Report of the GOFC-GOLD/CEOS Workshop on Land Cover Change Accuracy Assessment

as part of the
Third GOFC-GOLD Land Cover Symposium

Friedrich-Schiller University
Jena, Germany
13 – 17 October 2008

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GOFC-GOLD Report No. 38

Land Cover Project Office
Jena, Germany
June 2009

Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) is a coordinated international effort to ensure a continuous program of space-based and in situ forest and other land cover observations to better understand global change, to support international assessments and environmental treaties and to contribute to natural resources management.

GOFC-GOLD encourages countries to increase their ability to measure and track forest and land cover dynamics by promoting and supporting participation on implementation teams and in regional networks. Through these forums, data users and providers share information to improve understanding of user requirements and product quality.

GOFC-GOLD is a Panel of the Global Terrestrial Observing System (GTOS), sponsored by FAO, UNESCO, WMO, ICSU and UNEP. The GOFC-GOLD Secretariat is hosted by Canada and supported by the Canadian Space Agency and Natural Resources Canada. Other contributing agencies include NASA, ESA, START and JRC. Further information can be obtained at http://www.fao.org/gtos/gofc-gold

Executive summary

On 14 October 2008, the Workshop Accuracy Assessment of Land Cover Change and Area Estimates was held as part of the 3rd GOFC-GOLD Land Cover Symposium (13-17 October 2008) at University Jena, Germany. An international group of 70 remote sensing and accuracy assessment experts attended the meeting including GOFC-GOLD LC-IT members, scientists from international research institutions, technical experts from private companies, as well as representatives from space agencies.

The GOFC-GOLD land cover implementation team (LC-IT) and the CEOS WGCVland validation subgroup have been working on developing and implementing a land cover harmonization and validation framework. These joint activities between the CEOS WGCV and the GOFC-GOLD LC-IT received a further push during the CEOS Cal/Val meeting 2008 in Avignon, France (http://www.star.nesdis.noaa.gov/smcd/CEOS/WGCV29/-WGCV28_Minutes_v2.pdf). The workshop at Jena was a continuation of these activities focusing on the issue of accuracy assessment for land cover change and area estimates. The objective of the meeting was to synthesize experiences in a related "best practices" type document and to provide dedicated technical input to ongoing international processes. The best practices document is under development and is planned to be released in 2010.

In two presentation sessions, experiences on approaches for accuracy assessments of land cover change and area estimates have been reviewed and discussed. These accuracy assessment experiences were developed in the context of ongoing near-operational land monitoring projects and programs. In breakout group discussions, critical issues and possible strategies to address them were discussed. One major outcome is the definition of an outline of the "best practices" document and the contributing authors. Furthermore, the cooperation of the GOFC-GOLD LC-IT and the CEOS WGCV group has been strengthened. The following priorities have been defined for future collaboration:

- Continue the cooperation between GOFC-GOLD and the CEOS land WGCV subgroup and support of international projects
- Use and make available existing global reference databases (i.e. from GLC2000 and GLOBCOVER projects)
- Define standard accuracy assessment standards, definitions, and procedures for fine-scale land cover change and area estimates
- Plan and foster the implementation of an operational validation component of global land cover monitoring (i.e. development of ECV that would enable both calibration and validation of land dynamics)
- Use "application specific weighting" for accuracy reporting to link land cover observations to areas of societal benefits
- Continue to communicate and contribute to political and policy level activities, including the UNFCCC/SBSTA and GEO (work plan tasks)

In particular, the specification of consensus procedures for the accuracy assessment for fine-scale land cover change and area estimates will be an important follow up activity of this workshop.

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Acronyms

CEOS	Committee on Earth Observation Satellites
CLC	CORINE Land Cover
CFS	Canadian Forest Service
EC-JRC	European Commission Joint research Center
ESA	European Space Agency
FAO	Food and Agriculture Organization
Fire-IT	Fire Implementation Team
GEO	Group on Earth Observation
GLC2000	Global Land Cover 2000
GOFC-GOLD	Global Observation of Forest Cover and Global Observation of Land Dynamics
GTOS	Global Terrestrial Observing System
LC	Land cover
LC-IT	Land Cover Implementation Team
LIDAR	Light Detection and Ranging
LPV	Land Product Validation
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
PO	Project Office
PRODES	Programa de Cálculo do Desflorestamento da Amazônia
REDD	Reducing Emissions from Deforestation and Degradation
SAR	Synthetic Aperture Radar
SDSU	South Dakota State University
TREES	Tropical Ecosystem Environment Observation by Satellite
WGCV	Working Group on Calibration Validation

