Integration of Aerosol Observations

Objectives, Methodology, and Science Questions

Overall Objective:

Improve the interpretation of satellite observations to diagnose near-surface conditions relating to air quality.

Methods:

1) Relate column observations to surface conditions for aerosols and key trace gases O3, NO2, and CH2O
2) Characterize differences in diurnal variation of surface and column observations for key trace gases and aerosols
3) Examine horizontal scales of variability affecting satellites and model calculations

Some science questions regarding aerosols and PM2.5:

- **What is the relationship between satellite aerosol measurements (e.g. AOT) and measured surface PM2.5?**
- **Can satellite measurements be used to adequately characterize PM2.5 spatial gradients/distributions?**
- **How do various factors affect the relationship between satellite aerosol measurements and surface PM2.5?**
  - **PBL height**
  - **Vertical distribution**
  - **Meteorology (e.g. relative humidity)**
  - **Surface reflectance**
  - **Aerosol optical and microphysical properties**

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  - **Aerosol optical and microphysical properties**

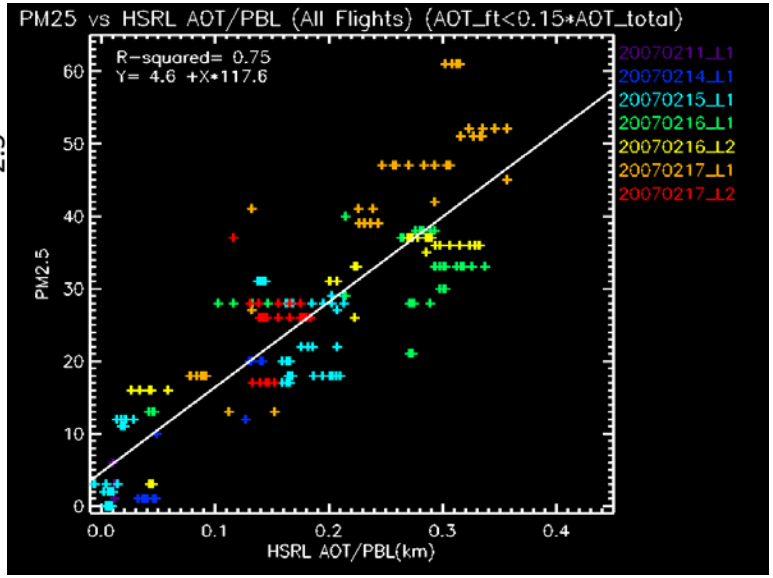
Examination of relationship between surface PM2.5 and satellite (MODIS) measurements of AOT over San Joaquin Valley – February 2007

Science Questions:

- What is the relationship between satellite AOT and measured surface $PM_{2.5}$?
- What are the effects of PBL height and vertical aerosol distributions on the relationship between column AOD and surface $PM_{2.5}$?

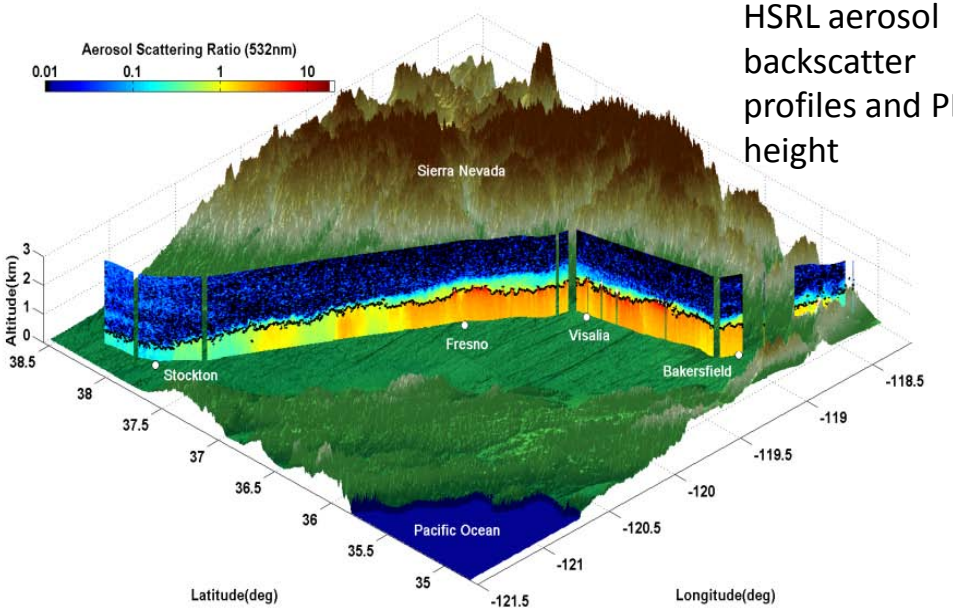
Airborne HSRL data used to:

- define PBL height
- evaluate MODIS research AOT retrievals
- determine AOT above/below PBL



AOT/PBL Height (HSRL)

San Joaquin Valley, California



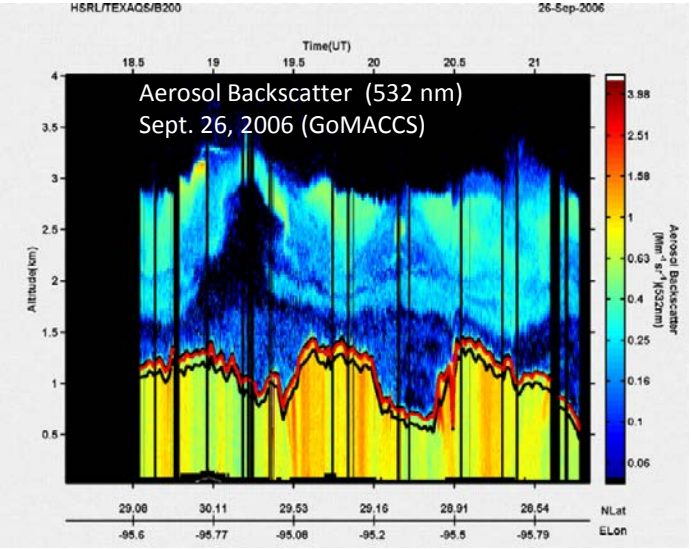
HSRL aerosol backscatter profiles and PBL height

Normalizing AOT with PBL height (z_i) significantly improves correlation with surface $PM_{2.5}$ (r^2 increases from 0.36 to 0.75)

(From Al-Saadi, Szykman, et al. AMS Meeting Presentation 2008)

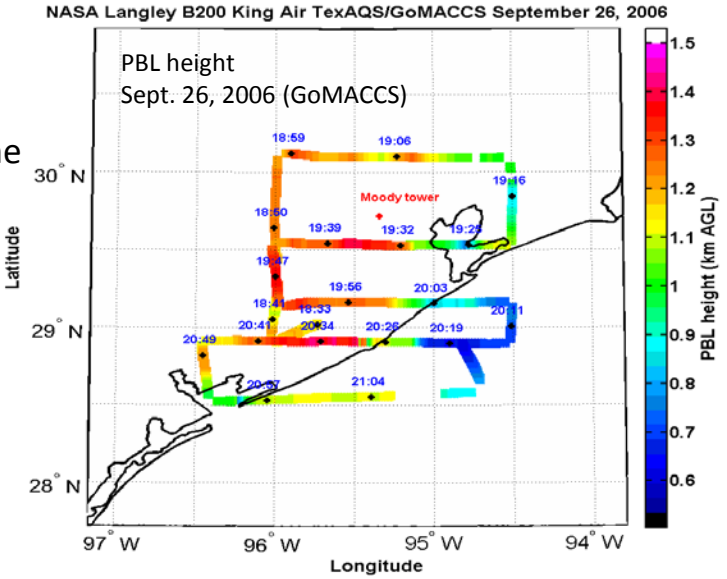
Planetary Boundary Layer (PBL) Height Retrievals and AOT from High Spectral Resolution Lidar (HSRL)

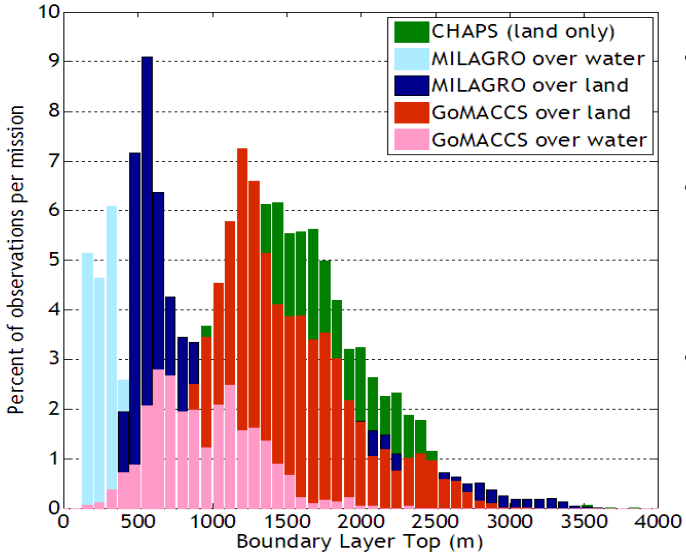
Airborne HSRL provides measurements of the spatial variability of PBL height



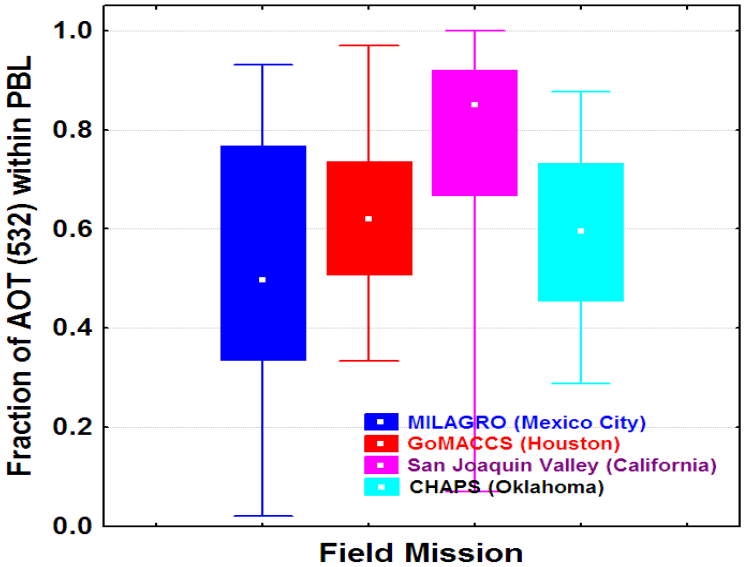
HSRL data used to determine:

- PBL height
- Upper and lower limits of the backscatter transition (i.e. entrainment) zone
- Fraction of aerosol optical thickness within PBL



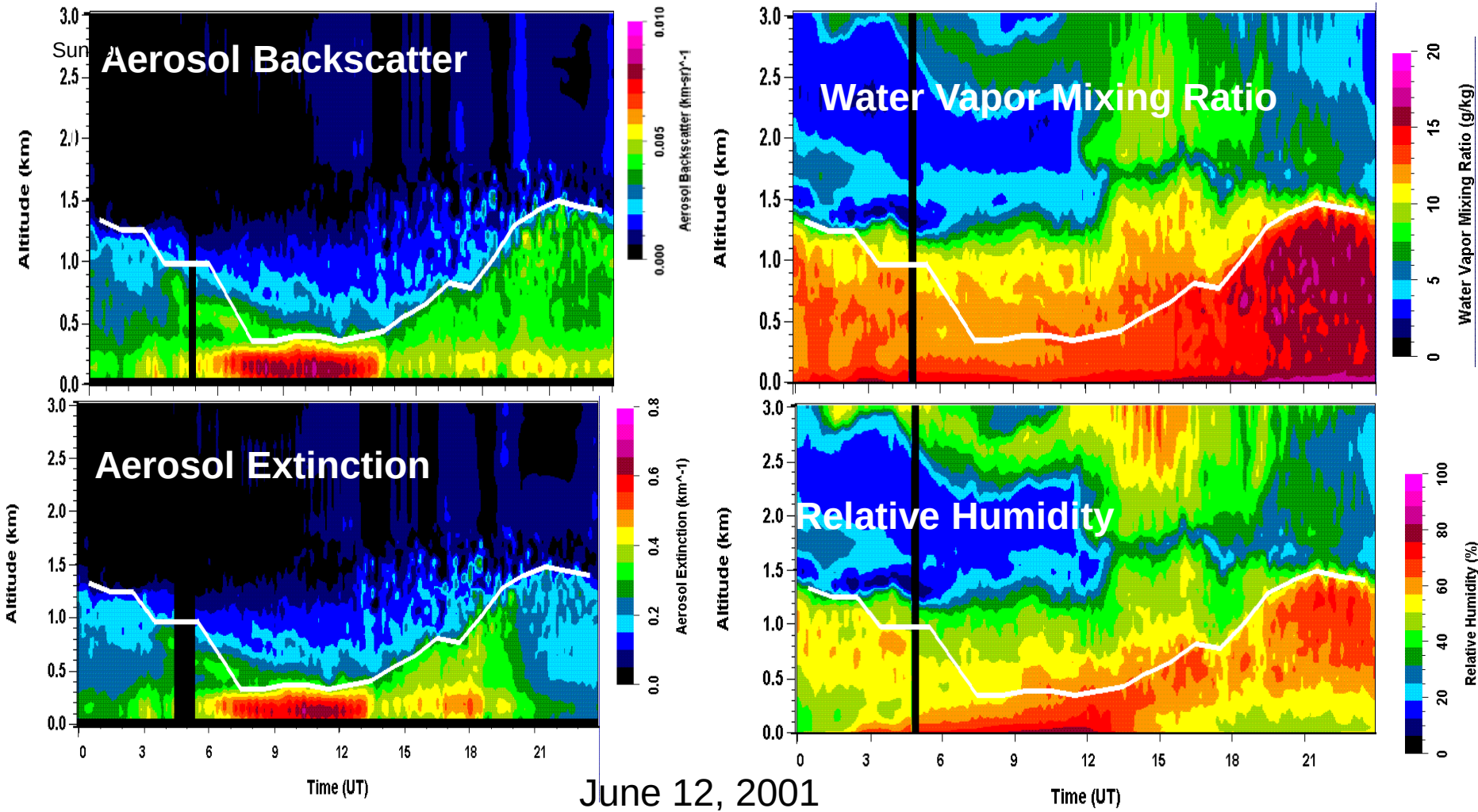


- PBL heights over water significantly lower than PBL heights over land
- Large fraction (40-50%) of AOT above PBL during MILAGRO, GoMACCS, CHAPS
- Most (80-90%) of AOT within PBL during San Joaquin Valley Mission



Surface Based Lidar PBL Height Retrievals

- Surface based lidar provides temporal variation of PBL height
- Example here is from DOE SGP Raman Lidar which operates 24/7 and measures water vapor, aerosol backscatter, extinction profiles



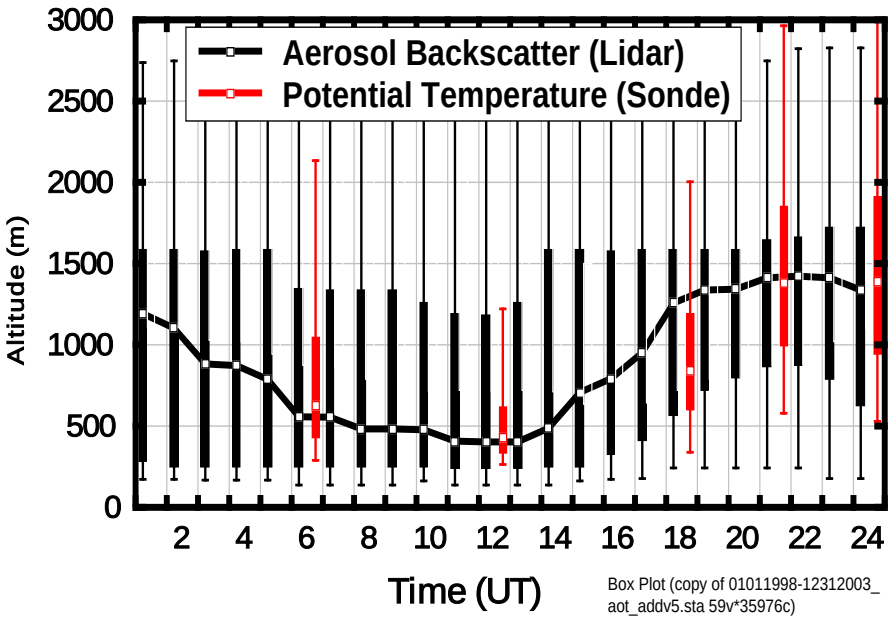
June 12, 2001

Surface Based Lidar PBL Height Retrievals

- Surface based lidar provides temporal variation of PBL height
- Example here is from DOE SGP Raman Lidar which operates 24/7 and measures water vapor, aerosol backscatter, extinction profiles
- At SGP (Oklahoma), amount of AOT within PBL
  - varies with time of day
  - does not vary significantly with season or AOT
- Significant fraction of AOT (>25%) is above PBL

Boundary Layer Height (1998-2003)

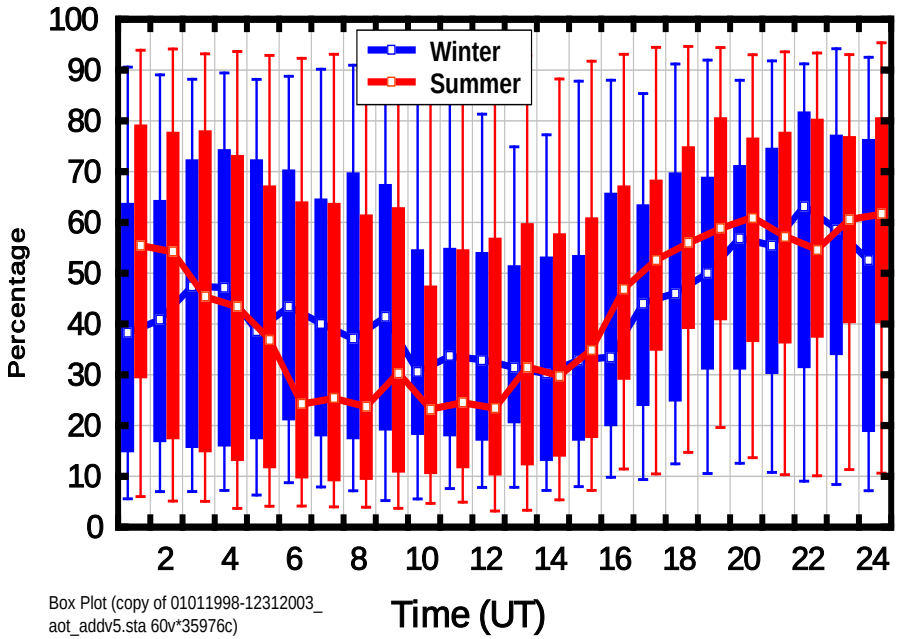
Median; Box: 25%, 75%; Whisker: 5%, 95%



Box Plot (copy of 01011998-12312003_ aot_addv5.sta 59v*35976c)

