Applications of Satellite Data for Ozone Exceptional Events

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EPA Region 8

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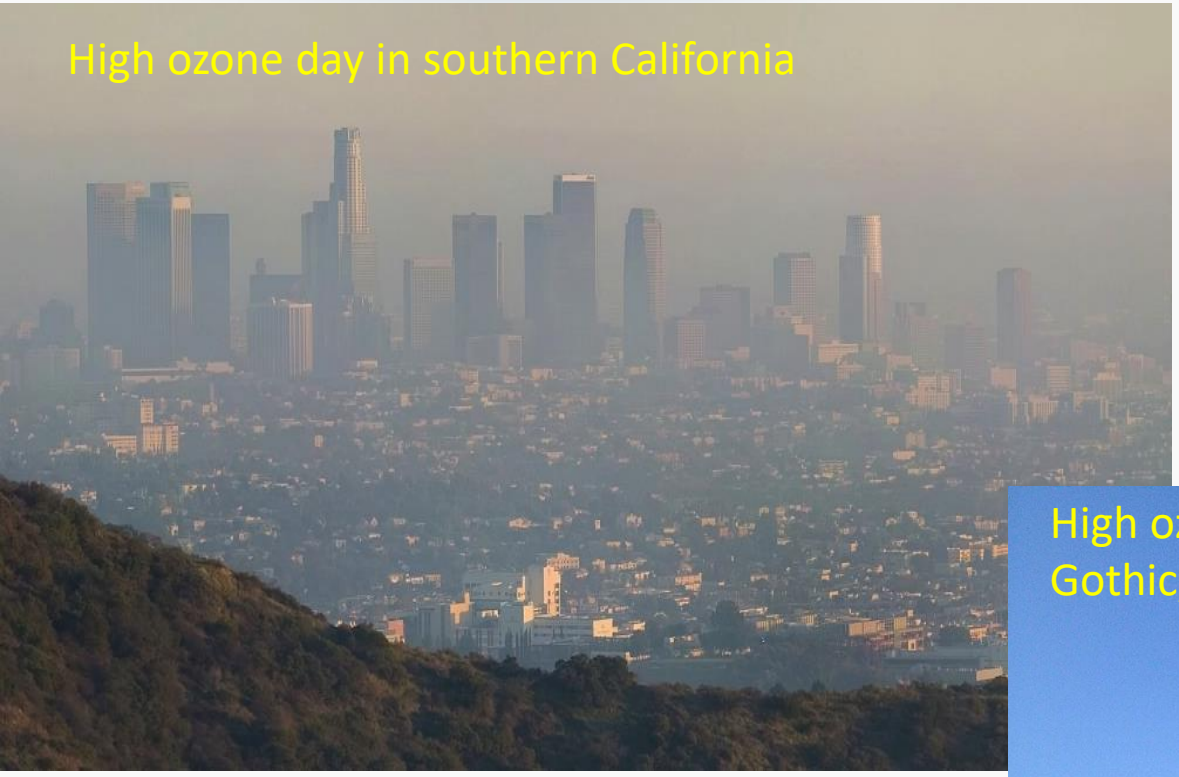
Applications of Satellite Data

- Develop improved air quality models:
  - Improved evaluation of meteorological and photochemical models.
  - Develop top-down constraints on emissions inventories.
  - Assimilation of satellite data into meteorological and air quality models: for precursor concentrations; O3 in the stratosphere and free troposphere.
- Inform air quality management decisions:
  - Identification of exceptional events (stratospheric intrusions, high wind events, wildfires) that contribute to O3 and PM.
  - Use of indicator ratios to identify the limiting precursor for production of O3 and PM2.5.
- Health Impacts studies:
  - Current epidemiological studies for O3, oxidants and PM are based on sparse monitoring data. High spatial resolution TEMPO data should be useful for new health effects assessments of O3 and total oxidants: https://www3.epa.gov/ttn/naaqs/standards/ozone/data/20140829healthrea.pdf

Ozone is used as an indicator of oxidant air pollution



High O3 days associated with Stratospheric intrusion can have very low concentrations of other oxidants.

Can TEMPO provide better, multipollutant indicators of oxidant air pollution?

EPA, State and Tribe Planning Needs

- States, Tribes and EPA use photochemical models to develop Implementation Plans (SIPs, TIPs, or FIPs) that demonstrate:
  - Attainment of National Ambient Air Quality Standards for O3 and PM2.5
  - Good Neighbor SIPs for interstate transport of O3.
  - Progress toward regional haze goal of natural visibility conditions at Class I Areas.

- Air Quality goals are evaluated for a subset of days:
  - O3 attainment is typically evaluated for the ten highest modeled O3 days.
  - Regional haze goal is evaluated for the 20% worst anthropogenic impairment days and for the 20% best visibility days.

TEMPO high temporal resolution will be valuable for episodic and day specific analyses.

Analysis of Specific Events or Episodes

- Models should accurately simulate background O3, PM2.5 and natural haze levels on individual days:
  - Background O3, PM2.5 and natural haze levels are highly variable in space and time.
  - Do models accurately represent background O3, PM2.5 and natural haze on the subset of days used for air quality planning?
  - Can the next generation of satellite data help provide more accurate estimates of daily O3, PM2.5 and natural haze?

- Days with high O3 or PM2.5 caused by Exceptional Events can be excluded from the planning process.
  - For O3 and PM2.5, states prepare an exceptional event demonstration for review and approval by EPA.
  - For regional haze, data analysis methods are used to estimate the natural haze level on each day.
  - **Hope that TEMPO data will make it easier to identify exceptional events.**

Stratospheric Intrusion Workgroup

- Workgroup meeting semi-monthly since 2012, include federal and state research and air quality management communities.
- Lin et al. (2015) show "more frequent late spring stratospheric intrusions when the polar jet meanders towards the western United States, such as occurs following strong La Niña winters."
- Few stratospheric O_3 events in 2015 and 2016 (during El Niño conditions) but winter 2016/17 had La Niña conditions, and 2017 had several possible intrusion events with maximum daily 8-hour (MD8) averages approaching or exceeding the NAAQS:
  - March 18: 95 ppb (87 ppb regulatory) at Mt Washington NH.
  - April 9: 74 ppb in Colorado Springs.
  - April 22: 82 ppb Gothic, CO; 80 ppb Navajo Lake, NM; 75 ppb Centennial, WY; and five others sites in UT, CO and NM exceed 70 ppb.
  - April 23: 71 ppb NREL, CO; 71 ppb Rocky Flats, CO
  - Several additional days with MD8 between 65 to 69 ppb.

