(original goal:)
Impacts of grid spacing and physical parameterizations on WRF simulations of convective system rainfall and morphology

WRF-DTC visit 2005

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Iowa State University

Change in project plans was made to emphasize WRF-RR and address NOAA-GSD needs

- Large domain (452 x 338 points on 13 km grid – CONUS and then some…)
- 35 vertical levels
- WSM-5 class microphysics, Dudhia/RRTM radiation, MYJ PBL, RUC land-surface, Grell-Devenyi (GD) cu scheme

Broad Goals

- Use 13 km WRF-RR configuration (large domain version of model provided by Tanya Smirnova) to best benefit GSD
- Investigate simulations of warm season convective systems (usually in 2005) to:

  --- explore possible improvements in use of Grell-Devenyi scheme

  --- perform controlled test of PBL schemes and possibly make needed modifications in schemes
- Investigate model depictions of mesoscale circulations in 13 km and 4 km runs (2005 and BAMEX cases) and compare with observations

Sensitivity to convective scheme

- 5 cases were simulated using a 12 UTC initialization, and integrated for 24 hours (one of the 5 was integrated for 30 hrs)

Exploration of Grell scheme impacts (sensitivity to convective schemes)

- 5 cases were simulated using a 12 UTC initialization, and integrated for 24 hours (one of the 5 was integrated for 30 hrs)

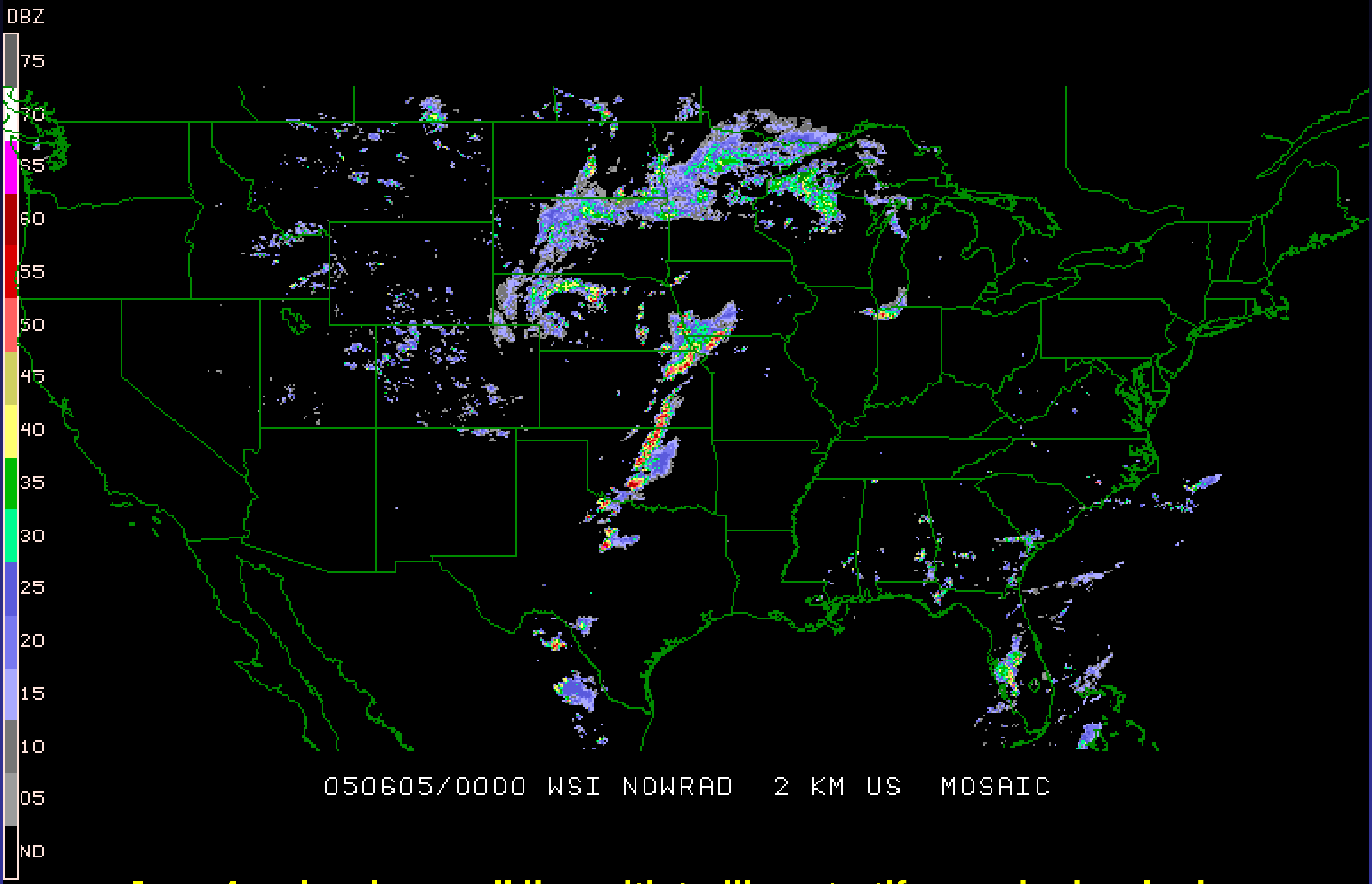
June 4 2005

June 8 2005

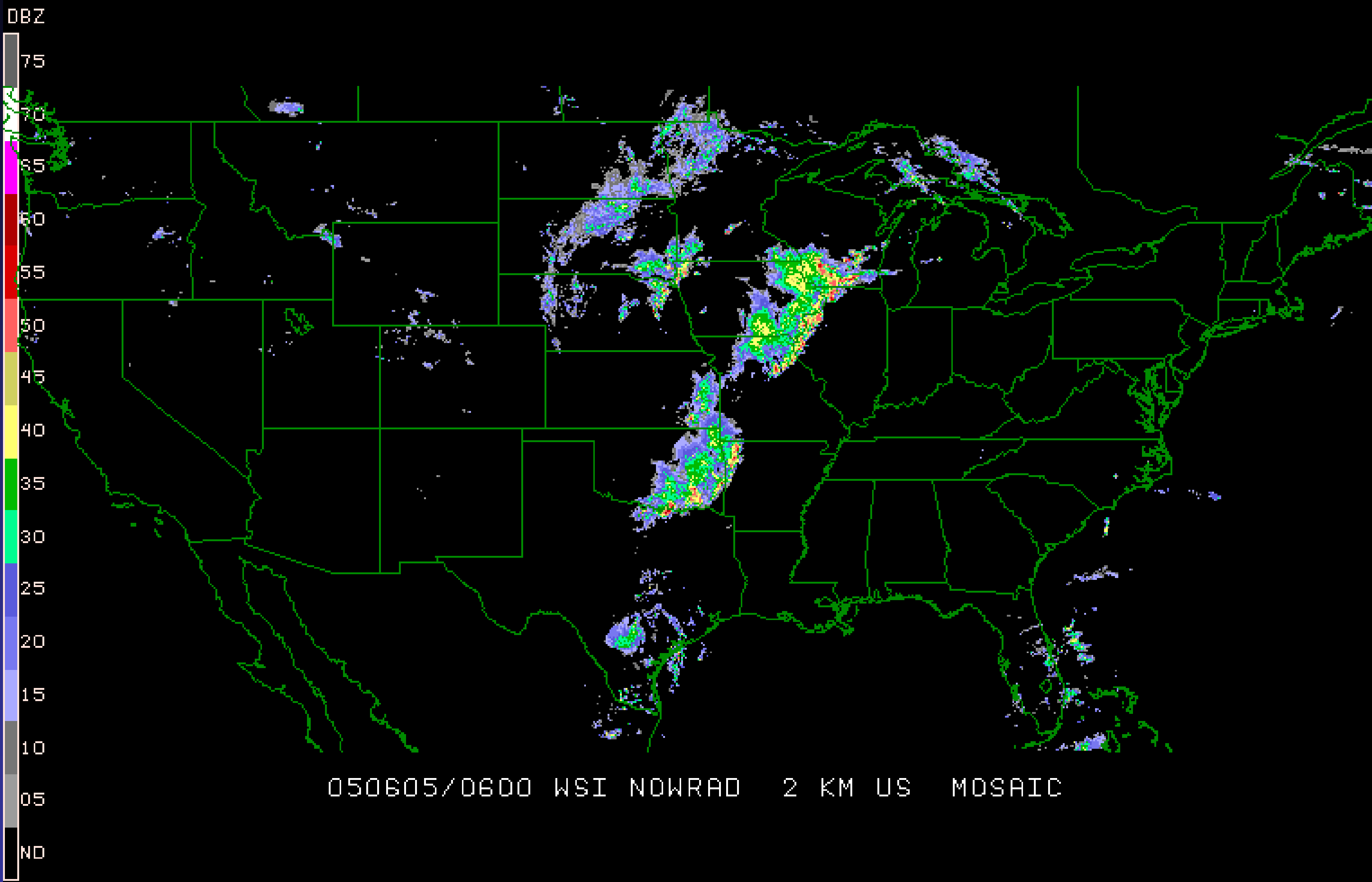
June 9 2005

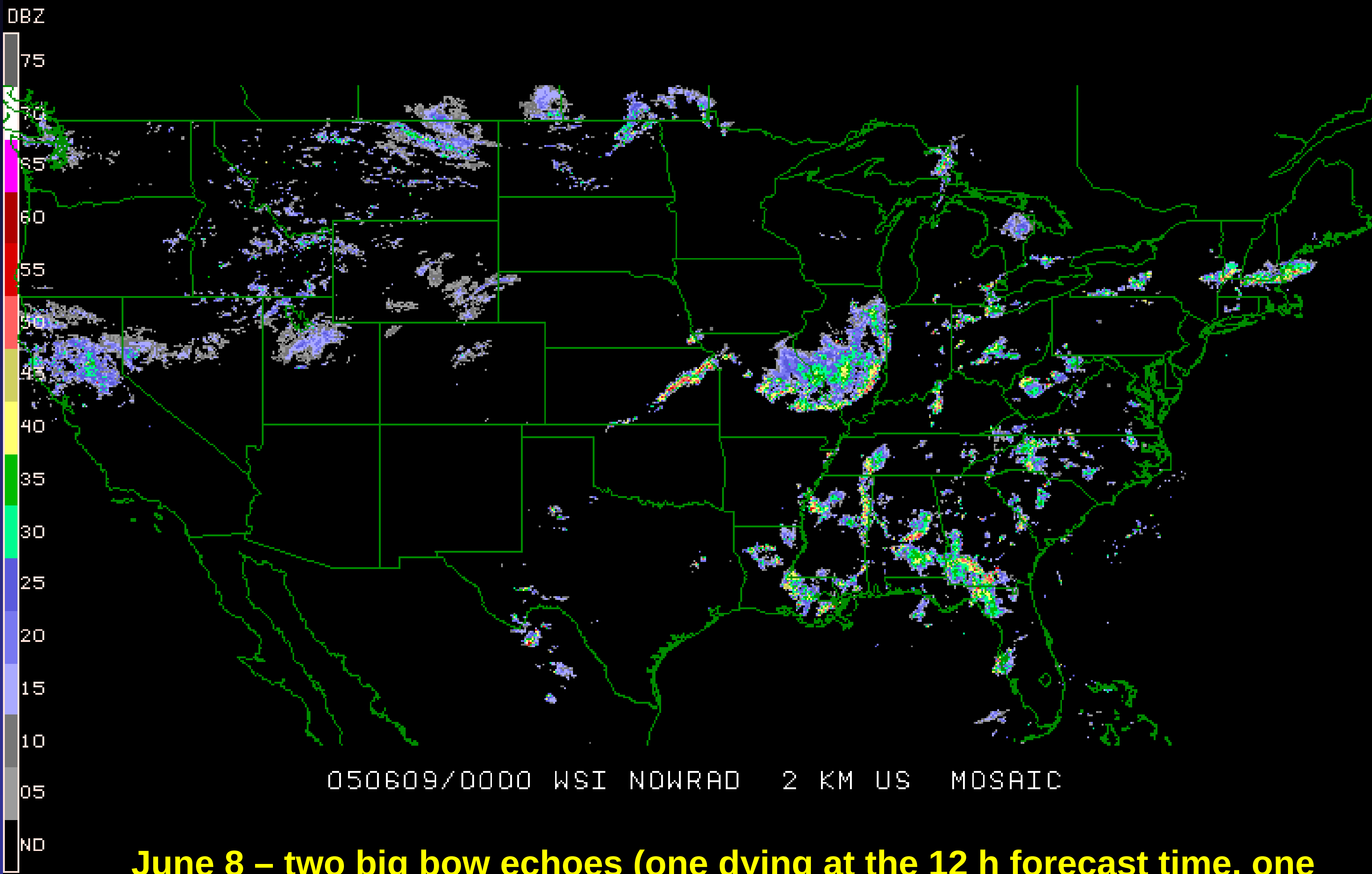
June 10 2005 (30 hr)

June 12 2005

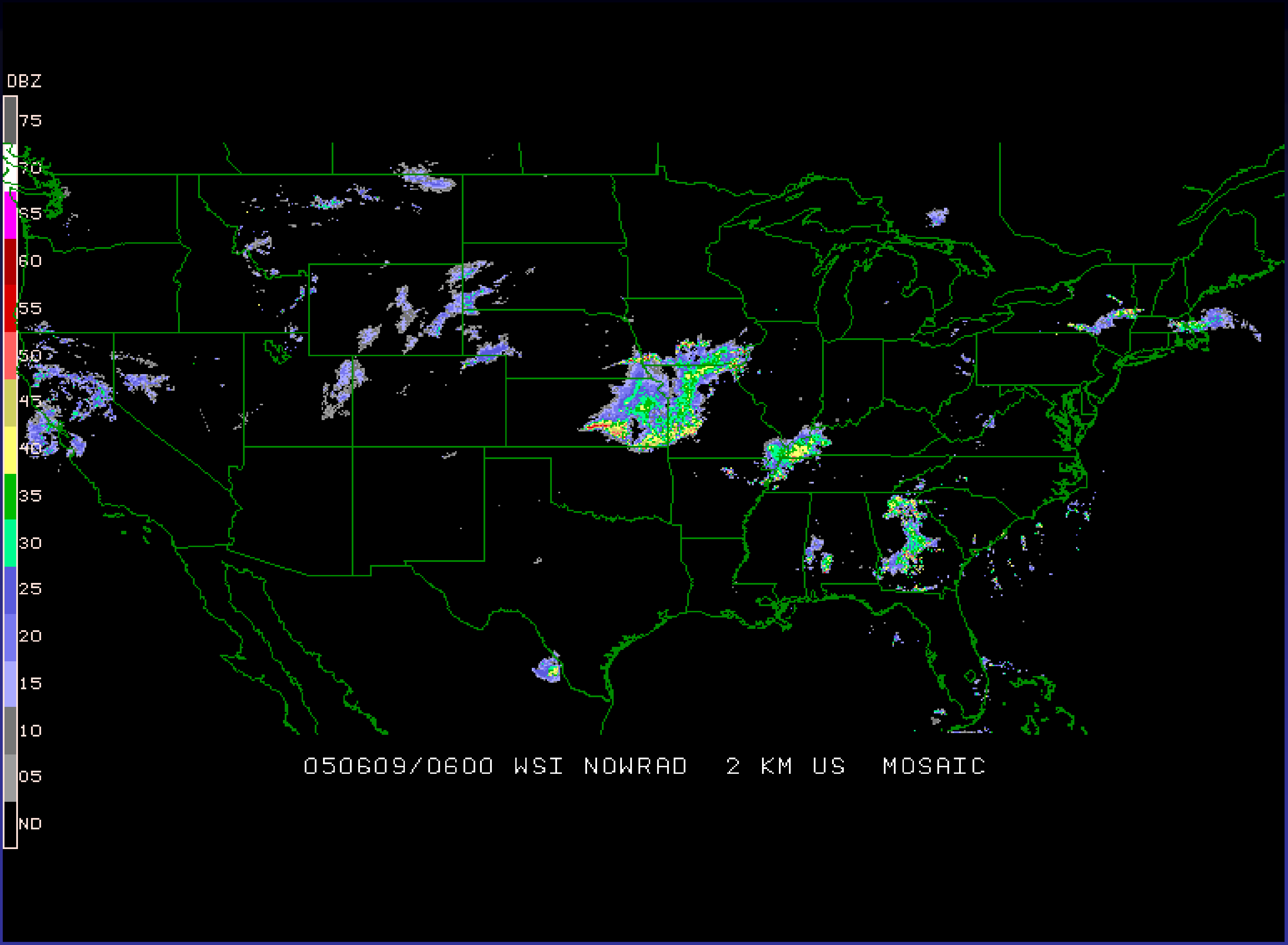


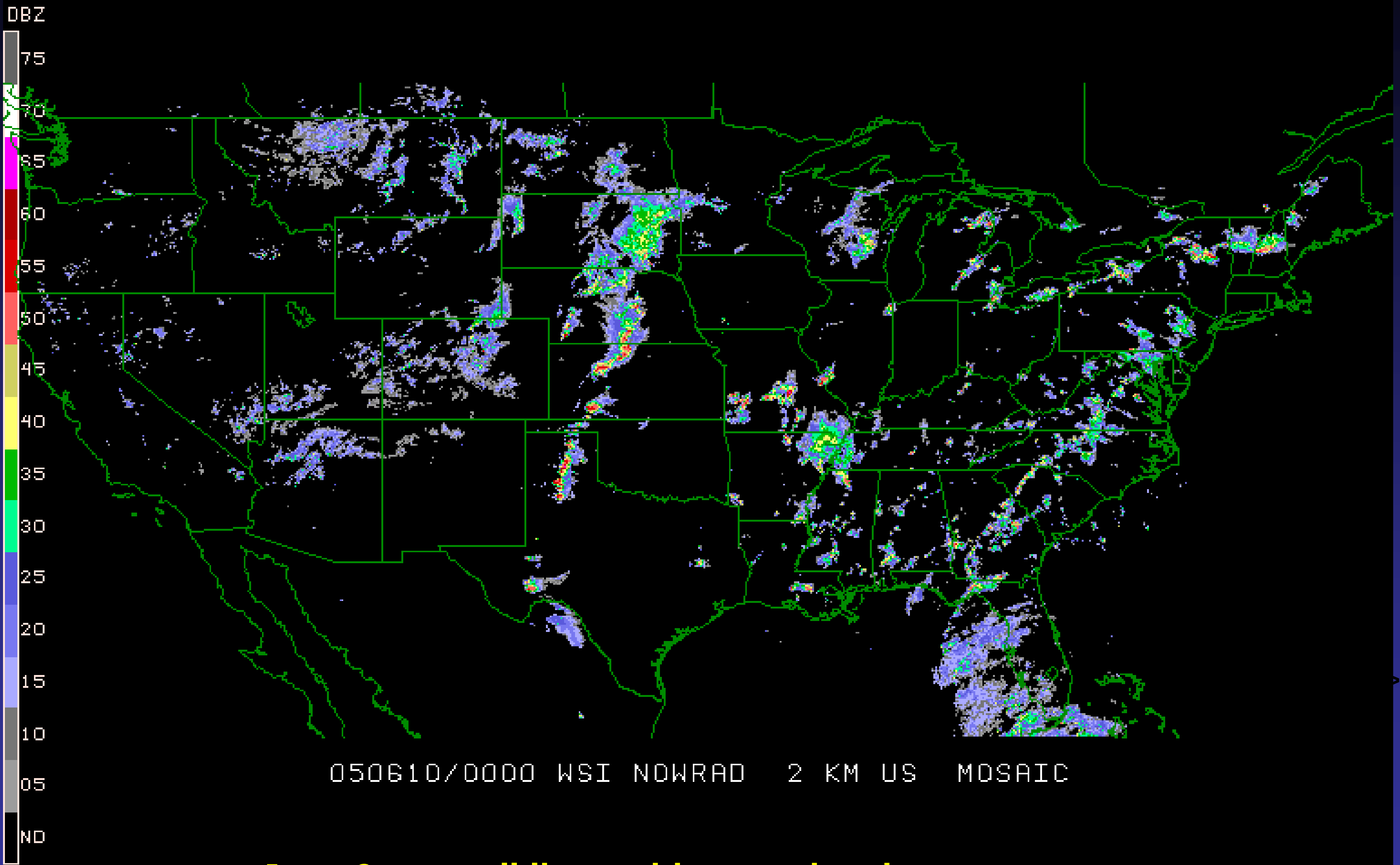
June 4 – classic squall line with trailing stratiform rain developing


DBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
05
ND
050605/0600 WSI NOWRAD 2 KM US MOSAIC

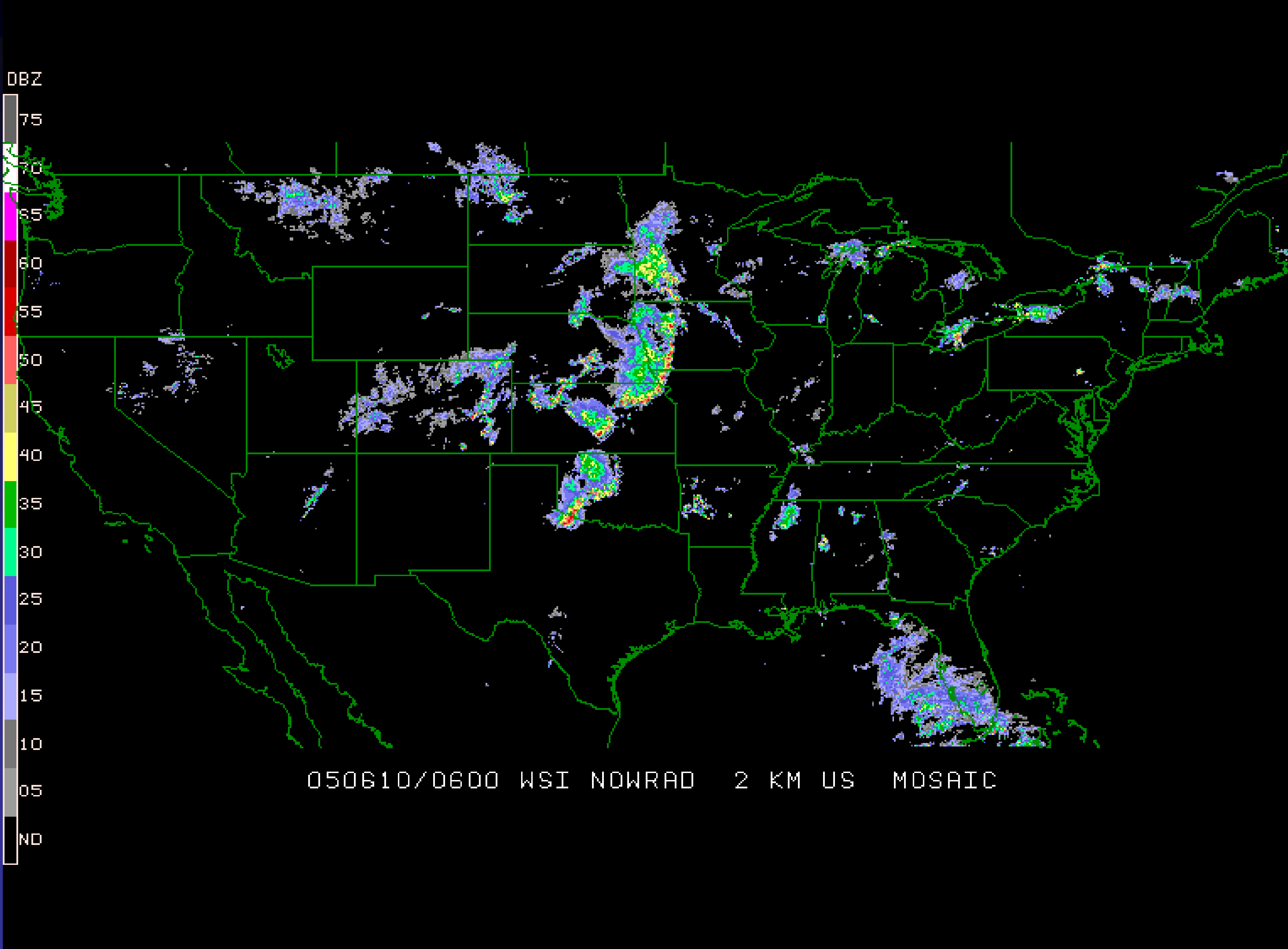


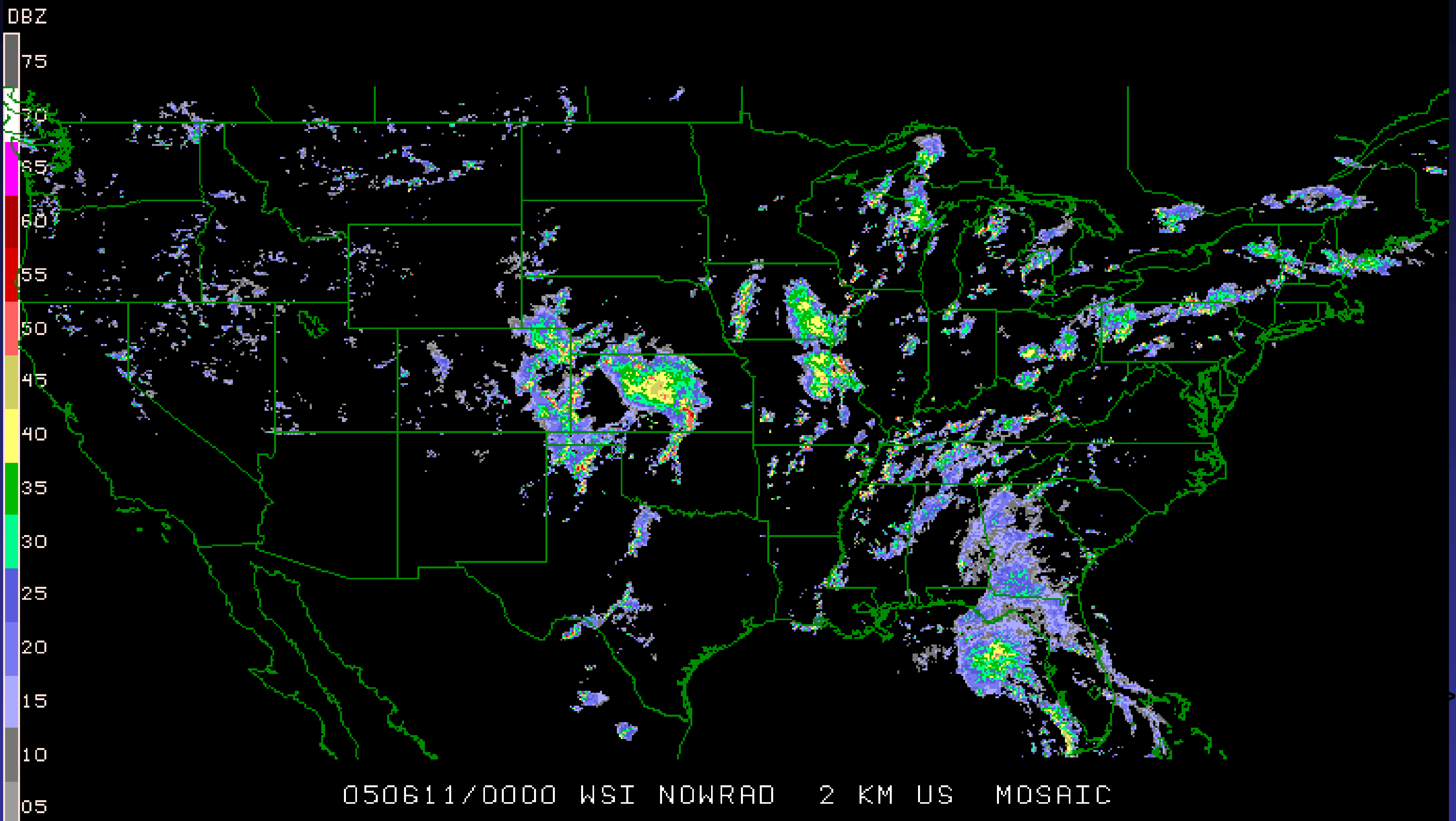
June 8 – two big bow echoes (one dying at the 12 h forecast time, one just developing)


DBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
05
ND
050609/0600 WSI NOWRAD 2 KM US MOSAIC

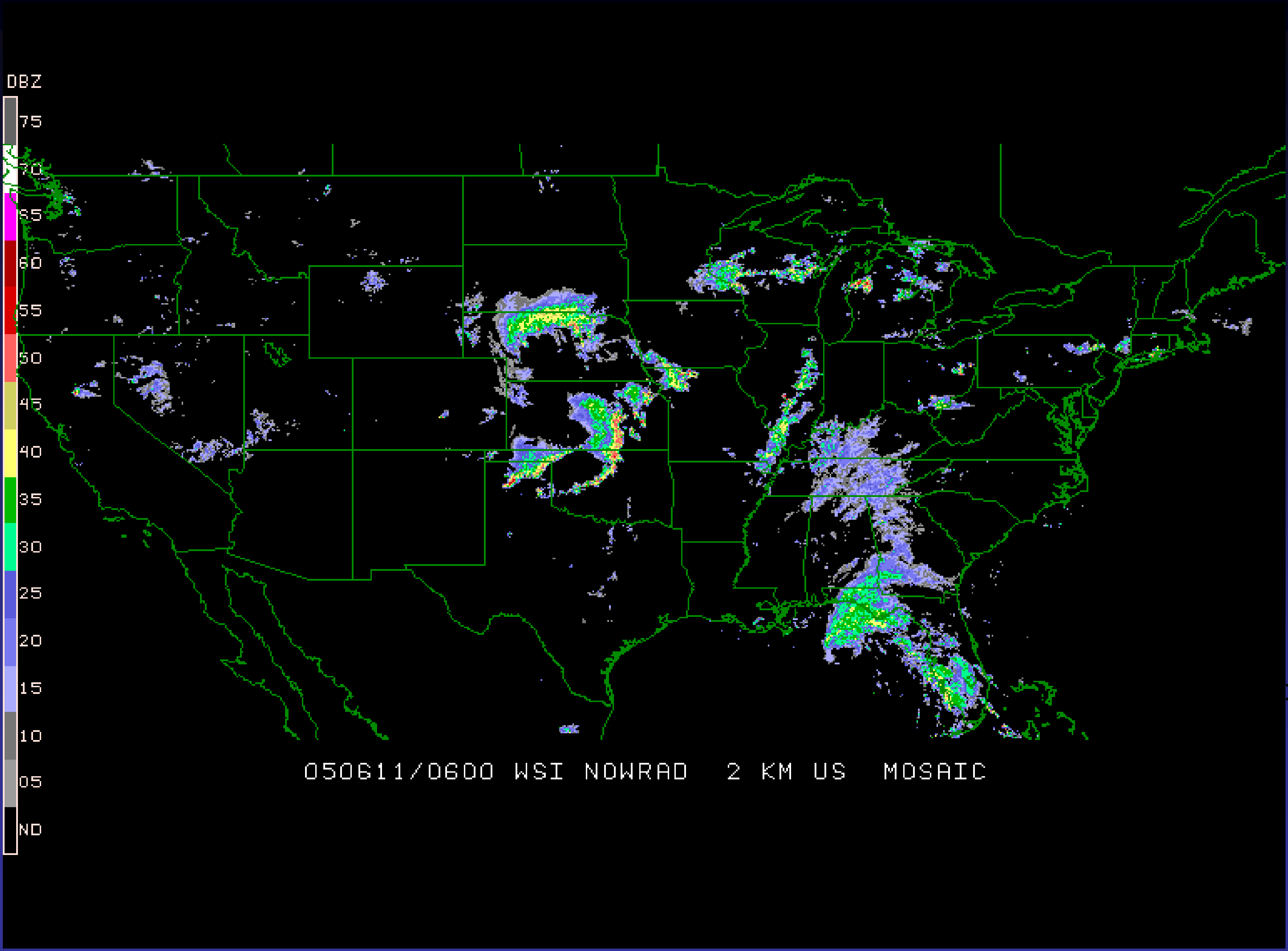


June 9 – squall lines with some bowing segments


DBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
05
ND
050610/0600 WSI NOWRAD 2 KM US MOSAIC



June 10 – convective clusters (some squall lines) – also note tropical system


DBZ
75
70
65
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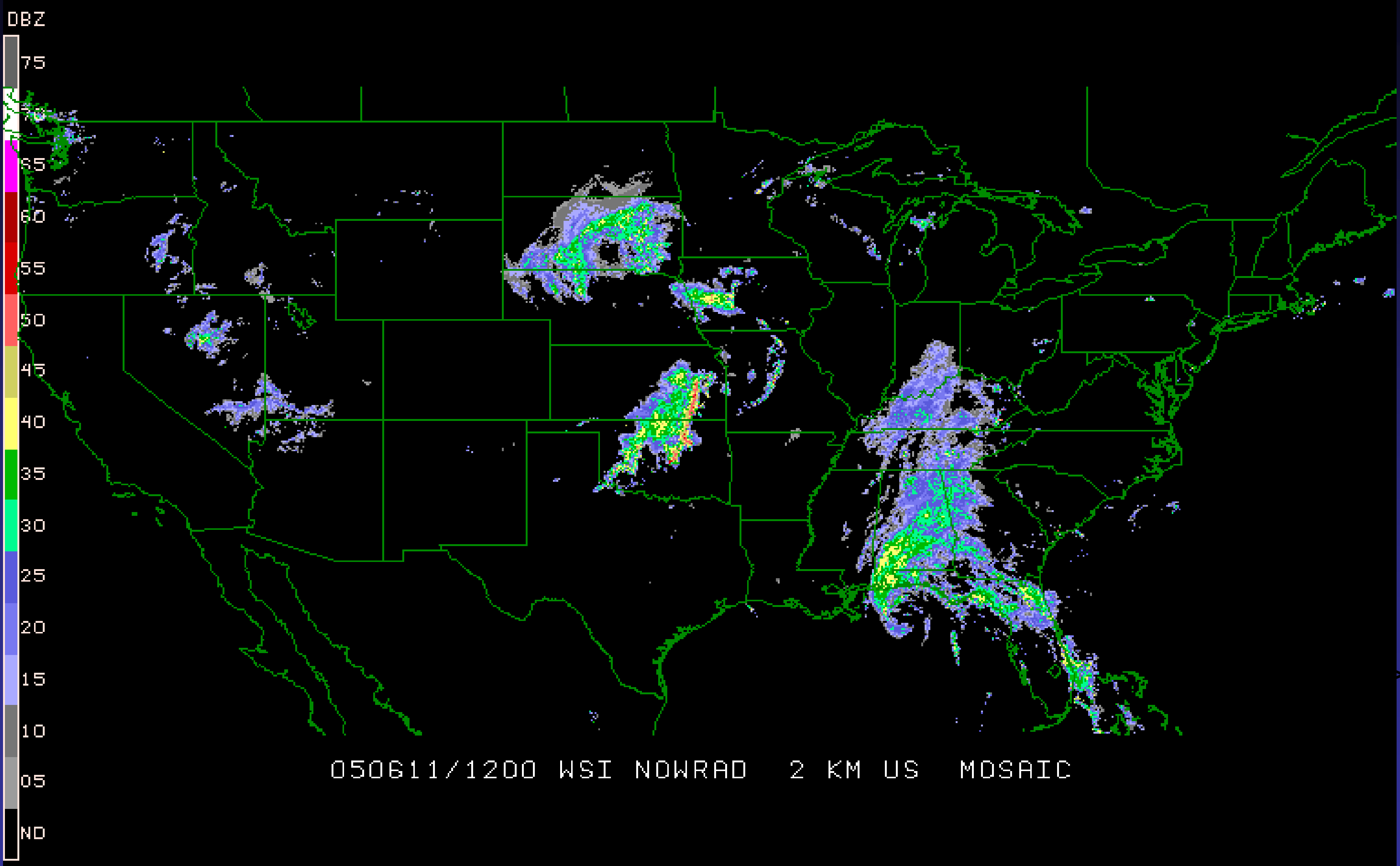
45
40
35
30
25
20
15
10
05
ND
050611/0600 WSI NOWRAD 2 KM US MOSAIC


DBZ
75
70
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60
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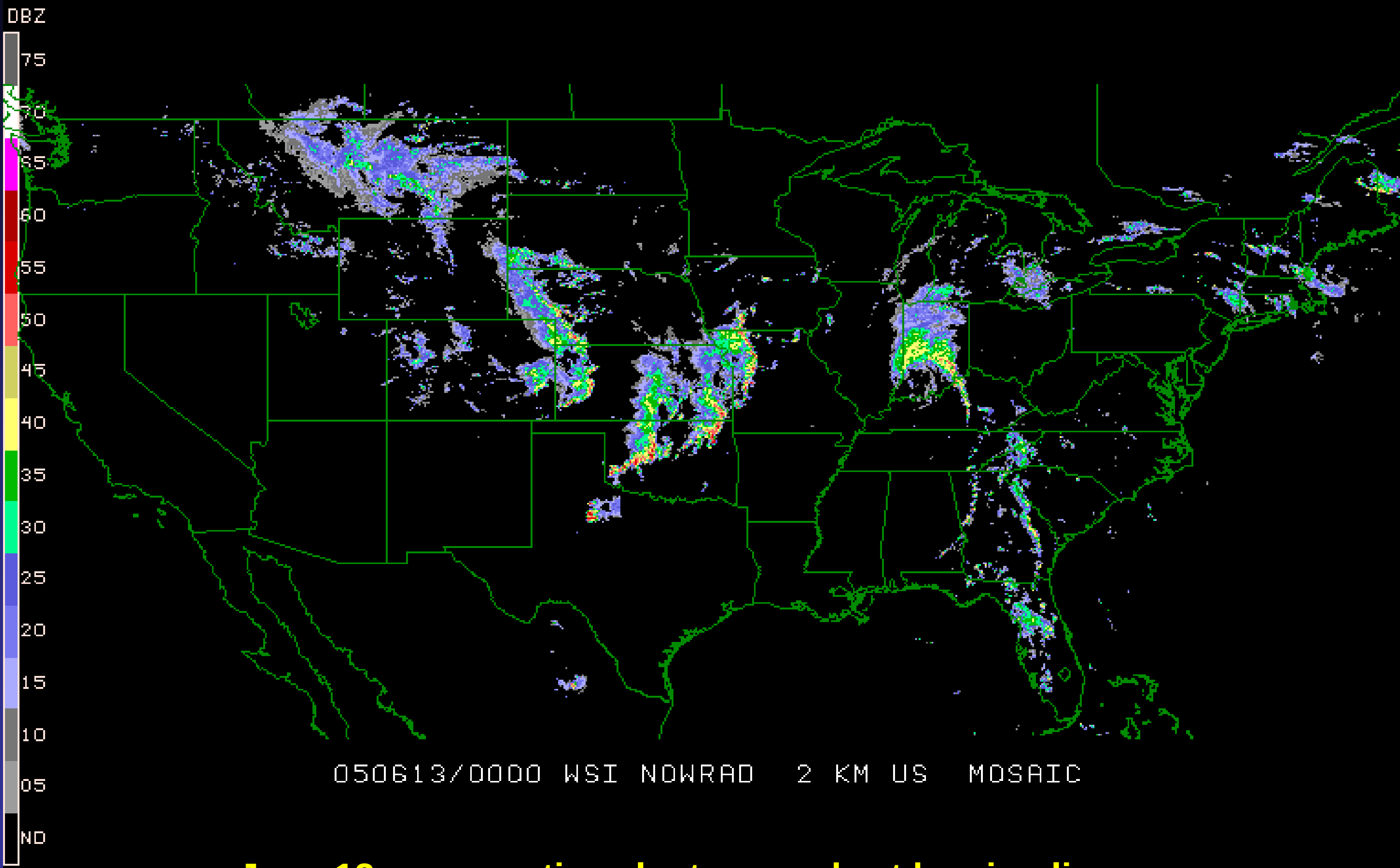
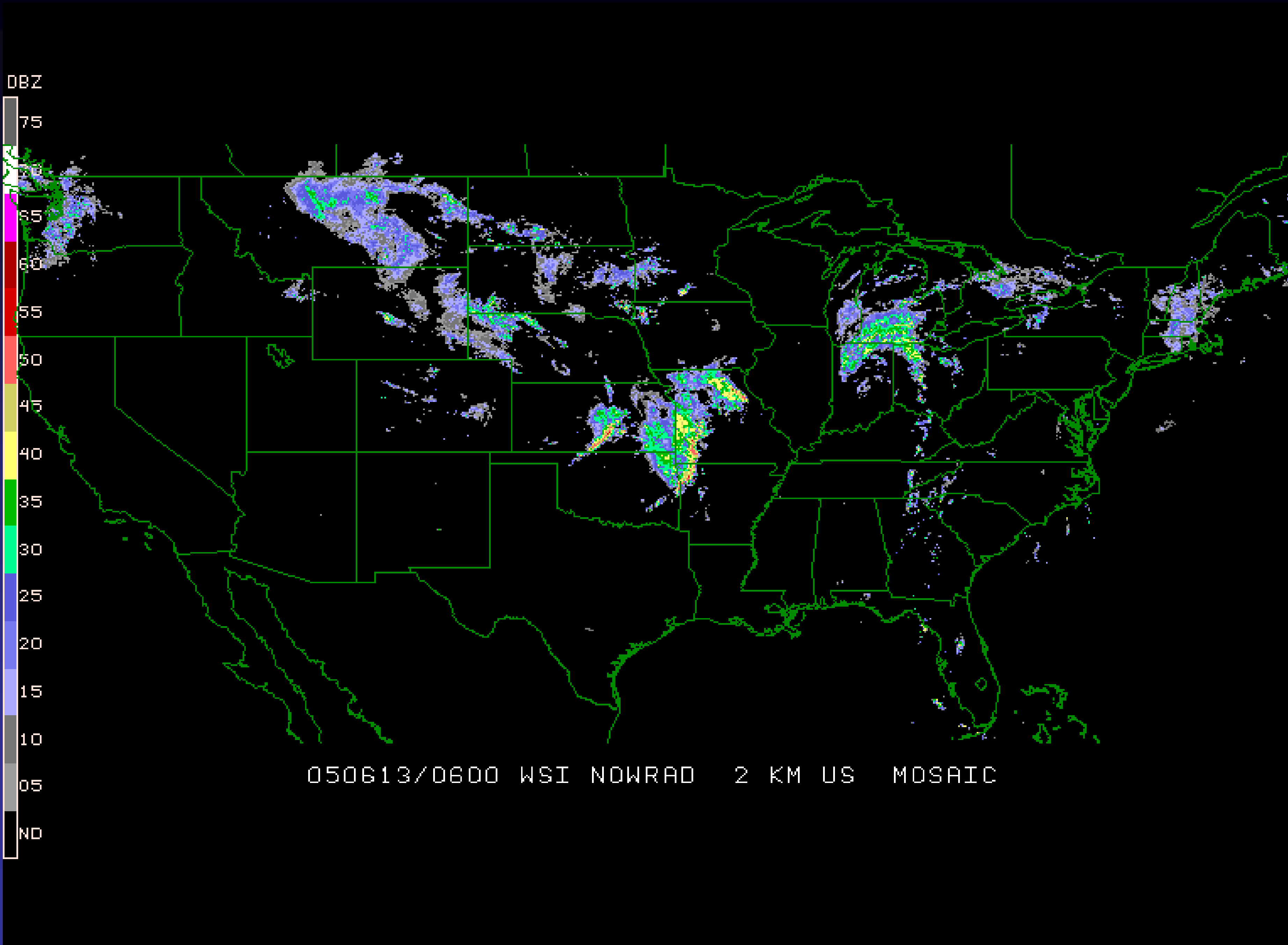
05
ND
050611/1200 WSI NOWRAD 2 KM US MOSAIC



