Update on Development of Nudging FDDA for Advanced Research WRF

Dave Stauffer[1], Aijun Deng[1], Jimy Dudhia[2] and Tanya Otte[3]

[1]The Pennsylvania State University

[2]NCAR

[3]NOAA/EPA

2005 Joint WRF/MM5 Workshop

27- 30 June 2005

Boulder, CO

UPDATE: MM5 FDDA IN BATTLEFIELD
Rapidly Relocatable Nowcast-Prediction System (RRNPS) for US Army: MMS-Profiler

- MM5-based system with FDDA run locally on the battlefield to provide Warfighter MET.
- Fielded to active Army units and approved for full rate production.
- Provides Local and Target Area MET
- Provides MET Messages every 15-30 minutes
- Provides as a minimum MET Parameters
  - Temperature, Humidity
  - Pressure
  - Wind Speed, Wind Direction
  - Target Area: Ceiling, Visibility, Precip Rate, Precip Type

… RRNPS adapted for DOD DTRA in-house weather support by Penn State (Titan Team)

Smiths Detection and Penn State University

Flux-Form Equations in Mass Coordinate

Hydrostatic pressure coordinate:

hydrostatic pressure π

$$\eta = \frac{(\pi - \pi_t)}{\mu}, \qquad \mu = \pi_s - \pi_t$$

Conserved state variables:

$$\mu, \quad U = \mu u, \quad V = \mu v, \quad W = \mu w, \quad \Theta = \mu\theta$$

Non-conserved state variable: $\phi = gz$

Flux-Form Equations in Mass Coordinate

Inviscid, 2-D equations without rotation:

$$\frac{\partial U}{\partial t} + \mu\alpha\frac{\partial p}{\partial x} + \frac{\partial p}{\partial \eta}\frac{\partial \phi}{\partial x} = -\frac{\partial U u}{\partial x} - \frac{\partial \Omega u}{\partial \eta}$$

$$\frac{\partial W}{\partial t} + g\left(\mu - \frac{\partial p}{\partial \eta}\right) = -\frac{\partial U w}{\partial x} - \frac{\partial \Omega w}{\partial \eta}$$

$$\frac{\partial \Theta}{\partial t} + \frac{\partial U\theta}{\partial x} + \frac{\partial \Omega\,\theta}{\partial \eta} = \mu Q$$

$$\frac{\partial \mu}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial \Omega}{\partial \eta} = 0$$

$$\frac{d\phi}{dt} = gw$$

Diagnostic relations:

$$\frac{\partial \phi}{\partial \eta} = -\mu\alpha, \qquad p = \left(\frac{R\theta}{p_0\alpha}\right)^{\gamma}, \qquad \Omega = \mu\dot{\eta}$$

Height/Mass-Coordinate Model, Time Integration

3rd Order Runge-Kutta time integration

advance $\phi^{t} \rightarrow \phi^{t+1}$

$$\phi^{*} = \phi^{t} + \frac{\Delta t}{3} R\left(\phi^{t}\right)$$

$$\phi^{**} = \phi^{t} + \frac{\Delta t}{2} R\left(\phi^{*}\right)$$

$$\phi^{t+1} = \phi^{t} + \Delta t \, R\left(\phi^{**}\right)$$

Amplification factor $\phi_t = i k \phi; \quad \phi^{n+1} = A \phi^{n}; \quad |A| = 1 - \frac{(k\Delta t)^4}{24}$

WRF Mass-Coordinate Model Integration Procedure

Begin time step

Runge-Kutta loop (steps 1, 2, and 3)

(i) advection, p-grad, buoyancy using $\left(\phi^t, \phi^*, \phi^{**}\right)$

Nudging FDDA (ii) physics if step 1, save for steps 2 and 3

(iii) mixing, other non-RK dynamics, save…

(iv) assemble dynamics tendencies

Acoustic step loop

(i) advance U,V, then μ, Θ, then w, ϕ

(ii) time-average U,V, Ω

End acoustic loop

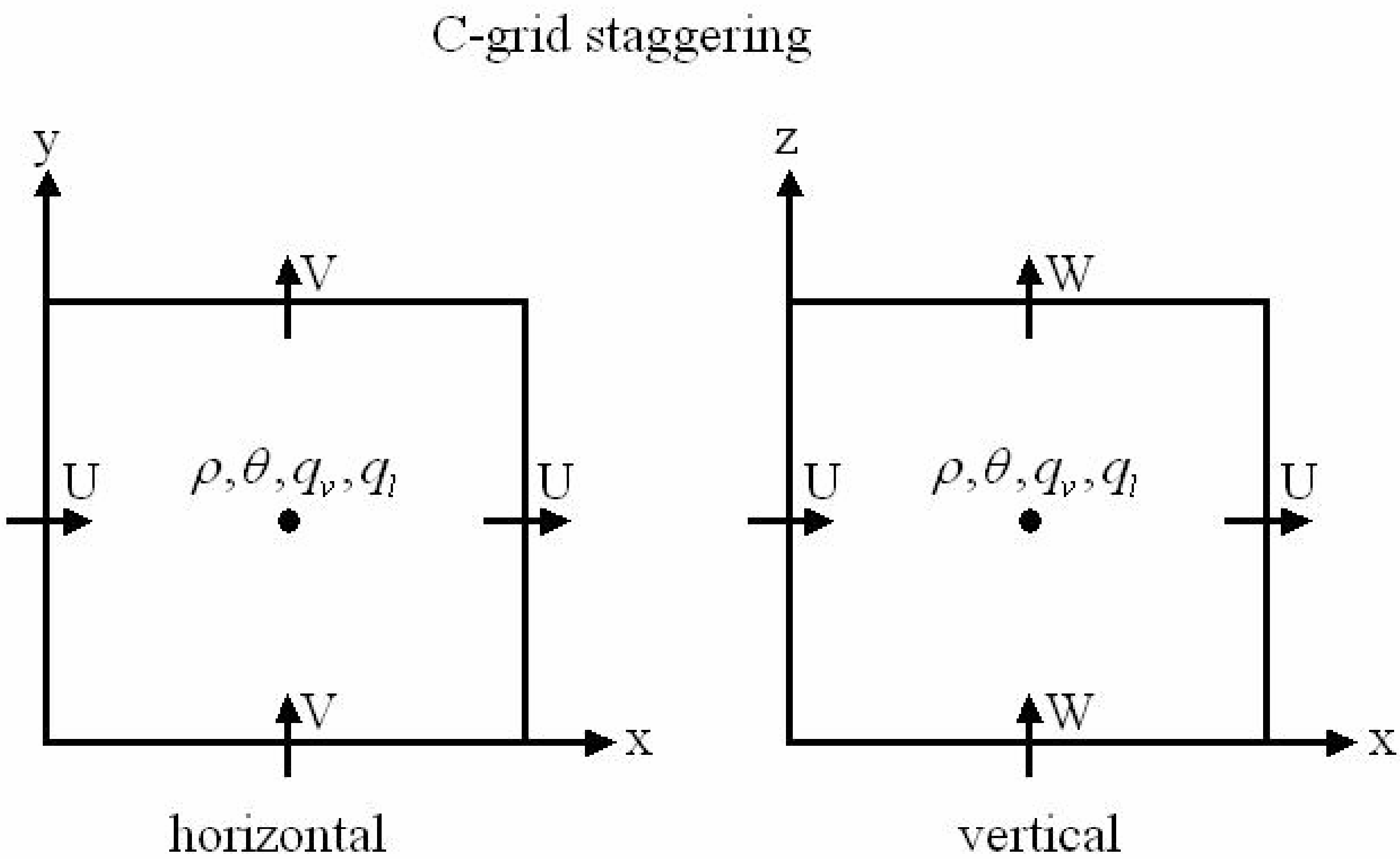
Advance scalars using time-averaged U,V, Ω

End Runge-Kutta loop

Adjustment physics (currently microphysics)

End time step

Height/Mass-coordinate model, grid staggering



Note: Nudging FDDA on staggered grid while physics on non-staggered grid…

Nudging FDDA

$$\frac{\partial \alpha}{\partial t} = G \bullet (\alpha_{ob} - \alpha) + \ldots$$

$$\int_0^t (\,)\, dt \Rightarrow \alpha(t) = (\alpha_0 - \alpha_{ob}) \bullet e^{-Gt} + \alpha_{ob}$$

$$\alpha(t) = (\alpha_o - \alpha_{ob}) \bullet e^{-Gt} + \alpha_{ob}$$

$$\frac{1}{G} \equiv e-\ folding\ time \quad O(1h)$$

Nudging FDDA in WRF

$$For\ \alpha = \Theta = \mu \bullet \theta$$

$$\frac{\partial \Theta}{\partial t} = \ldots + \mu \frac{\partial \theta}{\partial t} + \theta \frac{\partial \mu}{\partial t}$$

$$\frac{\partial \Theta}{\partial t} = \ldots + \mu \bullet G_\theta \bullet W \bullet (\theta_{ob} - \theta)$$

$$+ \theta \bullet G_\mu \bullet W \bullet (\mu_{ob} - \mu)$$

$$where\ W = w_{xy} \bullet w_\eta \bullet w_t$$

3D Analyses from MM5 Frontend…

- “mm5_p_convert” (written by Wei Wang/NCAR)
- Converts multi-time pressure-level data from MM5 Frontend (REGRID, RAWINS, LITTLE_R) into HINTERP fields
  - Introduces MM5 frontend data into WRFSI-formatted output
  - Enables common initial conditions and lateral boundary conditions for “fair” comparsion of MM5 and WRF simulations from fields based on the same surface and pressure-level analyses. (Note that there are still differences in the state variables and horizontal / vertical grid structures between the two models)
  - Enables WRF analysis nudging towards frontend MM5 system (Rawins) analyses
- Passes through to WRF common domain definitions and underlying static fields (lat, lon, terrain, land use, etc.)
- Requires special version of VINTERP to create input for REAL

