Weather and climate focus

An evaluation of the efficacy of using observed lightning to improve convective lightning forecasts.

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Forecast Particulars

1) 4 km WRF running operationally over central and eastern US.
2) Forecasts made with total lightning assimilation (EarthNetworks) and without.
3) Lightning forecasts compared to USPLN (WSI) CG lightning.

*Fierro, Alexandre O., Edward R. Mansell, Conrad L. Ziegler, Donald R. MacGorman, 2012: Application of a Lightning Data Assimilation Technique in the WRF-ARW Model at Cloud-Resolving Scales for the Tornado Outbreak of 24 May 2011. *Mon. Wea. Rev.*, **140**, 2609–2627.

Outline

1) How Long Does Assimilation Help?
2) Review of Dates; 2-6 hour forecasts
3) Text Book Assimilation Case
4) Using Forecast and Observed Lightning to Filter Spurious Convection
5) 4 km vs 1.3 km forecasts (case study)
6) The Moore Oklahoma Tornado (A Forecast Every 10 Minutes!)

	0 to 3 hr	3 to 6 hr	6 to 9 hr	9 to 12 hr	12 to 15 hr	15 to 18 hr
≥ 1 3 hr^{-1}						
12 km	**0.62**/0.54	0.52/0.52	0.42/0.45	0.41/0.43	0.37/0.38	0.38/0.38
24 km	**0.75**/0.68	0.67/0.67	0.58/0.61	0.56/0.59	0.52/0.54	0.52/0.53
48 km	**0**.87/0.83	0.80/0.81	0.74/0.76	0.75/0.77	0.71/0.73	0.71/0.72
96 km	0.95/0.93	0.91/0.92	0.89/0.89	0.90/0.91	0.89/0.90	0.89/0.89
≥ 5 3 hr^{-1}						
12 km	**0.59**/0.50	0.41/0.41	0.26/0.27	0.23/0.26	0.23/0.20	0.27/0.27
24 km	**0.74**/0.66	0.57/0.57	0.43/0.43	0.38/0.40	0.39/0.36	0.43/0.41
48 km	**0.88**/0.83	0.74/0.76	0.64/0.66	0.60/0.61	0.59/0.58	0.64/0.63
96 km	0.95/0.93	0.88/0.89	0.85/0.85	0.85/0.87	0.86/0.87	0.89/0.89
≥ 10 3 hr^{-1}						
12 km	**0.55**/0.48	0.33/0.34	0.16/0.18	0.14/0.15	0.12/0.10	0.17/0.17
24 km	**0.71**/0.65	0.52/0.52	0.33/0.32	0.25/0.26	0.25/0.21	0.29/0.29
48 km	0.86/0.83	0.71/0.71	0.56/0.58	0.44/0.42	0.45/0.41	0.50/0.51
96 km	0.94/0.93	0.86/0.85	0.80/0.81	0.69/**0.75**	0.79/0.76	0.87/0.86
≥ 25 3 hr^{-1}						
12 km	0.30/0.26	0.13/0.17	0.05/0.09	0.05/0.04	0.03/0.02	0.03/0.04
24 km	0.48/0.47	0.34/0.30	0.16/0.15	0.10/0.07	**0.09**/0.03	0.08/0.12
48 km	0.69/0.72	**0.59**/0.52	0.32/0.31	**0.23**/0.15	**0.21**/0.12	0.20/**0.27**
96 km	0.87/0.87	**0.82**/0.77	0.58/0.54	0.46/0.42	**0.48**/0.37	0.60/0.59
≥ 50 3 hr^{-1}						
12 km	**0.11**/0.06	0.01/0.04	0.00/0.05	0.00/0.00	0.00/0.00	0.00/0.00
24 km	**0.24**/0.15	0.07/0.06	0.07/0.09	0.00/0.00	0.00/0.00	0.02/0.03
48 km	**0.47**/0.33	*0.33/0*.18	0.19/0.19	0.00/0.00	0.00/0.00	0.09/**0.19**
96 km	**0.64**/0.58	**0.71**/0.50	**0.41**/0.35	0.06/0.10	0.03/0.03	0.10/**0.32**
≥ 100 3 hr^{-1}						
12 km	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
24 km	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
48 km	0.00/0.00	**0.11**/0.00	0.00/0.00	0.00/0.00	0.00/0.00	**0.19**/0.00
96 km	**0.19**/0.00	**0.74**/0.00	**0.17**/0.00	0.00/0.00	0.00/0.00	**0.19**/0.00

Table 2: Equitable Threat Scores from 4 times daily 18 hour forecasts with/without lightning assimilation from 06 UTC 19 March 2012 until 03 UTC 21 March 2012. Lightning assimilation was 3 hours prior to the start of each forecasts.

Dates in May 2013

Day	Tornadoes	Wind	Hail	Total
03	0	0	0	0
04	5	6	0	11
05	0	0	1	1
06	1	5	16	22
07	0	2	30	32
08	7	32	116	155
09	4	26	57	87
10	0	84	50	154
11	0	20	5	25
12	0	2	0	2
13	0	22	1	23
14	0	23	1	24
15	7	22	31	60
16	4	24	19	47
17	7	17	56	80
18	16	72	92	186
19	34	355	199	558
20	37	281	129	447
21	0	307	104	414
22	0	145	57	202

Table 1: Dates for which forecasts with lightning assimilation were compared against those without, using the operational forecast domain.

5 CG per Hour

With Assimilation

rad	1	2	3	4	5	6
3	0.1053342	0.1086158	0.1014796	0.0989761	0.0928743	0.0924427
6	0.1522928	0.1588068	0.1502413	0.1467092	0.1345260	0.1355766
9	0.1987999	0.2086821	0.1966181	0.1960046	0.1793785	0.1785824
12	0.2443969	0.2544122	0.2395375	0.2429846	0.2221230	0.2201735
15	0.2930783	0.3026199	0.2844520	0.2925783	0.2664750	0.2652537
18	0.3327163	0.3444808	0.3217670	0.3340377	0.3043660	0.3042642
21	0.3679952	0.3848772	0.3572045	0.3731776	0.3412309	0.3425284
24	0.3988979	0.4222354	0.3908725	0.4088155	0.3759936	0.3789466

rad	2	3	4	5	6
3	0.0916241	0.0875891	0.0899680	0.0829150	0.0719188
6	0.1368254	0.1319247	0.1373904	0.1212010	0.1090941
9	0.1820810	0.1754237	0.1844351	0.1626183	0.1468598
12	0.2237317	0.2172159	0.2280718	0.2036869	0.1841382
15	0.2677939	0.2611833	0.2740051	0.2476134	0.2253138
18	0.3063571	0.2972036	0.3133305	0.2857990	0.2620516
21	0.3440187	0.3310539	0.3514513	0.3227665	0.2982225
24	0.3794436	0.3633997	0.3869917	0.3574710	0.3330544

With Assimilation

rad	1	2	3	4	5	6
3	0.0683783	0.0701325	0.0702631	0.0615039	0.0630403	0.0627524
6	0.1125634	0.1150166	0.1088079	0.1018167	0.1016762	0.0979818
9	0.1575180	0.1615673	0.1494245	0.1466424	0.1437031	0.1363951
12	0.2022175	0.2049875	0.1896962	0.1899702	0.1823051	0.1753179
15	0.2501244	0.2509203	0.2324403	0.2350235	0.2222609	0.2181275
18	0.2887690	0.2918947	0.2672625	0.2719445	0.2571629	0.2549264
21	0.3229130	0.3322841	0.2999866	0.3070024	0.2921282	0.2909113
24	0.3527649	0.3699533	0.3314120	0.3395257	0.3260773	0.3254322

10 CG per Hour

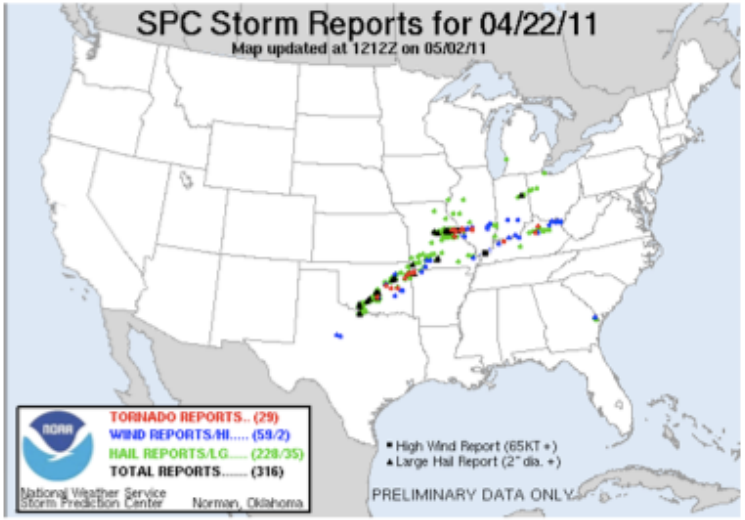
rad	2	3	4	5	6
3	0.0582378	0.0562281	0.0543185	0.0513930	0.0436819
6	0.0959669	0.0915460	0.0933759	0.0844073	0.0700591
9	0.1356869	0.1298701	0.1356074	0.1198677	0.1000797
12	0.1737903	0.1682069	0.1756511	0.1536974	0.1313365
15	0.2147386	0.2086483	0.2176236	0.1904238	0.1673303
18	0.2516467	0.2410140	0.2536496	0.2235781	0.2008807
21	0.2884535	0.2709797	0.2890927	0.2566408	0.2349239
24	0.3233338	0.2999236	0.3226554	0.2883269	0.2683621

