Session Introduction

SIT Chair
CEOS SIT Technical Workshop 2020
Session and Agenda Item #2.2.1
9 September 2020
SST-VC ARD Perspectives
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CEOS SST-VC SST-VC co-leads
CEOS SIT Technical Workshop 2020
Session and Agenda Item #2.2.2
9 September 2020

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Introduction

• A working ARD definition review
• ARD survey for Oceans
  o Results of the MODIS Aqua/Terra Surface Temperature (SST) ARD assessment and recommendations
  o Review of assessment criteria and recommendations
  o ARD delivery and services for L1/L2 - a thought experiment
• Ways forward with other ocean datasets
• Summary
An ARD definition

• Time series data pre processed for further scientific (and interdisciplinary) analysis
  o Ready for
    ▪ Time series analysis
    ▪ Subsetting
    ▪ Regridding/Reprojection/Recombination/Reformatting
    ▪ New compute platforms (e.g., cloud, noSQL database)
  o Processed for
    ▪ Environmental and physical corrections at pixel level
    ▪ Big Data format
  o Documented for
    ▪ Data processing, quality, and error assessment
• ARD foundation definition separate from deployment or services
Level 4 SST ARD existing example

- Cloud based AWS MUR in Zarr format
  - Created by Chelle Gentemann (Farallon Institute) et al.
  - Part of the Amazon Web Service (AWS) Open Data Registry on their cloud platform
    - [https://registry.opendata.aws/mur/](https://registry.opendata.aws/mur/)
    - GitHub: [https://github.com/pangeo-gallery/osm2020tutorial](https://github.com/pangeo-gallery/osm2020tutorial)
  - Provides a complete ecosystem based on Pangeo, Xarry, Dask, Jupyter and Binder to manipulate the MUR Zarr dataset on a few or >100 CPUs
  - Compute credits provided by Amazon
  - Supported by the NASA IMPACT program
• Goal: assess the ARD readiness of **GHRSSST MODIS Aqua/Terra SST Level 2P** datasets
  - Together represent multi decadal SST observations starting in 1999 (Terra) and 2002 (Aqua)
    ▪ Combined 100 TB size
  - Recently reprocessed to v2019.0 with improved cloud screening
  - Have been available in a GHRSSST specification since 2006
    ▪ Complete CF/ACDD/ISO granule metadata
    ▪ Pixel level uncertainty, quality flagging and auxiliary information
The Assessment

- Using the CAR4L Surface Temperature template
  - Four sections: General, Per Pixel, Radiometric/Atmos Corrections, Geo Corrections
  - Total 36 assessment factors
- Overall nearly every category sufficiently addressed (More details next slide)

<table>
<thead>
<tr>
<th></th>
<th>Threshold</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Metadata</td>
<td>15 Pass/ 1 Partial Pass / 0 Fail</td>
<td>11 Pass / 3 Partial Pass/ 2 Fail</td>
</tr>
<tr>
<td>Per pixel</td>
<td>7 Pass / 0 PP / 1 Fail / 5 NA</td>
<td>2 Pass/ 4 PP / 2 Fail / 5 NA</td>
</tr>
<tr>
<td>Rad/Atmos Corrections</td>
<td>5 Pass/ 0 PP/ 0 Fail / 2 NA</td>
<td>5 Pass/ 0 PP /0 Fail / 2 NA</td>
</tr>
<tr>
<td>Geo Corrections</td>
<td>1 PP</td>
<td>1 PP</td>
</tr>
</tbody>
</table>
Based on these assessment results we rank these MODIS SST datasets with a “grade” of: B+ / A-

Positive factors

- Complete granule level metadata in CF /ACDD in netCDF4 data model
- Complete pixel level quality and uncertainty information
- Well described coordinate systems
- Bonus: all variables described with `coverage_content_type` attribute (ISO 19115 adapted to ACDD v1.3)
  - defines variable as physical measurement, quality information, auxiliary information etc.
- Bonus: variables described with CF standard names where appropriate
Review continued

• Negative factors
  o Algorithm and other provenance information not completely documented
  o Quality level “condition” tracing not readily available
  o Solar and satellite viewing angles missing
• Other observations
  o Some factors not relevant
   ▪ Projection information.
     ▪ These are unprojected L2 products
     ▪ Pixels don’t “line up” as in gridded L3/L4
   ▪ Geometric Correction not as applicable
  o Some factors are more important than others
What would a L2 MODIS SST ARD service look like?