1 Background and objectives

Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) is a coordinated international effort to ensure a continuous program of space-based and in situ forest and land cover observations, to better understand global change, to support international assessments and environmental treaties and to contribute to natural resources management. GOFC-GOLD encourages countries to increase their ability to measure and track forest and land cover dynamics by promoting and supporting participation on implementation teams and in regional networks. Through these forums, data users and providers share information to improve understanding of user requirements and product quality.

Previous efforts of GOFC-GOLD and the CEOS Calibration/Validation working group have resulted in an international consensus document on the validation of global land cover maps (http://landval.gsfc.nasa.gov/pdf/GlobalLandCoverValidation.pdf). This workshop is a continuation of these activities, focusing on the issue of accuracy assessment for land cover change and area estimates. The goal is to synthesize experiences in a related "best practices" type document and to provide dedicated technical input to ongoing international processes, i.e. in the context of the UNFCCC efforts on reducing emissions from deforestation and degradation (REDD). The specific objectives of the workshop are:

- Review, discuss, and synthesize experiences on approaches for accuracy assessments of land cover change and area estimates from both the technical and scientific community, and from the context of ongoing near-operational land monitoring projects and programs;
- Provide a forum to identify and discuss critical issues and outline avenues on how to resolve them; and
- Promote consensus development, and make recommendations towards developing a “best practices” technical document and “good practices” technical input to specific monitoring processes.

2 Participants

The workshop brought together more than 70 recognized scientists and experts in the field of earth observation. Participants included GOFC-GOLD LC-IT members, scientists from international research institutions, technical experts from non-governmental organizations or private companies, as well as representatives from space agencies. The full list of participants is provided in Appendix A.

3 Agenda

The workshop was structured in two presentation sessions and one session of group discussions. The first group of presentations provided background information on validation activities of GOFC-GOLD and the CEOS Calibration/Validation group. The second session focused on project experiences and validation requirements. During the afternoon, related issues and the outline of the best practices document were discussed in groups. A detailed agenda is included in Appendix B. With permission of the speakers, all presentations of the workshop are available as Adobe PDF on the Website of the LC-IT PO under: http://www.gofc-gold.uni-jena.de/sites/Jena08.php.

4 Summary of presentations and discussed topics

4.1 SESSION 1: Opening and background

The workshop organizers, **Curtis Woodcock (**LC-IT Co-Chair) and **Martin Herold** (LC-IT) welcomed all participants and opened the workshop.

Curtis Woodcock (LC-IT Co-Chair) reviewed current GOFC-GOLD activities in the context of land cover validation. This involves the development of standard methods for global land cover accuracy assessments (STRAHLER et al. 2006), participation in the development of new datasets (e.g. GlobCover validation), the comparative validation of different products and the accuracy assessment of fine-scale land cover change and area estimates. Driving forces for these activities are international initiatives, including the United Nations Framework Convention on Climate Change (UNFCCC) and the Group on Earth Observation (GEO), as well as other global land cover monitoring and assessment initiatives such as GlobCover and the FAO Forest Resources Assessment 2010. Key activities for the GEO global land cover task (DA-07-02) and the operational land cover validation framework developed by GOFC-GOLD were highlighted.

Frédéric Baret (INRA) presented objectives and activities of the Land Product Validation Subgroup (LPV) of the CEOS working group on calibration and validation (WGCV, http://lpvs.gsfc.nasa.gov/). This subgroup wishes to foster the quantitative validation of global land products (derived from remote sensing data), to increase quality and efficiency of global satellite product validation and to develop and promote international standards and protocols. He presented results from a study on the representativeness of a global network of test sites (BARET et al. 2006). Validation activities include the extension of previous efforts of an On-Line-Interactive-Validation-Exercise (OLIVE). In conclusion, the necessity for a closer collaboration with the land cover communities and corresponding agencies such as GEO was expressed.