Percentage of AOT below BL Height

Median; Box: 25%, 75%; Whisker: 5%, 95%



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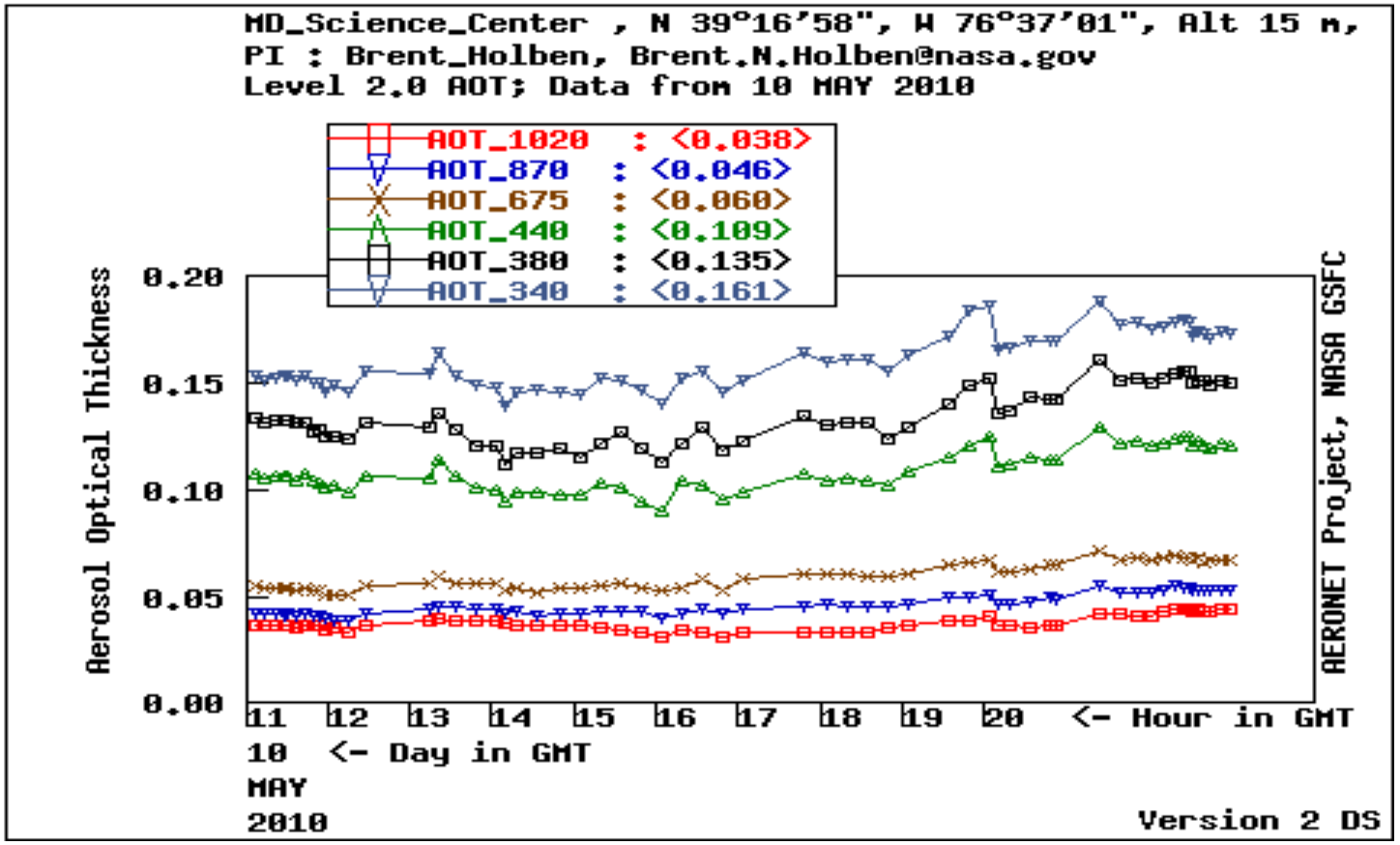
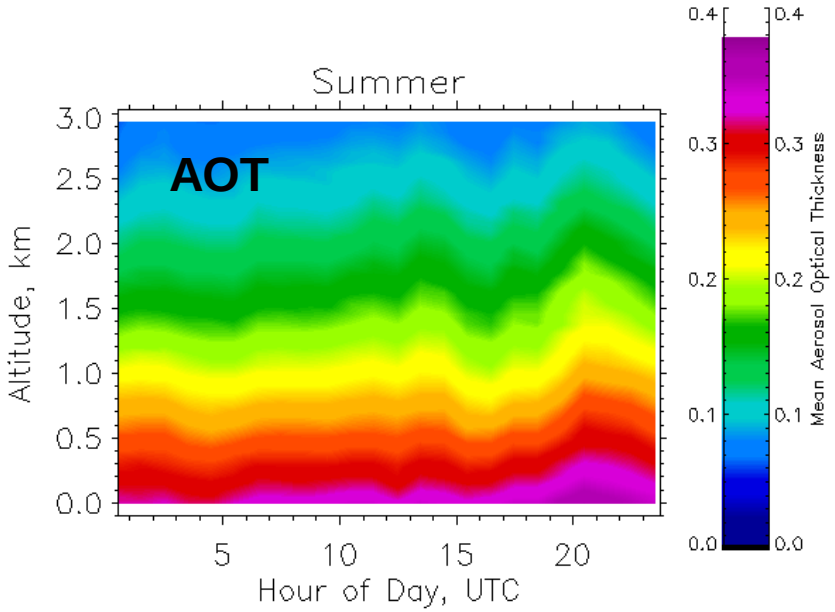
Diurnal AOT Variability from AERONET

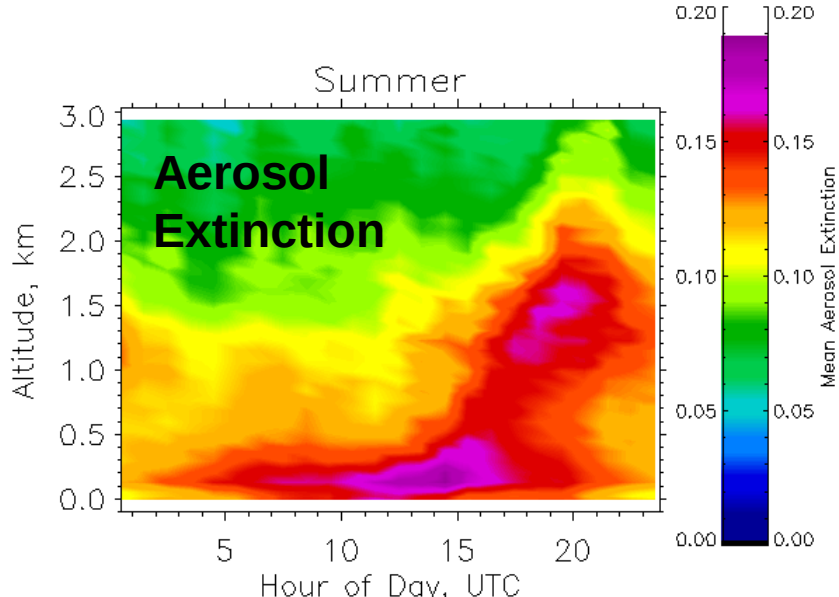
AERONET data can provide measurements of temporal variability of AOT and aerosol properties

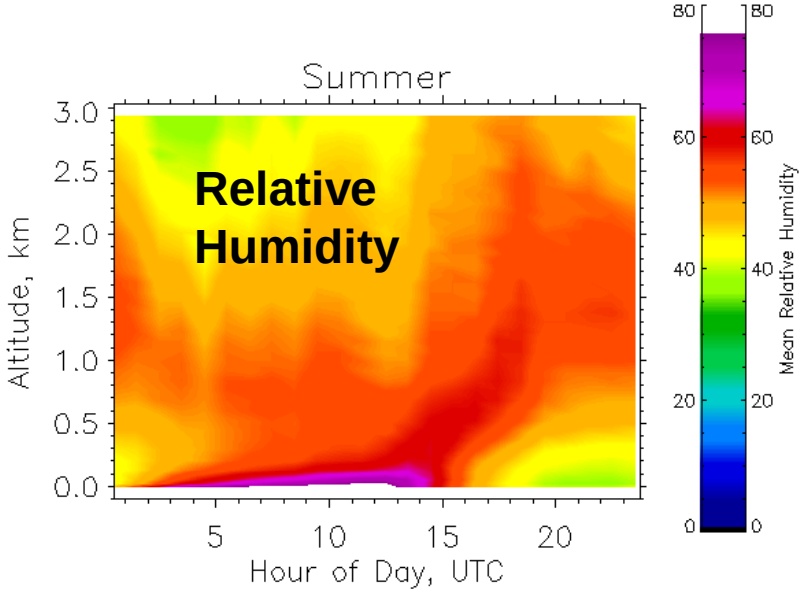


Temporal variability of AOT and aerosol vertical distribution



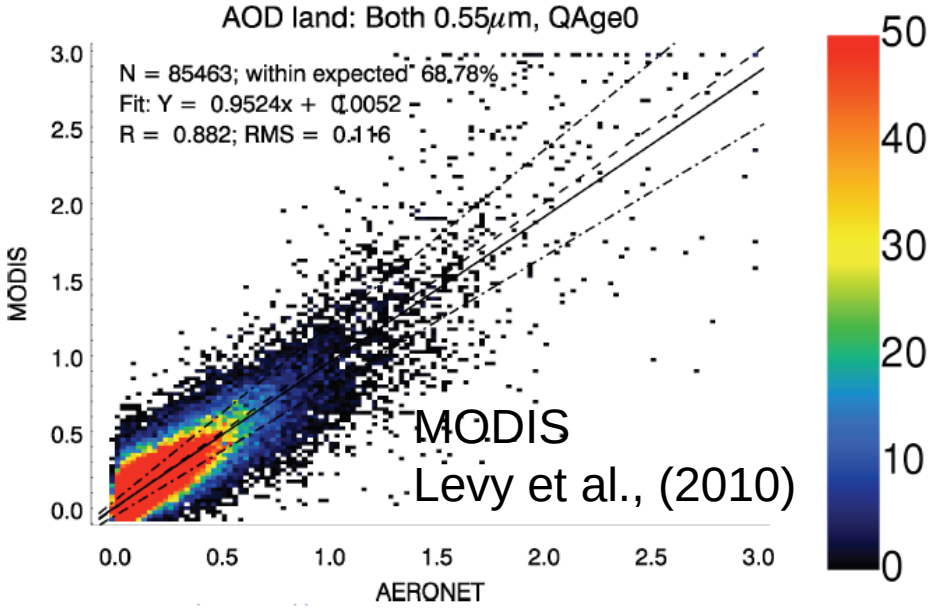
- DOE ARM SGP Raman lidar data 1998-2010
- Relatively small diurnal variability of AOT
- Large diurnal variability in vertical distribution of aerosol extinction
- Diurnal variability of aerosol extinction related to relative humidity
- Surface measurements will be critical to examine diurnal variability of aerosol optical and microphysical properties and RH near surface





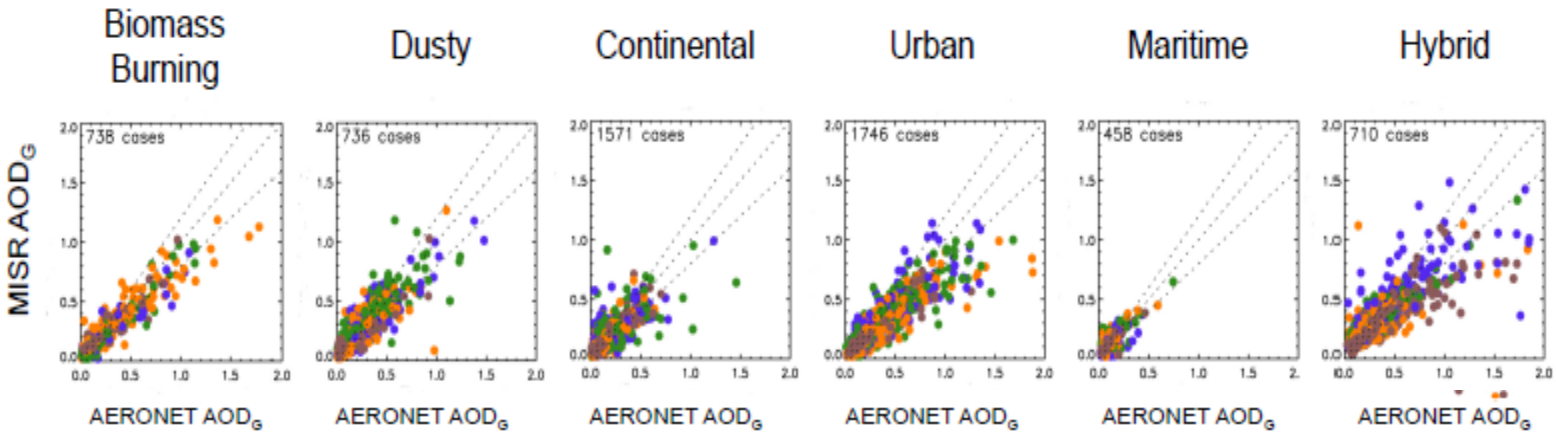
Assessment of Satellite Aerosol Measurements

AERONET Assessments of Satellite Aerosol Measurements



MODIS
Levy et al., (2010)

AERONET measurements have been the standard measurements used to assess satellite aerosol retrievals



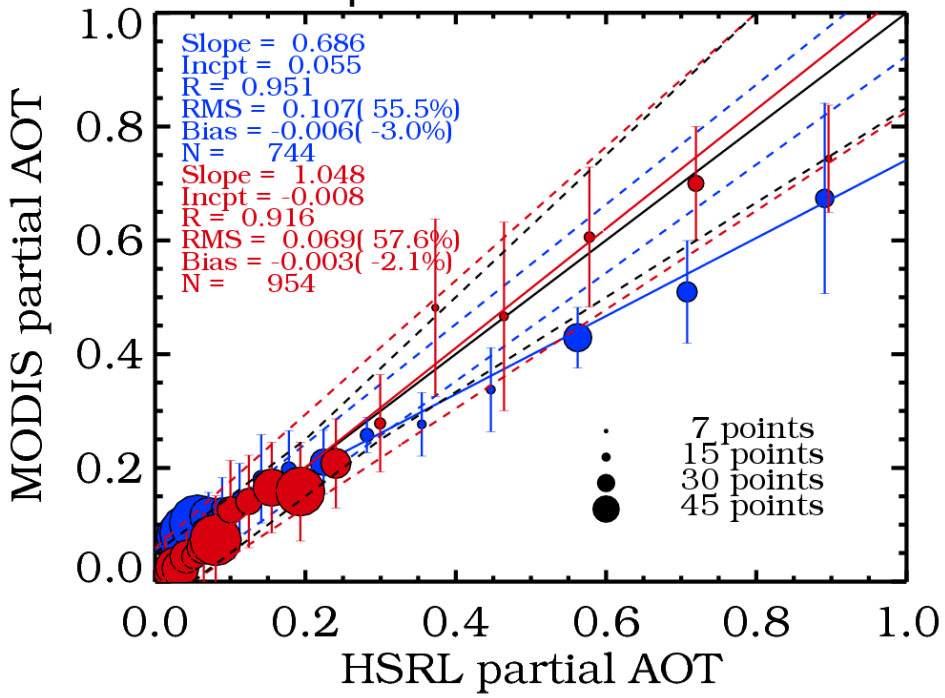
MISR Kahn et al. (2010)

HSRL Data Used to Assess Satellite Aerosol Retrieval Performance

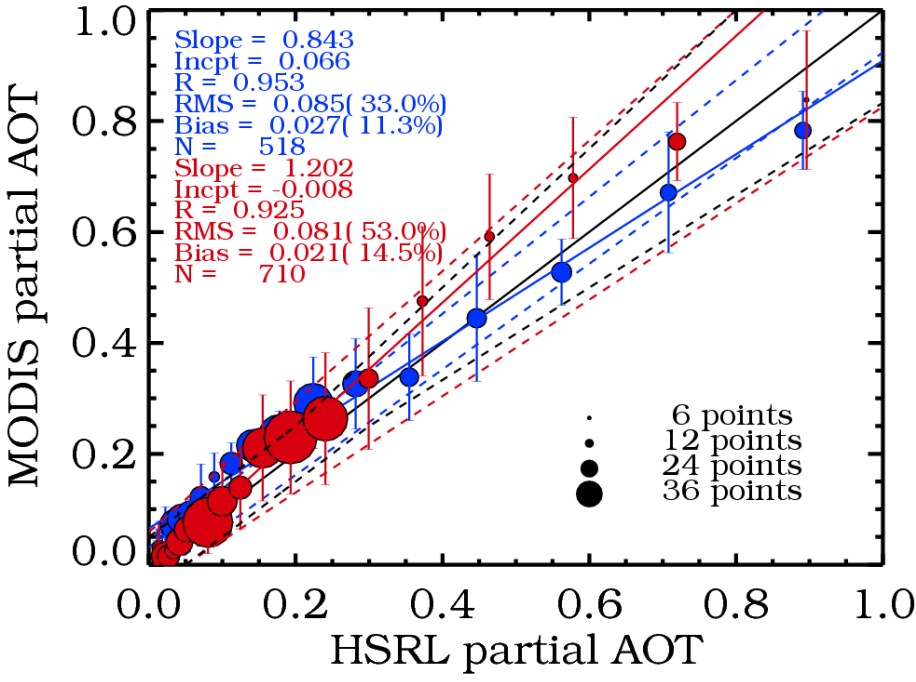
- Methodology – use HSRL AOT to evaluate satellite AOT
  - Mar 2006 – Feb 2008 cases
  - # HSRL flights: 64 Aqua MODIS, 64 Terra MODIS, 20 MISR
- Results
  - Land – at least 60% of cases had differences within 0.05 0.15AOT
  - Water - at least 50% of cases had differences within the larger of 0.05 or 20%

➢ Most satellite AOT values agree with HSRL AOT values within uncertainty estimates

Aqua MODIS vs. HSRL



Terra MODIS vs. HSRL



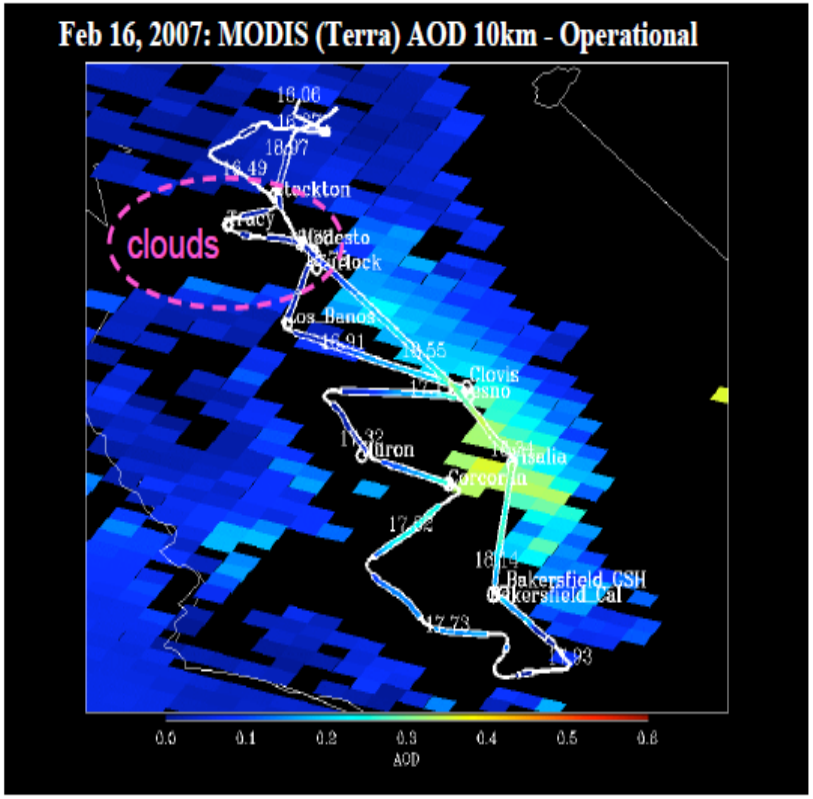
(Burton et al., 2010)

HSRL Data Used to Assess Satellite Aerosol Retrieval Performance over San Joaquin Valley - 2007

Operational MODIS Retrieval

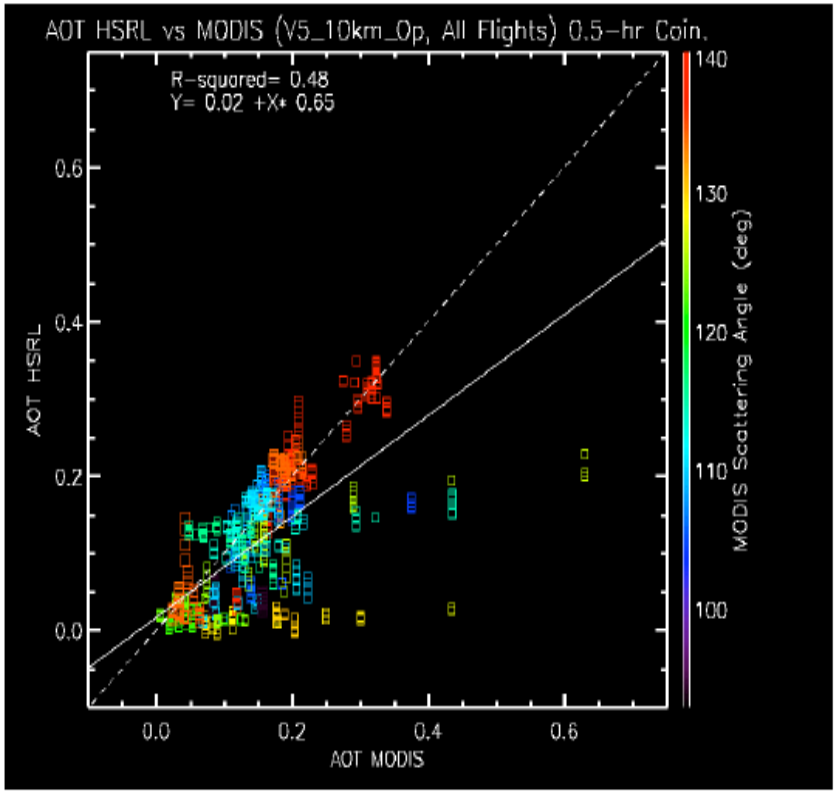
HSRL AOD overlaid on MODIS AOD (V5 10km Operational)

