Extending The CERES Cloud Climate Record Using MODIS and AVHRR Data

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Collaborators

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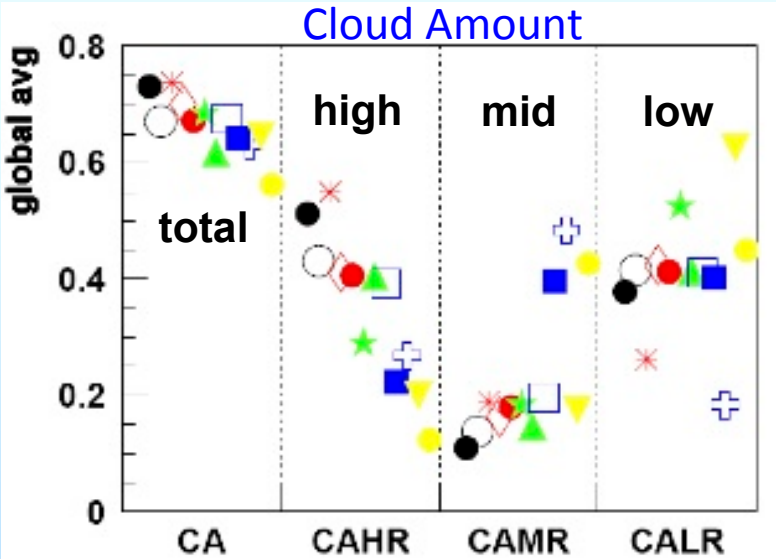
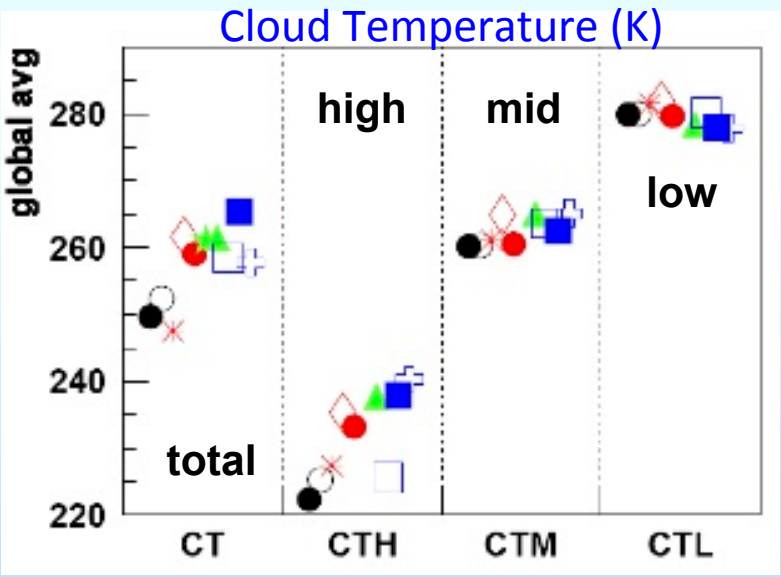
Background

- **Satellite cloud climatologies vary with sensor and algorithm**
  - ISCCP uses multiple LEO/GEO satellites & a VIS-IR method (Rossow et al)
  - PATMOS-X uses AVHRR with a 4-channel technique (Heidinger et al.)
  - MODIS team uses MODIS with >10 channel method (King et al.)
  - CERES team uses MODIS with 4 and 12 channel technique (Minnis et al.)
  - Different NWP-based input atmosphere analyses (NCEP/NCAR, MERRA, MOA)
  - Different treatment of surface albedos & emissivities, & calibrations
  - Treatment of pixels (e.g., in blocks or individually)





GEWEX Cloud Assessment, Stubenrauch et al., 2011

■ ISCCP ✚ ATSR ● AIRS-LMD ▲ MODIS-CE ▼ MISR ● CALIPSO-ST
□ PATMOSX ✳ HIRS ◇ TOVS ★ MODIS-ST ● POLDER ○ CALIPSO-GOCCP

Motivation

- Different approaches yield different answers that tend to reflect the uncertainties in the cloud record

=> How accurate are the trends? Are they independent of approach?

- *The more techniques we use, the better we understand the uncertainties as long the methods are reasonable. We can use these uncertainties to constrain climate models*

- CERES is developing a climate data record (CDR) of clouds and radiation fluxes

  - 2000 (Terra), 2002 (Aqua), 2011 (S-NPP) → 2016 (JPSS) → 20??
  - CERES cloud algorithm differs from the MODIS Science Team algorithm
    - *Reasonable, relatively well validated & understood*
    - *Results constitute a cloud CDR*

- Can we extend that cloud CDR back in time?

  - AVHRR has the core channels used by the CERES cloud algorithms

- **GOAL: Develop a cloud CDR from AVHRR data for NOAA NCDC that is consistent (as possible) with CERES, yet extends from ~1980 to the present**

  - Extend CERES clouds back in time using an adaptation of CERES algorithm
  - ERBE has collected broadband radiation measurements from 1984-2003
    - *Make a CERES-like radiation product (led by S. Kato) using AVHRR clouds for NOAA NCDC and NASA MEaSUREs*

CDR Project Outline

- **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
- **Source Data**
  - AVHRR 1, 2, & 3: 1978 – present
  - SMS-1 & 2; GOES-1 thru present
  - SCHIAMACHY hyperspectral data (2004-2009)
- **Deliverables**
  - Calibrated 0.64, 0.86, and 1.6-μm radiances (calib. coefficients)
  - Cloud temperature, height, optical depth, effective particle size, water path, phase; surface skin temperature, spectral albedo
- **Essential Climate Variables addressed**
  - Cloud properties, radiation budget
- **Current/Expected User Communities:**
  - GEWEX, GCM community, energy, aviation, (re-)insurance

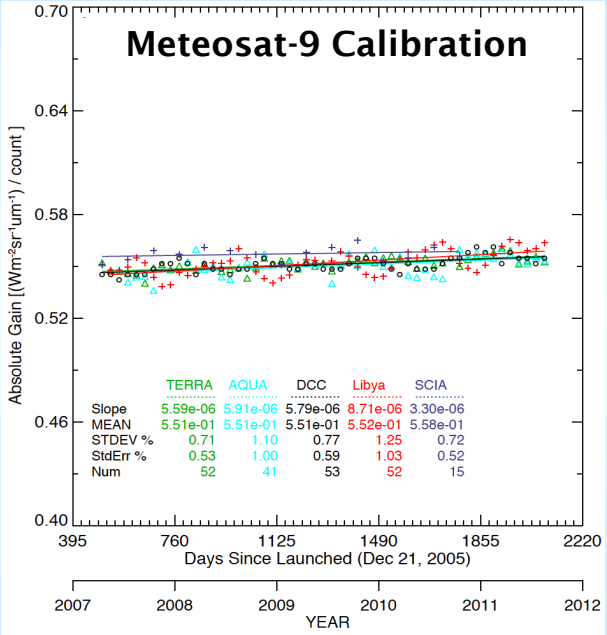
Calibration Methodology Description

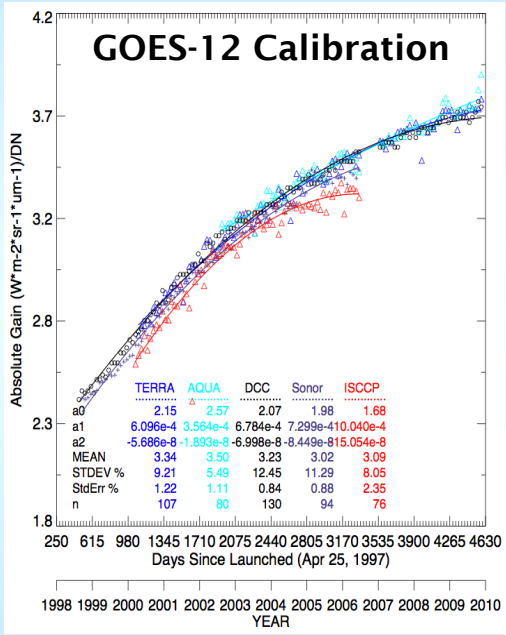
- **3 Calibration Methods, all independently referenced to Aqua-MODIS**
  1) **Ray-matched coincident GEO counts and MODIS radiances** averaged over a 0.5˚x0.5˚ ocean grid near the sub-satellite point (±15˚ lat by ±20˚ lon area)
  2) **Deep Convective Cloud Technique** (DCC; Doelling et al. 2013)
  3) **Invariant-site Approach** (Libya-4, Dome-C, etc.; Bhatt et al. 2012)
  - SCIAMACHY hyperspectral sensor used to account for spectral band differences for the visible channels (Doelling et al. 2013)
  - IASI hyperspectral sensor to be used to account for spectral band differences for the IR channels

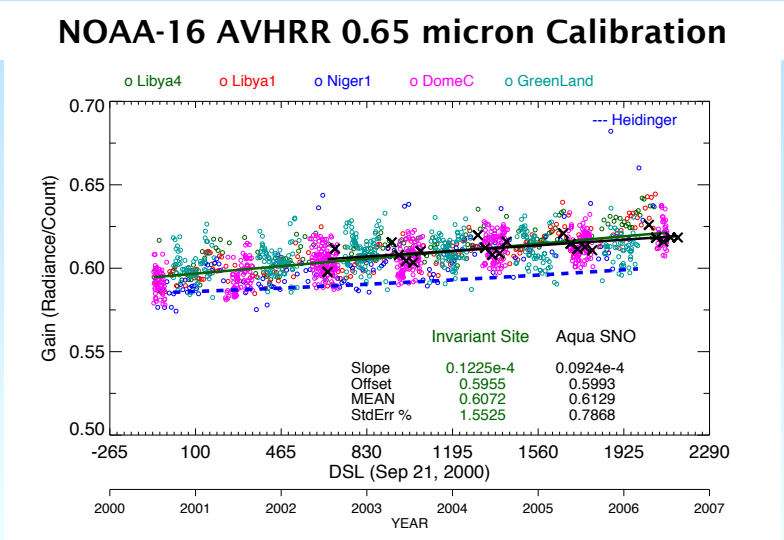
- **Calibration of GEO sensors using the three methods above**
  - Use GEO-provided space count offset
  - Perform monthly calibration transfers to derive monthly gains
  - Compute timeline trend from monthly gains

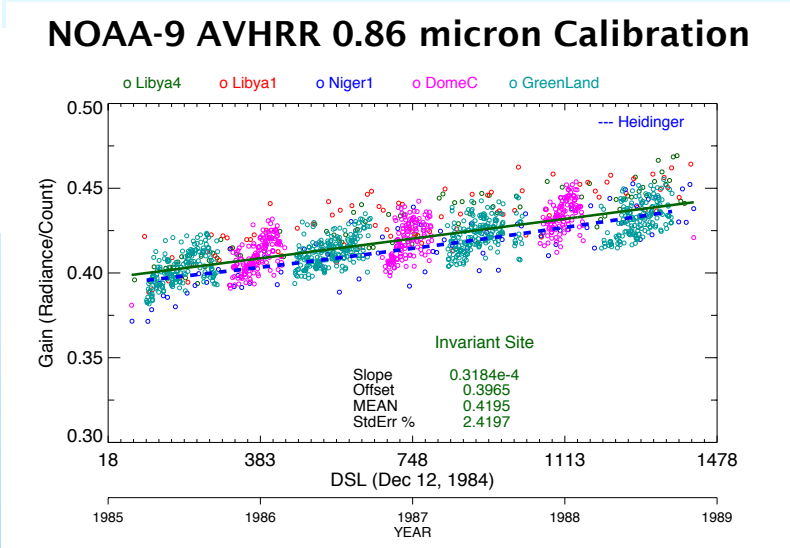
- **Calibration of NOAA AVHRR sensors**
  - **During MODIS timeframe**
    - Simultaneous nadir overpass (SNO) comparisons with MODIS establish standard gain trend
    - Invariant-site and DCC techniques validated by SNO method during AVHRR-MODIS overlap period.
  - **Prior to MODIS, use combination of invariant-site and DCC techniques referenced to Aqua-MODIS to determine AVHRR gain trend**

GEO and AVHRR Calibration Examples

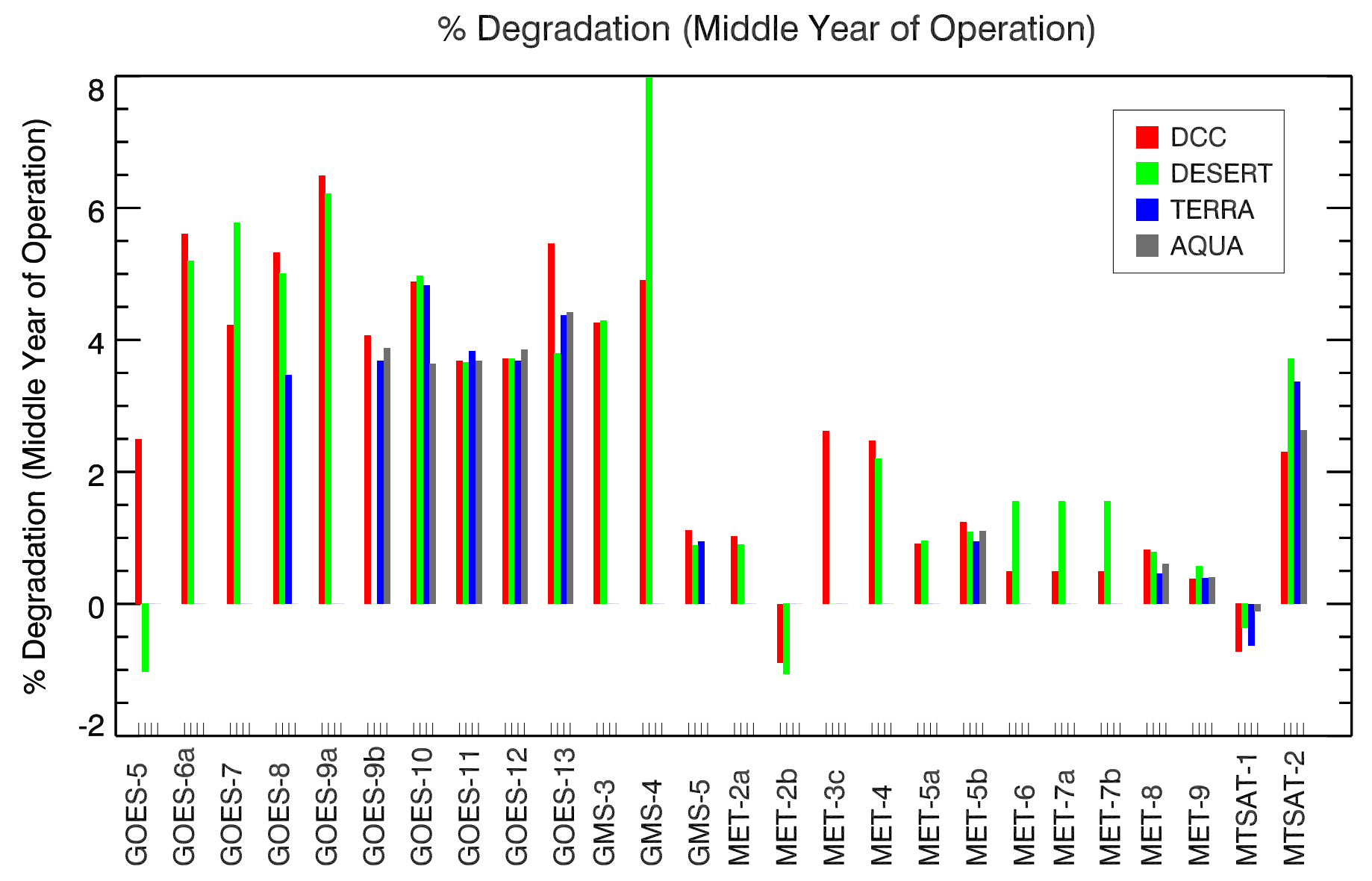








GEO Calibration Summary



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

- Re-navigate, calibrate, and noise filter (pre-NOAA-15 3.7 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, MODIS-ST, PATMOS-X
    - Test and tune using scenes across diverse regions, surface types, and seasons
    - Make changes as necessary, up to 1-hour time difference between A-Train & N18
  - Apply to AVHRR back to TIROS-N (1978-2010)
    - TIROS-N, NOAA-6, -8, and -10 will be processed later due to lack of 12 μm channel
    - Need method for cloud detection/retrieval when 1.6 μm replaces 3.7 μm (N-15/17)

- Adapt CERES Ed4 Cloud Property Retrieval System to AVHRR
  - Adapt algorithm to limited AVHRR channels
  - Apply to AVHRR back to TIROS-N (1978-2010), compare with PATMOS-X and ISCCP

NASA LaRC AVHRR Cloud and Clear-Sky Radiation Property Climate Data Record: Ancillary Inputs

- NASA Modern Era Retrospective Analysis for Research and Applications (MERRA) 3-D thermodynamic and ozone profiles at 42 vertical levels with surface fields and snow/ice cover maps at a 0.5 x 0.66˚ spatial resolution. MERRA data quite comparable to GEOS-5

