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Contents:

Traceability to SI for EO measurements

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Overview.
Over the last few years, a significant fraction of CEOS WGCVs meeting time has been taken up with the issue of "traceability to the SI system of units for Earth Observation (EO) measurements". This has culminated in two recommendations being endorsed by CEOS Plenary 14 held in Brazil in November 2000.

1/ All EO measurement systems should be verified traceable to SI units for all appropriate measurands.

2/ Pre-launch calibration should be performed using equipment and techniques that can be demonstrably traceable to and consistent with the SI system of units, and traceability should be maintained throughout the lifetime of the mission.

These recommendations in many ways follow closely those adopted by the 20^{th} General Conference of Poids et Mesures (CGPM) (the international body responsible for SI). This meeting concluded that "those responsible for studies of Earth resources, the environment, human well-being and related issues ensure that measurements made within their programmes are in terms of well-characterised SI units so that they are reliable in the long term, are comparable world-wide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Convention du Metrè."

This article summarises the background to these recommendations and presents an interpretation of their meaning, to encourage debate amongst Agencies and users of EO data, for measurands for which traceability to SI is comparably weak but feasible (e.g. spectral radiance, irradiance, reflectance etc), in the Ultra-Violet to Thermal Infrared spectral regions.

Terminology
In order to discuss the issue of traceability, it is essential that the metrological terminology is clearly and consistently defined. At present relatively common terms are frequently misinterpreted and misused when applied to metrology, causing lack of clarity and understanding. The following are formal, internationally agreed definitions [1] and it is recommended that they are adopted when writing and reviewing documents and articles for EO work.

SI units	- **The coherent system of units adopted and recommended by the General Conference of Weights and Measures (CGPM).**
Accuracy of measurement	- **Closeness of the agreement between the result of a measurement and a true value of the measurand.**
Precision	- **No metrological definition except to state that it should never be used in the context of accuracy and, because of possible confusion its use, should normally be avoided in metrological applications.**
Repeatability of results of measurements	- **Closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement.**
Reproducibility of results of measurements	- **Closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement.**
Uncertainty of measurement	- **Parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand**
Error of measurement	- **Result of a measurement minus a true value of the measurand**
Stability	- **Ability of a measuring instrument to maintain constant its metrological characteristics with time.**
Traceability	- **Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually through an unbroken chain of comparisons all having stated uncertainties.**

Of these definitions “traceability” is of particular relevance to this article and requires a clear unambiguous chain of calibrations back to the primary SI quantity with well defined uncertainties. The addition of the term “demonstrable” in the CEOS WGCV recommendation above requires that the chain can be audited, i.e. more is required than just a declaration of traceability.

Background

Over the last decade or so there has been a rapid increase in the range and scope of applications of EO data. These range from the improvement of maps, through to mineral resourcing, monitoring of agriculture for improving yield, and the assessment of taxes/subsidies, monitoring of indicators of climate change through to weather prediction etc. In many cases, the accuracy, traceability and quality assurance of the data is of secondary interest to the end user and thus is not always considered or documented in detail by the data provider. The user is more interested in general trends or higher level products such as: vegetation type, marine pollutants, algae etc, taking as read that the data provided will be of sufficient quality and accuracy for their needs. They are rarely interested in the detail of the primary quantities being measured such as spectral radiance or reflectance, and even less so in their associated uncertainty budgets and traceability. Only the data providers, the instrument builders and the closely associated primary science teams or major operational organisations such as the meteorological agencies, express any significant interest in such information. Only they express concern if the spectral radiance measured by the sensor has an accuracy of ±2 % or 5 %, whether this is pre-flight or maintained in-orbit, and to a lesser extent whether any of these values are reliable and consistent with those of other similar sensors flown by others. However, there are now growing expectations on the use of Earth Observation data to support key decisions by governments concerning the sustainable development and good stewardship of our environment. These may even involve legal proceedings to decide on compensation claims when environmental accidents occur or to determine compliance with internationally negotiated environmental treaties. This puts increasing demands on the scientific process to deliver information that can be proven to be reliable.

Need for Traceability

For example in determining climate change, the measurements made may need to record small changes (a few percent per decade) in key parameters and may be measurements extending over many years [2]. The reliable measurement of such small changes far exceeds the performance of any instrument in-flight today. Given the relatively short lifetime of most space-based instrumentation, the detection of such changes will require a long-time series of measurements using instruments flown on a series of satellites into the foreseeable future. Each instrument needs to be calibrated traceably against a standard which can be shown to be stable over the complete timescale. To ensure compatibility with other instrumentation and measurements this standard needs to be internationally recognised with a defined accuracy, and measurements made with reference to it must also be shown to be reliable. One way of achieving this would be to develop a closer working relationship between instrument builders, funding agencies, end users, and those agencies responsible for developing and maintaining international metrology standards - the national metrology institutes (NMIs). Such a relationship if sustained, would benefit all stages of an EO missions life, i.e. from concept through to post-flight calibration and operation.

Any increased involvement of NMIs would complement that of already established calibration teams situated within companies, organisations and academia but more to add value to those teams. NMI involvement could include independent peer review of calibration and measurement strategies, ensuring consistent representation of data and treatment of uncertainties and take up of new technologies and concepts, provision of advice on measurement protocols, and techniques and the organisation of comparisons etc.

The following example presented by Michael Weinreb of NOAA at the CEOS WGCV 17 meeting in November 2000 [3], demonstrates how without fully documented traceable measurements of all sub-systems, can lead to fairly severe consequences.