Sfc Analyses from MM5 Frontend…

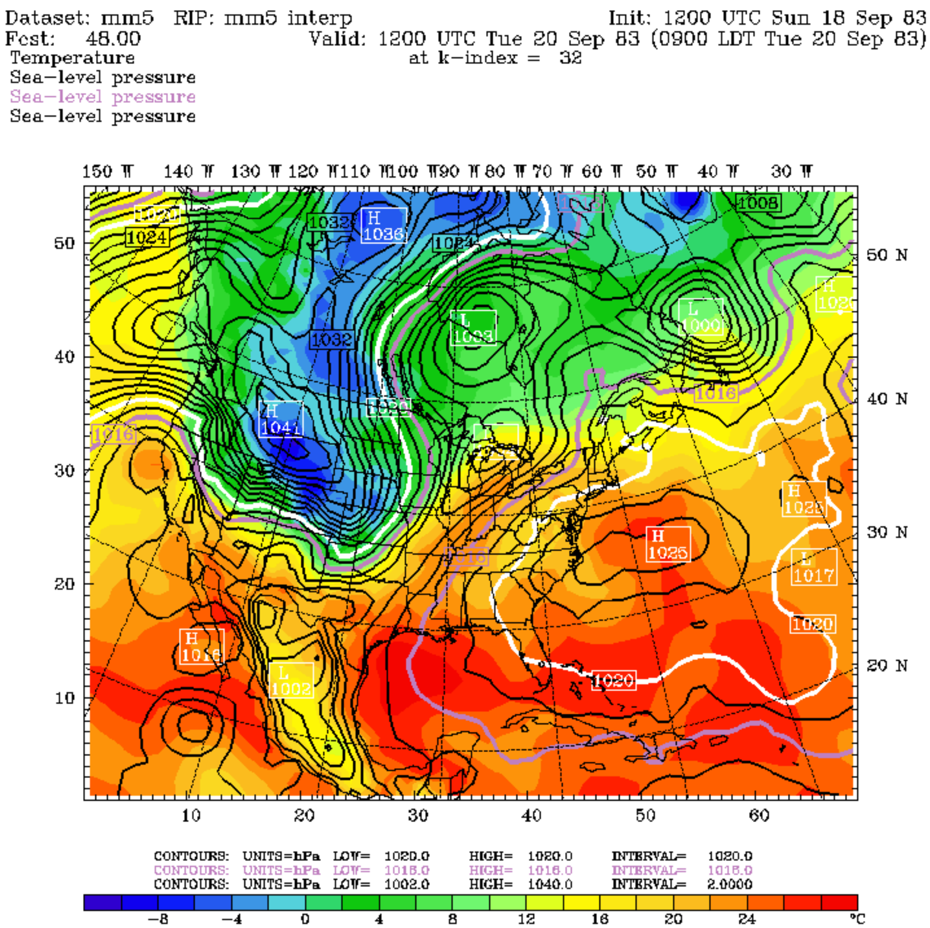
- **“wrfsfcfdda” (written by Tanya Otte /NOAA/ARL)**
- **Converts RAWINS/LITTLE_R “SFCFDDA” files to WRF I/O API**
- **Includes all SFCFDDA 2D fields, plus U- and V-component winds on C grid, PSFC, θ**
- **Files will be used for surface analysis nudging in WRF**
- **Files will also support soil moisture nudging option in Pleim-Xiu LSM**

Preliminary Results

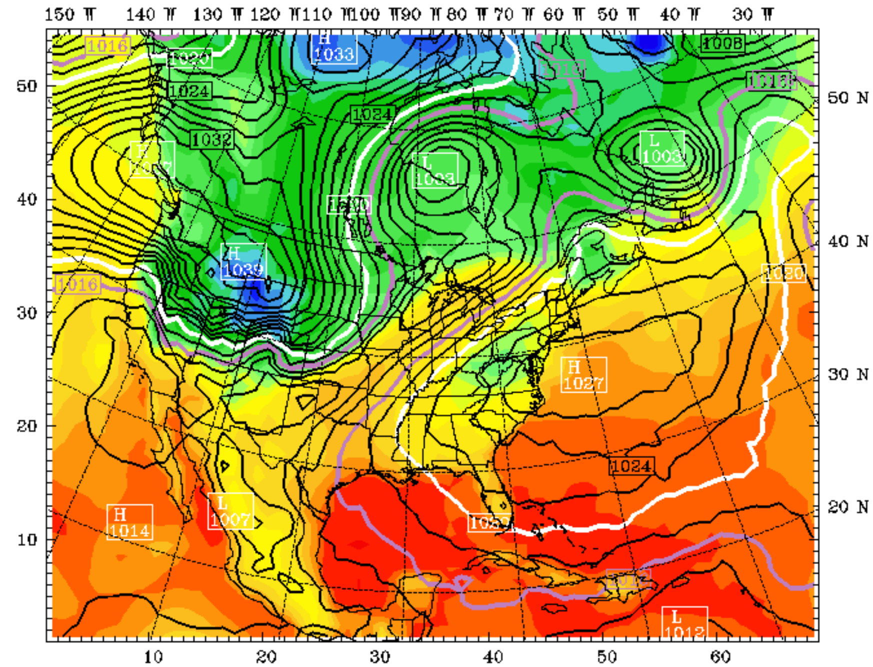
Demonstration of WRF Analysis Nudging:

- **Based on 12-hourly MM5 front-end 3D analyses…**
- **Nudge u, v, θ (G = 3 X 10 $^{-4}$ s^{-1})**
- **Nudge q_v (G = 1 X 10 $^{-5}$ s^{-1})**
- **Show results at 48 h for CAPTEX83 (18-20 September 1983)**

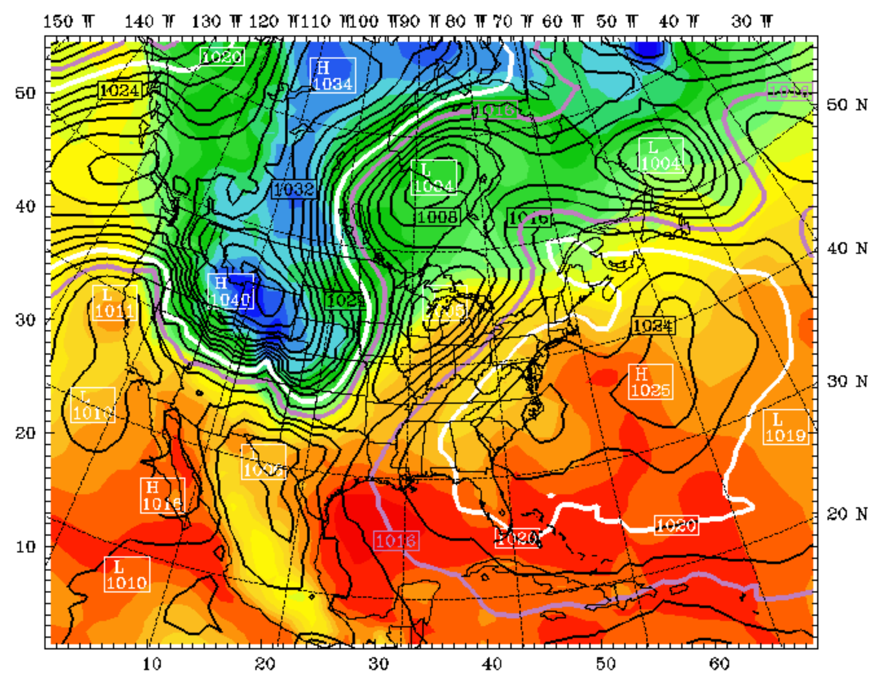
Surface Temperature and Sea Level Pressure



