Atmospheric and Environmental Research

A Severe Weather QuickOSSE to Examine the Impact of Super Constellations of GPS Radio Occultation Satellites

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Central question:

Given the the current and projected sampling of COSMIC & COSMIC-2 (i.e., 1,800 and 5,000/10,000 global profiles/day),

what would the impact of 1-3 orders of magnitude <u>more</u> profiles from a GPS RO constellation be on severe weather forecasting?

That is, examine the potential of 50,000 – 2,500,000 global profiles/day.

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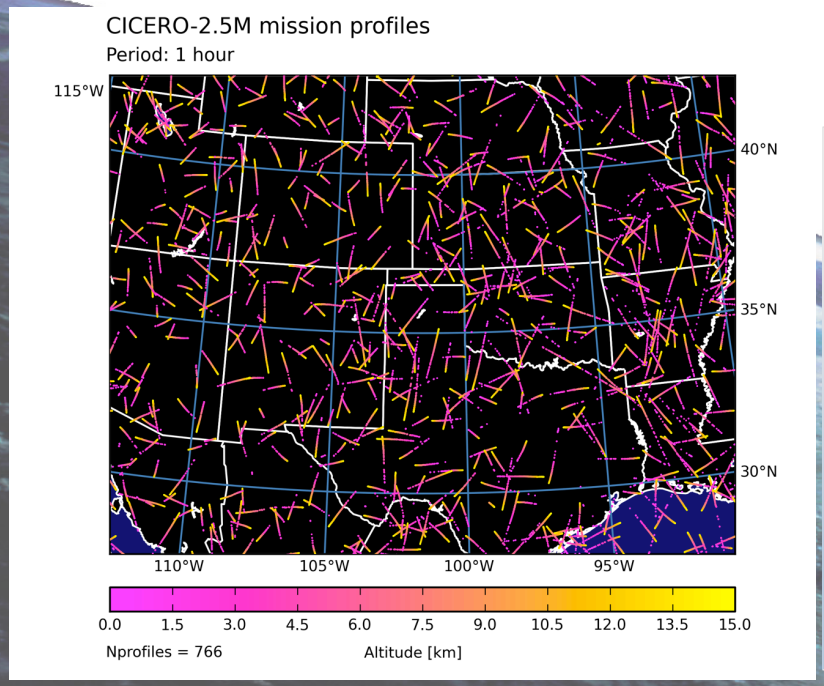
Severe Weather Impact Study: Radio Occultation

Atmospheric and Environmental Research

- The problem: severe wx forecasting needs improvement; more data density should help
- The approach: OSSE that adds GPS-RO data to NWP and examine effect on severe wx forecast
  - WRF/DART ensemble data assimilation
  - verification against Nature Run (i.e., "true") updraft helicity and 2-meter sensible weather
  - simulated GPS-RO observations for a variety of constellations; 60 K – 2.5 M profiles/day globally
- The payoff: quantify expected forecast improvements as a function of GPS-RO data density; looking for inflection points



← Approximate GPS-RO sampling over study domain for ***1 hour***, assuming
  - a future constellation that could produce up to 2.5M global profiles/day, e.g., approx. 1,200 microsats – "superconstellation"

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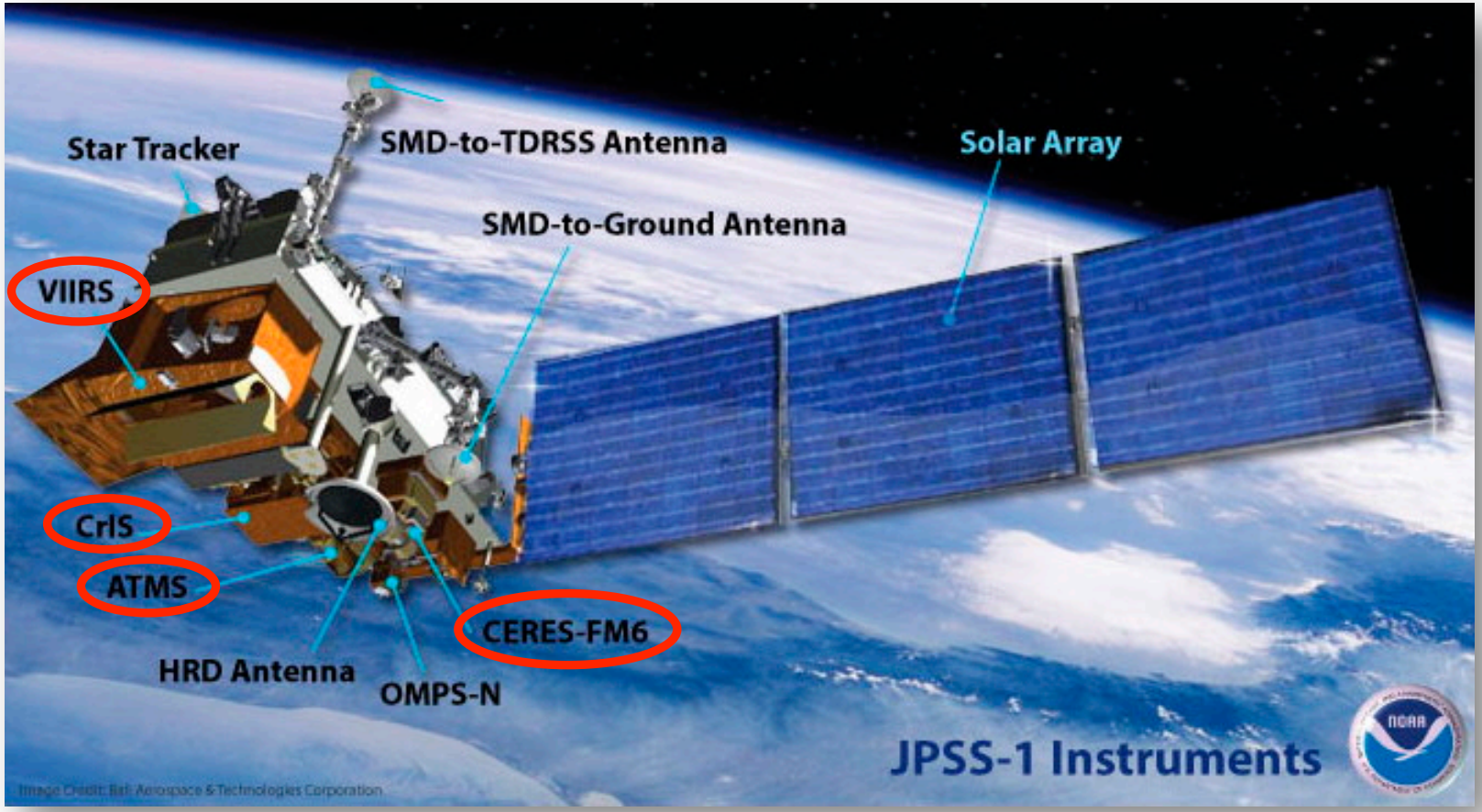
JPSS Today

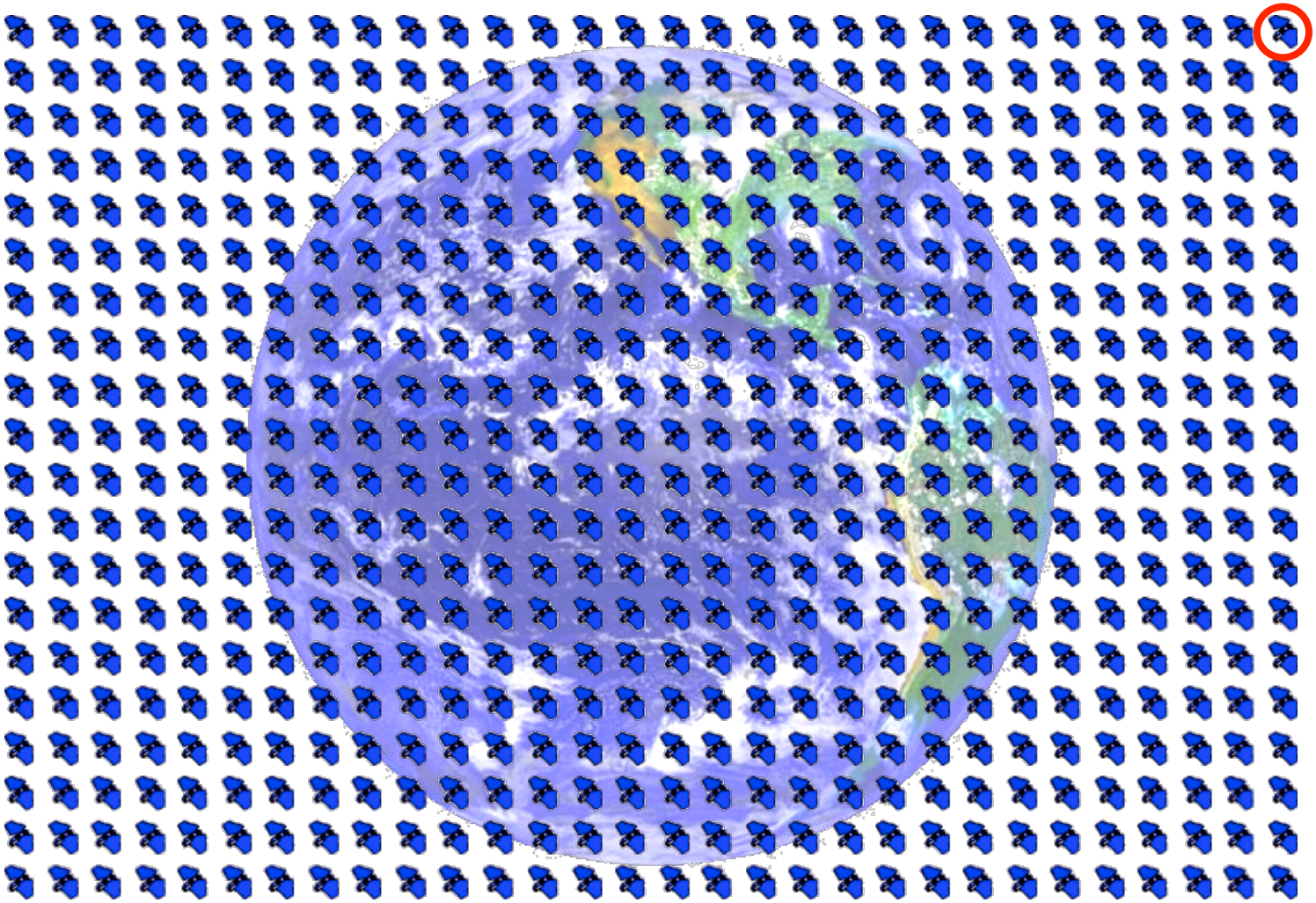


Four weather sensors on two platforms: **$11.3 billion** life cycle cost

Average cost-to-orbit: more than **$800 million** per sensor

Slide courtesy Tom Yunck, GeoOptics.

What $800,000,000 will buy <u>today</u>:



600 CICERO satellites to orbit, **>1,000,000** profiles/day

Slide courtesy Tom Yunck, GeoOptics.

Outline

- Severe Weather OSSE (18)
- Simulated CICERO data (Community Initiative for Continuing Earth Radio Occultation) (8)
- Vertical thinning of GPS RO data (1)
- Analysis Results (17)
- Forecast Impacts (11)
- Conclusions and looking ahead (1)

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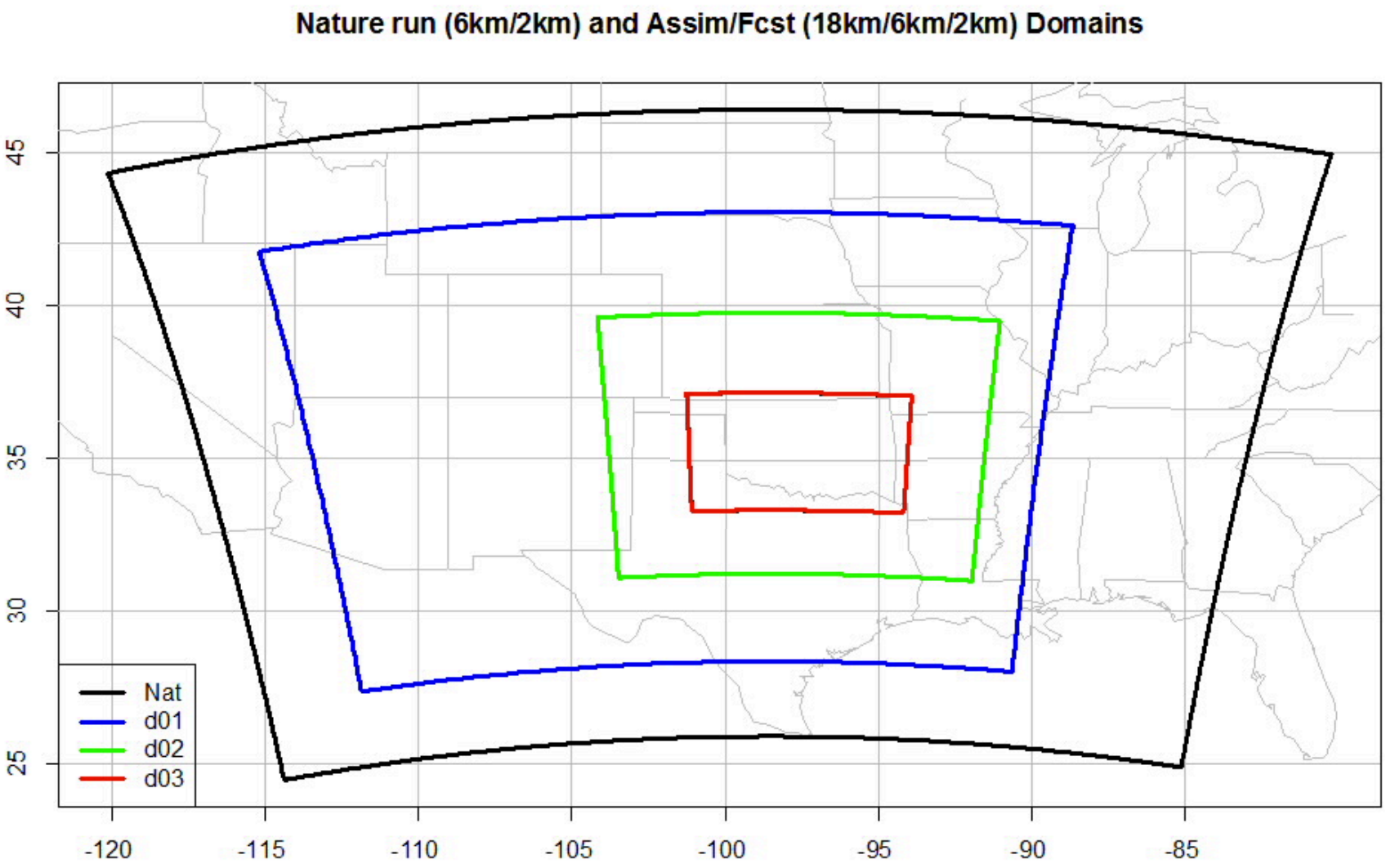
Nature run (6km/2km) and Assim/Fcst (18km/6km/2km) Domains
45
40
35
30
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-120
-115
-110
-105
-100
-95
-90
-85
Nat
d01
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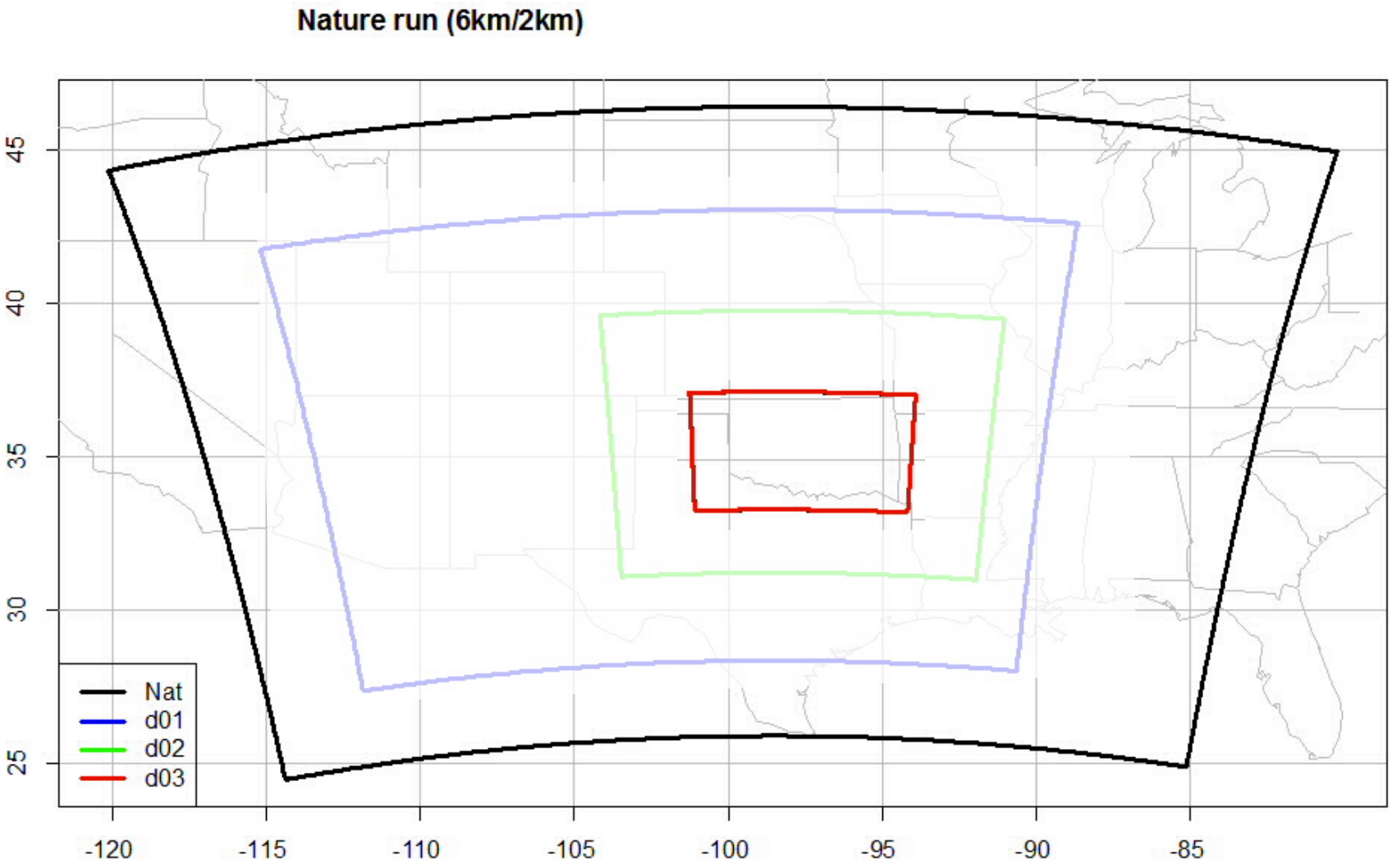
Nature run (6km/2km)
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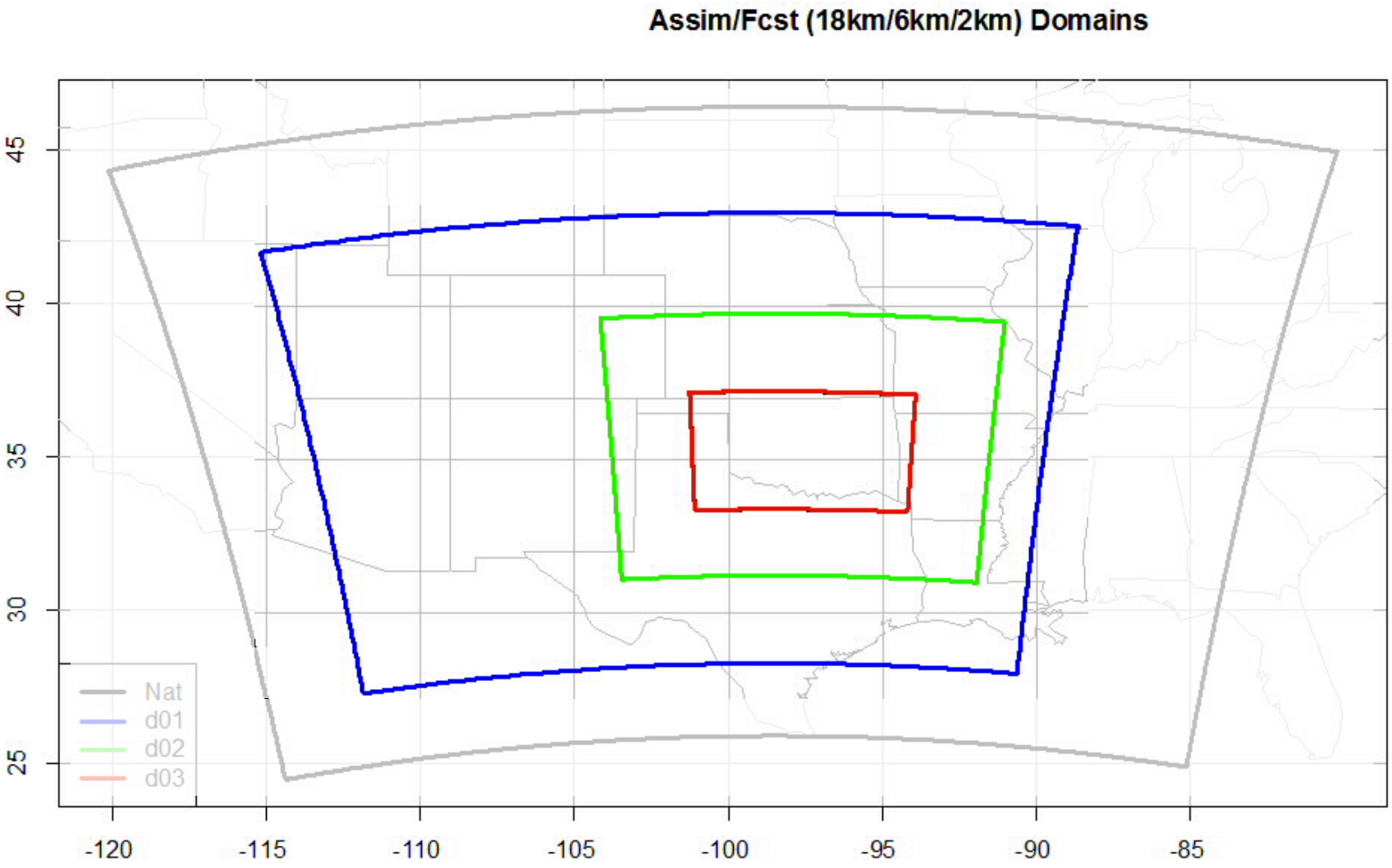
Assim/Fcst (18km/6km/2km) Domains
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35
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-120
-115
-110
-105
-100
-95
-90
-85
Nat
d01
d02
d03

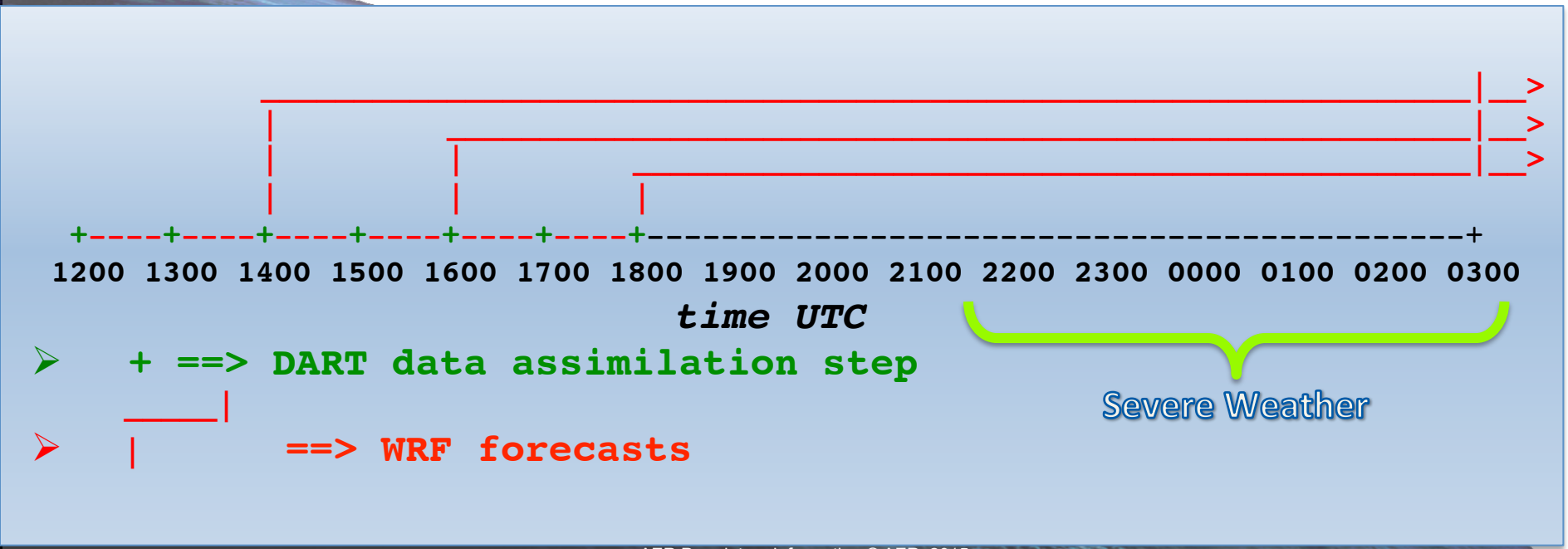
Severe Weather OSSE

Assimilation system is WRF DART, using the built-in GPS-RO non-local, excess phase forward operator.

Uses a 24-member, multi-physics ensemble of WRF forecasts to estimate localized, flow-dependent background error covariances.

Severe weather for El Reno case occurred between 2100 UTC 31 May – 0300 UTC 1 Jun 2013.

