Land Product Quality & Validation

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(¹Sigma Space Corp / NASA GSFC, ²University of Zurich)
Outline

• NASA Land Quality Assessment
• Sources and Propagation of Error
• Validation Process
• International Land Validation Activities
• Summary / Recommendations
The research & application usages of satellite derived products put a high priority on providing statements concerning product performance.

- **Quality Assessment**: Evaluate product scientific quality with respect to intended performance.

- **Validation**: Quantify product accuracy by comparison with “truth/reference data” distributed over a range of representative conditions.

NASA’s EOS MODIS program includes a dedicated Land QA team.

Validation is an explicit responsibility of the investigators to assess the accuracy of their products.
MODIS LAND QA

- Evaluate product scientific quality with respect to intended performance
- A routine near-operational activity
- Results are stored in the product as per-pixel flags and metadata at the product file level
- The QA process is the first step in problem resolution, may lead to
  - update of production codes
  - science algorithms
  - to rectify issues identified through QA
Sources of Error

- Errors may be introduced by numerous, sometimes interrelated, causes that include:
  - Instrument errors
  - Incomplete transmission of instrument and ephemeris data from the satellite to ground stations
  - Incomplete instrument characterization and calibration knowledge
  - Geo-location uncertainties
  - Use of inaccurate ancillary data sets
  - Software coding errors
  - Software configuration failures (whereby interdependent products are made with mismatched data formats or scientific content)
  - Algorithm sensitivity to surface, atmospheric and remote sensing variations
  - Errors introduced by the production, archival and distribution processes
Examples of Error

Data loss in granule 21:40 on day 2011035 due to FOT Contact Error

Striping in LSR product from the Mirror Side Polarization Difference in band 3 of Terra MODIS

MODIS data affected by Partial Solar Eclipse on Jan 04, 2011

Stripes of Fire in granule 08:30, day 2005068 Band 21 was degraded, Error in the new emissive LUT used by the L1B

Gridded LSR from 2008213.h09v05. shows geo-location error – resulting from a maneuver which was later waived – too late

LST – dependency on latitude, traced to the Cloud Mask which is an input to LST algorithm
QA Result Storage

- The MODLAND QA result storage format is designed to accommodate diverse users including the Science Team, production managers & data users.

- Formal QA results are descriptive statements concerning product quality, stored within each product during the processing as:
  - **Pixel Level QA bits**: Contains quality of the observation at each pixel. Used in the processing chain and propagated to downstream products.
  - **File level QA metadata**:
    - Percentage Cloud cover, land, water, good retrieval.
    - Science QA metadata - generic statement about the QA of the product.
## C5 MODIS Vegetation Index

- Many product switching to just
  - 0: good quality
  - 1: other quality

<table>
<thead>
<tr>
<th>Possible Shadow</th>
<th>Possible snow/rice</th>
<th>Land/Water flag</th>
<th>Ocean coasts and lake shorelines</th>
<th>Lake only</th>
<th>Shallow inland water</th>
<th>Ephemeral water</th>
<th>Deep inland water</th>
<th>Moderate or continental ocean</th>
<th>Deep ocean</th>
<th>Mixed cloud present</th>
<th>Adjacent cloud detected</th>
<th>Aerosol Quality</th>
<th>Atmospheric BRDF Correction performed</th>
<th>VI Usefulness</th>
<th>QA4EO Workshop</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - No</td>
<td>0 - No</td>
<td>00 - Shallow</td>
<td>000 - Land</td>
<td>001 - Shallow only</td>
<td>002 - Shallow inland water</td>
<td>003 - Ephemeral water</td>
<td>004 - Deep inland water</td>
<td>005 - Moderate or continental ocean</td>
<td>006 - Deep ocean</td>
<td>0 - No</td>
<td>0 - No</td>
<td>0 - No</td>
<td>0 - No</td>
<td>000 - Highest quality</td>
<td>001 - Lower quality</td>
</tr>
<tr>
<td>1 - Yes</td>
<td>1 - Yes</td>
<td>000 - Ocean</td>
<td>0000 - Land</td>
<td>0001 - Ocean only</td>
<td>0002 - Ocean shallow inland water</td>
<td>0003 - Ocean ephemeral water</td>
<td>0004 - Ocean deep inland water</td>
<td>0005 - Ocean moderate or continental ocean</td>
<td>0006 - Ocean deep ocean</td>
<td>1 - Yes</td>
<td>1 - Yes</td>
<td>1 - Yes</td>
<td>1 - Yes</td>
<td>0000 - Highest quality</td>
<td>0001 - Lower quality</td>
</tr>
</tbody>
</table>

