NMMB Model Changes as Part of the NAMv4 Upgrade

Brad Ferrier[1,2], Eric Aligo[1,2], Zavisa Janjic[2],
Eric Rogers[2], Jacob R. Carley[1,2], Matt Pyle[2],
Dusan Jovic[1,2], Tom Black[2], Geoff DiMego[2]

[1] I.M. Systems Group, Inc. (IMSG)
[2] NOAA/NWS/NCEP/EMC

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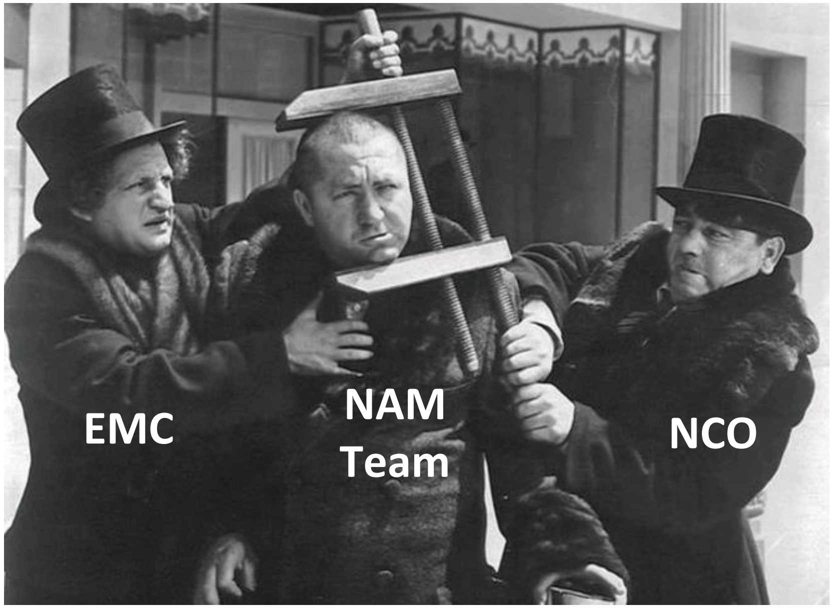
Background

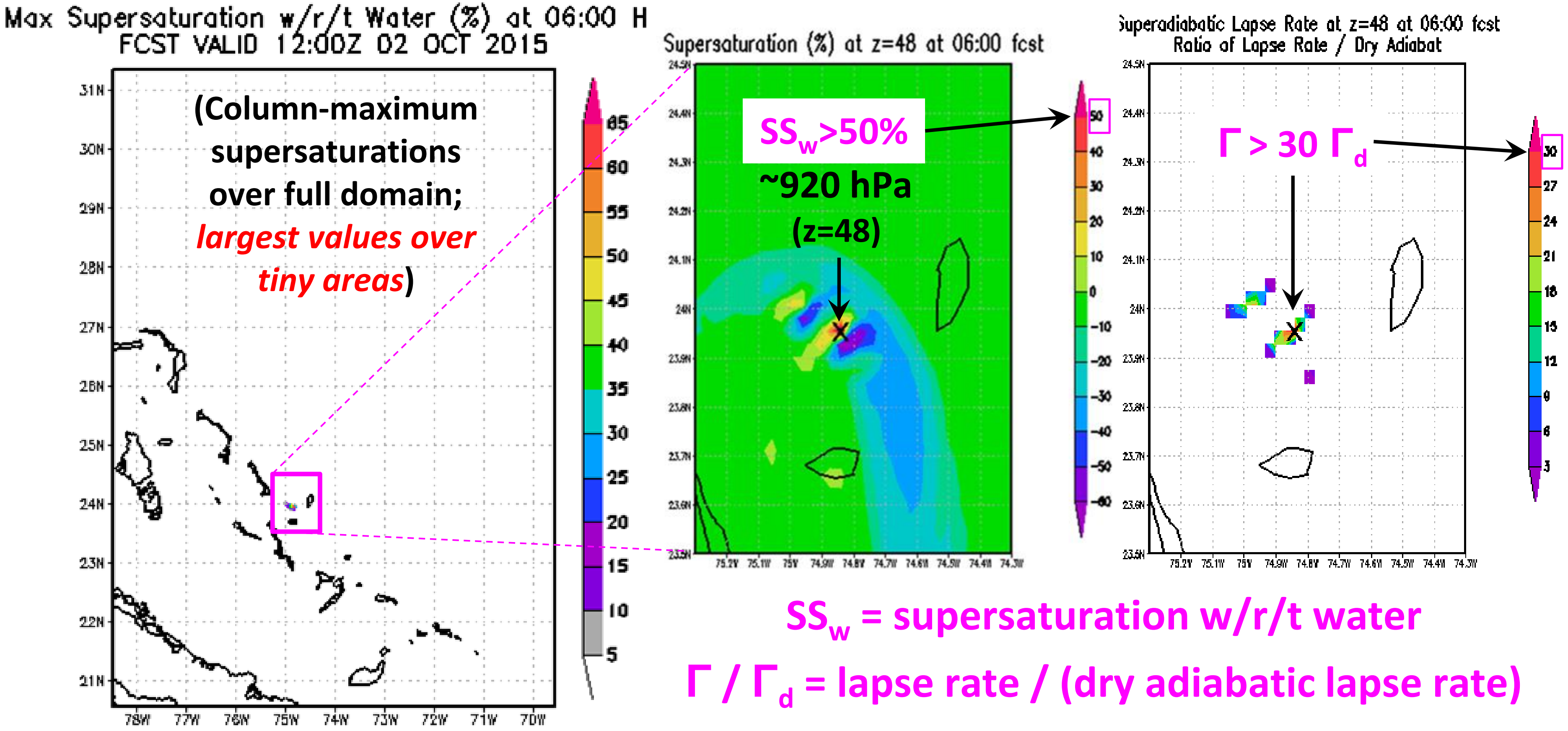
- **Production 4-km NAM CONUS nest had 3 failures (aborted runs) associated with Hurricane Joaquin (20150929 – 20151002)**
  - **Needed to run “BMJ lite” for stability (small amount of deep convection)**
- **There was also a failure in the 3-km real-time parallel NAM nest**



Summary of Model Changes
(aka “Joaquin changes”)

1. **Update moist processes every other time step (sfc layer, land sfc, PBL, & microphysics for all domains; GWD & convection in parent only)**
2. **Advect specific humidity every time step** (rather than every other time step)
3. **Calculate cloud condensation every time step to remove supersaturations**
4. **Mix out superadiabatic layers that form in strong updrafts**

Numerical Instability (1 of 3)



Max Supersaturation w/r/t Water (%) at 06:00 H
FCST VALID 12:00Z 02 OCT 2015

(Column-maximum supersaturations over full domain; *largest values over tiny areas*)

Supersaturation (%) at z=48 at 06:00 fcst

SS_w>50%

~920 hPa (z=48)

Superadiabatic Lapse Rate at z=48 at 06:00 fcst
Ratio of Lapse Rate / Dry Adiabat