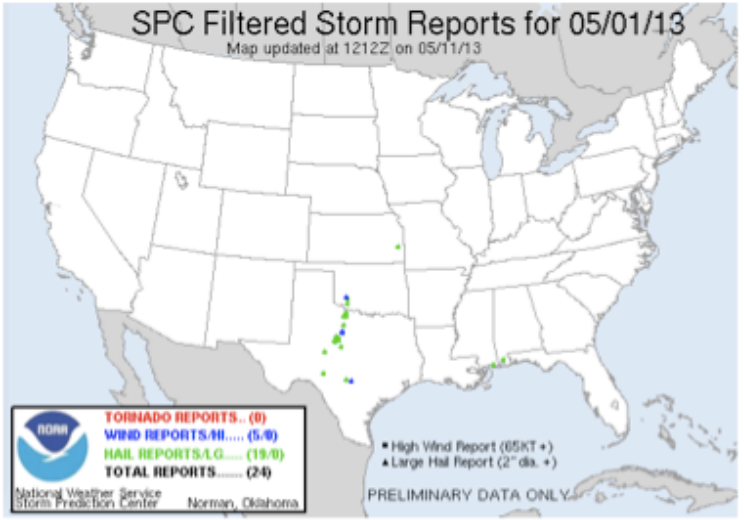
With Assimilation

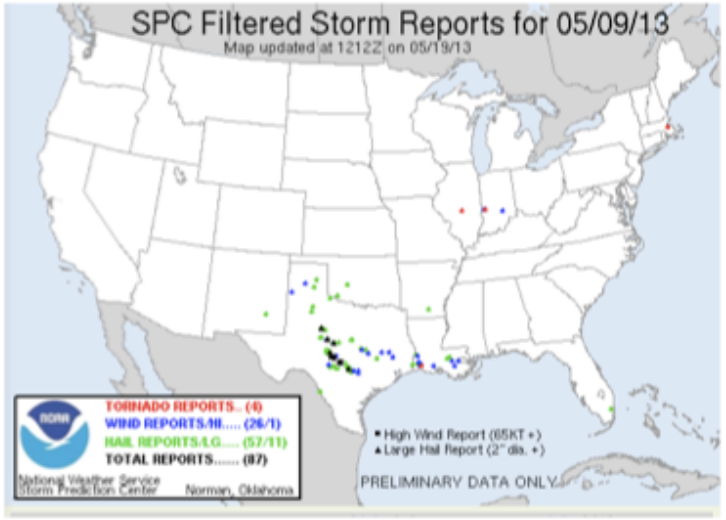
rad	1	2	3	4	5	6
3	0.0178067	0.0258130	0.0279888	0.0123910	0.0273749	0.0255863
6	0.0376112	0.0502445	0.0494822	0.0300646	0.0505766	0.0451803
9	0.0637564	0.0756921	0.0789915	0.0518624	0.0751046	0.0736903
12	0.0925816	0.1019457	0.1107851	0.0759732	0.0991942	0.1054076
15	0.1252822	0.1304254	0.1426439	0.1018274	0.1257243	0.1374442
18	0.1537222	0.1569947	0.1676373	0.1242318	0.1497508	0.1627434
21	0.1801626	0.1850005	0.1906410	0.1470777	0.1750061	0.1862007
24	0.2042641	0.2124988	0.2131258	0.1698451	0.2000652	0.2093982

25 CG per Hour

rad	2	3	4	5	6
3	0.0287385	0.0260860	0.0096776	0.0155041	0.0158809
6	0.0558959	0.0535840	0.0277780	0.0321593	0.0237236
9	0.0827845	0.0810319	0.0476965	0.0497169	0.0358333
12	0.1078110	0.1076086	0.0689132	0.0656775	0.0515009
15	0.1333403	0.1331464	0.0934524	0.0819216	0.0722669
18	0.1570266	0.1518063	0.1169631	0.0974645	0.0930851
21	0.1821515	0.1683413	0.1410599	0.1146592	0.1151967
24	0.2067350	0.1847171	0.1642475	0.1320442	0.1382274







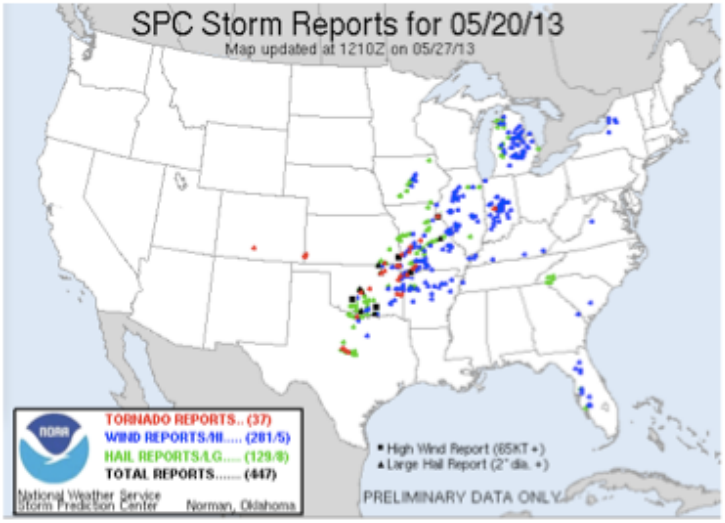


Figure 1: SPC storm reports for 22 04 2011, 01 05 2013, 09 05 2013, and 20 05 2013. Relevant storm reports for forecast simulation map results shown in this paper include: 18 tornadoes in MO, IL, and KY, as well as 80 hail reports, and 24 wind reports (top left); Oklahoma and Texas: 0 tornado, 21 hail reports and 4 wind reports (top right); Texas: 0 tornado, 71 hail reports, and 12 wind reports (bottom left); Oklahoma; 4 tornado events, 9 hail reports, and 0 wind reports (bottom right).

Figure 2: Nexrad composite radar showing reflectivity for convective storms over Texas at hourly time steps from 22 UTC 01 May 2013 until 06 UTC 02 May 2013. The source of the data can be found at:
http://gis.ncdc.noaa.gov/map/viewer/#app=cdo&cfg=cdo&theme=hourly&layers=0001&extent=-139.2:12.7:-50.4:57.8&srid=4326&node=gis&display=nexrad

