CEOS CAL/VAL NEWSLETTER Issue 4

Committee on Earth Observation Satellites
Working Group on Cal/Val

Contents:

CEOS WORKING GROUP ON CALIBRATION AND VALIDATION WGCV - STATUS REPORT

Dr S. M. Till (CCRS), Chair WGCV

The Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) ninth meeting was hosted by the Commonwealth Science and Industrial Research Organisation (CSIRO) at their Head Offices in Canberra, Australia from December 6-9, 1994. The meeting was chaired by Susan M. Till (CCRS). Members were present from Australia, Russia, Canada (CSA and CCRS), China, France, ESA, Germany, USA (NOAA, NASA, EROS Data Centre USGS), the Commission of European Communities (CEC), the International Geosphere Biosphere Programme (IGBP), Inter-governmental Oceanographic Commission/Global Ocean Observing System (IOC/GOOS), and Eumetsat. In addition the meeting was attended by the chairs of subgroups on Terrain Mapping, Microwave Sensors and Infrared and Visible Optical Sensors (IVOS).

Meetings of the subgroups on Terrain Mapping and IVOS were held on December 5 to 6, 1994 at the same location.

The major topics discussed at WGCV9 were:

a) the need for the creation of a new WGCV subgroup on atmospheric chemistry

b) the strategic long term plan for the WGCV and its subgroups

c) the production of the Cal/Val dossier.

Subgroup on Atmospheric Chemistry

The CEOS Plenary had discussed the need for a WGCV Subgroup on Atmospheric Chemistry. WGCV noted that both the IVOS and the Microwave Sensors subgroups were already responsible for the calibration of all the sensors that could be used for atmospheric chemistry, and for the validation of the data from these sensors. WGCV considered that the addition of a number of experts on atmospheric chemistry to both of these groups would be the best way to immediately address the calibration and validation issues for atmospheric chemistry. As a result, the chairs of the IVOS and Microwave sensors subgroups will identify atmospheric chemistry experts and invite them to their future meetings.

A recommendation will be made to the CEOS Plenary that a dedicated group on atmospheric chemistry should not be set up under WGCV and that the best way to approach the cal/val issues for atmospheric chemistry is to strengthen the existing subgroups.

Strategic Long Term Plan

The latest version of the WGCV Strategic Plan had been presented to the CEOS Plenary in September, 1994. Members of the group had provided input , and in particular J Sherman of NOAA was acknowledged, and thanked for his considerable efforts.

The WGCV9 meeting was the first opportunity for the whole WGCV to review the contents of the September 1994 version of the plan. Only minor changes to the plan were identified as being necessary. There was considerably more debate on the terminology definitions which are included as an annex to the plan. A small group was set up, to be led by W Planet of NOAA, to establish agreed definitions before the next meeting of the WGCV.

The WGCV Strategic Plan should allow excellent visibility into the objectives and actions of WGCV and its subgroups not only to the CEOS members but to the wider cal/val community.

Cal/Val Dossier

At the previous meeting (WGCV8), it was agreed that (in order to make progress towards the production of the cal/val dossier) a Statement of Work (SoW) for the preparation of the dossier would be generated. This SoW was completed by M Hutchins (on behalf of the BNSC) and was reviewed by WGCV. A number of principal changes were identified:

- the cal/val dossier should be a stand-alone document rather than part of one of the existing CEOS dossiers
- to limit the scope of the cal/val dossier it should predominantly include material spanning a ten year period - i.e. 5 years of historical data and 5 years of planned activities.
- in addition to being produced as a paper document the dossier should be produced in a database form with suitable database query tools
- the cal/val dossier should be produced in a suitable form for it to be included on the CEOS Infosys on the Internet World Wide Web.

Funding for the production has now been identified, and a production schedule was established at the meeting to ensure that the cal/val dossier is completed by the next CEOS Plenary.

The dossier should provide a source of detailed information on calibration and validation, including test sites and facilities, and should lead to increased cooperation and coordination in the international earth observation community.

Other Items

In addition to the usual business of the Working Group, there were presentations on the work of CSIRO and a visit to the Tidbinbilla Deep Space Tracking Station. This was followed by an excellent barbecue hosted by CSIRO at a nearby Wildlife Park.

The next Working Group meeting, WGCV10, is to be hosted by the Russian Space Agency and will be held in Moscow, Russia during the week 26-30 June 1995. WGCV11 is expected to be hosted by CNES in Toulouse, France, in February 1996.

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TERRAIN MAPPING SUBGROUP

Prof. Ian Dowman (email idowman@ps.ucl.ac.uk fax 44 71 380 0453)

The 4th meeting of the subgroup was held December 5-6, 1994 at CSIRO in Canberra, Australia. The meeting was a good opportunity to disseminate information about the work of the sub group to people in Australia and to investigate new test sites in the region.

A number of presentations were given on aspects of terrain mapping with an emphasis on work in Australia. Reports were also received of results of terrain mapping from JERS-1 OPS and SAR and from SIR-C. A comparison of DEMs from ERS-1 using InSAR and SPOT was reported and a comparative test of different stereomatching algorithms on SPOT data.

