NAAPS Aerosol Analyses and Forecasts for Air Quality Applications

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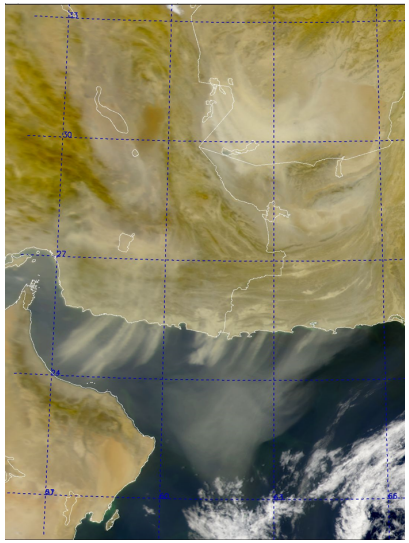
Outline

1. Navy Motivation and Approach
2. AQ Motivation and NASA interest
3. Description of NAAPS, Applications to LRT to CONUS
4. Summary

Motivation for Navy Aerosol Particle Forecasting

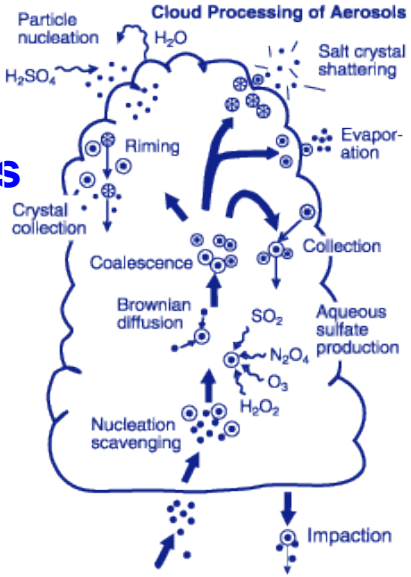
Delays operations

Inhibits intelligence gathering



Impairs sensors

Complicates weather prediction

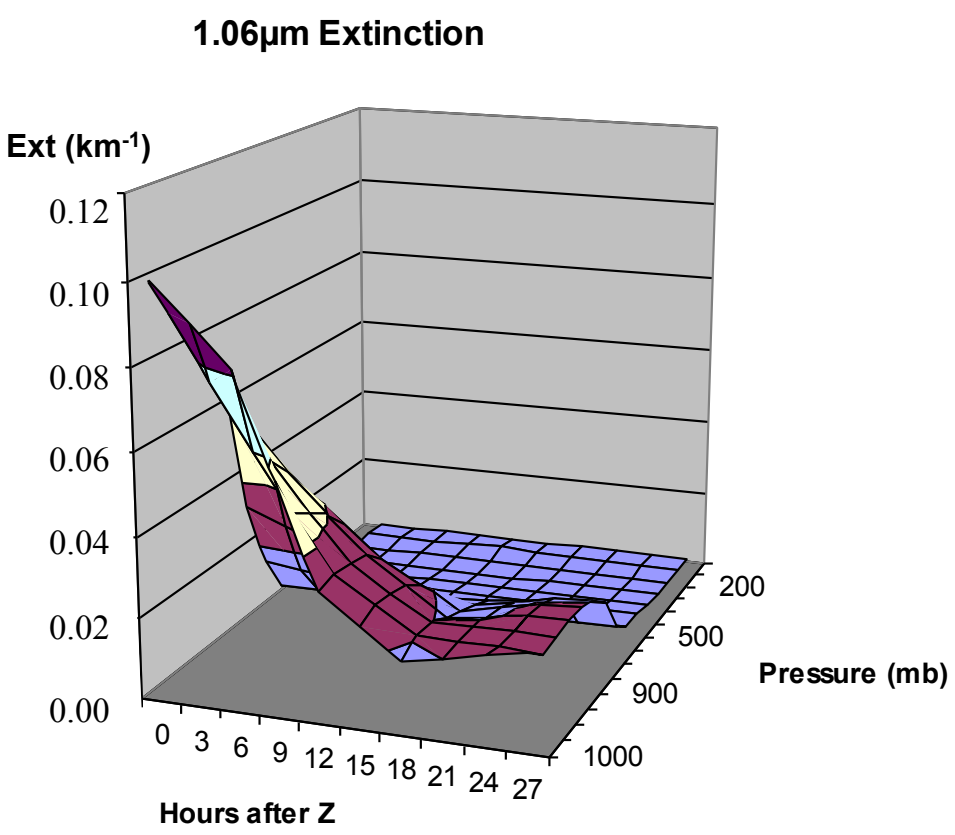


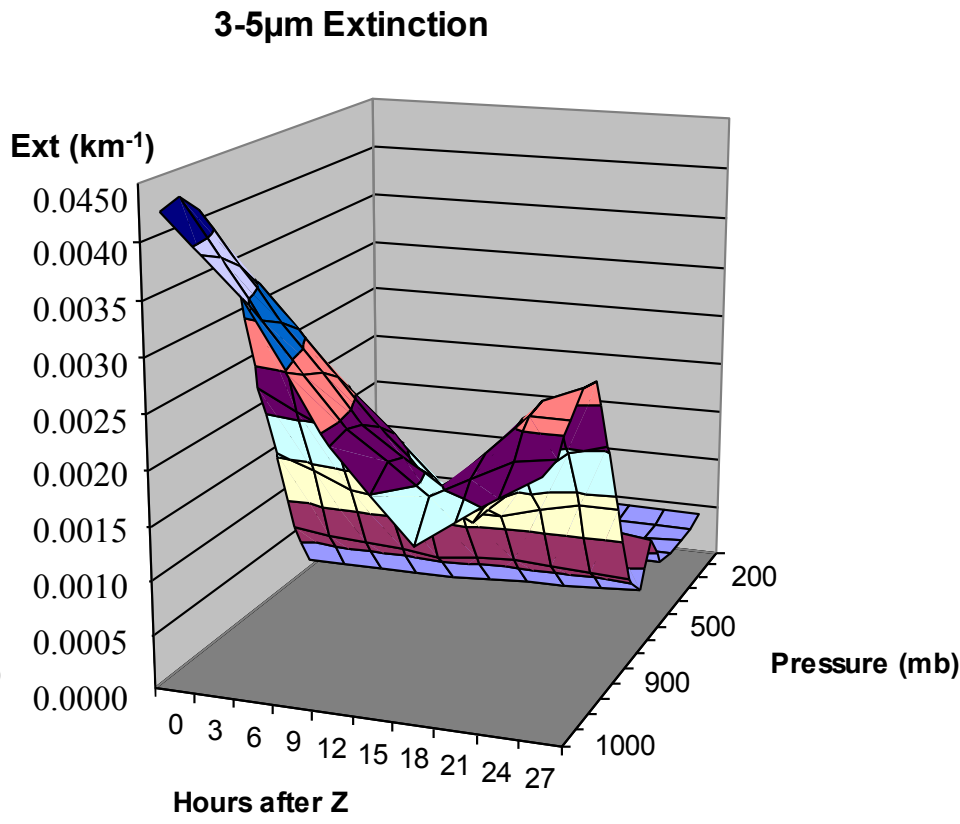
Limits use of laser weapons

The Holy Grail:

Forecast of Aerosol Radiative Properties

System forecasts extinction (km^{-1}) dependence on
Latitude, Longitude, Altitude, Time, and Wavelength
Sample profile for 12:00 GMT 10/04/2005 at 2S, 115E





First principles approach covers 5 dimensions: x, y, z, t, λ

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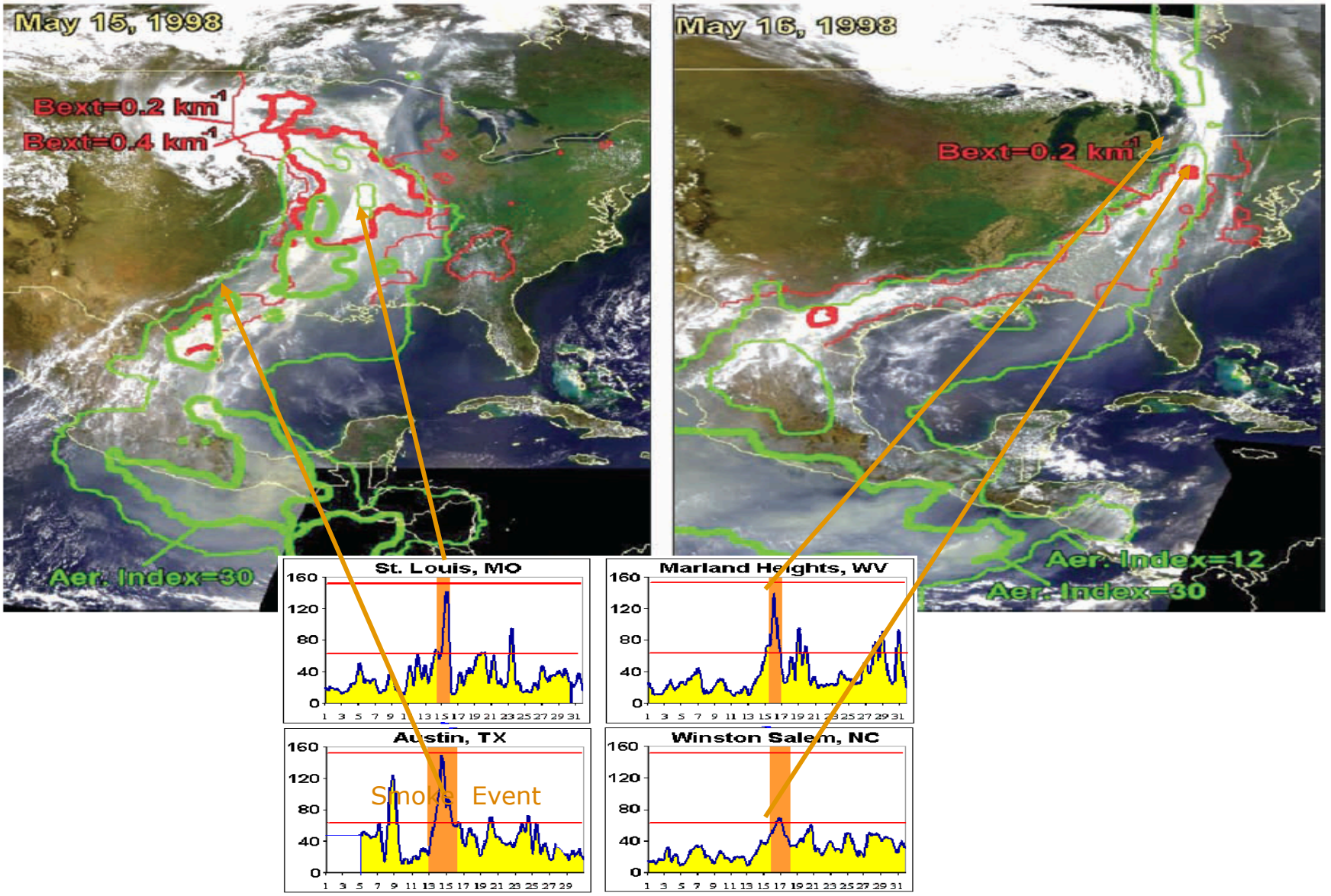
Long-Range Transport AQ Events

Highest PM concentrations can occur during dust and smoke events



OCONUS Dust Over CONUS: Impact of the "Perfect Dust Storm" on California

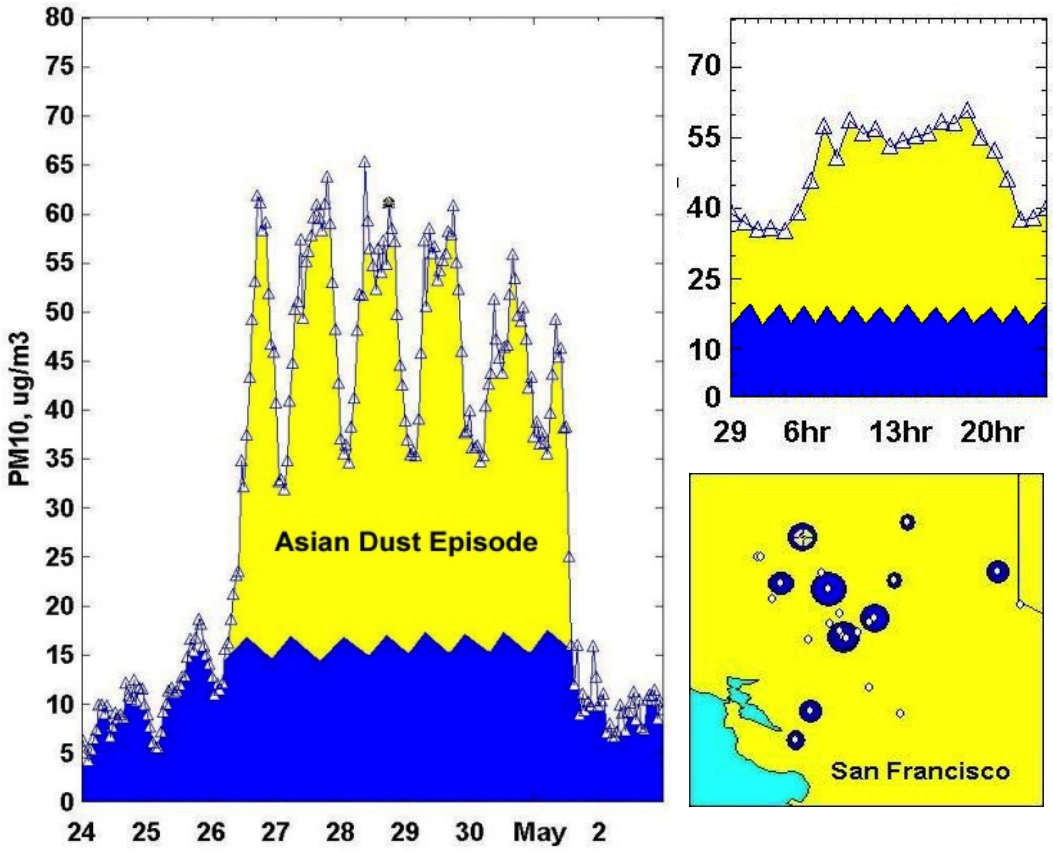
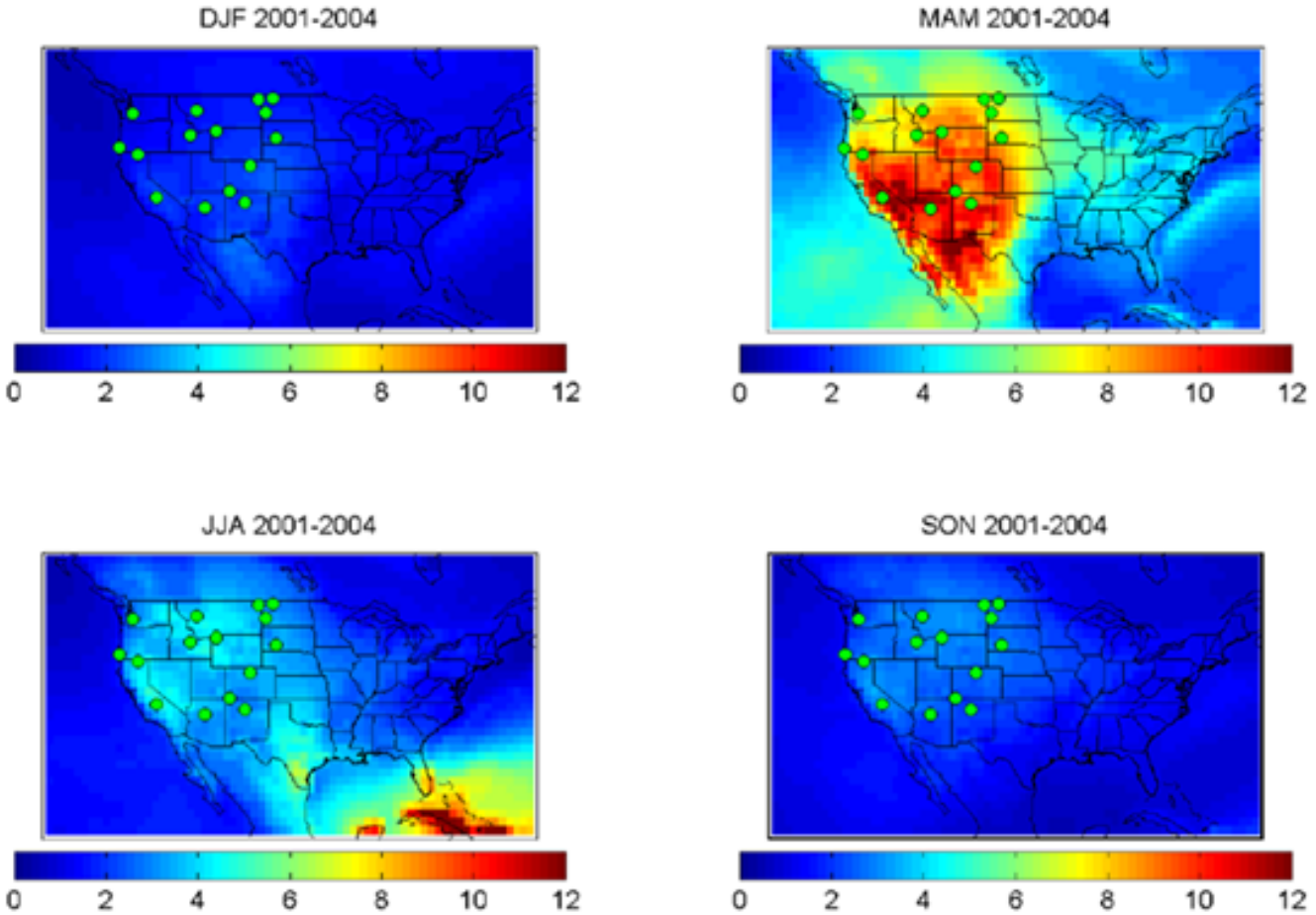


