Variational Assimilation of GLM-observed Total Lightning at Cloud Resolving Scales

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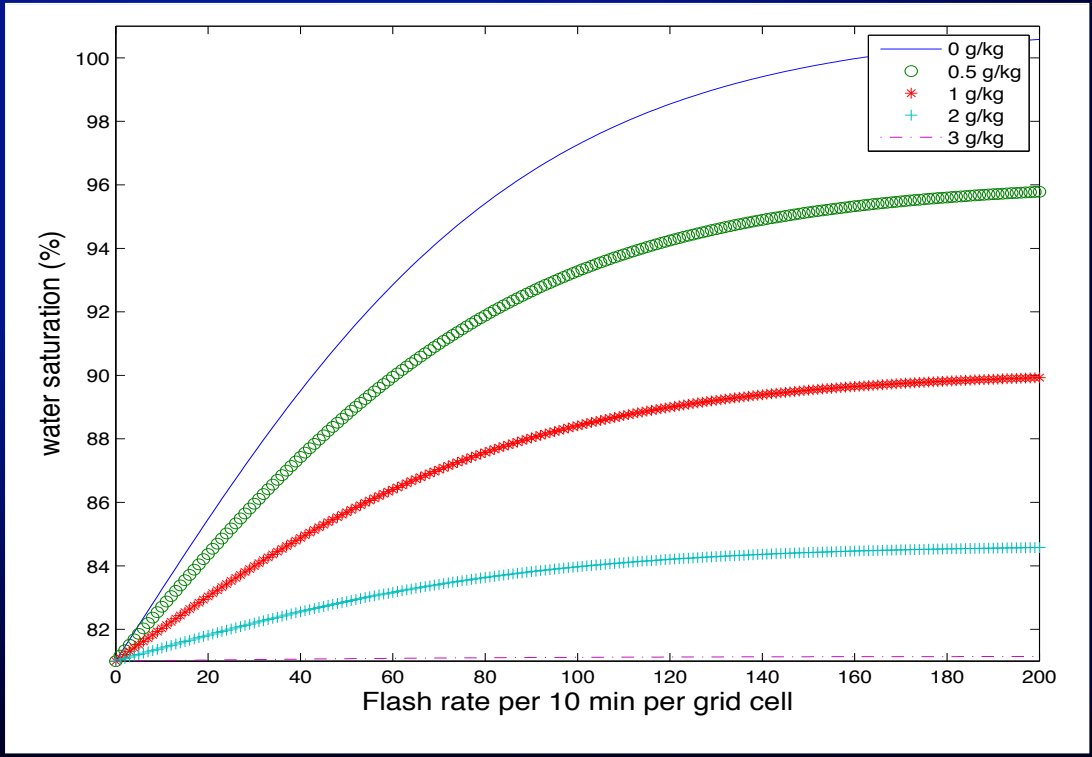
Photo credit: J. LaDue

Background

Q_v within a layer above cloud base is adjusted (increased) as a function flash rate (*X*) and simulated Q_g and Q_{sat_water}. Increasing Q_v at constant T boosts thermal buoyancy (via θ_v) and, ultimately, promotes updraft development.

$$Q_v = AQ_{sat} + BQ_{sat}\tanh(CX)\,[1 - \tanh(DQ_g^{\alpha})]$$

-Only applied whenever simulated RH and Qg < fixed thresholds: i.e., if the model already is in the right direction don't adjust Qv.



Fierro et al. (2012, 1014, 2016, 2018)

NEWS3DVAR Experiments

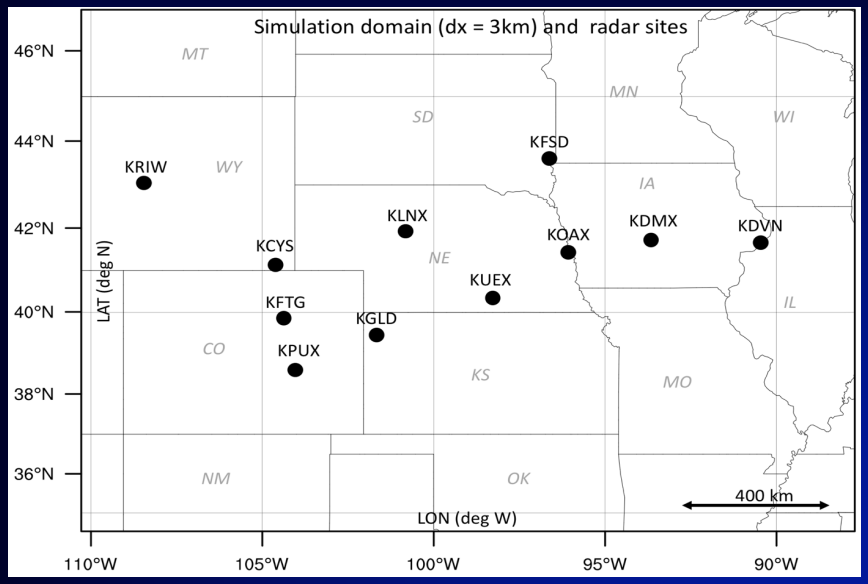
-Use a similar approach than Fierro et al. (2016, MWR).

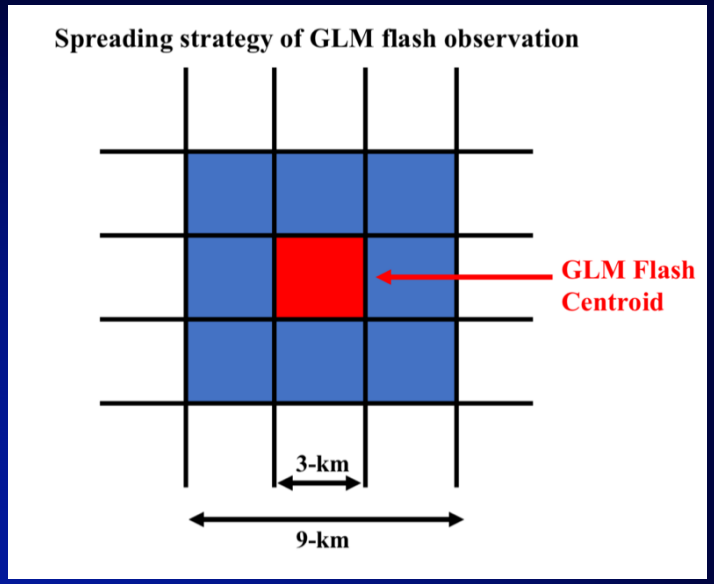
Experiments	Description	Data assimilated variationally	Model variables adjusted
CTRL	Control run	None	None
GLM	Lightning DA run.	GLM flash density rates.	q_v (LCL-3 km)
GLM_CONS	Lightning DA run with domain-wide q_v conservation.	GLM flash density rates.	q_v (LCL-3 km)
RAD	Radar DA run	Vr and dBZ	q_r, q_g, q_s, q_h, u, v, w, θ
RAD+GLM	Lightning + Radar DA run	GLM flash density rates, Vr and dBZ	q_v (LCL-3 km), q_r, q_g, q_s, q_h, u, v, w, θ