Hourly cycling data assimilation with WRF DART begins 1200 UTC and ends 1800 UTC; forecasts launched at 1400, 1600 and 1800 UTC out to 1200 UTC the next day (mirrors NSSL Spring Experiment)



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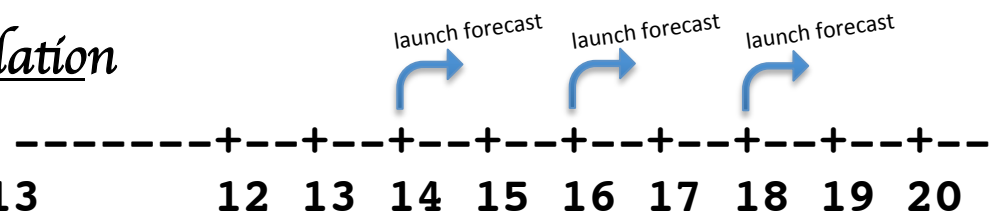
Experiment treatments/Ensemble member composition

1. Control – conventional data
2. C250K – Control + CICERO 250K constellation observations
3. C2.5M – Control + CICERO 2.5M constellation observations

Ensemble WRF-ARW physics components:

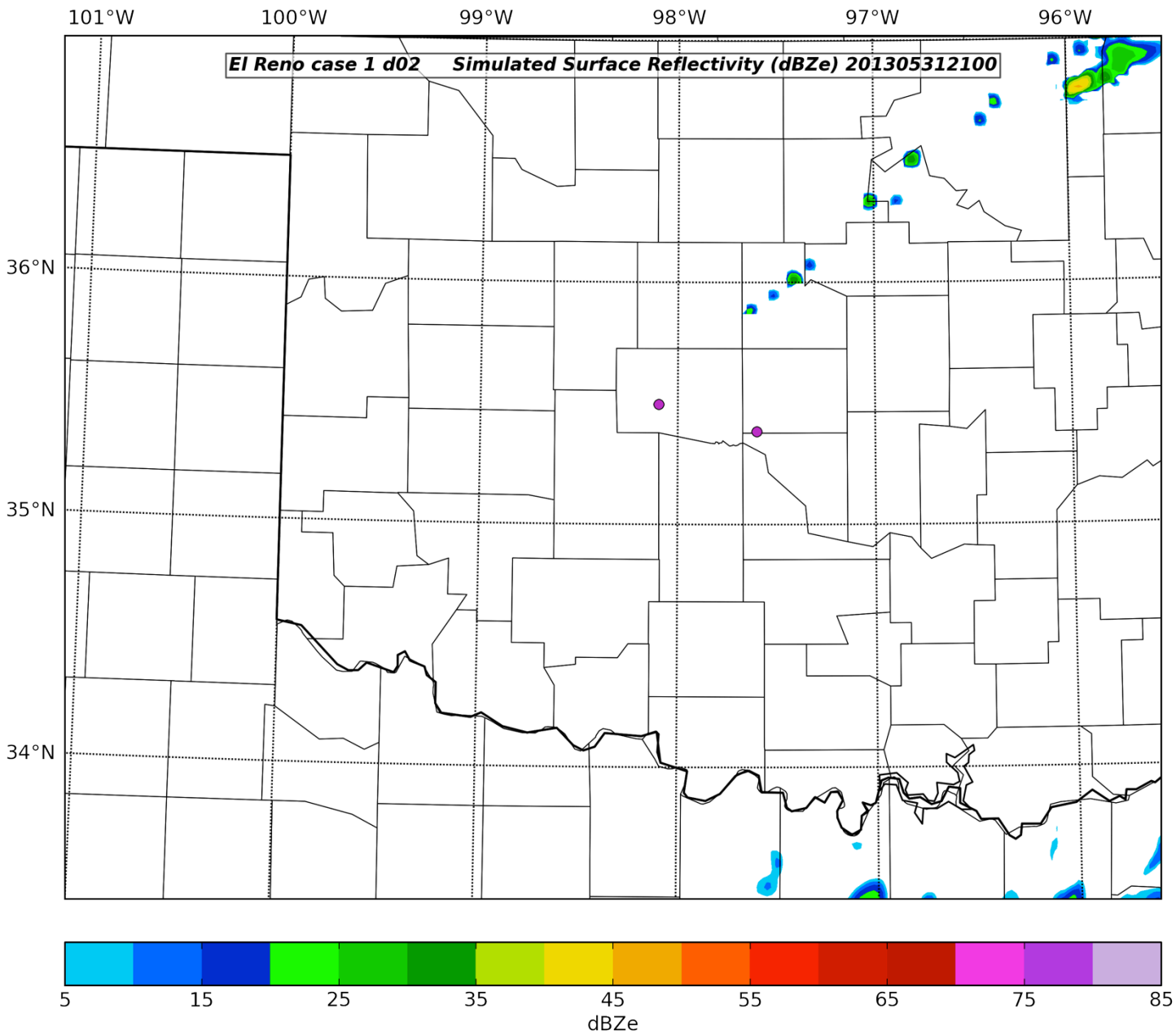
```
Rad: A: RRTM(LW:1)/Dudhia (SW:1)
     B: RRTMG (LW:4)/RRTMG (SW:4)
     C: Goddard (LW:5)/Goddard (SW:2)

PBL: A: sf_surface (2)/sf_sfclay (1)/bl_pbl (1): YSU
     B: sf_surface (2)/sf_sfclay (2)/bl_pbl (2): MYJ
     C: sf_surface (2)/sf_sfclay (5)/bl_pbl (5): MYNN
     D: sf_surface (7)/sf_sfclay (7)/bl_pbl (7): ACM2

Cu:  A: Kain-Fritsch (1)
     B: Grell-Freitas (3)
     C: Tiedtke (6)
```

Hourly, cycling data assimilation



OSSE uses simulated obs of non-local excess phase

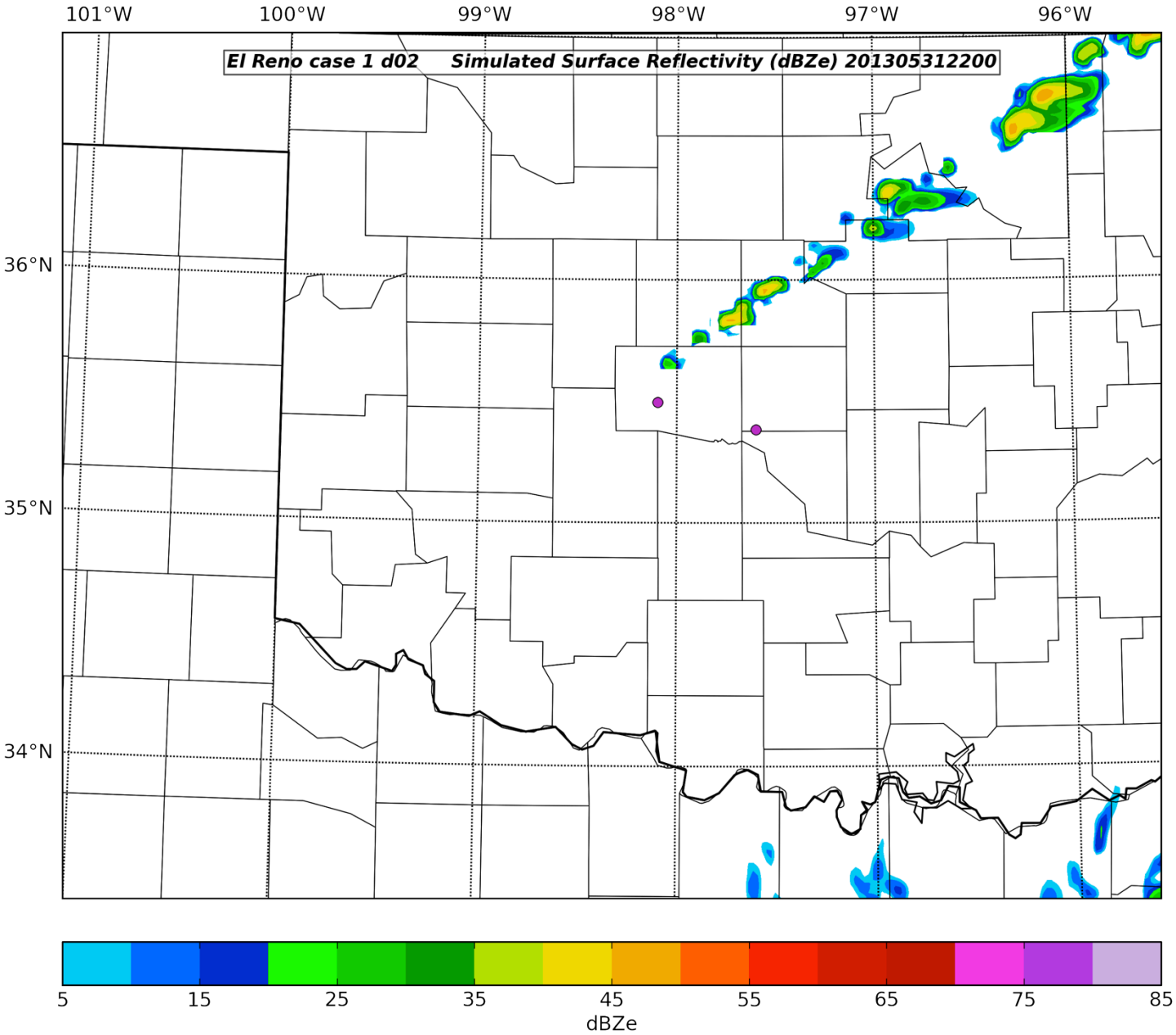
- Excess phase is the difference between vacuum and refracted limb paths
  - 140 m near the sfc to 10 m in lower stratosphere
- 2D obs operator integrates along straight ray paths (Sergey et al., 2004)
- “real” obs are sampled from the Nature Run and have expected errors added
  - obs error is a random Gaussian draw from expected errors
  - Expected errors are vertical profiles of climatological excess phase errors (fractional error and std dev)
  - Ranges from 1.3 – 0.2% from sfc to 17 km.