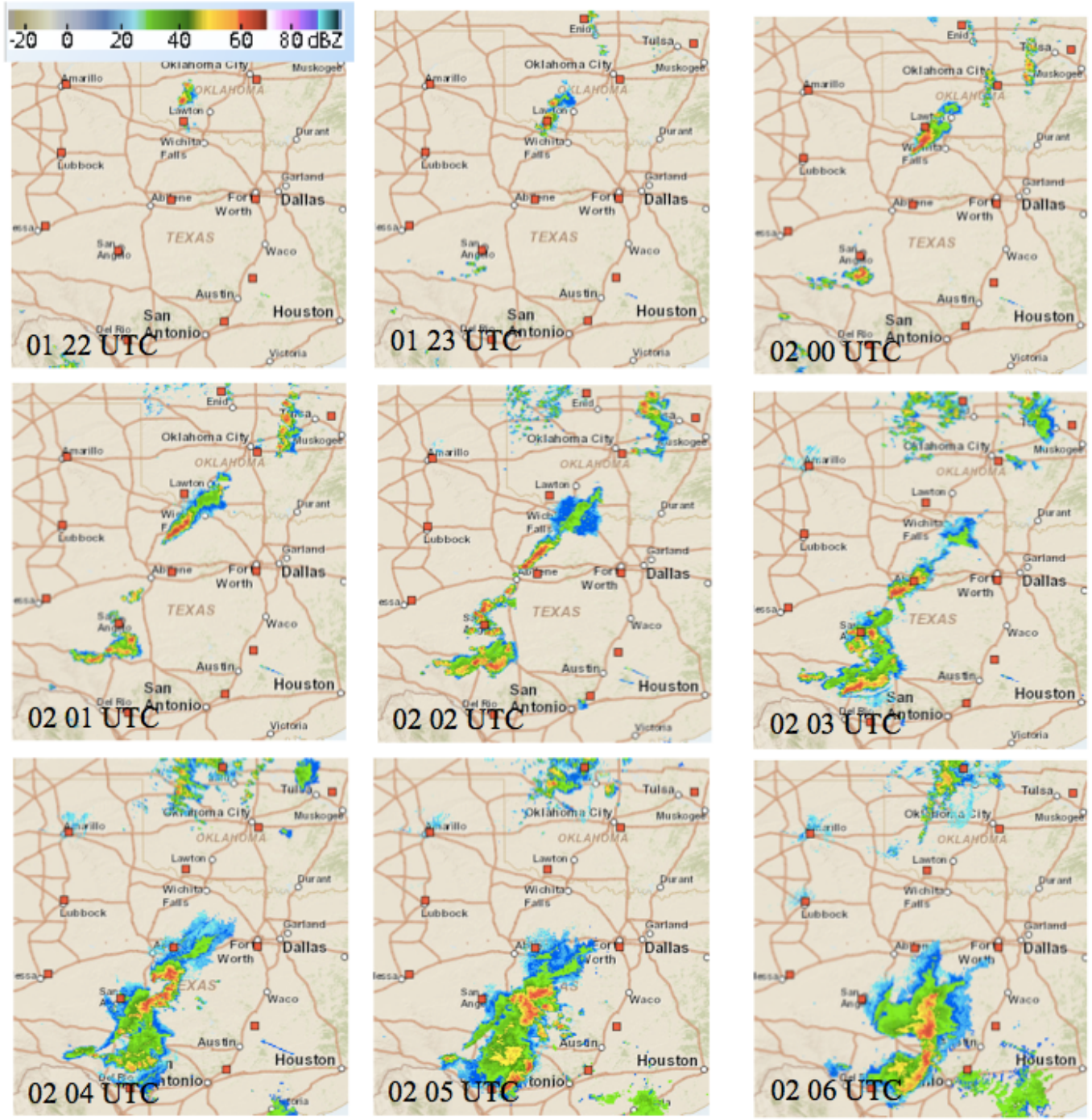
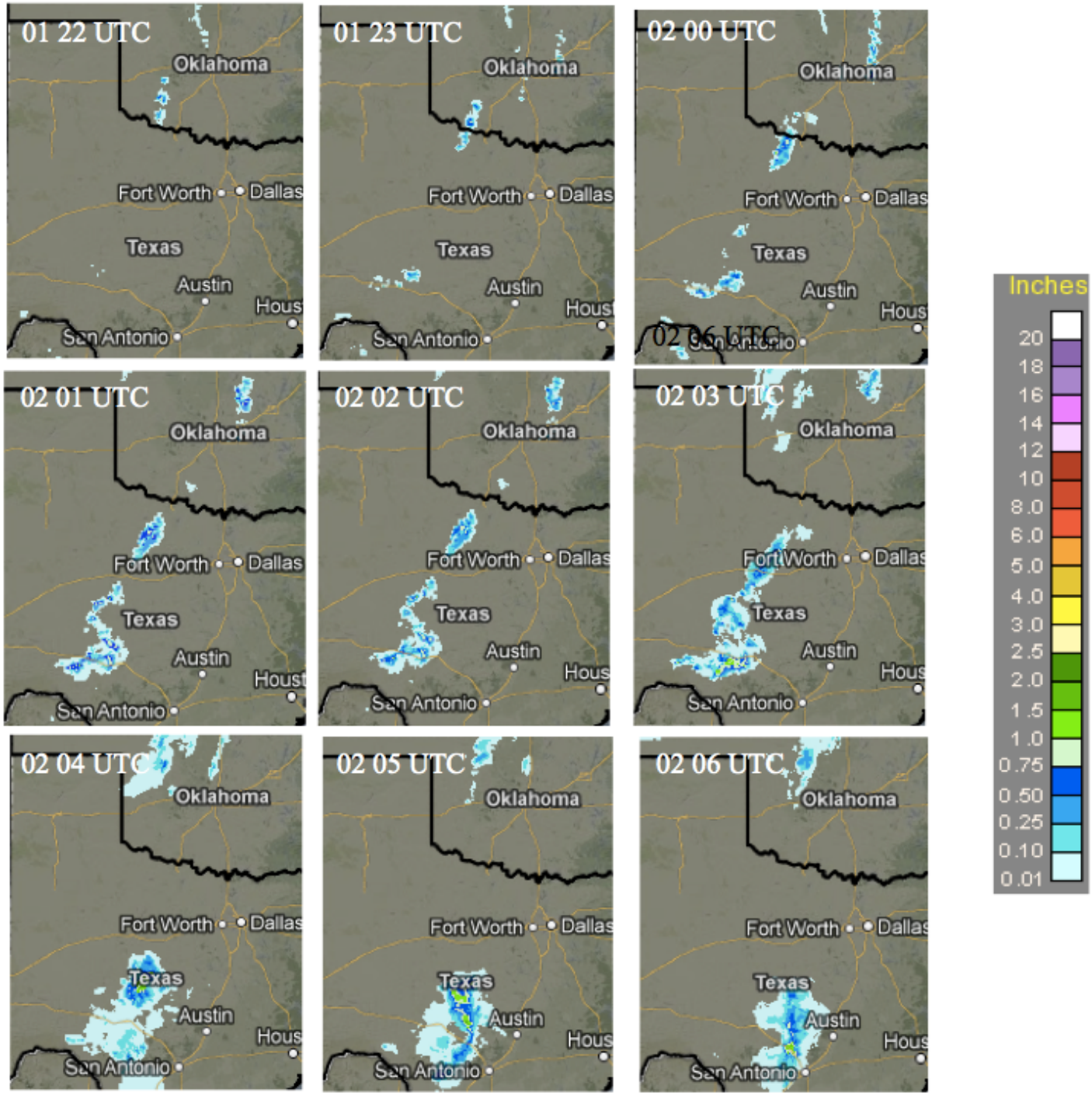

-20 0 20 40 60 80 dBZ
01 22 UTC
01 23 UTC
02 00 UTC
02 01 UTC
02 02 UTC
02 03 UTC
02 04 UTC
02 05 UTC
02 06 UTC
Oklahoma City
Tulsa
Amarillo
Lubbock
Wichita Falls
Lawton
Durant
Abilene
Fort Worth
Dallas
Garland
San Angelo
Waco
Austin
San Antonio
Houston
Del Rio
Victoria
TEXAS
OKLAHOMA

Figure 3: Hourly observed precipitation measured over Texas from 21 UTC 01 May 2013 until 06 UTC 02 May 2013. The hour on each map show the precipitation amounts observed from the previous hour until the hour shown. The data plotted on these maps is from the NWS River Forecast Centers, and is displayed as a gridded field with a spatial resolution of 4x4 km. The data is obtained from a multisensor approach consisting of rain gauge, WSR-88D NEXRAD radar, and satellite measurements. The url for these maps can be found at: http://www.srh.noaa.gov/ridge2/RFC_Precip/


01 22 UTC
01 23 UTC
02 00 UTC
02 01 UTC
02 02 UTC
02 03 UTC
02 04 UTC
02 05 UTC
02 06 UTC
Oklahoma
Fort Worth
Dallas
Texas
Austin
San Antonio
Inches
20
18
16
14
12
10
8.0
6.0
5.0
4.0
3.0
2.5
2.0
1.5
1.0
0.75
0.50
0.25
0.10
0.01

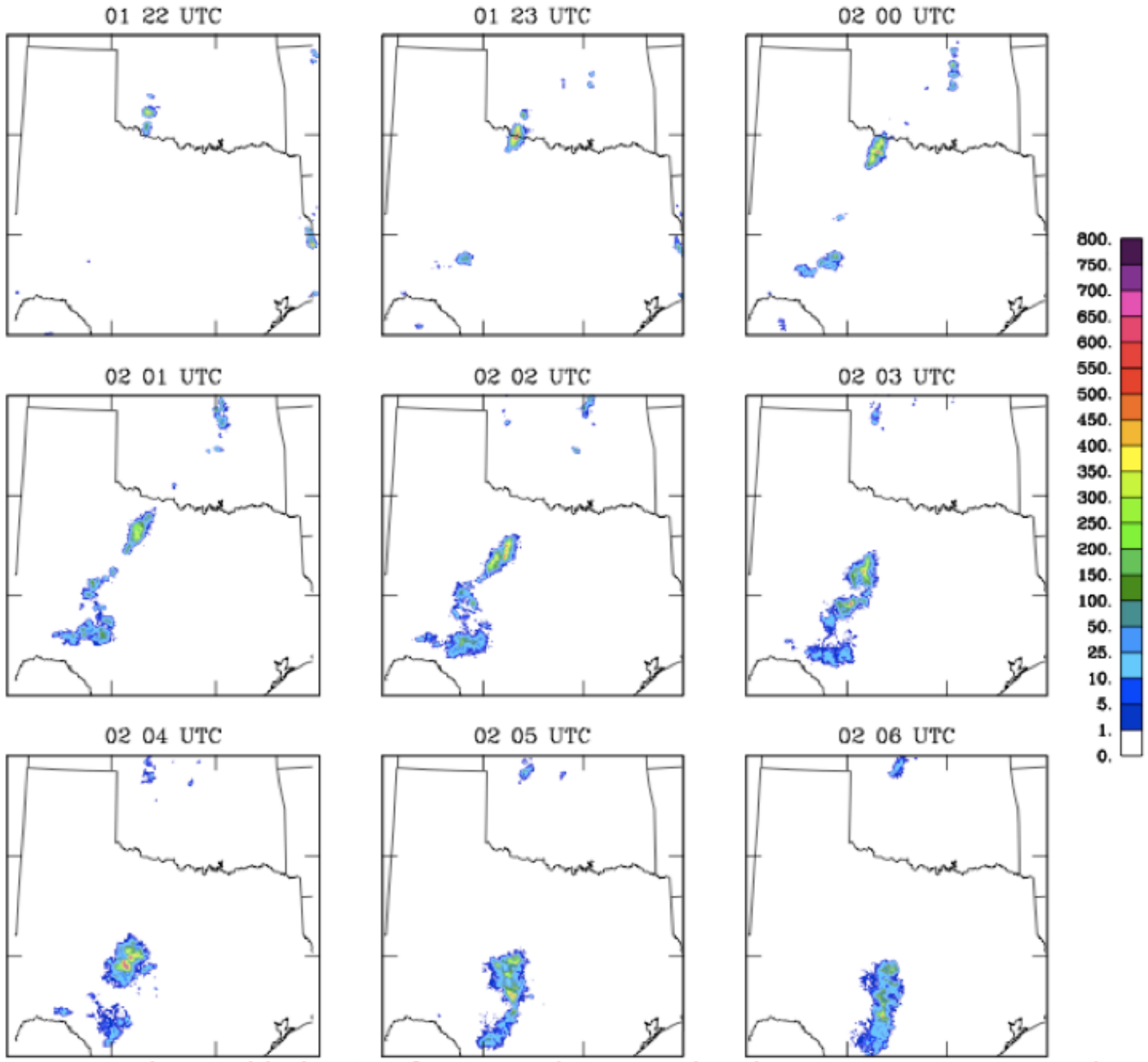


Figure 4: Hourly total lightning from EarthNetworks observations integrated to the 4 X 4 km grid elements within the forecast domain.