Adragna from CNES reported that when processing interferometric SAR, atmospheric conditions will affect the formation of the interferogram and that it was often difficult to distinguish between terrain effects and, for example, thick cloud. It appears that processing of InSAR to obtain an interferogram is becoming more sophisticated and that existing DEMs can be used to assist in this process.

A number of recurring themes are noted:

- increasing complexity of InSAR processing but significant robustness
- use of multiple images to improve interferogram
- increasing use of validation techniques based on theoretical modelling for differential InSAR.

The status of the test site dossier was reported. Information requested at the 3rd meeting has been received and the dossier updated with information provided on the following sites:

Kananaskis, Canada
Sudbury, Canada
Death Valley, U.S.A.
Drum Mountain, U.S.A.

It was reported that JPL are preparing a CD ROM of Death Valley but it was not confirmed that DEM data would be included.

Laurent Renouard reported that the Aix Marseilles data is now available on Exabyte and could be used by anyone signing the undertaking required by IGN. Anyone requiring the data set should contact Laurent Renouard at ISTAR on fax (33 93 95 83 29) or email (renouard@istar.fr).

The Drum Mountain USGS 3 arc second and 30m DEM data and the SPOT DEM produced by EROS Data Center is available via anonymous ftp. The address is edcftp.cr.usgs.gov and the directory is /pub/edcuser/gesch/drummtns. In that directory there is a README file which fully describes the available data sets. This ftp server is occasionally purged, so if the directory appears empty send an email to Dean Gesch at gesch@dg1.cr.usgs.gov.
The availability of data in Australia and Japan was reported. It is apparent that there is little DEM data with an accuracy suitable for validating DEMs from satellite sensors available. Most accessible data is derived from contours from 1:25 000 maps with vertical accuracy in the range 5 - 10m and with spacing of 200m or more.

The desirability of an Australian site was discussed. It was argued that algorithms could be tested on any site (e.g. Aix Marseille) and that this would be less expensive and allow comparison. On the other hand Australian users would like their data validated on Australian sites which had fairly unique vegetation. It was decided that further discussion should take place. Four possible sites were identified and people identified to collect more information.

For further information on the work of the sub-group contact:

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THE MICROWAVE SENSORS SUBGROUP

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The Microwave Sensors Subgroup (MSSG) held a successful two-day meeting on August 15 and 16, 1994, at the Jet Propulsion Laboratory, Pasadena, California. Dr Bill Wilson of JPL hosted the meeting.

Several interesting issues were discussed during the meeting, including:
(a) Expansion of the MSSG charter to include the (non-SAR) Active Sensors Cal/Val (real-aperture radar, altimeter, scatterometers, etc)
(b) Initiation of a project for studying the in-orbit monitoring of long-term calibration drift of passive microwave sensors with suitable surface "test sites" of known stable emissivity
(c) Concerns about the increasingly crowded spectrum and the "Sharing" of frequency allocations between the microwave remote sensing community and commercial users and the potential consequence of RF interference that may degrade the data quality, and
(d) Draft of Definitions of Specialised Terms frequently used by the MSSG.

Meeting attendees also reported on the status of major space sensor development projects, and plans for new sensors at NASA, ESA, NASDA, and the Chinese space community. The meeting ended with tours of the JPL's microwave calibration facility (used for SMMR and MSU), Aerojet Electro-System's Plant at Azusa, CA (AMSU-A Calibration facility) and the Hughes Space and Communication Company at El Segundo, CA (for the SSM/I and TMI).

In order to realise our goal of expanding the MSSG into the active sensors area, we would welcome new members/experts in this area to join our subgroup. People with interest and expertise in active sensors, e.g., the scatterometers, altimeters, and any hybrid type passive/active sensors are encouraged to participate in the MSSG activities.

The next MSSG meeting will be held on October 5 and 6, 1995. More details about the next meeting will be announced later. Please contact Jim Shiue with any questions or suggestions at the address below.

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X-SAR DATA PROCESSING AT DLR

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The Space Radar Laboratory (SRL) Missions

The SRL is a 3 frequency / multi polarization radar mounted on a space shuttle platform. The sensor system was developed and operated by NASA/JPL (US, L+C Band), DARA, DLR (Germany, X-Band), and ASI (Italy, X-Band). The goal of the project is to study the backscatter characteristics of 230 test sites under varying incidence angles, radar frequencies and polarizations. Today we look back on two most successful missions flown in April and October '94. In order to study seasonal changes the October flight essentially repeated the orbit of the April mission. The last 3 days, however, were dedicated to a 1 day repeat orbit for SAR interferometry.

