ESA's Climate Change Initiative and the Aerosol ECV

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ESRIN
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Acknowledgement to:

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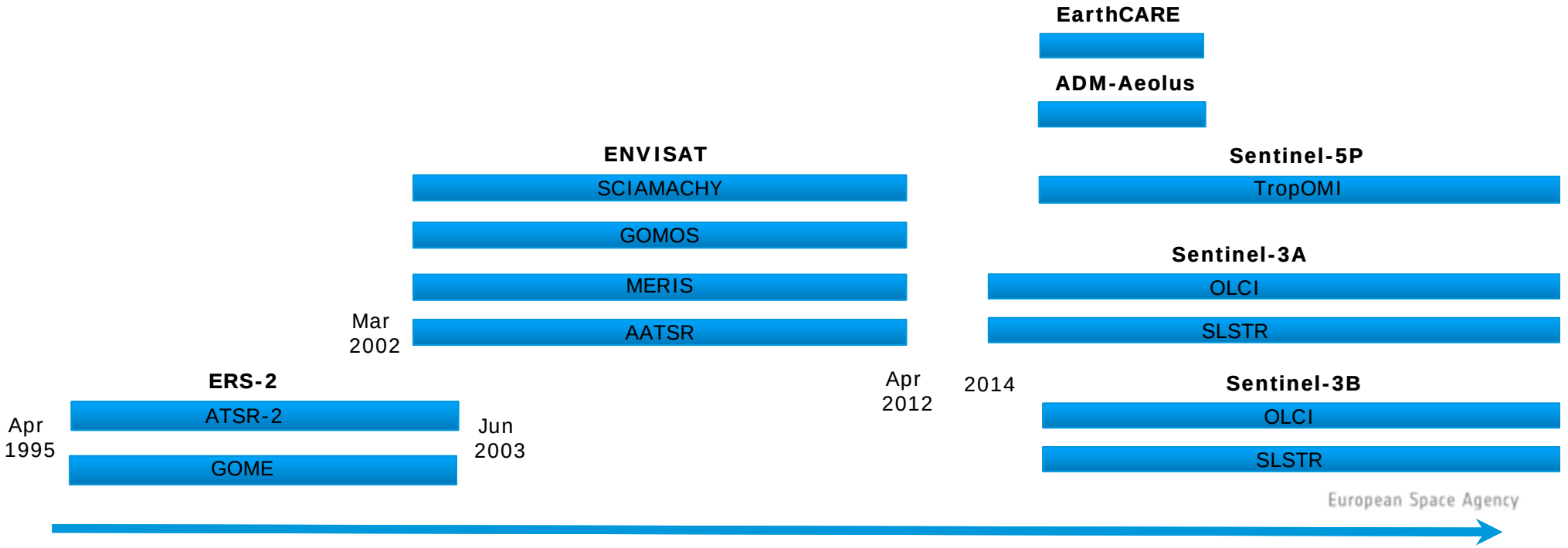
LOA/ICARE	Didier Tanre, Jacques Decscloitres, Pavel Litvinov, Francois-Marie Breon, Oleg Dubovic
BIRA	Christine Bingen, Charles Robert
KNMI	Deborah Stein-Zweers, Pepijn Veefkind
FUB	Rene Preusker, Juergen Fischer
NILU	Kerstin Stebel
PSI	Paul Zieger, Urs Baltensperger

17 years of Aerosol Obs from ESA Satellites

- ESA doesn't have an instrument dedicated to aerosol retrieval flying yet. (EarthCARE is coming soon ...)
- But information about aerosols is retrieved from several past instruments, often as a by-product of the atmospheric correction, e.g.: MERIS, (A)ATSR, GOME, GOMOS, SCIAMACHY
- Continuity instruments will fly again on the future Sentinel-3A, 3B and 5P satellites, from 2014.



DUE GlobAerosol

Project Description

- User requirements: NWP, transboundary pollution, air quality
- Focussed on meeting users needs with what was already available
- GMV, U. Oxford, RAL, LOA, 2004-2009
- Production of a 12 year global aerosol dataset (1995-2007)
- ATSR-2, AATSR, MERIS, SEVIRI (slots: 10, 13, 16 UTC)
- Algorithms: Oxford-RAL "ORAC" retrieval + MERIS std L2 AOD
- Products:
  - AOD, angstrom coeff, aerosol type
  - 10 km and 1 degree resolution, global, daily, monthly, in netCDF with CF conv.
  - Statistical fields (e.g. PDFs of AOD)
  - Included per-pixel uncertainty estimates on AOD.
- Project ended with CTM model comparison/assimilation case studies: GEOS-Chem (U. Edinburgh), GLOMAP (U. Leeds), IFS (ECMWF), LOTOS-EUROS (TNO), AEROCOM (MPI-M & LSCE)
- Data available from: www.globaerosol.info & ftp.globaerosol.info