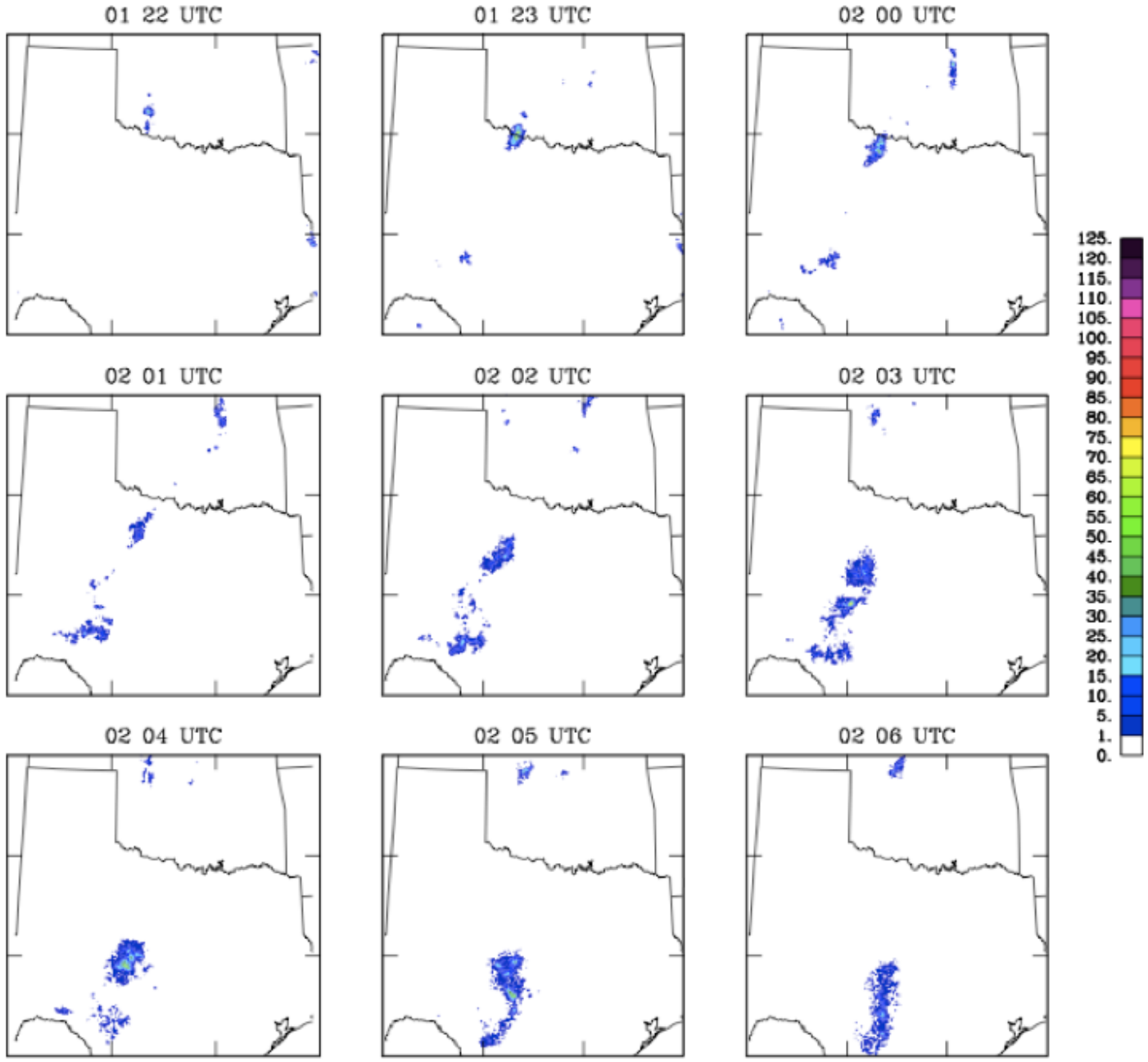


Figure 5: Hourly USPLNL cloud-to-ground lightning observations integrated to the 4 X 4 km grid elements within the forecast domain.

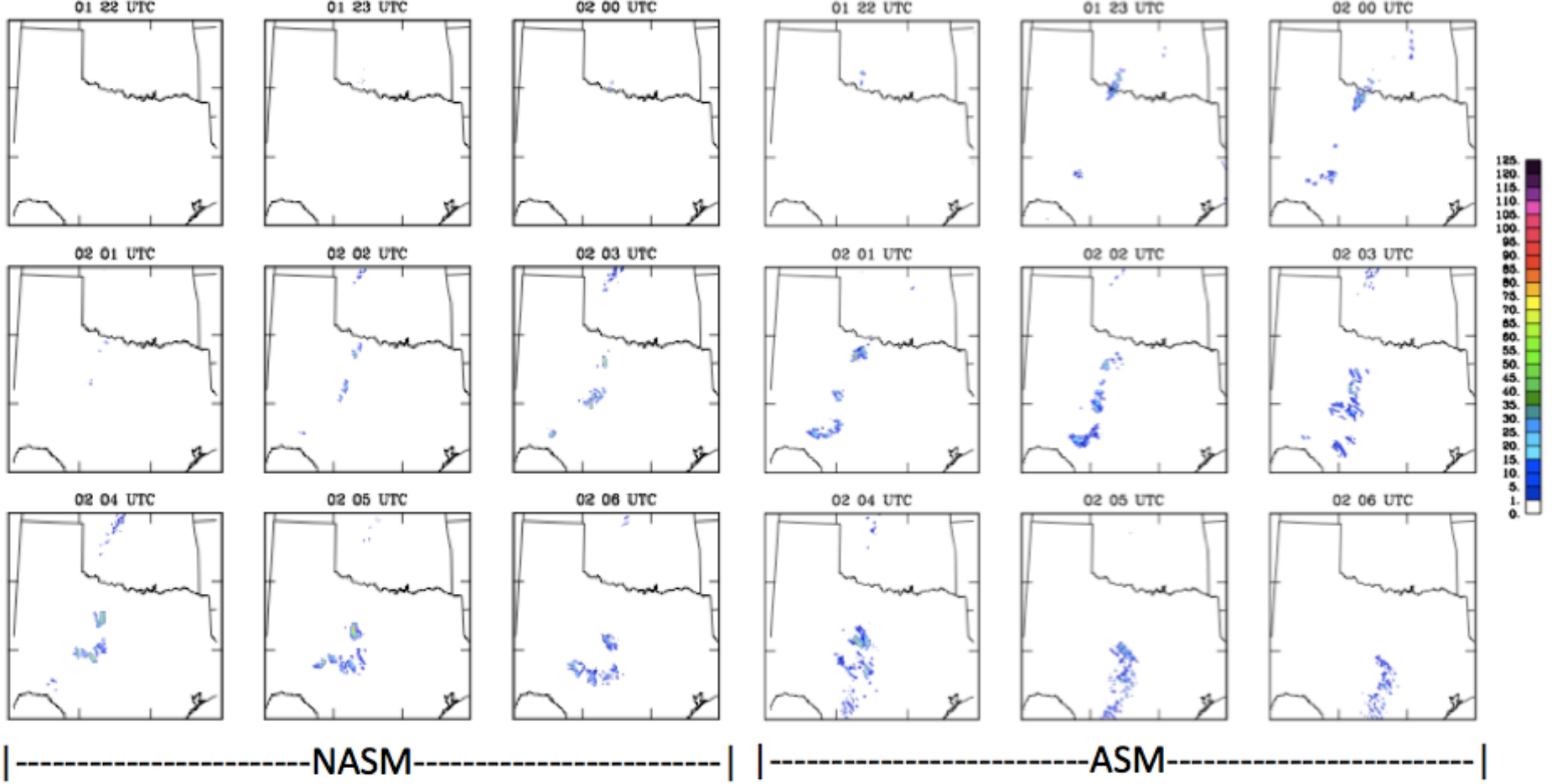


Figure6: Forecast cloud-to-ground lightning from forecasts NASM and ASM from 22 UTC until 01 May until 06 UTC 02 May 2013. The first three hours (22, 23, and 00) are during the RAP nudging period. In NASM, there is no lightning assimilation. In ASM, 10 minute lightning is assimilated into the model forecast. The actual forecast began 00 UTC 02 May.

