



IDEA

Infusing satellite
Data into
Environmental
Applications



Use of MODIS Satellite Observations in "Near Real Time" to Improve Forecasts of Fine Particulate Matter (PM_{2.5}) An Experimental Forecast Tool

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National Air Quality Conference
Baltimore, MD
24 February 2004

Acknowledgement:

Material for this Presentation is from Two Talks Recently
Given at the American Meteorological Society 84th
Annual Meeting in Seattle (12 January 2004)

1.2 Utilizing MODIS Satellite Observations in Near-Real Time to Improve AIRNow Next Day Forecast of Fine Particulate Matter, PM_{2.5}

James Szykman, John White, Brad Pierce, Jassim Al-Saadi, Doreen Neil,
Chieko Kittaka, Allen Chu, Lorraine Remer, Liam Gumley, and Elaine Prins

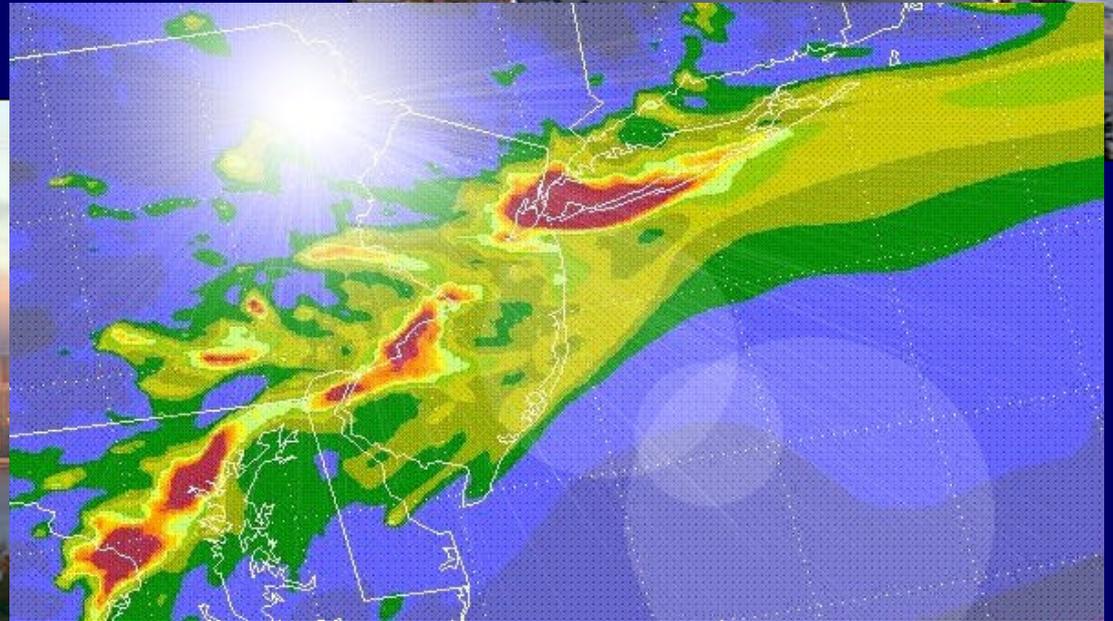
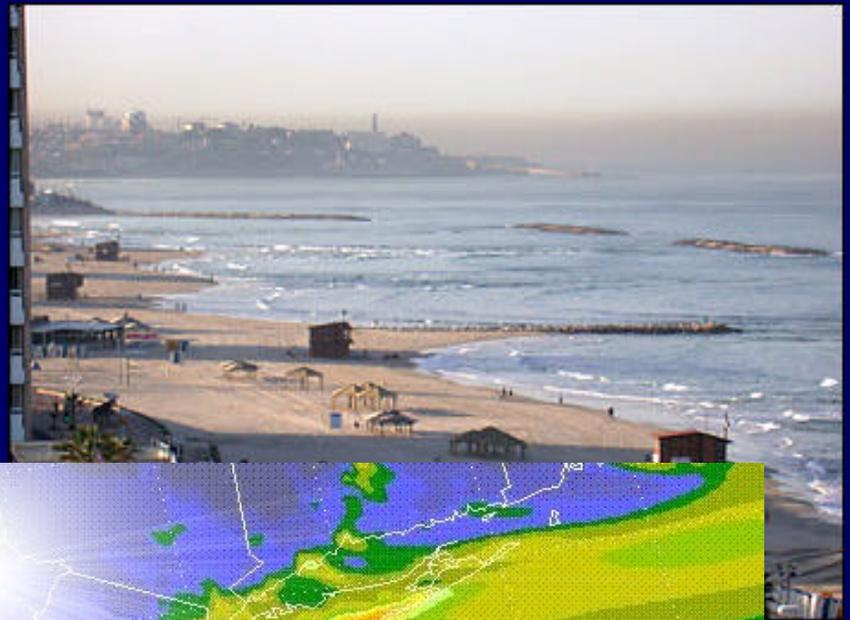
1.3 UTILIZING MODIS SATELLITE OBSERVATIONS TO MONITOR AND ANALYZE FINE PARTICULATE MATTER (PM_{2.5}) TRANSPORT EVENT

Chieko Kittaka, James Szykman, Brad Pierce, Jassim Al-Saadi, Doreen Neil, Allen Chu,
Lorraine Remer, Elaine Prins, John Holdzkom

Both Papers Available Electronically at:

http://ams.confex.com/ams/84Annual/techprogram/programexpanded_190.htm

IDEA: NASA-EPA-NOAA partnership to improve air quality assessment, management, and prediction by infusing (NASA) satellite measurements into (EPA, NOAA) analyses for public benefit.



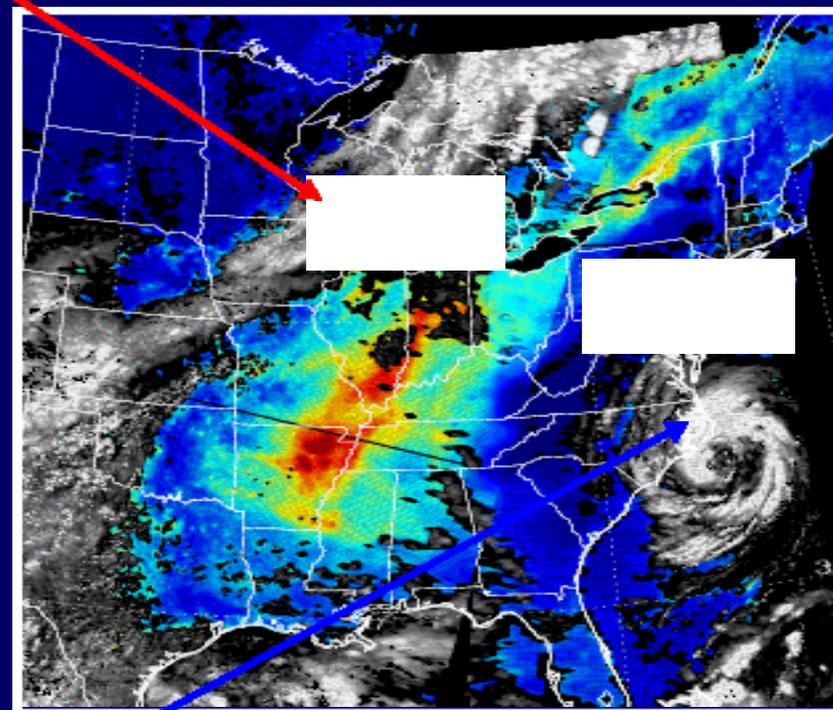
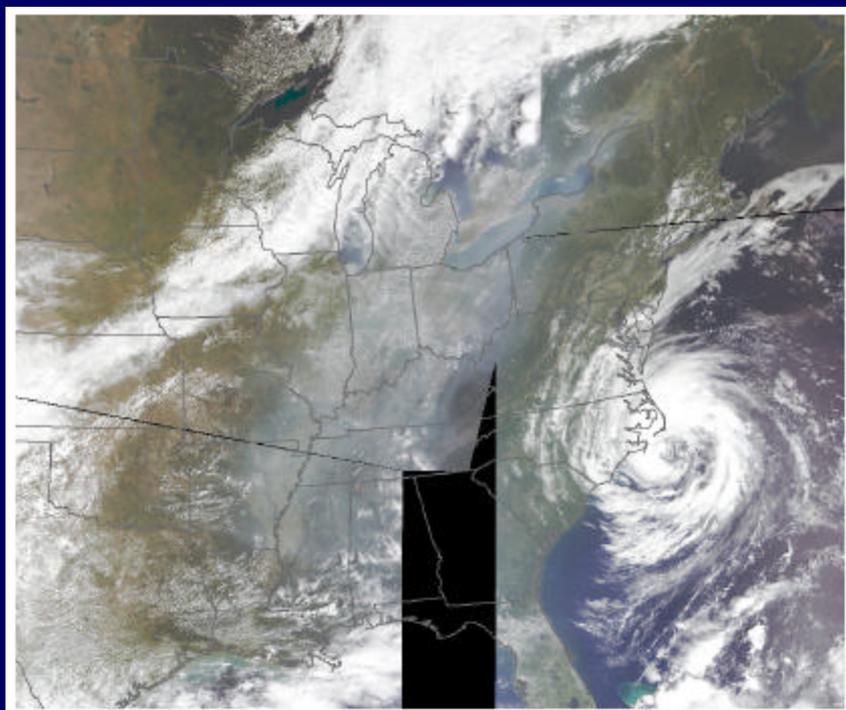
IDEA (Infusing satellite data into environmental air quality applications)

Part of NASA Earth Science Enterprise (ESE) Applications Program strategy to demonstrate practical uses of NASA sponsored observations from remote sensing systems and predictions from scientific research.

Visible Image vs. Atmospheric Retrieval

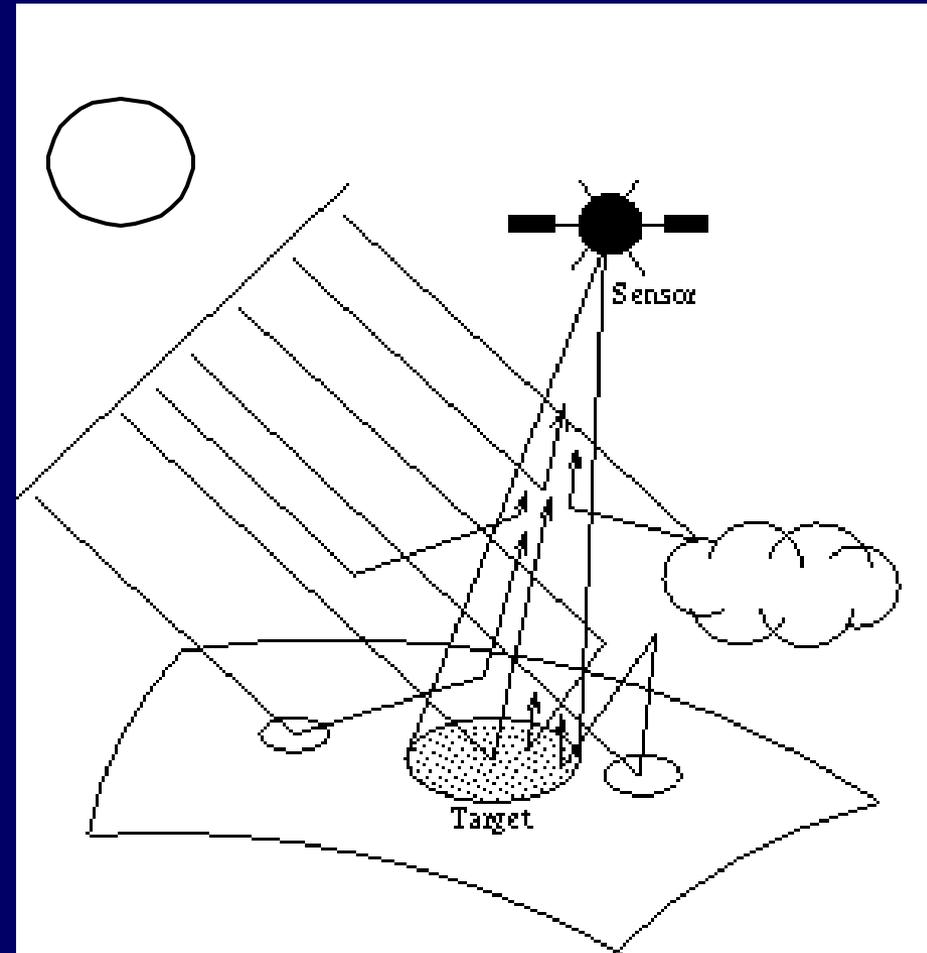
MODIS Sensor - Sept. 10, 2002

« Turning the Image into a Chemical Weather Map for Aerosols »



What the Sensor Signal Measures

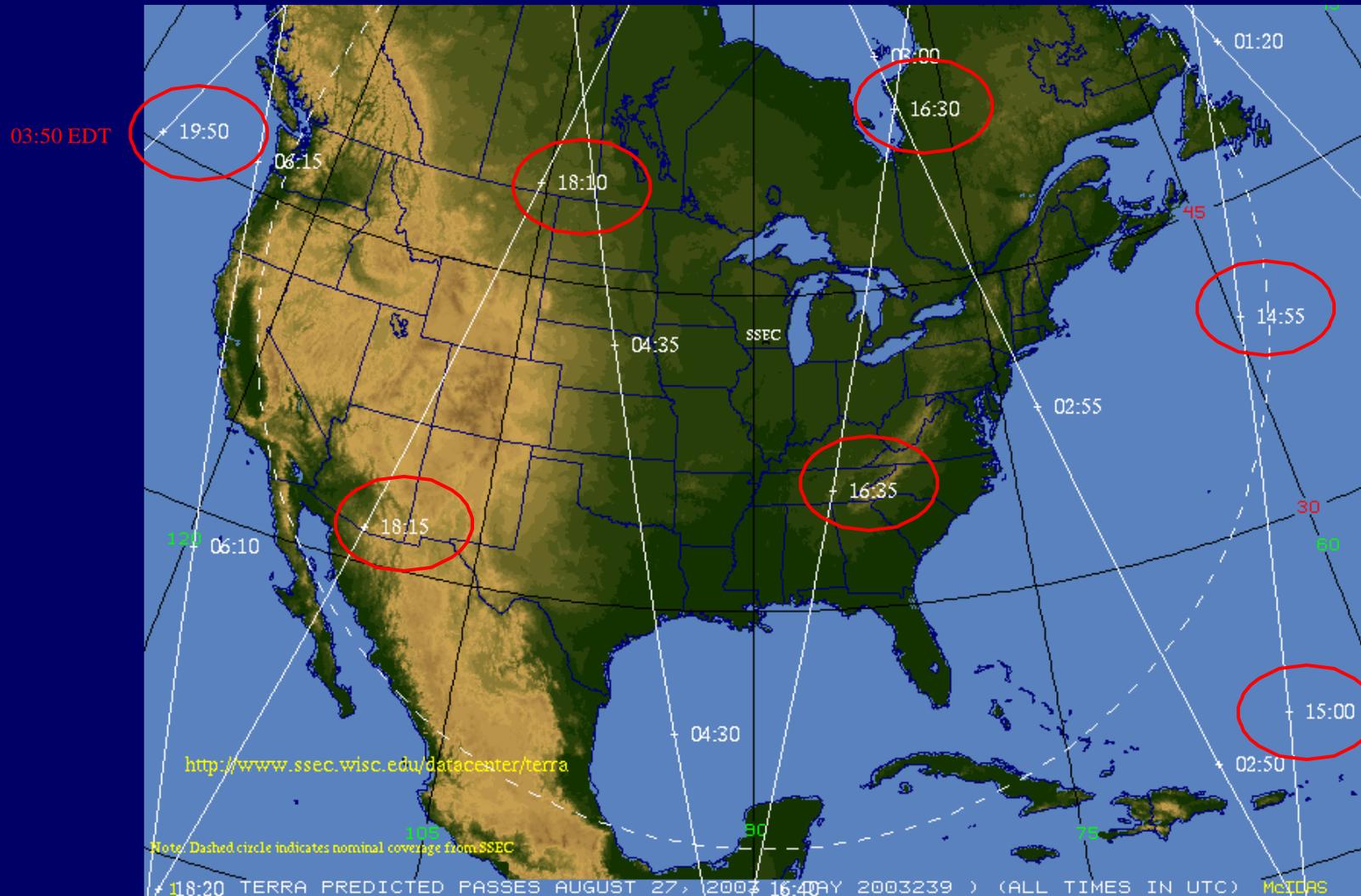
- The MODIS sensor measures solar radiation at different wavelengths and provides a derived column integrated aerosol optical depth.
- The sensor measurement does not provide direct data on the vertical profile of aerosols.
- Integration with meteorological data and ground aerosol measurements can help provide the proper context for the AOD data, making it useful for forecasting.



Some Details of MODIS $\hat{\sigma}_a$

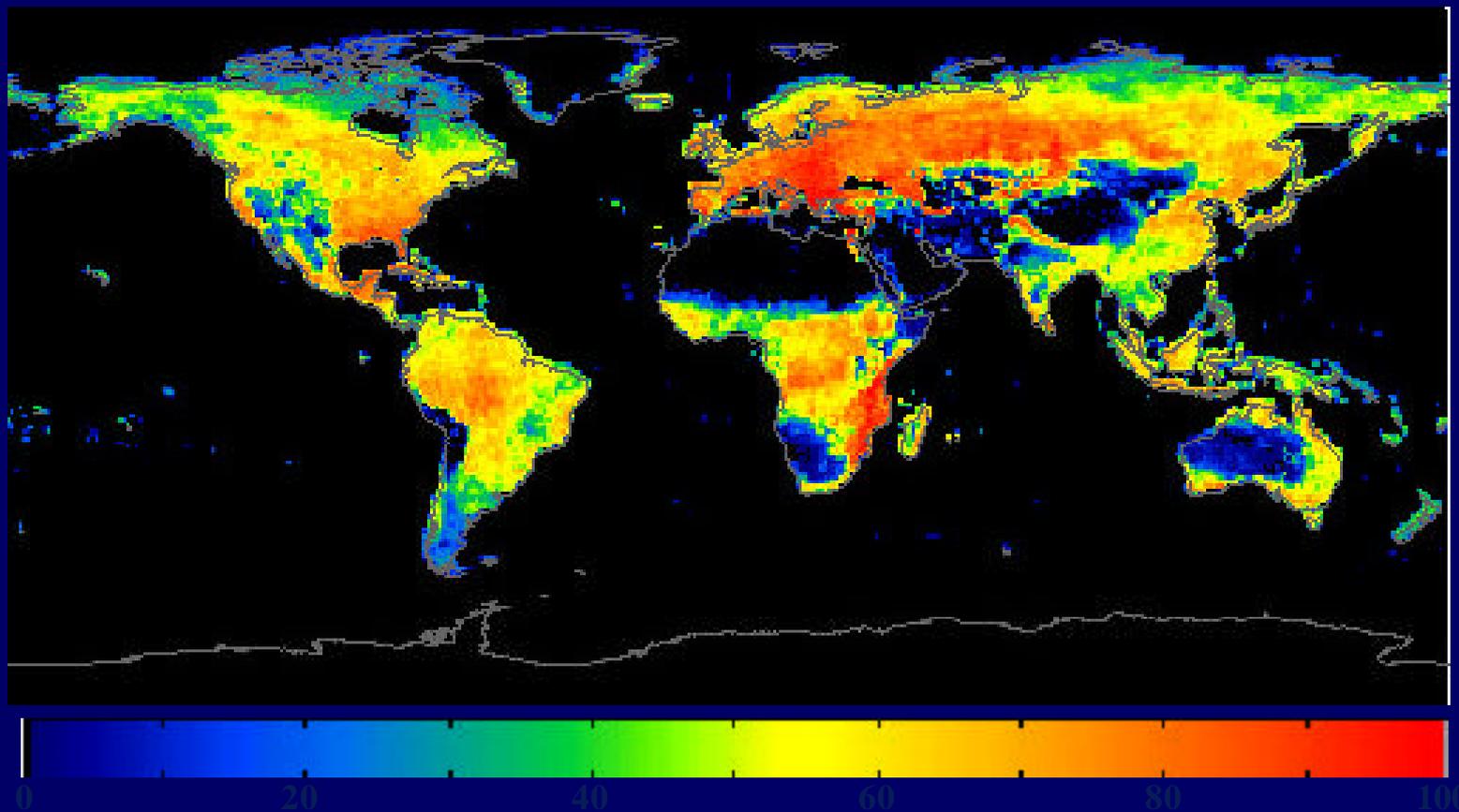
- Current spatial resolution of pixels - 10 km x 10 km
- Different algorithms are used to determine $\hat{\sigma}_a$ over land and ocean.
 - $\hat{\sigma}_a$ over land are accurate to within their calculated uncertainties $\pm 0.05 \pm 0.20 * \tau$ (Chu et al., 2002).
 - $\hat{\sigma}_a$ over ocean are accurate to within their calculated uncertainties $\pm 0.03 \pm 0.05 * \tau$ (Remer et al., 2002)

MODIS (Terra Satellite) Overpass Time 27 August 2003



Source: University of Wisconsin-Madison Space Science and Engineering Center

Frequency of Aerosol Retrievals



Fraction of Aerosol Retrievals for 150 days

Source: NASA/GSFC King et al., 2002



NASA MODIS - EPA AIRNow Data Fusion Demonstration

Improving Air Quality Index (PM 2.5) Forecasting

What: Near-Real-Time Data Fusion of MODIS AOD and EPA AIRNow Data (Currently using NOAA Bent Pipe w/ transition to MODIS Direct Broadcast)

When: Late August through September 2003

Who: NASA LaRC and GSFC

CIMSS/SSEC Univ. Of Wisc.-Madison & NOAA/NESDIS/ORA

US EPA OAR/OAQPS

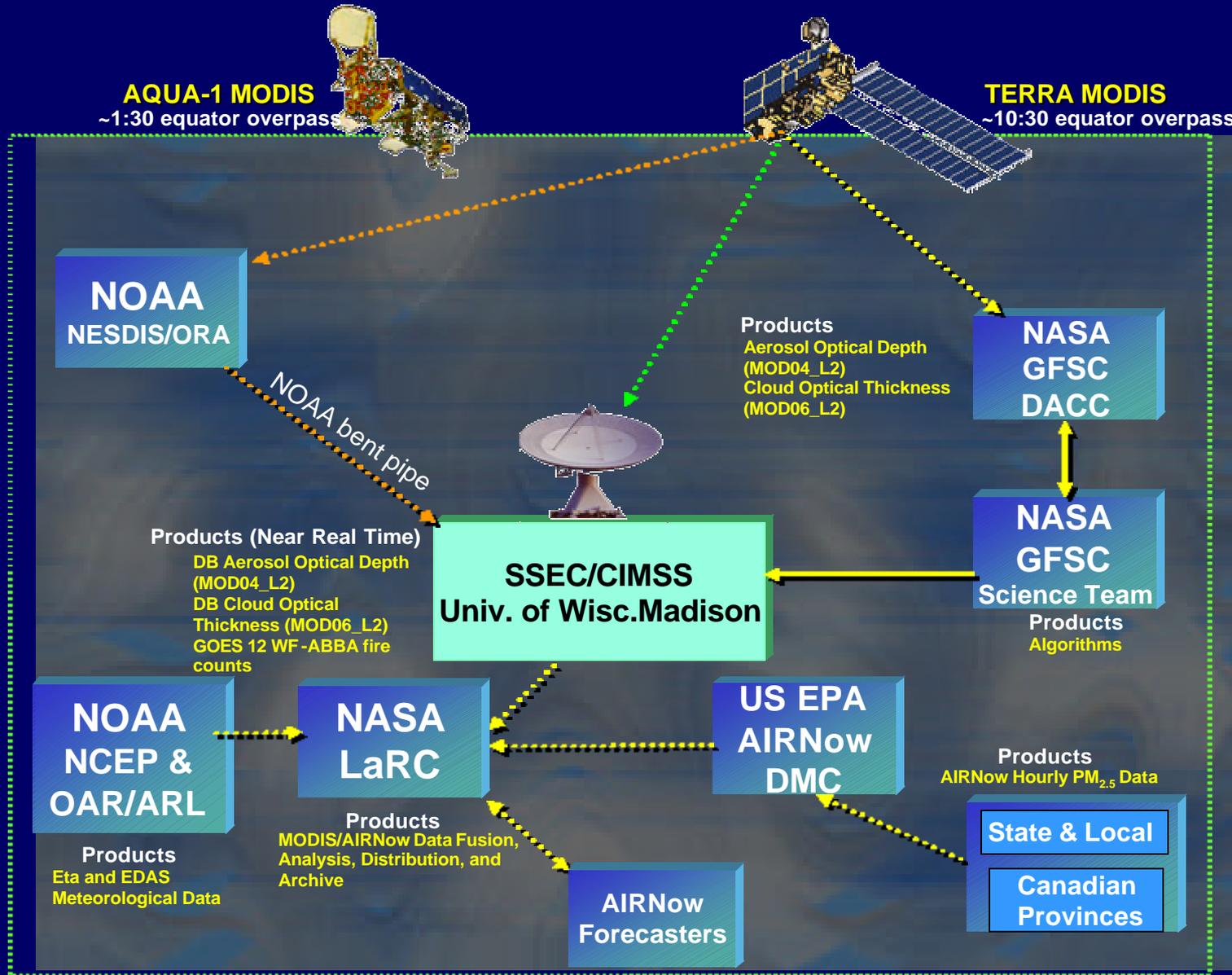
Select group of Air Quality Forecasters

Objective: Prototype a near-real-time product for Air Quality Forecasters

Goal: Improve accuracy of next day PM_{2.5} AQI forecast during large aerosol events

Prototype - US EPA AIRNow Use of MODIS Data

Not a Simple Straightforward Accomplishment

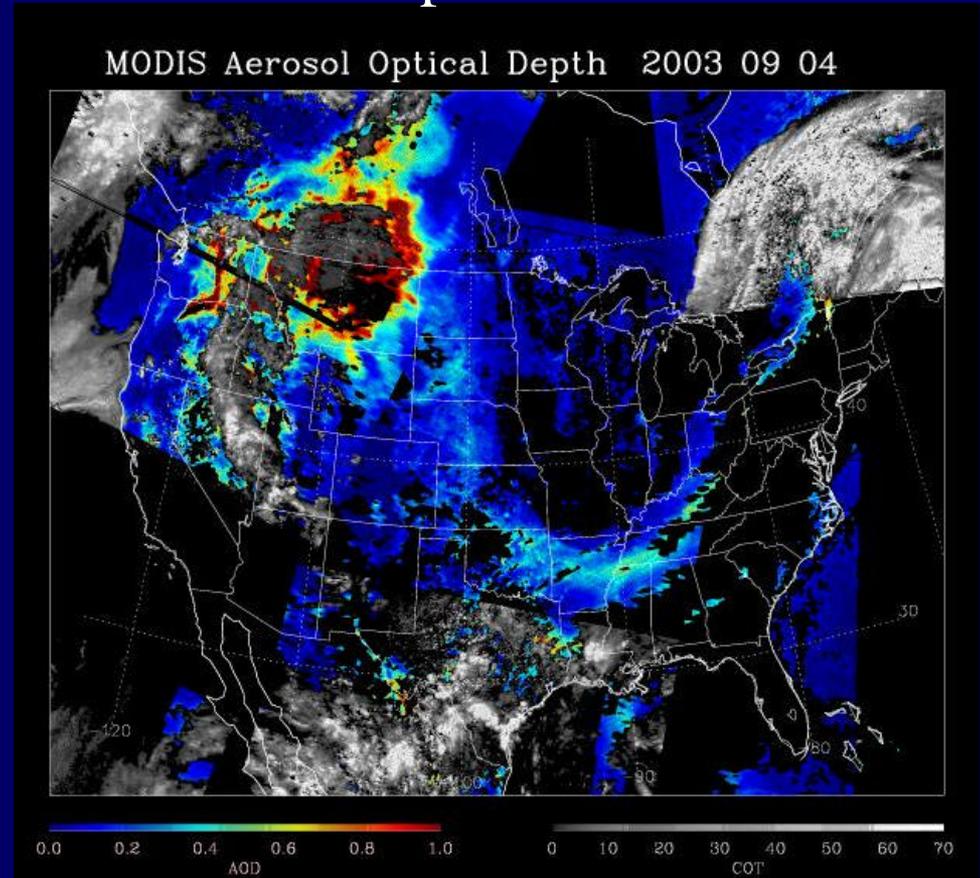


How Near-Real Time MODIS t_a Aids Forecast

04 September 2003

Provides a once daily, pseudo-synoptic view of aerosol loading across North America at a 10 km x 10 km spatial scale