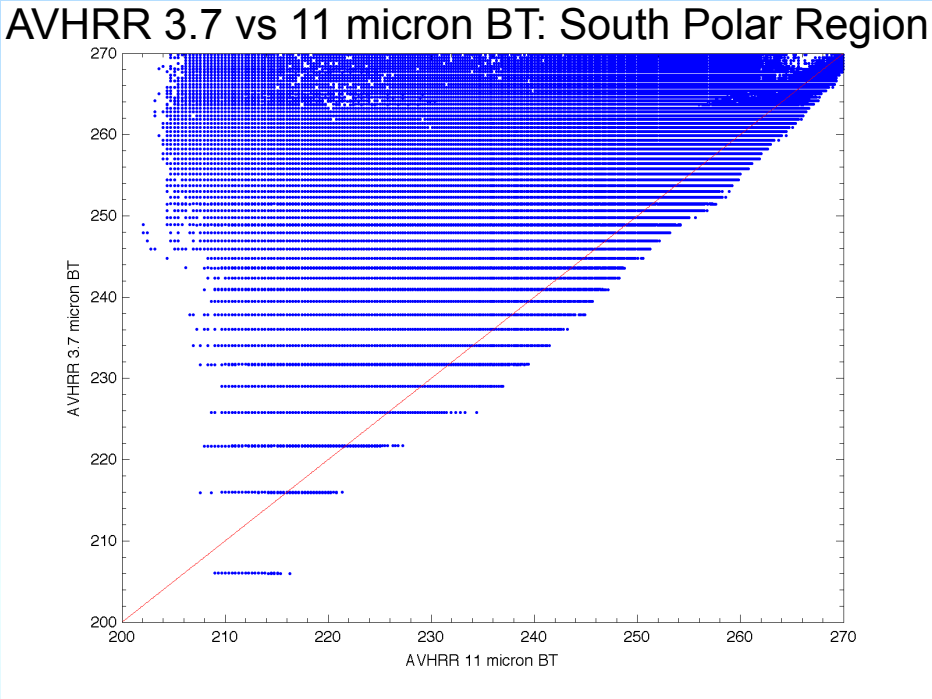
- 10-minute spatial resolution land surface elevation, land and water maps, IGBP ecosystem, and surface emissivity from CERES MODIS framework

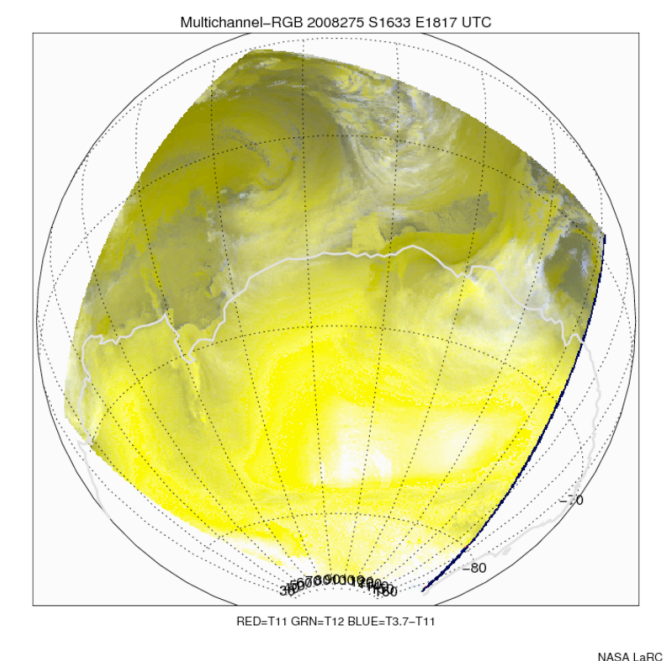
- Dynamically generated clear sky overhead albedo maps based on CERES Ed4 logic and clear-sky AVHRR observations

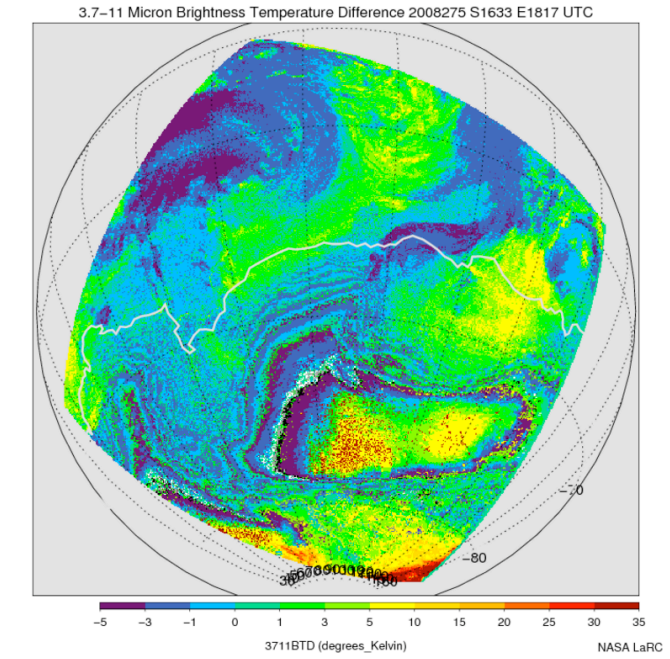
- Cloud microphysical models for spherical water droplets and roughened ice crystals

- Directional and bi-directional reflectance models for IGBP land surface types and ice- or snow-covered surfaces

AVHRR Data Challenges: 3.7 micron Calibration and Noise



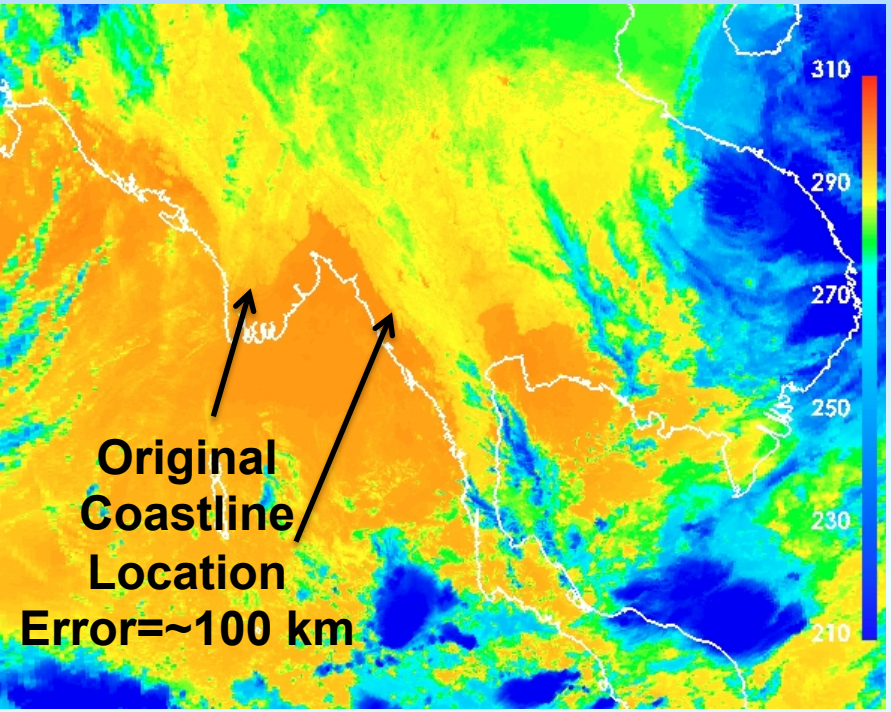


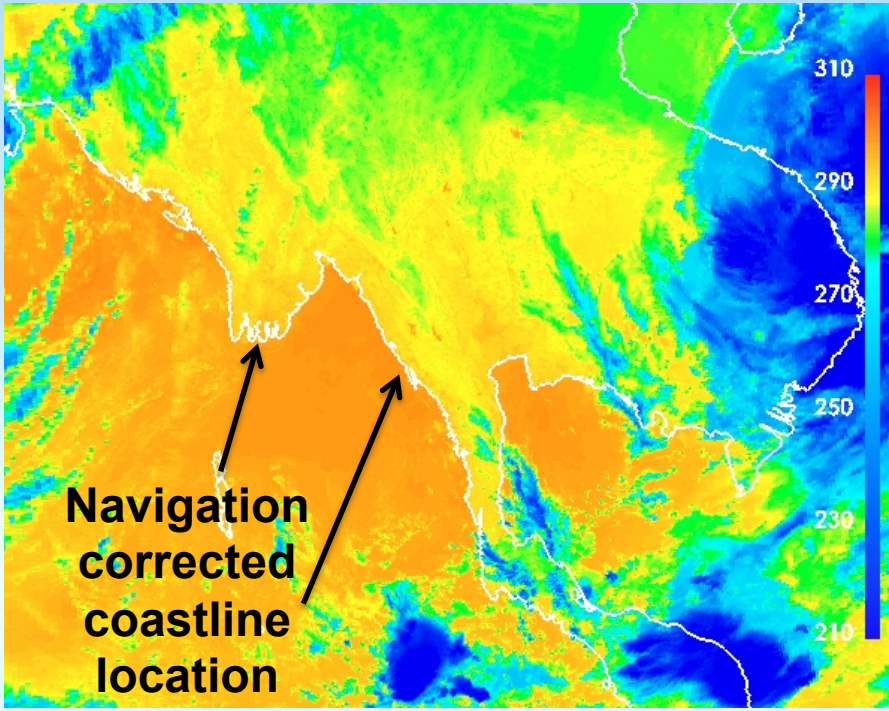


- **AVHRR 3.7 µm BT are "binned" with increasing bin separation at colder temperatures**

- **CERES cloud detection (and retrievals) utilize 3.7 µm information, thus we attempt to minimize errant/noisy results over extremely cold polar scenes using a conservative cloud mask**

AVHRR Data Challenges: Navigation Error

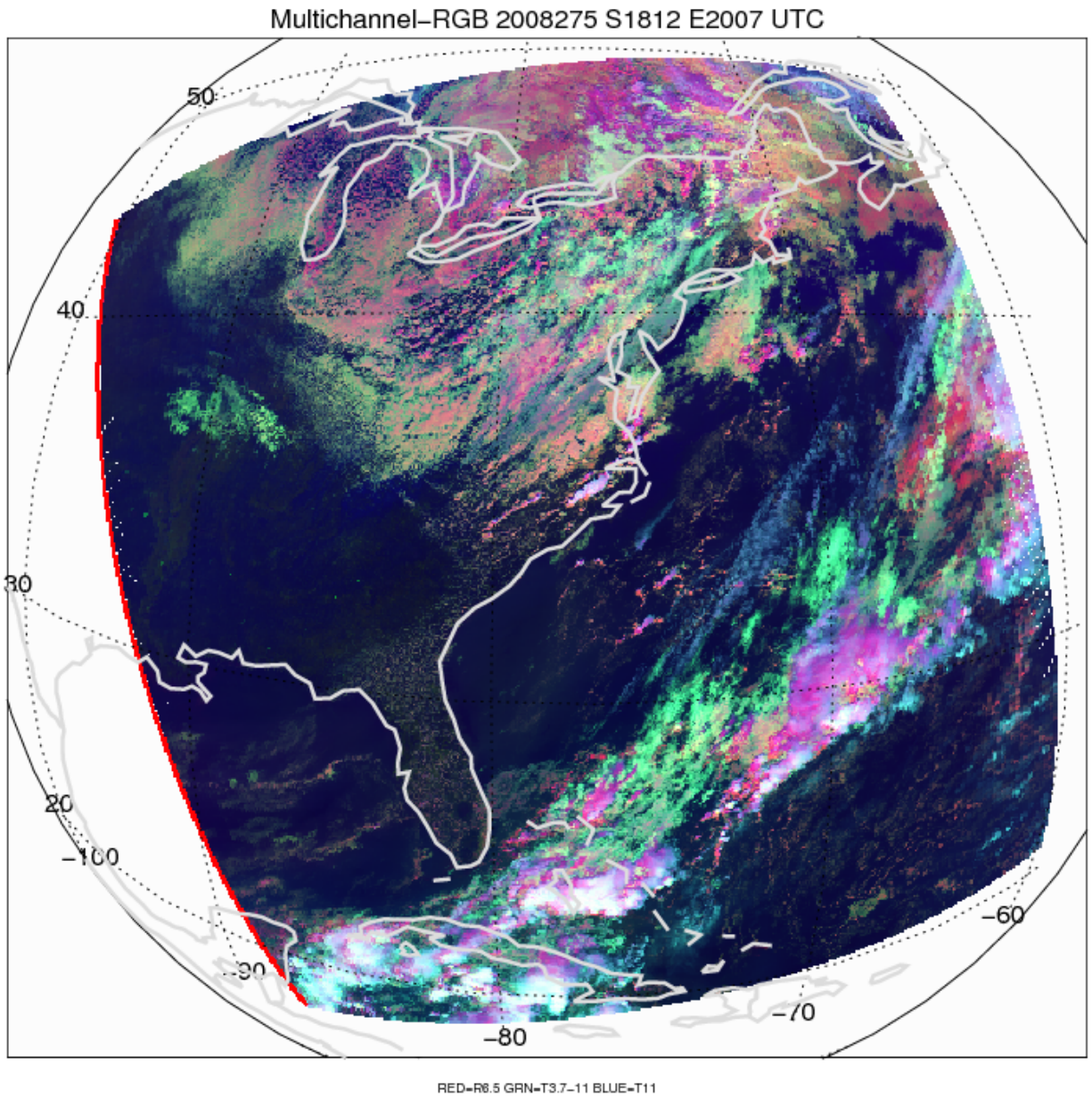




- Navigation error of > 100 km can be present within AVHRR data due to issues such as insufficient knowledge of satellite image acquisition times and satellite attitude angles, in additon to limited accuracy of orbit modeling

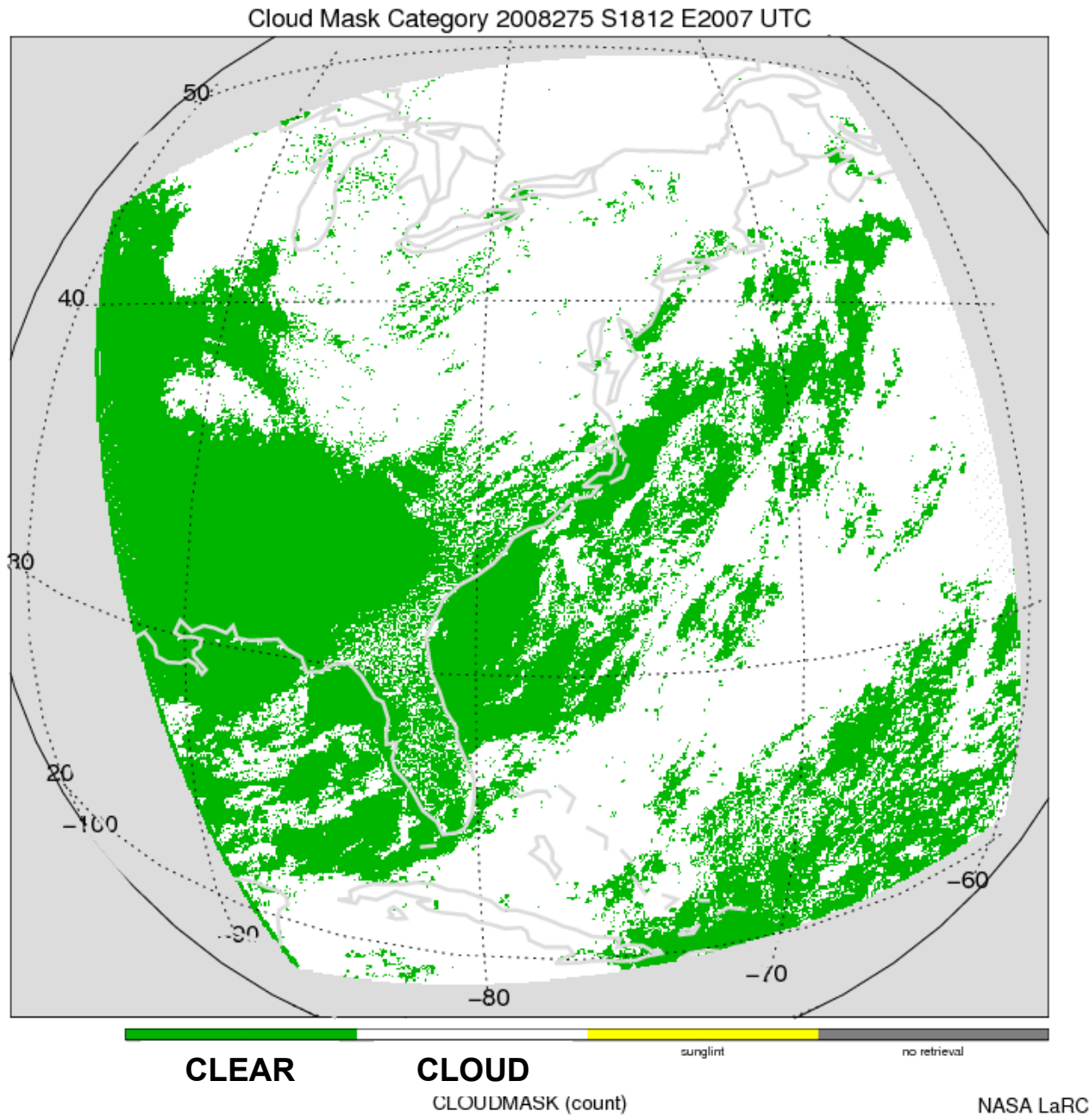
- Global database of ground control points used to correct navigation to within 1/3 of an AVHRR Global Area Coverage FOV (1-2 km)