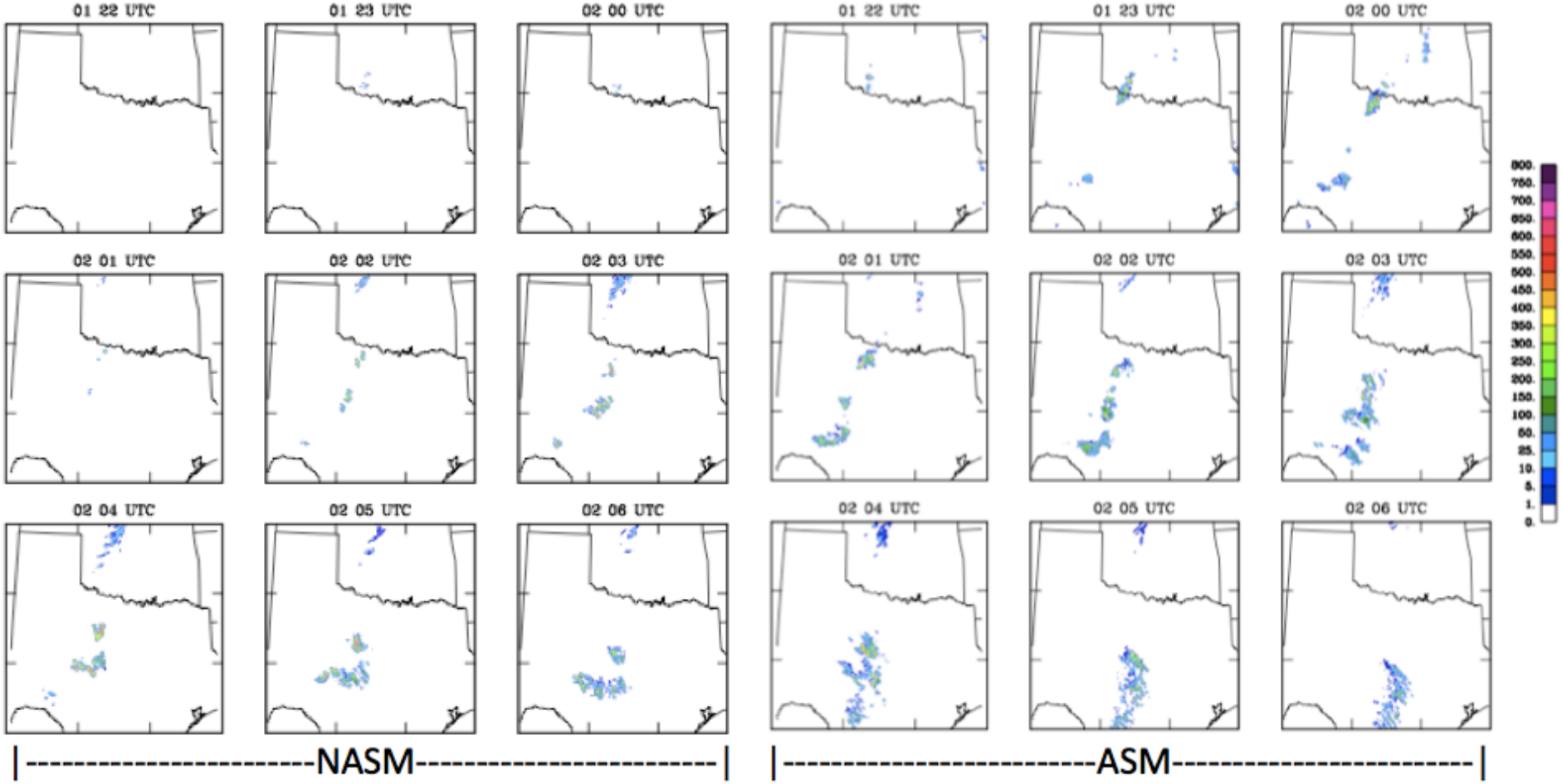


Figure 7: Same as Fig. 6, but for forecast hourly total lightning values.

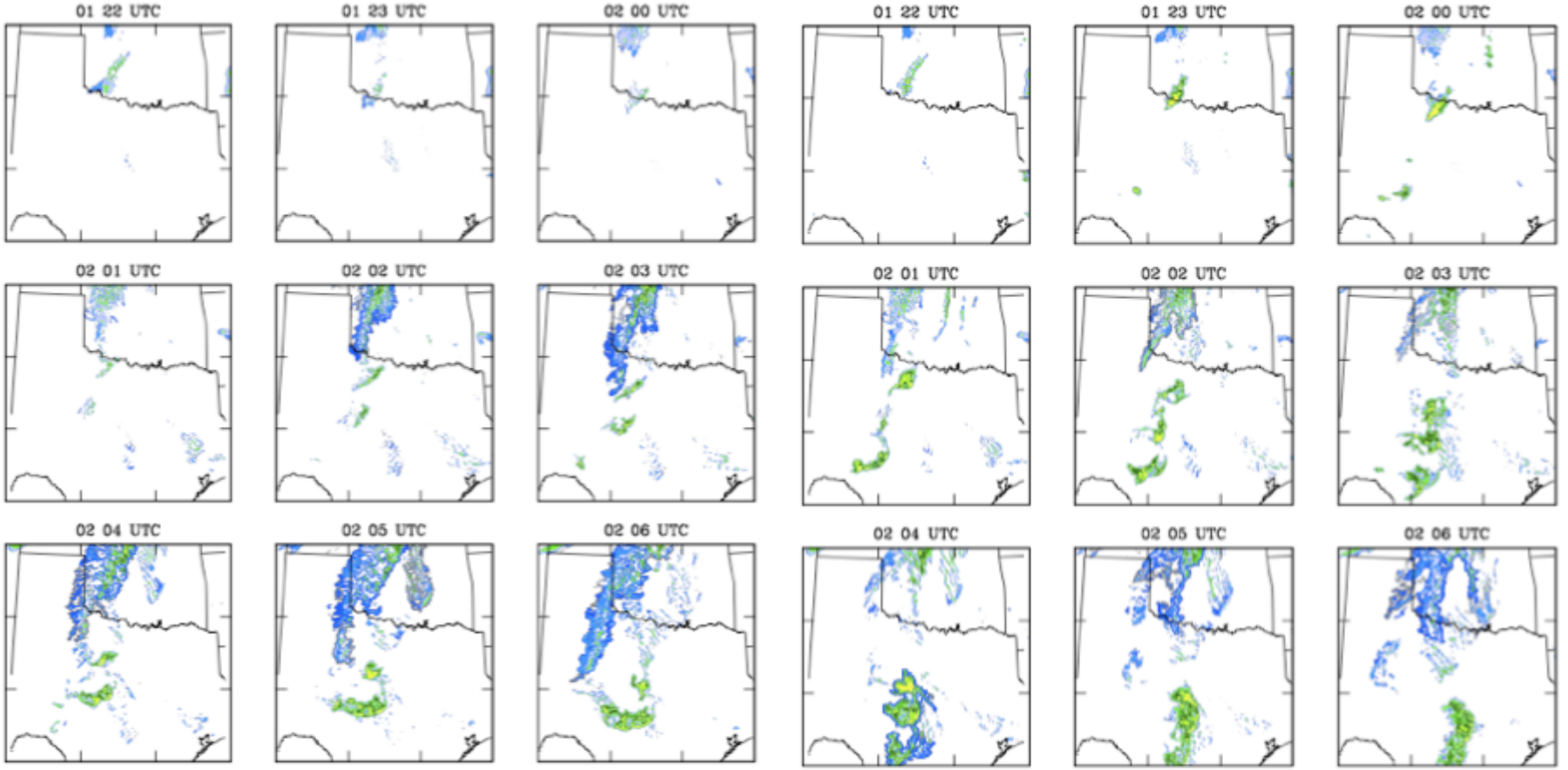


Figure 8: Calculated Radar from forecasts beginning 21 UTC 01 May 2013. Both forecasts are nudged by reanalysis data from the RAP from 21 UTC until 00 UTC 02 May. The forecast on the left ("NASM") does not have any lightning simulation during this three hour period. The forecast on the right uses lightning assimilation ("ASM) to force moist convection in the observed location. The grid spacing size is 4 X 4 km.

