# Developing and Testing a High-Resolution Ensemble-Based 6-10 Day Forecast System for Atmospheric Rivers and Heavy Precipitation over the Western U.S.

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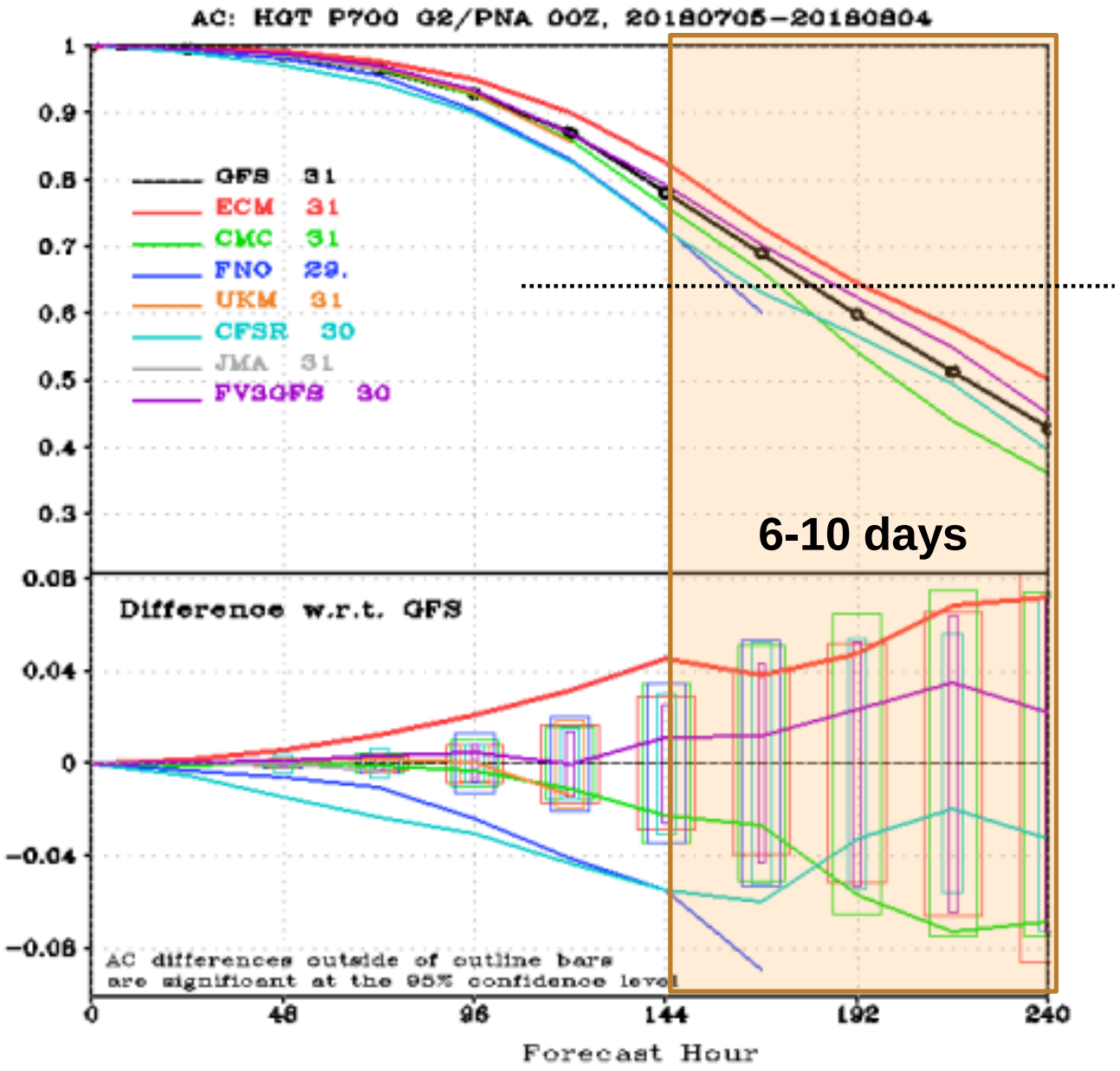
# Improving 1-2 Week Forecasts Over the Western U.S. with an Emphasis on Atmospheric Rivers

- Atmospheric rivers represent the most impactful weather feature of the western U.S.
- Associated with flooding, loss of life, and dam/reservoir safety.
- Skill in the second week can be critical, since it provides guidance for reservoir draw downs during multiple atmospheric river events
- The second event is the critical one

# 700 hPa AC die-off for the PNA Region



# This Project is Working to Attack the Problem in Two Main Ways

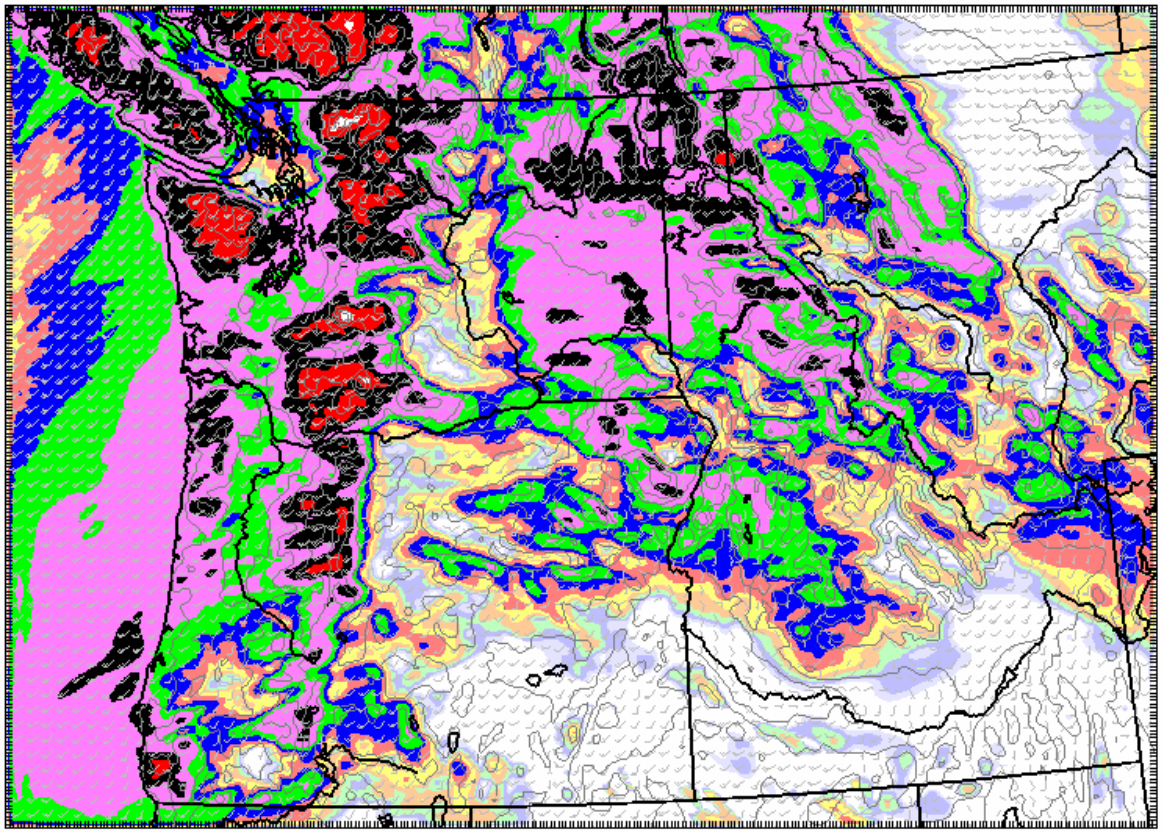
1. Test an operational 4-km ensemble system for the Northwest U.S., based mainly on GEFS.

