Calibration of Historical and Future AVHRR and GOES Visible and Near-Infrared Sensors & Development of a Consistent Long-Term Cloud & Clear-Sky Radiation Property Dataset

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- Goals
  - Calibrate AVHRR 0.64, 0.87, and 1.6-μm channels
  - Calibrate GOES & SMS imager 0.65-μm channels
  - Generate CERES-like cloud climatology from AVHRR record

GEO calibration procedure

- Aqua-MODIS 0.65-µm channel is the absolute calibration reference
  - 1.6% absolute calibration uncertainty
  - Stable within 1%/decade
- During MODIS time period use Aqua-MODIS ray-matched with GEO radiance pairs the as primary calibration approach
- Perform Terra-MODIS 0.65-µm (normalized to Aqua-MODIS using SNO), ray-matching with GEO radiance pair calibration
- Perform desert & deep convective cloud (DCC) calibration for each GEO domain
  - Sonoran for GOES-West and GOES-East, Libya-4 for Meteosat at 0° and 60°E, GMS/MTSAT Badain desert
  - Validate desert and DCC approach with ray-matched results
  - Rely on desert and DCC approach for historical GEOs
- Apply Spectral Band Adjustment Factors (SBAF) over each calibration domain to take into account the difference in spectral response between GEO and MODIS
- Combine desert and DCC calibration coefficients, by using the temporal standard error as the weighting function
- Calibration procedure validated by the consistency between methods
- Compare with ISCCP calibration and other sources

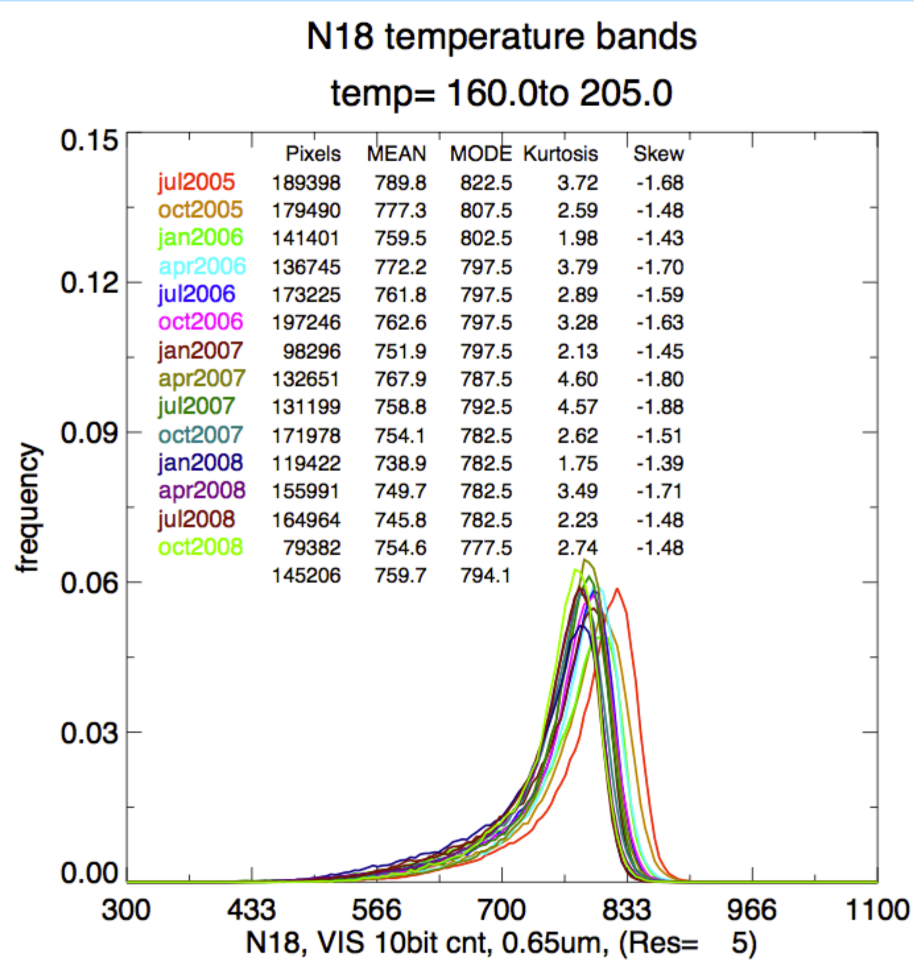
AVHRR calibration strategy

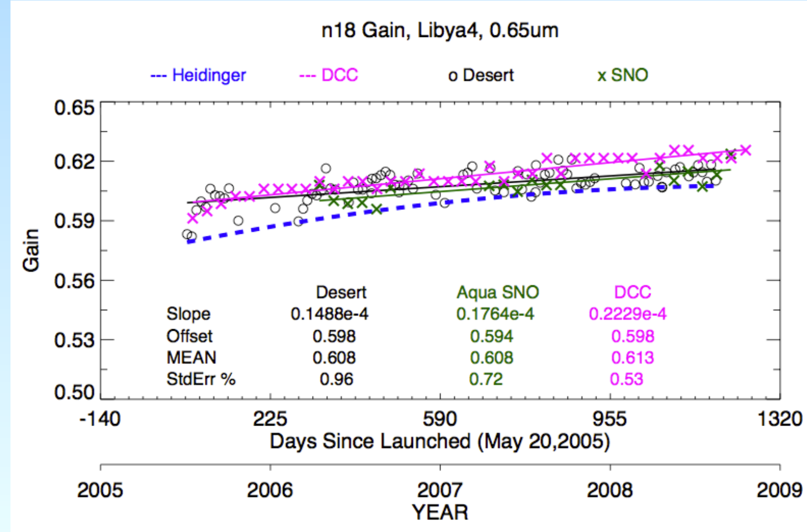
- Collection 6 Aqua-MODIS 0.65-μm is absolute calibration reference
  - 1.6% absolute calibration uncertainty
  - Stable within 1%/decade
- Use Aqua-MODIS & AVHRR simultaneous nadir overpass (SNO) radiances as primary calibration method during MODIS era
  - Validate desert, snow and DCC calibration methods using SNO as truth during MODIS era, use N15 for morning orbits
  - Verify that desert, snow and DCC calibration methods are independent of the drift in SZA, due to the NOAA satellite orbit degradation, using N16 and N17, which degrade to a terminator orbit
- Combine desert, snow and DCC calibration methods during the pre-MODIS era weighted by standard error about the trend
  - Consistency of 3 independent calibration methods validates the combined calibration coefficients => uncertainty factor
- Use SCIAMACHY based Aqua-MODIS and AVHRR spectral band adjustment factors (SBAF) to account for spectral response difference
- Compare with Heidinger and ISCCP calibration coefficients

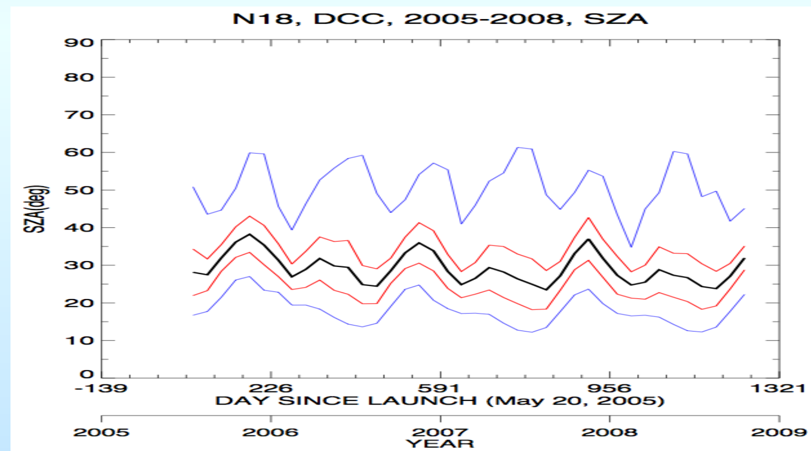
Project Description

CDR(s)	Period of Record and Temporal Resolution	Spatial Resolution & Projection Used (if applicable)	Update Frequency	Data file distinction criteria	Inputs	Uncertainty Estimates (in percent or error)	Collateral Products (unofficial or unvalidated & produced alongside)
FCDR Calibration gains of AVHRR channels 1, 2, and 3a Gains visible channels on GOES satellites	1978-present; twice daily	N/A	By satellite, monthly	Satellite number	Desert & Polar Clear-sky Albedo history, w/ SZA dependence, SBAF corrections, AVHRR channel data over deserts, SNO w MODIS, DCC pixels	MODIS era:~2% Pre-MODIS: 2-4%	

