A CERES-Consistent Cloud Property Climate Data Record Using AVHRR Data: Version 1 Delivery Results

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With Countless Contributions From

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LaRC AVHRR CDR Background

- **The NASA LaRC team has been supported by the NOAA NCDC (now NCEI) Climate Data Records Program since mid-2010 to develop a global shortwave reflectance and cloud property climate data record (CDR) using the 35+ year AVHRR time series**

- **Algorithms used to create this dataset are based upon those developed for CERES Edition 4 and have been adapted to work on 5-channel and ~4 km AVHRR data**

- **The LaRC AVHRR CDRs represent the highest spatial resolution long-term datasets of their kind**

- **NOAA-18 products have been produced from Aug. 2005 – Dec. 2010 and NOAA-19 from June 2009 – Dec. 2013**

AVHRR CDR Project Overview

GOALS

- Calibrate AVHRR 0.63, 0.86, and 1.61-µm channels
- Generate CERES-like cloud and clear-sky radiation products for every AVHRR pixel throughout the history of the instrument

ALGORITHMS

- Simultaneous Nadir Overpass, Deep Convective Cloud, and invariant polar/desert site techniques used for calibration
- CERES Edition 4 MODIS cloud mask and retrieval algorithm adapted to operate using 4 to 5-channel AVHRR radiances (Minnis et al. 2008 and 2011)

SOURCE AND ANCILLARY DATA

- 4 km AVHRR Global Area Coverage Data: 1978 – present
- MERRA surface, vertical profile, and snow/ice cover analyses
- SCIAMACHY spectral data: 2004-2009

DELIVERABLES

- AVHRR 0.63, 0.86 , and 1.61-µm calibration coefficients and a comprehensive set of derived cloud and clear sky products
- ATBD, software (for reference), data quality summary

AVHRR CDR Products and Ancillary Fields

Level 2 Swath Retrievals: CF-Compliant NetCDF-4, ~100 min orbit files (~12500x409 pixels)

Climate Data Record Products
Calibrated 0.63, 0.86, and 1.61-μm Reflectance
Cloud Mask
Cloud Thermodynamic Phase*
Cloud Optical Depth**
Cloud Liquid Water Droplet or Ice Crystal Effective Radius**
Cloud Effective Pressure, Temperature, and Height
* CDR Quality During Daytime Only
** CDR Quality During Daytime Over Snow/Ice Free Surfaces

Additional Products Included In CDR Output
Cloud Top Pressure, Temperature, and Height
Cloud Base Pressure, Temperature, and Height
Overshooting Convective Cloud Top Pixel Detection
Clear Sky Pixel Skin Temperature
AVHRR/Aqua CERES-Derived Shortwave Broadband Albedo
AVHRR/Aqua CERES-Derived Longwave Broadband Flux

Ancillary Fields: AZA, VZA, SZA, Skin Temp Quality Flag, MERRA snow & sea ice mask, cloud and clear sky category. Full set of fields required for CERES “cookie dough” processing available upon request

NOAA POES Satellite Equatorial Crossing Time

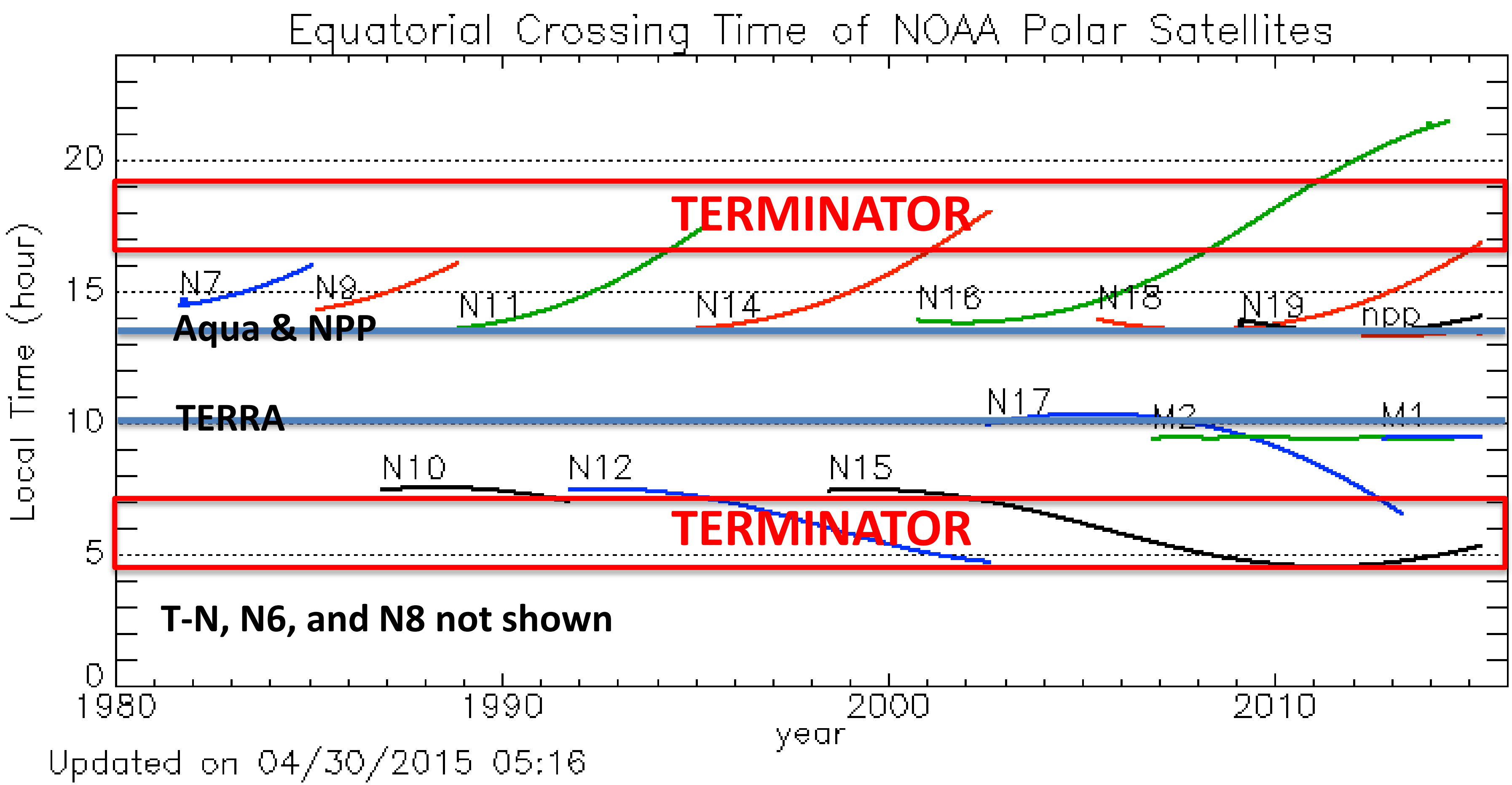
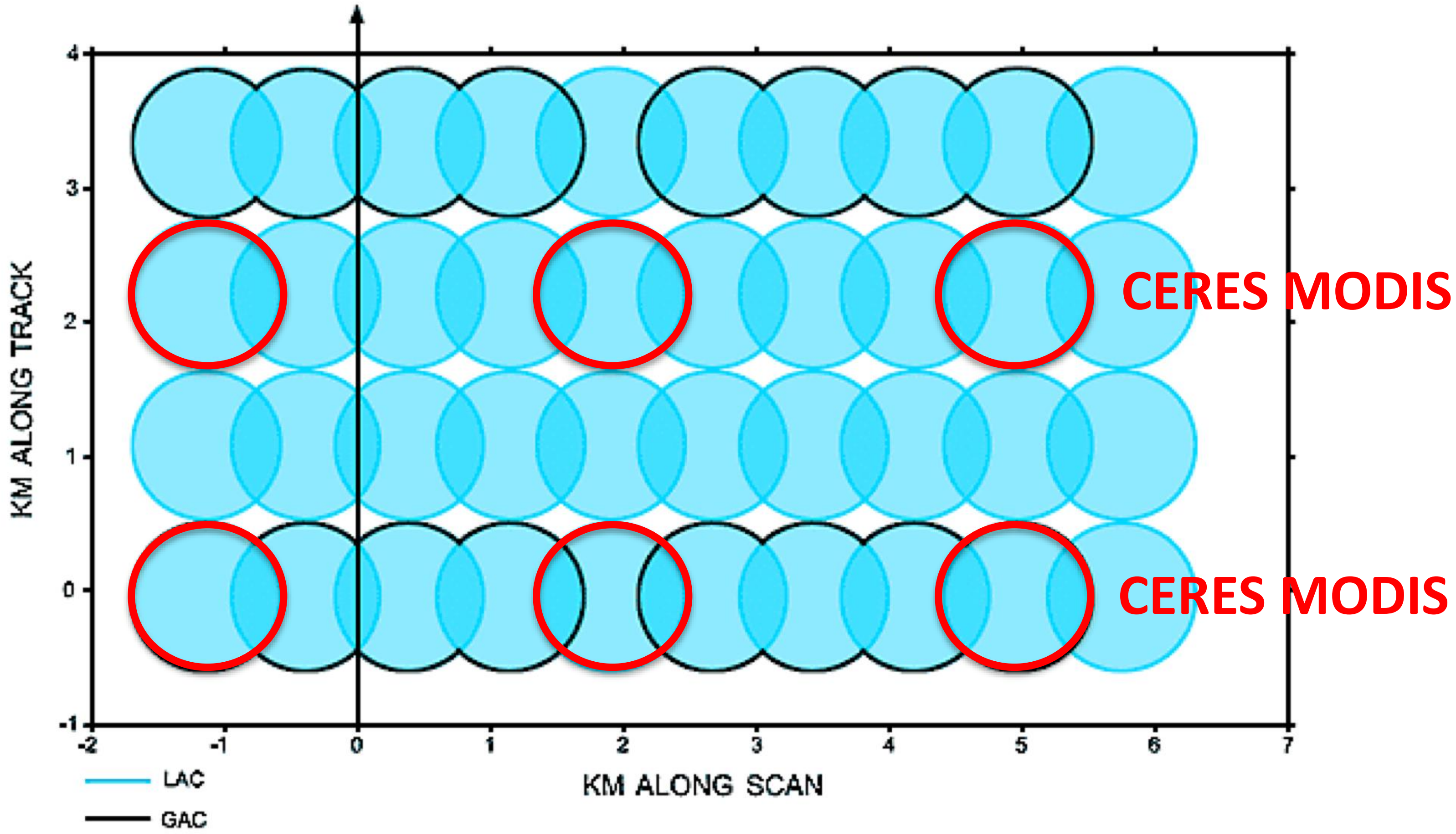


Image adapted from: http://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh_avhrr_ect.php

AVHRR Global Area Coverage (GAC) Data

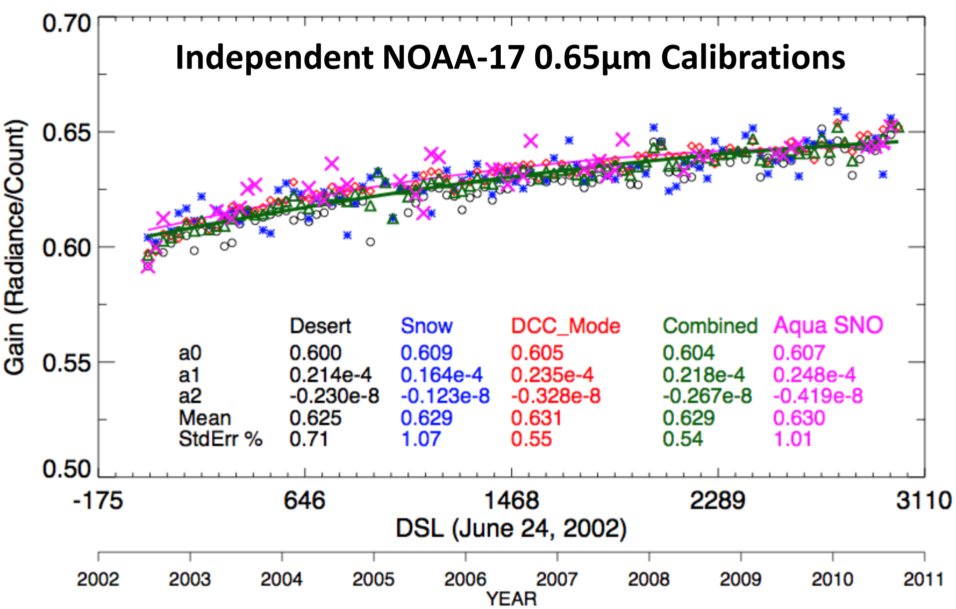
- **AVHRR has a 1.1 km FOV and this data is averaged across 4 FOVs along the scanline to create a GAC pixel data record.**