Figure 6. Diurnal pattern of dust of Northern California. a) Hourly PM10 concentration averaged over 12 stations in Northern California. b) Diurnal pattern of PM10 on April 29, 1998. c) Location of the hourly PM monitoring sites in

April 29, 1998

OCONUS Dust Over CONUS

Seasonal distribution of NAAPS simulation of non-N. American surface dust concentration (μg m-3) for 2001 – 2004.



NAAPS Application to AQ Analysis

Overall Objective: *Quantify the impact of Non-CONUS emissions on US AQ using remote sensing and model data provided to AQ Decision-Makers through DataFed.*

Baseline:

1. Exceptional events flagging
   - No standard information sources as evidence for EEs
   - Ad hoc flagging and reporting by the States
2. Background conditions for EPS Regional Haze Rule
   - No modeling studies of international influences were used to determine the default natural condition values
   - States lack standard method for quantifying impact
3. AQ Forecasting and sampling
   - LRT forecasts not freely available in a quantitative way

NAAPS Application to AQ Analysis

Approach

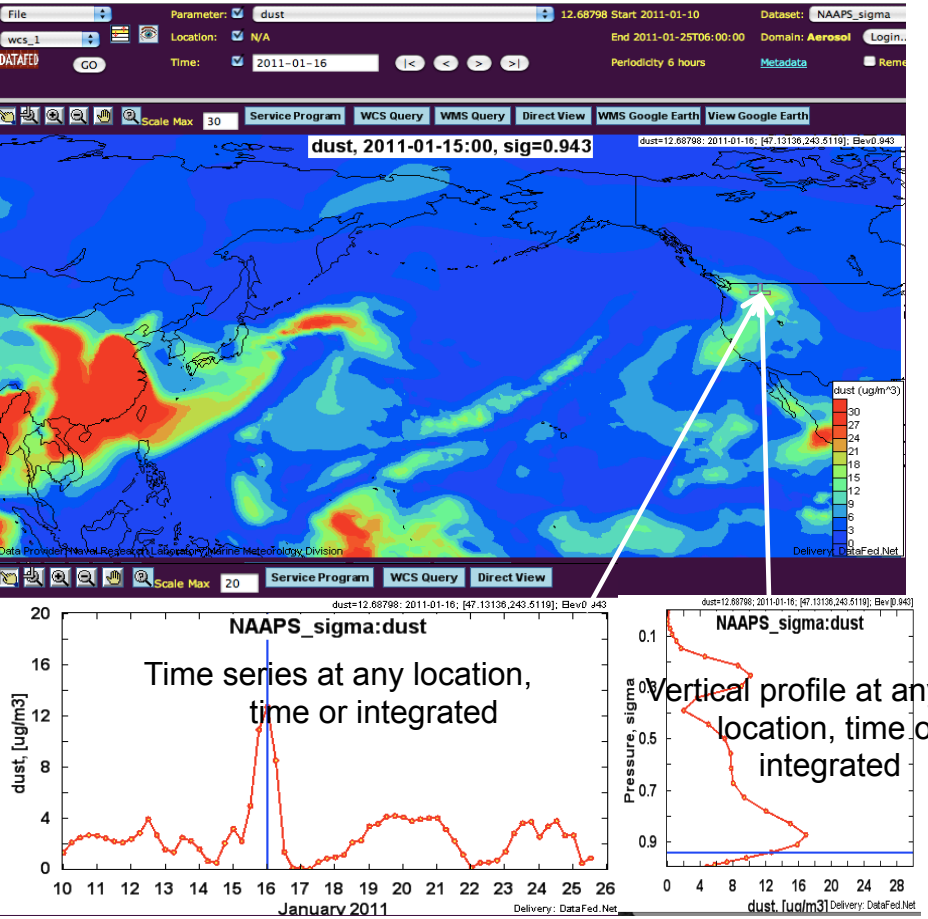
1. Exceptional events flagging
   - Distribute NAAPS via standard protocol through DataFed
2. Background conditions for EPS Regional Haze Rule
   - Use 10-year NAAPS reanalysis to identify background on 20% best and worst haze days
   - Use NAAPS sensitivity runs to estimate impact of projected emissions (e.g. HTAP scenarios)
3. AQ Forecasting and sampling
   - LRT forecasts distributed
   - NAAPS made available for boundary conditions for regional models
   - NAAPS forecasts used to guide measurements in field missions

NASA Interest: Sat. Data Usage in NAAPS

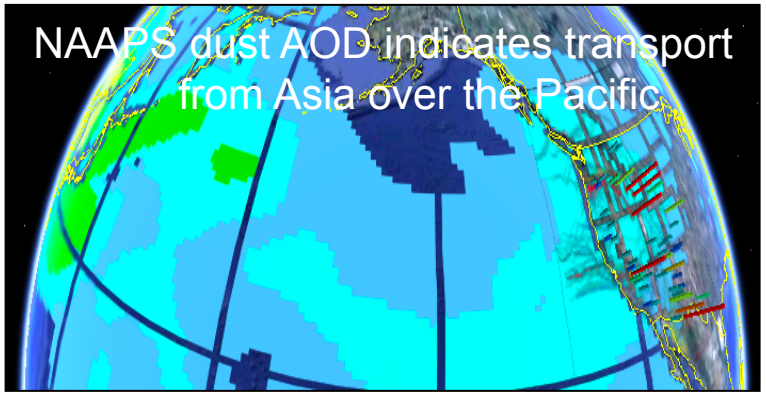
NAAPS Component	Assimilated Data
FLAMBE – Hourly, global, biomass emission fluxes in real-time and archived since 2000	**MODIS and GOES data used to produce gridded smoke emissions (FLAMBE, WF-ABBA)**
DSD – Global dust source database	**MODIS Dust Enhancement Product and TOMS AI used to identify dust sources**
NAVDAS-AOD – data assimilation, produces 6-hourly, global 3-d distributions of aerosol species (sulfate, smoke, dust, salt), in real-time and back to 2000	**NRL Level 3 version of MODIS AOD** **AERONET and CALIPSO climatology used for speciation** **R&D: CALIPSO used for 3-d var data assimilation and validation** **Tested but unused: MODIS Deep Blue, MISR, AVHHR AOD**
NAAPS Validation	**AERONET – AOD, absorption, size** **CALIPSO and MISR - Altitude**

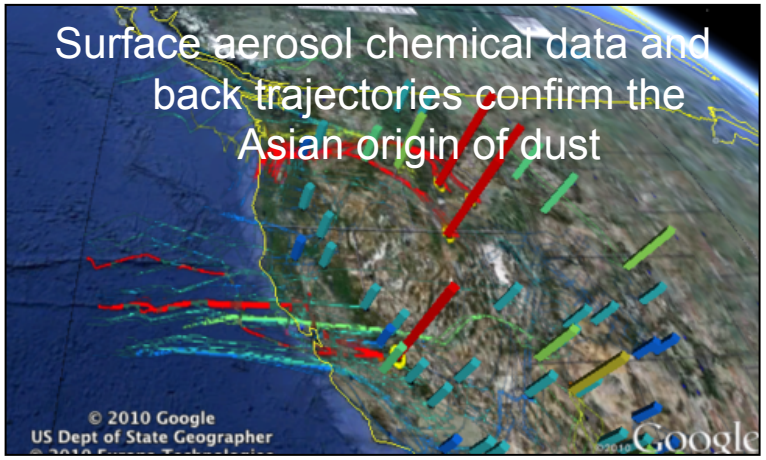
DataFed: Provides NAAPS Products for Exceptional Event Analysis

NAAPS data integrated with visualization and exploration tools and DSS applications.



NAAPS and other data combined for Exceptional Event analysis with EPA and States





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Forecast System Components

System	Function
NAVGEM	Forecasts dynamics
NAVDAS-AOD	Data assimilation for aerosols
FLAMBE*	Detects fires, determines smoke flux
NAAPS, COAMPS	Forecast aerosol concentrations
FAROP**	Calculates aerosol optical properties
TEDS, Metcast	Database and Distribution
MCSST†, TAWS‡ NPOESS	Applications

