# Implementation of FDDA into WRF

David R. Stauffer, Penn State University, University Park, PA; and A. Deng, T. L. Otte, J. Dudhia, A. M. Gibbs, and G. K. Hunter

# But First... An Update on Some Penn State MM5 Nudging Applications...

# MM5 Realtime Nowcast Prediction (Army Profiler)

# Rapidly Relocatable Nowcast-Prediction System (RRNPS) for US Army: MMS-Profiler

- MM5-based system run locally on the battlefield to provide Warfighter MET.
- Fielded to active Army units (early 2005)
- Approved for full rate production (June 2005)
- 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

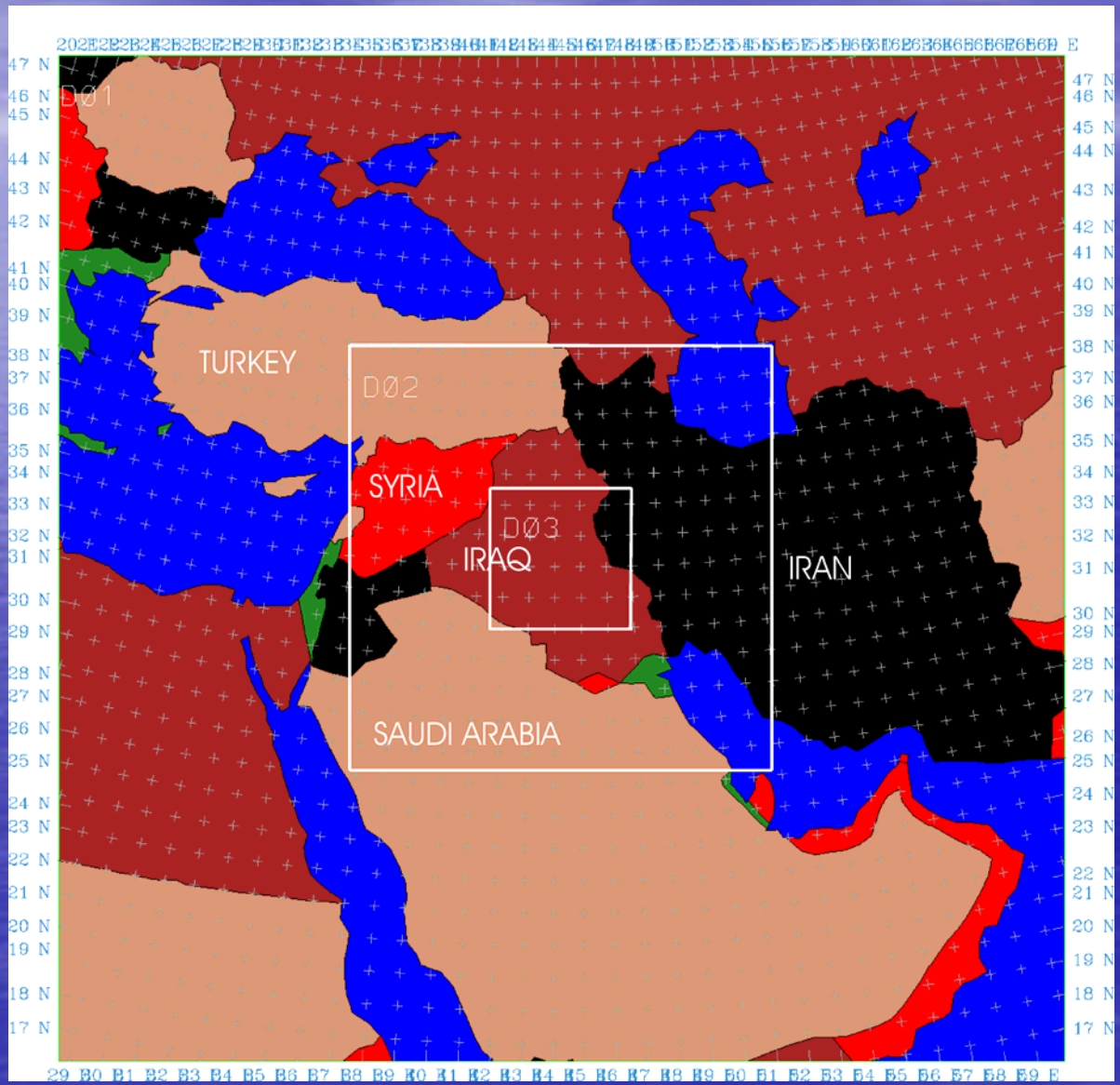
Smiths Detection and Penn State University

# MM5 Nowcast System for Army MMS-Profiler

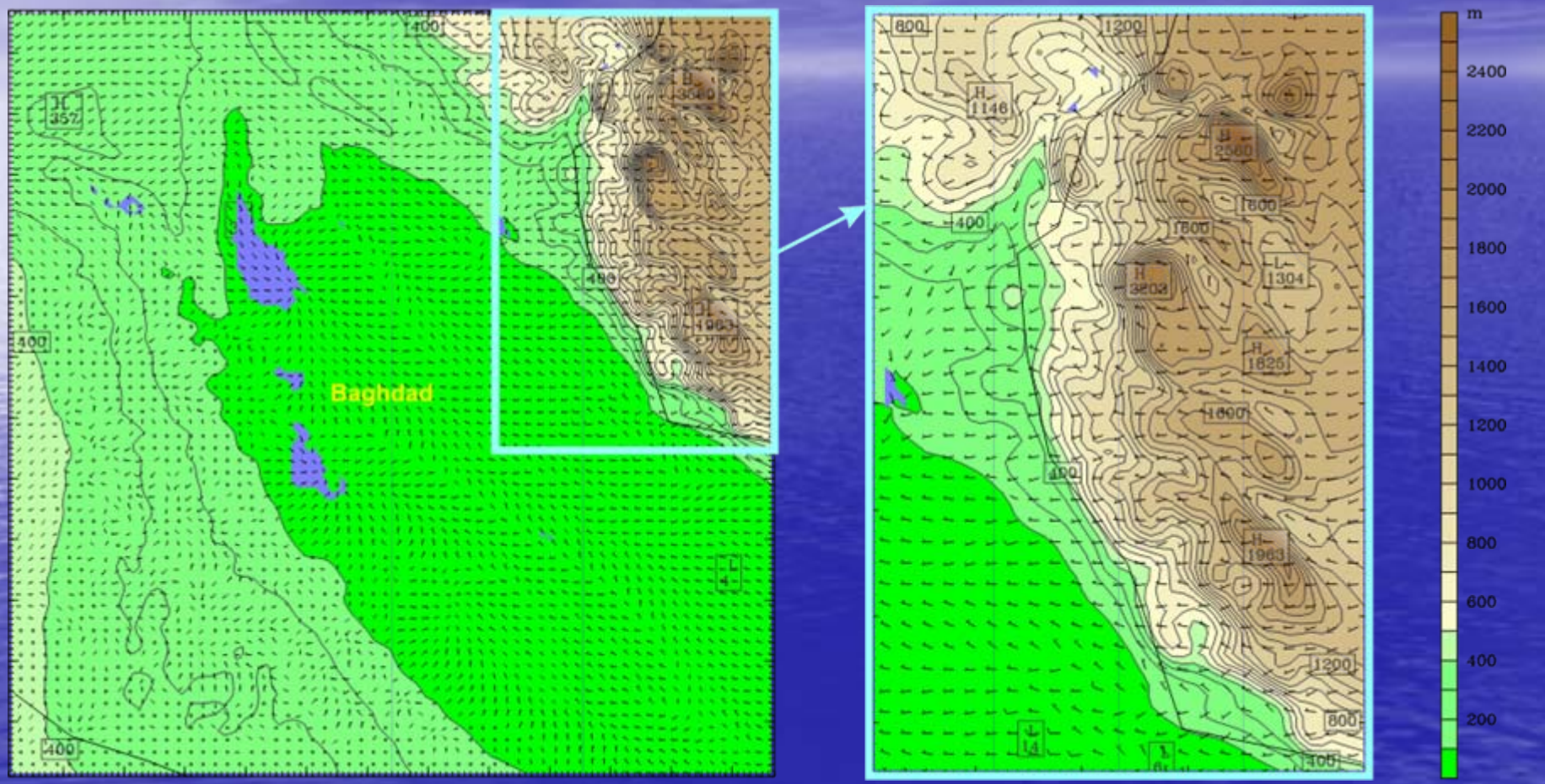

**The model is run in half-hour increments, continuously assimilating observations and staying just ahead of the clock to "predict" current conditions…**

# Profiler in Battlefield

# Worldwide Applications...

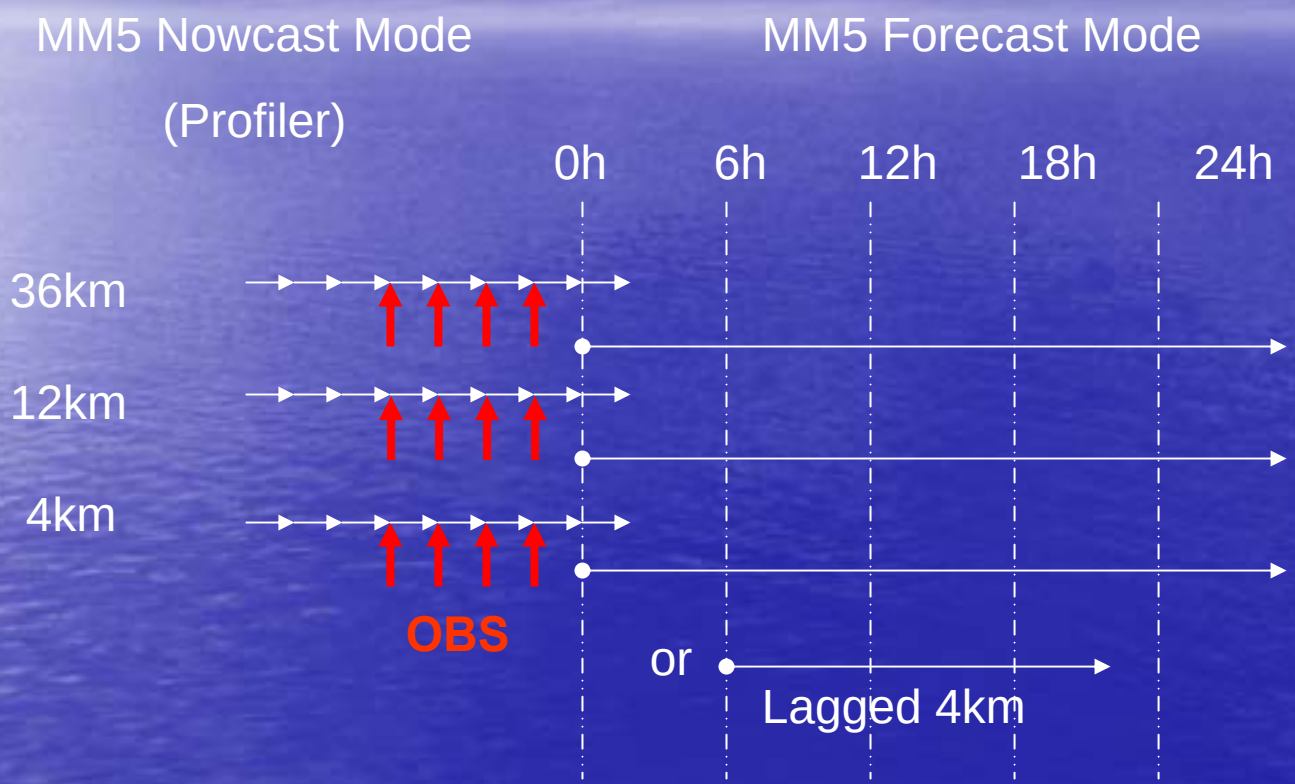


# Profiler Surface Wind on the 4-km Grid



# Penn State Numerical Weather Prediction for U. S. Marines METMF-R NEXGEN…

# METMF-R Nowcast Initialization



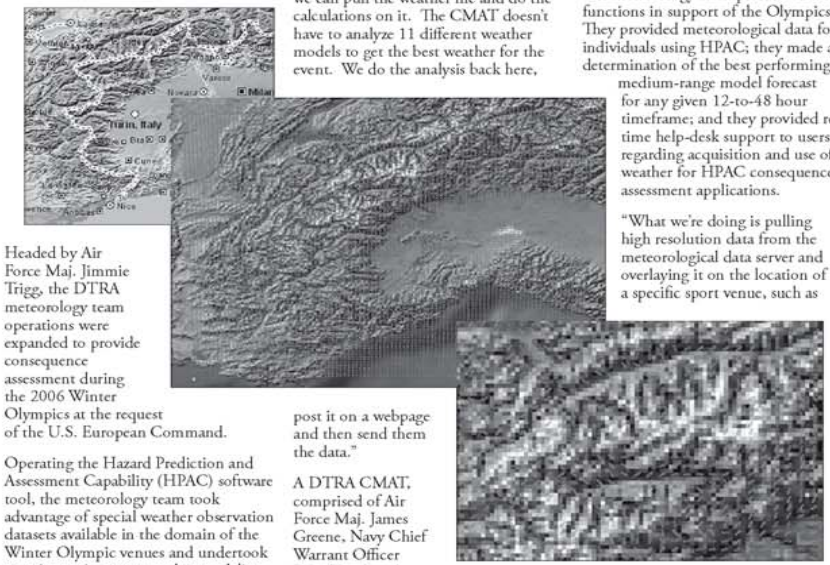
# Penn State-DTRA Winter Olympics Support...

Torino 2006

## DTRA team models wind, weather in support of Winter Olympics

*by Irene Smith*

Tracking snow and cold winds flowing from the Alps, the Defense Threat Reduction Agency's weather models and meteorology team supported the 2006 Winter Olympic Games in Turin, Italy.




Headed by Air Force Maj. Jimmie Trigg, the DTRA meteorology team operations were expanded to provide consequence assessment during the 2006 Winter Olympics at the request of the U.S. European Command.

Operating the Hazard Prediction and Assessment Capability (HPAC) software tool, the meteorology team took advantage of special weather observation datasets available in the domain of the Winter Olympic venues and undertook a project to improve weather modeling at high resolution.

The varied terrain provided a special challenge to the modelers on the meteorology team. Half of the Olympic venues were located in the mountains to the west of Torino, while the rest were located on the relatively flat plain in and around Pinerolo and the city of Torino to the east.

"Back at DTRA, we're making it easier for the Consequence Management Team (CMAT) to do their job," Trigg said. "If bad weather is predicted to happen during the curling competition, we can pull the weather file and do the calculations on it. The CMAT doesn't have to analyze 11 different weather models to get the best weather for the event. We do the analysis back here, post it on a webpage and then send them the data."

A DTRA CMAT, comprised of Air Force Maj. James Greene, Navy Chief Warrant Officer Peter Terrill and defense contractor Chris Schinnerer, was forward deployed to Stuttgart, Germany, to provide weather modeling to support hazard and consequence assessment operations

The HPAC and other tools use high-resolution weather data along with other environmental and source term information to produce estimates of the spread of accidentally or intentionally released hazardous material, such as chemical, biological, radiological, nuclear, and high explosive (CBRNE) agents.

The meteorology team performed three functions in support of the Olympics. They provided meteorological data for individuals using HPAC; they made a determination of the best performing medium-range model forecast for any given 12-to-48 hour timeframe; and they provided real-time help-desk support to users regarding acquisition and use of weather for HPAC consequence assessment applications.

"What we're doing is pulling high resolution data from the meteorological data server and overlaying it on the location of a specific sport venue, such as snowboarding," Trigg said. "Gathering 1.6 kilometer resolution data from the U.S. Air Force Weather Agency (AFWA), we then add high resolution weather data over the area and plot the flow and direction of the wind as it comes out of the mountains."

Prior to the Olympics, DTRA partners at Pennsylvania State University (PSU) and the U.S. National Center for Atmospheric Research (NCAR) established data collection and assimilation, and forecast modeling projects that used special weather station observations provided by Italy's ARPA Piemonte, the environmental agency for the region.

At Penn State, a version of the Mesoscale Model-5 (MM5) was prepared to use the special observation data to forecast weather in a four-nest configuration. At NCAR, versions of MM5 and the Weather Research and Forecast (WRF) models were integrated into a real-time four-dimensional data assimilation program which used the special Olympic weather data to initialize these models.

*Navy Chief Warrant Officer Peter Terrill (right) and defense contractor Chris Schinnerer, members of a DTRA Consequence Management Assessment Team forward deployed to Stuttgart, Germany, provide weather modeling to support hazard and consequence assessment operations at the Winter Olympics.*

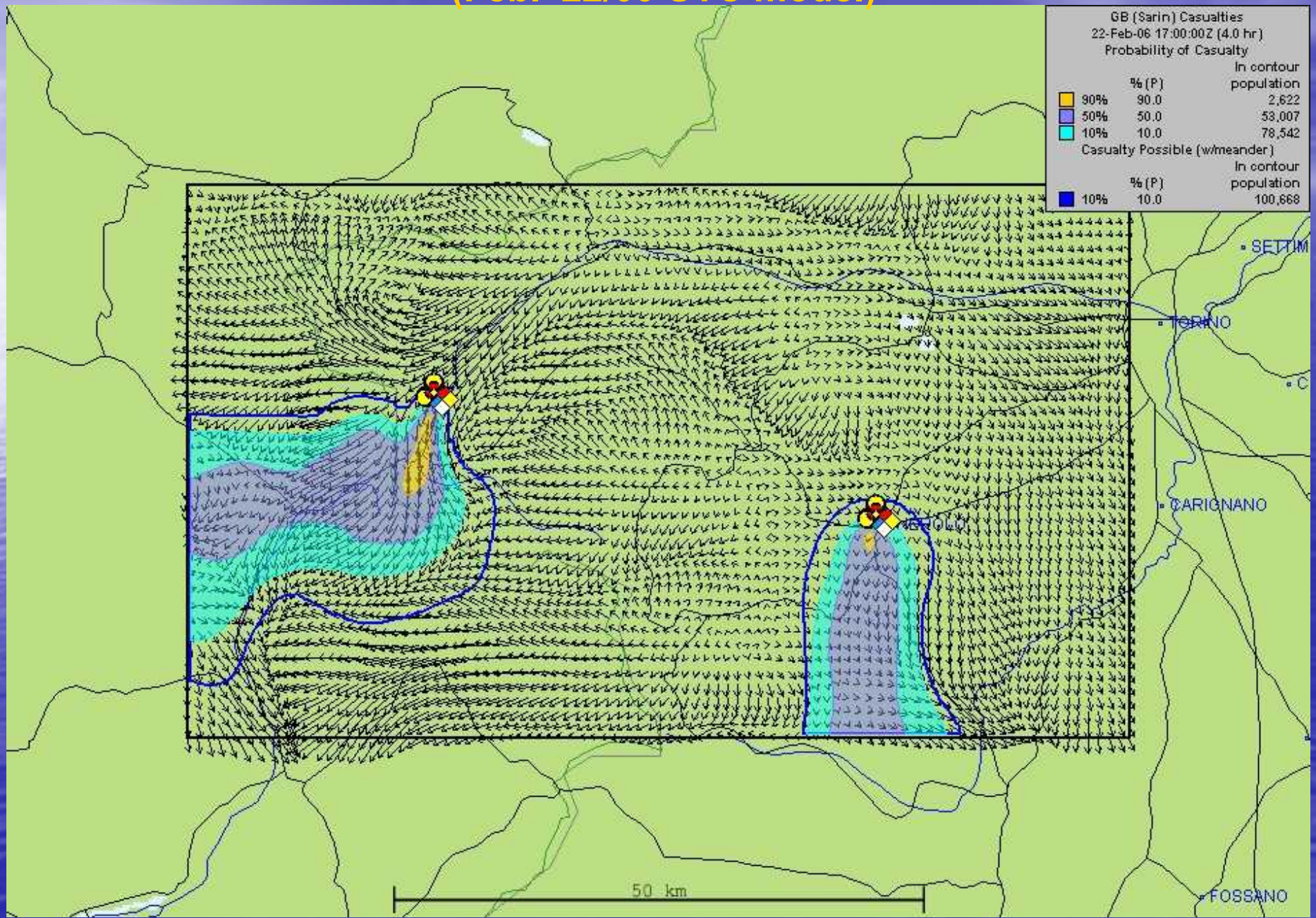

Dr. David Staufer, Penn State meteorology department, remarked, "It is very satisfying to apply our advanced technologies in numerical weather predication and data assimilation. So far our high-resolution meteorological modeling and data assimilation system has performed very well in capturing the localized mountain flows in and around the Olympic venues."

Two other DTRA partners provided independent weather forecast models against which the PSU and NCAR model data was compared against. The AFWA provided its MM5 forecast model data and the U.S. National Oceanic and Atmospheric Administration's National Centers for Environmental Prediction provided data from a special version of their WRF model.

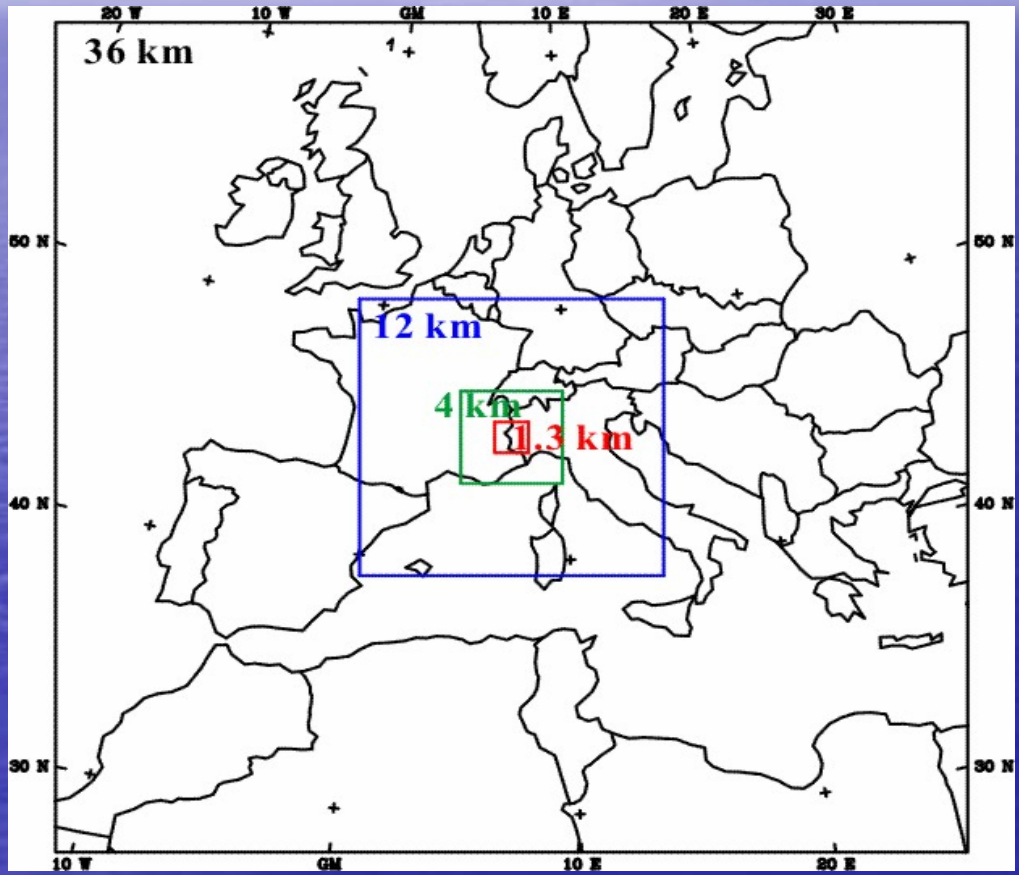
"We learned several important lessons during this project," Trigg said. "More research is needed for quantifying model uncertainties in the inputs and outputs of transport and dispersion models. The meteorology team and its partners used this experience to improve several areas of its weather support operations. We plan to expand upon this experience during upcoming field tests, and to further improve and expand the capability to provide accurate high-resolution weather forecast information to hazard and consequence assessment operations." ■

*Irene Smith is a DTRA public affairs specialist.*

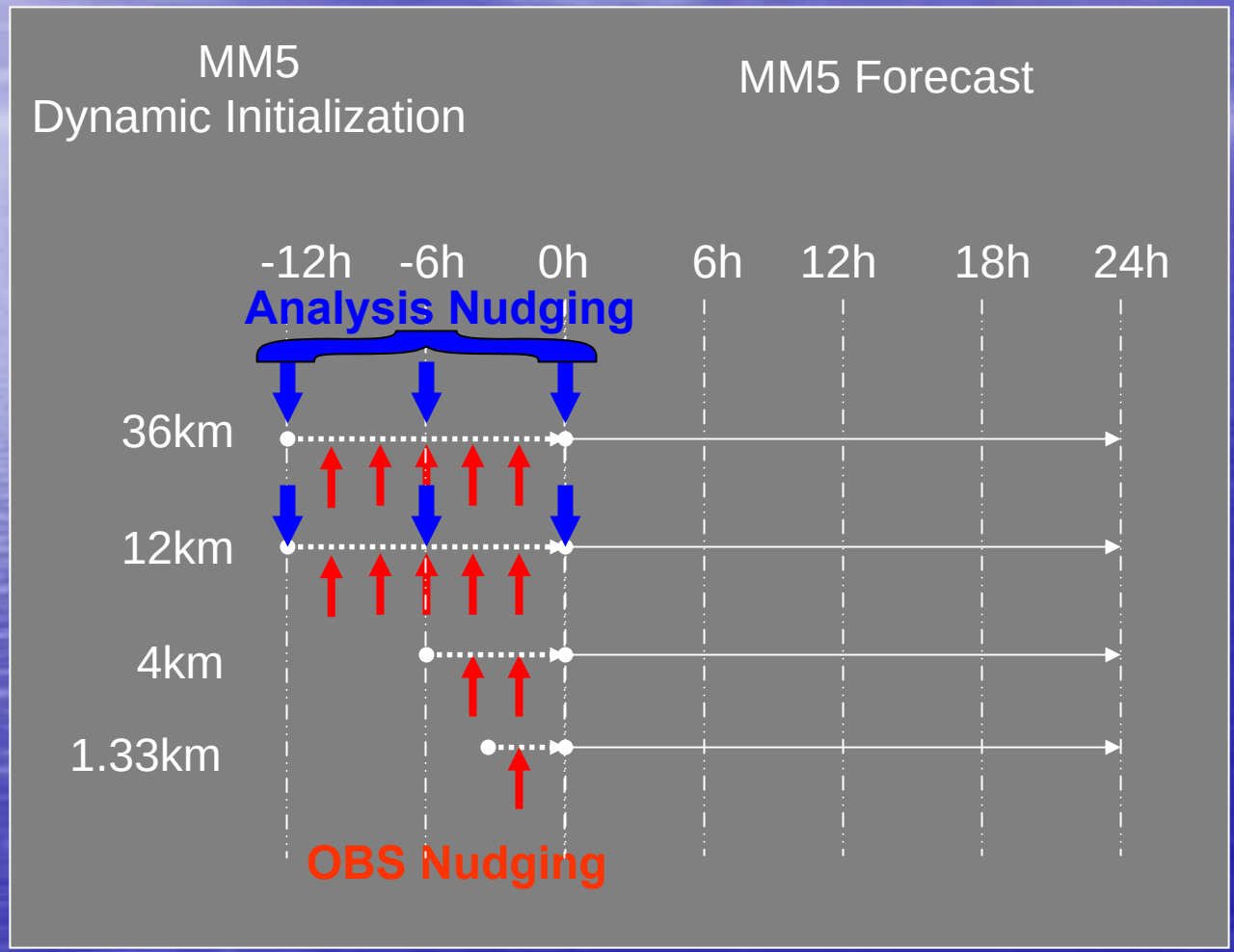
# PSU 1.3km Feb. 22/13-17 UTC plumes, Feb. 22/14 UTC winds (Feb. 22/00 UTC model)



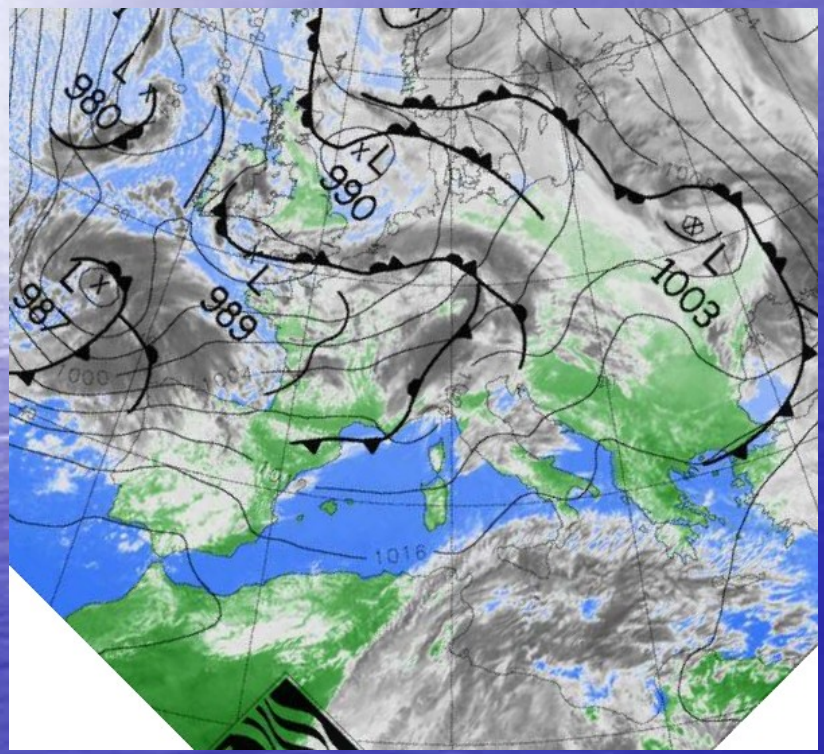
# MM5/WRF 4-Domain Configuration for 2006 Winter Olympics

