NOAA Technical Report NESDIS 55

REPORT OF THE WORKSHOP ON RADIOMETRIC CALIBRATION OF SATELLITE SENSORS OF REFLECTED SOLAR RADIATION, MARCH 27-28, 1990, CAMP SPRINGS, MARYLAND

Washington, D.C.
July 1990

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

NOAA TECHNICAL REPORTS

National Environmental Satellite, Data, and Information Service

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NESDIS 13 Summary and Analyses of the NOAA N-ROSS/ERS-1 Environmental Data Development Activity. John W. Sherman III, February 1984. (PB85 222743/43)

NESDIS 14 NOAA N-ROSS/ERS-1 Environmental Data Development (NNEEDD) Activity. John W. Sherman III, February 1985. (PB86 139284 A/S)

NESDIS 15 NOAA N-ROSS/ERS-1 Environmental Data Development (NNEEDD) Products and Services. Franklin E. Kniskern, February 1985, (PB86 213527/AS)

NESDIS 16 Temporal and Spatial Analyses of Civil Marine Satellite Requirements. Nancy J. Hooper and John W. Sherman III, February 1985. (PB86 212123/AS)

NESDIS 18 Earth Observations and the Polar Platform. John H. McElroy and Stanley R. Schneider, January 1985. (PB85 177624/AS)

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Edited by
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PREFACE

A NOAA/NESDIS workshop on **radiometric calibration of satellite sensors of reflected solar radiation** was held on March 27-28, 1990, in the World Weather building in Camp Springs, Maryland. The purposes announced prior to the workshop were to critically examine methodology and results, to estimate for the user community the most likely pre-launch and in-orbit channel gains, and to recommend technical improvements in calibration programs for visible channels.

The first day's session was a review of calibration methodology and results (pre-launch and in-orbit), as applied to AVHRR (and TM). The methods are also applicable to GOES calibration. Results for **instantaneous absolute gain** (deduced from a single day's data at White Sands, for example) suggested an absolute accuracy in the range ± 5 to 10% for AVHRR. Results for the long-term **trend in relative gain** (deduced from a year's AVHRR data over the Libyan desert, for example) suggested that a steady rate of change in gain can be characterized to better than ± 2% per year. Long-term degradation rates for AVHRR channels 1 and 2 range for different NOAA satellites range between 0 and 15% per year. There is evidence that the degradation in gain is not necessarily monotonic (i.e. it can rise as well as fall for sustained periods), and that it is not necessarily smooth (i.e. there may be sudden changes followed by long periods of relative stability). If these effects are present the accuracy (and utility) of vicarious measurements is reduced. There was general agreement that the data user community places highest priority on the correction of long-term trends in gain, and that gain correction information is most useful if it is available within a few weeks of real time.

On the second day two working groups were convened on calibration logistics (Bill Rossow, NASA/GISS, chairman) and on calibration accuracy (Bob Saunders, NIST, chairman). Their reports and recommendations are the end products of the workshop and the purpose of this report.

The task of estimating gains to be recommended to the user community was extensively discussed. The workshop decided to indefinitely postpone action on this task, for the following reasons:

- Successful completion requires a significant amount of research and a critical evaluation of data sets from different sources;

- This workshop is unsuited to the task because of time constraints, the incompleteness of available data sets, and potential conflicts of interest due to loyalty to a particular method;

- NOAA/NESDIS should take full responsibility for leading the task of organizing, gathering, analyzing and publishing in a timely manner all significant information on in-orbit calibration constants for all NOAA radiometers.

There were over 40 attendees at the workshop, at least 30 from outside NOAA. NASA was well represented (Goddard, Langley and Headquarters). Representatives were present from the USDA, USGS, EPA, the US Army Engineering Topographic Laboratory, NIST, the Universities of Arizona and Maryland, Georgia Institute of Technology, the Environmental Institute of Michigan, the Scripps Institution and from ITT, ST Systems and Hughes Corporation (SBRC).

The agenda is reproduced in Appendix A, the attendance list in Appendix B. The NIST report on AVHRR pre-launch calibration methodology at ITT is in Appendix C. Suggested NESDIS responses to the workshop recommendations, prepared by Peter Abel for the consideration of NESDIS/ORA managers, are in Appendix D. Paper copies of the viewgraphs are available from the Satellite Research Laboratory.

The urgency of improving knowledge of the calibration of AVHRR channels 1 and 2 was emphasized by Dr Teillet (Canada Centre for Remote Sensing) in a letter written on behalf of the IGBP Land Cover Change Steering Group. A copy of this letter is in Appendix E.

Working Group 1 report (Chairman, W. Rossow, NASA/GISS)

CALIBRATION OF SOLAR WAVELENGTH CHANNELS OF AVHRR

RECOMMENDATION I: ESTABLISH CLEAR REQUIREMENTS FOR CALIBRATION ACCURACY AND DELIVERY TIME

NOAA is the responsible agency in the US for collecting routine atmospheric and some oceanic observational data; NOAA is also responsible for analysis of some of these data. Some of the satellite data sets that NOAA collects are unique in their global coverage and spectral characteristics; thus, these data allow the US and NOAA to participate significantly in increasing world climate study activities. In order that these national responsibilities and the opportunities of world-wide scientific endeavors be met, NOAA must take a serious interest in the calibration of these data as a prime determinant of their quality and utility.

Within NOAA there are several scientific research groups that develop new data analysis methods and participate in on-going national and international research efforts. Like all scientists, these groups must be concerned for the quality of the data available to study Earth; therefore, these science groups must accept that calibration is of vital interest to their research and that of their colleagues. These groups should serve as the spokesmen for the whole research community by collecting existing statements of accuracy requirements and advocating NOAA actions to meet these requirements. In particular, the new NOAA Climate and Global Change Program must raise the importance of data calibration to higher visibility within the agency.

A. SCIENTIFIC USES OF AVHRR DATA

Scientific users of NOAA AVHRR, GOES VISSR, and other satellite radiometer data need assurances that the data products are consistent representations of Earth surface and atmospheric phenomena. Comparisons of one location to another and of one time to another are confounded by undocumented sensor-related changes unrelated to changes on Earth. Maintaining such consistency requires systematic monitoring of instrument performance, monitoring of relative changes in data calibration, and periodic determinations of absolute calibration. Systematic monitoring also insures prompt initiation of corrective actions, whether it involves sensor operations, ground processing procedures, or both. If this is not done by the data provider, an undue burden is placed on the users, particularly those who deal only with occasional observations or small samples of data.

B. CURRENT CAPABILITIES

Several techniques are available (published in the literature) that can be used to obtain post-launch calibrations or to monitor relative changes in calibration. These methods use specific deserts, ice/snow, clouds, and/or a variety of locations and surface types over the whole globe as targets. For specific times, some of these methods appear to be able to determine the absolute calibration to within about 10-15%; direct comparisons to calibrated aircraft instruments may be able to provide absolute calibrations to within 5-10%. After analyzing about a year of data, the relative accuracies in monitoring calibration drift are approximately 1-5% for sensors that degrade in a steady manner.

An inherent assumption for all of these techniques (except the direct aircraft comparison) is that the properties of the target and atmosphere are constant to within the same precision as claimed for the calibration determination. For long-term calibration stability assessments, this is equivalent to assuming that the Earth or some part of it is unchanging. For example, AVHRR Channel 1 ($0.6\mu m$) drift measurements would be affected by systematic changes in ozone or aerosols, Channel 2 would be affected by systematic changes in water vapor or aerosols, and the thermal IR channels would be affected by systematic changes in water vapor, atmospheric and surface temperatures, or carbon dioxide (for thermal sounding instruments).

C. NEEDED IMPROVEMENTS

We restate and endorse the requirements, documented elsewhere, for detecting long-term changes of the order of 1% (per year) in vegetation index or surface albedo, cloud albedo, surface and atmospheric temperatures, and cloud temperatures. These requirements translate into a requirement on the solar and thermal wavelength channels of the AVHRR and other satellite radiometers that the relative stability of their calibrations be known to within about 1% (per year) over time periods of decades.