2. Test an innovative way to improve upon GFS/GEFS: Ensemble Forecast Adjustment (EFA), which uses the temporal/spatial covariances from GEFS to improve week two forecasts.

## NOAA/NWS Forecasters and Others Need High-Resolution Ensemble Guidance for AR's

- GEFS is too coarse in resolution to get AR-related orographic precipitation correct in the mountainous West.
- GEFS has poor microphysics
- HREF is too small (7 members) and is poorly designed

UW MM5-GFS 4km Domain
Init: 00 UTC Mon 03 Dec 07
Fcst: 36 h
Valid: 12 UTC Tue 04 Dec 07 (04 PST Tue 04 Dec 07)
Total Precip in past 24 hrs (.01in)
Wind at 10m (full barb = 10kts)

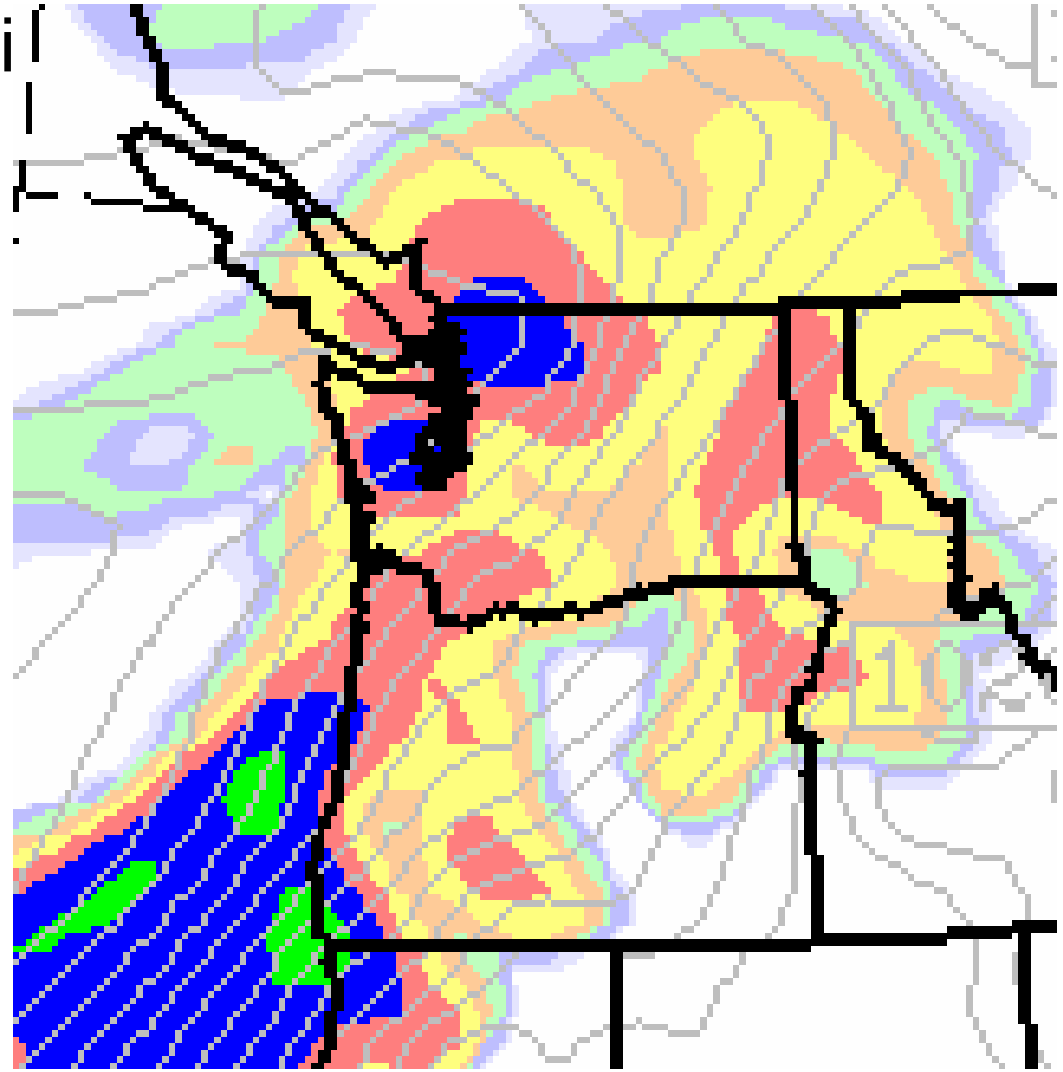


1/100 inch

0000 1 2 4 8 16 32 64 128 256 512 1024 2048

Model info: V3.7.4 Kain-Frsch MRF PBL Reisner 2 4 km, 37 levels, 1 sec

# 36-km: 3hr preci

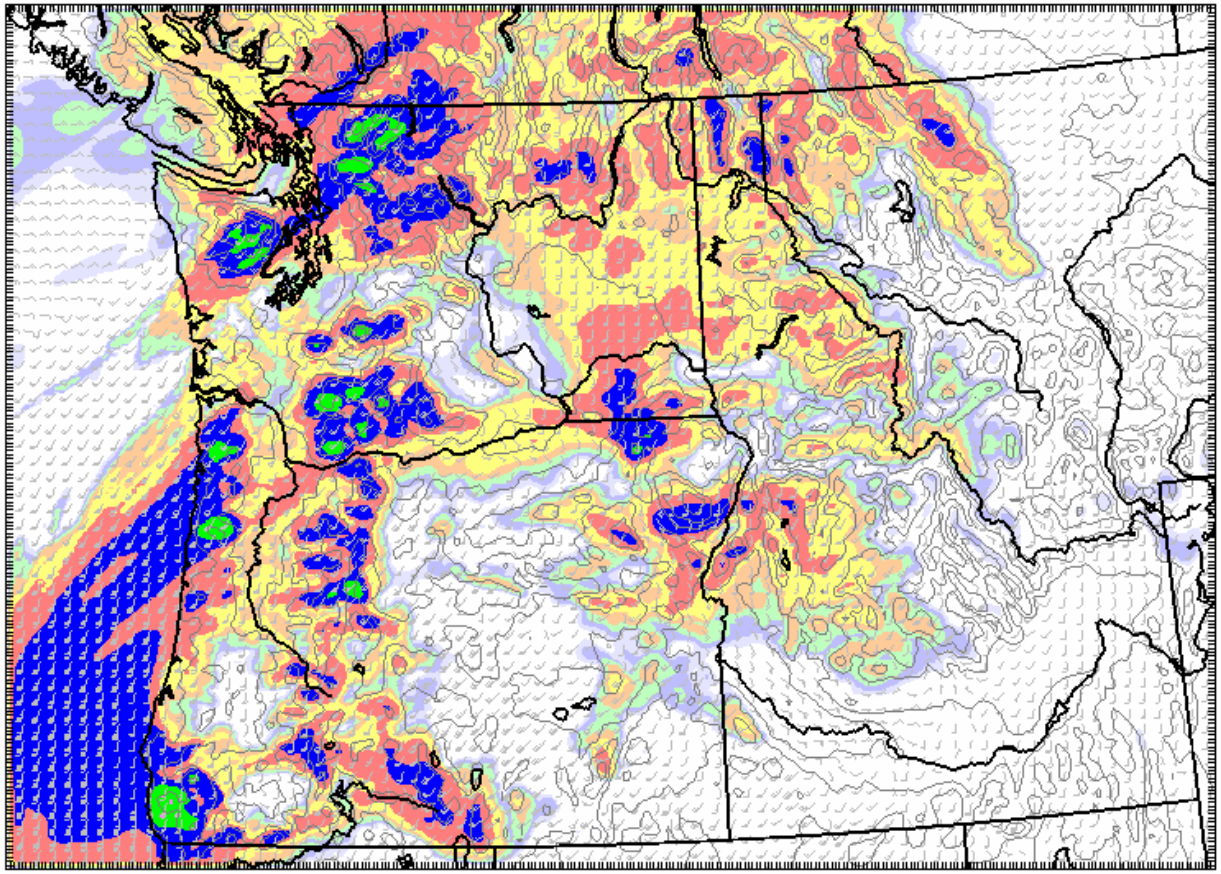


CONTOURS: UNITS=hPa LOW= 964.00 HIGH= 1038.0 INTERVAL= 2.0000

1/100 inch

.5 1 2 4 8 16 32 64 128 256 512 1024 2048

UW MM5-GFS 4km Domain
Init: 12 UTC Sun 02 Dec 07
Fcst: 12 h
Valid: 00 UTC Mon 03 Dec 07 (16 PST Sun 02 Dec 07)
Total Precip in past 3 hrs (.01in)
Wind at 10m (full barb = 10kts)