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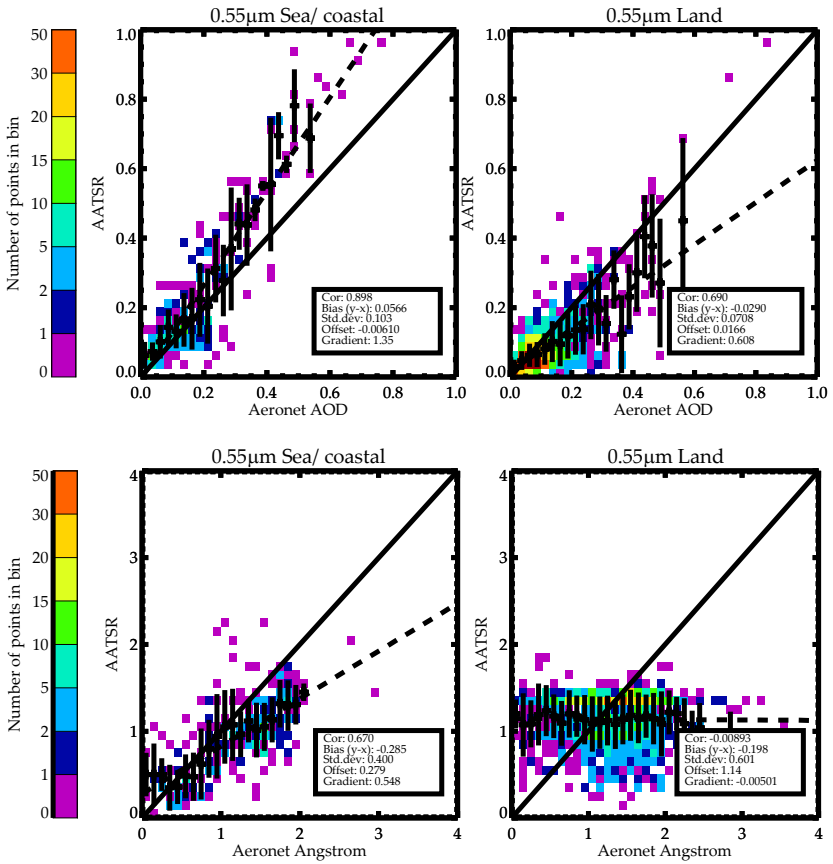
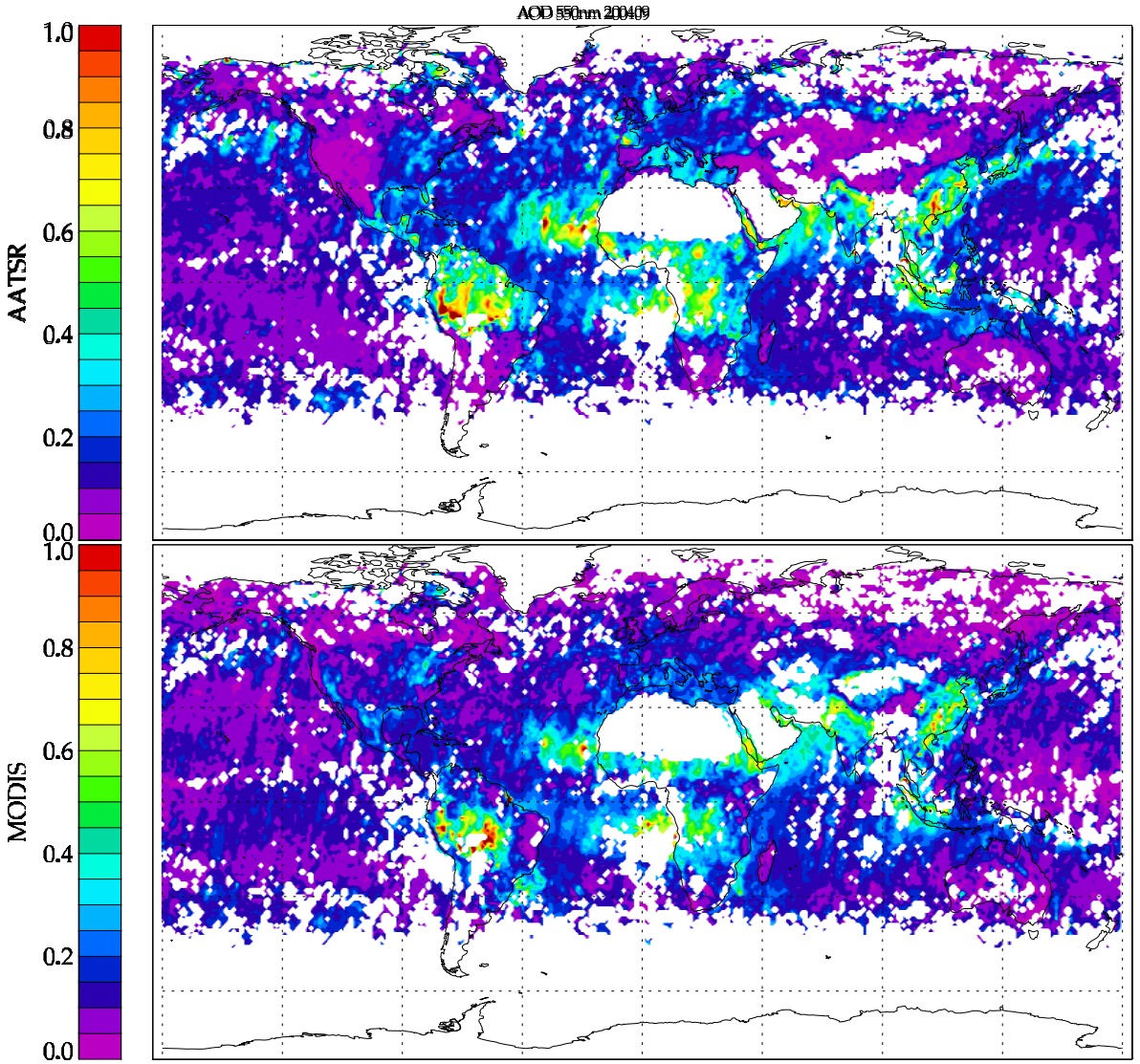
Oxford-RAL "ORAC" aerosol

G. Thomas *et al.*, AMT, vol 2, 679, 2009





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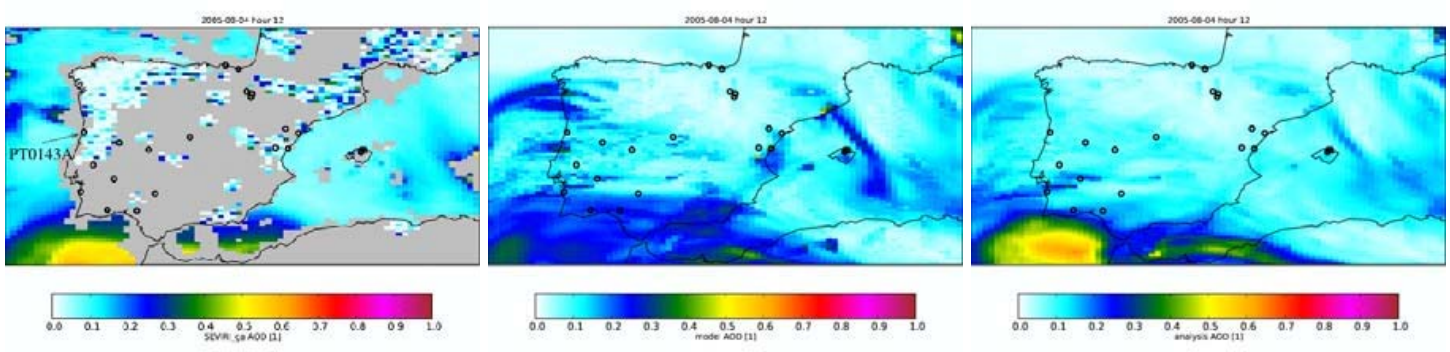
Lessons Learned - 1:

1. AATSR AOD (ORAC) agreed with MODIS and MISR about as well as MODIS and MISR agreed with each other.
2. ESA Std MERIS L2 AOD is good for atm correction of MERIS data, but not ideal as an aerosol product.
3. (A)ATSR retrieval had room for improvement, although regional and seasonal patterns were quite well captured.
4. SEVIRI showed good potential over ocean.
5. Comparison of satellite-AOD with model-AOD was valuable in both directions, but satellite AOD considered to need further improvement for routine model verification/assimilation.