Analysis of SI O3 Exceptional Events

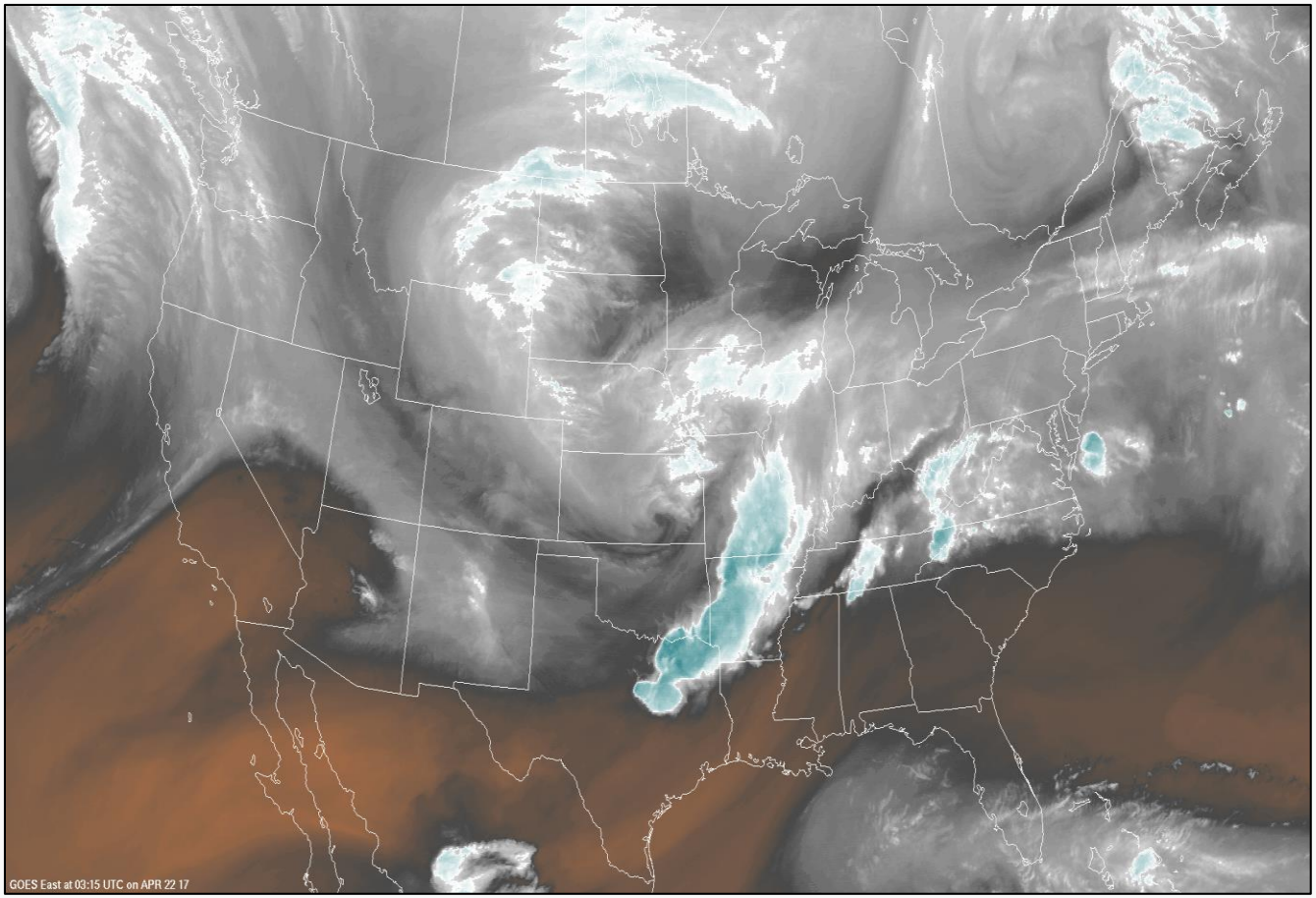
- Clear Causal Relationship between the Specific Event and the Monitored Concentration
  - Analyses showing stratospheric-tropospheric exchange
  - Analyses showing stratospheric air reached the surface
  - Air quality analyses showing the impacts of the intrusion at the surface
  - **Goal is to use TEMPO for these analyses.**

Resources for SI O3 Analyses

- NOAA RAQMS simulations and IDEA Trajectory analysis tool (Brad Pierce, NOAA).
- NCEP Global Forecast System model (GFS) analysis and forecast plots are generated each day at 12 hour intervals out to 5 days.
- Tropospheric Ozone Lidar Network (TOLNet) ground based lidars (Mike Newchurch, UAB; Andy Langford et al., NOAA/ESRL)
- Atmospheric Sounding, website hosted by Univ of Wyoming
- AirNow surface O3 monitoring by states, tribes and EPA
- Additional surface O3 sites by NOAA/GMD, NPS, FS and others.
- NOAA Rapid Refresh (RAP) model simulations: https://rapidrefresh.noaa.gov/
- **Satellite based measurements of O3, CO, NO2, HCHO, H2O and aerosol optical depth.**
- NASA AJAX aircraft observations.
- Staff at state environmental agencies with expertise in meteorological analysis and local conditions.

