Improving AQ Forecasting Through A Closer Integration Of Observations And Models

New requirements for NRT data, observing systems, and assimilation systems for chemical applications!!
Research Needs in AQ Data Assimilation

- Met focused impacts (clouds, soil moisture, etc.)

- Chemical Techniques (ensemble, Var, hybrid)
  - Diversity of models (and components) with DA capabilities (e.g., Aerosol mod, radiation)
  - Control targets: initial, boundary, emissions
  - What existing data to assimilate (little experience in multiple species assimilations)

- Observing systems
  - Observation impact on analysis; quantify “value” of observations
  - Spatial, temporal value

- Better estimates of:
  - background errors (e.g., flow dependent, ...)
  - observational errors,
  - model errors, and
  - the impact of error misspecification on analysis
Research Needs in AQ Data Assimilation

• New algorithmic developments:
  – ability to deal with non-Gaussian uncertainty (e.g., particle filters);
  – ability to account for model errors (e.g., weakly constrained 4D-Var);
  – ability to quantify posterior errors (e.g., second order adjoint)
  – ability to integrate the lessons learned so far (e.g., hybrid variational-ensemble methods)
  – higher computational efficiency (e.g., reduced order models)

• Challenges wrt to scales (resolution, multiscales,...)
• “coupled” met strategies (what species, techniques, impacts both ways, etc..)
• New computer science developments
  – Data management
  – Exploit accelerator architectures (e.g., GPUs)
• Computational resources/efficiency
• Testbeds
• Building community efforts – identity, articulation
FUTURE DIRECTIONS FOR IMPROVING AIR QUALITY PREDICTIONS -- Summary

✓ Further improvements will require reductions in key uncertainties (e.g., emissions, better basic understanding of some processes).

✓ There remain many observation needs and they need to be better articulated (NRT, 3-d components, geostationary).

✓ Closer integration of observations is needed, including closer integration with AQ and met forecasting elements.

✓ A growing set of tools and techniques to assist and apply data assimilation are available (KPP- adjoints, models for background errors, EnKf wrappers, etc.), BUT more work on chemical aspects and techniques needed.

✓ Need to continue to build the community and share experiences!
Backup Slides
Chemical Weather – A New Challenge/Opportunity For Weather And Other Services

Evolving complexity of observing systems, models, and applications.

Importance of Chemical Weather

- Effects of air quality and chemical exposure on human health.
- Effects of gases and aerosols on ecosystems and agriculture
- Effects of air quality and visibility on tourism
- Effects of UV radiation on ecosystems and humans
- Improvements of numerical weather prediction models

WMO: GAW Urban Research Meteorology and Environment Project -- GURME
Major Challenge: Lack of Observations
What’s wrong with this picture?
Observing Weather and Climate
FROM THE GROUND UP
A Nationwide Network of Networks
www.nap.edu/catalog.php?record_id=12540

Focus in CTM-modelling vs NWP (from Ø. Hov)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Numerical Weather Prediction</th>
<th>Chemical Transport Modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed</td>
<td>High wind speeds</td>
<td>Stagnant conditions</td>
</tr>
<tr>
<td>Wind direction</td>
<td>Not so important</td>
<td>Essential for S-R-relationships</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Heavy rain</td>
<td>Length of dry periods; low intensity rain</td>
</tr>
<tr>
<td>Temperature</td>
<td>High and low temperatures, freezing</td>
<td>High temperatures – fast reactions and large biogenic emissions</td>
</tr>
<tr>
<td>Clouds</td>
<td>Cloud cover</td>
<td>Type, location, lifetime</td>
</tr>
<tr>
<td>Convection</td>
<td>Precipitation</td>
<td>BL ventilation</td>
</tr>
<tr>
<td>TRH, T, Tmix</td>
<td>Not so important</td>
<td>Important</td>
</tr>
<tr>
<td>Specific humidity</td>
<td>Not so important</td>
<td>Important for [OH]</td>
</tr>
<tr>
<td>Ground surface</td>
<td>Important for fluxes of heat, momentum, moisture</td>
<td>Important for deposition, biogenic emissions</td>
</tr>
</tbody>
</table>

PM2.5
Soil Moisture Networks
Observations Priorities Stemming from Common Threads

MOST NEEDED:
- Height of the planetary boundary layer
- Soil moisture and temperature profiles
- High resolution vertical profiles of humidity
- Measurements of air quality and atmospheric composition above the surface layer

NEEDED:
- Direct and diffuse radiation
- Vertical profiles of wind
- Sub-surface temperature profiles (e.g., under pavement)
- Icing near the surface
- Vertical profiles of temperature
- Surface turbulence parameters
Assimilation of Key Meteorological Parameters are Needed to Improve AQ Prediction Skill

Section 3 – Introduction and Overview of Course

Design Period Simulations – Satellite Inputs
Retrospective – Data Assimilated for all Integration Period

Example: impact of met parameters

Geostationary Satellite Observations
- Insolation
- Skin temperatures
- Cloud Properties

MODIS
- Surface emissivity
- Surface albedo
- Skin temperatures

Satellite derived properties for photolysis rates

Physical Model
Recreates Physical Atmosphere

Chemical Model
Recreates Chemical Atmosphere

IMPACT OF PHOTOLYSIS ADJUSTMENT

30 ppb difference!