Arjo Segers, TNO
LOTOS-EUROS

Figure 1 *Aerosol Optical Depth valid for 2005-08-04, 11:00-12:00 .* ***Left:*** *AOD observed by SEVIRI, retrievals from Globaerosol; averaged over model grid and hourly intervals.* ***Middle:*** *simulation from free running model.* ***Right:*** *assimilated field.*

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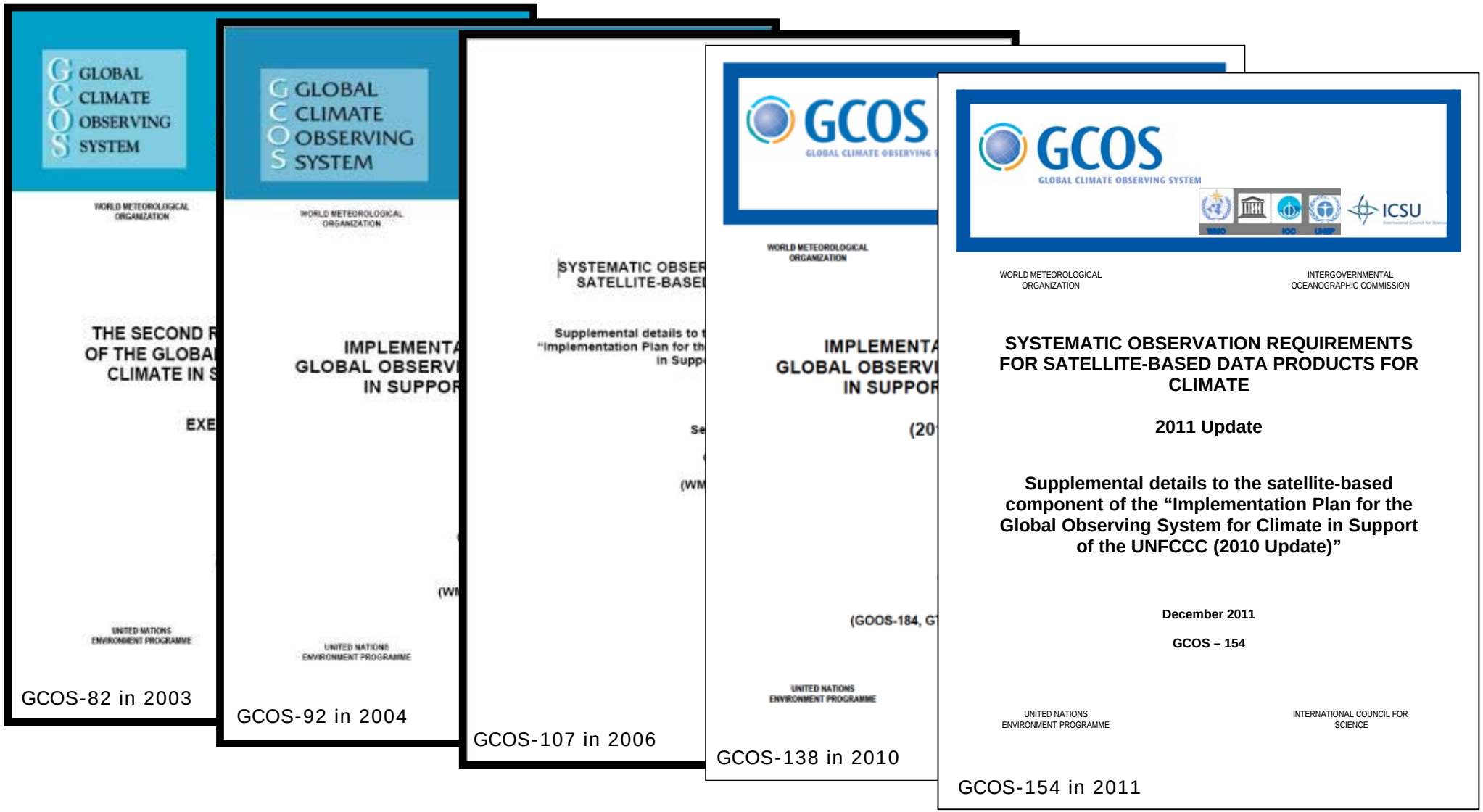
Lessons Learned - 2:

1. Many algorithmic technical issues, such as:
   - Desert dust and fire plumes often masked out by cloud clearing
   - Retrieal over bright surfaces (desert, snow) needs to be improved.
   - Regionally dependent positive biases and some of the variability in satellite AOD due poor cloud clearing.
   - Angstrom coeff was poorly correlated with AERONET over land.
   - Set of assumed aerosol optical properties insufficient to model reality.
2. Retrieving the aerosol type is *really* difficult (using retrieval cost function did not work)
3. Simple multi-satellite merged AOD product was not very useful.
4. Use of per-pixel uncertainties found to improve assimilation of SEVIRI AOD, compared to using fixed uncertainties.
5. Including the CTM model case studies was a good idea, as it resulted in very effective evaluation of the aerosol products.

=> Development and Reprocessing cycle is necessary to build on lessons learned to improve the satellite aerosol products:

Processing ➔ Evaluation ➔ Algorithm Improvement ➔ Reprocessing ➔ ... ➔ ...

GCOS Requirements for Satellite Observations



GCOS Requirements for Aerosol

Systematic Observation Requirements for Satellite Based Data Products for Climate
GCOS-154, Dec 2011

Product A.10.1 Aerosol optical depth
Product A.10.2 Aerosol single scattering albedo
Product A.10.3 Aerosol layer height
Product A.10.4 Aerosol extinction profiles from the troposphere to at least 35km

Benefits

- Improved aerosol products, thereby leading to a reduction in uncertainty as to the quantitative role of aerosols in climate forcing identified by the IPCC;
- Improved products that are needed to validate and improve the capability of climate simulation models and reanalyses to represent aerosol effects.

Target Requirements

Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
Aerosol optical depth	5-10km	N/A	4h	Max (0.03; 10%)	0.01
Single-scattering albedo	5-10km	N/A	4h	0.03	0.01
Aerosol-layer height	5-10km	N/A	4h	1km	0.5km
Aerosol-extinction coefficient profile	200-500km	<1km near tropopause, ~2km in middle stratosphere	weekly	10%	20 %

ESA's Climate Change Initiative

CCI Programme Objective:

"To realize the full potential of the long-term global Earth Observation archives that ESA together with its Member states have established over the last thirty years, as a significant and timely contribution to the ECV databases required by United Nations Framework Convention on Climate Change (UNFCCC)."

