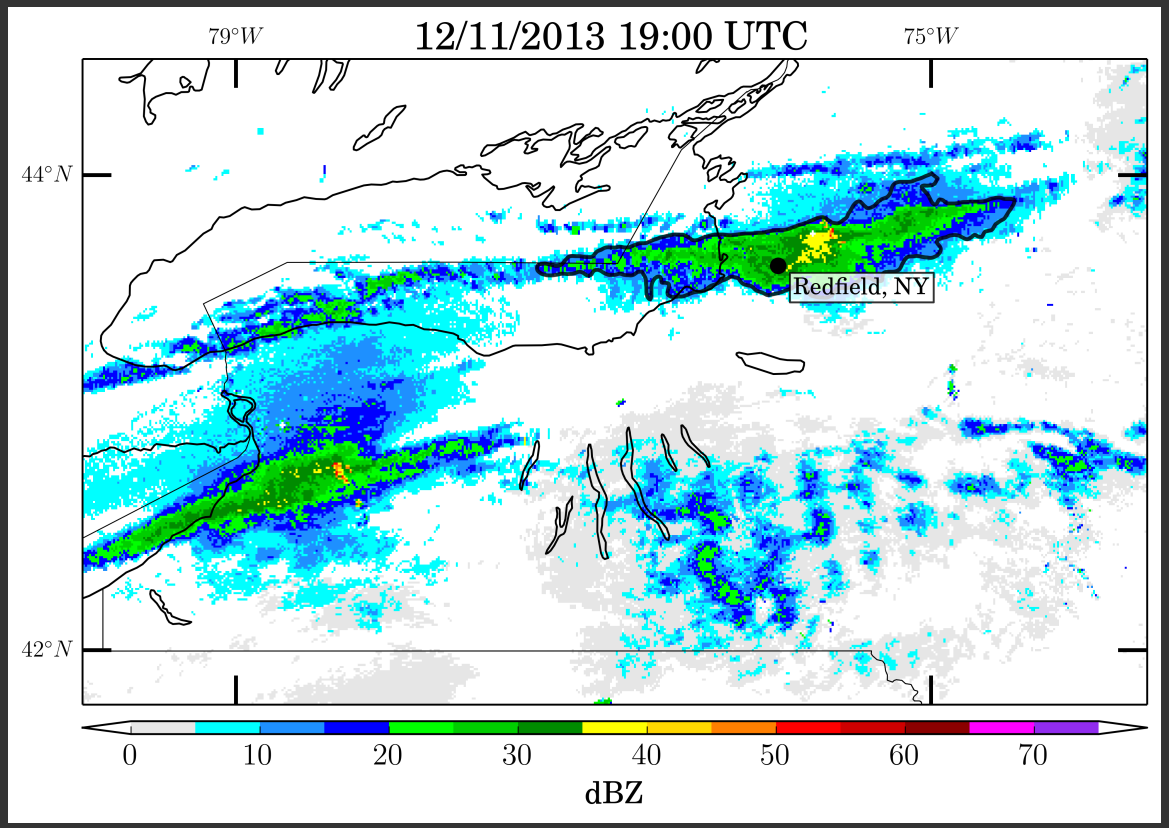
Lake-Effect Snow:

Evaluating forecasts of intense wintertime convection from a regional ensemble data assimilation system



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UMD-PSU DA Workshop 26-27 Jun 2017

Introduction

Just what exactly *is* lake-effect snow (LES)?

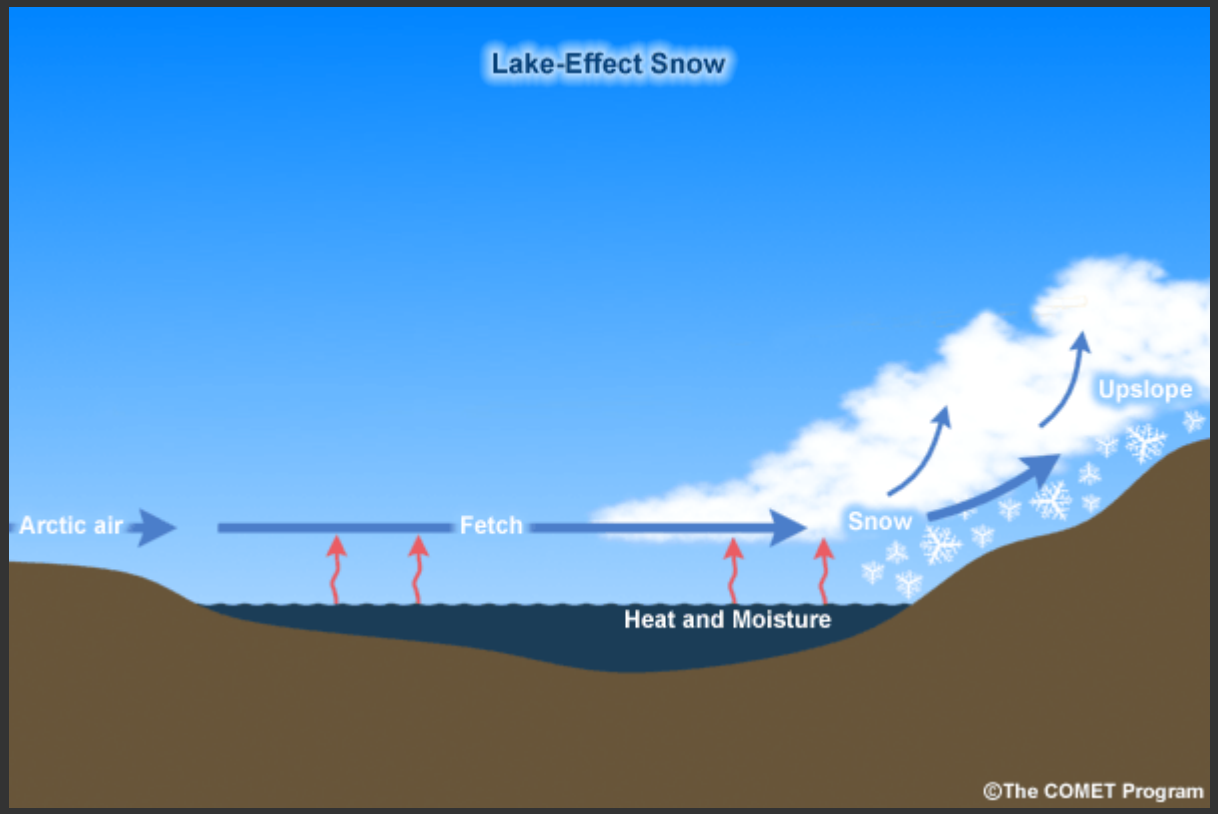


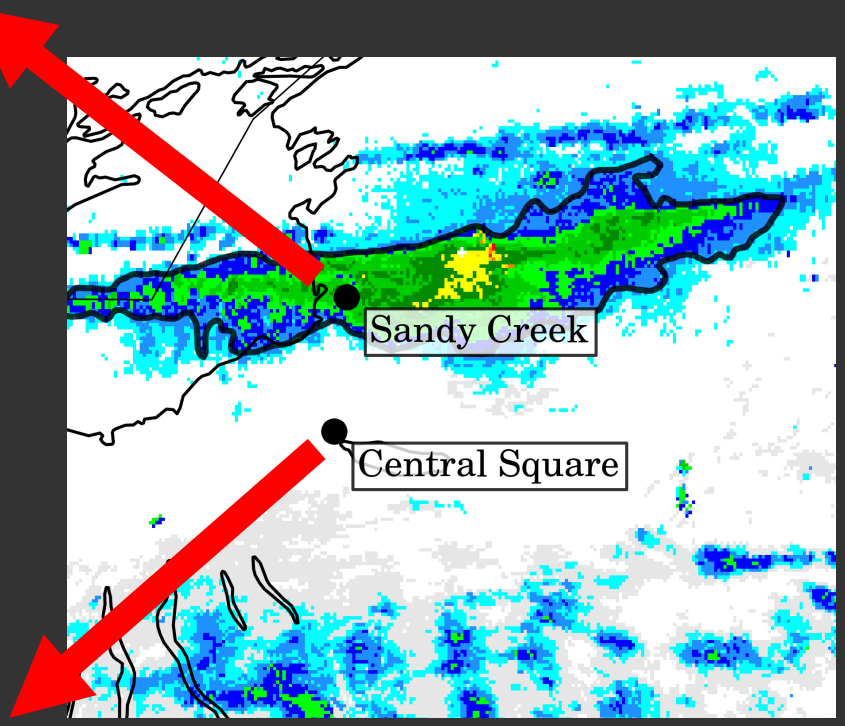
Image credit: UCAR

Important meteorological variables:

- lower-level wind speed and direction
- lower-level temperature and stability profiles (Niziol 1987, 1995)
- mid- and low-level temperature advection (Eipper et al., in preparation)

Important environmental variables:

- lake surface temperature
- lake surface ice coverage (Cordeira and Laird, 2008)
- lake shape and orientation (Laird et al., 2003)
- local topography at lake shore and inland (Onton and Steenburgh 2001; Alcott and Steenburgh 2013; Veals and Steenburgh 2015)



25 miles apart...

Questions

• Can a regional convection-allowing ensemble, with the contribution of higher-resolution DA, improve LES forecasts?

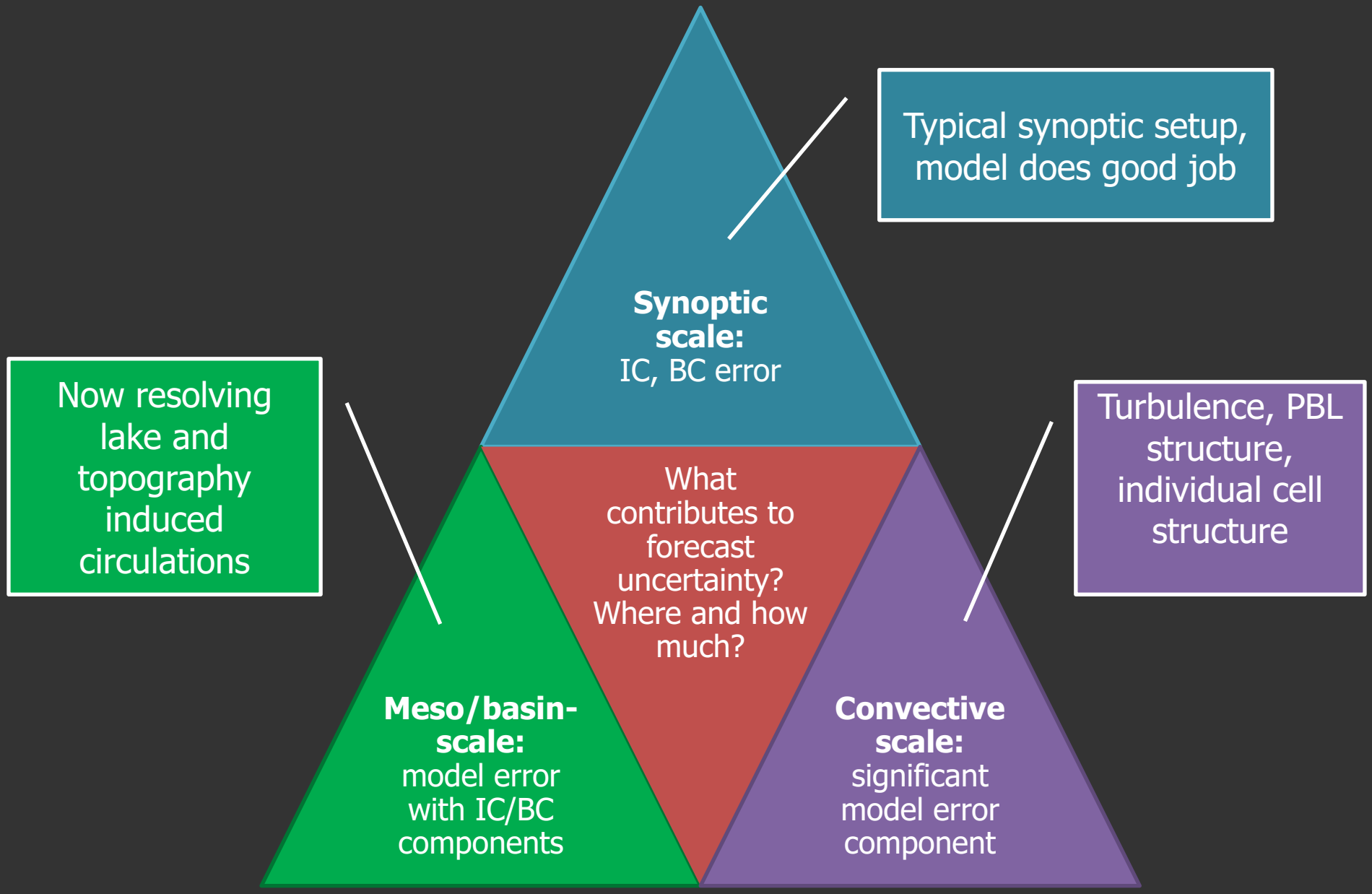
• What can we learn about the practical predictability timescales of LES processes?

Objectives

• Design and evaluate a regional enDA forecast system for eastern Great Lakes LES

• Explore predictability aspects of LES, including band properties and precipitation

A multi-scale applied predictability problem



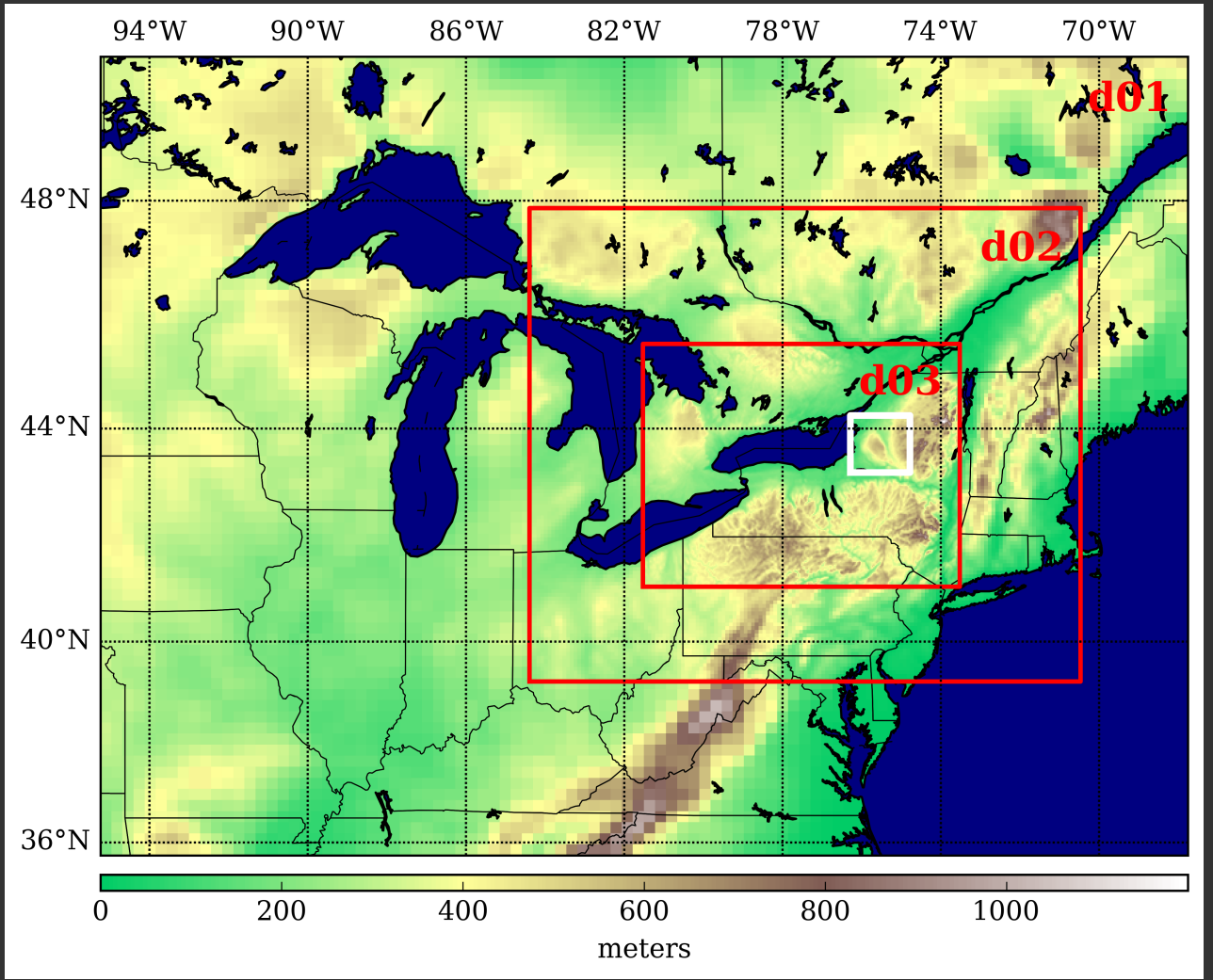
Ensemble Design

- Single physics ensemble
- Regional, balance resolution with computational time (R2O ideas)

Weather Research and Forecasting (WRF) V3.7.1

3 nested domains:
27, 9, 3 km
43 vertical levels

Parameterizations selected include:
Thompson MP;
MYJ PBL, Eta surface layer, NOAH LSM;
Dudhia & RRTMG short/longwave schemes;
Grell 3D cumulus domains 1&2 only



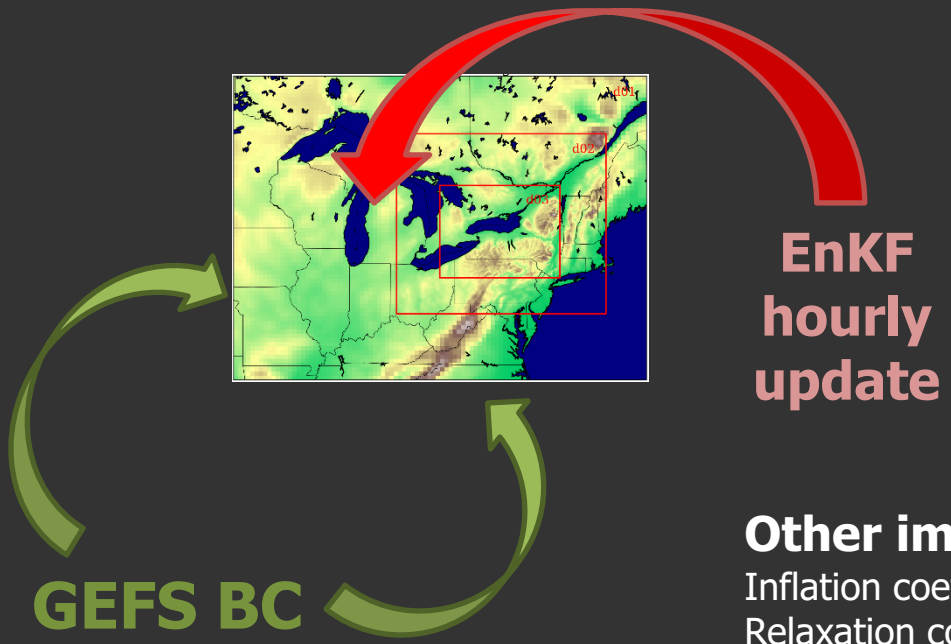
Regional ensemble data assimilation

21 ensemble members are initialized using initial and boundary conditions from the NCEP GEFS.