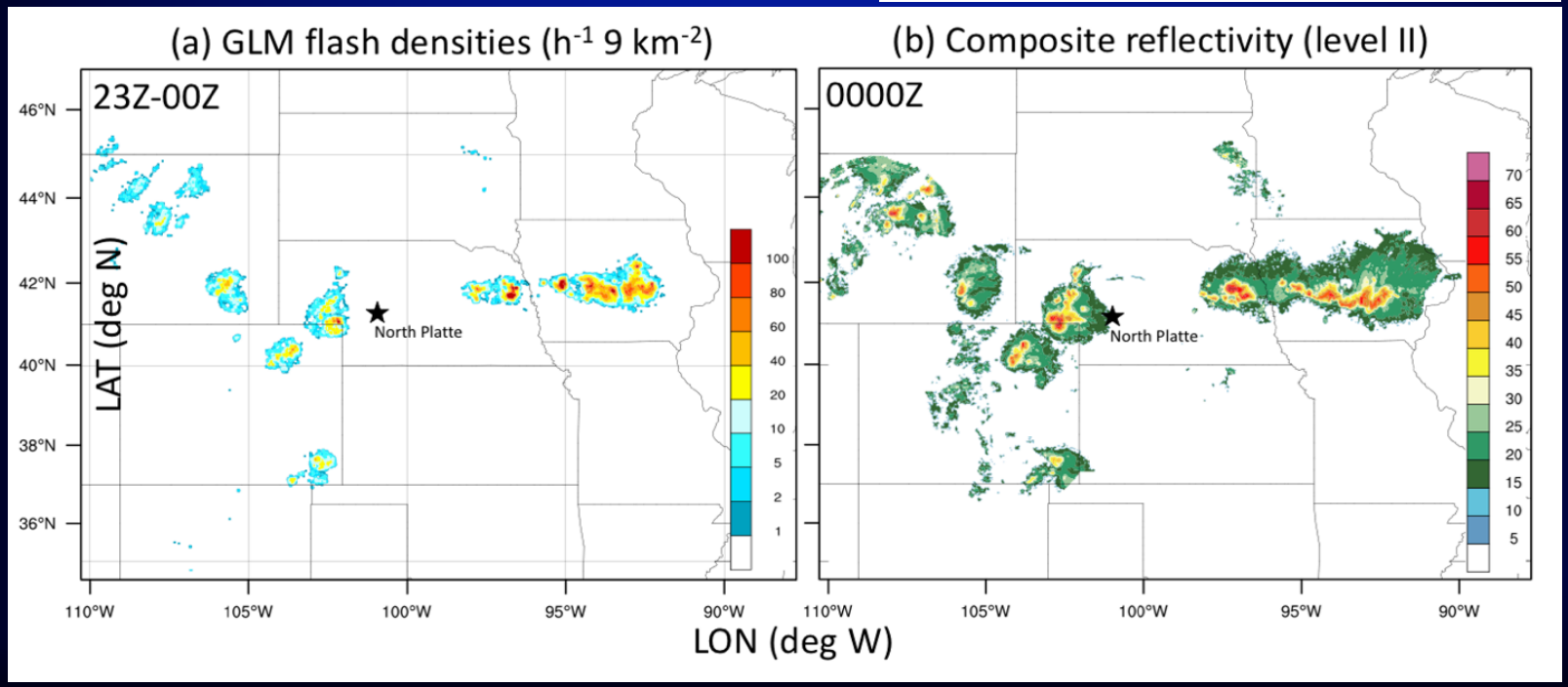
NB: level II data from ~11 radars were assimilated

Forecasts use NSSL 2-mom microphysics, Fierro et al. (2019, MWR).

Illustrative case: 7 June 2018, 00Z



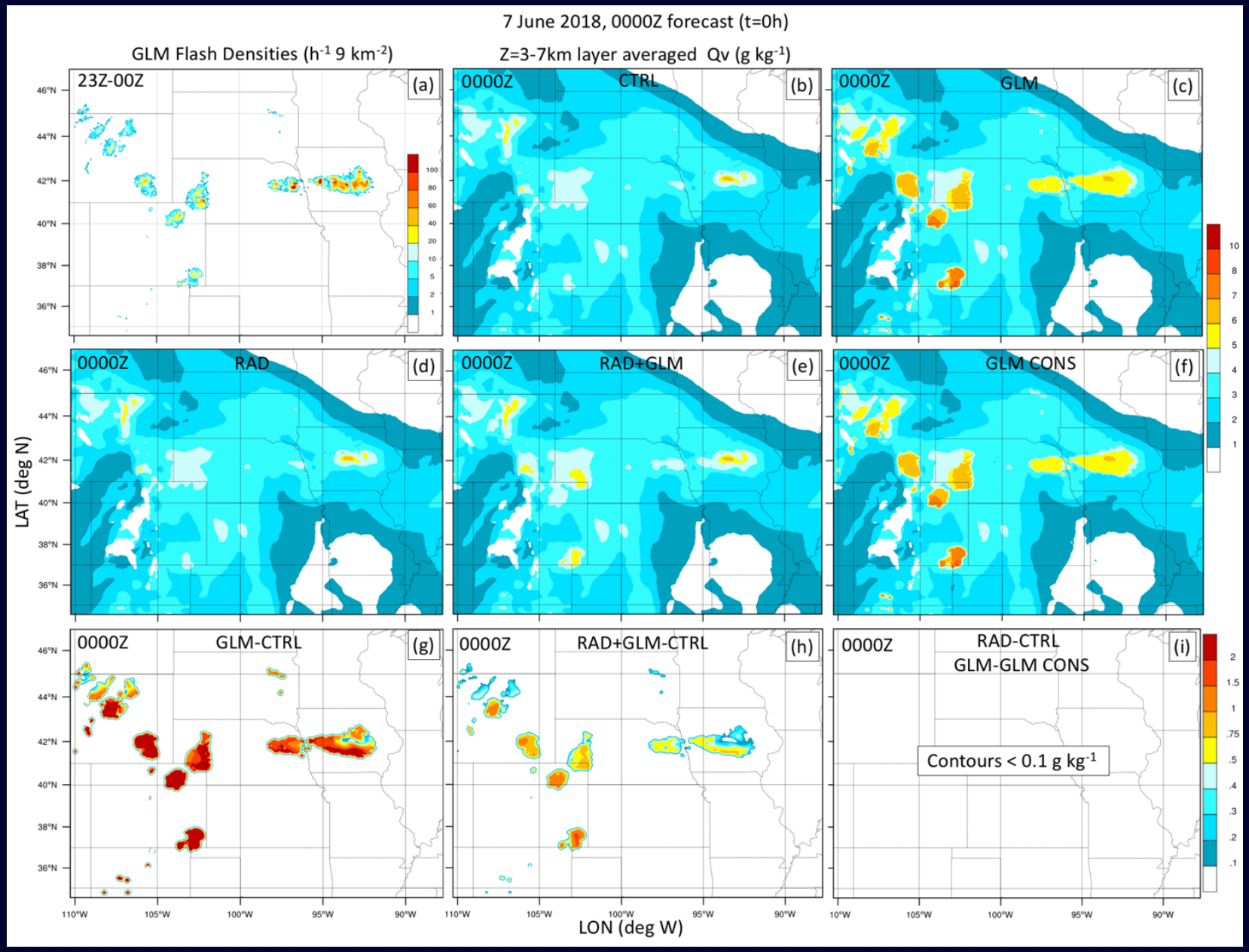




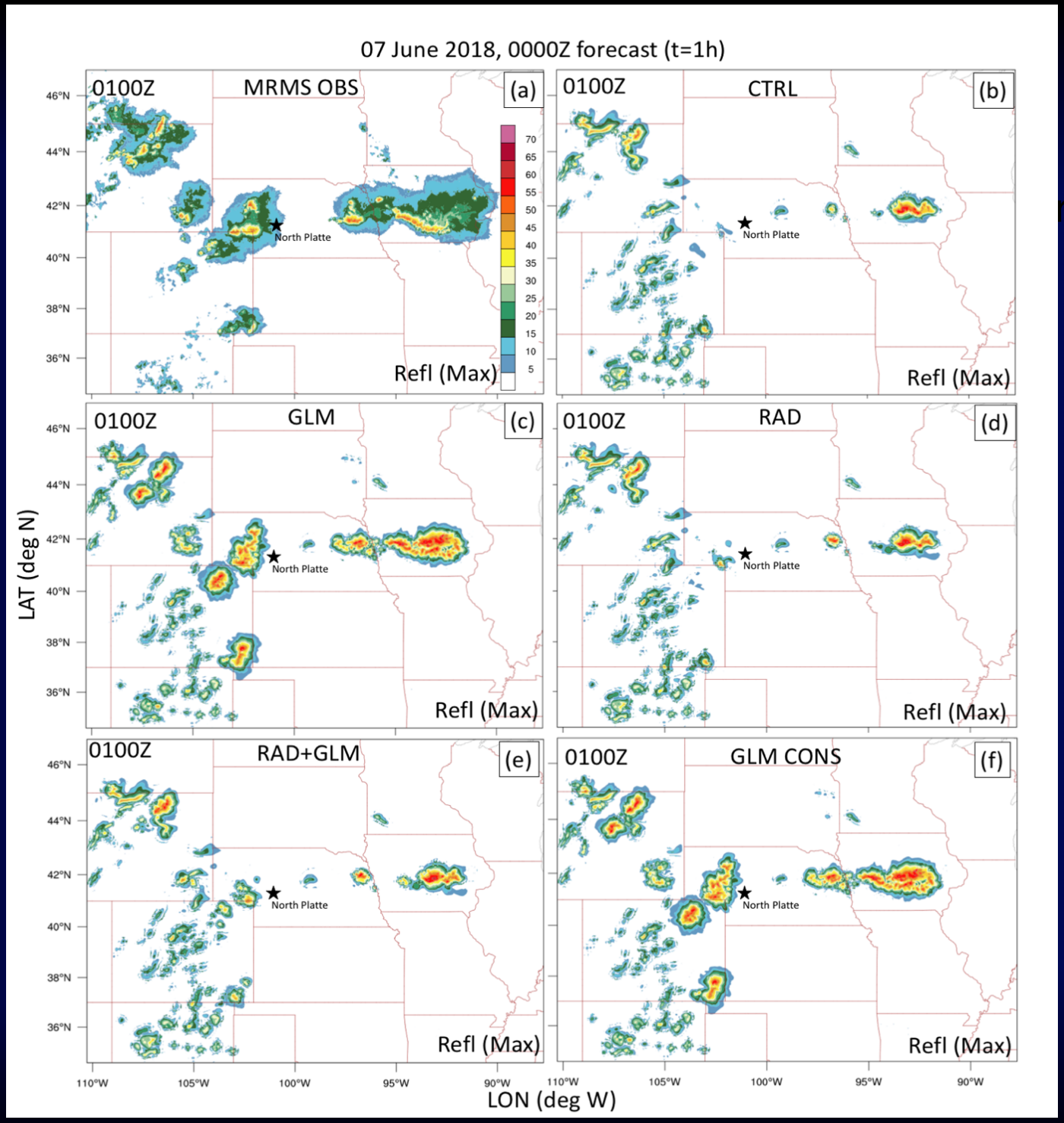
Fierro et al. (2019, MWR)

