On the scale and magnitude of surface precursors to simulated isolated convective initiation

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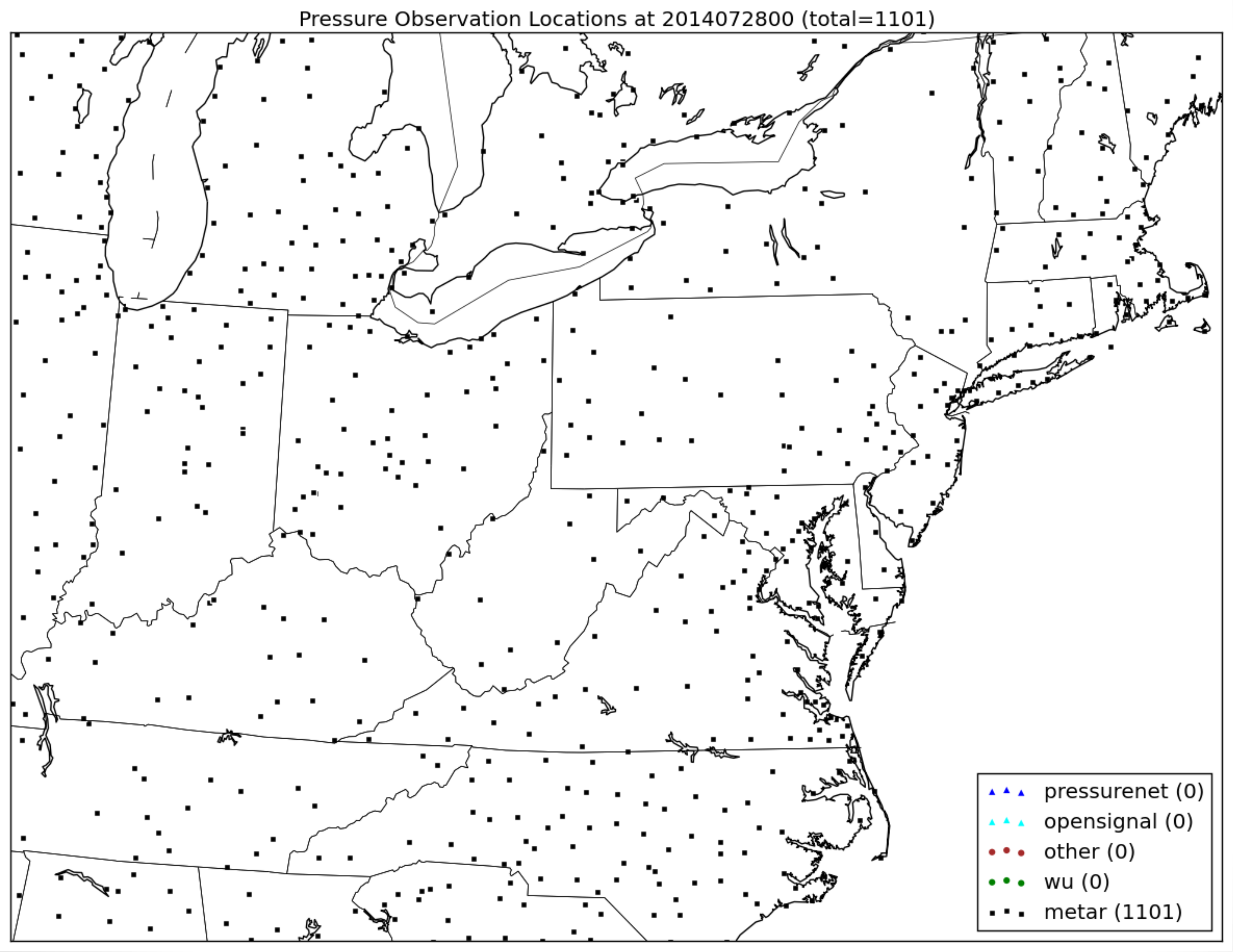
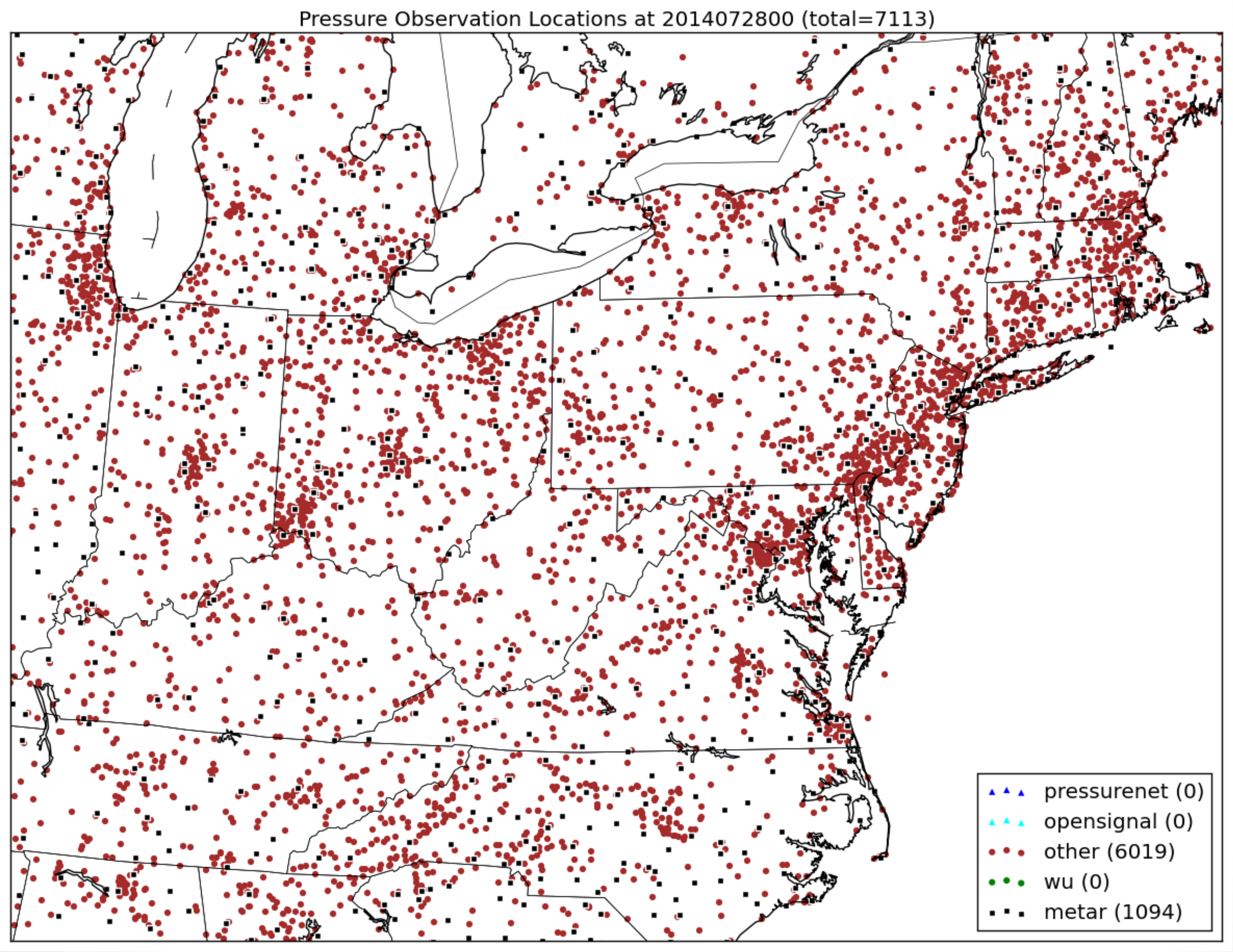
27th SLS – Madison, WI

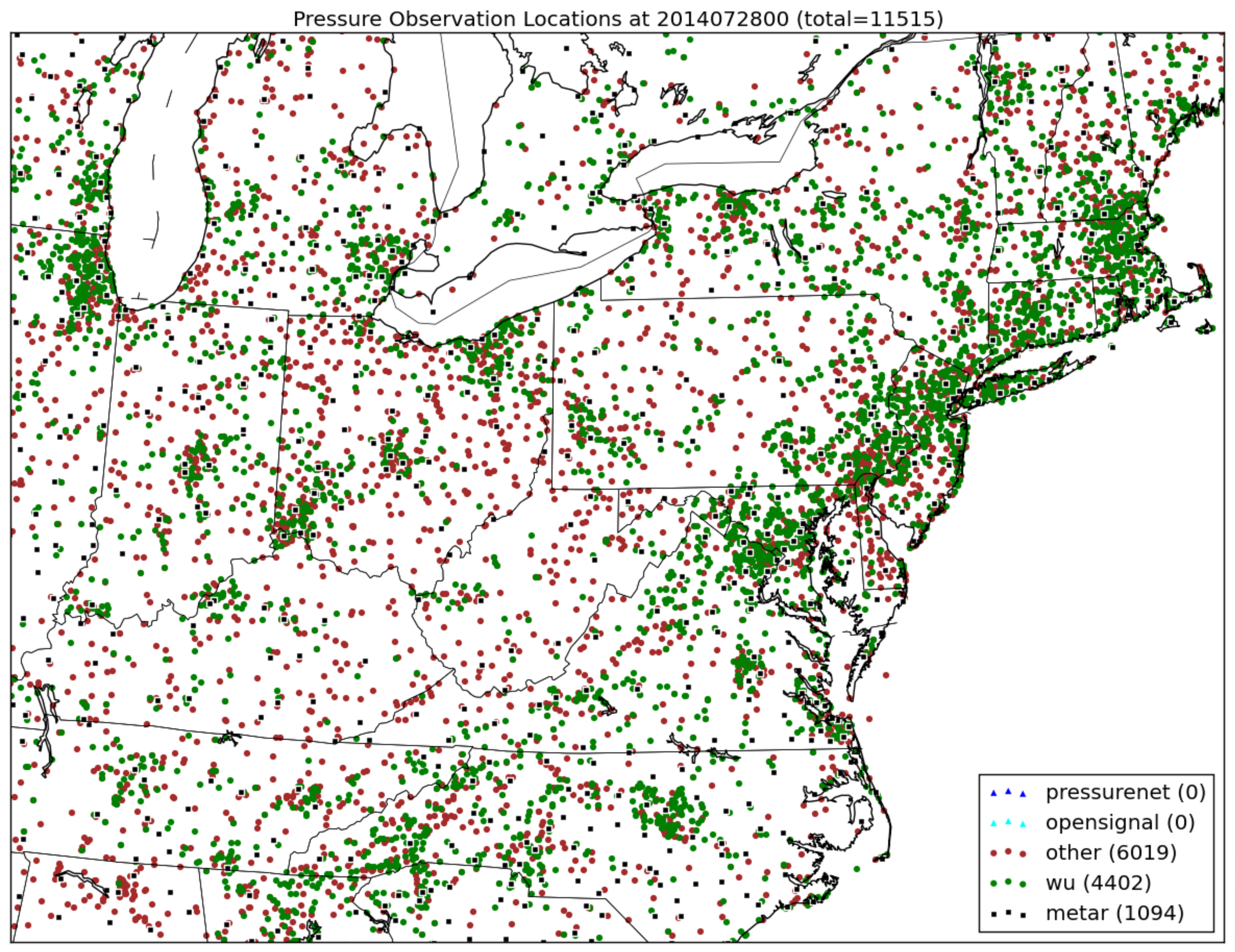
Dense Surface Observations



Dense Surface Observations

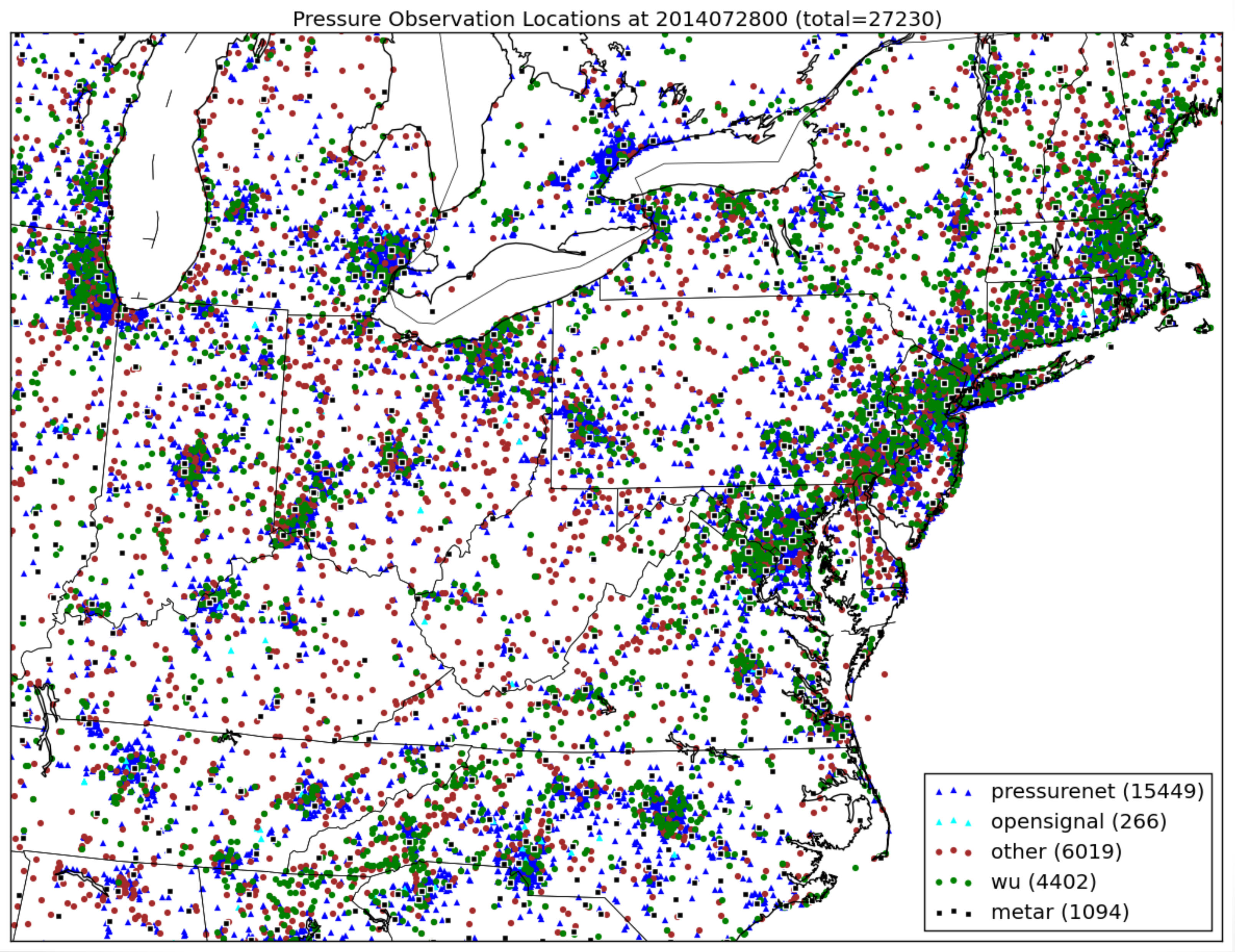


Dense Surface Observations



Madaus et al. 2013

Dense Surface Observations



Mass and Madaus 2013

Role of Surface in Convective Initiation (CI)

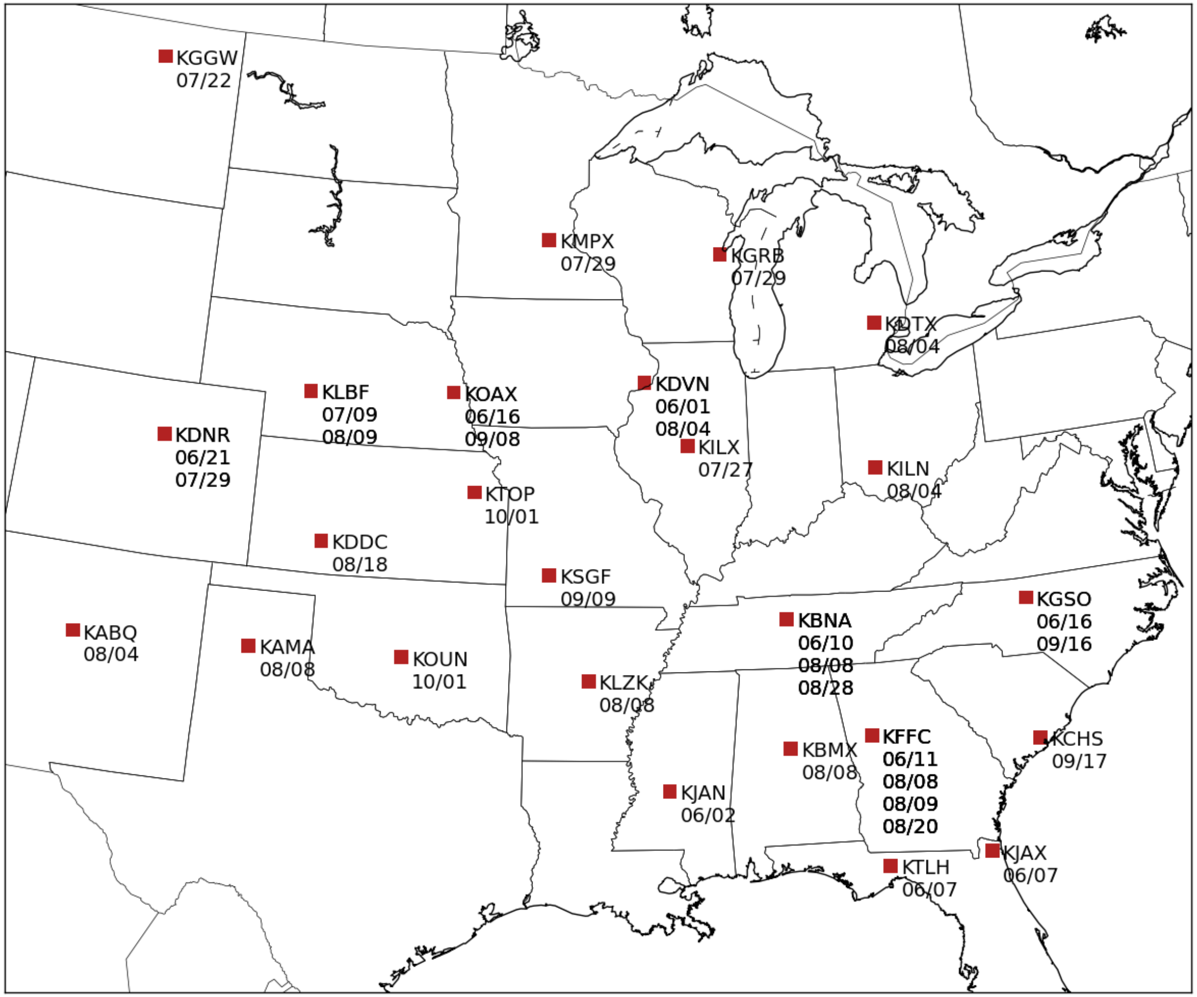
- Scale dependence of precipitation predictability is small-scale variability of low-level humidity, wind and temperature (Weckwerth 2000)
- Low-level convergence 15-90 minutes before CI (Weckwerth and Parsons 2006)
- Horizontal Convective Rolls and Misocyclones→ have surface signature (e.g. Weckwerth et al. 1996, Kain et al. 2013)
- Surface observations able to constrain boundary layer well (Hacker et al. 2007, Hacker and Snyder 2005)

Question

How well can assimilating dense surface observations constrain model forecasts of convective initiation?