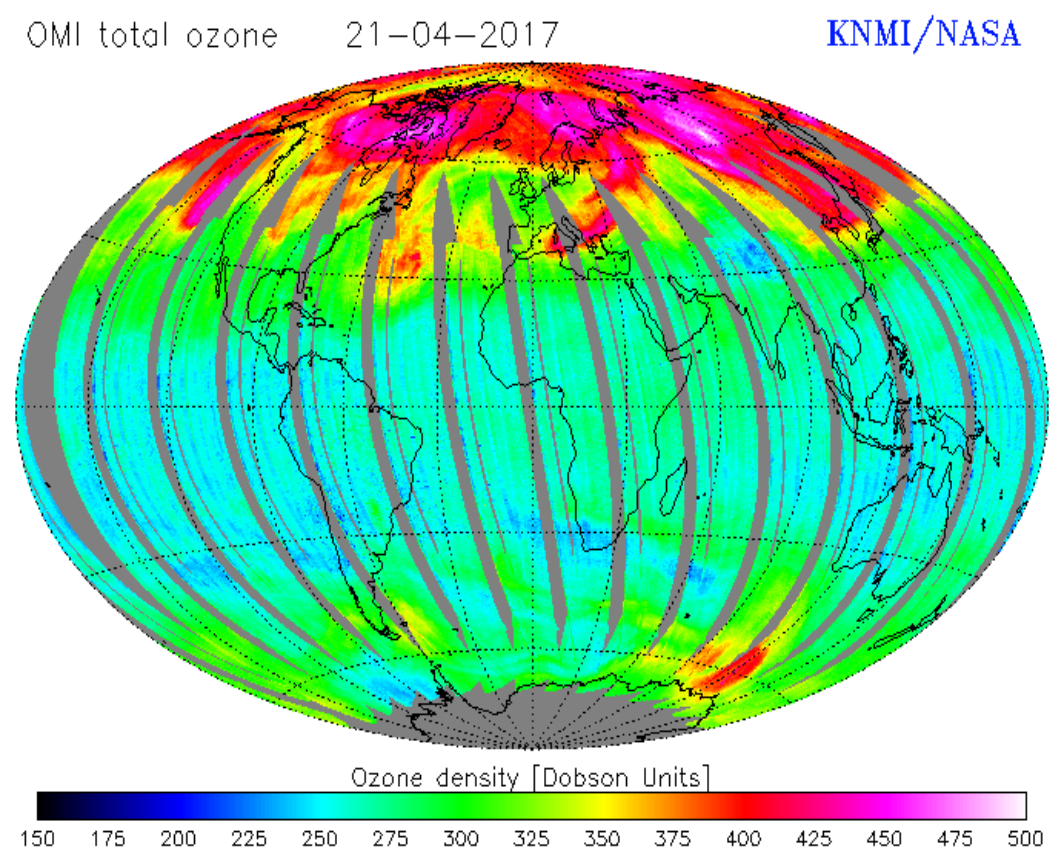
Satellite Data Example Plots

Water vapor imagery from the GOES-West satellite



Satellite Data Example Plots

Map of OMI satellite-estimated total ozone column data from the day before the event



TEMPO data products

- Satellite based measurements of O3, NO2, HCHO, H2O.
  - Expect very low mixing ratios of H2O, CO, NO2 and HCHO to be associated with stratospheric intrusions.
  - Mixing of wildfire or Asian transport plumes with stratospheric intrusions can make it more difficult to interpret.
  - High winds and wind blown dust associated SI events might or might not cause high with particulate matter and aerosol optical depth.

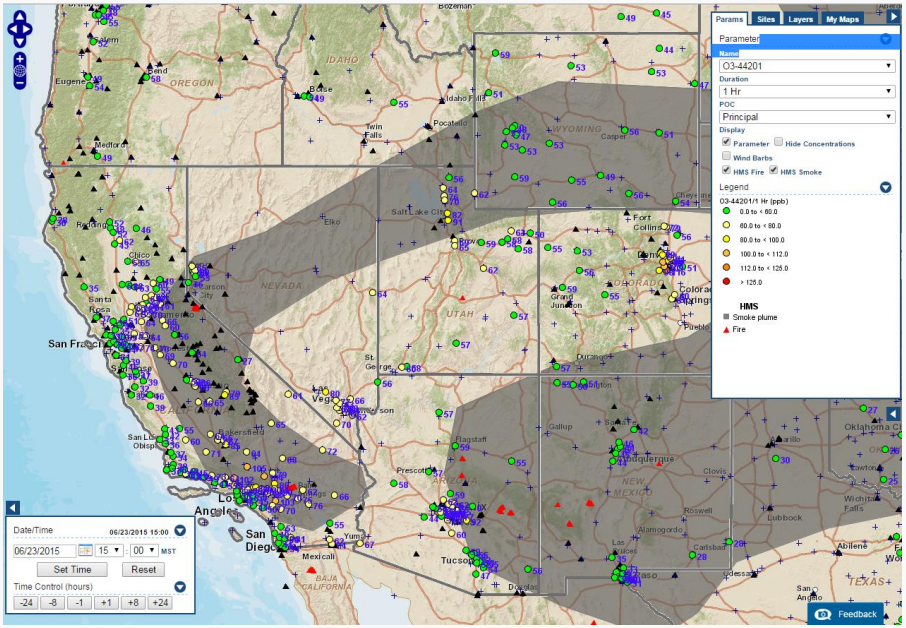
Will hourly TEMPO day aid in visualizing transported plumes?

Supplemented by trajectory analyses as Brad showed?

