Smoke and Dust Predictions using the HYSPLIT Model

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Outline

• 2011 Dust Implementation
• Recent Dust / Smoke Cases
• Ongoing Dust Issues
• Ongoing Smoke Issues
• NAM NMMB Upgrade
• Next NAM Upgrade
November 2011 Dust Implementation
Prediction of dust from dust storms over CONUS

• **Critical for air quality forecasts of particulate matter (PM)**
  - Windborne dust is a significant component of particle pollution
  - Dust emissions locally dominate PM (e.g. AZ and TX, 2011)
  - Challenges: when, how much and how far do dust emissions contribute to PM2.5?

• **Real-time information on dust emissions essential**
  - Dust emissions depend on soil characteristics, wind velocity, soil moisture

• **Effectively leverages existing capabilities**
  - NOAA/GFDL climatological map of dust sources from satellite observations
  - NOAA/NWS real-time information on soil moisture
  - NOAA/OAR expertise in dispersion prediction: HYSPLIT

• **Airborne dust impacts visibility, transportation safety, radiative forcing (and weather)**

Publications in peer-reviewed literature:


Model Components: Linked numerical prediction system

Operationally integrated on NCEP’s supercomputer
- NCEP mesoscale NWP: NAM (NMMB, 12km resolution)
- NOAA/OAR HYSPLIT dispersion for dust transport

Observational Input:
- NWS real-time weather observations assimilated in NAM

Gridded forecast guidance products

On NWS Telecommunications Gateway and NDGD
- Updated 2 times per day: 6z (available by 13z) and 12z (available by 17:30z)

Routine verification basis
- Near real-time NOAA/NESDIS dust-column product

Customer outreach/feedback
- NOAA/NWS field forecasters
- State & Local AQ forecasters, coordinated with EPA
- Public and Private Sector AQ constituents
History of NCEP Dust Forecasts

- Emission of dust based on climatology of source points built from MODIS Deep-Blue AOD values; friction velocity threshold had to be exceeded by background meteorology friction velocity for emission to occur

- Different climatologies for different months

- Initial version tested at EMC in early 2010 and began running in NCO production 5/18/10

- Showed skill but tended to produce unrealistically high concentrations in desert southwest and often failed to create dust emissions over the western plains (especially west TX)

- Product placed in experimental TOC directories
History of NCEP Dust Forecasts

- Revised version given to EMC in Spring 2011

- Criteria for determining potential dust source points relaxed to capture more plains events (critical AOD reduced from 0.75 to 0.5)

- In addition to friction velocity test, new test based on Bowen ratio (latent and sensible heat fluxes) to account for soil moisture/vegetation

- Allows for single climatology file since soil moisture/type now accounted with new tests

- Significant improvement in forecasts

- Implemented at NCO in November 2011; became operational NWS product 1/31/12
Use of the Bowen Ratio

Source points will emit dust if:
- afternoon Bowen ratio > 2.5
- abs LHF > 5
- abs SHF > 25
3 month average concentrations

OLD

NEW
Impact of Changes

Reduction of large concentrations in southwest

More small dust events predicted
Texas dust event on November 2

A widespread dust event occurred on Nov 2 beginning around 18Z in west central Texas. This event was the result of ~25kt synoptic scale winds ahead of a cold front. Through 0Z (Nov 3) the dust blew south covering all of west Texas and parts of southeast New Mexico.
Arizona event on 10/4/11

- 3 serious crashes on I-10 between Phoenix and Tuscon
- Many injuries and 1 fatality
- Southwest winds gusting to 35 kt with antecedent very dry conditions

Threat well-captured by old and new configurations, but new version showed better location and coverage.
CONUS Dust Forecast Guidance: Verification Approach

- First real-time verification for dust from dust storms in daily use
- Based on NOAA/NESDIS Dust Mask Algorithm from MODIS imagery:
  - Product quality will be determined based on sunglint, solar zenith angle, dependence of thresholds used for detection on viewing geometry

- “Footprint” comparison for average column concentrations >1ug/m³:
  - Critical Success Index or figure-of-merit statistics:
    \[
    \text{Critical Success Index} = \frac{(\text{Area Pred} \cap \text{Area Obs})}{\text{Area Pred. U Area Obs}}
    \]
- Initial skill target 0.05
Validation of MODIS Dust Mask Product (V6.3.4) using CALIPSO Vertical Feature Mask Product

MODIS dust mask product in a 5 X 5 km² around a CALIPSO observation are used for matchup. Table on this slide shows the summary of results. Formulae for Accuracy and POD are shown below the table.

In 2010, 63 CALIPSO scan lines had dust cases. These scan lines over the US provided with thousands of pixels for comparison with MODIS dust mask product.

Examples of individual cases are shown in the following slides. Each slide has a CALIPSO scan line, MODIS dust mask product corresponding to the CALIPSO scan line, CALIPSO vertical profile, MODIS dust mask granule, MODIS deep blue and conventional AOD products (when two are available an average is taken). The table on the bottom left shows the agreement information and accuracy and POD are listed as well.