Experiments

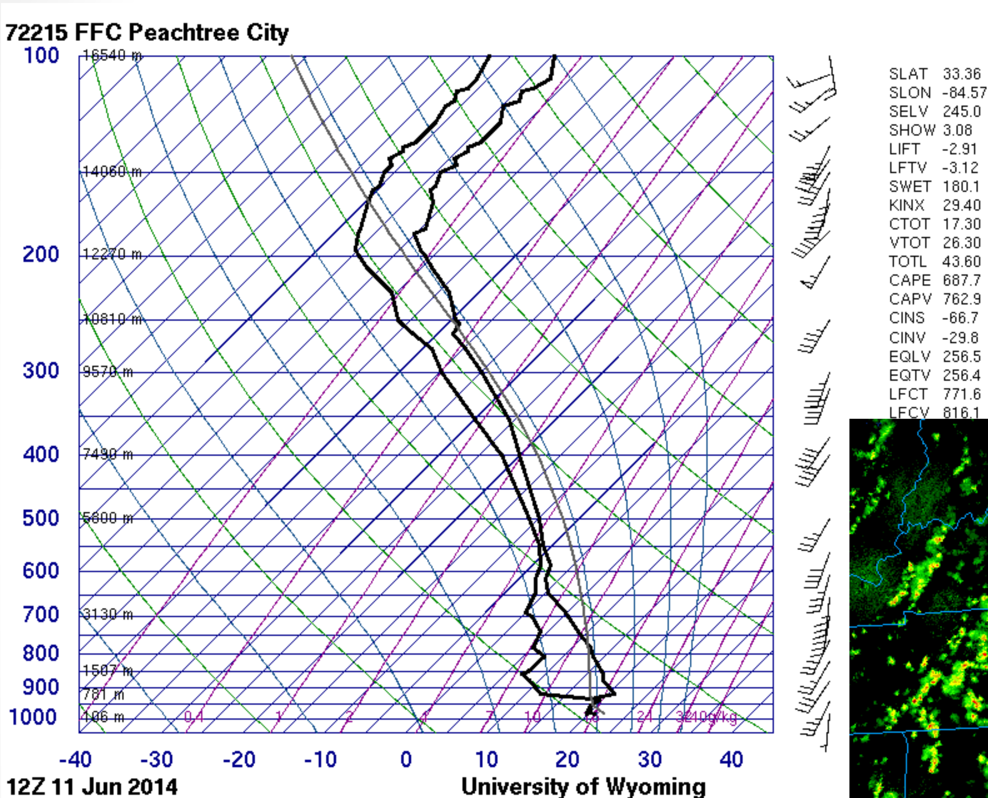
- Directly examine the impact of surface observations on convective initiation, beyond the larger mesoscale
  - 30 cases
  - May-October, 2014
  - “Air-mass” storms
    absent large-scale
    forcing
  - ALL cases associated
    with at least one
    severe storm
    report



Experiments

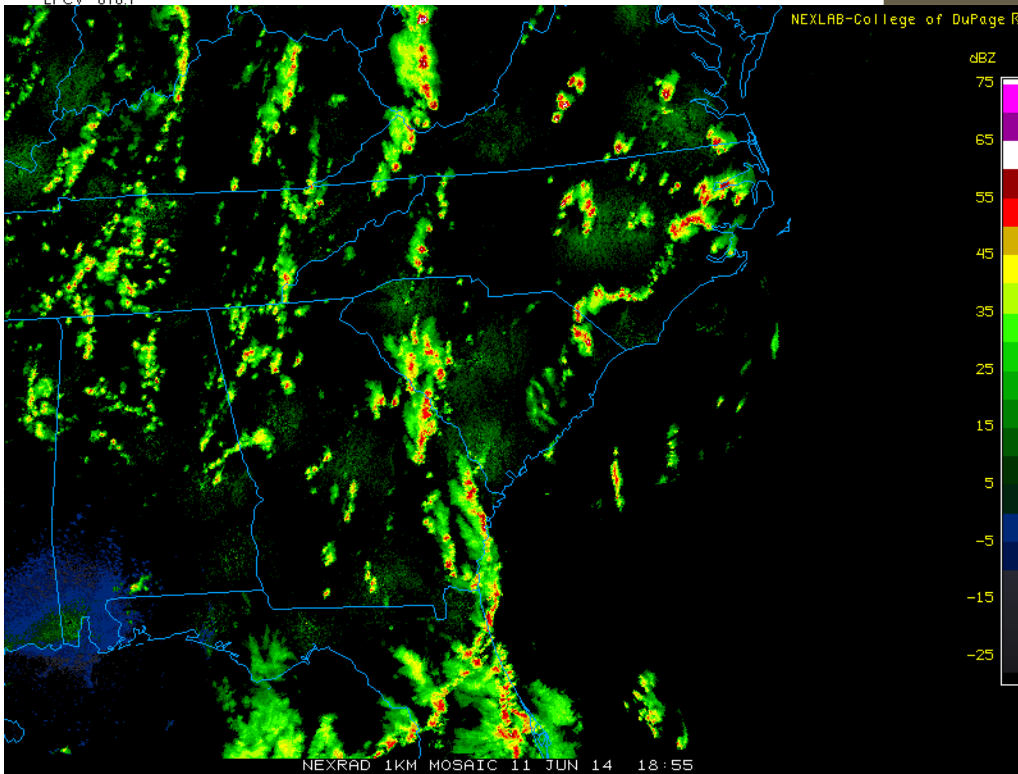
- Simulations with CM1 (r17) (Bryan and Fritsch 2002; Bryan 2002)
  - Initialize at 12Z with real soundings
  - Fixed surface fluxes
  - 0.2 K random T perturbations at start
  - 104km x 104km x 18km domain
  - 200m resolution “truth” run (e.g. Nowatarski et al 2014)
    - 50m dz in PBL
  - 1 km resolution—100 member ensemble
    - 150m dz in PBL
  - YSU PBL, NASA-Goddard MP and radiation

KFFC June 11, 2014



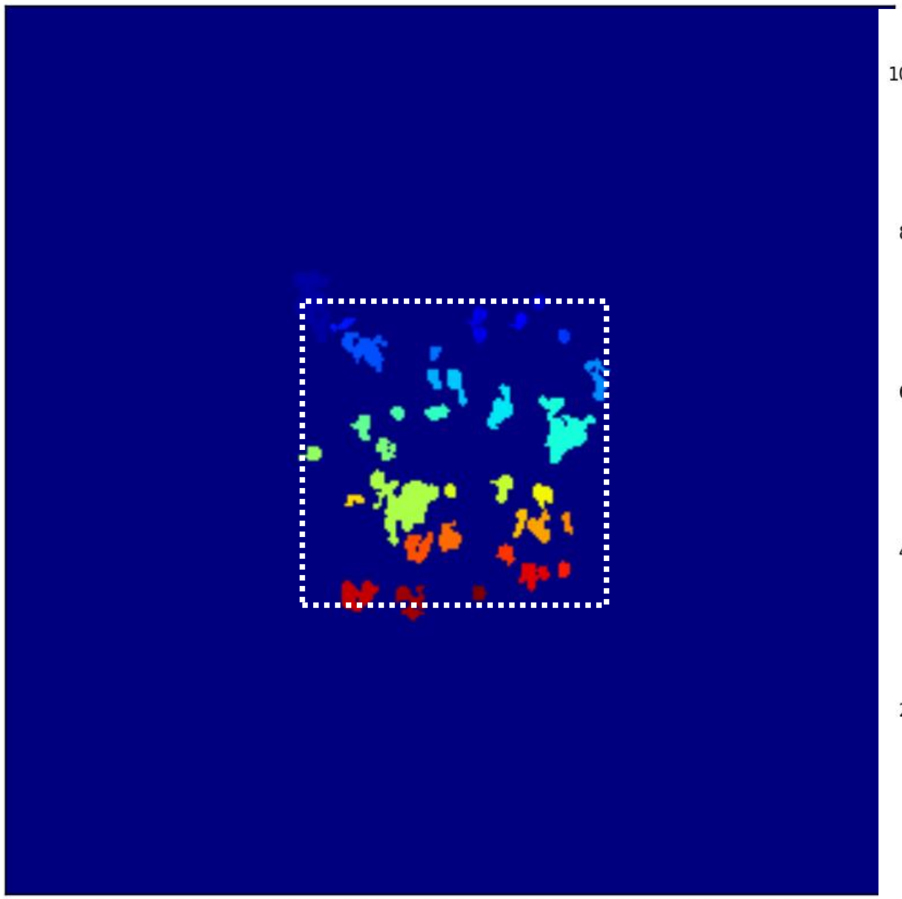
http://weather.uwyo.edu/

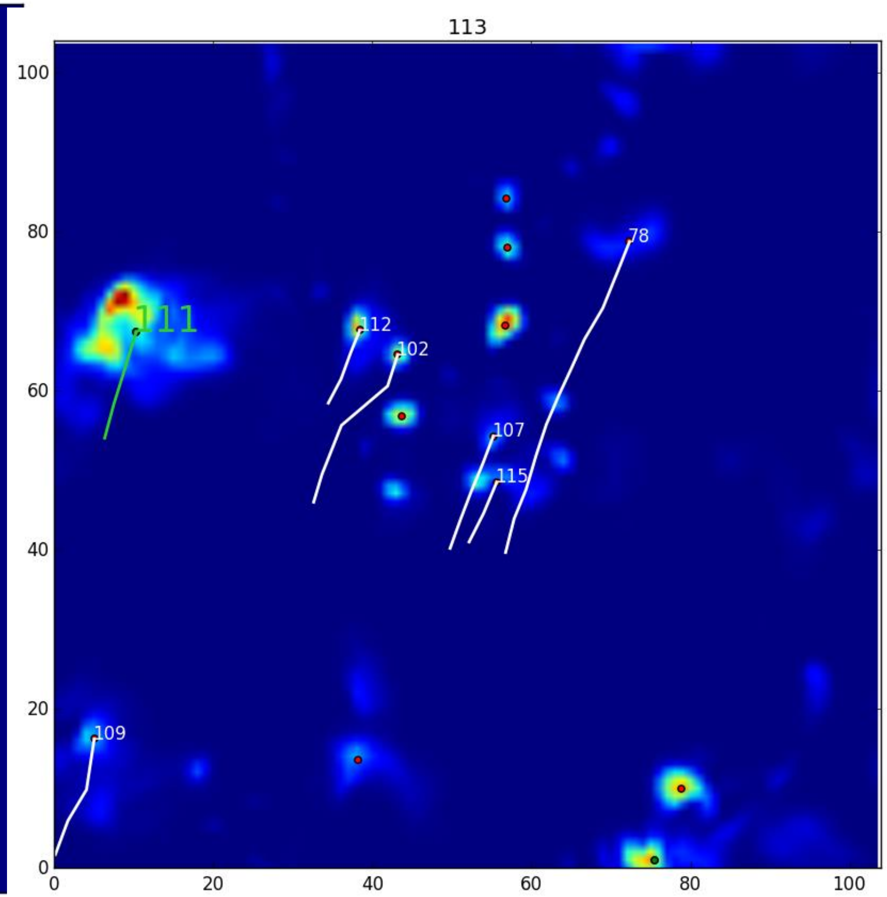
http://www.mmm.ucar.edu/imagearchive/



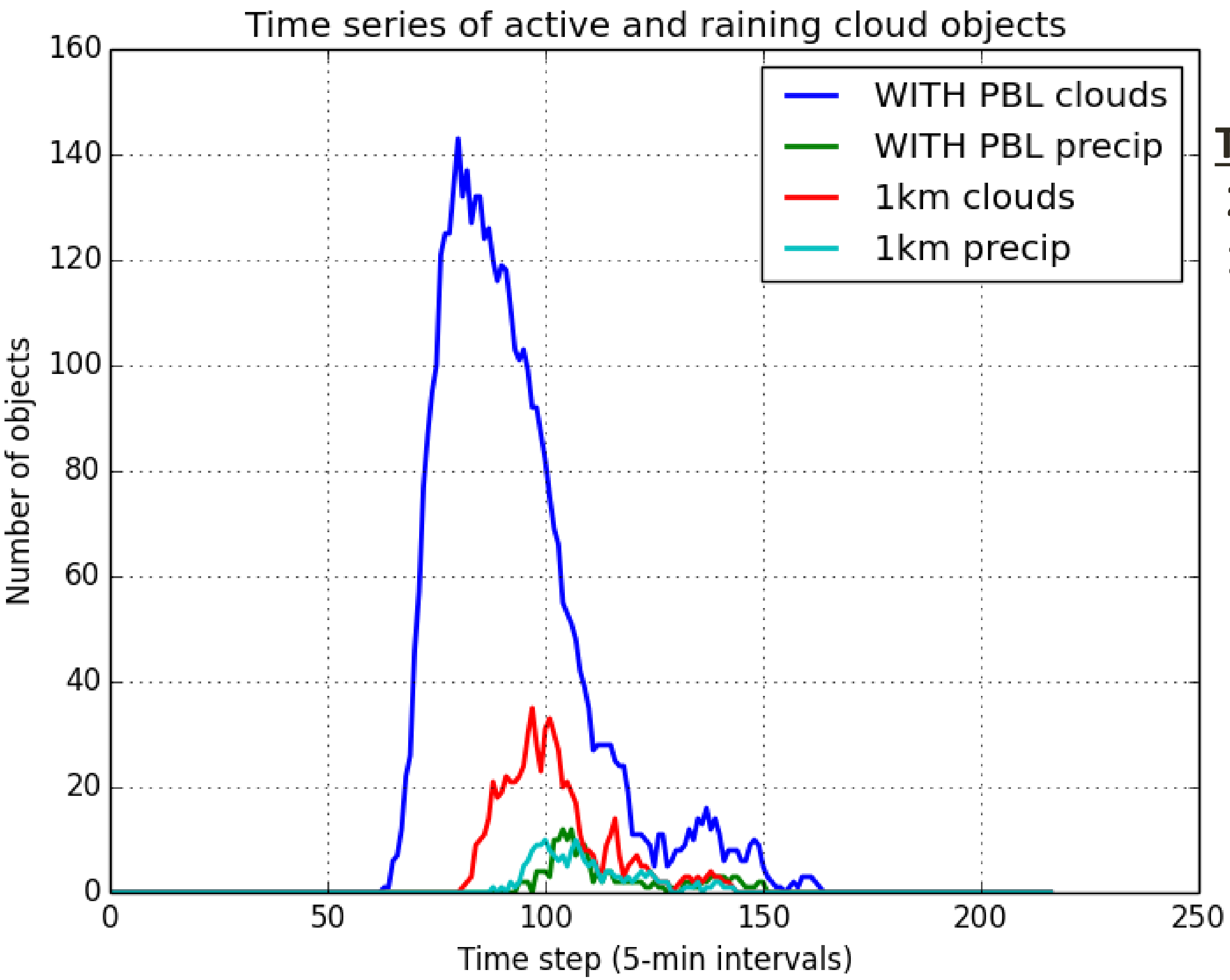
Object-based tracking

- Based on the Method for Object-based Diagnostic Evaluation (MODE) (Davis et al. 2006/2009 ; Wolff et al. 2014)
- Thresholding based on Kang and Bryan 2011





Storm Objects



<u>Total Precipitating Storms</u>

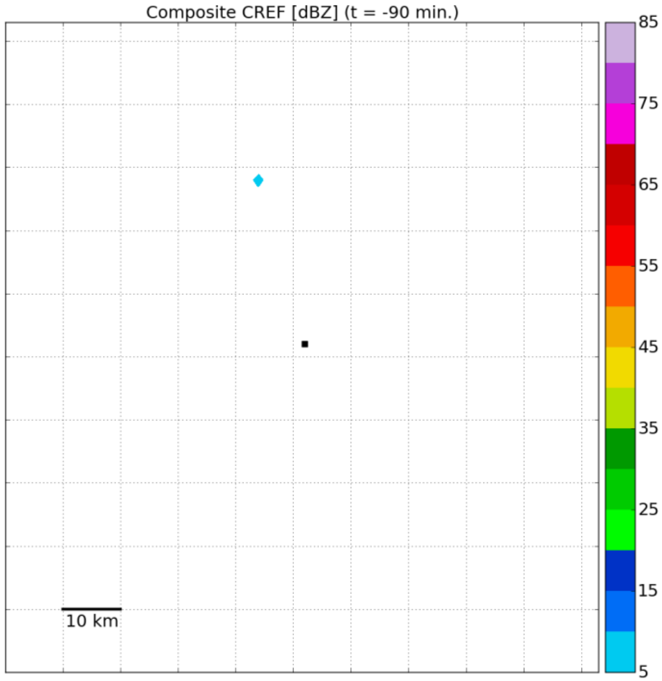
200m → 14

1km → 8-18

Surface Field Composites (1km)

- 1256 precipitating storms from 100 ensemble members (1km)
- Centered at location where precipitation begins
- Examine surface fields from 90 minutes before convective precip

Composite of Precipitating Objects



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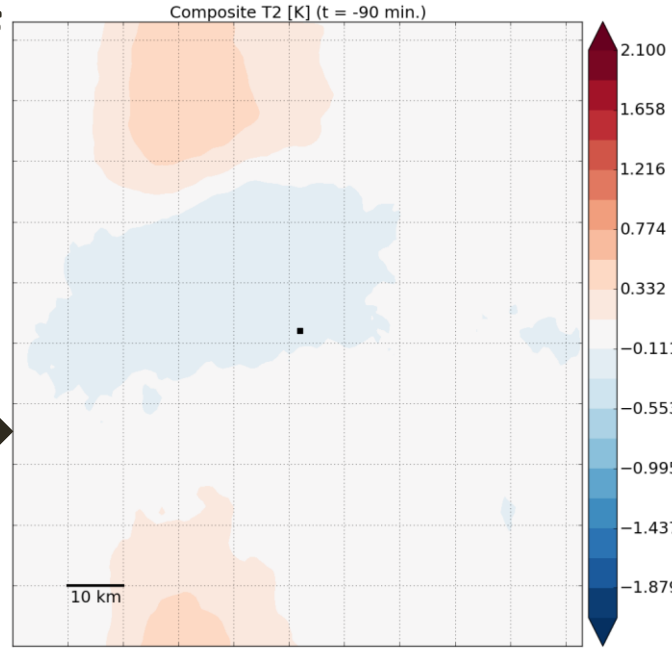
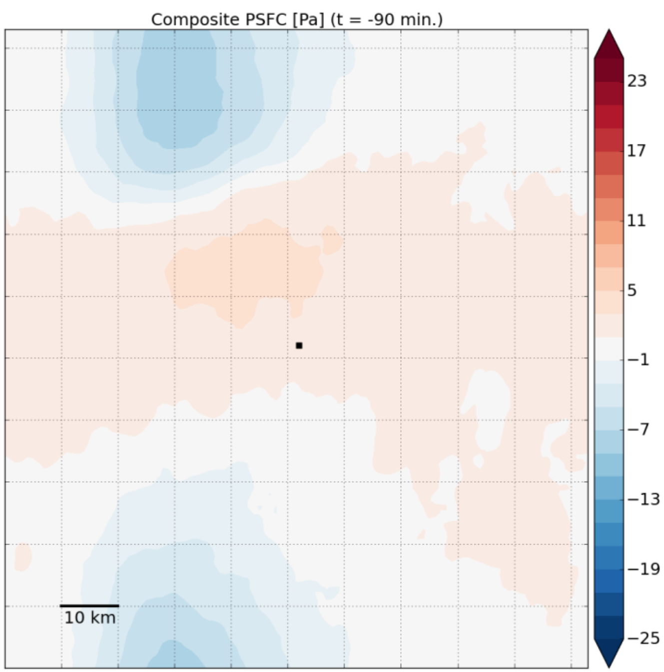
T2 →

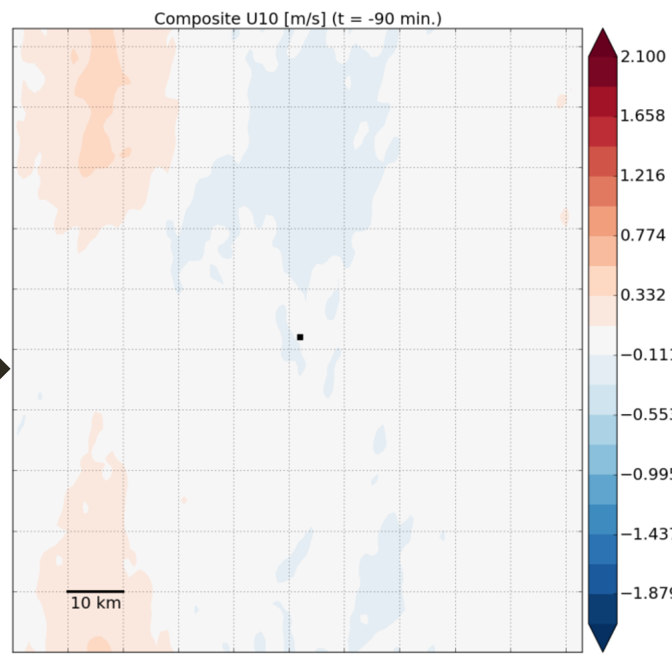


90 min
To Precip.



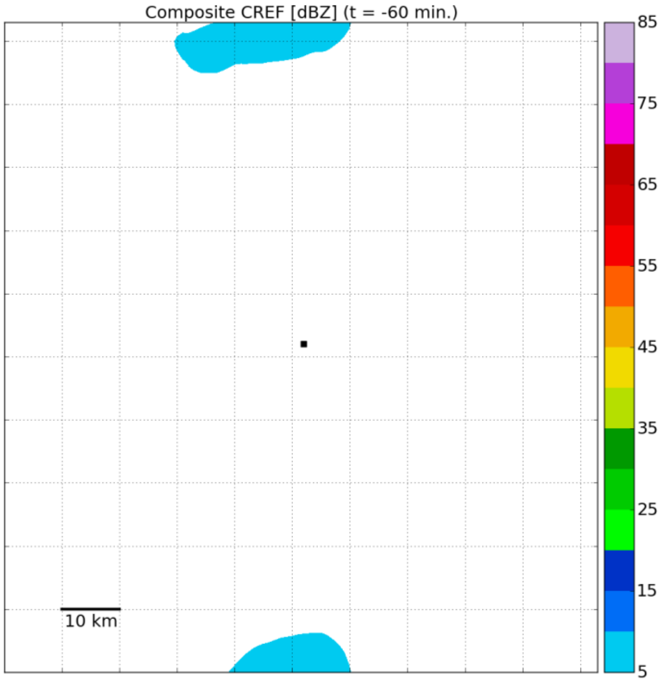
← PSFC

U10 →



1km res.