**Possible Shadow**
- 0: No shadow
- 1: Yes shadow

**Possible Snow/Rice**
- 0: No snow/rice
- 1: Yes snow/rice

**Land/Water Flag**
- 00: Shallow
- 000: Ocean
- 0000: Land

**Ocean Coasts and Lake Shorelines**
- 000: Land
- 0001: Ocean only

**Adjacent Cloud Detected**
- 0: No adjacent cloud
- 1: Yes adjacent cloud

**Aerosol Quality**
- 00: Climatology
- 01: Low
- 02: Average
- 03: High

**VI Usefulness**
- 0000: Highest quality
- 0001: Lower quality
- 0002: Lowest quality
- 1101: L1B data faulty
- 1111: Not useful not processed

**Modland QA**
- 00-11: VI produced good quality and no other reasons for null return
- 01-11: VI produced, but most probably cloudy, check other quality
- 10-11: VI produced, but check other reasons than cloud
# QA Metadata

<table>
<thead>
<tr>
<th>QA Metadata Name</th>
<th>Valid values</th>
<th>Populated</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Automatic Quality Flag</strong></td>
<td>Passed, Failed, Suspect</td>
<td>during production by science software</td>
</tr>
<tr>
<td>Automatic Quality Flag Explanation</td>
<td>Explanatory text (255 Characters)</td>
<td>during production by science software</td>
</tr>
<tr>
<td><strong>Science Quality Flag</strong></td>
<td>Passed, Failed*, Suspect*, Inferred Passed, Inferred Failed*, Being Investigated, Not Being Investigated</td>
<td>after production by the Science Team / LDOPE</td>
</tr>
<tr>
<td>(*caution, do you want to order this ?)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science Quality Flag Explanation</td>
<td>Explanatory text (255 Characters)</td>
<td>after production by the Science Team / LDOPE</td>
</tr>
</tbody>
</table>
MODIS Land Validation

- **MODIS QA Process** evaluates product scientific quality with respect to intended performance

- **MODIS Validation:**
  - Assess by independent means, accuracy of data products derived from system outputs
  - Facilitate the coordination and development of data and methods for global validation of NASA EOS land products through use of shared field, airborne, and satellite datasets and international collaboration
  - Onus on individual product teams, with supplemental funding

http://landval.gsfc.nasa.gov/
Relation to International Activities

- MODIS land – establishment of the CEOS WGCV Land Product Validation Sub-group in 2000

Validation stage hierarchy:

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>Product accuracy is assessed from a small (typically &lt; 30) set of locations and time periods by comparison with in-situ or other suitable reference data.</td>
</tr>
<tr>
<td>Stage 2</td>
<td>Product accuracy is estimated over a significant set of locations and time periods by comparison with reference in situ or other suitable reference data. Spatial and temporal consistency of the product and with similar products have been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature.</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Uncertainties in the product and its associated structure are well quantified from comparison with reference in situ or other suitable reference data. Uncertainties are characterized in a statistically robust way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and with similar products have been evaluated over globally representative locations and periods. Results are published in the peer-reviewed literature.</td>
</tr>
<tr>
<td>Stage 4</td>
<td>Validation results for stage 3 are systematically updated when new product versions are released and as the time-series expands.</td>
</tr>
</tbody>
</table>
# MODIS Land Product Validation Status

