# High Vertical Resolution MM5 in the Western United States

prepared for:
Ad-hoc Met. Group

prepared by:

Dennis McNally
Alpine Geophysics, LLC

24 June 2010

# Motivation

- More recent interest in simulating cold period air quality events
- Important issue in Southwestern Wyoming and North Eastern Utah
- May be important in other urban areas
- May be useful for “CALPUFF” modeling using the MMIF tool

# Motivation (cont.)

- Upper Green Winter Ozone Study (UGWOS) suggests key mechanism is a thermal structure with elevated inversion to cap mixed layer
- Necessary to limit vertical precursor mixing to get sufficiently high concentrations to make ozone efficiently

# Motivation (conc.)

- May be useful for “CALPUFF” modeling using the MMIF tool
  - CALMET traditionally run with shallower surface layers than MM5

# Traditional MM5 Vertical Structure

- Developed to address "traditional" air quality
- 100 mb model top
- ~38 meter thick layers near ground
- Instantaneous mixing in AQ model into ~38 meter layer artificially dilutes precursors
- 5 layers below 250 meters
- Cell Tops
  - 38,77,115,154,232,310,389

| k(MM5) | sigma | press.(mb) | height(m) | depth(m) |
|---|---|---|---|---|
| 34 | 0.000 | 10000 | 15674 | 2004 |
| 33 | 0.050 | 14500 | 13670 | 1585 |
| 32 | 0.100 | 19000 | 12085 | 1321 |
| 31 | 0.150 | 23500 | 10764 | 1139 |
| 30 | 0.200 | 28000 | 9625 | 1004 |
| 29 | 0.250 | 32500 | 8621 | 900 |
| 28 | 0.300 | 37000 | 7720 | 817 |
| 27 | 0.350 | 41500 | 6903 | 750 |
| 26 | 0.400 | 46000 | 6153 | 693 |
| 25 | 0.450 | 50500 | 5461 | 645 |
| 24 | 0.500 | 55000 | 4816 | 604 |
| 23 | 0.550 | 59500 | 4212 | 568 |
| 22 | 0.600 | 64000 | 3644 | 536 |
| 21 | 0.650 | 68500 | 3108 | 508 |
| 20 | 0.700 | 73000 | 2600 | 388 |
| 19 | 0.740 | 76600 | 2212 | 282 |
| 18 | 0.770 | 79300 | 1930 | 274 |
| 17 | 0.800 | 82000 | 1657 | 178 |
| 16 | 0.820 | 83800 | 1478 | 175 |
| 15 | 0.840 | 85600 | 1303 | 172 |
| 14 | 0.860 | 87400 | 1130 | 169 |
| 13 | 0.880 | 89200 | 961 | 167 |
| 12 | 0.900 | 91000 | 794 | 82 |
| 11 | 0.910 | 91900 | 712 | 82 |
| 10 | 0.920 | 92800 | 631 | 81 |
| 9 | 0.930 | 93700 | 550 | 80 |
| 8 | 0.940 | 94600 | 469 | 80 |
| 7 | 0.950 | 95500 | 389 | 79 |
| 6 | 0.960 | 96400 | 310 | 78 |
| 5 | 0.970 | 97300 | 232 | 78 |
| 4 | 0.980 | 98200 | 154 | 39 |
| 3 | 0.985 | 98650 | 115 | 39 |
| 2 | 0.990 | 99100 | 77 | 38 |
| 1 | 0.995 | 99550 | 38 | 38 |
| 0 | 1.000 | 100000 | 0 | 0 |