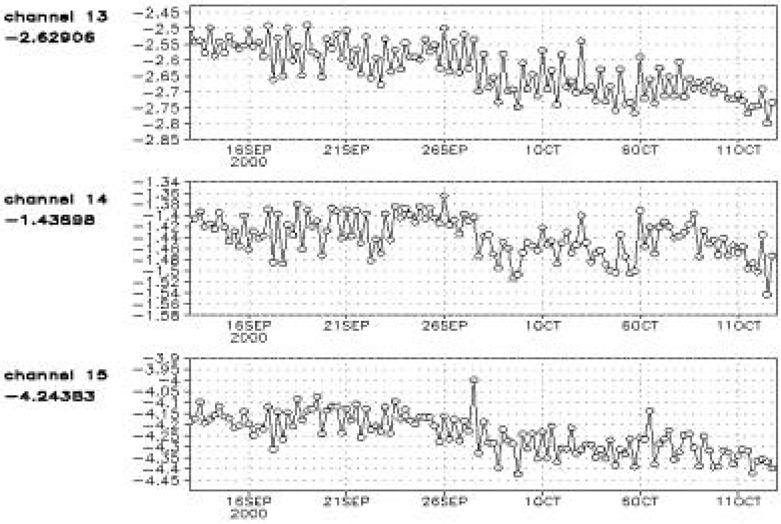

Figure 1. On-Orbit discrepancies between observed and calculated brightness temperatures for HIRS on NOAA-14. Channel 15 is in error by more than 4 K.

Figure 1 [4] shows the on-orbit differences of observed to calculated brightness temperature for channels 13 to15 of HIRS on NOAA-14, channel 15 having a difference of more than 4 K. The discrepancy is similar for the same channel on GOES 8 and all HIRS on previous NOAA flights. The reason for the discrepancies is not as yet explained but an indication may become apparent when one looks at the calibration procedures more closely. In terms of traceability, the instrument is calibrated in the conventional way by viewing a black body target and so is unlikely to introduce an offset/error which is spectrally dependent. It is not uncommon for changes to occur within an instrument on transit from ground to orbit. However, for this to be so reproducible between different instruments is relatively unusual and suggests that the offset is unlikely to be mechanical in nature or caused by the detector, since this is similar to those used on other channels. This leaves the spectral defining filter. It is relatively easy to show that a wavelength offset of 1 cm^{-1} in the value assigned to the filters spectral transmission profile is equivalent to around 0.9 K when used to calculate brightness temperature. Results from further analysis by the organisation performing the calibration of spectral transmission profile indicate that there may have been some errors in the calibration procedures which could account for a wavelength shift of around 4.5 cm^{-1} (approx 5 K) see Figure 2. In particular the temperature of the filter during calibration was different to that when used in-orbit and this (as is well known) is likely to cause a shift in the position of the transmission peak. Although this would not fully explain the differences observed in this particular channel (although it may be the cause of errors in channels 13 and 14) it is perhaps indicative of the type of error that may be responsible. Another possibility is that the filters transmission profile simply moved on transit to orbit. Whilst highly plausible technically such an effect should have been identified during pre-flight tests.

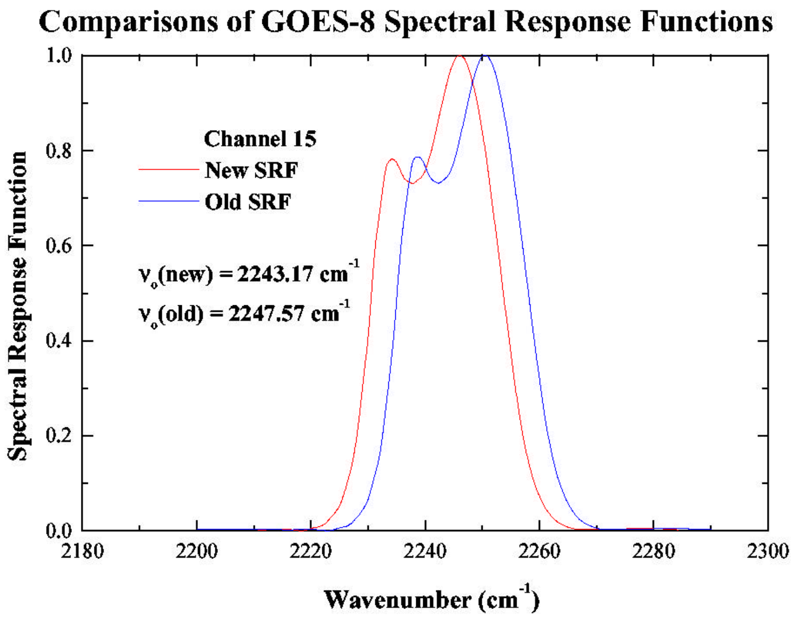

Figure 2: Showing correction in spectral response function of filter used in channel 15 of GOES 8 as identified by the calibration laboratory.

It is of course arguable as to whether this situation would have been prevented even if more rigorous traceability systems were in place. However, if there had been an intercomparison of the measurement procedure (which will be the case in the future) with an independent body like NIST, then it seems likely that the possibility of such an error would have been identified earlier.

Many of the active members of CEOS WGCV recognise the need for improved traceability and support greater involvement of NMIs, but they also recognise that it must be driven by user demand for improved Quality Assurance and by Space Agencies and other funding bodies for full demonstrable traceability for appropriate measurands. NMIs also have to develop an understanding and interest in the specific issues of importance to the EO community.

Current demand for traceability in the pre-launch and post launch phases

The product requirements emanating from EO data users are translated into the sensor domain by a team of instrument scientists and product developers. In a few instances NMIs already play an important role at this stage. Some of the traceability issues that should be addressed at the pre-launch stage and would benefit from greater involvement of the NMIs as expressed by a major user are:

- Radiometric characteristics of the sources of calibration e.g., lamp illuminated integrating sphere sources, thermal “black body” radiation sources (particularly the route of traceability for the radiometric quantities in the IR);
- Stability characteristics of optical components, detectors, mirrors, filters, optical coatings etc as a function of expected environmental conditions both on ground and in-orbit as well as normal operation;
- Characterization of the way in which instruments respond to radiant flux as a function of location, polarization, temporal domain, temperature of the detector, local environment and amount of flux (linearity);
- Establishment of rigorous procedures for pre-launch calibration to ensure the accuracy of calibration based on instrument and sub-system characterization, and the traceability of the same to SI units;
- Review of concepts and input to the design of on board calibrators where proposed; and
- A reasonable, reliable evaluation of the extent to which the results of the above could be used to evaluate the satellite sensor performance in orbit.