N18 deep convective cloud (DCC) calibration

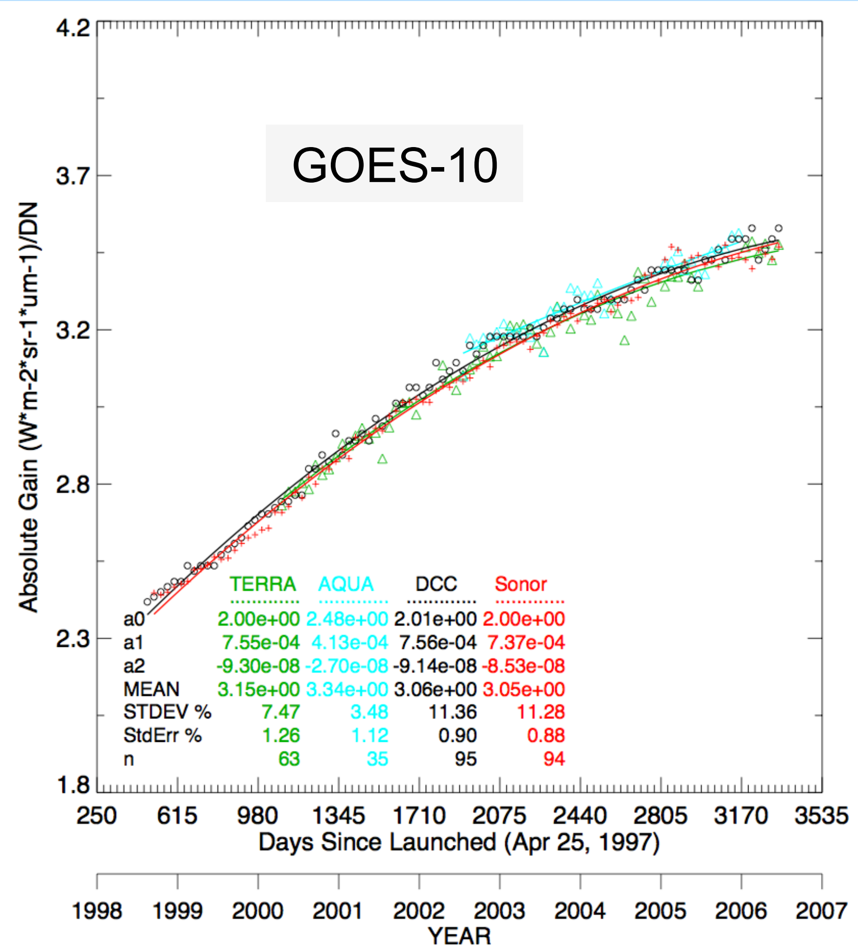


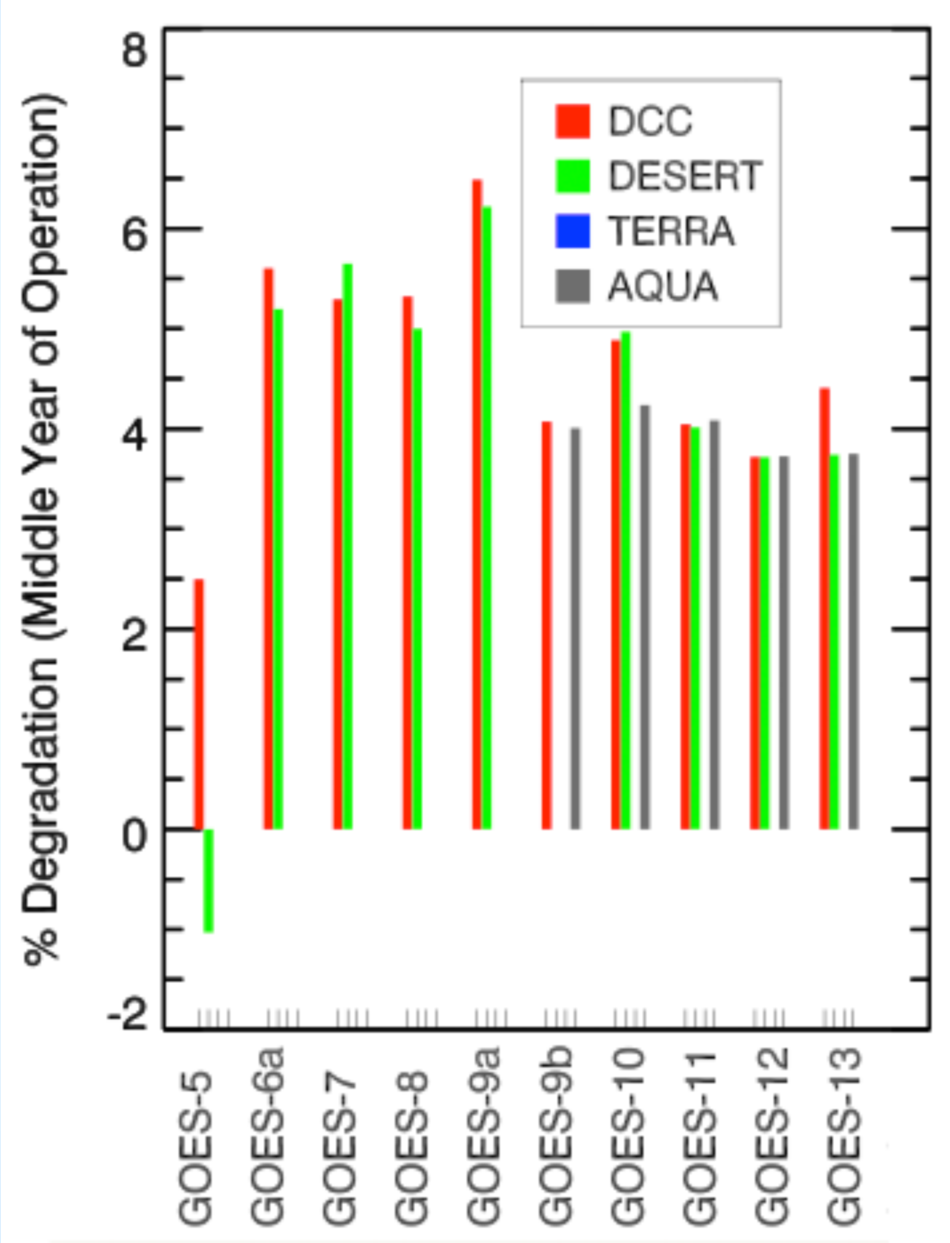




- Use mode of monthly PDF of DCC reflectances to track the AVHRR visible calibration
- Tracks Desert and Aqua SNO calibration trends
- N18 orbit was stable from 2005 - 2008

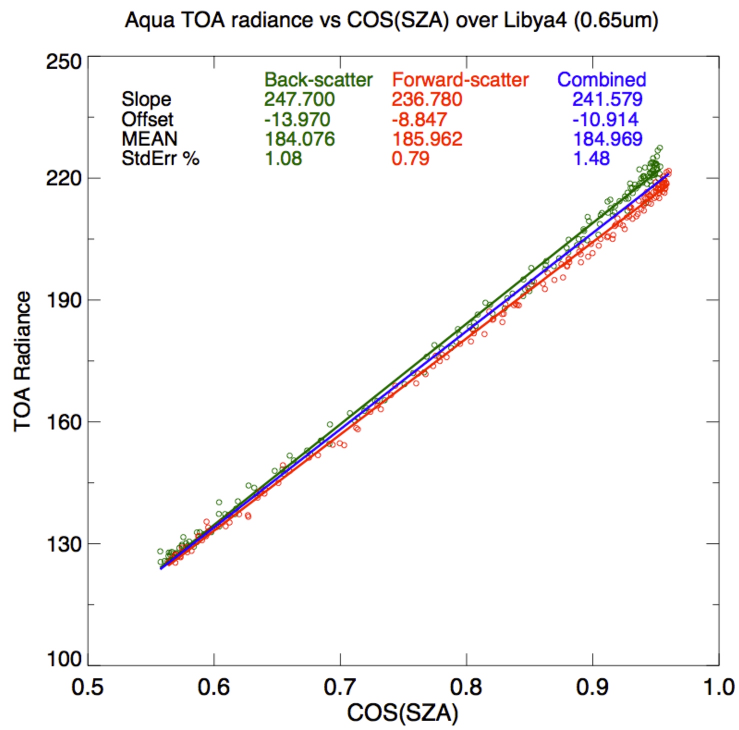
GOES Visible Channel Gains

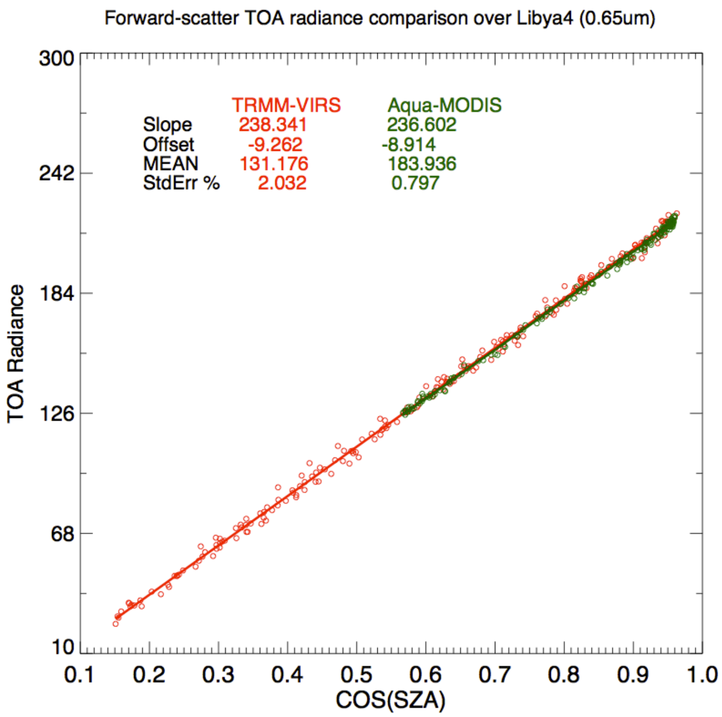




- Excellent consistency from various approaches, except GOES-5
  - more analysis needed

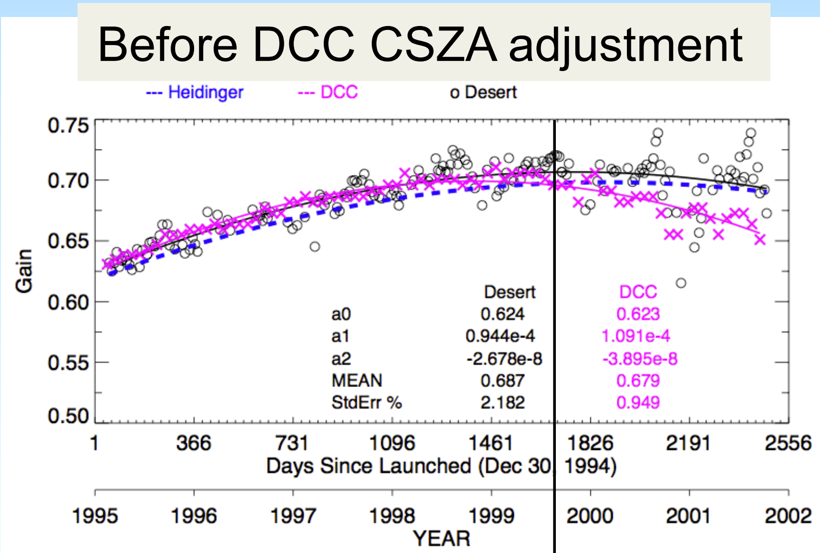
AVHRR desert calibration

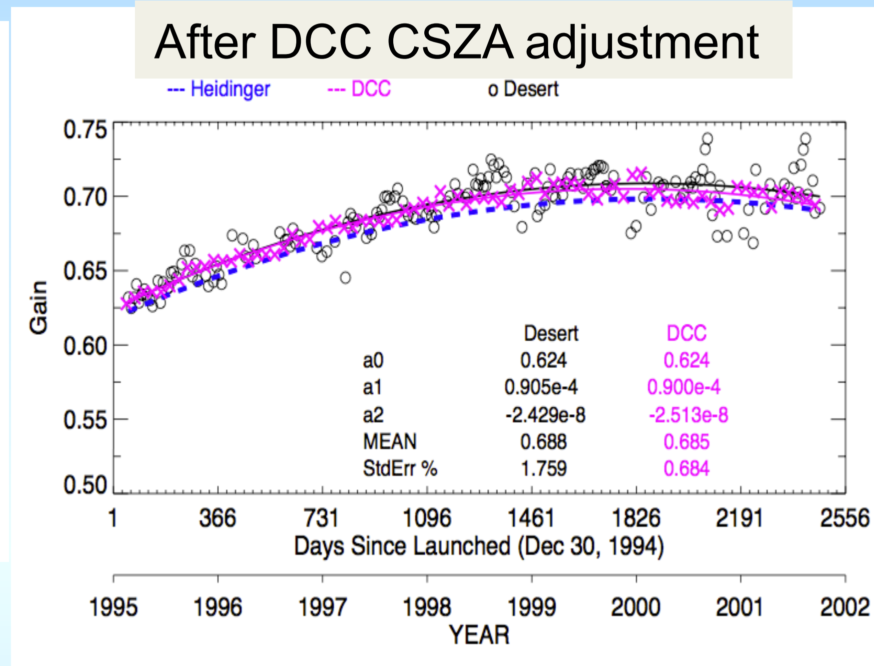


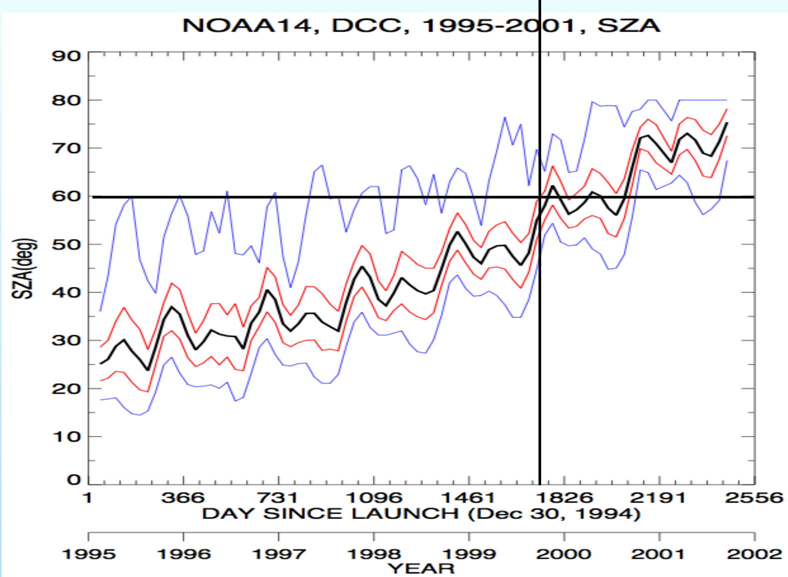


- Use Libya-4, Libya-1, Arabia-1, & Niger-1 as invariant desert targets to mitigate desert inter-annual variability
- Use near-nadir reflectances & model the Aqua-MODIS forward & backscatter reflectances by cosine SZA (CSZA) separately. Standard error goes from 1.48 to ~1
- VIRS reflectances on TRMM precessionary satellite validate linearity of CSZA reflectance model up to 82° SZA
- This approach also improves the Dome-C and Greenland calibrations

Extended DCC Calibration
Example: N14 deep convective cloud (DCC) calibration







- Before DCC CSZA adjustment, DCC calibration method was valid only for SZA < 60°
- Model DCC calibration as function of CSZA using N14 desert to demonstrate
- Derive model using N16 & N17 DCC calibration compared with Aqua SNO
- DCC calibration now valid for SZA < 80°