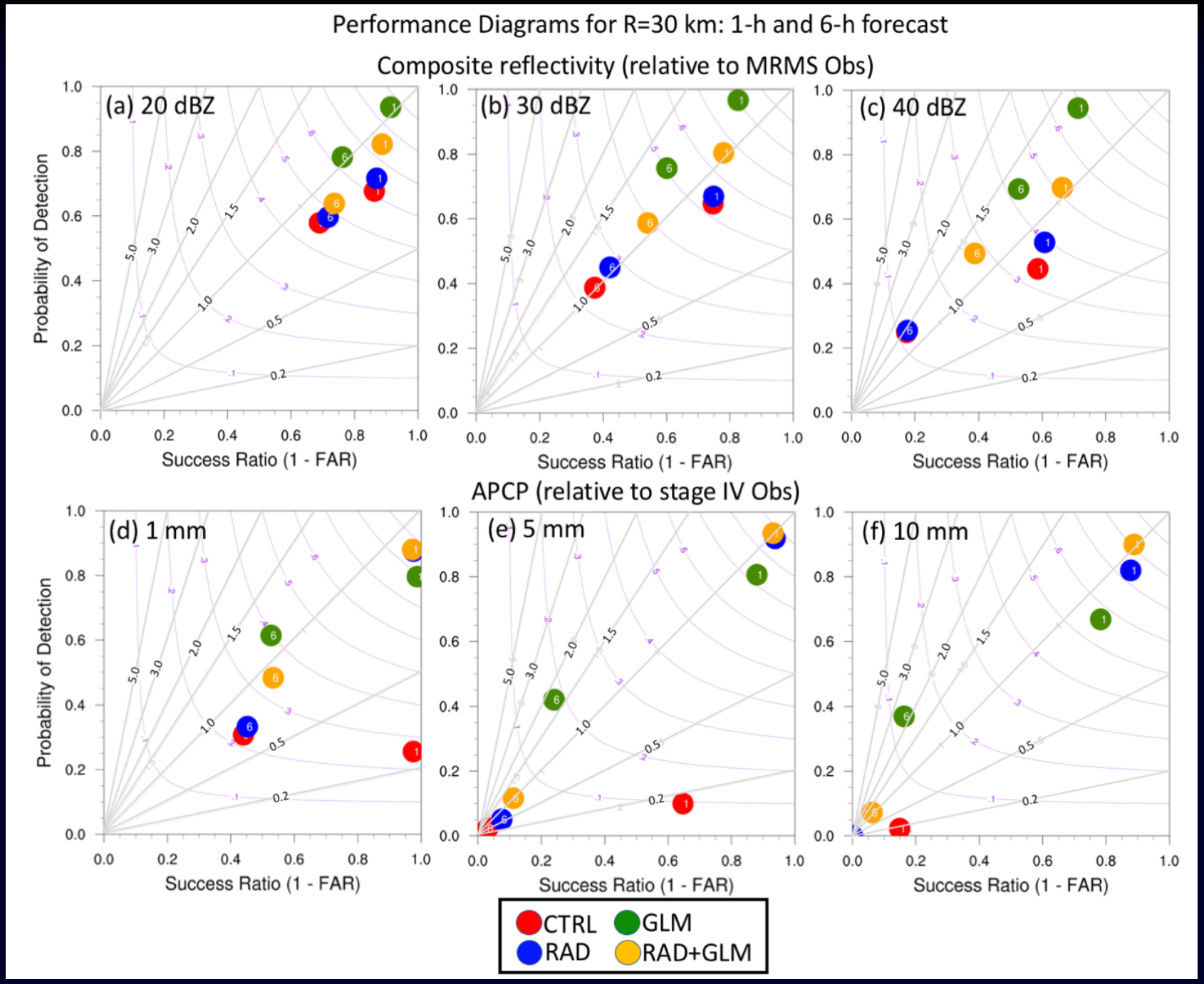
7 June 2018, 00Z

GLM flash densities/Qv fields/Qv differences



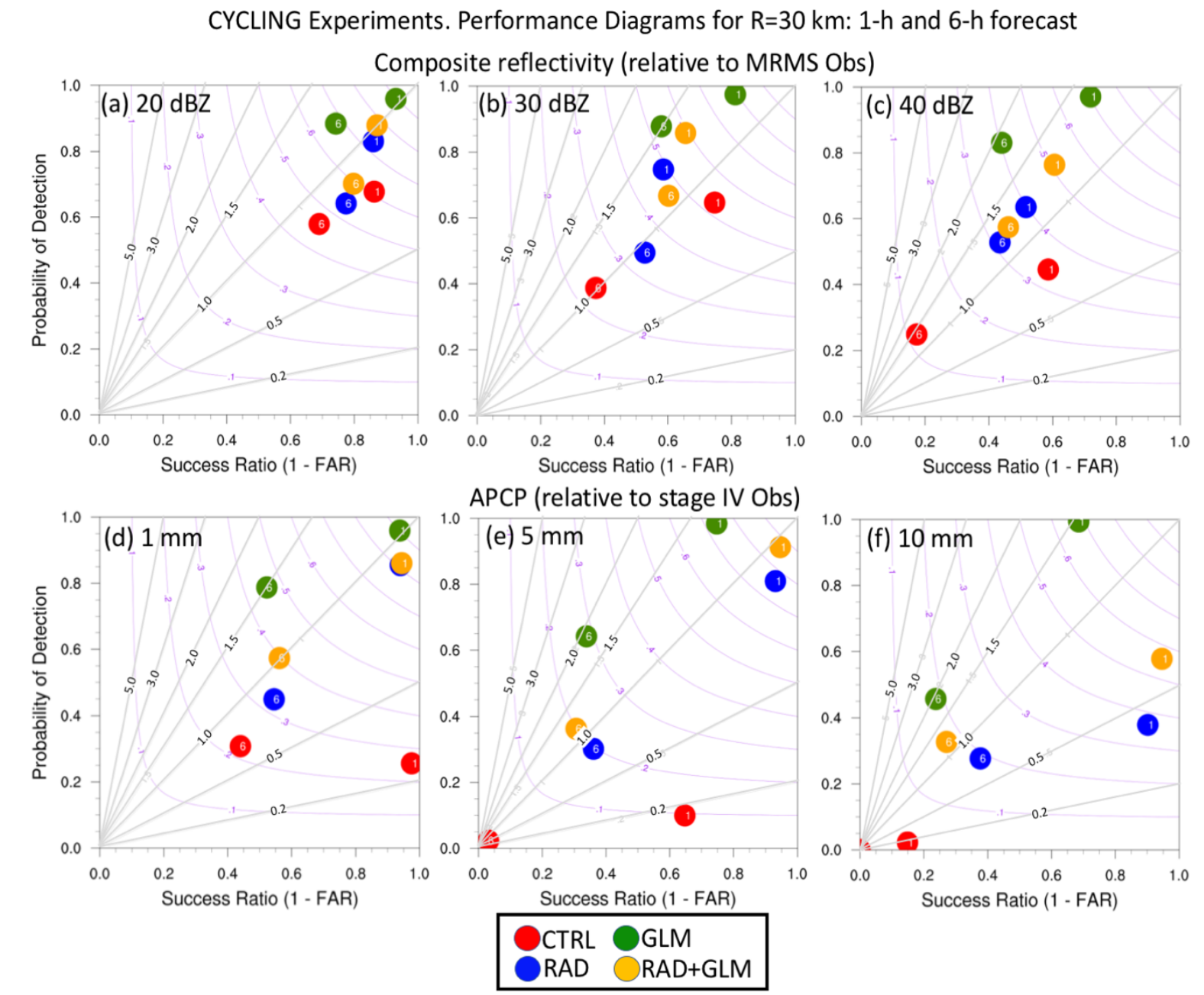
1st test: No 3DVAR cycling → Background = CTRL