Nature Run

WRF Simulated Radar Reflectivity

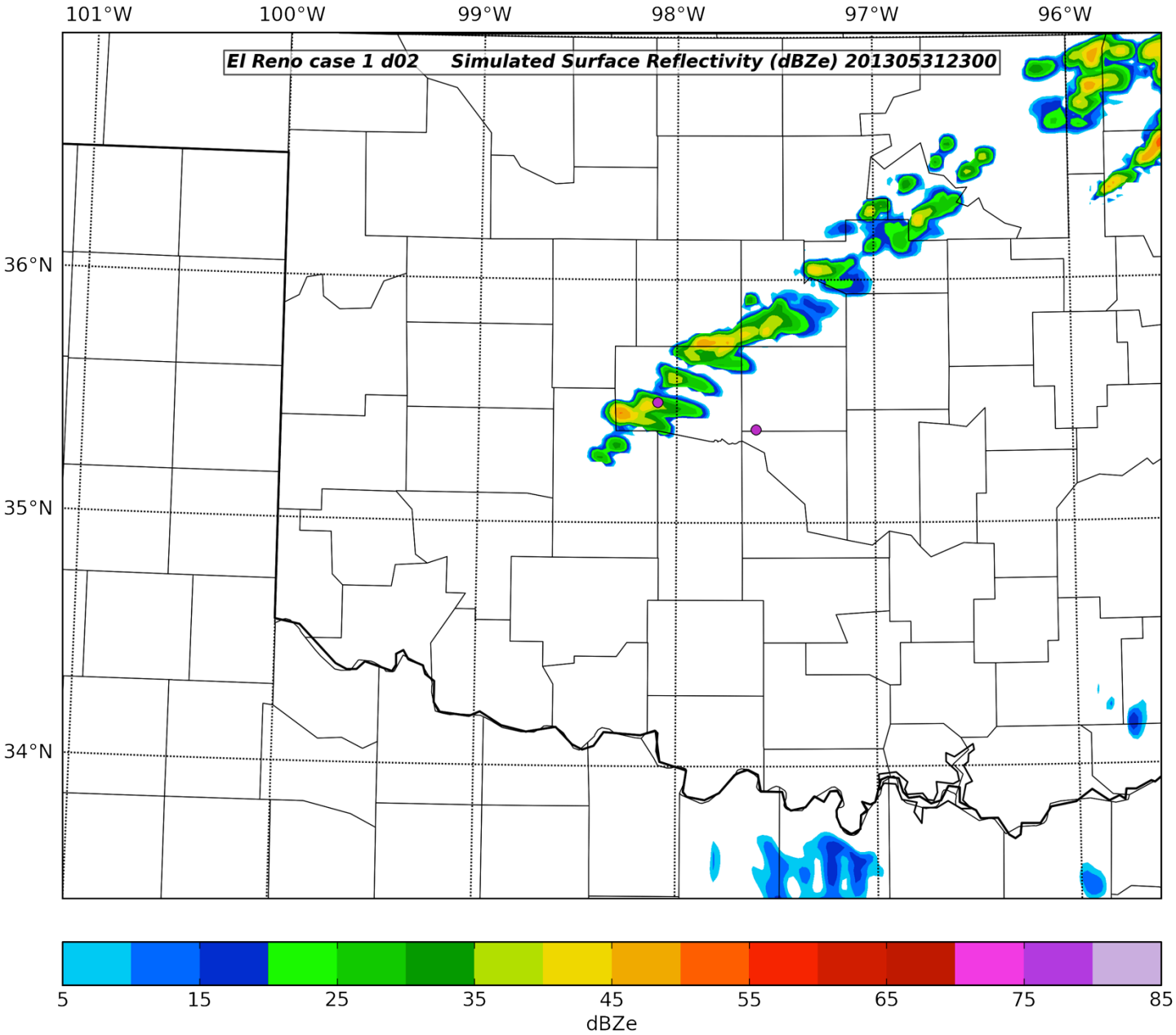
21Z May 31



Nature Run

WRF Simulated Radar Reflectivity

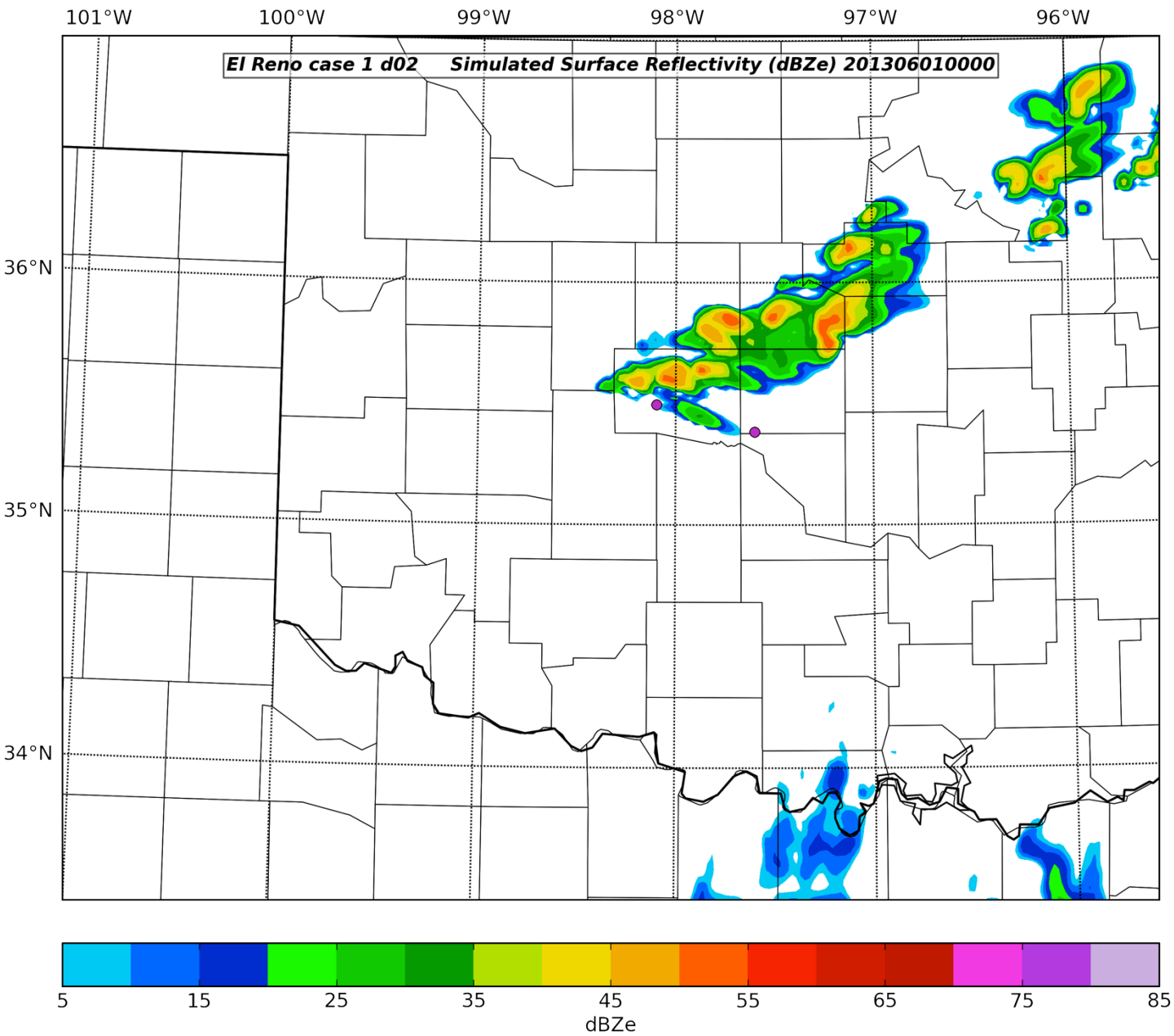
22Z May 31



Nature Run

WRF Simulated Radar Reflectivity

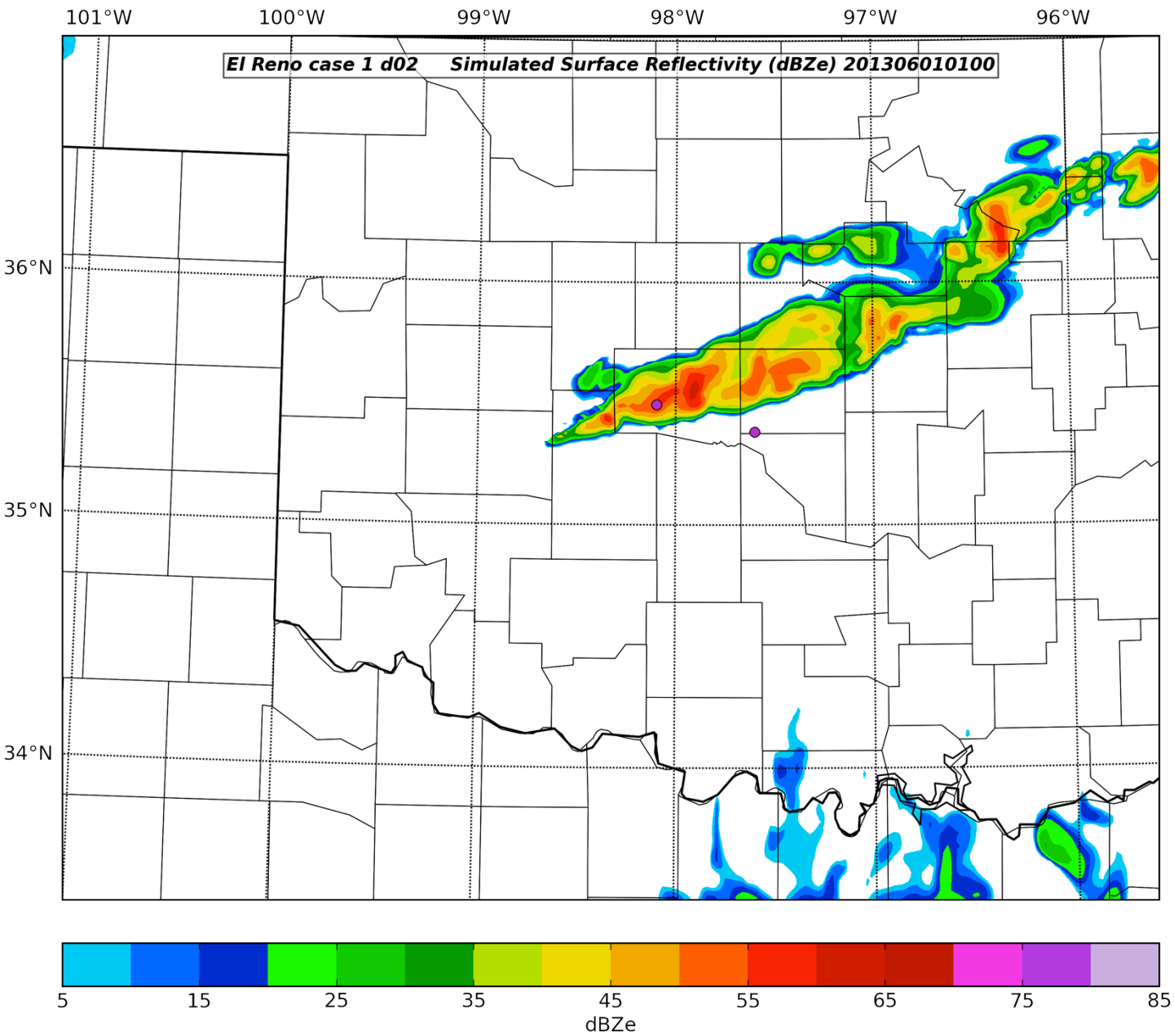
23Z May 31



Nature Run

WRF Simulated Radar Reflectivity

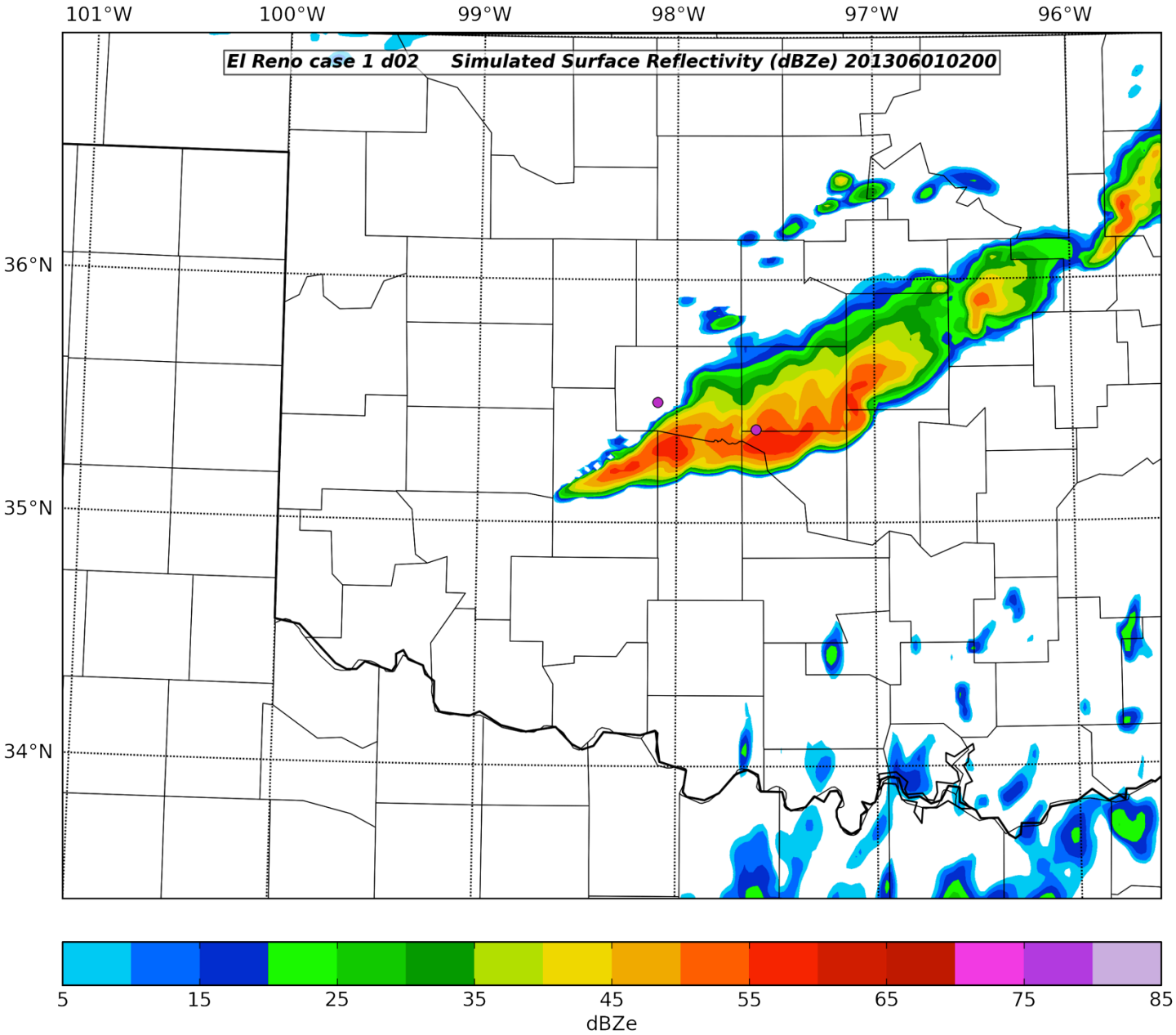
00Z June 1



Nature Run

WRF Simulated Radar Reflectivity

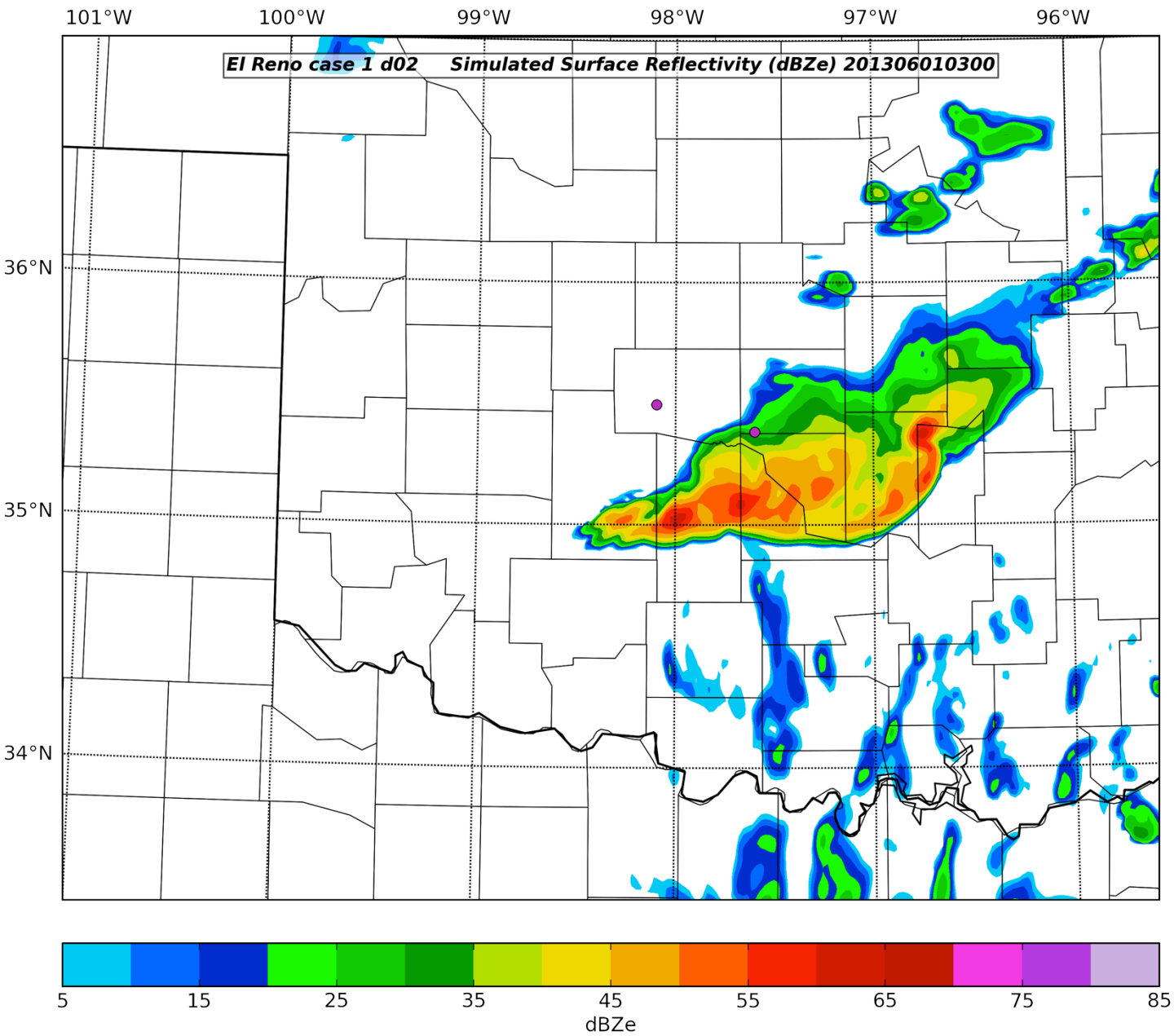
01Z June 1



Nature Run

WRF Simulated Radar Reflectivity

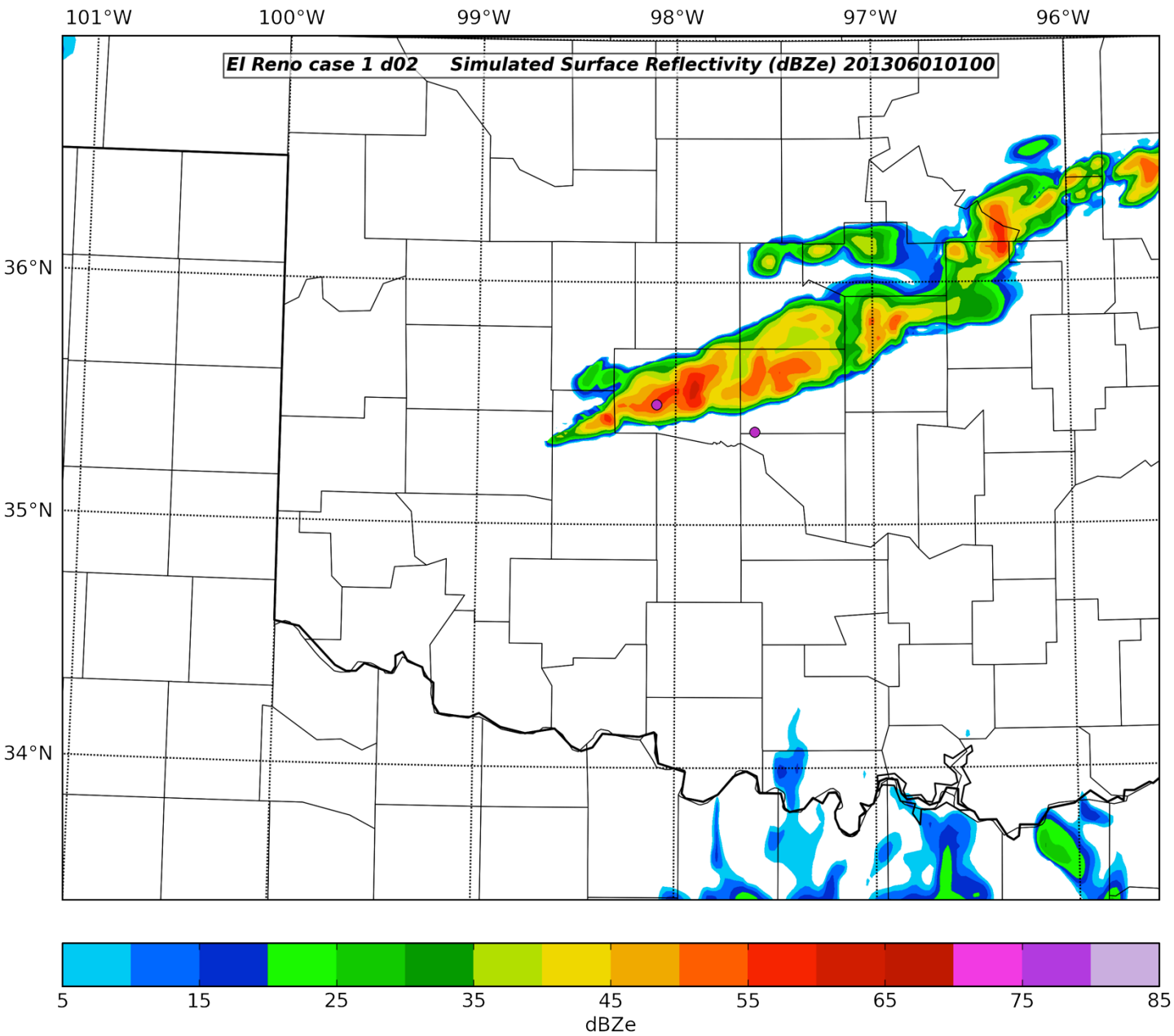
02Z June 1



Nature Run

WRF Simulated Radar Reflectivity

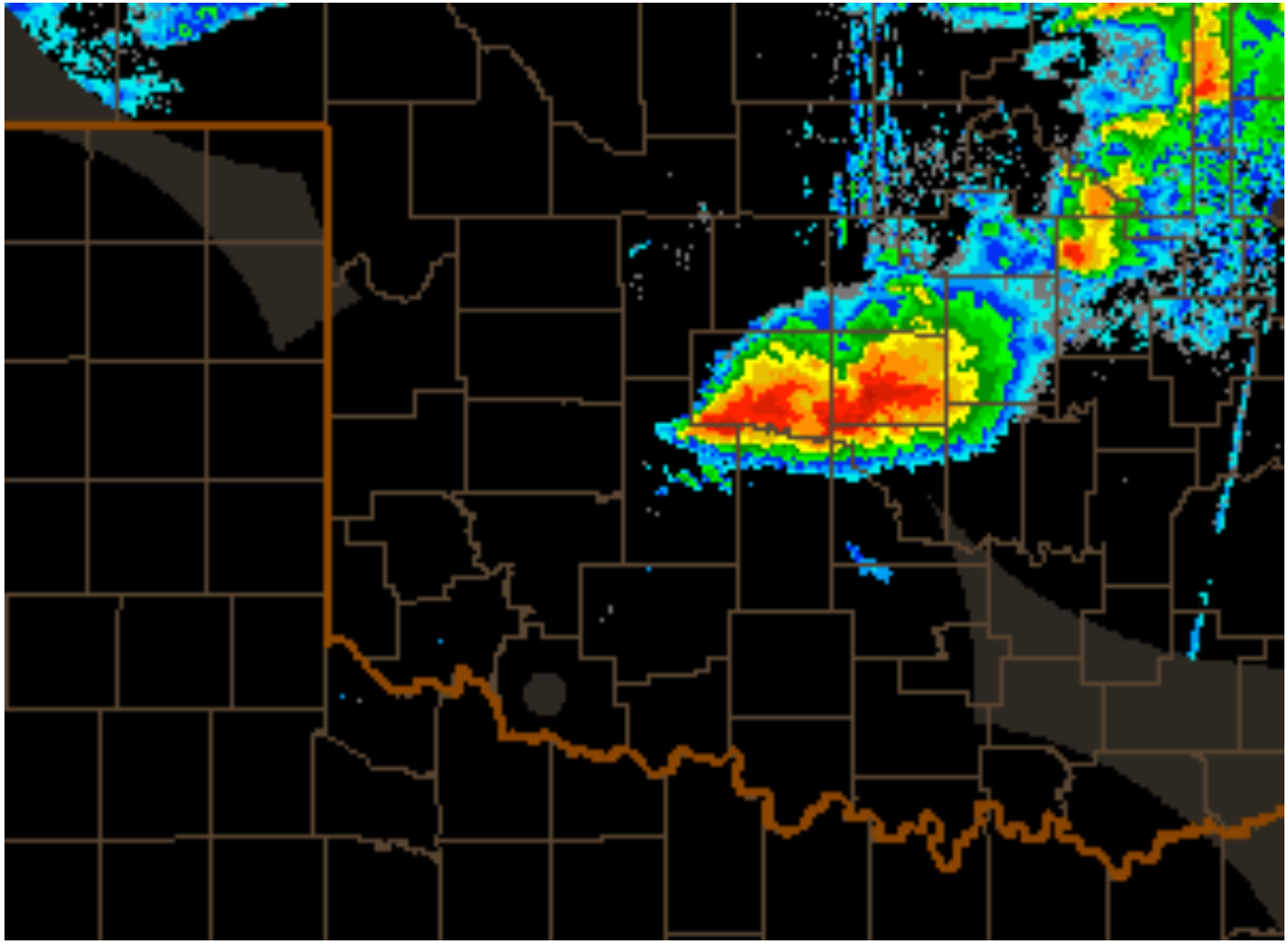
03Z June 1



Nature Run

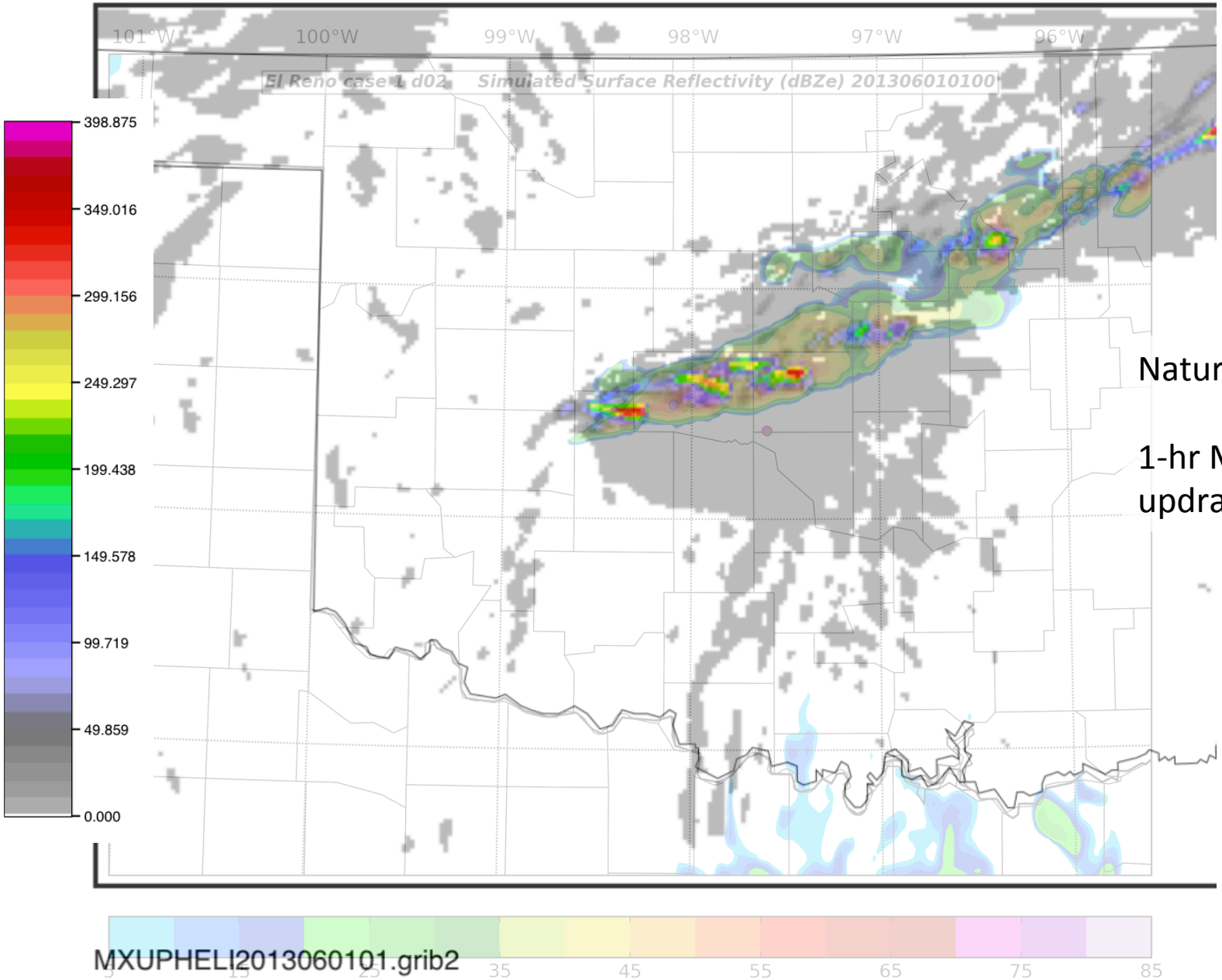
WRF Simulated Radar Reflectivity

01Z June 1



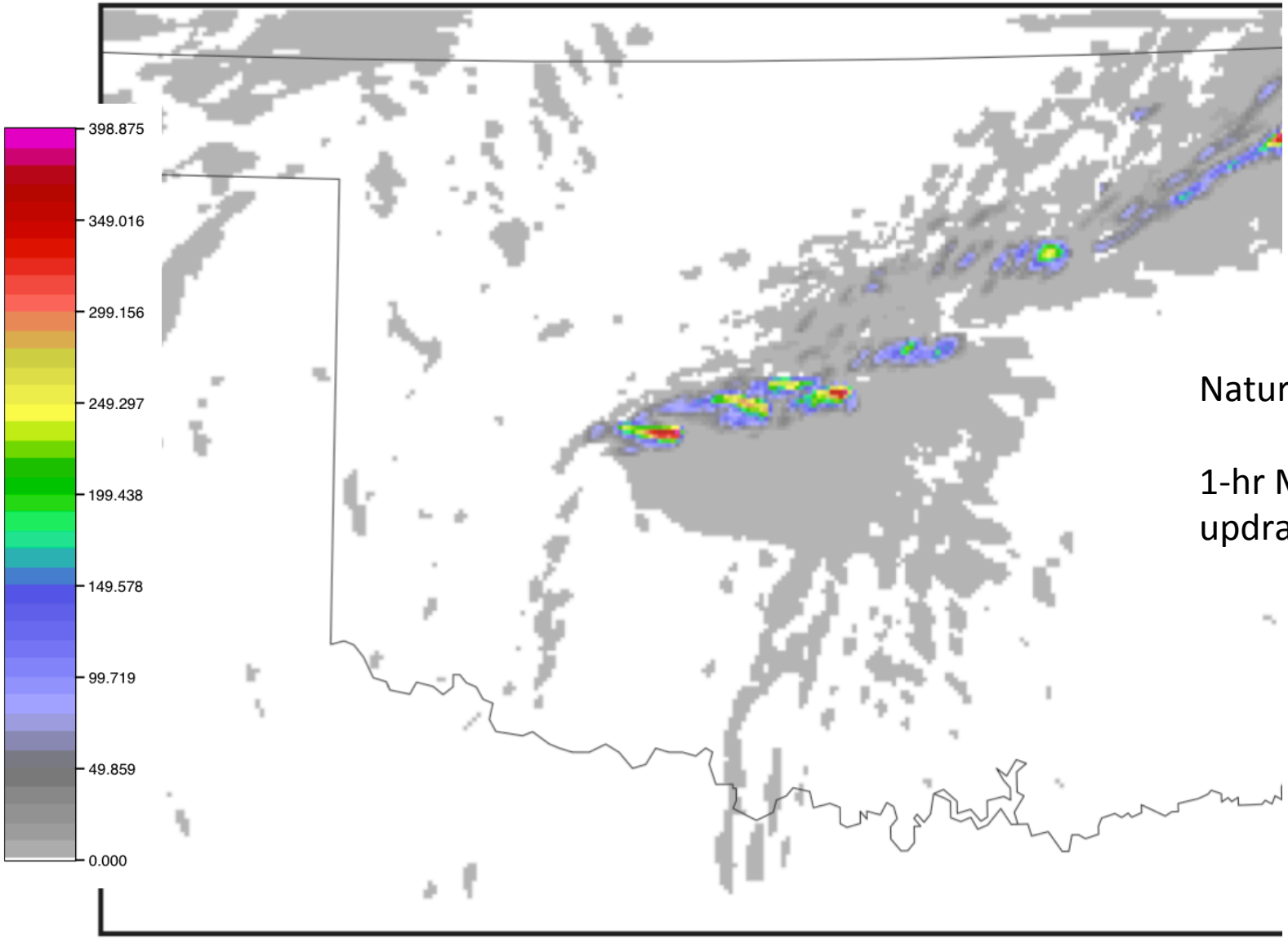
Observed Radar Reflectivity

01Z June 1



Nature Run

1-hr Maximum updraft helicity



Nature Run

1-hr Maximum updraft helicity

MXUPHELI2013060101.grib2

Simulating CICERO data (1/8)

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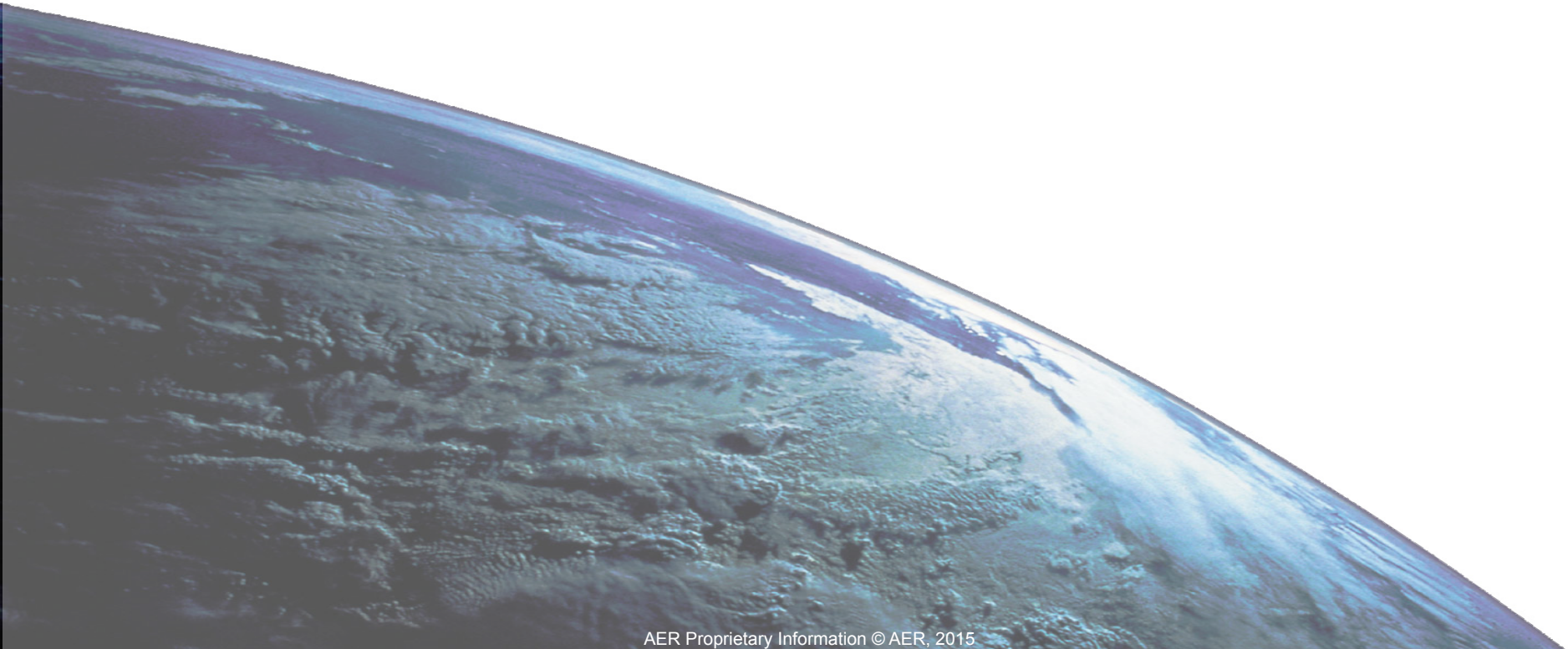
- transformation of real COSMIC -> simulated CICERO constellations



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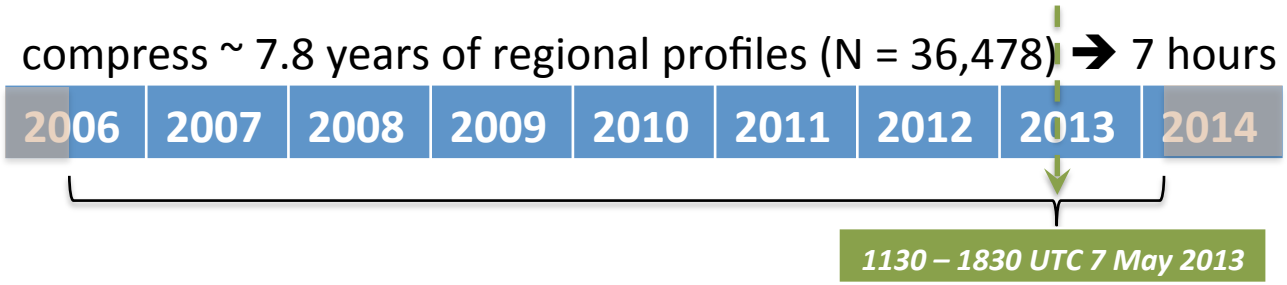
Conversion of COSMIC RO profiles to simulated CICERO profiles

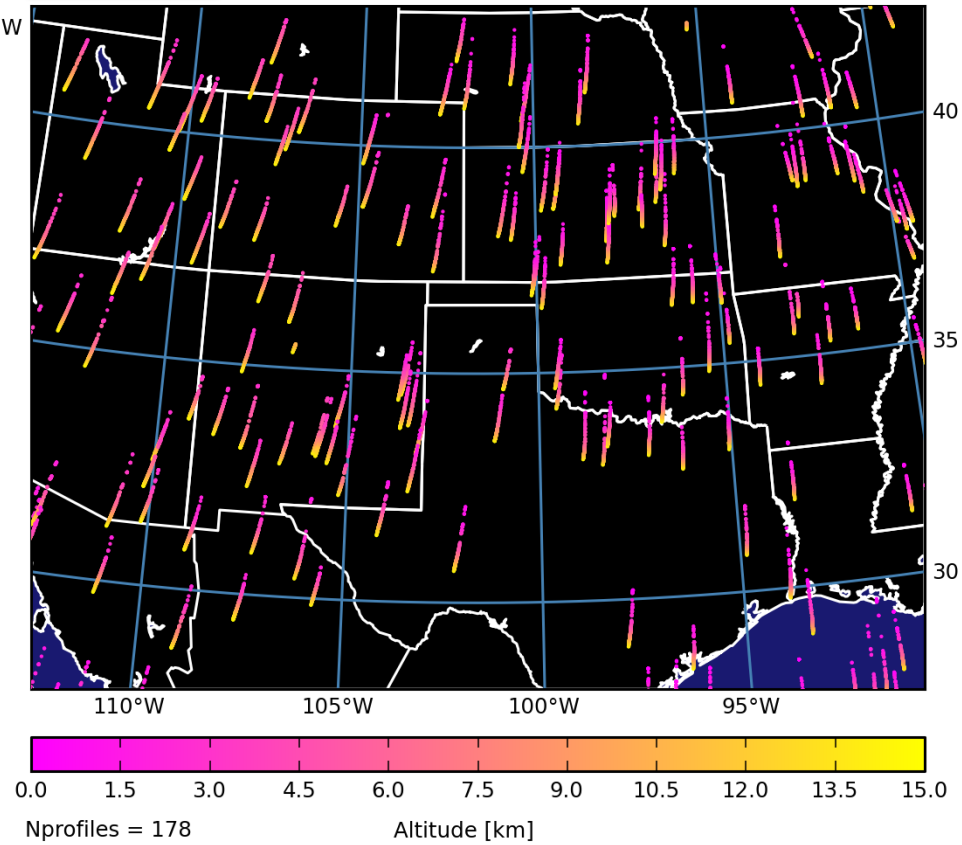
Time: compress ~ 7.8 years of regional profiles (N = 36,478) ➔ 7 hours