The X-SAR Sensor

The X Band sensor operates at a frequency of 9.6 GHz at VV polarization. The passive antenna measures 12 x 0.4 m and is mounted on a structure tiltable to off-nadir angles between 15 and 55 degrees. The data is recorded on board at a rate of 45 MBit/s and partially downlinked via TDRSS. The X-SAR sensor offers a large number of modes which were extensively used during the missions:

Pulse bandwidth : 9.5 MHz or 19.0 MHz
Pulse repetition frequency: 1240 - 1860 Hz
Receiver gain range : 40 dB
Quantization : 4/4 Bit or 6/6 Bit, I/Q

X-SAR Data Processing at DLR
DLR took the task to process the X-SAR raw data to digital precision products, archive them and deliver copies to users. The available products are generated in CEOS format and called RAW (annotated sensor raw data), SSC (single look, slant range, complex), MGD (multi look, ground range, detected), GEC (geocoded, ellipsoid corrected) and GTC (geocoded, terrain corrected). If applicable, a high quality photo print can be ordered together with the digital data.

In order to perform this operational processing of SAR data a production chain was developed and implemented at DLR which generates standard image products on Exabyte cassettes from the sensor specific raw data tapes. Heart of the chain is the X-SAR precision processor. Within less than 30 minutes this processor computes a calibrated full resolution image which also meets the strong requirements for SAR interferometry.

Calibration and Image Quality

For the processor development it was a challenge to produce calibrated images from all possible sensor operation modes. This means to stabilise the gain of the total system sensor, viewing geometry and SAR processor.

During both missions DLR performed elaborate field calibration campaigns. 20 ground receivers were used to measure both azimuth and elevation antenna pattern and to verify the stability of the transmitted pulse power. The absolute calibration constant was derived by evaluation of 15 trihedral corner reflectors, the largest ones measuring 3 meters. Both, above measurements as well as the sensor internal calibration loops revealed a sensor stability easily meeting the requirements.

Additionally the results of the calibration efforts could be verified by the evaluation of rain forest data acquired under a wide range of incidence angles (25 - 61 degree), resolutions (9.5 / 19.0 MHz) and PRFs (1395 - 1736 Hz). All measurements made so far on point targets and rain forest show that X-SAR data are calibrated to within +/- 1dB.

The measured focusing capabilities of the sensor/processor system measured on the complex image are close to the theoretical limits:

resolution range/azimuth	: 1.04 /1.45 pixel
PSLR range / azimuth	: 13.3 / 15.6 dB
ISLR range / azimuth	: 9.8 / 12.7 dB

First Results from Advanced Applications

During both missions multi temporal and especially multi frequency/multi polarization composites were generated from the X/C/L band images at JPL and DLR which clearly showed the enormous classification potential of the SRL. During the second mission X-SAR interferograms of surprising quality both between the first and second mission (6 months separation) and between 2 days of the second mission were generated.

Data Distribution

After a short phase where the access is restricted to the principal investigators the X-SAR data will be available for anyone at costs covering only the media generation process.

Electronic catalogue systems (ISIS and GISIS) are currently being set up which will allow one to order data and to view quicklooks of the processed data and footprints of the unprocessed data via Internet or modem dialup. Up to date information can be requested via World Wide Web at http://129.247.162.47/welcome.html. The full resolution images are delivered to the user on Exabyte cassettes.

Summary

Despite the experimental character of the SRL mission, the acquired data proved to be a valuable source of high quality SAR data. Using data of different frequencies and polarizations will drastically improve image classification. The navigation and attitude system of the shuttle platform is so stable that the data can be processed without problems. SAR interferometry is possible even on the sensible X-band data.

References

submitted to the IEEE-TGARS special issue on SIR-C/X-SAR:
"X-SAR Interferometry: First Results", J. Moreira et al.
and"X-SAR Calibration and Data Quality", M. Zink, R. Bamler

THE ARCTIC LIDAR OBSERVATORY FOR MIDDLE ATMOSPHERIC RESEARCH (ALOMAR)

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The Arctic Lidar Observatory for Middle Atmospheric Research (ALOMAR) was officially opened on the island Andøya (69°30'N, 16°00'E) in Northern Norway in June 1994. ALOMAR is founded by the Norwegian Space Centre/Andøya Rocket Range and several international partners. The ALOMAR research facility is established as an international centre for studies of the high latitude middle atmosphere in the height range from 10 to 100 km. ALOMAR will serve as a research facility which provides simultaneous measurements of a wide range of important atmospheric parameters through the five lidar instruments, a VHF radar (the ALOMAR SOUSY Radar) and other related ground-based instruments. The large collection aperture (2 x

1.8 m diameter) and state-of-the-art lasers used in the lidar systems will provide very high spatial and temporal resolution at most altitudes. ALOMAR will through these instrumentation provide information on the dynamic and the photochemical processes of the middle atmosphere. ALOMAR will find its applications within:

- Ground based studies of atmospheric parameters
- Environmental monitoring through ozone studies
- Ground based studies of Ultraviolet radiation and biological effects
- Satellite calibration and validation
- Meteorology and atmospheric modelling

