CGMS

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NOAA Report on Climate Product Research Development

In response to CGMS Recommendation 34.10

This paper provides information to CGMS-XXXV on activities at NOAA/NESDIS/STAR with respect to the generation of climate products. The paper presents our current work with respect to monitoring variability and trends in clouds, aerosols, precipitation, OLR, ozone, temperature and vegetation.

NOAA Report on Climate Product Research Development

1. Introduction

This paper provides information to CGMS-XXXV on activities at the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) which are directed towards the generation of long-term satellite-based climatologies. The paper presents our current work with respect to monitoring variability and trends in clouds, aerosols, precipitation, OLR, ozone, temperature and vegetation.

2. AVHRR Pathfinder Atmospheres Extended (PATMOS-x) (Andrew Heidinger)

The AVHRR Pathfinder Atmospheres Extended (PATMOS-x) is a cloud climatology developed within the NOAA/NESDIS Center for Satellite Applications and Research (STAR). The development of PATMOS-x was part of a larger STAR effort to develop an infrastructure for AVHRR reprocessing and data improvement. PATMOS-x is a successor to the original PATMOS which was developed in the 1990's. PATMOS-x differs from PATMOS in that it uses new algorithms to compute a full suite of cloud properties and also processes data from the morning orbits, which doubles the diurnal sampling. PATMOS-x benefits from recent calibration and geolocation improvements and is based on algorithms developed within NESDIS for operational processing of the AVHRR. The products provided by PATMOS-x include various cloud amounts, such as estimates of the total, ice-phase, water-phase, high, middle and low cloud amounts. PATMOS-x also provides information estimates of cloud height, cloud emissivity, cloud optical thickness and cloud particle size. In general, we have attempted to develop AVHRR algorithms that are physically consistent with those from MODIS where possible. The baseline resolution of the PATMOS-x products is a 55 km equal-area. In addition, PATMOS-x includes selected non-cloud products that allow for improved feedback studies. For example, PATMOS-x includes a dust amount product that has been used successfully to quantify correlations with SST variations and hurricane frequency. The strength of PATMOS-x is that it delivers consistent cloud properties from all orbits in order to provide a sampling of roughly 4 times per day. In this way, PATMOS-x complements the International Satellite Cloud Climatology Project (ISCCP) which possesses superior diurnal sampling but inferior spectral information

Accomplishments

- Developed AVHRR geolocation improvements
- Developed new AVHRR reflectance calibration tied to MODIS.
- Generated a first version of complete PATMOS-x products from 1981 to 2006.
- Participated in the GEWEX cloud climatology assessment workshops (2004, 2006).
- Received media interest regarding published dust/hurricane studies.

Recommendations

- Host PATMOS-x data in a publicly assessable location with proper documentation.
- Fund scientists/students to continue data analysis and data improvement activities.
- Hold workshops to achieve community consensus on AVHRR calibration approaches.
- Investigate options to fill in holes in the CLASS GAC archive for the 1980's.
- Work with global partners to migrate non-USA HRPT data into CLASS.

3. Status of SSM/I Climate Data Sets at NESDIS (Ralph Ferraro and Fuzhong Weng)

Satellite measurements from the Defense Meteorological Satellite Program's (DMSP), Special Sensor Microwave/Imager (SSM/I) is the longest time series of satellite microwave imager in existence today, nearly 20 years in length (starts in July 1987). These observations are being followed with a nearly identical sensor, the Special Sensor Microwave Imager/Sounder (SSMIS), which will continue to operate for at least the next decade. This sensor will ultimately be replaced by something comparable on the converged NOAA/DMSP polar satellite program, NPOESS, continuing this record of passive microwave measurements well beyond 2020 (at present, the NPOESS microwave sensor is undergoing review).

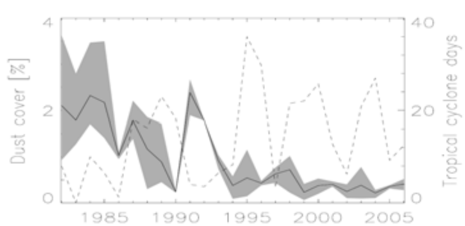
Through several years of support from NOAA/Office of Global Programs, the SSM/I data have been used to generate a valuable time series (monthly, 1.0 and 2.5 degree grid) of hydrological products (including rain, snow, ice, cloud liquid water, and total precipitable water) which are archived at NCDC and are updated on a monthly basis (http://lwf.ncdc.noaa.gov/oa/satellite/ssmi/ssmiproducts.html). They contribute significantly towards NOAA's Climate Mission Goal (e.g., NCEP's *Climate Diagnostic Bulletin)* and international programs (e.g., the Global Precipitation Climatology Program – GPCP). Examples of these products are shown below.

However, there are several serious flaws that need to be corrected to make these products true Climate Data Records (CDRs), as detailed in the NRC report published in 2004 (Climate Data Records From Environmental Satellites. *National Research Council of the National Academies).* This work must continue over the next several years, however, funding sources have not been identified. Some initial efforts have been undertaken at NESDIS/STAR and NESDIS/NCDC over the past two years to address some of these deficiencies and to move towards CDR's. The list of tasks and their status are as follows:

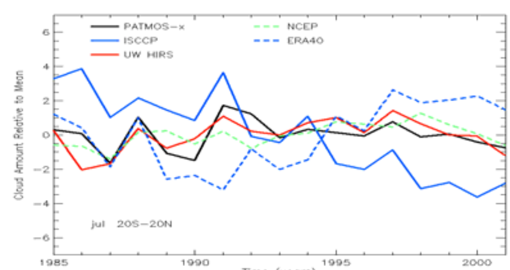
- Obtain and establish a baseline SSM/I TDR data set in a standard format that will be accessible by the scientific community. In particular, the data sets from the first five years of SSM/I operation were provided in several formats. In addition, develop a metadata database that will contain all of the necessary information on the sensor so that the newly developed calibration information can be repeated by the science community. This data will be archived at NCDC. **Status:** Nearly 95% of the SSM/I TDR archive has been "rescued" and are being QC'd. A prototype data format is under development (NetCDF).

- Perform non-linear and inter-sensor calibration of the entire SSM/I and SSMIS time series (seven satellites at present) to remove the biases and correct the diurnal variation from the orbit drifts. Special treatment for the F-16 SSMIS will be required. This will then be used to regenerate the SSM/I TDR and SDR data sets, which will be archived at NCDC. These will form SSM/I and SSMIS (henceforth referred to as SSM/I/S) FCDRs. **Status:** Preliminary corrections have been developed for a few of the satellites.

- Utilize the full swath FCDR data to generate improved EDRs (the current products are generated by a 1/3 degree daily gridded, 1 K accuracy data set). These will form the initial TCDRs using the legacy algorithms already in place. **Status:** Some sensitivity studies have been conducted to determine the impact of using the less precise data.



A time series of PATMOS-x dust cover over the hurricane formation region in the Atlantic. This has been found to correlate strongly with the frequency of tropical cyclones.



Comparison of PATMOS-x Tropical cloud amount to those from other climatologies. PATMOS-x agrees best with UW HIRS and does not show long-term trend seen in ISCCP.

- Use newly developed algorithms to improve the TCDRs, as well as some potential new products such as emissivity over land, snow and ice; ice and cloud water content over land, and a soil wetness index. **Status:** An updated precipitation algorithm is being used to develop an improved SSM/I time series, in combination with similar estimates from other satellites.

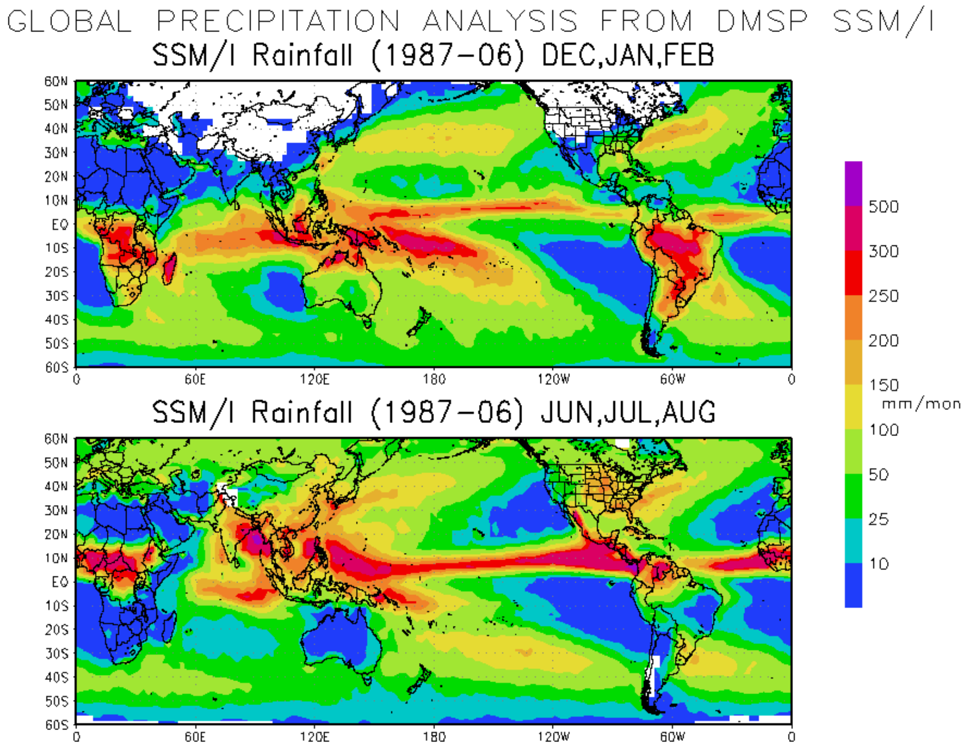


Figure 1: Seasonal mean rainfall (mm/mon) derived from nineteen years of SSM/I data.

