NOAA flight planning support and satellite aerosol and cloud retrieval validation during TORERO

R. Bradley Pierce and Andrew Heidinger
NOAA/NESDIS/STAR

Allen Lenzen[1], Todd Schaack[1], Ryan Spackman[2], Ru-Shan Gao[2], David Fahey[2]
Chris Hostetler[3], Rich Ferrare[3], David Winker[3]
[1] University of Wisconsin-Madison, [2]NOAA ESRL Chemical Sciences Division, Boulder, CO,
[3]NASA Langley Research Center, Hampton, VA

Satellite Validation: Geostationary Operational Environmental Satellite – R Series (GOES-R)

- **Advanced Baseline Imager (ABI): Improved spectral (3X), spatial (4X), and temporal (5X) resolution over current GOES**

ABI Visible/Near-IR Bands

GOES-R imager band	Wavelength range (µm)	Central wavelength (µm)	Nominal subsatellite IGFOV (km)	Comments for daytime viewing
1	0.45-0.49	0.47	1	"blue" visible Aerosol over land
2	0.59-0.69	0.64	0.5	GOES heritage "red" visible High res animations
3	0.846-0.885	0.865	1	Vegetation state Aerosol over water
4	1.371-1.386	1.378	2	Cirrus/upper level cloud
5	1.58-1.64	1.61	1	Cloud-top phase and particle size Snow distinction
6	2.225-2.275	2.25	2	Distinguish land, cloud, snow, and ice properties

Schmit et al, 2005

ABI IR Bands

GOES-R imager band	Wavelength range (µm)	Central wavelength (µm)	Nominal subsatellite IGFOV (km)	Comments
7	3.80-4.00	3.90	2	GOES imager heritage
8	5.77-6.6	6.19	2	GOES imager heritage
9	6.75-7.15	6.95	2	GOES sounder heritage
10	7.24-7.44	7.34	2	GOES sounder heritage with spectral modifications
11	8.3-8.7	8.5	2	Cloud-top phase Ash/dust, SO_2, sulfates
12	9.42-9.80	9.61	2	Ozone. GOES sounder heritage with spectral modifications
13	10.1-10.6	10.35	2	Surface and cloud temperatures, low level moisture, dust and volcanic ash
14	10.8-11.6	11.2	2	
15	11.8-12.8	12.3	2	
16	13.0-13.6	13.3	2	Heritage from GOES imager and sounder: temperature, cloud characteristics.

Schmit et al, 2005

GOES-R ABI Cloud Products

1. Clear sky mask (binary, 4-level, and test results)
2. Cloud Phase
3. Cloud Type
4. Cloud-top Height
5. Cloud-top Temperature
6. Cloud-top Pressure
7. Day/Night Cloud Optical Depth
8. Day/Night Cloud Particle Size
9. Day/Night Liquid Water Path
10. Day/Night Ice Water Path

Aerosol Products

1. Aerosol Detection (Smoke and Dust)
2. Aerosol Optical Depth (AOD)
3. Aerosol Particle Size (Ångström exponent)

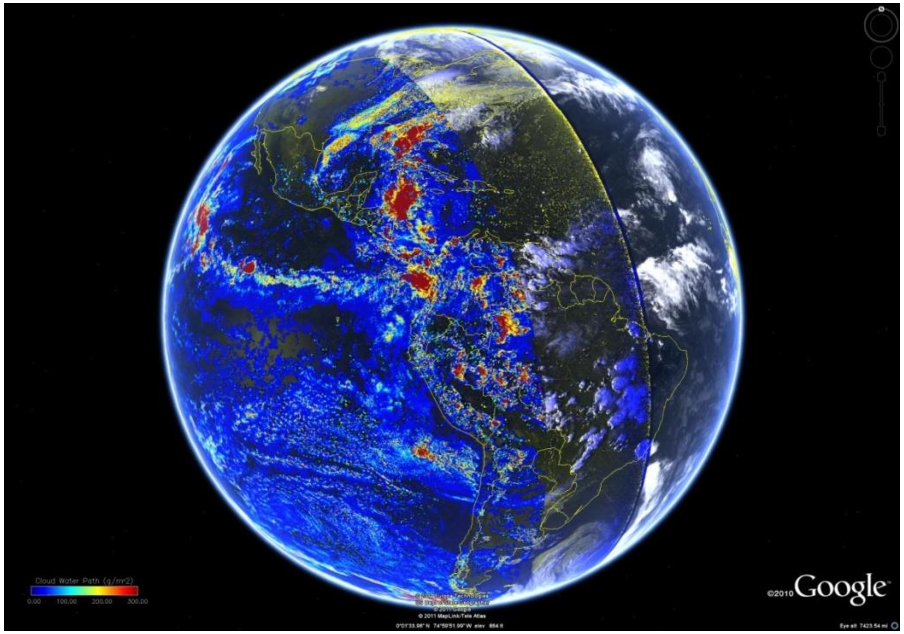
Surface Products*

1. Surface SW Flux
2. Surface LW Flux
3. Albedo/SST

Legacy Sounder Products*

1. Temperature profile
2. Water vapor profile

Real-Time GOES-12 Imager Processing at CIMSS



GOES-R Cloud water path

*Subset that can be validated during TORERO

Opportunities for GOES-R Cloud, Aerosol, Surface, Sounder Validation during TORERO

HSRL (day and night)

- Cloud optical depth for optically thin clouds
- Cloud detection
- Verification of multilayer cloud detection
- Separation of cloud from suspended aerosol layers.
- Aerosol optical depth
- Aerosol detection

HARP (day only)

- Multispectral estimate of cloud microphysics.
- Surface Albedo

AMAX-DOAS (day only)

- Aerosol optical depth

MTP

- Legacy Temperature Profile

GV Insitu

- Legacy Temperature/moisture Profile

Ship (day/night)

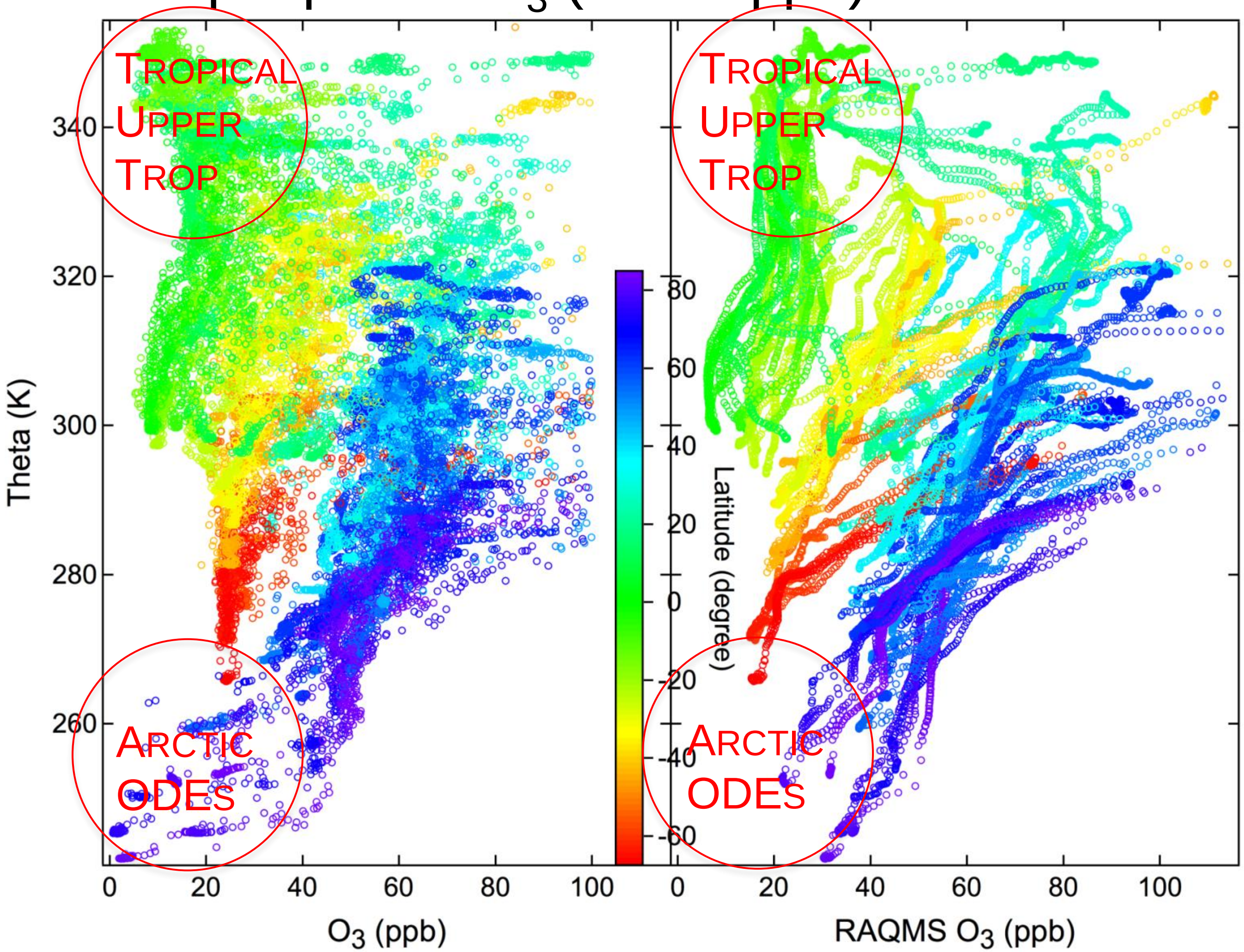
- Surface downwelling SW Flux
- Surface downwelling LW Flux

TORERO Flight Planning Support: Real-time Air Quality Modeling System (RAQMS) chemical and aerosol forecasts

1) Real-time assimilation of MODIS Terra and Aqua AOD, MLS stratospheric ozone profiles, and OMI total column ozone
2) Unified stratosphere/troposphere chemistry module [Pierce et al., 2007]
3) Extended carbon bond scheme for oxidation of nonmethane hydrocarbons (NMHC) [Zaveri and Peters,1999]
4) Four product isoprene oxidation [Carter, 1996].
5) Tropospheric Halogen Chemistry: BrO from sea-ice
6) Goddard Chemistry Aerosol Radiation and Transport (GOCART) aerosol mechanism [Chin et al., 2002]
7) 5-day global 1x1 degree forecasts

HIAPER Pole-to-Pole Observation (HIPPO) III

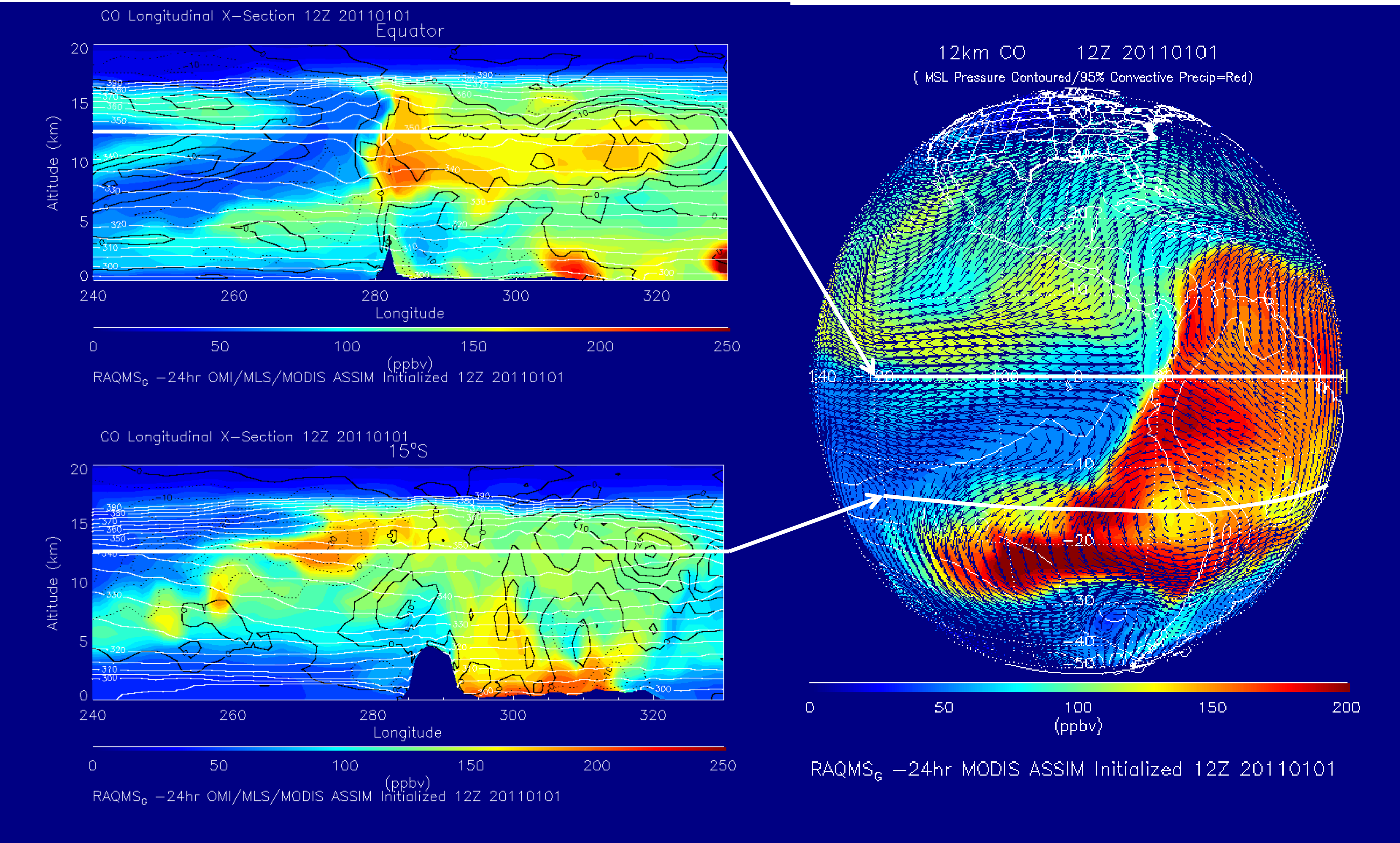
Tropospheric O_3 (< 100 ppb) as functions of θ



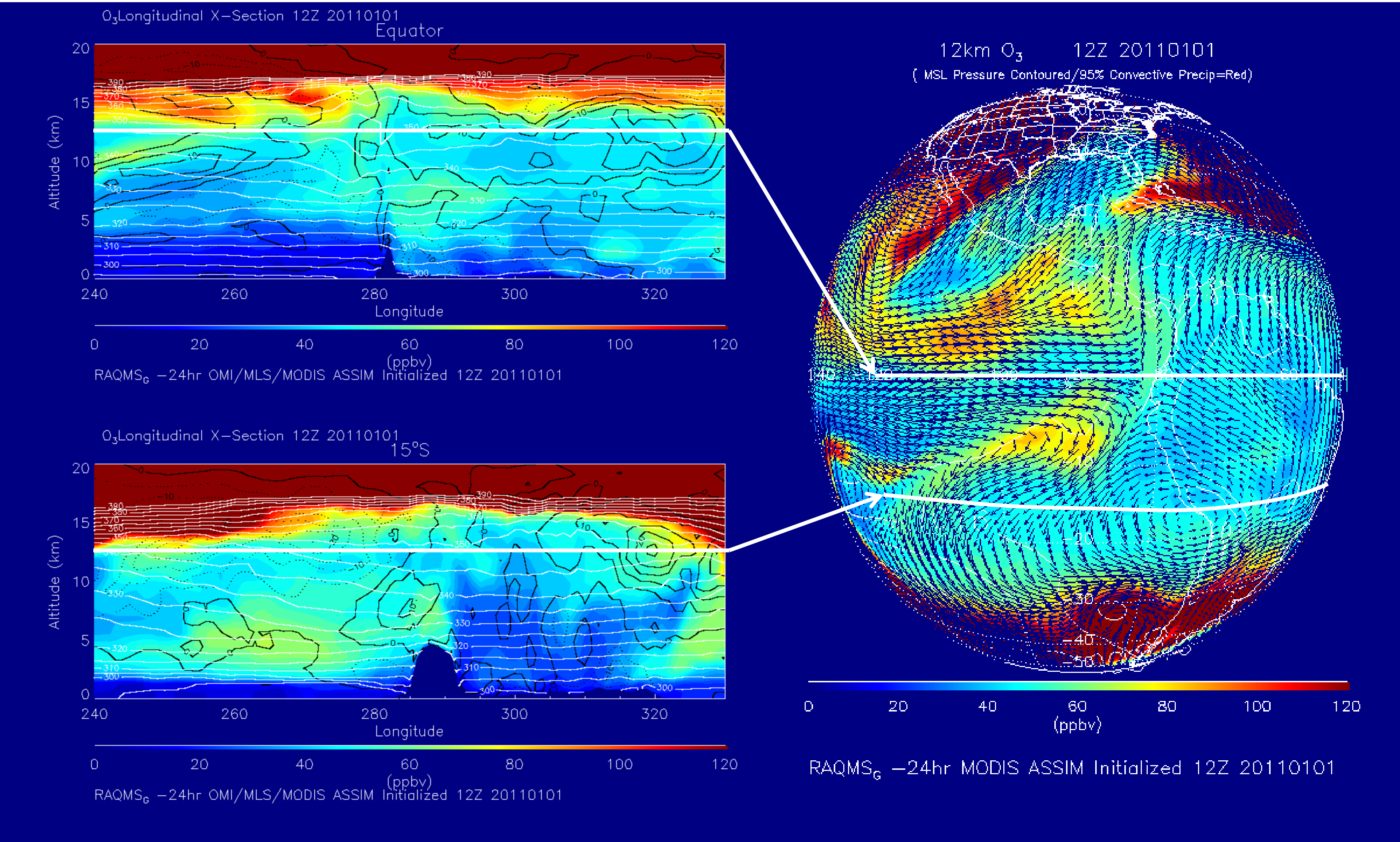
Pacific Ocean: March 20-April 20, 2010

HIPPO III O3 data provided by Ryan Spackman, Ru-Shan Gao and David Fahey (NOAA ESRL)