June 12 – convective clusters -- short bowing lines

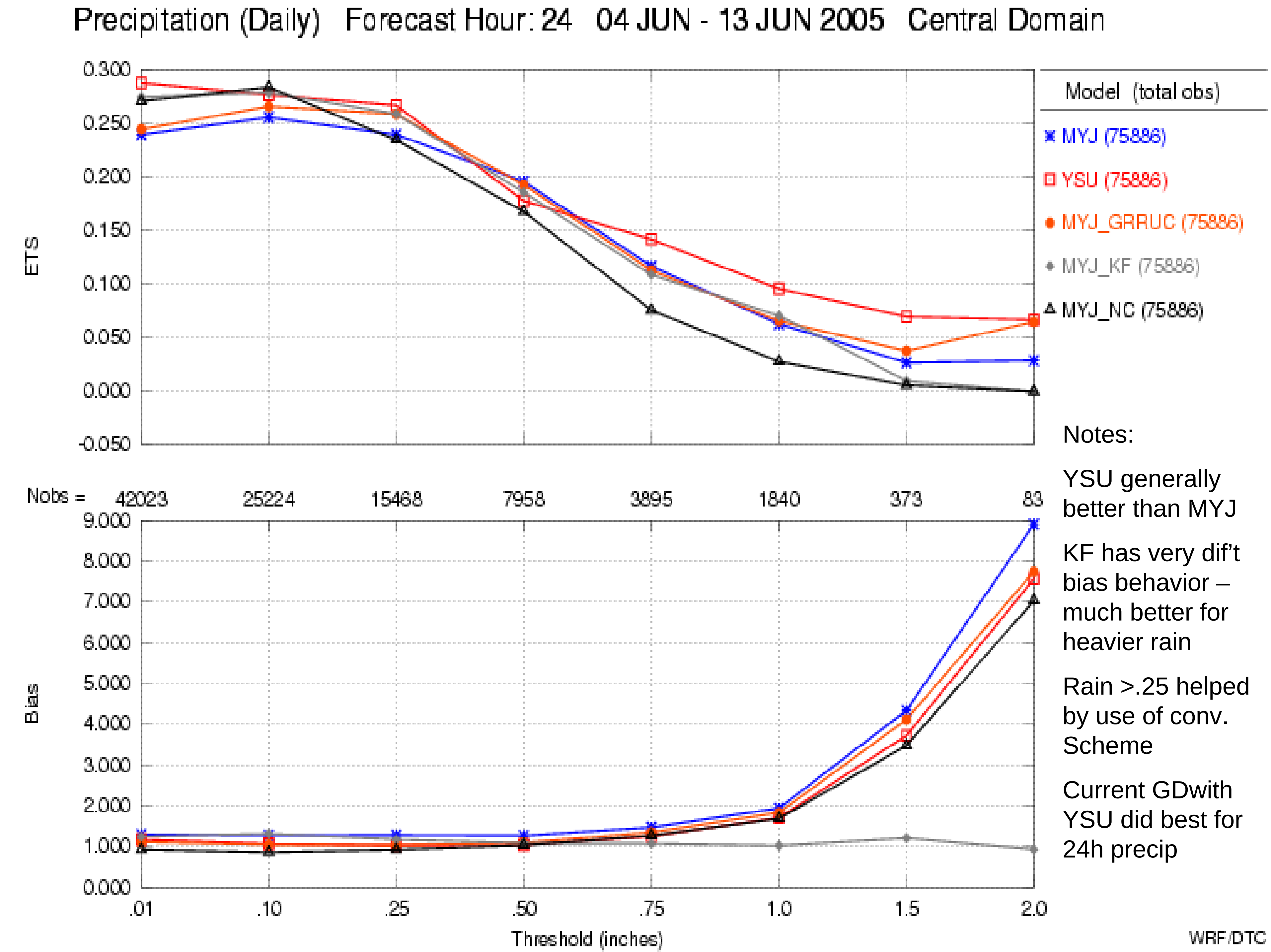

DBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
05
ND
050613/0600 WSI NOWRAD 2 KM US MOSAIC

Tests Performed

- For all 5 cases, both YSU and MYJ PBLs were used
- For all 5 cases, 4 km fully explicit runs were also performed
- For June 4 and 9, 4 km runs with GD were performed
- For June 4, 9, 10, 12, 13 km runs without GD were performed (no conv. Scheme)
- These 4 cases were also used for runs with modification in GD (to reduce low-level drying), runs with RUC-GD version, and runs with KF substituted

Objective Precipitation Verification

- WRF output was fed to the post-processor (with help from L. Bernardet and M. Demirtas) and “bucket” programs
- A. Loughe fed this output to the RTVS system and created a user-friendly web page for computation of several objective measures of performance
- http://www-ad.fsl.noaa.gov/users/loughe/projects/wrf/PBL_expt_summer_2005_RT/



Notes:

YSU generally better than MYJ

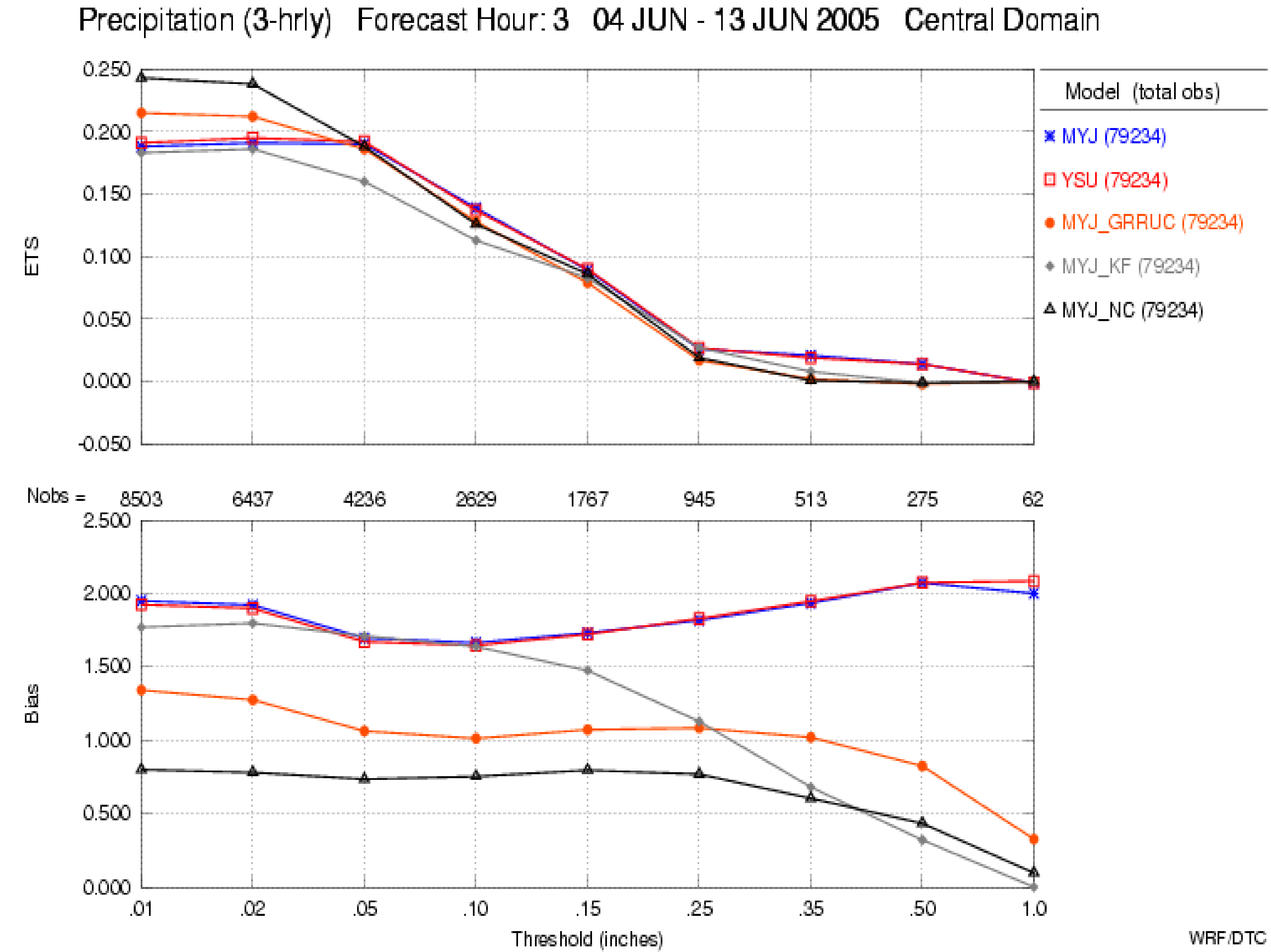
KF has very dif't bias behavior – much better for heavier rain

Rain >.25 helped by use of conv. Scheme

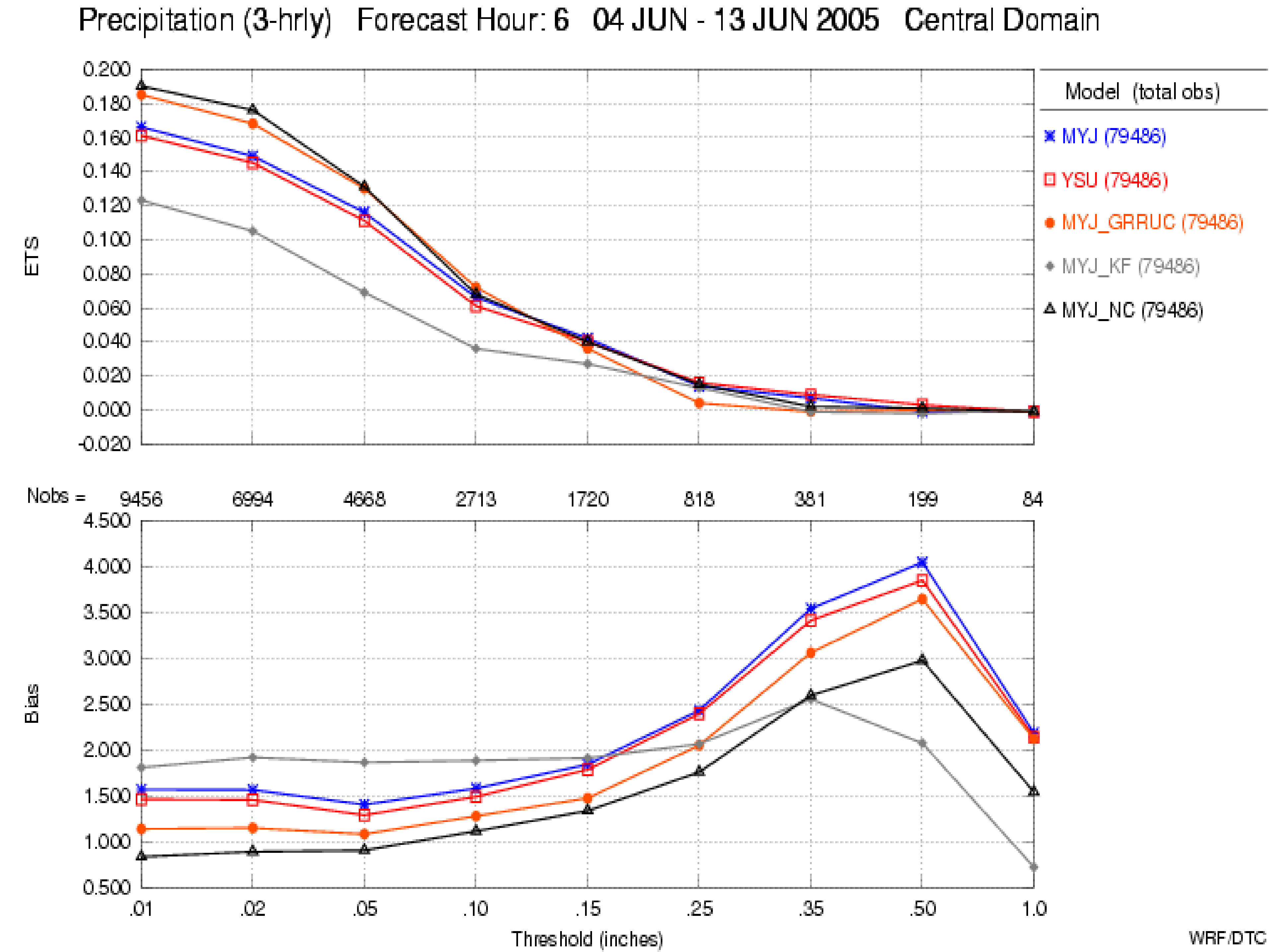
Current GDwith YSU did best for 24h precip

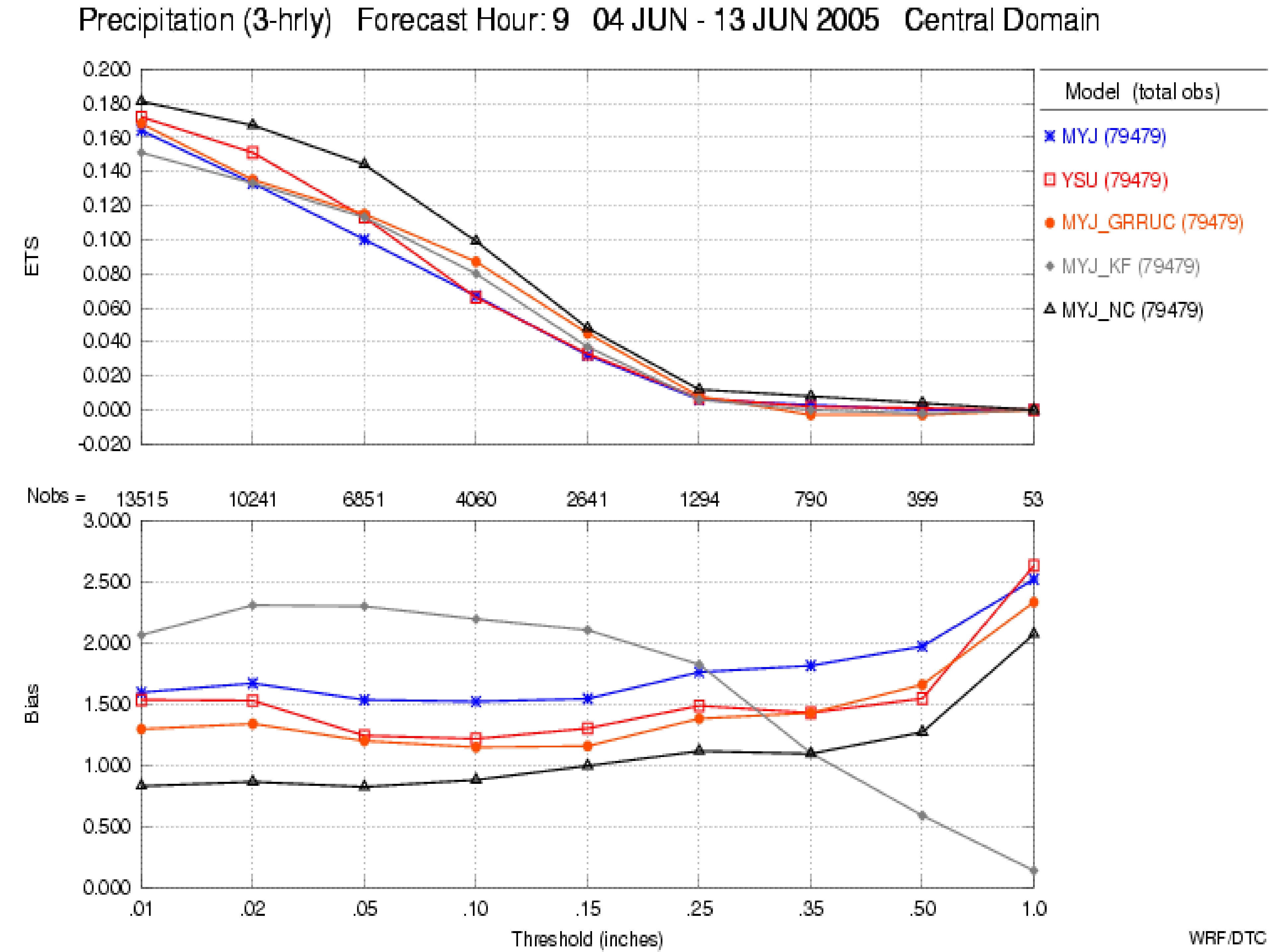
3-hr trends in precipitation forecasts more complex

- Diurnal trends in ETS apparent (maxima in 0-3 h forecast, and around 06-09 UTC, minimum around 21-03 UTC period)
- "No convective scheme" in 13 km runs does best for light amounts prior to 3 UTC (15 h forecast)
- Difficult to find a clear "winner" overall in ETS or BIAS
- Despite overall high bias in 24 h period, all versions show low bias issues in 00-09 UTC period