Using the PSU WRF-EnKF system (Zhang et al., 2006; Meng and Zhang, 2007, 2008a,b), data is assimilated hourly on all domains beginning 00 UTC 10 Dec until the event end 12 UTC 12 December. Observations include conventionally available:

- **METAR, ships, buoys**
- **Radiosonde, ACARS, GOES winds**

Boundary conditions are updated with the latest GEFS every 6 hours.

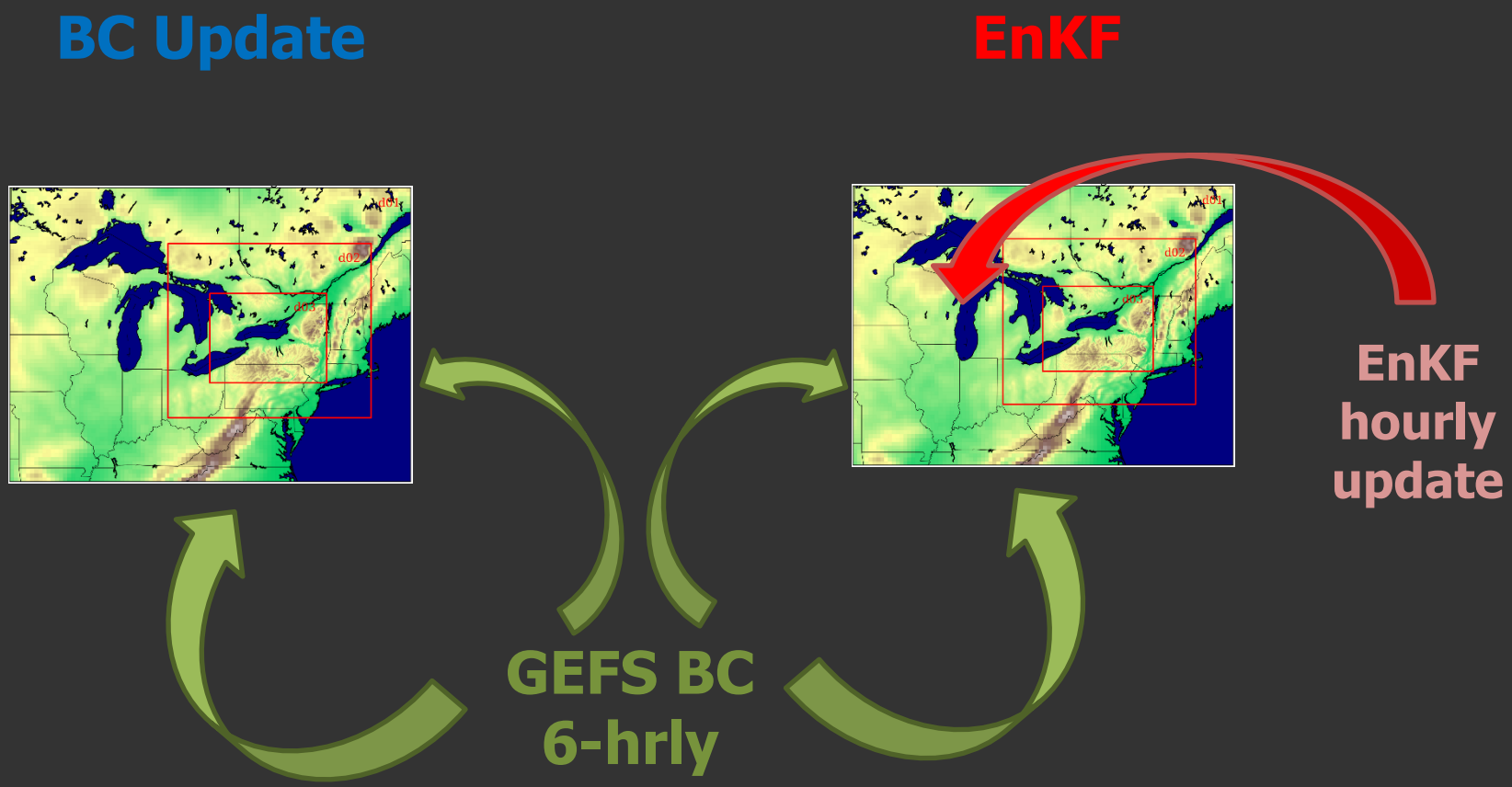


Other important EnKF parameters:

Inflation coefficient: 1.0
Relaxation coefficient: 0.8
Surface ob ROI: 500 km H, 10 levels V
Upper air ob ROI: 1000 km H, 15 levels V
Obs window: +/- 30 min

Comparisons

As a complementary experiment, the setup is repeated but EnKF is **not** used; this experiment is termed **BC update**.

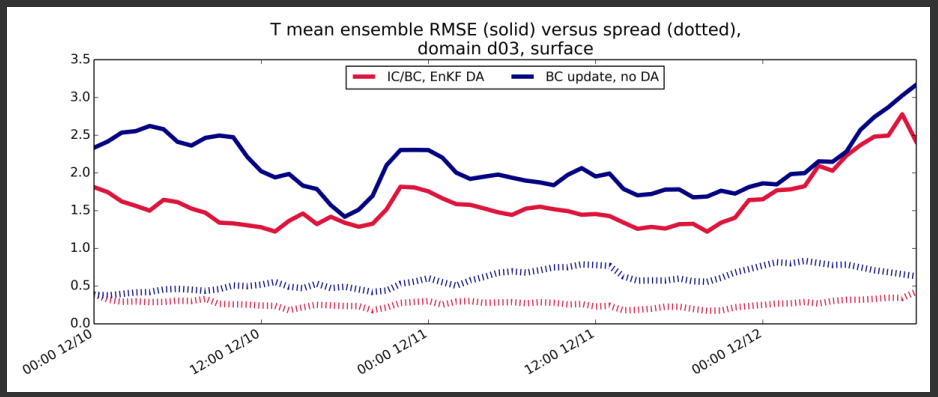


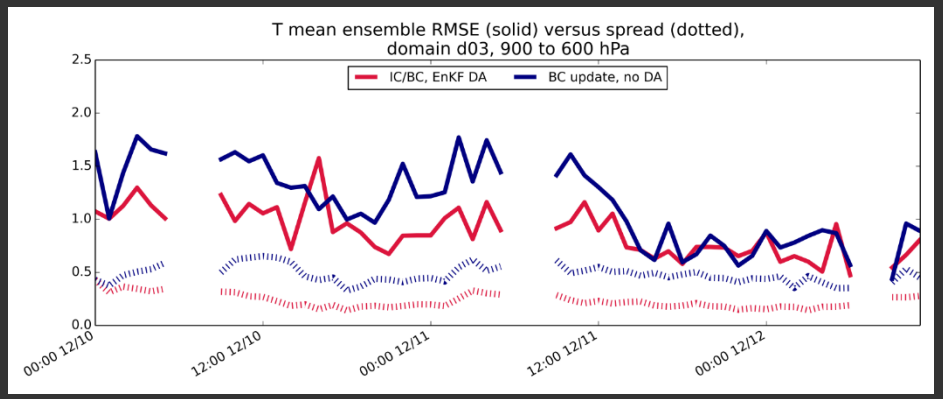
Error Characteristics

Surface-based

Low- to mid-troposphere

T





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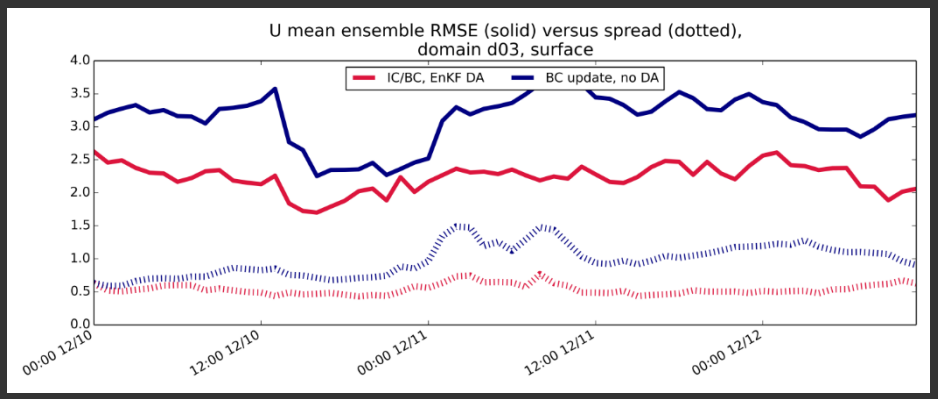
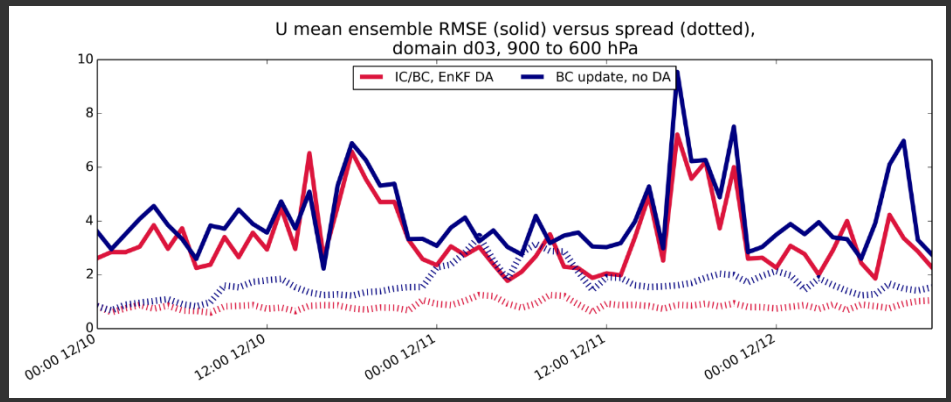
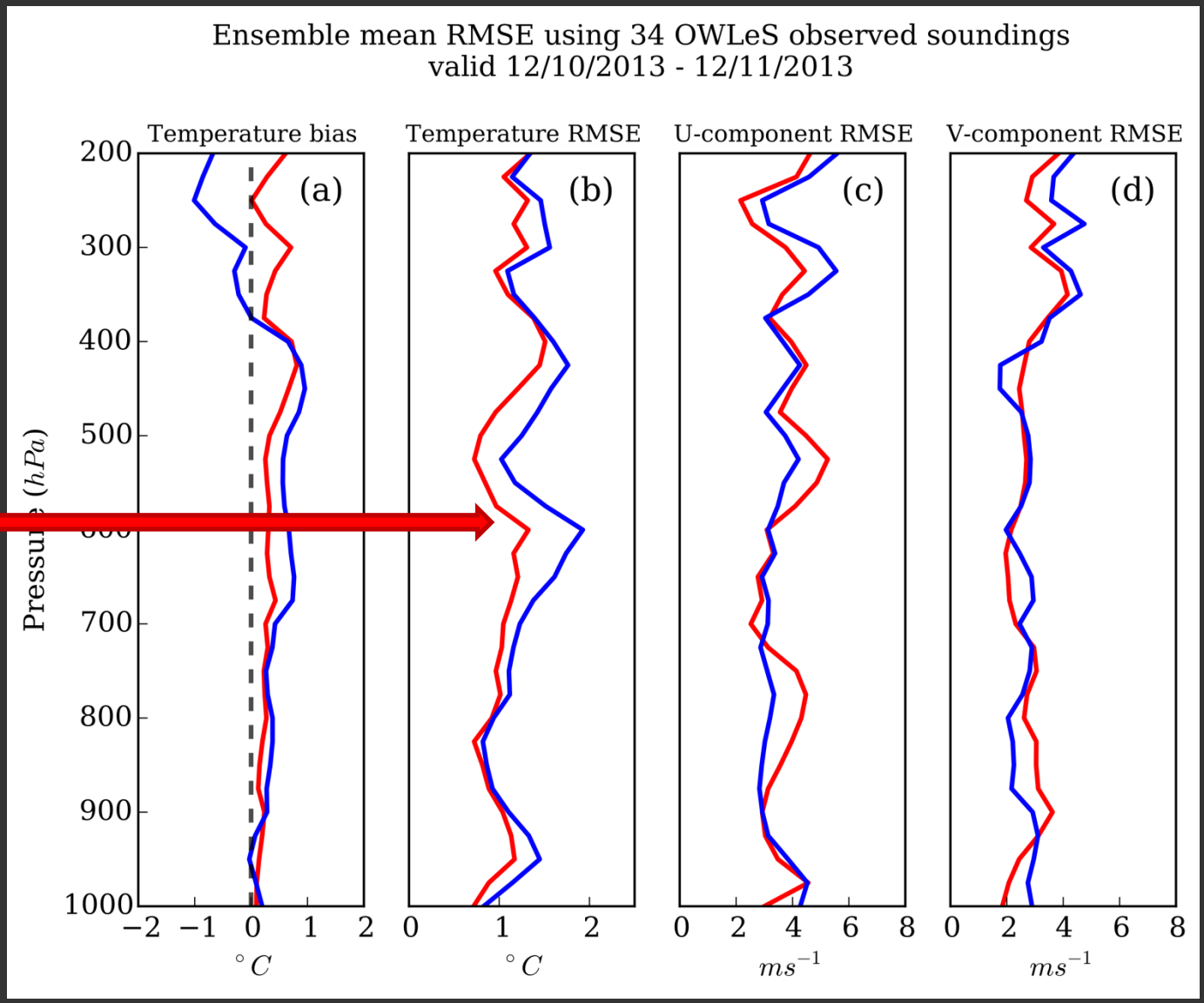




Regional EnKF versus BC Update

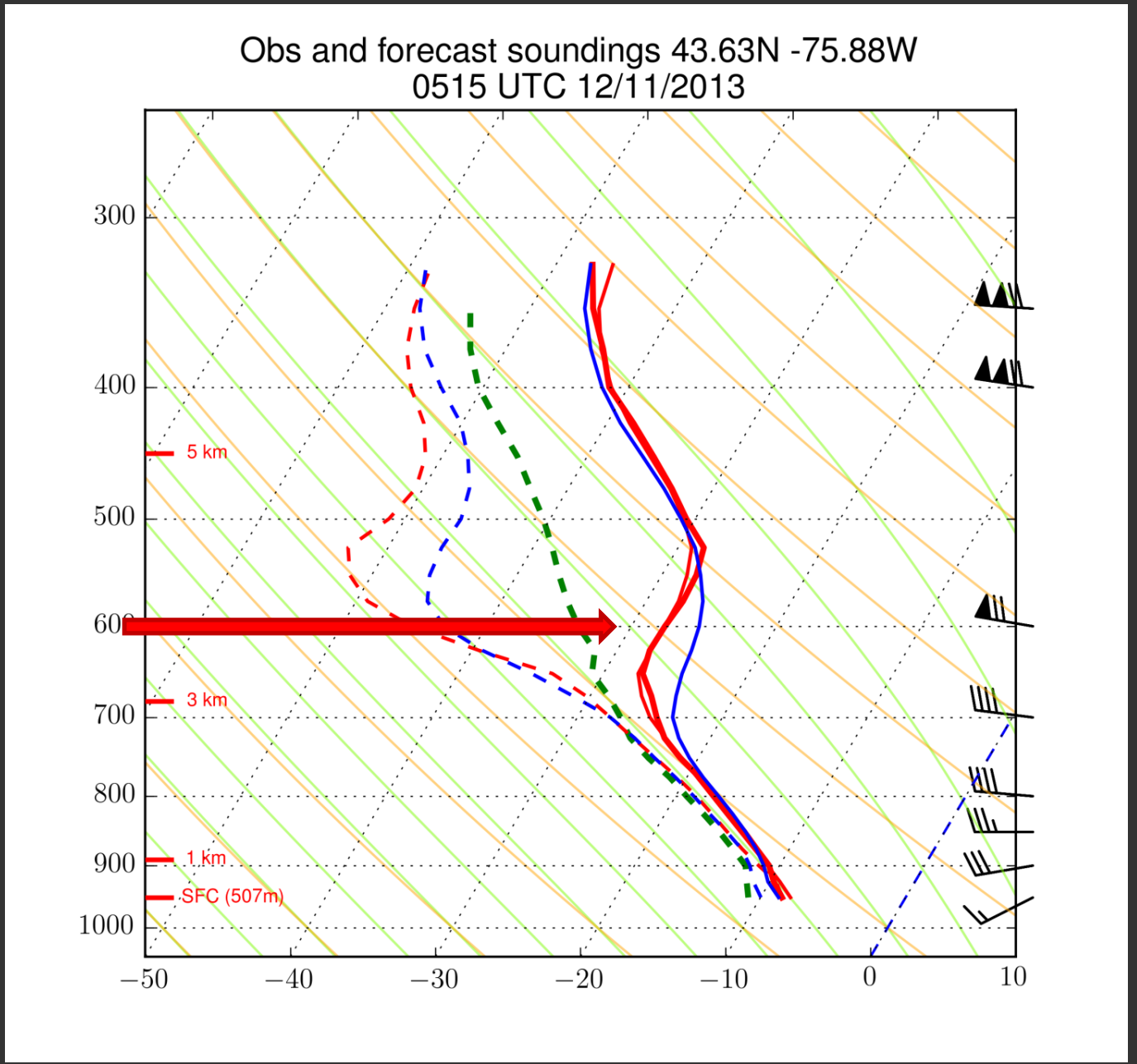


BC update (blue) versus DA (red) ensemble mean using independent radiosonde observations from the Ontario Winter Lake-effect Systems (OWLeS; Kristovich et al., 2016) field campaign.