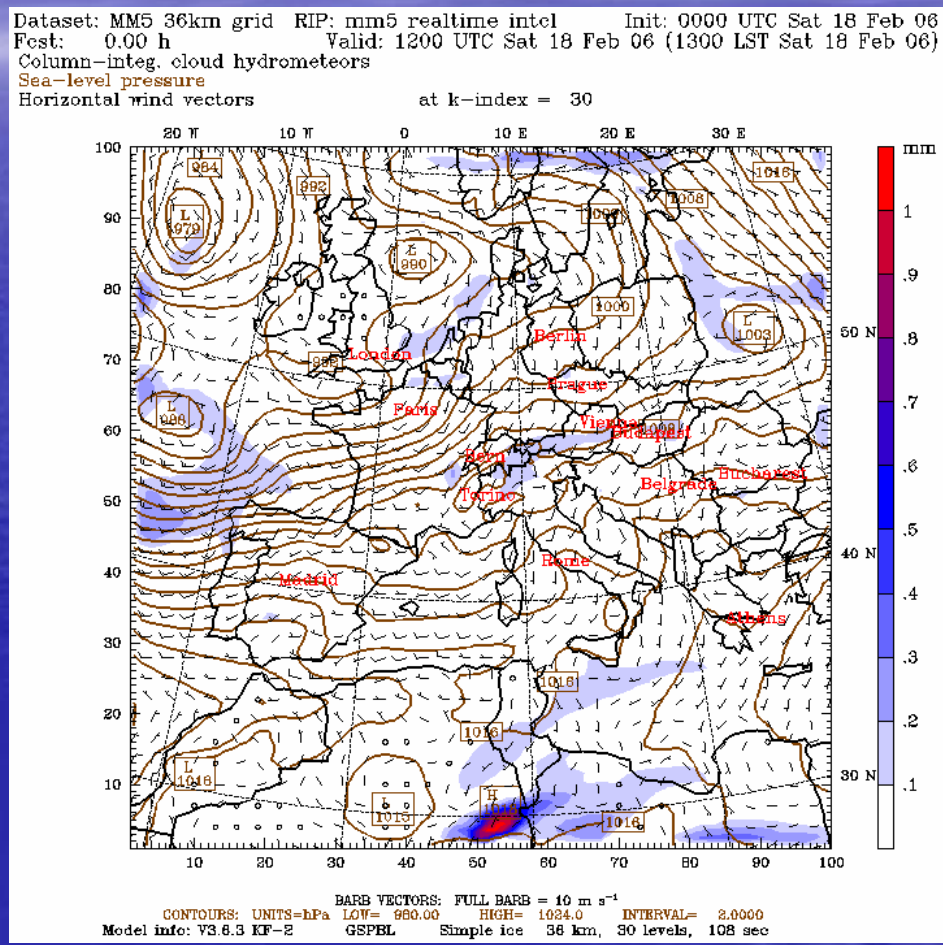


# MM5 Initialization Scheme used for 2006 Winter Olympics

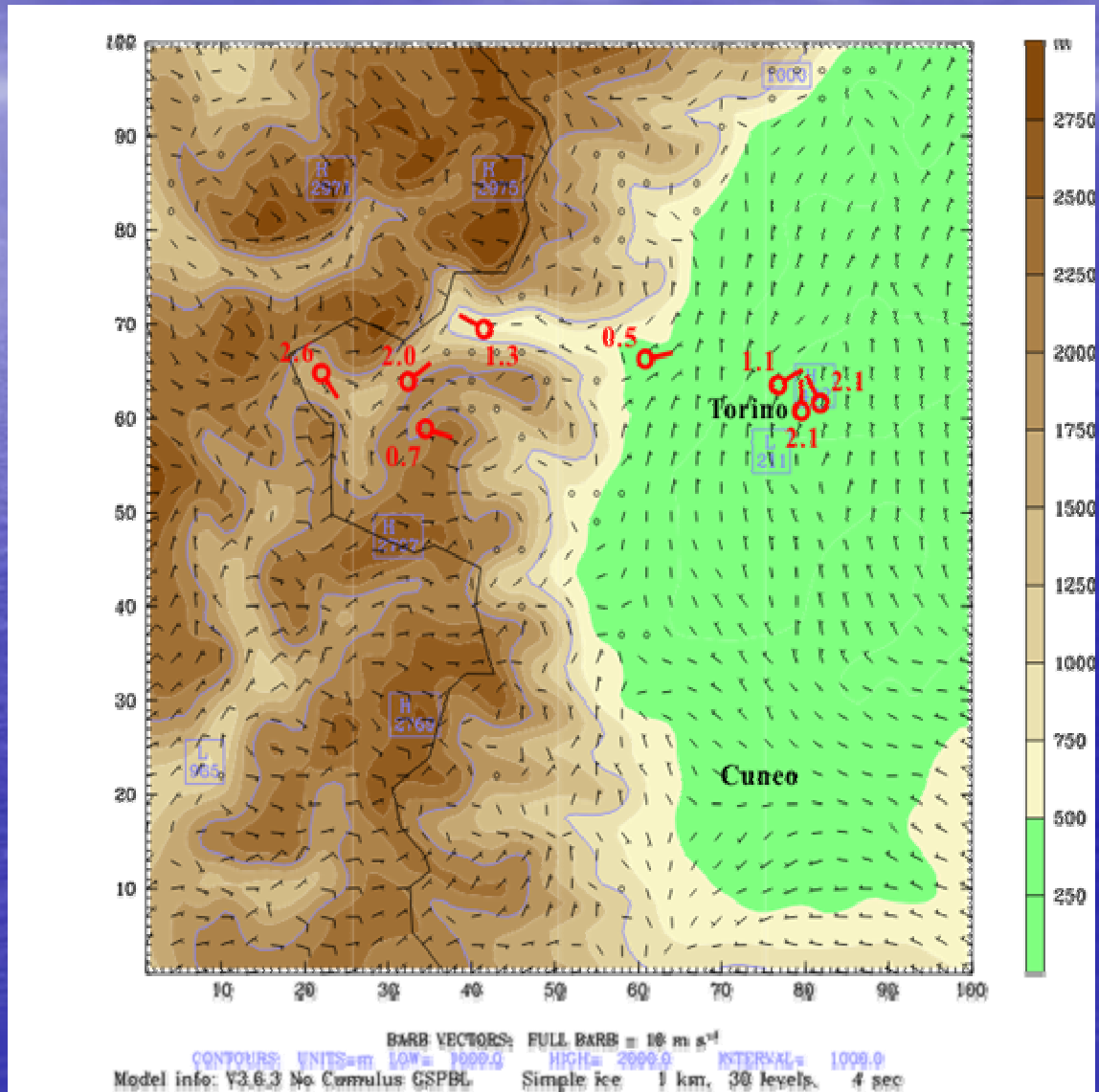


# Observed and Model Cloud (t=0h) 1200UTC February 18, 2006



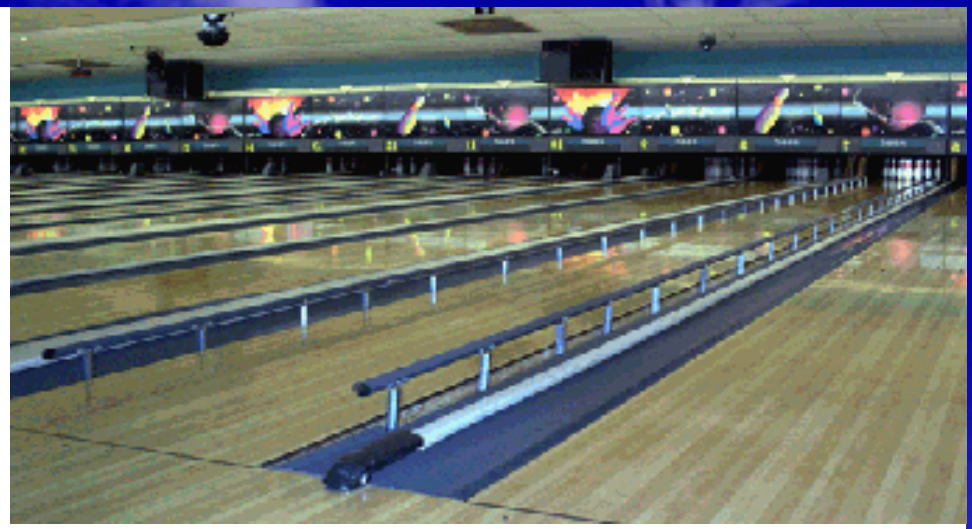



# 18-h Forecast of Surface Layer Winds with Mesonet Observations (red) on 1.3 km Domain Valid at 18 UTC, 21 February 2006

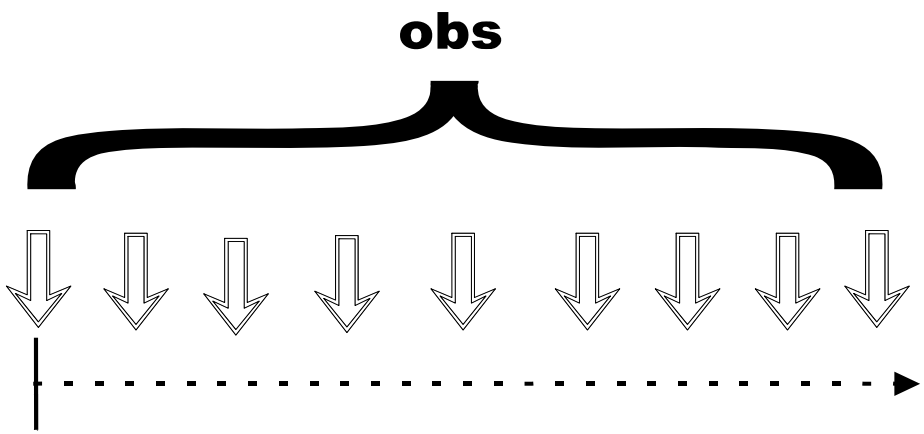


# Historical-Mode (Episodic) Applications...

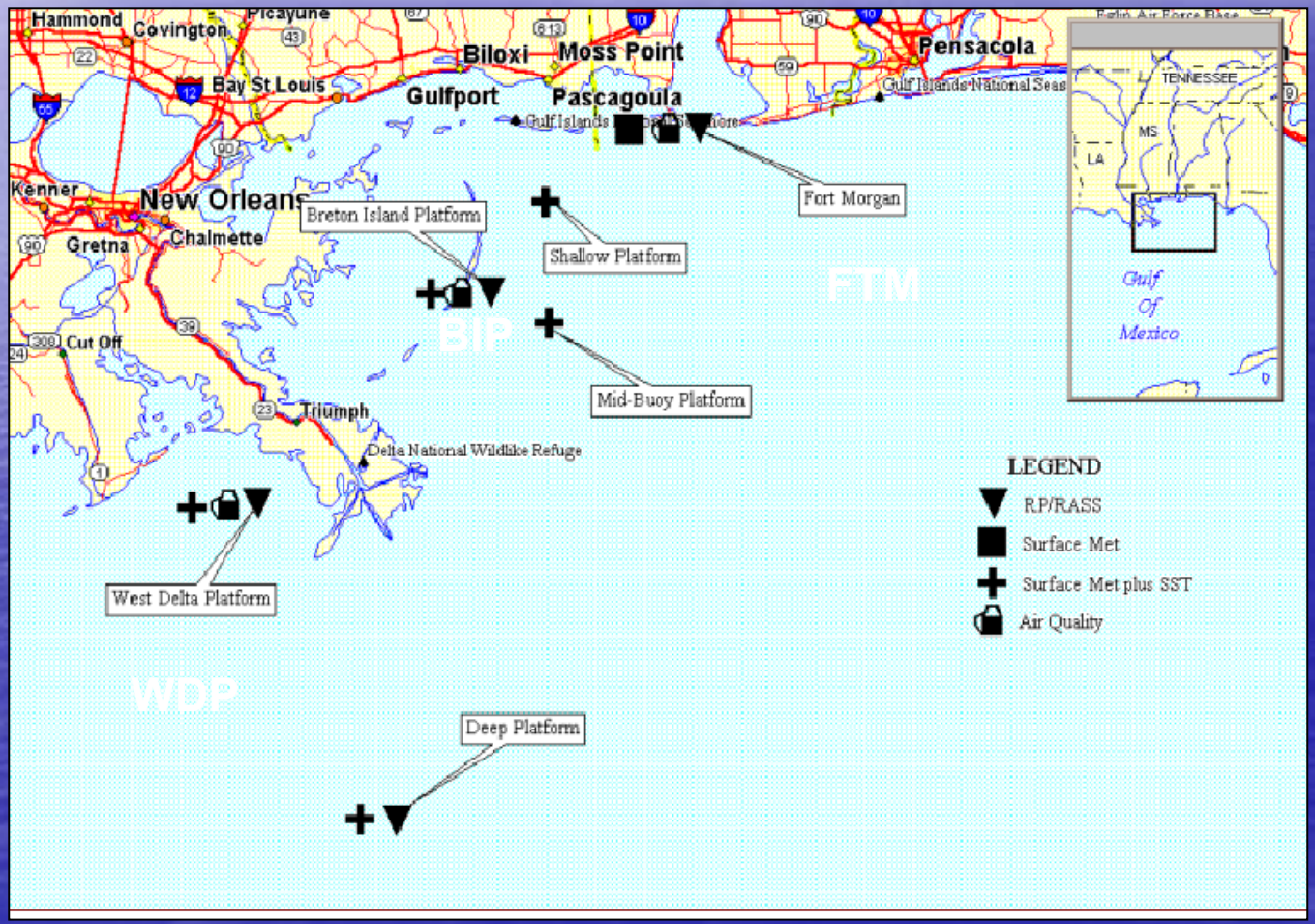
Improved Meteorology for Input to Air-Chemistry Models



## Dynamic Analysis

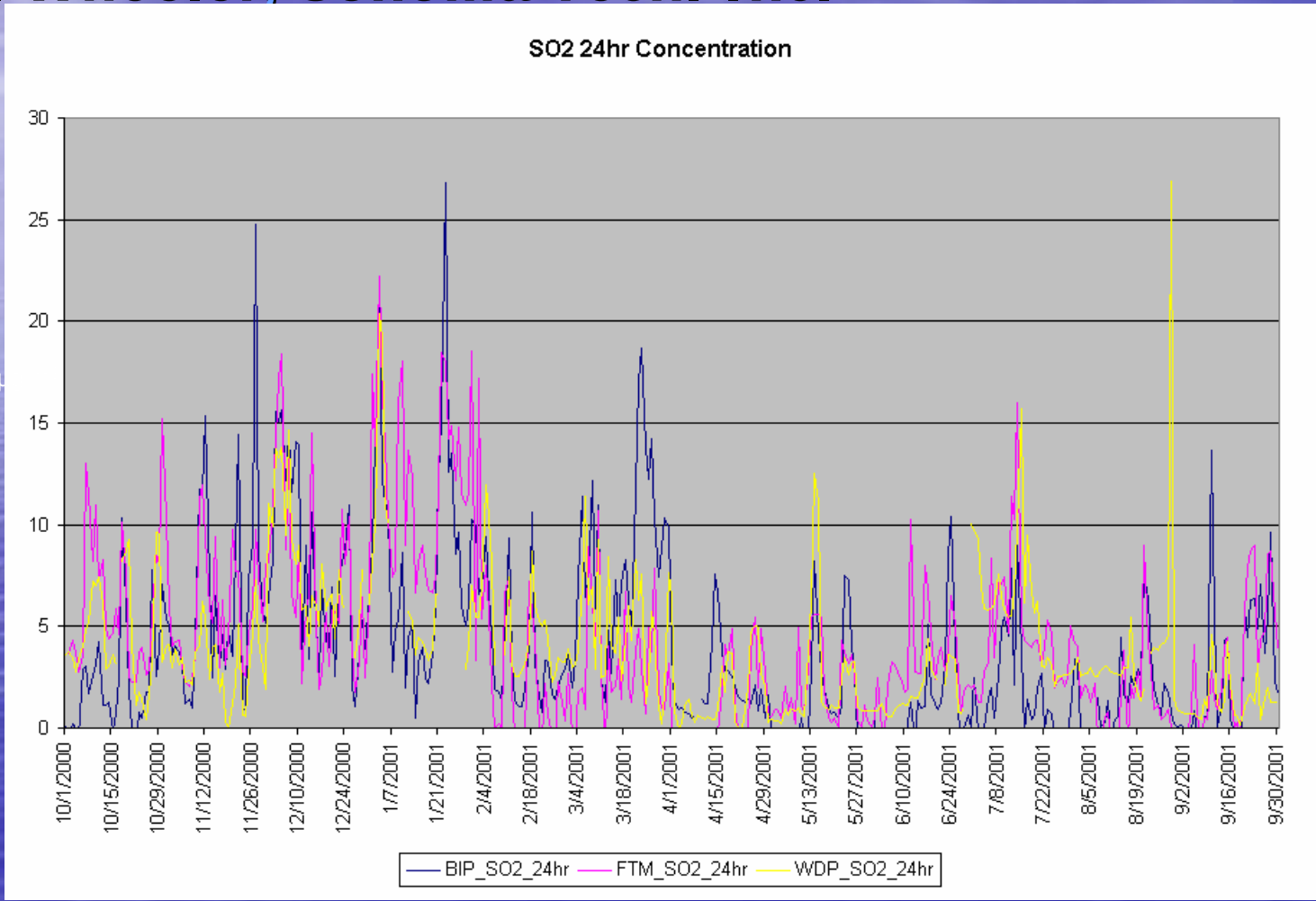


# Breton National Wilderness Area:Air Quality Monitoring Sites for Year-Long Modeling Study (M. S. student - J. Zielonka)

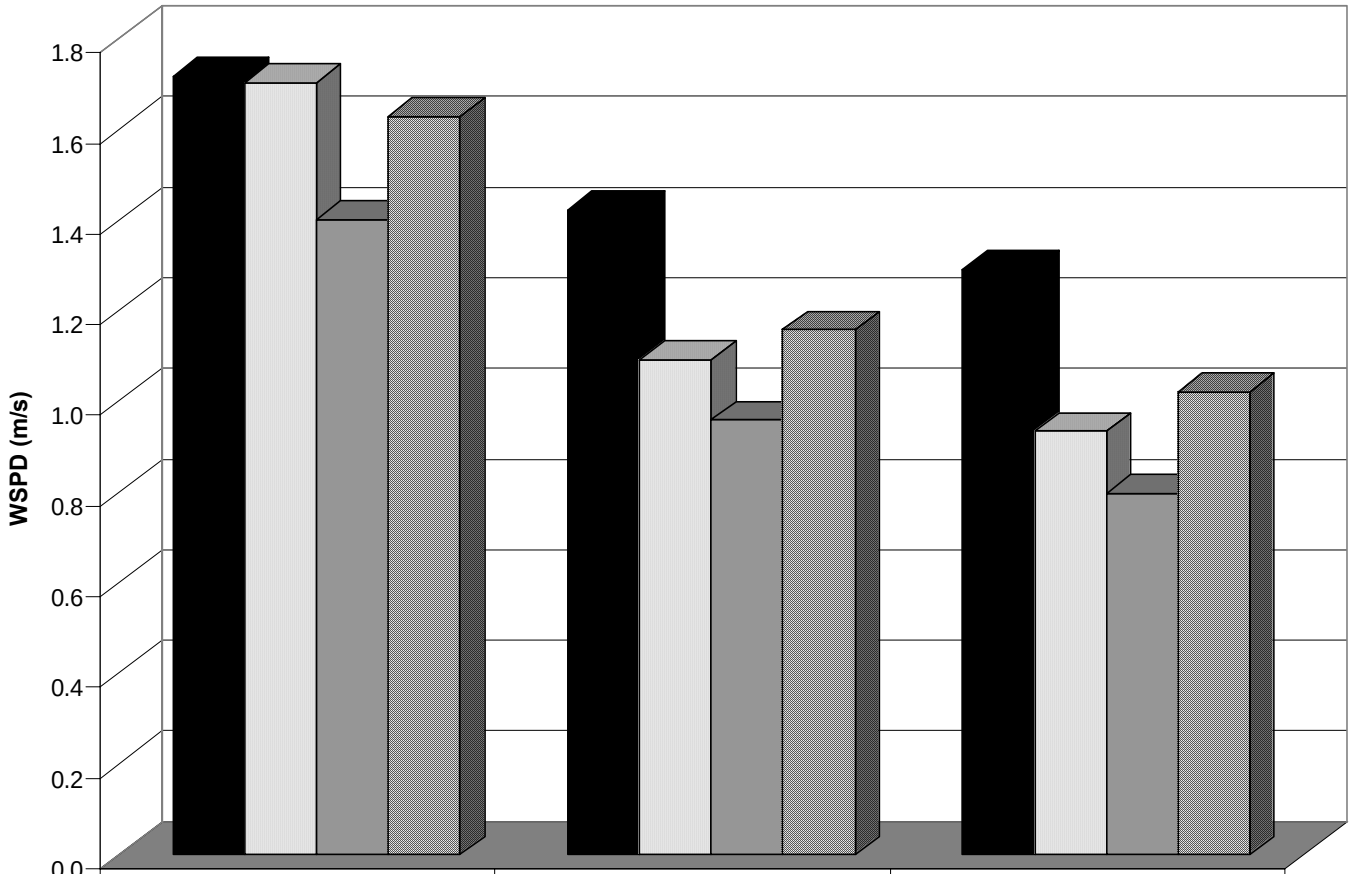


# Time Series Analysis:

## Neil Wheeler, Sonoma Tech. Inc.

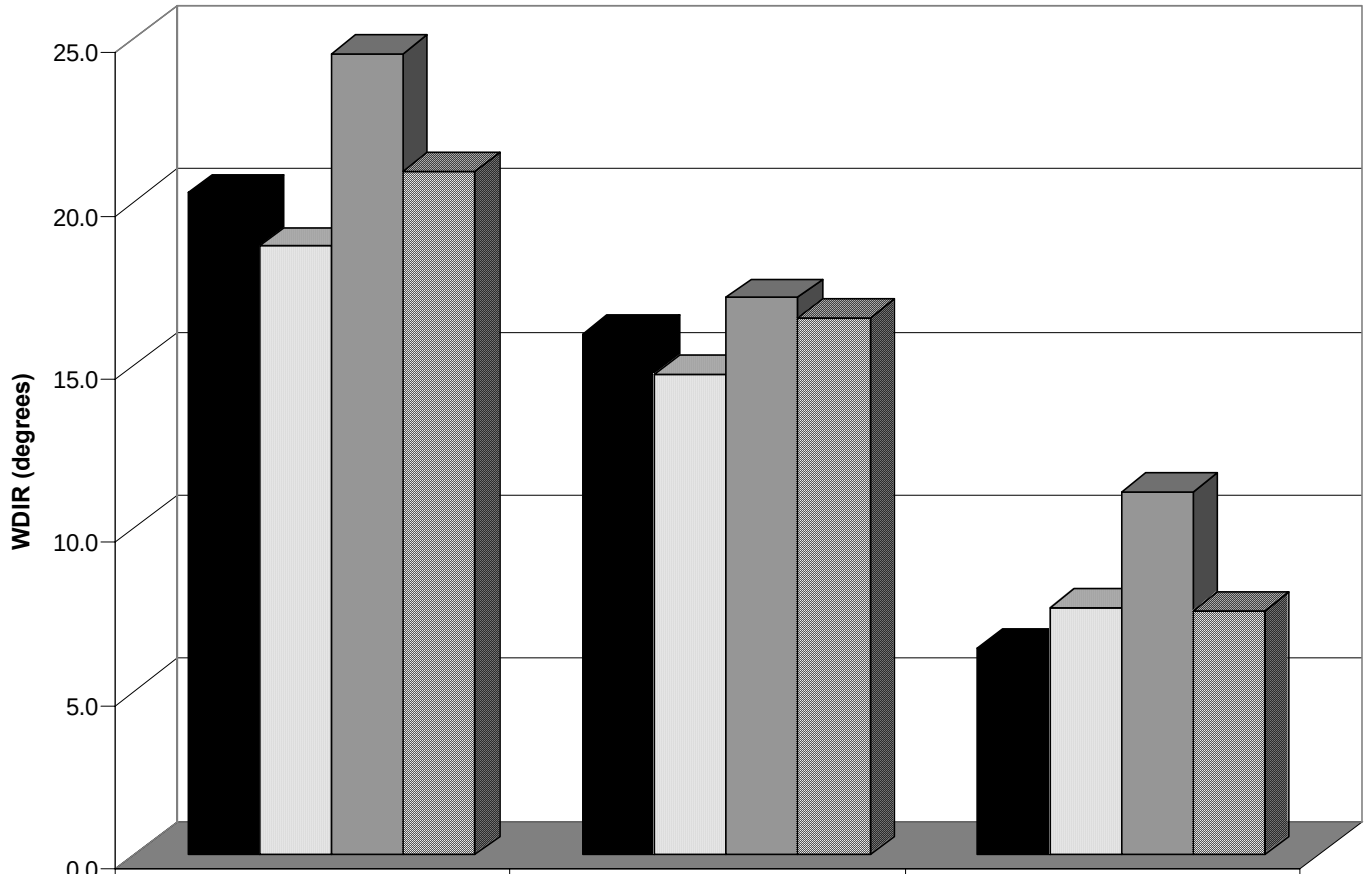


## Mean Absolute Error Seasonal Means for WSPD



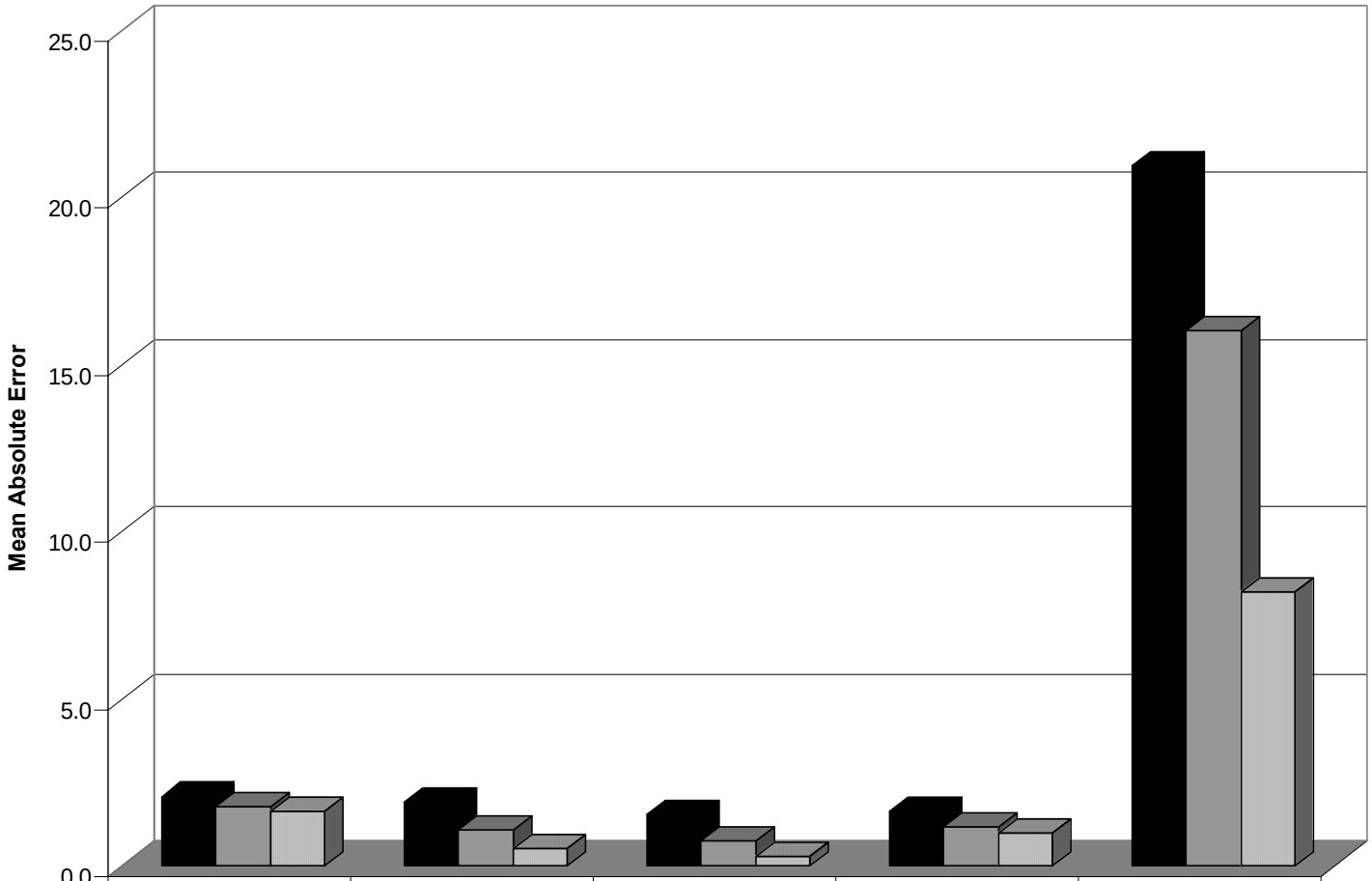

| | SFC | 30-1000m | ALAS |
|---|---|---|---|
| Winter | 1.7 | 1.4 | 1.3 |
| Spring | 1.7 | 1.1 | 0.9 |
| Summer | 1.4 | 1.0 | 0.8 |
| Fall | 1.6 | 1.2 | 1.0 |

## Mean Absolute Error Seasonal Means for WDIR




| | SFC | 30-1000m | ALAS |
|---|---|---|---|
| Winter | 20.3 | 16.0 | 6.3 |
| Spring | 18.6 | 14.7 | 7.6 |
| Summer | 24.5 | 17.1 | 11.1 |
| Fall | 20.9 | 16.4 | 7.5 |

## Mean Absolute Error - Annual Means




| | VWD (m/s) | TEMP (°C) | MIXR (g/kg) | WSPD (m/s) | WDIR (degrees) |
|---|---|---|---|---|---|
| SFC | 2.1 | 1.9 | 1.5 | 1.6 | 20.9 |
| 30-1000m | 1.8 | 1.1 | 0.8 | 1.2 | 16.0 |
| ALAS | 1.6 | 0.5 | 0.3 | 1.0 | 8.2 |

# WRF Model and Nudging Methodology

# Flux-Form Equations in Mass Coordinate

Hydrostatic pressure coordinate:

Dry hydrostatic pressure $p_{dh}$

$$\eta = \frac{p_{dh} - p_{dht}}{\mu_d}, \quad \mu_d = p_{dhs} - p_{dht}$$

Conserved state variables:

$$\vec{V} = \mu_d \vec{v} = (U, V, W), \quad \vec{\Omega} = \mu_d \dot{\eta}, \quad \Theta = \mu_d \theta, \quad Q_m = \mu_d q_m$$

