National Park Service
U.S. Department of the Interior

Air Resources Division

Projecting future visibility conditions with modeling – techniques and uncertainties

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Regional Haze Teach-In #4: Modeling
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So true…

It is dangerous to make forecasts, especially about the future.

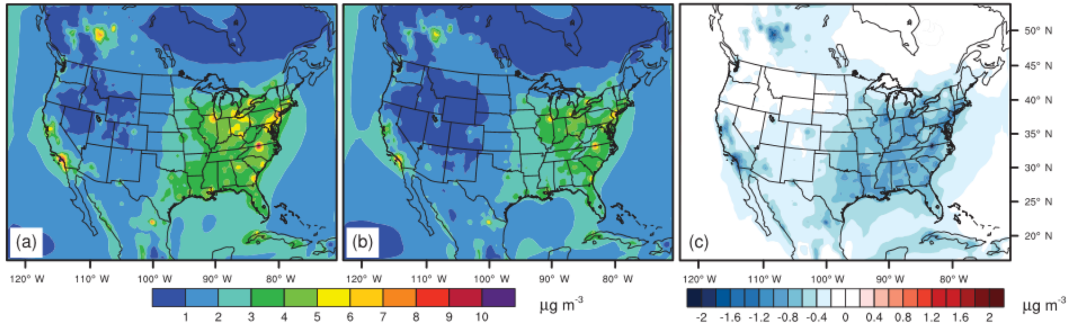
-Yogi Berra

Overview

- The recipe for modeling future haze
- Why it’s a little more complicated than that

How do we predict future visibility?

- Simple answer:
  - Run an air quality model for current conditions (the “base” year)
  - Run an air quality model for future conditions
  - Use these two simulations to make scaling factors (i.e., “relative response factors”, or RRFs)
  - Apply these RRFs to available monitoring data
  - Does haze in the future get better or worse?

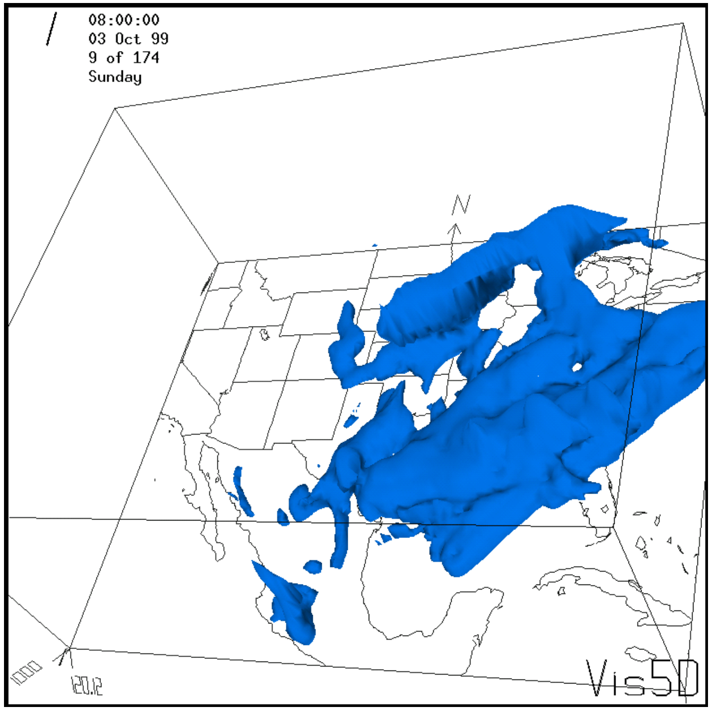


Zhang et al., Atmos. Chem. Phys., 16, 9533–9548, 2016 www.atmos-chem-phys.net/16/9533/2016/

Figure 3. The 3-year average $PM_{2.5}$ ($\mu g\, m^{-3}$) distributions in 2050 from **(a)** S_REF, **(b)** S_RCP45 and **(c)** the total co-benefits (shown as the difference between S_RCP45 and S_REF). Blue colors in panel **(c)** indicate an air quality improvement.

Run a model for the base year

- Choose a base year
  - Is it recent?
  - Is it "representative"?
- Develop your modeling platform
  - Regional air quality model
  - Emissions inventory
  - Meteorology
  - Boundary conditions