# High Resolution Vertical Grid Structure

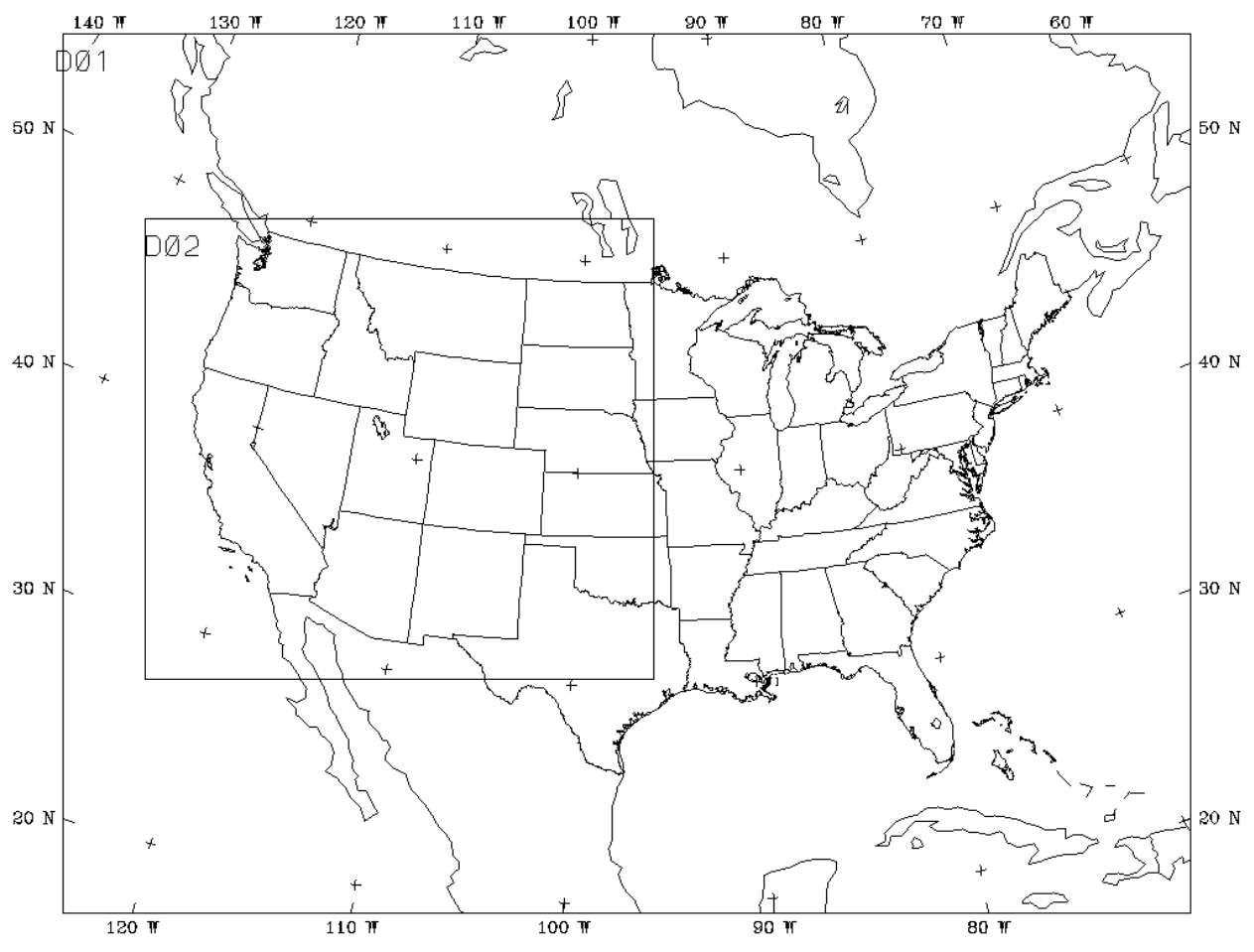
- 50 mb model top
- ~38 meter thick layers near ground
- Instantaneous mixing in AQ model into ~38 meter layer artificially dilutes precursors
- 10 layers below 250 meters
- Cell tops at:
  - 8,12,24,40,57,73,97,122,163

