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Forecasting a Better Future

National Aeronautics and Space Administration

Numerical Air Quality Prediction Models at Baron Advanced Meteorological Systems: Toward the Future

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and

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2009 National Air Quality Conference: Air Quality Forecast Models, Wednesday, March 4, 2009; Dallas, TX

Talk Outline

- Introduction to NAQP at BAMS
- Updating and re-thinking emissions (from a data-assimilating land-surface modeling perspective)
- Using satellite data: real-time AOD assimilation and emissions improvements
- Very high resolution forecast modeling
- Summary

Introduction:
Baron Adv. Met Systems: 11th year in Operational Numerical Air Quality Systems

- **MAQSIP-RT**
  - **Began in 1998**
  - **Participated in all major field programs since 2000**
    - **TXAQS-2000, NEAQS-2001, 2002, 2004 (McHenry, et al., 2004, Bull. Amer. Meteorological Society), TEXAQS-06**
    - **Performance Statistics leader among all models forecasting ozone throughout all of these field programs**

- **CMAQ-DA (improved SOA)**
  - **NASA grant/cooperative agreement – Data-Assimilation Version**
    - ***TERRA/AQUA-MODIS Deep Blue for PM***
    - **EPA AIRNOW sfc PM**
    - ***OMI-based NO2 emissions cross-checks***

- **Both MAQSIP-RT and CMAQ-DA**
  - **Coupling to NASA Land-Information System:**
    - ***VERY HIGH resolution (1km CONUS) for improved:***
      - ***Emissions and surface meteorology***
    - **45/15/5km availability; 5-day forecast; *New 3-km real-time forecast availability***

- **MATC–H (under development)**
  - **Multi-scale Atmospheric Transport and Chemistry – Hybrid Parallel**

Introduction:
Baron Adv. Met Systems 11th year in Operational Numerical Air Quality Systems

- **Goal: To continually improve operational decision support for issuance of air quality forecasts by numerous clients**
  - **TOOLS *DIFFER* FROM NATIONAL EPA/NCEP CMAQ model in all cases – thus they all add value:**
    - **almost all meteorological forecasts are based on more than one model—**
    - **WHY NOT AIR QUALITY?? BAMS provides the additional hi-value modeling systems that allow AQ forecasters to make forecasts with increased confidence and certainty**

Introduction:
Baron Adv. Met Systems 11th year in Operational Numerical Air Quality Systems

Model DataFlows

Met Data Ingest

MESOCALE MODEL (MM5 or WRF)

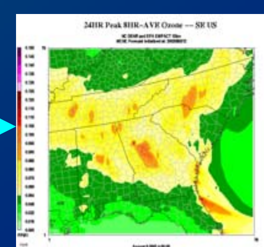
SMOKE-RT
Em

ystem)

Photochemical Model (MAQSIP-RT)

Chemical Data Ingest and Assimilation: Deep Blue; PM Surface

Photochemical Model (CMAQ w/ improvements)



Guidance Products

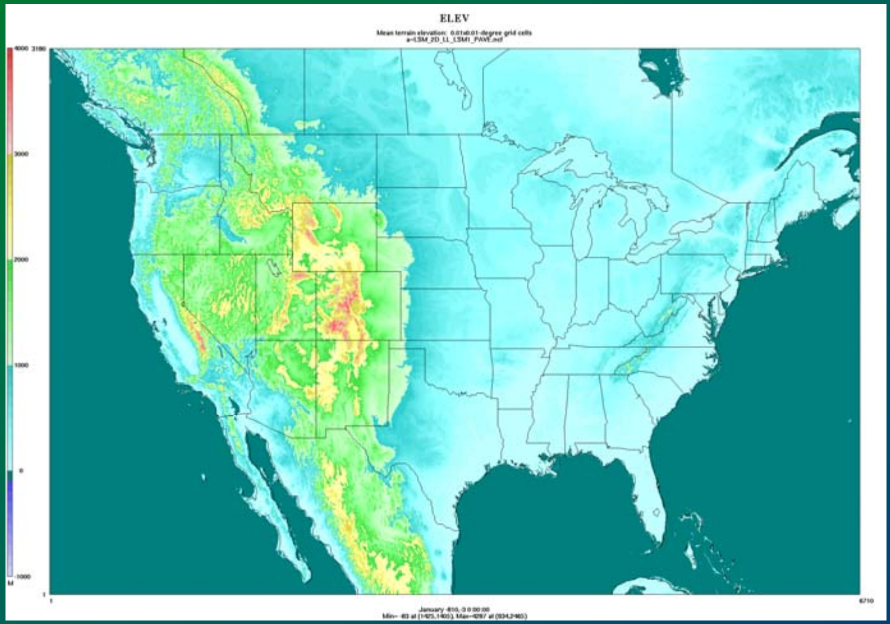
Updating and *Re-thinking* Emissions (from a Land-Surface Modeling Perspective)

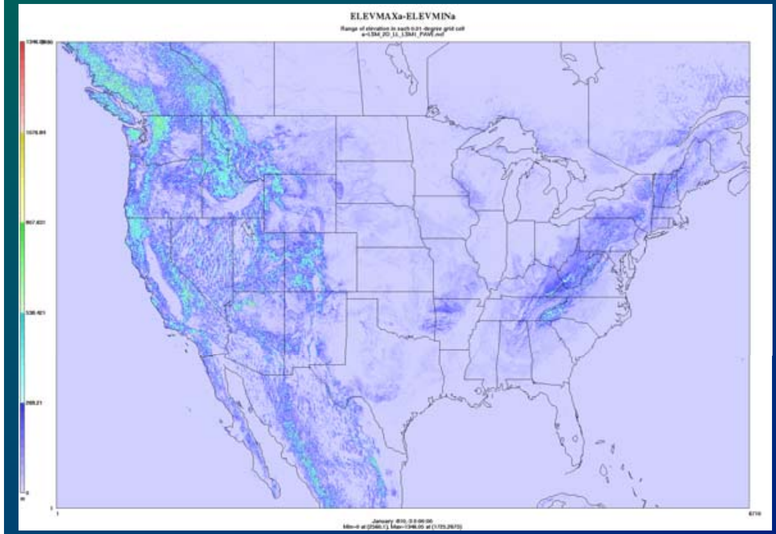
- **LSM: standalone, real-time**
  - **Very high resolution: 1km or 3km "super CONUS"**
    - **Terrain: NHD+ (30-meter resolution terrain, Albers grid) → CONUS TERRAIN; re-sampled USGS 30-arc second outside of US**
    - **LU/LC: NLCD (30-meter resolution Albers grid) → CONUS; outside of US, utilize USGS 30-arc second (900-meter) global**
    - **SOILS: USGS 30-arc second (900-meter) global data**
  - **Assimilating *observed* precipitation *and* snow-pack in *real-time***
  - **Utilizing "best-possible" *downscaled-to-1km* surface meteorology other than precipitation:**
    - **2-meter Temp, Mixing ratio, 10-meter wind speeds, surface pressure**

To the maximum extent possible, harmonize and unify *all* emissions with the LSM

Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> GIS Data (Terrain)





NHD+ Terrain @ 30-meters: averaged to 1km

Max/Min terrain at each 1km grid location

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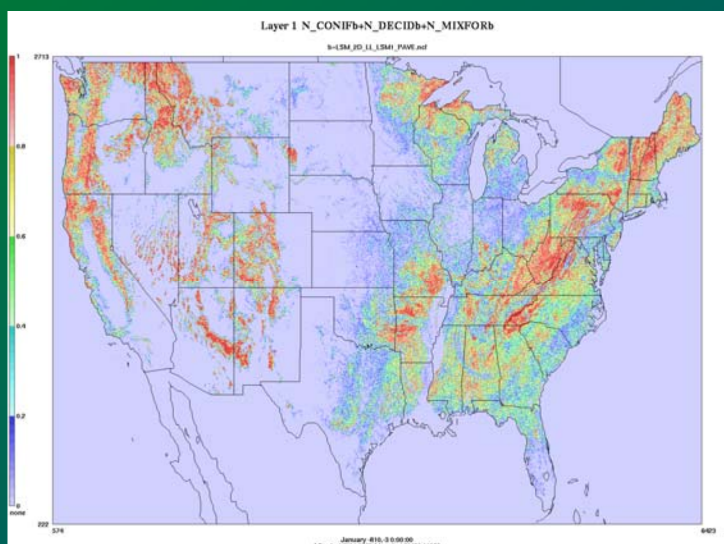
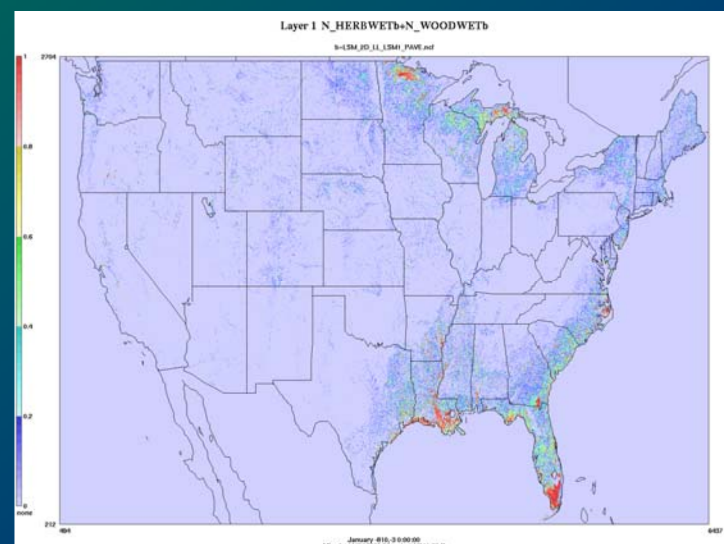
LU/LC categories by number: NLCD w/in CONUS, USGS in Canada/Mexico

Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> GIS Data (LU/LC)



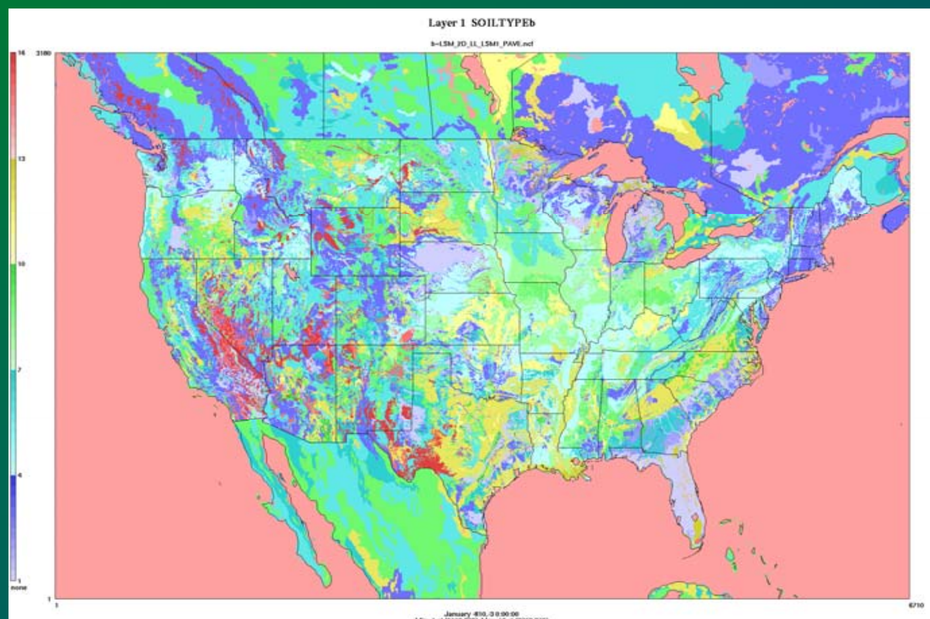
NLCD Total Forest fraction at 1km resolution, From 30-meter native data



NLCD Wetland fraction at 1km resolution, From 30-meter native data

Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> GIS Data (Soils)

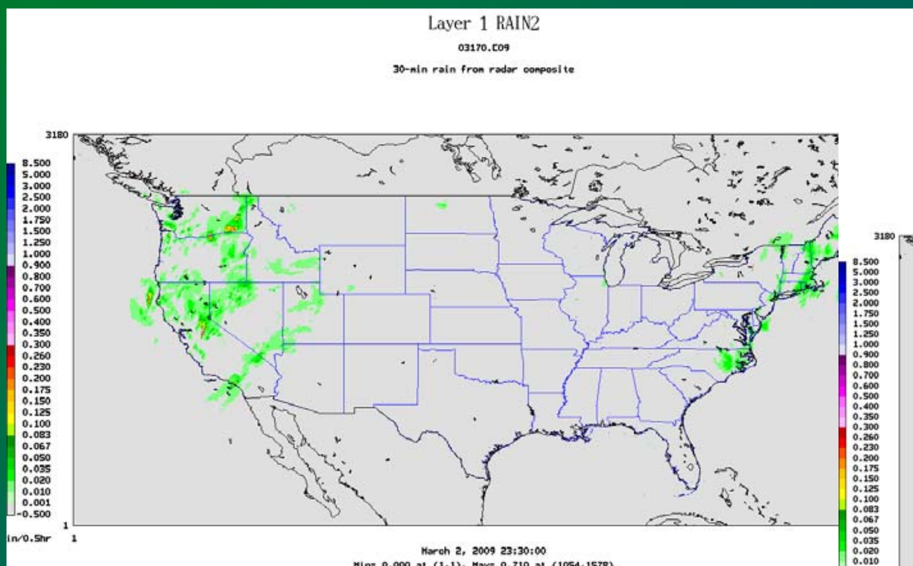


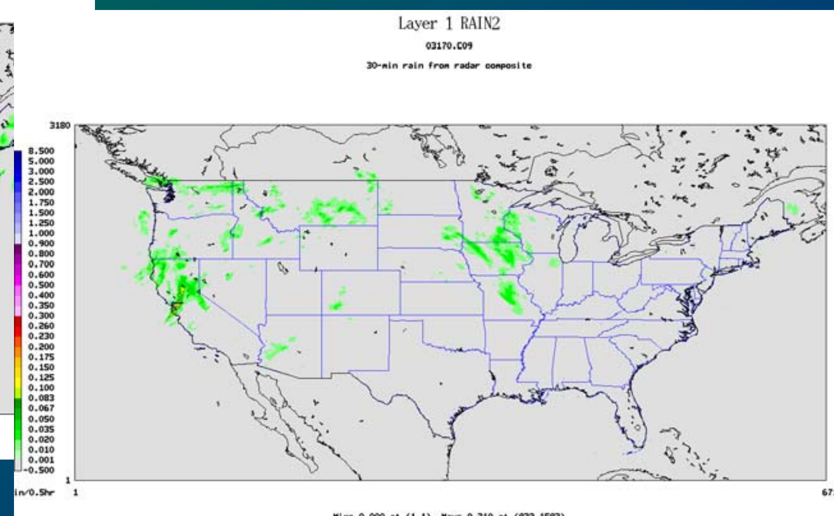
Soil parameter values for LSM typically aggregated from native 30-arc second data using fractions projected onto USLSM grid

USGS “dominant” soil categories (1-16) on BAMS USLSM grid for US, Canada, Mexico

Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> Data-Assimilation in Real-Time





Real-time radar-precipitation rate estimation from ~160 radars in the US at 1km resolution: input to soil-moisture and plant transpiration in real-time