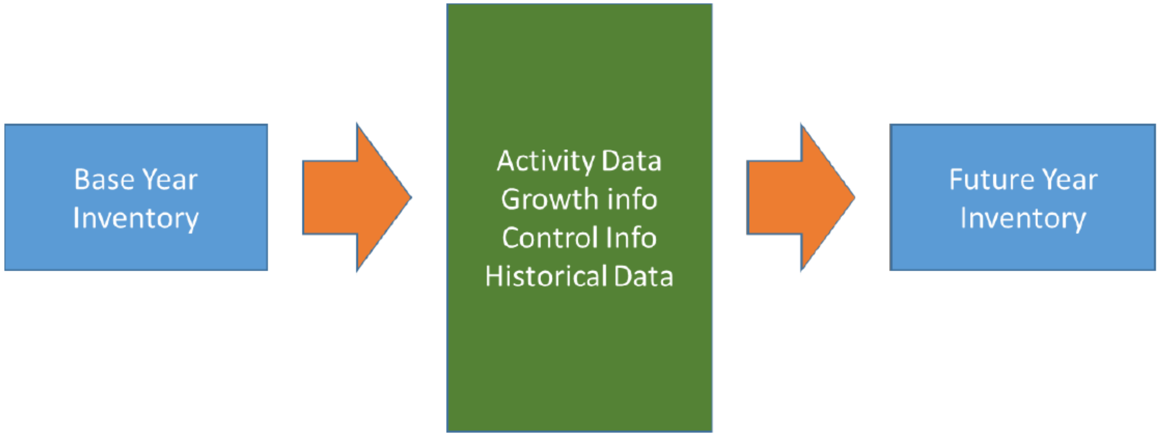
- Spend a lot of time looking at the results
  - Is it good enough?
  - Is it better at some things than others (e.g., sulfate v. dust)?

What inputs do we have for the future?

- Base year
  - Emissions, meteorology, boundary conditions
- Future year
  - Emissions, ~~meteorology~~, ~~boundary conditions~~
- We can't credibly simulate future meteorology or boundary conditions. But we can assess **how haze responds to estimated future changes in domestic anthropogenic emissions**. And this is the policy-relevant issue.

Run a model for the future year

- Choose a future year, like 2028
- Use the same modeling platform as the base year, but update the emission inventory to reflect future emissions



- Run the model again, this time with the future inventory, but keep the meteorology and boundary conditions the same

Relative Response Factor (RRF)

- We don't really trust the model in an absolute sense, i.e., in its ability predict absolute concentrations
- But we assume that it **can predict the relative change in a concentration** in response to a change in emissions
- Use this to **scale current observed concentrations** with the Relative Response Factor (RRF). This yields an estimated future concentration:

$$\textit{future concentration}_i = (\textit{observed concentration}_i)(\textit{RRF}_i)$$

Relative Response Factor (cont'd)

- The RRF for haze is the ratio of the average modeled future concentration and the average modeled base concentration during the 20% "best/least impaired" and "worst/most impaired" days:

$$\mathrm{RRF}_i = \frac{\overline{S_{i,\mathrm{F}}}}{\overline{S_{i,\mathrm{B}}}}$$

where

$$\overline{S_{i,\mathrm{F}}} = \frac{\sum_{d=0}^{D} S_{i,\mathrm{F},d}}{D} \qquad \overline{S_{i,\mathrm{B}}} = \frac{\sum_{d=0}^{D} S_{i,\mathrm{B},d}}{D}$$

A few details about RRFs

- The premise of this approach is that we trust
  - the observations
  - the model's ability to estimate relative changes
- It is a way of "anchoring" model results to the "reality" of the observation
- If the modeling platform was perfect then we wouldn't bother with RRFs, but would use instead the absolute values of the base and future concentrations

Are RRFs really independent of model bias?

- A study of ozone RRFs showed significant variation (0.78 – 0.95)
- Would this be the case for haze RRFs?

