NOAA’s National Air Quality Forecast Capability:
Targets and Needs

NOAA Chemical Modelling Workshop
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NOAA’s National Air Quality Forecast Capability: Targets and Needs

• Background on NOAA’s AQ Forecast Capability

• Operational Perspectives
  – Links to Operational AQF capabilities
  – Links to NUOPC

• Recommendations
National Air Quality Forecast Capability

Current and Planned Capabilities

Near-term: 1-day forecast guidance for ozone and smoke
- Operational for Contiguous US (CONUS) as of September, 2007
- Nationwide by FY10

Intermediate (5-7 years):
- Implement quantitative capability to forecast particulate matter concentration
  - Particulate size ≤ 2.5 microns

Longer range (within 10 years):
- Extend air quality forecast range to 48-72 hours
- Include broader range of significant pollutants
National Air Quality Forecast Capability
End-to-End Operational Capability

Model Components: Linked numerical prediction system

- Operationally integrated on NCEP’s supercomputer
  - NCEP mesoscale NWP: WRF-NMM
  - NOAA/EPA community model for AQ: CMAQ

Observational Input:
- NWS weather observations; NESDIS fire locations
- EPA emissions inventory

Gridded forecast guidance products

- On NWS Telecommunications Gateway and EPA servers
- Updated 2x daily

Verification basis

- EPA compilation:
  - Ground-level ozone observations

Customer outreach/feedback

- State & Local AQ forecasters coordinated with EPA
- Public and Private Sector AQ constituents
Operational AQ forecast guidance

www.weather.gov/aq

CONUS Ozone Expansion Implemented September, 2007

Smoke Products Implemented March, 2007

Further information: www.nws.noaa.gov/ost/air_quality
Transition to Operations: Phased Development, Testing, Implementation

**Phased Testing**

**Research**
- Does the science work?

**Developmental Testing**
- Does it work with operational systems?

**Experimental Testing**
- Does it meet deployment readiness criteria?

**Deploy into Operations**

**Key S&T Tests**
- $O_3$ -- Summer 2007

More advanced PBL mixing in CMAQ (CB05)

PBL mixing (ACM2) in CMAQ, CA off-road emissions, dry deposition upgrades

NAM and emissions data updates; Plume rise correction

"Does the science work?"

"Does it work with operational systems?"

"Does it meet deployment readiness criteria?"
### Operational Readiness Criteria Summary: Example, Expanded Ozone Predictions

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Lead</th>
<th>Metric</th>
<th>Dates</th>
<th>Status</th>
<th>Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective Evaluation: Accuracy</td>
<td>NCEP</td>
<td>&gt; 90%</td>
<td>5/4/07 – 8/31/07</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Subjective Feedback</td>
<td>OCWWS</td>
<td>Positive on balance</td>
<td>5/4/07 – 8/31/07</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Production Readiness</td>
<td>OCIO, NCEP</td>
<td></td>
<td></td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>On-time delivery</td>
<td></td>
<td>&gt; 95 %</td>
<td>5/4/07 – 8/31/07</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Back-up</td>
<td></td>
<td>In place</td>
<td>6/1/06</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Data retention</td>
<td></td>
<td>In place</td>
<td>6/1/06</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Near-real time verification*</td>
<td>NCEP</td>
<td>In place</td>
<td>6/1/06</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Final go/no go decision</td>
<td>NWS</td>
<td></td>
<td>9/10/07</td>
<td>C</td>
<td>C</td>
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</tbody>
</table>

* NESDIS automated (objective) product

**Key**
- Complete
- On schedule
- At risk
- Remedial Action Required
Purpose:
• Provide predictions of poor AQ with enough accuracy and lead time for people to take actions to limit adverse effects of poor AQ

Statement of Need, State/Local Air Quality Forecasters:
• Operational predictions of ground-level concentrations of ozone, PM and other pollutants of concern
• Hourly information, on 5-km grid resolution, updated twice each day

Objectives:
• National Forecast Capability for ozone ($O_3$), particulate matter ($PM_{2.5}$), and other pollutants of concern
• Target Full Operational Capability: $O_3$, FY 10; $PM_{2.5}$, FY15

Current Capabilities, October 2007
• Operational capabilities: Ozone and Smoke Predictions for CONUS
• Experimental capabilities (FY08): Ozone, smoke upgrades
• In development: Components for quantitative PM2.5 prediction
Operational Air Quality Forecasting:

**Development of PM Forecast Capability**

CTM for regional AQF

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**Progress with ozone**

- Mature technology; Gas-phase chemistry relatively well understood
- Pollutant emissions inventory successful for capturing daily chemical inputs important for O3 prediction