The ALOMAR facility may serve as a validation and calibration site and facility for various earth observation remote sensing sensors. Specific plans are already made to use the ALOMAR facility for the calibration of the Global Ozone Monitoring Experiment (GOME) sensor of the ERS-2 satellite, which is due for launch in April, 1995. The ALOMAR facilities may also serve as a validation and calibration site for other types of sensors where the atmosphere affects the remotely sensed signal measured by the sensor. The surrounding oceanic area is well suited for combined atmospheric and ocean surface observations. Optically this ocean region is of the so called Case 1 water type, where the phytoplankton pigments are the main optically predominant water constituent. Combined ALOMAR observations and ship observations of the marine physical, optical and biological conditions will be useful for the validation and calibration of earth observation sensors such as the US Sea Viewing Wide Field of View Sensor (SeaWiFS), the Japanese Ocean Colour and Temperature Sensor (OCTS) and the European Envisat sensors such as the Medium Resolution Imaging Spectrometer (MERIS), the Michelson Interferometric Passive Atmospheric Sounder (MIPAS) and the Global Ozone Monitoring by Occultation of Stars (GOMOS) sensor systems. These sensor systems are all due for launch within the next few years.

ALOMAR Science and Observations

ALOMAR is designed to perform studies of the stratosphere (15 - 50 km), the mesosphere (50 - 90 km) and the lower thermosphere (90 - 100 km). These regions are important for the energy and radiation balance of the Earth's atmosphere and for the development of the weather and climate, entities affected by natural and antrophogenic release of gases and aerosols. One example is the depletion of atmospheric ozone. Today more precise and extended measurements in the middle atmosphere are requested, in particular at high latitudes where changes introduced by antrophogenic releases have the largest amplitude. The high latitude location of ALOMAR is within the Arctic auroral zone and at the edge of the polar vortex. Furthermore its location at the Andøya Rocket Range, and near the EISCAT radar facility and the observatories of the University of Tromsø, will all facilitate the opportunity for integrated advanced scientific studies and environmental monitoring. This infrastructure will allow use of ALOMAR and other ground-based observations in combination with ship, satellite, sounding rocket, balloon and aircraft measurements. The long range airport located next to the Andøya Rocket range, facilitates the co-ordination between the ALOMAR measurements and execution of airborne campaigns.

Modes of Operation

ALOMAR has two different operational modes; continuous operations and campaign based operations. Continuous operations are used for monitoring and control which will provide important information about the long term atmospheric variations. ALOMAR can be operated in a semi-automatic mode in which instrument status and safety systems are monitored from a central operation room. This mode will minimise the requirements for scientific personnel during long term and climatological measurements. Campaign based observations from ALOMAR can be combined with measurements from ships, aircraft, balloons, sounding rockets and satellites to yield a detailed description of the atmosphere and earth environments over a time limited period. Satellite calibration and validation studies may be performed in campaign mode. Several parameters, typically ozone profile and aerosol densities, will be measured from the ALOMAR and surrounding systems and analysed together with satellite measurements. This activity is used to establish reference values for satellite instrumentation, on for example the ability to measure atmospheric parameters, as well as restitution of the earth surface signal, after "atmospheric correction" of the satellite data. Lidar observations depends on the cloud situation in the troposphere. Several years of lidar operation from And¿ya have shown that observations are feasible in average 30% of the time. For example in the winter of 1991/92 130 nights of observation gave 55 series high quality measurements.

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USE OF THE MOON FOR CALIBRATION

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An ubiquitous problem in remote sensing is the maintenance of calibration through the trauma of launch and over the life of the spacecraft. The responsivity of imaging instruments commonly changes substantially from the pre-launch calibration value, making in-flight calibration essential. The Moon is the only object accessible to terrestrial orbiting spacecraft that is within the dynamic range of most imaging instruments and is stable enough to provide a calibration target (Kieffer and Wildey, 1985). Although the Moon itself is extremely stable, its photometric properties are neither spatially uniform nor near to Lambertian, and it librates asynchronously with phase. Thus, the detailed illumination and observation geometry must be considered. Because the full Moon has abrupt edges against a negligible radiance background, lunar observations are also useful for characterisation of geometric response. At present, radiometric knowledge of the lunar brightness is on the order of 15% (e.g., Lane and Irvine, 1973), not adequate to provide good radiometric calibration. A ground-based telescope program is underway with the objective of determining lunar radiance with an accuracy of about 2% (Kieffer and Wildey, 1992, 1994; Wildey and Kieffer, 1993).

Nature of the Moon

The Moon has a radius of 1738 km and its average distance from the Earth is 384000 km. Expressed in terms normally used for spaceborne imaging instruments (footprint at nadir), when viewed by a satellite in a 705 km altitude orbit, the full Moon would have an apparent diameter of 6.5 km; an instrument with nominal 250 m resolution would see the Moon as being 26 pixels in diameter. To a geosynchronous satellite viewing the Moon past the Earth, it has an apparent diameter of 290 km.