- Level 2 data are ungridded. But a preferable format for power users that have requirements for the native data space/time resolution.
- With an assumption that they are stored in a cloud environment so processing could occur next to the native data. Necessary services for L2 manipulation would be:
  - A granule discovery service (e.g., Earthdata search, STAC)
  - A subsetting service (e.g., Harmony API)
  - A reprojection service (e.g., Harmony API with GDAL)
  - A reformatting service (e.g., Harmony API)
- In principal if you had all of these and compute assumptions were met one could create a gridded “data cube” at the exact spatial and temporal regions of interest.
Applications to other SST datasets

- The CARD4L assessment can be applied to other GHRSSST datasets as well.
- The GHRSSST catalog currently represents over 90 datasets.
- An ongoing activity in the SST-VC will be to engage other GHRSSST dataset producers of popular datasets to do an assessment.
- Because of the common data/model the answer should mostly be the same.
  - But there are nuances in the algorithm documentation/uncertainty derivation/auxiliary information that a survey can draw out.
  - Possible outcome: Consideration of consistent definitions and terminology e.g. harmonisation of SST definitions such as SSTskin, SSTsub-skin so that different sensors are delivering data formulated (and with uncertainties assessed) in the same way.
Summary

• Provided a review of an ARD definition and a working example of a L4 SST ARD
• Presented the results of an assessment of L2P MODIS Aqua/Terra SST datasets
  o Overall very positive outcome
    ▪ Coordinate systems, uncertainty information, quality information documented
    ▪ Standardized metadata for machine readability
  o The foundation state of these datasets are ARD and lend themselves to further data manipulation services (thought experiment)
  o CAR4L assessment could be improved with a quantitative scoring and factor weighting
• More ARD assessments will be performed in the SST-VC community and collaboration with others is welcomed
• There are ongoing complementary NASA/Interagency ARD activities such as CEOS COVERAGE, CEOS Interoperability Lab, NASA/ESA MAAP etc.
The Atmospheric Composition Virtual Constellation (AC-VC) goal is to collect and deliver data to improve monitoring, assessment, and predictive capabilities for changes in the ozone layer, air quality, and climate forcing.

The atmospheric constituents products are typically column/profiles of trace and greenhouse gases:
- ozone profiles
- aerosol optical depth
- column-averaged carbon dioxide
- ...

Most atmospheric composition instruments are sampling systems, not imagers.

A constellations of polar orbiting (LEO) and geostationary (GEO) air-quality sensors is being deployed:
- The provision of standardized LEO/GEO air-quality ARD will be critical to support direct analysis using multi-sensor data
- The operational products of current missions like TROPOMI/Sentinel-5 Precursor already cover several characteristics expected from analysis ready data.
CARD4L Description Document and TROPOMI/S5P L2 products

- **General Metadata**
  - Compliant

- **Quality Metadata**
  - Compliant

- **Measurement-based / Radiometric Calibration**
  - Not applicable

- **Geometric Calibration**
  - Atmospheric products are usually provided in the satellite-grid and not in a regular-grid

- **Solar and View Angle Correction**
  - This “Correction” is not applicable. The radiative transfer modeling used for atmospheric retrievals takes into account solar and view angles

- **Atmospheric Correction**
  - Not applicable
CARD4L PFS Requirements and TROPOMI/S5P L2 products

- **General Metadata**
  - Traceability, Metadata Machine Readability, Data Collection Time, etc.
    - Compliant
  - Geometric Correction Methods, Spectral Bands, etc.
    - Not applicable

- **Per-Pixel Metadata**
  - Metadata Machine Readability, Solar and Viewing Geometry, etc.
    - Compliant
  - Incomplete Testing, Saturation, etc.
    - Not applicable

- **Radiometric and Atmospheric Corrections**
  The name of this requirement is misleading for atmospheric products, but the content applies
  - Measurement, Measurement Uncertainty
    - Compliant