Proposed to ESA Ministerial Council in Nov 2008.

Result: 6 Year Programme / 75 Meuro.

Table 1: ECVs for which satellite observations make a significant contribution (GCOS-138)

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	Surface wind speed and direction; precipitation; upper-air temperature; upper-air wind speed and direction; water vapour; cloud properties; Earth radiation budget (including solar irradiance); carbon dioxide; methane and other long-lived greenhouse gases; and ozone and aerosol properties, supported by their precursors.
Oceanic	Sea-surface temperature; sea-surface salinity; sea level; sea state; sea ice; ocean colour.
Terrestrial	Lakes; snow cover; glaciers and ice caps;, ice sheets; albedo; land cover (including vegetation type); fraction of Absorbed Photosynthetically Active Radiation (FAPAR); Leaf Area Index (LAI); above-ground biomass; fire disturbance; soil moisture.

CCI Projects

DUE Projects

14 CCI Projects

www.esa-cci.org

cloud_cci	***DWD (D)***
ozone_cci	***BIRA (B)***
aerosol_cci	***DLR/FMI (D/FI)***
ghg_cci	***U Bremen (D)***
sst_cci	***U Edinburgh (UK)***
land_cover_cci	***UCL (B)***
sea_level_cc	***CLS (F)***
ocean_colour_cci	***PML (UK)***
glaciers_cci	***U. Zurich (CH)***
fire _cci	***U.Alcala (E)***
sea_ice_cci	***NERSC (N)***
soil_moisture_cci	***TU Wien (A)***
ice_sheet_cci	***DTU Space (DK)***
CMUG	***UKMO - Hadley Centre (UK)***

Agency

CCI Project Cardinal Requirements

1. Develop and validate algorithms to meet GCOS ECV requirements for (consistent, stable, error-characterized) global satellite data products from multi-sensor data archives

2. Produce, within an R&D context, the most complete and consistent possible time series of multi-sensor global satellite data products for climate research and modelling

3. Optimize impact of ESA EO missions data on climate data records

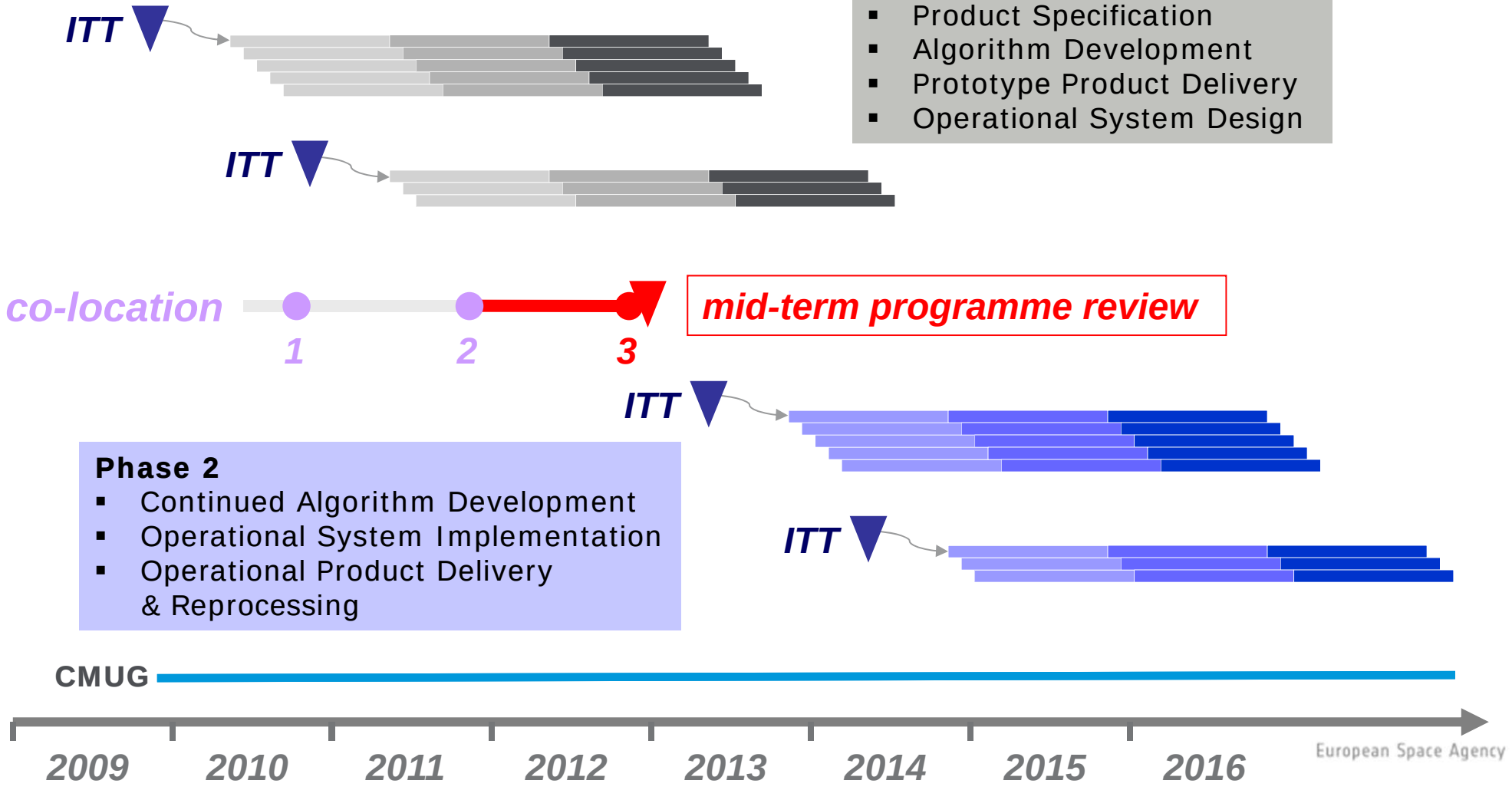
4. Generate complete specifications for an operational production system

5. Strengthen inter-disciplinary cooperation between international earth observation, climate research and modelling communities, in pursuit of scientific excellence

Not forgetting some CCI Principles:

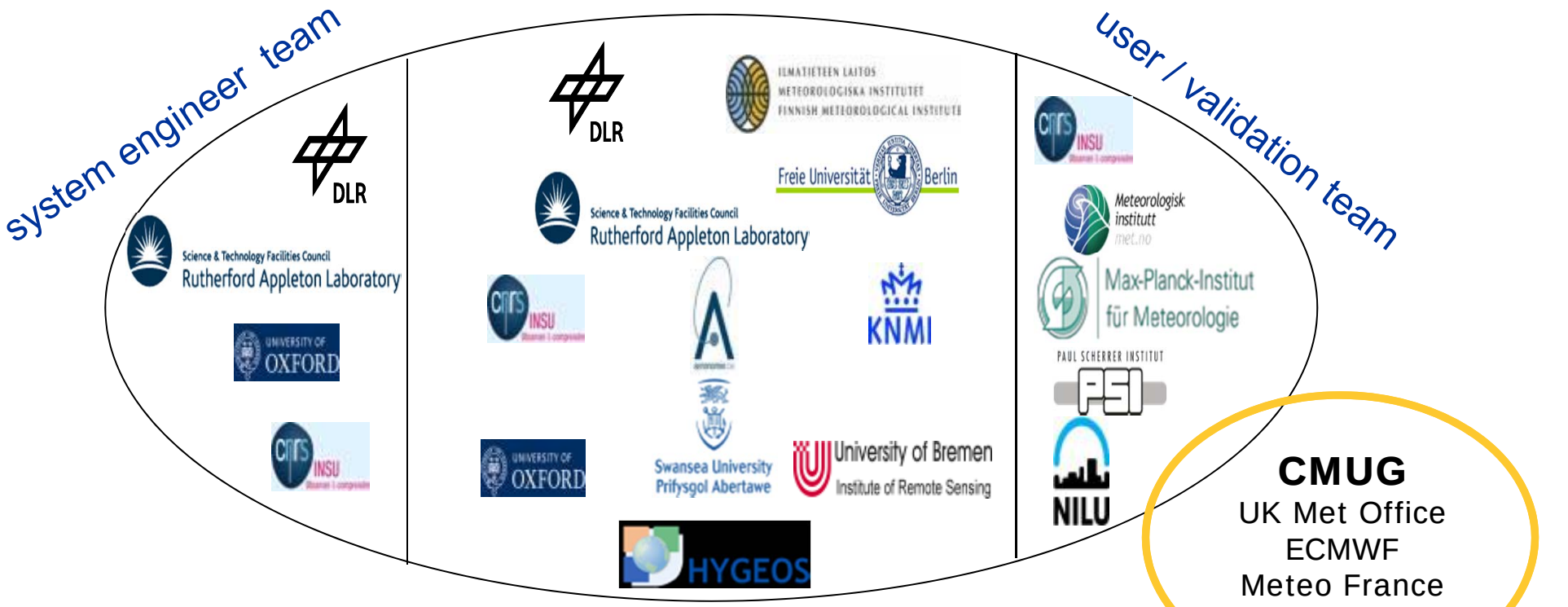
Transparency, open access to documentation and results, international collaboration, rigorous uncertainty characterisation

CCI Programme Overview



Aerosol CCI Project

Science Leaders:
Thomas Holzer-Popp (DLR) & Gerrit de Leeuw (FMI)



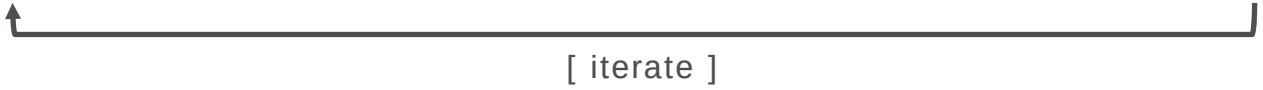
Phase 1: July 2010 – July 2013

www.esa-aerosol-cci.org

Aerosol CCI Project

Approach

- Cyclic: user requirements ➔ development ➔ production ➔ validation ➔ user-evaluation



[iterate]

- Focus on common problems: e.g. surface reflectance, cloud-clearing, aerosol optical properties, auxiliary data, product uncertainty specification, long term consistency, ...
- Investigate the relative strengths and weaknesses of different algorithms through intercomparison on an equal footing.
- Perform idealised synthetic case studies
- Validation against AERONET, WMO-GAW
- Intercomparison with MODIS, MISR, POLDER, AEROCOM models, etc
- Evaluation by aerosol modellers and CMUG
- Develop an operational system to sustainably deliver aerosol ECV from satellite data

Aerosol CCI Project

Precursor Algorithms

- AATSR: ORAC (Oxford/RAL), ADV (FMI), Swansea (Swansea)
- MERIS: BAER (Bremen), ALAMO (HYGEOS), ESA Std MERIS AOD (LOV, LISE)
- AATSR+MERIS: Synergy (Swansea), SynAO (FUB)
- AATSR+SCIAMACHY: SYNAER (DLR)
- POLDER/PARASOL (LOA)
- OMI/AAI (KNMI)
- GOMOS/AERGOM (BIRA)

Deliverables (aim to meet GCOS requirements)

- Global 10km, 0.5deg, daily/monthly, AOD, angstrom, type*, absorption* in netCDF/CF-Conventions
- Single-sensor aerosol information from (A)ATSR, MERIS, PARASOL, OMI, GOMOS
- Synergy retrieval from AATSR+MERIS, AATSR+SCIAMACHY

Schedule

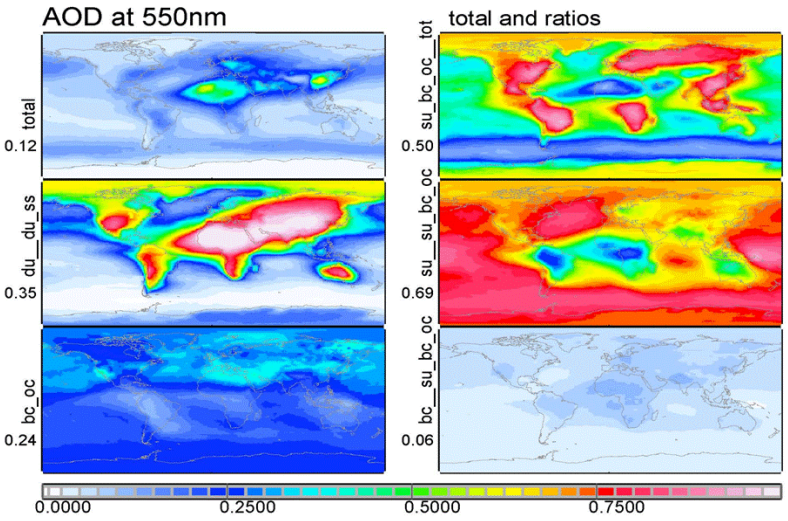
- First validated data sets for "golden year" 2008 will be available from Oct 2012

