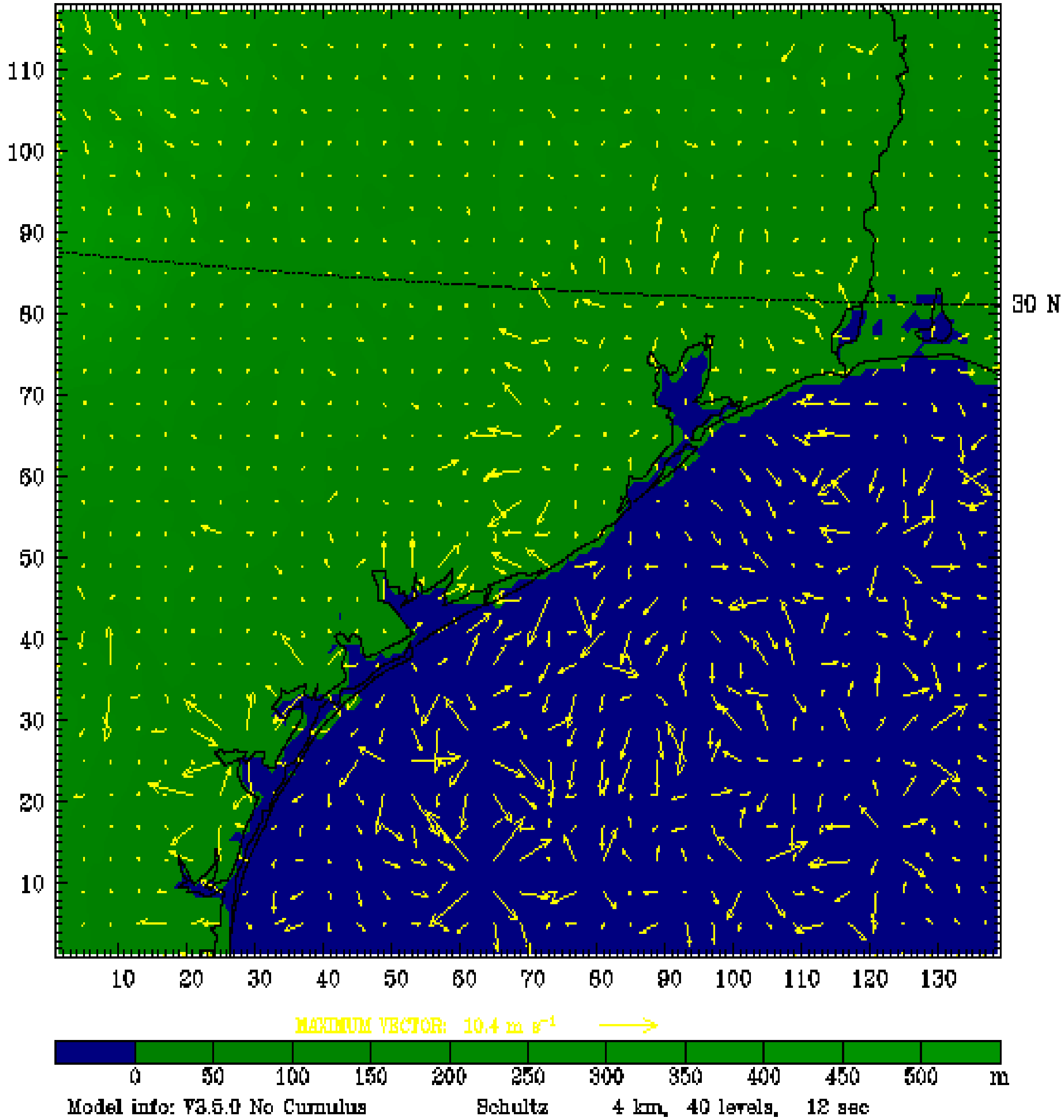
MM5 Sensitivity Tests

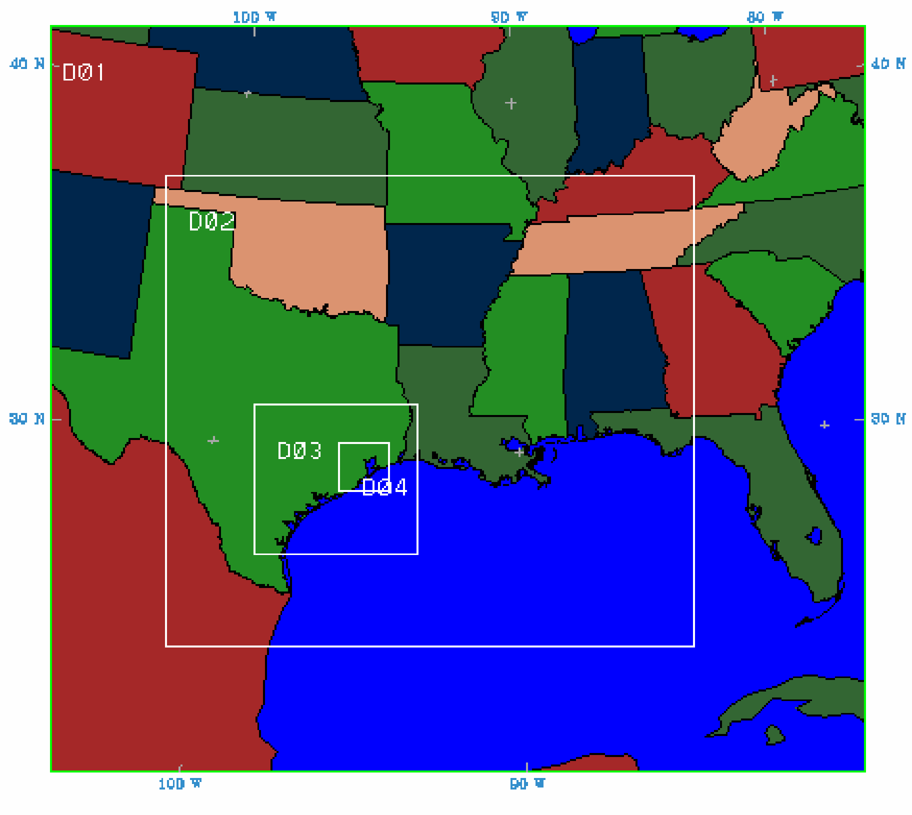
- RAMS and MM5 meteorological simulations were performed for the period 6-11 September 1993 (now August 2000 also) for Houston/Galveston
  - MM5 was run in both:
    - 3-grid configuration (4 km finest grid)
    - 4-grid configuration (1.33 km finest grid).
- Statistical verification results of MM5 were acceptable
- Examination of the MM5 meteorological fields, several undesirable features were apparent. The most notable of these features were:
  - Consistent under-prediction of the sea breeze development
  - Under-prediction of surface wind speeds over land during the day
  - Creation of explicit, grid-scale thunderstorms (even on a 4km grid) which generated very strong outflows. These outflows were so strong at times that the low-level wind field was completely disrupted.

ATmospheric, Meteorological, and Environmental Technologies



MM5 Sensitivity Tests

Grid	# of X points	# of Y Points	Vertical Levels	$\Delta x/\Delta y$ (km)
1	72	66	41	36
2	139	124	41	12
3	139	118	41	4
4	127	118	41	1.33



MM5 Sensitivity Tests

- Sensitivity simulations for the 24-hour period of 0000 UTC 8 September 1993 to 0000 UTC 9 September 1993.
- More than 20 different simulations were performed in the process of investigating the sensitivity of the MM5 results to various parameterizations, options, and grid resolution.
- Series of experiments categorized as:
  - control simulations
  - PBL tests
  - microphysics tests
  - FDDA tests
- *FDDA not used on most of these runs. 24 hour runs should not need it!*

MM5 Sensitivity Tests

Run tag	No. grids	Dura-tion	Micro-physics	Cu parm	PBL	Bucket scheme	Shal-low cu	Iz0topt	Imvdif	FDDA grid ndgng
Runorig4	4	4 days	Schultz	Grell	G-S MY	NO	NO	NA	NA	YES BL, UA
Runold2	2	24 hrs	Schultz	Grell	G-S MY	NO	NO	NA	NA	NO
Runa	2	24 hrs	Simple ice	KF2	MRF	YES	NO	0	1	NO
Runa4	4	24 hrs	Simple ice	KF2	MRF	YES	NO	0	1	NO
Runb	2	24 hrs	Reis1	KF2	MRF	YES	NO	0	1	NO
Runc	2	24 hrs	Reis 1	KF2	G-S MY	YES	NO	NA	NA	NO
Rund	2	24 hrs	Reis1	KF2	ETA MY	YES	NO	NA	NA	NO
Runold4	4	24 hrs	Schultz	Grell	G-S MY	NO	NO	NA	NA	NO
Rune	3	24 hrs	Reis1	KF2	ETA MY	YES	NO	NA	NA	NO
Runf	3	24 hrs	Reis1	KF2	MRF	YES	YES	0	1	NO
Runf2	3	24 hrs	Reis1	KF2	MRF	YES	NO	0	1	NO
Rung	3	24 hrs	Reis1	KF2	MRF	YES	YES	2	0	NO
Runh	3	24 hrs	Reis1	KF2	MRF	YES	YES	2	1	NO
Runi	3	24 hrs	Reis1	KF2	ETA MY	YES	YES	NA	NA	NO

MM5 Sensitivity Tests

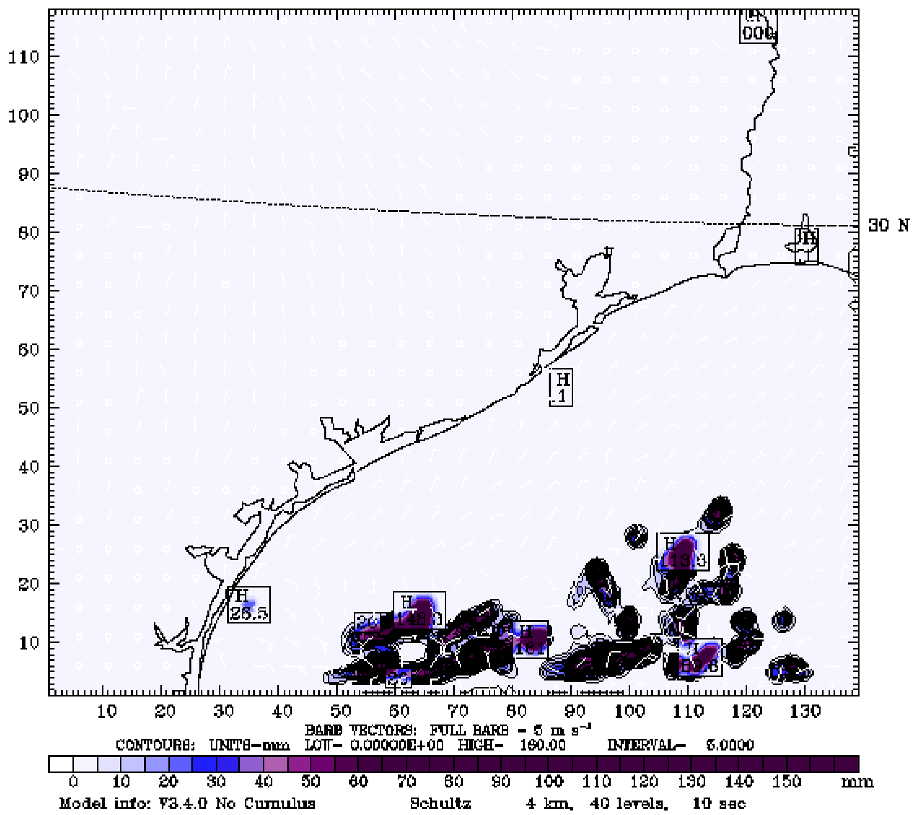
Run tag	No. grids	Dura- tion	Micro- physics	Cu parm	PBL	Bucket scheme	Shal- low cu	Iz0topt	Imvdif	FDDA grid ndgng
Runj	3	24 hrs	Reis 1	KF2	G-S MY	YES	NO	NA	NA	NO
Runj2	3	24 hrs	Reis 1	KF2	G-S MY modified	YES	NO	NA	NA	NO
Runk	3	24 hrs	Reis 1	KF2	Blacka- dar	YES	NO	NA	NA	NO
Runl	3	24 hrs	Simple ice	KF2	MRF	YES	NO	0	1	NO
Runm	3	24 hrs	Reis 2	KF2	MRF	YES	NO	0	1	NO
Runn	3	24 hrs	Schultz	KF2	MRF	YES	NO	0	1	NO
Runo	3	24 hrs	Reis 1	KF2	G-S MY	YES	NO	NA	NA	YES BL, UA
Runnew4	4	4 days	Reis 1	KF2	MRF	YES	NO	0	1	YES UA ONLY
Runnew3	3	4 days	Reis 1	KF2	MRF	YES	NO	0	1	YES UA ONLY
Runnew4b	4	4 days	Reis 1	KF2	MRF	YES	NO	0	1	YES UA>.85

ATmospheric, Meteorological, and Environmental Technologies

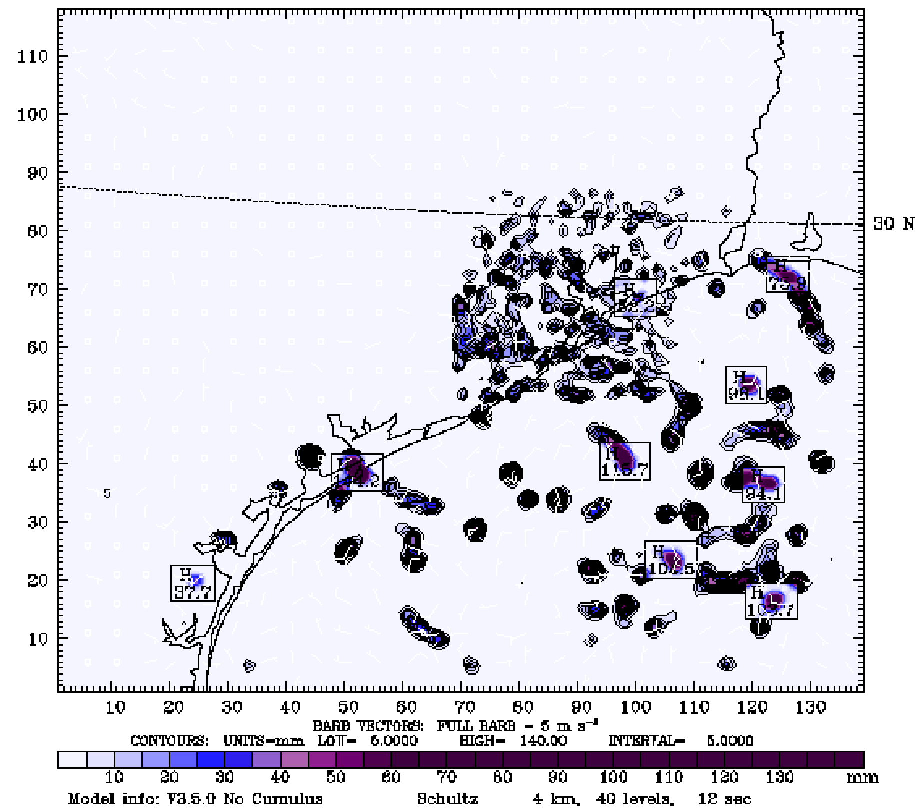
MM5 Sensitivity Tests

6 hr precipitation over grid 3 valid at 1800 UTC 8 September for:

a) with FDDA and GS



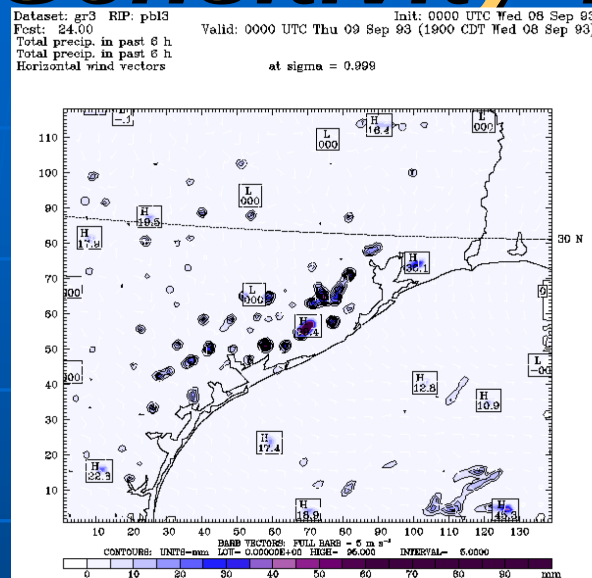
b) no FDDA and GS.



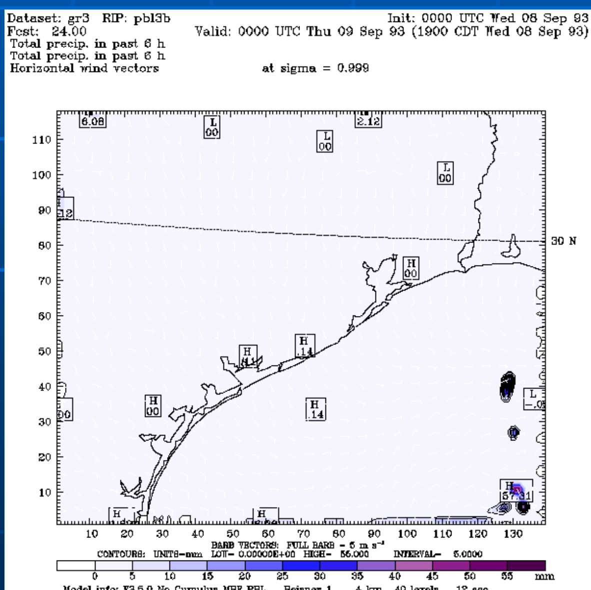
ATmospheric, Meteorological, and Environmental Technologies

MM5 Sensitivity Tests

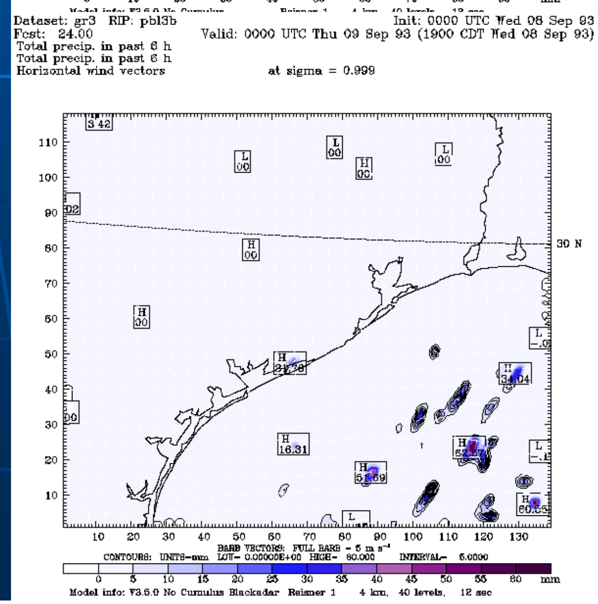
6-hr precipitation on grid 3 at 0000 UTC 9 September