Validation & Quality Assurance

- FCDR, Calibration
  - Determine uncertainties using multiple techniques
    - DCC, Polar, Desert, NSRT
- FCDR, Product quality
  - Comparison with other sources (e.g., Heidinger, ISCCP)
  - Examination of trends in downstream products (e.g., τ)

NASA LaRC AVHRR Cloud and Clear-Sky Radiation Property Climate Data Record: Production Approach

- Re-navigate, calibrate, and noise filter (pre-NOAA-15 3.75 µm channel) AVHRR observations

- Adapt CERES Ed4 mask to AVHRR (0.65, 0.86, 3.7, 11, 12 µm, 4 km)
  - Test & tune mask using MODIS (1 km)
    - CERES Ed4 uses AVHRR channels + 1.38, 2.1, 8.5, 13.3 µm
  - Apply to NOAA-18, compare with Aqua MODIS & CALIPSO
    - Test and tune using individual scenes across diverse regions, surface types, and seasons
    - Make changes as necessary, 1-hr time difference between A-Train & N18
  - Apply to AVHRR back to NOAA-7 (1981-2010)
    - TIROS-N, NOAA-6, -8, and -10 will be processed later due to lack of 12 µm channel
    - Method for cloud detection and retrieval when 1.6 µm replaces 3.7 µm needs development

- Adapt CERES Ed4 Cloud Property Retrieval System to AVHRR
  - Adapt algorithm to limited AVHRR channels
    - Test & refine using MODIS and retest using NOAA-18
  - Apply to AVHRR back to NOAA-7 (1981-2010)

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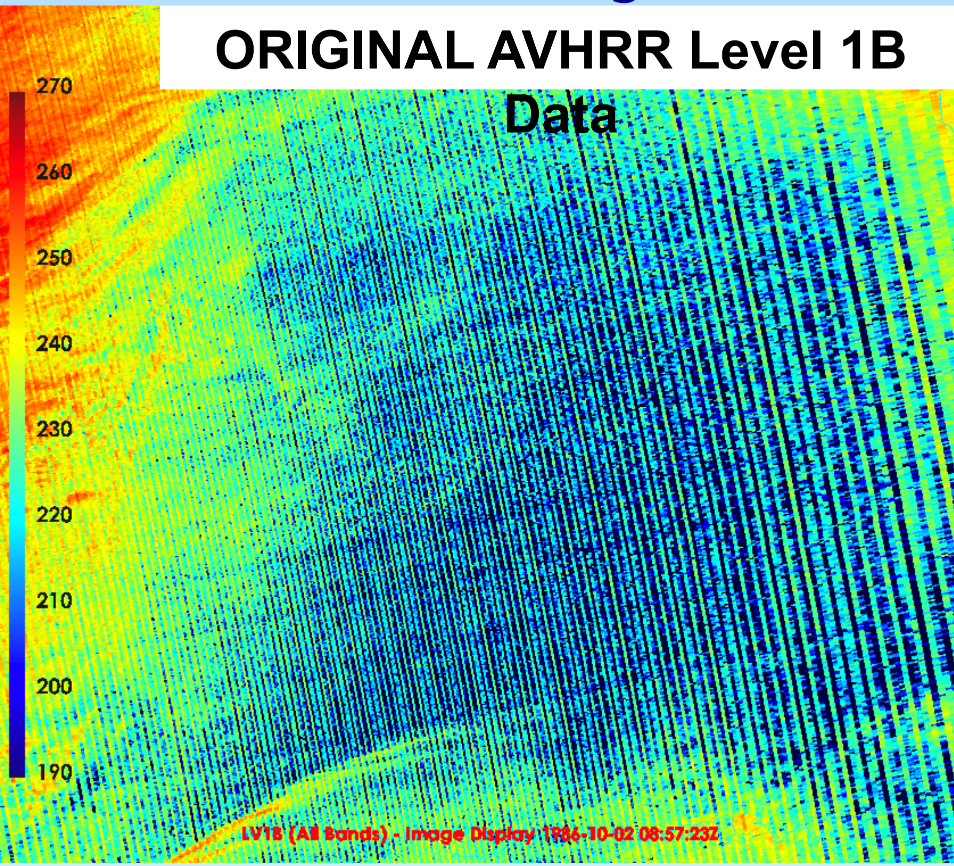
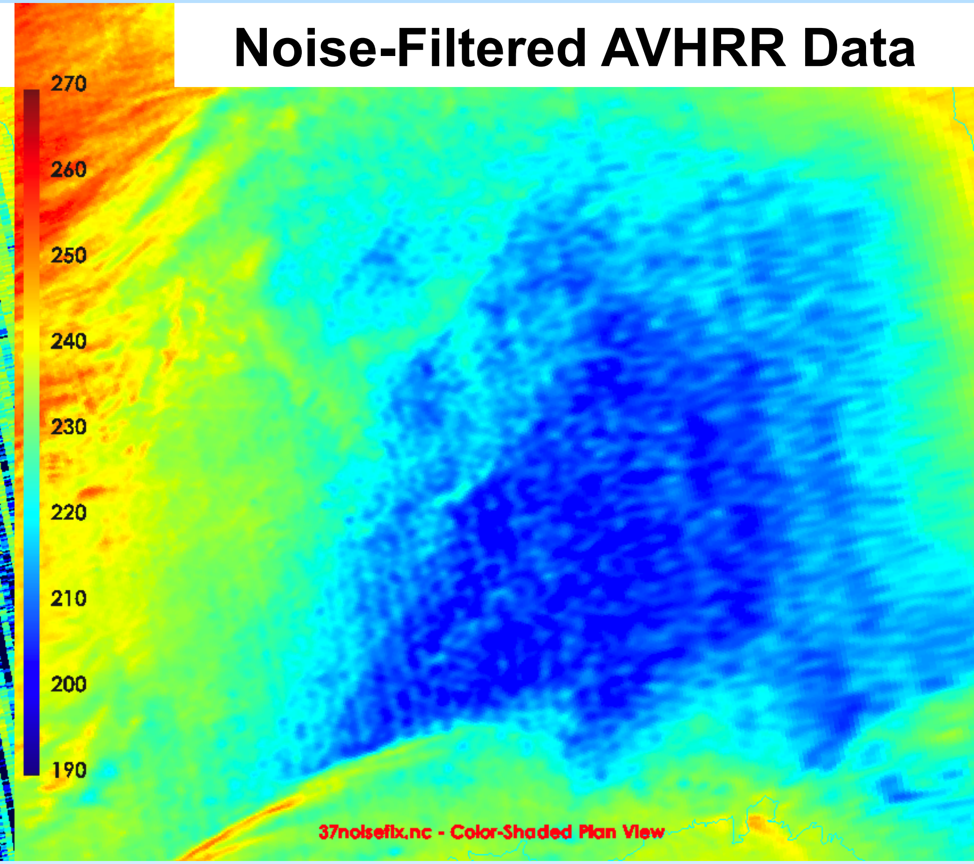
TCDR Cloud amt, top/eff ht, top/eff temp, Phase, Re, τ, clear VIS, LWP/IWP, IR radiances	1978-present; twice daily	4 km	By satellite, monthly	Satellite number and orbit TCDR or FCDR	4/5 channel AVHRR data; sfc alt., land %, snow/ice, MERRA, clear albedo maps	TBD	Skin temp, IWP/LWP, BB albedo & OLR, OTs, icing potential

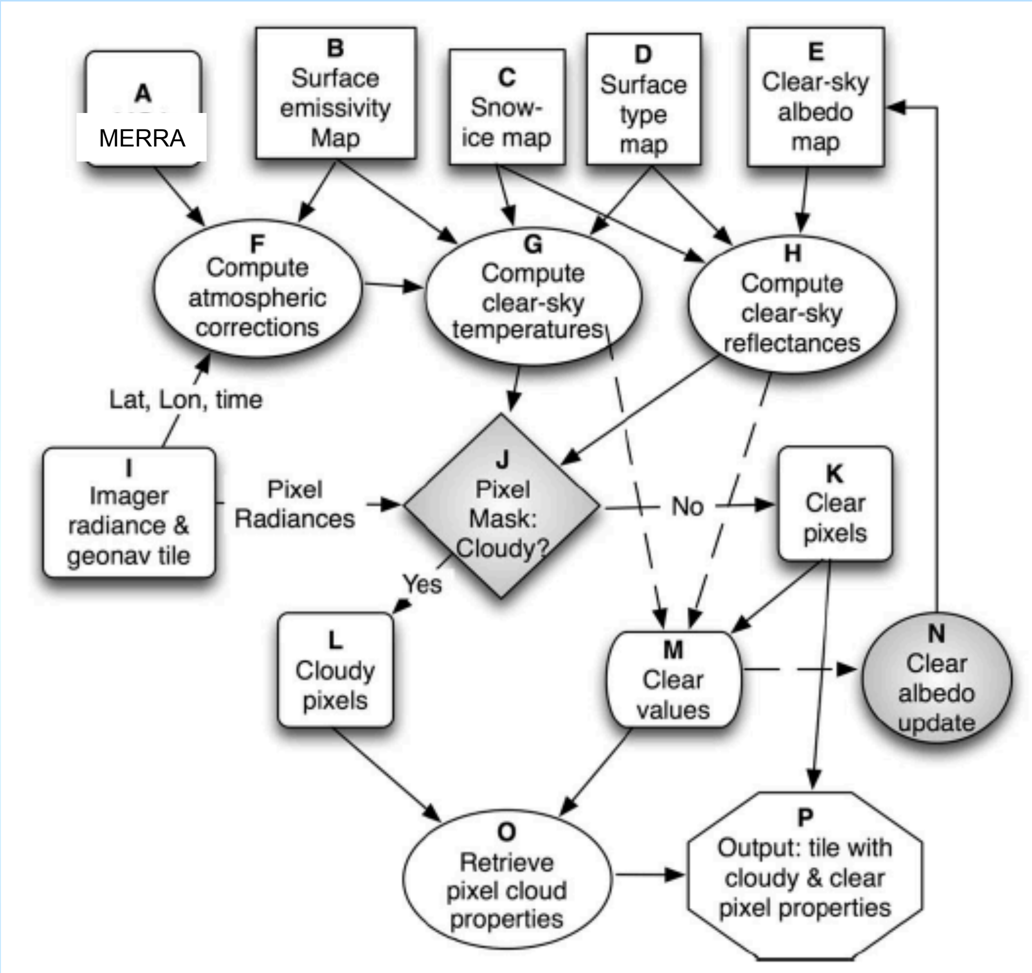
AVHRR Data Challenges
NOAA-6 through NOAA-14 3.75 micron Channel Noise





- AVHRR 3.75-µm channel data prior to NOAA-15 suffers from significant “striping” oriented along track and noise at cold temperatures
- These issues impact cloud mask and retrievals if not addressed
- Noise filter uses Fast Fourier Transform to minimize striping and spatial smoothing that increases in intensity with colder 11 µm temperatures