**PM: More challenging**

- More complicated chemistry (approx 10X more species involved)
- Real-time source inputs (e.g. dust, fire) are significant additions to inventory-based emissions
- Longer atmospheric lifetimes of both primary and produced particles
- Reliable prototype model for PM and ozone not yet available
- AQ Program outlined a decision process for developing prototype model for combined PM and O3: CTM for regional AQF
Operational Air Quality Forecasting: Key Technical Risks and Mitigation

Technical risks/mitigation for implementing full operational capabilities:

<table>
<thead>
<tr>
<th>Technical Risk</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inaccurate estimates of chemical boundary conditions for US, based on climatology</td>
<td>Real-time, speciated chemical information from global-scale models</td>
</tr>
<tr>
<td>Inaccurate predictions of chemical species: ozone</td>
<td>Ongoing updates to pollutant emissions inventories from EPA on; continued monitoring of O3 prediction accuracy/verification</td>
</tr>
<tr>
<td>Inaccurate predictions of chemical species: PM2.5</td>
<td>For candidate models: monitoring of PM test-prediction accuracy/verification; continued development of missing or deficient components (dust, smoke, SOA, nitrates, sulfates,...)</td>
</tr>
<tr>
<td>Inaccurate predictions of driving boundary-layer meteorological conditions</td>
<td>Closer coupling between weather and AQ modules; improvements ongoing in accuracy, resolution of NCEP's NAM</td>
</tr>
<tr>
<td>Run-time exceeds 2.5-hour prediction window and processor capacity</td>
<td>NOW: Adaptations/optimizations to CTMs for NCEP operational supercomputing environment</td>
</tr>
<tr>
<td></td>
<td>FUTURE: Closer coupling of meteorological and CTM modules; additional supercomputing processors for AQF</td>
</tr>
</tbody>
</table>

Mitigation involves:
- Incorporation of improved CTM in global scale models
- Improved, more comprehensive CTM for regional AQF
Air Quality Forecasting
AQ Model Decision Framework

Purpose
• Process for NOAA’s AQ Program to select, from available approaches and components, those best suited for an operational quantitative forecast model for particulate matter (PM$_{2.5}$)

Model Requirements
• Timing: NOAA’s AQ Team, to recommend to NWS a prototype AQ model in FY09 that is suitable to transition to operations by FY11.
• Prediction accuracy: must predict ozone with sufficient accuracy to meet existing performance measures and must also predict speciated PM2.5.
• Ownership: NOAA must have rights to review and modify source code for models and related processing programs.
• PM model run-time: PM predictions, including associated interface processors must run at NCEP in a 2.5-hour window on the supercomputer processors available for air quality operations.
Criteria for Evaluating Model Configuration Options

**Forecast/Analysis**
- Which approach provides the best forecast guidance for ozone and PM2.5?

**Sustainability**
- Which approach best represents the current scientific understanding?
- Which approach provides the most flexibility for future improvements and extensions?

**Compatibility**
- What are the computational requirements of each approach?
- How easy will the choice be to implement/integrate?

**Efficiency**
- Which approach affords the best efficiency for software and model system maintenance, and integration with both regional and global applications?
**Decision Process**

- Sequential, focusing earlier on the decisions that constrain successive choices.
- Decisions may be deferred if available information is inadequate, but efforts to resolve key uncertainties should be initiated.
- If prior decisions have led to an undesirable result, decisions may be revisited.
- NWS and OAR will work closely together to make decisions, in NOAA’s AQ Matrix Program.
  - The line office with final authority for making decisions will depend on the phase of the project:
    - Specifying operational constraints for the system--Lead: NWS
    - Research that produces the prototype modeling system--Lead: OAR
    - Recommendation to NWS for prototype for initial operational capability (FY09Q3)--Lead: OAR
    - Transition of the prototype to operations--Lead: NWS
    - Operations--Lead: NWS
  - During the research phase the following process will be used:
    - A technical team of OAR and NWS personnel selected by the management team will consider issues and make recommendations; may also include recommending new research activities to provide information required to reach a decision.
    - An OAR-led management team with members from both OAR and NWS will make decisions.
    - Periodically a peer panel composed of independent experts will conduct a scientific peer review of the research activities.
Operational Perspectives:
NOAA’s Atmospheric Chemistry Models
Linkage to NUOPC

National Unified Operational Prediction Capability, the next-generation global weather forecast system, being planned:

- Tri-agency effort: NOAA, Navy, AirForce
- Framework to couple modules for data assimilation, dynamics, physics
- Aerosol module important for data assimilation; also dynamics, physics of NWP

NOAA’s AQ Forecast capability requires chemical boundary conditions (BC):

- NUOPC could provide the required speciated chemistry for BC—especially critical for PM
NUOPC Vision: A National Global Modeling System (Slide courtesy F. Toepfer)
NUOPC Vision II: A National Global Modeling System

NUOPC Component System

Application Driver

ESMF Superstructure
(component definitions, communications, etc)

