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

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CDR Team Meeting
August 2-3, 2011

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 spectral data (2004-2009)
- Deliverables
  - Calibrated 0.63 & 0.86-μm radiances (calib. coefficients)
  - Cloud temperature, height, opt. depth, effective particle size, water path, phase; sfc skin temperature, spectral albedo
- ECVs addressed: cloud properties, radiation budget
- Current/expected user communities: GEWEX, GCM community, energy, aviation

- CALIBRATION
- CLOUDS

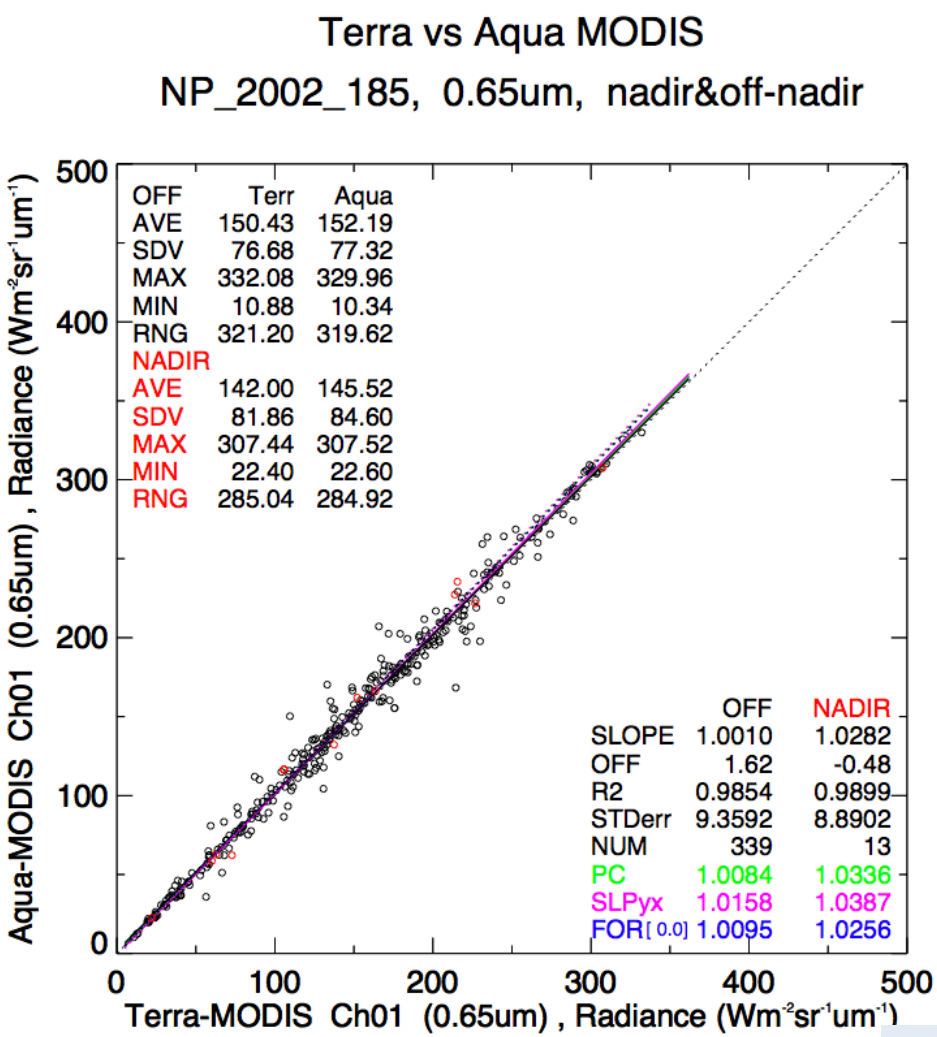
Project Description

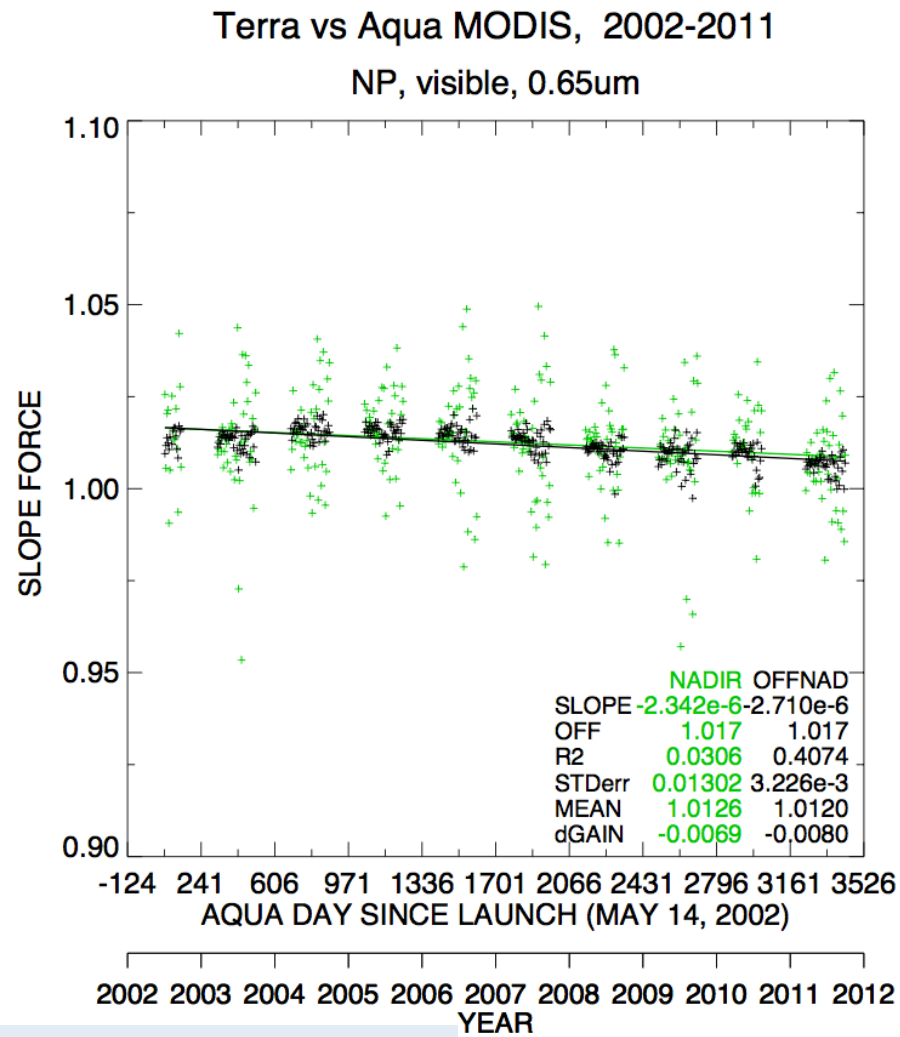
- Use Aqua-MODIS as the absolute calibration reference
  - Aqua more stable
  - Better characterized
  - Not based on the absolute calibration of Aqua of Terra
- Develop imager spectral corrections using SCIAMACHY
  - Use ratios for cross-calibration *(Doelling et al., GSRL, 2012a,b)*
  - Perform AVHRR DCC and desert calibration
  - NOAA orbits degrade over time, Accuracy limited to SZA < 55˚
  - Develop DCC BRDF corrections using VIRS
- Use Geostationary satellites as calibration references
  - Have a set image scheduling, always have data w/ SZA < 55˚
- Calibrate each GEO independently
  - 2000-2008 GEOs use MODIS/GEO ray-matching, DCC and deserts
  - 1985-1999 GEOs are based on DCC & desert only, tied to 2000+
- Transfer all simultaneous GEO calibrations to a given AVHRR
  - All GEO calibrations should yield same AVHRR degradation
  - AVHHR DCC-> trend mean of GEO cross-calibrations-> gain
- Compare with ISCCP & other published calibration coefficients

Project Description

CDR(s) (Validated Outputs)	Period of Record	Spatial Resolution; Projection information	Time Step	Data format	Inputs	Uncertainty Estimates (in percent or error)	Collateral Products (unofficial and/or unvalidated)
AVHRR/ GOES Visible (~0.65 μm) & NIR channel gains	1981 – 2010	N/A	Monthly	ASCII	Navigated AVHRR channels	TBD	GMS, MTSAT, Meteosat visible channel gains
AVHRR cloud properties: Cld frac, temp, hgt, Re, phase, pres, COD, LWP/IWP	1981 - 2010	4-km	2/day	netcdf	AVHRR radiances, MERRA analysis, sfc emis & clear albedo emis, model LUTs	TBD	Clear-sky & skin temp, BB radiative fluxes, overshooting top detetection

Terra/Aqua MODIS Collection 6 SNO





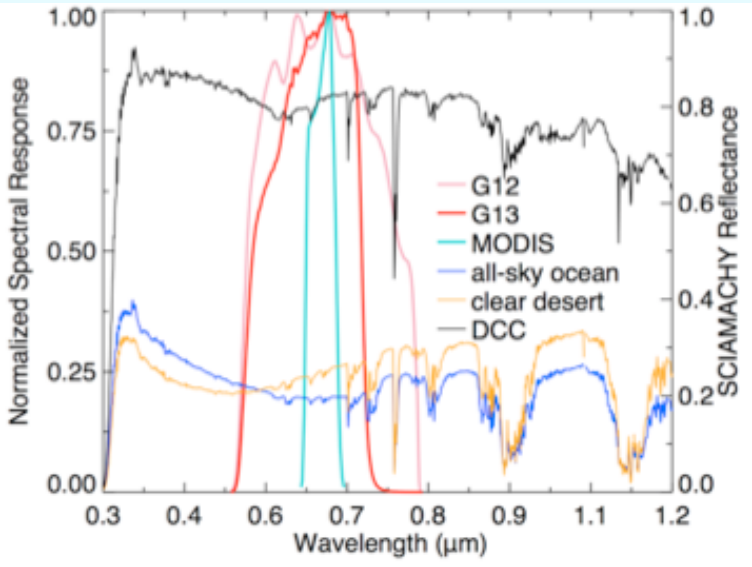
Multiply Terra by the fit to scale to Aqua

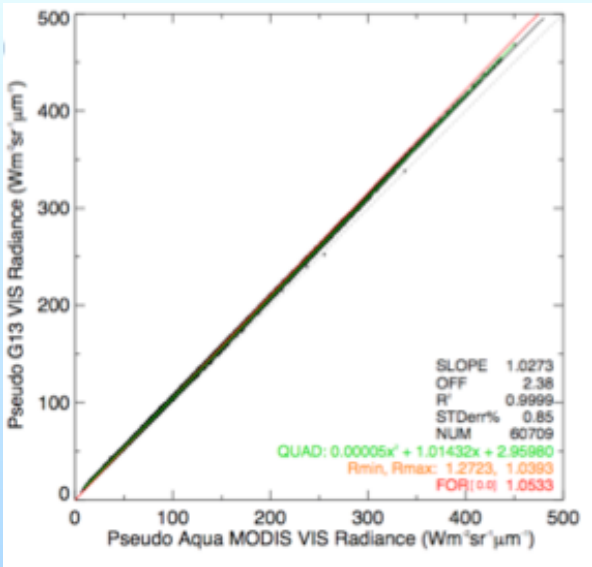
SCIAMACHY Spectral Corrections

- SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY (SCIAMACHY) makes hyperspectral measurements on-board ENVISAT.
- SCIAMACHY data has been used to develop spectral band adjustment factors (SBAF)

$$SBAF = \frac{\int R_{GEO}(\lambda).\rho_{SCIA}(\lambda)d\lambda / \int R_{GEO}(\lambda)d\lambda}{\int R_{AQUA}(\lambda).\rho_{SCIA}(\lambda)d\lambda / \int R_{AQUA}(\lambda)d\lambda}$$

  - ρ_{SCIA} is scene dependent SCIAMACHY spectra (All-sky Ocean, DCC, or Desert)
  - R_{GEO}/R_{AQUA} are spectral response functions (SRFs) for the GEO/MODIS sensor

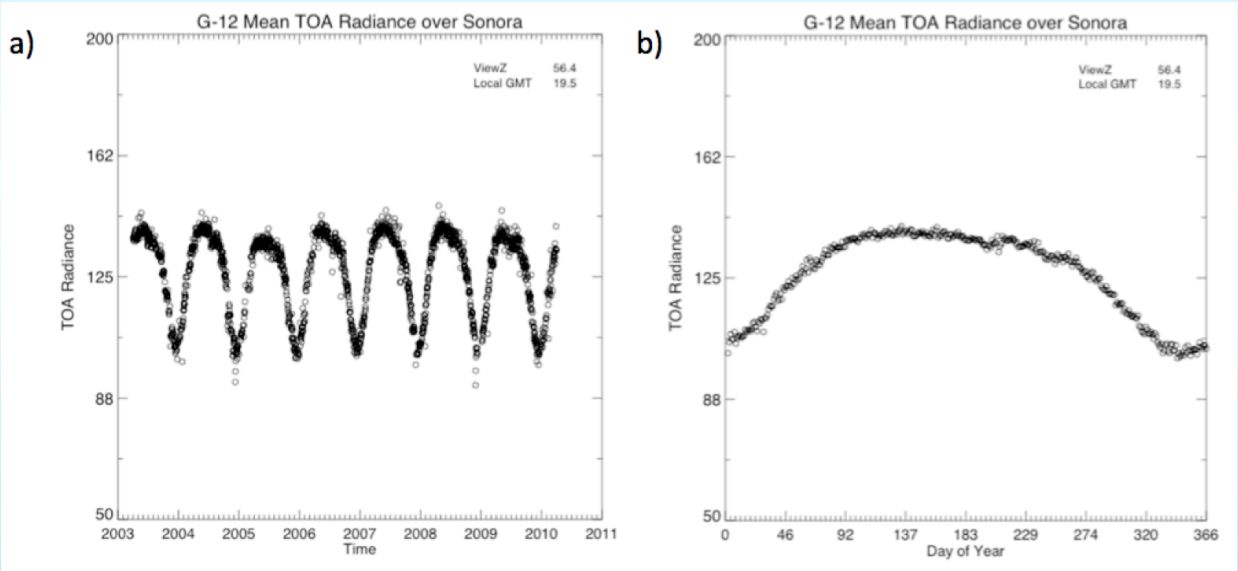




Desert Absolute Calibration Methodology

Seasonal Desert Model- For each GEO domain/desert combination (ie. GOES-W/Sonora, GOES-E/Sonora, 0E/Libya, etc.):

- Choose contemporary GEO with adequate timeline (>3 yrs)
- Apply MODIS-Aqua/GEO ray-match gains to the cloud free GEO raw desert counts to get TOA spectral radiance for the desert throughout lifetime of the GEO (Fig. a).
- Average each day of year to get a 365 day seasonal model (Rad_{model}) (Fig. b)



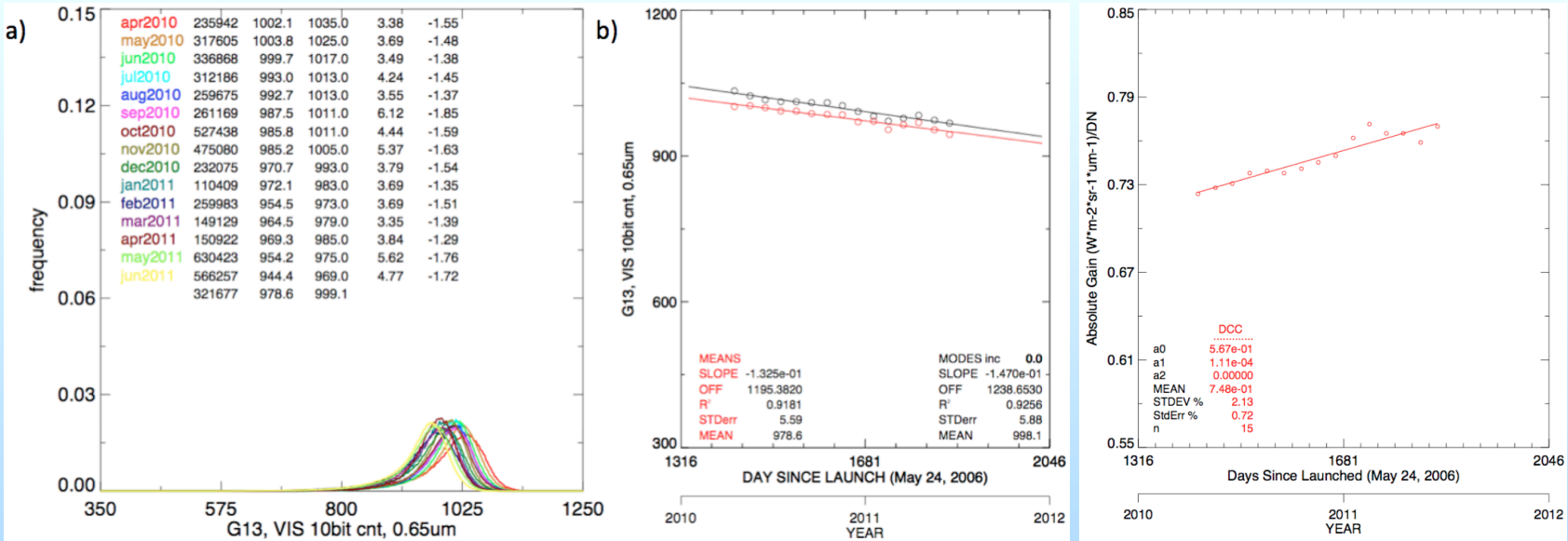
- Find absolute gain for un-calibrated GEO in same location by comparing the raw desert counts vs the seasonal model over the historical GEO lifetime
- Find absolute gain for a month: $AbsoluteGain_{GEO} = Rad_{model} * SBAF/Counts_{GEO}$