Space: rotate profiles/azimuths from COSMIC (preferred) orientations ➔ random

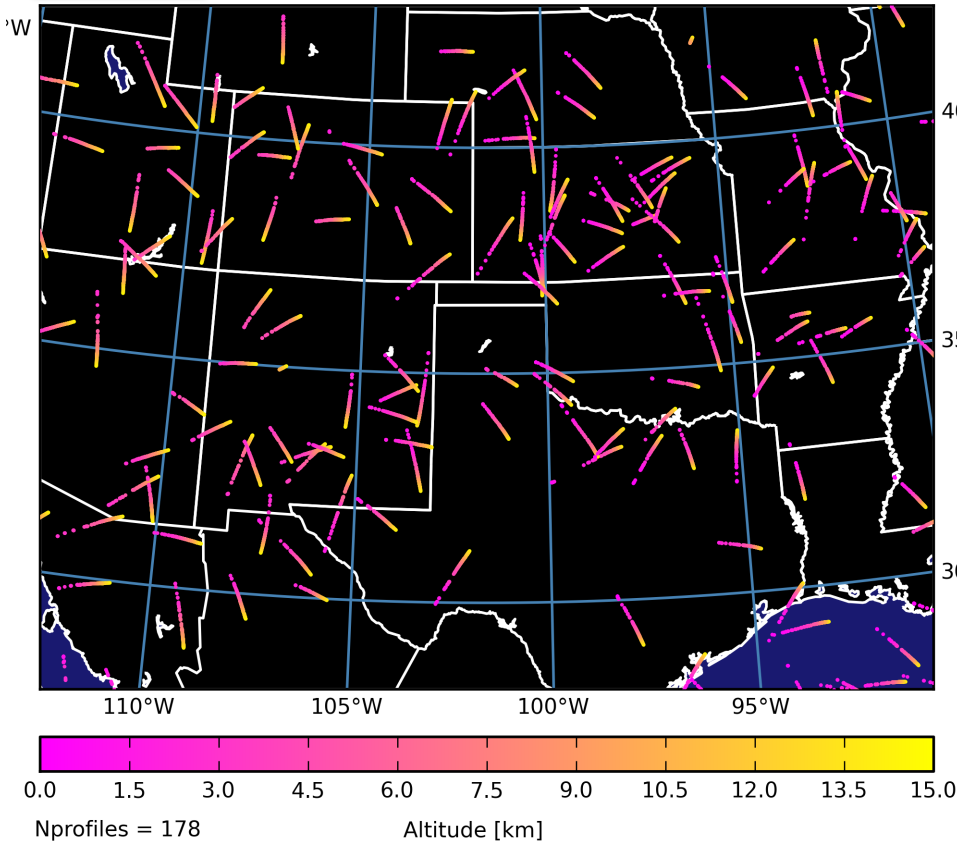
COSMIC/G22 profiles, rising occultations

Period: 7.8 yrs (May 20, 2006 - Feb 27, 2014)



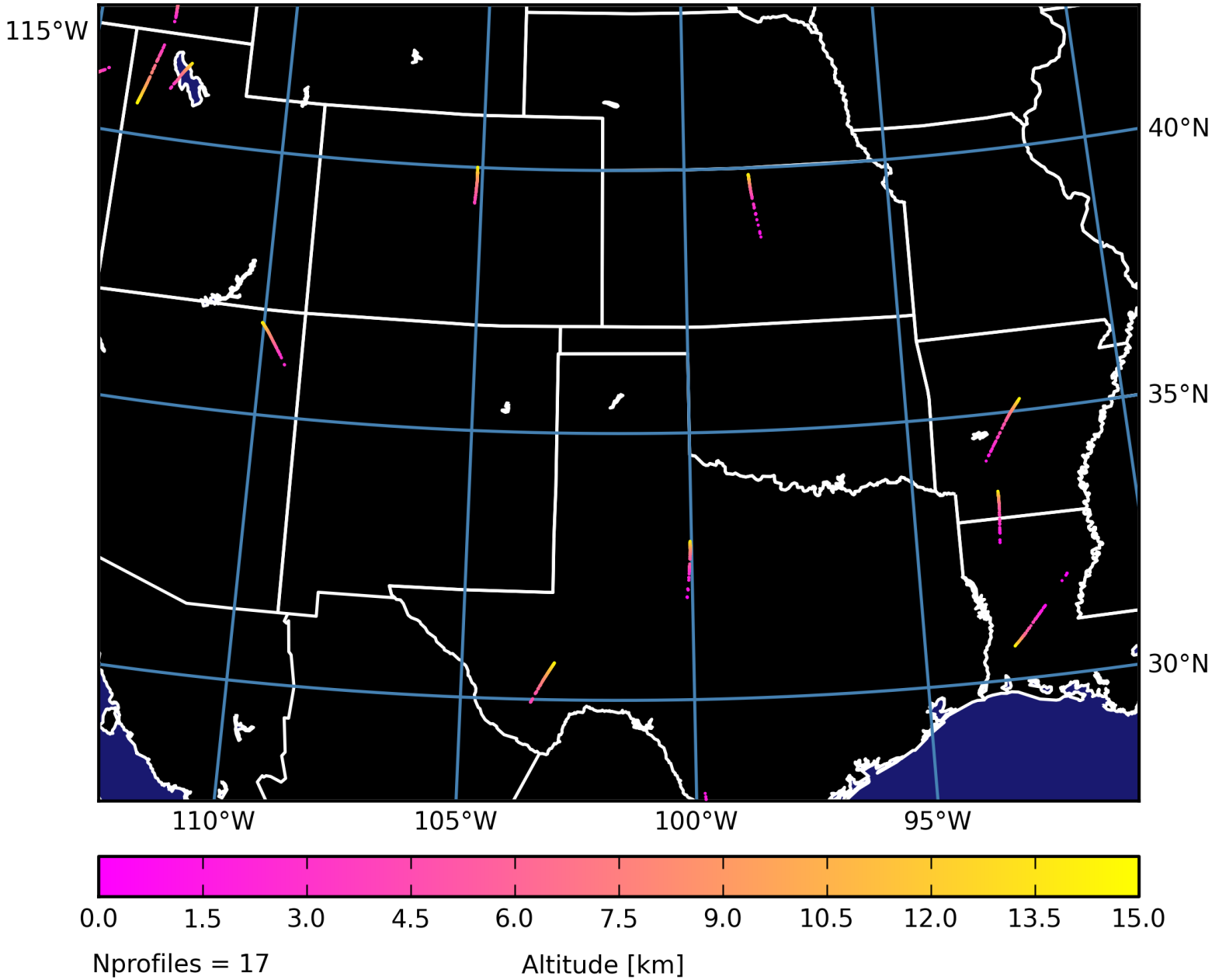
CICERO/G22 profiles, rising occultations

Period: 7 hrs (May 31, 2013, 1130 - 1830 UTC)



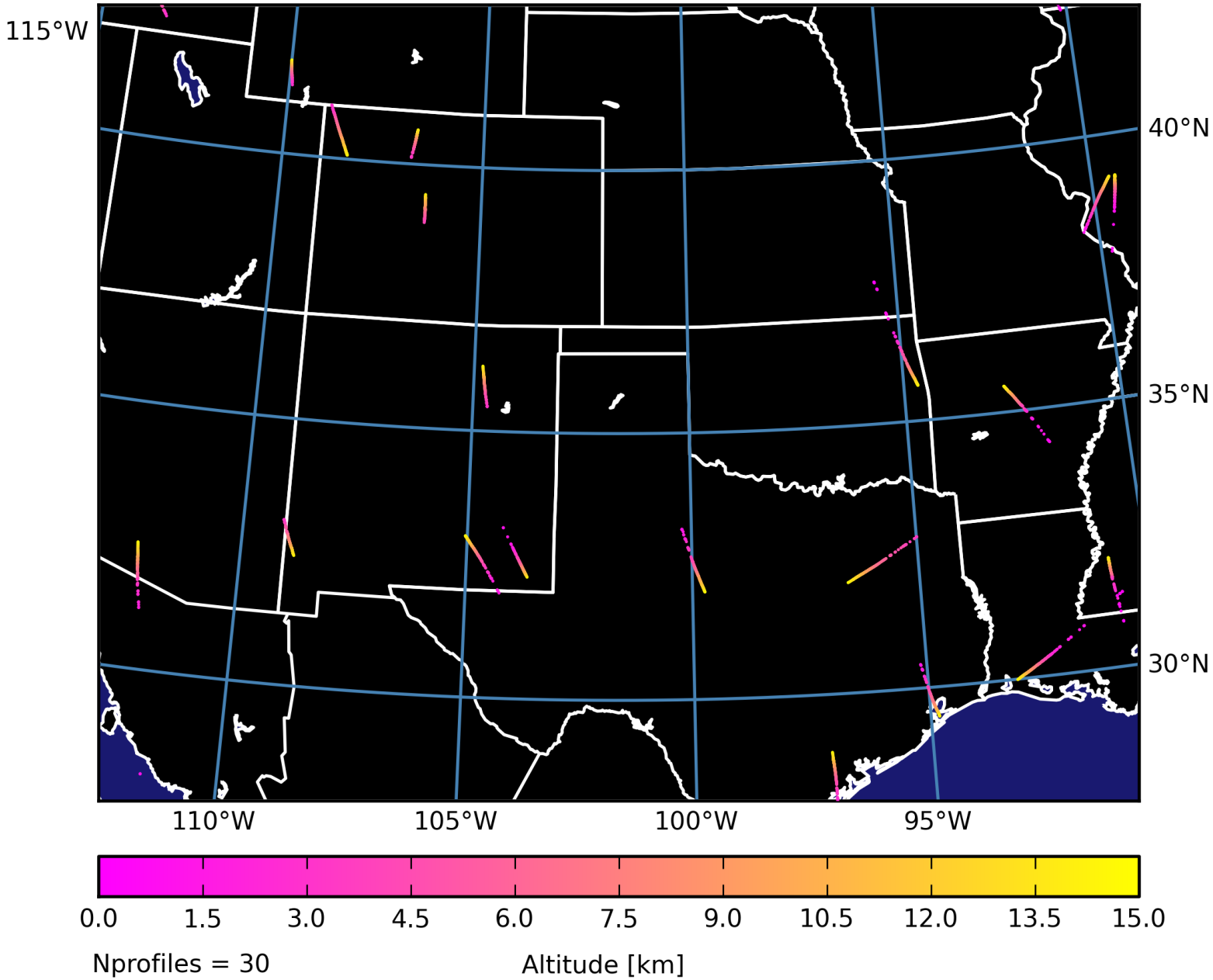
CICERO-60K mission profiles (simulated)

Period: 1 hr



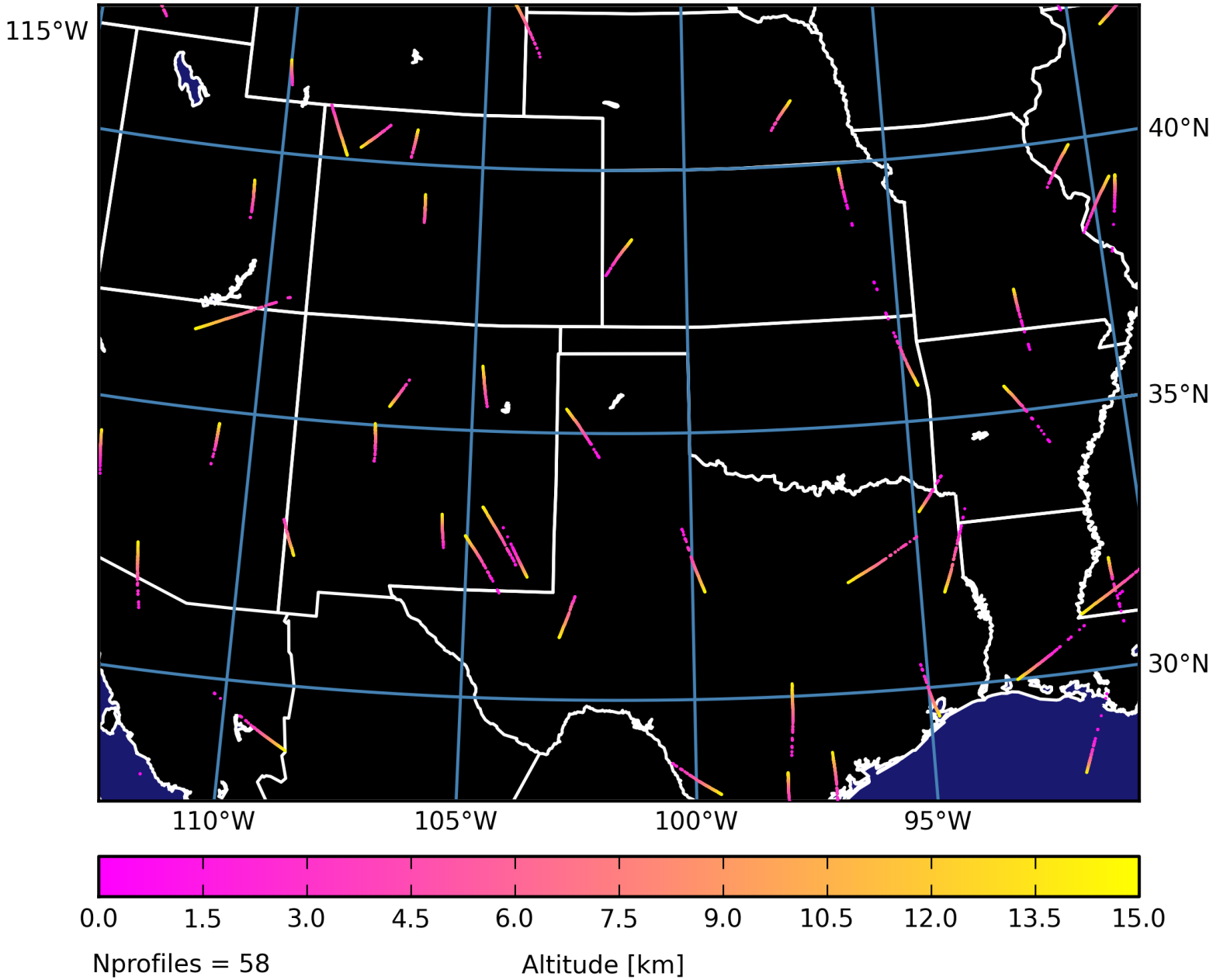
CICERO-100K mission profiles (simulated)

Period: 1 hr



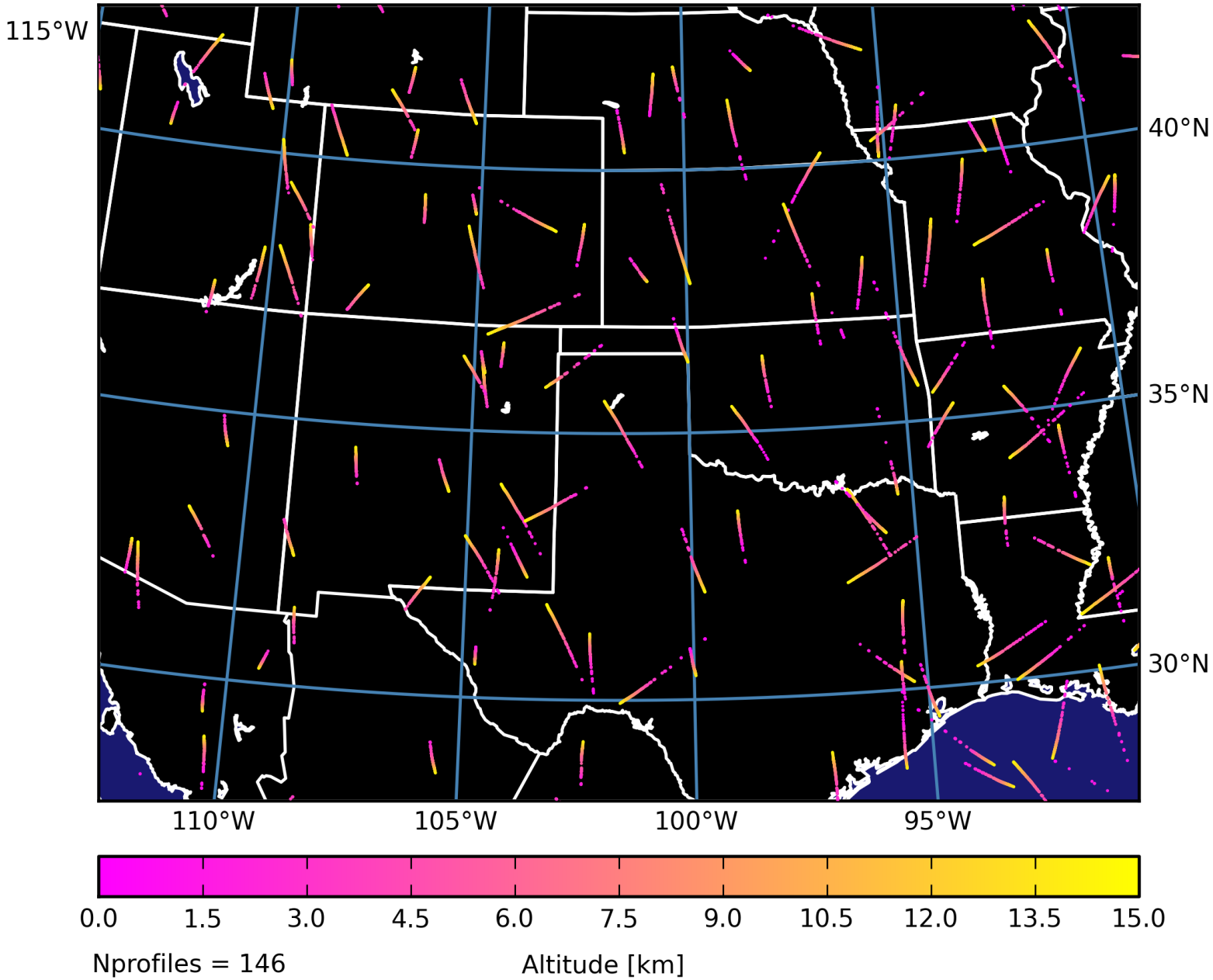
CICERO-200K mission profiles (simulated)

Period: 1 hr



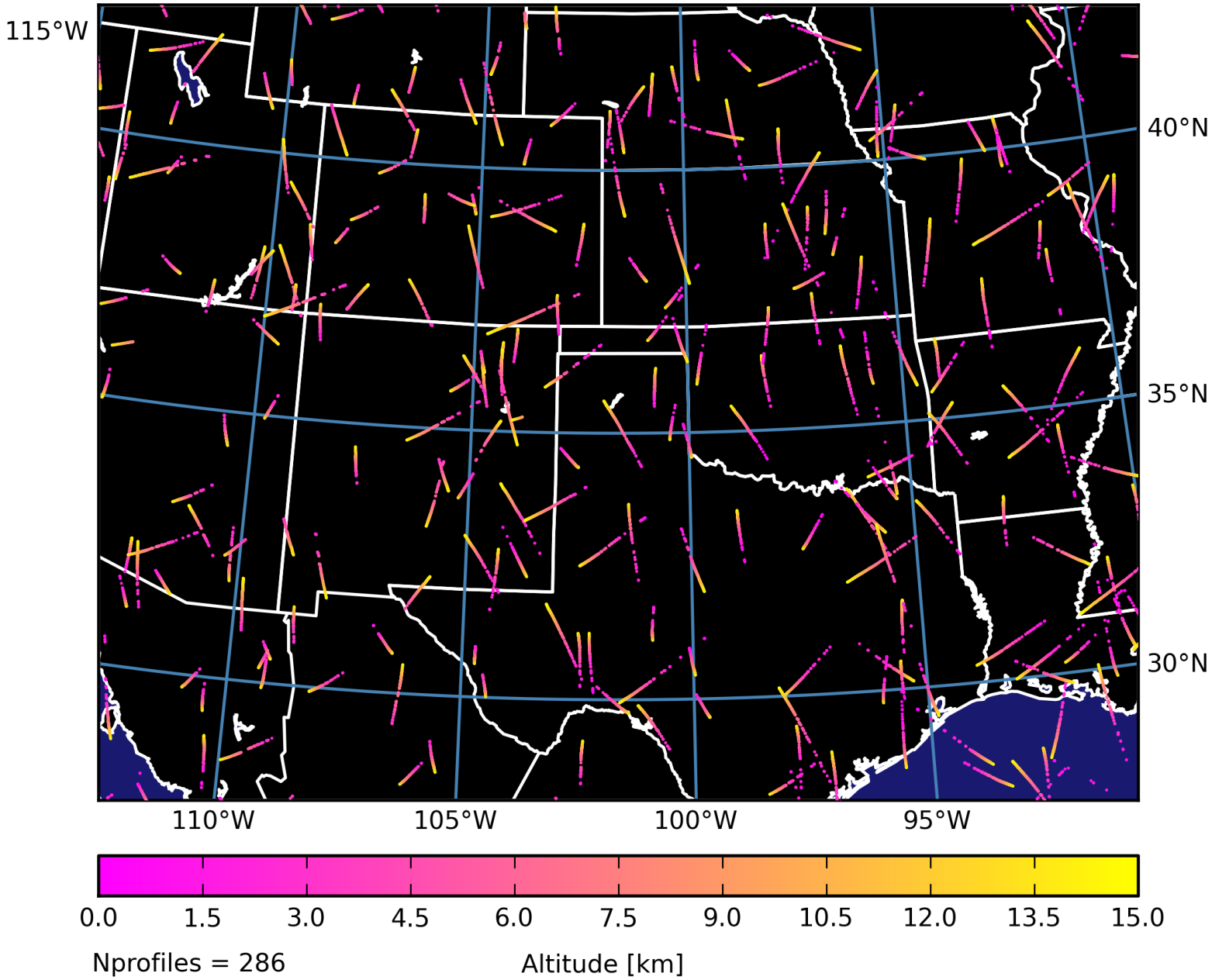
CICERO-500K mission profiles (simulated)

Period: 1 hr



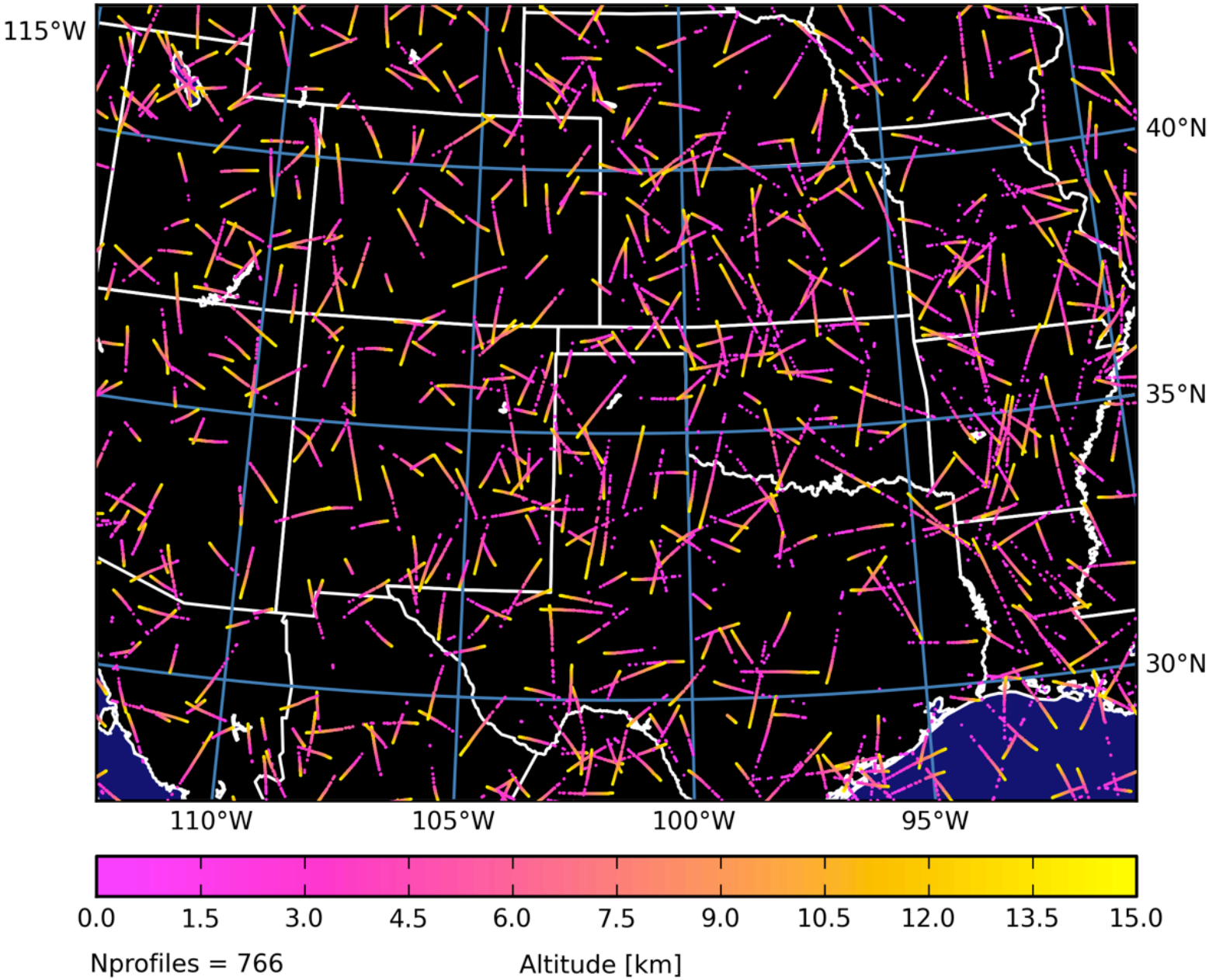
CICERO-1M mission profiles (simulated)

