AN OVERVIEW OF THE UARS DATA VALIDATION EFFORT

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UARS: An Introduction

1) Upper Atmosphere Research Satellite

- •) Launched Sept. 1991
- •) In planning and development stages since late 1970's
- •) Measures temperature, chemical species, winds, solar inputs

2) Similarities to EOS

- •) Data collected and processed at a Central Data Handling Facility.
- •) Data distributed via high speed network to Remote Analysis Computers at investigator sites
- •) Science Team (users) include instrument PIs and theoretical PIs.

3) Differences

- •) UARS is a one platform mission
- •) Highly focused on upper atmosphere research
- •) Quantitative global measurements of atmospheric parameters (as opposed to determination of spectral or spatial contrast, event counting, etc)
- •) No imagery

UARS Validation Chronology

1) Validation not recognized as a fundamental requirement at the outset of the program. (due to semantics, oversight??)

2) A series of events in 1988 focused the need:

   A) Within the UARS team it became apparent that some additional structure was required to unify;
      •) Calibration
      •) Algorithm verification
      •) Error analysis
      •) Correlative measurements
      •) A priori knowledge: (climatology, theory, modeling)

   B) The release of the Ozone Trends Panel Report

3) UARS Validation Working Group created 1989

4) Validation Plan completed 1991

5) Plan Implementation 1991-92

NASA Reference Publication 1208

1988

Present State of Knowledge of the Upper Atmosphere 1988: An Assessment Report

R. T. Watson and Ozone Trends Panel,
M. J. Prather and Ad Hoc Theory Panel,
and M. J. Kurylo and NASA Panel for Data Evaluation
NASA Office of Space Science and Applications
Washington, D.C.

NASA recognizes the need for timely international scientific assessments when important new information becomes available as has occurred since the last major international scientific assessment (WMO, 1986). Reports based on Nimbus 7 satellite Solar Backscatter Ultraviolet (SBUV) and Total Ozone Mapping Spectrometer (TOMS) data claimed that large global decreases have occurred since 1979 in the total column of ozone (about 1% per year) and in its concentration near 50 km altitude (about 3% per year). Data from the ground-based Dobson network also indicated that the total column content of ozone had decreased on a global scale significantly since 1979, although to a lesser extent than suggested by the satellite data. Further, there has been a significant amount of new research focussed on understanding the extent and cause of the depletion of ozone in the spring-time over the Antarctic.

NASA and the rest of the scientific community believed that it was imperative to evaluate whether the Nimbus 7 satellite data had been analyzed correctly, and if so, whether the reported decreases were due to natural causes such as a decrease in solar radiation (from solar maximum in 1979 to solar minimum in 1986), the 1982 volcanic eruption of El-Chichon, or the 1982 El-Nino event, or whether it was due to human activities such as the use of chlorofluorocarbons (CFCs). Therefore, during the fall of 1986 NASA decided to coordinate and cosponsor with the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization (WMO), and the United Nations Environmental Program (UNEP) a major review of all ground-based and satellite ozone data. A panel (the Ozone Trends Panel) composed of eminent scientists from federal agencies, research institutions, private industry, and universities was selected.

NASA
National Aeronautic and Space Administ
Scientific and Techi Information Divisior

Zen And The Art Of Data Validation (circa 1989)

1) What Is Data Validation?

A) What it is not.

i) Header information
ii) Flags marking data anomalies
iii) Limit checks
iv) Verifying that the software didn't bomb
v) Documentation

(These are all Quality Assurance Issues...Necessary but not Sufficient)

B) Also, What it is not: Comparing Profiles With Someone Else. *(A component but not an end in itself)*

C) What it might Be. *(The Process of Demonstrating that a Collection of Data Represents the Real Atmosphere Within a Quantifiable Uncertainty)*

D) What it always is.

i) Overlooked in program planning.
ii) Underestimated in terms of time, effort and resources required.
iii) The most frustrating part of the mission.

2) Why Is It Important?

UARS is not measuring <u>anything</u> for the <u>first</u> time. It is adding to a cumulative base of knowledge (in some cases, extensive) and therefore must be compatible with existing and future sources of information

Evolution of UARS Data Validation Plan

1) Identification of issues within the Validation Working Group.

2) Mandatory requirement that each investigation team prepare a plan for their activities.