# Flux-Form Equations in Mass Coordinate

## Moist Equations:

$$\frac{\partial U}{\partial t}+(\nabla\cdot\vec{V}u)_\eta+\mu_d\alpha\frac{\partial p}{\partial x}+(\tfrac{\alpha}{\alpha_d})\frac{\partial p}{\partial\eta}\frac{\partial\phi}{\partial x}=F_U,\quad \frac{\partial V}{\partial t}+(\nabla\cdot\vec{V}v)_\eta+\mu_d\alpha\frac{\partial p}{\partial y}+(\tfrac{\alpha}{\alpha_d})\frac{\partial p}{\partial\eta}\frac{\partial\phi}{\partial y}=F_V$$

$$\frac{\partial W}{\partial t}+(\nabla\cdot\vec{V}w)_\eta-g[\frac{\alpha}{\alpha_d}\frac{\partial p}{\partial\eta}-\mu_d]=F_W,\quad \frac{\partial\Theta}{\partial t}+(\nabla\cdot\vec{V}\theta)_\eta=F_\Theta$$

$$\frac{\partial\phi}{\partial t}+\frac{1}{\mu_d}[(\vec{V}\cdot\nabla\phi)_\eta-gW]=0,\quad \frac{\partial Q_m}{\partial t}+(\vec{V}\cdot\nabla q_m)_\eta=F_{Q_m}$$

$$\frac{\partial\mu_d}{\partial t}+(\nabla\cdot\vec{V})_\eta=0$$

where

$$(\nabla\cdot\vec{V}a)_\eta\equiv\frac{\partial Ua}{\partial x}+\frac{\partial Va}{\partial y}+\frac{\partial\Omega a}{\partial\eta},\qquad (\vec{V}\cdot\nabla a)_\eta\equiv U\frac{\partial a}{\partial x}+V\frac{\partial a}{\partial y}+\Omega\frac{\partial a}{\partial\eta}$$

# Flux-Form Equations in Mass Coordinate

Diagnostic Equations:

$$\frac{\partial \phi}{\partial \eta} = -\alpha_d \mu_d$$

$$p = p_0 \left( R_d \theta_m / p_0 \alpha_d \right)^{c_p / c_v}$$

where

$$\alpha = \alpha_d (1 + q_v + q_c + q_r + q_i + \ldots)^{-1}$$

$$\theta_m = \theta \left(1 + q_v \frac{R_v}{R_d}\right) \approx \theta (1 + 1.61 q_v)$$

# Height/Mass-Coordinate Model, Time Integration

3rd Order Runge-Kutta time integration

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

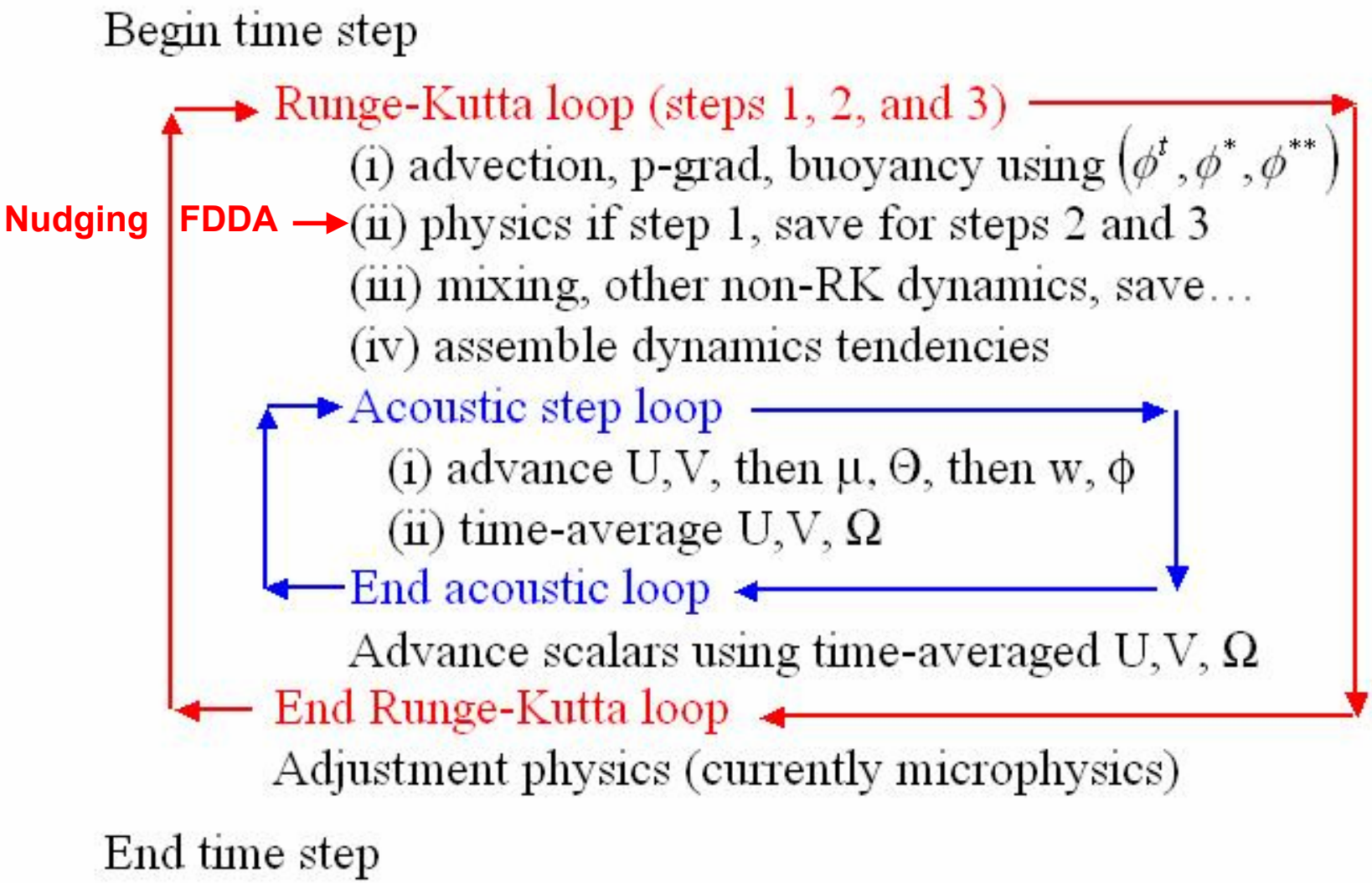
$$\phi^* = \phi^t + \frac{\Delta t}{3} R\left(\phi^t\right)$$

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

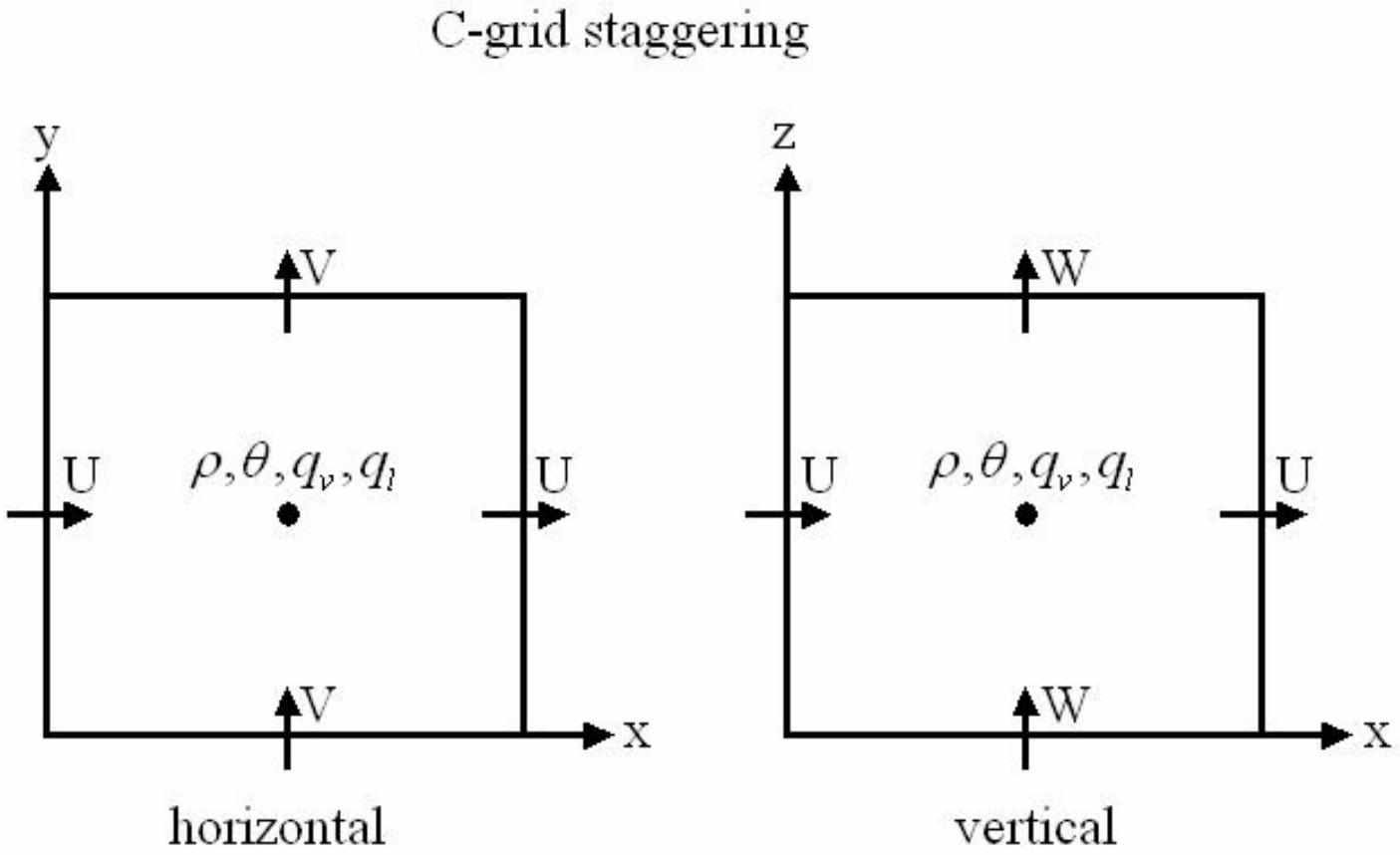
$$\phi^{t+1} = \phi^t + \Delta t\, R\left(\phi^{**}\right)$$

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



# Height/Mass-coordinate model, grid staggering




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

# Nudging FDDA

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

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

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

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

# Nudging FDDA in WRF

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

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

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

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

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

# Experimental Design / Set-Up

# Demonstration of WRF Analysis Nudging:

- Assimilate 12-hourly MM5 front-end 3D analyses on 108-km, 36-km, 12-km grids
- Nudge u, v, theta ($G = 3 \times 10^{-4}\ s^{-1}$)
- Nudge $q_v$ ($G = 1 \times 10^{-5}\ s^{-1}$)
- Show results with and without FDDA at 48 h for CAPTEX83 (18-20 September 1983)
- Compare results subjectively to the analyses and statistically to observations
- Test no-nudging in the PBL option

# 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
- Note: New WRF Preprocessing System (WPS) code replacing SI in WRF 2.2 in September 2006 will have VINTERP in REAL...

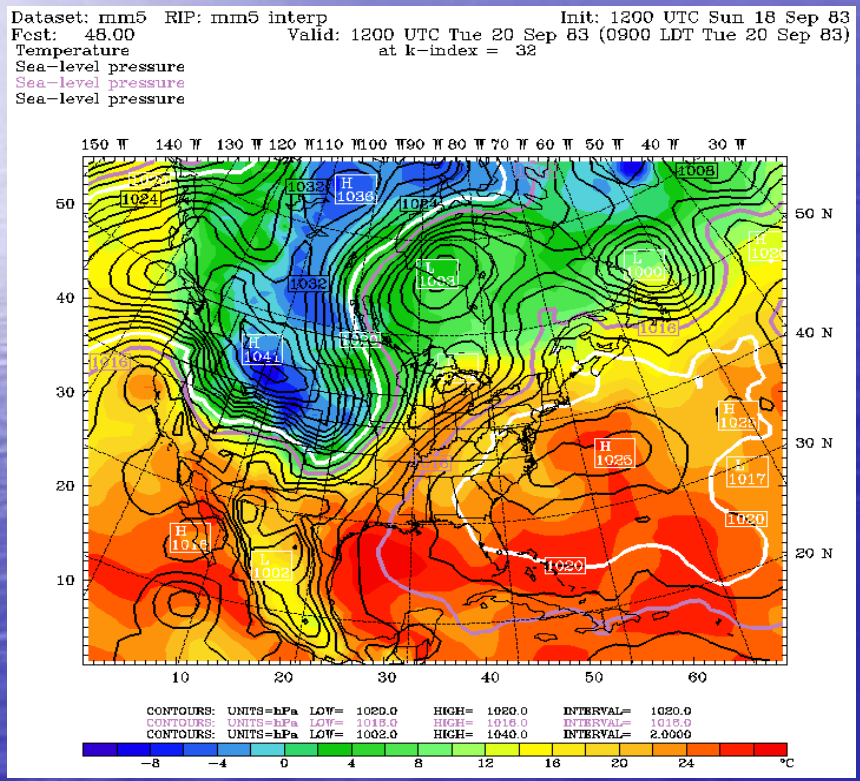
# Sfc Analyses from MM5 Frontend...

- "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, THETA
- Files will be used for surface analysis nudging in WRF
- Files will also support soil moisture nudging option in Pleim-Xiu LSM

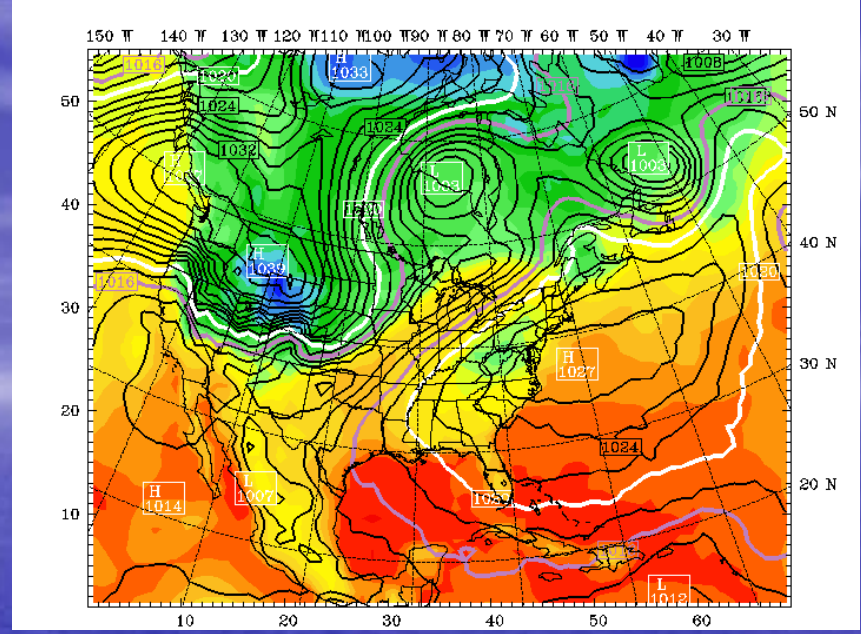
# Preliminary Results:

# 108-km grid

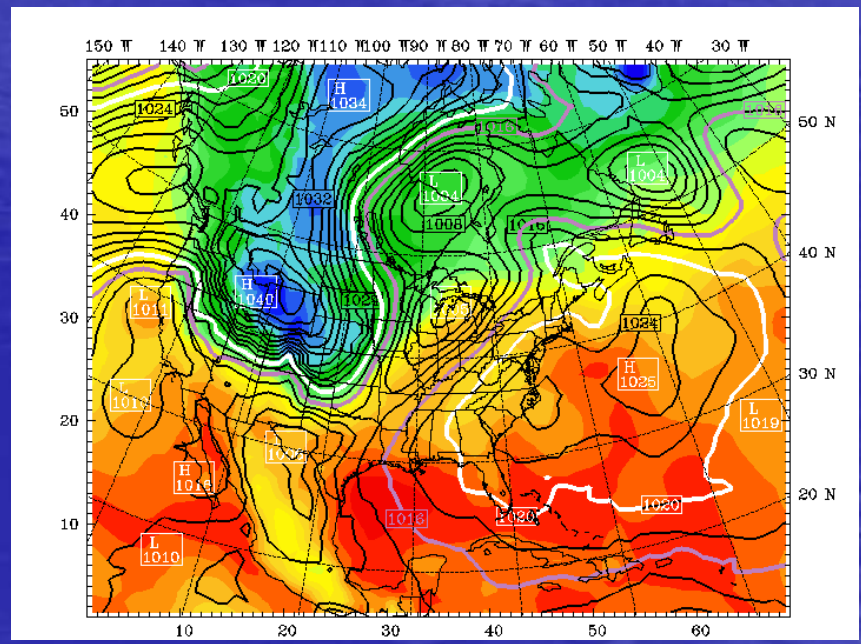
# Surface Temperature and Sea Level Pressure




MM5 ANALYSIS

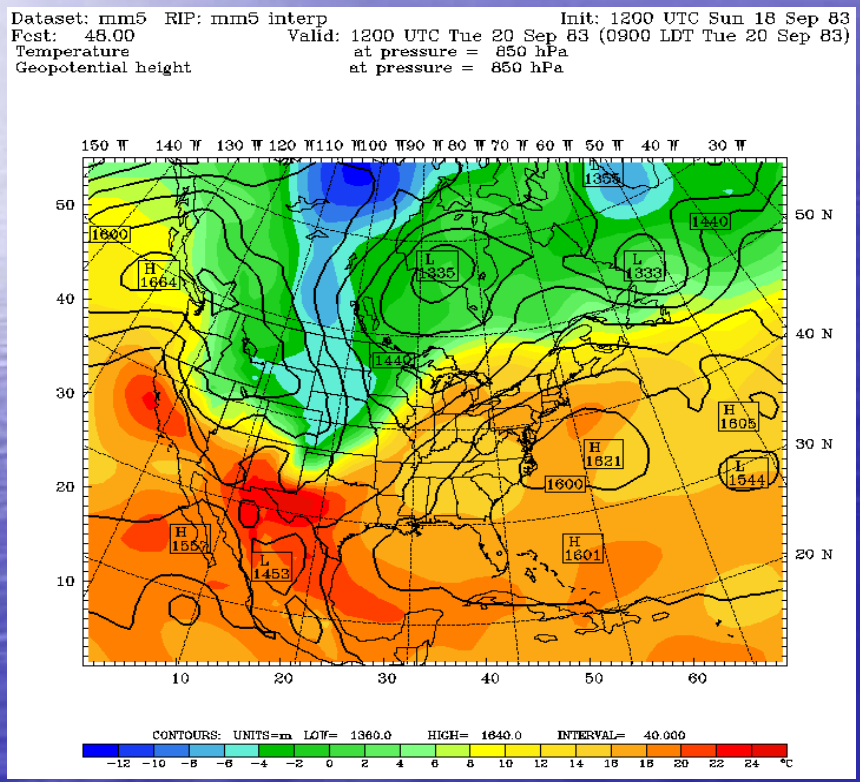


WRF NO FDDA

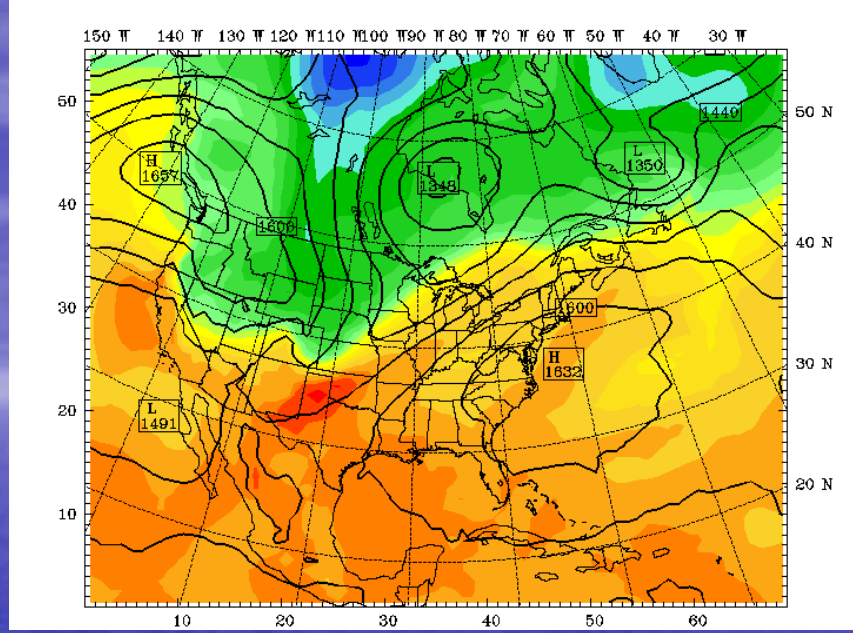


WRF FDDA

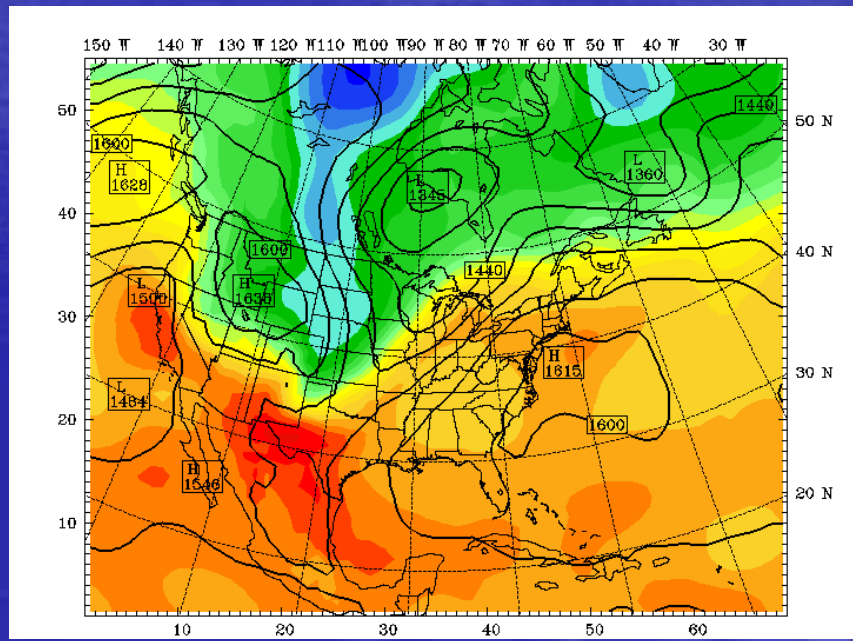
# 850 hPa Temperature and Geopotential Height




MM5
ANALYSIS

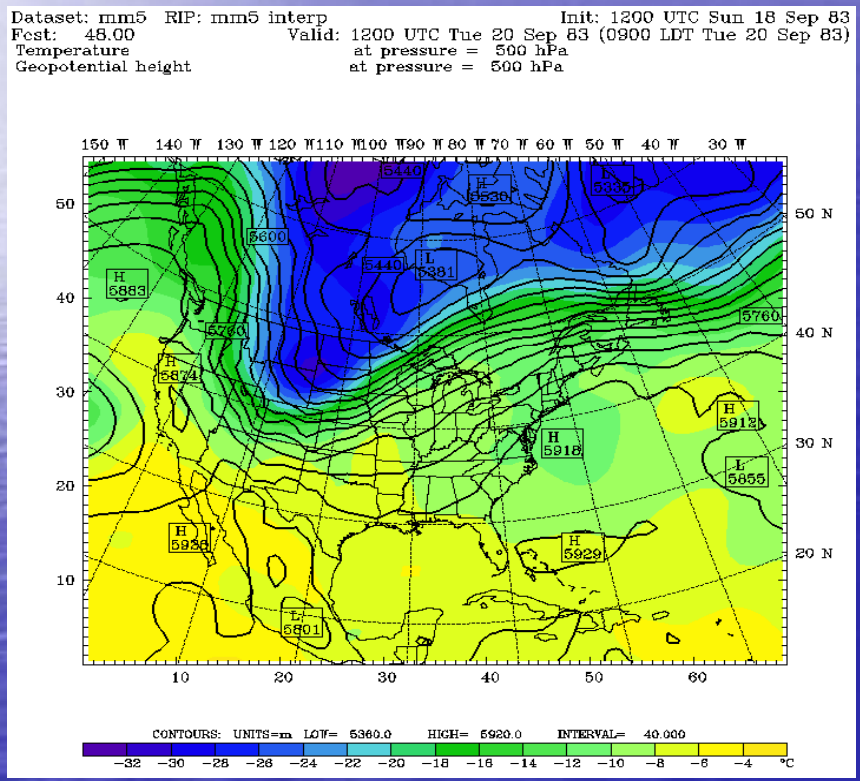


WRF NO FDDA

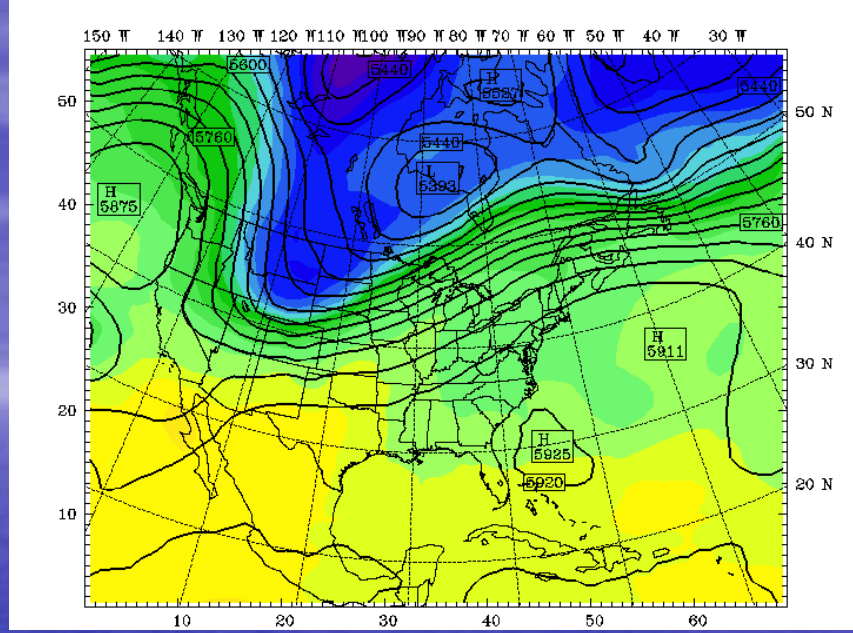


WRF FDDA

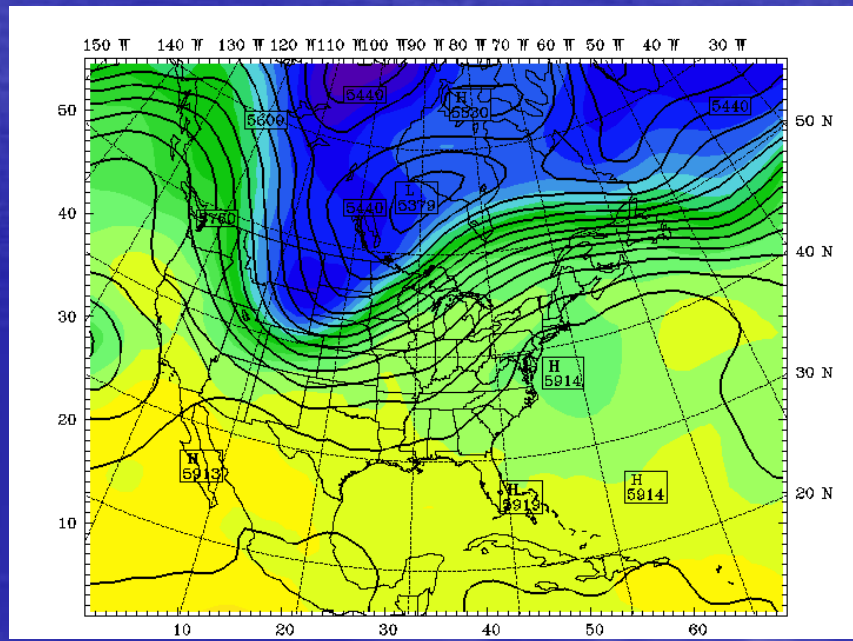
# 500 hPa Temperature and Geopotential Height




