Use of Satellite Radiative Properties to Improve Air Quality Models and Emission Estimates

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THE ROLE OF PHYSICAL ATMOSPHERE IN AIR QUALITY CHEMISTRY

Insolation/Temperature:
• impacts biogenic emissions (soil NO, isoprene) as well as anthropogenic evaporative loses.
• Affects chemical reaction rates and thermal decomposition of nitrates.

Moisture:
• Impacts gas/aerosol chemistry, as well as aerosol formation and growth.

BL Heights:
• Affects dilution and pollutant concentrations.

Winds:
• Impacts transport/transformation

Clouds:
• Impact all of the above.
• Impact photolysis rates (impacting photochemical reactions for ozone and fine particle formation). Also impacting biogenic HC emissions.
• Impact transport/vertical mixing, LNOx, aqueous chemistry, wet removal, aerosol growth/recycling and indirect effects.
Use of Satellite Observation to Improve the Performance of Meteorological / Air Quality Models in Support of Regulatory AQ Community

- Targeting the needs of regulatory air quality community (SIP and SIP related activities).
- Utilizing satellite observation for improved representation of clouds and their radiative impact: photolysis rates, biogenic emissions, vertical mixing, etc.
Activities Within AQAST

- Improved representation of chemical reactions:
  - Satellite-derived photolysis rate (TT projects: AQ Reanalysis and DYNAMO)

- Improved estimate of biogenic emissions:
  - Satellite-derived PAR (Photosynthetically Active Radiation) (TT projects: AQ Reanalysis and DYNAMO)
  - Improved near surface temperature (TT projects: AQ Reanalysis and DYNAMO).

- Better data archiving/delivery:
  - Coordinating with RSIG.
ADJUSTING PHOTOLYSIS RATES IN CMAQ BASED ON GOES OBSERVED CLOUDS

- This technique is included in the standard release of CMAQ
- Cloud albedo and cloud top temperature from GOES is used to calculate cloud transmissivity and cloud thickness
- The information is fed into MCIP/CMAQ
- CMAQ parameterization is bypassed and photolysis rates are then adjusted based on GOES cloud information

Adapted from: Pour-Biazar et al., 2007
Clouds at the Right Place and Time

- Current Method for insolation and photolysis while improving ozone predictions, physical atmosphere is inconsistent with model dynamics and cloud fields.
- What if we can create an environment that is conducive to cloud formation/removal.
FUNDAMENTAL APPROACH

Use satellite cloud top temperatures and cloud albedos to estimate a **TARGET VERTICAL VELOCITY (Wmax)**.

- Adjust divergence to comply with Wmax in a way similar to O’Brien (1970).
- Nudge model winds toward new horizontal wind field to sustain the vertical motion.
Assimilation technique shows large gains in agreement index. Very effective at both producing and dissipating clouds.
The assimilation technique improved agreement between model and GOES observations.

The daily average percentage change over the August 2006 time period was determined to be 15%.
Temperature bias is reduced.

Mixing ratio bias is decreased.
Better agreement in cloud pattern between assimilation simulation and GOES.
Satellite-Derived Photosynthetically Active Radiation (PAR)

\[ PAR = \frac{1}{hc} \int_{4}^{7} I(\lambda)d\lambda \quad (\text{W m}^{-2}) = \frac{1}{hc} \int_{4}^{7} I(\lambda)d\lambda \quad \text{(quantum}^{-2} \text{s}^{-1}) \]

= Insolation \times CF

\[ CF = \frac{PAR}{Insolation} = 0.42 + 0.28 \times ODFactor \times Zfactor \]


\[ \tau = \frac{8\alpha_c}{(1 - \alpha_c)^2}, \quad \text{where} \quad \alpha_c = \text{cloud albedo} \]
Functional Form of Correction Factor

\[ CF = 0.42 + 0.28 \times \left( 1 - 1.8 \times \frac{1}{\sqrt{10}} \right) \times \left( 1 + 0.1 \times \left( 1 - \sqrt{\cos(Z)} \right) \right)^{-\tau} \]
GOES Insolation Bias Increases From West to East

We are working with George Diak to correct this issue.
Performing bias correction before converting to PAR.
Satellite-derived insolation and PAR for September 14, 2013, at 19:45 GMT.
PAR Requests and Status of Deliverables

- **2013:**
  - Requests: DYNAMO, Texas Discover-AQ studies
  - Status: Processed and delivered

- **2012:**
  - Requests: The Texas Commission on Environmental Quality (TCEQ)
  - Status: Being processed.

- **2011:**
  - Requests: Wisconsin Department of Natural Resources (DNR), DYNAMO
  - Status: June-July 2011 has been processed and delivered. Rest of the year being processed.