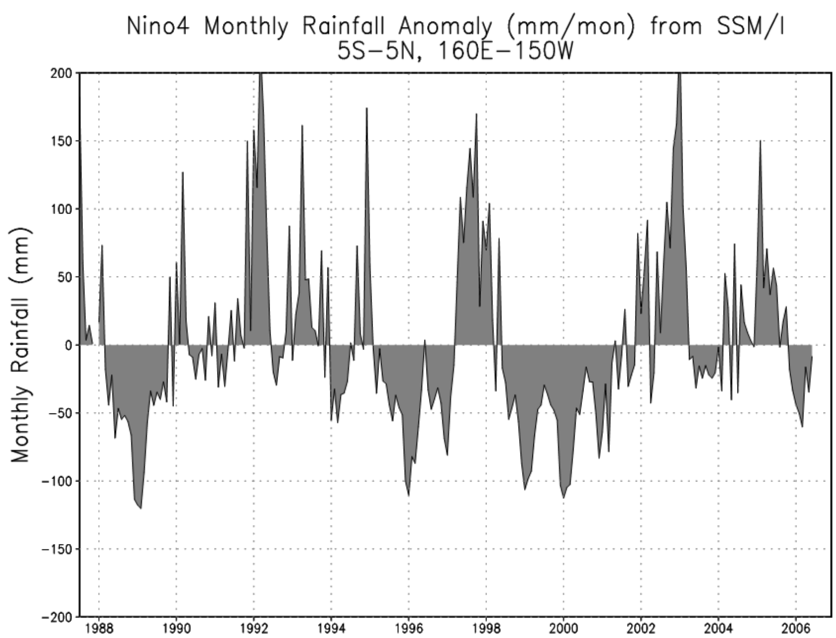


Figure 2: Monthly rainfall anomaly for the Nino4 region based on the SSM/I climatology. The positive (negative) anomalies correspond to warm (cold) SST events.

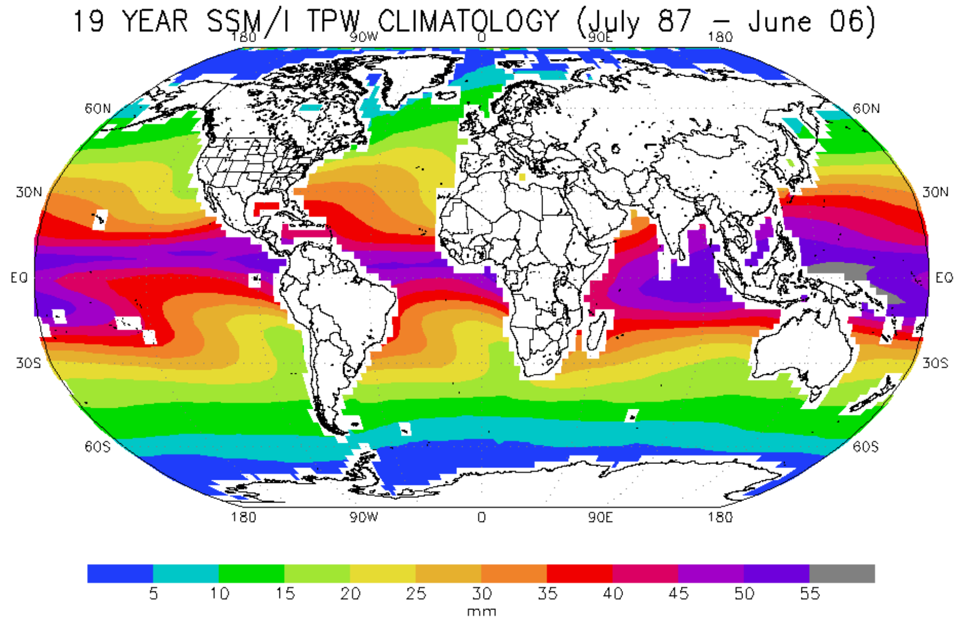
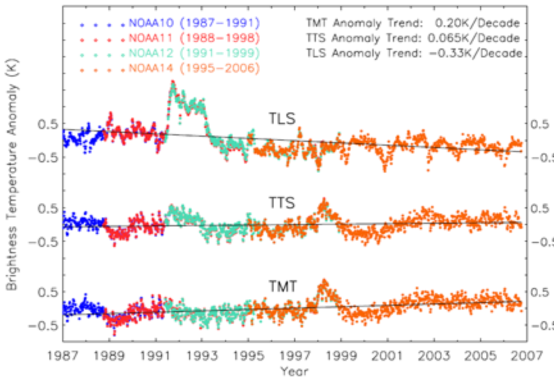


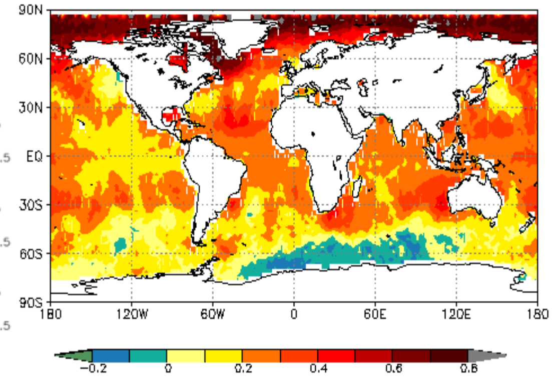
Figure 3: Global annual total precipitable water (TPW) (mm) based on 19 years of SSM/I measurements.

4. MSU Temperature Trends (Cheng-Zhi Zou)

The earth's surface is widely believed to be warming at a pace of 0.17 K per decade during the last 30 years. The confidence on the surface temperature trends largely relies on the dense surface observational network. However, the degree to which the atmospheric temperature has changed during the last several decades is a subject of debate in the science community. Because the conventional observations such as those from radiosondes are sparse in the atmosphere and they have different error structures due to different observational practice in different countries, atmospheric temperature trends derived from these observations are questionable. The Microwave Sounding Unit (MSU) onboard NOAA polar-orbiting satellites is uniquely positioned for detecting the long-term atmospheric temperature trends with scales and coverage that other conventional measurements cannot offer. However, the atmospheric temperature trends obtained for the MSU/AMSU observations are also under debate since different research groups obtained different results in previous studies

To reconcile this problem, scientists in the Center for Satellite Applications and Research (STAR) have re-calibrated MSU instruments on four different NOAA satellites, using the technique of *simultaneous nadir overpasses*, and produced a new set of data that are well-intercalibrated for climate research. The new dataset has removed the biases of the MSU instrument going from one satellite to another wherever satellite observations overlap, thus yielding accurate climate trend analysis. Using this new dataset, STAR has reported that the globally averaged temperature trend of the mid-troposphere over the ocean is obtained to be 0.20 Degree Kelvin (K) per decade for the period of 1987-2006, suggesting the troposphere is warming slightly faster than the surface of the Earth. Recently, the vertical and horizontal spatial structures of the atmospheric temperature trends are further investigated by STAR (See Figures 1a and 1b below). In particular, the tropopause is warming at a rate less than the mid-troposphere (0.065 K per decade) for the same period, while the lower stratosphere shows a larger cooling trend (-0.33 ^{0}C per decade) to compensate the warming trend in the troposphere (Figure 4a). In horizontal regional scale, the Tropics is warming at a rate about 0.1-0.3 K per decade, while the Arctic ocean is found to be warming 2 times faster (0.6-0.7 K per decade) than the Tropics. Some cooling trends are found across the Southern Atlantic and Indian Oceans close to the Antarctic continent, but the area-averaged temperature trends over the entire Southern Ocean is positive (0.05 K per decade). However, it is much smaller than the Arctic region.





