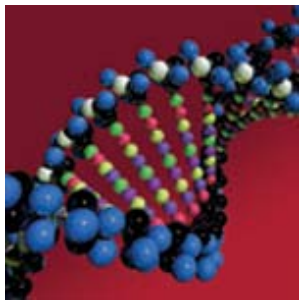
CAMx Vertical Transport Over Complex Terrain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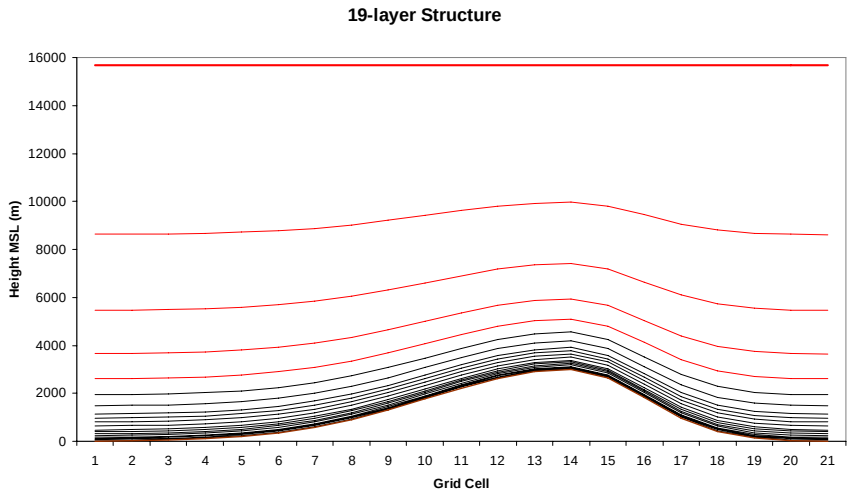
ENVIRON

Introduction

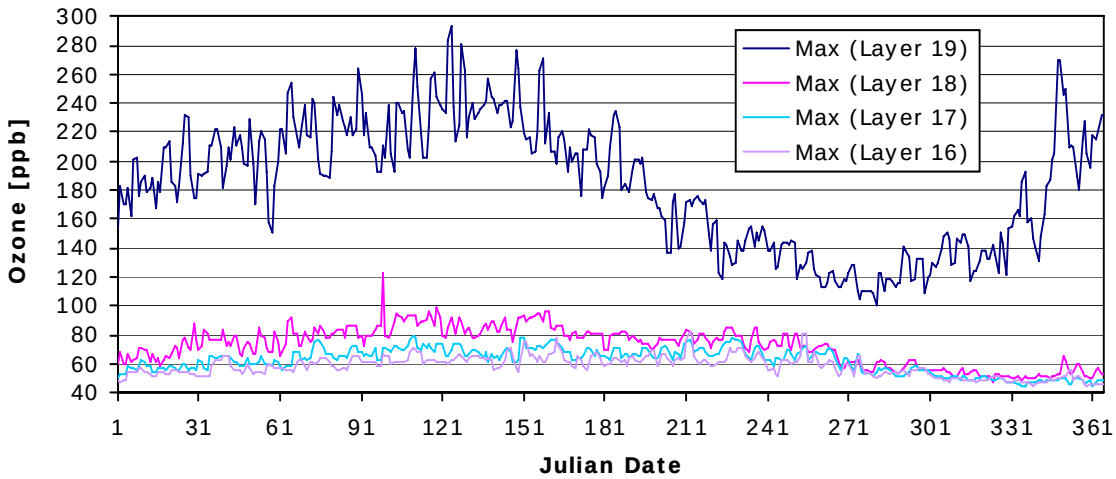
- CMAQ (2002 WRAP) and CAMx (2005 FCAQTF) simulate high springtime ozone over Rocky Mountains
  - Typically ~20 ppb higher than remote measurements
- Result from stratospheric ozone levels in top layer
  - Generated by lateral boundary conditions (BCs)
    - Derived from output of GEOS-CHEM global chemistry model
- Stratospheric ozone is rapidly transported to surface over high/complex terrain
  - Sierras, Cascades, Rockies

Introduction

- Both of these CMAQ and CAMx runs use 19 layers
  - Top layer spans 8-15 km



- 2002 ozone BCs in layer 19 range 100-300 ppb



Introduction

- Contributors to high ozone over the Rockies:
  - High surface altitudes (2-3 km)
    - Surface is closer to stratosphere
  - Deep PBL mixing and convection (through 4-6 km)
    - Couple surface to mid-troposphere
  - Vigorous resolved vertical circulations (through 4-8 km)
    - Transport layer 19 ozone downward
- API funded study to investigate this issue that found the following problems:
  - Coarse vertical grid structure (more aloft layers help)
  - GEOS-CHEM BC interface (better interpolation helps)
  - Vertical velocities (filtering/smoothing helps)
  - CAMx vertical solver technique (alternative approach helps)
    - Does CMAQ have similar vertical advection solver issues?