† NRL Atmospheric Variational Data Assimilation System – Aerosol Optical Depth

*Fire Locating and Modeling of Burning Emissions

**Forecast of Atmospheric and Optical Radiative Properties

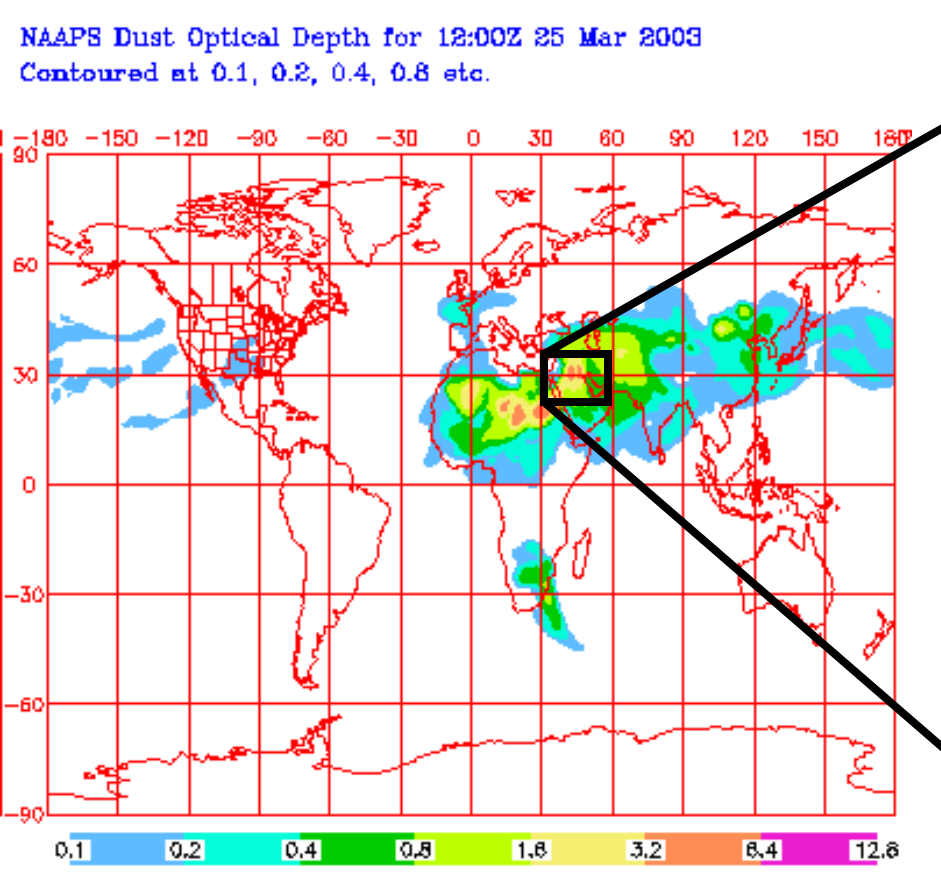
† Multi-channel Sea Surface Temperature

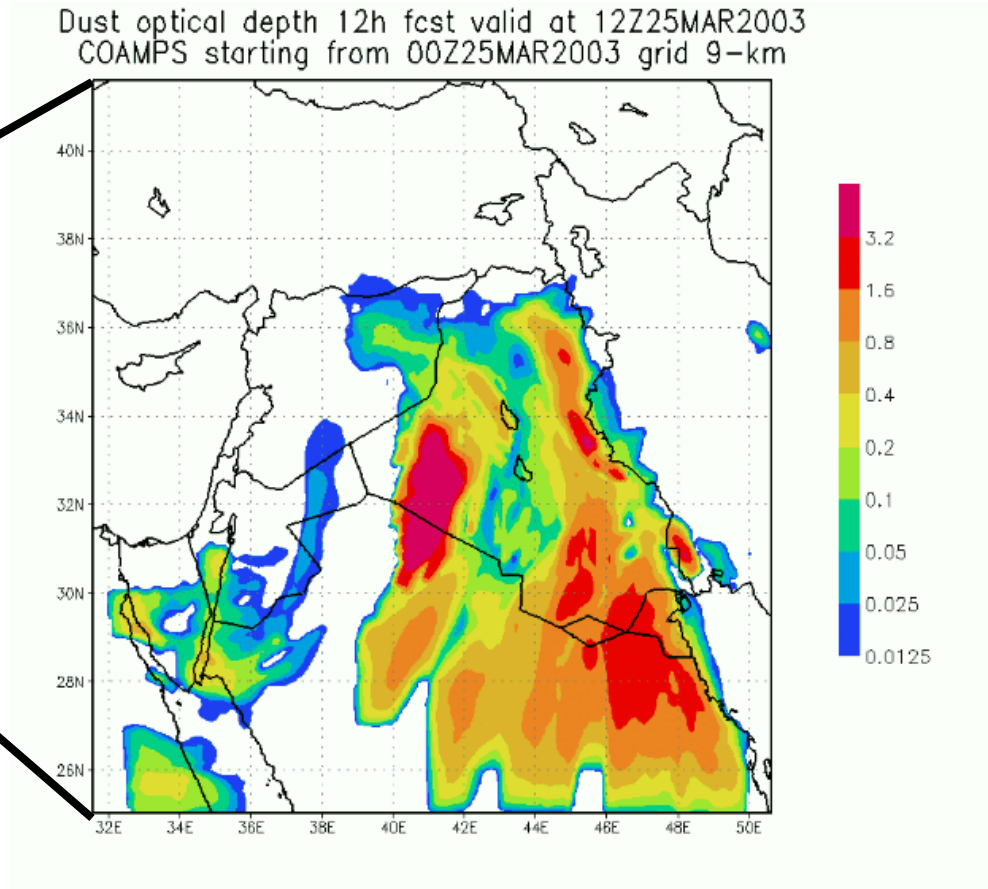
‡ Target Acquisition Weapons Software

Aerosol Forecasting Approach: Telescoping Strategy

NAAPS Global Model: 6-day forecast, four times daily

COAMPS Regional Model: 3-day forecast, twice daily



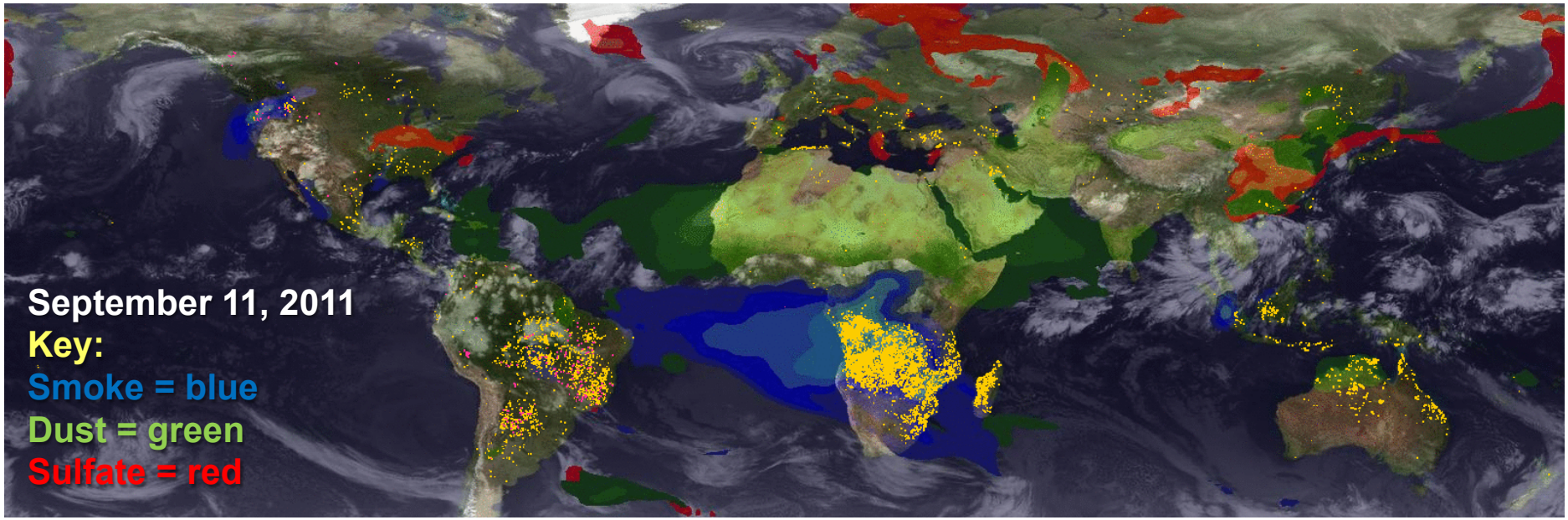


12-hour dust forecasts for 12Z 25 March, 2003

DoD Requires Global Forecasting: Navy Aerosol Analysis and Prediction System

Purpose: Forecast of aerosol concentrations globally
Method: Solve the advection-diffusion equation at each grid point for each species m :

Species: Dust, smoke, salt, sulfate, sulfur dioxide
Advection and turbulent mixing: Controlled by dynamical model NAVGEM
Sources and sinks: Dependent on dynamics and **remote sensing**
Initial State: Based on previous forecast and **remote sensing**
NAAPS is the only operational, multi-species model with data assimilation.



NAAPS: Navy Aerosol Analysis and Prediction System

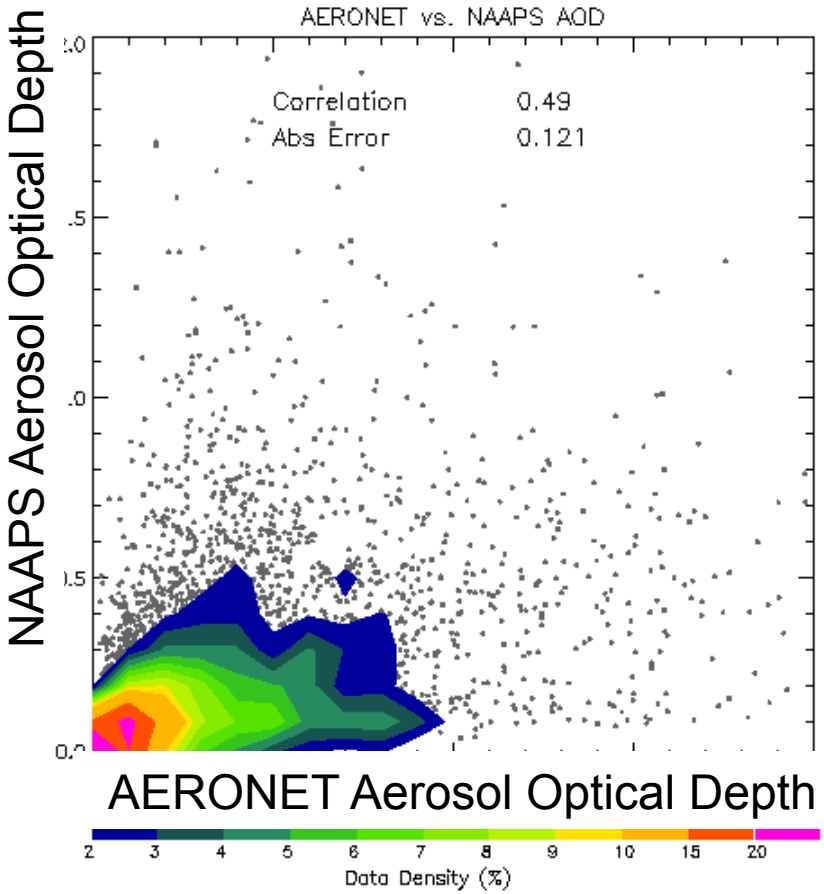
- The only operational model producing twice-daily, 6-day global forecasts of SO_2, sulfate, dust, smoke, and salt
- Off-line model driven with operational global weather model (NOGAPS) provides forecasts of P, T, q, u, v, w, K_z, cloud parameters, precip., stress, and ground wetness at 6-hour intervals on 1X1 degree grid; 25 levels to 100 mb
- Semi-Lagrangian horizontal transport; finite element horizontal diffusion; finite element vertical transport
- SO2 emission from GEIA inventory; oceanic DMS emission
- Dust deflation depends on threshold velocity, forecasted stress and ground wetness; 1 size bin
- Salt emission depends on surface wind speed
- Smoke emission based on operational satellite detection of fires; 1 size bin
- Linear gas-phase chemistry; 1 sulfate size bin
- Dry deposition: function of specie, stress, stability, surface type
- Wet removal: function of precipitation rate, specie, cloud type
- *Modified DEHM model (Christensen, Atm. Env., 1998)
- OpenMP optimization

NAAPS Initialization with NAVDAS-AOD

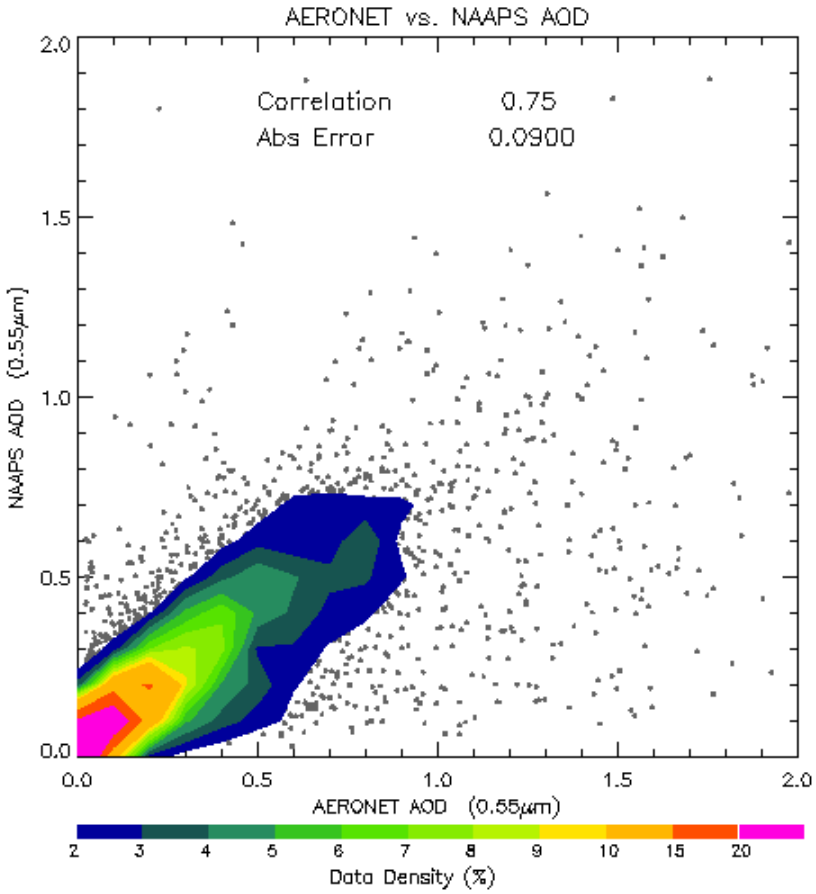
Purpose:	Data assimilation for aerosol optical depth (First ever operational implementation)
Status:	Operational, 4X day at FNMOC
Input:	MODIS AOD; (Quantitative use of satellite AOD data is problematic)
Future input:	NPP, AVHRR, MetOp, MSG, MTSAT, AATSR, GOES-R; (Anticipate continually evolving sensor suite)
Output:	
Aerosol analysis:	3-d distribution of four species
Horizontal resolution:	1x1°
Temporal resolution:	6 hourly
Distribution:	Internal, plots on web

Impact of Aerosol Data Assimilation, Applied Every 6 hours

Natural run



+ Land/Ocean MODIS
+ Land/Ocean MISR



Multi-sensor assimilation improve model performance.

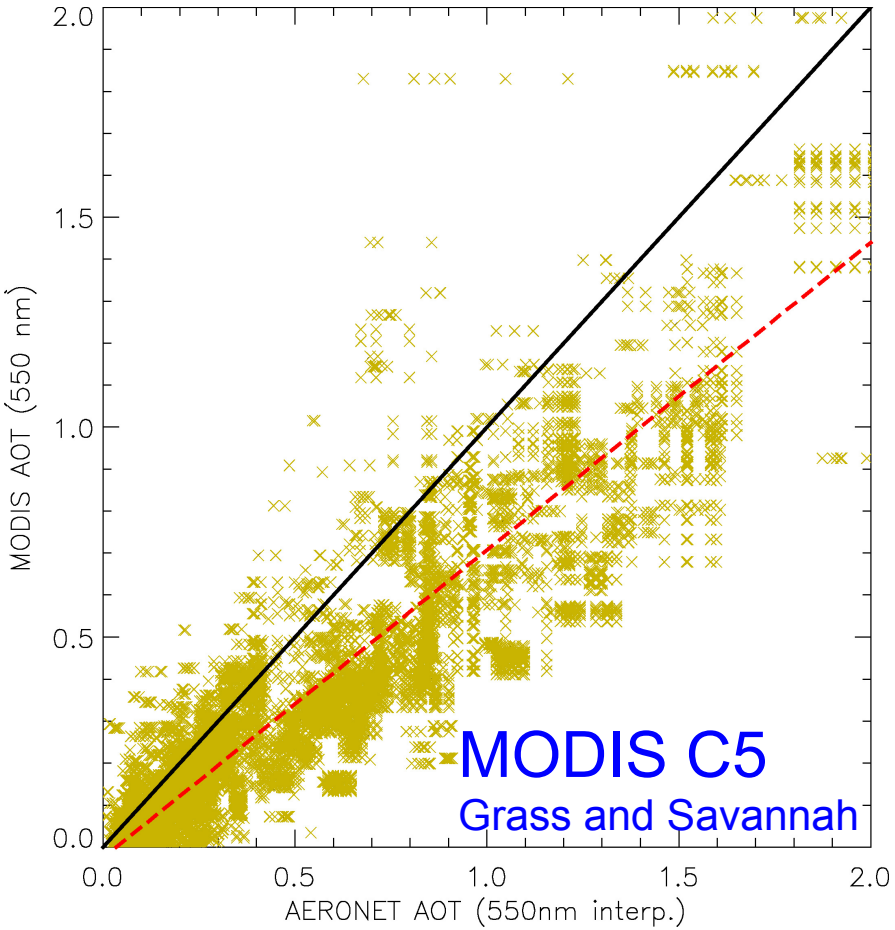
Cloud Artifacts and Albedo Uncertainties Make Over-Land AODs Problematic

Previous over land data AOD products were too poor in fidelity to even contemplate data assimilation

MODIS data collect 5 was released which is significantly improved, but still not sufficient for DA.