Aerosol CCI Project

Achievements since KO (26 July 2010)

- Climate Requirements Review (GCOS, CMUG, AeroCom) and Product Specification
- Common format products from precursor algorithms (bigger job than it sounds!)
- Common aerosol properties defined and implemented (optical properties, size distributions and heights)
  - types defined as mixtures of four simple components:

    fine/weak abs., fine/strong abs., sea-salt and non-spherical dust
  - component optical properties based on average properties measured by AERONET
  - AeroCom median model merged with AERONET to define monthly climatologies of the distribution of aerosol component fractions



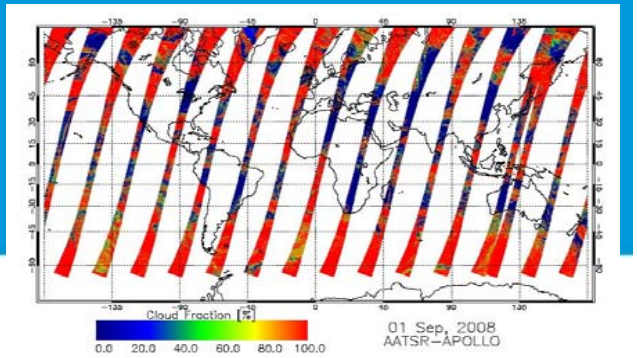
aerosol component	Refr. index, real part (55µm)	Refr. Index, imag part (.55µm)	reff (µm)	geom. st dev (σ_i)	variance (ln σ_i)	mode. radius (µm)	comments	aerosol layer height
Dust	1.56	0.0018	1.94	1.822	0.6	0.788	non-spherical	2-4km
sea salt	1.4	0	1.94	1.822	0.6	0.788	AOD threshold constraint	0-1 km
fine mode weak-abs	1.4	0.003	0.140	1.7	0.53	0.07	(ss-albedo at 0.55 µm: 0.98)	0-2 km
fine mode strong-abs	1.5	0.040	0.140	1.7	0.53	0.07	(ss-albedo at 0.55 µm: 0.802)	0-2 km

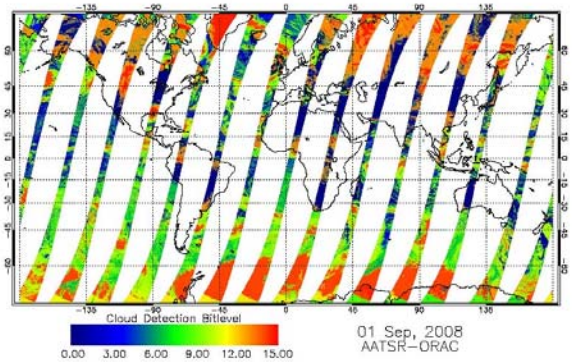
Aerosol CCI Project

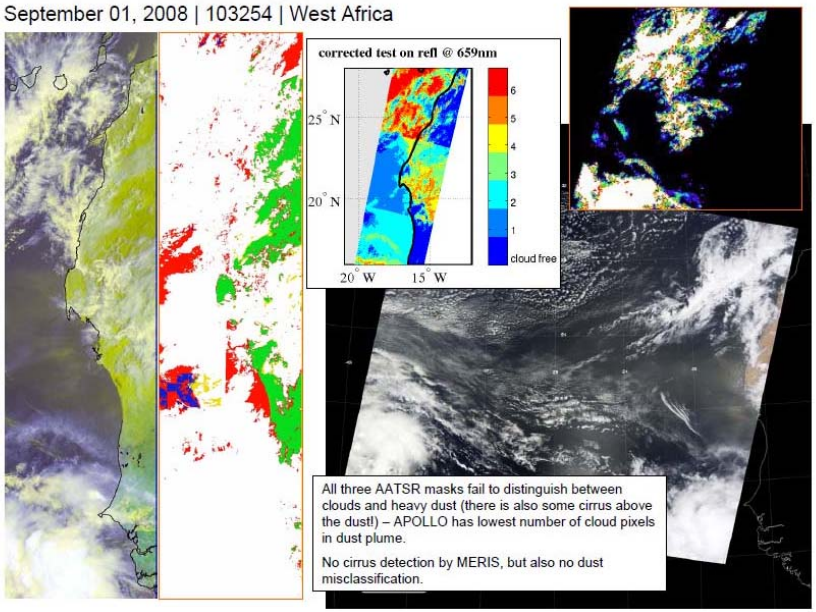
Achievements since KO – Part 2

Common cloud mask

- Probably biggest source of error, and particularly +ve AOD bias over ocean
- Intercomparison of precursor cloud clearing on four 1-day global fields and 17 test cases (incl. high aerosol dust and smoke plumes and difficult cloud cases)
- Operational flags generally found to be unsuitable for aerosol retrieval
- Selected APOLLO (AATSR), with addition of a dust flag and a "safety zone"
- Post retrieval pixel quality control (threshold on # cloud free pix per 10x10 km^2 grid box)