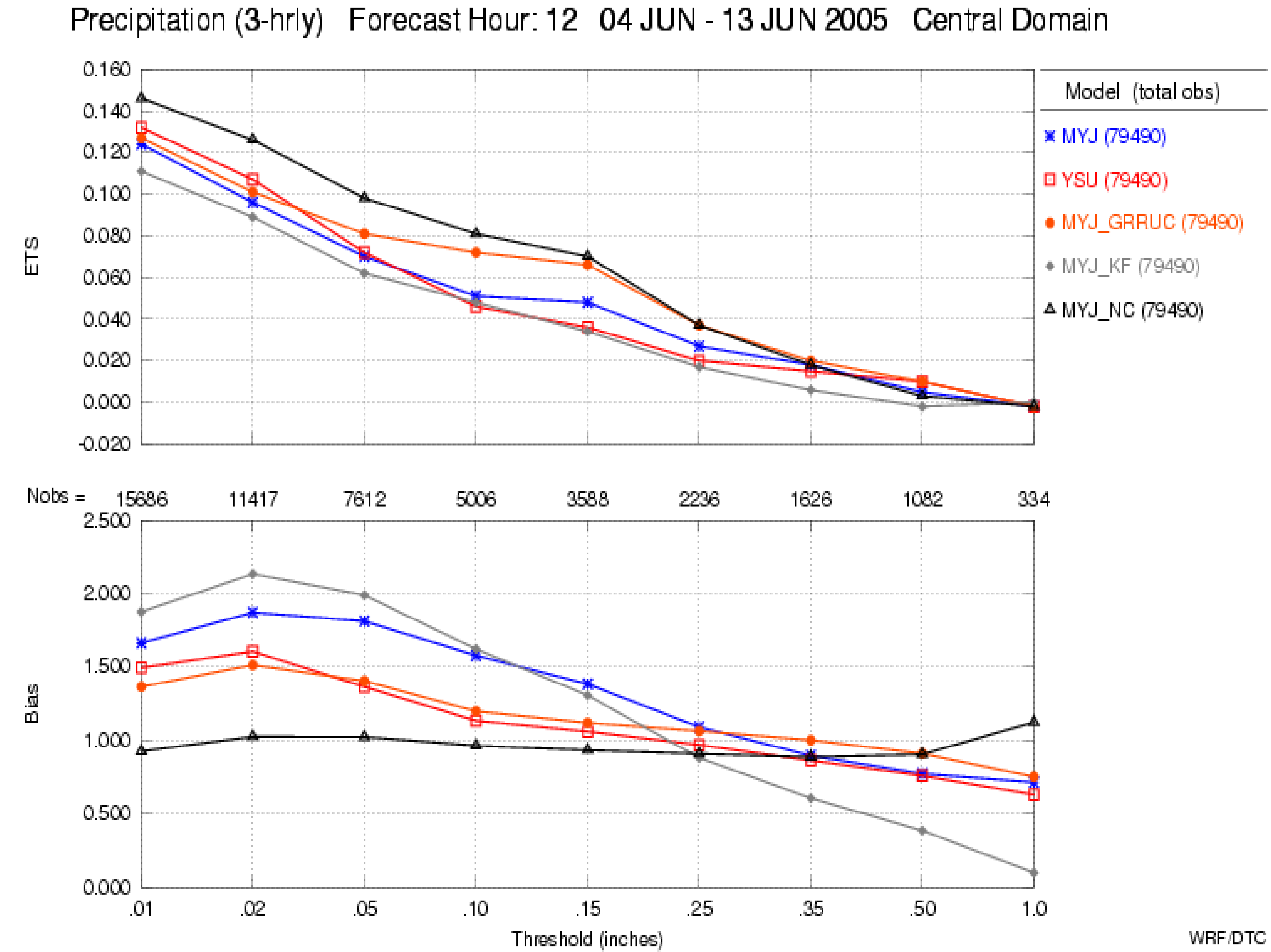


Precipitation (3-hrly) Forecast Hour: 3 04 JUN - 13 JUN 2005 Central Domain
Model (total obs)
MYJ (79234)
YSU (79234)
MYJ_GRRUC (79234)
MYJ_KF (79234)
MYJ_NC (79234)
ETS
0.250
0.200
0.150
0.100
0.050
0.000
-0.050
Nobs =
8503
6437
4236
2629
1767
945
513
275
62
Bias
2.500
2.000
1.500
1.000
0.500
0.000
.01
.02
.05
.10
.15
.25
.35
.50
1.0
Threshold (inches)
WRF/DTC

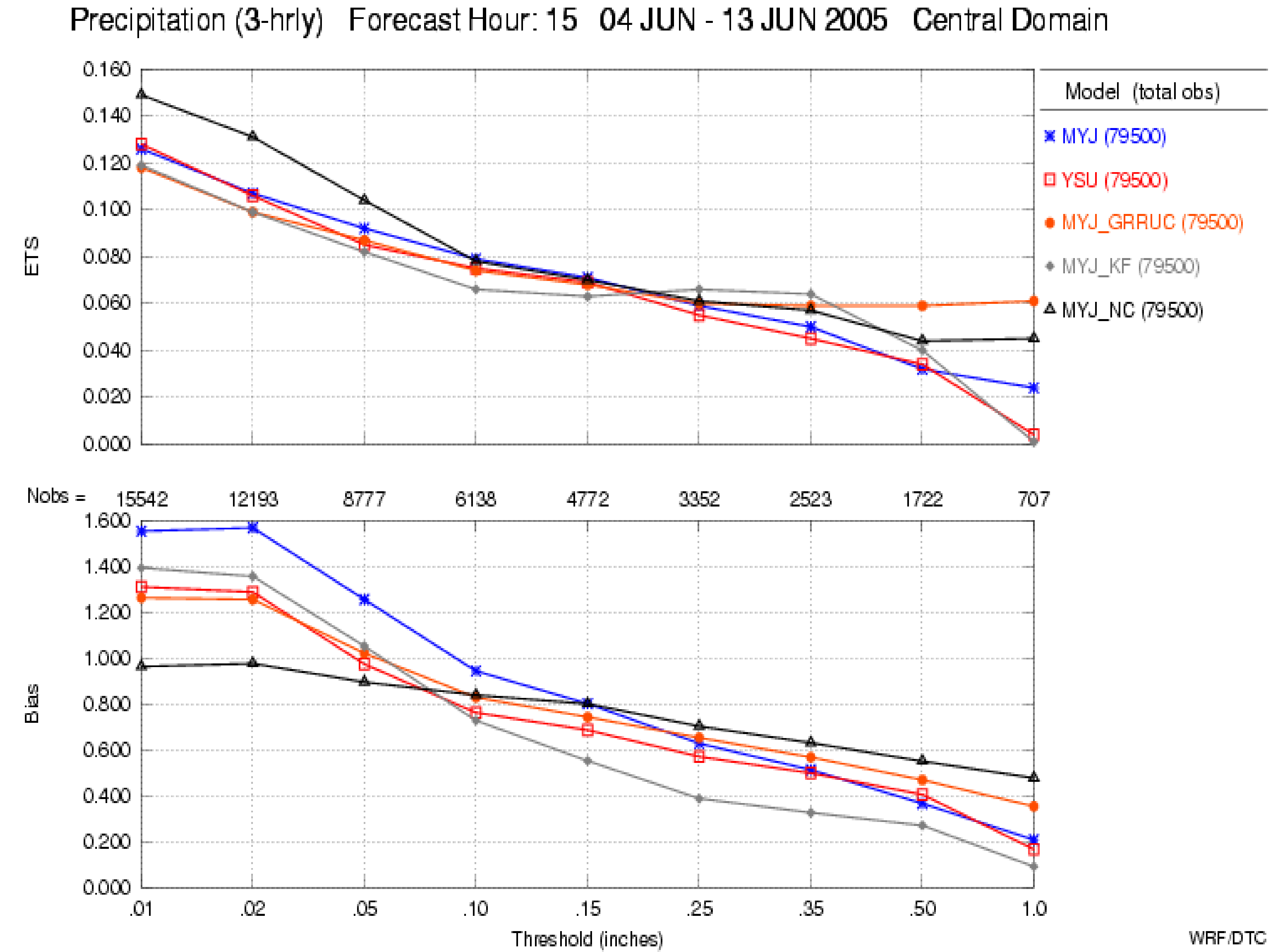

Precipitation (3-hrly) Forecast Hour: 6 04 JUN - 13 JUN 2005 Central Domain
ETS
Model (total obs)
MYJ (79486)
YSU (79486)
MYJ_GRRUC (79486)
MYJ_KF (79486)
MYJ_NC (79486)
Nobs = 9456 6994 4668 2713 1720 818 381 199 84
Bias
.01 .02 .05 .10 .15 .25 .35 .50 1.0
Threshold (inches)
WRF/DTC



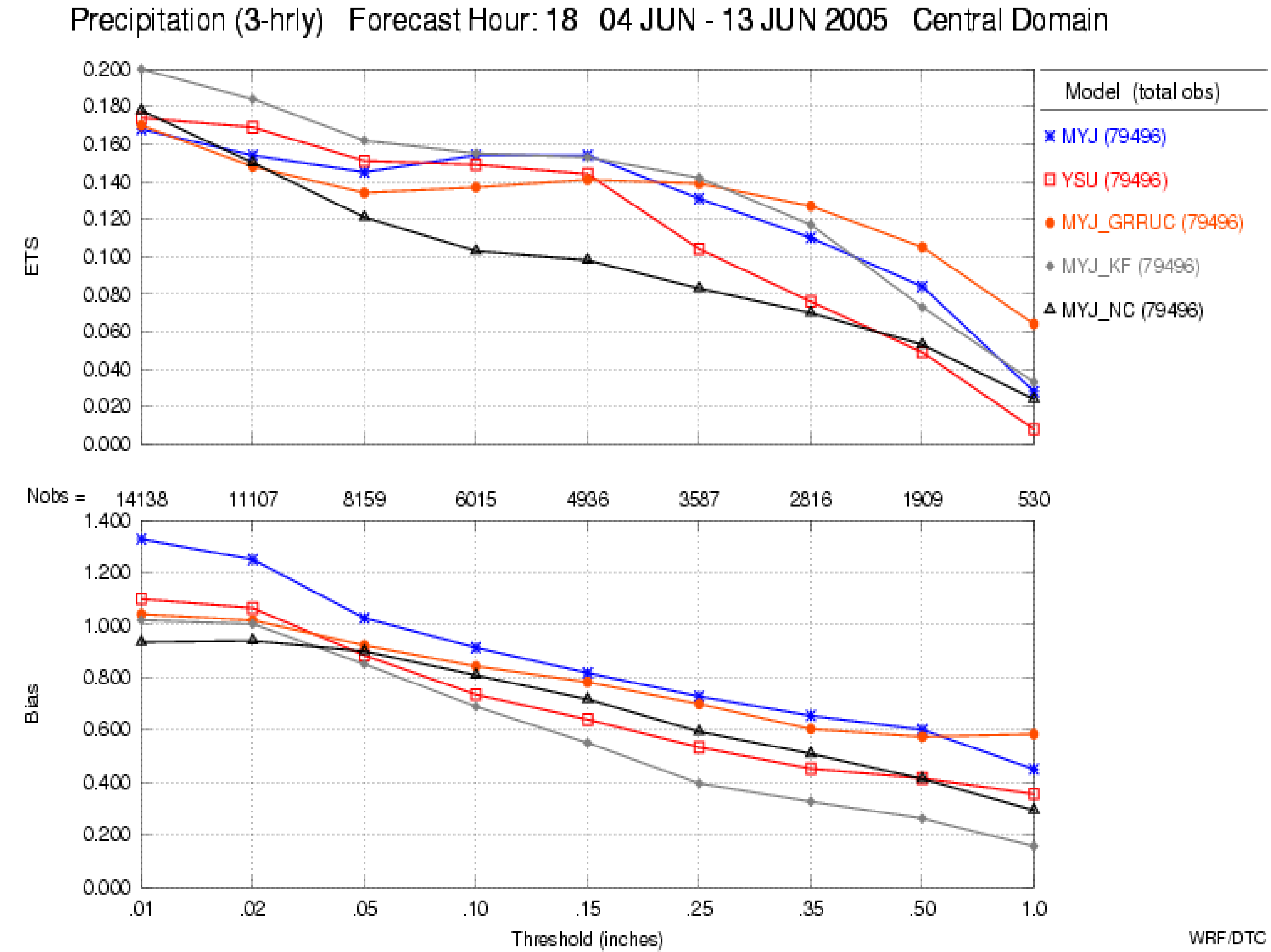
Precipitation (3-hrly) Forecast Hour: 9 04 JUN - 13 JUN 2005 Central Domain
ETS
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
Model (total obs)
MYJ (79479)
YSU (79479)
MYJ_GRRUC (79479)
MYJ_KF (79479)
MYJ_NC (79479)
Nobs = 13515 10241 6851 4060 2641 1294 790 399 53
Bias
3.000
2.500
2.000
1.500
1.000
0.500
0.000
.01 .02 .05 .10 .15 .25 .35 .50 1.0
Threshold (inches)
WRF/DTC

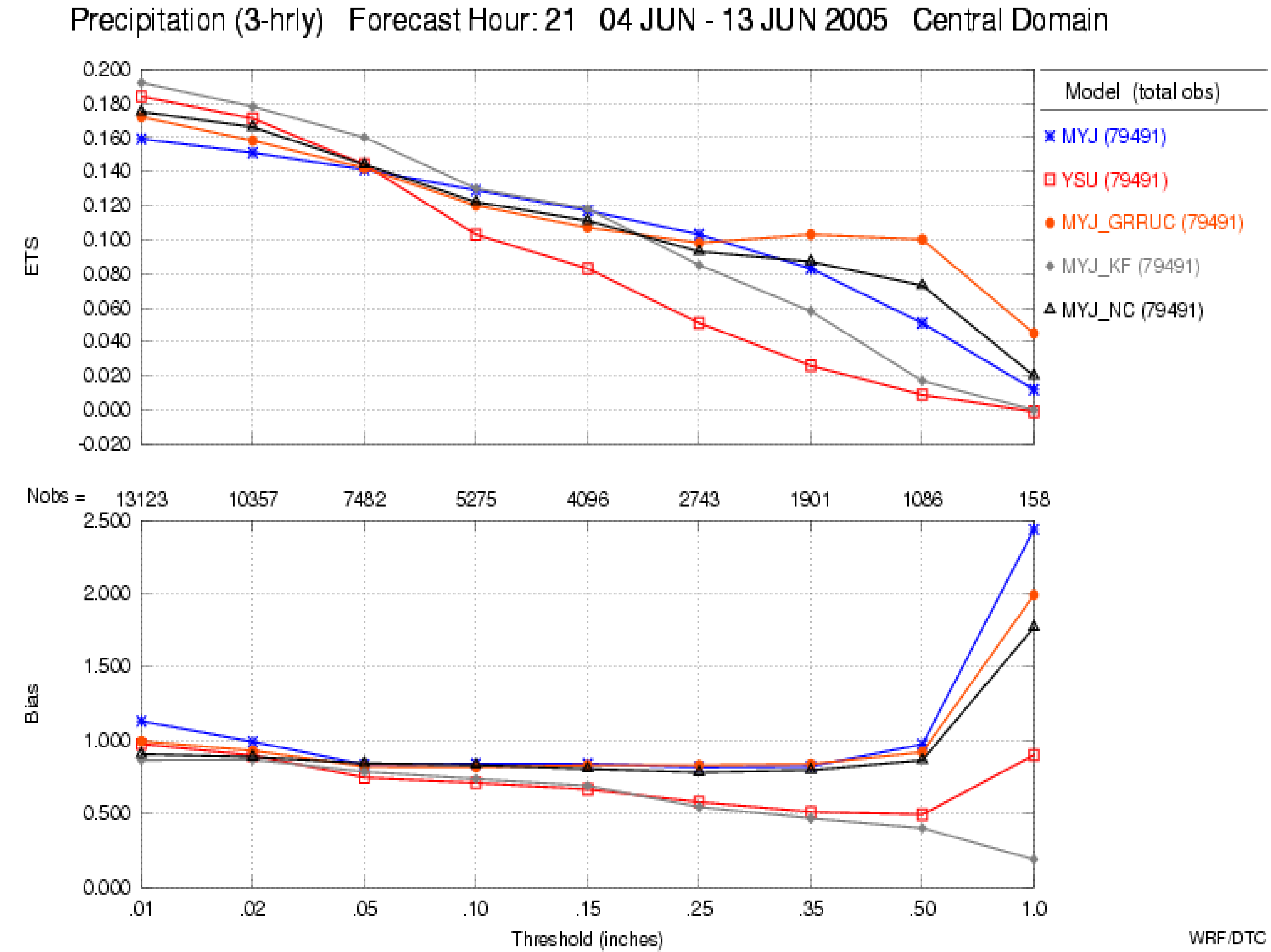


Precipitation (3-hrly) Forecast Hour: 12 04 JUN - 13 JUN 2005 Central Domain
ETS
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
Model (total obs)
MYJ (79490)
YSU (79490)
MYJ_GRRUC (79490)
MYJ_KF (79490)
MYJ_NC (79490)
Nobs = 15686 11417 7612 5006 3588 2236 1626 1082 334
Bias
2.500
2.000
1.500
1.000
0.500
0.000
.01 .02 .05 .10 .15 .25 .35 .50 1.0
Threshold (inches)
WRF/DTC

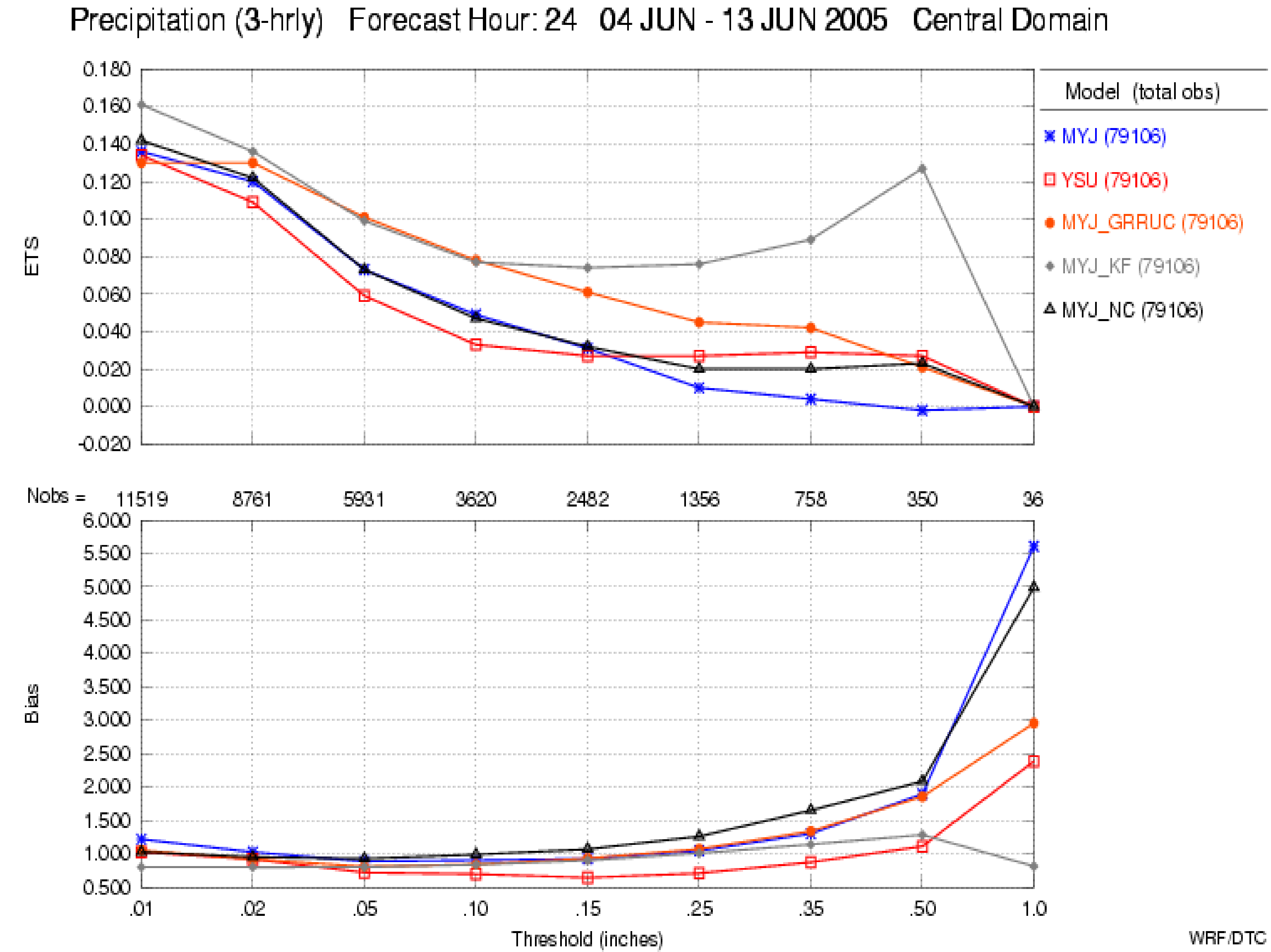


Precipitation (3-hrly) Forecast Hour: 15 04 JUN - 13 JUN 2005 Central Domain
ETS
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
Model (total obs)
MYJ (79500)
YSU (79500)
MYJ_GRRUC (79500)
MYJ_KF (79500)
MYJ_NC (79500)
Nobs =
15542
12193
8777
6138
4772
3352
2523
1722
707
Bias
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
.01
.02
.05
.10
.15
.25
.35
.50
1.0
Threshold (inches)
WRF/DTC