- Aircraft flight time approximately 3 hours, satellite view is single snapshot
- Visually, good agreement in AOD measured from aircraft and satellite
- However, no MODIS AOD retrieval over much of San Joaquin Valley



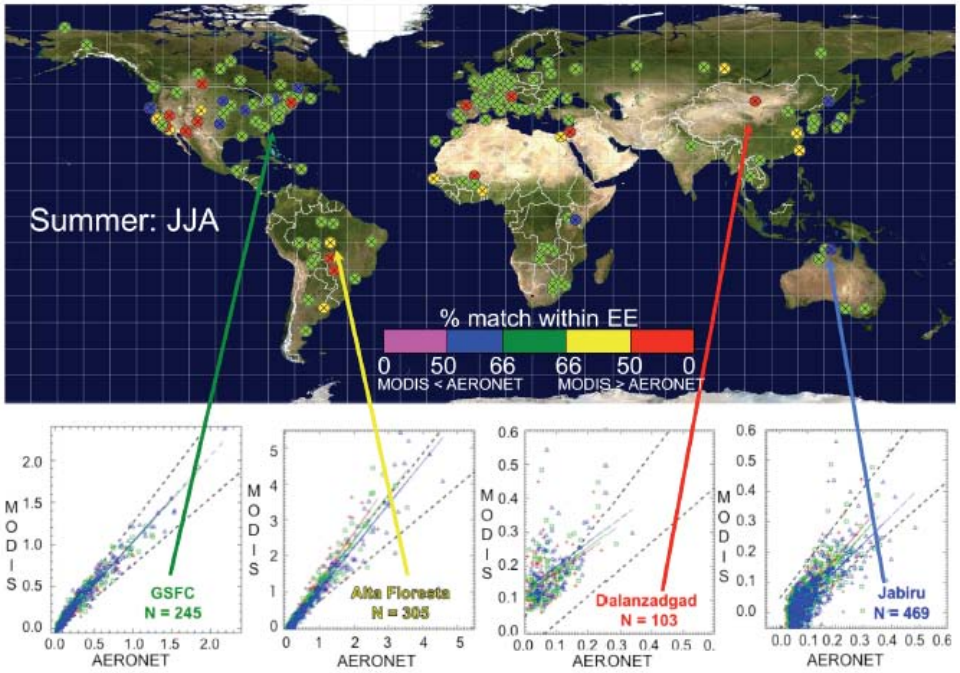
Correlation of HSRL and MODIS (V5 Operational) AOD , All Flights

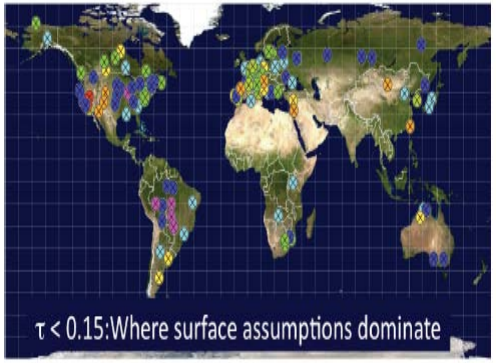
- Relatively poor overall fit (R^2 0.48, slope 0.65)
- MODIS AOD should be less influenced by surface reflectance at high scattering angles (combination of sun angle and instrument scan angle)

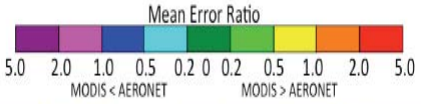


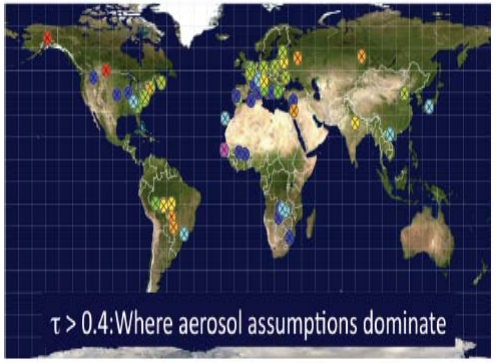
(From Al-Saadi, Szykman, et al. AMS Meeting Presentation 2008)

Satellite Aerosol Retrieval Performance Varies with Location









- MODIS compares best (negligible bias and good correlation) over sites that are both moderately "dark" and moderately "green". Such sites occur over the Eastern United States, Western Europe and Southern Africa.

- MODIS overestimates AOD where surfaces are brighter and less green. This includes the western US and Central Asia.

– MODIS underestimates AOD where the surface is unusually dark. These conditions are seen in parts of the Amazon forest, as well as Northern Australia and areas known for reddish color soils.

Levy et al., (2010)

HSRL Data Used to Assess Satellite Aerosol Retrieval Performance over San Joaquin Valley - 2007

Operational MODIS Retrieval – Large scattering angles only

HSRL AOD overlaid on MODIS AOD (V5 10km Operational)

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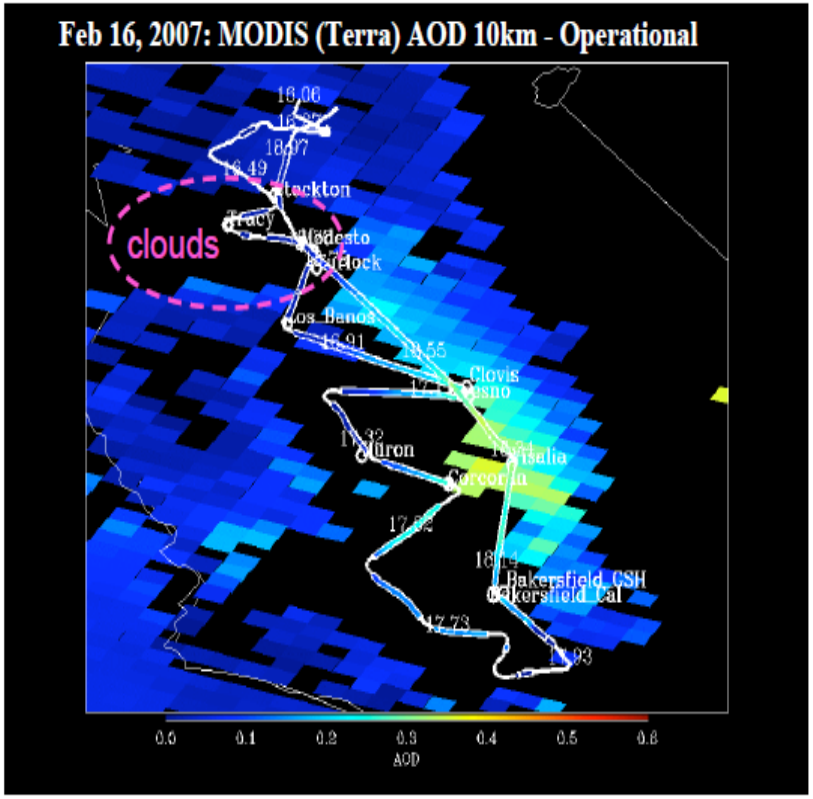
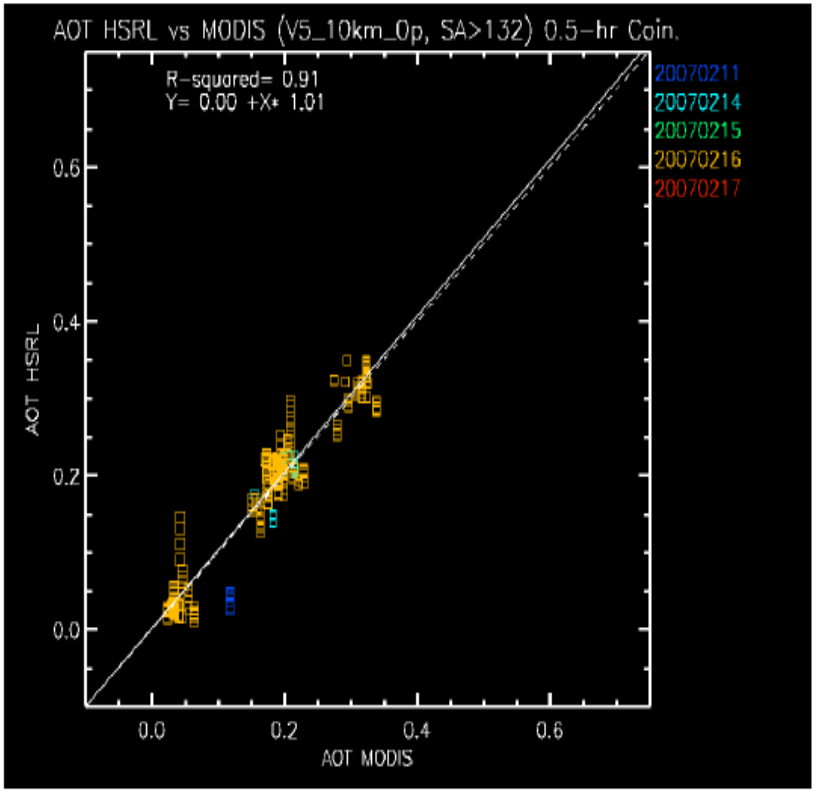
- Visually, good agreement in AOD measured from aircraft and satellite
- However, no MODIS AOD retrieval over much of San Joaquin Valley



Correlation of HSRL and MODIS (V5 Operational) AOD , SA>132 deg only

- Very good correlation when restricted to high scattering angles (R^2 0.91, slope 1.01), strongly suggesting most of variance results from uncertainty in characterizing surface reflectance in MODIS retrieval



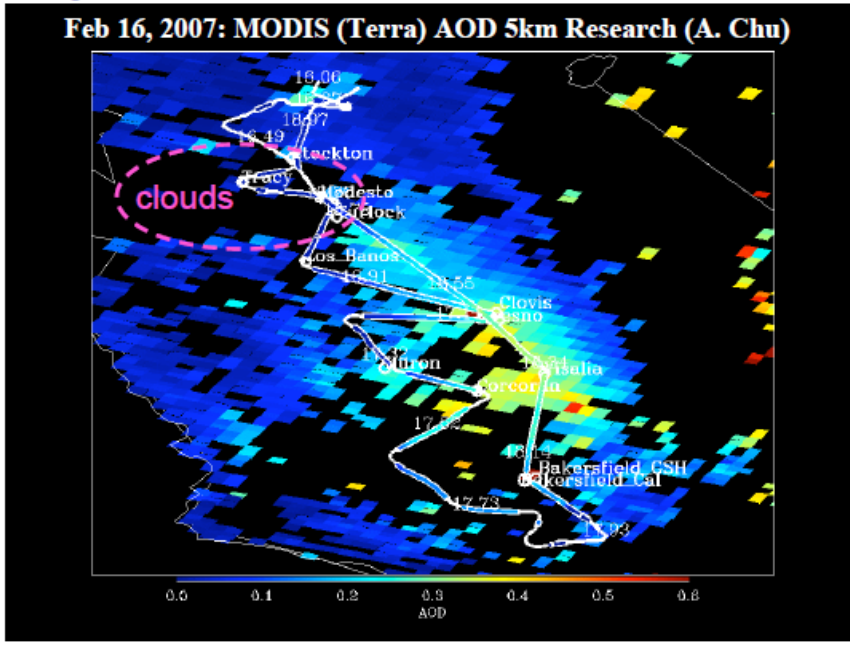
(From Al-Saadi, Szykman, et al. AMS Meeting Presentation 2008)

HSRL Data Used to Assess Satellite Aerosol Retrieval Performance over San Joaquin Valley - 2007

Research MODIS Retrieval (Allen Chu)

HSRL AOD overlaid on MODIS AOD (V5 5km Research Retrieval)

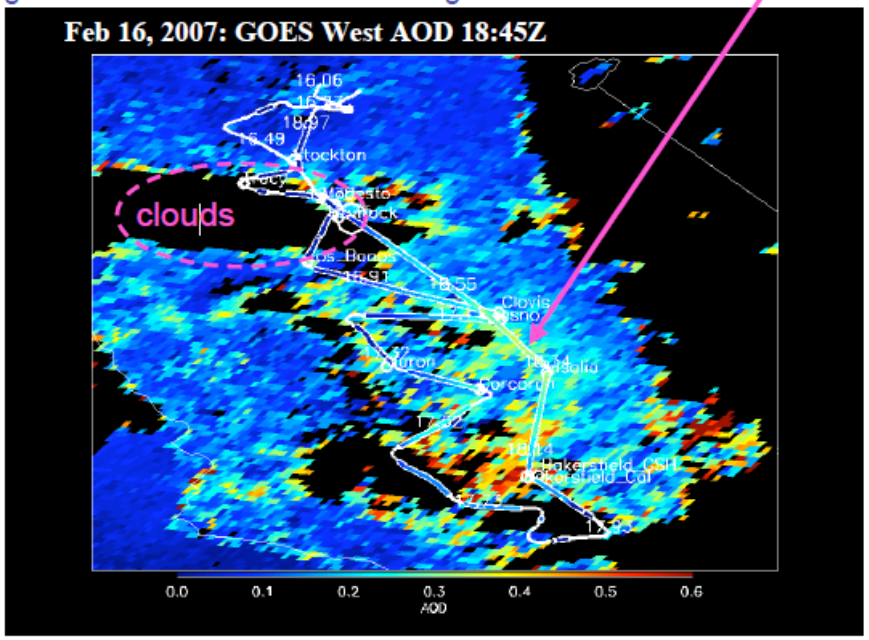
- At 5km resolution, finer-scale spatial features are evident within SJV
- However, fewer successful retrievals in southern part of SJV
- Note high value over Bakersfield



GOES Retrieval

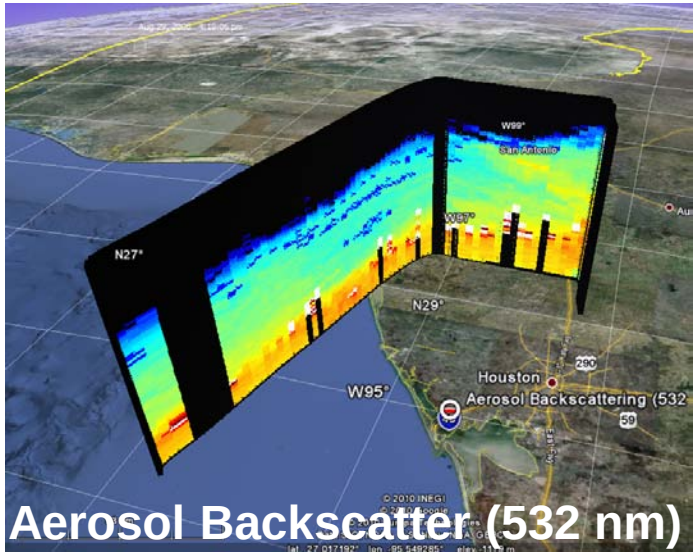
HSRL AOD overlaid on GOES-West AOD (Pre-operational)

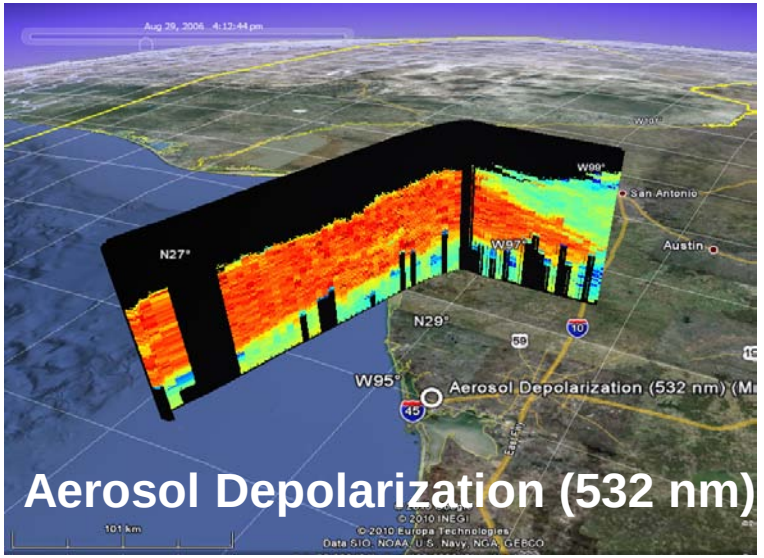
- 4km nadir resolution, every half hour, currently being validated
- Good correspondence during HSRL flight segment closest in time
- High satellite values in Bakersfield region



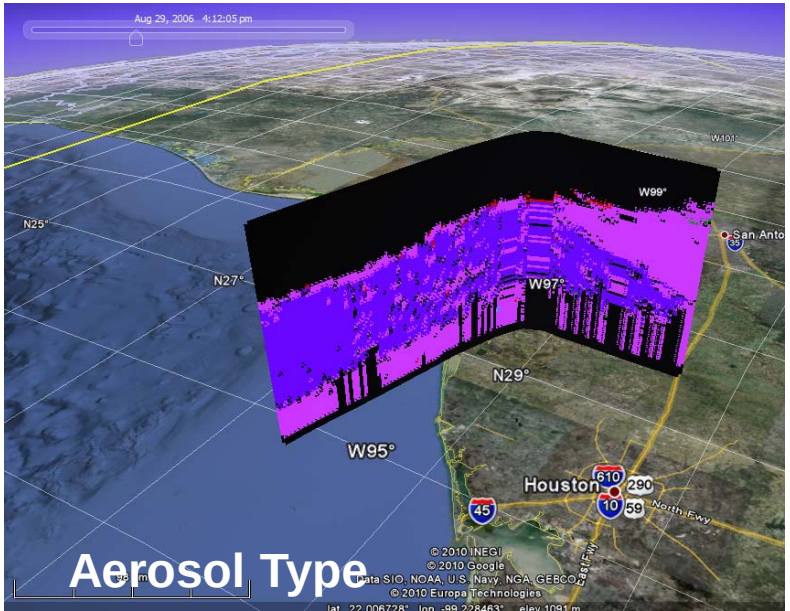
(From Al-Saadi, Szykman, et al. AMS Meeting Presentation 2008)

HSRL Observes Variation of Aerosol Types Near Houston
August 29, 2006



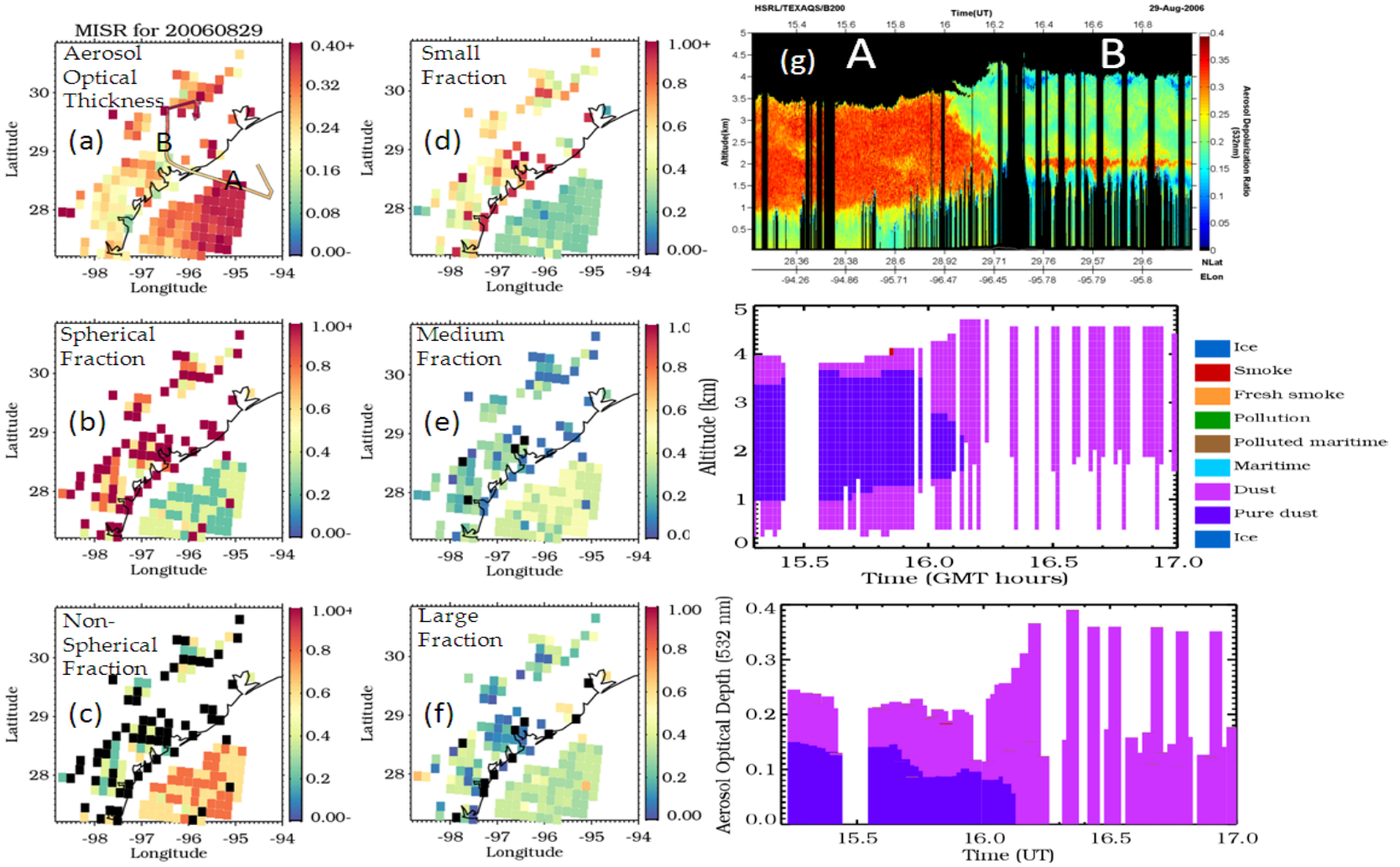


- Ice
- Smoke
- Fresh smoke
- Pollution
- Polluted maritime
- Maritime
- Dust mix
- Pure dust
- Ice