AVHRR Product Examples: 3-Channel False Color Composite

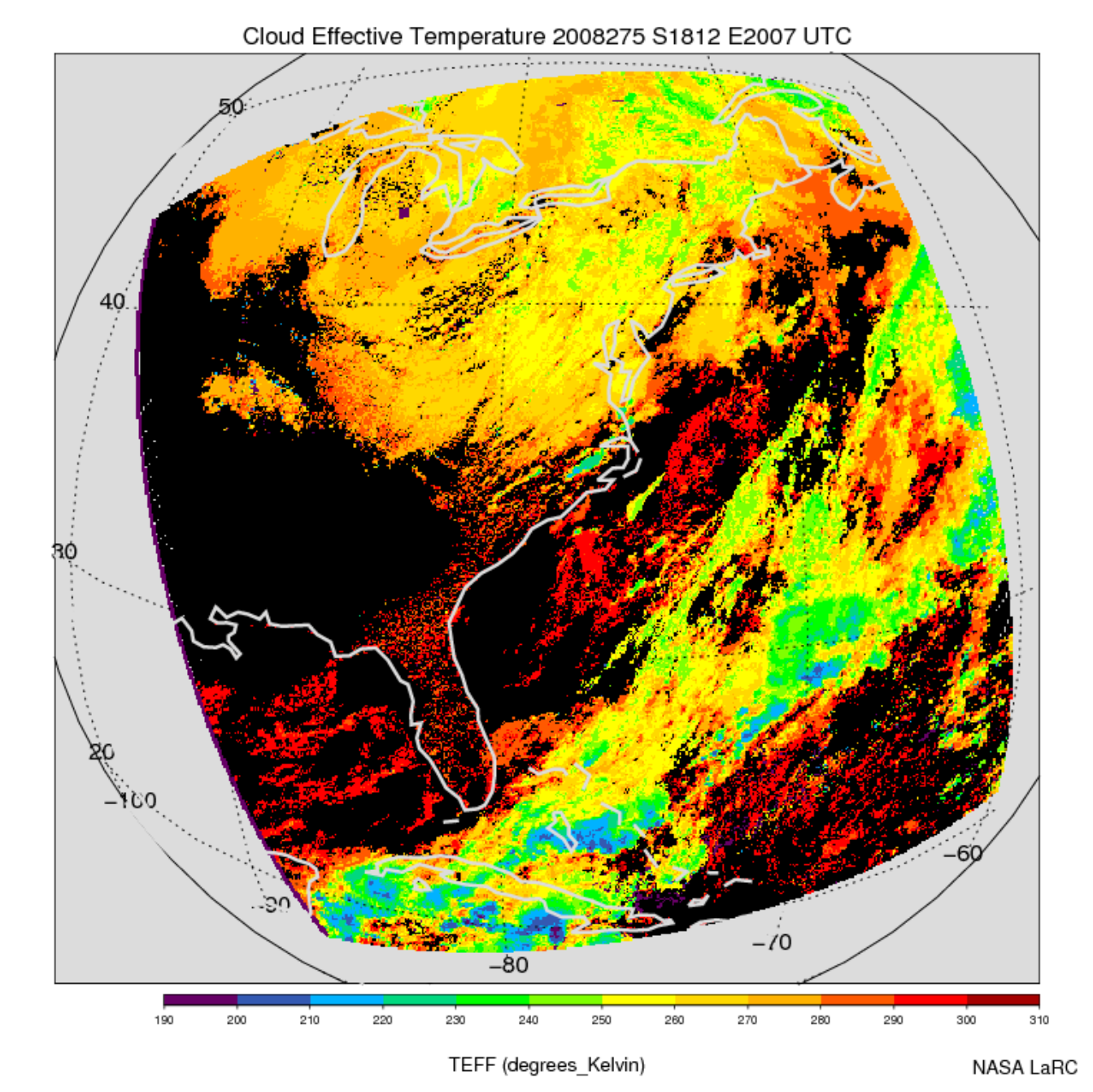


NASA LaRC

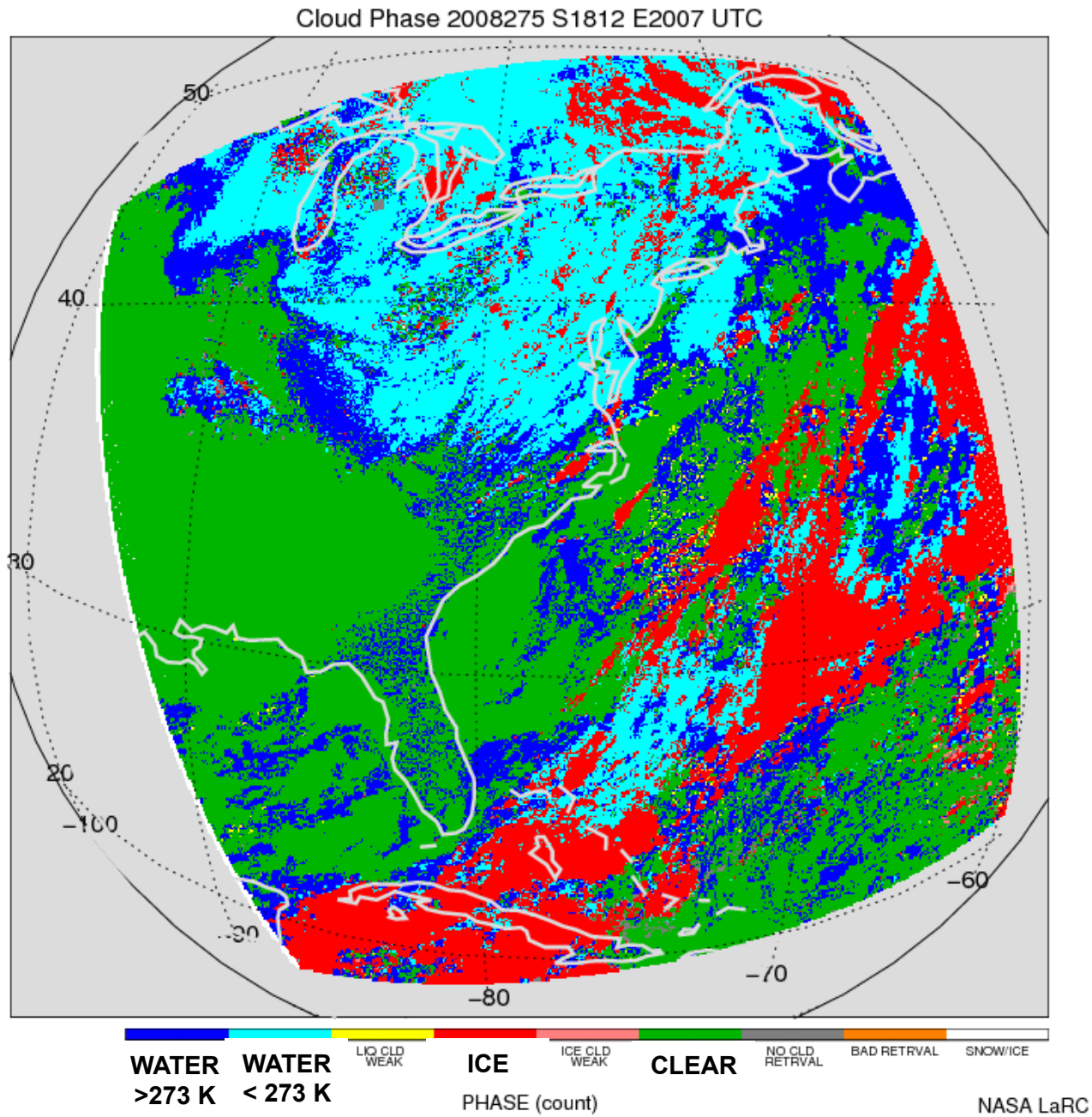
AVHRR Product Examples: Cloud Mask



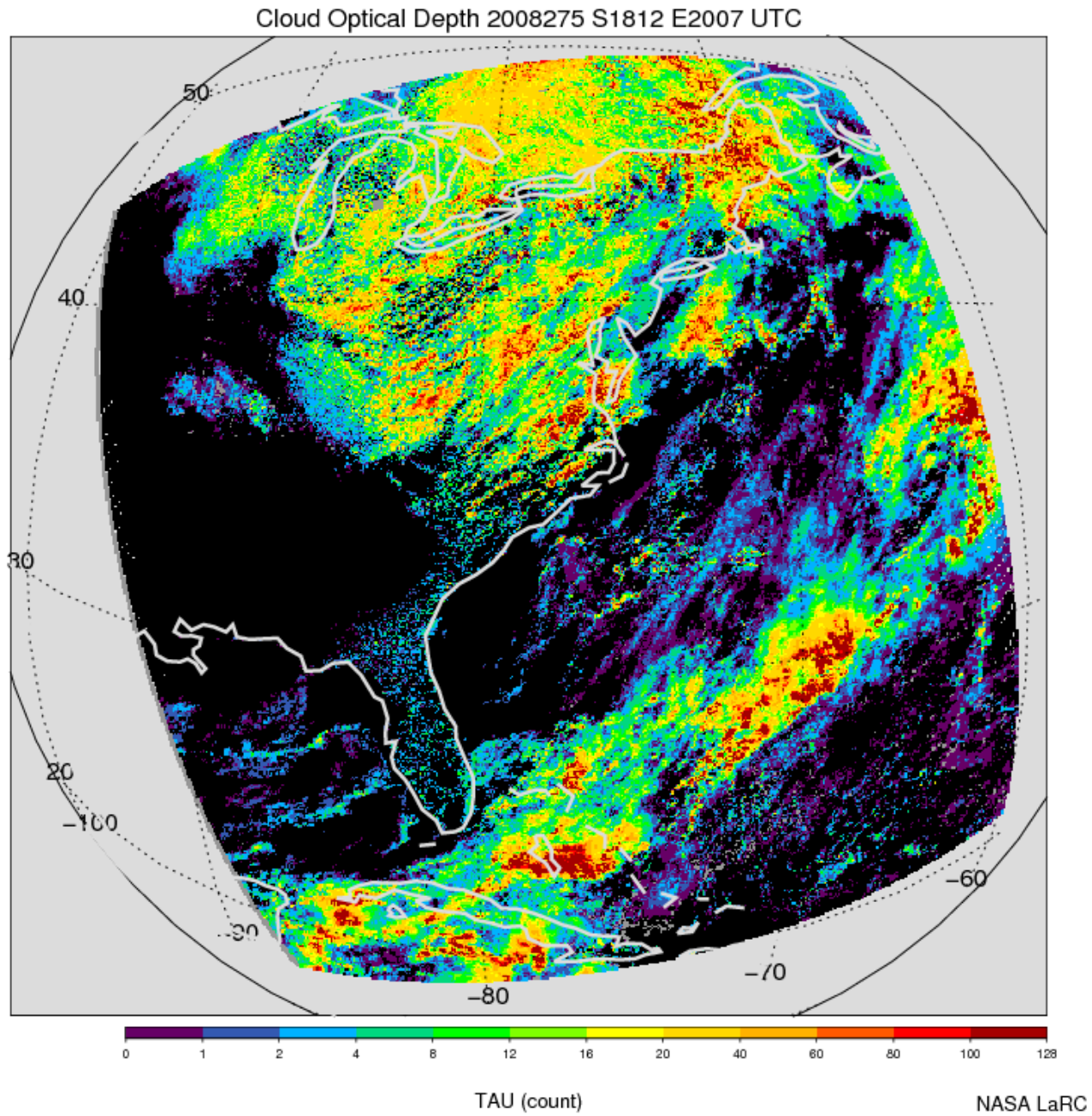
AVHRR Product Examples: Effective Cloud Temperature



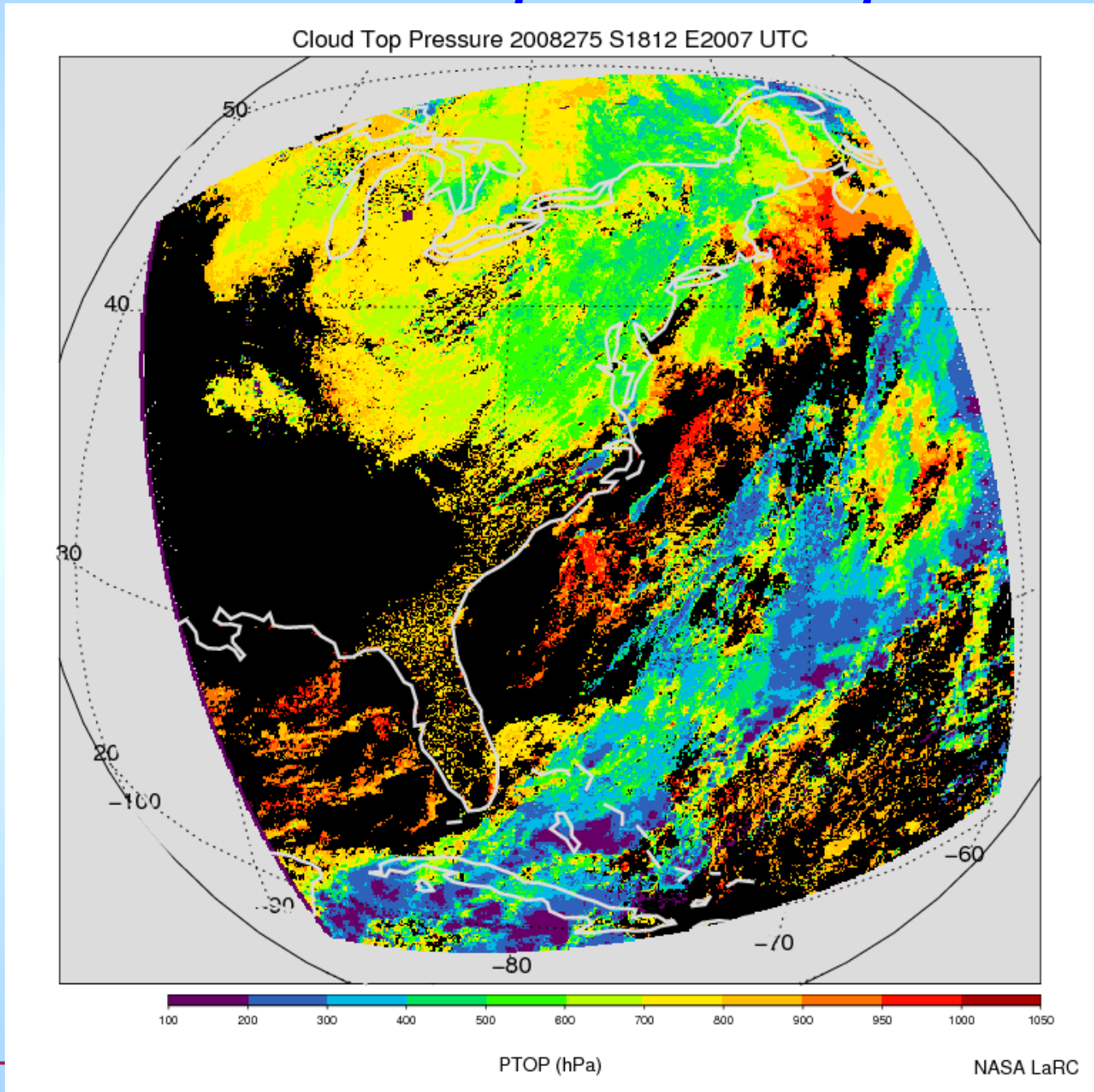
AVHRR Product Examples: Cloud Phase



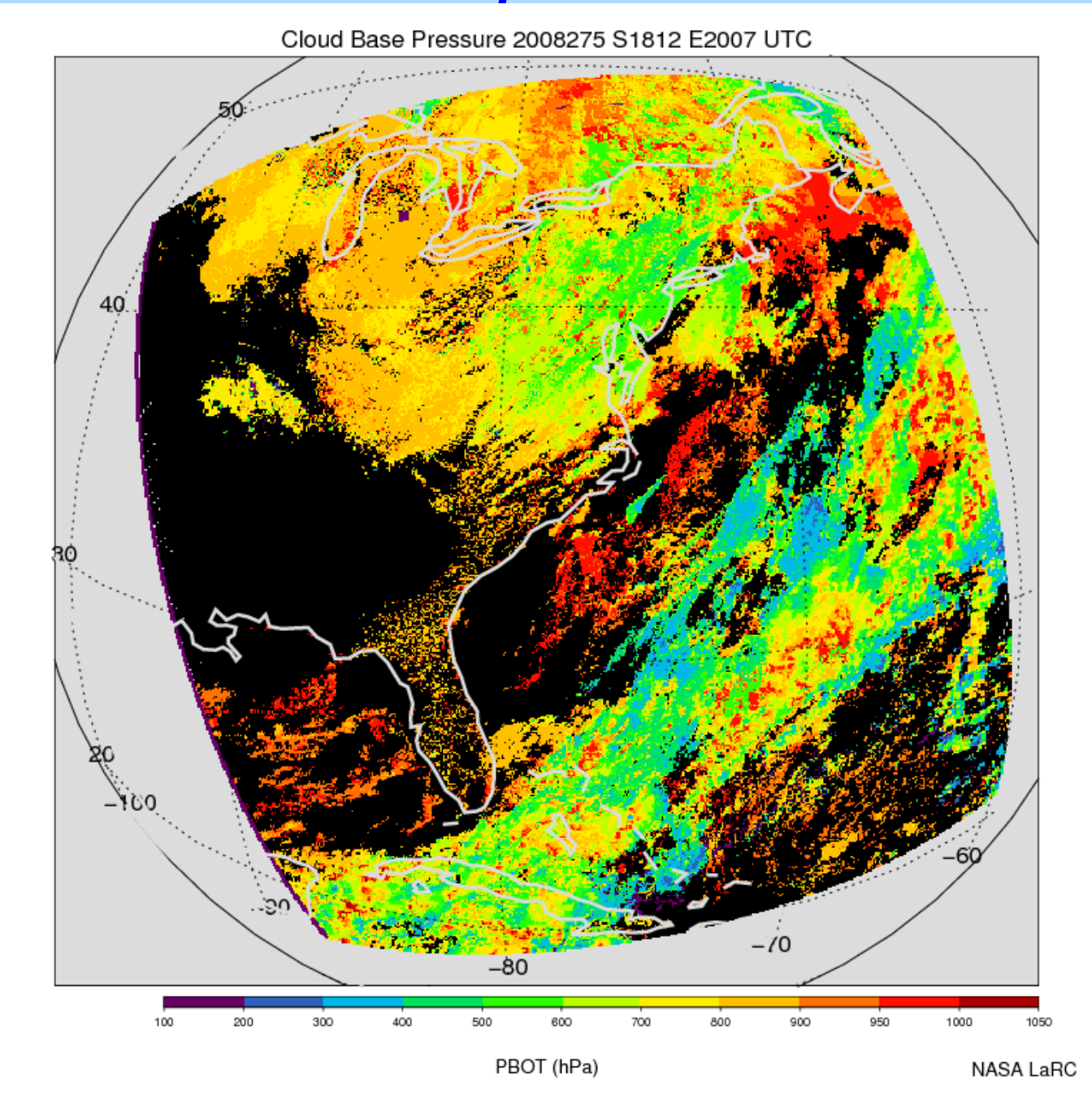
AVHRR Product Examples: Cloud Optical Depth



