Progress in making meaningful AVHRR Cloud Climate Records

Andrew Heidinger

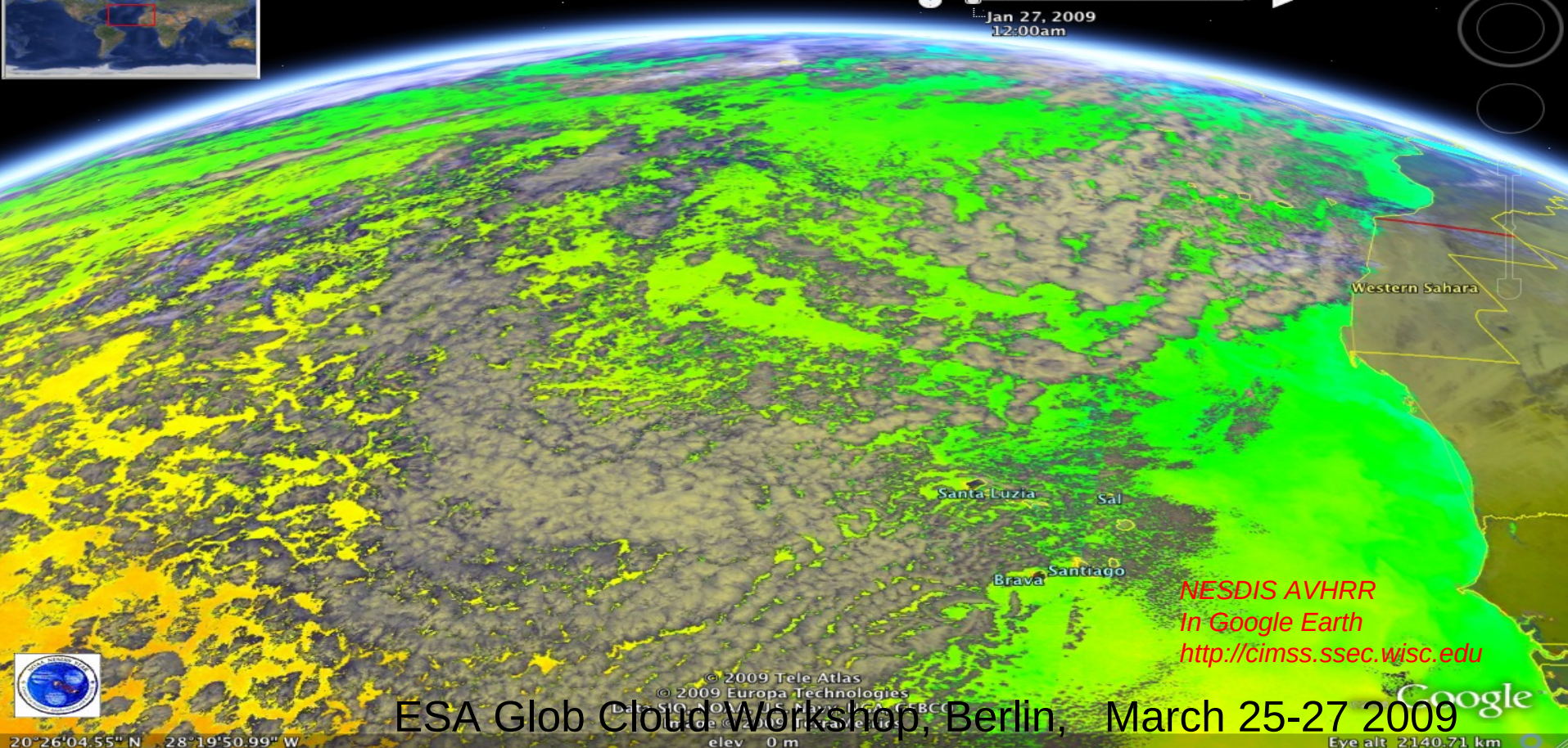
NOAA/NESDIS

Madison, WI USA

Andi Walther, Mike Foster and Amato Evan

UW/CIMSS

Madison, WI USA



NESDIS AVHRR
In Google Earth
http://cimss.ssec.wisc.edu

ESA Glob Cloud Workshop, Berlin, March 25-27 2009

Outline

- Use of imager (including AVHRR) data in data assimilation at NOAA.
- Our efforts to improve the AVHRR data quality.
- Work towards improving imager (including AVHRR) cloud products.

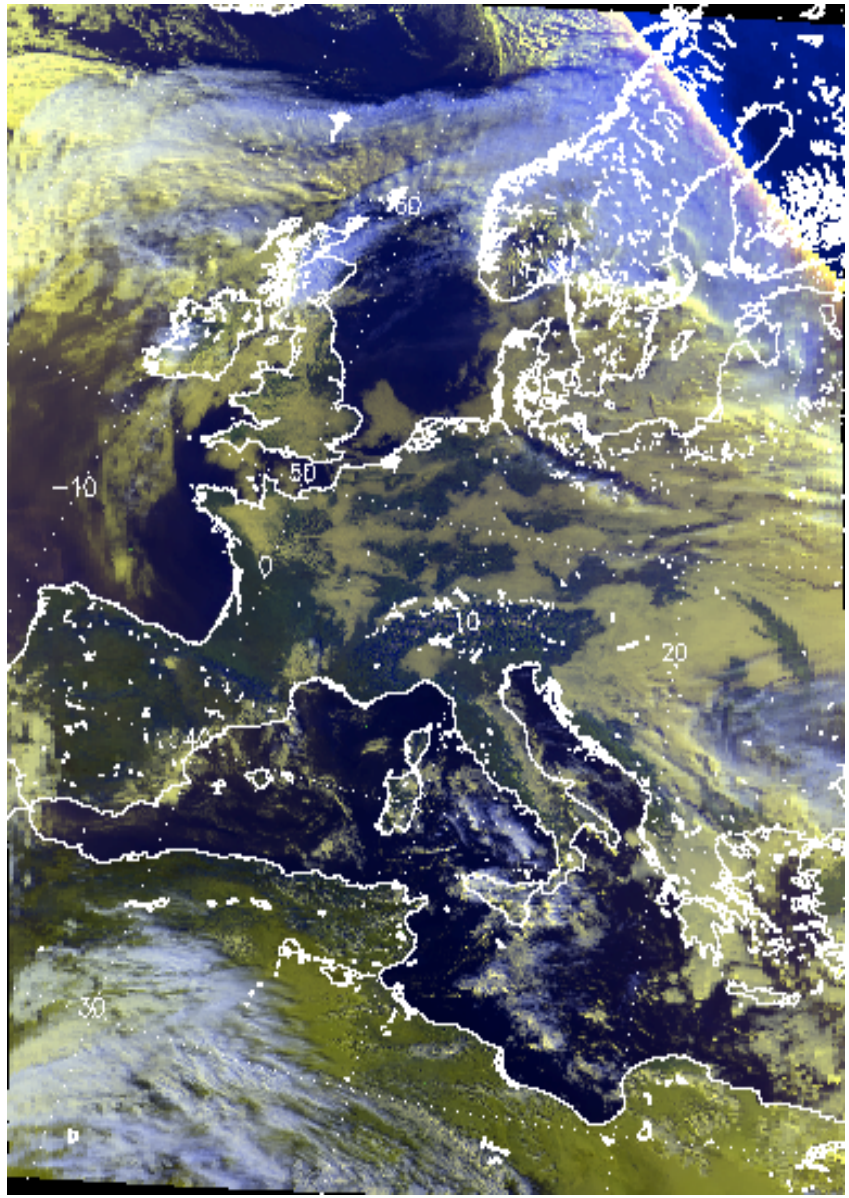
Why is the AVHRR Relevant?

- AVHRR was launched in 1978. Assuming METOP/3 reach its end of life in 2018, AVHRR will span 40 years.

- New methods have been devised to improve the geolocation and radiometric calibration and these are applicable to whole time series.

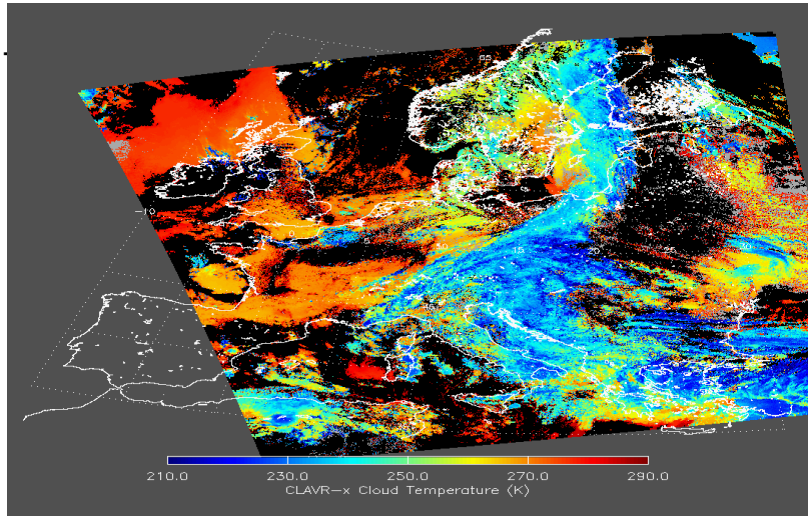
- With these improvements, one can argue that AVHRR cloud records approach MODIS quality over many regions of the world (ie ice-free oceans). Therefore, properly constructed AVHRR CDRs can extend MODIS-like CDR records back through the 1980's and 1990's.

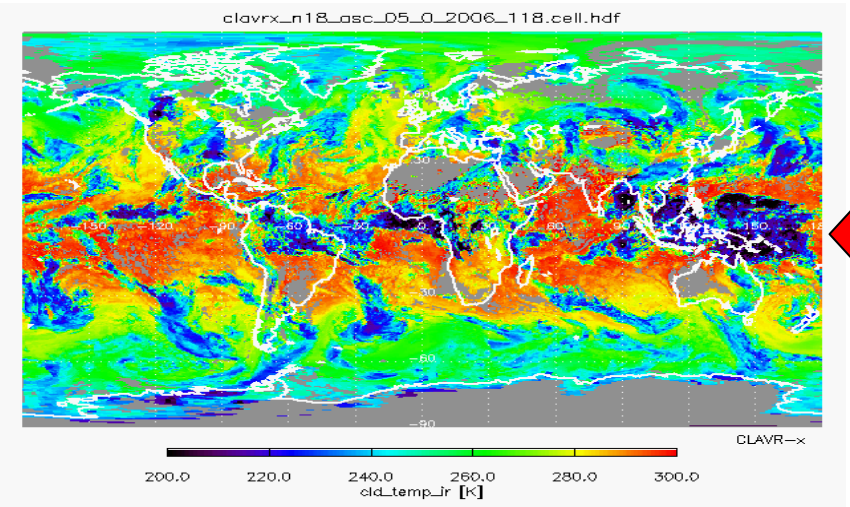
TIROS-N AVHRR November 1978

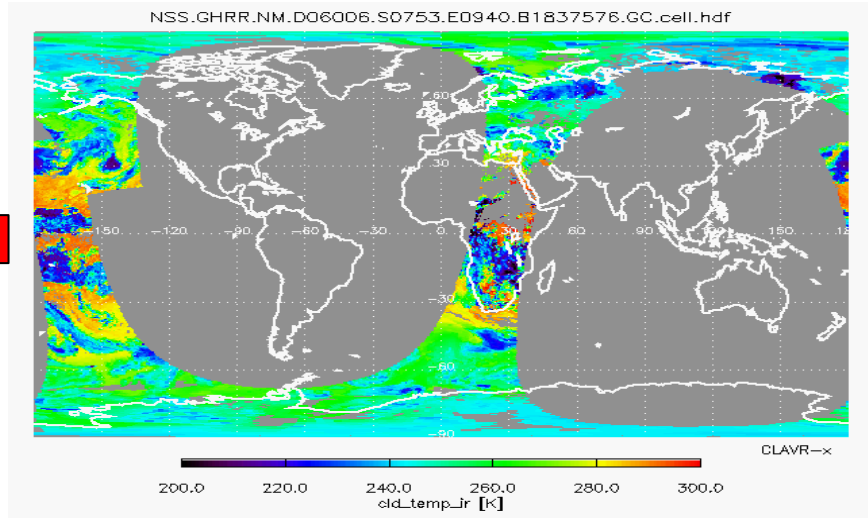


NOAA's Operational Use of the AVHRR:
Clouds from AVHRR Extended (CLAVR-x)

- 1km or 4km AVHRR data. Channels: 0.63, 0.86, 1.6/3.7, 10.8 and 12 microns.
- pixel-level products in hdf
- 55km gridded products daily and monthly
- We make a full-suite of cloud products (**mask, type, optical depth, particle size, height-temperature-pressure, emissivity, ir-microphysical index**)
- Same algorithms applied to GOES imagers through the GOES Surface Insolation Project.

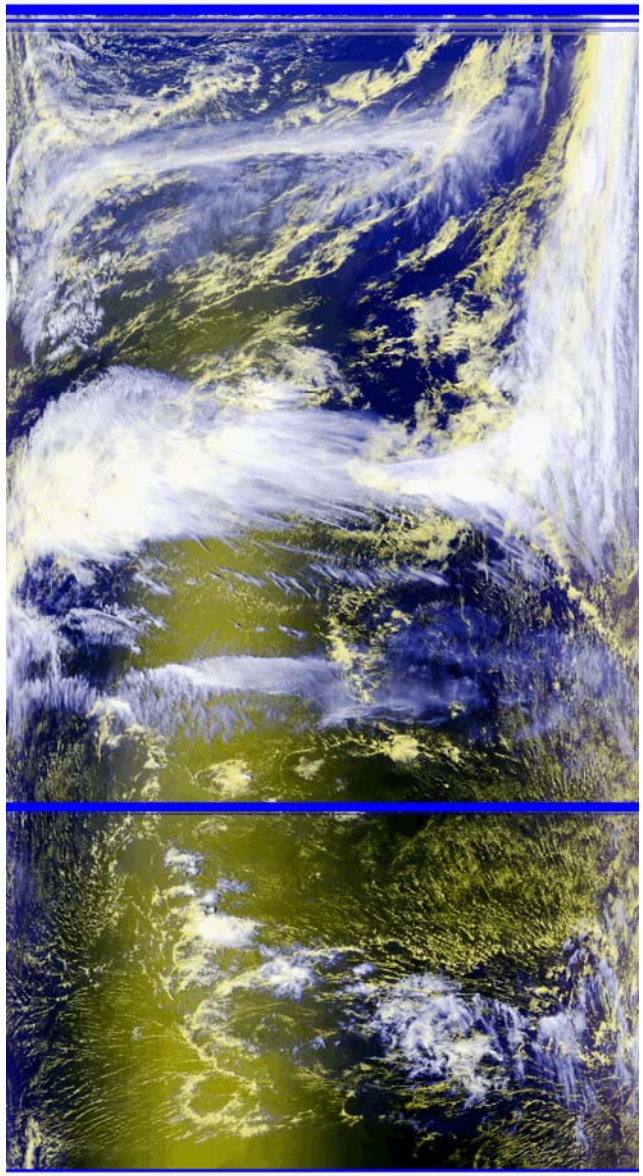






Sample NESDIS Imager Cloud Products: Cloud Type

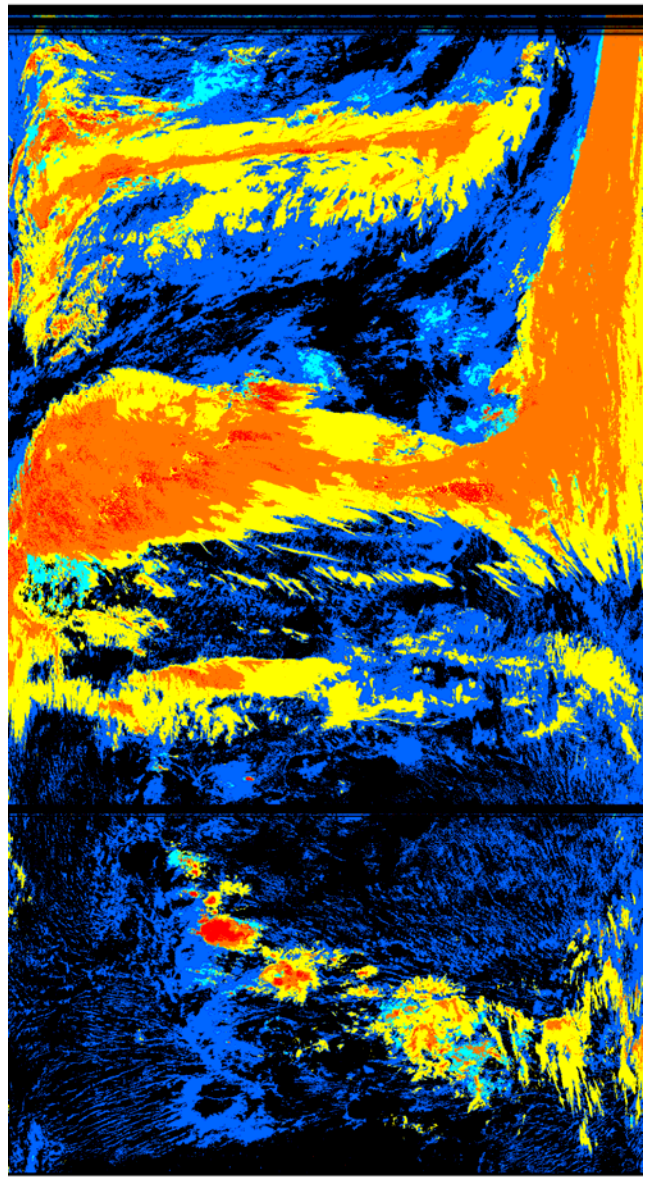
NSS.HRPT.NN.D09083.S0057.E0107.B1979394.EB



RGB Image (Red=R1, Green=R2, Blue=T4 reversed)