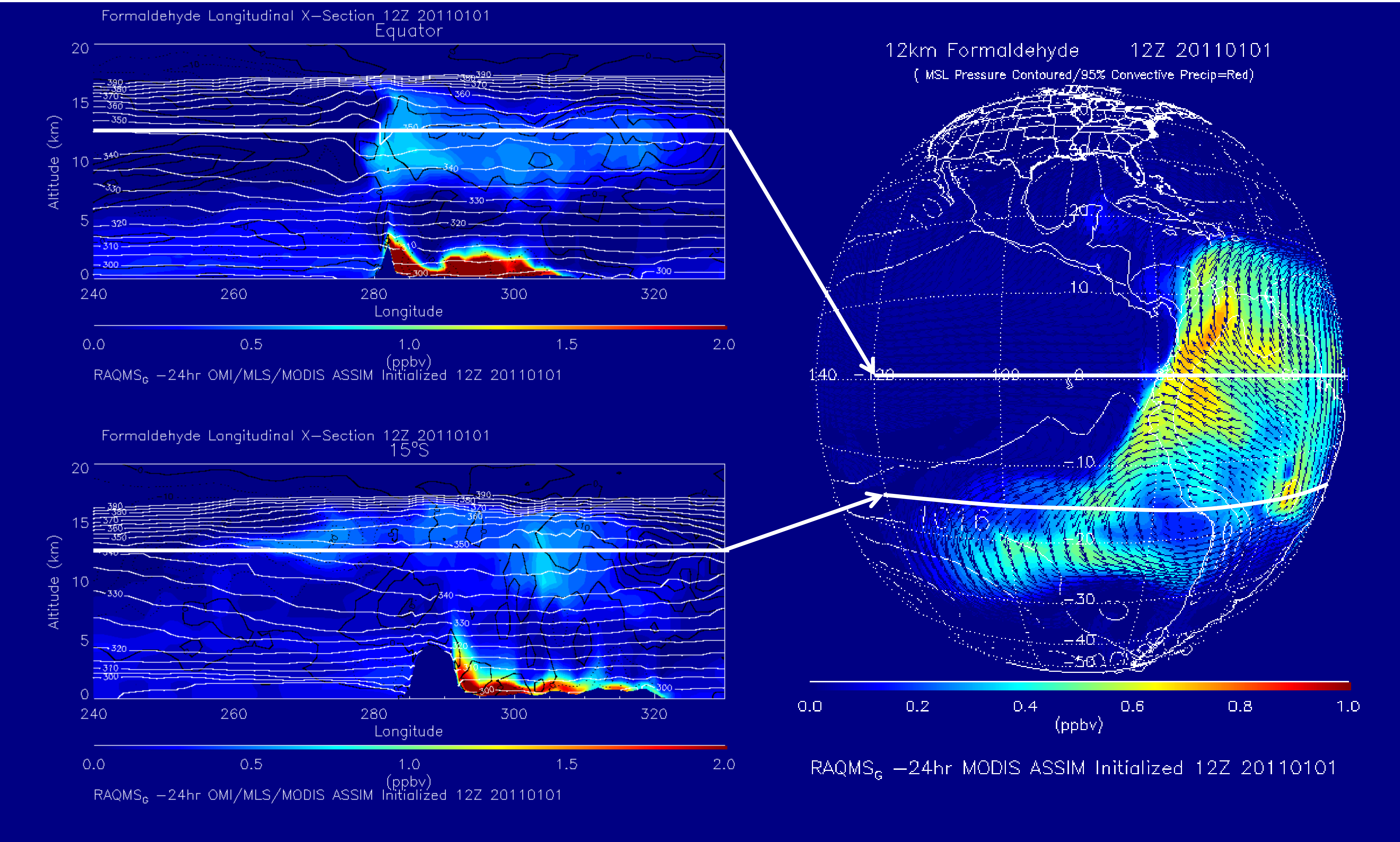
RAQMS CO predictions for TORERO Field of Operations (Jan-Feb, 2011)



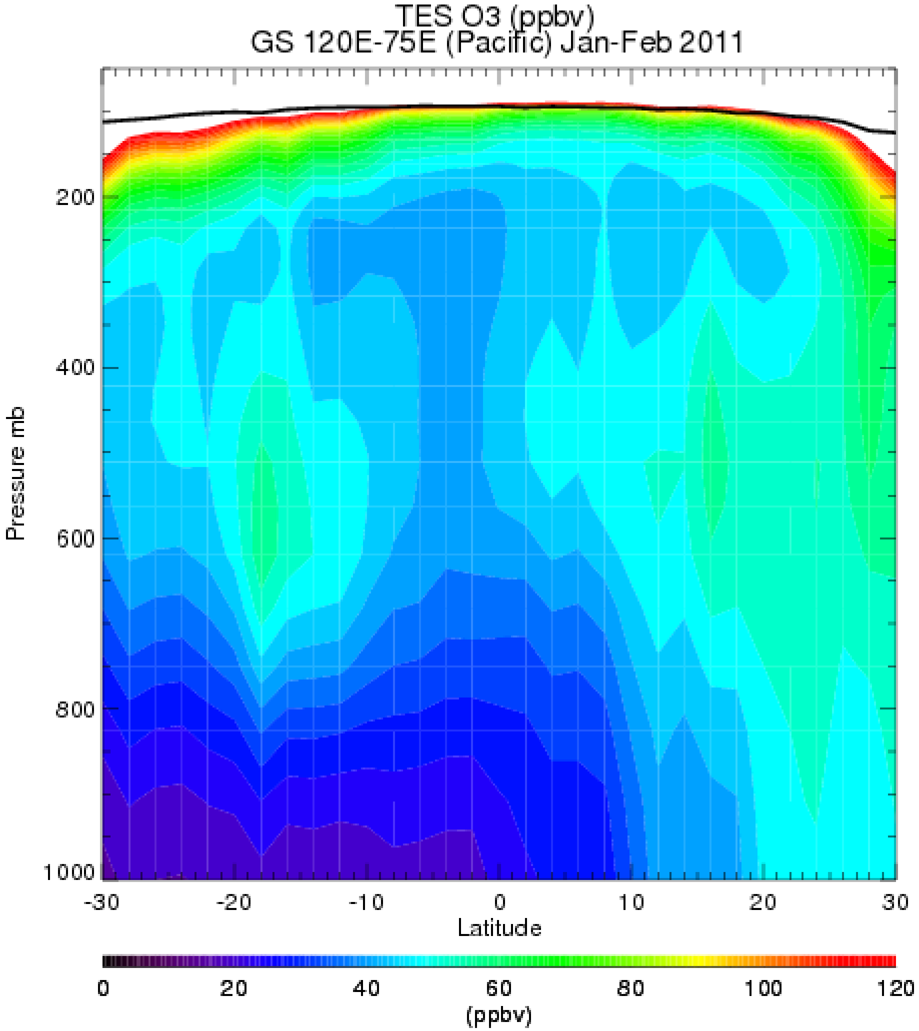
RAQMS O3 analysis for TORERO Field of Operations (Jan-Feb, 2011)

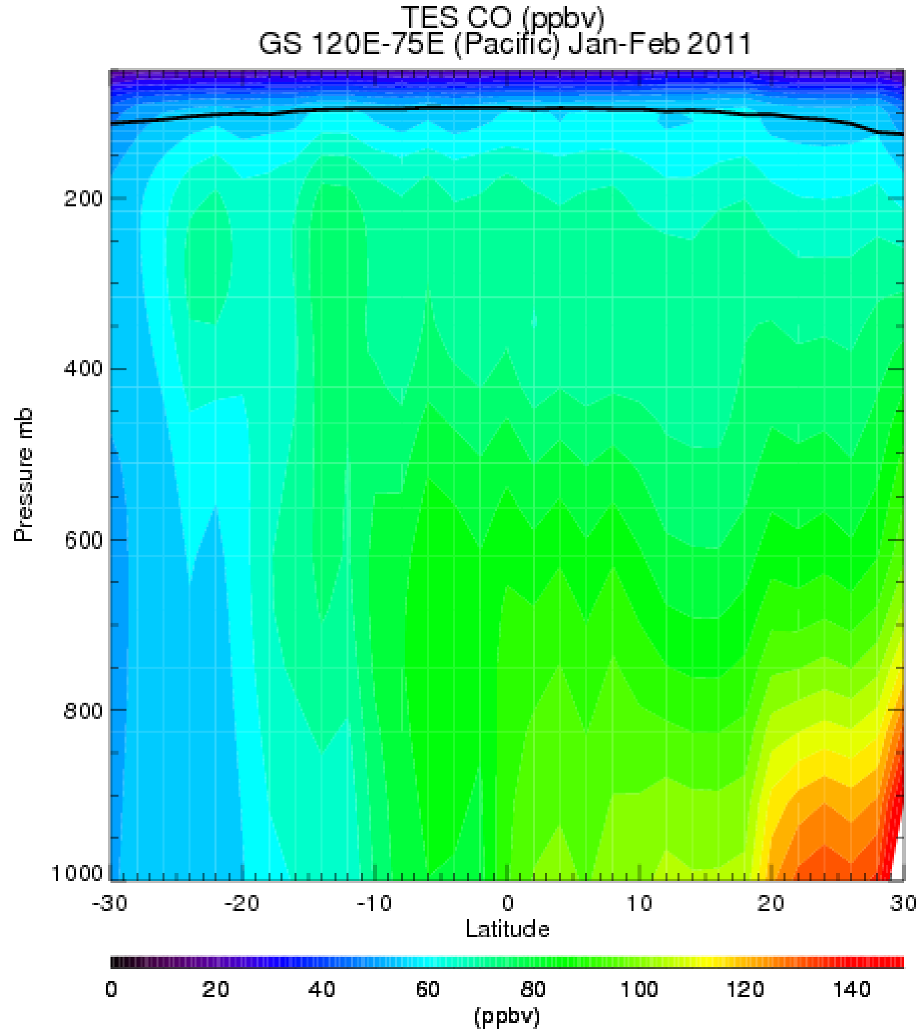


RAQMS CH2O predictons for TORERO Field of Operations (Jan-Feb, 2011)



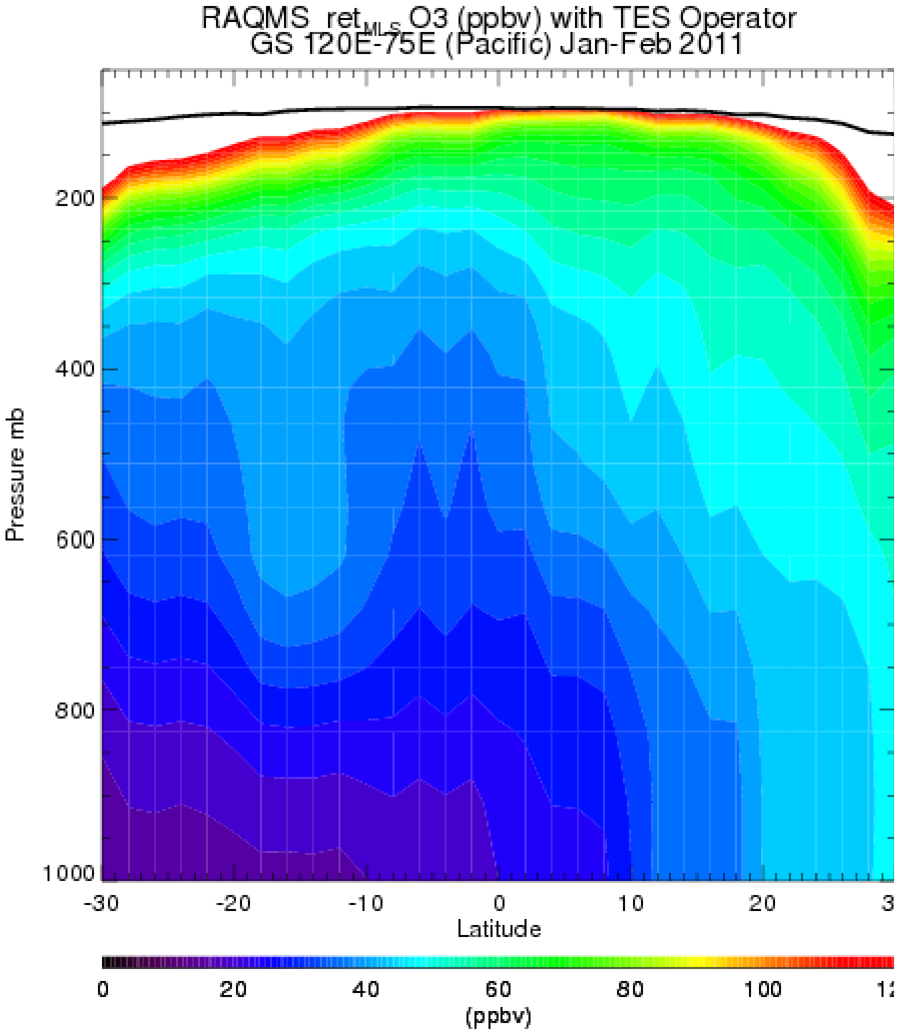
NASA Tropospheric Emission Spectrometer (TES) O3 and CO retrievals for TORERO Field of Operations (Jan-Feb, 2011)

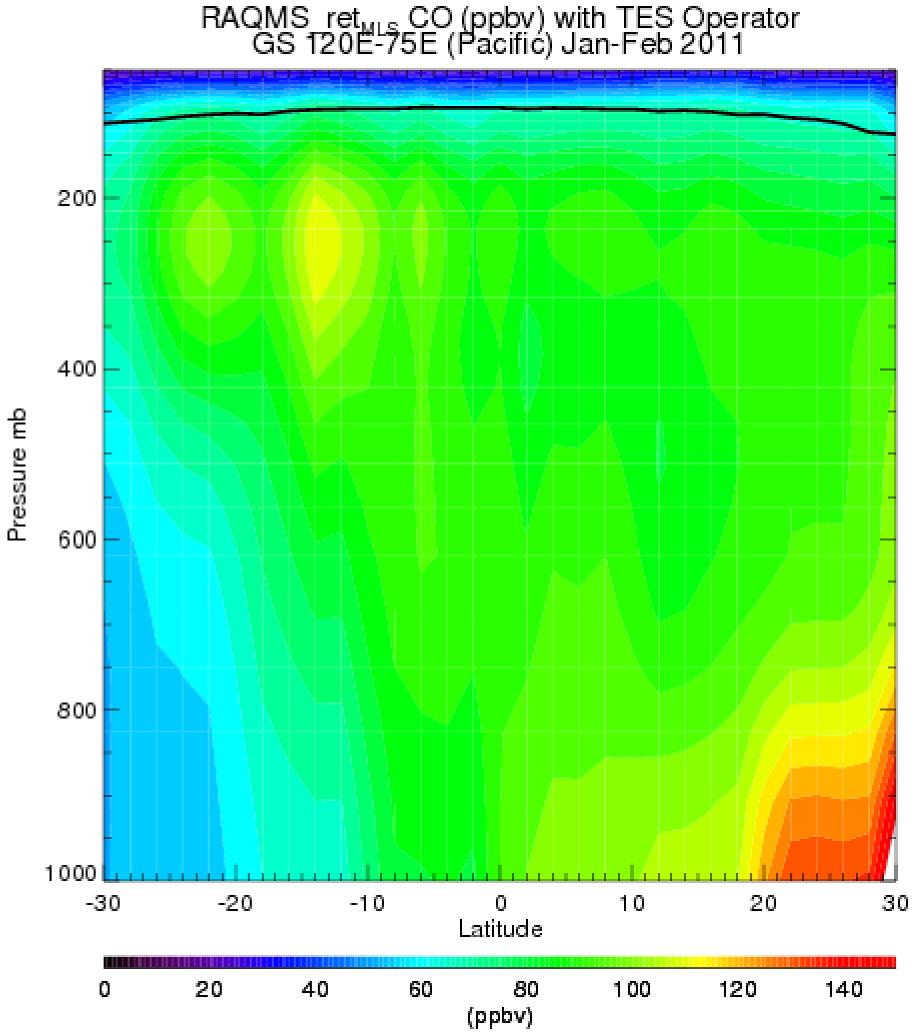




TES Tropical upper troposphere $O3_{min}$~35ppbv

RAQMS O3 and CO with TES Averaging Kernels ($RAQMS_{ret}$) for TORERO Field of Operations (Jan-Feb, 2011)

