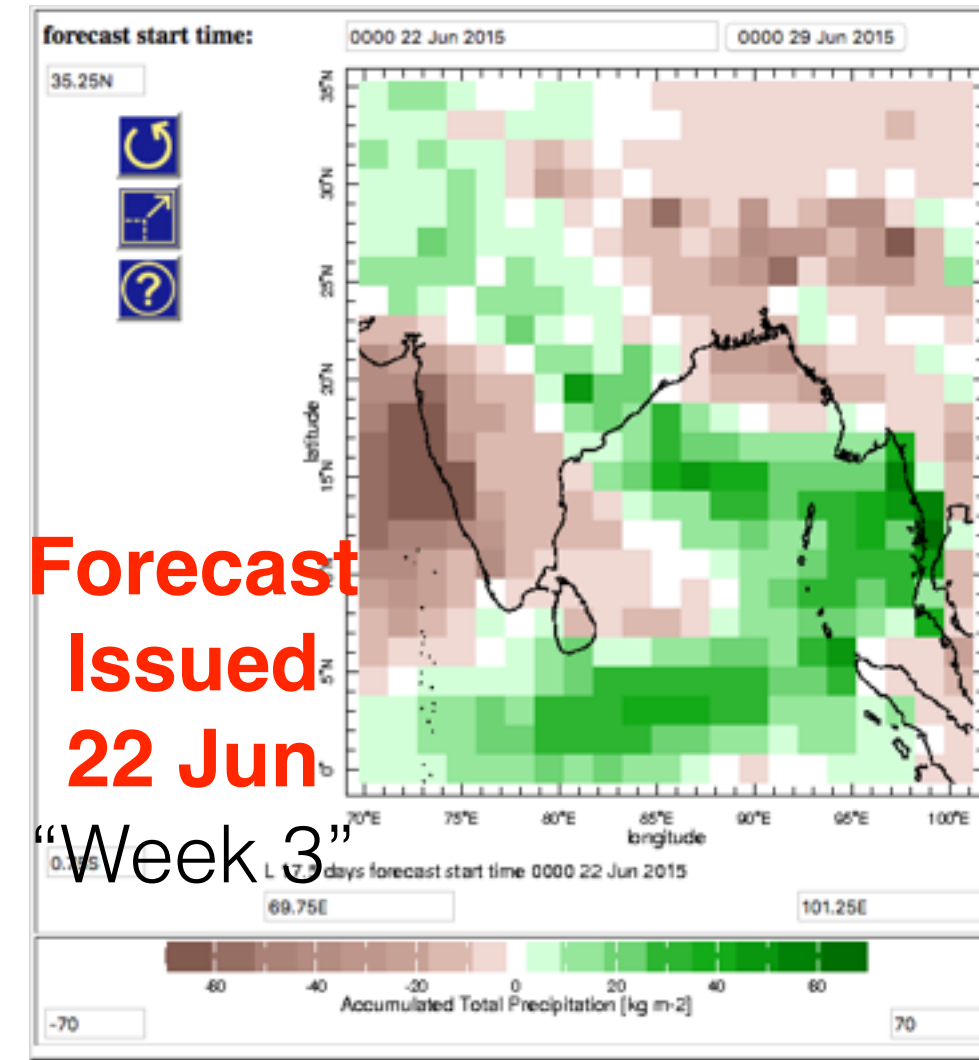
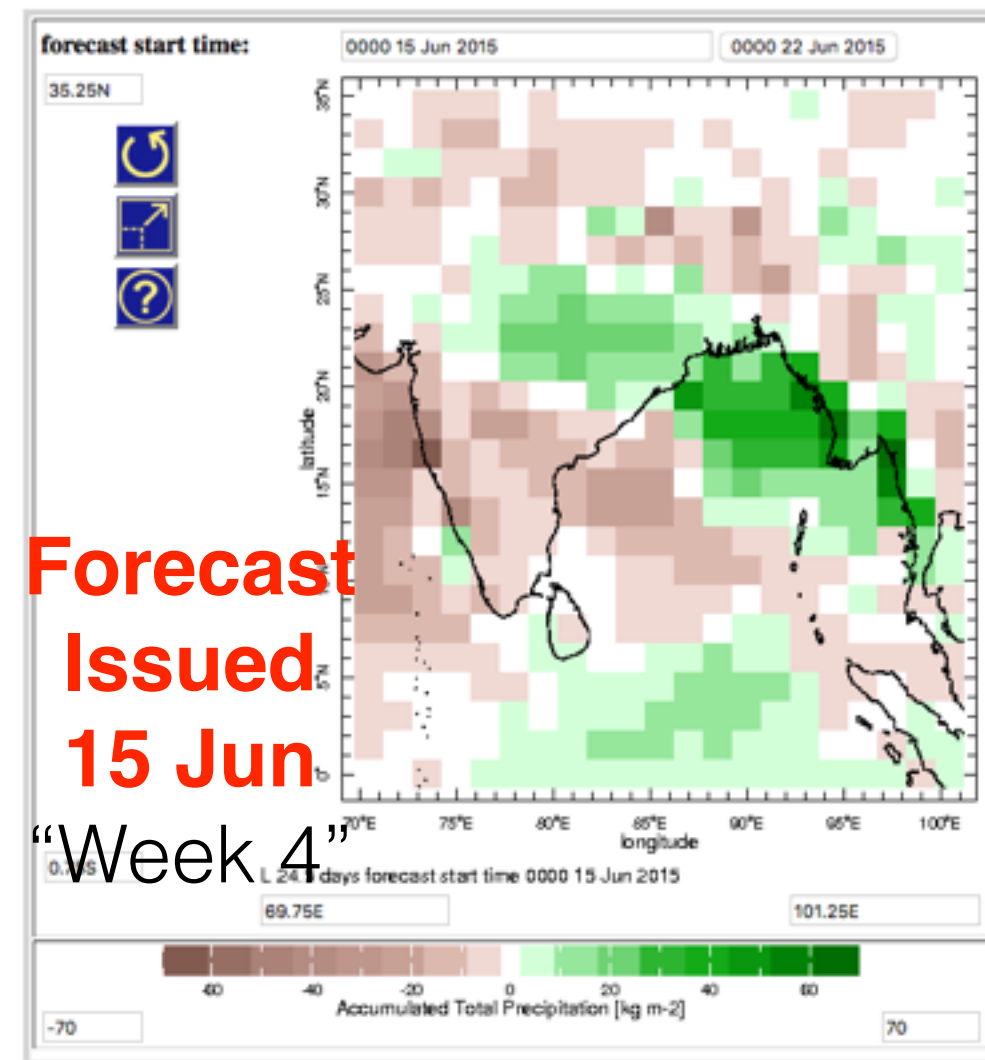
Example of S2S Data Base Use: Heavy rainfall over Bihar in 2015

Can S2S Forecasts capture it?



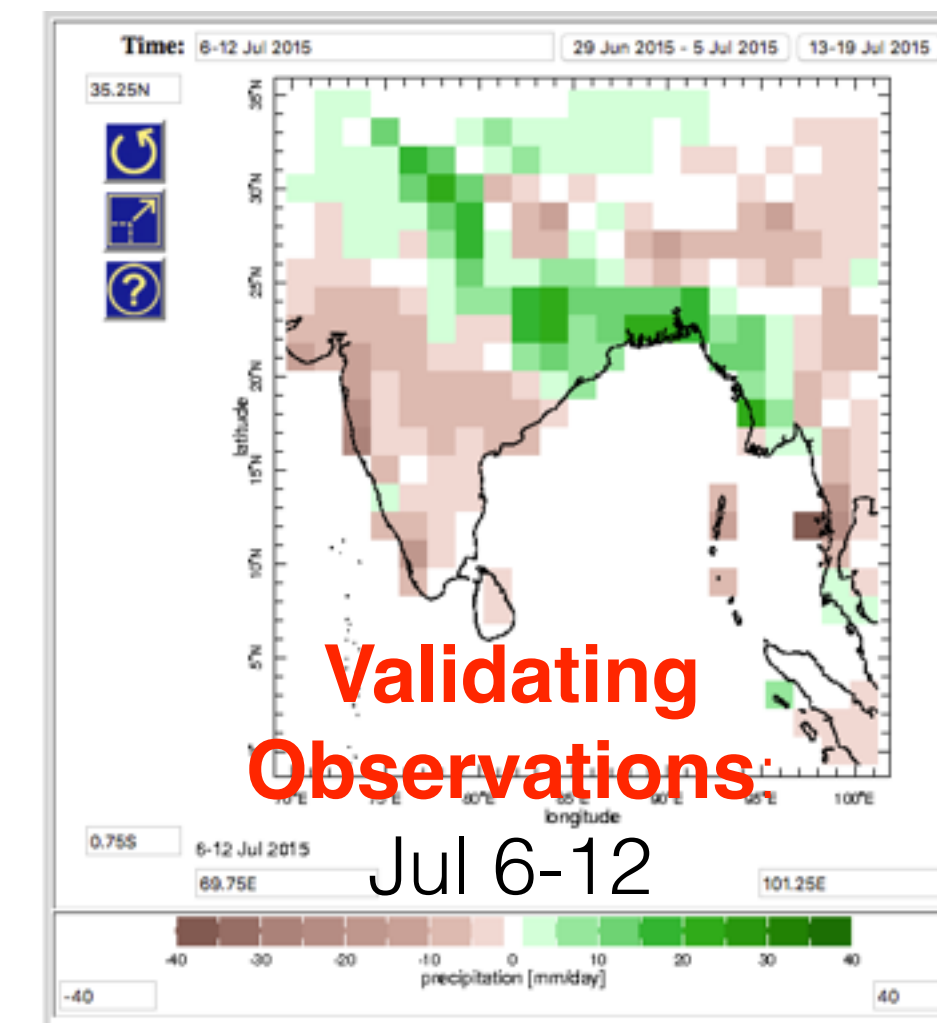
IRI Data Library

Diagnostics with S2S Database



ECMWF Forecasts
**valid for
Jul 6-12, 2015**

*Weekly average
precip anomalies*



IRI Data Library

Model Configurations

Status on 10th March 2016	Time range	Resolution	Ens. Size	Frequency	Re-forecasts	Rfc length	Rfc frequency	Rfc size
BoM (ammc)	d 0-62	T47L17	33	2/week	fix	1981-2013	6/month	33
CMA (babj)	d 0-60	T106L40	4	daily	fix	1994-2014	daily	4
CNR-ISAC (isac)	d 0-31	0.75x0.56 L54	41	weekly	fix	1981-2010	every 5d	1
CNRM (lfpw)	d 0-32	T255L91	51	weekly	fix	1993-2014	2/monthly	15
ECCC (cwao)	d 0-32	0.45x0.45 L40	21	weekly	on the fly	1995-2014	weekly	4
ECMWF (ecmf)	d 0-46	Tco639/319 L91	51	2/week	on the fly	past 20 years	2/week	11
HMCR (rums)	d 0-61	1.1x1.4 L28	20	weekly	on the fly	1985-2010	weekly	10
JMA (rjtd)	d 0-33	T319L60	25	2/week	fix	1981-2010	3/month	5
KMA (rksl)	d 0-60	N216L85	4	daily	on the fly	1996-2009	4/month	3
NCEP (kwbc)	d 0-44	T126L64	16	daily	fix	1999-2010	day	4
UKMO (egrr)	d 0-60	N216L85	4	daily	on the fly	1996-2009	4/month	3

Evaluation of sub-monthly hindcast skill of ECMWF & CFSv2

- Anomaly correlation and RMS error for 1999–2010 common hindcast period
- By trimester of forecast **starts**: JJA, SON, DJF, MAM
- ECMWF Mon & Thurs starts
- NCEP 3-day lagged ensembles (Sat-Mon, Tue-Thu)

Weekly Precip Skill vs Lead time – DJF

Week 1

Week 2

Week 3

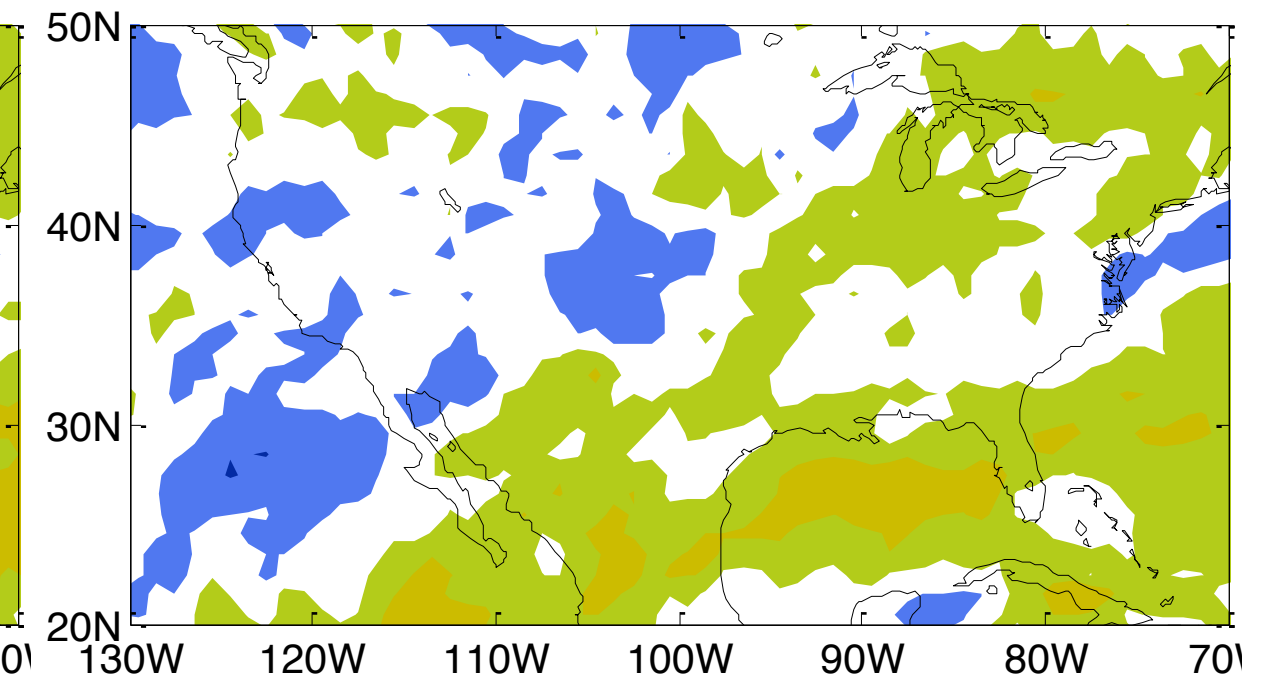
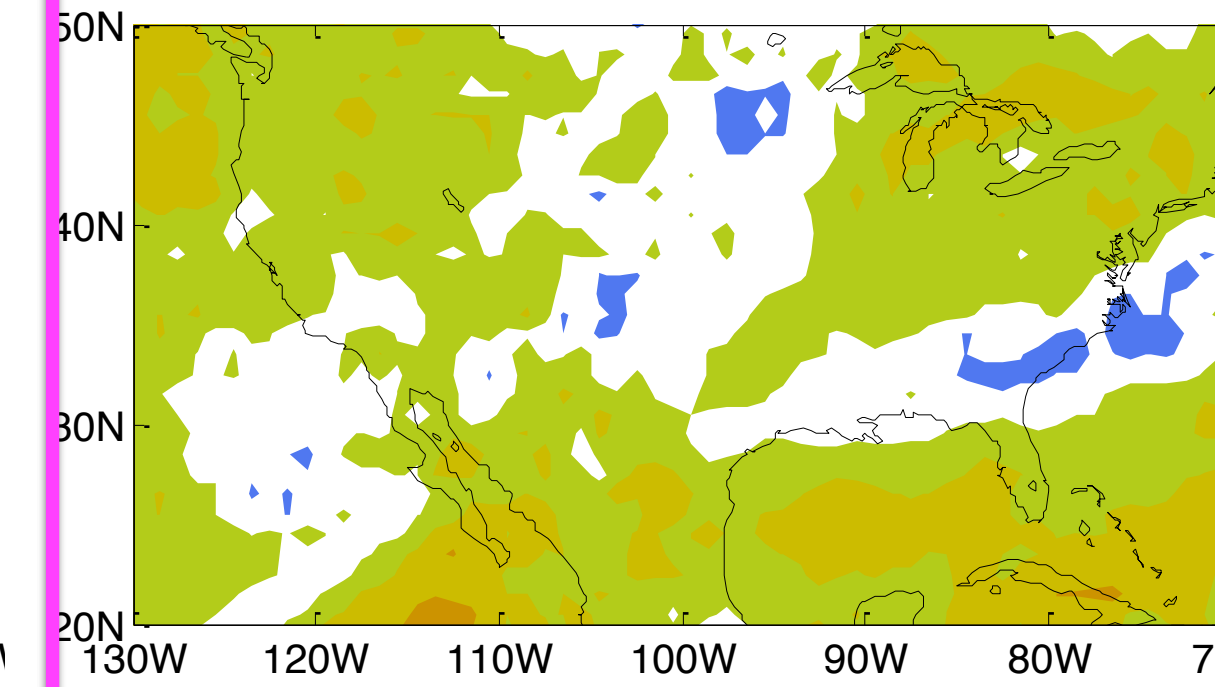
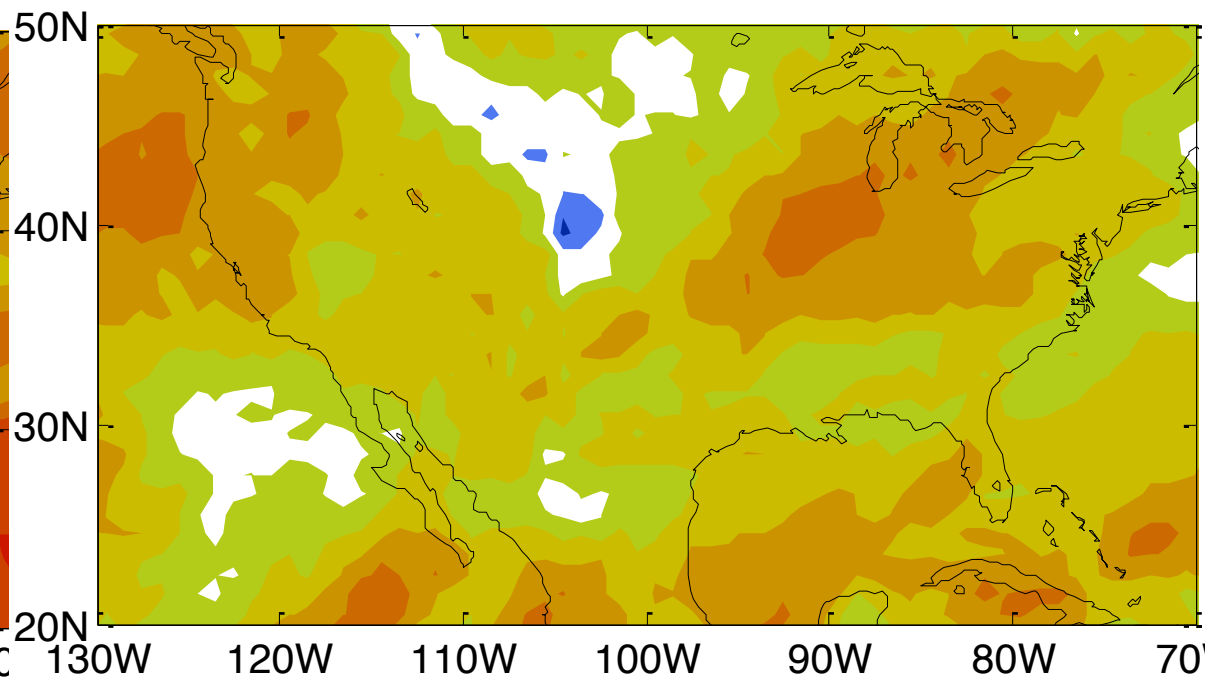
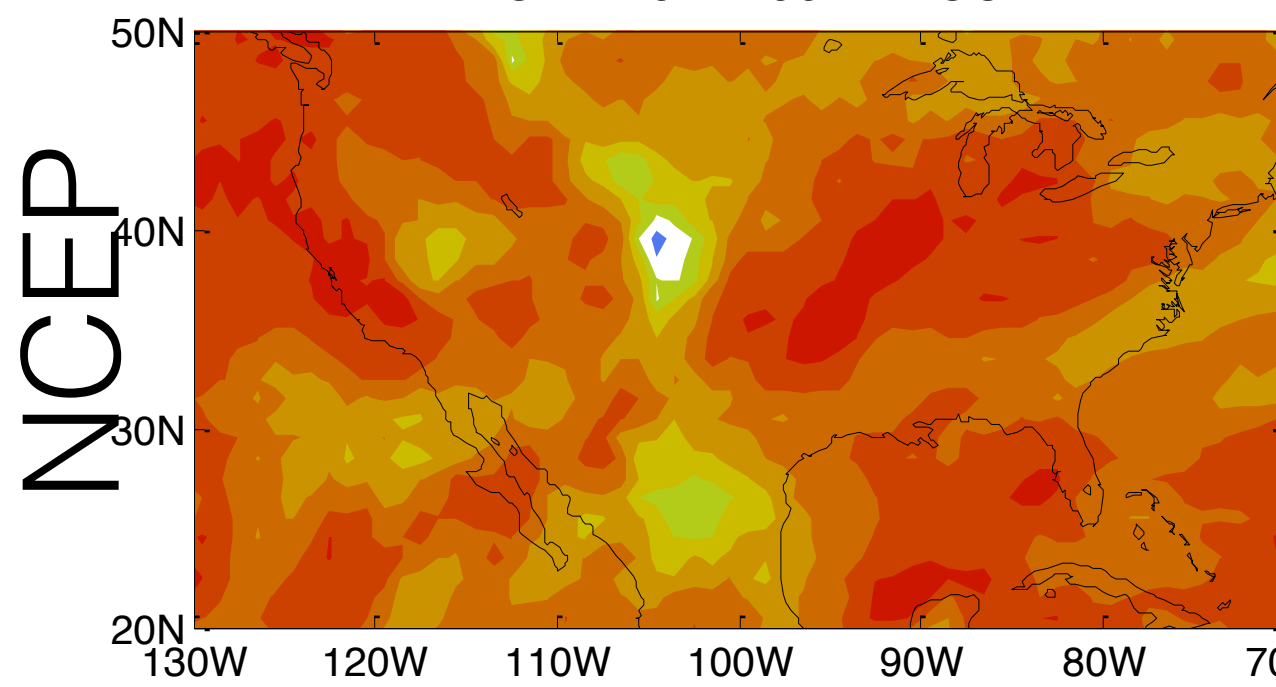
Week 4