MM5 ANALYSIS

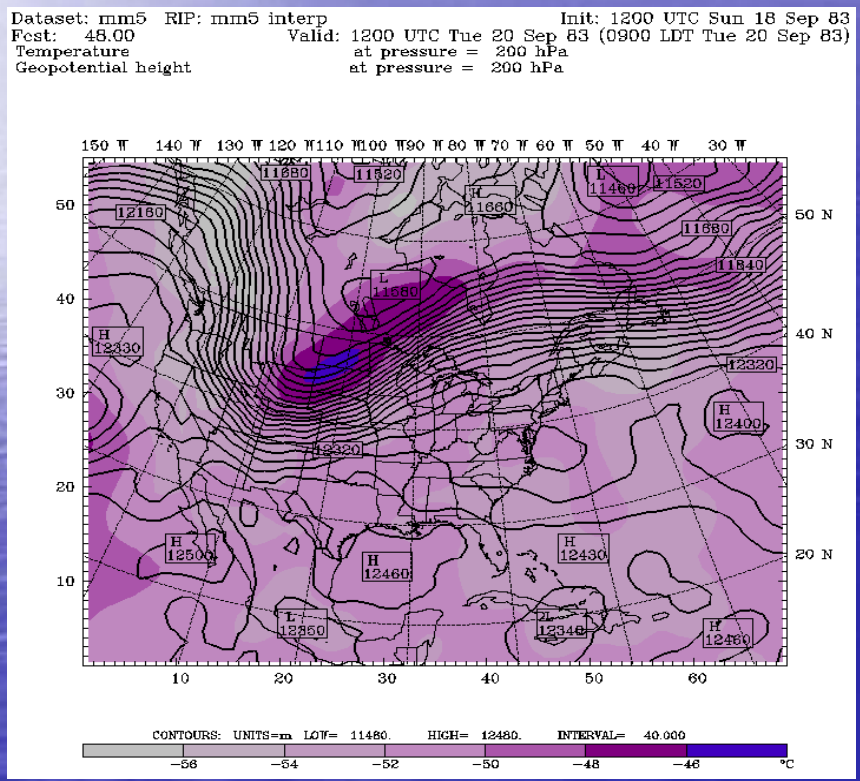


WRF NO FDDA

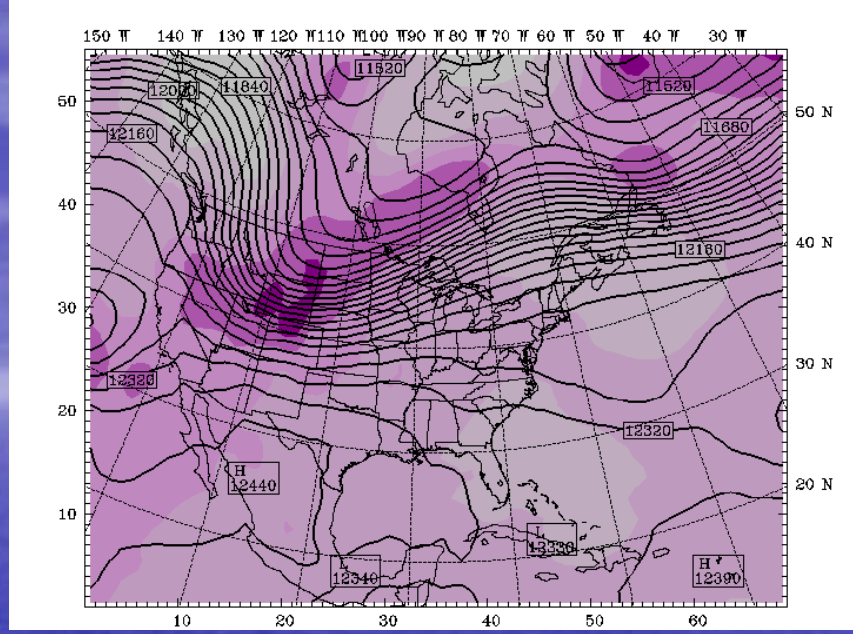


WRF FDDA

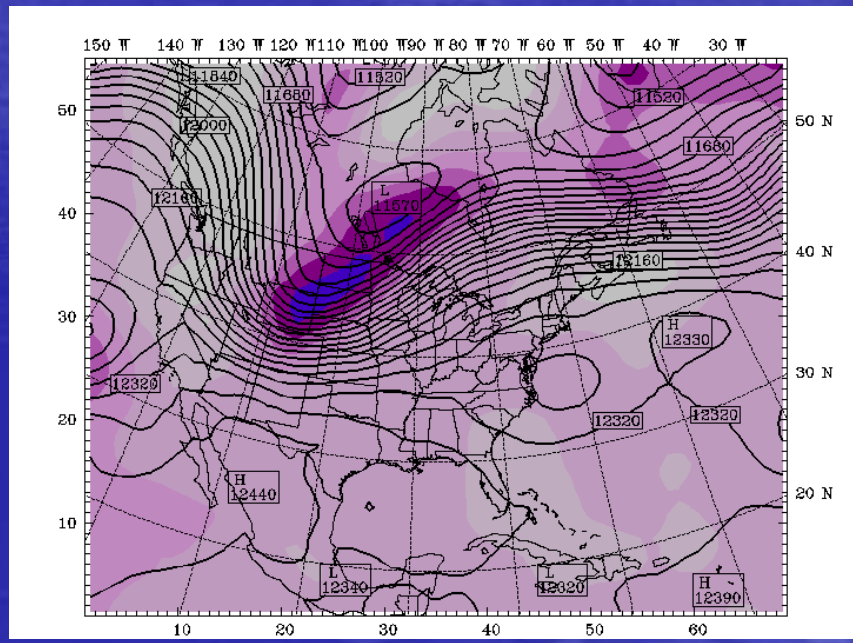
# 200 hPa Temperature and Geopotential Height




MM5
ANALYSIS

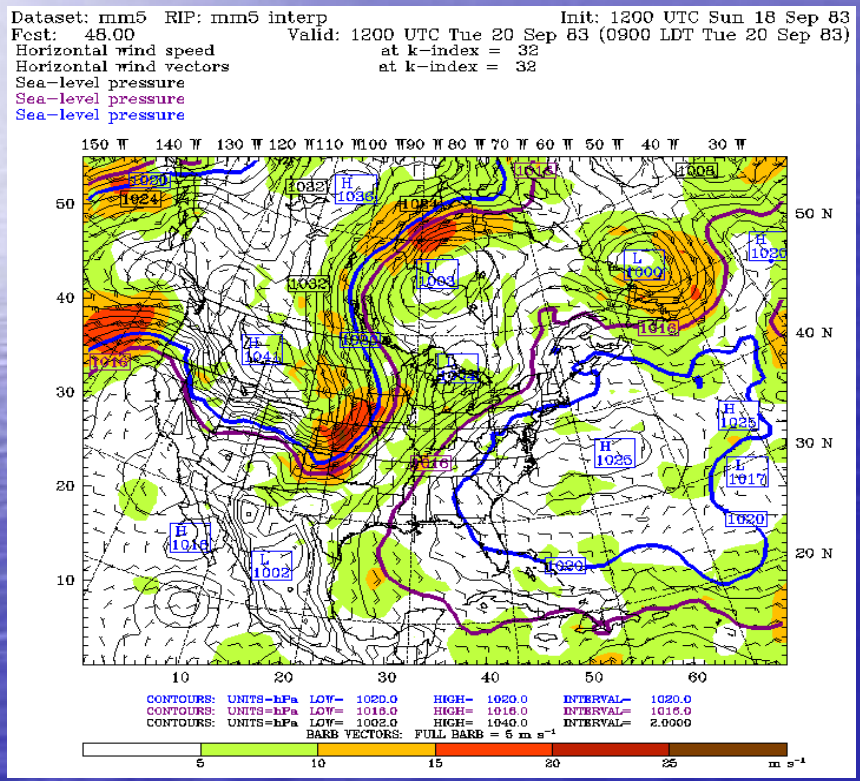


WRF NO FDDA

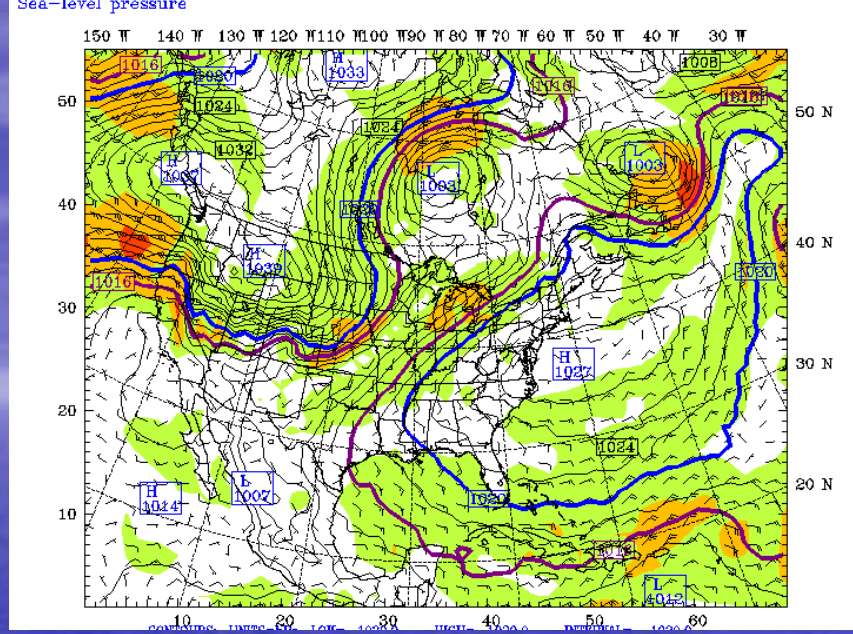


WRF FDDA

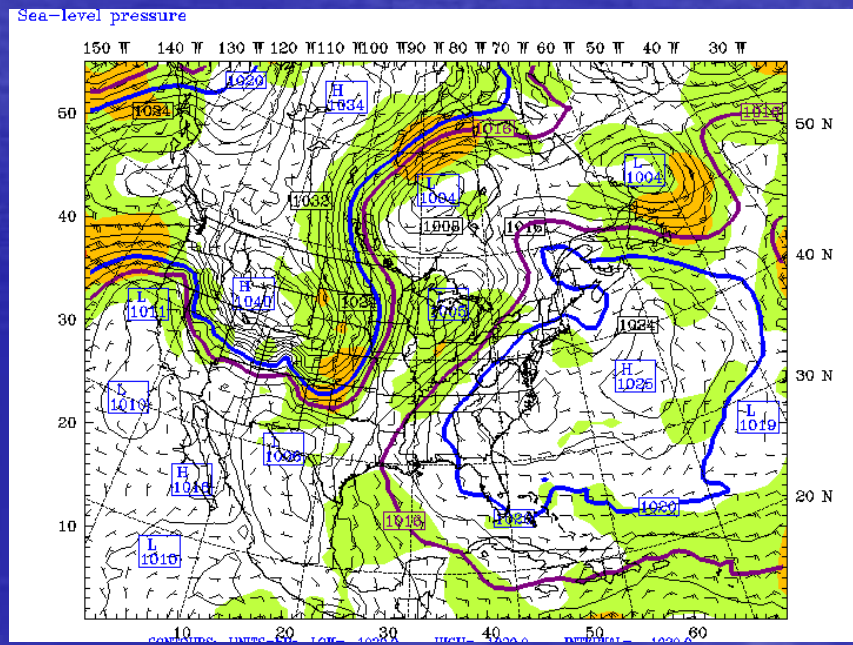
# Surface Winds and Sea Level Pressure




MM5
ANALYSIS

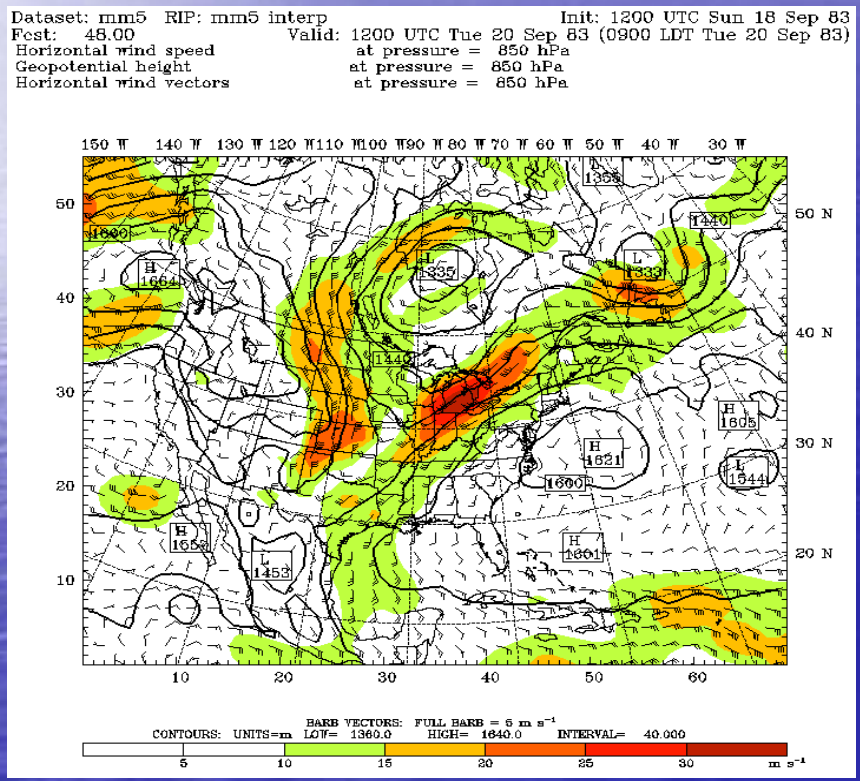



WRF NO FDDA

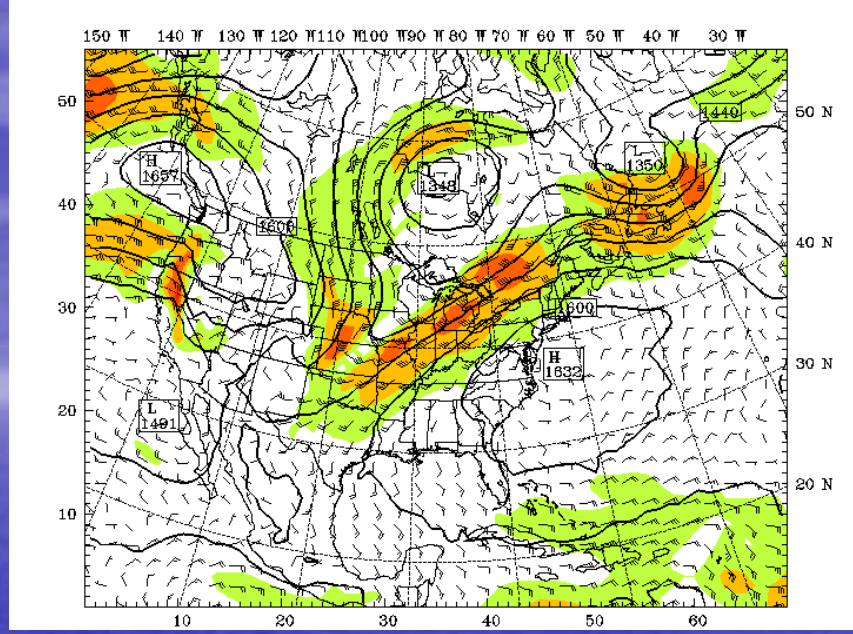



WRF FDDA

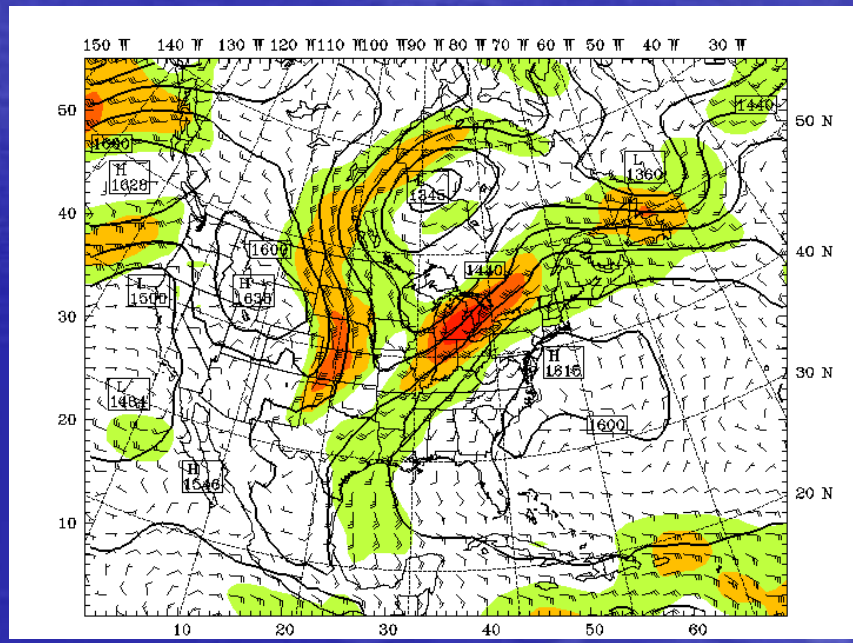
# 850 hPa Winds and Geopotential Height




MM5
ANALYSIS

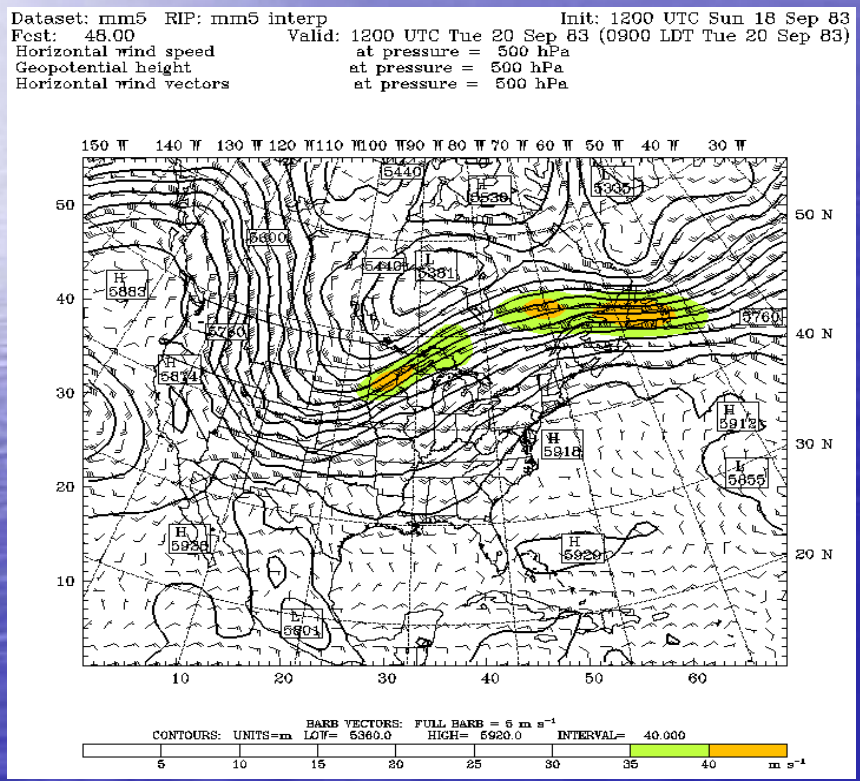



WRF NO FDDA

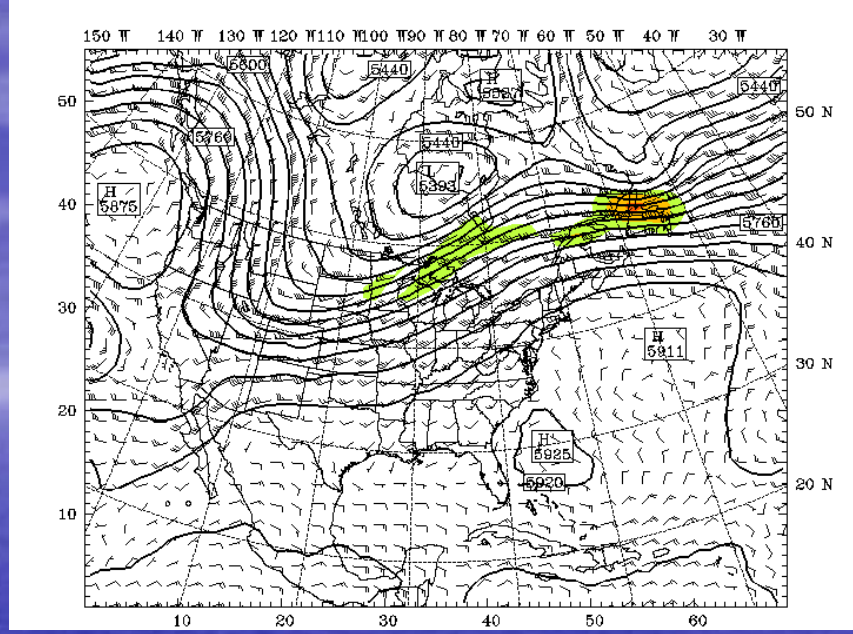



WRF FDDA

# 500 hPa Winds and Geopotential Height




MM5
ANALYSIS

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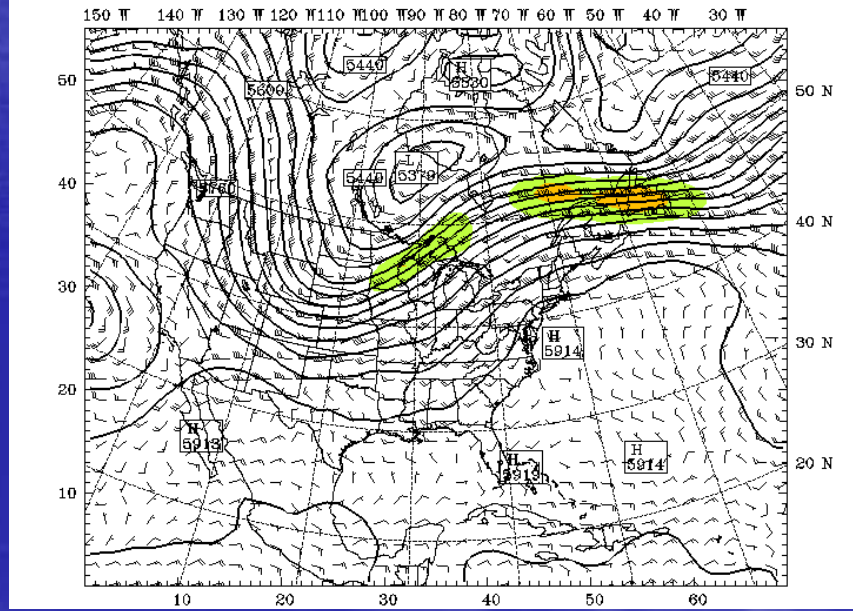
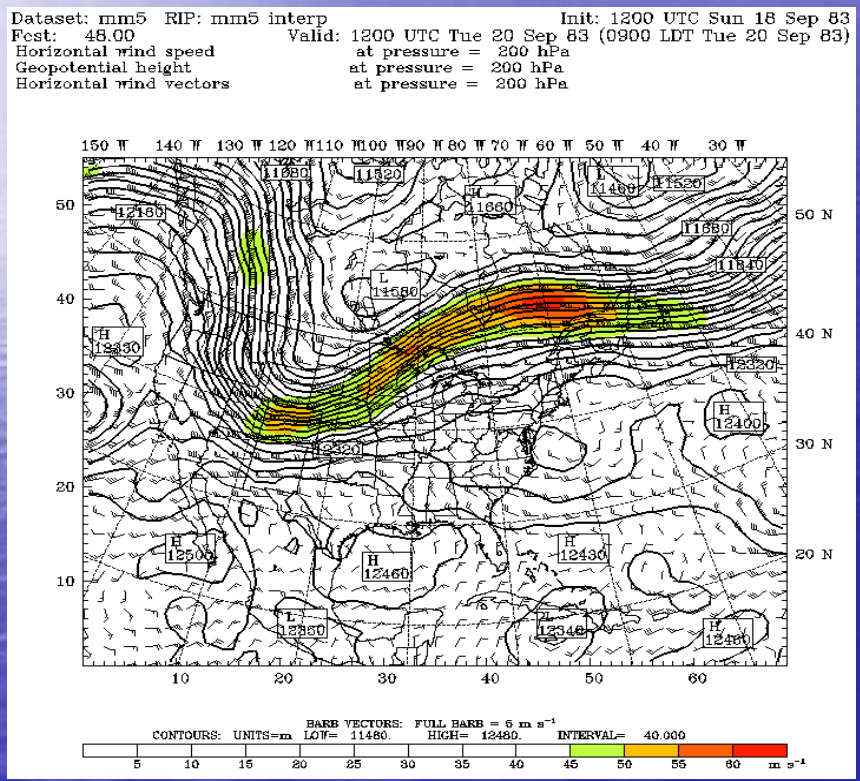
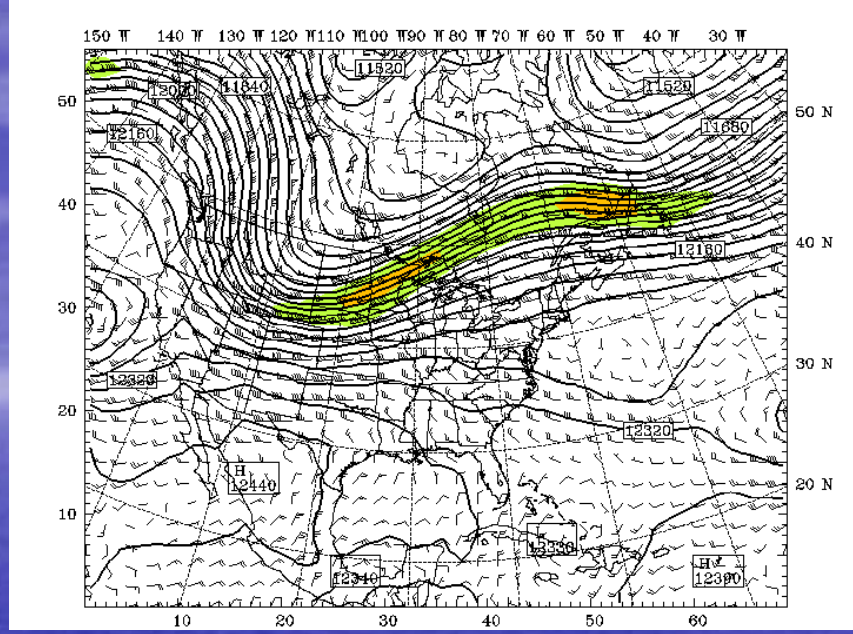



WRF FDDA

# 200 hPa Winds and Geopotential Height




MM5
ANALYSIS



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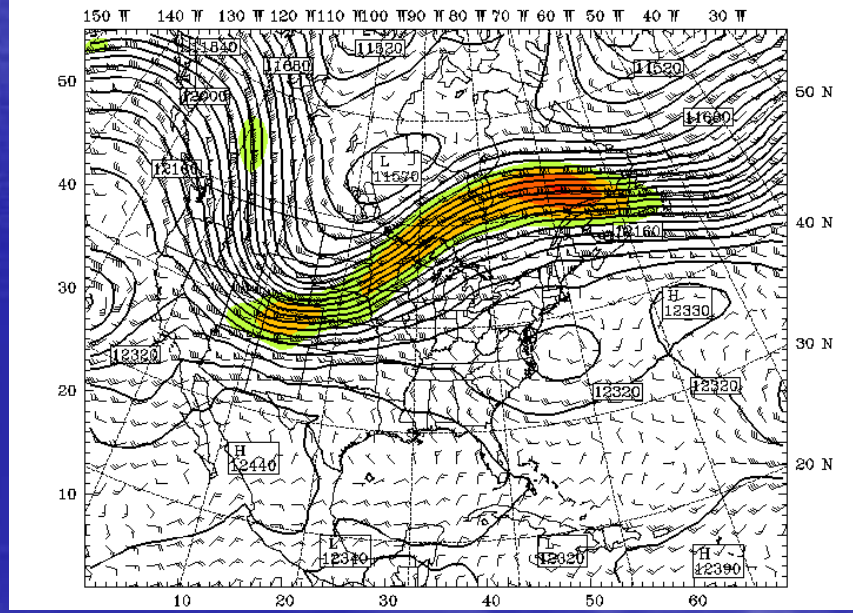
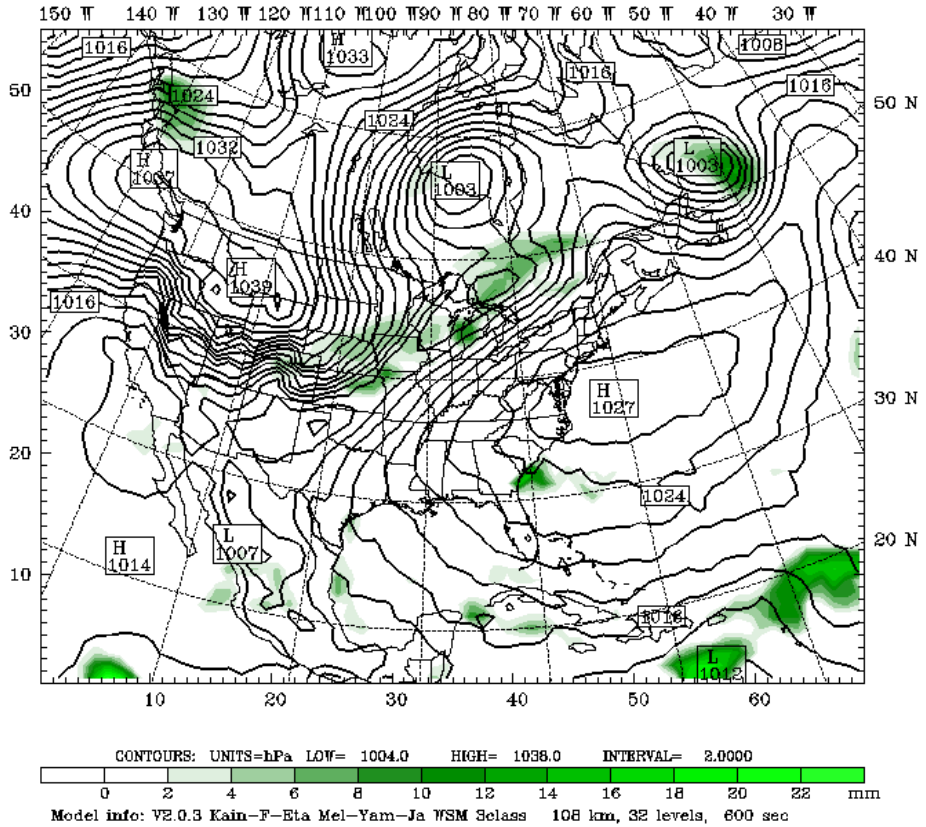
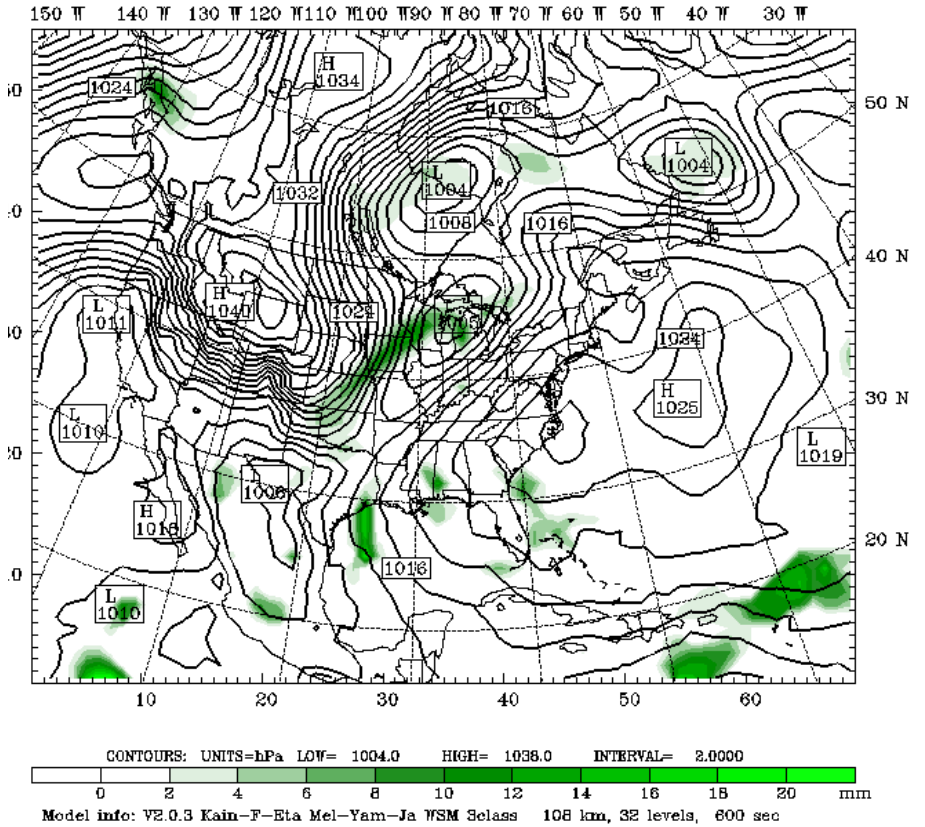