- **2006:**
  - Requests: For evaluation purposes.
  - Status: Being processed.
Summary

- We continue to support AQAST activities regarding improved AQ model performance.
- Currently there is a high demand for archived PAR product and we are trying to produce a reasonable product to be used as a preliminary version of data.
- We are hoping to include our WRF cloud correction technique in other AQAST modeling activities.
Acknowledgment

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Note the results in this study do not necessarily reflect policy or science positions by the funding agencies.
ADDITIONAL SLIDES
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Inaccurate cloud prediction results in significant under-/over-prediction of ozone. Use of satellite cloud information greatly improves O3 predictions.

Cloud albedo, surface albedo, and insolation are retrieved based on Gautier et al. (1980), Diak and Gautier (1983). From GOES visible channel centered at .65 µm.

Photolysis Adjustment (CMAQ-4.7)

Cloud top
Determined from satellite IR temperature

\[ \alpha_G \]

\[ \alpha_C \]

\[ \text{tr}_{\text{cld}} = 1 \cdot (\text{alb}_{\text{cld}} + \text{abs}_{\text{cld}}) \]
Satellite Method

Cloud top
Determined from satellite IR temperature

Transmittance =
1 - reflectance - absorption
Observed by satellite F(reflectance)

Cloud Base
Determined from LCL

Photolysis Rates

Determined from LCL

Satellite Method

WRF Method

Assume WRF derived cloud distribution is correct

Cloud top
Determined from model

Cloud Base
Determined from MM5

\[
J_{\text{below}} = J_{\text{clear}} \left[ 1 + \frac{1.6 \tau_{\text{cld}} \cos(\theta)}{\tau_{\text{cld}}} - 1 \right]
\]

\[
J_{\text{above}} = J_{\text{clear}} \left[ 1 + \frac{\alpha_i (1 - \tau_{\text{cld}}) \cos(\theta)}{\tau_{\text{cld}}} \right]
\]
Correcting Over-Prediction

- Objective: Create subsidence within the model to evaporate cloud droplets.
- Determine the model layer with the maximum amount of cloud liquid water (CLW).
- Determine the location that a parcel located at $Z_{\text{MaxCLW}}$ can be pushed down to so that it evaporates.

1D-VAR Inputs:

- $w_{\text{target}} = -\frac{Z_{\text{target}} - Z_{\text{par_mod}}}{\Delta t}$
- $Z_{\text{target}} = Z_{\text{MaxCLW}}$
- $ADJ_{\text{TOP}} = Z_{\text{ctop}} + 1000$ [m]
- $ADJ_{\text{BOT}} = Z_{\text{par_mod}} - 1000$ [m]
Correcting Under-Prediction

- **Objective:** Lift a parcel to saturation.
- Use GOES derived cloud top temperature and cloud albedo to estimate the location and thickness of the observed cloud.
- Use this estimated cloud thickness to determine the minimum height a parcel at a given model location needs to be lifted to reach saturation.

**1D-VAR Inputs:**

- \( w_{target} = \frac{Z_{Saturation} - Z_{par_mod}}{\Delta t} \)
- \( Z_{target} = Z_{Saturation} \)
- \( \text{ADJ\_TOP} = Z_{target} + \text{Cloud Depth} \)
- \( \text{ADJ\_BOT} = Z_{par_mod} - 1000 \text{ [m]} \)
Air Quality Modeling Systems

Physical Atmosphere
- Clouds and microphysical processes
- Atmospheric dynamics
- Boundary layer development
- Fluxes of heat and moisture
- LSM describing land-atmosphere interactions

SCIENCE + ART
- Aerosol Cloud interaction

Chemical Atmosphere
- Heterogeneous chemistry, aerosol
- Transport and transformation of pollutants
- Photochemistry and oxidant formation
- Natural and anthropogenic emissions
- Surface removal

Winds, temperature, moisture, surface properties and fluxes

SCIENCE + ART
- Less Absorption More Transmission
- More Absorption Less Transmission
- Clean Cloud
- Polluted Cloud
- Cloud deepens Rain deeper for Crystals
Use of Satellite Observation to Improve the Performance of Meteorological / Air Quality Models in Support of Regulatory AQ Community

Motivation:

- To improve the fidelity of the physical atmosphere in air quality modeling systems such as WRF/CMAQ.
- Models are too smooth and do not maintain as much energy at higher frequencies as observations. Surface properties and clouds are among major model uncertainties causing this problem. NWS stations are too sparse for model spatial resolution and are not representative of the grid averaged quantity. On the other hand, satellite data provide pixel integral quantity compatible with model grid.

Relevant Activities:

- Targeting the needs of regulatory air quality community (SIP and SIP related activities).
- Utilizing satellite observation for improved representation of clouds and their radiative impact: photolysis rates, biogenic emissions, vertical mixing, etc.
- Improving representation of surface energy budget and boundary layer evolution by utilizing satellite observation: Insolation, albedo, Moisture availability, and bulk heat capacity.
Better agreement in cloud pattern between assimilation simulation and GOES is also observed for insolation.