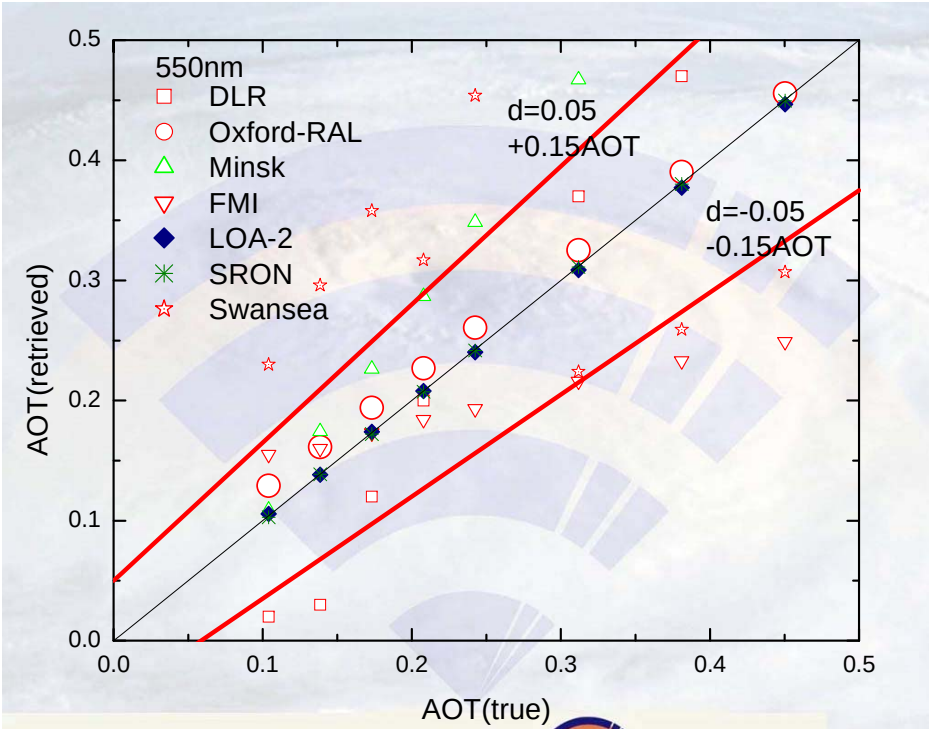






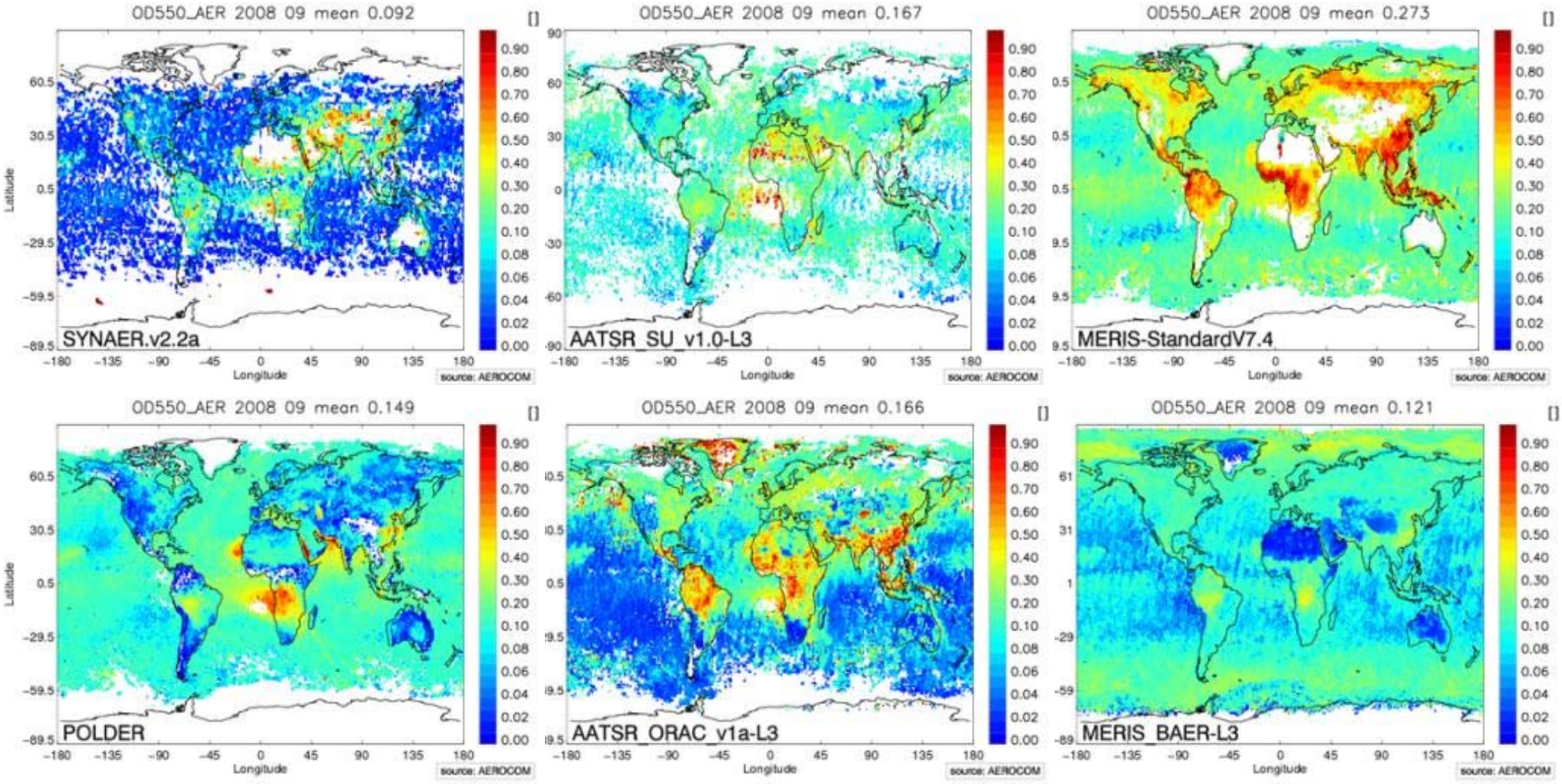
Achievements since KO – Part 3

- Lots of experimental algorithm variations tried out.
- Algorithm intercomparison and evaluation on 4 months of 2008 for competing AATSR and MERIS algorithms, based on several experiments per algorithm – see next slide.
- Prototyping of AOD uncertainties for all algorithms
- Synthetic case studies:
  - Extremely valuable feedback for the algorithm developers
  - General validation cannot be made on a few idealised cases
- Definition of an operational Aerosol ECV production system
- Algorithm devlopment (not covered further here):
  OMI Aerosol Absorbing Index
  GOMOS stratospheric aerosol extinction profiles



Aerosol CCI Project

Product Validation and Algorithm Selection – Starting Point



Product Validation and Algorithm Selection

Objective:

- Identify the best performing AOD retrieval (as well as best performing algorithm elements)

Protocol:

- Evaluations performed by independent partners assessing many different characteristics
- Data used for tuning retrievals was not used in validation
- Exercise was open to external participants

Intercomparison:

- Best performing algorithm variants were submitted to the round-robin.
- AATSR: FMI, Ox/RAL, Swansea, DLR/Synergy
- MERIS : ESA Std, HYGEOS/ALAMO (ocean only), BAER was not delivered in time.
- PARASOL std algorithm (fine mode only over land)
- Global, March, June, Sep, Dec 2008
- Reference data: AERONET, MODIS, MISR
- Did not consider the uncertainty estimates

Product Validation and Algorithm Selection – Results

(Hot off the press, thanks to Stefan Kinne)

	global	ocean	land
– MISR v22	.62	.66	.59
– MODIS aqua	.55	.60	.50
– MODIS terra	.61	.63	.58
– SEAWIFS	.56	.58	.55
– AATSR F v13	-.57	-.60	-.55
– AATSR S v30	-.46	-.48	-.48
– AATSR O v11	.39	.40	-.39

What do these scores mean ?

