Lessons learned from 3 years ESA Climate Change Initiative on improving aerosol retrieval algorithms

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Larisa Sogacheva (FMI)
The goal of the ESA climate change initiative is to produce essential climate variables (ECV) using satellite data, following GCOS requirements.

Users and advisors: climate change community

Focus on European satellites; not exclusively

13 different areas, among which aerosols

Aerosol-cci:

- Started July 2010, 3 years
- Work closely with AEROCOM
- Independent validation
- Initial focus on understanding differences between different algorithms and algorithm improvement
Aerosol-cci brings together the most prominent European aerosol retrieval groups.

Non-European groups contribute.
understand differences of various products

integrate major European EO teams

work with AEROCOM user community

focus on ENVISAT and European sensors
## Aerosol_cci products

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensor (Algorithms)</th>
<th>Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOD, Ångström</td>
<td>MERIS (ALAMO)</td>
<td>2008, over ocean</td>
</tr>
<tr>
<td>AOD, Ångström</td>
<td>POLDER</td>
<td>2008, over ocean</td>
</tr>
<tr>
<td>Absorbing Aerosol Index</td>
<td>OMI (GOME, TOMS)</td>
<td>1978 – 2012, global</td>
</tr>
<tr>
<td>Stratospheric extinction</td>
<td>GOMOS (SCIAMACHY)</td>
<td>2008, global</td>
</tr>
<tr>
<td>AOD, Ångström</td>
<td>MERIS (BAER, STD)</td>
<td>2008, global</td>
</tr>
<tr>
<td>AOD, aerosol type</td>
<td>SCIA/AATSR (SYNAER)</td>
<td>3/6/9/12 2008, global</td>
</tr>
<tr>
<td>AOD, Ångström</td>
<td>AATSR/MERIS</td>
<td>3/6/9/12 2008, global</td>
</tr>
<tr>
<td>Stratospheric extinction</td>
<td>GOMOS/OSIRIS (merged)</td>
<td>2003, global</td>
</tr>
<tr>
<td>AOD, aerosol properties</td>
<td>POLDER (multi-pixel algorithm)</td>
<td>Example scenes, land</td>
</tr>
<tr>
<td>Absorbing AOD (SSA)</td>
<td>AATSR</td>
<td>Examples, glint areas</td>
</tr>
</tbody>
</table>

All products contain pixel level uncertainties / flags
Analysis steps

- **Improve algorithms**: Workshops + experiments (1 month)
  - Optical models, cloud masks, (surface)
  - Post-processing (cloud contamination, bright surface)
  
  Holzer-Popp, et al., AMT 2013

- **Select algorithms**: Round robin exercise (4 months)
  - Best versions for all algorithms
  
  de Leeuw et al., RSE 2013, in press

- **Produce selected ECV products** (entire 2008)
  
  Kinne, et al., in preparation

- At all steps application of the *same validation tools and statistics*
  - Level 2 and level 3
  - Global + regional statistics
  - Scoring (spatial / temporal correlation)
  - Against AERONET / MAN + MODIS / MISR / CALIPSO
Aerosol models
- Choose common aerosol models
- Non-spherical dust model

Aerosol climatology:
- Use common aerosol climatology for the algorithms, where aerosol mixture is not retrieved

Surface reflectance treatment
- compare and improve surface treatment

Cloud detection/screening
- Common cloud mask
- Dust detection
- Sun glint
- Consistency between Aerosol-CCI and Cloud-CCI cloud masks
## Aerosol components

<table>
<thead>
<tr>
<th>aerosol component</th>
<th>refract index real p. (55μm)</th>
<th>refract index imag p. (.55μm)</th>
<th>reff (μm)</th>
<th>geom. st dev (σi)</th>
<th>variance (ln σi)</th>
<th>mode# radius (μm)</th>
<th>comments</th>
<th>aerosol layer height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust</td>
<td>1.56</td>
<td>0.0018</td>
<td>1.94</td>
<td>1.822</td>
<td>0.6</td>
<td>0.788</td>
<td>non-spherical</td>
<td>2-4km</td>
</tr>
<tr>
<td>sea salt</td>
<td>1.4</td>
<td>0</td>
<td>1.94</td>
<td>1.822</td>
<td>0.6</td>
<td>0.788</td>
<td>AOD threshold constraint #</td>
<td>0-1 km</td>
</tr>
<tr>
<td>fine mode weak-abs</td>
<td>1.4</td>
<td>0.003</td>
<td>0.140</td>
<td>1.7</td>
<td>0.53</td>
<td>0.07</td>
<td>(ss-albedo at 0.55 μm: 0.98)</td>
<td>0-2 km</td>
</tr>
<tr>
<td>fine mode strong-abs</td>
<td>1.5</td>
<td>0.040</td>
<td>0.140</td>
<td>1.7</td>
<td>0.53</td>
<td>0.07</td>
<td>(ss-albedo at 0.55 μm: 0.802)</td>
<td>0-2 km</td>
</tr>
</tbody>
</table>