Period: 1 hr

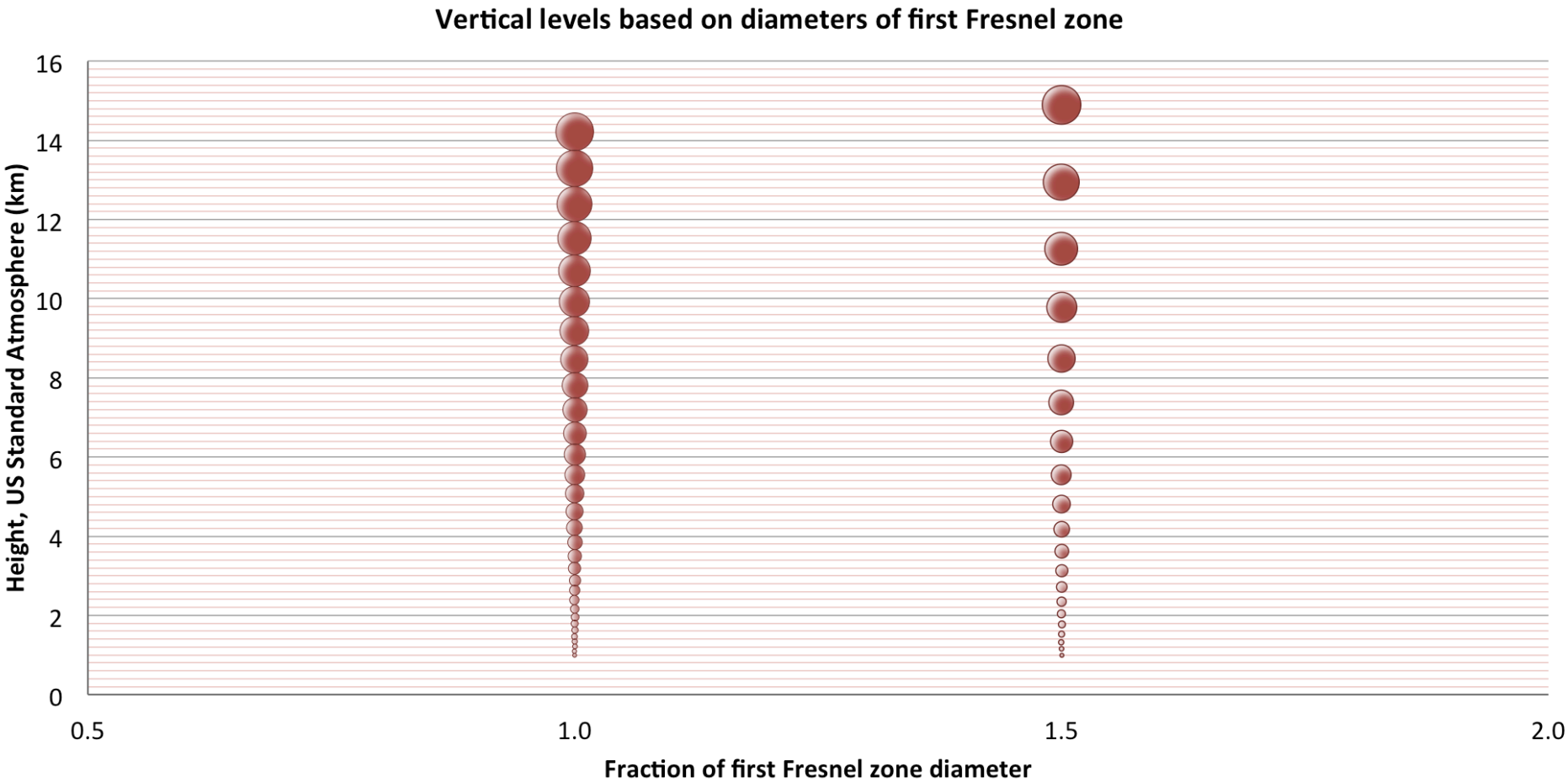


CICERO-2.5M mission profiles

Period: 1 hour



Vertical thinning



(32) (20)

Analysis Results (1/17)

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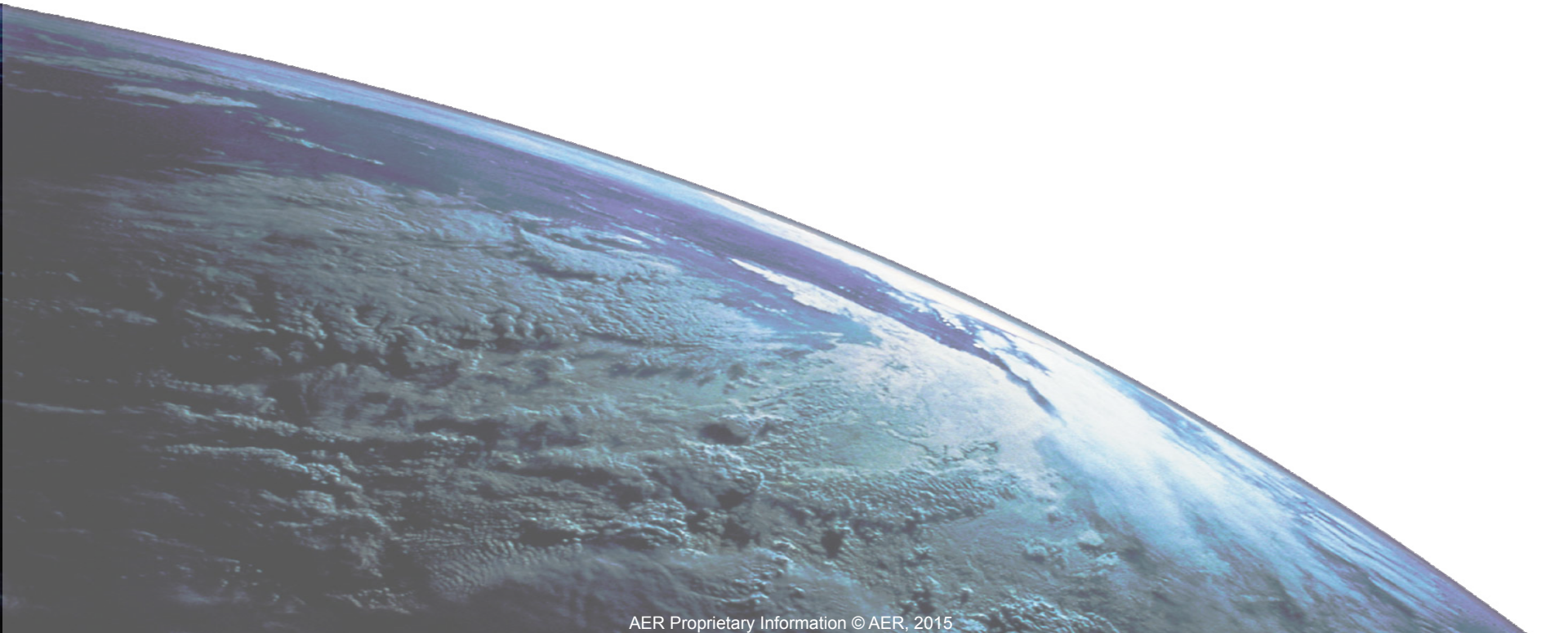

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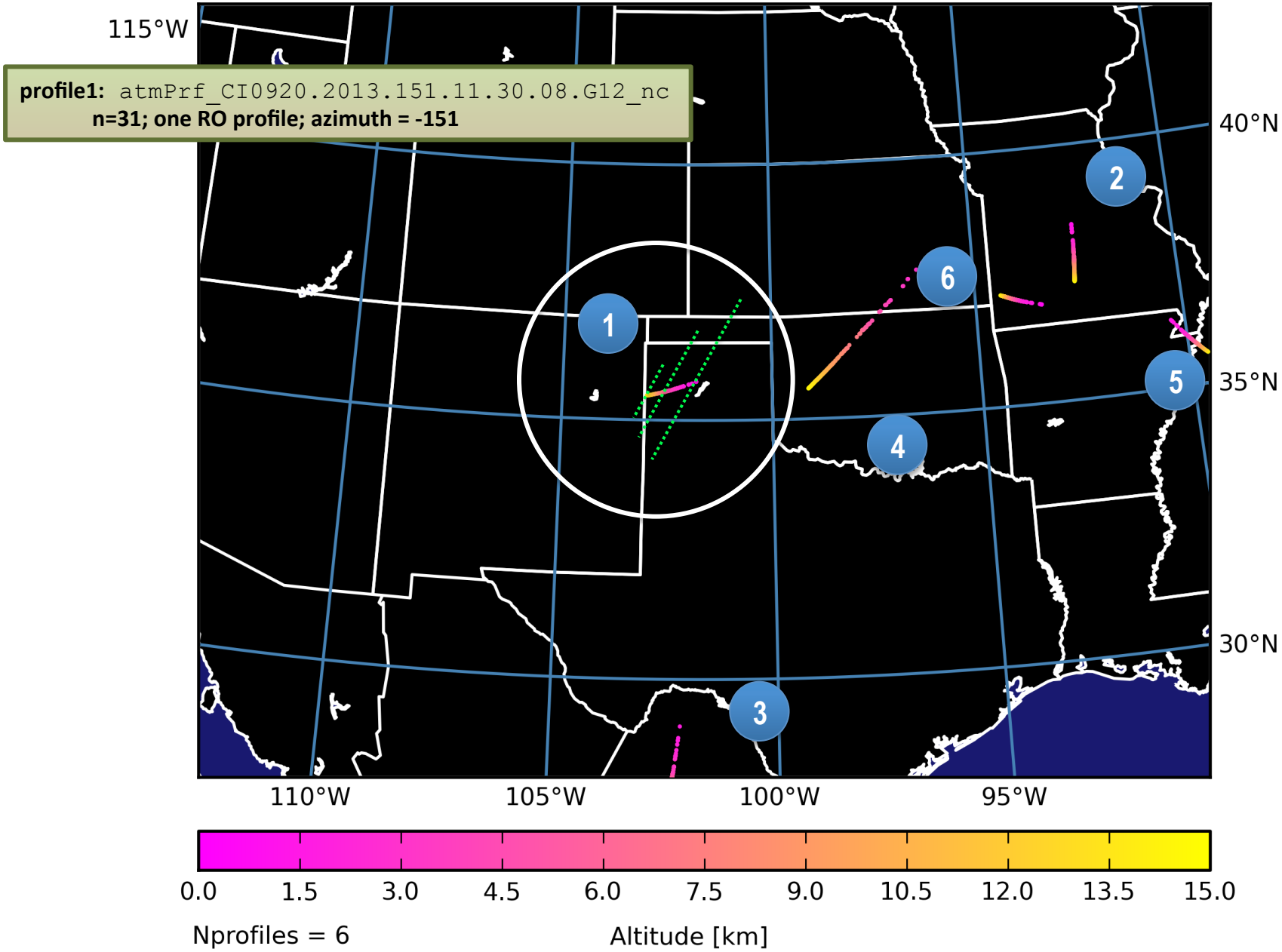
CICERO-2.5M mission profiles

Period: 30 seconds (11:30:00-11:30:30 UTC May 31, 2013)

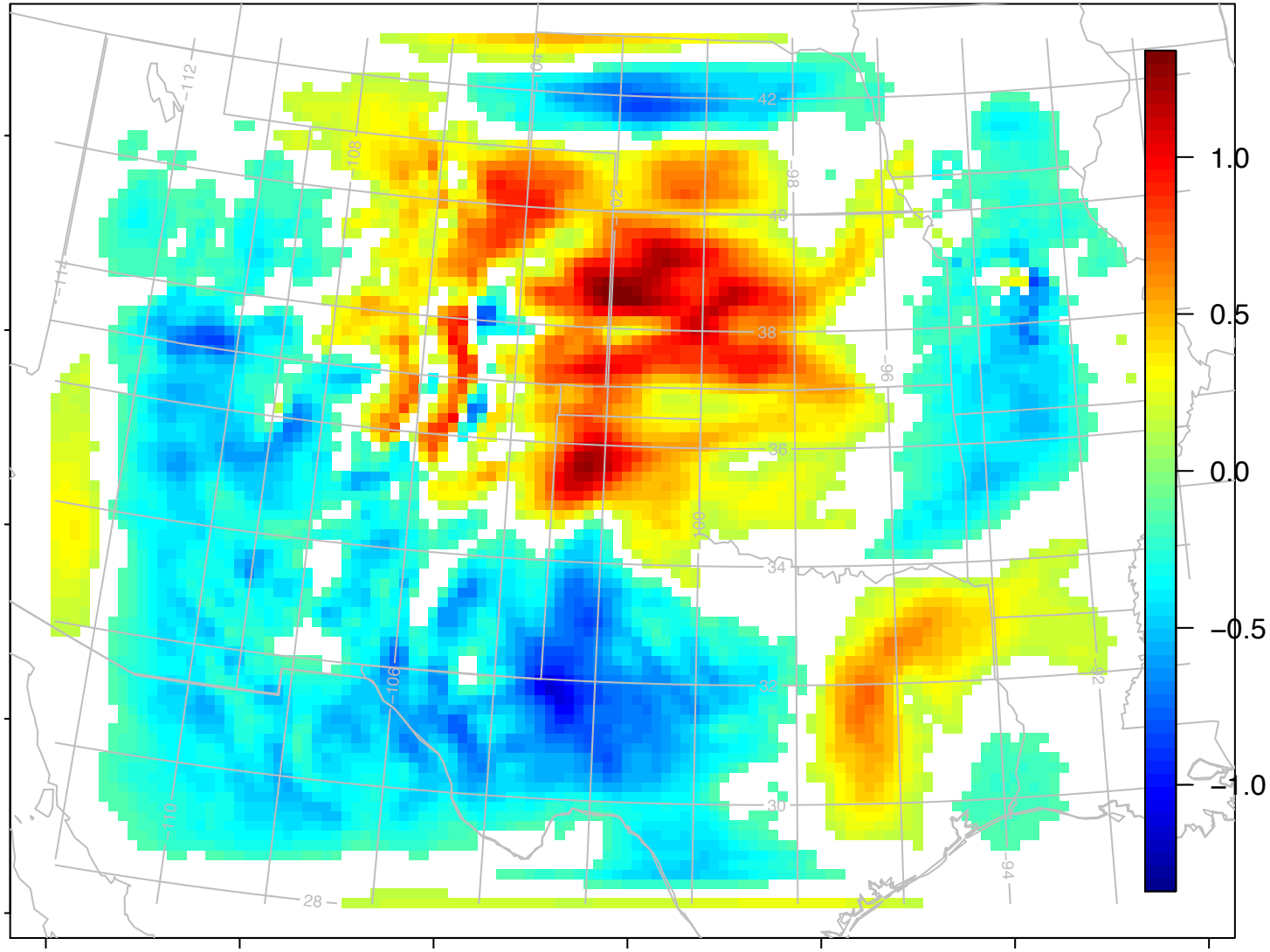


Single Profile experiments : horizontal localization

Temperature Increment (C)

Model Level 4 km AGL

<u>No</u> Horizontal localization

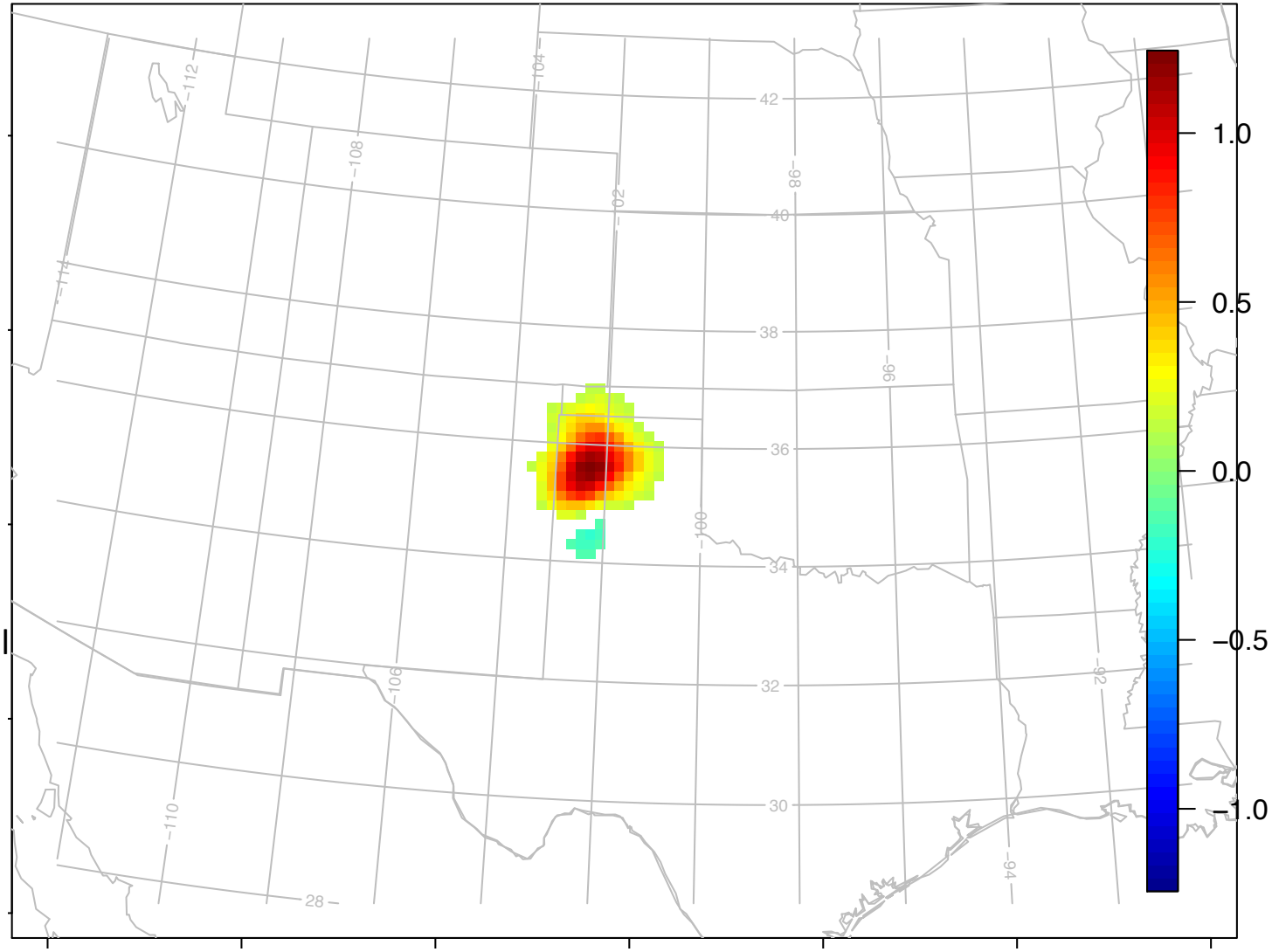


Single Profile experiments : horizontal localization

Temperature Increment (C)

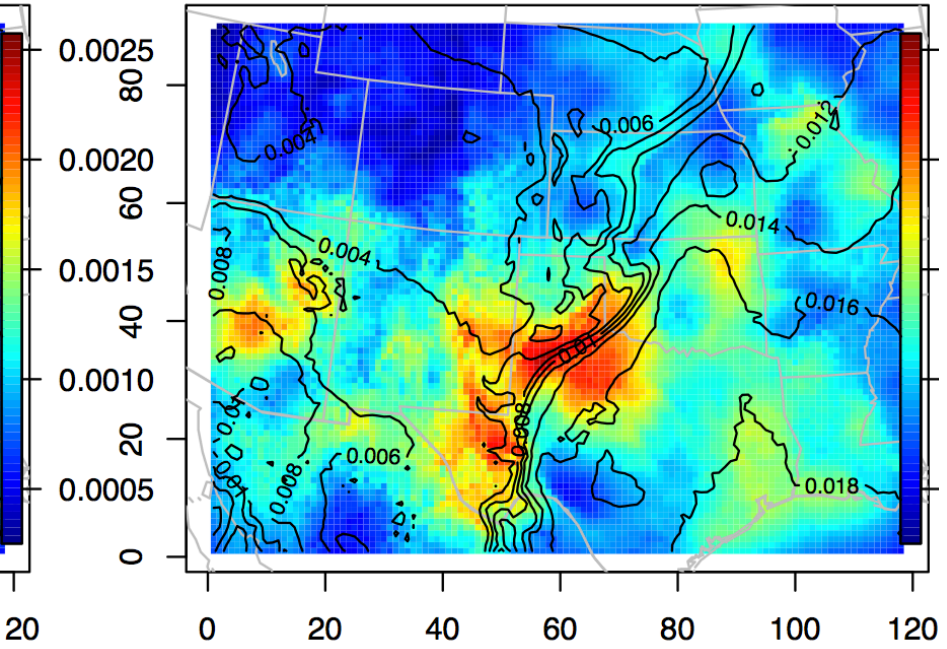
Model Level 4 km AGL

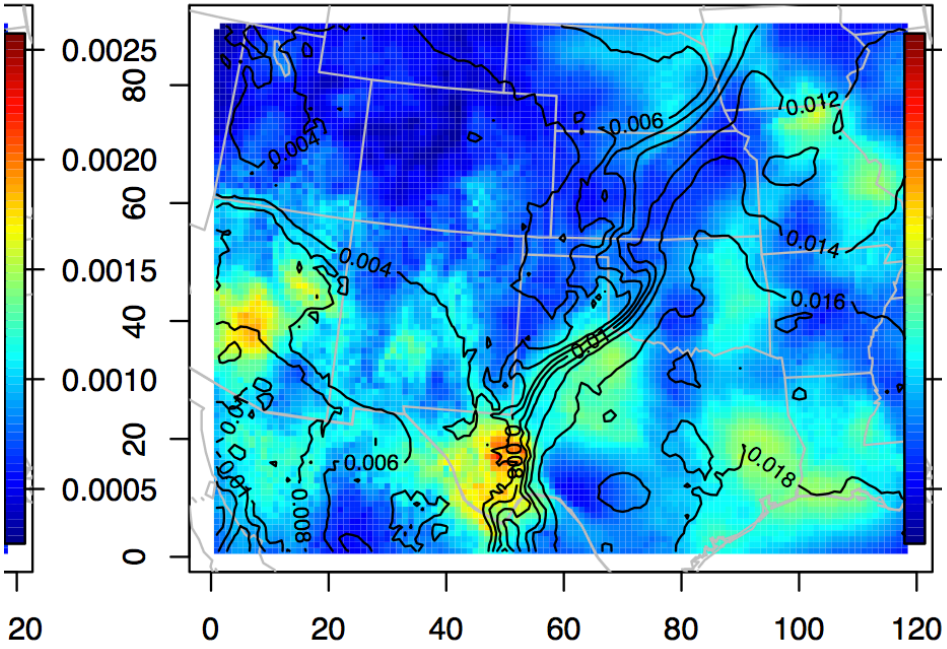
<u>With</u> Horizontal Localization to ~ 300 km (half-width) diameter



WRF-DART, hour 2, water vapor mixing ratio at ~ 140 meters AGL analysis

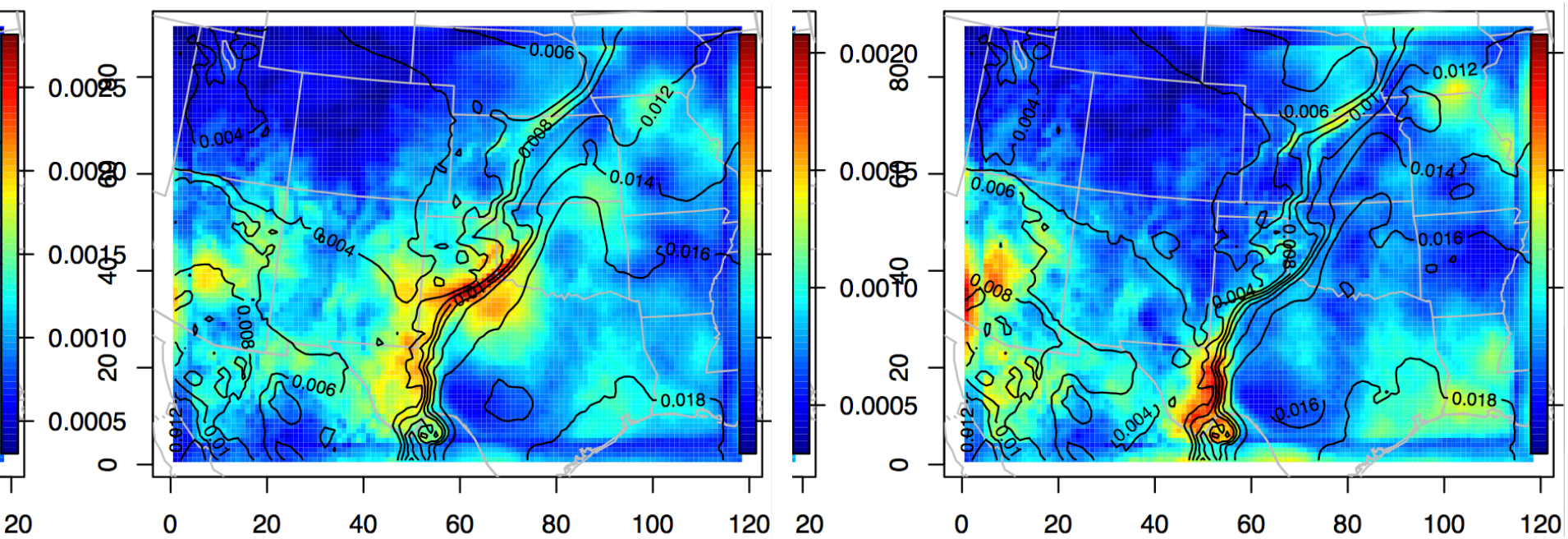
Cntl *1200 UTC May 31, 2013*	*Cntl + CICERO 2.5M* *1200 UTC May 31, 2013*