While pre-launch activities help in evaluating the extent to which the instrument meets specifications, it is in the post-launch environment that the issue of traceability to SI units becomes critical. This is particularly so for the post-launch calibration of satellite sensors in the visible and near-infrared where effective vicarious techniques have been developed. Estimates of attainable accuracy in the derived radiances vary from about 5 to 10 %, with appropriate atmospheric corrections. Since the user community has expressed a keen need for satellite radiation measurements with higher accuracy, the issue of on board calibrators is raised often. This leads to the very often asked questions;

- What is the attainable accuracy of radiation measurements in the visible and near-infrared with on board calibrators?
- What is attainable through vicarious techniques?
- Are the results from on-board and vicarious techniques in agreement?

This article does not attempt to answer any of these questions but more to ask the additional question – **Will we ever be able to reliably answer these questions?**

The only way to answer this last question in the affirmative is to ensure that all measurements are made traceable to SI and have reliable estimates of their uncertainty; without this it is impossible to compare with any meaning the results and performance of different research groups, techniques, instruments and calibration sites. In this context it is important to note that this includes not only the pre-flight activities described above, but also all the equipment associated with ground calibrations and validations throughout the life of a mission (which may exceed any one satellites lifetime). These include the field spectro-radiometers both portable and site-based, aircraft spectro-radiometers, sun-photometers, ocean buoys etc. These support instruments need to have associated with them, and consequently the measurements they make, well documented, auditable traceability chains demonstrating the uncertainty of the measurements made. This does not mean that each instrument must go to a NMI for calibration, but it should mean that each instrument has been calibrated by an organisation using a procedure that has in some way been audited by a NMI. This audit could take a number of forms but is likely to include a direct bilateral comparison or participation in some more formal intercomparison or round-robin exercise. It is unsatisfactory for users to rely solely upon a manufacturers data sheet or even a calibration certificate without clear demonstrable evidence that the calibration has independent verification of its uncertainty statement. There are many examples of organisations using transfer standards originating from NMIs, but underestimate the size of their uncertainties in making follow-on measurements and thus inadvertently passing on inadequately calibrated equipment to their customers whilst still claiming “traceability”. This practise causes confusion to the end user and also unfairly bias against those organisations which carry out their procedures with greater rigour.

It is of course important to emphasise that even if full traceability for these quantities is achieved, there are many additional sources of uncertainty which will effect the final accuracy of the users higher level data products, e.g. atmospheric correction. However, whilst traceability to SI will not immediately solve these problems or necessarily improve the conversion algorithms from radiances to “leaf index”, without it, it becomes meaningless to try.

Current best practice

Whereas there are a number of historical examples of space-borne EO missions with less than satisfactory accuracy, calibration, consistency and stability of the higher level data products (representing geophysical variables), in recent years several Space Agencies have responded to the more stringent requirements in this respect. Pathfinder projects were launched to improve the long-term historical time series and satellites with well defined calibration were launched. A striking example of the reliability of these procedures was the seamless transition from ESA 's ERS-1 to ERS-2 operation in terms of radar image calibration (level-1) and wind/wave products (level-2). This practise will be continued for the upcoming Envisat mission and demonstrates that in general this region of the electro-magnetic spectrum is reasonably well developed (at least in terms of calibration). NASA also has put great emphasis on calibration during the development of its SeaWiFS and EOS programs. In the latter case, the emphasis stems in part from the need of users to know the accuracy of data that will be used in combination derived from some dozens of instruments located on several different platforms. With the establishment of thematic global programmes like “Ocean colour” and “Mission to planet Earth” NASA has developed a new strategy for ensuring the quality of EO data. This strategy was designed to improve the rigour of calibration and accuracy claims for the instrument, and calibration teams and facilities involved in the support of missions like SeaWiFS and Terra. NASA engaged the support of NIST, the US NMI to work with it and the instrument teams to select a consistent and appropriate method of assessing and presenting uncertainties to be adopted for these missions. They also developed dedicated transfer standards in order to carry out "round-robin" comparisons between the various instrument calibration teams, both within the US and elsewhere, so as to ensure equivalence. As a result of these activities NASA now has a higher level of confidence in the likely performance of the instruments.

The accuracy, calibration, consistency and stability requirements of such missions were and will be achieved partly in collaboration with NMIs and involved "round-robin" campaigns with secondary standards to achieve inter-agency consistency. However, although relatively large, these are fairly specific missions and in general the direct involvement of NMIs is fairly rare, and, similarly, inter-agency and inter-team comparisons are not often carried out. This may be as a result of timing difficulties, or lack of perceived value.

During the development phase of a project the Agencies are usually the consumers buying components, subsystems or complete satellites with payloads. Sometimes Agencies involve NMIs at this stage to ensure the quality of these elements.

During the operational phase of the mission the Space Agencies appear as the data providers and the "user community" represents the consumers. It is the consumer interest that is served by knowledge about the quality of EO data and products. This knowledge is generated by co-operation between several groups, including the Agencies themselves, qualified users who understand instrument characterisation and calibration, existing standards organisations, commercial calibration laboratories, accreditation laboratories, instrument test facilities and university groups. The decision to involve the NMIs in this phase should be made by the user community and should be derived from the data quality requirements of the relevant data products.

Traceability to SI and the Mutual Recognition Arrangement (MRA)

In October 1999 Directors of the NMIs of 38 states which are signatories of the convention of the metre agreed to a new arrangement under which calibration certificates and measurements made in one country would be automatically accepted in another, without the need for individual bilateral agreements. This arrangement is the Mutual Recognition Arrangement (MRA) [5]. It operates through comparisons organised by the consultative committees of the Comite International des Poids et Mesures (CIPM).