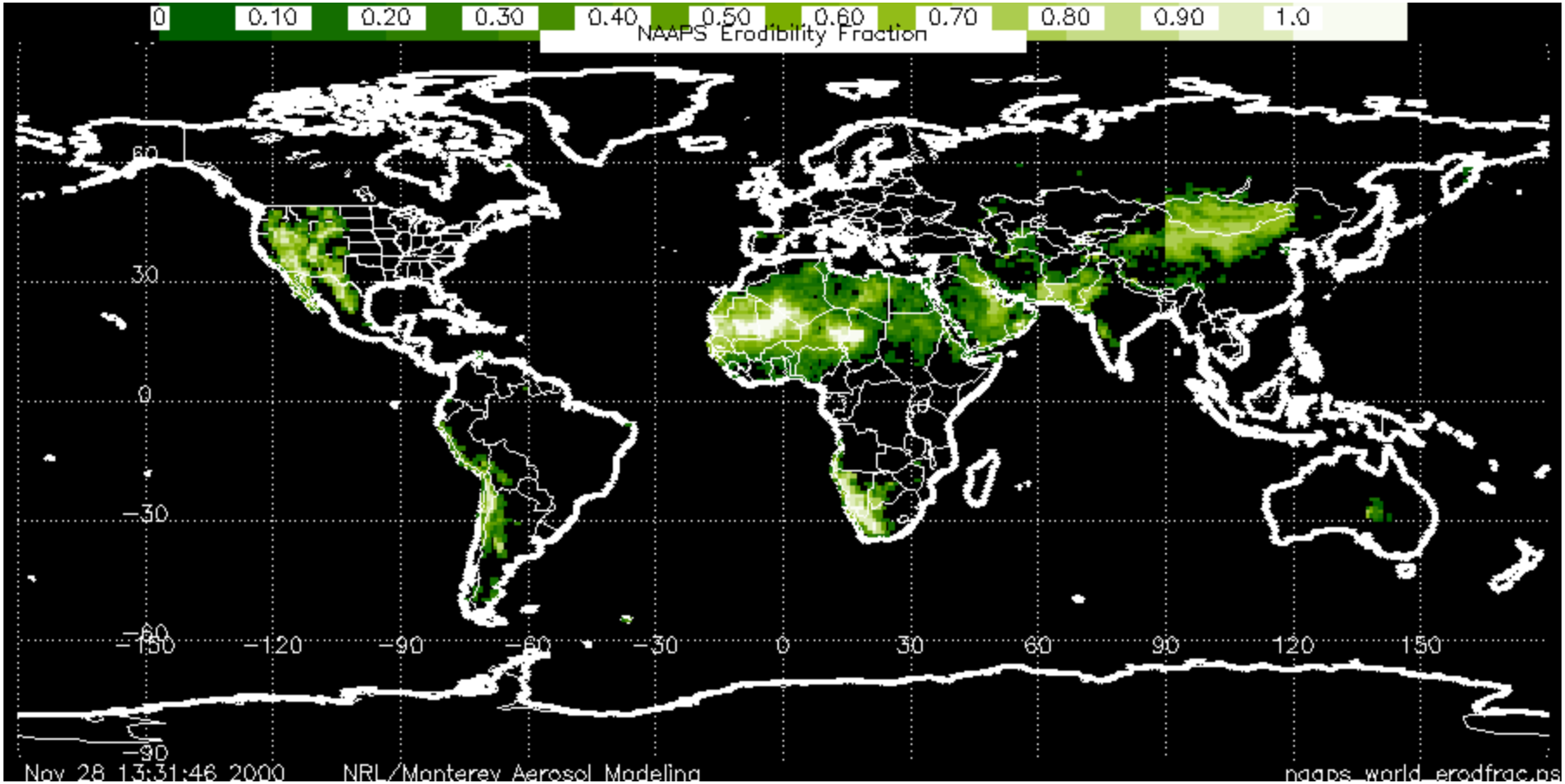
Biases are mostly related to lower boundary condition or aerosol microphysics.

Goal is to have a suitable MODIS data postprocessor for over-land DA.



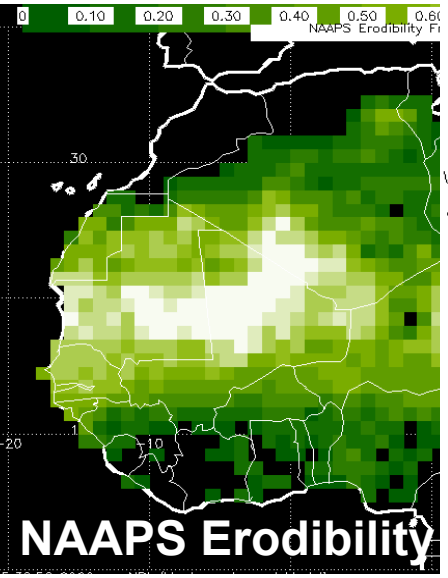
Dust in NAAPS

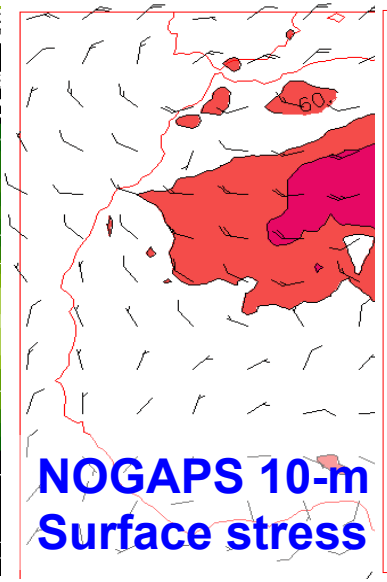
- **Dust emission** depends on:
  - Erodibility: Function of TOMS AI and USGS landuse type

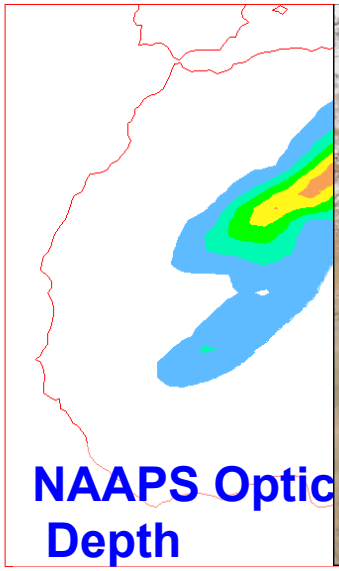


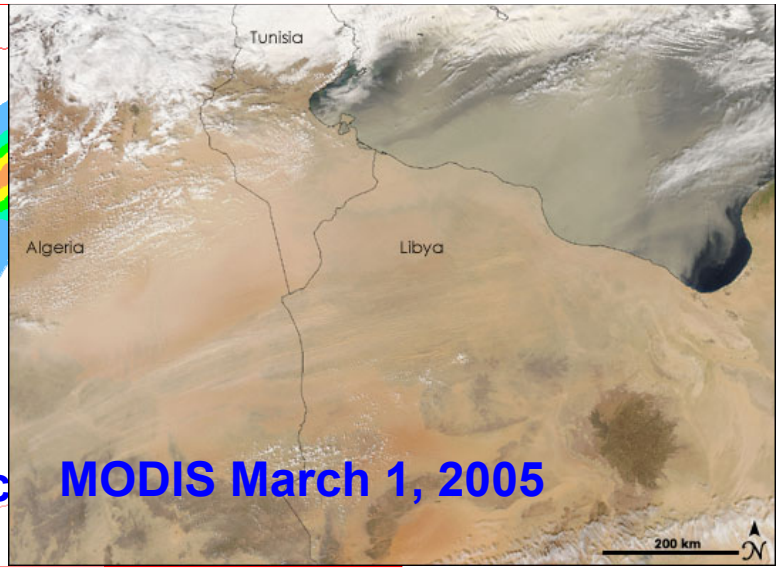
Dust in NAAPS

- **Dust emission** depends on:
  - Erodibility: Function of TOMS AI and USGS landuse type
  - Friction velocity (stress) must exceed threshold value
  - Ground wetness < 0.3
  - Snow free
  - Flux is proportional to square of surface stress
- **Validation**: qualitative comparison with satellite imagery



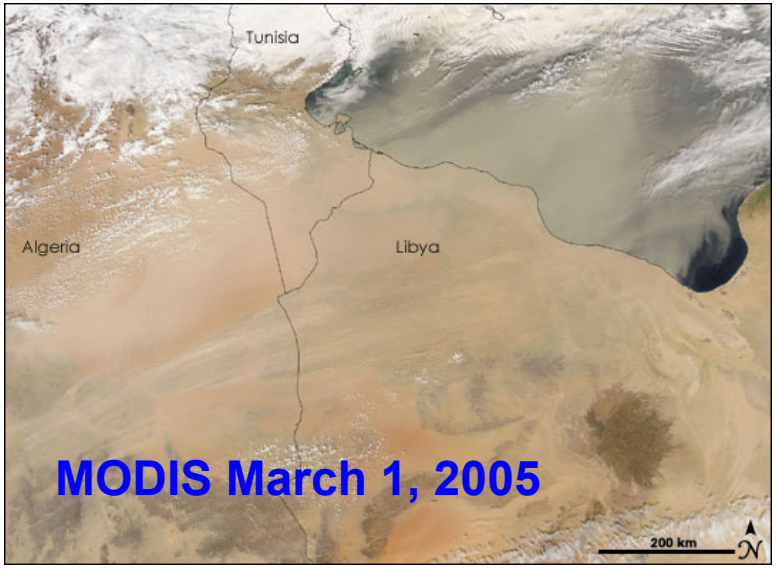


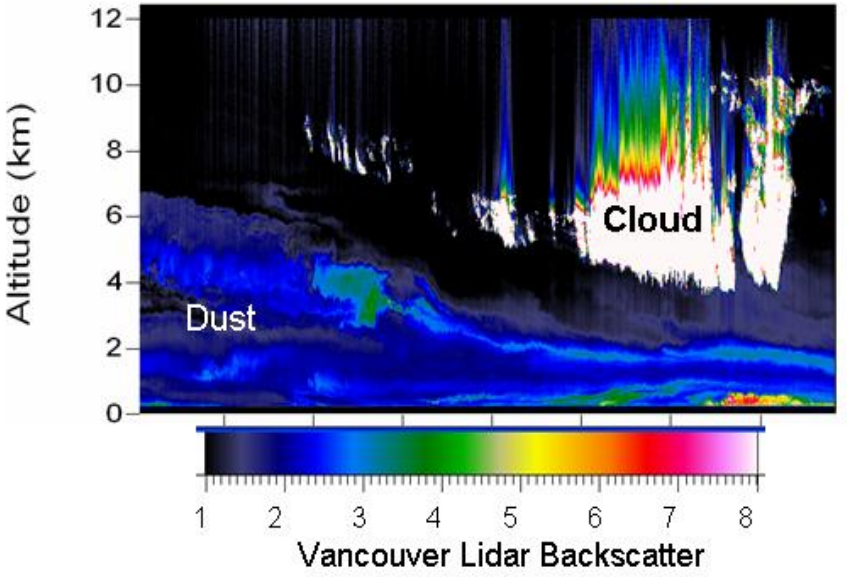


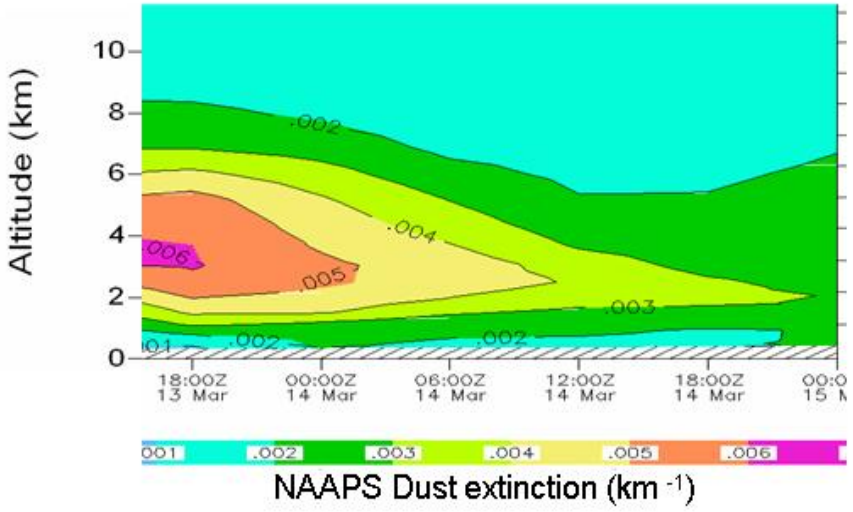


NAAPS Dust Simulation: Transport of African Dust to Calif. Coast

Study of long-range transport of Saharan Dust across Asia and the Pacific to N. America, March 2005 – Verified by NAAPS