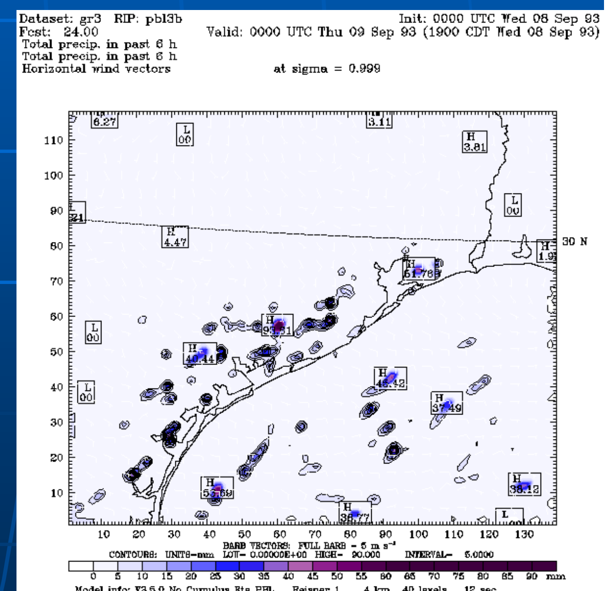
b) **GS pbl**



a) **MRF pbl**



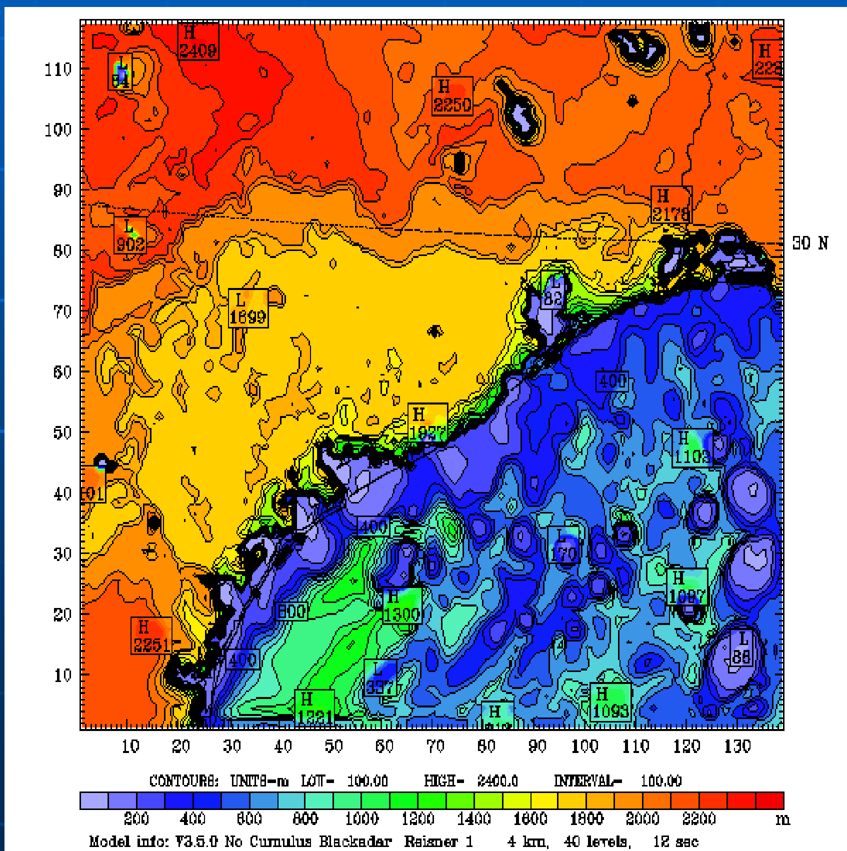
c) **Blackadar pbl**



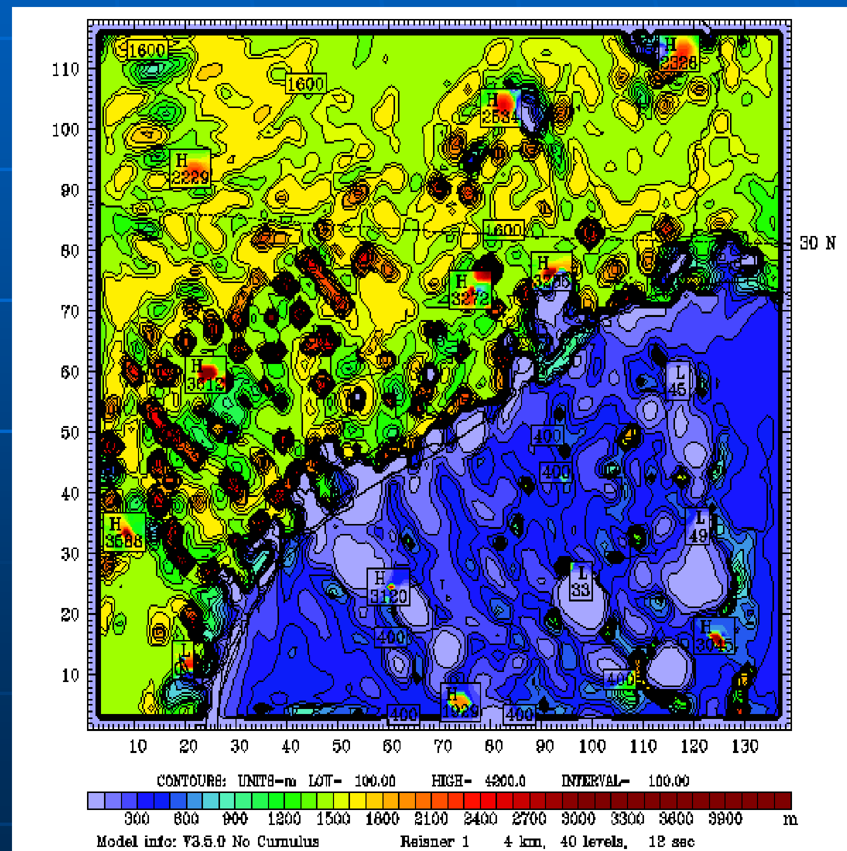
d) **ETA MY pbl**

MM5 Sensitivity Tests

PBL height – 1800 UTC



MRF

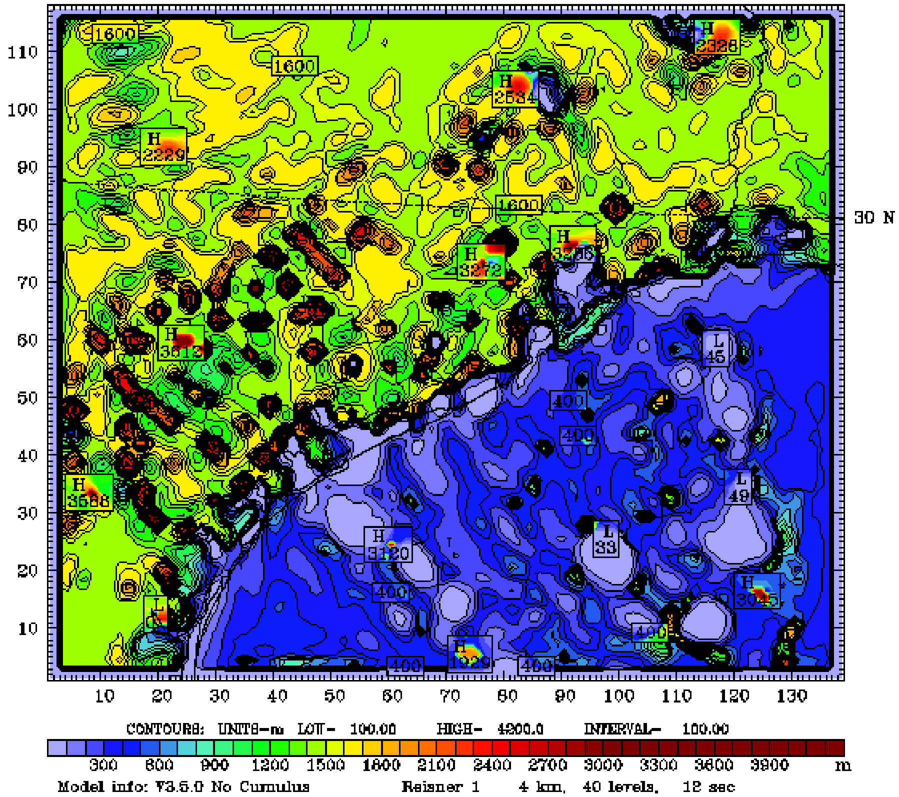


GS

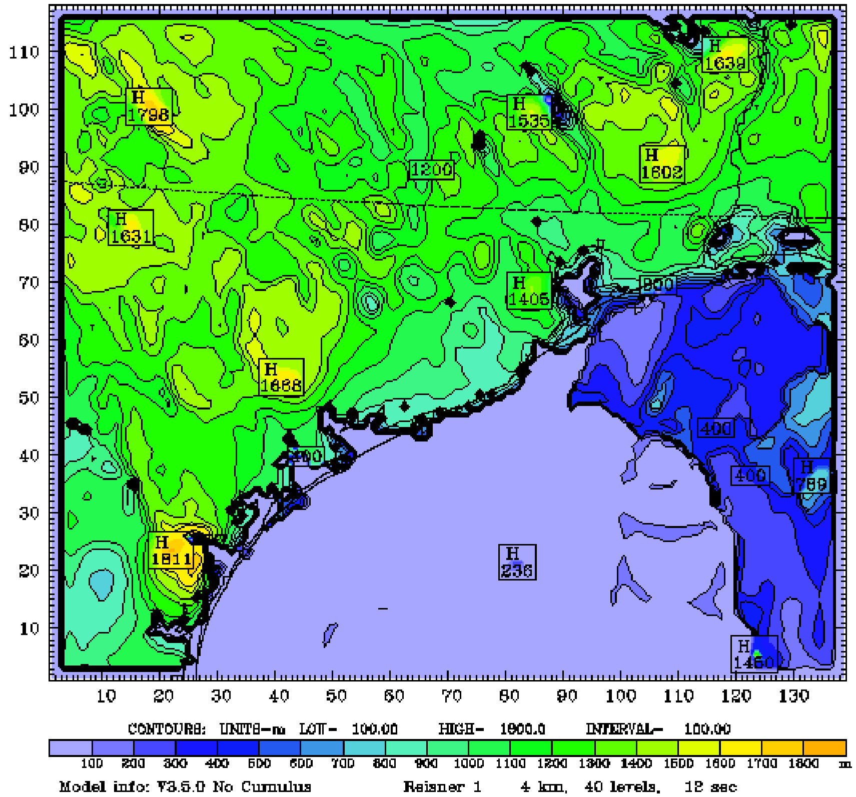
ATmospheric, Meteorological, and Environmental Technologies

MM5 Sensitivity Tests

PBL height – 1800 UTC



GS/no FDDA



GS/FDDA

MM5 Sensitivity Tests

- The cause of the convection:
  - GS and ETA TKE schemes not mixing heat upward from the surface fast enough.
  - Larger than realistic superadiabatic layer near surface was maintained.
  - Non-hydrostatic dynamics creates positive buoyancy tendency.
  - If boundary layer depth reaches significant fraction of horizontal grid spacing, grid-scale "thermals" develop. These are larger and stronger than realistic.
  - FDDA nudging acts as horizontal numeric filter, forcing circulations to even larger scale.
  - Resolved deep convection is produced.

MM5 Sensitivity Tests

- Under-prediction of surface wind speed: Low bias for the surface wind speed is primarily controlled by the PBL scheme as it interacts with the land surface scheme.

- Lack of sea breeze circulations: The lack of good sea breeze development in the previous simulations was caused by a combination of three things:
  - estimating the sea surface temperature from the lowest atmospheric level temperature
  - the over-development of grid-scale convective cells whose cold surface outflow both overwhelmed and thermally suppressed any developing sea breeze circulations
  - using the FDDA analysis nudging through the entire depth of the atmosphere.

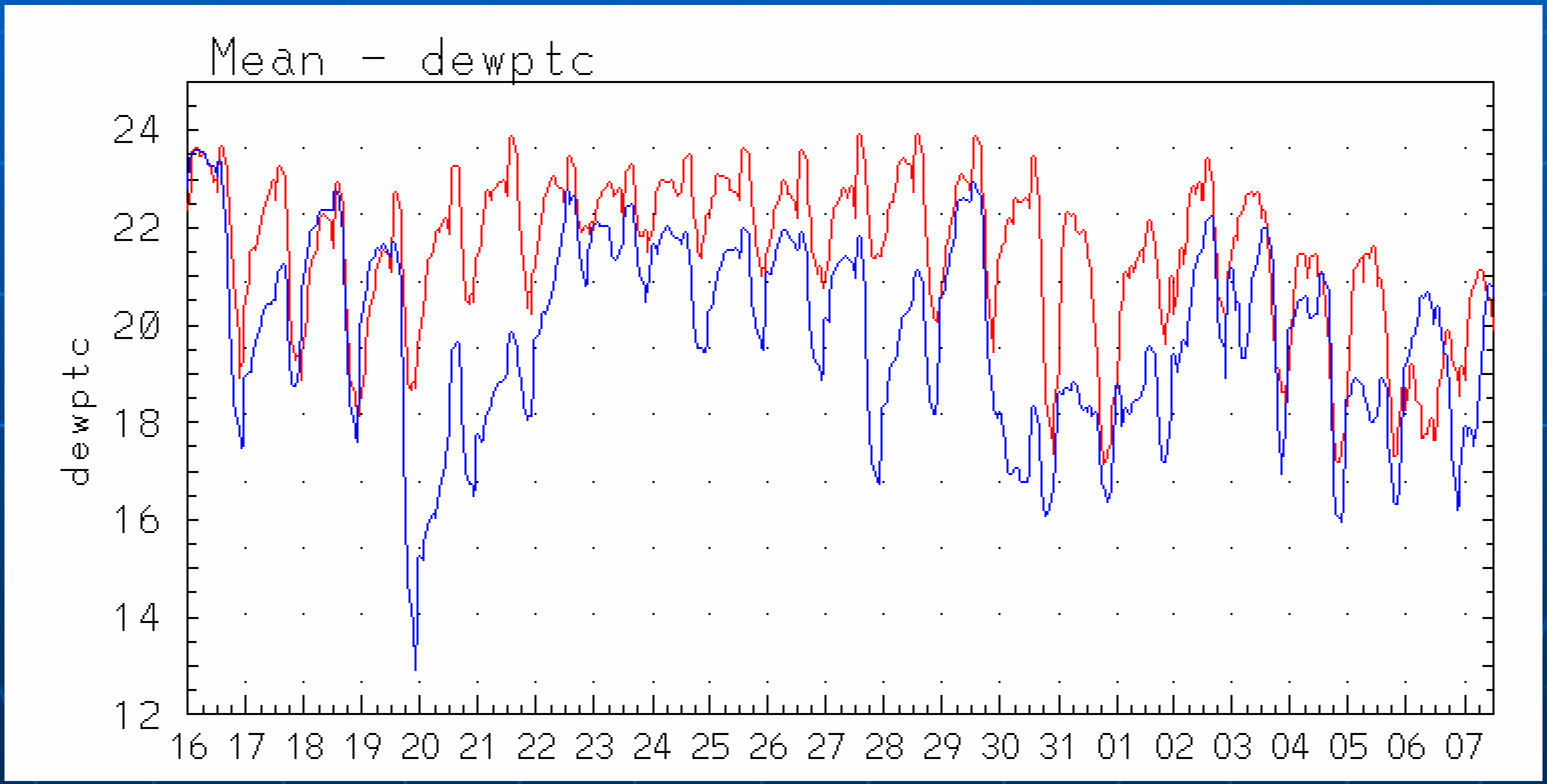
MM5 Sensitivity Tests

- Recommendations:
  - Gayno-Seaman scheme should not be used at higher resolutions without further testing
  - Non-hydrostatic dynamics should be further tested in situations where non-hydrostatic effects are *expected* to occur.
  - Testing of the OSU/NCEP ETA and Pleim-Xu Land Surface Model (LSM) schemes.
  - FDDA should be used with caution.
  - The grid nudging parameters should be tested and adjusted for the smaller grid scales.
  - Use of the FDDA observation nudging scheme should be considered. Observation nudging may be more appropriate for smaller scales. But still, many parameters should be tested and adjusted.

Low surface moisture bias

- Significant dewpoint drop in the Houston vicinity is observed in the MM5 simulation during the afternoon of 20 August.
- Observed dewpoints did lower from about 23 to 16C, but MM5 dewpoints dropped to as low as 6C at some stations.
- Corpus Christi soundings 19/1200 UTC and 20/0000 UTC indicate that boundary layer moisture was quite shallow, confined below 925mb with drier conditions aloft.
- EDAS moisture data at 850mb shows a specific humidity minimum of 4 g/kg immediately east of Galveston Bay.
- MM5 simulation showed a deep mixed boundary layer of up to 3000m at this time, mixing the dry air aloft down to the surface.
- Another example of the MRF scheme high PBL bias.

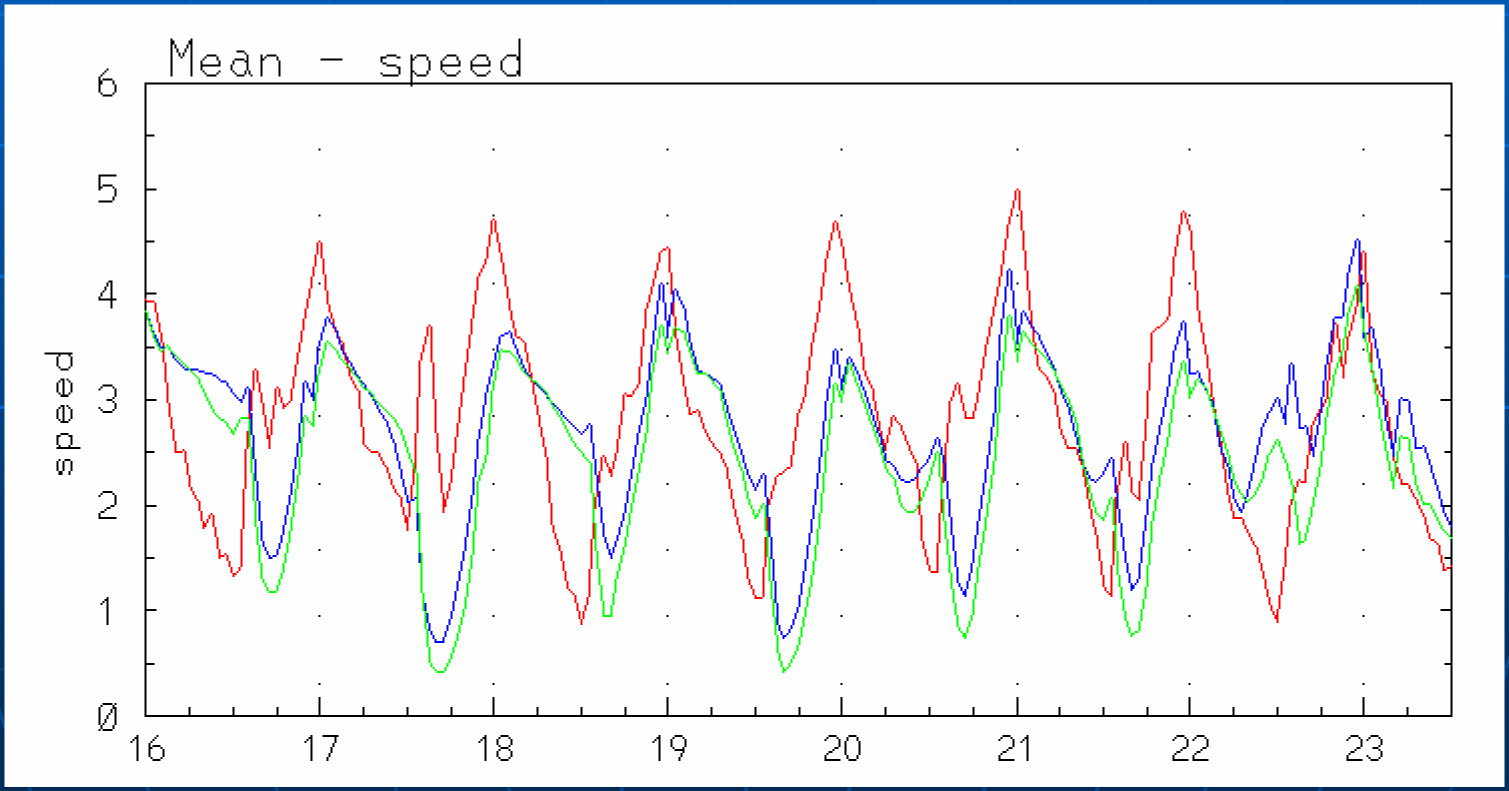
Low surface moisture bias



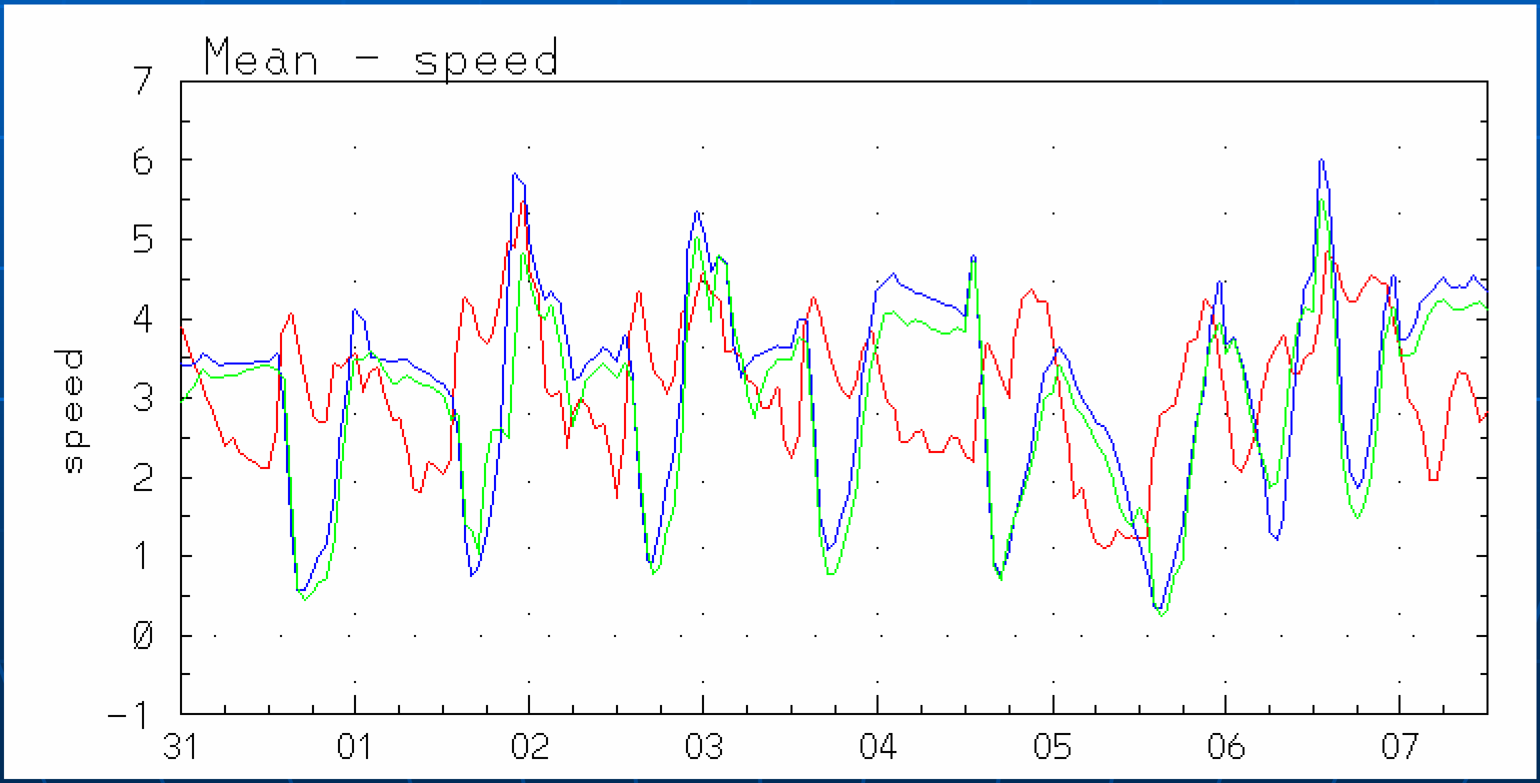
Low daytime wind speed bias

- Control run results indicate that MM5 simulated wind speeds tended to be slow during the daylight hours. This is especially apparent on August 17 and then from August 30 forward.
- Wind speed starts to slow around 1400 UTC, at the time when the observed wind speed increases.
- Cross-sectional analysis revealed that while winds are weak up to 1km, vertical mixing of the boundary layer should still increase the shelter height wind speed.

Low daytime wind speed bias



Low daytime wind speed bias



Low daytime wind speed bias

- Short sensitivity runs were performed to analyze the effects of the MM5 roughness length on the low-level wind speeds. Three sensitivity simulations were completed:

  1) the roughness length was reduced by two-thirds for the four land use categories that are most prevalent is southeast Texas, excluding the urban category

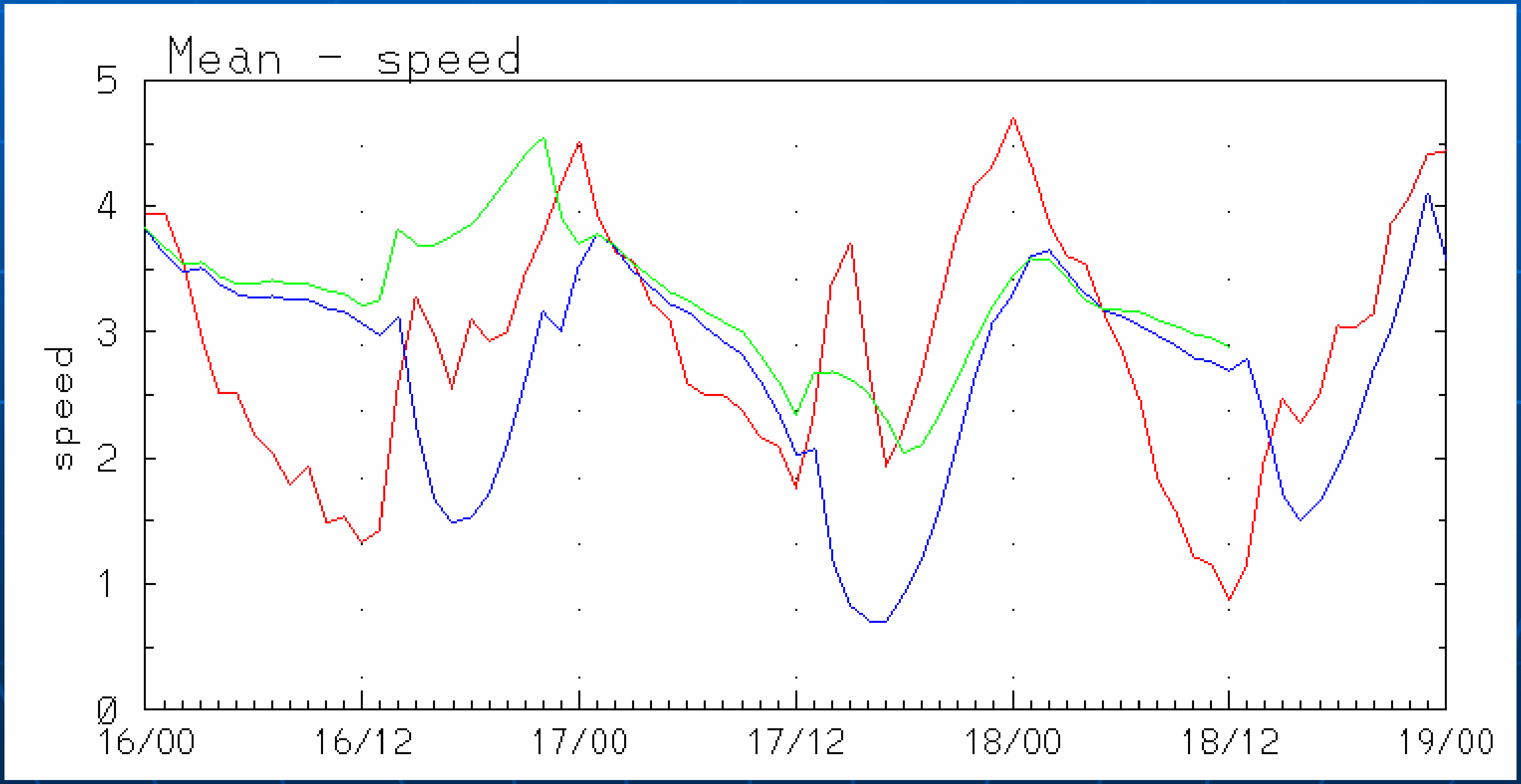
  2) the roughness length was reduced by two-thirds for all land use categories

  3) the roughness length was reduced to 0.1 mm, which is the same value used over water.
- Comparison of simulated wind speeds with observations showed only a marginal improvement in daytime wind speed bias for 1 and 2.
- The third sensitivity experiment, while exhibiting a high-speed bias, shows a more realistic diurnal cycle of wind speed with wind speeds increasing during the daylight hours.