Composite of Precipitating Objects



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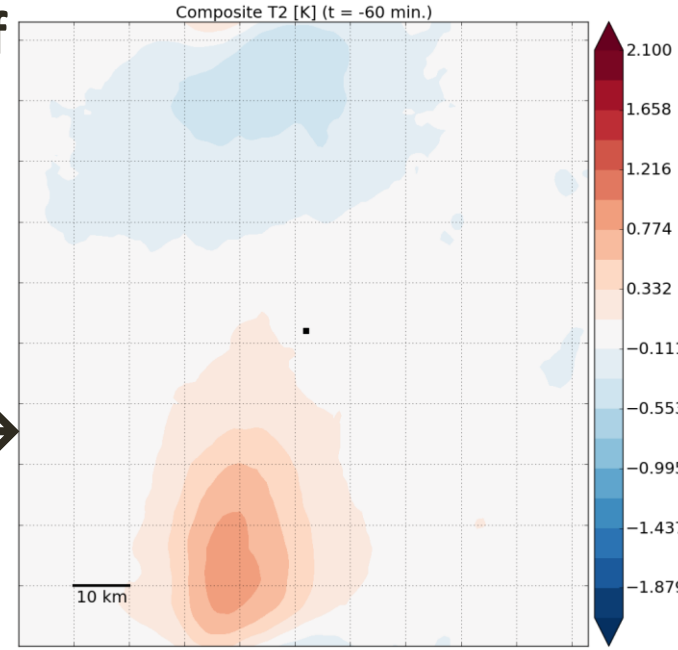
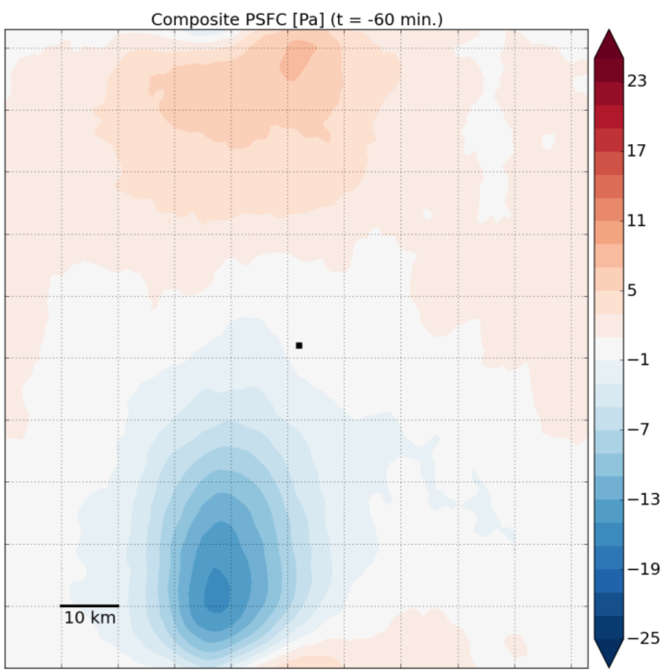
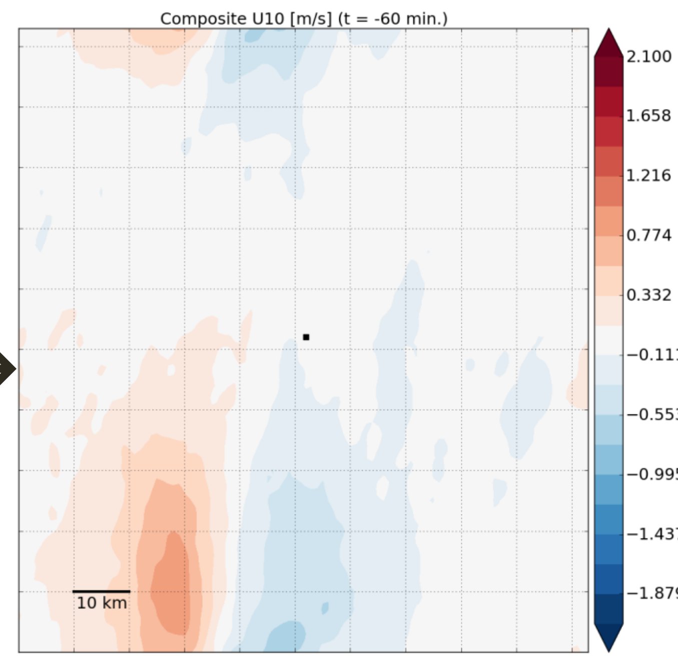


60 min
To Precip.



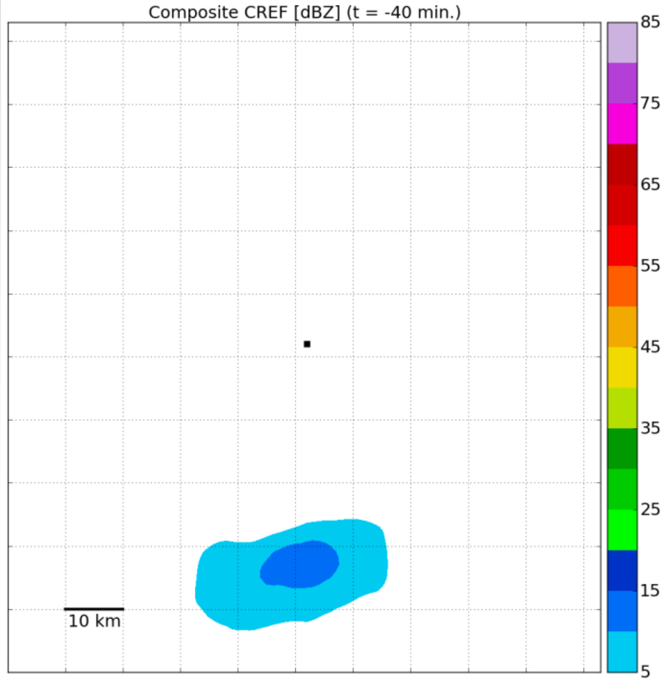
← PSFC

U10 →



1km res.

Composite of Precipitating Objects



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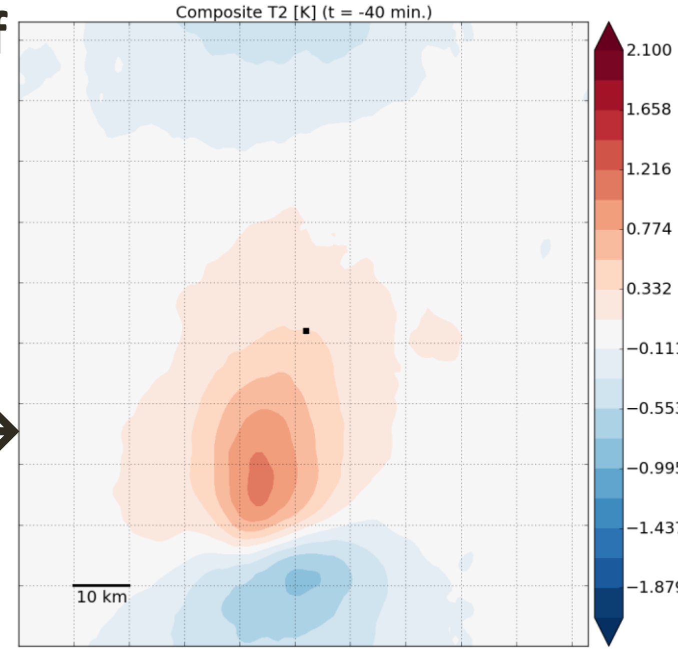
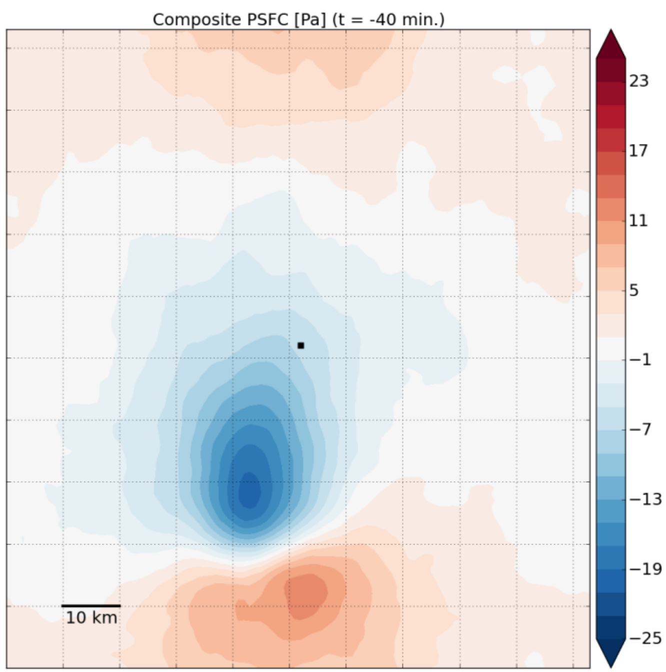


40 min
To Precip.



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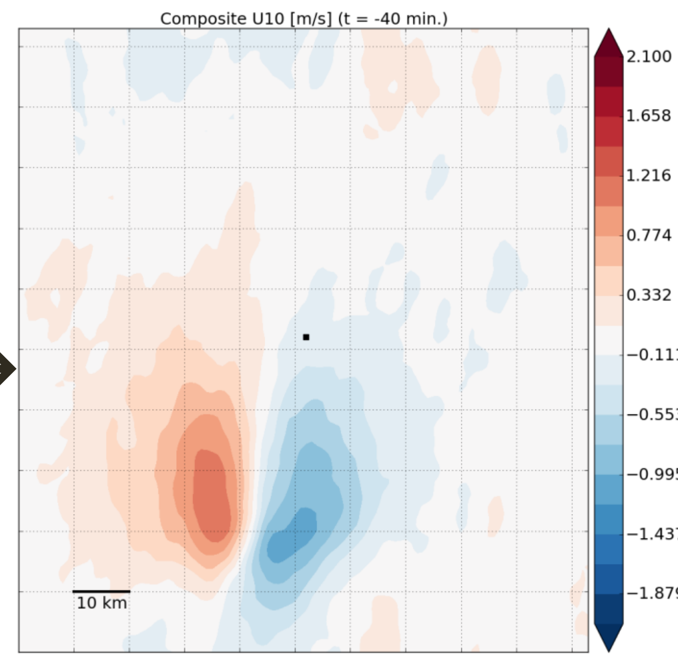
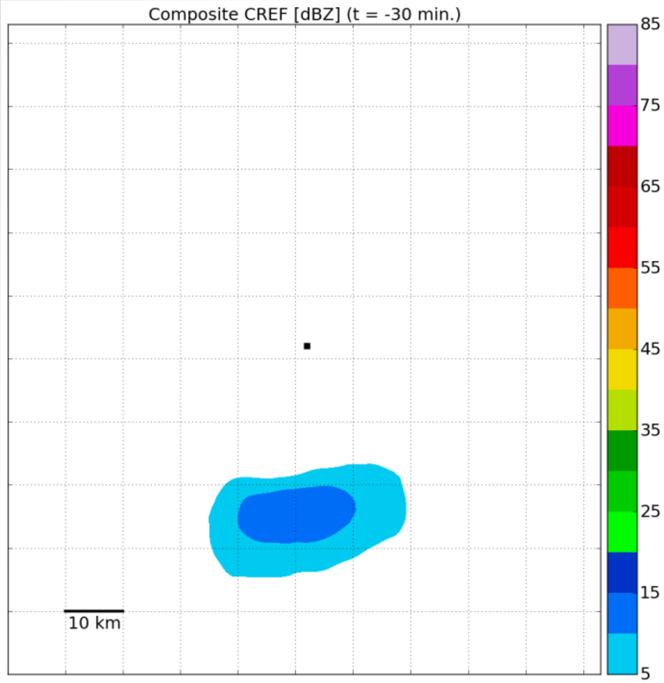


1km res.

Composite of Precipitating Objects



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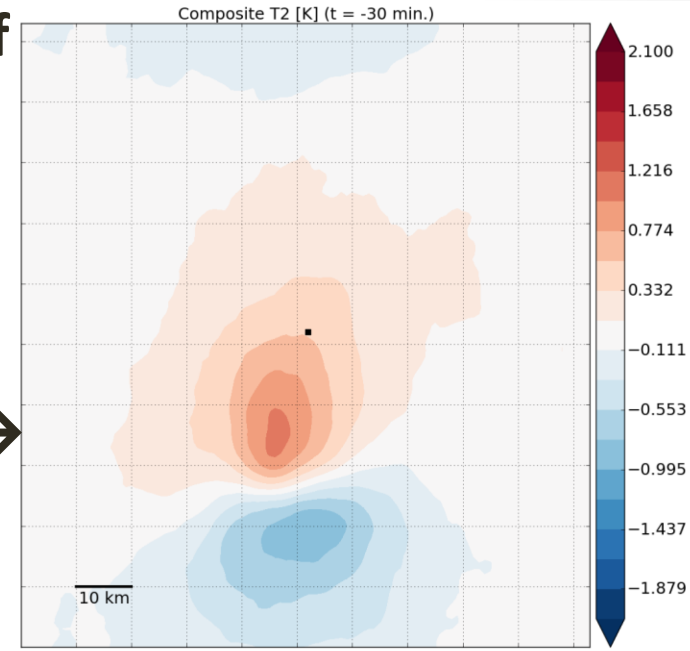
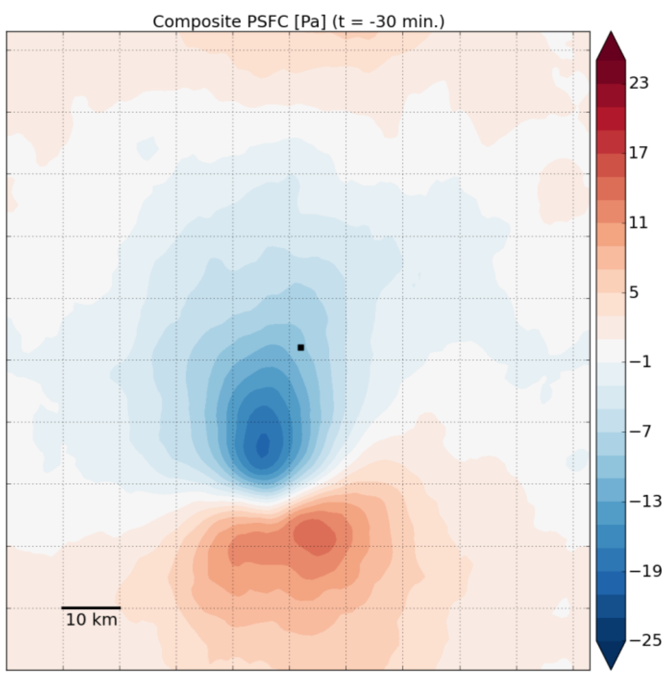
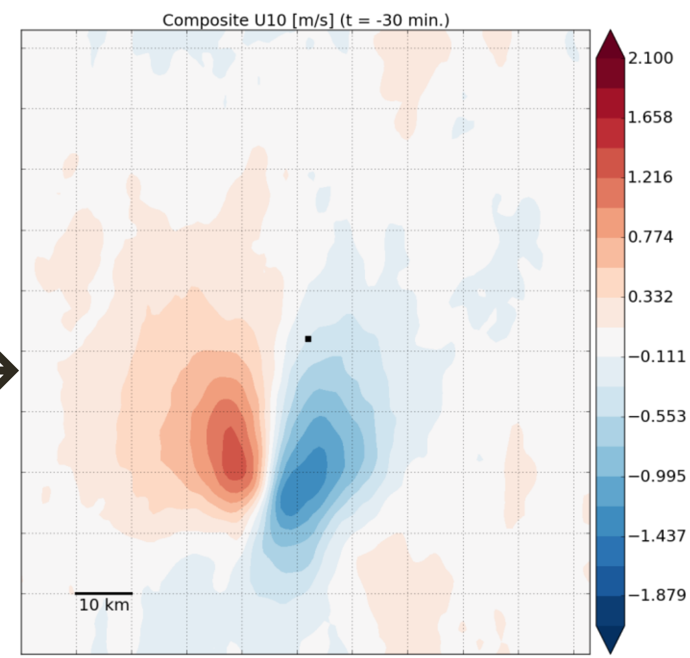


30 min
To Precip.



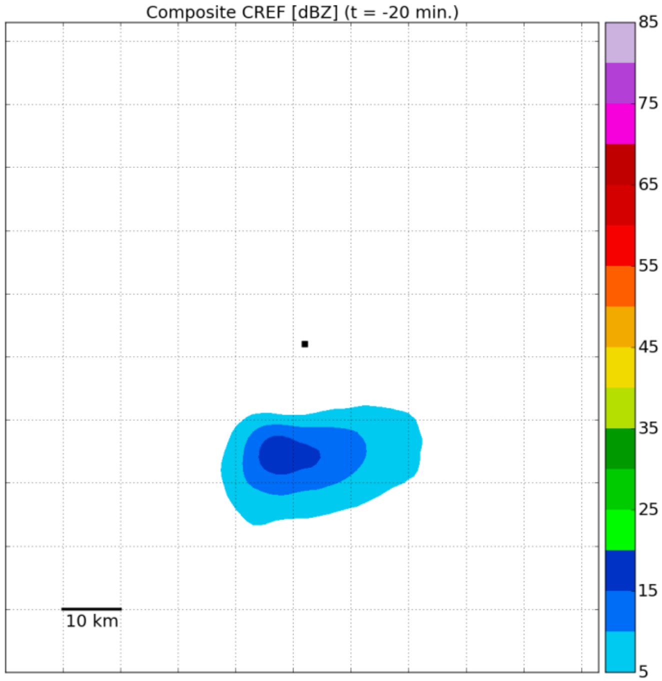
← PSFC

U10 →



1km res.

Composite of Precipitating Objects



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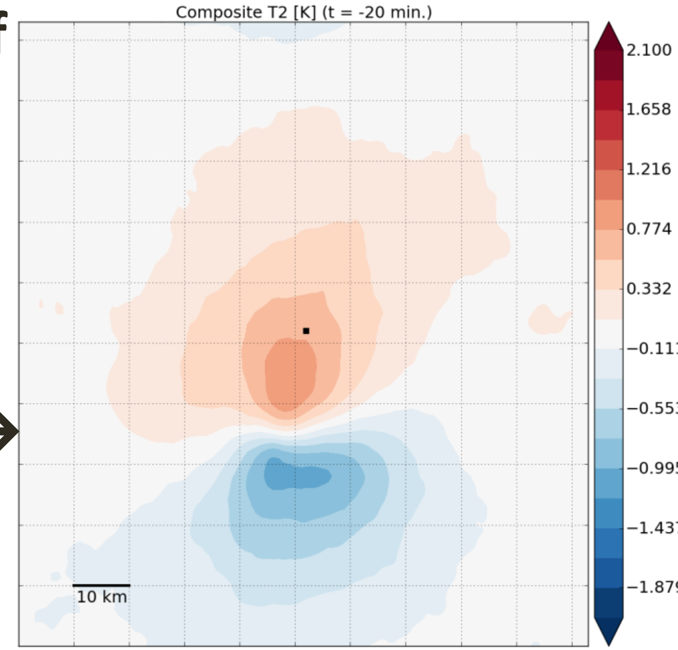
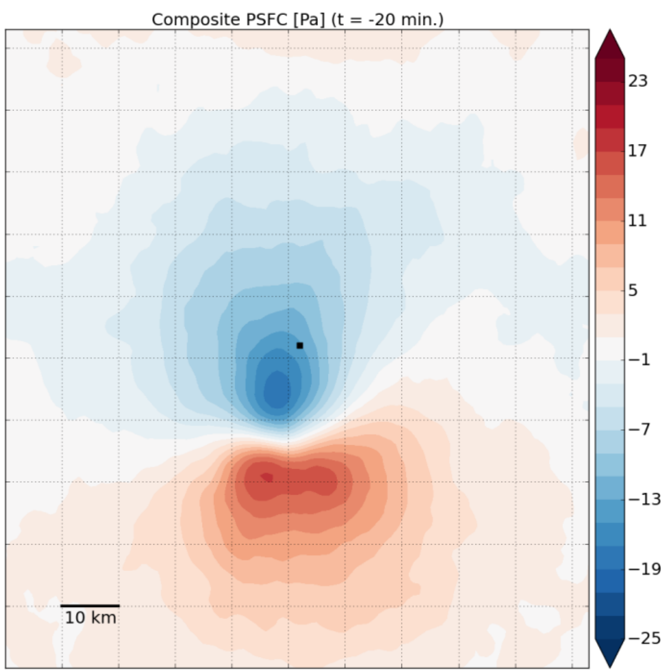


20 min
To Precip.



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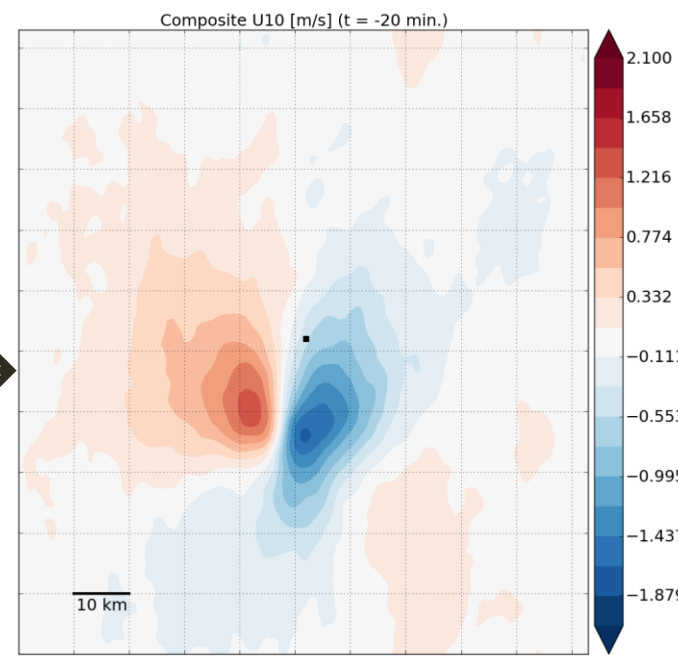
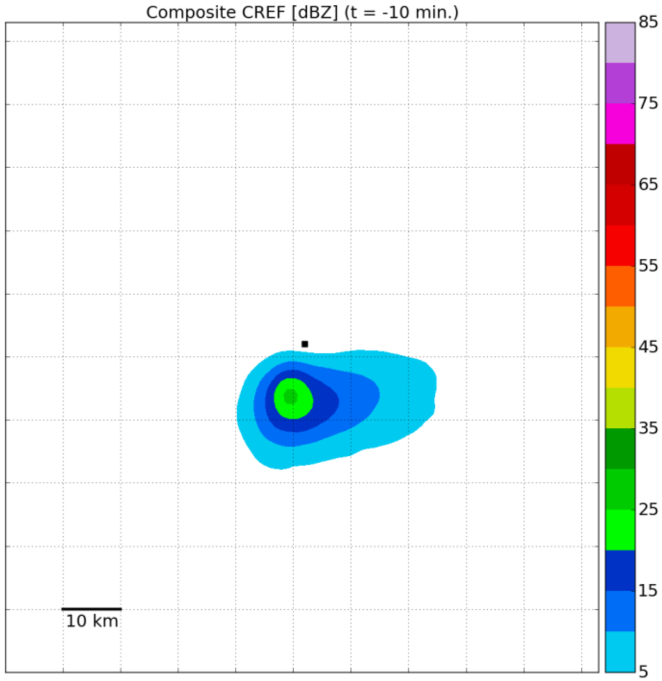


1km res.