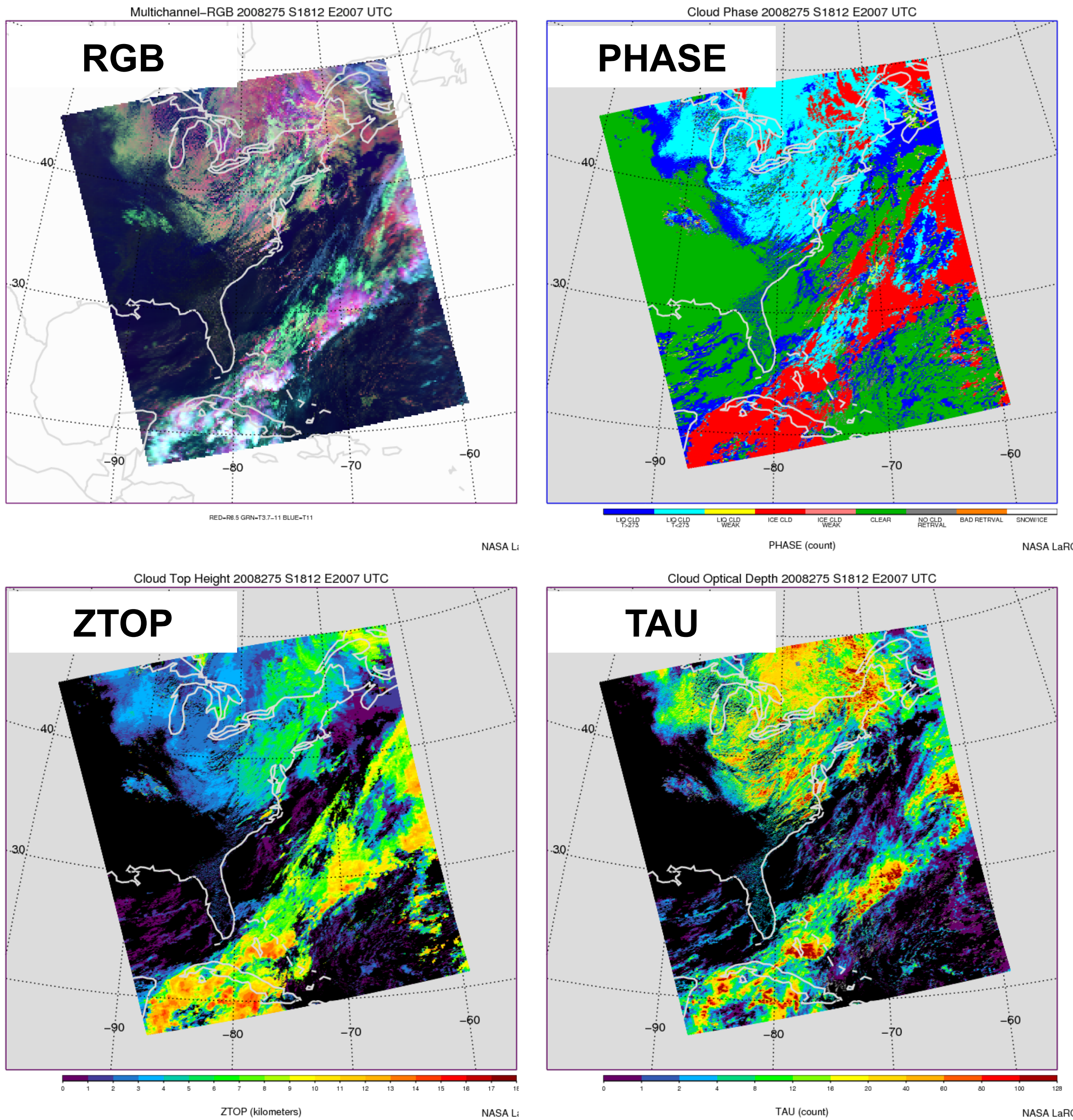
Production Approach



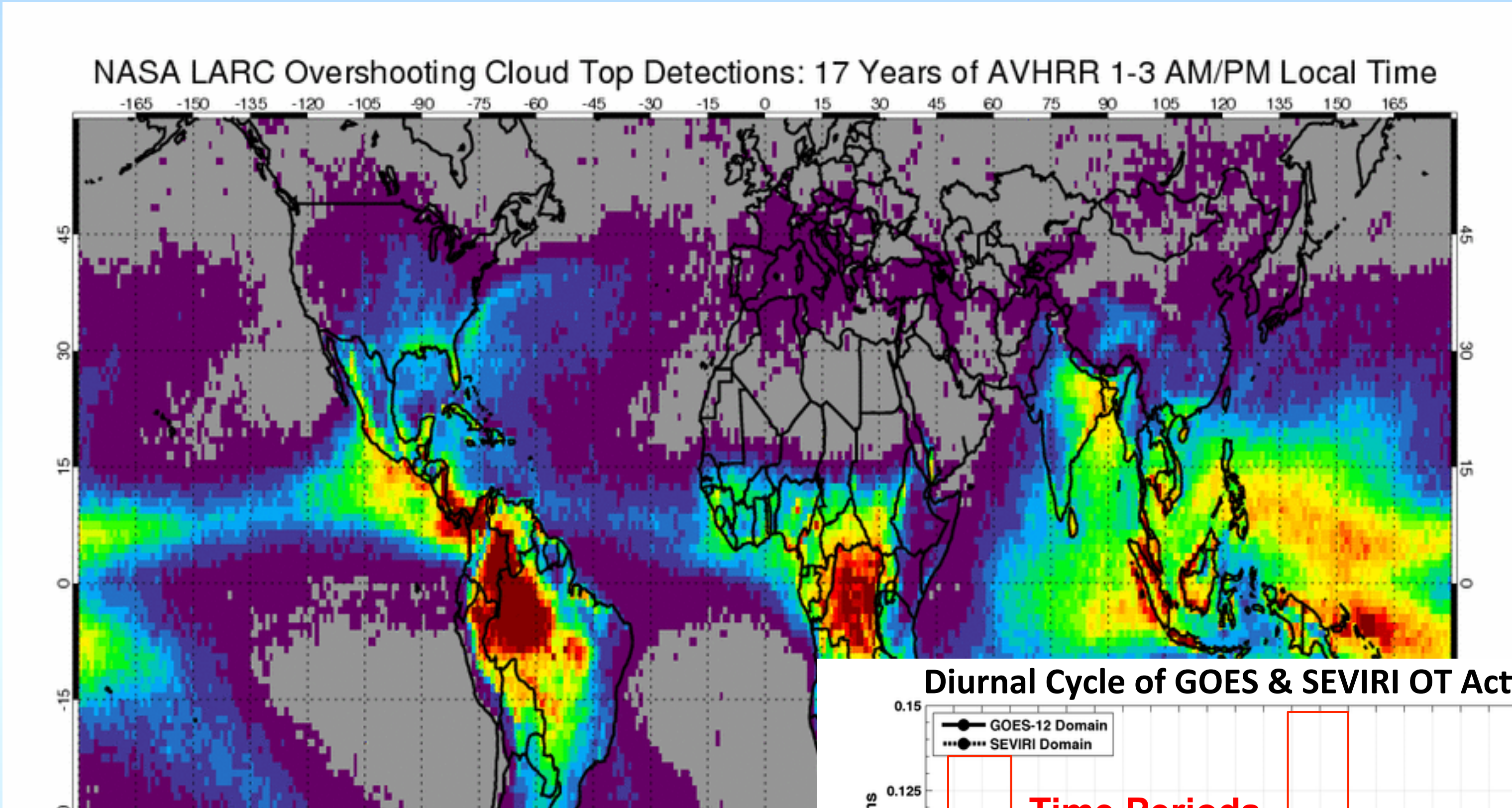
- AVHRR data are processed 1 orbit file at a time (~1.5 h) in chunks of 1000 scan lines
- Data analyzed in tiles across scan lines, 8 x 12 pixels
- Background and profiles same for all tile pixels
- Output includes original radiances & all parameters

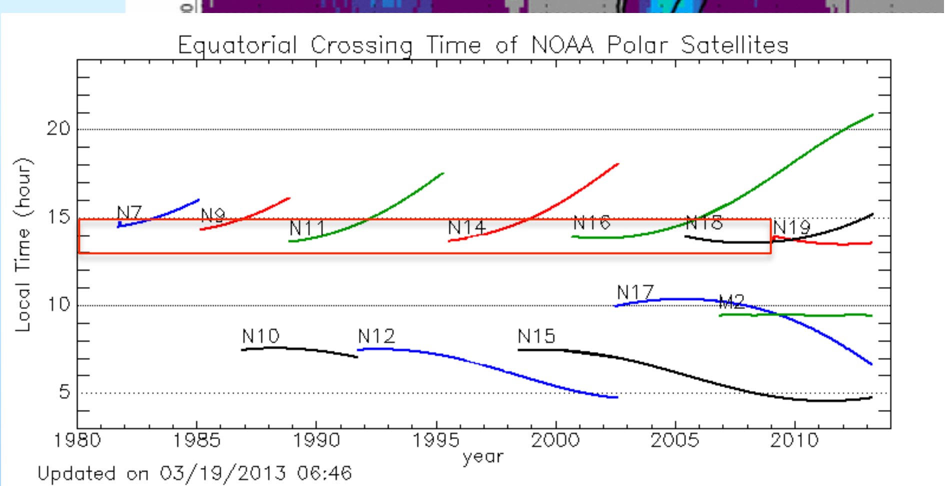
Example: Pixel-Level AVHRR Cloud Property Retrievals

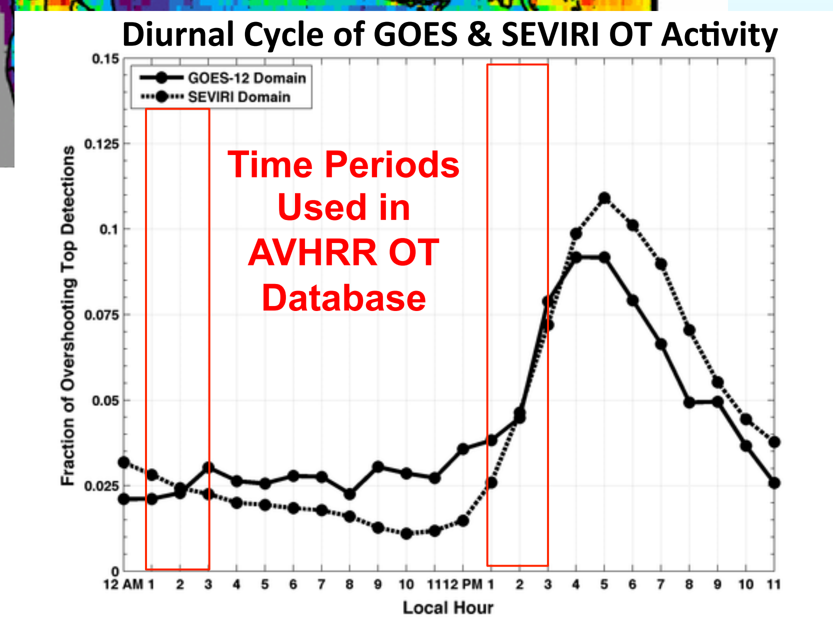
1/10/08



NOAA AVHRR Global Gridded Overshooting Top Detections 0100-0300 AM/PM Local Time, 17 Years of Orbits