NCEP DJF Week-1 ACC

NCEP DJF Week-2 ACC

NCEP DJF Week-3 ACC

NCEP DJF Week-4 ACC

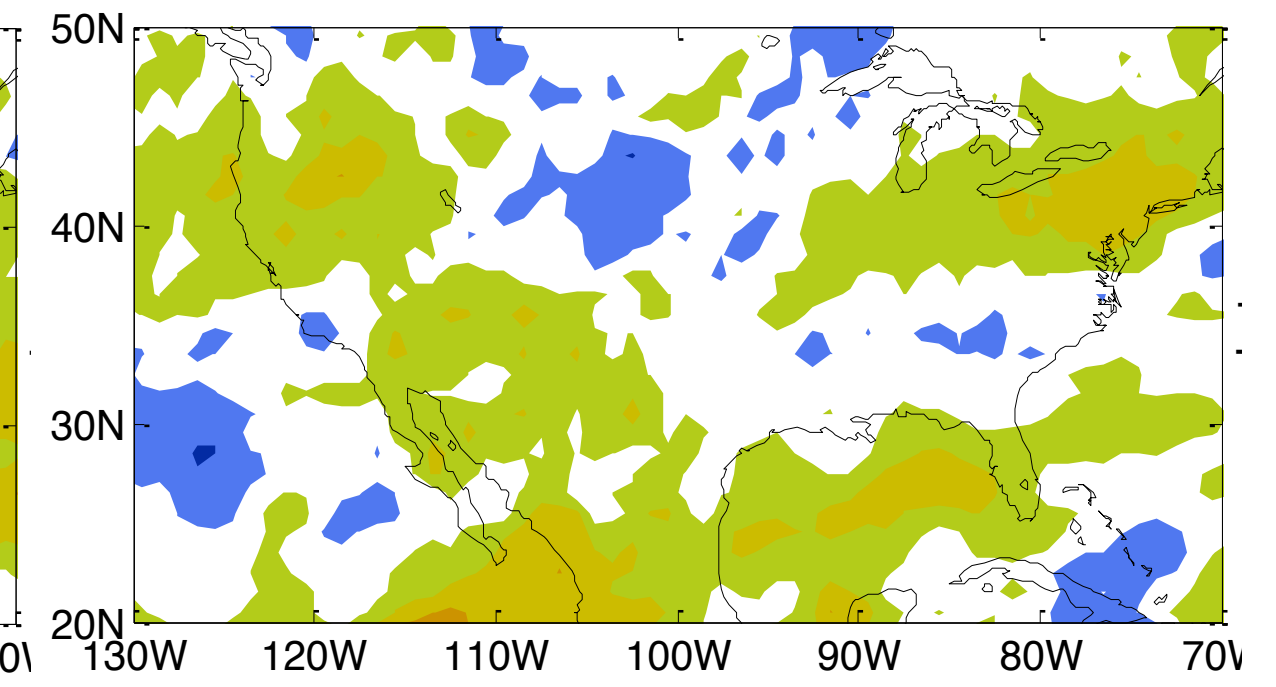
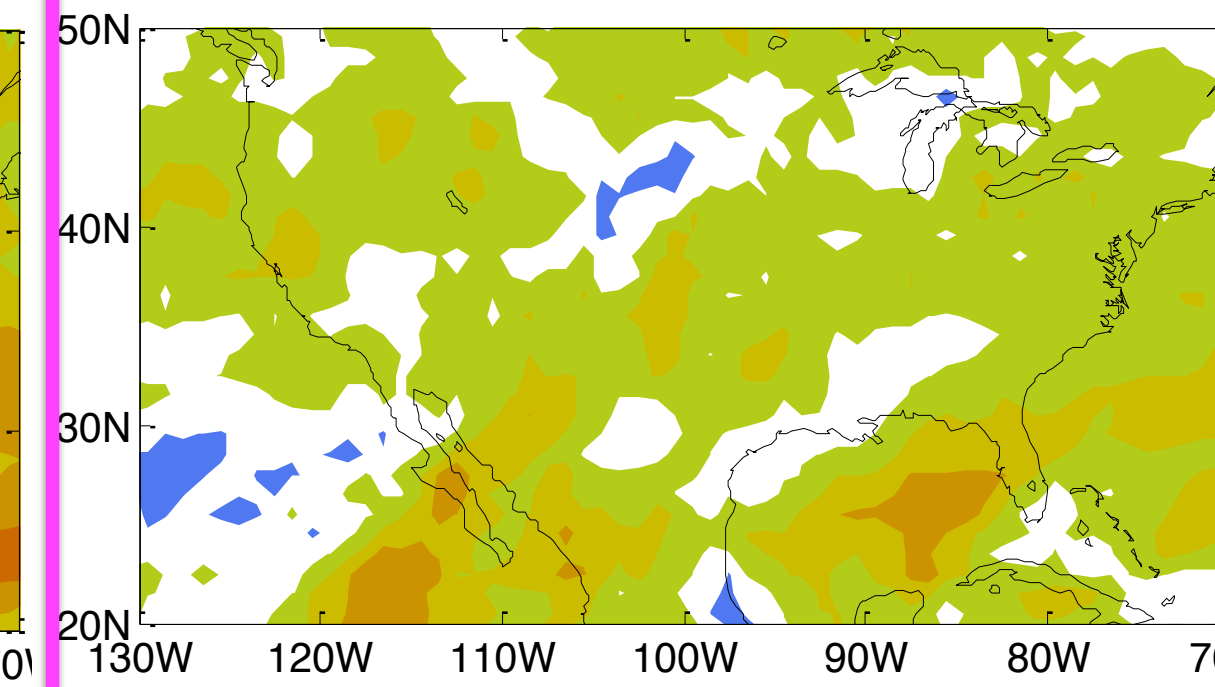
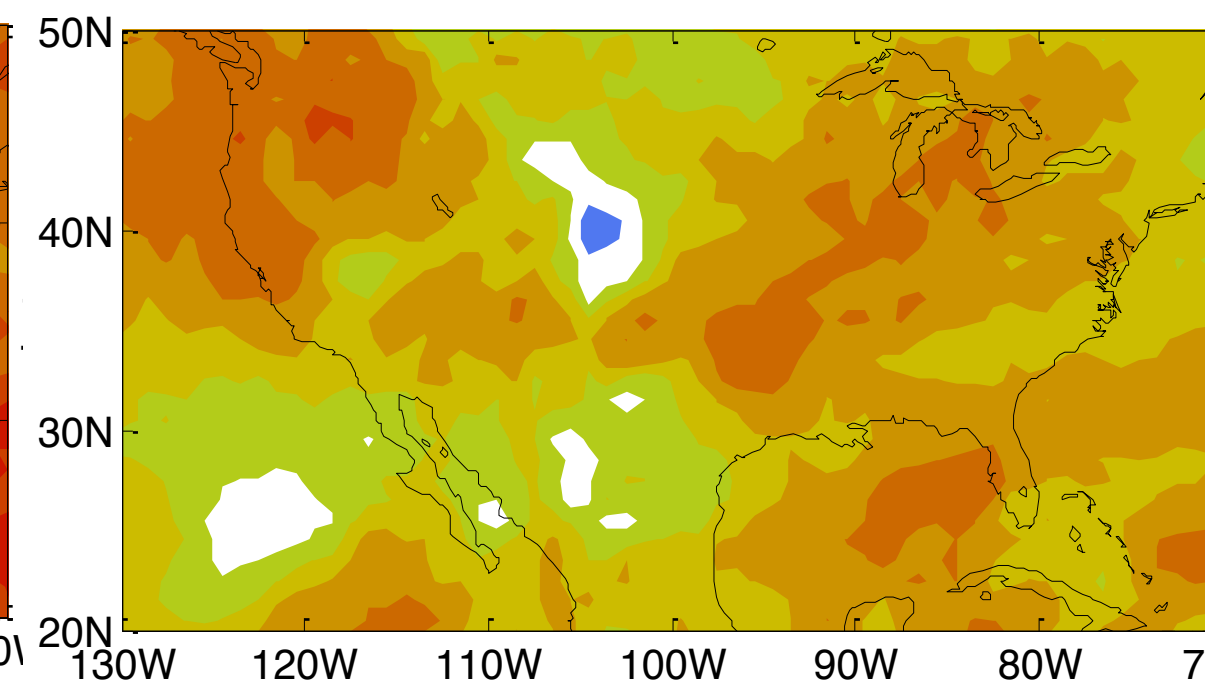
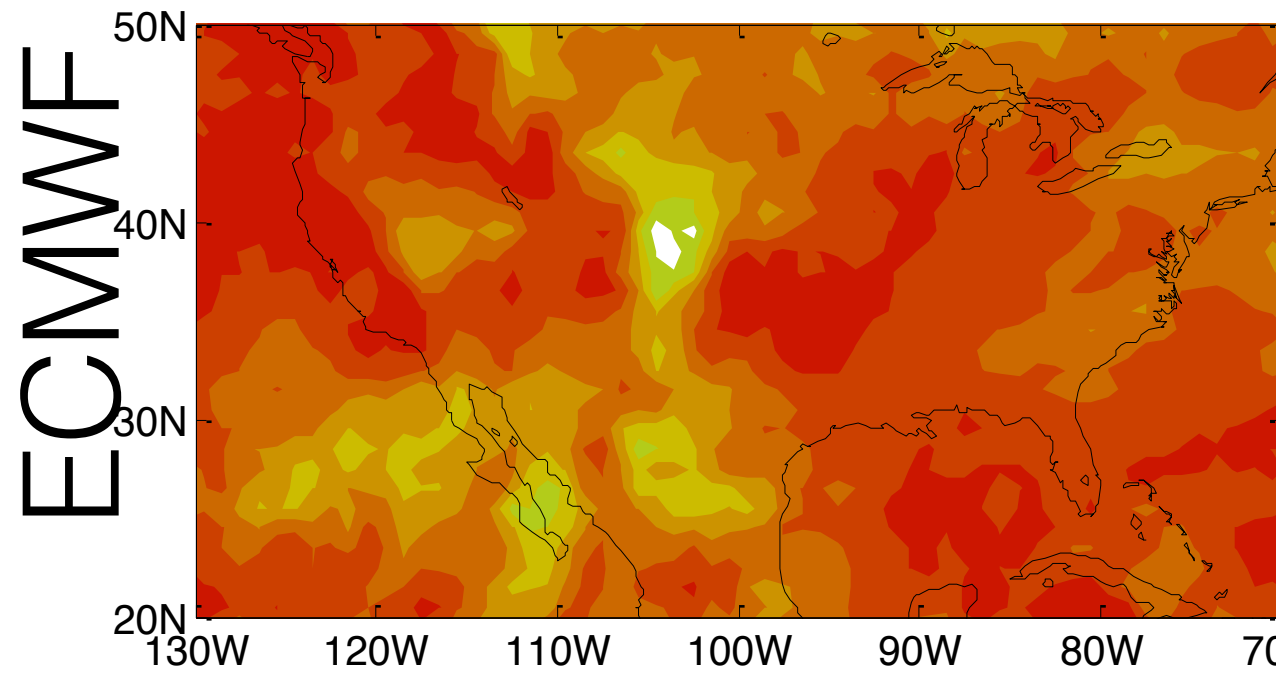


ECMWF DJF Week-1 ACC

ECMWF DJF Week-2 ACC

ECMWF DJF Week-3 ACC

ECMWF DJF Week-4 ACC



Anomaly correlation coefficient

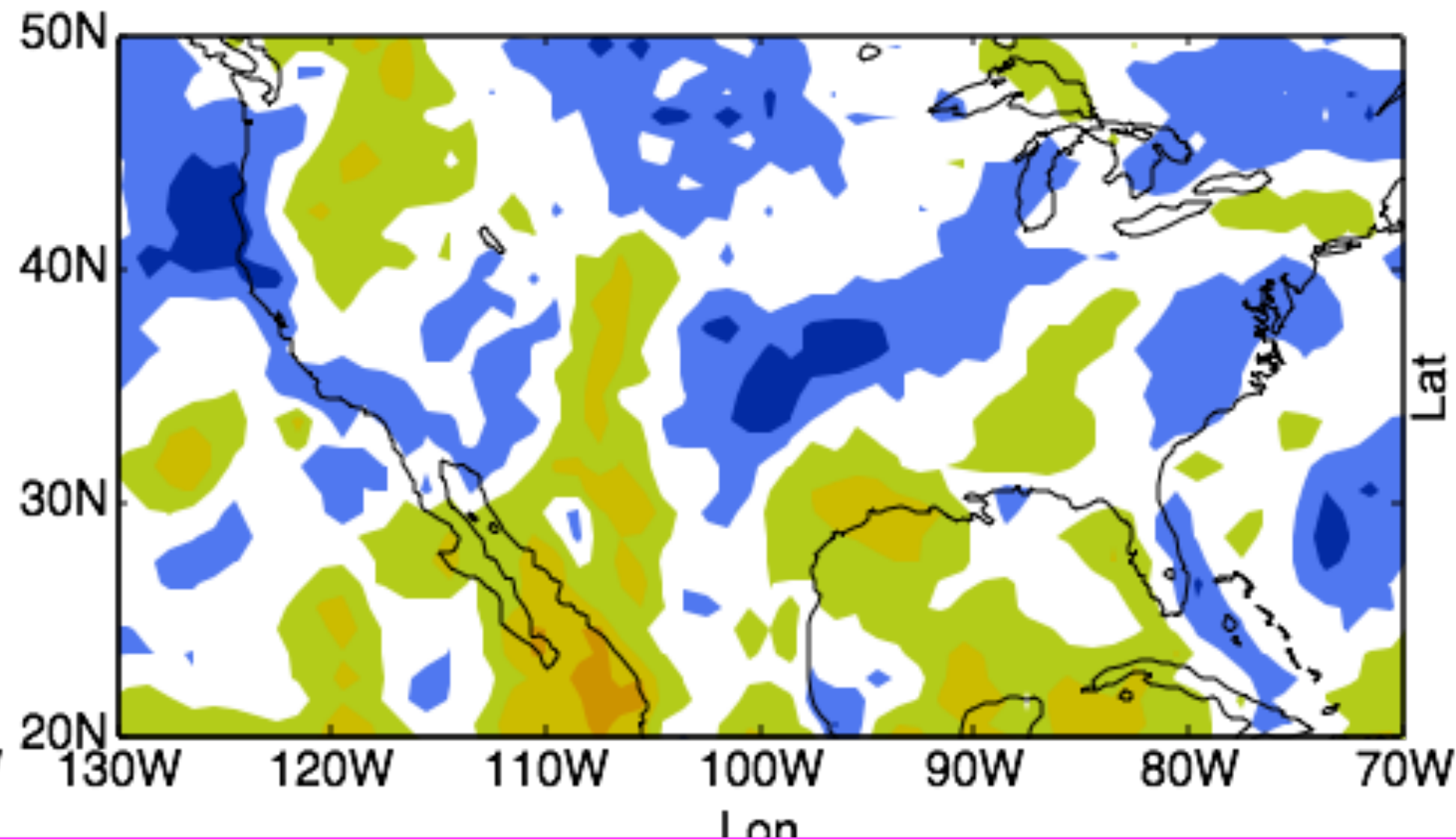
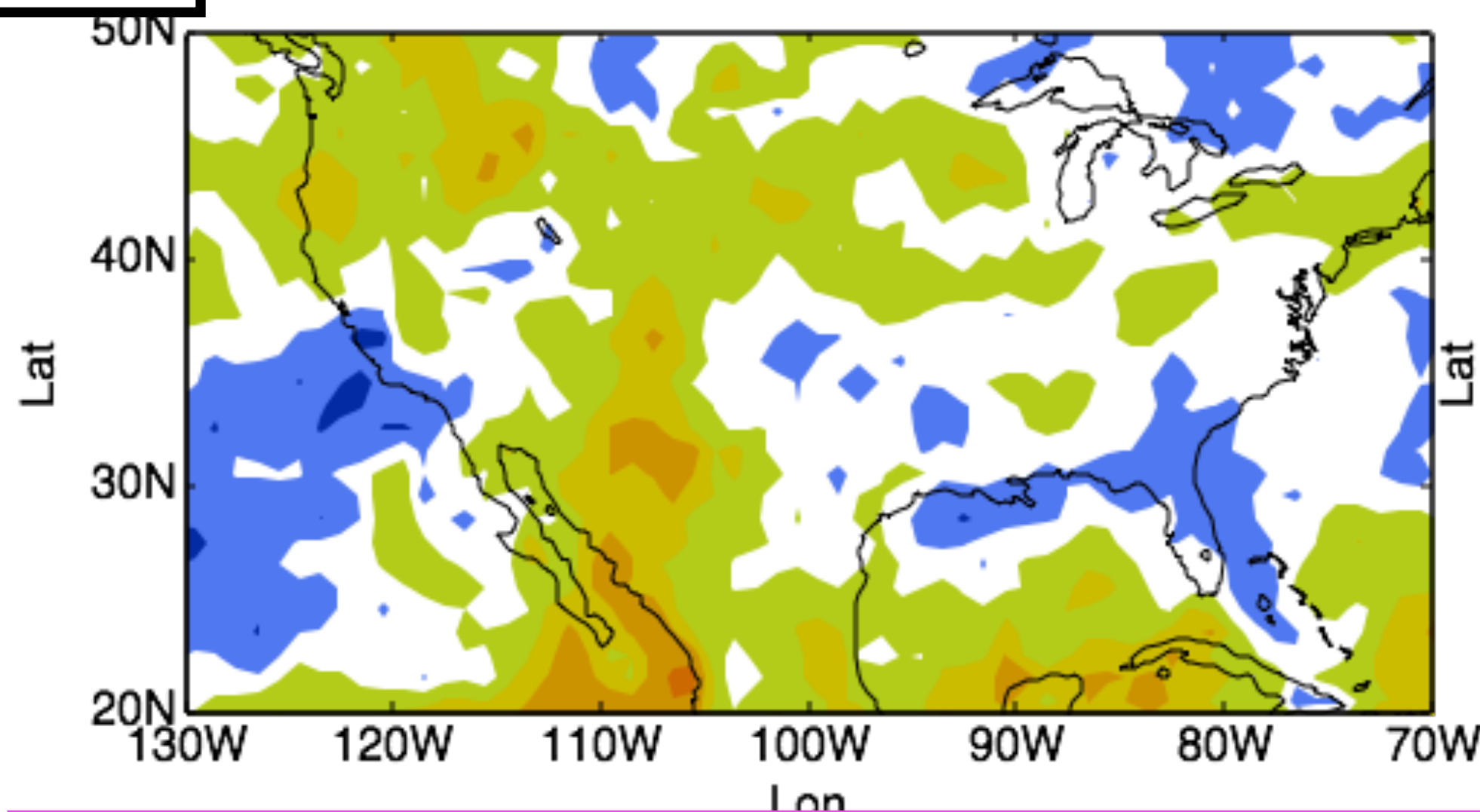