07 June 2018, 0000Z forecast (t=1h)
0100Z
MRMS OBS
(a)
0100Z
CTRL
(b)
0100Z
GLM
(c)
0100Z
RAD
(d)
0100Z
RAD+GLM
(e)
0100Z
GLM CONS
(f)
North Platte
Refl (Max)
70
65
60
55
50
45
40
35
30
25
20
15
10
5
46°N
44°N
42°N
40°N
38°N
36°N
110°W
105°W
100°W
95°W
90°W
LAT (deg N)
LON (deg W)



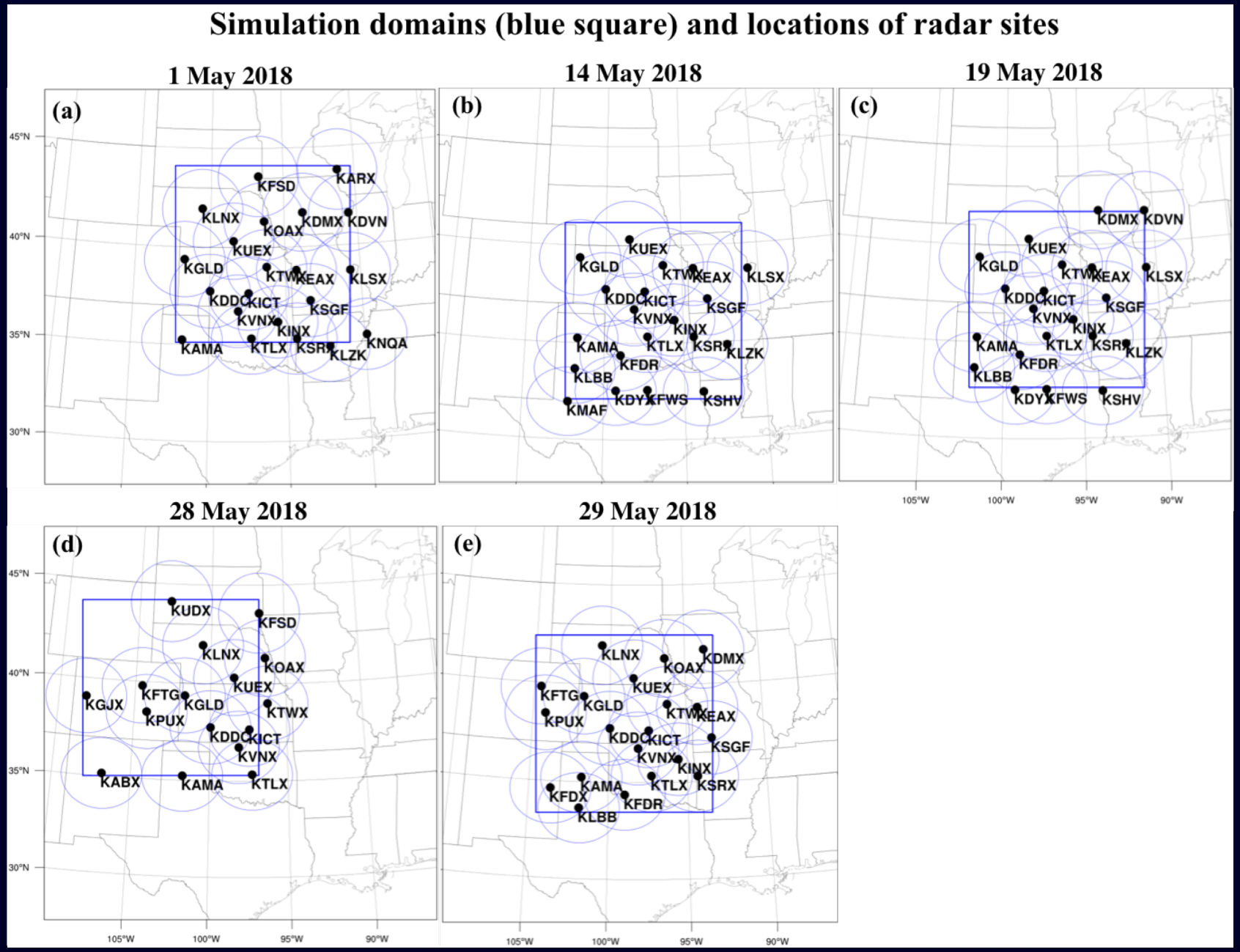
1-h forecasts of rainfall and composite dBZ notably improved by radar and/or GLM DA.
6-h forecast improvements wane but remain generally superior to CTRL (no DA)

7 June 2018, 00Z: with 3DVAR cycling



Overall similar results than without cycling.

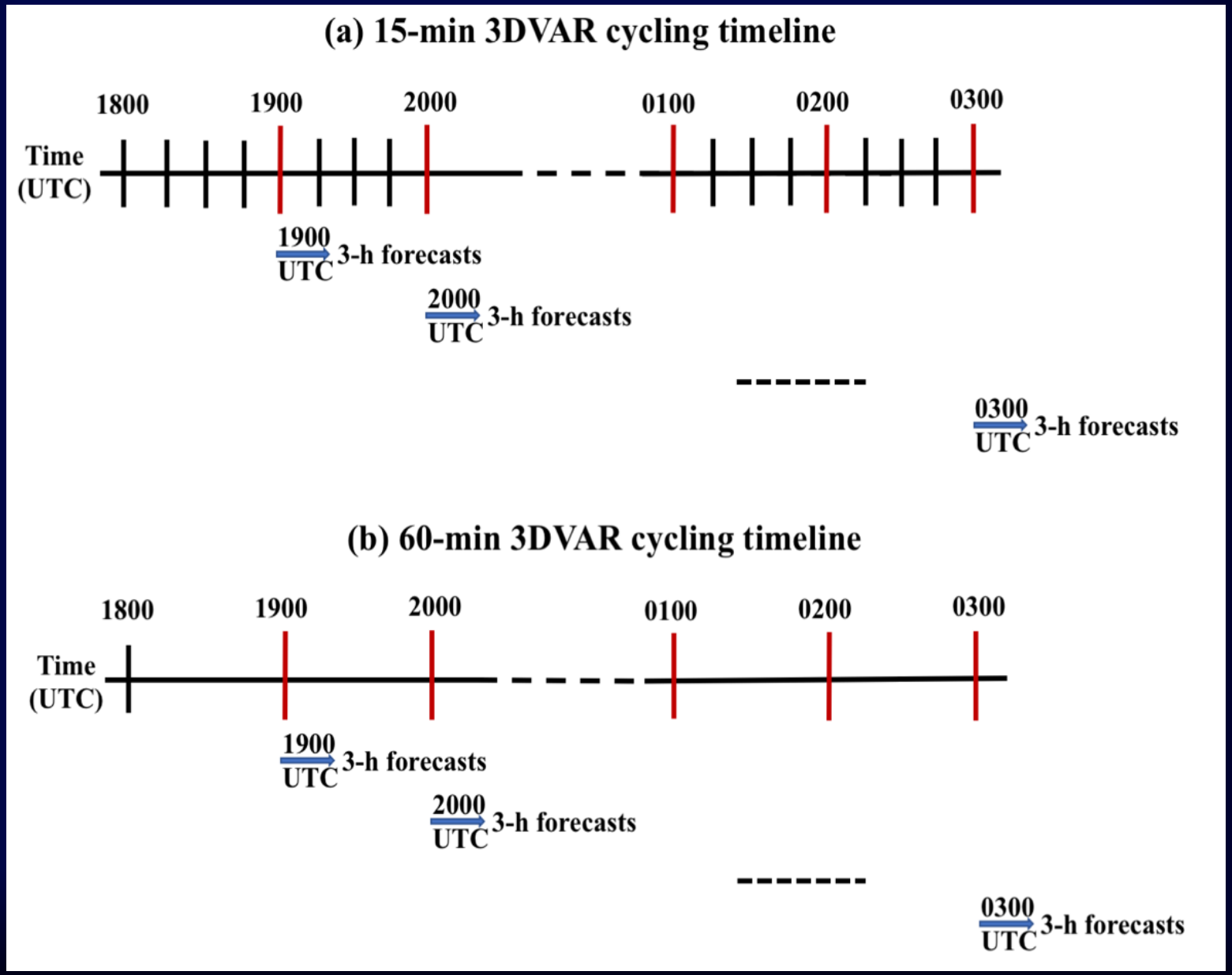
Testing more cases with 3DVAR cycling:



Hu, Fierro et al. (2019, MWR)

Testing more cases with 3DVAR cycling:

DA run workflow:



Testing more cases with 3DVAR cycling:

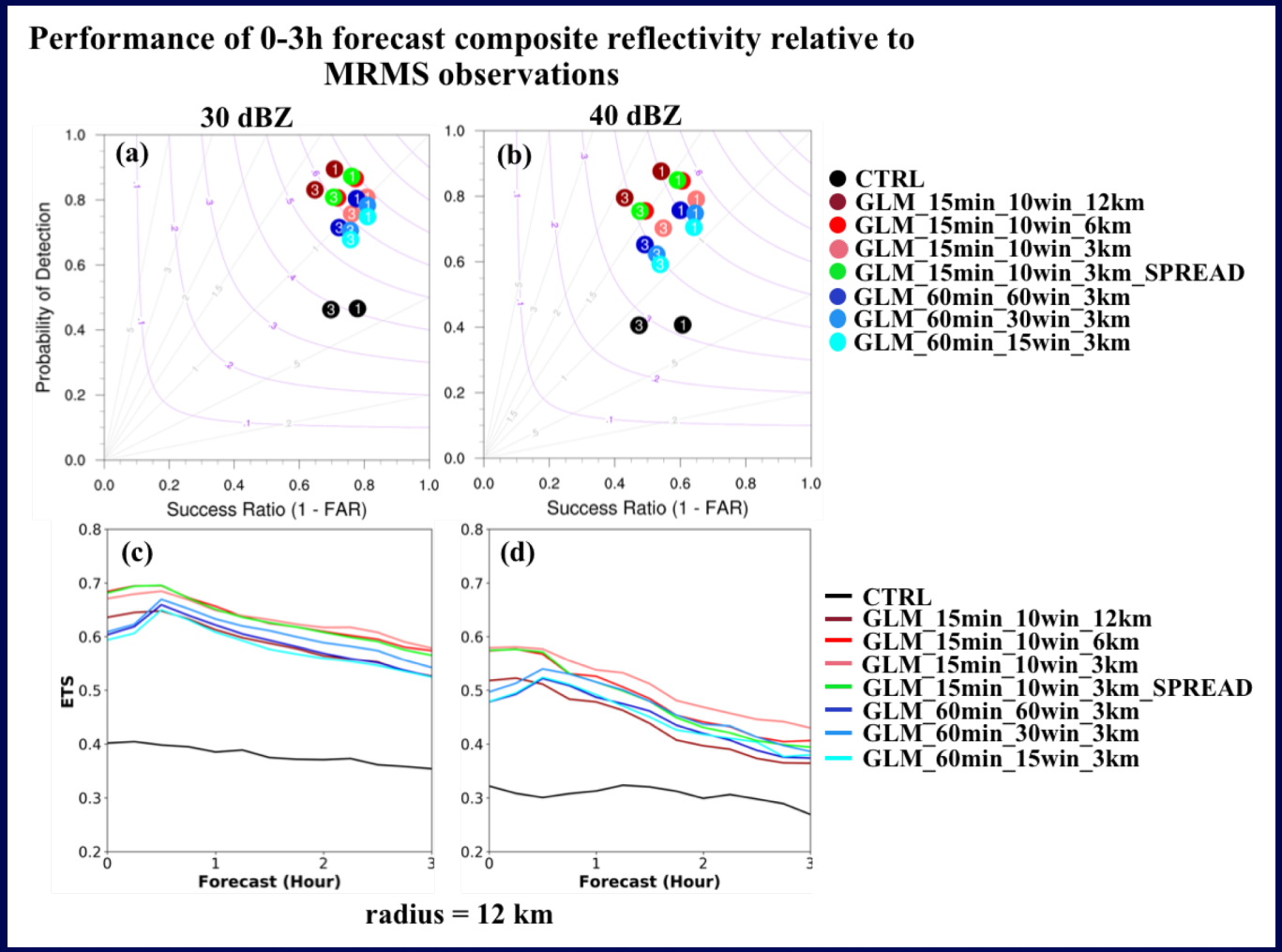
Seeking an "optimal" configuration of GLM DA:

Experiment	DA cycle freq (min)	GLM rates Δt (min)	Horizontal decorrelation length L2 (km)
GLM_15min_10win_12km	15	10	12
GLM_15min_10win_6km	15	10	6
GLM_15min_10win_3km	15	10	3
GLM_15min_10win_3km_Spread	15	10	3
GLM_60min_60win_3km	60	60	3
GLM_60min_30win_3km	60	30	3
GLM_60min_15win_3km	60	15	3

Hu, Fierro et al. (2019, MWR)

Testing more cases with 3DVAR cycling:

Aggregate performance (precip):



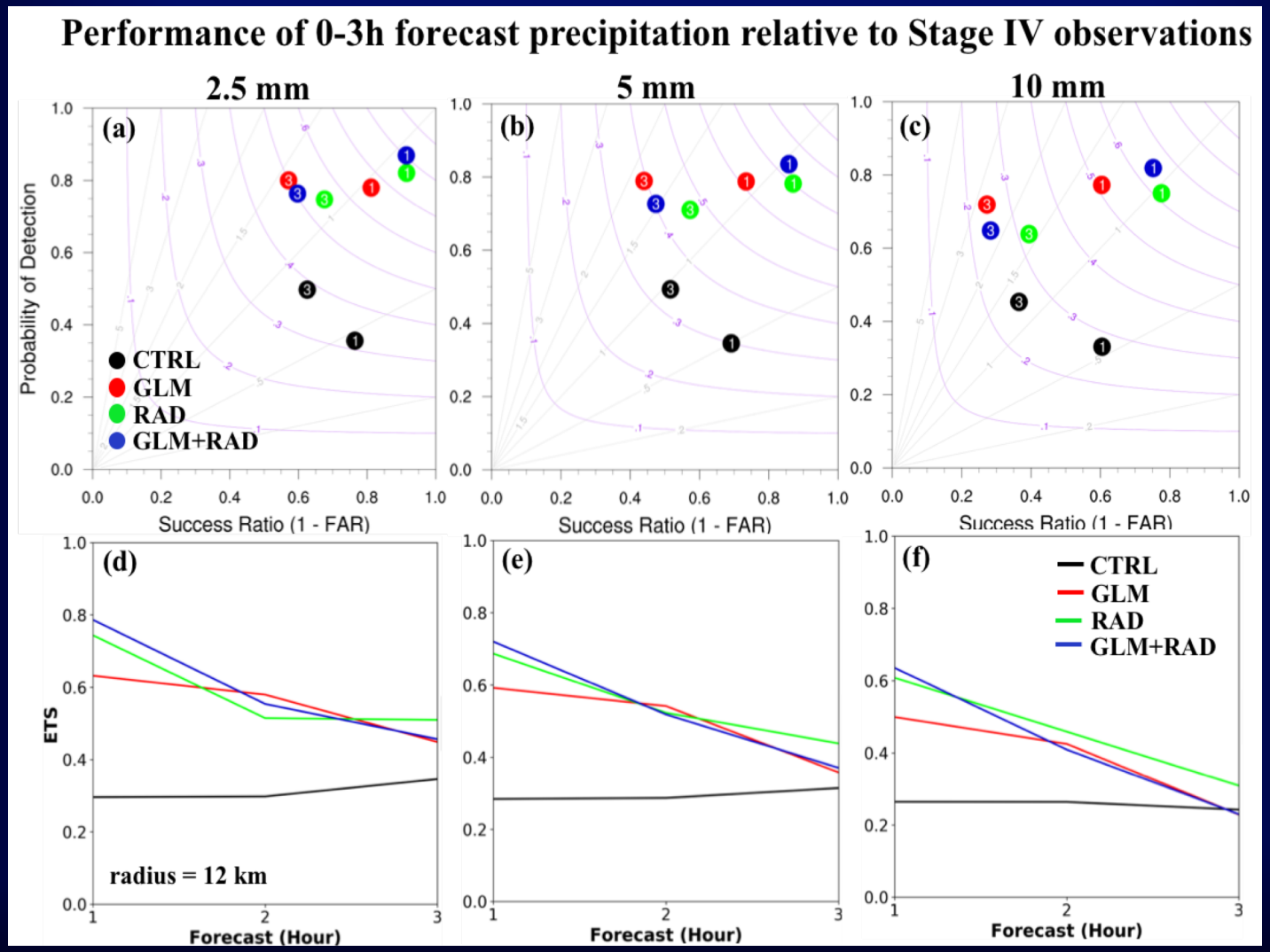
Best results: L2=3km, DA cycle freq=15 min and Δt=10 min.