DCC Absolute Calibration Methodology

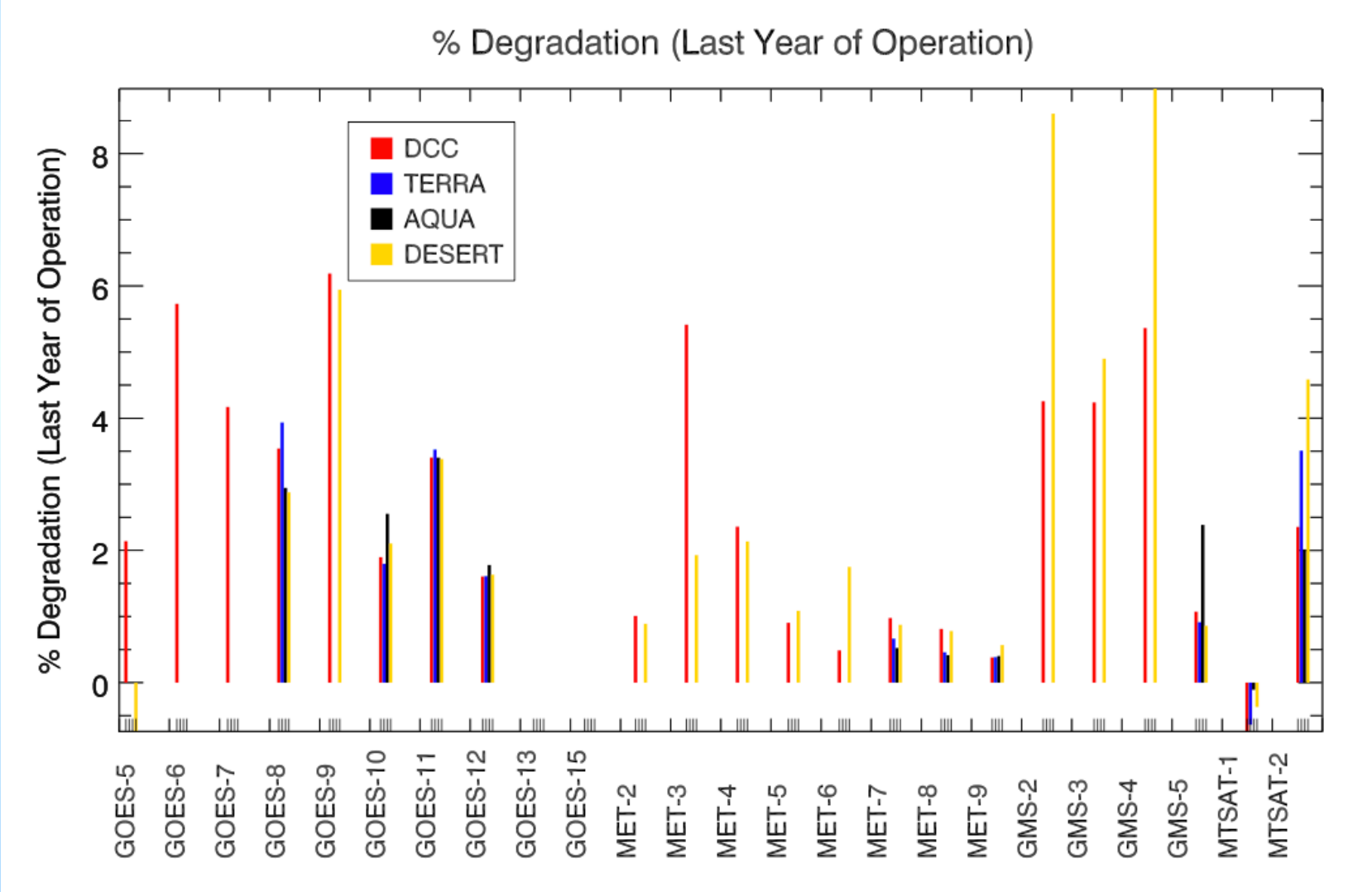
- For GEO, DN were used instead of spectral radiance
- Finding absolute gain for a given month:

$$GEODCC_{Expected} = AquaDCC_{Expected} \times SBAF$$

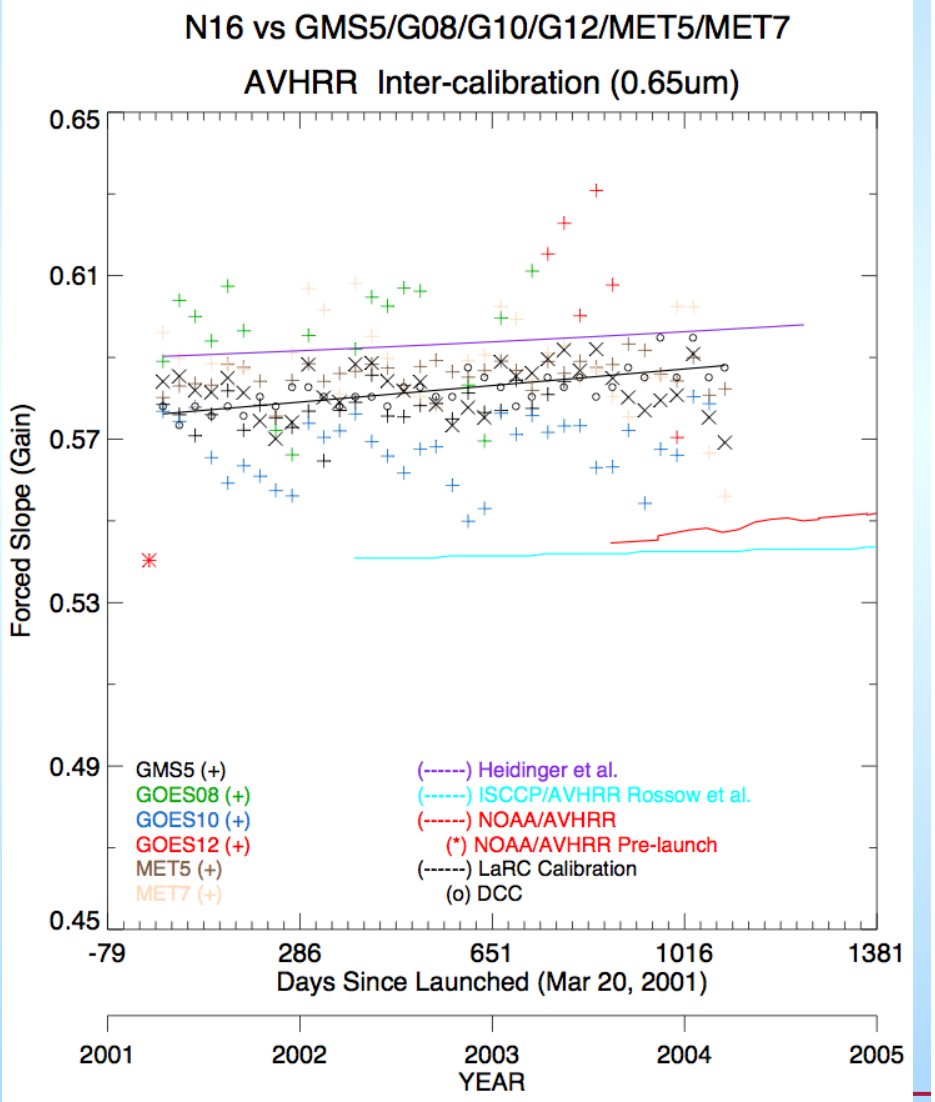
$$AbsoluteGain_{GEO} = GEODCC_{Expected} / GEODCC_{NormalizedMode}$$

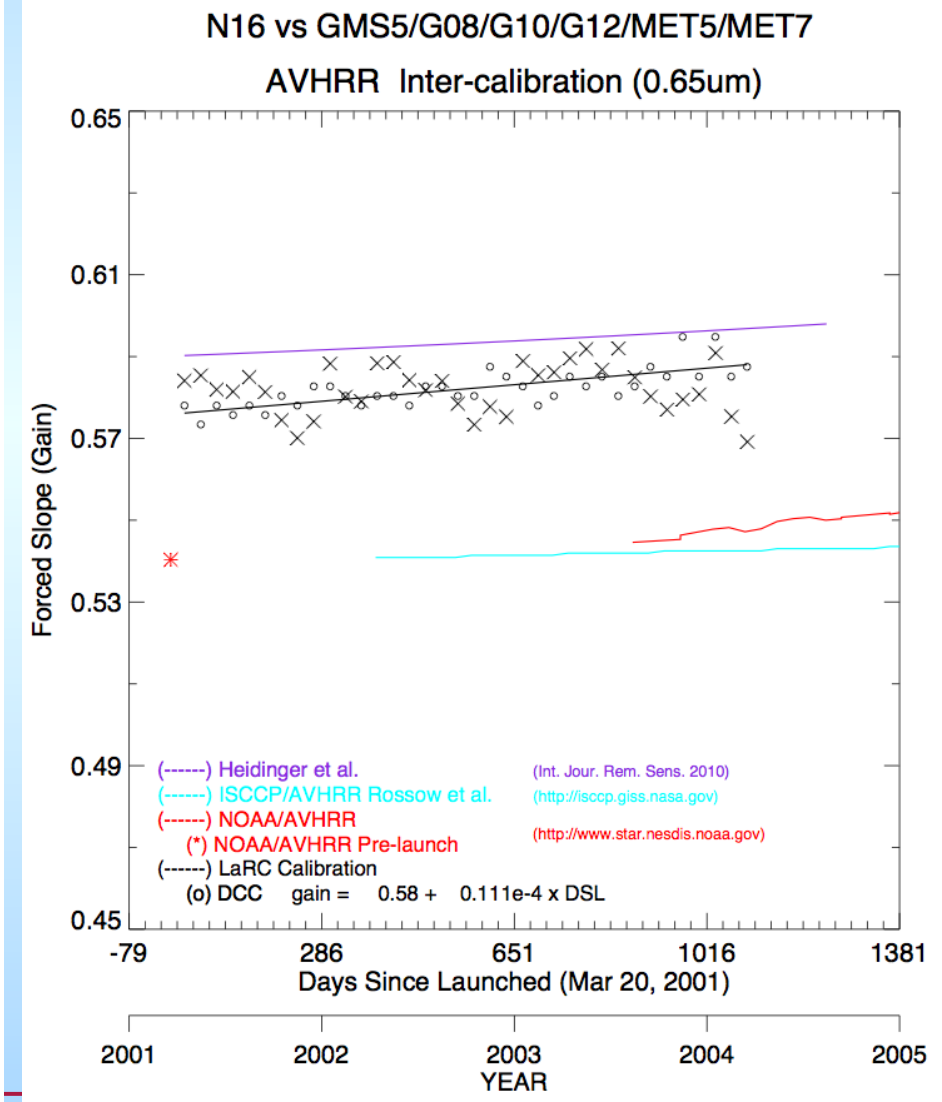


GEO Calibration Summary

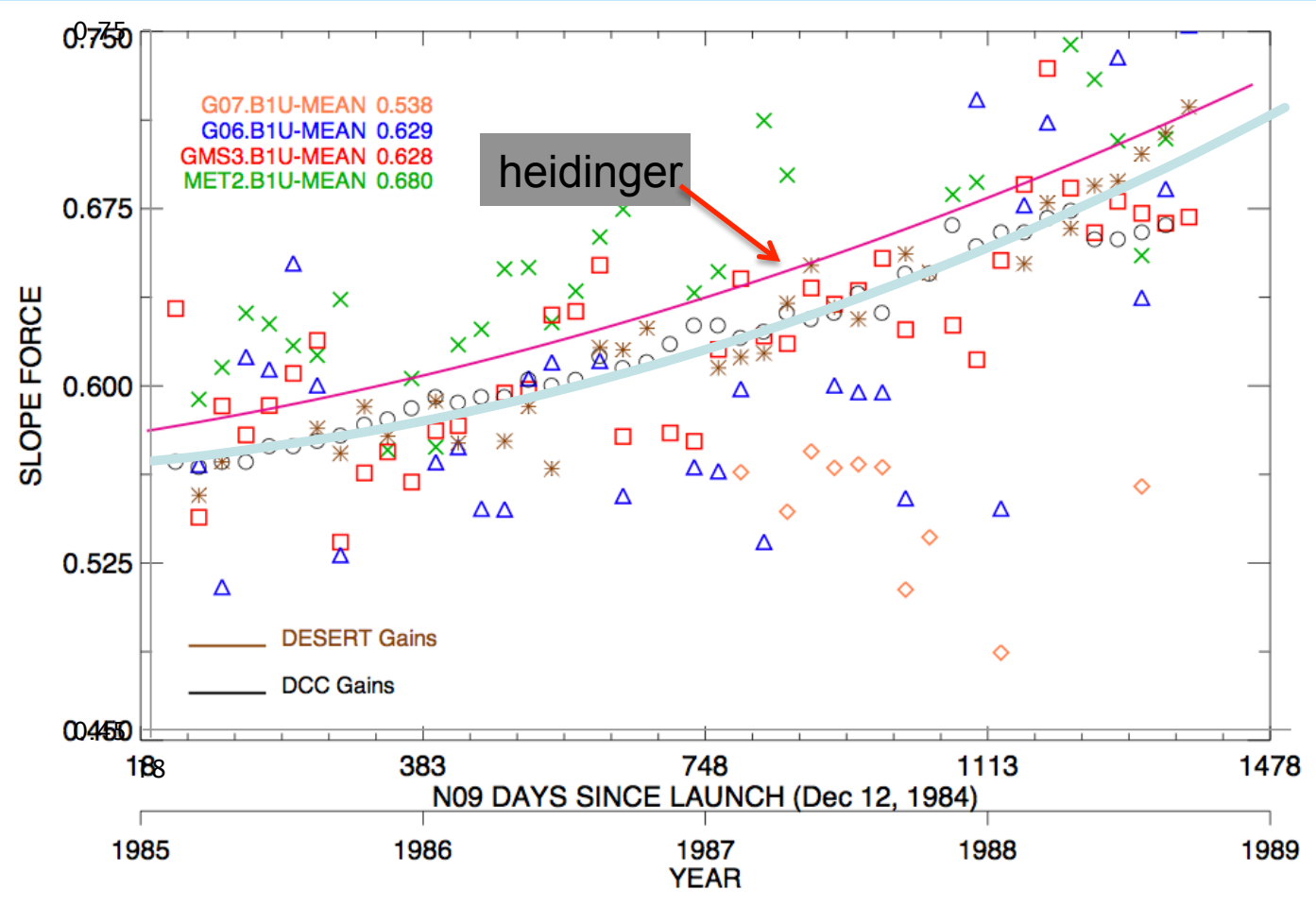


NOAA16 AVHRR calibration (will be updated to reference of Aqua-MODIS C6)





NOAA-9 AVHRR calibration (will be updated to reference of Aqua-MODIS C6)



Calibration Production Approach

- AVHRR images navigated using method described last year
- Spectral corrections created for all imagers w/SCIAMACHY
- Perform GEO desert calibrations
- Perform GEO DCC calibrations
- Perform GEO-AVHRR ray-matched calibrations
- For AVHRR 1.6 and 0.85 μm need desert/DCC directly
  - Aqua MODIS 1.6-μm not good for cross calibration (Coll 6?)
  - MODIS 0.86 not good for DCC because of saturation (Coll 6)