| k(MM5) | sigma | press.(mb) | height(m) | depth(m) | delta-sigma |
|---|---|---|---|---|---|
| 45 | 0.000 | 5000 | 18872 | 1826 | 0.027 |
| 44 | 0.027 | 7565 | 17046 | 1722 | 0.033 |
| 43 | 0.060 | 10700 | 15324 | 1654 | 0.040 |
| 42 | 0.100 | 14500 | 13670 | 1358 | 0.040 |
| 41 | 0.140 | 18300 | 12312 | 1159 | 0.040 |
| 40 | 0.180 | 22100 | 11152 | 1015 | 0.040 |
| 39 | 0.220 | 25900 | 10137 | 906 | 0.040 |
| 38 | 0.260 | 29700 | 9231 | 819 | 0.040 |
| 37 | 0.300 | 33500 | 8412 | 749 | 0.040 |
| 36 | 0.340 | 37300 | 7663 | 691 | 0.040 |
| 35 | 0.380 | 41100 | 6973 | 642 | 0.040 |
| 34 | 0.420 | 44900 | 6331 | 600 | 0.040 |
| 33 | 0.460 | 48700 | 5732 | 563 | 0.040 |
| 32 | 0.500 | 52500 | 5168 | 531 | 0.040 |
| 31 | 0.540 | 56300 | 4637 | 503 | 0.040 |
| 30 | 0.580 | 60100 | 4134 | 361 | 0.030 |
| 29 | 0.610 | 62950 | 3774 | 347 | 0.030 |
| 28 | 0.640 | 65800 | 3426 | 335 | 0.030 |
| 27 | 0.670 | 68650 | 3091 | 324 | 0.030 |
| 26 | 0.700 | 71500 | 2767 | 210 | 0.020 |
| 25 | 0.720 | 73400 | 2556 | 206 | 0.020 |
| 24 | 0.740 | 75300 | 2350 | 202 | 0.020 |
| 23 | 0.760 | 77200 | 2149 | 198 | 0.020 |
| 22 | 0.780 | 79100 | 1951 | 194 | 0.020 |
| 21 | 0.800 | 81000 | 1757 | 190 | 0.020 |
| 20 | 0.820 | 82900 | 1567 | 187 | 0.020 |
| 19 | 0.840 | 84800 | 1380 | 183 | 0.020 |
| 18 | 0.860 | 86700 | 1197 | 180 | 0.020 |
| 17 | 0.880 | 88600 | 1017 | 177 | 0.020 |
| 16 | 0.900 | 90500 | 840 | 87 | 0.010 |
| 15 | 0.910 | 91450 | 753 | 86 | 0.010 |
| 14 | 0.920 | 92400 | 667 | 86 | 0.010 |
| 13 | 0.930 | 93350 | 581 | 85 | 0.010 |
| 12 | 0.940 | 94300 | 496 | 84 | 0.010 |
| 11 | 0.950 | 95250 | 412 | 84 | 0.010 |
| 10 | 0.960 | 96200 | 328 | 83 | 0.010 |
| 9 | 0.970 | 97150 | 245 | 82 | 0.010 |
| 8 | 0.980 | 98100 | 163 | 41 | 0.005 |
| 7 | 0.985 | 98575 | 122 | 24 | 0.003 |
| 6 | 0.988 | 98860 | 97 | 24 | 0.003 |
| 5 | 0.991 | 99145 | 73 | 16 | 0.002 |
| 4 | 0.993 | 99335 | 57 | 16 | 0.002 |
| 3 | 0.995 | 99525 | 40 | 16 | 0.002 |
| 2 | 0.997 | 99715 | 24 | 8 | 0.001 |
| 1 | 0.998 | 99810 | 16 | 8 | 0.001 |
| 0 | 0.999 | 99905 | 8 | 8 | 0.001 |
| 0 | 1.000 | 100000 | 0 | 0 | |

# Test Simulations

- MM5
- Annual 2005 and 2006
- National 36km
- “EPA” Western 12km Domain
- Compared with 34-layer MM5 simulation performed for USEPA
- Evaluated against TDL surface and CPC precipitation
- Caveat: Comparing Level 1 against observations.

# EPA Western US Configuration




**36/12**
**ETA**
**KF2**
**Pleim-Xiu**
**Reisner 2**
**RRTM**

# Model Comparison
# Temperature
# (yellow 34l better, green 46l better)

## Bias (K)

| Levels | Region | Jan '05 | Feb '05 | Mar '05 | Apr '05 | May '05 | Jun '05 | Jul '05 | Aug '05 | Sep '05 | Oct '05 | Nov '05 | Dec '05 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34l | ALL | -0.13 | 0.13 | -0.20 | -0.22 | -0.22 | -0.36 | -0.08 | 0.29 | 0.09 | 0.01 | 0.03 | -0.24 | -0.08 |
| 46l | ALL | -0.42 | -0.10 | -0.35 | -0.31 | -0.25 | -0.32 | -0.07 | 0.23 | -0.09 | -0.30 | -0.40 | -0.72 | -0.26 |
| 34l | CO | 0.27 | -0.31 | -1.16 | -0.99 | -0.41 | -0.16 | -0.39 | 0.27 | 0.24 | 0.12 | 0.02 | 0.11 | -0.20 |
| 46l | CO | -0.44 | -0.87 | -1.51 | -1.24 | -0.53 | -0.26 | -0.51 | 0.10 | -0.03 | -0.29 | -0.74 | -0.84 | -0.60 |
| 34l | UT | 0.64 | 0.37 | -0.57 | -0.92 | -0.36 | -0.43 | -0.32 | 0.28 | 0.56 | 0.74 | 1.06 | 0.89 | 0.16 |
| 46l | UT | 0.04 | -0.13 | -0.85 | -1.15 | -0.56 | -0.64 | -0.64 | 0.05 | 0.13 | 0.16 | 0.32 | 0.14 | -0.26 |
| 34l | WY | 0.50 | 1.42 | -0.68 | -0.86 | -0.05 | 0.28 | -0.12 | 0.83 | 0.62 | 0.54 | -0.22 | -0.14 | 0.18 |
| 46l | WY | -0.17 | 0.78 | -0.95 | -0.96 | -0.13 | 0.22 | -0.27 | 0.68 | 0.34 | 0.14 | -0.88 | -0.99 | -0.18 |