During night, image shows only T4 reversed

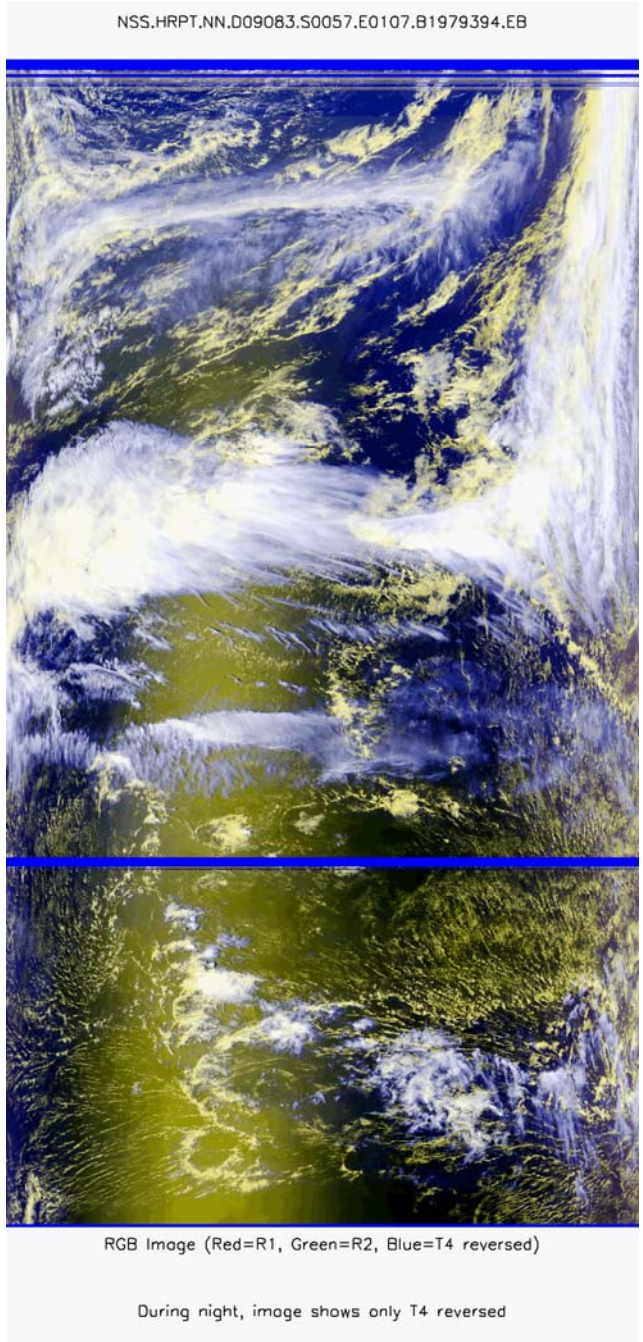
NSS.HRPT.NN.D09083.S0057.E0107.B1979394.EB

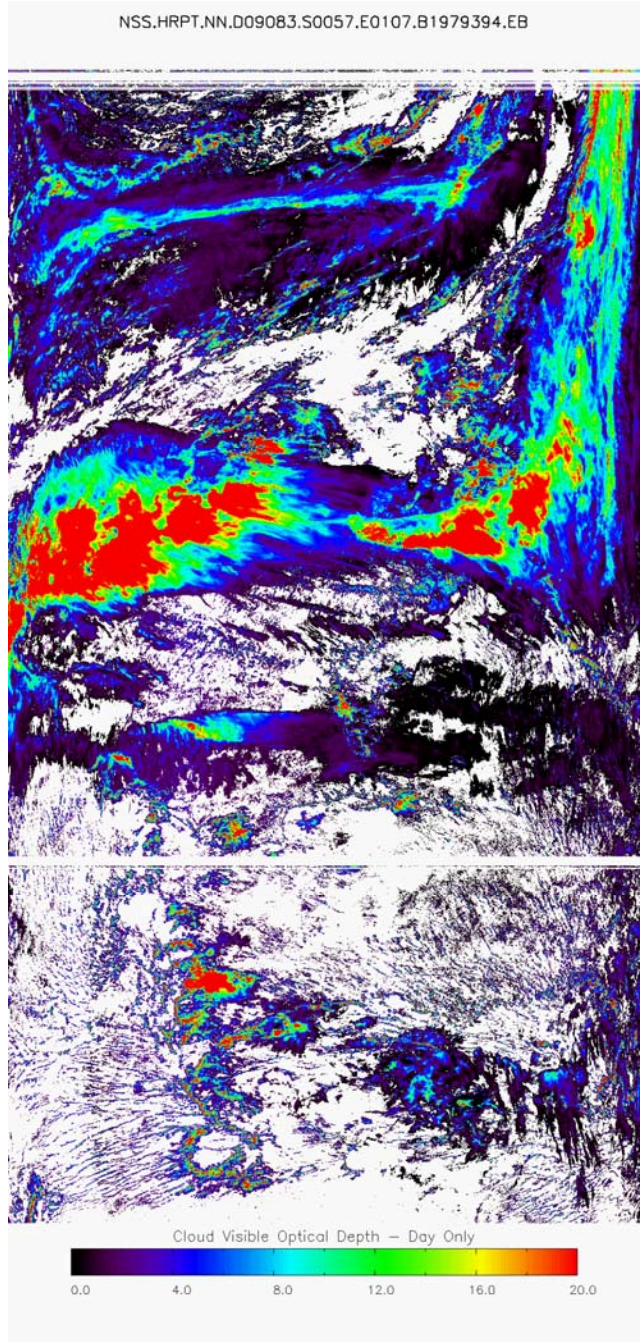


cloud type

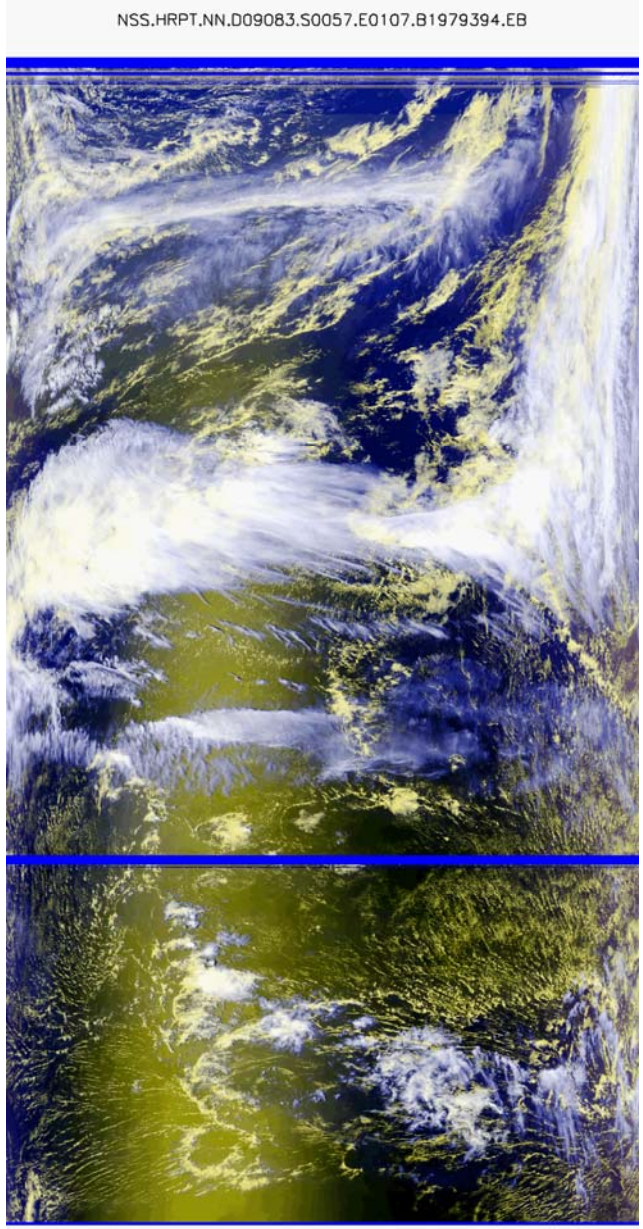
Prob. Clear	Fog	Water	Super-Cooled Water
Opaque Ice	Cirrus		Multi-layer

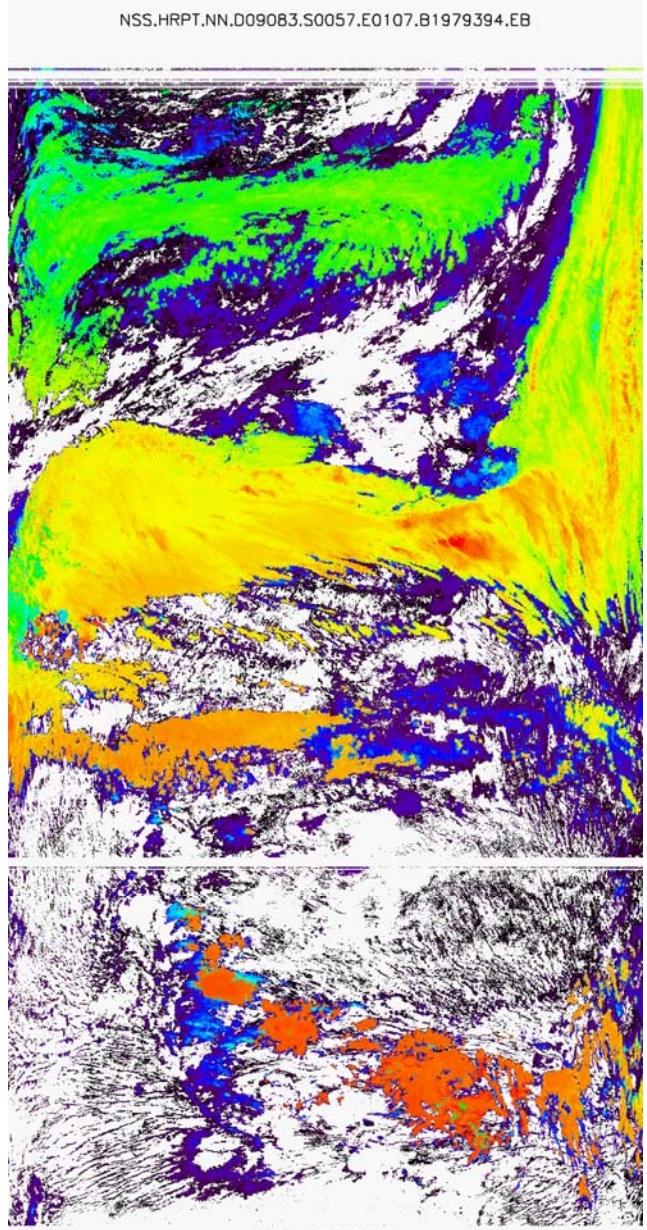
Sample NESDIS Imager Cloud Products: Cloud Optical Depth





Sample NESDIS Imager Cloud Products: Cloud Height

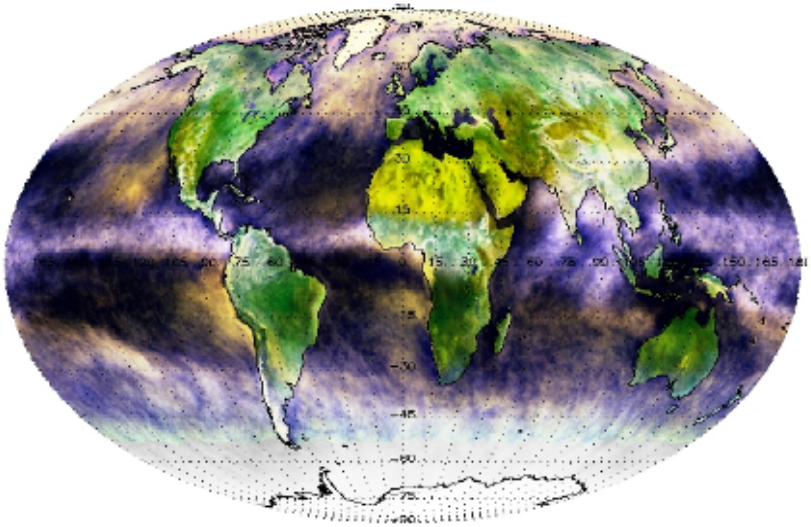




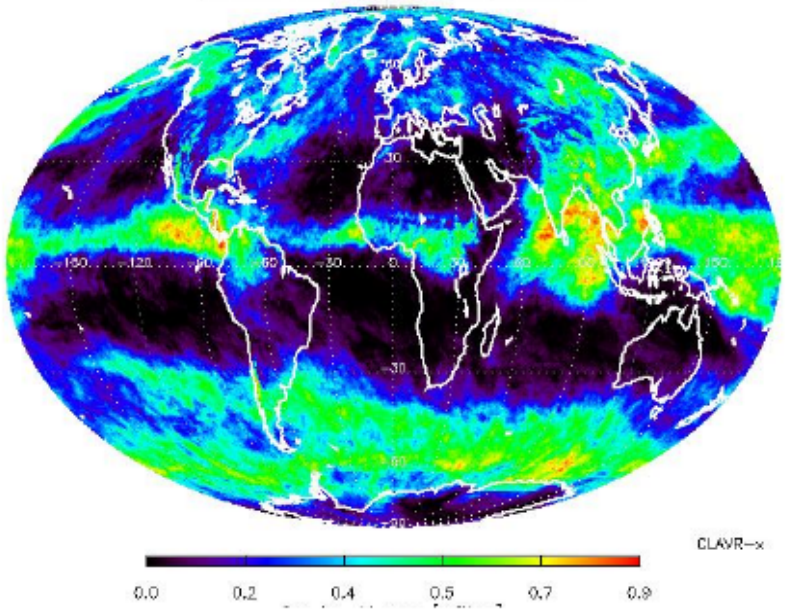
Contribution of AVHRR Cloud Climatologies

- When METOP-C finishes, the AVHRR data record should span more than 40 years. (1978-2018?).
- ISCCP is certainly a successful project and will continue, but the AVHRR climatologies complement ISCCP in the following ways
  - ➢ Even though ISCCP provides consistent 8 times per day sampling, it does so with large day/night differences.
  - ➢ With more spectral information, the AVHRR can provide more day/night consistency though with coarser temporal sampling (4 times per day).
  - ➢ The AVHRR data-sets maintain the full spatial resolution of the data and therefore can utilize techniques and generate important spatial metrics missing in ISCCP.
  - ➢ AVHRR provides excellent temporal and spatial coverage of the polar regions.
- Similar arguments can be made as to how the AVHRR cloud CDRs complement those being developed from other long-term sensors including sounders.
- The CM-SAF is also pursuing an AVHRR cloud climatology in collaboration with NESDIS.

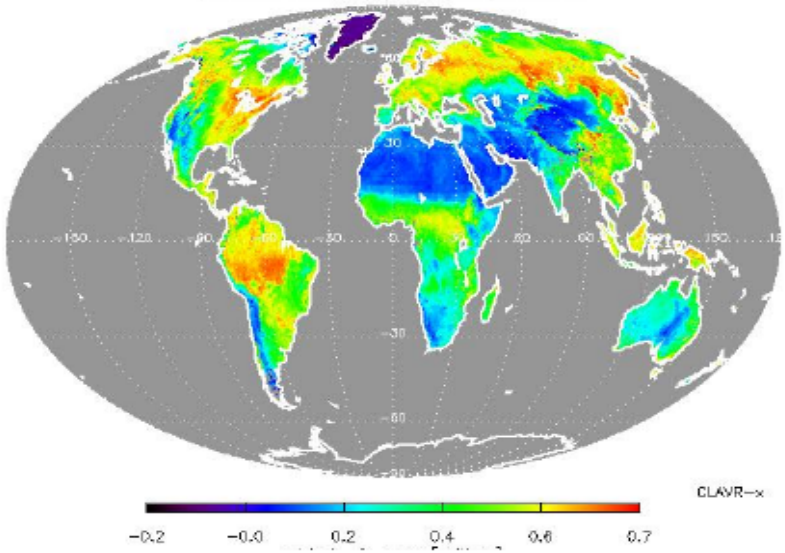
1981-2008 PATMOS-x data available here http://cimss.ssec.wisc.edu/patmosx



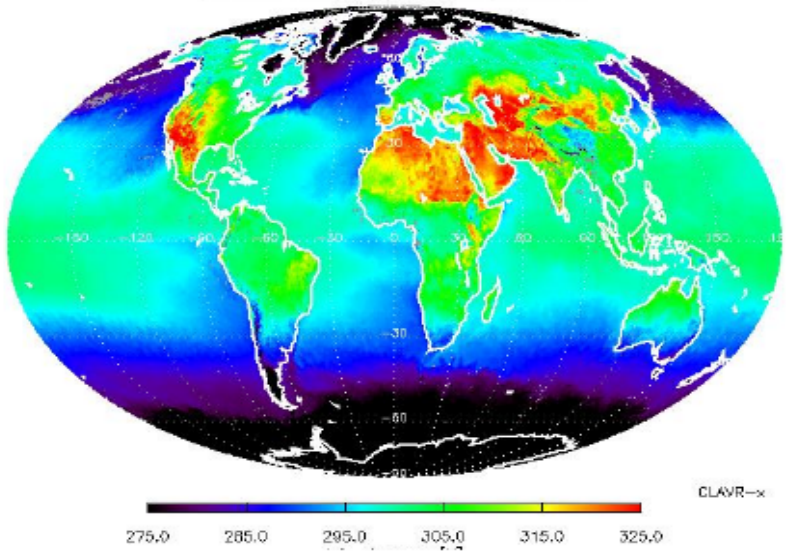
False Color Composite



Ice Cloud Fraction



Atmospherically Corrected NDVI



Surface Temperature

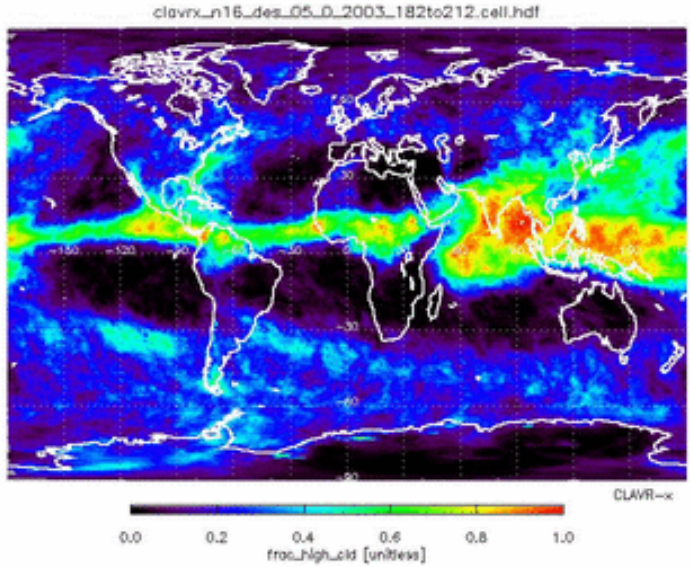
PATMOS-x Temporal Sampling (High Cloud Amount)

We have tried to build a system that captures the needed temporal/spatial resolution for cloud climate research. One of the big concerns using AVHRR for climate is orbital drift.