HSRL and MISR Observe Variation of Aerosol Types Near Houston August 29, 2006

- MISR and HSRL see different aerosol types in Houston region
  - small spherical particles inland – dust+urban mix
  - large nonspherical particles over water – Saharan dust



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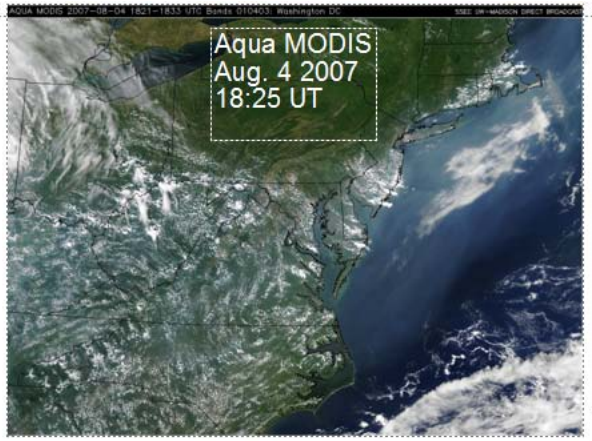
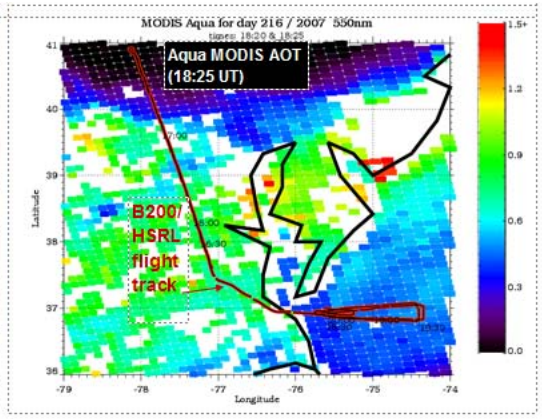
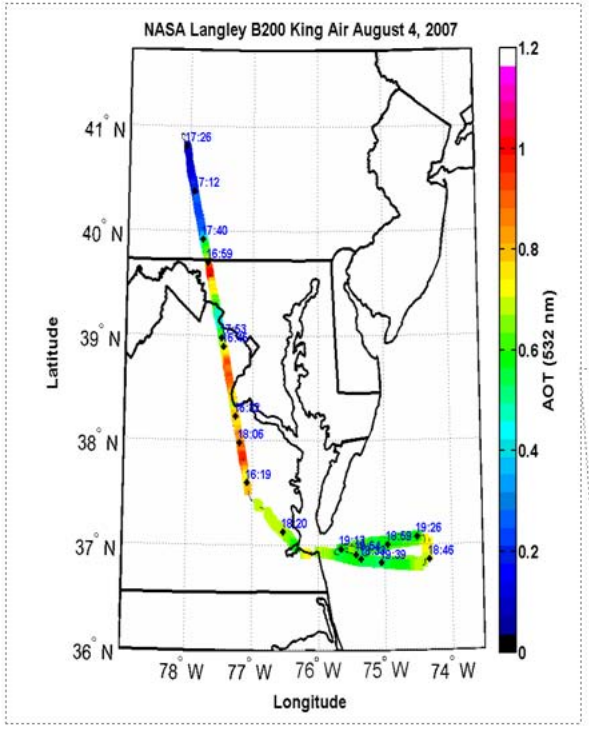
HSRL Measurements used to evaluate satellite retrievals of aerosol optical depth – August 4, 2007

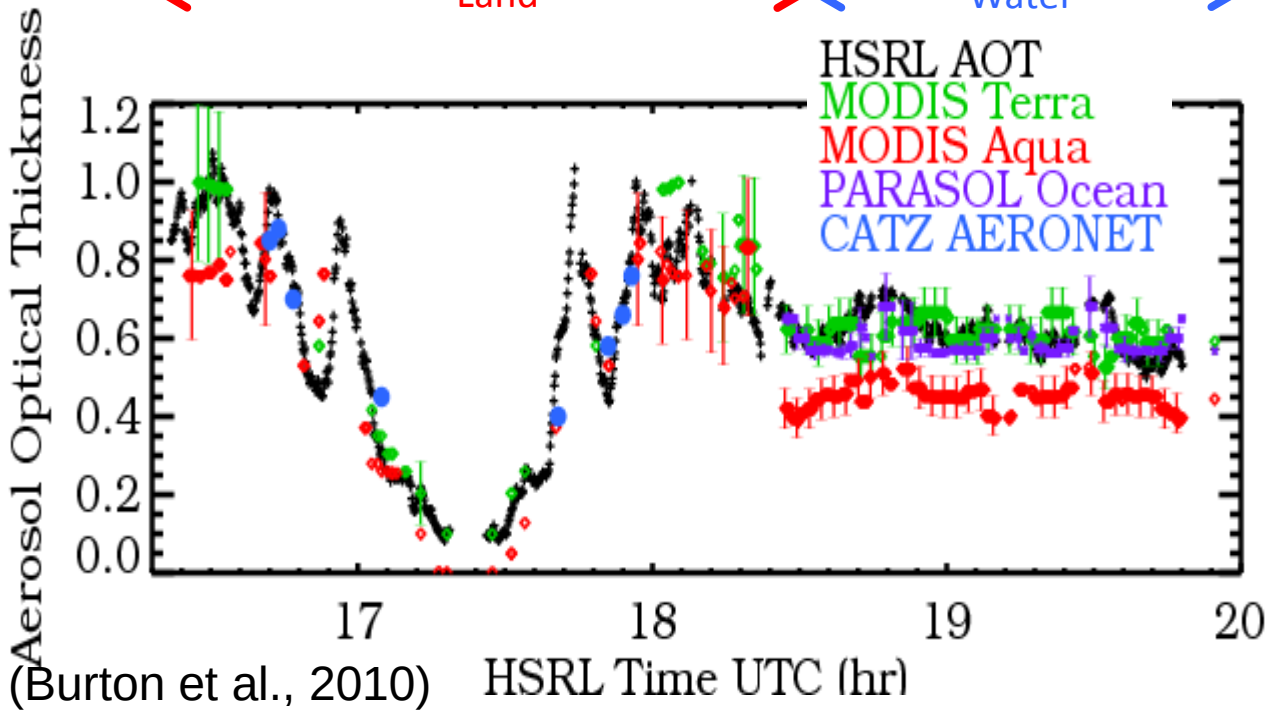




AOT Over land:
- Terra and Aqua MODIS, HSRL, and AERONET agree

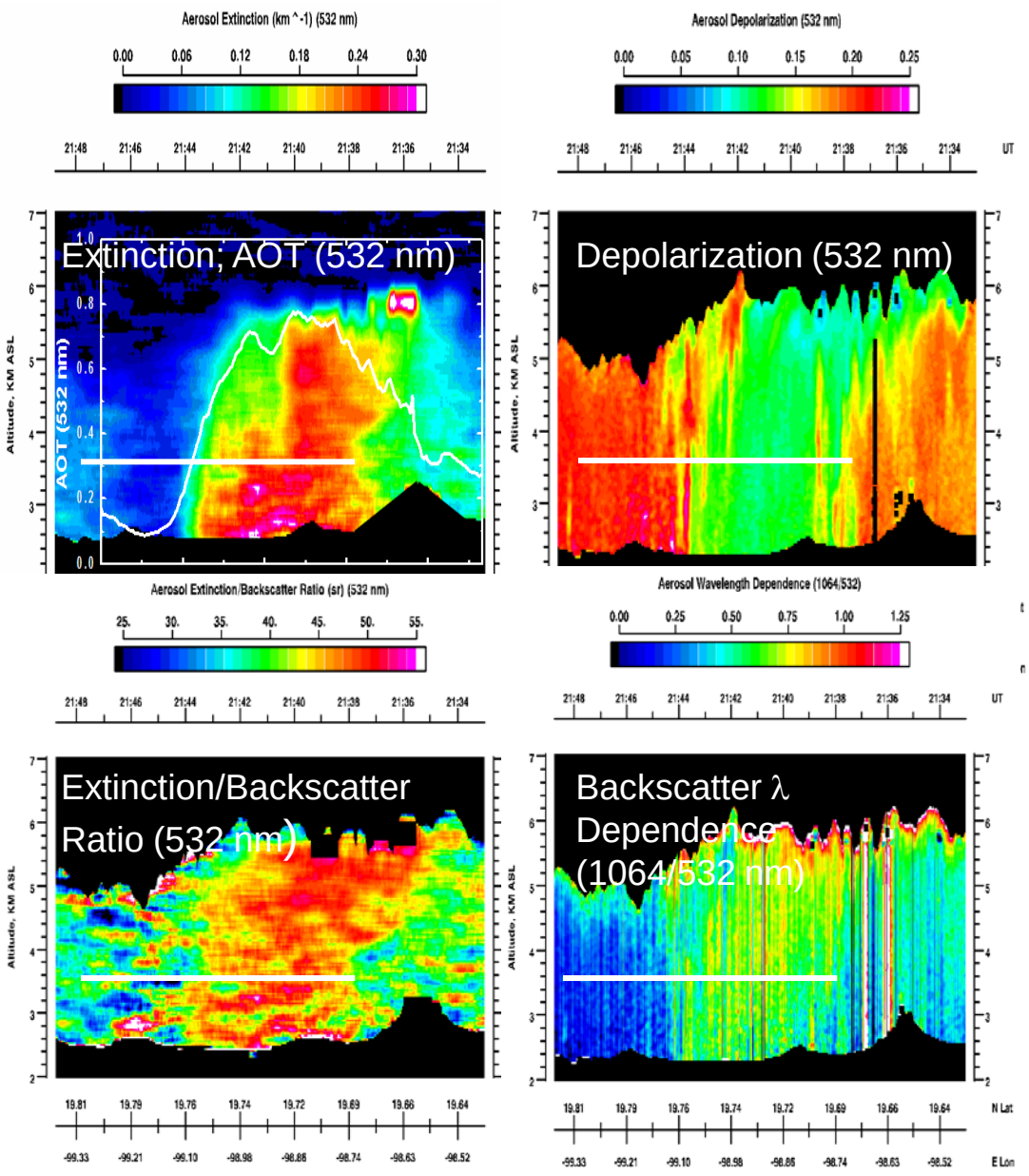
AOT over water:
- Terra MODIS , PARASOL, and HSRL agree
- Aqua MODIS AOT about 0.2 (33%) low



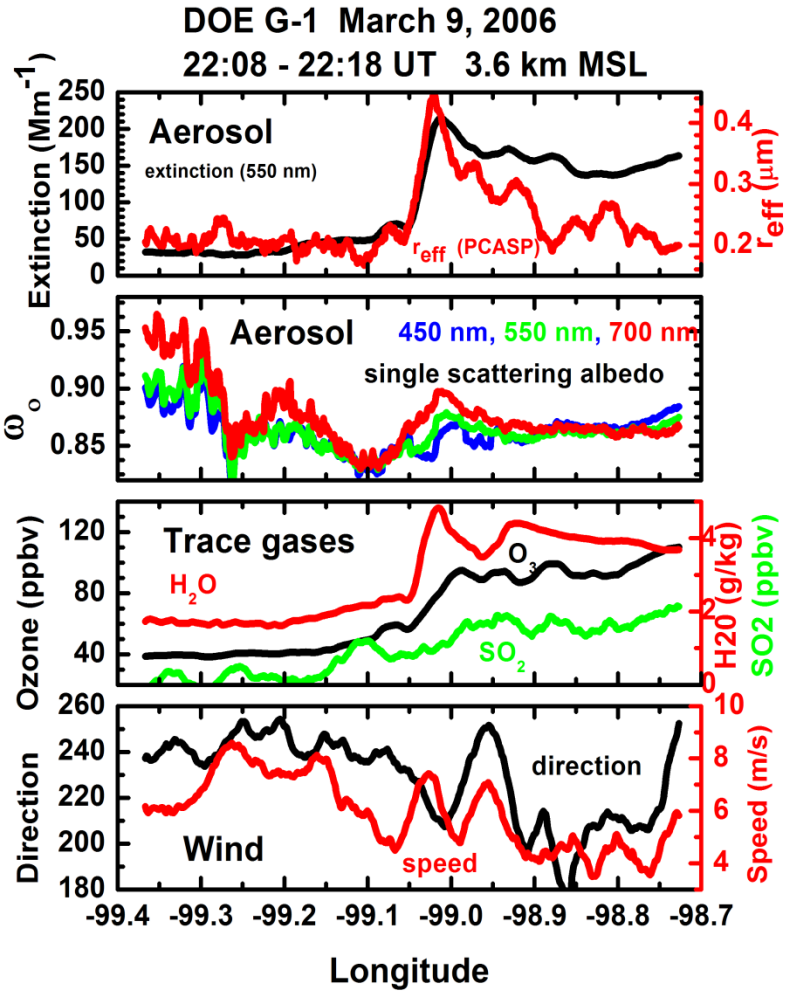


(Burton et al., 2010)

Airborne in situ measurements provide details on spatial and temporal variabilities of aerosol parameters



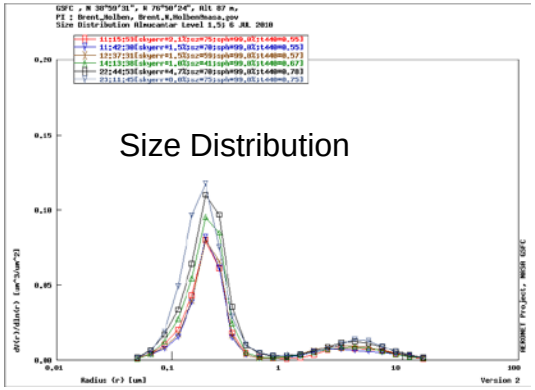
NASA King Air & DOE G-1 coordinated fight – March 9, 2006

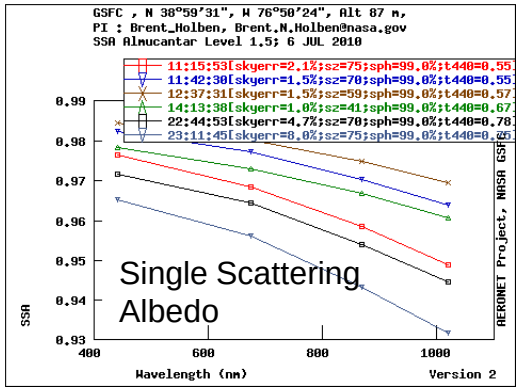


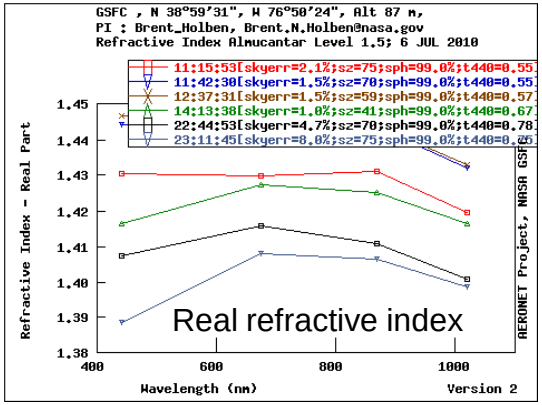
PRELIMINARY DATA

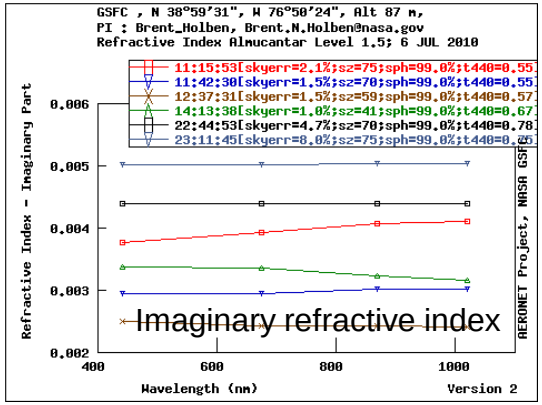
Assessment of AERONET retrievals of aerosol microphysical and optical properties

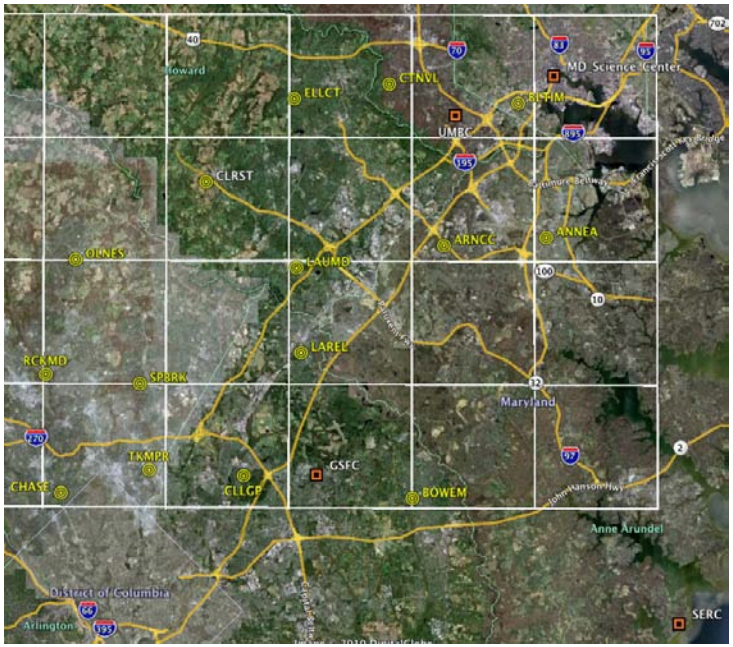
Airborne in situ aerosol measurements will be important for assessing AERONET aerosol retrievals and the temporal and spatial variabilities of the retrieved aerosol parameters