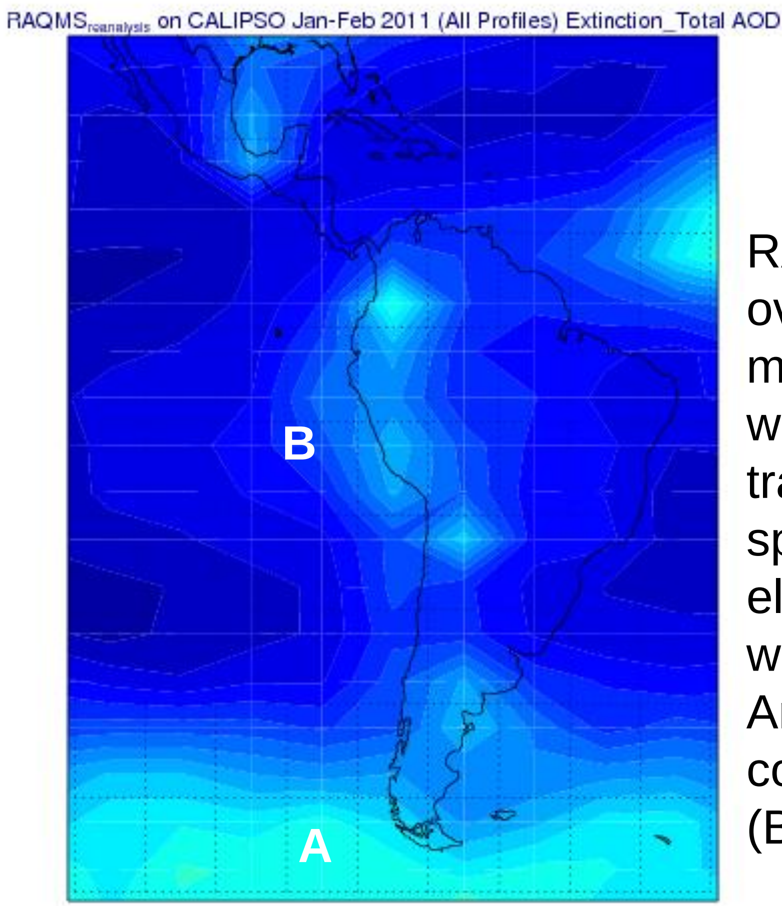




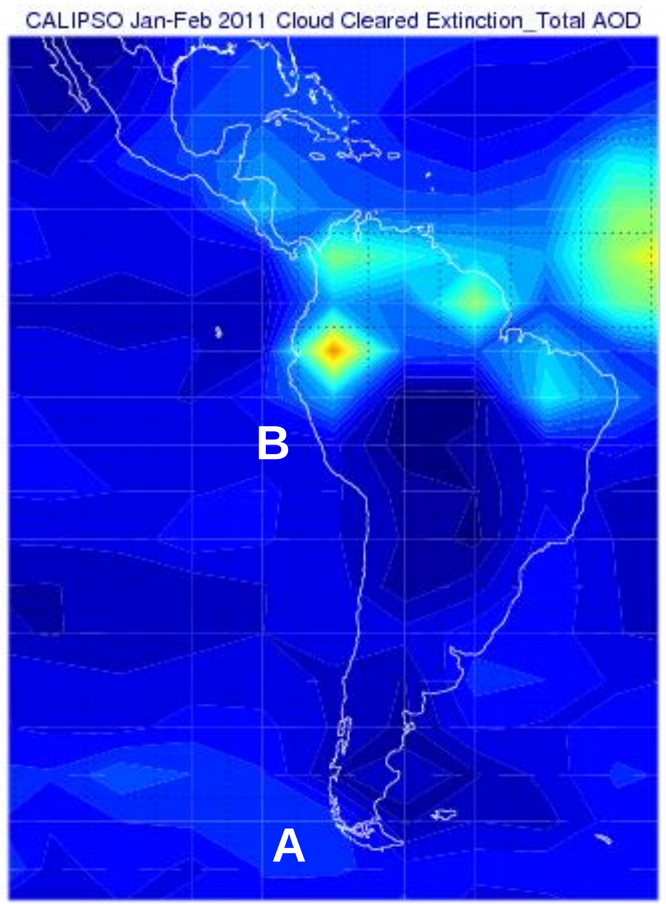
RAQMS overestimates O3 & CO in tropical upper troposphere

CALIPSO vs RAQMS AOD Jan-Feb 2011

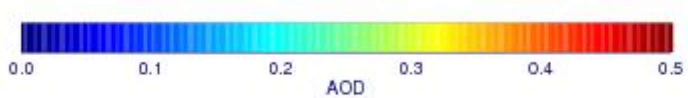
V3-01 aerosol profile retrievals (Dave Winker, NASA LaRC)

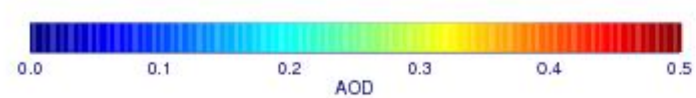


RAQMS overestimates magnitude of AOD within SH storm track (A) and spatial extent of elevated AOD within South American convective outflow (B)

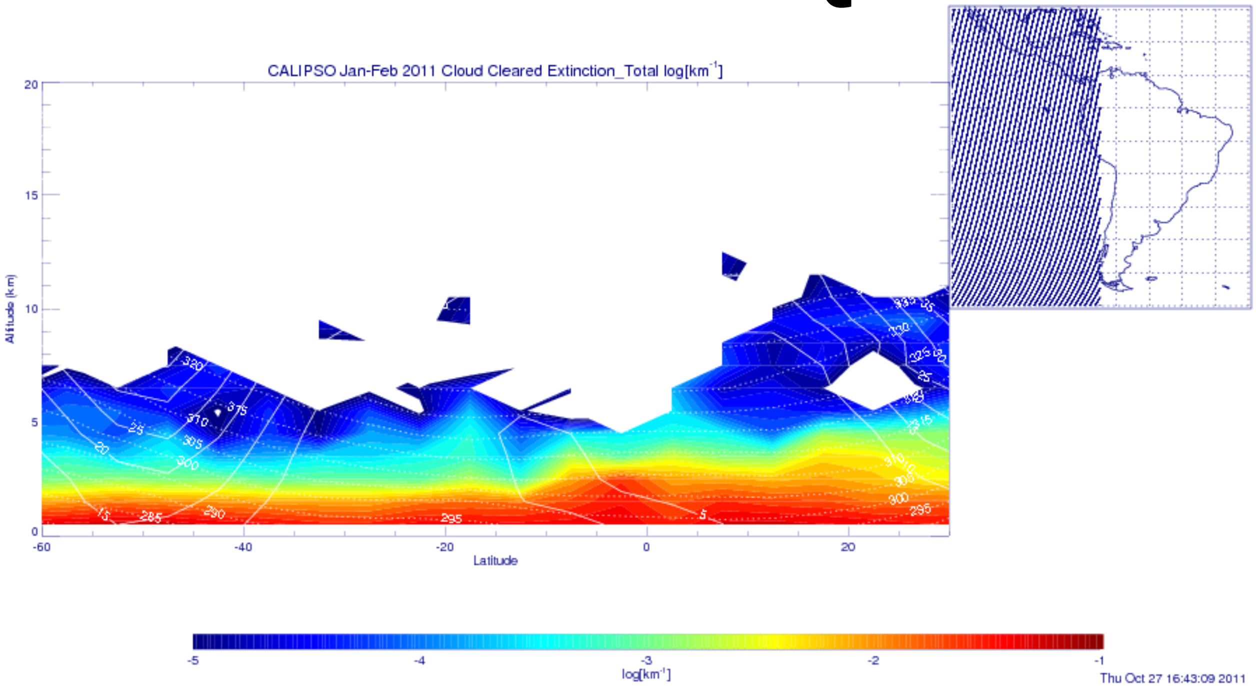


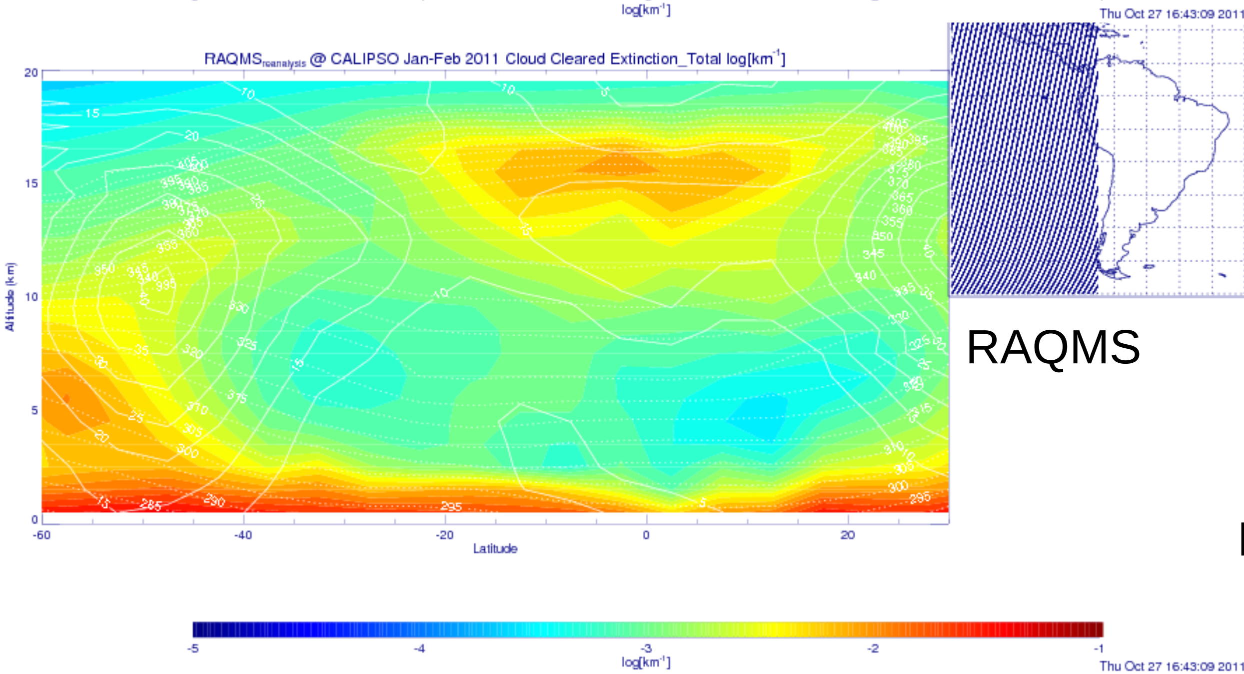
5º Lat, 10º Lon, 1km bins, CAD< -20, COT=0.0 QC=0,1 (unadjusted retrievals)





CALIPSO vs RAQMS Aerosol Extinction: Jan-Feb 2011





RAQMS

RAQMS underestimates marine boundary layer aerosol extinction and overestimates aerosol extinction in the tropical upper troposphere and SH storm track relative to CALIPSO

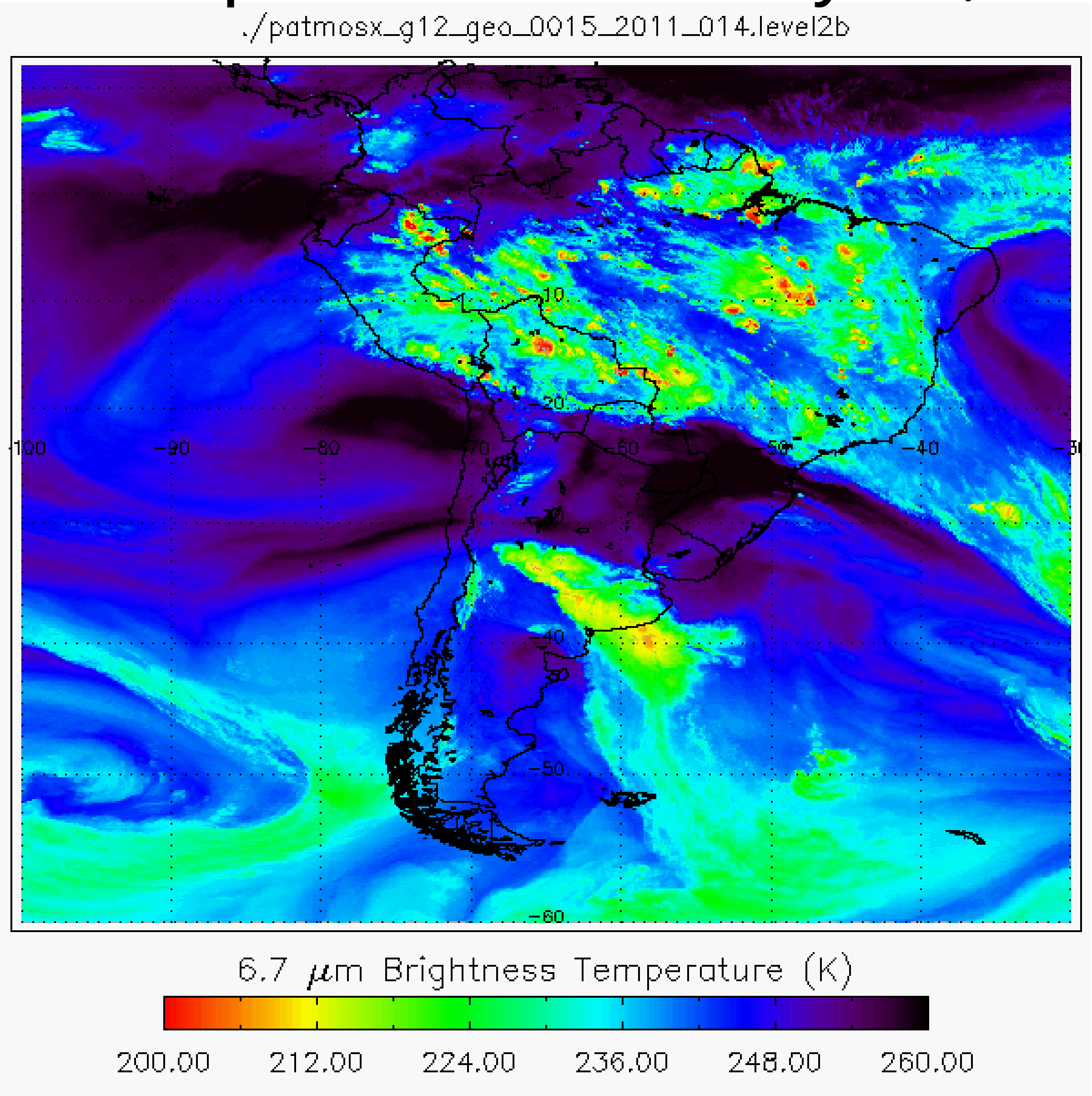
Note log scale!