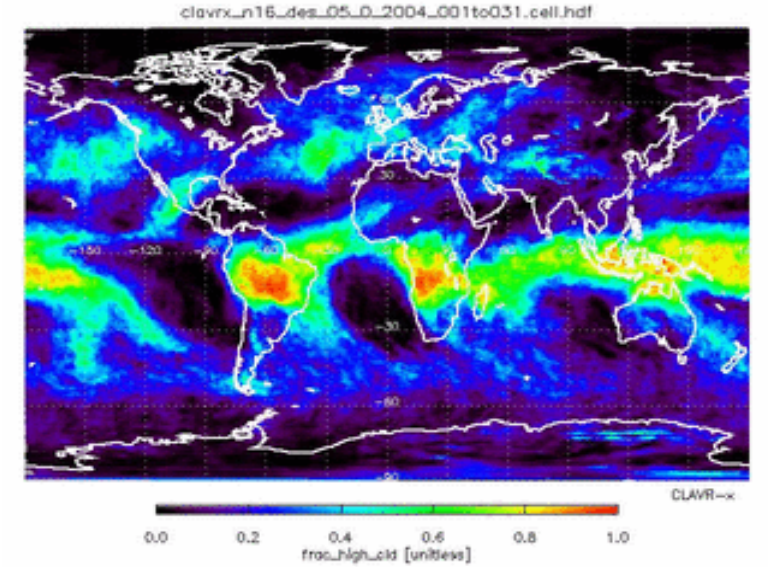
•Sensitivity to orbital drift is mitigated by processing all data (am,pm,terminator)

•Seek algorithmic solutions that are consistent from satellite to satellite (inter-annual) and for all viewing geometries (seasonal)

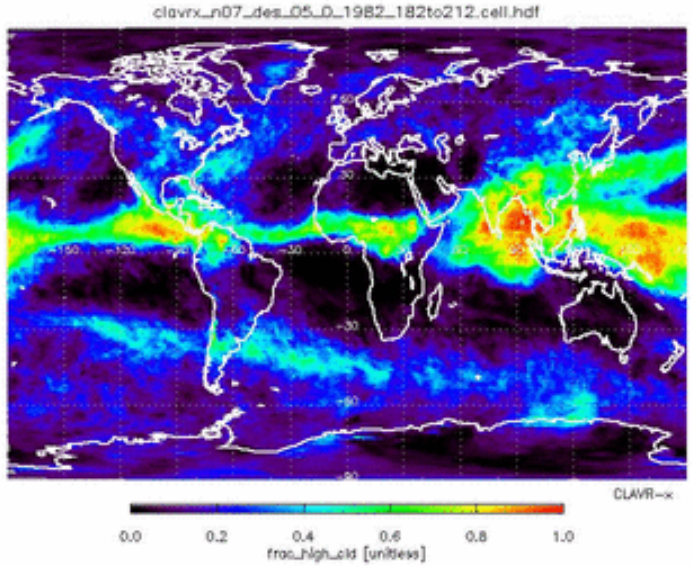
Diurnal Cycle: July 2004 NOAA-15,16,17



Seasonal Cycle: NOAA-16 Des. 2004

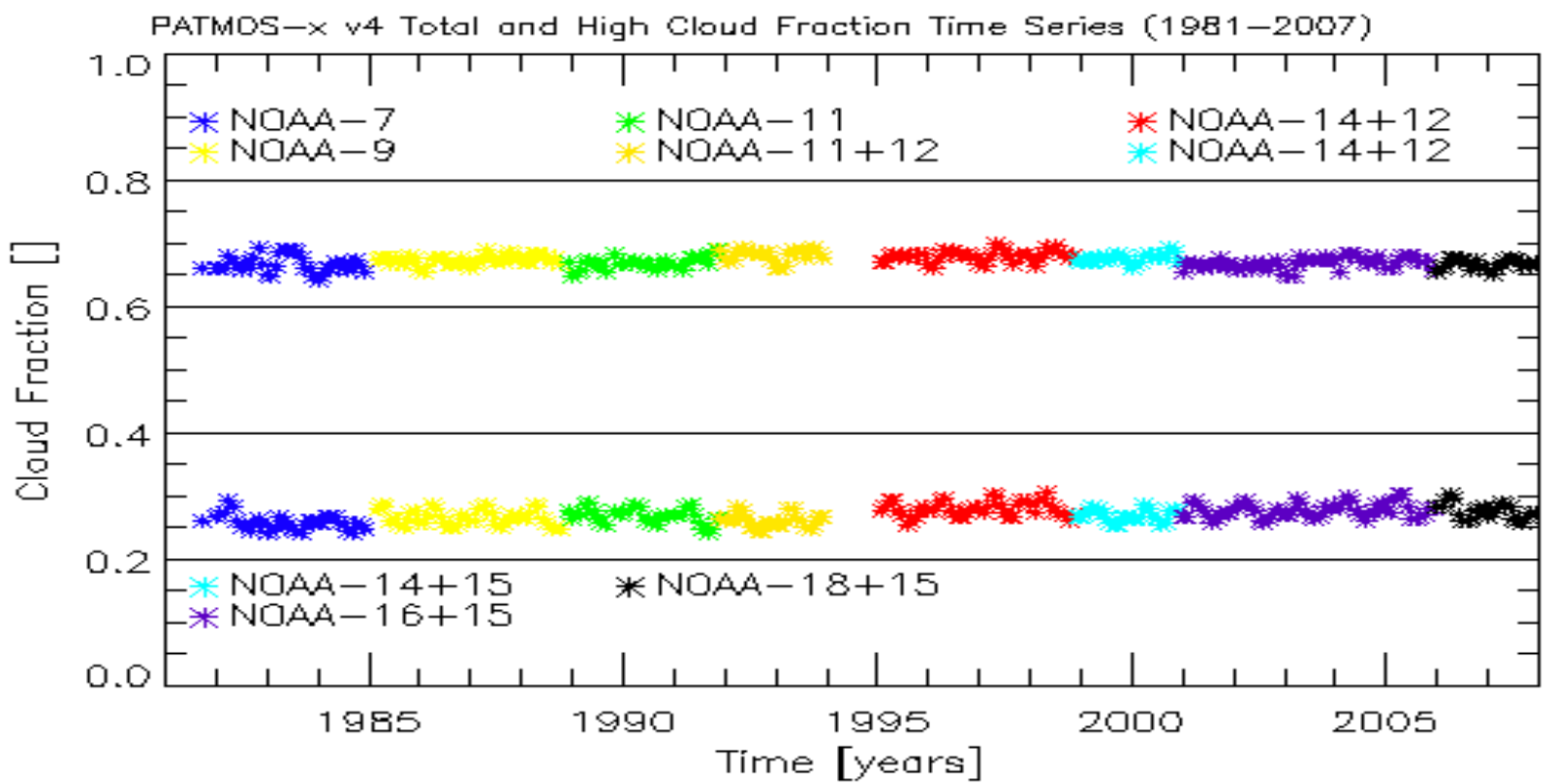


Inter-annual Cycle: July 1982-2004



AVHRR Pathfinder Atmospheres Extended (PATMOS-x)

- CLAVR-x modified for climate
- 55 km gridded products
- Limited 4 km level-2 files will be generated in next version.
- Run at National Climate Data Center
- Data publicly available. ***Roughly 20 groups have downloaded the v4 dataset***.
- Current processing is from 1981 to 2008. Efforts underway to incorporate AVHRR/1 (1978-1991)



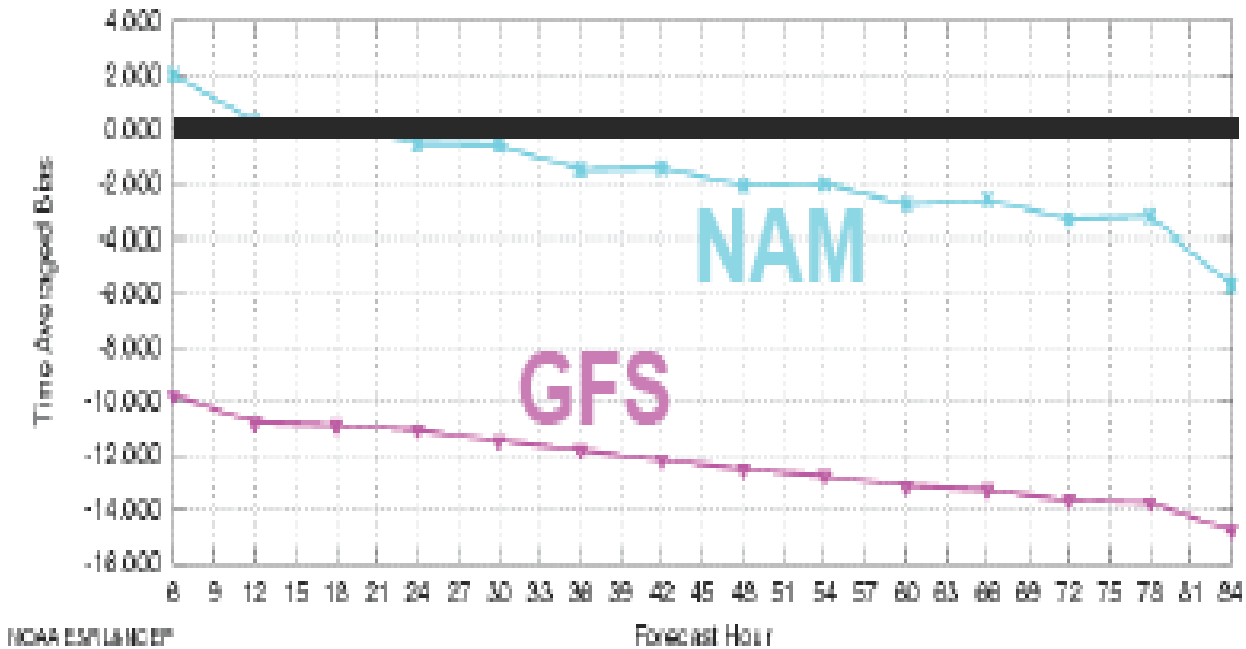
NESDIS AVHRR Cloud Product Impact for NWP

- NCEP uses cloud amounts (H/M/L) for verification. Interested in microphysics next. (Brad Ferrier)

- NCEP uses AVHRR cloud mask for a IR-window radiance assimilation quality flag. Similar use of GOES imager.

- UW/CIMSS model assimilates AVHRR+GOES+MODIS cloud-top pressures.

Bias



AVHRR DATA IMPROVEMENT ACTIVITIES

- To really tap the potential of the 30+ years of AVHRR data for cloud climatology, one needs to tackle the issue of calibration.
- Without on-board calibration of the solar reflectance channels, the AVHRR reflectance calibration changed greatly over time. Often, the prelaunch calibration was never accurate at any time after launch.
- Over the years, many clever and accurate techniques were developed to determine the AVHRR reflectance channel calibration values. (Rayleigh Scatter, Desert Reflectance, Deep Convective Clouds …)
- We are funded to conduct standard analyses and characterize the impact on CDRs of the existing long-term calibration data-sets (ISCCP, LTDR, PATMOS-x and NESDIS).
- In addition, we are trying to seek consensus on the step by step assumptions employed by each method and see if consensus can be achieved.

- A similar effort is underway in the thermal calibration world.

AVHRR DATA IMPROVEMENT ACTIVITIES Contd.

• The current publicly available AVHRR reflectance calibrations sources are:

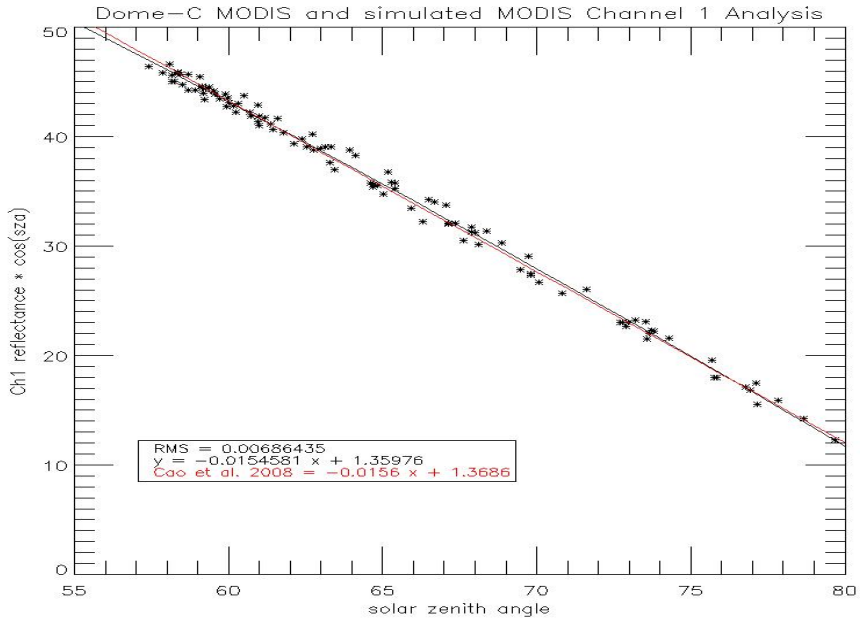
- ISCCP (0.63 micron only)
- LTDR - NASA Land Pathfinder
- NESDIS - Libyan Desert Method
- PATMOS-x
- NASA LaRC (limited temporal extent)

•Analysis of the above calibrations shows the agree to only +/- 10%

• We are working with the above groups and hope to identify root causes for these discrepancies.

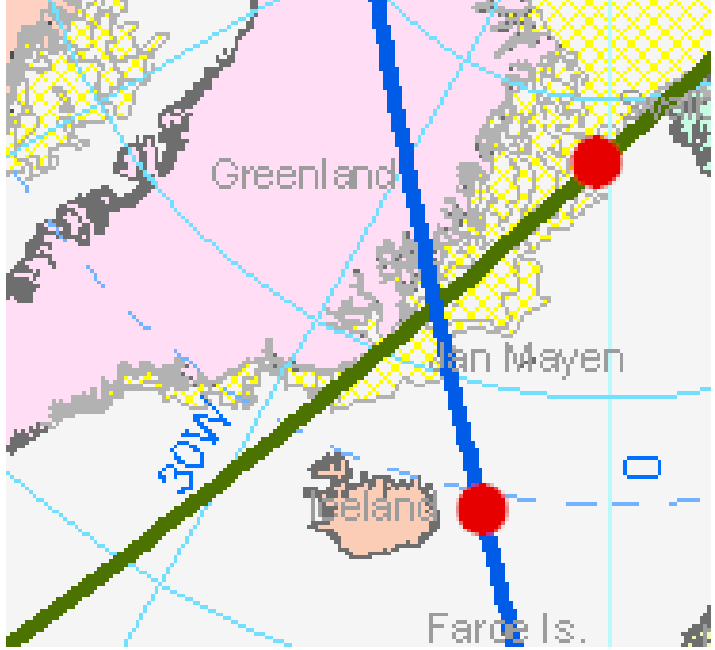
DOME-C Target (75S,123E) Reference Reflectance

- DOME-C appears to offer very stable surface reflectance reference and is being instrumented.
- MODIS observations over DOME-C serve as the AVHRR reference.
- Models of the nadir reflectance from two-different groups for DOME-C agree very well.
- DOME-c is superior to desert targets because of the lack of water vapor and it provides daylight observations for afternoon and morning sensors.
- DOME-C results in morning satellites erratic when solzen > 70 deg.

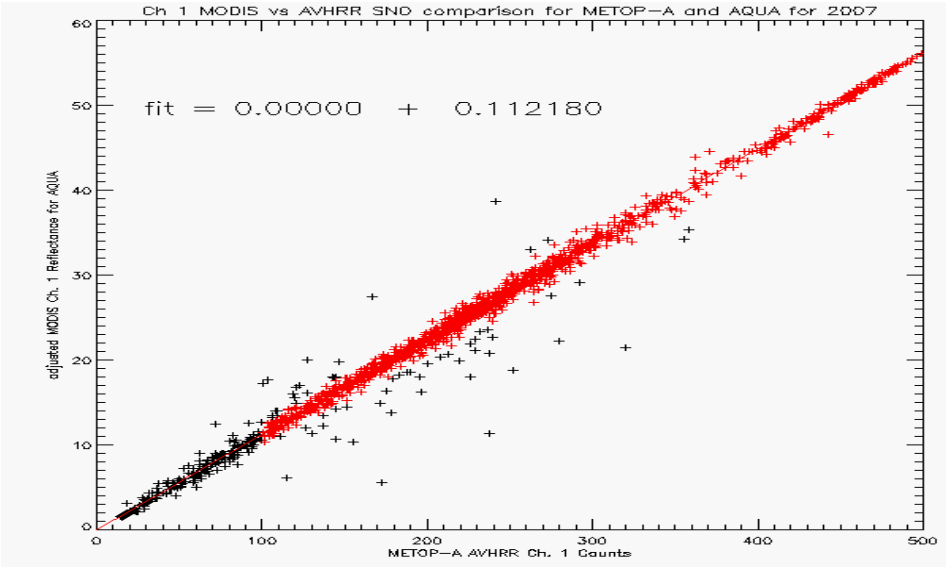


MODIS to AVHRR Simultaneous Nadir Overpass (SNO)

- We have computed them for all GAC data from all relevant AVHRR sensors (TIROS-14 to METOP-A) for both AQUA and TERRA.
- Refl = Slope * (Count - Dark_Count)
- Slopes of the scatter-plots of one AVHRR's counts versus another's gives the ratio of the two calibration slopes.
- Dual-gain sensors treated in the same way.
- We averaged all SNO's over a month to compute the slope.
- We have 52 slopes provided by MODIS/AVHRR SNO data.