Approach

- CAMx 2005 FCAQTF run
  - Inert, ozone only, no sources/sinks
  - Single 12-km regional grid covering western U.S.
  - Track ozone IC/BC over April 2005
    - Original IC/BC from 2002 GEOS-CHEM extraction (WRAP)
    - New IC/BC from 2005 GEOS-CHEM extraction
- API-funded work
  - Task 1: Test smoother-desmoother (memo 2/18/09)
  - Task 2: Test divergence minimization (memo 4/20/09)
  - Task 3: Test density/wind filter (completed)
  - Task 4: Test best of 1-3 on full photochemical FCAQTF run
  - Task 5: EPA interaction/transfer technology to MCIP/CMAQ

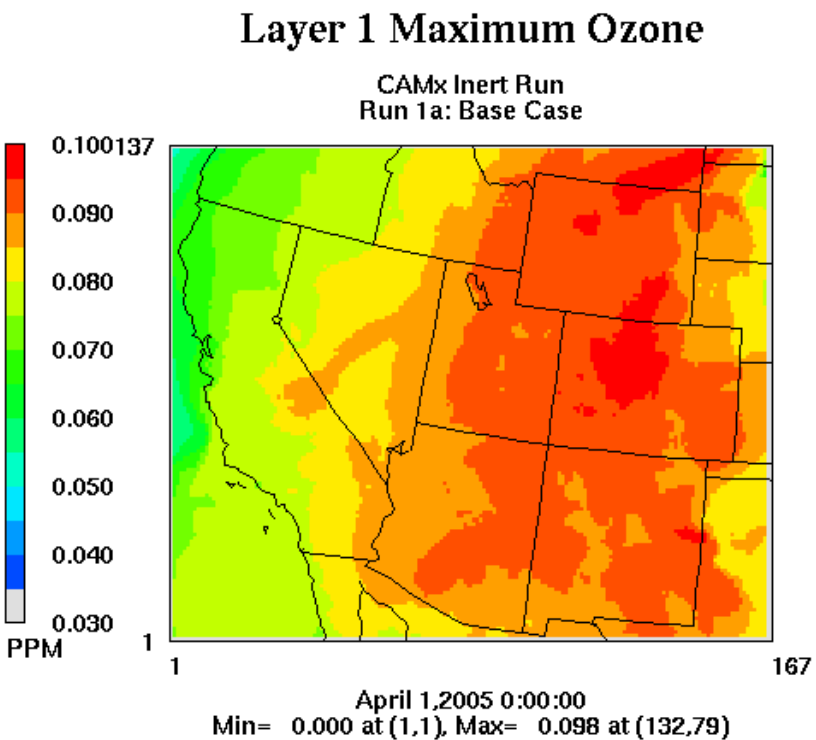
Approach

- ENVIRON in-kind investigations
  - Improved treatment of CAMx top boundary condition
    - Zero flux top BC rather then set BC top concentration aloft
  - Tested alternative vertical grid structures/resolution
  - Implemented alternative (2005) lateral BCs
    - Use 2005 GEOS-CHEM global model output
  - Reviewed GEOS-CHEM interface and improved technique
    - Correct GEOS-CHEM BC interpolation program
  - Implement revised CAMx vertical advection solver

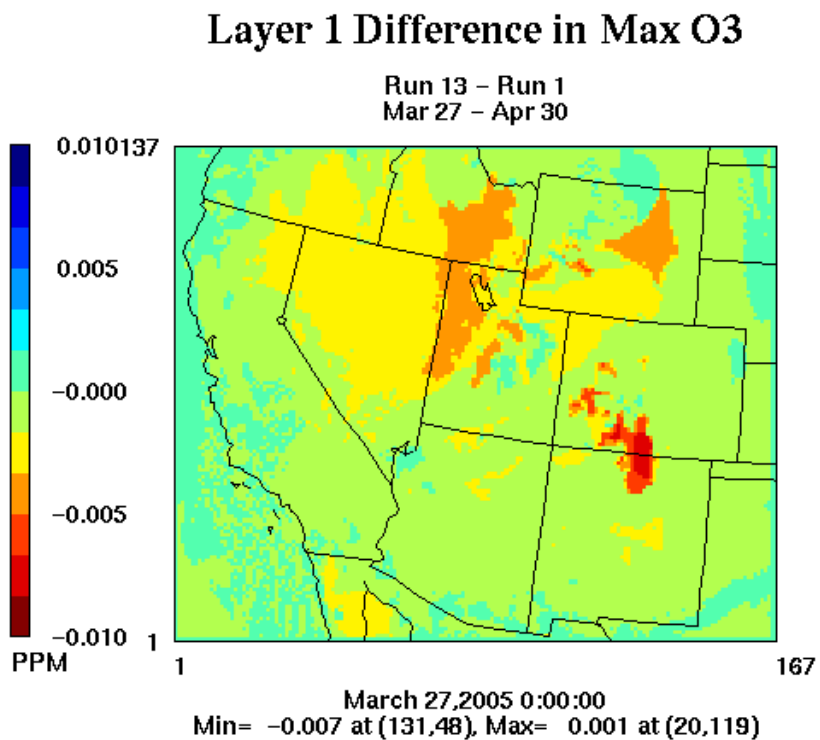
Smoother-Desmoother

- Approach of Yang and Chen (2008)
  - Applied to input horizontal winds to calm vertical velocity
  - Applied aggressively to upper layers only
  - Results in <5 ppb change in April maximum ozone