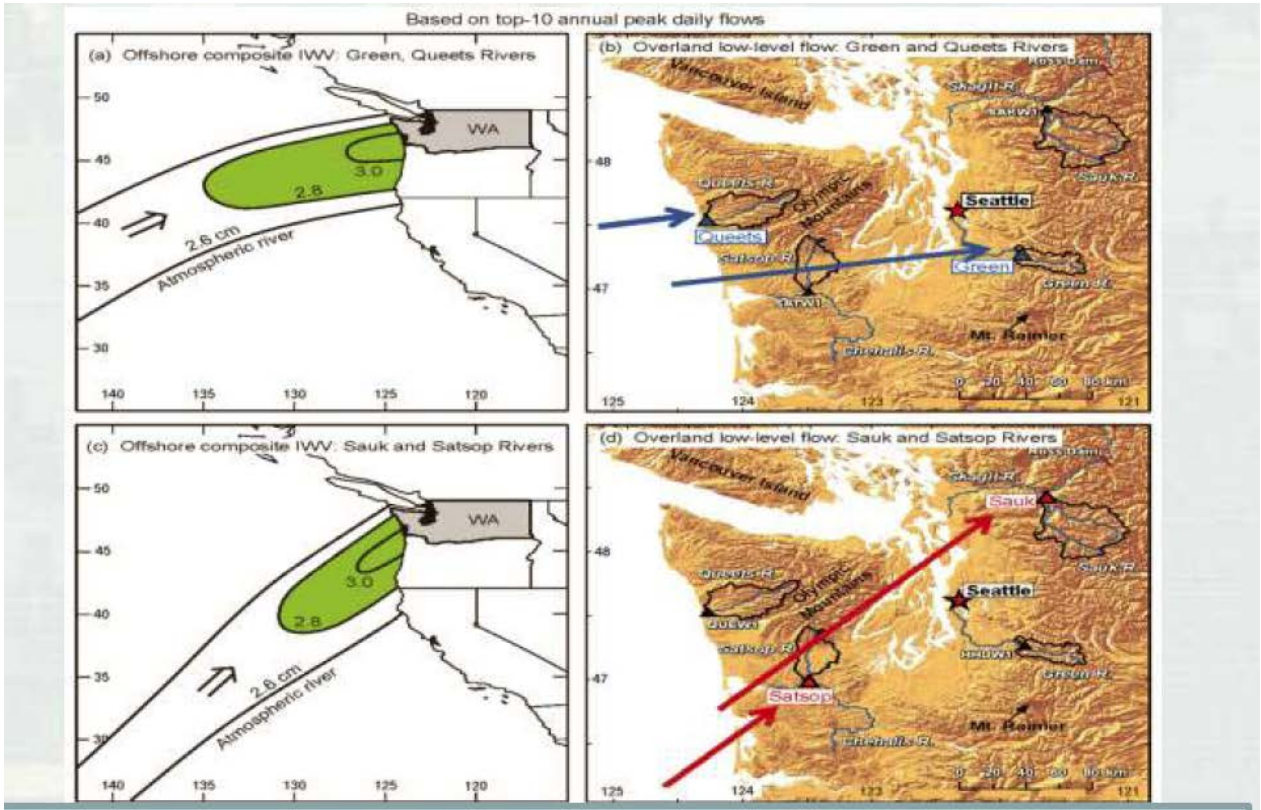


1/100 inch

.5 1 2 4 8 16 32 64 128 256 512 1024 2048

Model info: V3.7.4 Kain-Frsch MRF PBL Reisner 2 4 km, 37 levels, 1 sec

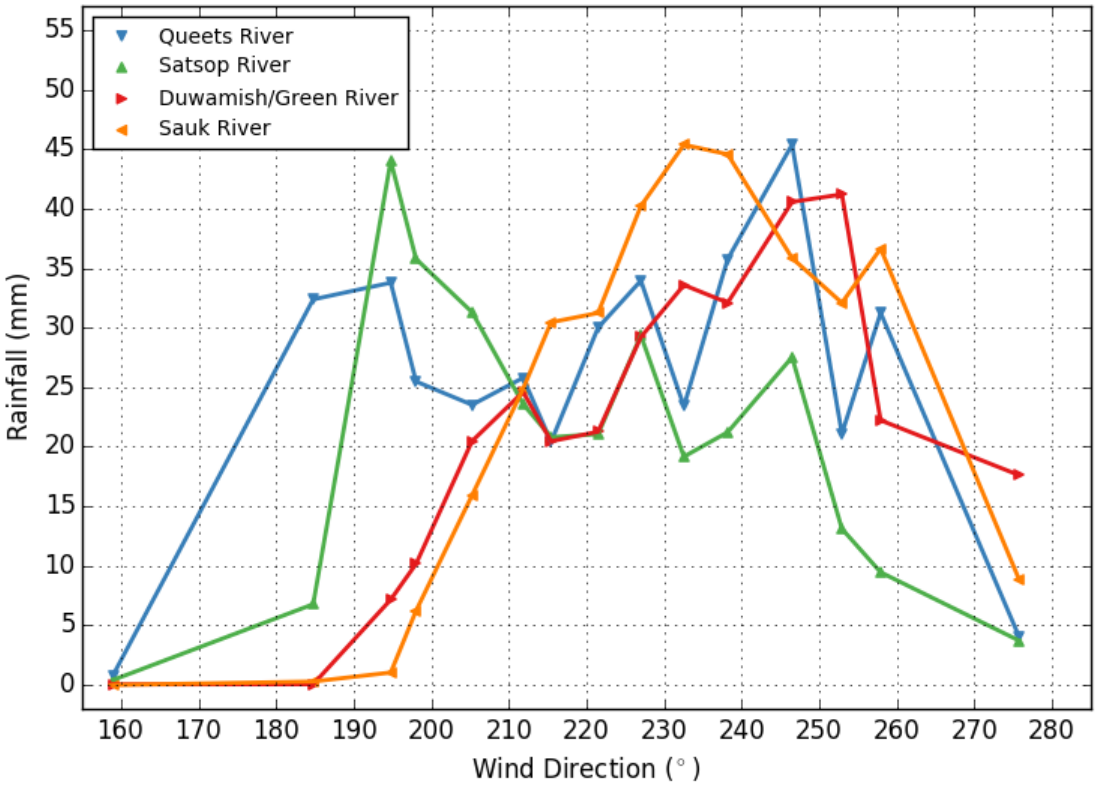
# Small Changes in Direction or Orientation Can Have Large Impacts on Precipitation

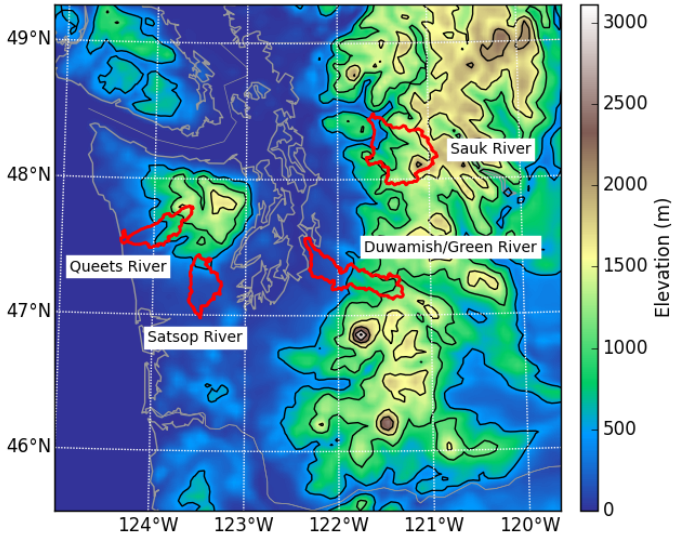



**AR orientation and river basins**

*Flooding in Western Washington: The Connection to Atmospheric Rivers*
(Neiman, Schick, Ralph, et al)

# Picard and Mass 2017



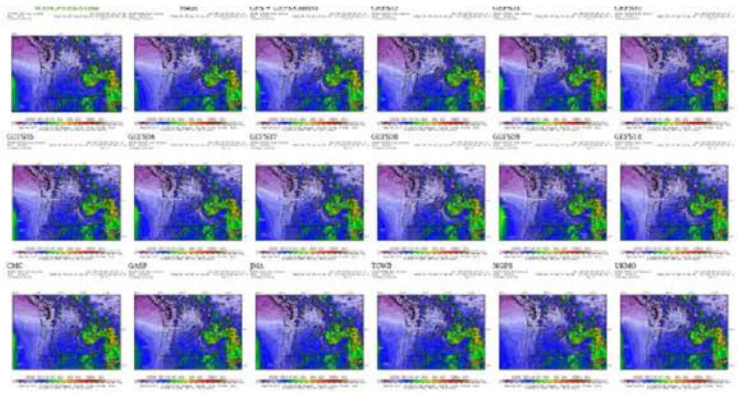
## Building a high-resolution West Coast ensemble system, with AR's being the most important use

- Run 25-30 members at 4-km using WRF ARW, with stochastic physics (stochastic kinetic energy backscatter (SKEB) scheme or the stochastic perturbation of physics tendencies (SPPT))
- IC and BC diversity from using 20 GEFS members, plus inputs from major global systems (UKMET, NAVY NAVGEM, CMC, Australia)
- Two cycles a day.  Initially 72 hr, but will eventually go to 240 hr with a subset.