Mike Wulder (CFS) spoke about general aspects of the accuracy assessment of land cover change. The validation of land cover change needs to consider different aspects of change, including the magnitude, extent, and type of change. He underlined the importance of spatial and temporal resolution influencing costs, coverage, and the detectability of change types and its timing. The expected accuracy varies for different change types and is much less in the case of subtle forest changes (e.g. defoliation) compared to replacement disturbances (e.g. clear-cuts or burned forests). In general, it is recommended to assess change types (considering magnitude and extent) in a simple and consistent way by following existing standards and definitions.

Stehman, Steve (State University of New York) presented methods and concepts for assessing the accuracy of land cover change. Each validation approach includes a sampling and response design, i.e. the protocols used for choosing the locations of the validation sites and their comparison to the map product, and a final analysis, i.e. calculation of accuracy measurements. The presentation addressed each step of the process and emphasized desirable criteria and requirements. The second focus was on land cover area estimation (see GALLEGO 2004). Accuracy assessment and area estimation objectives are closely linked. Model-assisted estimation provides a unifying framework for analysis (confusion matrix approach for accuracy assessment, regression approach of area estimation).

Giles Foody (University of Nottingham) focused on two important aspects when applying an accuracy assessment: the inaccuracies in the ground truth data and the quality and size of the sampling sites. The interpretation of the error matrix is influenced by imperfect ground truth data. Errors in the ground 'truth' can lead to systematic bias that underestimates accuracy but this is correctable. In the second part, different aspects and the statistical background for the sample size determination were addressed. The required sample size may be quite large, and users need to be aware of the danger of using inappropriate size (FOODY 2008).

4.2 SESSION 2: Project examples, experiences and requirements

Matthew Hansen (SDSU) presented accuracy assessment approaches of LC change products from MODIS and Landsat. The assessment of change is challenging because reference information for different time steps is required, and change is typically rare and not randomly distributed. The presentation addressed the definition of change (spatial dimension, thematic definition, and temporal context), different types of errors, legend aggregation and stratification. Another aspect is the available test data. Recommendations include; independently derived data sets, e.g. spatially explicit reference data at same or finer scale (sample-based or wall-to-wall), inventory data and contextual information on drivers of change. Different validation examples were presented with examples from the PRODES project and the Landsat Global Forest Monitoring Project (http://globalmonitoring.sdstate.edu/projects/gfm).

Javier Gallego (EC-JRC) focused on biases that influence quantitative indicators of the accuracy. The quality of the accuracy estimation depends on various factors related to sampling errors of the reference data (number of sampling units, sampling rate), non-sampling errors (identification mistakes, location, nomenclature) and their relation. The problems were illustrated on GLC2000 and the CORINE Land Cover validation that is based on sampled ground survey data (LUCAS, Land Use/Cover Area-frame Survey) and the TREES-2 project.

Peter Cacetta (CSIRO) spoke about the Australian land cover change project as part of the National Carbon Accounting System (NCAS). The assessment is done based on wall-to-wall Landsat data for various time steps from 1972 to 2006 using a semi-automated, scalable approach in order to improve the estimates for UNFCCC reporting. The project stages of all 3 phases were presented. The validation of the land cover information is done by Independent, systematic validation by aerial photo interpretation of random sites for multiple dates across Australia. An online map service provides products and related information (for Western Australia): http://landmonitor.landgate.wa.gov.au/. Publications are available at: http://www.-climatechange.gov.au/ncas/publications/index.html.

Steffen Kuntz (GSE Land) presented initiatives toward European standards for high geo-information quality. The Kopernikus Land Quality Assurance (QA) approach is a European attempt towards standardised GMES products. Presently this approach is not a fixed method but an iterative process including learning curves by all stakeholders leading finally to a European consensus. He introduced the validation method and addressed statistical considerations, i.e. problems of sample size, sampling raster and stratification strategy.

Martin Herold (University Jena) addressed the requirements and data needs from UNFCCC (LULUCF and REDD). The IPCC Good Practice Guideline requests that uncertainties be quantified and reduced as far as practicable. Factors affecting the quality of satellite based monitoring were reviewed leading to practical considerations to avoid them. For example, the accuracy assessment approach for a national REDD study in Vanuatu was presented. In conclusion, the general need for standard methods for assessing accuracy of land cover change was underlined, especially with regard to developing countries where the implementation of statistically robust validation procedures is currently limited. Key issues to be considered in this context are the principle of conservativeness and uncertainties in trends.