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

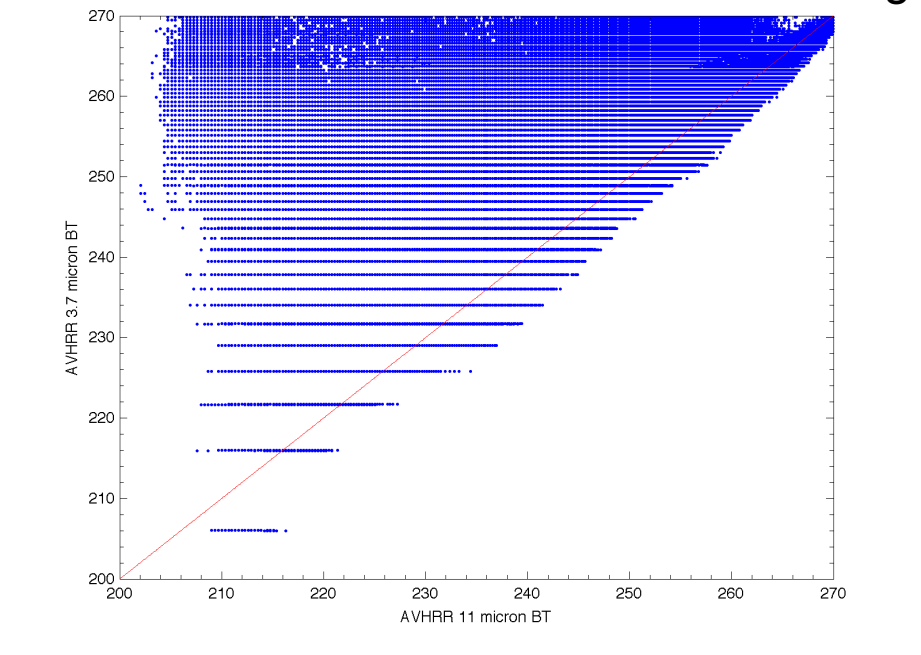
- Adapt CERES Ed4 Cloud Property Retrieval System to AVHRR
  - Adapt algorithm to limited AVHRR channels
    - Test & refine using MODIS and retest using NOAA-18
  - Apply to AVHRR back to NOAA-7 (1981-2010)

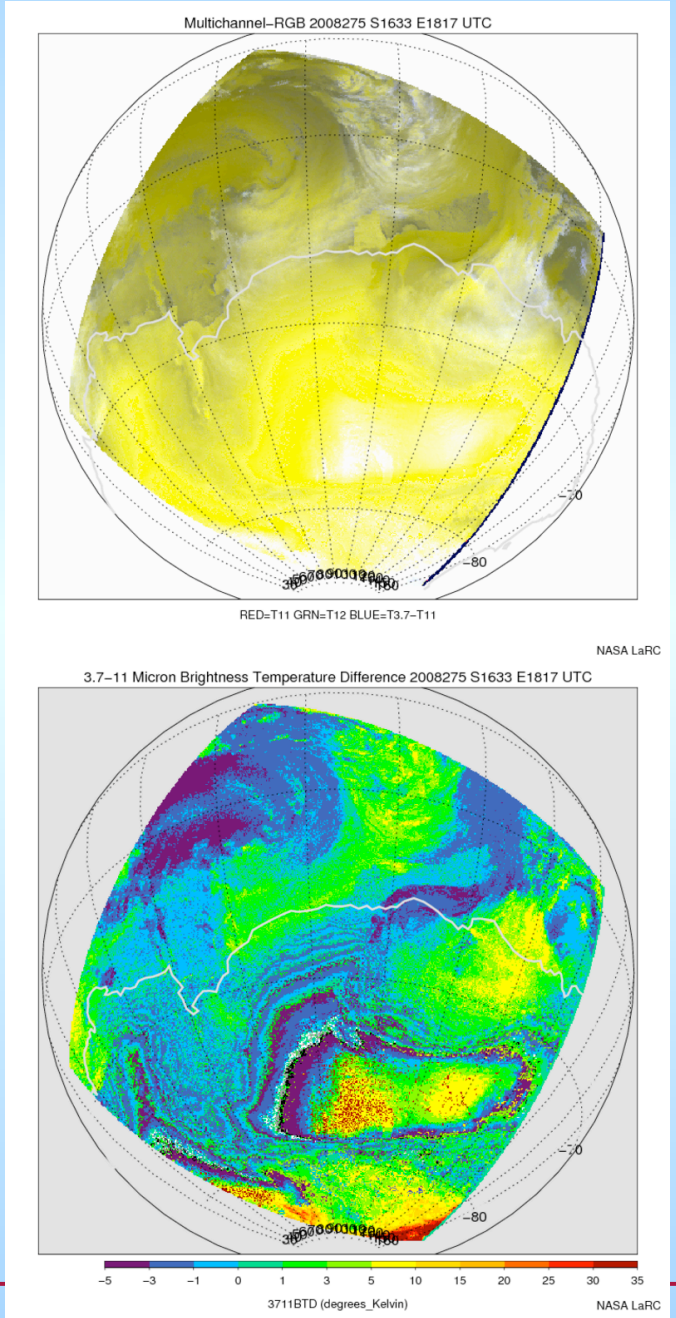
NASA LaRC AVHRR Cloud and Clear-Sky Radiation Property Climate Data Record: Ancillary Inputs

- 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
- 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 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 vs 11 micron BT: South Polar Region

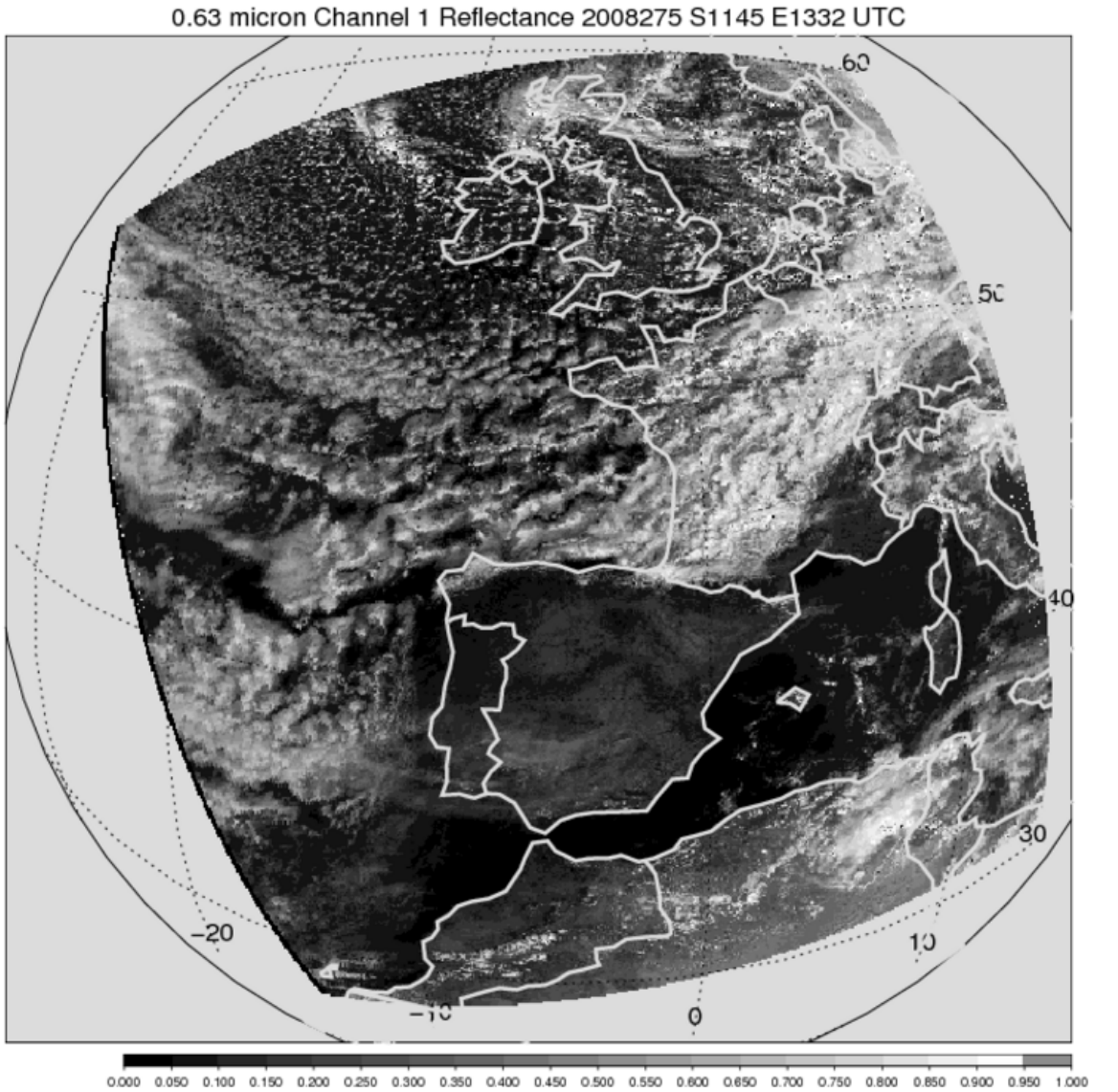




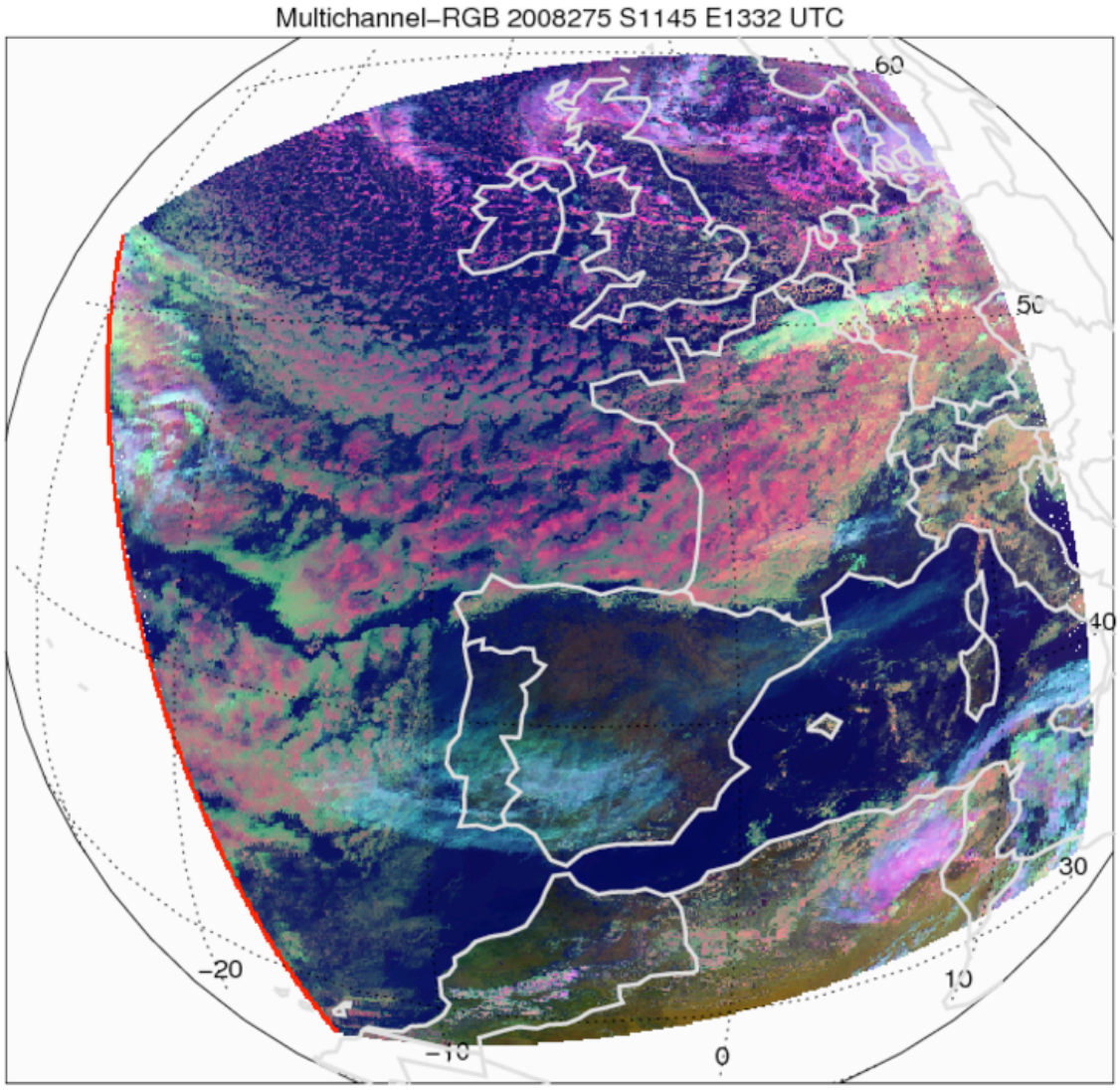
- AVHRR 3.7 micron BT are "binned" with increasing bin separation at colder temperatures

- CERES cloud detection and retrievals utilize 3.7 information, so we must use alternative fields to minimize errant/noisy results

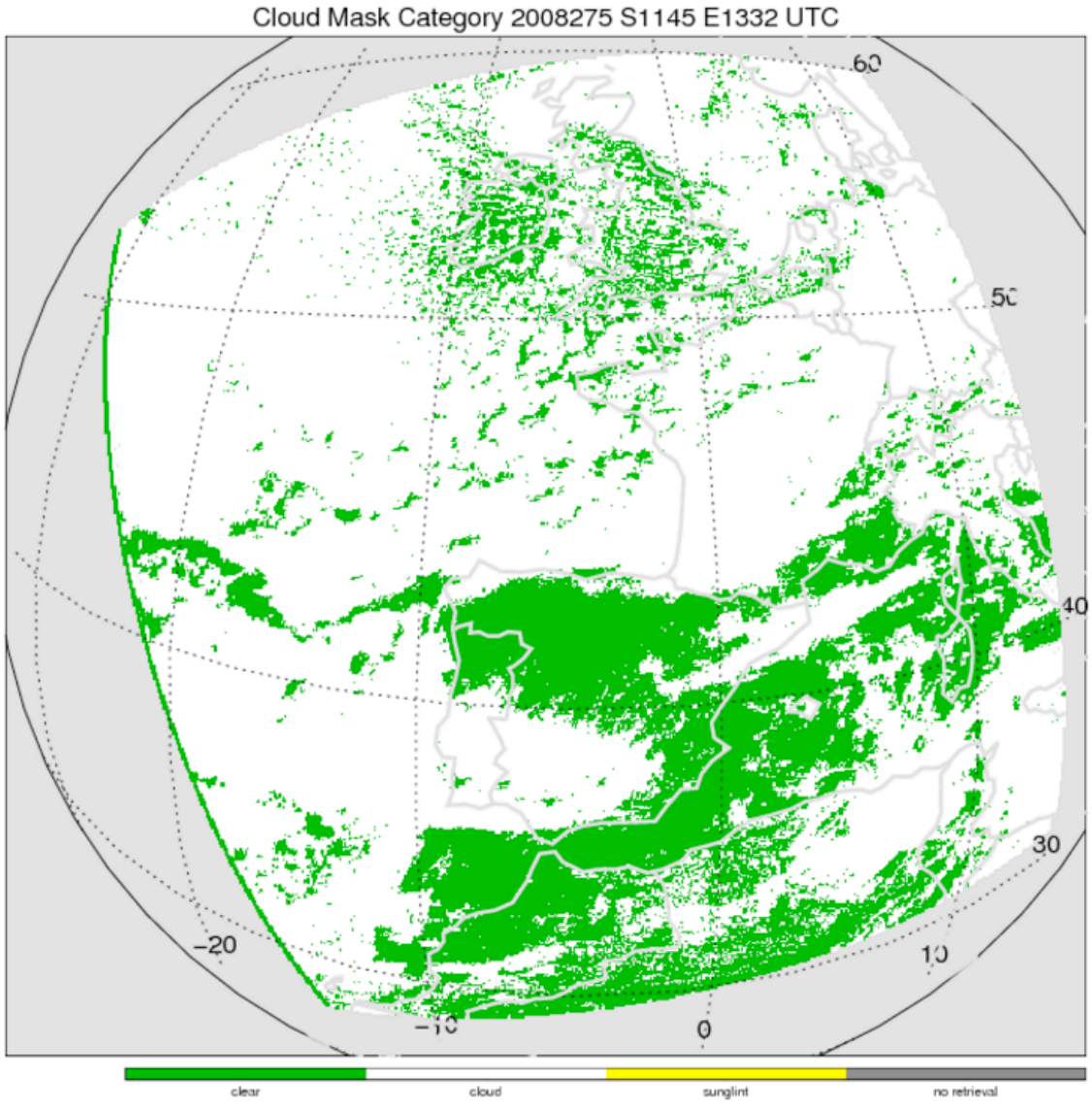
AVHRR Product Examples: Calibrated 0.65 Reflectance



AVHRR Product Examples: RGB Composite



AVHRR Product Examples: Cloud Mask



CLOUDMASK (count)