Weeks 3+4

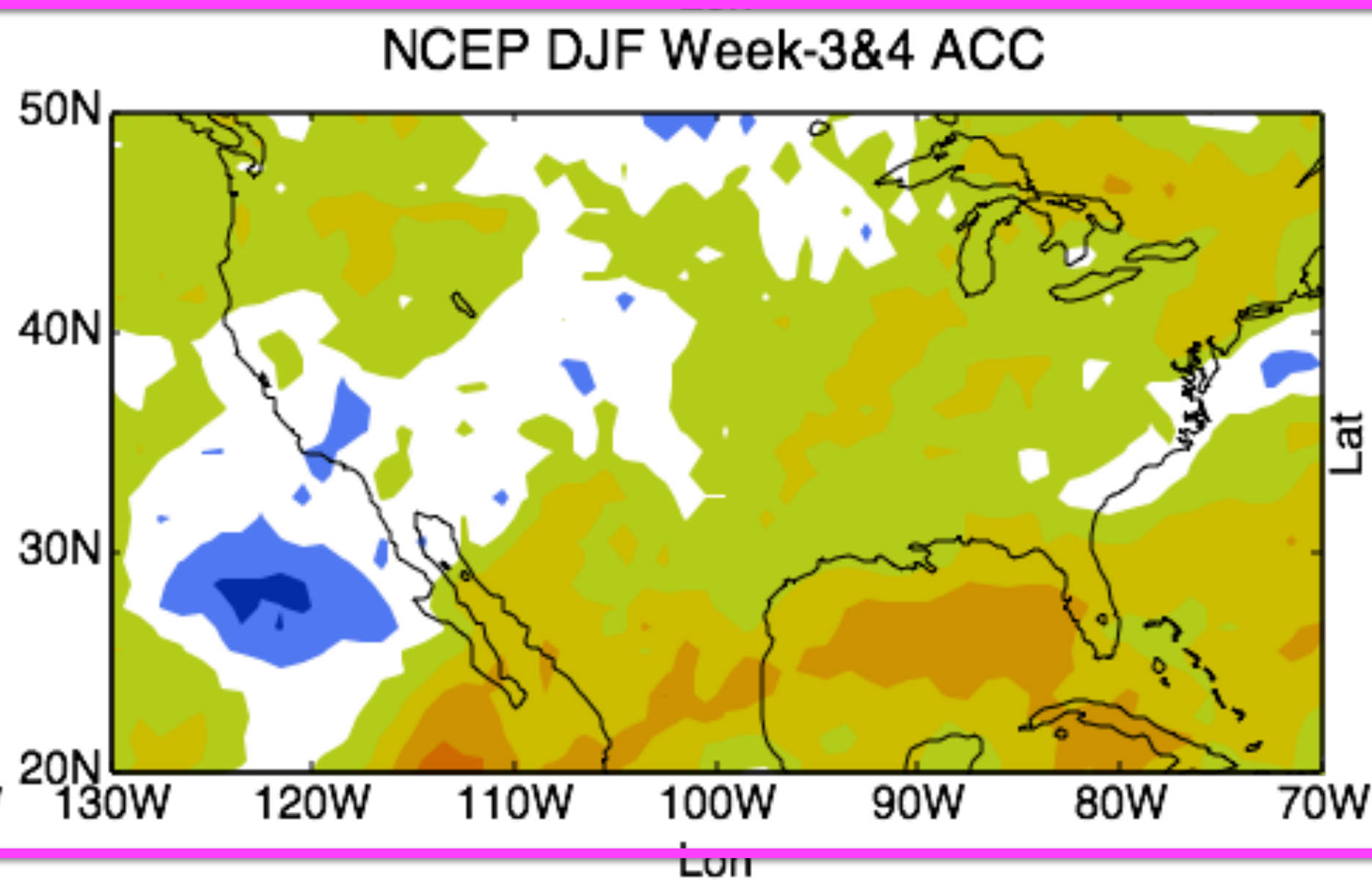
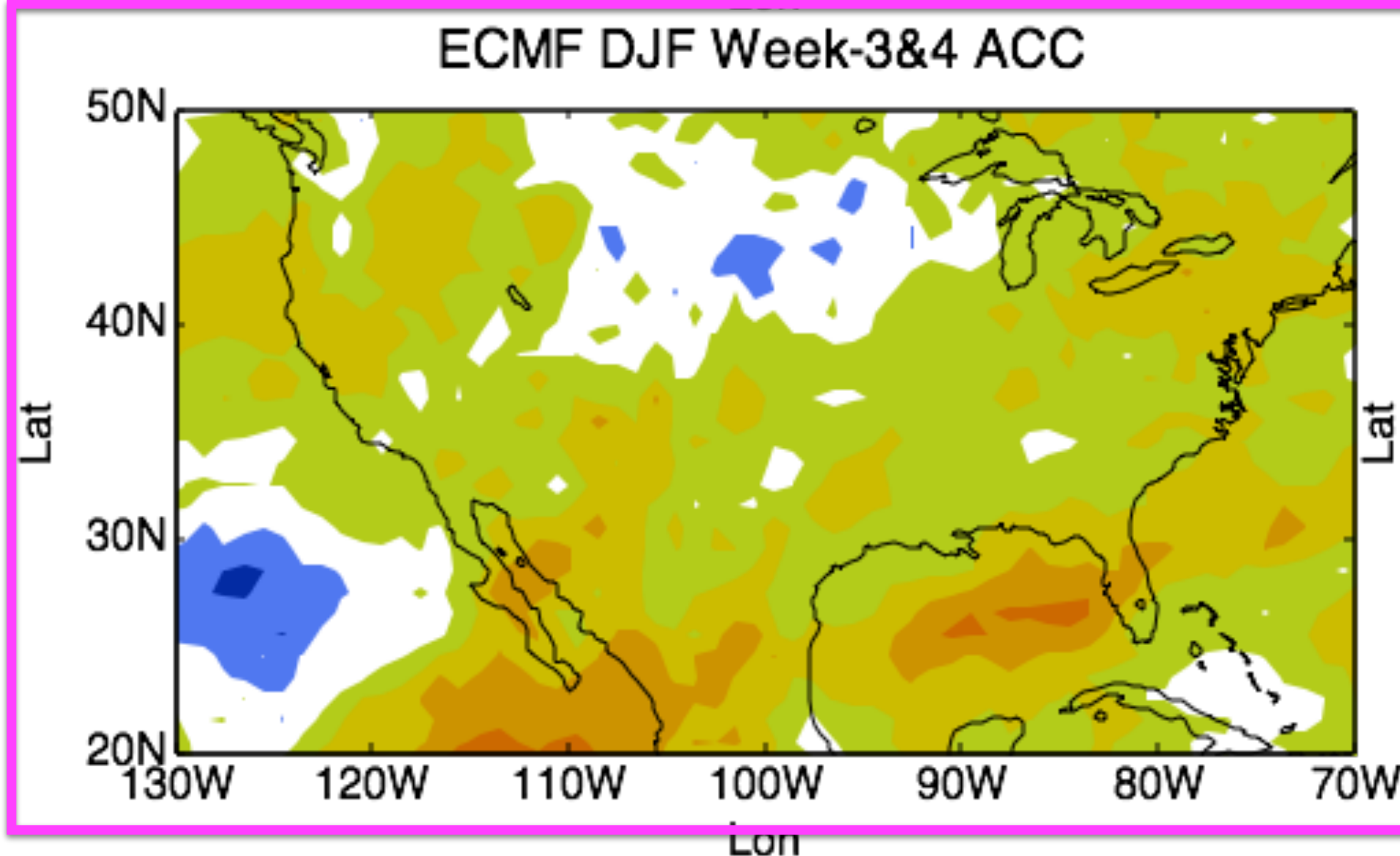
ECMWF
ECMF JJA Week-3&4 ACC

NCEP
NCEP JJA Week-3&4 ACC

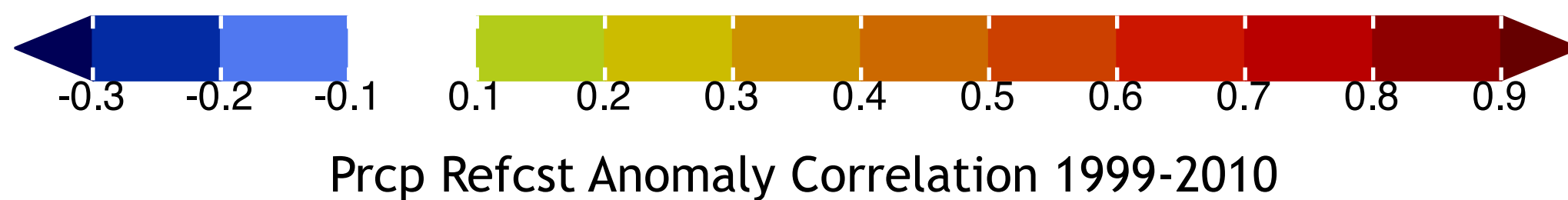
JJA



DJF

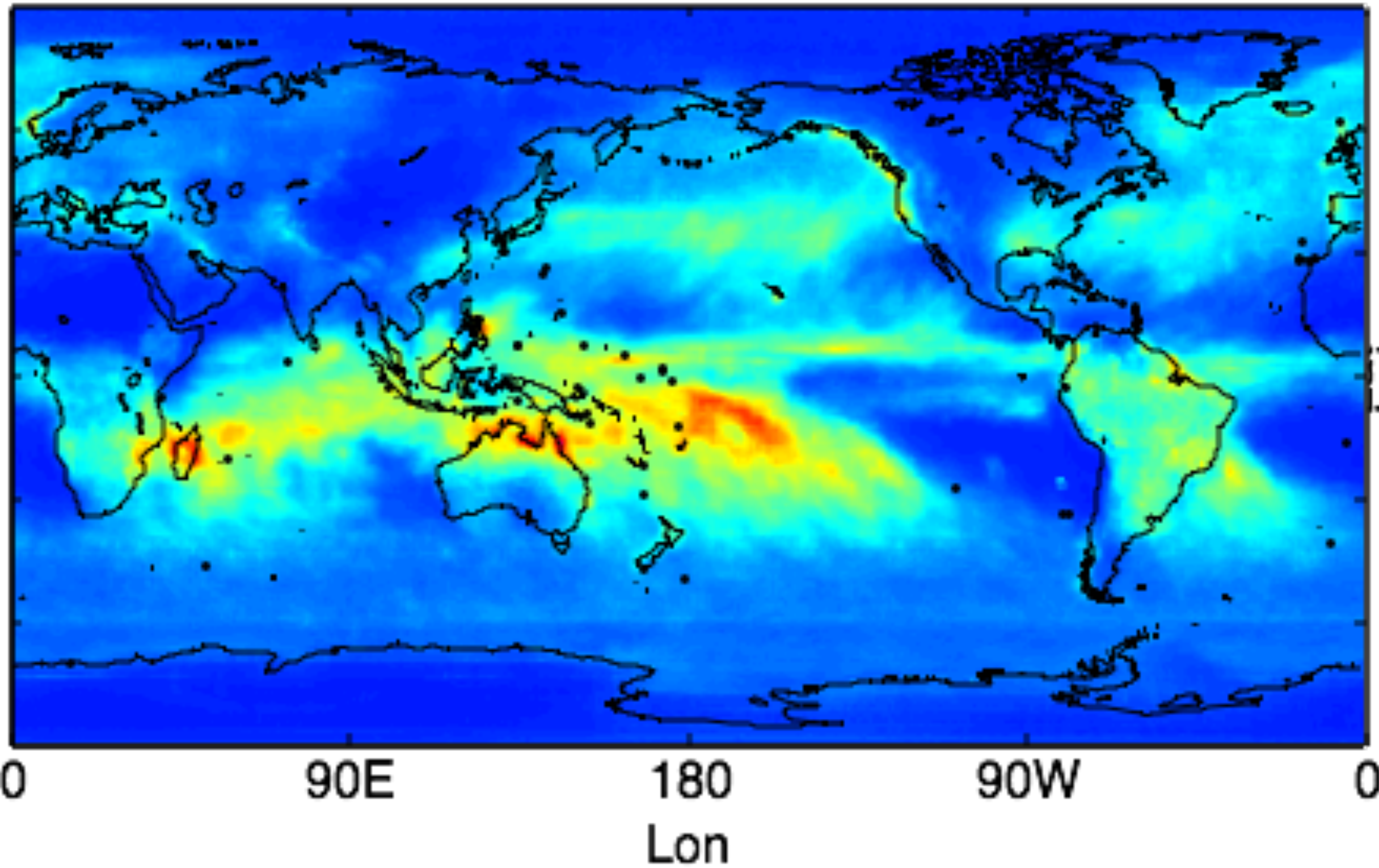


*Gain in skill over
Wks 3 & 4 individually*

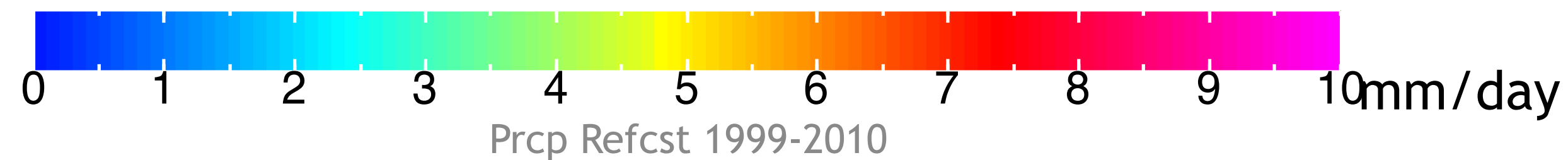
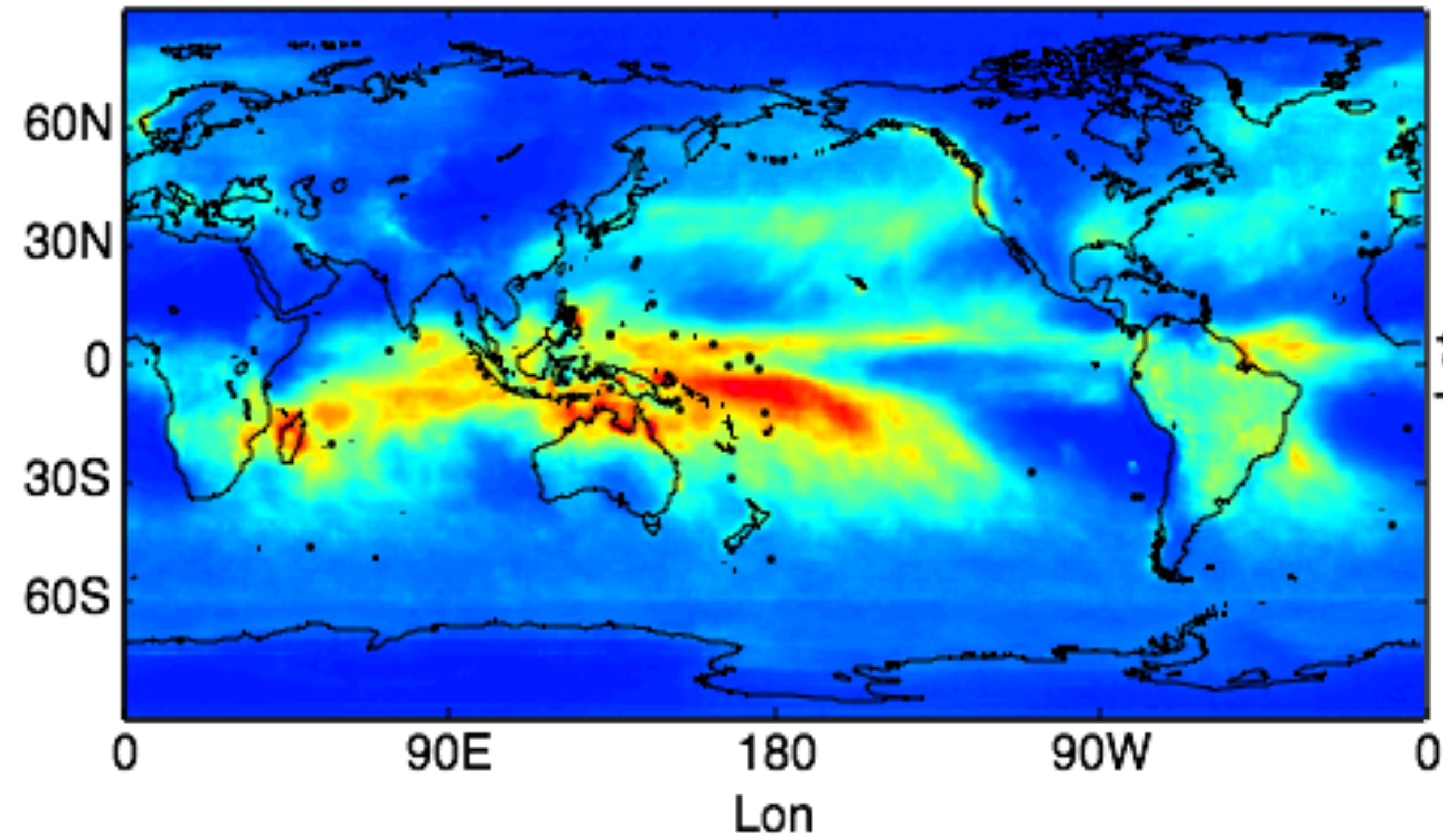


RMS Precip Error - DJF

ECMF DJF Week-3&4 RMSE



NCEP DJF Week-3&4 RMSE



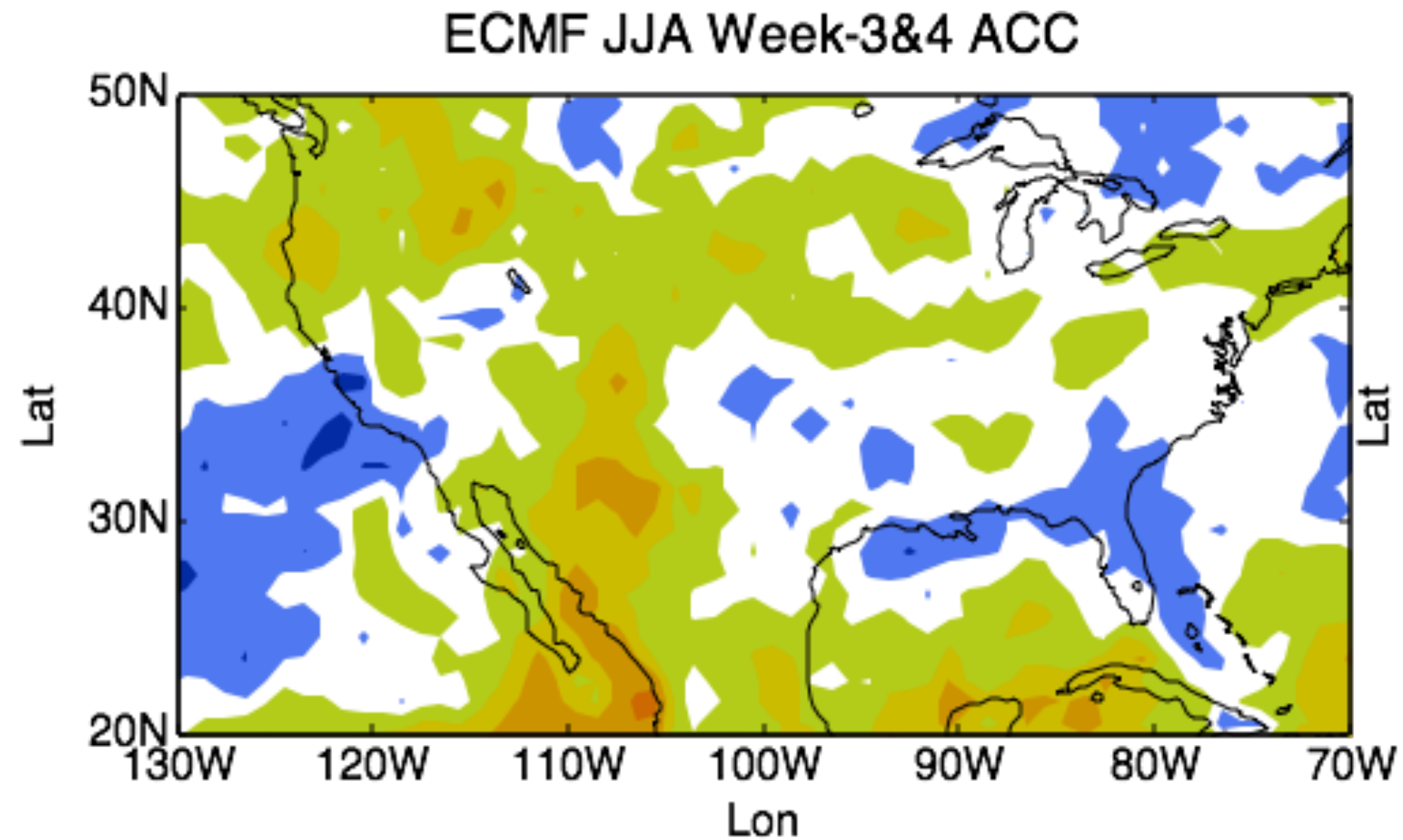
*Trop precip errors
are larger in NCEP*

Seasonality of W3+4 skill

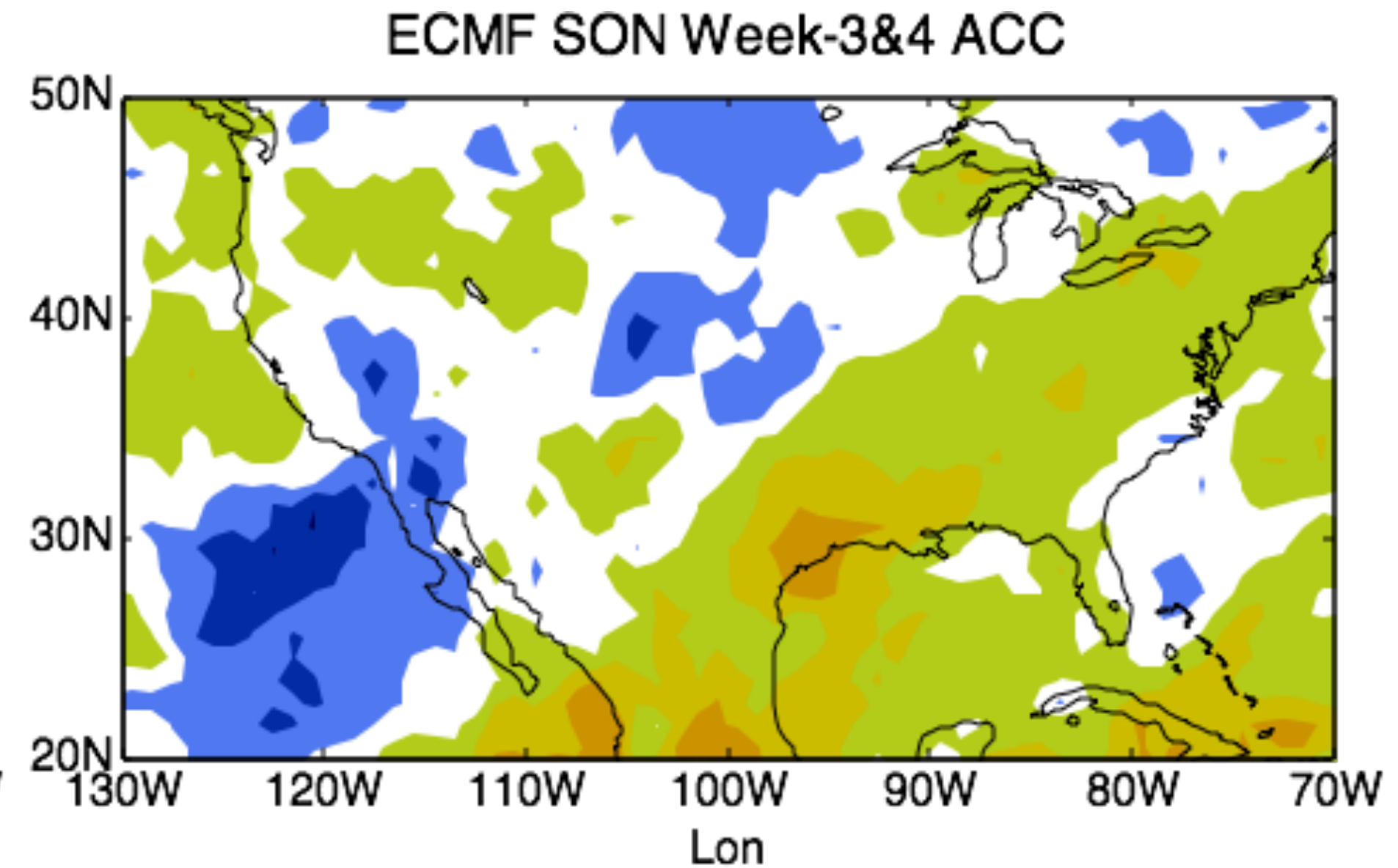
Precip, 500hPa Geopotential, 2m Temperature

