Improving Air Quality Model Chemistry for Snow and Cold Conditions

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Air Quality in Utah: Science for Solutions
13 January 2015
Project Purpose

• This project looks to improve on two pieces to the difficult wintertime ozone modeling puzzle
  – Atmospheric chemistry for Uintah Basin conditions
  – Treatment of snow cover
Are chemistry changes needed for Utah’s winters?

• Photolytic effect of **sunlight**
  – Little variation with temperature

• Chemistry of **NOx** and similar molecules
  – Cold conditions are understood
  – NOx chemistry is important for ozone from surface through stratosphere

• Chemistry of **VOC**
  – Models developed for summer ozone
  – There is potential for improvement
  – Focus on the most abundant VOCs in Uinta: **Alkanes**
Alkane chemistry

VOC \[\rightarrow NO \rightarrow 1-\alpha \rightarrow \alpha \rightarrow \text{Ozone production} \rightarrow \text{Organic nitrate}\]

- Fraction \((\alpha)\) of organic nitrate formed depends on temperature and pressure (altitude)
- But models hold \(\alpha\) constant
  - Including this dependency should improve winter chemistry modeling
  - Important for Utah conditions

\[\alpha = \frac{\text{Ozone production}}{\text{VOC} + \text{NO}}\]

\[\text{50\% increase in } \alpha\]

\[\text{winter} \rightarrow \text{summer}\]
Model snow cover treatments

• **Surface reflectivity or “albedo”**
  – Fraction of UV energy reflected back through atmosphere
  – **Old**: albedo = 50% when any snow is present
  – **New**: albedo depends on snow coverage and age

• **Atmospheric deposition to surface**
  – Removal of pollutants via diffusion, impaction, absorption
  – **Old**: snow covers 80% of surface when any snow is present
  – **New**: snow cover consistent with albedo treatment

• **Surface chemistry**
  – Reactions on surfaces may be source of ozone precursors
  – **Old**: no specific snow compartment
  – **New**: snow compartment added
Surface albedo with snow

Shallow snow increases albedo by >10x

Sparse shrubs, other elements remain exposed

Over large area, snow albedo depends on land cover

Photo from NOAA

Courtesy of Univ. of Utah: Photo by Chris Santacroce
Model improvements for snow albedo

- Snow depth/cover and age/albedo functions from NCAR/WRF meteorological model

Example Snow Depth and Albedo

- Low vegetation covered faster/completely, maximizing snow albedo
- New snowfall increases snow depth and “freshens” the albedo
- Original albedo assumption
Model surface deposition

- One-way irreversible loss from atmosphere to surface
- Diffusion to surface elements (soil, vegetation, water, structures)
  - Uptake rates depend on surface type
- Diurnal/seasonal variations
  - Winter: stable, cold, dry, low leaf activity/density → reduced deposition
- Snow cuts off pathways to buried surface elements
  - Further reduces deposition rates
Model surface chemistry update

- Optional model component:
  - Two-way transfer between atmosphere and surface system
  - Chemical interactions among deposited material form products that re-emit

- Updated to include snow with soil and vegetation compartments

- Models need to account for snow surface-atmosphere chemistry interaction
  - May be an important piece of atmospheric chemistry
Initial ozone simulation of Uinta Basin

- **Model:**
  - CAMx v6.1
  - Add chemistry and snow treatment updates

- **Domain:**
  - UDAQ 4-km grid
  - February 1-7, 2013

- **Datasets:**
  - UDAQ-derived meteorology and emissions
  - UBOS 2013 measurements
Initial ozone simulation of Uinta Basin

Original CAMx v6.1

Effect with New Snow + Chemistry Update + Surface Model w/ Snow

- Total effect of all model updates: 10-20 ppb $O_3$ *increase*
  - Snow albedo/deposition update: $O_3$ *increase*
  - Winter chemistry update: $O_3$ *decrease*
  - Surface chemistry update: $O_3$ *increase*

- Surface chemistry configured for testing purposes only!
  - Highly speculative, currently no conclusive evidence for a surface chemical pathway
Initial ozone simulation of Uinta Basin

- **O₃** is too low in UB, but OK outside
- **O₃** is inhibited and suppressed in UB
  - NOx-rich, VOC-poor

**Western background site**
- Fruitland
  - 40-60 ppb

**Eastern background site**
- Rabbit Mtn

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**Graphs**
- **Original Model**
  - New snow + Chemistry
- **Update + Surface Model w/ Snow**
  - Ozone (ppb) vs. Date

**Sites**
- Horsepool
  - 20-50 ppb
Summary

• Model updates
  – Winter chemistry update
    ▪ Cold temperature pushes NOx out of ozone cycle, reduces ozone
  – Snow albedo and deposition update
    ▪ Higher albedo, reductions in deposition increase ozone
  – Snow surface chemistry
    ▪ May be a source of emissions that increase ozone production
    ▪ Complex, uncertain, inconclusive – more study needed

• Updates insufficient to simulate ozone at measured levels
  – NOAA modeling achieves higher ozone with 2xVOC, NOx/3 (Ahmadov et al., 2014)
  – Needed improvements to emissions, winter meteorological modeling, surface-atmosphere interactions, etc.

• ENVIRON continuing to assist UDAQ with model improvements
  – Response to alternative emissions, surface chemistry processes
Thank You