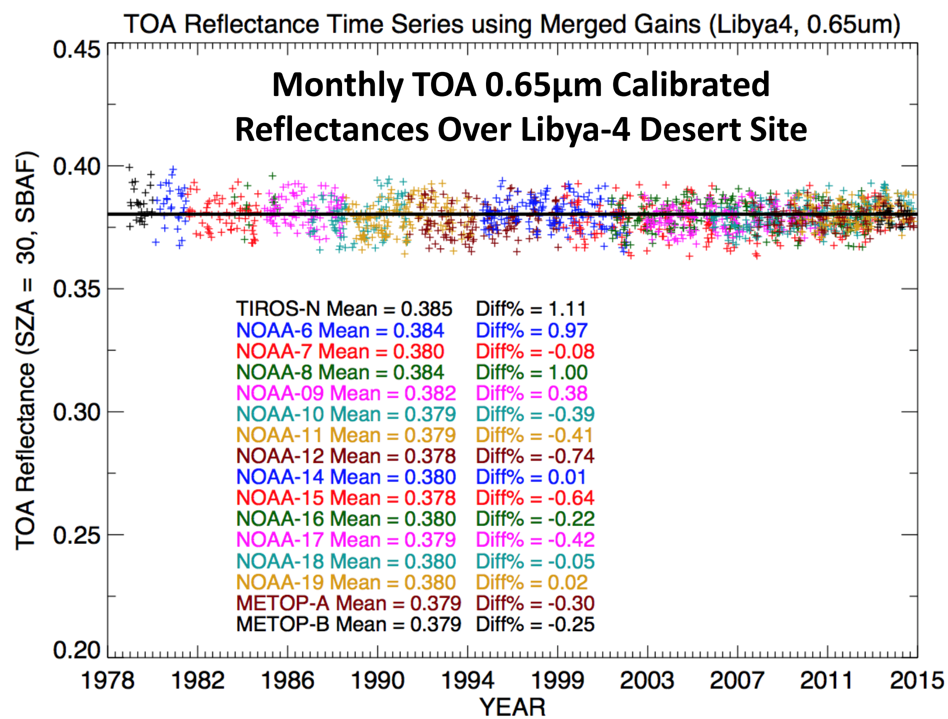
- **Every 3rd scanline is included in the GAC dataset, resulting in a spatial resolution of "4 km"**



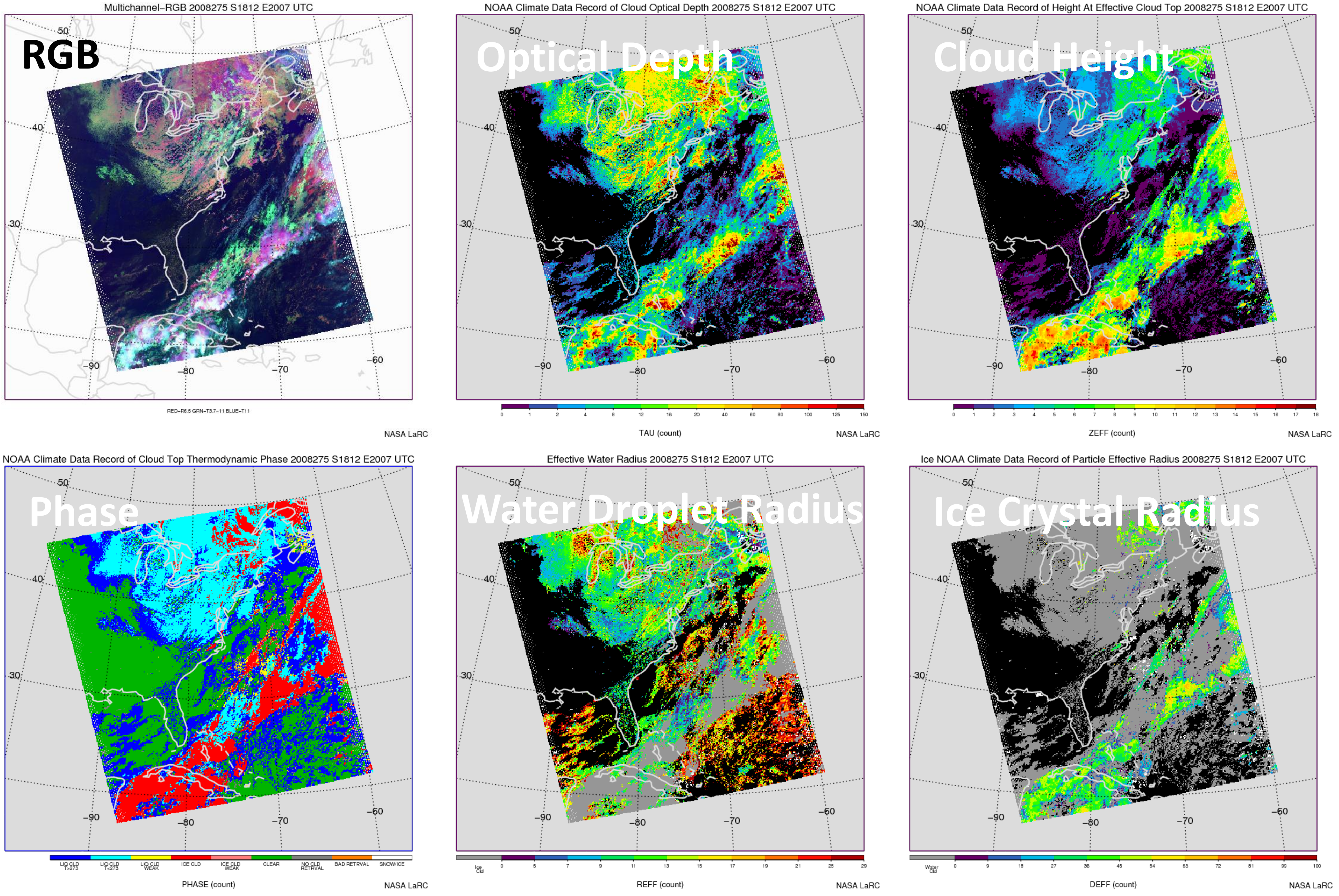
AVHRR Shortwave Channel Calibration

- **Three calibration Methods, all independently referenced to Aqua-MODIS**
  - 1) SNO, 2) Deep Convective Cloud Technique (DCC), 3) Invariant-site Approach (Libya-4, Libya-1, Arabia-1, Niger-1, Dome-C, Greenland)
  - SCIAMACHY hyperspectral based spectral band adjustment factors (SBAF) to account for visible spectral band differences between AVHRR and Aqua-MODIS
- **Use NOAA-16 calibrated (SNO) radiances to develop invariant target and DCC SZA-dependent models**
  - The NOAA orbits eventually degrade into terminator orbits, requiring models that have a full SZA range
  - Invariant desert and polar targets radiance models were characterized using NOAA-16 radiances
  - DCC nadir-corrected radiances with SZA>40° were normalized to the NOAA-16 radiances
  - Validate the invariant target and DCC calibrations against SNO during the MODIS time frame
- **Calibration of NOAA AVHRR sensors**
  - The AVHRR gains derived from the invariant-site and DCC approaches are combined using an inverse-variance-weighted regression approach





~4 km AVHRR Global Area Coverage Pixel Level Products



LaRC AVHRR Cloud Mask Pixel Validation

2008 Seasonal Months

- **Global Fraction Correct: Day=86%, Night=83%   CERES MODIS Day & Night=90%**
- **Non-Polar Fraction Correct: Day=87%, Night=88%   CERES MODIS Day & Night=91%**

- AVHRR land error dominated (75+%) by missed cloud
- Ocean error an equal balance of missed and false cloud
- Significant dropoff in cloud detection capability for CALIPSO $\tau < 0.4$

Land Surface Type, Geographic Region, and Time of Day of Comparison	Fraction of Correctly Identified AVHRR Clear and Cloudy Pixels	Number of Matches
DAYTIME (0° ≤ SZA < 82°)		
Land, 60 S – 60 N, No Snow/Ice Cover	0.848	285570
Land, Polar, No Snow/Ice Cover	0.878	30665
Ocean, 60 S – 60 N, No Snow/Ice Cover	0.875	844315
Ocean, Polar, No Snow/Ice Cover	0.943	70071
Land & Ocean, Global, Snow/Ice Covered	0.825	404235
NIGHT (SZA ≥ 82°)		
Land, 60 S – 60 N, No Snow/Ice Cover	0.870	288234
Land, Polar, No Snow/Ice Cover	0.875	23678
Ocean, 60 S – 60 N, No Snow/Ice Cover	0.888	879729
Ocean, Polar, No Snow/Ice Cover	0.951	100782
Land & Ocean, Global, Snow/Ice Covered	0.715	727283

LaRC AVHRR Cloud Phase Pixel Validation

2008 Seasonal Months

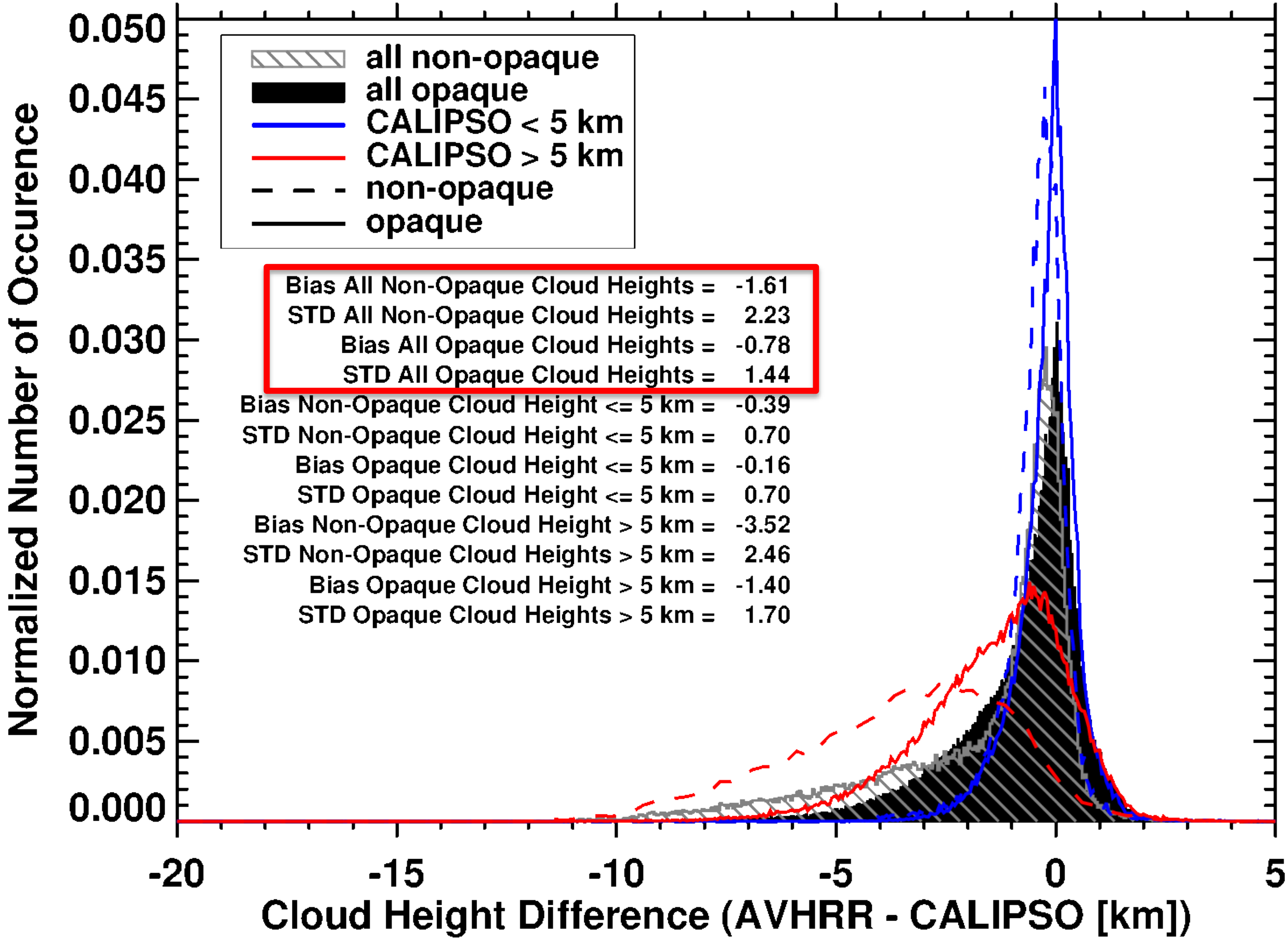
- **Global Fraction Correct: Day and Night=90%   CERES MODIS Day=97%   Night=94%**