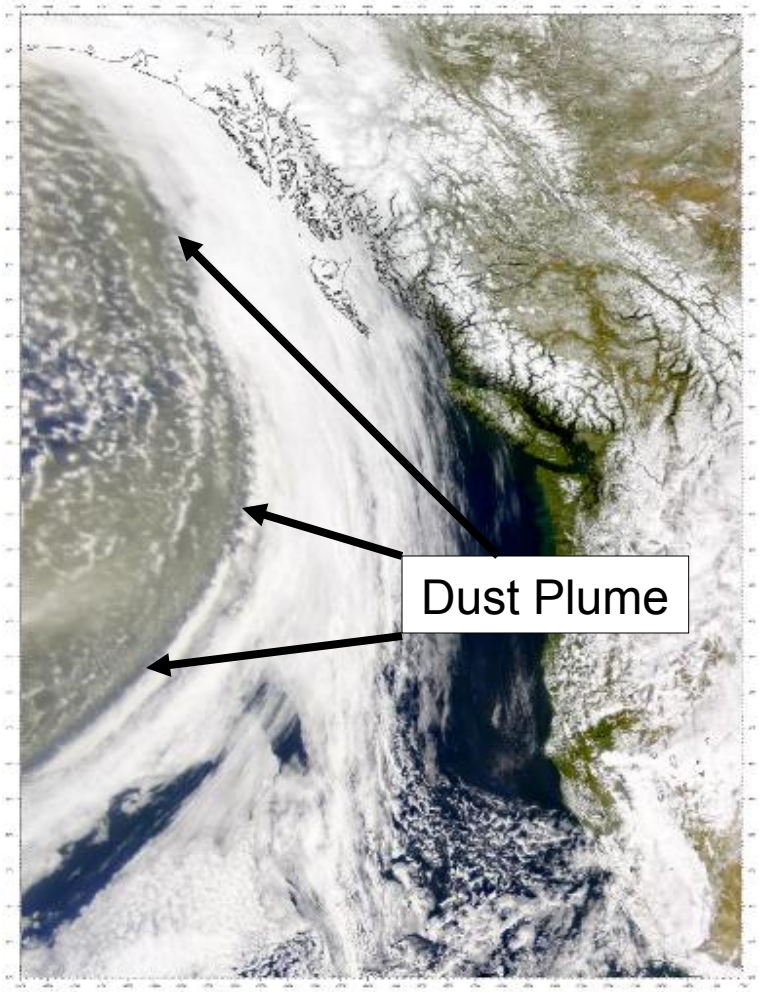


March 13-15, 2005

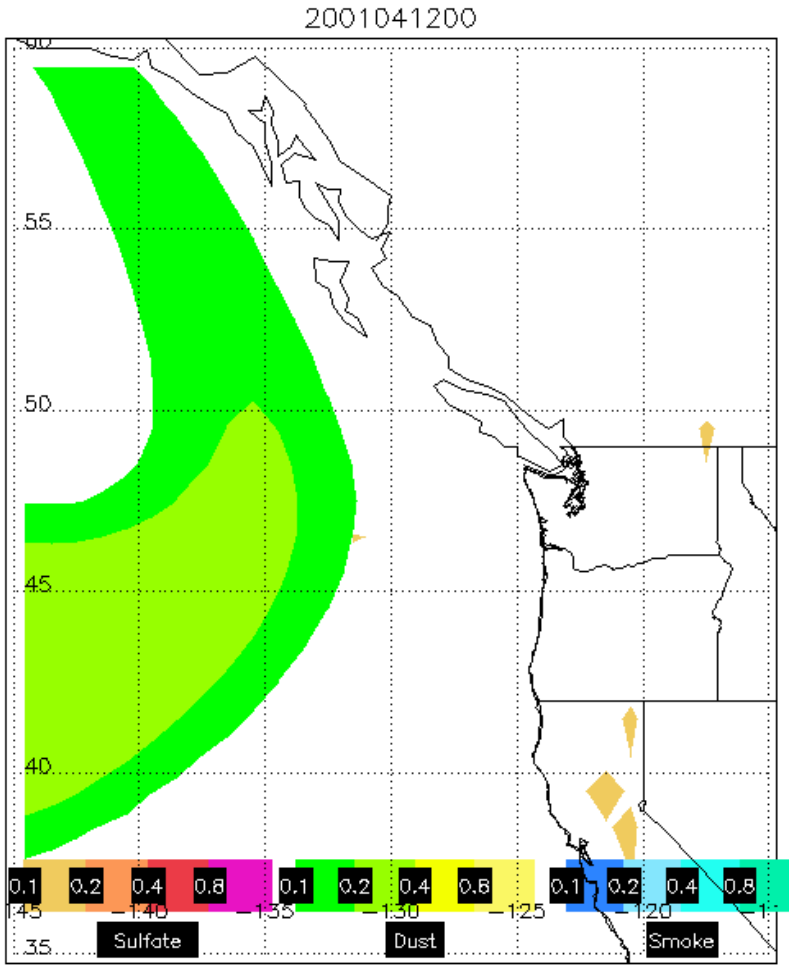
Study of long-range transport of Saharan Dust to N. America, March 2005, 2007, McKendry, I. G., K. B. Strawbridge, N. T. O'Neill, A. M. Macdonald, P. S. K. Liu, W. R. Leaitch, K. G. Anlauf, L. Jaegle, T. D. Fairlie, and D. L. Westphal , Trans-Pacific transport of Saharan dust to western North America: A case study, J. Geophys. Res., 112, D01103, doi:10.1029/2006JD007129

NAAPS Dust Simulation, April 11, 2001: Asian dust approaching N. America behind a cold front

SeaWiFS Imagery
11 April 2001



NAAPS Dust Optical Depth
April 11, 2001



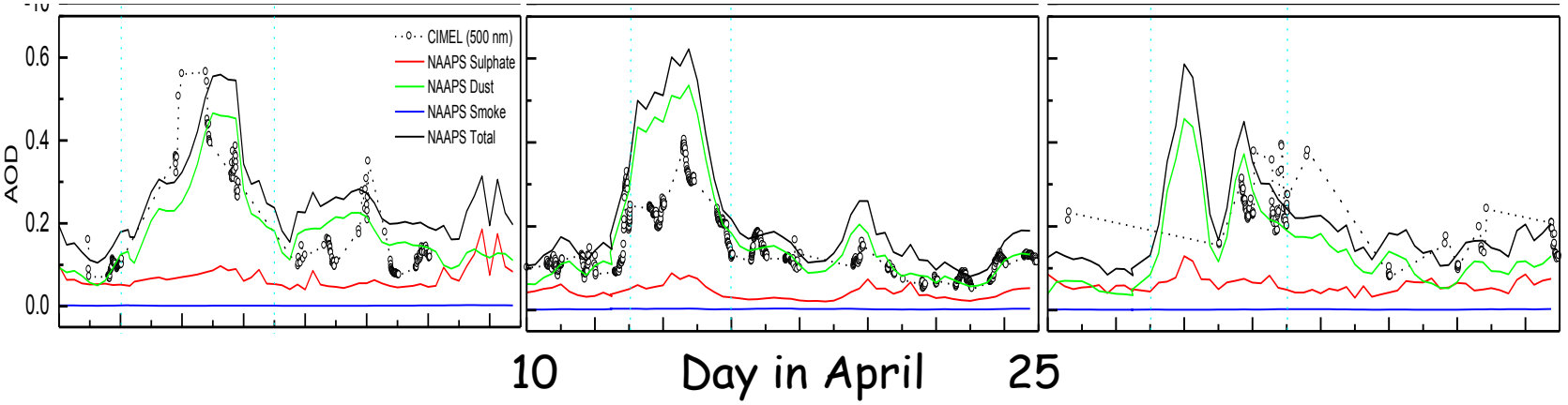
NAAPS Dust Simulation, April 2001: Measurements and simulation of dust crossing N. America

Saturna Island, British Columbia

Rogers Dry Lake, California

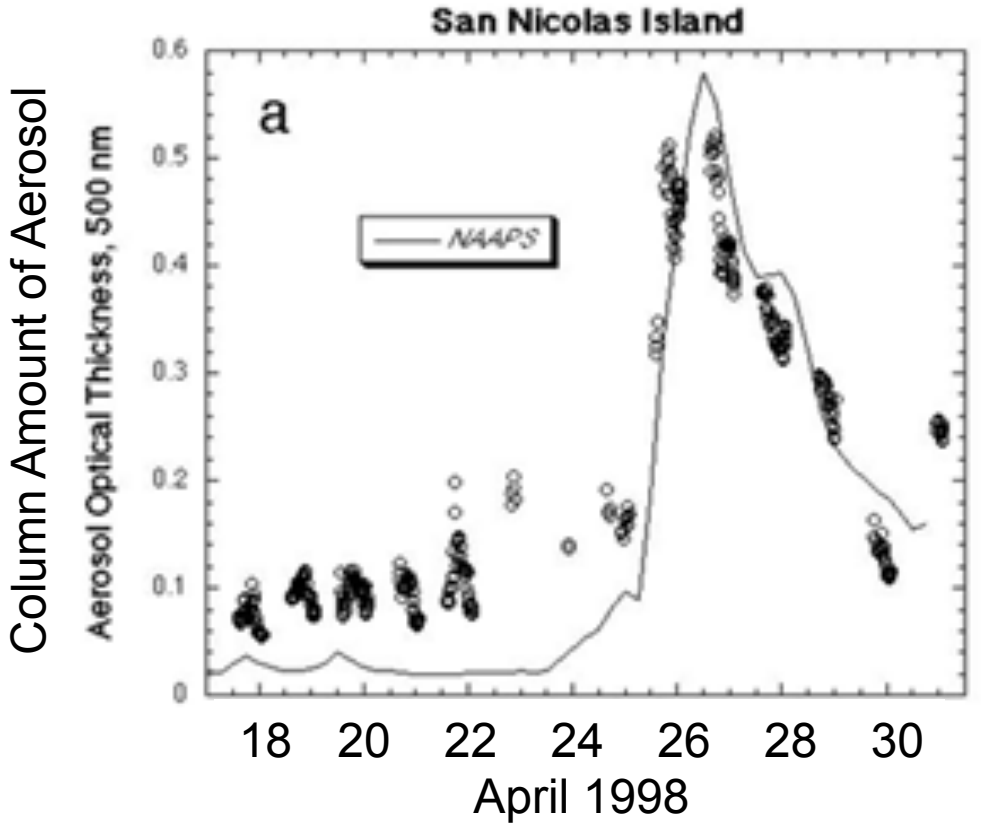
Missoula, Montana

Column Amount of Aerosol



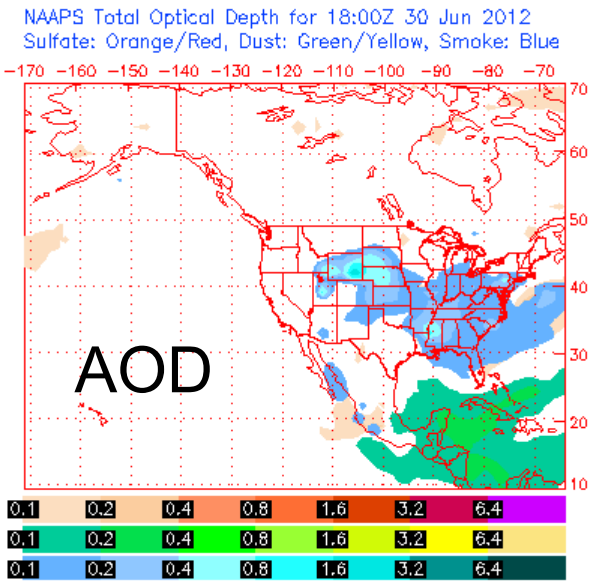
Black symbols – Observations
Black solid line – Simulation

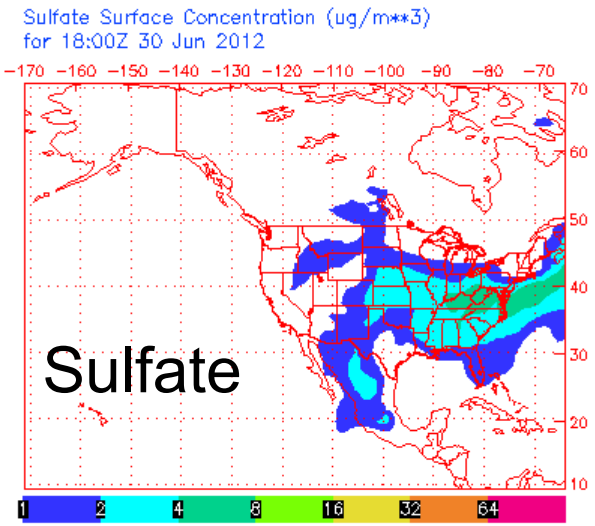
NAAPS Dust Simulation: Transport of Dust from "Perfect Dust Storm" to Calif. Coast

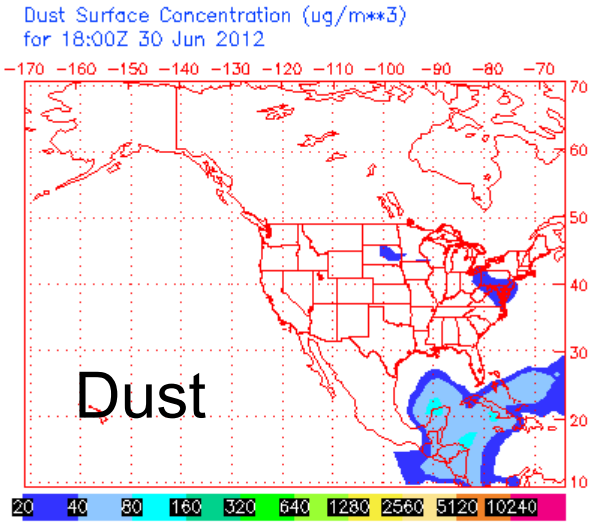


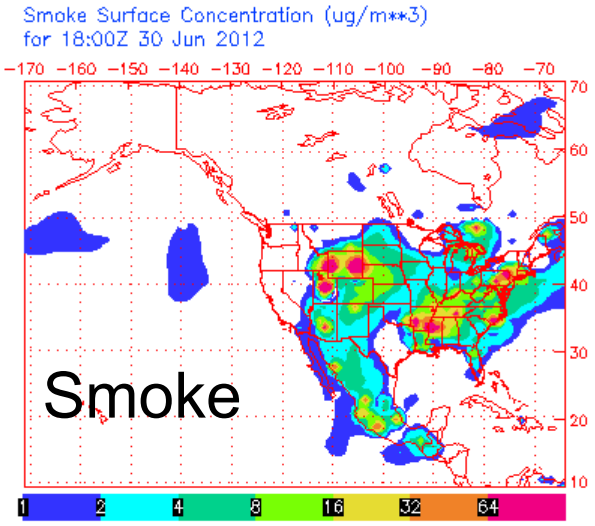
Time series of observed and simulated aerosol optical thickness at 500 nm at San Nicolas Island during April 18 - May 1, 1998. (Tratt et al., 2001.)