Same for CREF.

Testing more cases with 3DVAR cycling:

Test optimal GLM settings against/with level II radar.

Aggregate performance over all 45 forecasts (precip):

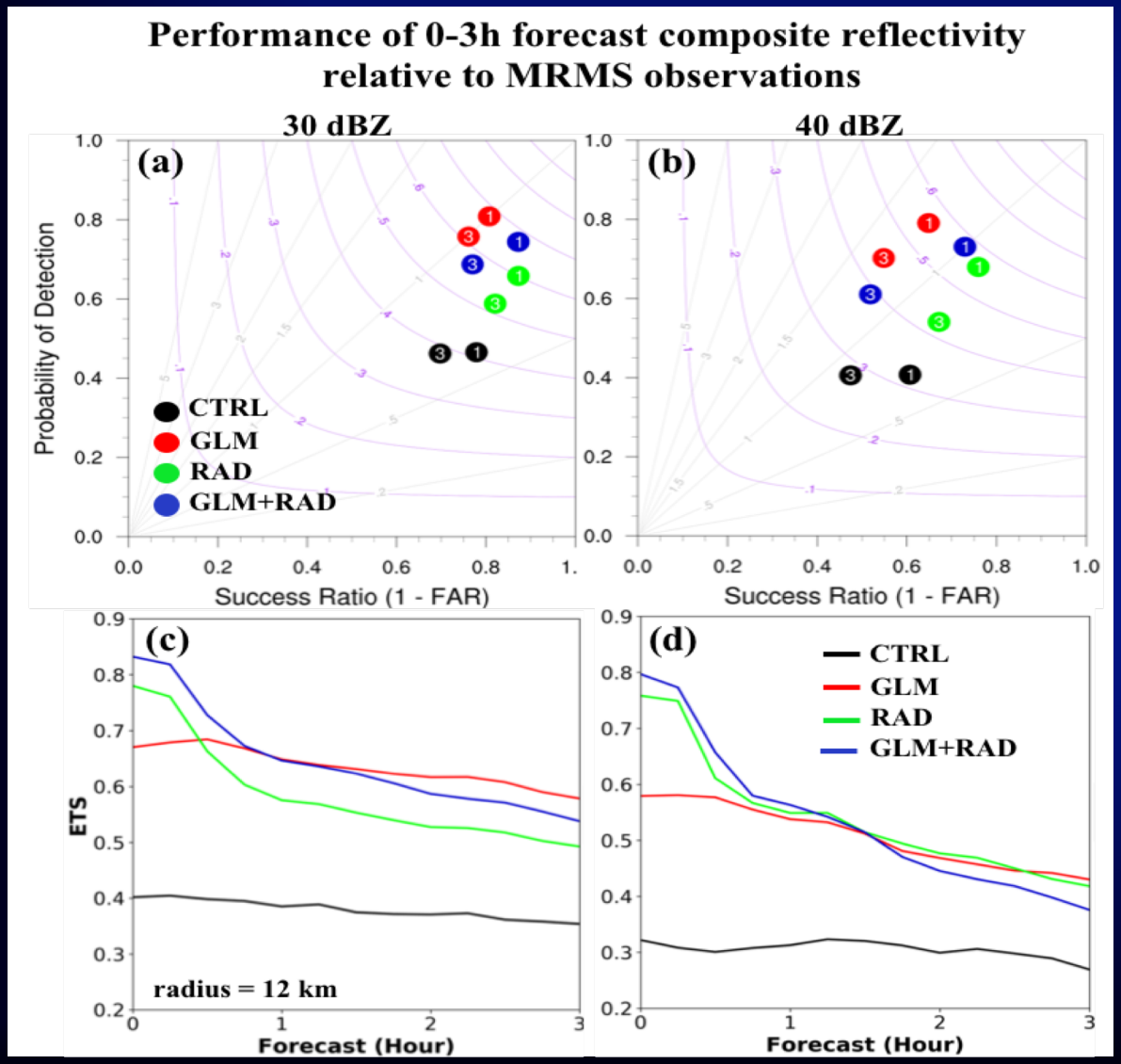


1 and 3-h forecasts of rainfall notably improved by radar and/or GLM DA without increasing frequency bias significantly (<2).

Testing more cases with 3DVAR cycling:

Test optimal GLM settings against level II radar.

Aggregate performance over 45 fcsts (dBZ):



1 and 3-h forecasts improvements for composite dBZ are qualitatively similar than for rainfall.

Ongoing and future work

- Run additional cases in real time during Spring 2020 spanning various convective modes.
- Combine Radar and GLM DA with sfc obs such as Mesonet and/or satellite products (e.g. VIL, Lai et al. 2019)
- Develop/Implement dynamic weighting between radar and lightning during the DA.
- Continue to work on producing real-time evaluation graphics, which could be used during real time experiments (e.g., HWT).
- Start thinking about hybrid ensemble-3DVAR implementation for lightning.
- Parallel work also evaluating GSI-EnKF DA of GLM FED Data using Qg-based obs operator (Kong, Xue, Fierro et al. 2019, MWR).

GLM-related recent works

Fierro, A. O., Wang. Y, Gao J., and E. R. Mansell, 2019: Variational assimilation of radar data and GLM-lightning derived water vapor for the short-term forecasts of high-impact convective events. *Accepted to Monthly Weather Review. In Press.*

Fierro, A. O., Stevenson S. and R. Rabin, 2018: Evolution of GLM-observed total lightning in Hurricane Maria (2017) during the period of maximum intensity**.** *Monthly Weather Review.* Volume **146**, 1641–1666.

Fierro, A. O., Zhao G., Liu S., Wang Y., J. Gao, K. Calhoun, C. L. Ziegler, E. R. Mansell and D. R. MacGorman, 2018: Assimilation of total lightning with GSI and NEWS3DVAR to improve short-term forecasts of high impact weather events at cloud resolving scales. *JCSDA Quarterly Newsletter*, No. **58**, Winter 2018, pp5 -12. doi: 0.7289/V5CJ8BR2.