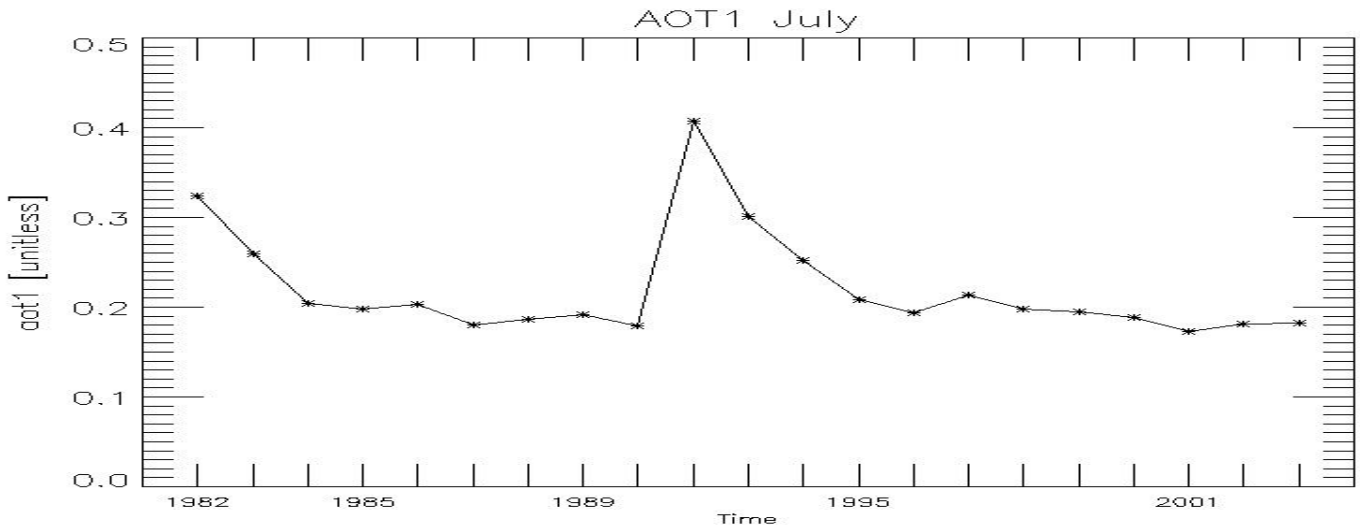
Example AQUA/METOP Ch1 SNO



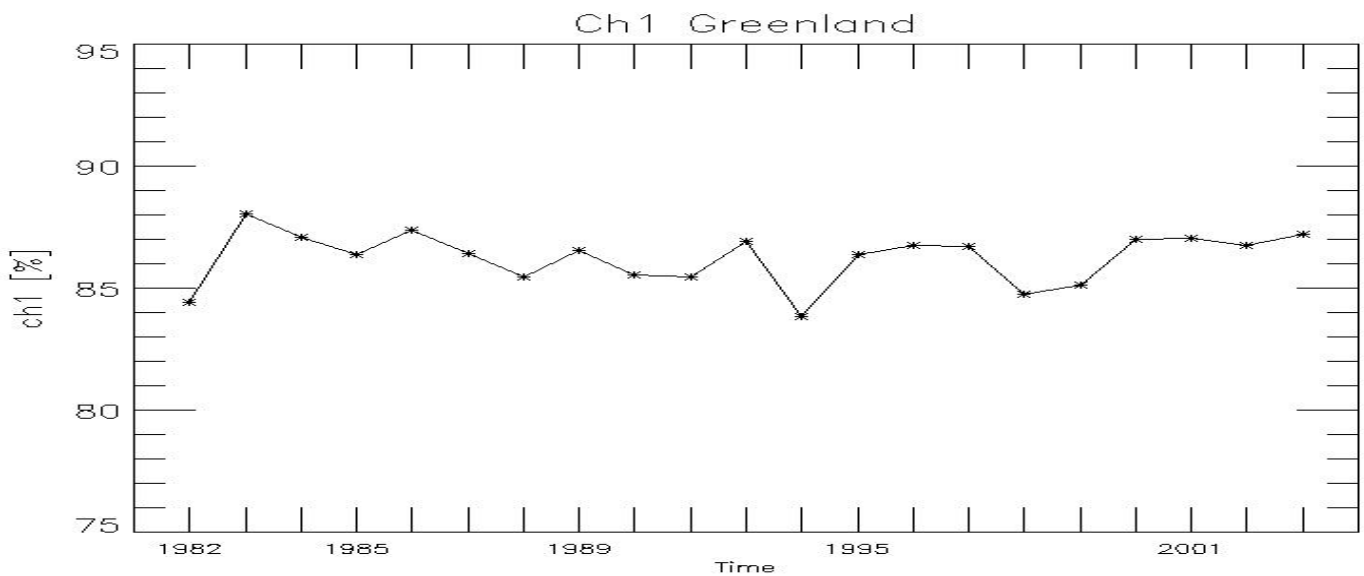
Our results are here --> http://cimss.ssec.wisc.edu/clavr/calibration/modis_avhrr/modis_sno.html

Long-Term Stability of Solar Reflectance based CDRs

Ref. Cal. Produces continuous AOT time series (dark surface).



Ref. Cal. produces continuous Greenland reflectance time series (bright surface).



Advances in Cloud Optical and Microphysical CDRs.

- While the physical basis used in estimating cloud optical depth and particle size are mature, the application of this approach can result in widely varying results.

- This is true for algorithms that employ similar lookup tables or forward models.

- **Andi Walther's Poster** describes our work in trying to understand the impact of the chosen retrieval methodology (*direct, optimal estimation and swarm*). These impacts can be very large and have not often been addressed fully in the literature.

Advances in Cloud Optical and Microphysical CDRs.

- Another major issue is the generation of meaningful CDRs or level-3 information from the level-2 or pixel-level results.

- Our comparisons between PATMOS-x and MODIS reveal that the level agreement for pixels where both methods retrieve is very good.

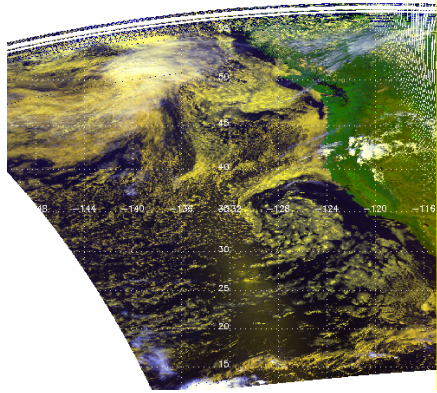
- Differences exist in determining which pixels are used in the retrieval and used to generate Level-3 values.

- For example, MYD06 products are more restrictive (for valid reasons) than the PATMOS-x products.

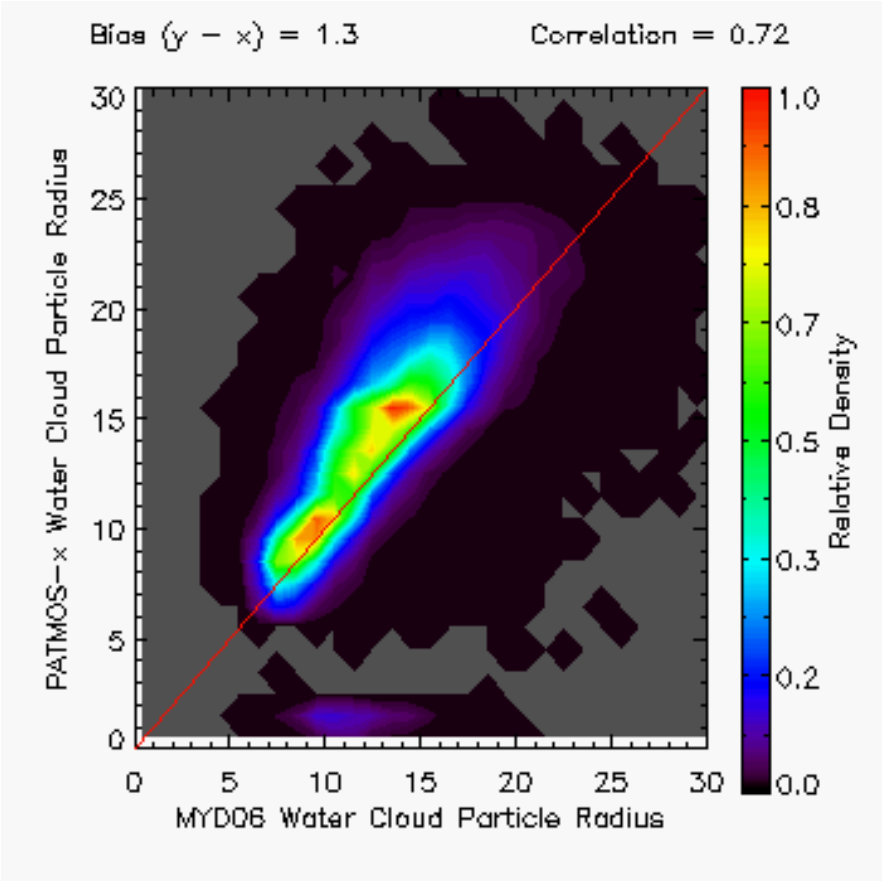
- This difference in “cloud masking” results in large level-3 differences even though the retrievals are very consistent at the pixel level.

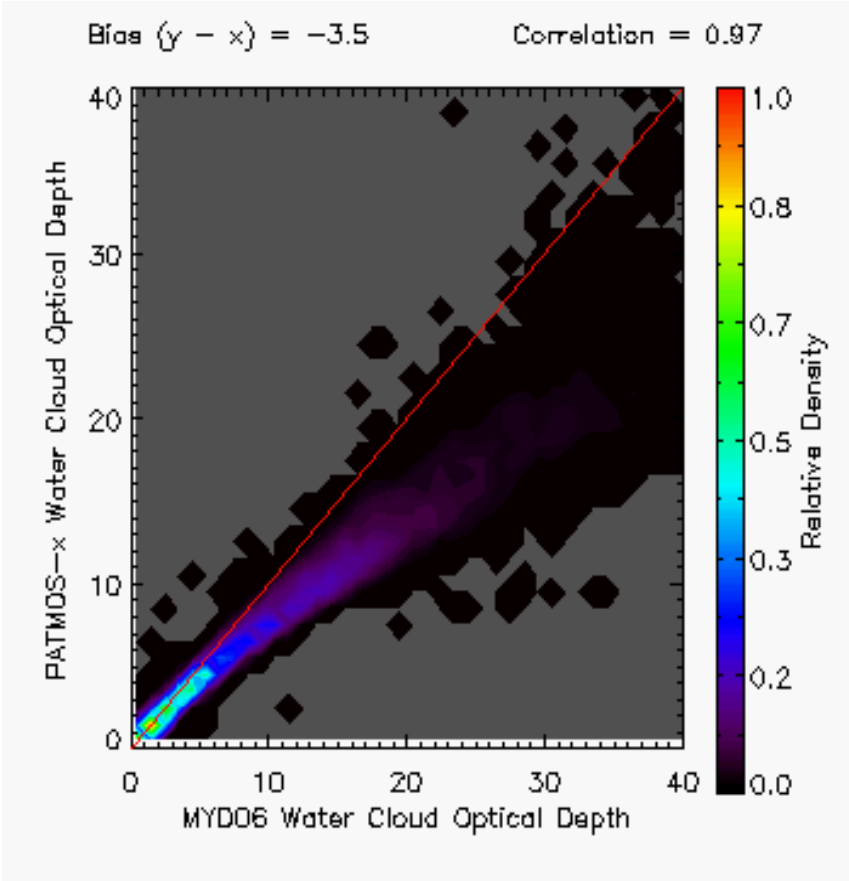
- We are developing strategies to create level-3 products that are constrained by the distribution of the reflectances in addition to the pixel-level results. *In a sense, we are trying to recover the true distributions of optical depth and particle size based on the limited samples generated from the level-2 data.*

Advances in Cloud Optical and Microphysical CDRs.

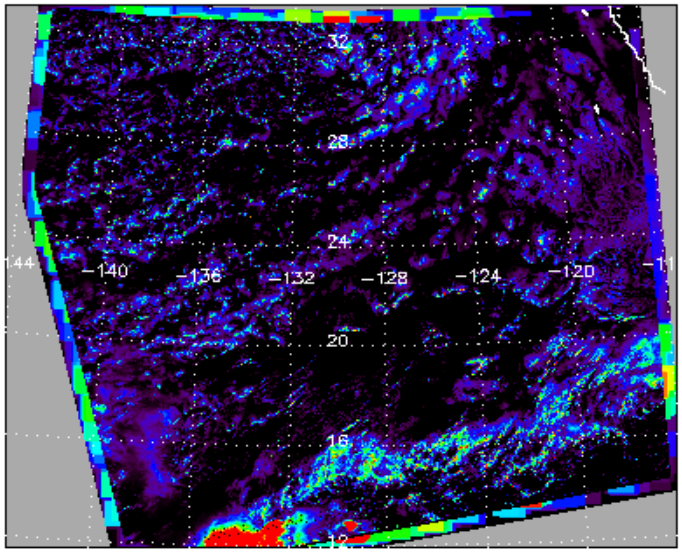


Example of the high level of agreement between PATMOS-x and MYD06 optical depth and particle size for a scene with high temporal and spatial coincidence.



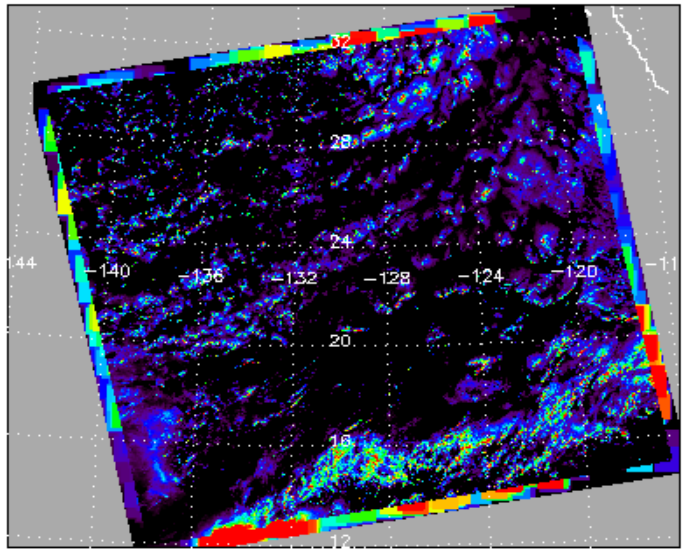


Example Images of PATMOS-x and MYD06 Level-2 and Level-3 Optical Depth Fields.



PATMOS−x Optical Depth

0.00 6.00 12.00 18.00 24.00 30.00



MYD06 Optical Depth

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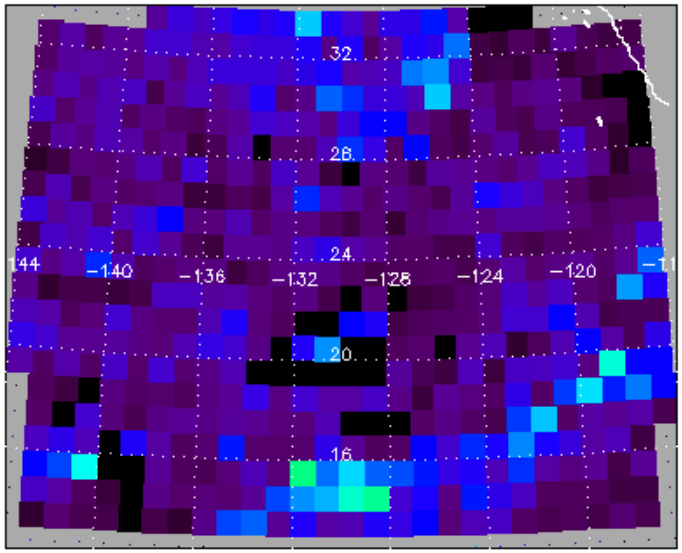

PATMOS−x L3 Optical Depth

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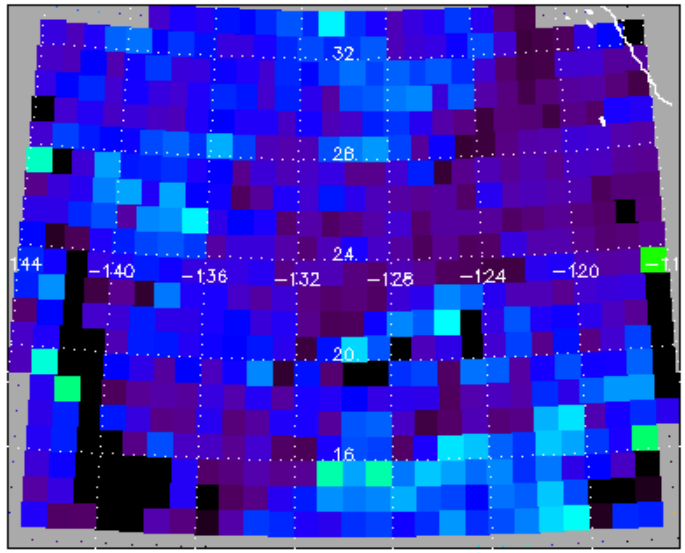

Modis L3 Optical Depth

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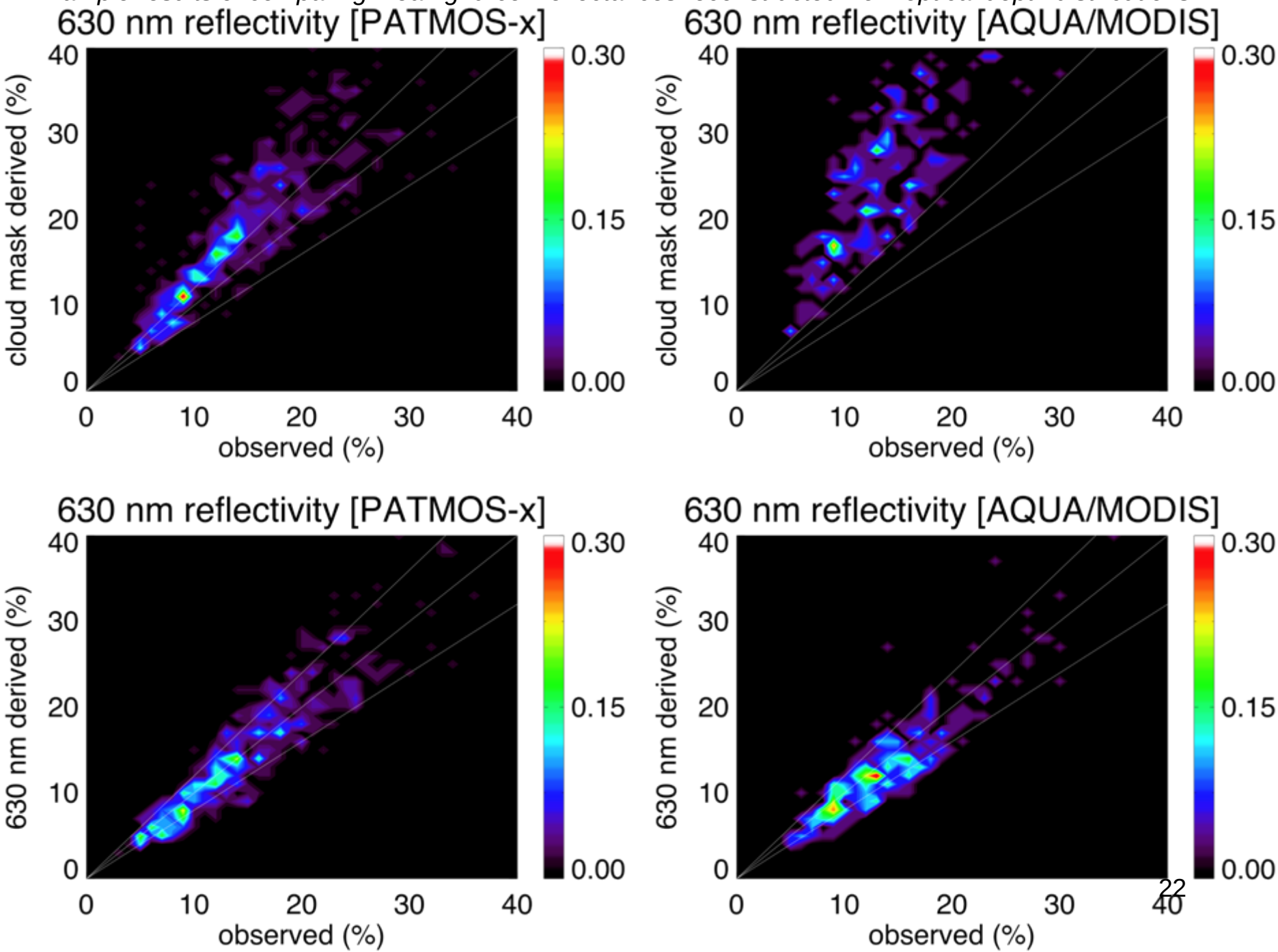
Example results of comparing mean grid-cell reflectances reconstructed from optical depth distributions.