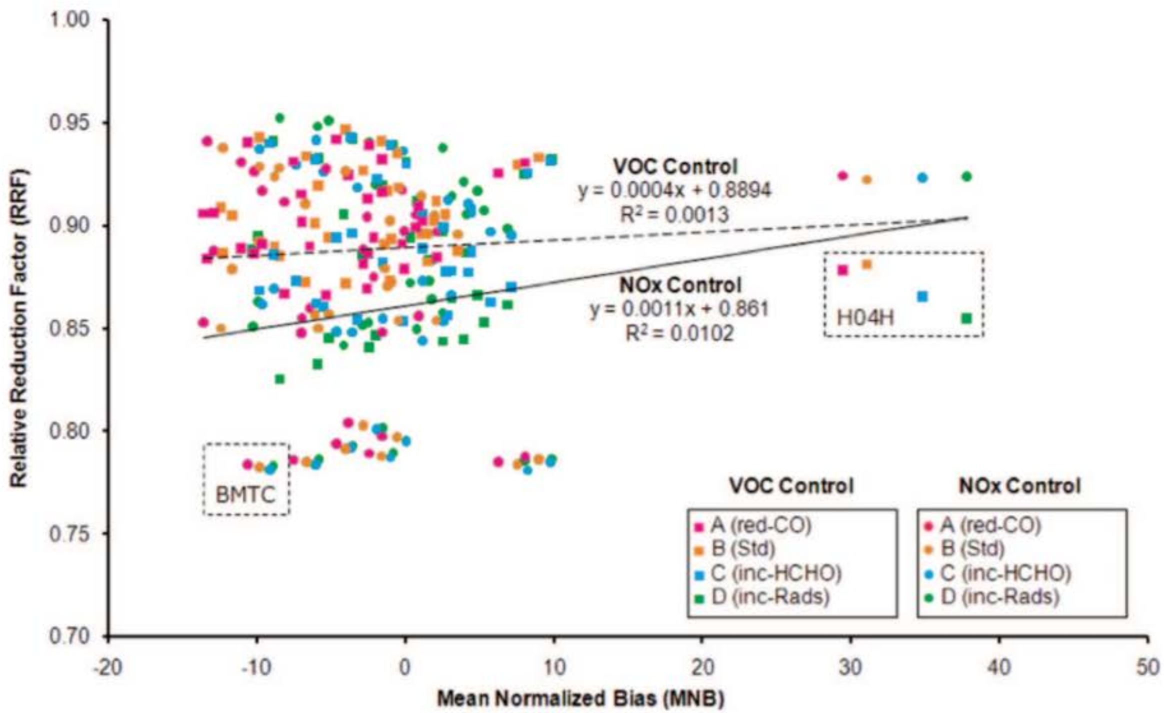


Figure 5. RRF plotted against episode MNB using 8-hr average O_3 concentrations for all sites and scenarios. RRFs resulting from the NO_x control scenario are marked by ×, and those resulting from the VOC control scenario are marked by □. Regression lines with corresponding equations and R^2 values are included. The clustering effect is illustrated with dashed boxes for the H04H monitor under VOC controls and BMTC monitor under NO_x controls.

Vizuete et al., 2010, JAWMA, http://dx.doi.org/10.3155/1047-3289.60.7.838

How many RRFs do we need for haze?

- We need to calculate several different RRFs to reflect 1) each IMPROVE species and 2) the 20%“best/worst” **observed** days (this may change to “most impaired/least impaired”days)

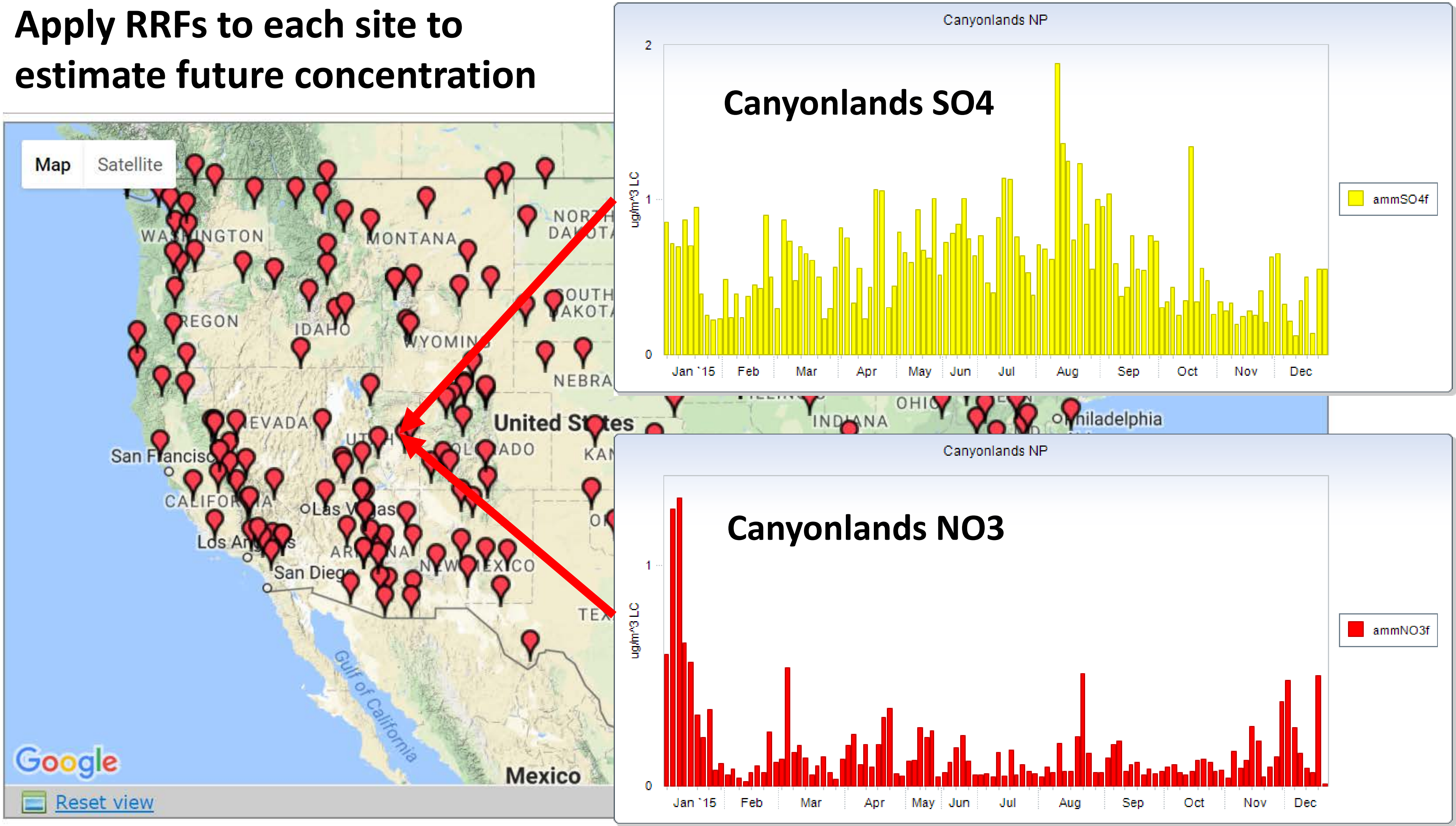
IMPROVE:	**CAMx:**
$[(NH_4)_2SO_4]$	= 1.375 x PSO4
$[NH_4NO_3]$	= 1.290 x PNO3
[OMC]	= POA + SOA1 + SOA2 + SOA3 + SOA4 + SOA5
[EC]	= PEC
[Soil]	= FPRM + FCRS
[Coarse Mass]	= CPRM + CCRS