## Error (K)

| Levels | Region | Jan '05 | Feb '05 | Mar '05 | Apr '05 | May '05 | Jun '05 | Jul '05 | Aug '05 | Sep '05 | Oct '05 | Nov '05 | Dec '05 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34l | ALL | 2.56 | 2.39 | 2.34 | 2.28 | 2.15 | 2.16 | 2.33 | 2.26 | 2.35 | 2.32 | 2.56 | 2.53 | 2.35 |
| 46l | ALL | 2.48 | 2.28 | 2.20 | 2.08 | 1.93 | 1.95 | 2.09 | 2.02 | 2.04 | 2.03 | 2.27 | 2.36 | 2.14 |
| 34l | CO | 2.98 | 3.00 | 3.09 | 3.06 | 2.79 | 2.70 | 3.00 | 2.56 | 2.76 | 2.67 | 3.09 | 3.08 | 2.90 |
| 46l | CO | 2.99 | 3.14 | 3.22 | 3.07 | 2.51 | 2.39 | 2.68 | 2.32 | 2.45 | 2.37 | 2.94 | 2.98 | 2.76 |
| 34l | UT | 2.55 | 2.58 | 2.63 | 2.54 | 2.30 | 2.61 | 2.94 | 2.80 | 2.96 | 2.73 | 2.92 | 2.81 | 2.70 |
| 46l | UT | 2.37 | 2.59 | 2.60 | 2.46 | 2.09 | 2.37 | 2.67 | 2.55 | 2.62 | 2.27 | 2.40 | 2.48 | 2.46 |
| 34l | WY | 3.04 | 3.41 | 2.66 | 2.58 | 2.05 | 2.22 | 2.71 | 2.75 | 2.74 | 2.56 | 2.64 | 3.16 | 2.71 |
| 46l | WY | 3.01 | 3.24 | 2.70 | 2.53 | 1.85 | 1.98 | 2.35 | 2.44 | 2.42 | 2.30 | 2.57 | 3.14 | 2.54 |

# Model Comparison
# Mixing Ratio

## Bias (g/kg)

| Levels | Region | Jan '05 | Feb '05 | Mar '05 | Apr '05 | May '05 | Jun '05 | Jul '05 | Aug '05 | Sep '05 | Oct '05 | Nov '05 | Dec '05 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34l | ALL | 0.14 | 0.10 | 0.08 | 0.12 | 0.05 | 0.11 | 0.19 | 0.12 | 0.18 | -0.01 | 0.12 | 0.09 | 0.11 |
| 46l | ALL | 0.22 | 0.20 | 0.18 | 0.22 | 0.15 | 0.17 | 0.26 | 0.20 | 0.20 | 0.04 | 0.18 | 0.12 | 0.18 |
| 34l | CO | 0.21 | 0.08 | 0.12 | 0.34 | 0.16 | 0.05 | 1.08 | 0.17 | 0.32 | -0.14 | 0.01 | 0.15 | 0.21 |
| 46l | CO | 0.29 | 0.19 | 0.23 | 0.52 | 0.26 | 0.11 | 1.12 | 0.29 | 0.36 | -0.07 | 0.11 | 0.21 | 0.30 |
| 34l | UT | 0.27 | 0.13 | 0.41 | 0.27 | -0.12 | 0.21 | 1.30 | 0.96 | 0.55 | 0.15 | 0.04 | 0.23 | 0.37 |
| 46l | UT | 0.31 | 0.23 | 0.61 | 0.52 | 0.11 | 0.46 | 1.58 | 1.23 | 0.75 | 0.24 | 0.10 | 0.28 | 0.54 |
| 34l | WY | 0.27 | 0.28 | 0.16 | 0.27 | -0.34 | -0.42 | 0.46 | 0.61 | 0.35 | -0.02 | 0.09 | 0.22 | 0.16 |
| 46l | WY | 0.29 | 0.38 | 0.26 | 0.41 | -0.21 | -0.33 | 0.57 | 0.73 | 0.43 | 0.07 | 0.17 | 0.24 | 0.25 |