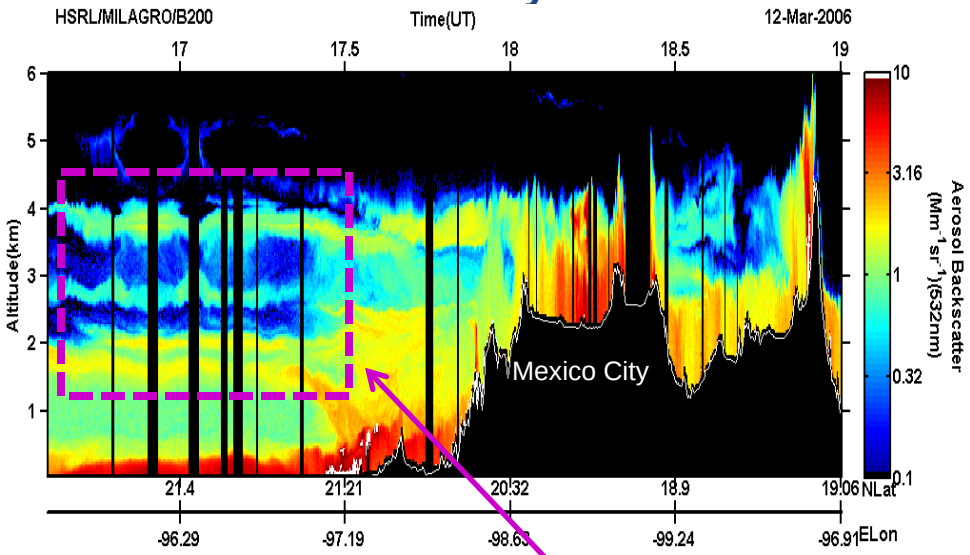


Assessment of Model Aerosol Simulations

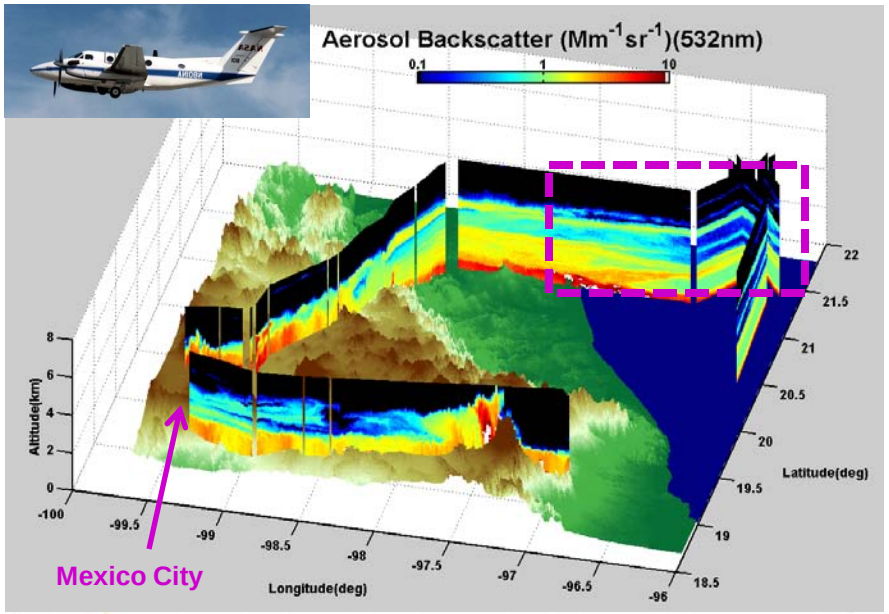
Airborne HSRL Measurements used to Evaluate WRF-Chem Model

Pacific Northwest NATIONAL LABORATORY

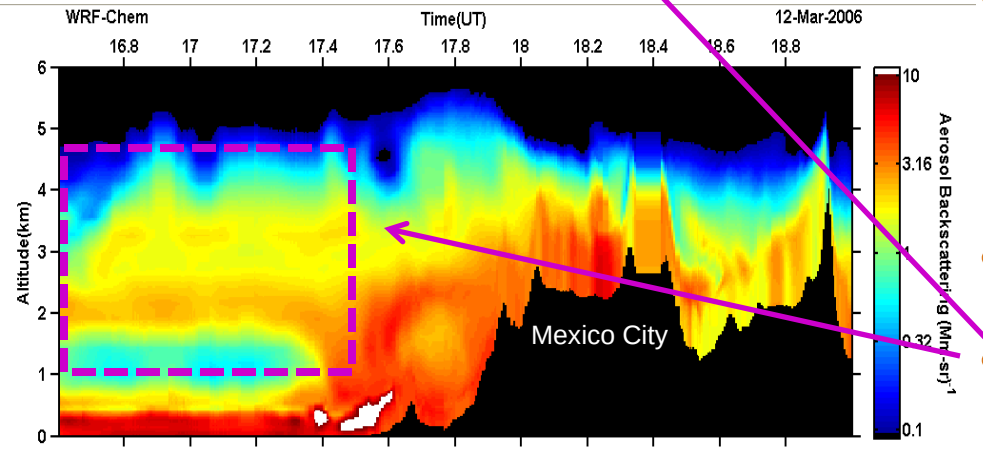
Backscatter measured by airborne HSRL



NASA/LaRC B200/HSRL March 12, 2006



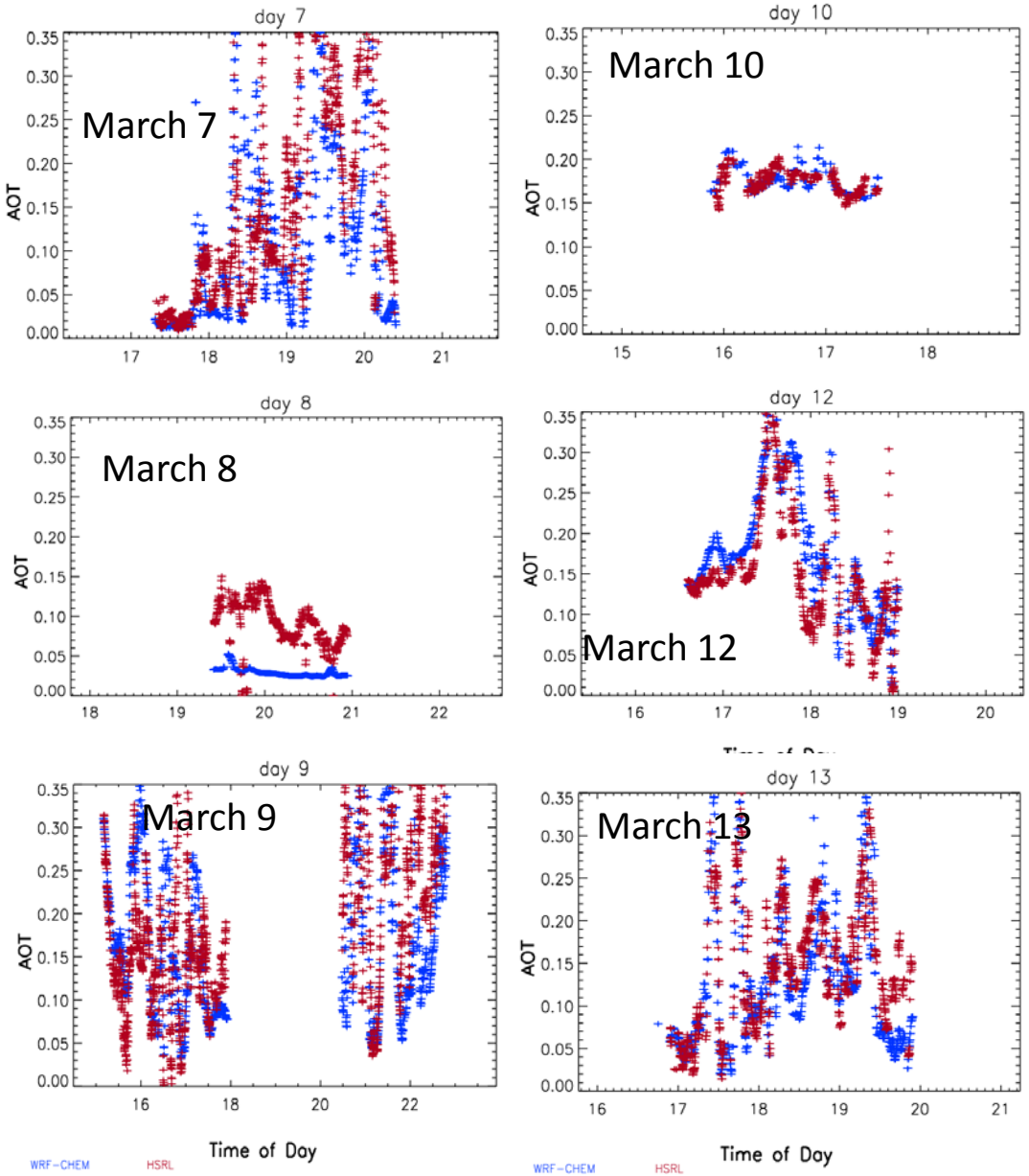
Backscatter predicted by WRF-Chem model



WRF-Chem (Jerome Fast – PNNL)

- **Airborne HSRL data:**
  - **reveal complexity of mixing and transport of particulates**
  - **used to indirectly evaluate meteorological predictions**
- **Model can reproduce most aspects of PBL in vicinity of Mexico City**
- **Model requires smaller vertical grid spacing to resolve shallow layering observed by lidar**

HSRL / WRF-Chem Aerosol Optical Thickness Comparison

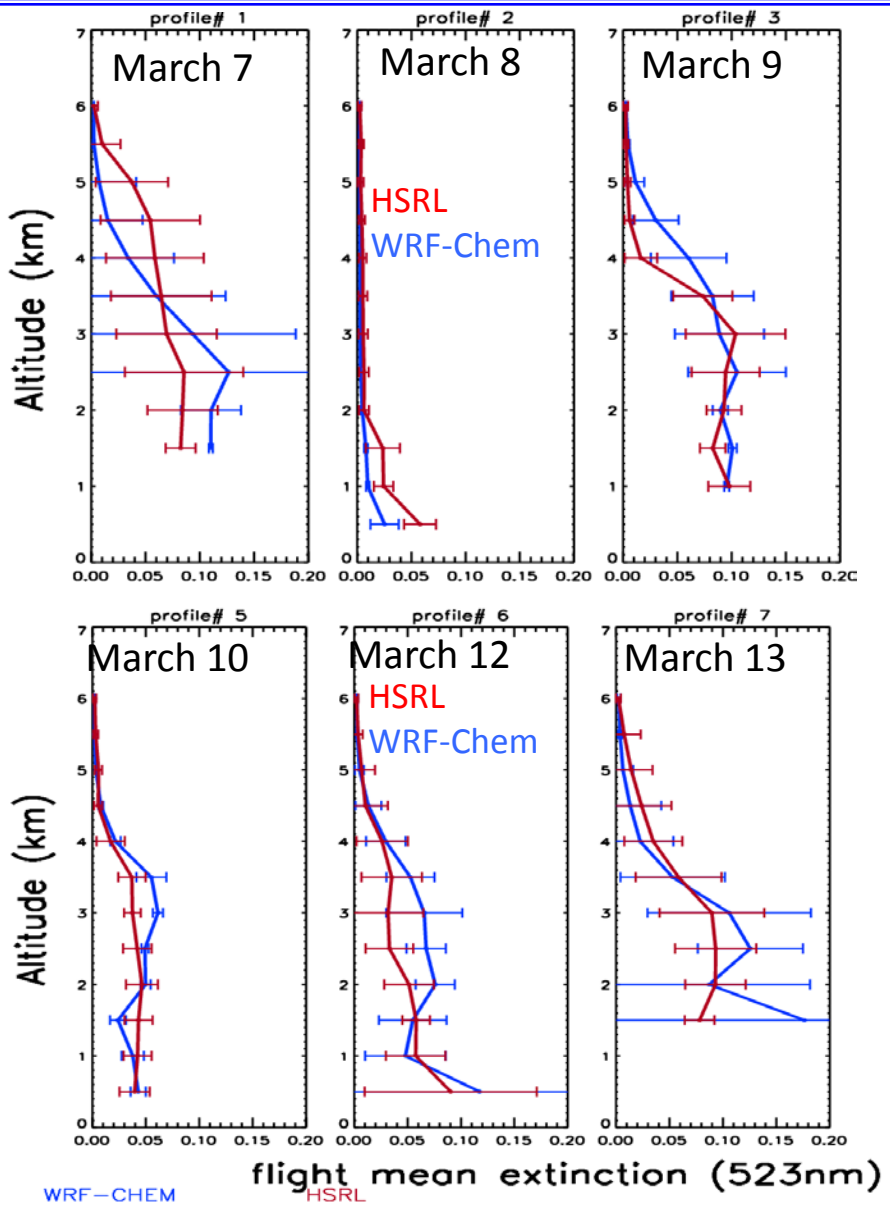


WRF-Chem aerosol optical thickness in very good overall ageement with HSRL

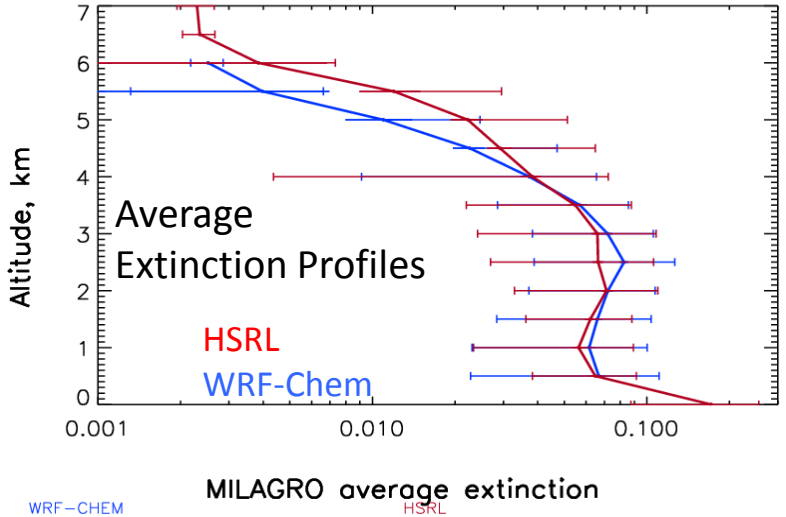
Overall Summary

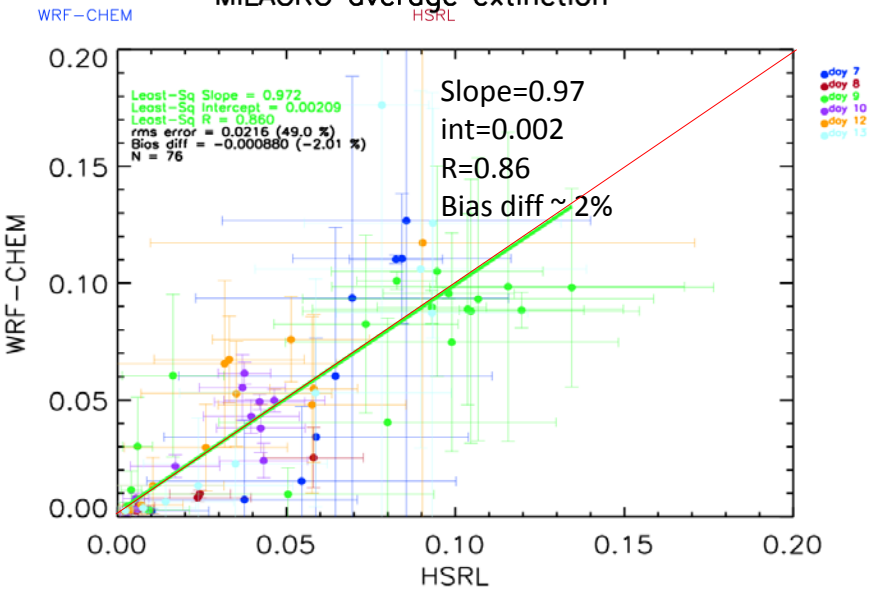
- Performance varies with location WRF-chem overestimates backscatter and extinction over Gulf and coast - perhaps too much model dust?
- Some fine scale layers only crudely represented by model
- Some differences between measured and modeled PBL growth rate

HSRL / WRF-Chem Aerosol Extinction Comparison



WRF-Chem aerosol extinction profiles in very good overall ageement with HSRL

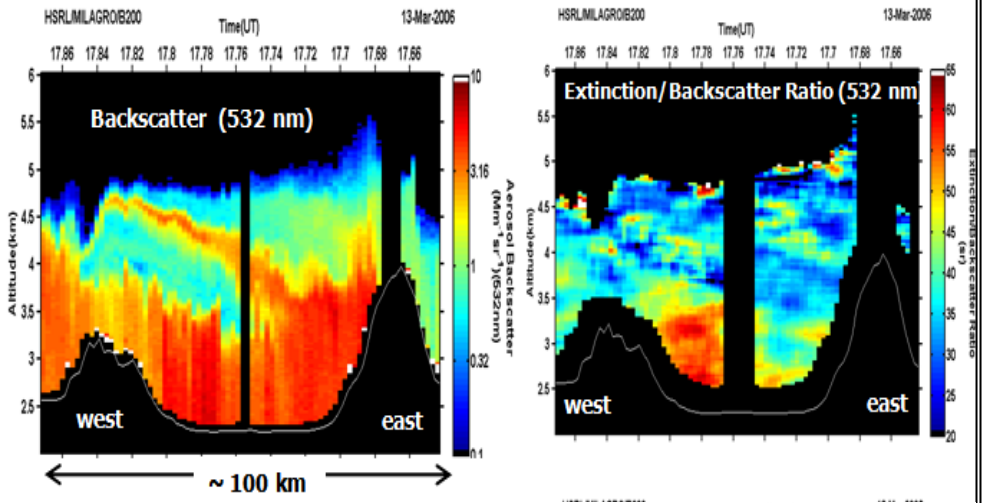




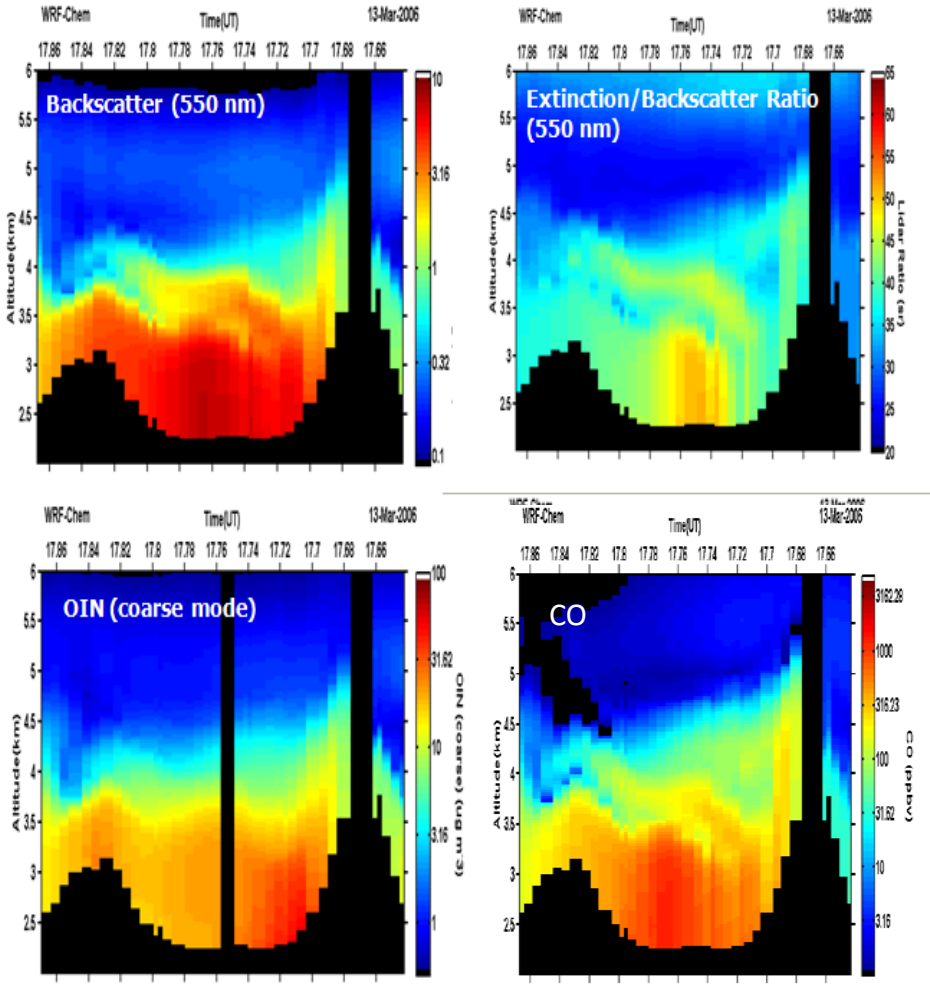
HSRL / WRF-Chem Example – March 13, 2006

➢ High resolution WRF-Chem shows much of the small scale structure shown in HSRL data

HSRL



WRF-Chem

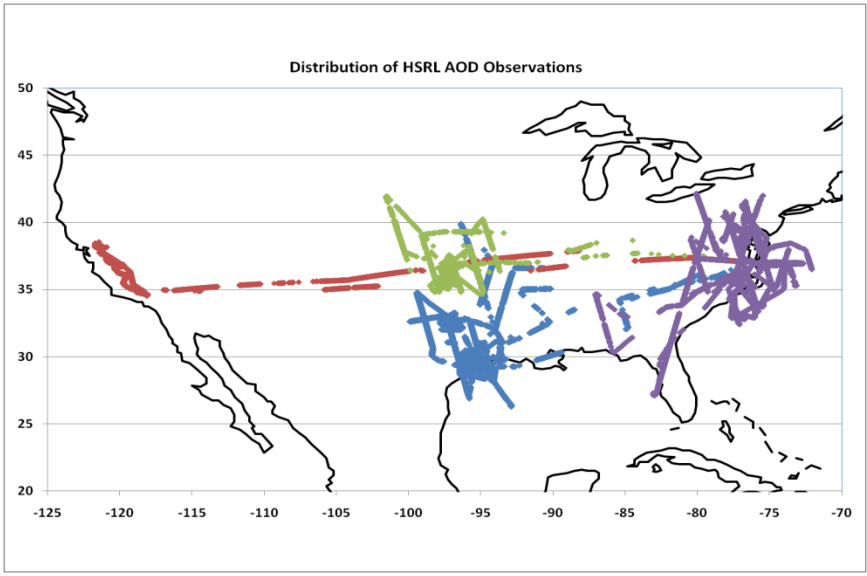


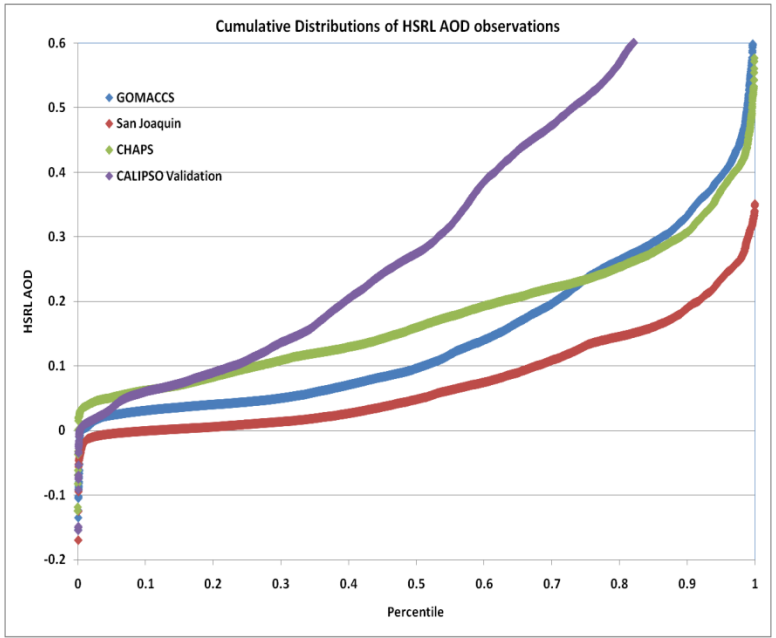
Thank you!