BASE



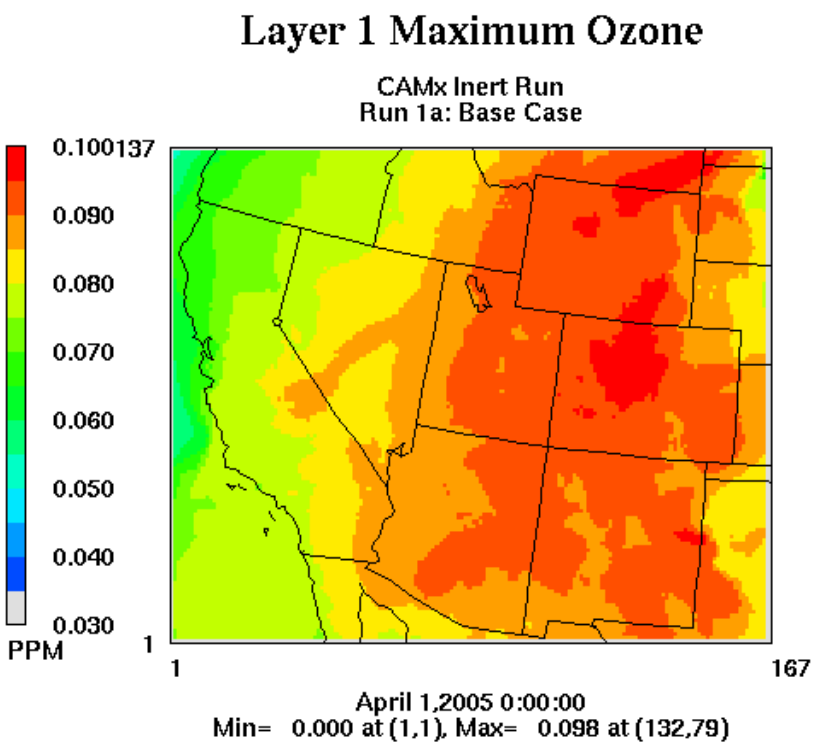
DIFFERENCE FROM SMOOTHING



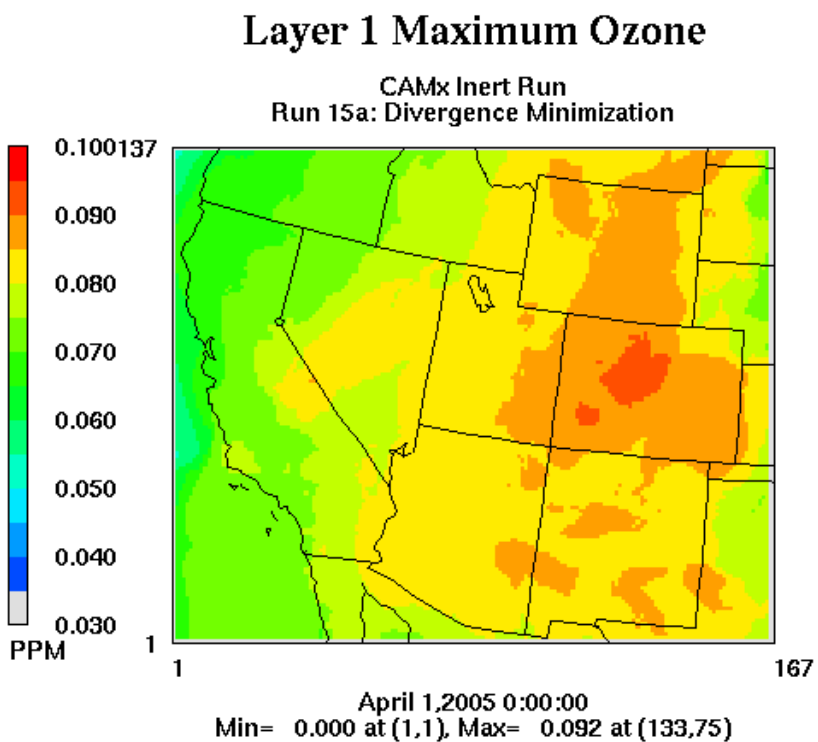
Divergence Minimization

- Adapted from CALMET
  - Applied to input horizontal winds to reduce vertical velocity
  - Applied aggressively to upper layers only
  - Results in <10 ppb change in April maximum ozone

BASE



DIV-MINIMIZED



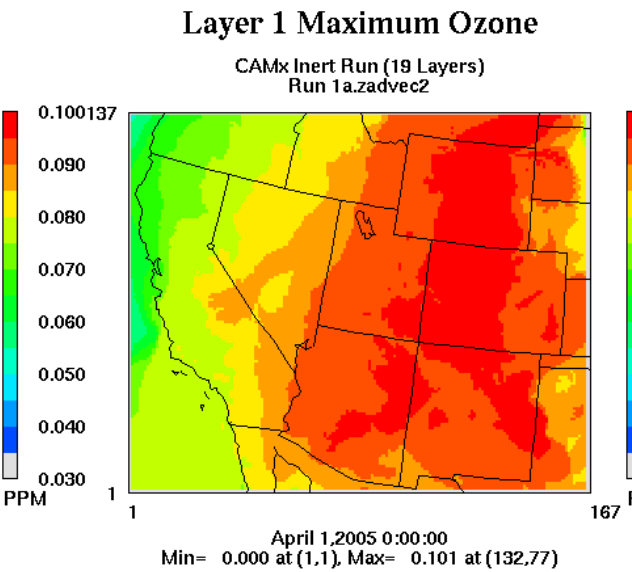
Divergence Minimization

- Puzzling/troubling results for vertical velocity profiles in upper layers
  - Led to big dilution of layer 19 ozone
  - Associated with use of much lower ozone top boundary conditions (70 ppb) than in CAMx top vertical layer (Layer 19)
- CAMx was revised to use "zero-gradient" top boundary conditions for all subsequent tests
  - Ignores top boundary condition input
  - Removes artificial dilution of top layer