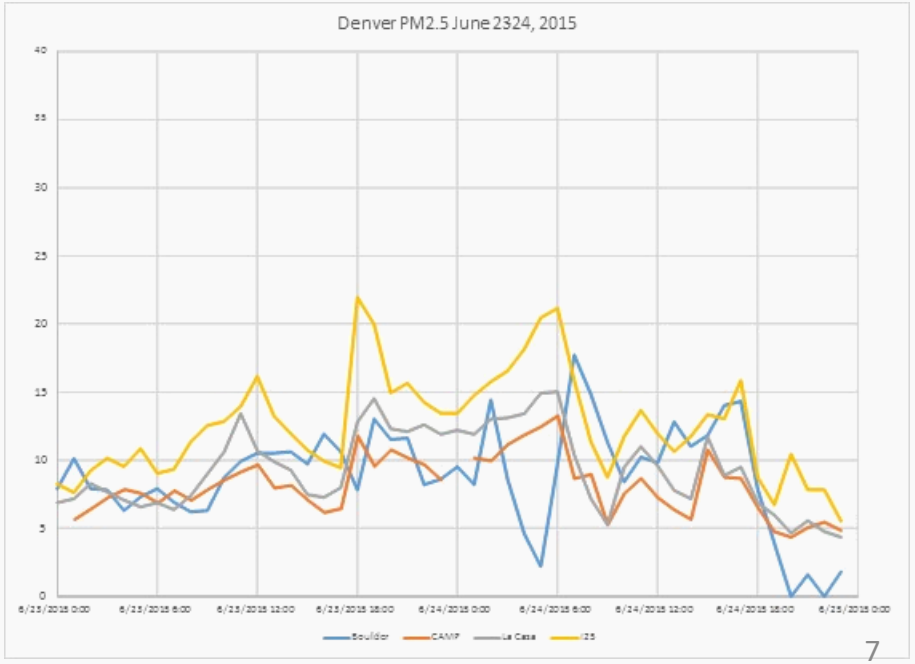
Wildfire Exceptional Event Complexity

- Denver O_3, June 23, 2015: 91 ppb (hourly 122 ppb).
- Smoke from California Fires north and Arizona fires south of Denver.
- Urban 8-hour O_3 at 91 ppb was 35 ppb higher than the highest rural site in Colorado, at 56 ppb.
- Smoke impact, if any, is ambiguous.

Wildfire Plumes, June 23, 2015



Smoke Impacts on PM_{25}?



Nested 36/12/4-km Model Domains

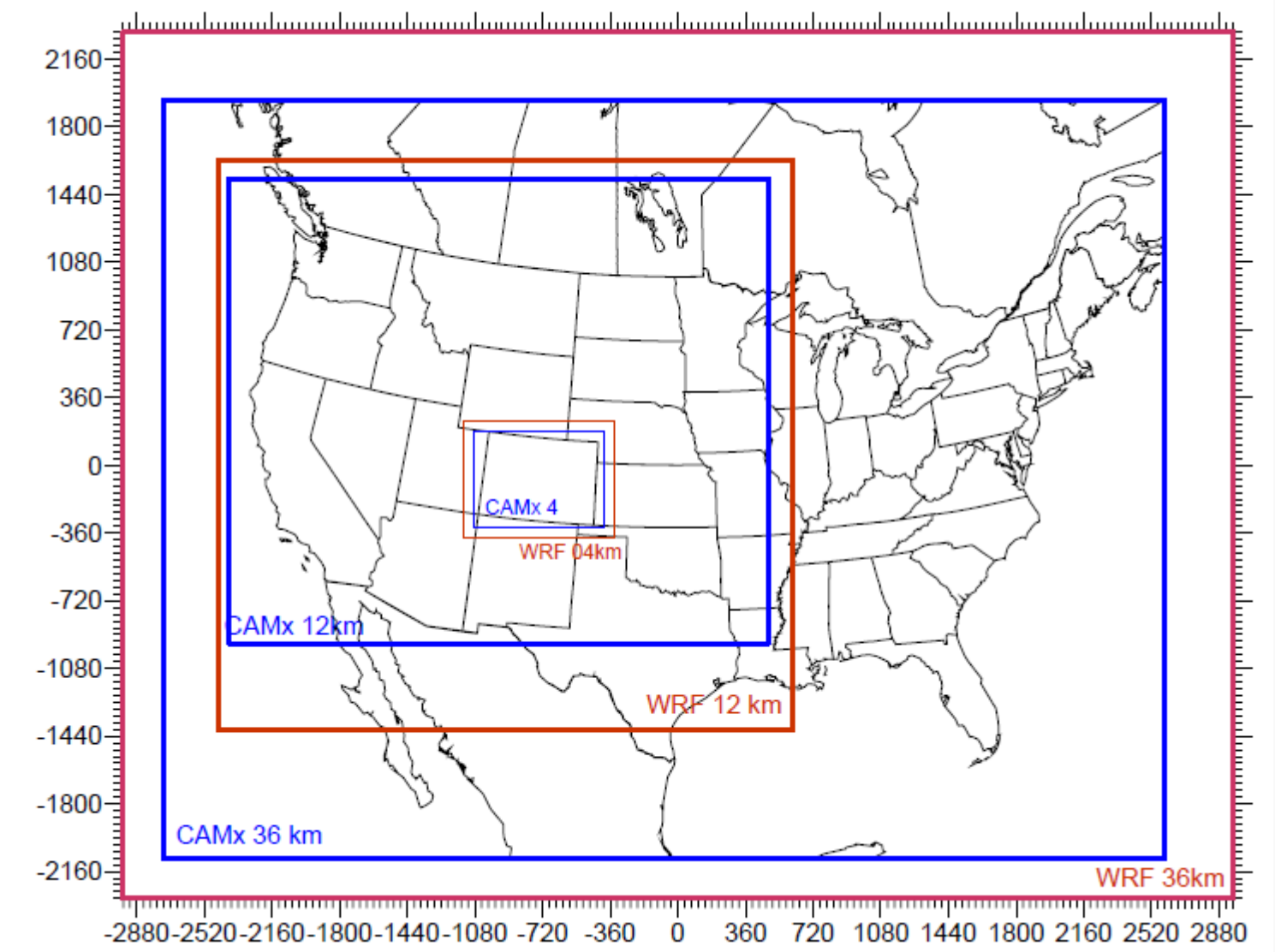
WRF and CMAQ or CAMx

Vertical Grid:

Typically 20 to 40 layers from the surface up to the lower stratosphere at 50 mb.