Use of CALIPSO/CALIOP to Improve and Characterize Cloud Remote Sensing from Passive Sensors

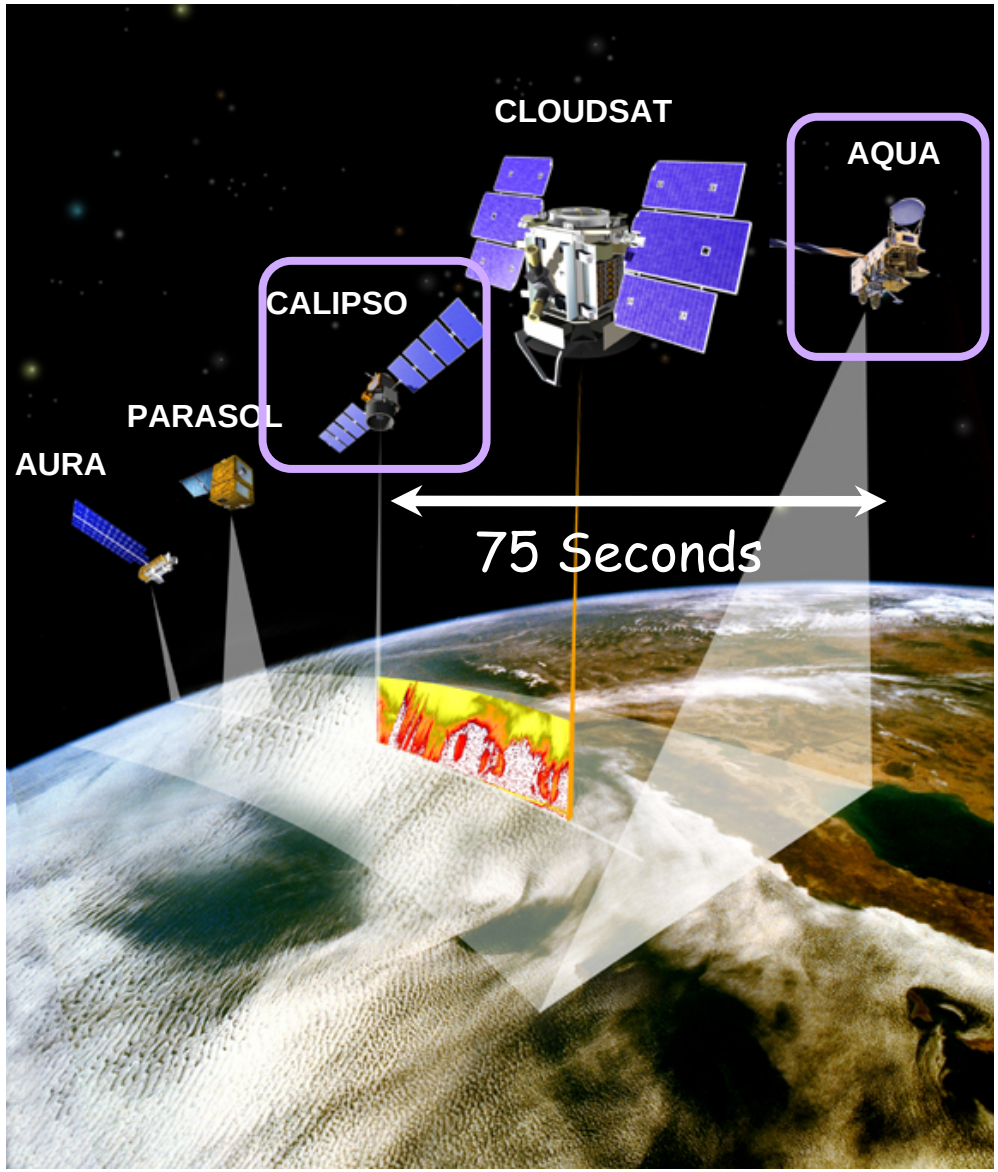
CALIOP data: about 80 m resolution

AVHRR cloud products at both 1 & 4 km

AVHRR on NOAA-18 and NOAA-19 overlapped with the CLOUDSAT and CALIPSO missions.

This provides an ability to assess an important source of cloud CDRs directly with having to use MODIS as a surrogate.

We have use A-train validation for our Geostationary validation and algorithm development (GOES-R AWG).



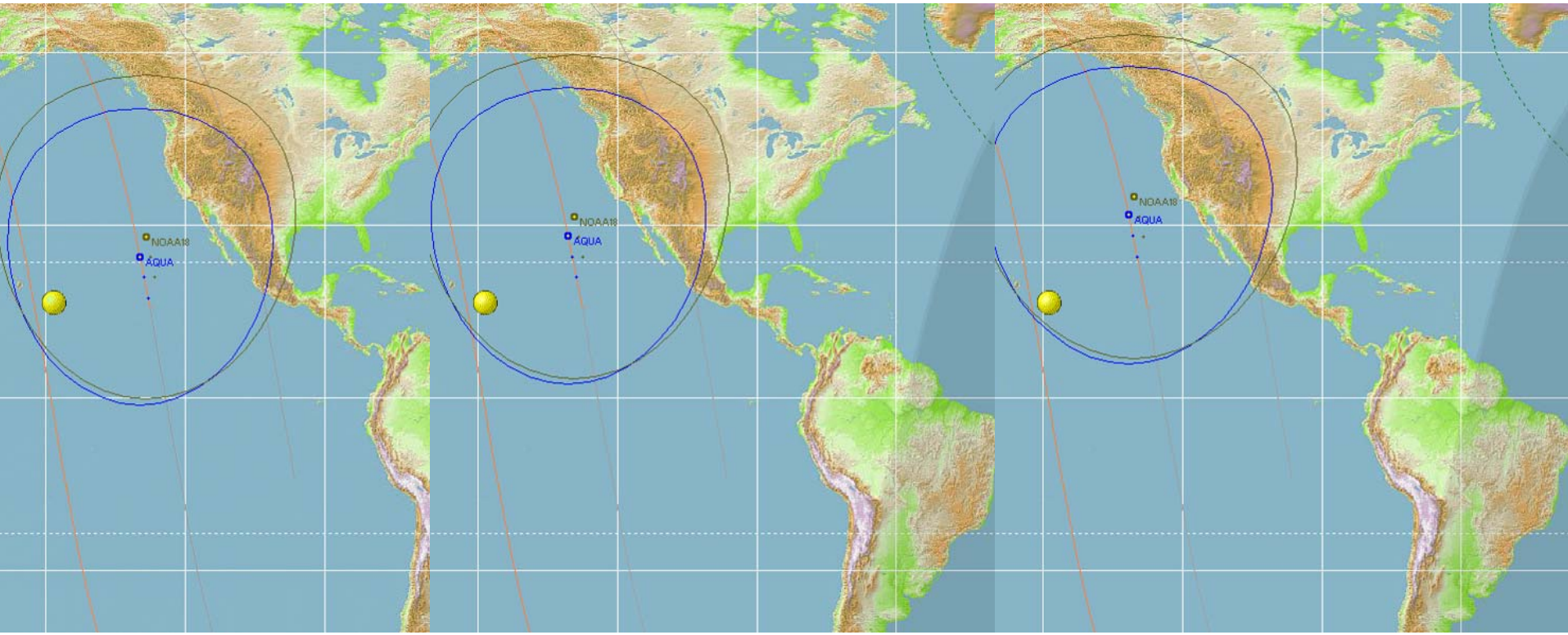
SSEC

Example of NOAA-18 and AQUA Period of Coincidence

•One such period occurred for the AQUA/MODIS granule from 21:55 on August 6, 2006.

•This scene occurred off the coast of California where NOAA-18 HRPT was available from CLASS. Therefore the spatial resolutions are similar.

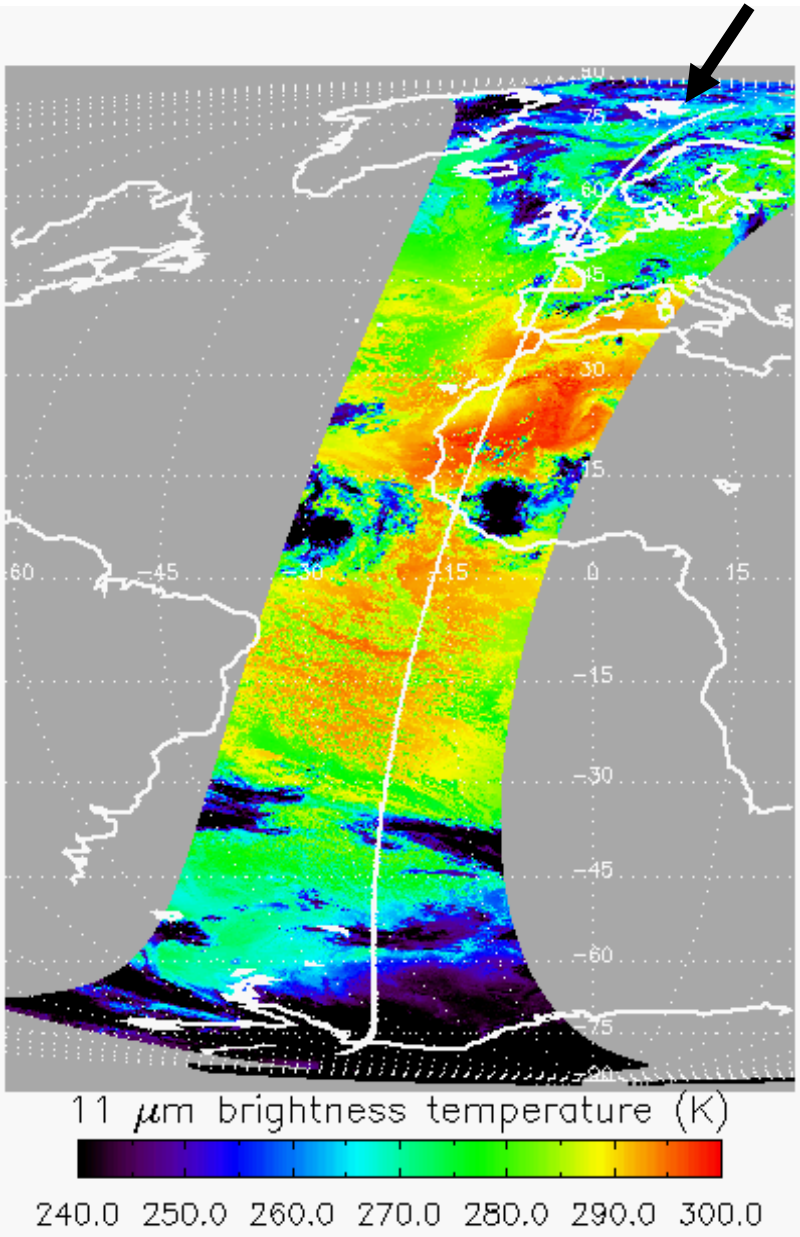
WxTrack Generated Output For this Time Separated By One Minute

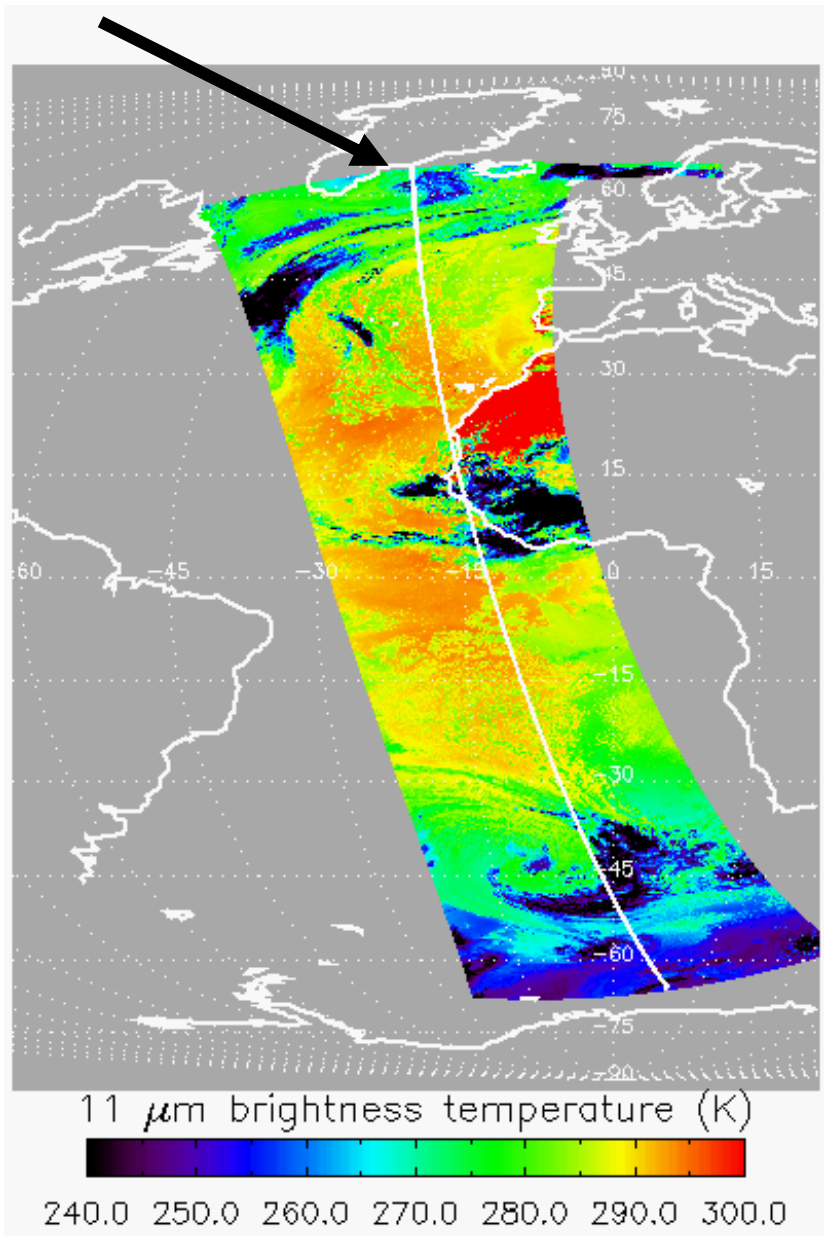


AQUA and NOAA-18 were roughly 1 minute apart.

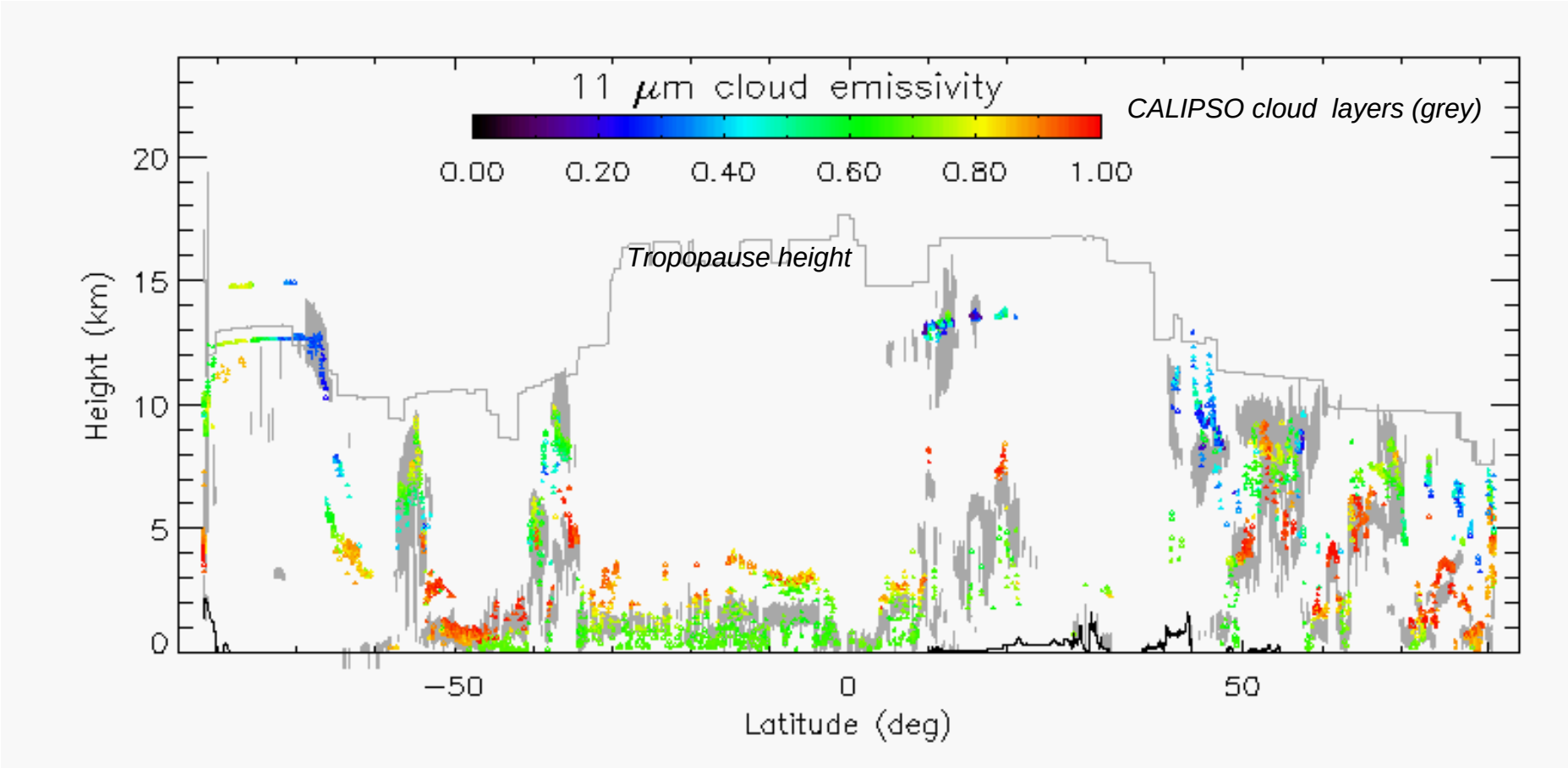
Example of CALIPSO and NOAA-18 Colocated Orbits