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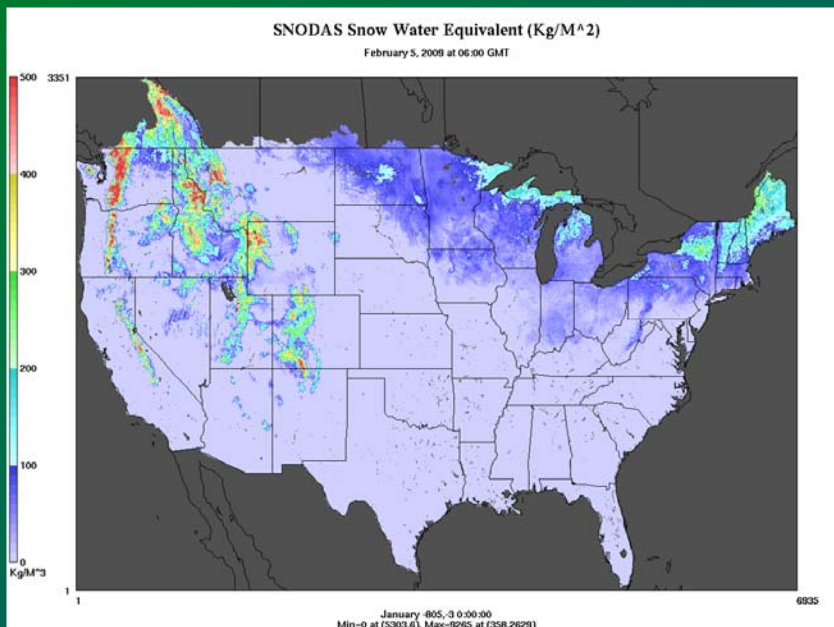
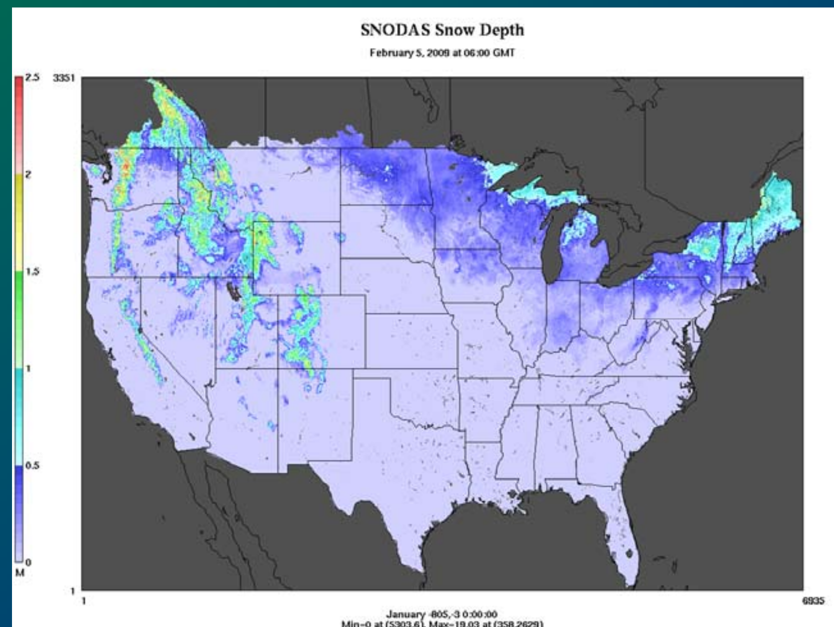
Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> Data-Assimilation in Real-Time





Real-time snow water equivalent and snow-depth data updated daily: snow-melt runoff contributes to soil-moisture/temperature, snow-pack modifies soil-atmosphere interaction

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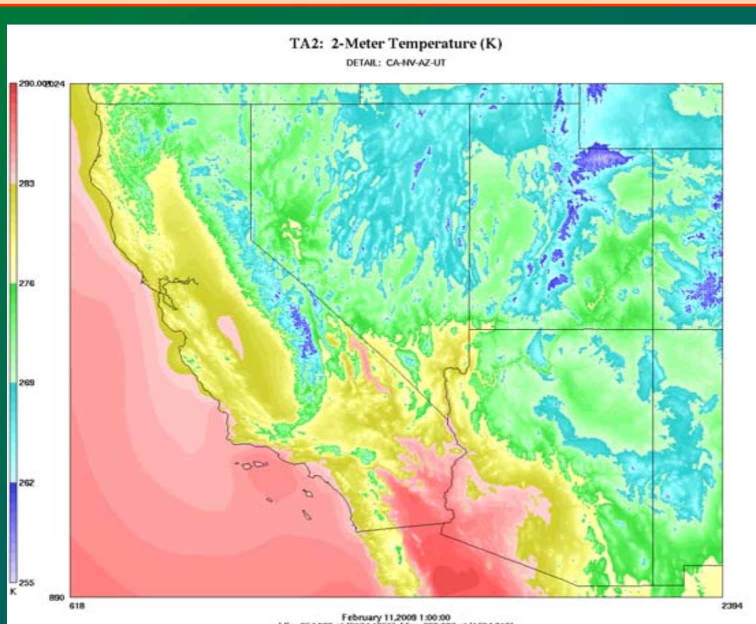
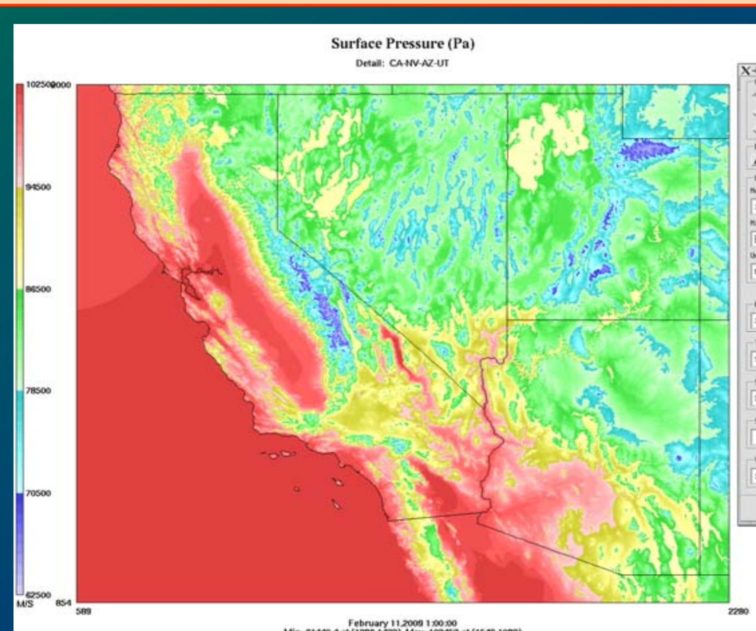
Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> Downscaled Forcing Data

Utilizes highest resolution BAMS CONUS+ Meteorological model and applies terrain correction to surface meteorological forcing variables



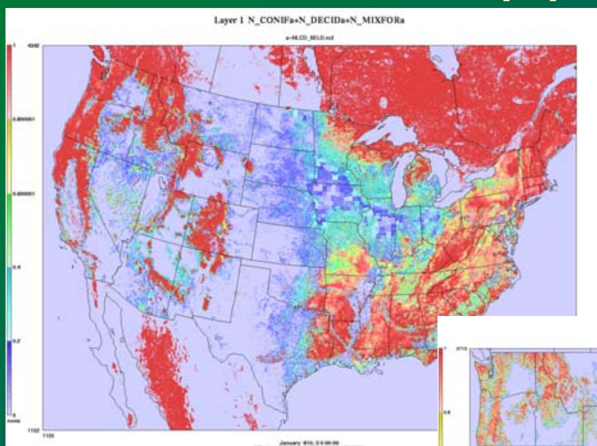


Terrain-corrected 2-meter temperature (left) and pressure (right)

Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> Emissions Coupling

(1) Biogenics



"Old" BELD3 total forest

"Re-Normalized" BELD3 total forest

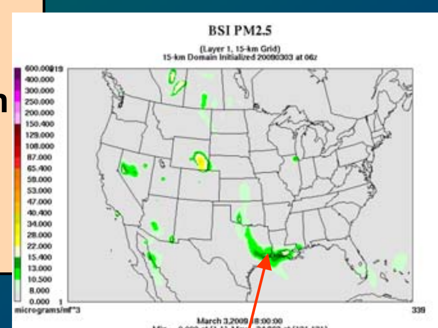
- *Re-normalize all BELD3 categories consistent w/ NLCD*
- Implement recent emission factor updates from EPA
- Deploy BEIS3.14 on the same 1km or 3km maps as operational USLSM
- Implement much improved seasonality consistent with LSM 365-day greenness fraction dataset: *realistic growing season!*
- Meteorological forcing for BEIS 3.14:
  - Observed radar-based precipitation
  - Observed precipitation history for soil NO
  - Observed/analyzed snow-pack
  - Downscaled surface meteorology
- LSM Soil-state forcing for BEIS 3.14:
  - Soil-moisture from LSM for soil NO

Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> Emissions Coupling

(2) Fires and Dust

- Fire emissions (locations and source strength improvements)
  - HMS (already in use)
  - SMART-FIRE / FIRMS under consideration
  - LU/LC from NHD+
  - Soil moisture/plant stress from operational LSM at 1km resolution
  - Downscaled meteorological surface forcing variables:
    - Wind, temperature, RH



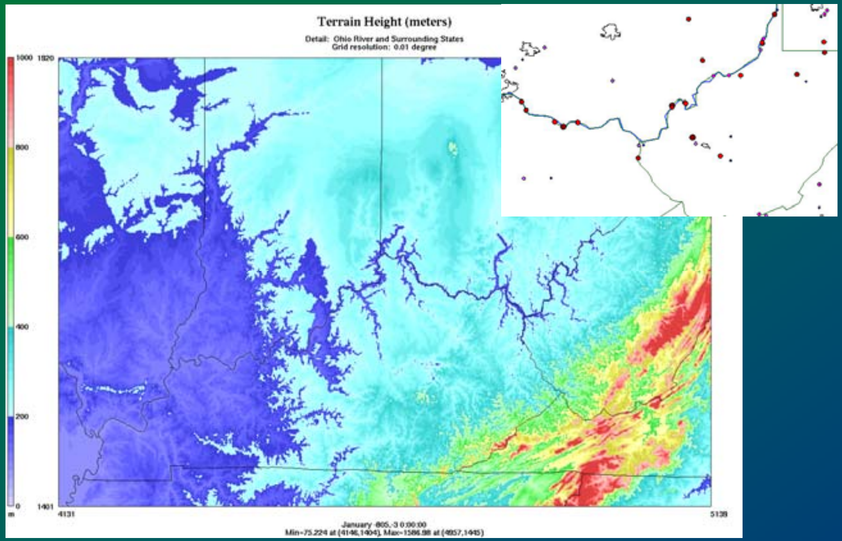
- Dust emissions at 1km resolution:
  - Soil types at 1km resolution
  - Soil moisture at 1km resolution from real-time LSM
  - Downscaled meteorological surface forcing variables:
    - Wind, temperature, RH, etc.