$\Gamma > 30\ \Gamma_d$

SS_w = supersaturation w/r/t water

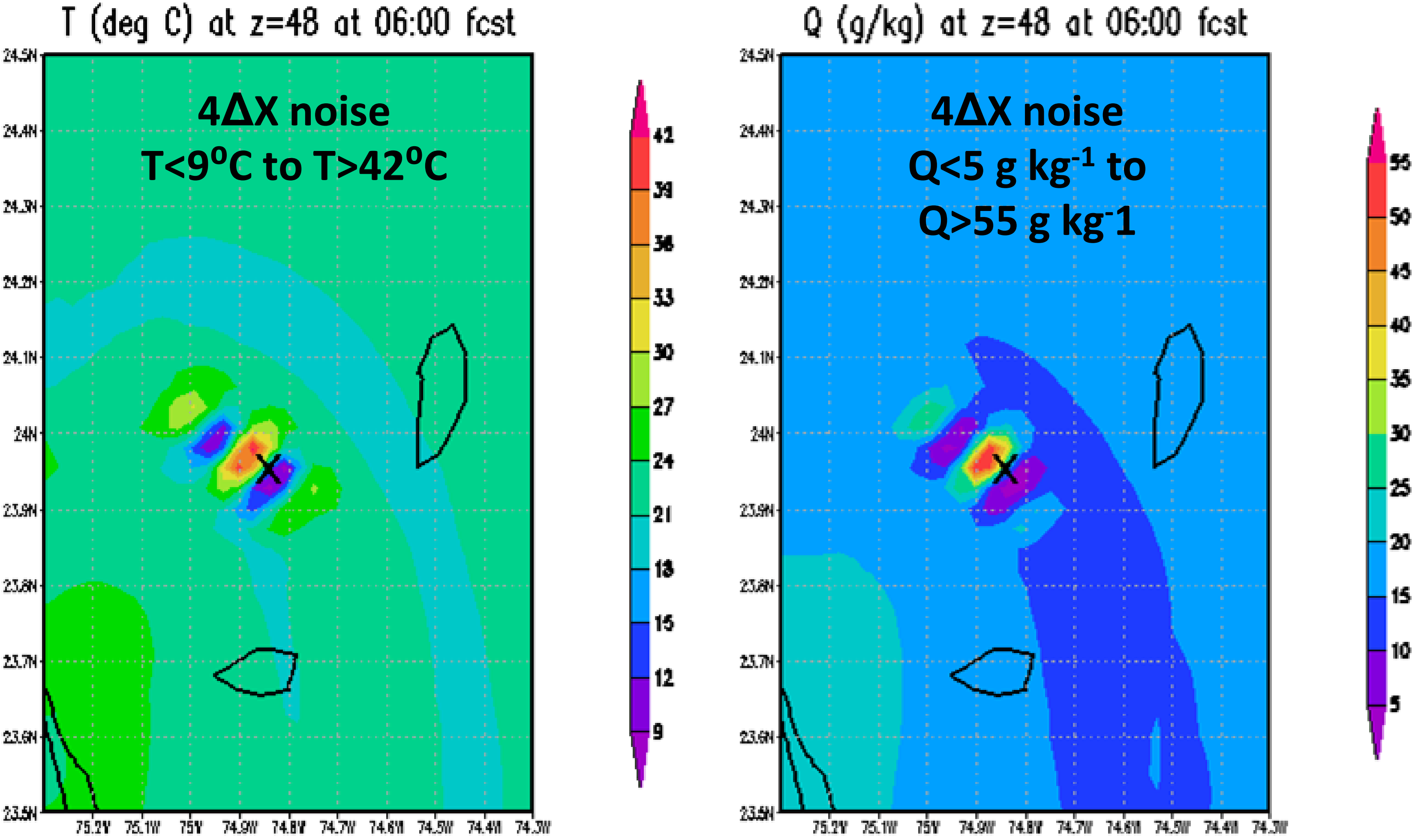
Γ / Γ_d = lapse rate / (dry adiabatic lapse rate)

3-km/60 L (30 hPa top) NMMB run over small domain

- Moist physics called every other time step (from 1 every 4)
- Moisture variables advected every other time step

Numerical Instability (2 of 3)

~920 hPa


T (deg C) at z=48 at 06:00 fcst

4ΔX noise
T<9°C to T>42°C

Q (g/kg) at z=48 at 06:00 fcst

4ΔX noise
Q<5 g kg^{-1} to
Q>55 g kg^{-}1

Large instabilities at 880 – 950 hPa

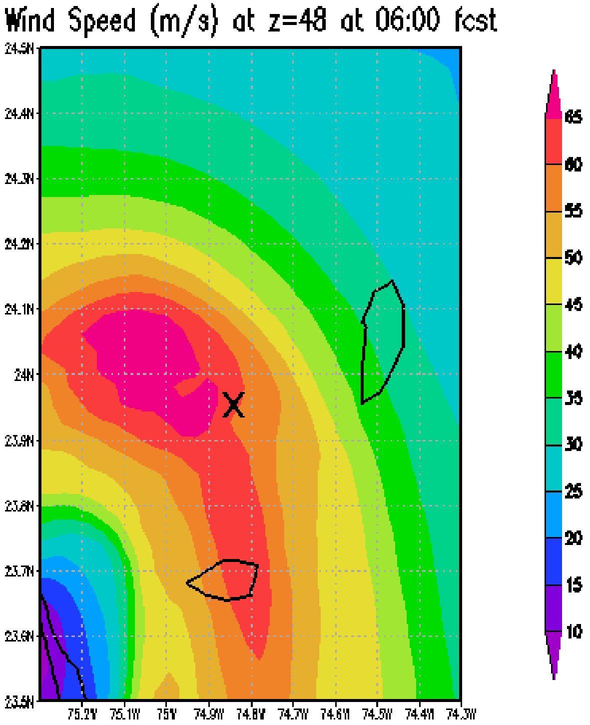
Numerical Instability (3 of 3)

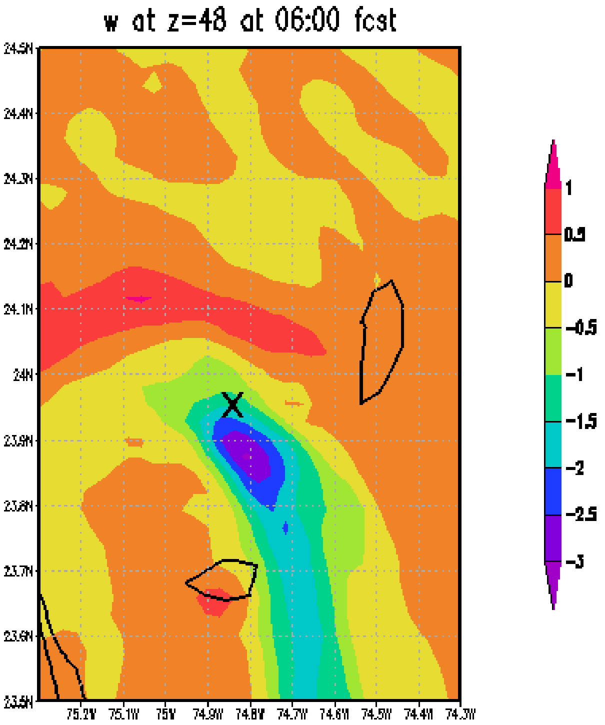
- **Numerical instability was eliminated when**
  - **Advecting moisture fields every time step**
  - **Did not require updating moist physics every time step**

Left: Instability appeared along the outer edge of a local wind maximum.

Right: It developed at the leading edge of modest ***descent***. Vertical motions were generally weak and well behaved.

The instability led to the model failures.