The most important of these are the so called "Key Comparisons" of the most basic quantities associated with each SI base unit (generally <10 for each SI unit) and involve a sub-set of NMIs which have a proven historical record of research activity in the technical area, and which also geographically cover the globe. The results of these Key Comparisons establish the level of equivalence between NMIs for the specific quantities being compared. This is followed by a series of geographically regional comparisons of the same quantity to bring all the other NMIs into the system. The results of all the comparisons, together with the level of equivalence between each laboratory are then entered on to a database and available to all via the WWW. This process then ensures that all calibrations performed within any country can be compared to those in any other providing that appropriate checks are made on the secondary laboratories. This process is illustrated below in Figure 3.

A long term goal for the EO community might be to establish a similar database of EO related quantities populated by information from the calibration teams of the world about their measurement capabilities but with the quality of the data underwritten by comparisons/audits organised by NMIs. (In essence, an enhancement of the NASA calibration/validation dossier). Such information could then be reliably used to compare results made with different instruments or at different calibration sites, allowing the user to easily remove calibration offsets without having to debate which is the "correct" answer.

Future

It is important for the operational Agencies and other users to see clear demonstration that traceability will lead to the improved assessment of the accuracy of radiance determinations. The use of retrievable, SI traceable spectroradiometers mounted on aircraft and space-borne platforms such as the International Space Station offer great potential in this context. Instruments can be calibrated before and after each field campaign in laboratories that maintain traceability to a NMI. The SI-traceable, retrievable instruments can then be used to determine the radiance that should be measured by the satellite radiometers during under or over flights under congruent path conditions. This, together with an appropriate and well understood atmospheric model will serve to calibrate the satellite instrument absolutely in the absence of on-board calibrators, or to monitor the performance of the on-board calibrators when they are present. There are instances when this method has been used to characterise a satellite instrument, but they have been more of an exception than the rule.

The following schematic shows how such a traceability strategy might be established within a geographical region. The NMIs serving that region would then compare with those serving other regions to ensure global consistency.

Conclusion
The adoption by CEOS plenary of the recommendations of CEOS WGCV on traceability to SI is an important step towards the availability of reliable high quality EO data. However, it is only if the respective Space Agencies implement the full meaning of these recommendations and together with: user groups, national and international operational agencies and organisations, seek to encourage that all measurements in support of EO are fully traceable, will significant progress be made.

References

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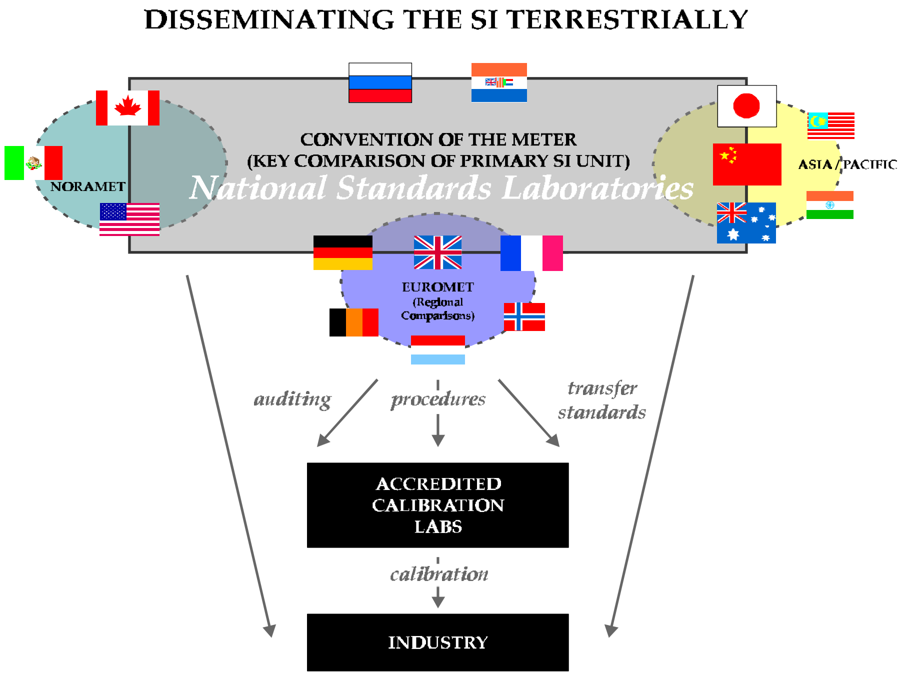

Figure. 3. Typical terrestrial traceability chain for SI units. A group of NMIs carry out Key Comparisons of primary quantities such as spectral irradiance and then provide links to that comparison within regional groupings. Each NMI then provides traceability to its local industry either directly or through secondary accredited laboratories.