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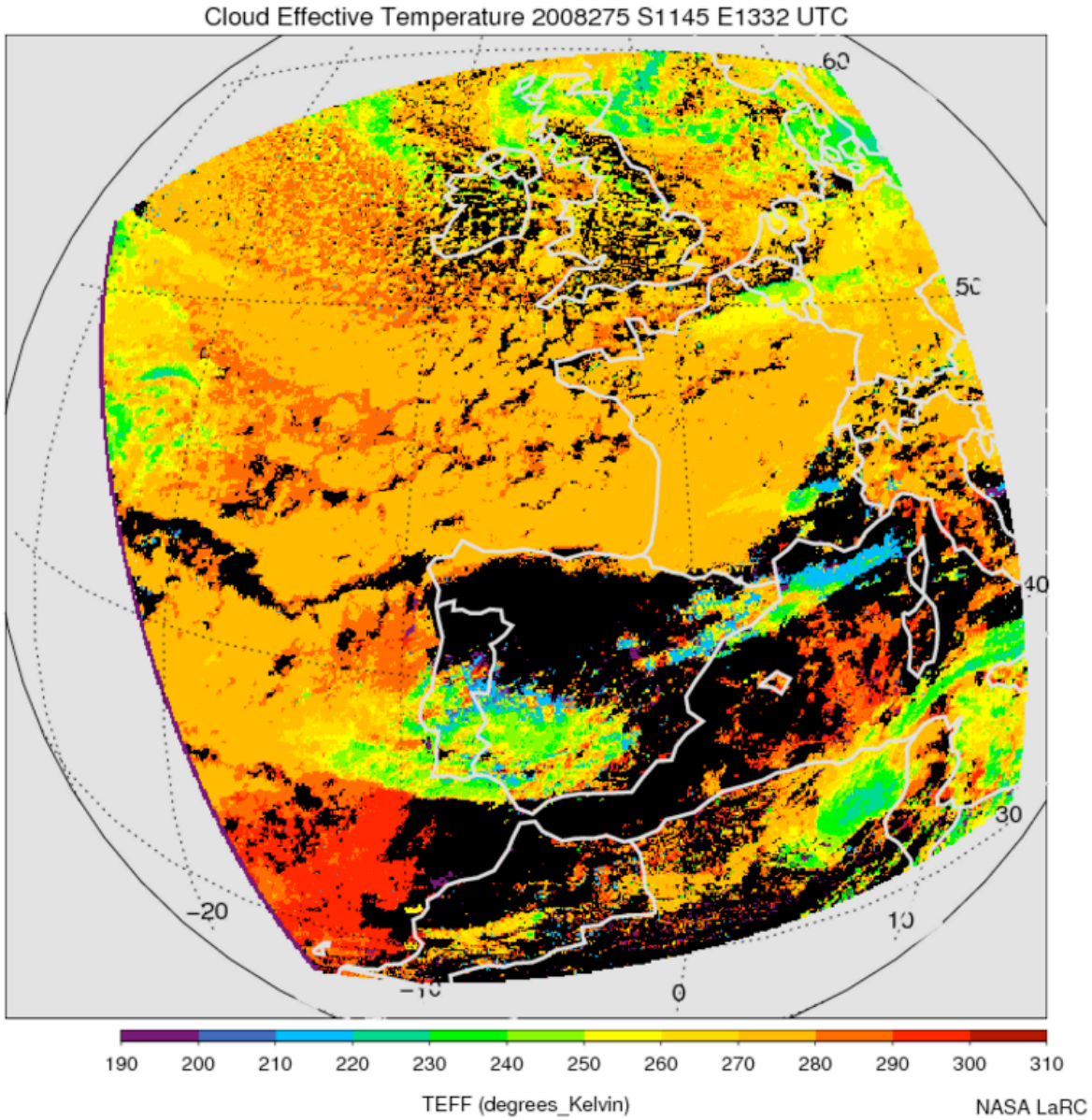
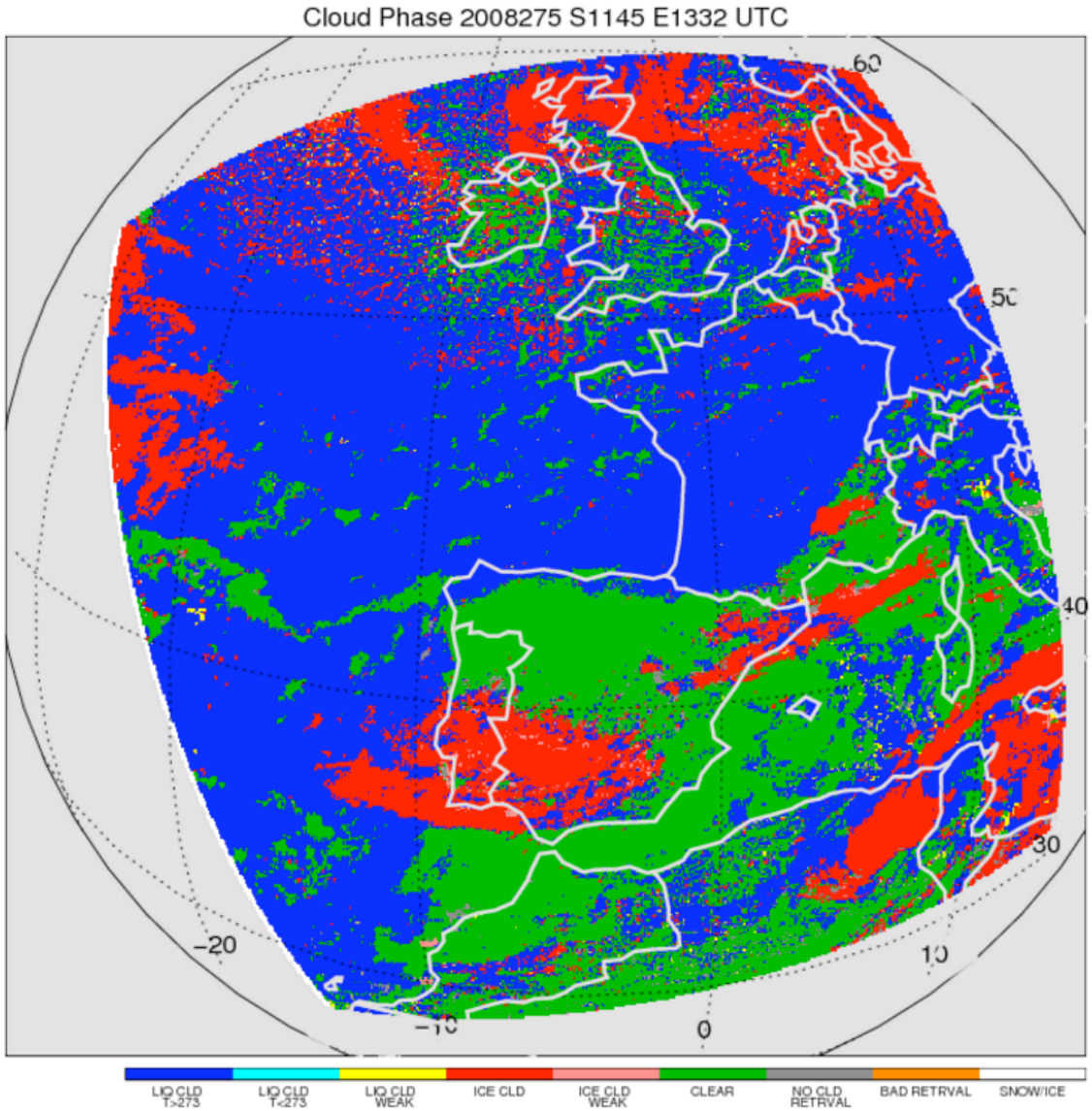
AVHRR Product Examples: Cloud Temperature



AVHRR Product Examples: Cloud Phase



PHASE (count)

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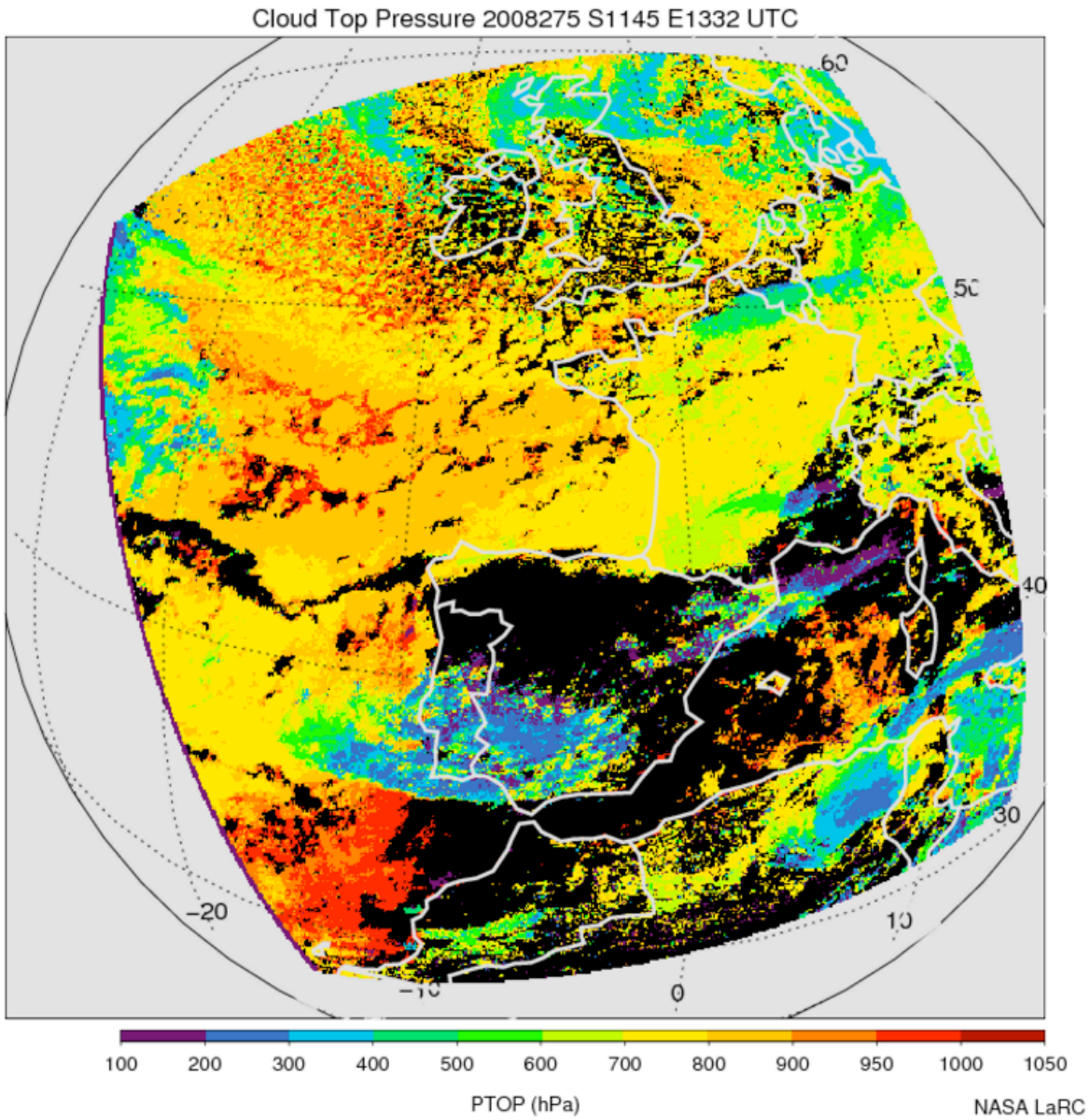
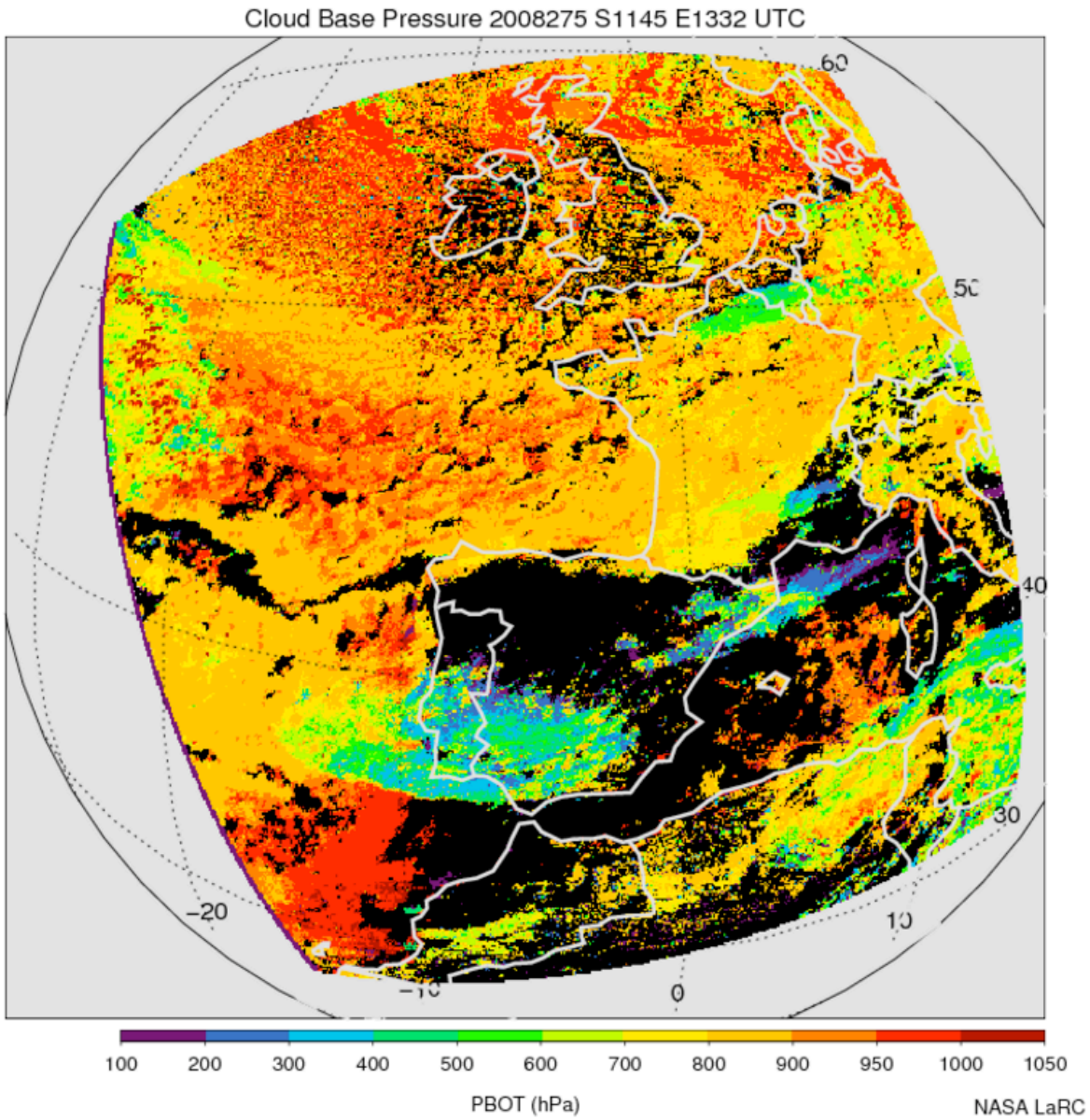
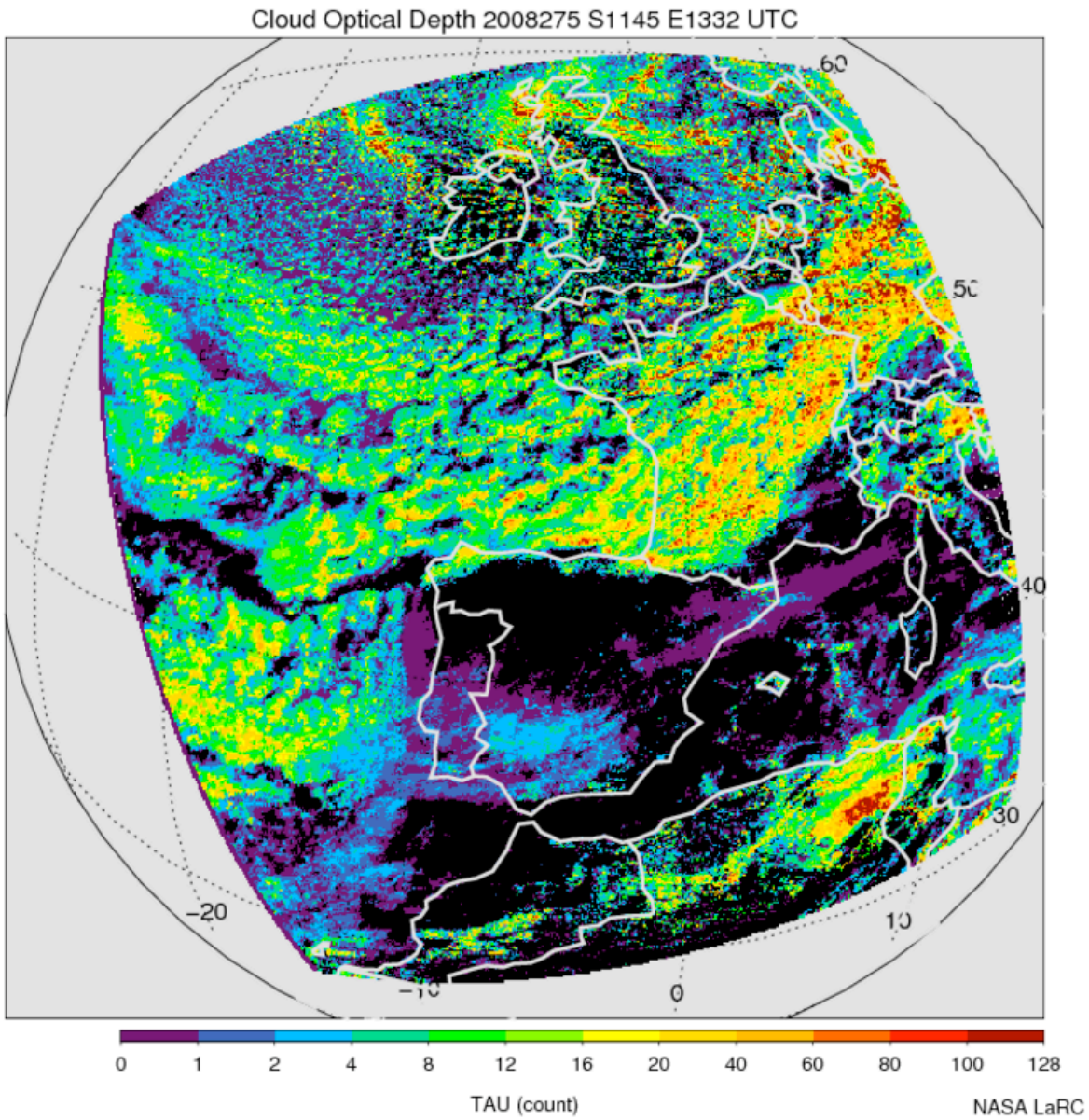
AVHRR Product Examples: Cloud Top Pressure