- Regional transport influences
- Natural event influences
- Re-circulation influences



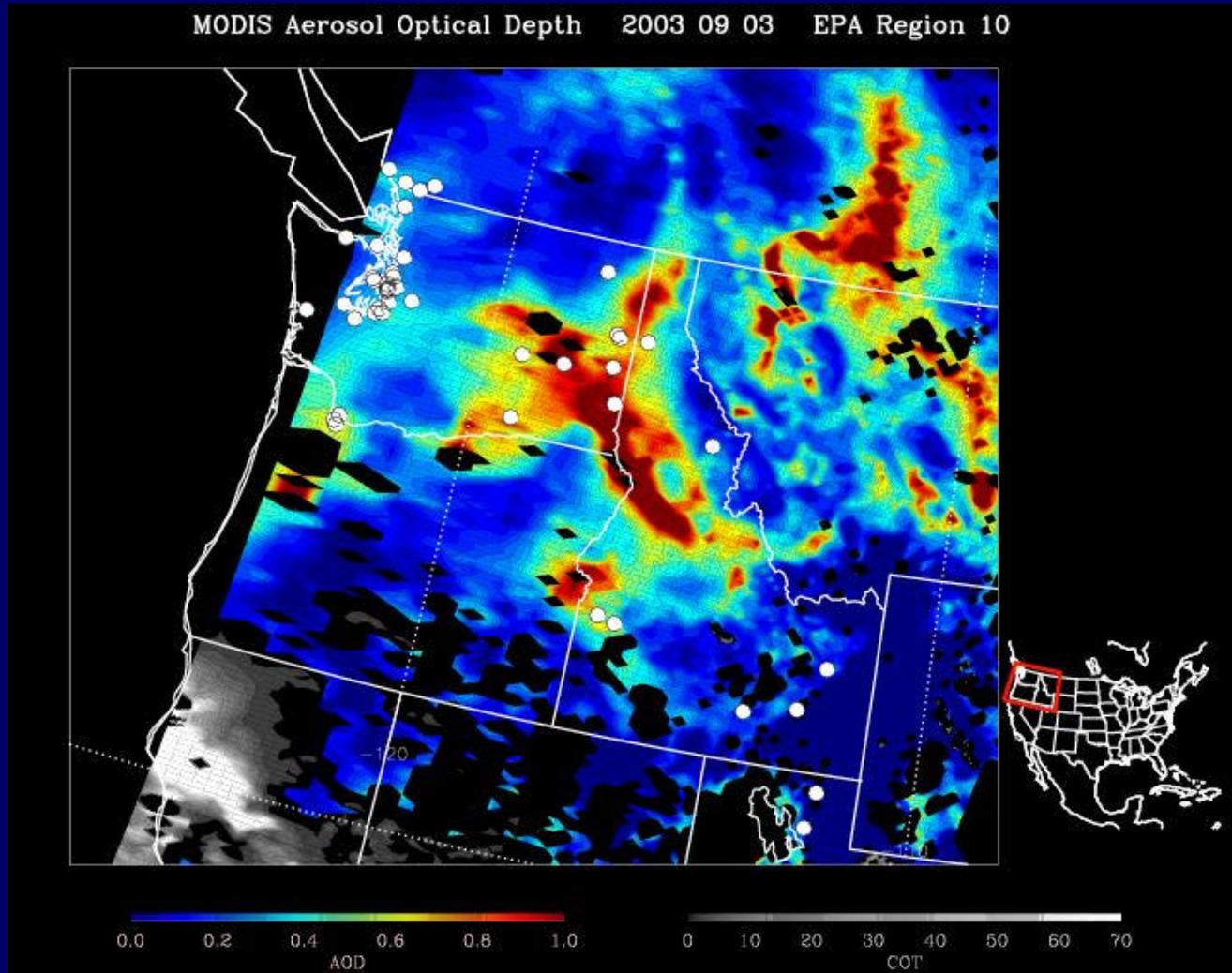
MODIS/AIRNow

Forecast Tool Products

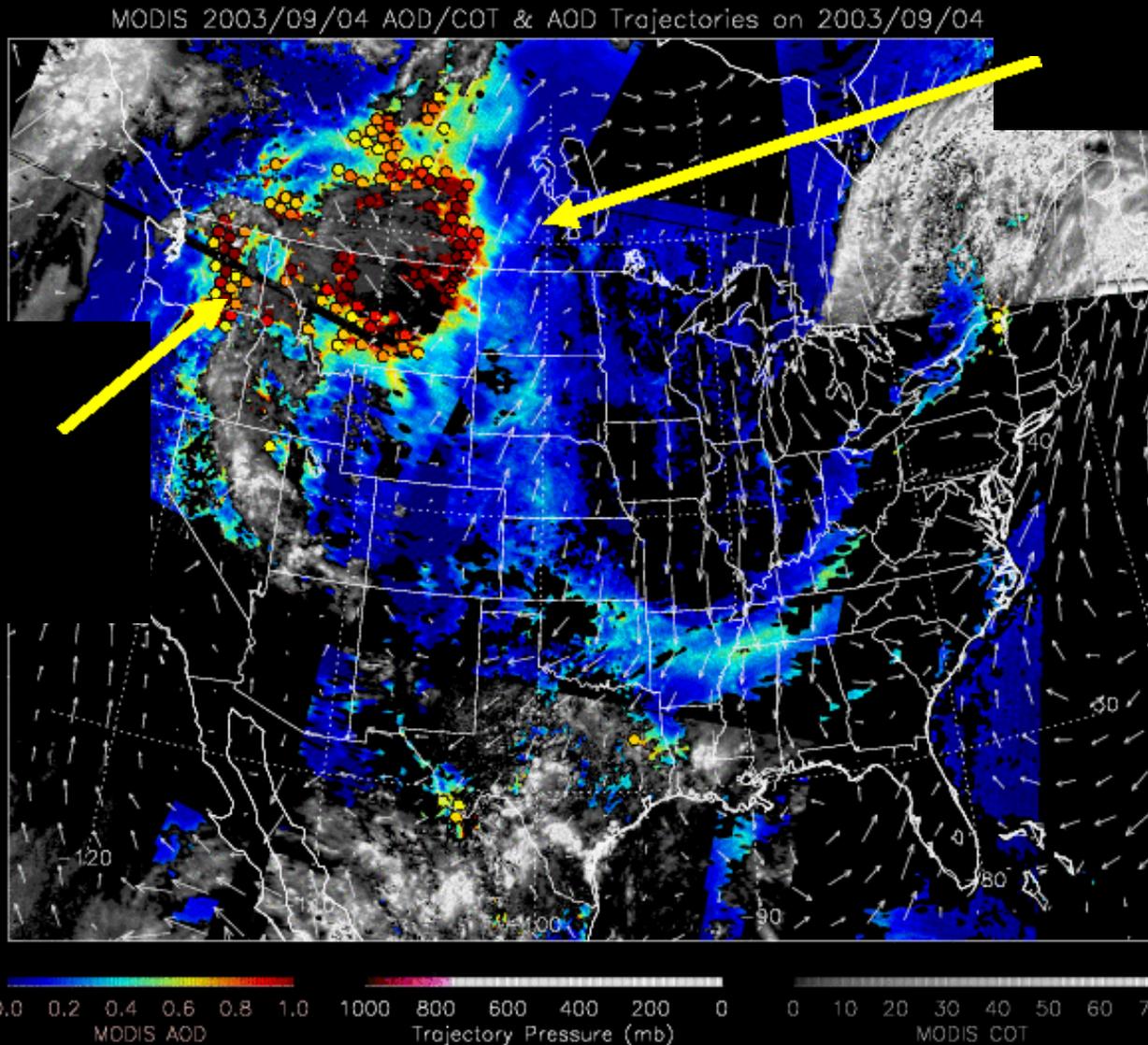
- Regional Summary Plots of MODIS Aerosol Optical Depth and Cloud Optical Thickness
- MODIS Aerosol Optical Depth 48 hour Air Parcel Forecast Trajectories Forecast
- Composite PM_{2.5}/MODIS Aerosol Optical Depth Data Fusion 3-day Animation
- Time-series between MODIS Aerosol Optical Depth and PM_{2.5} (1hr and 24hr) Mass Concentration
- National Correlation Map between PM_{2.5} and MODIS Aerosol Optical Depth

Regional Summary Plots of MODIS Aerosol Optical Depth and Cloud Optical Thickness

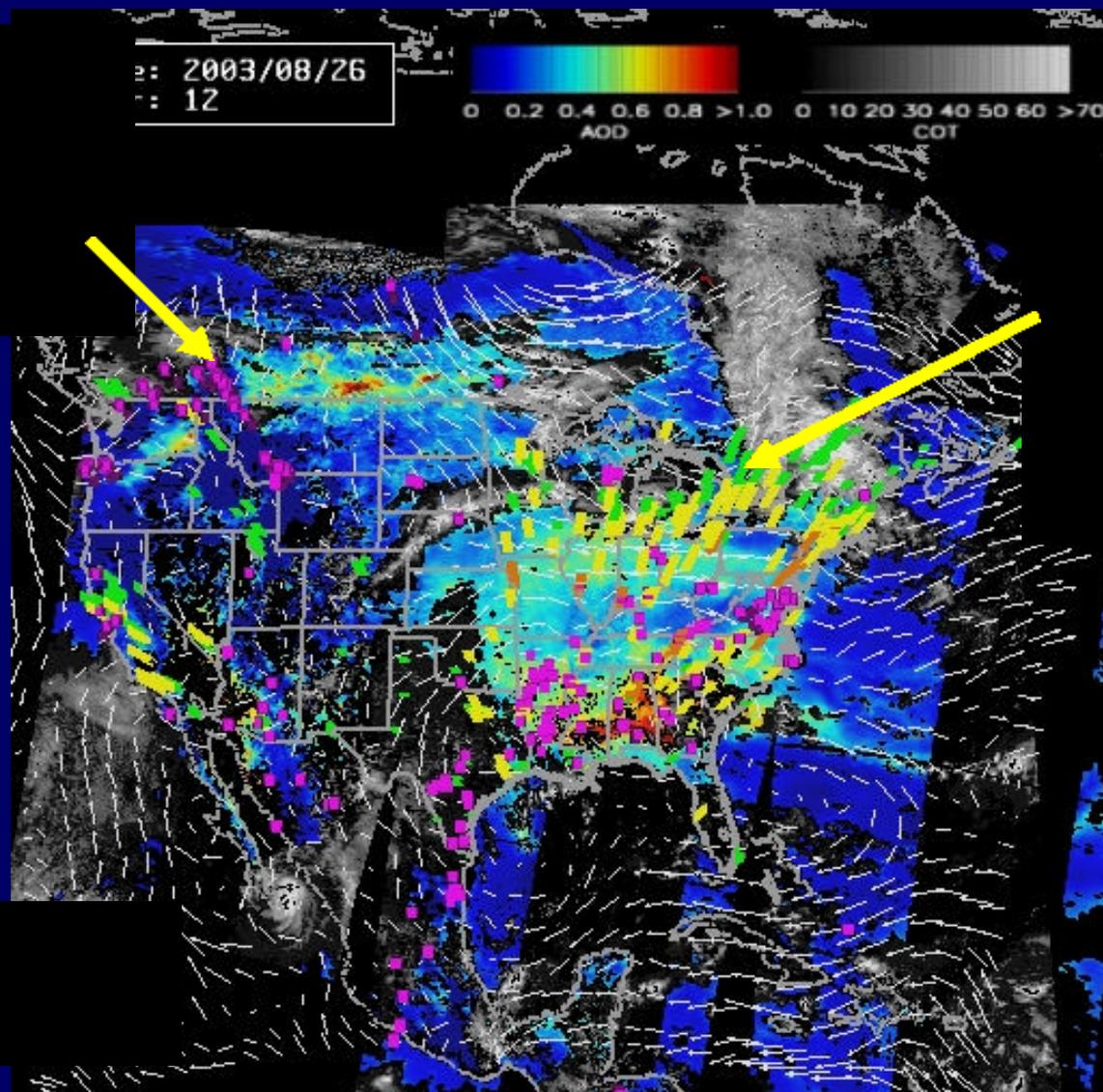
03 September 2003



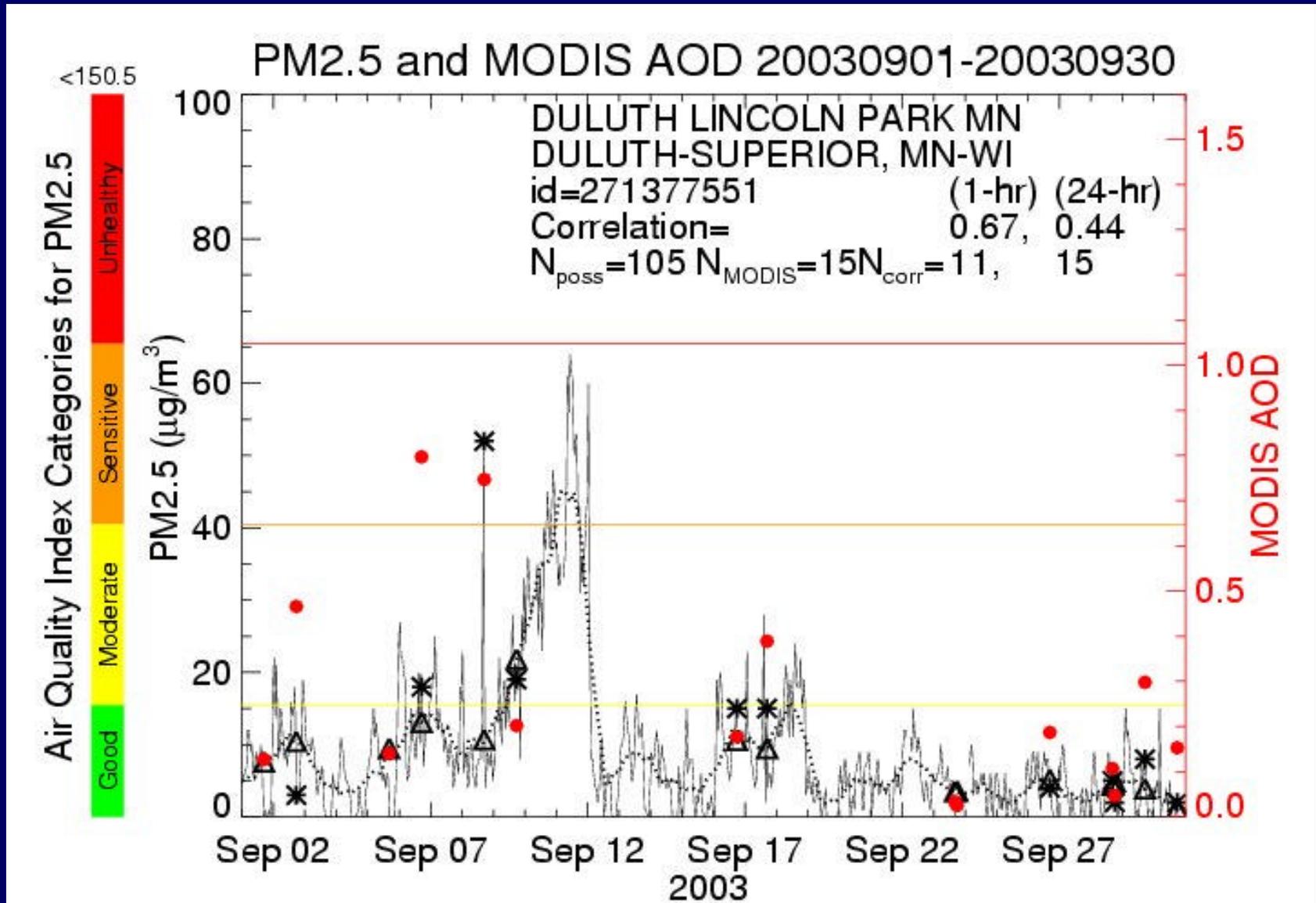
MODIS Aerosol Optical Depth 48 hour Air Parcel Forecast Trajectories (04 September 2003)



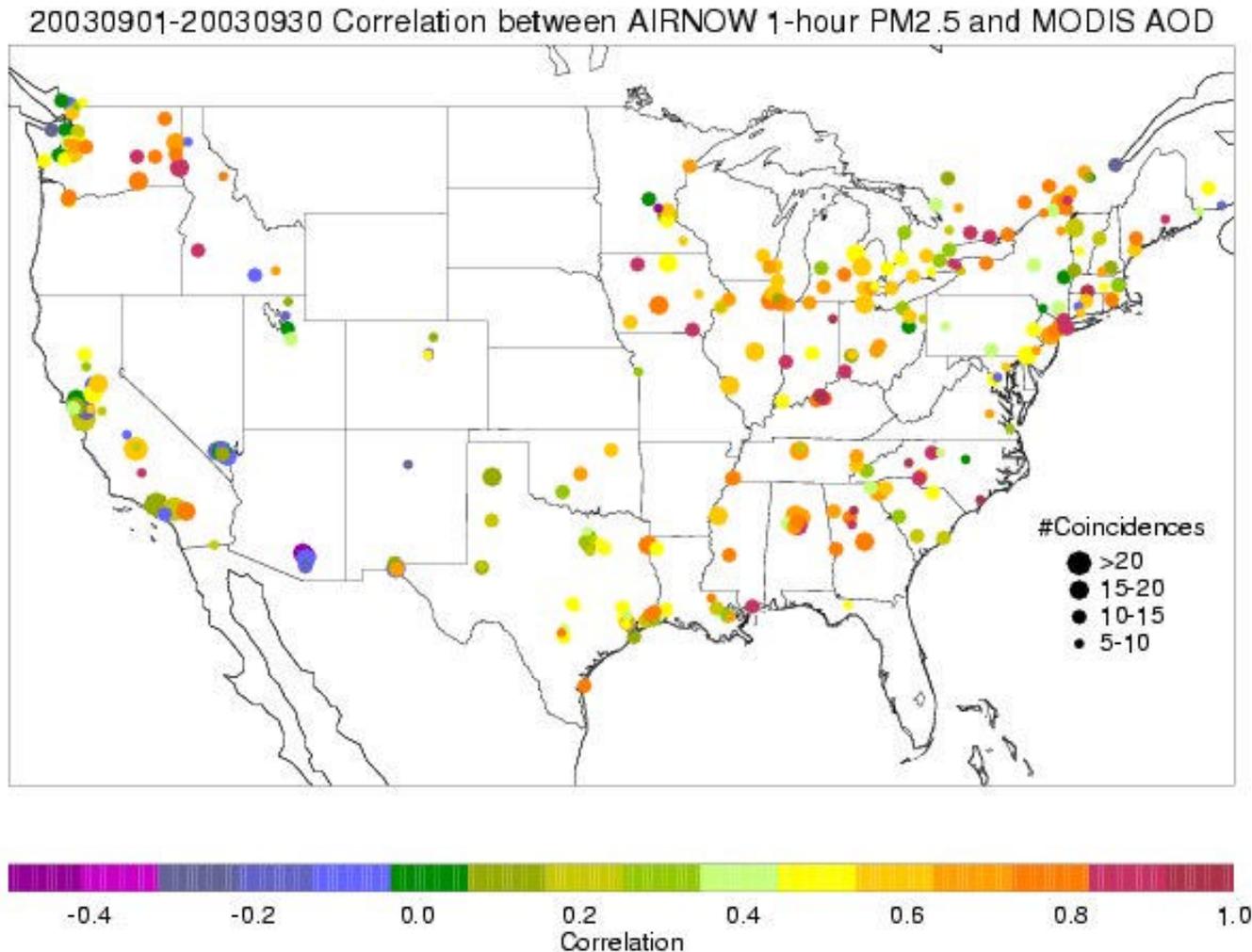
Composite PM2.5/MODIS Aerosol Optical Depth Data Fusion 3-day Animation



Time-series between MODIS Aerosol Optical Depth and PM2.5 (1hr and 24hr) Concentrations



National Correlation Map between PM2.5 Mass Concentration and MODIS Aerosol Optical Depth

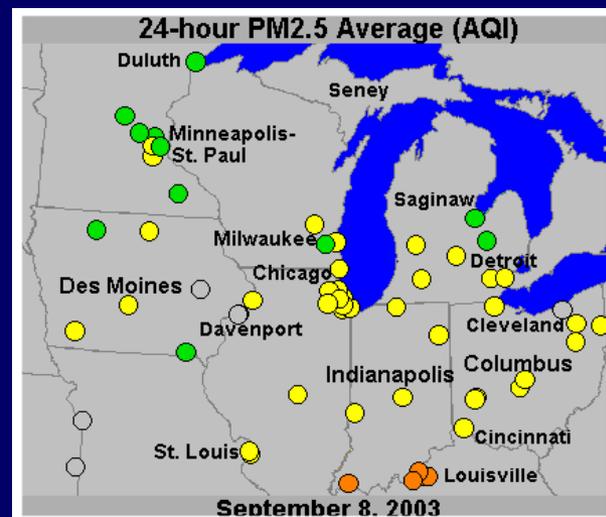
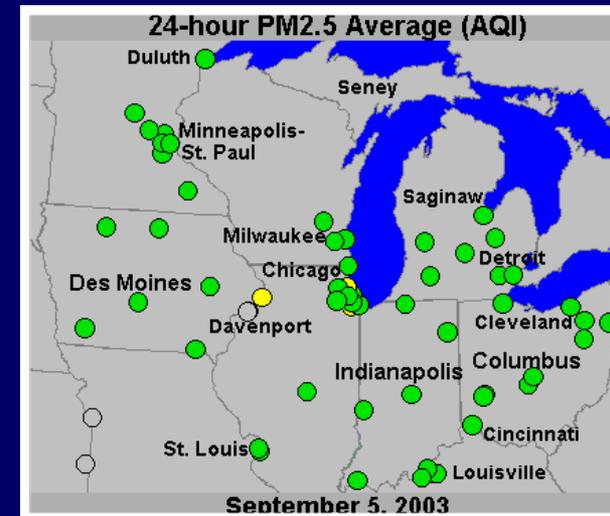


Operational Use of Satellite Data for Air Quality

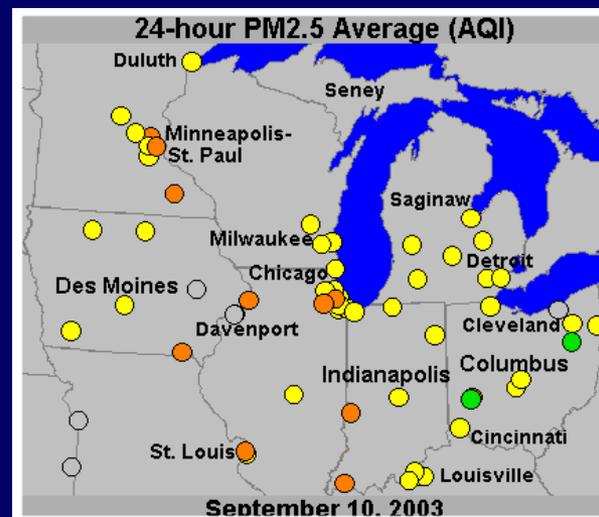
Can satellite data be used in near-real-time to provide synoptic-scale features for air quality forecast?

- PM2.5 levels reached **Moderate** to **Unhealthy for Sensitive Groups** on 8th - 12th in the Midwest.