- the more away from zero …. the better
- the sign indicates the overall bias direction
- only involving regions with scores

MERIS not shown due to insufficiently significant statistics

Much lower coverage of AATSR compared to MODIS means that this comparison is biased to areas where MODIS performs poorly

PARASOL best ocean retrieval overall

MERIS ALAMO (HYGEOS) better than ESA Std product over ocean.

Ocean retrievals validated with coastal AERONET sites – did not use MAN data yet

Product Validation and Algorithm Selection – More Lessons Learned

- Team approach was successful to understand algo sensitivities and improve critical modules, resulting in clearly improved algorithms.
- Strong user involvement in the validation is essential
- More cycles of algorithm development and evaluation are needed

Last word on outcome from Stefan…

- *"Current CCI retrievals for AOD have NOT (yet) reached the maturity of most US products"*
- *"ATSR (especially FMI) products are more competitive, but all CCI products lack coverage… usually less data than MISR"*

Where do we go from here?

Next 12 months (already funded)...

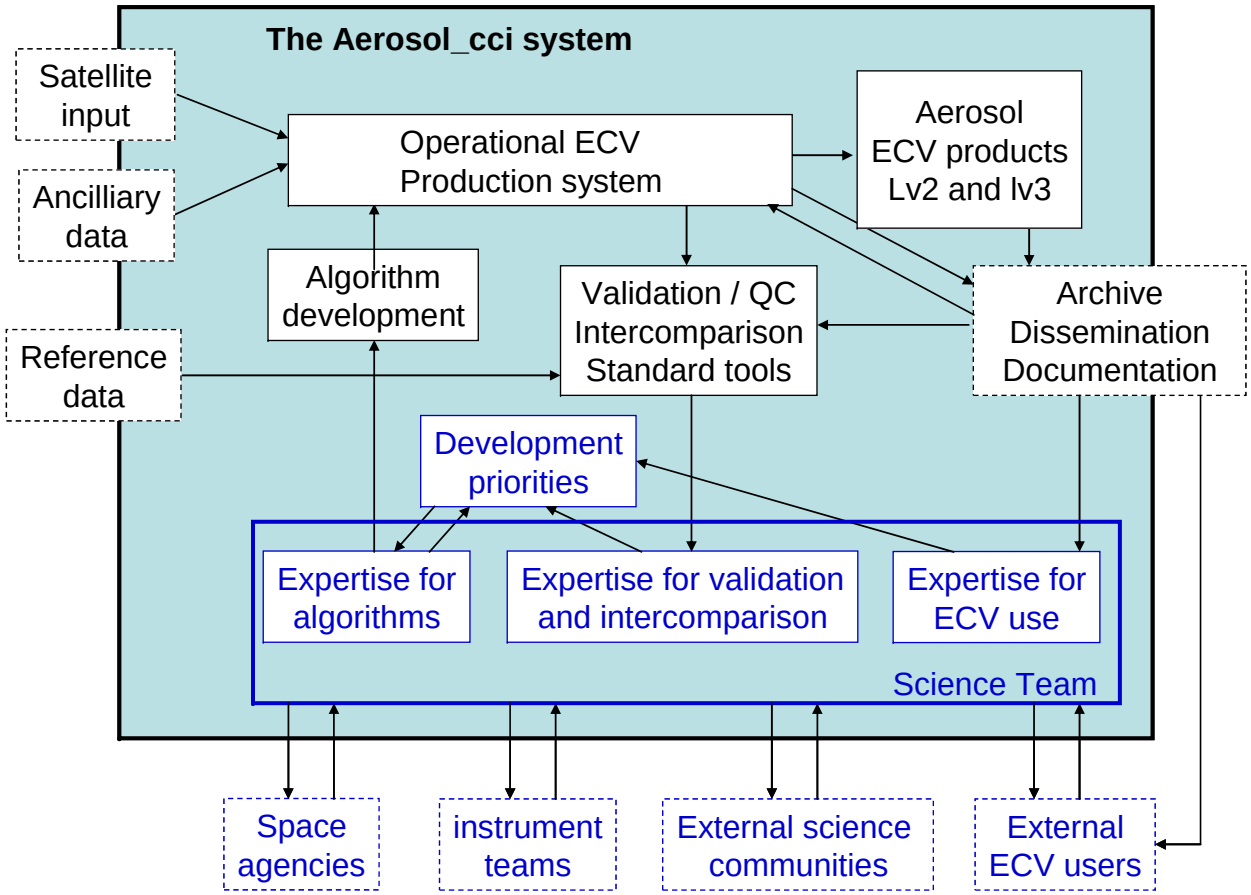
- Production of one-year data sets from all candidate algorithms, followed by further validation and intercomparison, delivery of first "official" validated Aerosol_CCI data set (Oct 2012).
- Investigate and intercompare different approaches to handle surface reflectance (V.important over land)
- Further work on cloud masking, synthetic case studies, etc
- Work towards consistent cloud/aerosol products – collab. with Cloud_CCI project
- Investigate humidity effects on aerosol optical properties.
- Start development of AATSR+MERIS synergy algorithms in CCI
- Processor perf. optimisation of new POLDER/PARASOL algorithm over land – aim to use as virtual AERONET site.

After (planned, but not yet funded)...

- Production of full 17yr ATSR-2 + AATSR aerosol time series with best performing algorithm (requires work on ATSR-2/AATSR overlap).
- Production of full time series of MERIS, OMI, GOMOS, etc aerosol products
- Intercomparison with other long time series aerosol CDRs (AVHRR, SeaWIFS, MODIS, MISR, TOMS, ...)
- Development of an operational ECV production capacity

Operational System Specification

Or: How to implement "*operational*" production of climate data records.



And finally...

Some Questions for ICAP:

Q1: Aerosol_CCI

– Does anything need to be done to help **NWP** (i.e. ICAP) community benefit from work done in Aerosol_CCI for **climate**?
  e.g. Conversion to BUFR format, NRT production, model integration tools, assimilation experiments, specific bias corrections, specific intercomparisons, ...

Q2: Sentinel-3

What needs to be done to maximise the ICAP community benefit from Sentinel-3 ?

– OLCI & SLSTR aerosol retrieval development (algorithms & validation) ?
– AOD data set production?
– Model integration tools?

Q3: Is there a need for a regular forum for satellite aerosol experts and modellers to meet?

– Does it exist already?