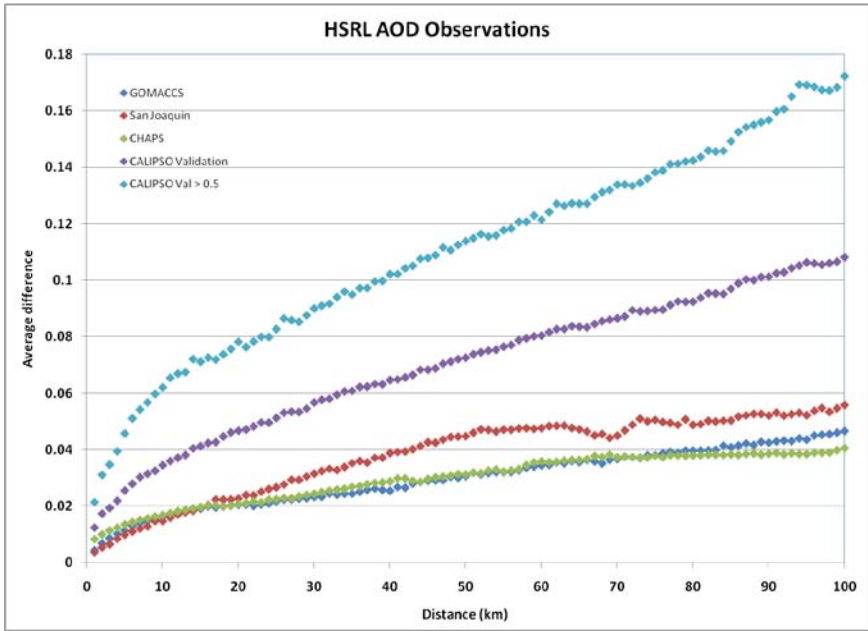
Questions?

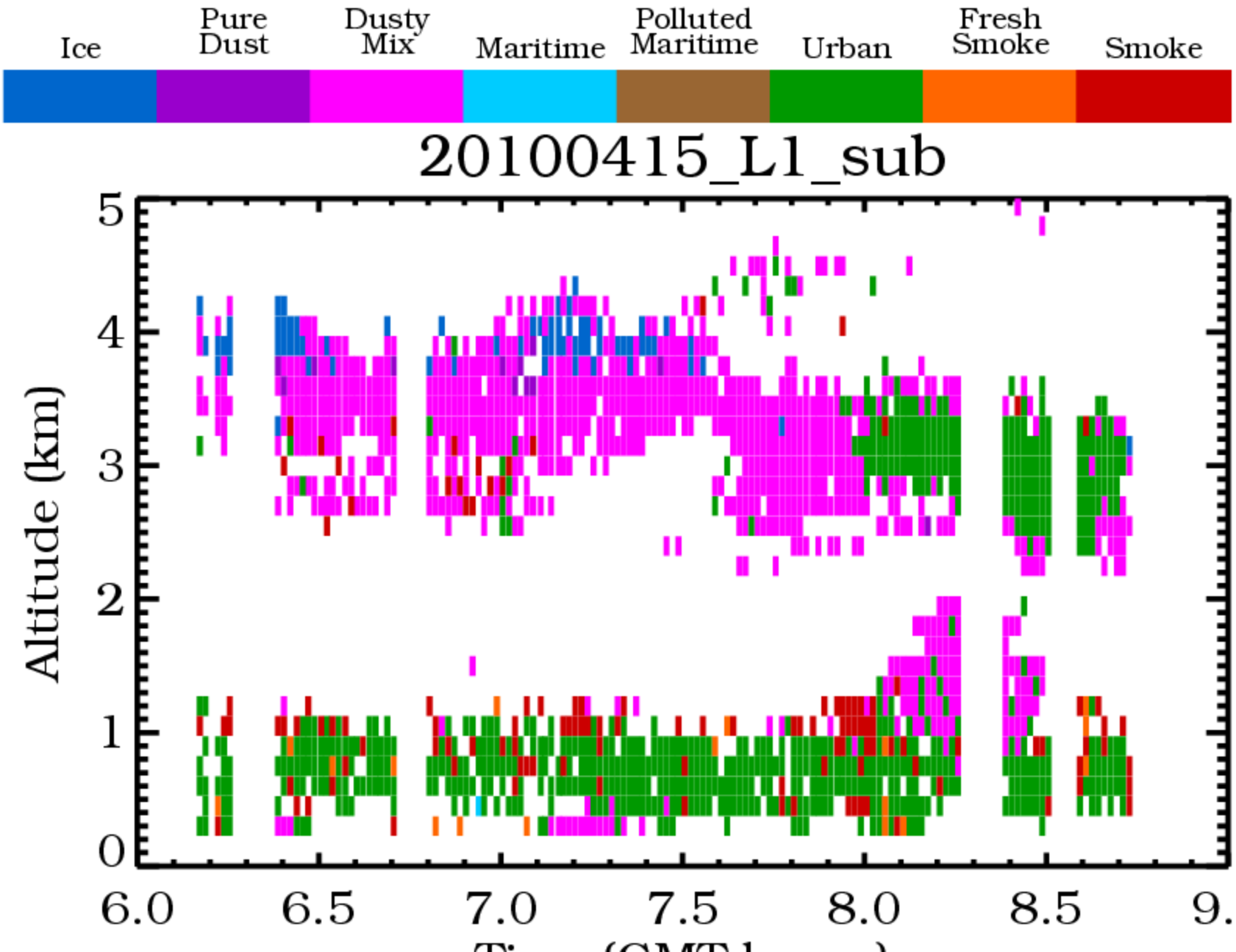
Spatial Variability in AOD based on HSRL observations

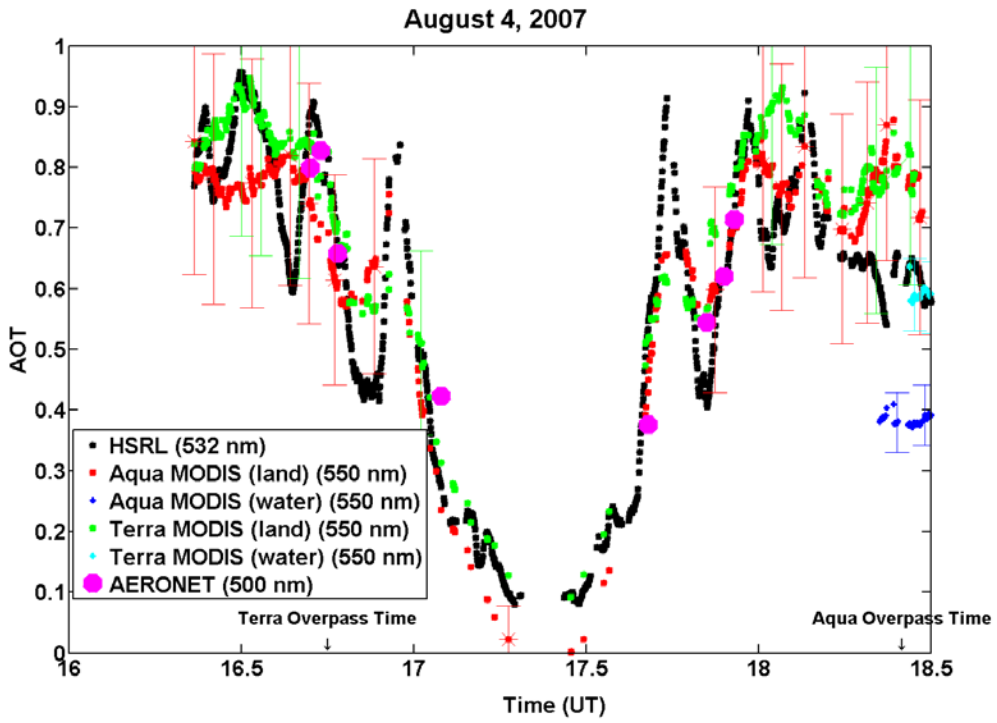
Structure functions (q=1) were performed for each set of flights as well as for the CALIPSO validation flights only for AOD > 0.5 (roughly the upper quartile of data).








Ice
Pure Dust
Dusty Mix
Maritime
Polluted Maritime
Urban
Fresh Smoke
Smoke
20100415_L1_sub
Altitude (km)
0
1
2
3
4
5
6.0
6.5
7.0
7.5
8.0
8.5
9.0


August 4, 2007
AOT
Time (UT)
HSRL (532 nm)
Aqua MODIS (land) (550 nm)
Aqua MODIS (water) (550 nm)
Terra MODIS (land) (550 nm)
Terra MODIS (water) (550 nm)
AERONET (500 nm)
Terra Overpass Time
Aqua Overpass Time
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
16
16.5
17
17.5
18
18.5

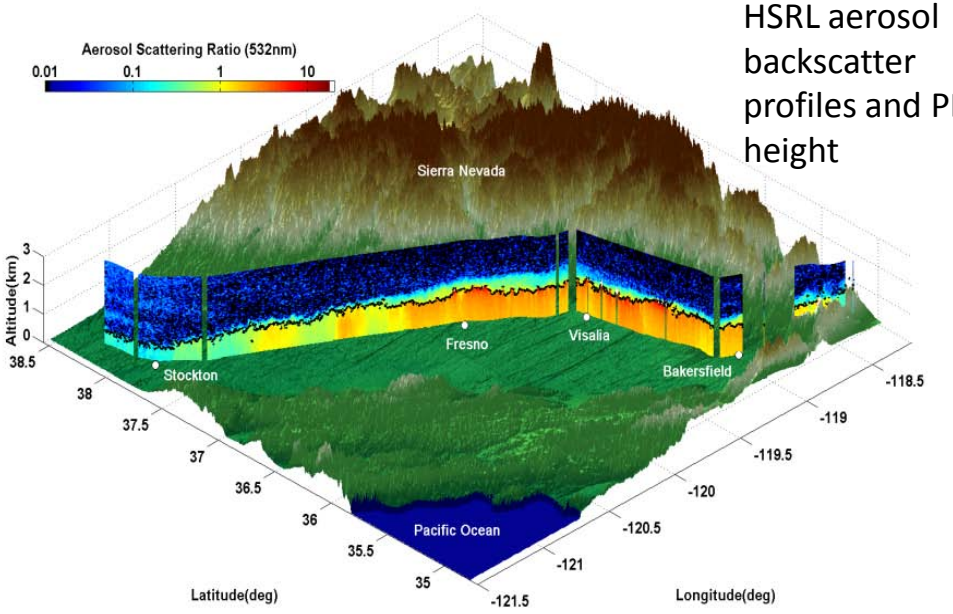
Exmaination of relationship between surface PM2.5 and satellite (MODIS) measurements of AOT over San Joaquin Valley – February 2007

Science Questions:

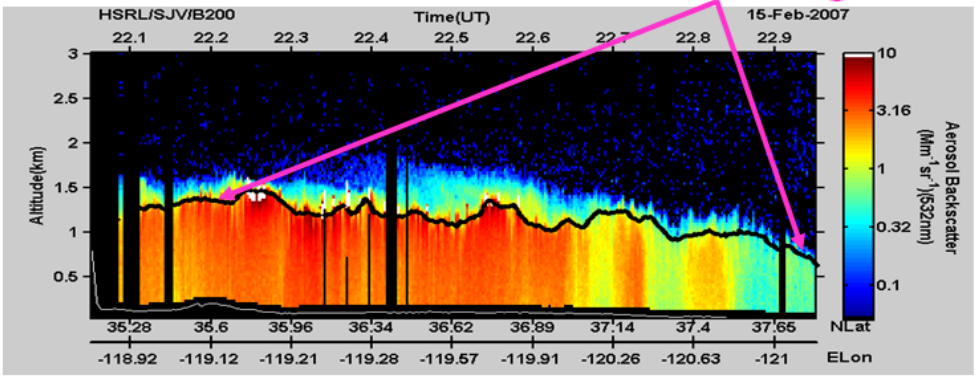
- What is the relationship between satellite AOT and measured surface $PM_{2.5}$?
- Can satellite measurements be used to adequately characterize $PM_{2.5}$ spatial gradients/distributions?
- What are the effects of PBL height and vertical aerosol distributions on the relationship between column AOD and surface $PM_{2.5}$?

San Joaquin Valley, California

HSRL aerosol backscatter profiles and PBL height



HSRL Aerosol Backscatter and PBL heights



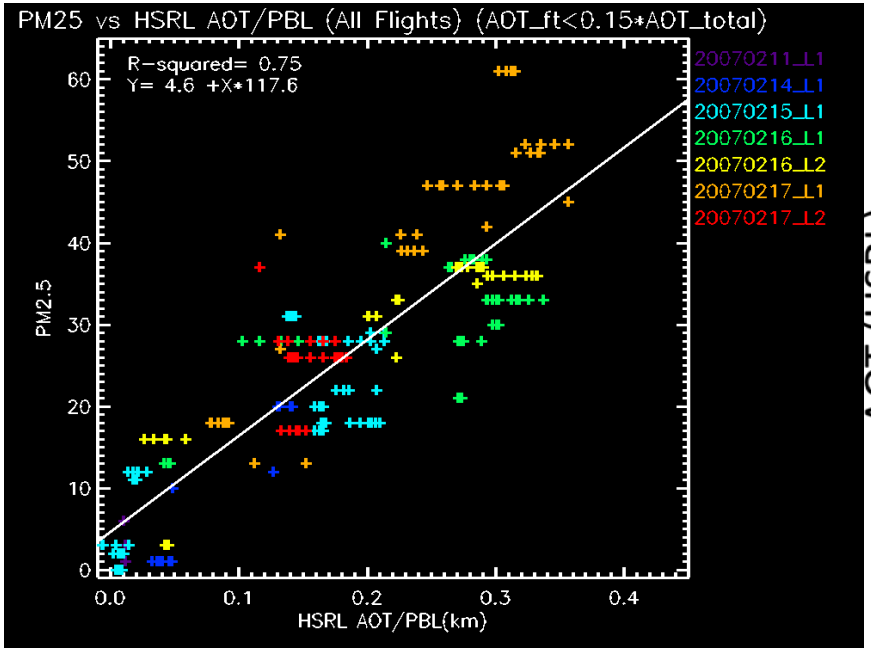
HSRL data used to:

- define PBL height
- evaluate MODIS research AOT retrievals
- determine AOT above/below PBL

Airborne Aerosol Lidar Measurements for Air Quality Research

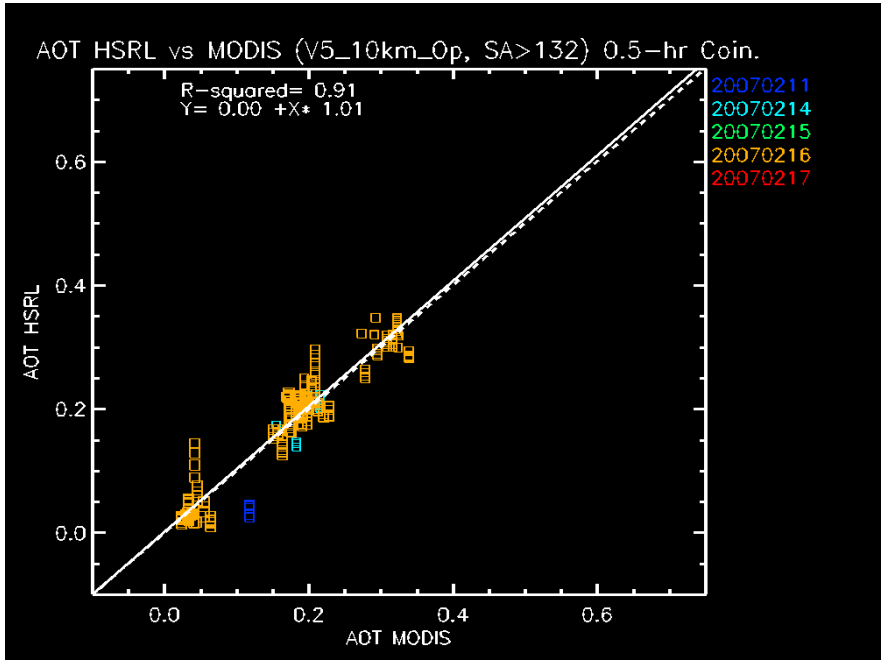
- Normalizing AOT with PBL height (z_i) significantly improves correlation with surface $PM_{2.5}$ (r^2 increases from 0.36 to 0.75)

- Very good correlation between MODIS and HSRL AOT when MODIS retrievals restricted to large (>132 deg) scattering angles – reduces dependence of MODIS AOT on surface reflectance



Surface $PM_{2.5}$

AOT/PBL Height (HSRL)



AOT (HSRL)

AOT (MODIS)

Airborne Aerosol Lidar Measurements for Air Quality Research

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  (r^2 increases from 0.36 to 0.75)