MM5 ANALYSIS

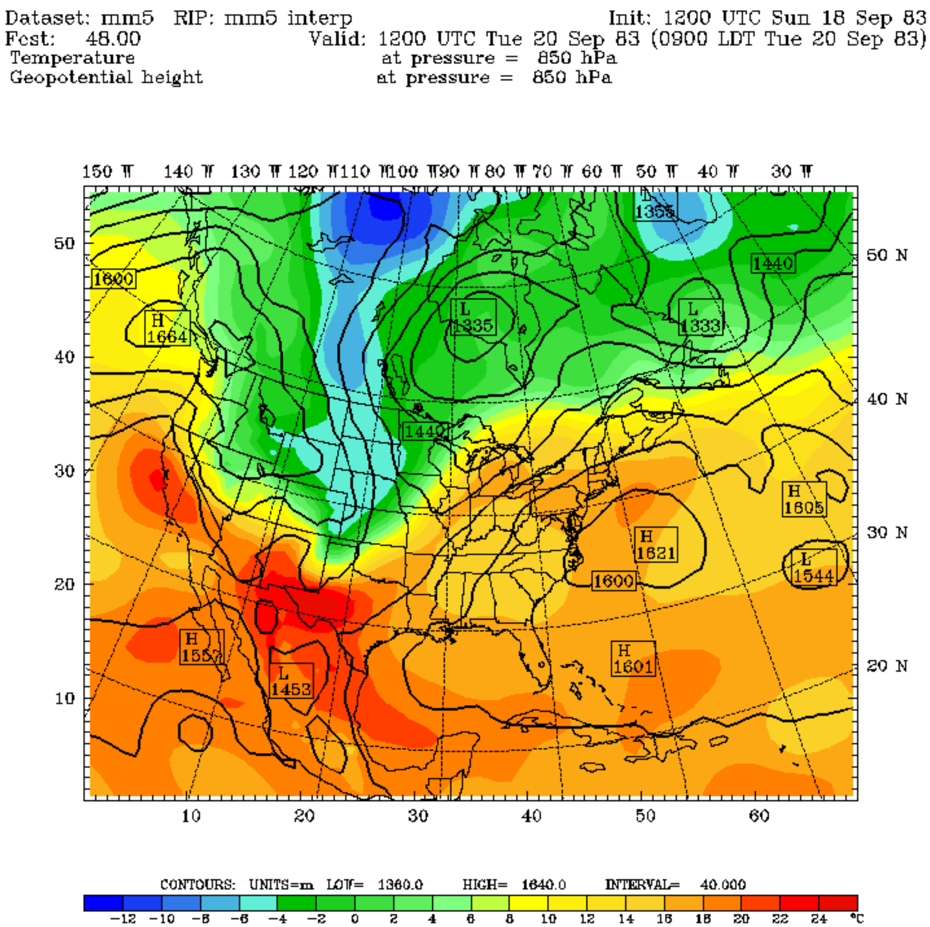


WRF NO FDDA

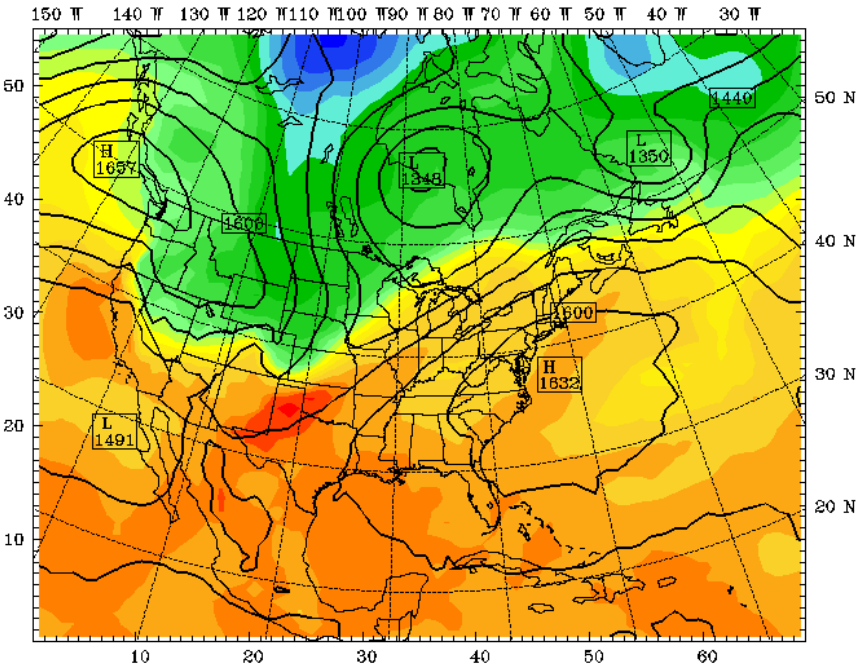


WRF FDDA

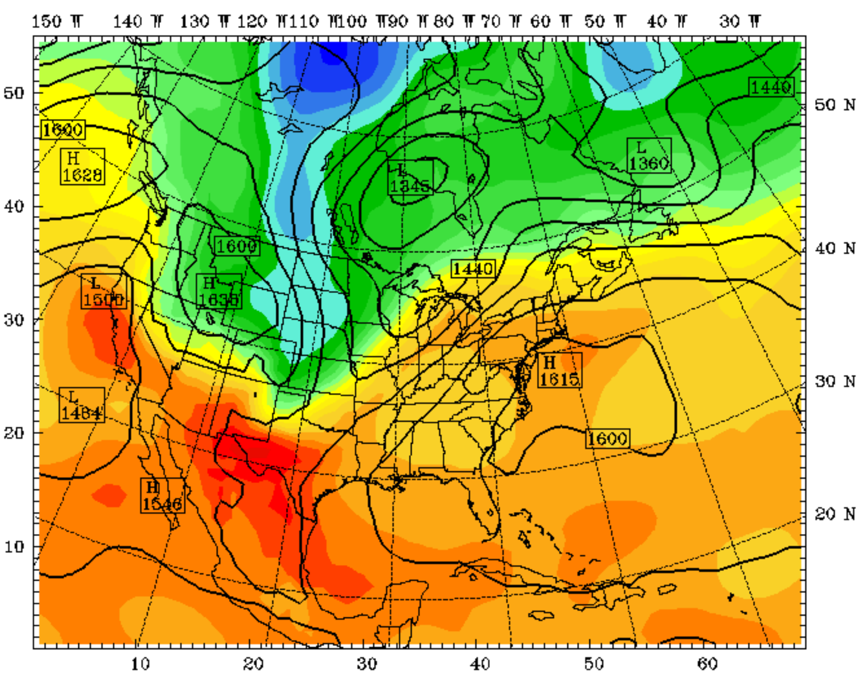
850 hPa Temperature and Geopotential Height



MM5 ANALYSIS

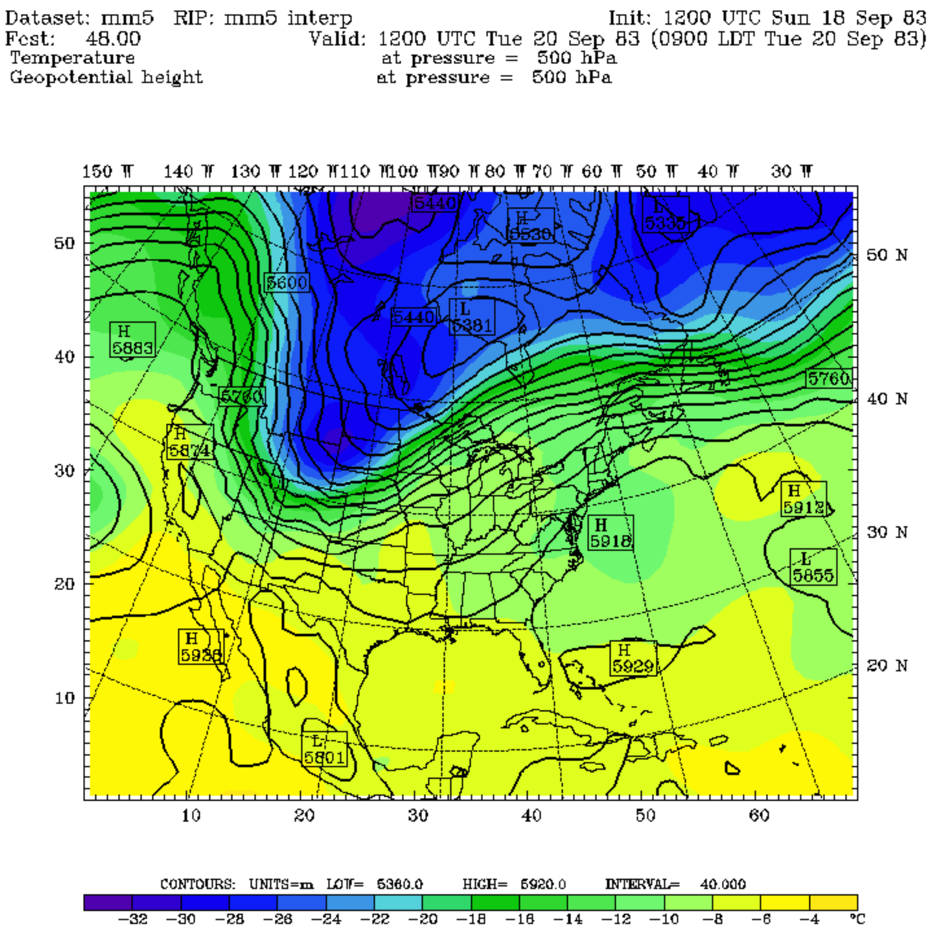


WRF NO FDDA

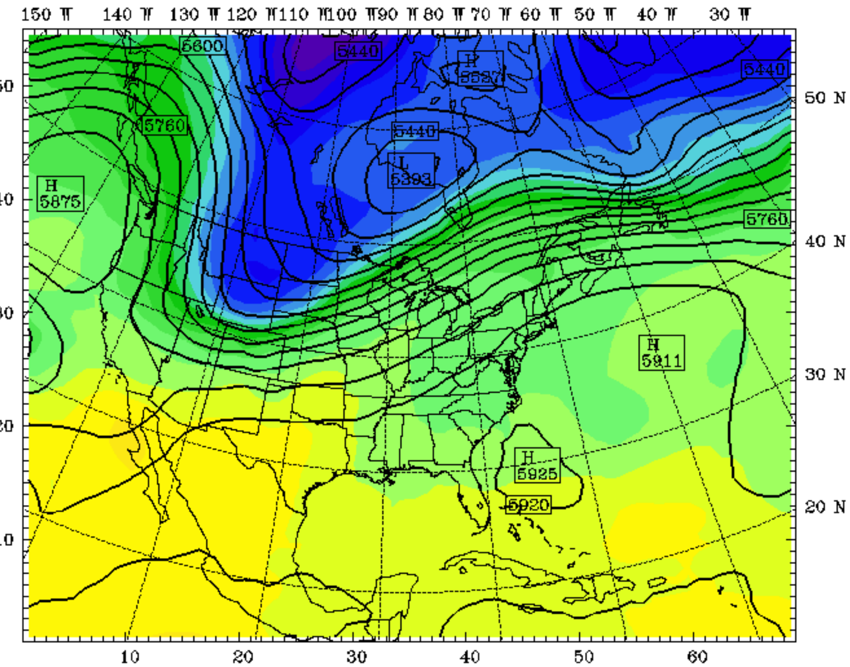


WRF FDDA

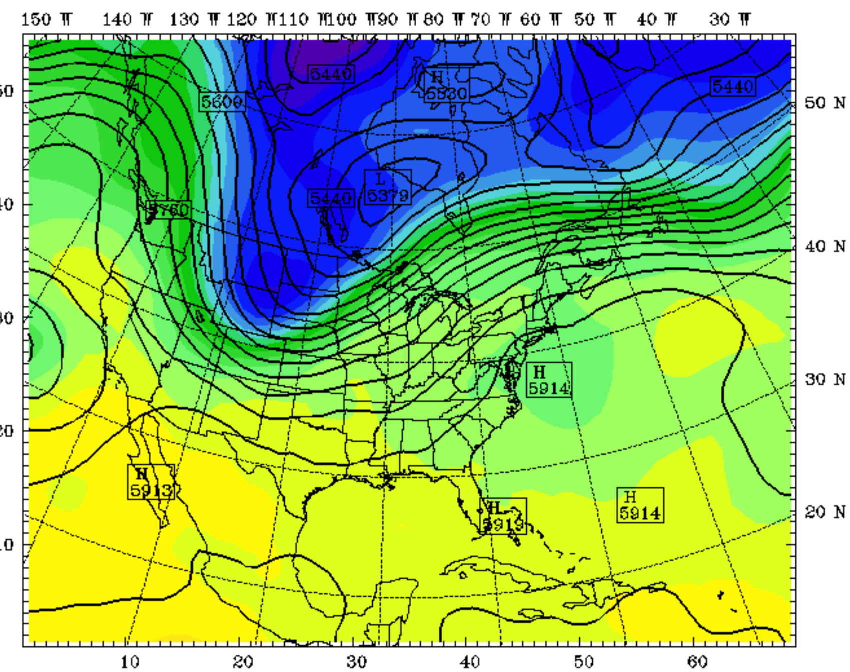
500 hPa Temperature and Geopotential Height