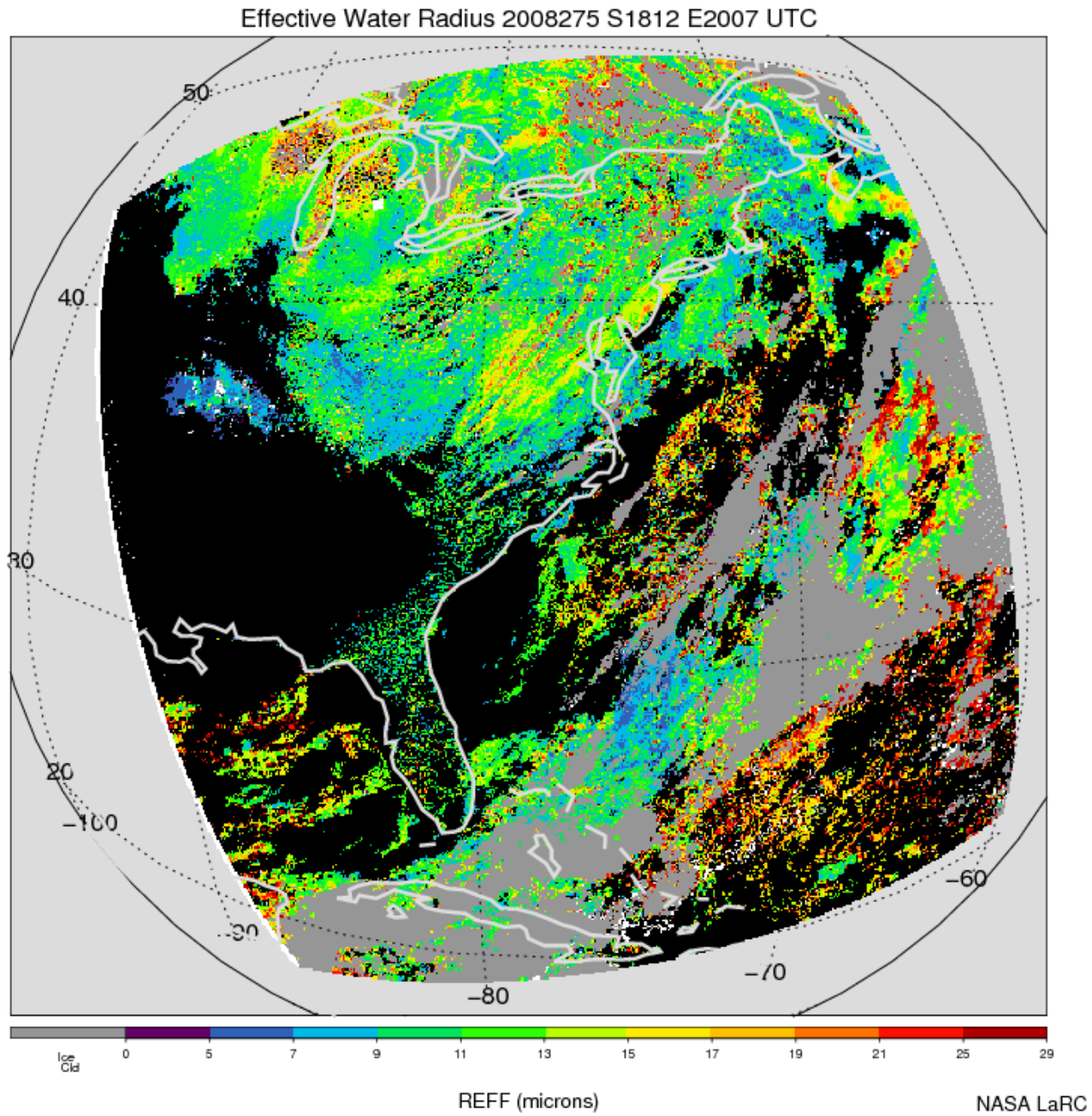
AVHRR Product Examples: Cloud Top Pressure



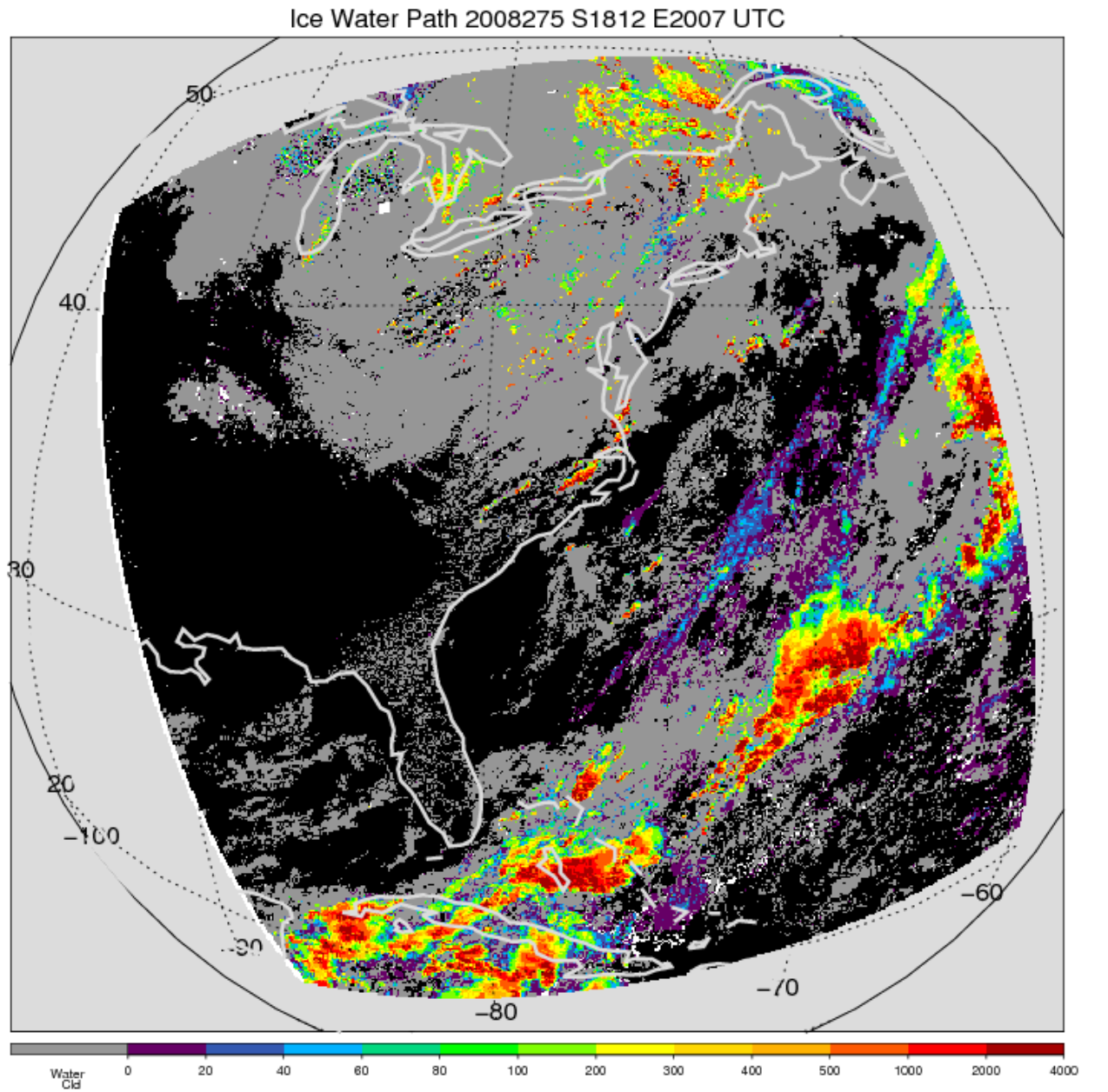
AVHRR Product Examples: Cloud Base Pressure



AVHRR Product Examples: Water Droplet Effective Radius



AVHRR Product Examples: Ice Water Path



Objective Overshooting Convective Cloud Top (OT) Detection

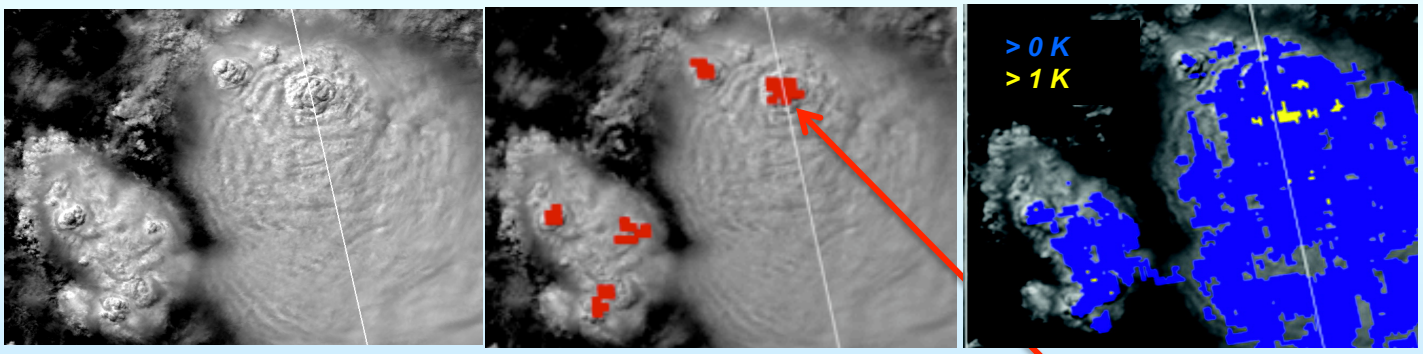
- A method to objectively detect overshooting convective cloud tops using IR imagery was initiated within the NASA Applied Sciences program for aviation safety applications and was completed by the GOES-R ABI Algorithm Working Group (Bedka et al. 2010-2012)

- This objective OT detection algorithm utilizes IR BT and spatial gradient thresholding with NWP tropopause temperature information to identify OTs at their characteristic spatial scale

- OT detection output is used within the CERES Ed4 and LaRC AVHRR frameworks to elevate cloud top heights above the tropopause based on difference between 11 μm BT and tropopause temp, using 8 K/km lapse rate derived from CloudSat and MODIS OT observations

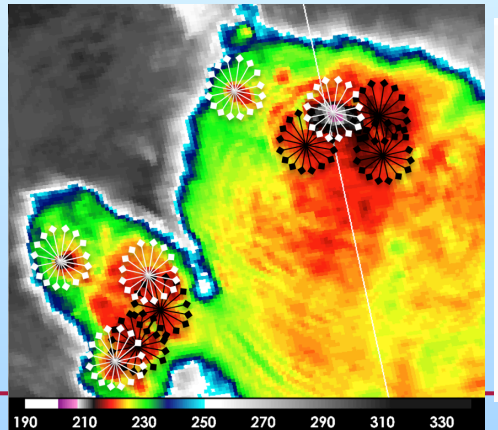
MODIS 250 m Visible and 1 km IR Window With Overshooting Top Detections

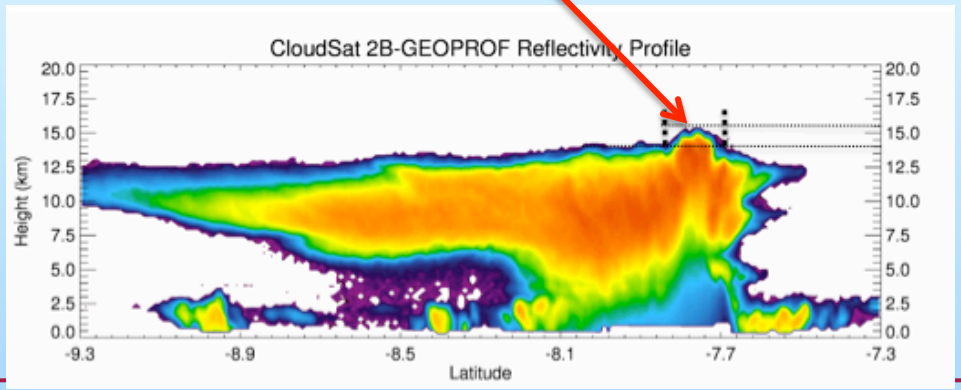
MODIS 1 km WV-IR BT Difference > 0 K



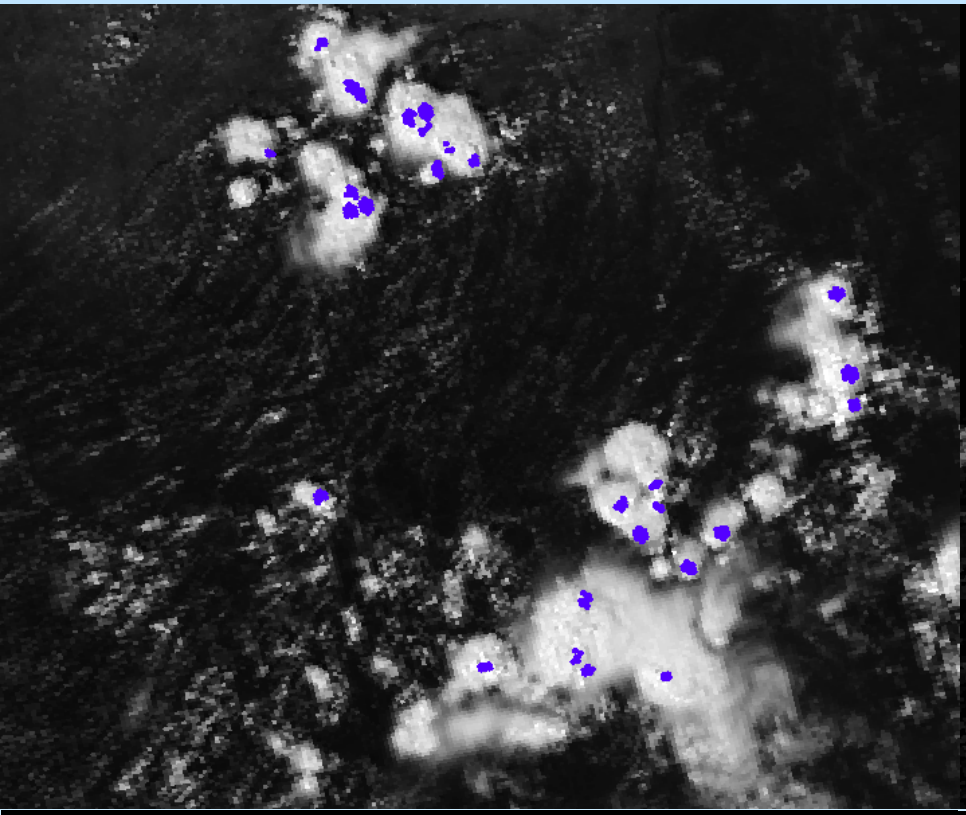
White: Region meets OT detection criteria

