

Workshop

Production and Validation of DEMs and Terrain Parameters from Spaceborne Sensors

CEOS WGCV, ISPRS WGII/4, WGIII/6

University College London, May 26th - 28th

REPORT

Themes and organisation

This meeting was designed to bring together scientists working in the area of production and validation of land surface parameters from spaceborne sensors. There was a particular emphasis on the production and use of Digital Elevation Models (DEMs) in relation to validation of land parameters derived from the EOS mission. Participants were invited from the EOS land science teams and from the DEM community, represented by the WGCV Terrain Mapping Sub group, (TMSG). In addition two ISPRS working groups concerned with SAR were invited to contribute to the meeting.

Alan Belward, chair of CEOS WGCV, and Ian Dowman, chair of WGCV TMSG convened the meeting.

Objectives

- Identify existing validation activities relating to land surface related parameters (DEMs, fAPAR, LAI, Cover Maps).
- Identify the role of terrain models in validation of land surface related parameters.
- Identify gaps in collaborative activities related to calibration and validation for land surface related parameters.
- Develop validation protocols for land surface related parameters.
- Define a role for WGCV subgroups in validation.

Programme

The final programme is included at Appendix 1. A list of participants is at Appendix 2.

Main points from presentations and discussion

(Overhead slide presentations are available as Annex 1)

Session 1 - Missions

SRTM (Farr)

- objective to obtain DEM at 3m spacing for 80% of Earth's landmass during 11 day flight;
- data to be validated and validate products available for distribution within 12 months;

- the only control to be used in deriving DEM will be coast crossings; control points are required for validation and these should come from existing national DEMs and GPS traverses; logistical and political problems in organising this;
- test sites with corner reflectors required/planned? at Cunnamulla (Australia) and Fort Irwin and Rosamond Lake (California);
- level 1 data will be available freely, level 2 data would be restricted.

ISSUES

- ¶ *availability of control, international collaboration required;*
- ¶ *restrictions on data, pressure required to remove restrictions.*

Envisat (Denos)

- opportunities for SAR interferometry were discussed.

Ikonos (Kladias)

- DEMs will be produced in TIN, Grids and contours;
- correction to image data will be accomplished by GCPs, satellite position and attitude and GPS.

ISSUES

- ¶ *availability of data a reasonable cost to science community;*
- ¶ *availability of sensor orientation data.*

Vegetation canopy LIDAR (Hofton)

- 2 or 4km spacing, 1m vertical accuracy, 25m footprint;
- will provide canopy structure and topographic structure;
- Costa Rica test site.

Session 2 - Projects

GOFC (Ahern)

- moving forward with 3 primary themes: forest fire mapping and monitoring, forest cover characteristics and changes, forest biophysical functioning;
- needs continuing efforts and international collaboration for success.

Global monitoring for environmental security. (Belward)

- Baveno Manifesto calls for an examination of the issues associated with the elaboration of a common agenda towards global monitoring of the environment;

- the agenda foresees a Green paper on 'Europe and global environmental monitoring' after extensive consultation and discussion.

Landmap (Morley)

- DEM of whole of Great Britain to be produced from ERS IfSAR;
- DEM to be used for geocoding of SAR images;
- validation from GPS traverses and GPS and from comparison of geocoded SAR and Landsat.

Session 3 - requirements

Status document updated see appendix 4

- requirements difficult to define as people limited by expectations; could be useful to update 1993 NASA document.

ACCURACY ISSUES:

- ¶ *What is effect of an error on output?*
- ¶ *Assessment must be related to discipline.*
- ¶ *Cost benefits - to orthorectify or not ('cost of error bars').*
- ¶ *Space agencies to specify requirements for instruments.*

Session 4 - Terrain models for global monitoring

Global 5 arc minute DEM from ERS altimeter data (Bamber)

- can be produced with low mean error but large random errors(79m).

Quality assessment of global topography using radar and laser altimetry (Muller)

- no suitable reference set, all possibilities flawed in some way;
- need GPS traverses.

ISSUES

- ¶ *What is the best way of validating DEMs?*
- ¶ *Need international collaboration to provide test sites and globally distributed control.*
- ¶ *Data from new sensors must be used but international effort required.*

Terrain mapping requirements for GOFC products (Ahern)

- Produced mapping accuracy requirements:
- Errors not significant for vertical sensors such as Landsat TM.