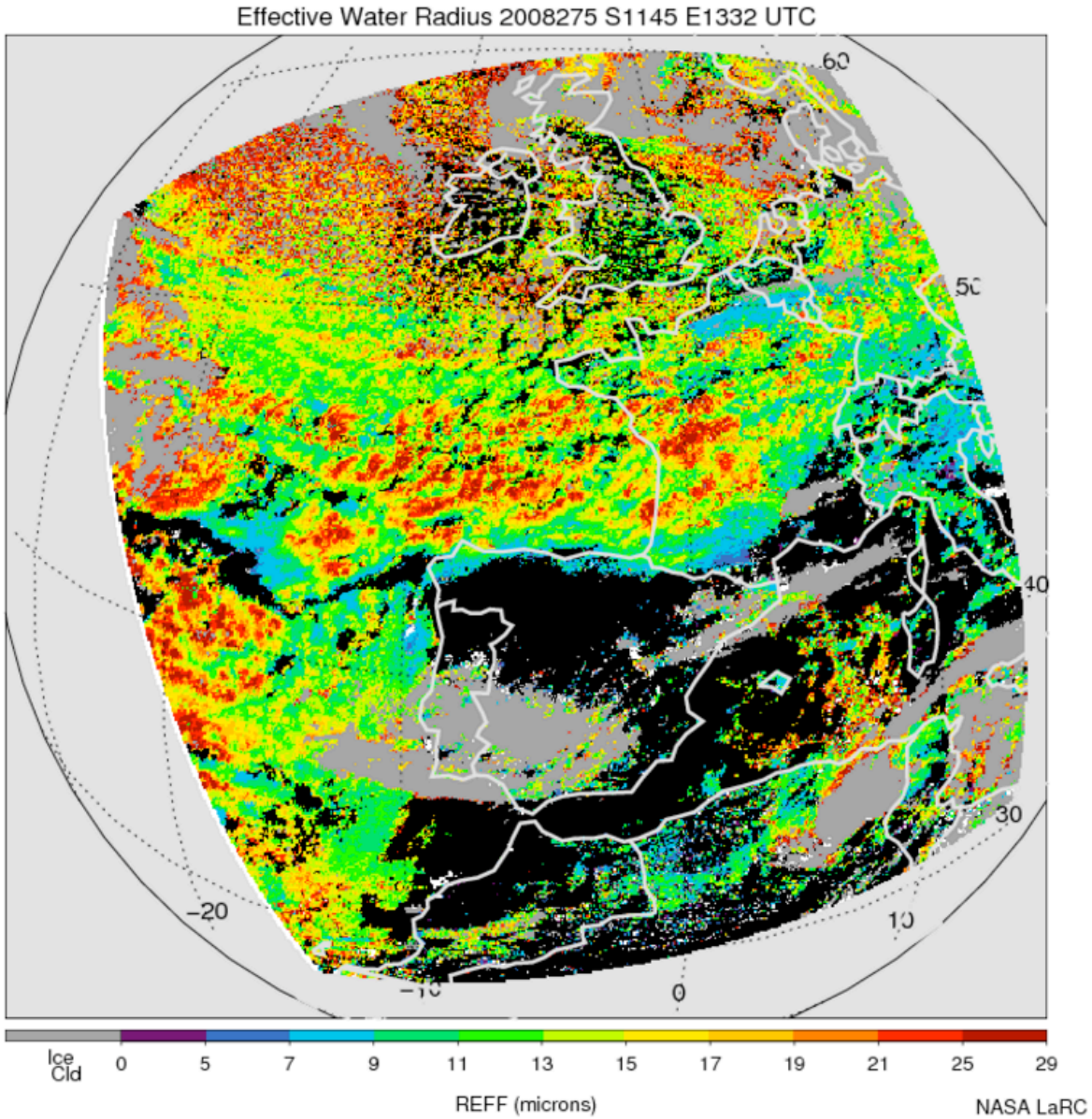
AVHRR Product Examples: Cloud Base Pressure



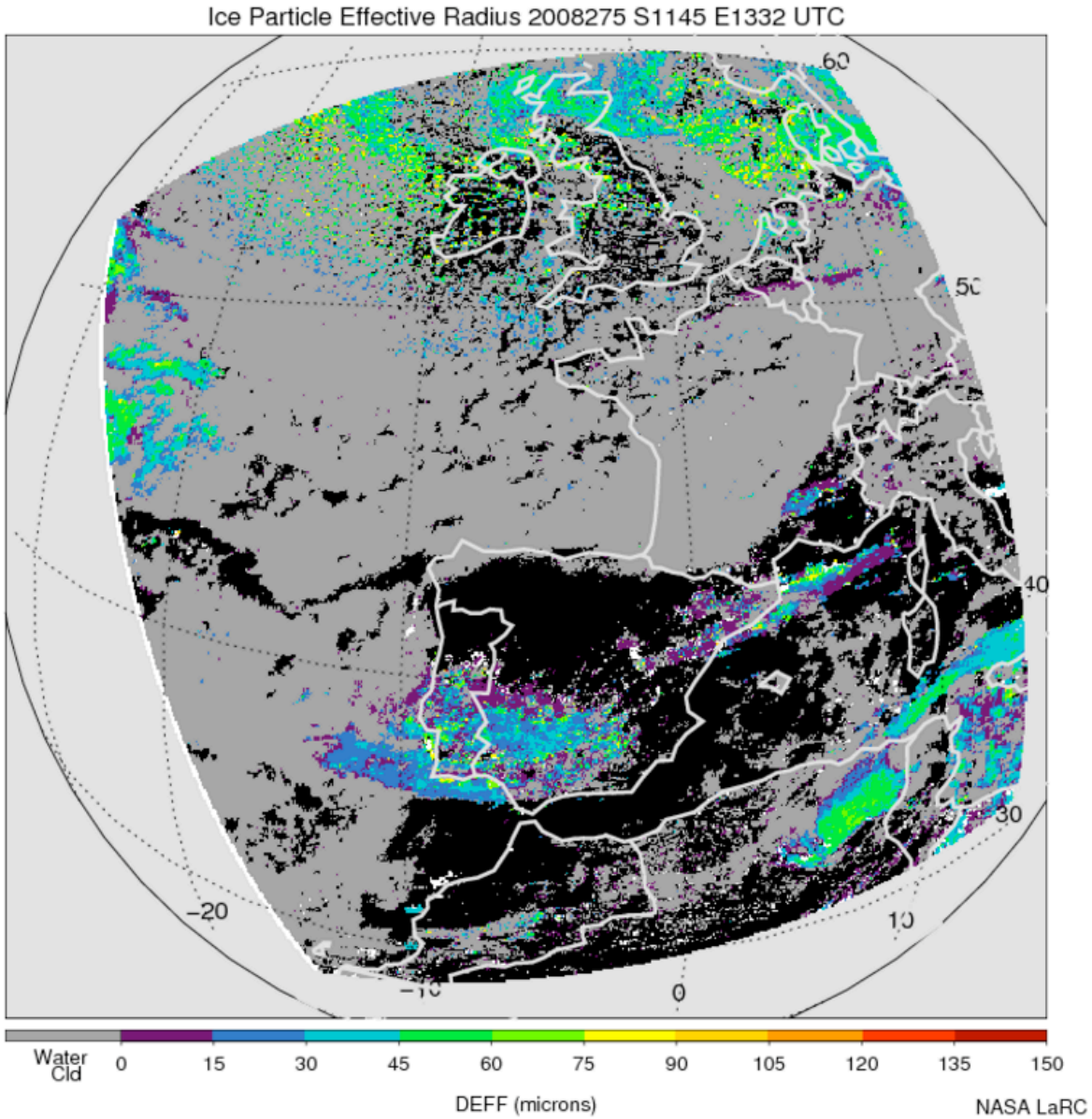
AVHRR Product Examples: Cloud Optical Depth



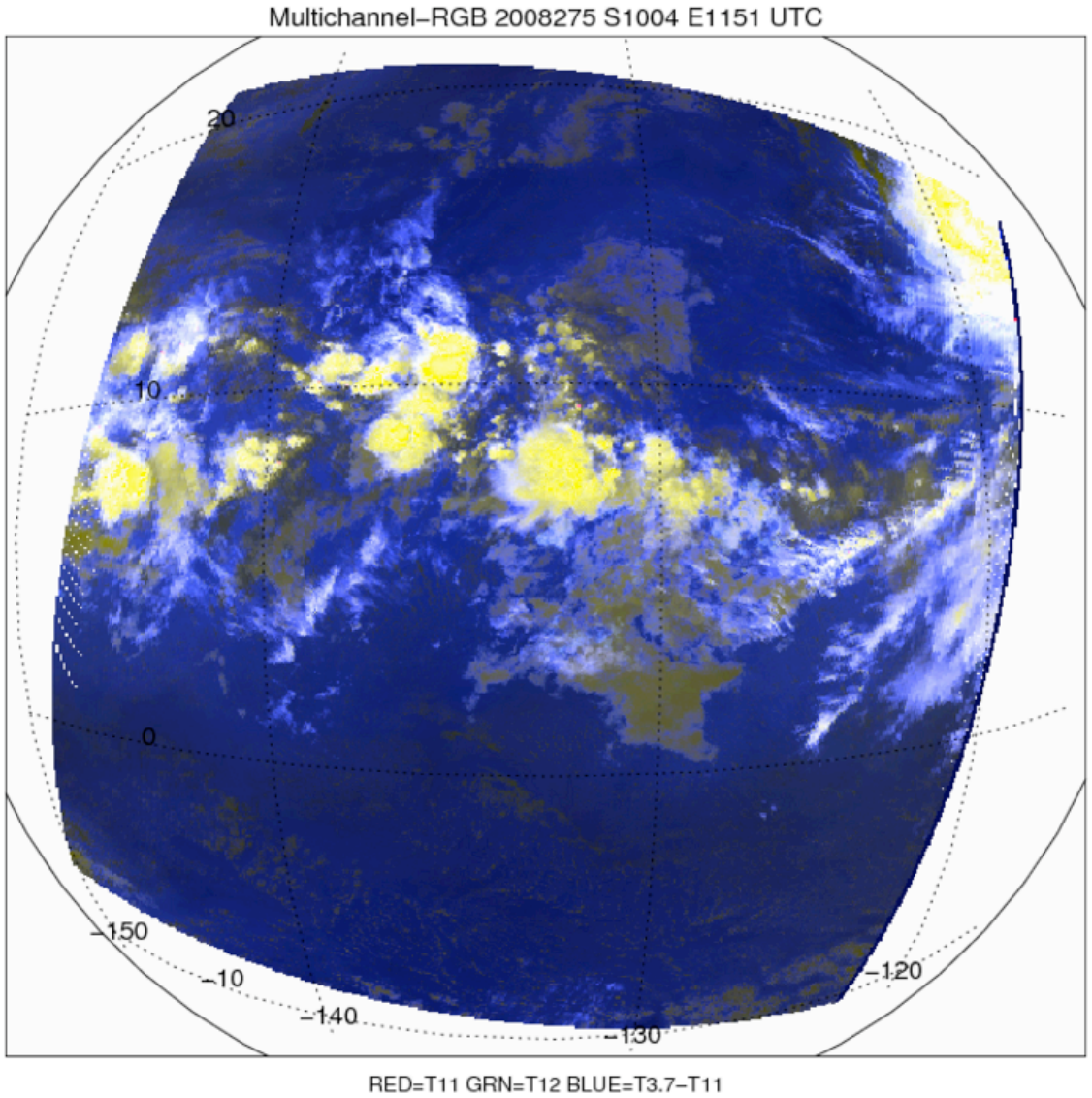
AVHRR Product Examples: Water Droplet Effective Radius



AVHRR Product Examples: Ice Particle Effective Radius



AVHRR Product Examples: Night-time RGB Composite



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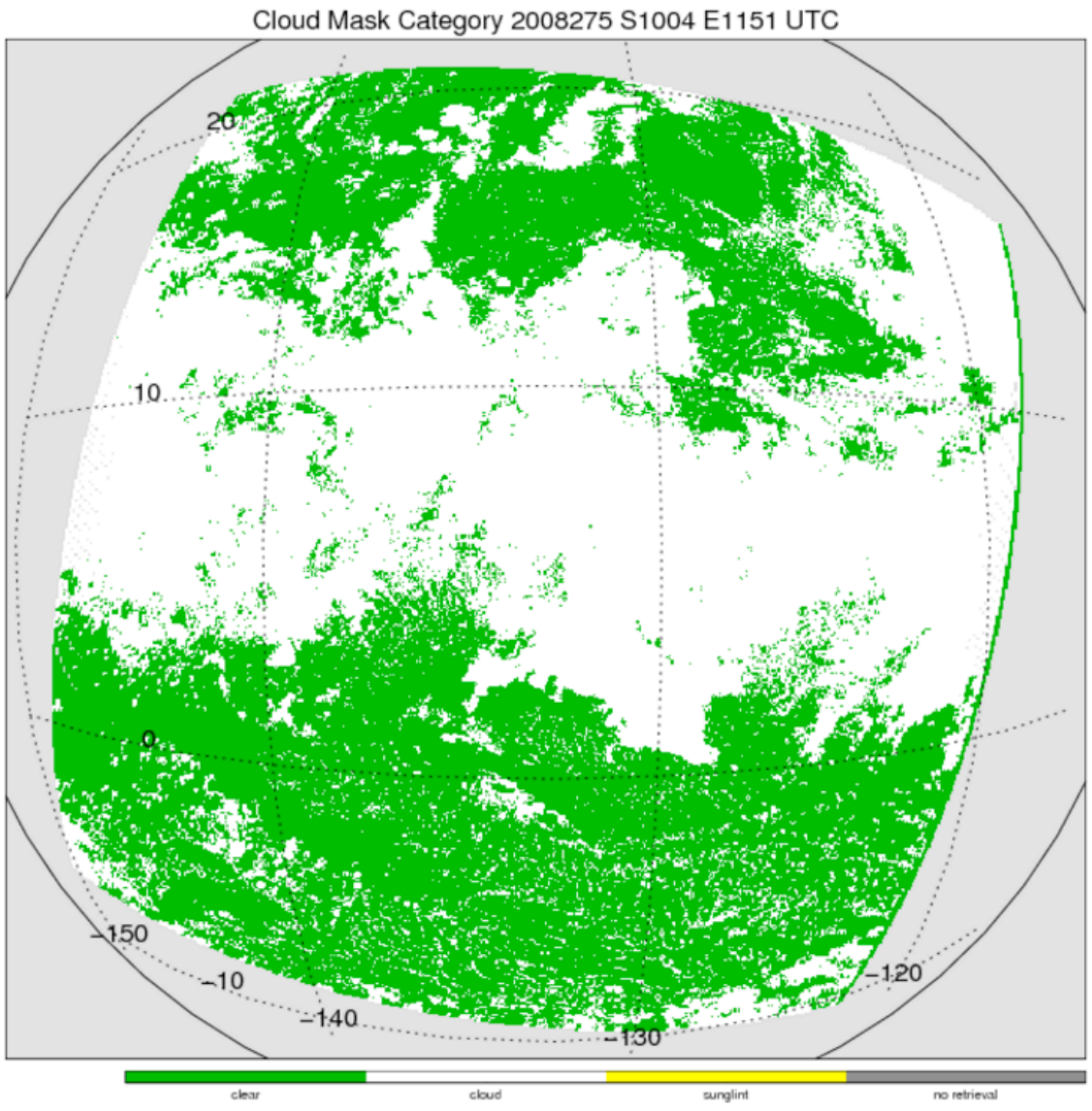
AVHRR Product Examples: Night-time Cloud Mask