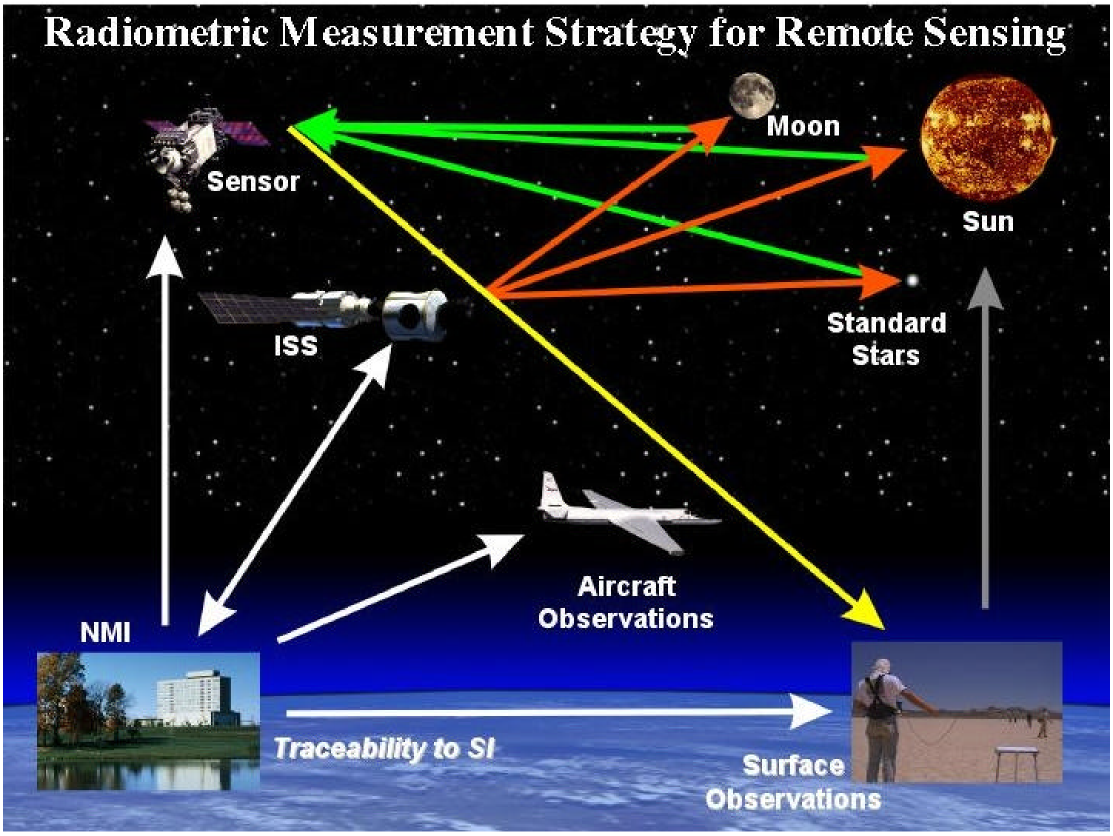

Figure 4. Reliable EO data can only be assured if all components of a measurement system can demonstrate traceability to SI. Even if intermediate sources such as the Sun or Moon are utilised for a particular instrument, to ensure these results can be compared to others, these sources must also be characterised in a fully traceable manner.

SAR Subgroup

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In the framework of the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation, a SAR Workshop jointly organized by ESA and CNES was held in Toulouse from 26th to 29th October 1999. The meeting was hosted by the Radar Systems Department of CNES.

The workshop, attended by 180 participants from 17 countries, was organised in the form of plenary sessions allowing 20 minutes for presentations and 5 minutes for questions. For the first time, a poster session was also organized. The programme content and preparation was supported by an International Technical committee composed of 36 experts representing the various disciplines.

A web site has also been prepared for the workshop and papers are available on-line at http://www.estec.esa.nl/CONFANNOUN/99b02.
A total of 120 presentations (65 orals and 55 posters) were given during the CEOS'99 meeting

Each workshop session was followed by a round table in order to allow further discussions on questions prepared by the session Chairs and rapporteurs, and on specific issues raised during the presentations. On the last day of the workshop, a session was organised to summarize the different sessions of the workshop and to draft recommendations for the CEOS WGCV.

The Workshop proceedings Reference ESA SP450 have been published in March 2000. The 730-page volume presents the workshop results in the form of full length papers, seed questions prepared for the round tables, sessions summary reports and finally all recommendations brought up to the CEOS WGCV. A synthesis of the discussions related to suggestions on the workshop format can also be found at the end of the proceedings.

The CEOS SAR workshop was more than ever the forum to interchange at the highest level of the SAR Systems Engineering field. We were able to discuss in depth key technical problems and to help better define future SAR instruments and their performances. These discussions confirmed that various technical issues remain to be solved and the SAR subgroup will continue to meet every year in order to address them. The next CEOS SAR subgroup meeting will be hosted in Japan by NASDA/EORC from the 2nd to 5th April 2001. Further information the CEOS SAR 2001 workshop can be found at http://www.eorc.nasda.go.jp/JERS-1/conference/ceos_sar/index.htm.

This meeting will also be an opportunity for me to hand over my current position as Chair of the CEOS SAR Subgroup. I look forward to our next meeting and to the continuing success of the CEOS SAR Subgroup.

Terrain Mapping Subgroup

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The activities of the sub group during the past year have concentrated on keeping abreast of current sensor development and validation activities. There has also been collaboration with ISPRS to produce a book on global data sets. The period culminated in a workshop meeting of the group held in Gaithersberg, Maryland on 23rd-24th October 2000.

Two important sensors have been launched during the past year. The first was the Shuttle Radar Topography Mission which successfully collected interferometric SAR data over the whole of the Earth's land surface between 60 N and 56 South. This data is now being processed to produce a Digital Elevation Model (DEM) with 1" spacing and accuracy of ±16m. The validation of this data is particularly important to the sub group, because of the immense value of the dataset and the problems posed in processing such a large data set to such high accuracy. The other sensor of interest is Aster on the Terra satellite, producing optical stereoscopic data. The commercial IKONOS sensor is also of interest to the group. A number of other sensors are being constructed, these include the Vegetation Canopy Lidar (VCL), ICESat and airborne sensors such as GeoSAR which will be valuable for validation of satellite products.

The workshop meeting was attended by 13 people representing many of the US agencies involved in generation and validation of DEMs. The new developments were discussed and the following issues were highlighted.

Specification of accuracy

A single figure is not adequate to specify accuracy over a heterogeneous area. Segmentation of the image would enable accuracy to be attributed to areas with different topography or landcover, but this information involves additional work and the information may not be available. There is a significant problem in knowing the accuracy of the reference data and the only data available may be worse than the new product. The presentation of data on accuracy and reliability was also discussed and it was agreed that visualisation of these parameters can greatly help understand the data. USGS demonstrated very good practice in generating accuracy data and presenting source information but this was given as text.

Test sites

The Terrain Mapping sub group produced a directory of test sites suitable for validating DEMs with accuracy in the 5-20m range, generated from sensors such as SPOT and ERS tandem data. These are not suitable for validating high resolution terrain information (HRTI) an much work is being done now with reference data generated from airborne IfSAR and LIDAR sensors. Test sites are now required which give high accuracy and which are covered by data from airborne sensors. Several sites were identified:

Morrison, Colorado established by USGS.
Kaintuck Hollow, Missouri, established by USGS.
Nevada, DoD/DoE
Costa Rica, established for VCL

Data from all of these is, or is expected to be, available for general use. It was recommended that the TM group should update the data base of test sites and use a format which is compatible with terrain information.