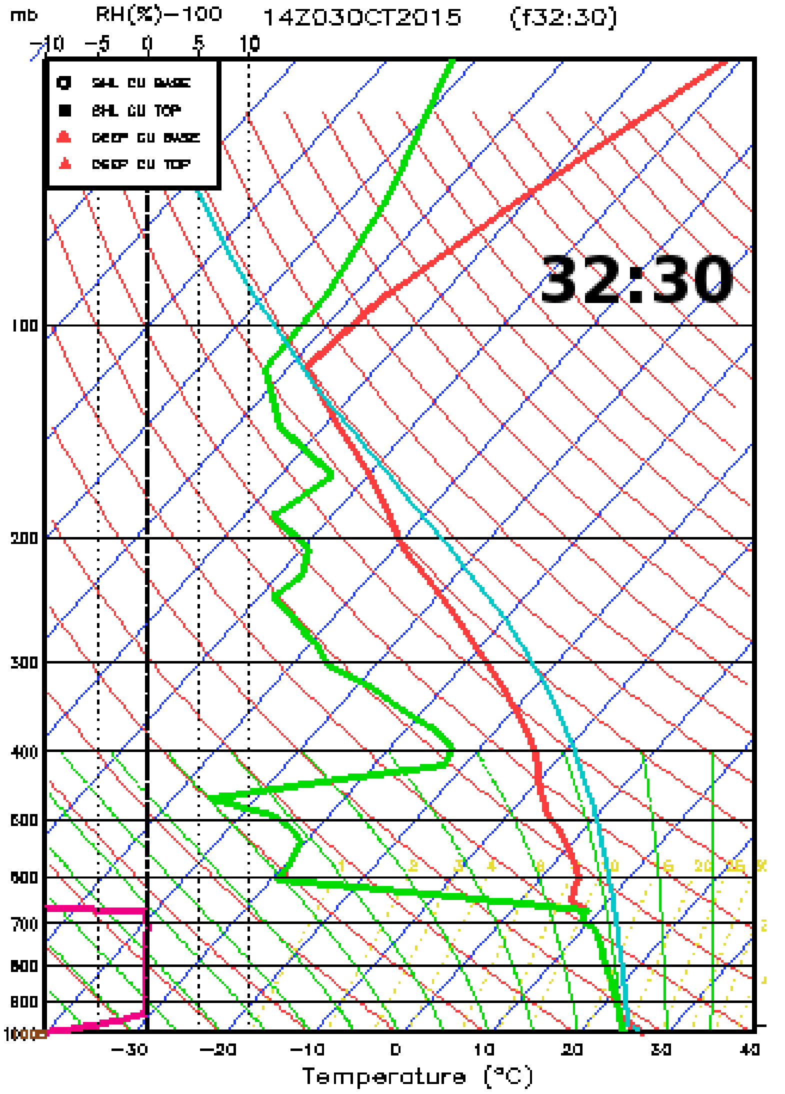


Advecting Specific Humidity Every Time Step

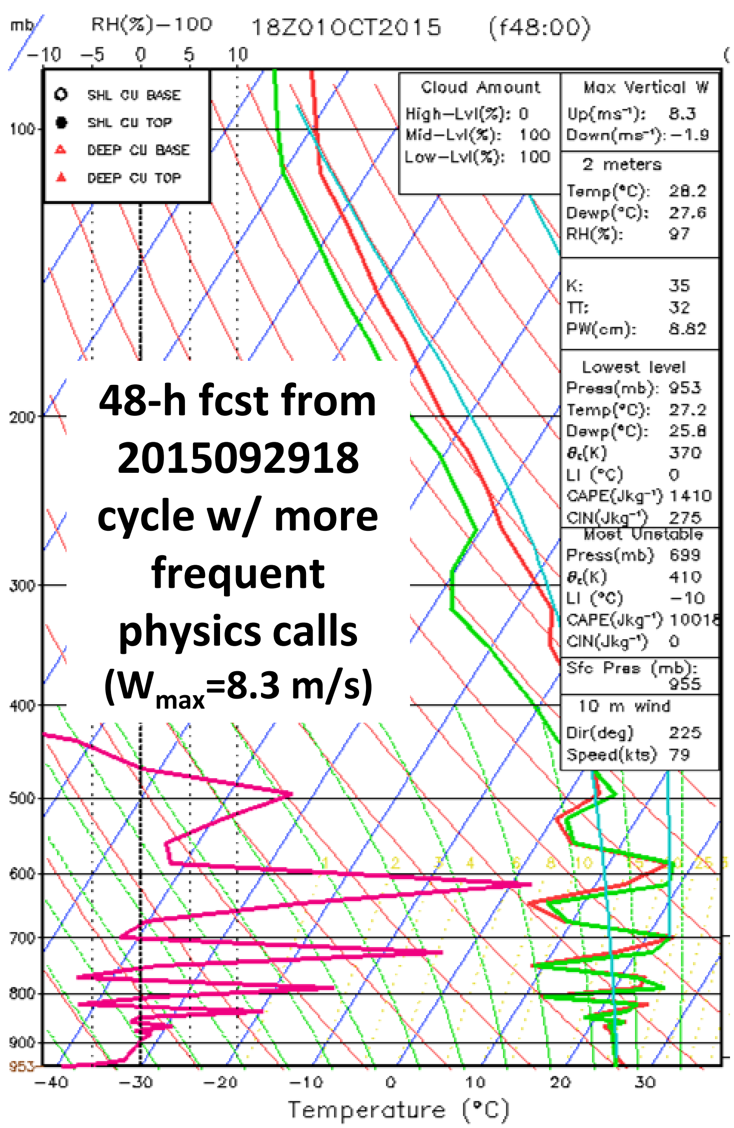
- **Advecting all “scalars” (TKE, Q, Q_{cw}, Q_r, Q_{ci+s}, Q_g) required at least a 20% increase in computing resources**
  - **Code was restructured so that only Q can be advected every time step, the other variables can be advected every *other* time step**
  - **Code infrastructure was made more efficient**
  - **Led to a smaller (<10%) increase in computing cost**

Noisy Temperature Profiles (1 of 6)

- **But high-frequency oscillations (noise?) remained even in runs where all fields were advected and moist processes were updated every time step (right; 5-min skew-Ts from 32 h 30 min to 33 h 30 min).**
- **Also seen in other runs for different cycles with different physics options (next slide).**
- **Oscillations are transient.**
- **Many more runs were made with 5-min output to study cause(s).**



Noisy Temperature Profiles (2 of 6)



Cloud Amount
High−Lvl(%): 0
Mid−Lvl(%): 100
Low−Lvl(%): 100

Max Vertical W
Up(ms⁻¹): 8.3
Down(ms⁻¹): −1.9

2 meters
Temp(°C): 28.2
Dewp(°C): 27.6
RH(%): 97

K: 35
TT: 32
PW(cm): 8.82

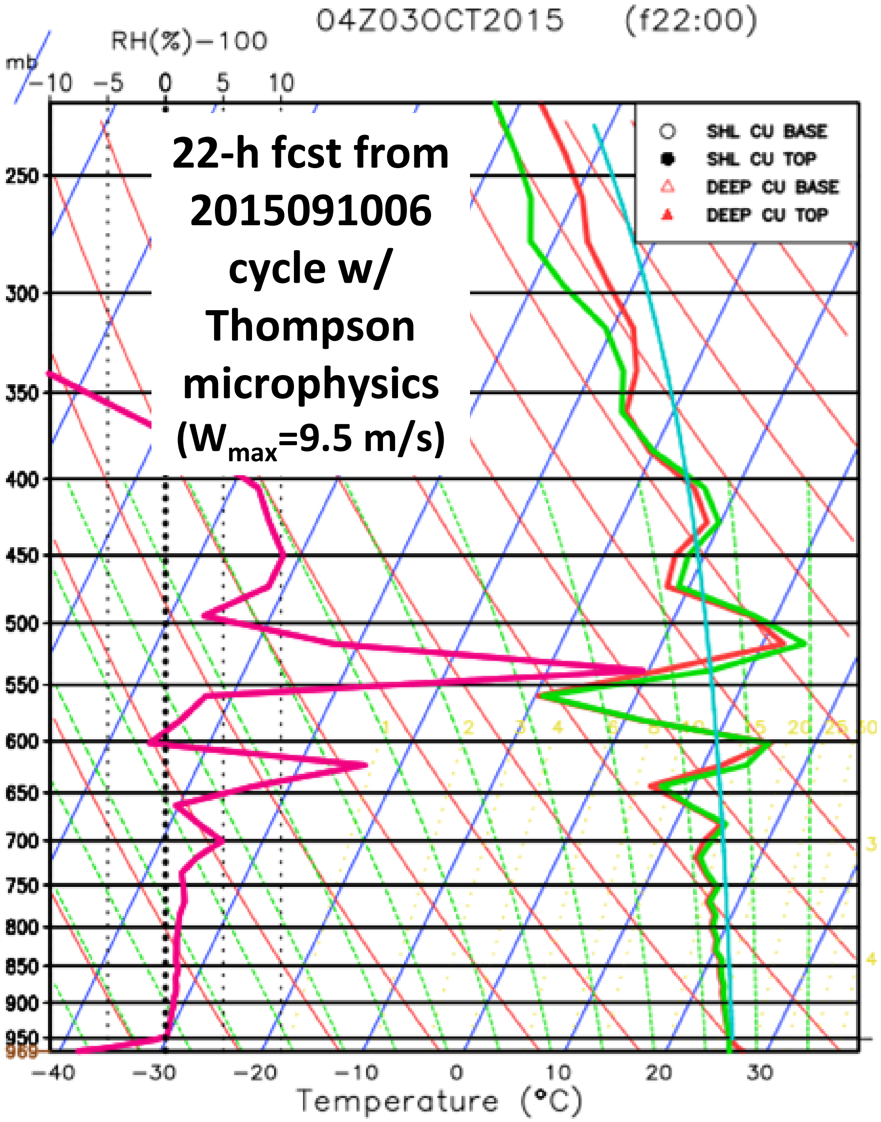
Lowest level
Press(mb): 953
Temp(°C): 27.2
Dewp(°C): 25.8
θ_e(K) 370
LI (°C) 0
CAPE(Jkg⁻¹) 1410
CIN(Jkg⁻¹) 275

Most Unstable
Press(mb) 699
θ_e(K) 410
LI (°C) −10
CAPE(Jkg⁻¹) 10018
CIN(Jkg⁻¹) 0