(a) (b)

Figure 4 (a): Time series and trend observed by the MSU instrument on board NOAA satellites for different atmospheric layers. The abbreviations TMT, TTS, and TLS refer respectively to Temperature Middle Troposphere, Temperature Tropopause and Stratosphere, and Temperature Lower Stratosphere. **(b)**: Spatial distribution of the mid-tropospheric temperature (TMT) trend for 1987-2006. Unit in K per decade.
Please visit: http://www.orbit.nesdis.noaa.gov/smcd/emb/mscat/mscatmain.htm

Recommendations:

1. Using the SNO technique to intercalibrate all MSU/AMSU satellites and remove intersatellite biases. This intercalibration includes all MSU and AMSU channels.
2. Produce a well-intercalibrated, bias-removed MSU/AMSU radiance dataset for the climate community to evaluate and use.
3. Produce high-level long-term climate products based on the SNO inter-calibrated radiance for climate research.
4. Use other satellite observations such as GPS RO data to validate/calibrate the MSU/AMSU observations over the locations and temporal periods where no overlap observations occur between the MSU/AMSU satellites.
5. Assimilate the biased-removed MSU/AMSU radiance data into the reanalysis systems to produce next-generation reanalyses for climate research.
6. Extend the SNO technique to intercalibrate multiple SSM/I satellites

5. SBUV/2 Ozone Record: Updated Accomplishments (Larry Flynn)

The NOAA SBUV/2 instruments are continuing the ozone record. The Version 8 total ozone and profile algorithms developed for TOMS and SBUV/2 have replaced the older Version 6 algorithms in both the reprocessing and operational systems. The operational SBUV/2 data from NOAA-16 and NOAA-17 were used to monitor the Antarctic Ozone Hole and appeared in the WMO Ozone Hole Bulletins (1) and the NOAA Southern Hemisphere Winter Summary (2). Sample plots from the latter are shown on the next page and in Slides 3 & 4 of the attached presentation.
(1) *E.g.*, http://www.wmo.ch/web/arep/06/ant-bulletin-7-2006.pdf
(2) http://www.cpc.ncep.noaa.gov/products/stratosphere/winter_bulletins/sh_06/.

Long-term data records from the SBUV(/2) series were used in the latest WMO 2006 Ozone Assessment. We plan to extend the record provided in the 2004 DVD as follows:

Tasks: Reprocess and validate the SBUV/2 ozone profile and total ozone data records for NOAA-14 (1996-2003), NOAA-16 (2004-2007), NOAA-17 (2002-2007), and NOAA-18 (2005-2007) with retrospective calibration and characterization. Provide the new extended record on DVD and at web sites.

Impact: We will extend the 25-year SBUV/2 CDRs (1979-2003) by four years, and fill in a gap in the late 1990s. Provide the new 29-year record to the global research and assessment community at the 2008 Quadrennial Ozone Symposium. These four years cover a period of interest for ozone recovery characterization. The division of the attribution of this neonascent recovery between dynamics and chemistry is open to debate. The extended CDR is expected to be used by the 2010 Ozone assessment panel.

We are working with the OMI and GOME-2 teams to ensure that both operational and long-term monitoring make the best and consistent use of ozone products from current sensors. We are using Near-Real-Time OMI products and processing GOME-2 data operationally with the Version 8 total ozone algorithm. Ozone monitoring at NOAA will continue with one more SBUV/2 on NOAA-N; followed by the OMPS on NPP and NPOESS. We are also colaborating the Chinese as they prepare for the launch of the SBUS and TOU instruments on FY-3.

TOMS	Total Ozone Mapping Spectrometer
SBUV	Solar Backscatter Ultraviolet instrument
OMI	Ozone Monitoring Instrument
GOME	Global Ozone Monitoring Experiment
SBUS	Solar Backscatter Ultraviolet Sounder
TOU	Total Ozone Unit
OMPS	Ozone Mapping and Profiler Suite

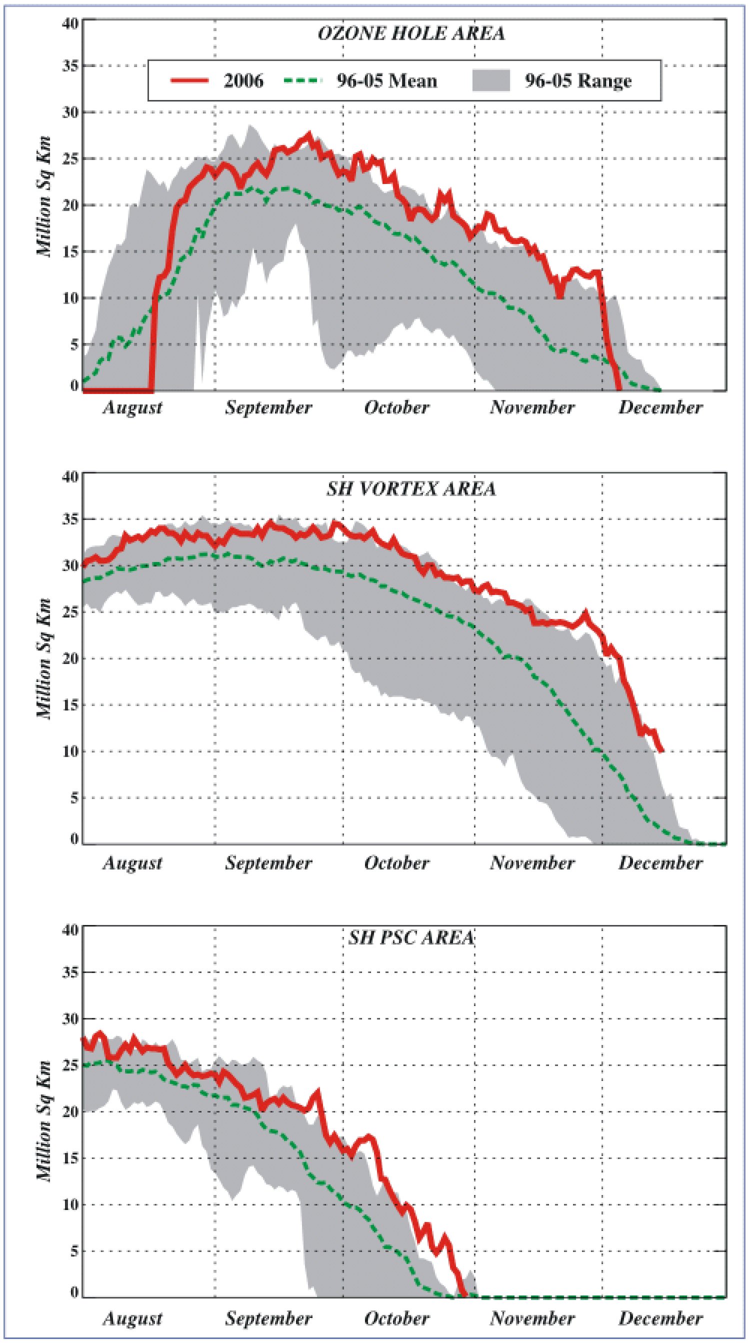


Figure 13. Time series of area of the ozone hole (total ozone < 220 DU), size of SH polar vortex (defined as -32 PVU contour enclosed area at 450K isentropic surface), and size of area of temperature < -78 C (also on the 450K isentropic surface). The shaded region illustrates the range of area sizes over the past ten years. The dashed line is the daily mean area for the past ten years.

Figure 13 taken is from the Southern Hemisphere Winter Bulletin at http://www.cpc.ncep.noaa.gov/products/stratosphere/winter_bulletins/sh_06/.

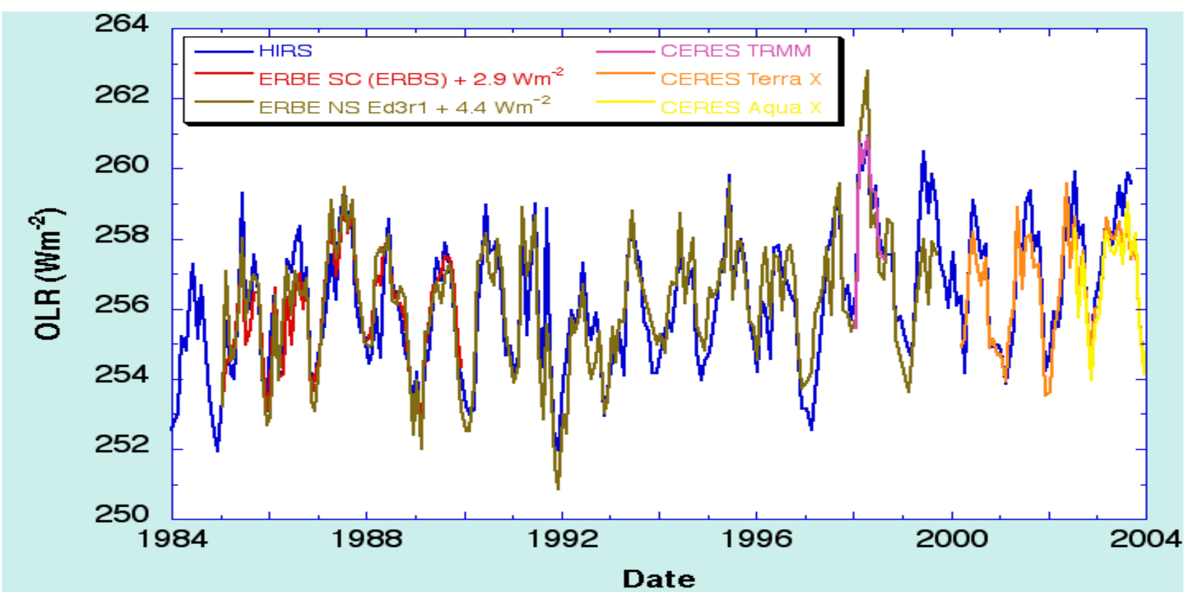
6. Status of the Outgoing Longwave Radiation Climate Data Record at NESDIS (Hai-Tien Lee (CICS/ESSIC-NOAA))

The longest available global Outgoing Longwave Radiation (OLR) time series were derived using observations from the NOAA TIROS-N series operational polar-orbiting satellites. Available since 1979, the NESDIS operational OLR product estimated from the Advanced Very High Resolution Radiometer (AVHRR) observations has significantly contributed to numerous studies, including Earth Radiation Budget, ENSO monitoring, large scale precipitation estimate, and tropical wave variability, etc. Nevertheless, the quality of the AVHRR OLR product was impaired primarily by the limitations of the single channel retrieval algorithm, and the orbit drift induced biases and discontinuity in the time series. Overall, current operational earth radiation budget production environment is not yet capable of generating climate quality data.