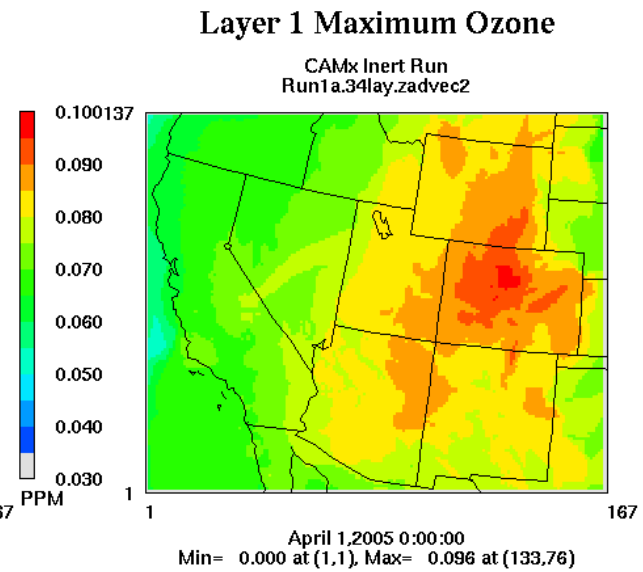
More Model Layers

- Reprocess input meteorology, no smoothers/filters
  - Zero-gradient top boundary condition
  - Full 34 MM5 layer structure
    - Runs ~2x slower than 19 layers, 10-15 ppb ozone reduction
  - Intermediate 22 layers to improve resolution aloft
    - Runs ~1.1x slower than 19 layers, ~10 ppb ozone reduction