- **Geometric Corrections**
  Not applicable
• The usability of Atmospheric Level-2 products as ARD is limited, Level-3 (gridded data) and Level-4 (fluxes, sources/sinks) are needed to create useful ARD products
  o Atmospheric instruments often provide incomplete spatial coverage and/or temporal coverage on time scales over which the trace gas or aerosol concentrations can be changed by local production/loss or transport.
  o The observed concentration of an atmospheric trace gas or the abundance of an aerosol species is determined by both its local sources and sinks and by the ambient wind field.
  o In general, atmospheric Level-2 products can’t be ingested in Geospatial Data Cubes

• Considerable work is needed to adapt and extend the CARD4L Framework (Definition, PFS and Product Assessment) to the Atmosphere domain
  o AC-VC propose to perform a study of the requirements for specific atmospheric ARD products including reactive gases, aerosols and greenhouse gases.
  o That study could evolve into a white paper and/or a roadmap for a future atmospheric ARD Framework.
AC-VC backup link to PPT

- [https://drive.google.com/file/d/1PErXKmywnO0oY4bnVo6TXusAxJfldk_a/view?usp=sharing](https://drive.google.com/file/d/1PErXKmywnO0oY4bnVo6TXusAxJfldk_a/view?usp=sharing)
CEOS-COAST & CEOS ARD

Paul M. DiGiacomo
NOAA/NESDIS
CEOS-COAST Chair

CEOS SIT Technical Workshop 2020
Session and Agenda Item #2.2.4
9 September 2020
• CEOS Coastal Observations and Applications Study Team (CEOS-COAST): Initiated at 33\textsuperscript{rd} CEOS Plenary to define a CEOS Coastal Strategy and facilitate engagement with key international stakeholders

• Bridging land and aquatic observations within CEOS, helping to integrate across multiple CEOS entities and domains, both thematic and technical.

• Leveraging CEOS Systems, services and interoperability approaches, including the CEOS Analysis Ready Data (ARD) framework already demonstrated for terrestrial and oceanic applications.

• Facilitating the broader utilization of Earth observations for greater societal benefits within coastal zones and enhancing CEOS engagement with external stakeholders such as GEO, IOC/GOOS, UN Environment, WMO and the UN Decade of Ocean Science for Sustainable Development (2021-2030).
• CEOS Coastal Observations and Applications Study Team (CEOS-COAST): Initiated at 33rd CEOS Plenary to define a CEOS Coastal Strategy and facilitate engagement with key international stakeholders

  • Bridging land and aquatic observations within CEOS, helping to integrate across multiple CEOS entities and domains, both thematic and technical.
  • Leveraging CEOS Systems, services and interoperability approaches, including the CEOS Analysis Ready Data (ARD) framework already demonstrated for terrestrial and oceanic applications.

Goals of this session (Emphatic yes to All!):
- Review outcomes from the SST-VC ocean domain ARD survey and what CEOS ARD for SST might look like.
- Share the work on the USGS Aquatic Reflectance Demonstration Product and related Product Family Specification
- Explore what changes may be needed to the CARD4L Framework to allow it to go ‘beyond land’; agree on those steps.
- Present and discuss the proposal to have LSI-VC work with other VCs to generalise the CARD4L Definition so that it is applicable to all domains.
- Identify options to expand the CEOS ARD for Land Framework to Oceans and Atmosphere. Identify leads from non-land areas (Coasts, Ocean, Atmosphere) to work through CEOS ARD for those areas.
• **What**: Successful realization and utilization of trans-boundary Analysis Ready Data (ARD) will be one of the unifying factors & primary engines that drives the COAST effort forward (NB: heritage/non-ARD data sets are of vital importance as well)

• **Why**: Because there have been significant challenges to date, and more so great opportunities looking ahead, in bridging and coordinating geophysical satellite data across the land-sea (~aquatic) interface, as well as *in situ* and diverse biological (and ultimately socio-economic) data sets – ARD provides a common framework!

• **How**: As COAST moves toward implementation, we will guide and leverage current and planned capabilities and approaches within CEOS for ARD, i.e., SST-VC, CARD4L/LSI-VC, USGS Aquatic Reflectance Demo, COVERAGE and WGISS/SEO
CEOS Coastal Observations & Applications Study Team: COAST

Cross-Cutting Needs:
- Analysis ready data
- Tools, products & services
- User-centric web portals

COAST Project Component
Land to Sea Impacts (~ biological/ecological)

Ecosystems, Water Quality & Habitats
- Sediment loading (benthic habitat impacts)
- Coastal eutrophication (SDG 14.1.1. et al.)