**Dubovik et al., 2002**

Possible Combinations:
1. Mix FM1 & FM2 > FM
2. Mix CM1 & CM2 > CM
3. Mix FM & CM
AEROCOM median, monthly distribution of aerosol components, derived from 12 global models

March

June

September

December
Consistency between Aerosol-CCI and Cloud-CCI cloud masks
Top to bottom:
Baseline,
RR results (best algorithm selected by each group),
Comparisons with AEROCOM median and other algorithms
Analysis tools

- ICARE statistical inter-comparison (level2)
  - versus AERONET
  - versus other satellites (MODIS, MISR, POLDER)
- MPI scoring (level2)
  - Spatial and temporal patterns, bias, noise
  - versus AERONET
- AEROCOM model inter-comparison (level3)

ICARE L2 for ORAC, 4 months over ocean:
Validated products: Lv3 scoring (correlations x,t)
• Scores ATSR Swansea 4.0 versus Swansea 1.0 established against AERONET.
AEROCOM interface

http://aerocom.met.no/cgi-bin/aerocom/surfobs_annualrs.pl?MODELLIST=CCI-AEROSOL-products
AEROCOM interface
AEROCOM interface
### Select algorithms: AATSR4Land

**Common point filter**

<table>
<thead>
<tr>
<th>Algorithm name</th>
<th>NumObs</th>
<th>#</th>
<th>R-CORR</th>
<th>RMS</th>
<th>NMB</th>
<th>%</th>
<th>RMSbc</th>
</tr>
</thead>
<tbody>
<tr>
<td>AATSR_ADV.v1.42</td>
<td>1394</td>
<td></td>
<td>0,822</td>
<td>0,102</td>
<td>-29,7</td>
<td>0,105</td>
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</tr>
<tr>
<td>AATSR_ORAC.v2.02</td>
<td>1394</td>
<td></td>
<td>0,823</td>
<td>0,091</td>
<td>-9,4</td>
<td>0,091</td>
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<tr>
<td>AATSR_SU_v4.0</td>
<td>1394</td>
<td></td>
<td>0,863</td>
<td>0,081</td>
<td>-7,7</td>
<td>0,083</td>
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<tr>
<td>MISR_V31_1x1</td>
<td>276</td>
<td></td>
<td>0,856</td>
<td>0,085</td>
<td>-11,2</td>
<td>0,081</td>
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<tr>
<td>MODIS5.1aqua</td>
<td>1185</td>
<td></td>
<td>0,749</td>
<td>0,114</td>
<td>7,1</td>
<td>0,108</td>
<td></td>
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<tr>
<td>MODIS5.1terra</td>
<td>1285</td>
<td></td>
<td>0,744</td>
<td>0,114</td>
<td>1,5</td>
<td>0,113</td>
<td></td>
</tr>
</tbody>
</table>

- Common point filter reduces number of data points
- AATSR: in general high correlation, low RMS
- SU v4.0 has highest R, lowest RMS, **better than all reference data sets**
- All AATSR retrievals outperform MODIS5.1
- AATSR has significantly less coverage
LV3: AATSR4Sea
Common point filter