Some current statistical calibration monitoring methods can detect changes of 1-2% per year; however, they require retrospective analysis of data collected over one to two years and must assume that the targets used for monitoring, usually some portion of Earth, do not change. Other types of monitoring of Earth, for example, vegetation status, need similar (though slightly less stringent) calibration accuracies obtained with shorter delays. This requirement cannot presently be met by existing techniques in some cases.

Five steps should be taken: (1) implementation of more detailed recording and dissemination of instrument performance statistics, (2) implementation of several operational methods to determine calibration, (3) recording and dissemination of the history of the results of the calibration determination, (4) periodic application of more accurate retrospective calibration monitoring techniques and comparisons to aircraft calibrations to refine the accuracy of the calibration, and (5) implementation an "on-board" calibration system that both monitors relative calibration and provide absolute calibration information.

RECOMMENDATION II: IMPLEMENT AN IMPROVED CALIBRATION MONITORING SYSTEM

A. SCIENTIFIC COORDINATION AND EVALUATION

Scientific oversight of all stages of the calibration assessment is crucial, not only to insure that the proper information is developed and archived, but also to evaluate the "success" of the procedures and refine their accuracies. The best way to accomplish this oversight is to support an active in-house scientific use of the data, to review periodically what is learned both in-house and in the research community at large, to establish formal procedures for influencing the operational data processing, and to publish the results of this activity on a regular schedule.

B. INSTRUMENT PERFORMANCE HISTORY

NOAA should keep and publish a statistical history of instrument performance, including command activities, engineering housekeeping data, and statistics of the measurements themselves. Any change in instrument status should be recorded permanently. This information assists in identifying anomalies in the data, determining causes of sudden changes in calibration, and in assessing overall stability of the data record.

C. RAPID ASSESSMENT (< one month)

NOAA has several major customers for AVHRR data that require calibrated visible data in a timely manner. These agencies (including NMC, the Climate Analysis Center, USDA, DoD) use the data for monitoring short-term and interannual climate variations, detecting and describing drought areas, assessing agricultural conditions, and producing surface products such as snow cover, vegetation index, and sea ice maps. AVHRR data better meets requirements for these uses and products if it is periodically recalibrated to remove instrument drifts. Post-launch calibrations, even at the 5% level achievable by several of the current techniques, are preferable to continued use of the pre-launch calibrations over the life of the instrument.

Several recent AVHRR sensors have drifted on the order of 15% over their orbital lifetimes. Stability of 5% (per year) meets the goals of this class of user. The workshop recommends that NESDIS implement several quick-response, vicarious calibration techniques (of which several were described at the workshop) to meet the requirements of this class of users. The use of more than one method is imperative to cross-check the weaknesses and differences in sensitivity of the methods.

A 5%-accurate calibration at the end of a 5 year mission comes close to achieving a determination of drift at the 1% per year level. Thus, the history of the calibration coefficients produced by the "rapid-response" methods should be archived and made published in a timely and routine way. Such "quick-look" calibration information will be revised and corrected by more careful study of longer-term data records.

D. RE-ASSESSMENT (< 2 years)

The global coverage available from the suite of instruments on NOAA's polar orbiting meteorological satellites makes them central to global change monitoring. Although designed for applications that did not require high accuracy, the instruments have proven capable of providing information on the state of and the changes in our climate system. Global change research requires due attention be paid to monitoring long-term "calibration drift", since climate changes are by their very nature small and occur over decadal or longer time periods. Since the lifetime of a single satellite is short, a series of satellites must be employed. Therefore, it is imperative that the drift of individual instruments be monitored accurately (to within 1%) and that all new instruments be normalized to a reference standard using overlapping data sets. The Climate and Global Change Program in NOAA must take immediate steps to see that the above recommendations are carried out. Otherwise, the ability to monitor climate changes properly will be in doubt.

The workshop recommends implementation of routine monitoring of long-term calibration changes that combines the history of the "rapid-response" calibrations with one or more statistical target monitoring procedures and periodic direct aircraft calibrations. Periodic workshops should be held to assess the longer-term performance of the radiometers, evaluate the several calibration results, and determine a best and final calibration for the data. These results should be published.

E. DISSEMINATION OF CALIBRATION INFORMATION AND RESULTS

Data tapes should contain three kinds of information (instead of the one kind currently provided): instrument characteristics (including spectral responses, linearity tests, polarization, and noise levels), pre-launch calibration results, and a dated post-launch history of calibration. All calibration estimates should include error estimates.

The User's Guide should contain much information that is repetitive of that found on the data tapes (instrument characteristics, pre-launch calibration results), as well as a history of instrument performance, calibrations, and the results of periodic calibration assessments. Prompt reporting of any data anomalies and regular reports on the scientific attributes of the data can be made to the user community at large by posting this information on publicly and electronically accessed data bases. NOAA should maintain a bibliography of all studies of instrument characteristics and performance, calibrations and stability.

One would expect the uncertainty of calibrations to decrease with time after launch. Earlier processed data sets could then be reconciled using more accurate values based on more extensive analysis. Regular workshops should be held to re-evaluate and refine calibration estimates and to assess uncertainties. The results of these periodic assessments should be published and included in all current data documentation.

F. "ON-BOARD" CALIBRATION

All available post-launch calibration methods, except for direct comparison to aircraft instruments, assume in one fashion or another that their target does not change. In particular, the more accurate methods for monitoring long-term trends make the assumption that some part of or all of the Earth remains constant. This precludes direct detections of climate change with these data, since the "climate" is assumed unchanging to provide sufficient data stability. Moreover, the "rapid-response" methods are limited in accuracy primarily by shorter-term changes in the atmosphere and target that are not adequately monitored. Both of these approaches to post-launch calibration would, therefore, be improved by the availability of independent information, such as can be provided from an "on-board" instrument monitoring capability. Although there are difficulties with absolute calibrations from such on-board instrumentation, these difficulties can complement those of other techniques; that is, the combination of on-board and ground analyses would be better than any one approach. To meet needs for both improved short-term calibration knowledge and for long-term stability, an on-board calibration an stability monitoring system (at 1% per year accuracy level) should be added to the AVHRR-4 system.

Working Group 2 Report (Chairman, R. Saunders, NIST)

1. Recommendations:

Recommendation 1: Implement the NIST recommendations for pre-launch calibration

The group agreed that the most urgent problem in calibrating reflected-solar channels on NOAA radiometers is to correct for in-orbit changes in gain. This is because most quantitative applications of the data derive from examination of extended time series of observations, so that stability of instrument response is crucial. Because AVHRR quantitative products are either indices (like NDVI) or empirically modeled from reference data sets (albedo), stability is presently more important than absolute accuracy. High absolute accuracy is very desirable to maintain continuity between successive instruments in an operational series, and for wider applications such as ISCCP, but this task is complicated by variable viewing geometry (caused primarily in the NOAA/POES system by different equator crossing times and orbital precession), and to some extent by differences in spectral response functions from instrument to instrument.

Although improvement of absolute accuracy is not urgent for present applications (because error budgets are dominated by instability terms), demands for higher absolute accuracy are expected to increase in the near future as routine in-orbit stability monitoring of visible channels is introduced (it is planned for AVHRR/4), as user requirements tighten (for programs associated with Global Change initiatives), and as NOAA products increasingly rely on results from sequential satellite systems considered as a single intercalibrated data source. Improvement in the absolute accuracy of pre-launch calibration from the present level of $\pm$ 5 to 10% is therefore desirable. Because the cost is relatively low in dollars and very low in anticipated schedule impacts the group recommends that NOAA implements the recommendations of the NIST report on pre-launch calibration of AVHRR. A copy of the NIST report is in Appendix B. The group stressed that an on-board stability monitor is necessary for AVHRR.