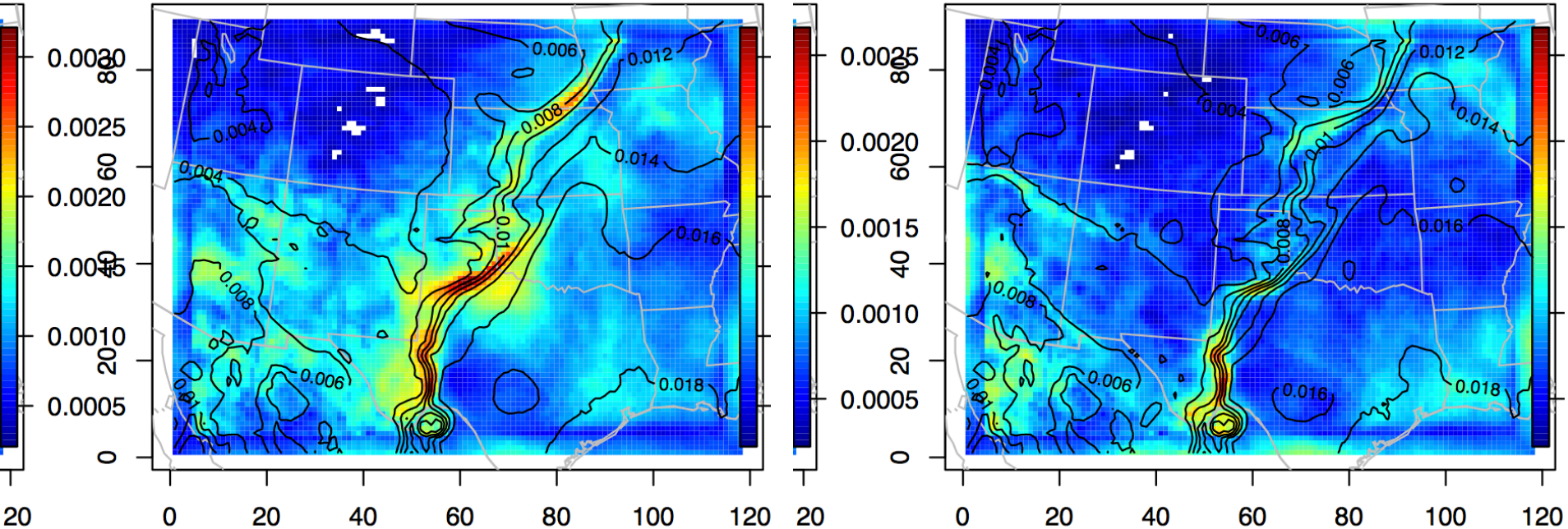
WRF-DART, hour 2, water vapor mixing ratio at ~ 140 meters AGL analysis

Cntl *1300 UTC May 31, 2013*	*Cntl + CICERO 2.5M* *1300 UTC May 31, 2013*



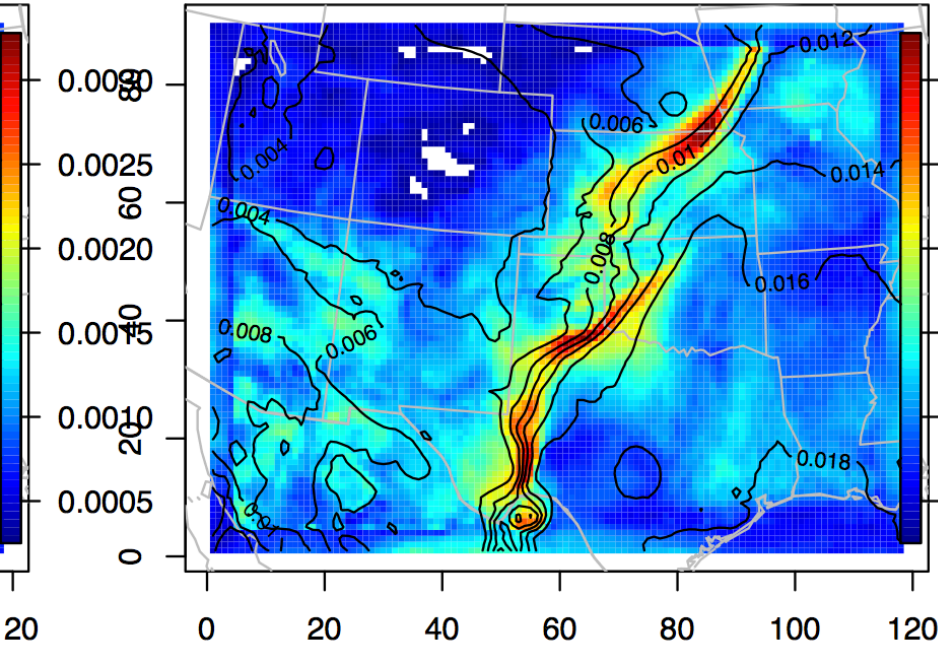
WRF-DART, hour 3, water vapor mixing ratio at ~ 140 meters AGL analysis

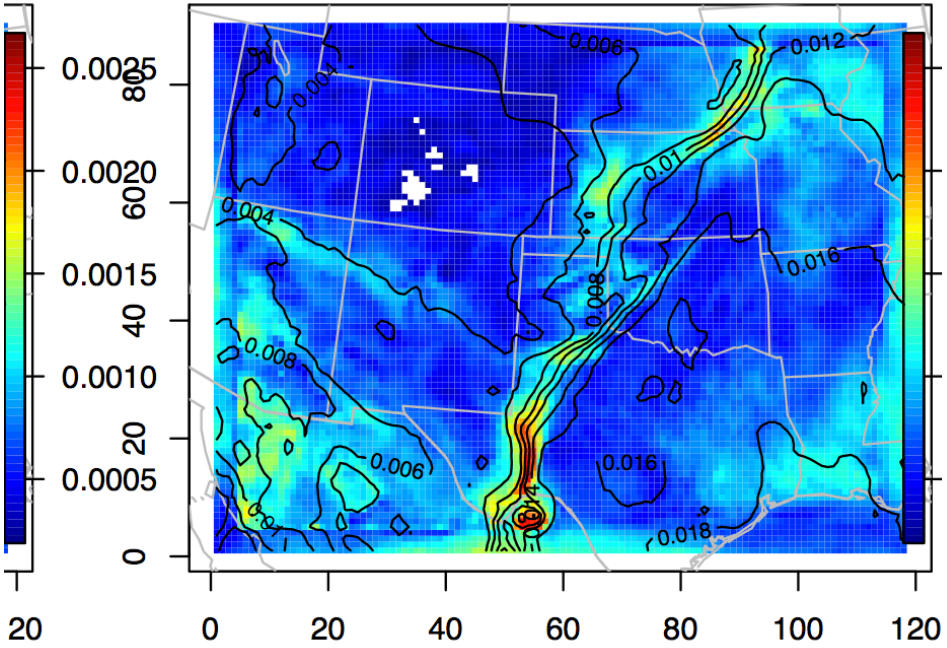
Cntl *1400 UTC May 31, 2013*	*Cntl + CICERO 2.5M* *1400 UTC May 31, 2013*



WRF-DART, hour 4, water vapor mixing ratio at ~ 140 meters AGL analysis

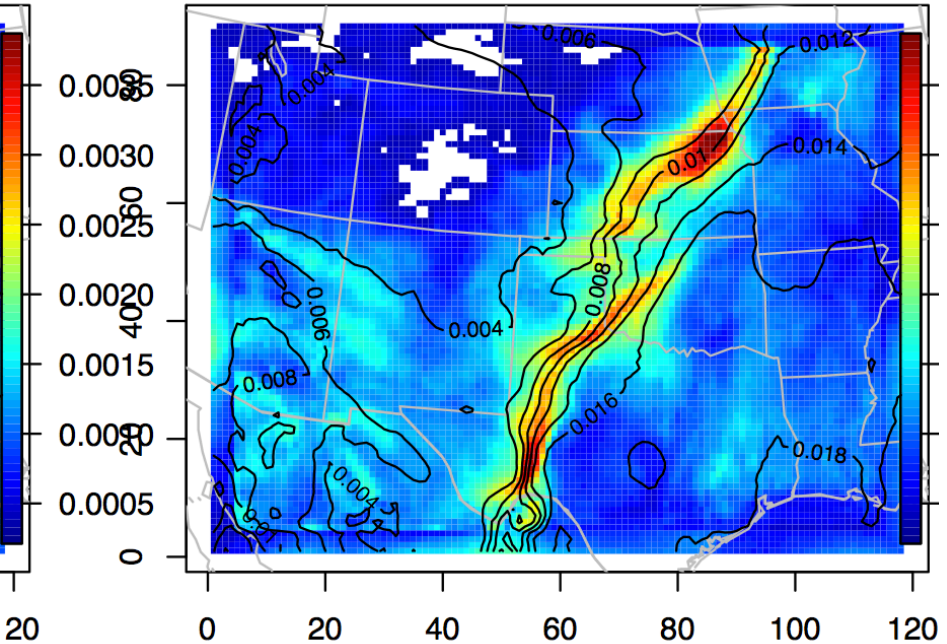
Cntl *1500 UTC May 31, 2013*	*Cntl + CICERO 2.5M* *1500 UTC May 31, 2013*

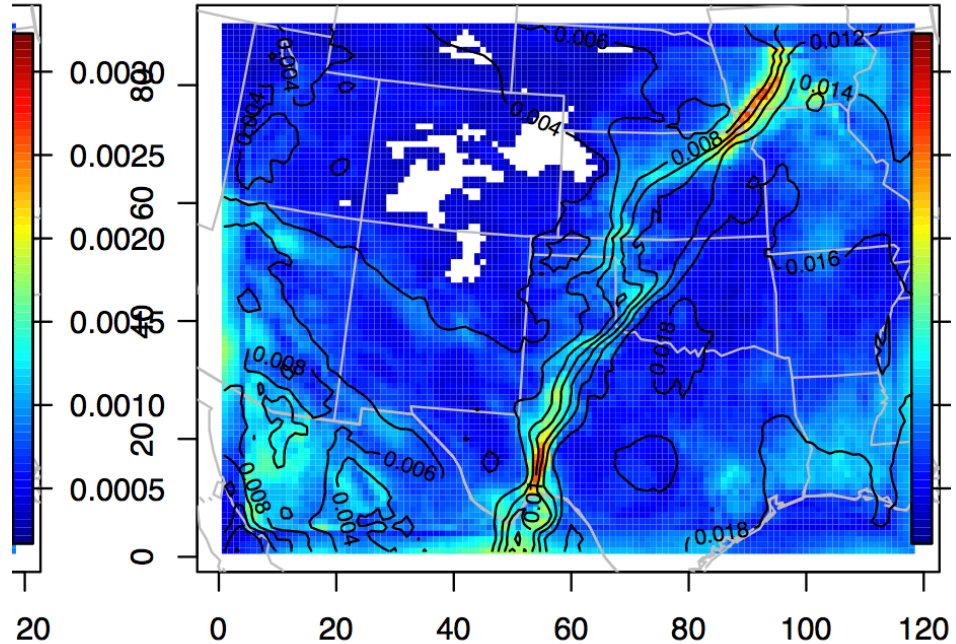




WRF-DART, hour 5, water vapor mixing ratio at ~ 140 meters AGL analysis

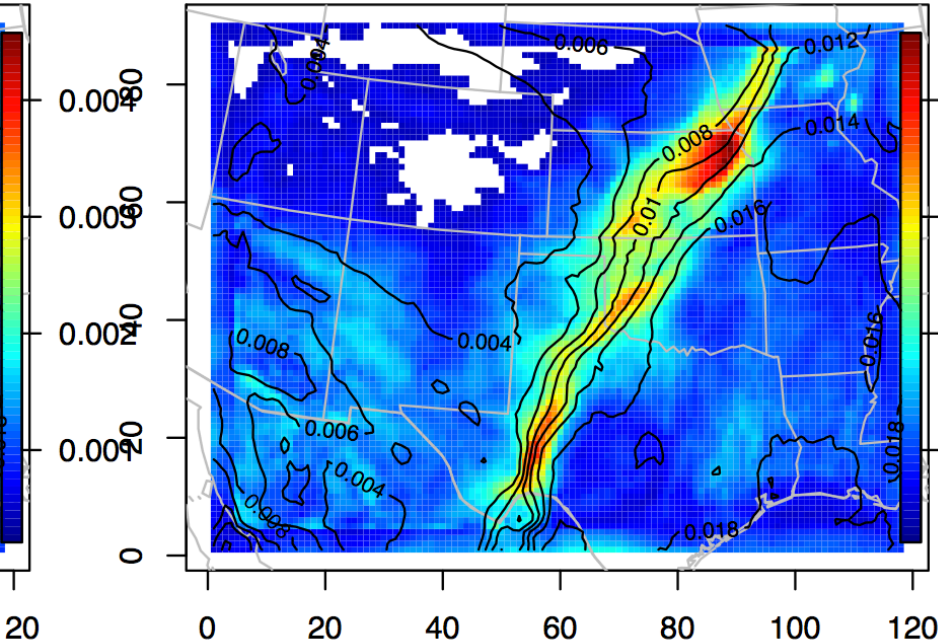
Cntl *1600 UTC May 31, 2013*	*Cntl + CICERO 2.5M* *1600 UTC May 31, 2013*

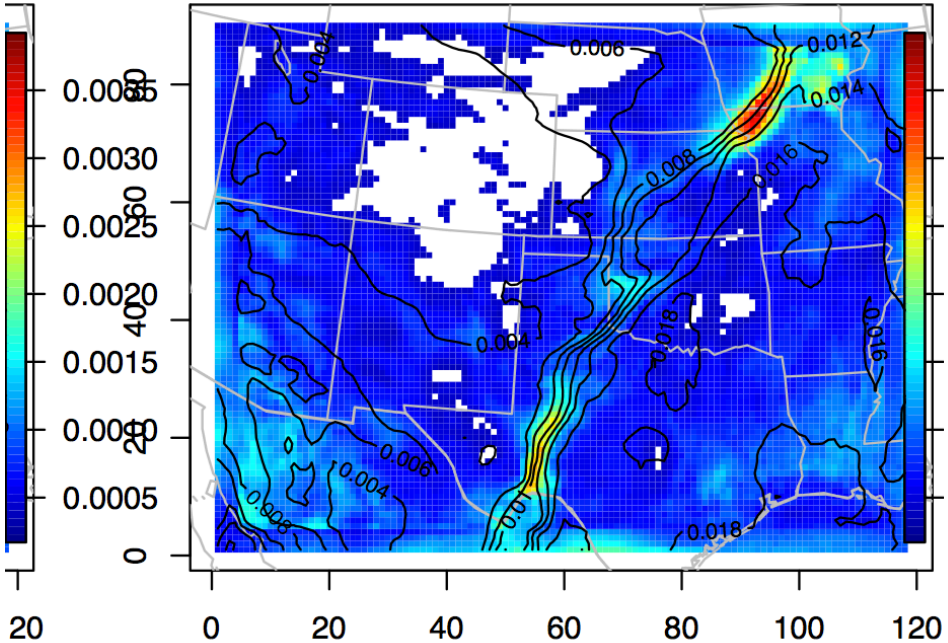




WRF-DART, hour 6, water vapor mixing ratio at ~ 140 meters AGL analysis

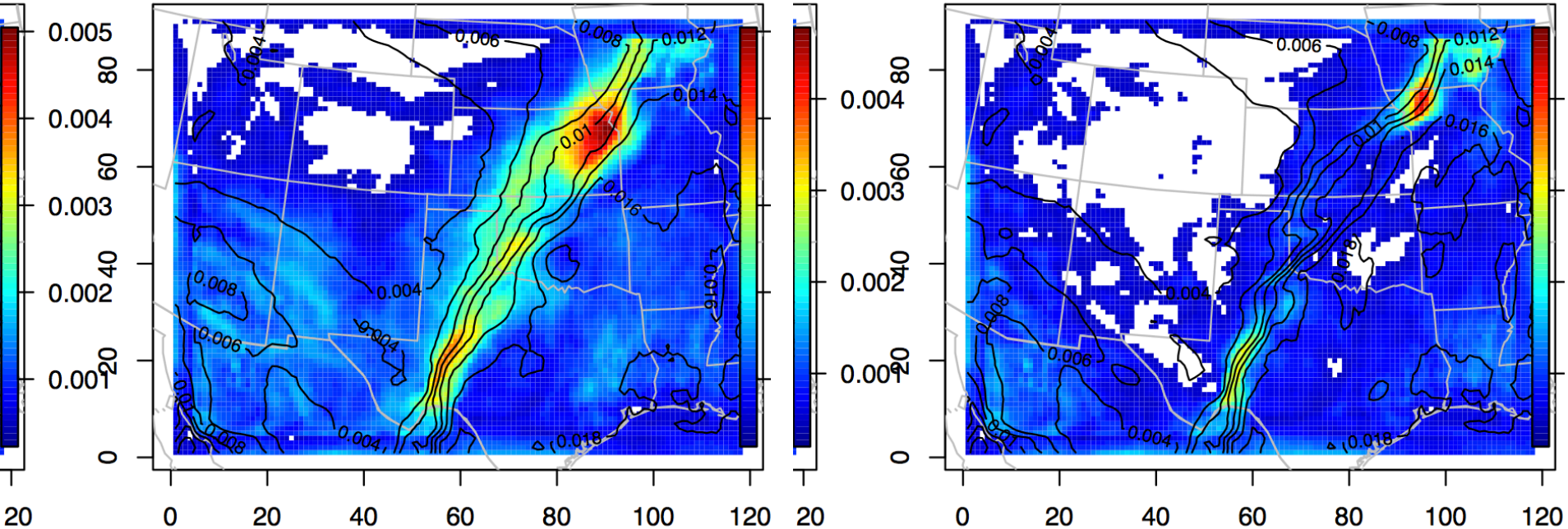
Cntl *1700 UTC May 31, 2013*	*Cntl + CICERO 2.5M* *1700 UTC May 31, 2013*



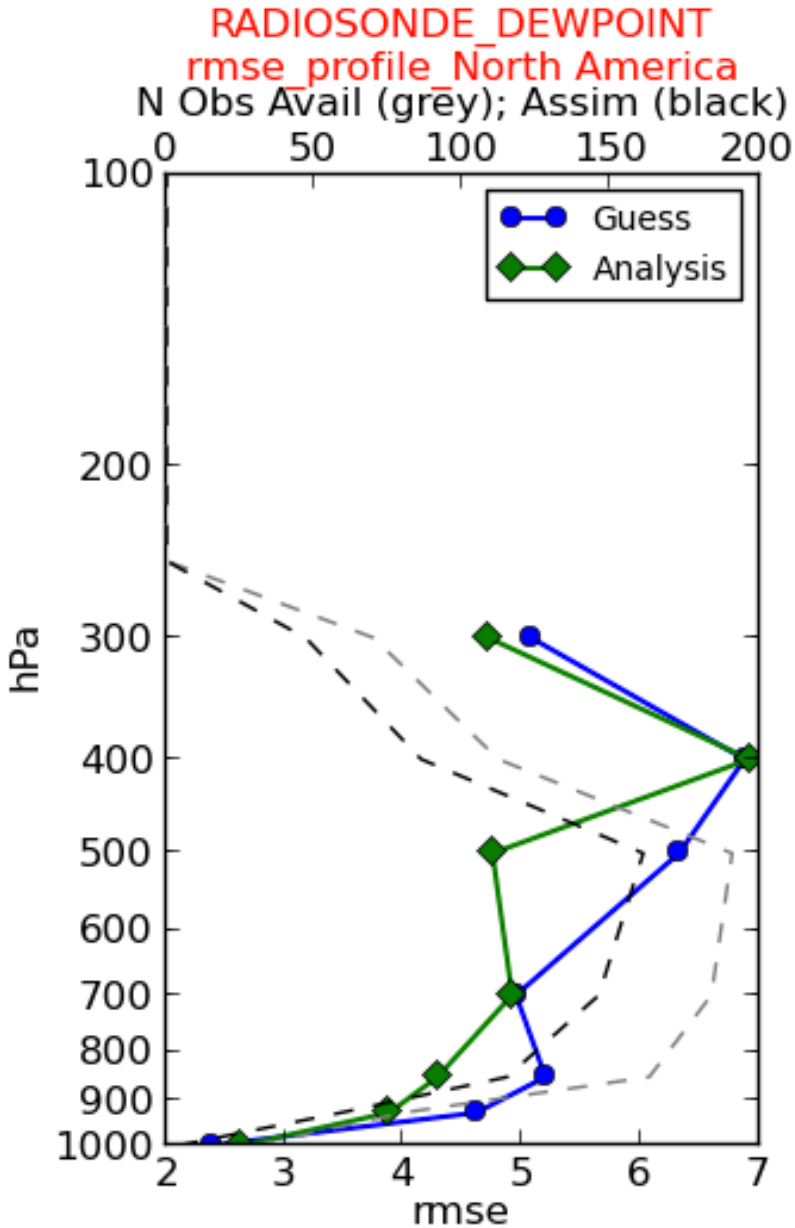


WRF-DART, hour 7, water vapor mixing ratio at ~ 140 meters AGL analysis

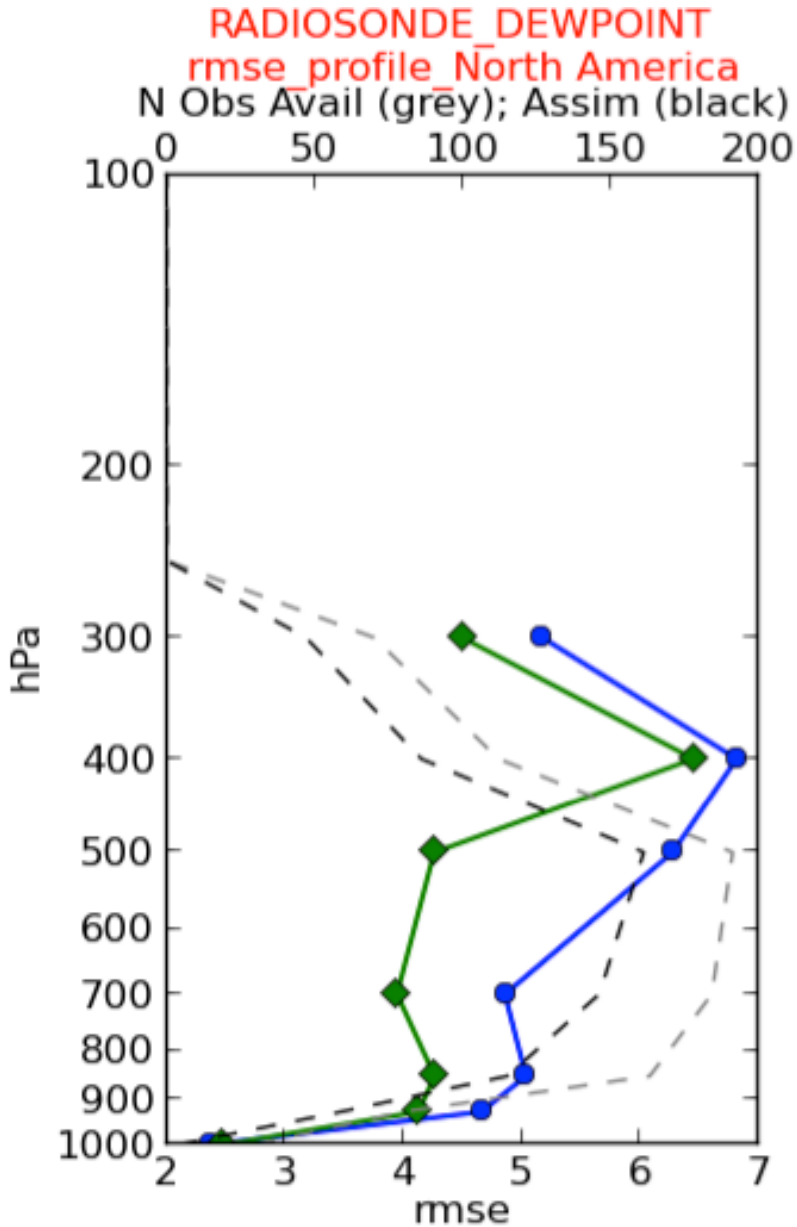
Cntl *1800 UTC May 31, 2013*	*Cntl + CICERO 2.5M* *1800 UTC May 31, 2013*