It was also recognised that there is a serious problem when validating DEMs in dealing with surface features. Traditionally a 'bald earth' DEM has been produced but optical sensors produce 'digital surface models (DSMs)' or reflective surfaces. IfSAR DEMs will include buildings but will penetrate the vegetation canopy to largely unknown amount. LIDAR on the other hand will produce both canopy and ground level. Processing algorithms will produce bald earth DEMs but often the reliability of these is unknown as assumptions are made about the height of the canopy and the surface beneath. Much more needs to be known about these processes.

There is a requirement for validation data beyond high resolution DEMs when validating global or continental data sets. Experience has been gained with using discrete check points, profiles collected by Kinematic Differential GPS, plane surfaces such as airports and sea surface. It was noted that a fully validated coastline would be very useful for future validation.

It was recommended that CEOS should promote the establishment of a global data base of control information. NOAA, NESDIS may be in a position to set up such a database.

The requirement for airborne data such as IfSAR and LIDAR suggests the need for CEOS members to be involved with the collection and archiving of airborne data and for the involvement of commercial companies who collect such data.

Tracability

The issue of tracability was discussed and the USGS products were noted to give very good information about the source of the data and its reliability.

Issues with new systems

The availability of IKONOS high resolution optical data is an important step forward for users requiring high resolution data. However its use for scientific work and validation is hampered by the lack of, sensor parameters, calibration data or of information on validation. Through its contacts with industry through its involvement with the setting up of an industry forum CEOS may be able to promote the use of a rigorous cal/val approach, as used with SRTM, for example, to all satellite operators.

Other issues

A number of other issues were discussed:

- A standard format for sensor parameters should be established. The SPICE format used for extra terrestrial missions was a good example of what is needed for Earth observing systems/
- CEOS should promote the use of validation data sets and provide information on those which exist.
- CEOS should collaborate with other bodies such as ISPRS.

Conclusion

Terrain mapping is an essential requirement for processing many types of data and the validation of such data is important. The complexity of sensors and the processing of the data make the necessity for accurate reference data critical. There is an urgent need to increase the number of data sets available for validation and the for the promotion of validation processes using all available sources.

Summary of recommendations

- Work is needed on presentation of accuracy information.
- Sub group to update directory of test sites.
- CEOS to encourage members to set up test sites and make information widely available.
- CEOS should encourage good cal/val practice by commercial operators.
- Standardisation of sensor parameters.
- CEOS to collaborate with other organisations such as ISPRS.

The CEOS Calibration/Validation Dossier: Recent Activities

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Since 1993, the CEOS Calibration/Validation (Cal/Val) Dossier has provided the international Earth remote sensing science community with a central repository for information on current and planned cal/val activities and a means to foster collaboration on common cal/val issues. In 1995, NASA's GSFC augmented information contained in a pilot version of the dossier produced by Smith System Engineering, Surrey, U.K and electronically archived all data. In 1999, additional work was performed to include new submitted information, update existing information, and improve the overall functionality of the dossier. This article describes work performed on the dossier in 1999 and 2000.

In 1999 and 2000, work was perfomed primarily in three areas of the cal/val dossier. These included data collection, database and interface design, and server functionality. Activities in these areas are described below.

Data Collection

The objectives of the work performed in this area were to solicit new information for the dossier and to update existing information in the dossier. The first step in accomplishing those objectives was to identify researchers who could provide relevant information to the dossier. The set of three questionnaires on calibration laboratories, test sites, and field instruments and the cover letter, which were initially formulated in 1995, were updated. As a parallel activity, a list of over 300 recipients of the cover letter and questionnaires was assembled primarily from the 1995 list, the CEOS Working Group for Calibration and Validation (WGCV) contact list, and the invitation list to the May 1999 Ispra meeting. In June 2000, the cover letter and questionnaires were sent by e-mail to the names on the master list.

Database and Interface Design

A significant amount of work was done in updating the dossier database and in improving the interface design. The dossier now is comprised of several tables into which is stored information obtained from the completed questionnaires. Information storage is accomplished using the Oracle Relational Database Management System. Tables are queried using a set of special functions via world wide web interfaces. Interface programs are written in PERL 5.0, while ORAPERL and DB programs are used to provide a web-oracle interface. The efficiency and speed of entering, accessing, and updating data in the dossier is significantly increased.

The interface design of the dossier includes the ability to access the Oracle database, to access information in the database, and to provide the web interface for user information and display of results. Interfaces to the Oracle database have been developed using ORAPERL and DB software packages. DB functions are used to validate general user access and to monitor authorized user access to the server. PERL programs are used to provide user functions such as accessing questionnaires, querying databases, and revising/updating information. Common library functions accessed using various PERL programs are used to protect the quality of the data and to notify the server administrator of errors. Lastly, the world wide web server on which the dossier resides uses an Apache http server and the Unix operating system on a Sun workstation. This server is available 24 hours a day, 7 days a week.

Server Functionality
Server access is largely unrestricted for submitting and browsing information in the dossier. Upon accessing the server, the system displays USERID=GUEST and PASSWORD=GUEST as the login for general users. Authorized users are required to enter their USERID and PASSWORD. A system of predefined access levels within the user categories are created based on the functions to be performed by specific users. For example, level 1 users are allowed to browse information in the dossier and submit information to the dossier. All general users are level 1 users. Level 2 users are authorized users, have level 1 access, and can update/revise information in the dossier and change user passwords. Level 3 are also authorized users, have super user access, can perform all level 1 and 2 functions, and can create users, change passwords, or other information in the database.