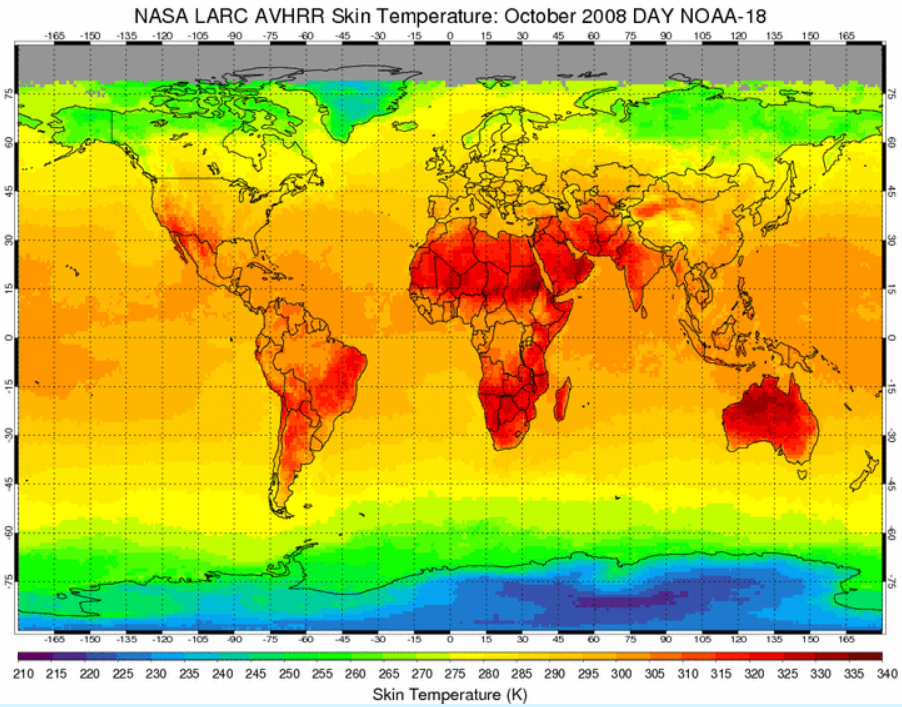




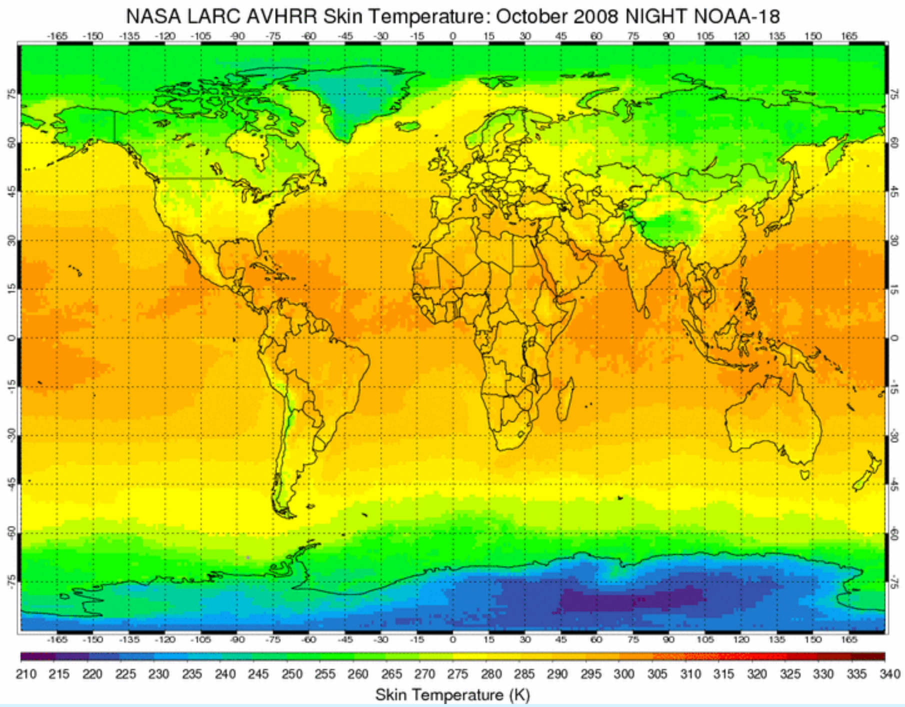


October 2008 AVHRR Skin Temperature

Daytime



Night-time



- Correlated k-distribution radiative transfer approach used to compute atmospheric transmissivity. This is then used to derive a surface IR temperature from the observed 11-μm clear-sky TOA IR temperature
  - Application of surface emissivity model yields land/ocean surface skin temperature
- Sea-surface temperature has been compared with 0.25° NOAA OISST product. Land surface temperature to be validated with ARM IR thermometers and compared with MODIS Land Surface Temperature product

Validation & Quality Assurance

- TCDR, Cloud Properties
  - Plane-parallel modeling uncertainties
    - Sensitivity analyses, previous publications
  - Comparisons with reference observations
    - CALIPSO: cloud heights, thin τ
    - AMSR-E LWP, SST
    - CERES, PATMOS-X: all parameters

- TCDR, Product quality
  - Statistical examination of trends and anomalies
  - Monthly mean distribution maps
  - Histograms of products

NASA LaRC AVHRR Cloud Property CDR: Quality Assurance

Three approaches for NASA LaRC AVHRR Cloud Property CDR Quality Assurance:

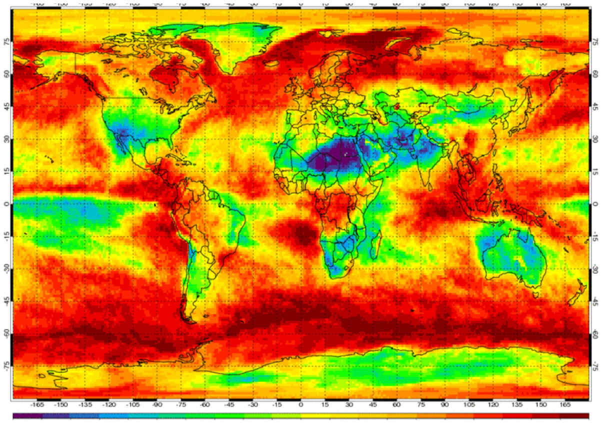
1) Detailed interactive inspection of pixel-level output using McIDAS-X and –V and IDL-based graphical output with Flash toggle/zoom/fade features

2) Comparison with other gridded monthly-averaged cloud property climatologies such as LaRC CERES MODIS, GSFC MODIS, ISCCP, PATMOS-X, and CALIPSO to ensure that AVHRR results are reasonable

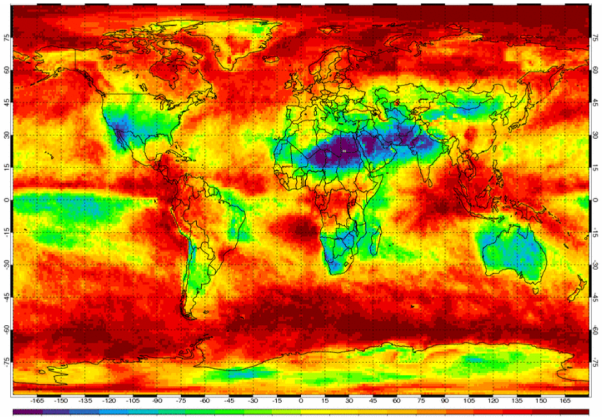
3) Pixel-level product comparison with space/ground-based instrumentation or other proven “truth” datasets
   a) Cloud Mask -> CALIPSO
   b) Cloud Top Height -> CALIPSO
   c) Cloud Base Height -> CloudSat
   d) Cloud Optical Depth -> CALIPSO and CloudSat
   e) Liquid Water Path -> AMSR-E
   f) Sea Surface Temperature -> NOAA Optimal Interpolation SST product
   Land Surface Skin Temperature -> DOE ARM IR Thermometer over the SGP site

Monthly Average Cloud Fraction: October 2008, Day+Night

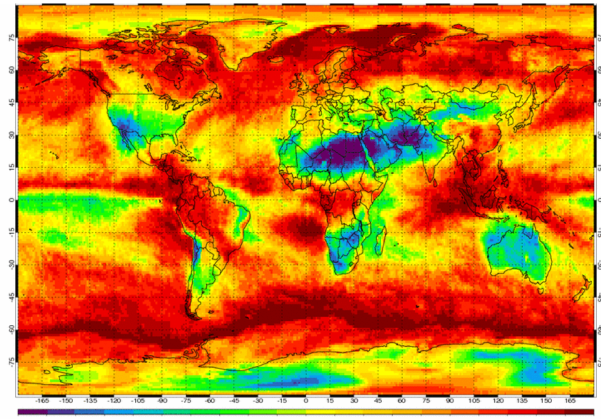
LaRC NOAA-18



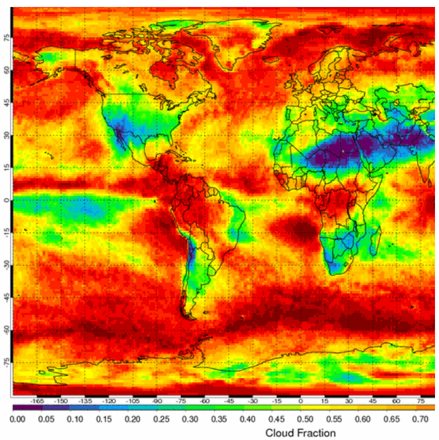
CERES Edition 4

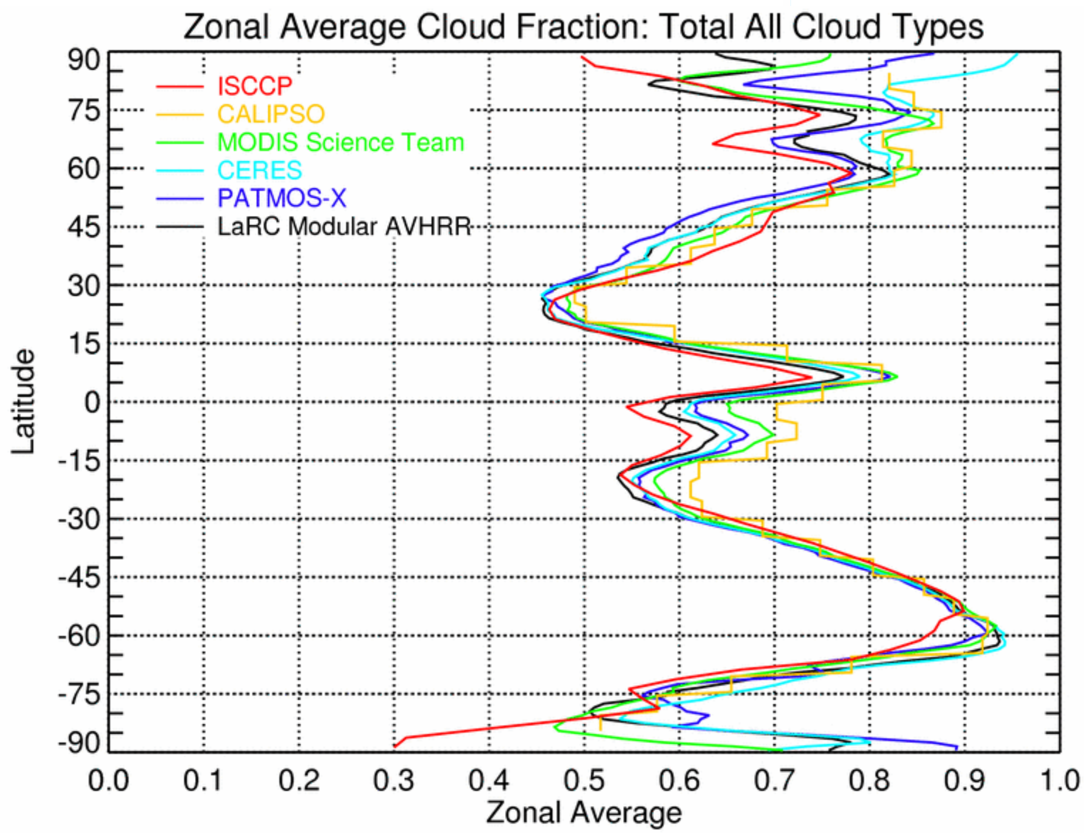


MODIS Science Team (Col. 5)

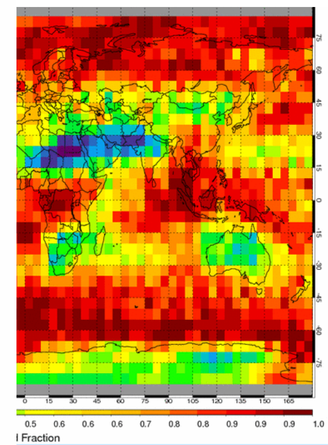


PATMOS-X





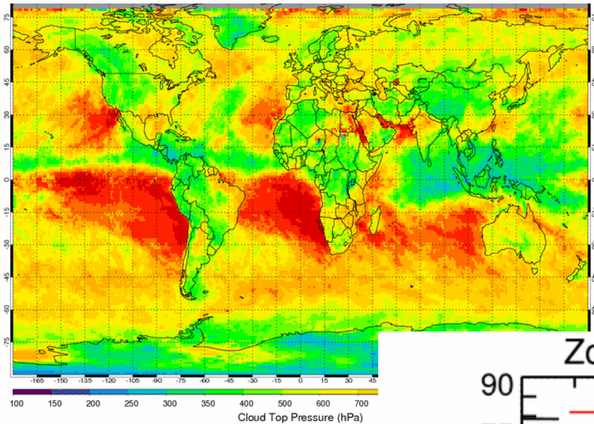
IPSO



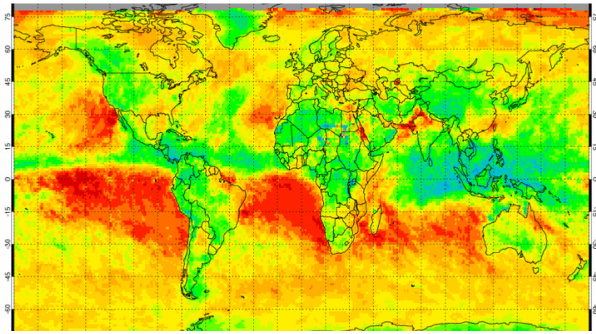
Cloud Fraction	La	CALIPSO
Day		0.679
Night		0.729