Using independent observations during the event, it appears EnKF corrects wind and temperature errors throughout much of the troposphere.

How will this impact forecasts?

Inversion height/strength is important because…

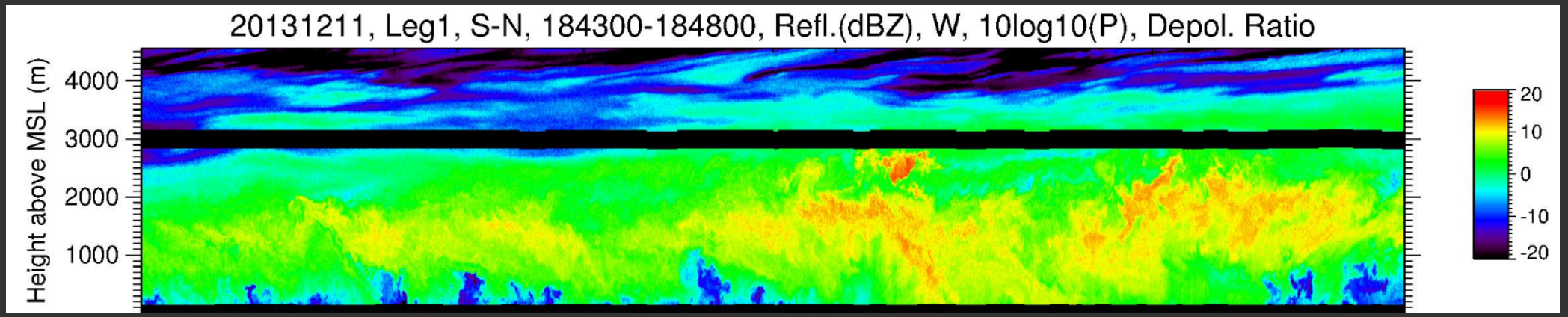


Observed: Thick red/dashed green

EnKF: Thin red

BC Update: Thin blue

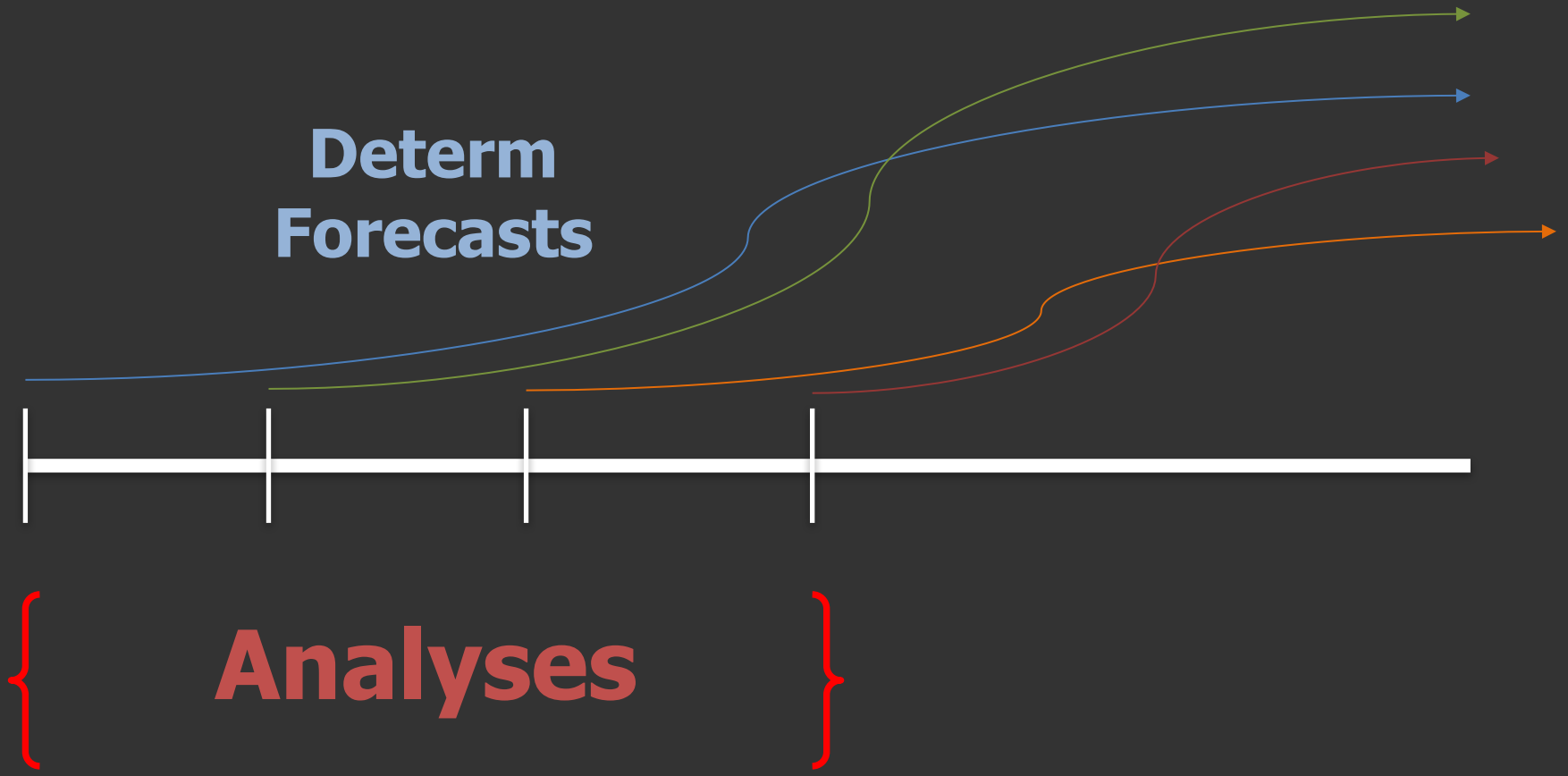
…it strongly controls height and strength of LES convection.

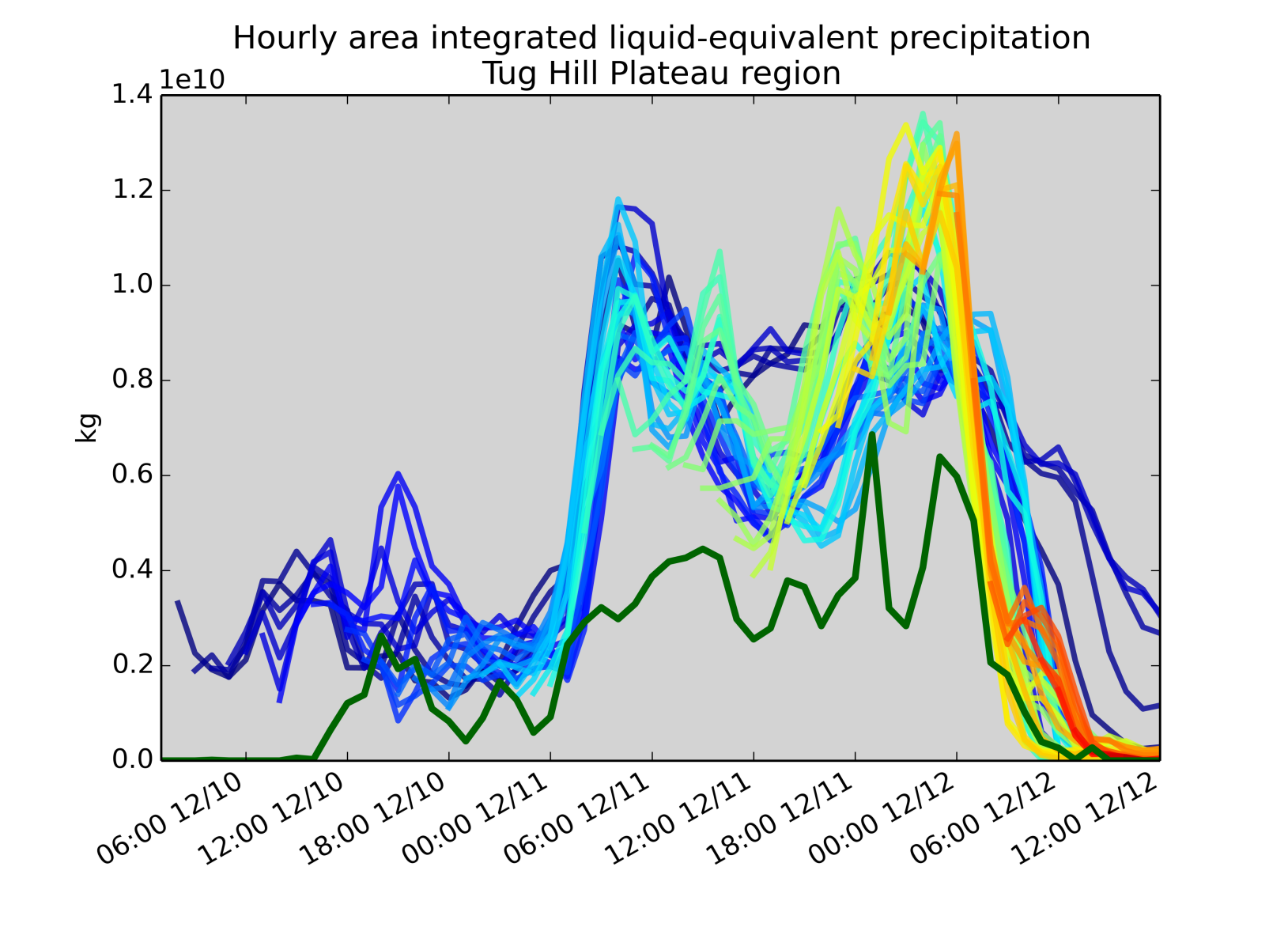


UWyo King Air LIDAR South-North Pass

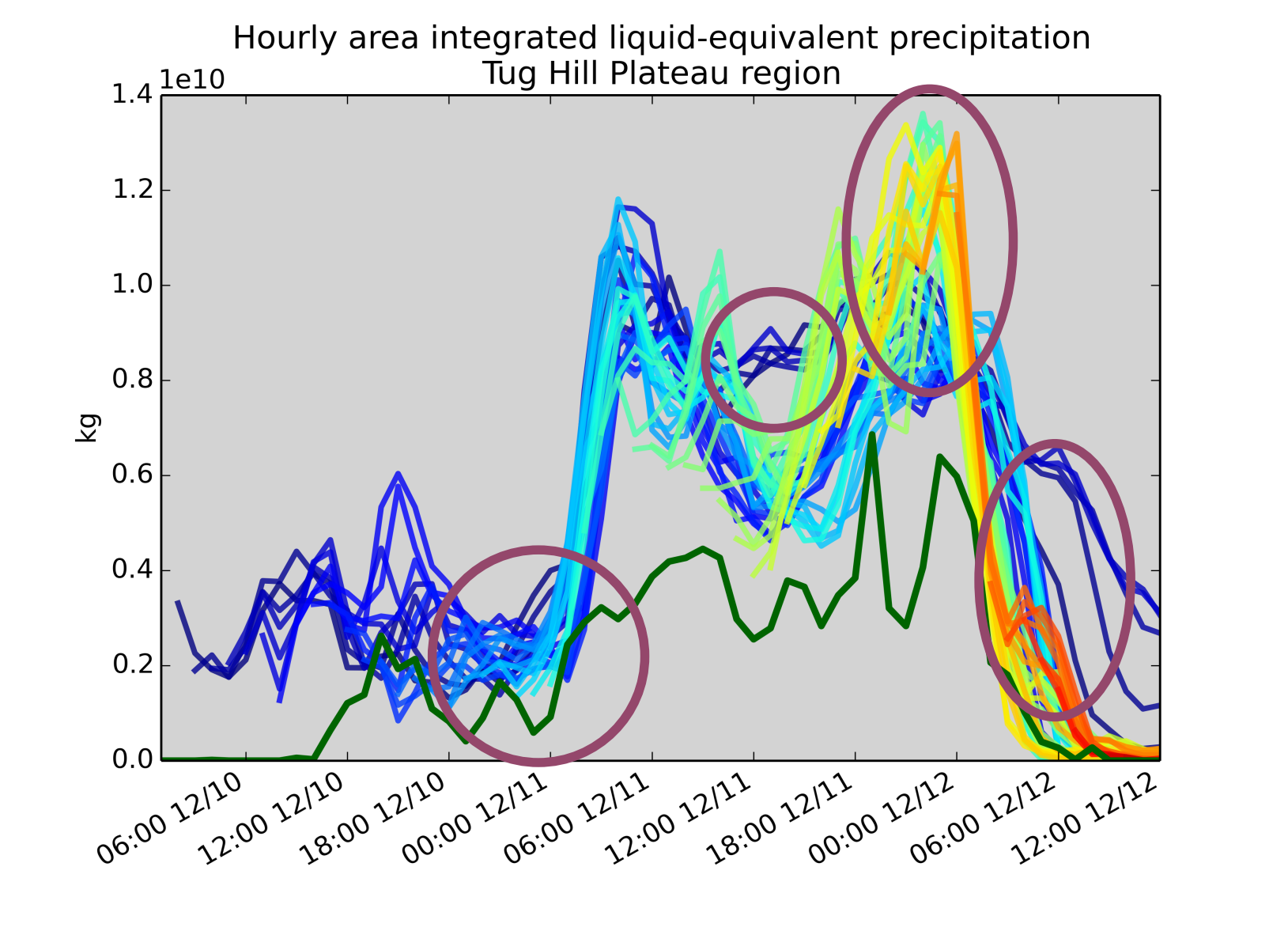
LES predictability as function of initial-condition error

Given improved IC from EnKF, deterministic forecasts are initialized using the analysis mean for IC and GFS BC.