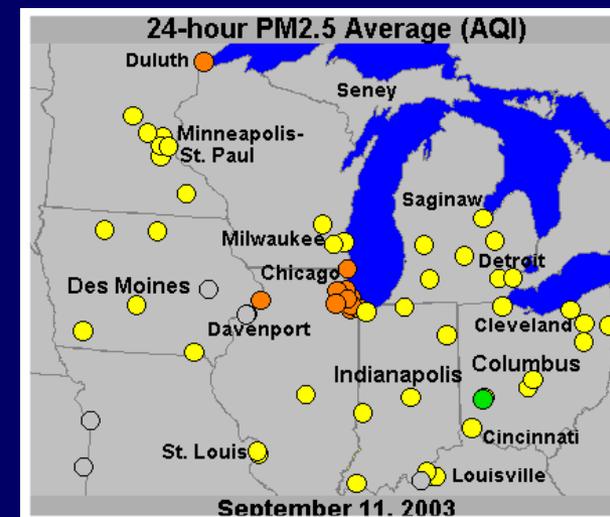
September 5, 2003



September 8



September 10



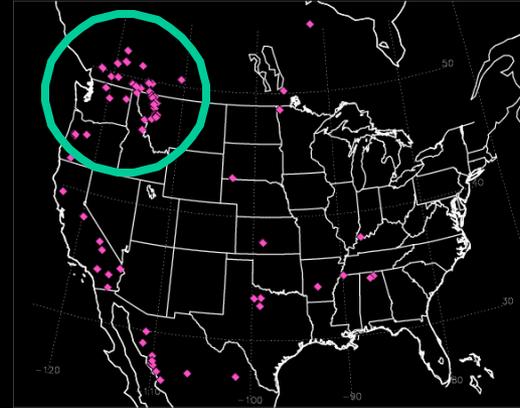
September 11

Historic wildfire events in Pacific NW and British Columbia during 2003

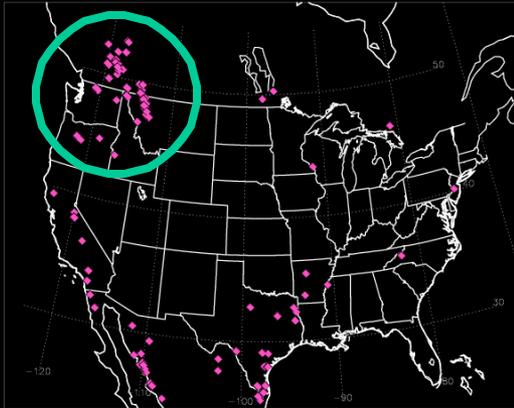
WF_ABBA Fire Pixels 20030904



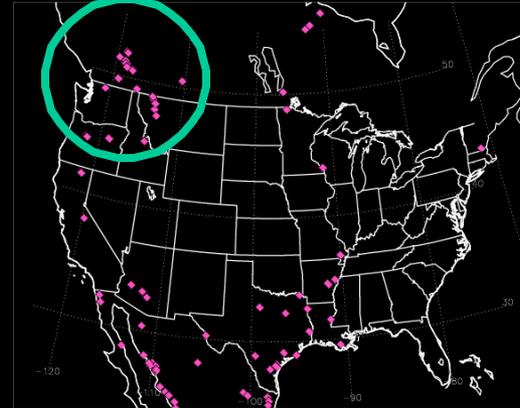
WF_ABBA Fire Pixels 20030905



WF_ABBA Fire Pixels 20030908



WF_ABBA Fire Pixels 20030907



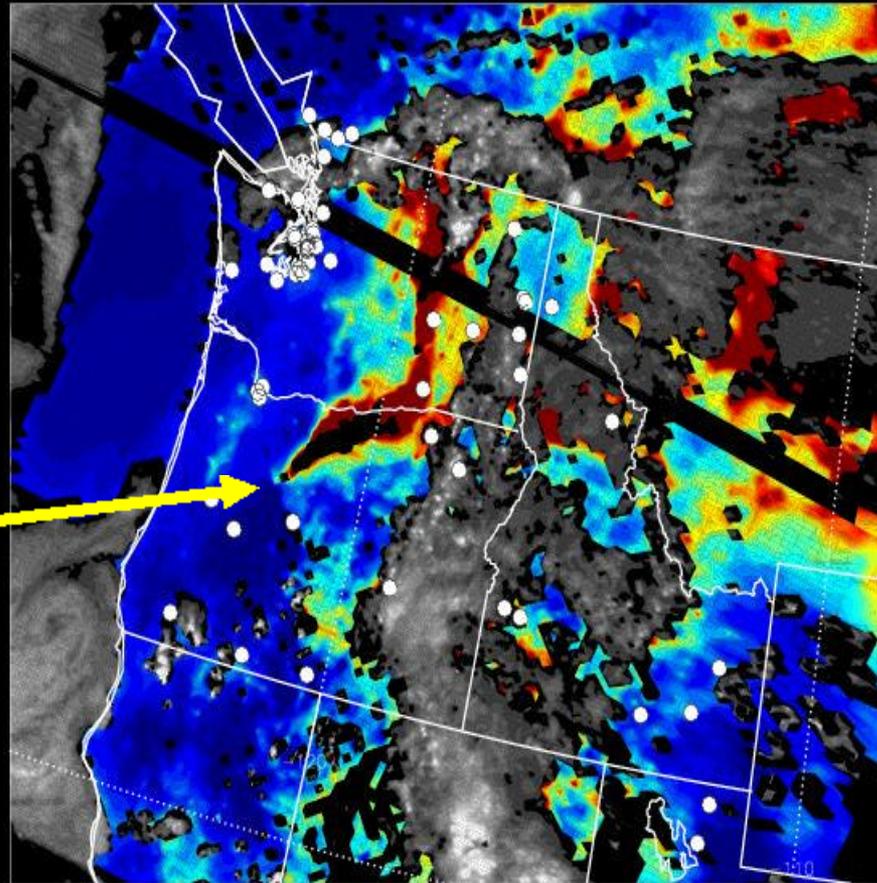
MODIS observations of Pacific NW wildfires on Sep. 4, 2003

Bear Butte Fire & Booth Fire wildfire complex
Northwest Oregon on September 4, 2003



Visible image

MODIS Aerosol Optical Depth 2003 09 04 EPA Region 10



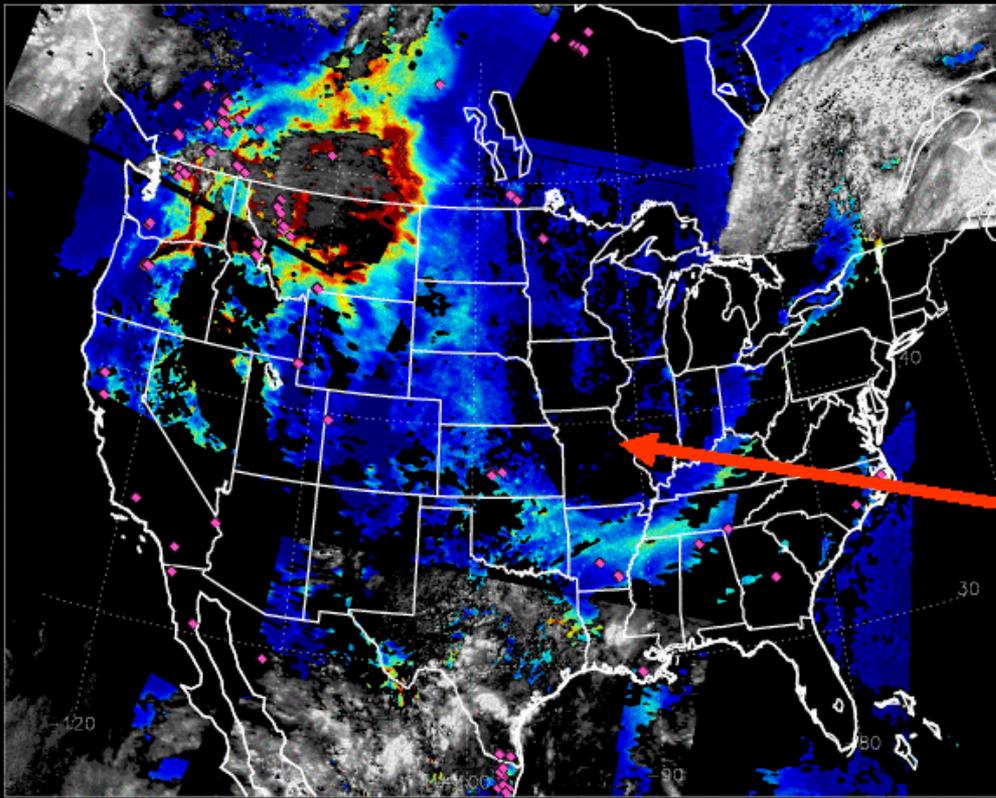
0.0 0.2 0.4 0.6 0.8 1.0
AOD

0 10 20 30 40 50 60 70
COT

Aerosol Optical Depth

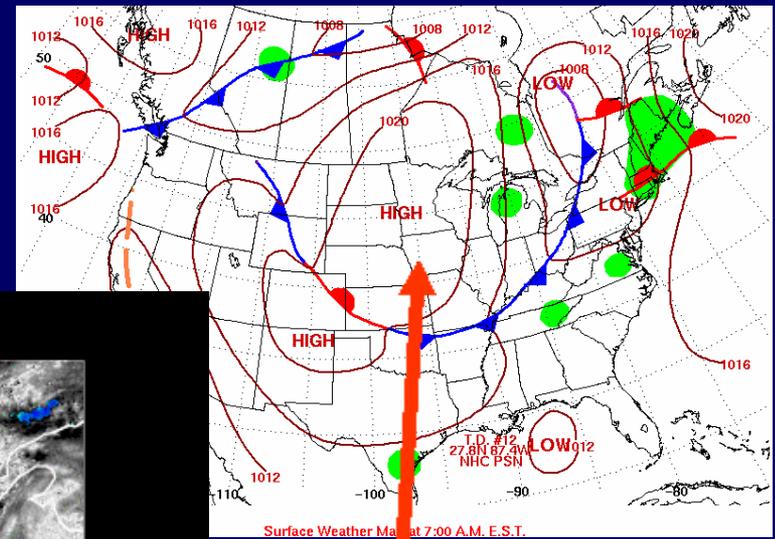
September 4, 2003

MODIS Aerosol Optical Depth 2003 09 04



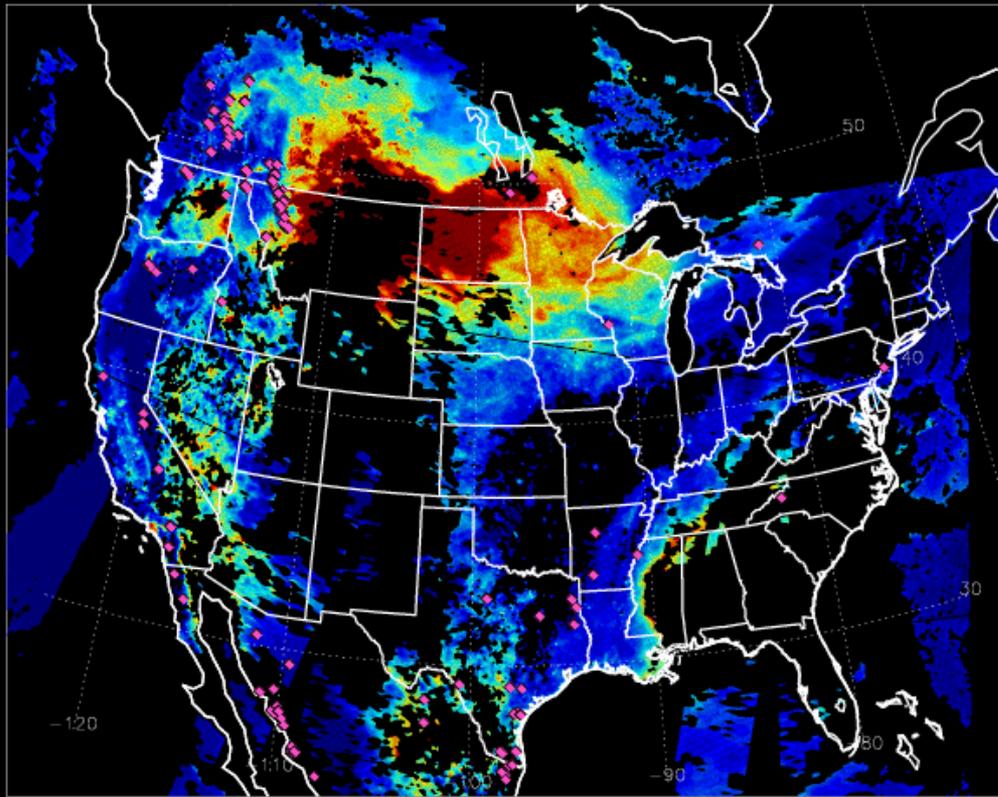
0.0 0.2 0.4 0.6 0.8 1.0 0 10 20 30 40 50 60 70
AOD COT

MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots



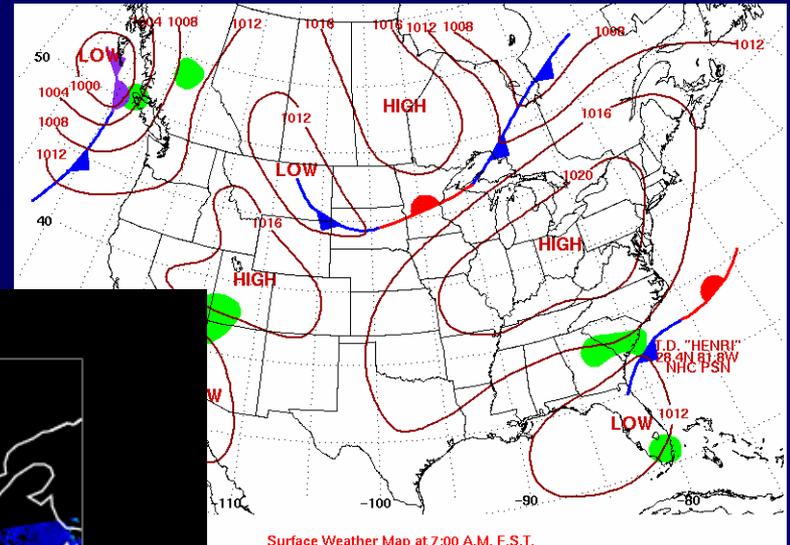
September 6, 2003

MODIS Aerosol Optical Depth 2003 09 06



0.0 0.2 0.4 0.6 0.8 1.0
AOD

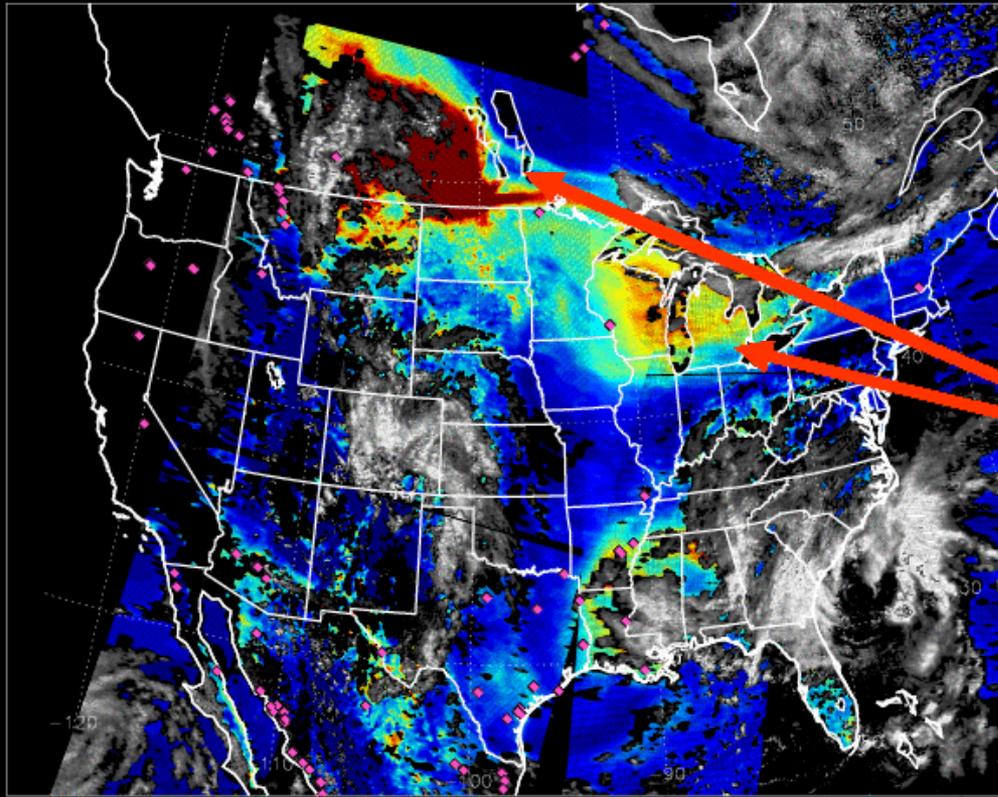
MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots



www.hpc.ncep.noaa.gov

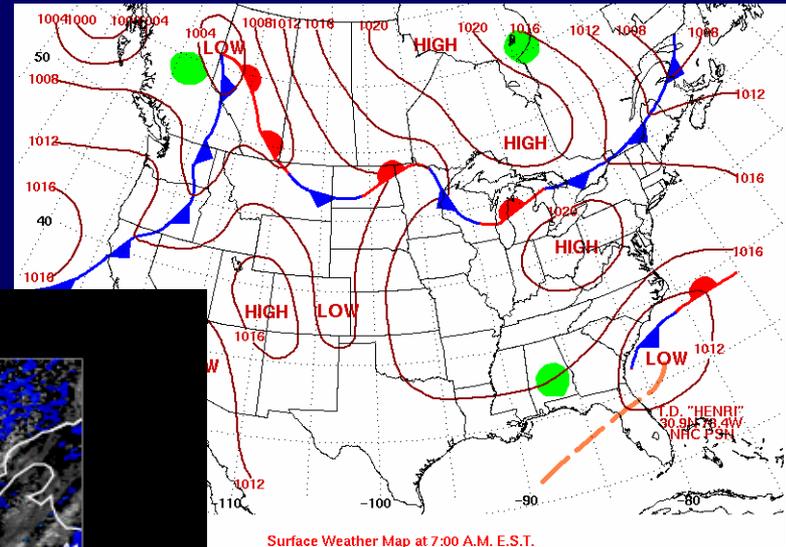
September 7, 2003

MODIS Aerosol Optical Depth 2003 09 07



0.0 0.2 0.4 0.6 0.8 1.0 0 10 20 30 40 50 60 70
AOD COT

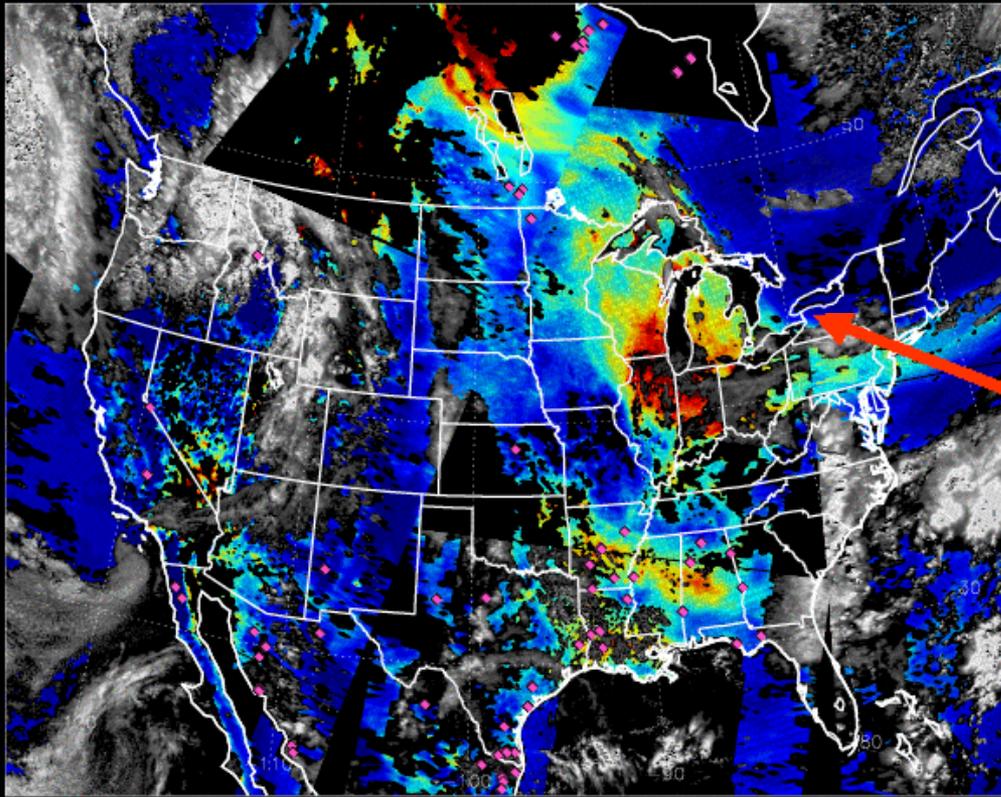
MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots



Surface Weather Map at 7:00 A.M. E.S.T.

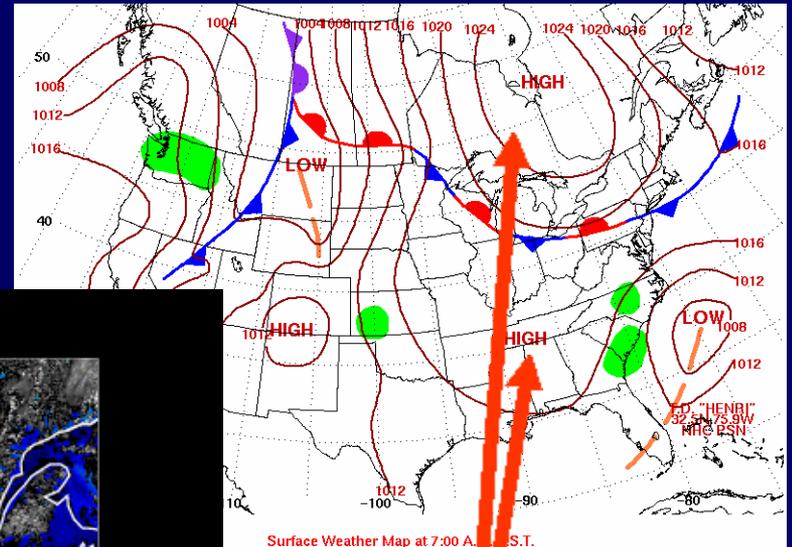
September 8, 2003

MODIS Aerosol Optical Depth 2003 09 08



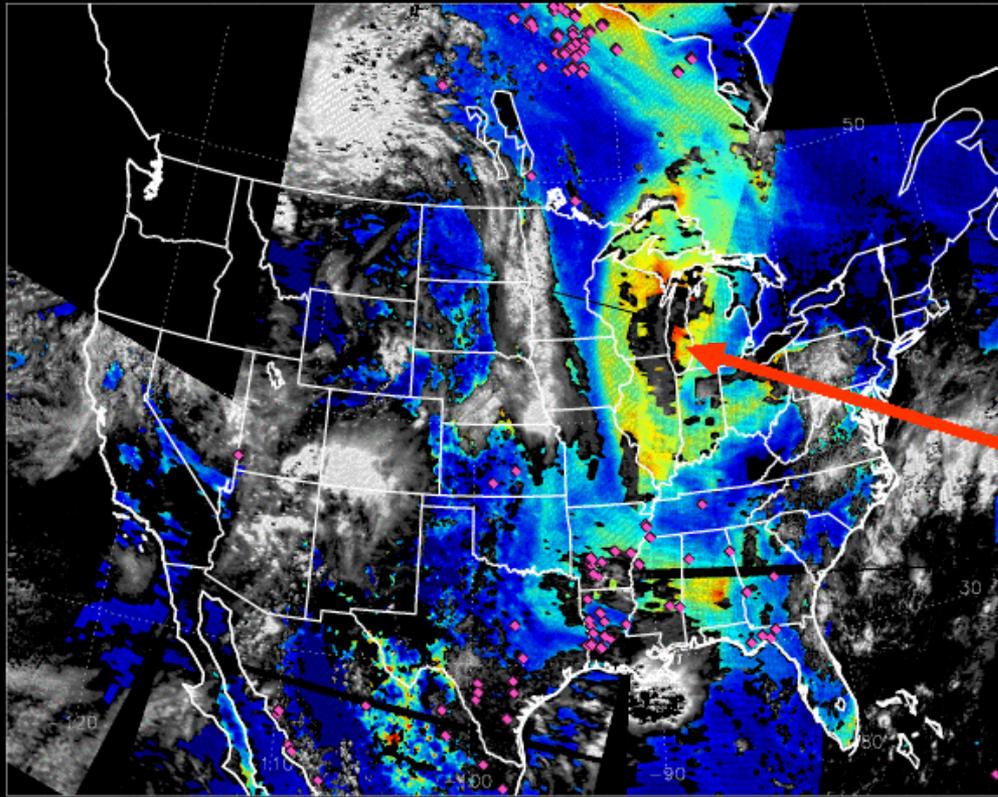
0.0 0.2 0.4 0.6 0.8 1.0 0 10 20 30 40 50 60 70
AOD COT

MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots



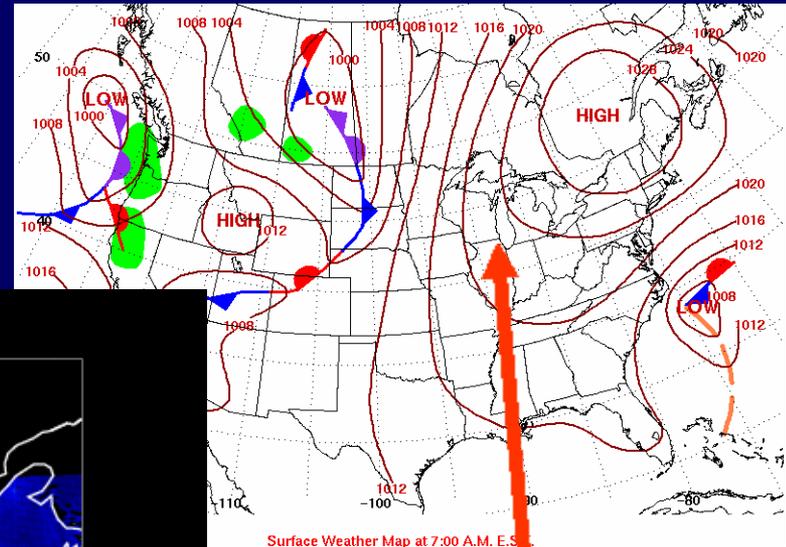
September 9, 2003

MODIS Aerosol Optical Depth 2003 09 09



0.0 0.2 0.4 0.6 0.8 1.0 0 10 20 30 40 50 60 70
AOD COT

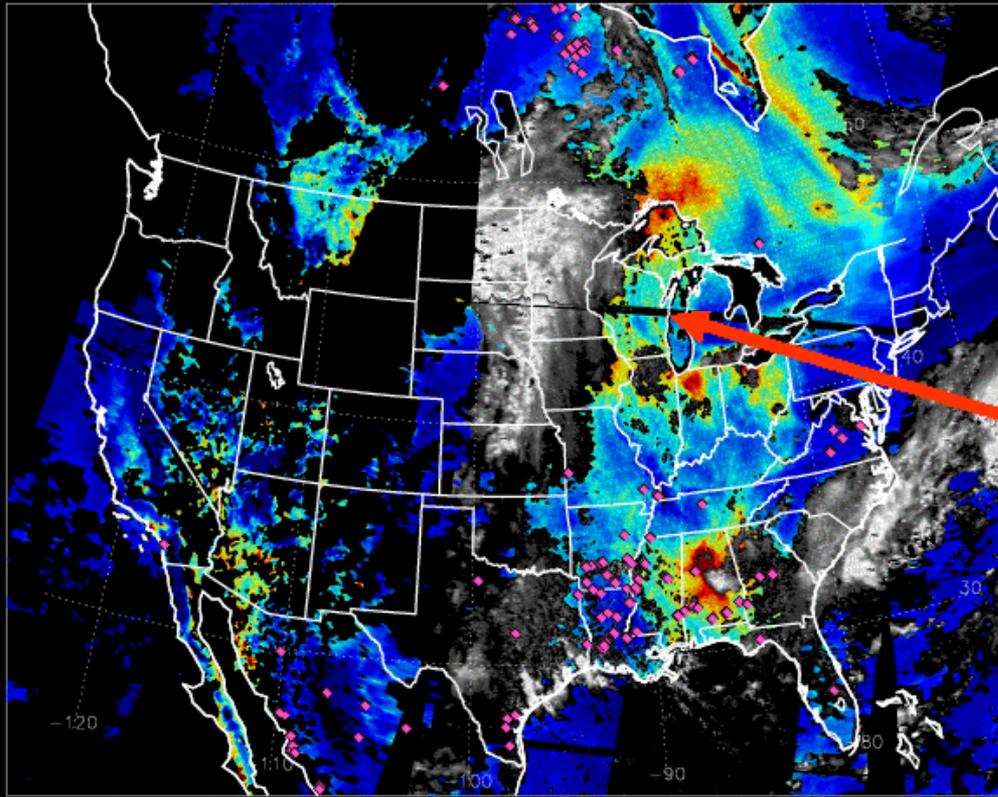
MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots



Surface Weather Map at 7:00 A.M. E.S.