The Moon is weakly colored, with reflectivity increasing smoothly from the visible (10% at 500 nm at 10^0 phase) to the near-infrared (25% at 2.5 m). Spectral reflectivity, normalised to 550 nanometer, varies about 10% over the face of the Moon, while reflectivity at 550 nm varies about a factor of 3. Because spectral features on the Moon are broad, the detailed solar spectral radiance features are incorporated into the calibration and allow accurate calibration in terms of reflectance. This is particularly helpful if small shifts in an instrument spectral passband occur. The Moon is not Lambertian, but brightens dramatically at small phase angles; this "opposition effect" increases up to the point where lunar eclipse begins. Current knowledge of the lunar photometric function is limited to a few wavelengths, for a few small areas or for the spatially integrated lunar brightness (the lunar irradiance). The lunar irradiance has small negative polarization at small phase angles, is approximately 0 at 24^0, and increases to about +8% at phase angles near 90^0. Because the Moon's surface can locally become as hot as 400K, thermal emission becomes significant at longer wavelengths, however its contribution is consistent from month to month.

Observations of the Moon will provide an excellent measure of scattered light sensitivity. This could be particularly important if contamination of optics might occur over the life of an instrument. For instruments for which the Moon's diameter subtends many pixels, an observation of the Moon is similar to a knife edge test being run in many directions, and the point spread function can be estimated.

The Moon is accessible to all spacecraft, from any nation. In addition to its utility as a calibration source, it can be used for cross-calibration between instruments that could not normally view the same scene near-simultaneously.

Earth-based Observing Program

The objective of the telescope program is to develop radiometric knowledge of the Moon adequate to support calibration of a variety of current and anticipated spacecraft imaging instruments. The specific goal is the development of a radiometric model at a number of wavelengths in the 0.4 to 2.5 um region with an angular resolution of 4.4 arc seconds (8.9 arc seconds beyond 1 um) covering the full range of lunar libration over all phase angles between eclipse and 90^0.

A dedicated observatory has been built at the USGS in Flagstaff with capabilities specifically designed for the lunar characterisation program. The facility is highly automated, so that efficient observation of the Moon and a plethora of standard stars can be carried out throughout every photometric night during the bright half of each month. A small (20 cm diameter) telescope, with minimum optics (primary and secondary mirror, bandpass filter, dewar window and detector; no flats or dichroics) is pointed alternately at the Moon and a set of standard and extinction stars. "Standard" stars are each viewed once each night; this provides a radiometric connection of the system to the stellar color/magnitude system. "Extinction" stars are each viewed many times each night over a range of elevation angles; this provides the correction for atmospheric extinction and the extrapolation to exo-atmospheric radiance. About 50 stars are viewed during a full night. An aperture stop that makes the telescope diffraction-limited to prevent image under-sampling is placed in front of the telescope when viewing the Moon.

Separate telescopes are used for the VNIR (0.35-1.0 um) region and SWIR (1.0-2.5 um) regions. The VNIR system is in place, utilising an astronomic-quality 512-pixel square silicon CCD and can accommodate up to 34 bandpass filters. Two sets of filters are currently in place; one set has pairs of filters in each of the conventional stellar photometry bands; the small wavelength offset between filters in each pair allows for precise stellar color correction. A second filter set approximates the passbands of several spacecraft instruments and is identical (same production run) as the filters in the Univ. of Arizona transfer radiometer (Bigger and Slater, 1993). The SWIR system is under design, is expected to utilise a 256 pixel square array, and is planned to be operational in about one year.

Connection to the laboratory radiance system is provided through two radiance sources. A large Spectralon flat inside the dome, illuminated by a 100 watt FEL lamp at a non-standard distance (3.4 m), can be viewed by the full-aperture telescope; the lamp enclosure is outside the dome to avoid scattered light. An all-Spectralon dual integrating sphere is placed outside the dome to be used with the lunar aperture stop in place. A set of precision apertures is placed between the main 15 cm sphere and the satellite 7.5 cm sphere which contains a 30 watt tungsten-halogen lamp. These sources will be visited periodically as part of the EOS "round-robin" radiometer activity, providing a direct connection to national standards. The sources will also be used for "flat-fielding" the arrays.

The lunar observations will be reduced to images of exo-atmospheric radiance, and then resampled onto a uniform selenographic grid which supports the highest resolution that the telescope program can attain. For each grid point and each pass band, the observations accumulated over time and representing a range of both libration and phase angle are reduced to a photometric model. Then, for a specific spacecraft observation of the Moon, the precise illumination and observation geometry is reproduced to interpolate the model and produce in each pass band a radiance image of the Moon with an angular resolution of 4 arc-seconds. This image can then be compared with the Level 1 product of the instrument observation (calibrated radiance) to quantify any discrepancy between the lunar and instrument calibration systems.

Telescope observations are planned to extend at least 4-1/2 years (one quarter of the lunar precession cycle) in order to cover nearly the full range of lunar libration. The lunar libration of approximately 7^0 in both latitude and longitude is about 7 times the radius of the Earth as seen from the Moon. This libration and the rotation of the Earth allow a single observatory to cover most of the selenographic directions that might be used for satellite observations.

Although thermal observations are not being made by this program, the wavelength range and angular coverage of solar reflectance measurements will allow good estimates of the bolometric albedo. Because the Moon is close to thermal equilibrium in the daytime, it may be possible to construct a thermal model of the Moon whose uncertainty is small enough to be beneficial in calibrating mid-infrared instruments. However, if the dynamic range of these instruments is set to the warmest surface temperatures on Earth (excluding volcanic areas) they will saturate near the sub-solar region of the Moon.