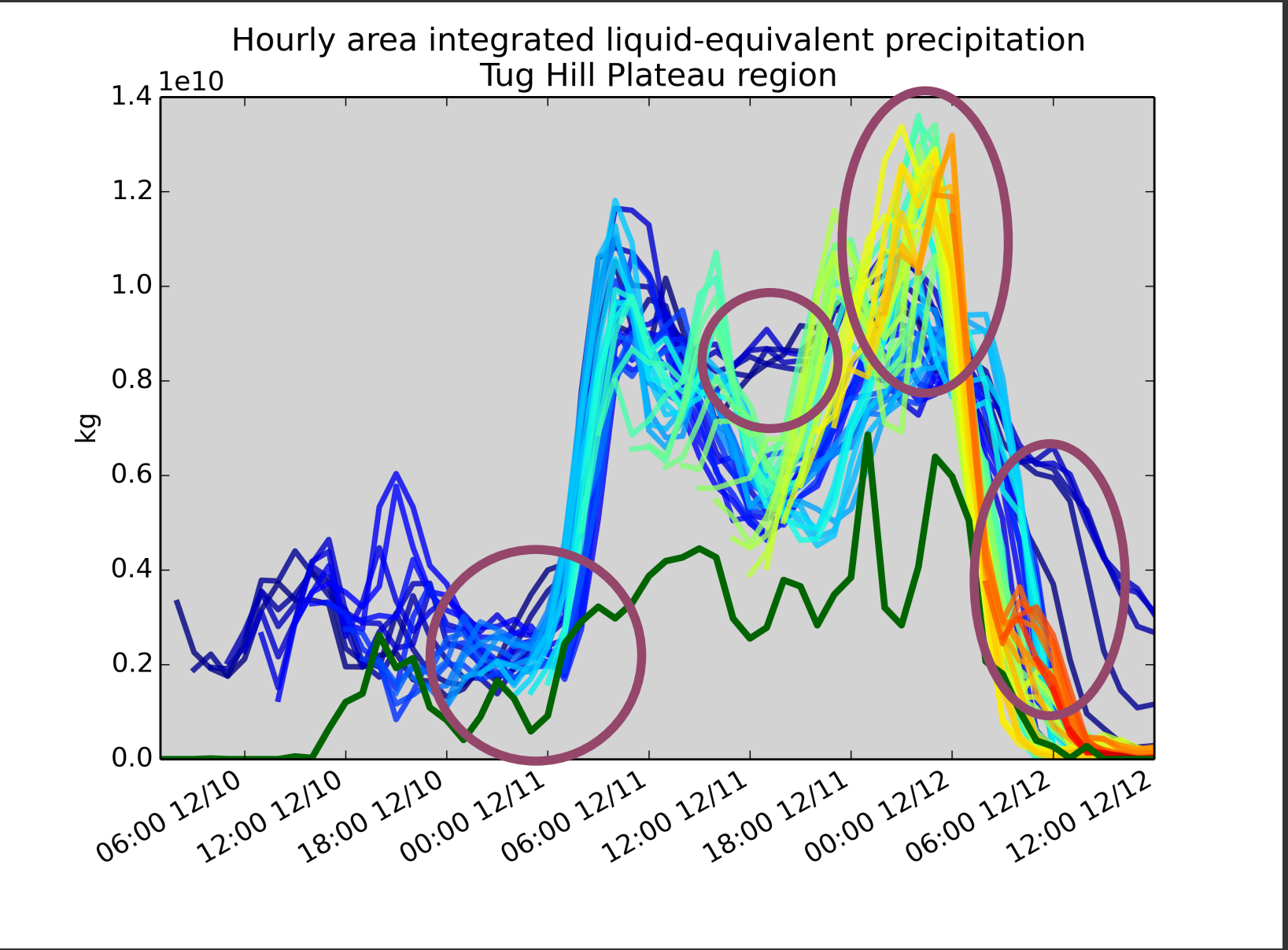




Precipitation integrated over the Tug Hill Plateau (NY) region. Colors correspond to individual forecasts; Darker colors correspond to forecasts launched at earlier times. Dark green is estimate from Stage IV.



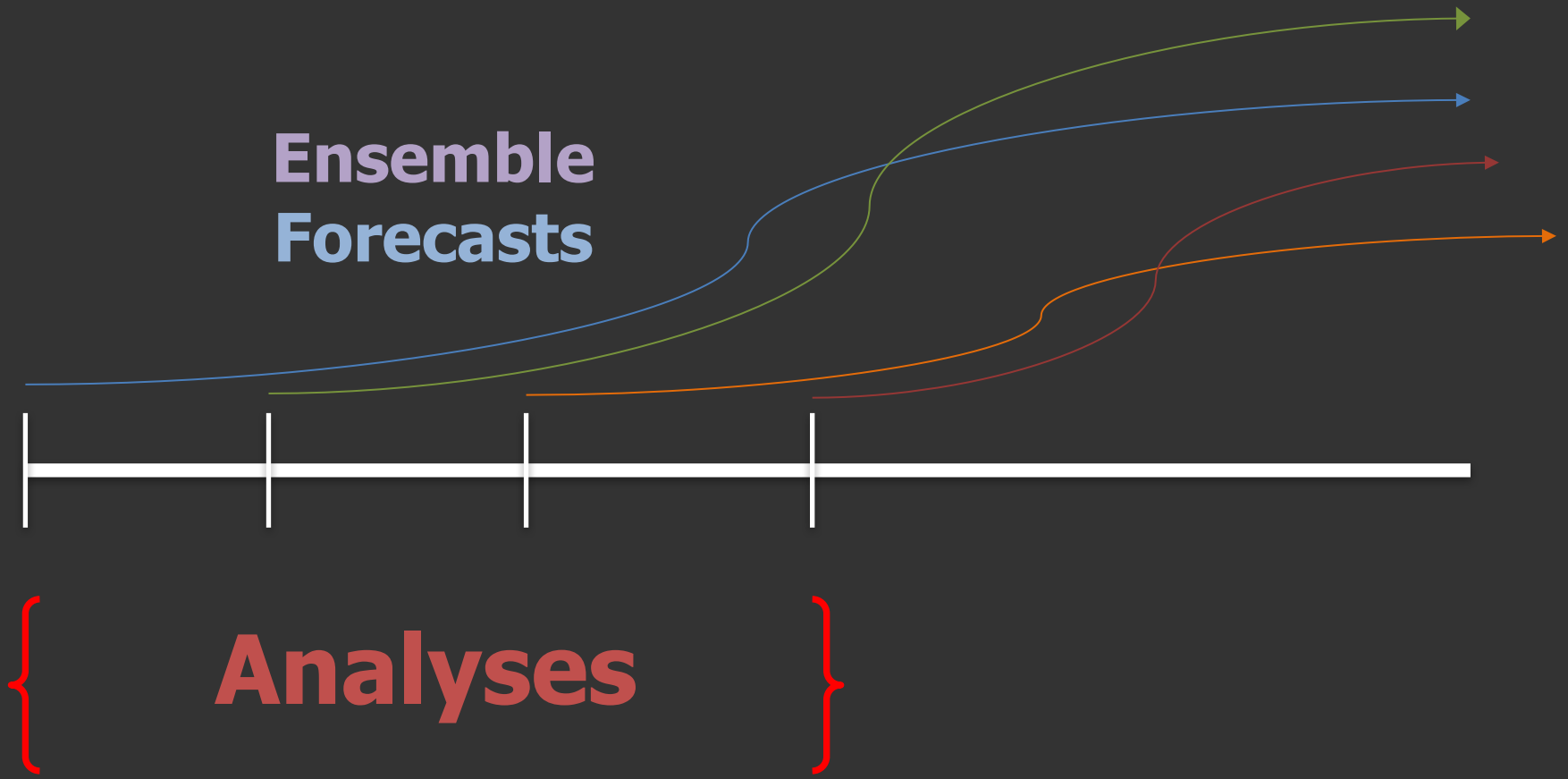
This time-lagged ensemble shows uncertainty in both precipitation timing and intensity as a function of IC error. Can ensemble forecasts reproduce this uncertainty?

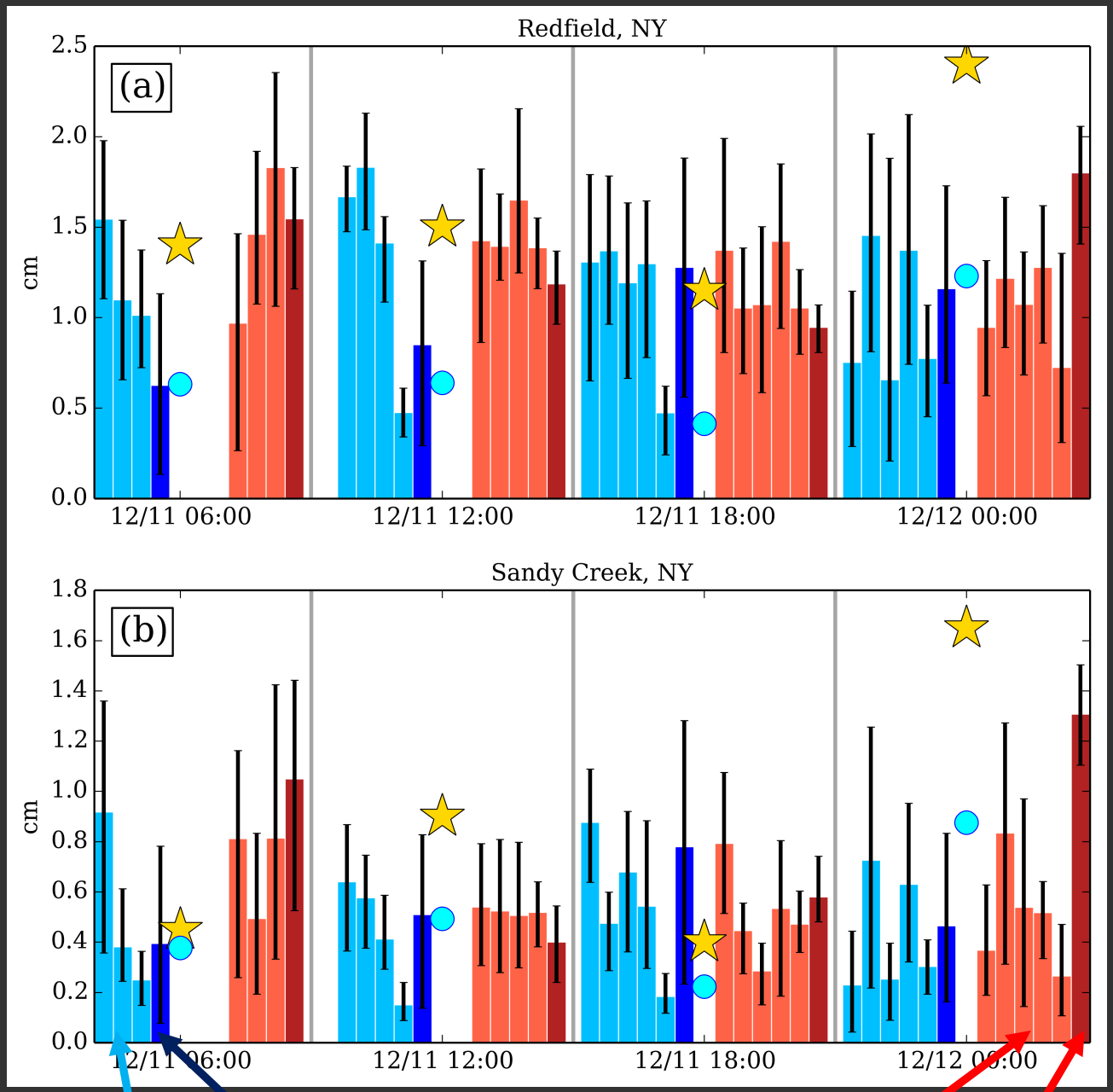


This time-lagged ensemble shows uncertainty in both precipitation timing and intensity as a function of IC error. Can ensemble forecasts reproduce this uncertainty, and where does it stem from?

At given intervals, run ensemble forecasts initialized from EnKF analysis members and GEFS BC.

As comparison, cold-initialize a second ensemble forecast with GEFS IC/BC.





BC Update

EnKF-init

GEFS-init

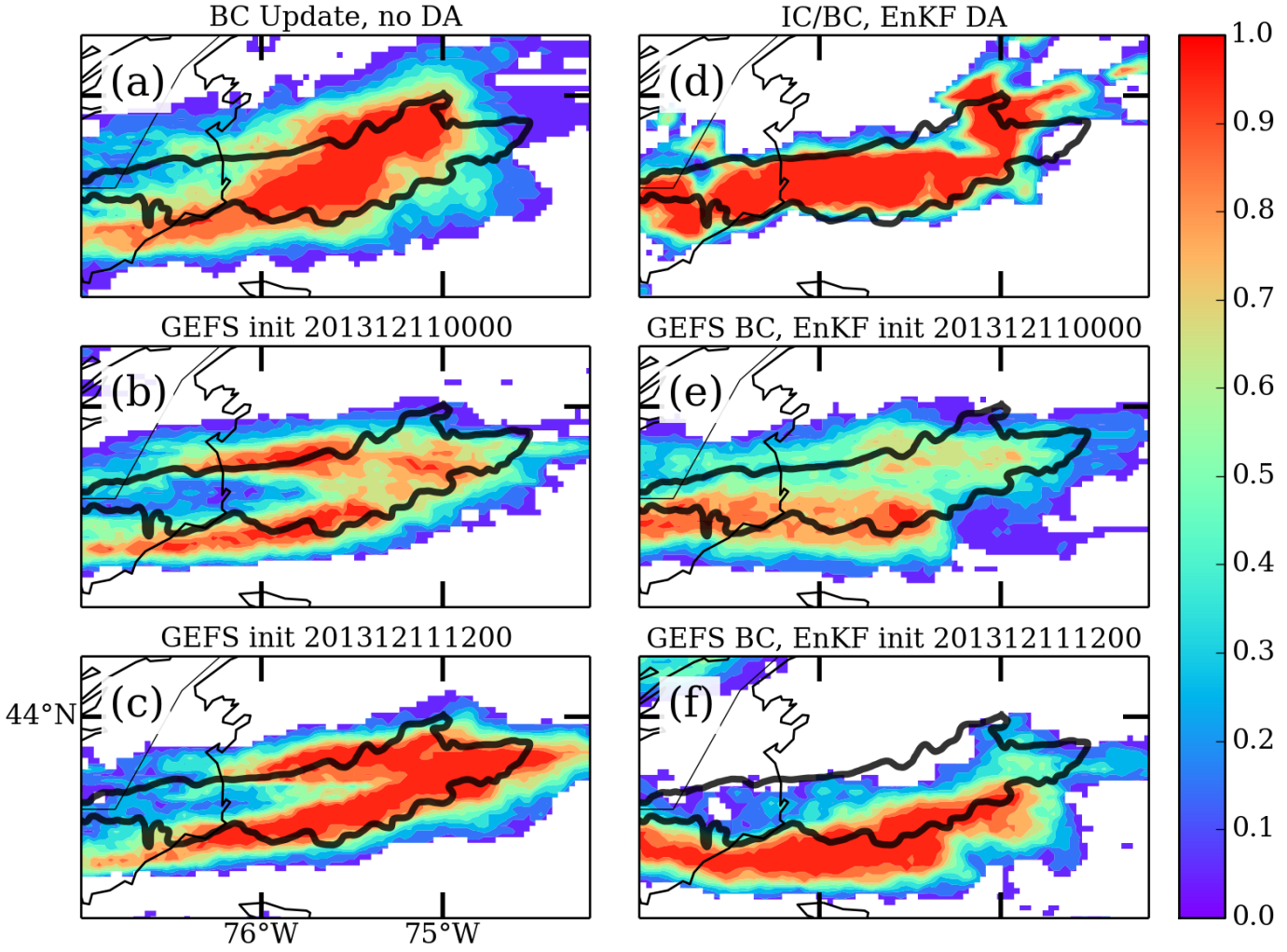
EnKF analysis

Ensemble mean (**colored bars**) and 90th and 10th percentile members (**top and bottom error bars**, resp.) as compared to in-situ observed snow-water equivalent (**star**) over 6-hour accumulation periods.
(Stage IV indicated by blue dot)

Forecasts initialized every 6 hours beginning 12 UTC 10 Dec.

In-situ data from Steenburgh (2014).

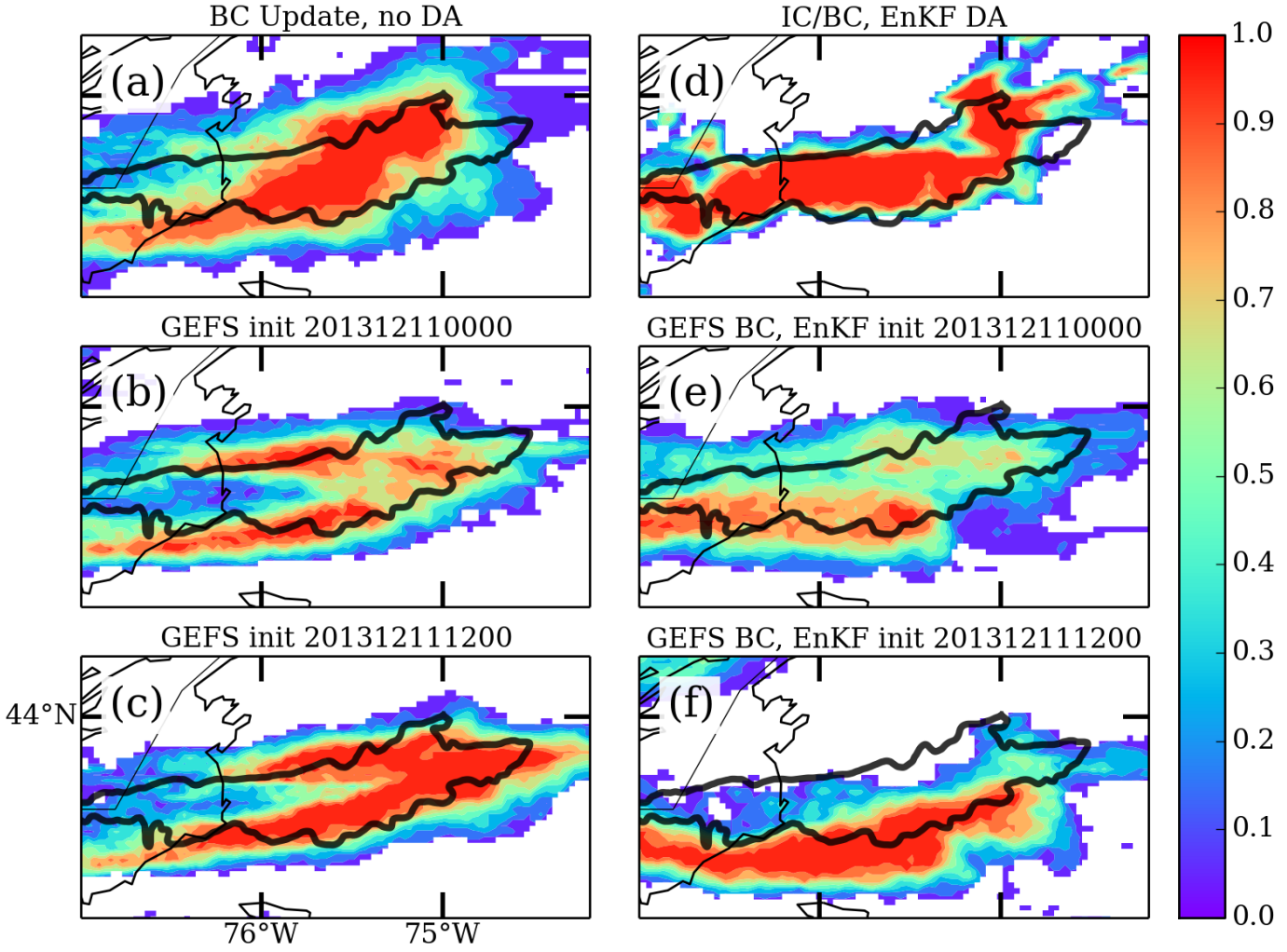
Position error?