Example of TORERO Flight planning support:

January 14, 2011

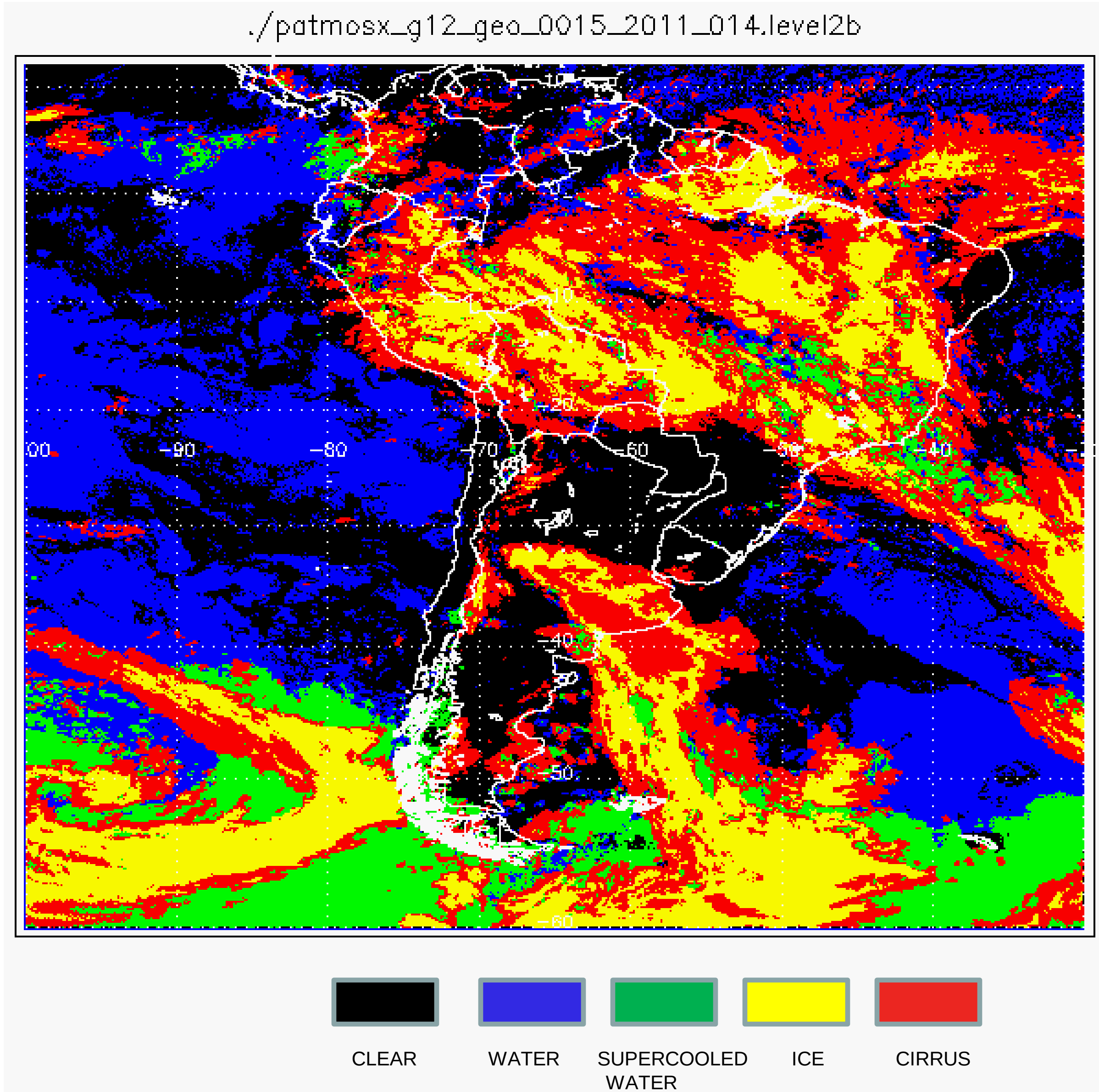
Tropical Upper-troposphere Convective outflow

GOES-12 6.7μm (Water Vapor Channel) Brightness Temperature : January 14, 2011



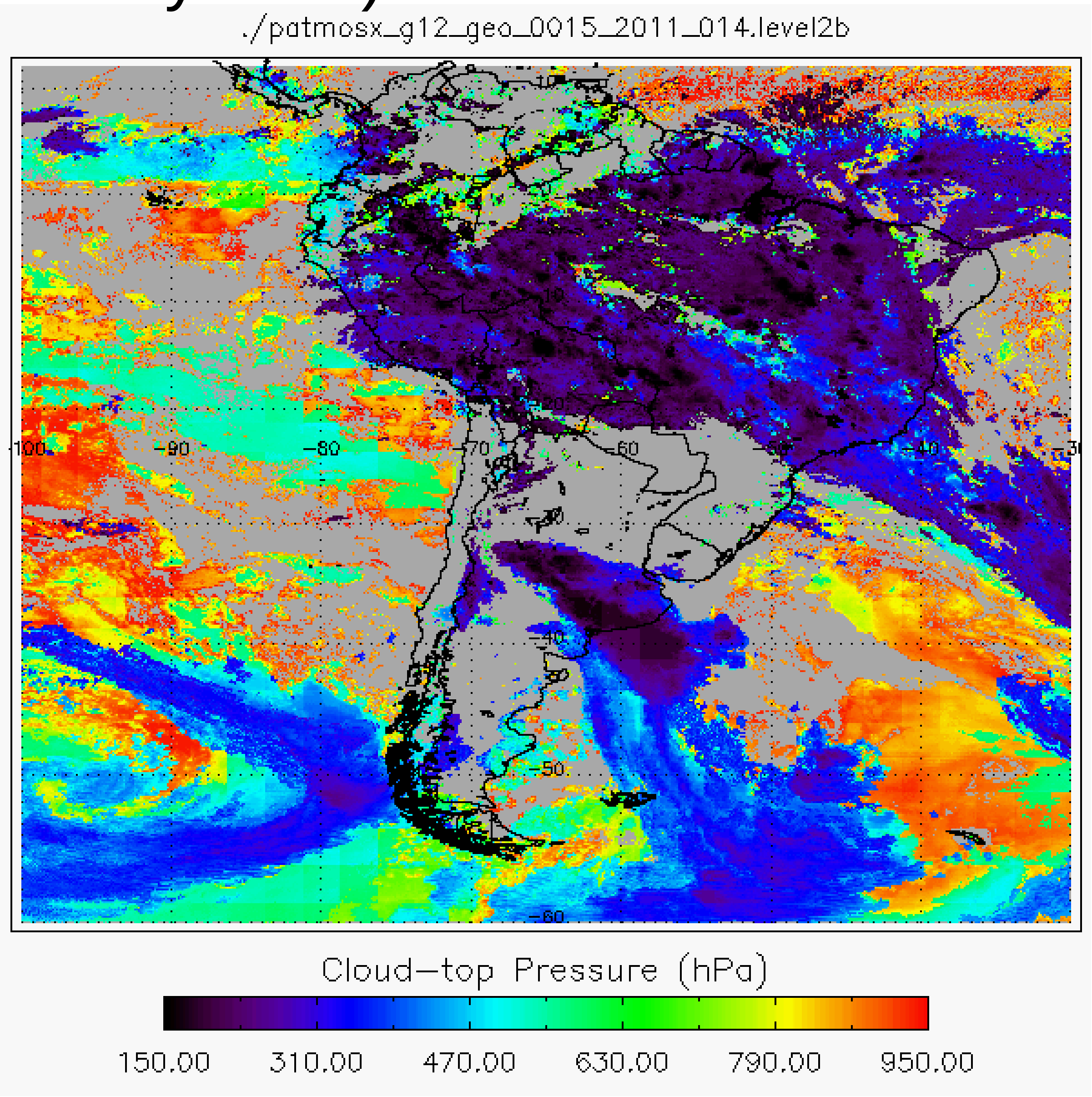
Note: NRT imagery will be provided during TORERO

GOES-R Cloud Type retrieval
(GOES-12 Proxy Data)



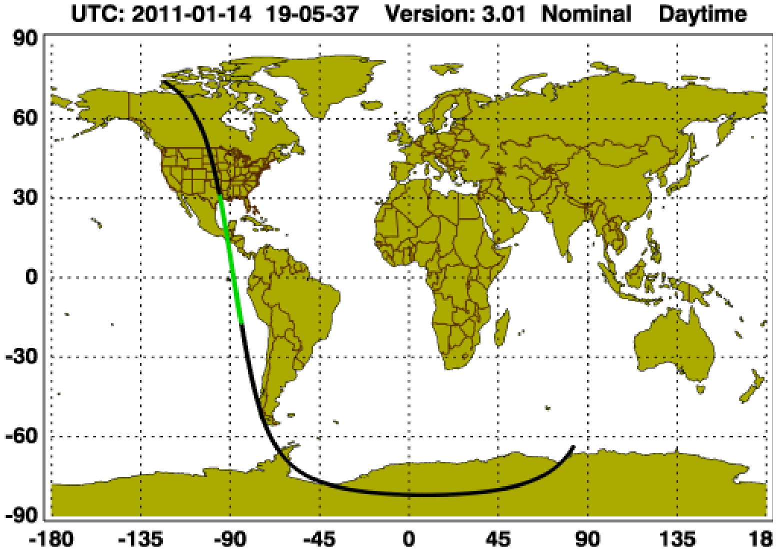
Note: NRT product will be provided during TORERO

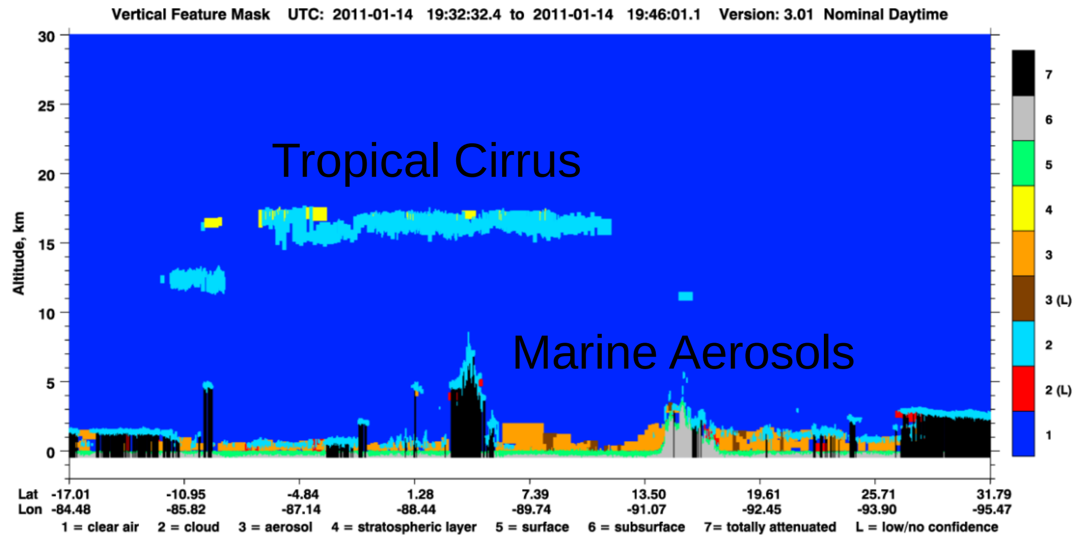
GOES-R Cloud-top Pressure retrieval
(GOES-12 Proxy Data)

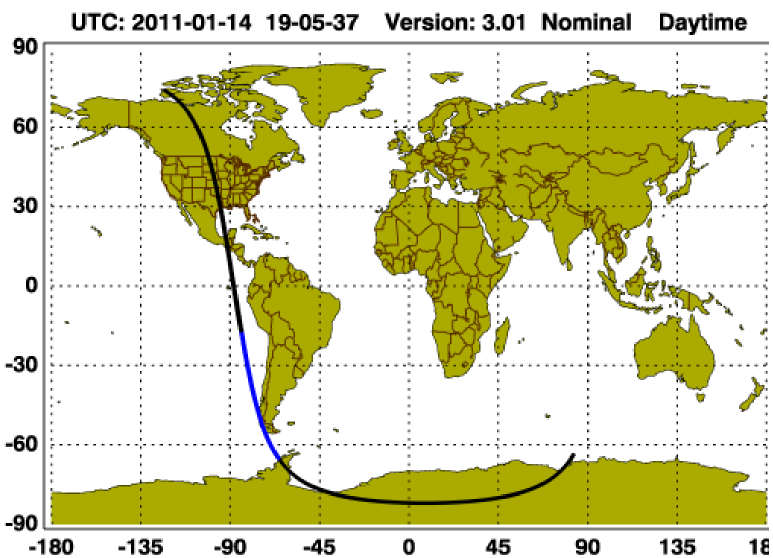


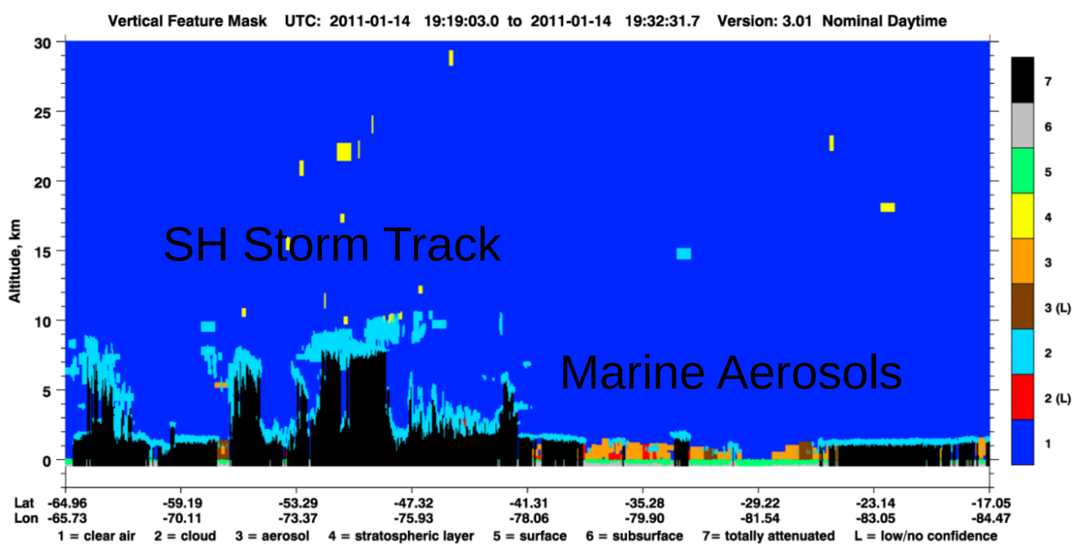
Note: NRT product will be provided during TORERO

