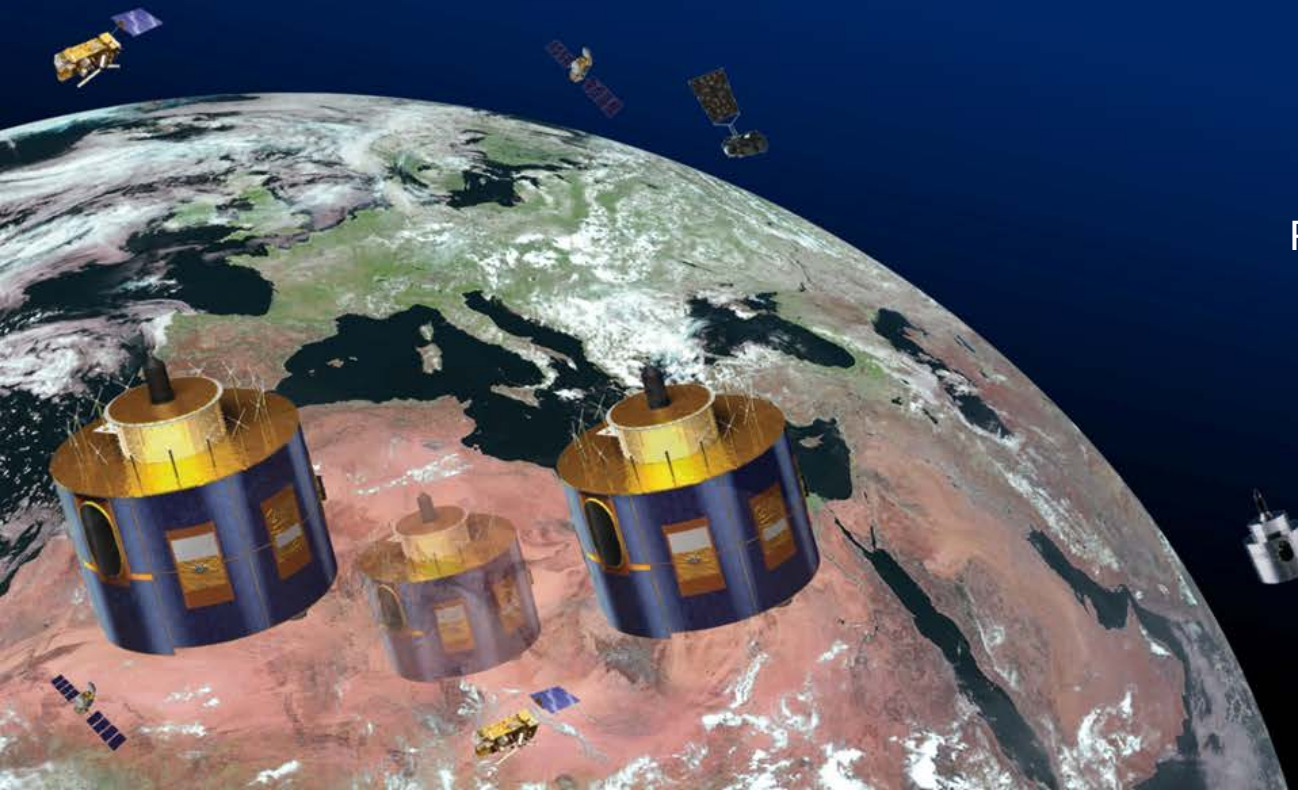
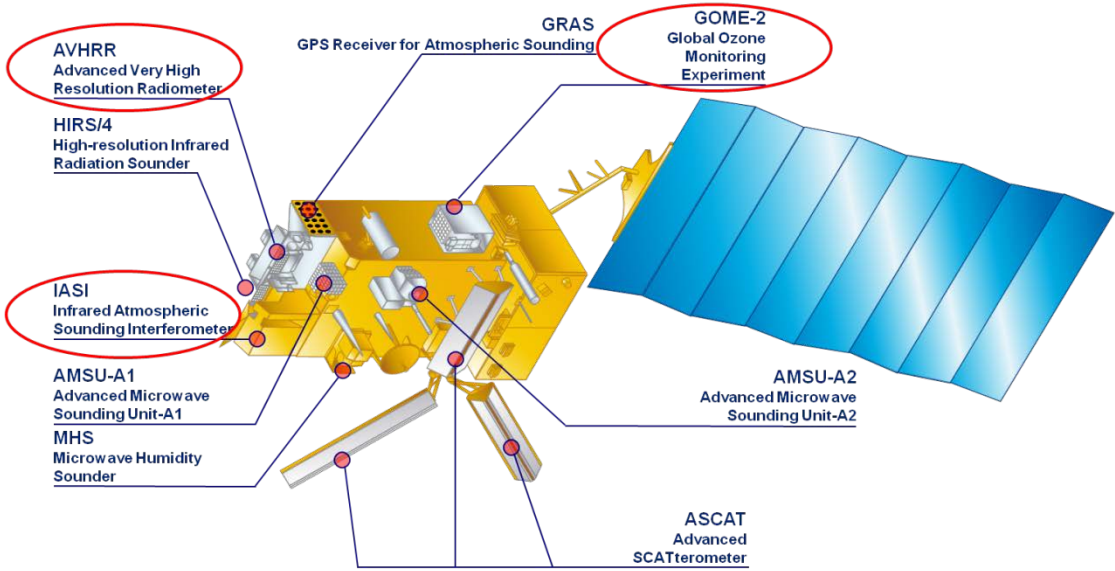
Polar Multi-sensor Aerosol product - PMAp