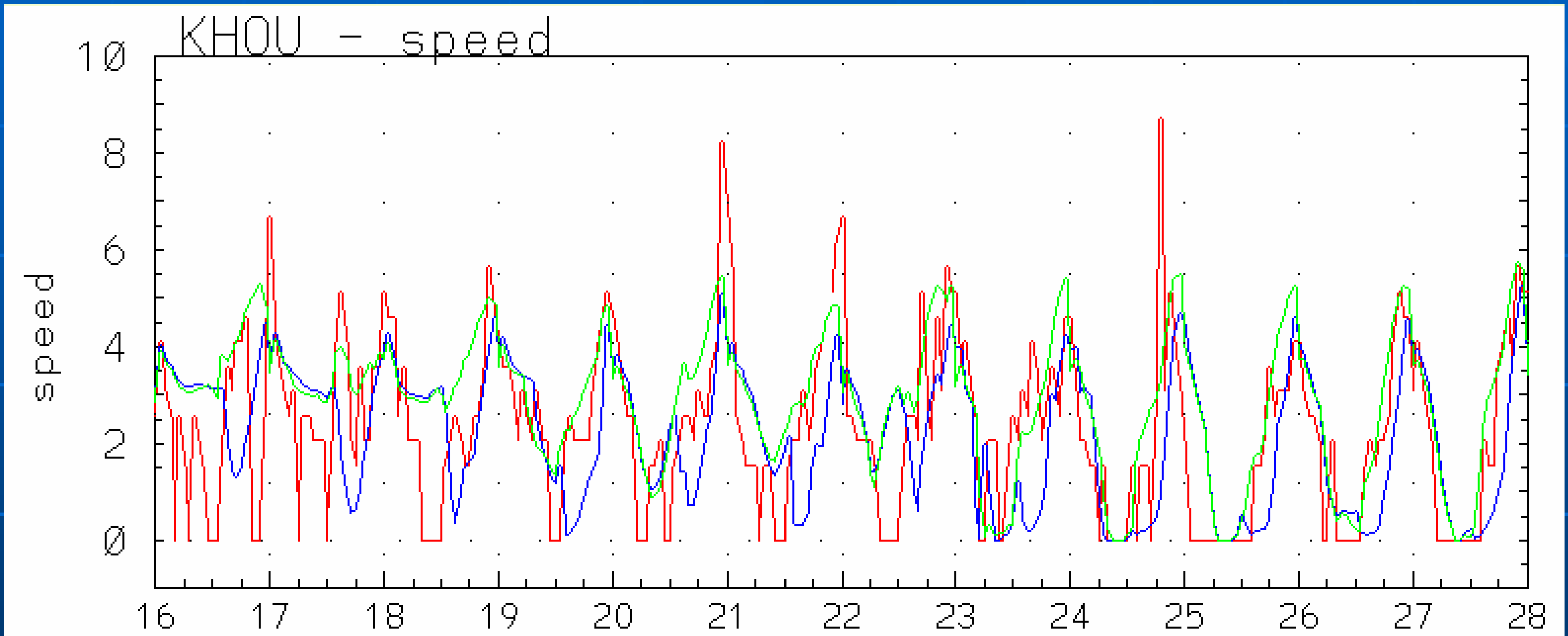
Low daytime wind speed bias

- Jimy Dudhia (NCAR/MMM) indicated that in the MRF boundary layer scheme, there is a contribution (when the boundary layer is unstable) from a "convective velocity" (VCONV) to the total wind speed that is used in the U* computation.
- VCONV raises the momentum flux transfer into the ground, and results in lower near-surface wind speeds. A short sensitivity run was performed in which this convective velocity contribution was removed. A comparison of simulated wind speeds with observations shows higher daytime wind speeds and an overall improvement in the temporal profile of the daytime winds.

Low daytime wind speed bias



Low daytime wind speed bias



MRF PBL Scheme

- We have performed numerous sensitivity simulations for both the 1993 and 2000 episodes for the Houston-Galveston region
- Major component was testing the various PBL schemes
- Like others, the results consistently showed that MRF scheme usually worked best
- Also like others, the MRF scheme consistently overestimates the height of the PBL, which is crucial for good air quality simulations.

MRF PBL Scheme

- MRF PBL scheme described by Hong and Pan (1996), which followed very closely on earlier work of Troen and Mahrt (1986).
- First implemented in the NCEP MRF model
- Developed with MRF model in mind, relatively coarse horizontal and vertical resolution with a requirement that very little computer resources be used
- Later implemented in MM5 by Dudhia and Hong
- Several aspects to the scheme (stable vs. unstable boundary layers, diffusion above and below the boundary layer height). Focused on the regime that seems to cause the most problems, diffusion within the unstable boundary layer

MRF PBL Scheme

- MRF scheme is based on the use of a profile function (O'Brien) for the vertical exchange coefficient
- Sub-grid diffusion schemes based on the O'Brien profile function date back to at least the early 1970's
- Called a "non-local" scheme by Hong and Pan, this scheme still produces an eddy exchange coefficient where the mixing is done locally (i.e., from layer to layer). The computation of the eddy viscosity coefficients is done taking into account "non-local" effects (e.g., the O'Brien profile function)
- Usual use of the term "non-local diffusion" in the literature refers to a scheme that can mix characteristics of the atmosphere beyond the adjoining layer

MRF PBL Scheme

- The MRF scheme requires the computation of a PBL height. Similar schemes have prognosed the height; the MRF scheme uses a diagnosis on each timestep. This diagnosis is based on the definition of a bulk Richardson number:

$$Ri = \frac{\frac{g}{\theta_v}\frac{\partial \theta_v}{\partial z}}{\left(\frac{\partial V}{\partial z}\right)^2}$$

where *g* is gravity, *V* is the wind speed, and *θv* is virtual potential temperature.

MRF PBL Scheme

- Two assumptions are then made by Troen and Mahrt:
  - The Richardson number will be assumed to apply over the depth of the boundary layer.
  - A critical Richardson number can be defined and used over this depth to compute the boundary layer height.
- Typically, the bulk Richardson number is used to determine if the vertical wind shear is adequate to overcome the level of stability and make a layer prone to turbulence. Usually, this has been applied to relatively shallow layers (e.g., of order 100 m), not to entire boundary layer depths which can reach several kilometers.
- When applied to shallow layers, the theoretical value of the critical Richardson number is usually taken to be 0.25. If the value is more than this, the flow is likely to be laminar; when the value is less, turbulence is likely. Various researchers have used a larger number for the critical Richardson due to discretization and numerical arguments.

MRF PBL Scheme

- If we make the assumptions of Troen and Mahrt, replace ∂*z* with the symbol *h* for PBL height, and discretize over the entire PBL depth:

$$h = Ri_{cr} \frac{\theta_{va} \left| V(h) \right|^2}{g\left(\theta_v(h) - \theta_s\right)}$$

  where *V(h)* and *θ(h)* are the wind speed and virtual potential temperature at height *h*, θ_{va} is the virtual potential temperature at the first model level above the ground, and θ_s is a representative air temperature near the surface.
- θ_s is further defined as: $$\theta_s = \theta_{va} + \theta_T$$
- where θ_T is a "scaled virtual temperature excess near the surface". Based on surface layer sensible heat flux and was considered necessary because the scheme was intended for vertical resolutions near the ground that were on the order of 30-50 m. It is limited to a maximum of 3K, since it could become large for small wind speeds.

MRF PBL Scheme

- Examination of the PBL computation suggests two immediate possibilities for reducing the PBL heights.
  - PBL depth is directly correlated to the critical bulk Richardson number (Ri_{cr}). The MM5 code uses a Ri_{cr} value of 0.5. Since this number is somewhat arbitrary, lower values could be tested.
  - Scaled virtual temperature excess is designed to account for a near-surface temperature that is warmer than the lowest-level model temperature. Given that current mesoscale model implementations typically utilize higher grid resolution near the ground than used in global models, the scaled virtual temperature excess term may be too large for these applications.
- Several short diagnostic simulations were run to determine the characteristics of the PBL height and eddy viscosity coefficients that were produced by the MRF scheme.
  - In early afternoon, the temperature excess was typically 1-2K, with the eddy viscosity coefficients reaching as large as 1000-1500 m^2/s.
  - A short sensitivity simulation was completed removing the scaled virtual temperature excess contribution. PBL heights were reduced by as much as 1000 m during the afternoon hours.

MRF PBL Scheme

- Seems there might be hope to reduce the daytime PBL heights to more reasonable values. The magnitude of the eddy viscosity coefficients should also be investigated, since the values produced are much larger than typical. However…
- Profile schemes can provide an adequate result in a "classic" PBL (surface-based, well-mixed from the ground to a strong capping inversion)…
- … but are unable to correctly simulate features that deviate from this classic case, e.g., sea breezes.
- As the cooler marine air moves ashore into a deep well-mixed PBL, an internal boundary layer is developed. A profile scheme will diagnose some boundary layer height.
- If the PBL height is diagnosed at the level of the internal boundary layer, then vertical mixing will be shut down in the remainder of the mixed layer that lies atop the marine air.
- If the PBL height is diagnosed at the top of the existing deep mixed layer, then the internal boundary layer will be quickly mixed out.
- In any scenario, the physical process is not represented correctly.

Beyond MRF

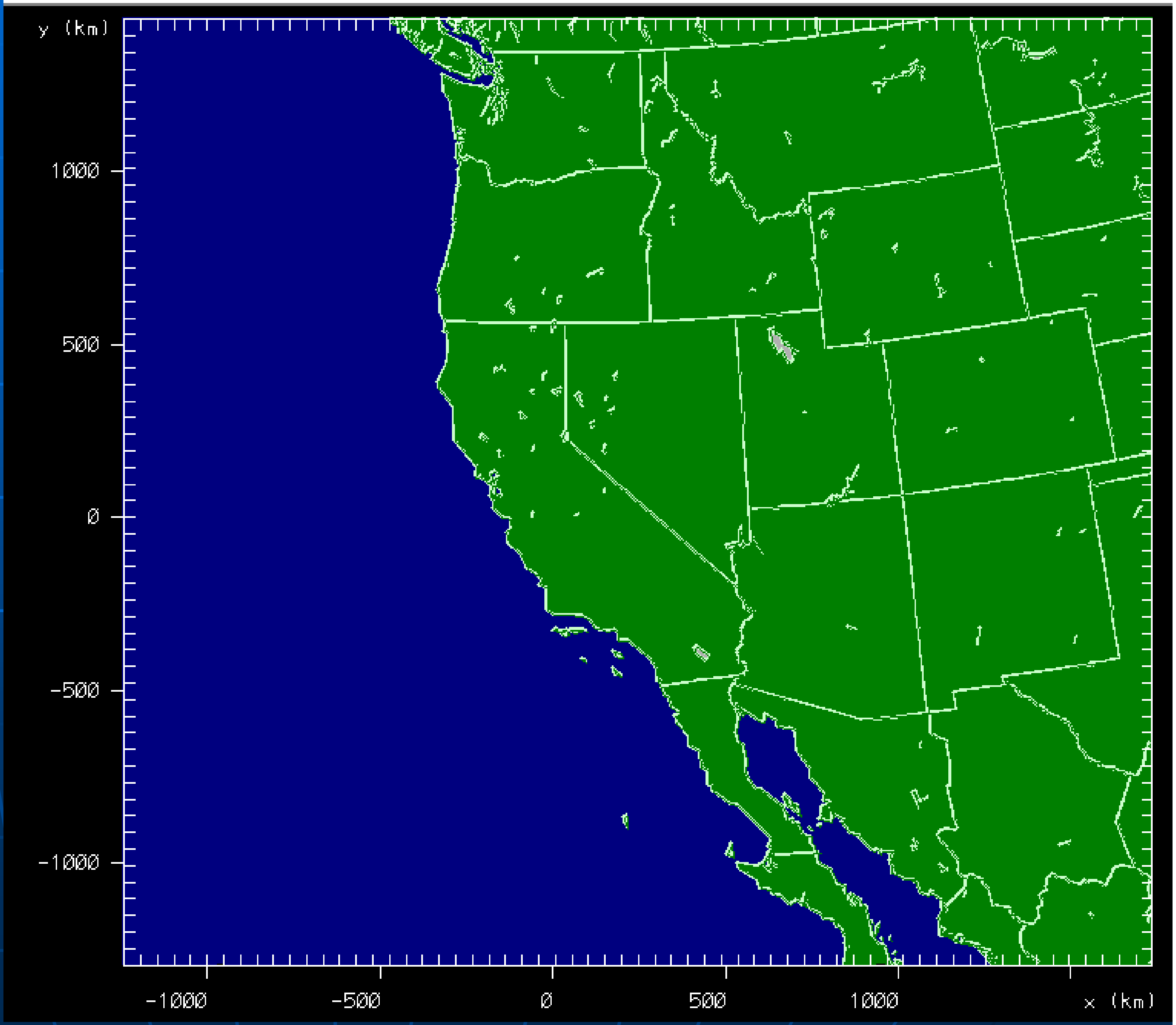
- We recommend investigating replacements for the MRF profile-based scheme.
- In theory, a TKE-based scheme (such as Mellor-Yamada) can more correctly simulate these types of "non-classic" situations.
- But as mentioned, the current implementations of TKE schemes in MM5 usually provide worse results than the MRF scheme.
- However, most other models (RAMS, COAMPS, ARPS, etc.) use TKE schemes almost exclusively.
- In our experience with RAMS in Texas (and other places), there has been little bias in the PBL depth.
- We recommend a review of the MM5 TKE schemes, comparison with other models' schemes, and possible modification of the MM5 schemes to allow them to work for more general situations.

Meteorological Modeling for BAAQMD

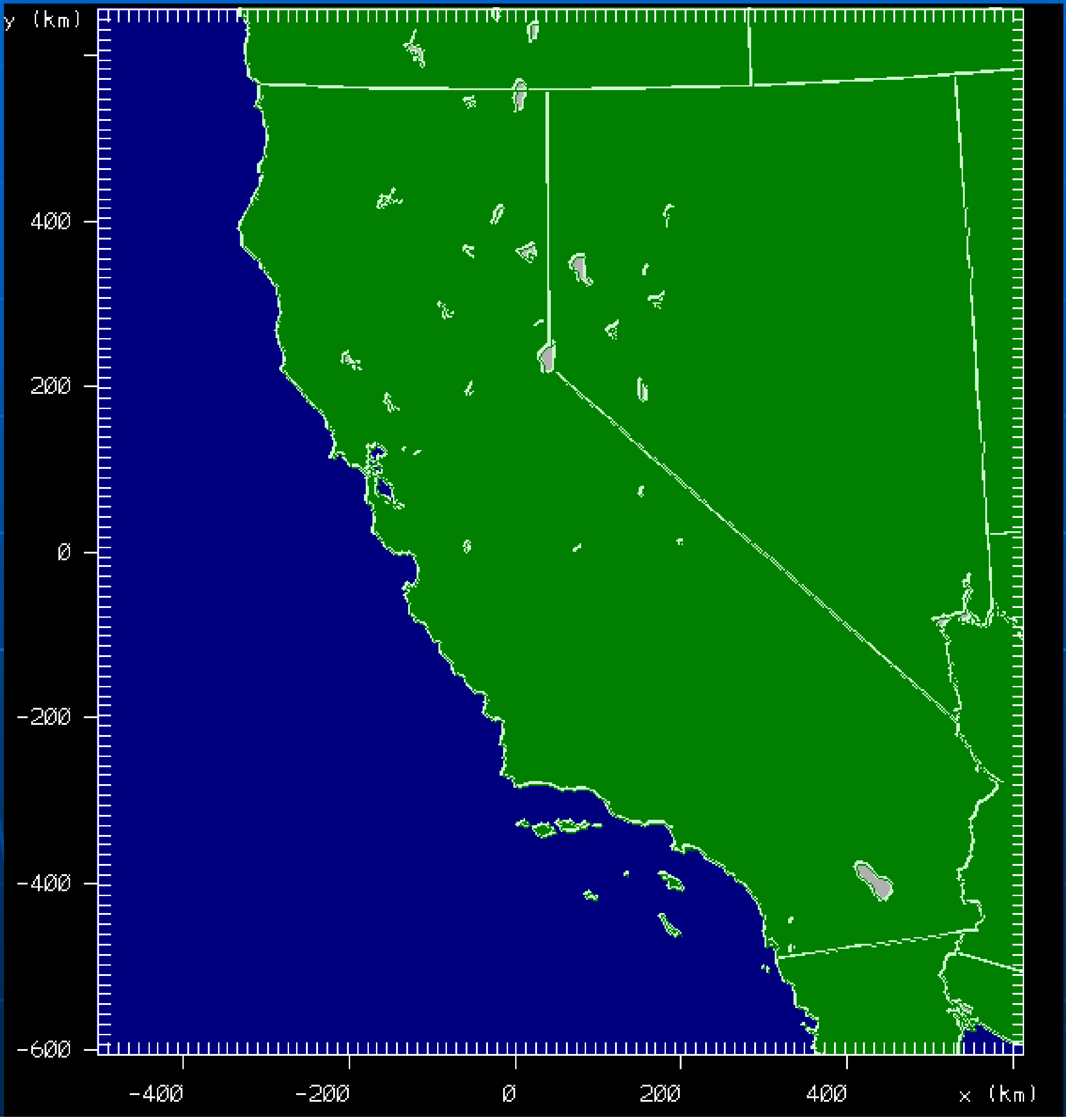
RAMS Horizontal Grid Structure

Grid	# of X Points	# of Y Points	Vertical Levels	Δx (km)	Δy (km)	Δz (m) (Lowest)
1	63	58	41	48	48	10
2	94	106	41	12	12	10
3	191	200	41	4	4	10
4	130	170	41	1	1	10