Observed O_3 vs Model Predictions
(South MDS, lon=90.67, lat=90.71)

例: impact of met parameters

McNider et al., 2009

Improved Boundary Layer Heights

McNider et al., 2009
Major Challenge: Need to Estimate ALL Emissions at Appropriate Scales (*places new responsibilities for NMHCs*)

- **Major Challenge**: Need to Estimate ALL Emissions at Appropriate Scales (places new responsibilities for NMHCs)

- **Anthropogenic**
  - Mobile
  - Point
  - Biomass burning
  - Dust
  - Volcanic

- **Natural**

  - Links to meteorological parameters (T, RH, WS, Radiation, etc.)

- **Global Distribution of Lightning Activity**

- **Domain 1**
  - $\Delta x = 12$ km
  - Anthropogenic: NE189
  - Biomass Burning: MODIS hotspot
  - Dust: $f(r)$
  - Volcanic: $SO_2$ estimated
  - Biogenic: none at present

- **Domain 2**
  - $\Delta x = 3$ km
  - CO emission rates:
    - purple = low
    - red = high
  - Nonlinear scale

- **Impact of LNOx on O3** (Days with CMAQ03 > 75 ppbv)

- **Pickering et al., 2009**
Major Challenge: Emissions are a large source of uncertainty in AQ Forecasting: Emissions change over scales often not captured in current inventories, but updated inventories are needed for many applications

Change of SO2 emission in China between 2000 and 2007

Streets et al., in prep.
Major Challenge: Scales

Boundary Conditions representative of many upstream processes are needed in AQ applications.
Major Challenge: Linking Meteorology, Air Quality and Human Health

Additional measurement and modeling requirements are needed for urban applications
Environmental Prediction into the Next Decade: Weather, Climate and the Air We Breathe (Day 2 Summary)

Weather/Climate services

Environmental Services (Atmosphere)

provide data & information on

- Climate forcing by gases and aerosols
- Long-range pollutant transport
- Air quality
- Dust outbreaks
- Solar energy
- UV radiation
- Flooding/high impact precip. & connections to water QQ

Environmental agencies
Section 3 – Introduction and Overview of Course

A Major Challenge: Characterizing The Interactions Between Air Pollution, Weather And Climate That Are Many And Complex

Both effect on regional weather and climate (precipitation)

Study shown that heavy aerosol loading in east China increases atmospheric stability and reduces precipitation in this region.

800,000 excess deaths per year globally no region immune!

100-yr integrated radiative forcing for year 2000 global emissions

Projected changes in surface $O_3$ (2050-2000) during the peak $O_3$ season due to climate change

Impact of 2000-2050 climate change only (prescribed future climate: HadGEM SRES A1B)
Integrated Air Quality – Weather – Climate Services for the Betterment of Both

Three dimensional observing systems & Geostationary Satellite Obs

GALION Surface-based LIDAR

GAW/AERONET/SKYNET Surface-based AOD

PM

Integrated Air Quality Met. Models and assimilation systems

Real & NRT data flows

Section 3 – Introduction and Overview

AREP GAW

AQ Services

Linkages

GHGs

Air polls.
Environmental Prediction into the Next Decade: Weather, Climate and the Air We Breathe (Day 2 Summary)

Prediction: A Challenge of Scales and Integration

Common Challenges

- More Observations (x 10?)
  - Atmosphere
  - Ocean
  - Terrestrial
  - Satellites
  - Improved Instrumentation
- Improved Modeling to Serve Smaller Footprints
  - Transport (x 10?)
  - Boundary Layer Understanding
  - Assimilation, Inversion, Diagnosis
  - Prediction
- Enhanced Computing Capacity

QA/QC, Data Management

NRT data flows

Air Quality ↔ Weather ↔ Climate

But larger geographic extents

Modified after Pierce NASA/Langley

Global-Regional-Urban nesting of CTMs
Effects of Boundary Conditions are significant and improve predictions.
Further improvement in predictions requires reductions in the uncertainty associated with the GCTM BCs.