CLOUDMASK (count)

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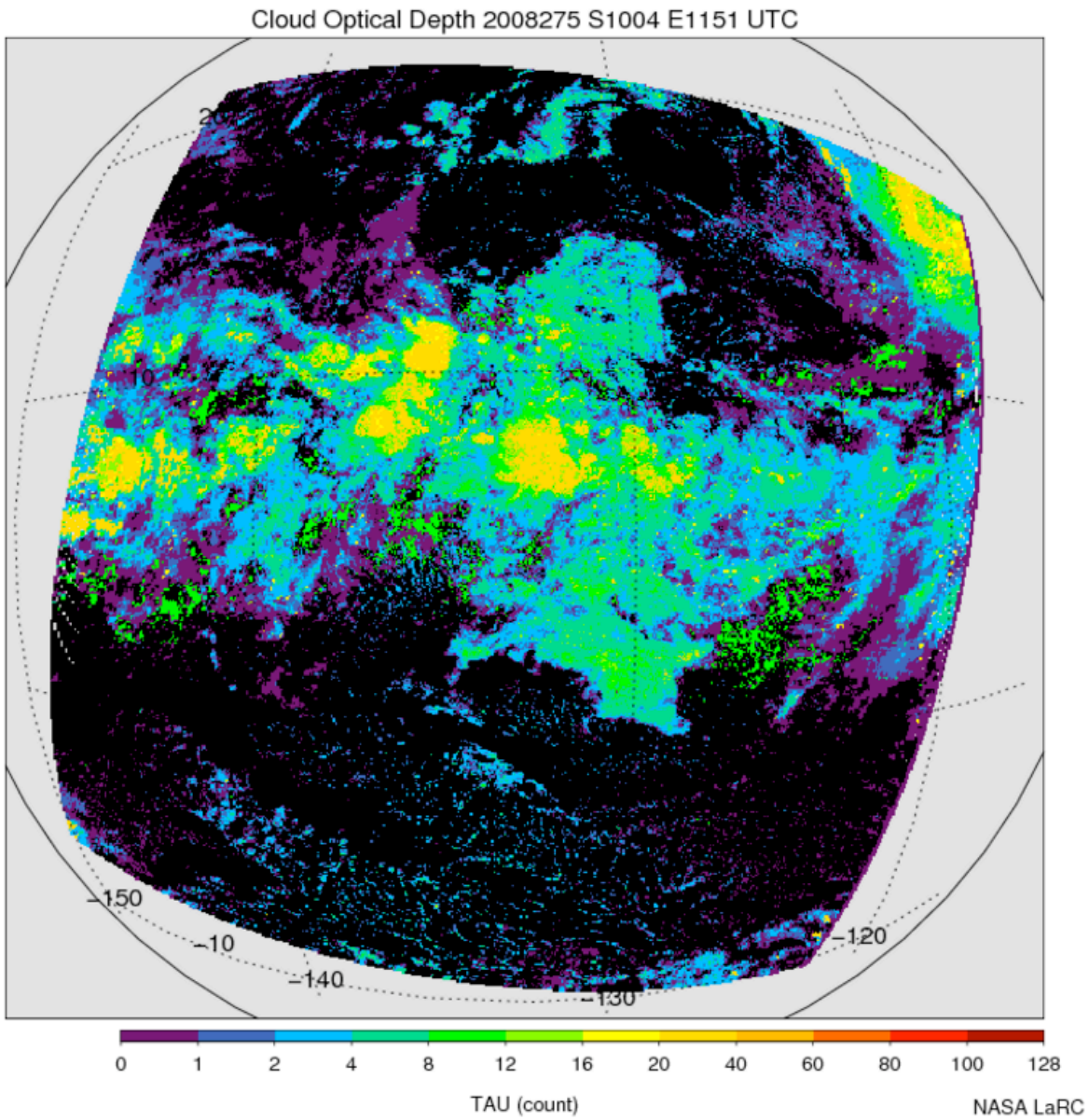
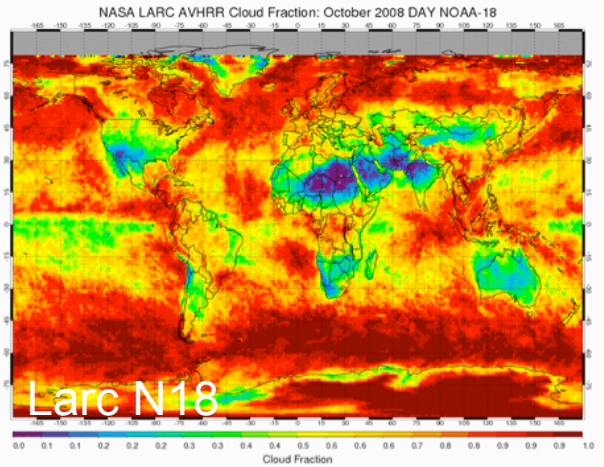
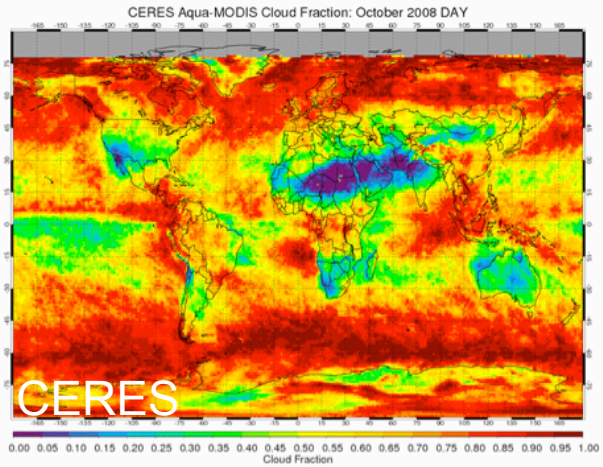
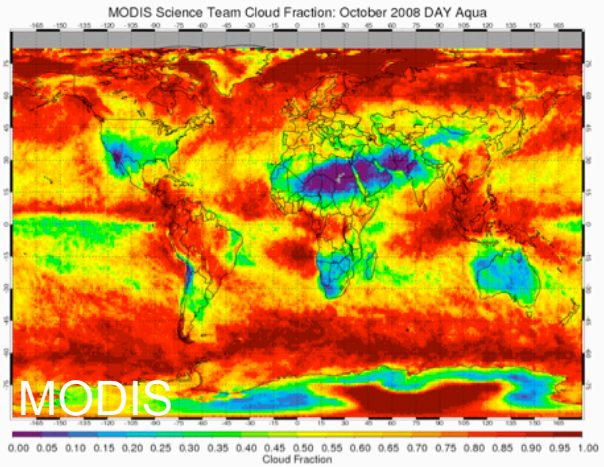
AVHRR Product Examples: Night-time Cloud Optical Depth

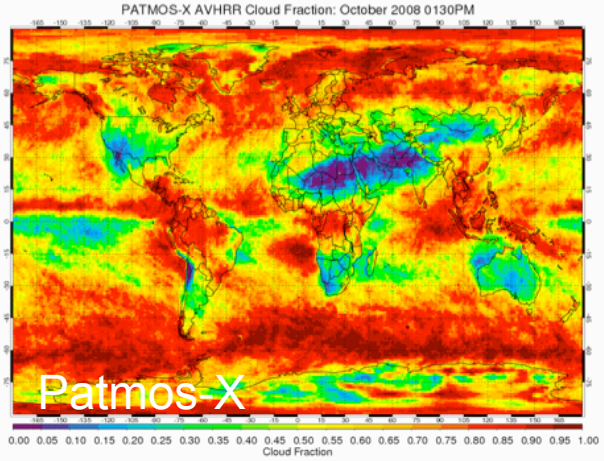


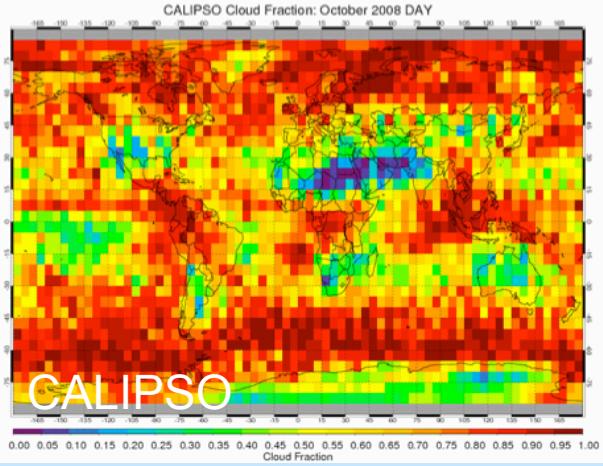
Oct 2008
Daytime Monthly Average Cloud Fraction

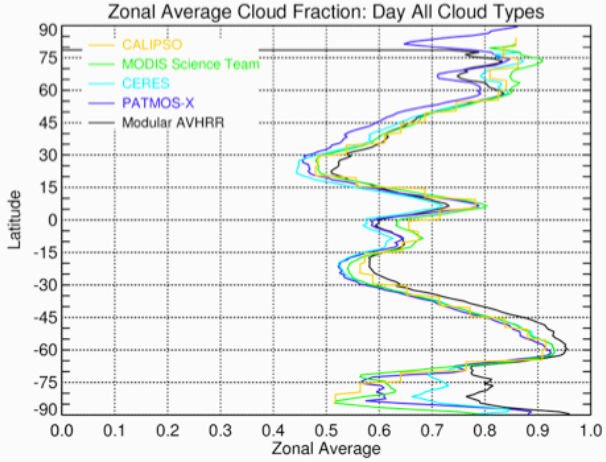




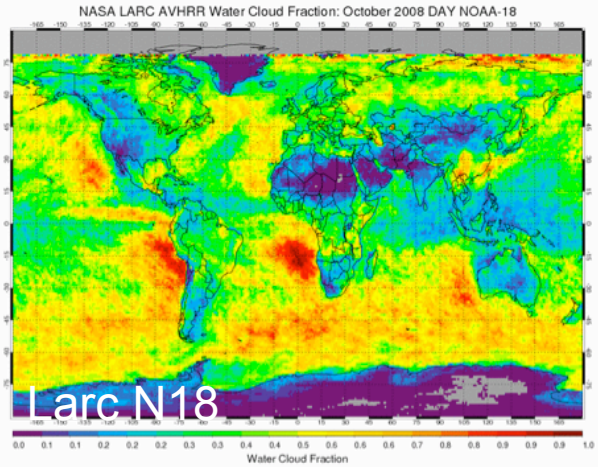


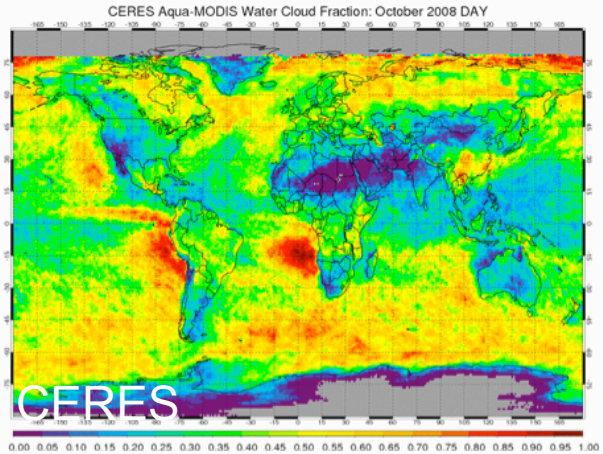


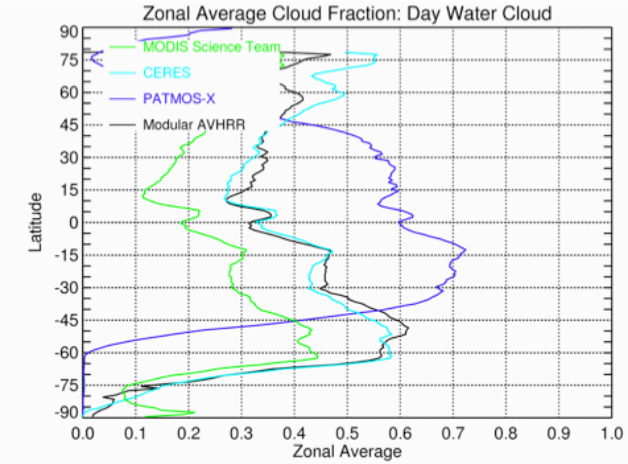


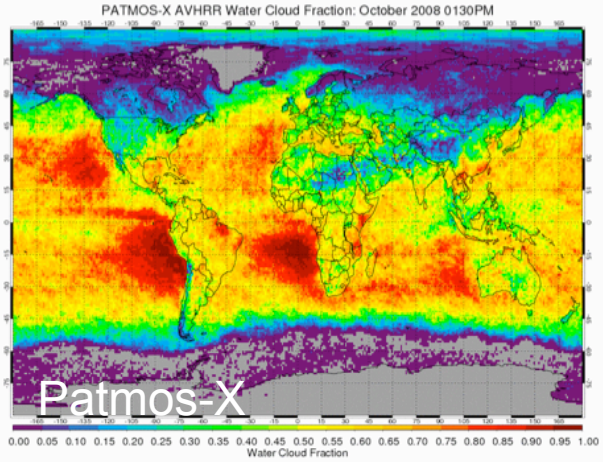


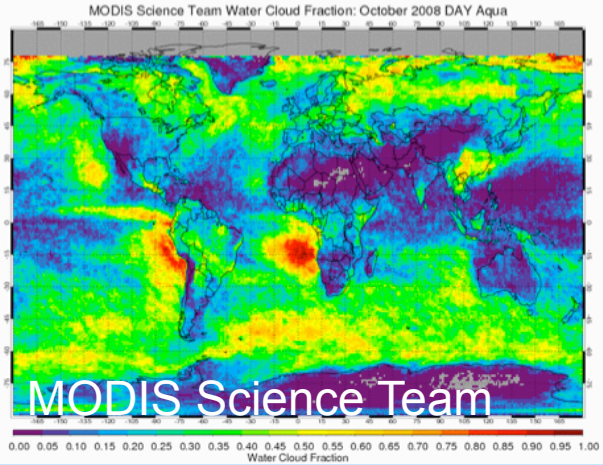
NOAA-18 AVHRR Oct 2008
Daytime Monthly Average Cloud Fraction: Water Cloud