Black: Region not cold enough relative to surrounding anvil

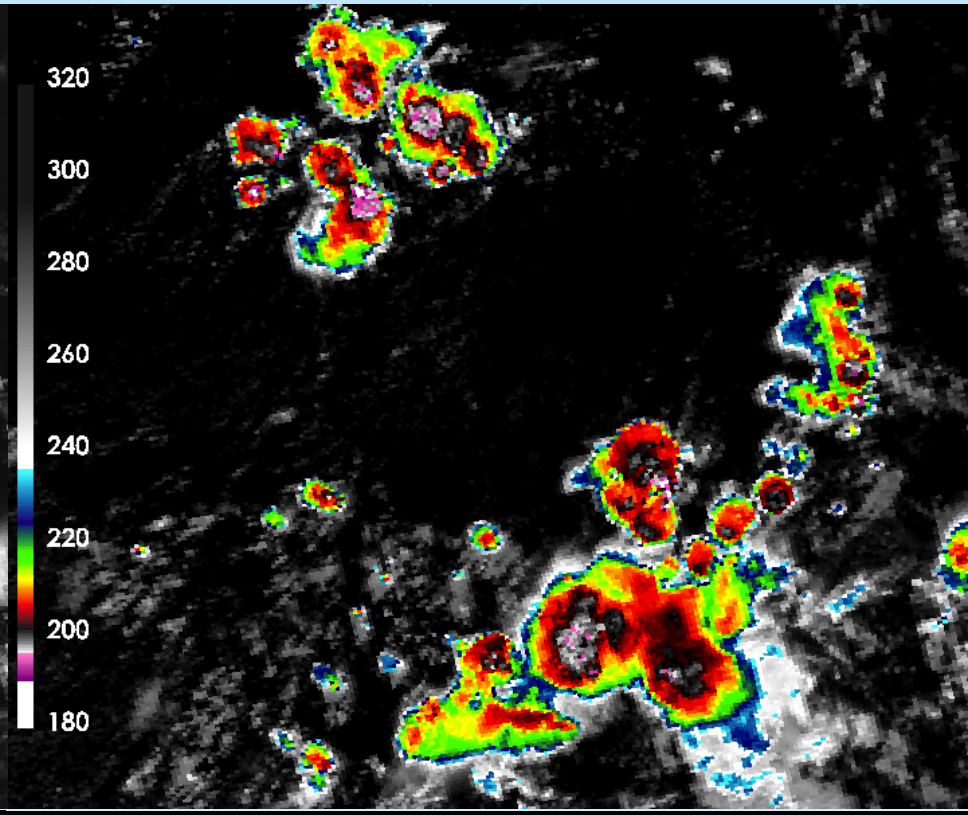




Objective Overshooting Convective Cloud Top Detection: NOAA-18 over The Congo



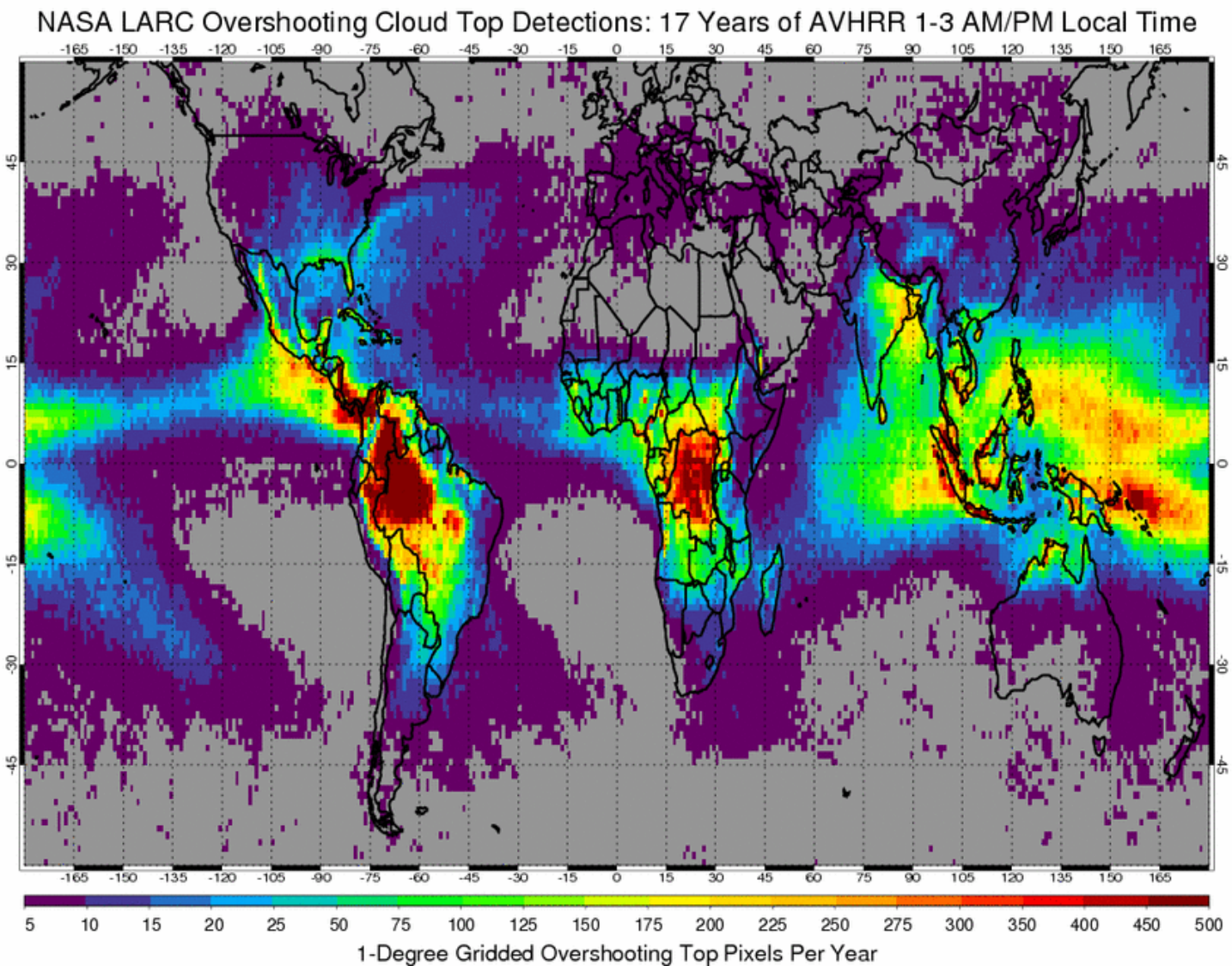
Overshooting Top Detections
atop NOAA-9 Visible



NOAA-9 Color Enhanced IR Window

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

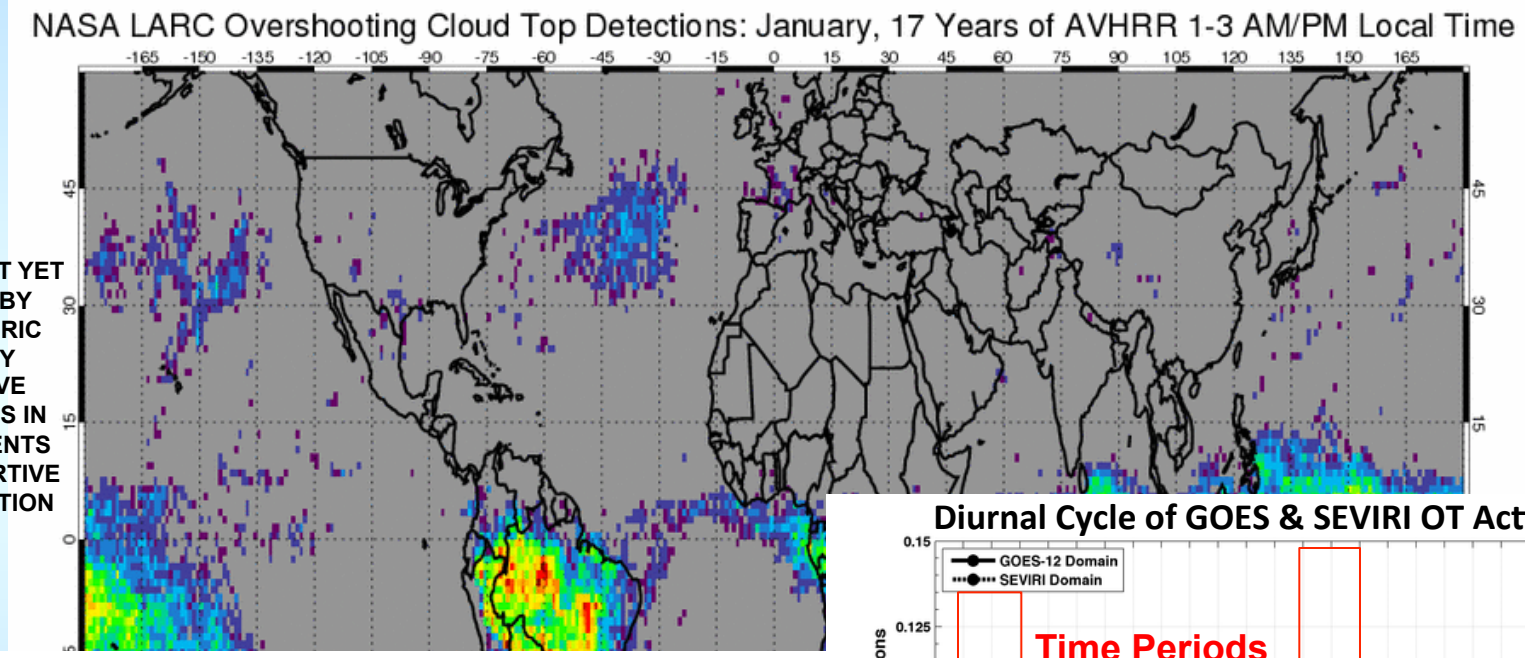
OT detections will be produced for all AVHRR observations from 1978-2010 within a Cloud Property Climate Data Record being developed at NASA LaRC

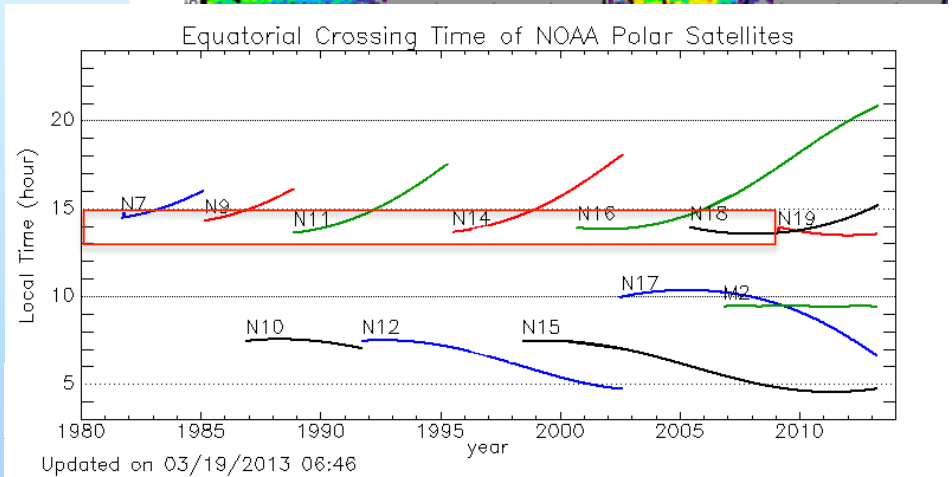


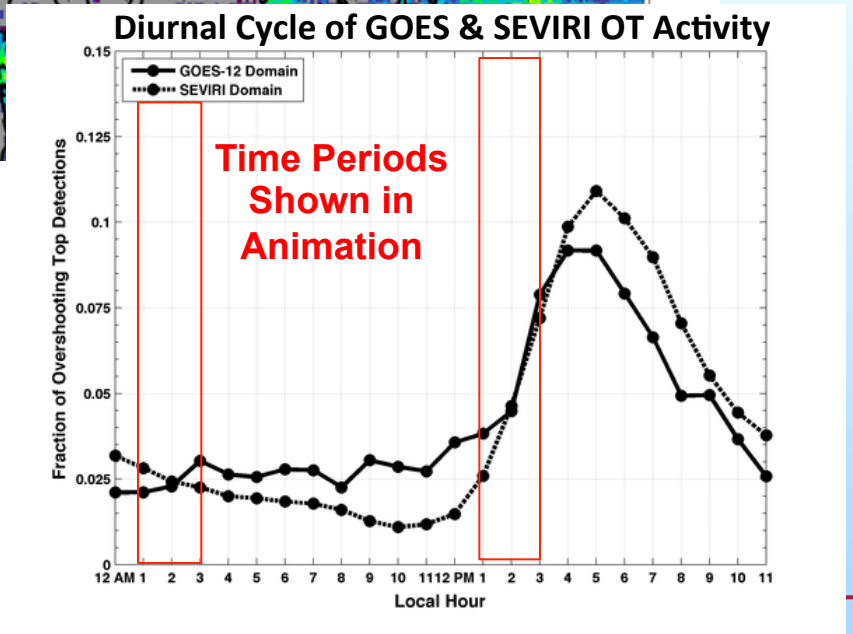
NOAA AVHRR Global Gridded Overshooting Top Detections 0100-0300 AM/PM Local Time, 17 Years of Orbits

OT detections will be produced for all AVHRR observations from 1978-2010 within a Cloud Property Climate Data Record being developed at NASA LaRC

NOTE
RESULTS NOT YET FILTERED BY ATMOSPHERIC STABILITY TO REMOVE DETECTIONS IN ENVIRONMENTS NOT SUPPORTIVE OF CONVECTION

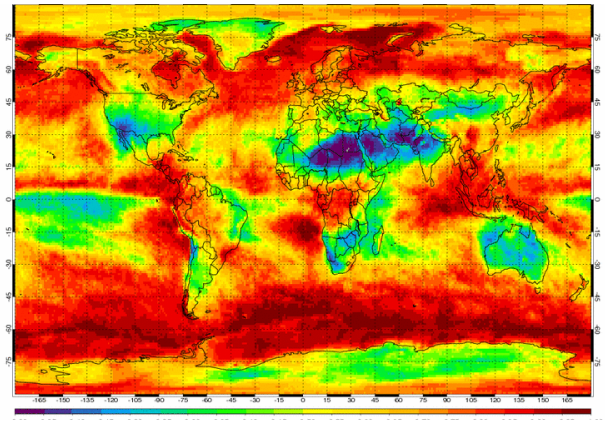




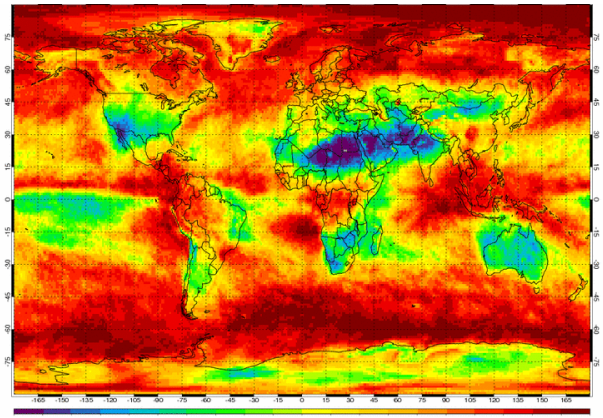


Global Cloud Fraction: October 2008, Day+Night

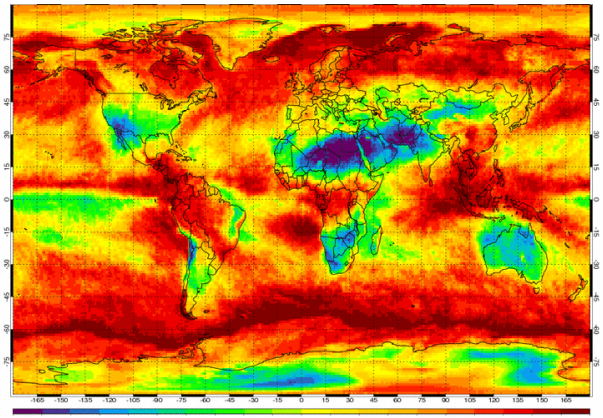
LaRC NOAA-18



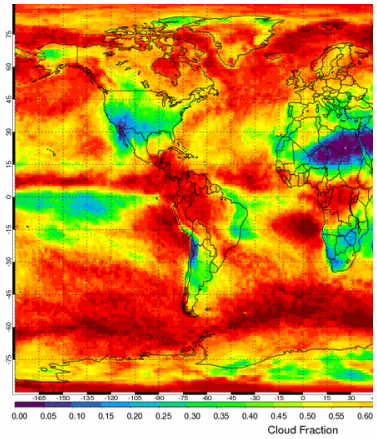
CERES Edition 4

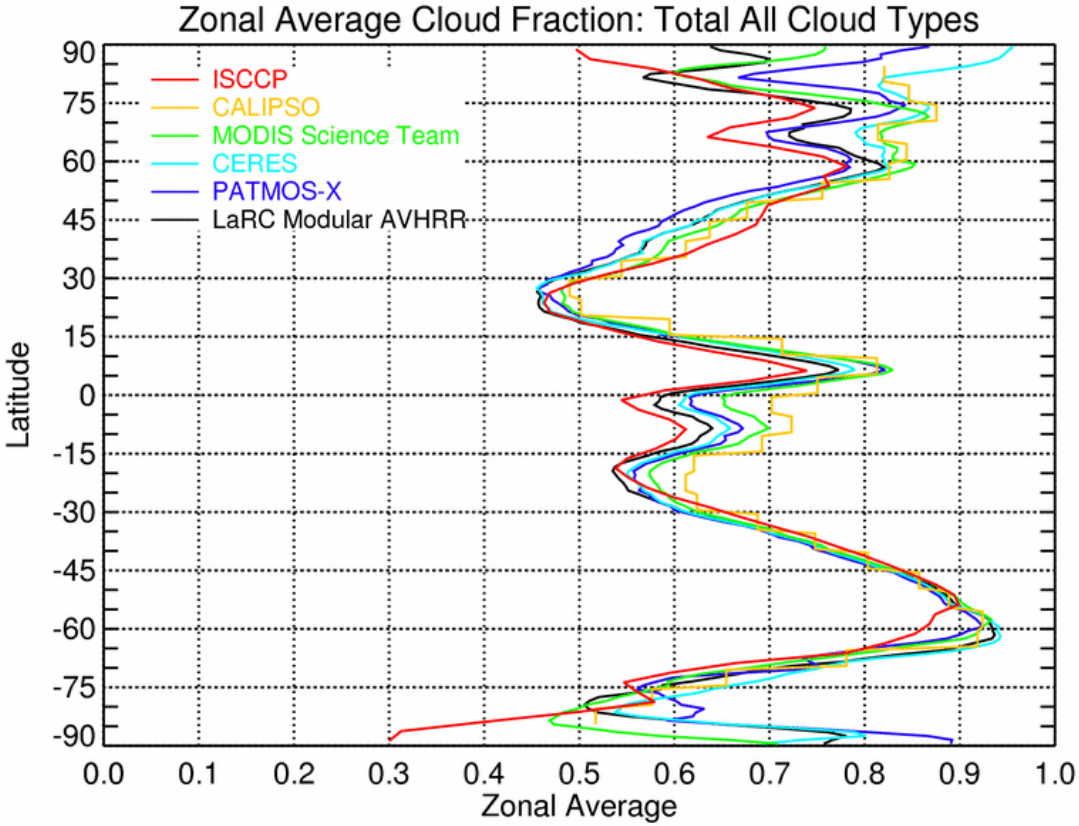


MODIS Science Team (Col. 5)

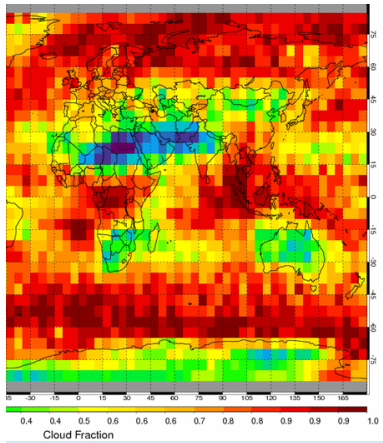


PATMOS





CALIPSO



Cloud Fraction	-ST	CALIPSO
Day		0.679
Night		0.729

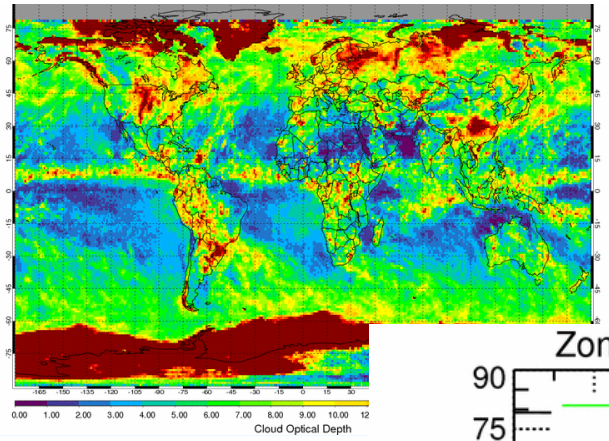
NASA LaRC AVHRR Cloud Mask Validation vs. CALIPSO