- Day water phase assignment 3x more likely to be incorrect than ice
- Night water and ice phase have near equal error

Land Surface Type, Geographic Region, and Time of Day of Comparison	Fraction Correct	Number of Matches
DAYTIME (0° ≤ SZA < 82°)		
Land, 60 S – 60 N, No Snow/Ice Cover	0.893	56535
Land, Polar, No Snow/Ice Cover	0.877	6418
Ocean, 60 S – 60 N, No Snow/Ice Cover	0.926	322785
Ocean, Polar, No Snow/Ice Cover	0.908	23529
Land & Ocean, Global, Snow/Ice Covered	0.778	74066
NIGHT (SZA ≥ 82°)		
Land, 60 S – 60 N, No Snow/Ice Cover	0.899	66437
Land, Polar, No Snow/Ice Cover	0.820	5408
Ocean, 60 S – 60 N, No Snow/Ice Cover	0.919	331800
Ocean, Polar, No Snow/Ice Cover	0.832	29719
Land & Ocean, Global, Snow/Ice Covered	0.874	172102

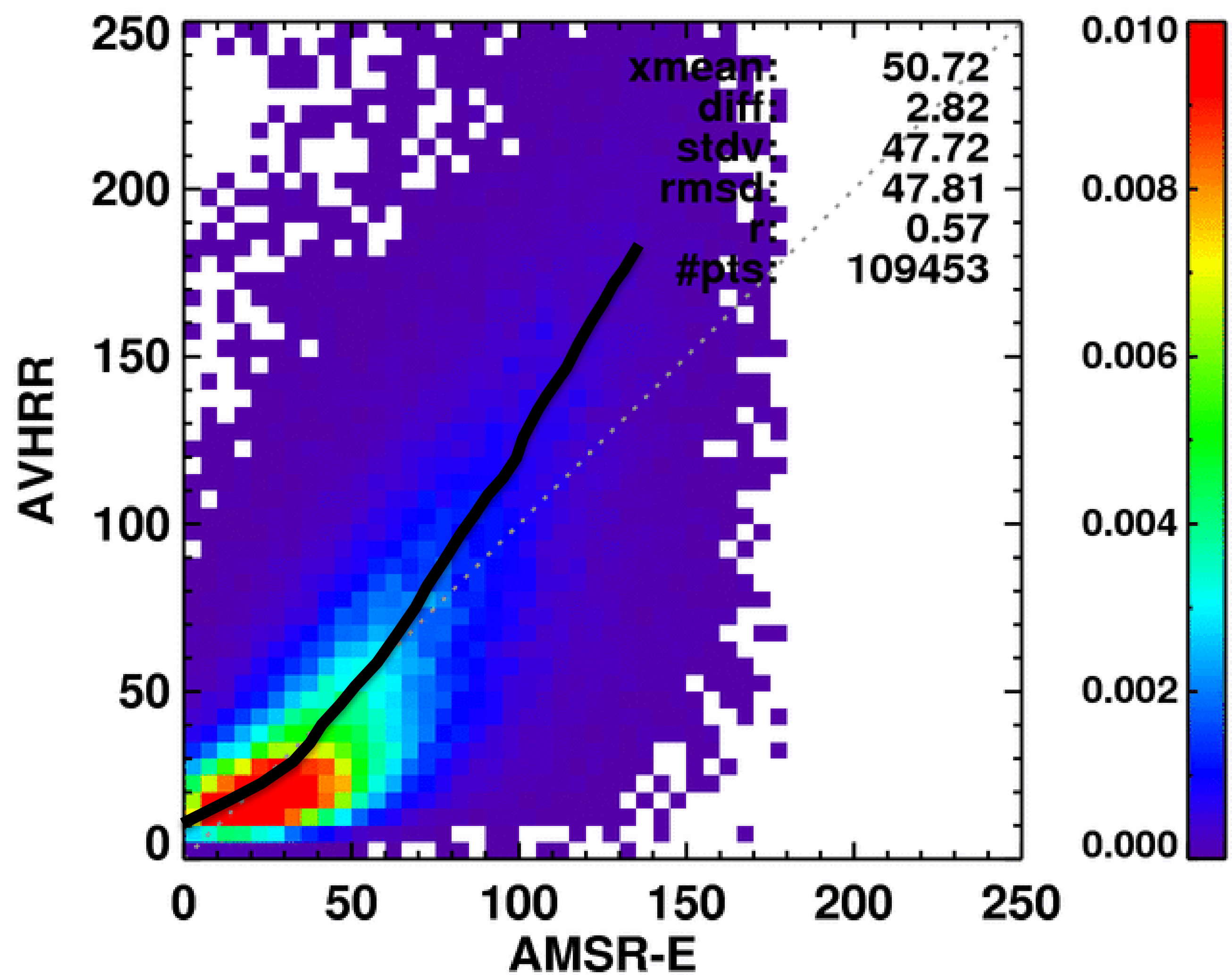
LaRC AVHRR Cloud Top Height Validation

2008 Seasonal Months



AVHRR Daytime Liquid Water Path vs. AMSR-E

AVHRR LWP=0.6667*optical_depth*effective_radius



AVHRR Narrowband->Broadband SW & LW Flux

NB-BB fits derived for:
- each month of 2008
- Global, 3 scene types (land, ocean, snow)
- Day/night fits for LW

Grid & Match: 2008 NOAA-18 AVHRR SW NB alb A_{nb}, LW flux M_{nb} to 1° nested grid CERES Aqua SFC BB SW A_{SW}, LW M_{LW}

Fit matched data to:

$$A_{SW} = a_0 + a_1 * A_{nb} + a_2 * A_{nb}^2 + a_3 * \ln(1/\mu_o)$$

$$M_{LW} = A_0 + A_1 * M_{nb} + A_2 * M_{nb}^2 + A_3 * M_{nb} * \ln(colRH)$$

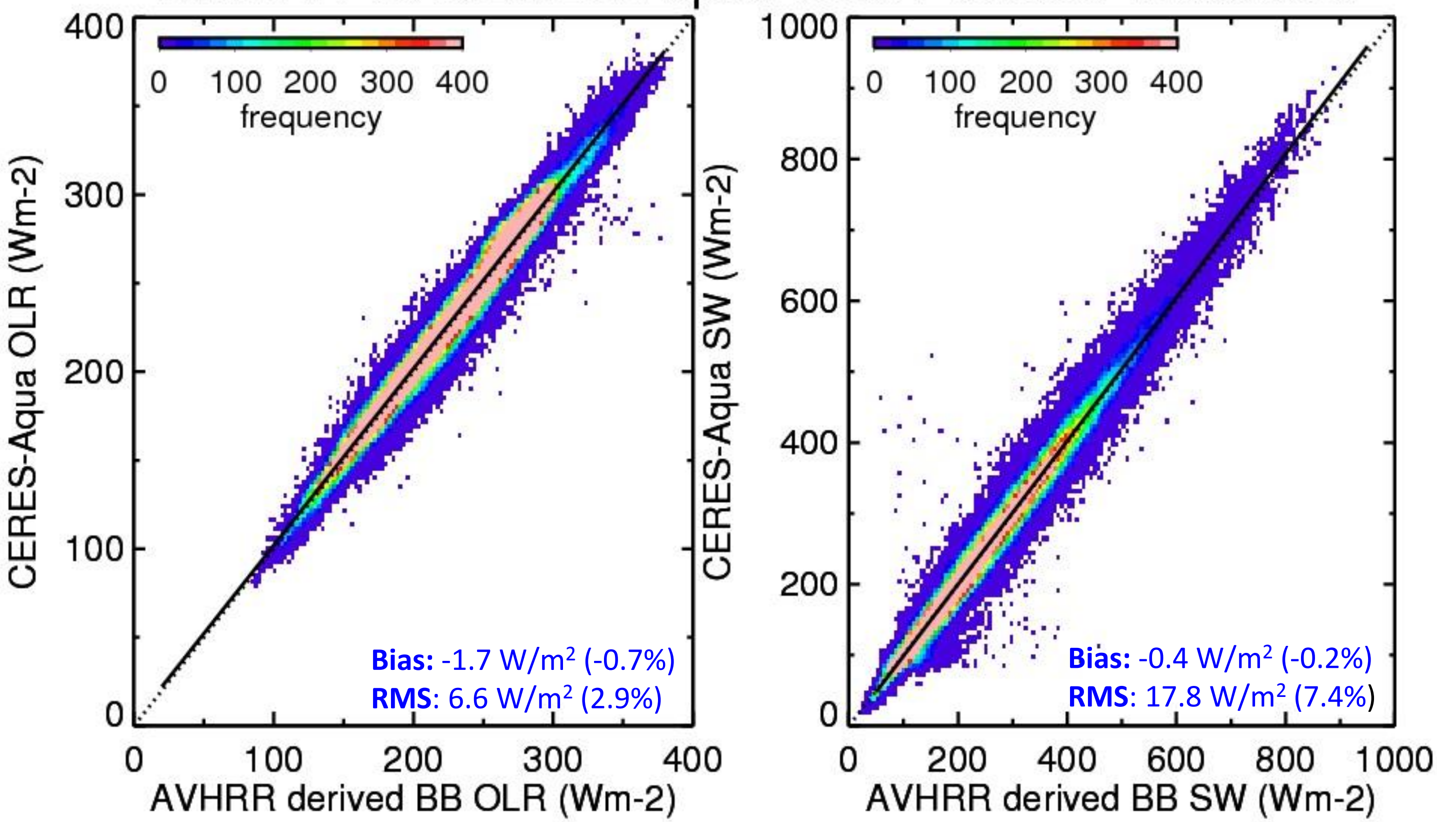
where A_{SW} = *SW albedo;* M_{LW} = *LW flux or OLR;*

μ_o = *cos(SZA),* colRH= column-weighted RH (from MERRA)