MM5 ANALYSIS

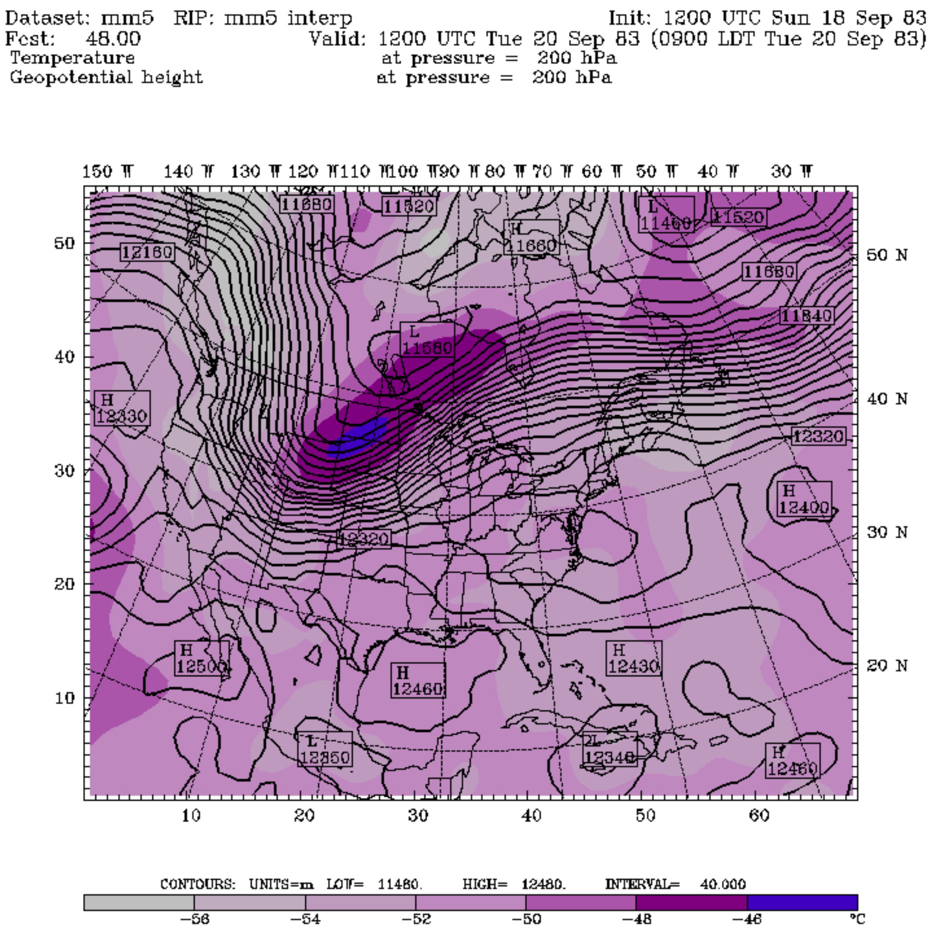


WRF NO FDDA

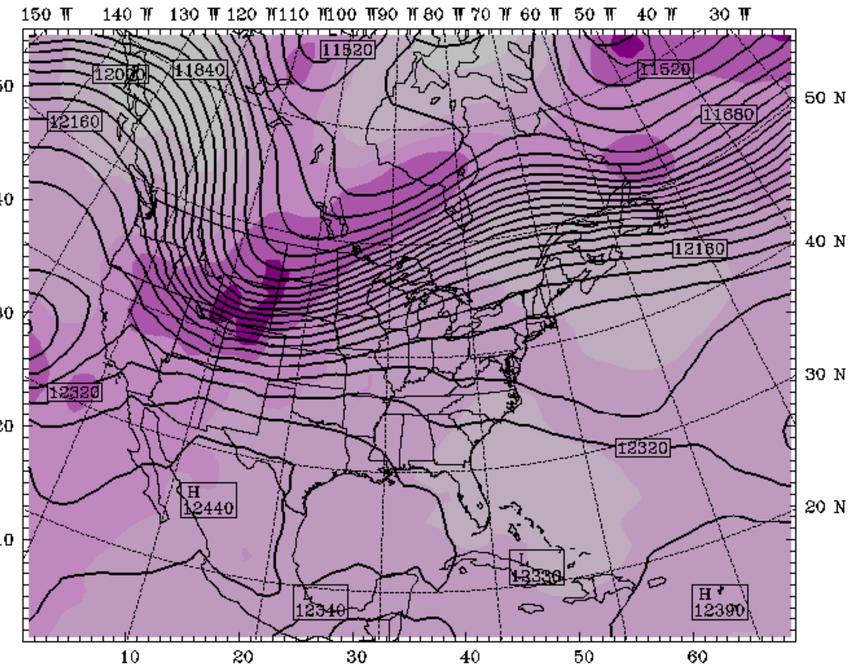


WRF FDDA

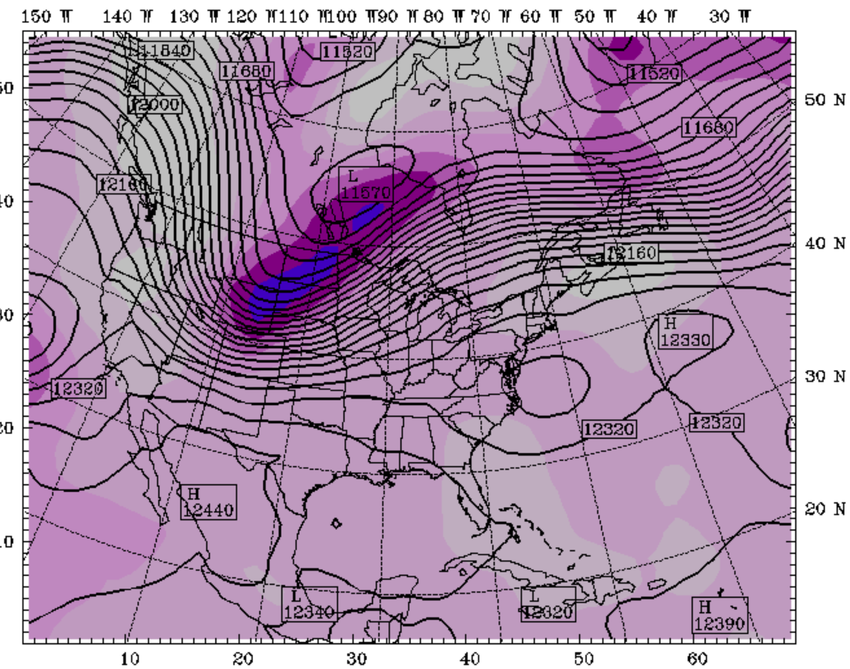
200 hPa Temperature and Geopotential Height