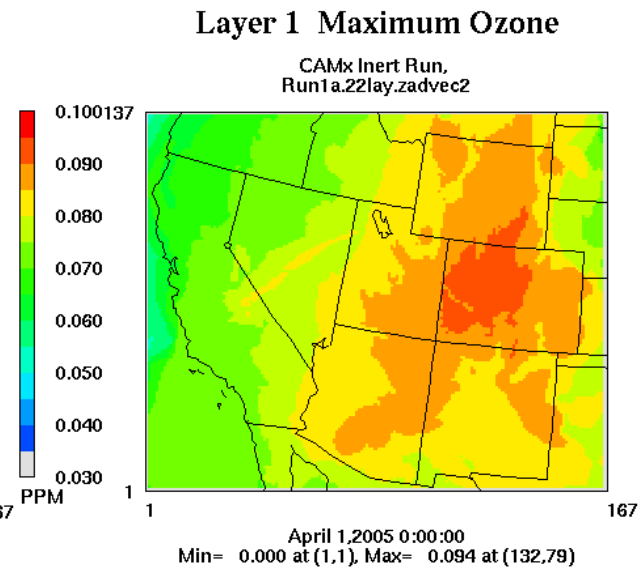
19-layer



34-layer



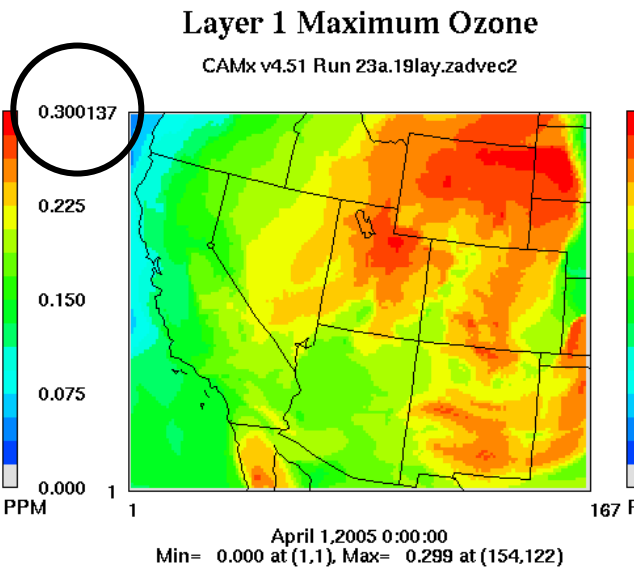
22-layer



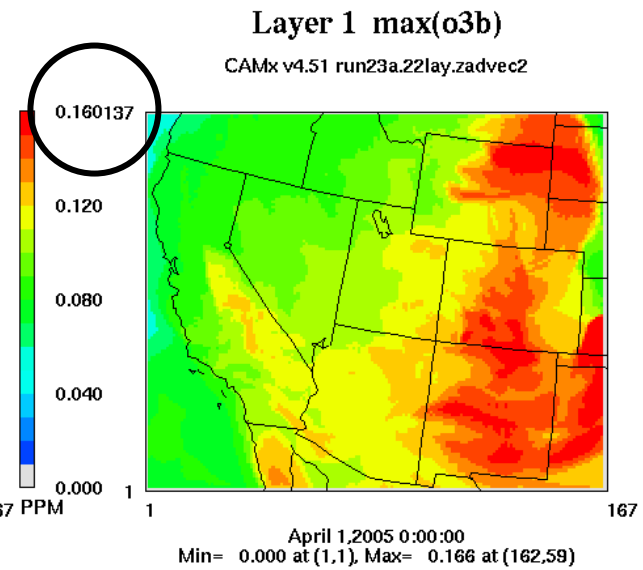
2005 Day-Specific BCs

- New BCs, original met inputs, no smoothers/filters
  - Zero-gradient top boundary condition
  - Higher stratospheric ozone, higher surface ozone, different patterns
  - 2002 monthly averaging removed day-specific ozone variations
  - NOTE CHANGES TO COLOR SCALE!