CALIPSO TRACK



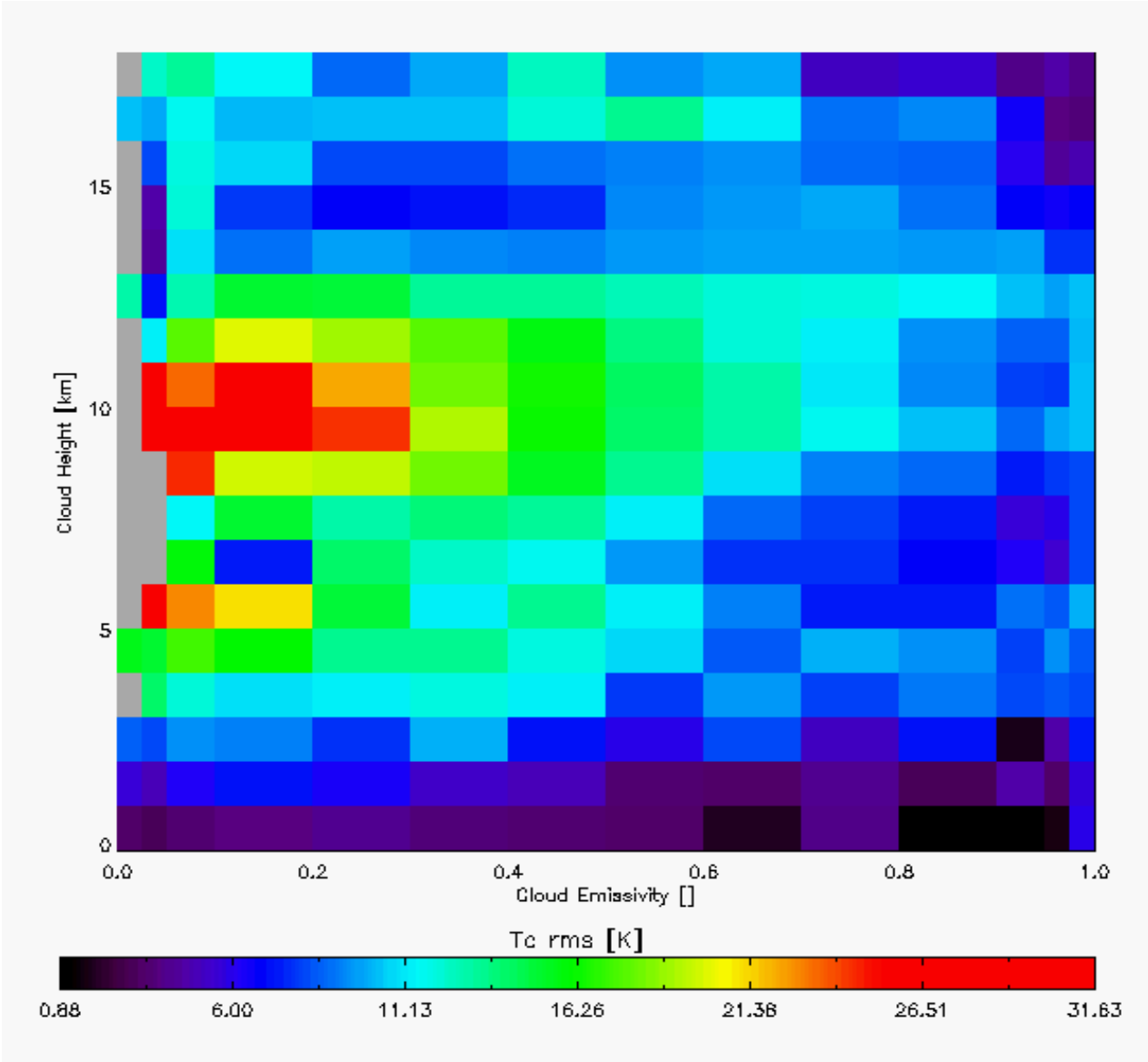


Comparison of AVHRR Split-Window Cloud Heights against CALIPSO

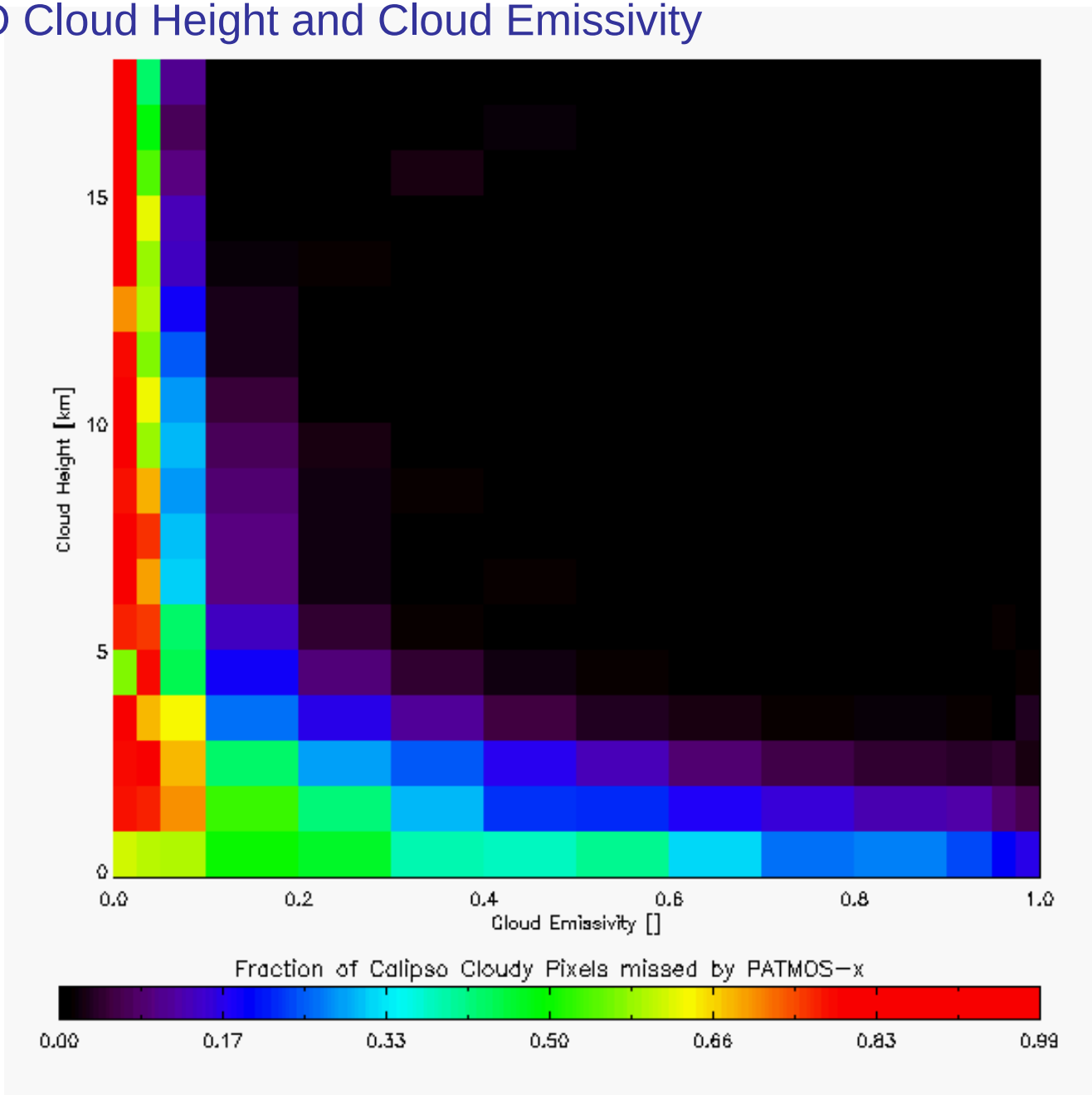


Cloud emissivity = (Observed Radiance - Predicted Clear Radiance) /
(Blackbody Radiance at CALIPSO Height - Predicted Clear Radiance)

Global Characteristics of AVHRR Cloud Temperature as a Function of CALIPSO Cloud Height and Cloud Emissivity



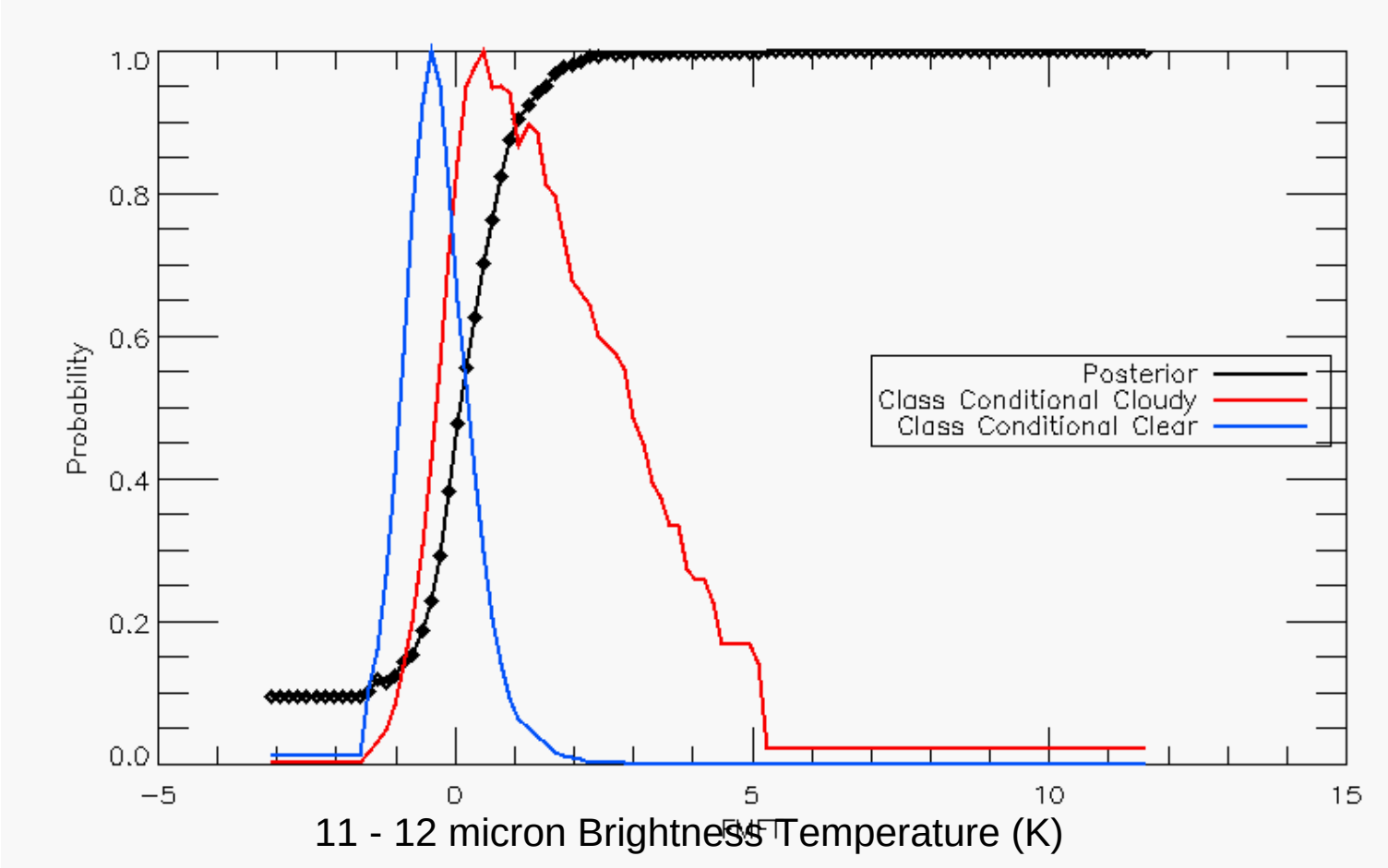
Global Characteristics of AVHRR Undetected Cloud as a Function of CALIPSO Cloud Height and Cloud Emissivity



CALIPSO-Derived Bayesian Cloud Detection

- Bayesian techniques have applied to imager cloud detection in the past. Most often, the training data-set is manually cloud-cleared scenes and this is done often for oceanic surfaces or small regions.
- CALIPSO provides a very sensitive signal for cloud detection for all surfaces.
- We have used our CALIPSO/NOAA-18 colocated data-sets to derive the conditional classifiers for clear and cloudy pixels for several spectral and spatial signatures.
- Our goal is to replace the current threshold technique for our climate processing system.
- We are actually applying a Naïve-Bayesian approach where each classifier is treating independently.
- Skill scores are used to judge the improvement offered by additional metrics.

Example of a Bayesian Classifier - The Split-Window Brightness Temperature Difference Relative to Clear Sky



CALIPSO derived Bayesian Cloud Detection Statistics

	POD day+night	POD night	% of pixels with Posterior Probability < 0.1 or > 0.9
Ocean	0.92*	0.93	86%
Land	0.91	0.90	91%
Arctic	0.78	0.78	51%
Antarctic	0.75	0.74	43%

* - includes glint effects.

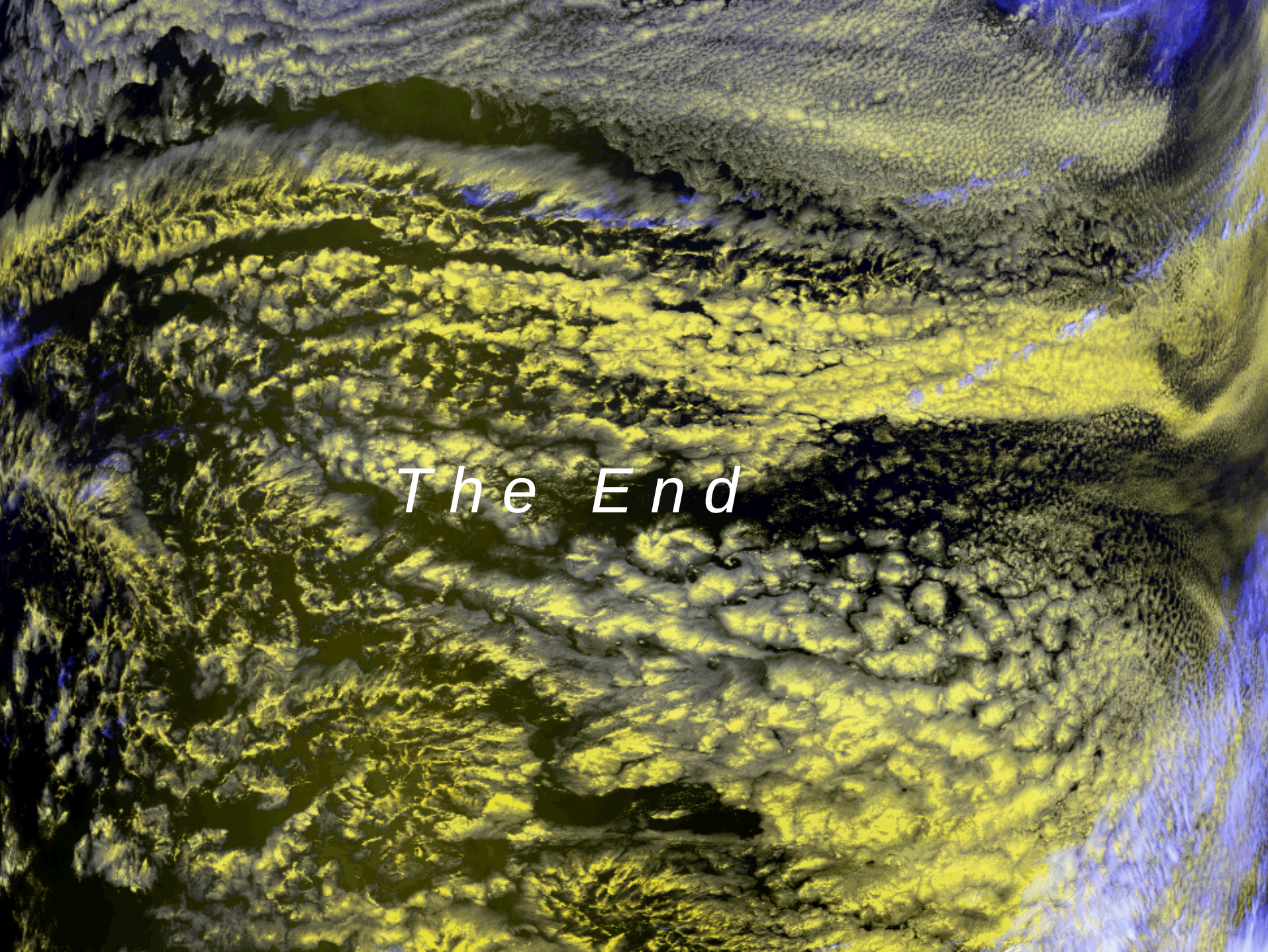
Conclusions

- Though outclassed in capabilities by newer images, the AVHRR provides a uniquely long data-record. Both NESDIS and the CM-SAF are pursuing cloud climatologies to exploit this long record.

- Progress is being made in reconciling the existing and generating improved calibration information for the AVHRR reflectance channels. These new methods are tied to MODIS and should offer accuracies of ≈5% (twice the MODIS value).

- We are also tackling other important issues in cloud CDR generation. Namely, the development of level-3 products for optical depth and particle size that capture the level-2 information but also are consistent with the reflectance distributions. These approaches should result in algorithm-independent (or cloud-mask independent) level-3 products.

- The A-train is playing a large role in our algorithm validation and development efforts for GOES-R, GOES and AVHRR. It allows us to more fully characterize our performance. In addition, it opens up the possibility of developing synergistic approaches that use the A-train to improve our passive remote sensing (Bayesian Cloud Detection).


The End

QUESTION #1 . Which current cloud parameters observed from satellite are most useful.

- NCEP finds bulk cloud amounts to be a useful statistic for model verification. ISCCP, AFWA (US Air Force) and CLAVR-x (NESDIS AVHRR) are currently used.

- NCEP requires all products in GRIB format.

- Simple assimilation techniques using the limited information on the vertical extent of clouds appears to be useful.

- NCEP is also planning on using satellite derived microphysics to verify cloud parameterizations. Presumably this would start with cloud-top phase.

QUESTION #2. Which important cloud parameters are currently missing from satellite observations for
- data assimilation in weather and climate models?
- evaluation of weather and climate models?
-satellite retrievals schemes?

- Level-3 products that do not suffer from the filtering required to obtain accurate Level-2 products. (i.e. ignoring of cloud edges)

- Level-3 products that are consistent with the radiance distributions.

