Cloud Detection and Cloud Property Retrievals From Current and Historical Satellite Imagers at NASA LaRC

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INTRODUCTION

One of the most pressing climate issues identified by the IPCC's Fourth Assessment is the need for a long-term analysis of cloud properties to better understand the impact of cloud radiative forcing on various aspects of climate, especially surface temperature and its diurnal variation. To understand this radiative forcing over long time periods, it is necessary to measure global cloud properties using a consistent set of proven algorithms applied to a long-term record of consistently calibrated and quality-controlled satellite imager data. Knowing how clouds vary with climate change and how well climate models reproduce such variability through modeled feedbacks is critical to understanding how well the models can predict climate. In addition, cloud properties derived from these calibrated satellite observations can be used to improve the representation of clouds in global reanalyses.

As part of the NOAA NCDC Climate Data Record (CDR) program, we are currently developing a Thematic CDR (TCDR) consisting of cloud amount, phase, optical depth, effective particle size, height, and temperature extending back to 1978 using data from the Advanced Very High Resolution Radiometer (AVHRR) instrument. The TCDR will be consistent with cloud properties derived from MODIS for the Clouds and Earth's Radiant Energy System (CERES) program, though some modifications to these algorithms will be required to operate on the 5-channel and lower spatial resolution AVHRR Global Area Coverage (GAC) data. Stable and accurate visible channel calibration is ensured through matching modern AVHRR data with that of Aqua MODIS using observations of deep convective clouds, desert scenes, and simultaneous ray-matched observations. These calibrations are then transferred back in time through the use of time-overlapping LEO and GEO data.

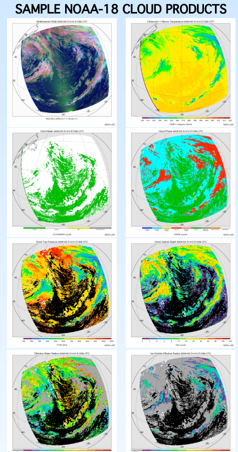
Within the CERES program, hourly global cloud mask/properties and fluxes are derived from the geostationary (GEO) satellite observations. CERES temporal interpolation uses the hourly GEO clouds and fluxes in-between MODIS and CERES observations to derive daily means. The CERES-MODIS retrieval algorithm has been adapted to process real-time and historical GEO datasets from 60° S-60° N latitude. During daytime, cloudy pixels are analyzed with the visible infrared solar-infrared split-window technique (VISST), which matches the observed values with theoretical models of cloud reflectance and emittance. At night and near twilight, cloudy properties are determined using the solar-infrared infrared split-window technique (SIST).

EFFORTS TOWARD AN AVHRR CLOUD PROPERTY CLIMATE DATA RECORD AT NASA LaRC

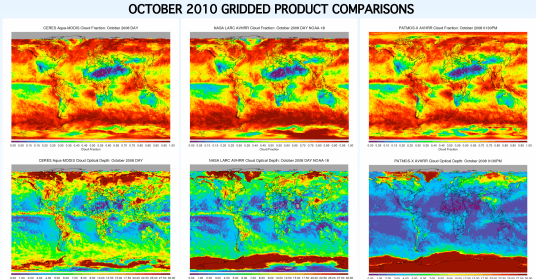
AVHRR CLIMATE DATA RECORD PROJECT DESCRIPTION

- Goals
  - Calibrate AVHRR 0.64, 0.87, and 1.6-μm channels
  - Calibrate GOES & SMS imager 0.65-μm channels
  - Generate CERES-like cloud macro- and micro-physical property climatology for the entire AVHRR data record
- Algorithms
- CERES MODIS cloud mask and retrieval algorithm adapted to operate using 5-channel AVHRR radiances (Minnis et al. 2008 and 2011)
- Near Simultaneous Ray-Matched and Deep Convective Cloud techniques used for calibration (Hu et al. 2004; Morstad et al. 2011)
- Source Data
  - 4 km AVHRR Global Area Coverage Data: 1978 – present
  - SMS-1 & 2; GOES-1 thru present
  - SCIAMACHY spectral data (2004-2009)
- Ancillary Data
  - NASA 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
  - Cloud microphysical models for spherical water droplets and roughened ice crystals
  - 10-minute spatial resolution land surface elevation, land and water maps, IGBP ecosystem, and surface emissivity also used in CERES MODIS cloud retrievals
  - Dynamically generated clear sky reflectance maps based on clear-sky AVHRR observations
- Deliverables
  - Calibrated 0.63 & 0.86-μm radiances for AVHRR and GEO instruments (calibration coefficients)
  - Pixel level cloud mask, temperature, height, optical depth, effective particle size, water path, phase; surface skin temperature, and spectral albedo
- Essential Climate Variables Addressed: Cloud properties and radiation budget
- Current/Expected User Communities: GEWEX and GCM communities. Energy, aviation, and reinsurance industries
- **Scheduled Project Completion: Summer 2013**

