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THE CGMS PROGRAM FOR INTERCALIBRATION OF SATELLITE SENSORS (GMS, GOES, METEOSAT, HIRS, AND AVHRR INFRARED WINDOW RADIANCES)

This paper summarizes activities within the CGMS regarding satellite intercalibration of IR radiance measurements; various approaches for intercalibration of different sensors on different platforms have been investigated. CGMS Members have been collaborating to define techniques for cross-calibration of all the geostationary and polar orbiting sensors. Initial focus has been on comparing the infrared window radiances measured by these systems; the goal is calibration within 1 K for IR and WV bands.

An attachment to this paper presents experience and recommendations from the ISCCP (International Satellite Cloud Climatology Project) concerning the need of satellite data users to make their own calibration adjustments. It is suggested that such an activity needs to be embraced by the satellite operating agencies on a routine basis.

THE CGMS PROGRAM FOR INTERCALIBRATION OF SATELLITE SENSORS (GMS, GOES, METEOSAT, HIRS, AND AVHRR INFRARED WINDOW RADIANCES)

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1. Introduction

This paper summarizes activities within the CGMS regarding satellite intercalibration of IR radiance measurements; various approaches for intercalibration of different sensors on different platforms have been investigated (Menzel, Schmetz, and Tokuno, 1998). The CGMS members have been collaborating to define techniques for cross-calibration of all the geostationary and polar orbiting sensors. Initial focus has been on comparing the infrared window radiances measured by these systems; the goal is calibration within 1 K for IR and WV bands.

There are many aspects of the data that need to be considered when an intercalibration of two sensors is considered. The following list mentions some of the more obvious ones:

- measurements from the two sensors must be collocated in space and time
- spectral response differences must be accounted for
- spatial resolution differences must be considered
- viewing angle differences must be minimized
- day night differences in the calibration must be investigated
- cloud contamination of the radiances must be considered
- scene uniformity must be considered
- statistical significance of the sample must be adequate

These aspects of the intercalibration are handled in various ways from one algorithm to another.

The purpose of the CGMS intercalibration program was to quantify the relative agreement of IR window brightness temperatures on the operational meteorological satellites. This has been achieved, however it is clear that further work is warranted. Routine, if not operational satellite intercalibrations, should be pursued; the advantages would be manifold as it would benefit:

- satellite operators by keeping track of the operational calibration
- operational users by providing an independent and immediate check of the relative performance satellite calibrations

- research users interested in climatological and multi-satellite applications by providing a relative assessment of the long-term consistency of operational satellite calibration. This would be appreciated by established reseach programmes such as ISCCP which have already established their own satellite intercalibration or normalization work (Brest and Rossow, 1992; Desormeaux et al., 1993). Continuation of such work is required since it will provide independent verification of the intercalibration at the operational centers.

To date users of satellite data have had to make their own calibration adjustments. The International Satellite Cloud Climatology Program (ISSCP) is an illustrious example; ISCCP has produced a multi-year multi-satellite calibrated data set by expending considerable energy to intercompare and adjust satellite infrared window and visible radiance measurements from the past fifteen years. The lessons learned from ISSCP are provided in the attachment of this document, along with their recommendations for long term calibration activities. This attachment has been provided by Dr. William B. Rossow upon request from the CGMS intercalibration team. ISCCP is a research effort with a finite lifetime; it can not and should not assume responsibility for the continued production of such a calibrated data set. Such an activity needs to be embraced by the satellite operating agencies.

2. The CGMS Program

At CGMS 25, it was agreed that designated CGMS members should collect some data sets with overlap between a polar orbiting sensor (HIRS or AVHRR) and some of the geostationary imagers (GMS, Meteosat, and GOES). These data sets were to include the spectral response functions of the IR and WV bands and the atmospheric state at the time of the intercomparison (surface temperature, atmospheric temperature and moisture profiles, T(p), and q(p)). As a result, each participant has processed one or more intercalibration data sets with their preferred algorithm and has presented results at subsequent CGMS meetings. The potential of satellite intercalibration has been demonstrated but routine or operational implementation is still pending.

3. Activity at EUMETSAT

The current calibration of the Meteosat IR channel is performed using ancillary information received routinely via the Global Telecommunications System of the World Meteorological Organization. Sea surface temperatures from NESDIS and atmospheric temperature and moisture from the European Centre for Medium Range Weather Forecasts are used; these sea surface temperatures are a blend of conventional observations (e.g. buoys), satellite observations (e.g. NOAA polar orbiting spacecraft) and climatology. The Meteosat calibration is performed in two independent steps: first an instantaneous vicarious IR calibration is derived with a constrained regression analysis from cloud-free sea surface observations (raw radiances) and calculated radiances using ECMWF short-term forecasts profiles and NESDIS SST. From the instantaneous calibration coefficient the operational calibration is determined via a statistical procedure that reduces short-term fluctuations in the calibration coefficient. This statistical process is different during eclipse periods. A more detailed description has been provided in EUM-WP-22 of CGMS 27 and in Gube et al. (1996).