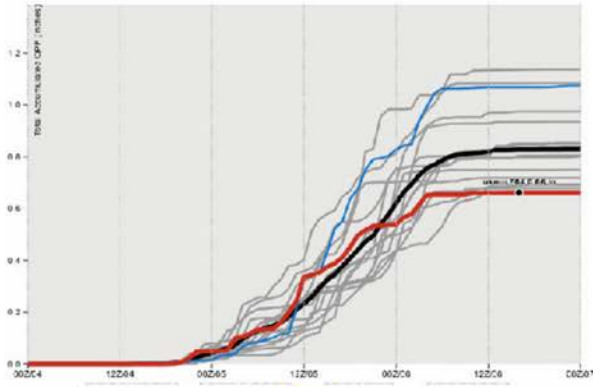
# Already working for the 00 UTC cycle (18 members)

**UW High-Resolution Ensemble Forecasts**

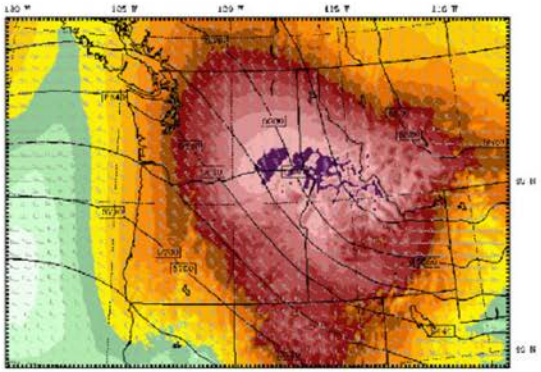
Supported by the Northwest Modeling Consortium. Return to Main NW Forecast Page.



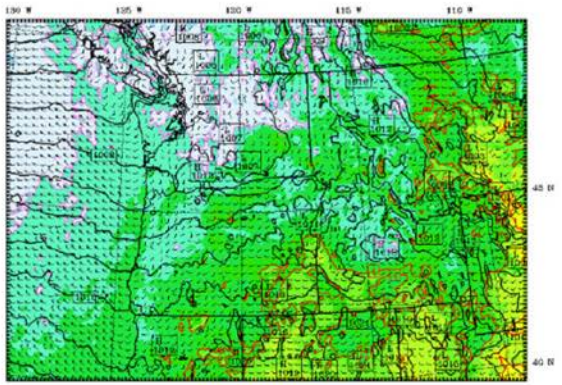
Show All Plots



Plumes



Mean and Spread



Loop Individual Members

**Adding stochastic physics and 12 UTC cycle this summer**

**By this fall, the convection-permitting ensemble will be ready for use by the forecast community for atmospheric river prediction**

**Subsequently, we can evaluate the value for the upcoming year.**

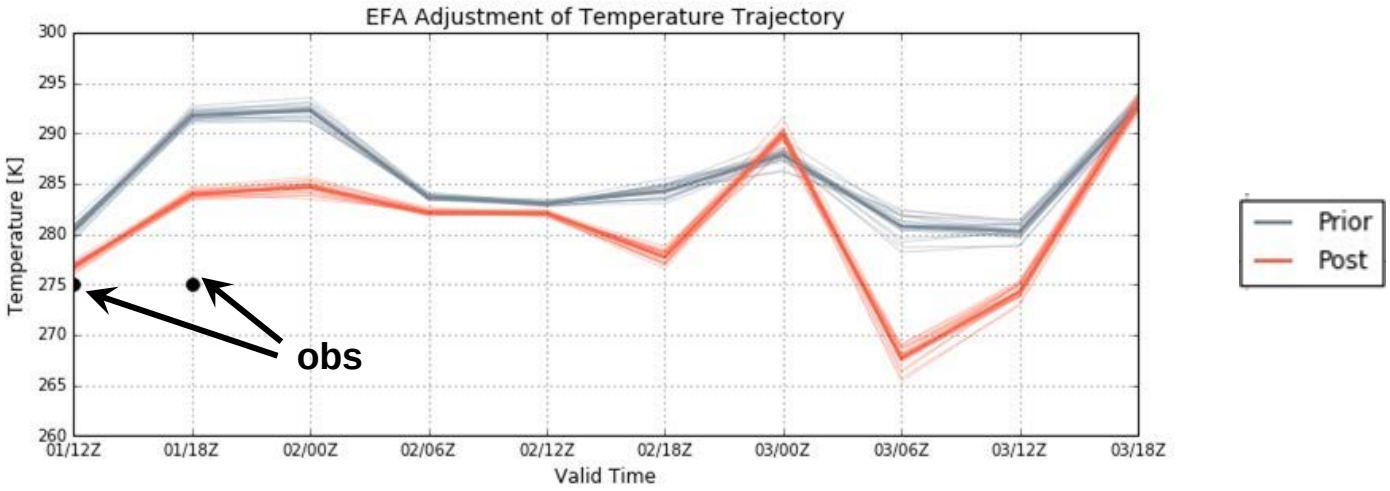
# Ensemble Forecast Adjustment

# **EFA**

Can we correct for some of GEFS deficiencies in week 2 statistically using ensemble temporal correlations?

# What is EFA?

**<u>Ensemble forecast adjustment</u>:** An offline data assimilation technique that uses *temporal* covariances in addition to spatial covariances to adjust the entire forecast using observations at one time (or several times) AFTER the forecasts are started.



## EFA Example

Consider a GEFS run at 00 UTC.