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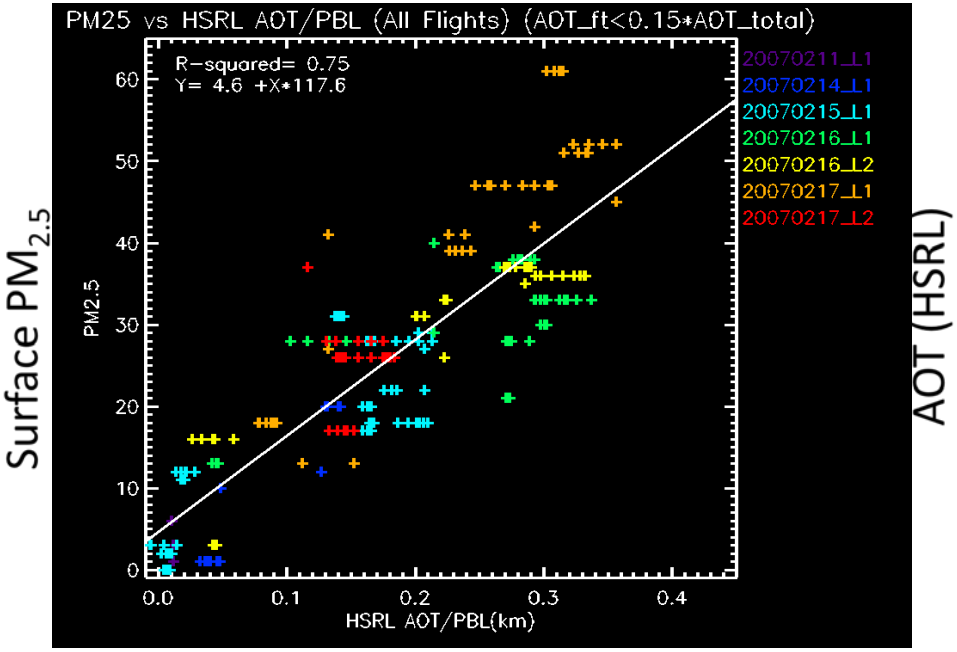
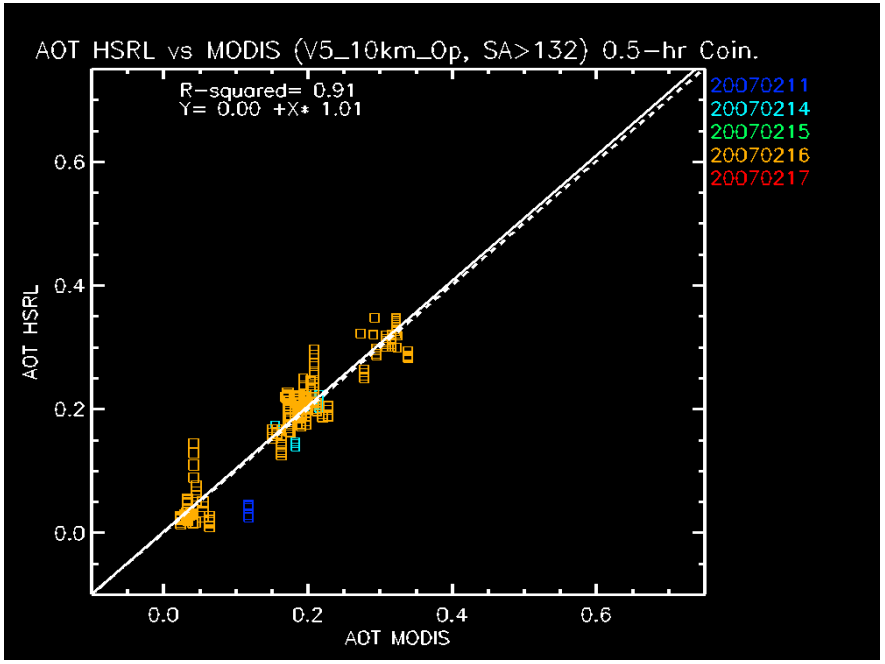
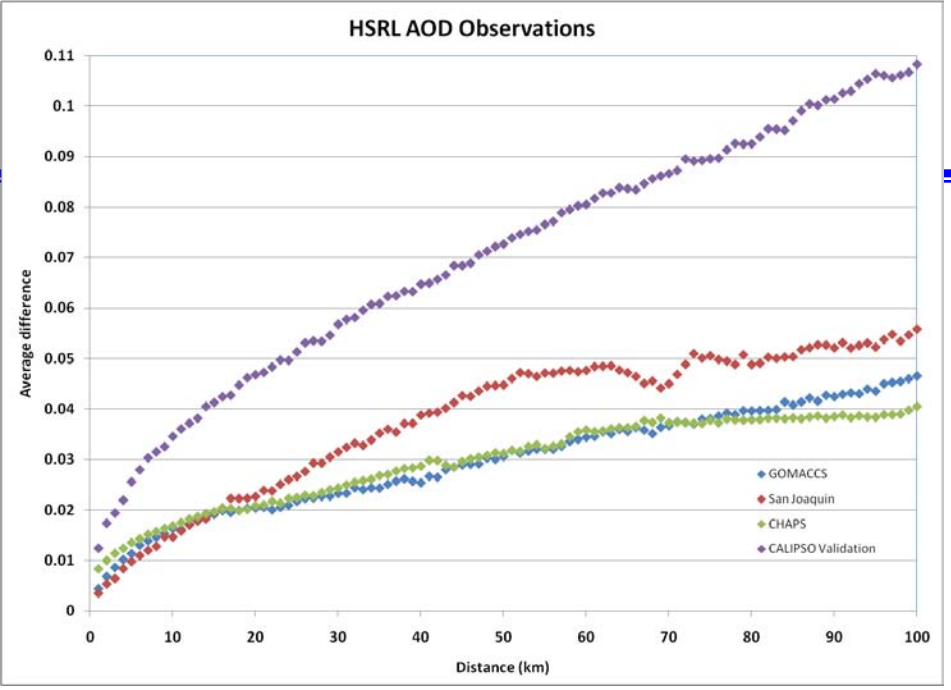
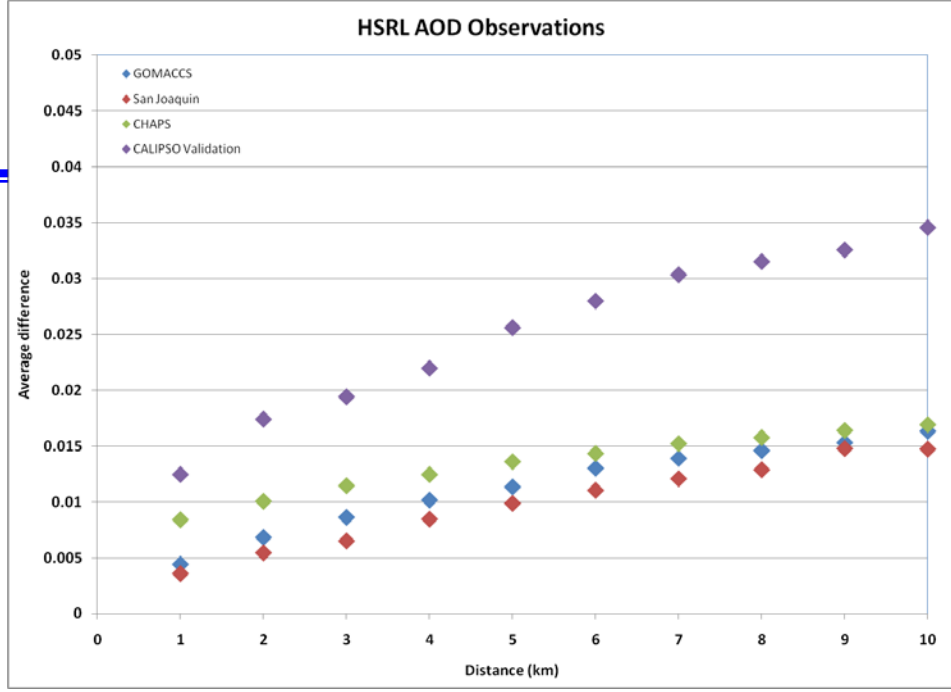


AOT/PBL Height (HSRL)



AOT (MODIS)


HSRL AOD Observations
Average difference
Distance (km)
GOMACCS
San Joaquin
CHAPS
CALIPSO Validation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Average difference
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CHAPS
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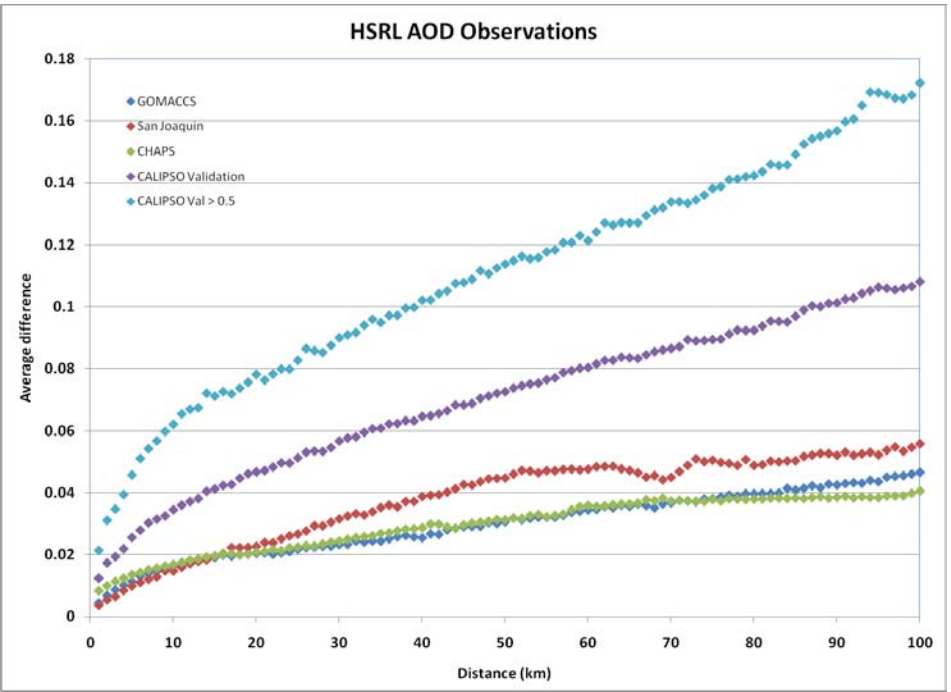
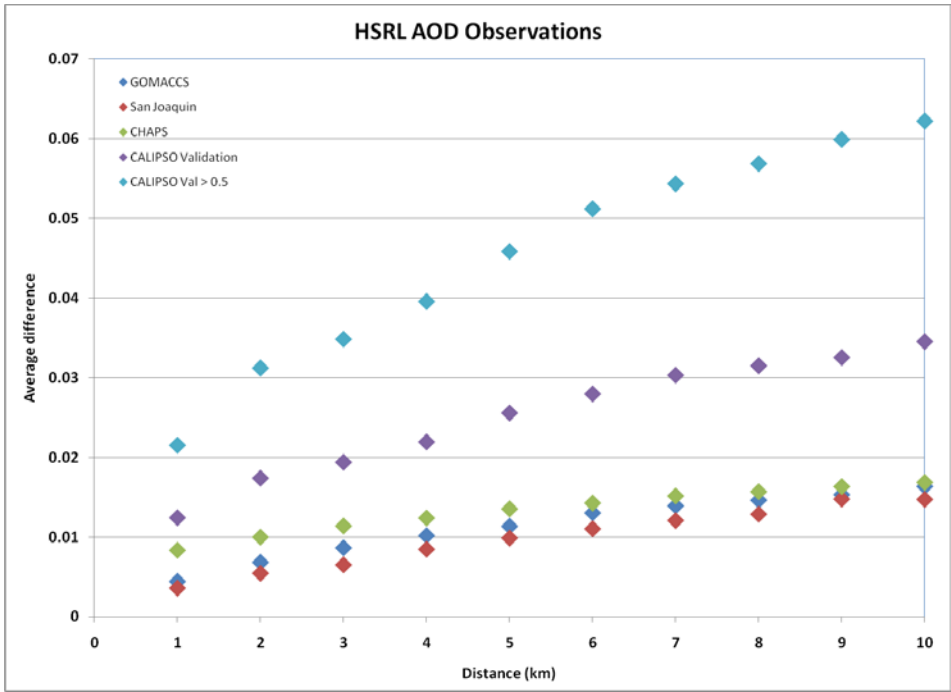

HSRL AOD Observations
Average difference
Distance (km)
GOMACCS
San Joaquin
CHAPS
CALIPSO Validation
CALIPSO Val > 0.5


HSRL AOD Observations
Average difference
Distance (km)
GOMACCS
San Joaquin
CHAPS
CALIPSO Validation
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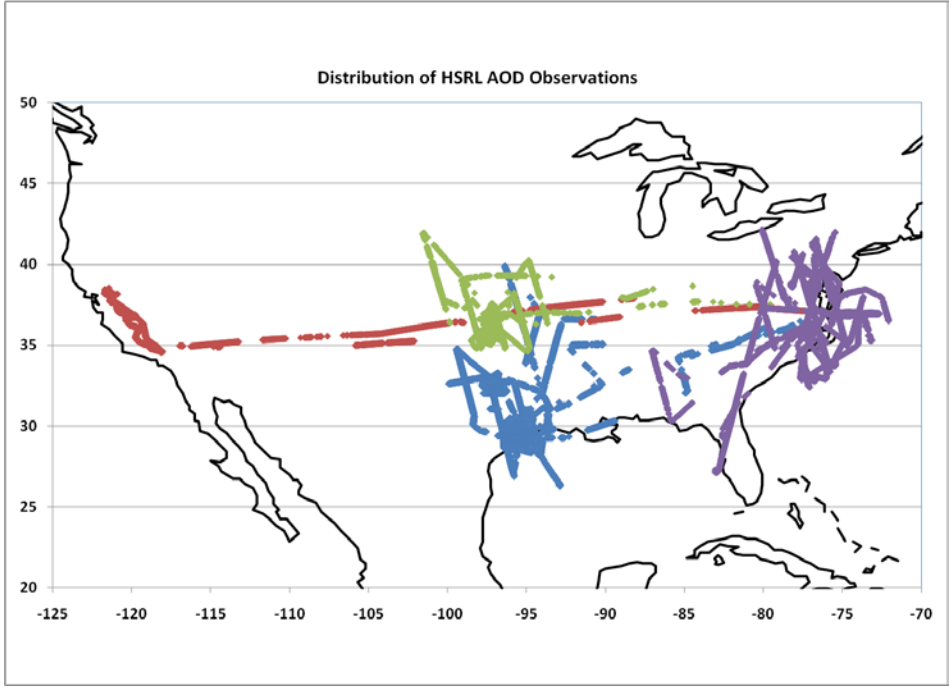
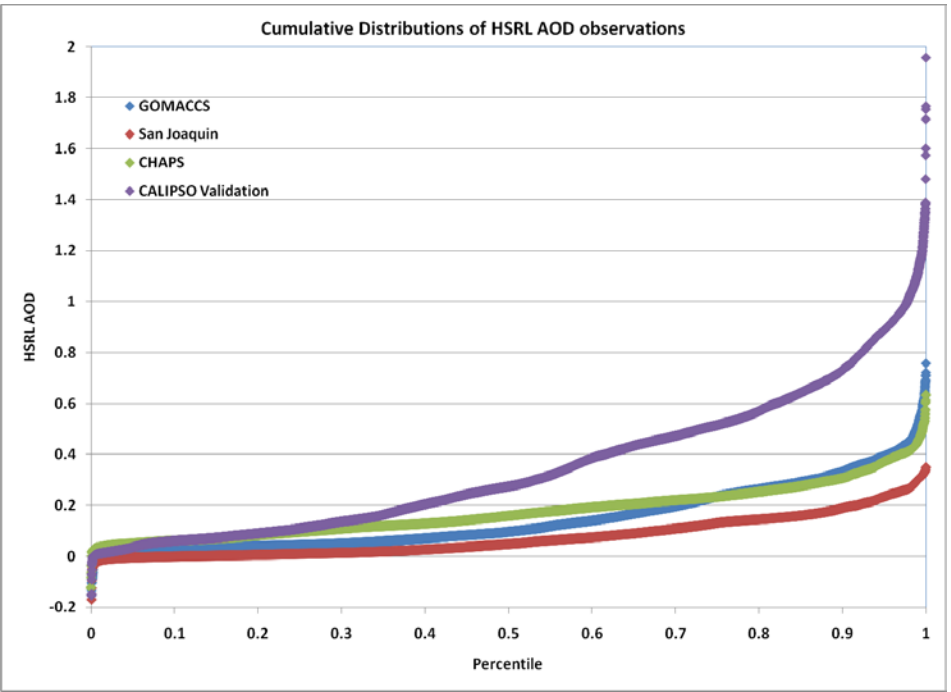
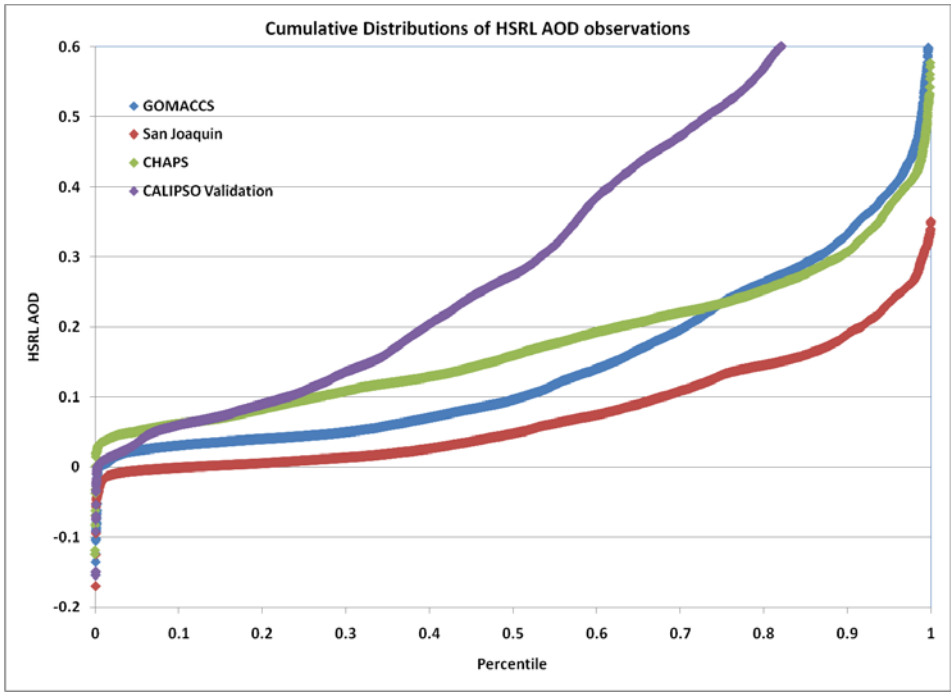
Spatial Variability in AOD based on HSRL observations

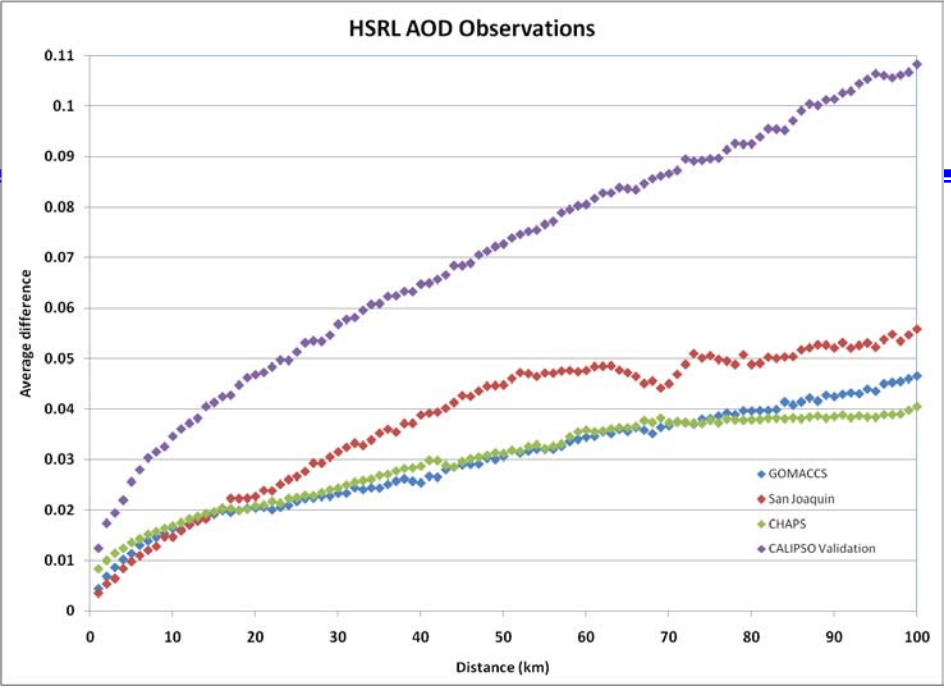
CALIPSO Validation flights encountered substantially higher AODs. Structure functions (q=1) were performed for each set of flights as well as for the CALIPSO validation flights only for AOD > 0.5 (roughly the upper quartile of data).