ECMWF Precip ACC Seasonality

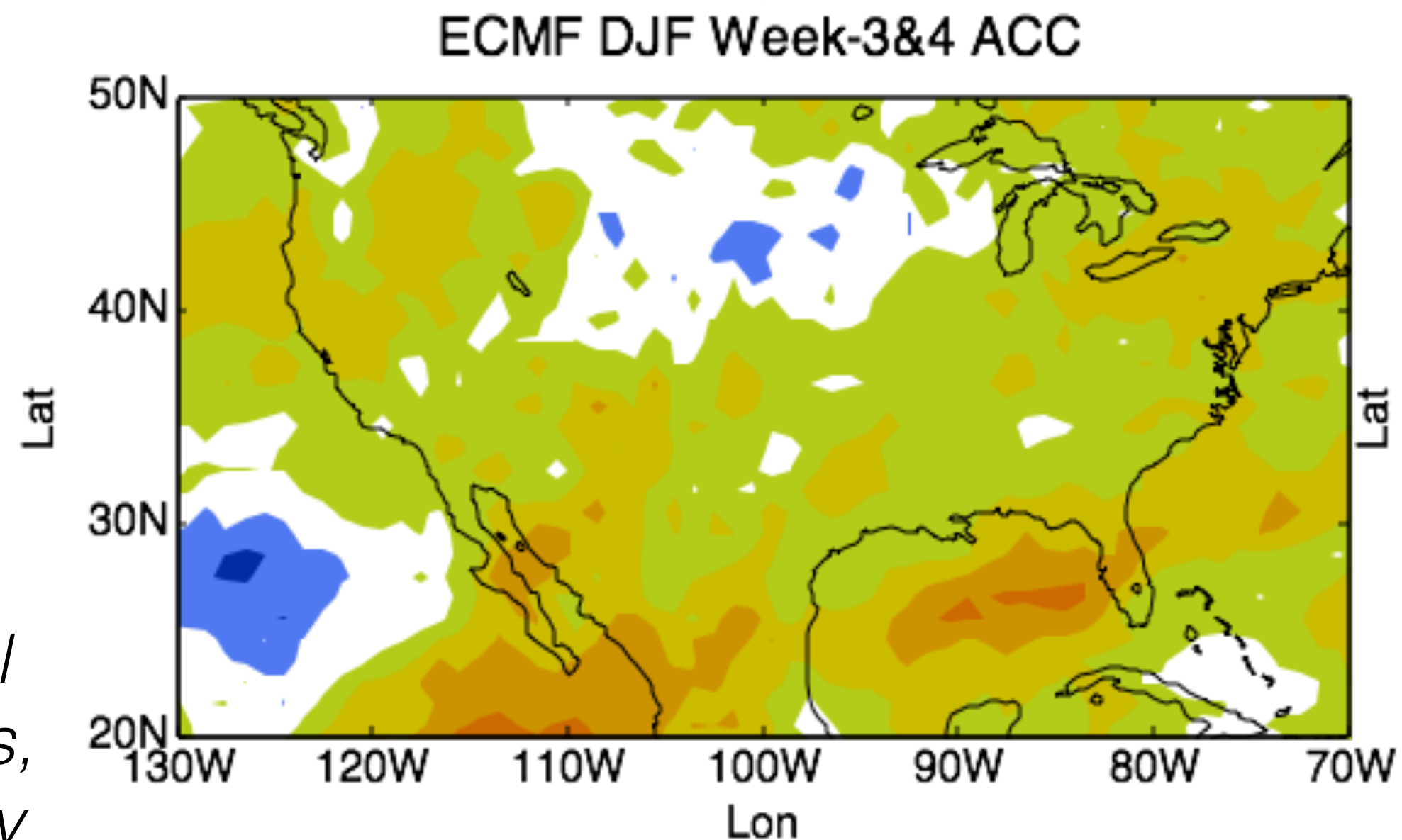
JJA



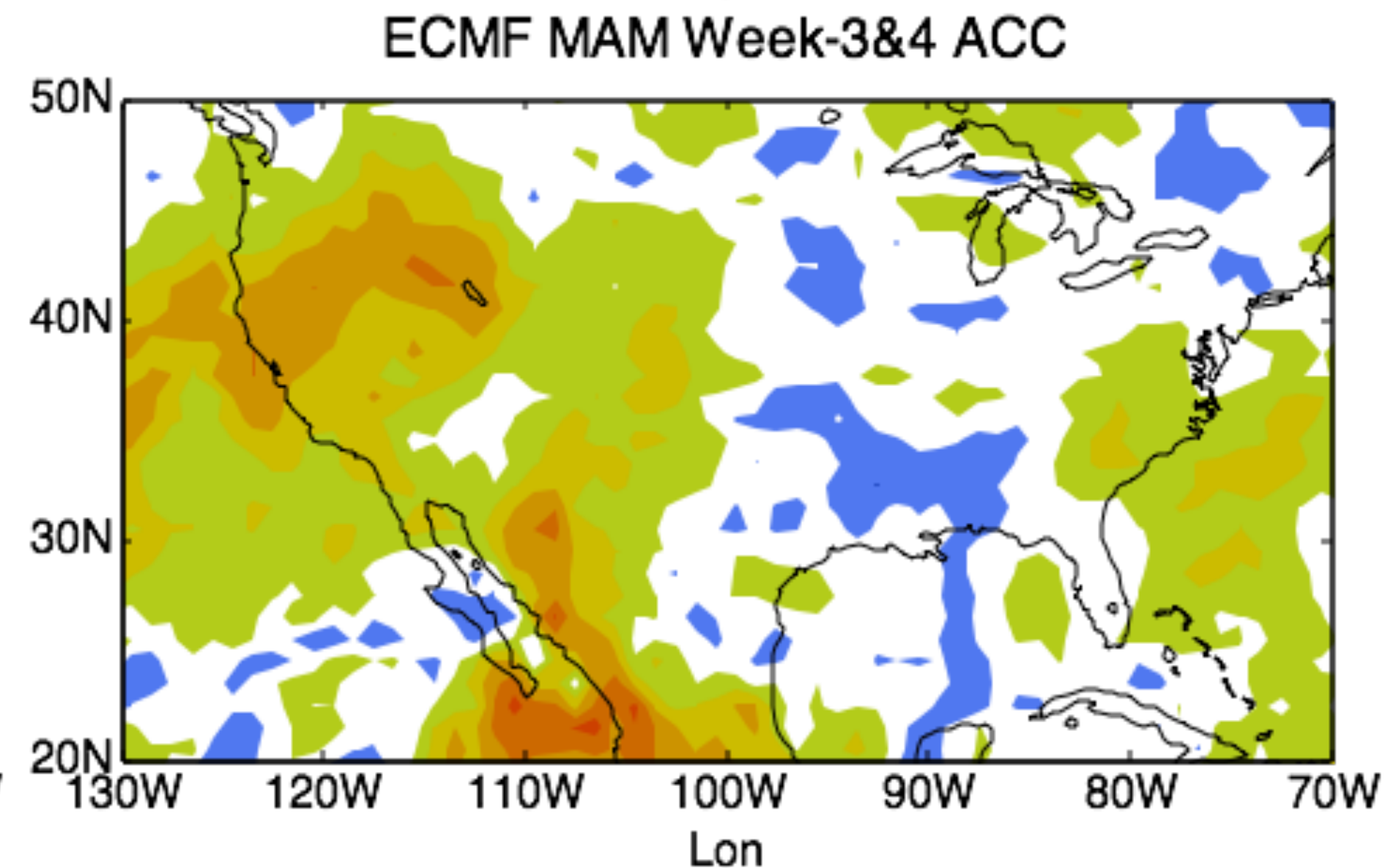
SON



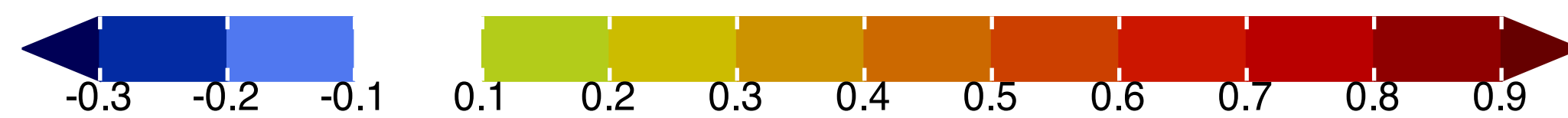
DJF



MAM

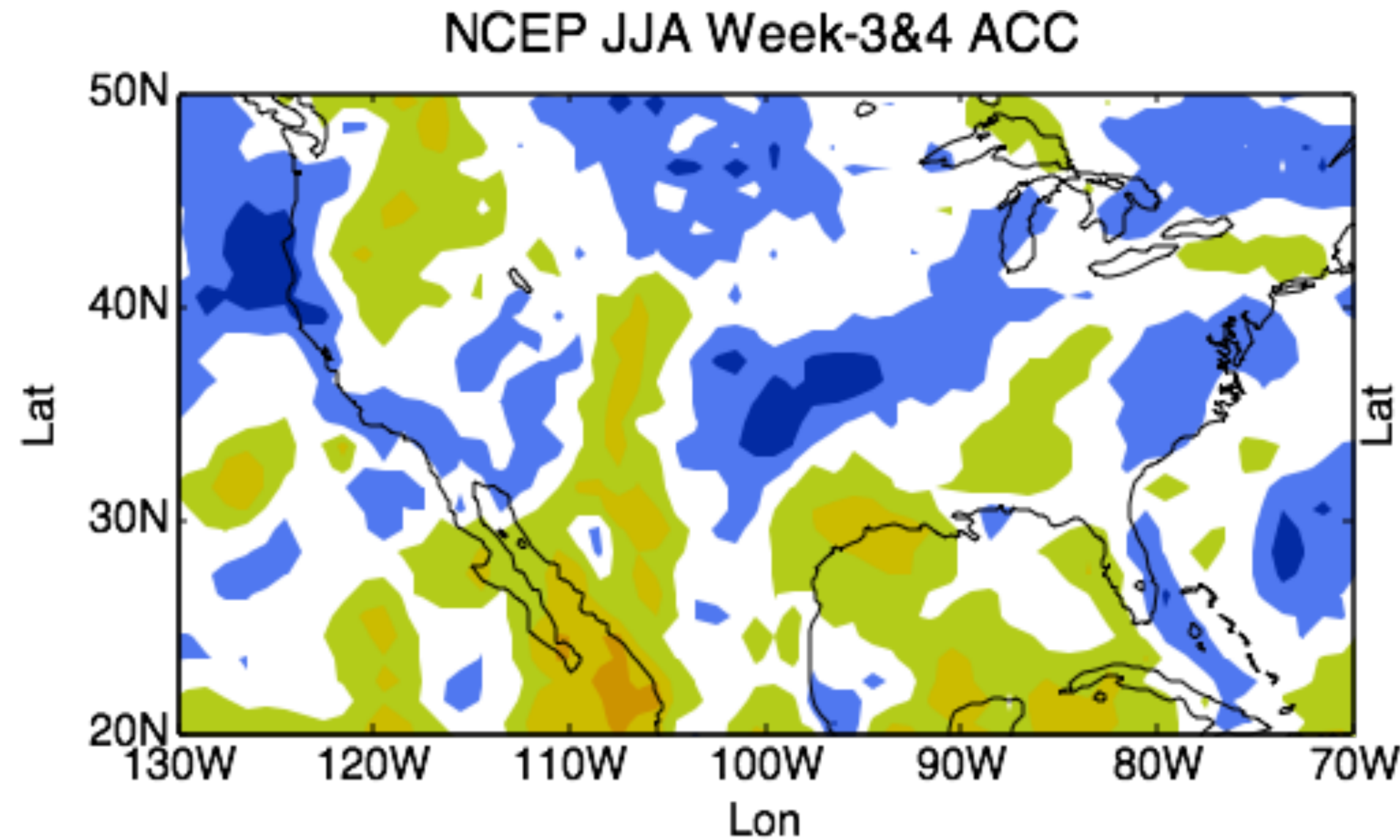


*Areas of skill
in all seasons,
although only
reach ~0.4.*

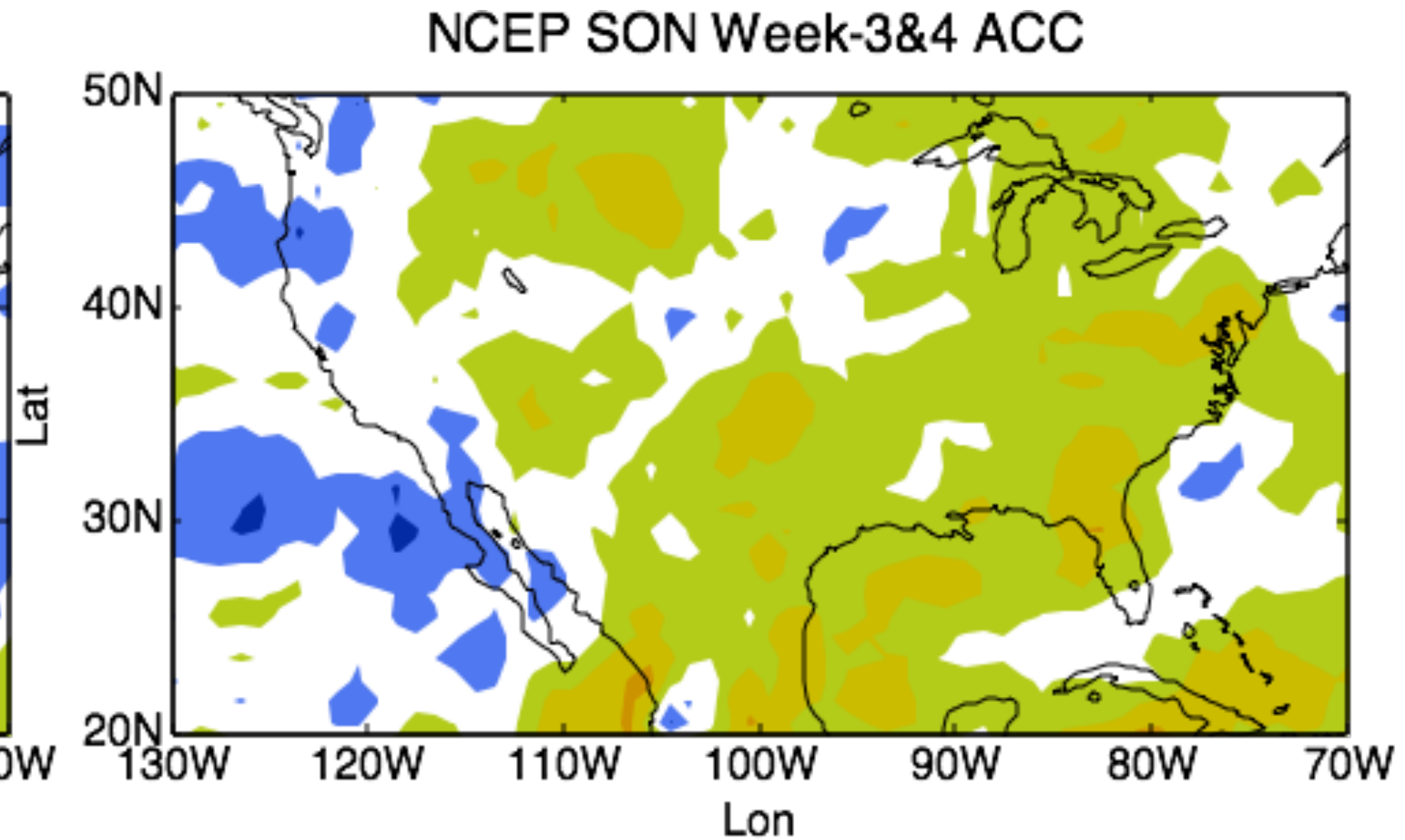


NCEP Precip ACC Seasonality

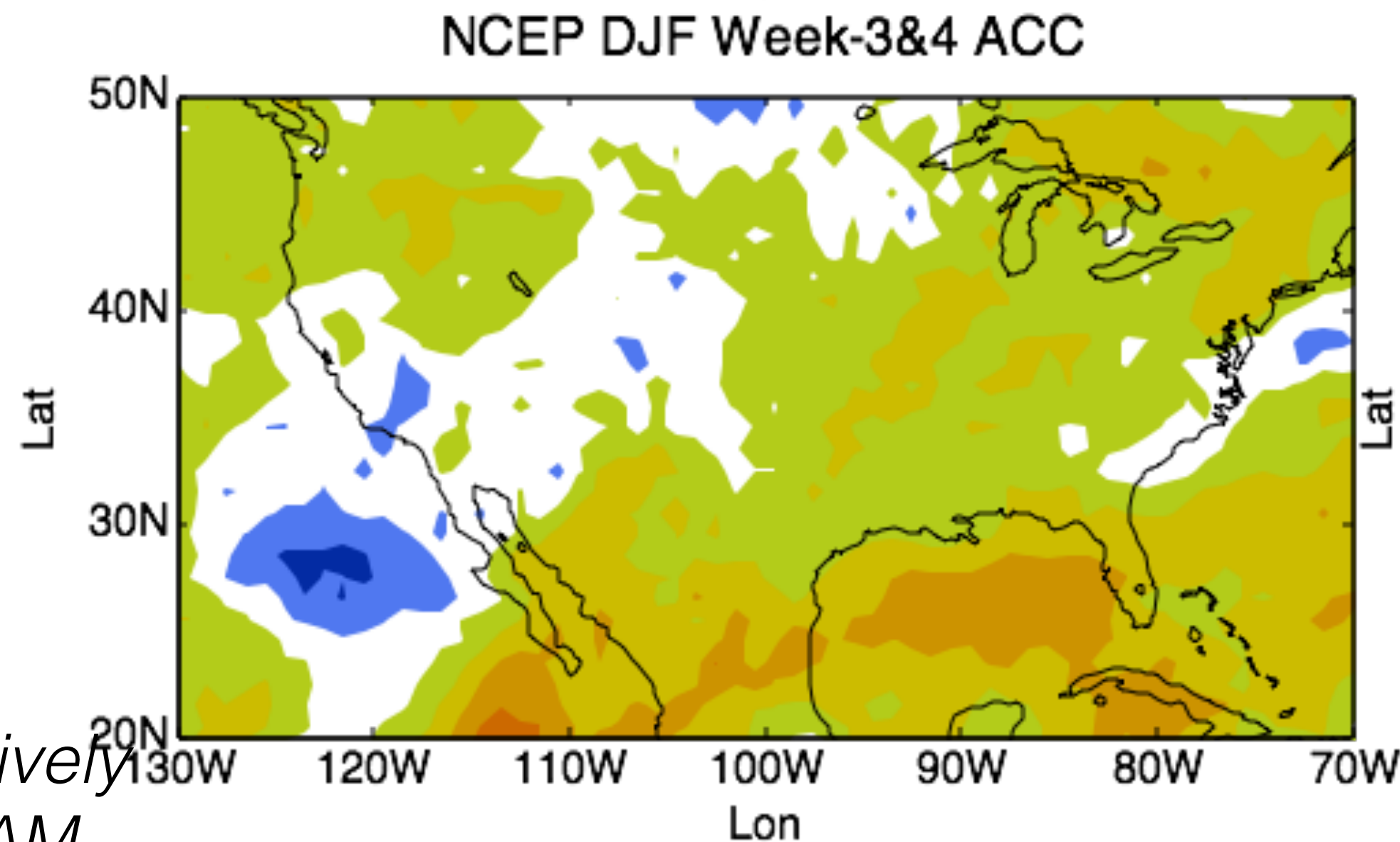