Recommendation 2: Strengthen instrument specifications for characterizing pre-launch performance

The group expressed some concern about the stability of the AVHRR calibration offset, and whether the space view is a true representation of the offset when the instrument is viewing the earth. This and other concerns derive from the lack of detail in the pre-launch characterization of the instrument.

The pre-launch characterization conforms to the requirements of the specification, but the specification defines an imager, not a radiometer, for which the system behavior must be known in greater detail. Imprecise knowledge of the field-of-view response, for example, contributes to the irreducible uncertainty of vicarious estimates of in-orbit gain. The group recommends that NOAA consider strengthening the specification requirements for pre-launch characterization of the performance and stability of the AVHRR.

Recommendation 3: Minimize susceptibility to in-orbit degradation through design changes

The in-orbit gain degradation in AVHRR is large (7% per year for NOAA-9), and its characterization as a function of time yields poor time resolution. It is therefore important to remove as much potential for in-orbit gain change as possible by prudent design of the instrument. If cosmic dust and satellite out-gas products are probably contaminating the scan mirror, launch sealing of the radiometer and in-orbit shielding of the scan cavity (addition of "cold traps" or other methods) may alleviate this condition. If the filter shifts with time, this change should be characterized before launch. Changing from interference to absorption filters (with the resulting S/N penalty) may largely avoid such shifts. The group recommends that reduction or elimination of the degradation through design changes should be considered for future instruments. The group believes that in-orbit onboard relative calibration is necessary to meet the majority of quantitative user requirements.

The group recognized that the precession of NOAA orbits, particularly for satellites ascending in the afternoon, is a major source of uncertainty in products derived from radiances in AVHRR channels 1 and 2. Stable viewing geometry would greatly reduce the effects of poorly known surface and atmospheric reflectance over specific targets, and the group recommends that orbit stabilization be seriously considered for future NOAA satellites. Stabilization involves changing the selection of orbital injection criteria to minimize the precession rate as well as the possibility of active drift control in orbit.

2. Summaries of methods discussed at the workshop:

Three Deterministic Methods for Calibrating AVHRR using Selected Ground Sites (P.N. Slater):

1. Reflectance-based Method using a Large Uniform Site:

Makes use of Edwards Air Force Base, which is uniform over more than one AVHRR pixel, see Figure 1. The spectral reflectance of a small representative area is measured as is the atmospheric optical depth at the time of near-nadir AVHRR image acquisition of the site. A radiative transfer code is used to predict the radiance of the site at the sensor. A ratio of the digital counts for the pixel surrounding the measured area to the spectral radiance provides a single point calibration of the system.

Advantages: Ground and atmospheric measurements at the time of image acquisition provide an accurate description of the calibration conditions. An expensive image from another calibrated sensor is not required.

Disadvantages: The surface is non-Lambertian and therefore accurate reflectance measurements are difficult. Pixel registration is difficult because the surrounding area is very non-uniform. The method only provides a single point on the calibration curve. The space offset is used and linearity in response is assumed which may not always be a good assumption. Requires a field campaign. Probable absolute uncertainty: $\pm 10\%$. (could be $\pm 5\%$ if a larger high reflectance surface can be found).

2. Reflectance-based Method using another Calibrated Sensor and Ground and Atmospheric Measurements:

This method has been used at White Sands Missile Range, see Figure 2. The spectral optical depths are measured at the times of image acquisition by TM or HRV and AVHRR. Sites on the TM or HRV images are located that are uniform over an area greater than one AVHRR pixel in size (2x2 AVHRR pixel areas or greater are preferred). The reflectance of that area is determined from the calibrated TM or HRV image and by the use of a radiative transfer code at the solar zenith angle which corresponds to the acquisition time. Small corrections are made to these reflectances in TM-3 and TM-4 or HRV-2 and HRV-3 which provide reflectances in Channels 1 and 2 of AVHRR. Bidirectional reflectance function corrections are made for illumination and viewing differences between AVHRR and the high resolution sensor. To predict the radiances in Channels 1 and 2 of the AVHRR, AVHRR reflectances and a radiative transfer program with the appropriate optical depths and solar zenith angle are used. An AVHRR pixel within the uniform area is registered and digital counts determined. A ratio of the digital counts to the radiance provides a point on the calibration curve. Other areas may be used to provide other points on the curve.

SENSOR IN–FLIGHT ABSOLUTE RADIOMETRIC CALIBRATION BY THE REFLECTANCE BASED METHOD

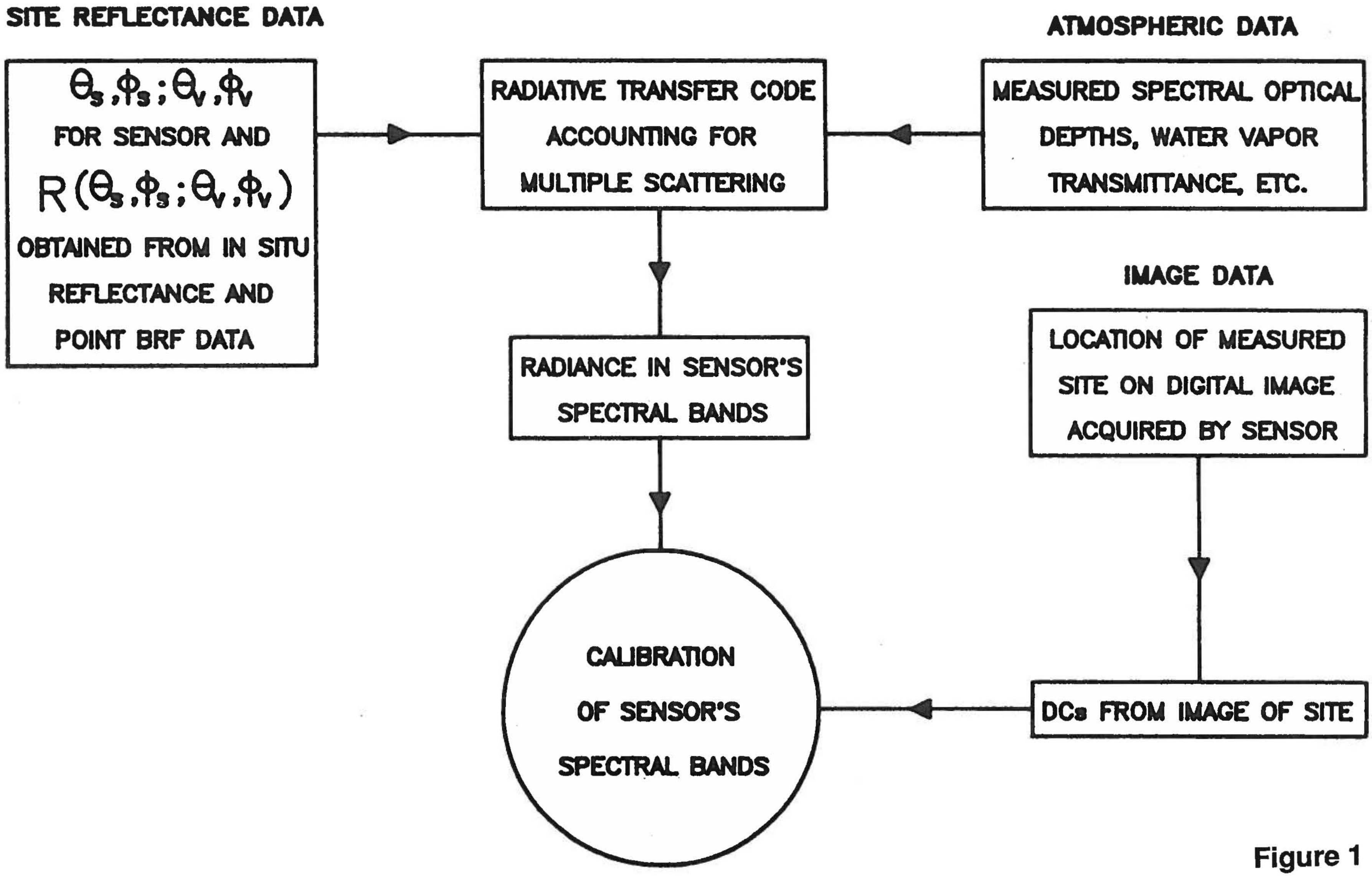

Figure 1

Advantages: Ground and atmospheric measurements at the time of image acquisition provide an accurate description of the calibration conditions. Several points on the calibration curve can be determined.