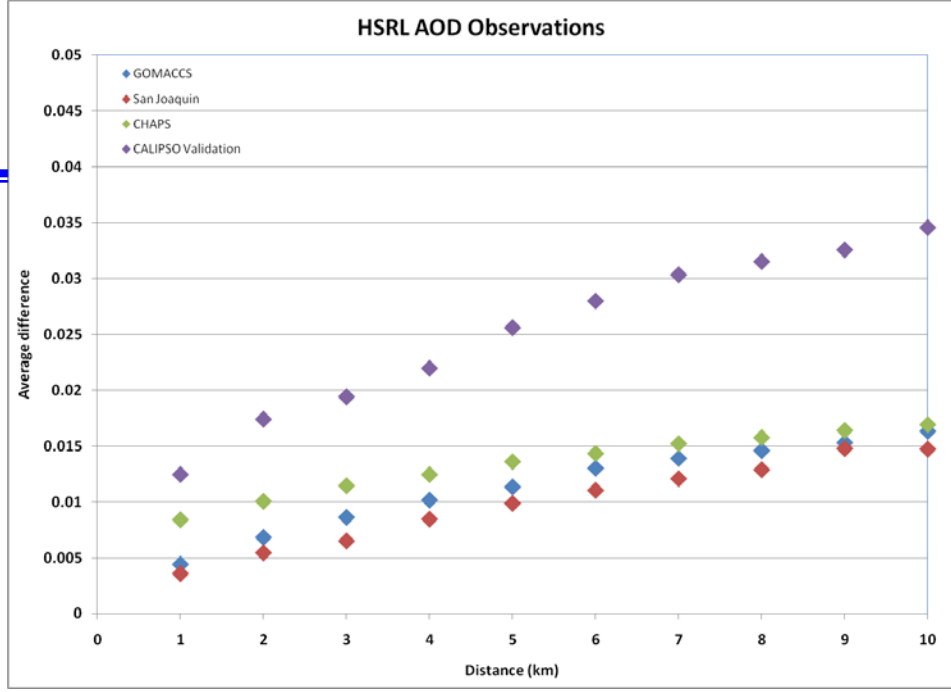
Results shown on following slide.








HSRL AOD Observations
Average difference
Distance (km)
GOMACCS
San Joaquin
CHAPS
CALIPSO Validation


HSRL AOD Observations
Average difference
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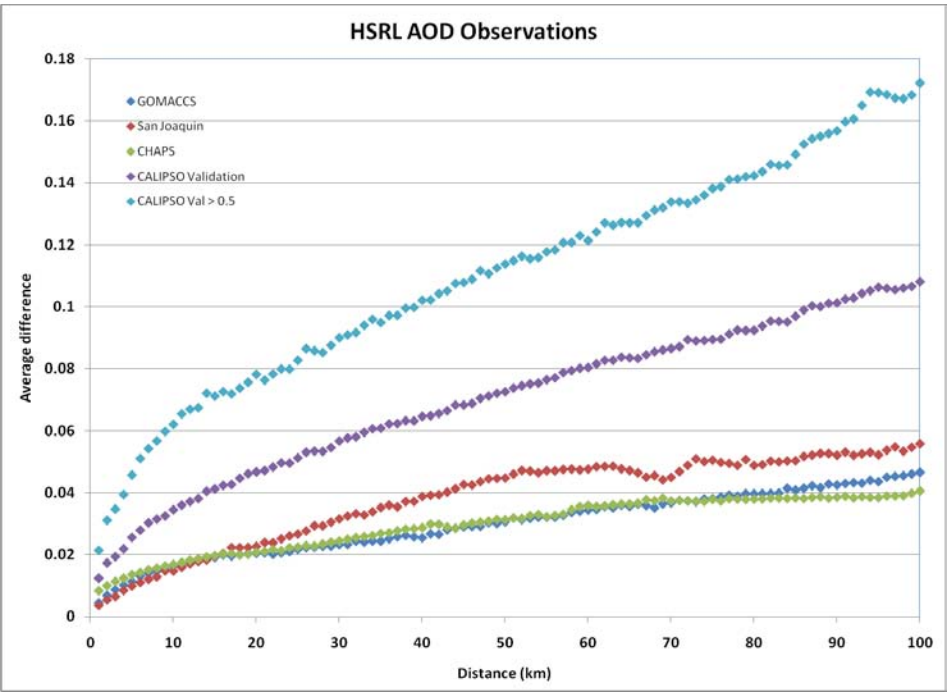
CHAPS
CALIPSO Validation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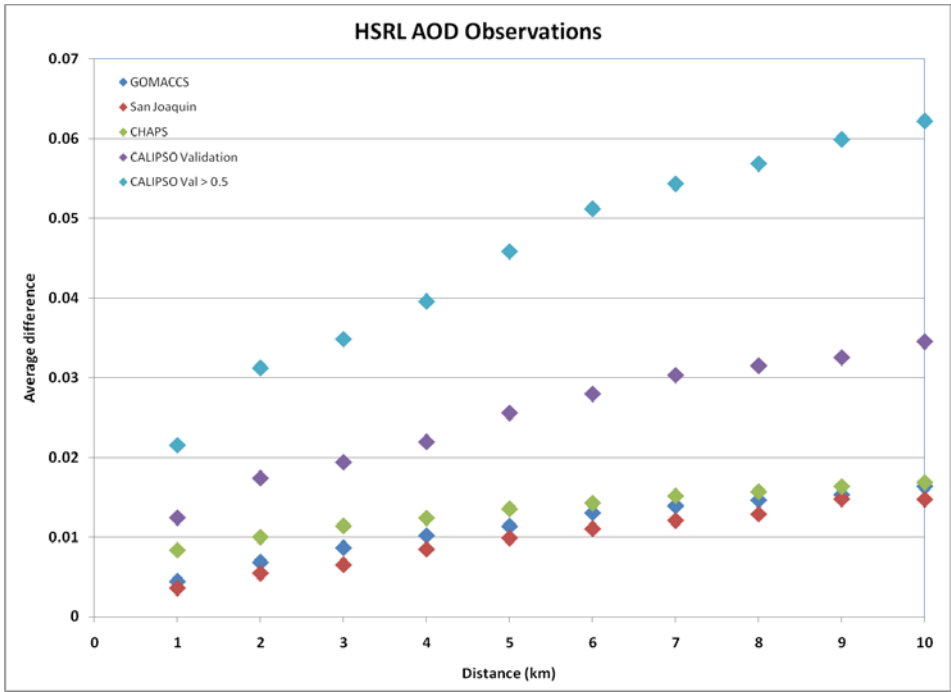
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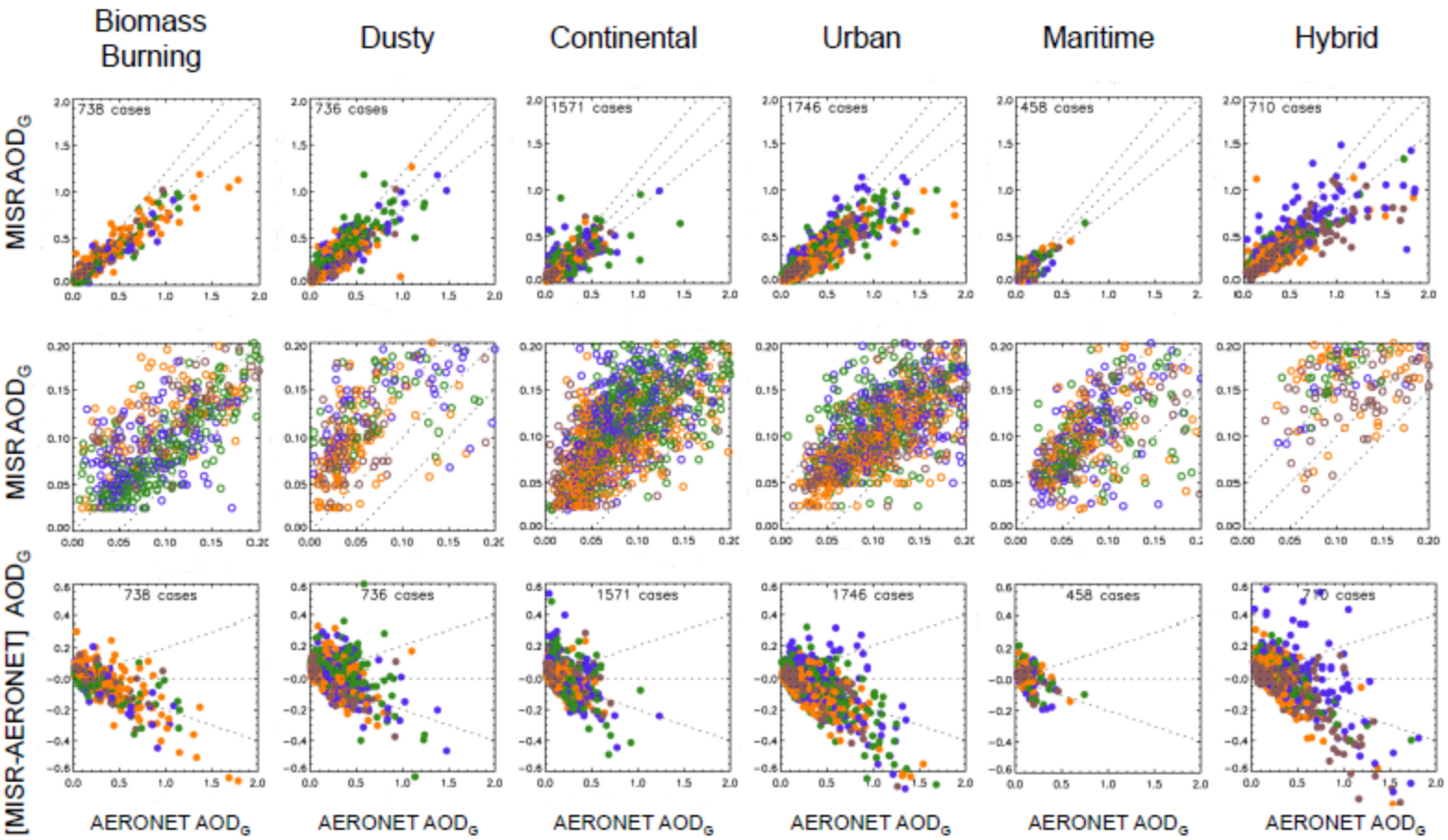
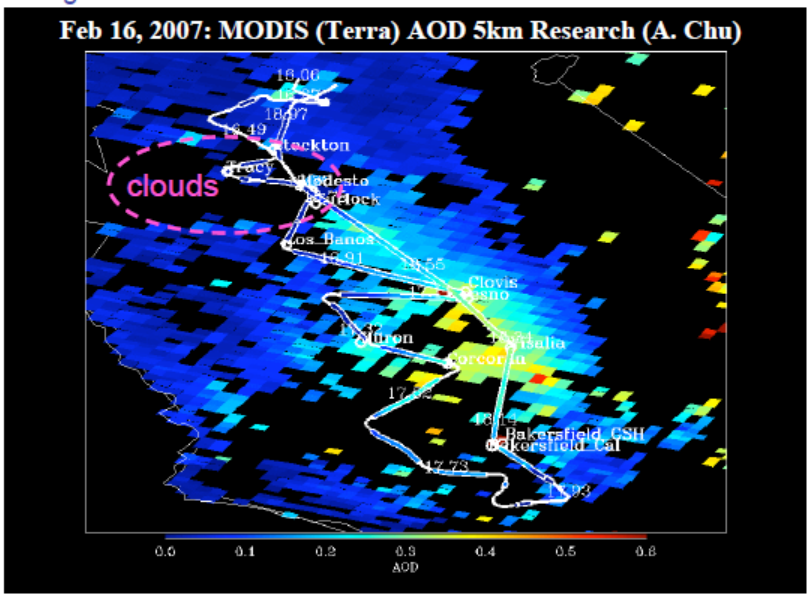
Average difference
Distance (km)
GOMACCS
San Joaquin
CHAPS
CALIPSO Validation
CALIPSO Val > 0.5


Biomass Burning
Dusty
Continental
Urban
Maritime
Hybrid
738 cases
736 cases
1571 cases
1746 cases
458 cases
710 cases
MISR AOD$_G$
MISR AOD$_G$
[MISR-AERONET] AOD$_G$
AERONET AOD$_G$
AERONET AOD$_G$
AERONET AOD$_G$
AERONET AOD$_G$
AERONET AOD$_G$
AERONET AOD$_G$

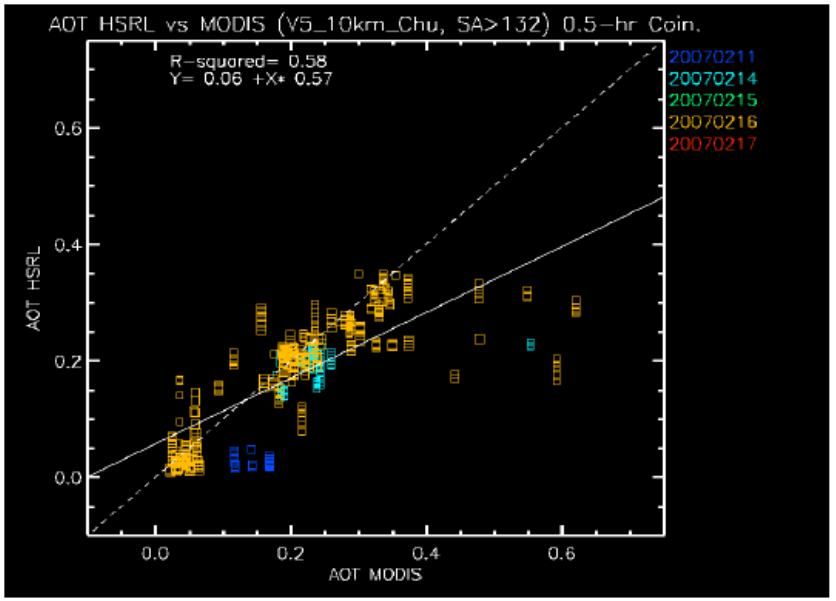
HSRL AOD overlaid on MODIS AOD (V5 5km Research Retrieval)

- At 5km resolution, finer-scale spatial features are evident within SJV
- However, fewer successful retrievals in southern part of SJV
- Note high value over Bakersfield



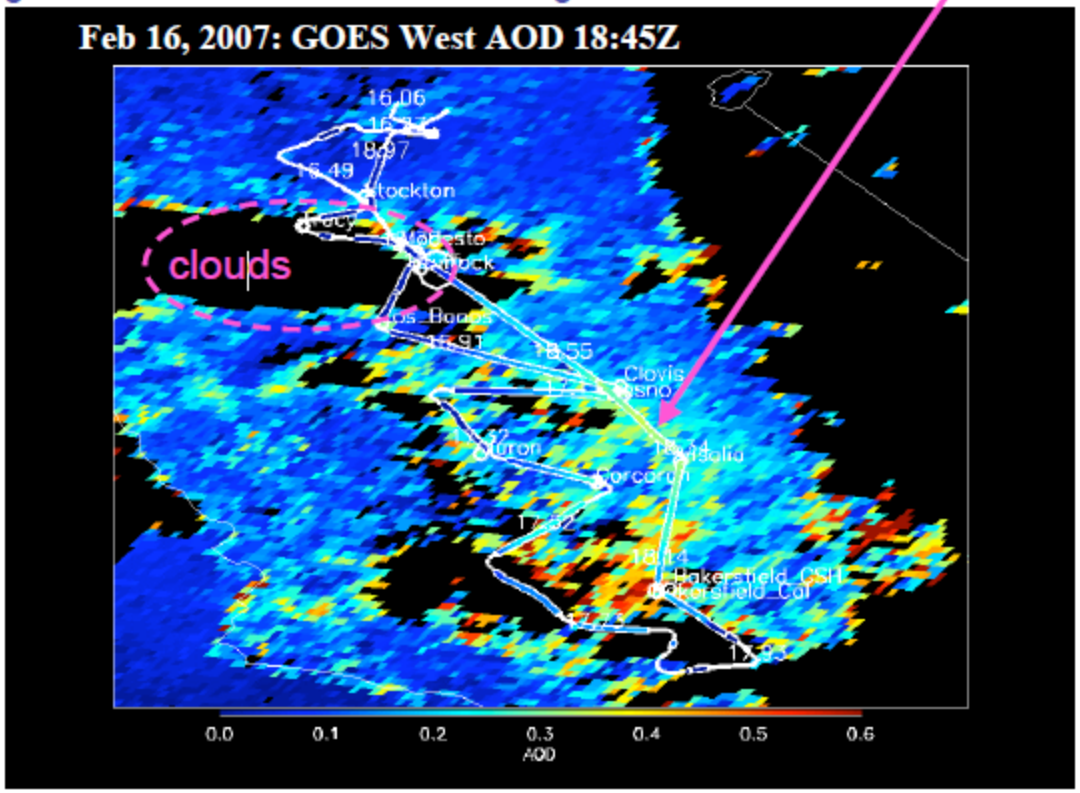
Correlation of HSRL and MODIS (V5 Research) AOD , SA>132 deg only

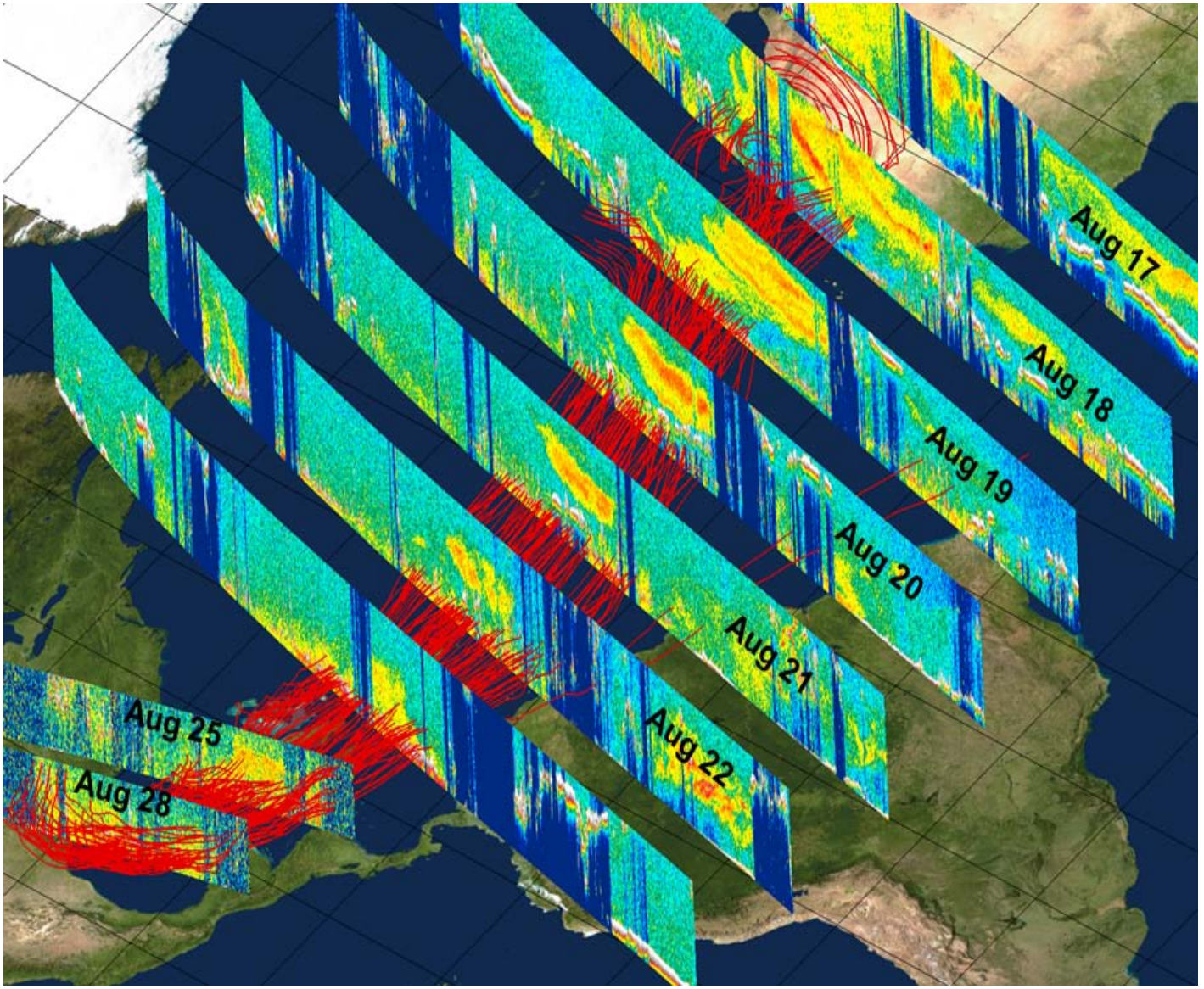
- Although research algorithm results in a larger number of valid retrievals, population of high-valued outliers adversely affects regression



HSRL AOD overlaid on GOES-West AOD (Pre-operational)

- 4km nadir resolution, every half hour, currently being validated
- Good correspondence during HSRL flight segment closest in time
- High satellite values in Bakersfield region




Aug 17
Aug 18
Aug 19
Aug 20
Aug 21
Aug 22
Aug 25
Aug 28