Past research at CICS has developed methodologies to generate climate quality OLR time series product from the operational High-resolution Infrared Radiation Sounder (HIRS) radiance observations. A system was proposed that would allow operational generation of the HIRS OLR Climate Data Record (CDR); with consistent radiance calibration and retrieval algorithms, with continuity ensured by inter-satellite calibration, and with diurnal models to minimize temporal integral errors. Most importantly, these end-to-end solutions include product validation and monitoring, science maintenance, algorithm improvement and address issues of future instruments (e.g., IASI, CrIS) that ultimately will ensure the validity, availability and longevity of this product for the foreseeable future.

The HIRS OLR climate data record for 1979 to 2003 has been constructed, supported by the Integrated Program Office. It was shown to have excellent quality compared to the broadband instruments observations from the Earth Radiation Budget Experiment (ERBE) and the Clouds and the Earth's Radiant Energy System (CERES). The HIRS OLR shows a comparable stability as in the ERBS non-scanner OLR measurements, about 0.3 Wm^{-2} per decade. Note that the ERBS wide-field-of-view (WFOV) non-scanner is by so far considered the most stable earth radiation budget instrument. The mean differences of HIRS and the broadband OLR products are within the limit of the absolute radiometry accuracy, about 2% in ERBE and 1% in CERES. The rms differences of HIRS and CERES monthly mean OLR products are about 5 Wm^{-2}.

The HIRS OLR Climate Data Record is a very valuable data set for climate monitoring and global change study purposes. Because of its stability, it can act as a transfer standard that stitches together the piecewise broadband OLR time series from the past, and probably for the future the broadband observations from EOS Aqua and NPOESS platforms.

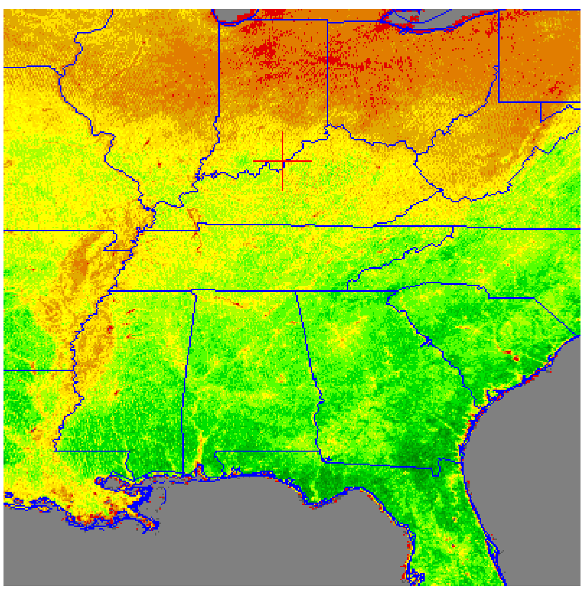


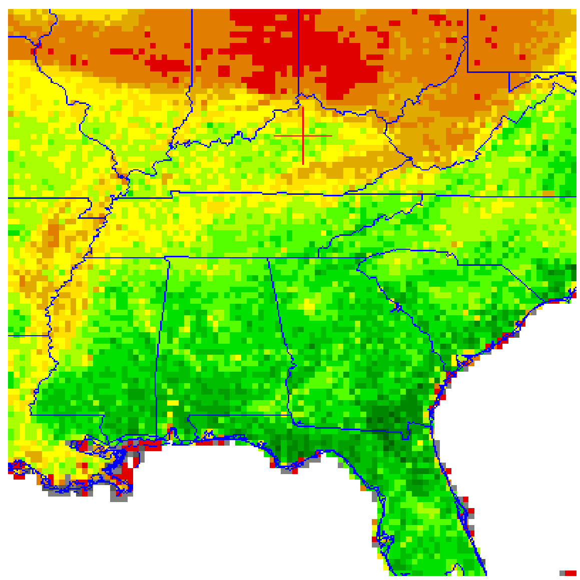
7. Global Vegetation Index and Vegetation Health Climatology (Felix Kogan)

The Advanced Very High Resolution Radiometer (AVHRR) on NOAA polar-orbiting satellites have been providing continues global measurements of reflectance and emission in four spectral bands since 1981. The current nearly 30-year AVHRR-based time series and products have been widely used for monitoring and assessment of vegetation health, drought, climate analysis, weather parameters, environmental conditions and socioeconomic activities.

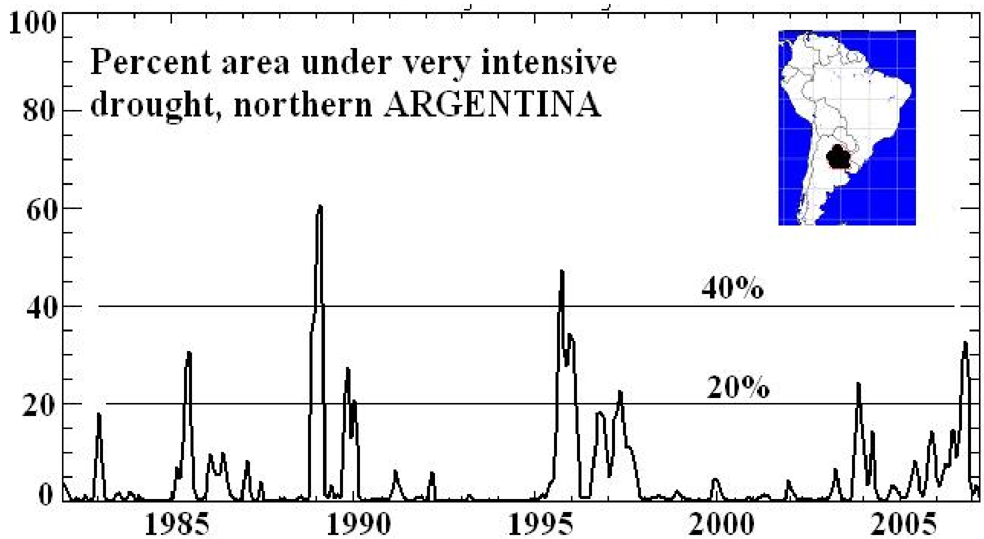
Prior to 2005, two long-term global data sets produced from NOAA/NESDIS AVHRR Global Area Coverage (GAC) product were available: GIMMS developed by NASA in 2003 and GVI-2 developed by NOAA in 1985. Both data sets have some advantages and shortcomings: GIMMS data set has better spatial resolution (8 km versus 16 km for GVI-2) but inferior temporal resolution (10-day versus 7-day composit). GVI-2 provides fourteen parameters and products (including NDVI) while GIMMS provide NDVI only. GVI-2 data set is updated in real time continuously, while GIMMS only periodically. In recent years, a lot of requests came from policy, decision makers, private sector and scientists to improve the quality of long-term AVHRR data set. A new dataset, GVI-X has been generated to improve the spatial and temporal resolution. This data set is the best produced presently because it is (a) the longest; (2) has the highest spatial (4 km) and temporal (7-day) resolution; (3) the most recent pos-launch calibrations were applied; (4) contains maximum (fourteen) original parameters and eight products (including such unavailable before products as drought, vegetation health, fire risk, ENSO impacts, malaria etc); (5) has higher accuracy; and (6) easy understandable nomenclature. This data set is the best in the world in terms of quality, longevity, composition and is ready to be applied to variety of tasks.

Below is a comparison between the new 4 km resolution GVI vs the original 16 km.





An example of a vegetation health index time series for northern Argentina is shown below.



8. Inferring Cloud Trends with HIRS data (Paul Menzel)

The International Satellite Cloud Climatology Program (ISCCP) has collected the largest global cloud data set using visible and infrared measurements from the international suite of weather satellites. As a supplement multi-spectral infrared measurements from the National Oceanic and Atmospheric Administration polar orbiting High Resolution Infrared Radiometer Sounders (HIRS) have been used for enhanced cirrus detection. Using regions of the infrared spectrum with differing sensitivity to atmospheric carbon dioxide, the HIRS measurements probe the atmosphere to different depths and reveal thin ice clouds high in the atmosphere. Since 1979, HIRS measurements have found clouds most frequently in two locations; (1) the Inter-Tropical Convergence Zone (ITCZ) in the deep tropics where trade winds converge and (2) the middle to high latitude storm belts where low pressure systems and their fronts occur. In between are latitudes with fewer clouds and rain called sub-tropical deserts over land and sub-tropical high pressure systems over oceans.