<table>
<thead>
<tr>
<th>Product</th>
<th>Name</th>
<th>Stage</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOD09 C5</td>
<td>Surface Reflectance</td>
<td>2 (3)</td>
<td>+/- (0.005 + 5 %)</td>
</tr>
<tr>
<td>MOD10/29 C5</td>
<td>Snow / Sea Ice</td>
<td>2 / 2</td>
<td>92 %</td>
</tr>
<tr>
<td>MOD11 C4.1/5</td>
<td>Land Surface Temperature</td>
<td>2</td>
<td>+/- 0.5-1.0 K</td>
</tr>
<tr>
<td>MOD12 C5</td>
<td>Land Cover / Dynamics</td>
<td>2 / 1</td>
<td>&gt; 75-80 %</td>
</tr>
<tr>
<td>MOD13 C5</td>
<td>NDVI / EVI</td>
<td>3</td>
<td>+/- (0.002 + 2%)</td>
</tr>
<tr>
<td>MOD14 C5</td>
<td>Active Fire</td>
<td>3</td>
<td>100 m2 @ 800 K 75%</td>
</tr>
<tr>
<td>MCD 45 C5</td>
<td>Burned Area</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>MOD15 C5</td>
<td>LAI / fPAR</td>
<td>2 / 1</td>
<td>+/- 0.50-0.66 / +/- 0.12</td>
</tr>
<tr>
<td>MOD17 C4</td>
<td>GPP / NPP</td>
<td>2</td>
<td>+/- 10%</td>
</tr>
<tr>
<td>MOD29 C5</td>
<td>Sea Ice</td>
<td>2</td>
<td>92%, +/- 1.3 K</td>
</tr>
<tr>
<td>MCD43 C5</td>
<td>BRDF / Albedo</td>
<td>2</td>
<td>+/- 5%</td>
</tr>
<tr>
<td>MOD44 C4</td>
<td>VCF</td>
<td>1</td>
<td>+/- 11-16 %</td>
</tr>
</tbody>
</table>
Core Sites

- EOS Core sites
  - Easily accessible / existing research facilities / heritage
  - Homogeneous land cover
  - Represent globally extensive/important biomes
MODLAND Validation

• Well characterized across North America

MOD12 Land Cover  - Stage 2
Aeronet, Volunteer field data - Point-Pixel

MOD13 Vegetation Index  - Stage 2
Landsat, ASTER, SPOT, Ikonos, AVIRIS, FLUXNET, Field- Scaling

MOD15 LAI / ƒ PAR  - Stage 2/1
Landsat, SPOT, Ikonos, AVIRIS, FLUXNET, Field- Point - Pixel, Scaling

MOD17 Gross/Net Primary Production  - Stage 2
Landsat, FLUXNET, Field- Point - Pixel, Scaling

MCD43 BRDF / Albedo - Stage 1
Landsat, ASTER, Ikonos, BSRN, FLUXNET, Aeronet- Scaling
Validation Datasets

- Science data networks
- Independent field campaigns
- Volunteer networks
  - GLOBE, NPN, Plantwatch
- Automatic weather stations
- Coordinated field campaigns
Validation Methods

- Spatial representativeness
- Temporal seasonality
- Image acquisition must be co-incident with field campaign

High resolution imagery (20-30m) *Landsat  
*Quickbird  
*ASTER

LAI Hemiphot

LAI reference map

Transfer Function

Aggregate & Relate

Accuracy Assessment

Moderate Resolution LAI

Working Group on Calibration & Validation
Validation Methods

- **Product inter-comparison:**
  - Evaluation of spatial & temporal *consistency* between products
  - Highlights regions/temporal periods where detailed direct validation studies are warranted

- Does **NOT** constitute validation or accuracy assessment
International Validation Activities

CEOS WGCV Land Product Validation Sub-group:

• Foster **quantitative validation** of *higher level global land products* derived from remotely sensed data, in a traceable way, and to relay results so they are relevant to users

• To increase the quality and efficiency of global satellite product validation by developing and promoting international standards and protocols for:
  • Field sampling
  • Scaling techniques
  • Accuracy reporting
  • Data / information exchange

• To provide feedback to international structures (GEOSS) for:
  • Requirements on product accuracy and quality assurance (QA4EO)
  • Terrestrial ECV measurement standards
  • Definitions for future missions
Sub-group structure

Chair: Joanne Nightingale 2010 - 2013  
(NASA GSFC)

Vice-Chair: Gabriela Schaepman-Strub  
(University of Zurich)