Composite of Precipitating Objects



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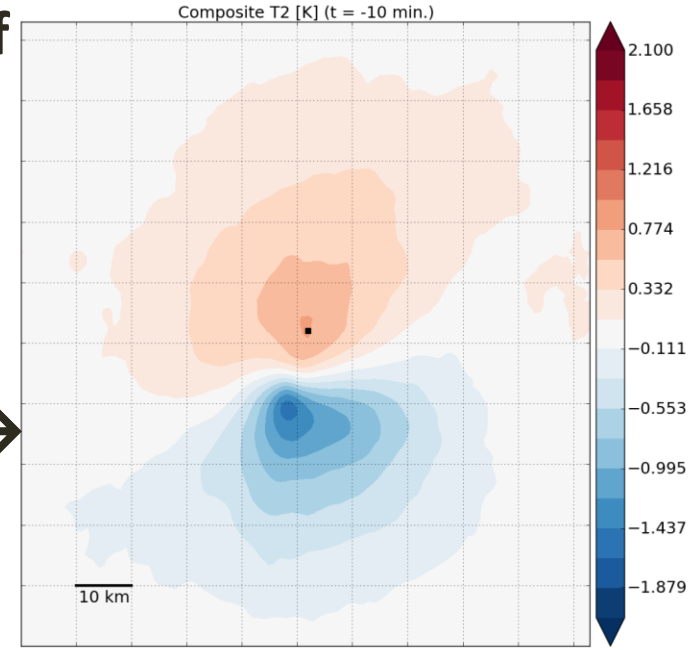
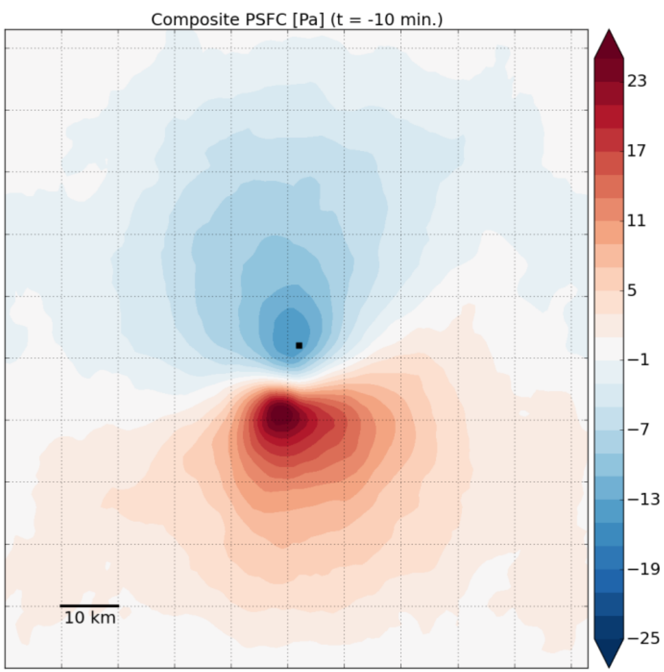


10 min
To Precip.



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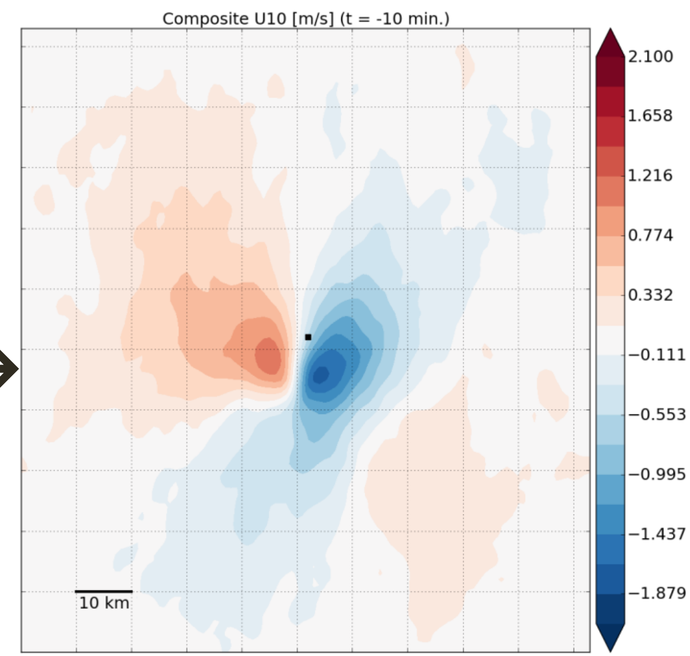
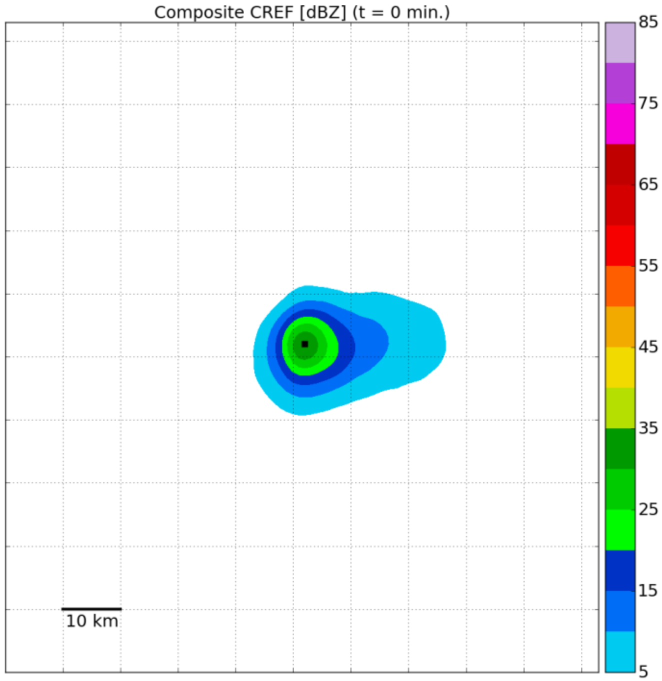


1km res.

Composite of Precipitating Objects



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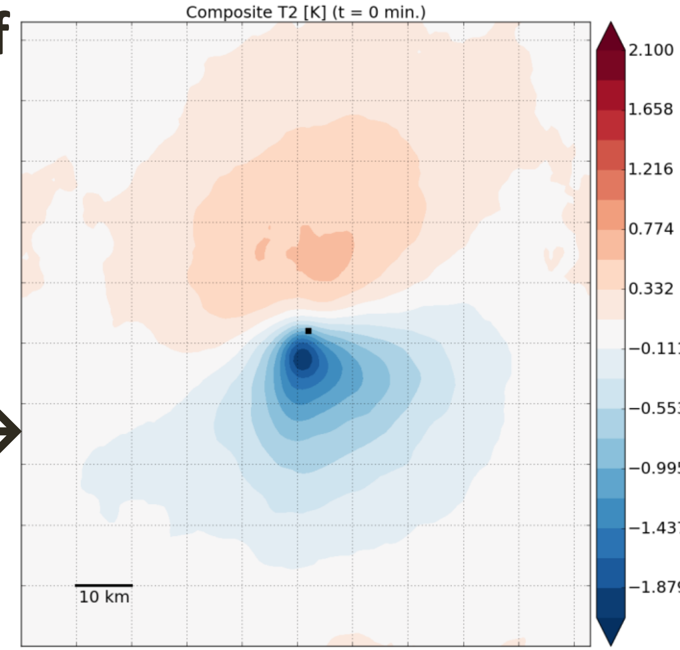
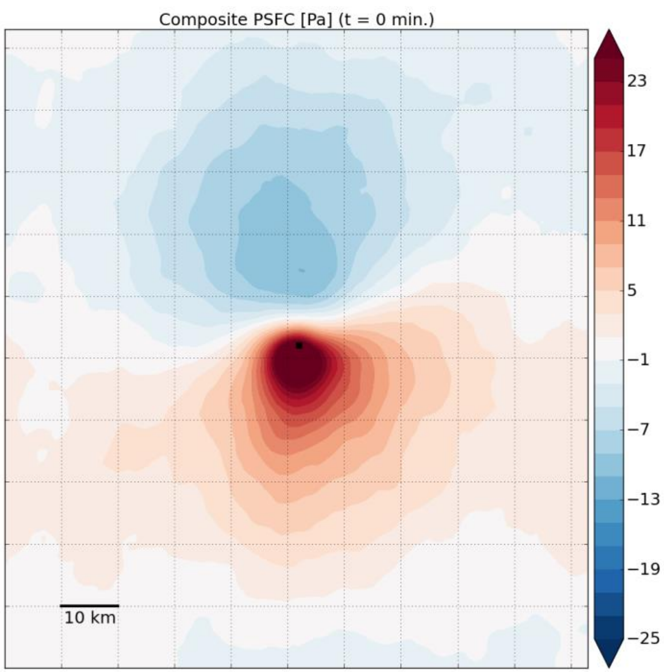


0 min
To Precip.



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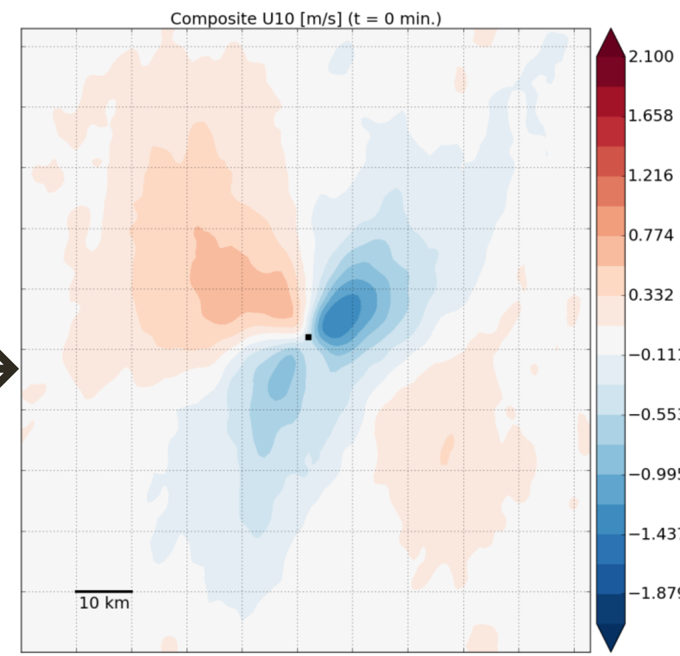
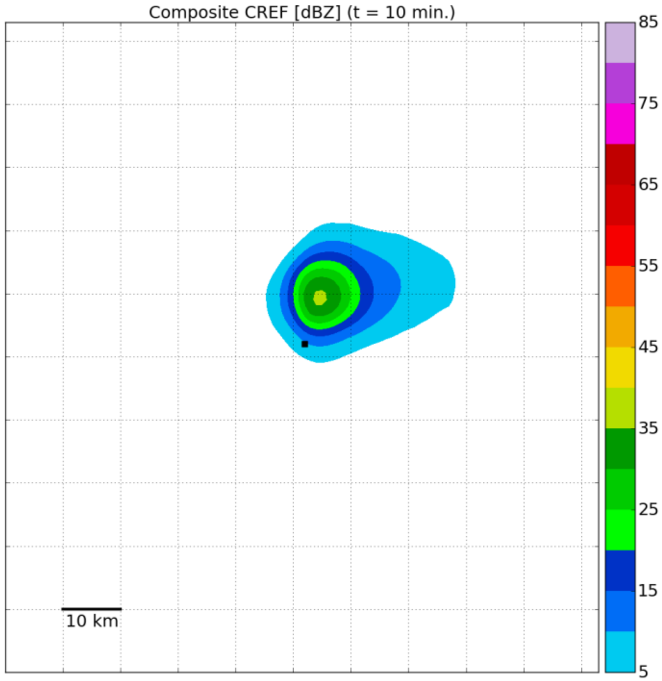


1km res.

Composite of Precipitating Objects



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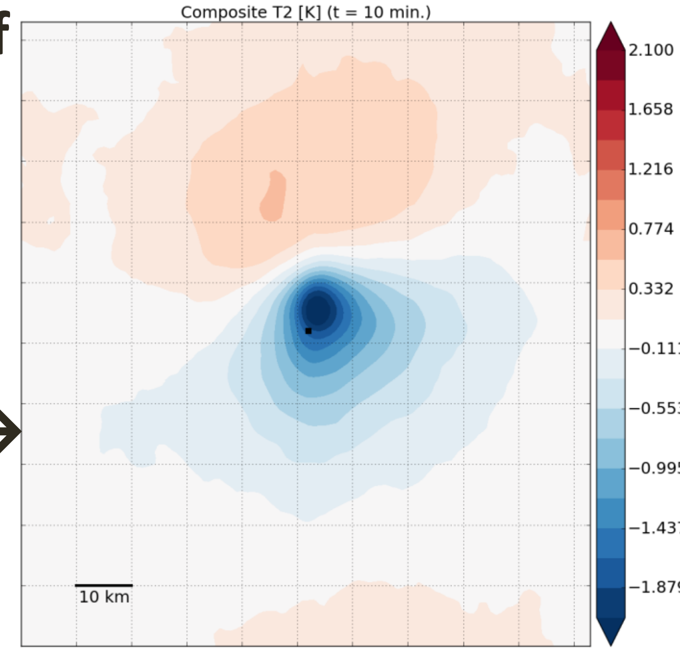
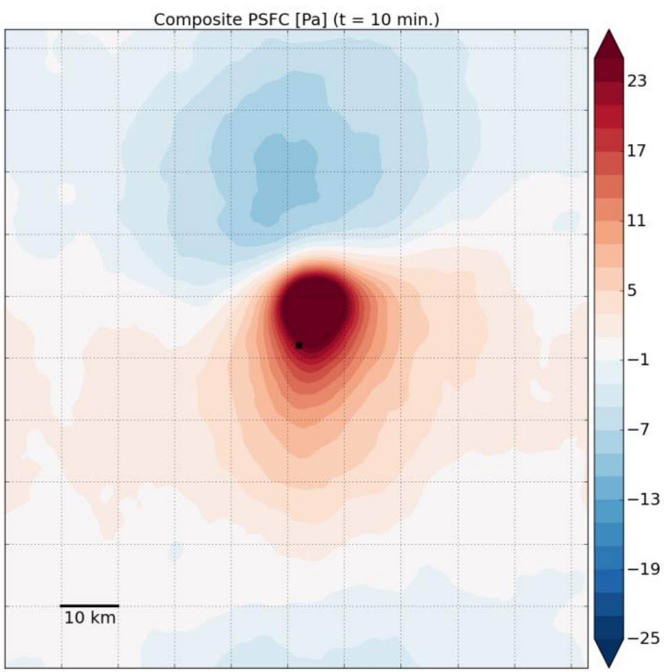


10 min After Precip.



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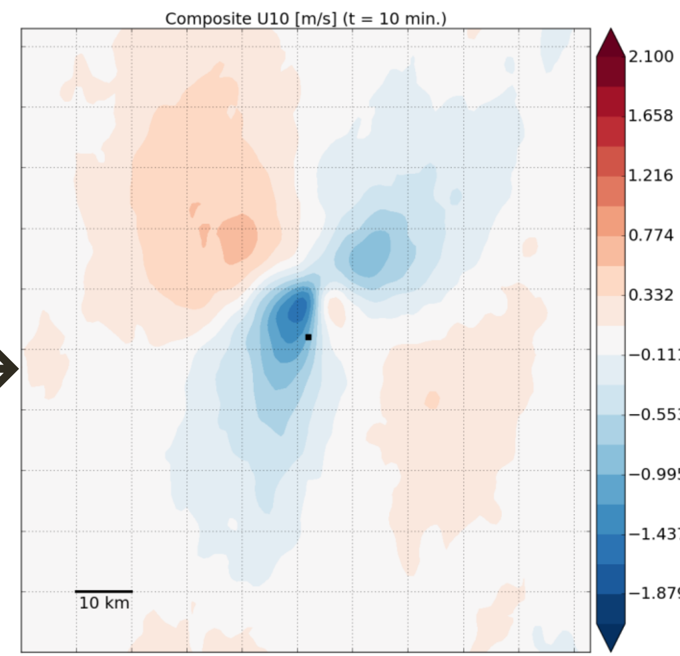
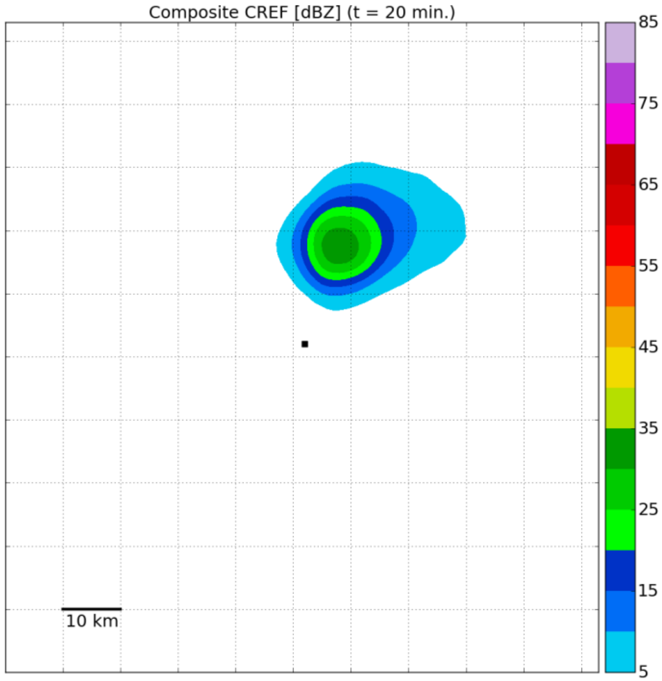
U10 →



1km res.

Composite of Precipitating Objects



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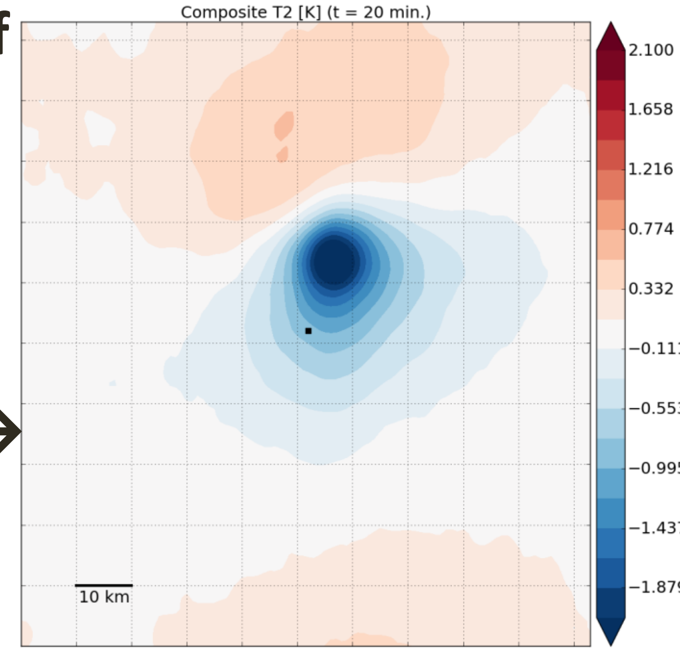
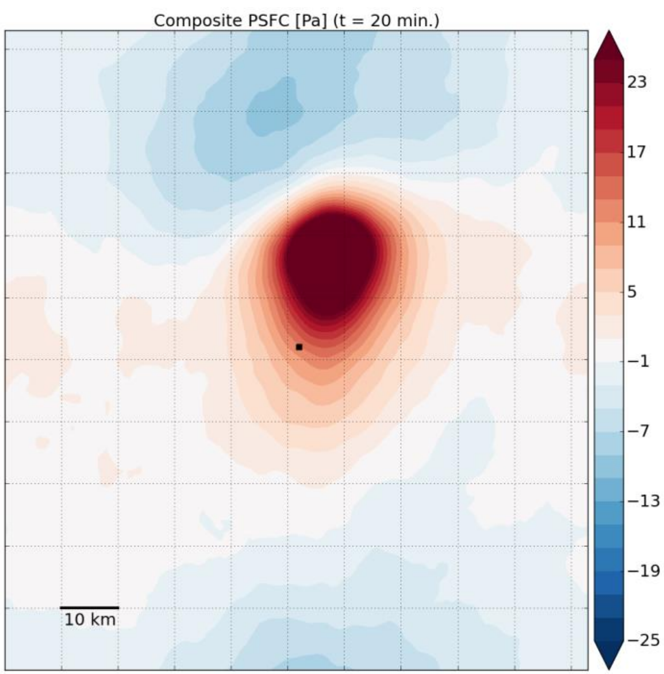


20 min
After Precip.



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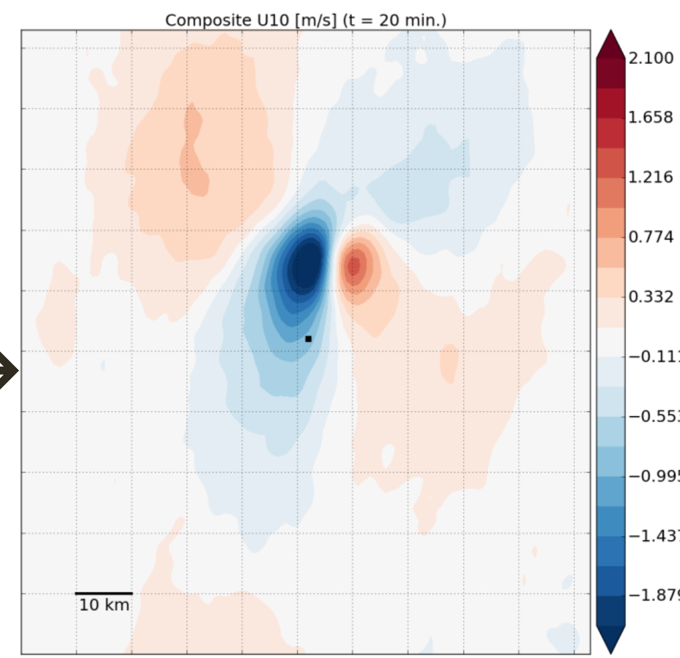
U10 →

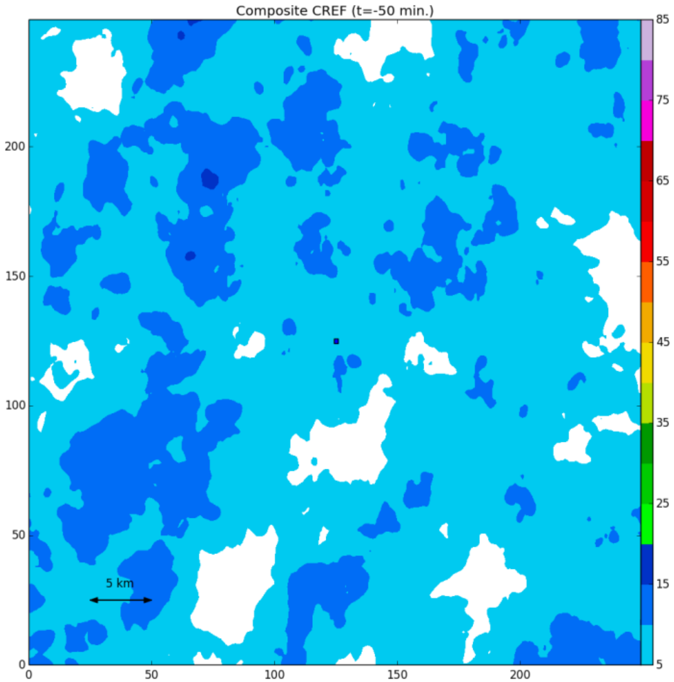


1km res.