Sfc Pres (mb): 955

10 m wind
Dir(deg) 225
Speed(kts) 79

48-h fcst from 2015092918 cycle w/ more frequent physics calls (W_{max}=8.3 m/s)



22-h fcst from 2015091006 cycle w/ Thompson microphysics (W_{max}=9.5 m/s)

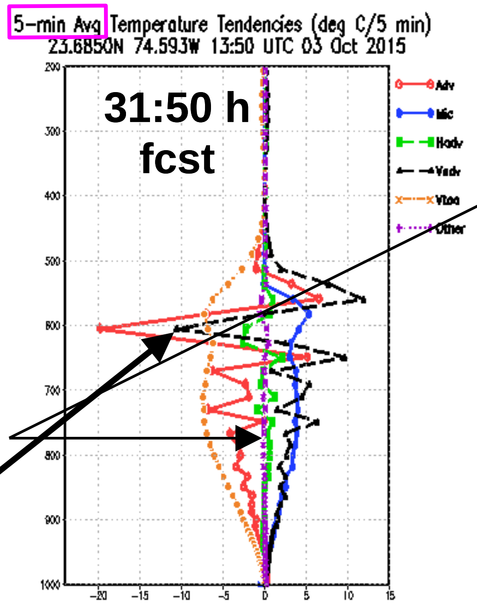
Noisy Temperature Profiles (3 of 6)

- Adv
- Mic
- Hadv
- Vad
- Vtoa
- Other

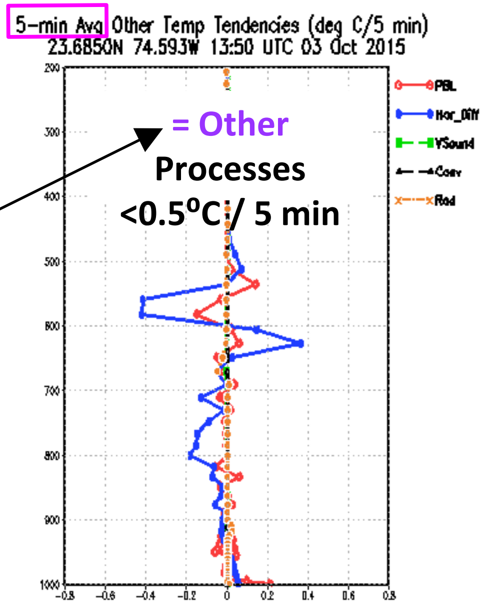
Large oscillations in Vadv

Adv=Vadv
+Hadv
+Vtoa

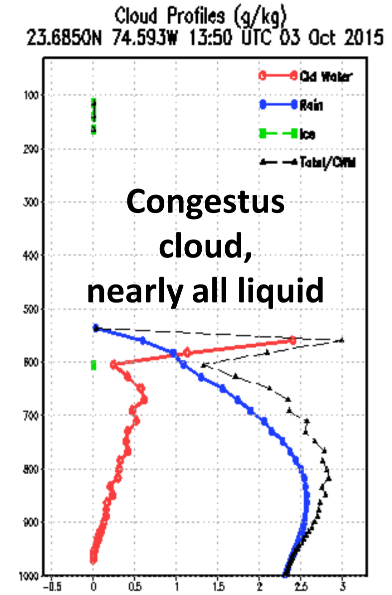
(Mic=micro)


5-min Avg Temperature Tendencies (deg C/5 min)
23.6850N 74.593W 13:50 UTC 03 Oct 2015

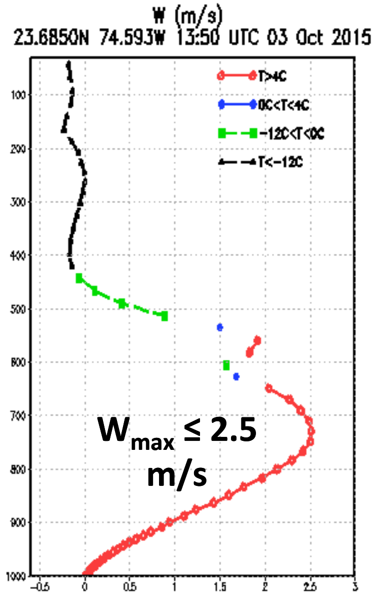
31:50 h fcst


5-min Avg Other Temp Tendencies (deg C/5 min)
23.6850N 74.593W 13:50 UTC 03 Oct 2015