<table>
<thead>
<tr>
<th>Cases</th>
<th>True Positive</th>
<th>False Negative</th>
<th>True Negative</th>
<th>False Positive</th>
<th>Accuracy (%)</th>
<th>POD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>564</td>
<td>476</td>
<td>9649</td>
<td>4422</td>
<td>67.59</td>
<td>54.23</td>
</tr>
</tbody>
</table>

True Positive (TP): MODIS and CALIPSO say dust
True Negative(TN): MODIS and CALIPSO say no dust
False Negative(FN): MODIS says no dust but CALIPSO says yes
False Positive(FP): MODIS says dust when CALIPSO says no

POD = TP/(TP+FN)
Accuracy = (TP+TN)/(TP+TN+FP+FN)
### Detection of CALIPSO MODIS Samples

<table>
<thead>
<tr>
<th>Detection Type</th>
<th>CALIPSO</th>
<th>MODIS</th>
<th>Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>True positive</td>
<td>yes</td>
<td>yes</td>
<td>103</td>
</tr>
<tr>
<td>False negative</td>
<td>yes</td>
<td>no</td>
<td>9</td>
</tr>
<tr>
<td>True negative</td>
<td>no</td>
<td>no</td>
<td>74</td>
</tr>
<tr>
<td>False positive</td>
<td>no</td>
<td>yes</td>
<td>46</td>
</tr>
</tbody>
</table>

**Accuracy** = 76.29%

**POD** = 91.96%

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**MODIS Dust Mask Algorithm CDR**

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**MYD.A2010119.2010 (v6.3.4)**

**MYD04.A2010119.2010**

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**Aerosol Optical Thickness**

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**MODIS Dust Mask Algorithm CDR**

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**October 20, 2011**
Wallow Wildfire in Arizona

- Fire began May 29, 2011, consumed more than 700 square miles and 29 homes; 10% contained (on June 13, 2011)²³
- 7 injuries³; more than 9000 people evacuated²
- 60mph winds contributed to its rapid spread¹
- Code orange air quality forecast issued for Albuquerque for 4 days (June 6, 8, 9, 13) - NWS prediction included high smoke concentrations
- Hazardous air quality predicted by NAQFC and observed in Springerville, AZ
- NAQFC joined coordination calls with state, local, federal agencies in AZ and NM, and USFS Fire Science Lab (Seattle)
NWS smoke prediction

1Hr Vertical Smoke (micrograms/m^3) Sat Jun 04 2011 5PM EDT
(Set Jun 04 2011 21Z)

Vertical column smoke at 21 Z on 06/04
Wallow North fire, Arizona: 2011/157 - 06/06 at 20:40 UTC
Aqua 1km pixel size

Vertical column smoke at 21Z on 06/06
Ongoing Dust / Smoke Issues and Challenges
The Challenges of Simulating Hawaii Smoke
Detection of Alaska Fires Prior to Data Cutoff Time
Bowen Ratio Method Not Perfect
Long Runtimes on Dusty Days
Phoenix, AZ dust event on July 5

• Massive dust storm hit Phoenix, AZ in the evening on July 5, 2011
• Cloud was reported to be 5,000 feet when it hit, radar shows heights from 8,000-10,000 feet tall and 50 miles wide
• Originated from convection near Tuscon
• Stopped air traffic for over an hour
• Arizona DEQ reported a PM10 concentration of 6,348 ug/m³ during peak of storm at site in downtown Phoenix
• Storm moved through Phoenix at 30-40 mph


How this event differs from previous 2 cases

- **Phoenix event generated by strong outflow**
  - MESOSCALE winds in common “dry” monsoon convective environment

- **The west TX and other AZ event feature dust emissions**
  - generated by **SYNOPTIC** wind field

- 12 km NAM background cannot resolve this type of convective outflow

- Regardless, the dust simulation **CAN** show an environment (based on soil moisture) favorable for significant dust emissions in the presence of sfc winds strong enough to exceed the friction velocity threshold

- Possible future tie-in to higher-resolution NAM runs which can resolve convection
Runtime & optimal node apportionment for NMMB nesting with a Fire Wx nest over CONUS (30 nodes): 12 hr fcst in 1619 s [Matt Pyle]

- 3 km Puerto Rico nest 1.5/30 or 5%
- 3 km CONUS FireWx nest 1.33 km 5/30 or 17%
- 4 km CONUS nest 17/30 or 57%
- 6 km Alaska nest 2/30 or 7%
- 12 km parent 3/30 or 10%
Dots represent water points. Domain is Chesapeake Bay.
NMMB stands for Nonhydrostatic Multiscale Model on B-grid [Zavisa Janjic]

B-grid is just an E-grid rotated 45 degrees (and vice-versa)
Day 1, 2, 3 CONUS Vector Wind RMS error: Dashed = PLL NAM, Solid = Ops NAM

- Sept - Nov 2010
- Dec 2010 – Feb 2011
- March – May 2011
- June – August 2011
10-m Wind Verification

24-hr 10-m Wind Western US 18 September 2011 to 18 November 2011

WEST

24-hr 10-m Wind Eastern US 18 September 2011 to 18 November 2011

EAST
PBL Height Verification

24-hr PBL Height 18 September 2011 to 18 November 2011

- NAM RMS; MEAN = 7.50535E+02
- GFS RMS; MEAN = 5.04905E+02
- NAM BIAS; MEAN = 4.04701E+02
- GFS BIAS; MEAN = -2.89545E+01

TKE-based
PBL Height Verification II

24–hr PBL Height 18 September 2011 to 18 November 2011

NAM RMS, MEAN = 7.3972E+02
NAM BIAS, MEAN = -2.67945E+02

Ri-based
Ongoing NAM Tests
Current NAM Parallel

- Ensemble Kalman Filter (ENKF) used in GSI
- Changes to gravity wave drag
- Changes to convective scheme to make scheme trigger less frequently
- Use of RRTM radiation
GFS F84 MEAN ERRORS – Week of 8/30

00z

06z

12z

18z
WEEKLY NAM F84 MEAN ERRORS

00z

06z

12z

18z
48-72hr precip for July 07 12 UTC - July 8 12 UTC