Lateral BC from Global Models:

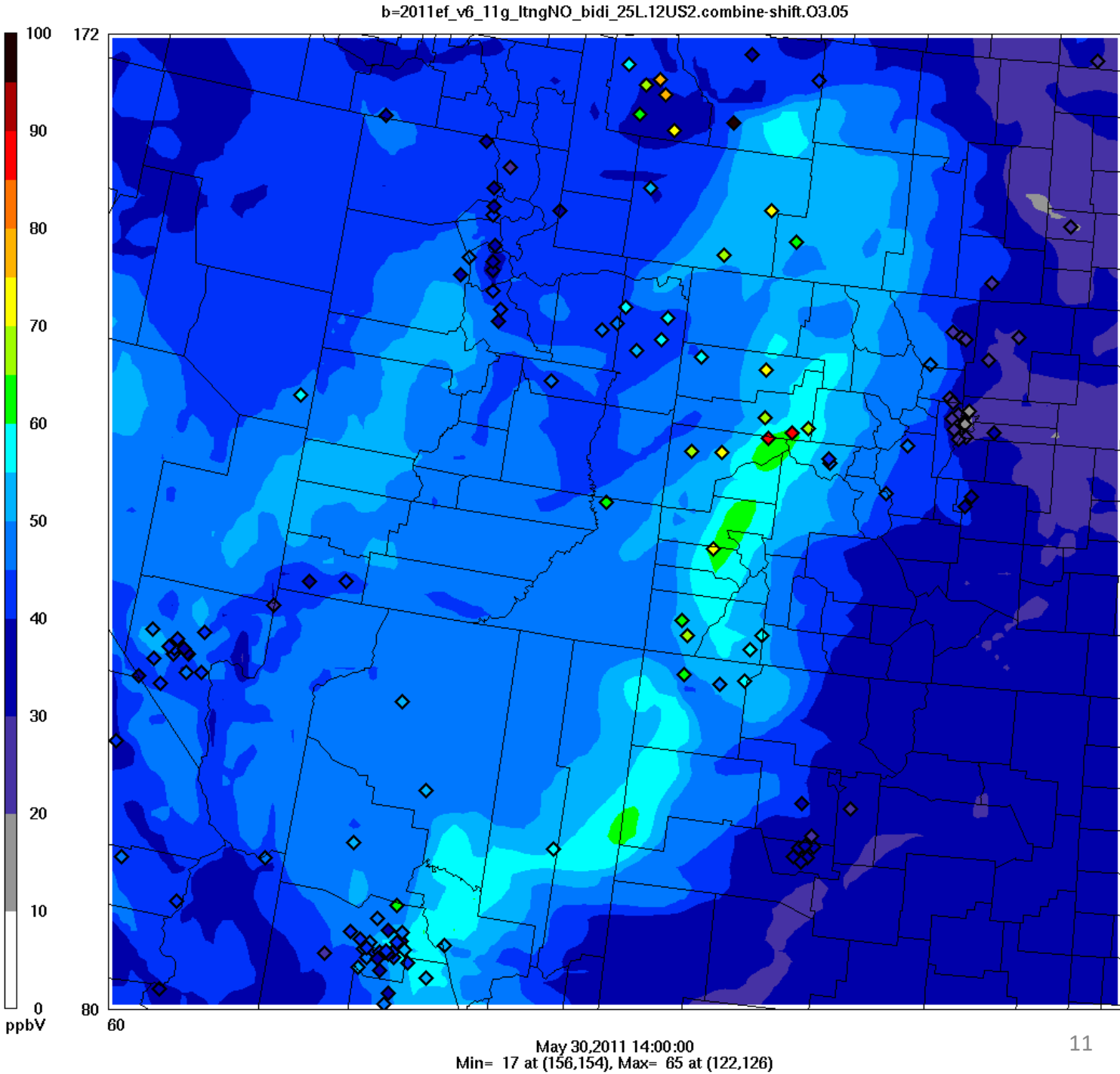
MOZART
GEOS-Chem
AM3
RAQMS



Ozone Attainment Planning

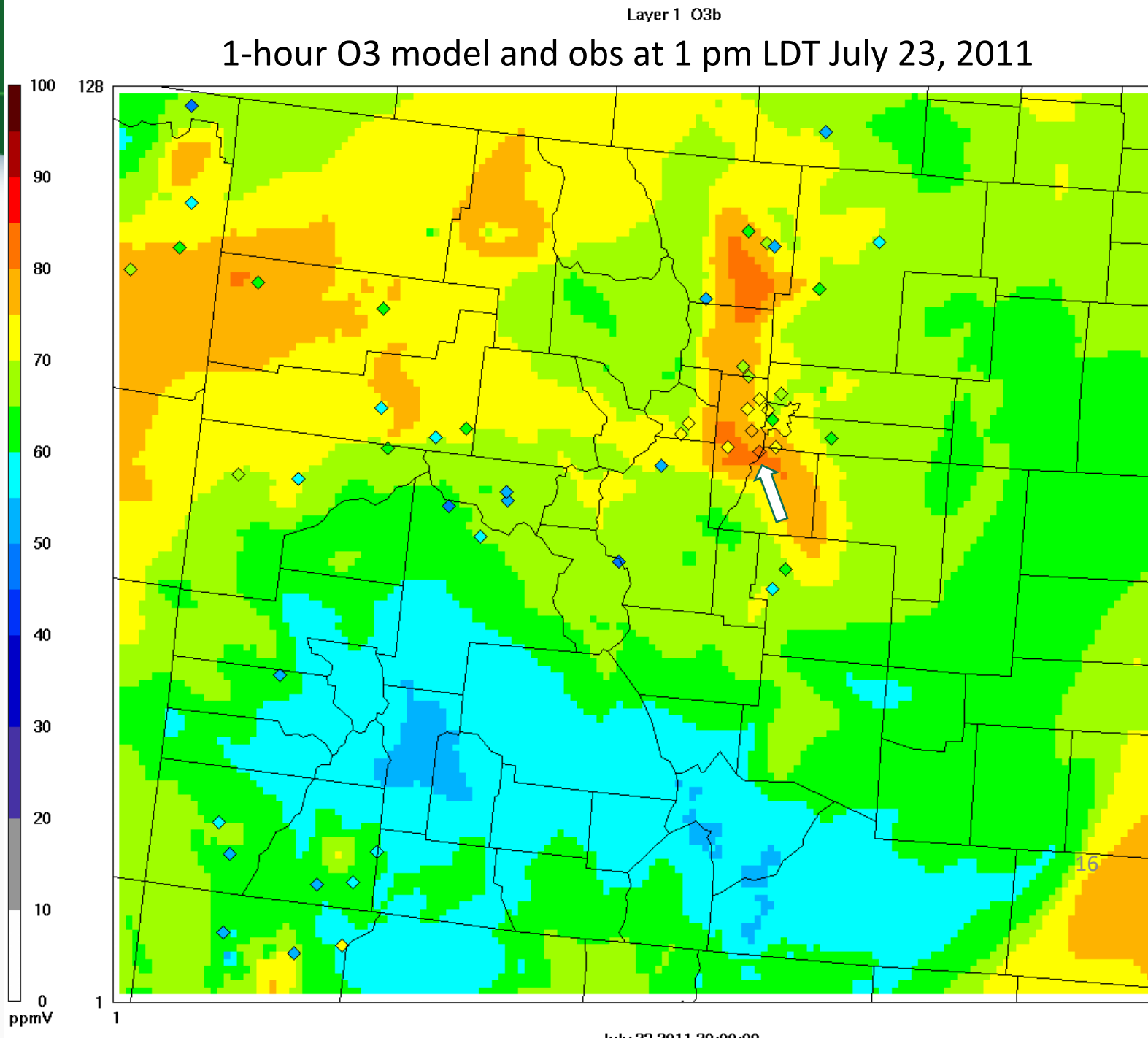
- Model evaluation is completed for historical O3 episodes to assess if the model is reliable for projecting future changes in O3.
- The base year O3 design values is calculated as the weighted average of 5 years of the 4th highest daily 8-hour average O3.
- Model O3 relative response factor (RRF) is used to project the future O3 design value.
  - RRF = Future model O3/Base year model O3 (average ratio for the ten highest modeled O3 days.
  - Future O3 design value = (RRF)(Base Year O3 Design value)
  - The Relative Response Factor approach is adopted to correct for model bias.
- The state successfully projects attainment of the O3 NAAQS if the future design value does not exceed the NAAQS.