Surface Field Composites (200m)

- 14 storms from single 200m “truth” run
- Small sample size →noisier

Composite of Precipitating Objects



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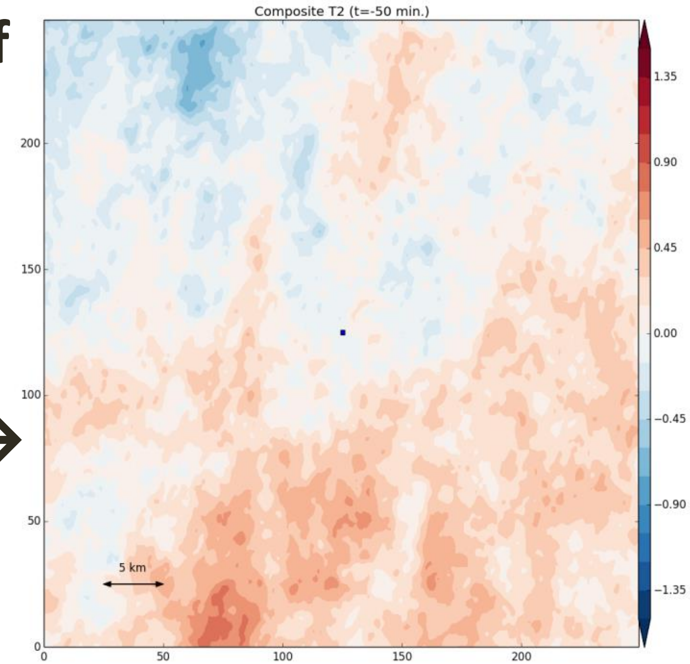
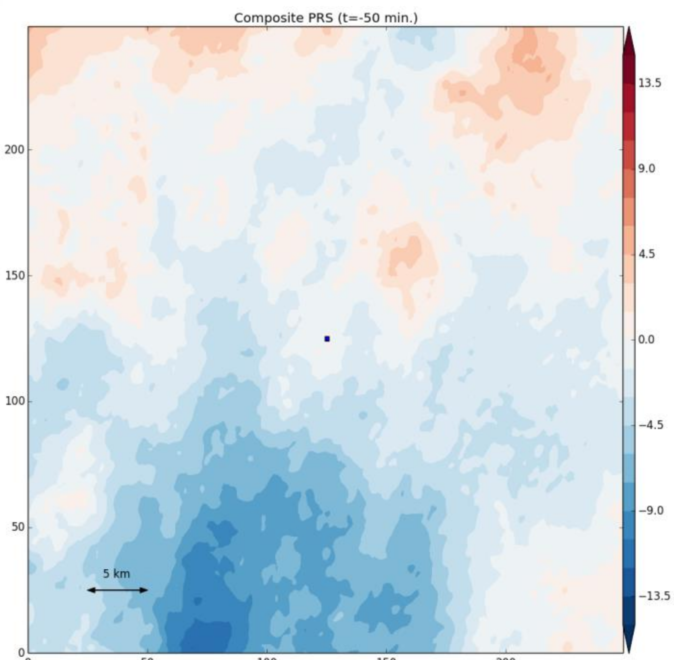
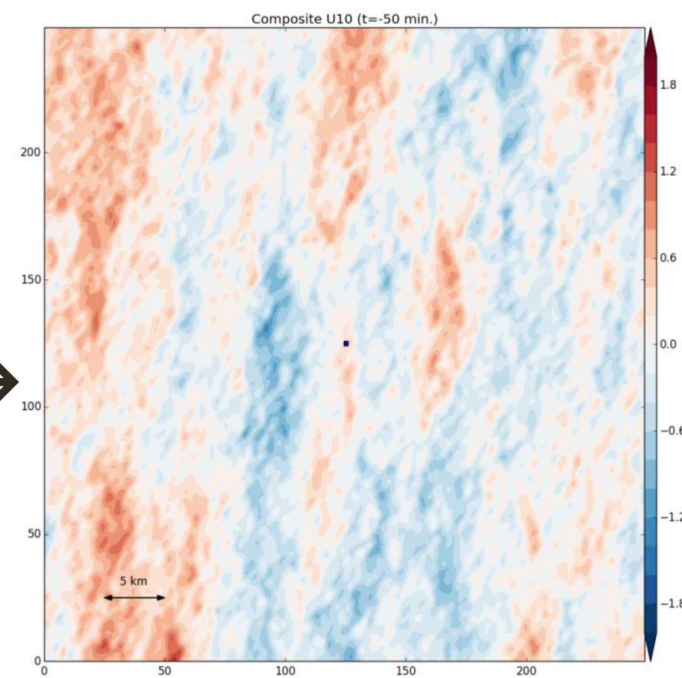


50 min
To Precip.



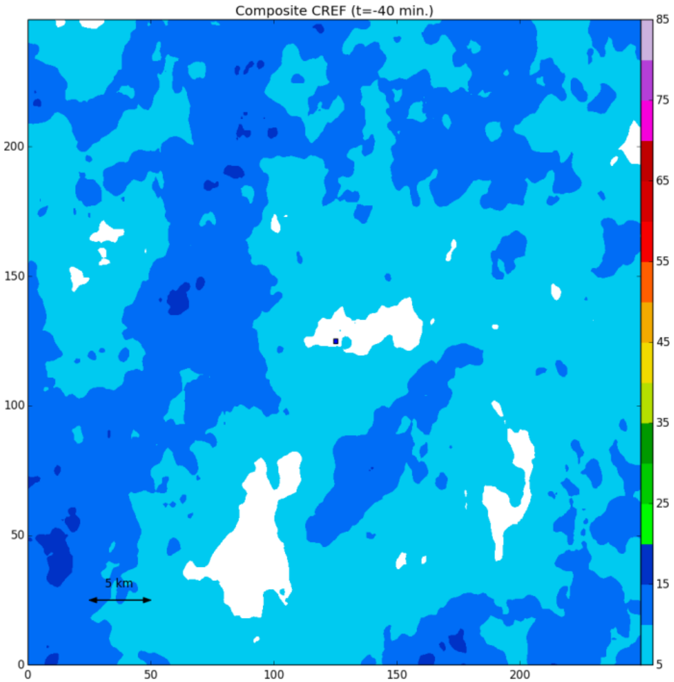
← PSFC

U10 →



200m res.

Composite of Precipitating Objects



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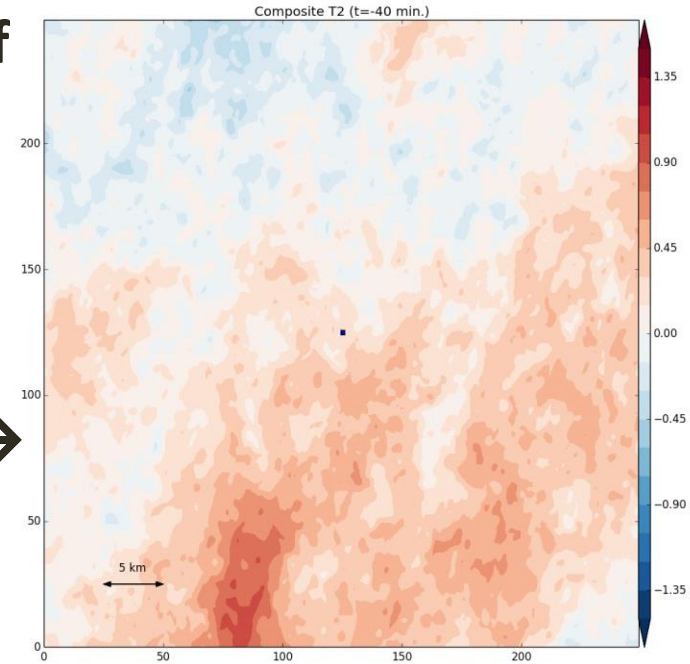
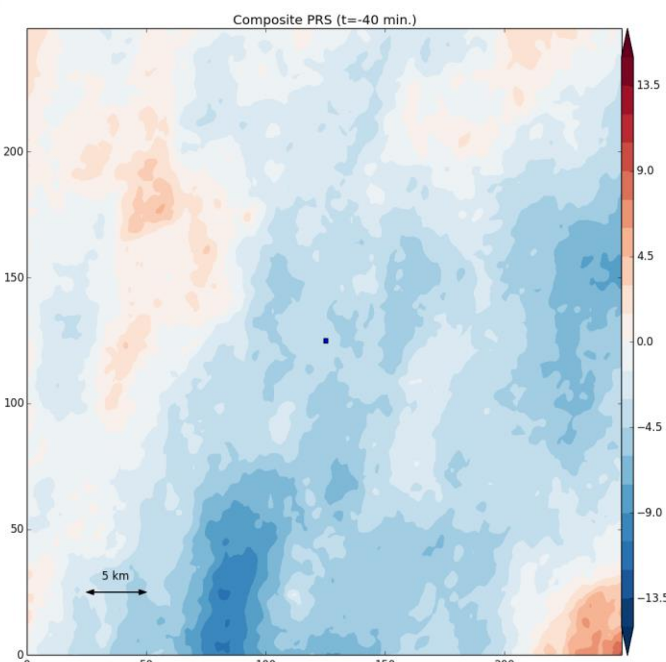
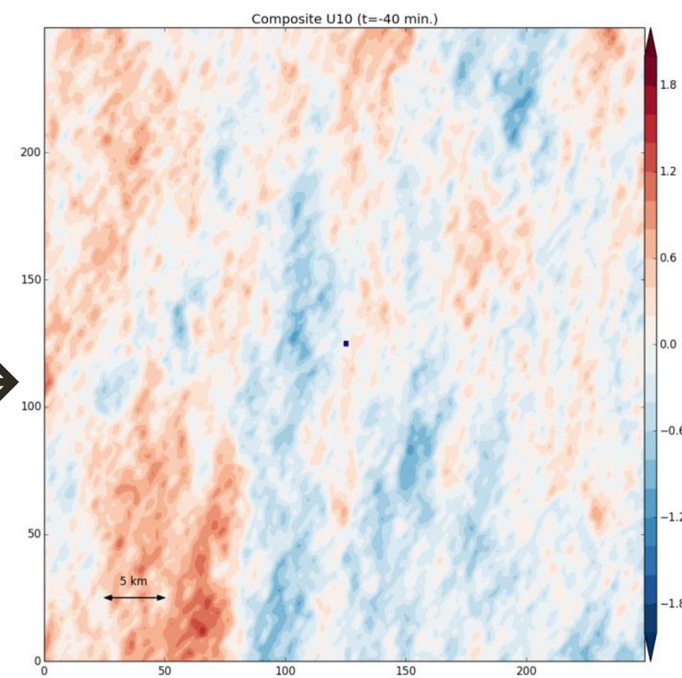


40 min
To Precip.



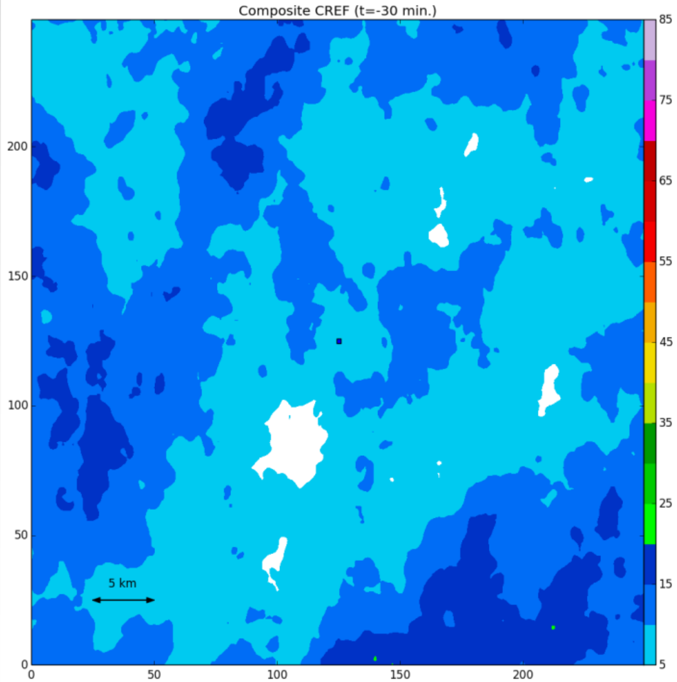
← PSFC

U10 →



200m res.

Composite of Precipitating Objects



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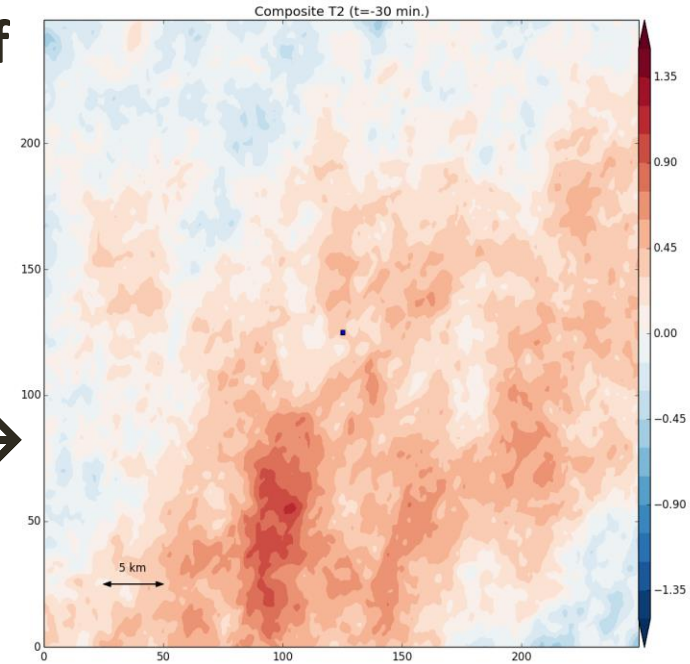
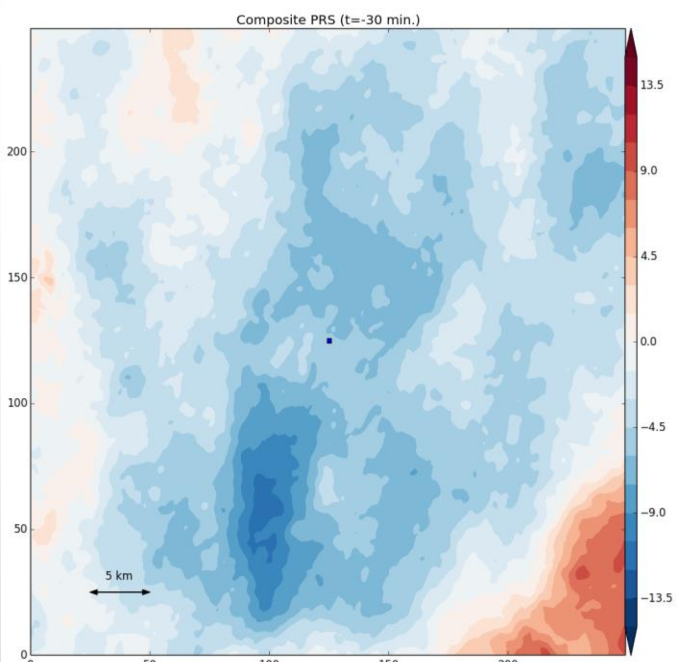
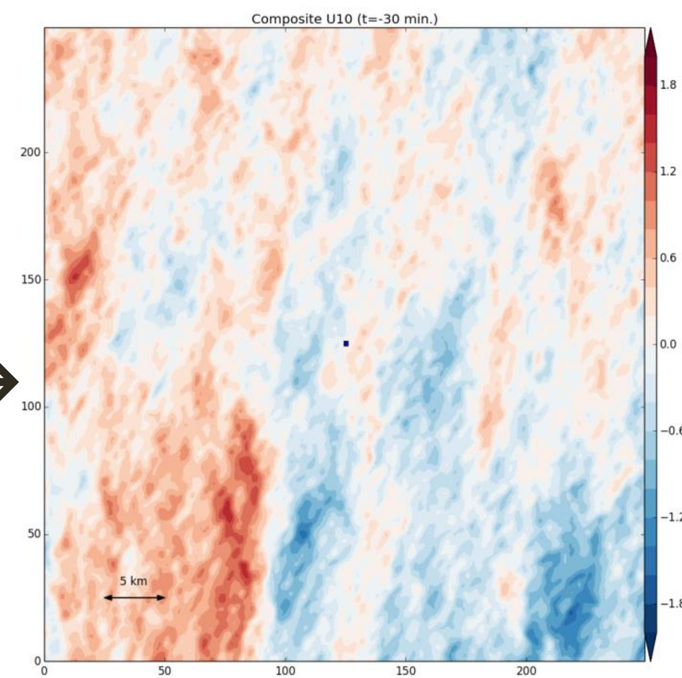


30 min
To Precip.



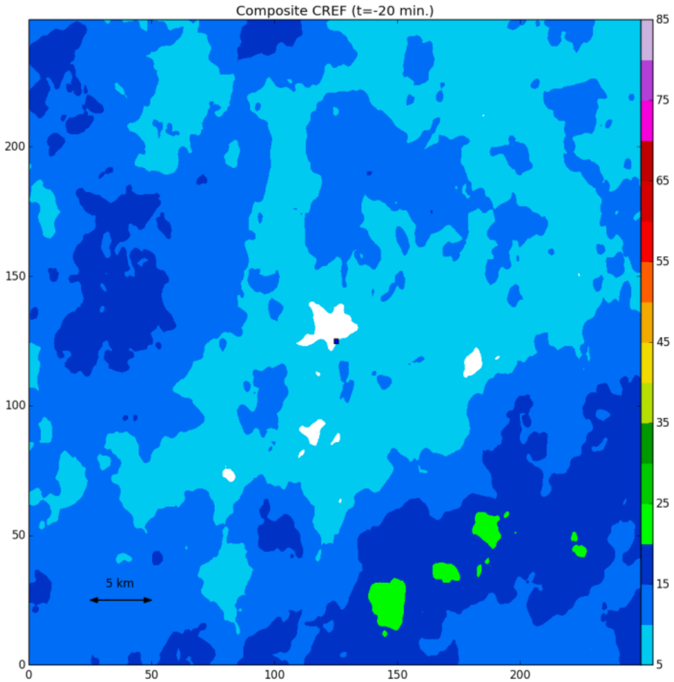
← PSFC

U10 →



200m res.

Composite of Precipitating Objects



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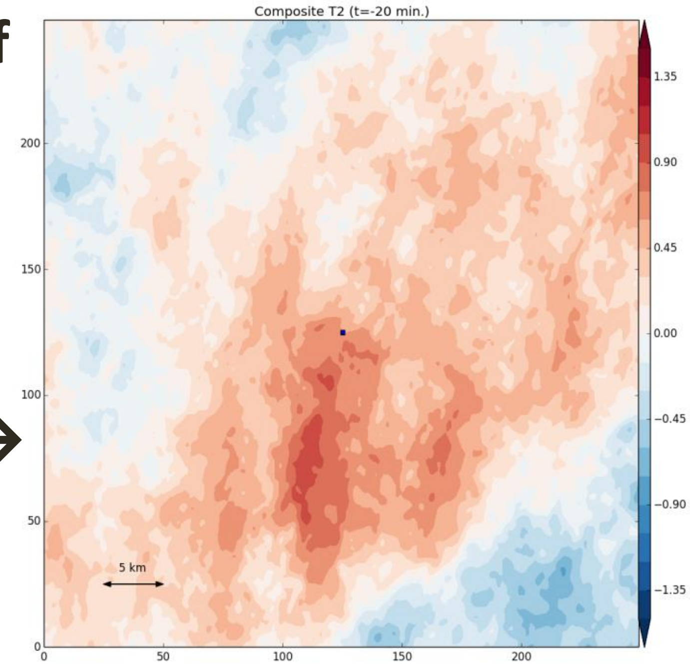
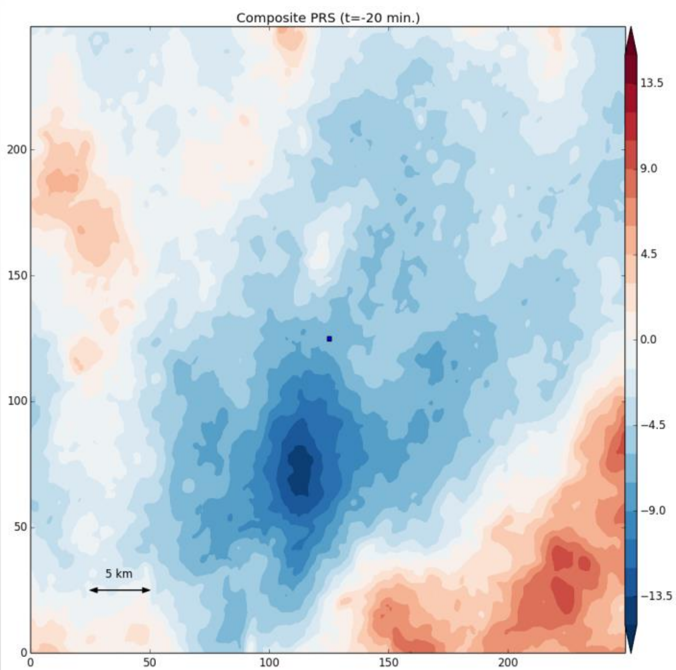
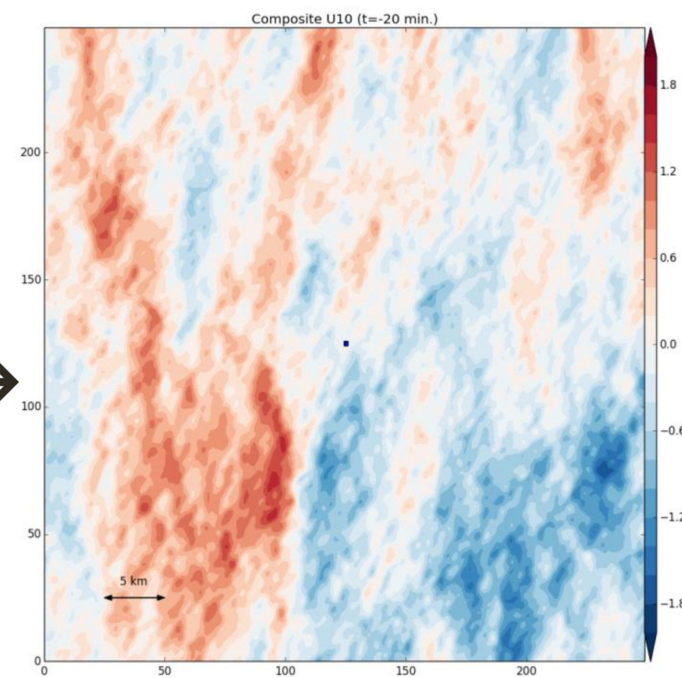


20 min
To Precip.