WRF FDDA

# Precipitation and Sea Level Pressure



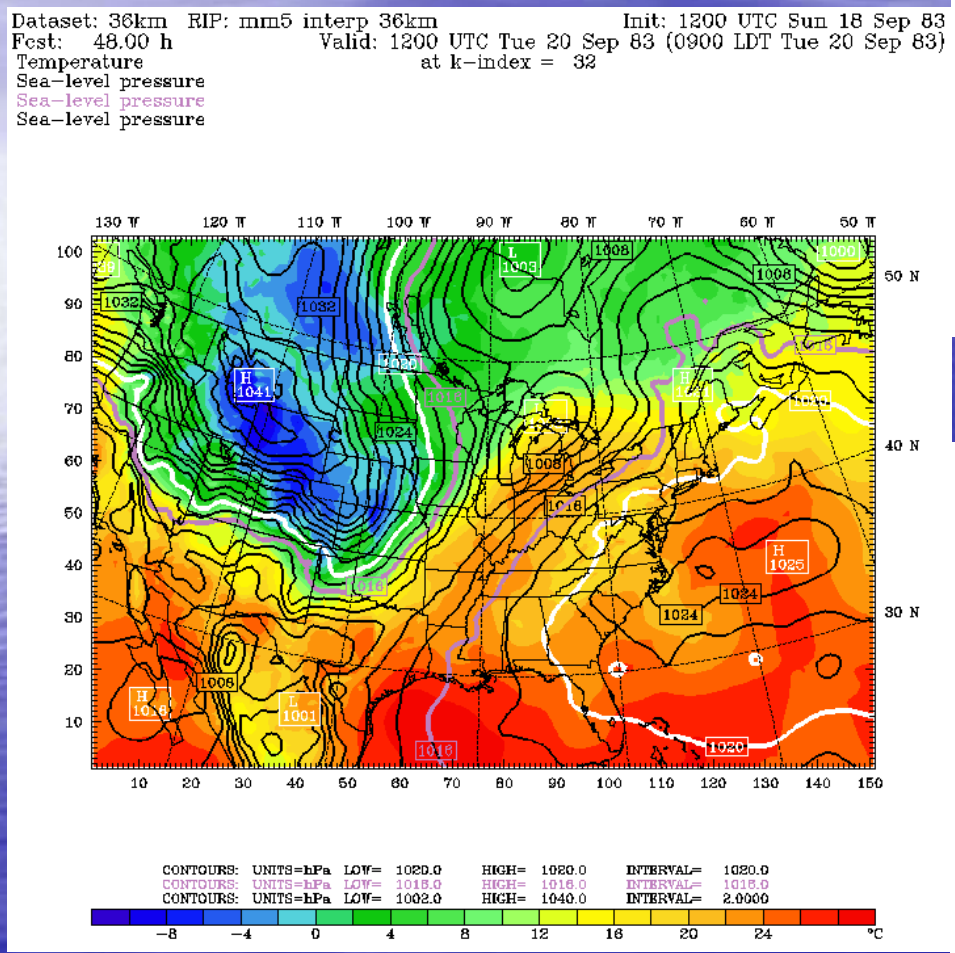

WRF NO FDDA

WRF FDDA

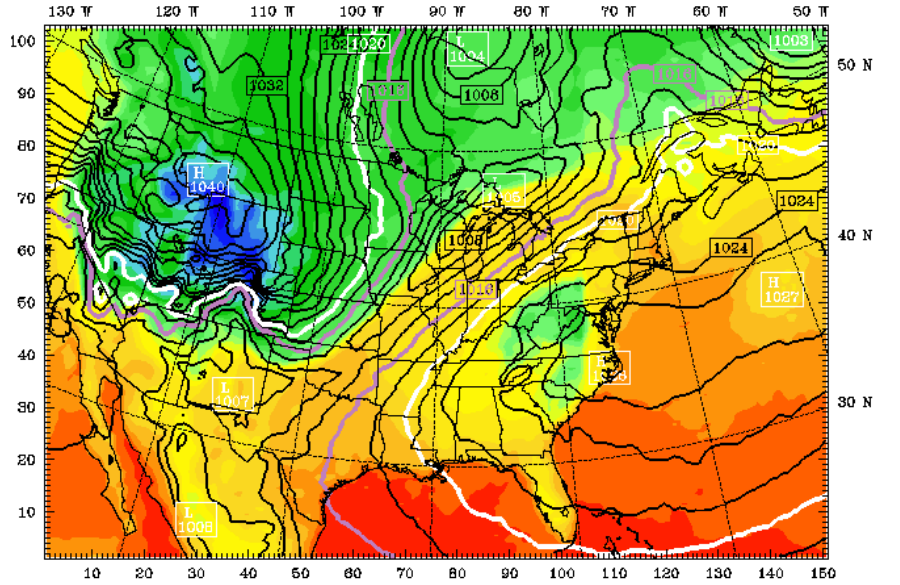
# Preliminary Results:

# 36-km grid

# Surface Temperature and Sea Level Pressure




MM5 ANALYSIS



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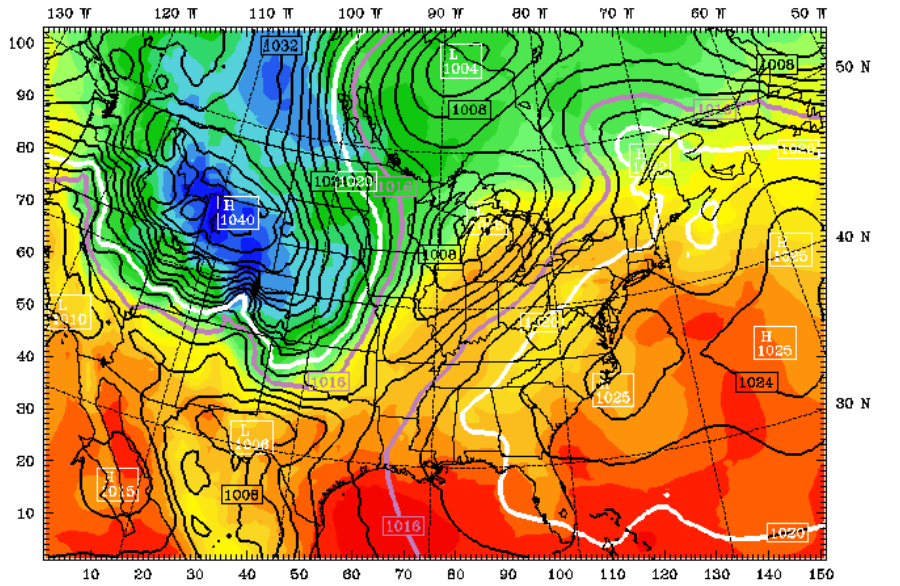
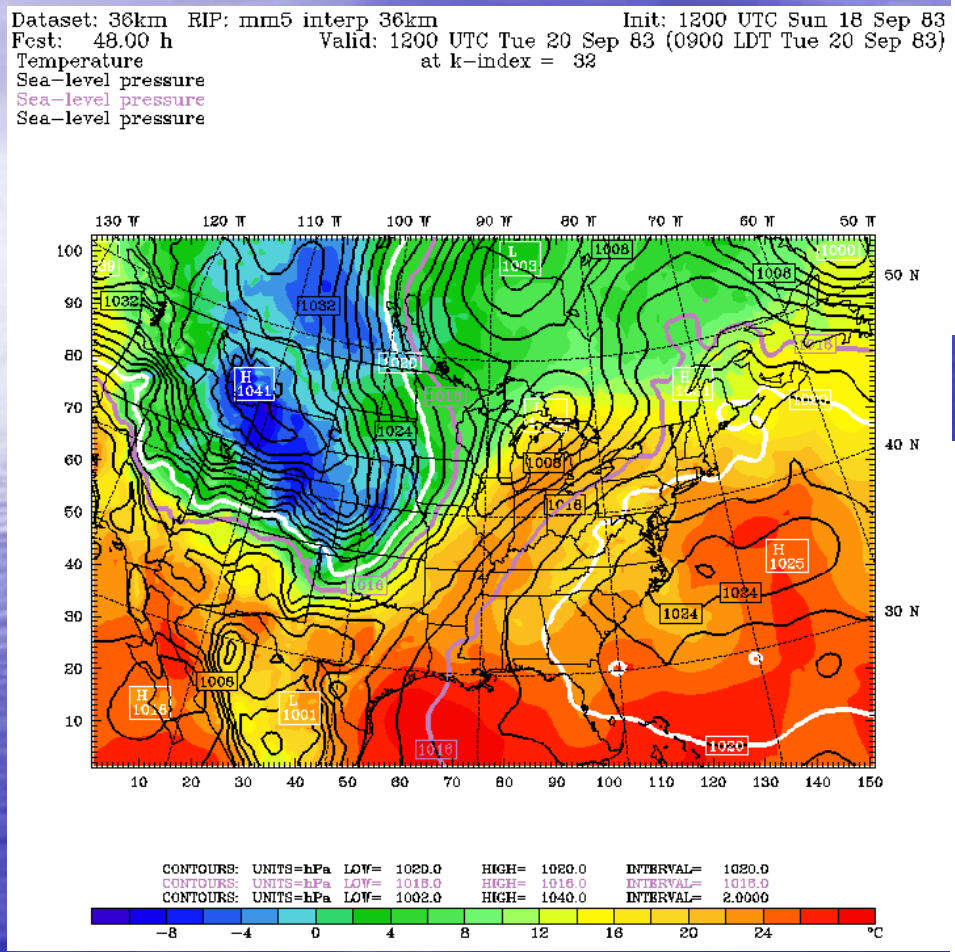
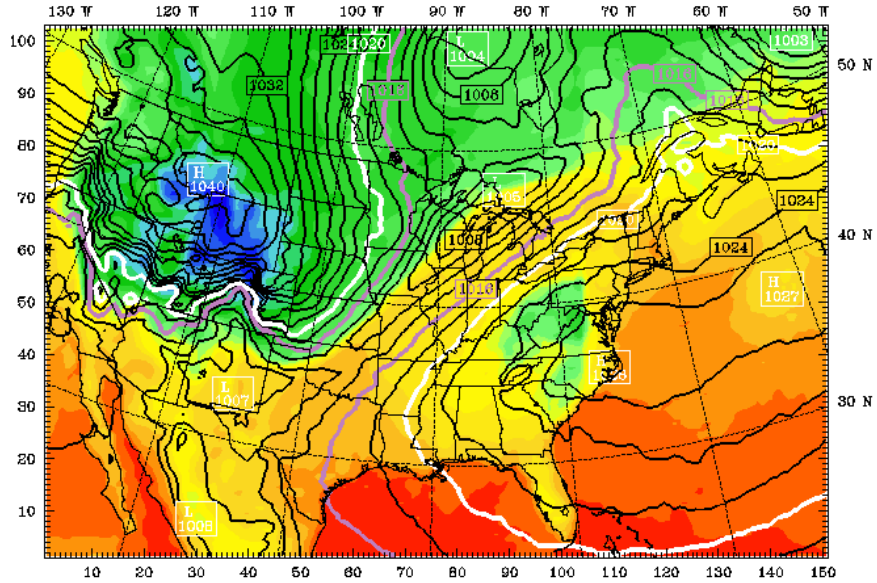


WRF FDDA

# Surface Temperature and Sea Level Pressure




MM5 ANALYSIS



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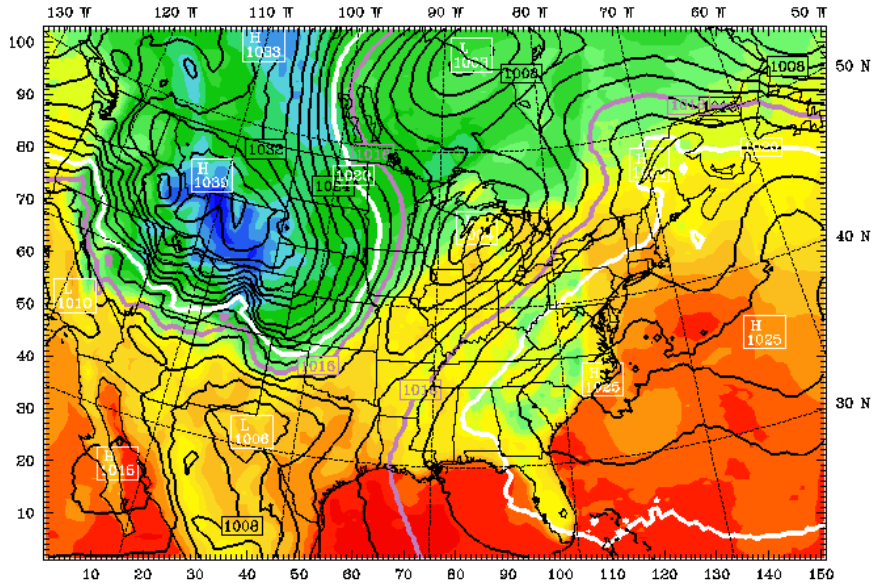
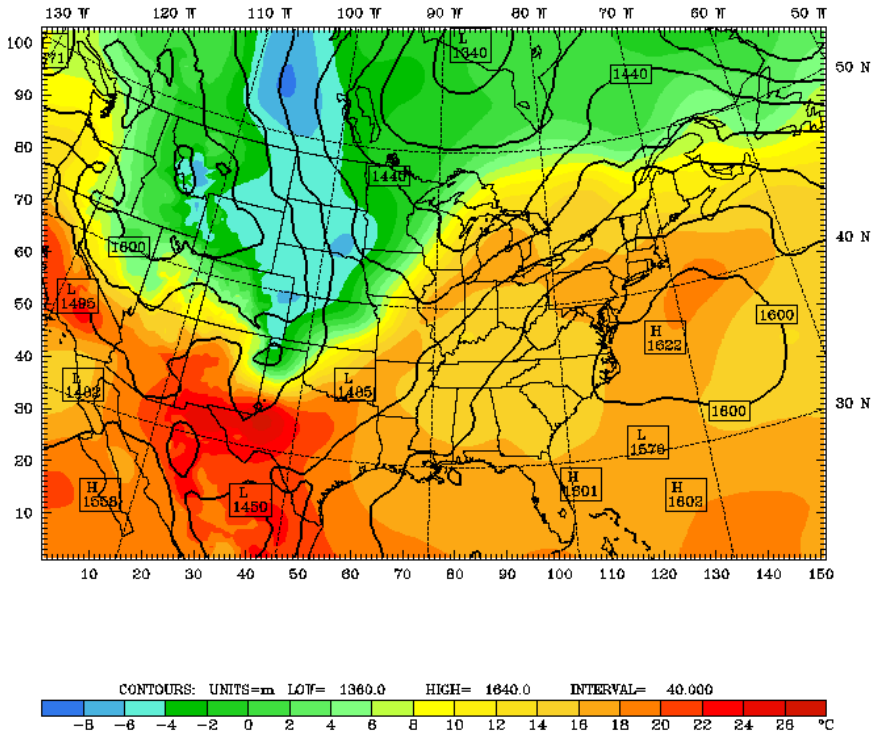


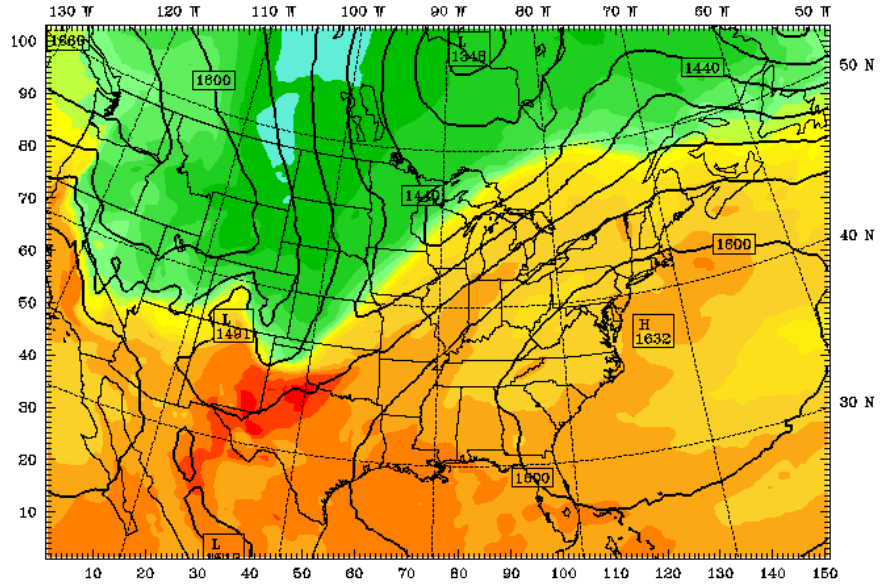
WRF FDDA above PBL

# 850 hPa Temperature and Geopotential Height

Dataset: 36km RIP: mm5 interp 36km Init: 1200 UTC Sun 18 Sep 83
Fcst: 48.00 h Valid: 1200 UTC Tue 20 Sep 83 (0900 LDT Tue 20 Sep 83)
Temperature at pressure = 850 hPa
Geopotential height at pressure = 850 hPa




MM5 ANALYSIS

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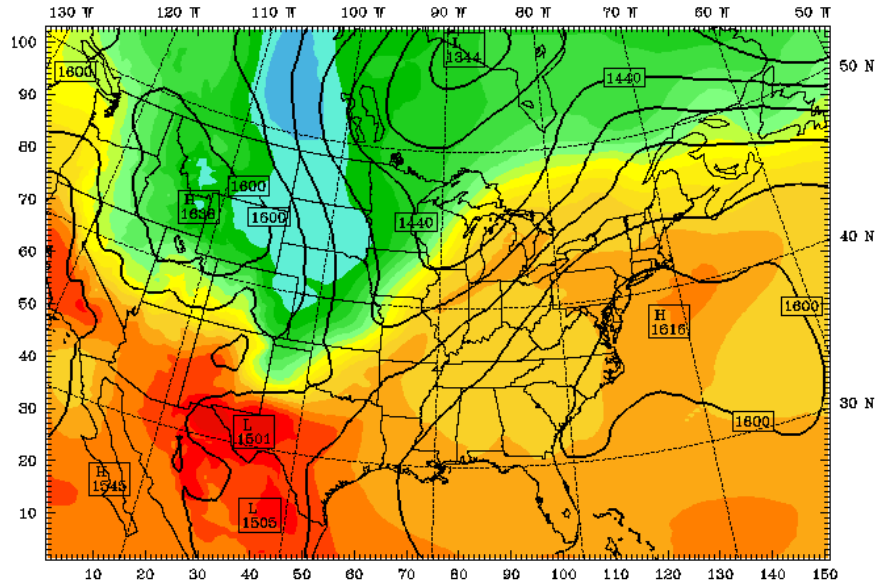
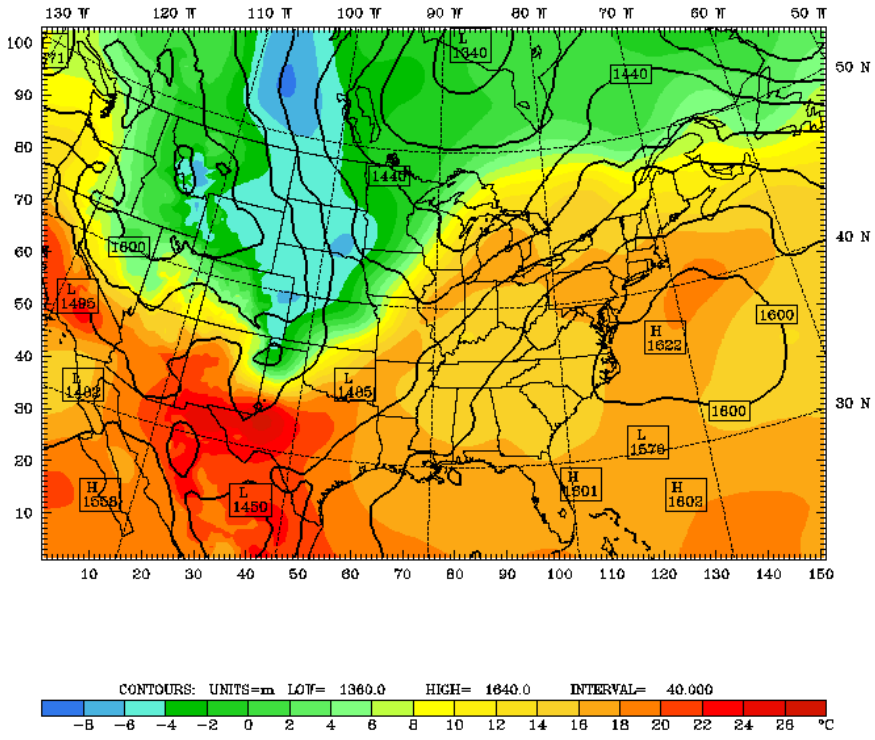


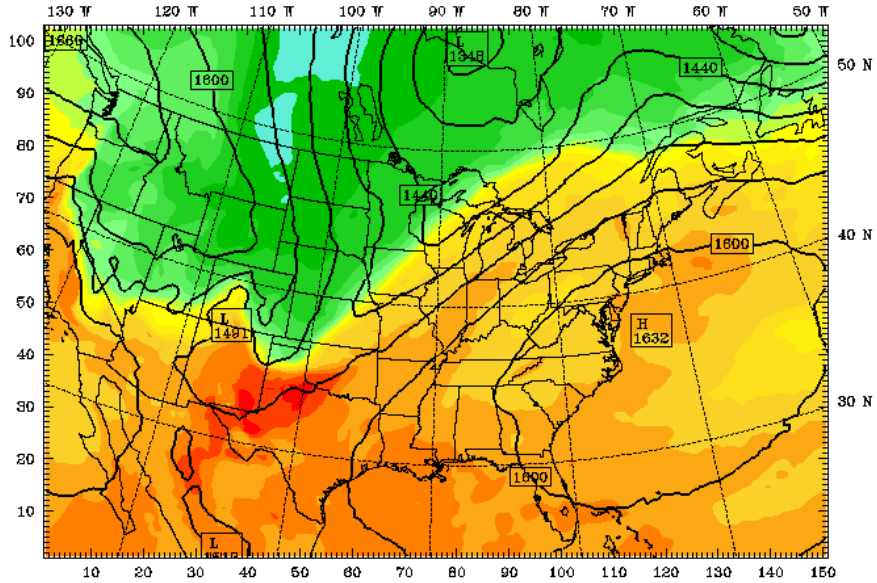

WRF FDDA

# 850 hPa Temperature and Geopotential Height

Dataset: 36km RIP: mm5 interp 36km Init: 1200 UTC Sun 18 Sep 83
Fcst: 48.00 h Valid: 1200 UTC Tue 20 Sep 83 (0900 LDT Tue 20 Sep 83)
Temperature at pressure = 850 hPa
Geopotential height at pressure = 850 hPa




MM5 ANALYSIS



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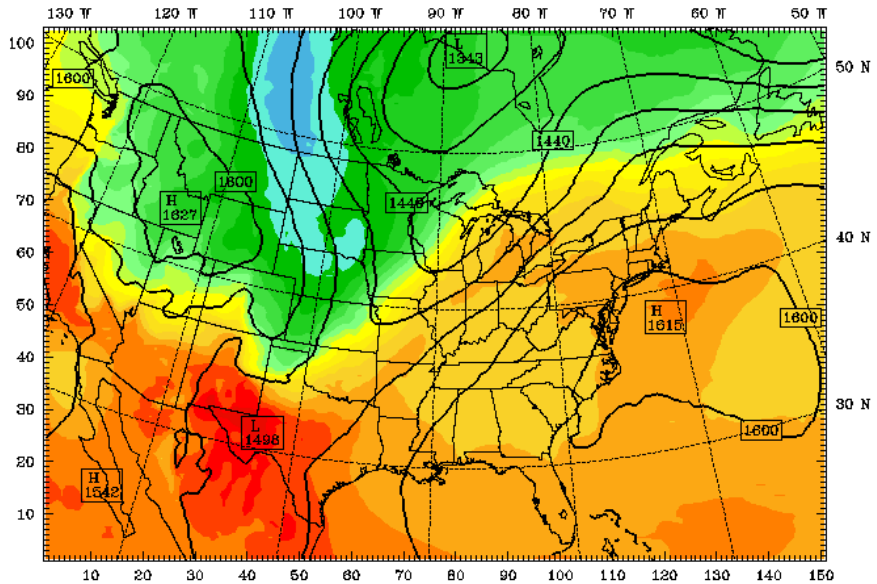
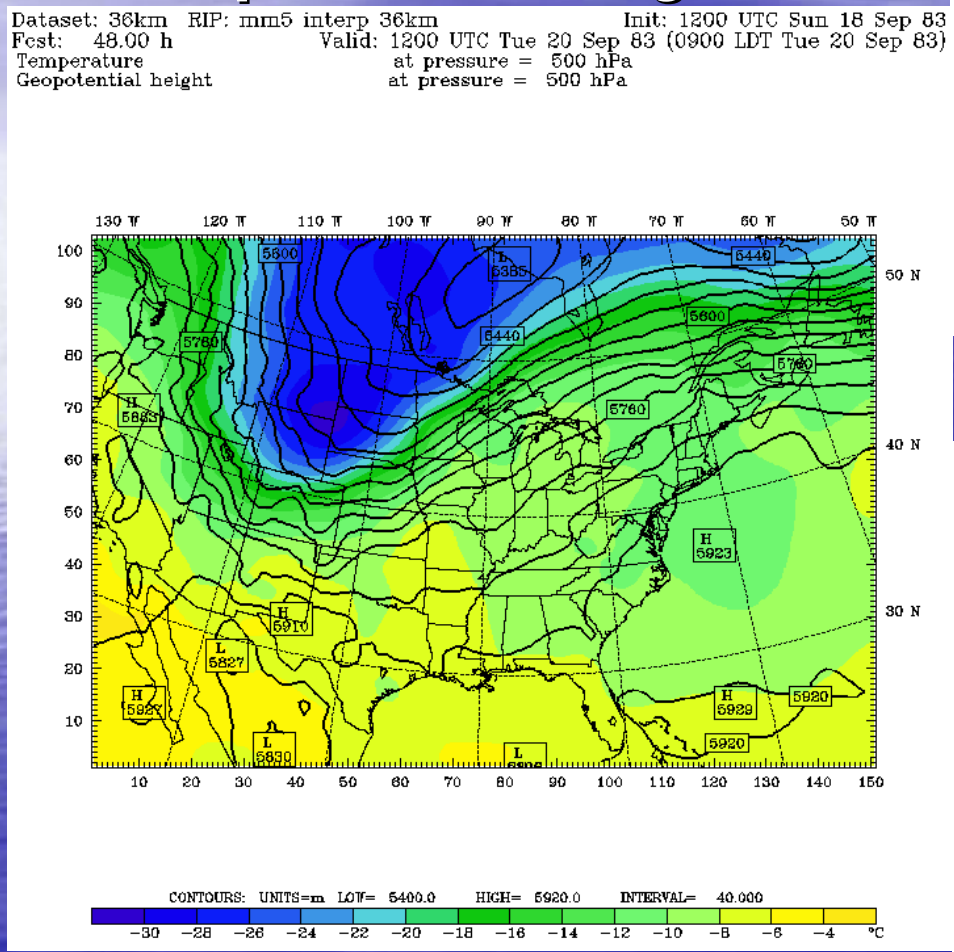
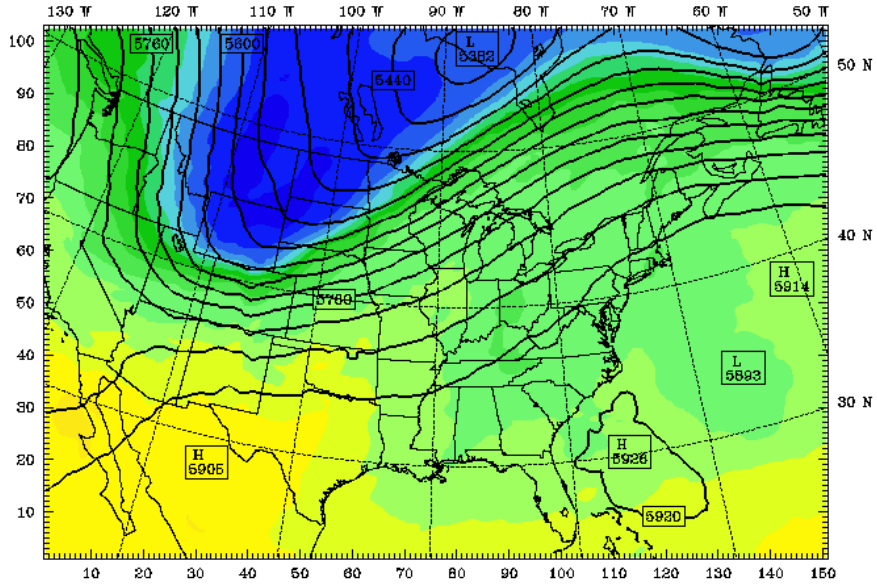