<table>
<thead>
<tr>
<th>Algorithm name</th>
<th>NumObs</th>
<th>R-CORR</th>
<th>RMS</th>
<th>NMB</th>
<th>RMSbc</th>
</tr>
</thead>
<tbody>
<tr>
<td>AATSR_ADV.v1.42</td>
<td>87</td>
<td>0.884</td>
<td>0.06</td>
<td>21.10</td>
<td>0.06</td>
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<tr>
<td>AATSR_ORAC.v2.02</td>
<td>87</td>
<td>0.889</td>
<td>0.09</td>
<td>17.90</td>
<td>0.06</td>
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<tr>
<td>AATSR_SU_v4.0</td>
<td>87</td>
<td>0.781</td>
<td>0.08</td>
<td>-11.50</td>
<td>0.08</td>
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<td>MISR_V31_1x1</td>
<td>5</td>
<td>0.984</td>
<td>0.06</td>
<td>3.64</td>
<td>0.07</td>
</tr>
<tr>
<td>MODIS5.1aqua</td>
<td>64</td>
<td>0.916</td>
<td>0.05</td>
<td>4.79</td>
<td>0.05</td>
</tr>
<tr>
<td>MODIS5.1terra</td>
<td>57</td>
<td>0.905</td>
<td>0.05</td>
<td>1.39</td>
<td>0.05</td>
</tr>
</tbody>
</table>

- Low number of reference measurements!
- AATSR: in general high correlation, low RMS
- ADV1.42 and ORAC 2.02 have highest R
- AATSR retrievals are weaker than reference datasets
Was the 4 months analysis representative for the 12 months?

<table>
<thead>
<tr>
<th>Model name</th>
<th>NumObs</th>
<th>R-CORR</th>
<th>RMS</th>
<th>NMB</th>
<th>RMSbc</th>
</tr>
</thead>
<tbody>
<tr>
<td>AATSR_SU_v3.0</td>
<td>1155</td>
<td>0.809</td>
<td>0.132</td>
<td>-13.7</td>
<td>0.138</td>
</tr>
<tr>
<td>AATSR_SU_v3.1</td>
<td>5128</td>
<td>0.795</td>
<td>0.127</td>
<td>-18.8</td>
<td>0.138</td>
</tr>
</tbody>
</table>
Major improvements over precursor AOD datasets

Regional scoring differences between both versions (scoring grows with increased spatial + temporal correlations and decreased bias; based on daily data)
Pixel level uncertainties

Land
Number (-1 ≤ p ≤ 1): 91%

Ocean/Coast
Number (-1 ≤ p ≤ 1): 69%
Global AOD time series

**ENVISAT-AATSR (CCI)**

Evaluated against ~150 AERONET sun photometer surface sites

**Terra-MODIS (NASA)**
equivalent evaluation
Regional time series

N Africa

East Asia
Regional time series

N America

Europe
Stability: RMS

Yearly RMS WORLD

- ECMWF_FBOV.1x1
- MODIS5.1aqua
- MODIS5.1Terra
- AATSR_SU_v4.1

source: AEROCOM
Overall achievements

- Significant algorithm improvement towards GCOS requirements
  - Aerosol optical depth (AATSR; MERIS, PARASOL ocean)
  - Stratospheric extinction (GOMOS)

- AATSR time series 2003 – 2012 consistent with AERONET

- Improved product content and auxiliary information
  - Individual pixel-level uncertainties in products
  - Consistency with Cloud_cci
  - Model simulator for absorbing aerosol index
Activity:
- ECMWF / MACC-II planned data assimilation (early 2014)
- Inter-comparison to other satellites, models
- Example aerosol-cloud interaction study at DLR

Problems
- Limited length of ECV datasets
Lessons learned (1)

- critical mass of experts / open exchange on problems and solutions highly beneficial; including active involvement of users

- 3 steps meaningful to consolidate discussions into improved datasets

- round robin exercise: statistical significance with four months of global data (in 4 seasons); seasonal + regional analysis needed

- prototype system “near science” ensures flexibility for changing user requirements, algorithm, analysis tools
Lessons learned (2)

- 3 AATSR algorithms performing almost equal -> combination needs further investigation (uncertainty-weighted ensemble, combination over different regions) – requires harmonized uncertainties

- Uncertainties demonstrated but need further consolidation and harmonization

- Aerosol type information (Ångström exponent, mixing fractions, pre-scribed aerosol type, absorption AOD) needs further work - highly relevance for applications (e.g. aerosol-cloud interaction)

- Further work needed on surface treatment (nadir algorithms), cloud clearing

- different AOD algorithms and instruments valuable to show uncertainties
Aerosol_cci products
main advantages