3) Creation of a "Generic" plan outline.

4) Development of Investigator specific plan outlines.

5) Review of Investigator specific draft plans

6) Investigator specific final plans

7) Collection of all investigator plans into overall plan

Pre/Post Launch Validation Activities

1) Pre-launch:

A) Formulate Plans
B) Identify resource requirements
C) Begin development of tools and procedures

2) Post-launch:

A) Organize into issue/parameter specific Validation Sub-Groups
- •) Temperature/Pressure/Altitude registration
- •) Trace gas concentration
- •) Winds/Dynamics
- •) Solar Measurements
- •) Data gridding/mapping procedures
- •) Energetic Particles

B) Investigator teams work through their validation plans

C) Report findings

D) Take corrective actions as necessary (instrument operation, data processing)

GENERIC P.I. DATA VALIDATION PLAN OUTLINE

1.0 INTRODUCTION

1.1 Brief Experiment Overview, Including Measurements to be Validated and Altitude Ranges

1.2 Brief Validation Criteria

1.3 Validation Approach

- Approach to Level 1, 2, and 3 validation (e.g. validate most understood parameters first, e.g. temperature and least understood parameters last)

2.0 DESCRIPTION OF EXPERIMENT PHYSICAL MODEL

2.1 Instrument Concept and Basic Equations

2.2 Forward Radiance Model

- Radiative transfer
- Numerical approximations
- Physical constraints (e.g. line parameters summary, plus reference)

2.3 Inversion Approach

- Brief description of basic approach
- Constraint methods
- Numerical approximations
- Use of a priori information

3.0 DESCRIPTION OF INSTRUMENT CHARACTERIZATION AND CALIBRATION

3.1 Accuracy and Stability

- IFC, temperature effects, noise, scale, and bias error stability

3.2 Spectral Response and Registrations

3.3 Spatial Response

- FOV
- Off-axis rejection
- Crosstalk

3.4 Pointing

3.5 Electronics Response

- Amplitude and phase
- Crosstalk

3.6 Data System Errors

- Gain uncertainties
- Digitization errors

3.7 Summary of Uncertainties with References

4.0 ERROR ANALYSIS

4.1 Sensitivity to Errors in Instrument Model

4.2 Sensitivity to Errors in Forward Radiance Model

4.3 Sensitivity to Inversion Algorithm Errors, Including A Priori Assumptions

4.4 Spacecraft Effects

- Altitude
- Attitude rates
- Ephemeris

4.5 Uncertainties Due to Data Transmission (e.g. altitude Interpolation, True to Earth to IAU)

4.6 Estimate of Total Measurement Error

5.0 PRE-LAUNCH ACTIVITIES

5.1 Instrument P.I. Obligations

5.1.1 Define post-launch instrument verification procedures

5.1.2 Creation and comparison of Level 3AL data

- Sample test atmosphere for 3 days
- Synthesize radiances with production algorithm and add errors
- Perform retrievals
- Translate to standard latitudes for comparison

5.1.3 Identify and develop tools and methods which will expedite post-launch validation

5.2 Theoretical P.I. Support

- Contributions by theoretical P.I.'s that will aid data validation

6.0 POST-LAUNCH ACTIVITIES

6.1 Instrument P.I. Obligations

6.1.1 Implement instrument verification procedure

- Monitor calibration stability (e.g. scale factor, bias)
- Verify spectral registration
- Verify spatial response characteristics
- Evaluate correlation of instrument signals with orbital events such as (e.g. south Atlantic anomaly, other instrument turn-on events, terminator crossing)

6.1.2 Update error analysis as necessary

6.2 Theoretical P.I. Support

- Contributions by theoretical P.I.'s that will aid data validation

6.3 Intercomparisons

6.3.1 Guidelines

- Number of comparisons with correlative measurements, locations, times, coincidence criteria (time, space)

6.3.2 Climatology

6.3.3 Correlative measurements

6.3.4 Other UARS measurements

6.3.5 Theory and derived products

6.3.6. Targets of opportunity (e.g. ATLAS, NDSC)

7.0 IMPLEMENTATION

7.1 Detailed Schedule with Milestones

- Completion of on-orbit instrument verification in procedure plan
- Completion of on-orbit instrument verification in procedure plan
- Completion of initial on-orbit instrument verification procedures
- Validation of Level 1 products
- Validation of Level 2 products
- Validation of Level 3 products

7.2 Resource Requirements

- Personnel and equipment
- Funding
- Other

Lessons Learned
(Or Should Have Been)

1) Start Early: Should be part of initial program planning.