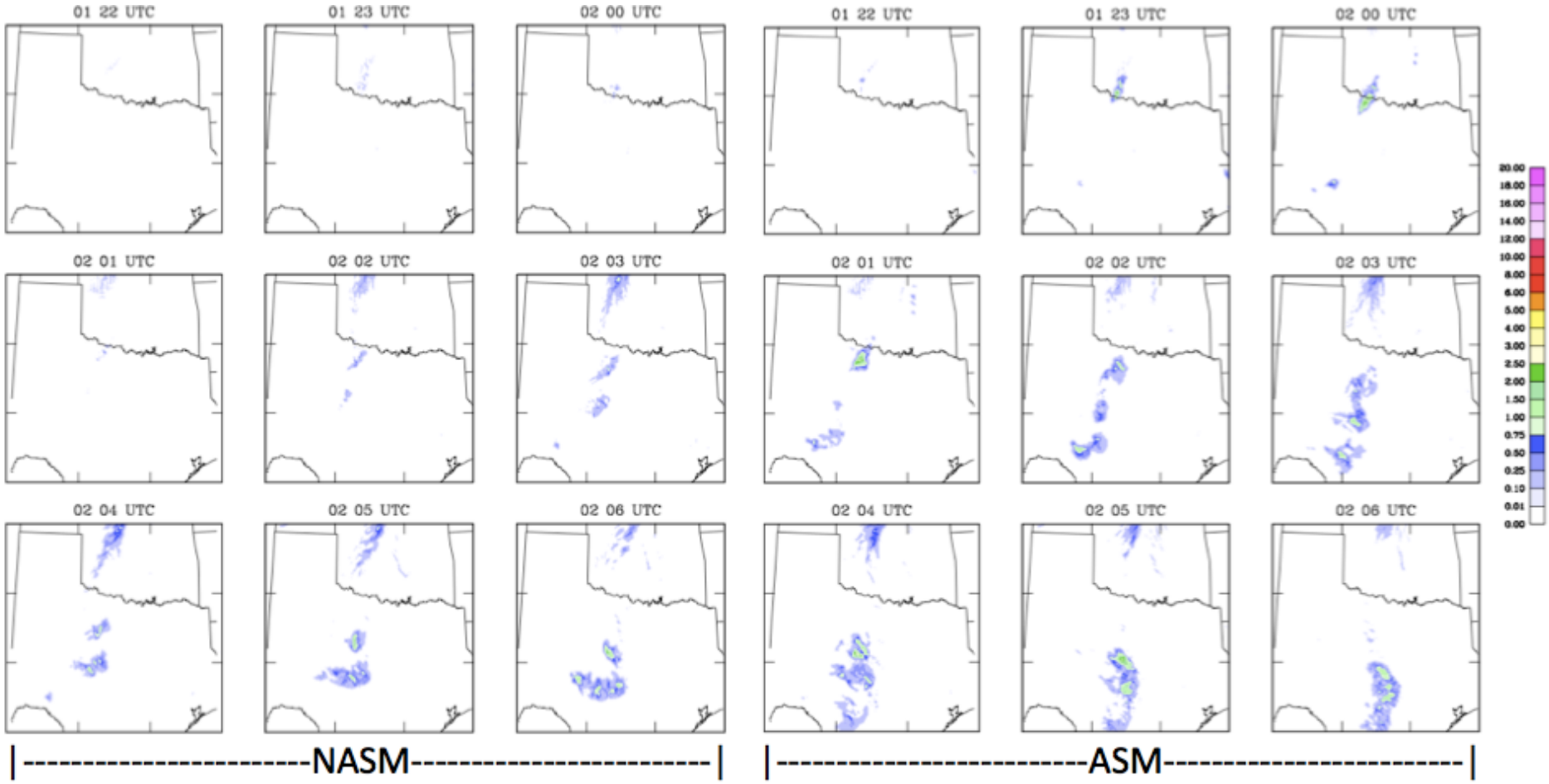


Figure 9: Same as Fig. 6 but for forecast hourly precipitation amounts.

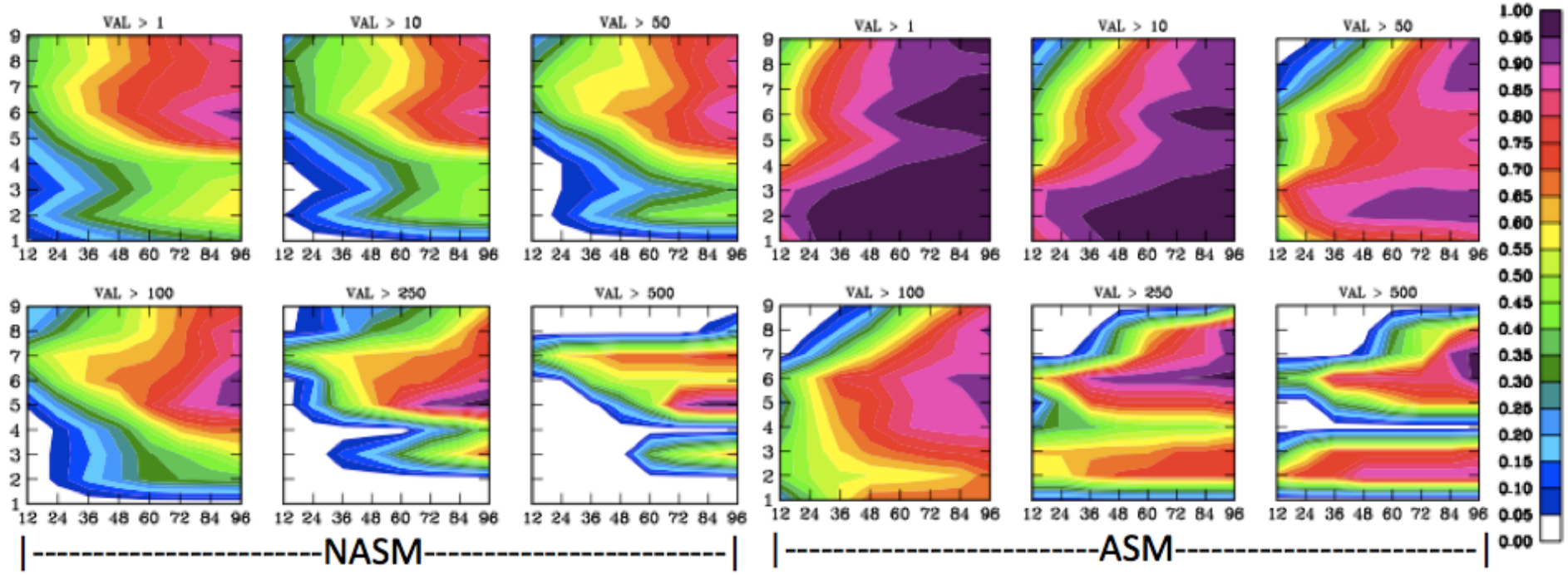
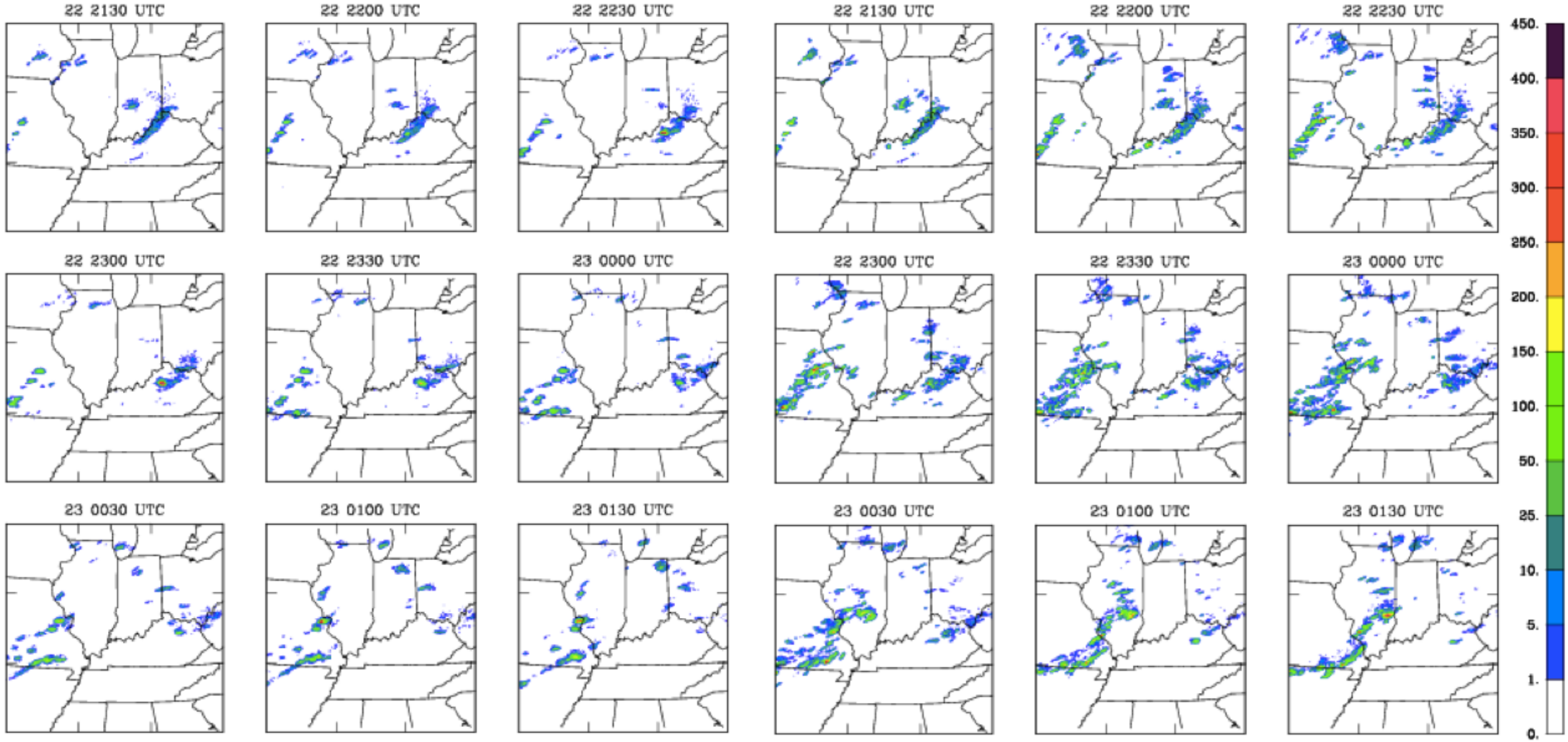


Figure 10: ETS values mapped from 21 UTC 01 May 2013 to 06 UTC 02 May 2013 for forecasts without (left) and with (right) lightning assimilation. The x-axis is neighborhood radius length (km) and y-axis is time (hr). The first three hours were when lightning assimilation was used (right).