Frédéric Achard (EC-JRC) focused on REDD and LULUCF implementation with respect to using coarse resolution data. CLC, JRC Forest cover maps and Eurostat LUCAS are examples of land cover assessments using medium resolution satellite data. In the case of LUCAS, to evaluate the accuracy of stratification, a comparison has been conducted between classification of the points according to photo-interpretation and ground observation (7 classes). The results show that orthophoto classification is quite accurate, but it has to be used only for stratification purposes, otherwise estimates are biased. Finally, the importance of ground surveys was underlined.

In the final presentation, **Pierre Defourny** (Université Catholic de Louvain, UCL) spoke about the accuracy assessment that was applied to the forest cover change assessment in the Congo Basin and for the GlobCover product. The Congo forest assessment was done by systematic sampling based on Landsat data, used an object-oriented approach and multi-date segmentation. The sampling strategy, processing chain and results of the change assessment were presented (DESCLÉE at al. 2006). The change rate estimates for different countries of Central Africa were validated and the results were used to improve the processing chain (DUVEILLER et al. 2008). In the frame of the GlobCover project, more than 4300 validation points have been used based on high-resolution interpretation by experts. The results and approach are fully described in the GlobCover land cover product report available at: ftp://uranus.esrin.esa.int/pub/globcover_v2/global/.

5 Breakout group discussions

The group discussions focused on the following questions and issues:

- What differentiates accuracy assessment of change?
- What do we need to consider above and beyond what we previously did for land cover?
- Response protocol and datasets
- Inherent need for unavailable reference data
- Defining and characterizing change (modification vs. conversion?) are we going to try to tackle magnitude of error?
- Bias toward interest in rare classes
- Area estimation is possibly more important than estimating the accuracy of the map (and trends)
- New perspectives on accuracy assessment and area estimation

Please find below the notes of the discussions.

5.1 Breakout Group 1: Baseline Case

Development of assumptions:

- Focus on change in categories
- Map of change, but not necessarily maps for two dates

Design and analysis represents 'best practices', add in exceptions later

Differences from CEOS 2006

- Reference data
    - May not have reference data at first time period (or it is not adequate)
    - Rarity of change classes
- Area estimation

Response design issues

- Unit of analysis
    - Pixel
    - Blocks (size)
        - Small blocks (e.g. 3x3 pixel)
        - Use as area based assessment
        - Pixels within blocks
    - Polygons
- Places difficult to decide if there is actually a change ('don't know')
- Reference data not available from probability sampling design
- Recommendations for protocols for consistency or resolution of difficult sites to label reference data (Curtis Woodcock and Mike Wulder have examples, possibly other examples)
- Encourage both a primary and secondary class when developing calibration validation data sets for change
- Encourage a single class call for each site (i.e., one primary class, one secondary class)
- Require labeling consensus if multiple interpreters are used
- Minimum mapping unit and impact on response design, sampling design, and analysis
- Maintain separate (but may be related) tracts for different approaches (pixel and polygon)

- Source of reference data, e.g. air photos, dense time series of Landsat, high spatial resolution satellite imagery, multi-sensor in the future (information available for quality control purposes on sensors)
- Trade offs or issues related to how much reference data from ground versus how much from other sources

Design Issues

- Stratification for 'rare' classes (to intensify sample in rare classes)
    - Various options
    - Map change
    - Areas of likely change
- Stratification is targeted to specific objectives, may not serve well for other objectives (prioritization of objectives)
- Stratification for multiple change periods
- Stratification and omission error, perception that stratification doesn't pick that up
- Stratification within the non change classes
- Sample size allocation to change and non change classes, should be able to apply standard error formulas to 'optimize' allocation
- May be cases where a priori stratification will be difficult (specify examples, REDD); no map on which to base stratification, could consider a model of change for strata, or just don't stratify; other stratification options include distance to population centers, population density. If attempting to map "deforestation" as relating a permanent land use change from forest, stratification may aid in guiding the survey and sample design in some nations (i.e., those that have regional trends in natural versus anthropogenic change agents).