2) Put in adequate resources to support the goals
   •) If you want fast results, expect to pay
   •) If you want to save money, expect to wait

3) Maintain better coordination between Validation planning/implementation and Correlative Measurement programs. Make sure they really compliment each other.

4) Test correlative measurements data flow and validation procedures/tools well before launch.

5) Divide the work:
   •) Instrument PIs are often overworked before and immediately after launch.
   •) Theoretical PIs are often under-utilized during this period.

6) Learn from the successes and mistakes of others: Be willing to adapt as time goes along.

7) Be realistic: (HQ is much better at setting goals than in providing the means to reach them.)

Implications for EOS

1) Use UARS as a "Living Laboratory" in an attempt to identify:
   - •) what works
   - •) what doesn't
   - •) how to do it better
   - •) what is realistic

2) Make sure Correlative Measurement programs are planned with validation requirements in mind. Make sure they have appropriate resources, lead time and coordination with EOS.

3) Enlist the "user" community to lend a hand: How should the work be divided?

   A) Instrument Teams take the lead in:
   - •) Calibration
   - •) Error analysis
   - •) Level-1 data products
   - •) Level-2 data products

   B) EOS "Users" take the lead in:
   - •) Validation program planning
   - •) Working group coordination
   - •) Correlative measurement liaison
   - •) Level-3 data products

4) Validation activities continue for the life of the program
   - •) There is an initial large "impulse" of activities with each launch
   - •) There is an ongoing "maintenance" effort for the life of each instrument

Statistical Characterization Group

① Stats. that characterize key attributes of Individual Data Sets

- char. sample spacing (vector?)
- char. spacing vs. gradient of parameter value (vector?)
- measures of heterogeneity
- variance surfaces / spatial interpolation
- n-dim. space-time interpolation

② Ways to characterize the Comparisons Among Data Sets.

- differences & ratios of 2-D & higher fields.
- movements of boundaries (2-D & higher)
- changes in density & density gradient (2-D & higher).

③ Representation Issues (including visualization

④ Interpretation Issues (patterns & exceptions) [illegible]

EOS Project Science Office
Data Product Validation Policy

<u>D R A F T</u>
March 31, 1992

INTRODUCTION

EOS is a planned 15 year, multiple instrument/platform in the Mission to Planet Earth (MTPE) program designed to monitor changes in the earth system. Numerous users of EOS data will rely on accurate EOS data products to derive higher generation data products. These data products and the resulting scientific analyses will serve to guide environmental and economic policy. The scientific community will rely on the veracity of the data products developed in part because of our validation policy for those products, and in part on the basis of the scientific reputation of the investigators who are responsible for those products.

In past satellite-based scientific investigations, data product validation has encompassed: (1) quality control checks on raw data; (2) generation of community-consensus, peer-reviewed algorithms that transform the radiance or reflectance measurements obtained from sensors into geophysical variables; and, (3) comparison of data products derived from satellite measurements with data products independently derived through techniques from orbiting, airborne, and ground-based instruments.

REQUIREMENTS LEVIED BY THE 1988 EOS ANNOUNCEMENT OF OPPORTUNITY

Validation of the data products is established by comparing data products with measurement values acquired by conventional measurement and analysis approaches. This experiment validation must be included in the Calibration Plan provided in the proposed Instrument Investigation. The Data Product Validation Plan must define the correlative measurements and in-orbit calibration plan which establishes conformance to the EOS Project Data Product Validation strategy. The instrument observables usually will be interpreted as physical parameters, and are represented as data products. Validation of the data products is established by comparing data products with those acquired by conventional measurement, analysis, and other approaches.

Specifically, the Data Product Validation Plan at a minimum must include:

(1) A description of independent measurement and analysis approaches to be used in experiment validation and how the validation data products are to be compared to the instrument-derived data products.

(2) A description of how the calibrations of instruments used in the validation network will be compared to the calibration of the instruments in space.

(3) An estimate of the accuracy and precision required in the validation data products so that they will be useful for this investigation.