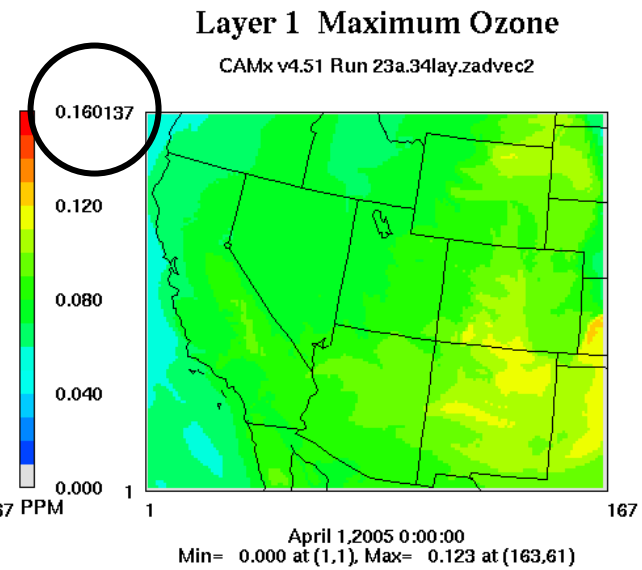
19-layer



22-layer

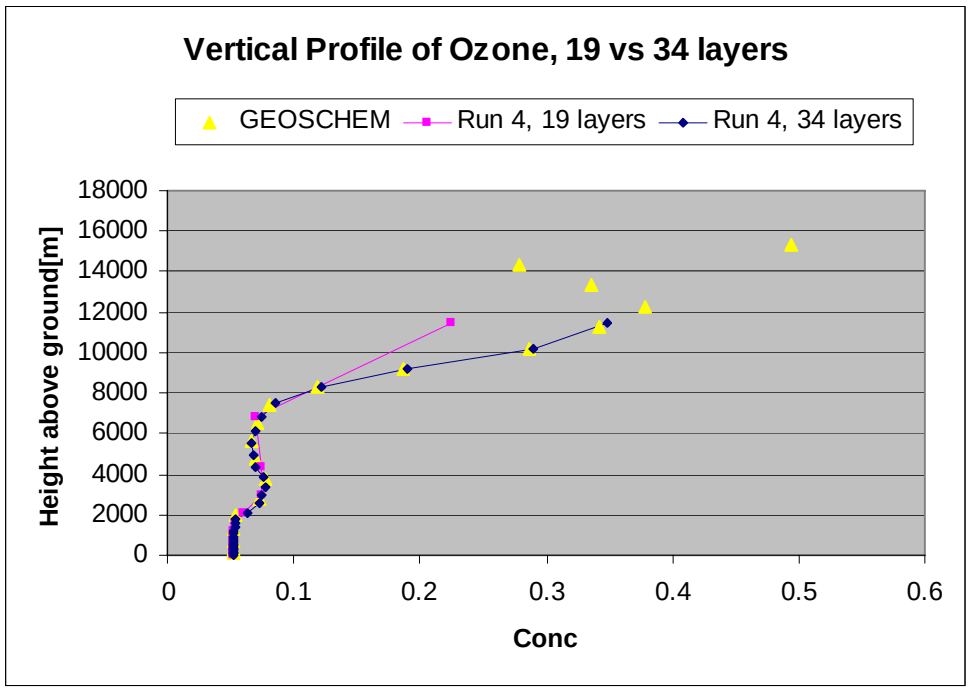


34-layer



2005 Day-Specific BCs

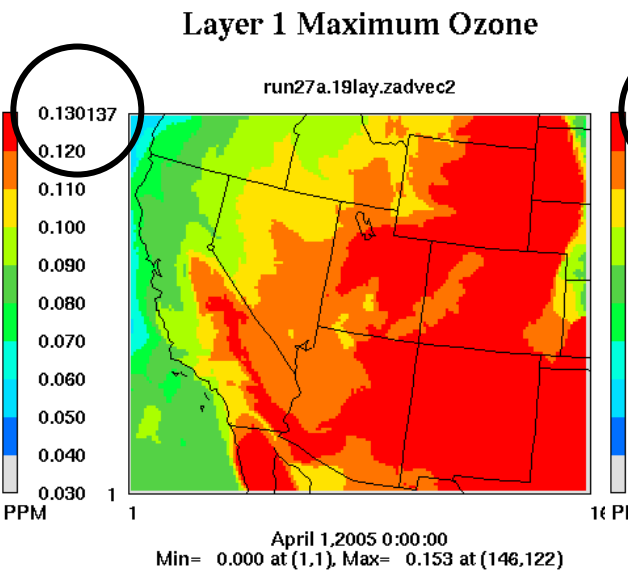
- Problem found in GEOS-CHEM interface program
  - Vertical interpolation was not consistent with CMAQ or CAMx layer structure definitions
  - Did not account for deep CMAQ/CAMx layers
    - Resulted in same ozone levels in 19, 22 and 34 layer cases
    - Fixed by converting to layer-weighting technique (compare profiles below)



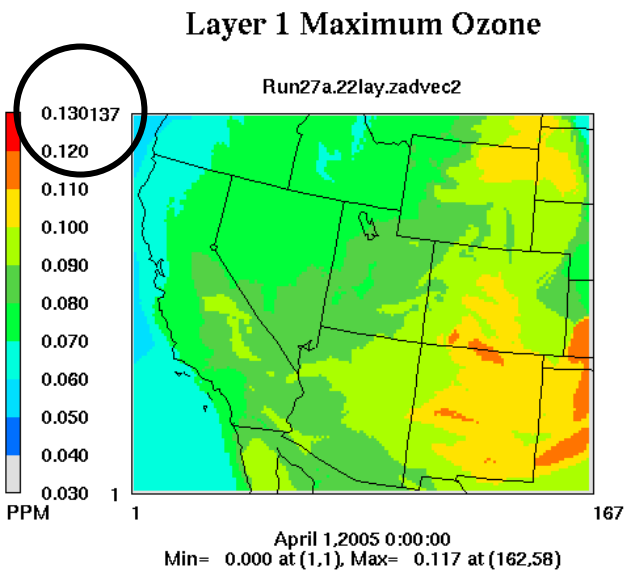
Improved 2005 BCs

- Fixed BCs, original met inputs, no smoothers/filters
  - Zero-gradient top boundary condition
  - Lower stratospheric ozone, lower surface ozone
  - Ozone still higher than with 2002 BCs