Apply 3rd-order correction to OLR to account for low/high end bias

Apply 2008 fits to corresponding months/scene types in rest of dataset

AVHRR vs CERES Aqua: Oct07 Global Validation



For Validated months of Jan,Apr,Jul,Oct07

LW, SW global biases < 1% (local biases can be greater)

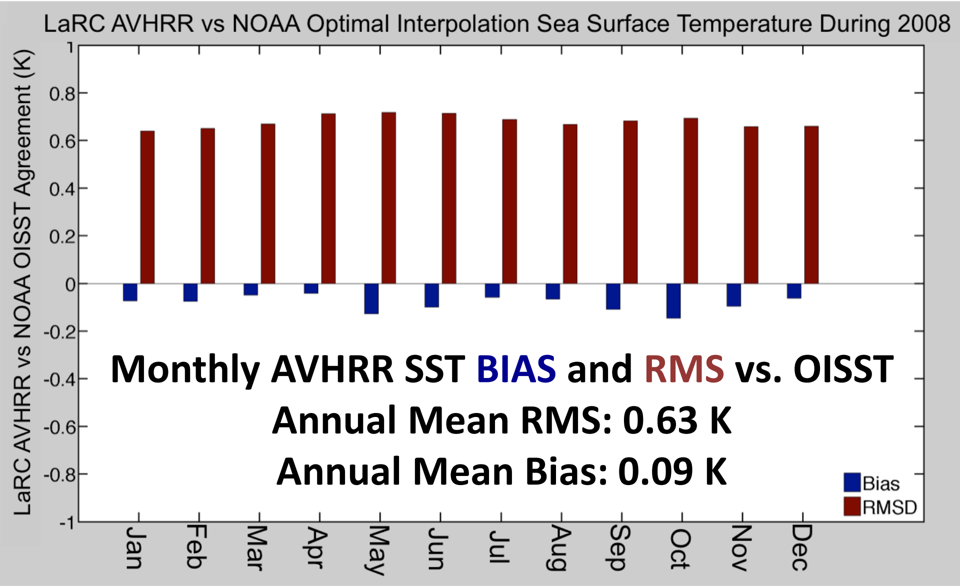
RMS range:
LW 2.9% - 3.2%
SW 7.4% -8.5%

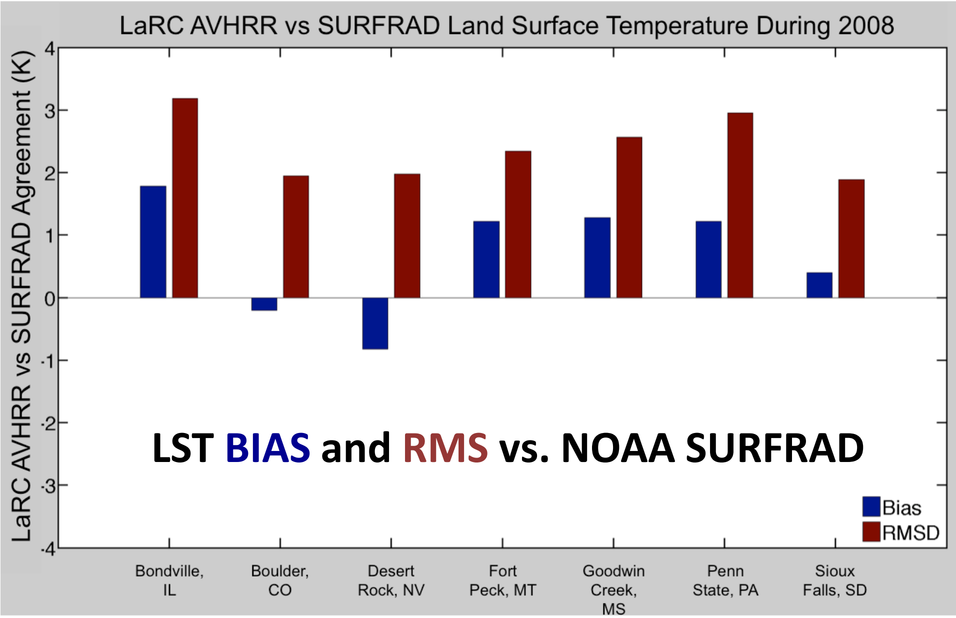
Efforts underway to improve methodology for V2

Sea/Land Surface Skin Temperature Comparisons

- **NOAA OISST: 0.25° daily product including AVHRR, AMSR (when available), and in-situ SST observations**

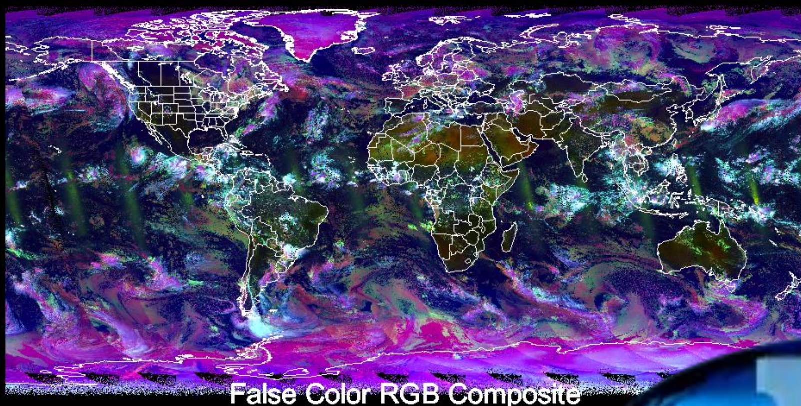
- **AVHRR pixel skin temperature during 2008 also compared with 8 NOAA SURFRAD sites**
  - SURFRAD upwelling radiation converted to skin temperature
  - ***Land heterogeneity within an AVHRR pixel contributes to relatively high RMS/bias***