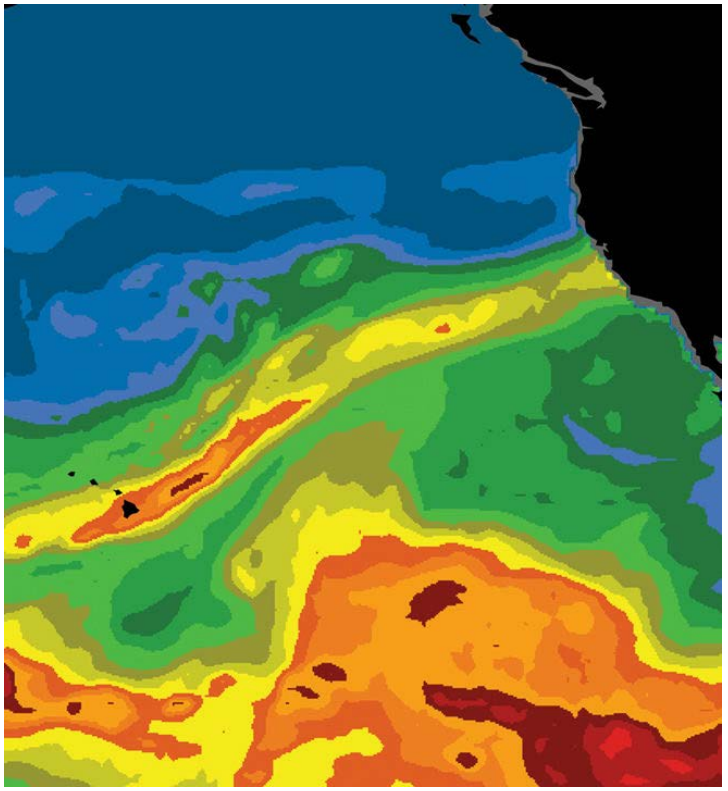
We can determine the error of the ensemble mean for say moisture flux at some point at 0300 UTC, telling us how far off the forecast is.

We can use the ensemble of forecasts to determine the correlation of the moisture flux at 0300 UTC at that point with other fields in the domain at future times.

We can then use the error to adjust the fields at future times.

# Application to Atmospheric Rivers

- We are now collecting a list of major atmospheric rivers that hit the West Coast during the past three years.
- We are also determining the subset for which the GFS/GEFS had major errors in week2.



# Current Work

- Have tested EFA for a couple of AR events.
- Rather than working with raw observations, we started by using analysis values to update the forecast.
- Applied EFA to assimilate sparsely sampled analysis grids (every third grid point at the equator, scaled by cosine of latitude elsewhere) for moisture flux
- Experimented with different analysis error variances and covariance length scales.
- Using GEFS, CMC, and European Center ensemble grids.
- Testing EFA on shorter forecasts first (48-h) using 6-h errors

# Preliminary Results: 14 Nov. 2015 AR

Analyzed moisture flux (color fill) at the verification time (00UTC 14 Nov.) and the 48h forecast valid at the same time in dashed lines.

Three ensemble systems

Classic AR

Solid lines show the 48h forecasted moisture flux field after EFA.

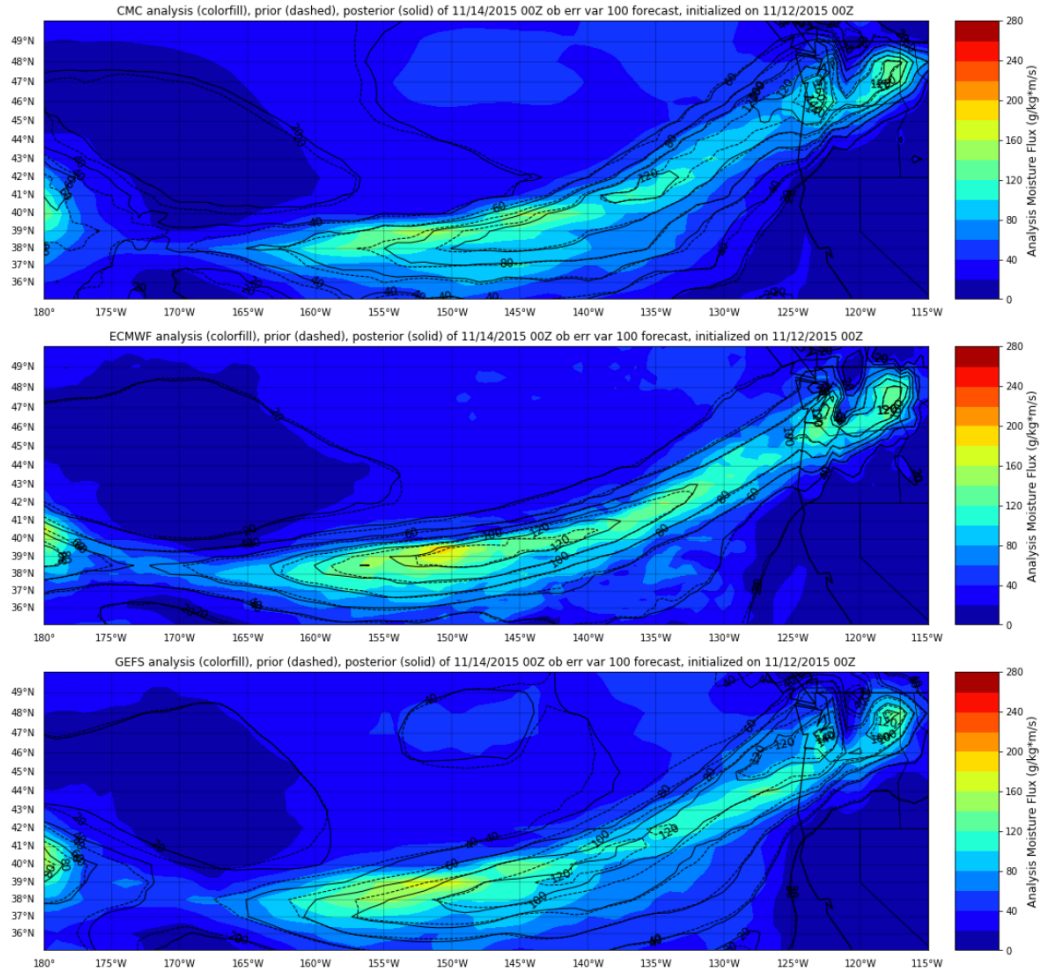



Figure 1. Moisture flux in the verifying analysis (colorfill), in the original 48h ensemble-mean forecast (dashed lines), and after EFA assimilation (solid lines). The CMC ensemble is shown on top; ECMWF in middle; and GEFS bottom.