Grid 1
48 km

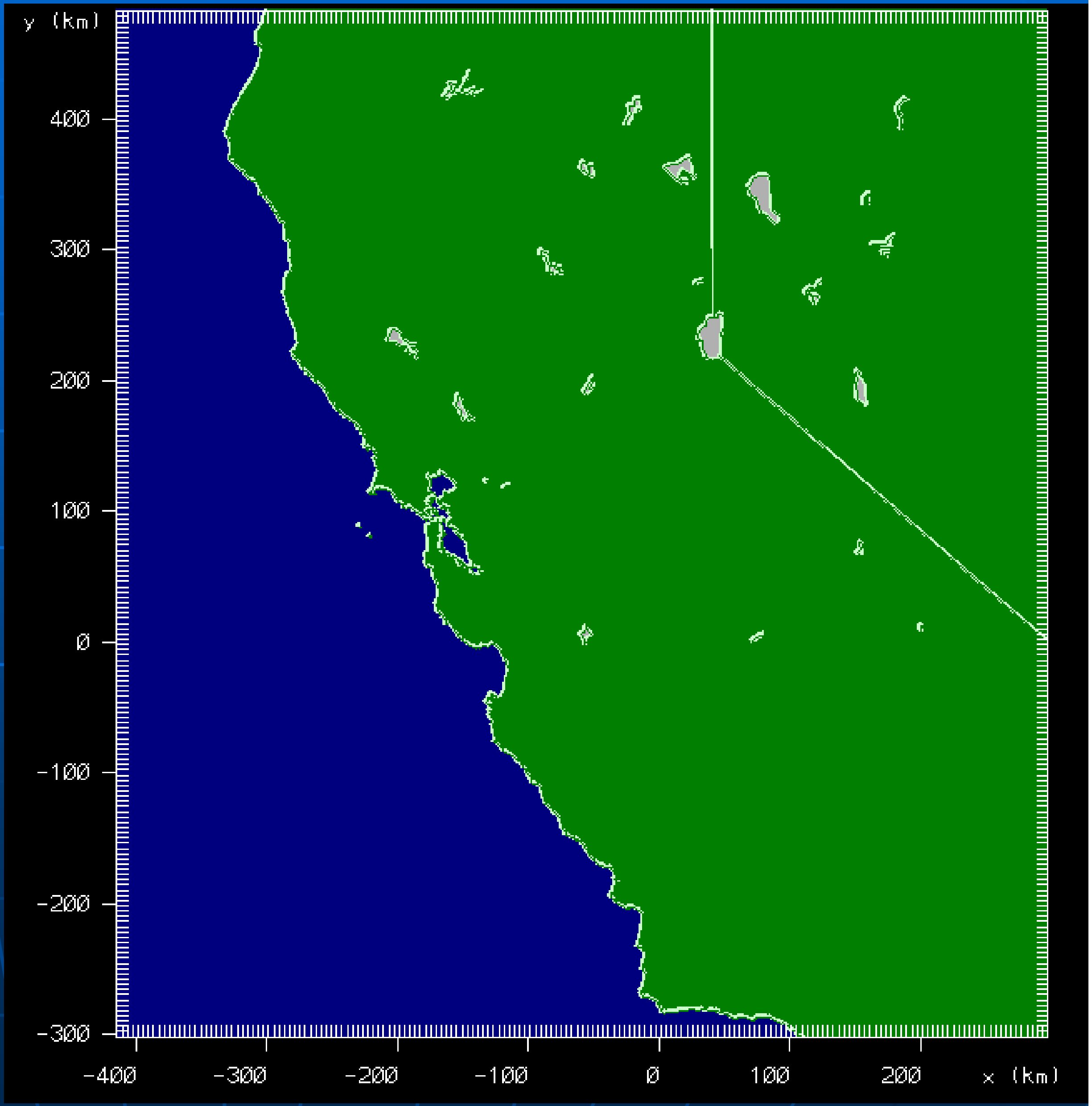


Grid 2
12 km



ATmospheric, Meteorological, and Environmental Technologies

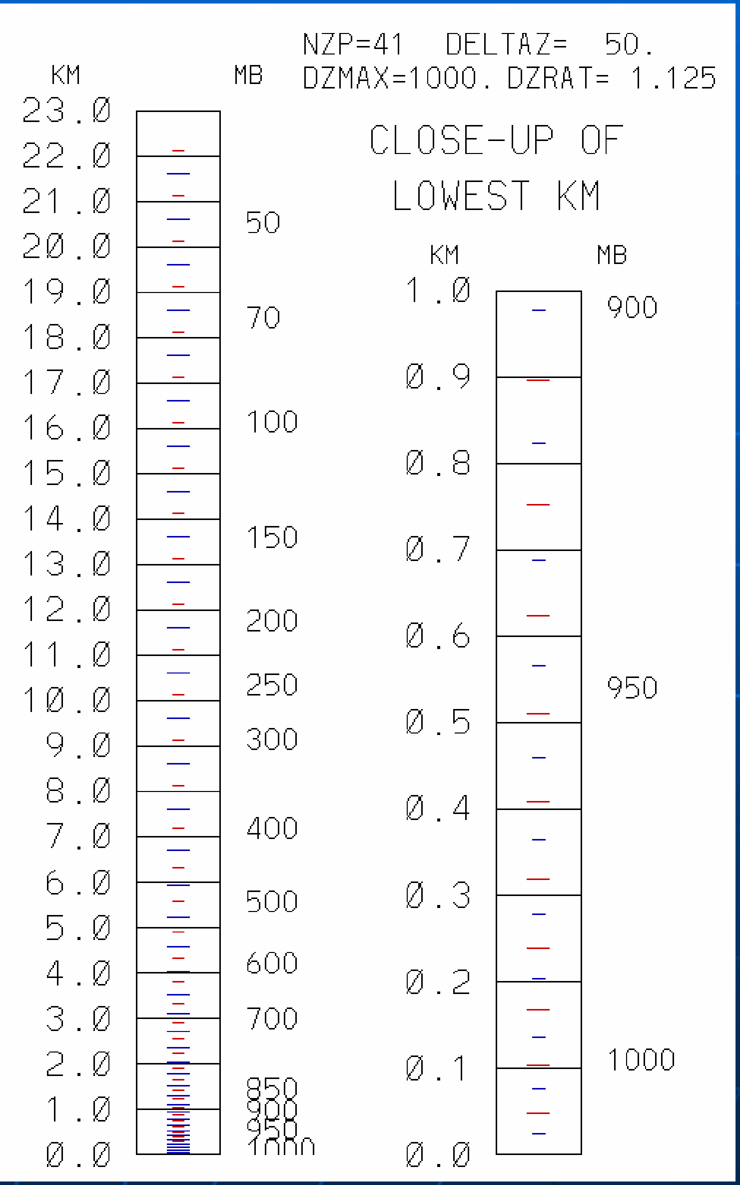
Grid 3
4 km



RAMS Vertical Levels

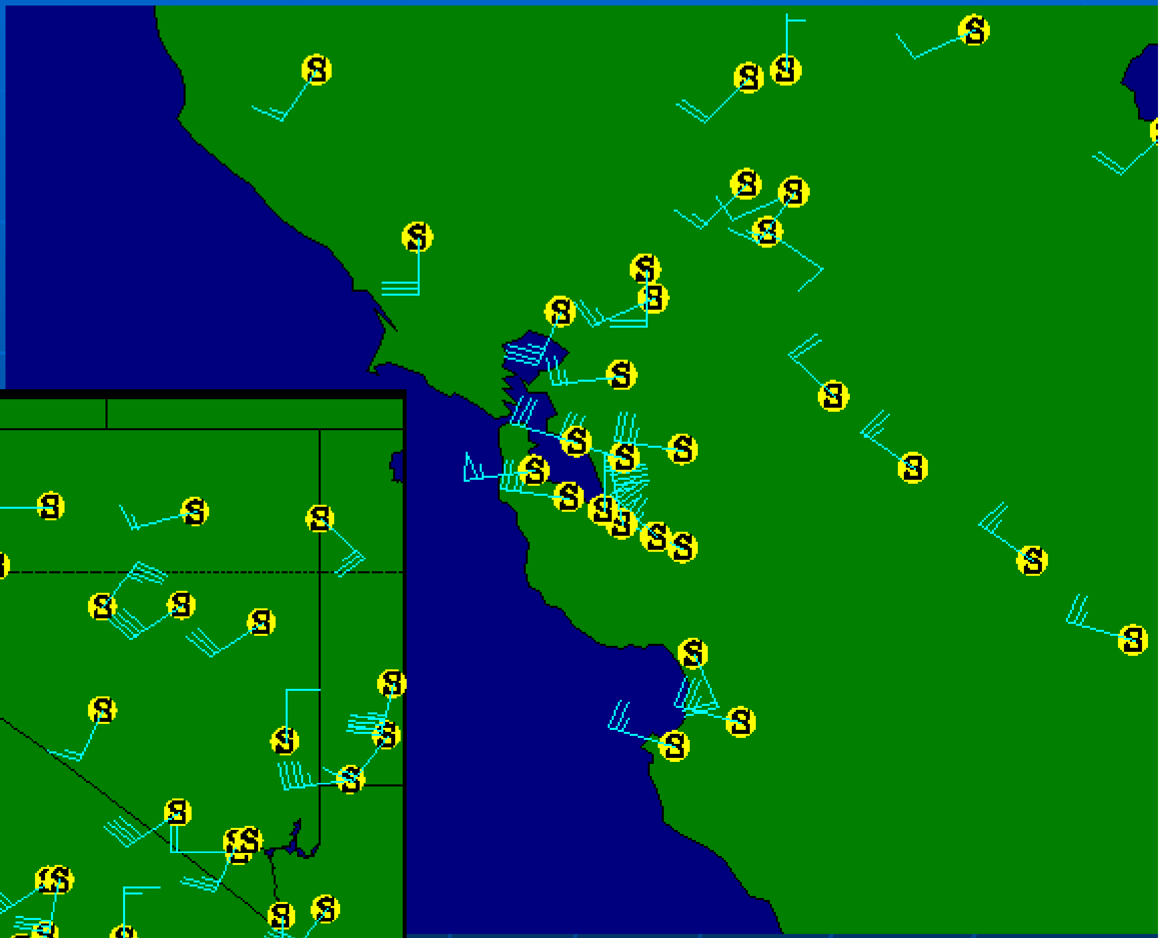
RAMS MODEL HEIGHTS (M)

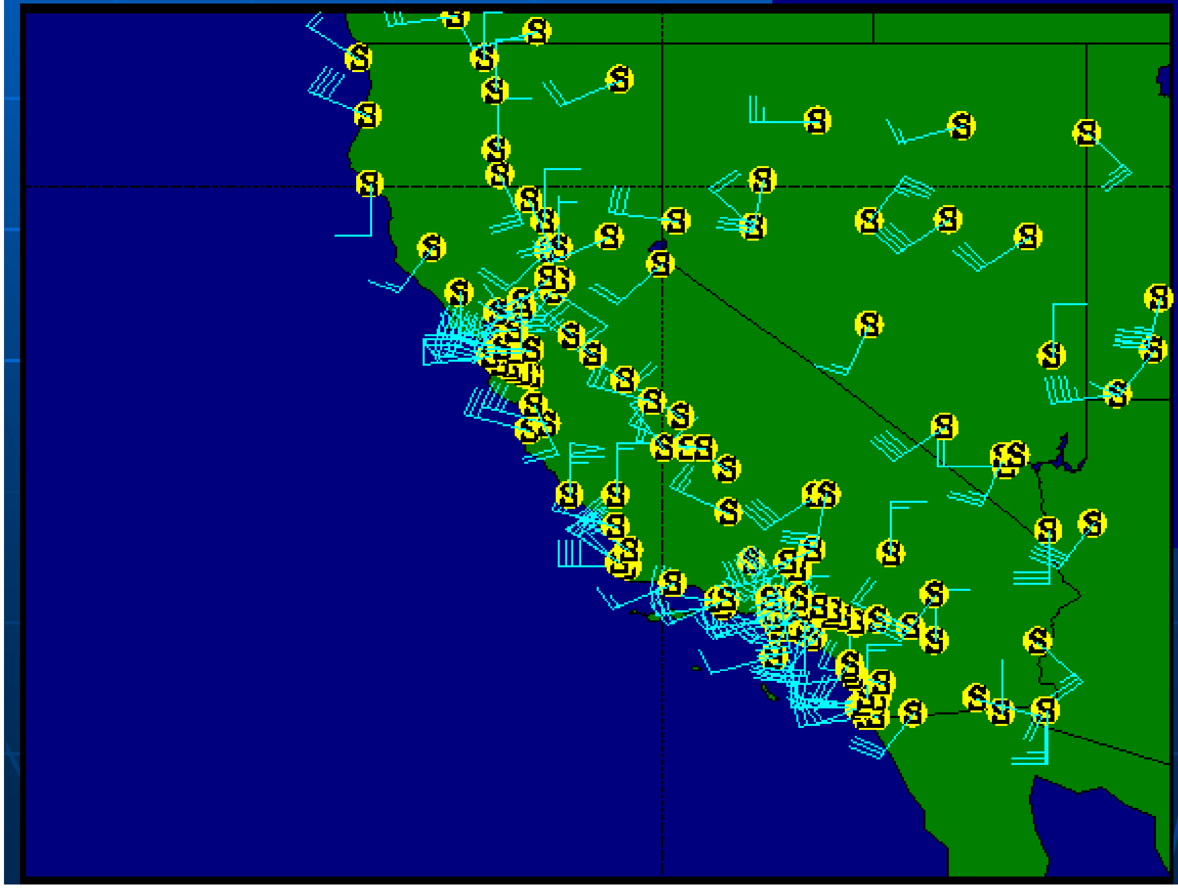
	W LEVELS	T LEVELS
41	22151.3	21651.3
40	21151.3	20651.3
39	20151.3	19651.3
38	19151.3	18651.3
37	18151.3	17651.3
36	17151.3	16651.3
35	16151.3	15651.3
34	15151.3	14651.3
33	14151.3	13651.3
32	13151.3	12651.3
31	12151.3	11651.3
30	11151.3	10651.3
29	10151.3	9651.3
28	9151.3	8648.1
27	8151.3	7666.2
26	7201.2	6766.5
25	6356.6	5970.2
24	5605.9	5262.4
23	4938.6	4633.3
22	4345.4	4074.0
21	3818.2	3576.9
20	3349.5	3135.1
19	2932.9	2742.3
18	2562.6	2393.2
17	2233.4	2082.8
16	1940.8	1807.0
15	1680.8	1561.8
14	1449.6	1343.8
13	1244.1	1150.1
12	1061.4	977.8
11	899.0	824.8
10	754.7	688.7
9	626.4	567.7
8	512.4	460.2
7	411.0	364.7
6	320.9	279.7
5	240.8	204.2
4	169.7	137.1
3	106.4	77.4
2	50.1	24.4
1	0.1	-22.8



ATmospheric, Meteorological, and Environmental Technologies

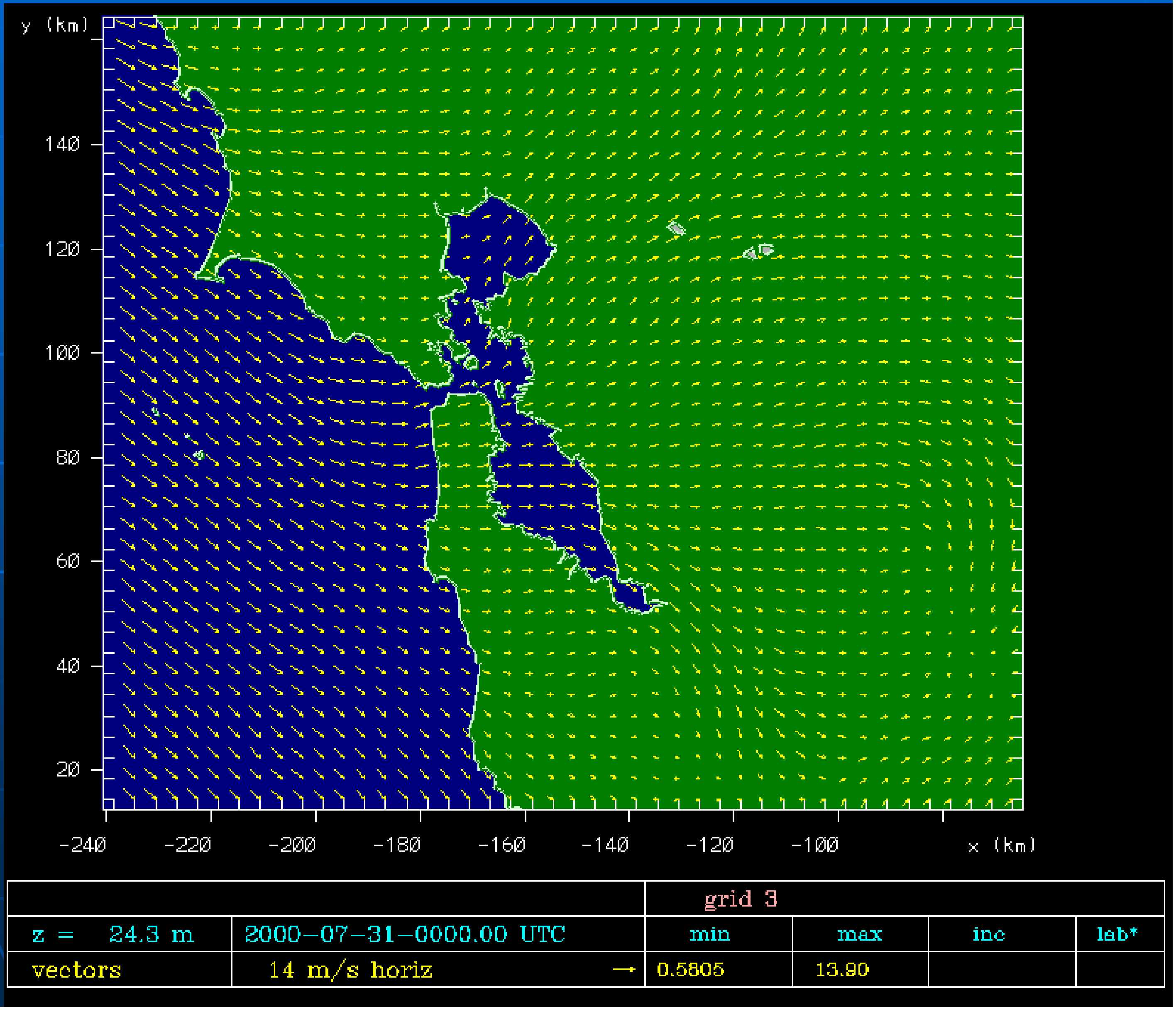
NCAR Surface Observations





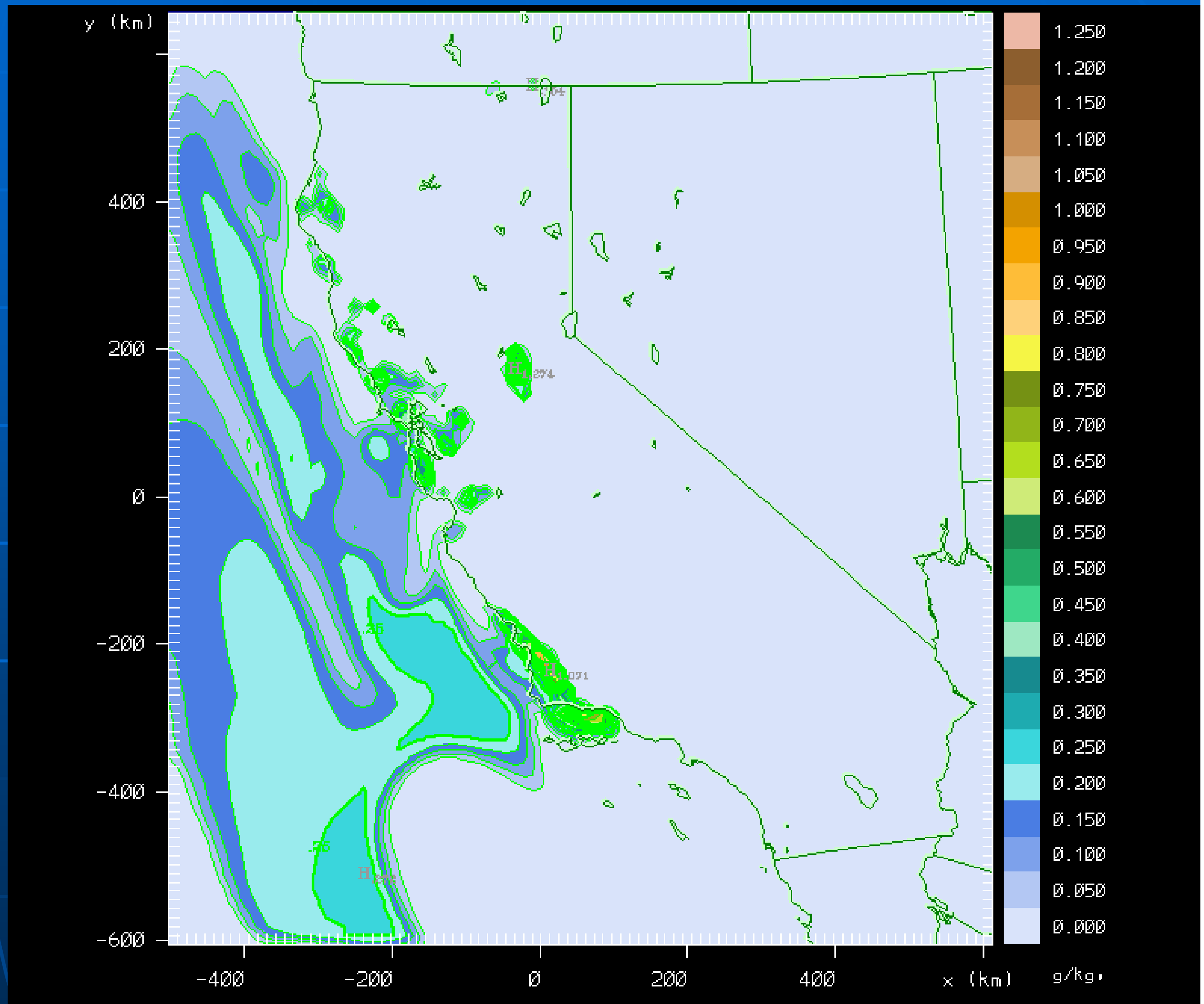
ATmospheric, Meteorological, and Environmental Technologies

Example wind field



ATmospheric, Meteorological, and Environmental Technologies

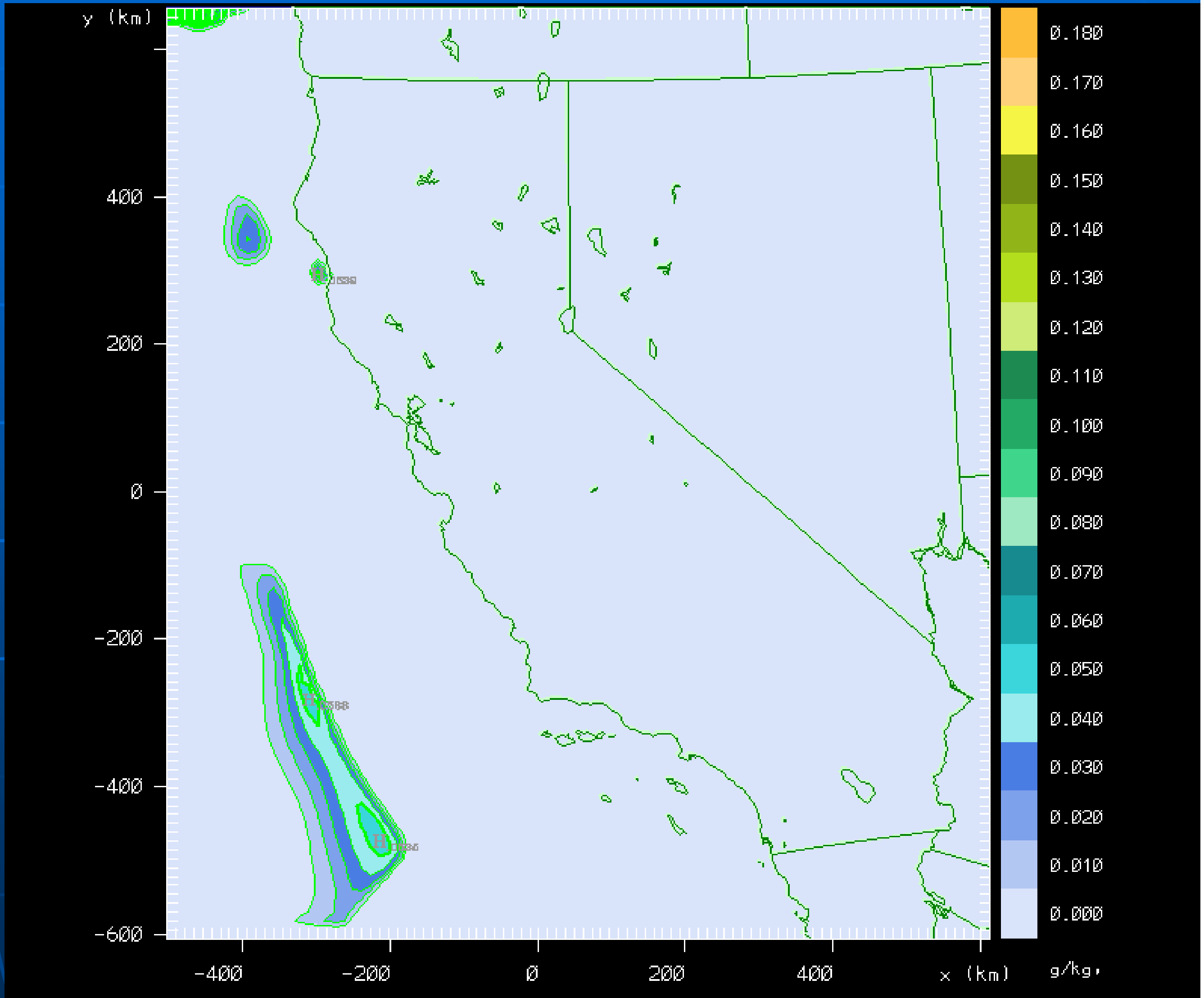
Cloud water lowest level 1200 UTC



		grid 2			
z = 24.3 m	2000-07-30-1200.00 UTC	min	max	inc	lab*
contour	cloud mix ratio (g/kg)	0.000	1.274	0.5000E-01	1e 0