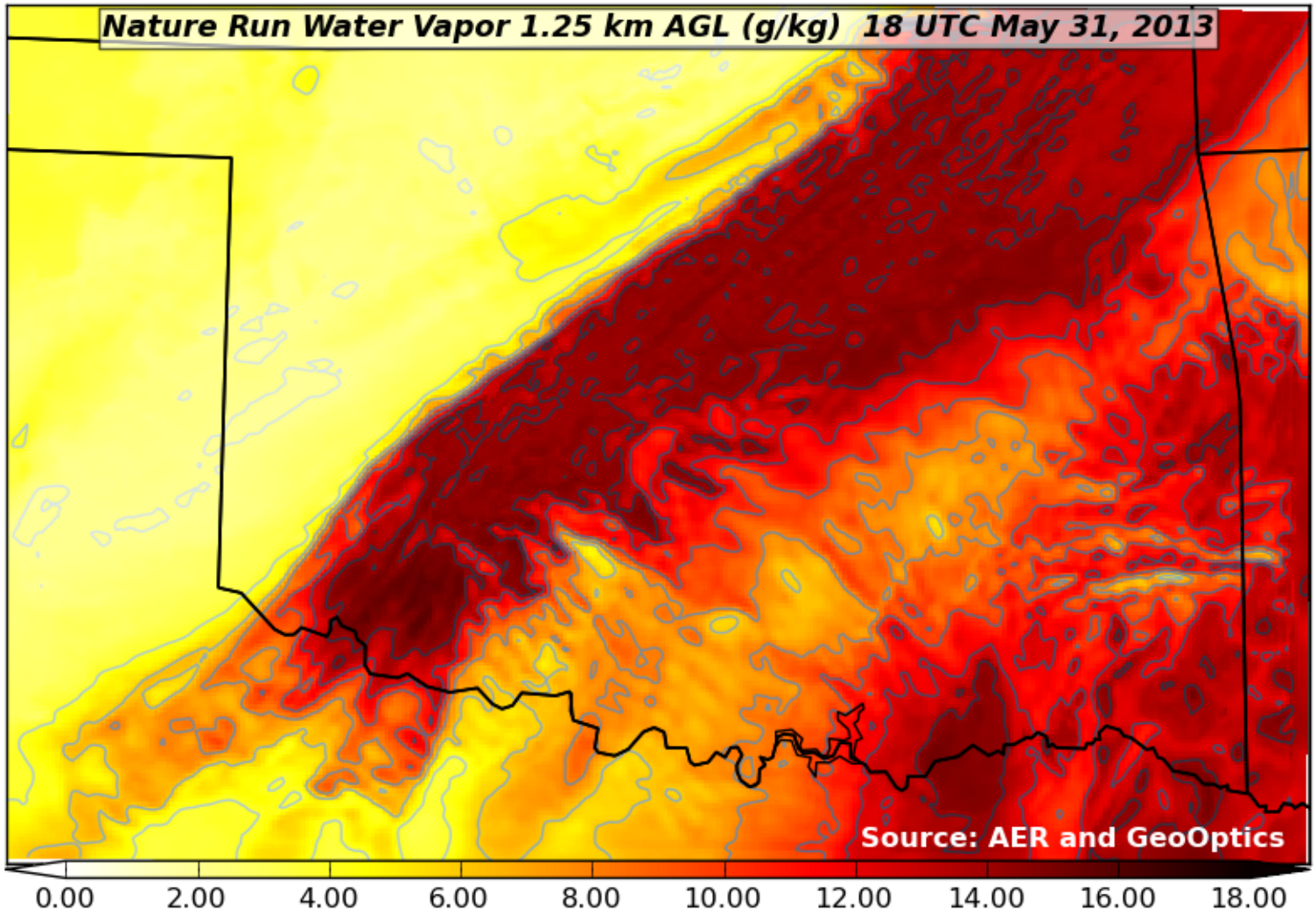
Control


RADIOSONDE_DEWPOINT
rmse_profile_North America
N Obs Avail (grey); Assim (black)
0
50
100
150
200
Guess
Analysis
100
200
300
400
500
600
700
800
900
1000
hPa
2
3
4
5
6
7
mse

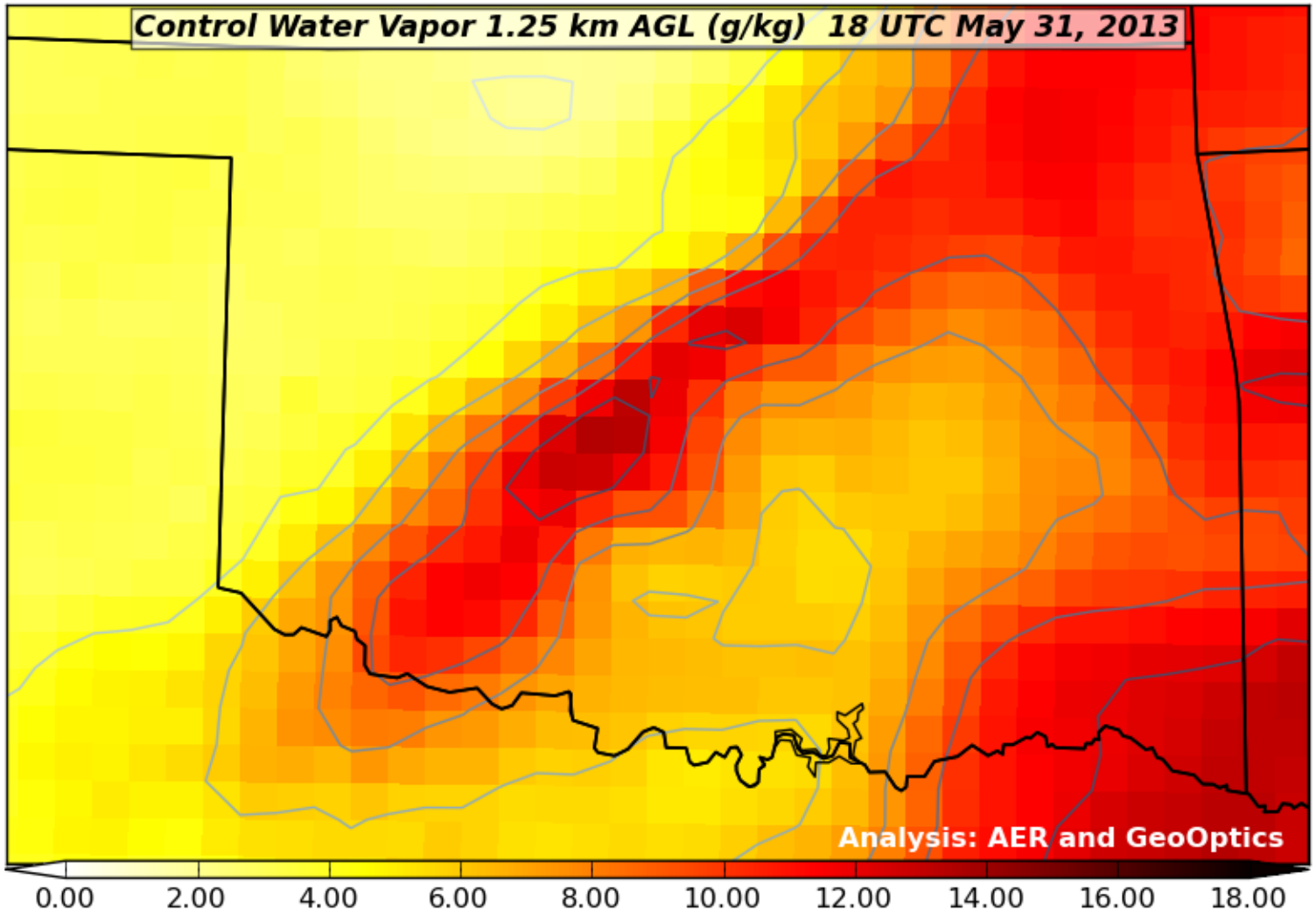
Control +CICERO 2.5M



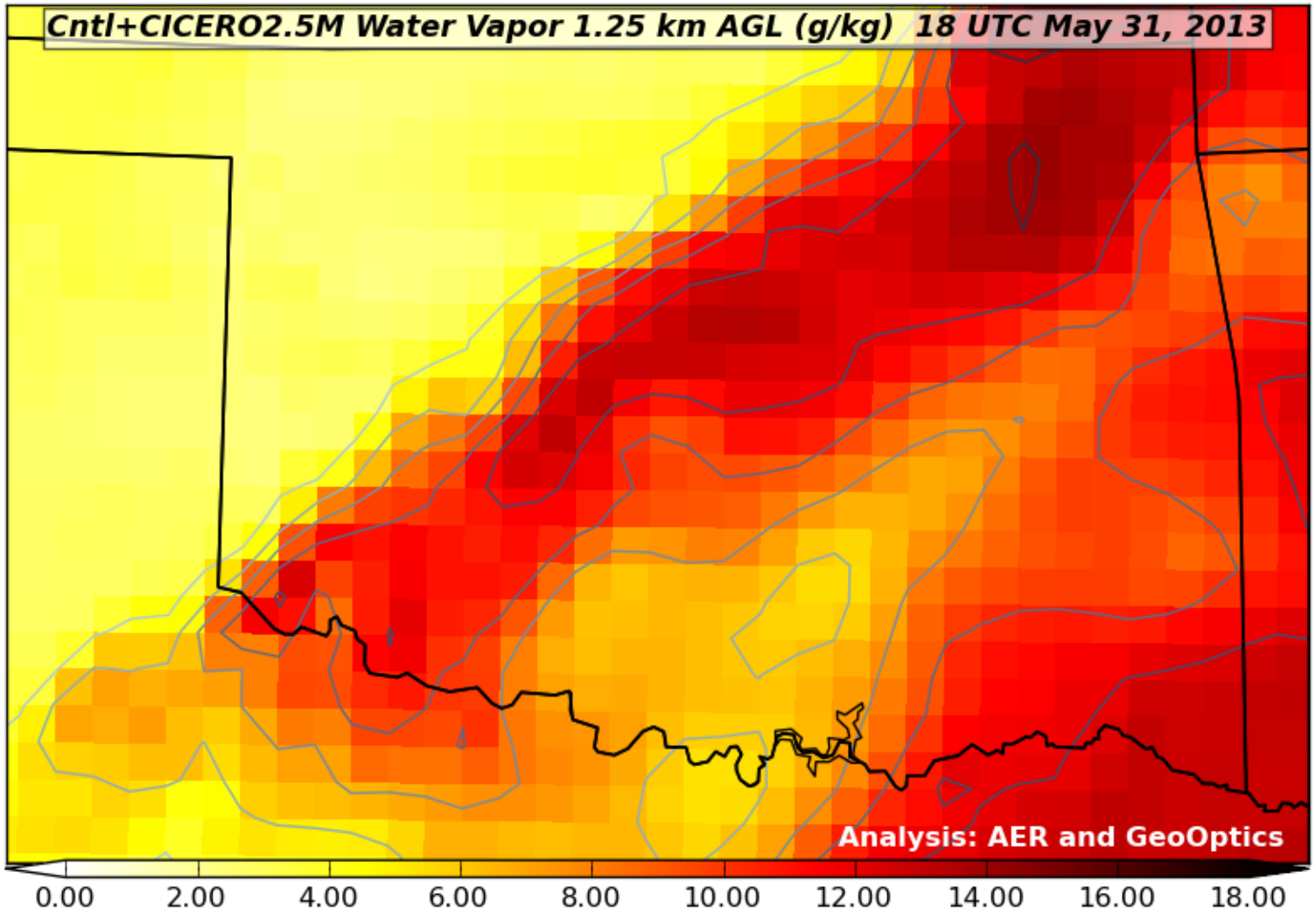
Analysis Impacts on water vapor



Analysis Impacts on water vapor

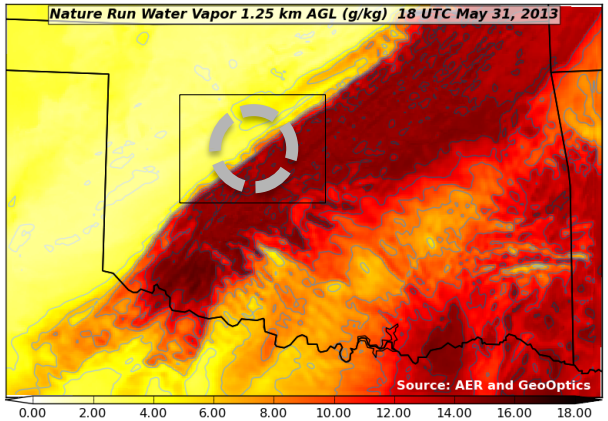


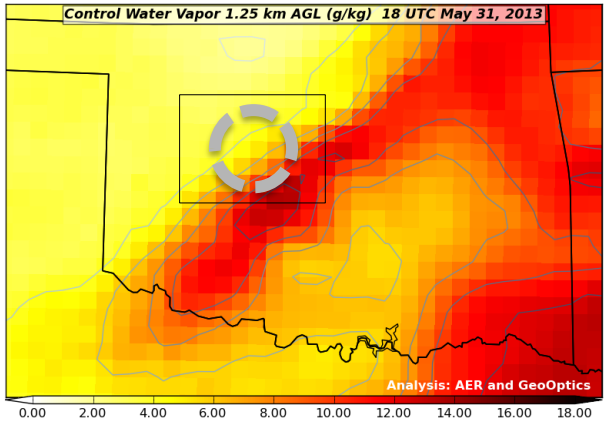
Analysis Impacts on water vapor

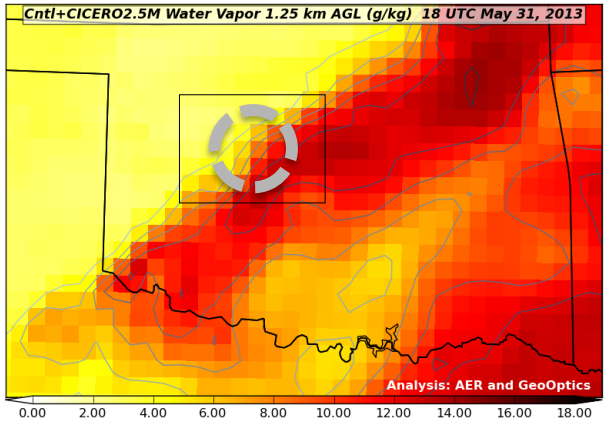


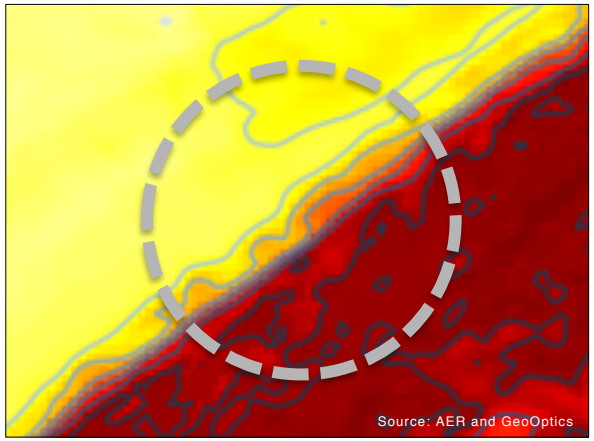
Analysis Impacts on water vapor

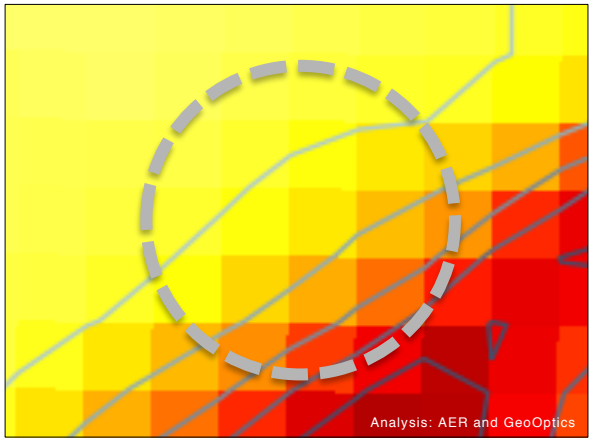
Nature Run "truth" | **Control (no RO)** | **C2.5M**

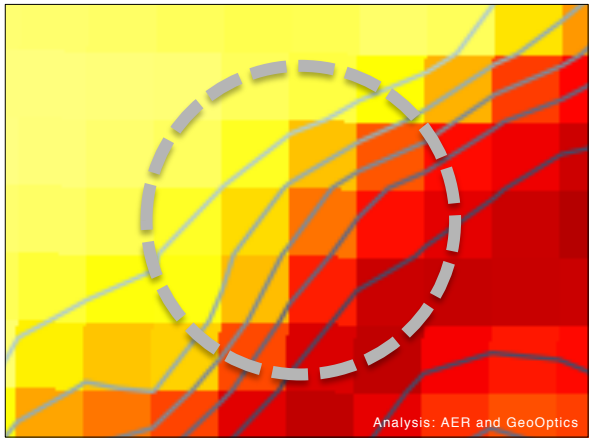












Forecast Impacts (1/11)

- Used closest ensemble member to ensemble mean for forecast IC
- Multi-physics forecasts created apples-to-oranges comparison; could not interpret results

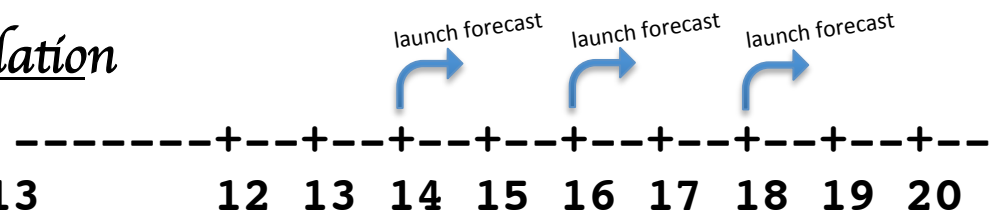
- MYNN PBL scheme chosen for default for all forecasts

- Forecast impacts on horizontal averages over the inner domain

Example: ensemble members nearest to analyses from the 24-member ensemble

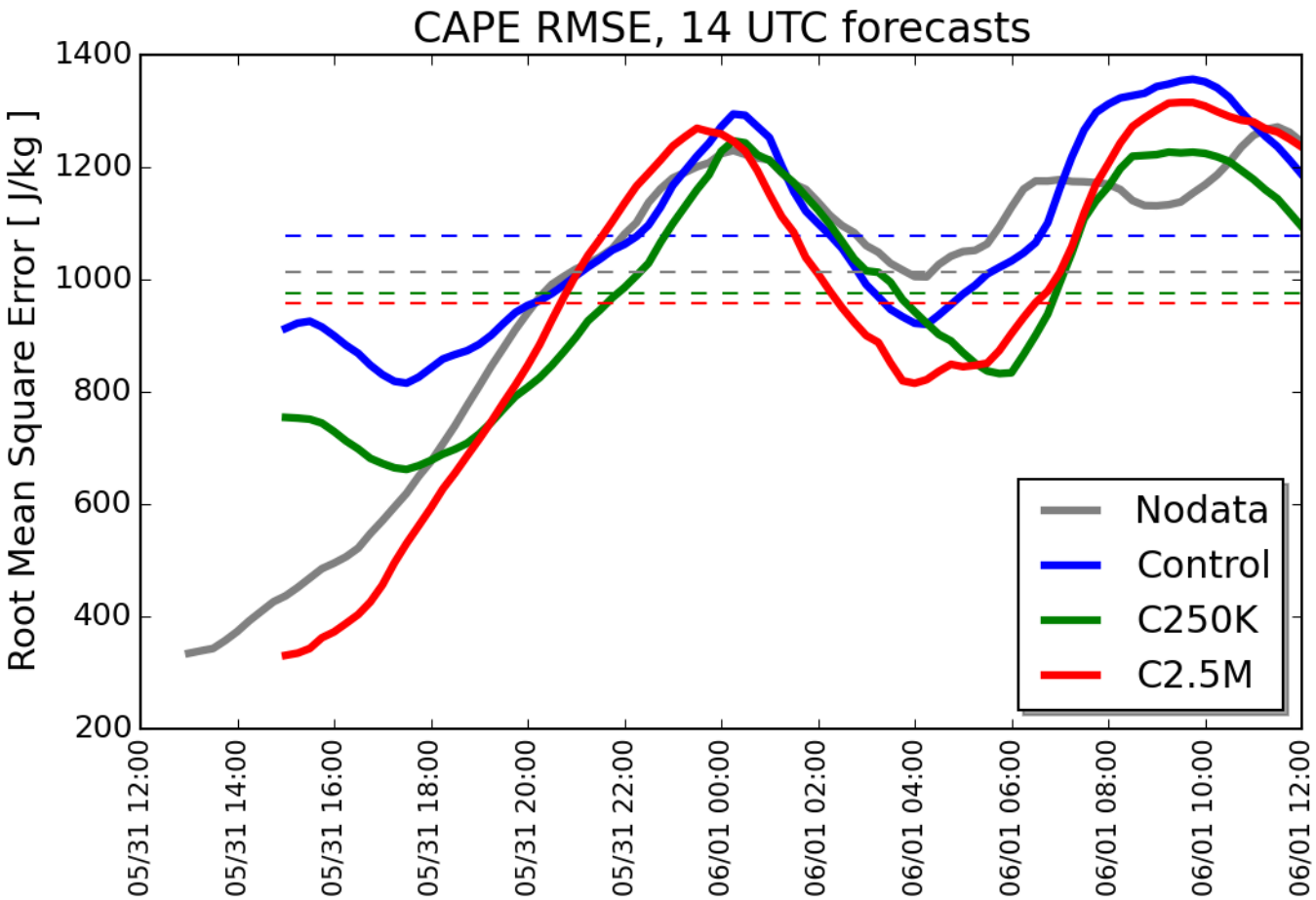
Exp	Time	niens	namelist	Rad	PBL	Cu
Control	14Z	6	B-B-C	RRTMG	MYJ	Tiedtke
Control	16Z	14	C-A-B	Goddard	YSU	G-F
Control	18Z	11	B-D-B	RRTMG	ACM2	G-F
C250K	14Z	18	C_B_C	Goddard	MYJ	Tiedtke
C250K	16Z	6	B-B-C	RRTMG	MYJ	Tiedtke
C250K	18Z	8	B_C_B	RRTMG	MYNN	G-F
C2.5M	14Z	15	C_A_C	Goddard	YSU	Tiedtke
C2.5M	16Z	6	B-B-C	RRTMG	MYJ	Tiedtke
C2.5M	18Z	14	C-A-B	Goddard	YSU	G-F