Hu J., **A. O. Fierro**, Y. Wang, J. Gao and E. R Mansell, 2019: An Evaluation of the Impact of Assimilating GLM-observed total lightning data on short-term forecasts of high-impact convective events. *Conditionally accepted to Monthly Weather Review.*

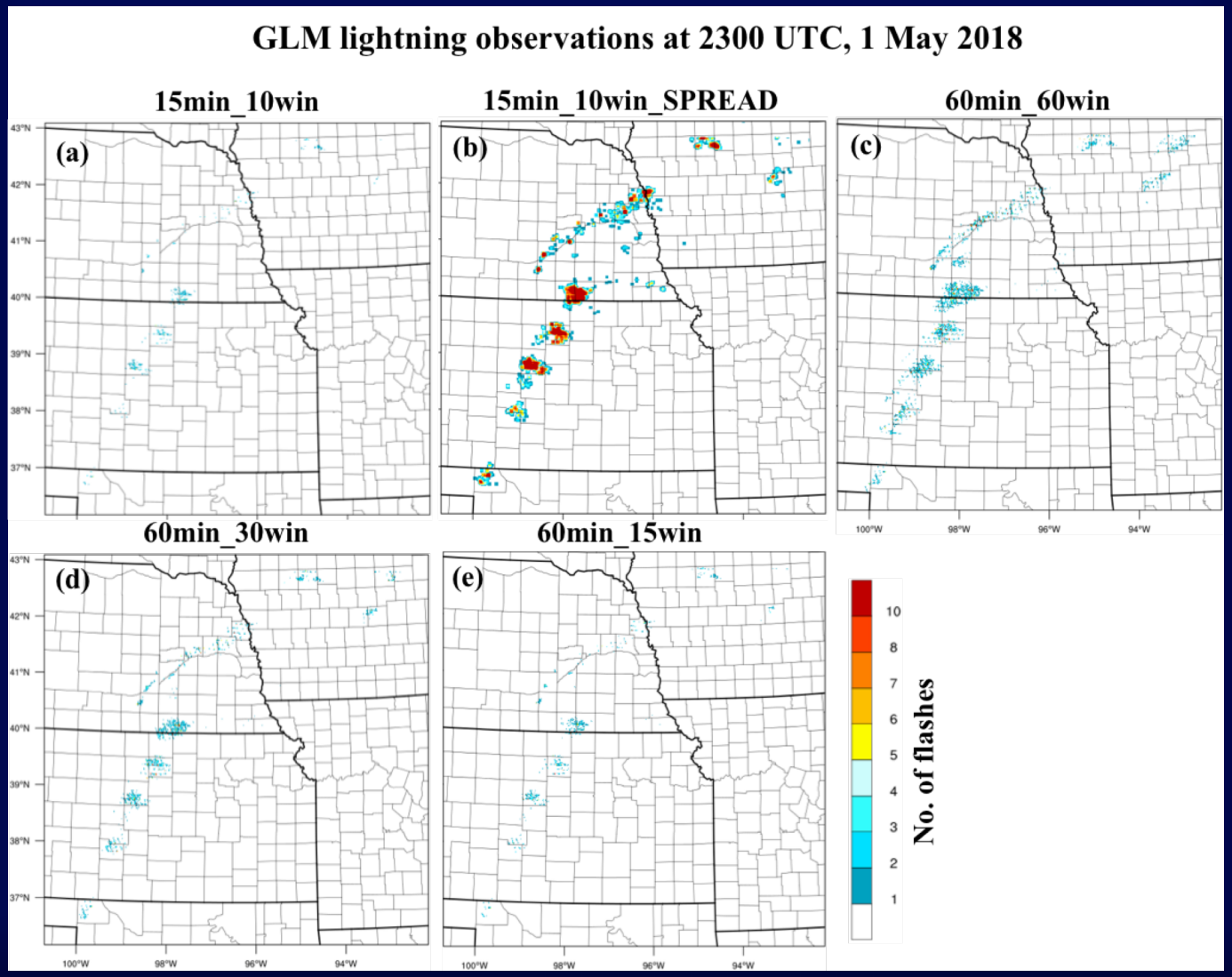
Rong K., M. Xue, **A. O. Fierro**, Y. Jung, C. Liu, E. R. Mansell and D. R. MacGorman, 2019: Assimilation of GLM-observed Flash Extent Density in GSI EnKF: Proof-of-concept for the Analysis and short-term Forecast of the 13 July 2018 Mesoscale Convective System. *Conditionally accepted to Monthly Weather Review.*

Lai A., J. Gao, S. Koch, Y. Wang, S. Pan, **A. O. Fierro**, C. Cui and J. Min, 2019: Assimilation of Radar Radial Velocity, Reflectivity and Pseudo Water Vapor for Convective-scale NWP in a Variational Framework. *Monthly Weather Review.* Volume **147**, 2877-2900.

Questions?
Issyk Kul, Kyrgyzstan-

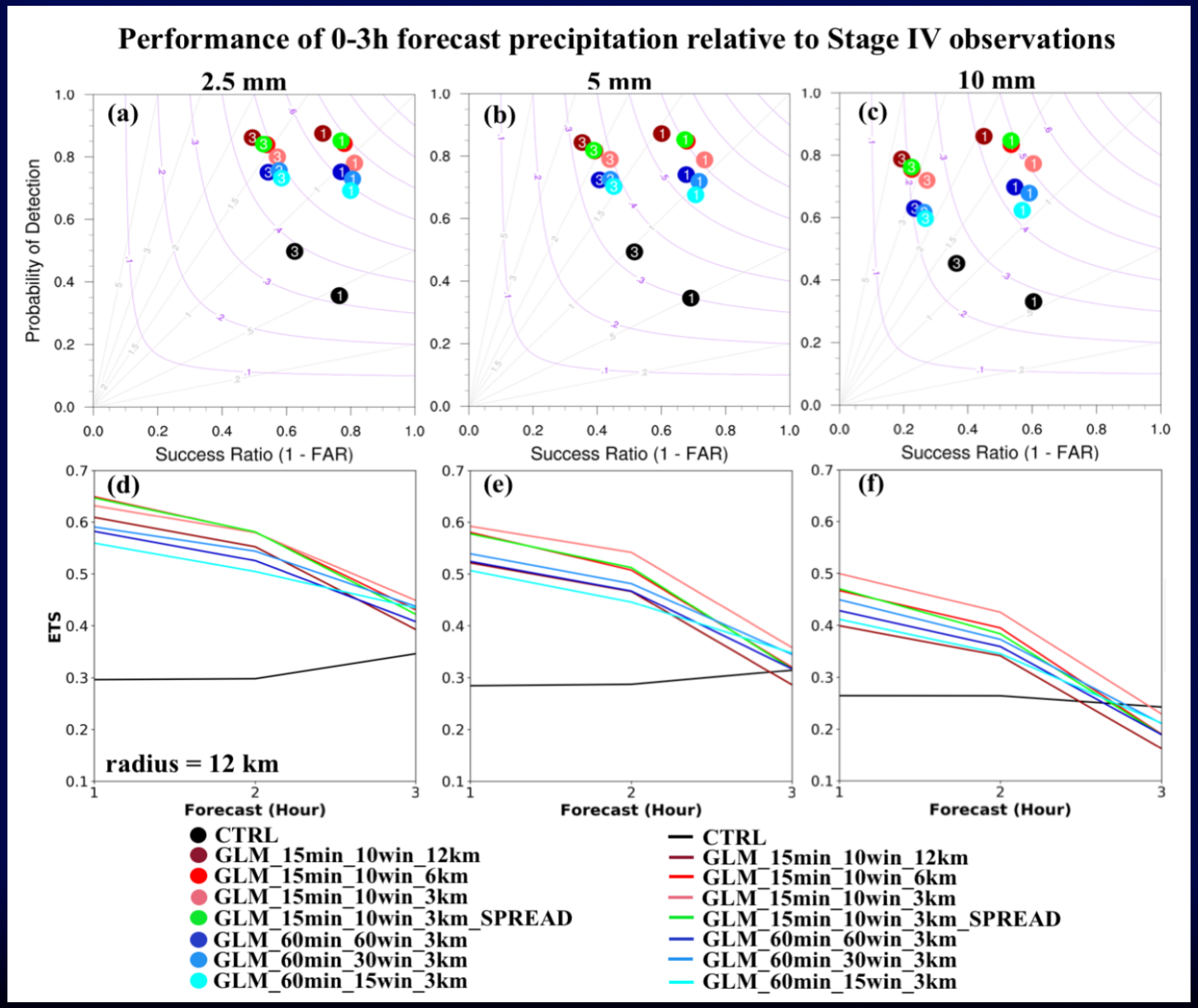
Testing more cases with 3DVAR cycling:

How does assimilated GLM flash densities look like?