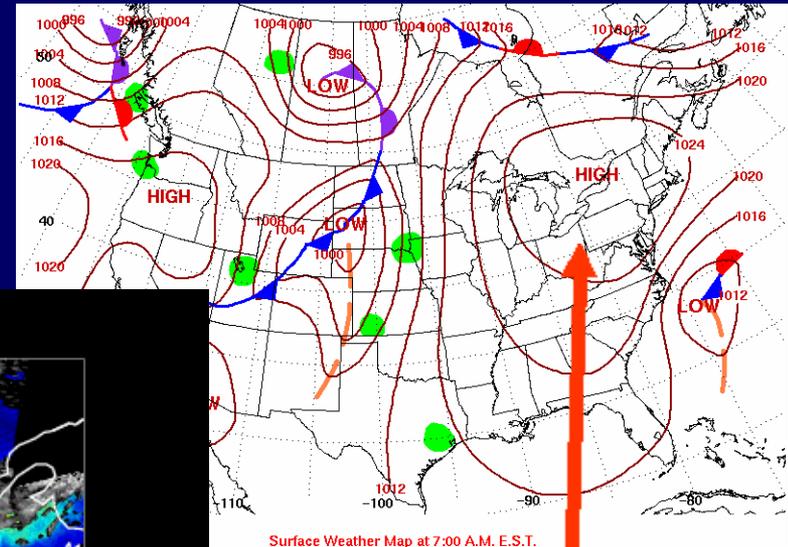
September 10, 2003

MODIS Aerosol Optical Depth 2003 09 10



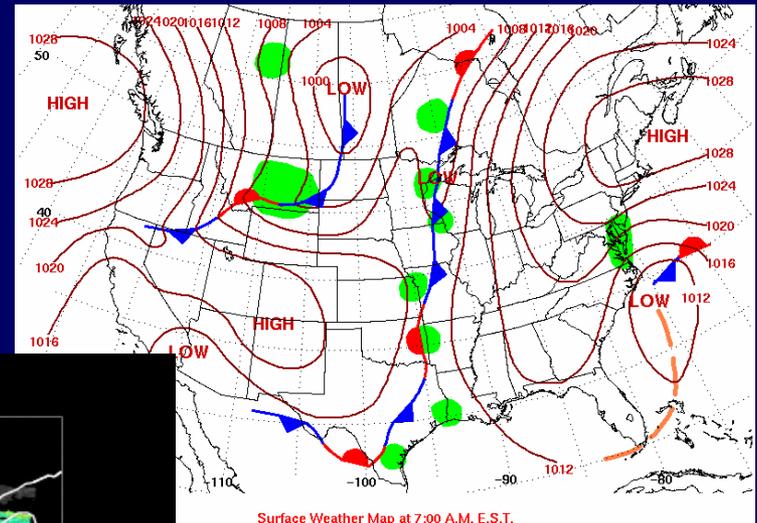
0.0 0.2 0.4 0.6 0.8 1.0 0 10 20 30 40 50 60 70
AOD COT

MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots

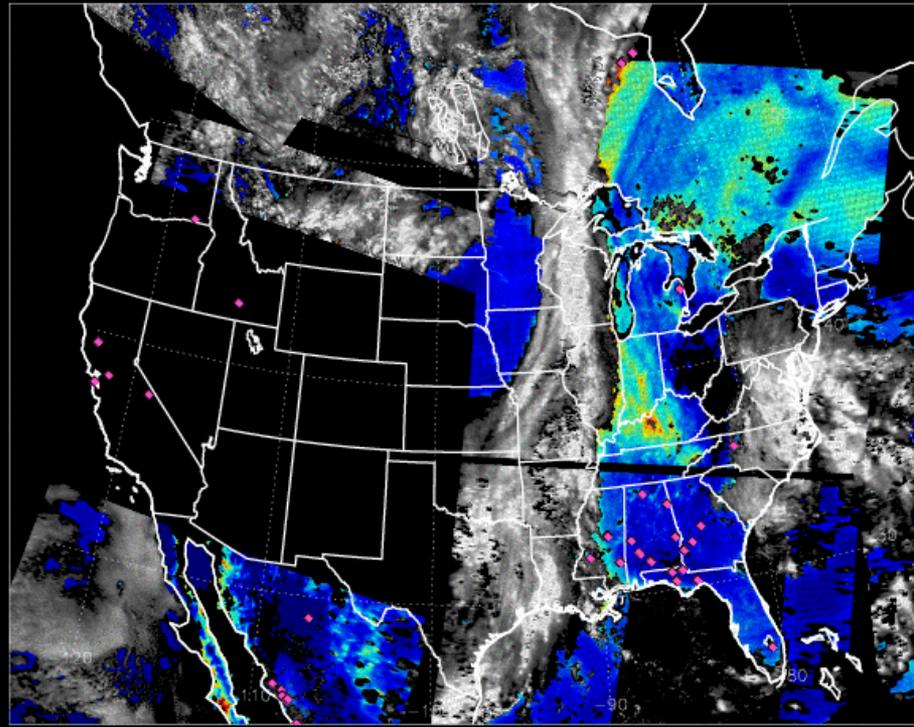


Surface Weather Map at 7:00 A.M. E.S.T.

September 12, 2003



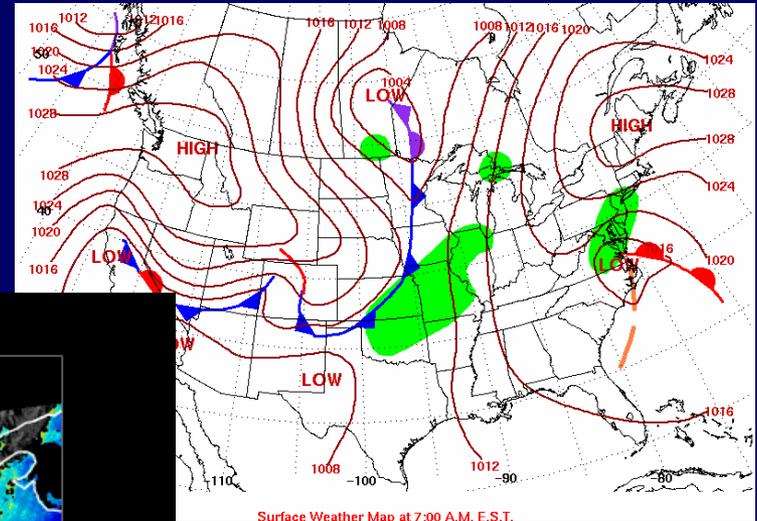
MODIS Aerosol Optical Depth 2003 09 12



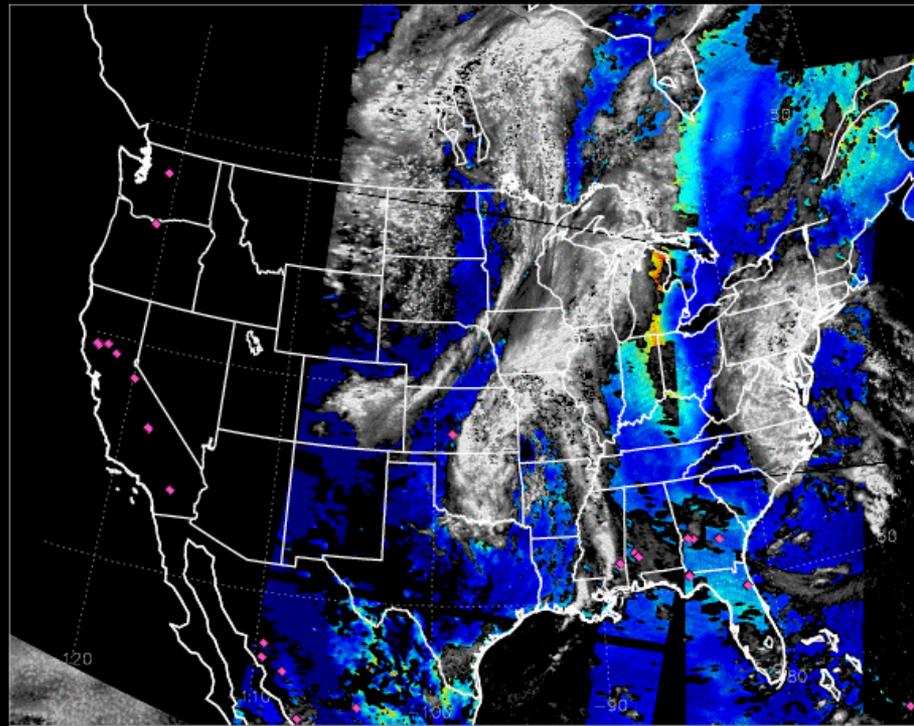
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AOD COT

MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots

September 13, 2003



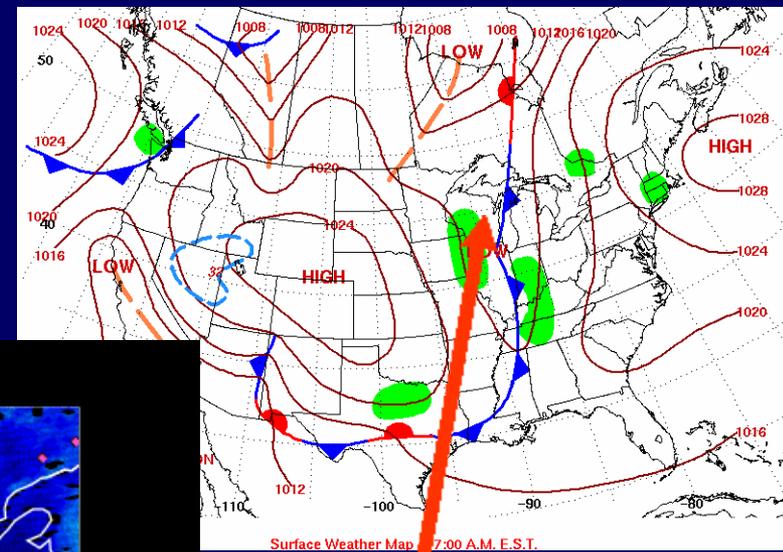
MODIS Aerosol Optical Depth 2003 09 13



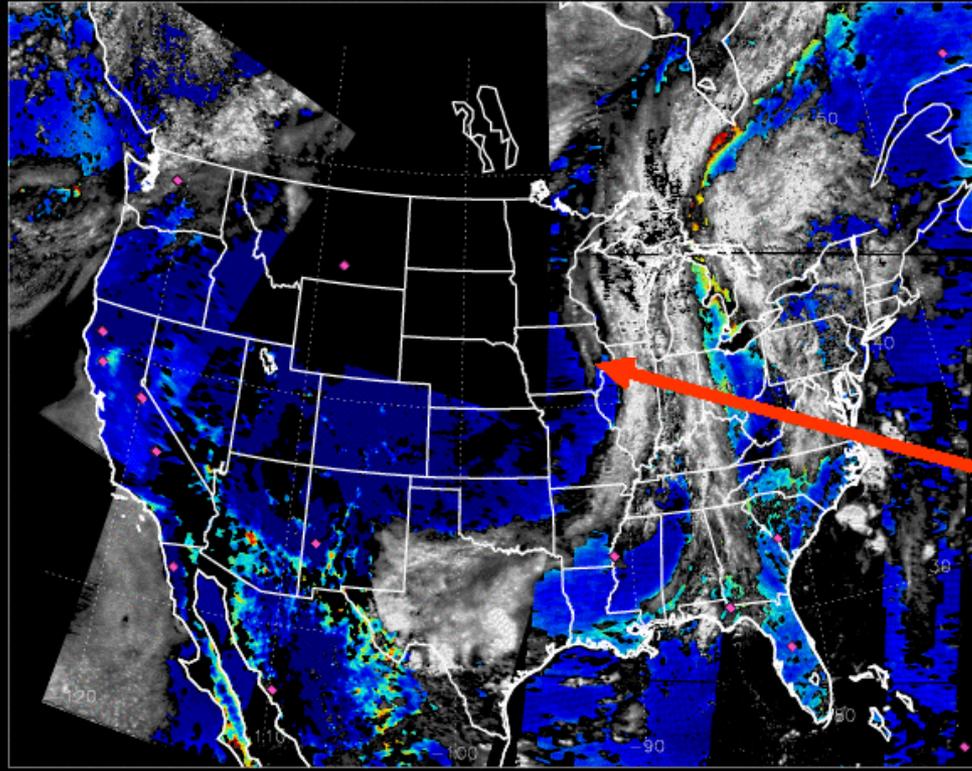
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AOD COT

MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots

September 14, 2003



MODIS Aerosol Optical Depth 2003 09 14



0.0 0.2 0.4 0.6 0.8 1.0 0 10 20 30 40 50 60 70
AOD COT

MODIS AOD: color contours
WF_ABBA Fire pixels: purple dots

Forward trajectory analysis using MODIS AOD

- 48 hour forward trajectories initialized at MODIS AOD > 0.6

Two sets of trajectories:

Trajectories #1: initialized at ~15Z Sep. 6

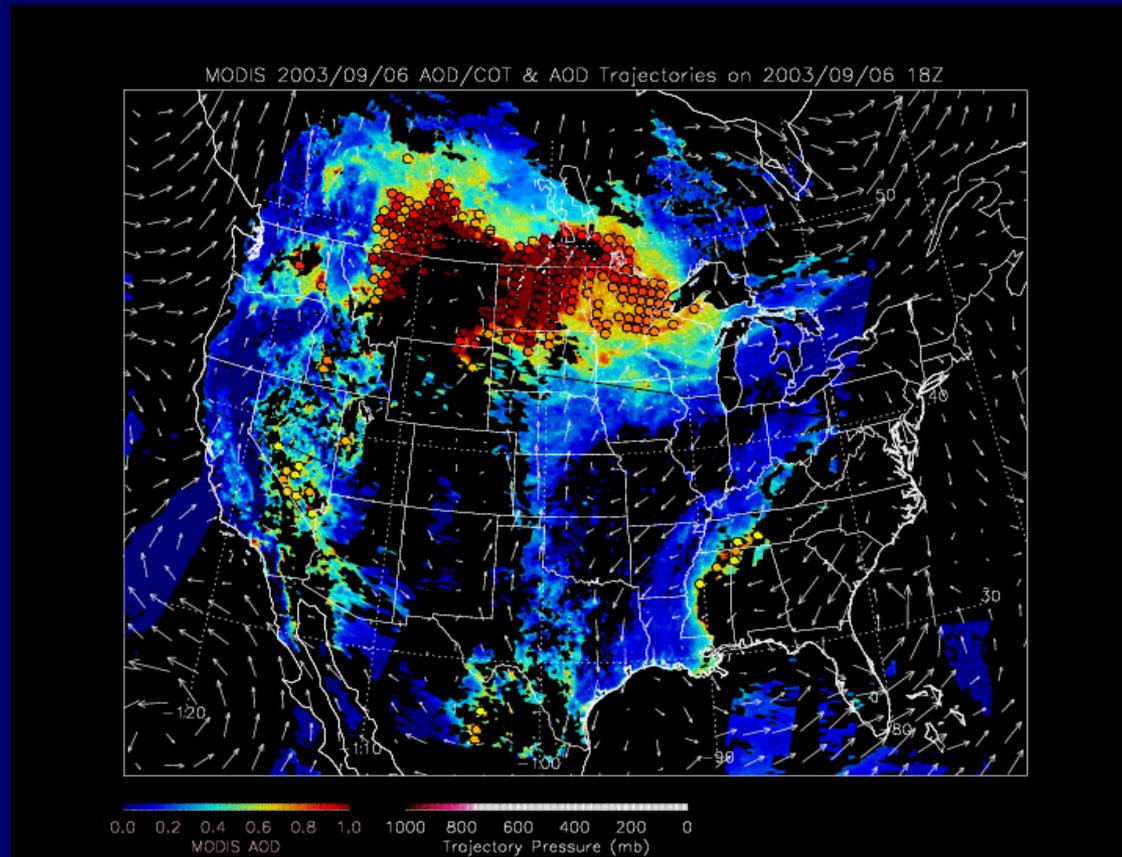
Illustrate advection of high AOD from the source regions to Midwest

Trajectories #2: initialized at ~15Z Sep. 7

Illustrate entrainment of high AOD into anti-cyclonic circulation over Midwest

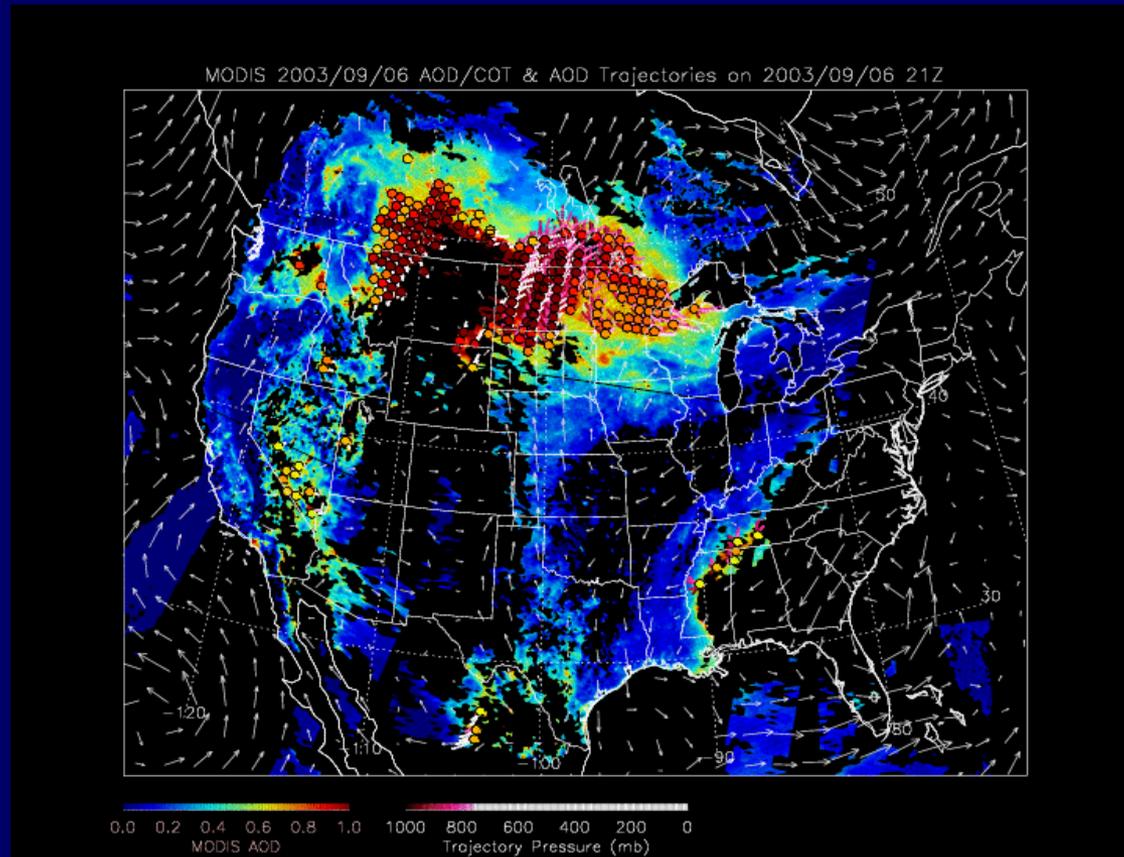
18Z Sep. 6

48 hour AOD trajectories
initialized at ~15Z Sep. 6



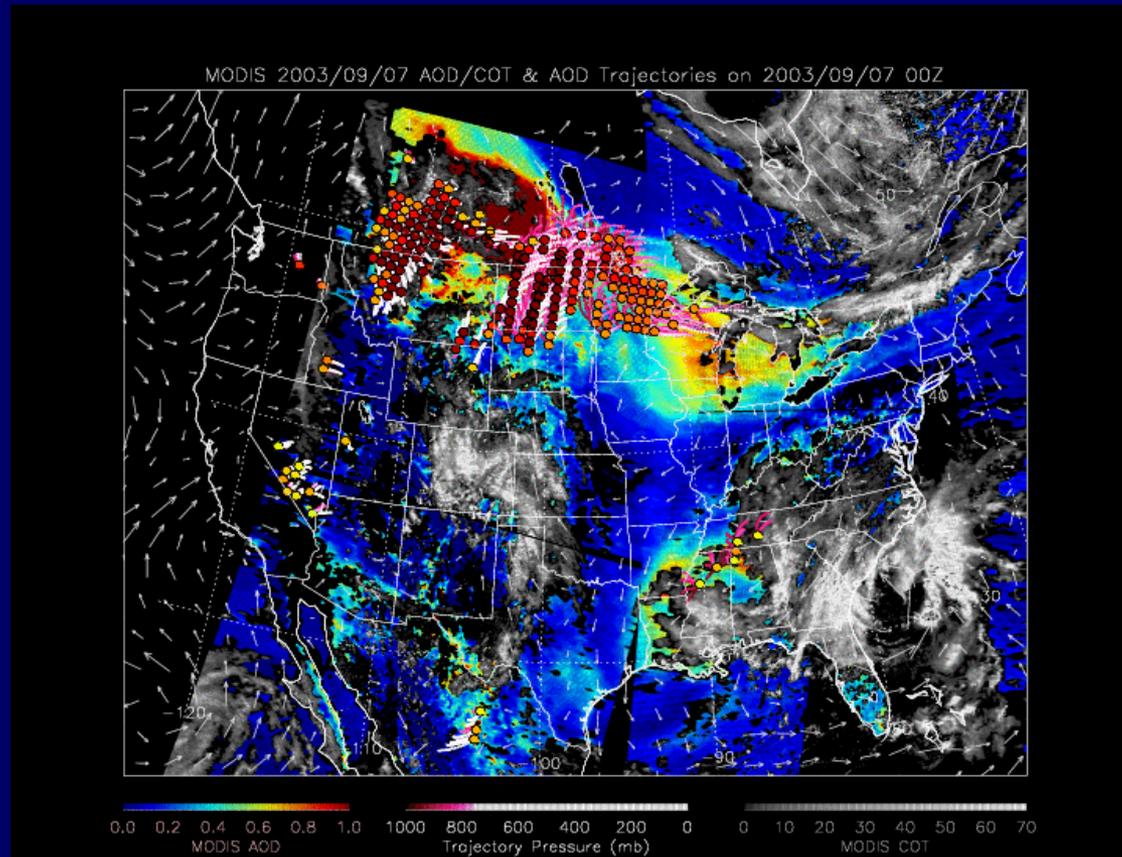
21Z Sep. 6

48 hour AOD trajectories
initialized at ~15Z Sep. 6



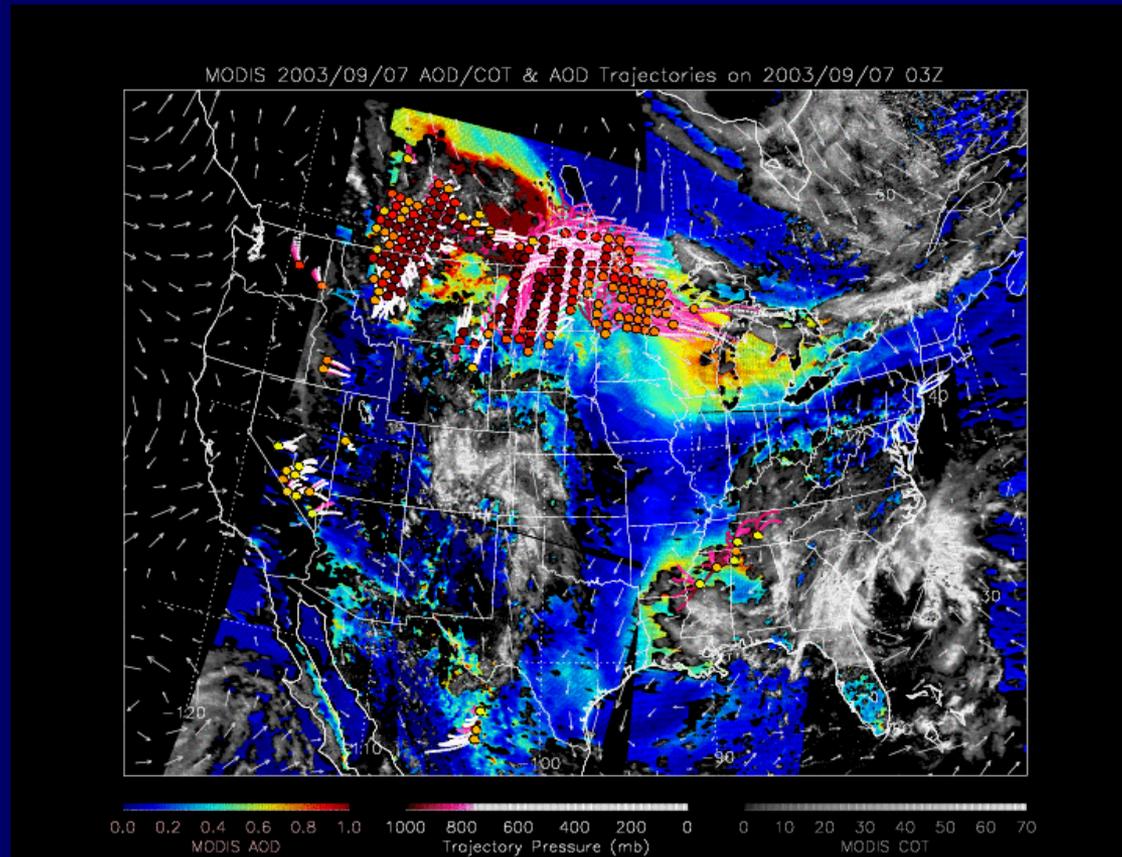
00Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 6



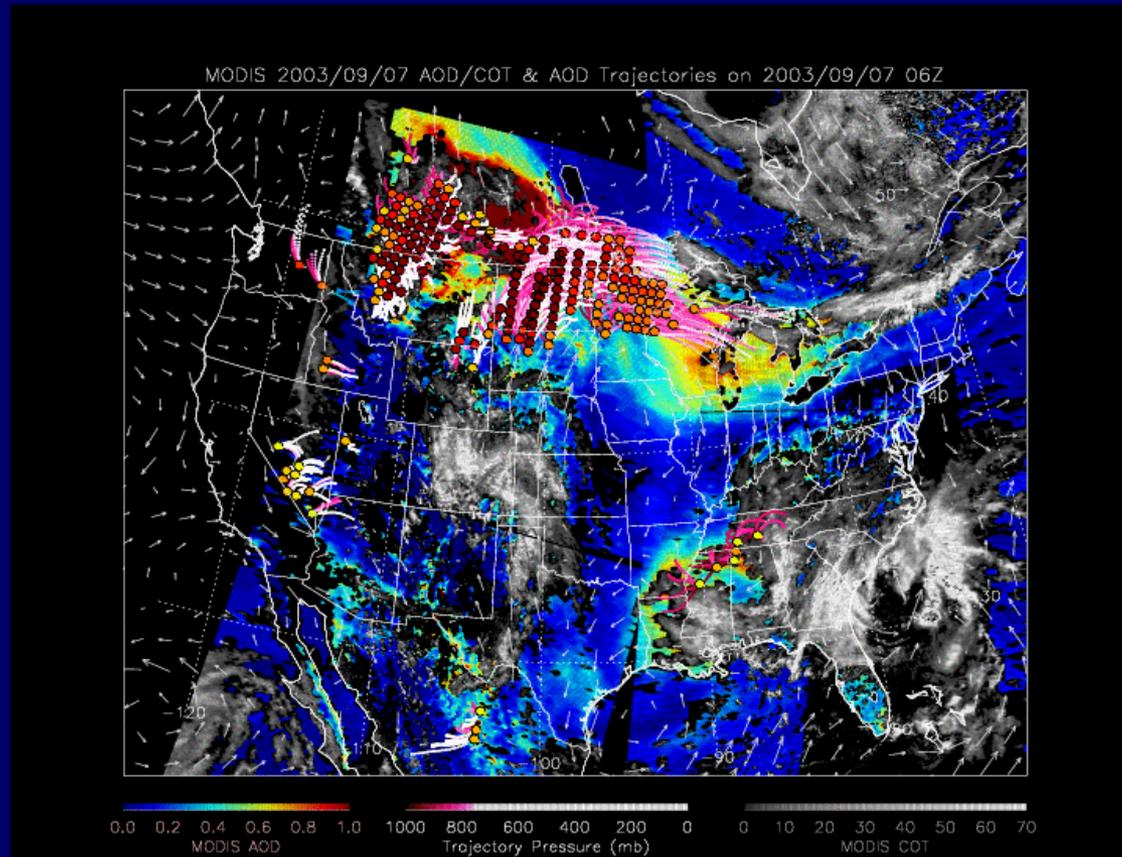
03Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 6