SAMPLE NOAA-18 CLOUD PRODUCTS

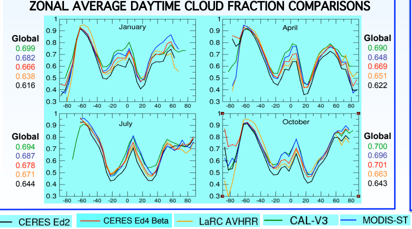


OCTOBER 2010 GRIDDED PRODUCT COMPARISONS



NOTE: The AVHRR cloud property retrieval software is currently being upgraded to match the logic used in CERES Edition 4 cloud retrievals. We expect closer agreement between AVHRR and CERES Edition 4 when this upgrade has been completed, though an exact match is impossible due to the limited spectral information available with AVHRR, especially over snow surfaces and within thin cirrus. The results shown here are not entirely representative of those that will be produced for the final AVHRR CDR. PATMOS-X datasets presented here were provided to the 2010 GEWEX Cloud Assessment

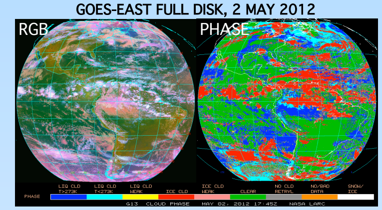
ZONAL AVERAGE DAYTIME CLOUD FRACTION COMPARISONS



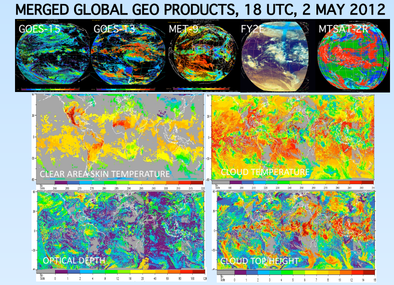
GEOSTATIONARY SATELLITE CLOUD AND SURFACE TEMPERATURE PRODUCT DATASET

- Recent geostationary satellites provide up to 1-hour global monitoring between ~60° S and ~60°N
- The CERES MODIS cloud retrieval algorithma (VISST (daytime)/SIST (nighttime)) has been adapted for the geostationary (GEO) satellite data processing
- Currently running hourly global GEO retrievals in real-time from GOES-15, GOES-13, MET-9, FY2-E & MTSAT-2R at 8-10 km resolution
- **Collaborative work underway with the NASA GMAO GEOS-5 team to assimilate 3-hourly merged global products e.g. skin temperature, cloud height, optical depth etc. to improve model forecasts**
- **Hourly global GEO products dataset from 2000-2012 at 8-10 km pixel resolution and 1° products will be available in early 2013**

GOES-EAST FULL DISK, 2 MAY 2012



MERGED GLOBAL GEO PRODUCTS, 18 UTC, 2 MAY 2012



NASA LANGLEY CLOUD PRODUCTS

Standard, Single-Layer VISST/SIST

0.65, 1.6 μm Reflectanc
3.7, 6.7, 10.8 μm Temp
12 or 13.3 μm Temp
Broadband Albedo
Broadband OLR
Clear-sky Skin Temperat
Icing Potential**
Pixel Lat, Lon
Pixel SZA, VZA, RAZ

Cloud Products
- Mask, Phase
- Optical Depth, IR emissivity
- Effective droplet Radius or ice crystal Diameter
- Liquid/Ice Water Path
- Effective Temp, height, pressure
- Top/ Base Pressure
- Top/ Base Height

Multi-Layer, CIRT, CO_2 channel only

Multilayer ID (single or 2-layer)

Products For Both The Upper and Lower Layers

effective temperature	optical depth, thickness
effective particle size	ice or liquid water path
top/base height and pressure	

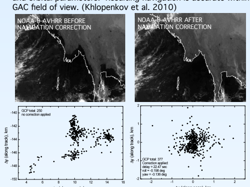
DATA PRODUCT FORMATS

- Pixel-level Product: retrieved at instrument nominal resolution *(netcdf format)*
- Gridded Product: 0.25° or 1.0° average separated by cloud height/phase *(netcdf format)*
  - includes surface radiative fluxes & skin temperature

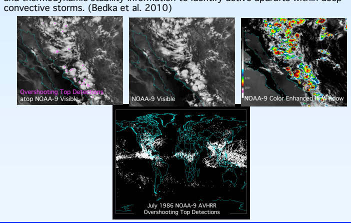
Visit *http://www-pm.larc.nasa.gov/global_geo_products* to access real-time and archived data

NEW COMPONENTS OF THE NASA LaRC AVHRR CDR

IMPROVED AVHRR NAVIGATION: Match AVHRR imagery to a composite database of global cloud-free MODIS visible and near-IR ground control points to compute image displacement vectors and correct satellite attitude and orbital parameters. Resulting navigation is accurate within ½ an AVHRR GAC field of view. (Khlopenkov et al. 2010)