Session 5a - DEMs

Automatic generation of DEMs from Stereo SAR (Sowter)

- key issue is to produce an affordable product which satisfies user needs, minimise use of ground control;
- validation by visual inspection;
- Cal/Val of orbit data required as product depends on this.

ISSUE

¶ *Cal/val of orbit*

Accuracy considerations for DEMs over equatorial forests (Polidori)

- use DEMs with other data in GIS;
- many applications, complementary sensors can provide required information;
- make use of all available information: in data used for DEM generation (SAR, optical, laser), and in the DEM itself, can find: albedo, texture, backscatter, coherence, canopy echo density, slope, incidence angle etc...
- well planned collaborative projects can give added value and give a very wide range of information;
- validation is possible by comparison of sensors.

High fidelity DEM generation using PAN and multispectral image data (Staetter)

- demonstrates advantages of using different data types.

X-SAR on SRTM (Noack)

- German survey shows that SRTM is required because it gives a homogeneous data set;
- quality is improved by using several scenes;
- need 10 GCPs per frame (cf JPL) for geocoding;
- use of hill shading enhances images and aids validation;
- slope can be extracted from phase information without unwrapping.

ERS tandem data for hydrological modelling. (Walker)

- importance of the right DEM for application.

Comparison of slope estimates from low resolution DEMs. (Drake)

- Fractal slopes show artefacts in GTOPO30 data in China.

Segmentation of multitemporal SAR (Corr)

- Demonstrates improved methods of segmentation.

Developments in SAR processing (Polidori)

- overview of ISPRS WG III/6.

ISSUES

- ¶ *what is the most useful new research needed for SAR?*
- ¶ *can we trust the technical literature concerning the operational status of SAR algorithms*
- ¶ *there are no clear standards for SAR image quality at user level?*
- ¶ *work needed on defining new directions for SAR research.*

Summary

The following theme was identified from the presentation and discussion:

- understand the data and the terrain:
 - know the user requirements
 - select the most suitable method

A number of other important points were discussed:

Validation

- visual methods widely used, display is important, e.g. DLR use of hill shading
- need ground control
- look for other methods such as landcover, fractal slopes

Political problems

- obtaining ground control
 - data distribution
 - quality of auxiliary data
- develop more collaboration

- data fusion and synergistic use of sensors
- test sites and control data
- agreed statement of sources of error and quality requirements

Session 5b validation of high level products

(see Appendix 3 for more detailed report)

Validation of AVHRR landcover products (Belward)

- validation built into project from the start;
- confusion between forest, forest and shrub and shrub classes.

ISSUES

- ¶ *collaboration will give a result with more value*
- ¶ *different groups have different requirements which would have to be reconciled.*

MODIS Land validation plans (Justice)

- NASA's validation requirements derive from their funding of higher level products rather than from just data acquisition;
- links established with other groups;
- new instrument validation required.

Validation of surface reflection, LAI and NPP (Morisette)

- complex models and collaboration required.

Australian cal/val activities (Prata)

- 3 test sites used with 7-14 day periods;
- 30 arc minute Global land Surface Temperature product from ATSR - needs to be carried out quickly which restricts physics which can be incorporated;
- land cover and percentage vegetation have large impact on surface temperature.

Geostatistics (Taylor)

- problem with mixed pixels - unbiased ground data needed to compensate;
- accuracy decreases with more classes - can be large variations.

ISSUES

¶ *more attention needs to be paid to sampling.*

Global tessellations for data modelling and sampling (Richards)

- problem of non equal area samples when using geographic co-ordinates - therefore used tessellation of hexagons.

Discussion

The discussion at the end of the session identified the following points:

there is a trend towards producing higher level products, and it is harder to validate these than it is to generate them;

many of the current and planned instruments are similar in characteristics and have been designed to monitor similar phenomena;

there is a need for validation;

the costs of obtaining field data for validation are high, particularly in proportion to the non-satellite budget of the observing systems.