NAAPS Dust Simulations: Transport of Saharan Dust to Texas, 30 June – 4 July 2012



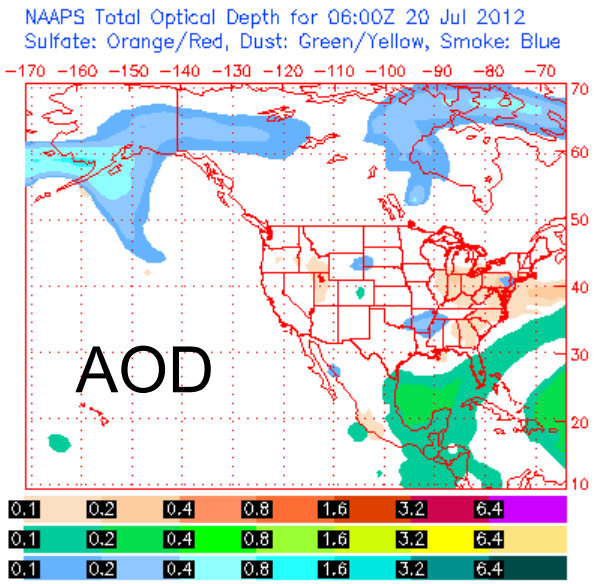


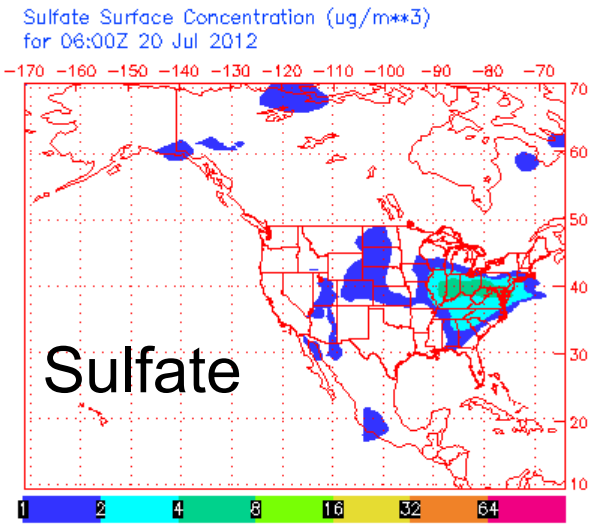


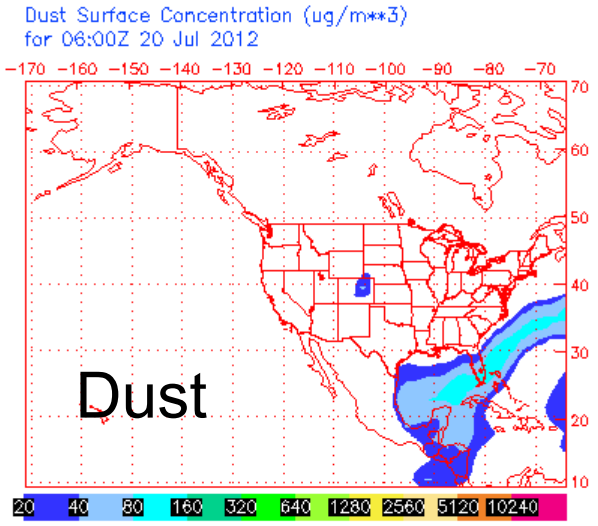


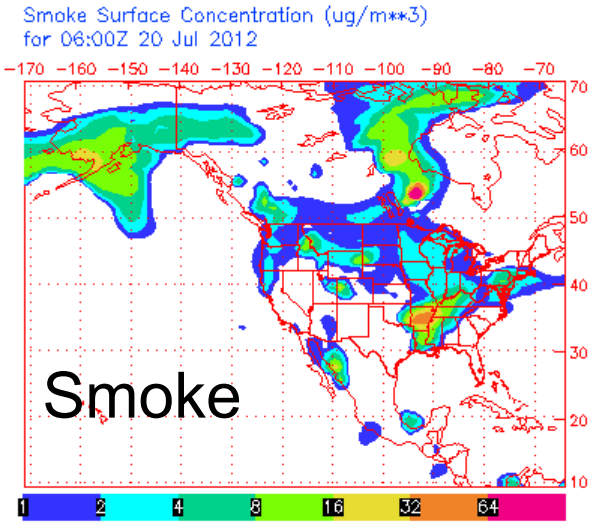
Sun Jul 1 03:55:38 2012 UTC NRL/Monterey Aerosol Modeling

NAAPS Dust Simulations: Transport of Saharan Dust to Texas 20-24 July 2012





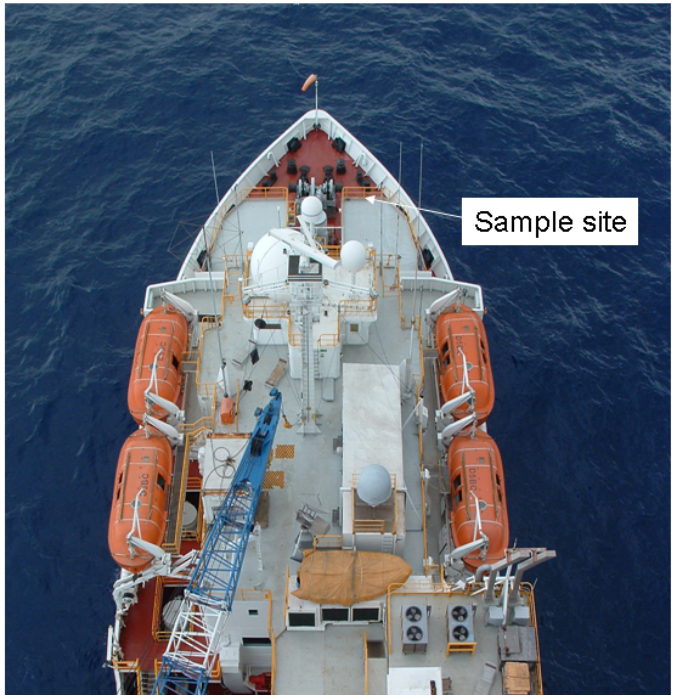


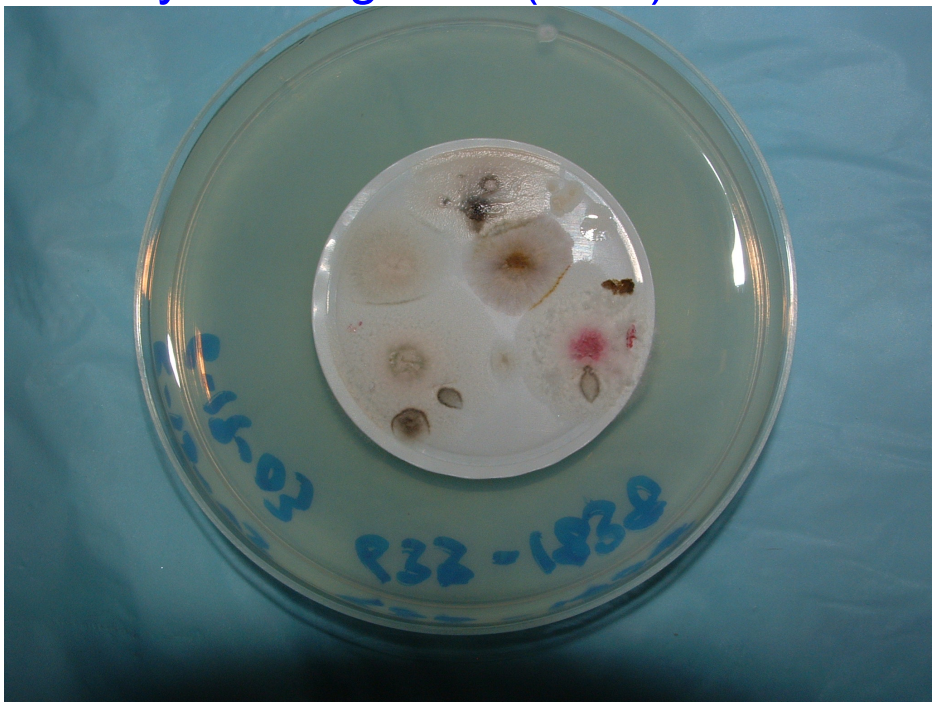


Fri Jul 20 15:55:55 2012 UTC NRL/Monterey Aerosol Modeling

NAAPS Dust Simulations: Transport of Dust-borne Microorganisms from Africa to the Caribbean

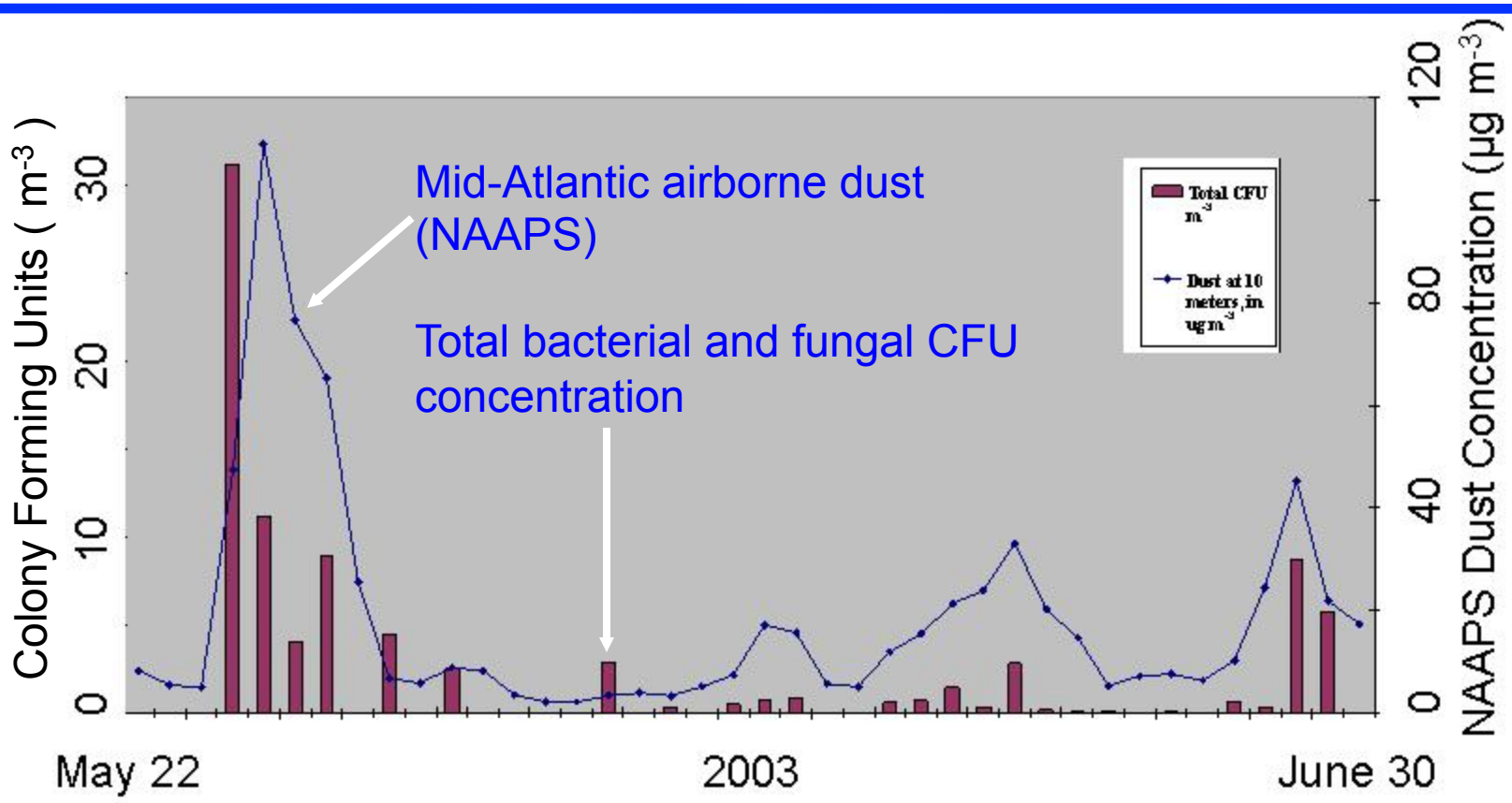
- Can culturable populations be detected at a mid-ocean site?
- Approach: Samples taken from 22 May to 30 June, 2003 aboard JOIDES *Resolution* during Ocean Drilling Program (ODP) Leg 209, 15°N, 45°W
- Daily air samples collected and incubated for 3-6 days to test for presence of bacterial and fungal colony-forming units (CFU)





2006, D. W. Griffin, D. L. Westphal, and M. A. Gray, Airborne microorganisms and African desert dust over the mid-Atlantic ridge, Ocean Drilling Program, Leg 209, *Aerobiologia*, doi 10.1007/s10453-006-9033-z.

NAAPS Dust Simulations: Transport of Dust-borne Microorganisms from Africa to the Caribbean



⇨Evidence of survival and transport of microorganisms from N. Africa to the mid-Atlantic

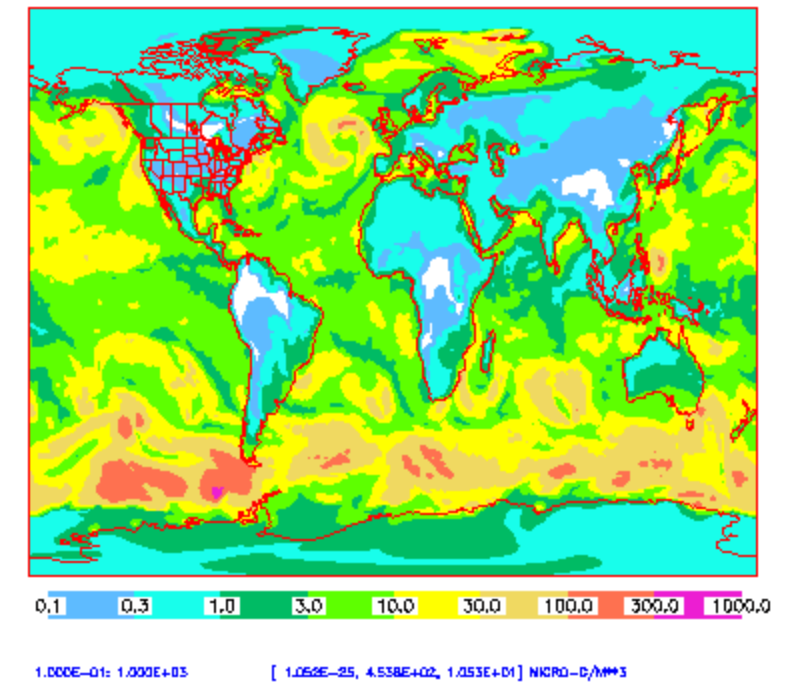
⇨Demonstrates value of models in studies of global transport of microorganisms (including pathogenic)