Analysis issues

- Error matrix description useful
- Area estimation will need to be added in (cases only interested in area, others interested in both area and accuracy)
- Mention analyses addressing reference data error
    - Basic description of what that error might be (e.g. interpreter consistency)
    - Basic quality control and consistency checks
- Confidence intervals for accuracy and area parameters
- Sampling errors of accuracy and area estimates (e.g. FRA accuracy)

Miscellaneous

- Cumulative evidence approach to accuracy assessment
- Effect of spatial resolution on accuracy of area estimates (also consider as related to accuracy of map change)
- May also need to consider the role of spectral resolution and the detectability of change types
- Temporal resolution and the time between T1 and T1 data used for identification of change will have impacts that vary by a range of issues, including geography (e.g., tropical vs boreal forest regeneration rates) through to change type (e.g., defoliation vs fire).
- Development of a better understanding of uncertainty of trend
- Analysis of Landsat-based dense time series' may form the basis for these types of investigations and development of trends by change type by region to guide definition of appropriate change intervals (i.e., T1 to T2 gaps)
- Include a section on future research, issues that need more work

WRITING
I. Scope of problem and Introduction (to include objectives, general description of problem addressed, foreshadow differences from earlier CEOS document, maybe a few key example applications).
II. Assumptions
III. Response design issues
IV. Analysis issues
V. Sampling issues
VI. Summary section on Recommendations
VII. Future research and unresolved issues.

5.2 Breakout Group 2: WRITING: Best Practices for Assessing Accuracy of Land-Cover Change and Estimating Area of Change

(order of sections can be re-arranged, section leads and contributors can be revised)
15 October 2008

1. Introduction (Curtis Woodcock and Martin Herold)
    a. General description of problem addressed – defining the scope
    b. Objectives of change accuracy (descriptive accuracy of change map, ability to estimate area of change, others? Assessment of net change to augment gross change assessment, or leave it at gross change?)
    c. Motivating examples, role of GOFC-GOLD, etc. Specify major ‘cases’ of change assessment that we will address, e.g. is it global change products, other?
    d. Document builds on earlier CEOS document, but key differences include … specify after document completed. Differences from Strahler (2006): 1) Quality (existence?) of reference data at first time period, 2) Change is rare; 3) Area estimation; 4) others?
    e. Brief revisit of three major components (response design, sampling design, and analysis), following but not repeating information in Strahler et al. (2006). The write-ups (following major sections) may need to provide some background, but the writing should focus very strongly on how the issues pertain directly to change with minimal redundancy with the information in Strahler et al. (2006) – in other words, we do not need as much background information in the change document.

2. Response design issues (Mike Wulder, Matthew Hansen, Frederic Achard, Giles Foody, Phillippe Mayaux)
    a. Assessment units for change and issues
        i. Pixels
        ii. Polygons
        iii. Blocks
    b. Reference labeling protocol and issues related to collecting reference data for each assessment unit, for example:
        i. Regard the assessment unit as homogeneous so reference data must be a single class (a class could be type of change)

ii. Unit is homogeneous (single class) according to map but mixture according to reference labelling
iii. Single reference label, primary and secondary label, fuzzy reference data
iv. Within a block or polygon, may have per pixel (spatially explicit) information on reference class, or possibly(?) just the area of each class in the polygon or block

c. Sources of reference data, strengths and weaknesses of each
d. Methods to increase consistency of reference labeling (e.g. how to best employ multiple interpreters)
e. Defining agreement (this should be in Strahler et al. 2006, so perhaps a quick overview). Depending on the assessment unit and labeling protocol, this may be more complex than just a 'crisp' label type comparison
f. Quantifying reference data error (labeling and location error, maybe Giles adds something)
g. Other topics to include, or indicate knowledge of:
    i. dense time series of Landsat
    ii. multi-sensor approach in the future (to include information available for quality control purposes on sensors – Paul Stephens comment)
    iii. Trade-offs or issues related to how much reference data from ground versus how much from other sources
    iv. There was discussion of causes of change. Change agent can be problematic, points to need for clear assumptions and / or limits to what is included
h. Short summary section on recommendations for response design, what are the best practices, and maybe what are practices to avoid.