(4) An estimate of the frequency, duration, location, and any appropriate special observing conditions required for the data validation measurements.

(5) Description of EOS validation measurement programs and the relationship between EOS validation measurement requirements and supporting major

national and international science field measurement campaigns, such as FIFE, GEWEX, TOGA, etc.

EOS PROGRAM OFFICE DATA PRODUCTS VALIDATION DEFINITIONS AND POLICY

According to the EOS program office an EOS data product of level 1 to 4 is considered to be validated when several criteria are chronologically met by that particular data products. The raw level 0 data from which the level 1 to 4 data products are derived must first pass a series of automated quality control (QC) checks by the Distributed Active Archive Centers (DAACs) for bit errors and data dropouts. Level 0 data is then transformed to a level 1 data product using level 1 algorithms and calibration coefficients. The Level 1 algorithms must pass preflight algorithm validation review, as must the calibration techniques used to determine the calibration coefficients. Level 1 testing and algorithms must pass a Peer Calibration Review process.

This perspective for data product validation does not include the comparison of EOS derived data products with independently derived non-EOS data products obtained through truth co-located measurements. This omission does not imply that the EOS program (1) does not recognized the importance of these data verification activities; (2) anticipates that these verification activities will not take place; or, (3) does not encourage that these verification activities take place. In fact, campaigns to compare EOS data with truth co-located measurements are viewed by the EOS program office as an important vehicle in broadening the scientific community's interest in EOS. The main ramification of removing these activities from under the data product validation umbrella is that correlative measurement campaigns are not planned to be funded by the EOS program.

The EOS Program Office definition of data product validation forces instrument investigators to more fully understand their instruments and algorithms by placing more importance on preflight calibration and characterization tests that represent instrumental flight operations, instrumental mathematical models, and algorithm verification. It also prompts instrument investigators and data producers to examine more closely their criteria for either accepting or rejecting a particular data set.

EOS PROJECT SCIENCE OFFICE POLICY

While it is the policy of the EOS Project Science Office that the guidelines identified in the Announcement of Opportunity are still useful, there are few funds available to do more than verify--via peer-reviewed processes--the suitability of algorithms. A measurement-based algorithm verification process likely will be over a rather limited time frame and for a limited set of environmental conditions for most of the data products. Still to be determined is how to deal with short-comings in a given algorithm after its official acceptance, whether these short-comings are due to incomplete capture of knowledge or due to a change in environmental parameters.

EOS PROJECT SCIENCE OFFICE

CROSS-CALIBRATION PLAN

D R A F T
March 31, 1992

INTRODUCTION

Synergistic use of EOS data requires that instruments produce compatible measurements, even when several sensors/satellites are used. The Project must develop a technique that yields congruous Level 1 data products when the instruments are calibrated by the individual sensor builders. The approaches being developed to accomplish this are round-robin laboratory comparisons and exposure of instruments to a common source after final calibration but previous to sensor integration onto the flight platform.

In addition, there exists the perception that all instruments will degrade in orbit, each at its own characteristic rate. By knowing how the instruments compare on the ground before launch, the earliest in-orbit comparisons will assist in establishing how these instruments have changed during launch. The combination of the long-term data sets then can be used to improve our understanding of each of these data sets. Our primary approach to supplementing the individual instrument calibrations for accomplishing this requirement of EOS is described in the Cross-calibration Plan.

In some sense. absolute calibration is not required for this activity. In principle, stable and precise calibrations could be used to meet these objectives. Nevertheless, experience has demonstrated that absolute calibrations are the only reliable approaches for accomplishing stable and precise calibrations. Cross-calibration has been added to supplement instrument absolute calibrations as the approach to making congruent data sets.

Cross-calibration was made an EOS baseline requirement as defined in the 1988 Announcement of Opportunity (AO). Each Instrument Investigation is required to allow for such activities.

There are several pre-flight instrument calibration alternatives:

(1) Bring all instruments to a single facility where final radiometric and geometric calibration will be validated. This might provide the best calibration, but it could be very expensive and establish delays in getting the flight instruments delivered.

(2) Have a transportable system that will be carried to the location where the instruments are being calibrated. This transportable system would be used to validate the local

calibration system and assure more compatibility between systems. This offers many of the advantages of the first, and fewer of the disadvantages.