Disadvantages: The accurate, current absolute calibration of the high resolution sensor must be known. A field campaign is required. Accurate pixel registration is a problem. Only near-nadir imagery should be used. Probable uncertainty is ±6%.

3. Reflectance-based Method with Respect to Another Calibrated Sensor with no Ground and Atmospheric Measurements:

This method also makes use of White Sands Missile Range, see Figure 3. It is the same as the previous method but standard atmosphere and historic data for the bidirectional reflectance function are assumed for correction. The method assumes that errors introduced by the use of a standard atmosphere to determine ground reflectance (downward path) are cancelled by the use of the same atmosphere for the upward path calculation.

Advantages: Does not require a field campaign. Calibration can be updated fairly frequently.

Disadvantages: Relies on the accurate, current absolute calibration of a high resolution sensor. Accurate pixel registration is a problem. Only near-nadir imagery should be used. Probable uncertainty is ±7%.

Aircraft Direct Calibration Method (B. Guenther):

The Aircraft Direct Calibration Method involves simultaneous observations of a satellite scene with a well-calibrated (standard) system air borne on a platform of sufficient altitude so the atmospheric corrections to the standard system observations needed to match the satellite observation are unimportant. This technique is being used for tracking the performance of AVHRR instruments for Channels 1 and 2 from 65,000 feet from a NASA ER-2 aircraft. The standard instrument is a double Ebert monochromator measuring between 400 and 1030 nm, and is calibrated according to NIST-traceable scales maintained with the Goddard large aperture integrator scales. Current demonstrated capability includes individual absolute measurements of ±9% (2 sigma) and trends of 6% from observations of cloud free scenes over White Sands, and other discernable surface targets. Improvements in the flight data system planned for the upcoming year will provide determination of about 2%. Improved standard instrument polarization characterization (and perhaps performance) is also needed over the coming year for demonstration of this 2% trend determination in the AVHRR radiance sensitivity.