Support: Jaime Nickeson  
(NASA GSFC)

8 Land Product Focus Groups – 2 international co-leads
<table>
<thead>
<tr>
<th>Focus Group</th>
<th>North America</th>
<th>Europe / Other</th>
<th>Listserv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Cover*</td>
<td>Pontus Olofsson (Boston University)</td>
<td>Martin Herold (Wageningen University, NL)</td>
<td>137</td>
</tr>
<tr>
<td>Fire* (Active/Burned Area)</td>
<td>Luigi Boschetti (University of Maryland)</td>
<td>Kevin Tansey (University of Leicester, UK)</td>
<td>73</td>
</tr>
<tr>
<td>Biophysical - LAI*</td>
<td>Richard Fernandes (NR Canada)</td>
<td>Stephen Plummer (Harwell, UK)</td>
<td>80</td>
</tr>
<tr>
<td>Biophysical - fAPAR*</td>
<td>Fred Huemmrich (NASA GSFC)</td>
<td>Nadine Gobron (JRC, IT)</td>
<td>80</td>
</tr>
<tr>
<td>Surface Radiation</td>
<td>Crystal Schaaf (Boston University)</td>
<td>Gabriela Schaepman (University of Zurich, SW)</td>
<td>41</td>
</tr>
<tr>
<td>Land Surface Temperature*</td>
<td>Simon Hook (NASA JPL)</td>
<td>Jose Sobrino (University of Valencia, SP)</td>
<td>65</td>
</tr>
<tr>
<td>Soil Moisture*</td>
<td>Tom Jackson (USDA)</td>
<td>Wolfgang Wagner (Vienna Uni of Technology, AT)</td>
<td>48</td>
</tr>
<tr>
<td>Land Surface Phenology</td>
<td>Jeff Morisette (USGS)</td>
<td>Jadu Dash (University of Southampton, UK)</td>
<td>76</td>
</tr>
<tr>
<td>Snow/Ice*</td>
<td>Dorothy Hall (NASA GSFC)</td>
<td>Jouni Pulliainen (Finish Inst of Meteorology, FI)</td>
<td>13+</td>
</tr>
</tbody>
</table>
Role of Focus Groups

• Engage community members (via listserv/website)
  – Periodic updates sent to mailing lists
  – Meeting announcements on website

• Organize topical workshops (of opportunity) within leadership term
  – Soil Moisture – May 2011
  – Land Cover – June 2011
  – LAI/fPAR/OLIVE – February 2012
  – Phenology – September 2012

• Expand LPV activities, field sites, collaboration **globally**

• Lead the development and writing of “best practice” **land product** validation protocols

• Lead **product inter-comparison** activities

• Define product error definitions for ECV’s / LTDR’s for the climate modeling community
Land Product Protocols

- “Best practice” internationally accepted standards for land product validation
  - Current: knowledge, data, tools & methods
  - Peer-reviewed
  - CEOS endorsed/published
  - Validation Protocol Special Issue online journal 2012

Draft validation protocols:
- Leaf Area Index
- Burned Area
- Land cover area change
Land Product Protocols

- Protocol key attributes:
  - **Background / product definitions** (ECV)
  - **Accuracy assessment** (comparison with in-situ, high resolution image reference data)
    - Existing data sets, field sites, sampling schemes, data quality issues
    - Spatial and temporal requirements for new datasets
  - **Product Consistency** (repeatability of products through time)
    - Address issues concerned with sensor calibration, data-reprocessing, algorithm refinement
  - **Product Inter-comparison**
  - **Recommendations / Conclusions**
LPV Website

- For additional information about each focus area please visit: http://lpvs.gsfc.nasa.gov/
Summary and Recommendations

- Accuracy requirements are not yet clearly defined by users
- Validation results are primarily used for algorithm improvement
- Scaling field measurements to high-resolution image reference maps is a fundamental validation approach
- Core sites, operational network data & product inter-comparison activities are essential for global validation
- Investment of time and resources into strengthening existing global networks is critical for Validation activities
- Development of international validation standards and protocols for LPV is necessary
- Space Agency investment in land product validation activities to improve quality, accuracy and uncertainty estimation is essential