ATmospheric, Meteorological, and Environmental Technologies

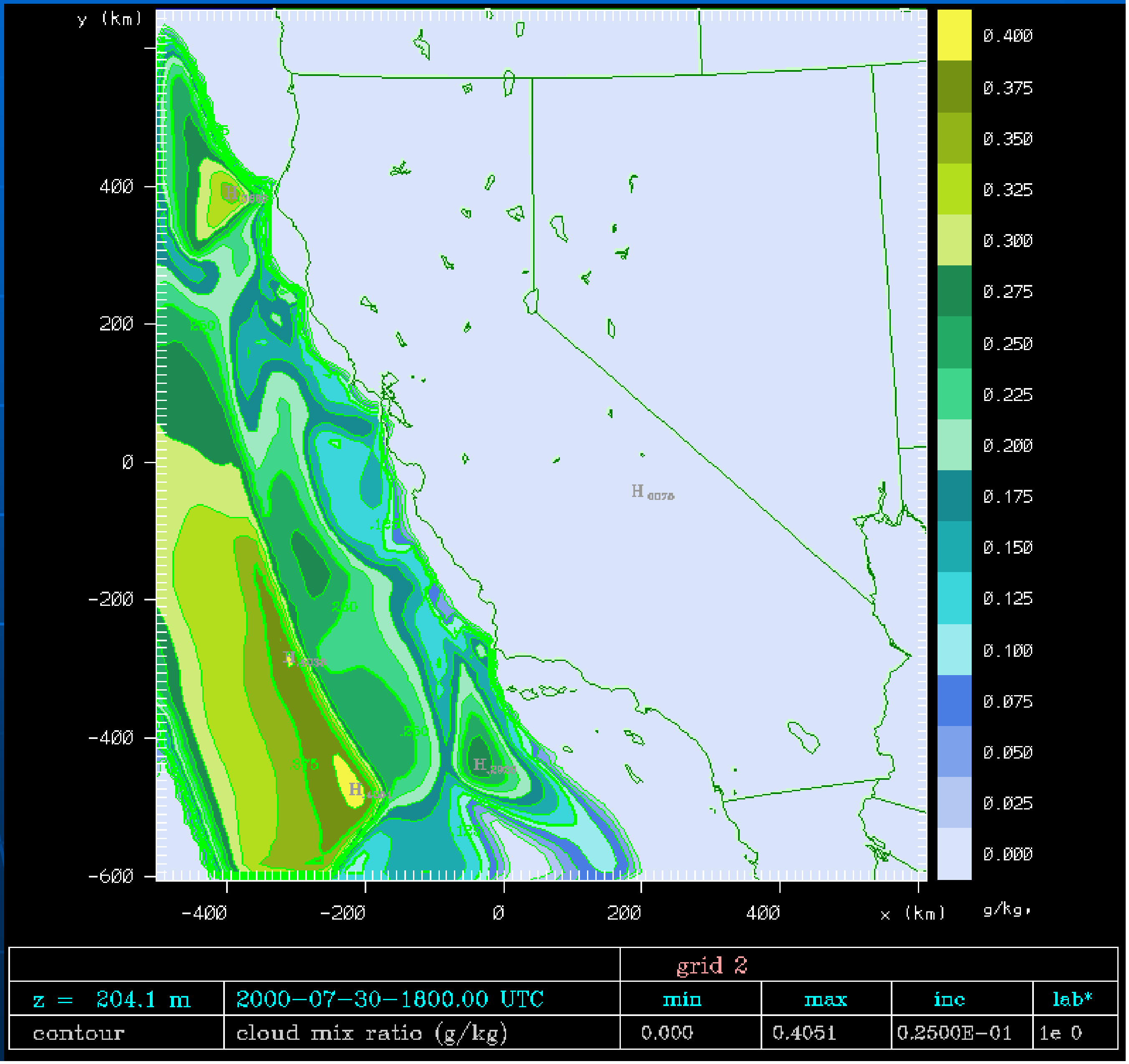
Cloud water lowest level 1800 UTC



		grid 2			
z = 24.3 m	2000-07-30-1800.00 UTC	min	max	inc	lab*
contour	cloud mix ratio (g/kg)	0.000	0.1802	0.1000E-01	1e 0

ATmospheric, Meteorological, and Environmental Technologies

Cloud water
200 m
1800 UTC

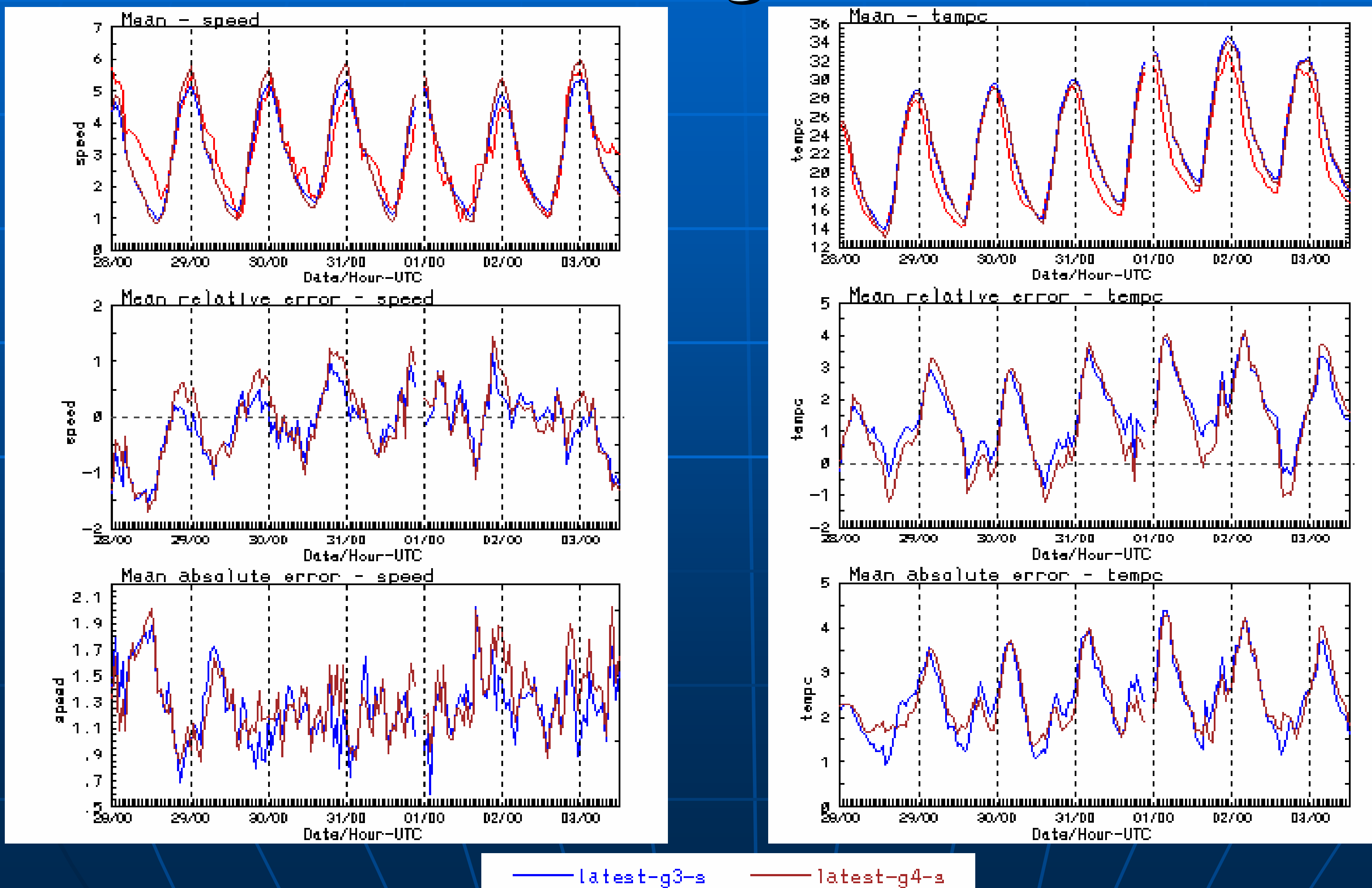


RAMS Episode 1 - Latest Configuration

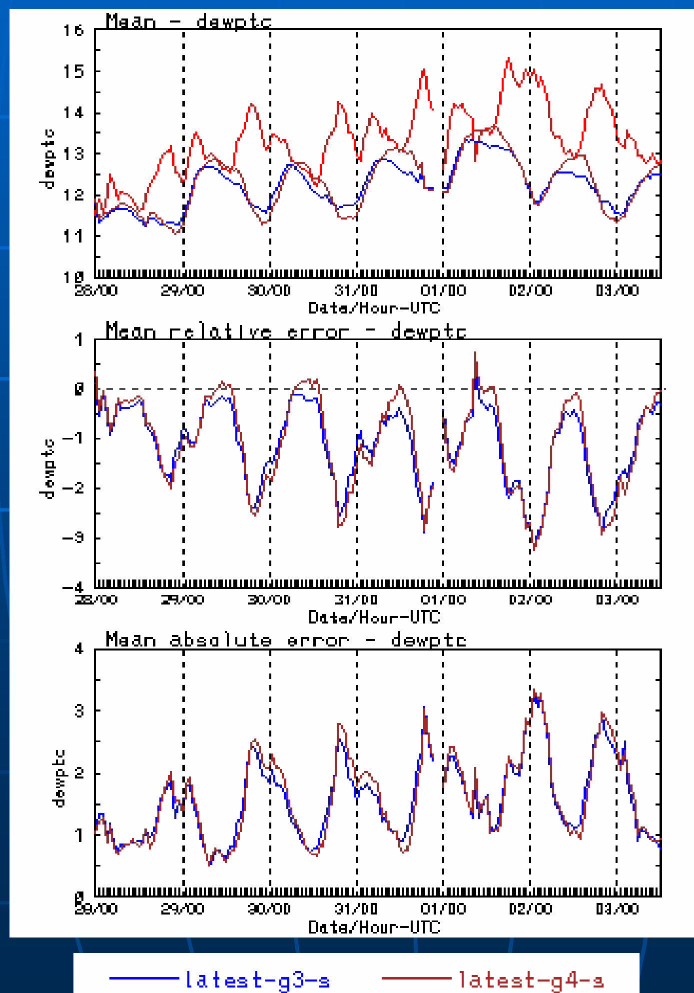
- 3 and 4 grids
- Extra smoothing of topography on SE quadrant of grid 3 (4 km)
- Analysis nudging with NCAR archived data – no ARB data
- Weak analysis nudging
  - 4.0, 5.0, 6.7, 10 hour timescales on grids 1-4
- Bay temperature constant at 19C
- No irrigated crop designation
- “Medium” soil moisture initial conditions

ATmospheric, Meteorological, and Environmental Technologies

RAMS Verification – Episode 1
3 vs. 4 grid runs

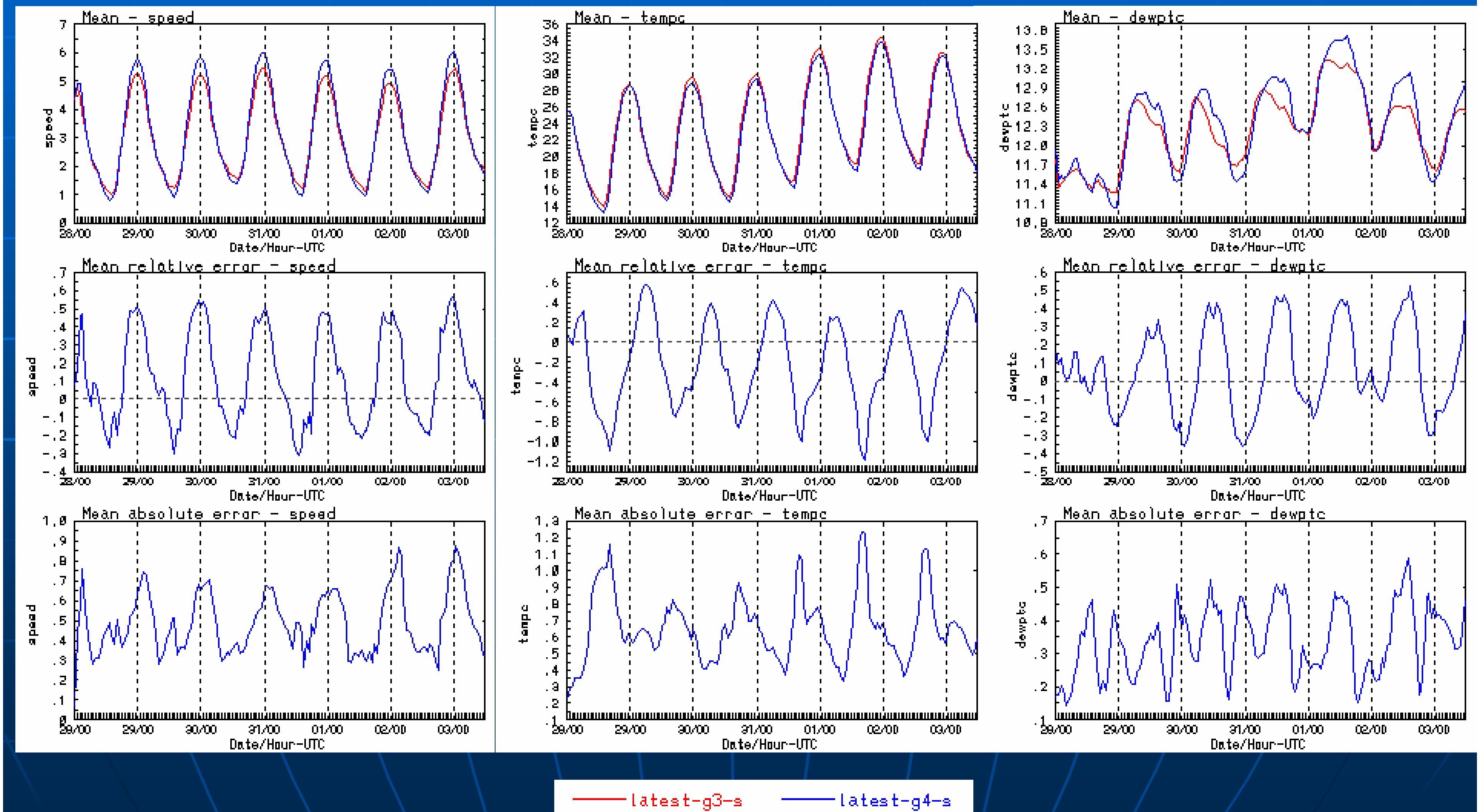


RAMS Verification – Episode 1
3 vs. 4 grid runs

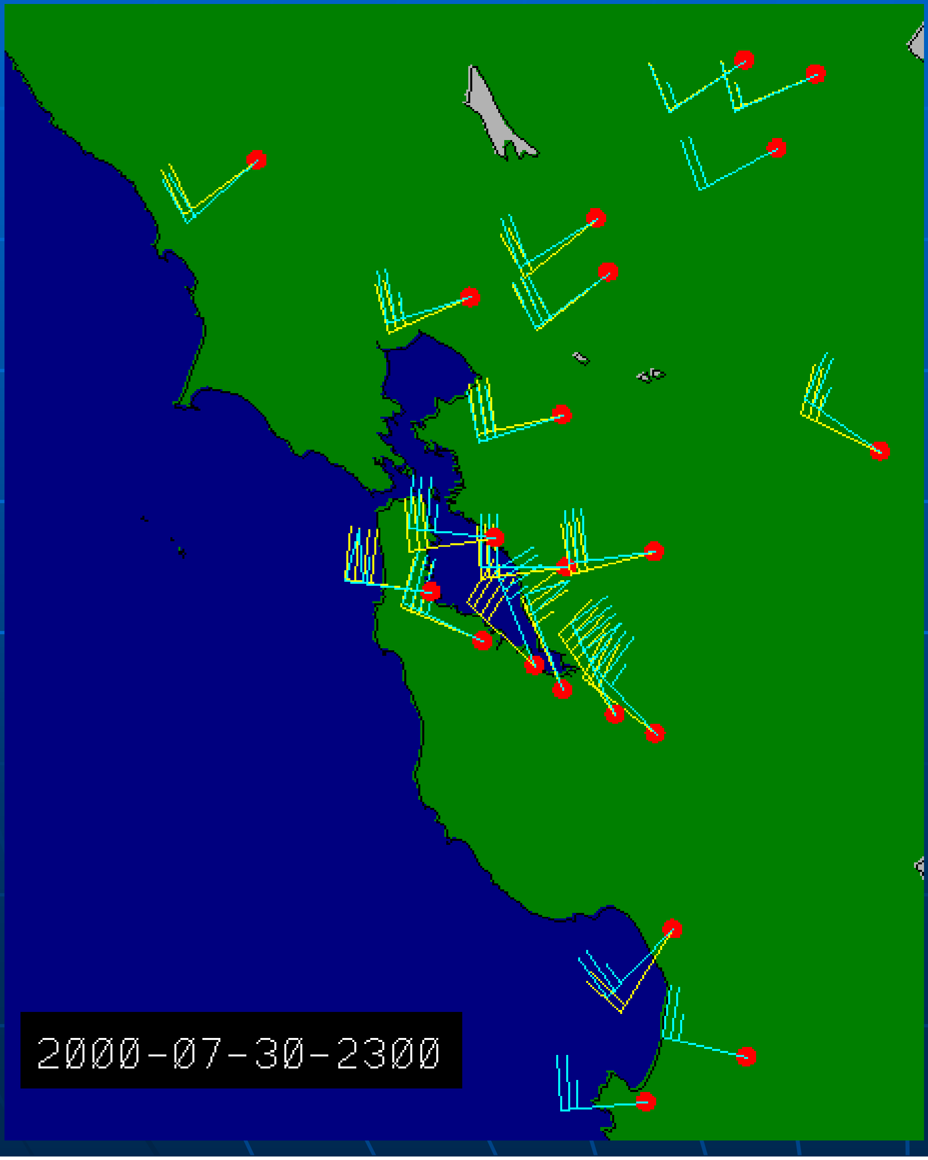


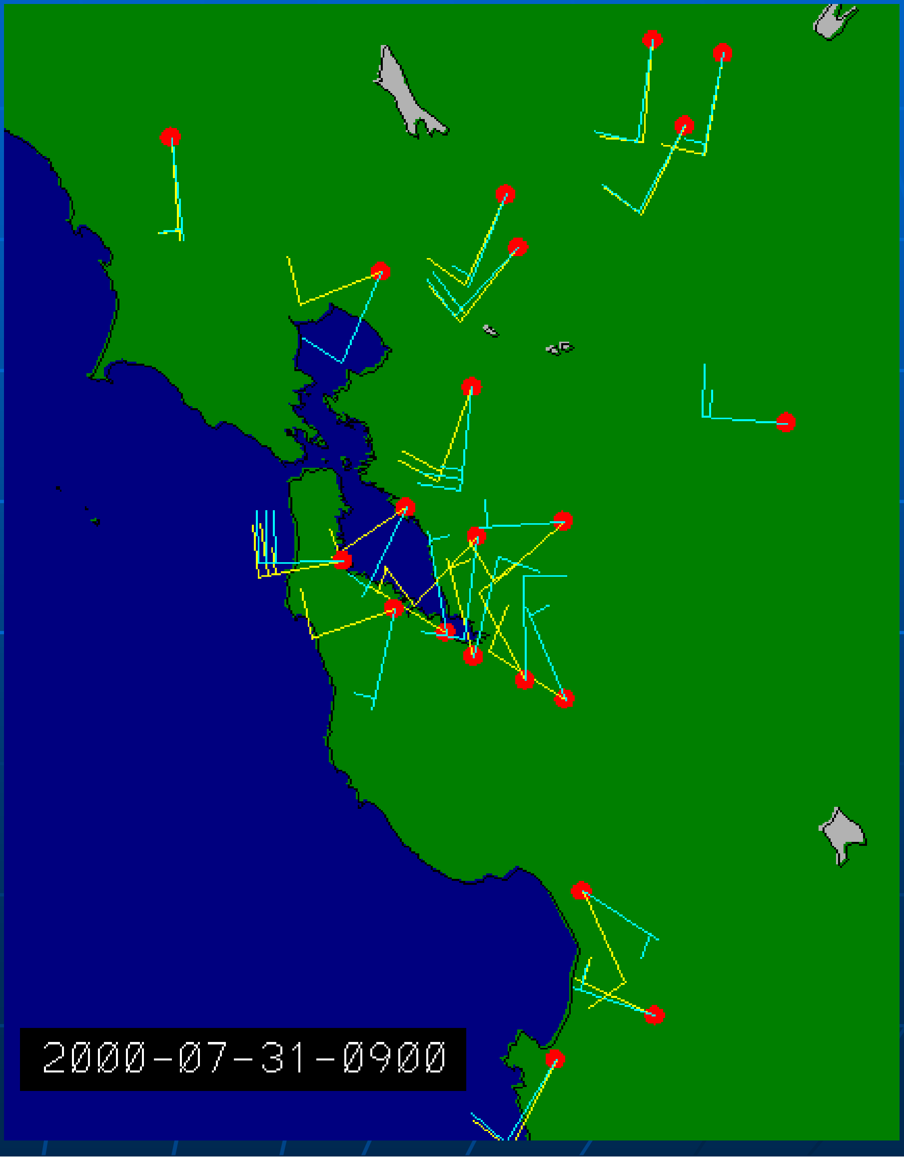
ATmospheric, Meteorological, and Environmental Technologies