JJA



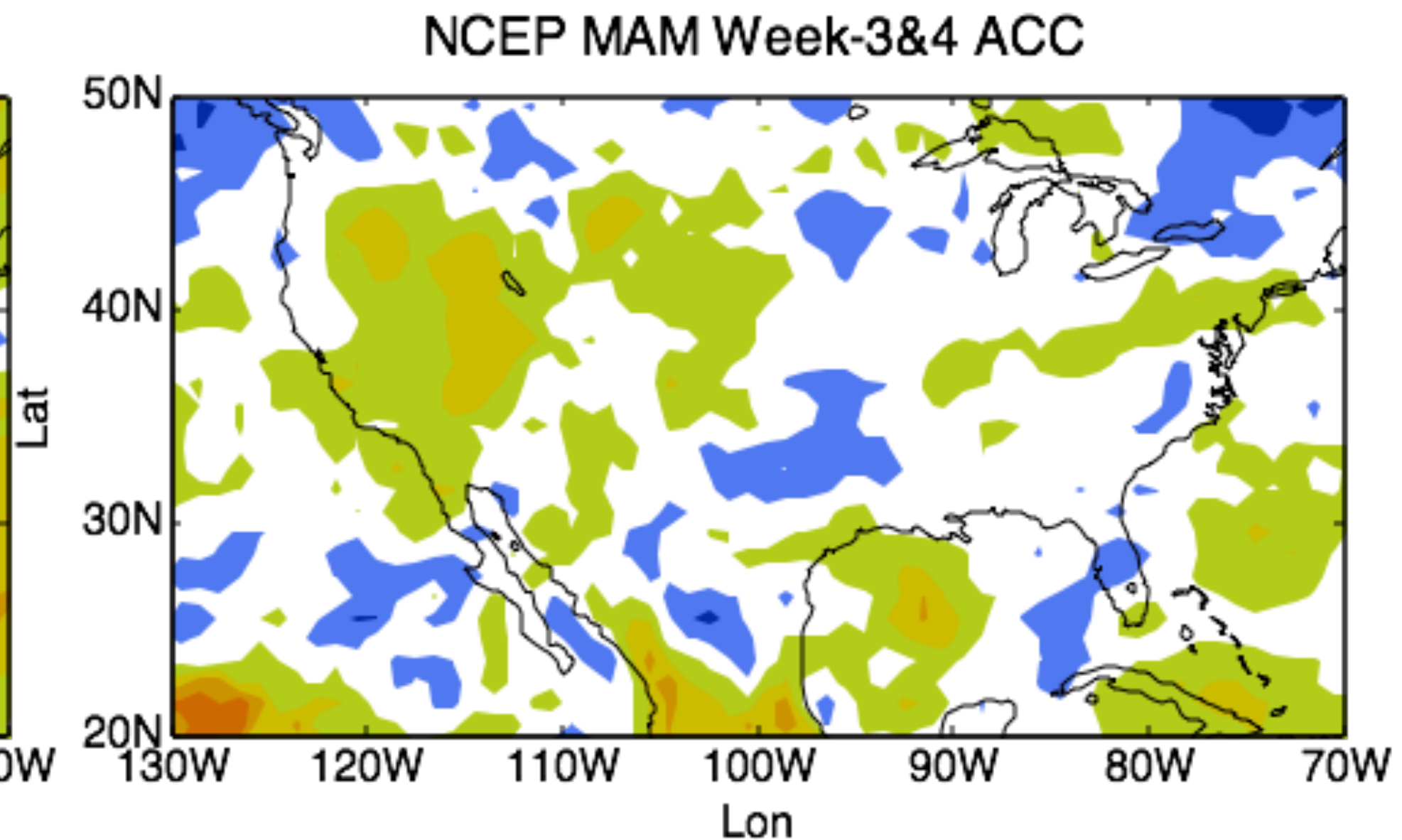
SON



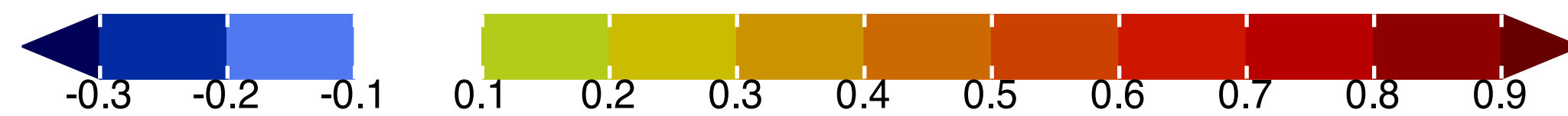
DJF



MAM



NCEP is relatively worse in MAM

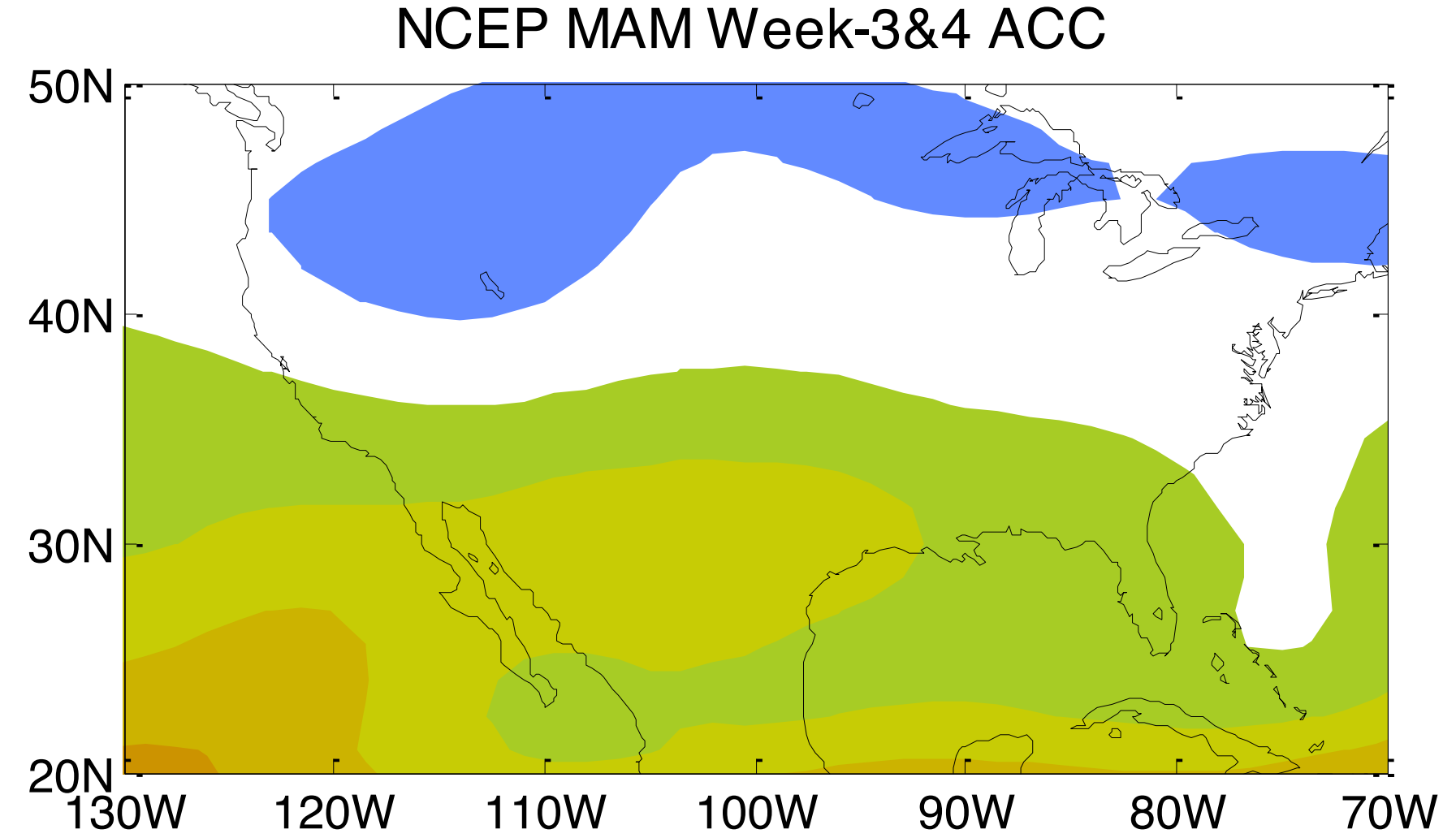
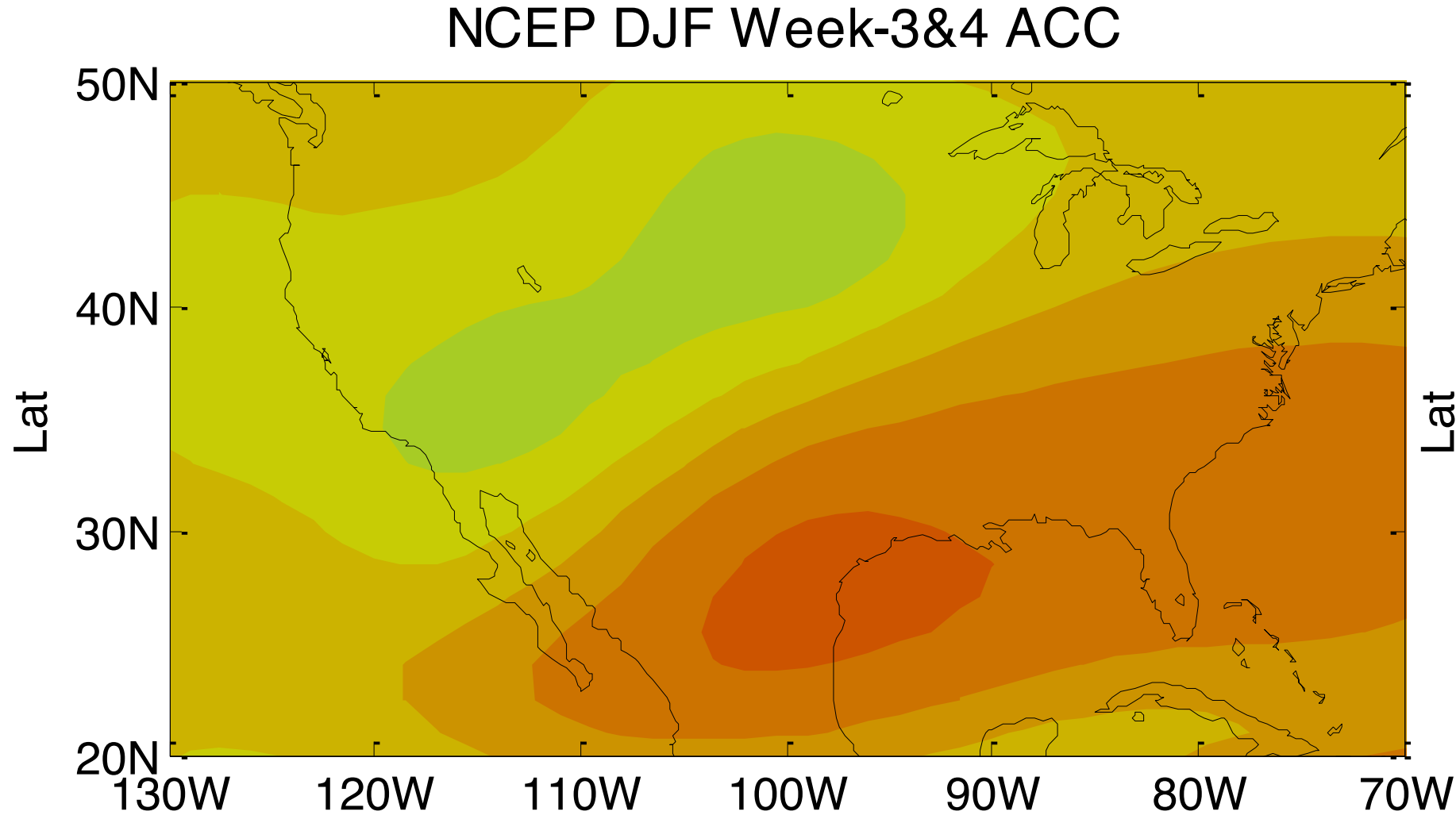


NCEP vs ECMWF 500 hPa Geopotential

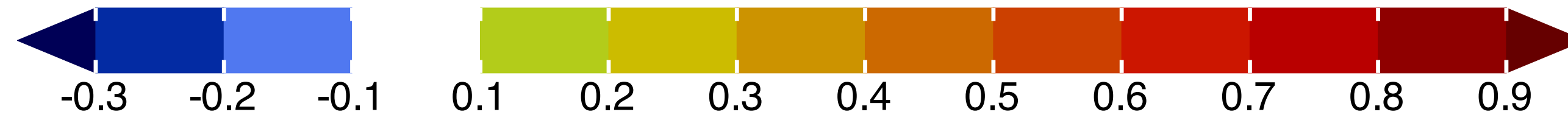
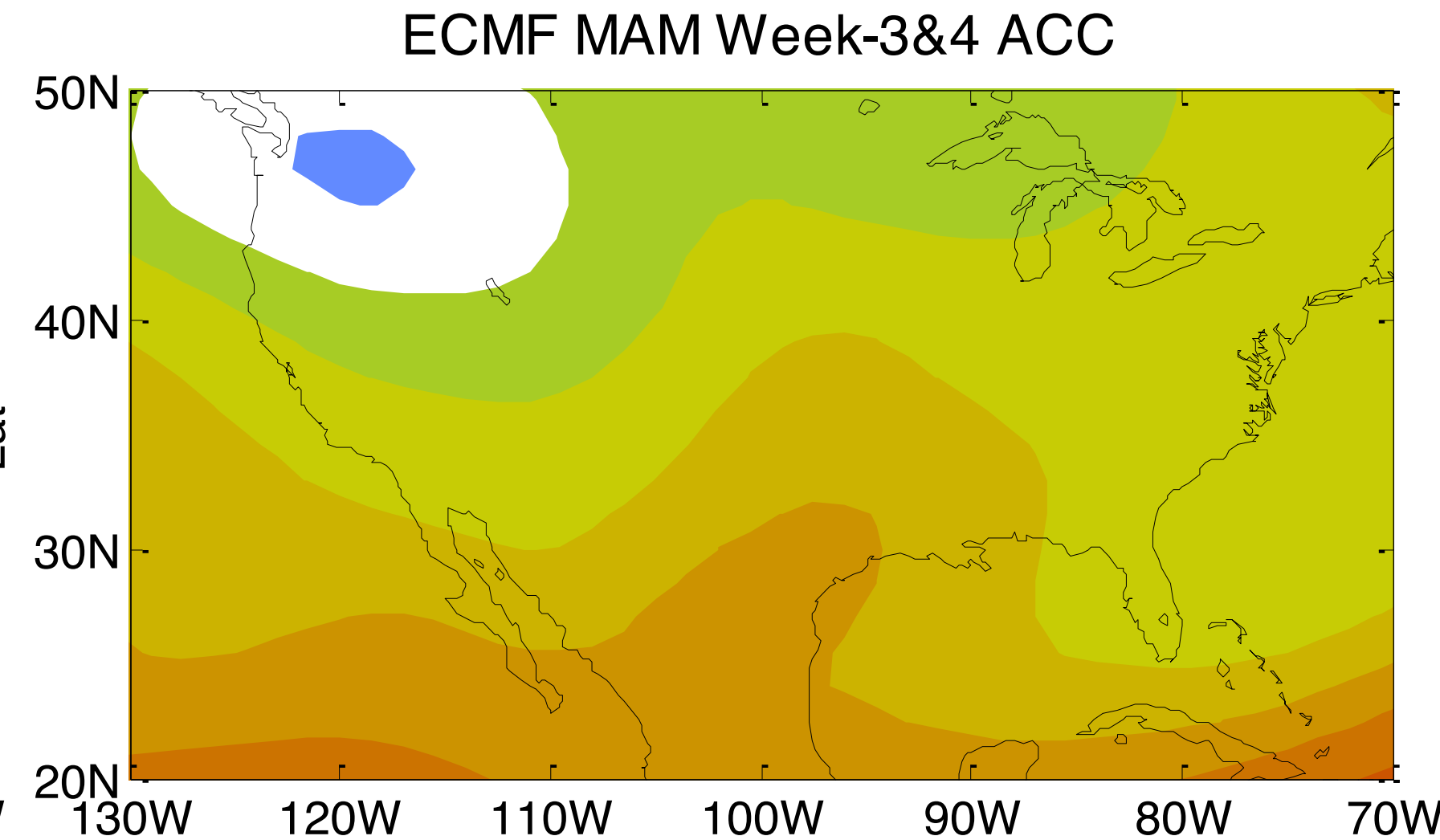
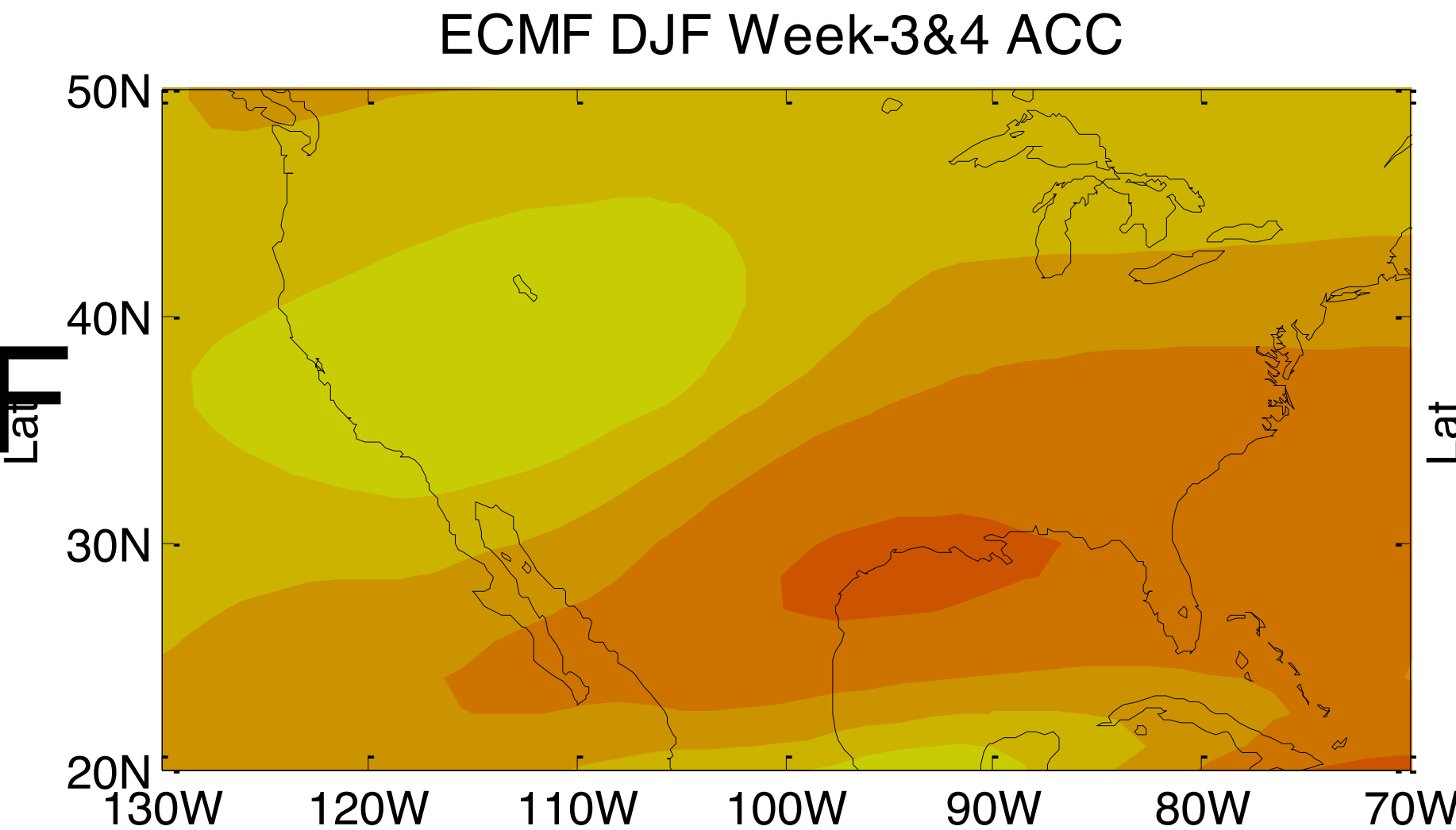
DJF