Details of the changes introduced by EFA depend on the modeling system (CMC top, ECMWF middle; GEFS bottom)

Observations are doing two things: shifting the band of large moisture flux, and change the magnitude of the moisture flux.

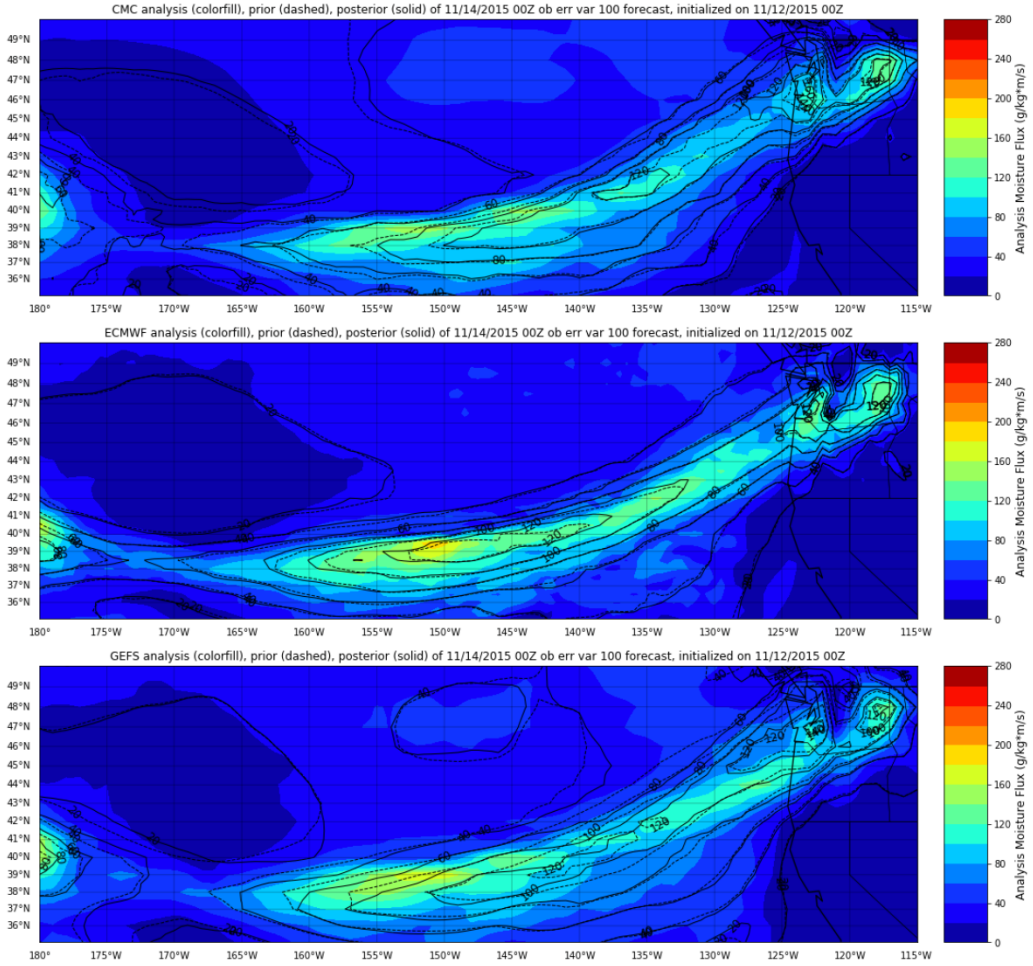
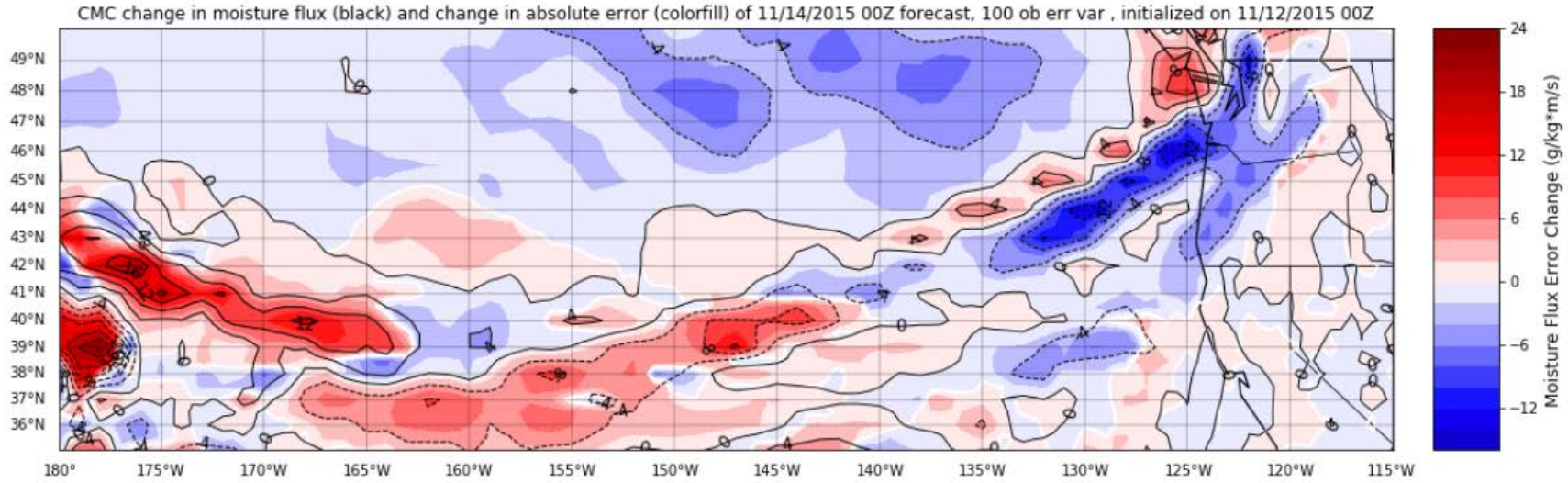