Comparison of 3 vs. 4 grid run



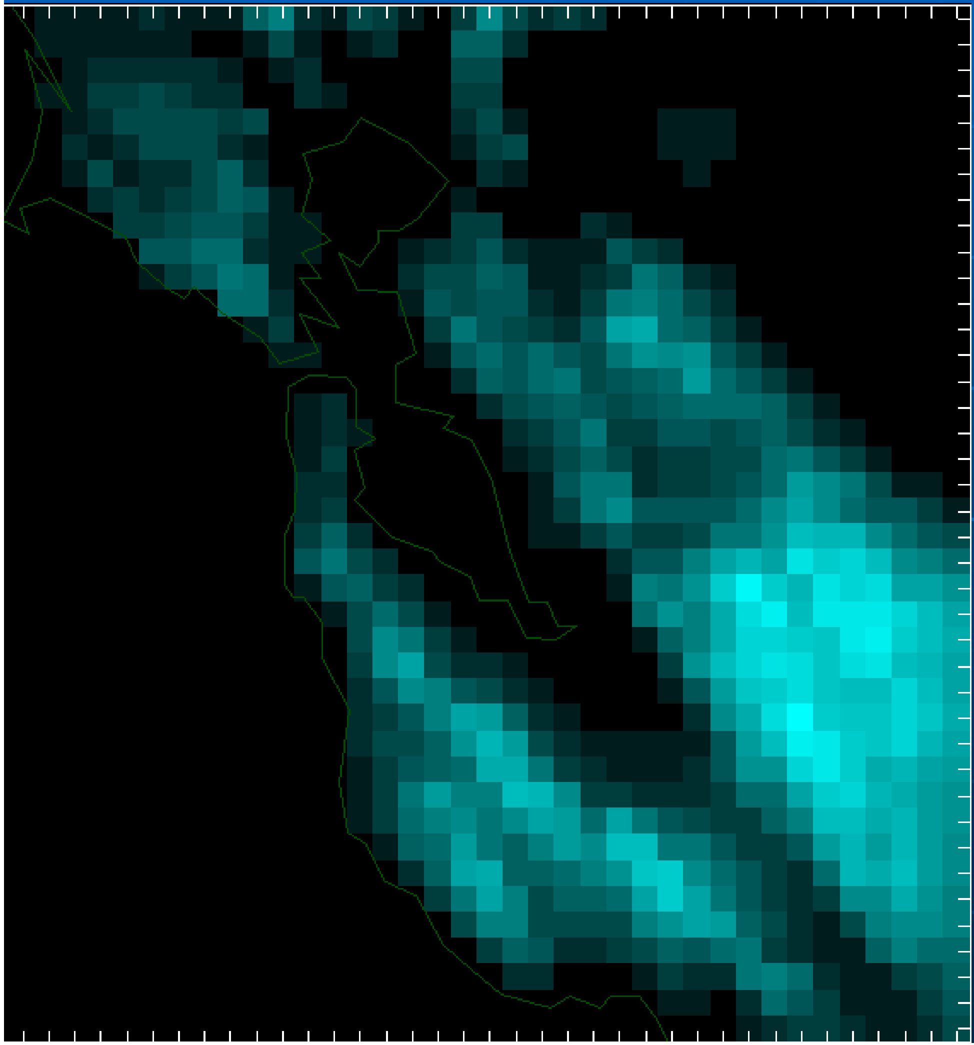
Comparison of 3 vs. 4 grid run

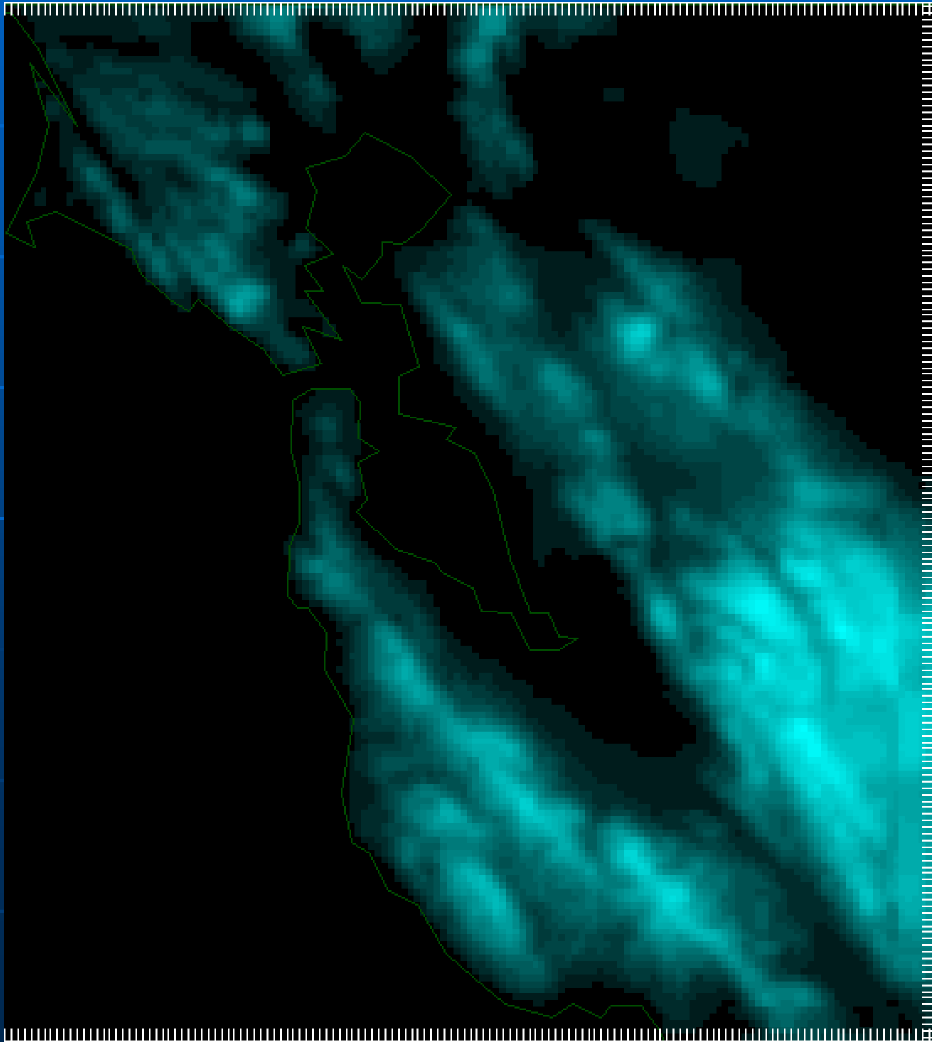




ATmospheric, Meteorological, and Environmental Technologies

4km and 1km topography



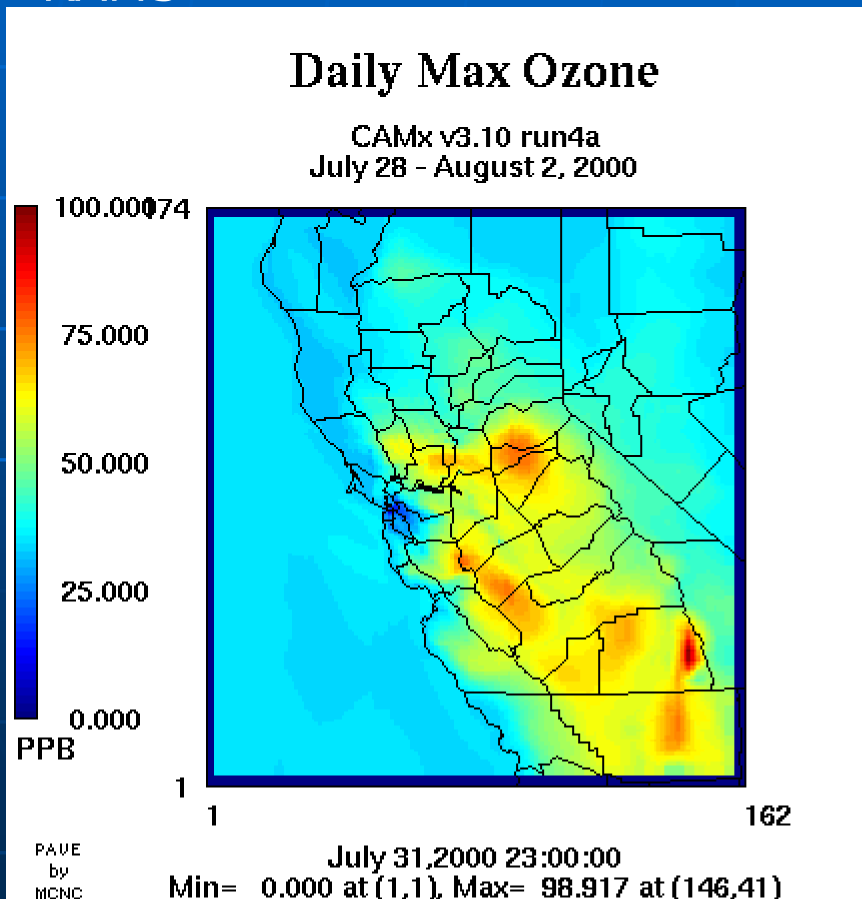


Next Steps for Episode 1

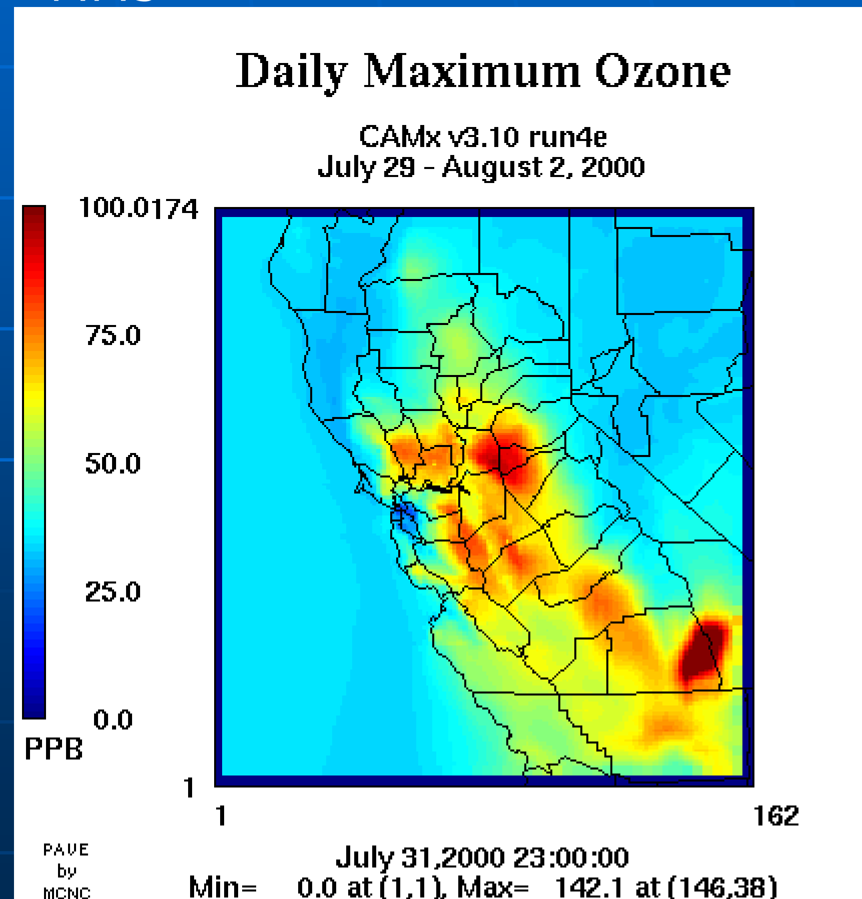
- Obs nudging FDDA will be started when QC'ed obs are available
- Large portion of errors probably dependent on localized conditions at the time (state of irrigation, etc.)
- Clusters of stations (e.g. Sacramento) show 2 similar, 1 very different. For example, 1 station might vary 5C temp, 7C dewpoint from others
- Difficult to account for even with obs nudging
- Since ozone performance was better with MM5 fields, we are analyzing the MM5 simulation to see if the meteorology is actually better, or if it was fortuitous.
- If the meteorology is in fact better, this will potentially give us guidance as to RAMS configuration.