Question #4. Which model improvements, complimented by satellite based information, are needed to better
forecast clouds in weather and climate models?

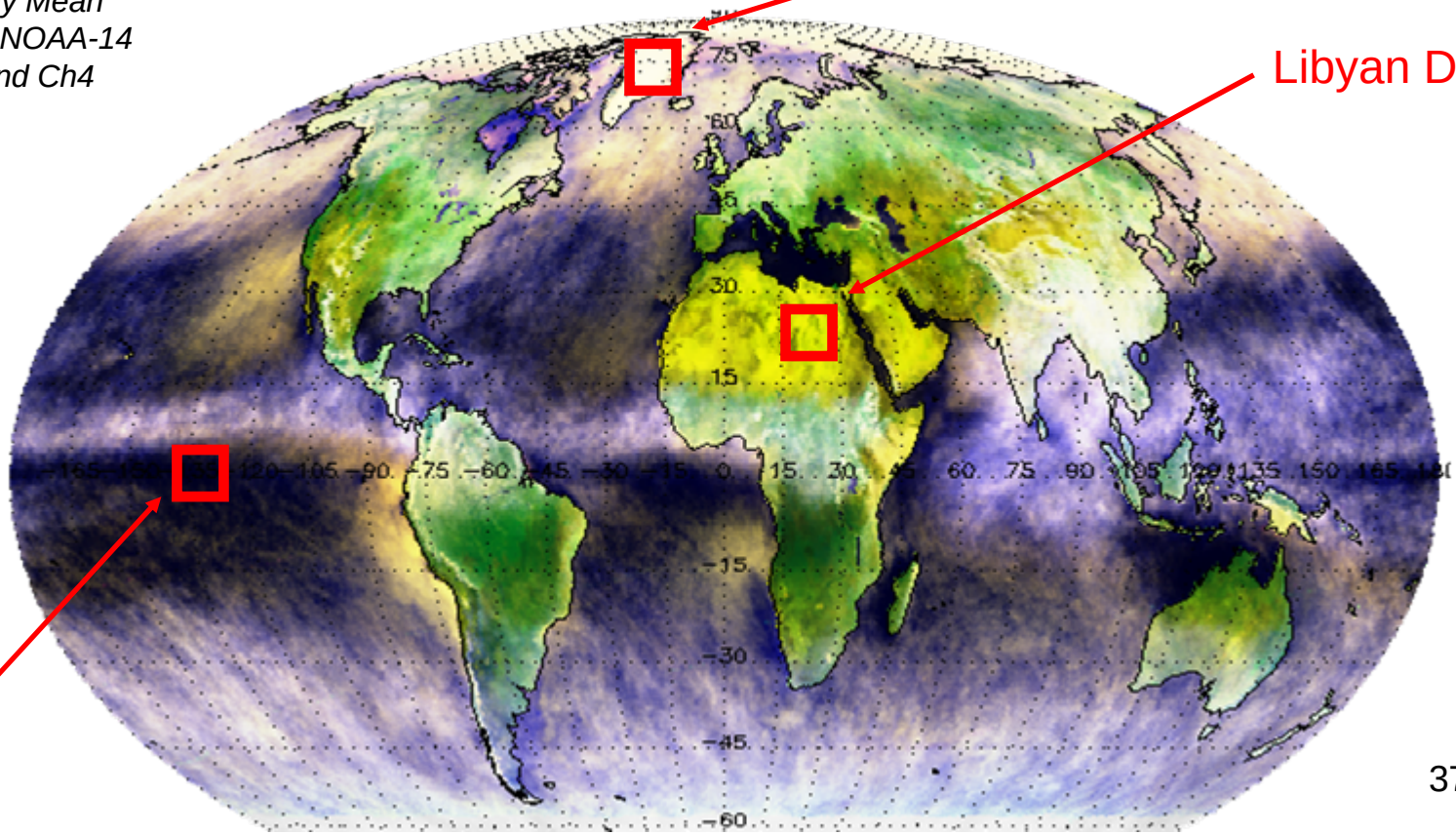
- Surface temperature biases from the NWP models limit our use of infrared window channels over land.

- NWP output needs to be instantaneous to facilitate satellite comparisons (not 6 or 12 hour averages)

Demonstration of the Problem

To characterize the current relative calibration agreement, we generated multi-decadal time-series of reflectances over targets with a wide range of reflectance (dark to bright). PATMOS-x data used to provide needed information (counts, angles, etc)

False Color Image from Monthly Mean (July 1996) NOAA-14 Ch1, Ch2 and Ch4

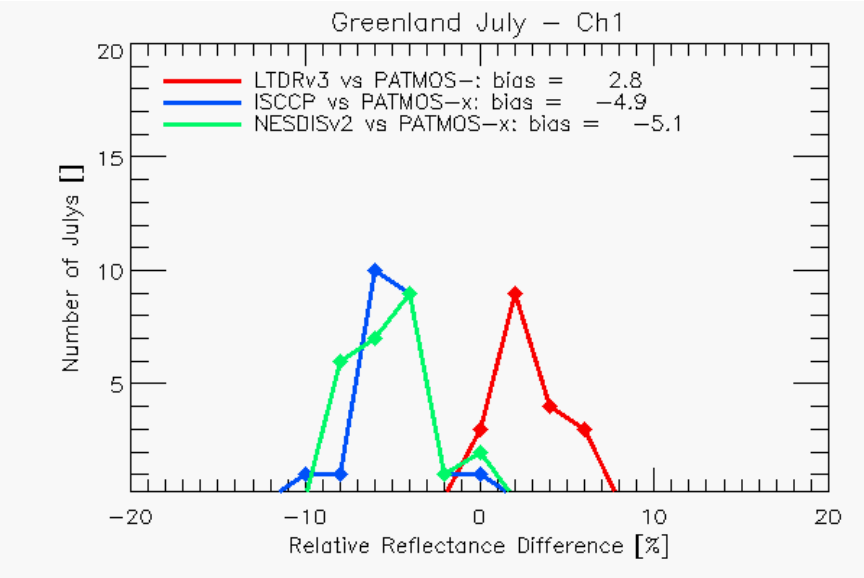


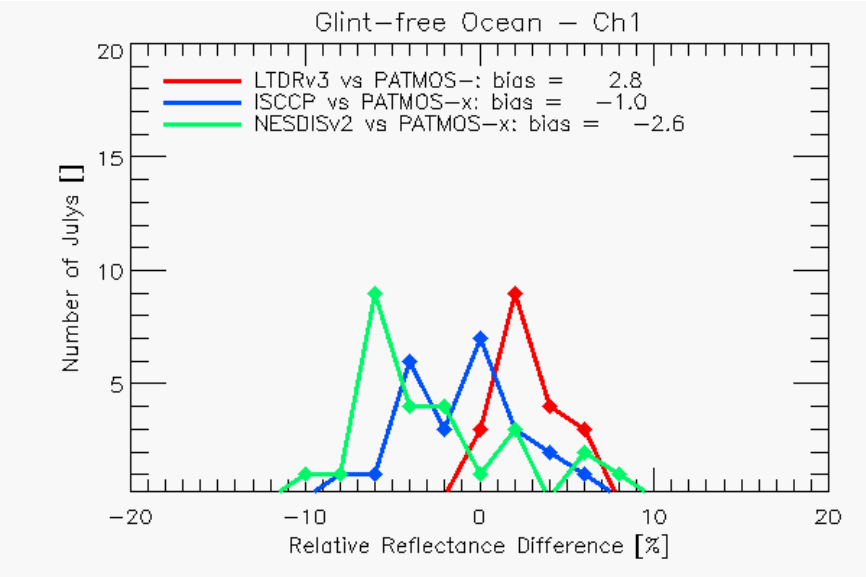
Comparison of Ch 1 for PATMOS-x, LTDR, NESDISv2 and ISCCP for 1981-2007

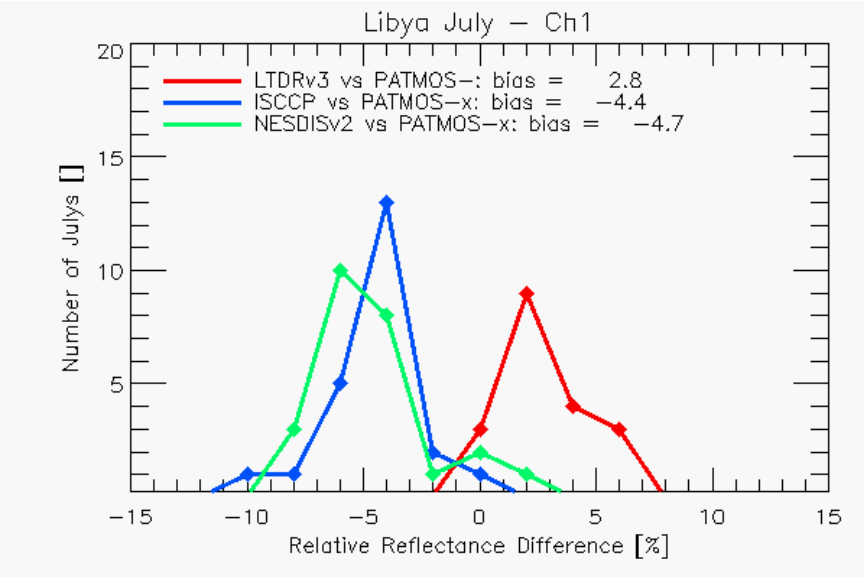
Relative Reflectance Difference = 100%*(Y-X)/X

where:

X = PATMOS-x
Y = LTDR or ISCCP or NESDISv2

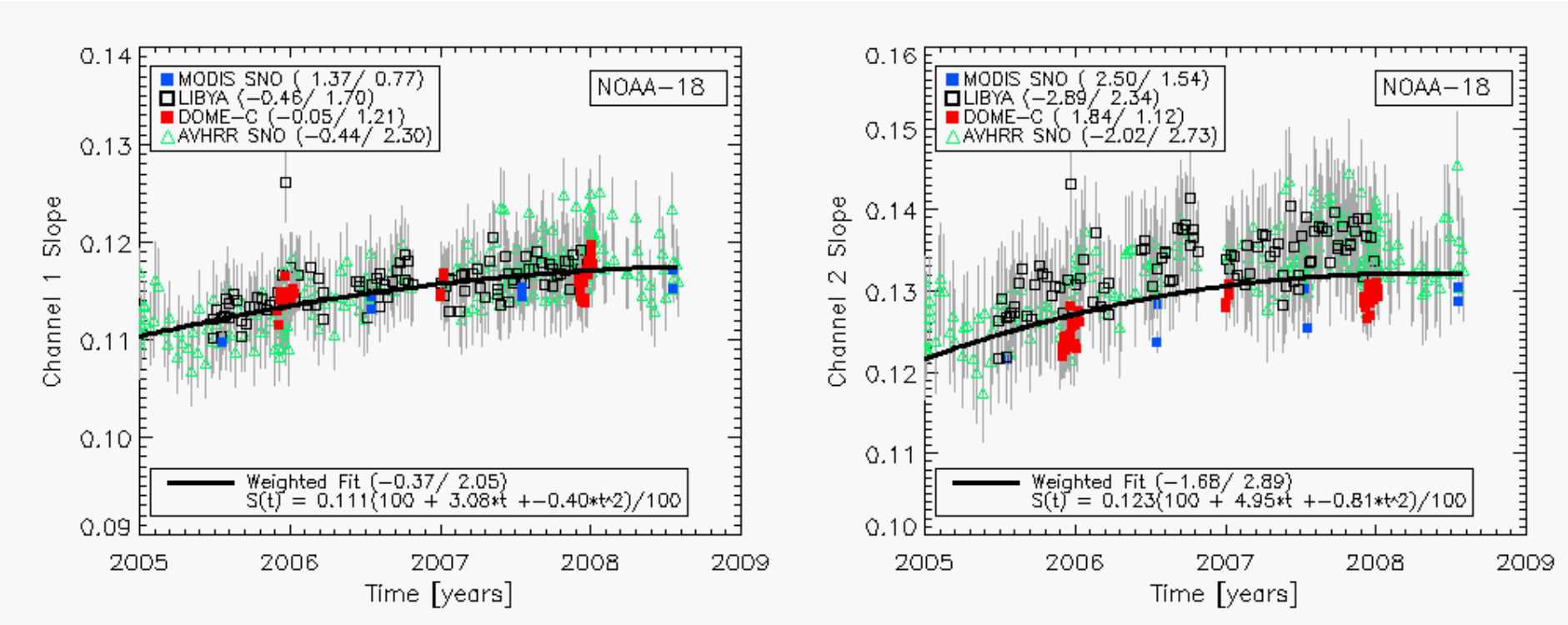






Results of Calibration Slope Estimates and Fits (NOAA-18 - a later AVHRR within the EOS era)

- Sources: DOME-C + Libyan Target + MODIS SNO
- AVHRR SNO's with NOAA-15,NOAA-17, and METOP-A
- Plot shows some features common in this analysis
  - Libya Channel-2 slopes larger than DOME-C and MODIS-SNO
  - Channel-2 MODIS slopes differ for AQUA and TERRA



Summary

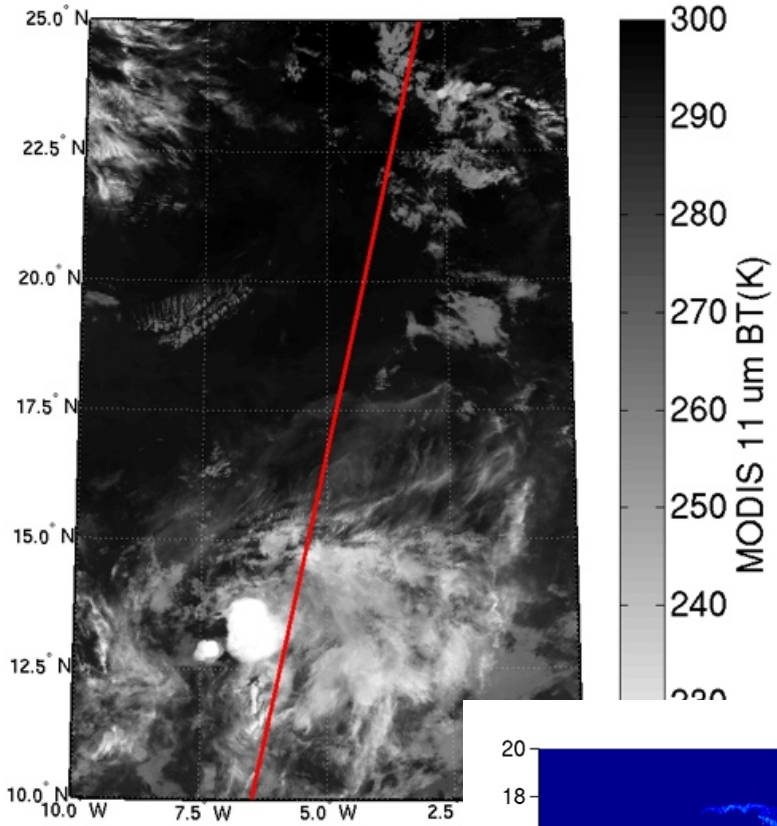
- We are actively pursuing improvements in cloud remote sensing. The AVHRR is only part of this effort. Much research is focused on GOES-R and NPOESS.

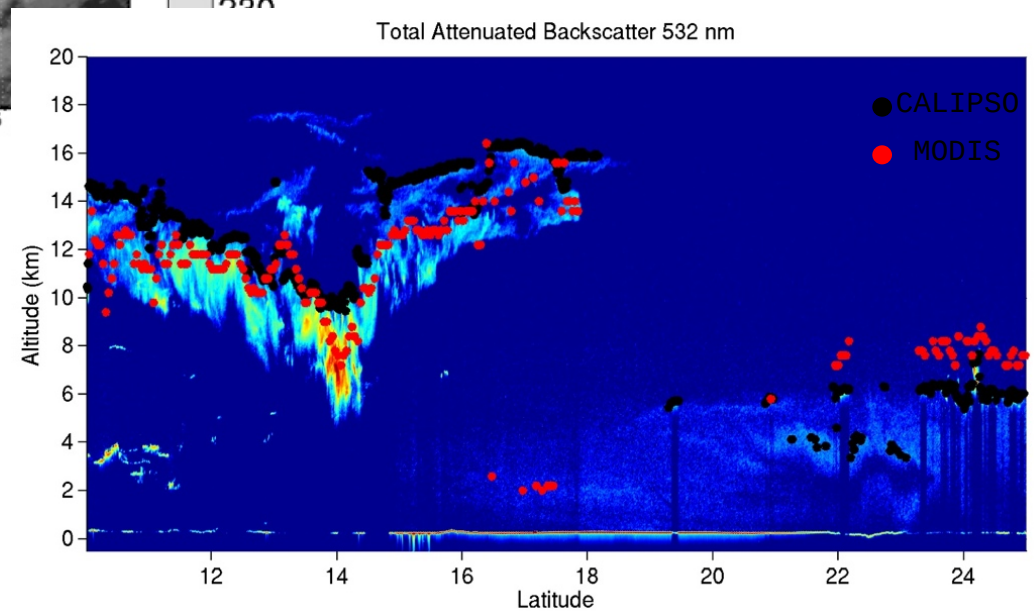
- NOAA/NESDIS has made progress in inter-calibrating the 30+ years of AVHRR data to allow for generation of consistent cloud products.