Precipitation (3-hrly) Forecast Hour: 18 04 JUN - 13 JUN 2005 Central Domain
ETS
Bias
Model (total obs)
MYJ (79496)
YSU (79496)
MYJ_GRRUC (79496)
MYJ_KF (79496)
MYJ_NC (79496)
Nobs = 14138 11107 8159 6015 4936 3587 2816 1909 530
.01 .02 .05 .10 .15 .25 .35 .50 1.0
Threshold (inches)
WRF/DTC

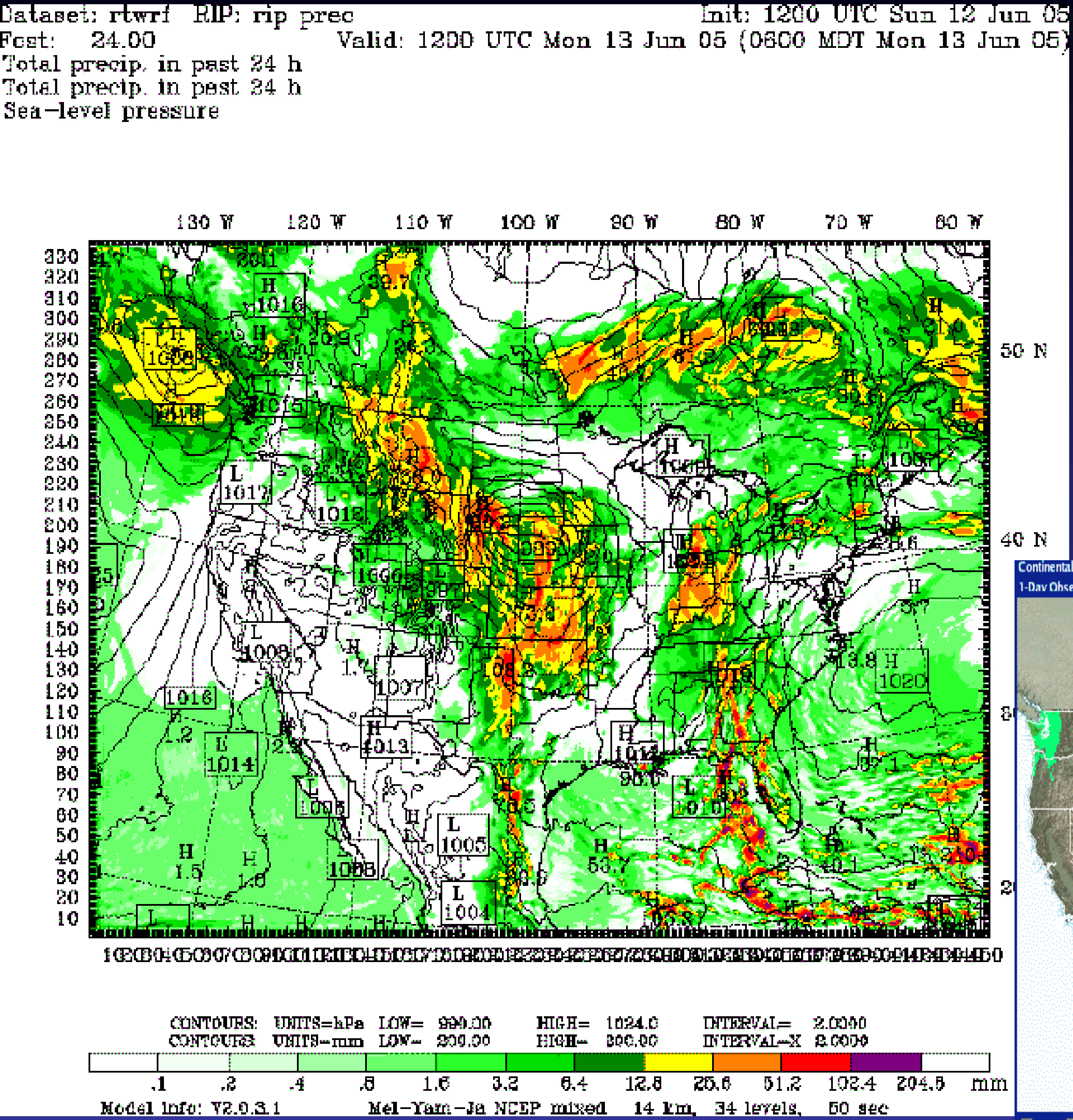


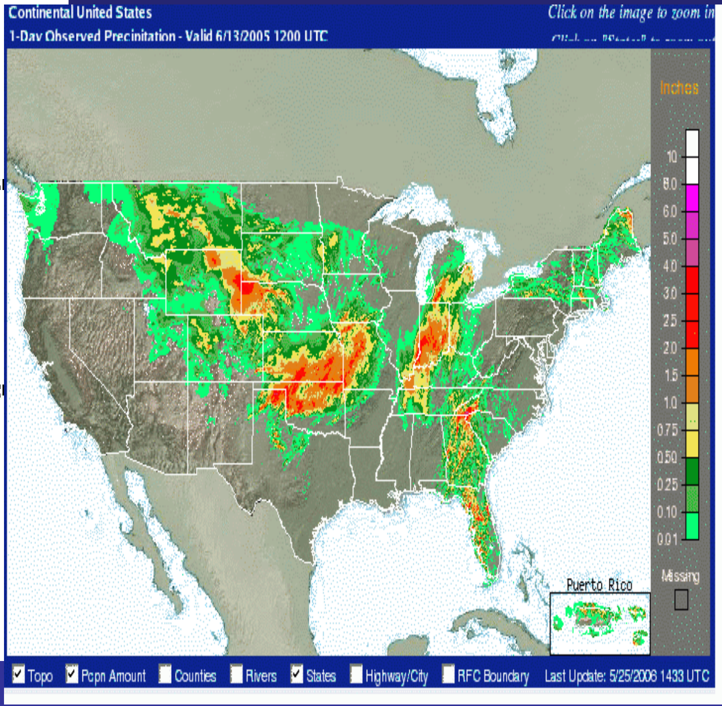
Precipitation (3-hrly) Forecast Hour: 21 04 JUN - 13 JUN 2005 Central Domain
Model (total obs)
MYJ (79491)
YSU (79491)
MYJ_GRRUC (79491)
MYJ_KF (79491)
MYJ_NC (79491)
ETS
0.200
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
Nobs =
13123
10357
7482
5275
4096
2743
1901
1086
158
Bias
2.500
2.000
1.500
1.000
0.500
0.000
.01
.02
.05
.10
.15
.25
.35
.50
1.0
Threshold (inches)
WRF/DTC

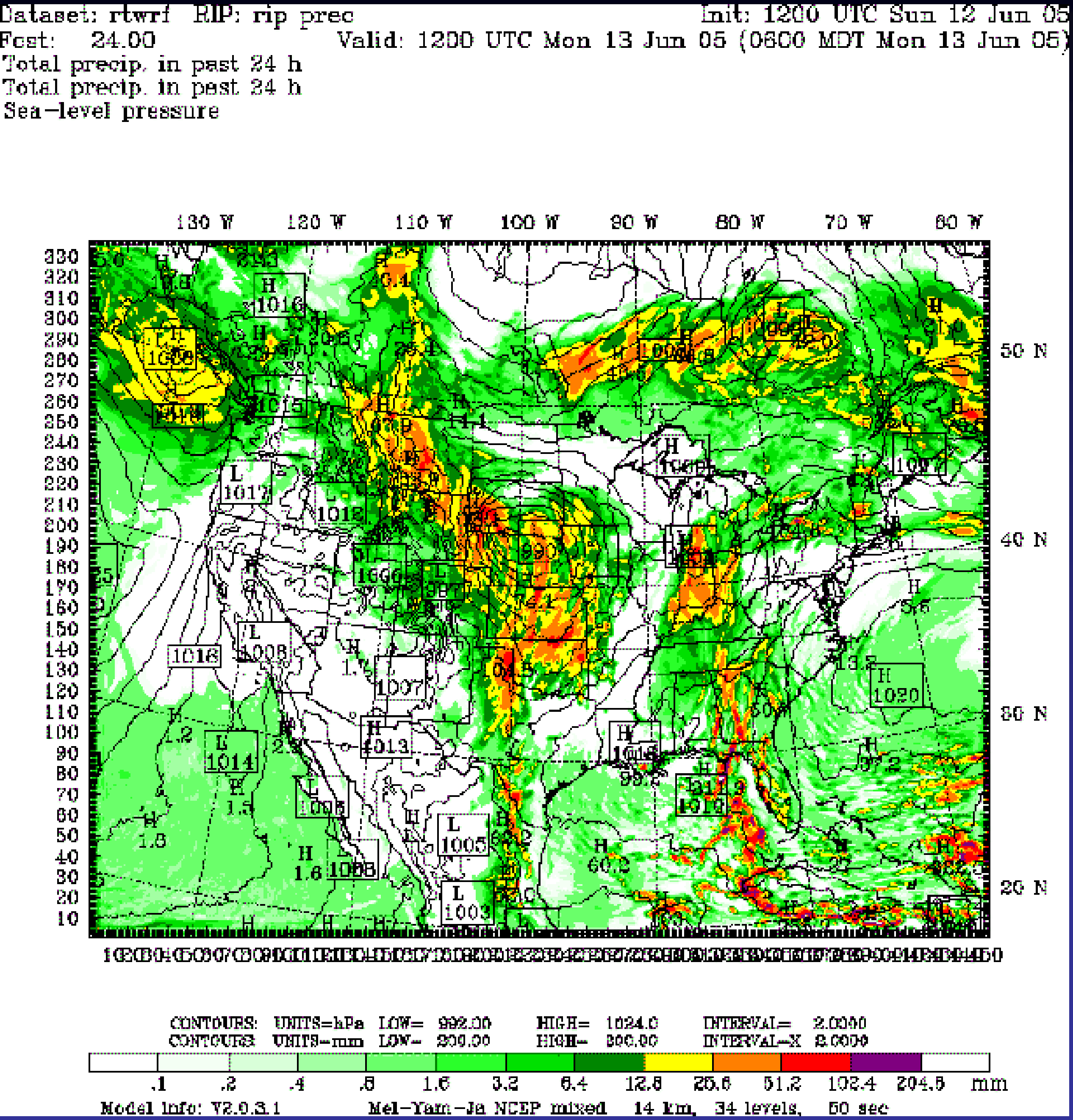


Precipitation (3-hrly) Forecast Hour: 24 04 JUN - 13 JUN 2005 Central Domain
Model (total obs)
MYJ (79106)
YSU (79106)
MYJ_GRRUC (79106)
MYJ_KF (79106)
MYJ_NC (79106)
ETS
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
-0.020
Nobs = 11519 8761 5931 3620 2482 1356 758 350 36
Bias
6.000
5.500
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
.01 .02 .05 .10 .15 .25 .35 .50 1.0
Threshold (inches)
WRF/DTC

24 hr precip
with normal
Grell-Devenyi







24hr precip with modified Grell-Devenyi

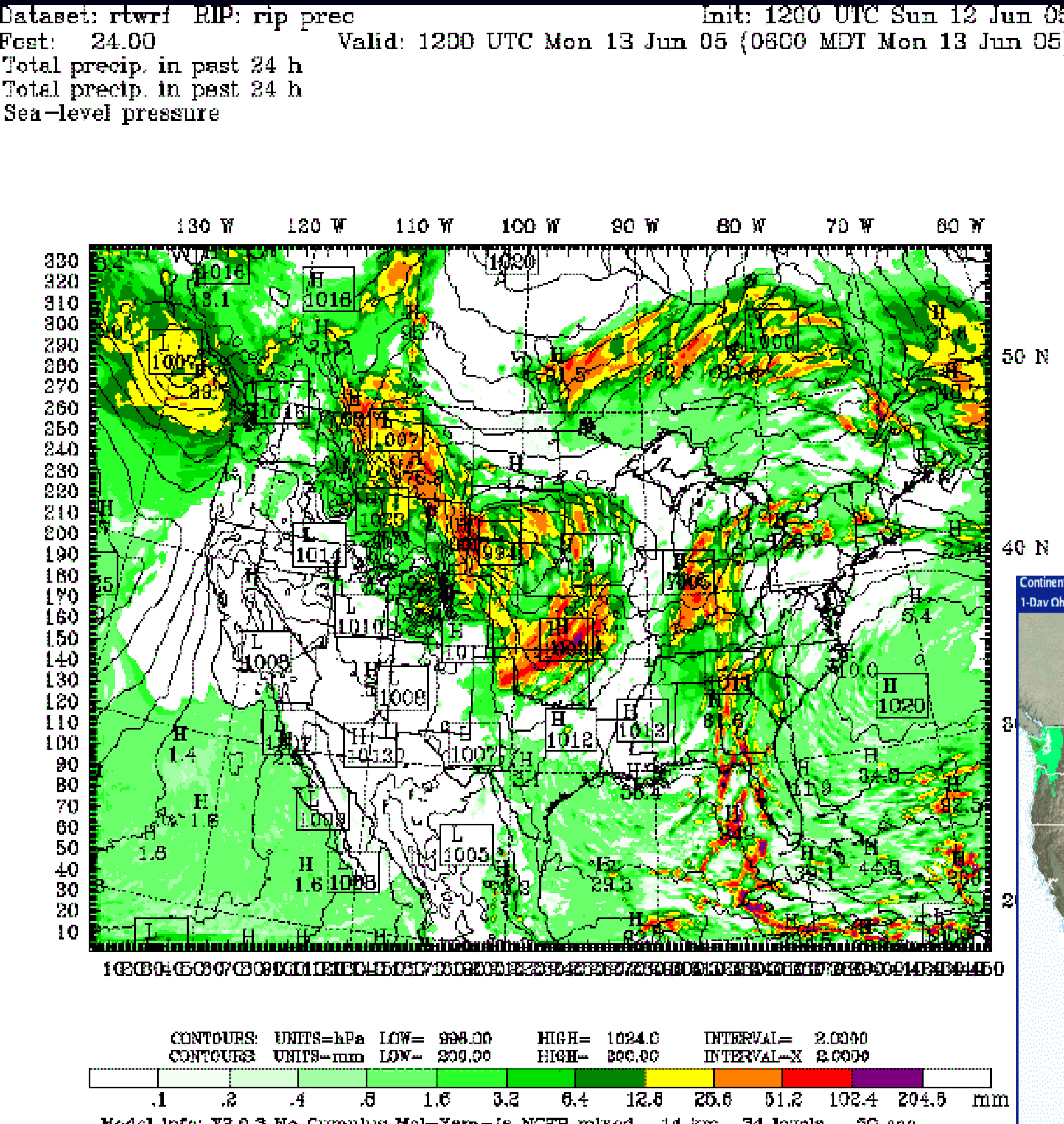
edtmax .9 instead of .8 (ratio of dwndrft base mass flux to updraft flux)

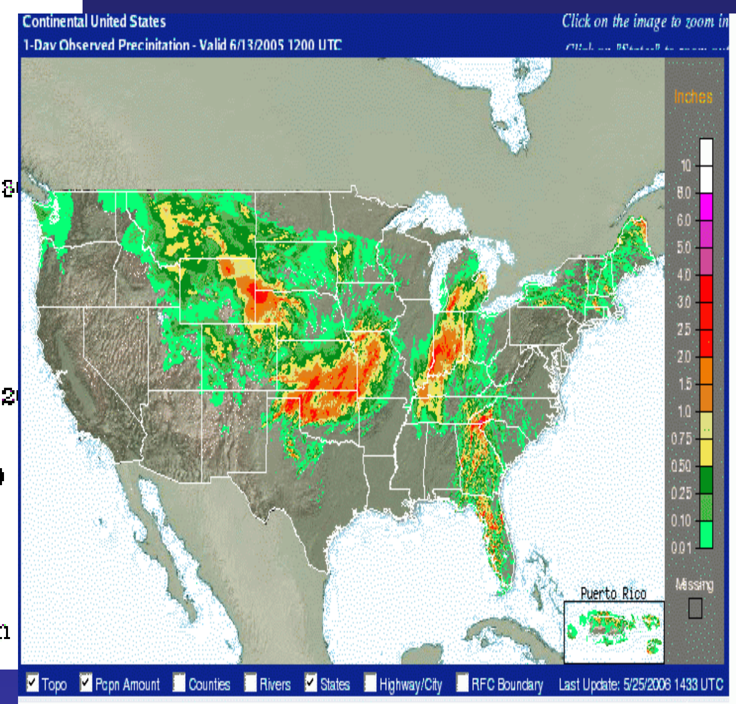
Cap_maxs and increment 175, 75 instead of 125,50

Einc = 10% instead of 20%

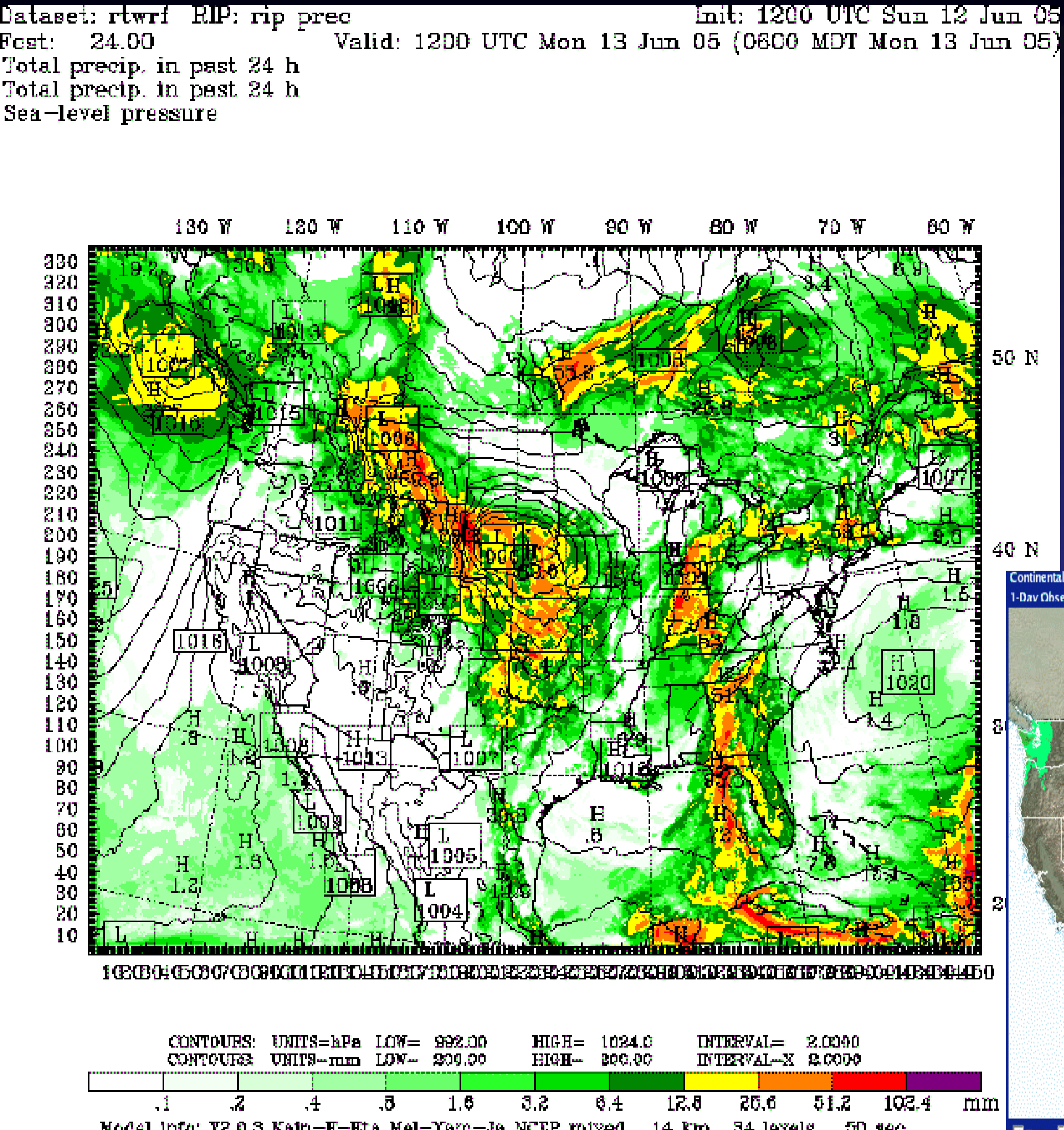
Edtc uses (k-1)*einc instead of (k-2)