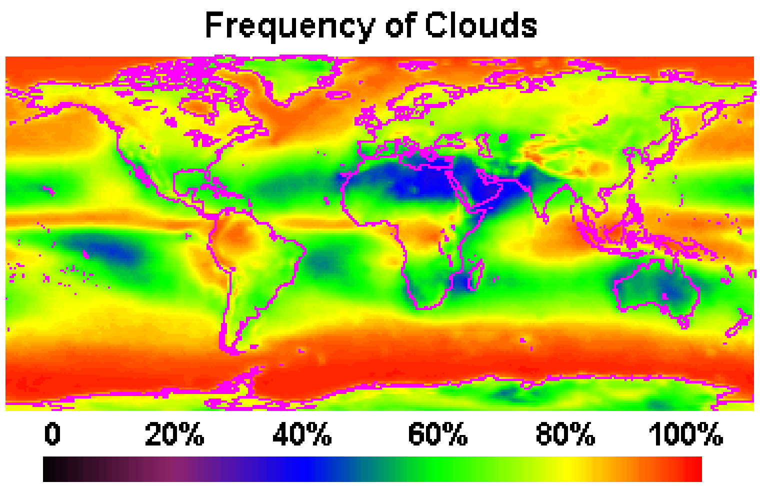
The decadal average cloud cover has not changed appreciably from the 1980s to the 1990s. Small increases occurred in the tropics, mainly in the Indonesian Islands. Small decreases occurred in the sub-tropics, the eastern Sahara and in the central Pacific Ocean from Hawaii westward. The decreasing trend in Antarctica is uncertain because cloud detection itself is very difficult in the cold temperatures of Antarctica. High cloud cover has changed some in the northern hemisphere winter season. Increases of 10% in the last decade for clouds above 6 km altitude occurred in the western Pacific, Indonesia, and over Northern Australia. Other fairly large increases occurred in western North America, Europe, the Caribbean, Western South America, and the Southern Ocean north of Antarctica. Decreases in high clouds occurred mainly in the tropical South Pacific, Atlantic and Indian Oceans south of the ITCZ.

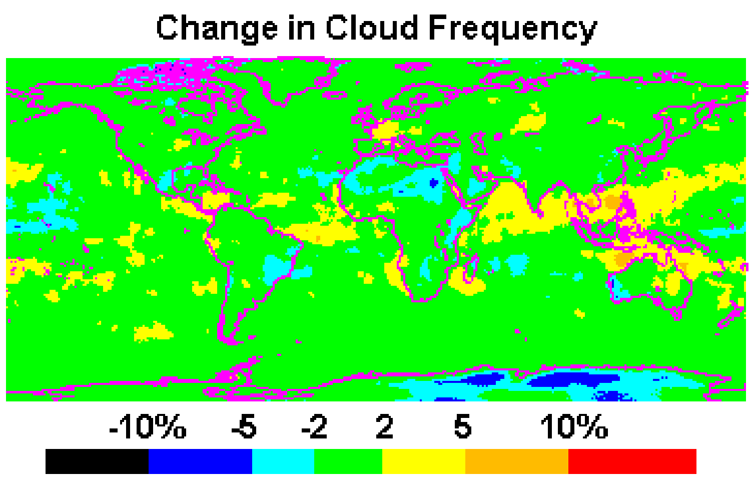
While jet aircraft have been suspected of increasing cirrus cloud cover from their contrails, these data do not reveal such a trend. Increases of high clouds seem to occur in areas of high air traffic, such as central and western North America and Europe, as well as areas of rare air traffic, such as the Southern Ocean around Antarctica. It appears that high cloud cover changes are mostly caused by larger weather systems.

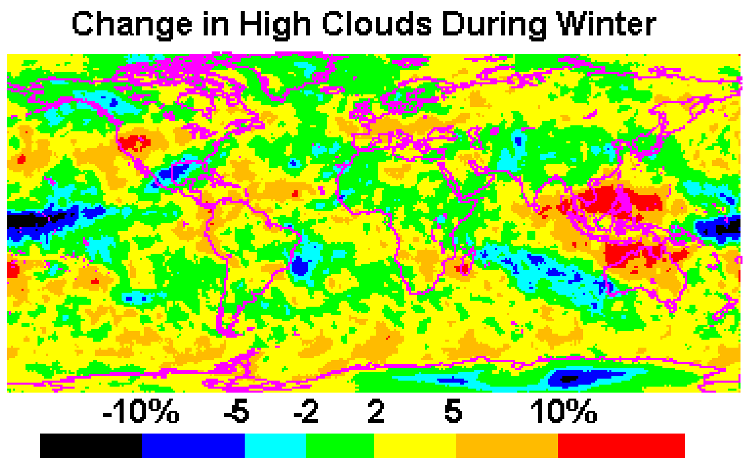
Globally averaged frequency of cloud detection (excluding the poles where cloud detection is less certain) has stayed relatively constant at 75%; there are seasonal fluctuations but no general trends. High clouds in the upper troposphere (above 6 km) are found in roughly one third of the HIRS measurements; a small increasing trend of ~ 2% per decade is evident. The most significant feature of these data may be that the globally averaged cloud cover has shown little change in spite of dramatic volcanic and El Nino events. During the four El Nino events winter clouds moved from the western Pacific to the Central Pacific

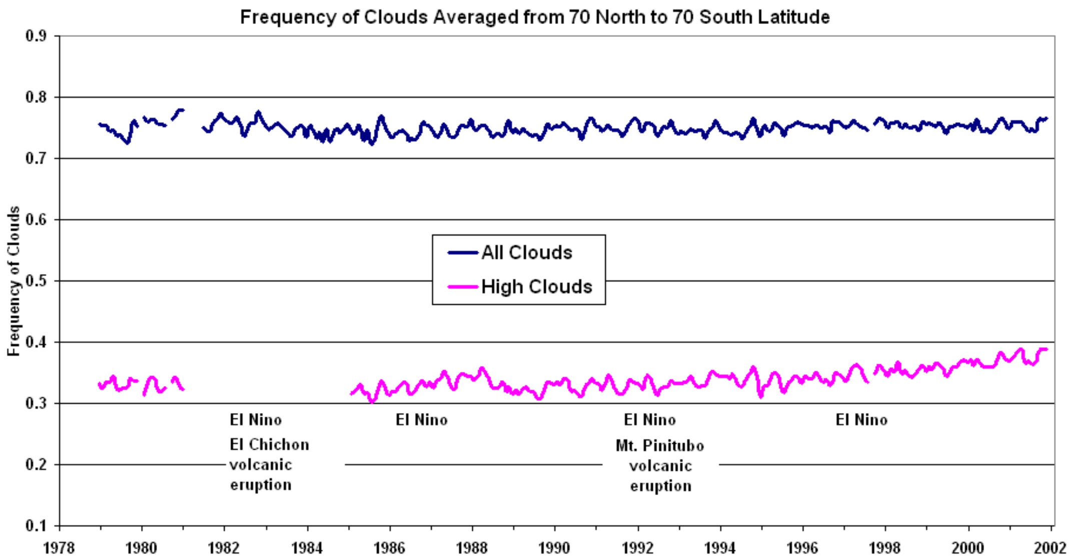
Ocean, but their global average in the tropics did not change. El Chichon and Pinitubo spewed volcanic ash into the stratosphere that took 1-2 years to fall out, but cloud cover was not affected significantly.

There are plans for reprocessing of the HIRS data in order to mitigate several known issues. These include (a) using simultaneous nadir overpasses on HIRS to extend the EOS calibration back to 1979 and thus establish a consistent calibration record, (b) developing and implementing improvements to radiative transfer models used in the data reduction, (c) allowing CO_2 and O_3 concentrations to change over time and location and resolving associated forward model issues, and (d) using surface emittance maps to better evaluate clear sky radiances. It is anticipated that with these improvements in the HIRS data processing, the decadal changes in cloud cover can be mapped more accurately.









9. The Extended AVHRR Polar Pathfinder (APP-x) Products (Jeff Key)

Recent studies have shown that the Arctic is expected to warm more than any other part of the earth in response to increasing concentrations of greenhouse gases. Arctic surface temperatures are projected to rise at a rate about twice the global mean over the next century. Sea ice extent is currently (summer 2007) at a record minimum and the July surface temperature at Barrow, Alaska was the highest on record. The ozone "hole" over the Antarctic continent is at a near-record size. Changes in large-scale circulation have resulted in increasing cloud amount in the Arctic spring, and decreasing cloud amount in the winter.

In order to study the spatial and temporal variability of recent changes in the Arctic and Antarctic climates, the extended AVHRR Polar Pathfinder (APP-x) product was created. APP-x augments the standard APP dataset, available from the National Snow and Ice Data Center, to include a full suite of cloud, surface and radiation parameters: cloud cover, optical depth, particle phase and size, top temperature and pressure, surface temperature and albedo, and surface and top-of-atmosphere radiative fluxes. This information is derived with algorithms specifically designed for the Polar Regions. Products have been validated with data collected during a number of field experiments, and through comparisons with other satellite, in situ, and model datasets. APP-x includes daily composites at both 04:00 and 14:00 local solar time (LST) over the period 1982 – 2004. Pixel size is 25 km, based on subsampled 5 km data. Monthly means are also available. Orbital drift does not significantly affect observed trends because the twice-daily image composites are comprised of orbits within a small time window of the target time. Two examples of APP-x parameters are given in Figure 5.