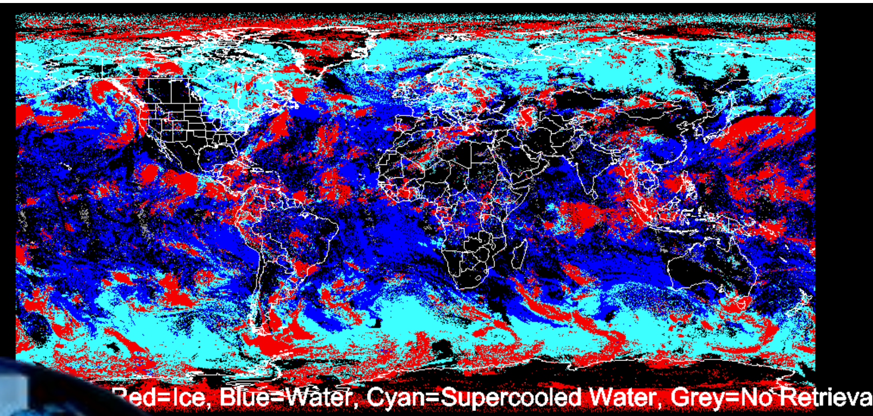


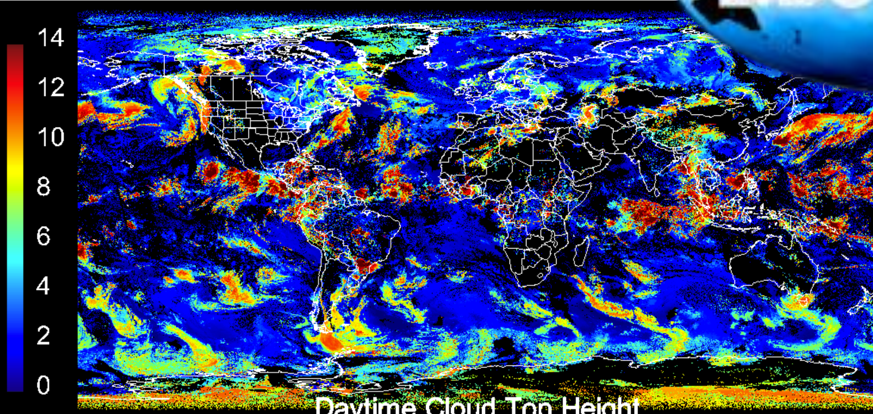


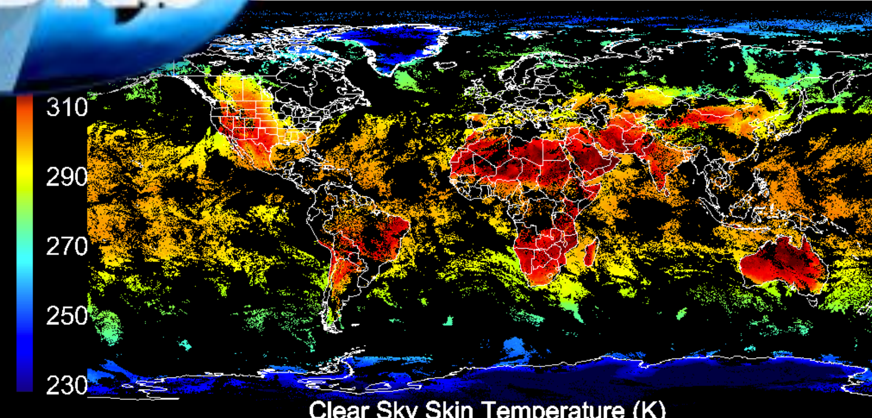
DAILY GRIDDED COMPOSITE PRODUCTS

~70 Million AVHRR GAC Pixels Included





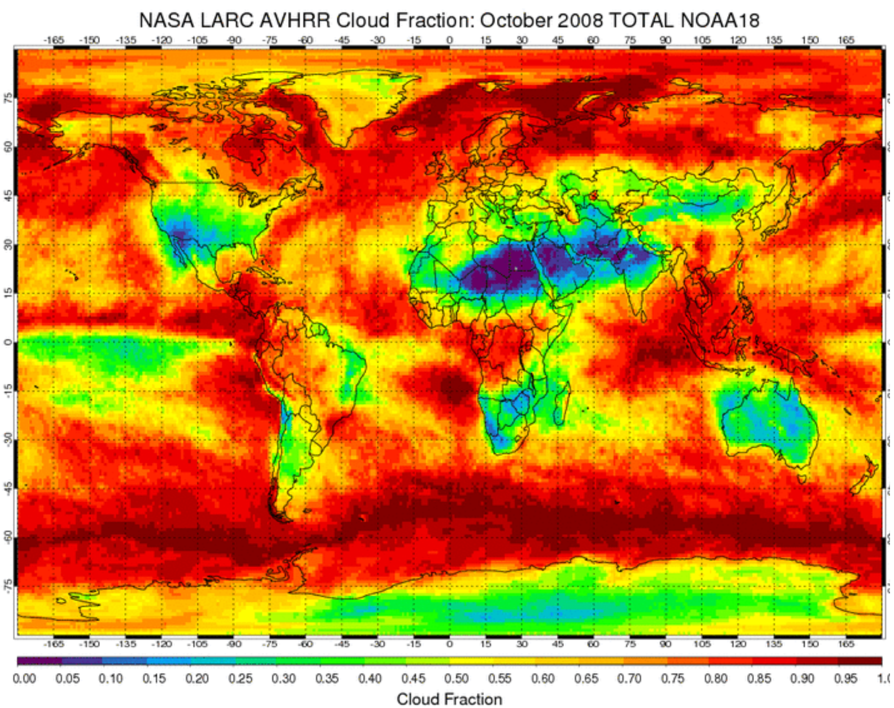


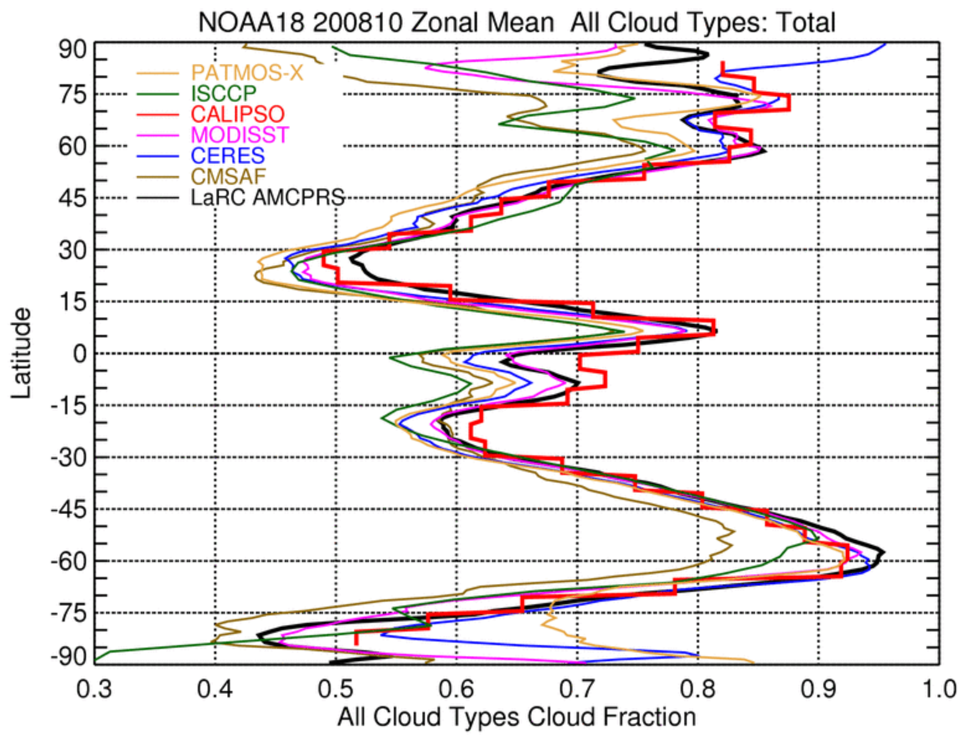


LaRC AVHRR Day/Night Combined Cloud Fraction

October 2008

~2.1 Billion AVHRR GAC Pixels Included





- LaRC AVHRR very closely aligned with MODIS Col. 6. Cloud mask designed to be very sensitive for the benefit of clear sky products

- Cloud amount uncertainty of 10+% quite common in non-polar regions. Uncertainty is 30+% in polar regions

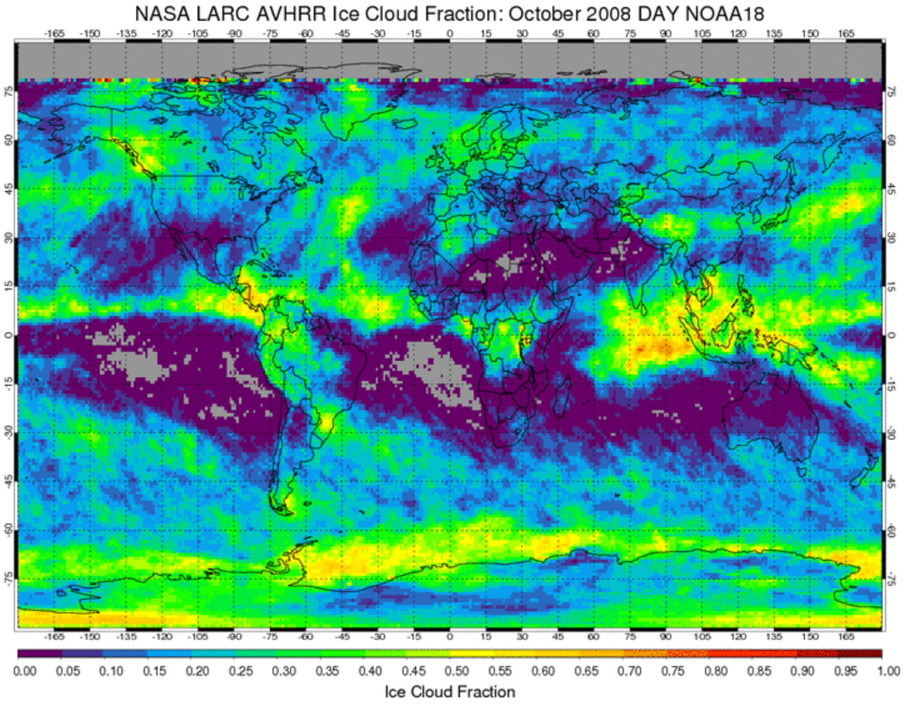
Day/Night Combined Cloud Fraction

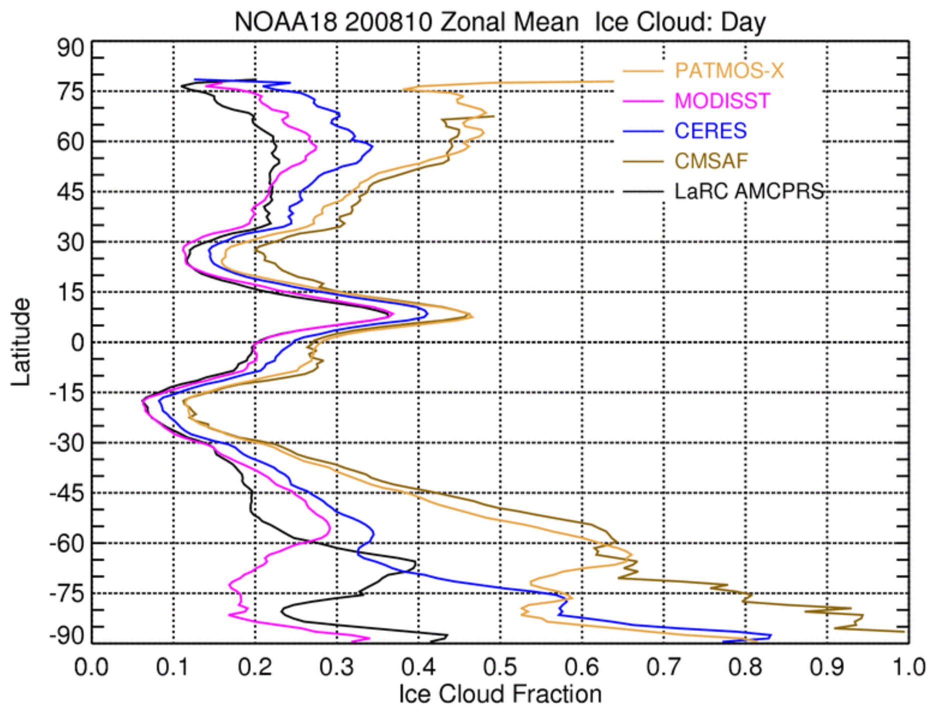
The Wide World of Climatologies

Month and Time of Comparison	NASA LaRC NOAA-18 AVHRR TCDR	CERES Aqua Edition 4	MODIS –ST Aqua Collection 6	ISCCP	EUMETSAT CMSAF AVHRR	PATMOS-X AVHRR	CALIPSO
January 2008 Total	0.694	0.666	0.687	0.672	0.624	0.654	0.717
April 2008 Total	0.688	0.655	0.655	0.647	0.603	0.629	0.705
July 2008 Total	0.680	0.655	0.662	0.633	0.601	0.619	0.692
October 2008 Total	0.697	0.671	0.679	0.649	0.623	0.631	0.703

LaRC AVHRR Ice Cloud Fraction Comparisons

October 2008



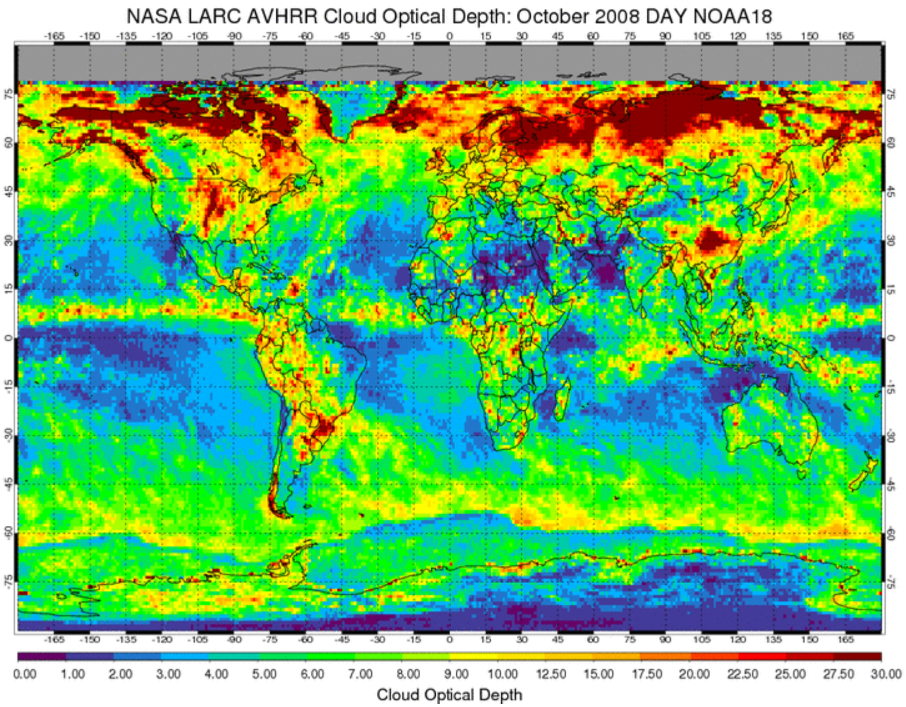


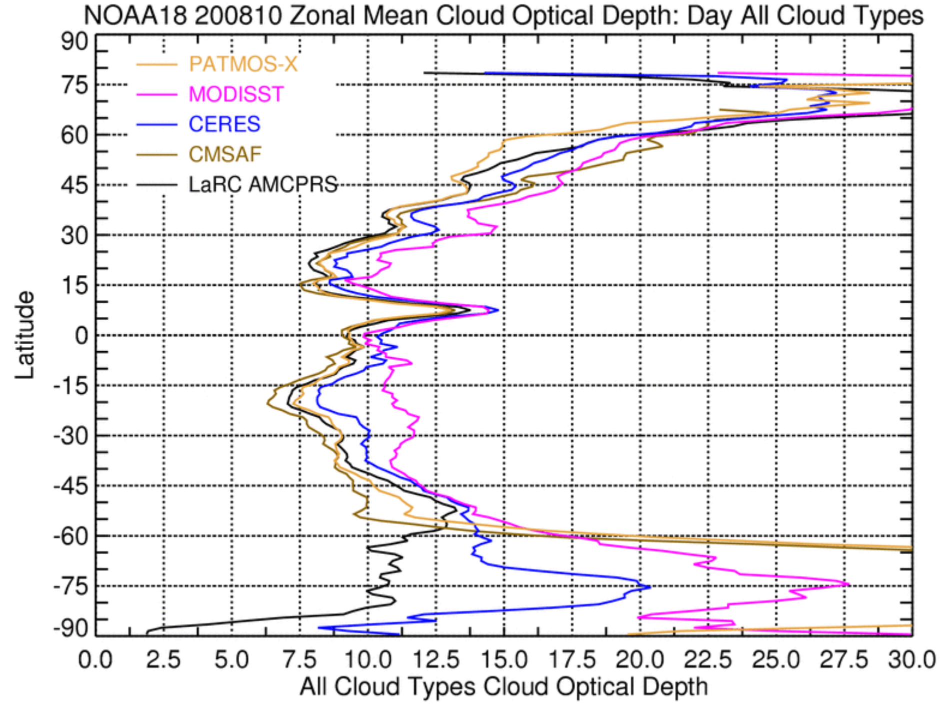
- **CALIPSO cloud temperature – phase histograms indicated that a change in some CERES temperature thresholds was necessary to improve AVHRR phase accuracy. Other bug fixes were also done (i.e. some cloud temp > 273 K classified as ice)**