Ensemble probability (colors) of exceeding composite reflectivity greater than 15 dBZ at 19 UTC 11 Dec; truth shown in black contour.

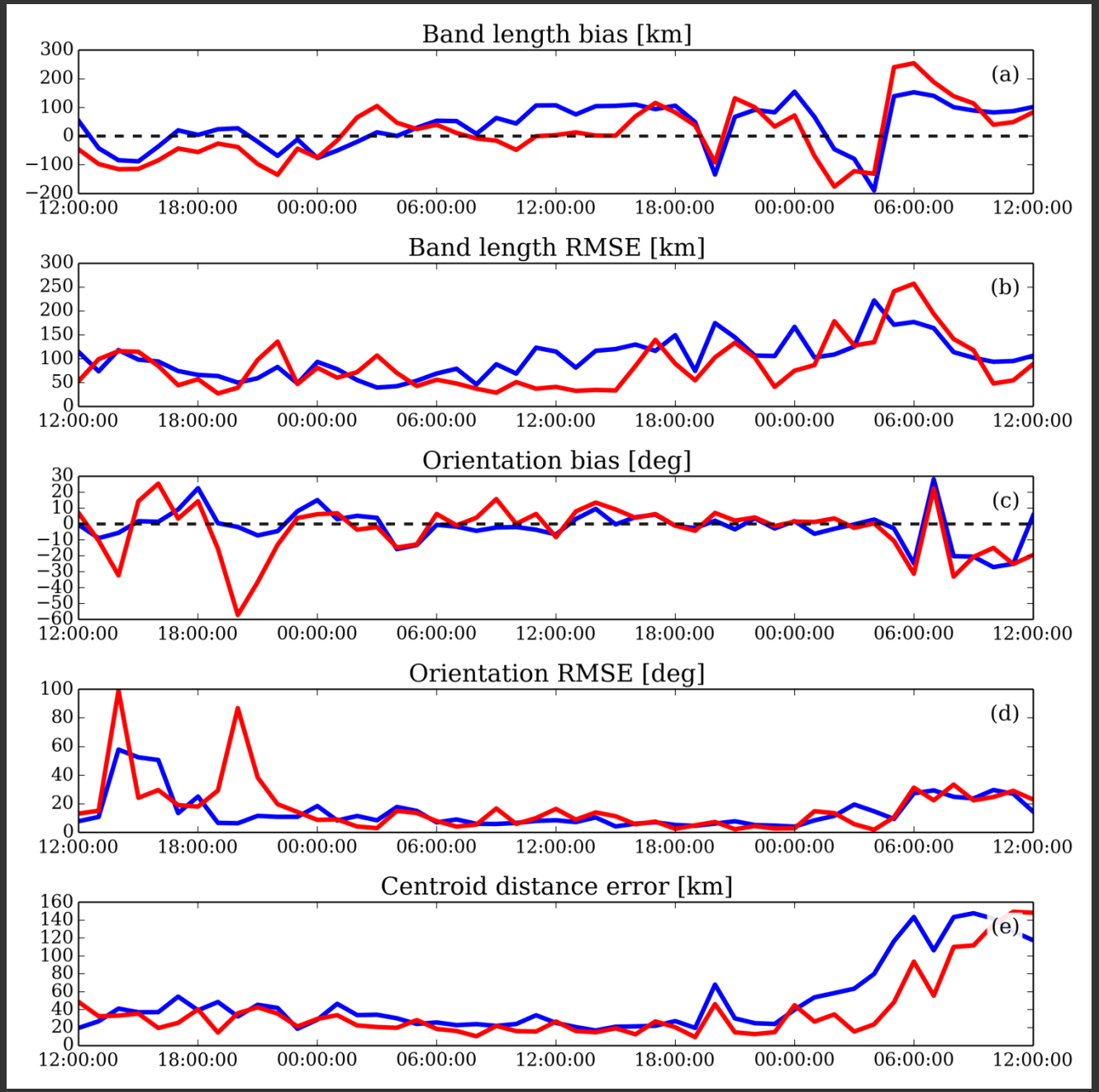
EnKF analysis recognizes single-banded structure in correct location; other forecasts do not.

Position error?



Ensemble probability (colors) of exceeding composite reflectivity greater than 15 dBZ at 19 UTC 11 Dec; truth shown in black contour.

EnKF analysis recognizes single-banded structure in correct location; other forecasts do not. Southern bias or morphology error?


Band length bias [km]
(a)
300
200
100
0
−100
−200
12:00:00
18:00:00
00:00:00
06:00:00
12:00:00
18:00:00
00:00:00
06:00:00
12:00:00
Band length RMSE [km]
(b)
300
250
200
150
100
50
0
12:00:00
18:00:00
00:00:00
06:00:00
12:00:00
18:00:00
00:00:00
06:00:00
12:00:00
Orientation bias [deg]
(c)
30
20
10
0
−10
−20
−30
−40
−50
−60
12:00:00
18:00:00
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06:00:00
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12:00:00
Orientation RMSE [deg]
(d)
100
80
60
40
20
0
12:00:00
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12:00:00
Centroid distance error [km]
(e)
160
140
120
100
80
60
40
20
0
12:00:00
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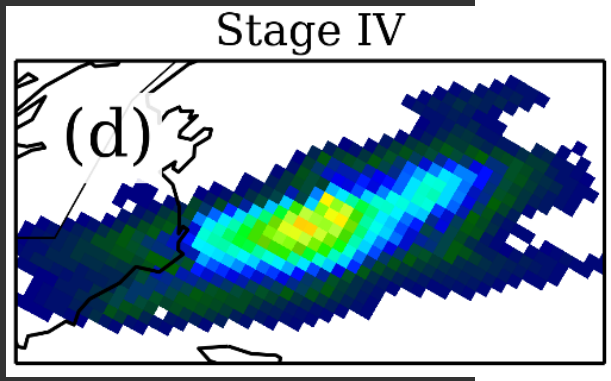
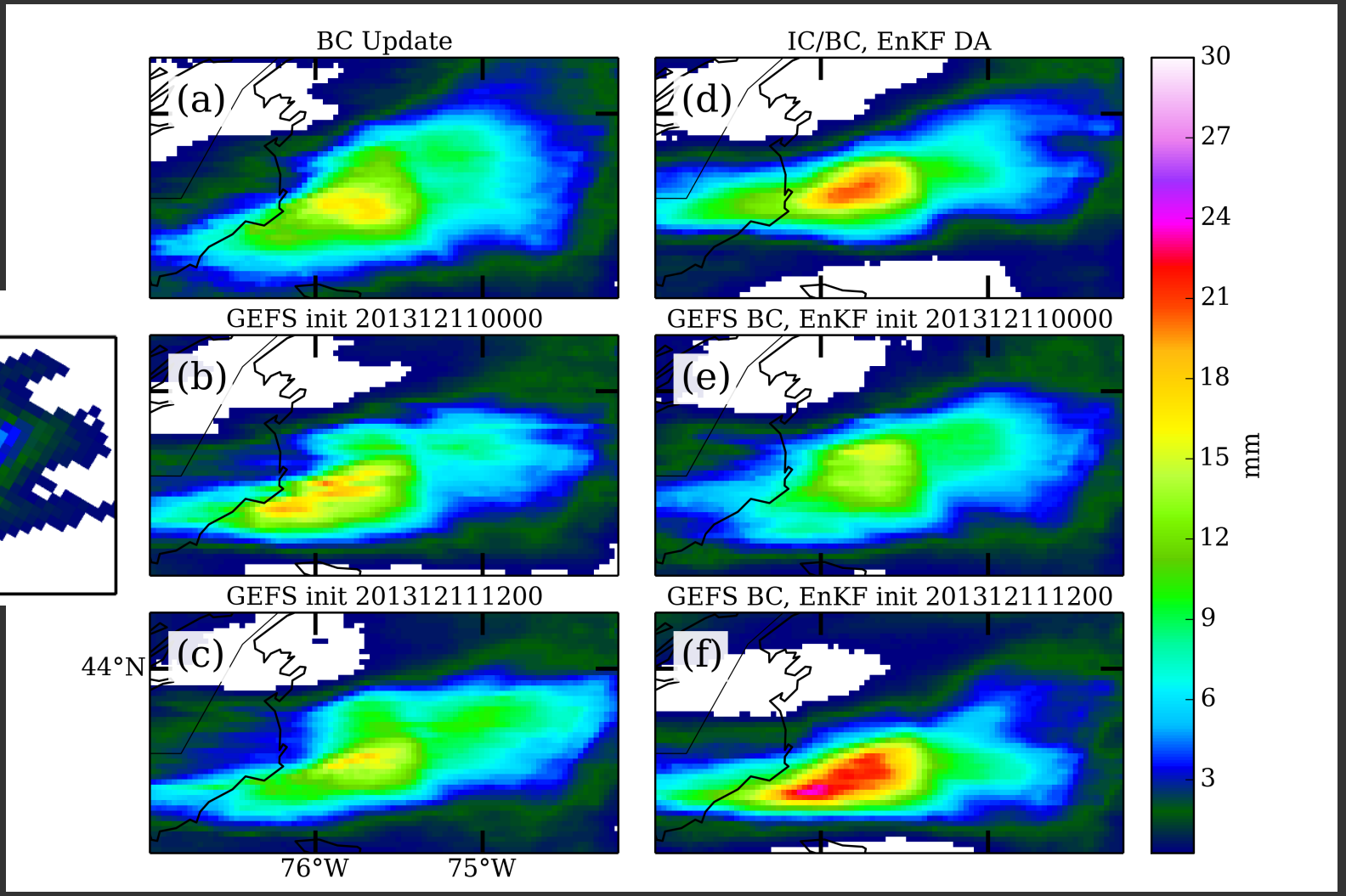
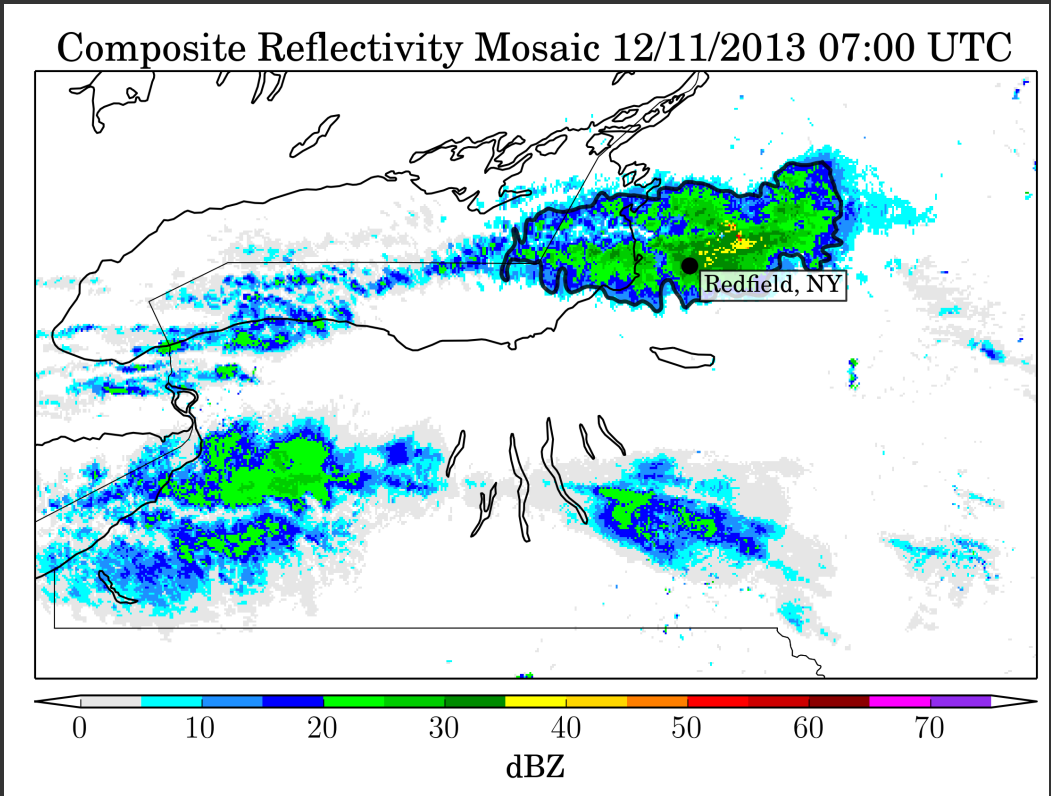
Precipitation error?

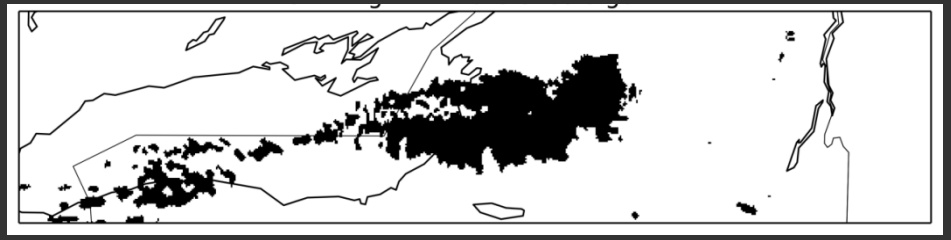


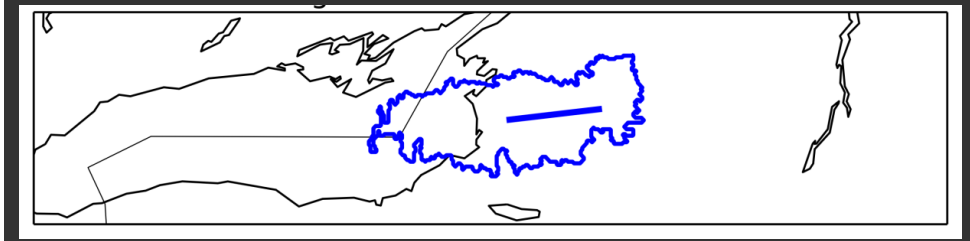


Ensemble 90th percentile precipitation for the 6-hour period 18 UTC 11 Dec to 00Z 12 Dec. Stage IV estimate included left.

EnKF analysis and most recent forecast produce precipitation values closer to observed on Tug Hill.