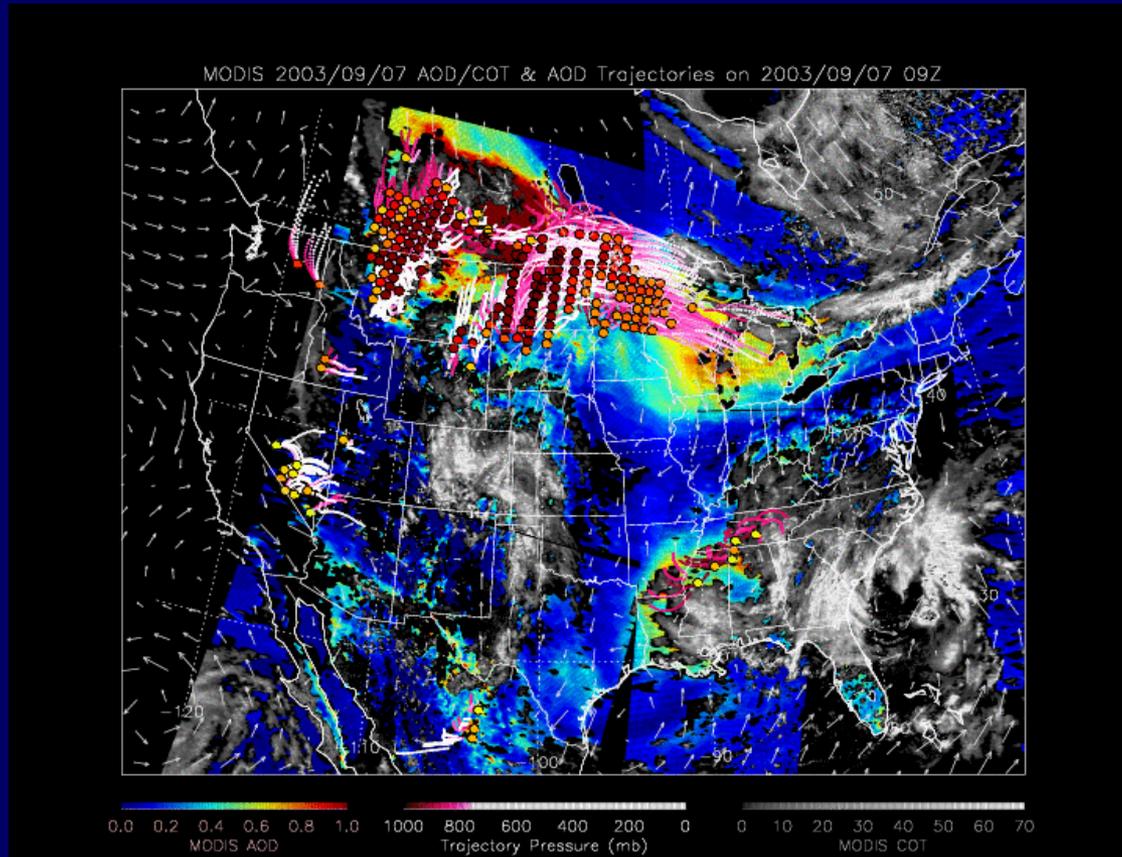
06Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 6



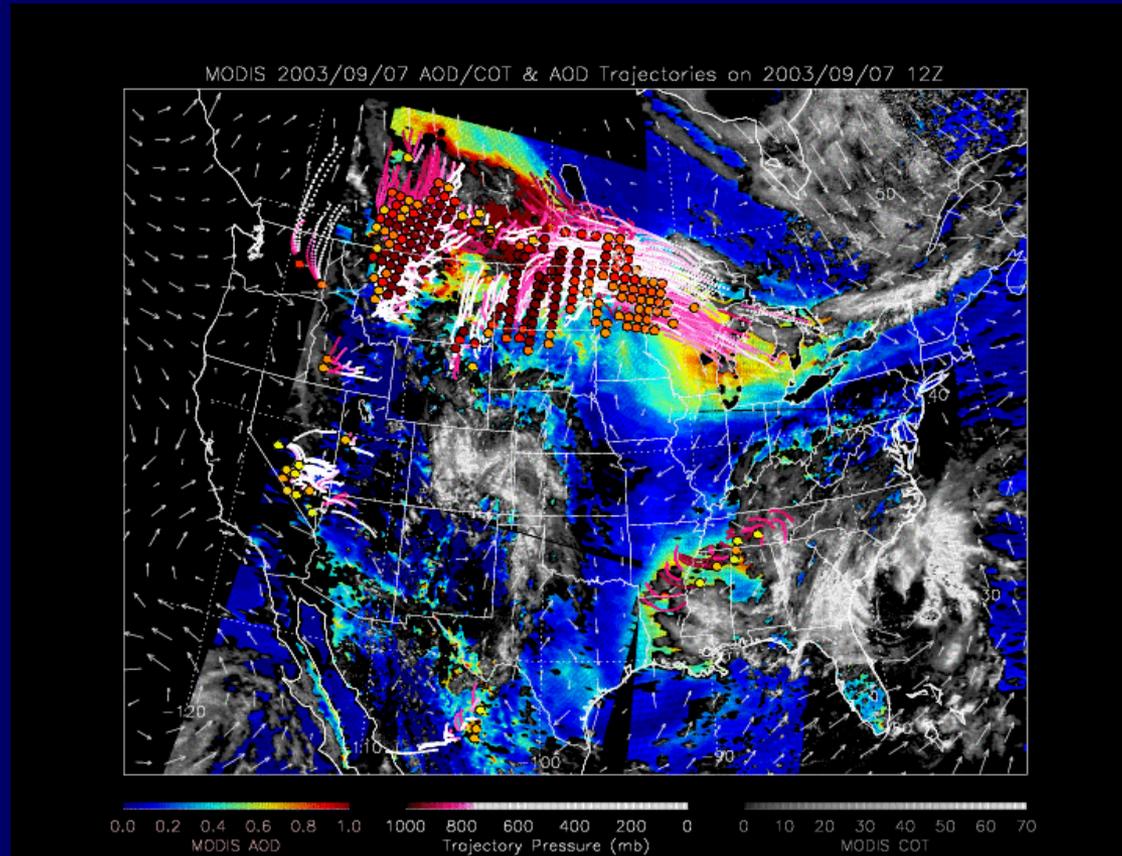
09Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 6



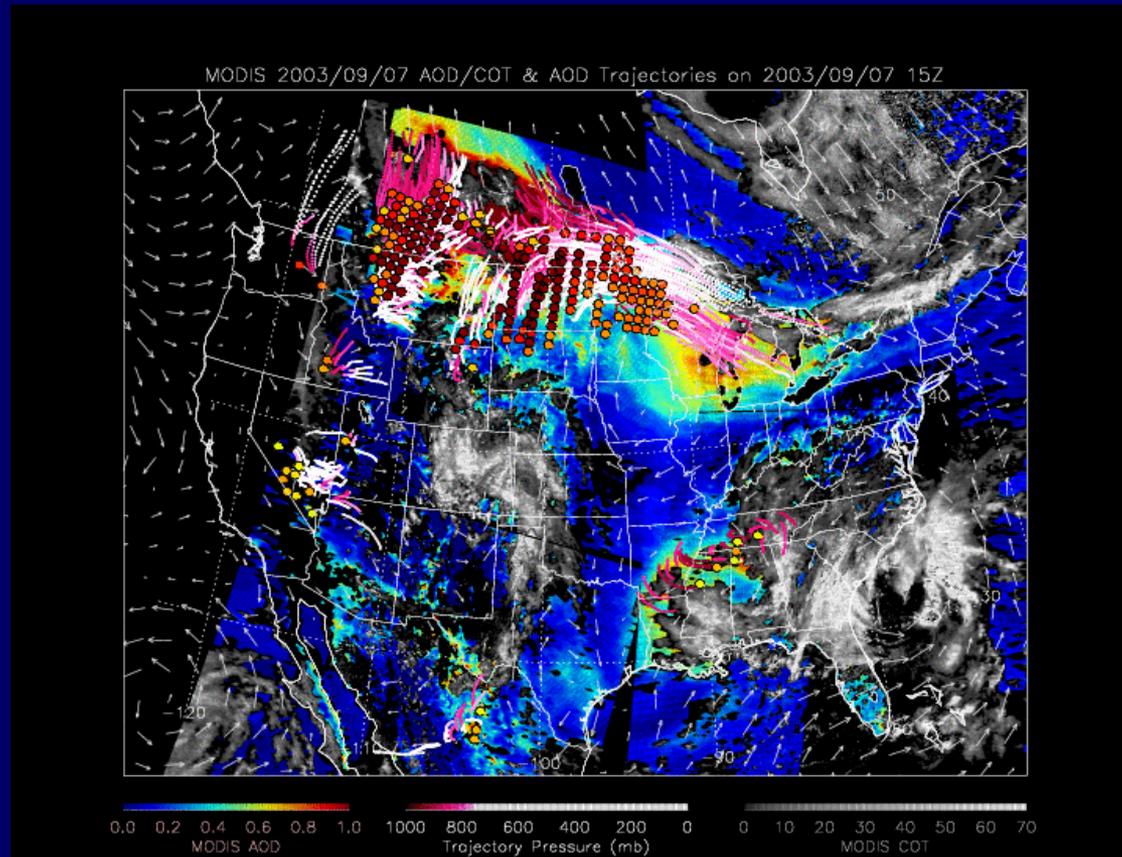
12Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 6



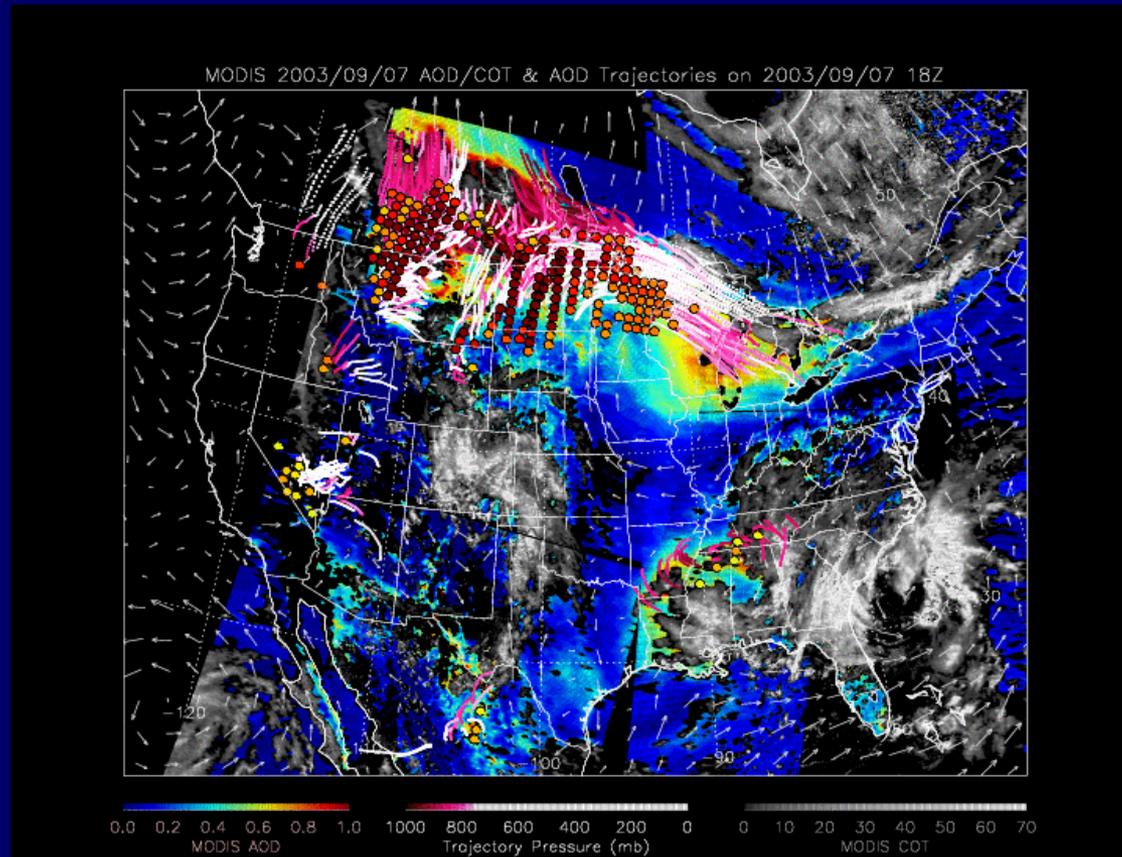
15Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 6



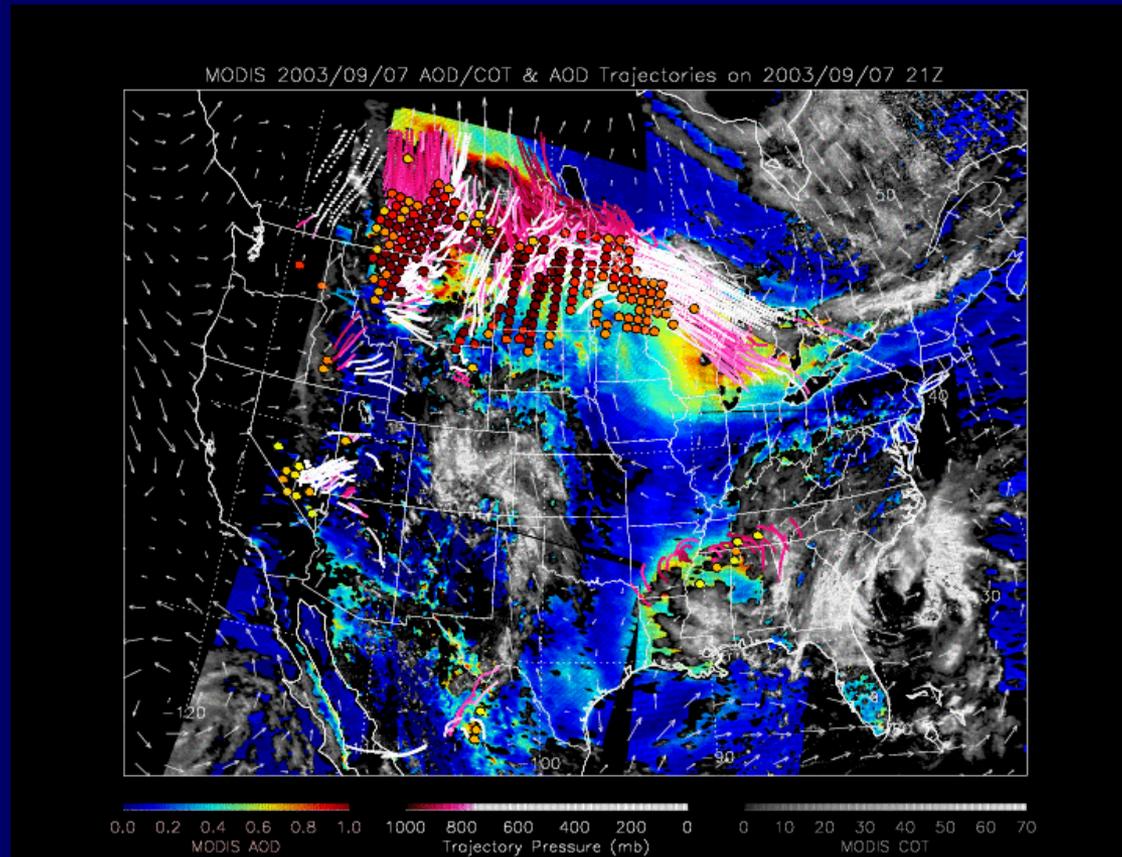
18Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 6



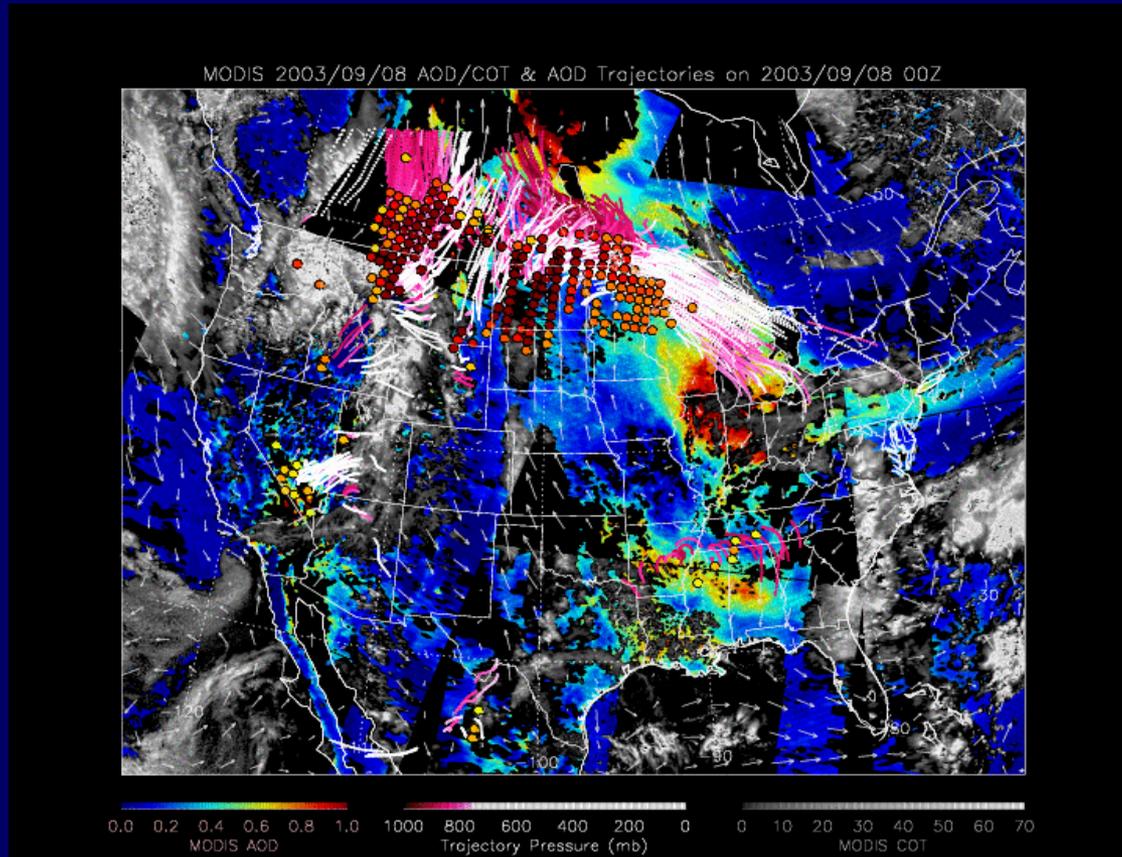
21Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 6



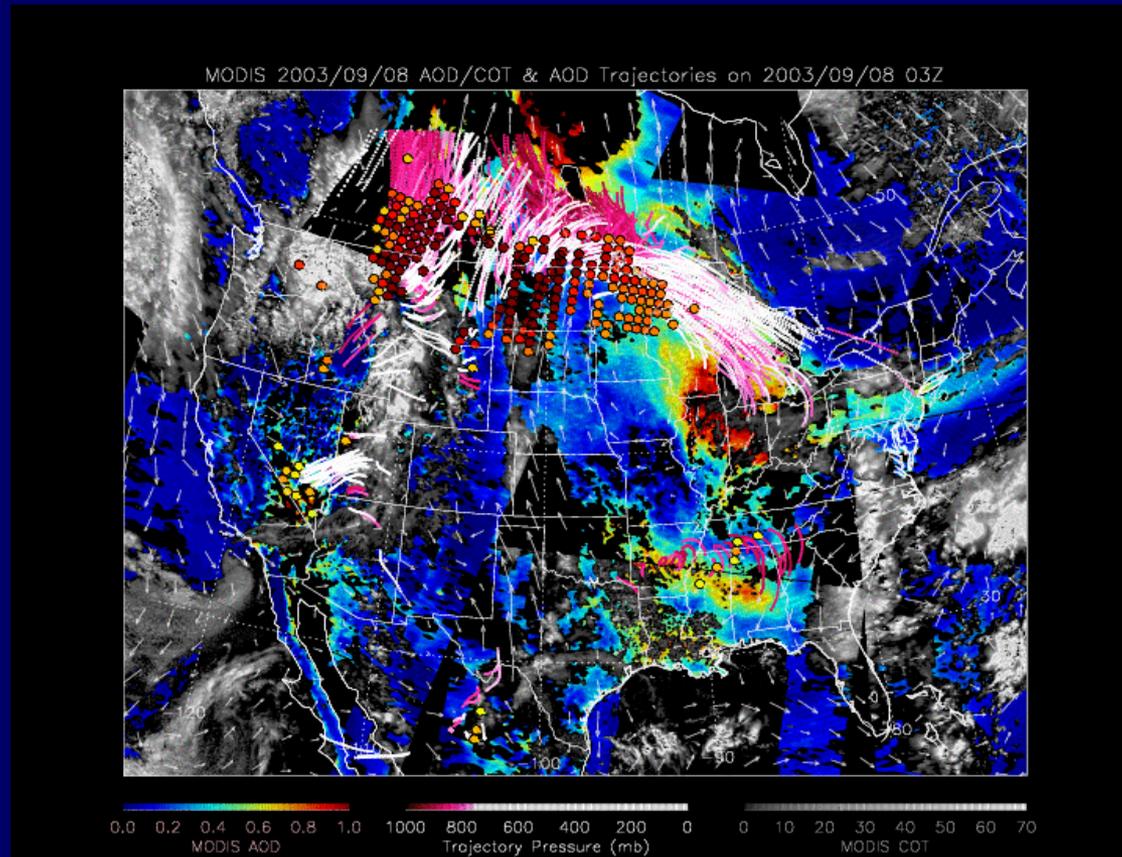
00Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 6



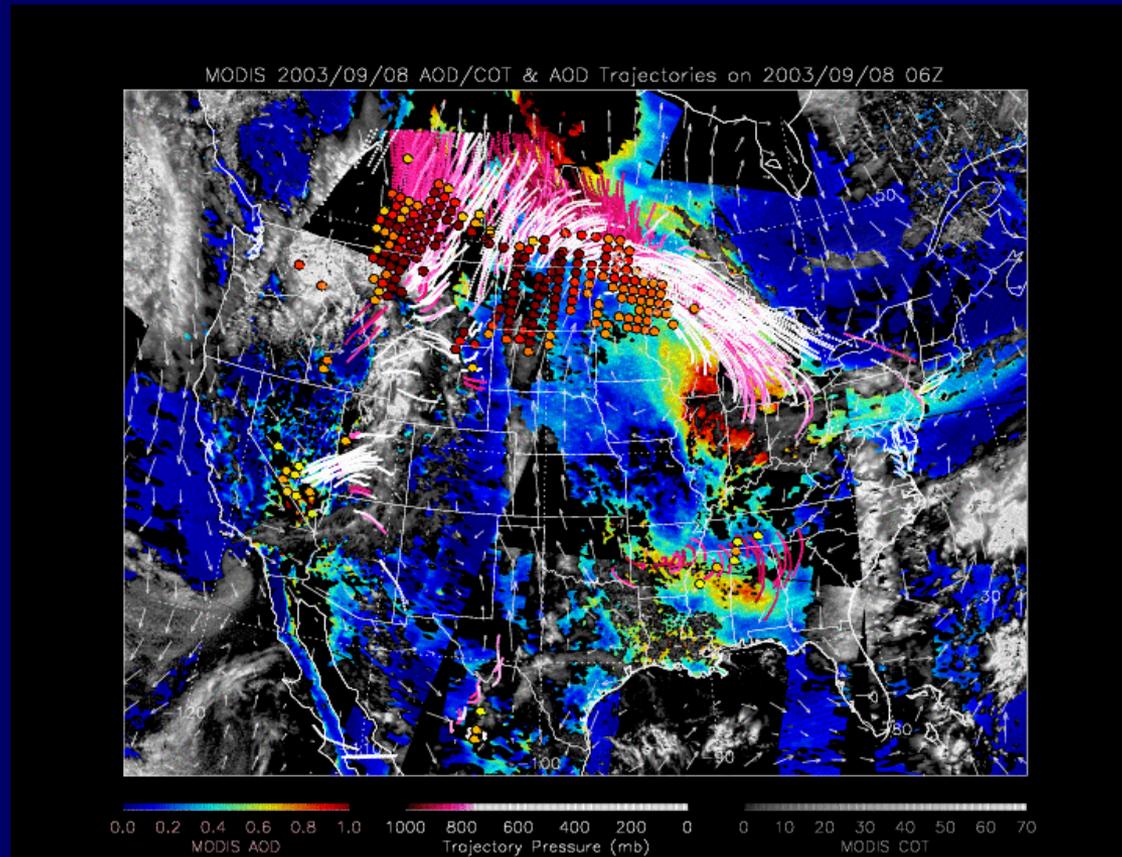
03Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 6



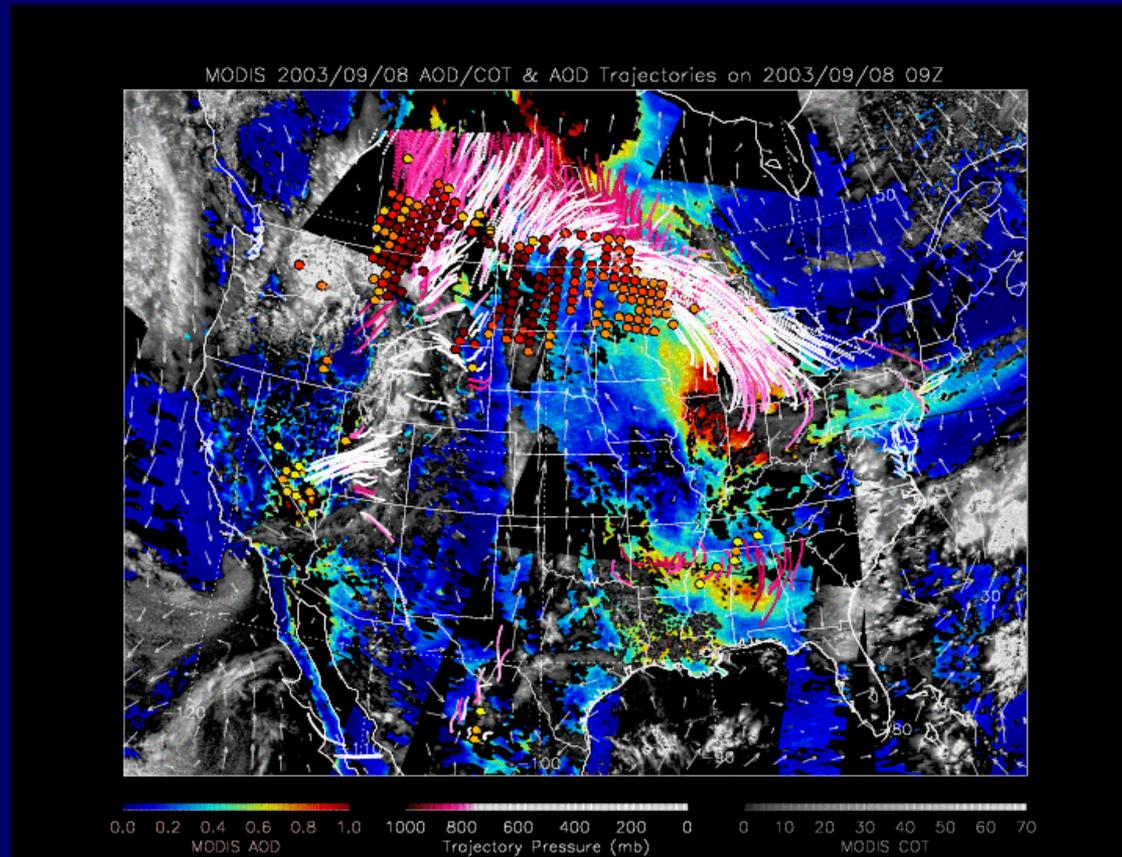
06Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 6



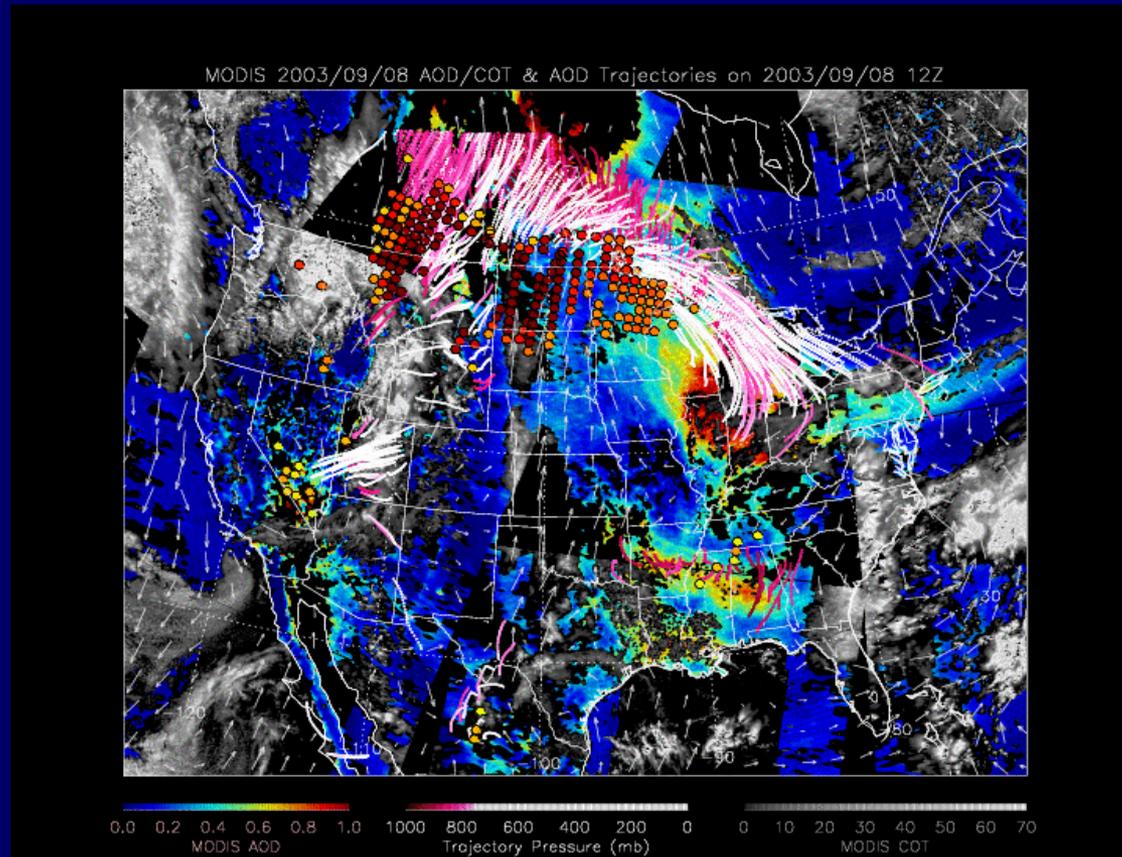
09Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 6