GROUND AND ATMOSPHERIC MEASUREMENTS AND REFERENCE TO ANOTHER CALIBRATED SATELLITE SENSOR

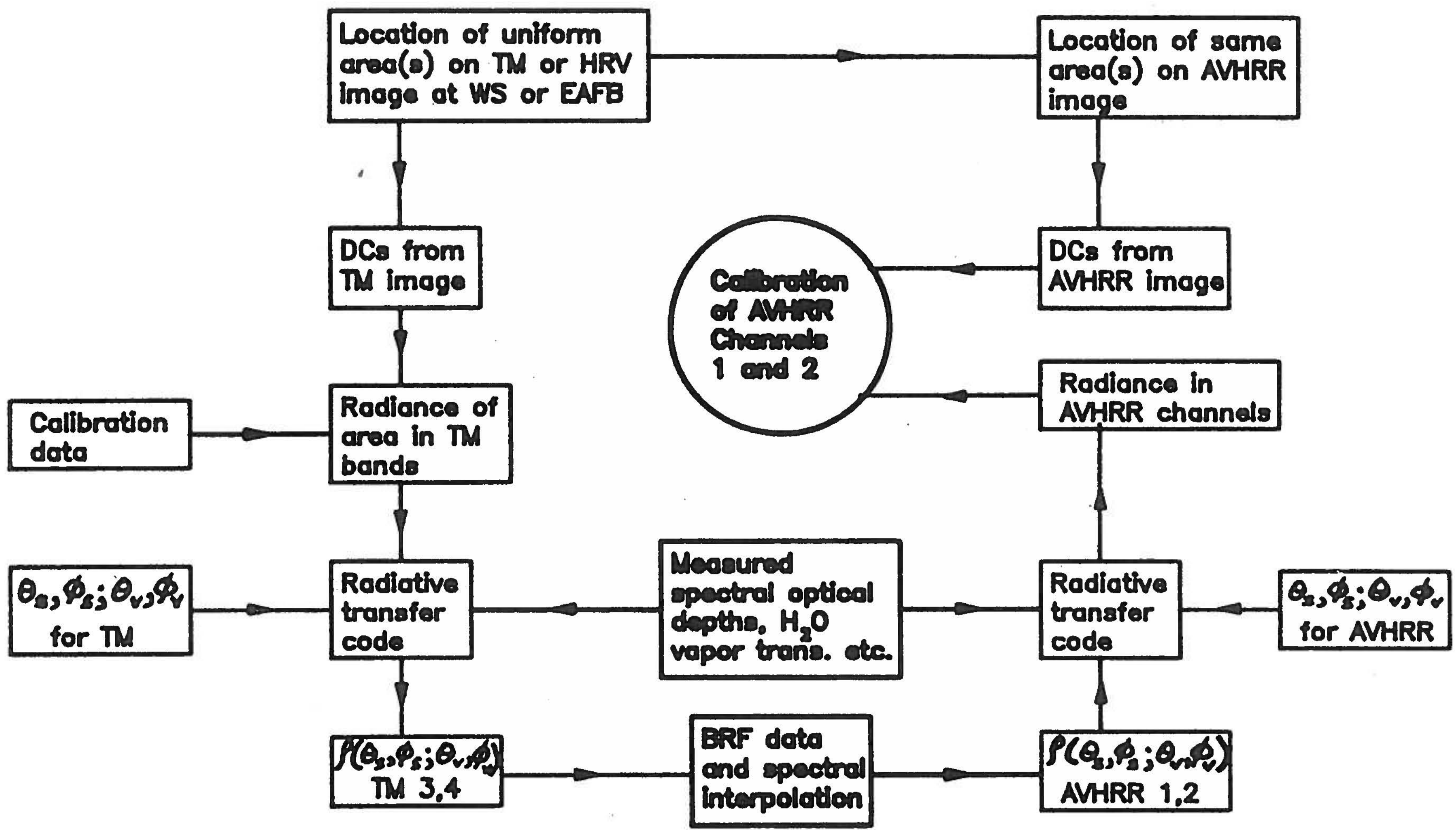

Figure 2

NO GROUND AND ATMOSPHERIC MEASUREMENTS BUT REFERENCE TO ANOTHER SATELLITE SENSOR

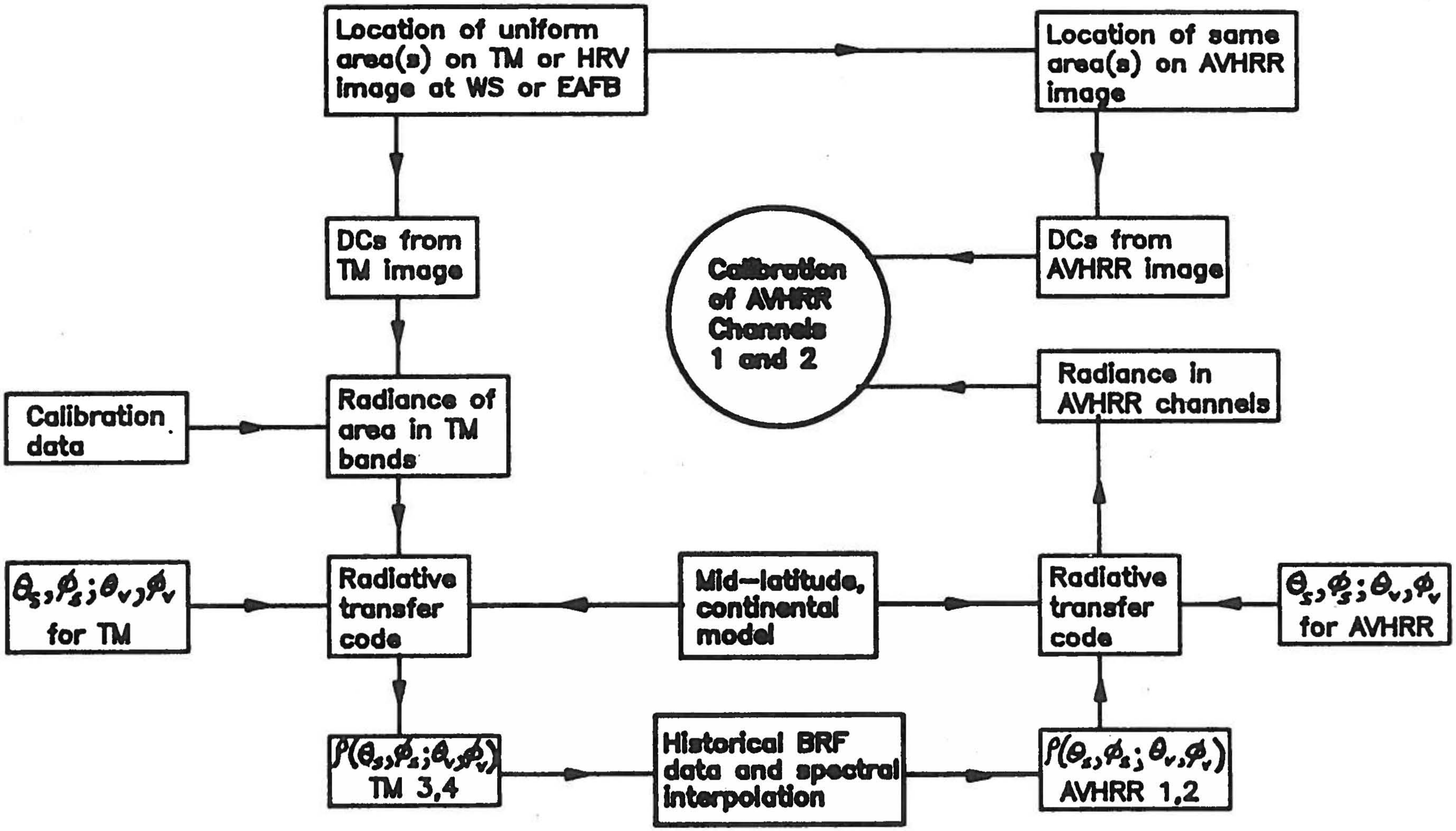

Figure 3

This technique is believed to be sensitive to changes of 10 nm in the full width half-maximum bandpass of the Channel 1 filter with time in orbit by observations of scenes with significantly difference spectral content. Computer models indicate this approach can be exploited by observations of sand, ocean and vegetated (soybean) surfaces to distinguish between spectrally flat and spectrally sensitive degradation. Data over White Sands, Lake Tahoe and a forest site in Oregon were obtained in July, 1989, for NOAA-11, but the results of this investigation are not currently available.

ISCCP AVHRR Visible Radiance Calibration Monitor by C.L. Brest and W.B. Rossow:

The radiance calibration monitor is a technique to check the calibration of AVHRR Channel 1 for degradation over time. In a modified form it is used to normalize succeeding polar orbiters to the adopted ISCCP relative standard of NOAA-7 July 1983. It is a statistical process which analyzes a large volume of data. Cloud detection/removal is accomplished by a reflectance filtering method. A surface retrieval is performed which accounts for Rayleigh scattering and ozone absorption. A variety of surface types and geographic targets are employed. The primary comparison is least-squares linear regression of mean monthly surface visible reflectance global maps from different time periods. We also compare radiance histograms for the various targets and land surface types. To date 6 1/2 years of data have been analyzed, starting in July 1983. Data have been analyzed from NOAA-7, 8, 9, 10, and 11. Results indicate significant differences in calibration of some of the satellites and significant degradation over time for most of them.

Desert and Ocean Calibration of AVHRR channels 1 and 2, (Yoram Kaufman and Brent Holben):

An inflight calibration for AVHRR visible and near IR bands is discussed and applied to NOAA-7 and NOAA-9 from 1981 to 1988. The approach, independent of ground support, relies on three unique earth-atmosphere phenomena: molecular scattering over the ocean for absolute visible band calibration; ocean glint to transfer the calibration from the visible band to the near-IR band; and desert reflection to monitor, independently, the stability of the visible and near-IR bands. The resulting two calibration methods differ in the brightness range and spectral response of the radiance source (molecular scattering v. desert reflection). Both methods agreed on calibration deterioration for NOAA- 9 of 8±3% in the visible band and 15±2% in the near-IR shortly after launch; and 18±1% in both bands three year later.

However, the ocean method showed an increase of 6% and 9% in the visible and near-IR respectively over the lifetime of NOAA-7 in contrast to a decrease of 10% and 12% in the two bands as predicted by the desert reflectance method. Possible reasons for the differences between the resultant calibration for NOAA-7 from the two methods are discussed. Recommendations for the absolute calibration of NOAA-7 and NOAA-9 are given in the test and comparison are made to other published AVHRR calibrations. The calibration deterioration results in a change in the vegetation index (NDVI) between 0.0 and 0.04. A simple correction scheme is suggested for uncorrected NOAA-7 and -9 NDVI and implications of the calibration ratio on AVHRR remote sensing are discussed.

Modeling White Sands: Frouin and Gautier's Method of Calibration:

We use Space and White Sands as calibration targets. Space, at zero intensity value, provides a low point on the calibration curve relating digital count to radiance, whereas White Sands, a highly reflective surface, provides a high calibration point. The reflected terrestrial radiance measured at satellite altitude is computed using a fairly accurate (2%) radiative transfer model. The model parameters, namely surface reflectance, water vapor and ozone amounts, optical properties and concentration of aerosols, are specified from climatological data and observations at the nearest meteorological sites. Surface reflectance is estimated from laboratory measurements of gypsum sand in dry and wet conditions using soil moisture data typical of the site. Aerosol optical properties (single scattering albedo, phase function) are those of the continental model recommended by the International Radiation Commission. Ozone amount is estimated at its climatological value, whereas water vapor amount is estimated from radiosonde observations. Visibility requested at nearby sites gives a measure of aerosol turbidity. The technique produces theoretical accuracies of 8 to 13% depending on the channel considered (visible or near-infrared), but might perform better as comparisons with high-flying aircraft measurements demonstrate.

Cloud Calibration Method (C.G. Justus):

A technique has been investigated for using surface irradiance measurements under overcast cloud layers, in combination with modeled radiative transfer, to compute cloud-top reflectance, for the purpose of using the bright cloud tops as calibration targets for satellite shortwave sensors. Using this cloud transmittance and modeling approach, we conducted a program of research on the applicability, precision and absolute accuracy which can be obtained for filter-band sensor calibrations for both GOES VISSR visible channel and NOAA Polar Orbiter AVHRR visible and near-IR channels.

This cloud-target satellite calibration technique is a new, simple, and relatively inexpensive approach which should complement other satellite calibration procedures.

Early in the project, a retrospective study of data from GOES VISSR was used in conjunction with archived surface irradiance measurements made at the Georgia Tech campus site. Some of these results were reported in an article published in Remote Sensing of Environment. More recently, a pilot study was conducted to determine the feasibility of implementing the cloud-top calibration for AVHRR using surface irradiance measured at five of the new NOAA Solar Radiation Network stations across the continental United States. AVHRR satellite data were also collected for the Boulder Solar Radiation Tower site (John DeLuisi) although the solar radiation data for this site have not yet been analyzed. NOAA-9 and NOAA-11 AVHRR calibration results of this pilot study from the period March, 1988 through June, 1989 are presented, along with earlier results from NOAA-7 calibrations.