CMAQ biased low at rural sites at 7 am, May 30, 2011. The model simulates a ridge of elevated ozone but is biased low by 30 ppb



1-hour O3 model and obs at 1 pm LDT July 23, 2011

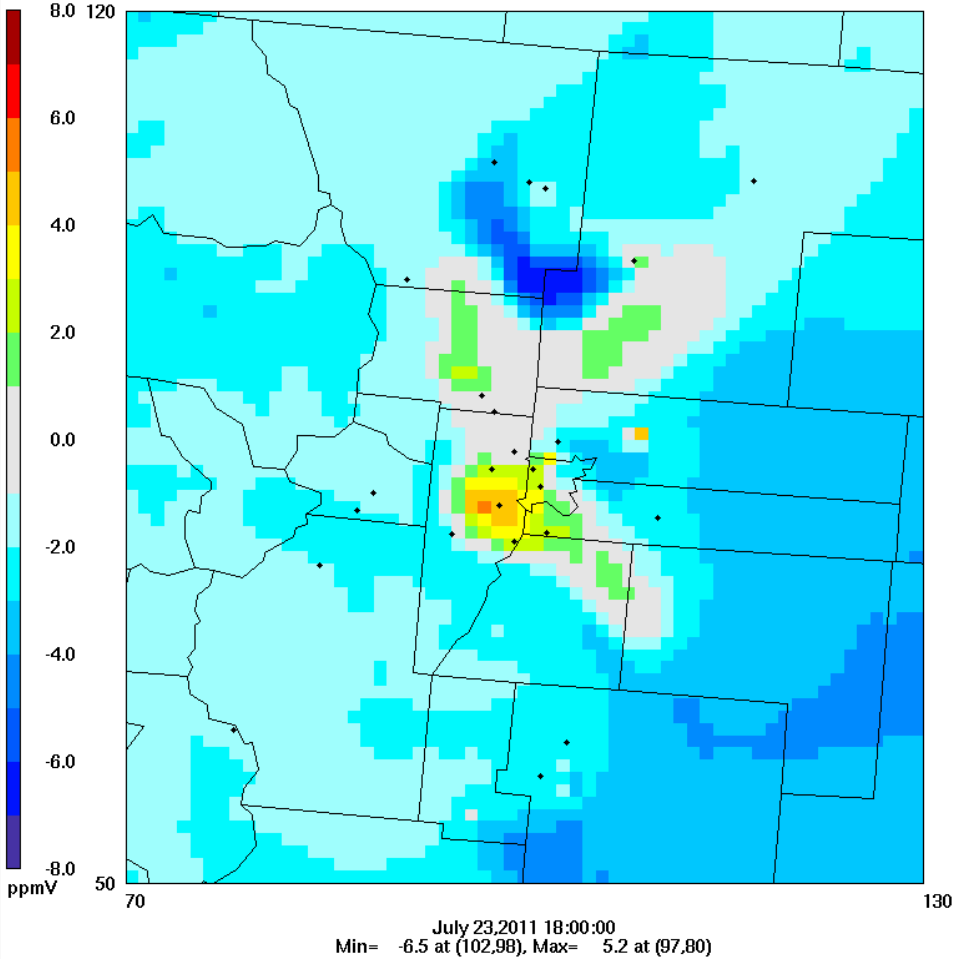
Model performs well in the Denver area but is biased high for regional ozone on July 23.