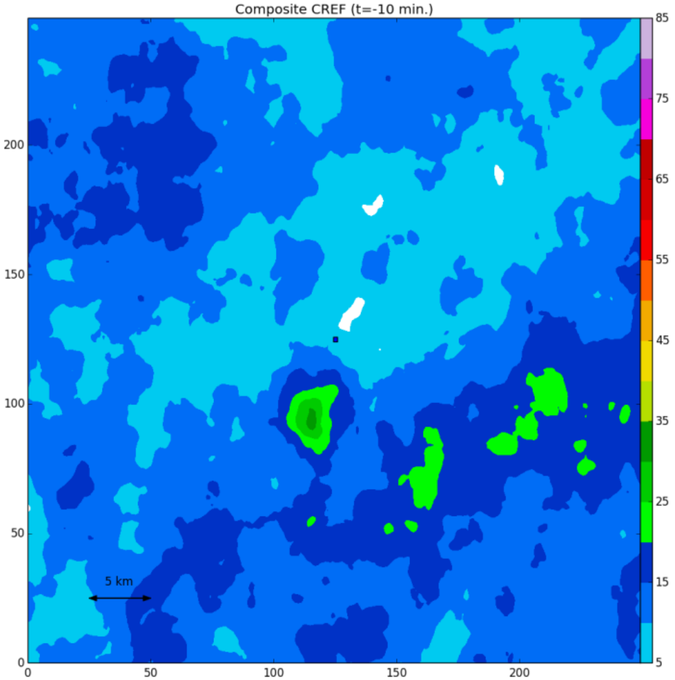
← PSFC

U10 →



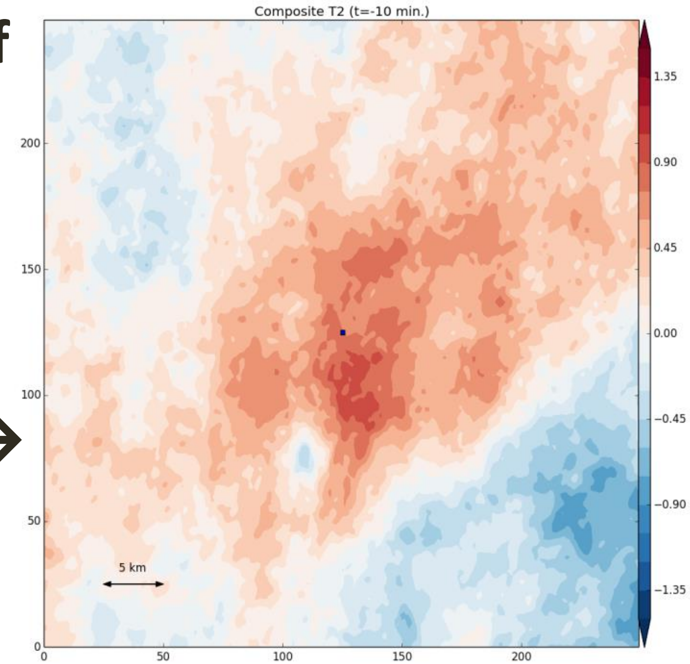
200m res.

Composite of Precipitating Objects

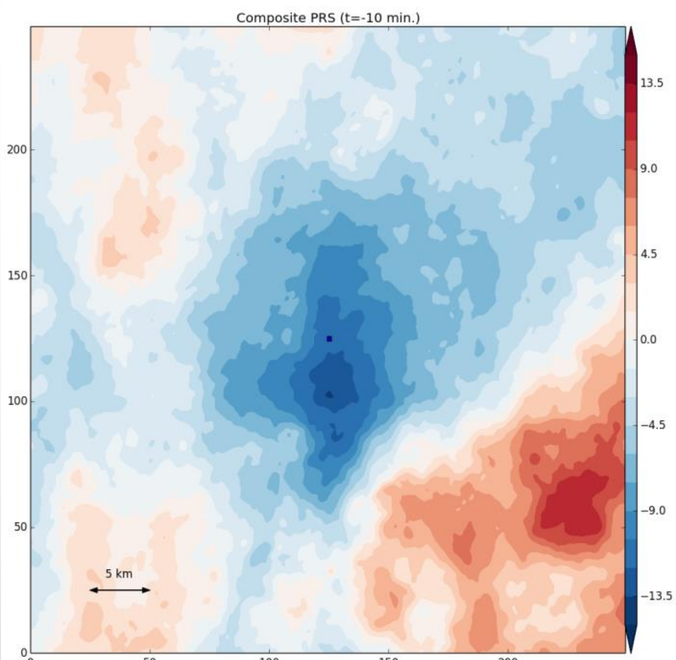


← CREF

T2 →

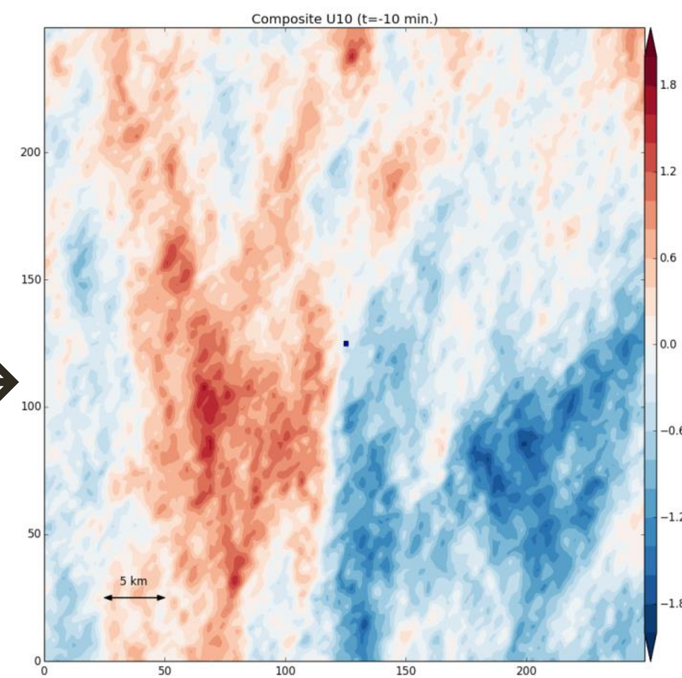


10 min
To Precip.



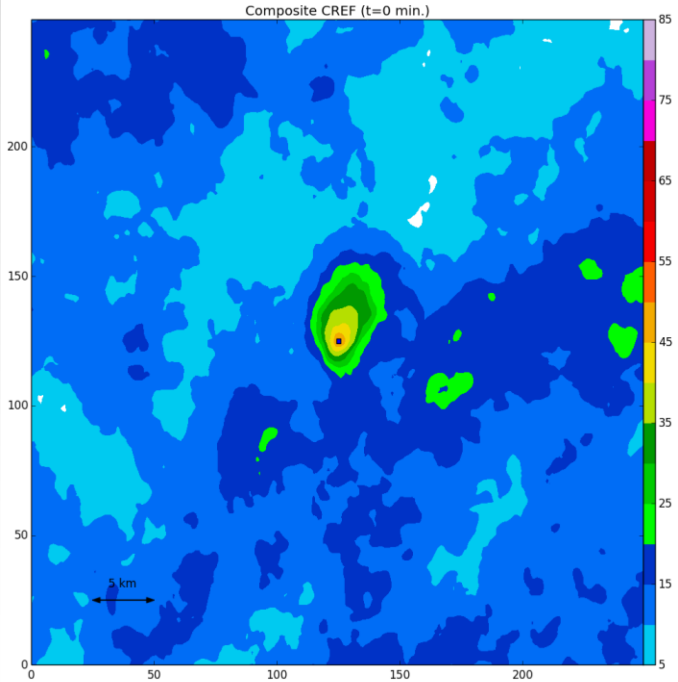
← PSFC

U10 →



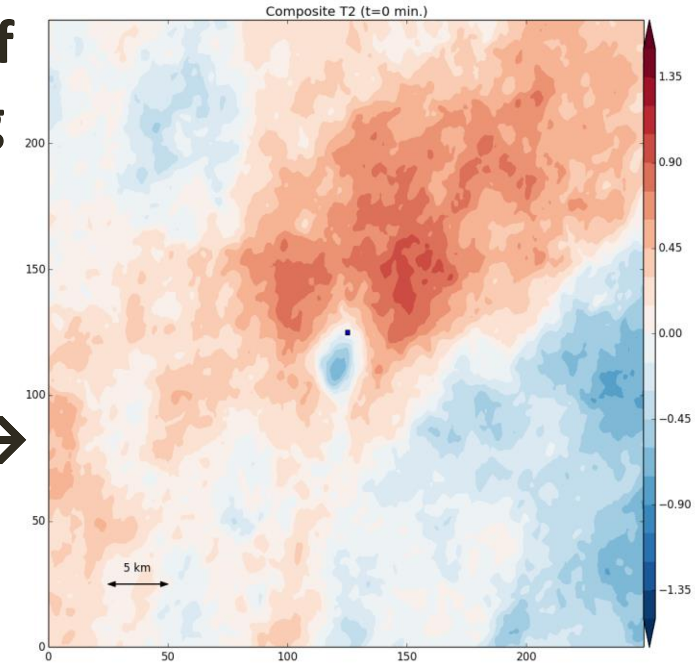
200m res.

Composite of Precipitating Objects



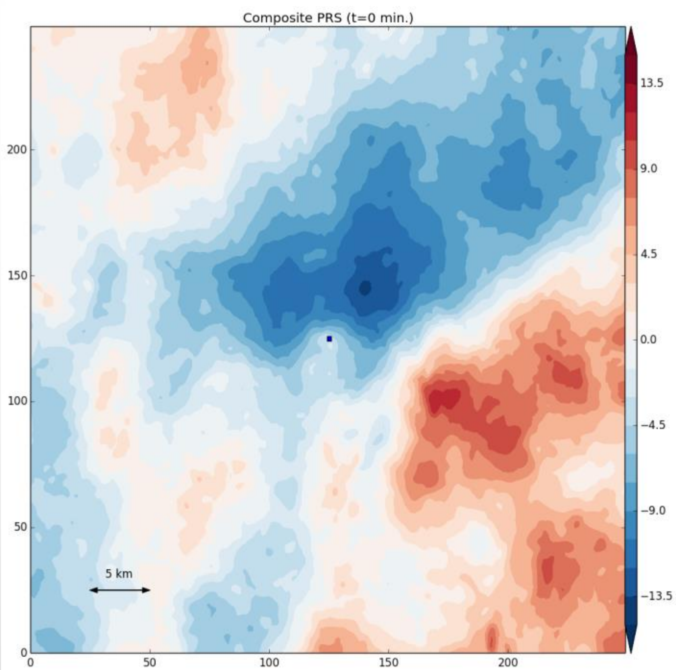
← CREF

T2 →



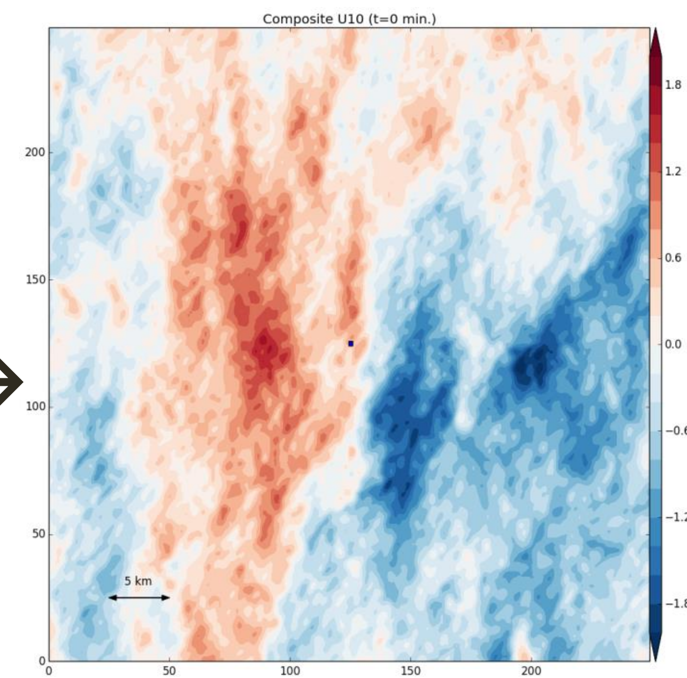
0 min

To Precip.



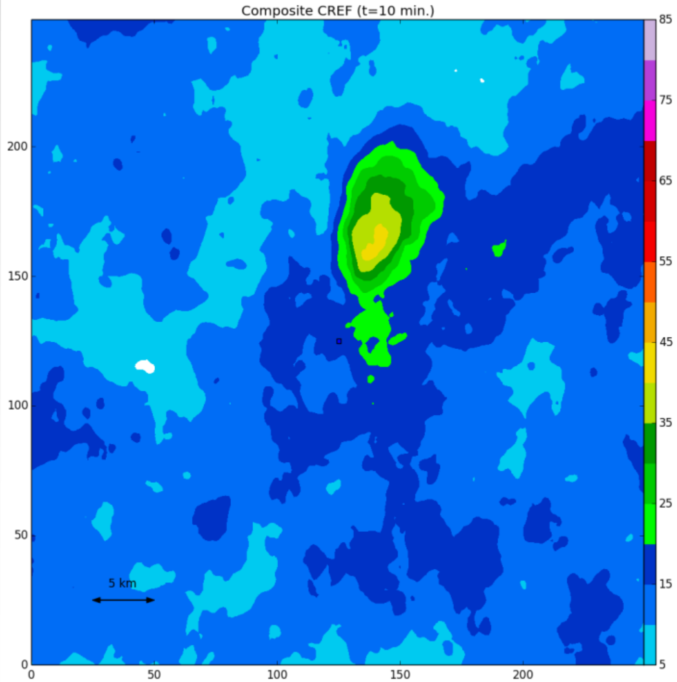
← PSFC

U10 →



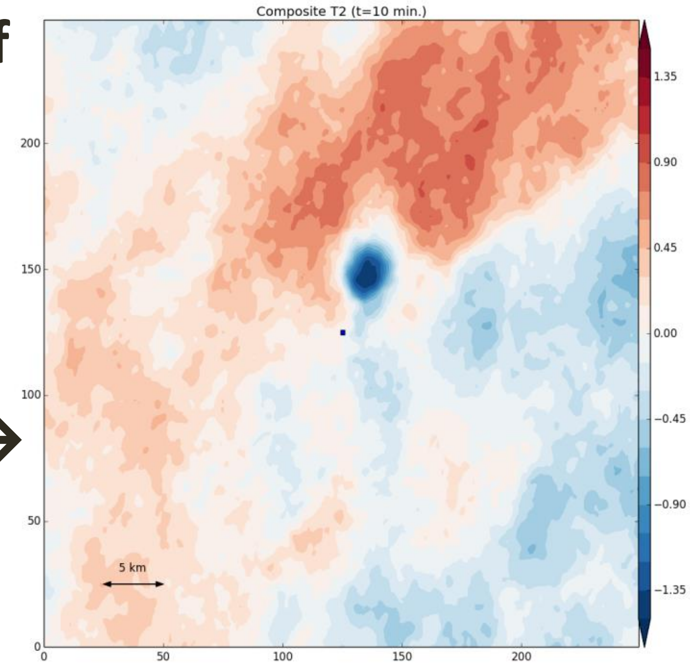
200m res.

Composite of Precipitating Objects

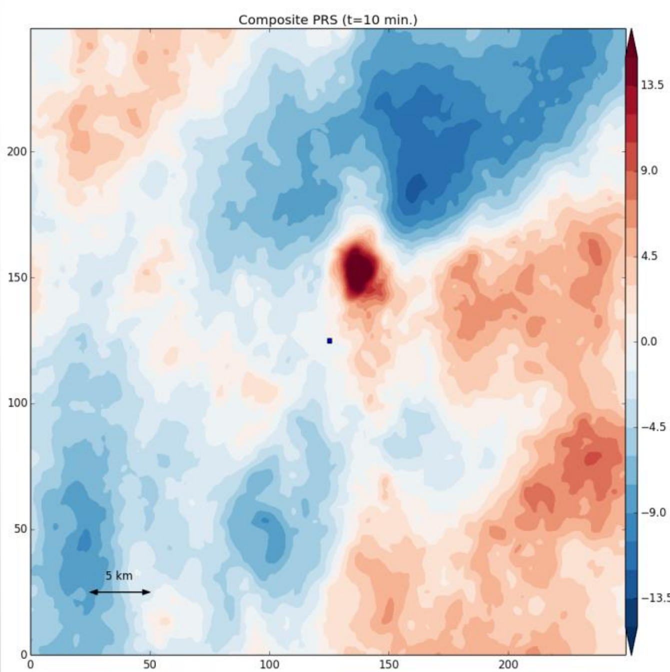


← CREF

T2 →

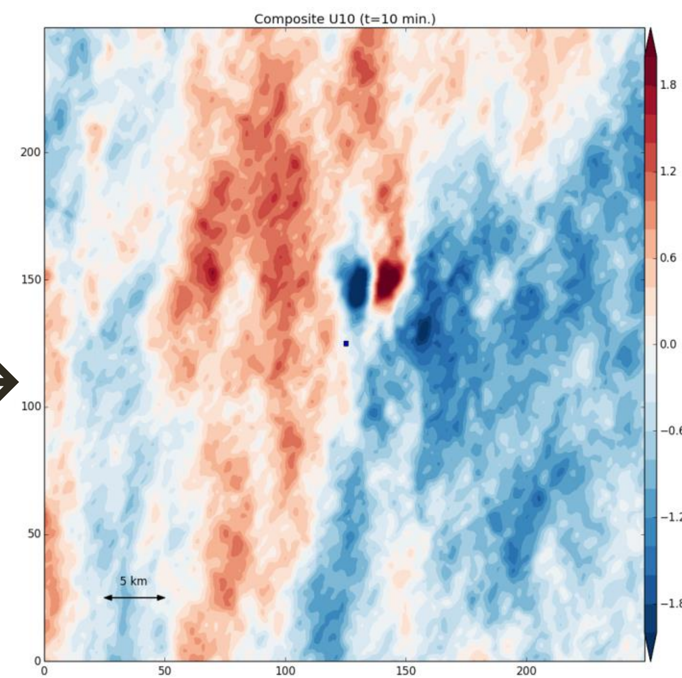


10 min
After Precip.



← PSFC

U10 →



200m res.

Compositing Summary

- Observable, coherent anomalies apparent 45-60 minutes before precipitation
  - 1-2 hours speculated predictability limit

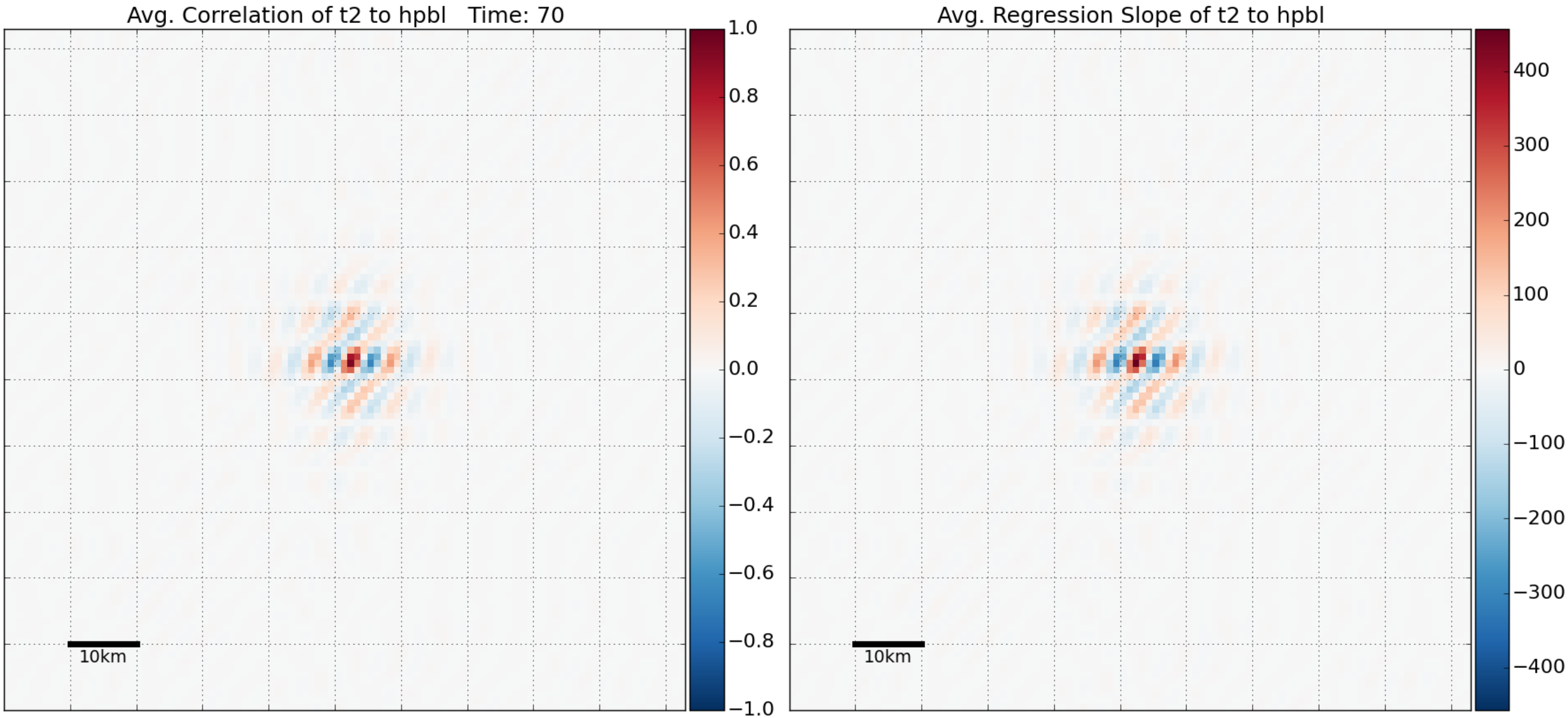
    (Droegemeier 1990, Weckwerth 2000)
- ~ 1 K temp,   1.5 m/s U,   0.1 hPa PSFC
  - Consistent with observed CBL variability preceding CI
- Scale on order of 3-5 km (200m)
- Weak anomalies in moisture (not shown)
- Similar anomalies at both resolutions!