October 2008 NASA LaRC AVHRR Cloud Mask Validation vs. CALIPSO	% of Clear and Cloudy AVHRR Pixels Correctly Identified
Polar Day Land Polar Day Water	83.0% 91.7%
Polar Night Land Polar Night Water	72.7% 84.1%
Mid-Lat Day Land Mid-Lat Day Water	87.4% 88.5%
Mid-Lat Night Land Mid-Lat Night Water	87.1% 89.8%
Tropical Day Land Tropical Day Water	84.3% 84.4%
Tropical Night Land Tropical Night Water	86.0% 86.3%

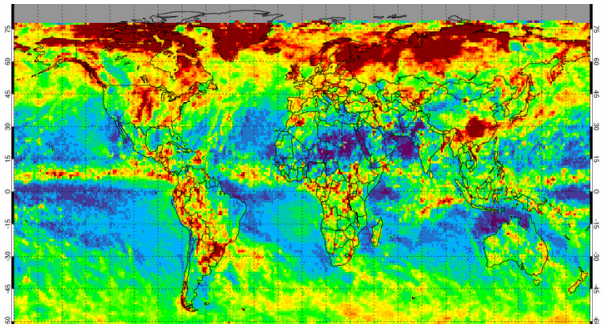
Percentages similar to CERES-CALIPSO comparisons

Monthly Average Cloud Optical Depth October 2008, Daytime

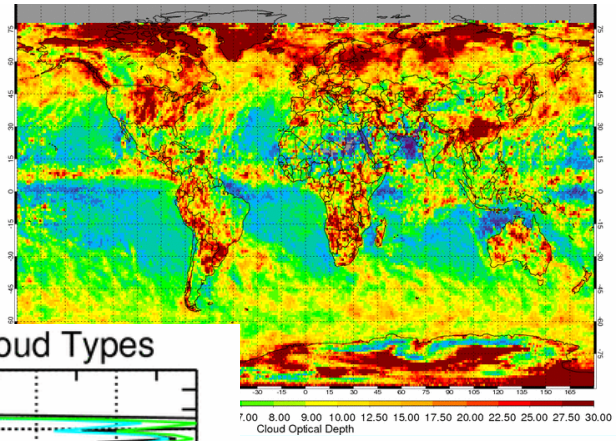
LaRC NOAA-18



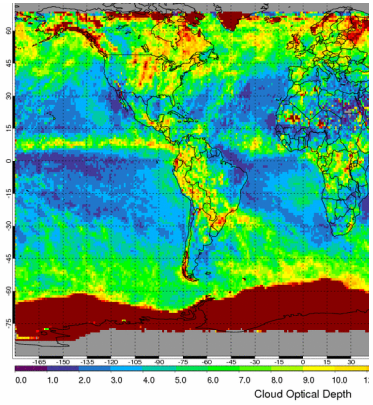
CERES Edition 4

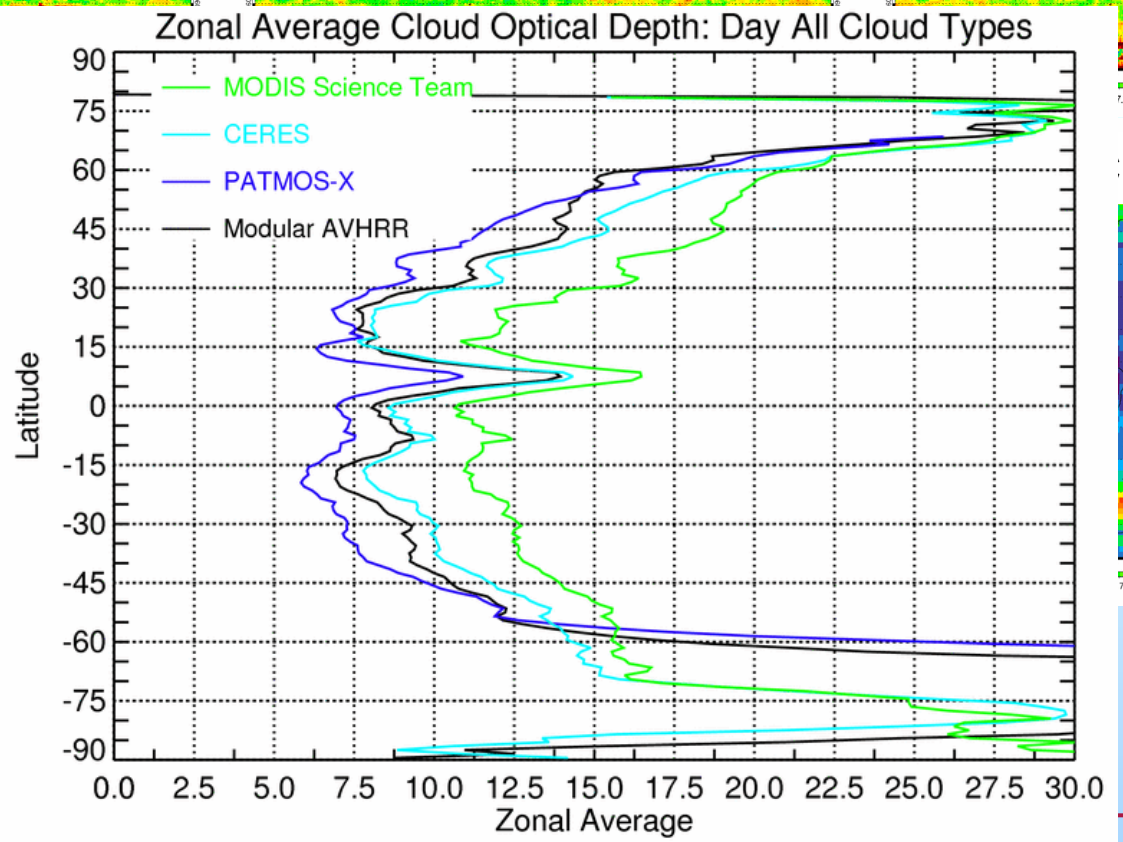


MODIS Science Team (Col. 5)

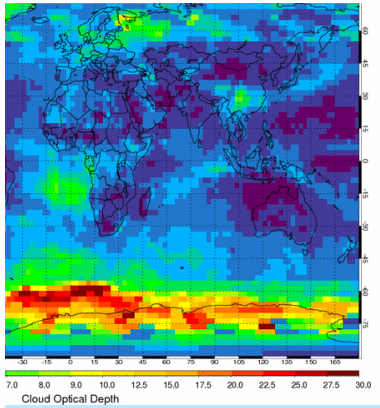


PATMOS





P (Units=?)



Impact of Spatial Resolution on Cloud Property Retrievals U.S. Central Plains, Aqua MODIS, April 2008

CLOUD FRACTION						
	WATER			ICE		
	1km	2km	4km	1km	2km	4km
Day	0.29	0.30	0.30	0.17	0.17	0.18
Night	0.17	0.17	0.17	0.32	0.32	0.32
Total	0.23	0.24	0.24	0.24	0.24	0.25

Domain-averaged cloud fraction not changing with resolution

CLOUD PRESSURE						
	WATER			ICE		
	1km	2km	4km	1km	2km	4km
Day	693.21	699.37	707.20	400.36	404.42	410.41
Night	763.35	763.67	765.26	317.67	319.20	322.5
Total	720.44	723.82	728.99	345.94	348.79	353.83

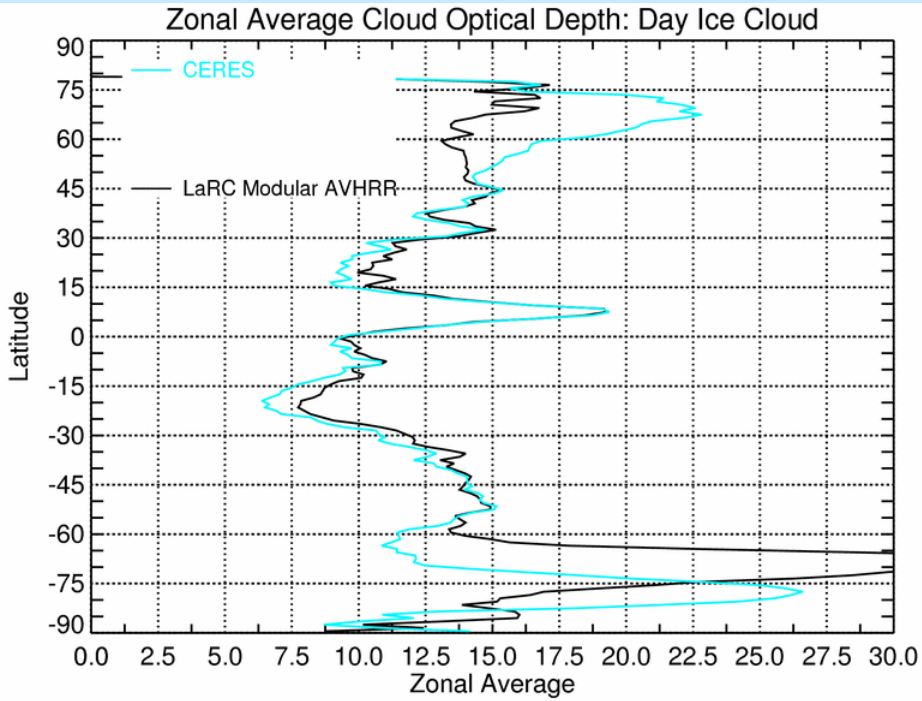
Cloud heights lower at 4 km for both water and ice

OPTICAL DEPTH						
	WATER			ICE		
	1km	2km	4km	1km	2km	4km
Day	20.19	18.95	17.62	23.76	23.54	23.47
Night	11.56	11.28	10.80	5.78	5.71	5.64
Total	17.08	16.24	15.25	12.12	12.08	12.1

COD reduced by 11% at 4-km resolution only for water clouds

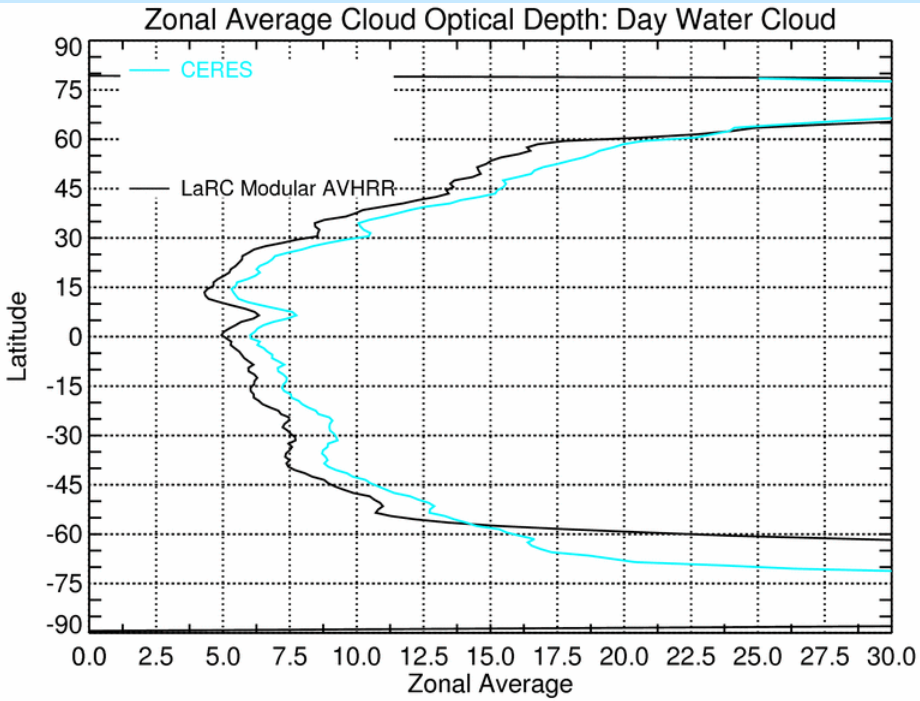
AVHRR/CERES Zonal Average Cloud Optical Depth Ice vs. Water Cloud

ICE CLOUD



- Good agreement over the tropics and mid-latitudes for ice clouds

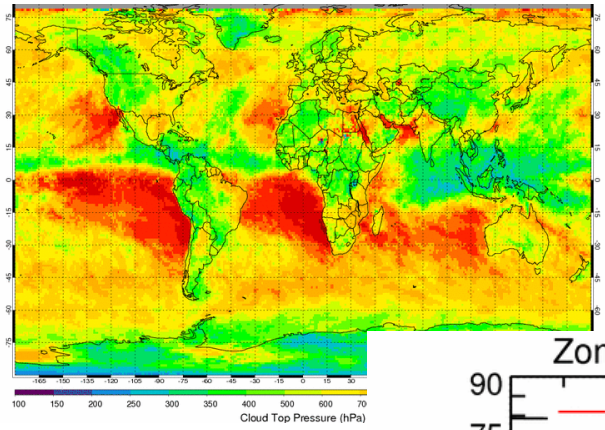
WATER CLOUD



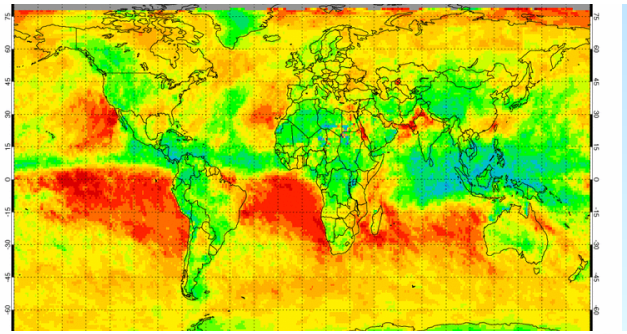
- CERES optical depth higher in all non-polar regions for water clouds