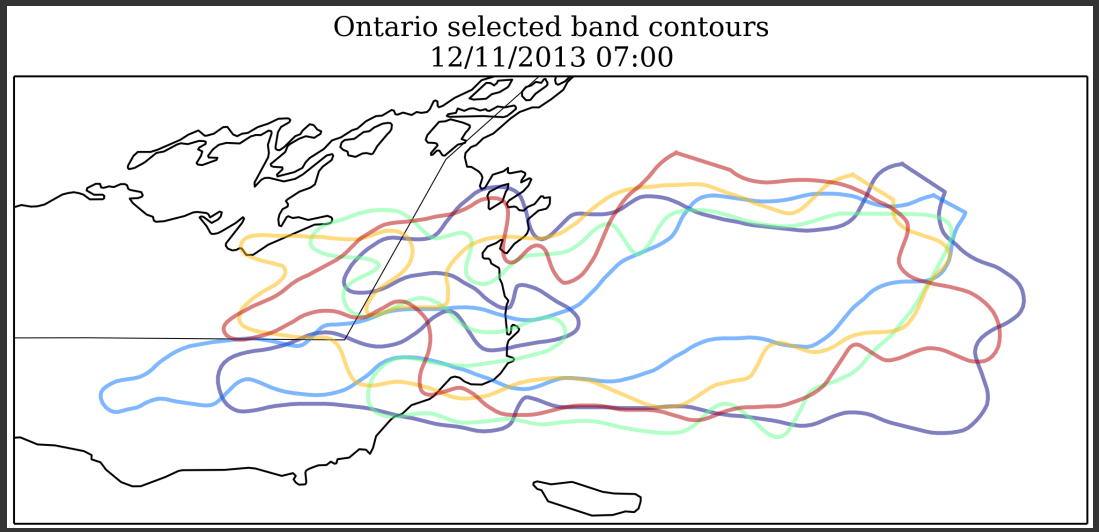




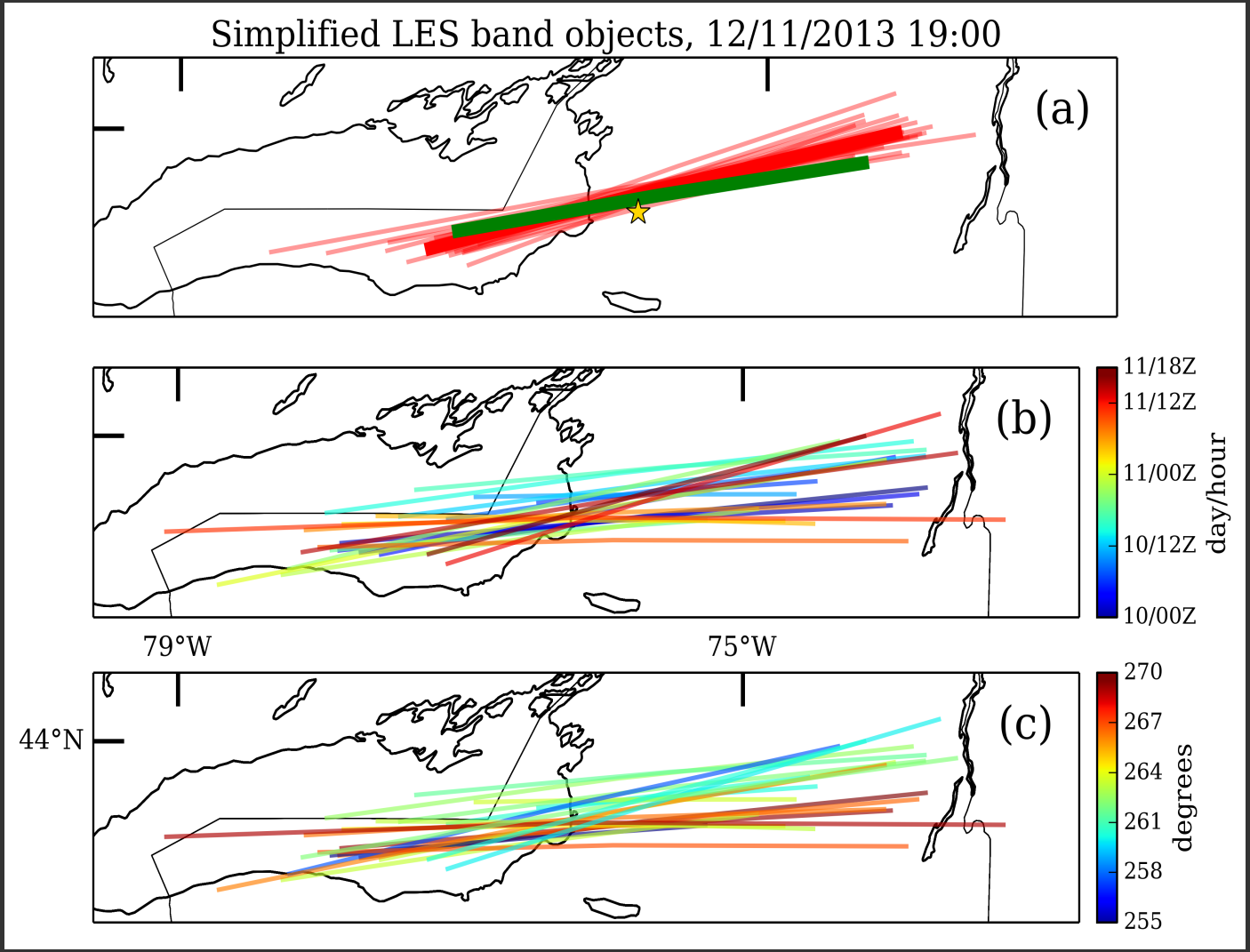
Band "objects" identified using simple image processing techniques.

Properties of these objects, such as length, width, area, and orientation, can be quantified.

Top, observed composite reflectivity and identified band object; right, subset of objects identified in ensemble output.



Even small uncertainty from environmental variables could play crucial roles in LES forecasts.



(a) Simplified LES band objects from the EnKF analysis 19 UTC 11 Dec;
(b) Objects identified from time-lagged ensemble colored by initialization time;
(c) Objects in time-legged ensemble colored by wind direction at valid time.

Conclusions

• Given the structure and sharp precipitation gradients that LES produces, ensemble forecasts provide much useful information.

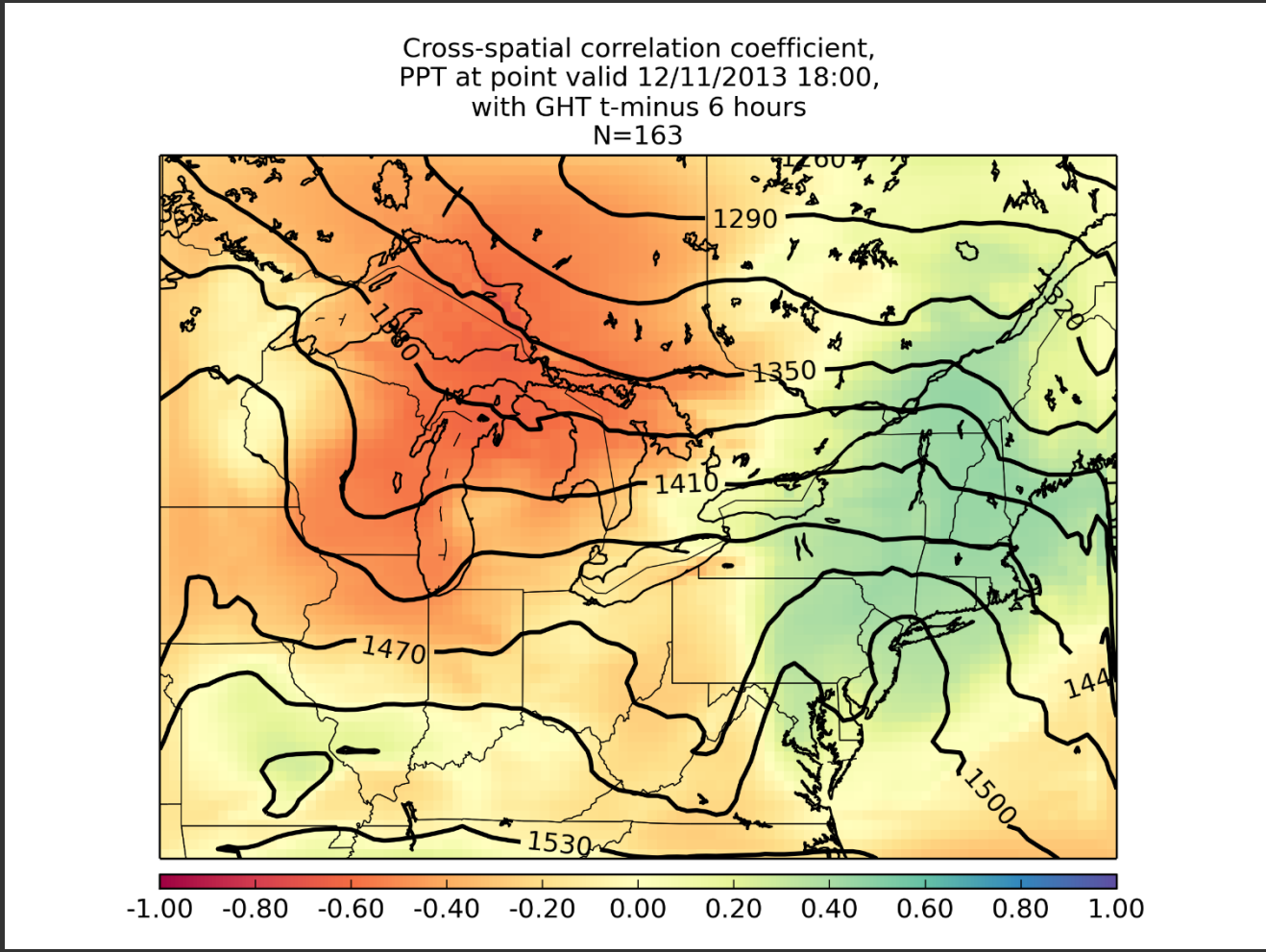
• Regional EnKF still provides useful reduction in IC error leading to improved short-term forecasts.

• Unfortunately, results from these short-term forecasts suggest that band position, structure, and precipitation may have limited predictability timescales inside 12-24 hours.

• However, this positive influence of even conventional observations demonstrates that there are avenues to better understanding the relative contributions to LES forecast uncertainty from different sources of error.

Future work

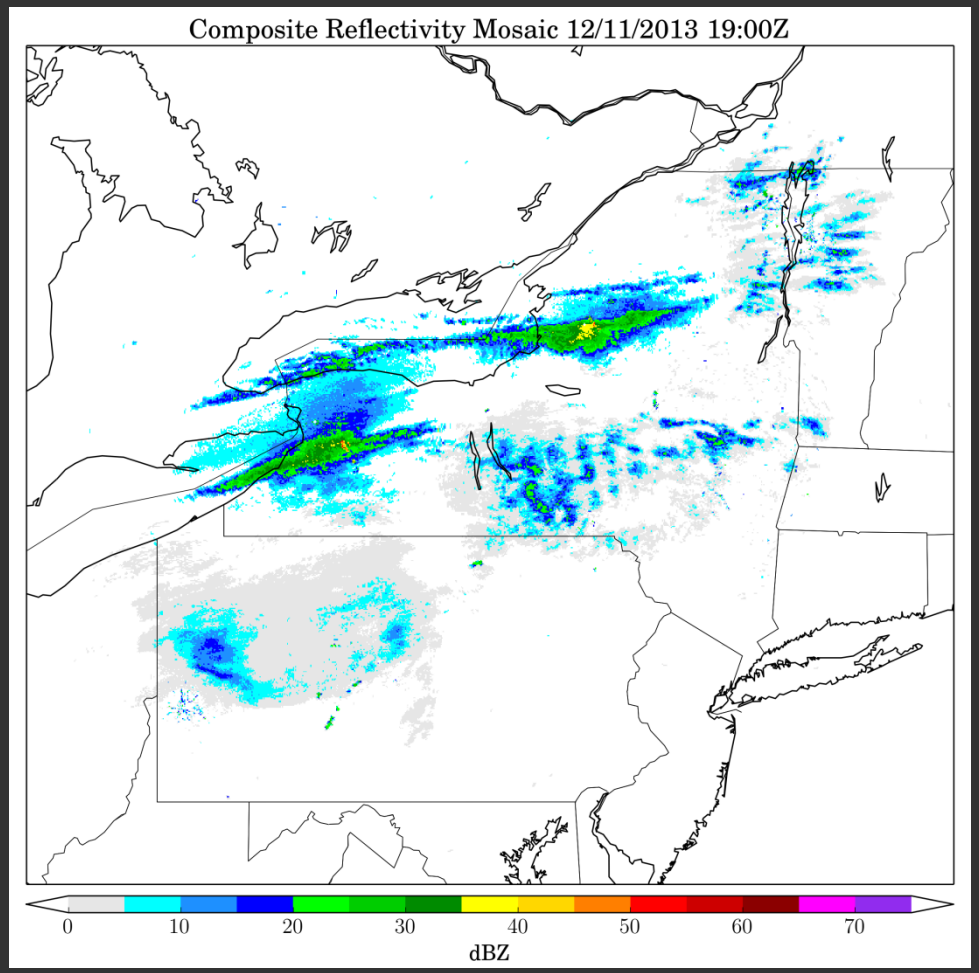
- Ensemble sensitivity to better understand influences of lake-effect processes and impact on forecast variability.

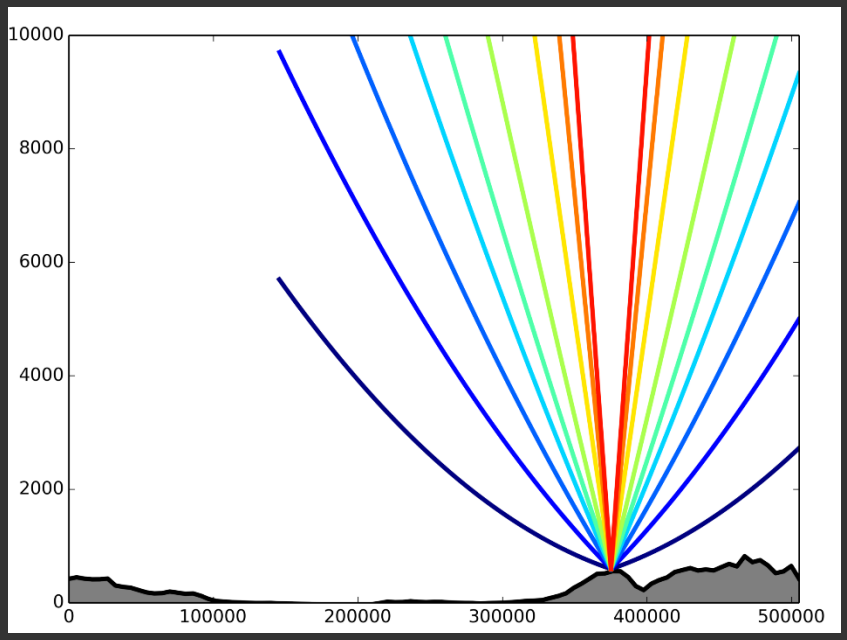


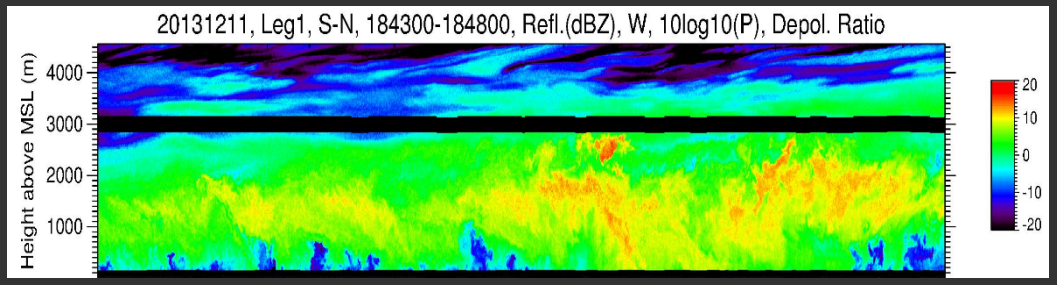
Cross-spatial correlation coefficient of 6-hour area-integrated area precipitation on Tug Hill with 850 hPa heights 6 hours earlier, perhaps indicative of shortwave influence on LES precipitation

Future work

- Analysis of short-term forecasts, more rapid DA with additional data (radar velocities, reflectivities, perhaps dual-pol) towards understanding smaller-scale processes that limit predictability







Acknowledgments

Steven Greybush, advisor

Fuqing Zhang for help, insight, and ideas in applying DA

George Young, **Daniel Eipper** for helpful discussions of lake-effect processes

Penn State University **Dept. Of Meteorology** and **Institute for CyberScience** for providing support and computational resources *heavily* involved in this ongoing study