- accuracy
  - Very high: PARASOL over ocean and 3 AATSR algorithms

- Coverage
  - ATSR-2 + AATSR enable time series 1995 – 2012

- Information content
  - Very high for PARASOL, good for AATSR
  - Absorption qualitative with absorbing index
  - Vertical with stratospheric product

- General
  - 3 year intensive team dialogue /efforts improved data
  - Significant improvement against baseline algorithms
  - Similar quality to MODIS / MISR over land
  - Pixel level uncertainties / quality indices
  - Documentation at Aerosol_cci website
Information + data

Documentation freely available at

http://www.esa-aerosol-cci.org/

Public open data access at

(user: cci / password: cci)

with acknowledgement to ESA CCI program
**Aerosol_cci Phase 2**  
**Proposed products 2014/15**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensor (Algorithms)</th>
<th>Coverage (planned) - status</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOD, up to 4 wavelengths</td>
<td>ATSR-2 + AATSR (ADV, SU, ORAC)</td>
<td>1995 – 2012</td>
</tr>
<tr>
<td></td>
<td>AATSR / MERIS</td>
<td>2003 - 2012</td>
</tr>
<tr>
<td></td>
<td>SYNAER</td>
<td>2003 - 2012</td>
</tr>
<tr>
<td>Dust AOD</td>
<td>IASI</td>
<td>2006 - 2015</td>
</tr>
<tr>
<td>Stratospheric extinction, AOD, size parameter</td>
<td>GOMOS</td>
<td>1984 - 2005</td>
</tr>
<tr>
<td></td>
<td>SAGE-II, ODIN, OSIRIS, GOMOS</td>
<td>2003 – 2012</td>
</tr>
<tr>
<td>Sentinel demo datasets</td>
<td>SLSTR AOD TROPOMI AAI</td>
<td>2015</td>
</tr>
</tbody>
</table>

**All products contain pixel level uncertainties**
AEROSAT
International Satellite Aerosol Science Network
unfunded, open, independent, international network of aerosol remote sensing scientists (retrieval experts, validation experts, data centers) and users of satellite data

close collaboration with related initiatives: AEROCOM (models), ICAP (forecasts) and AERONET (sun photometers)

Goals

- promote the use of satellite data
- achieve open and active exchange of information
promote the use of satellite data
- as complementary to other sources of information
- to better understand the role of aerosols on climate, climate change, air quality and atmospheric processes

achieve open and active exchange of information
- retrievals and their strengths and limitations
- match requirements of users to technical capabilities
- benefit from the latest technological advances
- standardization (data formats, data standards)
Information on the occurrence and properties of atmospheric aerosol is of crucial importance for climate and atmospheric research, numerical weather prediction and air quality monitoring. Satellite retrieval of aerosol properties, together with ground-based in-situ and remote sensing, and atmospheric models, are the essential tools used to provide aerosol information.

The International Satellite Aerosol Science Network (a.k.a. AERO-SAT) is an initiative to help strengthen collaboration between different research groups around the world working on satellite aerosol retrieval. The AERO-SAT constituting meeting took place in Hamburg (Germany), on 27 September 2013, in association with the 10th annual AeroCom meeting. The terms of reference, contact points and network participants are provided in the pages below.

AERO-SAT is an unfunded activity intended to be of mutual benefit to the scientific work of the network participants.

Objectives
To:
- Advance satellite aerosol retrieval research and product development by providing a mechanism to promote and facilitate international scientific collaboration.
- Federate the satellite aerosol community to provide a more powerful collective voice towards the ecosystem of international projects, funding agencies and space agencies.
- Coordinate scientific activities of mutual benefit (e.g. intercomparisons, common definitions, common tools, common formats, etc.)
- Stimulate communication and coordination between producers of satellite information on aerosol properties and the global user community.
- Identify best practice in retrieval development.
- Promote the long term continuity of satellite aerosol data set production.
- Encourage the open exchange of satellite, model and in-situ aerosol data streams, and harmonized access for users.
- Help users to understand the strengths and weaknesses of different satellite aerosol products by promoting activities to intercompare data sets.

Next Meeting
We aim to hold the next AERO-SAT meeting once again in cooperation with the AeroCom meeting in September 2014 in the USA (tbc).
THANK YOU FOR ATTENTION!