Observations

With Assimilation

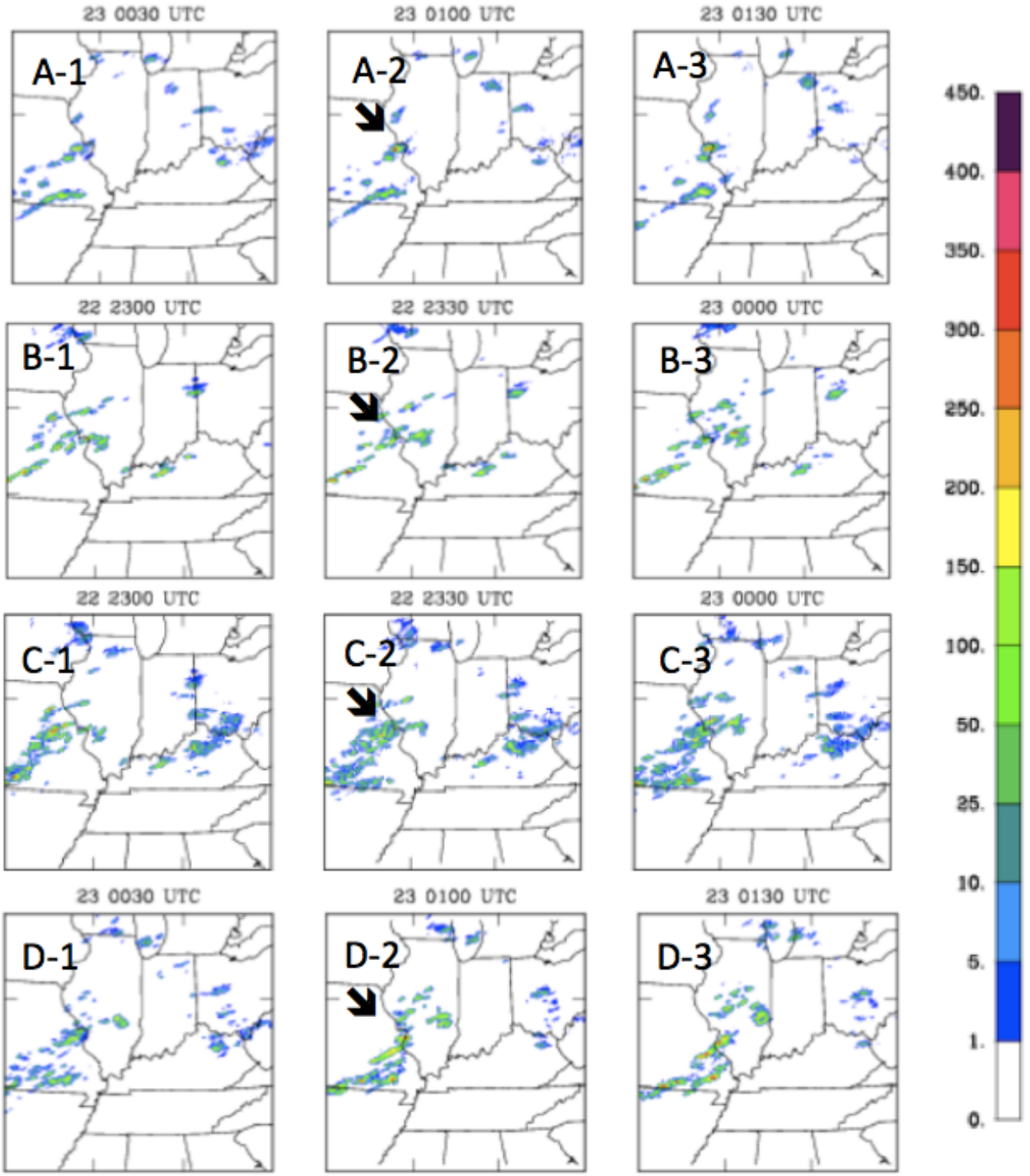


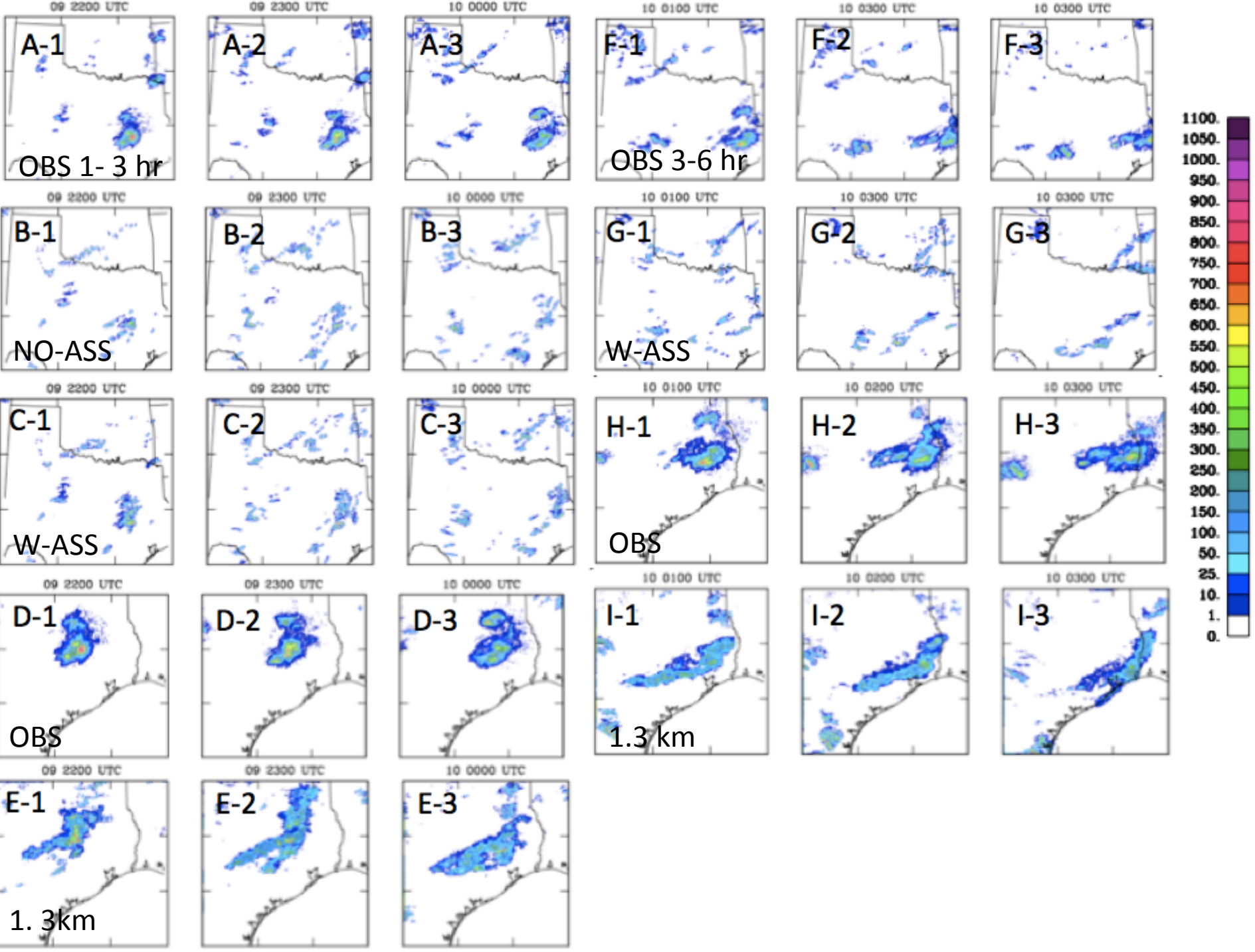
Observations

No Assimilation

Assimilation

Assimilation with Filtering




09 2200 UTC
A-1
OBS 1- 3 hr
09 2300 UTC
A-2
10 0000 UTC
A-3
10 0100 UTC
F-1
OBS 3-6 hr
10 0300 UTC
F-2
10 0300 UTC
F-3
09 2200 UTC
B-1
NO-ASS
09 2300 UTC
B-2
10 0000 UTC
B-3
10 0100 UTC
G-1
W-ASS
10 0300 UTC
G-2
10 0300 UTC
G-3
09 2200 UTC
C-1
W-ASS
09 2300 UTC
C-2
10 0000 UTC
C-3
10 0100 UTC
H-1
OBS
10 0200 UTC
H-2
10 0300 UTC
H-3
09 2200 UTC
D-1
OBS
09 2300 UTC
D-2
10 0000 UTC
D-3
10 0100 UTC
I-1
1.3 km
10 0200 UTC
I-2
10 0300 UTC
I-3
09 2200 UTC
E-1
1. 3km
09 2300 UTC
E-2
10 0000 UTC
E-3
1100.
1050.
1000.
950.
900.
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750.