The discussion also considered the potential for CEOS Working Group on Calibration and Validation to act as a coordinating body:

There is an opportunity to use the CEOS GOFc focus as a test-bed for developing improved land product validation coordination - making a CEOS WGCv contribution to IGOS development

Initiate an activity within CEOS WGCv on product validation, for selected GOFc products e.g.

- ⇒ Leaf Area Index (LAI)
- ⇒ fraction Absorbed Photosynthetically Active Radiation (fAPAR)
- ⇒ Active Fire, Burned Area
- ⇒ Land Cover Type and Characteristics e.g. continuous fields, Land Cover Change
- ⇒ Forest Biomass
- ⇒ Net Primary Productivity

It was agreed that calibration and validation activities had to be separated and that there might well be different requirements for different test sites. Any activities would build on current and planned land product validation initiatives.

Alan Belward pointed out that the following were needed for any new CEOS WGCv sub-group:

a mandate: the recent 15th Plenary of CEOS WGCv gave a mandate to the present meeting to make a new sub-group if required;

an agency to take ownership;

an individual to chair the sub-group: getting the right person is key.

The group prepared a recommendation which is presented in the next section.

Final Plenary session

Ian Dowman reported on the Parallel session on DEMs and proposed a series of actions which are listed below.

Chris Justice provided a summary of the Validation Breakout Session, outlining the discussion about an expanded role for the CEOS WGCV as a forum for coordinating land validation and about the validation of higher level products, particularly in the near-term context of GOF. The key recommendations (see below) were to:

initiate a validation sub-group within CEOS WGCV: its short-term goals had been outlined during the session;

recommend to CEOS WGCV Plenary to set up this sub-group, together with identified chair(s) and lead agency, and the plan to hold a Spring 2000 meeting.

It was recognised that there should be an expanded role for CEOS WGCV

- A number of trends are recognised:
 - increasing higher order products are harder to validate;
 - several current and planned instruments have similar characteristics and data products
 - need validation of these regional and global products, providing reliable accuracy statements
 - high cost of field data
- Co-ordinated international validation initiatives would be beneficial to multiple space agencies - maximising limited resources for land product validation;
- WGCV could provide the co-ordination forum and mechanism for the land community.

The following **Recommendation** was made:

New sub group within WGCV

The agreed recommendations of the group were to:

Initiate a Validation (Sub-Group) within CEOS WGCV, with a terrestrial (land) focus - whose goals would be to:

- ⇒ promote the quantification and characterisation of satellite land product accuracy;
- ⇒ share land product validation past experience and lessons learned;
- ⇒ move towards the generation of 'standardised products with known accuracy' from similar sensing systems in the context of data continuity;
- ⇒ establish relationships between like products, e.g. vegetation indices;
- ⇒ develop in-situ validation measurement standards, protocols and traceability;
- ⇒ coordinate international validation activities;
- ⇒ improve access to validation data sets.

The **proposed way forward** to implement the recommendations would be to:

Identify Sub Group Chair(s) and the lead agency (suggestions were for Jeff Privette to be Chair with a European co-Chair, and NASA to be the lead agency)

Hold a Spring Meeting (2000) on Land Validation and GOFc products - the Spring date should allow 1st results from Terra (EOS-AM) to be presented:

⇒ Preliminary Agenda

Generic Session on Validation Concepts Approaches - invited papers

GOFc Product Suite Breakout Sessions (invited speakers and discussants) focusing on Standardising Products, In-situ Measurement Protocols, Validation Sites, Data Access by Product Suite:

- SR/ LAI/ fAPAR Validation
- Land Cover / Land Cover Change
- Fire / Burned Area ?
- Forest Biomass
- NPP

⇒ Invitees would include representatives from different instruments contributing to GOFc:

Moderate resolution - ATSR, MODIS, GLI, MERIS, SPOT Vegetation

SAR community, VCL

High resolution community ?

⇒ Possible hosting of the workshop by CCRS

⇒ Results perhaps to be published in a Journal Special Edition on 'Land Product Validation', in about October 2000?

Alan Belward, as Chair of CEOS WGCV, agreed to take up the issue straight away with the CEOS Secretariat.