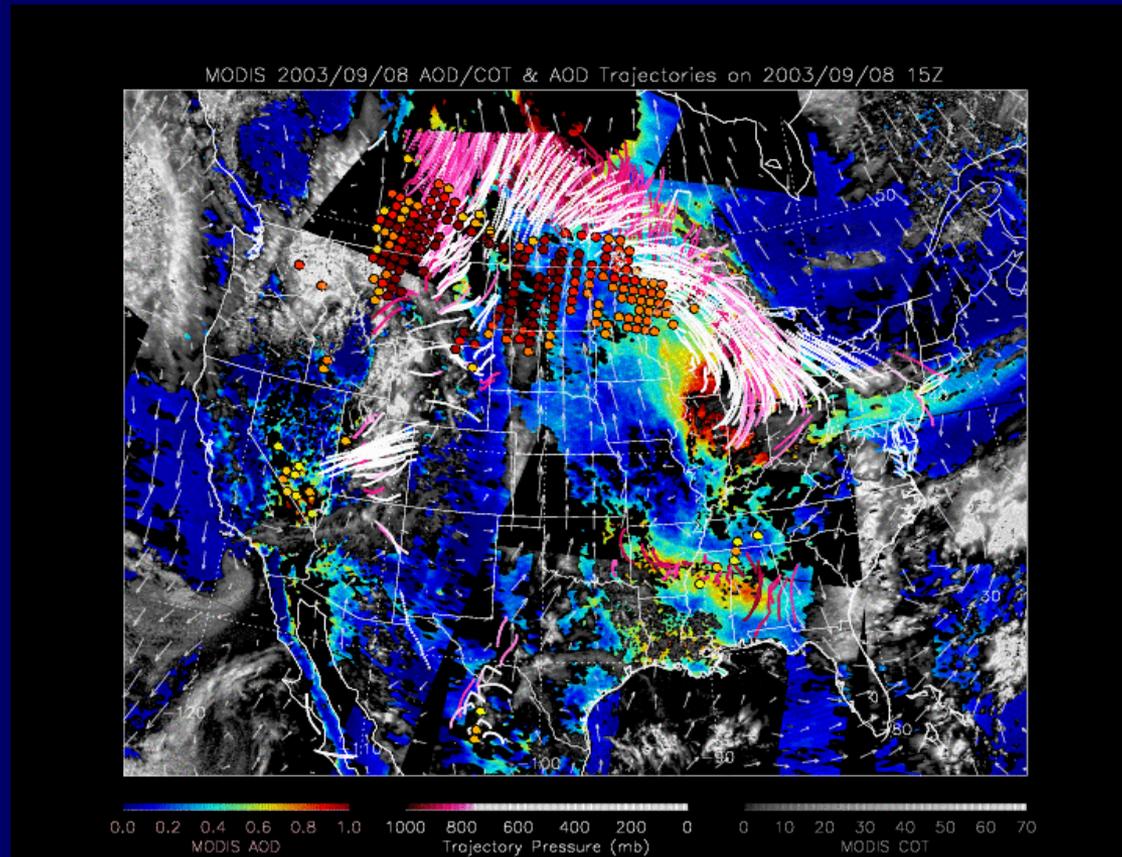
12Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 6



15Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 6



End of Trajectories #1

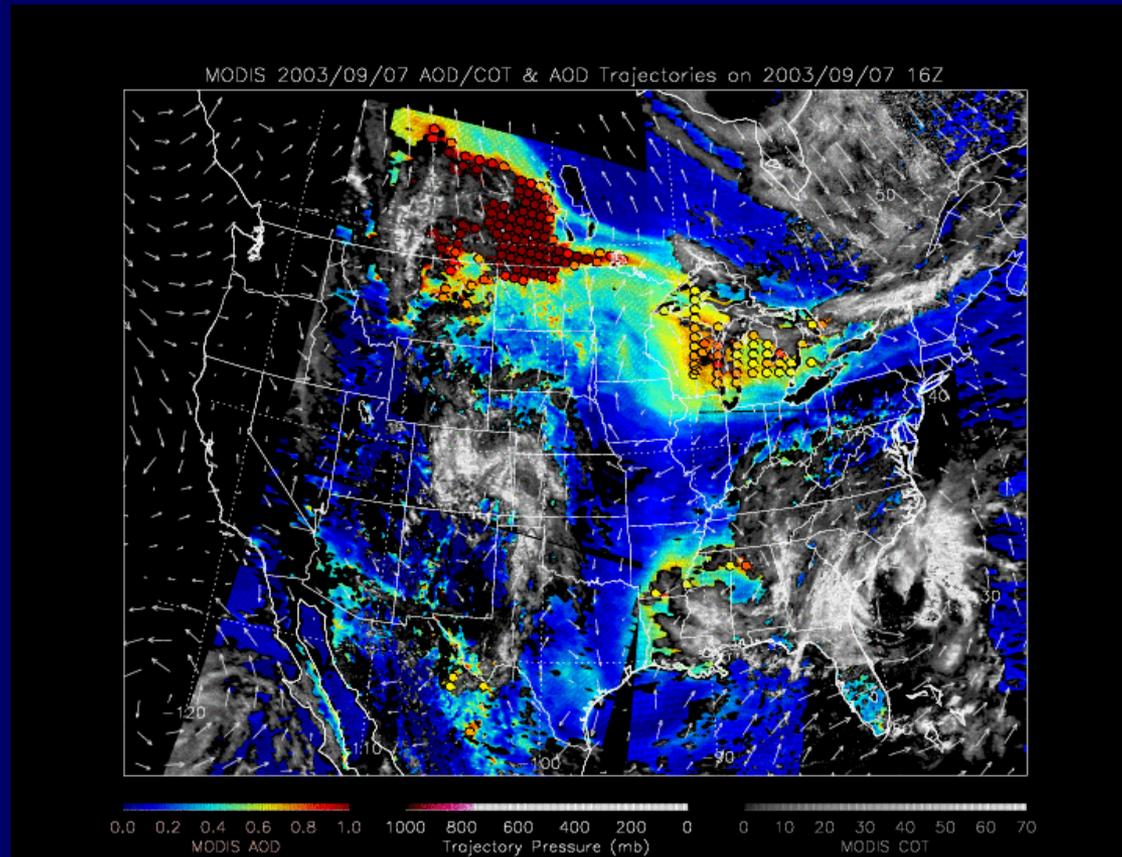
Trajectories #2:

initialized at ~15Z Sep. 7

*Illustrate entrainment of high AOD into
anti-cyclonic circulation over Midwest*

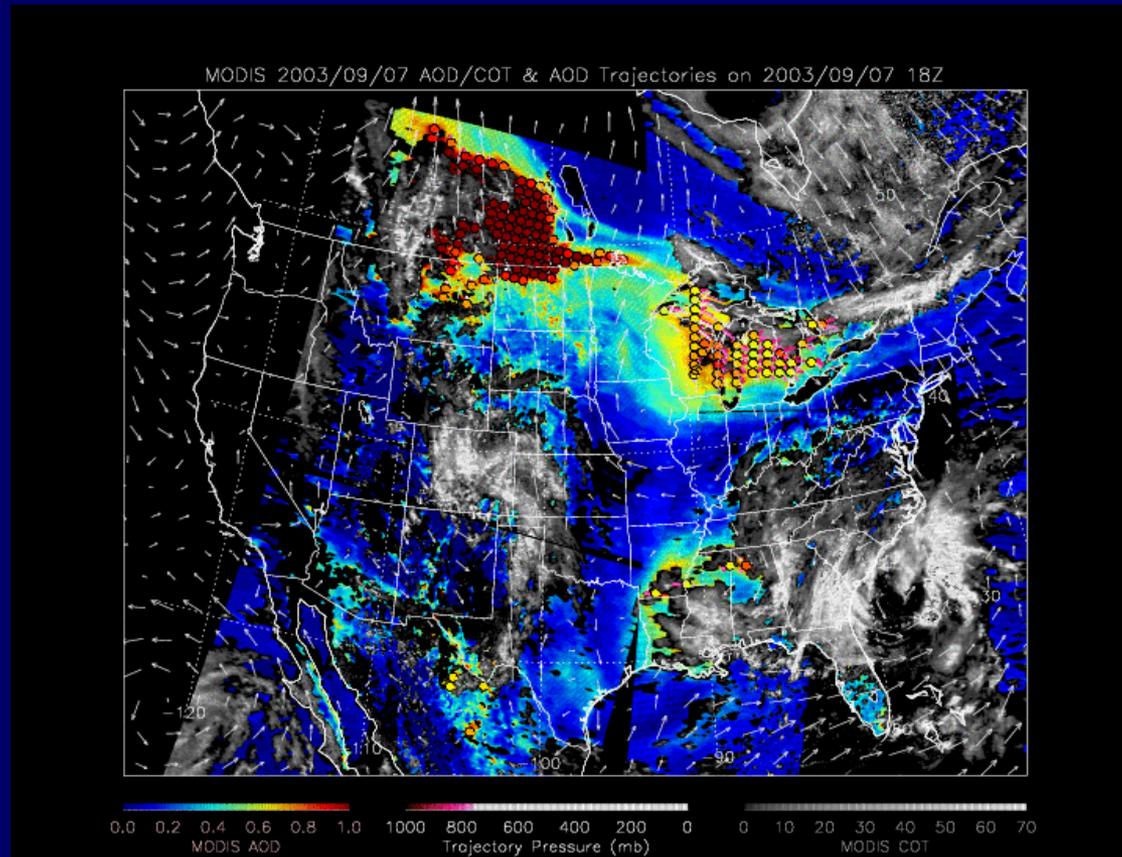
16Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 7



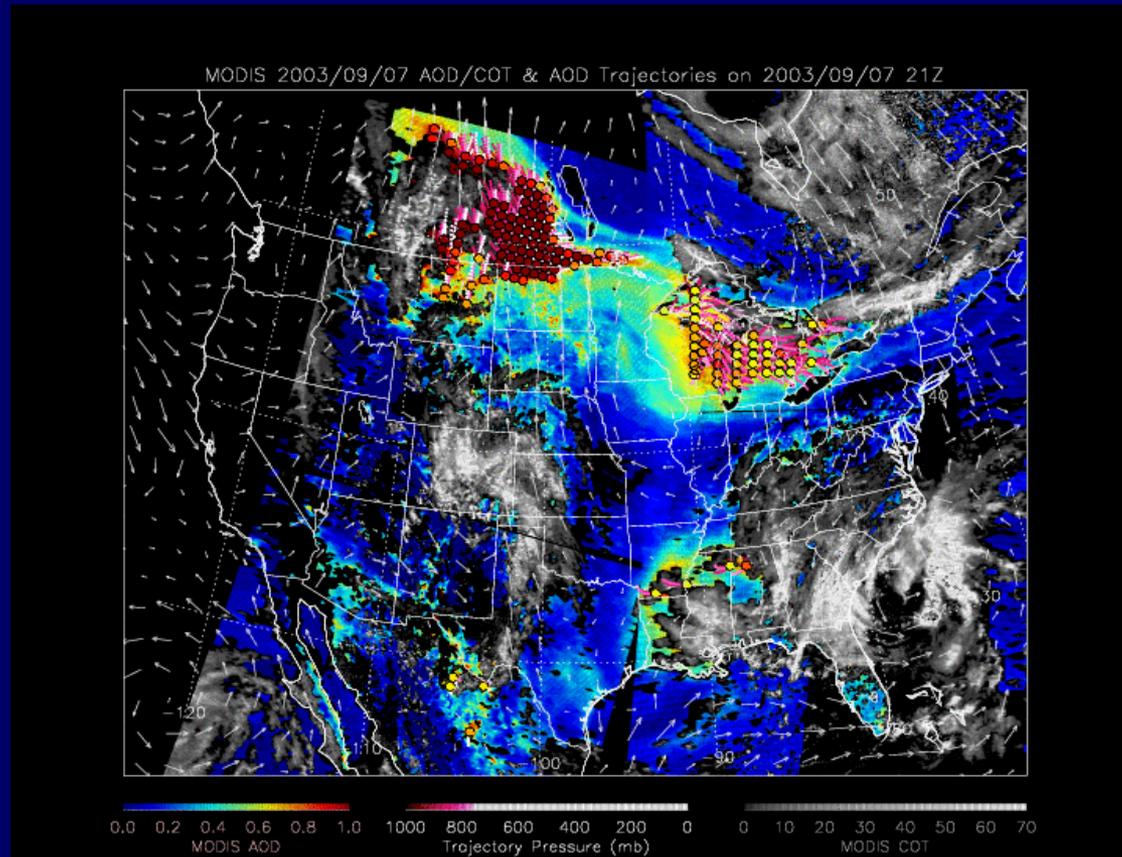
18Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 7



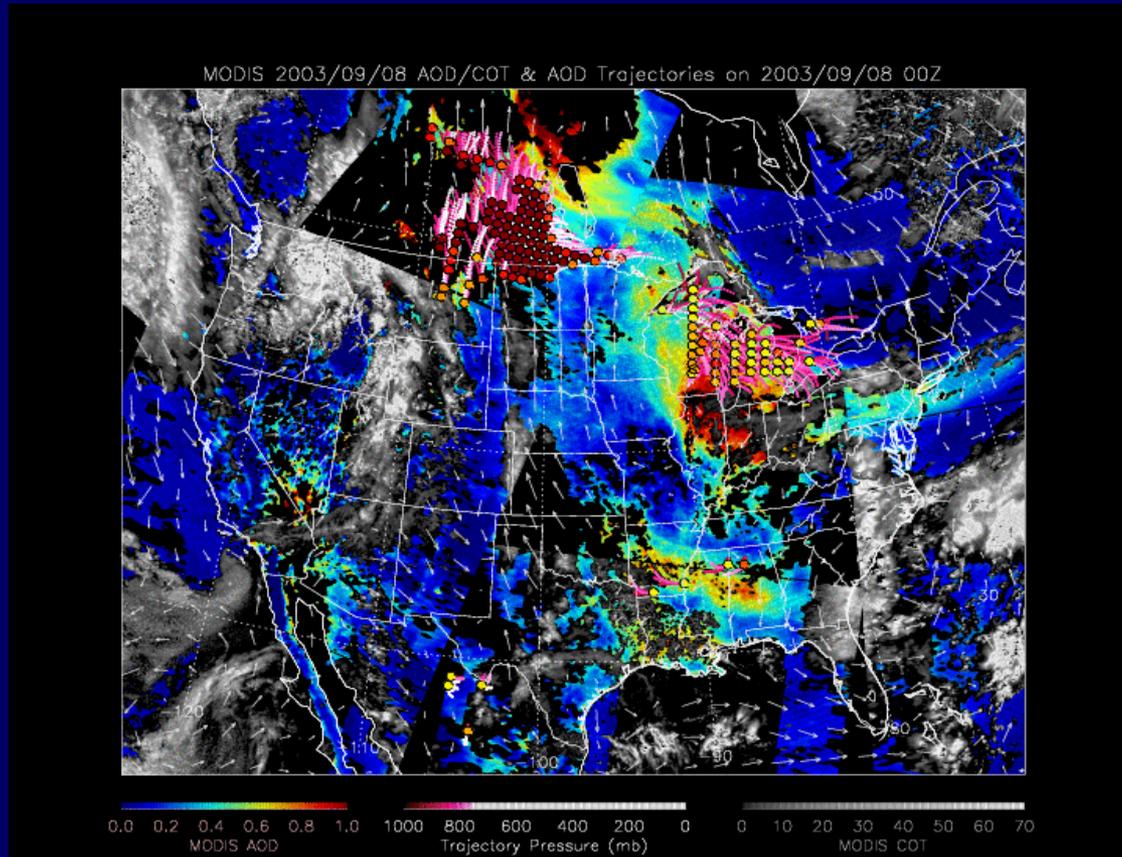
21Z Sep. 7

48 hour AOD trajectories
initialized at ~15Z Sep. 7



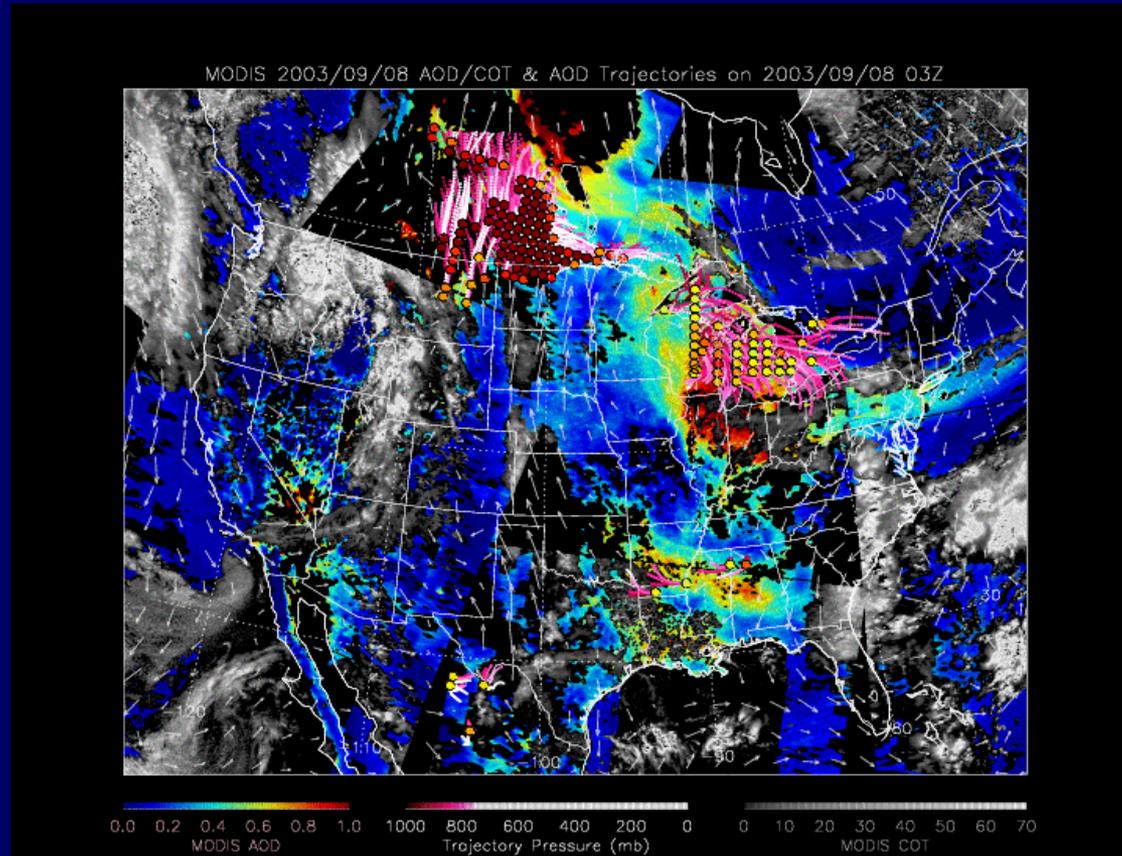
00Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 7



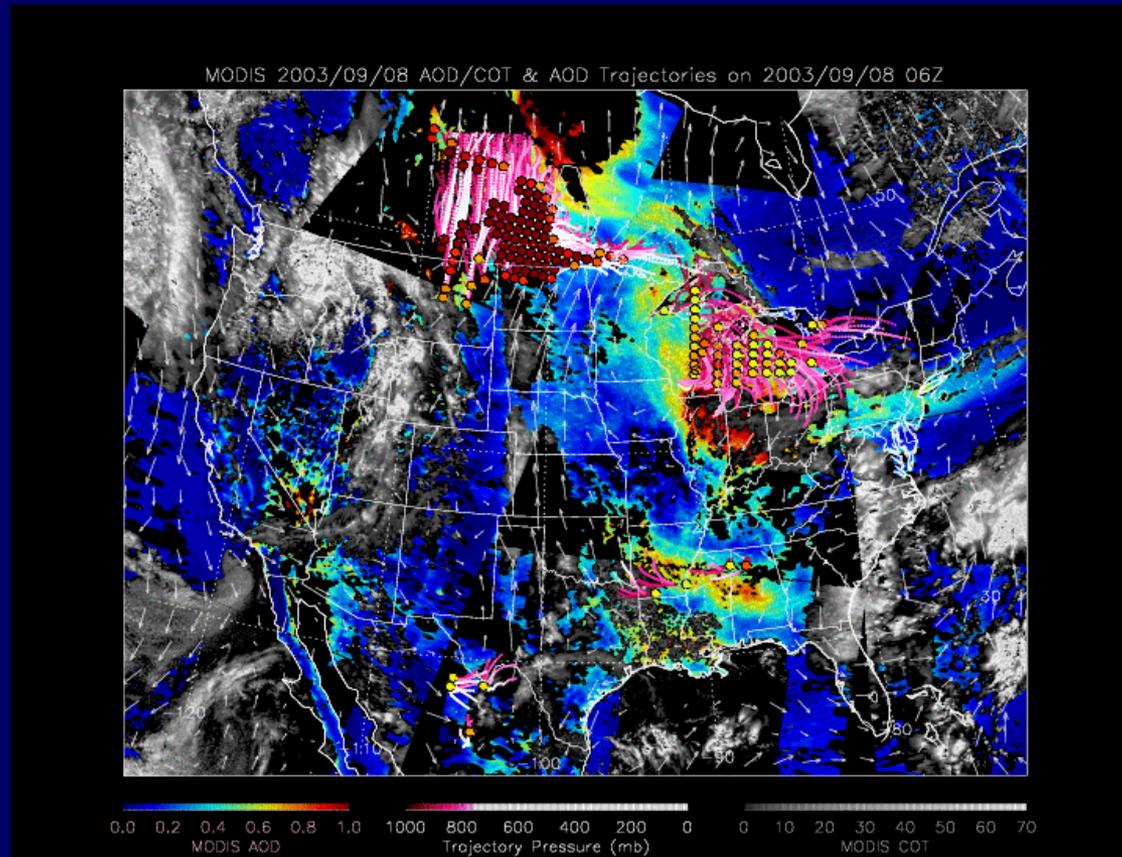
03Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 7



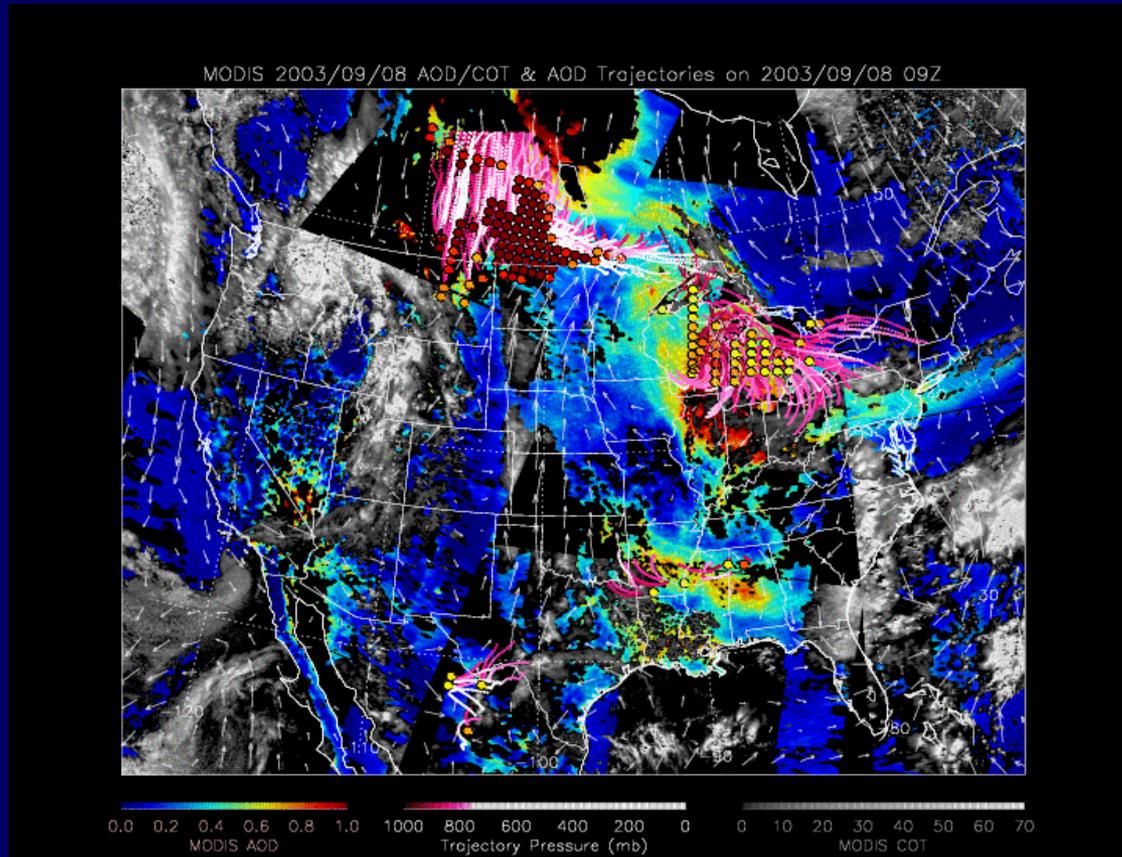
06Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 7