Hourly, cycling data assimilation



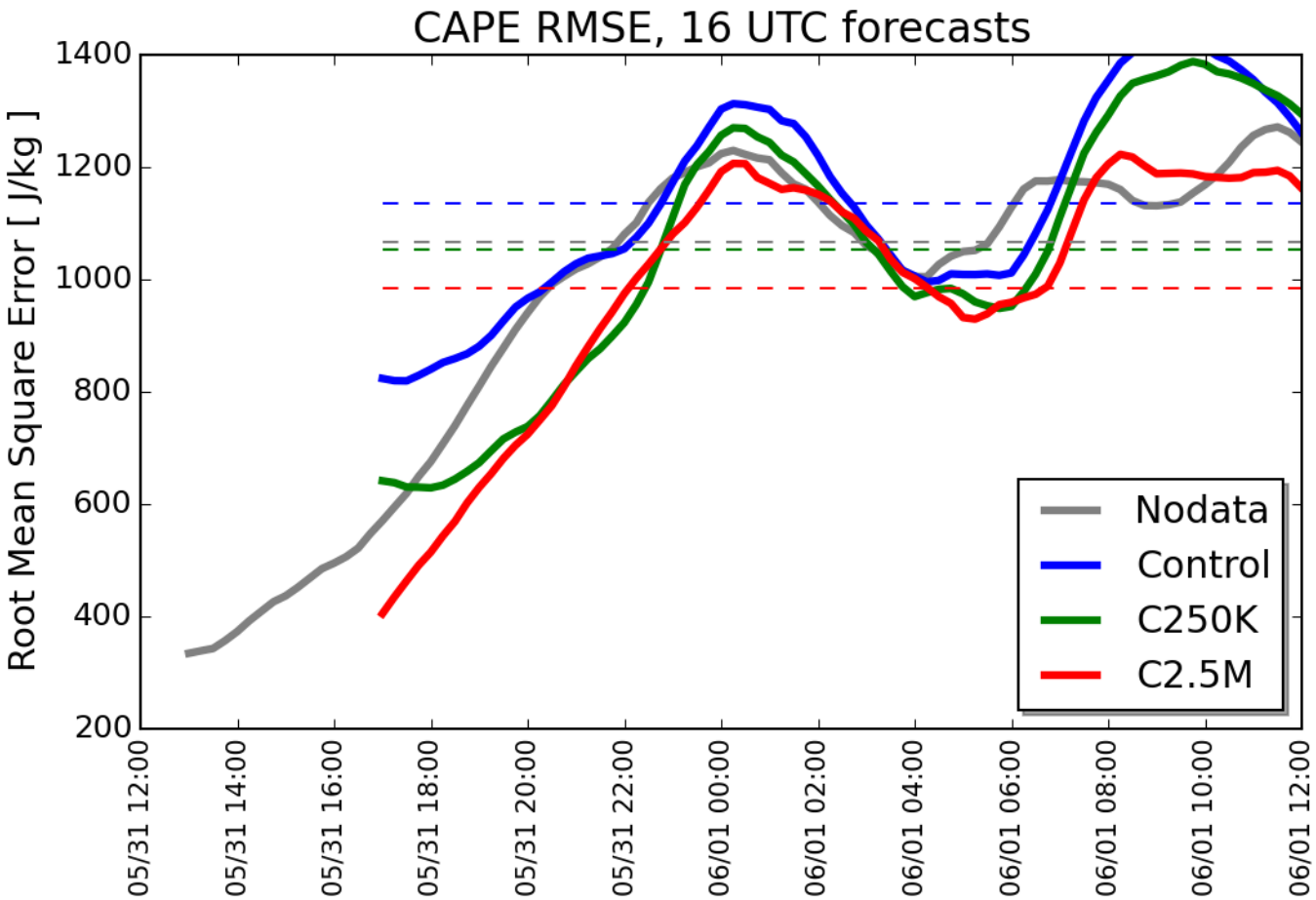
Forecast Impacts : CAPE

Vertically Integrated Quantities



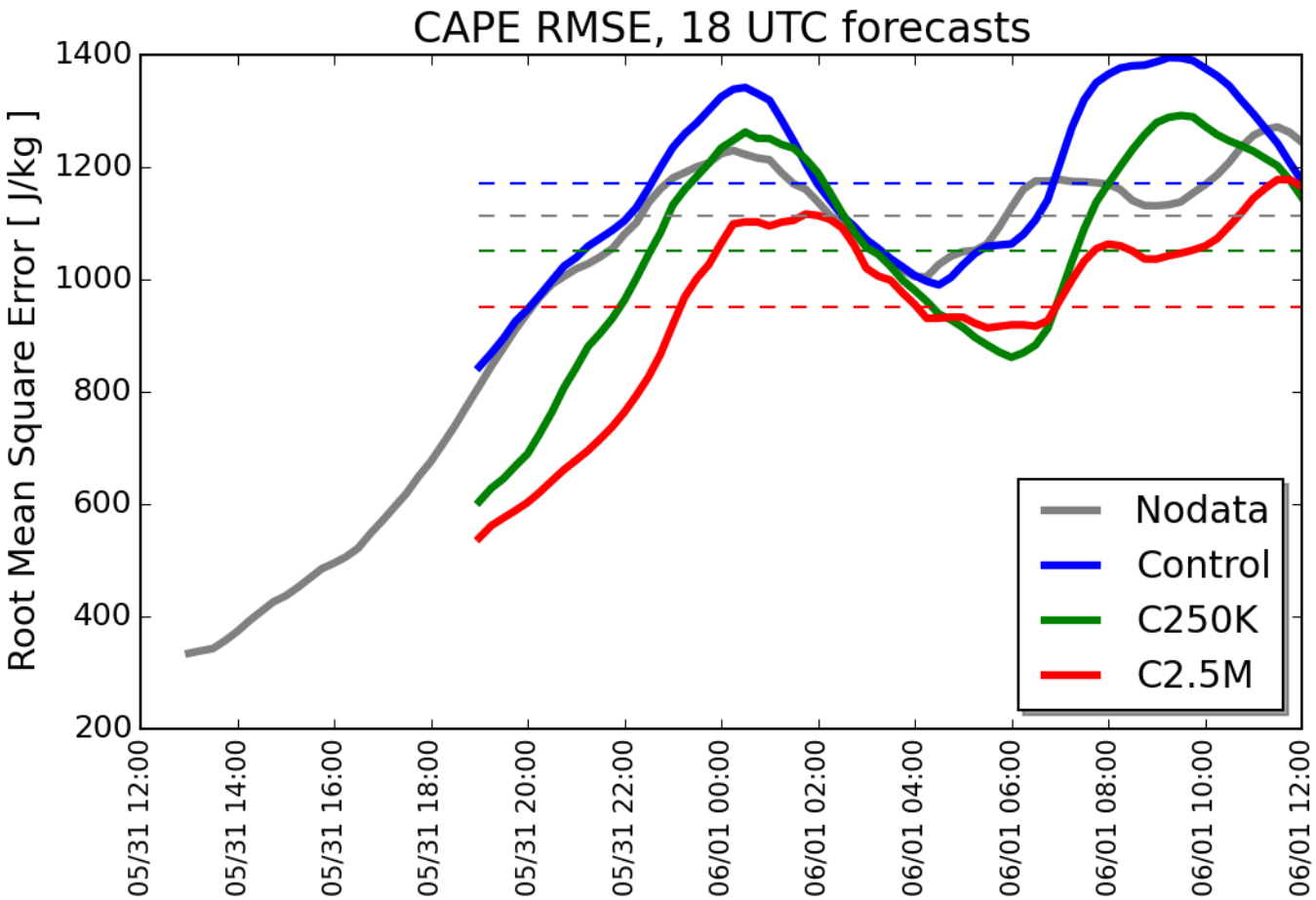
Forecast Impacts : CAPE

Vertically Integrated Quantities



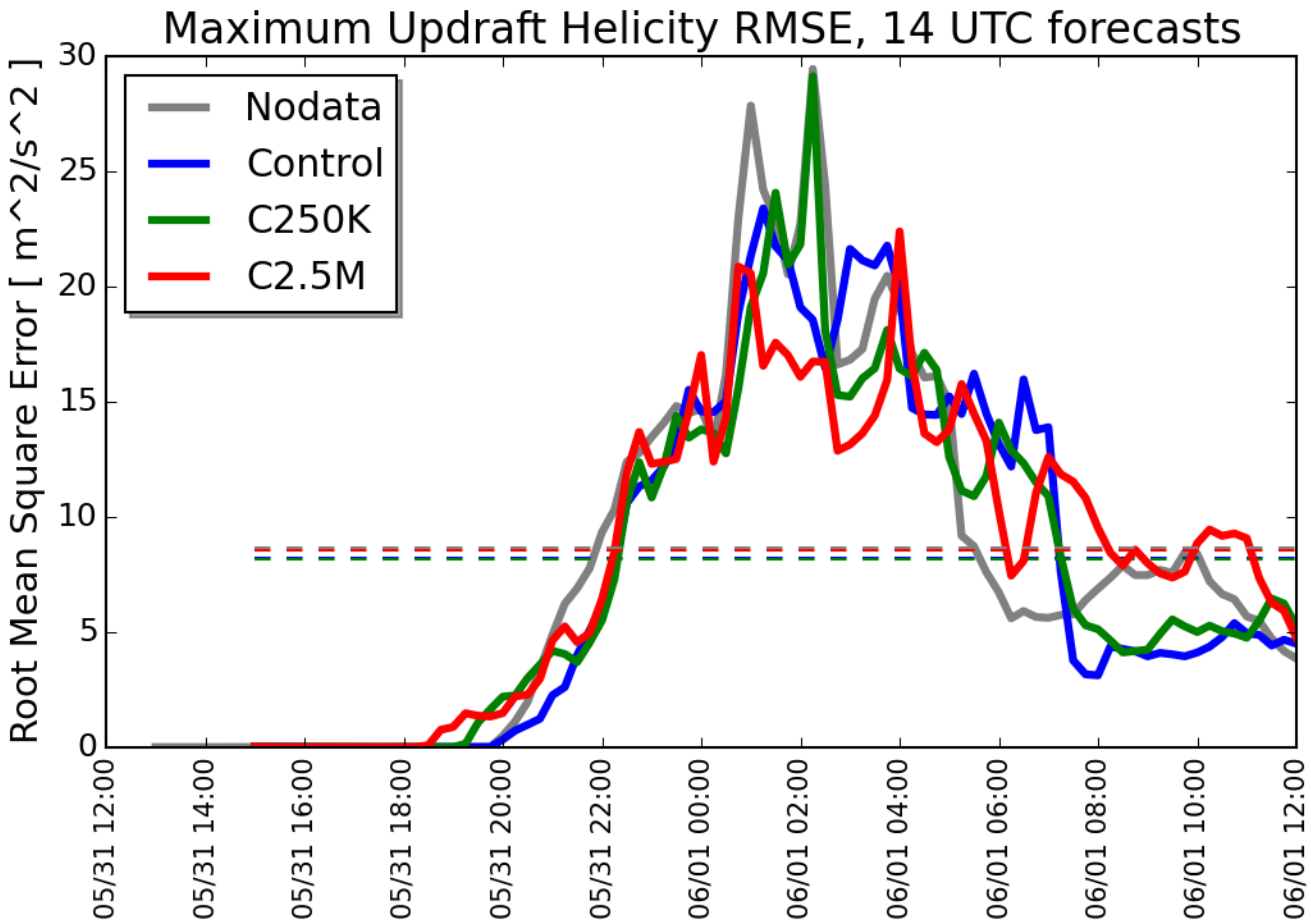
Forecast Impacts : CAPE

Vertically Integrated Quantities



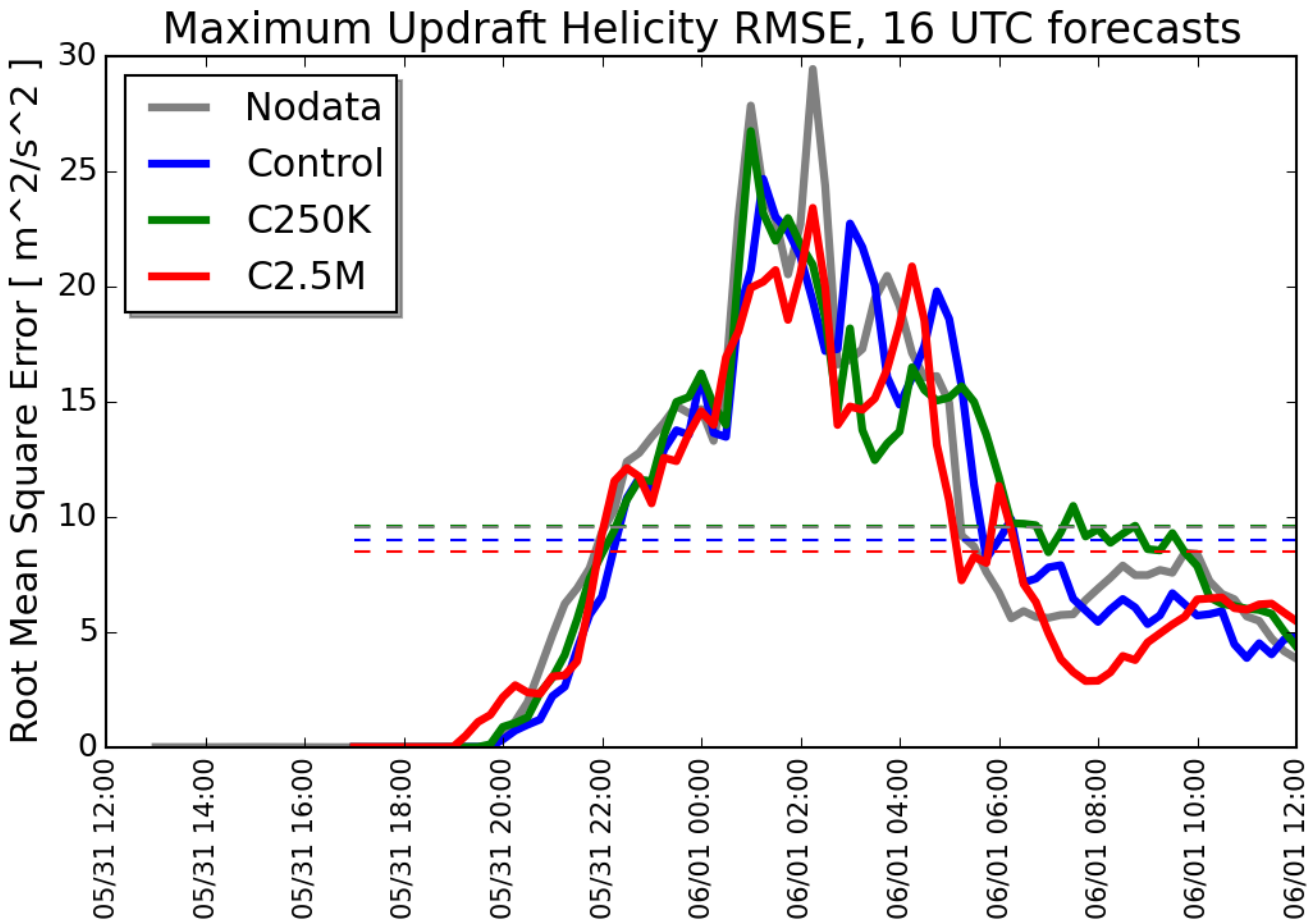
Forecast Impacts : updraft helicity

Vertically Integrated Quantities



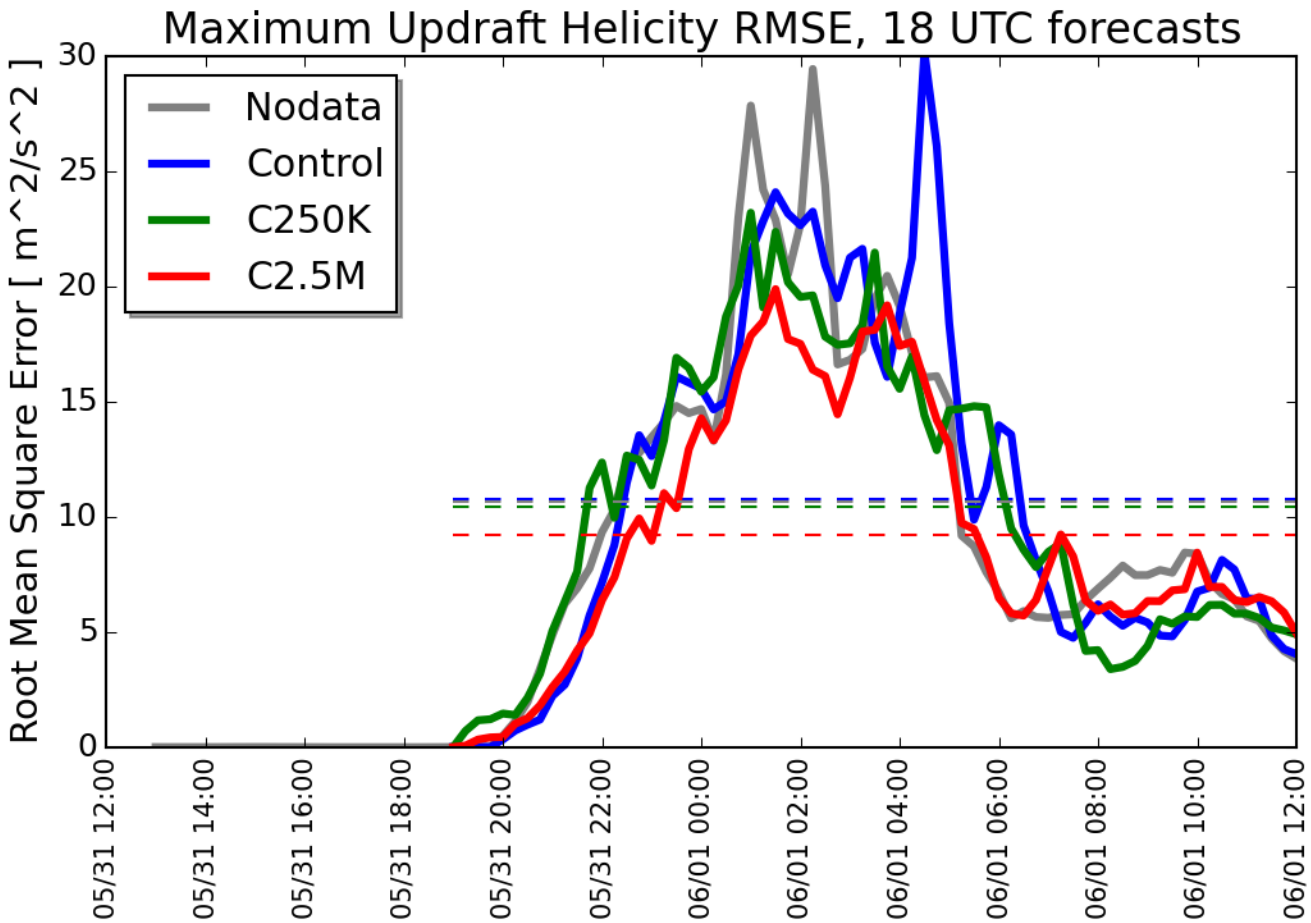
Forecast Impacts : updraft helicity

Vertically Integrated Quantities



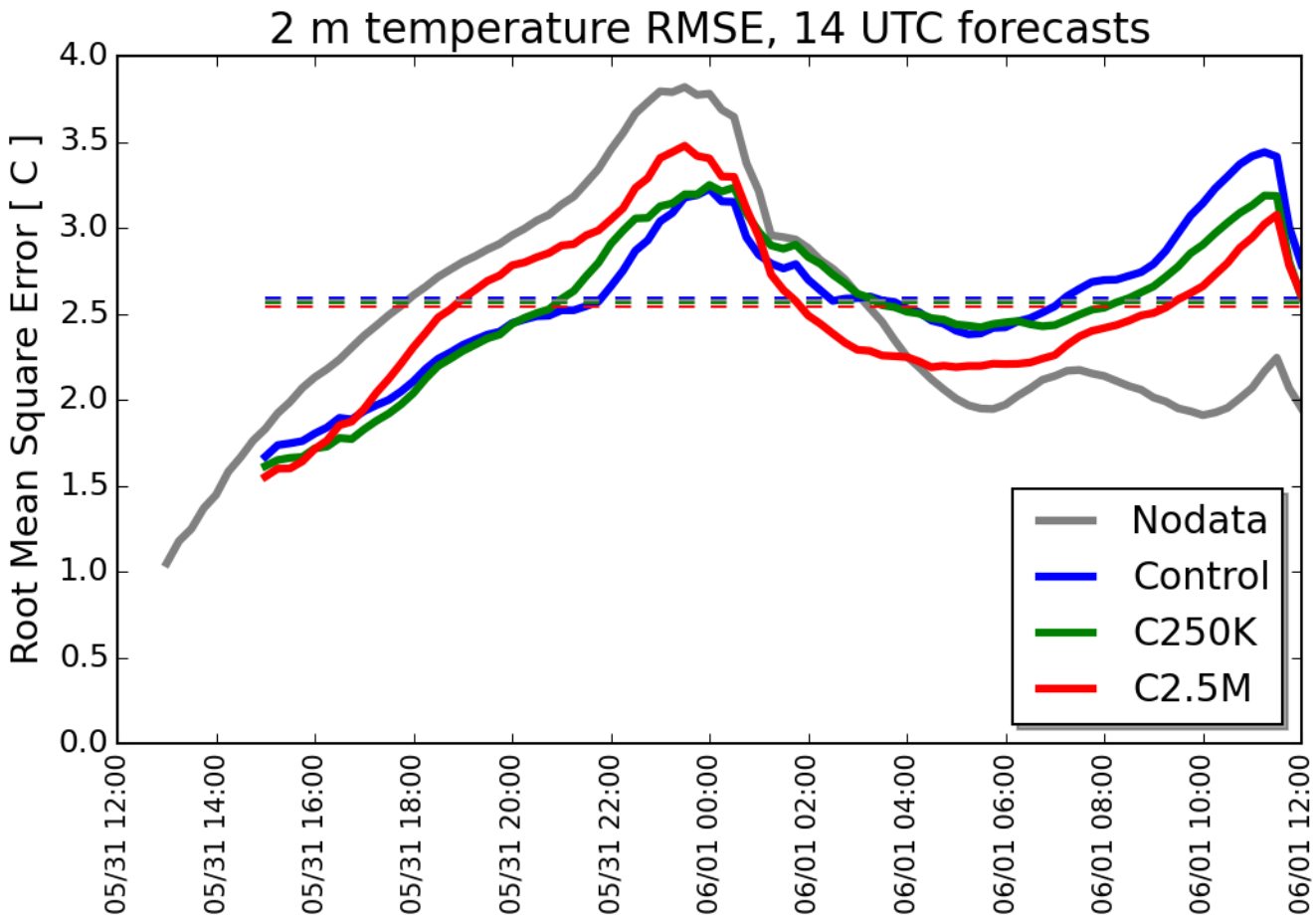
Forecast Impacts : updraft helicity

Vertically Integrated Quantities



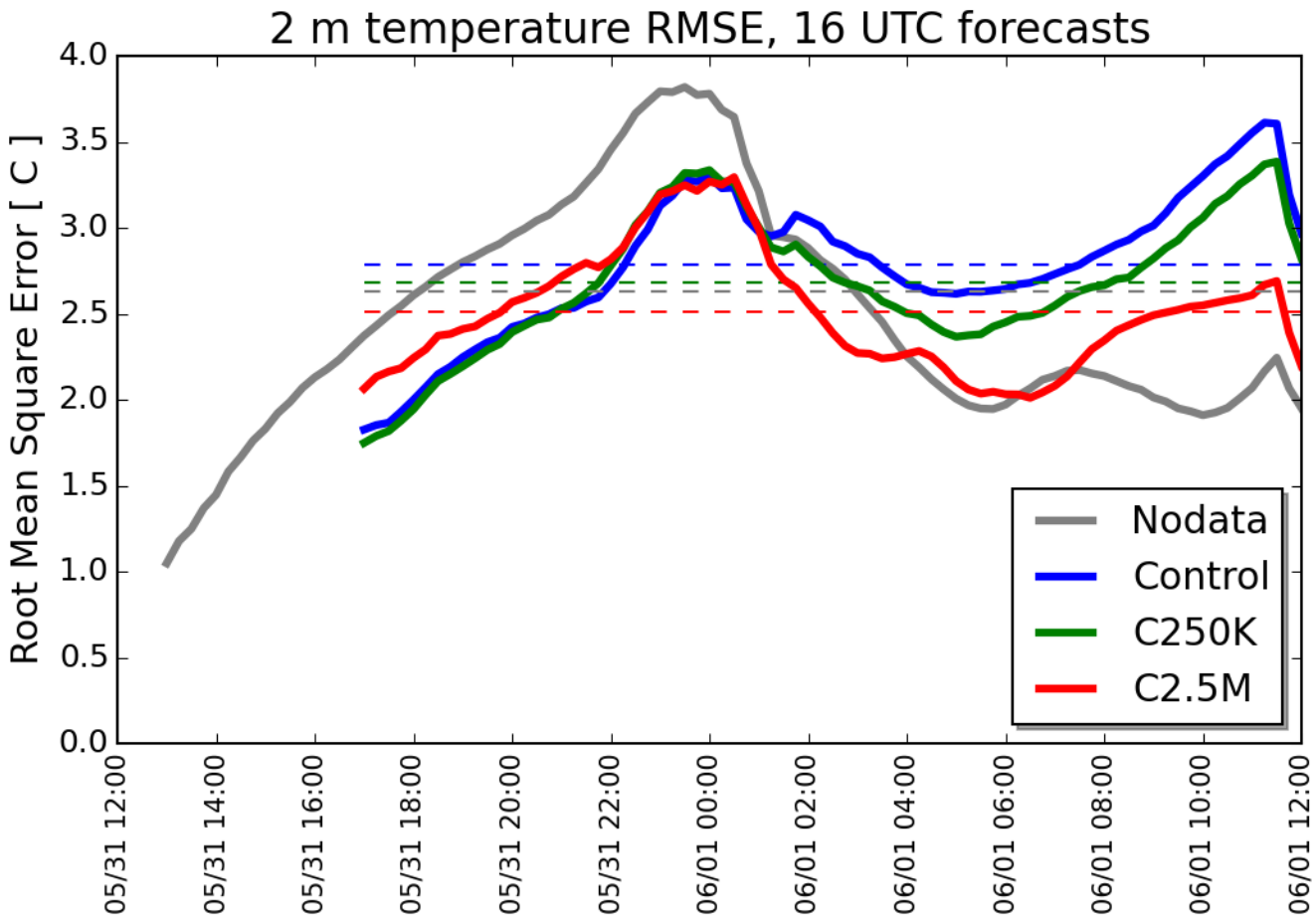
Forecast Impacts : surface temperature

Surface Sensible Weather



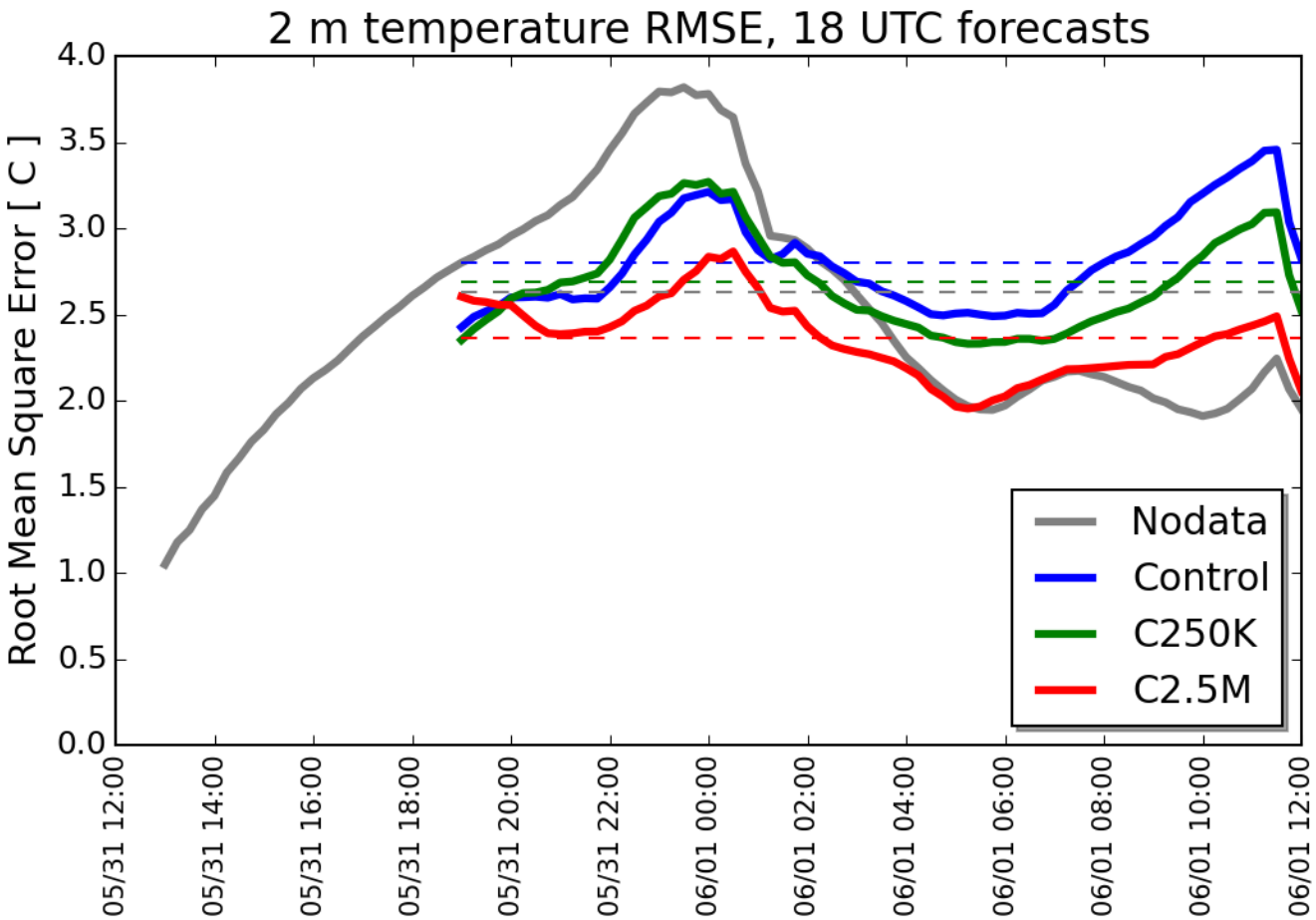
Forecast Impacts : surface temperature

Surface Sensible Weather



Forecast Impacts : surface temperature

Surface Sensible Weather



Conclusions and looking ahead

- An OSSE to explore the impact of very large GNSS RO constellations is nearly done.
- Focus is on severe weather impacts.
- First mesoscale, severe weather application/evaluation of RO data.
- Very positive results for tropospheric moisture analysis.
- Forecast results for this one case are overall positive.
- Finishing skill score validation across many variables.
- Writing into a journal article now.
- Hope to extend this work to evaluate impacts on a diverse set of cases.

Thank you for your attention!