MM5 ANALYSIS

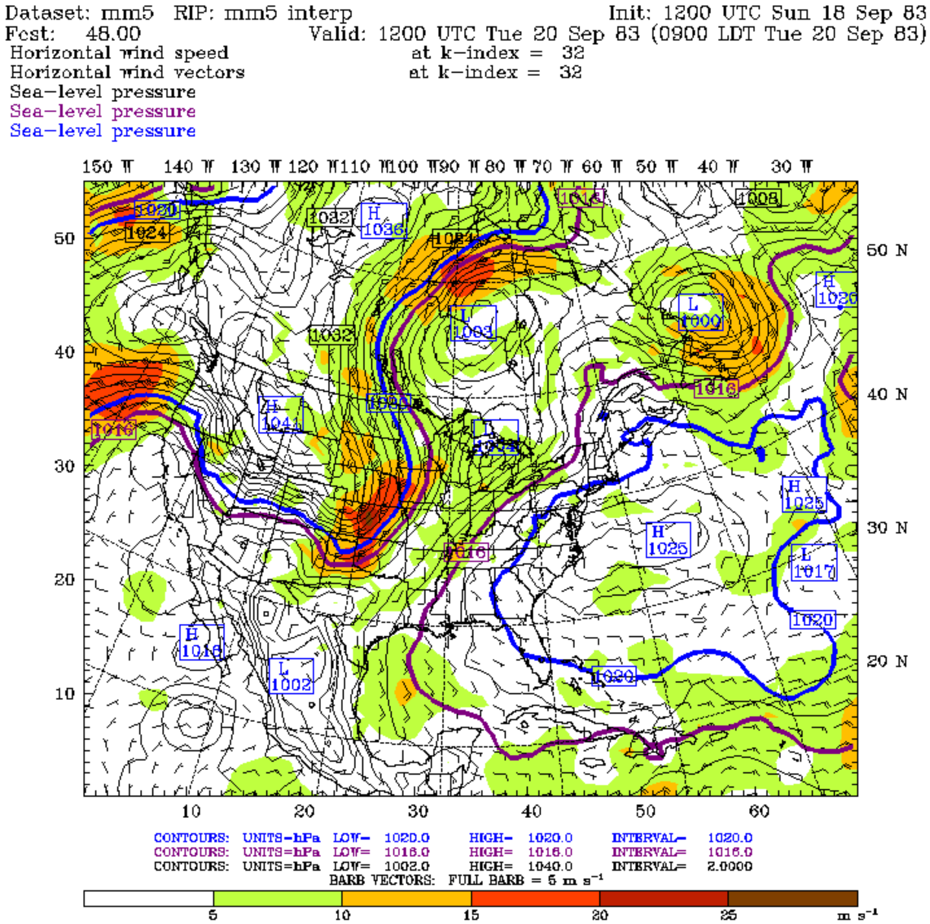


WRF NO FDDA

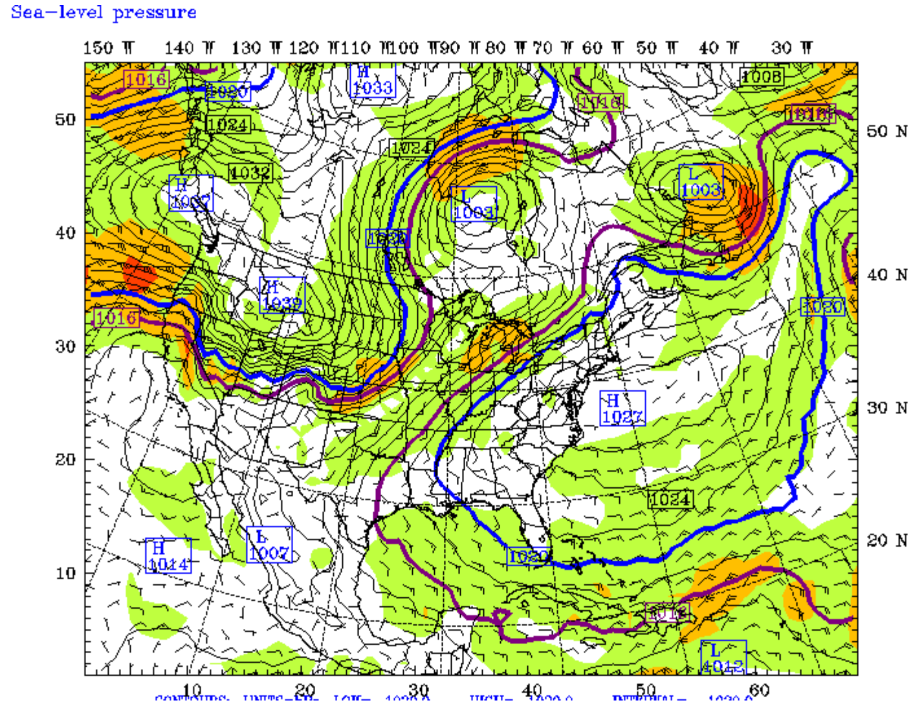


WRF FDDA

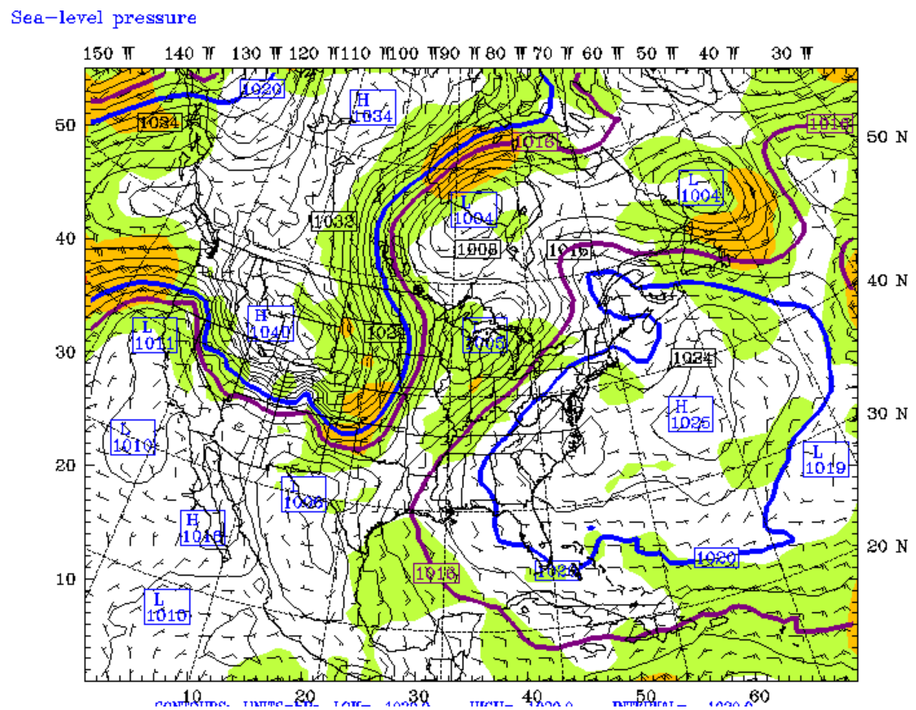
Surface Winds and Sea Level Pressure



MM5
ANALYSIS

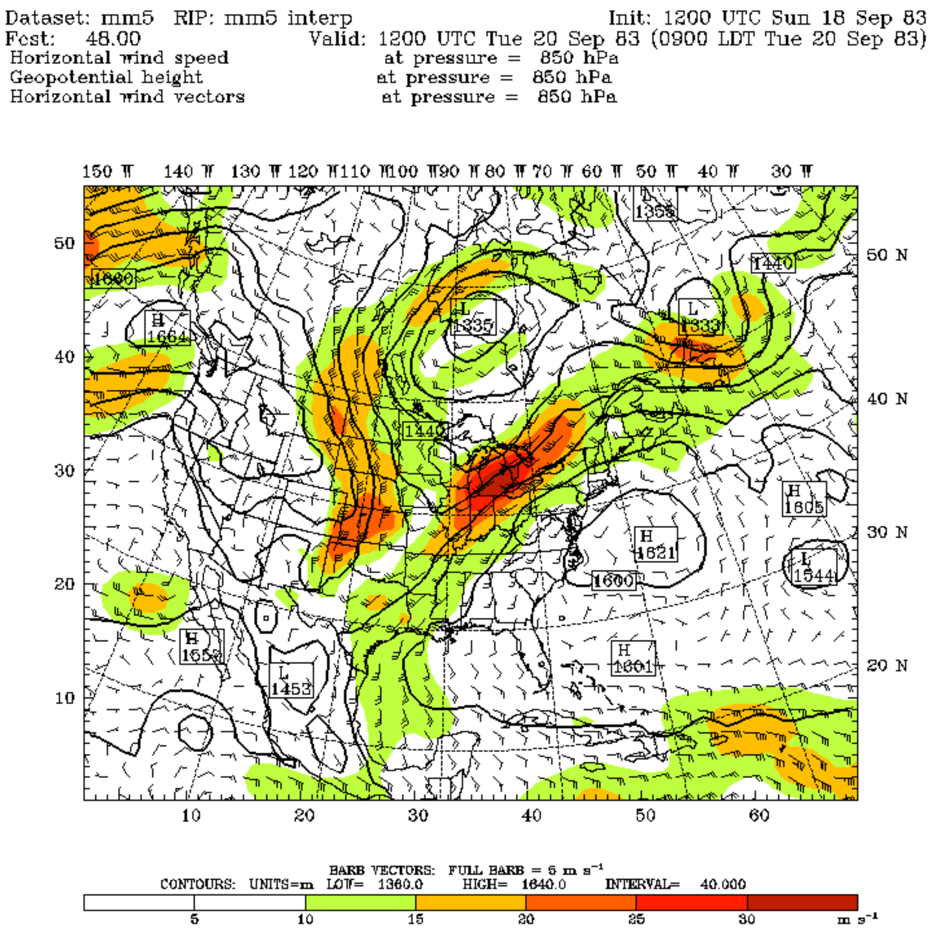


WRF NO FDDA

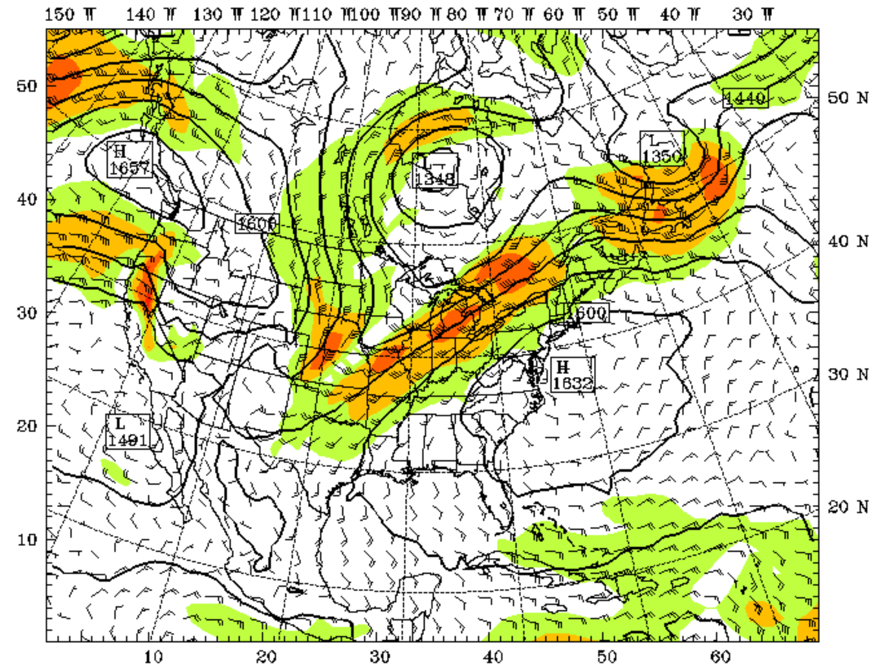


WRF FDDA

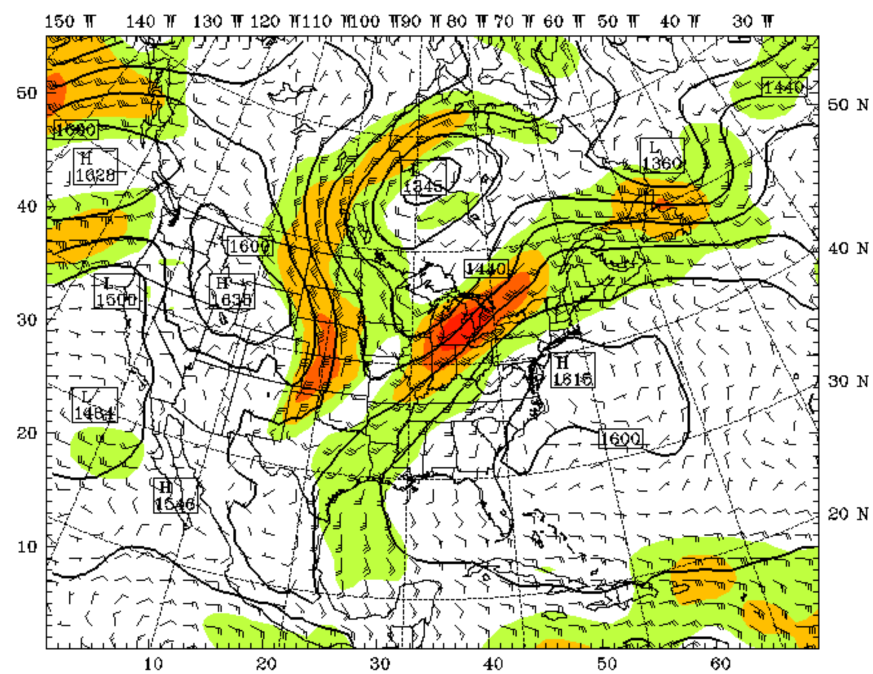
850 hPa Winds and Geopotential Height



MM5