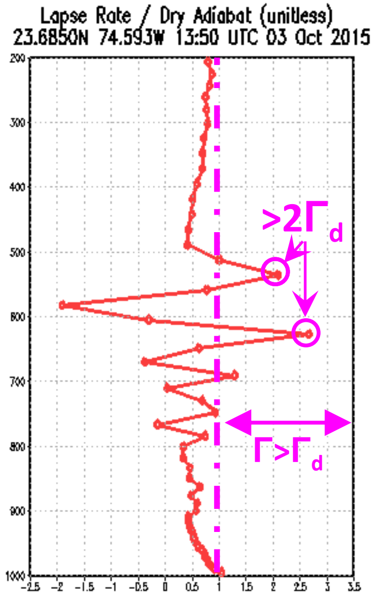
= Other Processes $<0.5^oC$ / 5 min


Cloud Profiles (g/kg)
23.6850N 74.593W 13:50 UTC 03 Oct 2015

Congestus cloud, nearly all liquid

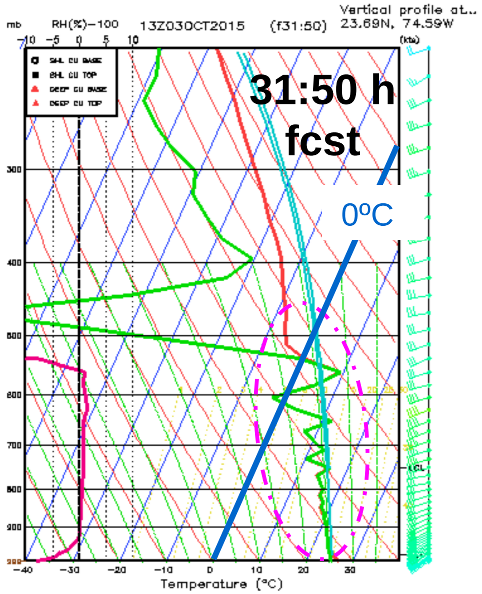

W (m/s)
23.6850N 74.593W 13:50 UTC 03 Oct 2015

$W_{max} \leq 2.5$ m/s


Lapse Rate / Dry Adiabat (unitless)
23.6850N 74.593W 13:50 UTC 03 Oct 2015

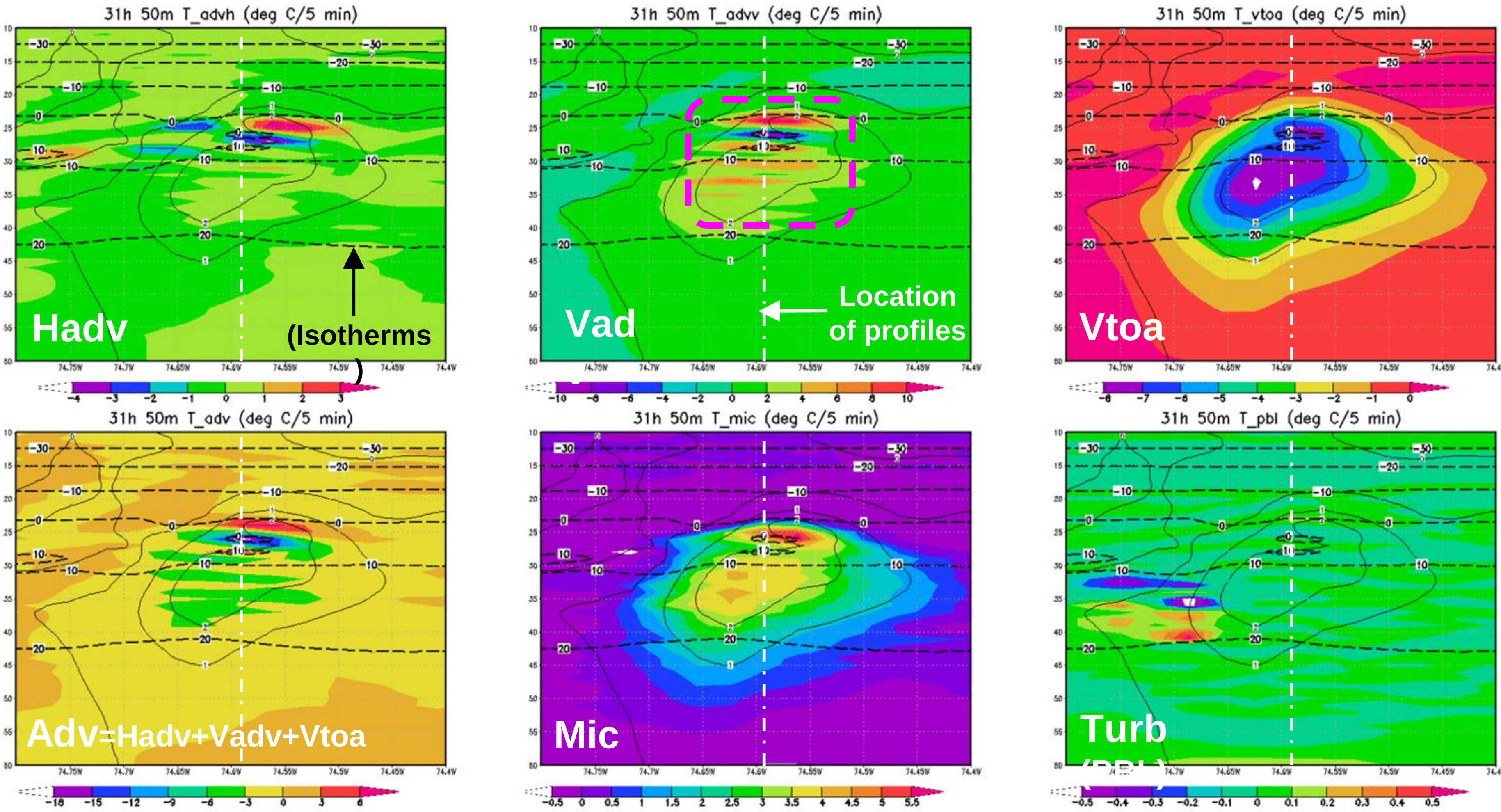
$>2\Gamma_d$

$\Gamma>\Gamma_d$


31:50 h fcst

0ºC

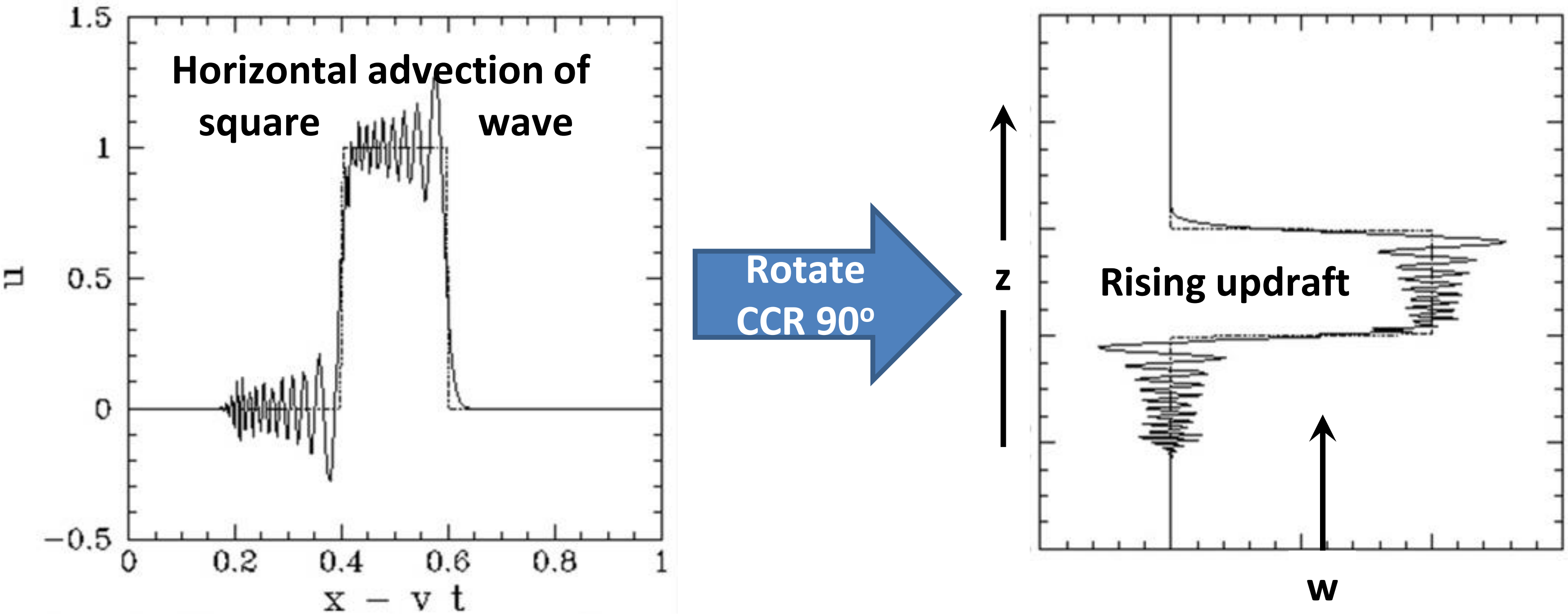
Noisy Temperature Profiles (4 of 6)



- E-W cross sections centered on profiles (every 5 min)
- Large oscillations in 5-min T changes by Vadv

Noisy Temperature Profiles (5 of 6)

- **Oscillations primarily due to Crank-Nicolson (CN) vertical advection (Vadv)**



“Unfortunately, the Crank-Nicholson scheme does a very poor job at advecting wave-forms with *sharp leading or trailing edges*…. It turns out that all *central difference* schemes for solving the advection equation suffer from a similar problem.” (Left figure & notes from Prof. Richard Fitzpatrick, Univ. Texas)

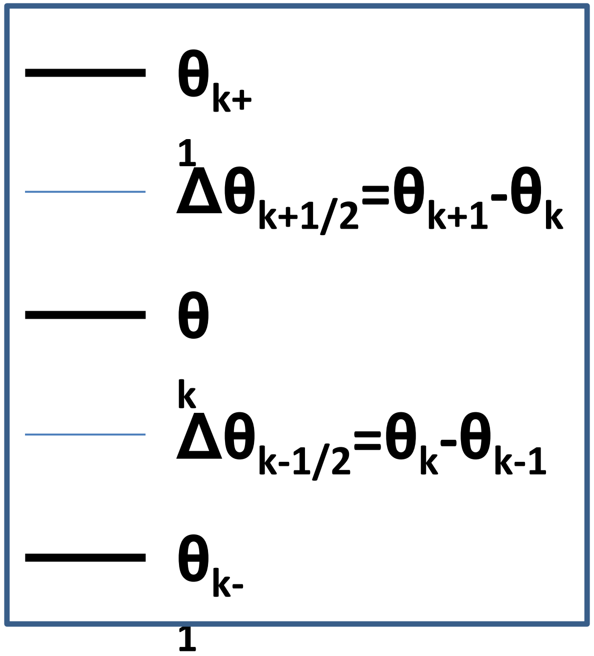
Noisy Temperature Profiles (6 of 6)

- The following changes were tested
  - Adjustments to CN off centering
  - Minimum TKE (function of height) increased by 10x from surface to model top
  - Run with different versions of shallow convection
  - Horizontal averaging (filtering) of vertical velocity
  - T, Q adjustments(only this was successful)
    - T adjust: mix out all superadiabatic layers ($\Gamma > \Gamma_d$)
    - Q adjust: remove supersaturations w/r/t water by cloud condensation every other time step when moist physics are not called
- Tens of thousands of profiles were analyzed from 5-min forecast output at locations where domain-maximum values occurred in updraft velocities, surface rainfall rates, lapse rates, and supersaturations

Temperature Adjustments

Rules

1. Only mix layers *<u>above the surface layer</u>* of a convective boundary layer (let's refer to as "elevated" layers)
2. Between highest & lowest unstable ($\partial\theta/\partial z<0$) layers:
   a. Mix (average) θ_{k+1}, θ_k, & θ_{k-1} if $\Delta\theta_{k+1/2} < \varepsilon$ & $\Delta\theta_{k-1/2} < \varepsilon$, $\varepsilon = -0.01^{o}C$
   b. Mix θ_{k+1} & θ_k only if $\Delta\theta_{k+1/2} < \varepsilon$ & $\Delta\theta_{k-1/2} \geq \varepsilon$
   c. Mix θ_k & θ_{k-1} only if $\Delta\theta_{k+1/2} \geq \varepsilon$ & $\Delta\theta_{k-1/2} < \varepsilon$
3. Iterate until all layers have been stabilized