Current and Future Dossier Status
Of the more than 300 emails sent out containing the cover letter and three questionnaires, approximately 14 percent responded by completing one or several questionnaires. The distribution of e-mails went to more than 23 countries, and the number of responses from these countries are shown in Table 1. More than 50 percent of the total questionnaires were mailed to USA facilities and a similar percentage (i.e. 14 percent) of responses were received from the USA. All of the responses save one provided information using the on-line submit feature of the Cal/Val world wide web server. The responses provided information on a total of 65 Test Sites, 14 Laboratories, and 21 Instruments. Responses are still being received, and additional responses need to be and hopefully will be encouraged by the member institutions of the CEOS WGCV.

In September 2000, Lalit Wanchoo presented a paper on the “CEOS Database of World-wide Calibration Facilities and Validation Test Sites,” at the EOS/SPIE Symposium on Remote Sensing in Barcelona, Spain.

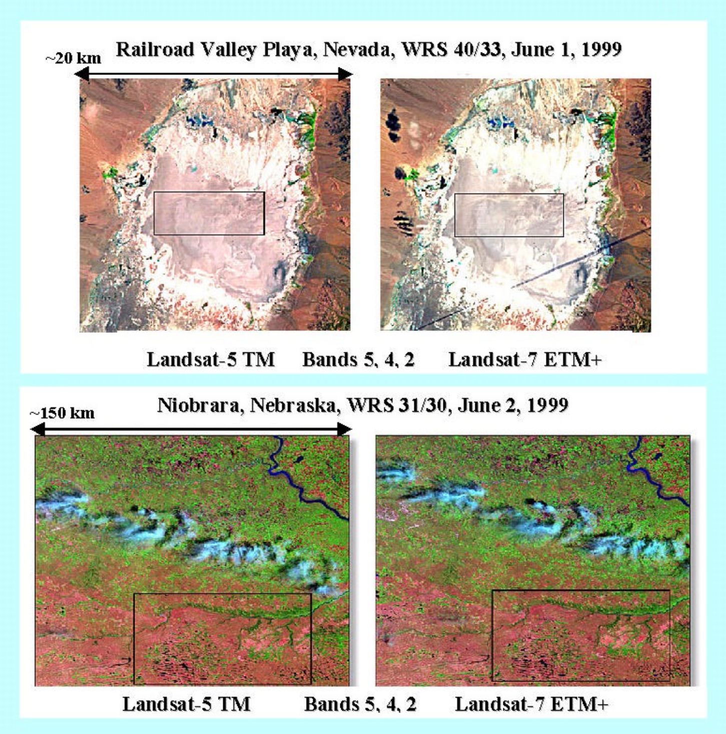
Country	Number Mailed	Responses Received
AUSTRALIA	8	5
JAPAN	11	2
BELIGIUM	1	
KENYA	1	
BRAZIL	2	1
MEXICO	1	
BRUSSELS	1	
NEW ZEALAND	2	1
CANADA	17	3
RUSSIA	7	
CHINA	10	1
SPAIN	1	
DENMARK	2	
SWEDAN	3	
FRANCE	14	
SWITZERLAND	5	2
GERMANY	15	
NETHERLANDS	2	1
INDIA	4	1
U.K.	26	
ISRAEL	1	
UKRAINE	2	
ITALY	9	1
USA	156	24
Total	303	42

Table 1: Distribution of Questionnaires to Various Countries World Wide received at end of September 2000.

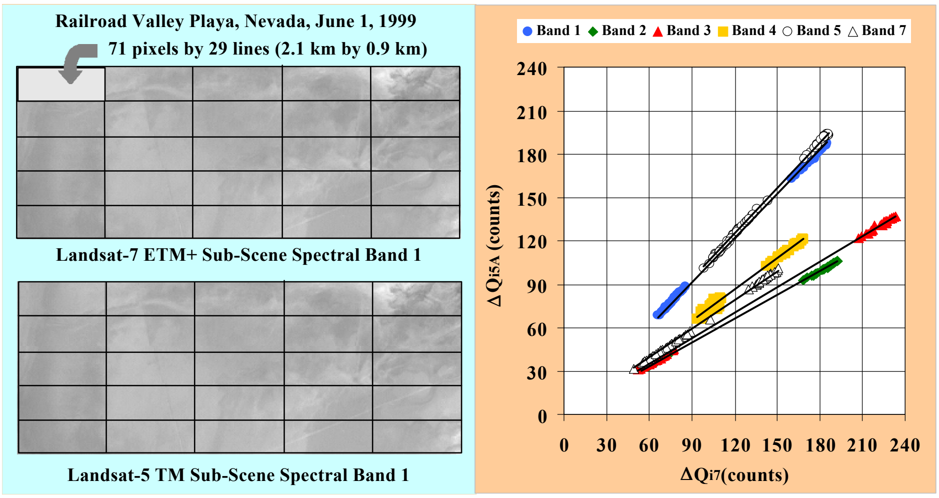
Radiometric Cross-Calibration of the Landsat-7 ETM+ and Landsat-5 TM Sensors Based on Tandem Data Sets

Overview of Methodology and Results of Radiometric Cross-Calibration Between Landsat-5 TM and Landsat-7 ETM+

A cross-calibration methodology has been formulated and implemented to use image pairs from the Landsat-7 / Landsat-5 tandem configuration period in early June 1999 to radiometrically calibrate the Landsat-5 Thematic Mapper (TM) with respect to the well-calibrated Landsat-7 Enhanced Thematic Mapper Plus (ETM+). Results have been obtained from a grid-cell analysis of two different tandem image pairs for which ground reference data are available (Railroad Valley Playa, Nevada and Niobrara, Nebraska). The methodology benefits considerably from the combination of darker and brighter sites for radiometric calibration. The use of large areas common to both the ETM+ and TM image data successfully avoided radiometric effects due to residual image misregistration. The most limiting factor in the cross-calibration approach is the need to adjust for spectral band differences between the two sensors, which requires knowledge about the spectral content of the scene. It was found that spectral band difference effects are more dependent on the surface reflectance spectrum than on atmospheric and illumination conditions. The cross-calibration approach applied to the two tandem image pairs yielded repeatable results (within 1.6 % on average) for TM responsivity coefficients in the six solar reflective bands. For spectral bands 1-4, the tandem cross-calibration results compare closely (within 1.4 % on average) to independent methods and results obtained by other groups. Additional work is needed to reduce the disagreement in results (11 % on average) from different groups for the two short wave infrared bands. The thermal band 6 has not been addressed in this work.