CALIPSO Vertical Feature Mask
Jan 14, 19:05Z 2011

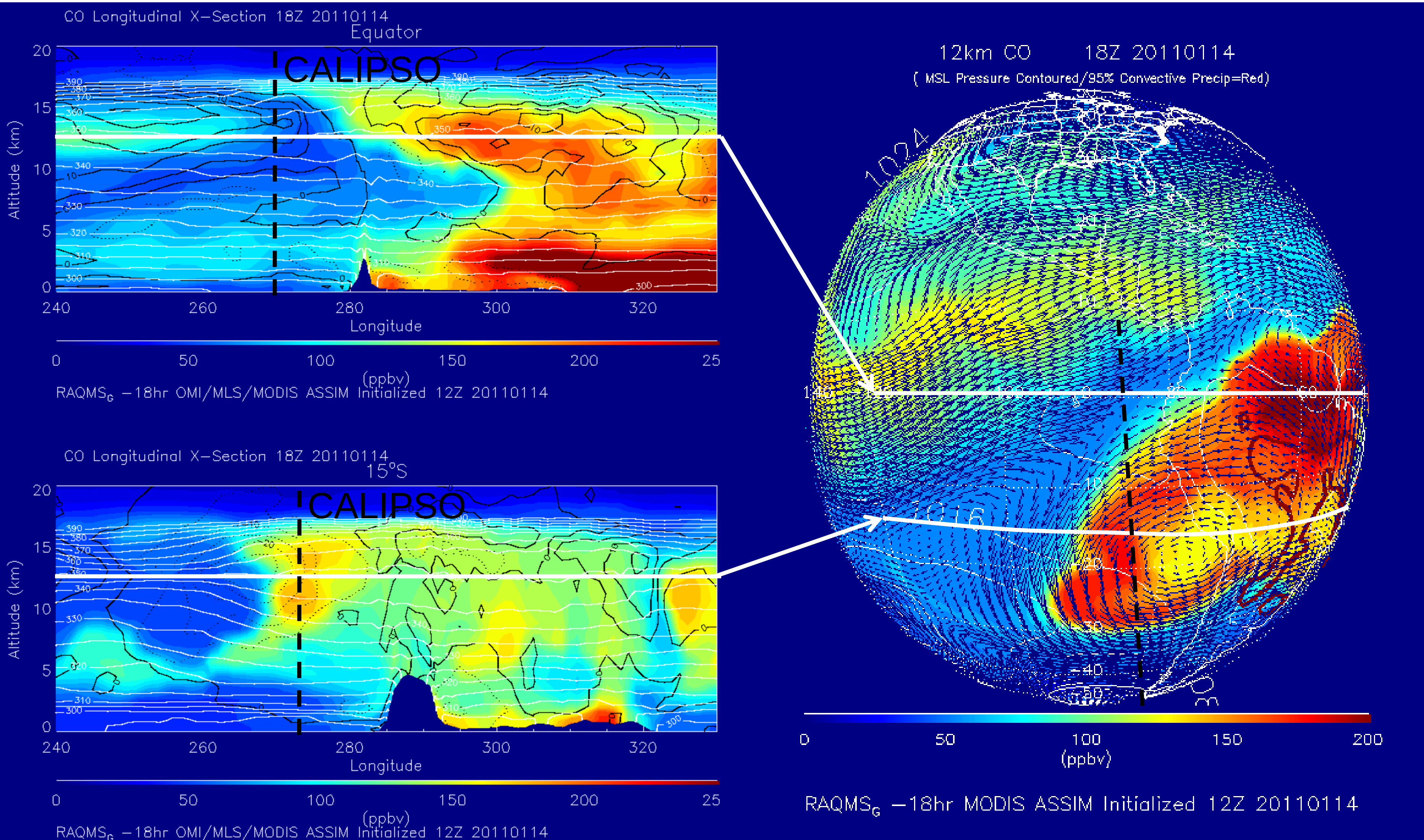




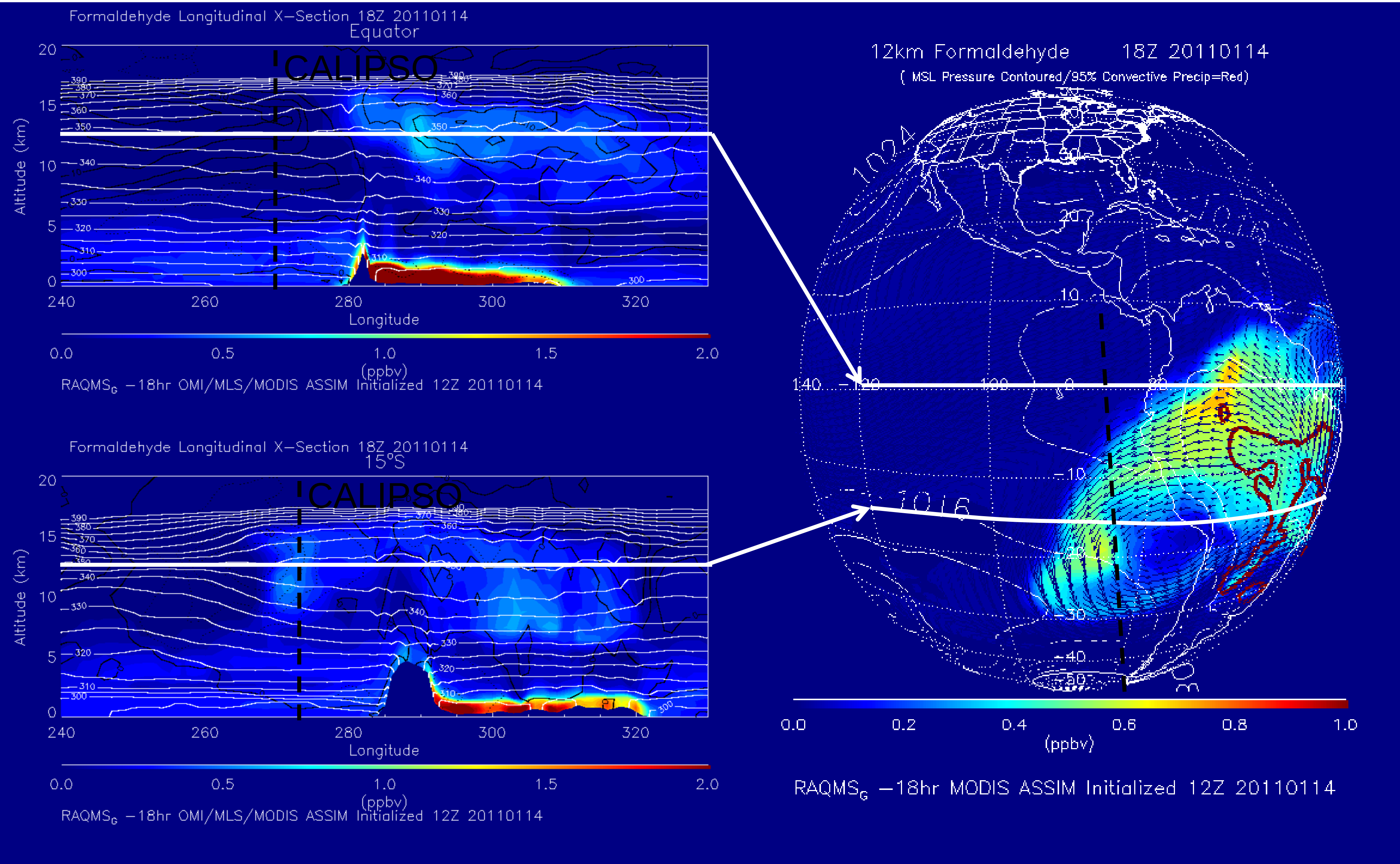




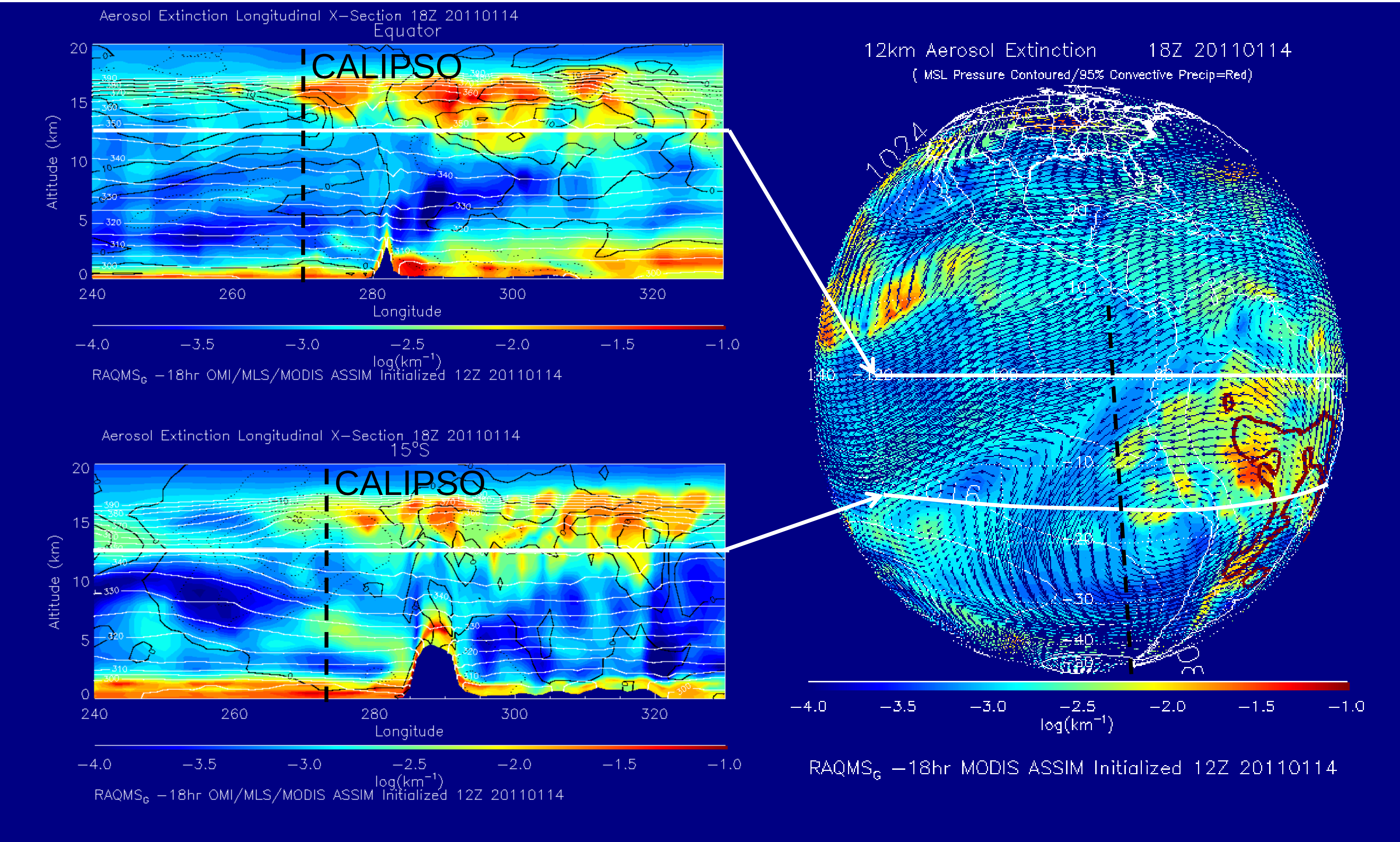
RAQMS CO predictions for TORERO Field of Operations (Jan 14 18Z, 2011)



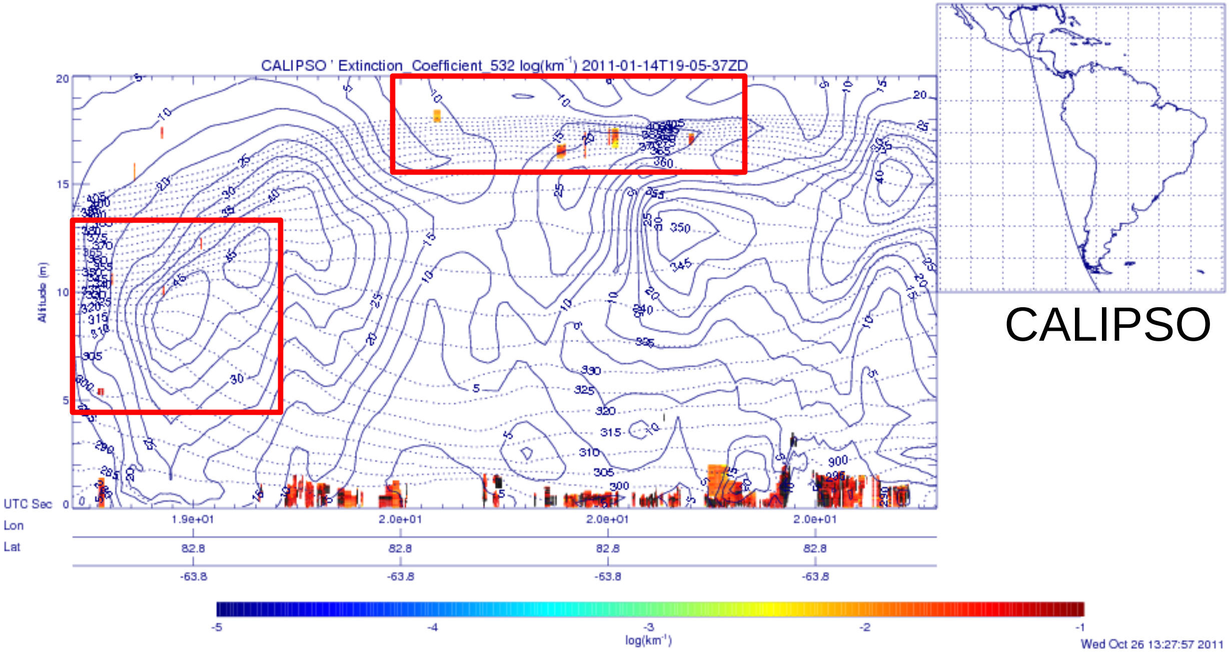
RAQMS CH2O predictions for TORERO Field of Operations (Jan 14 18Z, 2011)



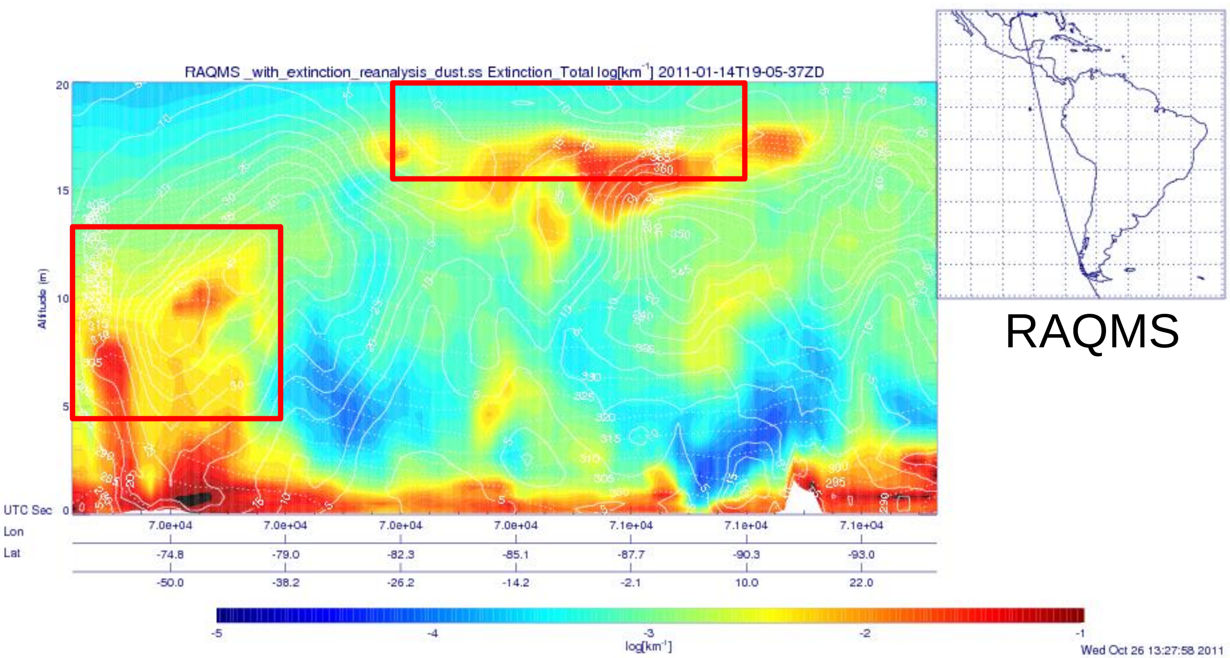
RAQMS Aerosol predictions for TORERO Field of Operations (Jan 14 18Z, 2011)