MM5 vs. RAMS CAMx results

RAMS

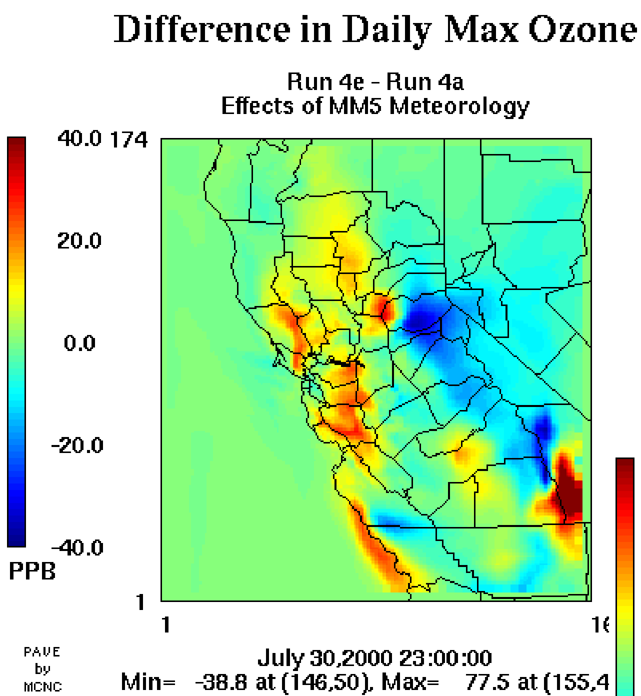


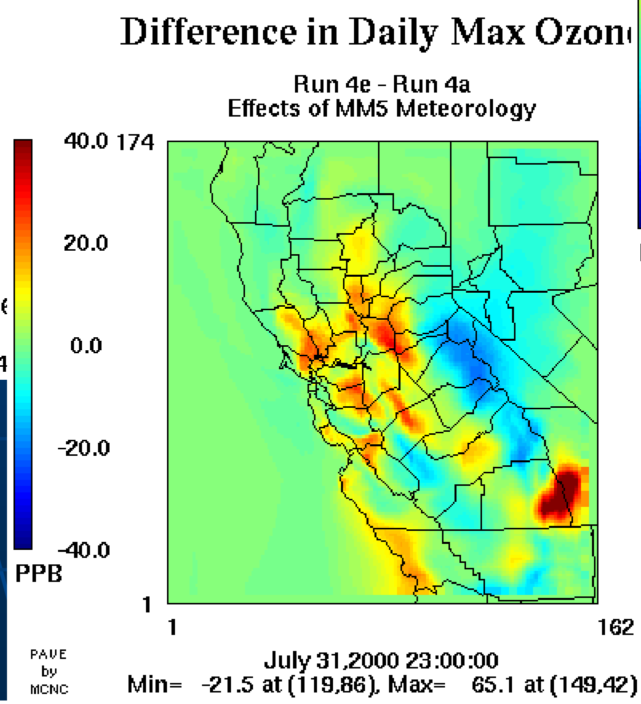
MM5

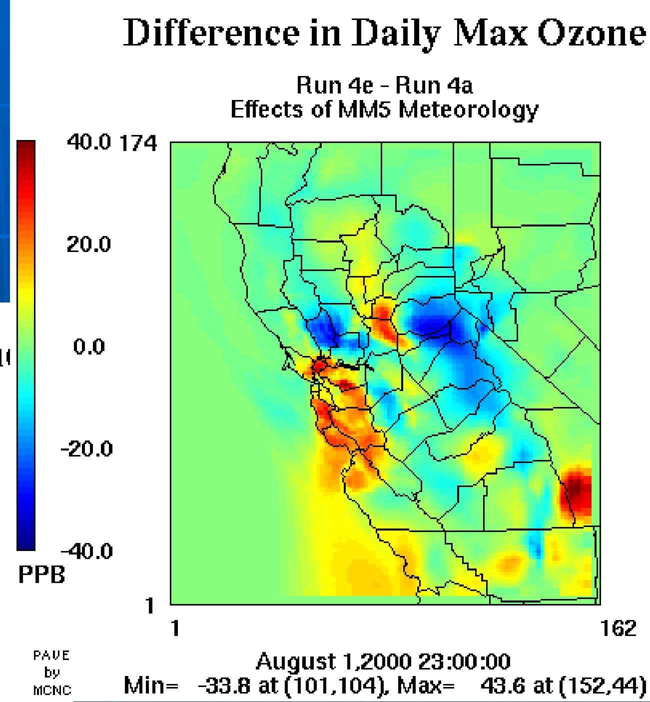


MM5 vs. RAMS CAMx results

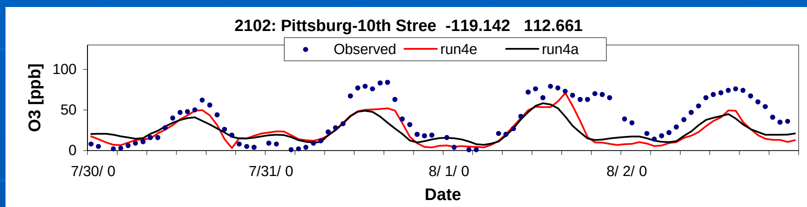
MM5 - RAMS

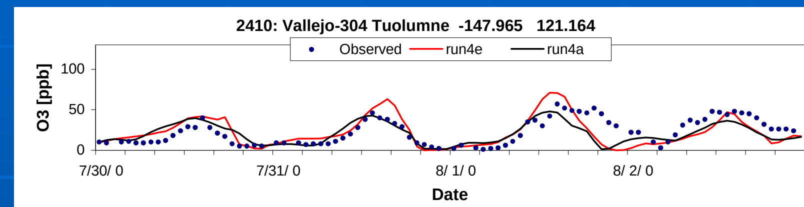


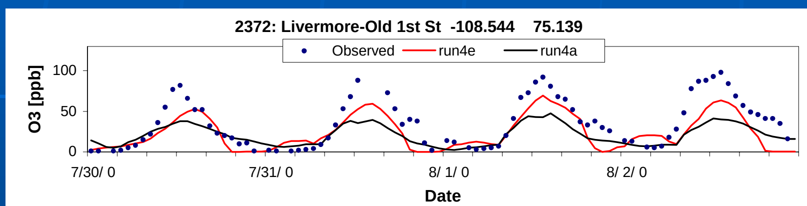


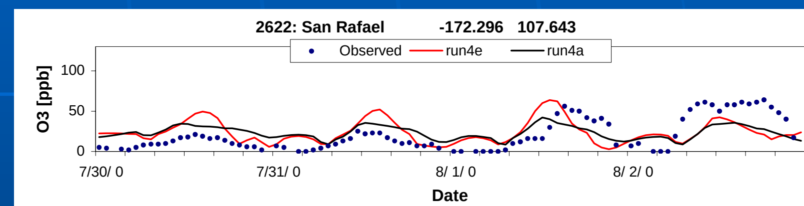


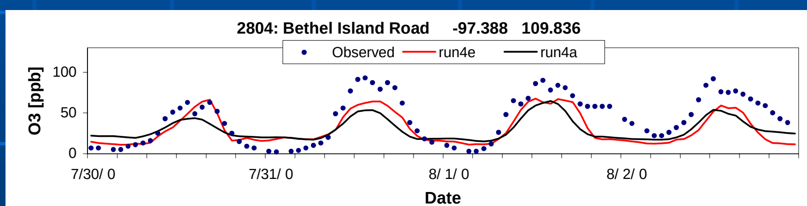
MM5 vs. RAMS CAMx results

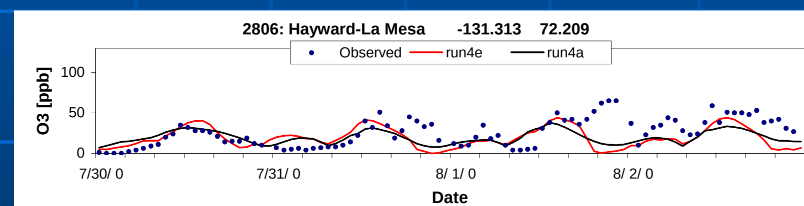


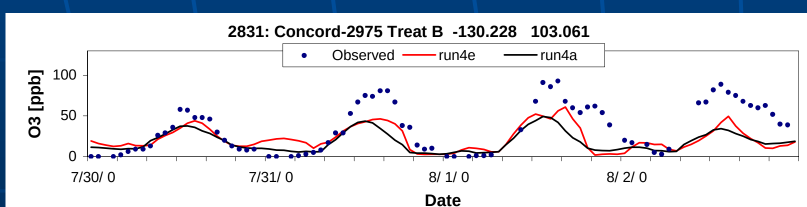


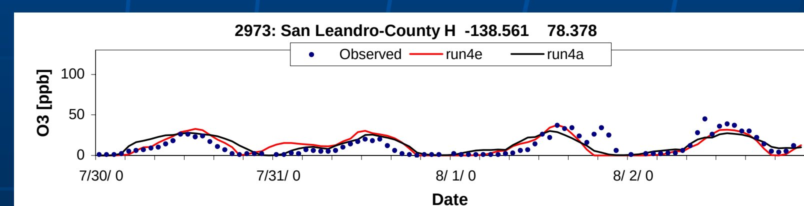


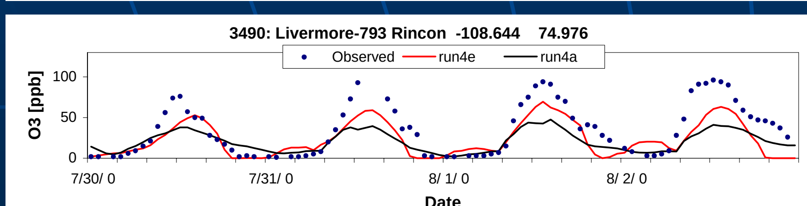


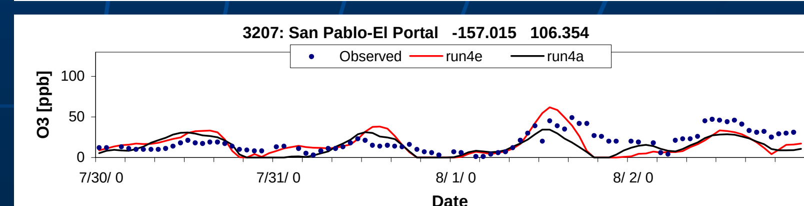




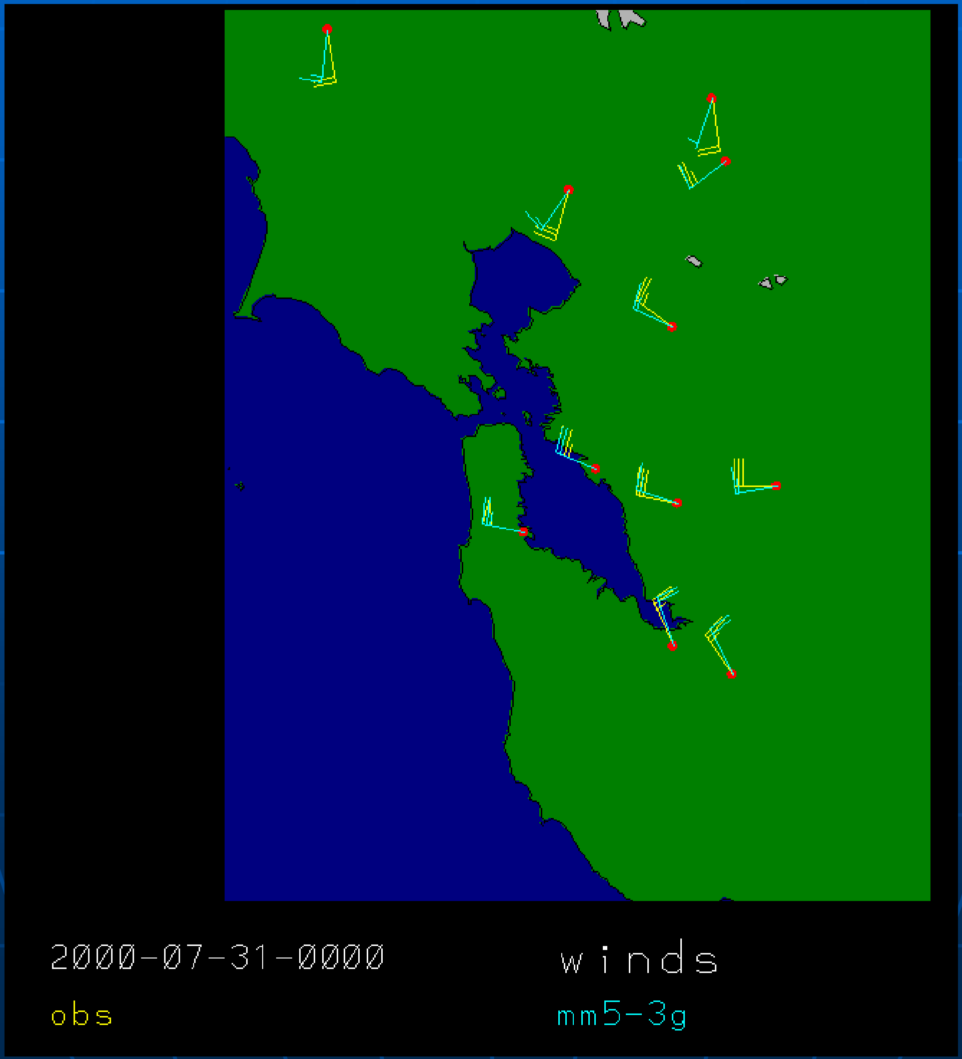






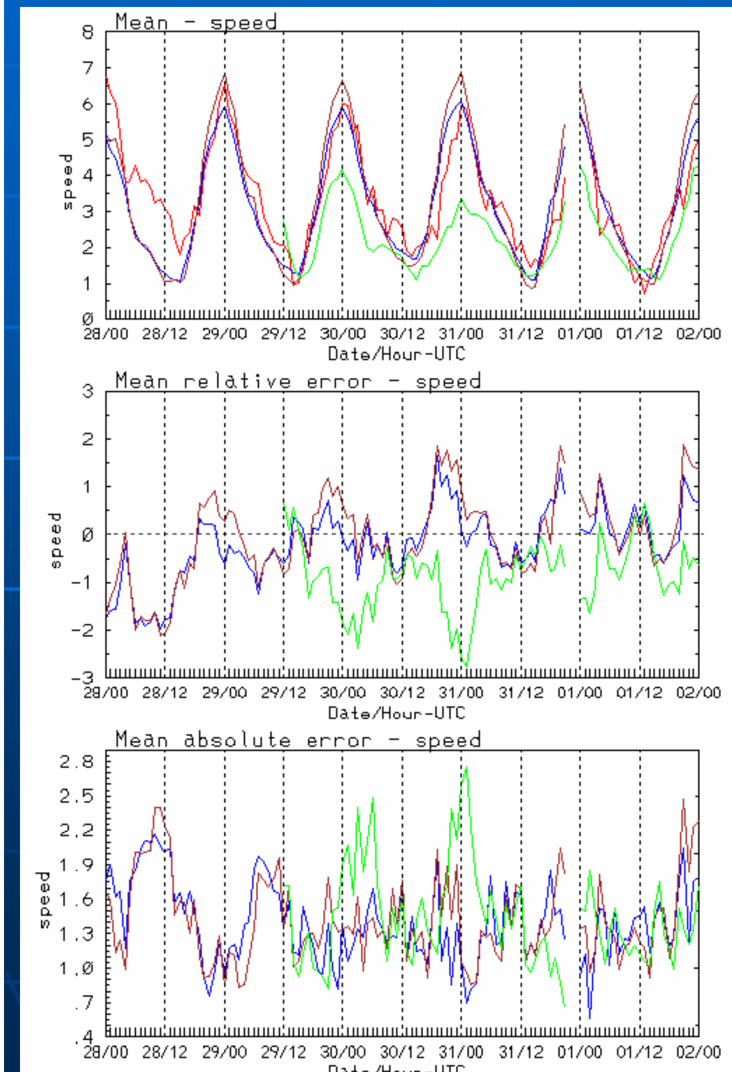


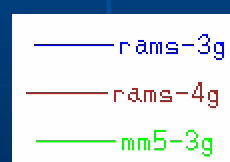
Verification domain A

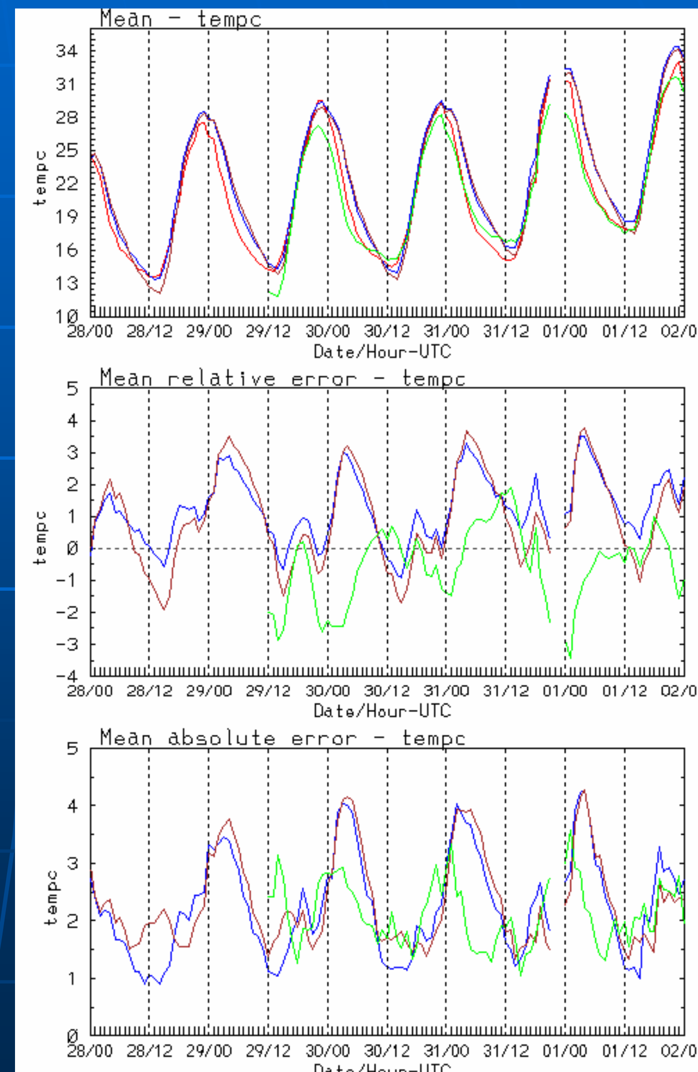


ATmospheric, Meteorological, and Environmental Technologies

Verification domain A

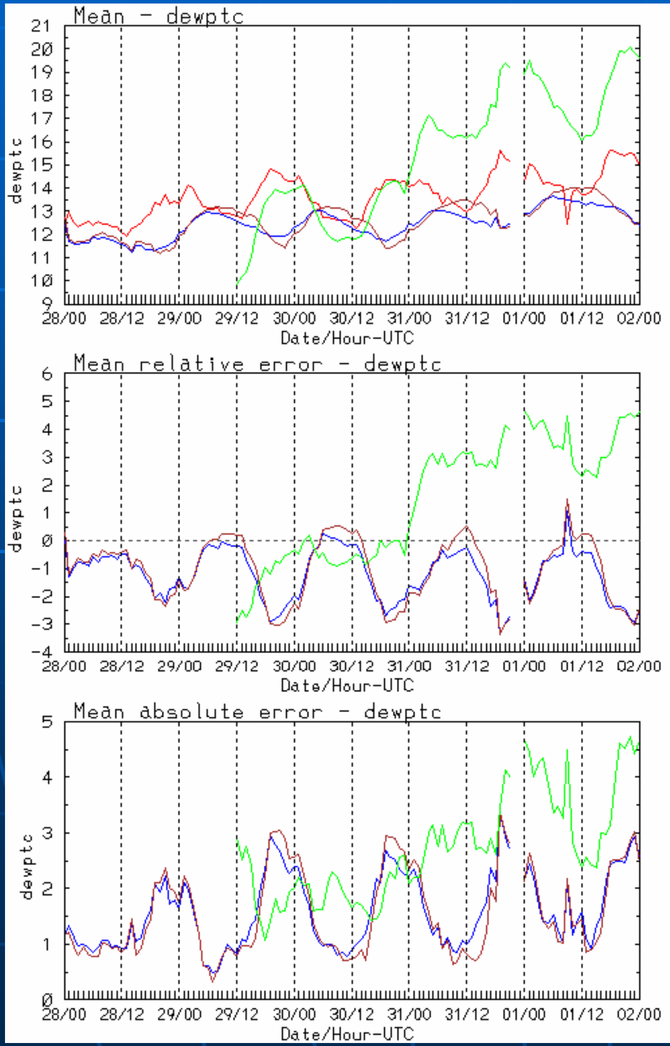


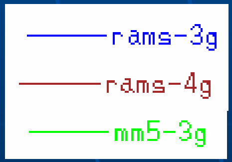




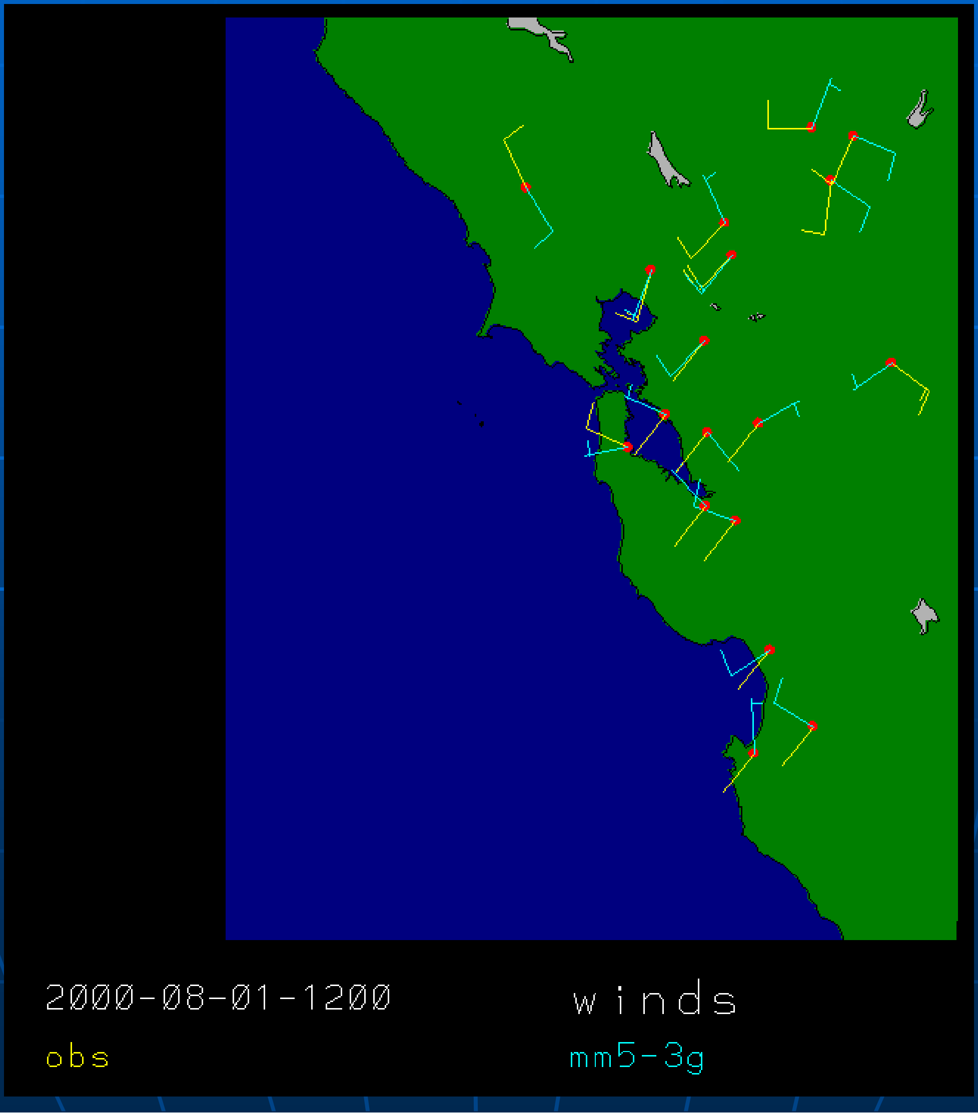
ATmospheric, Meteorological, and Environmental Technologies

Verification domain A

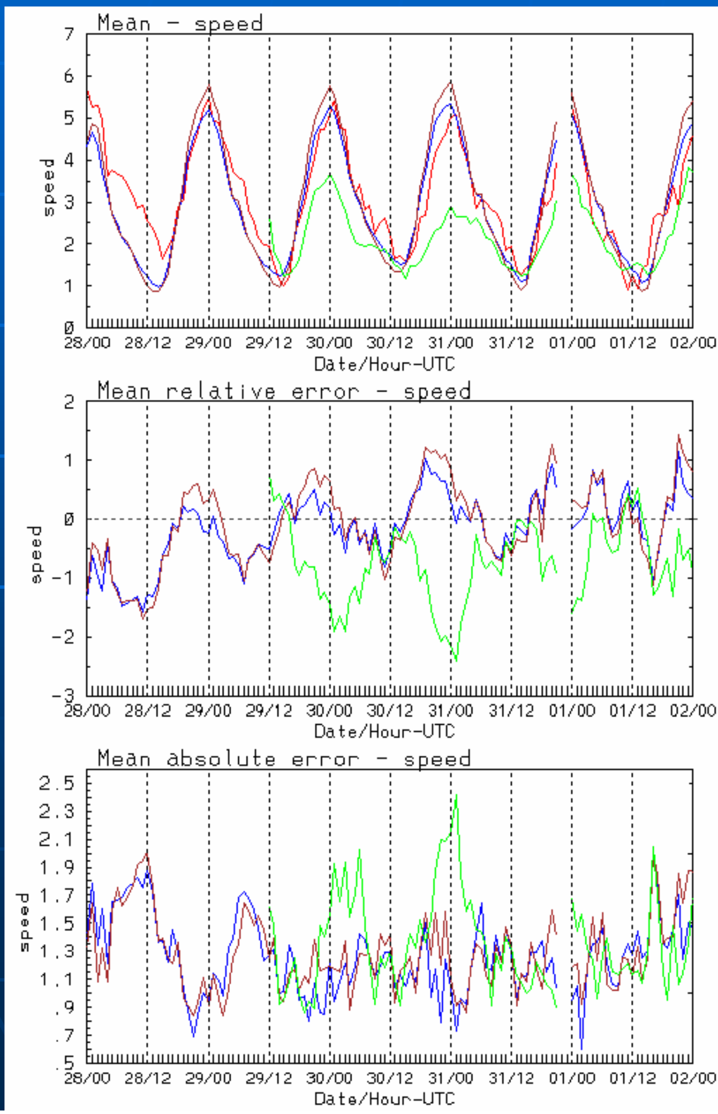


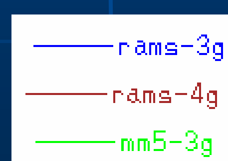


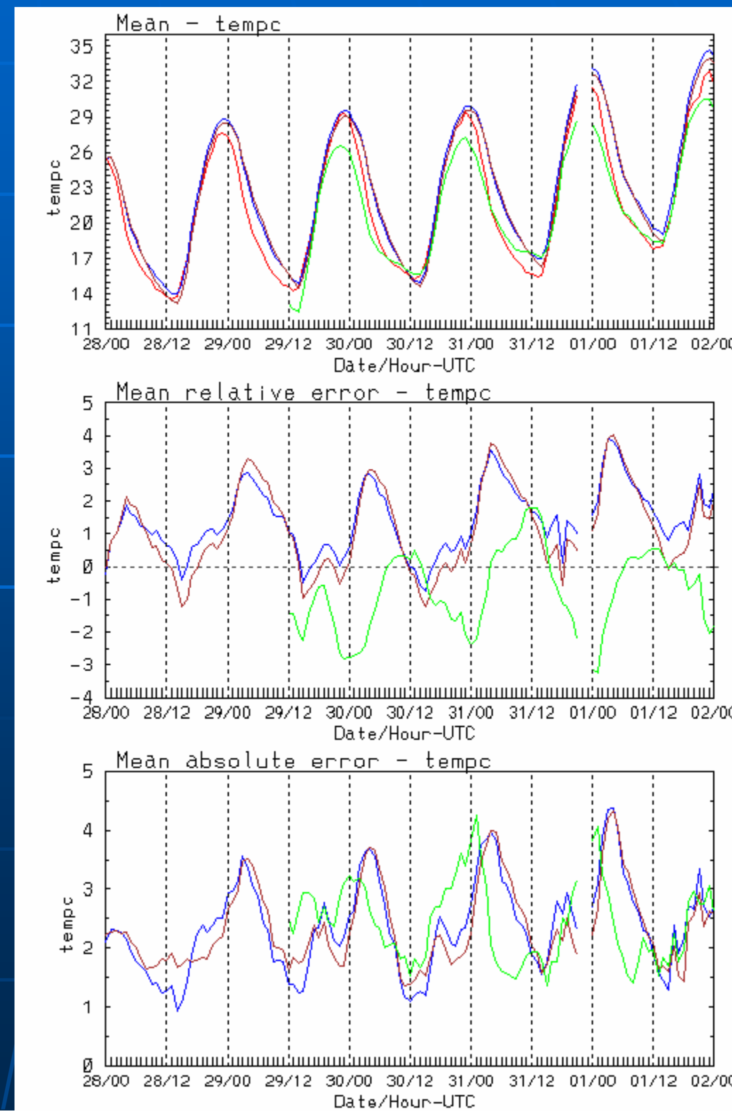
Verification domain B



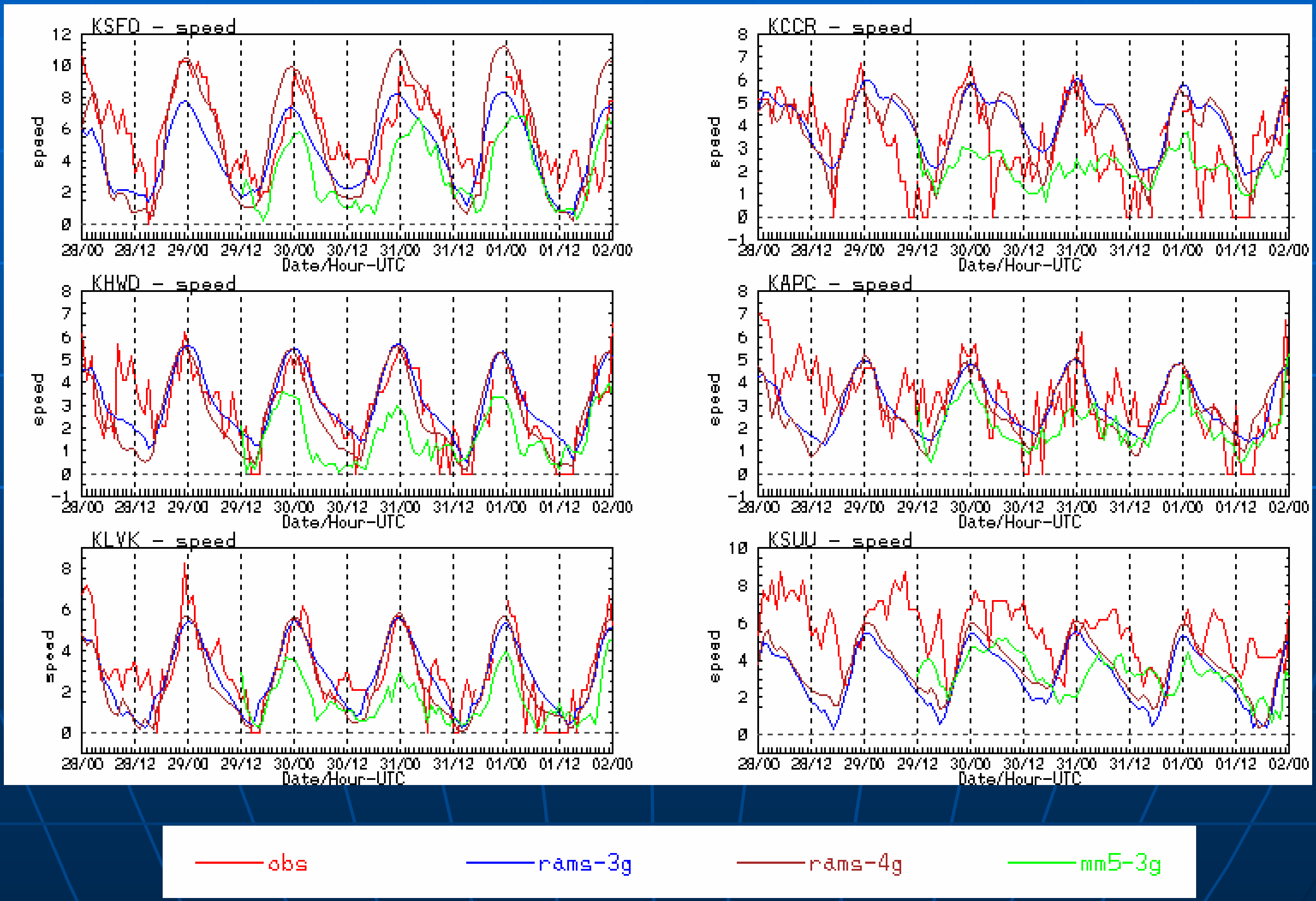
Verification domain B







Selected station verification



Episode 2 runs

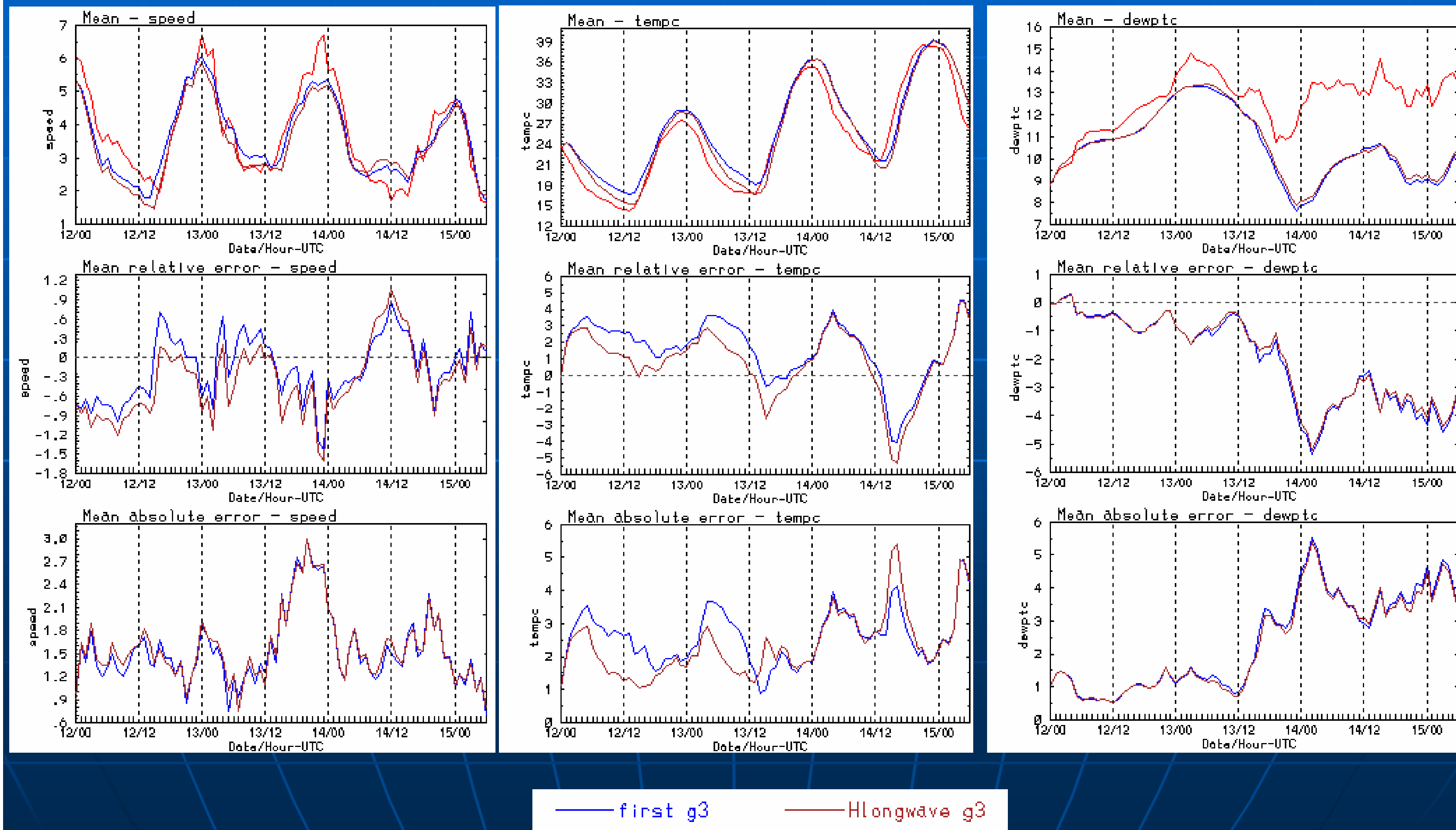
- 3 grid episode 2 runs performed
- Initial configuration – same as last episode 1 configuration
- Initial sensitivity runs testing soil moisture and longwave scheme.