Monthly Average Cloud Top Pressure October 2008, Daytime

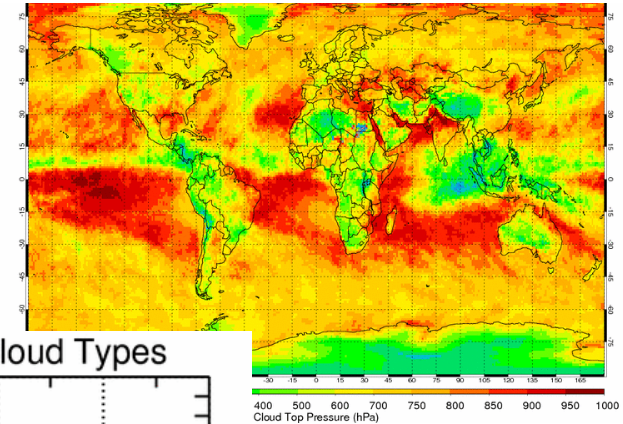
LaRC NOAA-18



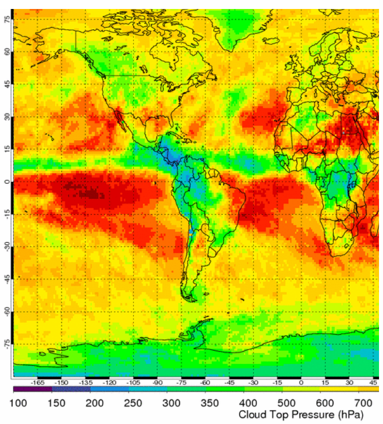
CERES Edition 4



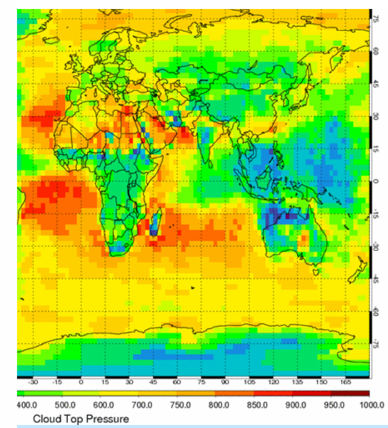
MODIS Science Team

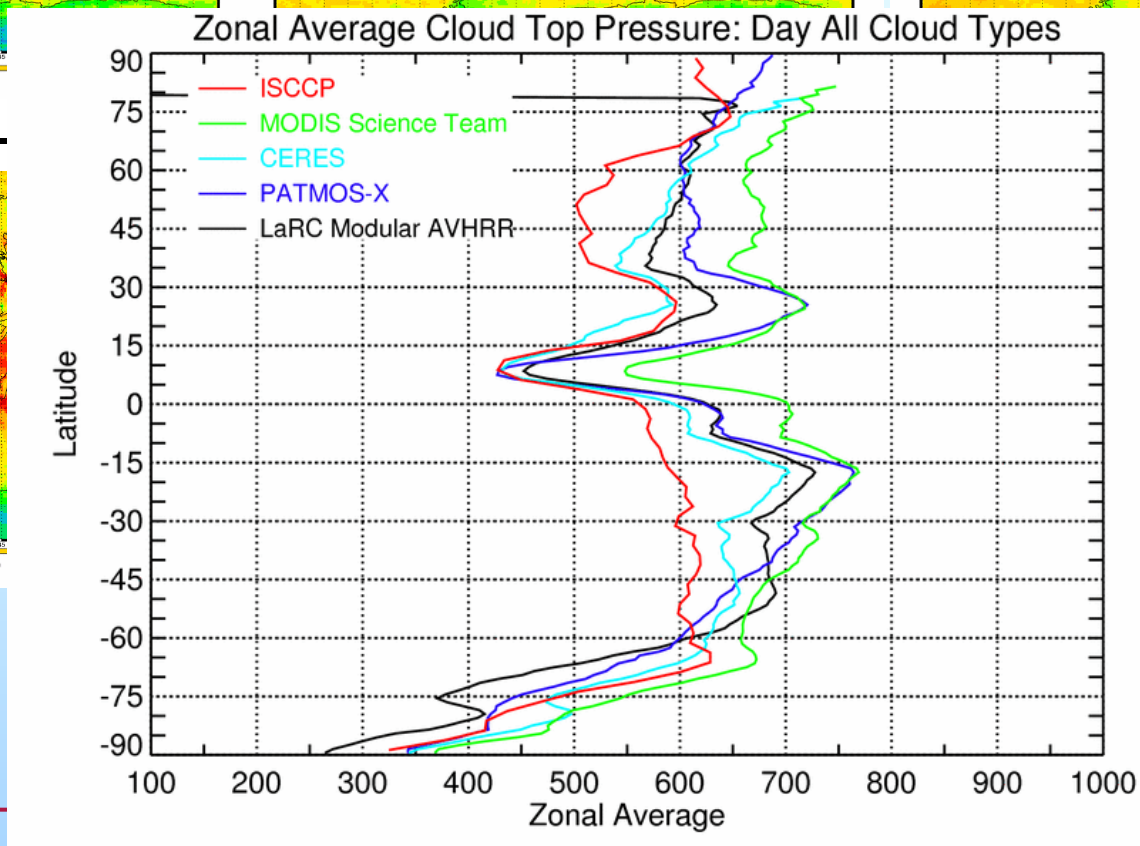


PATMOS-



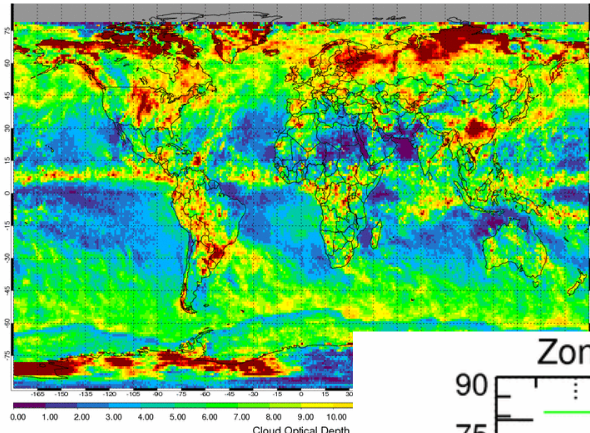
ISCCP



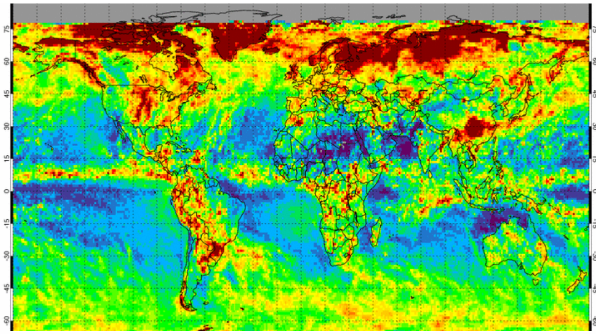


Monthly Average Cloud Optical Depth October 2008, Daytime

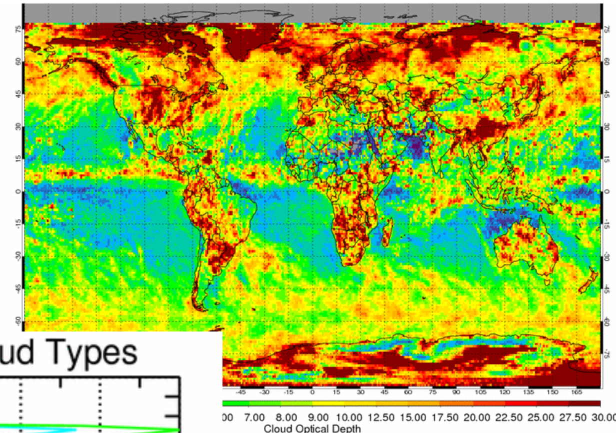
LaRC NOAA-18



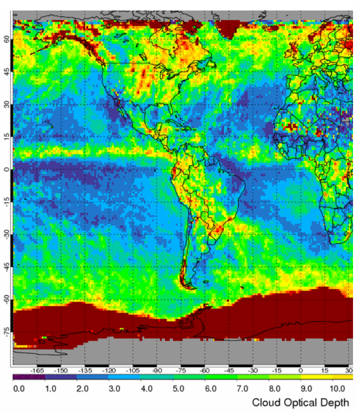
CERES Edition 4

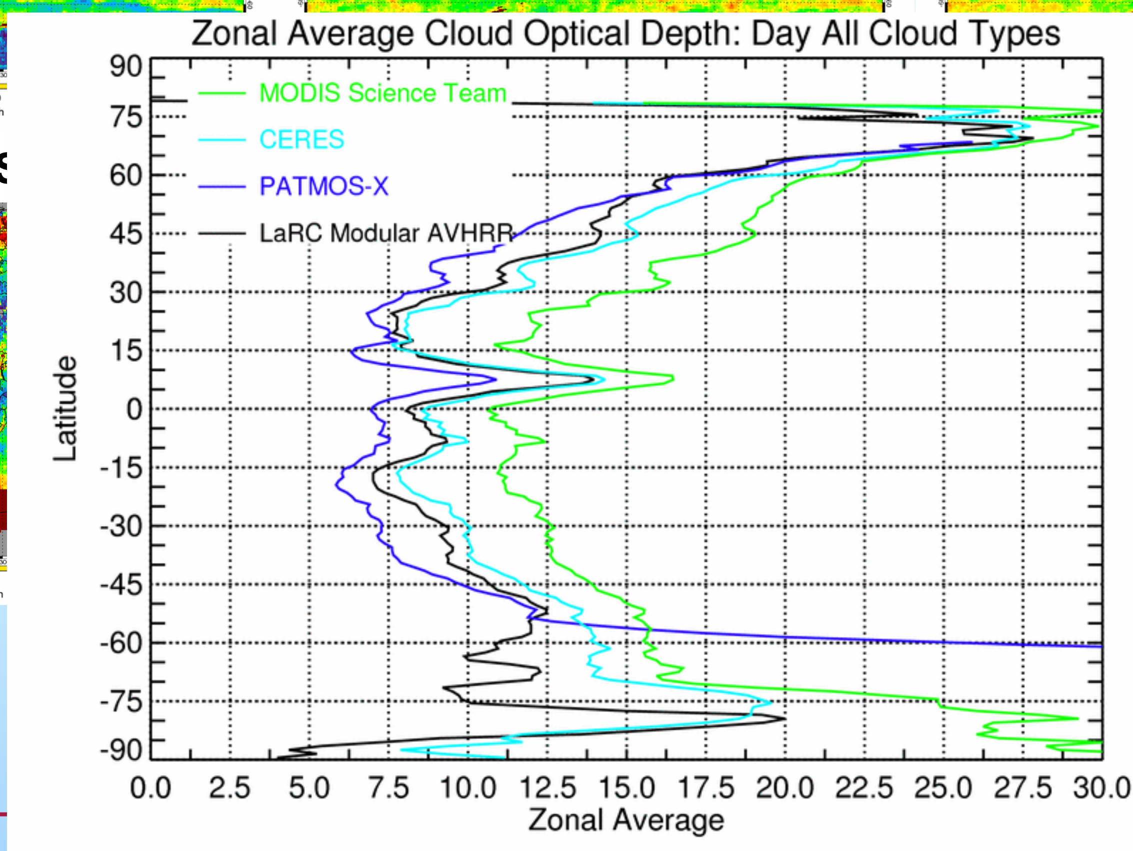


MODIS Science Team (Col. 5)