CALIPSO vs RAQMS Aerosol Extinction: Jan 14, 19Z 2011



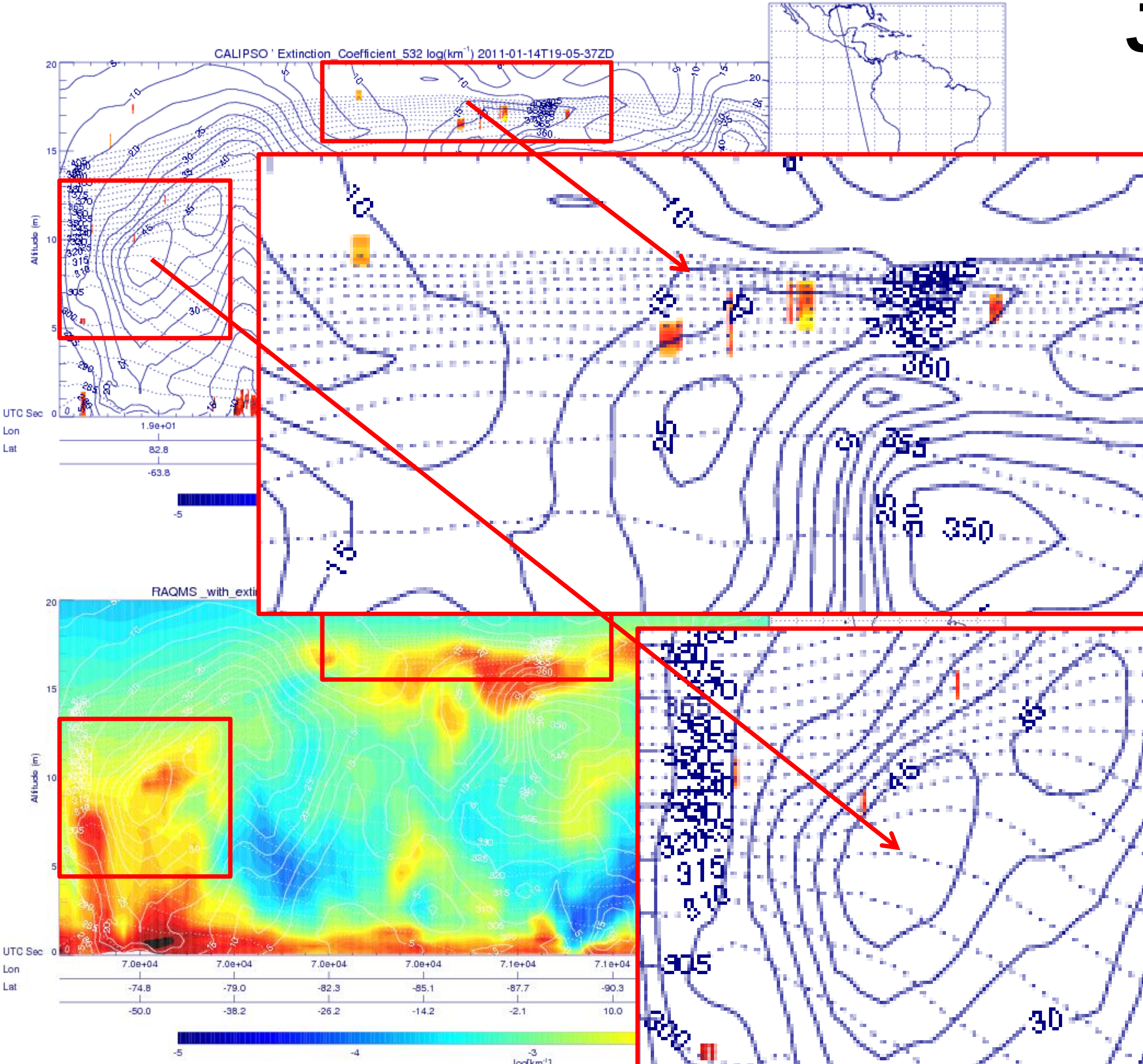
CALIPSO



RAQMS

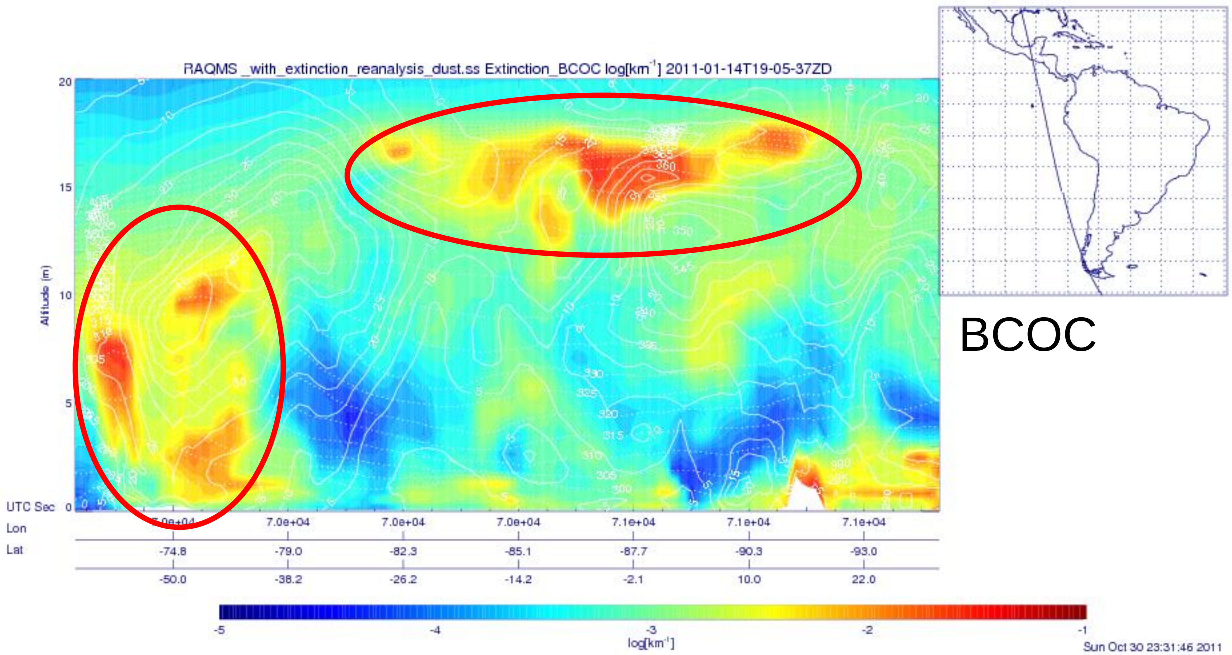
RAQMS overestimates the <u>spatial extent</u> of elevated aerosol extinction in the tropical upper troposphere and mid-latitude storm track relative to CALIPSO

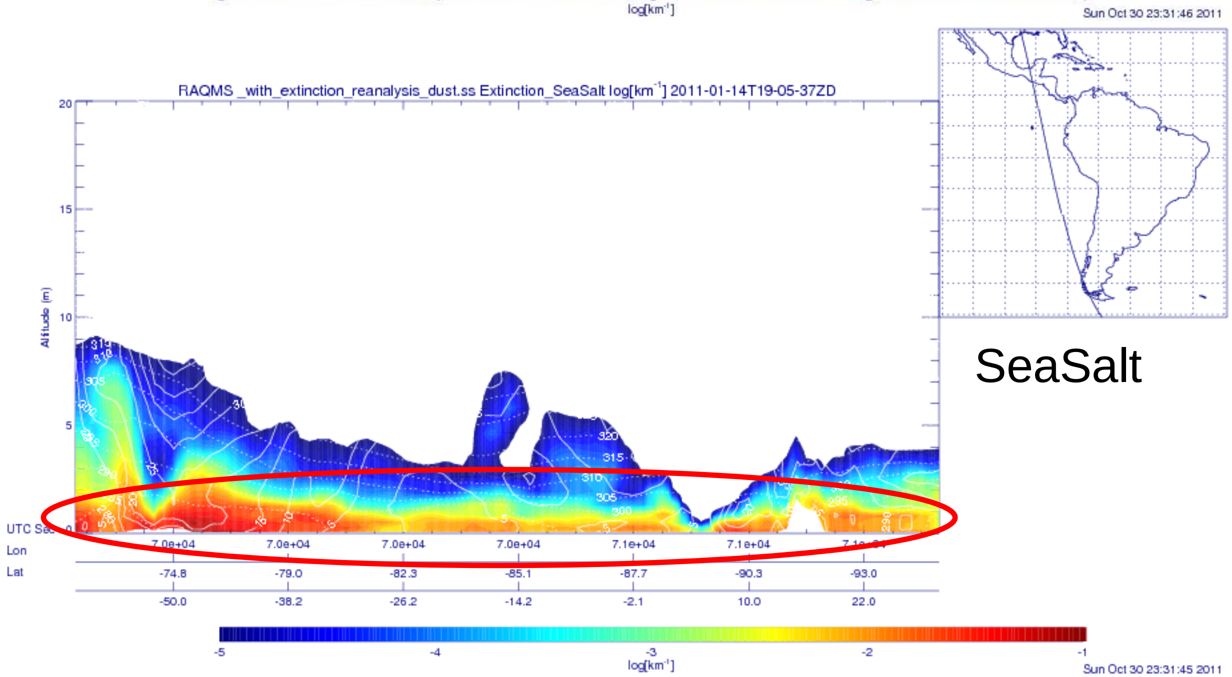
CALIPSO vs RAQMS Aerosol Extinction: Jan 14, 19Z 2011



RAQMS overestimates the spatial extent of elevated aerosol extinction in the tropical upper troposphere and mid-latitude storm track relative to CALIPSO

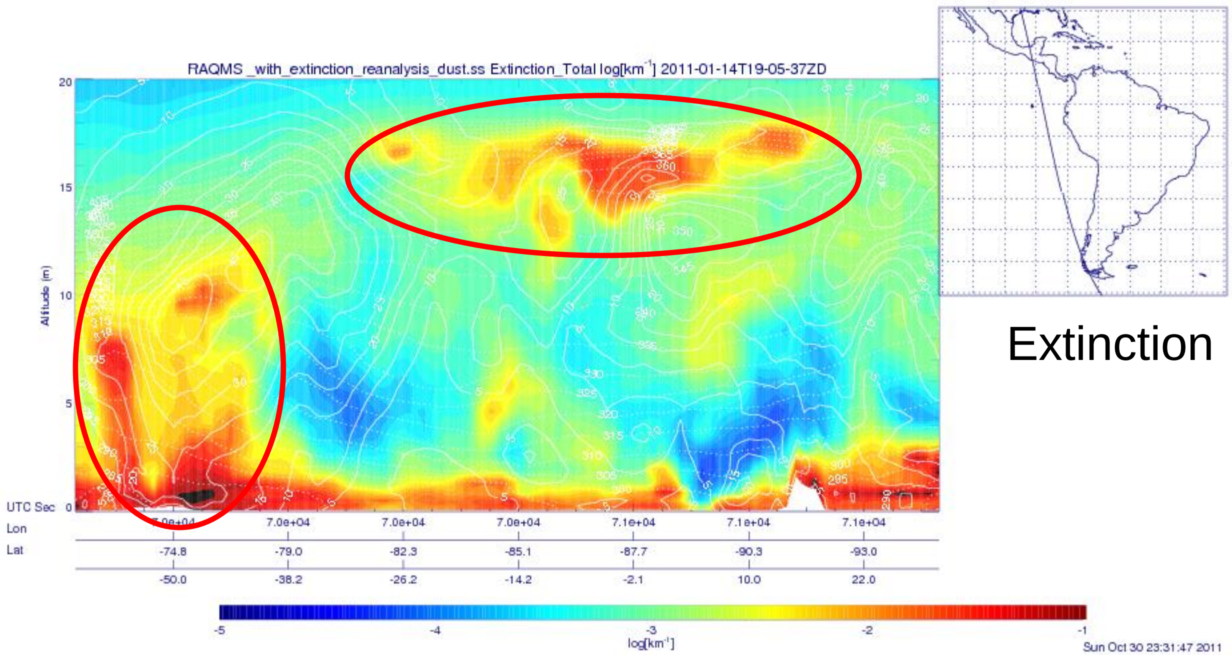
RAQMS BCOC and Sea-Salt Aerosol Extinction : Jan 14, 19Z 2011



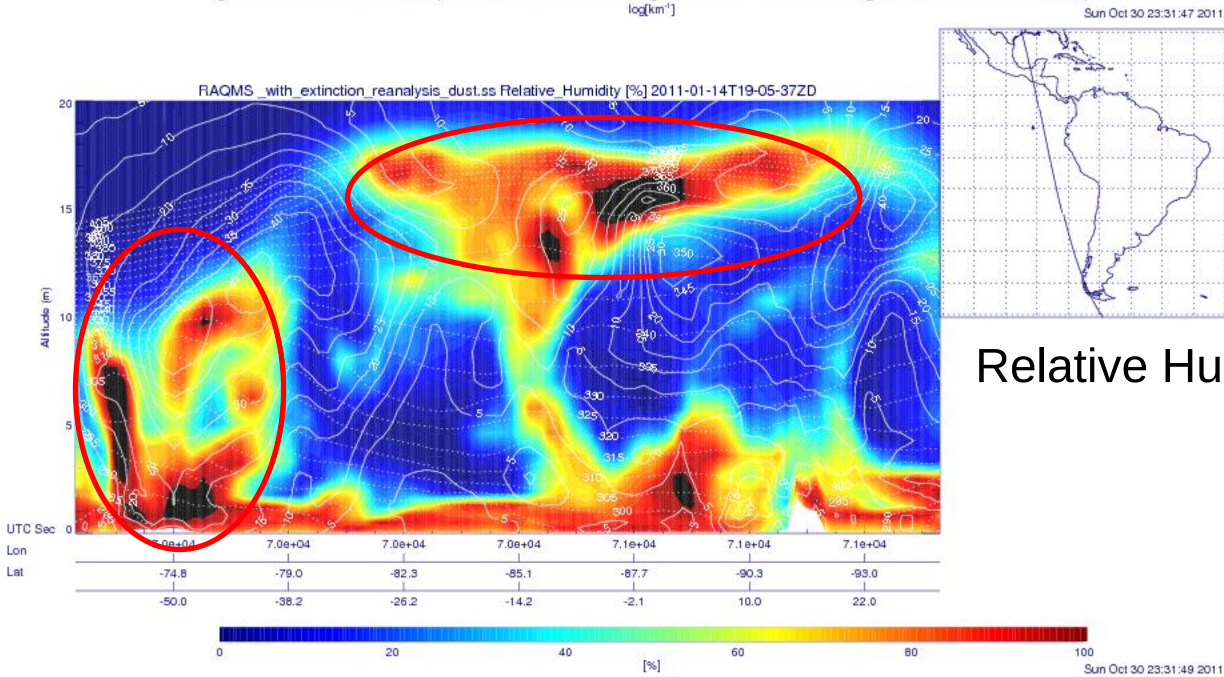


RAQMS elevated aerosol extinction is mostly Black and Organic Carbon (BCOC) except in marine boundary layer (SeaSalt)

RAQMS Aerosol Extinction and Relative Humidity: Jan 14, 19Z 2011



Extinction



Relative Humidity

RAQMS elevated aerosol extinction closely tied high relative humidity

Errors in estimating BCOC hydroscopic growth?

Contributions to TORERO hypothesis testing

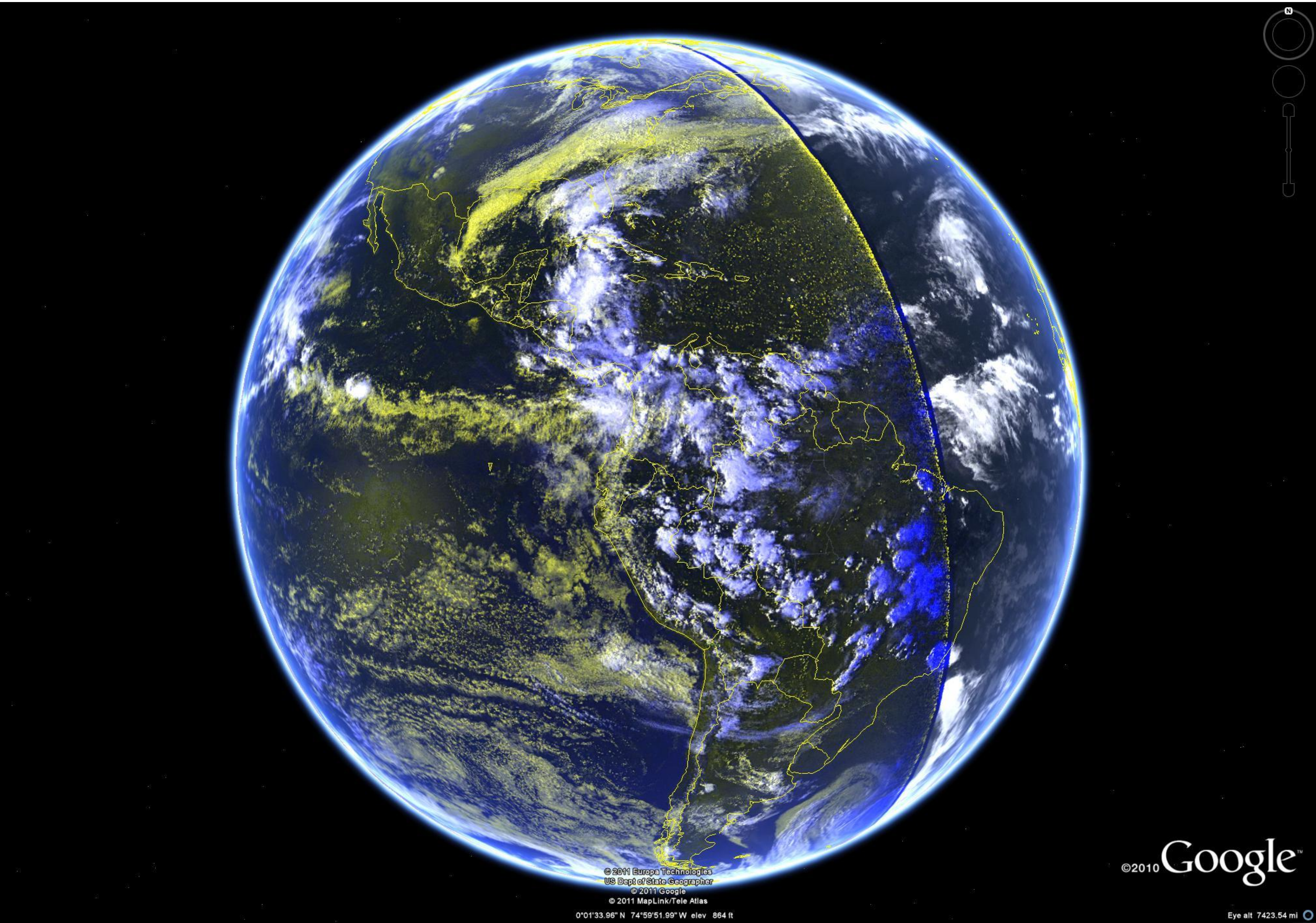
Hypothesis #1: Ocean sources of oxygenated VOC (OVOC) and reactive halogen species (RHS) impact atmospheric composition in the MBL, and in the FT as a result of deep convective transport.