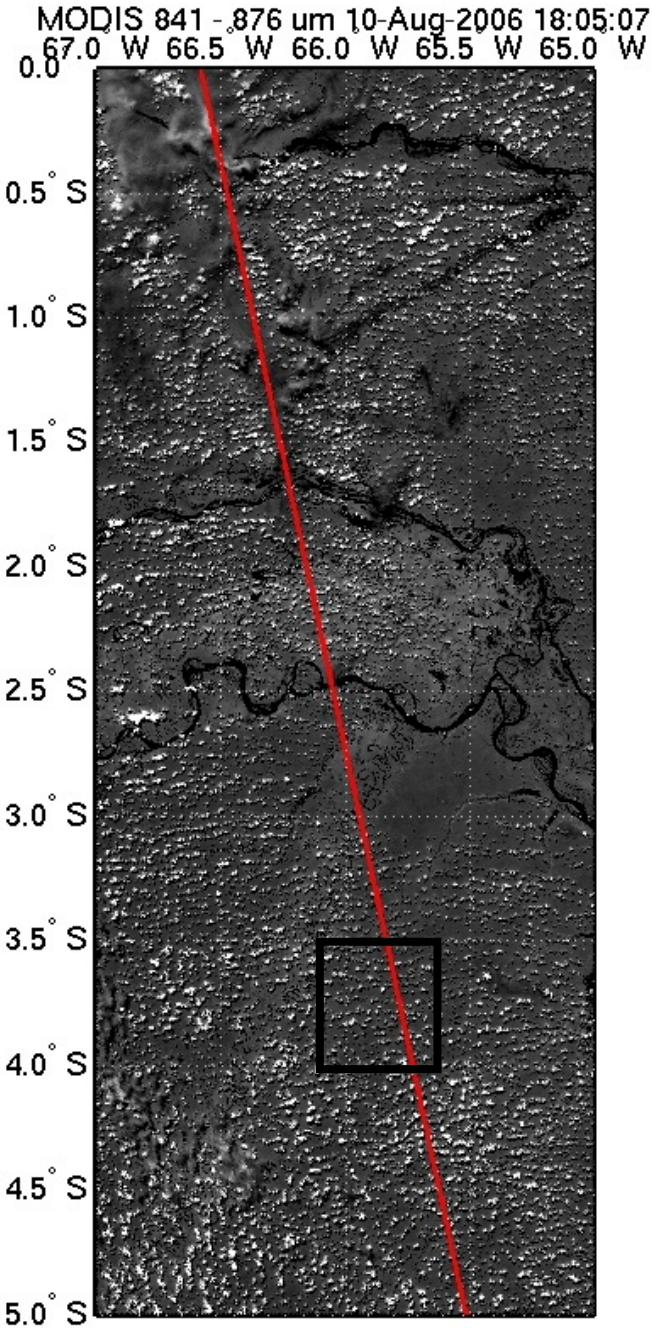
- The AVHRR record should span 40+ years when finished. With our CM-SAF colleagues, we are working to generate useful AVHRR cloud climate data records.

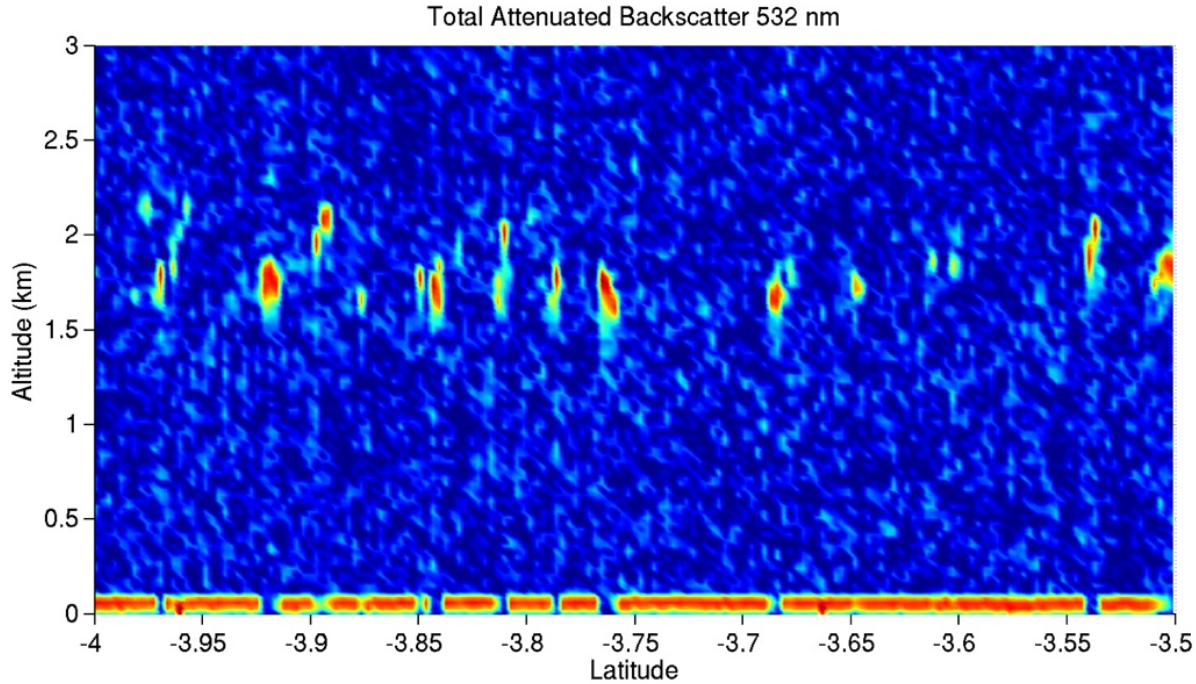
- We are pursuing advanced techniques to generate imager-based estimate of cloud optical depth and particle size that are accurate (Andi Walther) and capture the observed variability in observed radiance (Mike Foster).

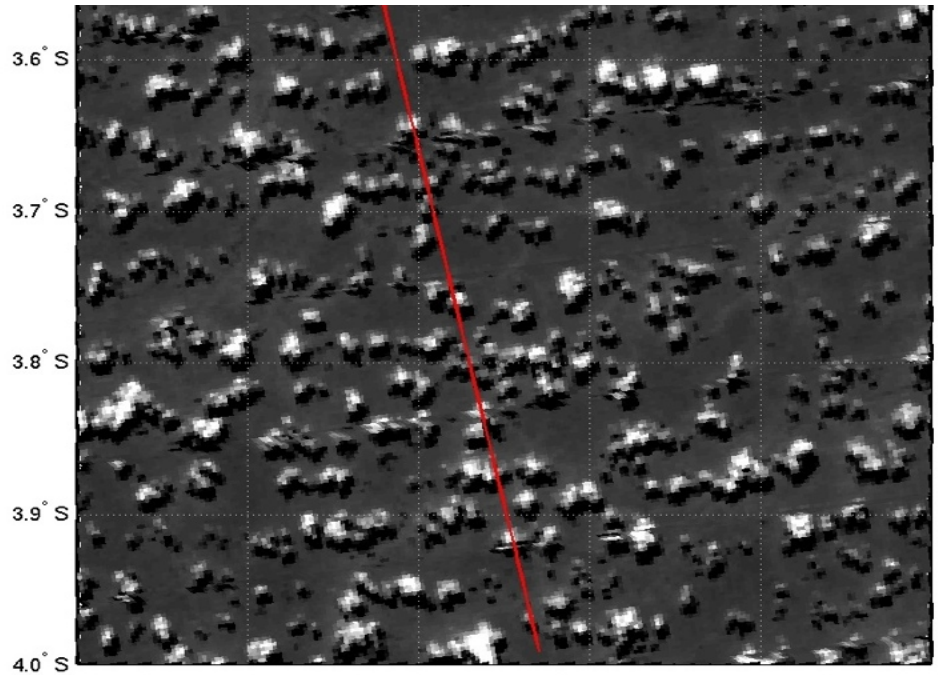
CALIPSO COMPARISON ILLUSTRATION (Provided by Bob Holz)





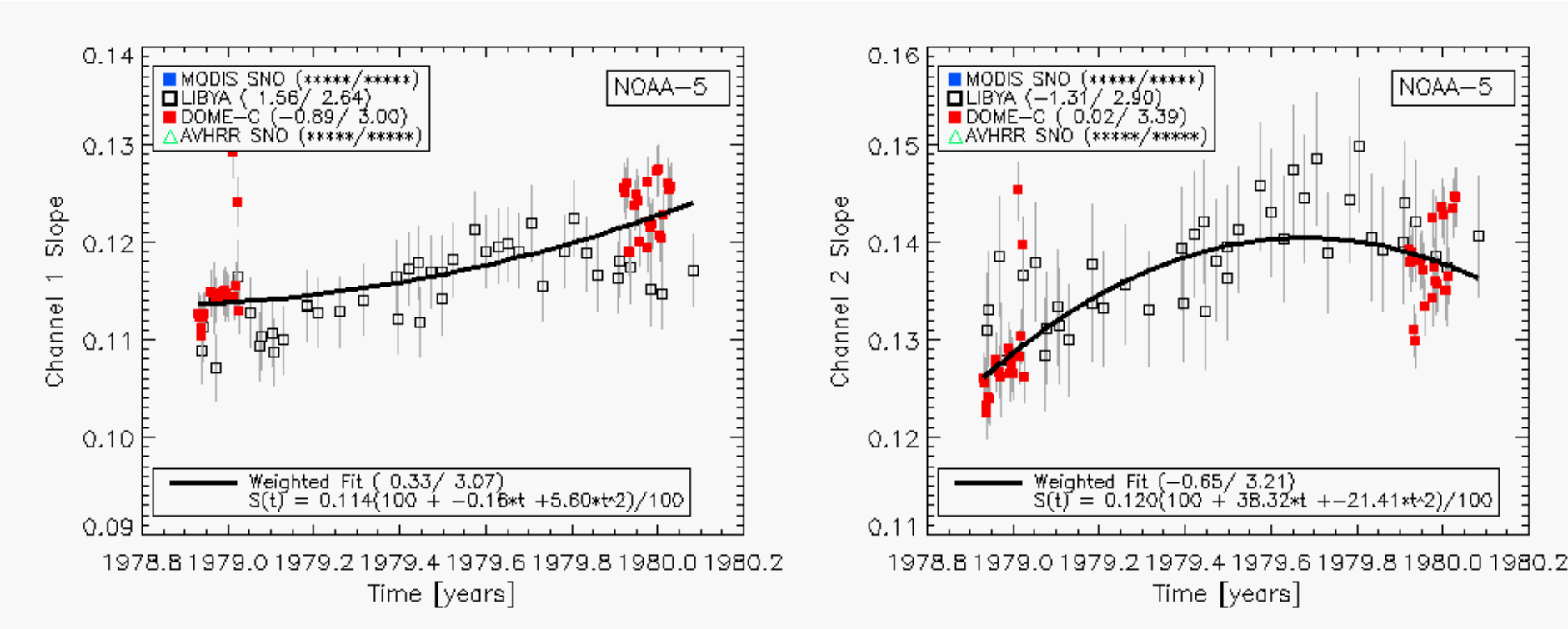

MODIS 841 - 876 um 10-Aug-2006 18:05:07
67.0 W 66.5 W 66.0 W 65.5 W 65.0 W
0.0
0.5° S
1.0° S
1.5° S
2.0° S
2.5° S
3.0° S
3.5° S
4.0° S
4.5° S
5.0° S


Total Attenuated Backscatter 532 nm
Altitude (km)
3
2.5
2
1.5
1
0.5
0
-4
-3.95
-3.9
-3.85
-3.8
-3.75
-3.7
-3.65
-3.6
-3.55
-3.5
Latitude


3.6° S
3.7° S
3.8° S
3.9° S
4.0° S

Example Calibration Slope Estimates and Fits for early pre-EOS AVHRR (TIROS-N)

- Sources: DOME-C + Libyan Target
- No AVHRR's SNOs
- Top legend gives statistics of fit relative to each slope source (bias,std-deviation) expressed as a % relative to the mean slope value
- Bottom legend gives statistics of fit to all values and fit coefficients.



Images for all AVHRR's are included at the end of this presentation..

Current NESDIS Operational Cloud Product Algorithm Philosophy

- Emphasis on the IR in cloud detection, typing and height estimation. Reduce day/night sensitivity.

- Physical retrievals of cloud properties using optimal estimation techniques. Provides error estimates and a common retrieval framework for all sensors.

- Heavy use of NWP data coupled with Fast Radiative Transfer Models (IR only)

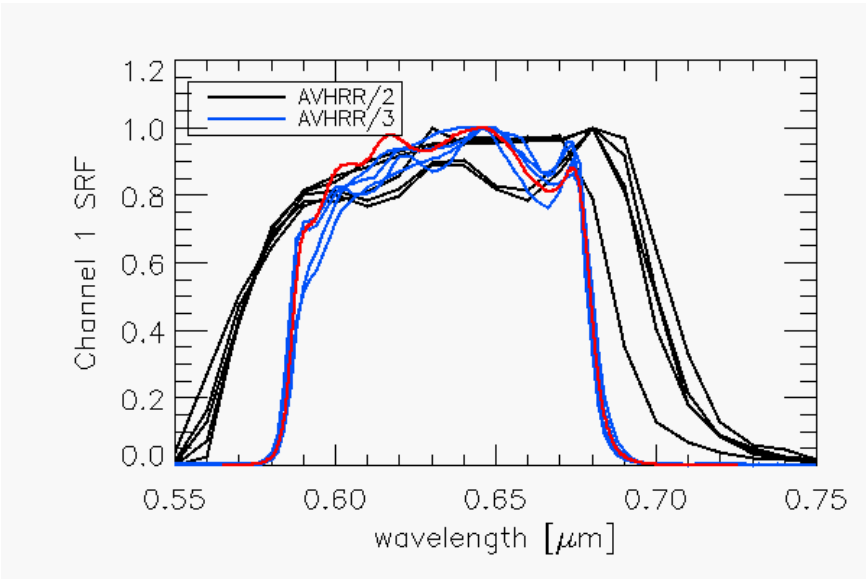
- Use of spatial and contextual information.

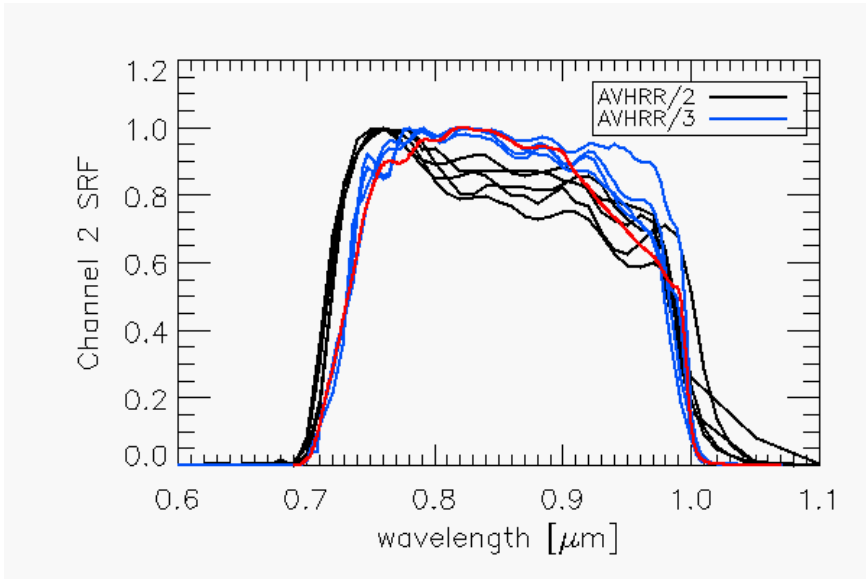
- Incorporation of high resolution ancillary data developed recently for MODIS including surface emissivity at 5 km, 1 km surface type, 1 km land/sea information.

- Validate against CALIPSO and products from other groups.

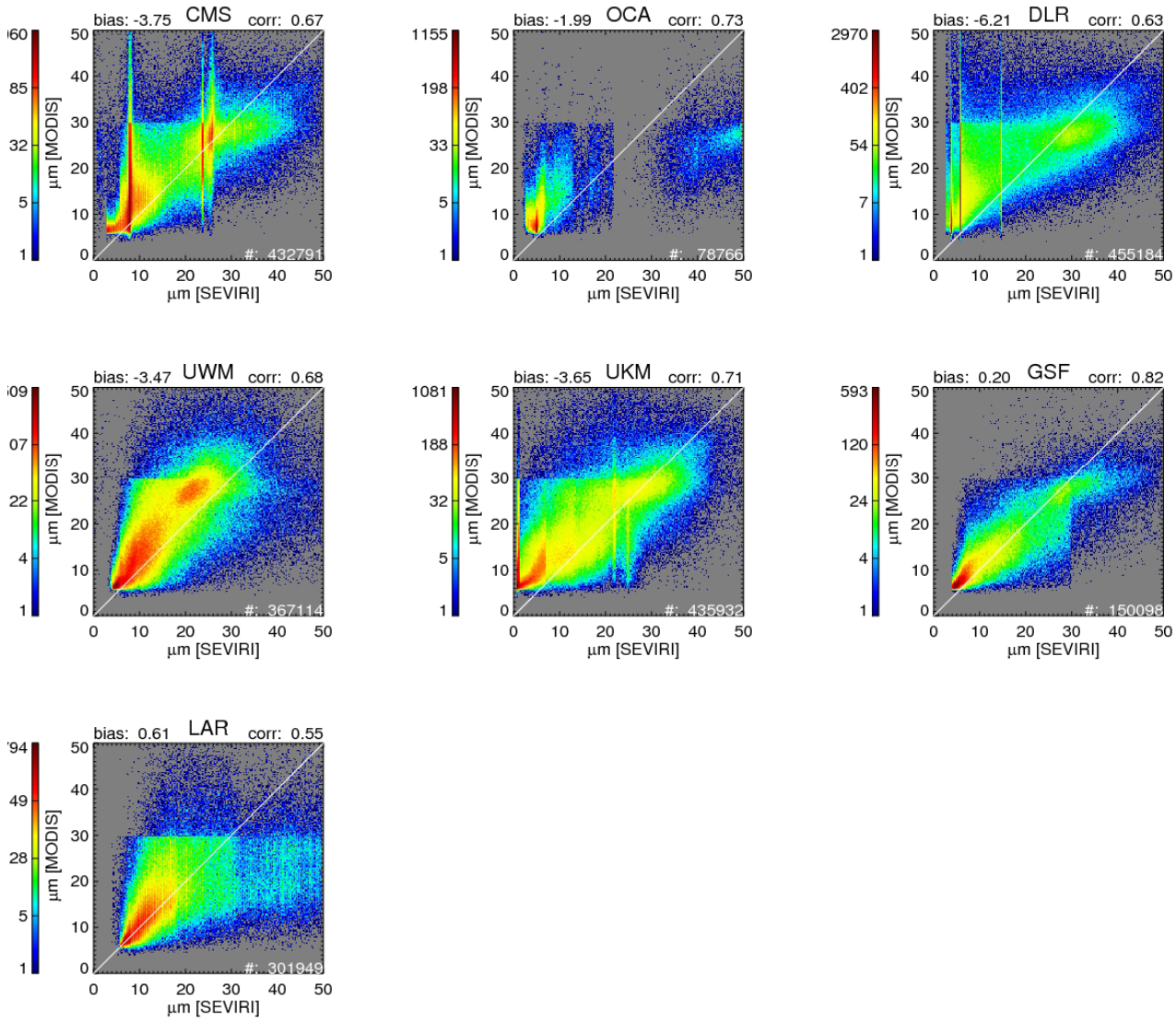
Other Issues Being Addressed by this Group

• Spectral Response Functions (SRF) vary between satellites and between sensor versions (AVHRR/2 and AVHRR/3)





Fred Wu leads an effort to explore the historical AVHRR SRF values
www.star.nesdis.noaa.gov/smcd/spb/fwu/solar_cal/spec_resp_func/index.html

• In addition, choice of solar spectral flux database can cause 1 - 2% differences in calibration slopes. CEOS recommends Thullier (2002)

SEVIRI-MODIS
CLOUD EFFECTIVE RADIUS
Day 20080613