3. Analysis issues (Giles Foody lead, others as above)
    a. Basic description via error matrix – usual accuracy measures, importance of standard errors and confidence intervals derived from them (quantifying uncertainty of accuracy estimates)
    b. We may need to include the reminder that the specific accuracy estimation and variance estimation protocols are dependent on the sample (i.e. we can't do the analyses as if the sample were simple random when strata and clusters are involved).
    c. Collapsed error matrix (2x2 change and no change), mention van Oort (2008) as another reporting format that is in a collapsed form.
    d. Estimating area (Steve Stehman)
        i. Bias of pixel counts for area estimation
        ii. Confusion matrix based estimators (Card 1982) and their limitations
        iii. Regression estimator
        iv. Synthesis via model-assisted estimation
        v. Quantifying uncertainty of area estimators
    e. Analysis accommodating reference data error (e.g. Hagen et al. 2003 for a general conceptual framework, but we could also suggest some simpler approaches)
    f. "Trend" in the change (Frederic Achard)
    g. Net change accuracy (Steve Stehman – if topic included)
    h. Short summary section: General recommendations on analysis

4. Sampling issues (Steve Stehman, Javier Gallego)
    a. List of desirable design criteria, importance of prioritizing
    b. Major design decisions: strata, clusters, systematic versus simple random protocols
    c. Stratification – rare change
        i. Motivated by goal of precise class-specific accuracy, particularly for the rare change types
        ii. Concerns about change omission error as related to stratification
        iii. Sources' of stratification
        iv. Existing change maps
        v. Variables correlated with change
        vi. Allocation of sample size to strata – guidelines for how to quantify
        vii. Situations where stratification may not be warranted
    d. Clusters – motivated by cost
        i. Cluster size issues (anything special pertaining to change?)
        ii. Clusters and relation to area estimation objective – stratifying clusters by quantity of change in the block
    e. Possible options for combining stratification and clustering
    f. General recommendations on sampling design

5. Special topics (catch all section)
    a. Cumulative evidence approach, what to do in the absence of adequate reference data (Matthew Hansen)
    b. Special needs and concerns of specific major projects, e.g. REDD, Curtis's work, Mike Wulder's work, etc.? Include one or two paragraphs per project, enough information to that a reader can see parallels between his/her project and the issues described for the specific projects we include. Not sure this is worth including if we don't resolve the specific needs and concerns.
    c. Effect of resolution on accuracy of area estimates (and also accuracy of map change, as above in summary)
    d. We have the list of change accuracy examples that Martin put together. We might include that here, although I think we have to be careful to be clear we are not endorsing any of these methods and we are not even critiquing them. Alternatively, we could evaluate some of them and endorse some as good practice? That may be a lot of work. The question is how can we use the past literature of examples? Include as an annotated table including theme, unique element(s), reference.

6. Future research and unresolved issues (Contributions from all)

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Appendix B – Agenda

GOFC-GOLD Workshop on Accuracy Assessment of Land Cover Change and Area Estimates		
Tuesday, 14.10.2008, Rose Halls, Room 102		
SESSION 1: Opening and background (10 min presentation + 5 min discussion)		
09.00-09.10 09.10-09.25 09.25-09.40 09.40-09.55 09.55-10.15 10.15-10.30	Opening and meeting objectives GOFC-GOLD validation activities CEOS Cal Val land activities Land cover change/events/magnitude/scales Change accuracy assessment: methodology Accuracy Assessment Methods and current challenges	Woodcock/Herold Woodcock Baret Wulder Stehman Foody
10.30-11.00 Break		
SESSION 2: Project examples/experiences and requirements (10 min + 5 min)		
11.00-11.15 11.15-11.30 11.45-12.00 12.00-12.15 12.15-12.30 12.30-12.45 12.45-13.00	Coarse scale estimates MODIS/Landsat JRC examples and methodologies Australian LULCC/NCAS methodology Methods for B4G analysis & CORINE upd REDD/LULUCF implementation Congo basin deforestation assessment exam. Discussions	Hansen Gallego Cacetta/Held Kuntz Herold/Achard Defourny
13.00-14.00 Lunch		
SESSION 3: Breakout group discussions		
14.00-14.10 14.10-16.00	Charge to breakout groups Breakout group discussions	All
16.00-16.30 Break		
SESSION 3: Breakout group reports		
16.30-17.30 17.30-18.30	Reports from breakout groups Concluding discussions and next steps	All
18.30 Adjourn and informal discussions		