Desert Calibration Method (W. Frank Staylor):

AVHRR channel 1 degradations were determined by comparing desert models with 68 months of observations of the Libyan Desert (20° to 30°N, 20° to 30°E). The comparisons revealed that the degradation rates were 0, 3.5% and 6.0% per year for NOAA 6, 7, and 9, respectively. An analysis based on zonal measurements covering half of Earth's surface suggests that these rates are applicable to all surface types.

3. Results presented or discussed by Working Group 2:

A. Calibration Results (using the method of Frouin and Gautier (1987)):

GOES-1 VISSR:

Date (year, day #)			
82 065	0.173	10-4	Reflectance /(8-bit count)^2
82 092	0.162	10-4	
82 127	0.177	10-4	
82 153	0.172	10-4	
82 183	0.182	10-4	
82 221	0.175	10-4	
82 265	0.205	10-4	
82 282	0.186	10-4	
82 308	0.203	10-4	

GOES-2 VISSR:

82 338	0.201	10-4
83 012	0.222	10-4
83 046	0.211	10-4
83 068	0.190	10-4
83 092	0.209	10-4
83 132	0.204	10-4

B. NOAA-11 AVHRR results, illustrating the spread in results from different methods:

Gain in units of Counts/(W/(m^2 sr micron))

Channel	ER2 (NASA/GSFC) (Guenther)	Ocean Calibration (NASA/GSFC) (Holben)	White Sands (U Az) (Slater)	Clouds (Ga Tech) (Justus)
1	1.81	1.67	1.79	1.8
2	2.79	2.4	2.52	2.7
Date	4/89	3/89	11/88	4/89

4. Subjective Comparison of Various Satellite Sensor Calibration Approaches:

The first version of Table 1 was provided by C.G. Justus as rapporteur for the Satellite Calibration Session of the COSPAR/WCRP International Workshop on Surface Radiation Budget for Climate and Global Change in Wurzburg, FRG, 30 October to 3 November, 1989. The present Table 1 is based on the original and is the work of P.N. Slater and C.G. Justus.

Notes on Table 1:

(a) Depending on number of auxiliary measurements required (e.g. surface albedo, match-up with LANDSAT, etc.) and degree of automation of these auxiliary measurements.

(b) Depending on number of sites used and availability of overcast conditions.

(c) Limited by uncertainties in cloud bidirectional reflectance factor and anomalous cloud absorption assumptions.

(d) Not intended as absolute calibration, but comparison with "anchor points" from absolute-technique calibrations yield high precision, high time resolution results.

(e) Absolute or relative accuracy depending on location in table.

(f) ER-2 flight costs are high, helicopter costs are much less.

(g) Accuracy mainly limited by registration uncertainty.

(h) Several improvements are being implemented to improve accuracy.

(i) Makes several assumptions regarding conditions of site and atmosphere.

References for Table 1:

1. P. Abel, G.R. Smith, R.H. Levin, and H. Jacobowitz, "Results from aircraft measurements over White Sands, New Mexico, to calibrate the visible channels of spacecraft instruments", Proceedings of SPIE, 924:208-214 (1988)

2. P.N. Slater, S.F. Biggar, R.G. Holm, R.D. Jackson, Y. Mao, M.S. Moran, J.M. Palmer, and B. Yuan, "Reflectance- and radiance-based methods for the in-flight absolute calibration of multispectral sensors", Rem. Sens. of Environ., 22:11-37 (1987)

Table 1 - Subjective comparison of various satellite sensor calibration approaches (L-low, M-medium, H-high)

	Absolute Methods					Relative Methods		
	Aircraft Overflight	Desert, Clear Sky	Desert, Clear Sky	Cloud-Top Target	Desert, Clear Sky	Global Normalization	Desert, Clear Sky	Desert, Clear Sky
Authors	Abel et al[1] Slater et al[2] Guenther et al[3]	Slater et al[2] Biggar et al[4] Teillet et al[5]	Frouin and Gautier[6]	Justus[7]	Whitlock[8]	Brest & Rossow[9]	Holben et al[10]	Staylor[11]
Cost per calibration point	H[f]	L-M[a]	L	L	L-M	L	L	L
Frequency of available calibrations	L	M-H[a]	M	M-H[b]	H	H	M-H	H
Potential for automation	L	L-H[a]	H	H	M	H	H	H
Reliance on radiative transfer calculations	M	H	M	H	H	L	L	L
Number of calibration targets available	L	L	L	M	L	H	L	M
Number of data points for testing linearity	L	L-M[a]	L	M	L	H	L	H
Accuracy achievable[e]	H[g]	M-H[h]	L[i]	M[c]	M	H[d]	H	H

3. B. Guenther, R. Galimore, B.L. Markham, and J. Cooper, "Results from the NASA ER-2 aircraft experiment at White Sands, N.M.", Meeting on radiometric calibration of satellite sensors of reflected solar radiation, NOAA/NESDIS, March 27-28, 1990

4. S.F. Biggar, R.P. Santer, and P.N. Slater, "Irradiance-based calibration of imaging sensors", in Proceedings of IGARSS 90, in press

5. P.M. Teillet, P.N. Slater, Y. Ding, R.P. Santer, R.D. Jackson, and M.S. Moran, "Three methods for the absolute calibration of the NOAA AVHRR sensors in flight", submitted to Rem. Sens. Environ. (1990)

6. R. Frouin and C. Gautier, "Calibration of NOAA-7 AVHRR, GOES-5, and GOES-6 VISSR/VAS solar channels", Rem. Sens. Environ. 22:73-101 (June, 1987)

7. C.G. Justus, "An operational procedure for calibrating and assessing the stability and accuracy of shortwave satellite sensors", NOAA cooperative agreement NA84AA-H-00010, November 1989

8. C.H. Whitlock, Personal communication describing a pilot calibration system, 1990

9. C.L. Brest and W.B. Rossow, "Radiometric calibration and monitoring of NOAA AVHRR data for ISCCP", Int. J. of Remote Sens., 1990

10. B.N. Holben, Y.I. Kaufman and J.D. Kendall, "NOAA-11 AVHRR visible and near-IR inflight calibration", letter accepted, Int. J. Rem. Sens., 1990

11. W.F. Staylor, "Degradation rates of the AVHRR visible channel for the NOAA 6, 7, and 9 spacecraft", J. Atmospheric and Oceanic Technology, 1990, in press

APPENDIX A: WORKSHOP AGENDA

Meeting on Radiometric Calibration of Satellite Sensors of Reflected Solar Radiation

NOAA/NESDIS, World Weather Building, Room 707
Camp Springs, MD
27-28 March 1990

AGENDA, TUESDAY 27 MARCH 1990

8:30	Welcome (E. Larry Heacock, Director, Office of Satellite Operations, NESDIS)
8:45	Announcements
8:50	Introduction and overview (Phil Slater, University of Arizona)
9:30	The relevance of AVHRR calibration to vegetation studies: Report on the CCRS workshop in Ottawa. (Garik Gutman, NOAA/NESDIS)
9:45	Results from the Georgia Institute of Technology cloud calibration algorithm. (C.G. Justus, Georgia Institute of Technology) Results of the cloud calibration algorithm obtained at NOAA/SRL. (Peter Abel, NOAA/NESDIS)
10:10	The calibration of AVHRR and GOES data in ISCCP data sets. (Christopher Brest, NASA/GISS)
10:35	Break
11:50	Results from the NASA ER-2 Aircraft Experiment at White Sands, NM. (Bruce Guenther, NASA/GSFC)
11:15	Calibration drift in AVHRRs on NOAA-6, 7, and 9. (Frank Staylor, NASA/LaRC)
11:40	Lunch
1:10	Use of desert reflectance for inflight calibration of the AVHRR visible and near-IR bands. (Brent Holben, NASA/GSFC)

1:35 Aircraft measurements of bidirectional reflectance at White Sands and its application to calibration problems.
(Brian Markham, NASA/GSFC)

2:00 Calibration results from radiative transfer models applied to AVHRR data.
(Robert Frouin, Scripps Institution)

2:25 *[1] The South Pole as a calibration target.
(Peter Abel, NOAA/NESDIS)

2:35 Pre-launch calibration accuracy.
(N. Rao, STX Corporation)

3:00 Break

3:15 Pre-launch calibration method and results for AVHRR.
(Roy Galvin, ITT Corporation)

3:40 National Institute of Standards and Technology (NIST) observations at ITT.
(Bob Saunders, NIST)

4:05 *[1] SBRC experience with the calibration of the Thematic Mapper.
(Jack Engel, SBRC)

4:30 The impact of calibration changes on operational image products.
(Kim Buttleman, NESDIS)

4:40 Discussion of tasks for the Working Groups.