COAST Project Component
Sea to Land Impacts (~ physical forcing)

Coastal Disasters/Hazards: Flooding & Inundation
- Large-scale coastlines: urbanized, rural/agricultural, mixed use
- Small-island states: Coral-reef lined

Products needed:
- Land cover/use
- Shoreline mapping/elevation
- Precipitation and Discharge
- Sediment and Nutrient loadings
- Habitat/water quality maps
- et al.

Partners/Stakeholders
- Blue Planet
- AquaWatch
- UN Environment
- IOC/WMO

COAST - all about the interfaces: Processes, Data, Geography, Science & People
What will make COAST happy? Trans-boundary CEOS ARD!
Key findings per CEOS-COAST White Paper #3: Cross-Cutting Tools, Systems & Services:

- COAST should leverage the CEOS Analysis Ready Data (ARD) framework, WGISS Interoperability Lab, Virtual Constellations, GHR SST, COVERAGE et al. developed approaches, tools, and services as available/fit for purpose.

- COAST should embrace…. the level of data that application developers desire, referred to as Analysis and Access of ARD in the CEOS Interoperability Terminology Report.

- Many COAST relevant ARD discussions were initiated or continued within CEOS sub-communities (CEOS/WGISS, GEO AquaWatch, LSI-VC, SST-VC) with COAST a likely benefactor of streamlined, open source, formats trending toward achievement of FAIR data principles (Findable, Accessible, Interoperable, and Reusable/Reproducible).

- GEO AquaWatch, in association with COAST, is providing recommendations to CEOS for core ARD requirements to be adopted for the aquatic side - including addressing when available land requirements / approaches incompletely characterize or fulfill aquatic data product needs, or are not applicable, at least not w/o corollary modifications to suit the aquatic realm. This includes actively supporting the Aquatic Reflectance Product Family Specification (PFS) Science Expert Review Panel led by N. Pahlevan, S. Labahn, C. Barnes and A. Siqueira.
Aquatic Reflectance

Chris Barnes / Nima Pahlevan
CEOS SIT Technical Workshop 2020
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Landsat Aquatic Reflectance is a provisional on-demand USGS product that provides nondimensional normalized remote-sensing reflectance for coastal and inland waters, assuming a perfectly Lambertian surface.

- **Region**: Global
- **Sensor**: Landsat 8 Operational Land Imager
- **Date availability**: April 2013 - present
- **Application**: coastal regions compared to highly eutrophic/turbid inland waters

Potential to make a valuable contribution to:
- Environmental monitoring capabilities for coastal and inland aquatic ecosystems
- Aquatic science
History of Algorithm Development

• Principal Investigator and USGS-NASA 2018-2023 Landsat Science Team member: Dr. Nima Pahlevan (SSAI at NASA/GSFC)

• The atmospheric correction algorithm is directly derived from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) Data Analysis System (SeaDAS) package distributed by NASA’s Ocean Biology Processing Group

• The remote-sensing reflectance output of SeaDAS is multiplied by Pi (i.e., ~3.142) to obtain a dimensionless reflectance referred to as Aquatic Reflectance
  o PI recommendation to make the product unitless
  o “Aquatic Reflectance” is an evolving product in the U.S. and international aquatic communities
The Aquatic Reflectance product is available for Landsat 8 visible bands only (i.e., Bands 1-4)

The near infrared (NIR) and short-wave infrared (SWIR) bands are consumed by atmospheric compensation and hence are not delivered in the final product (PI recommendation)

The processing flags (containing detailed information about the atmospheric correction), Landsat Level-2 Pixel Quality Assessment (QA), and metadata are also delivered within the product file package