BAMS operational CMAQ w/ HMS fires: March 3, 2009: 18Z

Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> Emissions Coupling

(3) Anthropogenic Point Sources



- **Implement point-source plume-rise with 1km / 3km scale terrain using downscaled meteorological model atmosphere *in 3D: where is stack top located in relationship to REAL TERRAIN?***
- **Use "best combination" of NEI 2005 and RPO-projected 2009, with other customizations from state/local as possible (currently evaluating)**
- **Use top-down NO2 satellite data as a cross-check.**

Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> Emissions Coupling

(4) Mobile Sources

- **Mobile-6 "lite"**
  - **12-km resolution (now running)**
  - **BAMS surface meteorology, e.g. T, RH**
    - **terrain-corrected / downscaled**

Updating and Re-thinking Emissions (from a Land-Surface Modeling Perspective)

LSM <-> Emissions Coupling

(5) Area / Non-road Sources

- **Use "best combination" of NEI 2005 and RPO-projected 2009, with other customizations from state/local as possible (currently evaluating)**
- **Upgrade ancillary data, e.g. spatial surrogates**
- **1km / 3km resolution consistent w/ USLSM**

Using Satellite Data: Real-time AOD assimilation and emissions improvements

Data Assimilation Module: Observation Space Formulation for AOD

$$T_{b\lambda} = H_{mt}(C_m) + \varepsilon_{b\lambda} \qquad (1)$$ **Model Mass Concentration to AOD**

$$T_{a\lambda} = T_{b\lambda} + P_b H^T [H P_b H^T + R_o]^{-1} [T_{o\lambda} - H(T_{b\lambda})] \qquad (2)$$ **Data Assimilation Step**

$$C_m = H_{tm}(T_{a\lambda}) + \varepsilon_m \qquad (3)$$ **Analyzed AOD to Model Mass Concentration**

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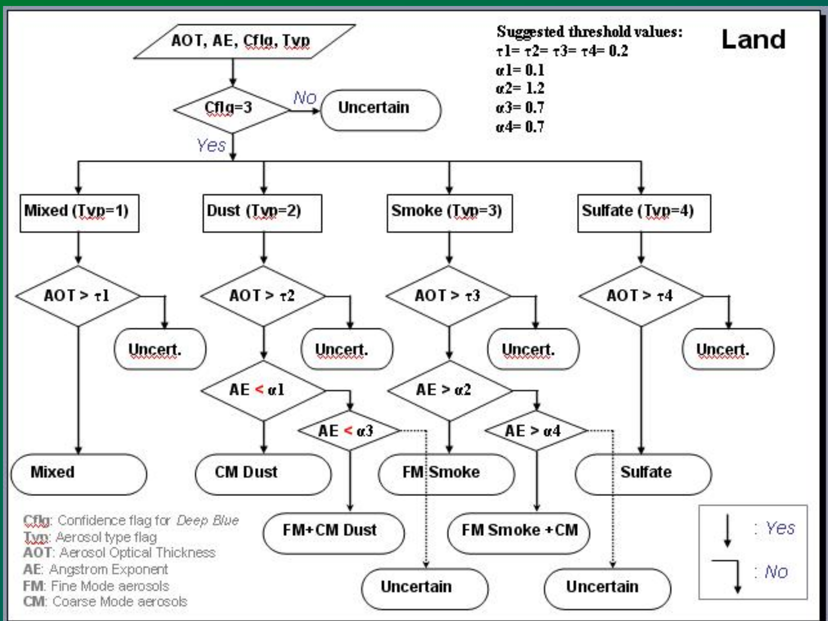
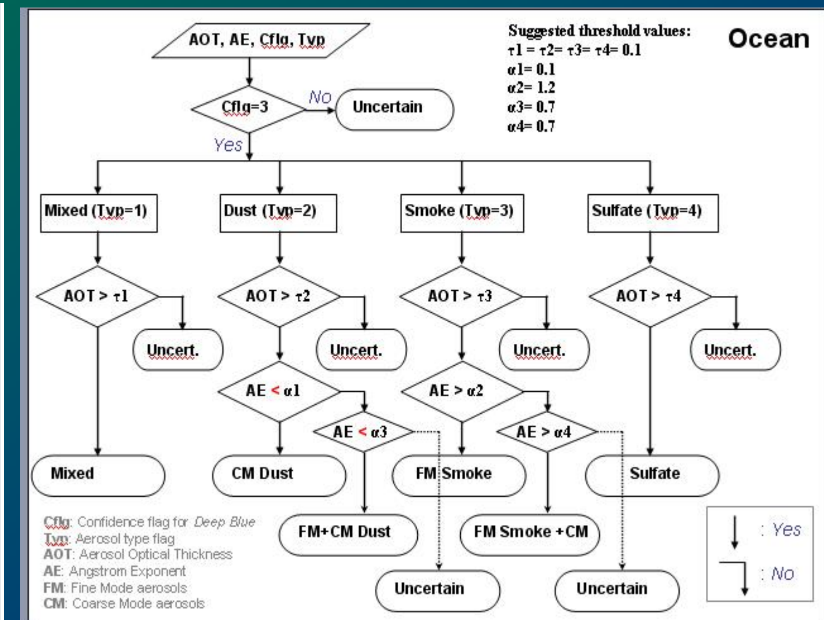
Using Satellite Data: Real-time AOD and emissions improvements

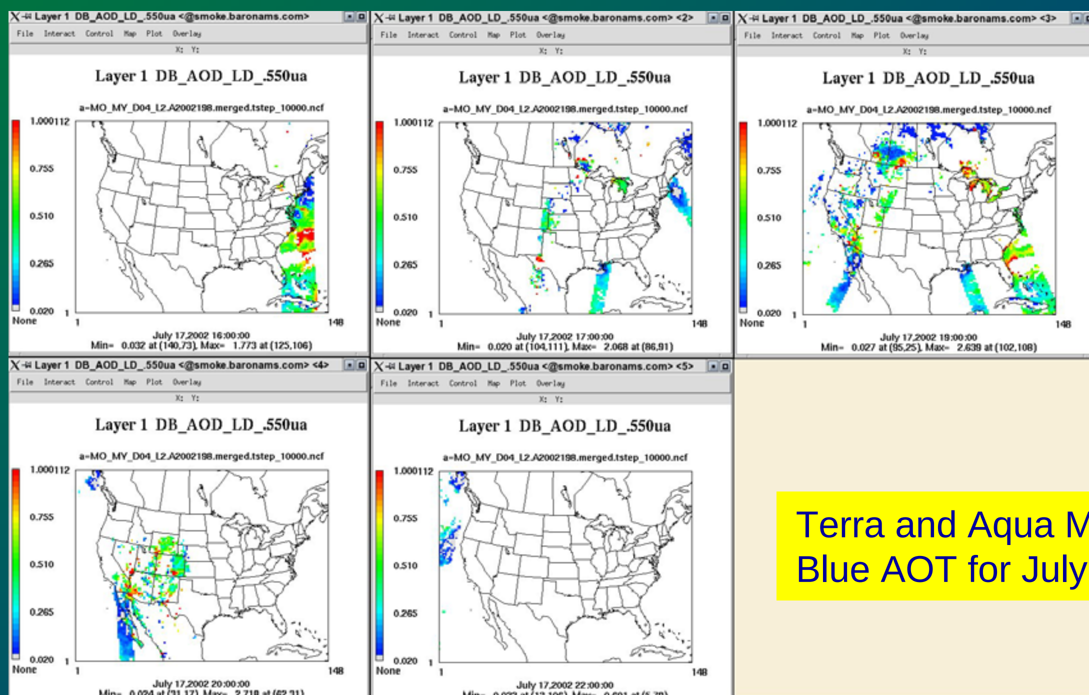
Data Assimilation Module: Decision Trees for Deep Blue AOD Observations