Horizontal Correlations

- Evaluate the most effective parameters for data assimilation
  - How dense do observations need to be?
  - How sensitive do observations need to be?
- To summarize impact, compute average *ensemble* correlations and regressions of surface variables to estimated PBL height
- Common CI criterion → HPBL=LCL (LFC for precip.) (Kang and Bryan 2011)

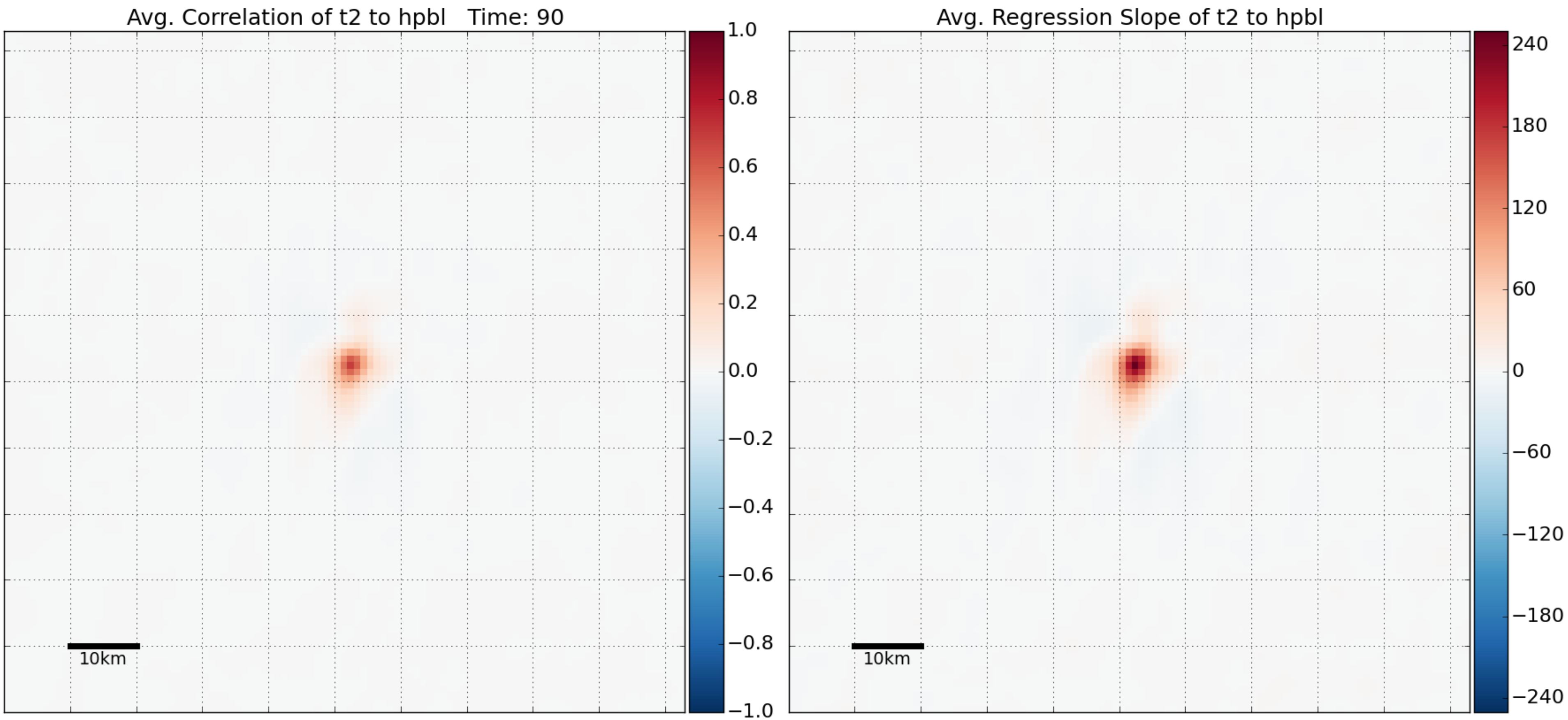
2m Temp. and HPBL

Pre-CI

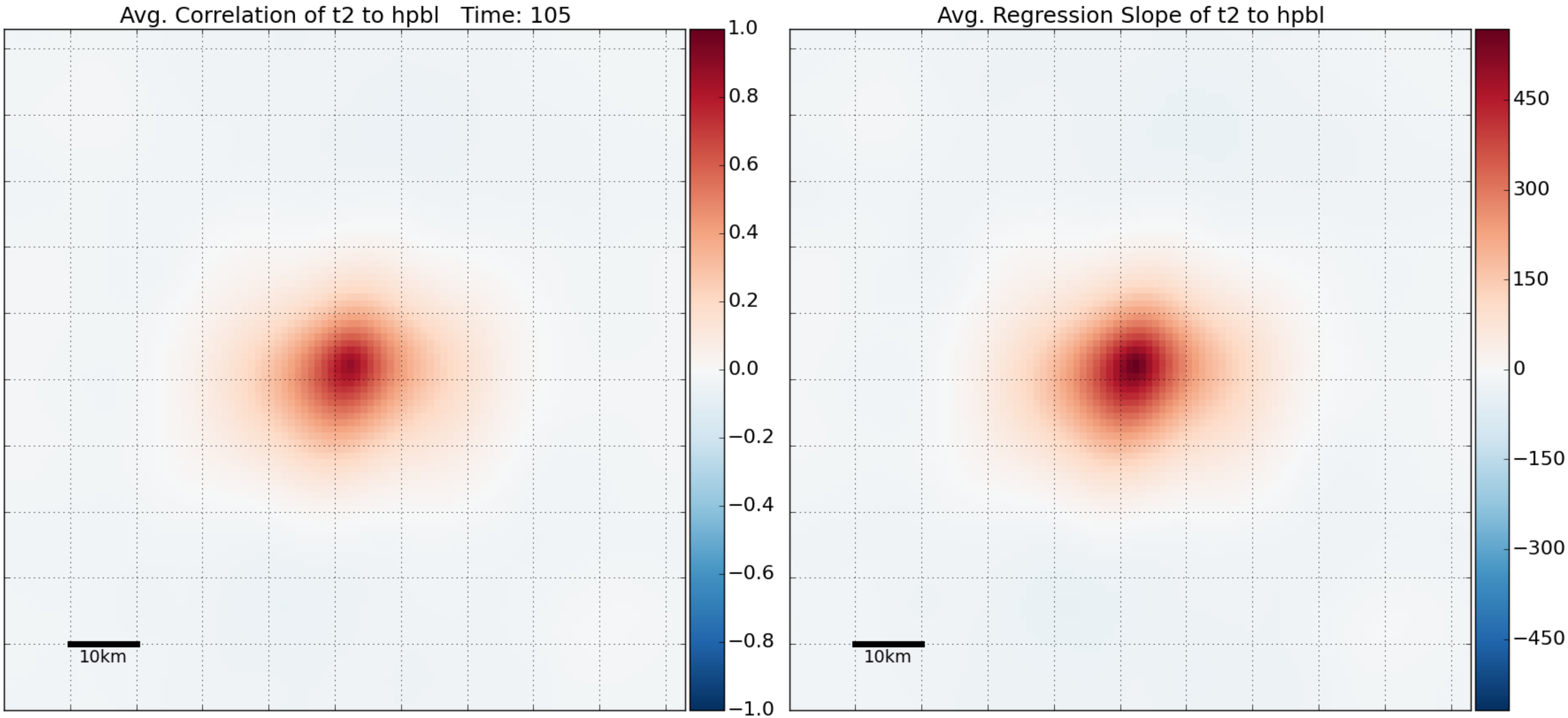


Avg. Correlation of t2 to hpbl Time: 70
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
10km
Avg. Regression Slope of t2 to hpbl
400
300
200
100
0
−100
−200
−300
−400
10km

~Time of CI


Avg. Correlation of t2 to hpbl   Time: 90
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
10km
Avg. Regression Slope of t2 to hpbl
240
180
120
60
0
−60
−120
−180
−240
10km

Post-CI



Avg. Correlation of t2 to hpbl Time: 105
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
10km
Avg. Regression Slope of t2 to hpbl
450
300
150
0
−150
−300
−450
10km

Correlations Summary

- Covariances capture horizontal convective roll structure in pre-convective environment (~20km decorrelation length)
- Rapid decrease in length scale as storms begin developing
- After storm development, cold pool dynamics apparent

Summary

- Increasing availability of dense surface observations from a variety of sources
- Experiments with idealized ensembles show promise
  - *Observable* anomalies in surface fields 45-60+ minutes prior to onset of precipitation
  - Surface observations strongly correlate through the depth of the CBL at feasibly observable length scales
    - Horizontal correlations vary with time → ensembles!

Next Steps

- Complete analysis for remainder of cases
  - How does correlation length scale vary with the environment?
  - How long are perturbations recognizable before onset of precipitation?
- Cycle the ideal ensembles
  - Does the data assimilation actually lead to improved forecast of CI?
  - Will model spin-up negate impact?
- Full-scale OSSE and OSE experiments
  - Can we realize improvements with large-scale dynamics included?
  - How well do our dense surface observations live up to expectations?

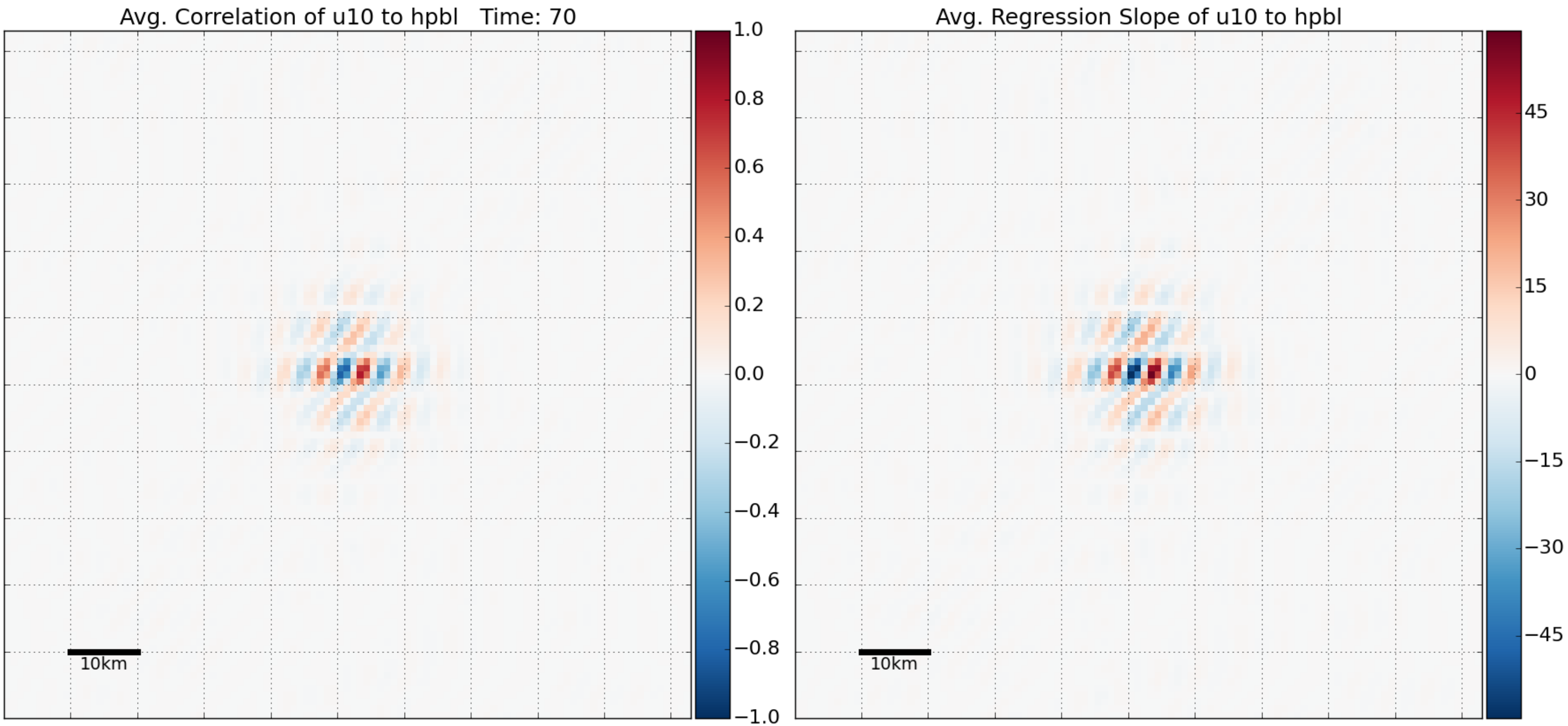
References

- Weckwerth, T. M. (2000). The effect of small-scale moisture variability on thunderstorm initiation. *Monthly weather review*, *128*(12), 4017-4030.
- Weckwerth, T. M., Wilson, J. W., & Wakimoto, R. M. (1996). Thermodynamic variability within the convective boundary layer due to horizontal convective rolls. *Monthly weather review*, *124*(5), 769-784.
- Weckwerth, T. M., & Parsons, D. B. (2006). A review of convection initiation and motivation for IHOP_2002. *Monthly weather review*, *134*(1), 5-22.
- Kain, J. S., Coniglio, M. C., Correia, J., Clark, A. J., Marsh, P. T., Ziegler, C. L., ... & Melick, C. J. (2013). A feasibility study for probabilistic convection initiation forecasts based on explicit numerical guidance. *Bulletin of the American Meteorological Society*, *94*(8), 1213-1225.
- Hacker, J. P., & Rostkier-Edelstein, D. (2007). PBL state estimation with surface observations, a column model, and an ensemble filter. *Monthly weather review*, *135*(8), 2958-2972.
- Hacker, J. P., & Snyder, C. (2005). Ensemble Kalman filter assimilation of fixed screen-height observations in a parameterized PBL. *Monthly weather review*, *133*(11), 3260-3275.
- Bryan, G. H., & Fritsch, J. M. (2002). A benchmark simulation for moist nonhydrostatic numerical models. *Monthly Weather Review*, *130*(12), 2917-2928.
- Nowotarski, C. J., Markowski, P. M., Richardson, Y. P., & Bryan, G. H. (2014). Properties of a Simulated Convective Boundary Layer in an Idealized Supercell Thunderstorm Environment. *Monthly Weather Review*, (2014).
- Kang, S-L, & Bryan, G.H. 2011: A Large-Eddy Simulation Study of Moist Convection Initiation over Heterogeneous Surface Fluxes. *Mon. Wea. Rev.*, **139**, 2901–2917.Madaus, L. E. , Gregory J. Hakim, and Clifford F. Mass, 2014: Utility of Dense Pressure Observations for Improving Mesoscale Analyses and Forecasts. *Mon. Wea. Rev.*, **142**, 2398–2413.
- Mass, C. F., & Madaus, L. E. (2014). Surface Pressure Observations from Smartphones: A Potential Revolution for High-Resolution Weather Prediction?.*Bulletin of the American Meteorological Society*.

Extra Slides

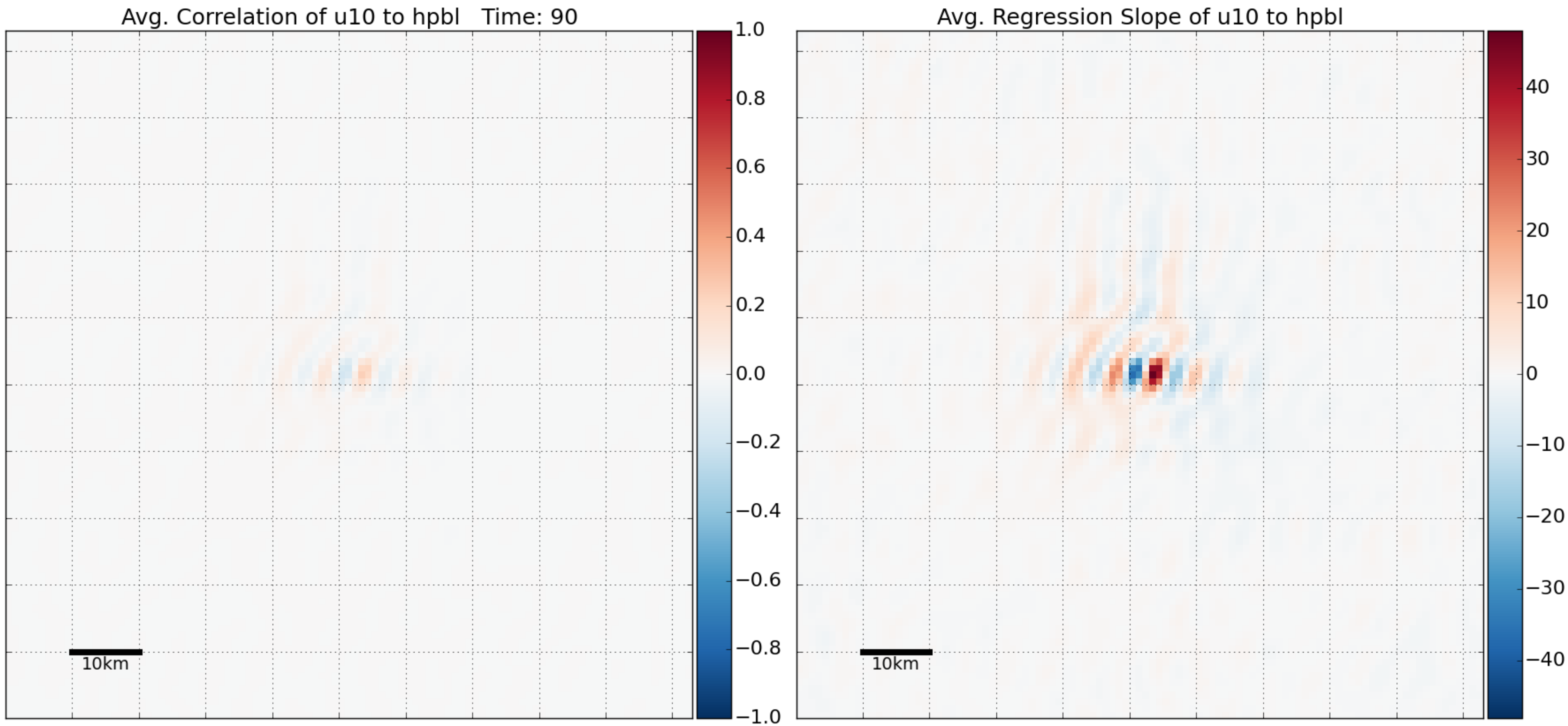
U-wind and HPBL

Pre-CI

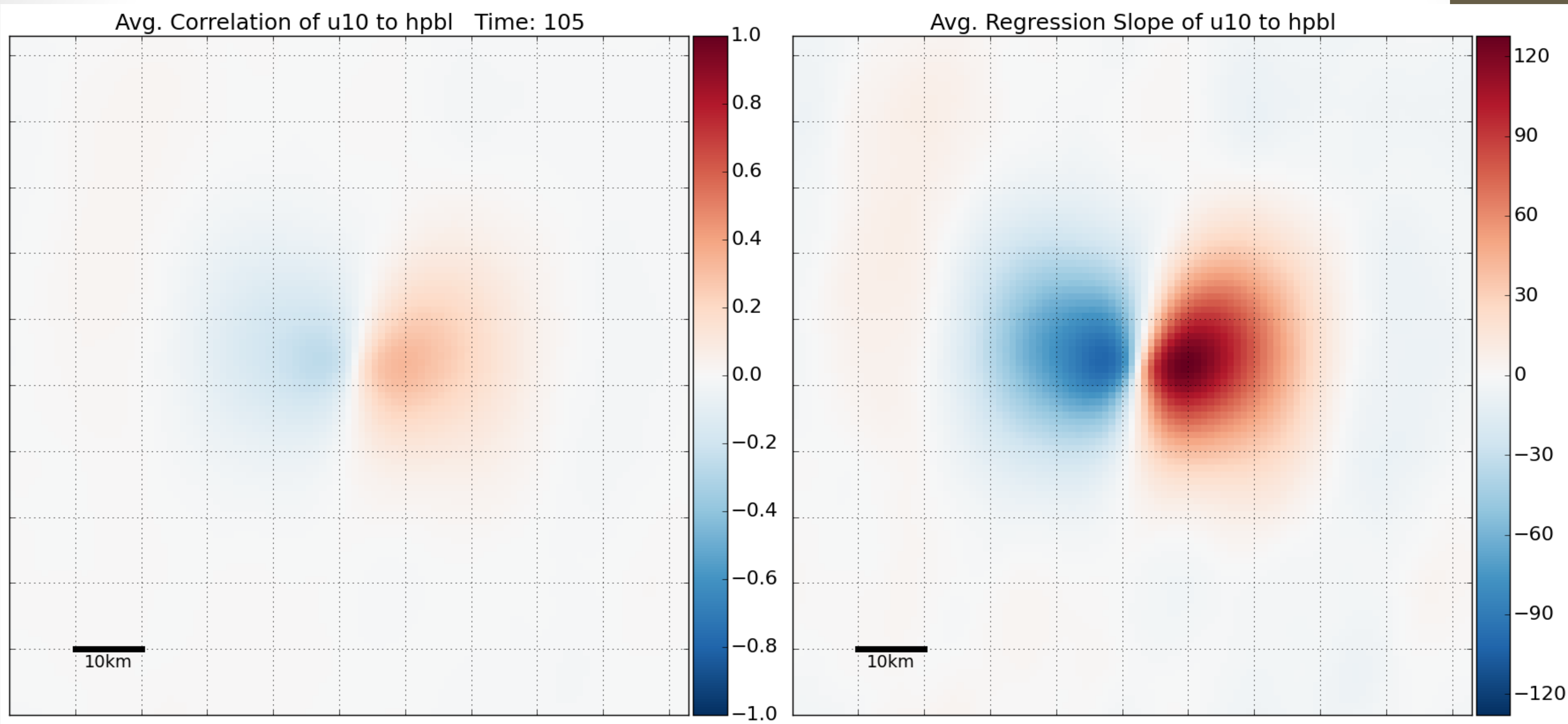


Avg. Correlation of u10 to hpbl Time: 70
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
10km
Avg. Regression Slope of u10 to hpbl
45
30
15
0
−15
−30
−45
10km