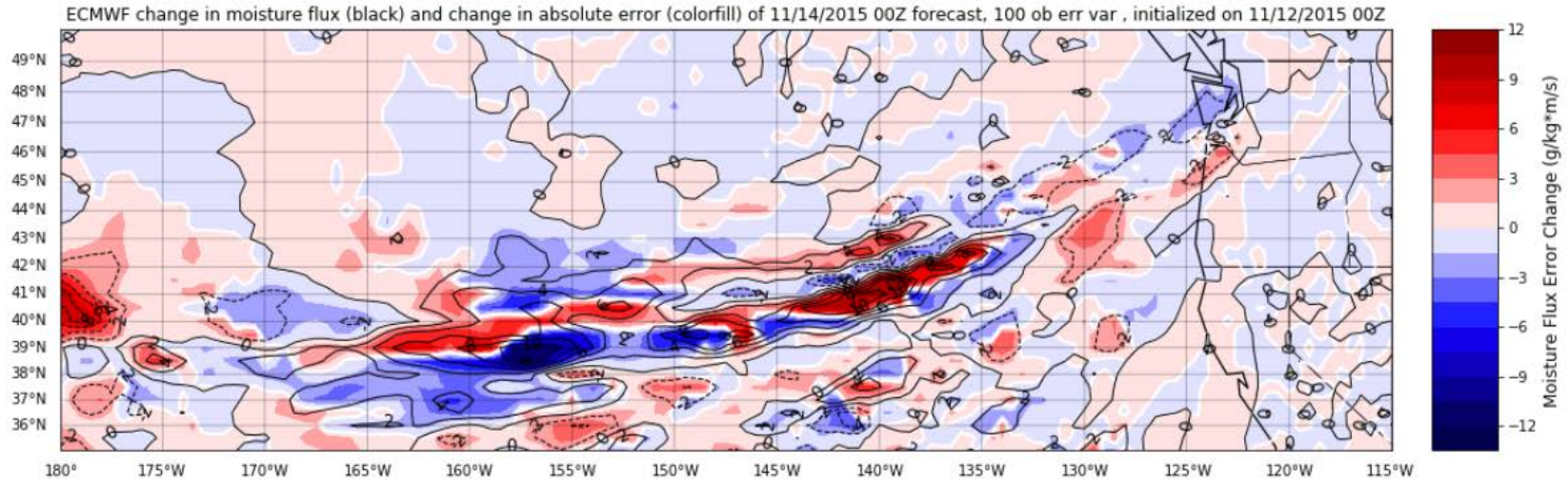

Figure 1. Moisture flux in the verifying analysis (colorfill), in the original 48h ensemble-mean forecast (dashed lines), and after EFA assimilation (solid lines). The CMC ensemble is shown on top; ECMWF in middle; and GEFS bottom.

**Next figure shows the change in in 48h forecasted moisture flux from EFA (contours), and the change in the ensemble-mean forecast error (color fill) due to EFA.**

**For the CMC ensemble, the main effect is a reduction in the moisture flux along the plume near the coast, which is associated with smaller forecast errors.**



For the ECMWF ensemble, the changes near the coast are small (the original forecast was quite good), and the larger changes offshore have a mix of positive and negative affect on errors



For the GEFS ensemble, the largest signal is an increase in moisture flux over Vancouver Island, which also increases forecast errors, and a reduction in moisture flux offshore along the band, which decreases forecast errors.

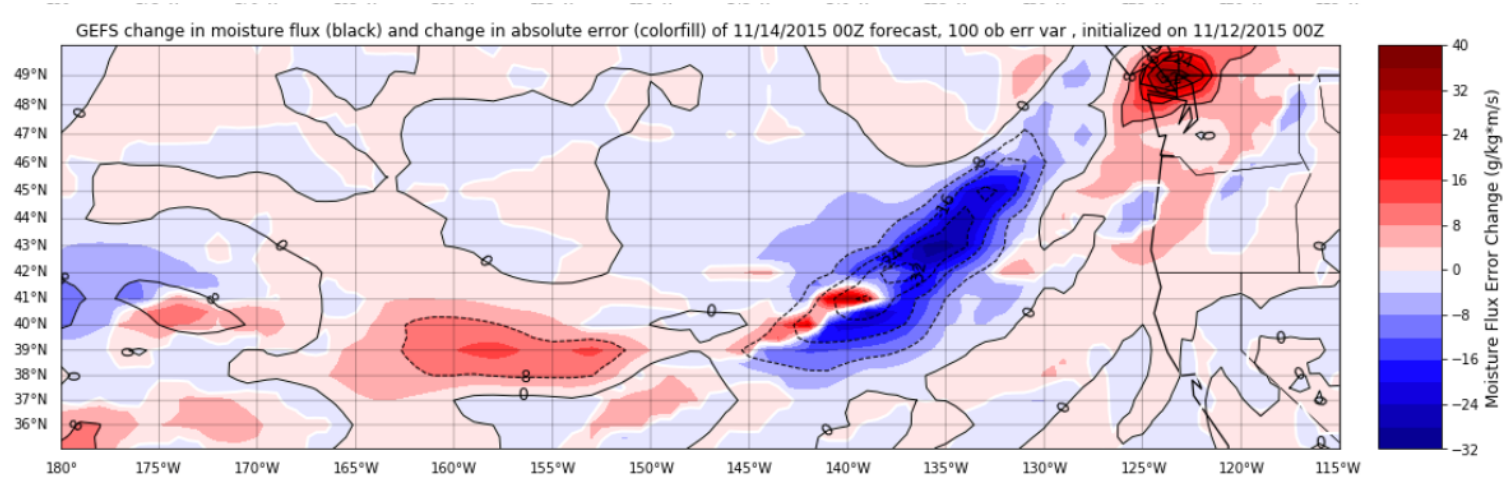



Figure 2. As in Figure 1, except for the change in moisture flux due to EFA (contours), and the change in forecast error due to EFA (colors).

# Initial Suggestions and Future Work

While this is just one case, it hints at the potential for EFA, since the largest reduction in error is indeed found where the changes are largest.

Ongoing research involves:

- Expanding this analysis to many cases, particularly model failure events
- Extending tests to 10 days
- Work on improving model-based covariances—intelligently deciding when to apply the changes..

The End