- **LaRC AVHRR daytime no retrieval fraction: 3% Night: 0.3%**

LaRC AVHRR Cloud Optical Depth Comparisons

October 2008



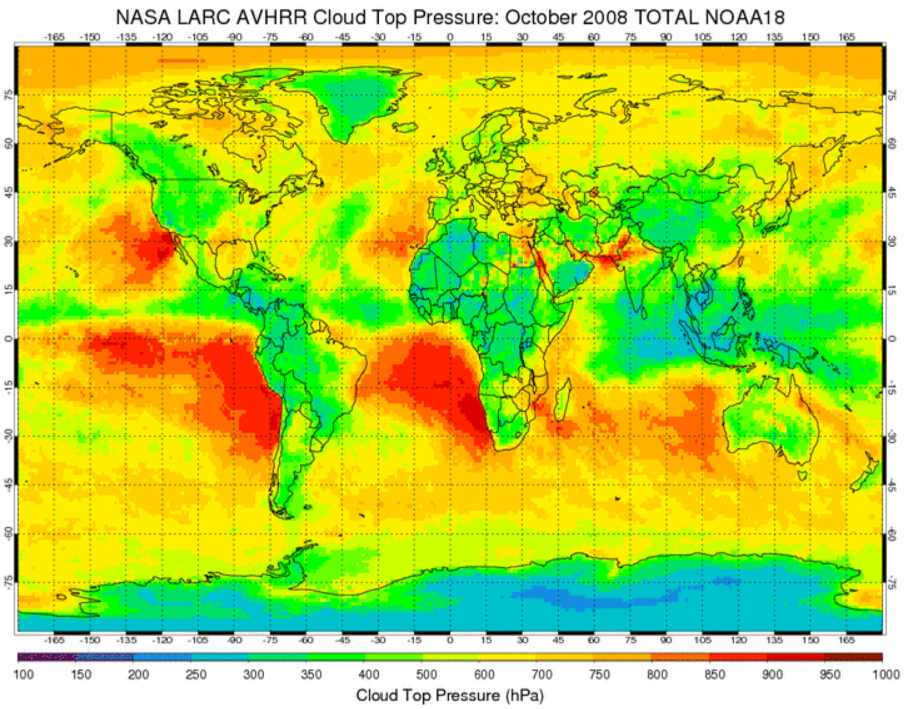


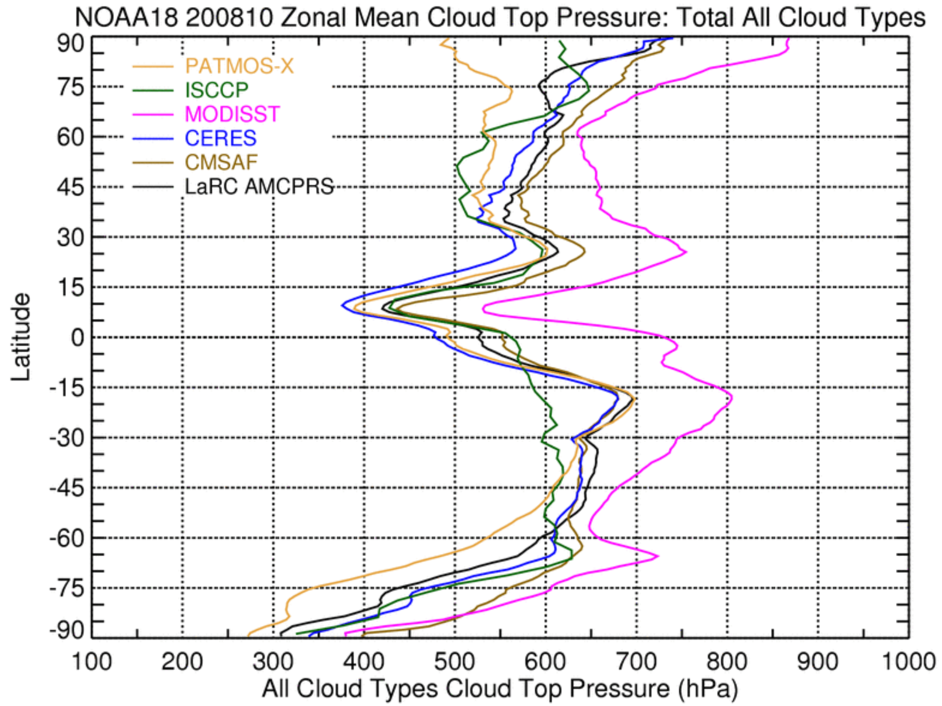
- **LaRC AVHRR optical depth (τ) systematically lower than CERES MODIS by 10+%**

- **Comparisons between 1 km HRPT and 4 km GAC τ retrieval indicates that GAC spatial smoothing decreases water cloud τ by 13% and ice cloud τ by 4%, helping to explain a large fraction of the AVHRR-CERES MODIS difference**

LaRC AVHRR Cloud Top Height Comparisons

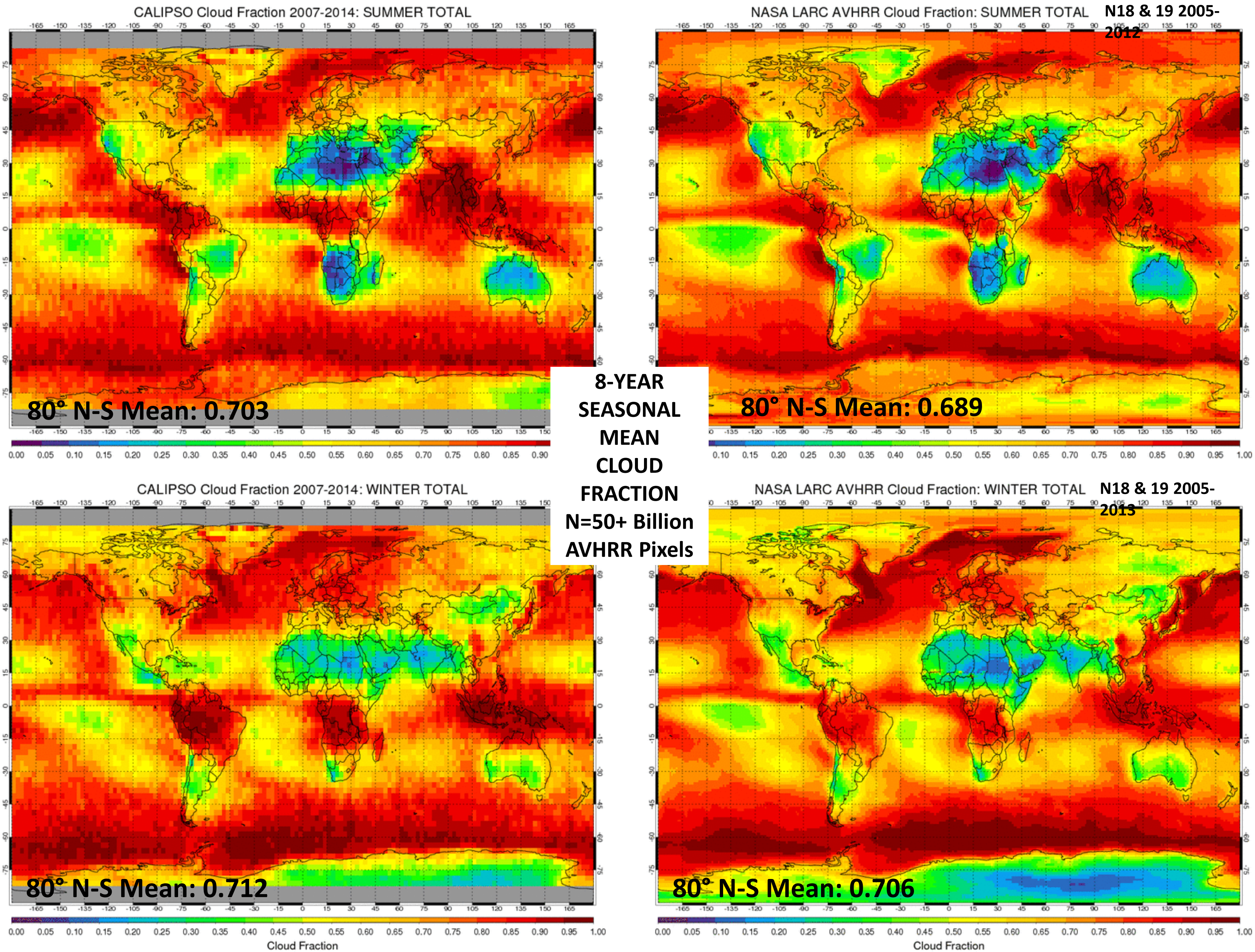
October 2008



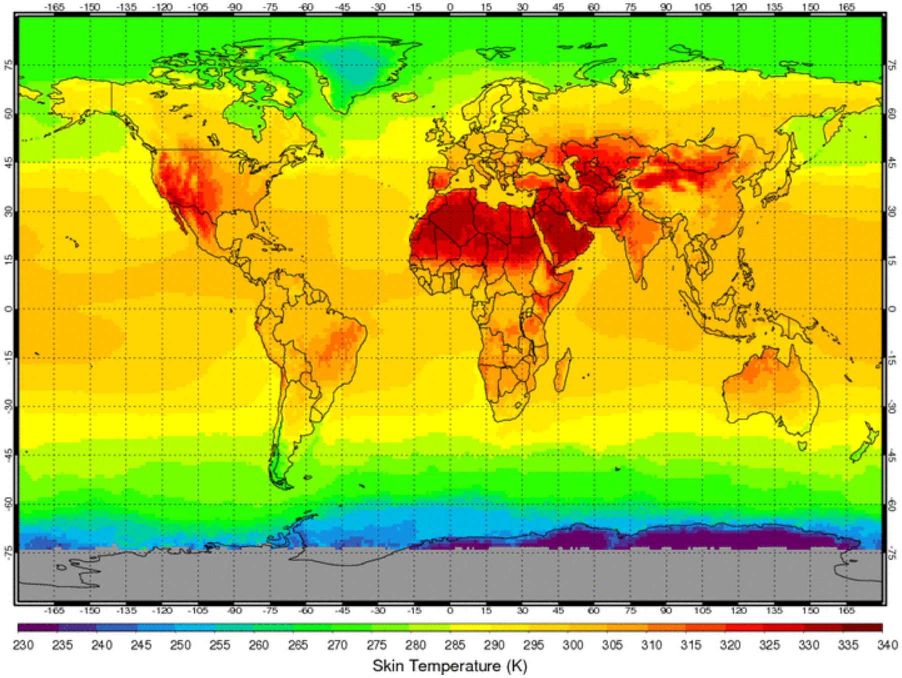


- **AVHRR lower than CERES by ~25 hPa on average, partly due to lack of CO2 channel on AVHRR. Spatial resolution may also have an impact here.**