Sea Salt in NAAPS

Sea salt in NAAPS

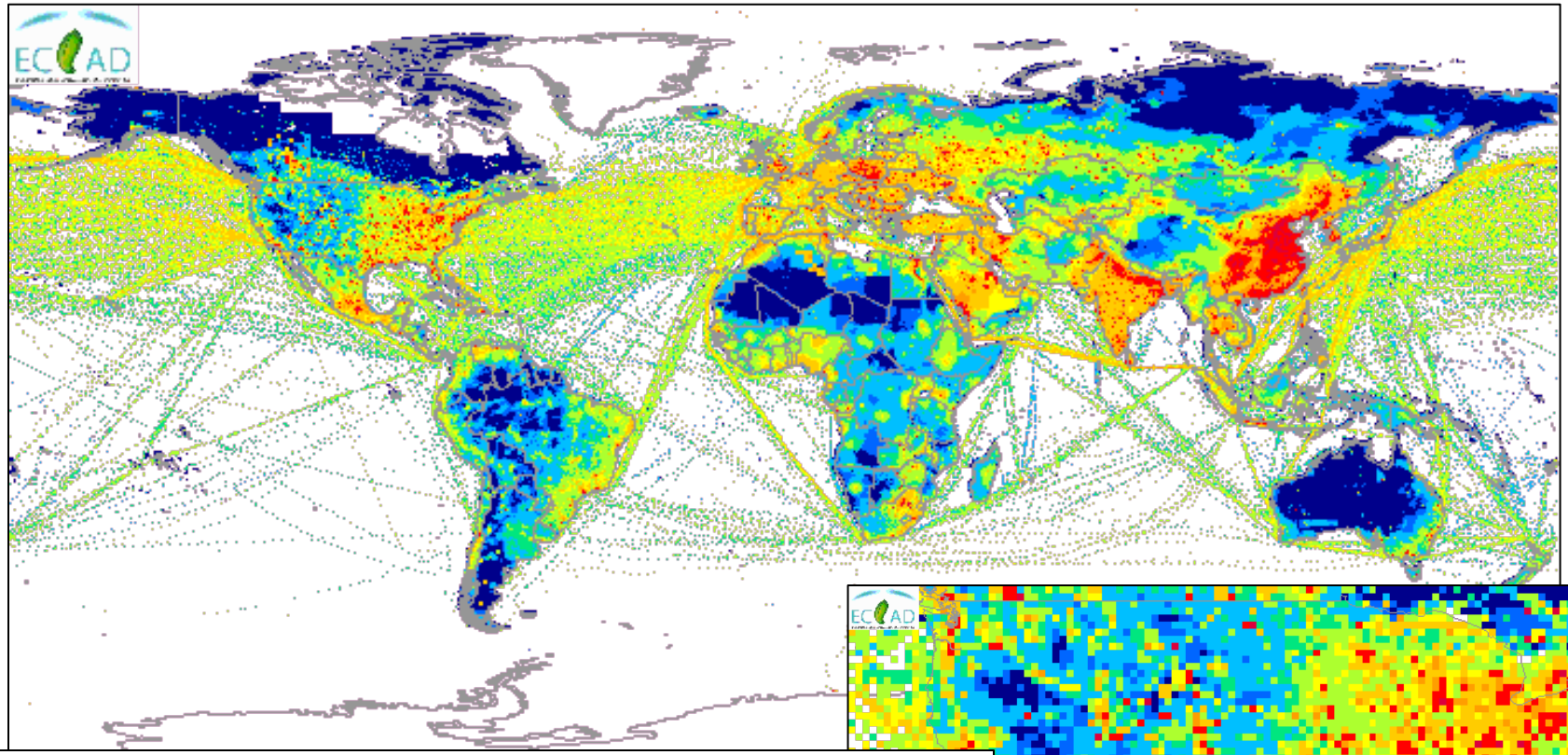
- Emission from the water's surface function of wind speed
- Vertical and horizontal advection and diffusion
- Dry and wet deposition
- Gravitational sedimentation

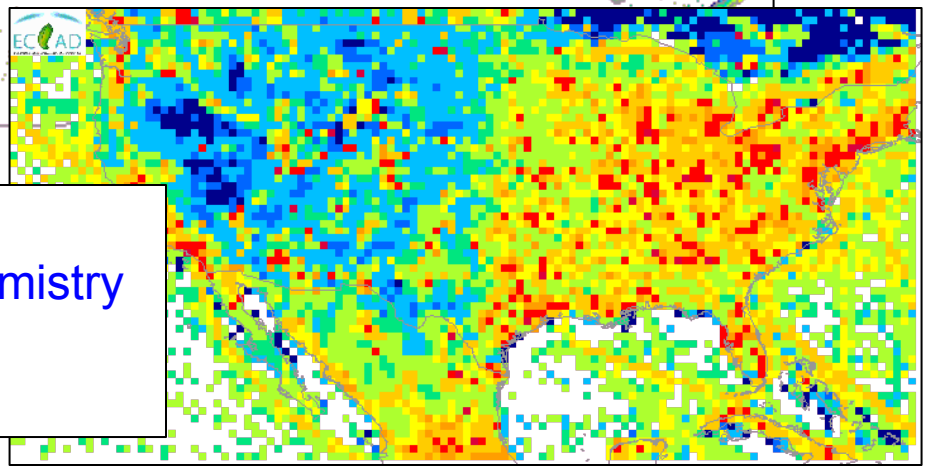
Forecasted Sea Salt Concentration at surface, May 10-15, 2006



Sulfate in NAAPS

MACCity Sulfur Dioxide Emissions (1/2 degree resolution), January 2010





SO2 and DMS emissions
Conversion to sulfate via simple linear chemistry
Removal via dry and wet deposition
Addition of POA and SOA in progress

Smoke in NAAPS

FLAMBE: Fire Locating and Modeling of Burning Emissions

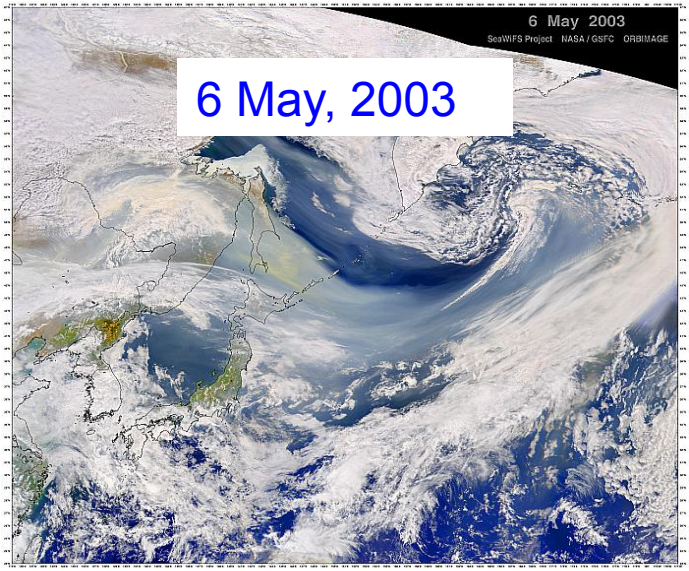
Input: GOES, MODIS

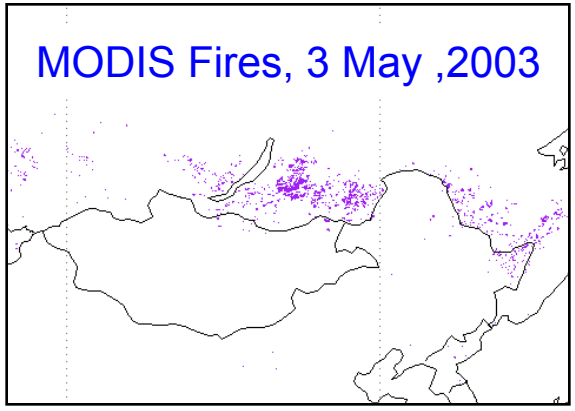
Output:

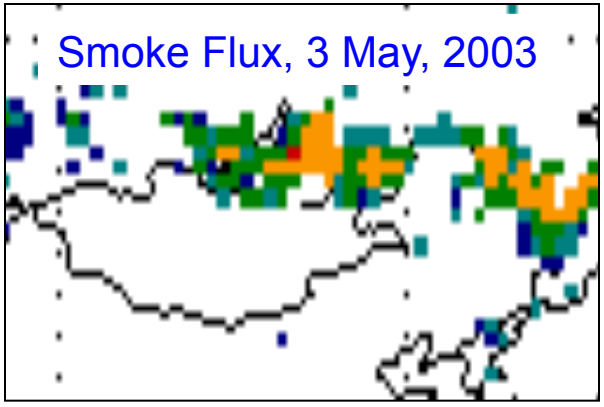
Fire parameters: Location (lat, lon)
Smoke flux, g m^{-2} s^{-1}

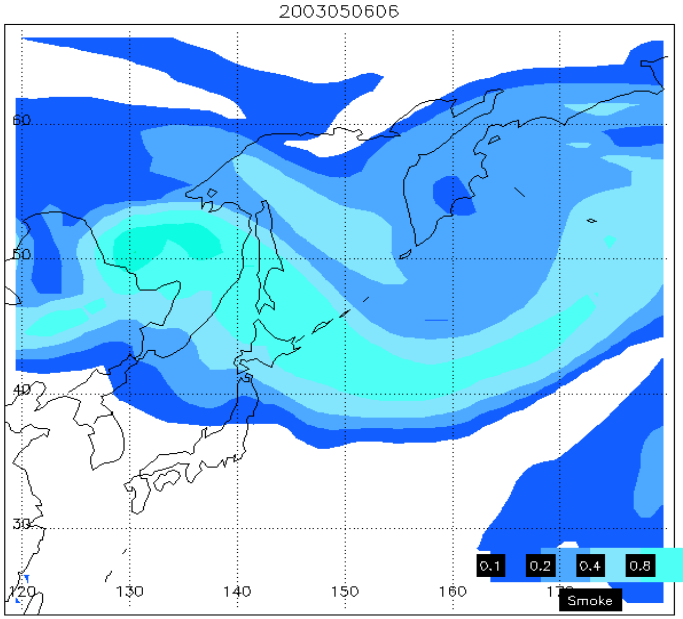
Horizontal res.: GOES: 4 km; MODIS: 1 km

Temporal res.: GOES: 30 min., MODIS: 2X Day



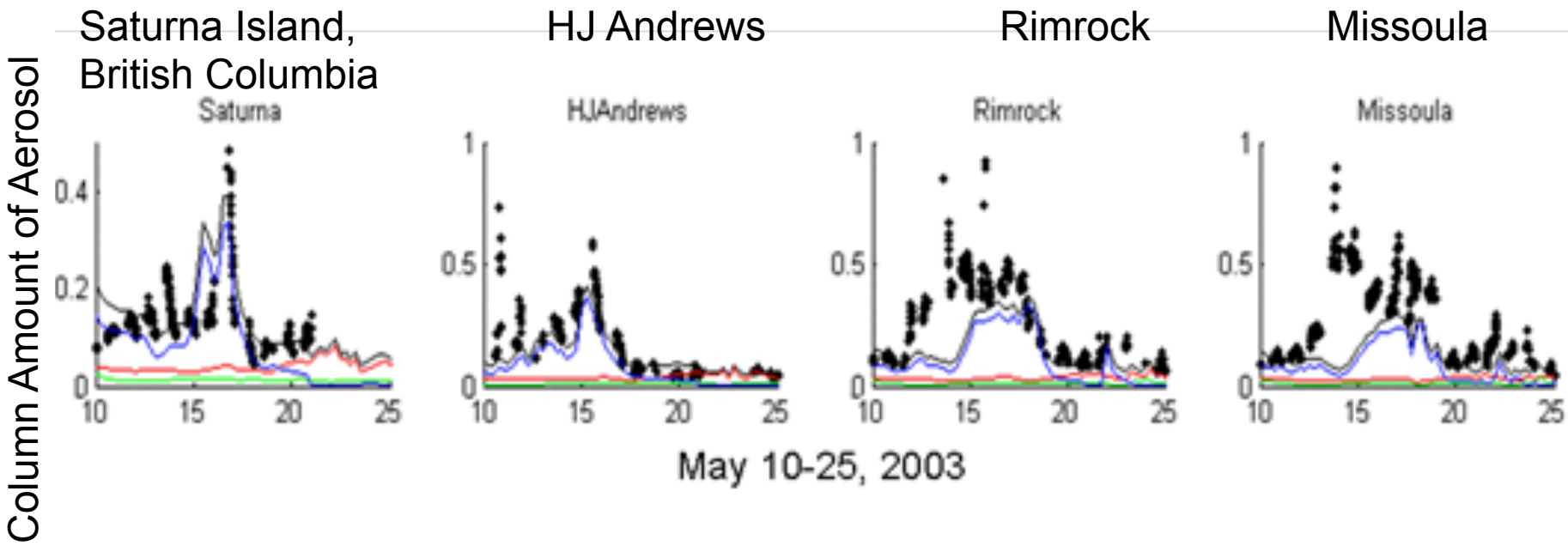






2004, Reid, J. S., E. M. Prins, D. L. Westphal, C. C. Schmidt, K. A. Richardson, S. A. Christopher, T. F. Eck, E. A. Reid, C. A. Curtis, and J. P. Hoffman: Real-time monitoring of South American smoke particle emissions and transport using a coupled remote sensing/box-model approach, Geophys. Res. Lett., 31, L06107, doi: 10.1029/2003GL018845.

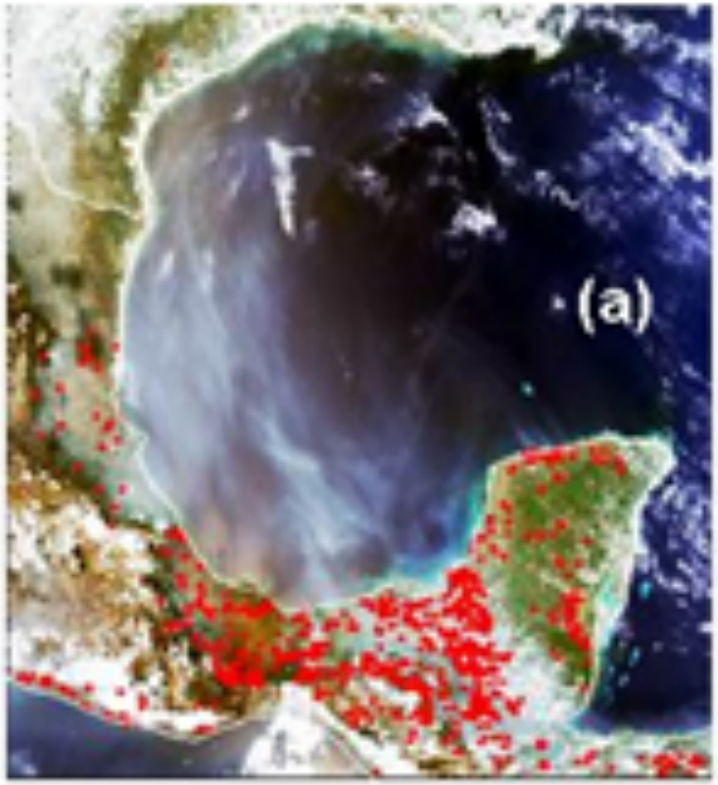
NAAPS Siberian Smoke Simulation, May 2003

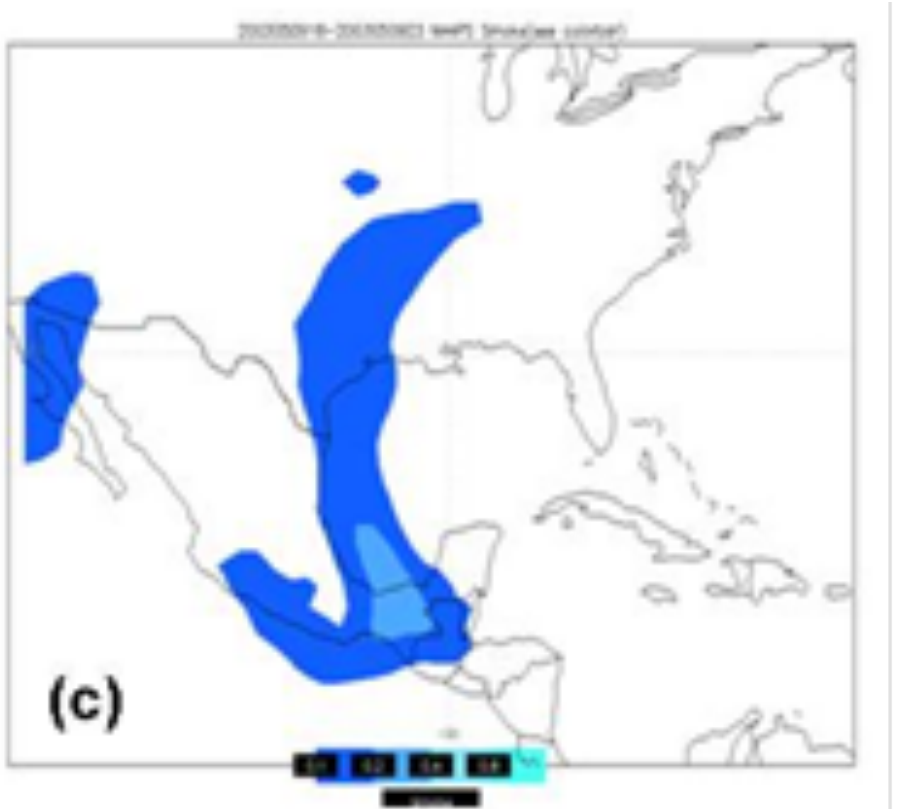


Black symbols – Observations Black solid line – Simulation

Comparison of NAAPS smoke Aerosol Optical Depth (blue lines) and AERONET AOD (diamonds) for several sites in N. America for 10-25 May, 2003 while under the influence of the Siberian Smoke Plume shown in Figure 5, (O'Neill, personal communication, 2003.)