ANALYSIS

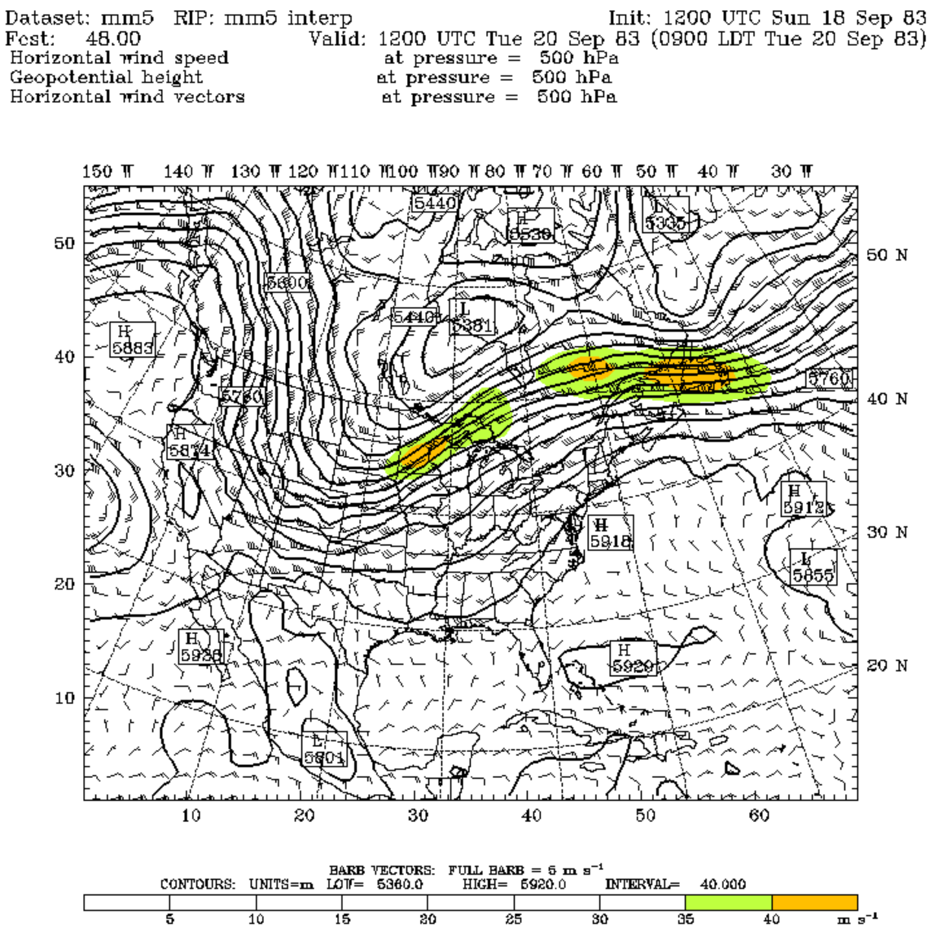


WRF NO FDDA

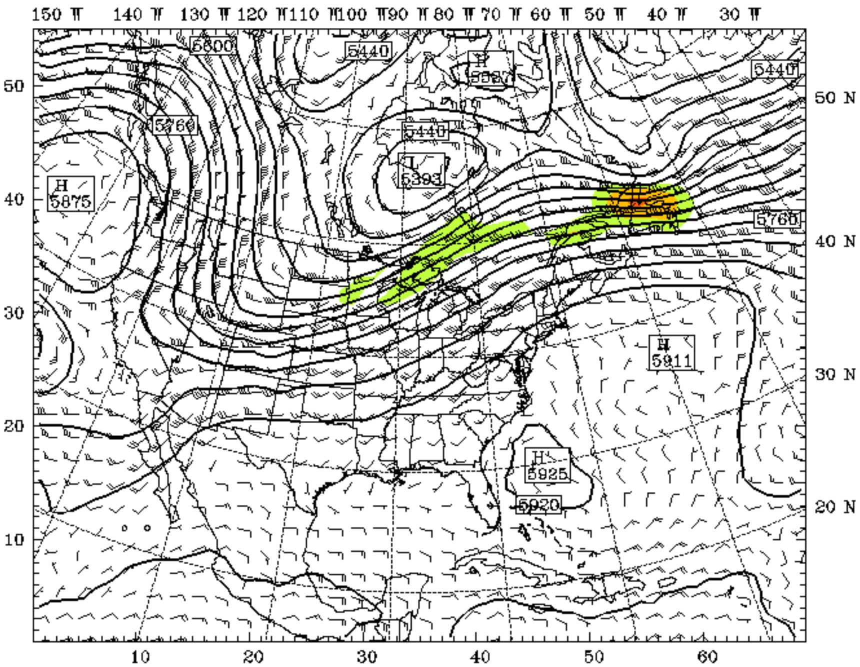


WRF FDDA

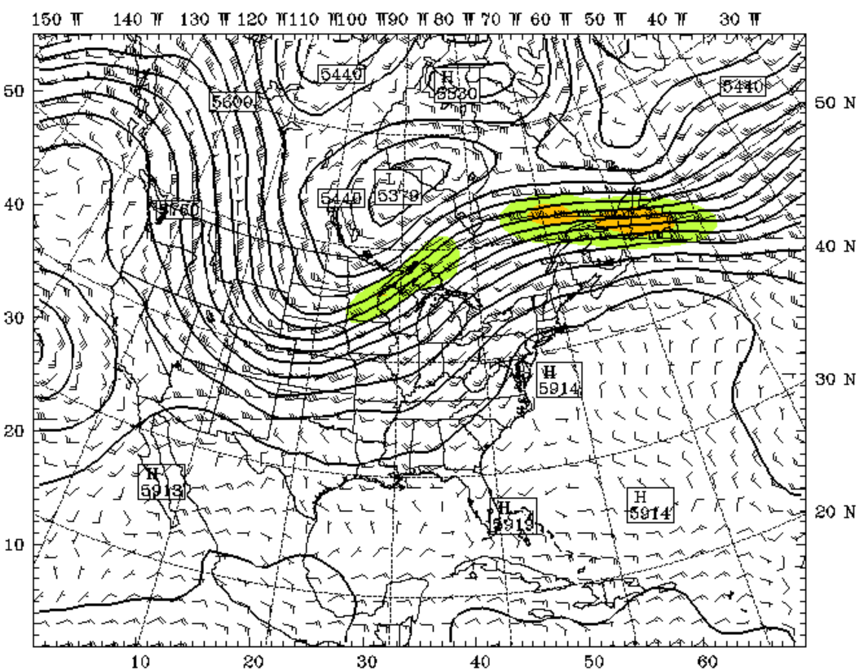
500 hPa Winds and Geopotential Height



MM5
ANALYSIS

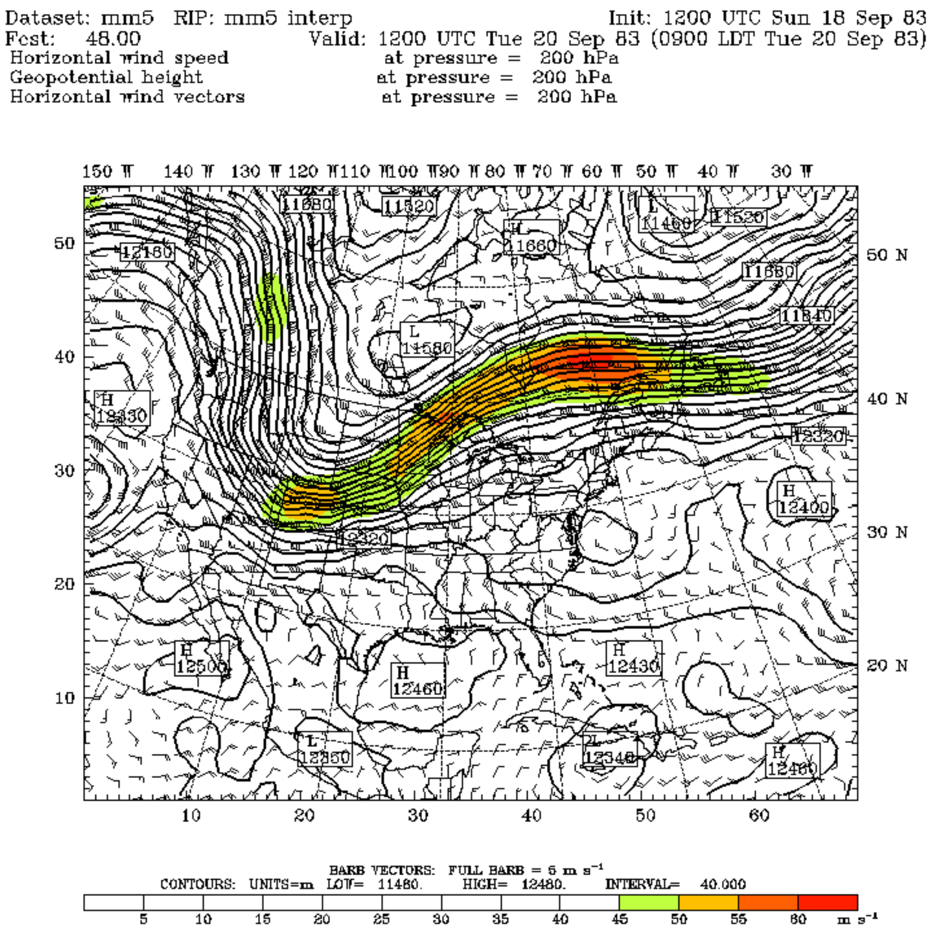


WRF NO FDDA

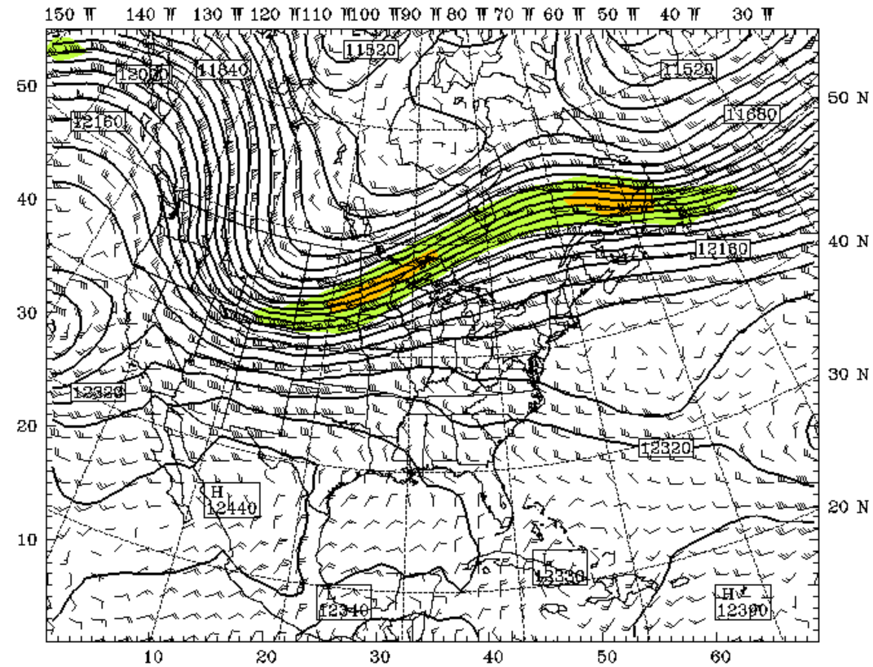


WRF FDDA

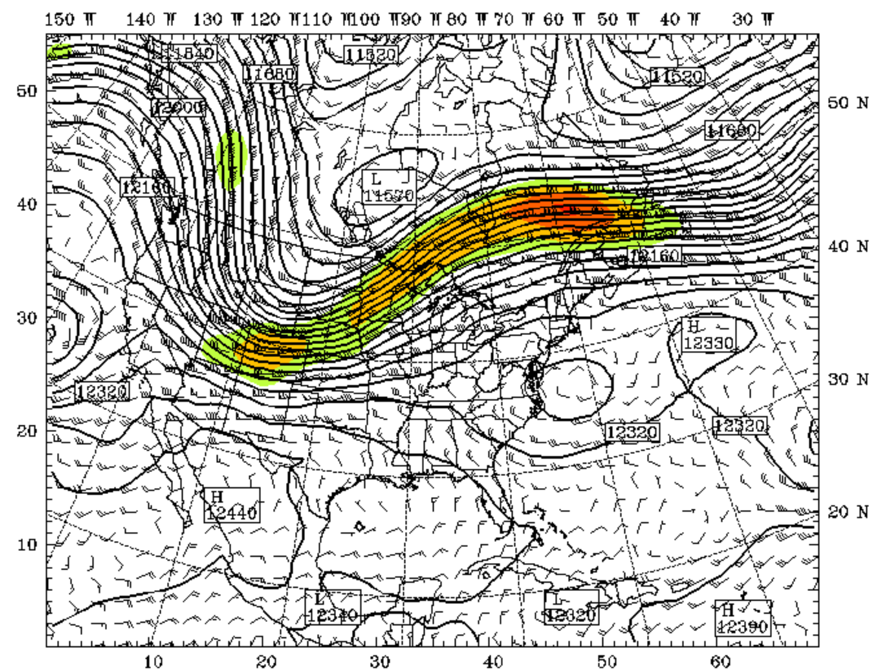
200 hPa Winds and Geopotential Height



MM5
ANALYSIS