5:15 Adjourn

7:15 Dinner at a local restaurant

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[1] Presentation of papers marked with * was cancelled.

AGENDA, WEDNESDAY 28 MARCH 1990

8:30	Presentation of additional papers, general discussion of the papers and the tasks for the Working Groups.
	*[1] Estimation of SBUV albedo measurements from ground-based Umkehr measurements. (John DeLuisi, NOAA/ERL; presented by Peter Abel)
	Working Groups convene
10:30	Break
10:45	Preparation of Working Group reports
12:00	Lunch
13:30	Working Groups present reports, conclusions and recommendations for discussion.
15:00	Adjourn

I. Working Group on Calibration Logistics (Chairman, W. Rossow, NASA/GISS). Potential topics include requirements for interagency coordination of calibration methodology and results (NASA/GSFC, NASA/LaRC, NASA/GISS, NOAA/NESDIS, NOAA/ERL, DoD, DoE, Universities); guidelines for necessary documentation and publication of results; and defining, justifying and prioritizing realistic hardware accuracy and precision requirements.

II. Working Group on Calibration Accuracy (Chairman, R. Saunders, NIST). Topics include characterization of the accuracy of the pre-launch and the various in-orbit calibration techniques, estimation of the most likely pre-launch and in-orbit sensitivities for the reflected solar channels of AVHRR and GOES, and identification of optimal measurement schemes for indirect in-orbit calibration.

APPENDIX B
Attendees

NAME		AFFILIATION	TELEPHONE
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Bob	Saunders	NIST	(301) 975-2355
R.A.	Schiffer	NASA/HQ	(202) 453-1680
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Zhou	Sisong	NOAA/NESDIS	(301) 763-8136
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Charles H.	Whitlock	NASA/LaRC	(804) 864-5675
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Harold	Yates	NOAA/NESDIS/CIARS	(405) 325-3819

APPENDIX C

<u>The NIST report dated 7 November 1989</u>

AVHRR Calibration Procedures

In an onsite visit to the contractor, NIST personnel reviewed the calibration procedures and standards used for the AVHRR instrument. The present procedures were reviewed for improving the calibration accuracy stated for the ground-based calibration of this instrument. An initial estimate is that the present calibration procedures result in accuracies no better than $\pm 5\%$. To achieve an improvement in the level of accuracy, substantial revision of the present techniques will be necessary.

1. Detailed Error Analysis

The calibration process must be studied from the fundamental optical physics viewpoint, the sources of error identified, and their effects on the final measurement determined. A comprehensive approach to this problem involves writing a measurement equation which incorporates all the relevant parameters and their relationships. In the present procedure, the back-scattered optical radiation from the AVHRR collecting mirror is directed back into the sphere exit port with undetermined effects. The presence of this scattered optical radiation is a significant departure from the conditions prevalent during the spectral radiance calibration of the exit port. The contribution to the overall error budget due to this problem should be evaluated theoretical and experimentally. NIST staff could undertake an evaluation of the measurement errors and give a recommendation for improvement.

2.Sphere Calibration

A review of the sphere calibration data showed that calibrations are performed only every few years. The sphere should be calibrated before and after each AVHRR calibration. The sphere throughput is proportional to r/(1-r) where r is the reflectance of the sphere coating. A small change in the reflectance of a highly reflecting material such as the $BaSO_4$ used in the present sphere causes a large change in the throughput. As the reflectance goes down, this effect of reflection variation gets smaller, but a highly reflecting coating is necessary to achieve a high radiant output.

It was observed that unfiltered room air freely circulated in the sphere. When not in use, the sphere should be sealed to minimize changes in its wall reflectance. When in use, clean air only should circulate in the sphere. NIST staff could train and assist in developing the proper use of the sphere source.
To achieve a reliable sphere source, considerably more attention to the calibration and care of the sphere will be necessary.

The sphere should be calibrated more frequently and a history of the calibration maintained. Departures or significant change from the baseline need immediate attention. The calibration schedule should closely bracket the calibration of the AVHRR.

3. Calibration Chain

If an overall improvement in accuracy is to be achieved, the calibration chain must be shortened. Each step of the present lengthy calibration chain introduces error.

The calibration strategy should be reviewed with contractor and a shorter defined process developed. The uncertainties should be propagated from step to step and the overall effect upon the AVHRR calibration estimated. More direct methods such as filter absolute silicon detectors, should be used to check the present method and to serve as a real time check on the sphere calibration.

The sphere should be modified to incorporate a stable silicon detector mounted in the sphere wall and viewing the portion of the wall opposite the exit port. This cell would monitor changes in the wall reflectance and yield information on the back scatter flux returned to the sphere by the AVHRR. A second high stability silicon cell equipped with a series of optical bandpass filters should be mounted external to the sphere and view the exit port. This cell will continuously monitor changes in the spectral radiance at the exit port. NIST staff is prepared help develop the appropriate diode packages and maintain their calibration over the period of the experiment.

4. AVHRR Calibration

The AVHRR should be calibrated as close to the time of its use as possible. This will help ensure that the AVHRR has the optimal calibration at the time of launch. This procedure will not ensure that the AVHRR can make the same accuracy measurements at a later date due to changing environmental circumstance that can affect the optics and detection in space and during launch.

It is recommended that the AVHRR be calibrated several times before launch. This will establish a calibration history and base line. It will also set a limit as to the accuracy that can be achieved in the use of the instrument once launched. While the difficulty is recognized, it is recommended that NOAA at least consider developing a strategy for calibration checks or calibration while in space orbit. If a scenario for the present AVHRR cannot be developed which address this problem, the insights gained can be used for future design considerations.

NIST staff can participate in all the above suggested investigations and help develop a long term strategy and measurement assurance to help improve the accuracy of the AVHRR calibration and thereby the measurement quality of the returned data after launch.

APPENDIX D

Suggested responses to the workshop recommendations prepared by Peter Abel on 31 May 1990

The recommendations of the NOAA/NESDIS workshop on **radiometric calibration of satellite sensors of reflected solar radiation**, held in WWB on March 27-29, 1990, are as follows. Full details are in the workshop report.

I. The Working Group on Calibration Logistics (Chairman, W. Rossow, NASA/GISS). Assigned topics included requirements for interagency coordination of calibration methodology and results (NASA/GSFC, NASA/LaRC, NASA/GISS, NOAA/NESDIS, NOAA/ERL, DoD, DoE, NIST, Universities); guidelines for necessary documentation and publication of results; and defining, justifying and prioritizing realistic hardware accuracy and precision requirements;

Recommendation 1.1: **Establish clear requirements for calibration accuracy and delivery time [to the user community]**

Recommendation 1.2: **Implement an improved calibration monitoring system**

II. The Working Group on Calibration Accuracy (Chairman, R. Saunders, NIST). Assigned topics included characterization of the accuracy of the pre-launch and the various in-orbit calibration techniques, and estimation of the most likely pre-launch and in-orbit sensitivities for the Solar Channels of AVHRR and GOES.