θ_{k+1}

$\Delta\theta_{k+1/2}=\theta_{k+1}-\theta_k$

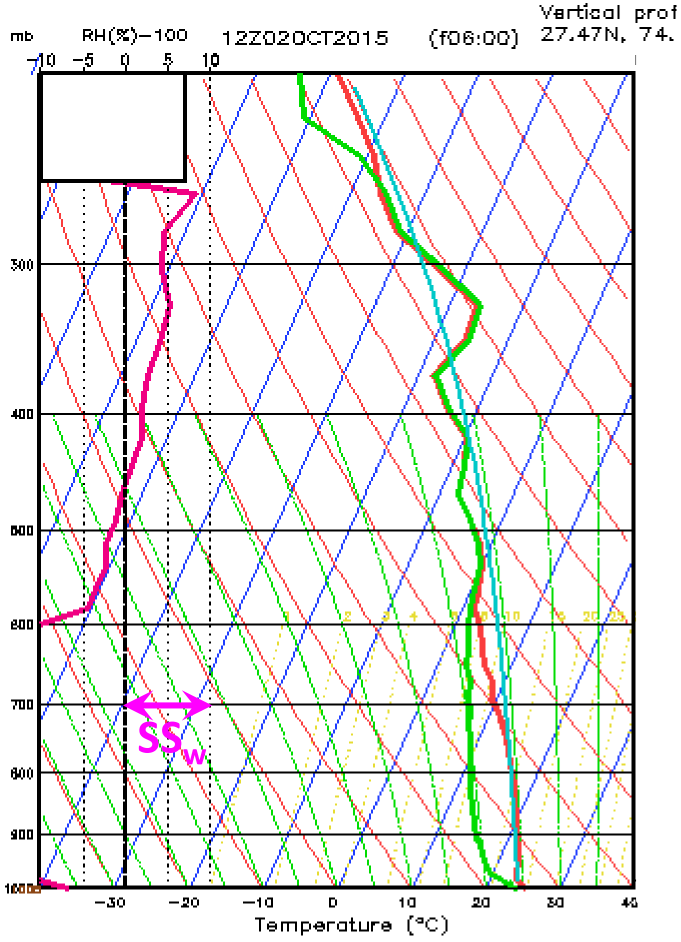
θ_k

$\Delta\theta_{k-1/2}=\theta_k-\theta_{k-1}$

θ_{k-1}

Most Extreme Examples (1 of 6)
(2015100206 - Joaquin)

Without T,Q filter



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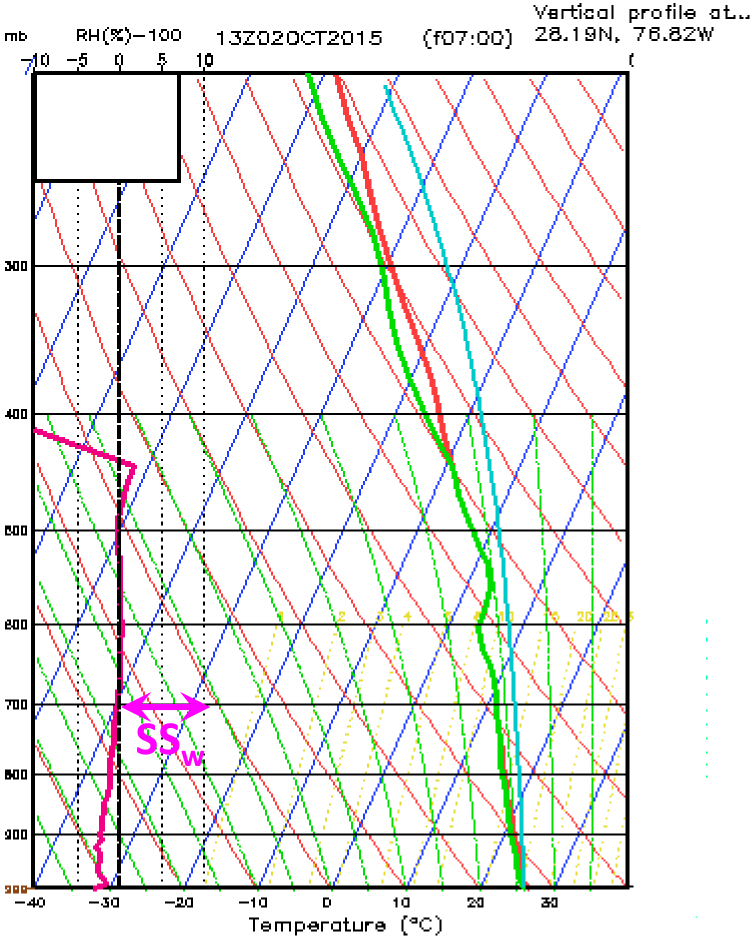
With T,Q filter



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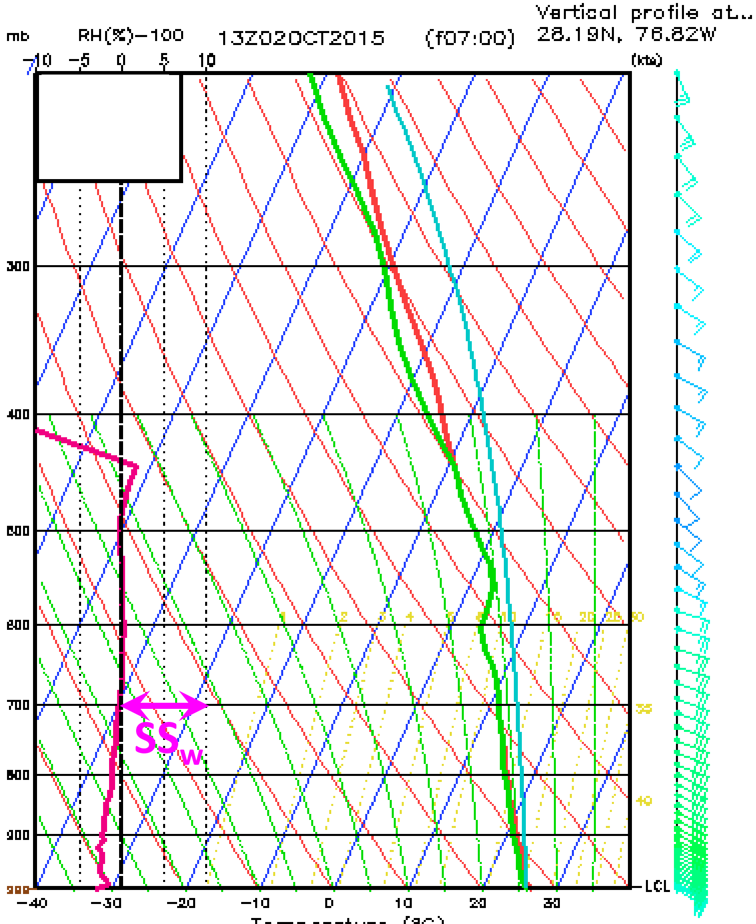
SS_w=supersaturation w/r/t water

Most Extreme Examples (2 of 6) (2015100206 - Joaquin)

With T,Q filter

NOTE

- **Areas of *modest* supersaturations are due to internal GrADS interpolation.**
- **Supersaturations are not found when relative humidity is written to NMMB history files.**
- **Moist absolutely unstable layers (MAULs) where $\Gamma_m < \Gamma < \Gamma_d$ are still present because only layers where $\Gamma > \Gamma_d$ are mixed out.**