MAM

NCEP



ECMWF



NCEP vs ECMWF 2m Temperature

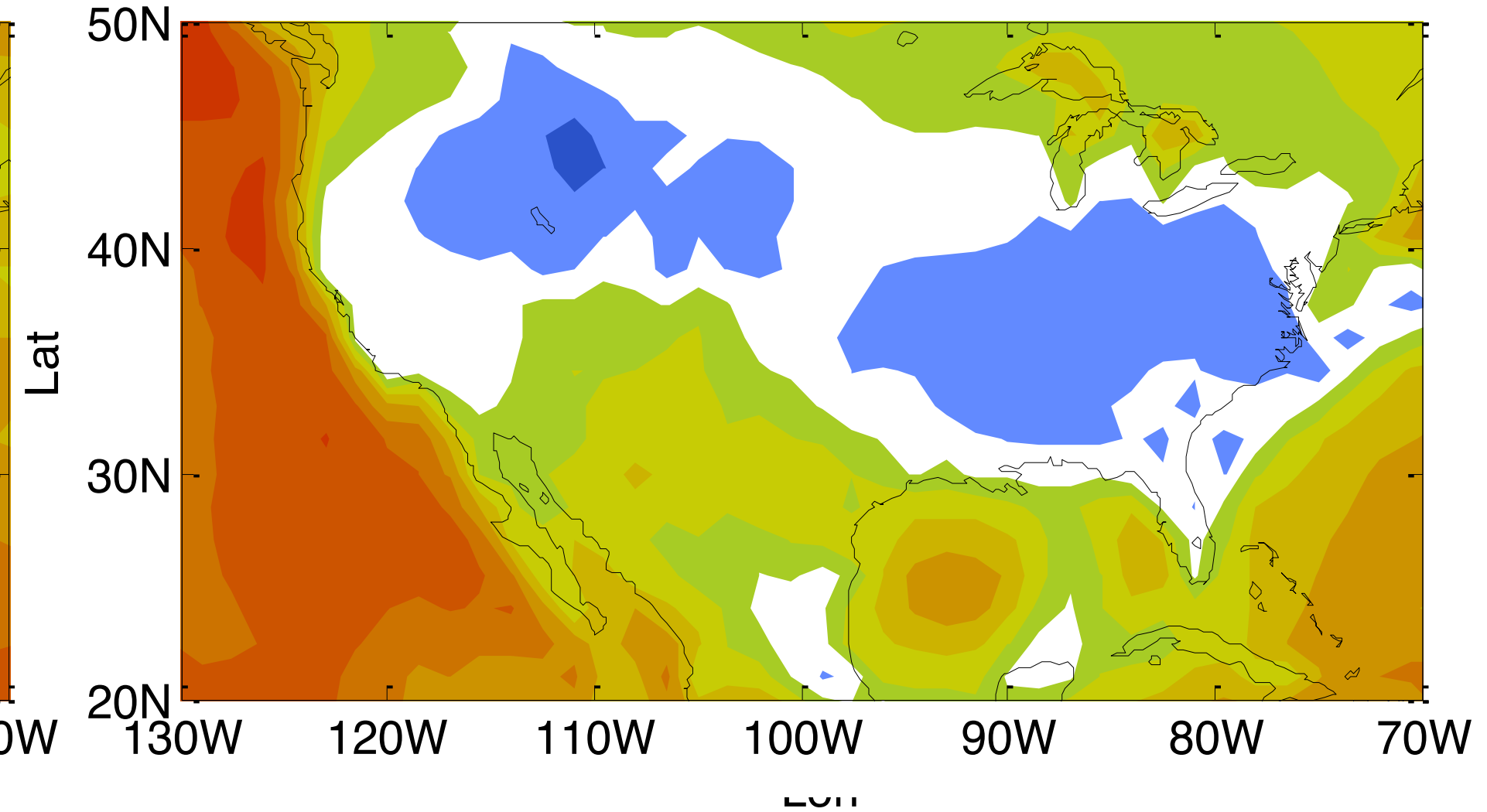
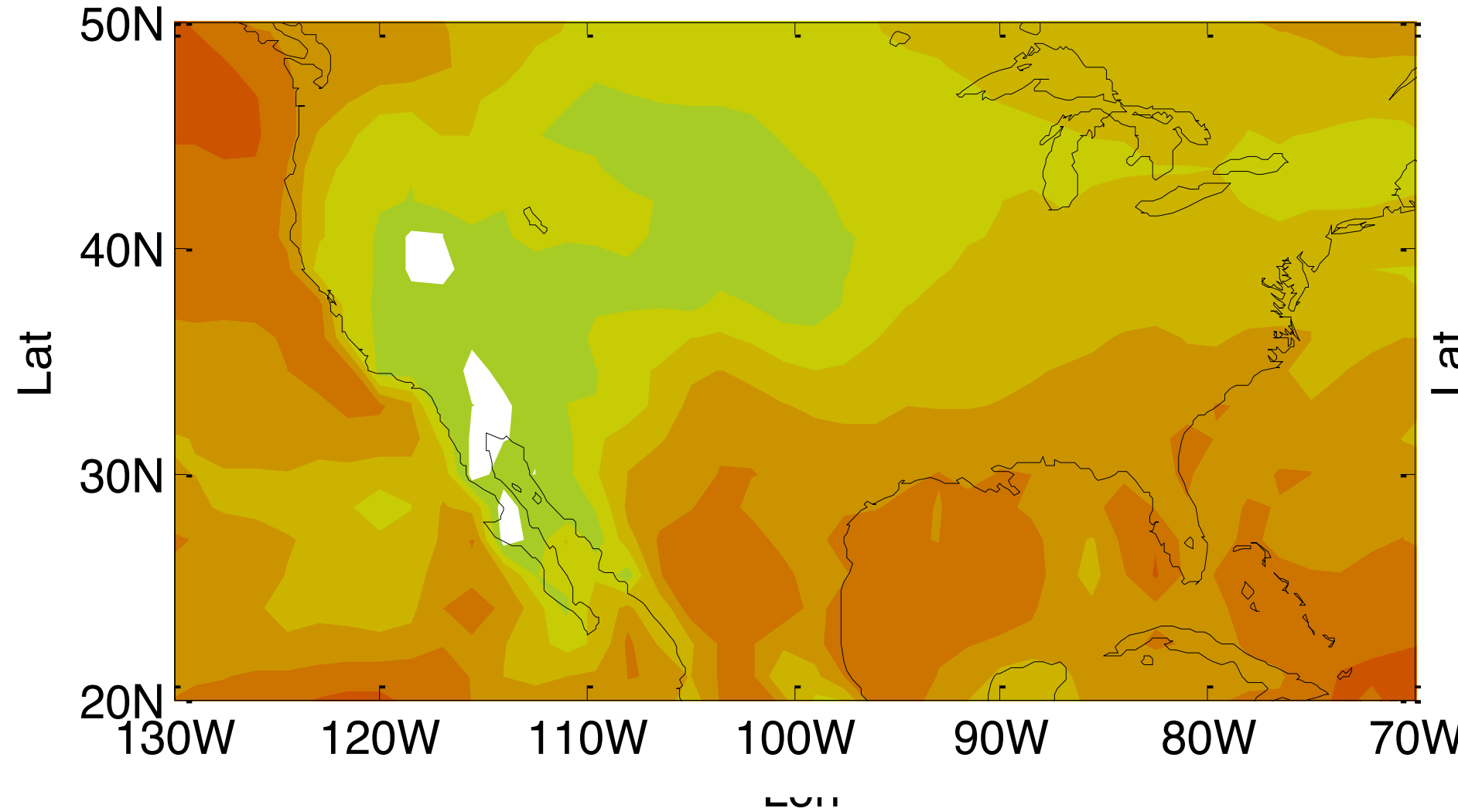
DJF

MAM

NCEP DJF Week-3&4 ACC

NCEP MAM Week-3&4 ACC

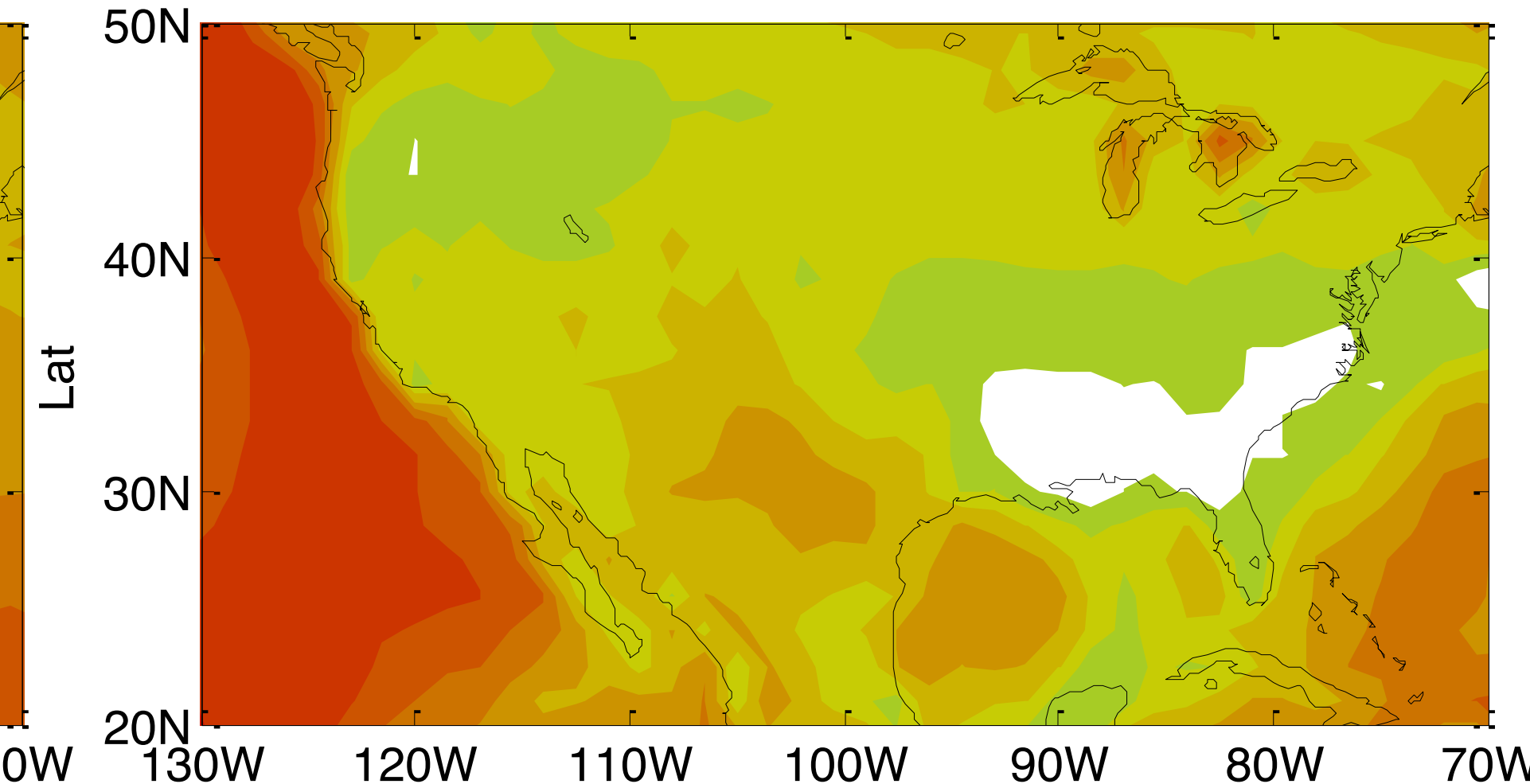
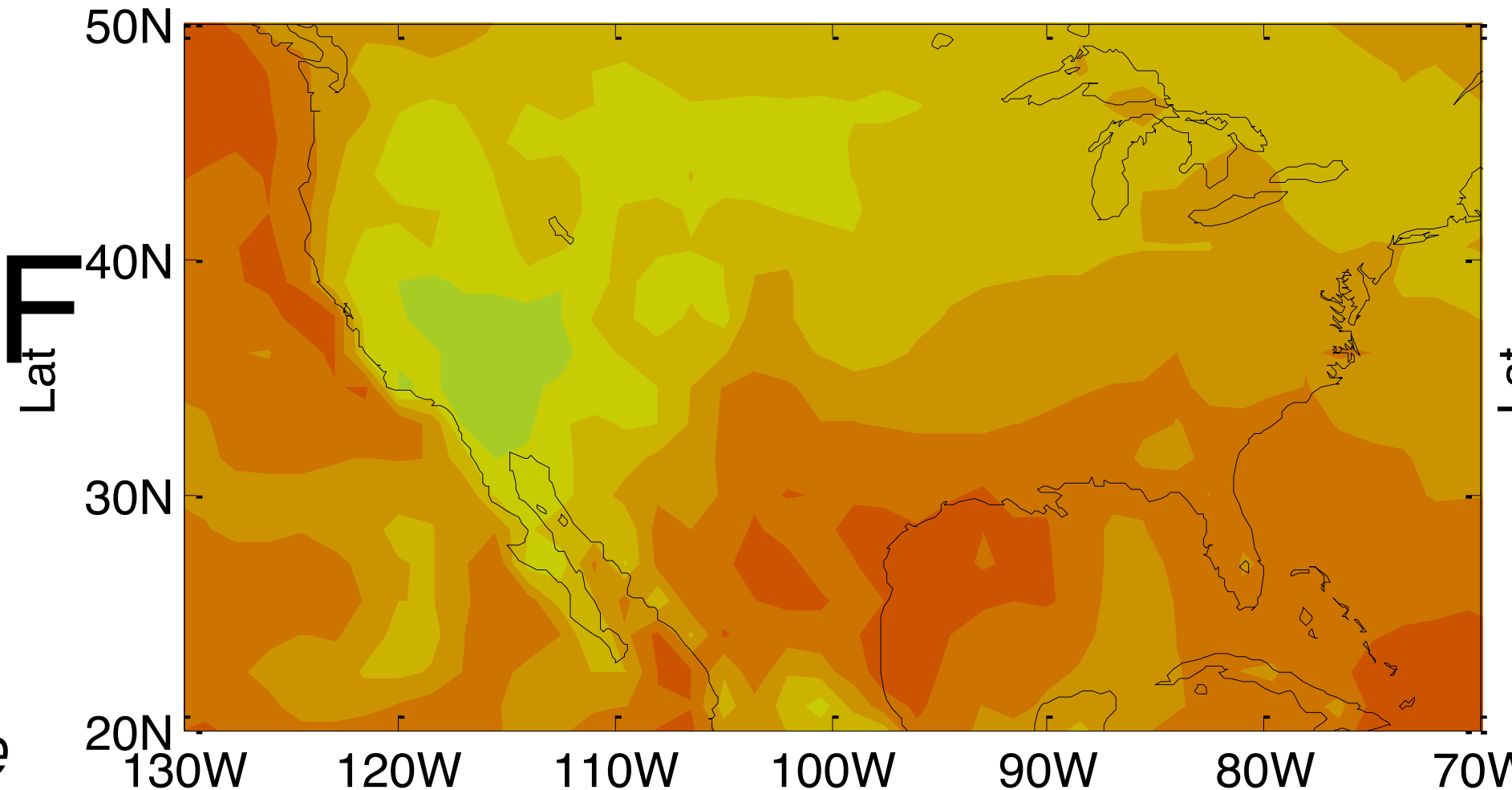
NCEP



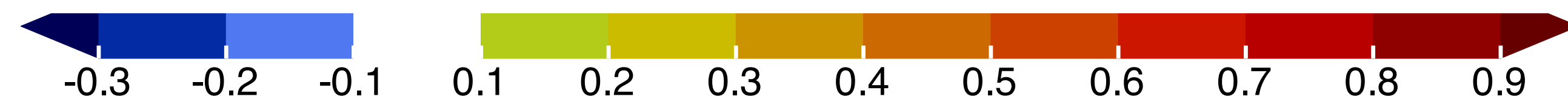
ECMWF

ECMF DJF Week-3&4 ACC

ECMF MAM Week-3&4 ACC



*NCEP MAM
performance
flagged*



Probabilistic Forecast Calibration using Quantile Regression

- **Distributional Regression** aims to provide the **conditional distribution** of the response variable given a set of explanatory variables
- **Quantile regression** is a reduced form in which the predictand is a quantile of the forecast PDF. **Logistic regression** is well suited to predicting a probability rather than a measurable physical quantity

$$\ln \left[\frac{p}{1-p} \right] = f(\mathbf{x}) \quad p = \Pr \{V \leq q\}$$

p is the probability of not exceeding quantile q
This equation is linear on the logistic, or log-odds scale

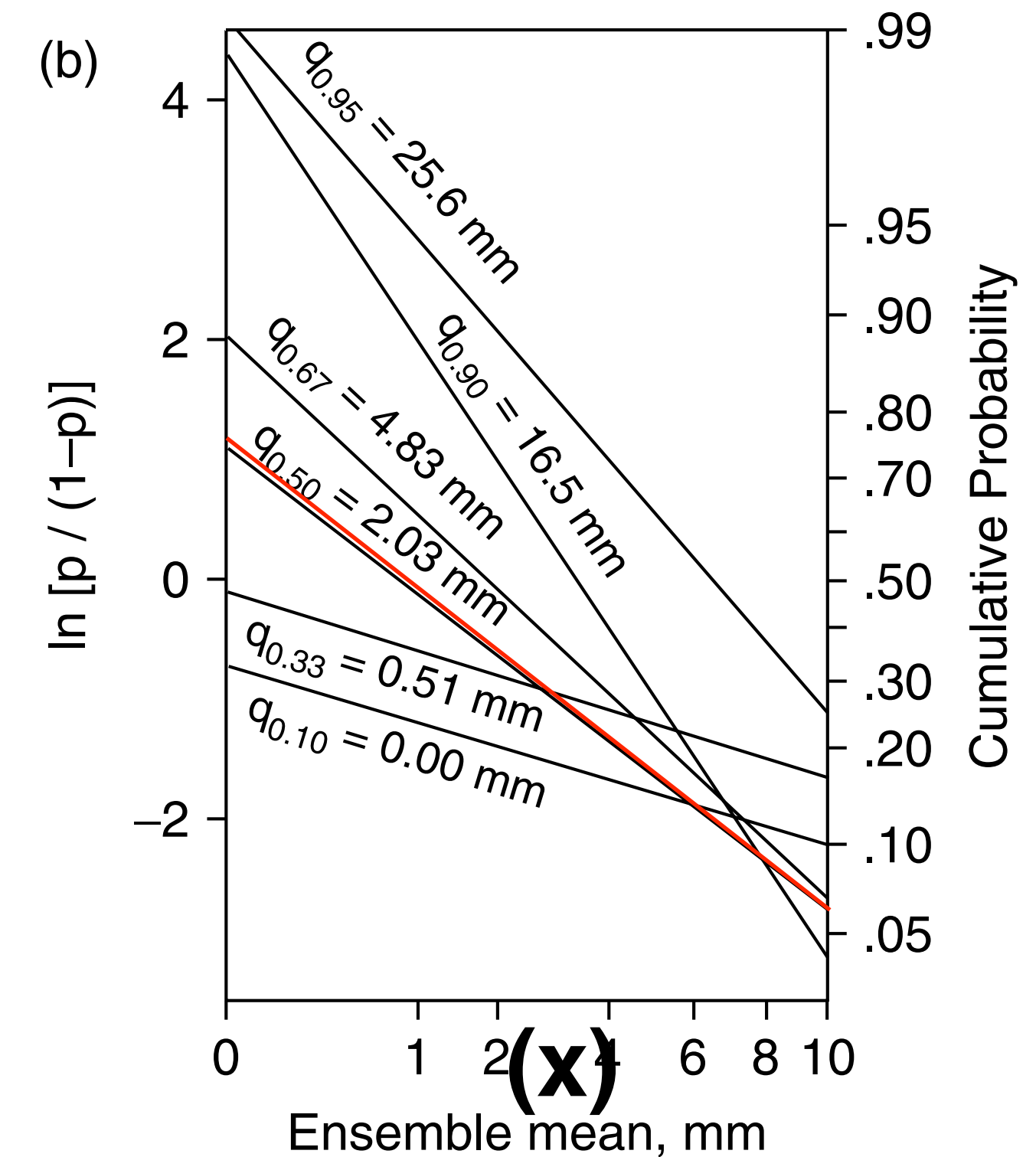
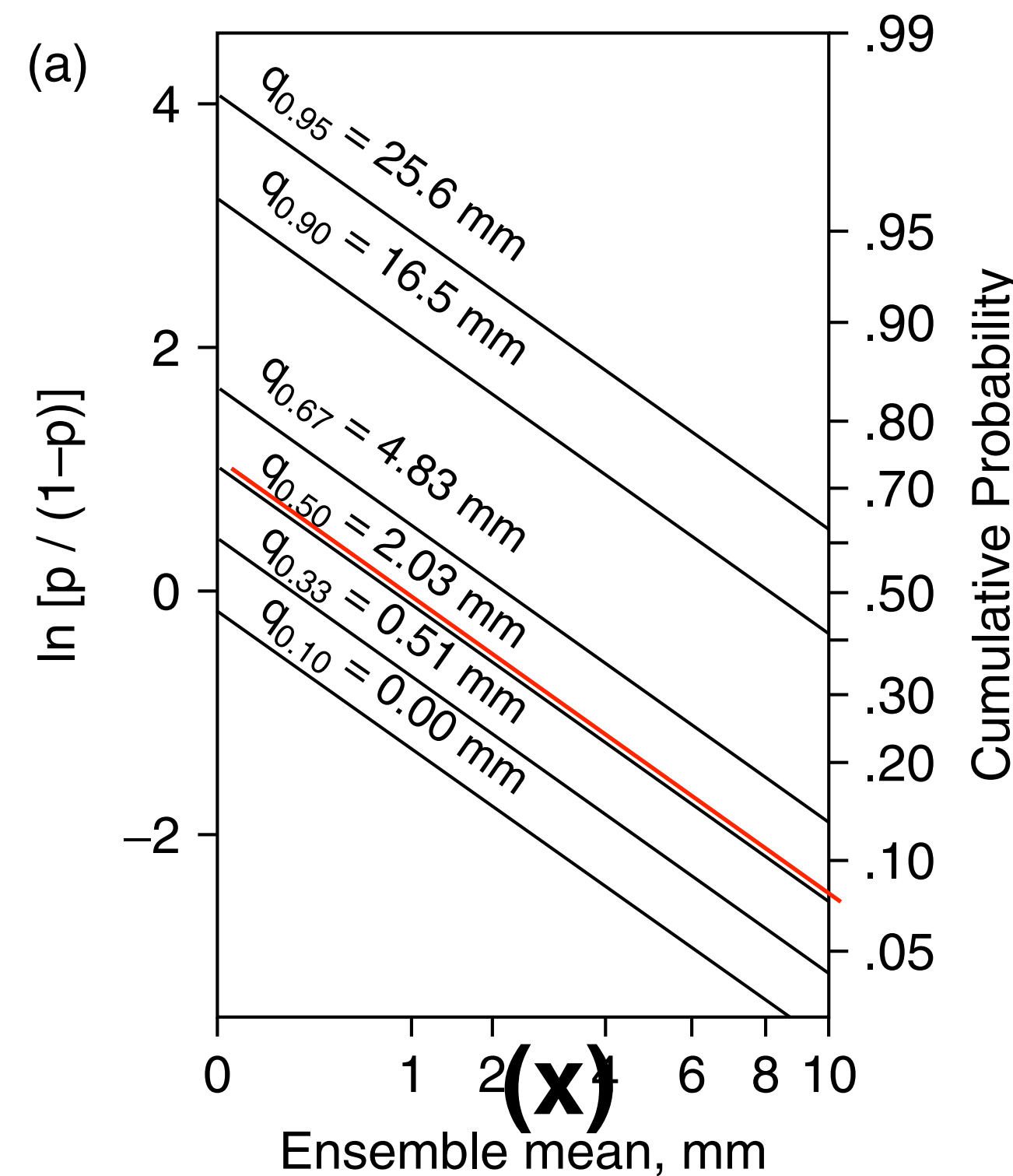
Extended Logistic Regression (ELR)