Dynamics
(1,2)

Physics
(1,2,3)

Multi-component ensemble

Stochastic forcing

ESMF Utilities
(clock, error handling, etc)

Coupler

Post processor & Product Generator
Verification
Resolution change

Chemical Transport Model (CTM)

AQ Forecast Model (CTM)

Analysis
Other Forecast Systems
Operational Perspectives: 
NOAA’s Atmospheric Chemistry Models 
Linkage to NUOPC

NUOPC

• CTM within NUOPC framework can provide source inputs, reactive transport, deposition for aerosols
• Tradeoffs between detailed, complex chemistry and large-scale total-aerosol impacts

NAQFC:

• Consistent CTM approach in global and regional scales minimizes model-induced uncertainty for operational AQ forecasts.
• Possibility for streamlining a comprehensive CTM used in higher-scale regional AQF.

Recommendation: Next-generation global weather model (NUOPC) incorporates operational AQF CTM, streamlined as necessary
NOAA’s Atmospheric Chemistry Models: 
*Research and Operational Capabilities*

- Many of the models were developed for specific research questions and/or applications
- Some are also used directly for operations or to improve NOAA operations
- Links to operational capabilities speeds transition of Research to Operations:
  - *Effectiveness for NOAA operations enhanced*
    - when user base includes both research and operations—e.g. CMAQ
    - when CTM includes NOAA operational input sources — operational observational input streams, data assimilation, weather models.
  - *Effectiveness for NOAA research enhanced*
    - wider application, user bases increase rate of improvements

Recommend: OAR and NWS work to increase linkage between research chemistry models and operational models
Operational Needs for AQF:

**NOAA’s Atmospheric Chemistry Models**

Global Aerosol Inputs:
- Real-time information on aerosol-forming emissions and processes that contribute to inputs to airborne PM in the US
  - Combines global real-time and episodic contributions, on species contributing to primary and secondary PM with available inventory and other data for the US

Regional Chemical Transport Modules:
- Reliable, short-term prediction of ground-level PM and ozone
  - Hourly concentrations accurately predict thresholds used by AQ forecasters in issuing alerts
  - Onset, severity, duration of poor AQ episodes: forecasts accurately predict max values for day 2 and beyond
- Simulate processes for production, reactive transport, deposition on scale of mesoscale weather models (currently 12km; approaching 4 km in future)
- Incorporate chemical boundary conditions (BC) from global chemistry model

Coupled to Operational NWP:
- Appropriate feedback between chemical and weather models
- Degree of coupling may be limited by timing (cannot add more than ~2 hrs to “off-line” meteorological forecast model production
- Appropriate precision for reactive transport processes
- Options for probabilistic information/ensembles

Effective, efficient use of operational supercomputing resources
- Modules for data assimilation and reactive chemical transport adaptable for use in both global and regional scales
- Interoperability of developmental modules with experimental and operational systems for accelerated transition of new S&T to operations
Recommendations

• OAR/NESDIS and NWS work to increase linkage between research chemistry models and operational models

• Next-generation global weather model (NUOPC) integrates regional operational AQF CTM, streamlined as necessary
Acknowledgments:

AQF Implementation Team

**OCWWS**  Mike Dion  Outreach, Feedback
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**OCIO**  Jerry Gorline  Dev. Verification

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  Ken Carey  Program Support

**OST**  Cindy Cromwell, Allan Darling, Bob Bunge  Product Archiving

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*Sarah Lu  NAM products
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  Jeff Young, David Wong  Code optimization
  George Pouliot, Daniel Tong  Emissions processingOA
  Ken Schere  ASMD Science oversight
  Roland Draxler, Glenn Rolph  HMS product integration with smoke forecast tool

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  George Stephens, Mark Ruminski  HYSPLIT adaptations
National Air Quality Forecast Capability: Current NWS Operational Links: Ozone

NCEP Numerical Weather Prediction
- Real-time Weather Obs: Monitoring, Rem Sensed
- Boundary Conditions From Global Weather Model
- Mesoscale Weather Model
- Weather Data Assimilation
- Atm Chemical Data Assimilation: 3-D or 4-D
- QC/QA
- Real-time Chem Observations: In-Situ Monitoring, Rem Sensed
- R-T Boundary Conditions, Trans-boundary transport Especially: Dust, Fires

Numerical Chemistry Prediction
- Emissions Preprocessing
- Pollutant Emissions Inventory
- Chem Transport Model: PM + Ozone
- Chem Transport Model: Ozone

Product Generation
- Verification

Forecast for public dissemination
- Customer Feedback

Current NAQFC Elements
- Planned FY08-FY13
- Increased obs inputs: Resource-dependent

Continuous SCIENCE/TECH Infusion
- Research, Development, Testing, Integration