A number of **actions were agreed for the Terrain Mapping sub group** to take forward:

- prepare recommendations for the establishment of a global GCP network;
- consider how orbit validation could be developed;
- update current status of sensors;
- produce a statement of DEMs available;
- produce DEM requirements document with a science rationale, taking into account the output from SRTM;
- liaise with validation group

Other **actions** were agreed:

- Chris Justice to produce a validation overview for publication;

- WGCV to encourage greater data availability through representations to CEOS Plenary.

Closing comments

Ian Dowman said in closing that the forthcoming Shuttle Radar Topography Mapping Mission (<http://www-radar.jpl.nasa.gov/srtm/>) would provide an important homogeneous benchmark for validating other datasets. Alan Belward added that only the surface of validation issues had been touched and that there was the need for further debate.

Ian Dowman reminded the meeting of the ISPRS Congress to be held in July 2000, and the 2 sessions of particular relevance: Session IC-8a IGOS and Session IC-8b CEOS/WGCV.

Appendix 1

WORKSHOP

Production and Validation of DEMs and Terrain Parameters from Spaceborne Sensors

CEOS WGCV ISPRS WGII/4, WGIII/6

University College London (May 26-28)

PROGRAMME

08:30 Registration (Room 1.17 Geomatic Engineering;

Day 1 (Wednesday, 26th May)

Session 1 Missions (Pearson Building G22)

Chair: Ian Dowman

09:30 Tom Farr

Jet Propulsion Laboratory.

The Shuttle radar topography mission: a global DEM.

10:00 Yves-Louis Desnos,

European Space Agency.

Envisat.

10:30 Nick Kladias,

Space imaging Europe.

The IKONOS system.

Break 11:00

11:30 Michelle Hofton,

Goddard Space Flight Centre.

The vegetation canopy lidar.

Lunch 12:30

Session 2 Projects (Pearson Blding G22)

Chair: Alan Belward

13:30 Frank Ahern,

Canada Centre for Remote Sensing.

The GOF C project in the IGOS context.

14:00 Alan Belward,

Joint Research Centre.

Global monitoring for environmental security.

14:30 Jeremy Morley

University College London

The Landmap project

Break 15:00

Session 3 (Chair: Ian Dowman)

15:30 Summaries & discussion of requirements and objectives for the meeting.

19:30 Workshop Dinner Spaghetti House (Goodge street)

Day 2 (Thursday, 27th May)

**Session 4 Terrain Mapping for Global Monitoring Presentation Time
(Pearson Building G22)**

Chair TBA

09:00 Jonathan Bamber,

Centre for Remote Sensing, University of Bristol.

A Global 5 arc minute DEM derived from satellite altimeter data.

09:30 Frank Ahern,

Canada Centre for Remote Sensing.

Terrain Mapping Requirements for Global Observation of Forest Cover Products.

10:00 Jan Peter Muller,

University College London.

Quality assessment of global topography using radar and laser altimetry.

10:30 Break

Parallel Sessions	
DEM generation & validation	Validation of high level products
Chadwick Building, Civil Engineering: Wolfson Room, 2.25	Chadwick Building, Geomatic Engineering: Class Room, 1.17
11:00 Andy Sowter, Synoptics Geo Applications Ltd. Automatic of production of DEMs from stereo SAR.	Alan Belward, Joint Research Centre. Landcover validation lessons learned from IGPB.
11:30 Laurent Polidori, Institut de Recherche pour le Developpement. Accuracy considerations for digital elevation models over equatorial forest.	Jeffrey Morisette, University of Maryland. MODIS land validation approach.
12:00 Christian Staetter, Institute for Photogrammetry, University of Stuttgart. High fidelity DTM generation using PAN & MS image data.	Chris Justice, University of Virginia. MODIS land validation plans.
12:30 Lunch	Lunch
13:30 Wolfgang Noack, Deutsches zentrum fur luft und raumfahrt-DFD. The generation of X-SAR DEMs and utilisation aspects.	Tim Richards, Joint Research Centre. Global tessellations for data modelling and sampling in the context of forest resources assessments.
14:00 Alec Walker, University College London. Assessing the potential of ERS tandem interferometric DEMs for hydrological modelling.	John Taylor, Cranfield University. Geostatics.
14:30 Nick Drake, Kings College London. Comparison of slope estimates from low resolution DEMs.	Fred Prata, CSIRO. Validation of satellite-derived land surface parameters at the Australian cal/val sites.