Recommendation 2.1: **Implement the NIST recommendations for pre-launch calibration**

Recommendation 2.2: **Strengthen instrument specifications for characterizing pre-launch performance**

Recommendation 2.3: **Minimize susceptibility to in-orbit degradation through design changes**

The key recommendation (1.1) is for NOAA to clearly state what it wants, based on requirements in the literature. The other recommendations are logical inferences made by the workshop based on the workshop's understanding of the needs of the user community and the assumption that the workshop's understanding is at one with NOAA's.

The problem with (1.1) is that NOAA's official requirements as partially defined (for example) by the AVHRR instrument specification for reflected-solar channels are not entirely consistent with NOAA's real requirements as represented by the list of advertised applications of the data. The official (contractual) requirements for AVHRR are for an imager, but the real (applications) requirements are for a higher quality instrument known as a radiometer. As the applications for VHRR and AVHRR data have evolved over the past decades, the instrument performance specification has changed very little. This is, of course, a consequence of NOAA's decision to buy instruments in bulk to save money and avoid scheduling conflicts, and is largely unavoidable given NOAA's operational responsibilities. There is no perfect solution for this issue, but the best compromise clearly depends more on constituencies and cost than on science. The science issues are well defined and the possible technical solutions are well known and uncontroversial, but may have uncertain error budgets.

The task of estimating gains to be recommended to the user community, was extensively discussed. The workshop decided to indefinitely postpone action on this task, for the following reasons:

Successful completion requires a significant amount of research and a critical evaluation of data sets from different sources;

This workshop is unsuited to the task because of time constraints, the incompleteness of available data sets, and potential conflicts of interest due to loyalty to a particular method;

NOAA/NESDIS should take full responsibility for leading the task of organizing, gathering, analyzing and publishing in a timely manner all significant information on in-orbit calibration constants for all NOAA radiometers.

I suggest the following NOAA responses to the recommendations:

1. Commit to publishing a well-advertised, easily available, peer-reviewed annual report that for each instrument
    - States instrument performance and data accuracy and quality control specifications in force for that instrument;
    - Describes established quantitative applications for the data and states NOAA's understanding of the data accuracy and quality control requirements for each;
    - Gives complete in-orbit performance data and associated uncertainty budgets;
    - Compares actual performance with user requirements;
    - States NOAA's plans for bringing actual performance into agreement with user requirements.

2. Expand vicarious calibration activities at NESDIS:
   - Increase the number of U.S. stations in the pilot operational cloud-calibration program from 6 to the maximum (approximately 30);
   - Begin pilot operational programs in the use of deserts as calibration targets, using the extensive experience obtained at NASA/LaRC and NASA/GSFC;
   - Begin a pilot operational program using clear ocean atmospheres as calibration targets, following the work at NASA/GSFC;
   - Examine how the time resolution of inferred calibration changes may be improved (for example by increasing the rate at which data is collected from terrestrial targets);

3. Formally agree with other agencies and organizations to increased effort in vicarious calibration:
   - Contribute to the continued funding of calibration activities at NIST, Georgia Tech., the University of Arizona, Scripps Institution, and NASA;
   - Coordinate joint calibration measurement programs at times of particular interest to NOAA (for example, just after the launch of the next NOAA POES);
   - Continue to host an annual workshop on in-orbit calibration issues

4. Implement the NIST recommendations for pre-launch calibration of the AVHRR and the GOES imager. In summary, these are:

   - Conduct a detailed error analysis of the pre-launch calibration/AVHRR system;
   - Improve the sphere handling procedures and the frequency and procedures for sphere calibration;
   - Shorten the pre-launch calibration chain and add self-calibrating detectors to the sphere;
   - Calibrate several times, at regular intervals before launch

5. Involve the broadly-defined user community in the process of defining future instrument specifications, perhaps by mandating an open period for comment on preliminary published specifications.

6. Accept the argument that in-orbit calibration is the only method with the potential for fully satisfactory performance. Specify in-orbit calibration of reflected-solar channels for future radiometers.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Surveys, Mapping and Remote Sensing Sector
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Your file *Votre référence*

Our file *Notre référence*
IGBP

20 March 1990

Dr. Peter Abel
Physics Branch
NOAA/NESDIS (E/RA14)
WWB, Room 711
Washington, D.C. 20233

Dear Dr. Abel:

A special meeting on "AVHRR Data Processing and Compositing Methods" took place in Ottawa, Canada, March 12-14, 1990. The meeting was initiated by the International Geosphere-Biosphere Program (IGBP) Land Cover Change Steering Group and eighteen people attended (list attached). The impetus for this gathering was an urgent requirement to address issues regarding the standardization of AVHRR data processing and compositing methods. Numerous agencies in various countries are embarking on large-scale land cover change investigations based on AVHRR data and it is important to standardize the methodologies involved as much as possible as we work toward continental and global products. The preprocessing methods are critical because they provide the quantitative underpinnings that are necessary for remote sensing to play a strong role in long-term, interdisciplinary studies on regional and global scales.

A key aspect of AVHRR preprocessing is radiometric calibration of the individual channels and a particular problem is the post-launch calibration of channels 1 and 2. A variety of approaches are being used to monitor the observed degradation in sensor performance and several of these were outlined at the meeting by Christopher Brest (GISS) and myself. These methods take a lot of effort and, in most cases, have provided few updates for any given AVHRR sensor. Although they show comparable trends, the results from the different approaches are not often in close agreement. The IGBP and related investigators are looking for clear trends, either from one reliable approach or from a middle-of-the-road solution such as the one Brian Markham has proposed for the NOAA-9 AVHRR. Therefore, we are essentially looking for guidance from your forthcoming calibration meeting in Washington, D.C. on the selection of appropriate calibration coefficients for operational use.

There are two aspects to the operational use of calibration coefficients that should be noted. One is the calibration of retrospective AVHRR data based on the best available results over time for each instrument. The other is the need to extrapolate recent calibration results when processing current data on a near real-time basis. Hence, there is an interest in clear historical trends and a concern about the frequency of calibration updates. With regard to extrapolating calibration results, preliminary reports on the problems with the NOAA-11 AVHRR calibration are particularly worrisome for on-going processing of NOAA-11 data.

Your meeting at the end of the month will undoubtedly come up with many suggestions for courses of action. Nevertheless, a few of the ideas that were mentioned in our meeting are worth passing on to you. Wherever and whenever possible and appropriate, different post-launch calibration methods should be tried at a common site and/or on a common data set. Also, it would be of considerable interest and use to have a periodic calibration update bulletin of some kind for the key remote sensing systems of interest, including AVHRR. The bulletin should be relatively brief, very widely disseminated, and issued once or twice a year.

I have agreed to act as the point-of-contact for the IGBP Land Cover Change Steering Group regarding calibration issues. It is very frustrating that I cannot attend your meeting because of bureaucratic constraints newly imposed here. On behalf of all of the attendees at our AVHRR preprocessing and compositing meeting, I wish you all the best for a successful calibration meeting.

Sincerely,

Phil Teillet

Dr. Philippe M. Teillet
Senior Research Scientist
(613)952-2756 (Phone)
(613)952-9783 (FAX)

PMT/ak

Attendees

Special Meeting on AVHRR Data Preprocessing and Compositing Methods

12-14 March 1990
Ottawa, Ontario, Canada

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BREST, C., GISS, New York, N.Y., U.S.A.

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D'IORIO, M., CCRS, Ottawa, Ontario, Canada.

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NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

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The major components of NOAA regularly produce various types of scientific and technical information in the following kinds of publications:

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TECHNICAL SERVICE PUBLICATIONS—Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

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