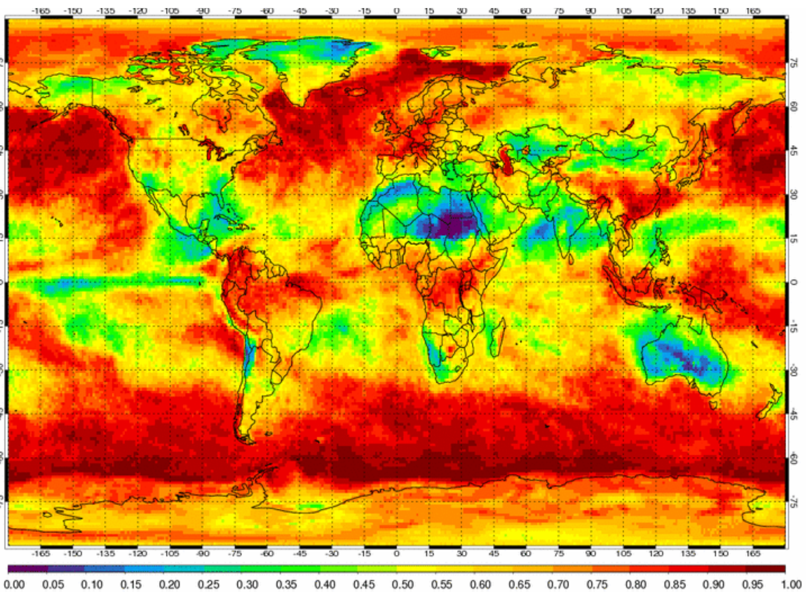
PATMOS



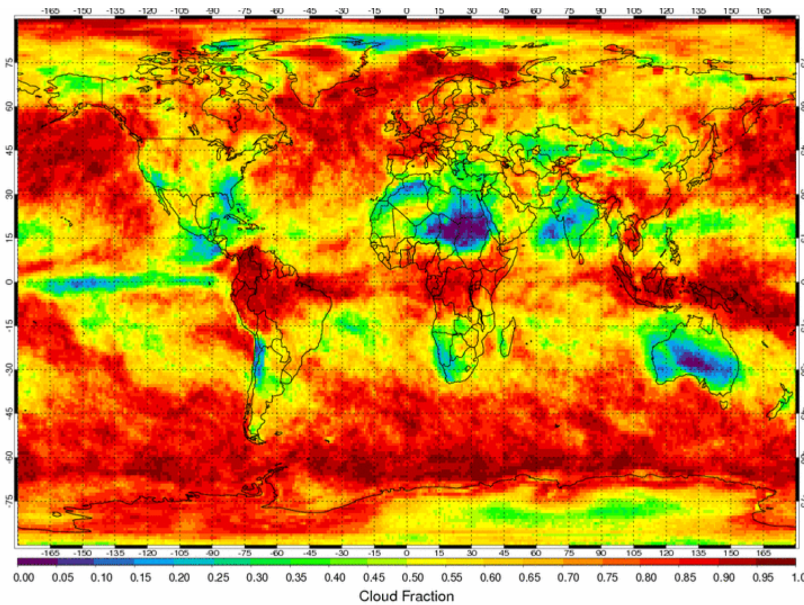


Global Cloud Fraction: April 1986, Day+Night

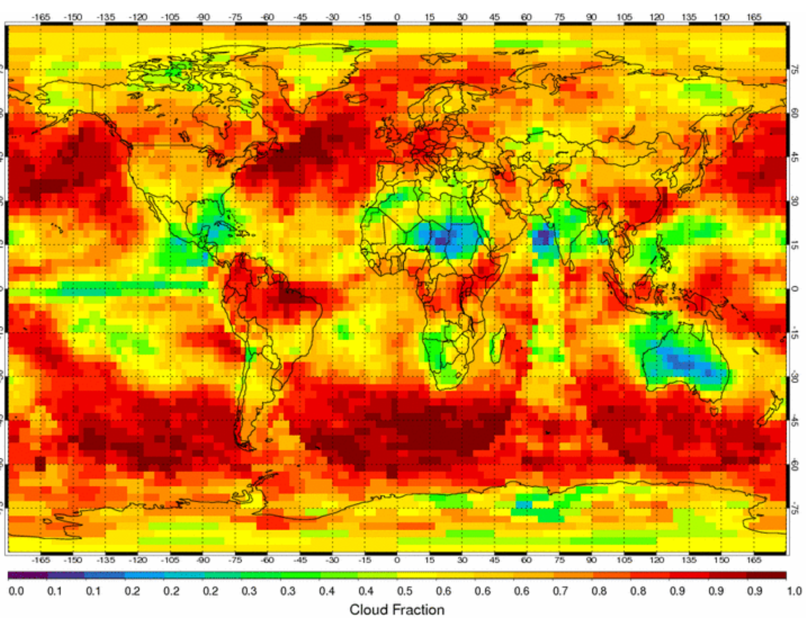
LaRC NOAA-18

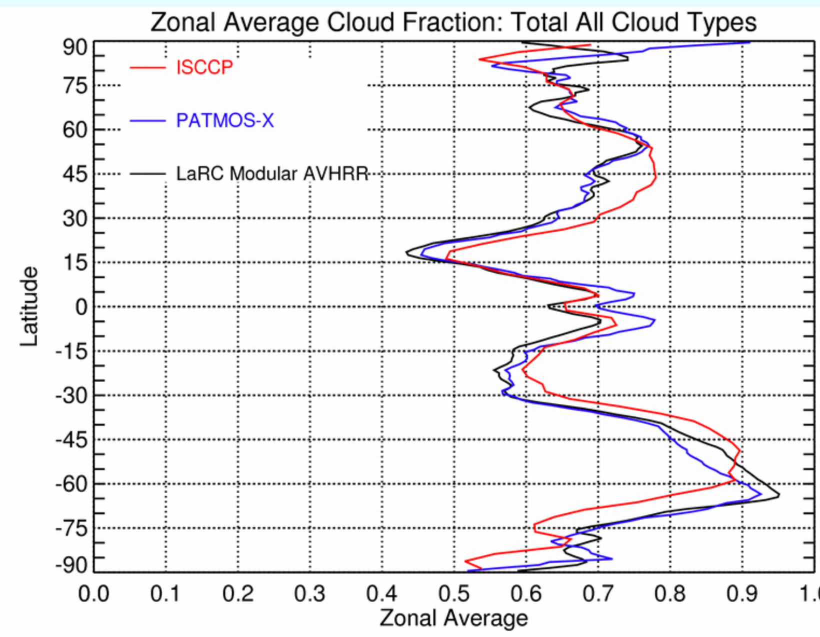


PATMOS-X



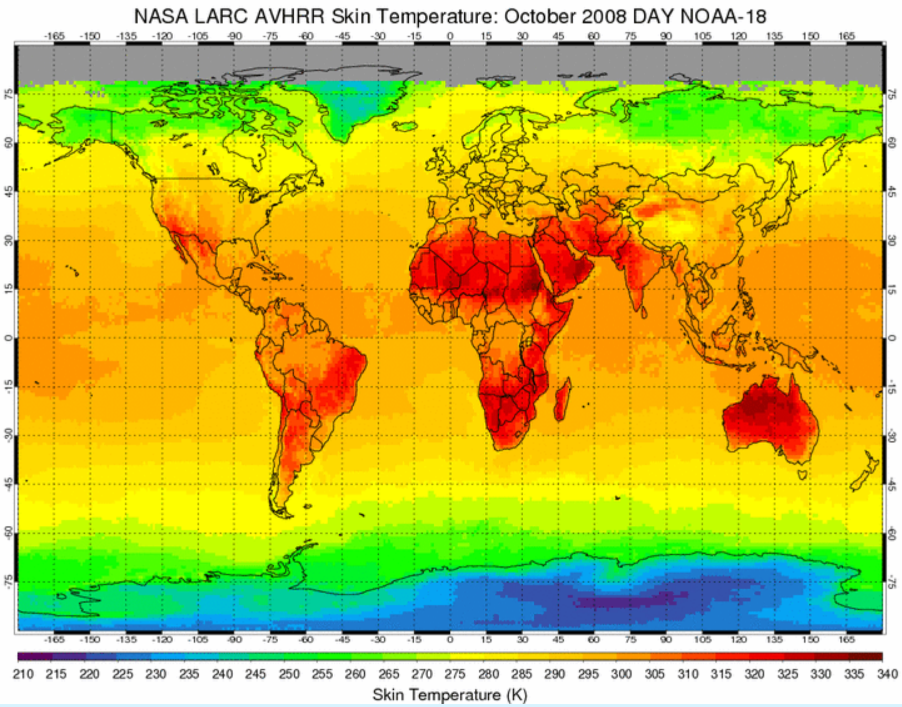
ISCCP



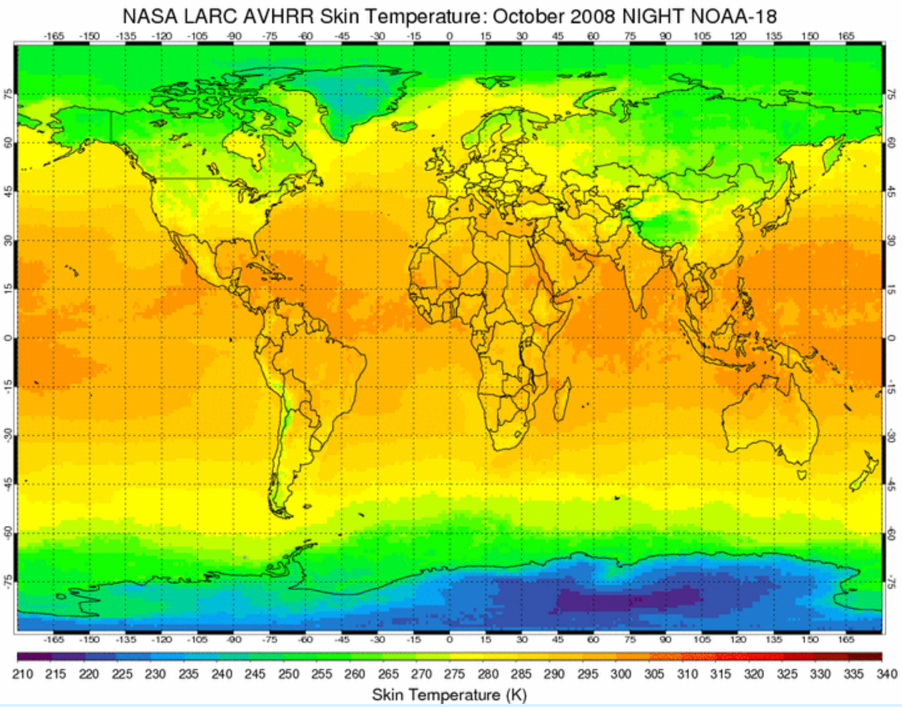


October 2008 AVHRR Skin Temperature

Daytime



Night-time



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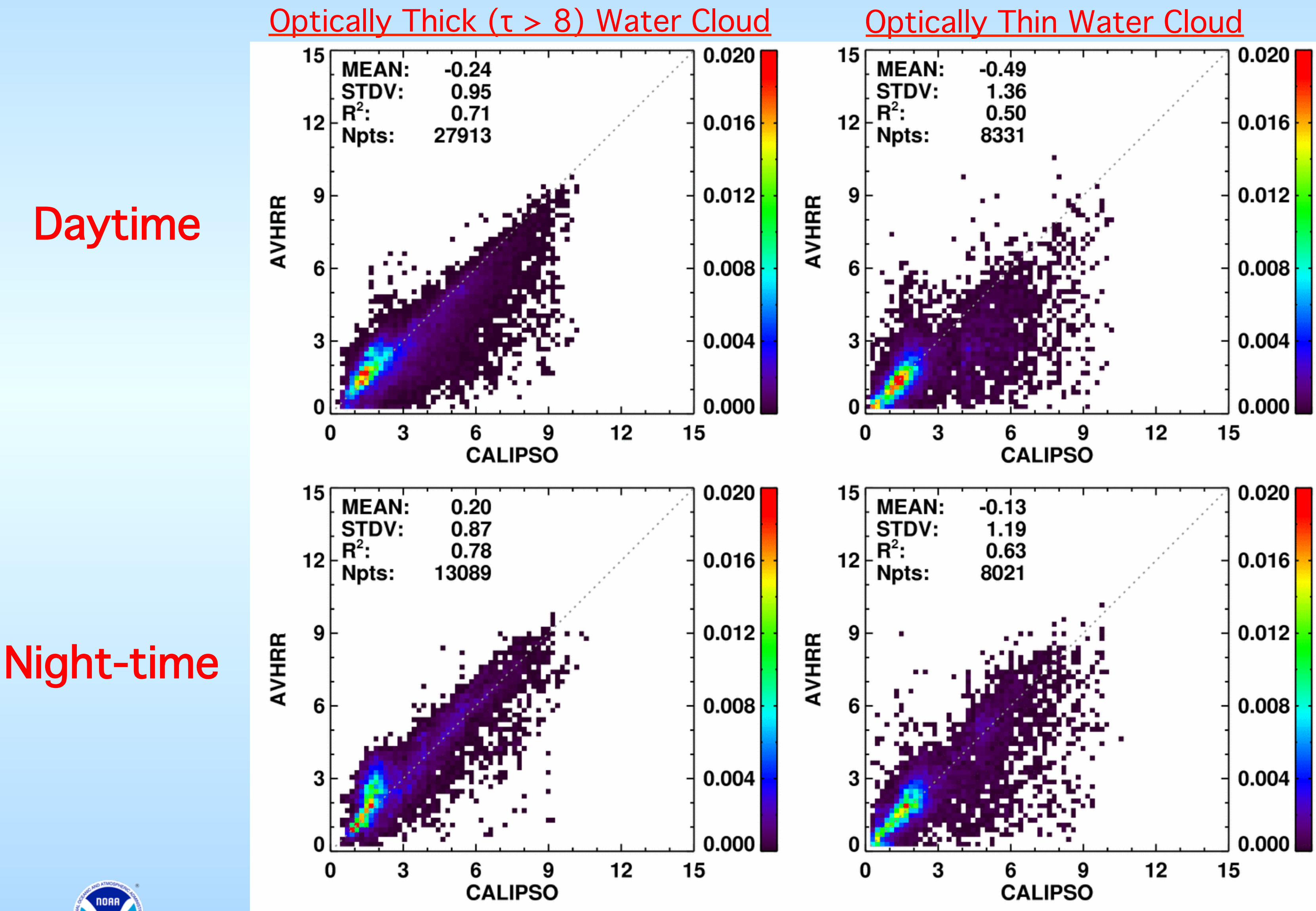
NASA LaRC AVHRR Cloud Mask Validation vs. CALIPSO