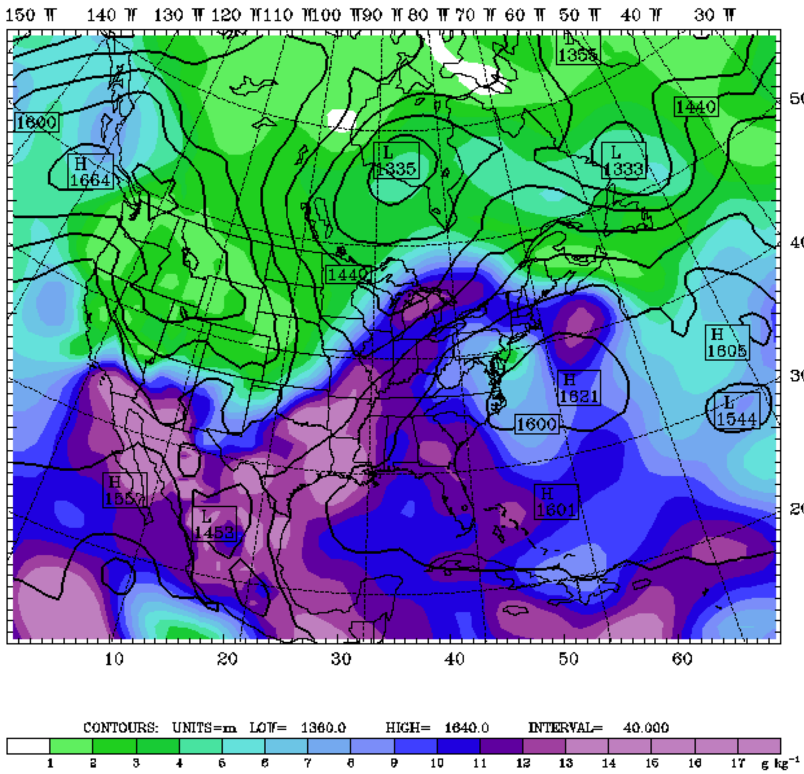
WRF NO FDDA



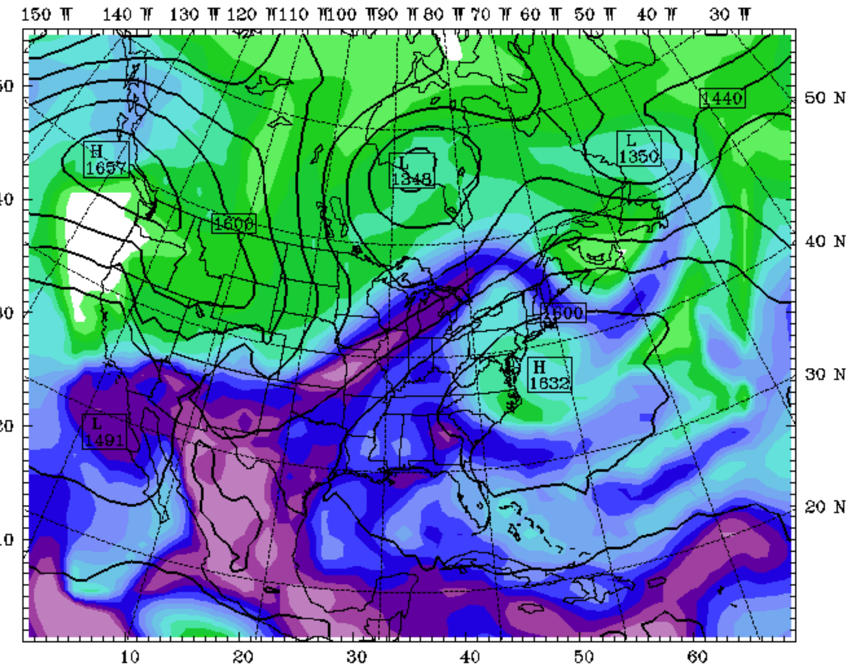
WRF FDDA

850 hPa Mixing Ratio and Geopotential Height

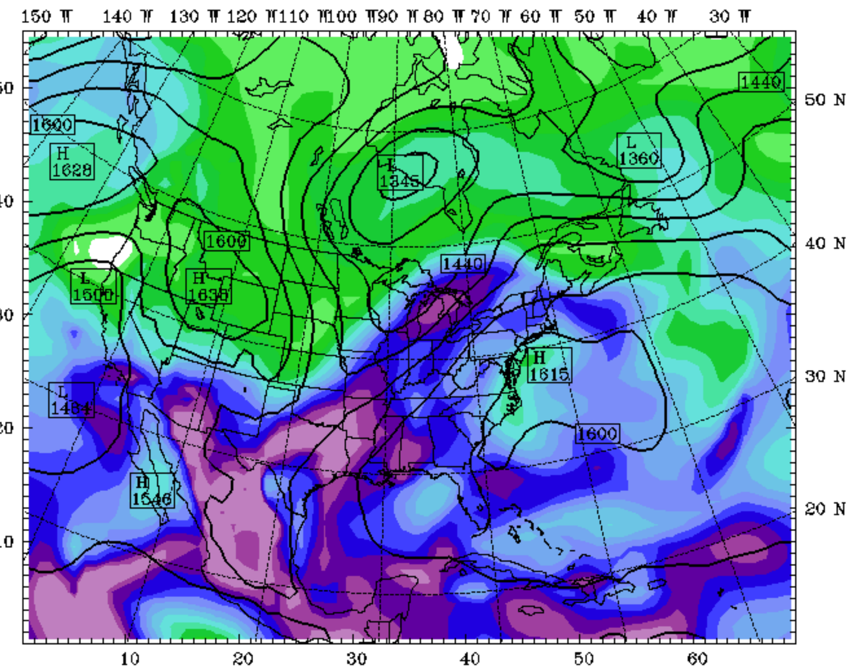
Dataset: mm5 RIP: mm5 interp Init: 1200 UTC Sun 18 Sep 83
Fcst: 48.00 Valid: 1200 UTC Tue 20 Sep 83 (0900 LDT Tue 20 Sep 83)
Water vapor mixing ratio at pressure = 850 hPa
Geopotential height at pressure = 850 hPa