<table>
<thead>
<tr>
<th>Description</th>
<th>Range</th>
<th>Valid Range</th>
<th>Scale Factor</th>
<th>Unit</th>
<th>Fill Value</th>
<th>Data Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquatic Reflectance (bands 1 to 4)</td>
<td>-4,720 to 31,420</td>
<td>0 to 31,420</td>
<td>0.00001</td>
<td>Unitless</td>
<td>-9999</td>
<td>INT16</td>
</tr>
<tr>
<td>Processing Flags</td>
<td>0 to 2³¹-1</td>
<td>0 to 2³¹-1</td>
<td>NA</td>
<td>NA</td>
<td>-9999</td>
<td>INT32</td>
</tr>
<tr>
<td>Level 2 Pixel Quality Assessment</td>
<td>0 to 65535</td>
<td>1 to 2047</td>
<td>NA</td>
<td>Bit Index</td>
<td>1 (bit 0)</td>
<td>UINT16</td>
</tr>
<tr>
<td>Level 2 XML Metadata file</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
### Pixel QA Processing Flags

#### Table 1: Pixel QA Processing Flags

<table>
<thead>
<tr>
<th>Bit</th>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>ATMFAIL</td>
<td>Atmospheric correction failed</td>
</tr>
<tr>
<td>1</td>
<td>LAND</td>
<td>Designated by the input land file (off for Landsat 8 processing)</td>
</tr>
<tr>
<td>2</td>
<td>PRODWARN</td>
<td>Intermediate product value falls outside the min/max range</td>
</tr>
<tr>
<td>3</td>
<td>HIQLINT</td>
<td>If glint coefficient &gt; glinthreshold (0.005). This is not checked for land or night pixels</td>
</tr>
<tr>
<td>4</td>
<td>HILT</td>
<td>Flags high total radiance (LT) measured by sensor (not used)</td>
</tr>
<tr>
<td>5</td>
<td>HISATZEN</td>
<td>View angle &gt; threshold (90 deg)</td>
</tr>
<tr>
<td>6</td>
<td>COASTZ</td>
<td>Cloud based on the bathymetry file, based on the latitude/longitude of the current pixel</td>
</tr>
<tr>
<td>7</td>
<td>SEADAS _ CLOUD</td>
<td>Cloud based on the SeaDAS algorithm</td>
</tr>
<tr>
<td>8</td>
<td>CLOUD _ SHADOW</td>
<td>Cloud shadow based on the cloud mask algorithm</td>
</tr>
<tr>
<td>9</td>
<td>CLOUD</td>
<td>Cloud based on the cloud mask algorithm</td>
</tr>
<tr>
<td>10</td>
<td>COCCOLITH</td>
<td>Flags a failure in the chlorophyll calculation</td>
</tr>
</tbody>
</table>

#### Table 2: Pixel QA Processing Flags (continued)

<table>
<thead>
<tr>
<th>Bit</th>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>TURBDW</td>
<td>Flags turbidity. If LwB4 / FomnB4 &lt; 0.0012. Where LwB4: water-leaving band 4 value, FomnB4: nominal F0 value for band 4 F0: the mean solar flux</td>
</tr>
<tr>
<td>12</td>
<td>HISOLZEN</td>
<td>Solar angle &gt; threshold (70 deg)</td>
</tr>
<tr>
<td>13</td>
<td>Unused</td>
<td>NA</td>
</tr>
<tr>
<td>14</td>
<td>LOWLW</td>
<td>If water-leaving radiance band 3 (LwB3) value &lt; 0.15 (rdwmin)</td>
</tr>
<tr>
<td>15</td>
<td>CHILFAIL</td>
<td>Flags a failure in the chlorophyll calculation</td>
</tr>
<tr>
<td>16</td>
<td>NAVWARN</td>
<td>Mainly used for fill pixels</td>
</tr>
<tr>
<td>17</td>
<td>Unused</td>
<td>NA</td>
</tr>
<tr>
<td>18</td>
<td>RRSWARN</td>
<td>Rrs &lt; min_valid or Rrs &gt; max_valid</td>
</tr>
<tr>
<td>19</td>
<td>MAXAERITE</td>
<td>Number of iterations for the aerosol corrections exceeds the maximum threshold (10)</td>
</tr>
<tr>
<td>20</td>
<td>MODGLINT</td>
<td>Glint coefficient &gt; minimumglint threshold (0.0001)</td>
</tr>
</tbody>
</table>

