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OPERATIONAL CALIBRATION PRACTICES--THERMAL INFRARED AND MICROWAVE

An overview of operational calibration procedures at NOAA/NESDIS for the polar orbiting AMSU-A instrument and the thermal infrared channels of the AVHRR and HIRS, and for the thermal infrared channels of the GOES Imager and Sounder is presented.

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The meteorological satellite radiometers calibrated by NOAA/NESDIS include the AVHRR (Advanced Very High Resolution Radiometer), the HIRS (High resolution Infrared Radiation Sounder), and the AMSU-A (Advanced Microwave Sounding Unit-A), which are carried on the NOAA polar-orbiting system of satellites, and the Imager and the Sounder on the GOES (Geostationary Operational Environmental Satellite) system of satellites. Collectively, these satellite radiometers sense upwelling radiation from the Earth/atmosphere system in the visible, near infrared, thermal infrared, and microwave parts of the spectrum. The on-orbit calibration procedures for the polar-orbiting satellite instruments are described fully by Kidwell[1]. Specific calibration procedures, both pre-launch and on orbit, for the AMSU-A are described by Mo[2,3]. On-orbit calibration procedures for the geostationary instruments are documented by Weinreb et al.[4,5] The purpose of this paper is to provide an overview of the calibration process for the channels in the thermal infrared and microwave. The visible and near-infrared channels, lacking on on-board calibration device, are calibrated on orbit with vicarious techniques, as is described in a companion paper[6].

The thermal infrared and microwave channels of all these instruments are calibrated essentially the same way, regardless of their wavelength location. Each instrument utilizes views of space and an on-board warm blackbody for calibration on orbit. The blackbody is in front of the scan mirror (infrared) or the reflector (microwave) and fills the instrument=s aperture, thereby providing a full-system calibration. The relationship between the incident radiant intensity and instrument output, the Acalibration function,@ is assumed to be quadratic. The quadratic term is small but is significant in some channels. It contributes just under 1% of the radiance in many of the microwave channels and the thermal infrared channels that utilize HgCdTe detectors. But it is negligible in the shortwave infrared channels that utilize InSb detectors. The coefficients of the quadratic terms are determined in pre-launch tests as functions of instrument and detector temperature, and these relationships are assumed to remain invariant throughout the life of each instrument. In orbit, the coefficient of the quadratic term is inferred from the appropriate instrument temperatures. Thereupon the coefficients of the remaining two terms of the gain function can be determined from observations of the two targets--space and the on-board blackbody.

Before launch, each instrument is calibrated in a thermal-vacuum chamber. Its output is recorded as it is illuminated by radiation from a laboratory blackbody, whose temperature is cycled over a number of discrete temperatures between approximately 180K and 320K. This process determines the calibration function. It is usually done several times, with the instrument held at several different temperatures within the range encountered on orbit, and in some cases for several different settings of the detector temperature, if, as in the case of the GOES instruments, there is more than one available. The only data from these tests that are carried forward to the on-orbit calibration are the coefficients of the quadratic terms of the calibration equation, as was mentioned previously. The laboratory measurements of the other coefficients (slope and intercept) are kept as a reference, but they are replaced on orbit by values determined continually from the space and blackbody data. The laboratory calibration functions, however, are used in an important diagnostic test before launch: they are applied to the count output of the instrument=s internal blackbody to derive its radiance temperature. The temperature of the internal blackbody measured in this way should be within approximately 0.1K of the temperature of the blackbody measured directly with its platinum resistance thermometers. If it is not (as occurs frequently with the GOES instruments), it implies that the laboratory calibration process is not fully understood at the 0.1K level of precision. NESDIS is soliciting the assistance of the National Institute of Standards and Technology to resolve these inconsistencies in tests of future instruments.

Besides the coefficients of the quadratic terms, there are two other quantities determined before launch that are applied in the calibration on orbit. One is the coefficients required to convert to temperature the raw count output of the thermistors (or platinum-resistance thermometers) of the internal blackbodies. The other is the spectral response functions of all the channels of each instrument. Accurate measurements of the spectral response functions may be difficult to obtain, but we cannot overemphasize their importance. Accuracy in the knowledge of the spectral response functions is required not only for accurate calibration, but also for success in inferring properties of the Earth=s surface and atmosphere from the satellite data.

The basic on-orbit calibration, as described above, is sometimes enhanced to handle unanticipated instrument anomalies. Examples of anomalies include the rapid changes in calibration intercepts affecting the HIRS in parts of the orbit when instruments change most rapidly[7,8,1], interference in calibration measurements by direct solar radiation or solar heating that affects the AVHRR[9] and the GOES imagers and sounders[5,10] in parts of their orbits, the east-west scan-position dependence of the reflectivities of the GOES scan mirrors[4], and striping in frames of data from the GOES imagers and sounders[5,11]. An additional step (but not an anomaly) in the calibration of the AMSU is the need to apply antenna-pattern corrections[12], derived from pre-launch tests, to measurements of antenna temperature to generate brightness temperatures of the Earth/atmosphere scenes.

We conclude with a few statements on calibration accuracy and stability, with examples from the GOES imagers and sounders. Uncertainties in absolute calibration arise primarily from three sources: (1) transfer of the calibration of a primary standard (at, e.g., the National Institute of Standards and Technology) to the secondary standard in the laboratory where the instruments are tested; (2) transfer from the secondary standard to the instrument=s blackbody during pre-launch tests; (3) on-orbit calibration procedures. For the GOES infrared instruments, the uncertainty in the absolute calibration was estimated by an analysis[13] performed while the instruments were being designed to be approximately 0.5K in the longwave infrared channels and 0.6K in the shortwave channels. These numbers should be increased by at least 0.1K to account for the effects of most of the unanticipated instrument anomalies mentioned in the preceding paragraph. In addition, solar heating and scattered solar radiation cause uncompensated errors as large as 1K in shortwave-channel observations during the hours near satellite midnight for approximately six months of each year[10]. Radiometric precision, e.g., variability from scan line to scan line or frame to frame (not at satellite midnight), is estimated from on-orbit observations[14] to be between 0.05K and 0.18K (rms), depending upon channel, for scenes at 300K. We have not determined repeatability over time periods longer than a few hours. To do this requires intercomparisons with stable independent observations, which are difficult to obtain.

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