Analyses of trends in the APP-x product have produced a number of significant findings:

- The Arctic has been cooling at the surface during the winter, particularly over the ocean, but warming at other times of the year, particularly over land. The surface albedo has decreased, especially during the autumn months. Cloud amount has been decreasing during the winter but increasing in spring and summer. If Arctic cloud cover had not been changing the way it has over the past two decades, surface temperatures would probably have risen at an even greater rate than what has been observed.
- Decreases in sea ice extent and albedo that result from surface warming modulate the increasing cloud cooling effect, resulting in little or no change in the radiation budget.
- Changes in summer albedo over Alaska correlate with a lengthening of the snow-free season that has increased atmospheric heating locally by 3 W/m^2/decade. Current trends in shrub and tree expansion could further amplify this by 2-7 times.

Recommendations

- Extend the APP-x product suite from 2005 to the present.
- Support improvements to retrieval algorithms for the Polar Regions.
- Fund data analysis activities.
- Achieve community consensus on AVHRR calibration and inter-satellite calibration.

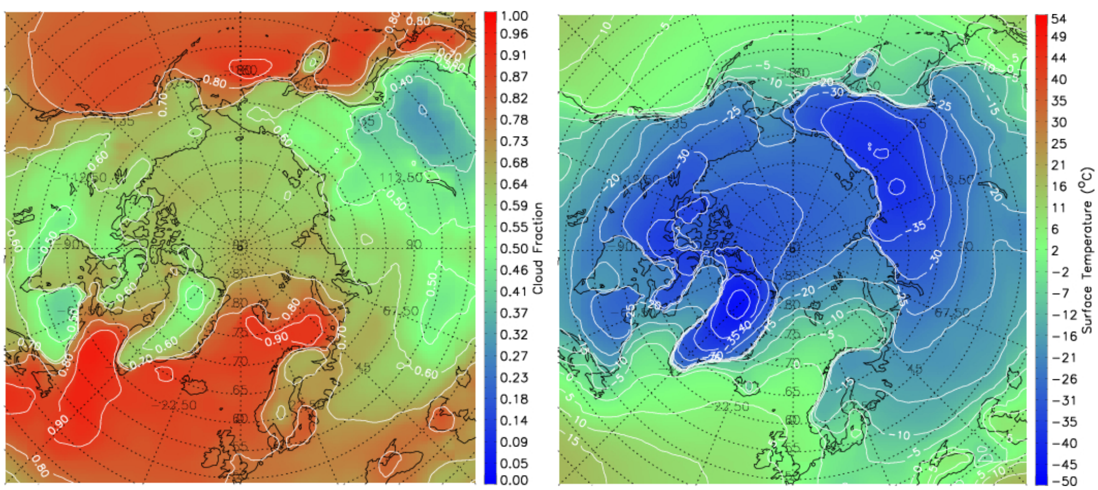


Fig. 5: The spatial distribution of cloud fraction (left) and surface skin temperature (right) at 14:00 local time for the period 1982-2004.

10. Blended Global 0.25° Grid and 6-hourly Sea Surface Winds (Huai-Min Zhang)

Advances in understanding the coupled air-sea system and numerical modelling of the ocean and atmosphere demand increasingly higher resolution data over the global ocean surface. Some applications require forcing parameters at temporal and spatial resolutions of up to 3 hours and 50 km. Observationally, these requirements can only be met by utilizing multiple satellite observations together with in-situ measurements. The integrated use of multiple-platform observations reduces both systematic bias errors and analysis errors of the blended products, which are important for climate studies and monitoring. In fact, we have designed an optimal GOOS climate SST observing system that best uses in-situ and satellite observations (Zhang et al. 2006a), and has become operational. Here we show another example – the production of high resolution sea winds over long time period.

Sea surface wind speed has been observed from long-term multiple satellites, ranging from one in the mid 1987 to six or more since mid 2002 (Figure 6). Detailed sampling studies showed that on a global 0.25°

grid, blended products with temporal resolutions of 6-hours, 12-hours and daily have become feasible since mid 2002, mid 1995 and January 1991, respectively (Zhang et al. 2006b). Thus four times per day global 0.25° snapshots have been produced since mid 1987 using spatial and time radius of 62.5 km and 6-hours, respectively. A 3-D near Gaussian interpolation was used to minimize aliases for the 6 times per day instantaneous fields. For many oceanography applications that use vector winds, wind directions are added from the NCEP Reanalysis 2. Reanalysis is chosen over NWP output for better climate consistency over time. The hybrid vector winds are available from July 1987 and onward (http://www.ncdc.noaa.gov/oa/rsad/seawinds.html). Evaluations of the blended wind speeds from the multiple satellites are being carried out in several international communities. These error statistics studies can be used to improve the blended products, including interpolation weighted by the estimated errors using an optimum interpolation method.

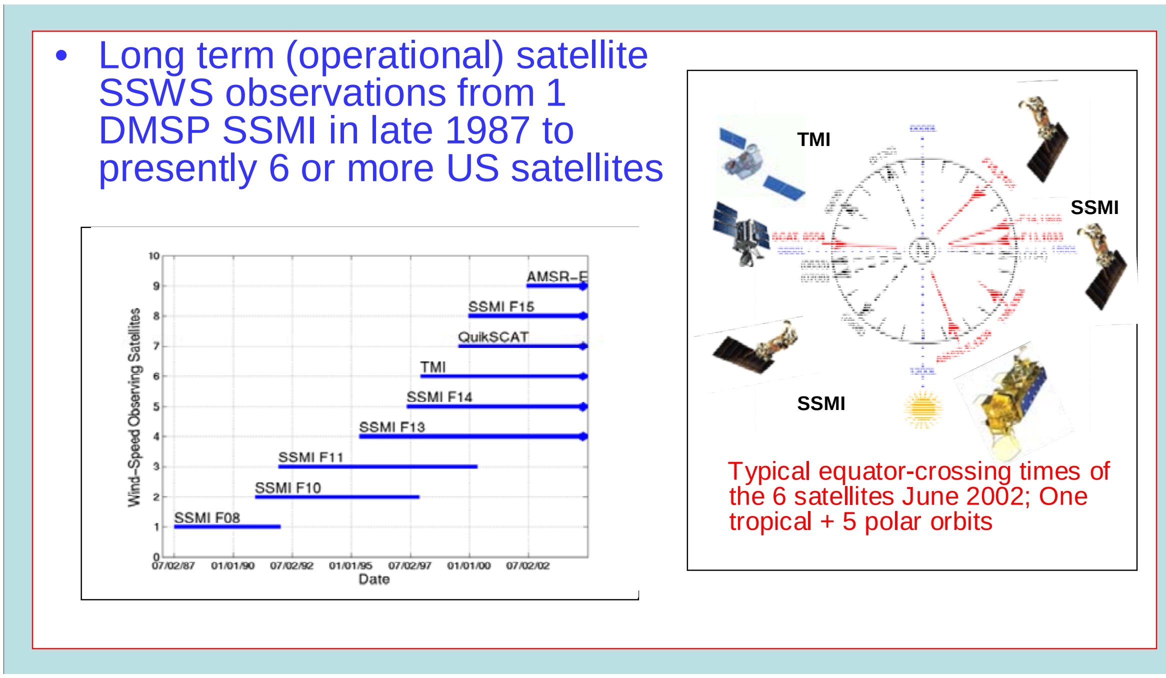


Figure 6: Timelines and tracks (schematic) of satellites that observe sea surface wind speeds.

11. Daily High-Resolution Blended Analyses for Sea Surface Temperature (Richard W. Reynolds)

Two new high resolution sea surface temperature (SST) analysis products have been developed using optimum interpolation (OI). The analyses have a spatial grid resolution of 0.25° and temporal resolution of 1 day. One product uses Advanced Very High Resolution Radiometer (AVHRR) infrared satellite SST data. The other uses AVHRR and Advanced Microwave Scanning Radiometer (AMSR) on the NASA Earth Observing System satellite SST data. Both products also use in situ data from ships and buoys and include a large-scale adjustment of satellite biases with respect to the in situ data. Because of AMSR's near all-weather coverage, there is an increase in OI signal variance when AMSR is added to AVHRR. Thus, 2 products are needed to avoid an analysis variance jump when AMSR became available in June 2002. For both products, the results show improved spatial and temporal resolution compared to previous weekly 1° OI analyses.

The AVHRR-only product uses Pathfinder AVHRR data (currently available from January 1985 through December 2005) and operational AVHRR data for 2006 onwards. Pathfinder AVHRR was chosen over operational AVHRR, when available, because Pathfinder agrees better with the in situ data. The AMSR&AVHRR product begins with the start of AMSR data in June 2002. In this product, the primary AVHRR contribution is in regions near land where AMSR is not available. However, in cloud-free regions, use of both infrared and microwave instruments can reduce systematic biases because their error characteristics are independent.