Using Satellite Data: Real-time AOD and emissions improvements

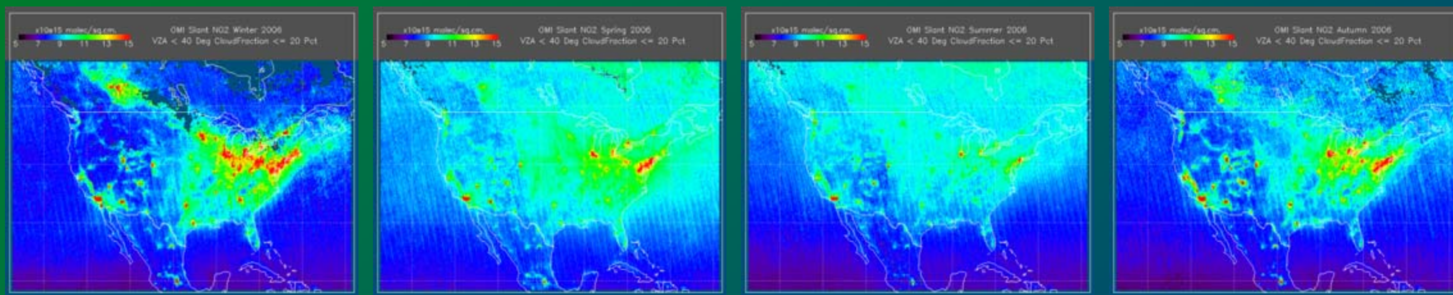
Data Assimilation Module: Sequential Progression of Assimilation "Steps" throughout any given day



Terra and Aqua MODIS "Deep Blue AOT for July 17, 2002

Using Satellite Data: Real-time AOD and emissions improvements

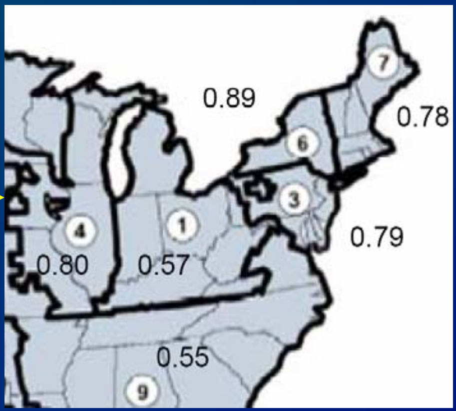
Total Column NO2 from OMI, seasonally averaged



winter **spring** **summer** **fall**

OMI NO_2 ratios of "base" to most "current" forecast year allow (with appropriate caveats) cross-checks against published reduction factors – at much higher resolution than the published factors themselves

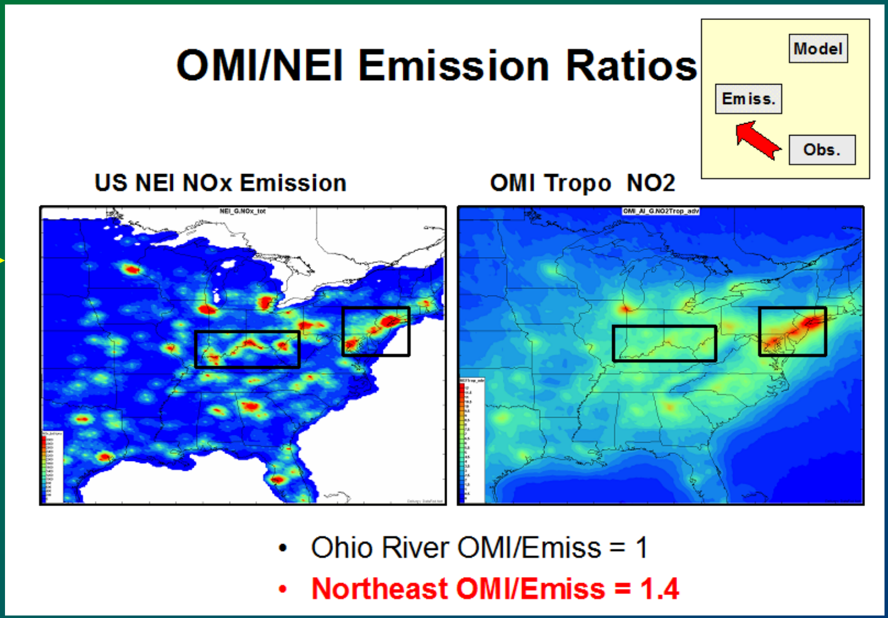
Example: Regional NO_x adjustments according to DOE: Point sources, 2004/2001



Using Satellite Data: Real-time AOD and emissions improvements

Comparison of OMI and NEI NOx point source data on a sub-regional level

Total NEI 2001 NO_x emissions from point, area, and mobile sources



Over the Northeastern megalopolis the ratio of the total observed NO2 and total NOx emission is about 40% higher than the corresponding ratio over the Ohio River Valley.

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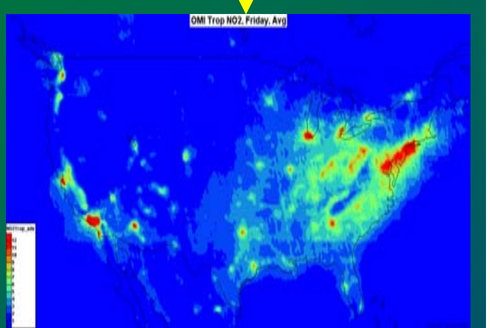
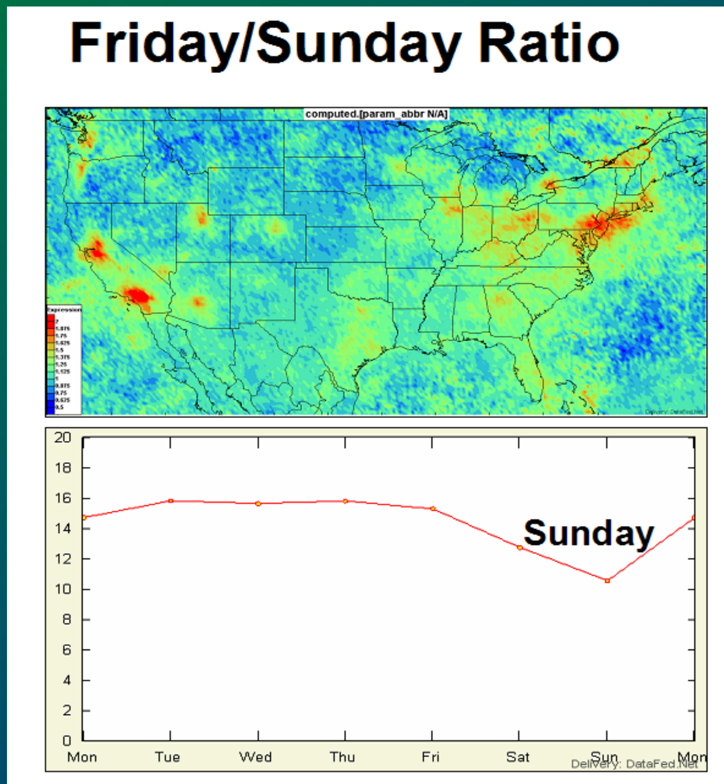
Using Satellite Data: Real-time AOD and emissions improvements

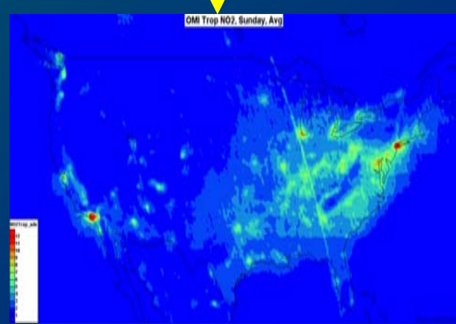
Comparison of OMI NO2 daily data: weekday versus weekend