$$\ln \left[\frac{p(q)}{1 - p(q)} \right] = f(\mathbf{x}) + g(q)$$

$$\ln \left[\frac{p}{1 - p} \right] = f(\mathbf{x})$$

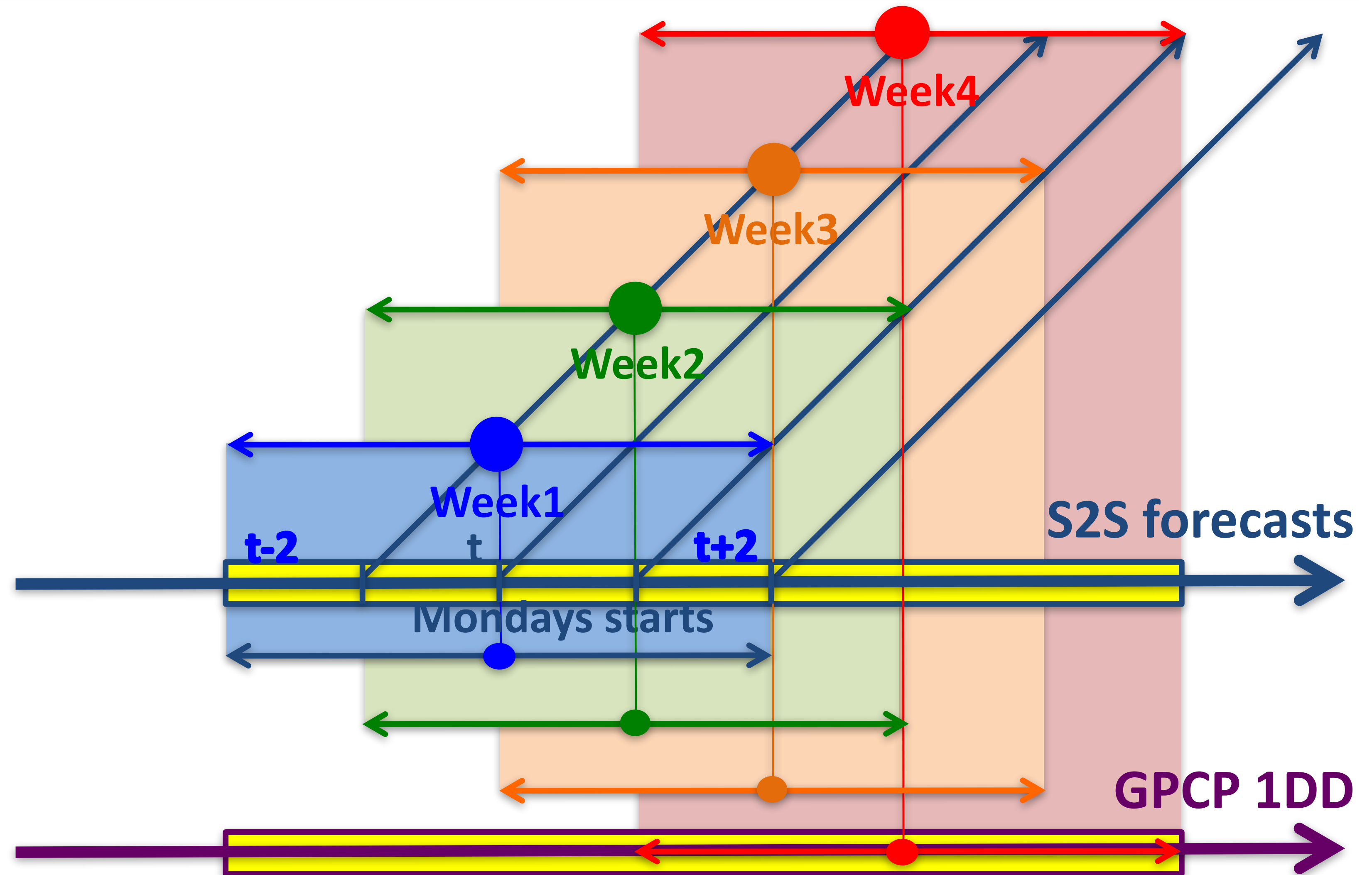
GFS Day 6–10 Precip
Forecast for Minneapolis
28 Nov – 2 Dec 2001

Wilks (2009)



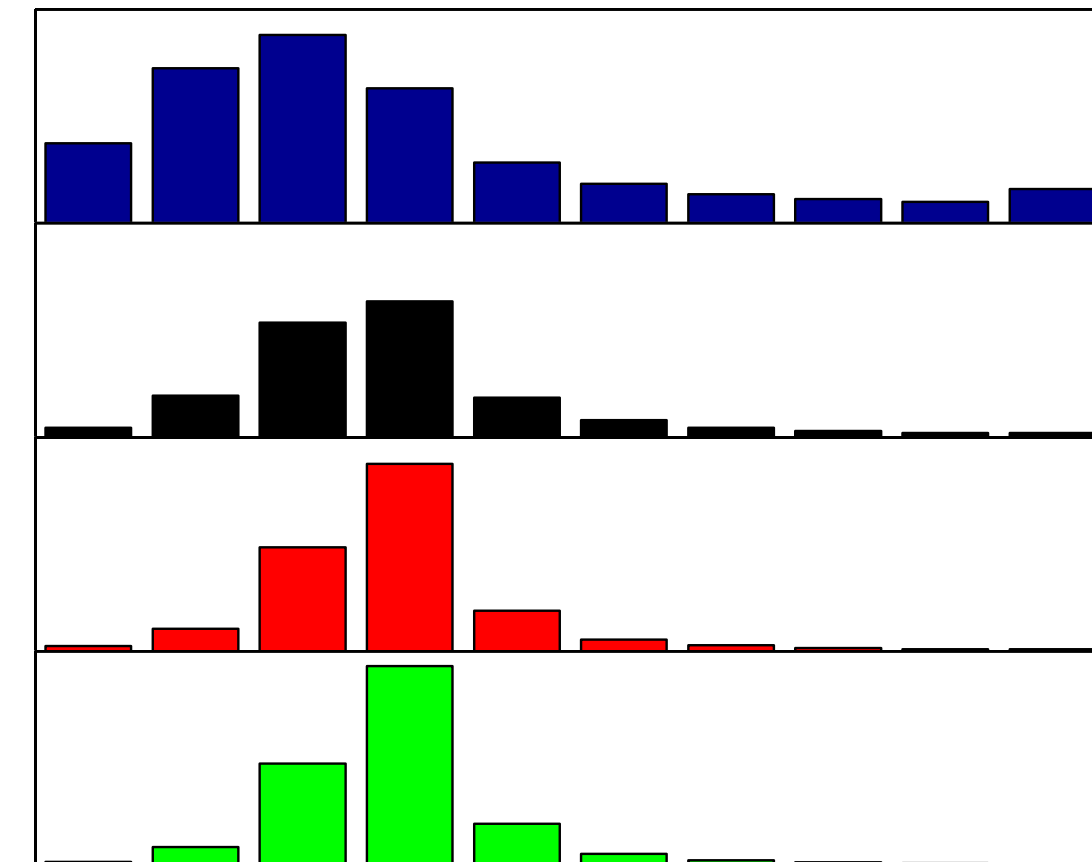
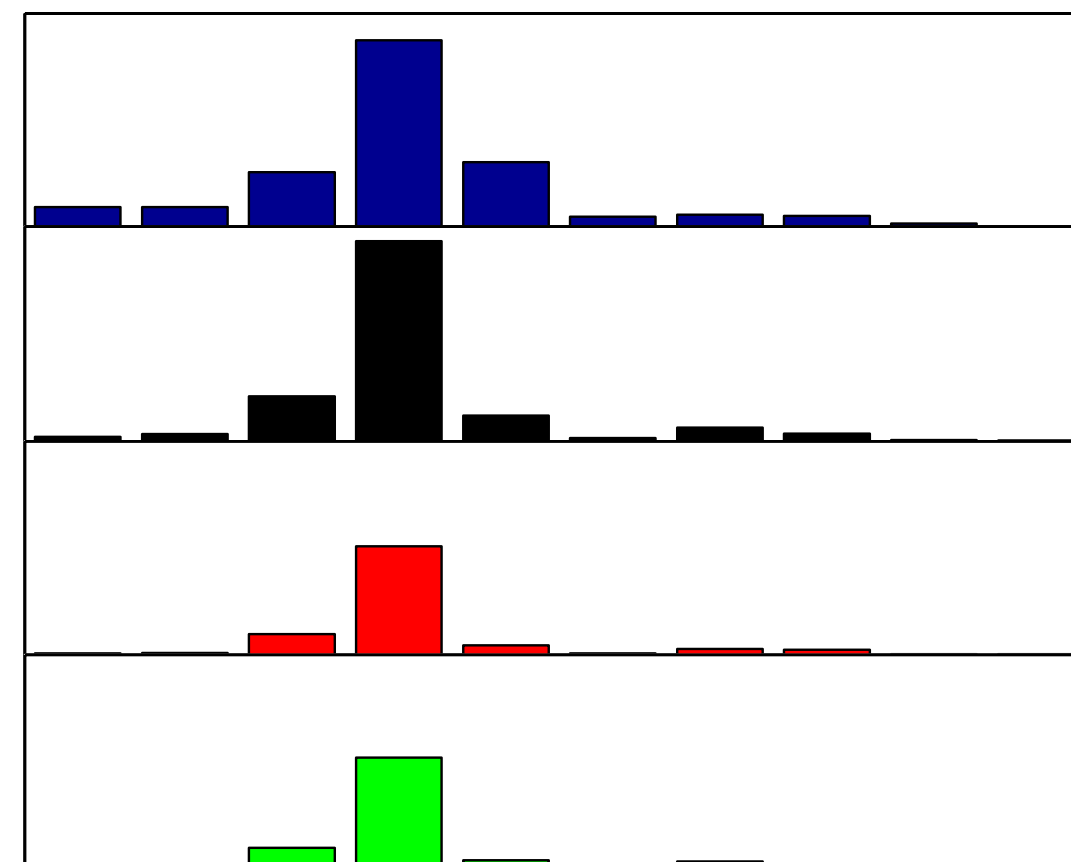
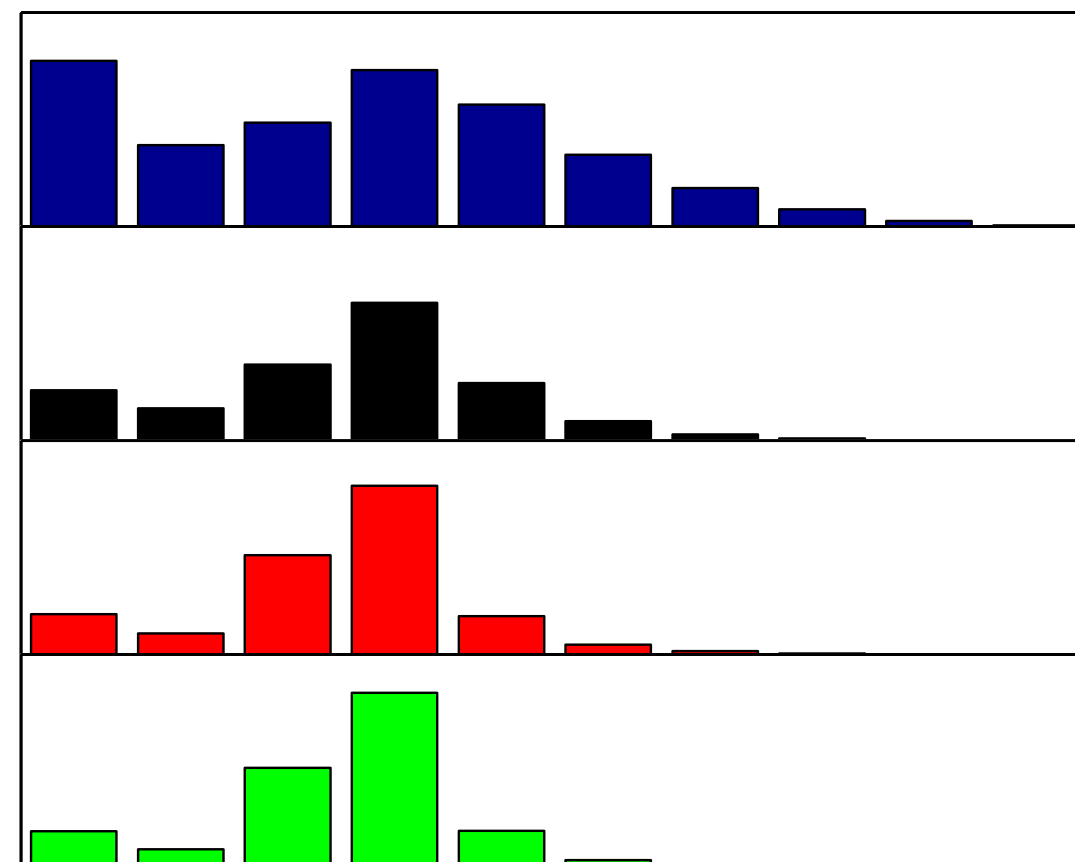
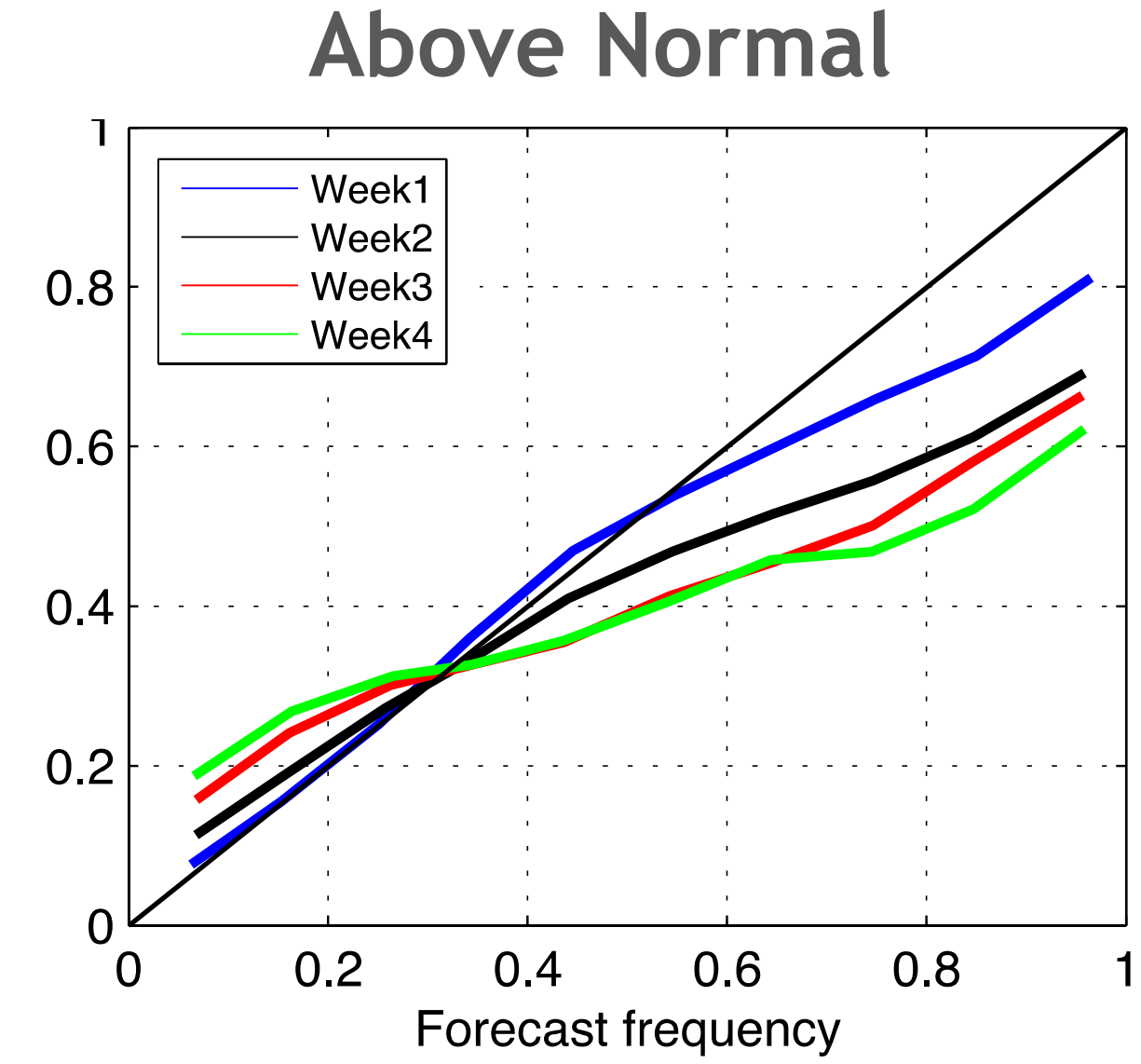
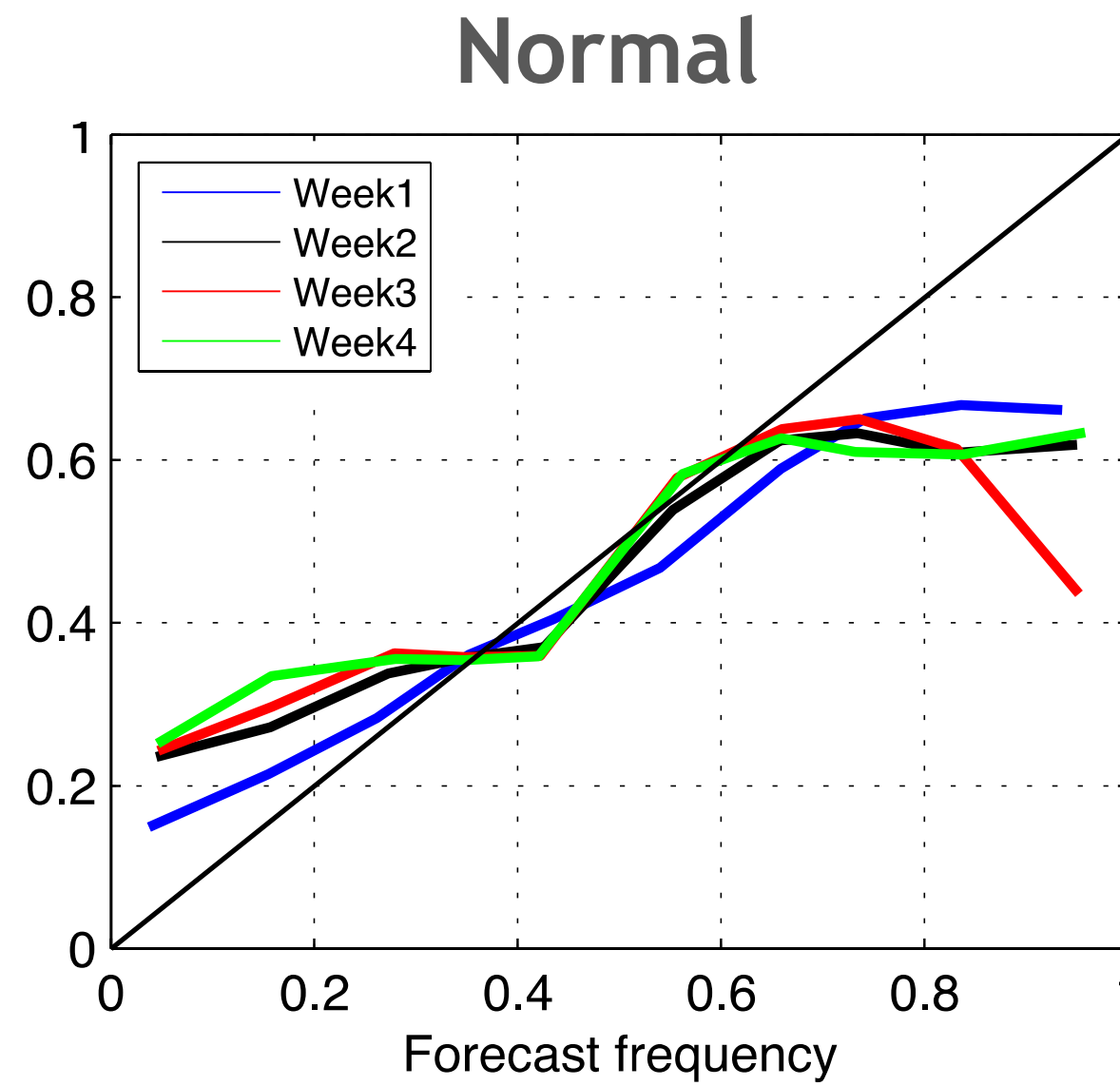
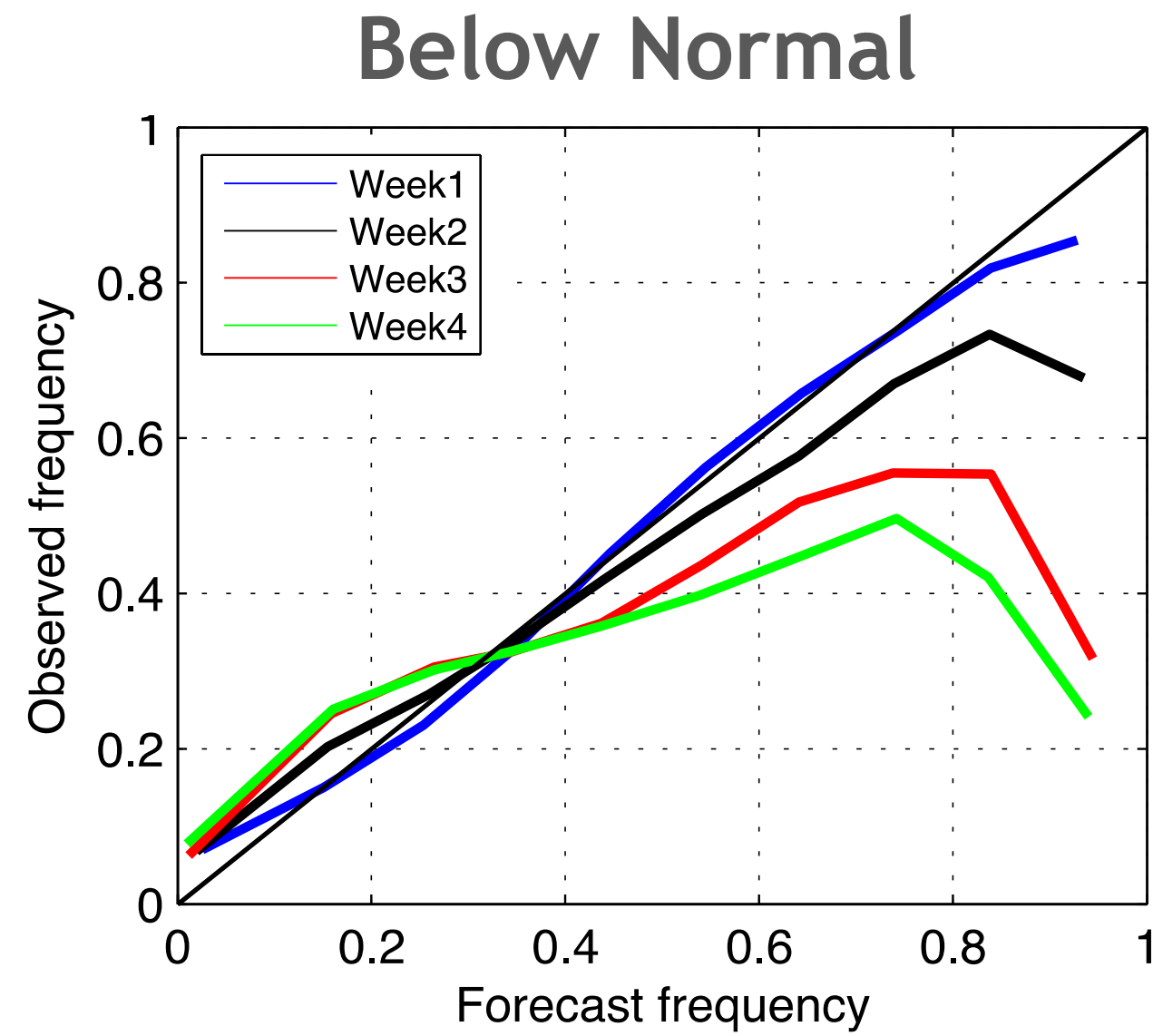
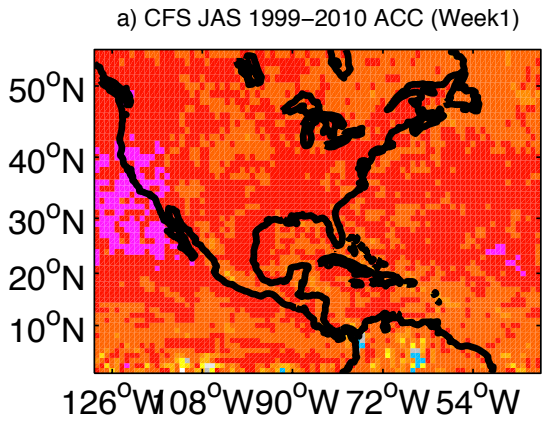
Extended Logistic Regression Set-up