More recently studies have been performed utilizing the blackbody onboard of Meteosat-7 for absolute calibration. Preliminary results are encouraging and show that i) the blackbody calibration can be used and ii) provides more stable results than the vicarious calibration. It also indicates that the current vicarious calibration is adequate.

Since the vicarious calibration is prone to bias errors, EUMETSAT has also developed a satellite intercalibration technique comparing Meteosat measurements with collocated NOAA-AVHRR or HIRS observations or with geostationary radiance observations from either GOES or another Meteosat satellite. The method described in Gube and Schmetz (1997) has been implemented and tested and is ready to be used routinely. The IR intercalibraton is detailed in König et al. (1999). The method uses target areas from two satellites collocated in time and space, corrects for differences in the spectral response functions, and considers the effects of different viewing geometry.

Results can be summarized as:

- cross-calibration between Meteosat-7 and HIRS IR window channels gives an agreement within 2% (bias for case studies for overpasses) or about 1.2 K at 290 K.
- cross-calibration between Meteosat-7 and AVHRR channel-4 on NOAA 14 is within 1 % or 0.6 K at 290 K.
- cross-calibration between Meteosat-7 and AVHRR channel-5 on NOAA 14 is within 2 % or or 1.2 K at 290 K.

Thus the envisaged goal of an agreement to within 1 K has nearly been achieved. Further analysis will study the potential causes of the remaining bias.

4. Activity at MSC/JMA

MSC has been working on the intercalibration of the infrared window on GMS-5 (IR sub-satellite resolution is 5 km) and NOAA-14 (IR sub-satellite resolution is 4 km for GAC). Using the intercalibration approach described in Wanzong and Menzel (1997) presented at CGMS 25, they have studied several cases. Data are selected for intercomparison when

- the observational time difference between GMS-5 and NOAA-14 is within 30 minutes in the daytime to reduce variability of meteorological conditions and to enhance removal of cloudy pixels using visible data.
- clear sky over ocean near nadir views within 10 degrees from sub-satellite point of both satellites are used to minimize the atmospheric effect due to differences of observational path and zenith angles, cloud contamination, and surface non-uniformities.

The selected region is subdivided into grid areas (0.25 latitude x 0.25 longitude) and the brightness temperatures corresponding to the clear part of every sub-grid area are extracted by a histogram technique to minimize the effect due to the difference in spatial resolution between GMS-5 and NOAA-14. The warmest brightness temperatures corresponding to 50% of the accumulated frequency in every sub-grid area are averaged and that average is designated as the representative clear sky value for that sub-grid area. The average brightness temperature of all the sub-grid averages for each satellite is then compared.

Results indicate that GMS-5 is colder by about 1.2 C than NOAA-14 AVHRR with a scatter of about 0.2 C. MSC found that there was no need for a correction near nadir for any atmospheric effect due to spectral response differences. LOWTRAN 7 calculations revealed differences less than 0.01K for view angles within 10 degrees from sub-satellite point. The results are detailed in Tokuno and Kurihara (1999).

5. Activity at NESDIS

Previous USA WPs have described the NESDIS approach for calibrating geostationary sensors with respect to a polar orbiting sensor (Wanzong and Menzel, 1997 at CGMS 25, Wanzong and Menzel, 1998 at CGMS 26). Radiances from both sensors with near nadir view of a scene containing mostly clear but also some cloudy skies are averaged to 100 km resolution. Differences in mean scene radiances are corrected for spectral response differences through clear sky forward calculation. The corrected mean differences are attributed to calibration differences.

Collocation in space and time (within thirty minutes) is required. Data is selected within 10 degrees from nadir for each instrument in order to minimize viewing angle differences. Measured means of brightness temperatures of similar spectral channels from the two sensors are compared. Data collection is restricted to mostly clear scenes with mean radiances greater than 80 $mW/m^2/ster/cm^{-1}$, no effort is made to screen out clouds from the study area. Data from each satellite is averaged to 100 km resolution to mitigate the effects of different field of view (fov) sizes and sampling densities (HIRS undersamples with a 17.4 km nadir fov, AVHRR GAC achieves 4 km resolution by undersampling within the fov, GOES imager oversamples 4 km in the east west by 1.7, and METEOSAT-5, METEOSAT-7, and GMS-5 have a nadir 5 km fov). Mean radiances are computed within the study area. Clear sky forward calculations (using a global model for estimation of the atmospheric state) are performed to account for differences in the spectral response functions. The observed radiance difference minus the forward-calculated clear sky radiance difference is then attributed to calibration differences.

An identical method is used for calculating the temperature difference between a geostationary satellite and the AVHRR instrument (ΔT_A).