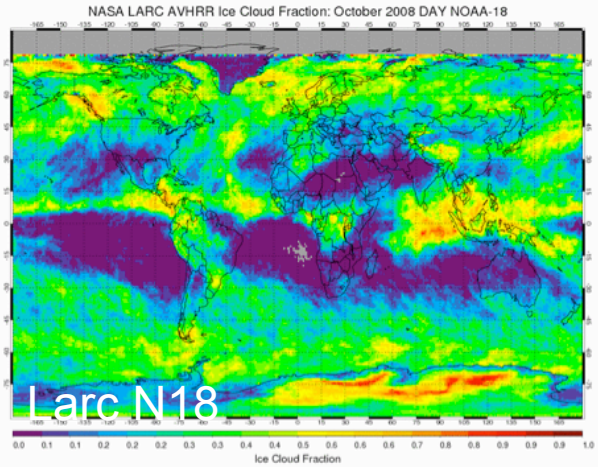


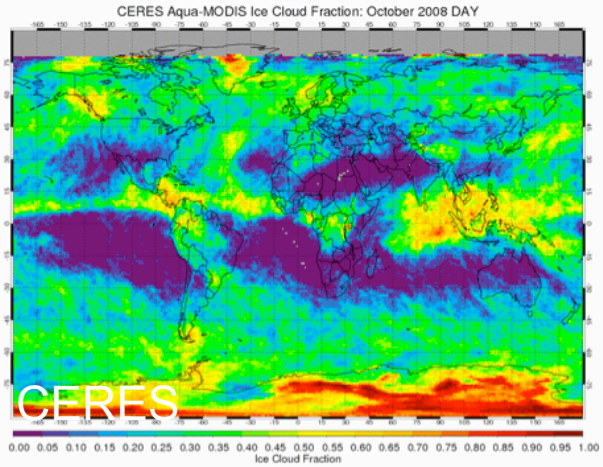


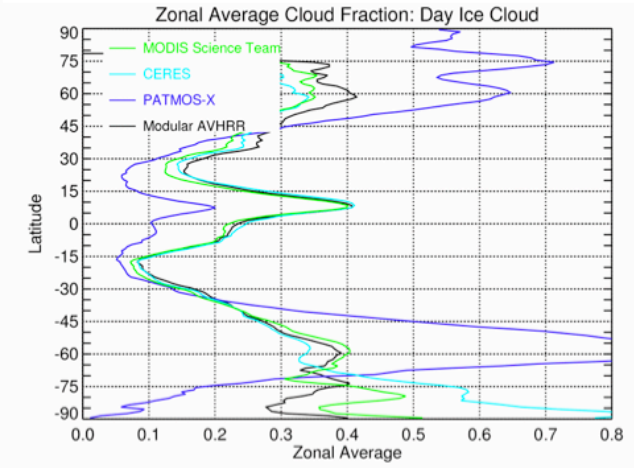


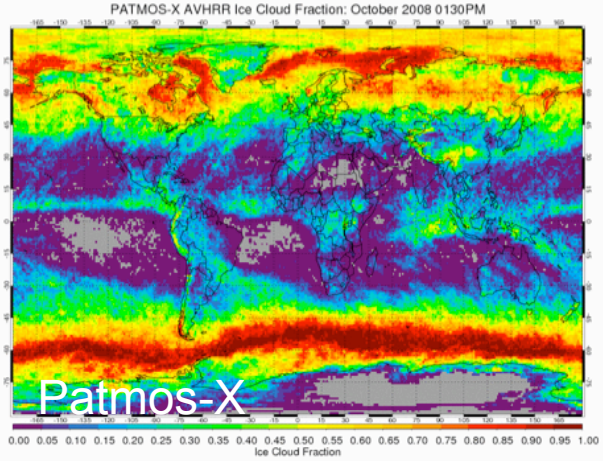


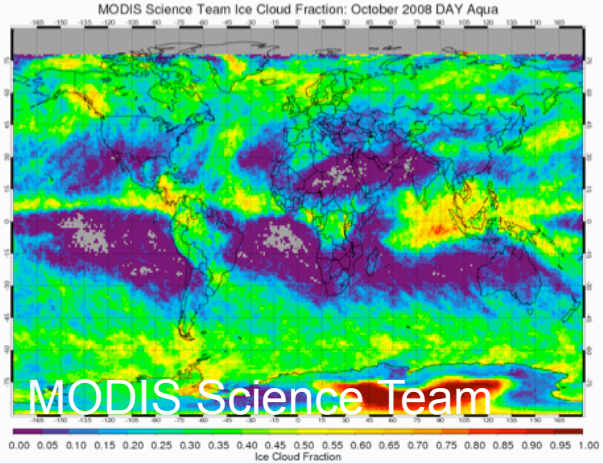
NOAA-18 AVHRR Oct 2008
Daytime Monthly Average Cloud Fraction: Ice Cloud



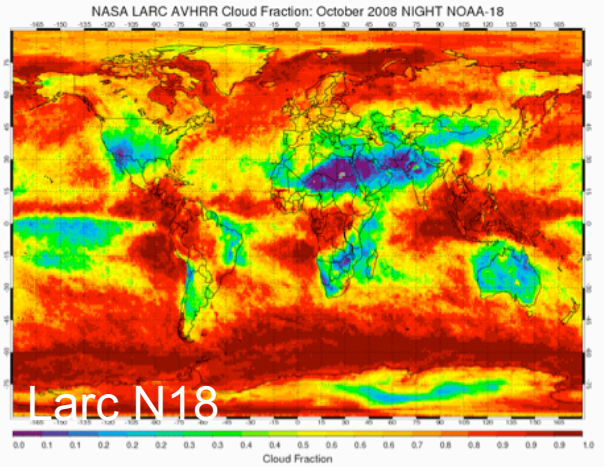


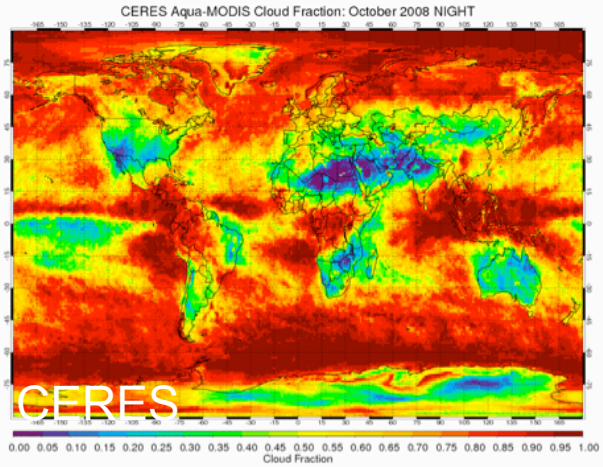


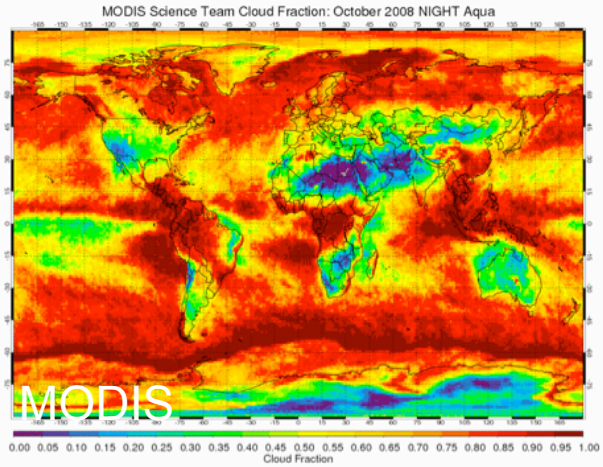


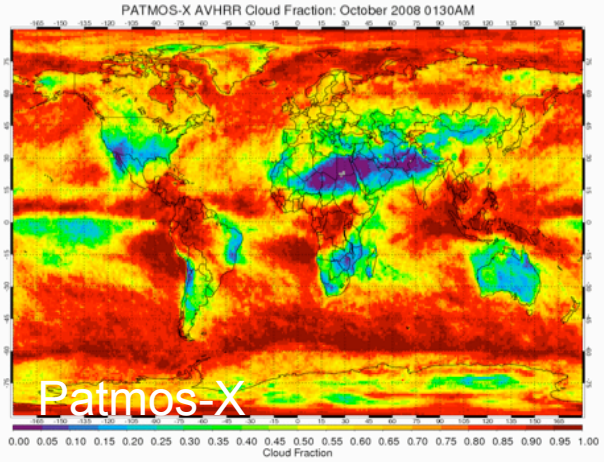


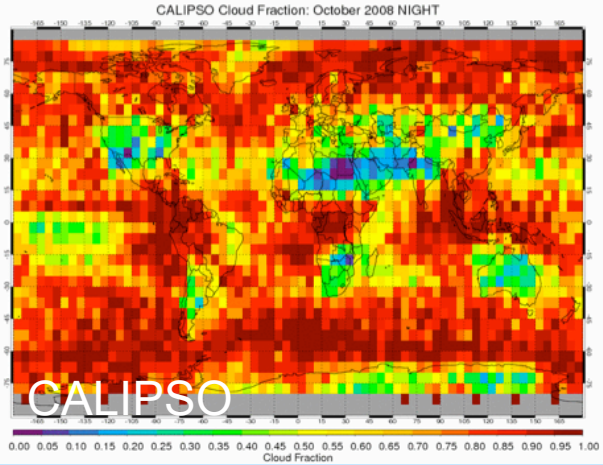
NOAA-18 AVHRR Oct 2008
Night Monthly Average Cloud Fraction

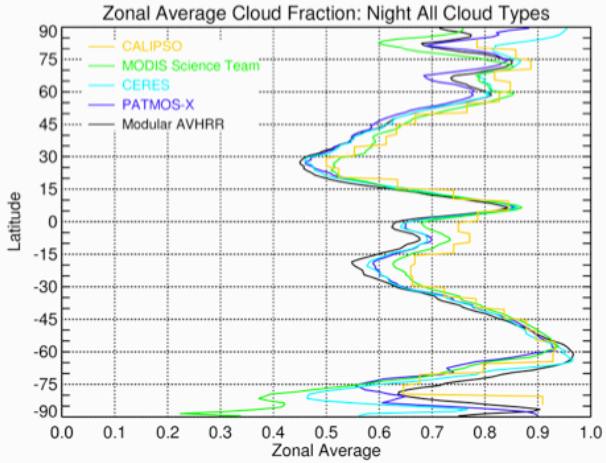






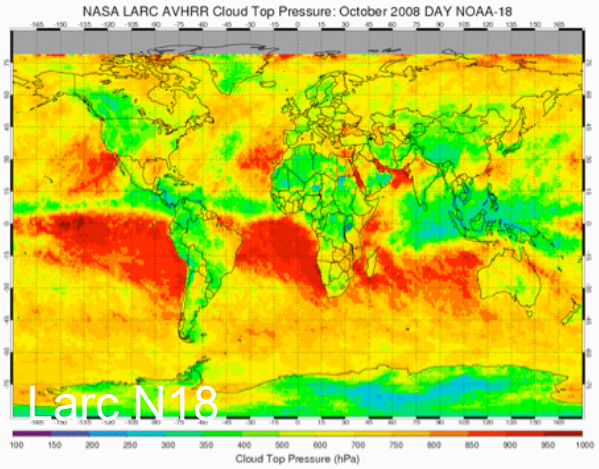


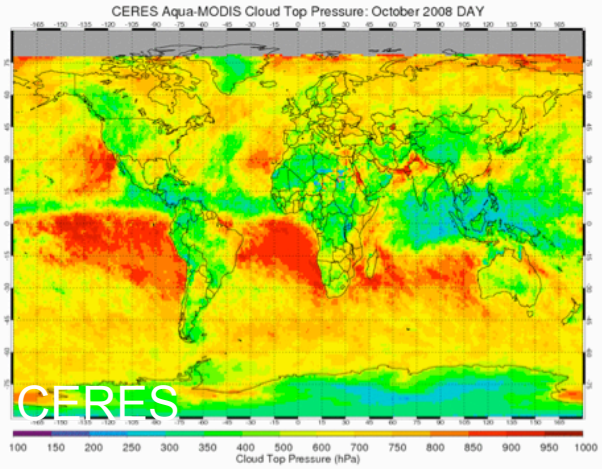


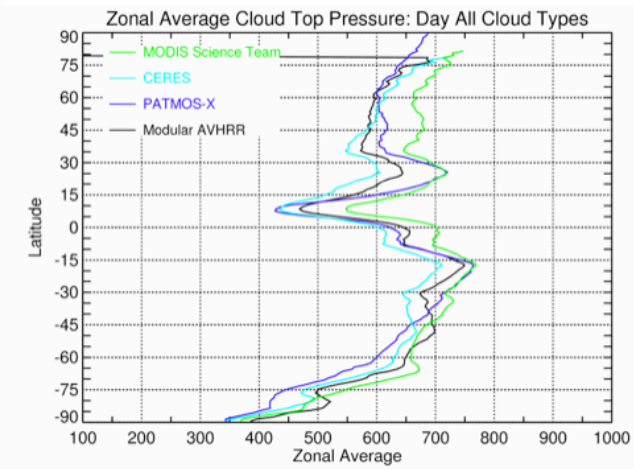


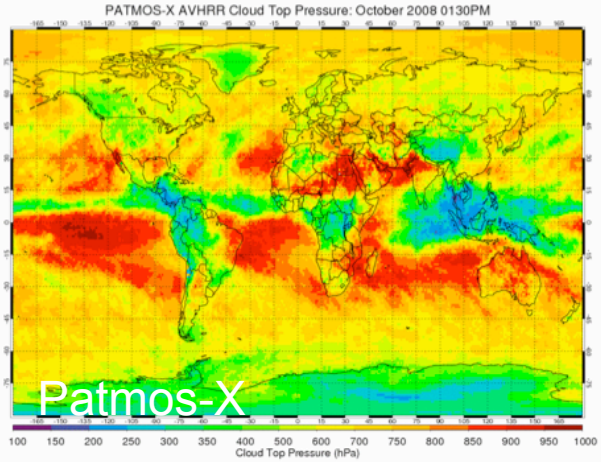
Cloud Fraction	LaRC AVHRR	PATMOS-X	CERES	MODIS-ST	CALIPSO
Day	0.684	0.644	0.650	0.676	0.679
Night	0.676	0.680	0.688	0.706	0.729

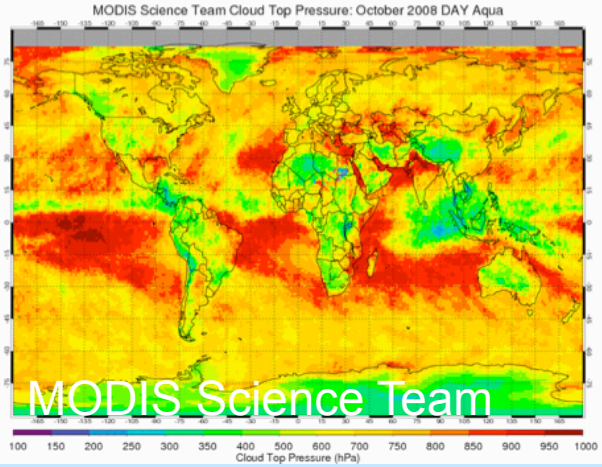
NOAA-18 AVHRR Oct 2008
Daytime Monthly Average Cloud Top Pressure



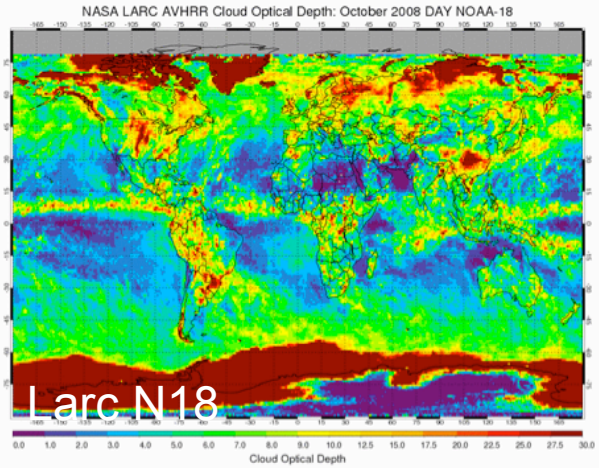


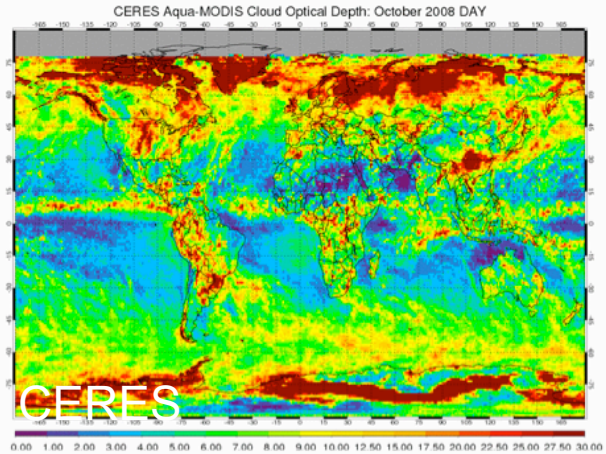


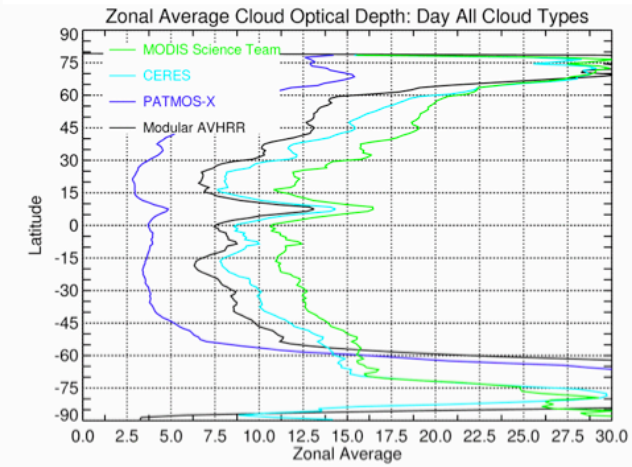


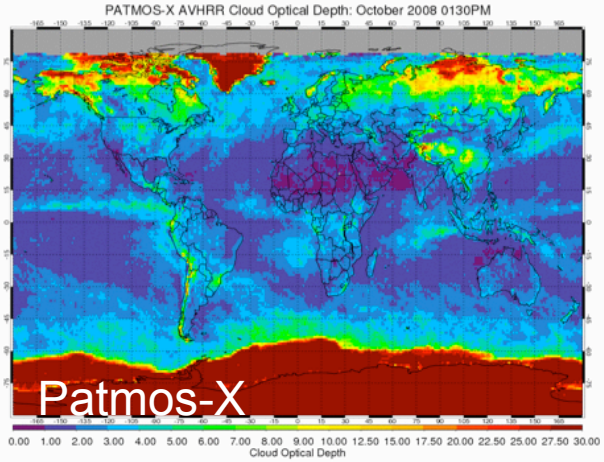


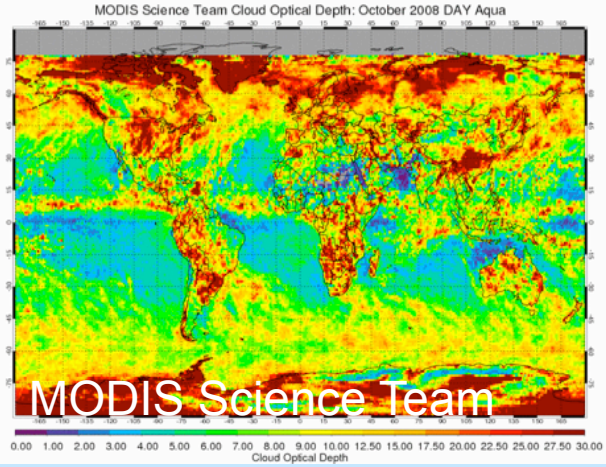
NOAA-18 AVHRR Oct 2008
Daytime Monthly Average Cloud Optical Depth