Monthly Average Cloud Top Pressure October 2008, Daytime

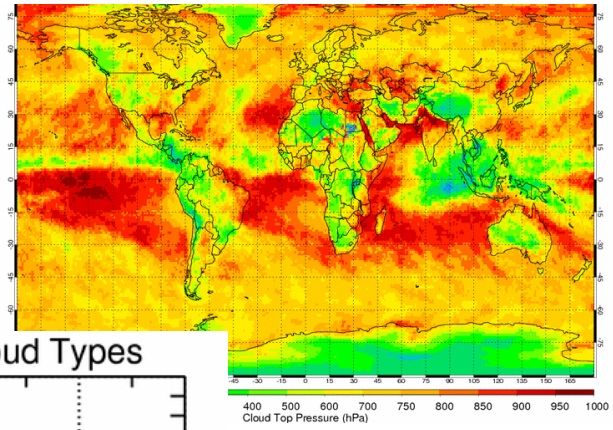
LaRC NOAA-18



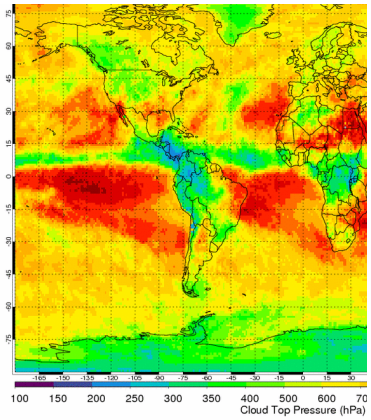
CERES Edition 4

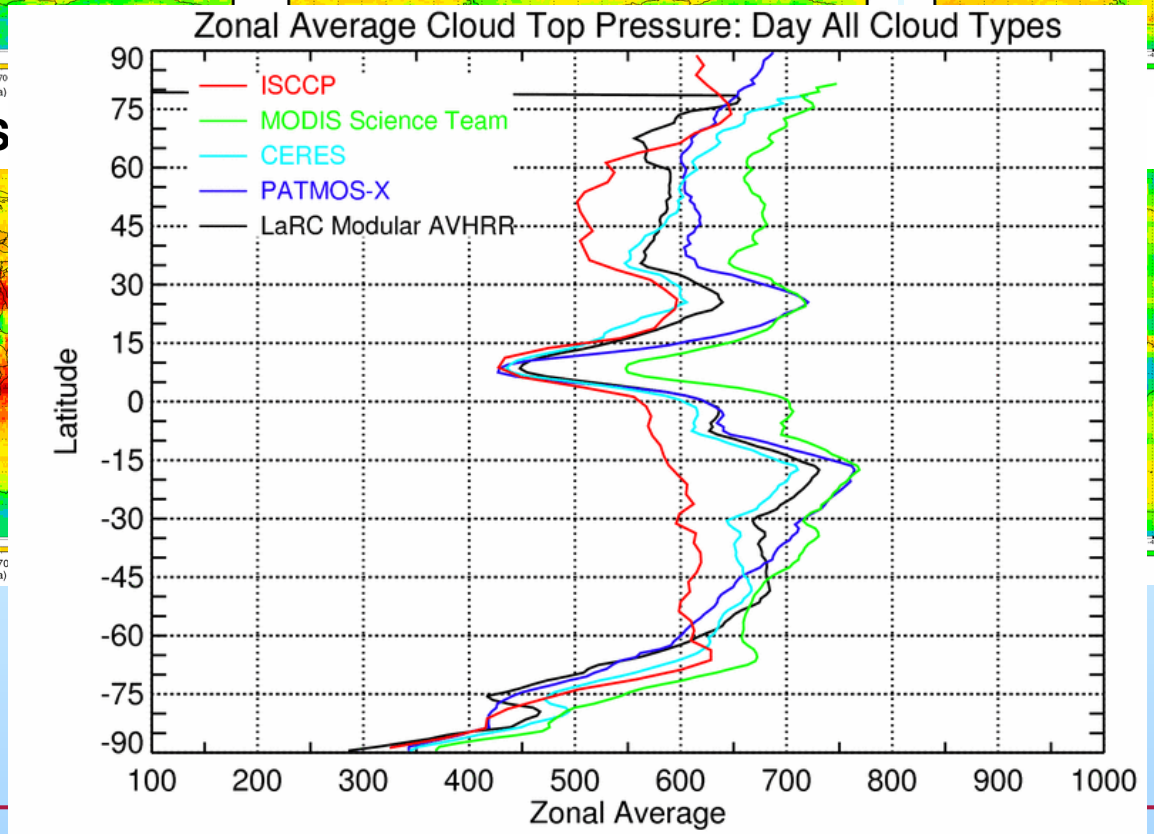


MODIS Science Team

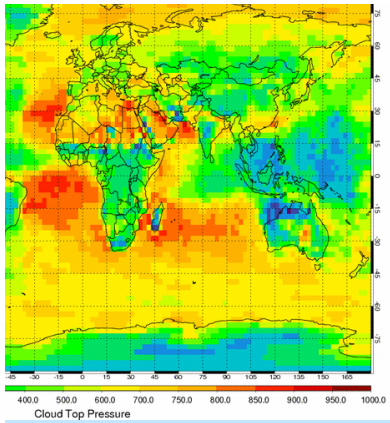


PATMOS





ISCCP



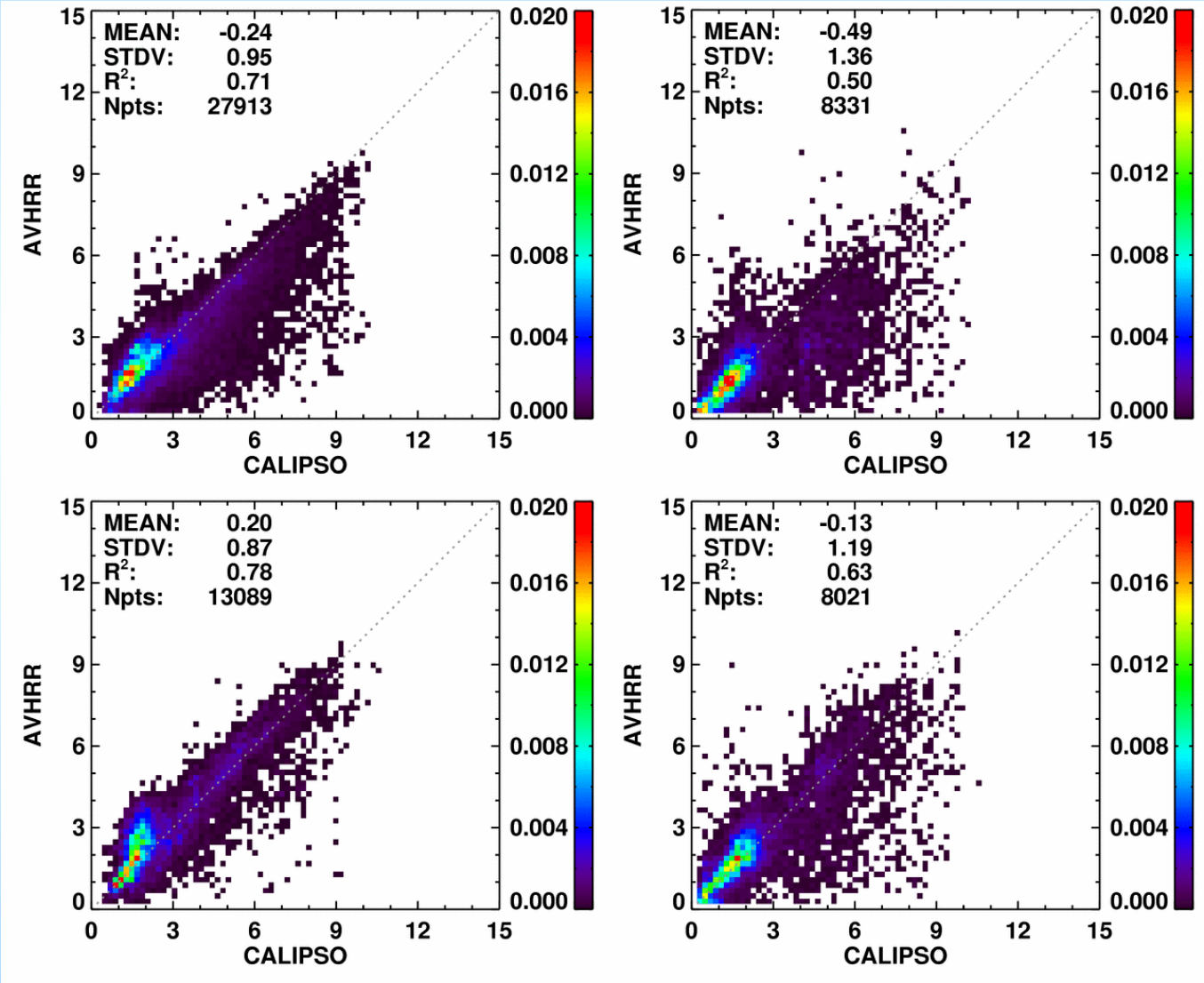
Pixel Level Cloud Top Height Validation Using CALIPSO, October 2008: WATER CLOUD

Optically Thick (τ > 8) Water Cloud

Optically Thin Water Cloud

Daytime

Night-time



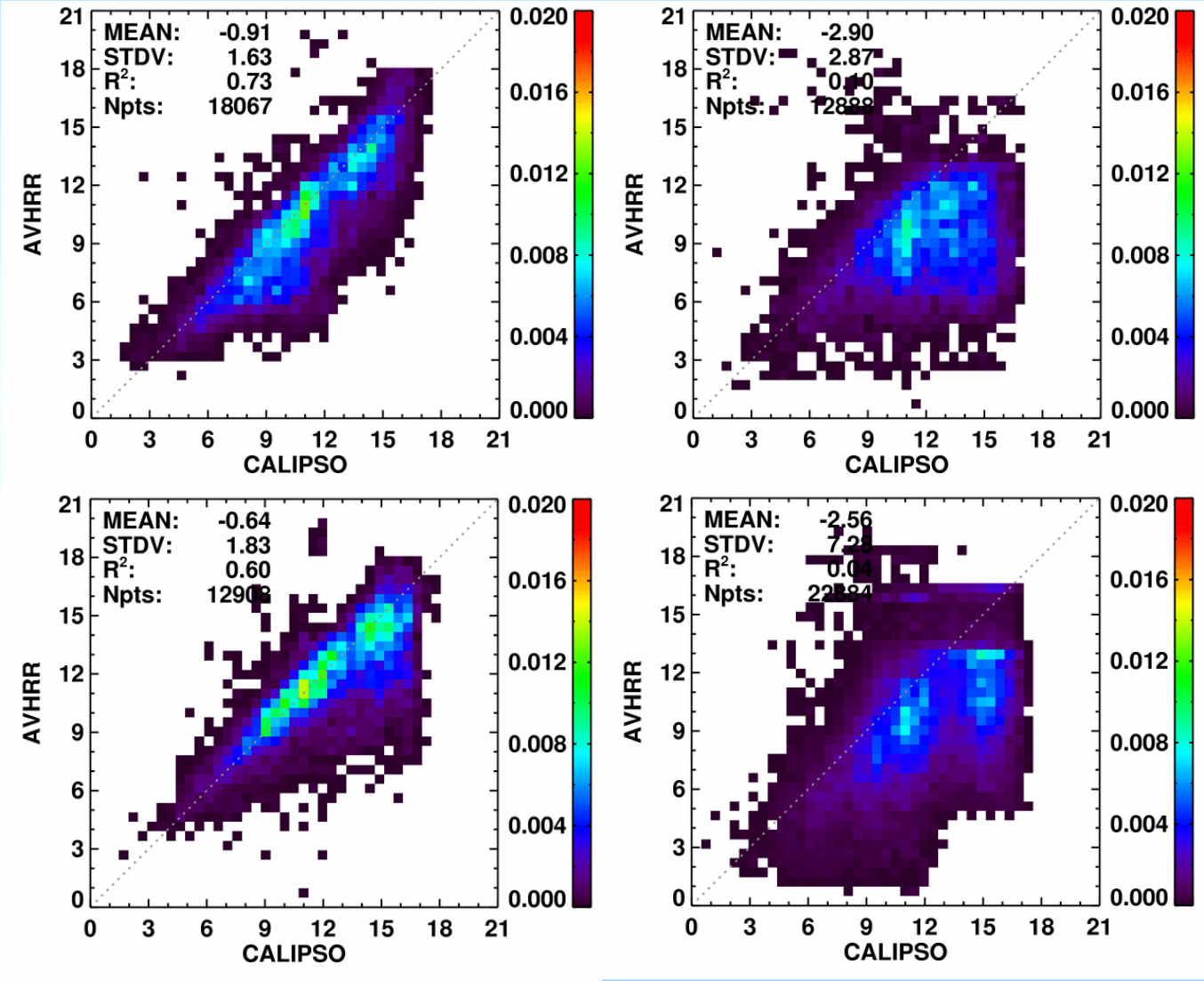
Pixel Level Cloud Top Height Validation Using CALIPSO, October 2008: ICE CLOUD

Optically Thick (τ > 8) Ice Cloud

Optically Thin Ice Cloud

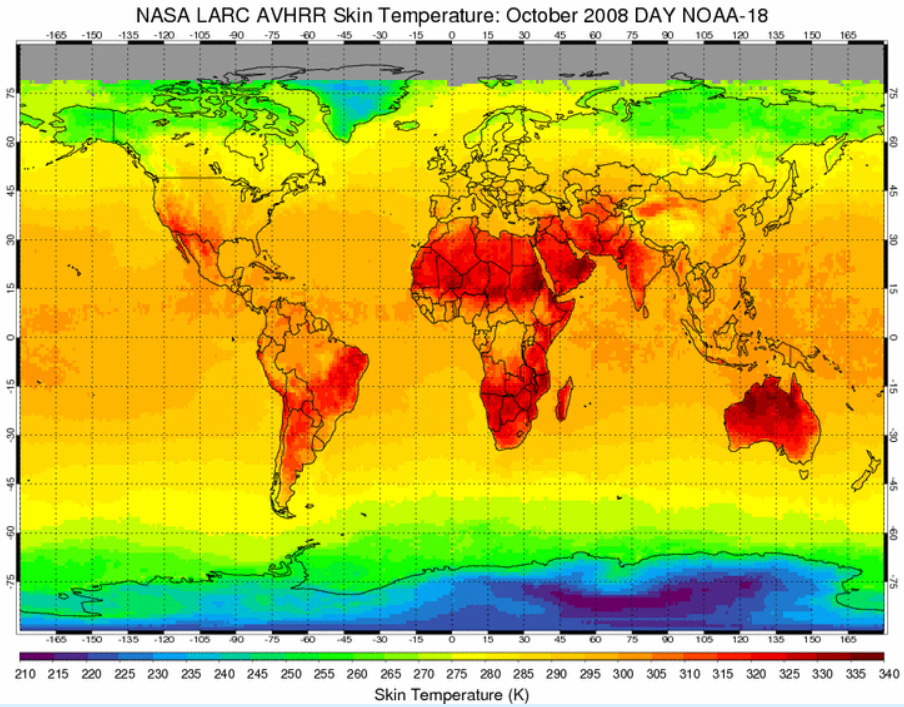
Daytime

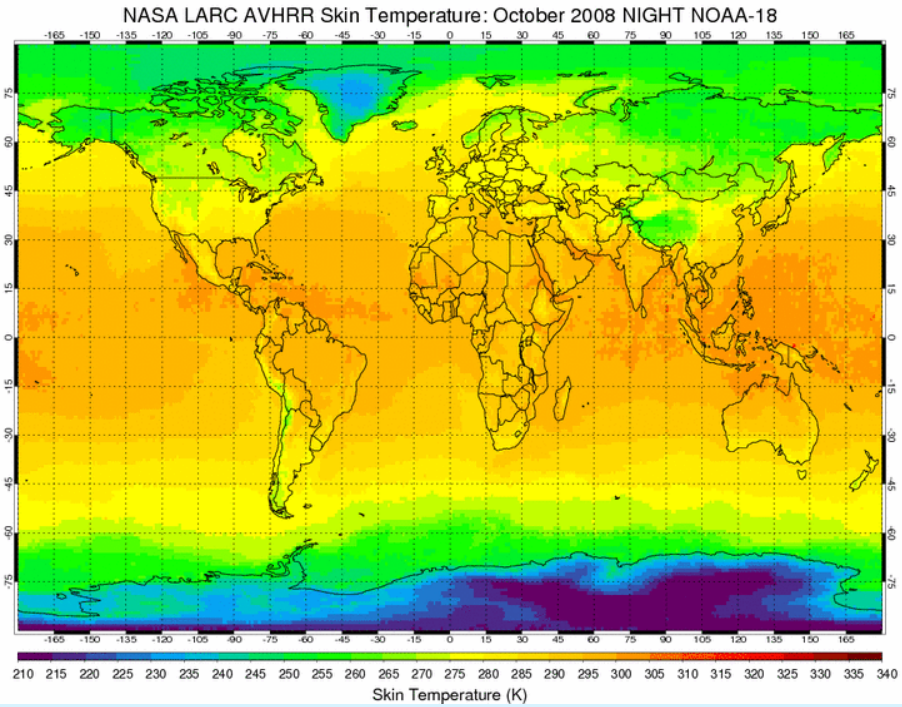
Night-time



Monthly Average Pixel Skin Temperature October 2008

Daytime **Night-time**



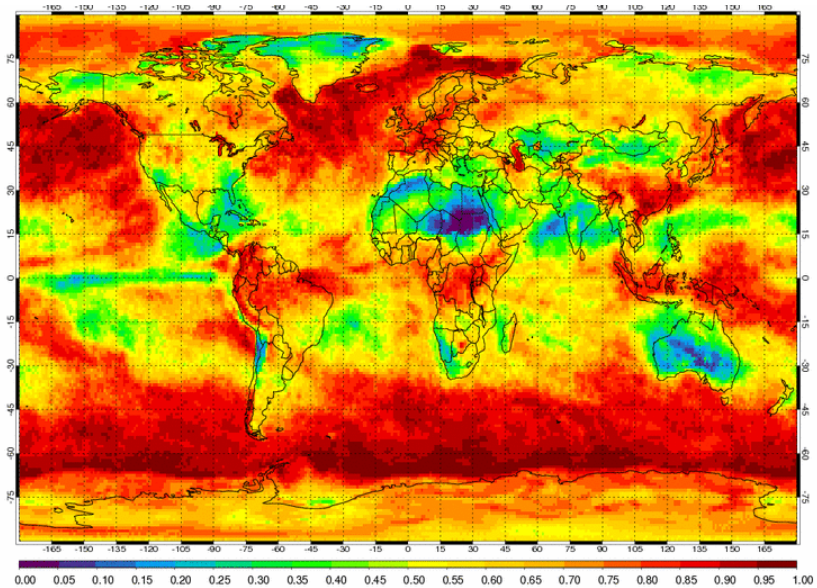


- Correlated k-distribution radiative transfer approach used to compute atmospheric transmissivity. This is then used to derive a surface IR temperature from the observed 11-μm clear-sky TOA IR temperature
  - Application of surface emissivity model yields land/ocean surface skin temperature

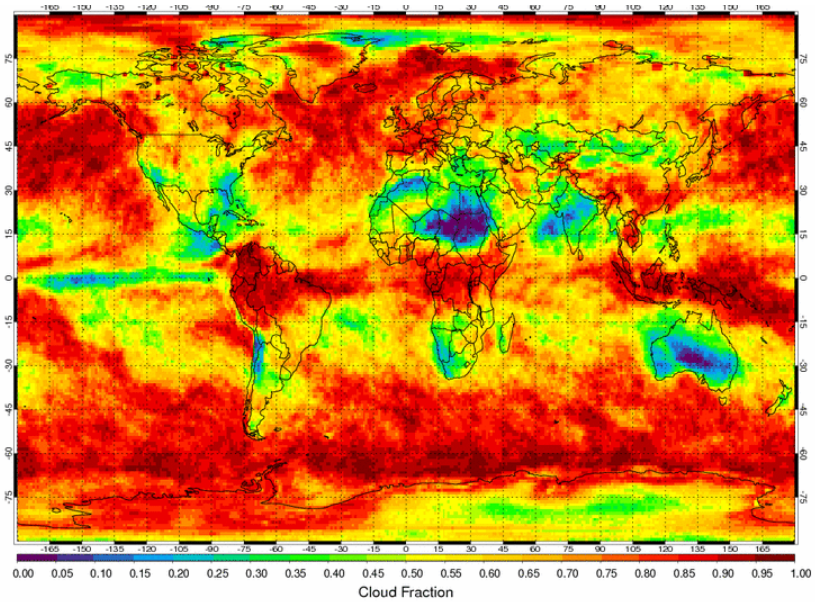
- Sea-surface temperature to be compared with current climatologies (NOAA OI, GHRSST, MICROS ACSPO). Land surface temperature validated with ARM IR thermometers and compared with MODIS Land Surface Temperature product