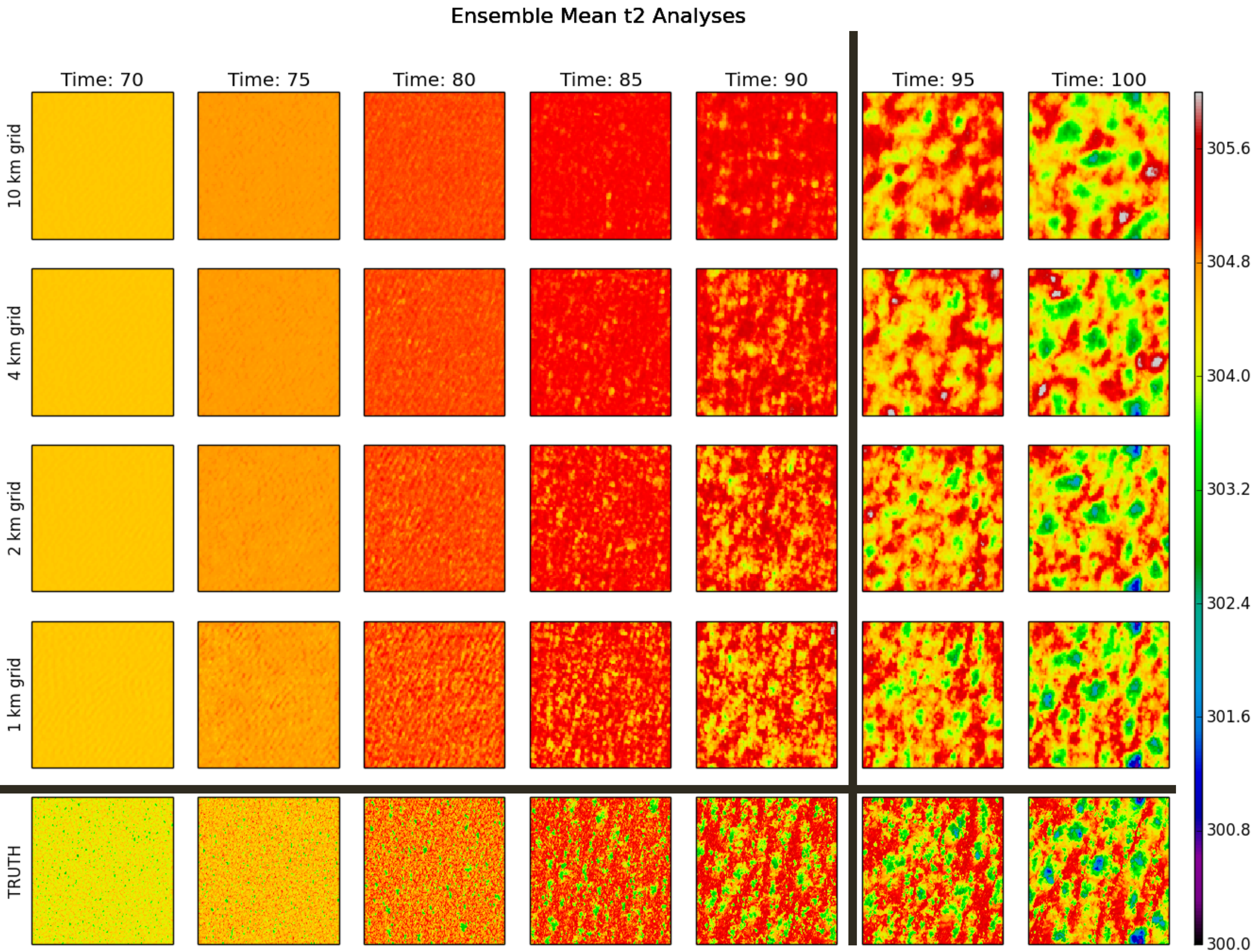
~Time of CI


Avg. Correlation of u10 to hpbl Time: 90
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
10km
Avg. Regression Slope of u10 to hpbl
40
30
20
10
0
−10
−20
−30
−40
10km

Post-CI

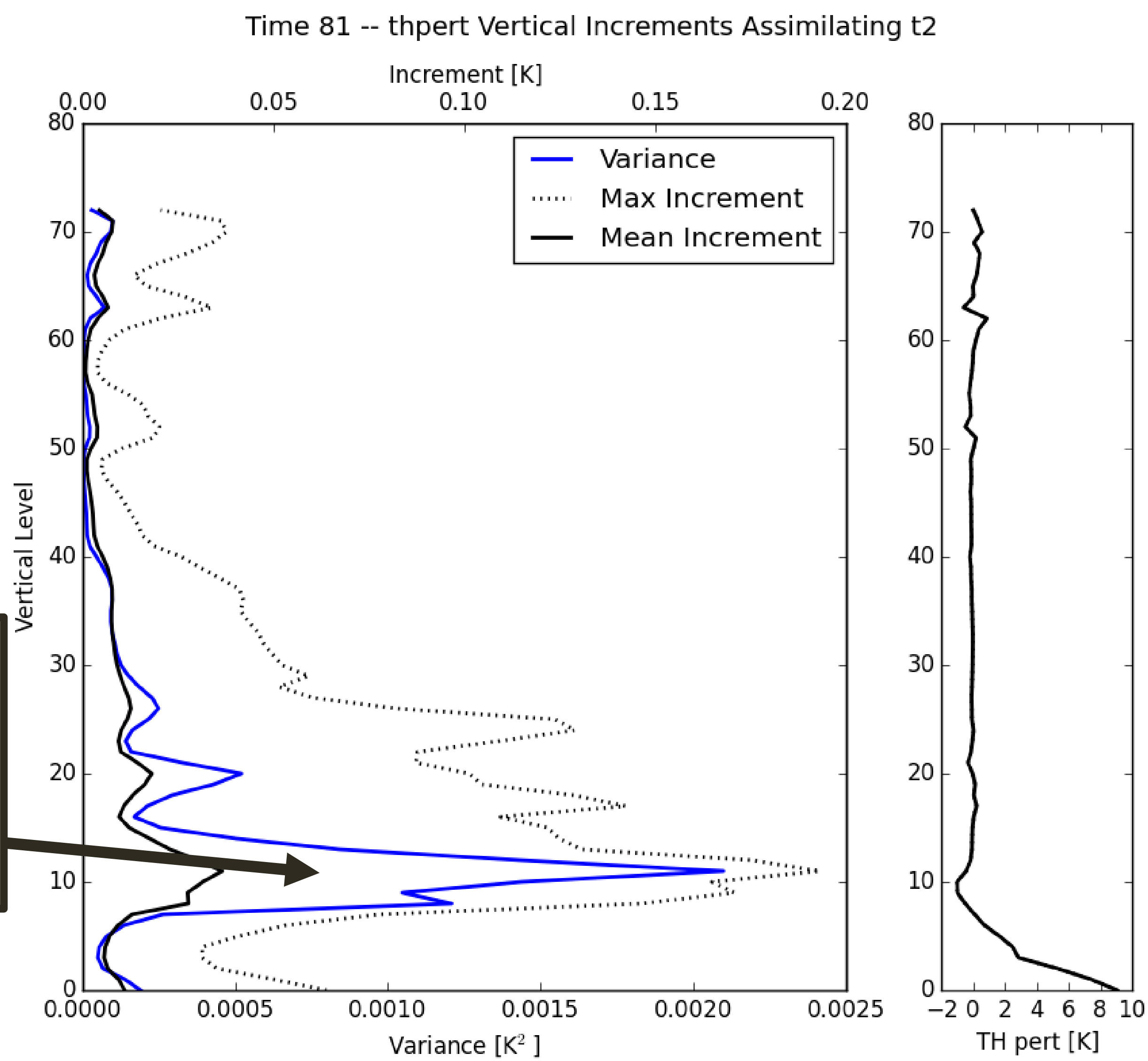


Avg. Correlation of u10 to hpbl   Time: 105
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
10km
Avg. Regression Slope of u10 to hpbl
120
90
60
30
0
−30
−60
−90
−120
10km


Ensemble Mean t2 Analyses
Time: 70
Time: 75
Time: 80
Time: 85
Time: 90
Time: 95
Time: 100
10 km grid
4 km grid
2 km grid
1 km grid
TRUTH
305.6
304.8
304.0
303.2
302.4
301.6
300.8
300.0

Vertical Profile of Adjustment

Pre-CI



Largest adjustments made to temperature at top of boundary layer

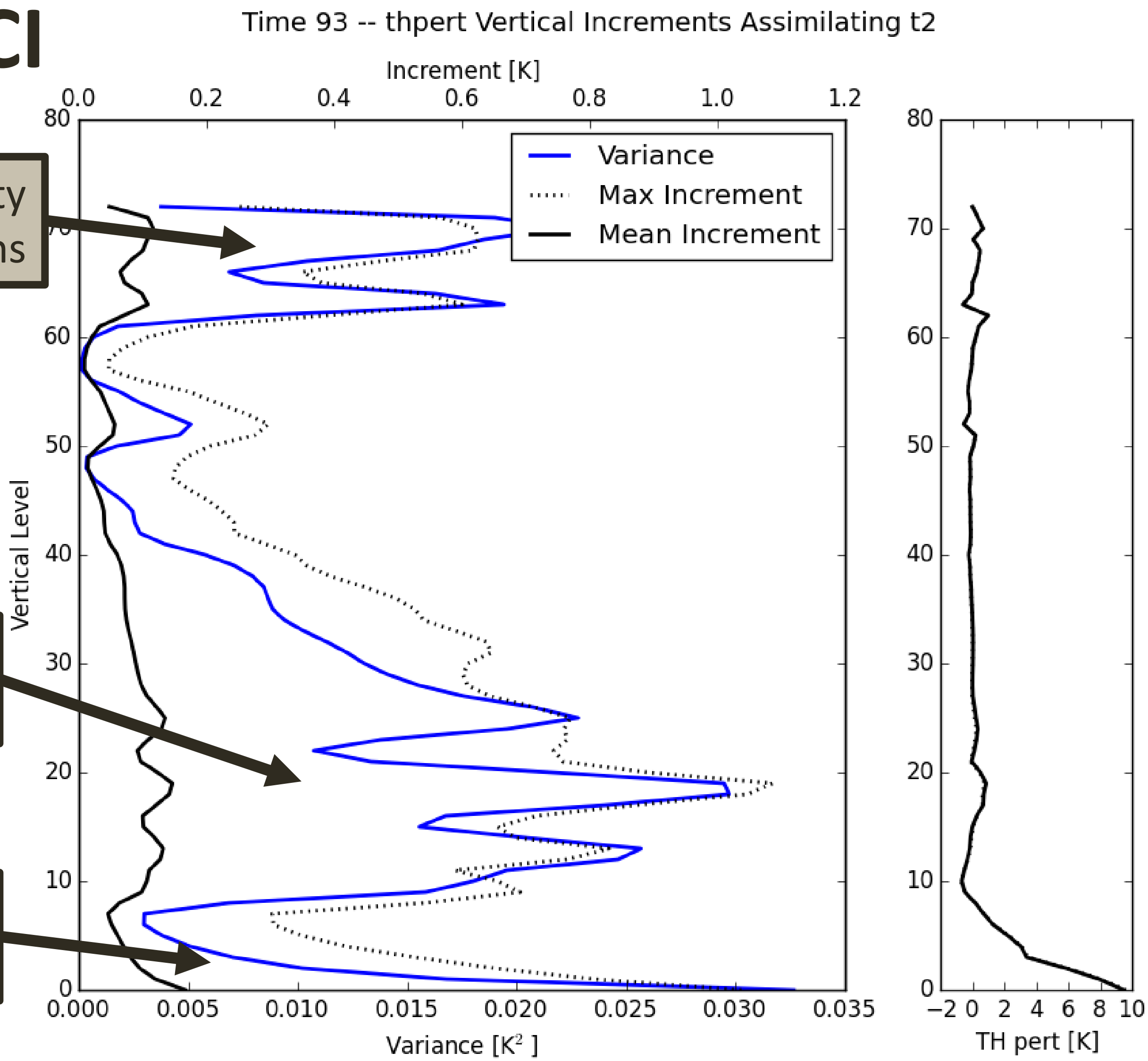
Vertical Profile of Adjustment

Time of CI

Anvil and gravity wave correlations

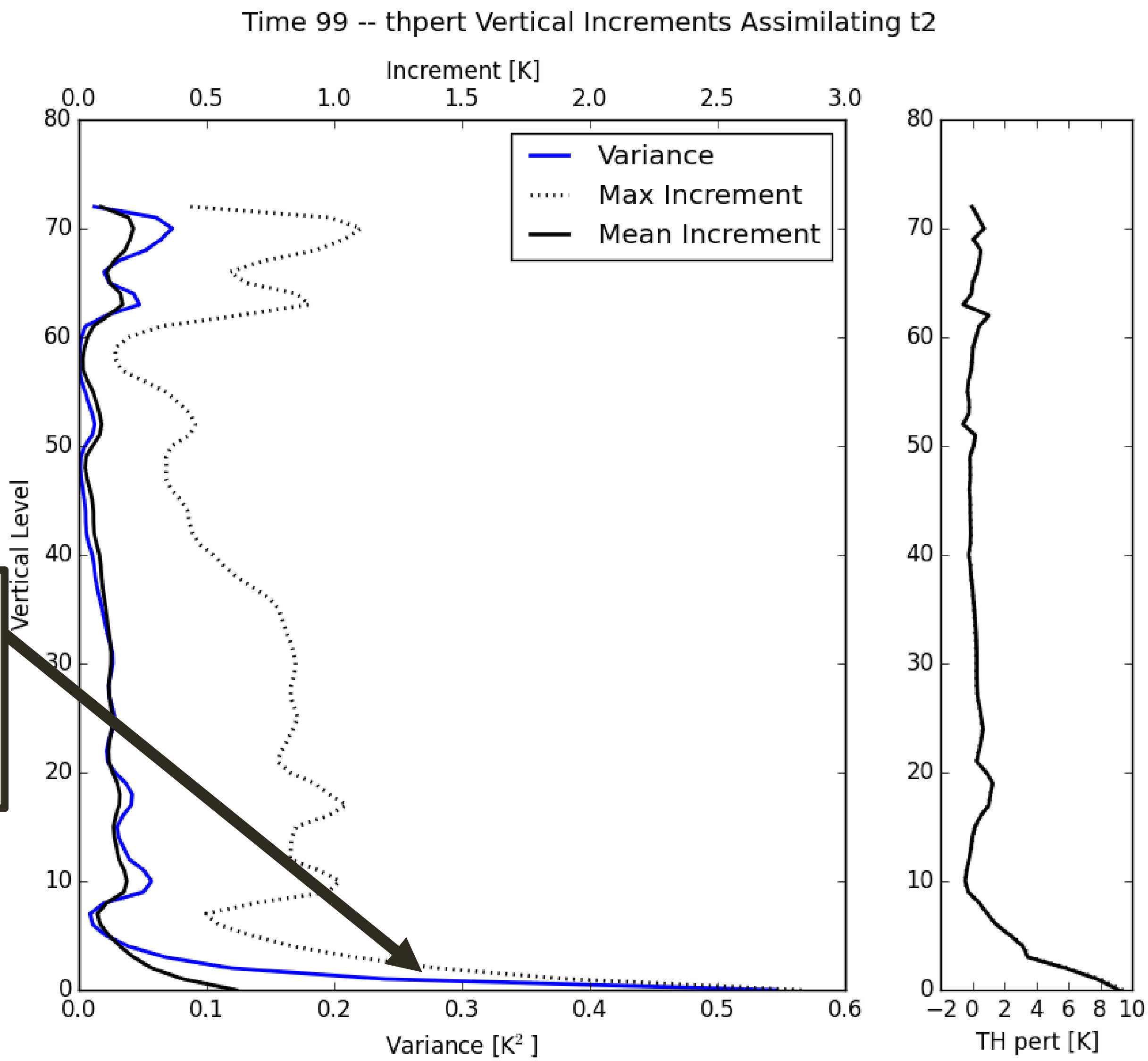
Large adjustments at and above BL

Surface increments becoming large



Vertical Profile of Adjustment

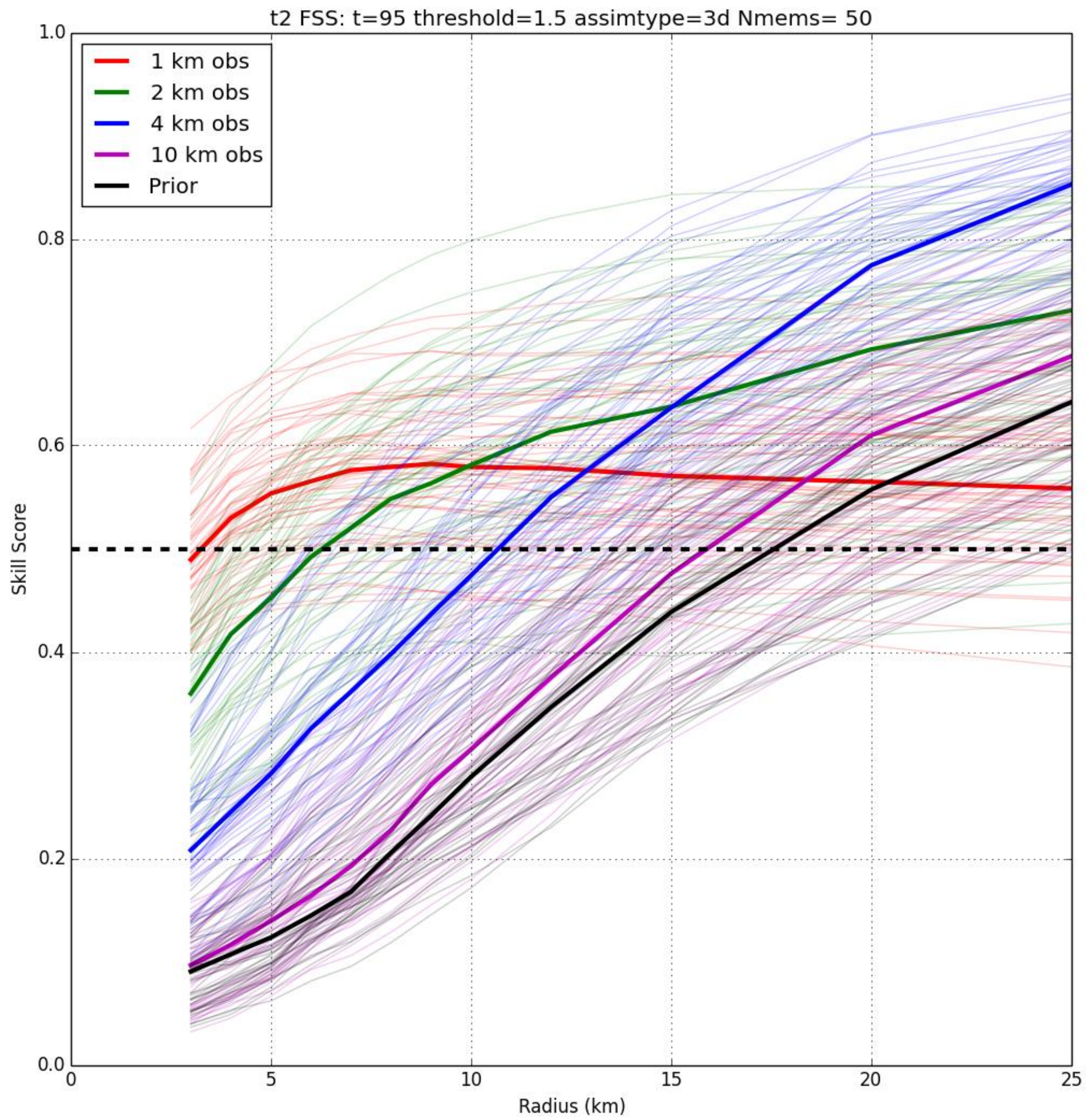
Post-CI



Strong adjustments limited to surface (cold pools)

Fractions Skill Score

REDO FIGURE



Missing Link