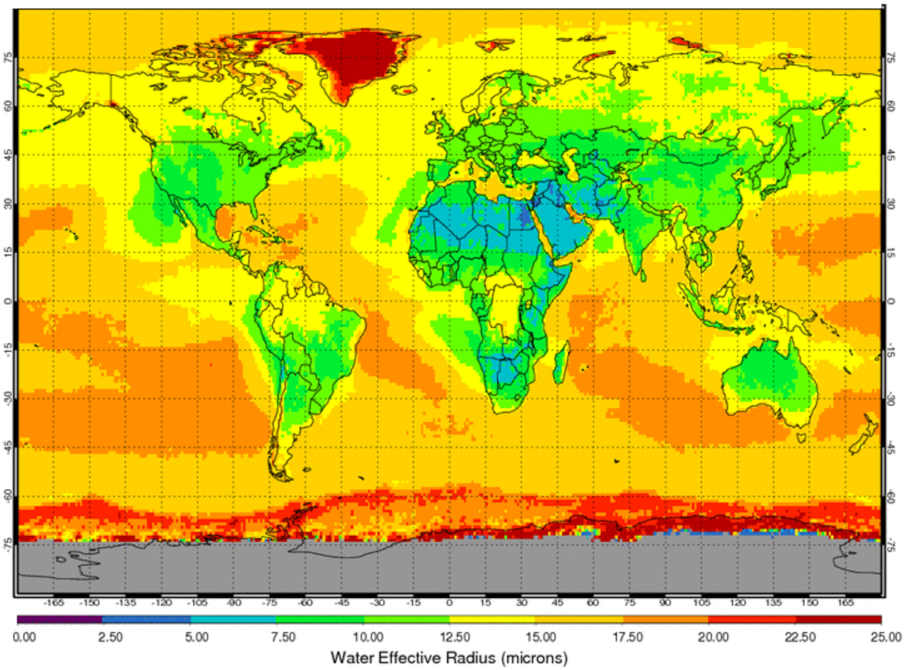
- **GSFC MODIS-ST systematically lower than other climos**


CALIPSO Cloud Fraction 2007-2014: SUMMER TOTAL
80° N-S Mean: 0.703
NASA LARC AVHRR Cloud Fraction: SUMMER TOTAL
N18 & 19 2005-2012
80° N-S Mean: 0.689
8-YEAR SEASONAL MEAN CLOUD FRACTION
N=50+ Billion AVHRR Pixels
CALIPSO Cloud Fraction 2007-2014: WINTER TOTAL
80° N-S Mean: 0.712
NASA LARC AVHRR Cloud Fraction: WINTER TOTAL
N18 & 19 2005-2013
80° N-S Mean: 0.706
Cloud Fraction
Cloud Fraction

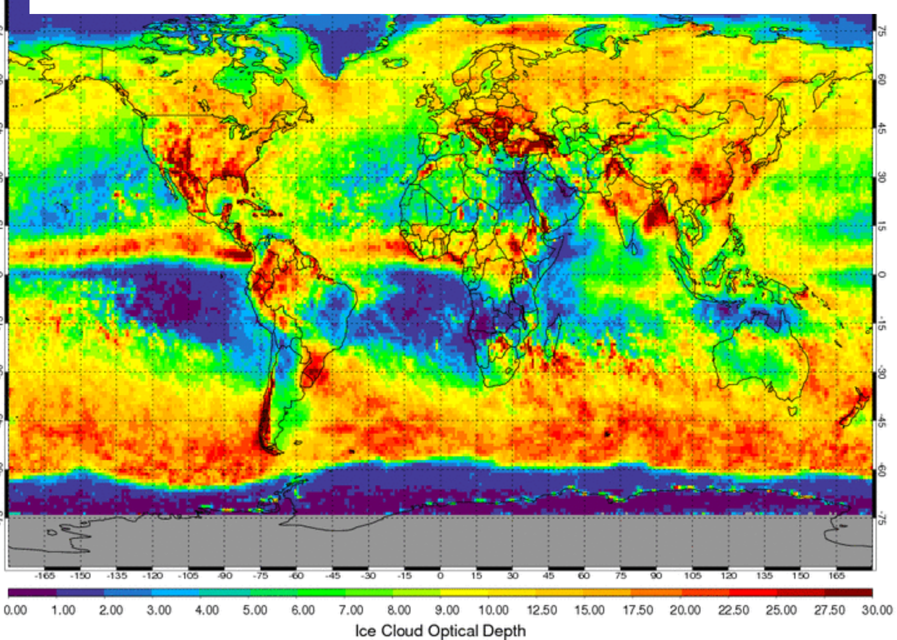
2005-2012 SUMMER DAY SKIN TEMP



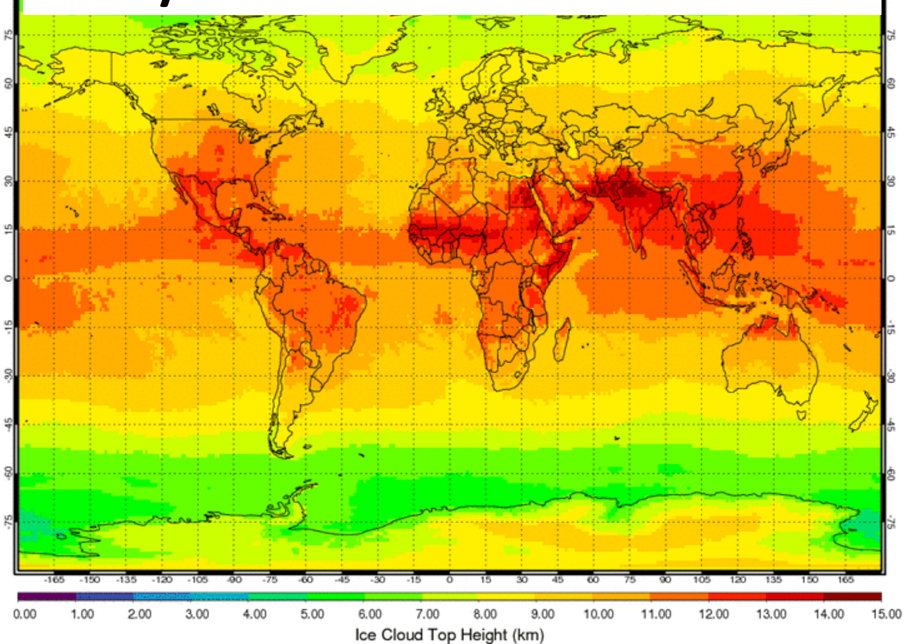
DAY WATER EFFECTIVE RADIUS



DAY ICE OPTICAL DEPTH

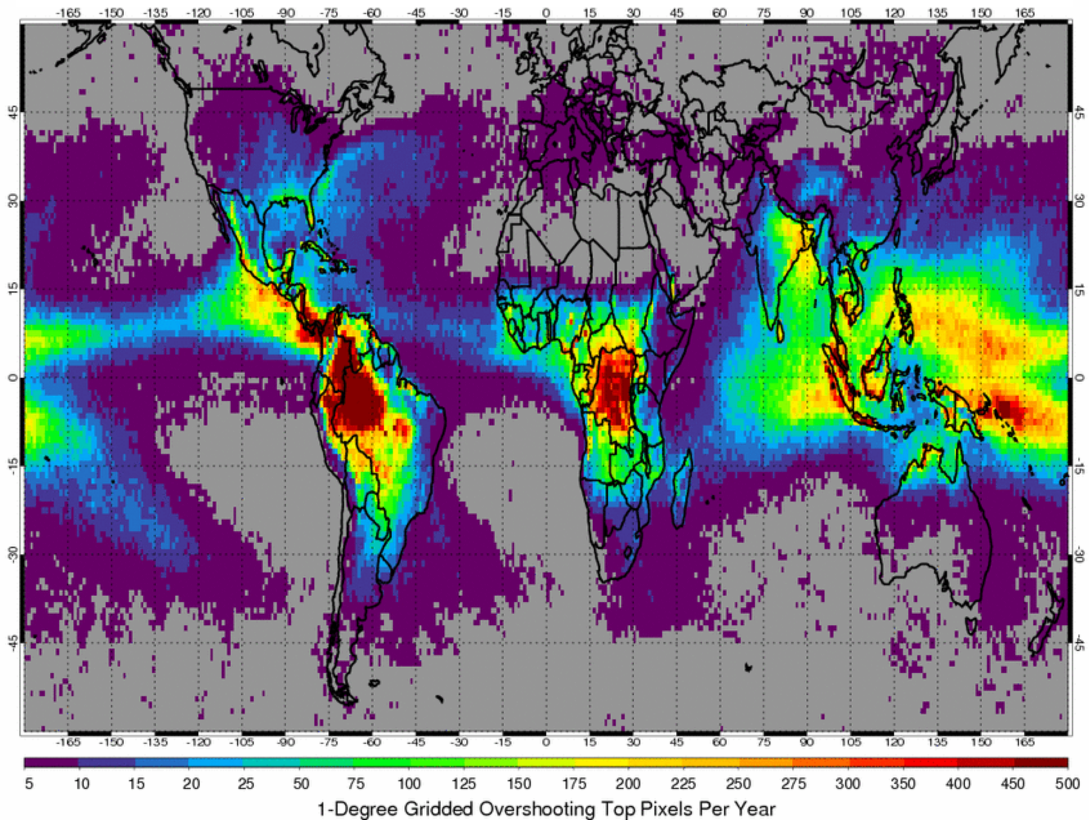


DAY/NIGHT ICE CLOUD HEIGHT



LaRC Overshooting Convective Cloud Top Detection

17 Years 1-3 AM/PM AVHRR Orbits

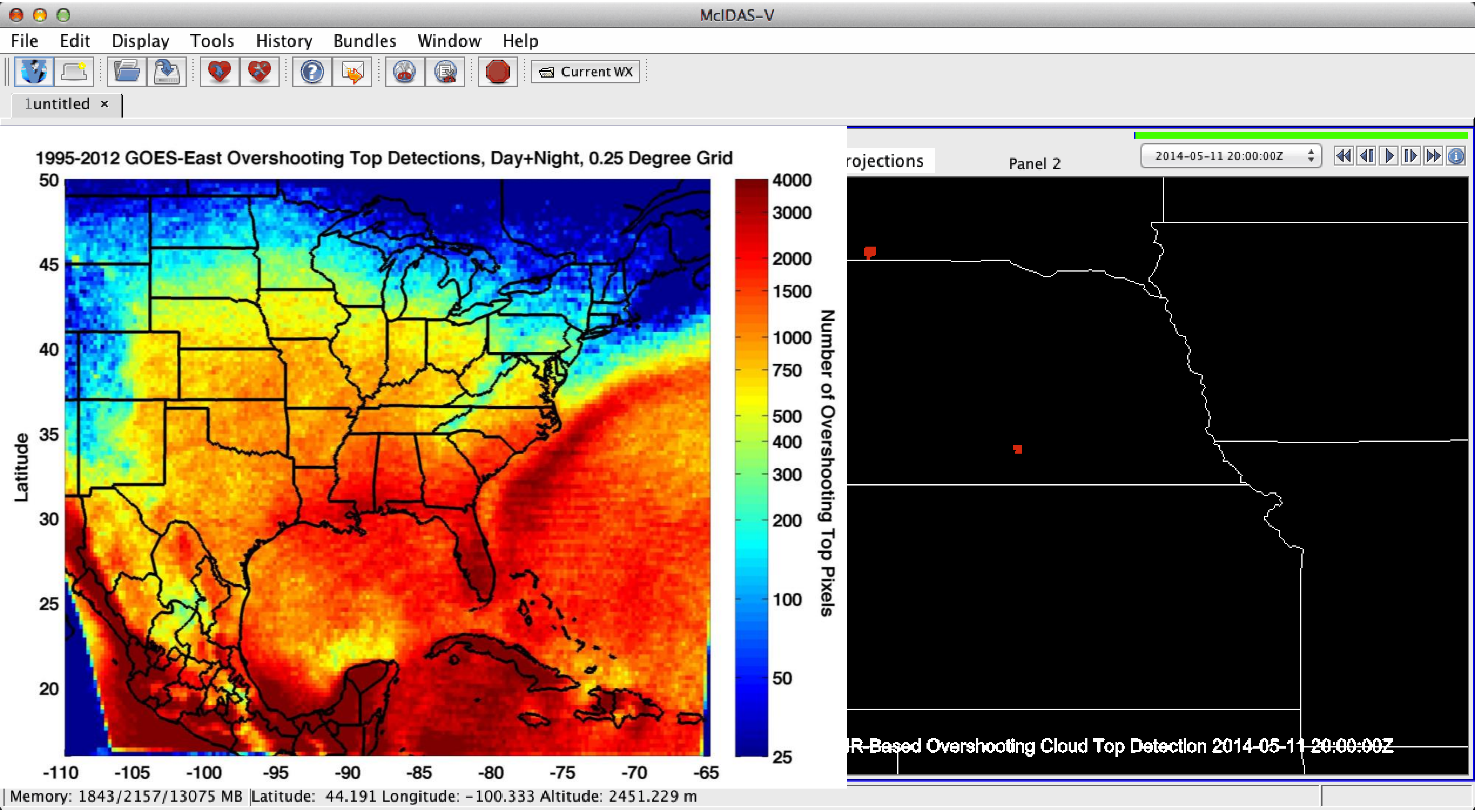


- **Product identifies significant penetrations of a convective cloud top through the surrounding anvil and MERRA-defined level of neutral buoyancy and tropopause**