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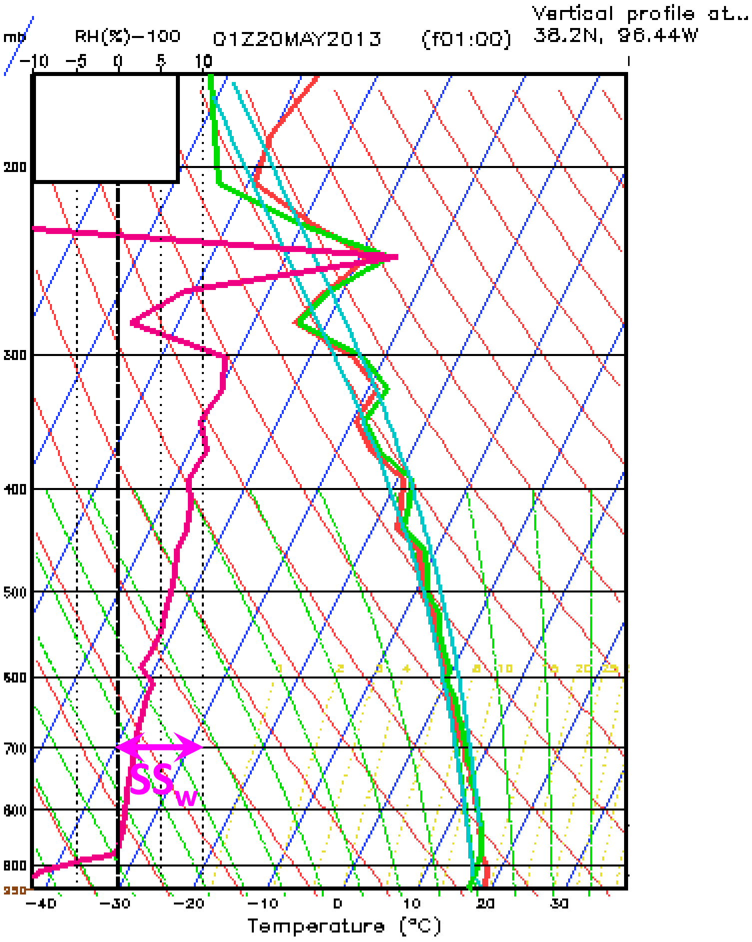
Most Extreme Examples (3 of 6)
(2013052000 – Moore, OK tornado)

Without T,Q filter



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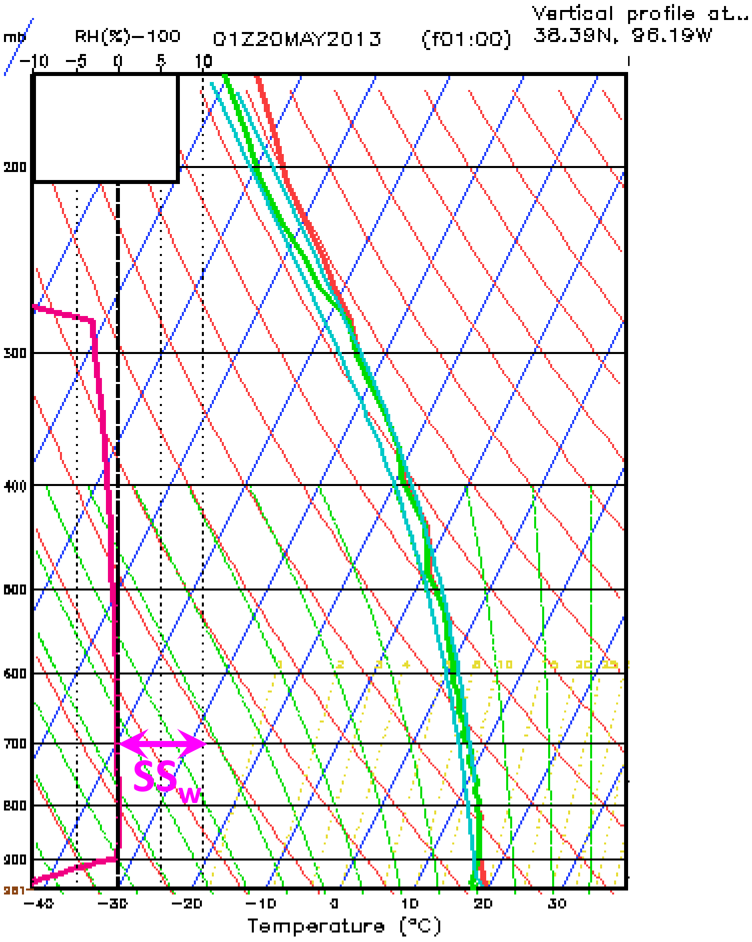
With T,Q filter



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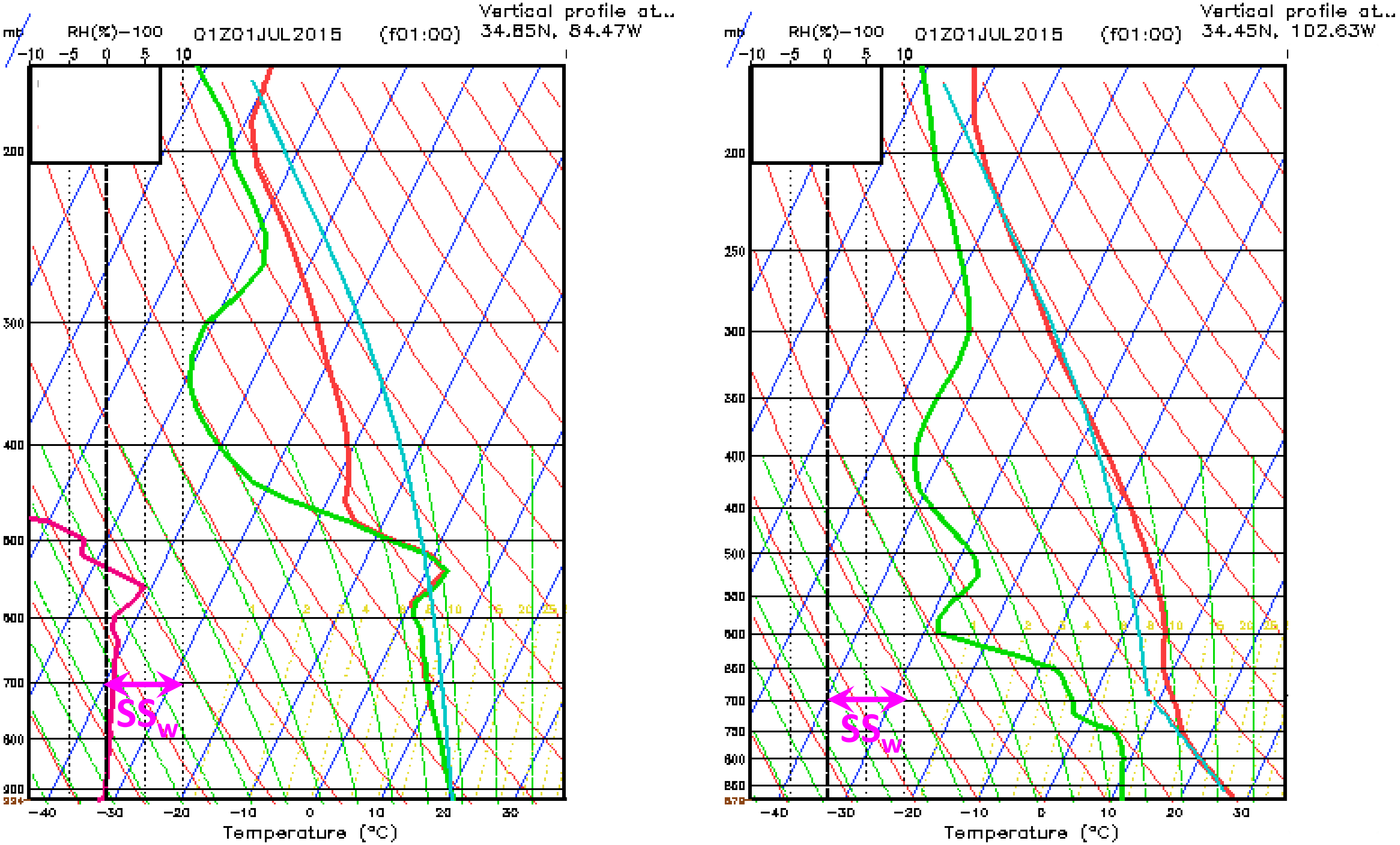
Most Extreme Examples (4 of 6)
(2016070100 – WPC Case)