MM5 ANALYSIS

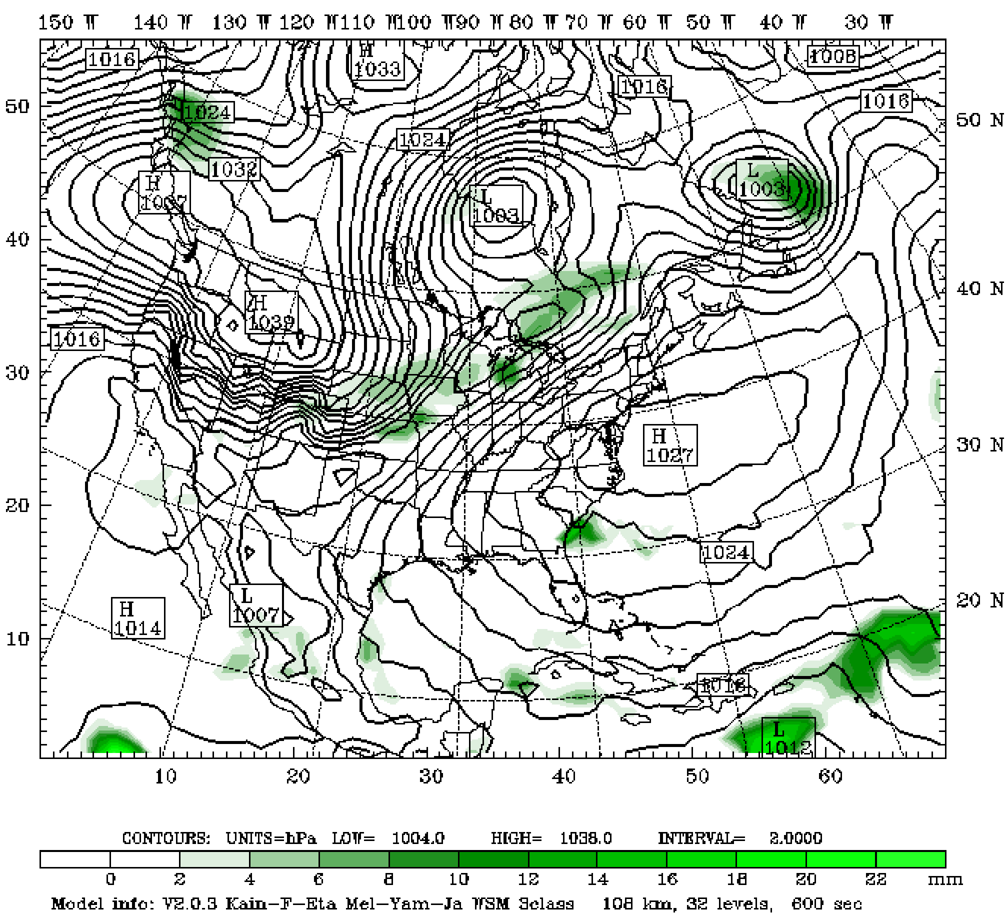


WRF NO FDDA

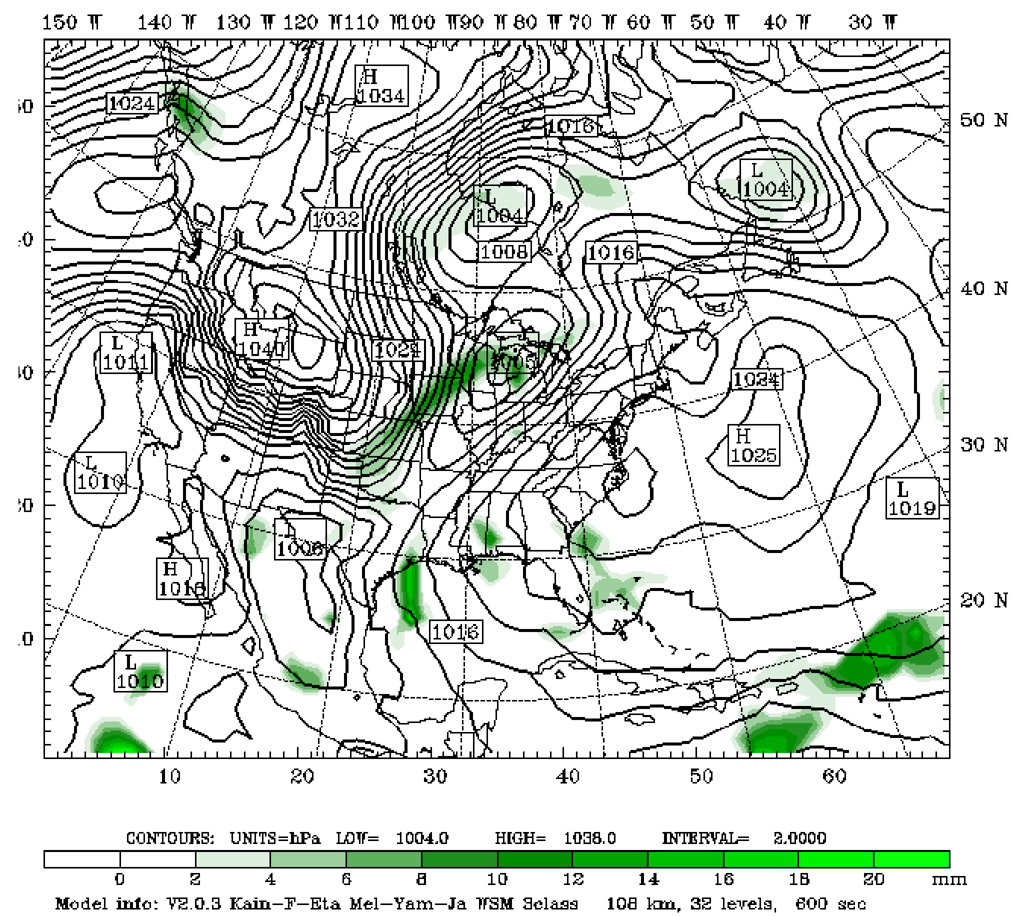


WRF FDDA

Precipitation and Sea Level Pressure



WRF NO FDDA



WRF FDDA

Summary

Analysis Nudging FDDA in WRF – ARW:

Preliminary capabilities:

3D analysis nudging of gridded fields (u, v, θ, q_v):

Analyses on WRF model surfaces (η)

- **External gridded analyses processed through Real**
- **Real input files created in "converter code" from Rawins surface and pressure-level gridded analyses (MM5 frontend).**
- **Real also processes other gridded fields (SI, 3DVAR)**

- **(Standard version of Real had to be modified to output more than first time period…)**

Currently uses linear temporal interpolations and uniform spatial weighting functions

Summary

Future capabilities:

More general temporal and spatial weighting functions, including use of PBL height, observation data densities, dynamic-initialization ramping functions, etc.

Surface analysis nudging using higher temporal resolution surface-gridded fields, applied at surface and throughout PBL (Stauffer et al. 1991).

- **Requires another "converter" using Rawins sfcfdda files since 3DVAR cannot currently produce surface-only analyses at intermediate times…**
- **Enables Pleim-Xu LSM soil moisture nudging capability**

- **List of nudging variables to be expanded (e.g., μ, vertical motion, cloud water, etc.)**

Acknowledgments

- **This work has been funded in part by U. S. Environmental Protection Agency and Kenneth Schere**

- **Wei Wang (NCAR) and Annette Gibbs and Glenn Hunter (Penn State) have also contributed time and supporting software…**

Disclaimer

"The research presented here was performed, in part, under the Memorandum of Understanding between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA) and under agreement number DW13921548. Although it has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their views or policies."

Supplementary Slides

WRF Output to MM5 Output Format

- “wrf2mm5” (written by Annette Lario-Gibbs / PSU
- Reads WRF output and converts it to MM5 output format.
- Produces outputs for use in VEROBS (PSU verification software).
- wrf2mm5 output can be read by VEROBS, RIP4 and READV3.

WRF Output to MM5 Output (cont’d)

- wrf2mm5 currently writes out u, v, T, q, pp, pstar, convective rain, non-convective rain, terrain, mapscale factors, Coriolis, latitude, longitude, landuse, pbl height, and sigmah.

- Can be easily modified to convert and write out other WRF variables for use in other post-processing programs.

Moist Equations in Mass-Coordinate Model

Moist Equations:

$$\frac{\partial U}{\partial t} + \alpha\mu_d \frac{\partial p}{\partial x} + \frac{\alpha}{\alpha_d}\frac{\partial p}{\partial \eta}\frac{\partial \phi}{\partial x} = -\frac{\partial Uu}{\partial x} - \frac{\partial \Omega u}{\partial \eta}$$

$$\frac{\partial W}{\partial t} + g\left(\mu_d - \frac{\alpha}{\alpha_d}\frac{\partial p}{\partial \eta}\right) = -\frac{\partial Uw}{\partial x} - \frac{\partial \Omega w}{\partial \eta}$$

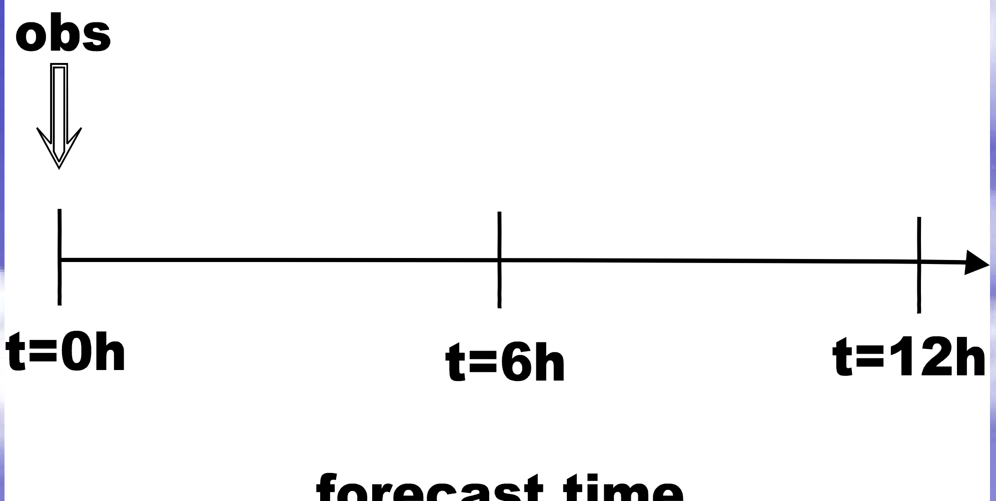
$$\frac{\partial \mu_d}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial \Omega}{\partial \eta} = 0$$

$$\frac{\partial(\mu_d q_{v,l})}{\partial t} + \frac{\partial U q_{v,l}}{\partial x} + \frac{\partial \Omega q_{v,l}}{\partial \eta} = \mu_d Q_{v,l}$$

Diagnostic relations:

$$\frac{\partial \phi}{\partial \eta} = -\alpha_d \mu_d, \qquad p = \left(\frac{R\Theta}{p_o \mu_d \alpha_v}\right)^{\gamma}$$

Cold Start - Static Initialization



Running Start - Dynamic Initialization