(3) Depend upon each instrument builder to provide the transfer of the calibration through analysis and testing traceable to NIST sources. This approach is now commonly used, and generally suffers from a lack of adequate documentation. The results depend very much upon the specific people performing the calibration and the project requirements.

From a logistical standpoint a single calibration facility or set of sources could lead to difficulties in launch scheduling. One cannot calibrate instruments until they have been built. Calibration is done as the last activity before shipping for integration. The use of a single set of sources or a single facility could lead to real difficulties in meeting the launch schedule. Cross-calibrations before instrument delivery also interfere with normal Project-contractor management interfaces.

Thermal detectors for satellite radiometry always should be calibrated in a vacuum. Therefore, vacuum calibration facilities should be the norm for calibration on most of the EOS instruments. Such a facility will need to accommodate any of the instruments, and certain benefits result if the facility is large enough to accommodate the entire EOS satellite. Sources for calibration will operate in a vacuum. The sources must be mounted precisely within the instrument field-of-view.

For EOS, a calibration scheme has been proposed that consists of several portable radiometers, each optimized for a certain spectral region. It is proposed that these radiometers be used in each instrument manufacturer's facility for comparison of the instrument calibration source scales. We refer to these as portable or traveling radiometers.

Great strides have been made in the past years in detector-based precision radiometry. For the visible portion of the spectrum quantum-response detectors are now available that have uncertainties on the order of 0.1%. There is a high probability that comparable accuracies can be achieved at wavelengths extending to 1500nm in the next several years. Thermal detectors operated at room temperature are accurate to 0.1% for high input power levels and 1% for lower power levels. Cryogenic radiometers are now available with uncertainties approaching 0.025% at modest power levels. This technology can be used directly in the construction of high-accuracy radiometric instruments or indirectly in the calibration of stable instruments. These technologies could be well-matched to verification of the manufacturer's calibration source scale.

There are pre-launch plans for the careful cross-calibration of the various laboratory sources using portable spectroradiometers and for a final cross-calibration of the instruments themselves at the spacecraft integration facility.

ROUND-ROBIN CROSS-CALIBRATION

During instrument construction, the prime means of comparison should be through the circulation of transfer radiometers. These would compare the working targets that are used in the calibration of individual instruments. The primary function of these detectors is to verify the calibration of sources that are used to calibrate EOS instruments with VIS/NIR channels (e.g., MODIS-N, ASTER, MISR). There is no perceived need for the circulation of standards for spectral or spatial calibration, as these topics can be handled through the use of standard procedures.

Radiometers used as transfer standard radiometers must be shown to be stable, and their use must be documented through an error budget analysis.

The AM Observatory is scheduled to be launched in June, 1998, and instruments will be delivered beginning two years before launch. The cross-calibration radiometers must be available by the summer of 1994 to support two years of testing before the instrument delivery.

CROSS-CALIBRATION AT INTEGRATOR'S SITE

The primary objective of the cross-calibration at the integrator's site is to determine the instrument-to-instrument bias when each instrument is looking at a well-controlled radiation field. This approach can establish the responsivitity of one instrument to another, but may not be useful in setting the absolute calibration scale of any one of them.

The EOS cross-comparison setup must accommodate a variety of instrument fields of view and aperture sizes, as well as operate over the full 0.4 µm to 15.4 µm waveband. Only radiometric comparisons will be made. Absolute calibration of the instruments shall be performed by the instrument builders prior to cross-comparison. The requirements for cold space view (i.e., 4K cold plate) are TBD for cross-comparison.

Cross-comparison will occur at the spacecraft integrator's site. The integrator must provide support for cross-comparisons in their integration and test flow procedures. It is not necessary to accomplish an observatory level (all instruments at once) cross-calibration, and most calibrations should be performed during thermal vacuum testing. The Panel recommendation that there be separate calibration sources for visible/near IR and thermal IR calibrations. For thermal IR the panel recommended a more extended source, not an integrating sphere.

Problems of cross-calibration at the spacecraft integrator's facility include tight schedules, difficulty in developing well-characterized targets of an appropriate common aperture, and the problem of controlling the setup and surroundings. There must be adequate time and facilities for detailed functional testing in thermal vacuum.

CONCLUSIONS

[TBD]