The long-term consistency of the Landsat data record relies heavily on the best efforts and co-operation of several agencies and universities for success. The user community deserves to have a consistent Landsat data record and the success of Landsat-7 is an opportunity to achieve this goal. The tandem cross-calibration approach provides a valuable “contemporary” calibration update for Landsat-5 TM based on the excellent radiometric performance of Landsat-7 ETM+. Once other, retrospective studies have been incorporated to establish a TM calibration record over its mission lifetime to date, an effort will have to be made to specify and implement algorithms for the proper calibration of archived raw TM data and, wherever possible, existing processed TM data sets.



The figure on the left illustrates the grid cell analysis scheme for the Railroad Valley Playa test site. The figure on the right plots grid-cell means for bias-corrected TM image counts adjusted for illumination and spectral band difference effects (DQi5A) versus bias-corrected ETM+ image counts (DQi7) for the two sub-scene pairs taken together. The lines are linear fits with zero-intercepts. TM responsivity Gi5 in spectral band i is given by Gi5 = Gi7 DQi5A / DQi7 , where Gi7 is ETM+ responsivity.

Spectral Band	1999 ETM+ Cross Calibration Gi5 (CPUR)	Prelaunch Laboratory Calibration Gi5 (CPUR)	Difference Relative to Prelaunch Gi5 (CPUR)
1	1.202	1.555	-23%
2	0.6540	0.786	-17%
3	0.8901	1.020	-13%
4	1.090	1.082	0.70%
5	7.929	7.875	0.69%
7	14.48	14.77	-1.9%

Gi5 = Landsat-5 TM responsivity in spectral band i in counts per unit radiance (CPUR), where radiance is in $W/(m^2\ sr\ \mu m)$. Responsivity coefficients from the tandem-based cross-calibration (using the Railroad Valley and Niobrara data sets taken together) are compared to prelaunch coefficients, where the percentage difference

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Publication:
P.M. Teillet, J.L. Barker, B.L. Markham, R.R. Irish, G. Fedosejevs, and J.C. Storey, “Radiometric Cross-Calibration of the Landsat-7 ETM+ and Landsat-5 TM Sensors Based on Tandem Data Sets”, in review, Remote Sensing of Environment, Special Issue on Landsat-7 Science.
Available from CCRS at: http://www.ccrs.nrcan.gc.ca/ccrs/eduref/ref/biblioe.html

Hand-Over of Chair to ESA

The Chair of the Working Group on Calibration and Validation was handed over to Yves-Louis Desnos of ESA at the conclusion of the 17th WGCV Plenary meeting at NIST in Gaithersburg at the end of October 2000. The hand-over marks the end of the chairmanship of Alan Belward (JRC-EC) and a period of intense debate and considerable achievement for the WGCV.

The issue that has aroused most discussion during the last 2 years concerns the merits of being able to trace EO measurements to an SI standard. The debate has centred around the way, and the extent to which traceability contributes to the improvement of the data and information (higher level products) derived from EO sensors, whether traceability is the best way to improve data quality and whether the extra effort and cost involved on the part of the agencies is merited by the likely benefits. The debate was illuminated at the 17th Plenary meeting by the participation of staff from NIST and the presentation of several case studies showing how traceability has contributed to data quality assurance. It has particular relevance to long time-series data where it is important to be able to merge data from different sensors and platforms into the same dataset. Time series data derived from Earth observation have in turn a high profile because of current concerns about climate change, as evidenced by the participation of CEOS at the Kyoto Protocol meetings. The debate about traceability has led to a cross-fertilisation of ideas and a much better understanding of the issues involved. Not least, it has resulted in the drafting of an agreed submission to CEOS Plenary setting out the considered view of the WGCV on the issue.

The period also saw the adoption by the WGCV of a new subgroup, the Land Products Validation (LPV) subgroup. The vision of the LPV stems from the need of users to understand the accuracy of the products they use and the fact that this understanding comes through validation of the products. There is currently a lack of expectation among users that they can make use of accuracy expressions because they have long been denied them. Therefore:

henceforward, all missions should have on-going validation based on standard packages
validation activities should be used to improve product generation algorithms iteratively
global change issues are vital, therefore a global validation strategy is required.

The GOFC will be the focus for LPV activities. The discussion preceding the adoption of the subgroup centred around 3 issues; whether the focus of the group was directed too much towards validation at the expense of calibration (since the consensus in WGCV is that the former is dependent on the latter); whether there was an unacceptable degree of overlap with the activities of the Infrared and Visible Optical Sensors subgroup, and whether it was appropriate to adopt a subgroup whose interests cut across the traditional WGCV subdivisions related to sensor type.

Other matters which have led to considerable discussion include the relationship of WGCV and CEOS Plenary and the outreach and educational responsibilities of the working group. The conclusions of these discussions are included in the WGCV Workplan for 2000-2002 available on the WGCV web site at http://wgcv.ceos.org.

We extend our appreciation to Alan Belward for his leadership of WGCV over the last 3 years. Many of the achievements that have been made are due to his hard work and vision. We extend a welcome to our new chair, Yves-Louis, and look forward to a continuing and growing contribution of calibration and validation to the quality and usefulness of Earth observation products.

FUTURE MEETINGS

WGCV18, at ESRIN, Frascati Italy, June 2001
Contact: Yves-Louis Desnos, WGCV Chair
Email: ydesnos@esrin.esa.it

Synthetic Aperture Radar

2-5 April 2001, Tokyo, Japan
See http://www.eorc.nasda.go.jp/JERS-1/conference/ceos_sar/index.htm.

General information on the WGCV, its subgroups and the previous issues of the WGCV Newsletter can be found at: http://wgcv.ceos.org

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