1. Separate ELR for each grid point of the 10x10 GPCP 1° grid over N Am. (y)
2. Ensemble mean forecasts as x
3. Trained on weekly terciles computed from 5-weeks multi-year averages
4. Leave-one-year-out cross-validation, 1999-2010
5. Done for 1x weekly starts and from each GCM separately (11 ECMF, 4 NCEP, 4 CMA members)



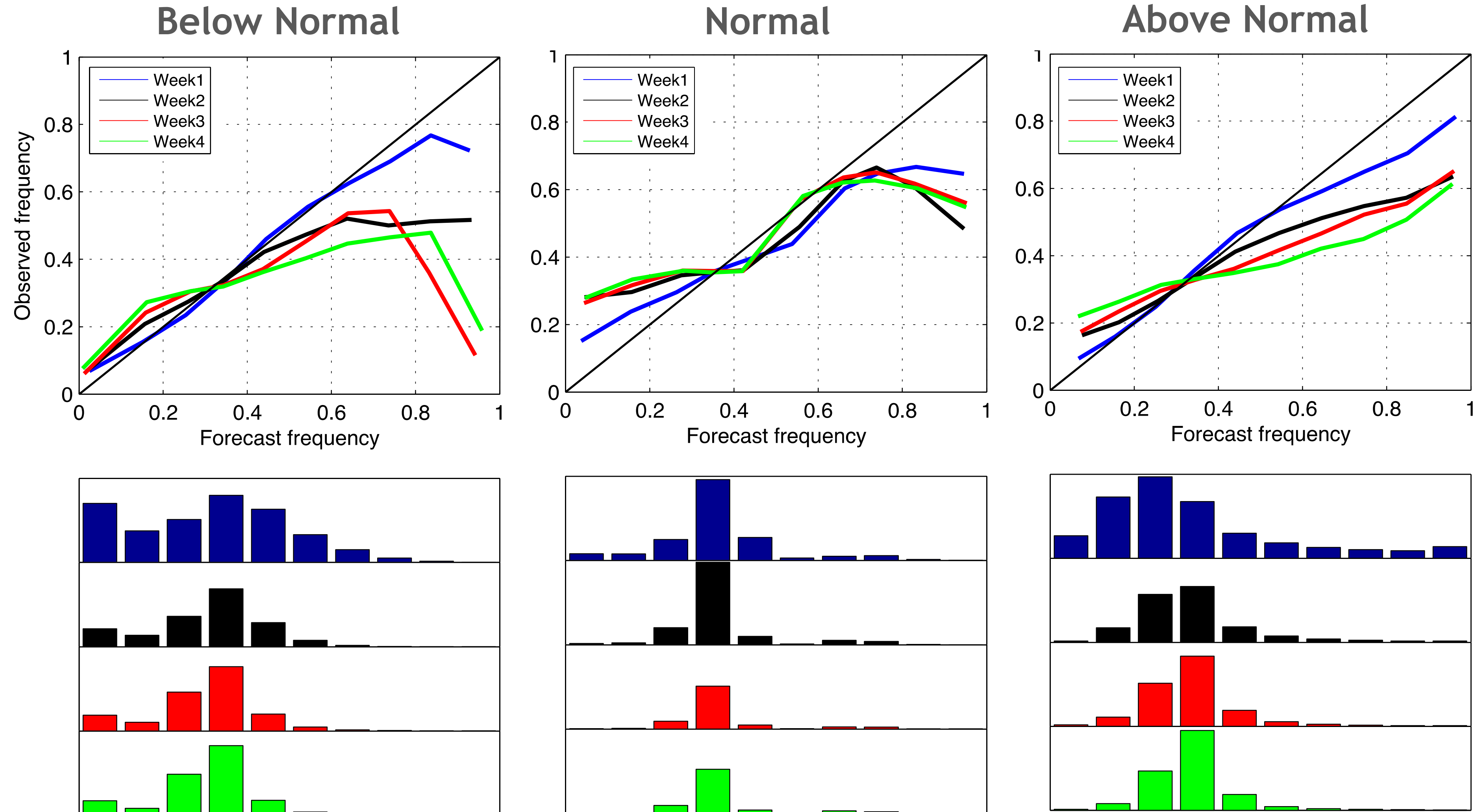
ECMF Reliability test: JFM 1999-2010

Diagrams below have been computed for all weekly starts of the JFM seasons from the 1999-2010 period using all gridpoints within N American sector (ocean+land points)



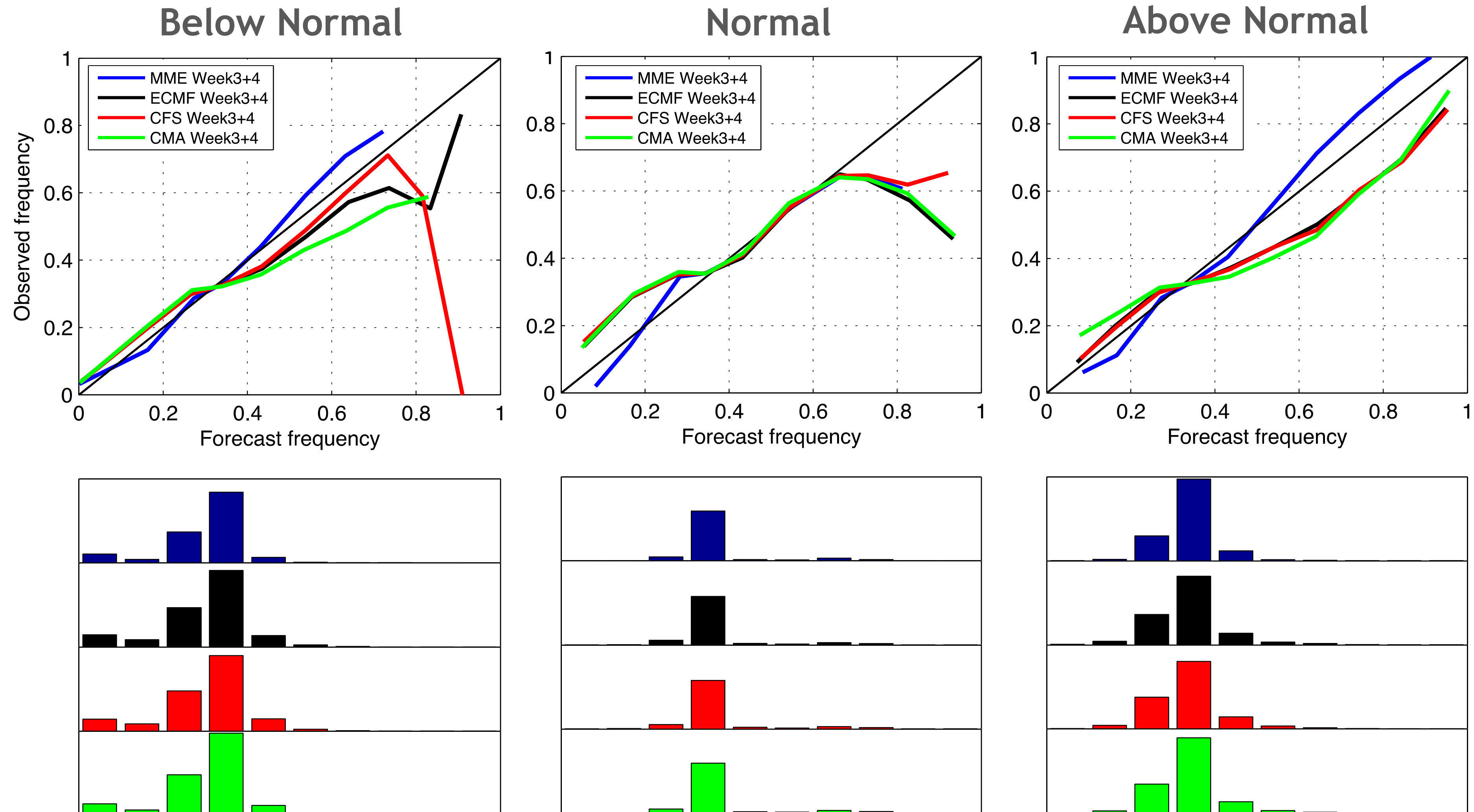
CFS Reliability test: JFM 1999-2010

Diagrams below have been computed for all weekly starts of the JFM seasons from the 1999-2010 period using all gridpoints within N American sector (ocean+land points)



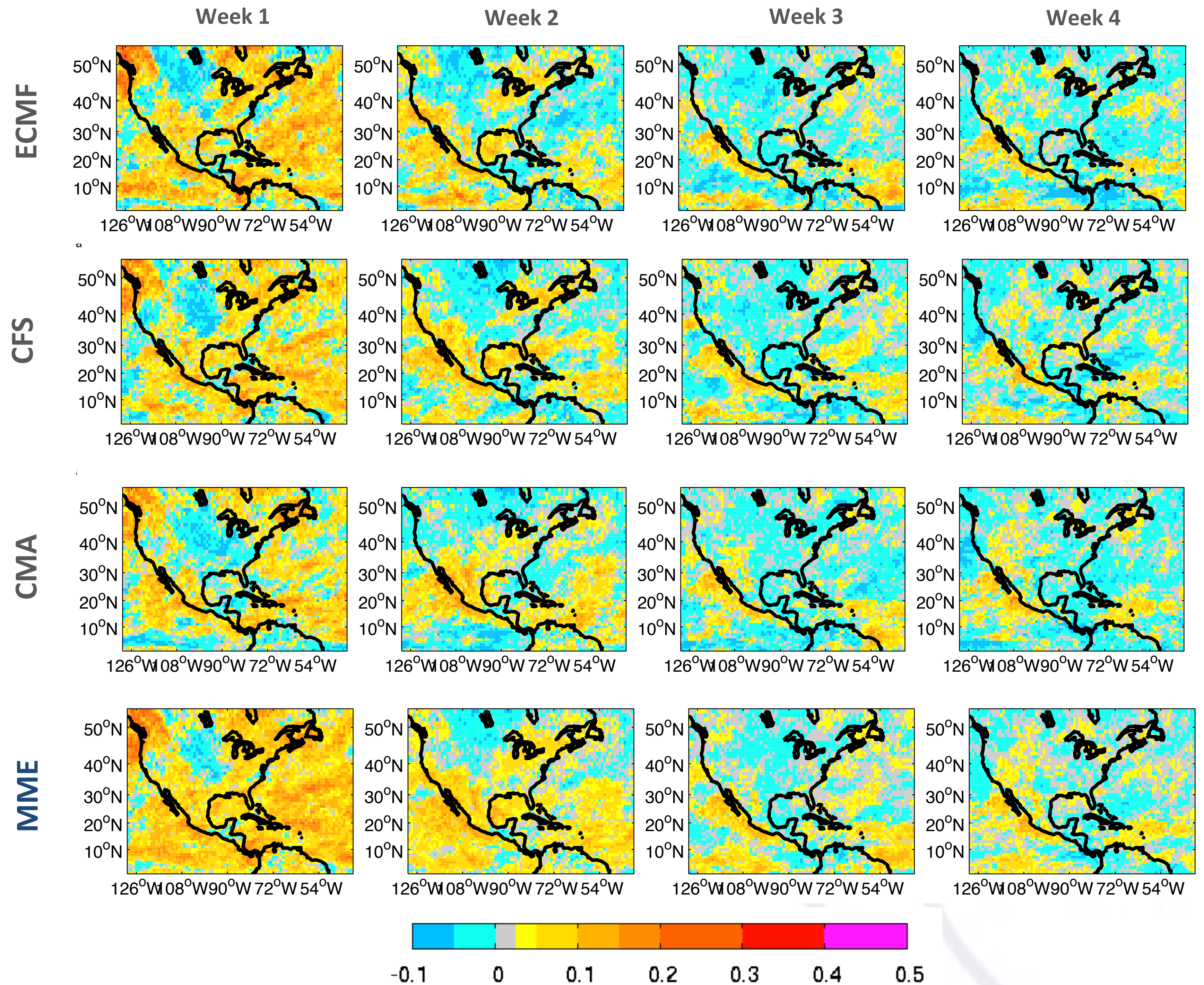
MME Reliability test Week3+4: JFM 1999-2010

Diagrams below have been computed for all weekly starts of the JFM seasons from the 1999-2010 period using all gridpoints within N American sector (ocean+land points)



RPSS

Precip, JFM
1999–2010



Summary of Main Results

- ECMWF and NCEP models have fairly comparable precip correlation skill, strongest in winter
- NCEP performance is comparatively poor in spring
- Extended Logistic Regression produces good probabilistic reliability in precipitation but sharpness and RPSS remain low, especially over land
- Multi-model combination of ECMWF+NCEP+CMA appears to improve reliability of tercile-category forecasts



NGGPS Columbia University Summary



- **Major Accomplishment in FY16:**
 - Archived subset of S2S forecast/re-forecast database in IRI Data Library (ECMWF, NCEP, CMA model subsets).
 - Evaluated ECMWF and NCEP week 1–4 re-forecast performance in weekly-averaged precip, 500hPa geopotential and 2m temperature (anomaly correlation, RME error).
 - Developed extended logistic regression calibration of sub-seasonal precip forecasts for ECMWF, NCEP and CMA models, together with a multi-model combination.
- **Priority Focus for FY17**
 - Improving extended logistic regression model for week 3-4 precipitation forecasts.
 - Diagnostics of ECMWF vs NCEP performance differences over the U.S.
 - Tailoring post-processing codes for NCEP usage.
- **Key Issue**
 - Developing well-calibrated sub-seasonal (week 3-4) probabilistic forecasts over the U.S.

Relevance to the priorities of R2O Initiative

- Area 2b. Service impacts: Weeks 3–4 forecast development
- Area 5. Advances in ensemble development.
- Area 6. Advances in post-processing

Planned Deliverables

- A peer-reviewed manuscript documenting individual S2S model performance (including CFSv2) over the U.S., with emphasis on weekly averages in weeks 2–4, gridded fields of precipitation and temperature, atmospheric indices such as the NAO and PNA, and diagnostics of predictability.
- A peer-reviewed manuscript describing the development and testing of the new MME methodology for sub-monthly forecasts.
- Implementation of a real-time S2S MME at CPC, built using the most skillful and models that are available to CPC in real time.
- Maintenance and updating of the North American Multi-Model Ensemble (NMME) archive of seasonal forecast model data in the IRI Data Library.