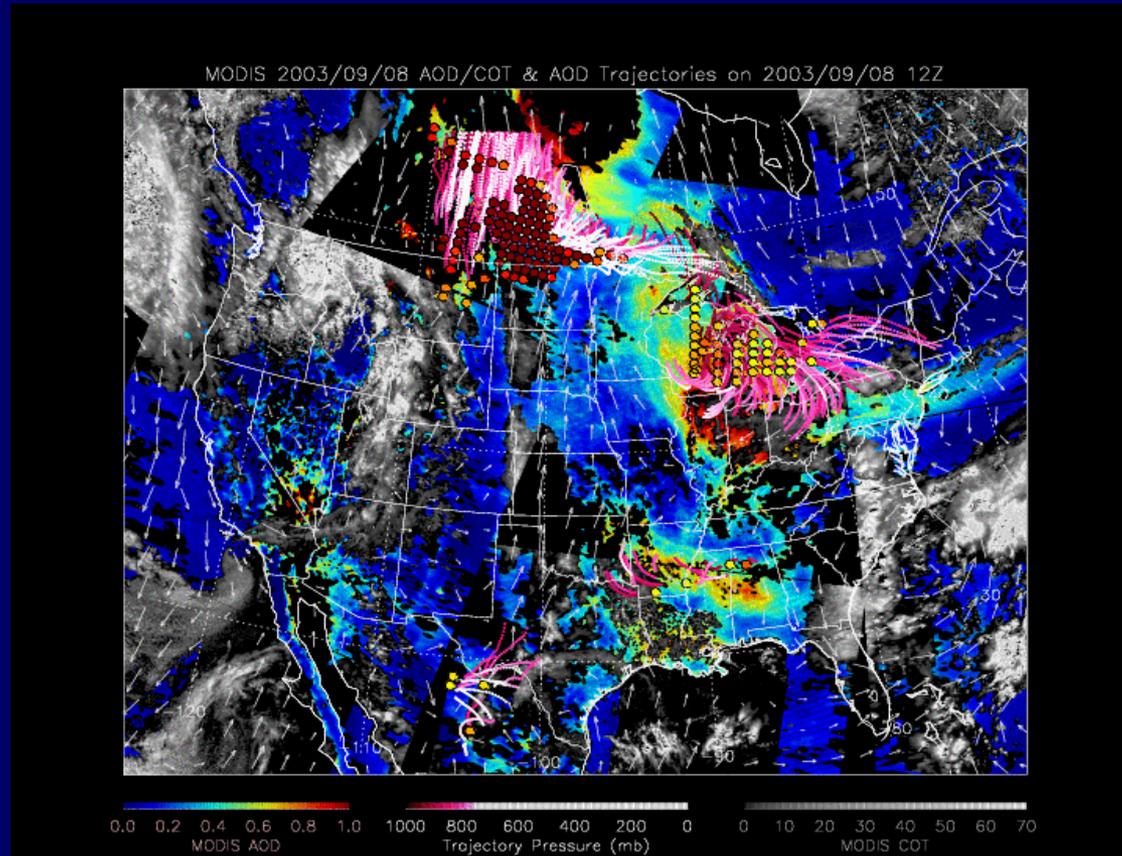
09Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 7



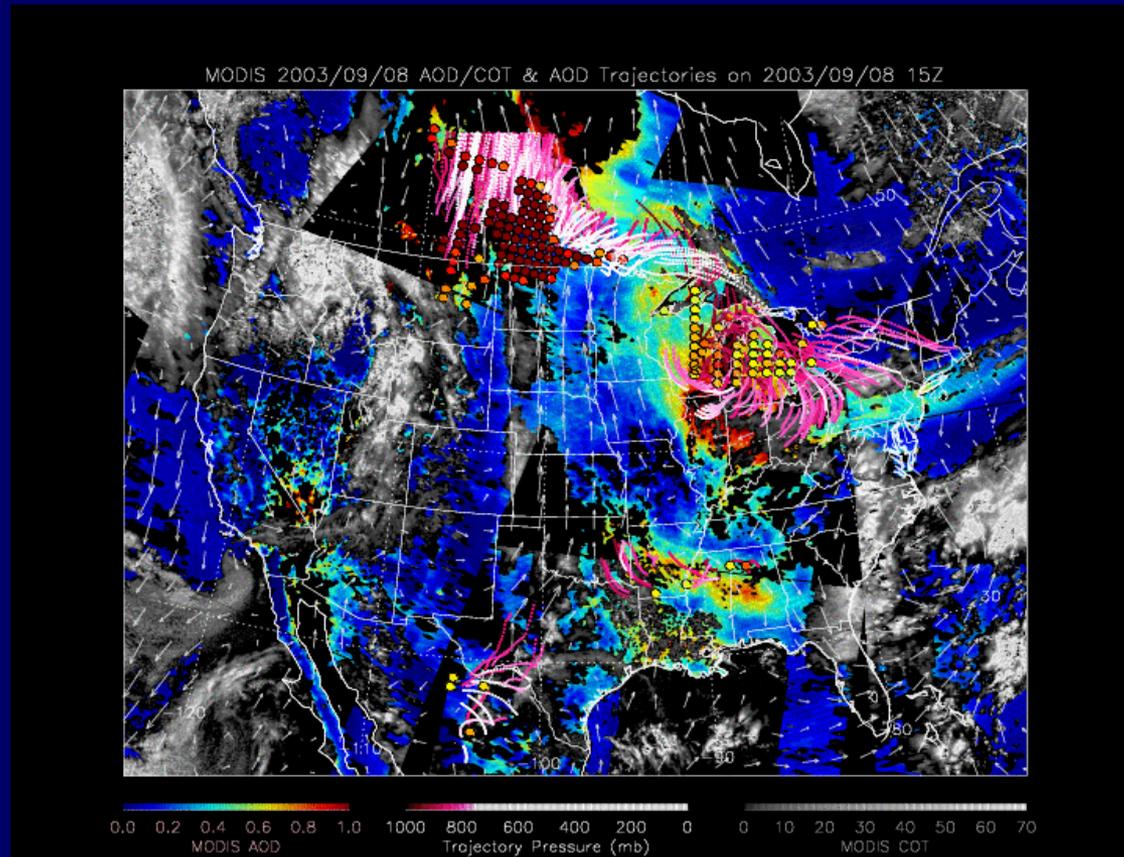
12Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 7



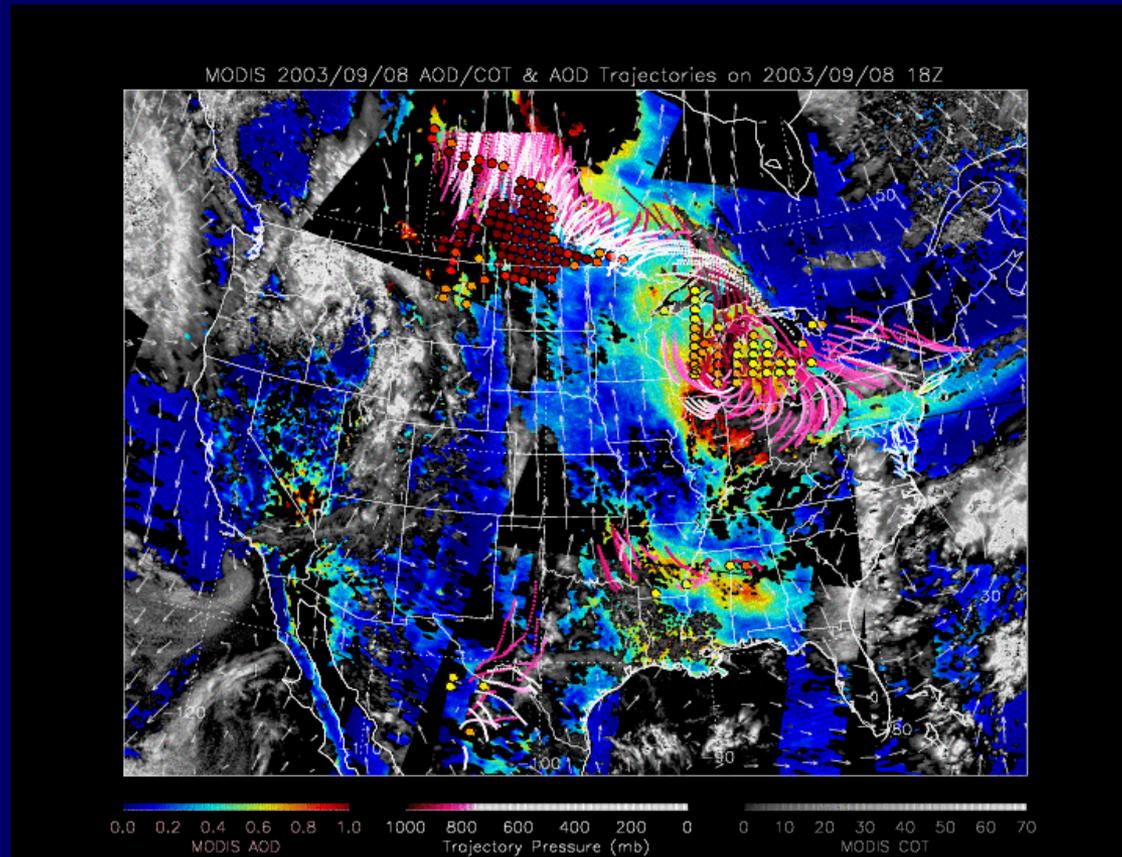
15Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 7



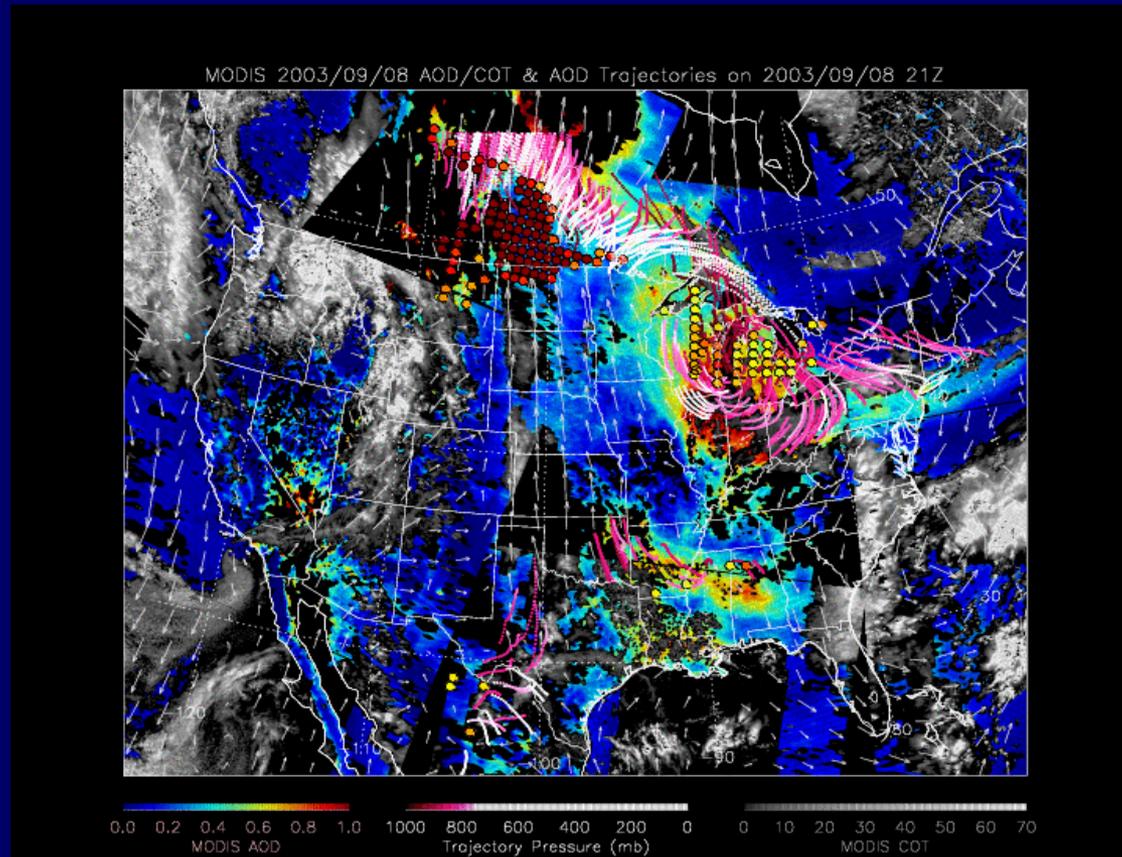
18Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 7