## Error (g/kg)

| Levels | Region | Jan '05 | Feb '05 | Mar '05 | Apr '05 | May '05 | Jun '05 | Jul '05 | Aug '05 | Sep '05 | Oct '05 | Nov '05 | Dec '05 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34l | ALL | 0.59 | 0.62 | 0.69 | 0.88 | 1.10 | 1.46 | 1.78 | 1.64 | 1.38 | 0.93 | 0.77 | 0.55 | 1.03 |
| 46l | ALL | 0.61 | 0.64 | 0.71 | 0.91 | 1.11 | 1.50 | 1.82 | 1.66 | 1.39 | 0.93 | 0.77 | 0.55 | 1.05 |
| 34l | CO | 0.55 | 0.60 | 0.59 | 0.82 | 1.01 | 1.47 | 2.02 | 1.56 | 1.27 | 0.79 | 0.61 | 0.43 | 0.98 |
| 46l | CO | 0.60 | 0.65 | 0.65 | 0.91 | 1.07 | 1.53 | 2.08 | 1.63 | 1.29 | 0.78 | 0.61 | 0.45 | 1.02 |
| 34l | UT | 0.60 | 0.58 | 0.75 | 0.78 | 1.11 | 1.44 | 2.12 | 1.87 | 1.27 | 0.86 | 0.65 | 0.53 | 1.05 |
| 46l | UT | 0.61 | 0.60 | 0.84 | 0.87 | 1.12 | 1.52 | 2.34 | 2.04 | 1.40 | 0.88 | 0.64 | 0.52 | 1.11 |
| 34l | WY | 0.47 | 0.53 | 0.54 | 0.74 | 0.86 | 1.44 | 1.60 | 1.57 | 1.14 | 0.68 | 0.51 | 0.42 | 0.88 |
| 46l | WY | 0.49 | 0.57 | 0.58 | 0.80 | 0.85 | 1.49 | 1.70 | 1.67 | 1.17 | 0.69 | 0.52 | 0.44 | 0.91 |

# Model Comparison
# Wind Index of Agreement

| Levels | Region | Jan '05 | Feb '05 | Mar '05 | Apr '05 | May '05 | Jun '05 | Jul '05 | Aug '05 | Sep '05 | Oct '05 | Nov '05 | Dec '05 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34l | ALL | 0.88 | 0.88 | 0.89 | 0.88 | 0.88 | 0.88 | 0.87 | 0.90 | 0.90 | 0.89 | 0.90 | 0.88 | 0.89 |
| 46l | ALL | 0.84 | 0.84 | 0.84 | 0.83 | 0.83 | 0.84 | 0.81 | 0.84 | 0.85 | 0.83 | 0.85 | 0.82 | 0.84 |
| 34l | CO | 0.82 | 0.82 | 0.81 | 0.82 | 0.81 | 0.81 | 0.80 | 0.81 | 0.80 | 0.80 | 0.80 | 0.80 | 0.81 |
| 46l | CO | 0.71 | 0.77 | 0.75 | 0.71 | 0.69 | 0.71 | 0.70 | 0.68 | 0.67 | 0.73 | 0.69 | 0.68 | 0.71 |
| 34l | UT | 0.70 | 0.74 | 0.71 | 0.77 | 0.76 | 0.73 | 0.75 | 0.78 | 0.75 | 0.74 | 0.76 | 0.78 | 0.75 |
| 46l | UT | 0.68 | 0.72 | 0.70 | 0.71 | 0.71 | 0.67 | 0.72 | 0.71 | 0.70 | 0.71 | 0.72 | 0.71 | 0.70 |
| 34l | WY | 0.79 | 0.80 | 0.78 | 0.78 | 0.81 | 0.80 | 0.80 | 0.78 | 0.81 | 0.79 | 0.79 | 0.81 | 0.80 |
| 46l | WY | 0.72 | 0.78 | 0.70 | 0.70 | 0.77 | 0.74 | 0.70 | 0.70 | 0.76 | 0.72 | 0.71 | 0.75 | 0.73 |

# Model Comparison Conclusion

- Precipitation results very similar (not shown)
- Statistically the 34-level configuration performs slightly better
- Model performance very similar
- Model configuration shows promise and warrants further testing in a AQ model

# Further Work

- Add WRF
  - Preliminary testing having trouble with dynamic time step
- Examine 4km domain
- Apply meteorology to AQ model