October 2008 NASA LaRC AVHRR Cloud Mask Validation vs. CALIPSO	% of Clear and Cloudy AVHRR Pixels Correctly Identified
Polar Day Land Polar Day Water	83.5% 93.8%
Polar Night Land Polar Night Water	72.9% 84.3%
Mid-Lat Day Land Mid-Lat Day Water	87.7% 88.8%
Mid-Lat Night Land Mid-Lat Night Water	87.2% 90.1%
Tropical Day Land Tropical Day Water	84.9% 85.1%
Tropical Night Land Tropical Night Water	85.5% 86.8%

Percentages similar to CERES MODIS-CALIPSO comparisons

Quality Assurance: Pixel Level Cloud Top Height Validation Using CALIPSO, October 2008: WATER CLOUD

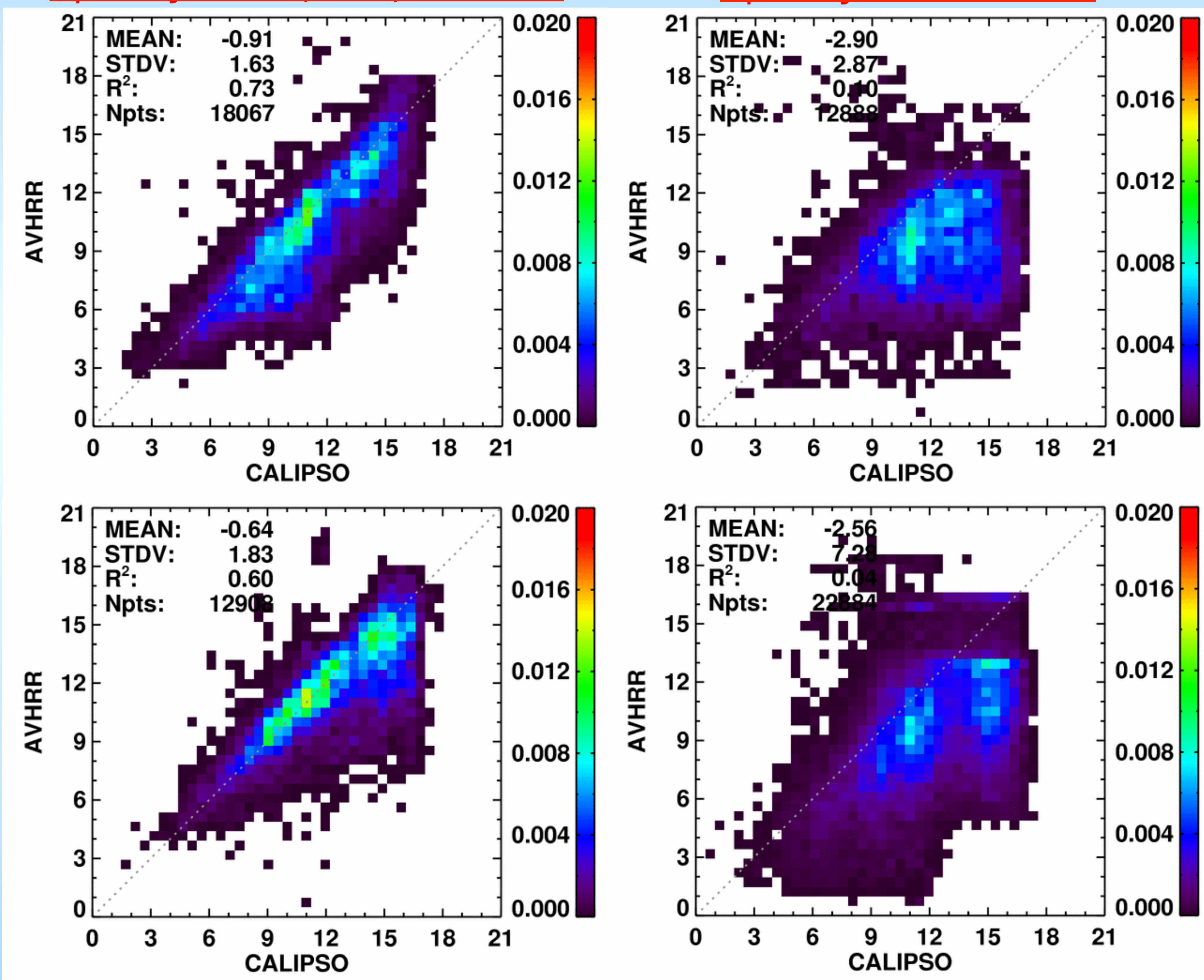


Quality Assurance: Pixel Level Cloud Top Height Validation Using CALIPSO, October 2008: ICE CLOUD

Optically Thick (τ > 8) Ice Cloud | Optically Thin Ice Cloud

Daytime

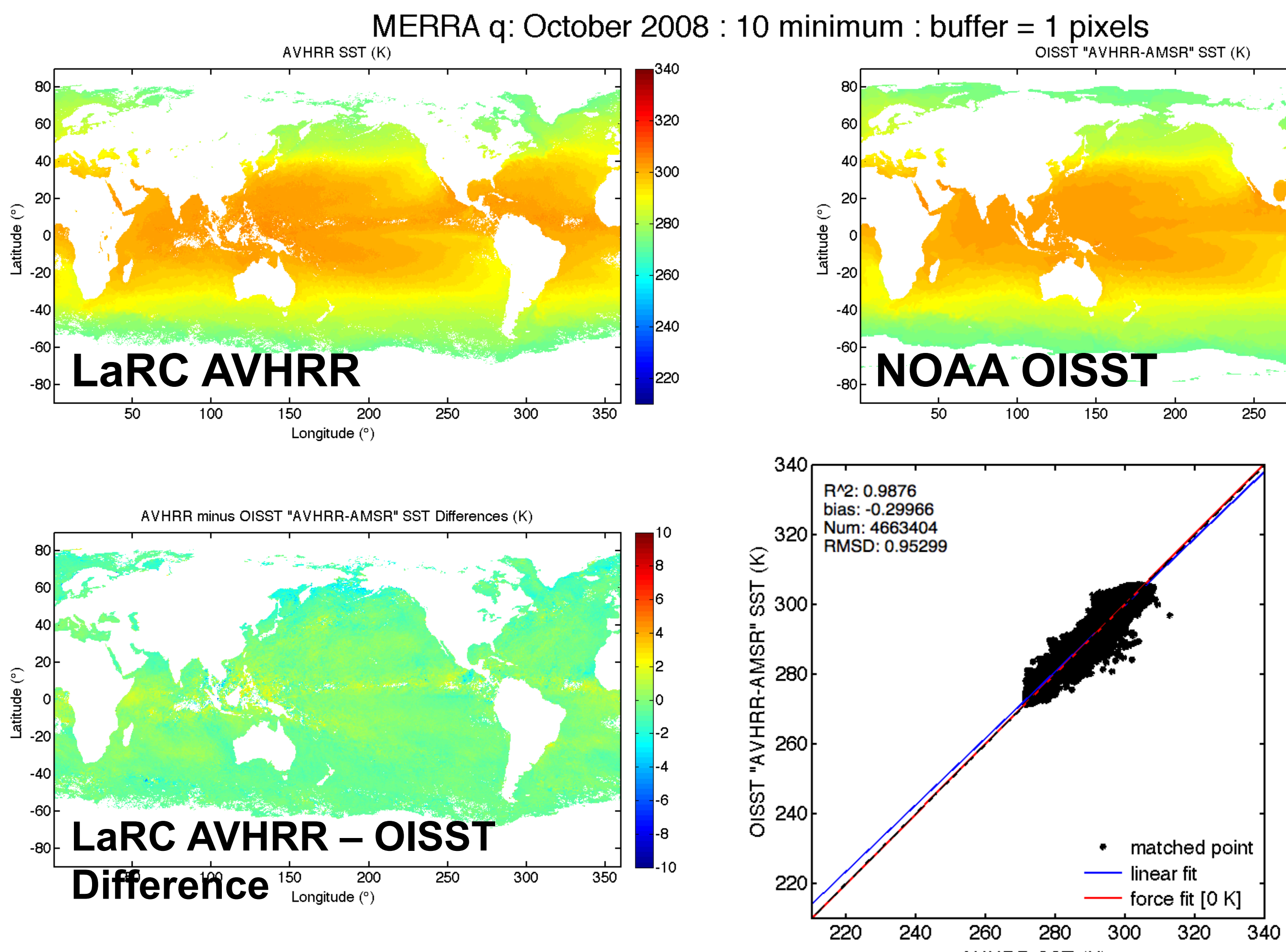
Night-time



Quality Assurance: October 2008 AVHRR Sea Surface Temperature Validation Vs. NOAA OISST

NOAA OISST: 0.25° daily product uses AVHRR, AMSR (when available), & in-situ SSTs

LaRC AVHRR pixel skin temperatures averaged at 0.25° across day/night. Skin temperature along cloud edges are excluded from validation



R^2=.987
Bias=-0.29 K
RMSD=0.95 K
 # Pts: 4.6 million

Uses & Applications

- AVHRR Calibration Use and Application
  - Enables accurate quantification of satellite-derived parameters

- Cloud & Other Retrieved Parameter Applications
  - **Solar energy sector:** site placement, expected surface radiation
  - **Agriculture:** crop selection based on cloud cover, surface temperatures?
  - **Aviation:** frequency of icing conditions, aviation-induced cloud changes, possible ceiling height frequencies
  - **Insurance:** frequency of severe storms indicated by storm size, overshooting tops
  - **Energy use:** trends in urban heat islands (Tskin)
  - **Assimilation:** in long-term GCM analyses, e.g., MERRA & NCEP

Schedule & Issues

- Accomplishments over past year and project status
  - Extended SZA coverage for DCC and desert coverage
  - Completed calibrations for NOAA-8 to 18, GOES 7-13
  - Obtained consistent results with CERES Ed4 in nonpolar regions
  - Developed skin temperature retrievals
- Milestones (with dates) to finish development & testing
  - Complete testing for 5b-channel (3.7 μm 24/7) 9/15/13
  - Deliver 1st 5b-ch results, 10/15/13, and new ones each month thereafter
  - Complete testing for 4-channel (no 12 μm), 12/15/13
  - Deliver 1st 4-ch results, 1/15/14, new ones each month thereafter
  - Complete testing of 5a-ch (1.6 μm daytime) 1/30/14
  - Deliver 1st 5a-ch results, 2/15/14, new ones each month thereafter
  - Documentation schedule already submitted
- Risks & concerns
  - may request a no cost extension to finish
  - Computer shutdowns and disk failures often slow things down