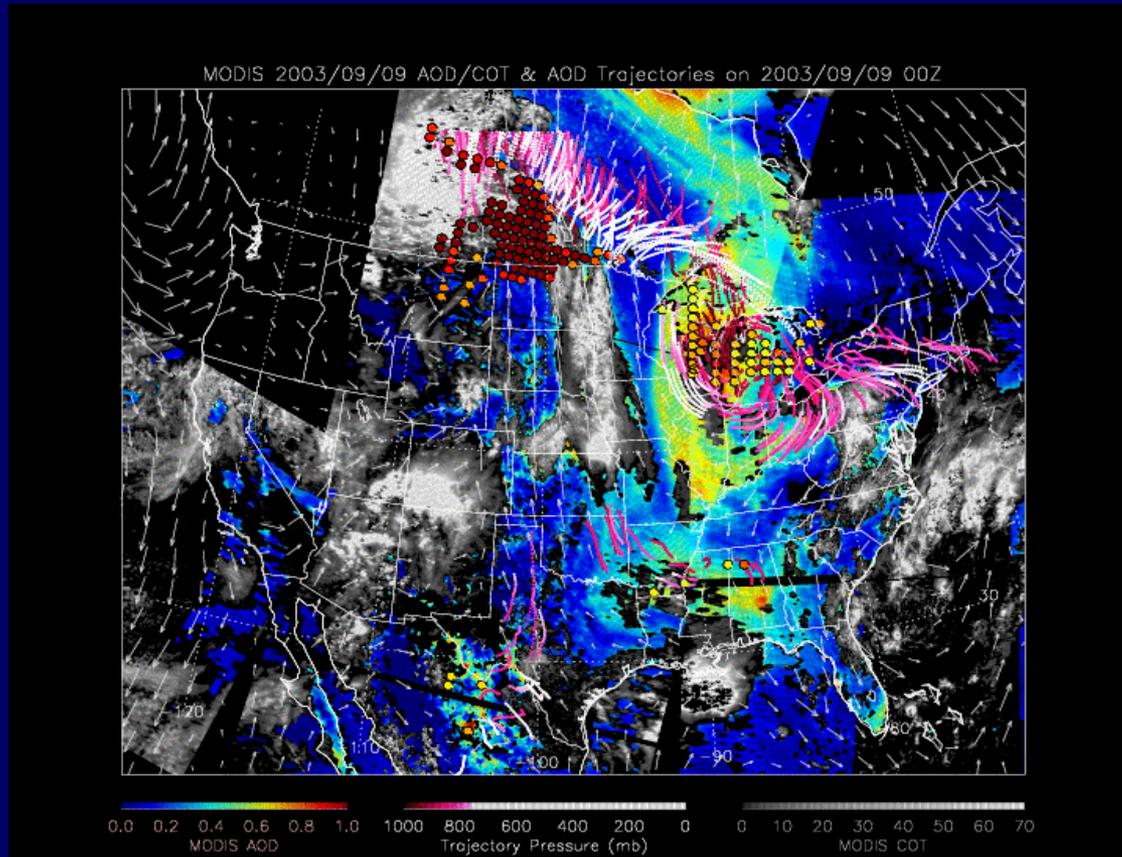
21Z Sep. 8

48 hour AOD trajectories
initialized at ~15Z Sep. 7



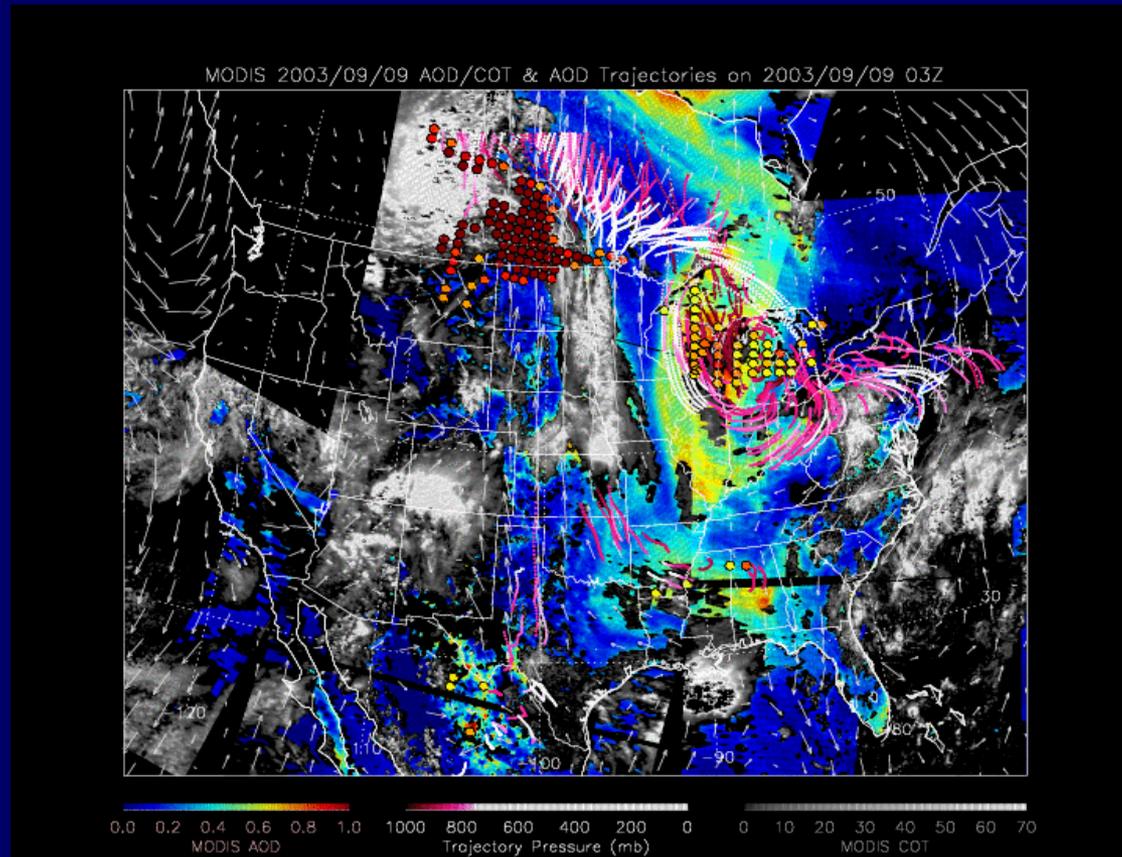
00Z Sep. 9

48 hour AOD trajectories
initialized at ~15Z Sep. 7



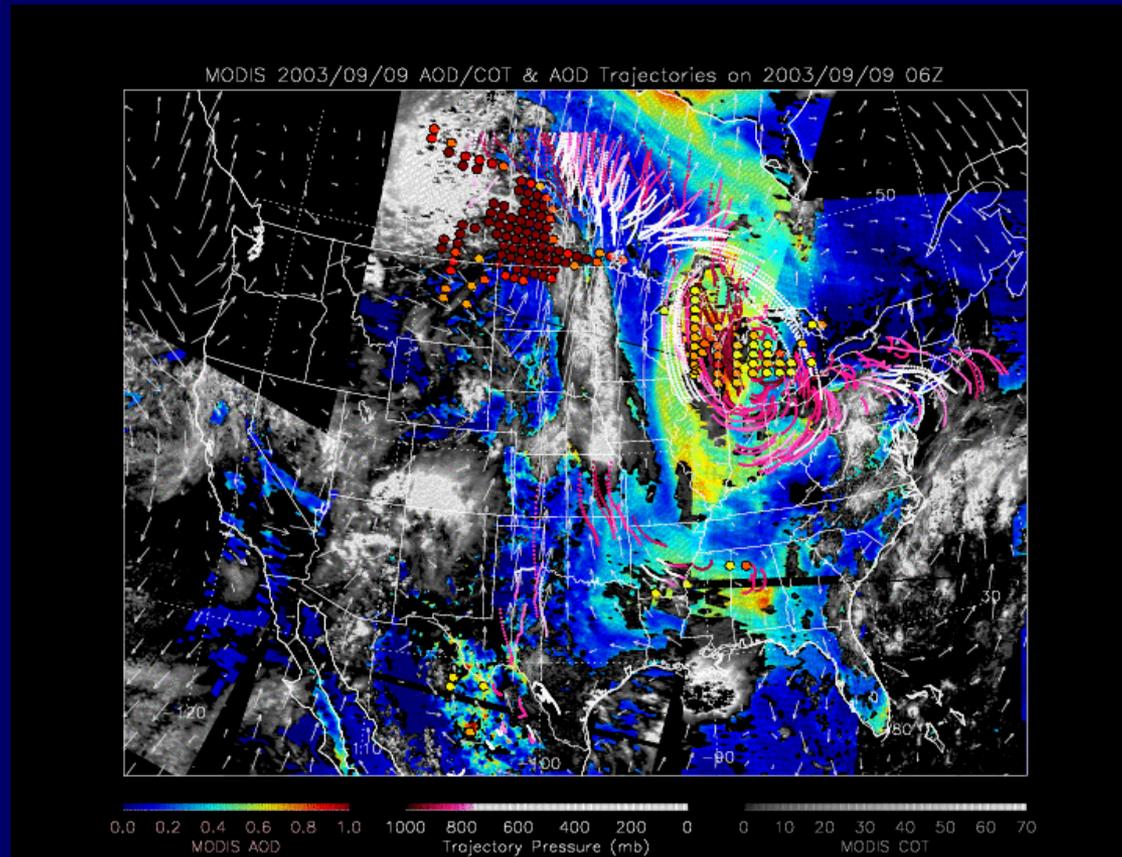
03Z Sep. 9

48 hour AOD trajectories
initialized at ~15Z Sep. 7



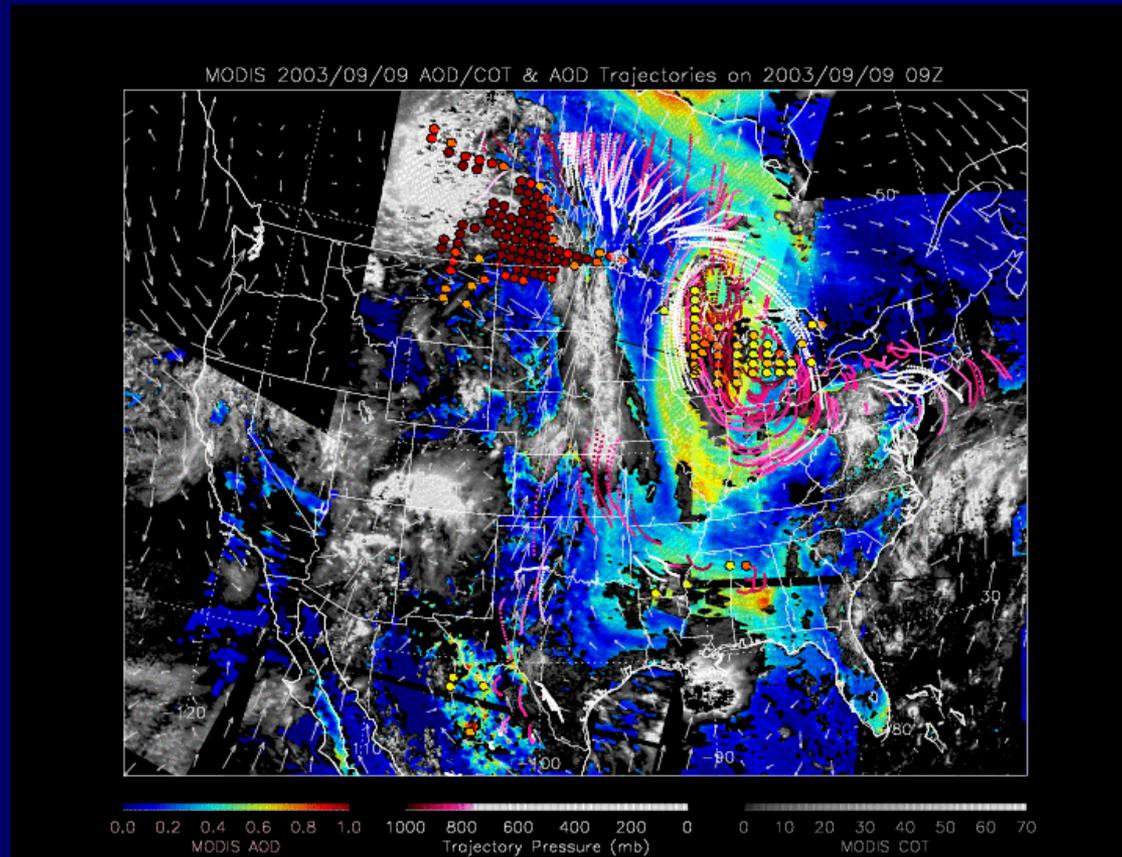
06Z Sep. 9

48 hour AOD trajectories
initialized at ~15Z Sep. 7



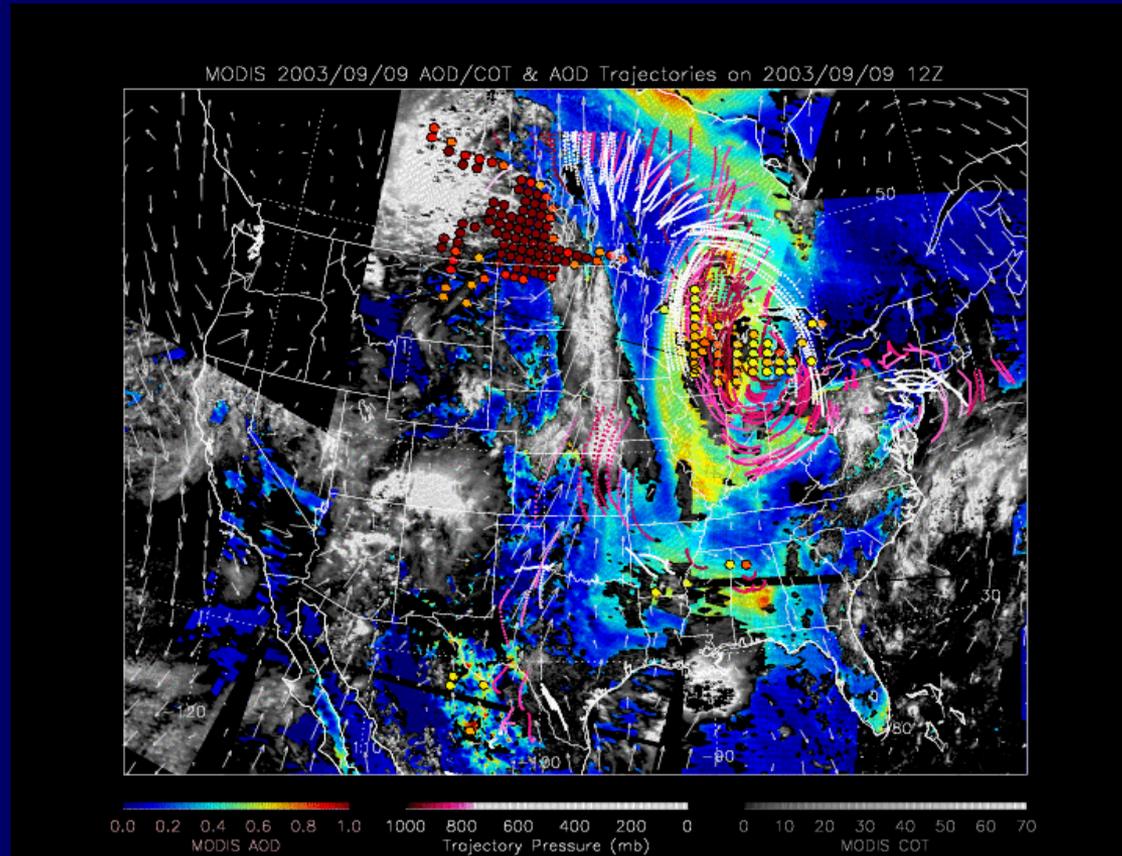
09Z Sep. 9

48 hour AOD trajectories
initialized at ~15Z Sep. 7



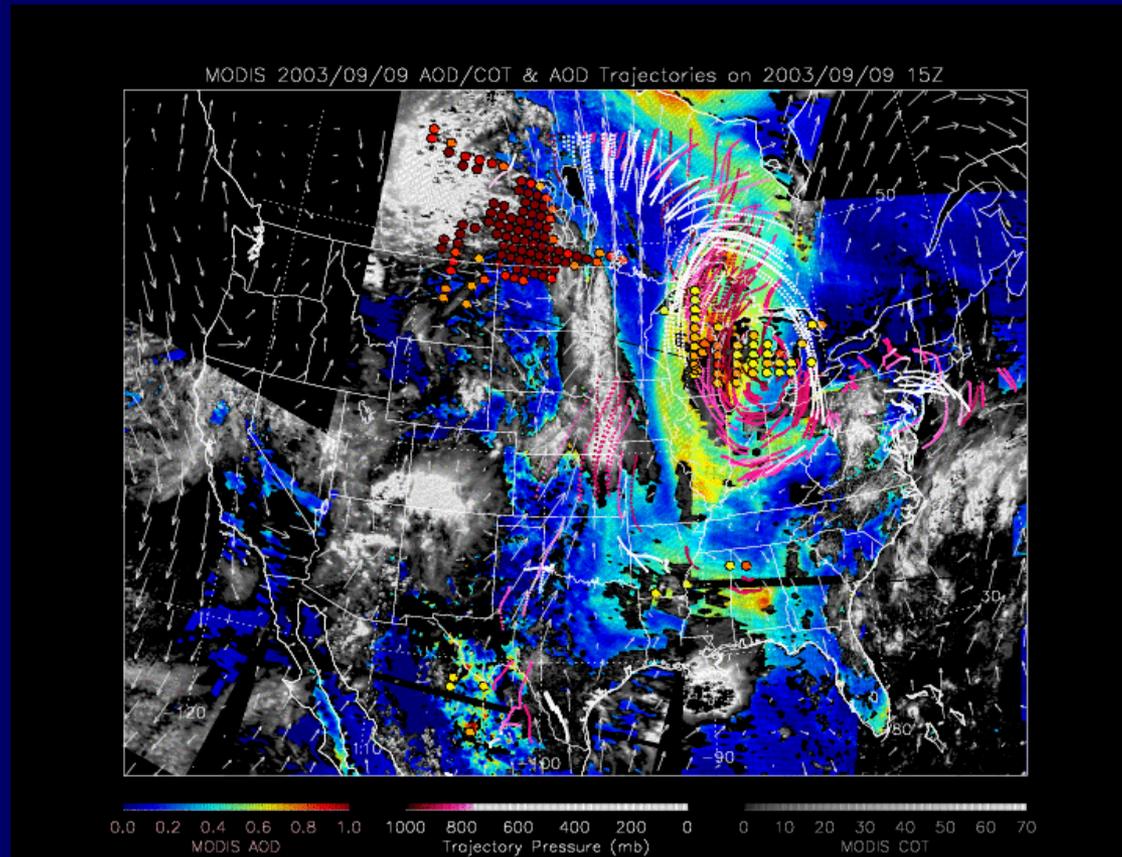
12Z Sep. 9

48 hour AOD trajectories
initialized at ~15Z Sep. 7



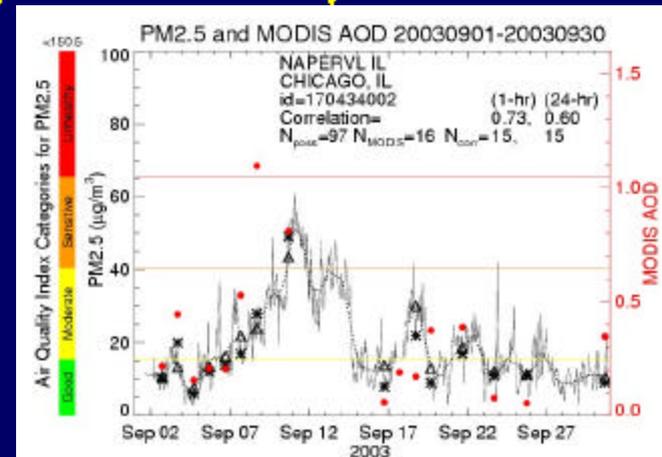
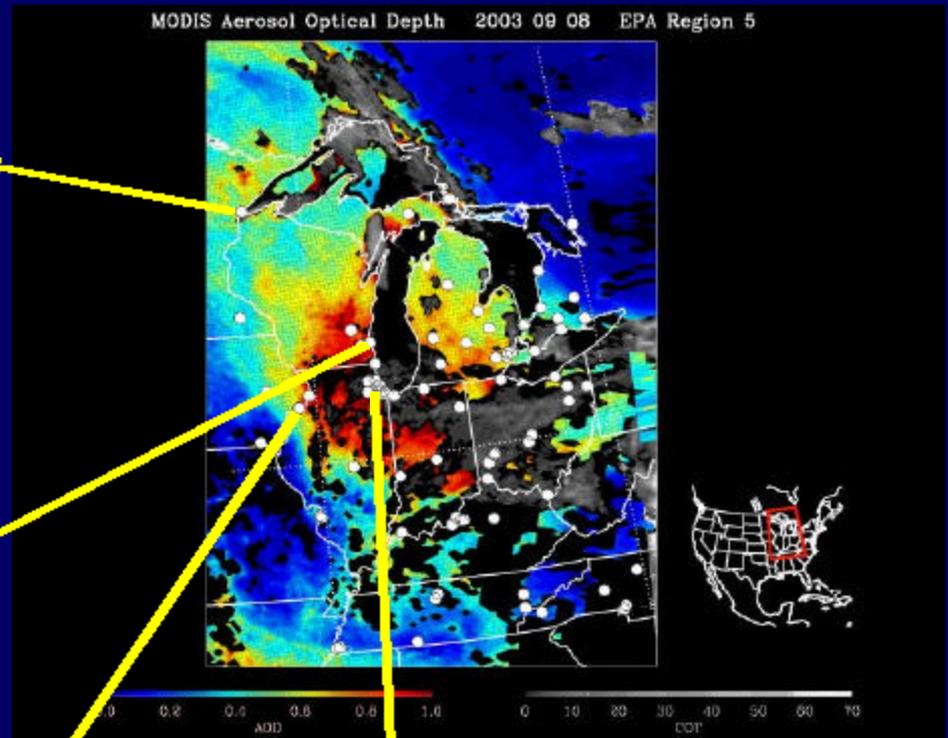
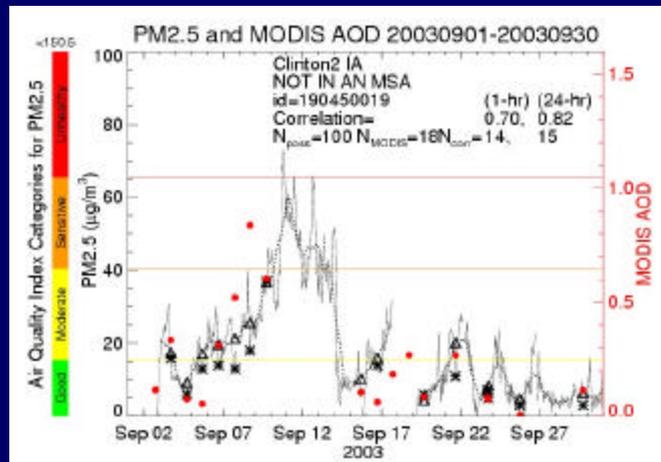
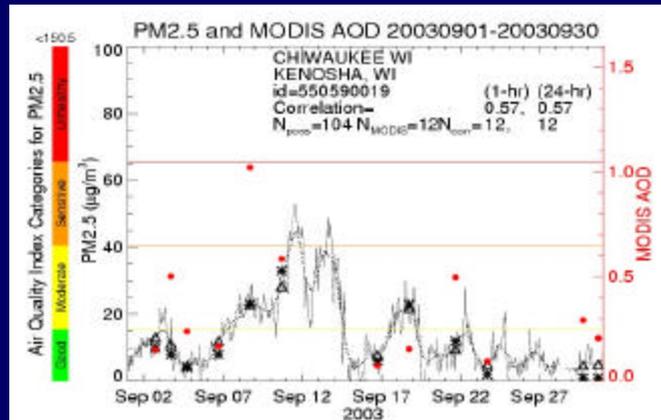
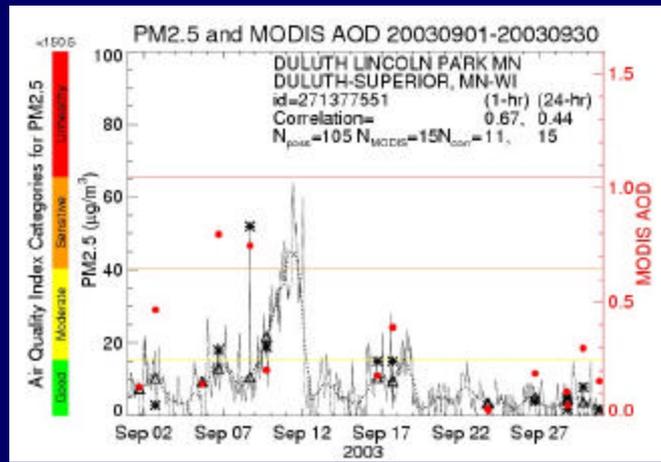
15Z Sep. 9

48 hour AOD trajectories
initialized at ~15Z Sep. 7

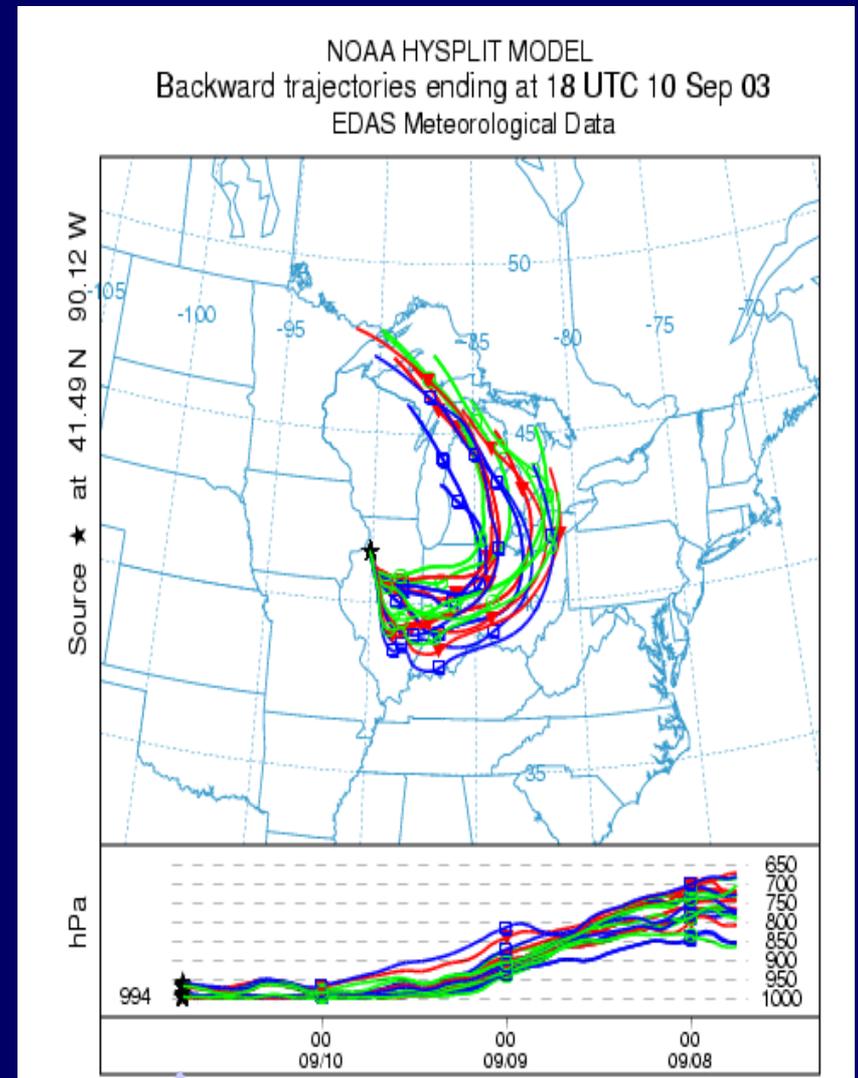
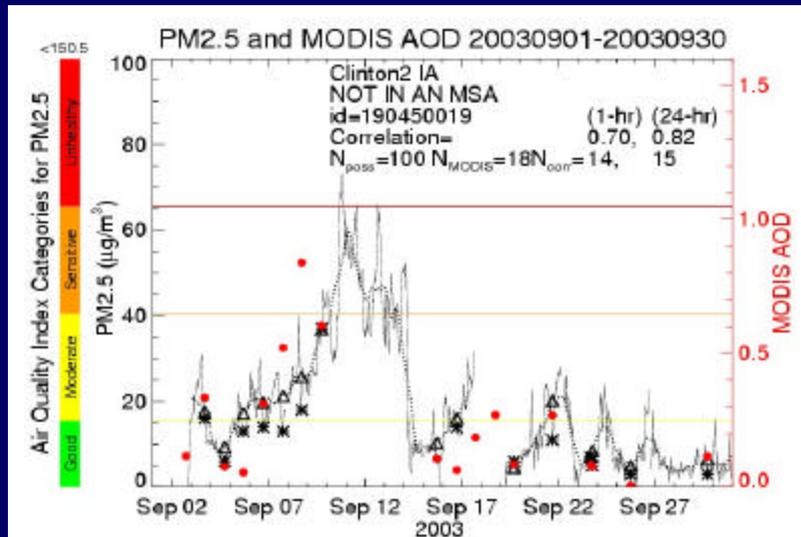


End of Trajectories #2

MODIS AOD Sep. 08

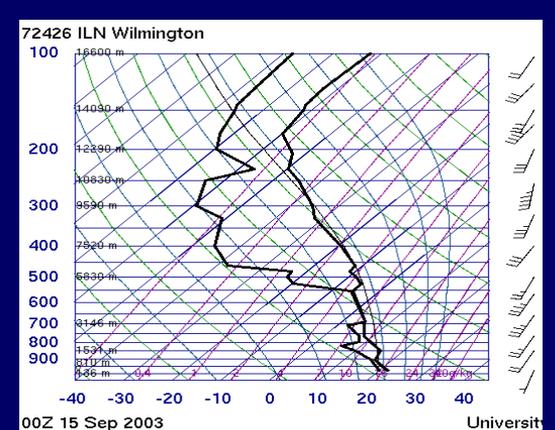
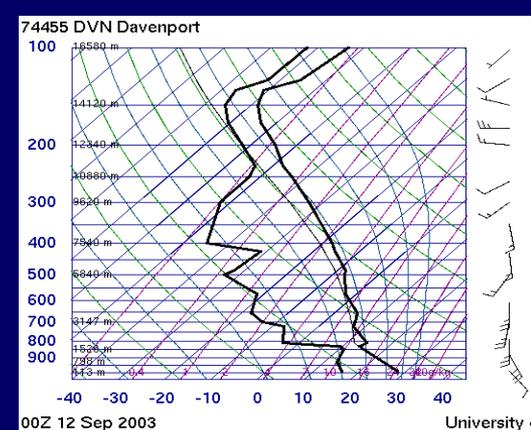
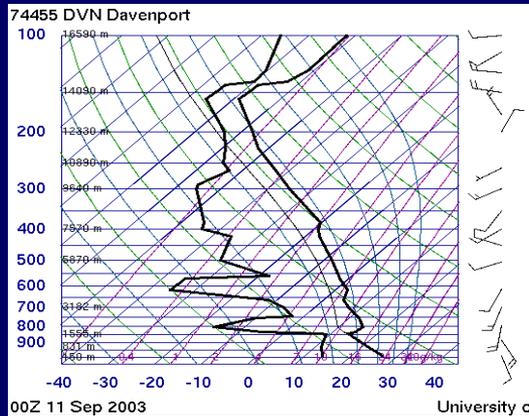
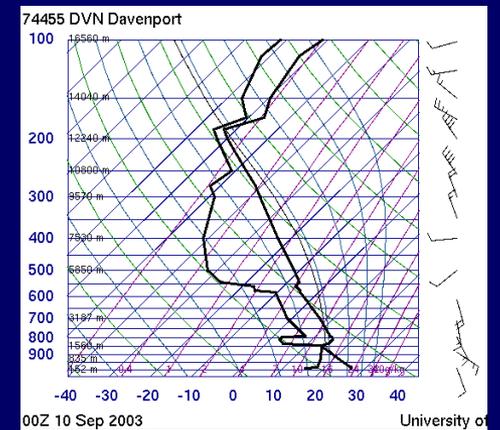
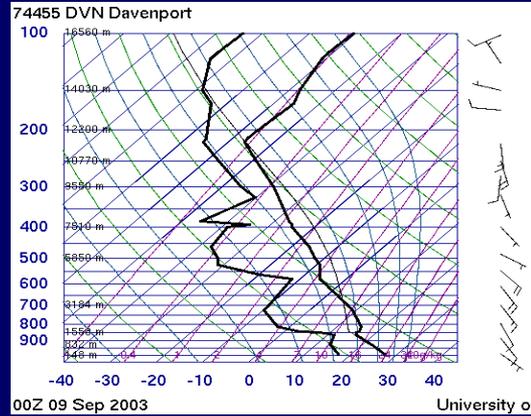
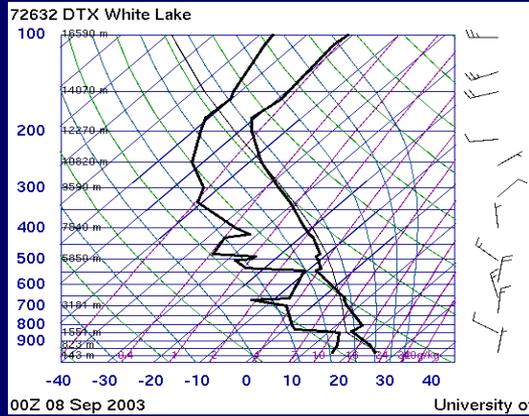


***Elevated surface PM2.5
influenced by descent of
high AOD within high
pressure system***



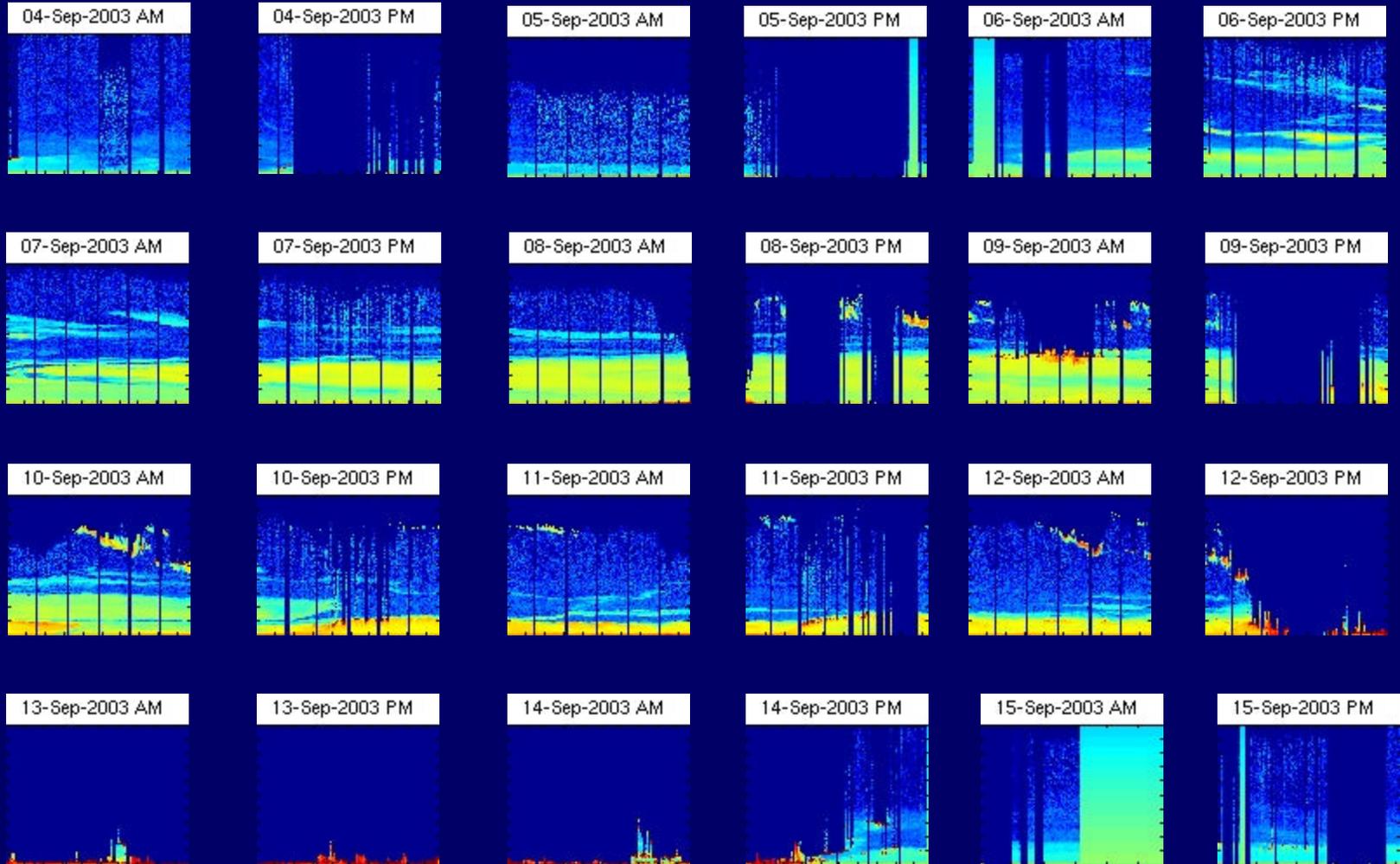
18Z 9/10

Midwest soundings show a pronounced inversion existed over September 6 – 15 capping boundary layer ~1.5km



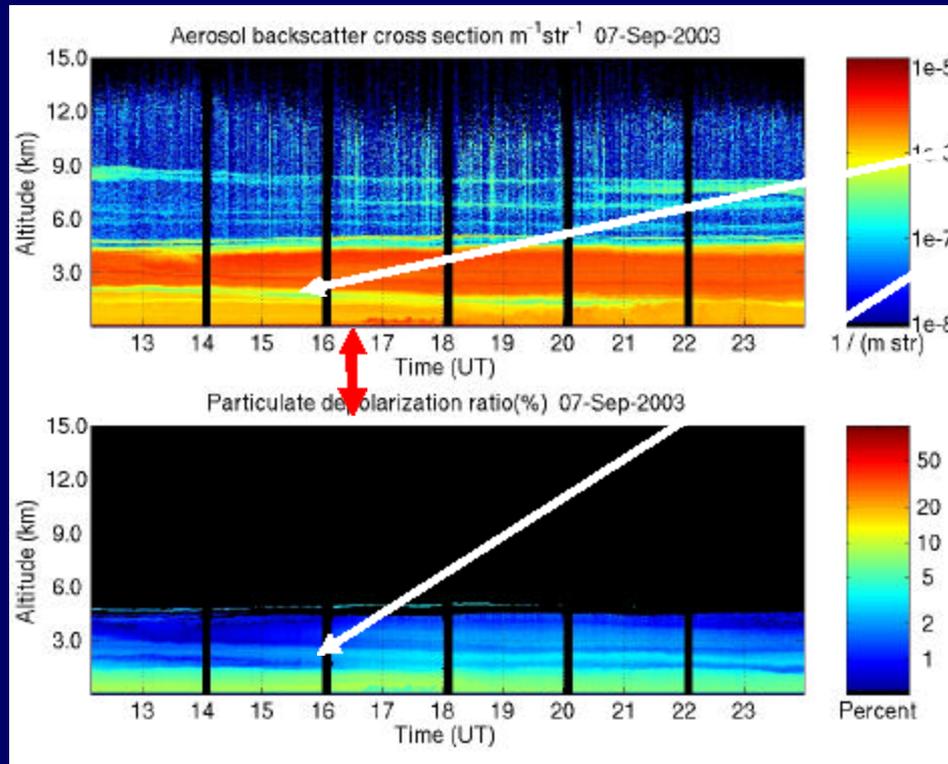
Acknowledgment: MacDonald et al., The Influence of Meteorological Phenomena on Midwest PM_{2.5} Concentrations: A Case Study Analysis, 2004 NAQC Short Courses, Baltimore, MD

High Spectral Resolution Lidar
Aerosol backscatter cross section $m^{-1} \text{ str}^{-1}$
SSEC Univeristy of Wisc.
04 – 15 September 2003



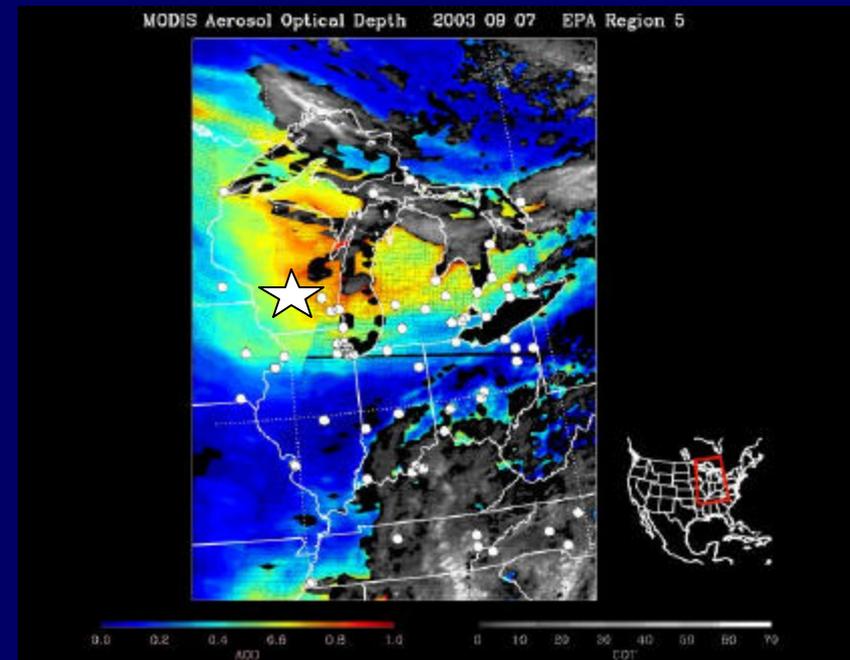
Source: SSEC University of Wisconsin Lidar Group

September 7 SSEC HSRL shows stratified aerosol layers between surface - ~5 km.



HSRL data shows a thin separation between aerosol layers ~1.5km, possibly associated with inversion.

MODIS AOD Sep. 07



Summary and Conclusion

- Successfully achieved goal.
 - Fusion and delivery of multiple input data sets in near-real-time.
 - Select group of forecasters routinely used the products to gain an understanding of large scales aerosol events.
- Timeliness of satellite data an issue in forecast cycle.
 - Implementation of MODIS AOD Direct Broadcast will help.
- Case study shows that utilizing satellite and surface observations, combined with trajectory analysis, can provide a powerful tool for monitoring and interpreting PM transport events.

Summary and Conclusion

- Case study illustrates the importance in proper characterization of the boundary layer.
- Limitations exist due to lack of vertical distributions of aerosols.

Future Work

- Transition from prototype to a pre-operational stage by late-spring 04.
- Refinements to current products based on forecaster feedback.
- Provide as a pre-operational forecast tool to all AQ forecasters linked with AIRNow.
- Researching feasibility to provide a boundary layer MODIS AOD product.

MODIS Aerosol Optical Depth ($\hat{\sigma}_a$)

Aerosol optical depth ($\hat{\sigma}_a$) is a measure of extinction of direct solar beam by transmittance through the atmosphere. (i.e., how much sunlight is prevented from traveling through a column of atmosphere). $\hat{\sigma}_a$ consists of additive contributions from Rayleigh scattering, gaseous absorption, and aerosol scattering and absorption.

$$\hat{\sigma}_a = \int_0^{\text{TOA}} \hat{\sigma}_{ext}(z) dz = \hat{\sigma}_{ext}(0) \times H_{eff} = f(rh) \times Q_{dext}(0) \times m_{dear}(0) \times H_{eff}$$

└─ $f(\text{ aerosol type})$

Higher AOD values indicate higher column aerosol loading, therefore lower visibility

Source: Kaufman and Fraser, 1983

Some Limitations of MODIS $\hat{\sigma}_a$

- Can not “see” through clouds. If pixel is dominated by clouds, no $\hat{\sigma}_a$.
- Present algorithm cannot distinguish between high AOD ($\hat{\sigma}_a > 3.0$) and low COT; result is pixel reported as cloudy.
- Competing processes of surface reflection and aerosol backscatter prevent consistent data retrievals over areas with high surface albedo.