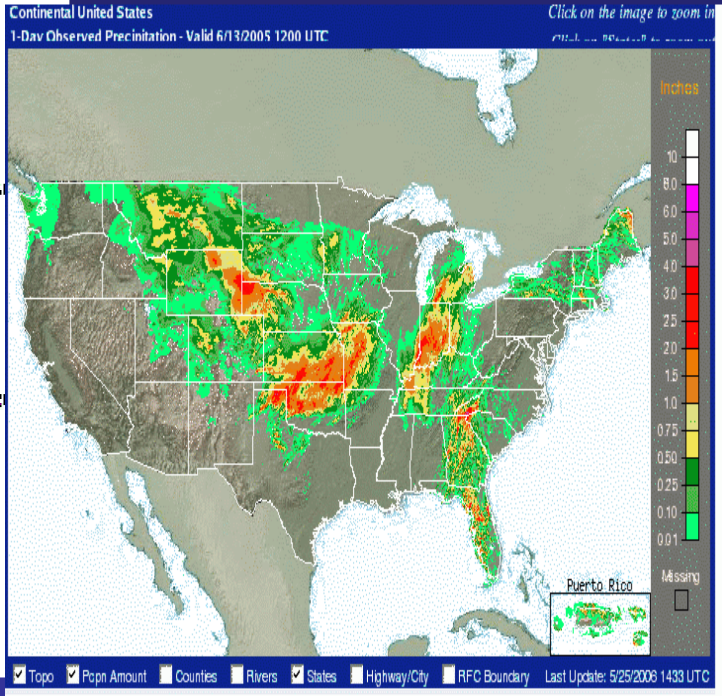
Fully explicit

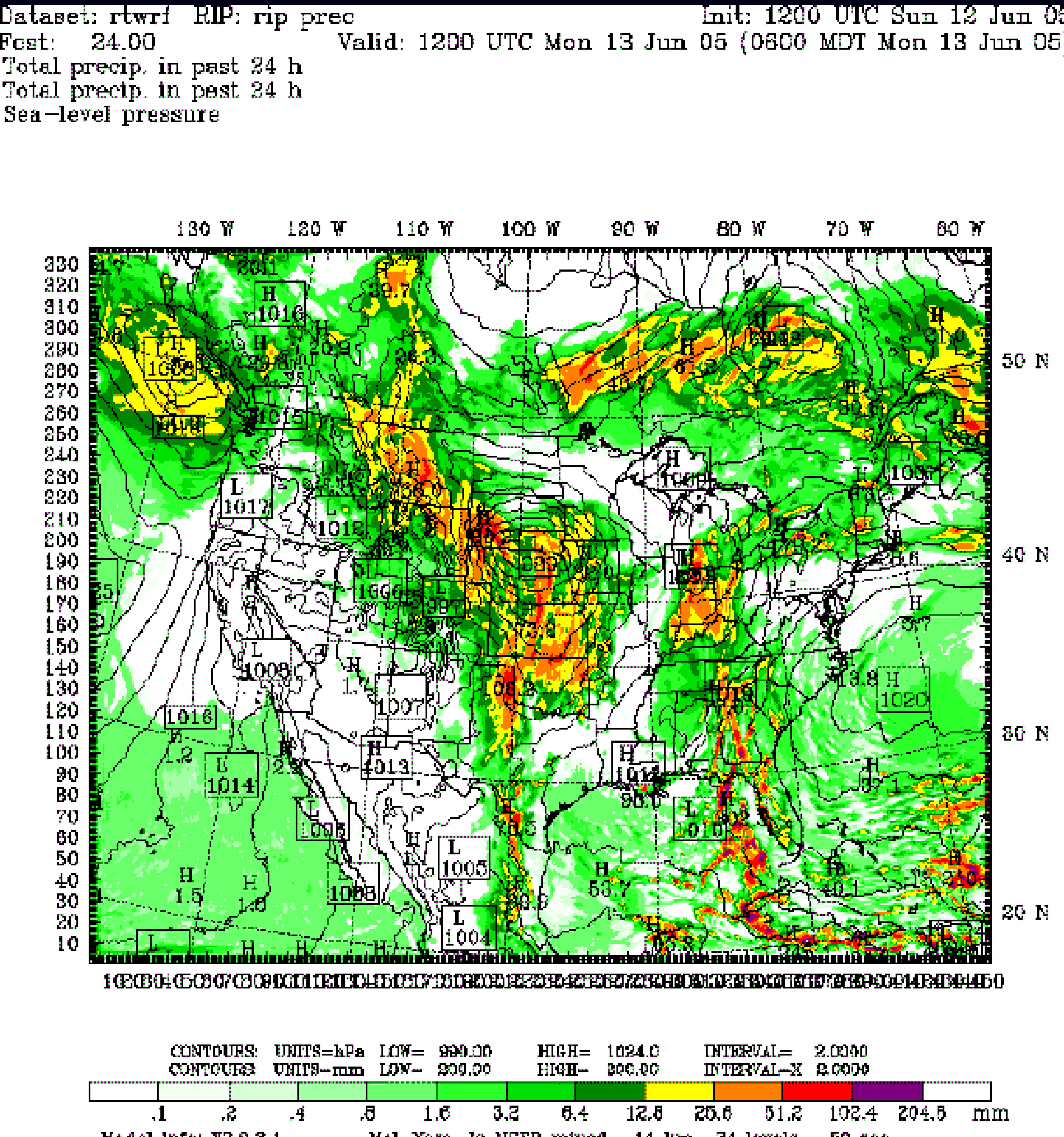




KF scheme

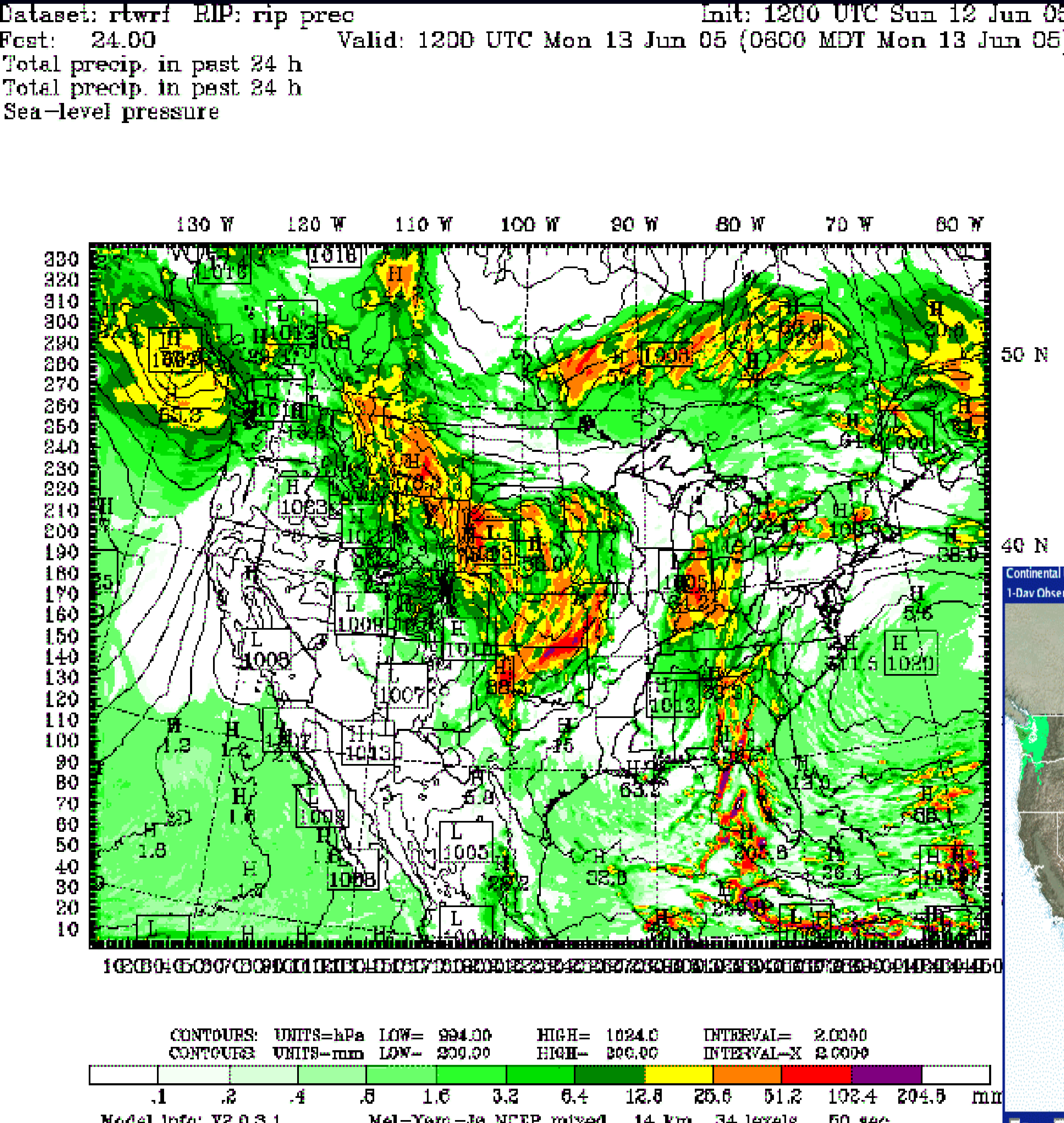

Dataset: rtwrf RIP: rip prec
Init: 1200 UTC Sun 12 Jun 05
Fcst: 24.00
Valid: 1200 UTC Mon 13 Jun 05 (0600 MDT Mon 13 Jun 05)
Total precip. in past 24 h
Total precip. in past 24 h
Sea−level pressure
130 W
120 W
110 W
100 W
90 W
80 W
70 W
60 W
50 N
40 N
CONTOURS: UNITS=hPa LOW= 992.00 HIGH= 1024.0 INTERVAL= 2.0000
CONTOURS: UNITS=mm LOW= 200.00 HIGH= 200.00 INTERVAL= 2.0000
.1
.2
.4
.8
1.6
3.2
6.4
12.8
25.6
51.2
102.4
mm
Model Info: V2.0.3 Kain−F−Eta Mel−Yam−Ja NCEP mixed 14 km, 34 levels, 50 sec

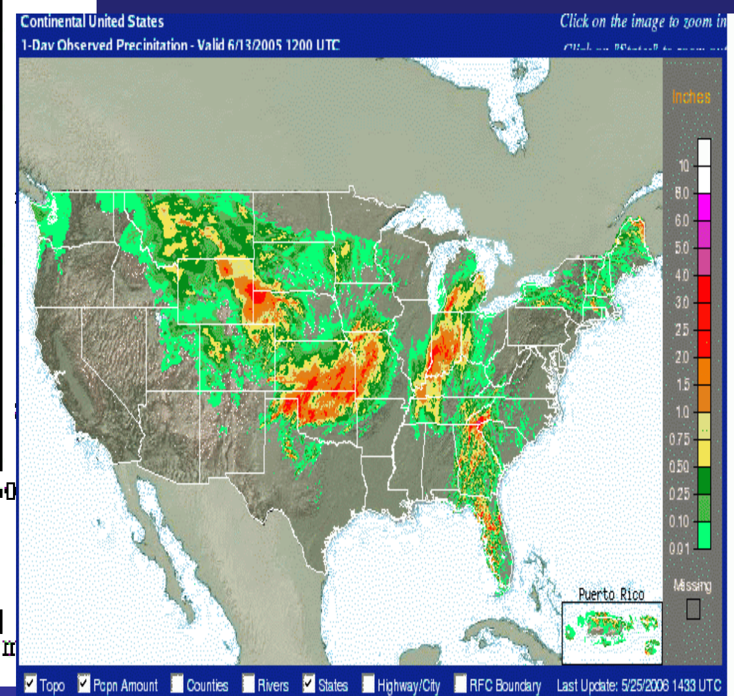

Continental United States
1-Day Observed Precipitation - Valid 6/13/2005 1200 UTC
Click on the image to zoom in
Inches
Puerto Rico
Missing
Topo
Pcpn Amount
Counties
Rivers
States
Highway/City
RFC Boundary
Last Update: 5/25/2006 1433 UTC



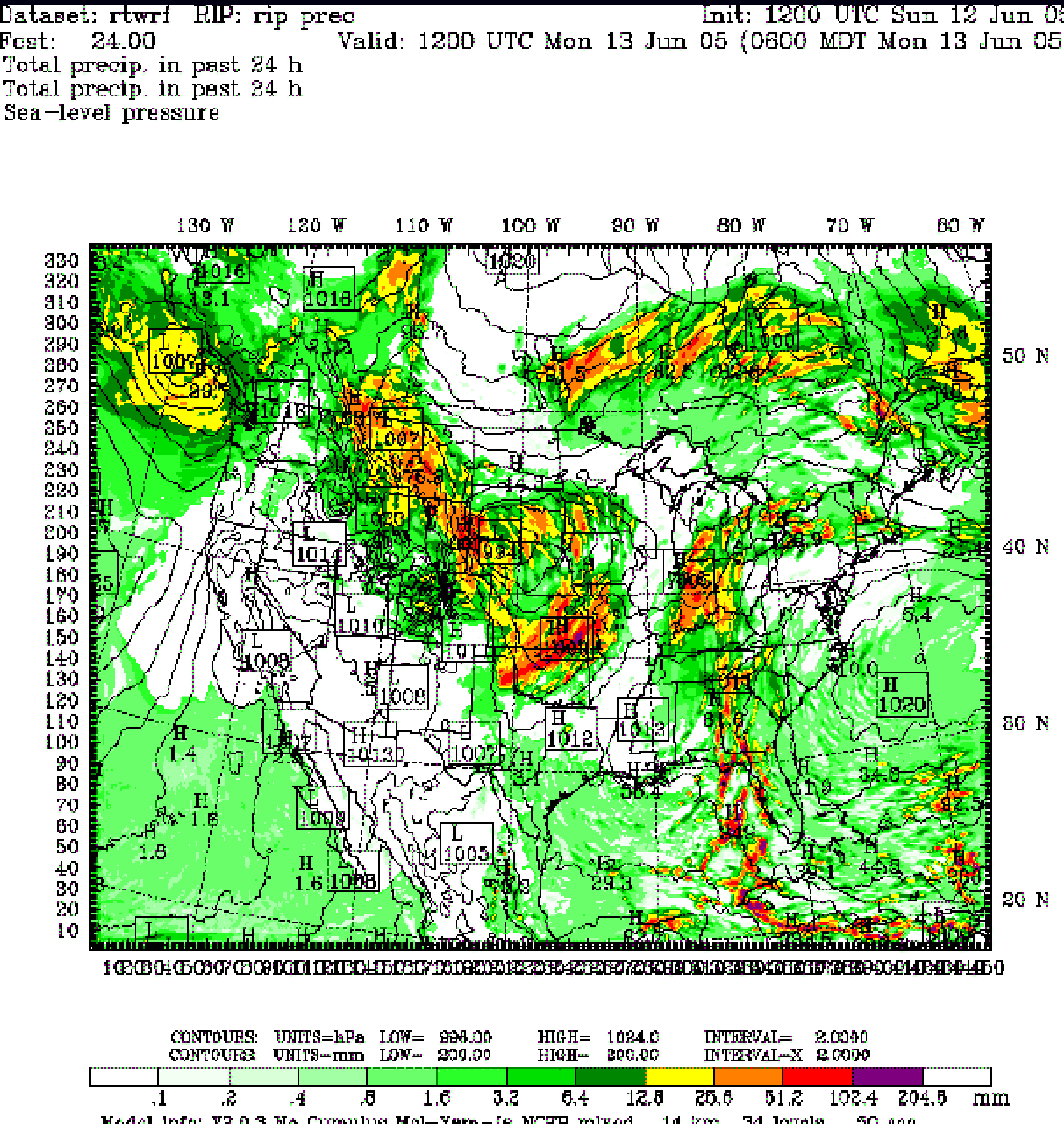
24 hr precip
with normal
Grell-Devenyi

GD-RUC

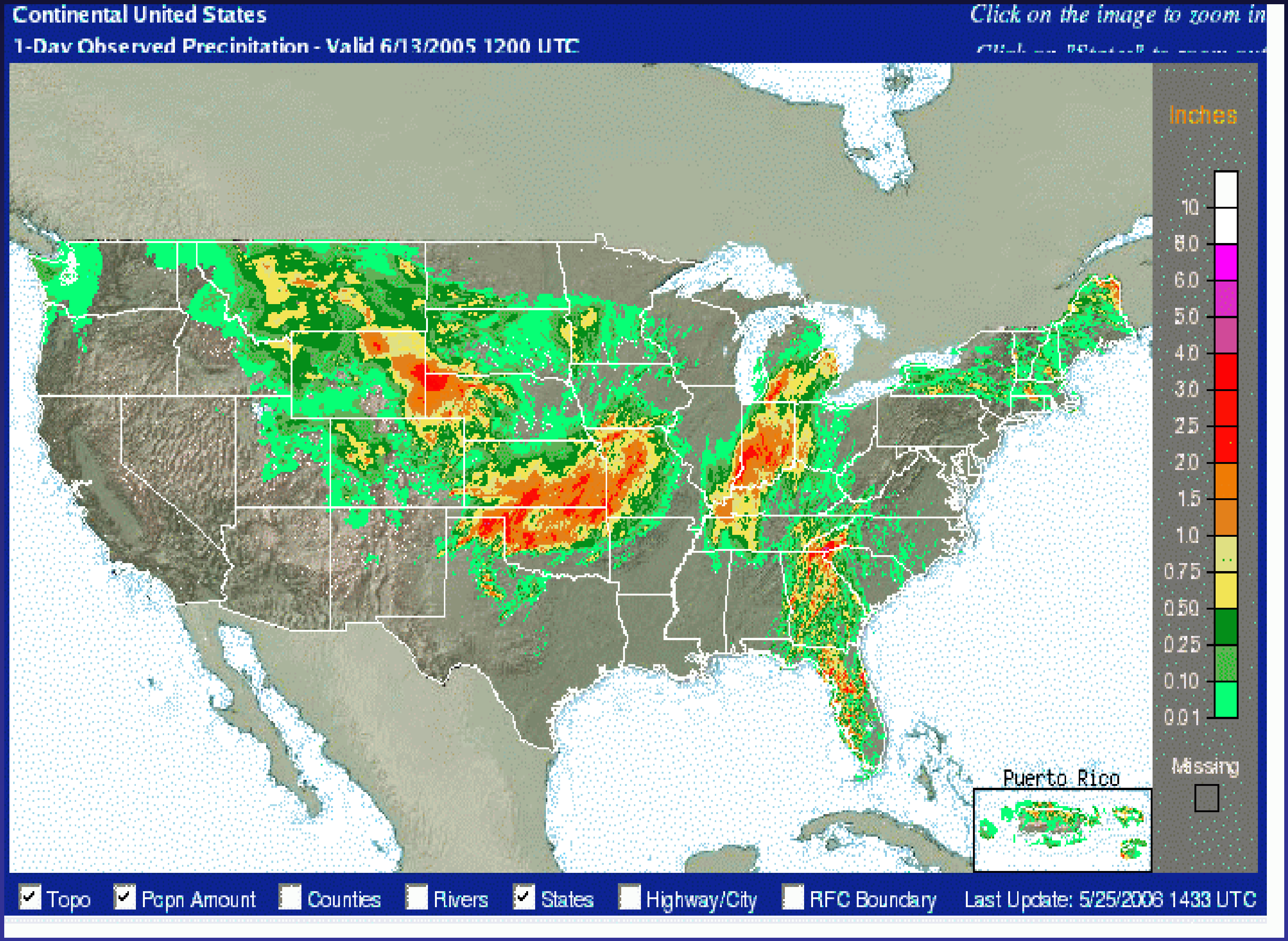

Dataset: rtwrf RIP: rip prec
Init: 1200 UTC Sun 12 Jun 05
Fcst: 24.00
Valid: 1200 UTC Mon 13 Jun 05 (0600 MDT Mon 13 Jun 05)
Total precip. in past 24 h
Total precip. in past 24 h
Sea-level pressure
130 W
120 W
110 W
100 W
90 W
80 W
70 W
60 W
50 N
40 N
CONTOURS: UNITS=hPa LOW= 994.00 HIGH= 1024.0 INTERVAL= 2.0000
CONTOURS: UNITS=mm LOW= 209.00 HIGH= 300.00 INTERVAL= 2.0000
.1 .2 .4 .8 1.6 3.2 6.4 12.8 25.6 51.2 102.4 204.8 mm
Model Info: V2.0.3.1 Mel-Yam-Ja NCEP mixed 14 km, 34 levels, 60 sec