Figure 7 shows examples of the magnitude of the 3-day mean Gulf Stream SST gradients centered on 1 October 2003. In addition to the AVHRR-only AMSR&AVHRR analyses, the AVHRR and AMSR input data are shown along with two additional analyses. The first additional analysis is the weekly 1° analysis produced at the National Center for Environmental Prediction (NCEP) from November 1981 to present and referred to as the OI.v2. The second additional analysis is the more recent NCEP daily 1/2° Real Time Global SST or RTG_SST analysis. In the figure AVHRR data show high resolution details in cloud-free regions, although the coverage for AVHRR data is less than half of the possible number of ocean grid points. AMSR data show smoother details because of the coarser footprint but with the expected better coverage except near land as AMSR SSTs cannot be retrieved within 75 km of land. The analyses fill in the missing AMSR and AVHRR data gaps with different smoothing. In particular, note the region of missing AMSR data due to precipitation contamination between 35°N and 45°N along 60°W. Here the AMSR&AVHRR daily OI correctly fills in the missing data. This procedure is not always done correctly. In the comparison, the OI.v2 is heavily smoothed, as expected. The RTG_SST and AVHRR OI are similar, showing much more detail. Here the RTG_SST is slightly smoother than the AVHRR OI. The highest resolution is obtained by the AMSR&AVHRR OI, which is similar to the AMSR data in most of the offshore regions. The improvement in the AMSR&AVHRR analysis resolution is due to the better AMSR coverage compared to AVHRR. The results for other western boundary currents (e.g., the Agulhas, the Kuroshio and Falkland Current regions, not shown) show the same rankings of gradients for the SST products and data.

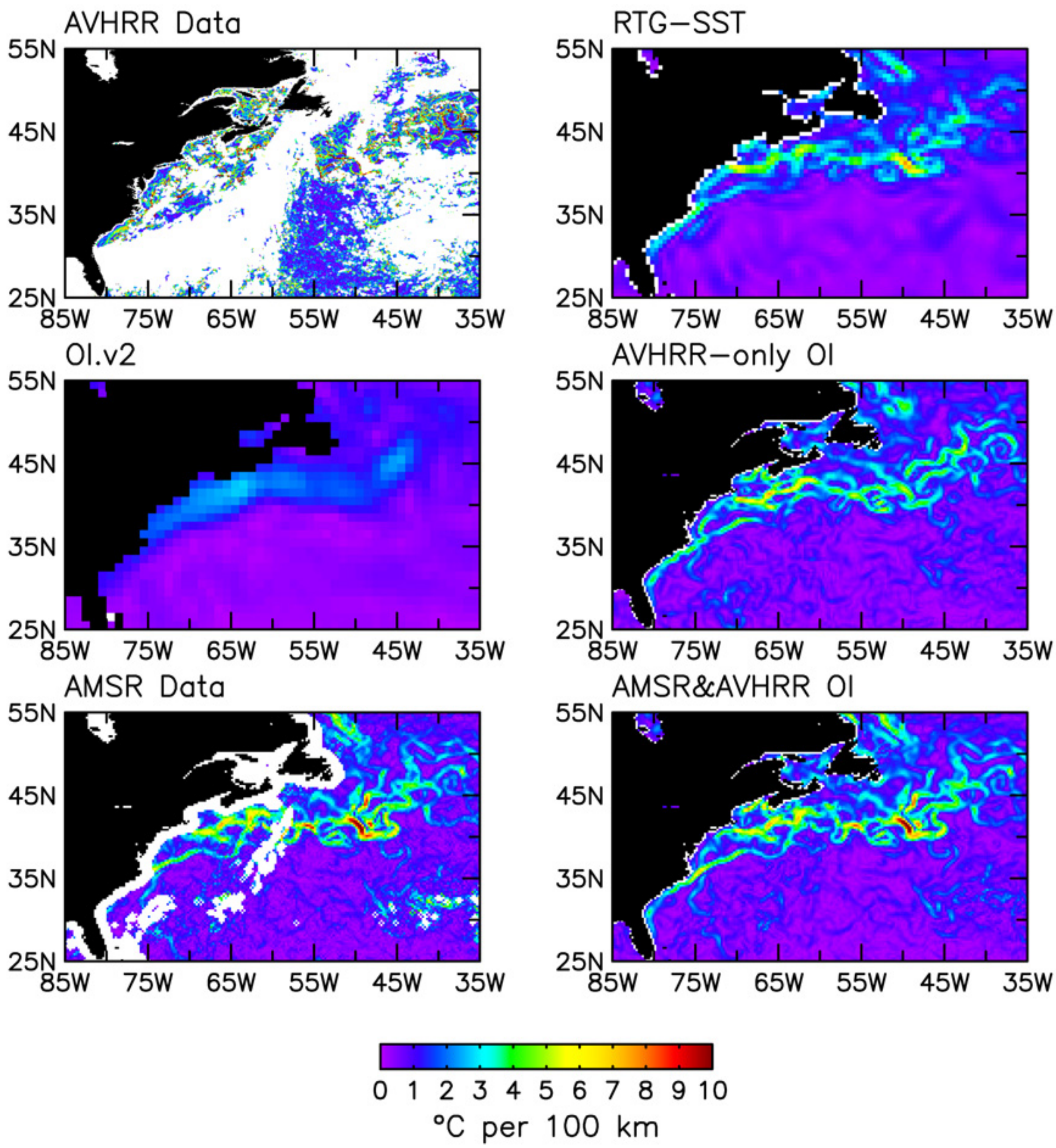


Figure 7: Three-day averages of SST gradient magnitudes for analyses and data centered on 1 October 2003 for the Gulf Stream region. The data products are AVHRR and AMSR. The analyses are: OI.v2, RTG_SST and the daily OI for AVHRR-only and AMSR&AVHRR. The analysis gradients are weakest for the OI.v2 and strongest for the daily OI using AMSR&AVHRR.

12. HIRS Long-term Time Series (Lei Shi)

The operational HIRS measurements started in the end of 1978 have provided nearly 29 years of observations from more than ten satellites. Due to the independence in the calibration which is based on individual HIRS instrument's channel spectral response function along with other factors, biases exist from satellite to satellite. These intersatellite biases have become a common source of uncertainty faced by long-term trend studies.

To inter-calibrate the HIRS data, the simultaneous nadir overpass (SNO) observations are used to remove the intersatellite biases and adjust the time series to a base satellite. Because the SNO data from the satellite intersections are obtained only over the high latitudes, the match-ups do not cover the high temperatures typically observed over the tropical regions. Additional intersatellite bias dataset is developed by using overlaps of satellite measurements from a selected tropical ocean region. Retrieval algorithms are developed to derive temperature and humidity profiles along with surface skin temperatures based on the inter-calibrated HIRS data. All data are generated at the original pixel resolution with the pixel's observation time attached. Details of these tasks are described below:

- Cloud-cleared and limb-corrected HIRS data: HIRS data from individual satellites are processed to remove cloudy pixels. Limb-correction is then applied. The clear-sky data, both with and without limb-correction, are produced in NetCDF format and placed online. The URL for the online data is http://www.ncdc.noaa.gov/oa/rsad/hirs-cs.html.
- HIRS upper tropospheric water vapor (UTWV): HIRS channel 12 data are inter-calibrated to a base satellite. The intersatellite biases for the temperatures outside the SNO range are estimated based on monthly means of every 10-degree latitude belt of overlapping satellites. The pixel-resolution data are mapped to 2.5 x 2.5 degree grids. Monthly means of inter-calibrated UTWV are computed. Time series of monthly data are compared with different calibration method used in the past and the result is found consistent.
- HIRS longwave channels: The cloud-cleared and limb-corrected data are calibrated to a base satellite based on both SNO and tropical ocean overlapping data.
- Temperature and humidity profiles: Temperature and humidity profiles are derived from inter-calibrated HIRS channels 2-12 based on radiative transfer model simulations.
- Surface skin temperature: surface skin temperature is derived from multi channels of inter-calibrated HIRS data. We are in the process of co-locating the retrieval with observation from the Climate Reference Network for comparison.

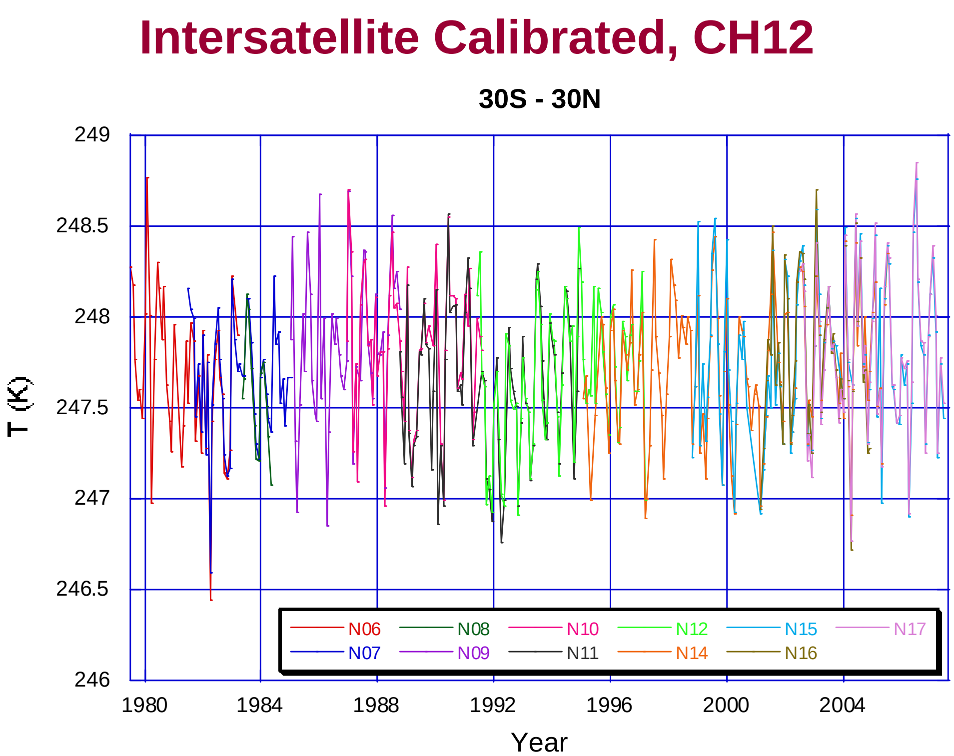


Figure 8: Monthly mean of inter-calibrated HIRS channel 12 data, averaged for 30S - 30N.