Spacecraft Observations

Spacecraft observations made anytime within one week of full moon will be supported by this program, but the Moon is brighter and more uniform near full moon. Phase angles less than 1.5^0 cannot be calibrated from Earth observations because of eclipse phenomena. Presently, published observations of lunar radiance can be used to estimate the signal levels expected as a function of phase angle.

Spacecraft observations which include all of the Moon will allow the most accurate analysis; a scan rate past the Moon should be no faster than normal nadir angular velocity; slower rates provide better statistics and yield an elongated image of the Moon. For example, for a spacecraft normally viewing nadir from 705 km, slewing across the Moon in 10 seconds would provide a nominal 250 m IFOV instrument about 5000 samples on the Moon, with a corresponding signal-to-noise improvement of about 70.
For low orbit nadir pointed spacecraft, a spacecraft attitude manoeuvre is required. The simplest is a "pitch hold" manoeuvre; when the Moon is in the extension of the spacecraft orbit plane, the spacecraft rotation rate is slowed to zero near the daytime equator crossing and held for one orbit. Lunar observation occurs when the spacecraft is over the night-side equator. Consideration must be given to the capability of the spacecraft to make such a manoeuvre safely, and for some instruments the thermal effect of the temporary absence of the terrestrial heat load may need to be considered. For geostationary satellites, the Moon will appear near the limb of the Earth during a 1-1/2 day period during one or two months near the spring and fall equinoxes.

Note: Readers familiar with any observing programs or spacecraft observations similar to those described here are asked to communicate with the author.

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BOREAS COMPLETED MAJOR FIELD CAMPAIGNS

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The Boreal Ecosystem-Atmosphere Study (BOREAS) is a large multidisciplinary study of the boreal forest-atmosphere system. Its primary goal is to improve our understanding of the interactions between the boreal forest and the atmosphere to clarify their roles in global change. BOREAS has two fundamental objectives: improvement of models which describe the exchanges of energy, water, heat, carbon and trace gases between the boreal forest and the atmosphere; and the development and testing of methods for applying the process models over large areas using remote sensing and integrative modelling techniques. As far as possible, the models should be based on remote sensing and meteorological input parameters.

Since the processes of mass and energy exchange between the forest and the atmosphere vary over a range of spatial and temporal scales a hierarchical, spatially and temporally integrated approach was adopted in the design of the project. It consists of background monitoring over three years with earth observation satellites and a network of automated meteorological stations distributed throughout the region; and a series of intensive field campaigns conducted at key periods during the annual growth cycle when a wide variety of measurements are made by atmospheric scientists, ecologists, hydrologists, biochemists, and remote sensing scientists. With the support of several U.S. and Canadian agencies led by NASA and CCRS, field preparations started in 1991. A 1000km x 1000km boreal region in Manitoba and Saskatchewan was selected for the study and two study sites (approximately 60km x 90km in size) near the extremes of the boreal forest belt were found: northern site west of Thompson, Manitoba, and southern site in the Prince Albert National Park - Candle Lake area in Saskatchewan. At each site, uniform stands representing principal ecosystem types in the region were selected based on cover type and stand age. In 1992, the BOREAS research team consisting of 80 Principal Investigators from the U.S., U.K., France and Canada was selected. Flux towers extending above the canopy and other supporting infrastructure were placed in each selected cover type in 1993, and a preliminary field campaign was carried out.

The major experimental data collection took place in 1994 during five field campaigns: cold; snow (February; hydrology and remote sensing of snow); snowmelt (April; remote sensing, hydrology, and trace gas measurements); and three growing season campaigns (May-June; July-August; September) with the full complement of measurements in the various disciplines. Instruments on nine flux towers were operated throughout the growing season.

The following satellite data were recorded by CCRS, most of them starting in early 1993: Landsat, SPOT, AVHRR (all passes), ERS-1, and JERS-1. GOES data were obtained by the University of Florida. The operation of SPOT-2 and -3 in 1994 was an added benefit, and both satellites were programmed to optimise coverage of the study sites and the BOREAS region. A complete set of airborne remote sensing data was obtained in 1994 (Table 1).

Special effort was made in data calibration. Overflights of ground reflectance targets and upward-looking atmospheric transmission measurements were made for optical airborne data and corner reflectors were deployed for airborne SAR flights. In addition, a set of automatic sunphotometers/radiometers was deployed throughout the year to obtain hourly visible and near infrared measurements to characterise aerosols, water vapour, etc. Airborne optical sensors were cross-calibrated by the use of an integrating sphere. Lake surface temperature data were collected for the calibration of thermal channels.

The calibration and processing of BOREAS data is underway. After calibration and quality checking is completed, the data will be placed in the BOREAS Information System and subsequently made available to the scientific community. The data set and early results are described in an upcoming publication (Sellers et al., 1995). The first special journal issue on BOREAS is planned for 1996.