- (6 species)(20% best) + (6 species)(20% worst) =

12 RRFs for each IMPROVE monitor

IMPROVE sites in the western US

Apply RRFs to each site to estimate future concentration



FED: Federal Land Manager Environmental Database
http://views.cira.colostate.edu/fed/

Well done, we've modeled future haze…

- …but it's a little more complex and subtle than that, and we should consider:
  - How well do we really simulate "now"?
  - Does the modeled atmosphere have the same response to perturbations as the real atmosphere?
  - How confident are we in the model inputs, especially future emission inventories?
  - Is there a way to quantify model uncertainties?
  - How do we treat future meteorology and boundary conditions?
  - How will regulations evolve?
  - How do we provide model results that are relevant to haze planners?

Estimates of future emissions

- Emission inventories are pretty complicated
  - Lots of different chemical species (NOx, VOCs, NH3, SO2, dust, etc.)
  - Fine spatial scale (12km or 4km) and temporal scale (hourly)
  - Many different source types
    - Mobile O&G EGUs Ag
    - Fires Shipping Biogenic Lightning
- We do a better job estimating some sources than others

Some sectors have a lot of detail for future

- More detail: Mobile, EGUs
- Somewhat less detail: Agriculture, Oil & Gas

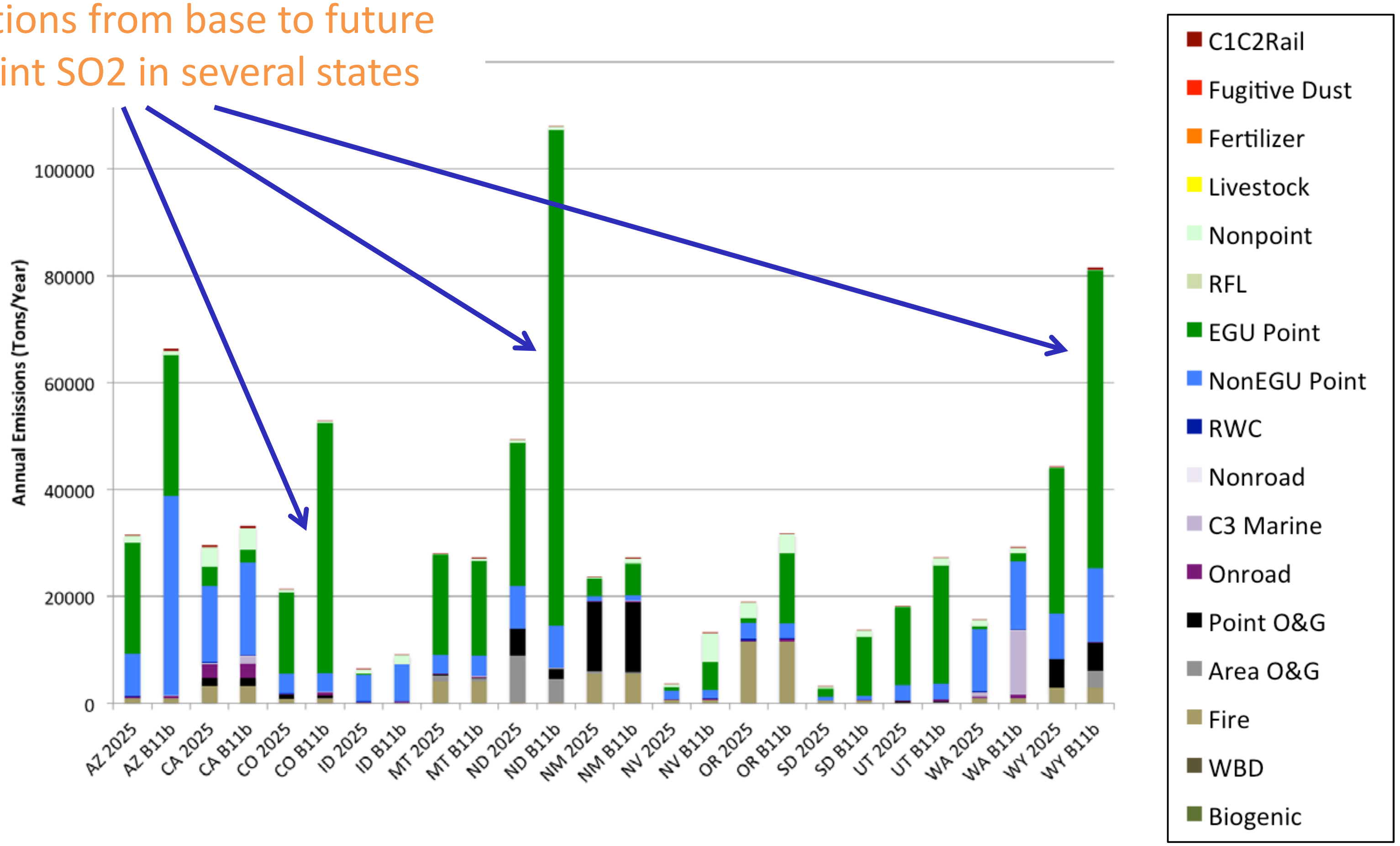
Onroad Projections Overview

- MOVES2014a is used to develop emission factors for light-duty and heavy-duty vehicles
- Main components adjusted for projections:
  - Regulatory impacts
  - Fuel changes
  - Inspection and Maintenance (I/M) programs
  - Age distributions
  - Future year Vehicle Miles Traveled (VMT) and other activity
  - Most of these changes are included in the approximately 300 representative county databases from which emission factors are computed

US EPA OAQPS, Emission Inventory and Analysis Group 31

SO2 should continue to decrease in the future

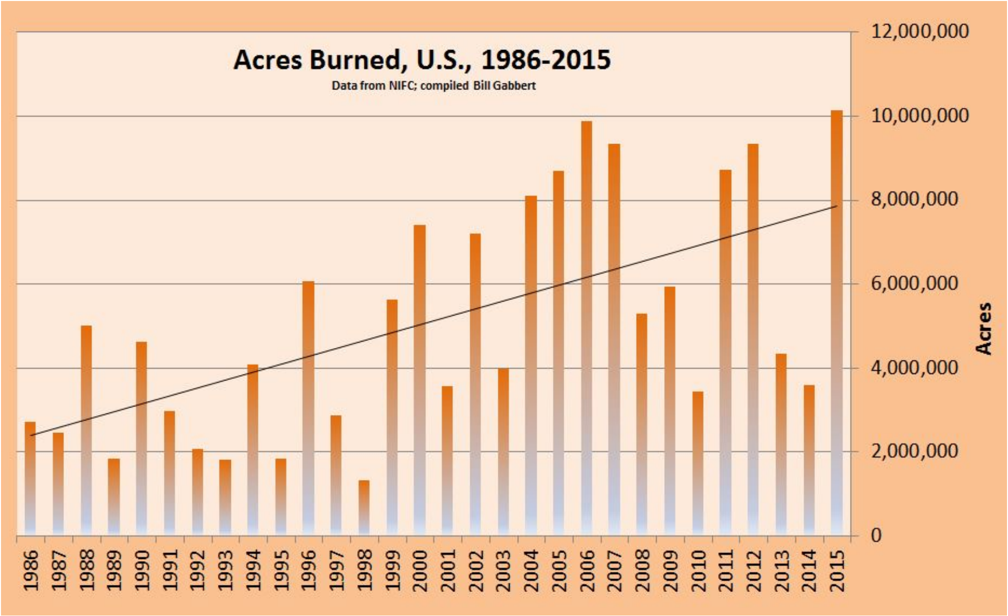
Big reductions from base to future in EGU Point SO2 in several states



IWDW-WAQS, 2015, http://views.cira.colostate.edu/documents/Projects/TSDW/Meetings/Technical_Committee_Call_20151029/WAQS_2011b_FutureYearEmissions_IWDW-WAQS_TechComm_29Oct2015final.pptx

But what can we say about future wildfires?