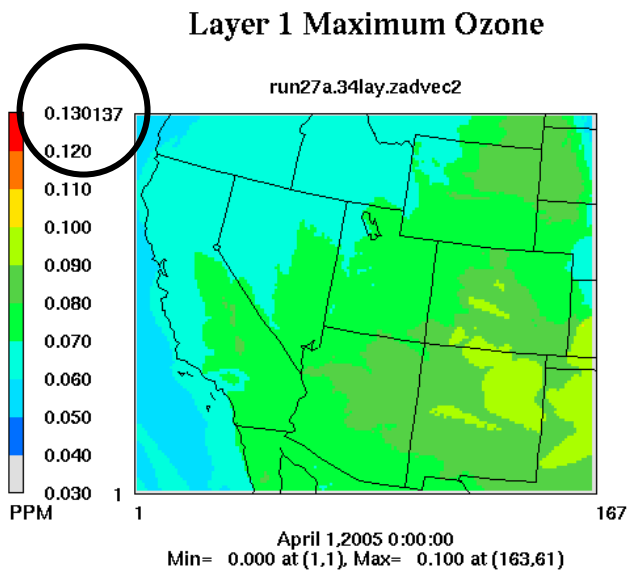
19-layer



22-layer



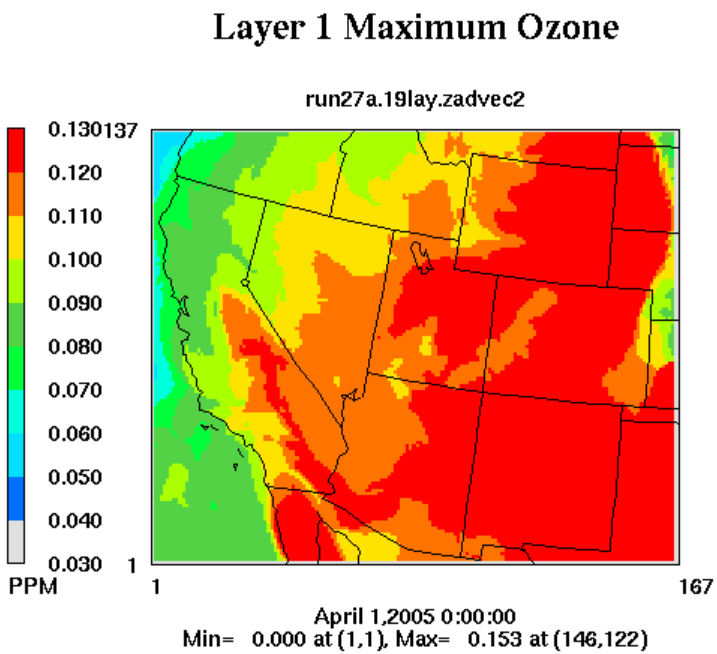
34-layer



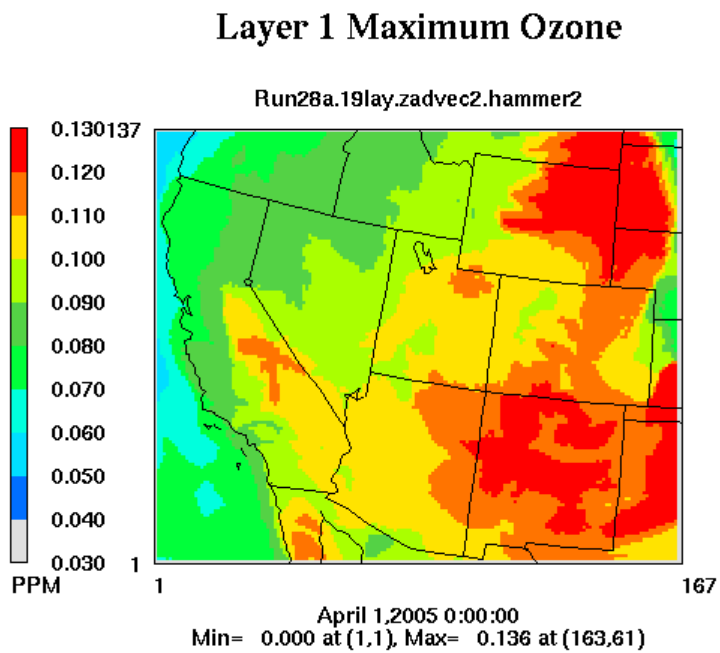
Density/Wind Filtering

- "Pressure Fixer" of Rotman et al. (2004)
  - Zero-gradient top BC, fixed 2005 lateral BC
  - Applied to input horizontal winds to reduce vertical velocity
  - Applied aggressively to upper layers only
  - Results in 10-20 ppb change in April maximum ozone

19-layer BASE



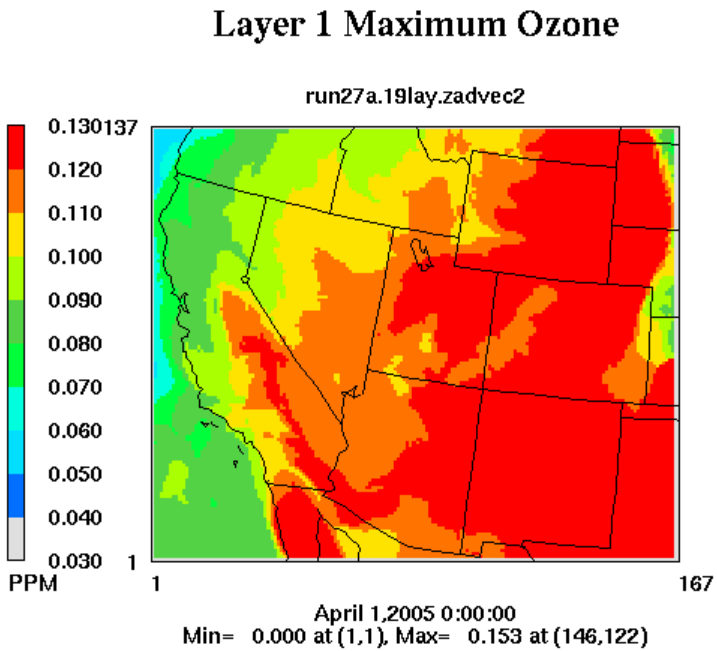
FILTERED



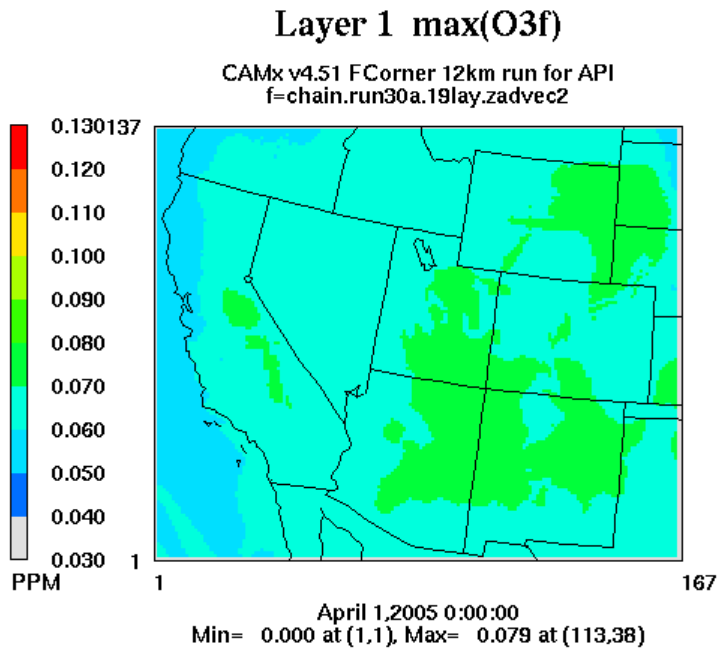
Revised Vertical Advection

- Original input meteorology, no smoothers/filters
  - Zero-gradient top BC, fixed 2005 lateral BC
  - Revised vertical velocity calculation to remove downward bias
  - Revised vertical solver to be consistent
  - Results in 40-70 ppb change in April maximum ozone