Testing more cases with 3DVAR cycling:

Aggregate performance (CREF):



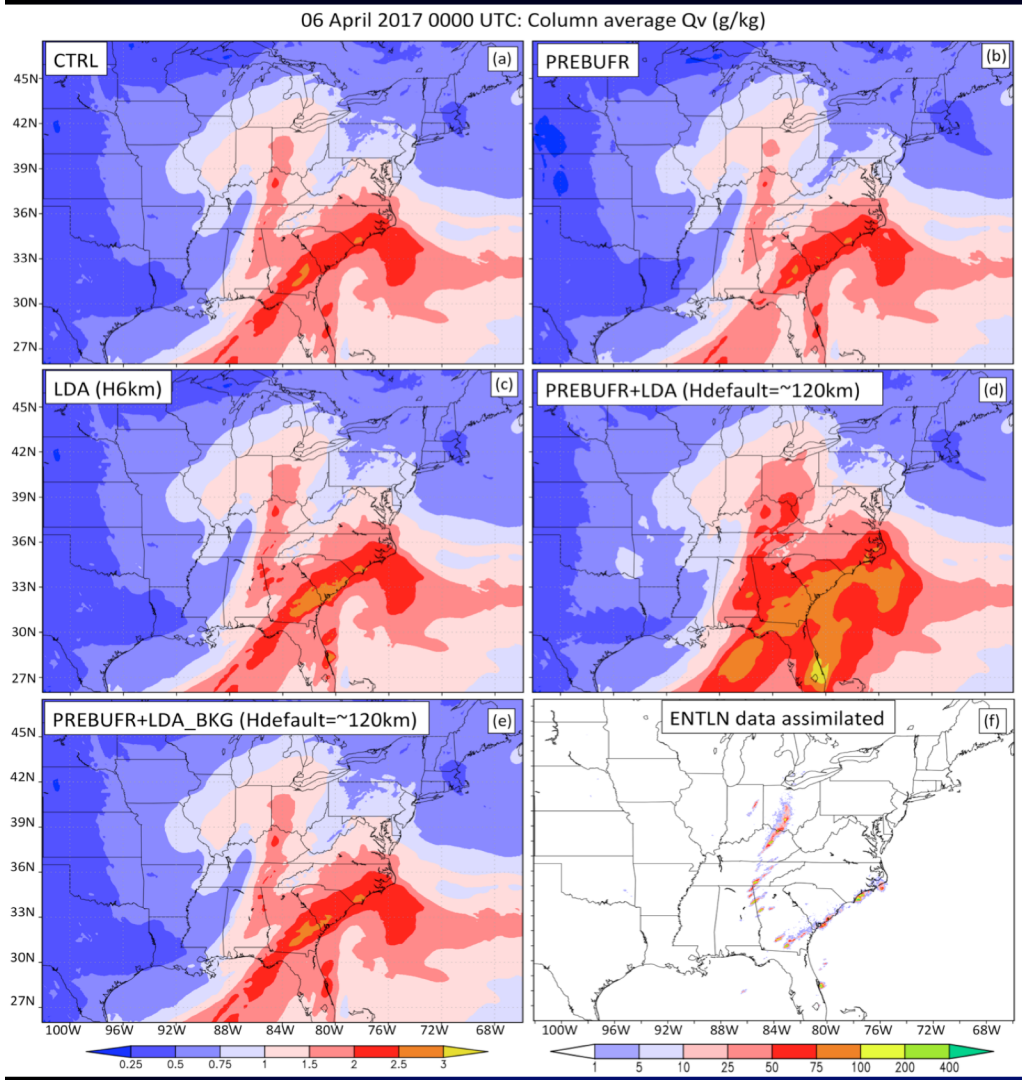
GSI Experiments

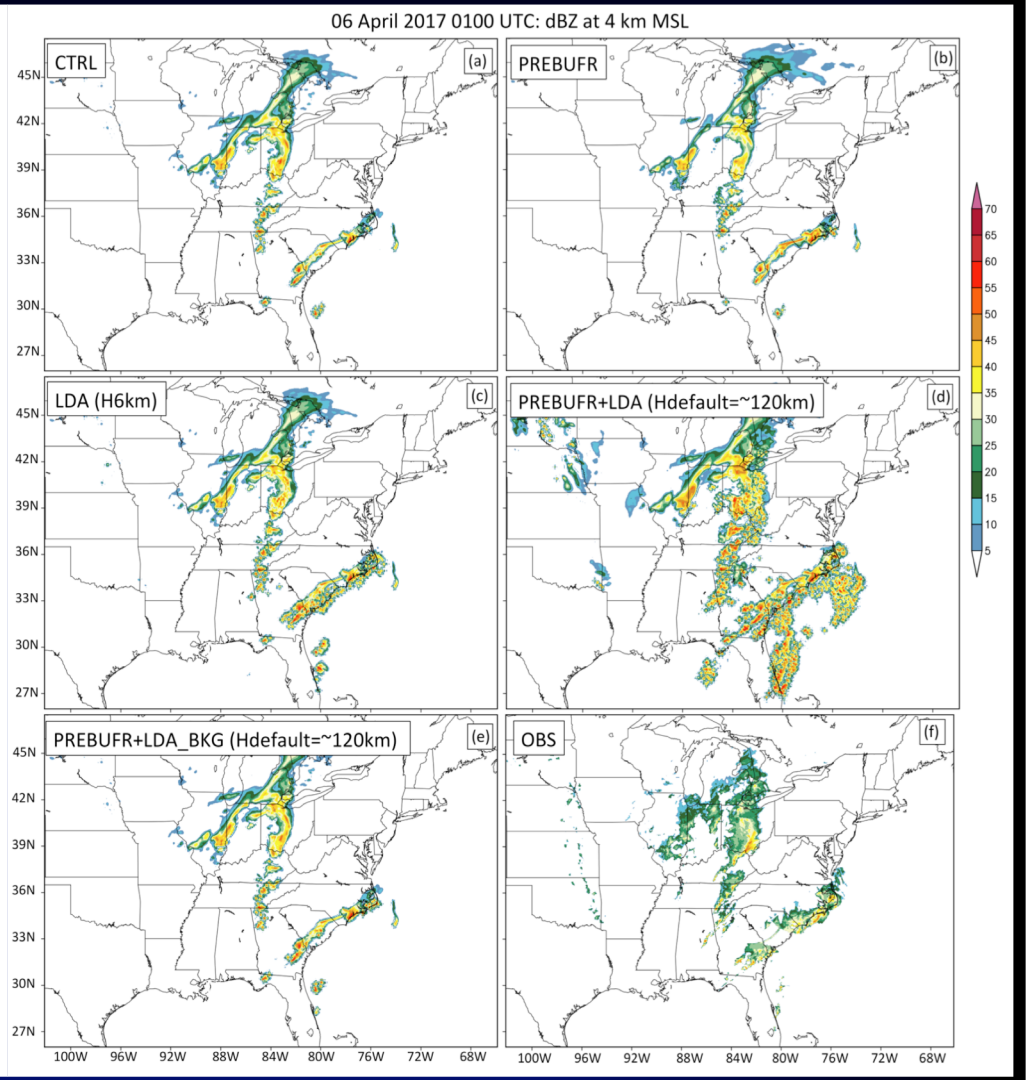
-Logical follow-on: apply this philosophy to GSI in quasi-realtime

Experiments	Description	Data assimilated	Model variables impacted
CTRL	Control run	None	None
LDA (H=6km)	Lightning DA run. horizontal length scale of 6 km.	ENTLN flash extent density rates.	q_v (LCL-15 km)
PREBUFR	PREPBUFR DA run	NCEP PREPBUFR data bundle	*
PEBUFR+LDA (H_default)	Lightning+PREPBUFR DA run. GSI default horizontal length scale ~100km.	NCEP PREPBUFR data bundle ENTLN flash extent density rates. ***No lightning=missing obs.***	q_v (LCL-15 km) + *
PEBUFR+LDA_ BKG (H_default)	Lightning+PREPBUFR DA run GSI default horizontal length scale ~100km.	NCEP PREPBUFR data bundle ENTLN flash extent density rates. ***No lightning=valid obs (zero innovation).***	q_v (LCL-15 km) + *

*NCEP ADP Global Upper Air and Surface Weather Observations (PREPBUFR format) are composed of a global set of surface and upper air reports: land surface, marine surface, radiosonde, pibal and aircraft reports from the Global Telecommunications System (GTS), profiler and US radar derived winds, SSM/I oceanic winds and TCW retrievals, and satellite wind data from the National Environmental Satellite Data and Information Service (NESDIS). The reports can include pressure, geopotential height, temperature, dewpoint temperature, wind direction and speed. Report time intervals range from hourly to 12 hourly. Source: https://gcmd.nasa.gov

GSI: representative case





-Strongly forced case -> good performance for CTRL. LDA still improves short term forecast when H <= 10km.

-GSI, however does not allow for multiscale VAR passes and assumes a large default H (~100 km) for all variables !

→ Not mature enough for assimilating convective scale information together with mesoscale data.

-> use of NSSL 3DVAR. (cf Fierro et al. 2018 JCSDA Quarterly Newsletter for details).