WRF FDDA above PBL

# 500 hPa Temperature and Geopotential Height




MM5 ANALYSIS



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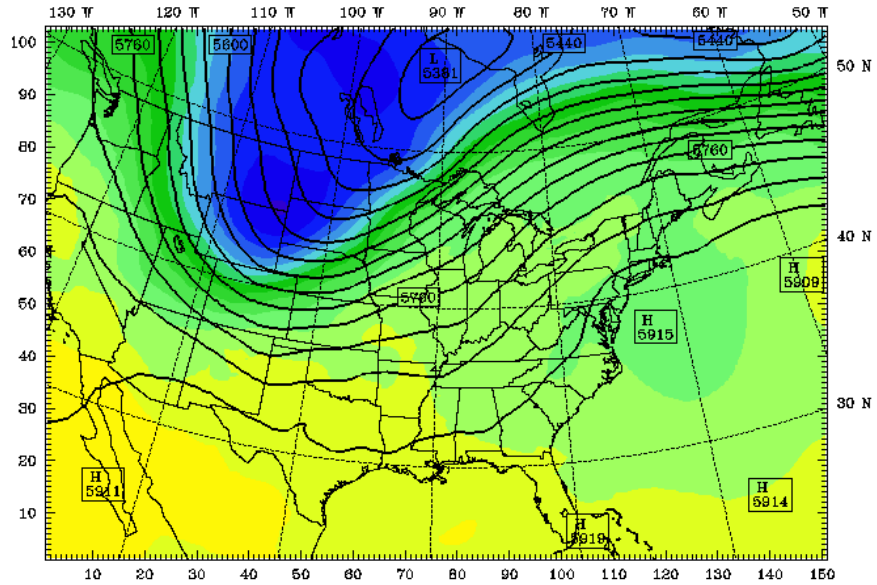
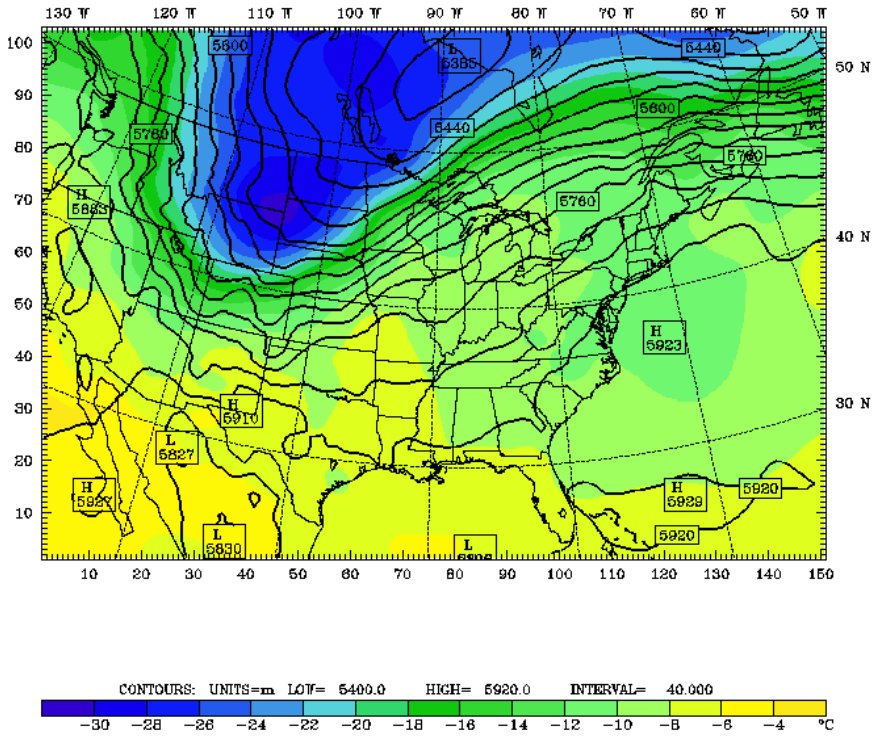


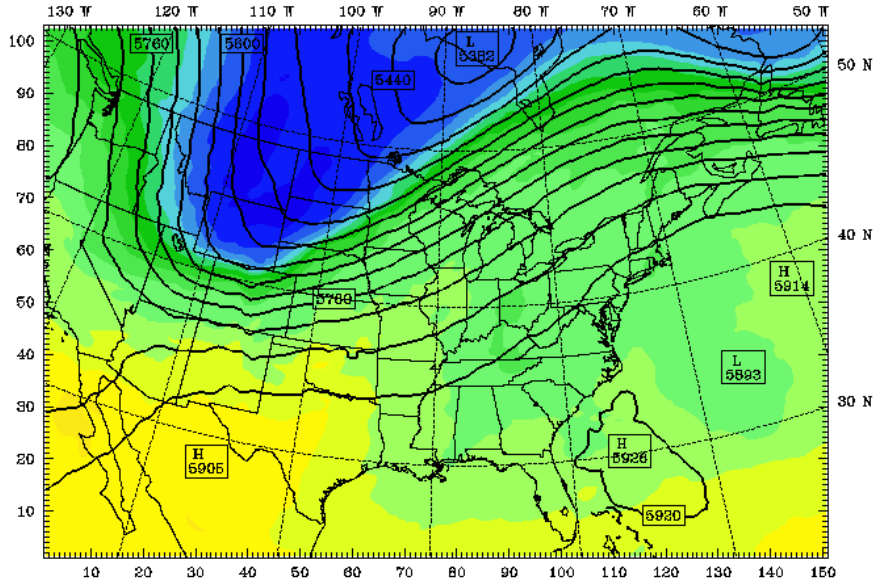
WRF FDDA

# 500 hPa Temperature and Geopotential Height

Dataset: 36km RIP: mm5 interp 36km Init: 1200 UTC Sun 18 Sep 83
Fcst: 48.00 h Valid: 1200 UTC Tue 20 Sep 83 (0900 LDT Tue 20 Sep 83)
Temperature at pressure = 500 hPa
Geopotential height at pressure = 500 hPa




MM5 ANALYSIS

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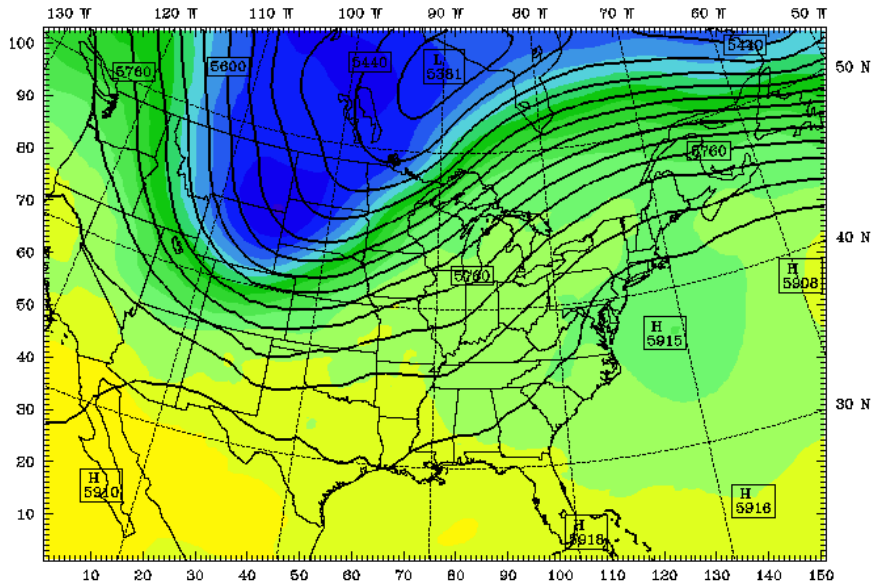
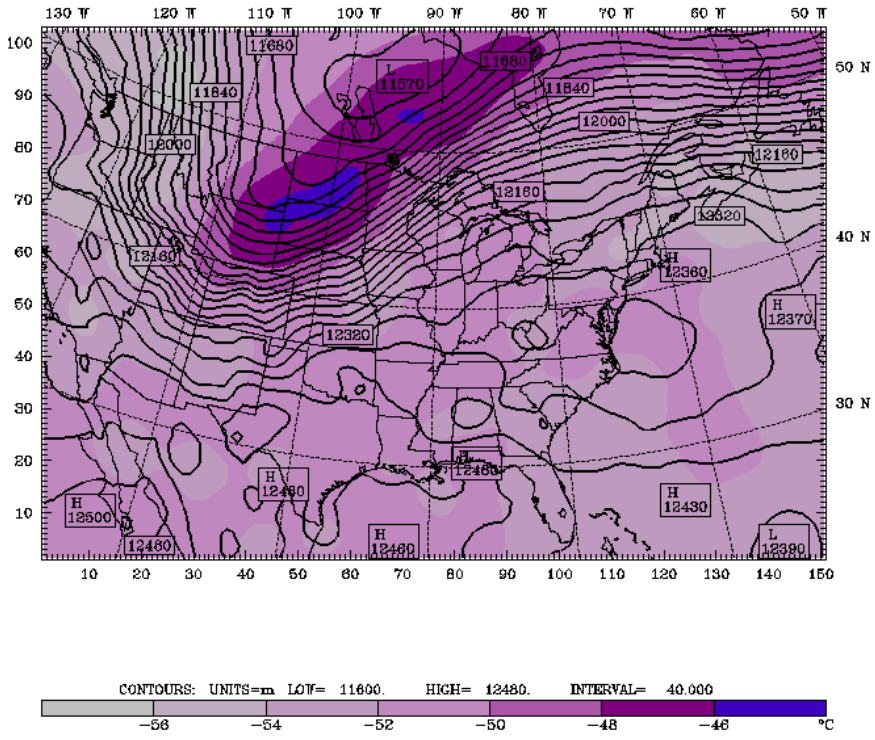


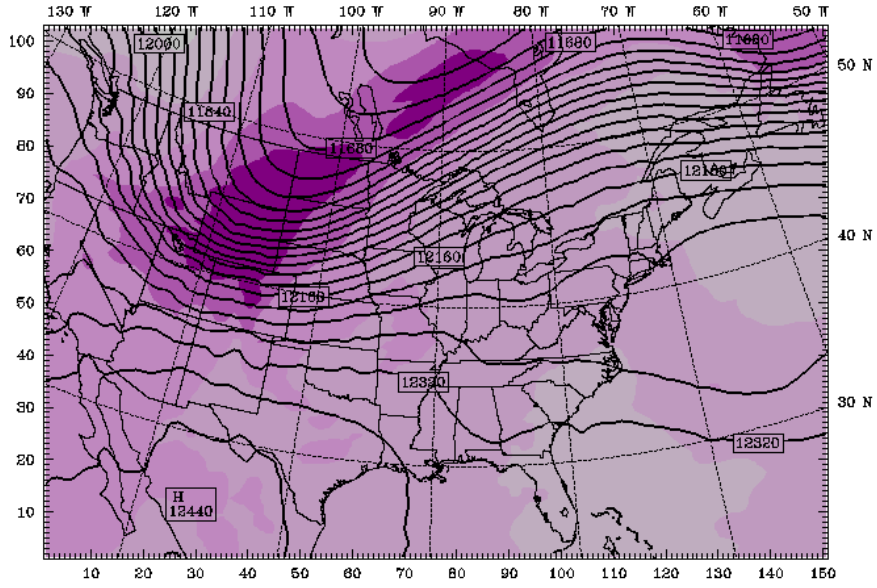

WRF FDDA above PBL

# 200 hPa Temperature and Geopotential Height

Dataset: 36km RIP: mm5 interp 36km Init: 1200 UTC Sun 18 Sep 83
Fcst: 48.00 h Valid: 1200 UTC Tue 20 Sep 83 (0900 LDT Tue 20 Sep 83)
Temperature at pressure = 200 hPa
Geopotential height at pressure = 200 hPa




MM5 ANALYSIS



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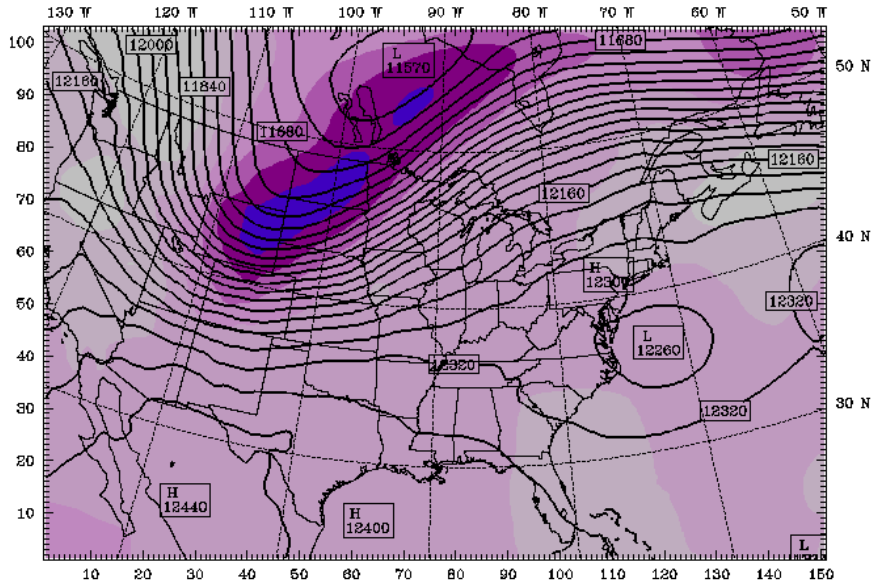
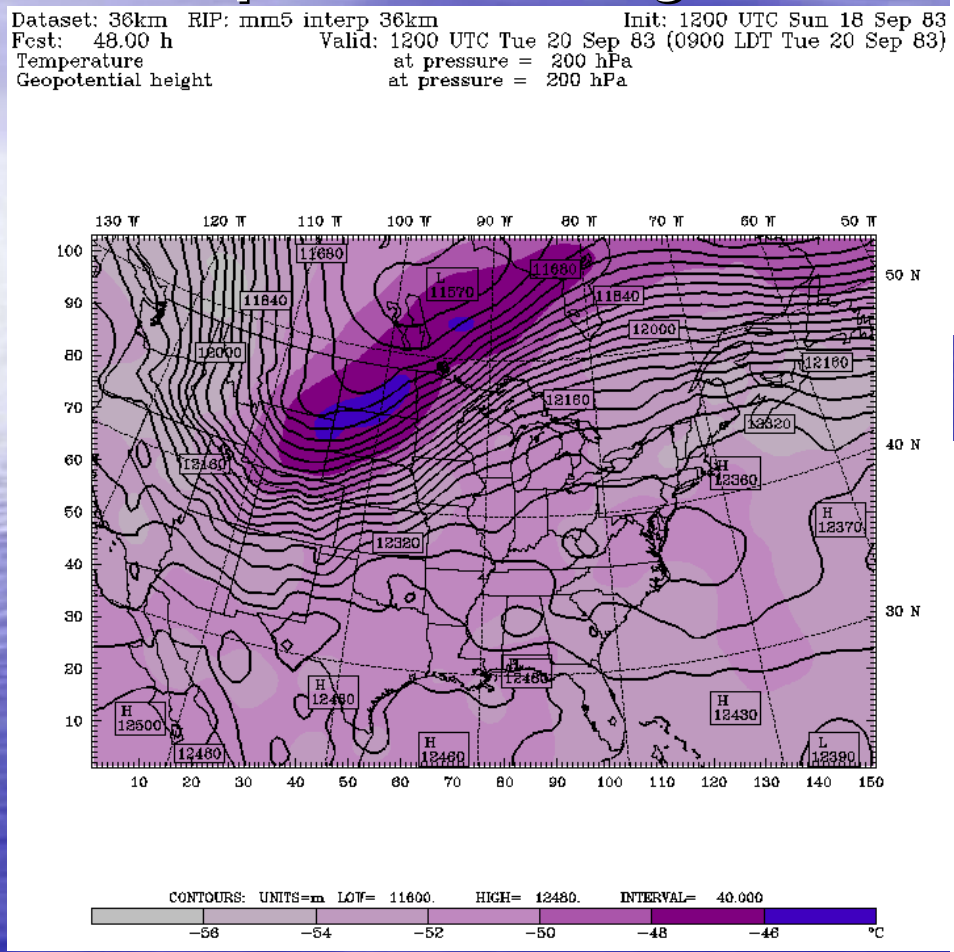
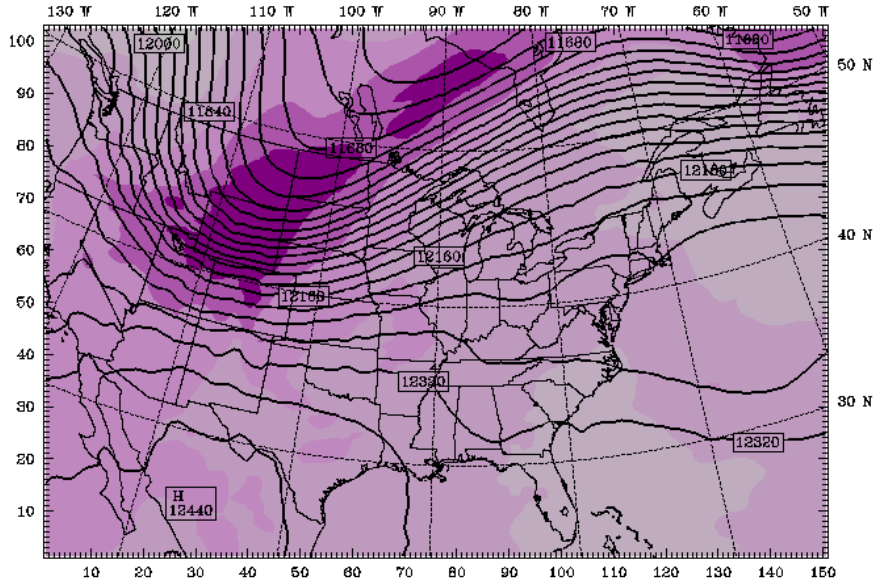


WRF FDDA

# 200 hPa Temperature and Geopotential Height




MM5 ANALYSIS



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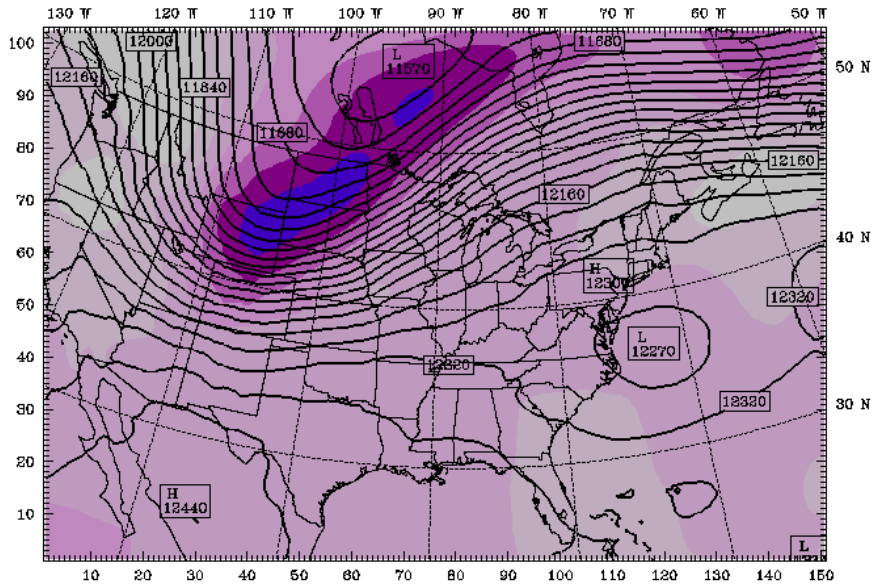
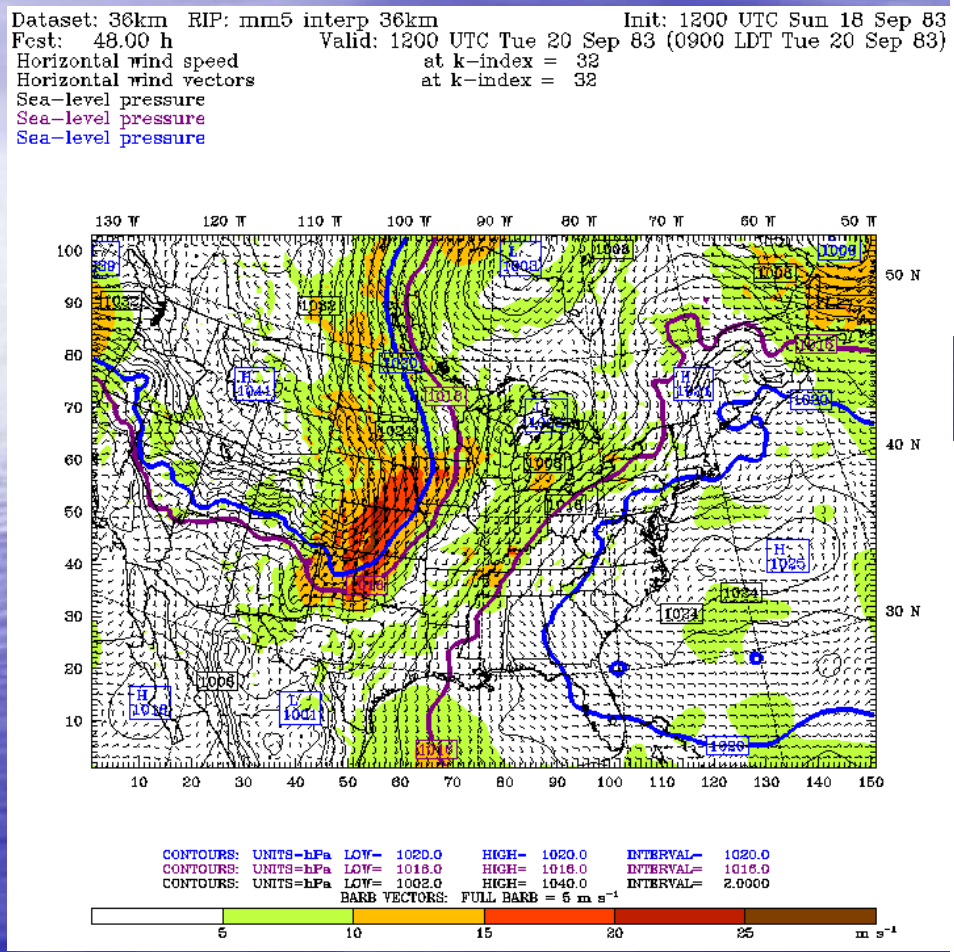
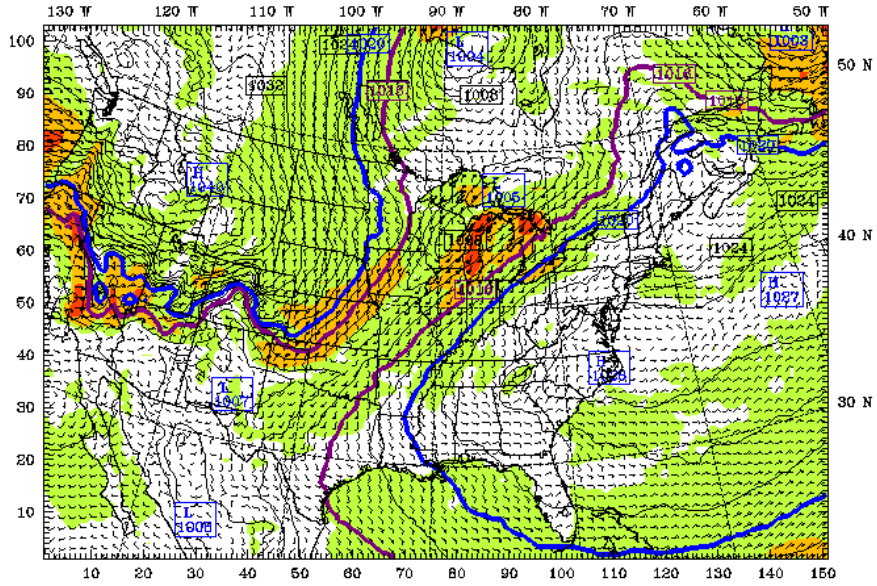


WRF FDDA above PBL

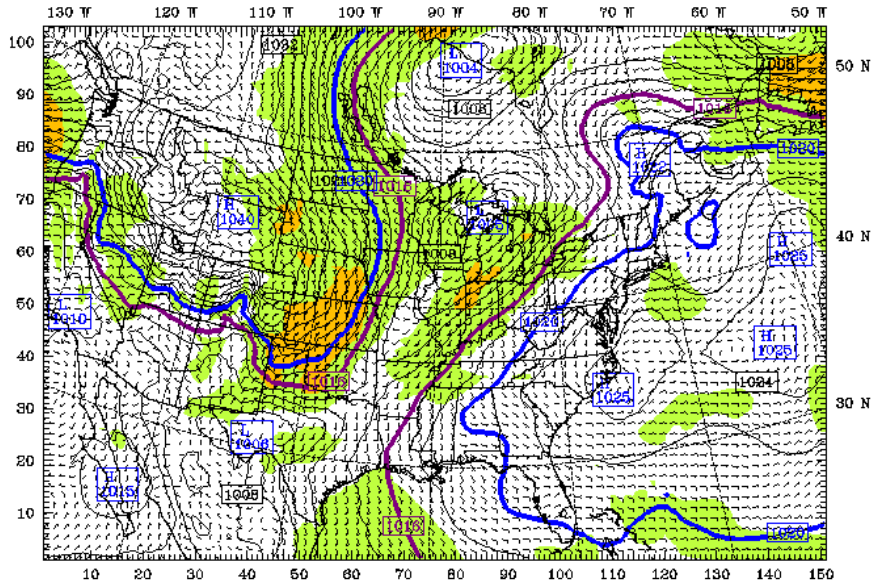
# Surface Winds and Sea Level Pressure




MM5 ANALYSIS

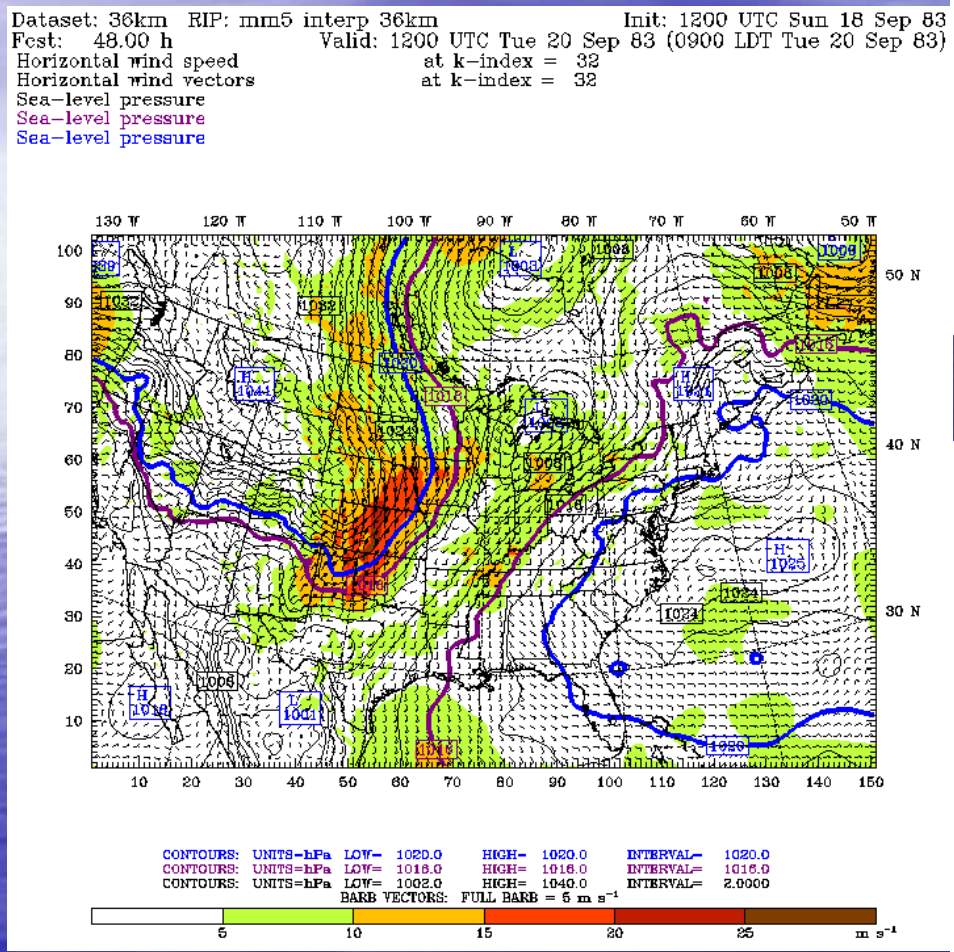


WRF NO FDDA

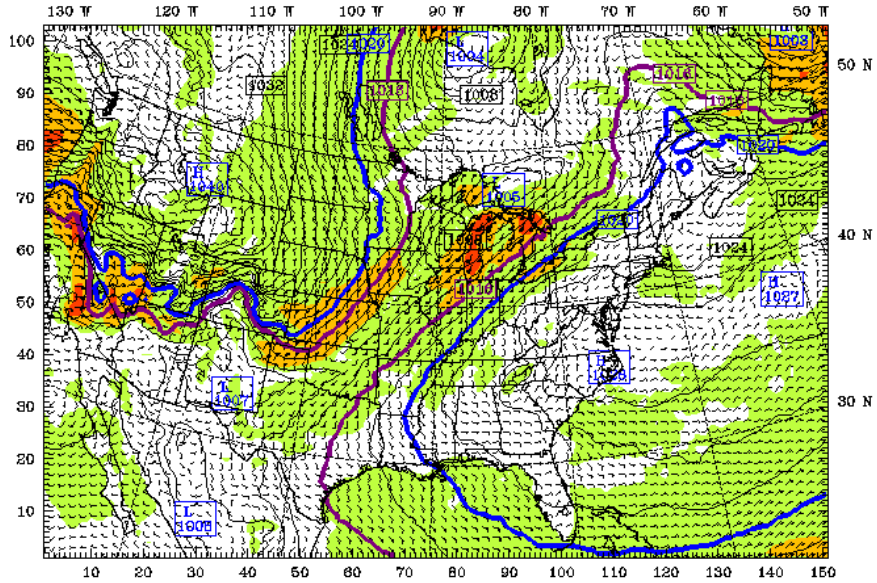


WRF FDDA

# Surface Winds and Sea Level Pressure




MM5
ANALYSIS



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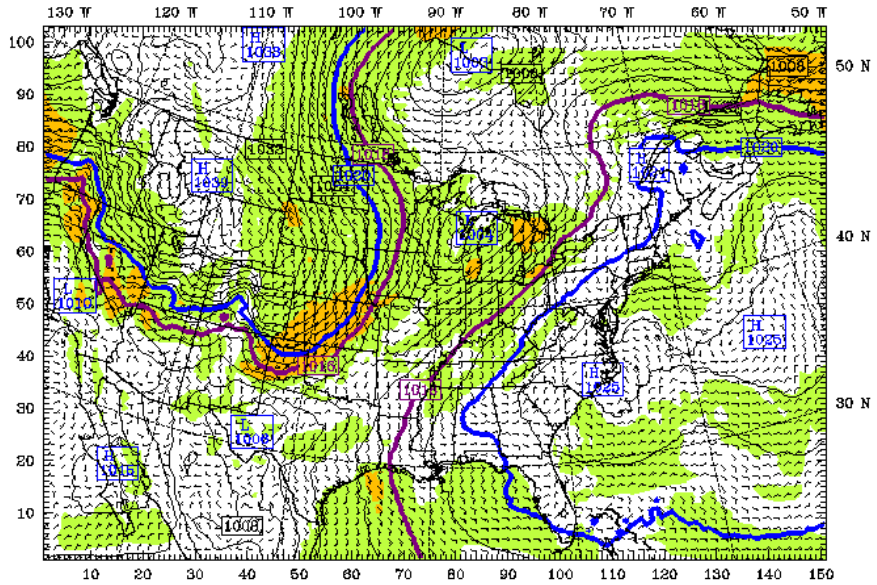
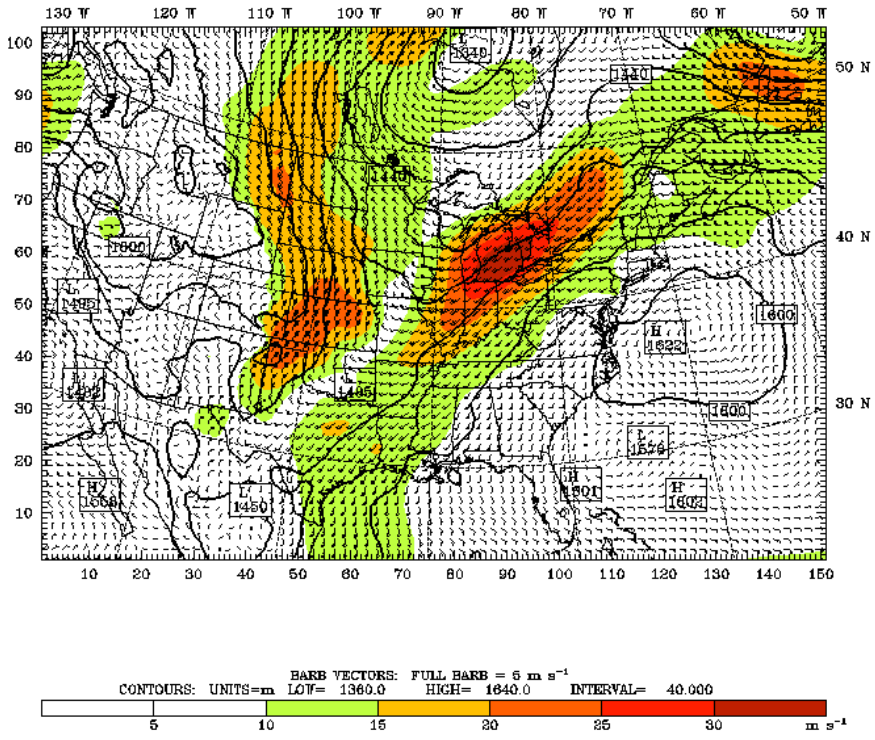