Continental United States
1-Day Observed Precipitation - Valid 6/13/2005 1200 UTC
Click on the image to zoom in
Inches
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
Missing
Puerto Rico
Topo
Pcpn Amount
Counties
Rivers
States
Highway/City
RFC Boundary
Last Update: 5/25/2006 1433 UTC

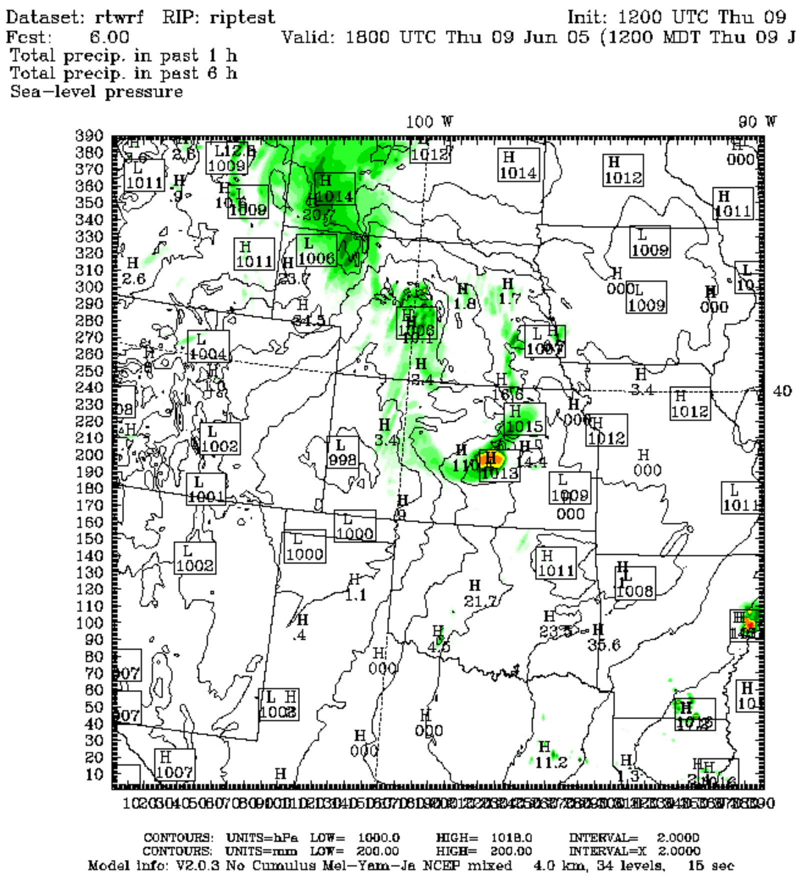
Fully explicit



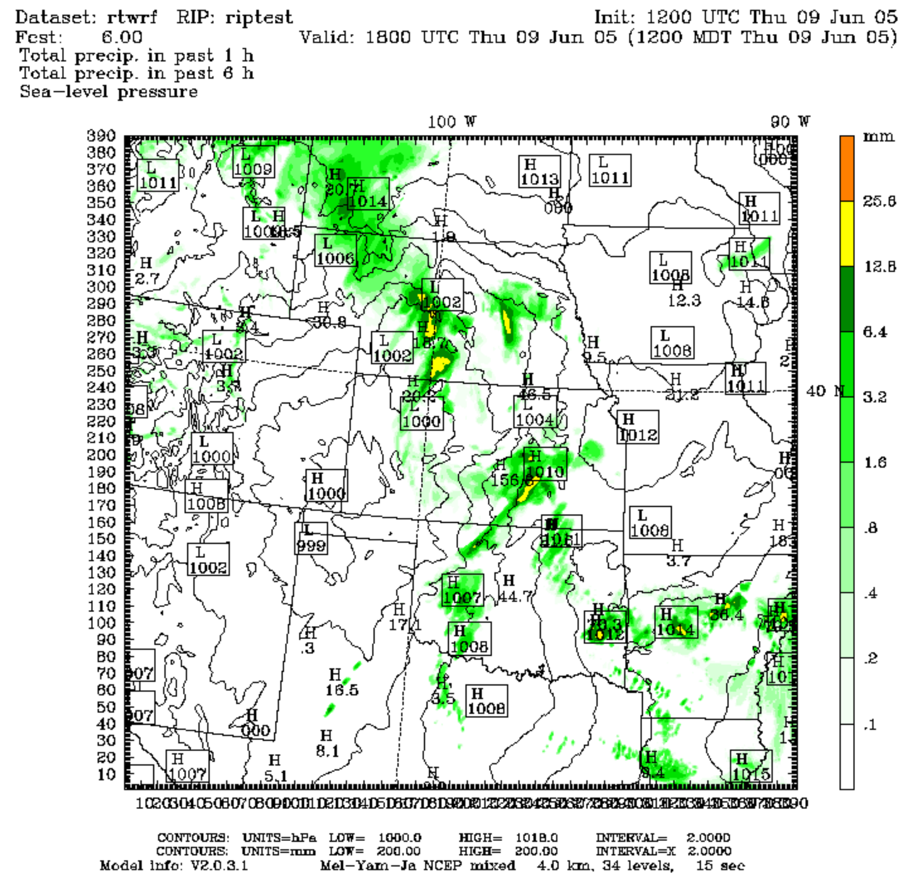
OBSERVATIONS



Use of GD scheme at 4km grid spacing has some noticeable impacts on one-hour precipitation field

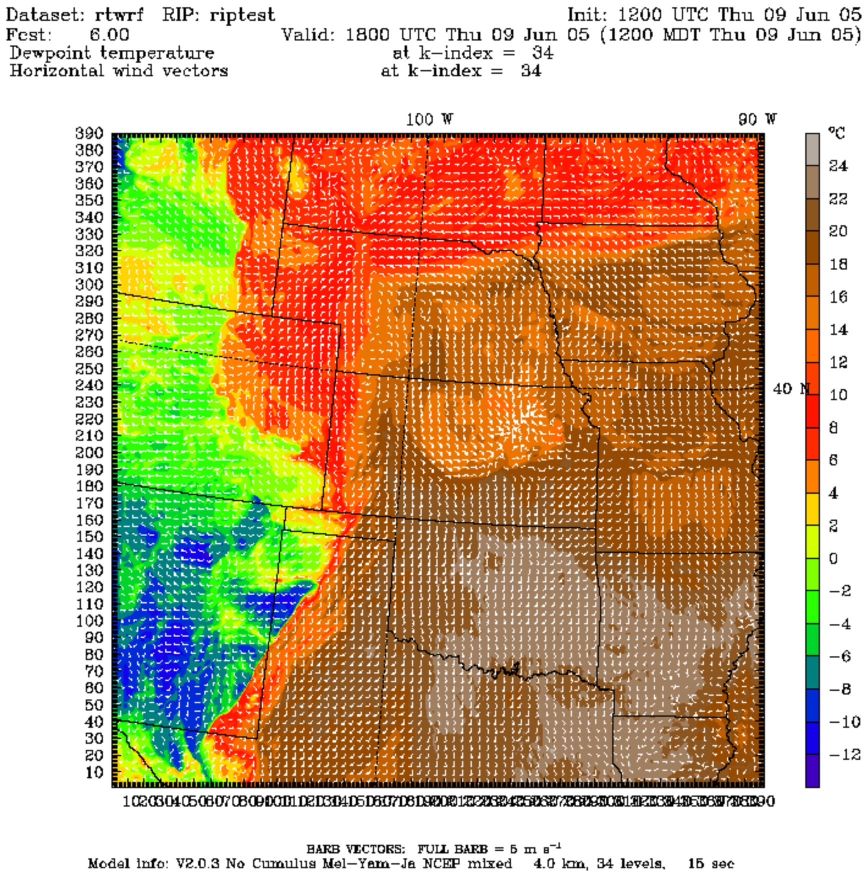


No Convective Scheme

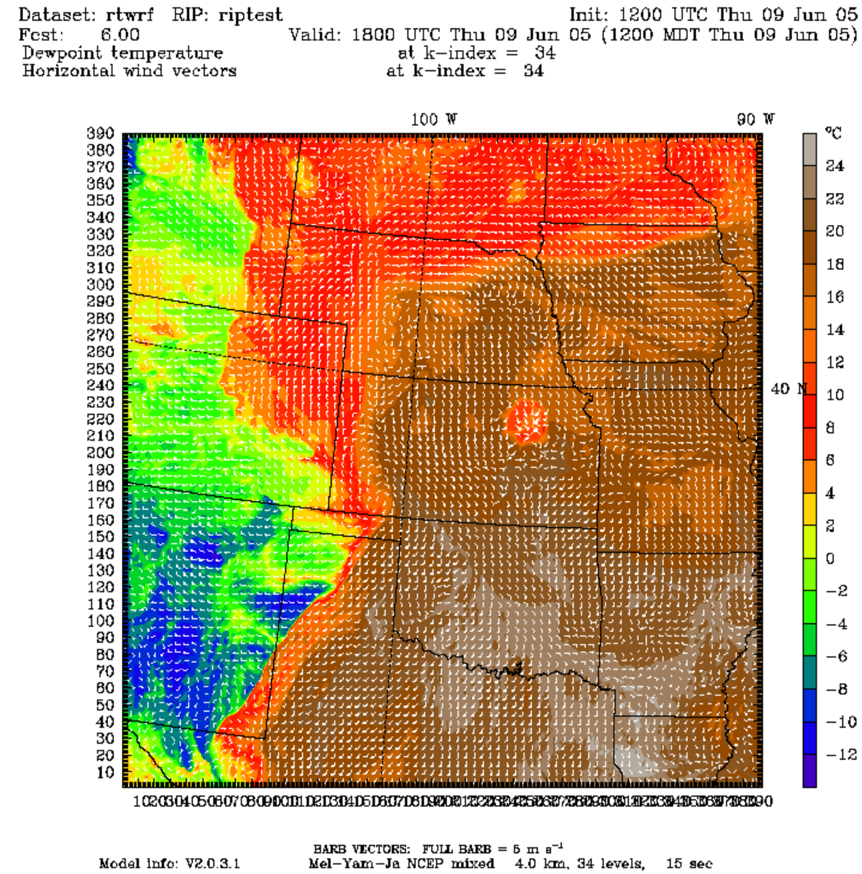


GD scheme

Even bigger impact on surface cold pool characteristics from use of GD at 4km



No Convective Scheme



GD Scheme

General Conclusions

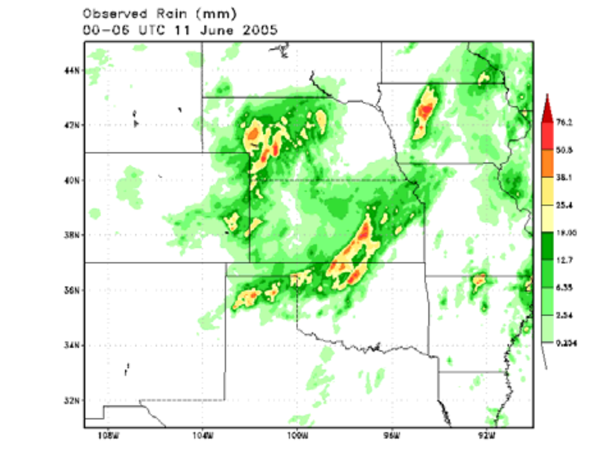
- Difficult to systematically improve precipitation forecasts for these warm season cases using the alterations attempted
- As was already suggested to us, the GD scheme may produce too much drying near the surface (cold pool was too intense though smaller in scale than in fully explicit run)
- Appears much more effort would be needed to determine best combination of closures to get best performance in GD

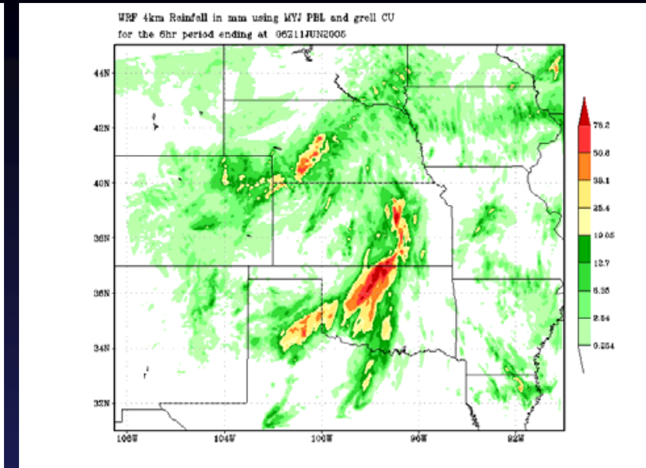
Mesoscale Circulation study (E. Aligo)

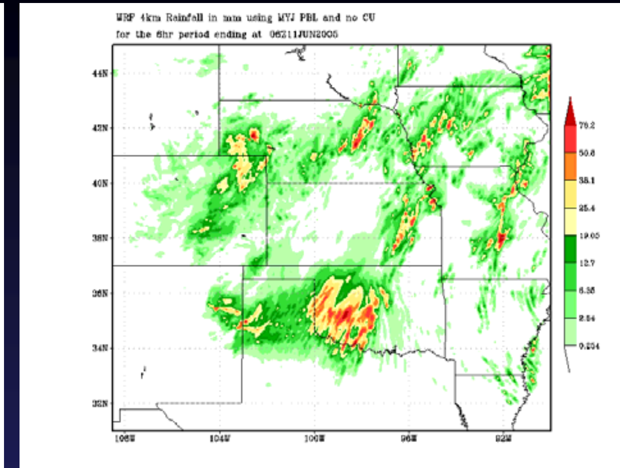
- For the same 5 cases plus additional BAMEX 2003 ones, observations of mesoscale circulations related to convective systems were used to verify the model predictions

Rainfall in 10-11 June 2005 case (comparison of 4 km with GD and without)

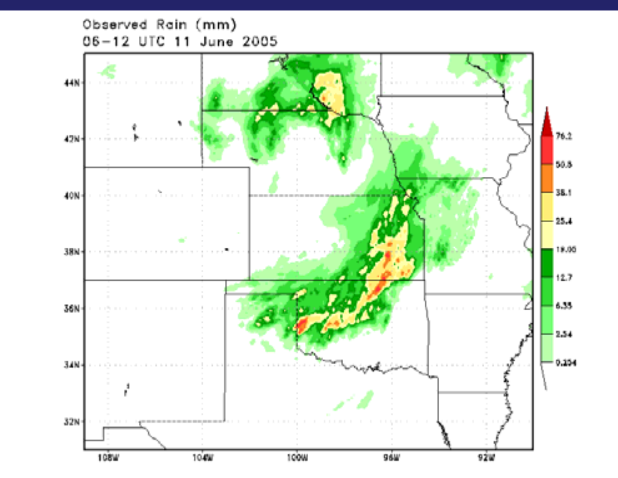
- Both runs missed some areas of rainfall
- Both runs developed convection in SW OK that evolved into 1 or more lines across OK
- No GD run developed a line too early and too far west in OK
- Both runs overpredicted rainfall and moved it too slowly (6 vs 20 m/s)

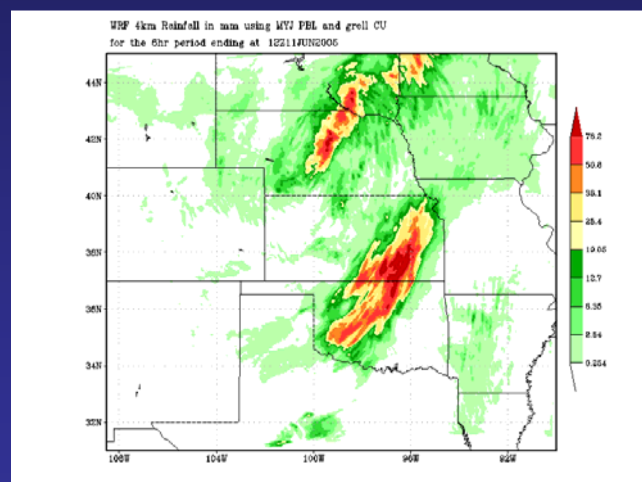


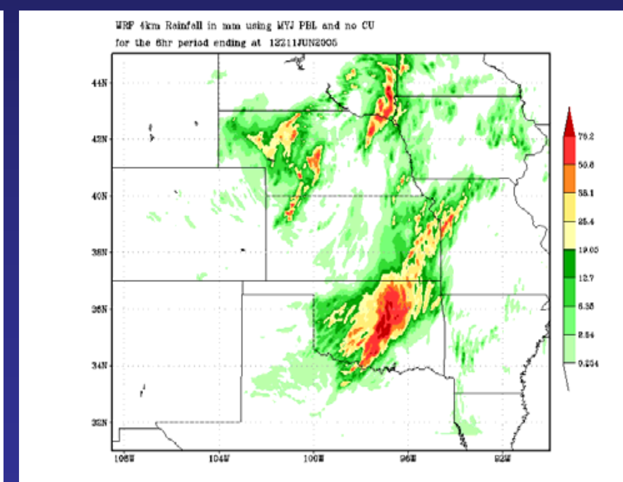




00-06 UTC on top







06-12 UTC on bottom

Observations **4km with GD** **4km without GD**

Wind comparison

- Time-to-space conversion used with 6 min. profiler winds from Lamont, Purcell and Haskell (2hr window)
- Radar showed 18-25 m/s RTF flow in ~1-2 km layer
- GD run was ~5 m/s weaker than no-GD run with these winds. No-GD run was too strong compared to profilers (25-30 m/s) but had better location (Note: radar winds were up to 35 m/s closer to ground)

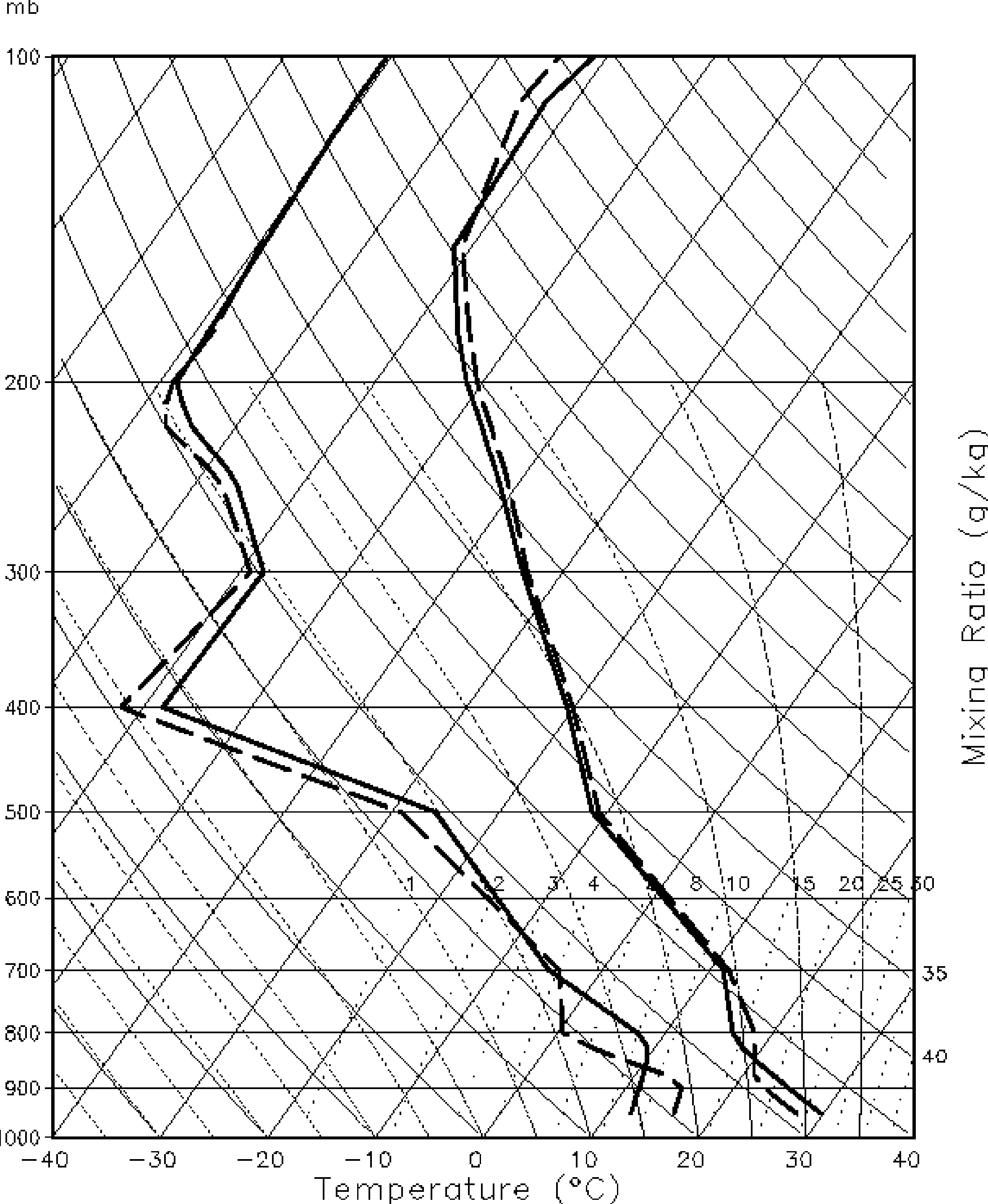
Near-sfc winds and temperatures

- Complicated interaction for outflow location and areal extent due to differences in convective evolution in 2 runs
- Horizontal temperature gradients overestimated by 2-3 C/60 km in both runs

PBL Scheme Study (I. Jankov)

- A controlled comparison of YSU (non-local mixing) and MYJ (local) PBL schemes and their impacts on PBL temperature and humidity was conducted with a goal of improving the MYJ scheme which typically had worse errors (too cool and moist)
- Seven 2005 events were studied from June: 4, 5, 7, 8, 9, 10, 12 using WRF-RR with 13 km grid spacing

- Subjective analysis of soundings was done at selected points. MYJ scheme was often too cool and moist within a too shallow PBL while the YSU scheme was too warm and dry in a too deep PBL.