- Increase in duration of fire season in western US by 41% between 1979 and 2015
- Climate change-induced fuel aridity has added 4.2M hectares to western US fire area between 1985 and 2015



http://wildfiretoday.com/2016/10/11/study-concludes-climate-change-has-doubled-acres-burned-in-western-u-s/

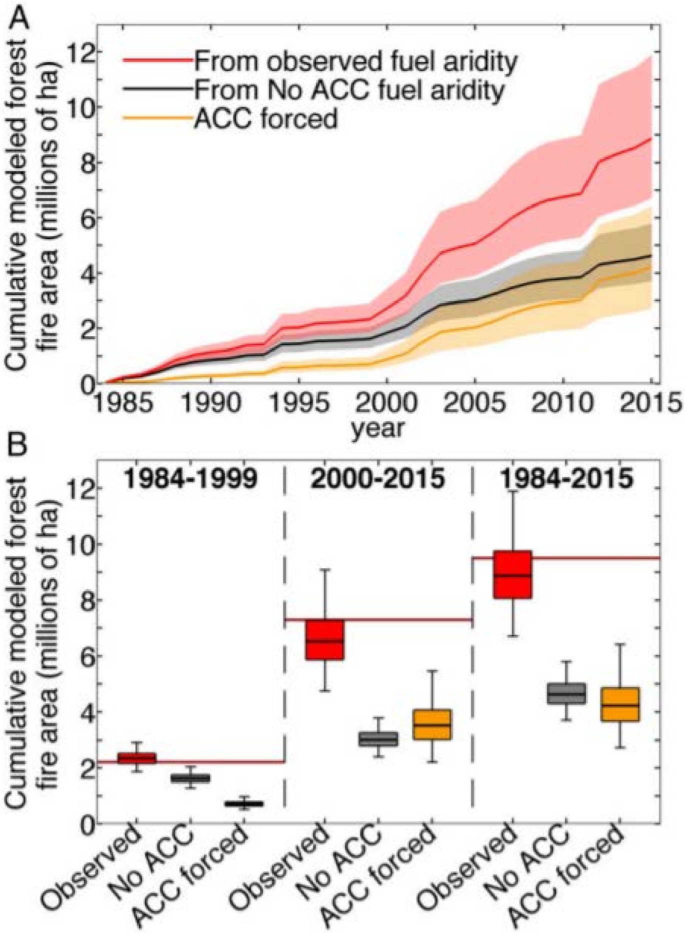
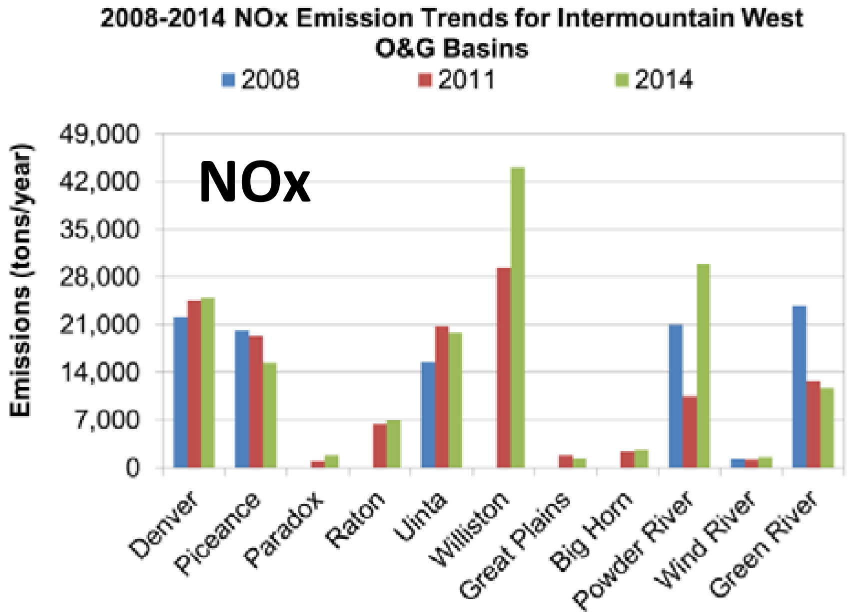