Typical Friday





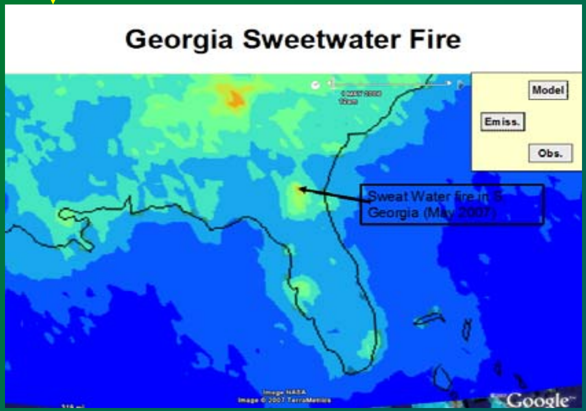
Typical Sunday

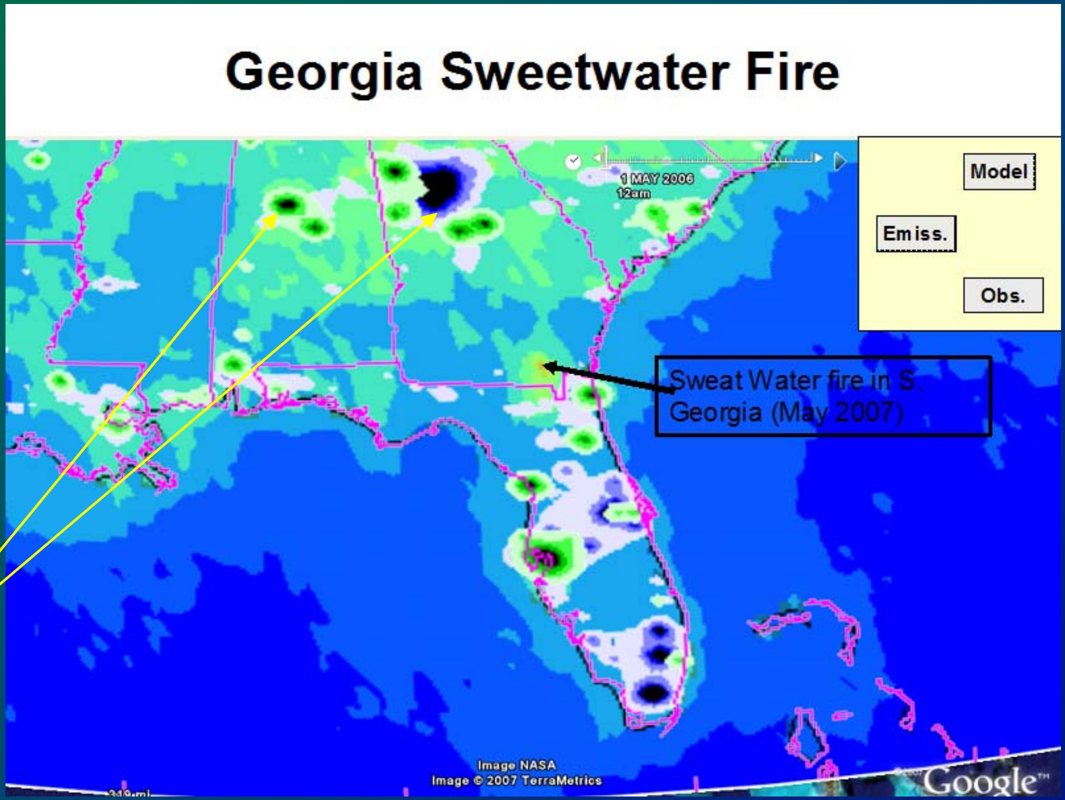


Using Satellite Data: Real-time AOD and emissions improvements

Monthly ave column NO2

Use of OMI NO2 daily data to estimate biomass flux



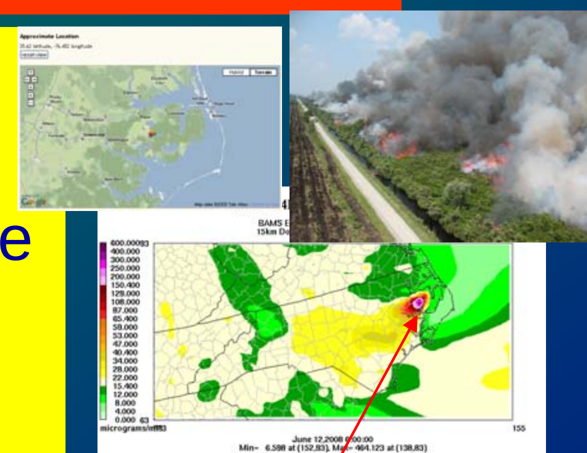


With superimposed NEI emissions: point sources in green, mobile in blue

Using Satellite Data: Real-time AOD and emissions improvements

Use of satellite-based NO_2 observations is being used (in various stages of development) to improve the current emission inventories for NO_x in multiple ways:

- quantification of exceptional source contributions such as biomass burning
- verification of emission factors for mobile and major point sources
- improving the temporal resolution of emissions, such as the weekly cycle
- Analyzing relative reduction factors between base and current year inventories

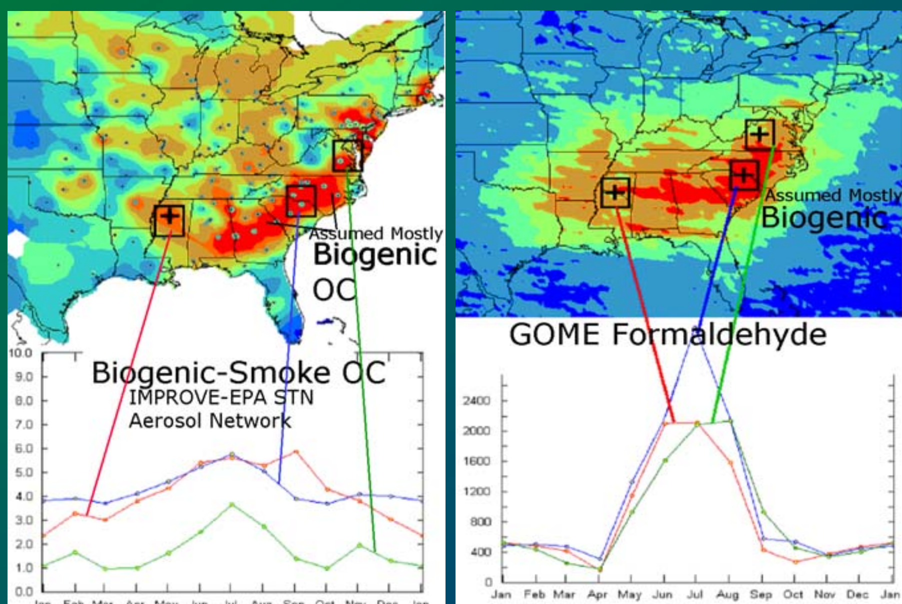


BAMS CMAQ forecast Evans Road Fire, NC

Using Satellite Data: Real-time AOD and emissions improvements

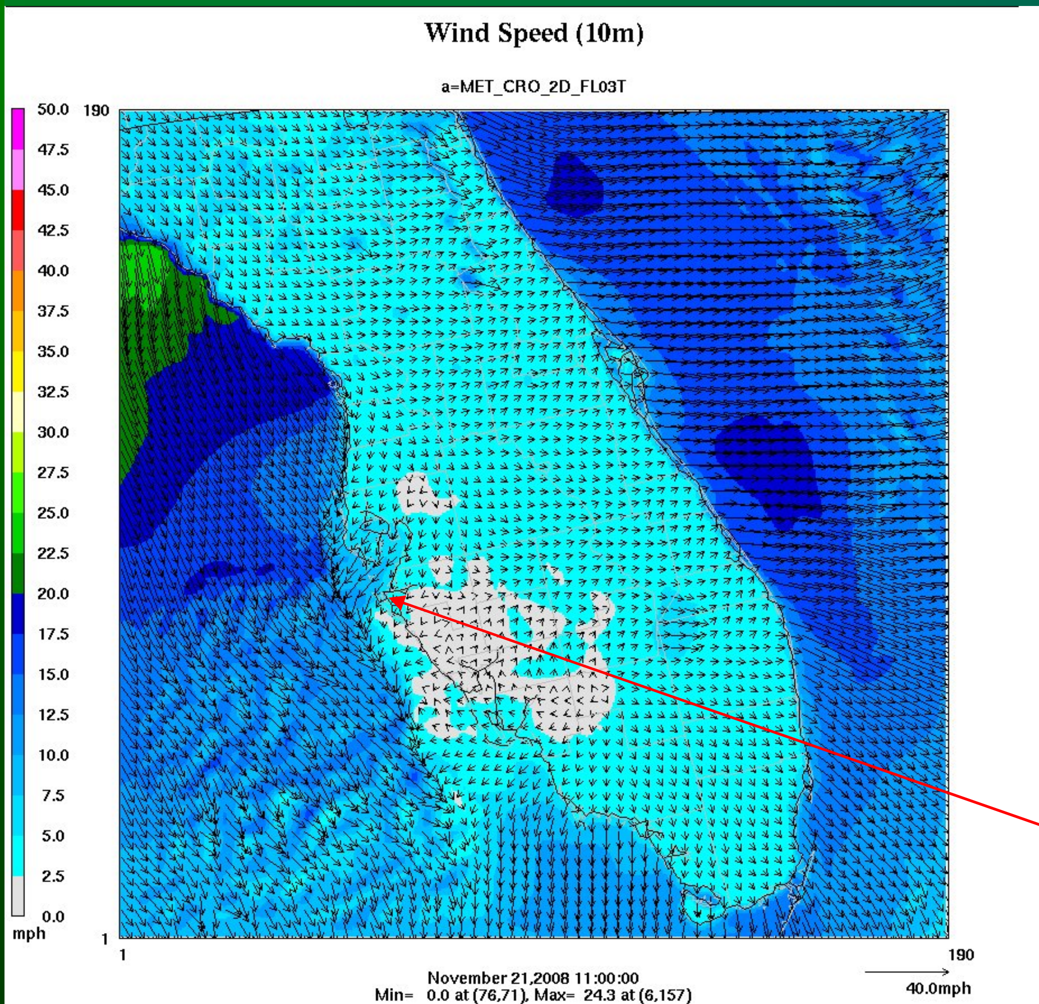
Use of satellite-based Formaldehyde (HCHO) observations