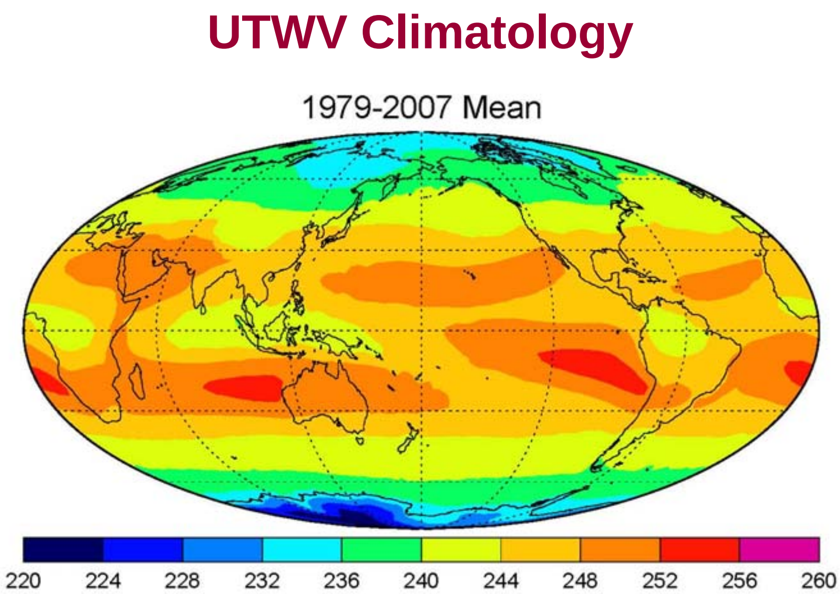


Figure 9: Climatology of UTWV based on data from 1979 to 2007.

13. HURSAT

In light of recently documented hypotheses relating long-term trends in tropical cyclone (TC) activity and global warming, the need for consistent reanalyses of historical TC data records has taken on a renewed sense of urgency. Such reanalyses rely on satellite data, but until now, no comprehensive global satellite data set has been available for studying tropical cyclones. In conjunction with the University of Wisconsin, NCDC developed a new hurricane satellite (HURSAT) data record that facilitates the reanalysis of TCs by providing satellite imagery in a standard format for the period of record 1983 to 2005. The data are collected from Japanese, European and U.S. geostationary satellites and the infrared window channel data, which are particularly relevant for TC analyses, have been recalibrated to reduce inter-satellite and time-dependent biases. Observations are provided at 3-hourly intervals on a 0.07°×0.07° (~8km) Lagrangian grid that follows the TC center. These observations of global tropical cyclones are provided in NetCDF format, following standard conventions to allow interoperability and ease of use. The data consist of ~169,000 observations of 2046 tropical cyclones. The global extent of the data set is shown in Figure 10. Observations within 250 km of a tropical cyclone center were counted, providing the spatial distribution of the 2046 cyclones in the data set. The primary drawback of the data set is apparent: a gap in observations over the Indian Ocean. Here, a 75° view zenith angle limit leaves an 8° gap between observations by Meteosat over the Prime Meridian and GMS at 140° East longitude. Conversely, the Pacific and Atlantic Oceans are more continuously observed.

This HURSAT record has been applied to the reanalysis of global trends in tropical cyclone activity. The accuracy of recently documented TC trends was in question based on the heterogeneity of the existing tropical cyclone records. To address this, Kossin et al. (2007) developed an objective algorithm to determine tropical cyclone intensity from HURSAT, forming a new intensity record which was used to reanalyze the trends. The results validated an increase in North Atlantic TC activity and a decrease in the East Pacific that was found in previous studies. However, it found no upward trend in other TC-prone basins (i.e., the Indian Ocean and the Western and Southern Pacific Ocean). Overall, the global activity (as measured by the Power Dissipation Index, PDI) since 1983 shows no significant change (Figure 11), which was different from the time series from the original best track data. The value of these data can be further enhanced by extending the period of record. Efforts are underway to extend the coverage back in time, potentially to 1981 for GMS and 1977 for GOES. Also, the data will be updated annually with the most recent TC locations.

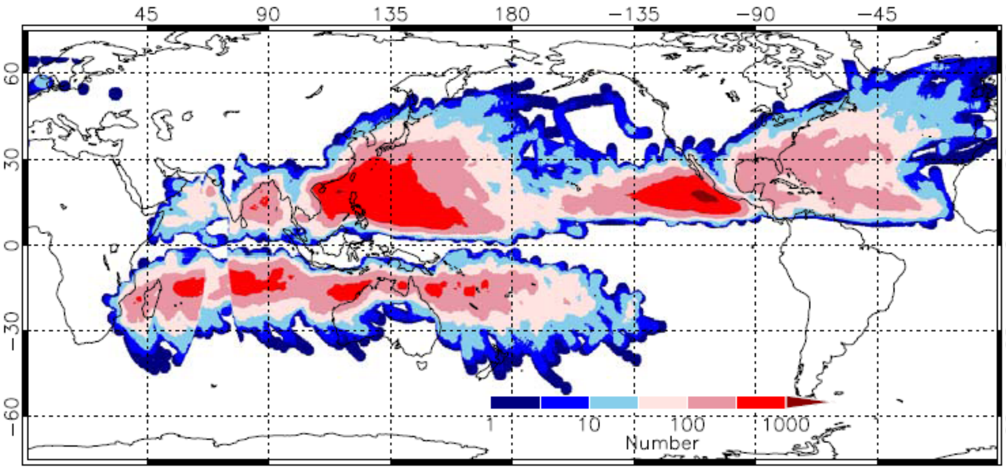


Figure 10: Spatial distribution of the number of observations within 250 km of a tropical cyclone for 1983-2005. The relatively data-void region in the S. Indian Ocean was not well-sampled until the Meteosat 5 coverage data began there in 1998.

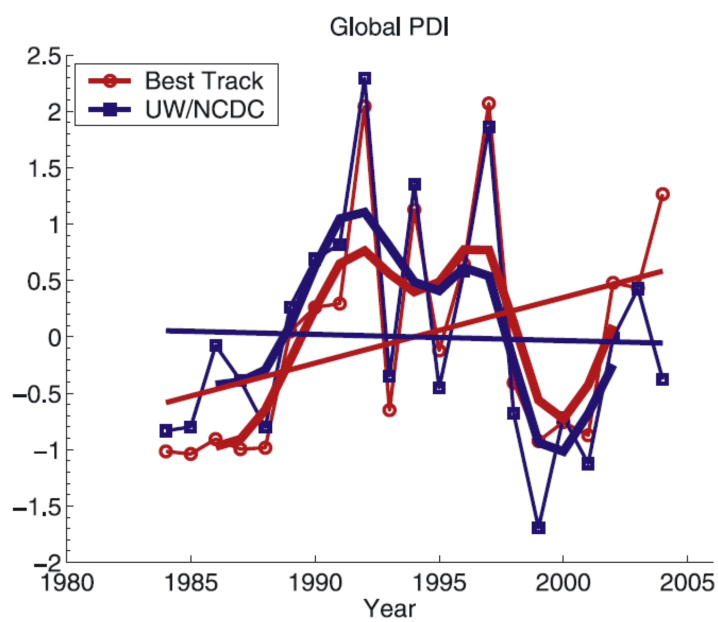


Figure 11: Comparison of normalized global annual Power Dissipation Index (PDI) as calculated by best track data (red) historical record and from the reanalyzed intensity based on the HURSAT data (UW/NCDC, blue). Thick lines are smoothed with a binomial filter and straight lines are the linear best-fits of the unsmoothed data.

14. Concluding Remarks

The CGMS is invited to take note of the NOAA activities to generate relevant datasets to monitor key climate variables. The paper presented our current work with respect to monitoring variability and trends in clouds, aerosols, precipitation, OLR, ozone, temperature and vegetation. It is suggested that CGMS recommend NOAA to continue these activities in order to provide critical datasets needed to document past and current changes of the Earth's environment.