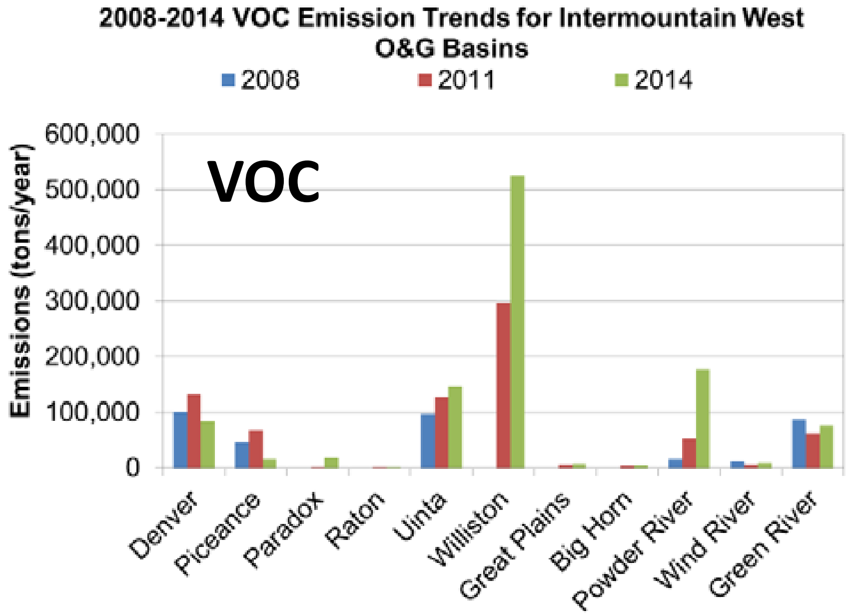
Fig. 5. Attribution of western US forest fire area to ACC. Cumulative forest fire area estimated from the (red) observed all-metric mean record of fuel aridity and (black) the fuel aridity record after exclusion of ACC (No ACC). The (orange) difference is the forest fire area forced by anthropogenic increases in fuel aridity. Bold lines in *A* and horizontal lines within box plots in *B* indicate mean estimated values (regression values in Fig. 1). Boxes in *B* bound 50% confidence intervals. Shaded areas in *A* and whiskers in *B* bound 95% confidence intervals. Dark red horizontal lines in *B* indicate observed forest fire area during each period.

Abatzoglou and Williams, 2016
http://www.pnas.org/content/113/42/11770

How variable are recent trends in O&G?

- Oil and gas emissions can change significantly over a short time period
- Some basins are more variable than others (Denver-Julesberg v. Powder River)



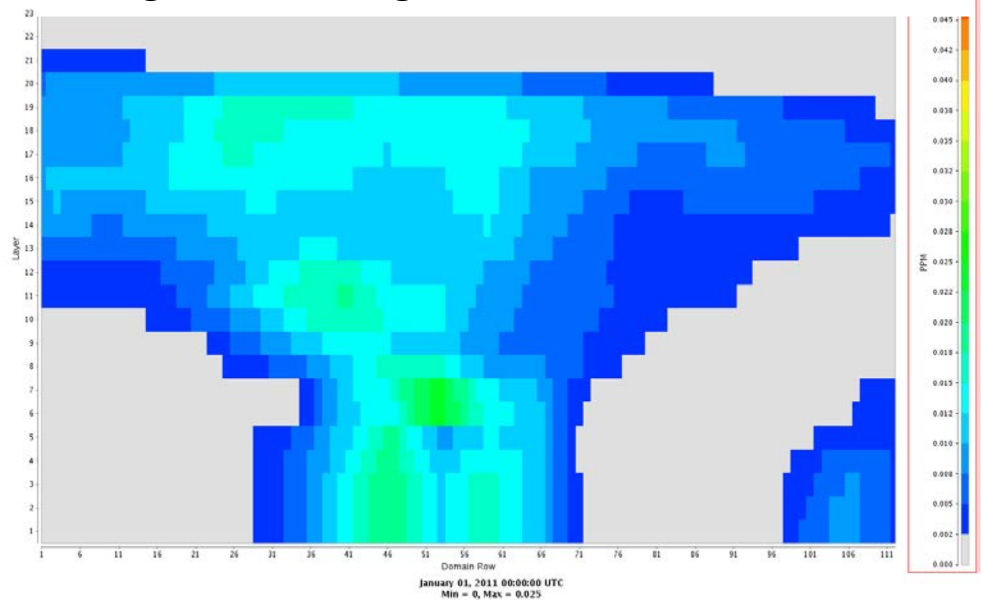


Ramboll-Environ, 2017, http://vibe.cira.colostate.edu/wiki/Attachments/2014_OG/WESTAR_2014_OandG%20EI_Memo_08Jun2017.pdf

How to treat future boundary conditions?

- BCs are a “source”
- International transport
- Option 1:
  - Hold constant
- Option 2:
  - Run a global model with
    - Estimated global future emissions
    - Current meteorology
  - Global inventories are being developed for future years (EDGAR, IPCC-RCP), but they’re less certain than domestic inventories