19-layer BASE



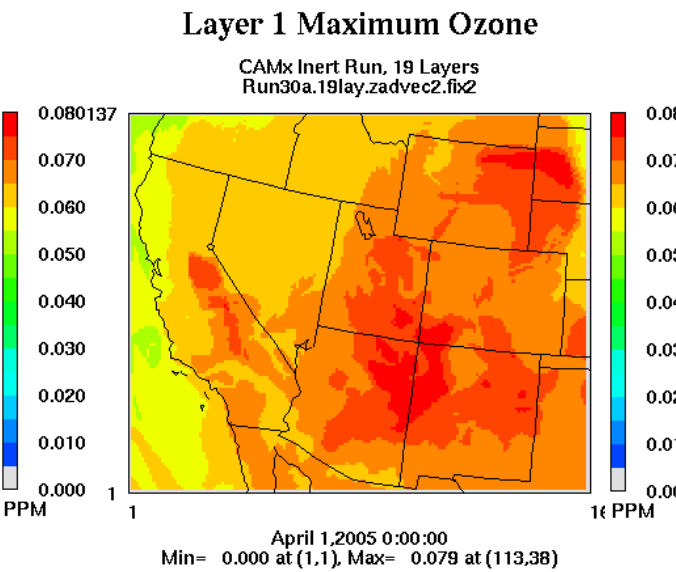
MODIFIED ADVECTION



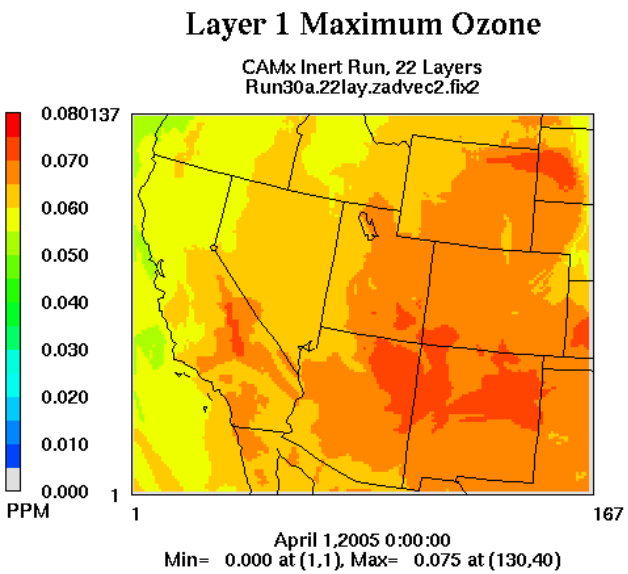
Revised Vertical Advection

- Comparison of 19, 22, and 34-layer configurations
  - Maximum surface ozone of 79, 75 and 75 ppb using 19, 22 and 34 vertical layers

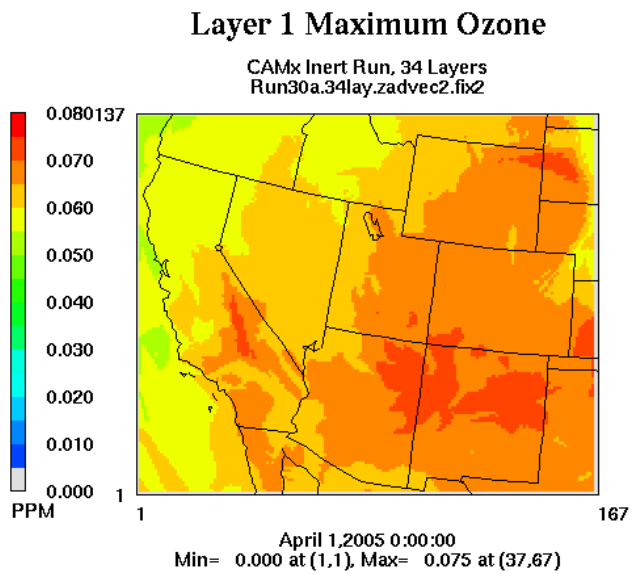
19-layer



22-layer



34-layer



Recommended Further Work for API Study

- Test modified CAMx for full photochemical applications
  - 2005 FCAQTF Database
  - O&G projects in Rocky Mountains
  - Evaluate spring and summer performance changes
  - Is external smoothing/filtering still necessary?
    - Evaluate photochemical results before developing a recommendation
- Document all results in summary report and conference paper
- CMAQ exhibits similar problems
  - Recommend reviewing vertical advection in CMAQ
  - If possible, integrate similar change and test on WRAP
  - Interact with EPA/ORD

Recommendations for Denver Modeling

- Don't believe a 36/12/4 km ozone source apportionment is needed given recent findings
  - Will just identify GEOS-CHEM BCs as main component of ozone transported into Denver NAA
- Instead recommend revised CAMx base case using latest vertical velocity algorithms and corrected 36 km GEOS-CHEM BCs
  - Process 2006 GEOS-CHEM output to make day-specific BCs for 36 km domain (with correct interpolation scheme)
  - Revised CAMx 36 km base case Jun-Jul 2006 using new VertVel
  - Revised CAMx 12/4 km base case Jun-Jul 2006 using new VertVel
    - Ozone model performance evaluation
  - Also desirable to update vertical layer structure (22 layers), but requires reprocessing MM4 data