Validation of OCI aerosol and cloud properties

Andrew Sayer
GESTARRII-UMBC at NASA GSFC
andrew.sayer@nasa.gov
## OCI required atmospheres data products and main heritage validation sources

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Range</th>
<th>Uncertainty goal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerosols</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AOD at 380 nm</td>
<td>0-5</td>
<td></td>
</tr>
<tr>
<td>AOD at 440, 500, 550, 675 nm</td>
<td>0-5</td>
<td></td>
</tr>
<tr>
<td>FMF at 550 nm</td>
<td>0</td>
<td>Max (0.06 or 40%)</td>
</tr>
<tr>
<td><strong>Clouds</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud mask</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>CTP (for COT&gt;3)</td>
<td>100-1000 mb</td>
<td>60 mb</td>
</tr>
<tr>
<td><strong>CLR</strong></td>
<td>5-100</td>
<td>Liquid: 25%; Ice: 35%</td>
</tr>
<tr>
<td></td>
<td>5-50 μm</td>
<td>Liquid: 25%; Ice: 35%</td>
</tr>
</tbody>
</table>

**Sun photometry**, e.g. Aerosol Robotic Network (**AERONET**) and Maritime Aerosol Network (**MAN**)  
**Ground/space lidar, radar, and microwave radiometers**  
**Cloud probes** on aircraft

Not an exhaustive list or guaranteed to always be available!
Aerosols
AERONET is the primary validation source for most satellite remote sensing and modeling approaches

- Hundreds of active sites covering a variety of aerosol and surface conditions
- High observation frequency, low latency, long time series
- Freely available data
- Consistent measurement, calibration, and processing protocols
- But:
  - Some sampling gaps
  - Limited densely-sampled (<<100 km spacing areas)

Sites active in 2022, from https://aeronet.gsfc.nasa.gov
Sun photometry provides accurate AOD and more

- **Autonomous operations**
- **Spectral AOD uncertainty 0.01-0.02**
- **Water vapour, derived Ångström exponent & FMF**
- **Sky-scans for additional aerosol properties**

Video by A. Sidel, from https://earth.gsfc.nasa.gov/climate/data/deep-blue/science

UMBC direct-Sun data from https://aeronet.gsfc.nasa.gov
The Maritime Aerosol Network is a ship-based complement to AERONET

- Hand-held instruments operated \textit{manually}
- AOD uncertainty $\sim0.02$
- Sparse but some common \textit{repeat routes}

Photo by B. Howl, from https://earth.gsfc.nasa.gov/climate/data/deep-blue/science

MAN cruises up to present, from https://aeronet.gsfc.nasa.gov
Typically, we spatially average satellite retrievals within ±25 km…
... and temporally average ground observations within ±30 minutes

Eck et al., ACP (2014)

Images used for timing illustration context purposes only; copyrights are owned by their respective owners and no challenge to copyright or trademark are implied.
Simple statistics can give us a basic picture…

- Measures relating to:
  - Degrees of *association* (correlation)
  - *Bias* (mean, median)
  - Error *magnitude* (mean or median absolute error; root mean squared error)
  - Performance *relative to expectation* or *goal* (pixel-level uncertainty, application requirement, etc…)

- Each has *caveats* relevant to interpretation!
  - Data are not independent random draws, skewed distributions, variable errors, etc…
  - Many papers use statistics *inappropriately*, please take care
... but more detailed analysis is warranted, where data volume permits

- Stratified analyses give insights relevant for data users as well as algorithm refinement
- Remember the retrievals we validate are a specific subset of the retrievals we have
  - Can generalise the statistics you get, but only so far
Clouds
Cloud systems can evolve really, really quickly

GOES-14 Super Rapid Scan from https://cimss.ssec.wisc.edu/satellite-blog/archives/13256
Pixel selection for matchups can be difficult

Holz et al., JGR (2008)
The most reliable ground truth for cloud mask comes from active sensors

- Lidar, radar, microwave radiometer…
- Highly sensitive but generally single track or single point
  - Curtain, not swath
- Limited spaceborne options in next few years
  - Several ground sites
  - Airborne data
- Other sensor types and human observers exist

Wang et al., JGR (2016)
Evaluating classifications use different metrics from continuous variables

- Most commonly, with a **confusion matrix**
  - Subset for dependence on e.g., surface type
- Overlap with metrics in e.g. machine learning, medical research disciplines
  - See right-hand side of https://en.wikipedia.org/wiki/Confusion_matrix

<table>
<thead>
<tr>
<th>Truth</th>
<th>Retrieval</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>True positive</td>
<td>False positive</td>
<td></td>
</tr>
<tr>
<td>False negative</td>
<td>False negative</td>
<td>True negative</td>
<td></td>
</tr>
</tbody>
</table>

Accuracy = \( \frac{TP + TN}{TP + FP + FN + TN} \)
Many resources to evaluate cloud mask are also useful for cloud altitude.
For cloud validation it can be useful to stratify by number of layers and optical thickness.

Single-layer, COT>3
True validation of COT and CER is difficult

- Limited/no large-scale true reference-quality data
  - Too many assumptions in most cases
  - Can use cloud probes on aircraft flying in spirals but limited scenes
    - Heterogeneity still a problem
    - Measurement uncertainty can be a problem
- Most of what is done is looking at consistency with other satellite products
  - This is not true validation

Painemal & Zuidema, JGR (2011)
Consistency checks are valuable but are not really validation

- How close is close enough?
- How close do we expect them to be?
- Are they consistent because they’re all good or because they’re all bad?
References and resources

- Satellite imagery is MODIS from https://worldview.earthdata.nasa.gov

- Aerosols
  - AERONET and MAN data from https://aeronet.gsfc.nasa.gov
  - Eck, T. F. et al. (2014), Observations of rapid aerosol optical depth enhancements in the vicinity of polluted cumulus clouds, Atmos. Chem. Phys., 14, 11633–11656, https://doi.org/10.5194/acp-14-11633-2014

- Clouds