Ammonia boundary conditions from MOZART along western edge of model domain



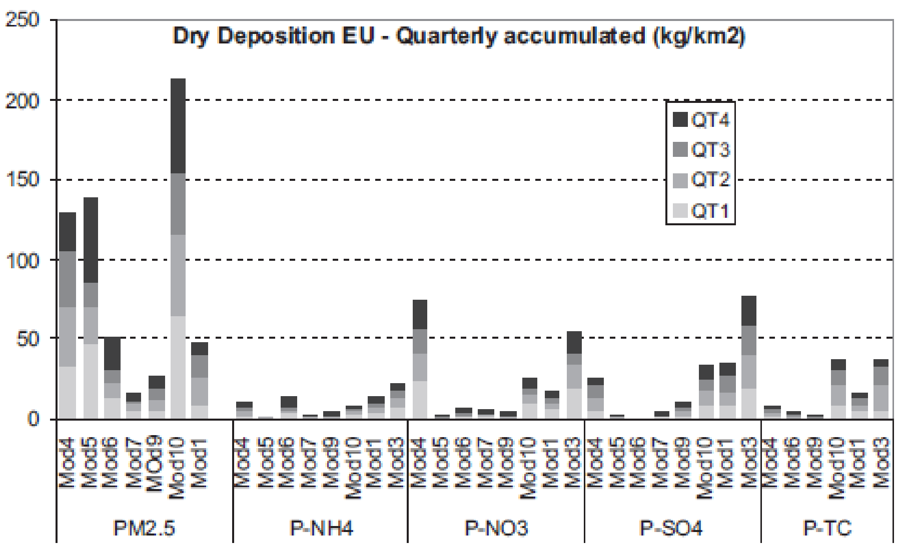
How to treat future meteorology?

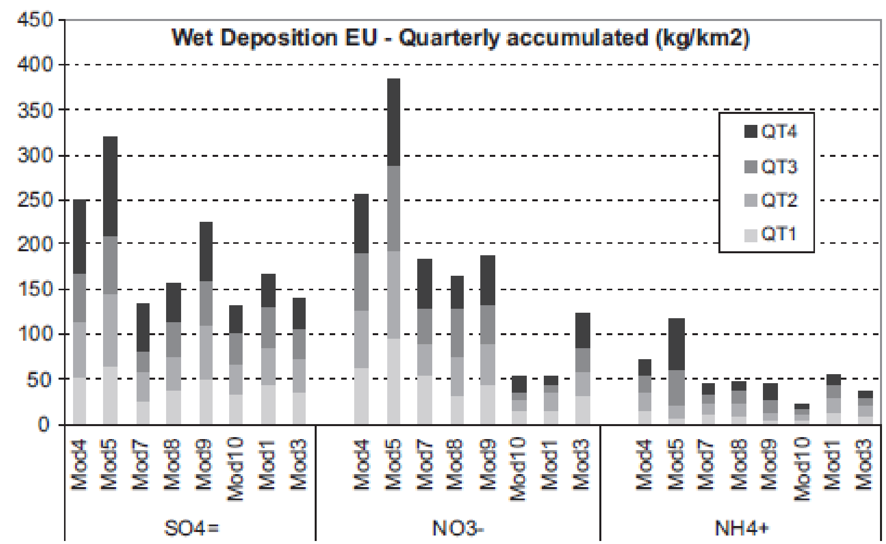
- We can’t; hold constant
- Why?
  - Air quality models require a very detailed treatment of the meteorology
  - For every hour and every grid cell:
    - Wind speed and direction   Temperature
    - Cloud cover   Precipitation
    - Humidity   etc.
  - The meteorological models use observations and analysis fields to improve performance, and we have no observations from the future

How to estimate inherent model uncertainty?

- Not easy, but can try
  - Sensitivity tests
  - Diagnostic evaluations
  - Dynamic evaluations
  - Ensembles
- Use an ensemble to 1) define a "best" predictive model or 2) evaluate predictive uncertainty

AQMEII multi-model ensemble:





Solazzo, et al., Operational model evaluation for particulate matter in Europe and North America in the context of AQMEII, Atmos. Env., 55, 2012, http://dx.doi.org/10.1016/j.atmosenv.2012.02.045.

“Rules on the Books” and future emissions

- (now defunct) Clean Power Plan
- Published closures of fossil EGUs / Resource Plans from utility companies approved by PUCs that identify decline rates in fossil-based production.
- Updated basin-level-based estimates of turnover for O&G equipment, control devices, and implementation of “best practices for fugitives” by SCC – what about greater production? (starting from current level of control and device)

“Rules on the Books” (cont’d)

- MOVES-based forecasts of SCC-level emission reductions
- Survey-based emissions reduction estimates of future emission rates for non-EGU point and nonpoint sources for western air agencies (starting from current level of control and device)
- Any available future-year emissions for offshore shipping, Canada, and Mexico available from other sources

Summary

- future haze = (current haze) x (RRF)
- Calculate the RRF (Relative Response Factor) by running an air quality model for a current year and a future year and taking the ratio of the particle concentrations that impact haze
- All we can really say about the future is how some anthropogenic emission categories will evolve, and that's still challenging:
  - Economics Regulations
  - Population growth Technology

Summary (cont’d)

- Although we can’t formally model some things that will impact future haze, we can say
  - Wildfires are likely to continue to get more severe
  - International transport (read: boundary conditions) will likely remain uncertain
    - Decreasing emissions from China, but increasing in India?
  - Changes in weather patterns likely
    - Frequency of El Nino/La Nina
    - Weakening of Southwest monsoon
  - Federal, state and local regulations will continue to evolve