Global Cloud Fraction: April 1986, Day+Night

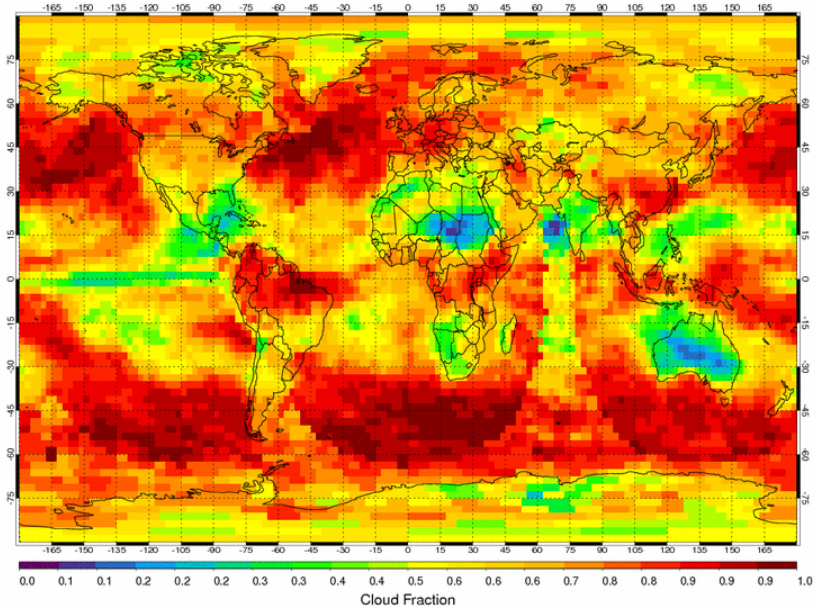
LaRC NOAA-18

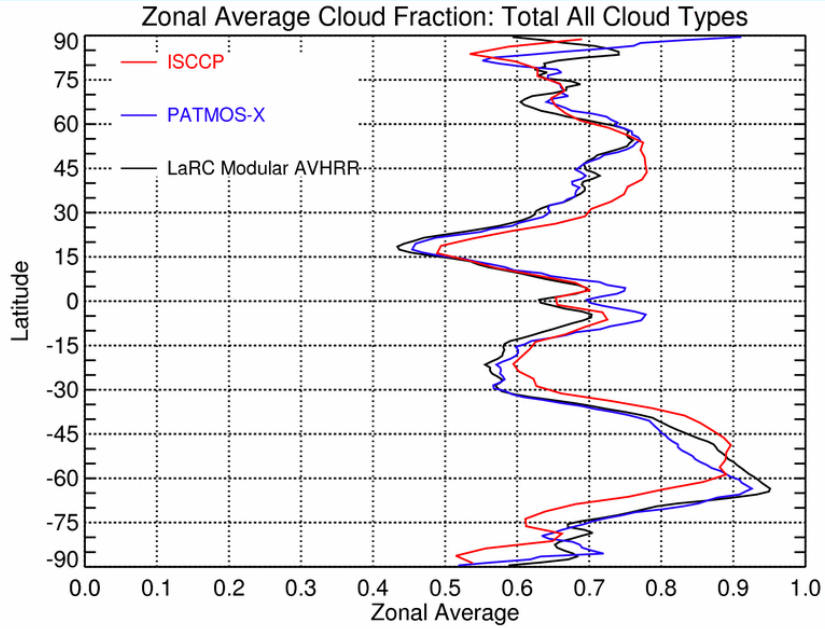


PATMOS-X



ISCCP





Summary and Future Work

- CERES cloud mask/retrieval logic has been adapted to operate with AVHRR data with the goal to extend the CERES cloud climate data record back to ~1980

- Monthly and seasonally averaged comparisons show that AVHRR results are consistent with CERES and fall within the bounds of other global climatogies prior to the MODIS era

- Efforts currently being directed toward improving retrievals over snow/ice surfaces and improving processing framework to reliably process large data volumes

- Need to develop mask/retrieval scheme when AVHRR channel 3 switches from 3.7 to 1.6 μm and older AVHRR's without a 12 μm channel

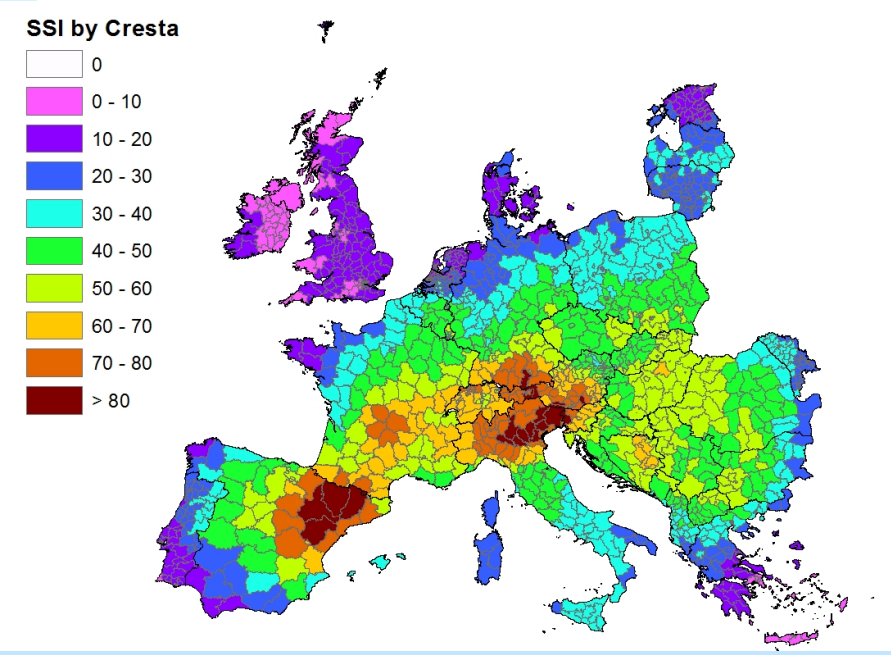
- Deriving trends in global cloud cover will be challenging due to changing observation times caused by degrading AVHRR orbits
  - Combine AVHRR results with new cloud climatology being derived from historical GEO imagers based on CERES cloud mask and retrieval logic (NASA MEaSUREs project)

Willis Pan-European Hail Model

Unique Hail Model for Europe

- 40 countries explicitly modelled
- First model for the insurance market to cover such a variety and number of countries
- Model based on ~ 38,000 individual historic convective storms
- **9 years of MSG SEVIRI satellite overshooting cloud top detection information a key component of the model**
- Simulation of 8,000 years
- ~ 560,000 stochastic events
- Country-specific vulnerability curves

Willis Re Hail European Storm Severity Index

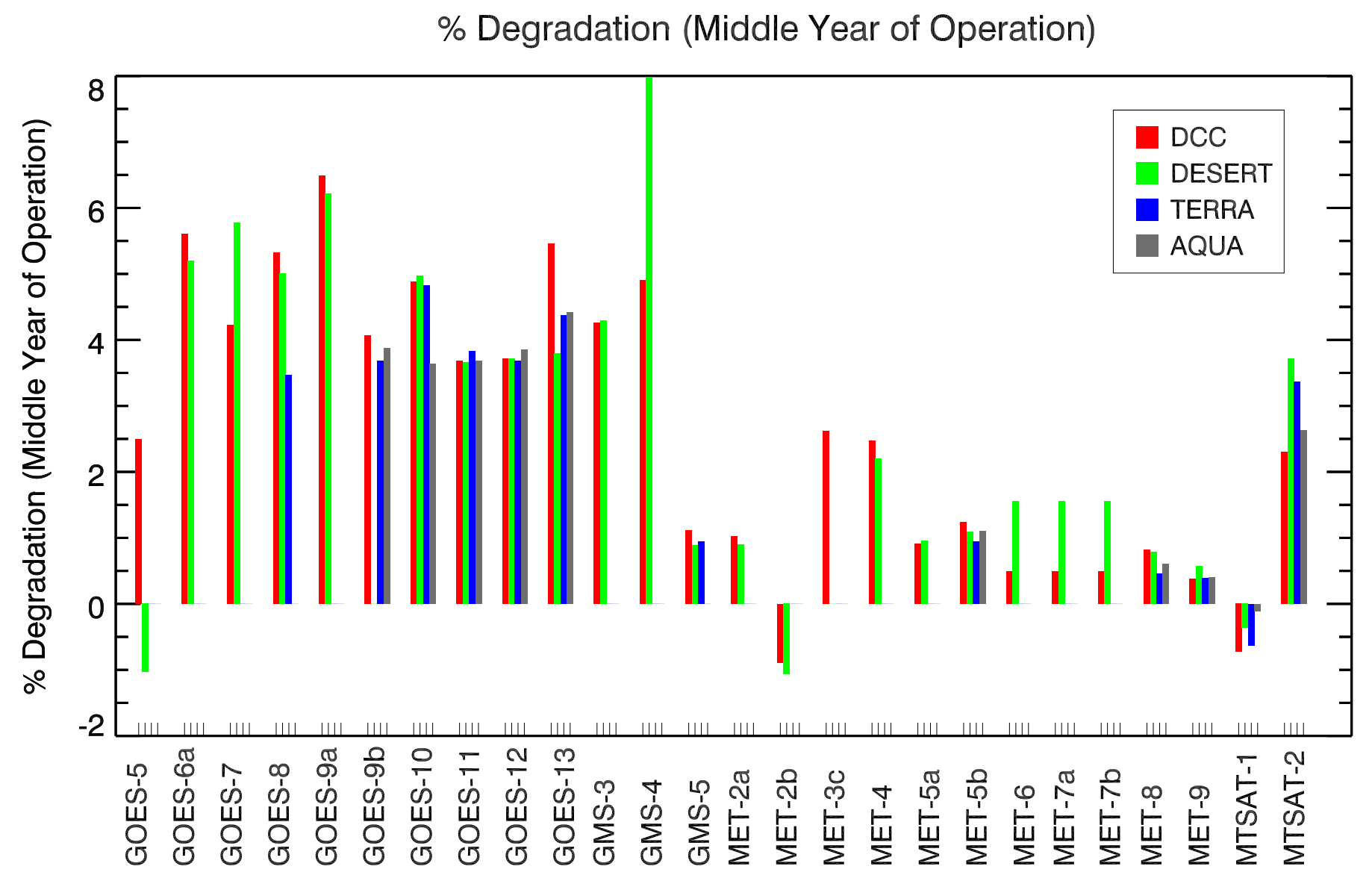


Willis Research Network

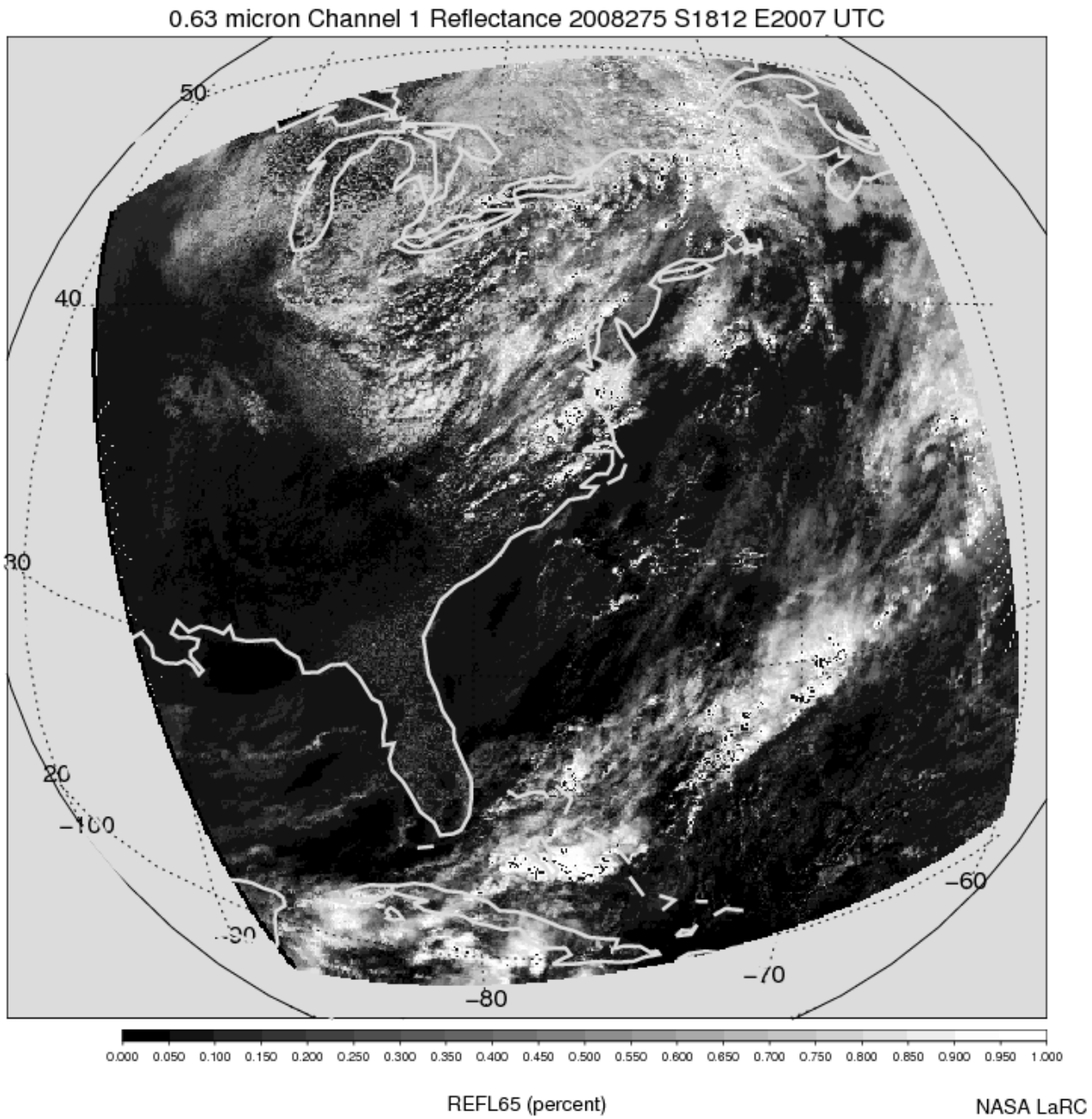
Willis Re

KIT Karlsruhe Institute of Technology

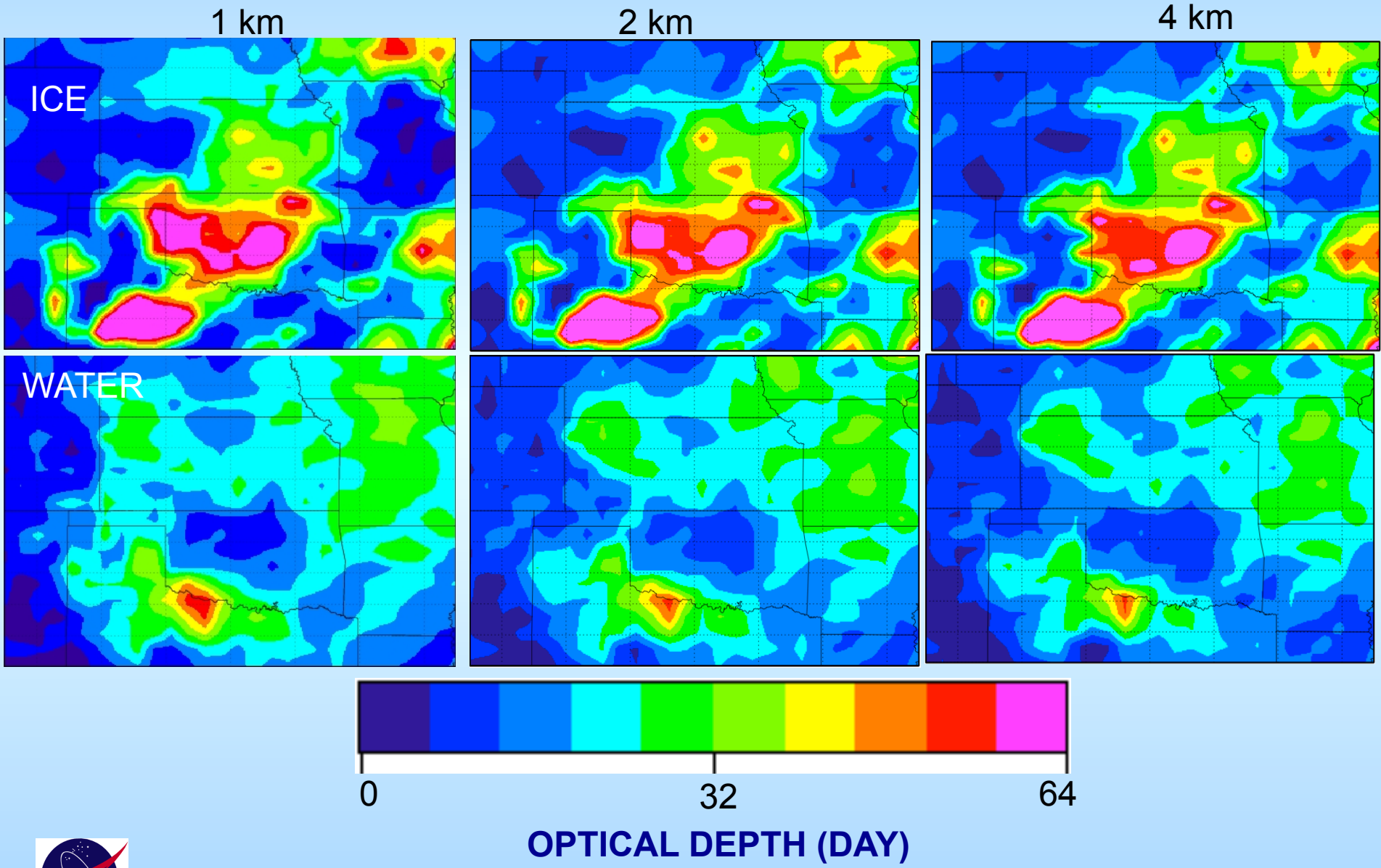
GEO Calibration Summary



AVHRR Product Examples: Calibrated 0.65 Reflectance



Impact of Resolution on Retrieved Cloud Optical Depth
Aqua MODIS, April 2008



AVHRR Data Challenges
Striping in 3.7 μm Channel, prior to NOAA-15