Results of more than 50 case studies (Gunshor et al., 1999) suggest the infrared window sensors on GOES-8, GOES-10, MET-5, MET-7, and GMS-5 are within 0.5 C of each other (and within 0.4 C of the NOAA-14 HIRS and AVHRR). Further studies are ongoing to explore seasonal or diurnal effects

6. Conclusion

Intercalibration of the polar orbiting and geostationary satellite systems is necessary to achieve consistency in data sets involving more than one sensor. Within the lifetime of one sensor, there is a need to determine fluctuations associated with the seasonal cycle for the spinning geostationary sensors (such as Meteosat, GMS, and GOES-VAS), with the diurnal and seasonal cycle for the three axis stable geostationary sensors (such as GOES-IJKLM, GOMS, and MTSAT), and with the day-night cycle for the polar orbiting sensors (such as NOAA, METOP, and NPOESS); each affects the temperature regime aboard the respective platform. For climate or trend analyses, all temporal transitions from one sensor to another (e.g., GOES-6 to GOES-7) should be covered with an independent sensor (e.g., NOAA-10). The community of satellite operators needs to begin a program to intercalibrate their current sensors; when individual sensors overlap in space and time, intercalibration reduces the calibration uncertainty. CGMS members are making good progress toward such a program. This work is being continued and expanded to other parts of the spectrum (e.g. water vapor bands, visible bands). It remains for CGMS to embrace these algorithms for intercalibrations on a routine or operational basis.

Therefore, CGMS 28 is requested:
- to approve the continued contact between ISCCP and CGMS on the issues of satellite intercalibration
- to encourage satellite operators to establish a routine satellite intercalibration and to establish regular reporting of their results in CGMS reports and on the www (CGMS home page). The format of the reports on these intercalibrations should be proposed by WG II of CGMS 28.

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CALIBRATION OF OPERATIONAL WEATHER SATELLITE MEASUREMENTS

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1. Background

For the past 17 years, the International Satellite Cloud Climatology Project (ISCCP) has been collecting and analyzing imaging data from all the operational weather satellites to produce a global cloud climatology as part of the World Climate Research Programme. To produce a data set of cloud physical properties that is both global and long-term in coverage and resolves mesoscale and diurnal cloud variations, ISCCP has had to estimate the absolute calibrations for all radiance measurements from all satellites in order to assemble a globally homogeneous data set. Orbital mechanics requires a multi-satellite approach to obtain mesoscale-to-synoptic resolution of cloud variations over the whole globe. The ISCCP version of the weather satellite imaging data is now the only version that is absolutely calibrated to a global standard across whole series of satellites operated by different nations. Such data not only has obvious value for climate studies, which must necessarily be global and multi-year in scope, but also, if produced in a timely fashion, could be used in making longer-range weather forecasts, which must use global models that should be initialized with global data. Up to now, these data have not been used as quantitative inputs to forecast models because there is no calibration standard: a data set assembled from all the weather satellites today would not be globally homogeneous. Even regionally-based research is now enhanced because the results, now based on a global standard, can be applied globally. However, ISCCP is a research effort with a finite lifetime, so that responsibility for the continued production of such a valuable data set must be taken on by the satellite operating agencies.

2. Recommendation

Current weather satellite instrument documentation and operational practices could and should be revised to make continued production of quantitative, global weather data sets from satellites possible for both long-range weather forecasts and climate research. Actions that can be taken to achieve this goal are as follows. (1) Instruments should be designed to insure that spectral and angular responses are "simple" and on-board calibration references should be provided for all channels. The latter need not provide high absolute accuracy, only high relative stability to enable monitoring of post-launch instrument behavior. Such on-board calibration reference measurements should be made at two points, at least, in the instrumental dynamic range and the data made part of the imaging data set. (2) Some extra care in performing pre-launch instrument characterization and calibrations, especially for short-wavelength channels, is needed to produce higher quality information. In particular, instruments should always be calibrated in environment chambers simulating space conditions. Needed characterization information includes spectral and angular response of the instrument and absolute calibration to a traceable international standard. Calibration measurements should be made at several points in the instrument range to test the linearity of its response and these data archived. If the space environment is expected to vary during operations (e.g., temperature), then calibration measurements should be made over the expected range of environmental variation. (3) Complete documentation of instrument characterization and calibration should be formally published and updated as needed instead of being filed away somewhere in the operating agency. This should include all the test data. Such information is usually produced by the instrument contractor, but often is not made available to data users. (4) Instrument and satellite engineering (housekeeping) information should be part of the data set. For example, this information could be reported in the header record of every image. (5) Several simple statistics of the instrument measurements can and should be routinely produced and monitored, the resulting data set should be part of the data archives and available, separately, to users. The ISCCP experience shows that the radiance statistics, even including observations of clouds, collected over whole images (for geostationary satellites) or the whole Earth (for polar orbiters), are sufficiently stable in time to be useful for monitoring instrument performance on orbit. For example, the 5th, 50th and 95th percentile values of visible and infrared radiances, when taken from histograms over whole images, are very stable in time. (6) The ISCCP experience shows that routine cross-comparison of imaging radiances with other satellites does not require a large effort (much less than one person-year with one small workstation or PC). For example, all geostationary satellites could be compared with underflying polar orbiters and adjacent geostationary observations a few times per month as ISCCP does now. The results of such a monitoring exercise should also be part of the data archives and made available, separately, to users.