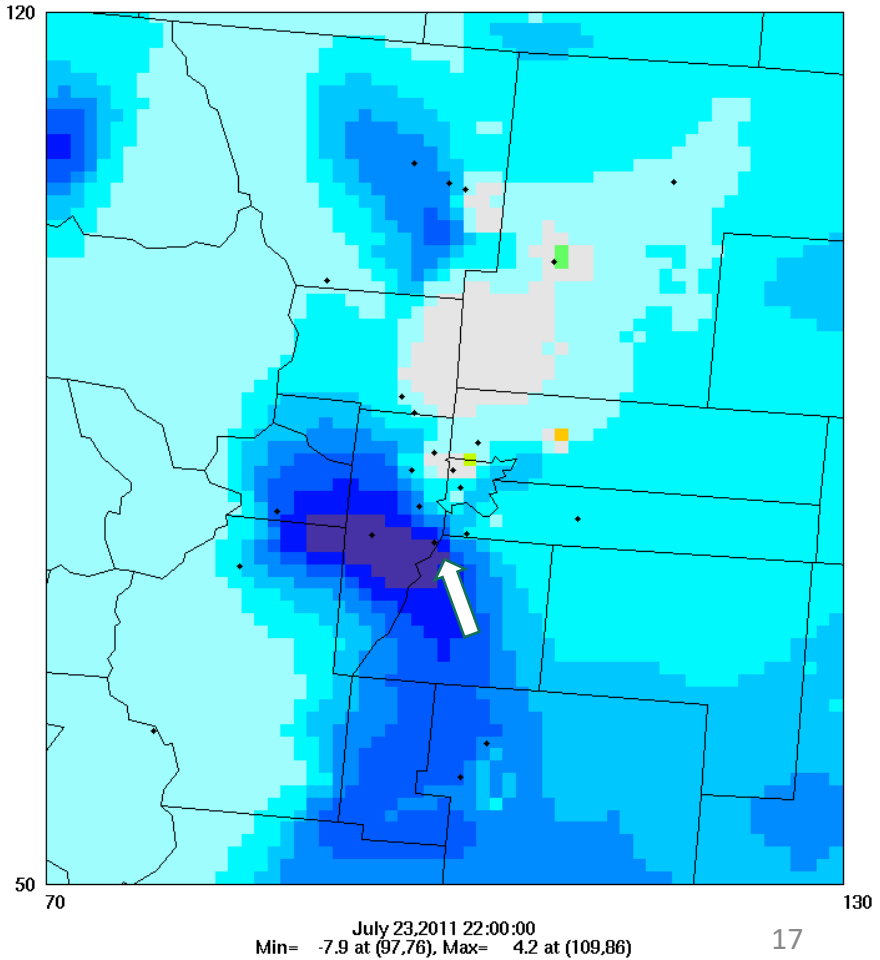
July 23 Model response (2017 – 2011) for 1-hour average O3

Hourly O3 NOx disbenefits in morning and benefits in afternoon. 8-hour average has small benefit.

Delta O3 at 11 am LDT



Delta O3 at 3 pm LDT



HCHO/NO2 Indicator

Schroeder et al., 2017. New Insights into the Column CH2O/NO2 Ratio as an Indicator of Near-surface Ozone Sensitivity:

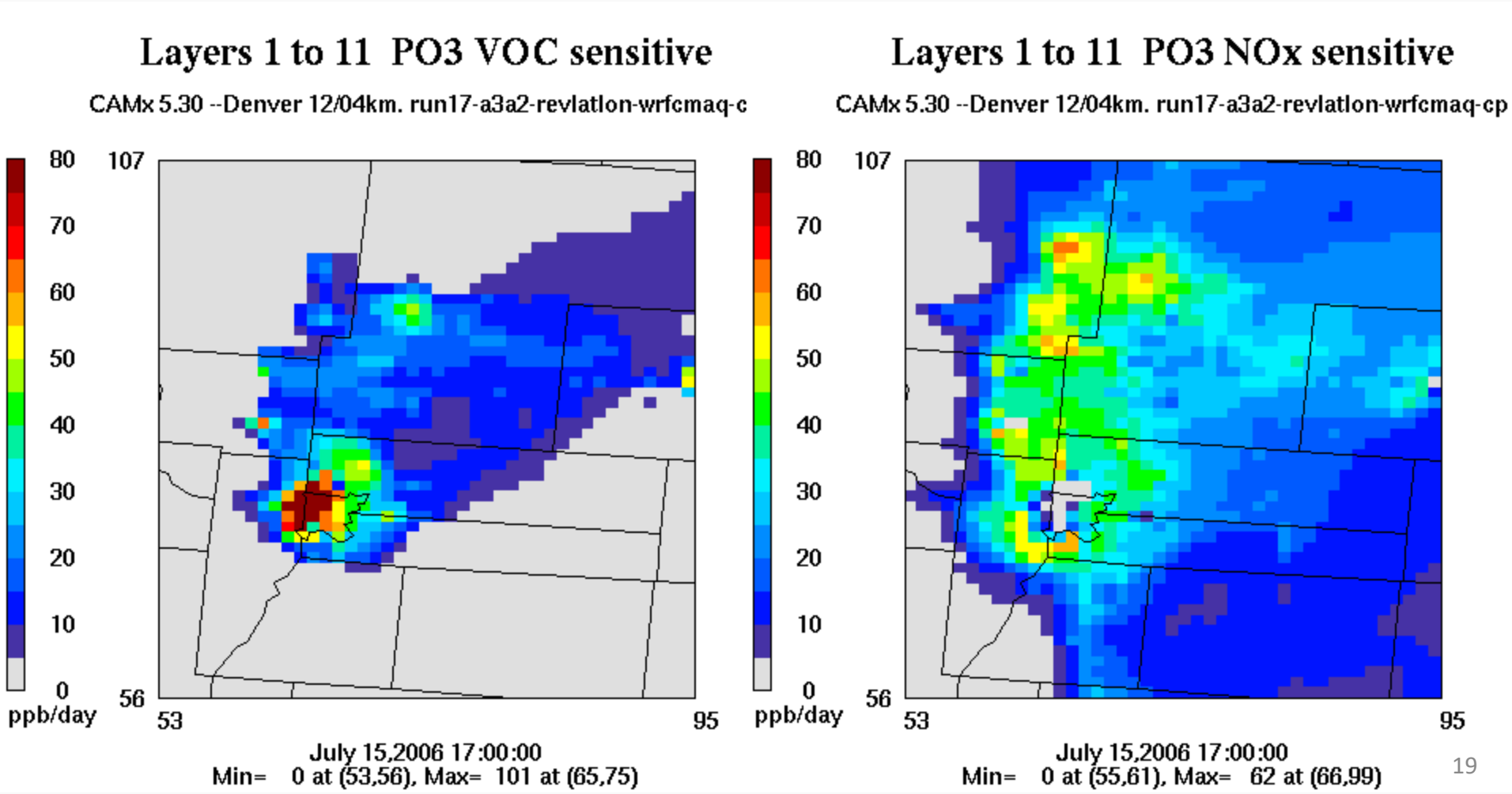
- Column measurements of HCHO/NO2 are a poor indicator of near-surface ozone sensitivity due to uneven vertical mixing in the lower troposphere.
- Long and short-term observations of changes in column HCHO/NO2 ratios may still provide useful information about the relative importance of O3 precursors

Jin et al., 2017, Evaluating a space-based indicator of surface ozone-NOx-VOC sensitivity over mid-latitude source regions and application to decadal trends:

- trends in HCHO/NO2 over the past decade indicate that a NOx emission control program will improve ozone air quality more now than it would have a decade ago.