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Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, J. den Hartog, J. Cihlar, M. Ryan, B. Goodison, P. Crill, J. Ranson, D. Lettenmeier, and D. Wickland, 1995. The Boreal Ecosystem-Atmosphere Study (BOREAS): an overview and early results from the 1994 field year. Bulletin of the American Meteorological Society. Accepted for publication.

CANADIAN OPTICAL CAL/VAL ACTIVITIES IN SUPPORT OF THE BOREAL ECOSYSTEM-ATMOSPHERE STUDY (BOREAS)

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Five major airborne field data collection campaigns for the BOREAS experiment were conducted between February and October 1994, focused at two boreal forest supersites in Canada (see Sellers et al. 1995 and companion article above by Cihlar). The two-fold objectives for the BOREAS data collection were:

(i) to advance boreal ecosystem science (i.e. to improve the understanding of the processes and states which govern the exchanges of energy, water, heat, carbon and trace gases between the boreal forest ecosystems and the atmosphere) and

(ii) to develop and validate remote sensing algorithms to transfer our understanding of these processes from local scales out to regional scales.

The latter objective coincides with the CEOS Cal/Val thrust; this report provides an outline of the Canadian optical airborne Cal/Val activities in the context of the entire BOREAS experiment. An array of airborne sensors were deployed specifically to address the need for Cal/Val of data products essential to BOREAS science goals as well as to provide the opportunity for algorithm development with application to specific advanced optical sensors: viz. AOCI & CASI for SeaWifs; MAS & AVIRIS for MODIS; ASAS & CASI for MISR; POLDER for POLDER; CASI for MERIS. The Canadian contribution to this airborne optical data set was with the York University-ISTS Compact Spectrographic Imager (CASI), which was deployed to BOREAS sites on all five 1994 field campaigns by ISTS in cooperation with the Ontario Provincial Remote Sensing Office (PRSO).

Radiometric calibration of an array of optical sensors in a multi-campaign field experiment required attention to issues of inter-sensor calibrations and temporal stability of each sensor's responsivity. Normal attention to these issues by individual experimenters was augmented by:
(i) pre-experiment intercomparisons of primary radiance standards between NASA(GSFC), JPL, and ISTS using a NASA integrating sphere radiance standard and radiometer that was transported to JPL and ISTS for this purpose, and
(ii) on-site availability of a NASA integrating sphere which facilitated field cross-calibrations of optical imaging sensors (ASAS, CASI, MAS, POLDER, TMS) during the primary 3 field campaigns.

For effective cross-sensor use by BOREAS scientists of Level 2b data products such as surface-leaving radiance or surface Bi-directional Reflectance Factor (BRF) attention was required to the data input needs for various atmospheric correction methods, as appropriate to the particular sensor altitudes and deployment configuration. To this end data are available from the BOREAS network of 8 ground-based sun photometers, augmented by 3 additional portable sun photometers brought by individual experimenters. Due to the large aerial extent of the BOREAS test areas, spatial variability of atmospheric optical properties may need to be assessed for some deployments and data from airborne sun-tracking sun photometers on the NASA C-130 and the NASA helicopter as well as downwelling spectral irradiance data collected in-flight with CASI are expected to be very important.

In addition to the above, some image data was collected over ground-characterised reflectance targets, a carefully prepared and maintained farmer's field for AVIRIS and for CASI, an asphalt tarmac and large canvas targets with reflectances between 5 and 33%. These measures are expected to yield accurate airborne optical Level 2b data over BOREAS test sites that will be important for algorithm development for data products at higher levels. The benefits will be significantly enhanced because the BOREAS airborne optical sensors will provide site specific measures of BRF at high spectral resolution (to 3nm, CASI), high spectral dimensionality (to 288 channels, CASI), broad spectral coverage (to 400 nm to 2500 nm, AVIRIS), angular detail (to +/- 70 degrees view angle, ASAS), and polarization character (POLDER).

Specific to the Canadian airborne optical Cal/Val contributions to BOREAS, it is useful to note that the York University/ISTS CASI was upgraded (Anger et al., 1994) prior to deployment at BOREAS. The most significant of the sensor upgrades were the installation of a CCD array with enhanced blue sensitivity, a new hyperspectral operating mode providing continuous image spatial sampling (over a reduced cross-track swath), and installation of a fibre in the sensor optical head to enable simultaneous collection of ancillary optical flux information. Irradiance probes were designed (at ISTS and U. de Sherbrooke) and installed in the roof and belly of the Piper Chieftain platform, coupled to optical fibres, permitting the CASI to sample upwelling and downwelling spectral irradiance in the same spectral bands as the radiance imagery. A swivel mounting apparatus for the CASI sensor head designed at ISTS provided the ability to collect multiple view imagery over the angular range +45 to -30 degrees. Therefore, the configuration of the CASI sensor deployed at BOREAS will provide site-specific BRF data at spatial resolutions typically 0.7 x 3 m, 2 x 4 m and 2 x 11 m, depending on the altitude and sensor operating mode. Most CASI spatial imagery was collected using a 15 channel bandset that closely mimicked proposed MERIS bands; centre wavelengths (and nominal bandwidths) were: 410 (10), 443 (10), 490 (10), 520 (10), 565 (10), 620 (10), 665 (10), 682 (5), 710 (5), 742 (5), 750 (10), 768 (10), 800 (10), 880 (15), 905 (15). Limited additional data was collected in the CASI full spectral mode (288 channels at 3 nm resolution) and in a new hyperspectral mode (72 channels at 8 nm resolution) using 404 cross-track spatial image elements. In addition, for low altitude CASI passes (at 150 m) over specific sites, data from the irradiance probes are being used to obtain surface spectral albedo between 400 and 900 nm, of interest in University of Florida validation of current algorithms for deriving surface albedo for BOREAS with GOES imagery.