15:00 Douglas Corr, Defense Evaluation Research Agency. New techniques for the segmentation of multi-temporal SAR data. Laurent Polidori, Institut de Recherche pour le Developpement. Developments in SAR processing	
15:30 Break	Break
Session 4 (16:00 - 17:30)	
Reports from parallel sessions & discussion Venue Pearson Blding G22	

Appendix 2

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Appendix 3

Report on the technical papers on Second Day, (27 May 1999), of the Workshop "Production and Validation of DEMs and Terrain Parameters from Spaceborne Sensors"

Technical Session

Jonathon Bamber (Bristol University, UK) opened the session with a presentation on the use of the ERS-1 168 day cycles ice mode radar altimeter (RA) data for the generation of a consistent and homogeneous DEM over land. The work has been published in *J. Geophys. Res.* (Bamber & Muller, 1998, vol.103, p.32,159-32,168). Several processing steps are required to achieve this, including waveform retracking and data filtering. Slope correction was not applied. The best, and most, returns were acquired over deserts, wet lands and ice sheets. After removal of erroneous waveforms and orbits, a global DEM on a 5 arc minute grid was produced and compared with the TerrainBase DEM. Enlargement of S. America showed significant features, including major hydrological features and the topographic connection between the Orinoco and the Amazon. For S. America the standard deviation of the mean height measurement was about 5 cm, which provided a check on the internal consistency of the dataset although there were some problems deciding where the returns were coming from in (for example) flooded forest. Comparison with the NGDC DEM showed no correlation of height error and increasing regional slope for Africa nor Australia in contrast to the ice sheets where the error increased with slope. Perhaps this is due to a greater proportion of returns from facets normal to the radar altimeter nadir over the rougher land surface.

In response to a question about the use of the DEM from **Ian Dowman** (UCL, UK), **Bamber** replied that it had been passed onto some global climate modellers but that it was not known if it had been used.

Andy Sowter (SynopticsGA, UK) asked if the RA returns in forested areas were from the canopy or from the ground. **Bamber** replied that it depended on the canopy cover and the underlying surface, for example if it was water; Wyn Cudlip of DERA (UK) has looked at this and had obtained an estimate of canopy height. The effect of the returns from both canopy and surface on the errors in the DEM are not known.

Frank Ahern (Canadian Centre for Remote Sensing) gave a presentation on terrain mapping requirements for Global Observing of Forest Cover (GOFC) products. He listed satellite data and higher level products that could be used for hot-spot and burn scar detection, mapping of forest characteristics and forest biophysical processes. The mapping accuracy requirements were based on "industry standards", of a total RMS horizontal error of about 0.5 pixels. Within GOFC where there would be merging of datasets to create products, then to maintain the accuracy an RMS horizontal error of 0.5 pixels is the worst acceptable. **Ahern** set out a simplified error model: square of total horizontal error of product = sum of squares of RMS horizontal mapping error from horizontal error and vertical error and the data registration error. **John Taylor** (Silsoe College, UK) pointed out that the error model assumes that the errors are independent and that may not be the case of a DEM produced from radar data that is used to correct the radar data. The results presented showed that for sensors such as Landsat TM, with an incidence angle of 7.5° at the edge of the scene, the displacements due to terrain errors in the DEM will not be too significant in derived products

Alan Belward (JRC, Italy) asked about levels of accuracy required for thematic products. **Ahern** replied by saying that it was hard to get an answer from the users as there was no single group that to give a response but the requirements of the Canadian Forest Service could be used as a surrogate. The accuracy of the products is commensurate with the resolution of the data which, even in the case of spaceborne sensors, is better than requirements. **Dowman** (UCL,UK), referring to the error model, pointed out that,

based on the figures presented, steeper slopes can lead to higher errors in height. Therefore, an extra term is required for the error component in z dependent on horizontal position. **Ahern** agreed that the model was simplified and could be improved.