Typical differences between YSU and MYJ PBL schemes – YSU solid with MYJ dashed in 6h forecast (18 UTC)

- **Soundings were grouped by whether conditions were clear or cloudy (using a 700 mb threshold of 70% RH to define the cloud regions). The differences in PBL schemes were more pronounced in clear conditions, implying a strong relationship to radiative heating. It was also found that the forecasts verifying at 12z did not demonstrate the large differences found for forecasts verifying at 00z, again supporting the idea that any problems in the schemes are related to daytime solar heating.**

- **Areally averaged Central Plains sensible and latent heat fluxes under clear sky indicated that during the daylight (especially around noon) MYJ has a noticeably lower sensible heat flux compared to YSU. Opposite is true for latent fluxes, but with less magnitude.**
- **Lower (higher) sensible (latent) heat fluxes and lack of entrainment at top of PBL support finding that MYJ often produces shallower /cooler/more moist PBLs. Thus, different Bowen ratios and handling of mixing may explain the causes of differences in performance between the schemes.**

- **Analysis of points (instead of area averages) suggests a dependence on vegetation type**
- **Corn belt sites did show MYJ having less sensible and more latent heat flux, with opposite the case for wooded areas**
- **However, regardless of sfc fluxes, PBL in YSU was always deeper with lower 2m q -- implying important influence of vertical exchange process differences in explaining differences in results from the two schemes**

Testing showed the different definitions of surface roughness lengths have a large impact on the Bowen ratio and this may explain some differences.

Both Z_{0q} and Z_{0t} are defined equal in the MYJ (and set to .1* Z_0 which is a routine assumption). A test increasing them to be equal to Z_0 warmed the PBL with deeper PBL depth (but not necessarily a valid option).

In YSU, effective Z_{0q} is lower than Z_0, with $Z_{0t} = Z_0$ (which may not be valid). This likely yields overpredicted sensible heat fluxes and underpredicted latent fluxes (a change to make them equal might help YSU problems).

Because MYJ scheme does not include temperature entrainment at the top of the PBL, a test was done prescribing the surface sensible heat flux to be 1.2 * H_s (taking into account some entrainment at top of PBL). This test did increase the PBL depth and result in warming and drying.

Look Back at 2004 DTC Visit

- I. Jankov and W. Gallus visited DTC during late summer 2004
- During that project, Gallus used archived DTC Retrospective Run data from August 2002 and combined it with new 8 km WRF runs for 15 August cases to perform a “more controlled” experiment on the sensitivity of rainfall forecasts to physics package, dynamic core, and initial conditions & grid spacing (*Gallus & Bresch paper to appear in MWR*)

Procedures

- **WRF-NMM runs using 8 km grid spacing and two different physics packages (NCAR, NCEP) were accessed from DTC archive (these used Eta initial/bc data) [A. Loughe assisted]**

  -- NCAR physics: Ferrier MP, YSU PBL, KF cu scheme, Dudhia/RRTM radiation, NOAH

  -- NCEP physics: Ferrier MP, MYJ PBL, BMJ cu scheme, GFDL radiation, NOAH

Procedures

- WRF-NMM runs using 8 km grid spacing and two different physics packages (NCAR, NCEP) were accessed from DTC archive (these used Eta initial/bc data) [A. Loughe assisted]
- **WRF-ARW runs using 8 km grid spacing and two different physics packages were performed by Gallus (using Eta initial/bc data) [J. Bresch assisted]**
- **WRF-ARW runs using 10 km grid spacing and 2 different physics packages with RUC/Eta initial/bc data were obtained from DTC archive.**

Procedures (cont.)

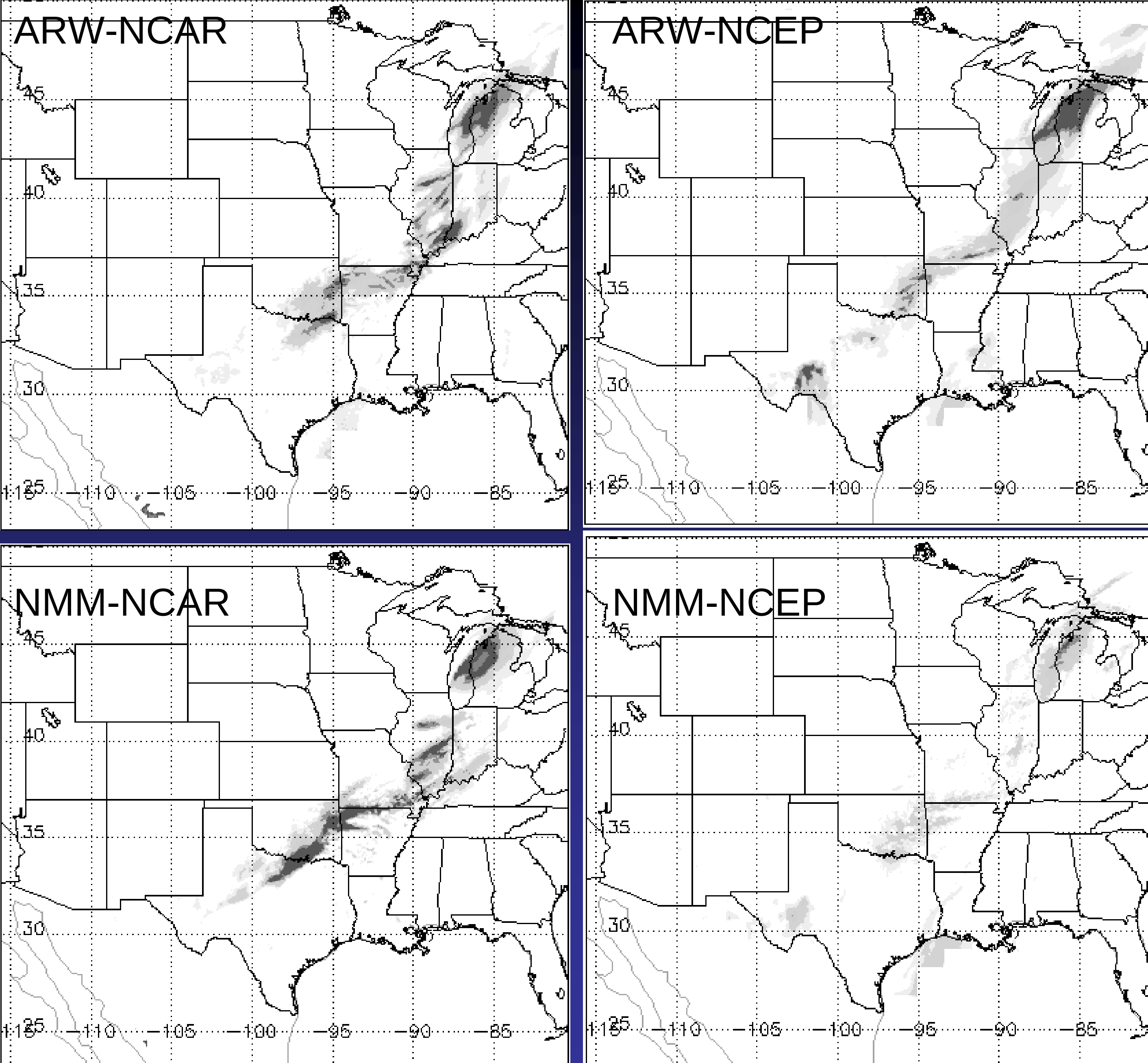
- 15 cases with active convective systems were chosen from the central USA and integrated for 48 hrs (to match the Retrospective Runs)
- Ebert-McBride verification system was used to evaluate all of the runs, providing range of objective skill measures (L. Wharton assisted)
- Correspondence Ratio computed between pairs of runs to determine impacts of changes in physics, dynamics, and initial conditions & grid.

15 cases used, with peak 6-h rainfall (mm) shown for the Stage IV observations and 4 model configurations, and domain rain volume in parentheses. Rain rates > 4 in./6h in red, < 3 in./6h in green

Case	Observed	ARW-NCAR	ARW-NCEP	NMM-NCAR	NMM-NCEP
8/3	3.24 (24.5)	4.60 (27.8)	2.22 (28.8)	5.49 (26.9)	1.70 (23.4)
8/4	4.38 (18.7)	7.34 (23.2)	2.77 (25.0)	4.56 (19.1)	1.23 (19.4)
8/5	4.74 (18.3)	5.45 (24.7)	1.85 (28.8)	4.63 (19.2)	1.38 (21.4)
8/8	4.43 (20.0)	4.57 (21.7)	2.78 (25.1)	5.85 (19.8)	1.43 (21.9)
8/9	2.57 (13.4)	4.20 (18.1)	2.83 (19.0)	4.65 (19.4)	1.68 (15.8)
8/11	2.84 (18.8)	3.69 (22.2)	2.23 (18.0)	3.11 (20.7)	2.10 (15.5)
8/12	3.56 (26.3)	3.27 (34.7)	2.42 (34.1)	6.69 (33.7)	1.69 (28.4)
8/13	4.80 (34.7)	4.20 (50.4)	3.49 (50.7)	2.80 (43.3)	1.30 (36.2)
8/16	3.16 (31.6)	4.09 (38.3)	2.77 (40.9)	5.15 (35.7)	2.03 (32.9)
8/18	4.48 (18.0)	2.70 (21.1)	3.29 (17.5)	4.91 (16.8)	1.33 (16.1)
8/20	3.53 (23.1)	4.33 (33.6)	4.87 (31.6)	5.09 (27.4)	1.48 (30.8)
8/21	4.11 (31.4)	7.25 (43.3)	2.41 (41.9)	4.69 (40.1)	2.08 (36.4)
8/22	3.05 (19.6)	6.74 (31.0)	3.42 (32.9)	4.85 (25.6)	1.18 (26.5)
8/26	3.30 (19.0)	5.09 (20.1)	2.72 (15.2)	4.99 (18.9)	0.78 (12.7)
8/28	2.81 (17.4)	2.84 (23.3)	2.94 (20.3)	7.37 (20.8)	1.23 (14.7)
AVE	3.67 (22.3)	4.65 (28.9)	2.87 (28.7)	4.99 (25.8)	1.51 (23.5)

Trends in rate and volume

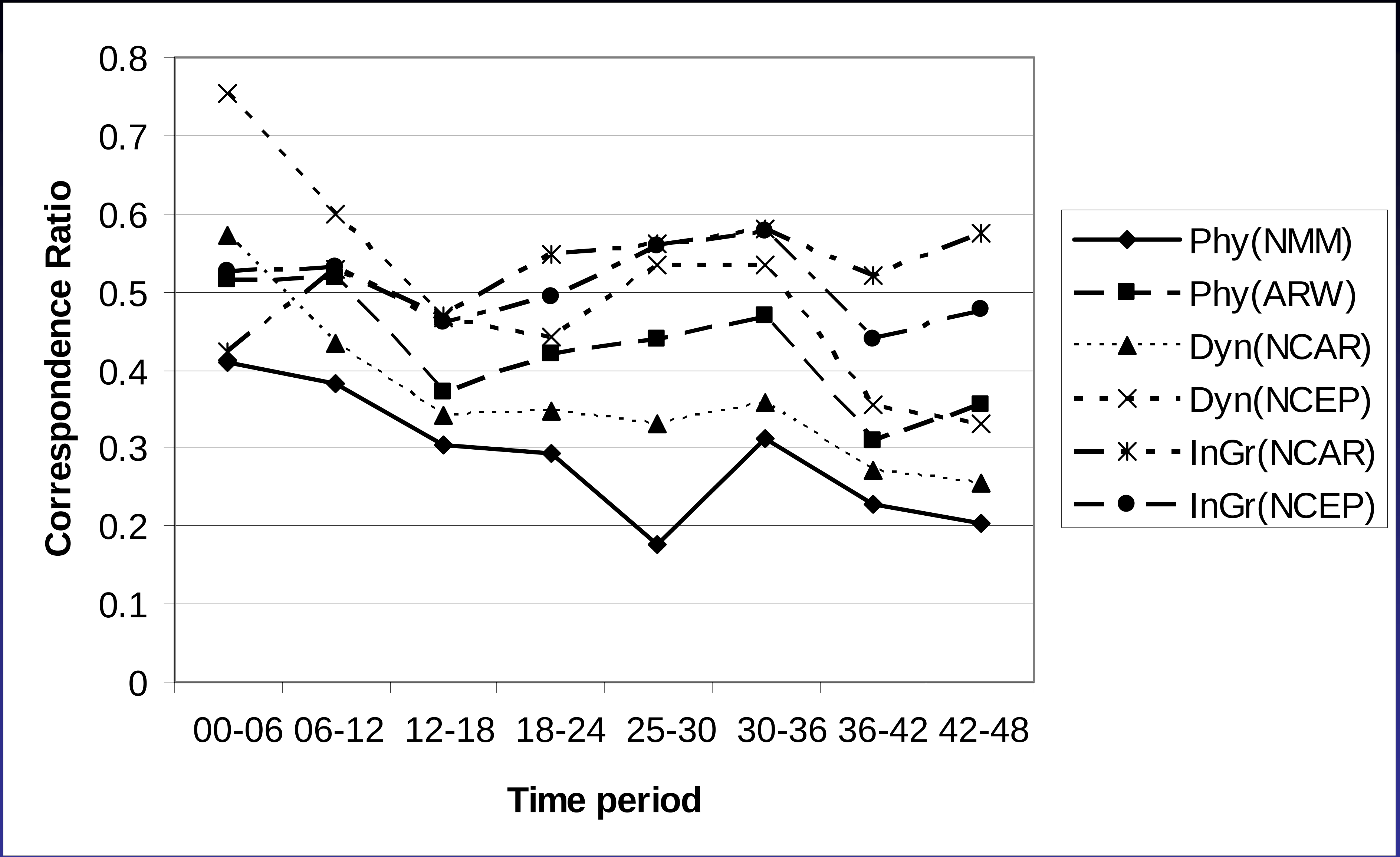
- Peak 6h rates overestimated when NCAR physics used, underestimated with NCEP physics
- All 4 configurations overestimated volume but ARW had worse problem than NMM. Also, especially bad problem in first 6 hours when NCEP physics used
- Some evidence that peak rates are affected most by physics package, but total volume is affected more by dynamic core



12-18 h forecast (00-06 UTC) from 12 UTC Aug 13 run

Good example of general trends –

More detail in NCAR physics, More volume in ARW dynamic core runs



CRs for a threshold of .01 inch as a function of time for 6 model comparisons (labels refer to process changed with the core or physics held constant shown in parentheses)

Ebert-McBride analysis of retro runs for all of August 2002

	ARW-NCEP	ARW-NCAR	NMM-NCEP	NMM-NCAR
# of CRAs	725	994	673	781
Good CRAs (obs+model)	483	622	401	540
Missed Systems	120	154	197	98
False Alarm Systems	122	218	75	143
RMS of shifted system	.501	.555	.489	.481
Displacement Error (km)	134.4	135.4	135.3	131.7
ERROR DECOMP				
-displacement	20.0%	21.6%	20.0%	22.2%
-volume	21.0%	23.3%	30.0%	21.6%
-pattern	59.0%	55.1%	50.0%	56.2%

Conclusions

- Sensitivity to a physics change or dynamic core change is a function of the dynamic core or physics package used
- Most sensitivity is to physics change with NMM core (for both .01 and .5 inch thresholds).
- Sensitivity to dynamic core change with NCAR physics was greater than that to a physics change in the ARW core (for .01 inch)
- Impact of initial condition/grid change was smaller than that of dynamics/physics, except in first 6-12 hours

Acknowledgments

- *Thanks to the WRF-DTC group for the invitations for visits in 2004-2005, and for help in accessing data and codes, running WRF and post-processing routines, and being partners in scientific discussion*
- *Thanks also to the NOAA GSD people for their interactions during the 2005 project*

Average ETS and BIAS scores for 6 configurations for 3 thresholds (in parentheses) red=best, green=worst

	ARW-NCAR	ARW-NCEP	NMM-NCAR	NMM-NCEP	ARW-NCAR (RUC-init)	ARW-NCEP (RUC-init)
ETS (.01)	.304	.293	.304	.274	.288	.288
BIAS (.01)	1.410	1.871	1.034	1.810	1.500	1.862
ETS (.25)	.145	.147	.159	.119	.145	.138
BIAS (.25)	1.284	1.225	1.101	0.924	1.352	1.280
ETS (.5)	.092	.085	.103	.058	.094	.078
BIAS (.5)	1.103	0.886	1.167	0.525	1.160	0.960

CR (.01)	Components Changed	CR (.5)	Components Changed
.311	All (APr-NRe)	.066	All (ARr-NPe)
.330	D+IG (NCAR)	.092	All (APr-NRe)
.347	**P (with NMM)**	**.105**	**P (with NMM)**
.356	D+P (AP-NR)	.113	D+P (AR-NP)
.374	All (ARr-NPe)	.113	D+IG (NCAR)
.401	D+P (AR-NP)	.142	D+P (AP-NR)
.424	**D (with NCAR)**	**.146**	**IG (with NCEP)**
.457	**P (with ARW)**	**.152**	**IG (with NCAR)**
.490	**IG (with NCAR)**	**.157**	**P (with ARW)**
.503	**IG (with NCEP)**	**.240**	**D (with NCEP)**
.565	**D (with NCEP)**	**.244**	**D (with NCAR)**

CRs ranked from most sensitive to least sensitive for comparisons of 2 runs.
Boldface indicates only one change made. D=dynamics, P=physics, IG=initial/grid