Latest RAMS configuration

- Same as episode 1, except:
  - Weaker analysis nudging
    - Base timescale: 6 vs. 4 hrs
    - ¼ strength for T and vapor
  - Initial soil moisture profile:
    - Ep1: SLMSTR = 0.30, 0.30, 0.30, 0.30, 0.25, 0.25, 0.25, 0.25, 0.2, 0.20, 0.20,
    - Ep2: SLMSTR = 0.55, 0.50, 0.45, 0.40, 0.40, 0.35, 0.35, 0.30, 0.25, 0.20, 0.15,

ATmospheric, Meteorological, and Environmental Technologies

Episode 2 – original vs. Harr. longwave



Meteorology for Episode 2

- More difficult meteorological situation than Episode 1
  - Earlier in season, different vegetation/soil characteristics
  - Upper level high dominates
  - Weaker winds in general, but…

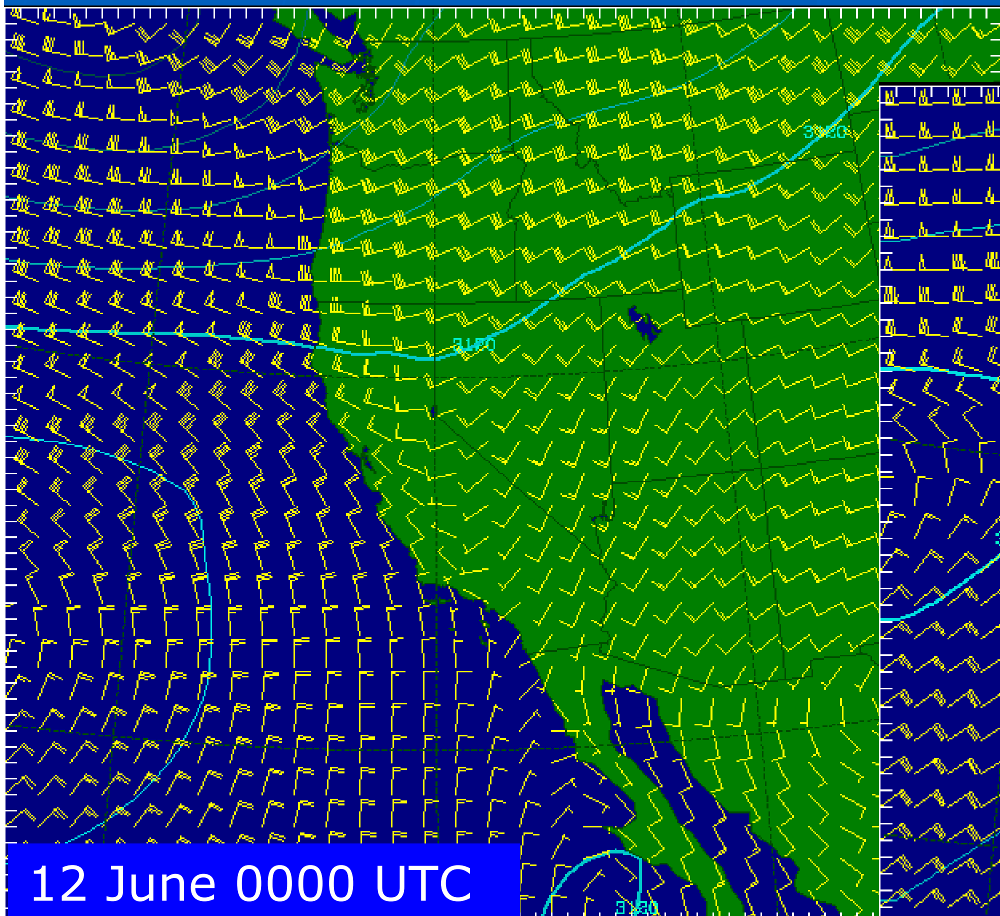
Meteorology for Episode 2

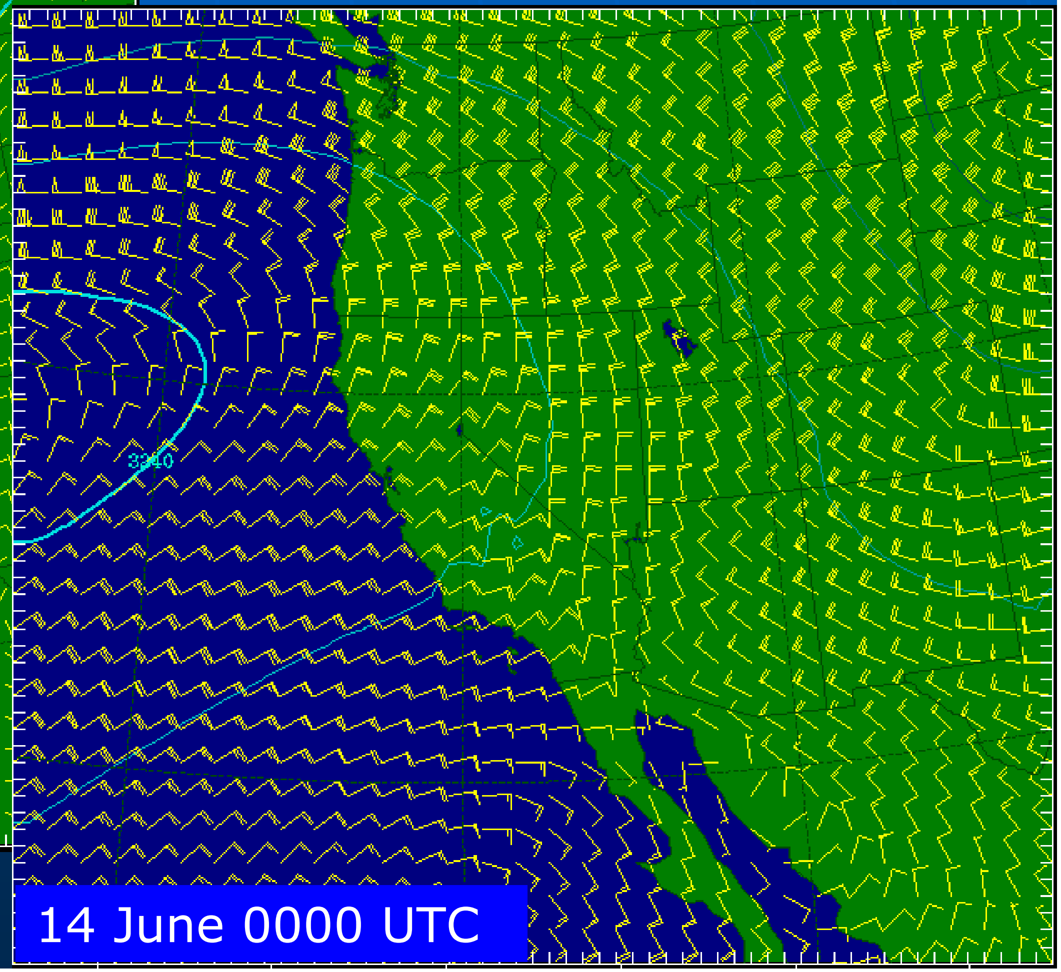
- Difficult to capture mountain-induced mid-level structure along with correct boundary-layer structure to correctly simulate downward momentum mixing and subsidence warming…
- *Especially 48-90 hours from initialization relying on FDDA*
- *4 km resolution also plays a role*

Meteorology for Episode 2

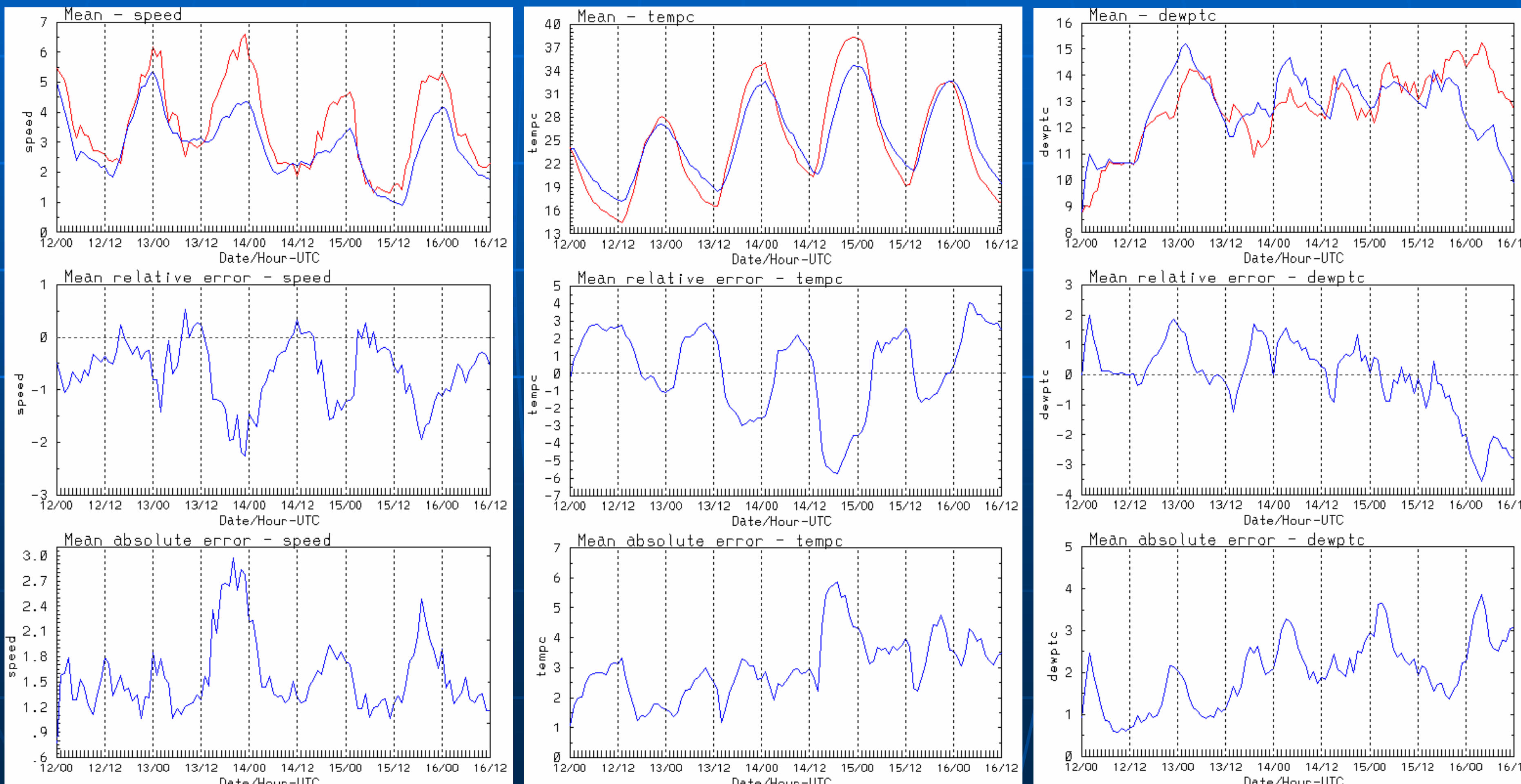
- Upper level high caused easterly mid-level flow, strongest on 14-15 June
- As surface high moved onshore, northerly flow channeled down Sacramento Valley
- Numerous interactions: easterly winds (downslope flow from the Sierras), northerly flow in the Central Valley, diurnal upslope flows, onshore flow from Pacific, and usual topographic effects

700 mb geopotential and winds

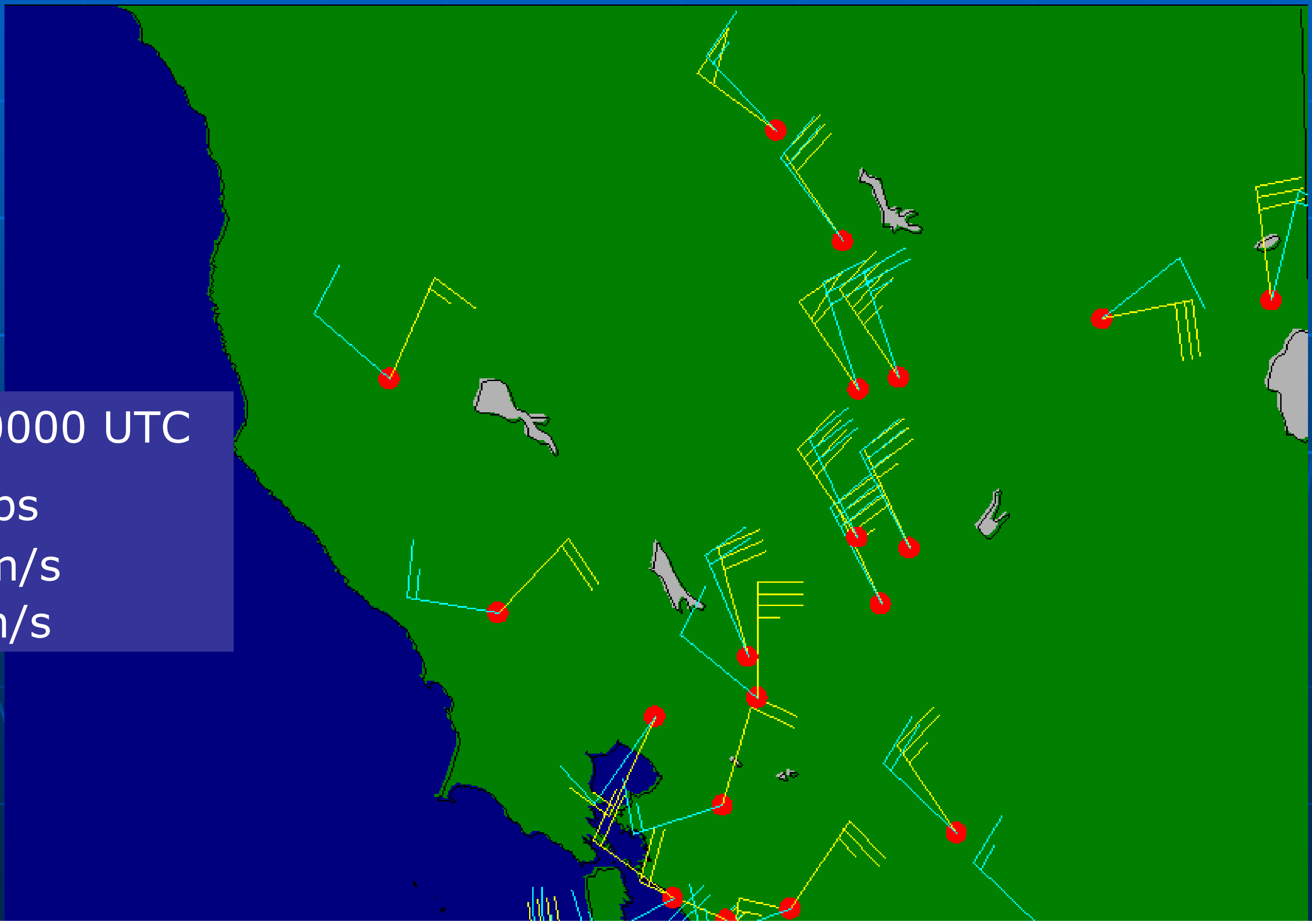




Episode 2 – Mean errors



Winds - 14 June 0000 UTC



14 June 0000 UTC

yellow=obs
flag=10 m/s
barb=2 m/s

Further tests

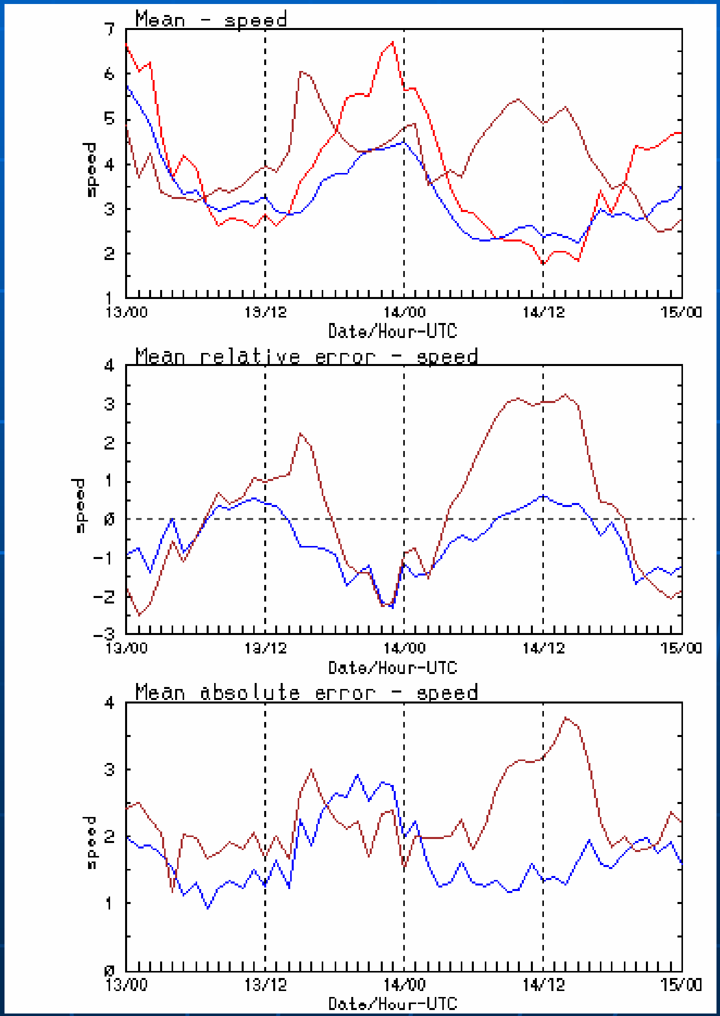
- Numerous additional sensitivity runs performed in attempt to improve 14-15 June performance:
  - Using reanalysis data:
    - Soil moisture adjustments (drier, wetter, drier valley/wetter mountains)
    - FDDA modifications (stronger, weaker, only mid/upper levels)

Further tests (continued)

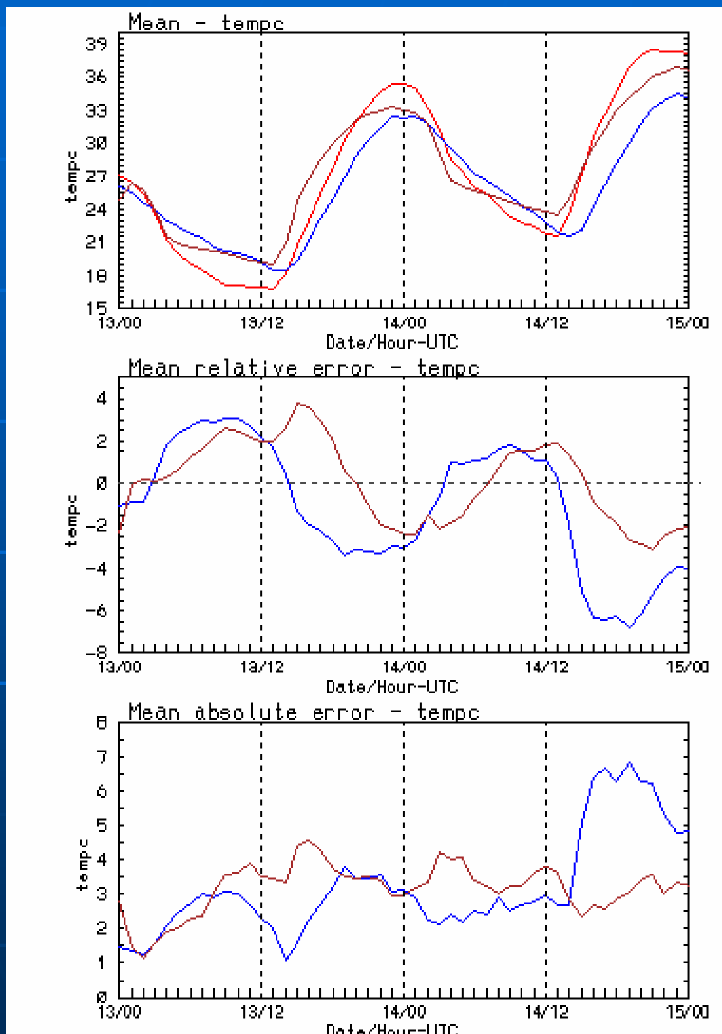
- Switch to EDAS analysis from reanalysis data
  - Numerous shorter tests without FDDA
  - Soil moisture, roughness length changes
  - Results similar but somewhat worse
  - Nothing made a substantial improvement
- Ran MM5 to compare results

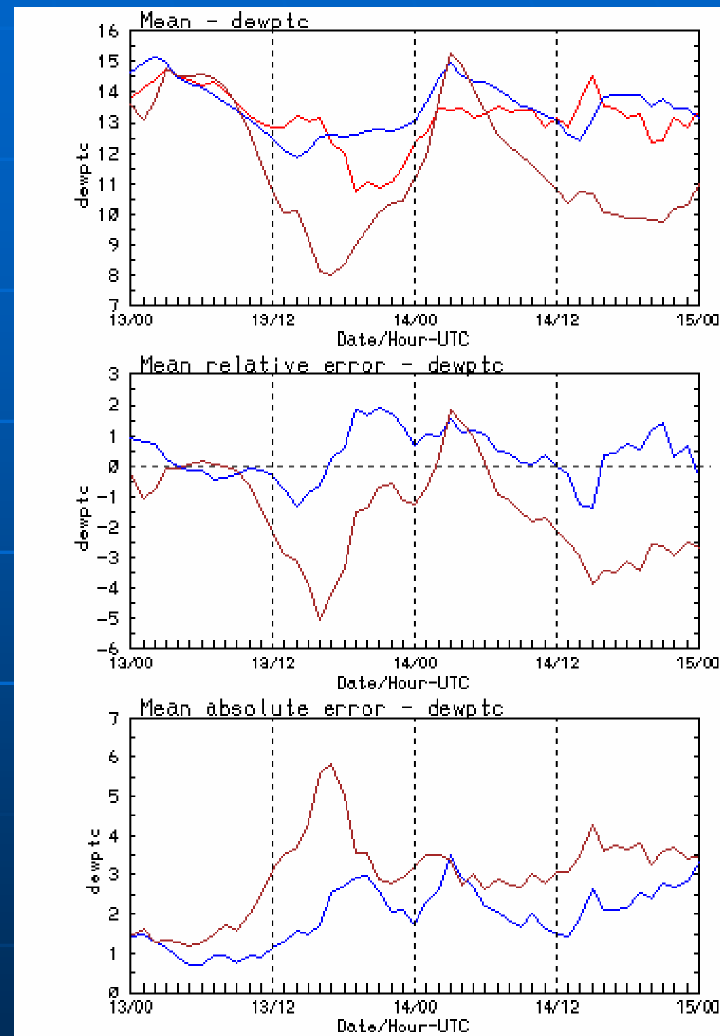
MM5 Test for Episode 2

- 48 hour run, 13-15 June, no FDDA



ATmospheric, Meteorological, and Environmental Technologies





Hypothesis for Behavior

- Most likely cause: since high pressure system is offshore, inadequate information in the large scale analysis (reanalysis or EDAS) to properly trigger correct evolution after models are initialized.
- Use of FDDA continues to nudge toward inadequate fields. Use of obs nudging may help, but strength of high system more controlled by upper levels where very few obs exist. Also, fewer obs to N/NE of Bay Area.

Next Steps for Episode 2

- If this episode is continued:
  - Attempt obs nudging FDDA
  - Expand coarse grid to have more of synoptic scale in domain at initialization.
  - Investigate performance of shorter runs, initializing at 15 June, 0000 UTC or 1200 UTC. Localized ozone exceedance on this day may not be strongly dependent on previous days.