#### Table 3: Pixel QA Processing Flags (continued)

<table>
<thead>
<tr>
<th>Bit</th>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>CHLWARN</td>
<td>Chlorophyll &lt; min_valid or chlorophyll &gt; max_valid</td>
</tr>
<tr>
<td>22</td>
<td>ATMWARN</td>
<td>If the value is invalid, then set ATMWARN. Also set if MAXAERITE is set. Based on ancillary QC flags (ozone, water vapor, RH, wind speed, surface pressure)</td>
</tr>
<tr>
<td>23</td>
<td>Unused</td>
<td>NA</td>
</tr>
<tr>
<td>24</td>
<td>SEANCE</td>
<td>Controle via the IceFile, based on the latitude/longitude of the current pixel</td>
</tr>
<tr>
<td>25</td>
<td>NAVFAIL</td>
<td>If there is an invalid latitude/longitude value</td>
</tr>
<tr>
<td>26</td>
<td>FILTER</td>
<td>NA</td>
</tr>
<tr>
<td>27</td>
<td>Unused</td>
<td>NA</td>
</tr>
<tr>
<td>28</td>
<td>Unused</td>
<td>NA</td>
</tr>
<tr>
<td>29</td>
<td>HIFOL</td>
<td>If degree of polarization for any band is &gt; hipol (0.5)</td>
</tr>
<tr>
<td>30</td>
<td>PRODFAIL</td>
<td>Processing failure (data values are outside the legal allowed, too many bands, illegal values, etc.)</td>
</tr>
<tr>
<td>31</td>
<td>Unused</td>
<td>NA</td>
</tr>
</tbody>
</table>
Now available on-demand through the USGS EROS Science Processing Architecture (ESPA) for Landsat 8 Collection 1 and eventually with Landsat 8 Collection 2 in mid-2021

- https://espa.cr.usgs.gov/

**Level-2 Products**

- Surface Reflectance - *Not available for thermal or panchromatic bands*
- Aquatic Reflectance - *Only Available for Landsat 8*
- Surface Temperature
- Top of Atmosphere Reflectance
- Brightness Temperature - *Thermal band TOA processing*
- Pixel QA
- Spectral Indices
Other Resources

- **USGS Landsat Missions Website:** usgs.gov/landsat
  - Package Content, Auxiliary Data, Caveats and Constraints & Documentation
  - Contact custerv@usgs.gov for additional product support
CARD4L
Product Family Specification

- Aquatic Reflectance CARD4L PFS currently in development
  - Lead by: **Nima Pahlevan** (NASA) & **Chris Barnes** (USGS/ KBR)
  - Coordinated by: **Andreia Siqueira** (GA)
  - Expert Review Panel from the aquatic user community
    - RIT - EPA - GEO Aquawatch
    - NASA - Kent State - USGS
    - U of MN - NOAA
    - ESA - EO Map Australia
    - CSIRO - IVOS

- Met with review panel in June and September, 2020
  - Further discussion on atmospheric adjacency effects and BRDF
  - Working on scheduling another review panel

- Next steps
  - Tech edit and distribute final draft PFS to LSI-VC for review
  - Review and endorse final AR PFS at LSI-VC-11 (target)
Discussion topics

• Beyond Land: Options to expand the CEOS ARD for Land Framework to Oceans and Atmosphere
  o Improving/Testing the Definition
  o Additions to the framework (e.g., advisory notes).
  o Options to trial the framework for Coastal, Ocean and Atmosphere data products
    o Improving ARD services and deployment
Committee on Earth Observation Satellites

Wrap-up

SIT Chair
CEOS SIT Technical Workshop 2020
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9 September 2020
Plenary report points
Additional materials
CEOS Analysis Ready Data for Land (CARD4L) are satellite data that have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets.

The definition of CARD4L is not exclusive or prescriptive. A range of data products will be produced by CEOS Agencies to meet the needs of a diverse user community and many of those products are analysis ready data to their users. However, this definition of CARD4L reflects the attributes of fundamental measurement products for the majority of global remote sensing users with land imaging applications, and are the minimum level required to support time series analysis and data interoperability. CARD4L will therefore be geophysical measurements that are comparable in space and time, with sufficient per-pixel (observation) metadata to enable users to select ‘observations of interest’ for their analyses.