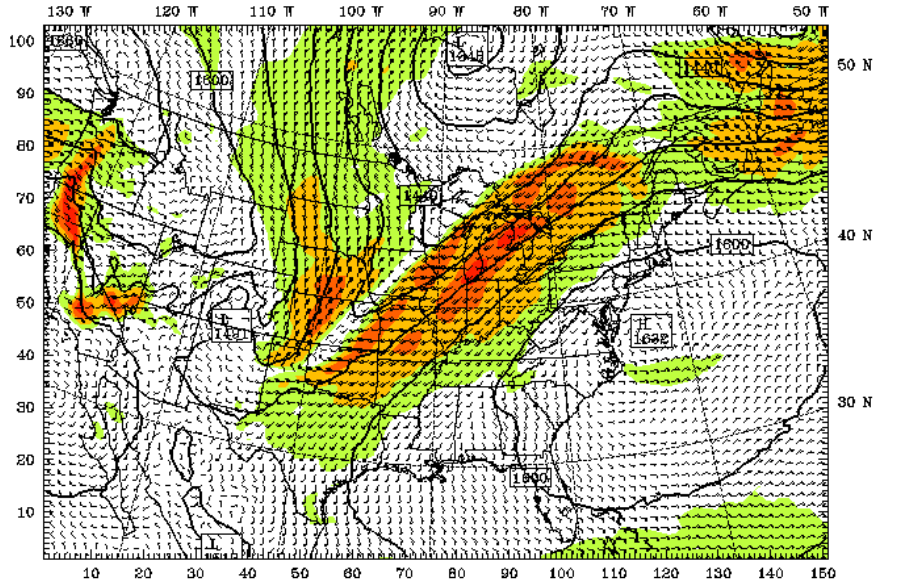
WRF FDDA above PBL

# 850 hPa Winds and Geopotential Height

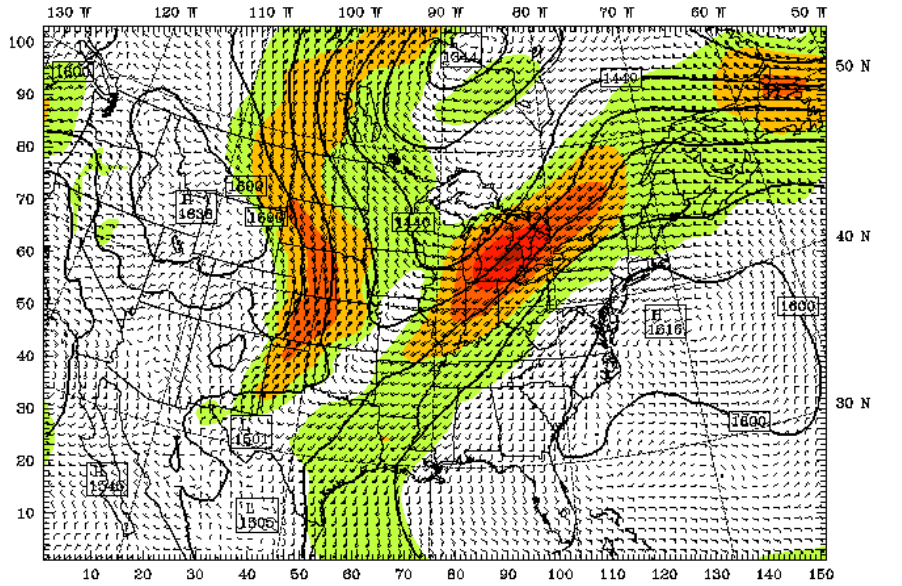
Dataset: 36km RIP: mm5 interp 36km Init: 1200 UTC Sun 18 Sep 83
Fcst: 48.00 h Valid: 1200 UTC Tue 20 Sep 83 (0900 LDT Tue 20 Sep 83)
Horizontal wind speed at pressure = 850 hPa
Geopotential height at pressure = 850 hPa
Horizontal wind vectors at pressure = 850 hPa




MM5 ANALYSIS

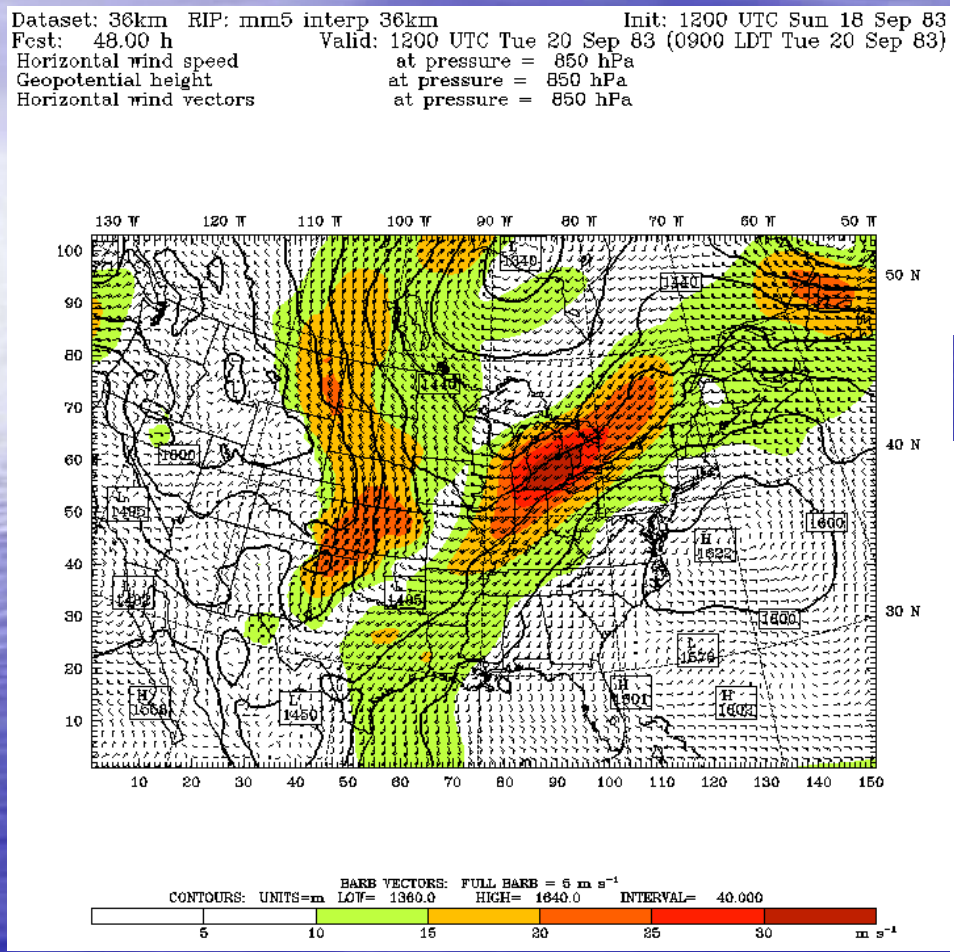



WRF NO FDDA

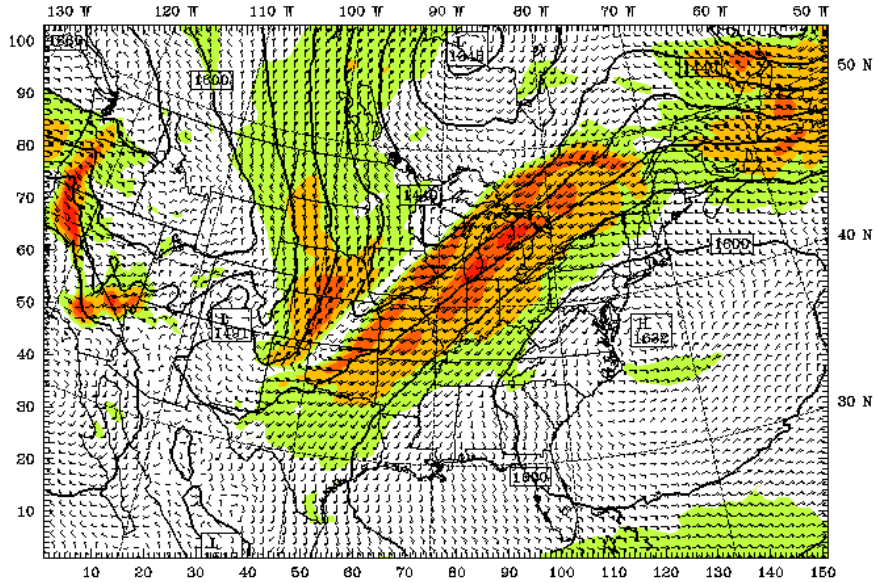



WRF FDDA

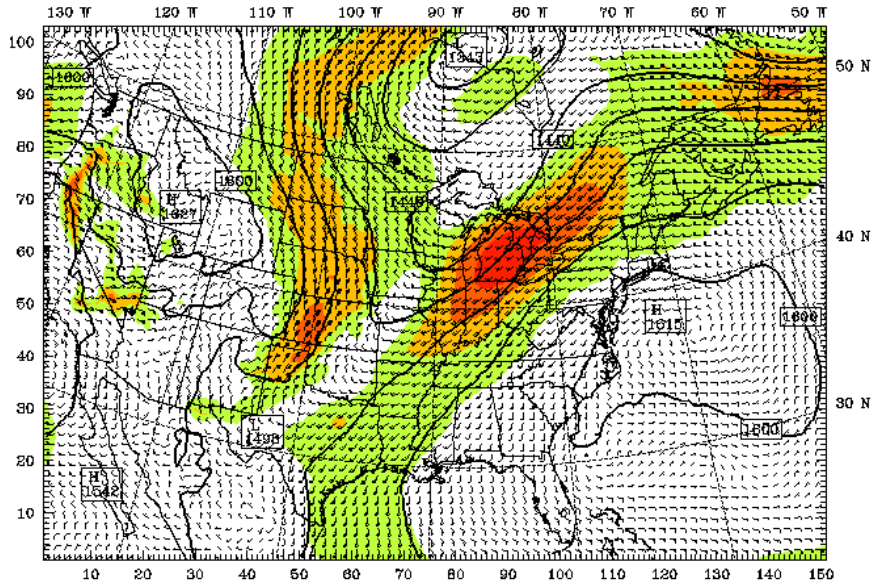
# 850 hPa Winds and Geopotential Height




MM5
ANALYSIS



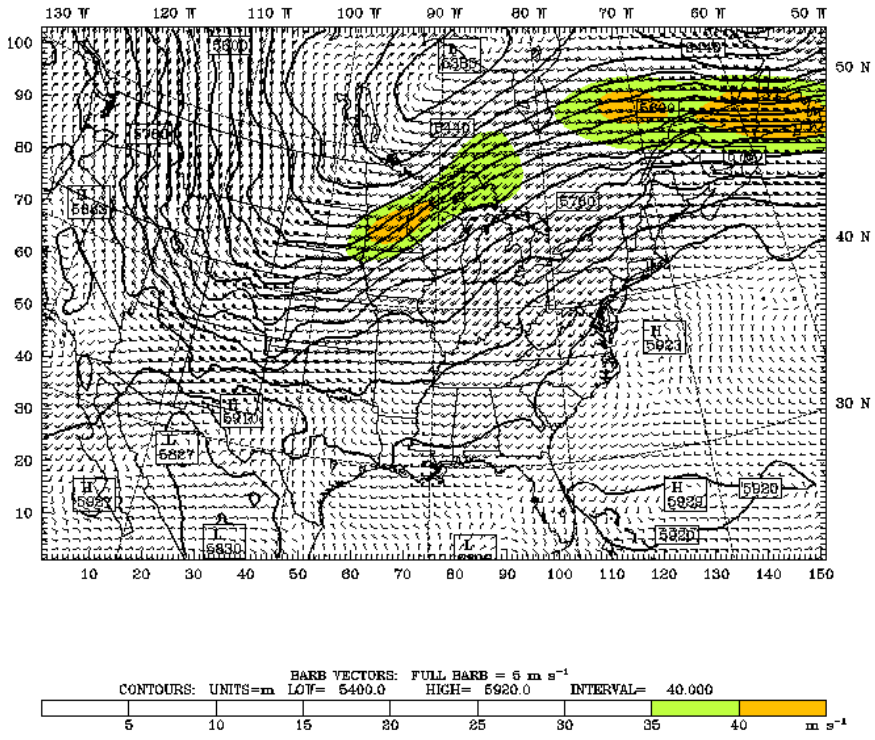
WRF NO FDDA



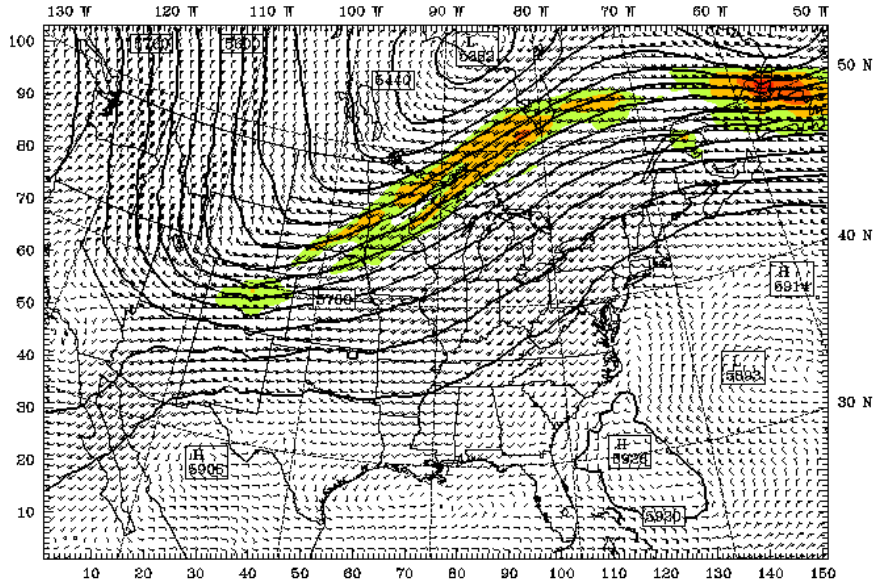
WRF FDDA above PBL

# 500 hPa Winds and Geopotential Height

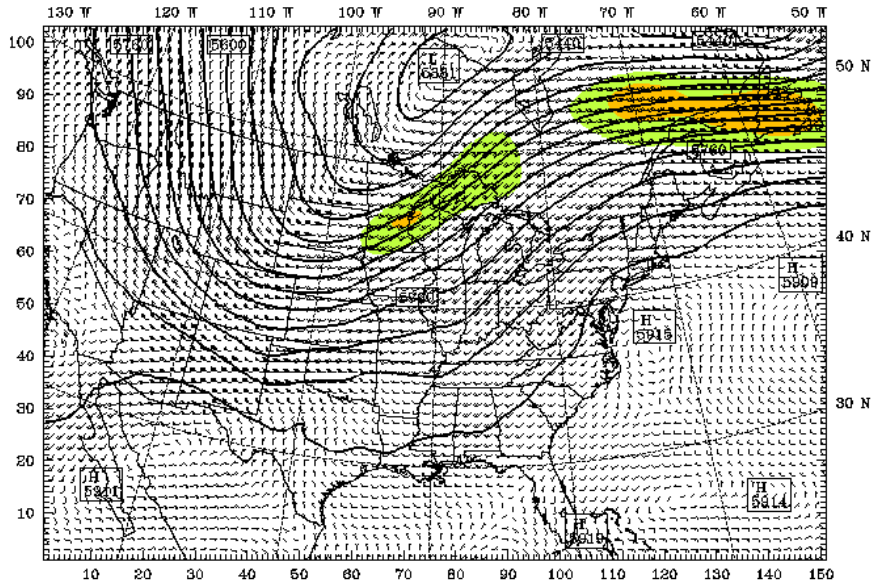
Dataset: 36km RIP: mm5 interp 36km Init: 1200 UTC Sun 18 Sep 83
Fcst: 48.00 h Valid: 1200 UTC Tue 20 Sep 83 (0900 LDT Tue 20 Sep 83)
Horizontal wind speed at pressure = 500 hPa
Geopotential height at pressure = 500 hPa
Horizontal wind vectors at pressure = 500 hPa




MM5 ANALYSIS



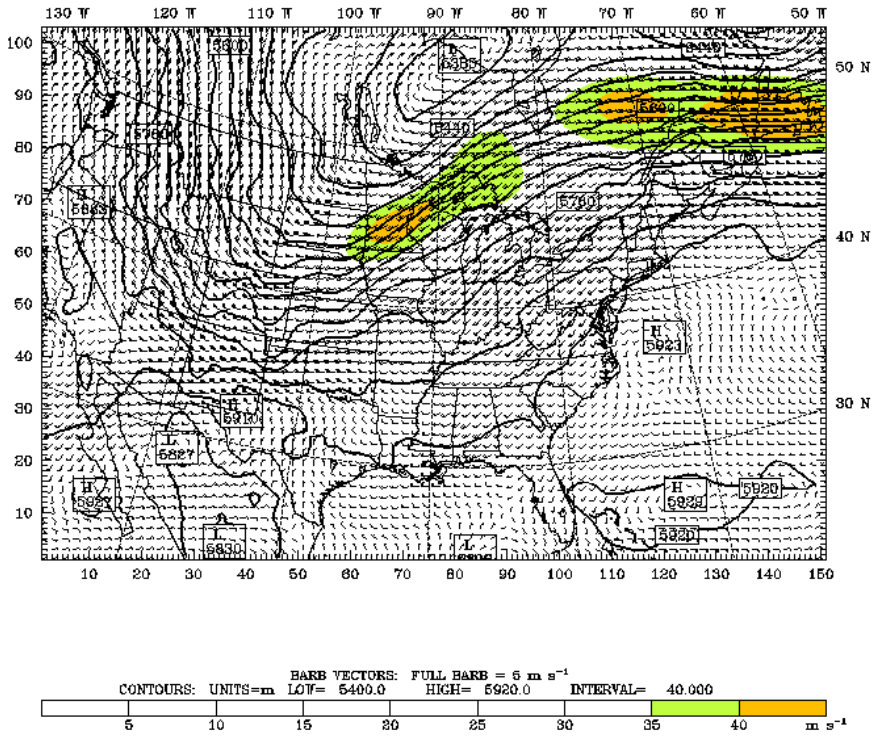

WRF NO FDDA



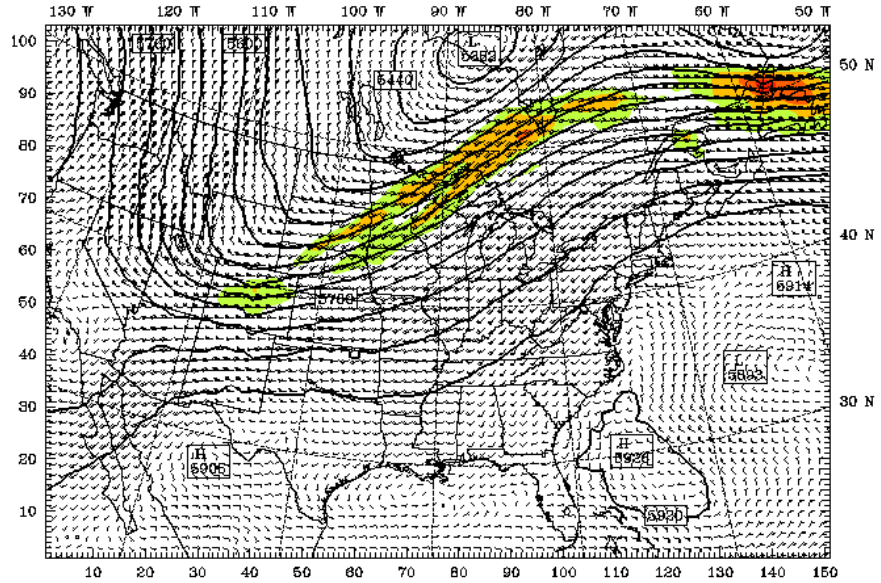

WRF FDDA

# 500 hPa Winds and Geopotential Height

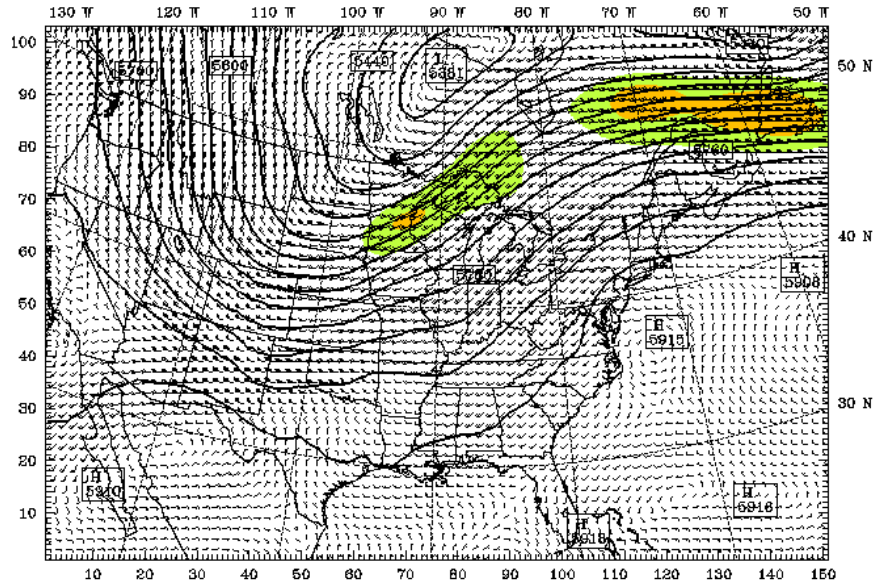
Dataset: 36km RIP: mm5 interp 36km Init: 1200 UTC Sun 18 Sep 83
Fcst: 48.00 h Valid: 1200 UTC Tue 20 Sep 83 (0900 LDT Tue 20 Sep 83)
Horizontal wind speed at pressure = 500 hPa
Geopotential height at pressure = 500 hPa
Horizontal wind vectors at pressure = 500 hPa




MM5
ANALYSIS



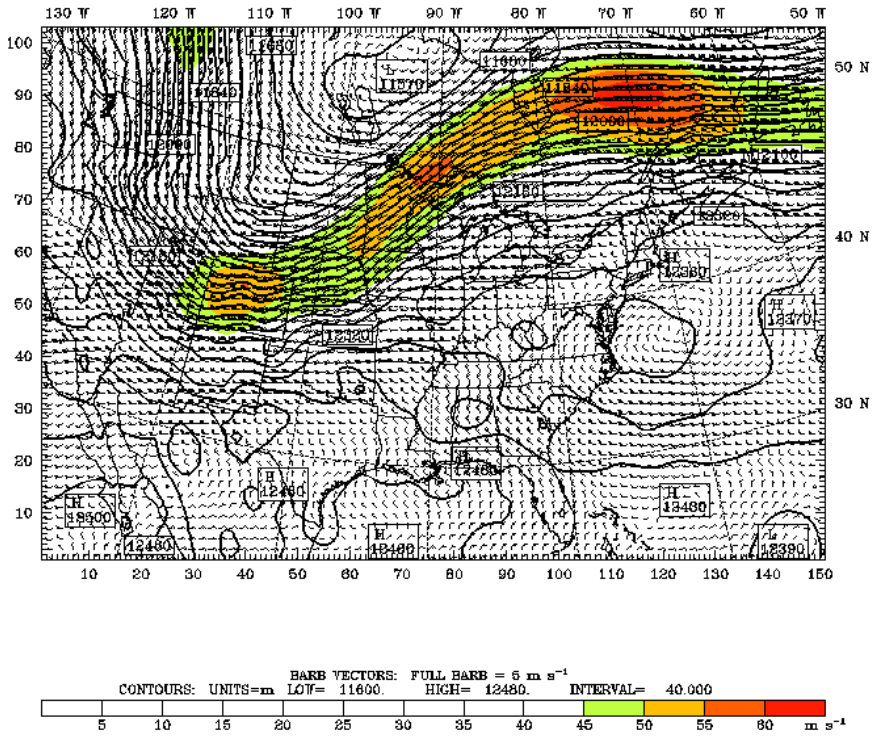

WRF NO FDDA



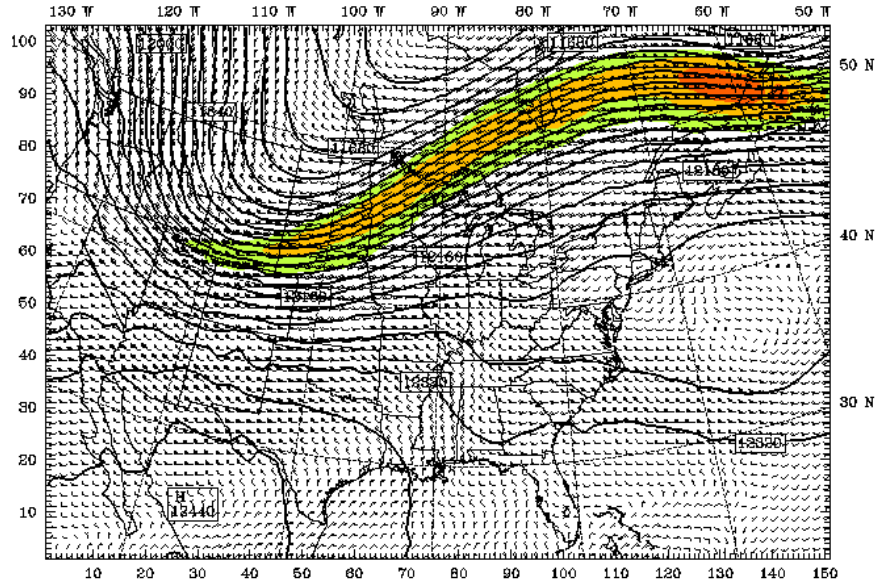

WRF FDDA above PBL

# 200 hPa Winds and Geopotential Height

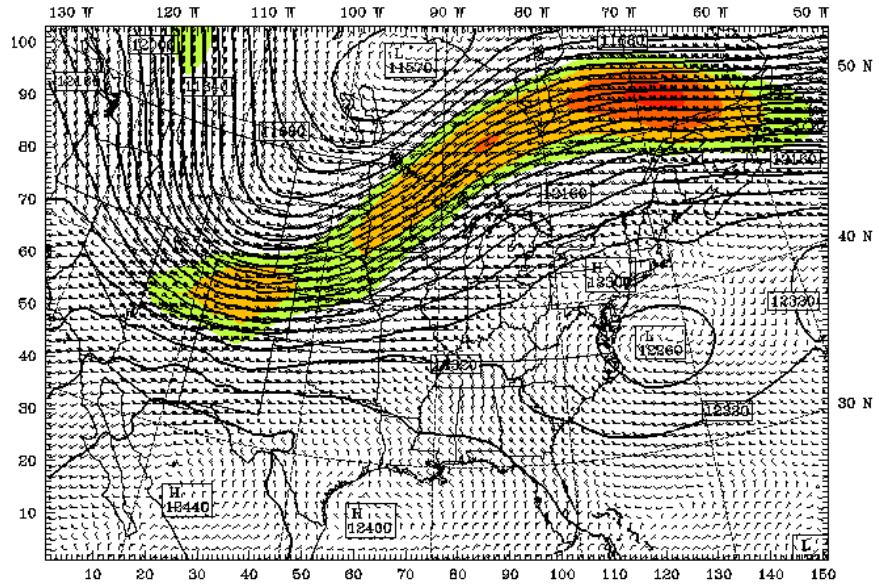
Dataset: 36km RIP: mm5 interp 36km Init: 1200 UTC Sun 18 Sep 83
Fcst: 48.00 h Valid: 1200 UTC Tue 20 Sep 83 (0900 LDT Tue 20 Sep 83)
Horizontal wind speed at pressure = 200 hPa
Geopotential height at pressure = 200 hPa
Horizontal wind vectors at pressure = 200 hPa