• As a observational surrogate for natural organic emissions (e.g. biogenic isoprene)

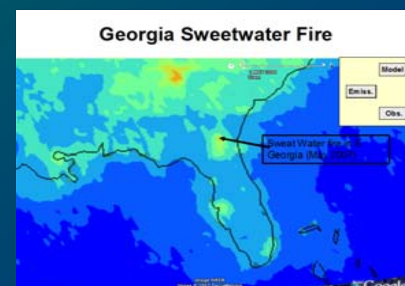


Our analysis suggests that the spatial-temporal pattern of isoprene emission, derived from formaldehyde measurements (GOME, SCHIAMACHI, OMI), may provide a valuable cross-check to improve biogenic secondary organics emissions from isoprene – especially when combined w/ the LSM-based approach discussed in the first part of the talk

Very High Resolution Forecast Modeling



Example: Operational 3km resolution Florida domain



Sea-breeze/land-breeze cycling much more realistic

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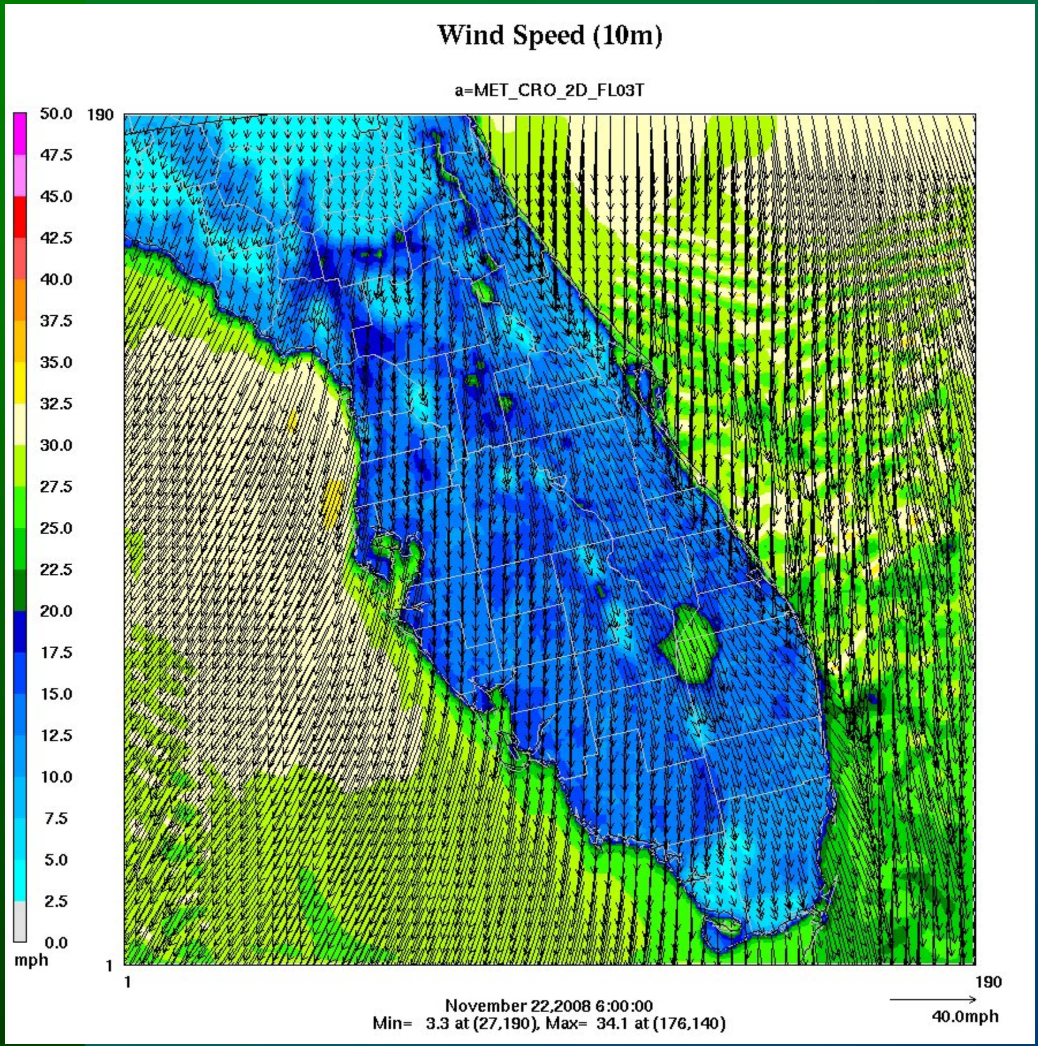
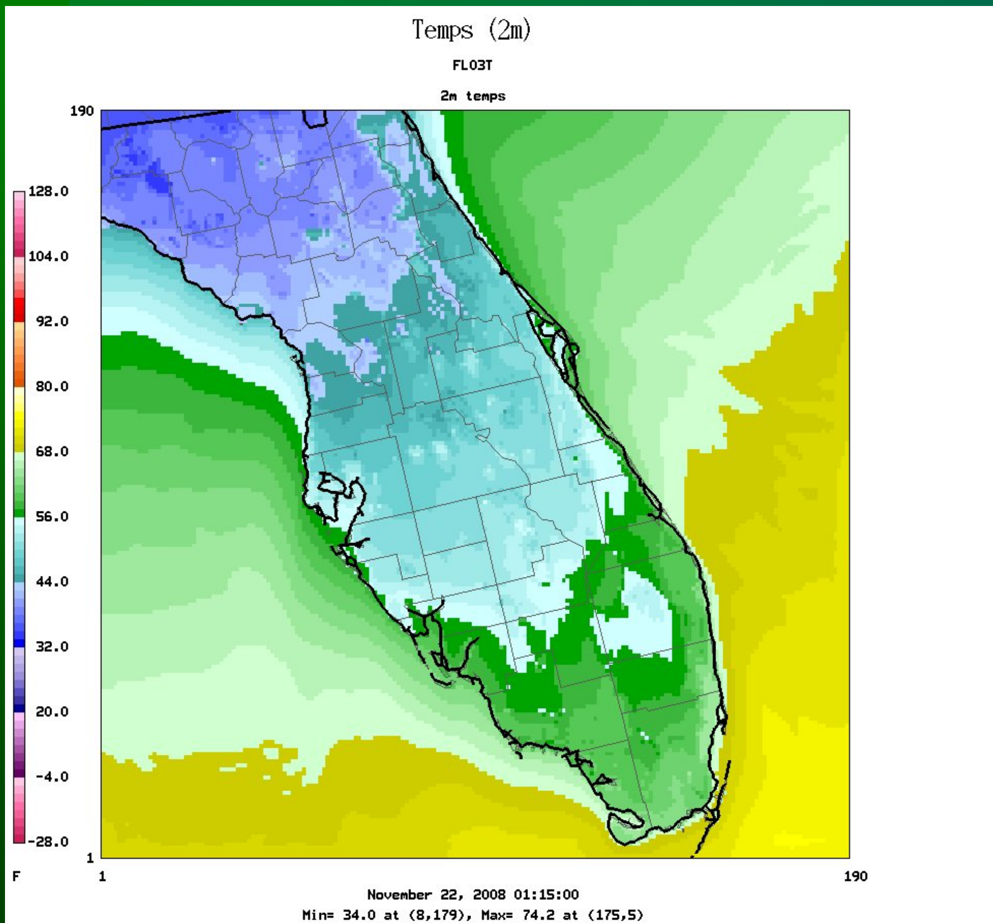