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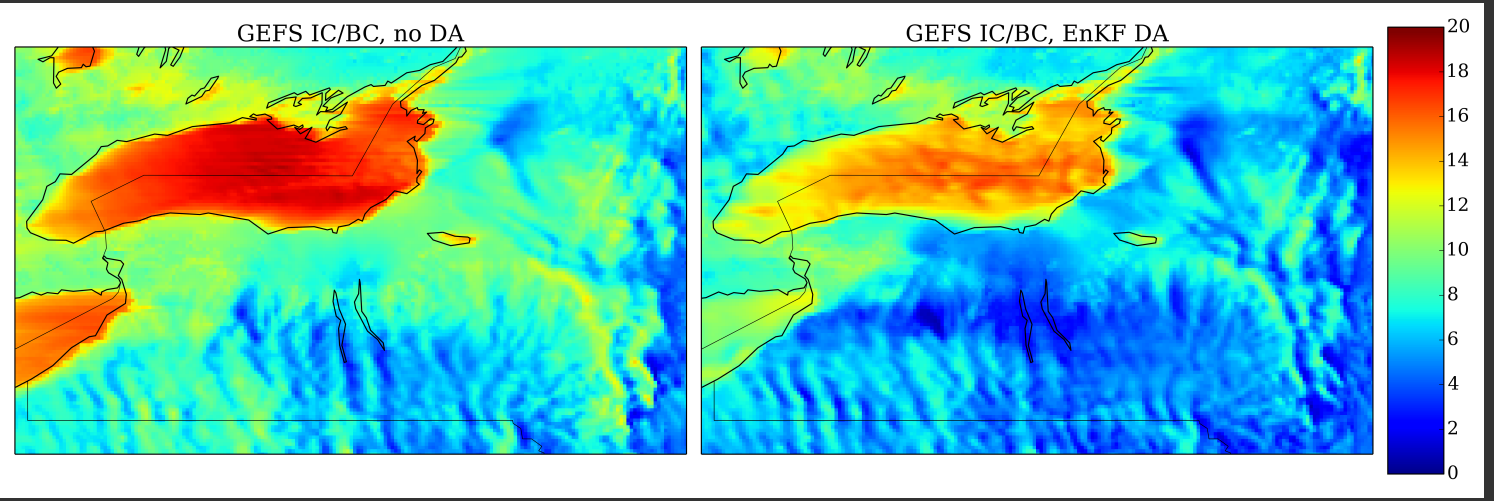
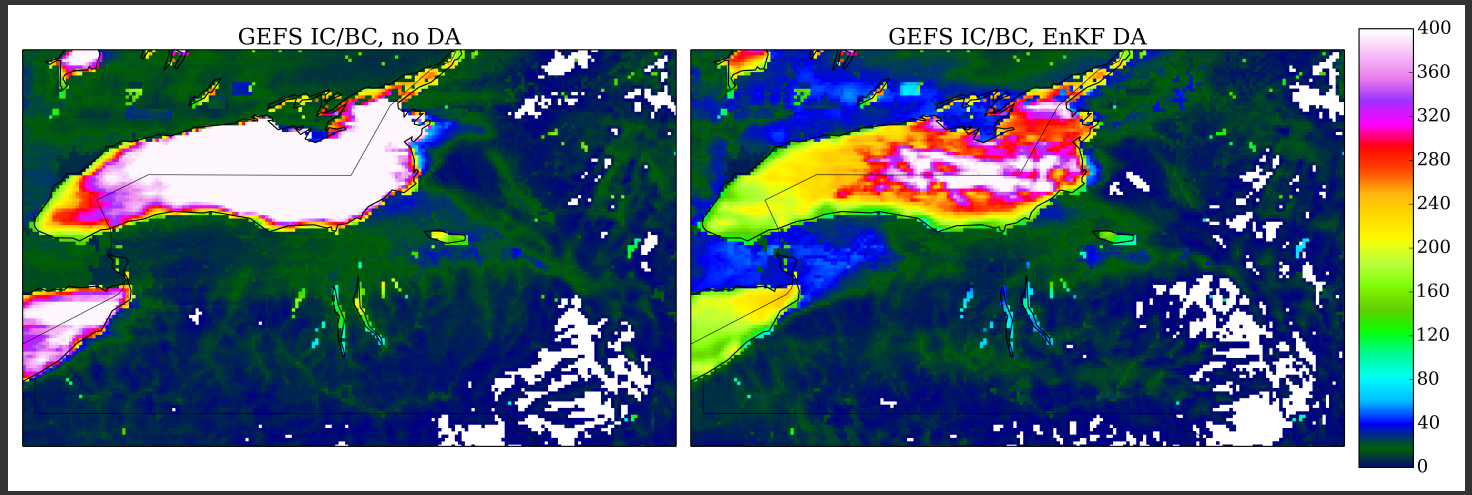
Extras

SUNY Oswego, facing north towards Lake Ontario, same time frame

Other questions



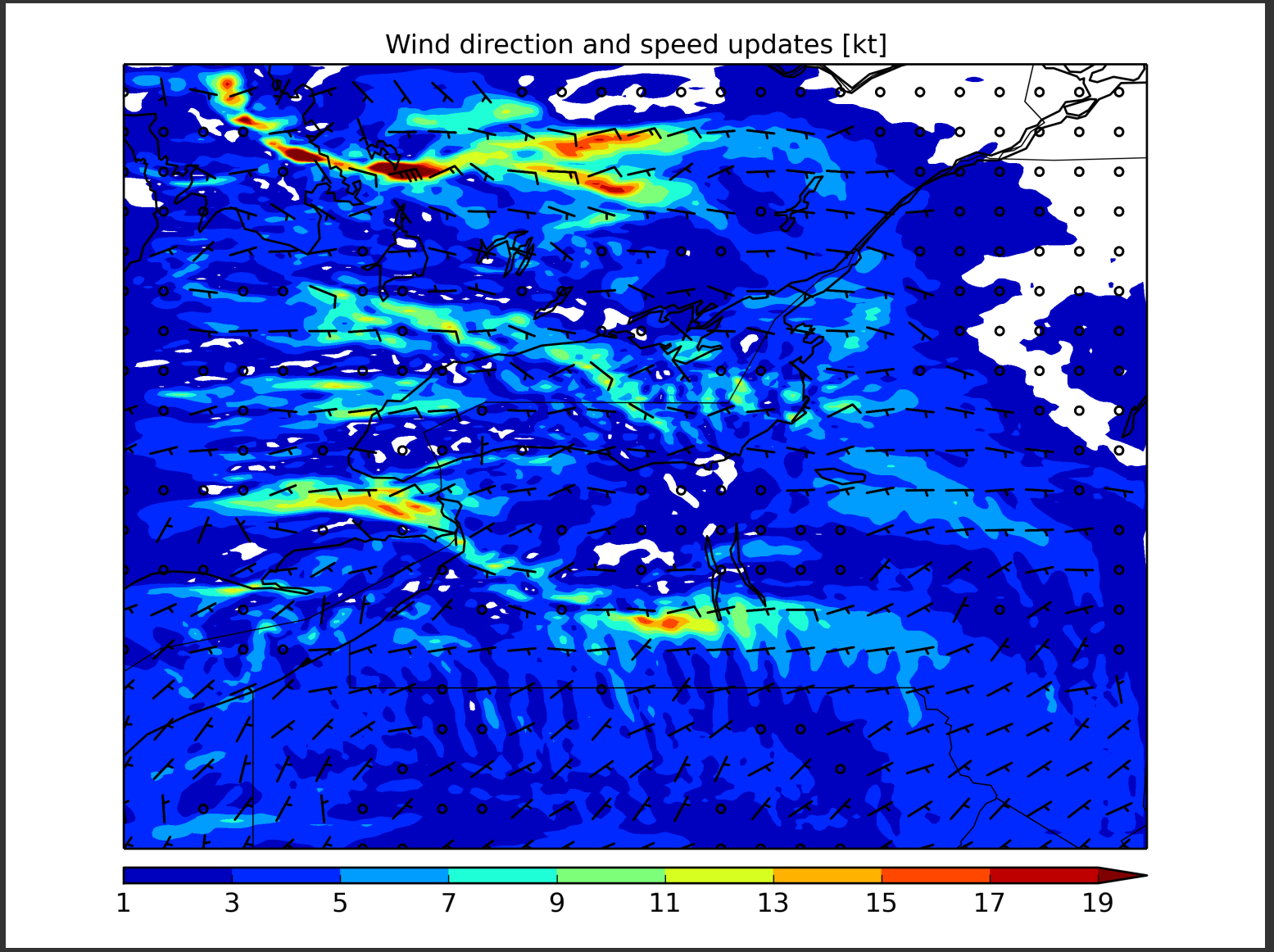
Ensemble mean 10m wind speed [m/s]



Ensemble mean surface latent heat flux [W/m²]

It's very likely that excess precip results from higher lake surface fluxes that come about through higher low-level wind speeds.

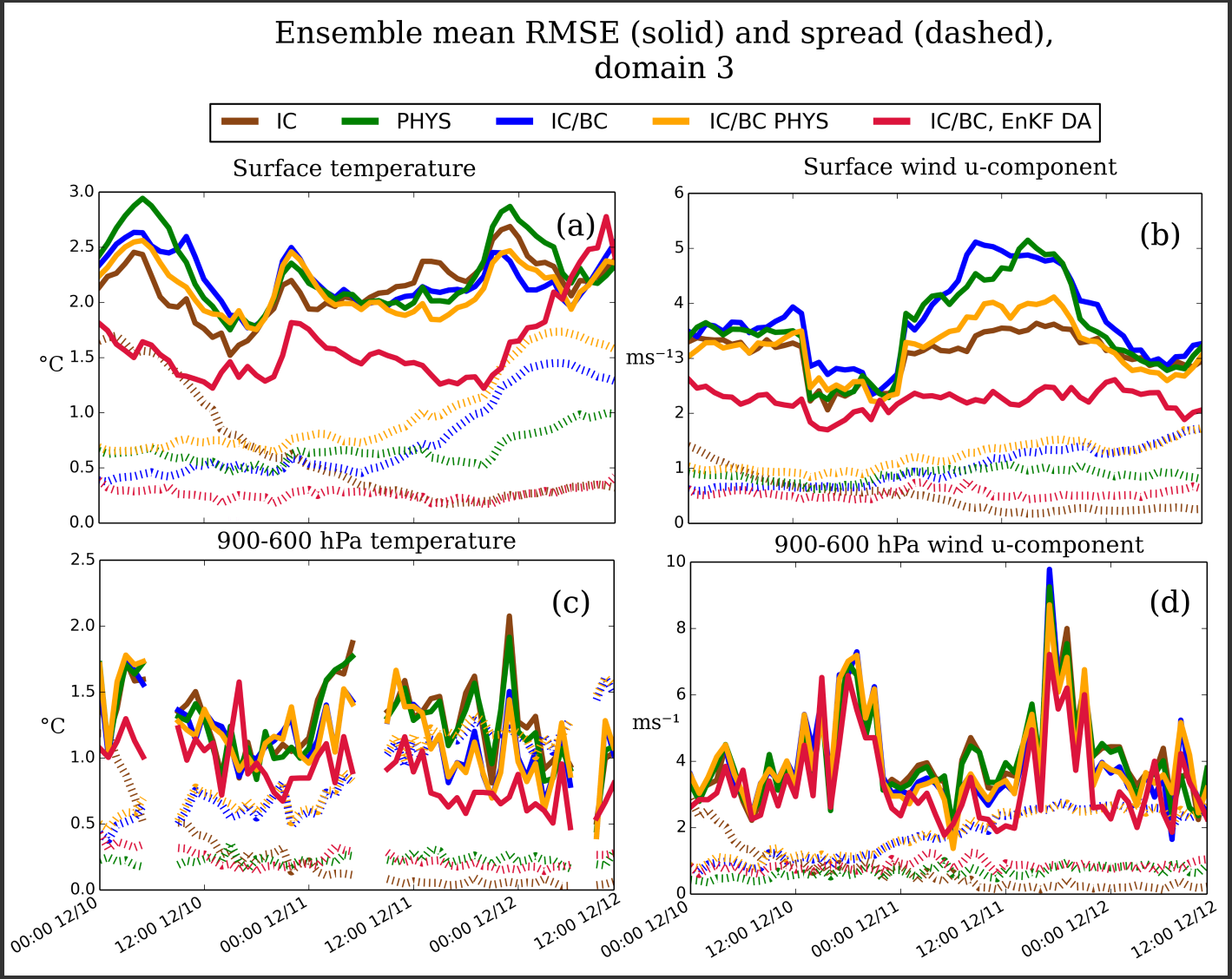
EnKF updates almost always slowing down flow over Lake Ontario



Ensemble design: investigation of perturbation impact

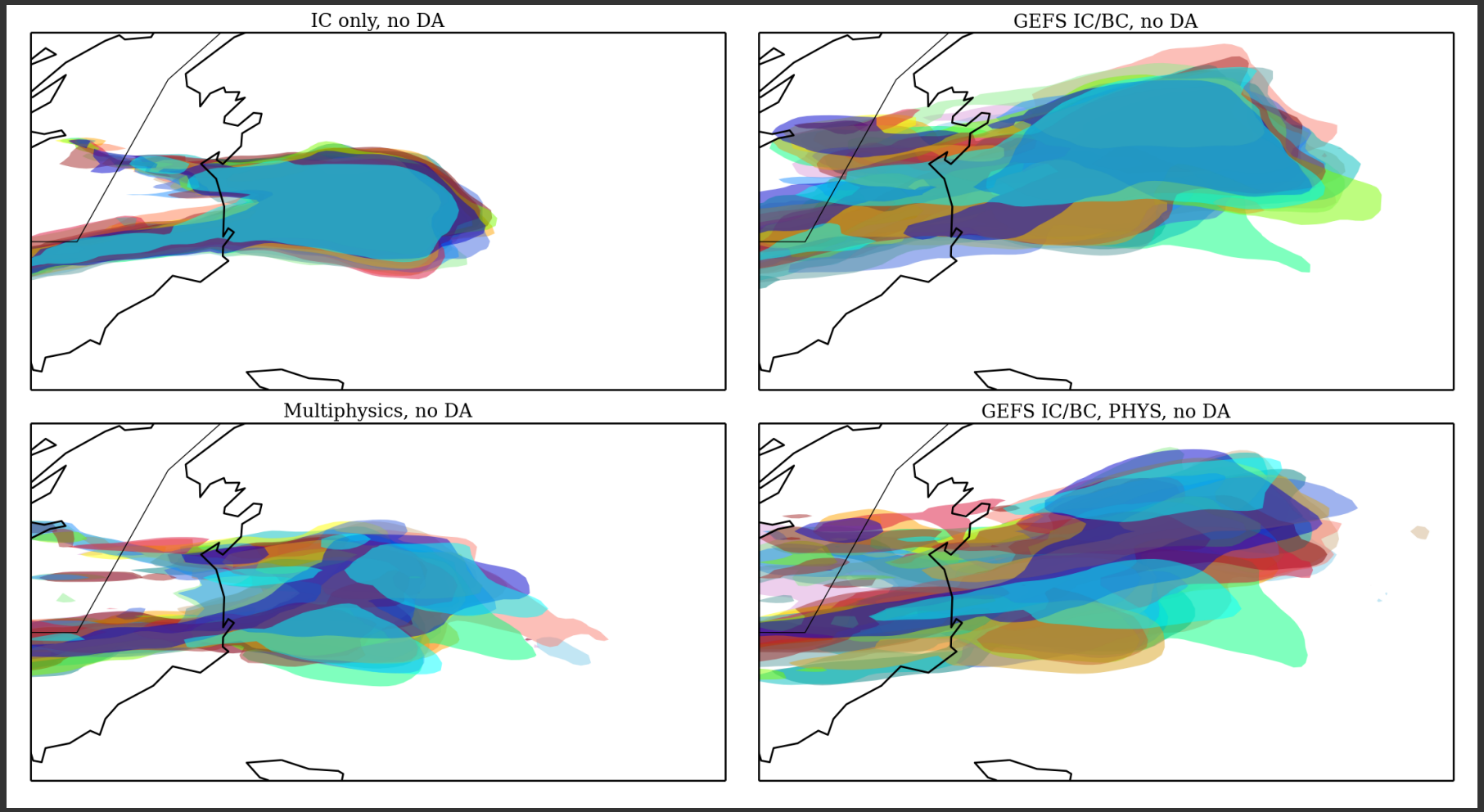
Ensemble name	Initial conditions, IC perturbation	Boundary conditions, BC perturbation	Physics
IC	GFS, Climatology background error statistics (CV3)	GFS, Only initial BC perturbation from CV3	Fixed
PHYS	GFS, None	GFS, None	Varying combinations of microphysics and boundary layer schemes
IC/BC	GEFS, GEFS member perturbation	GEFS, GEFS member perturbation	Fixed
IC/BC PHYS	GEFS, GEFS member perturbation	GEFS, GEFS member perturbation	Same as PHYS

Ensemble performance – Error and **spread** important

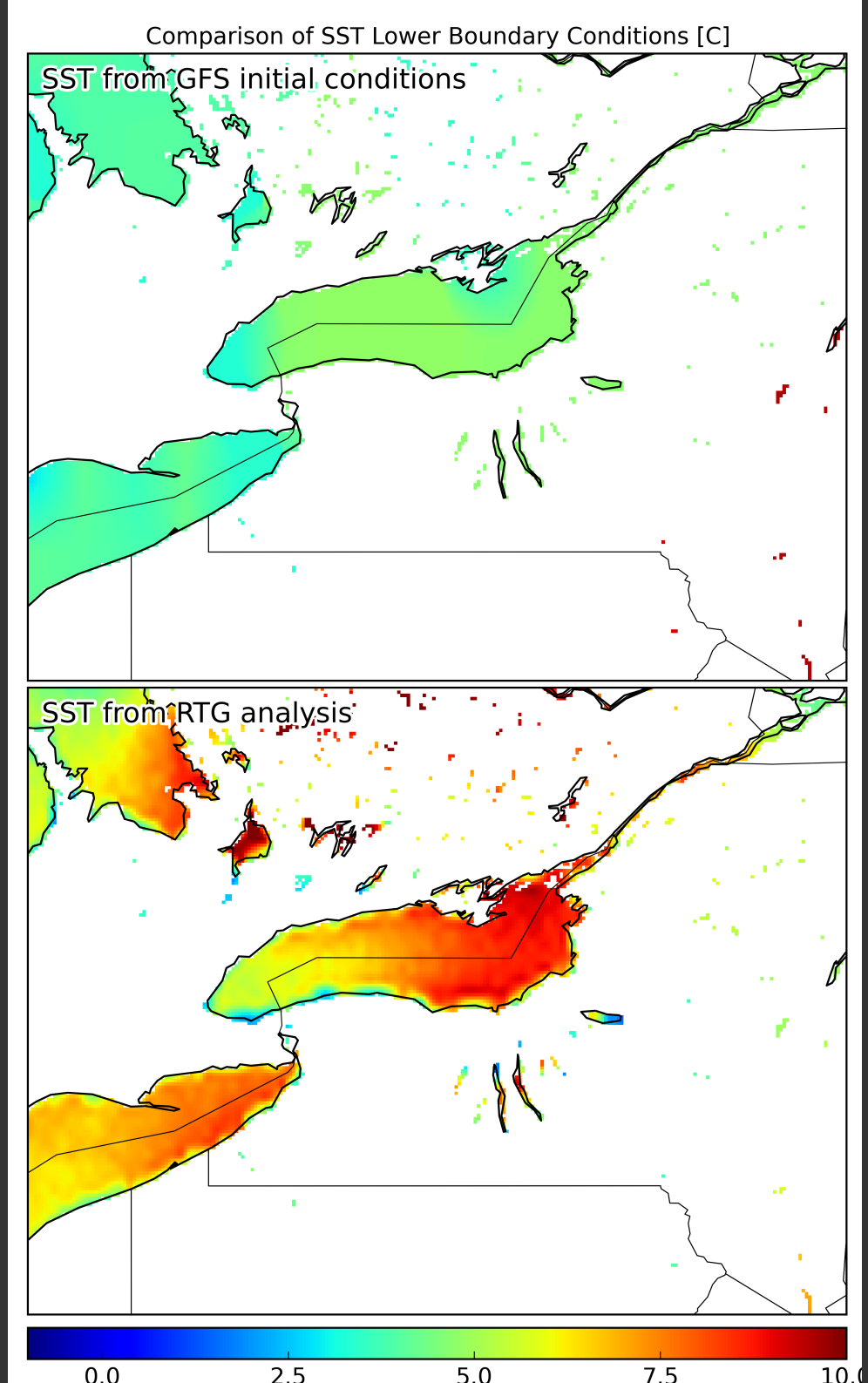


- Error profiles are similar, but large differences in spread suggest IC/BC best represents dominant source of uncertainty