Without (left) and with (right) Joaquin changes



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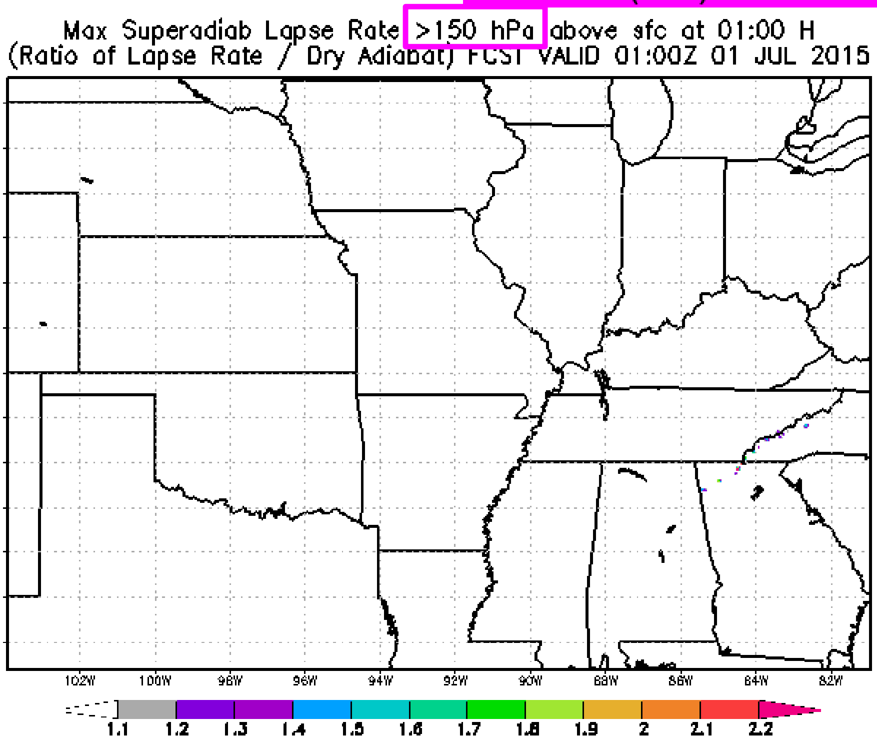
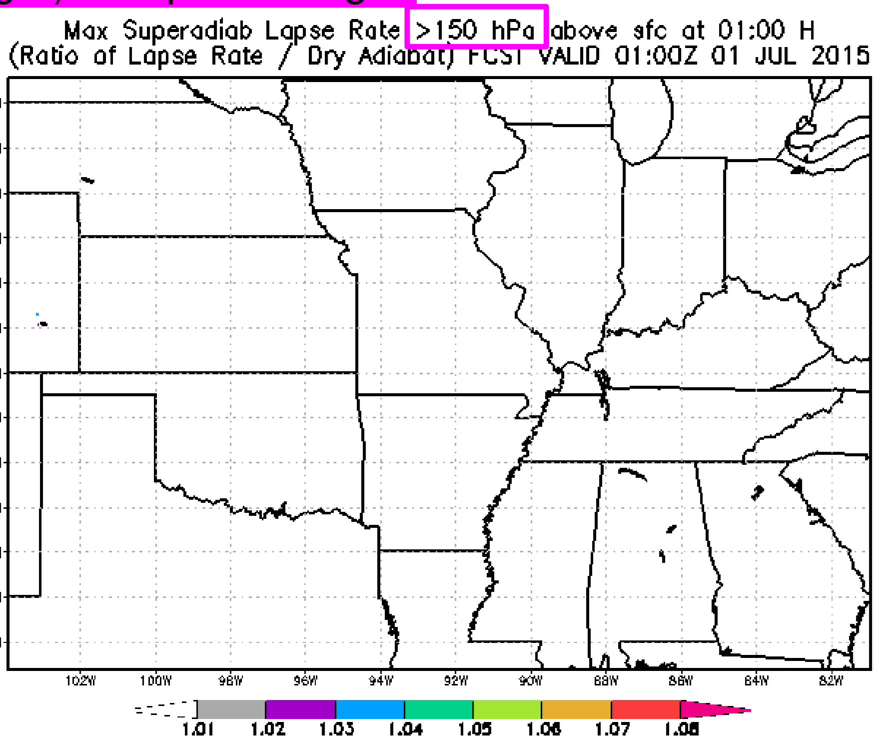
Most Extreme Examples (5 of 6)
(2016070100 – WPC Case)

Without (left) and with (right) Joaquin changes





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Max $\Gamma > 2\Gamma_d$

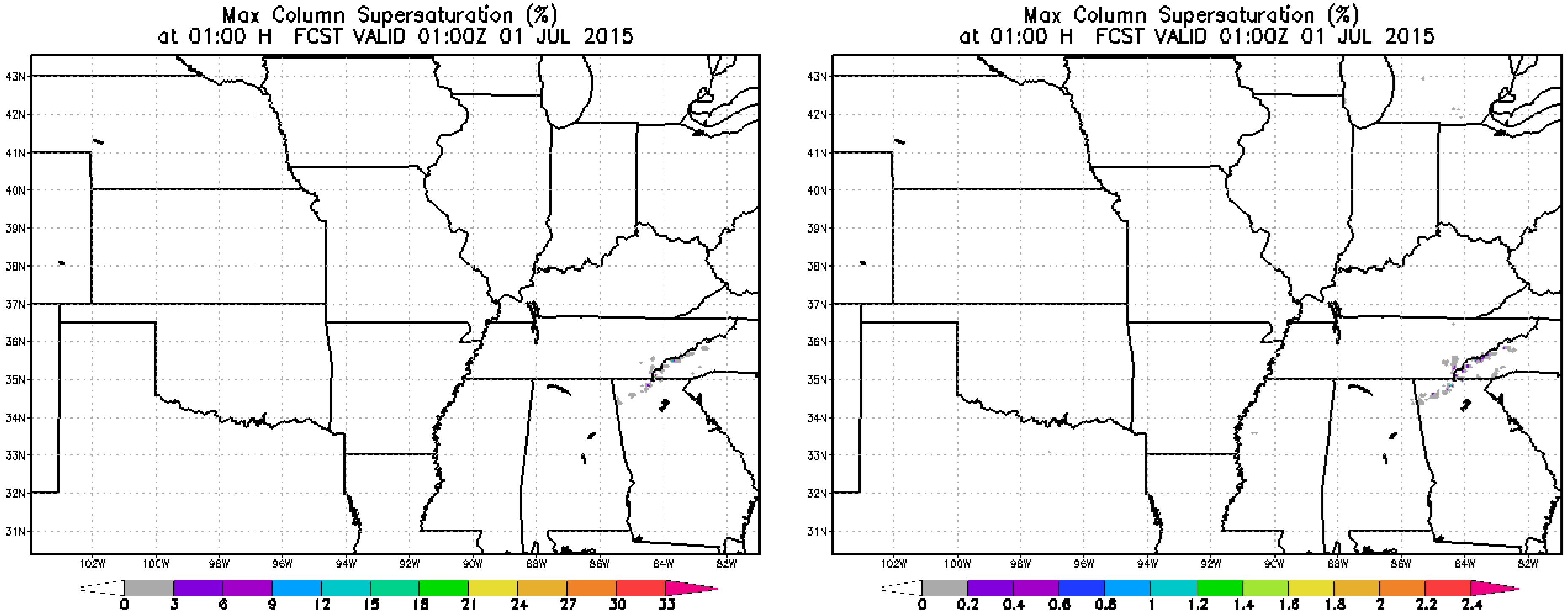
Large superadiabatic lapse rates above PBL occur over small areas of strong ascent

Max $\Gamma < 1.05\Gamma_d$

Lapse rates above PBL are effectively limited to $\leq\Gamma_d$

Most Extreme Examples (6 of 6)
(2016070100 – WPC Case)

Without (left) and with (right) Joaquin changes



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Max $SS_w > 10\%$

Max $SS_w < 0.1\%$

SS_w = RH-100 (in %)

(note some exaggeration of SS_w due to internal GrADS interpolation)

Summary (1 of 2)

- Several steps have been taken to make the NMMB model more stable in response to forecast failures with Hurricane Joaquin, and to improve forecast soundings from the parallel NAM CONUS nest
- Although experimental runs initialized from the operational NAM (surprisingly) did not show a dramatic impact on QPF, we have seen noticeable improvements in real-time parallel NAM CONUS nest QPF

Summary (2 of 2)

- **<u>Improved QPF due to</u>:**
  - Increasing CONUS nest resolution from 4 km (NEST) to 3 km (NESTX)
  - Data assimilation changes (Carley *et al.*, Liu *et al.*)
  - Microphysics changes (Aligo *et al.*)
  - And the changes described in this talk

(See Rogers *et al.* overview)