Very High Resolution Forecast Modeling

Example: Operational 3km resolution Florida domain

Surface Wind-speeds following cold-front passage: more realistic

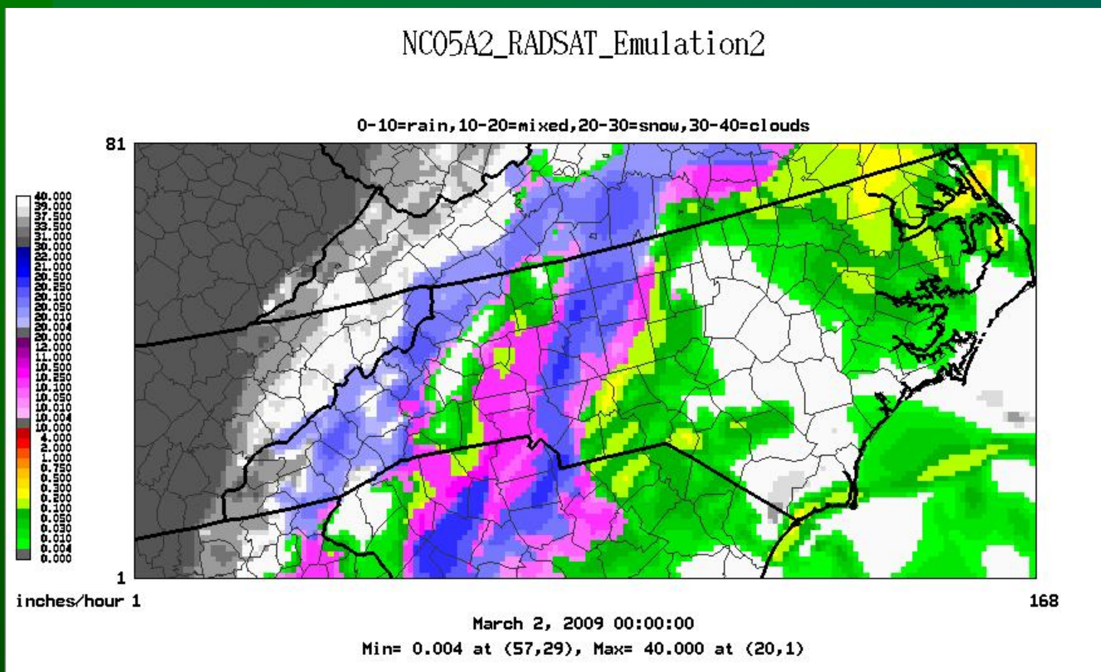
Very High Resolution Forecast Modeling



Example: Operational 3km resolution Florida domain

Surface Temperatures following cold-front passage: more realistic

Very High Resolution Forecast Modeling



Example: Operational 5km resolution North Carolina domain

Much more well-resolved precipitation, and…

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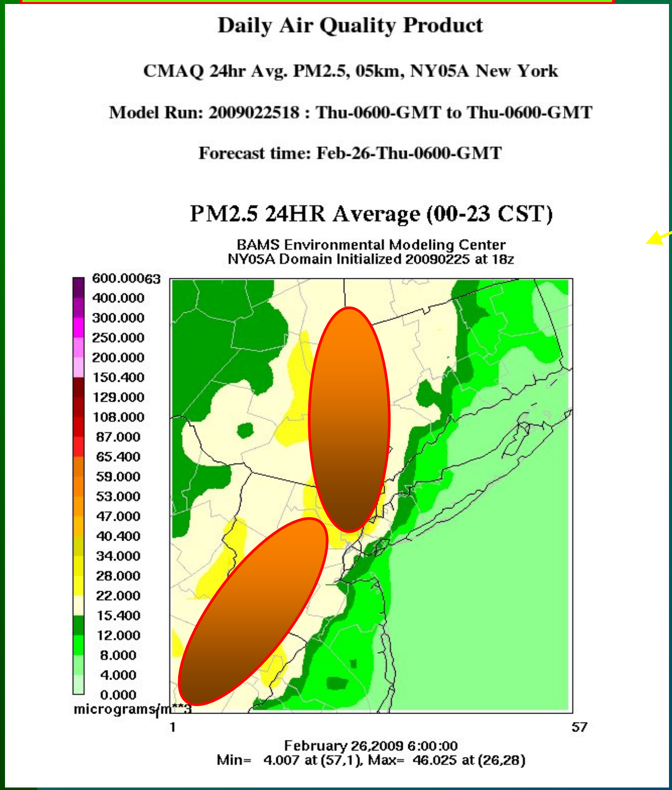
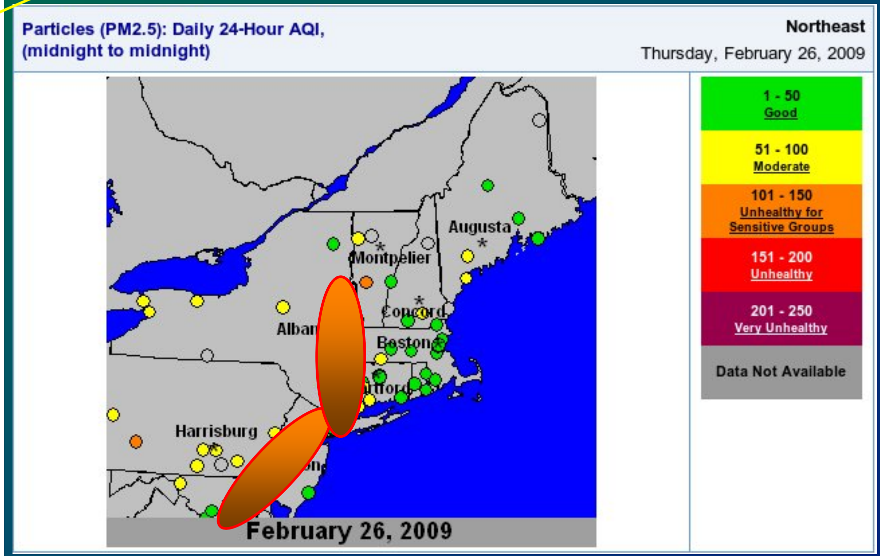
Very High Resolution Forecast Modeling

Forecast 24hr-ave PM2.5 versus obs

Example: Operational 5km resolution NYC vicinity domain





… Much more well-resolved Emissions:

Note local hotspot in NYC and plume orientation in fcst versus obs

Summary

- BAMS Continues to be the leading provider of air quality forecast decision support:
  - – Models
    - MAQSIP-RT
    - CMAQ-DA w/ improved SOA
    - Emissions Modeling
    - MATC-H
  - – Information Delivery (wide variety of approaches)

- BAMS is rapidly advancing forecast capability through model improvements
  - – Re-thinking Emissions from an LSM perspective: very high resolution
  - – Updating traditional inventories
  - – Improving fire detection / modeling
  - – Improving dust emissions modeling
  - – Data-assimilation of Deep Blue AOD (CMAQ)
  - – Using satellite-derived NO2 and HCHO to cross-check emissions
  - – Improving forecast meteorology (PBL, LSM)
    - Model science components
    - Downscaling to very high resolution terrain

- BAMS is rapidly evolving the ability to deliver timely forecast information to a variety of customers
  - – End-user Forecasters
    - Traditional Web-graphics
    - VIPIR-AQ
  - – Broadcast Television
    - VIPIR-AQ / OMNI
  - – On-board automobile XM-based system
    - Visibility
  - – GEOSS / Google Earth

BAMS AQ Forecast Systems:

The Leader in Advanced Air Quality Forecast Modeling for Decision Support

Please stop by our booth in the Exhibit Hall to learn more

Acknowledgements

- **Rudy Husar, Erin Robinson, Kari Hoijvari, Janja Husar** **(Center for Air Pollution Impacts and Trends Analysis, Wash U., St. Louis)**
- **Christina Hsu, , MJ Jeong, Jeremy Warner, Clare Salustro, Jay Herman (NASA Goddard)**
- **Mike Abraczinskas, Bebhinn Do (VISTAS RPO)**
- **Carlie Coats; Jeff Vukovich; Don Olerud, Ted Smith, Jesse O'Neal, Bob Imhoff (BAMS)**

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