- What can we learn about the chemical composition of cirrus clouds, and do they bias the satellite view of aerosols, and reactive gases?
  - *Understanding model aerosol extinction high bias in convective outflow*
  - *Treatment of initial hydrophilic and hydrophobic partitioning in biomass burning*
  - *Cirrus contamination in satellite AOD retrievals*
  - *Convective transport of isoprene oxidation products*

Hypotheses #3: Reactive gases released from the ocean are relevant to chemistry and climate.

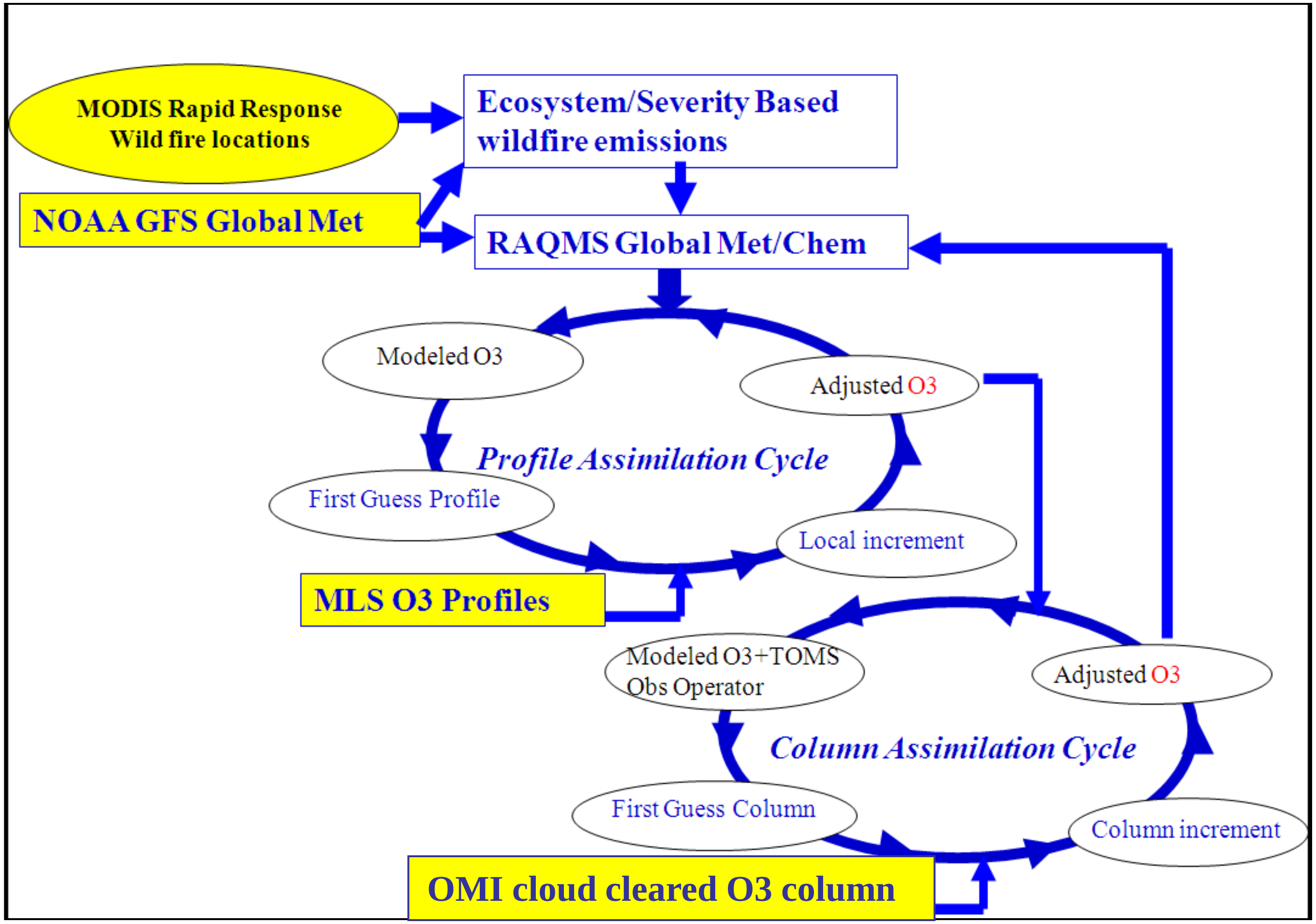
- How relevant are ocean sources of OVOC and RHS on global scales?
  - *RAQMS provides estimates of non-ocean sources of OVOC*

Example Images of Real-Time GOES Imager Processing at CIMSS (False Color Imagery



Extra Slides

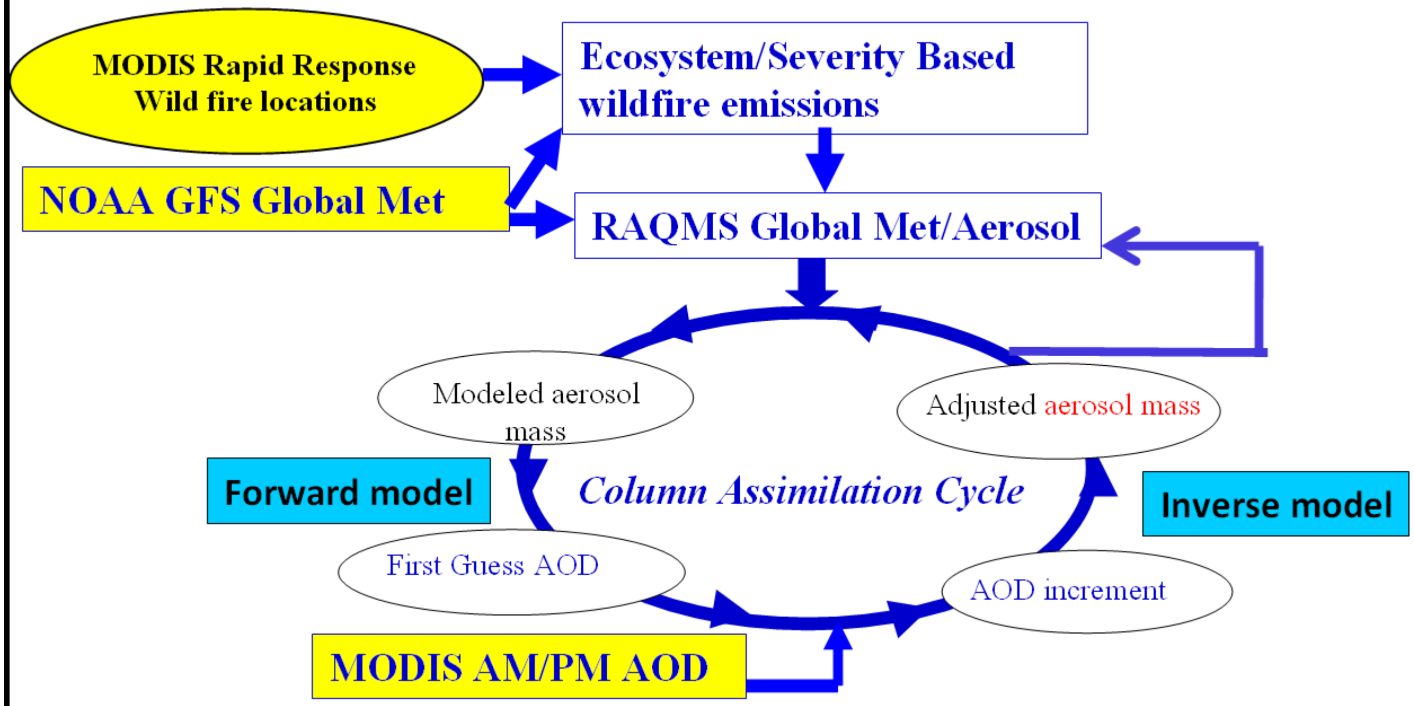
RAQMS O3 Assimilation Procedure



Demonstration of:

- **Real-time assimilation of Microwave Limb Sounder (MLS) stratospheric ozone profiles**
- **Real-time assimilation of Ozone Monitoring Instrument (OMI) total ozone column**
- **Real-time incorporation of Moderate Resolution Imaging Spectroradiometer (MODIS) fire detection**

RAQMS AOD Assimilation Procedure



<u>Forward model:</u>
Compute layer/species extinction based on tabulated extinction efficiency and hydroscopic growth factors

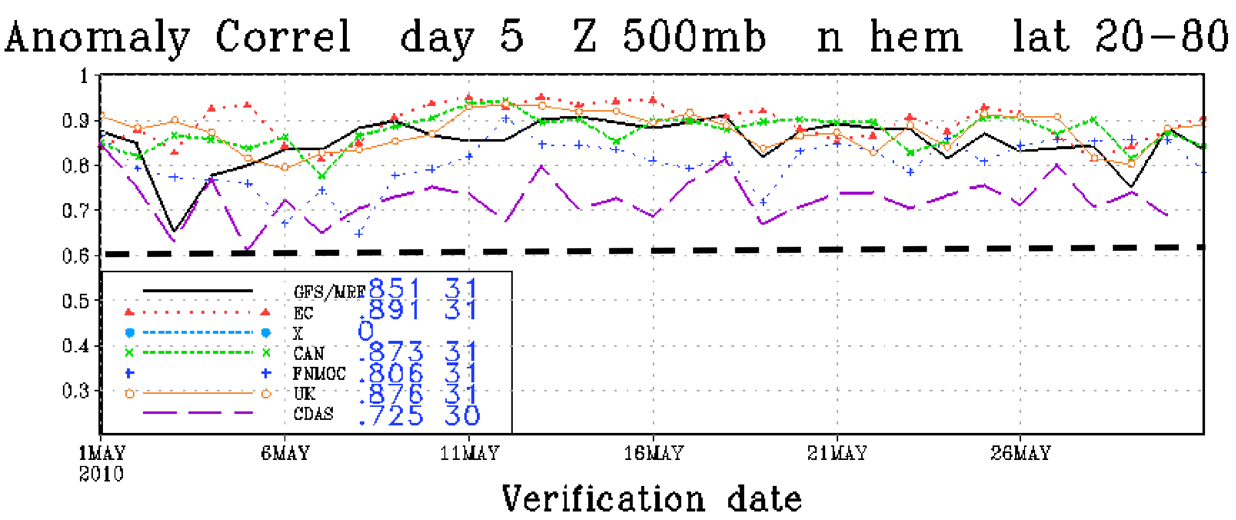
<u>Inverse model:</u>
Distribute total AOD increment across aerosol dry mass based on layer/species extinction accounting for extinction due to hydroscopic growth

Demonstration of:

- **Real-time assimilation of MODIS Aerosol Optical Depth (AOD)**
- **Real-time incorporation of MODIS based biomass burning emissions**

Assessment of RAQMS O3, CO, and Aerosol Extinction Forecast Skill

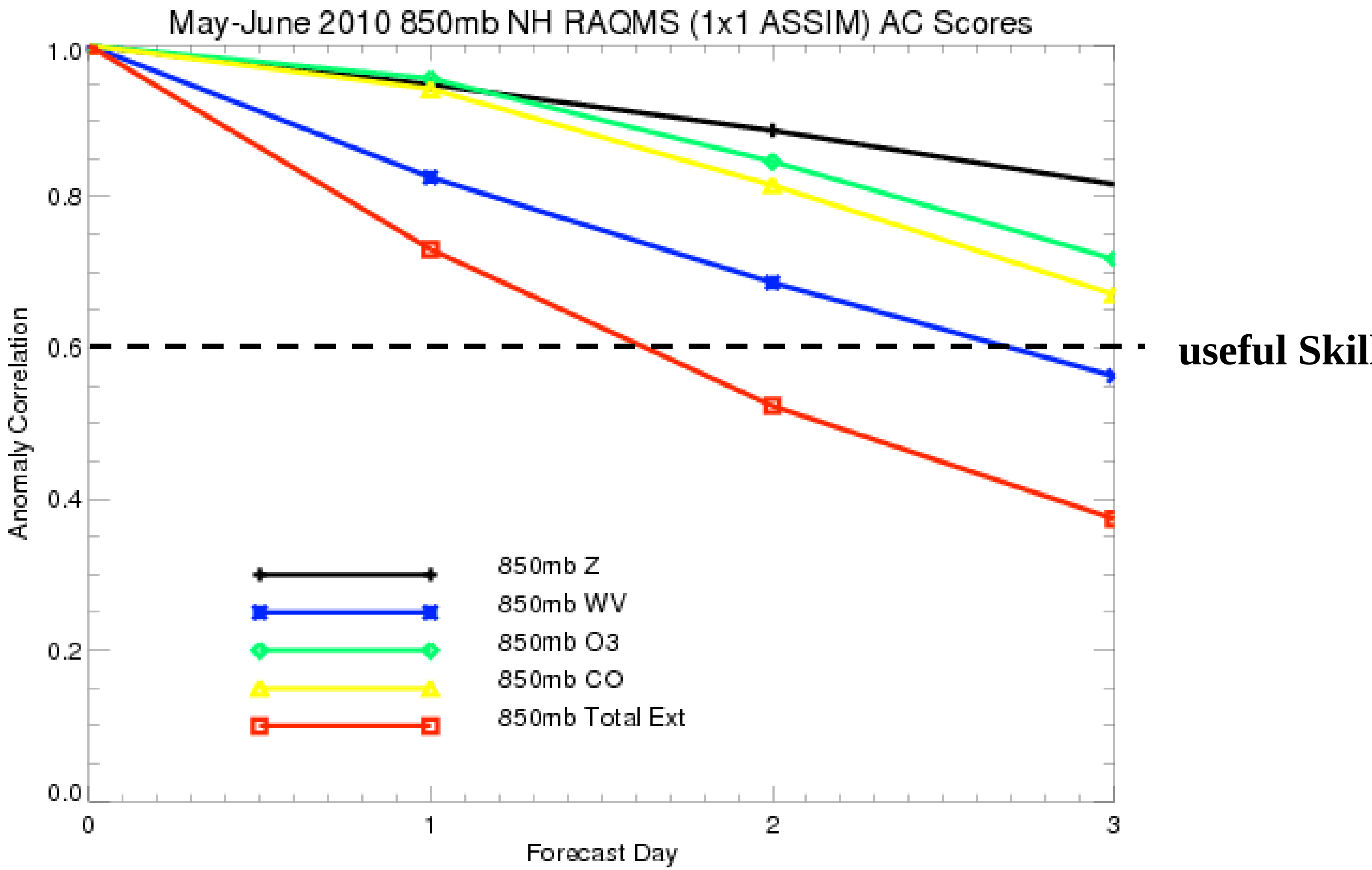
- Anomaly Correlations (AC)
  - Correlation between forecast and analysis
  - May-June mean removed
  - Spectrally truncated to wavenumber 20
  - Averaged from 20N-80N