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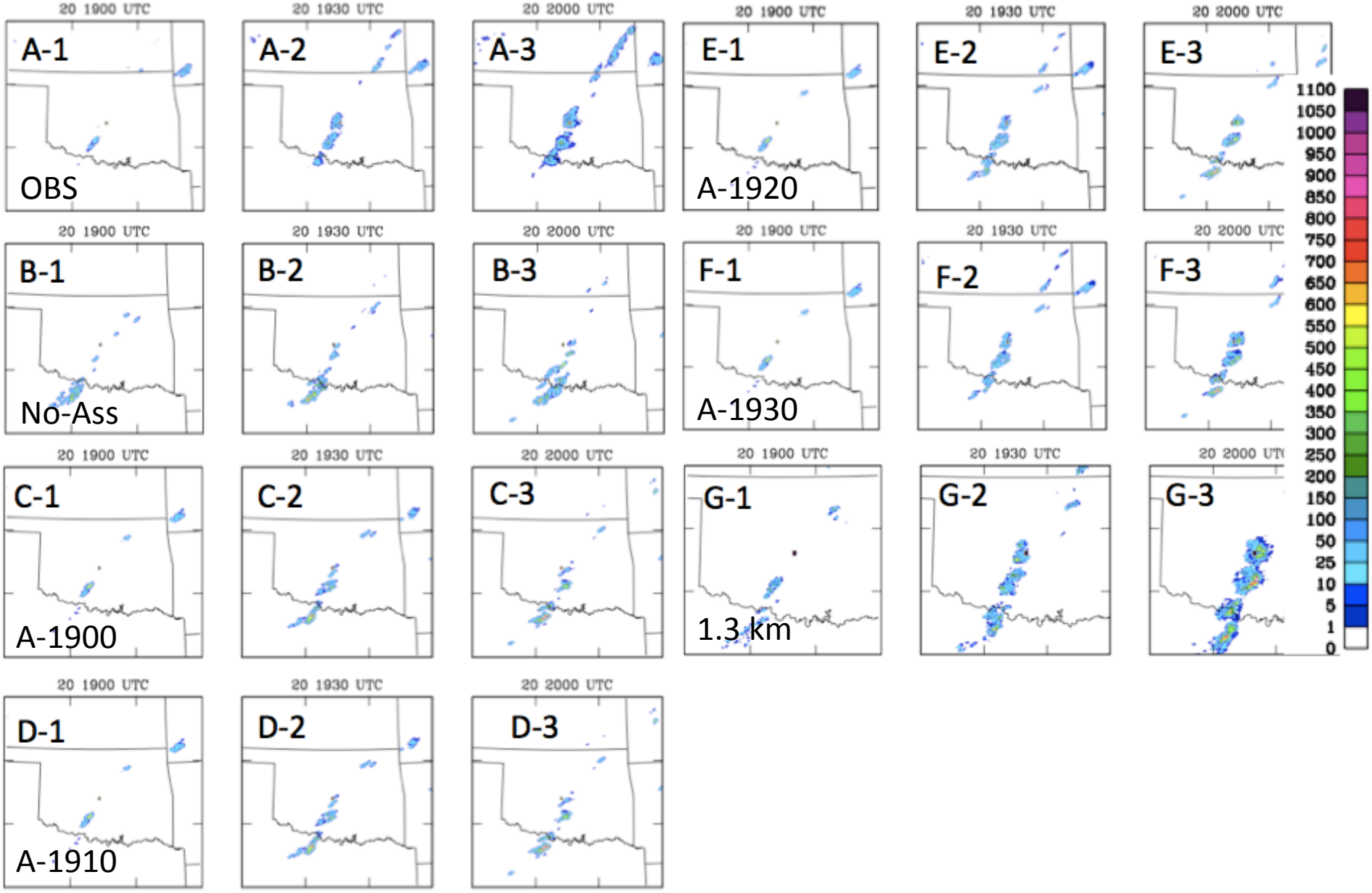
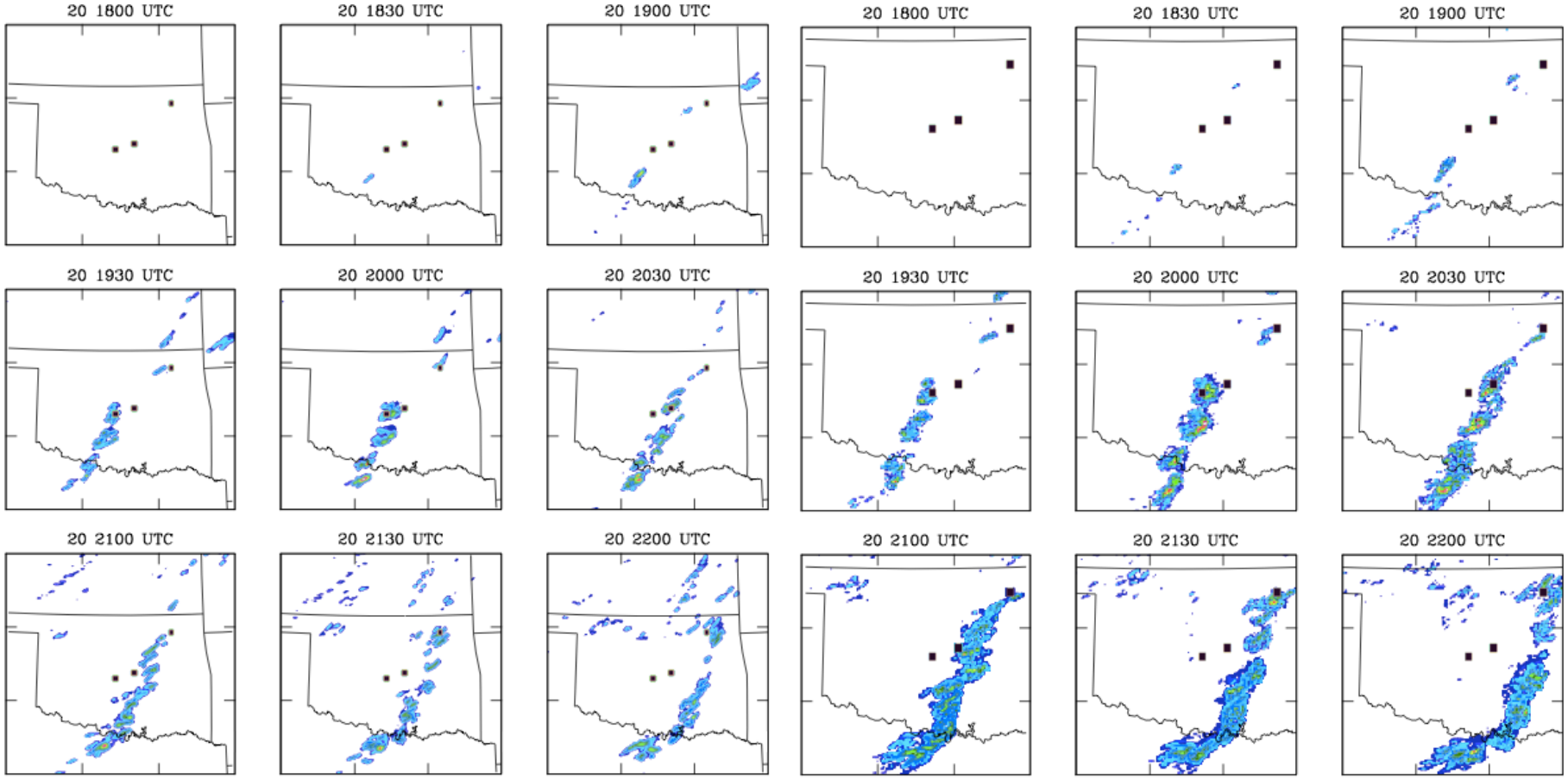
500.
450.
400.
350.
300.
250.
200.
150.
100.
50.
25.
10.
1.
0.

Moore Tornado Event (20 April 2013)



With Ass 4.0 km

With Ass 1.3 km



Conclusions

1) Assimilating lightning can improve forecasts at least up to six hours.
2) Lightning assimilation can make the difference between predicting any storm (and its mode) and no storm at all (or the wrong mode).
3) Using Predicted vs Observed Lightning to filter spurious convection can greatly improve the forecast.
4) Sometimes assimilation of lightning works better when the grid spacing 1.3 km, instead of 4.0 km.
5) To fully realize the value of assimilation, forecasts should be made at 10 minute intervals (or at least more than at greater frequency than hourly).