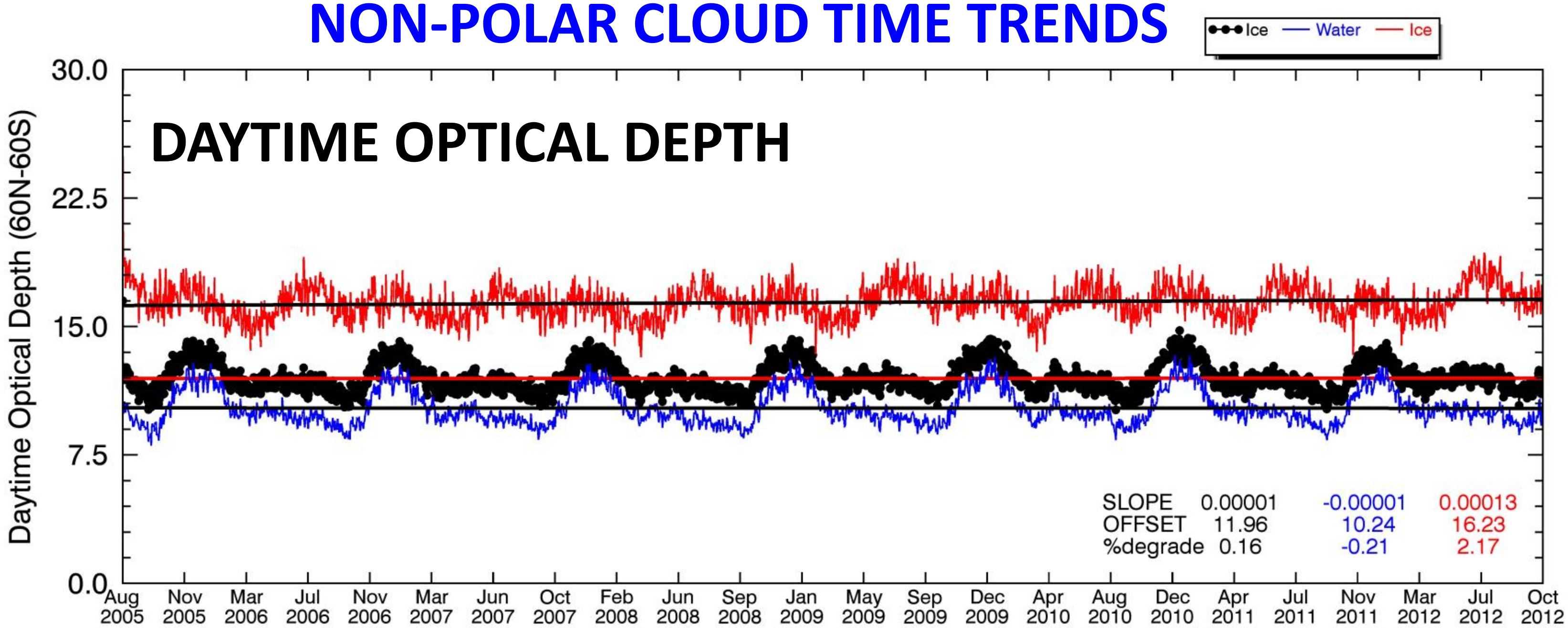
- **Product development supported by NASA Applied Sciences (~2007) and the GOES-R program. Product has been improved since the time the above graphic was produced.**

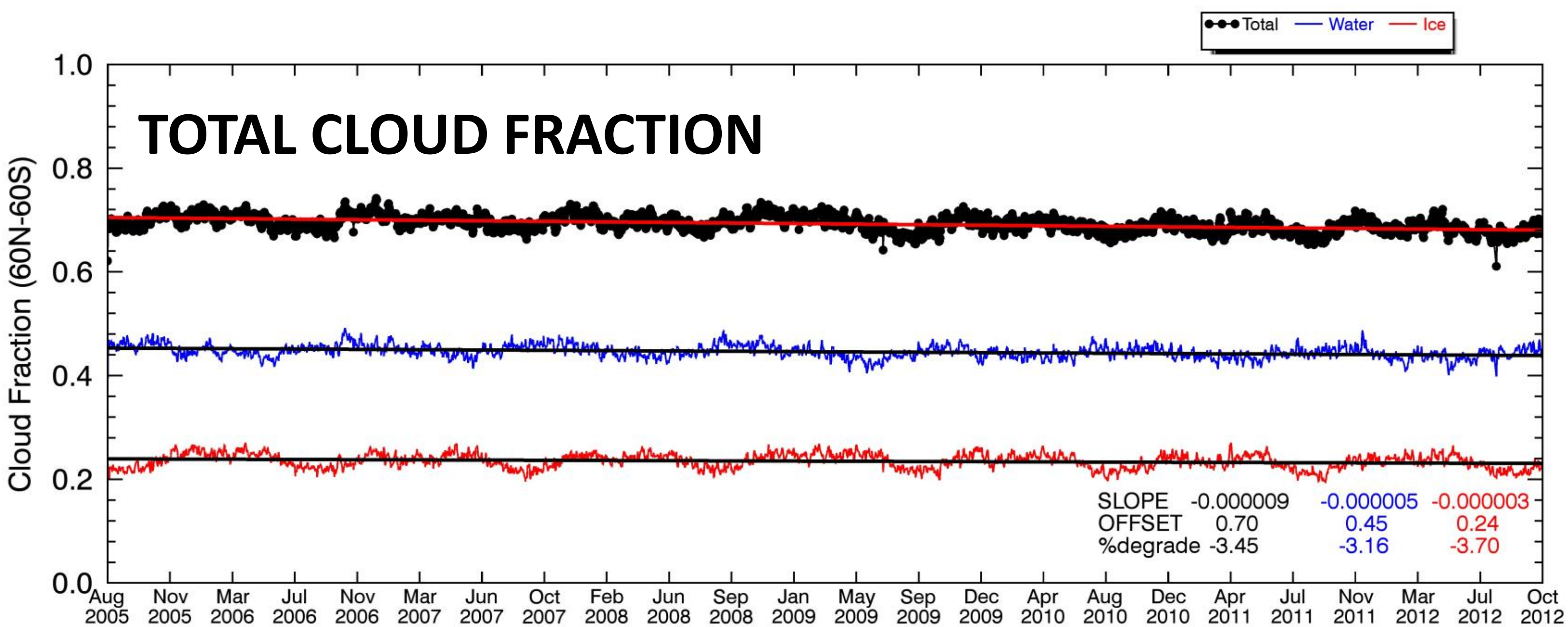
GOES IR-Based Overshooting Cloud Top Detection

- AVHRR OT detection algorithm can be applied to GOES to generate datasets useful for both short-term severe storm forecasting and climate analysis. GOES OT detection could be included in future GEO TISA cloud products.



NON-POLAR CLOUD TIME TRENDS





Need to explore time trends individually for each NOAA satellite

“Climate Data Record” or “Best Estimate”?

The AVHRR instrument and its operations were not initially designed to be for long-term climate monitoring. The AVHRR time series is impacted by a number of issues that challenge our ability to derive climate-quality trends:

1. Lack of IR channel inter-calibration across NOAA satellites, especially difficult pre-MODIS
2. Strong 3.7 µm channel noise (pre NOAA-15)
3. Orbit drift induces diurnal signal in time series
4. ~30 years of AVHRR orbits have day/night terminator within much of the swath, very challenging for cloud retrievals
5. No 12-micron channel on TIROS-N and NOAA-6, -8, and -10 AVHRRs
6. 1.6 / 3.7 micron channel switching during daytime for NOAA-17, and MetOp-A and -B
7. Inadequate historical observation density/quality in many regions within MERRA

Perhaps the LaRC AVHRR products should be considered a “best estimate” using the CERES Ed4 cloud logic rather than a CDR?

LaRC AVHRR Product Access

- **NOAA NCEI (formerly NCDC) to provide daily pixel-level swath products via CLASS ordering tool**
  - Ordering tool operational date TBD
  - 1 Day=2.3 Gb filesize

- **Pixel level swath data also immediately available to LaRC users on AMI computer system**

- **Daily composites and monthly mean products available upon request. Plan to formalize and release Level 3 datasets in CY16.**

- **Basic monthly mean product viewer:**

http://www-pm.larc.nasa.gov/cgi-bin/site/showdoc?mnemonic=MONTHLY-MEAN

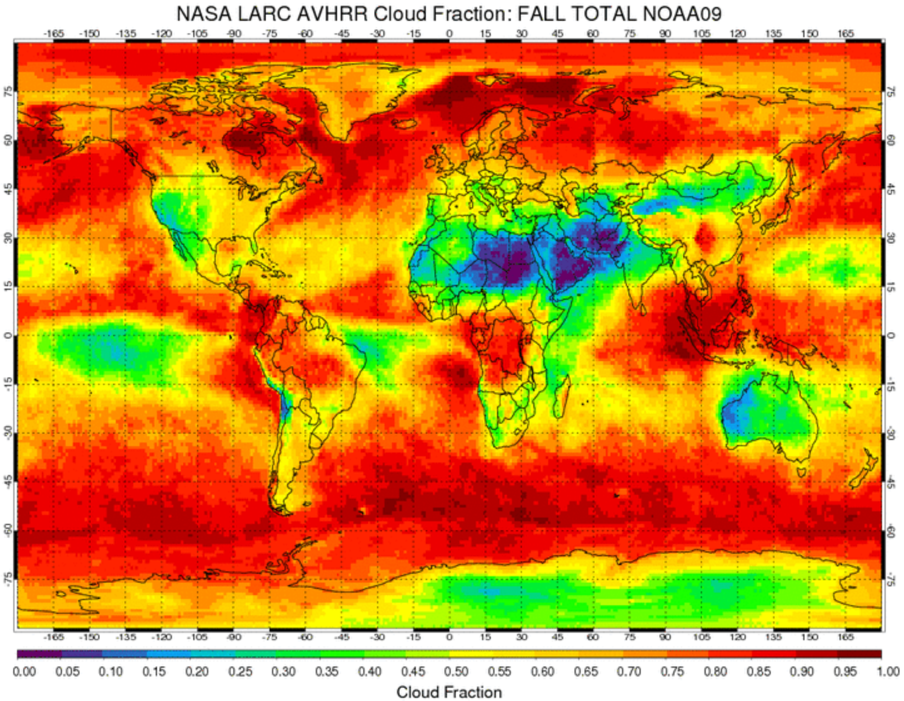
Current and Future Work

- Complete processing for nominal 5-channel AVHRR instruments. 1 year = 2.5 days of processing
- Complete mask and retrievals for AVHRRs with 1.6 µm and no 12 µm channel
- Continue detailed product evaluation and validation
- Support user requests for products, higher resolution regional climos?
- Complete algorithm documentation: ATBDs and peer-reviewed publications

LaRC AVHRR Day/Night Combined Cloud Fraction

NOAA-09 October 1985 & 1986

NOAA-9 OCTOBER 1985 & 1986



8-Year CALIPSO FALL