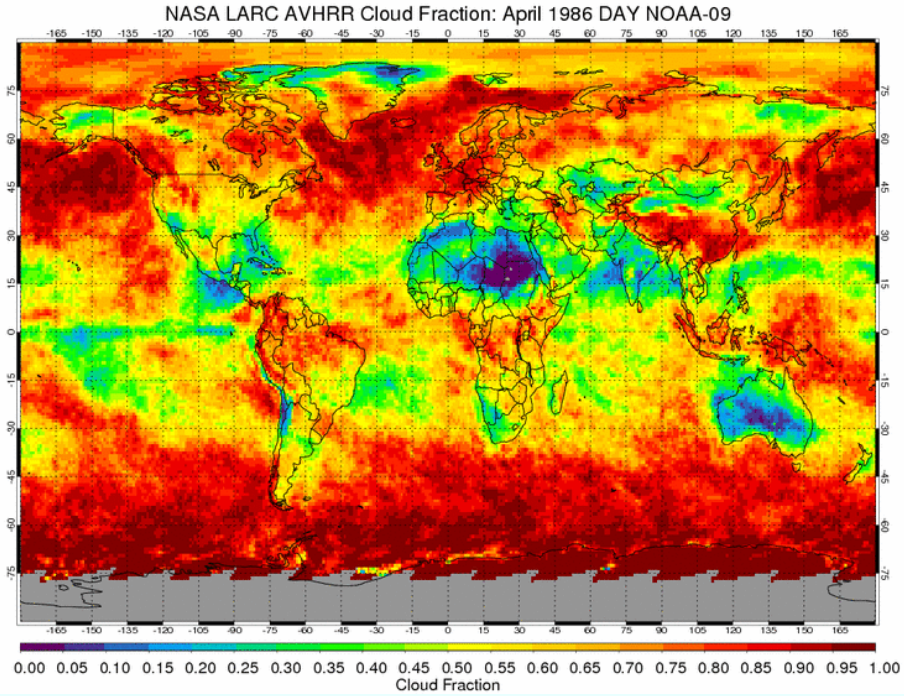


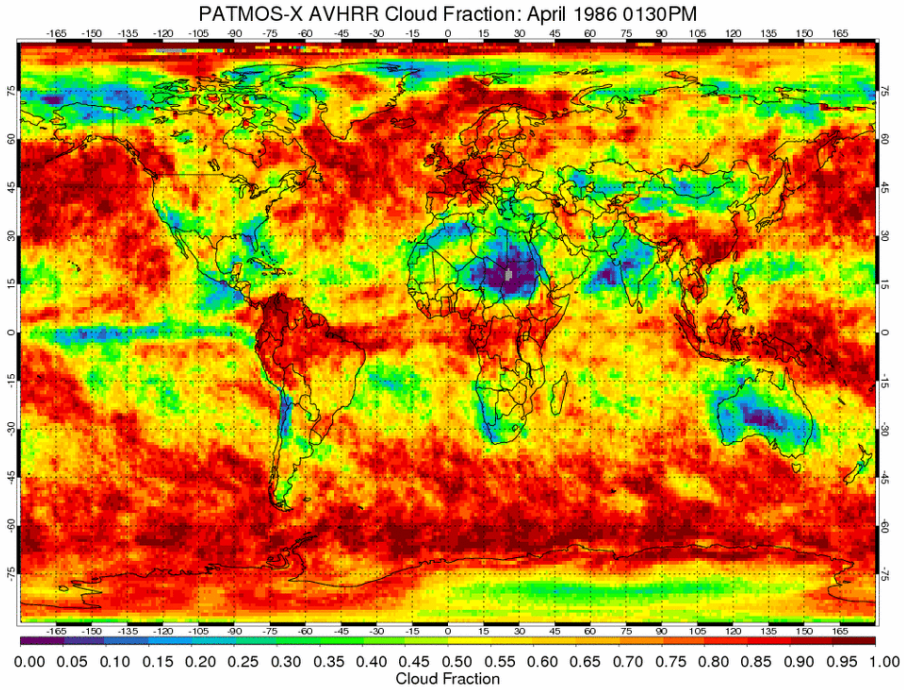




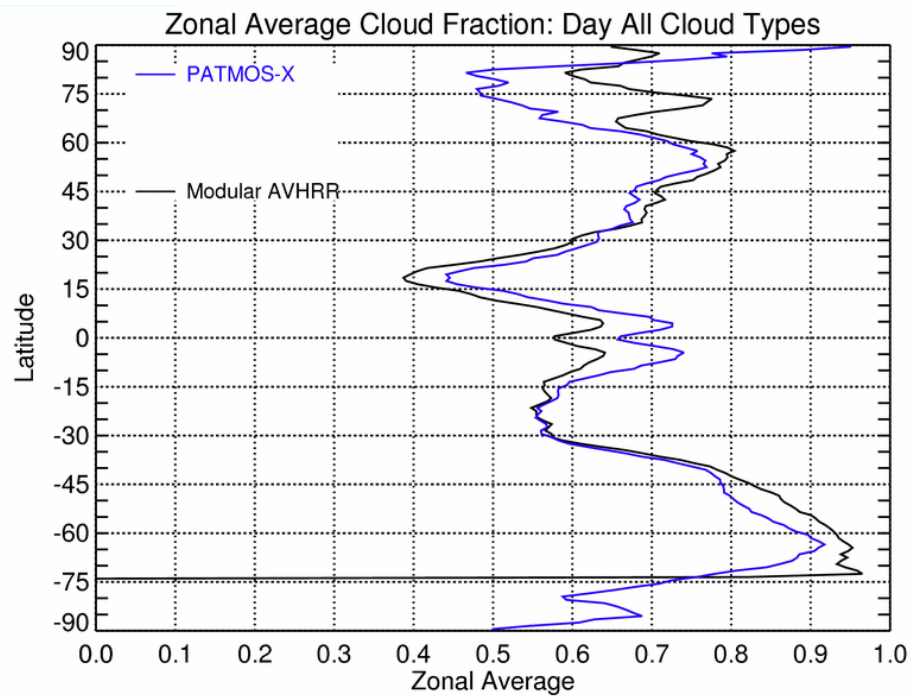








NOAA-9 AVHRR April 1986 Daytime Monthly Average Cloud Fraction



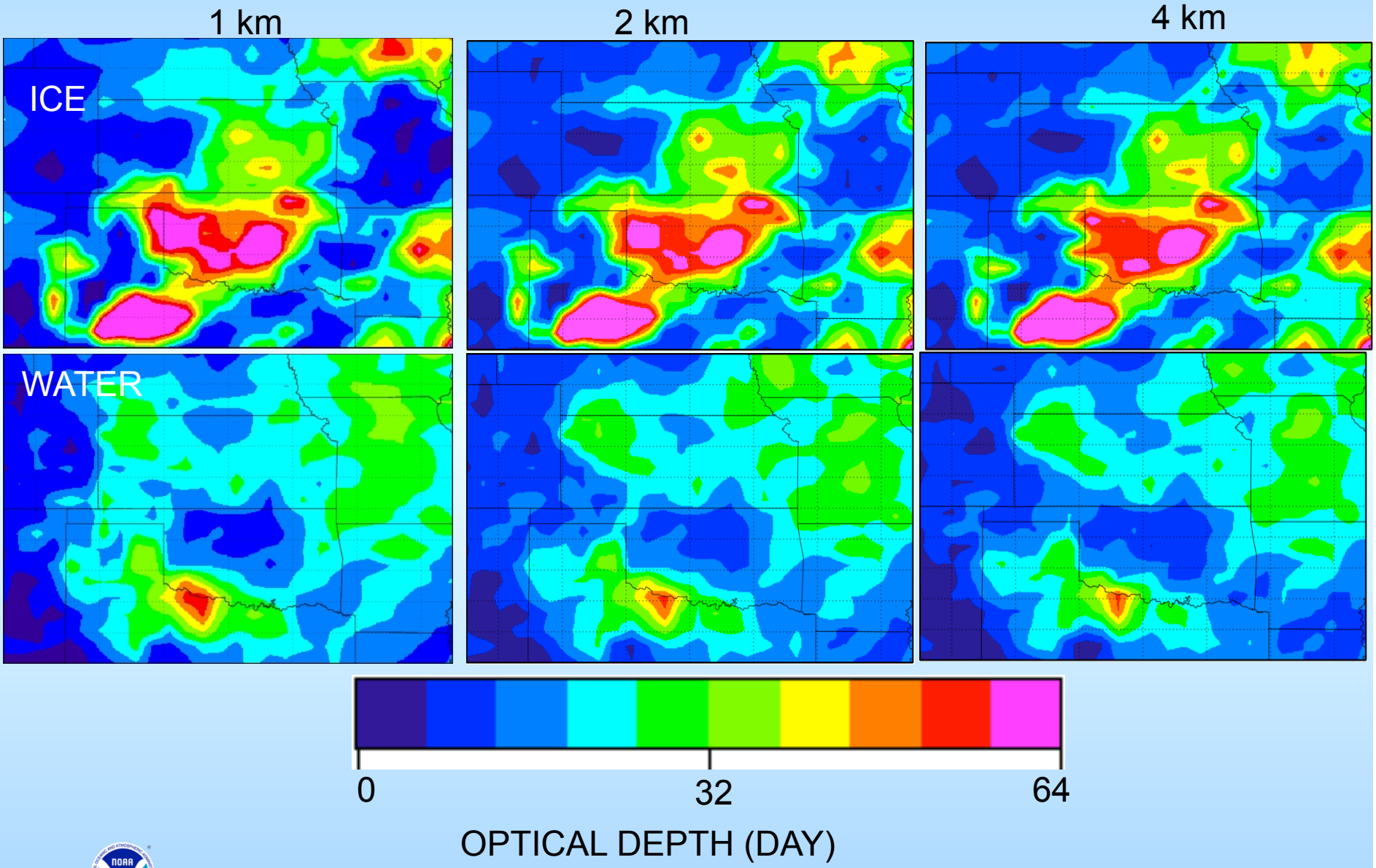
Quality Assurance Approach

- Calibration
  - Perform consistency checks among methods
    - DCC vs NSO vs desert
  - Conduct round robin comparisons
    - E.g, Calibrate AVHRR against 1 GEO, compare to other
  - Compare with other results
    - E.g., PATMOS< ISCCP

Quality Assurance Approach

- Clouds
  - Compare with other methods (e.g., CALIPSO, PATMOS)
  - Trend anomalies
  - Visual analysis
  - Compare with other LaRC results (e.g., N17 vs N18)
  - Sensitivity analyses
    - Compare mask/retrieval results when inputs are changed
      - NWP profiles (GFS vs. MERRA)
      - Ozone profiles (MERRA vs. climatology)
      - Clear sky reflectance / surface emissivity maps
      - Visible channel calibration
  - AMSR-E Liquid Water Path
  - ARM ground-based instrumentation
  - Field experiment remotely sensed or in-situ data

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



Impact of Resolution on Retrieved Cloud Properties
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

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

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

PARTICLE SIZE						
	WATER			ICE		
	1km	2km	4km	1km	2km	4km
Day	10.41	10.45	10.54	52.82	51.63	50.13
Night	8.76	8.75	8.71	61.89	63.21	64.79
Total	9.76	9.79	9.84	58.65	59.00	59.36

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

Calibration Applications

- Make quantitative analysis possible
  - E.g., Solar energy
  - cloud optical depth
- Climate trends
  - Removes sensor biases
- Vegetation studies (vegetation index)
  - Both channels must be calibrated

Cloud Product Applications

- Surface radiation budget (solar energy)
- Climate studies
  - regional albedo
    - Potential aerosol retrievals (air quality)
  - storm statistics
  - Urban heat island effects (clear areas)
  - Transportation: fog statistics
  - Reanalysis assimilation/validation
- Vegetation studies (vegetation index)
  - Forest & crop health (clear areas)

Earthquake Prediction

- U of Colorado scientists have method that may be able to detect earthquakes in clear areas a few minutes-to-hours before the quakes occur, they requested cloud data
  - Evident in electromagnetic activity that heats the air above the soon-to-move land
  - Electromagnetic activity seen in sudden warming of the ground & air above the anomaly
  - Cloud-screened data needed for refining the technique

Publications & Presentations

- Doelling, D. R., C. Lukashin, P. Minnis, B. Scarino, and D. Morstad, 2011: Spectral reflectance corrections for satellite intercalibrations using SCIAMACHY data. *Geosci. Remote Sens. Lett.*, **9**, 119-123, doi: 10.1109/LGRS.2011.2161751 .
- Wu, X., et al., 2011: Assessment of MetOp-A Advanced Very High Resolution Radiometer (AVHRR) Short Wave Infrared channel measurements using Infrared Atmospheric Sounding Interferometer (IASI) observations and line-by-line radiative transfer model simulations. *Intl. Jour. Remote Sens.*, **33**, 5240-5250.
- Doelling, D. R., B. R. Scarino, D. Morstad, A. Gopalan, R. Bhatt, C. Lukashin, and P. Minnis, 2012: The calibration of visible imagers using operational hyper-spectral SCIAMACHY radiances. Submitted, *IEEE Trans. Geosci. Remote Sens.*
- Minnis, P., D. R. Doelling, K. T. Bedka, R. Palikonda, Q. Z. Trepte, S. Bedka, B. Scarino, D. Morstad, and P. W. Heck, 2011: A CERES-like cloud property data record from AVHRR data. *2011 EUMETSAT Meteorol. Sat. Conf., Oslo, Norway, Sept. 5 – 9.*
- Trepte, Q., P. Minnis, R. Palikonda, K. Bedka, and S. Sun-Mack, 2011: Comparison of cloud detection using the CERES Ed4 and LaRC AVHRR cloud masks and CALIPSO Version 3 Vertical Feature Mask. *AGU Fall Mtg 2011*, 5-9 Dec., San Francisco, CA, A13B-0234.
- Shrestha, A. K., S. Kato, K. M. Bedka, P. Minnis, W. F. Miller, and T. E. Caldwell, 2011: Improvement of ERBE-derived TOA irradiance with AVHRR data and Aqua CERES angular distribution models. *AGU Fall Mtg 2011*, 5-9 December, San Francisco, CA, U41B-0010.
- Khlopenkov, K. and P. Minnis, 2011: Analysis and improvement of geo-referencing accuracy in long term global AVHRR data. *AGU Fall Mtg 2011*, 5-9 December, San Francisco, CA, IN21A-1413.
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Publications & Presentations

- Scarino, B., D. R. Doelling, D. Morstad, P. Minnis, and C. Lukashin, 2012: The calibration of LEO and GEO satellite imager radiances using hyper-spectral data from SCIAMACHY. *AMS 8th Ann. Symp. Future Oper. Environ. Satellite Sys.*, New Orleans, LA, 22 -26 January, P494.
- Palikonda, R., P. Minnis, D. A. Spangenberg, Q. Z. Trepte, J. K. Ayers, and B. Shan, 2012: Effects of pixel sampling on cloud climatologies. *AMS 18th Conf. Satellite Meteor., Oceanog., and Climatol.*, New Orleans, LA, 22 -26 January, P168.
- Bedka, K. R. Palikonda, and P. Minnis, 2012: A CERES-consistent cloud climate record from AVHRR data. *4th WCRP Intl. Conf. Reanalyses*, Silver Spring, MD, 7-11 May.

Schedule & Issues

- Project status and plans for next phase of the project
  - Calibrations nearly finished for main AVHRRs (afternoon orbit, 5-channel)
  - Account for variable SZA of other AVHRRs
  - Code complete except for polar optical depth retrievals
  - Run main AVHRRs this fall (N-18, N-16, N-14, N-11, N-9, N-7)
  - Calibrate odd AVHRRs (N-17, N-15, N-12, N-10, N-8, N-6, TIROS-N)
  - Alter code for odd AVHRRs, begin processing

- Risks and concerns
  - We will request a no cost extension to finish the odd AVHRR records
  - Computer system failures have been an issue
  - MODIS calibrations: Col. 6 will change reference (Terra for 1.6, 0.86 μm?)
  - Resolution effects compared to MODIS
  - IR calibrations & 3.7-μm cold end discretization
  -

- How can the CDR Program better assist you?
  - Continue funding