Jan Peter Muller (UCL, UK) talked about the quality assessment of global topography, such as EROS Data Centre's DEM and the CEOS GLOBE dataset, using radar and laser altimetry data. Validation strategies for assessing the accuracy and completeness of global datasets

There is a difference in scale between the point height *in-situ* data and derived heights from satellite data, which was overcome by using the nearest neighbour spot height elevation. Out of 150,000 points 30,000 points were rejected using *a priori* estimates of the accuracy of the source information. A lot of outliers remained, possibly due to the integrity of the point dataset. The radar altimeter data were screened for non-land points and standard deviation > 100 m. The spot height vertical rms of 0.49 ± 79 m compared to values of 11 ± 78 m and 14.5 ± 72 m for the EDC and MISR global DEMs respectively.

Shuttle laser altimetry (SLA) has been acquired for latitudes between $\pm 28.5^\circ$, with a difference in orbital crossing of 2-5 m. All heights were transformed to mean sea level. When SLA data were compared with GLOBE over the S American forests and the Libyan desert it was found that there were high differences between them which may be due to forest canopy. If GTOPO30 and GLOBE measure bare earth elevations and SLA measures the top of the canopy then it would be possible to measure canopy height, however, further evaluation has not substantiated such a clear cut situation.

For validation there is a need for *in-situ* data collected using differential GPS, in particular long transects of kinematic DGPS.

In response to a question from **Taylor** asking if the errors were normally distributed, **Muller** replied that they were not, rather the distribution had very long tails but was not skewed: 3σ was about 300 m for the DCW dataset. **Dowman** asked if the national mapping organisations could provide spot height data. **Muller** said that they had been asked but without much success to date. The Global Map Project funded by Japan could be a mechanism since it is the only organisation that includes most global players; perhaps a formal approach could be made through CEOS.

Validation Breakout Session

Presentations

Alan Belward started the session with a presentation on the IGBP DISCover validation campaign for 6 core products. The products were based on 1 km AVHRR data and since they were global in coverage they required international cooperation and involvement. A network of 31 countries, 19 scientists and 29 HRPT receiving stations was put together, with CEOS endorsement and data provided by the space agencies, but that forum was project specific and no longer exists although there are still some unresolved problems. Validation was built into the project from the start, with high resolution imagery being used as a surrogate for ground data. 25 samples per class were used with three interpreters blind-checking the results. The resulting accuracy was about 52% on a global basis for 17 classes but about 89% if the classification was collapsed to the level required by global modellers (essentially: Trees, Shrubs, Grass, Others): accuracy figures are in the public domain at: <http://keystone.geog.ucsb.edu/rsru/research.html> The main confusion was between forest classes, forest and shrub classes, and shrub classes. **John Taylor** elaborated on the validation scheme. Validation was carried out on a randomly chosen 1 km square sample with stratification based on the classification, with two extra samples located 20 km to the north and west, with a surrounding 40 km square box mapped to provide more information about the classification.

Discussion concentrated on the idea that if validation is part of the process then perhaps it should be organised, maybe as a forum within CEOS, of which IGBP is a member, to set out acceptable methods. Global validation is a huge cost but if everyone contributed to an agreed system then more might be got out of it than the currently fragmented community. However, the applicability of methods to different groups would have to be considered.

Chris Justice (NASA, USA) gave a presentation on the EOS-MODIS Land Science Team Validation Plans (<http://eosps0.gsfc.nasa.gov/validation/valpage.html>) on behalf of himself, Jeff Morisette, Jeff Privette and the MODLANDS Science Team. NASA's validation requirements derive from their funding of higher level products rather than just data acquisition. The validation approach is adopted from GCOS-TPOC GHOIT, ie it uses hierarchical measurement concepts. Sites used are the EOS land validation core sites, some established field sites for CTERS, FLUXNET and AERONET (<http://aeronet.gsfc.nasa.gov:8080/>), and some PI selected product specific sites. Links are being made to other groups, such as GLI, ATSR, MERIS, as well as participating in field intensive campaigns (eg FIFE). Part of the validation effort includes the development of a new validation instrument.