Wide-ranging activities focused on algorithm development and validation of Level 2c and 2d data products are also being conducted through collaborations with BOREAS scientists from other agencies. For water targets, combined CASI (Piper Chieftain low altitude) and AOCI (ER-2 high altitude) data collections were carried out over BOREAS lakes along transects which were subjected to simultaneous in situ optical and constituent sampling by collaborating scientists; a primary objective is to evaluate SeaWifs algorithms for atmospheric correction to retrieve water-leaving radiances and SeaWifs algorithms to derive pigment and dissolved organic carbon levels in Case II waters. For forest canopy targets, the characterisation of the seasonal change in the bi-directional reflectance properties of specific boreal forest species has been obtained from multiple-view imagery using airborne sensors: CASI imagery at low altitude and ASAS imagery at high altitude. These airborne data, augmented by extensive on-site tower-based canopy BRF data collection with NASA's PARABOLA, and measurements by numerous BOREAS science teams of understorey reflectance, of needle reflectance and transmittance, of canopy branching structure and tree architecture will permit a critical evaluation of canopy BRF interpretation models. Validated BRF models are expected to improve the usefulness of vegetation indices and to allow forest stand characteristics to be derived from MODIS-N or MISR on the EOS platform. Other collaborators are validating algorithms which link optical airborne data to key forest ecosystem parameters: Leaf Area Index (LAI) and canopy Absorbed Photosynthetically Active Radiation (APAR) measured on site.

More than 228 hours of CASI data were collected on 36 days in 1994 for the BOREAS experiment. Calibration to radiance is currently underway at ISTS and conversion to estimated surface reflectance is planned in the coming weeks with delivery to the BOREAS information system at NASA called BORIS expected to follow shortly. In addition, a BOREAS Global Hypermedia Research Information System (B/GHRIS) is being developed at YorkU/ISTS to aid our BOREAS team collaborators in locating and sharing data and information pertaining to the optical Canadian remote sensing component of the BOREAS project. It uses the World Wide Web (WWW) client/server software to allow collaborators to search, browse and retrieve distributed network accessible documents. Radiometrically and/or spatially subsampled CASI images are provided for browsing directly at the collaborator's site. Other information describing the sensors, sensor deployment, flight-lines, calibration, field campaigns, field data, calendar of events, bibliography and more are all now available, on-line at URL http://www.eol.ists.ca/, providing up-to-date status to collaborators on CASI data processing and data delivery to BORIS.

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Sellers, P.J., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, J. den Hartog, J. Cihlar, M. Ryan, B. Goodison, P. Crill, J. Ranson, D. Lettenmaier and D. Wickland (1995). The Boreal Ecosystem-Atmosphere Study (BOREAS): an overview and early results from the 1994 field year, Bulletin American Meteorological Society (accepted).

CALIBRATION EQUATIONS FOR NOAA AVHRR VISIBLE AND NEAR-INFRARED CHANNELS

NOAA/NESDIS has finally published post-launch calibration equations which characterise the time dependence of the radiometric calibration of AVHRR channels 1 and 2 on the NOAA-7, NOAA-9, and NOAA-11 spacecraft. They are given in the following report:

"Post-Launch Calibration of the Visible and Near Infrared Channels of the Advanced Very High Resolution Radiometer on NOAA-7, -9, and -11 Spacecraft", C. R. Nagaraja Rao and Jianhua Chen, NOAA Technical Report NESDIS 78, Washington, D.C., August 1994.

To obtain a copy, contact:

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FUTURE MEETING DATES

WGCV10: 26-30 June, 1995, Moscow, Russia.
WGCV11: February 1996, Toulouse, France.

Microwave Sensors Subgroup: 5-6 October 1995, venue TBD.

Terrain Mapping: TBD

IVOS: Ocean colour meeting, 30 April to 1 May 1995, Best Western Hotel, Lanham, USA

REMINDER

Issue 5 of the WGCV Newsletter is intended to be completed in July 1995. Contributions for inclusion in the next issue should be submitted to the Newsletter editor Mark Hutchins preferably by email to M_S_Hutchins@scs.dra.hmg.gb or by fax. to +44 1252 522959 by 15 May 1995.

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Information is transmitted amongst the WGCV between meetings by electronic mail. If you have information on calibration and validation activities or meetings or missions please contact your country WGCV representative or the WGCV Chair (till@ccrs.emr.ca).

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