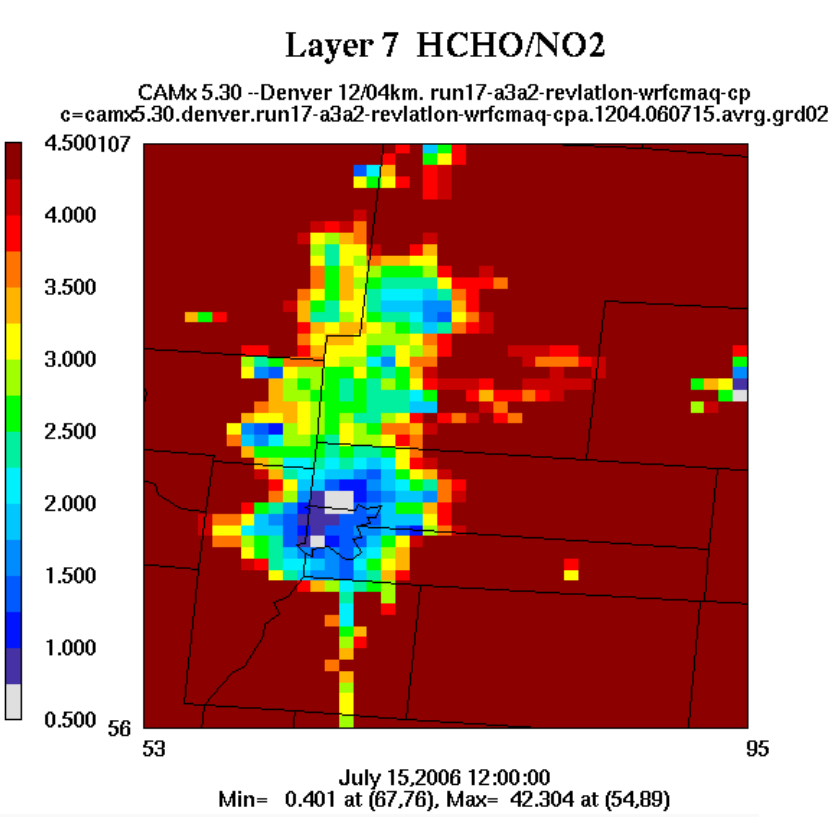
CAMx modeled PO3 Sensitivity

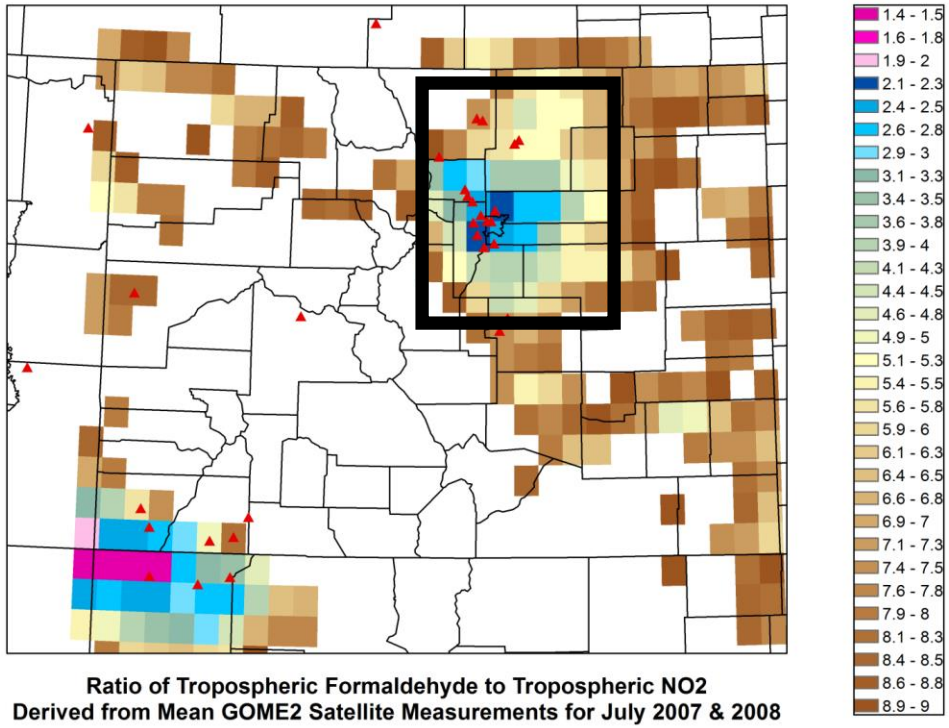
Hope to use TEMPO data to evaluate if the model accurately simulates PO3 sensitivity to VOC and NOx



CAMx modeled vs GOME2 HCHO/NO2

GOME2 HCHO/NO2 evaluated by Pat Reddy at CDPHE, used 2 month average to improve S/N ratio. Not quantitatively comparable to model hourly ratio but GOME2 indicates greater relative sensitivity to VOC in Denver Urban area, consistent with model PO3 sensitivity.





Ratio of Tropospheric Formaldehyde to Tropospheric NO2
Derived from Mean GOME2 Satellite Measurements for July 2007 & 2008

A ratio of 1.0 or lower may be indicative of VOC-limited or NOx-saturated photochemical conditions. All of the Front Range has ratios above 1.0.

gridded data source KNMI TEMIS - http://www.temis.nl/airpollution/no2.html

Summary

- State, Tribe and Federal Air Quality planners need:
  - High spatial resolution hourly measurements of O3 and precursors for urban and regional O3 planning.
  - Regional scale measurements of O3 and precursors for evaluation of O3 exceptional events and background O3 levels.
  - Measurements of speciated PM to evaluate natural haze levels and international transport of visibility impairing pollutants.