useful Skill

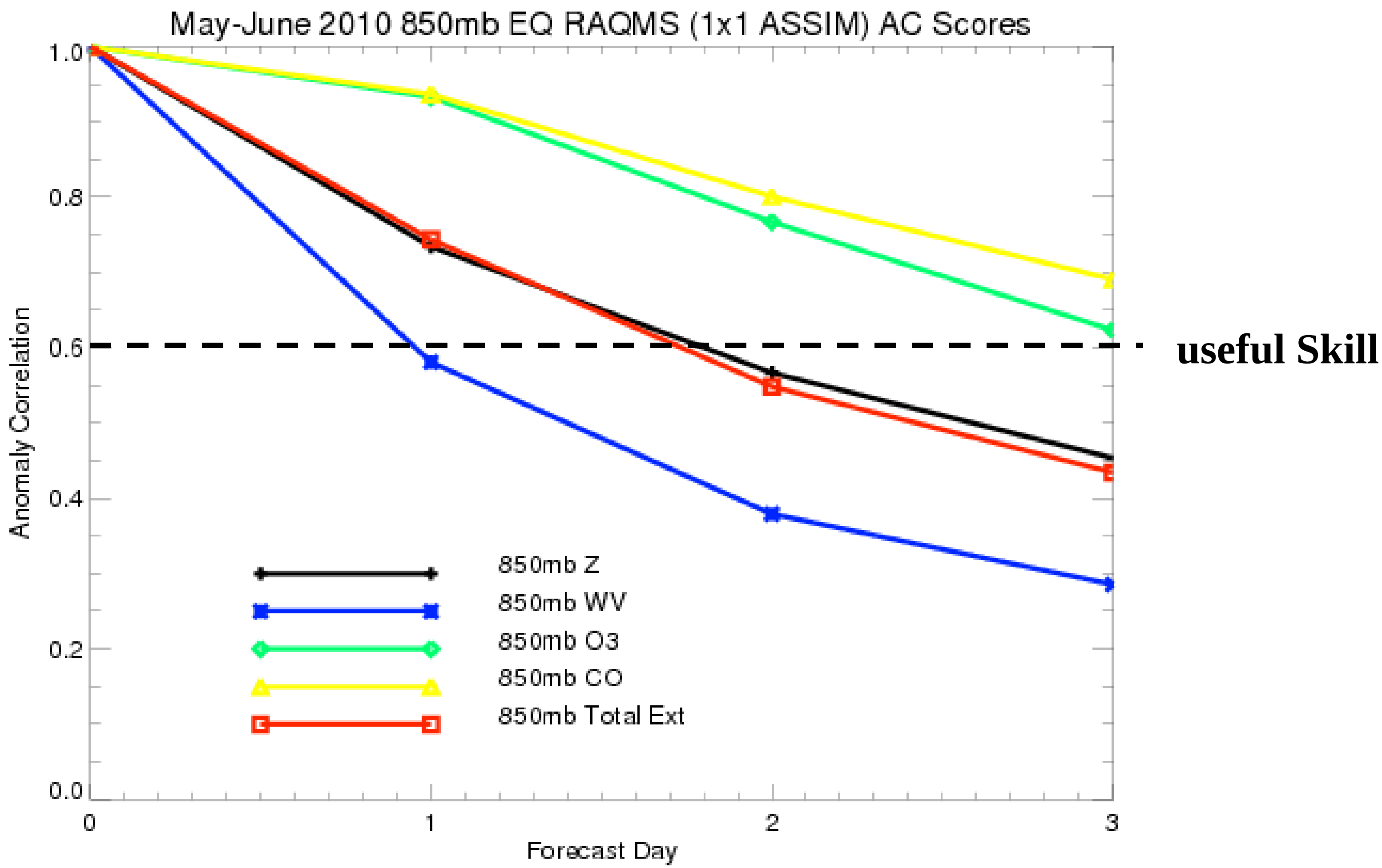
http://www.emc.ncep.noaa.gov/gmb/STATS/html/monarch.html

Northern Hemisphere 850mb May-June 2010 Anomaly Correlations (AC)
(With MLS/OMI/MODIS Assimilation)



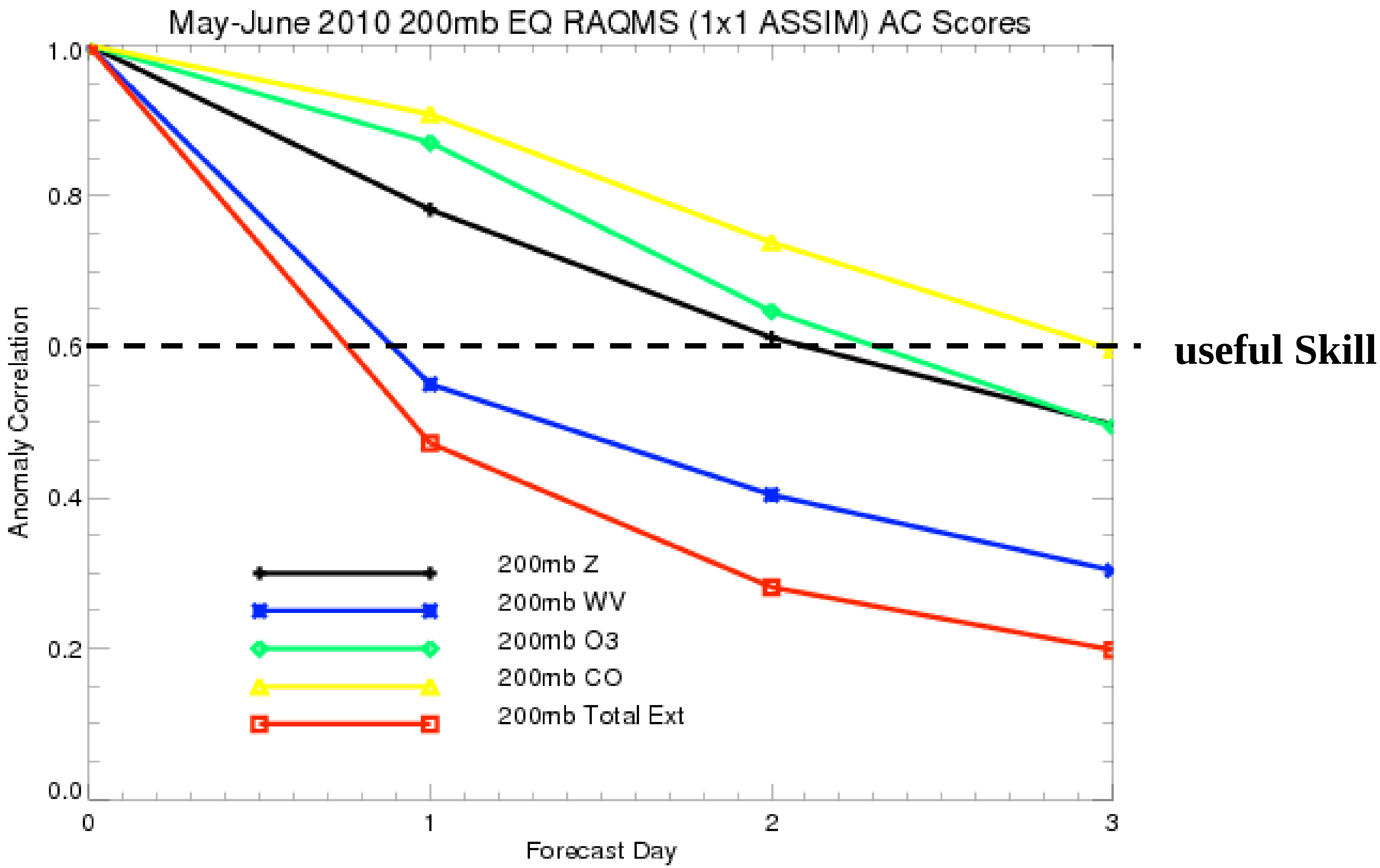
•Assimilation of O3 retrievals results in slight improvements in 850mb ozone forecasts
•Assimilation of AOD retrievals results in significant improvement in 850mb extinction forecasts with useful skill at ~1.5 days

Equatorial 850mb May-June 2010 Anomaly Correlations (AC)
(With MLS/OMI/MODIS Assimilation)



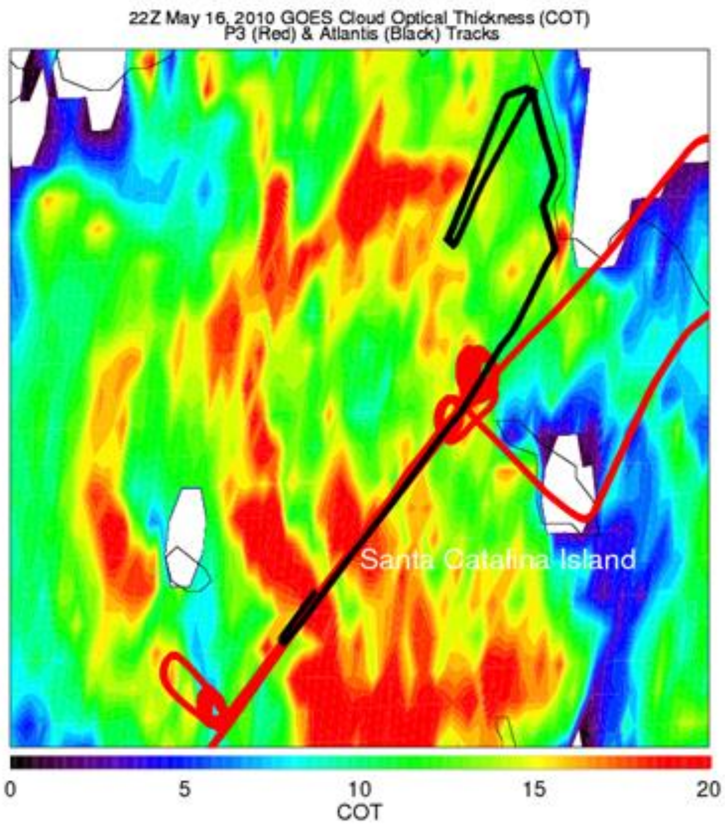
- Assimilation of O3 retrievals results in slight improvements in 850mb ozone forecasts
- Assimilation of AOD retrievals results in significant improvement in 850mb extinction forecasts with useful skill at ~1.5 days

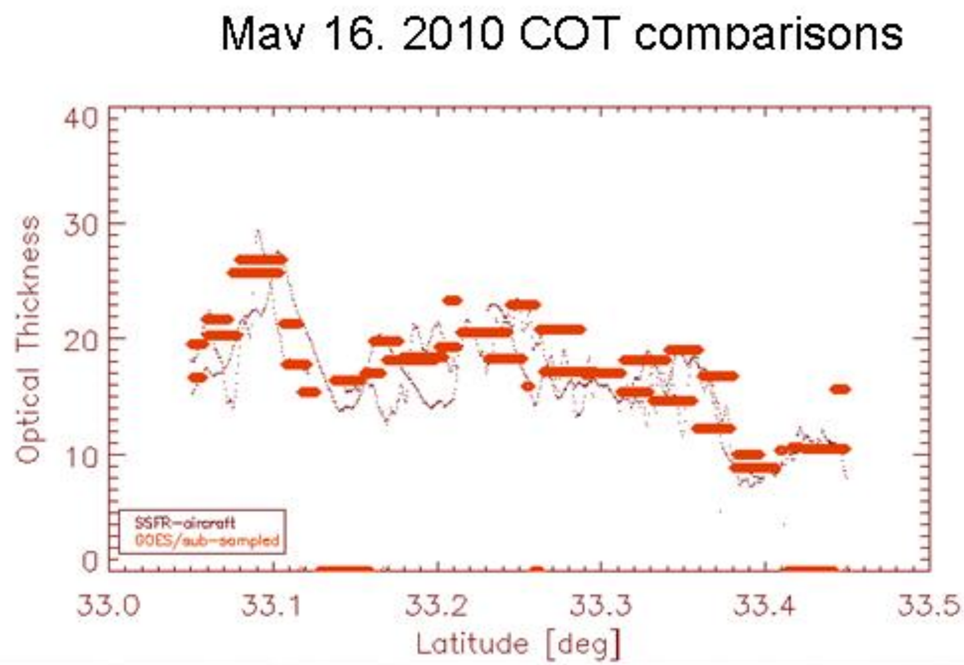
Equatorial 200mb May-June 2010 Anomaly Correlations (AC)
(With MLS/OMI/MODIS Assimilation)



•Assimilation of O3 retrievals results in slight improvements in 850mb ozone forecasts
•Assimilation of AOD retrievals results in significant improvement in 850mb extinction forecasts with useful skill at ~1.5 days

GOES/SSFR Cloud Validation during CalNex

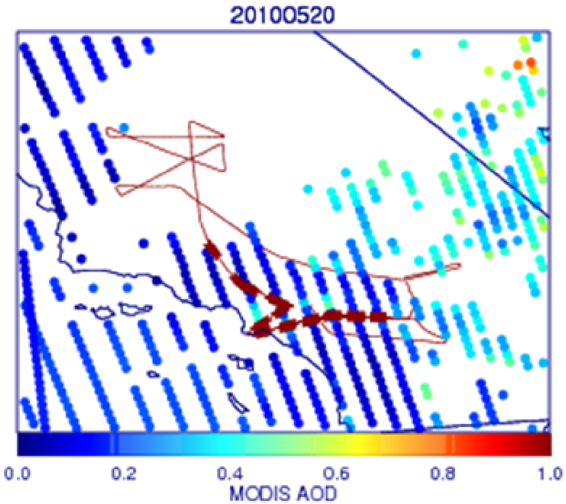


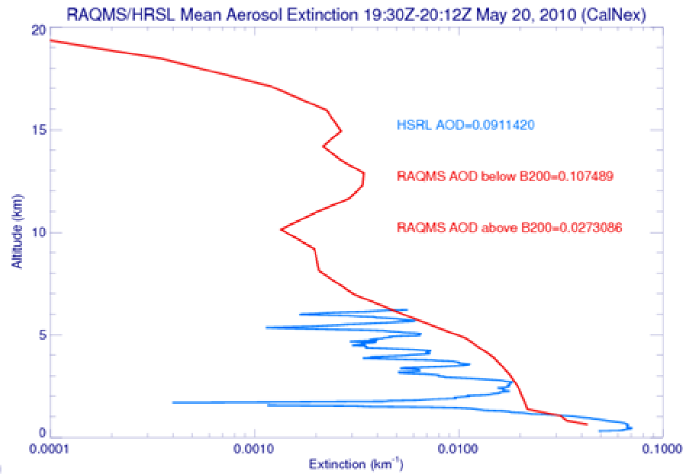


GOES-R ABI DCOMP Cloud Optical Thickness (COT) using GOES-11 0.6 and 3.9 micron channels off of Southern California at 22Z on May 16, 2010 along with P3 (red) and ship (black) tracks (left panel). Timeseries of SSFR aircraft (brown) spectral cloud optical thickness retrievals and GOES-11 DCOMP retrievals sub-sampled along the aircraft (red) (right panel).

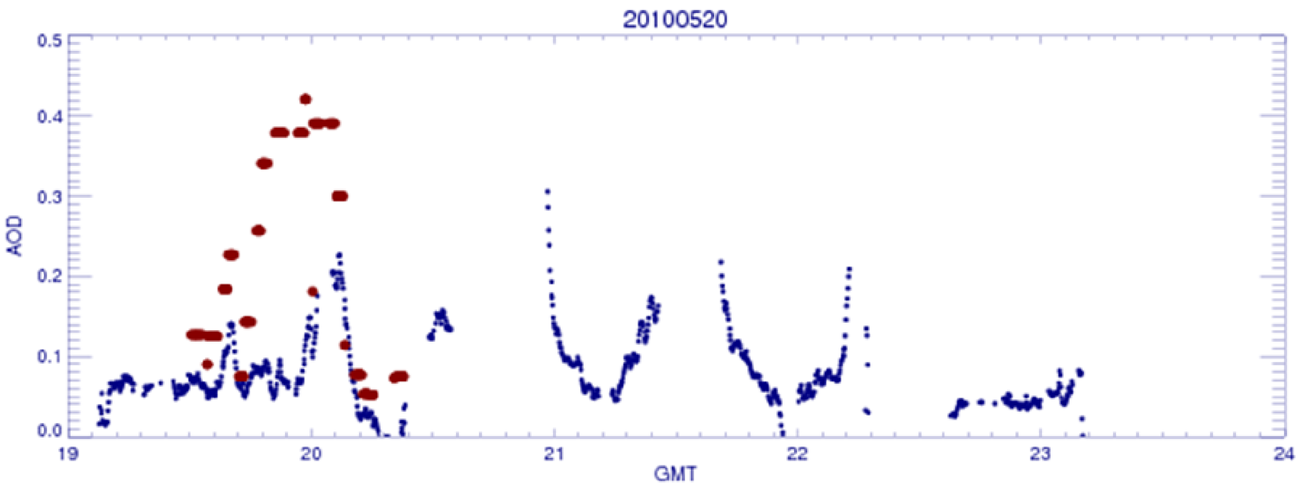
Solar Spectral Flux Radiometer (SSFR) data provided by Sebastian Schmidt (CU Boulder)

MODIS/HSRL AOD Validation during CalNex





High Spectral Resolution Lidar (HSRL) data provided by Chris Hostetler and Rich Ferrare (NASA LaRC)



Bias due to underestimate in urban surface reflectivity

MODIS V05 Aerosol Optical Depth (AOD), B200 flight track (red) and MODIS/B200 coincidences (thick red) over Southern California on May 20, 2010 (upper left panel). Timeseries of HSRL (blue) and coincident MODIS (red) AOD along the flight path (lower panel). Comparison between mean RAQMS and HSRL extinction profiles during the period where MODIS shows significant overestimates in AOD relative to HSRL (19:30- 20:12Z) (upper right).