MM5 ANALYSIS




WRF NO FDDA




WRF FDDA

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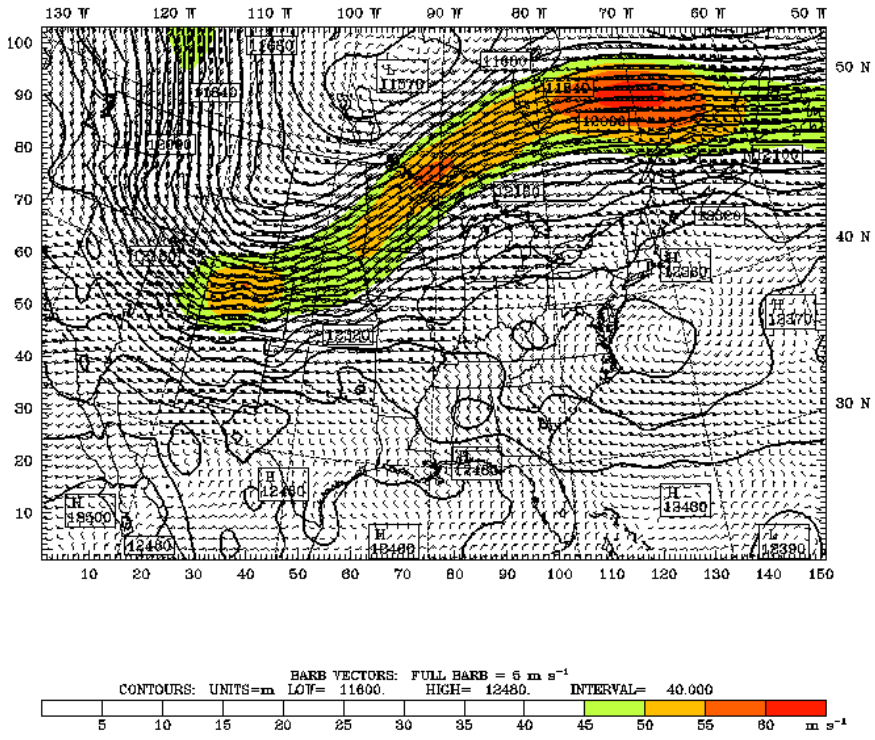
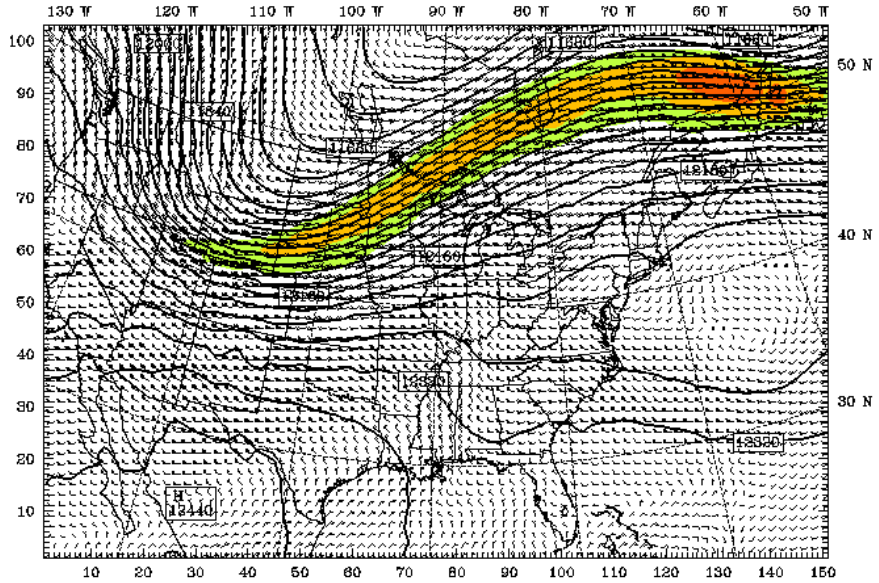
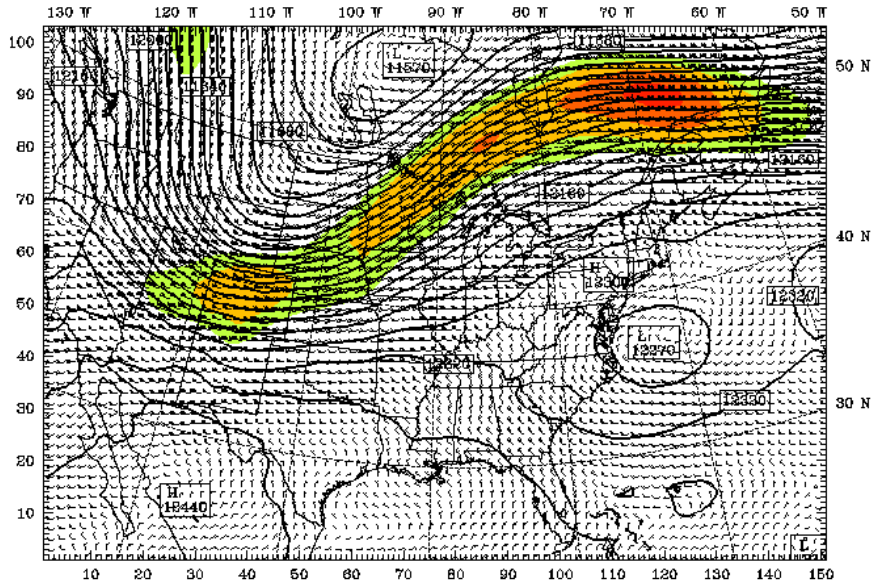



MM5
ANALYSIS

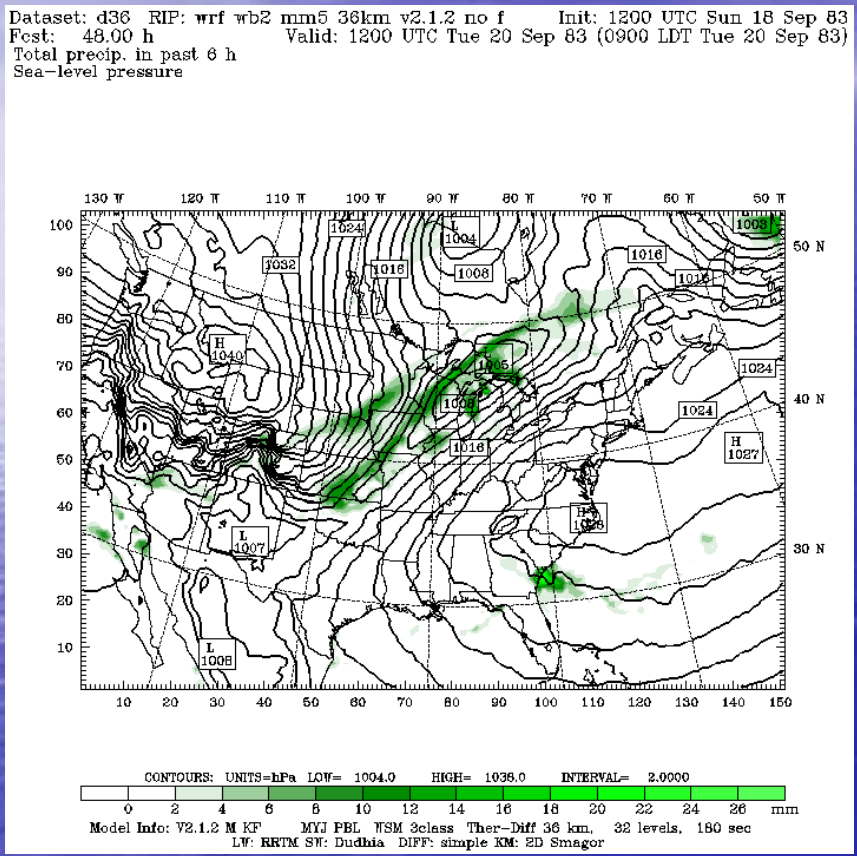


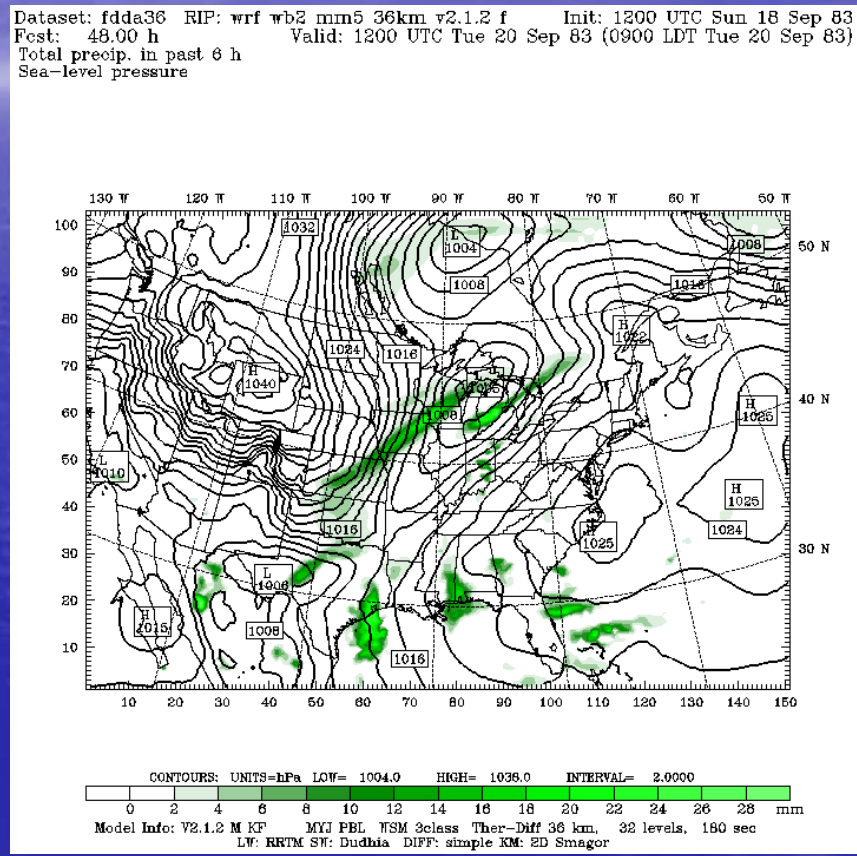

WRF NO FDDA




WRF FDDA above PBL

# Precipitation and Sea Level Pressure

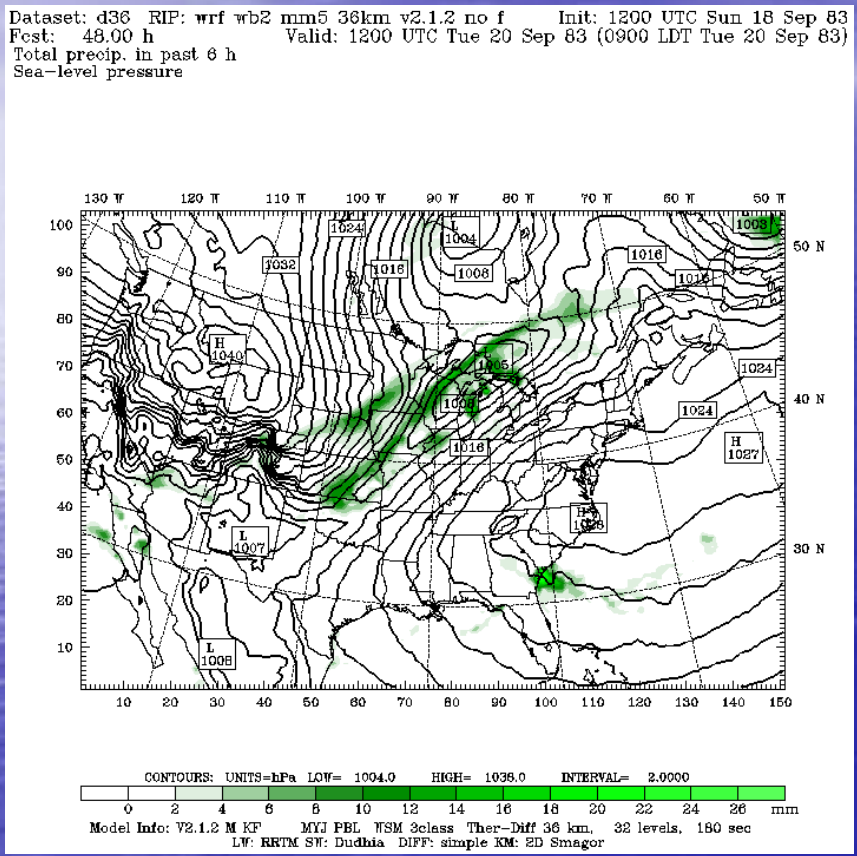


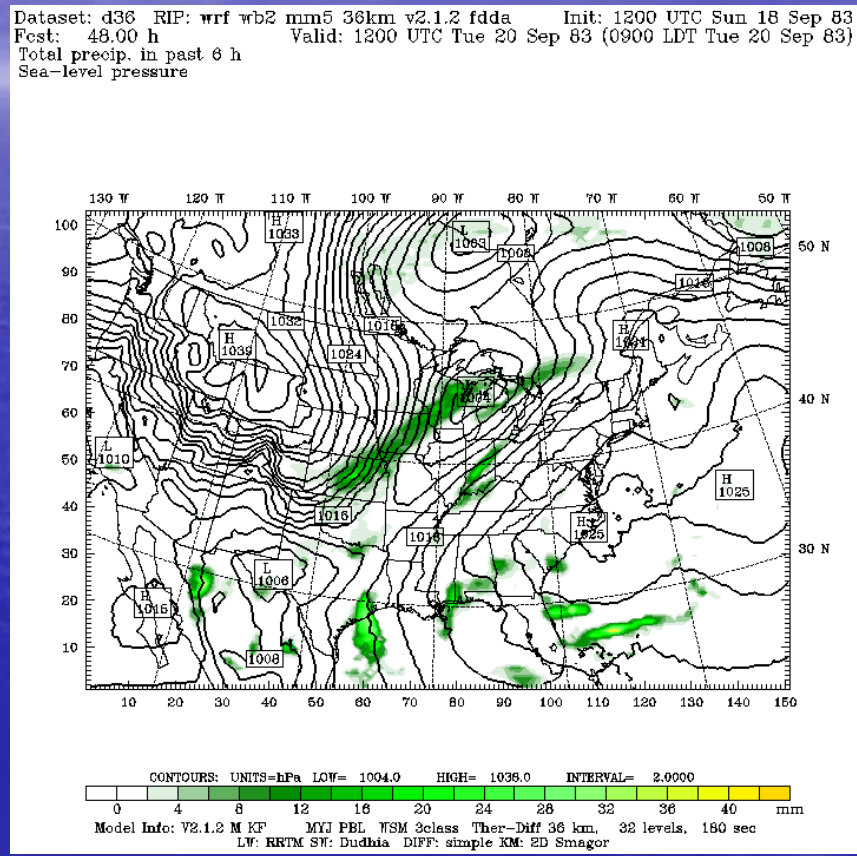




WRF NO FDDA

WRF FDDA

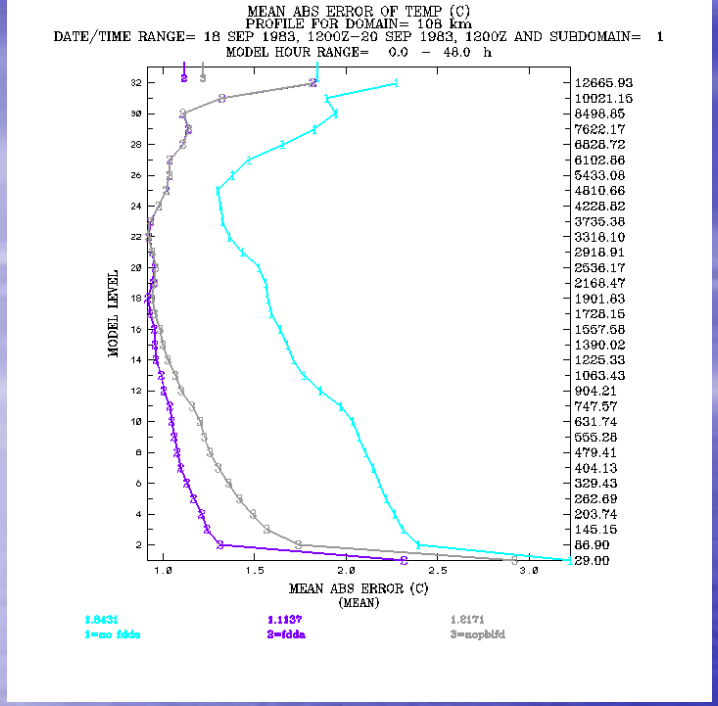
# Precipitation and Sea Level Pressure

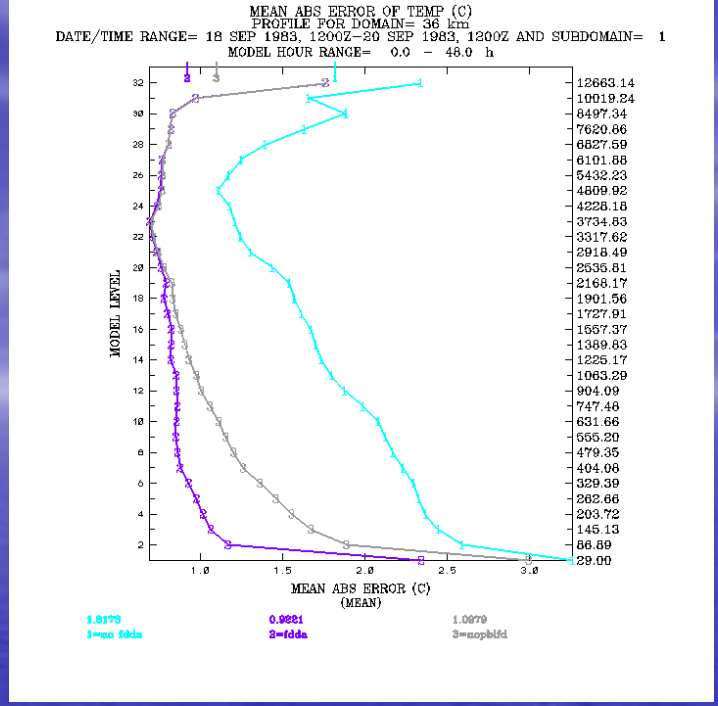


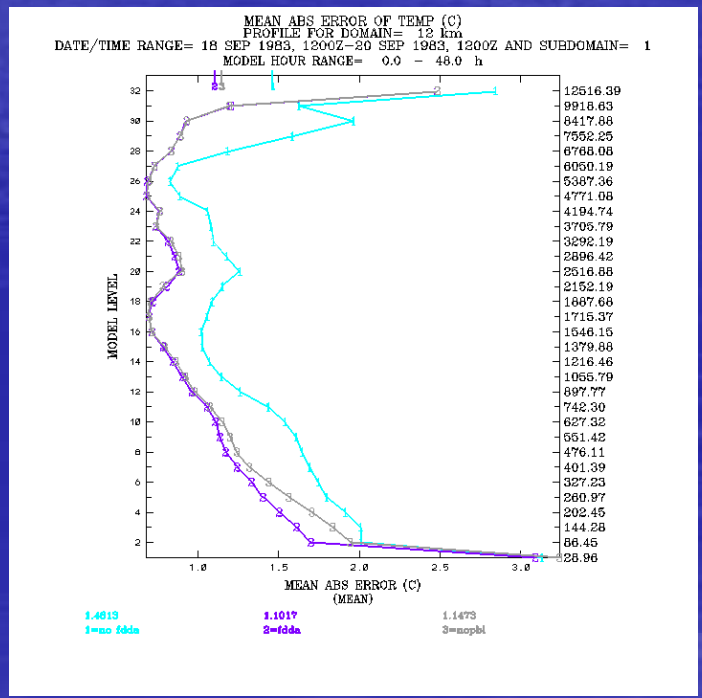

WRF NO FDDA

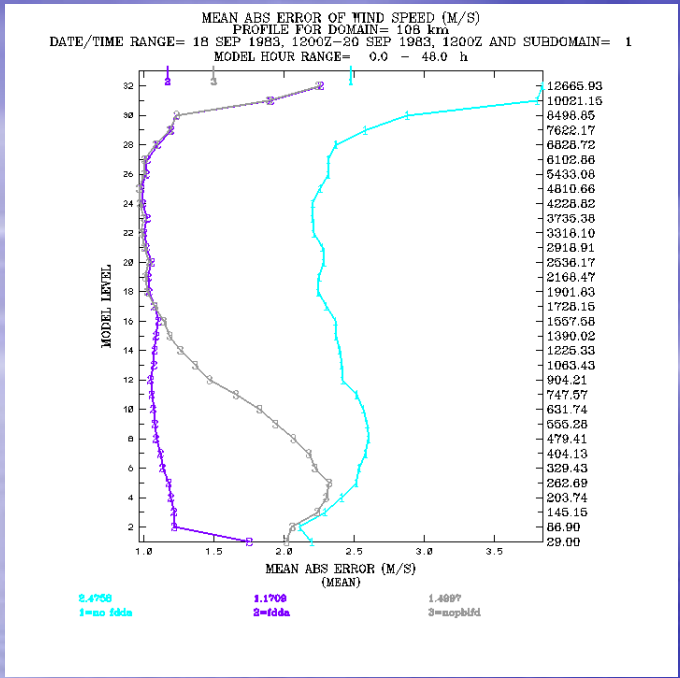
WRF FDDA above PBL

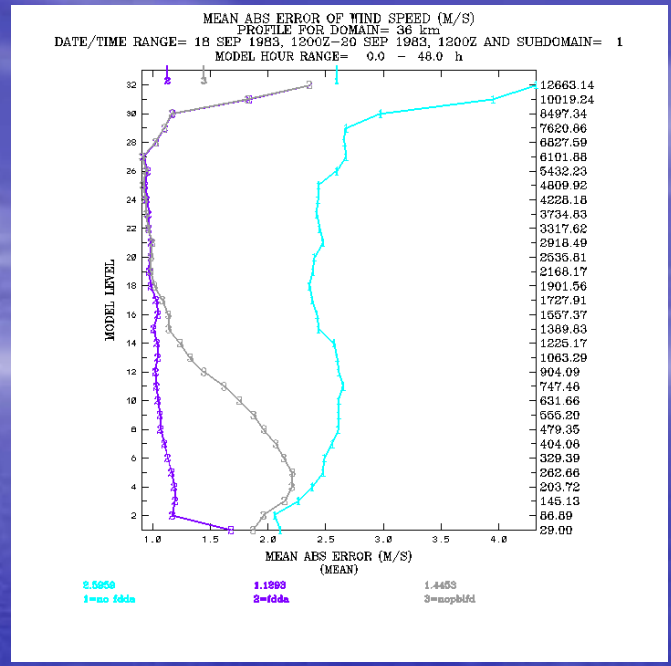


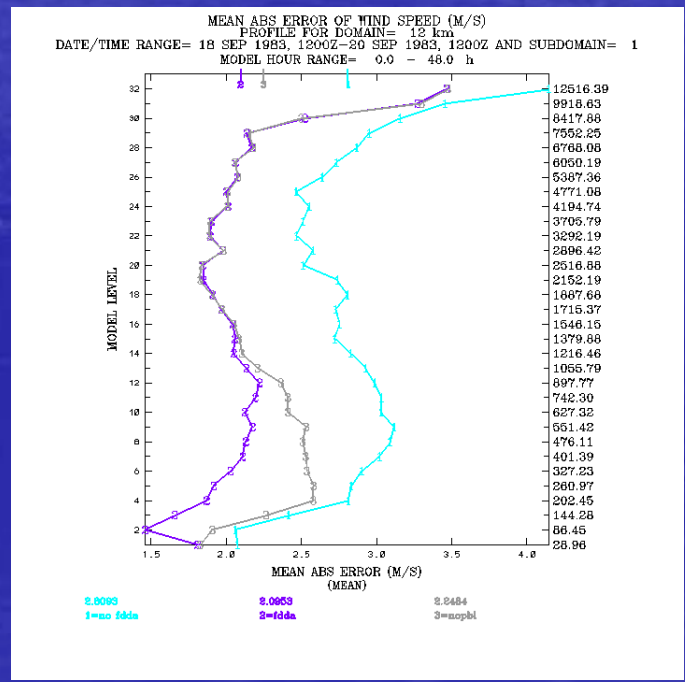




MAE of Temperature (C) for 108-km, 36-km, 12-km domains averaged over 48-h period

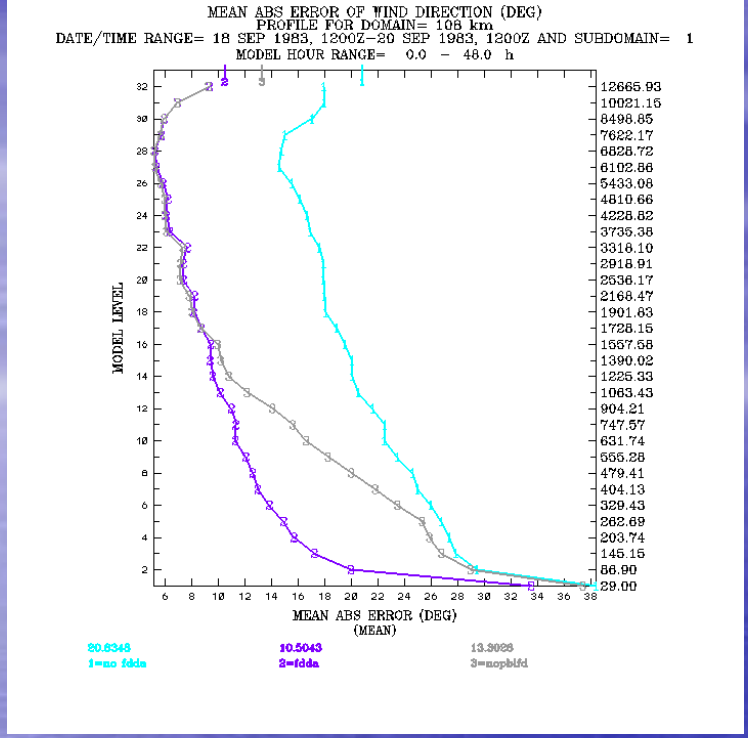


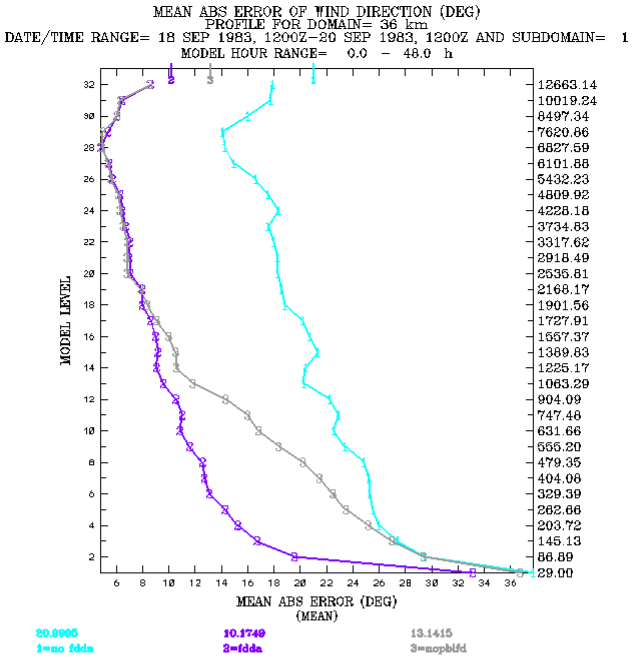


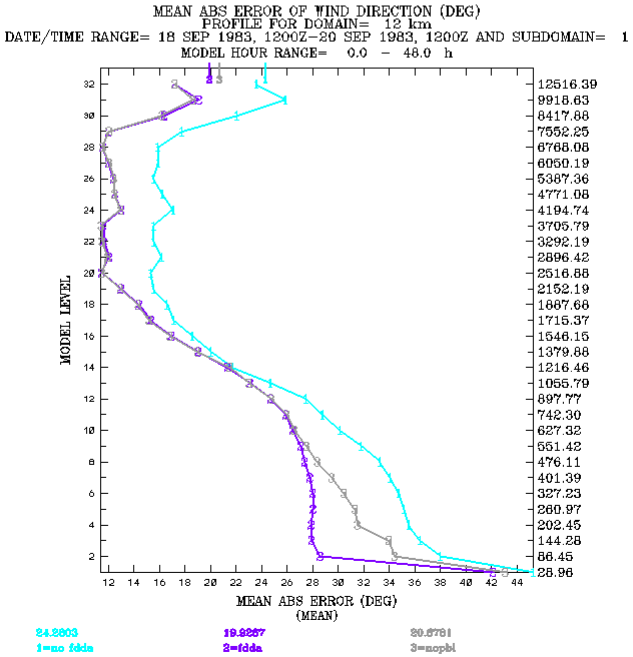




MAE of Wind Speed (m/s) for 108-km, 36-km, 12-km domains averaged over 48-h period




MAE of Wind Direction (deg) for 108-km, 36-km, 12-km domains averaged over 48-h period



# DISCUSSION

- WRF FDDA results show very good agreement with target analysis-nudging fields
- New “converter code” used to create WRF initial conditions from MM5 initial conditions is also attractive for translating front-end MM5 pressure-level gridded analyses (from Rawins or Little_r) to WRF infrastructure for analysis nudging
- WRF fields are meteorologically reasonable and show no signs of serious noise problems
- Optional use of PBL height for vertical weighting produces expected results

# DISCUSSION (cont'd)

- Statistics show reasonable, reduced error levels with nudging for all experiments
- WRF 3D analysis nudging FDDA works for nesting
- WRF 3D analysis nudging FDDA can also be excluded from model-predicted PBL
- Currently testing restart capability
- Currently works in OMP. MPI testing to be done.

# Summary

**Analysis Nudging FDDA in WRF – ARW:**

**Current 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…)**

**Uses as default linear temporal interpolations and uniform spatial weighting functions**

**Goal: Basic 3D analysis nudging with optional vertical weighting function based on PBL height in WRF 2.2 in September 2006*…**

***Implications of replacing SI with new WRF Preprocessing System (WPS) on schedule?**

# Summary

**Future capabilities with additional funding support:**

**More general temporal and spatial weighting functions, including use of 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 using "converter" on 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.)**
- **Hybrid 3DVAR/EnKF/nudging methods (with Li Li Lei, Ph.D. student)**
- **WRF obs nudging being coded by NCAR RAL – possible collaboration with Penn State in the future…**

# Acknowledgments


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

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

# Disclaimer

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