Jeff Morisette (NASA, USA) then talked about the validation of surface reflectance, LAI, and NPP. Validation protocols for the validation of surface reflectance were being built on previous experience, eg BOREAS, PROVE, HAPEX. There were links to the calibration support team and MODIS atmosphere team and interactions with the EOS funded PIs. For LAI and FPAR there is interaction with the BIGFOOT Project (<http://www.fsl.orst.edu/larse/bigfoot/intro.html>) who are, amongst other things, looking at the calibration of instruments and the errors and information loss when extrapolating fine grain (*in-situ* data) measurements to coarse grain (satellite acquired data). The algorithms being implemented for LAI and FPAR have different lookup values depending on the biome being sensed, which has led to validation being carried out in 6 different biomes. For NPP validation, micro-meteorological data are acquired from FLUXNET sites, 9 of which are EOS core sites. The MODIS algorithm is then run using the FLUXNET data instead of the DAO climatic data. The MODIS results are also placed into the site models. Meta-data for field data are stored in a centralised database at Oakridge DAC; further details can be found at <http://mercury.ornl.gov/servlet/landval.html> The meta-data editor can be accessed at <http://daacl.esd.ornl.gov/cgi-bin/MDE/MERCURY/access.pl>, use "guest" to register. Comments are welcome to Paul Kanciruk at pkk@ornl.gov.

Fred Prata (CSIRO, Australia) presented an overview of Australian calibration and validation activities. There are currently three cal/val sites: (1) Amburle located about 100 km west of Alice Springs; (2) Uardry, Hay, NSW, which is an extensive grass plain; and (3) Thangoo near the coast in NW Western Australia, which has just become operational and comprises acacia woodland. The main interest is in radiance, with measurements made of albedo and BDRF. Changes in albedo are observed over a period of 7-14 days, which has implications for 10 day composites, due to the large effect rainfall has on soil moisture and vegetation. Routine measurements made at 2 m (with a pyranometer suspended from a triangular arrangement of poles) have been compared with those from a tower and no significant difference was found. Vicarious calibration of the ATSR-2 data acquired in the 3 SWIR bands has been carried out using top of the atmosphere ATSR-2 data and modelled ATSR-2 data. Bias was calculated to be $\pm 6\%$ and $\pm \sigma$ equal to 3% of percentage albedo, which has implications for the accuracy of products. BRDF effects were particularly noticeable in nadir view composites of Australia, with less effect in forward view composites.

Prata also talked about the development of a proposed 30 arc minute Global Land Surface Temperature product using the ATSR 11 μ m and 12 μ m bands. Production of a global product needs to be carried out quickly which restricts the physics that can be incorporated, leading to the use of regression estimates.

Also, as an operational product there could not be any dependency on any other instrument. Two factors that have a large impact on surface temperature are land cover and percentage vegetation. Emissivity values have been produced for 12 one-month periods and 13 classes. Accuracies have been found to be to 1-3 C, with the worst results in the tropics.

John Taylor talked about overcoming confusion and error in statistics derived from remotely sensed imagery, based on experience of the EU's MARS Regional Inventories and land cover classification in Etosha, Namibia. One of the recurring points was that many pixels in a scene are "mixels" (mixed pixels), up to 15-30% for a SPOT scene, and this leads to classification errors. Unbiased ground data is needed in order to be able to compensate for these mixels, to overcome the spectral confusion between land cover types, to compensate for difference in classification algorithms and to determine and minimise ambiguity in class definitions of land cover types. Typical overall classification accuracies might be 60-75% for a single image with 8 to 12 classes, and 80-85% when 2 or more images are used. However, the accuracy reduces as the number of classes increases (more chance of mis-classification). The accuracy of *individual* classes can vary from 0% to nearly 100%. Area estimates by pixel counts can be wildly inaccurate, whereas area weighted regression estimates have been found to be much more accurate. The final conclusion was that more attention needs to be paid to sampling as the results can be given extra value by going the extra step.

Tim Richards (JRC, Italy) presented his results on global tessellations for data modelling and sampling in the context of forest resources assessments. When considering global datasets, the use of geographic coordinates (latitude and longitude) for the sampling frame does not lead to equal area samples which in turn leads to problems in producing unbiased estimators of change in forest cover. One proposed solution is to use a tessellation of hexagons covering the globe: a small number of pentagons (cf. soccer balls and Bucky Balls) are also needed but they can be made insignificant if the cell size is small enough. Although there are small area variations in the hexagons covering the Earth's surface, they are much less than if using other coordinate systems. After most of the research had been carried out it was found that the USDA had already implemented the use of a similar coordinate system.