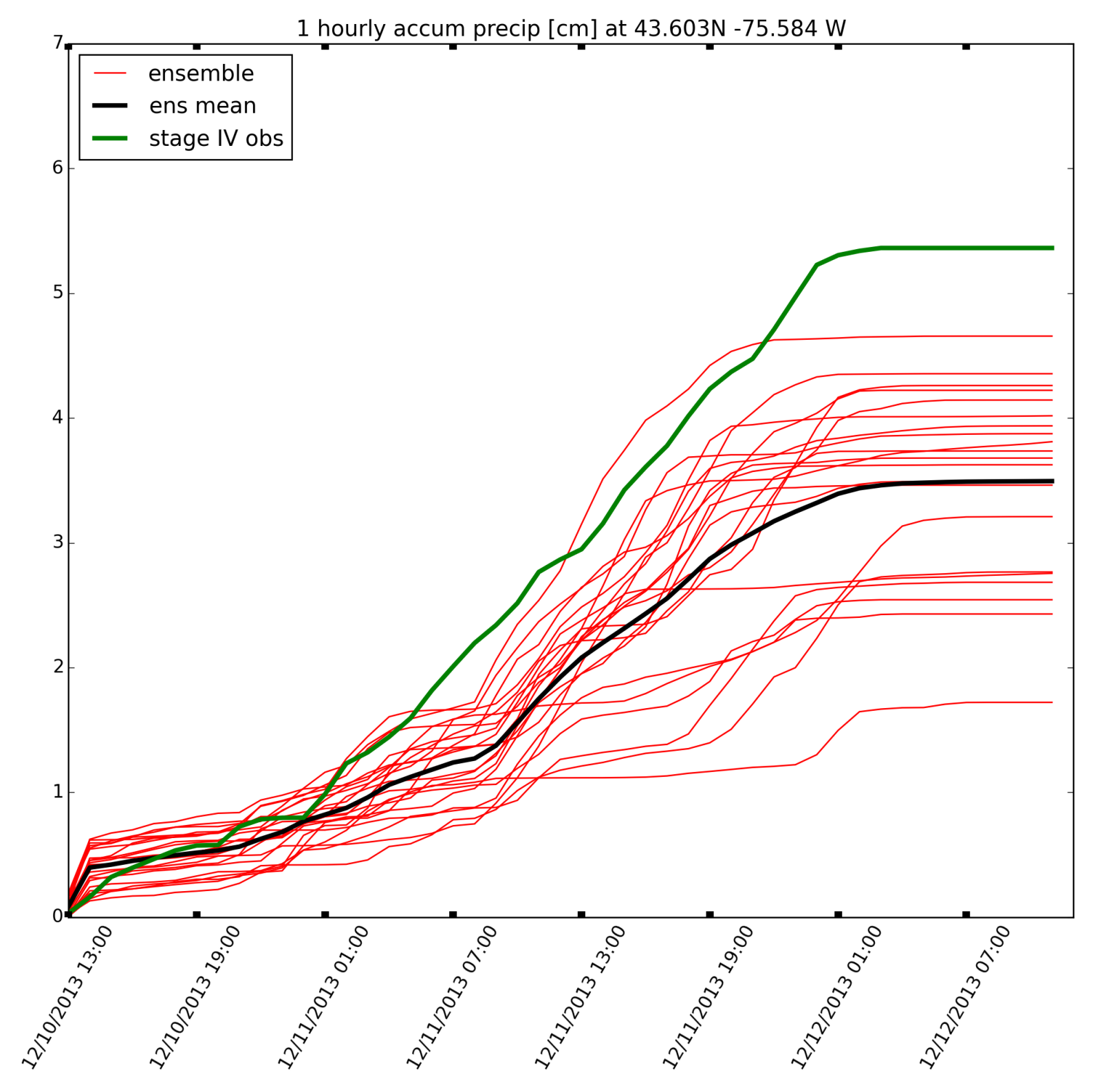
Ensemble dispersion impacts the forecast precipitation field



- Collapse of ensemble spread in IC, lack of spread in PHYS leads to overconfident and improper forecast


Comparison of SST Lower Boundary Conditions [C]
SST from GFS initial conditions
SST from RTG analysis
0.0
2.5
5.0
7.5
10.0

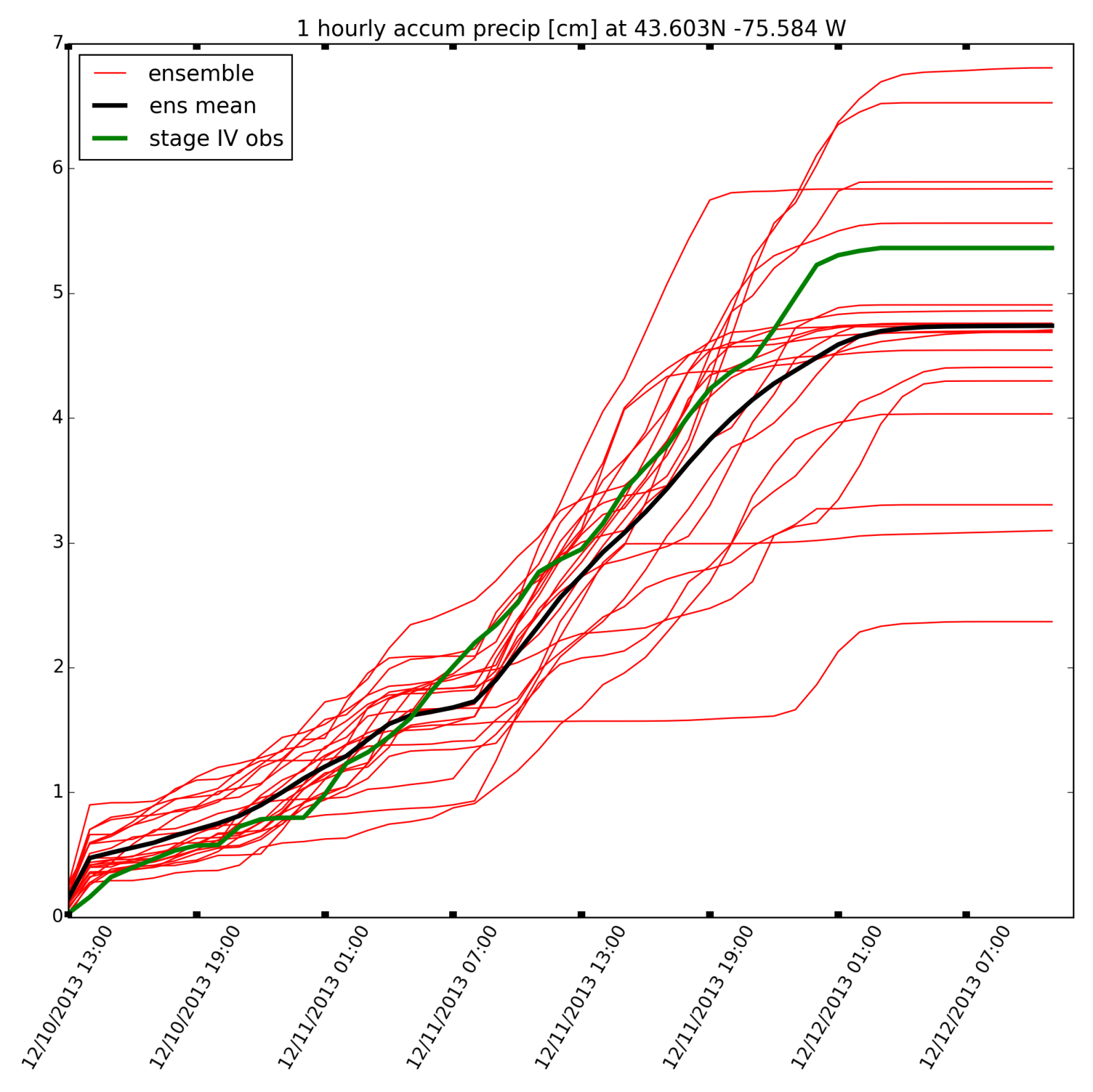
domain 3 (3km)


1 hourly accum precip [cm] at 43.603N -75.584 W
ensemble
ens mean
stage IV obs
0
1
2
3
4
5
6
7
12/10/2013 13:00
12/10/2013 19:00
12/11/2013 01:00
12/11/2013 07:00
12/11/2013 13:00
12/11/2013 19:00
12/12/2013 01:00
12/12/2013 07:00

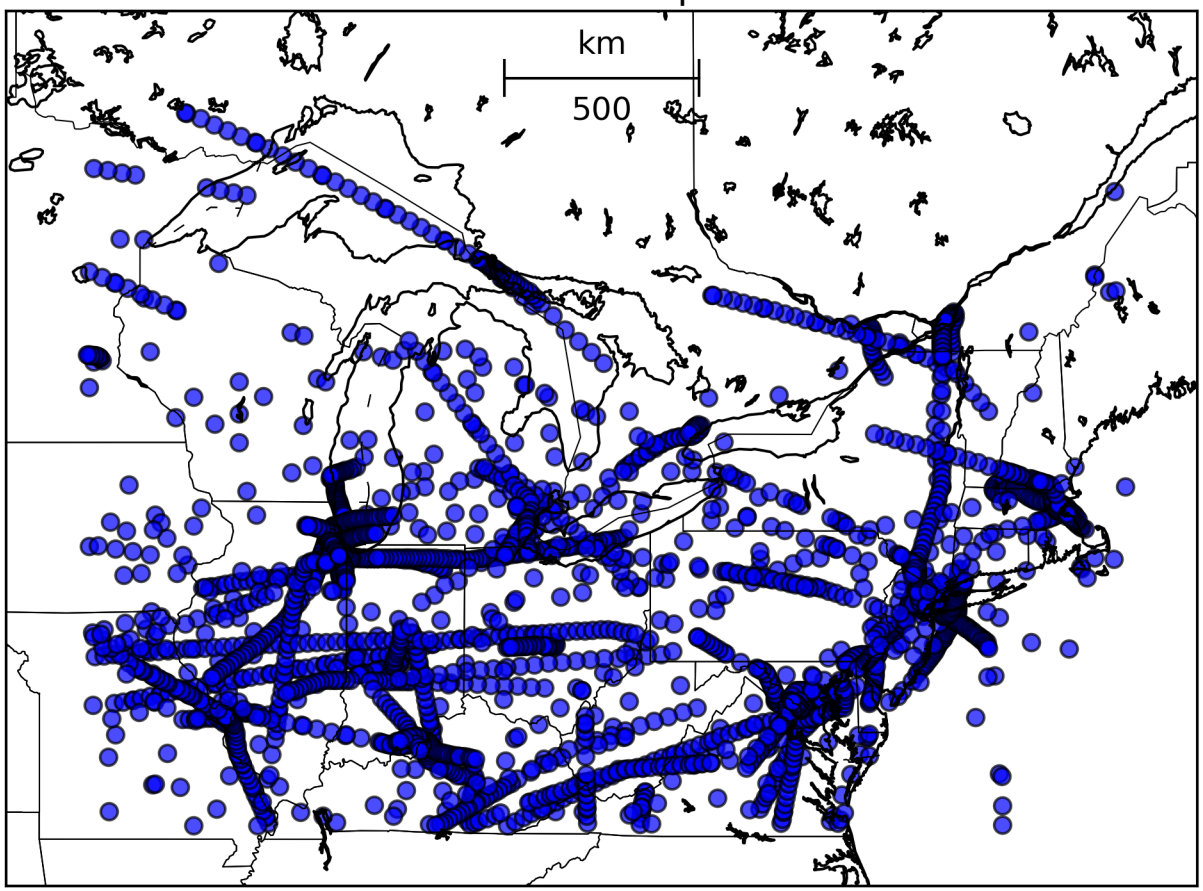
domain 3 (3km)

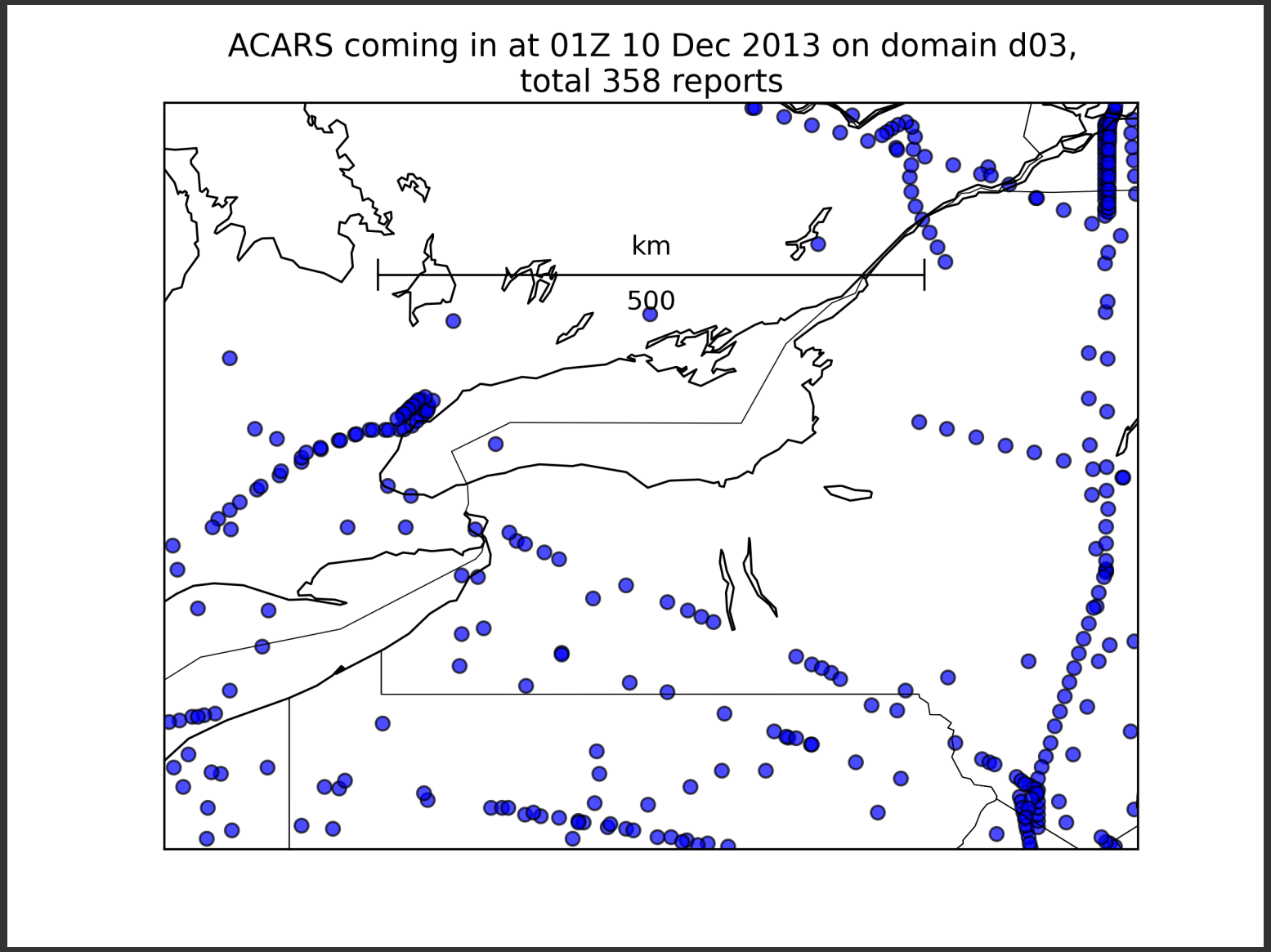
SST update forces much warmer lake, different spatial pattern of temp

Makes sense that precip increases



Majority of UA obs are ACARS




ACARS coming in at 01Z 10 Dec 2013 on domain d03,
total 358 reports
km
500