NAAPS Central America Smoke Simulation, May 2003

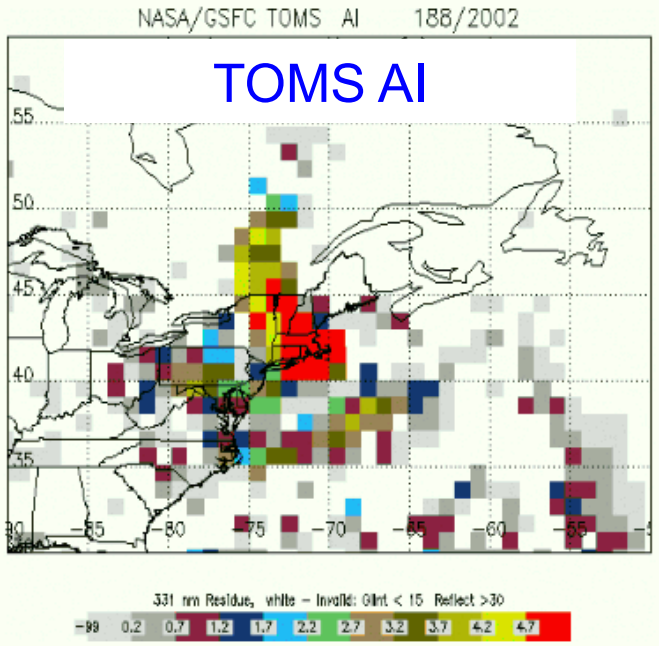


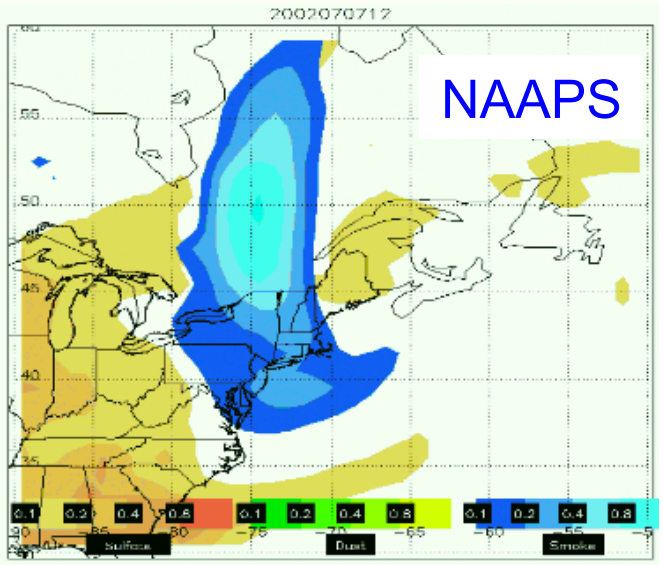


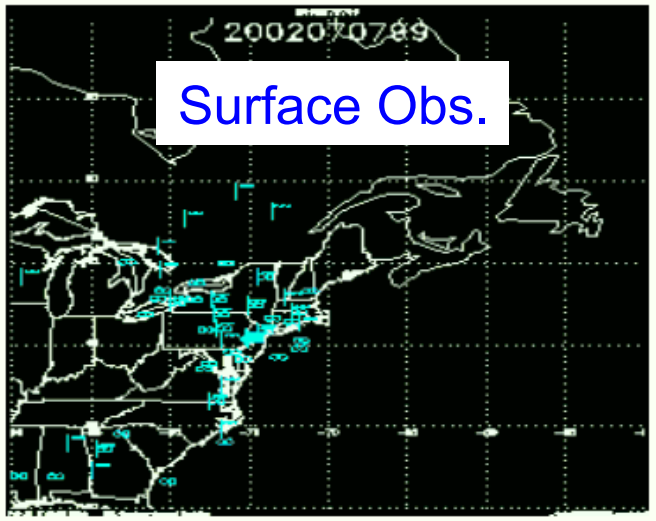
Left: MODIS/Terra true color image on May 9, 2003. Red dots are MODIS-detected fires.

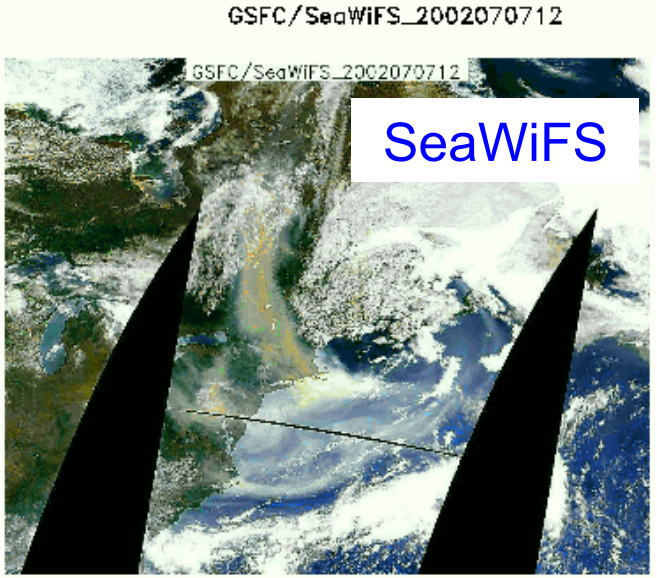
Right: NAAPS AOD simulation for 1800 GMT May 9, 2003, contoured at 0.1 and 0.2 AOD.

NAAPS Quebec Smoke Simulation, July 7, 2002





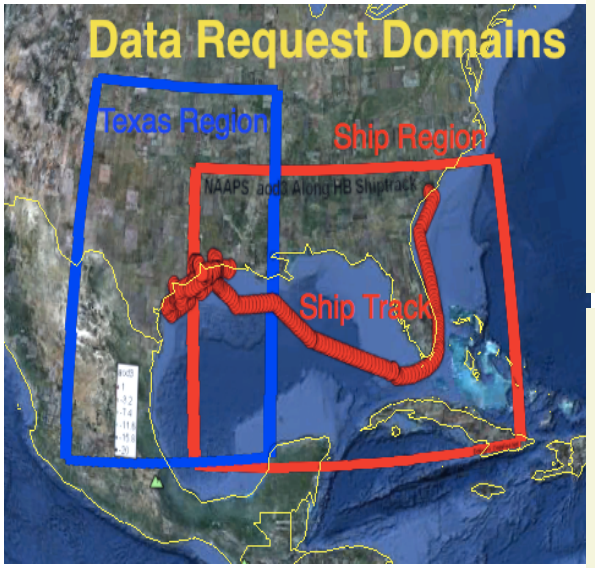


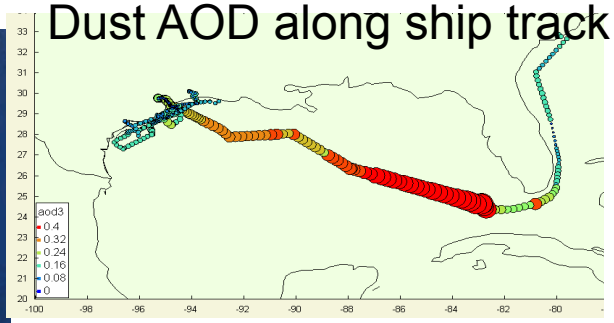


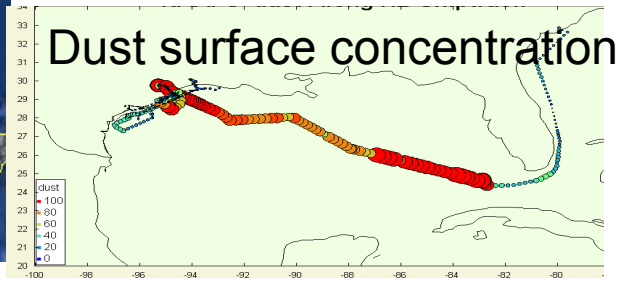
Validation of NAAPS forecast with satellite and surface observations for Quebec fires of 2002

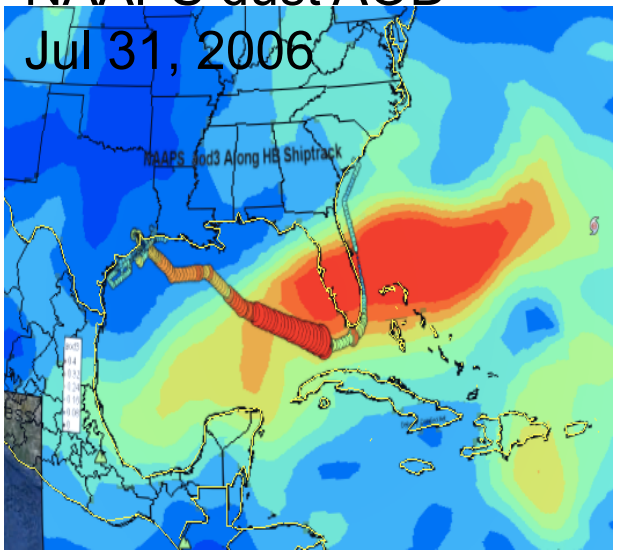
NAAPS Data Delivery Case: Sahara Dust Impact on Texas Air Quality, 2006

1. A NOAA-TCEQ project used LRT (NAAPS) for their analysis
2. NOAA data request forwarded to the NAAPS data archive at DataFed
3. The data are extracted and delivered as standard format files









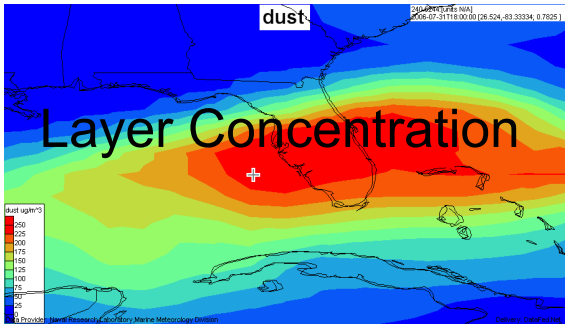
Dust surface concentration, vert. profile, AOD along the research ship track

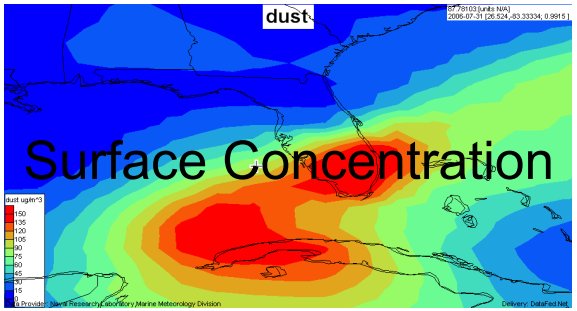
Gridded 4D NAAPS for TX-Mex and the ship track regions, May-Sep 2006

NAAPS Data Delivery Case: Sahara Dust Impact on Texas Air Quality, 2006

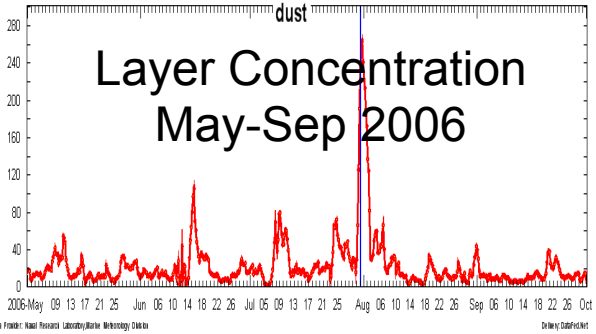
In DataFed, NAAPS data can be extracted along multiple dimensions

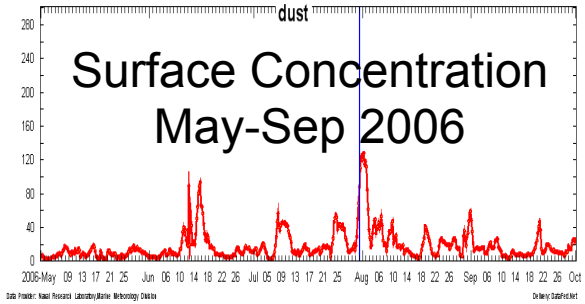
Spatial pattern at specified height, time





Time series at given height and location





The data extraction domain is defined by the DataFed GUI interface
Based on the data extraction, the 4D pattern can be explored
The user can then combine the NAAPS data subset with other data

Summary

1. The NAAPS operational multi-species model with data assimilation makes extensive use of NASA data.
2. NAAPS analyses are distributed via the existing DSS DataFed on a daily basis.
3. NAAPS data have been delivered to AQ analysts and forecasters for quantifying impact of LRT to CONUS.
4. Successfully tested as evidence for several exceptional smoke and dust events.

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NAAPS Aerosol Analyses and Forecasts for Air Quality Applications

END

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