DETECTION OF PENETRATING CONVECTIVE UPDRAFTS: Use spatial gradients and thresholding of IR window temperatures with MERRA tropopause temperature and thermodynamic stability information to identify active updrafts within deep convective storms. (Bedka et al. 2010)



ADDITIONAL FEATURES

- Independent calibration system tied to the Aqua MODIS 0.63 μm channel
- Methodology consistent with CERES MODIS retrievals from 2000-onward
- Cloud property retrievals during both day and night
- Ice cloud phase functions derived via roughened hexagonal crystals which helps to improve optical depth and particle size retrievals in thin cirrus (Yang et al. 2008)
- Estimates of cloud base during daytime using a parameterization based on optical depth and particle size
- Pixel-level skin temperature retrieval
- Dynamically updating clear sky reflectance maps over snow and non-snow surfaces
- Specialized BRDF and emissivity models with scene-, atmospheric-, and angular-dependencies to improve modeling of clear sky reflectance and brightness temperatures over ocean, sea ice, and snow surfaces
- Use 2-D fourier transform to identify and eliminate striping across track in pre-KLM series 3.75 μm channel radiances

REFERENCES AND ACKNOWLEDGEMENTS

Bedka, K. M., J. Brunner, R. Dworak, W. Feltz, J. Otkin, and T. Greenwald, 2010: Objective satellite-based overshooting top detection using infrared window channel brightness temperature gradients. *J. Appl. Meteor. And Climatol.*, 49, 181-202.

Hu, Y., B. Wielicki, P. Yang, P. Stackhouse, B. Lin, and D. Young, 2004: Application of deep convective cloud albedo observations to satellite-based study of terrestrial atmosphere: monitoring stability of space-borne measurements and assessing absorption anomaly. *IEEE Trans. Geosci. Remote Sensing, 42, 2594-2599.*

Khlopenkov, K., A. Trishchenko, and Y. Luo, 2010: Achieving subpixel georeferencing accuracy in the Canadian AVHRR Processing System. *IEEE Trans. Geosci. Remote Sensing,* 48, 2150-2161.

Minnis, P., L. Nguyen, R. Palikonda, P. W. Heck, D. A. Spangenberg, D. R. Doelling, J. K. Ayers, W. L. Smith, Jr., M. M. Khaiyer, Q. Z. Trepte, L. A. Avey, F.-L. Chang, C. R. Yost, T. L. Chee, and S. Sun-Mack, 2008: Near-real time cloud retrievals from operational and research meteorological satellites. *Proc. SPIE Europe Remote Sens. 2008, Cardiff, Wales, UK, 15-18 September, 7107-2, 8 pp.*

Minnis, P., Q. Z. Trepte, S. Sun-Mack, Y. Chen, D. R. Doelling, D. F. Young, D. A. Spangenberg, W. F. Miller, B. A. Wielicki, R. R. Brown, S. C. Gibson, and E. B. Geier, 2008: Cloud detection in non-polar regions for CERES using TRMM VIRS and Terra and Aqua MODIS data. *IEEE Trans. Geosci. Remote Sens., 46, 3857-3884.*

Minnis, P., S. Sun-Mack, D. F. Young, P. W. Heck, D. P. Garber, Y. Chen, D. A. Spangenberg, R. F. Arduini, Q. Z. Trepte, W. L. Smith, Jr., J. K. Ayers, S. C. Gibson, W. F. Miller, V. Chakrapani, Y. Takano, K.-N. Liou, Y. Xie, and P. Yang, 2011: CERES Edition-2 cloud property retrievals using TRMM VIRS and Terra and Aqua MODIS data, Part I: Algorithms. *IEEE Trans. Geosci. Remote Sens., 49, 11, 4374-4400.*

Morstad, D. L., D. R. Doelling, R. Bhatt and B. Scarino, 2011: The CERES calibration strategy of the geostationary visible channels for CERES cloud and flux products. *Proc. SPIE 8153, 815316; doi:10.1117/12.894650.*

Yang, P., G. Hong, G. W. Kattawar, P. Minnis and Y. Hu, 2008: Uncertainties associated with the surface texture of ice particles in satellite-based retrieval of cirrus clouds, Part II. Effect of particle surface roughness on retrieved cloud optical thickness and effective particle size, *IEEE Transactions on Geosciences and Remote Sensing*, 46, 1948-1957.

This work is supported by the NOAA Climate Data Record Program and NASA CERES Program. The authors thank Dr. Andrew Heidinger (NOAA STAR/ASPB) for providing the AVHRR GAC data used in this project. The authors also thank the CERES Clouds Subsystem team for providing the CERES Edition 4 Beta cloud mask and retrieval results.