R. Lang, A. Cacciari, A. Holdak, A. Kokhanovsky, M. Grzegorski, C. Retscher, R. Lindstrot, G. Poli, R. Huckle, N. Hao, S. Gimeno Garcia, and R. Munro



The Polar Multi-sensor Aerosol Product
Operational near-real time AOD from EPS/Metop

PMAp: Polar Multi-sensor Aerosol product
(from GOME-2, AVHRR and IASI on Metop)



- AOD @550nm over land & water surfaces, aerosol type classification

- at GOME-2 PMD spatial resolution
10x40 km^2 Metop-B; 5x40 km^2 Metop-A

- Retrieval over water
fully operational product since October 2014

- Retrieval over water & land **PMAp version 2**
fully operational product since February 2017

The PMAp *operational* AOD product

what it is - and what it not is...

“PMAp aims at delivering *operational* aerosol optical depth information from *Metop* making use of the operational infrastructure available for EPS data processing at EUMETSAT”

What does *operational* mean:

- **Delivery of products in a robust and well controlled way within 3 hours of sensing (“near real time”)**
- **higher than 98% availability**
- **Most products arrive within 1.5 hours of sensing at EUMETCAST system/user (3 hours cut-off time).**
- **Continuous monitoring and quality control (24/7 controller handled system with 1 hour response time in cases of contingencies)**
- **User help desk (ops@eumetsat.int)**

The PMAp *operational* AOD product
what it is - and what it not is...

"PMAp aims at delivering *operational* aerosol optical depth information from *Metop* making use of the operational infrastructure available for EPS data processing at EUMETSAT"

What does AOD from *Metop* mean:

None of the Metop instruments is uniquely suitable for aerosols

- **Imagers (AVHRR) do not have enough channels,**
- **Hyper-spectral instruments (GOME-2 / IASI) do not have high enough spatial r**
- **Huge amount of spectral information from the UV/VIS/NIR to the TIR (GOME-2 / IASI)**
- **VIS/SWIR/TIR at high spatial resolution from AVHRR**
- **Some polarisation information (Q/I Stokes fractions) from GOME-2**
- **Continuous sensor cross-calibration capabilities.**

But...

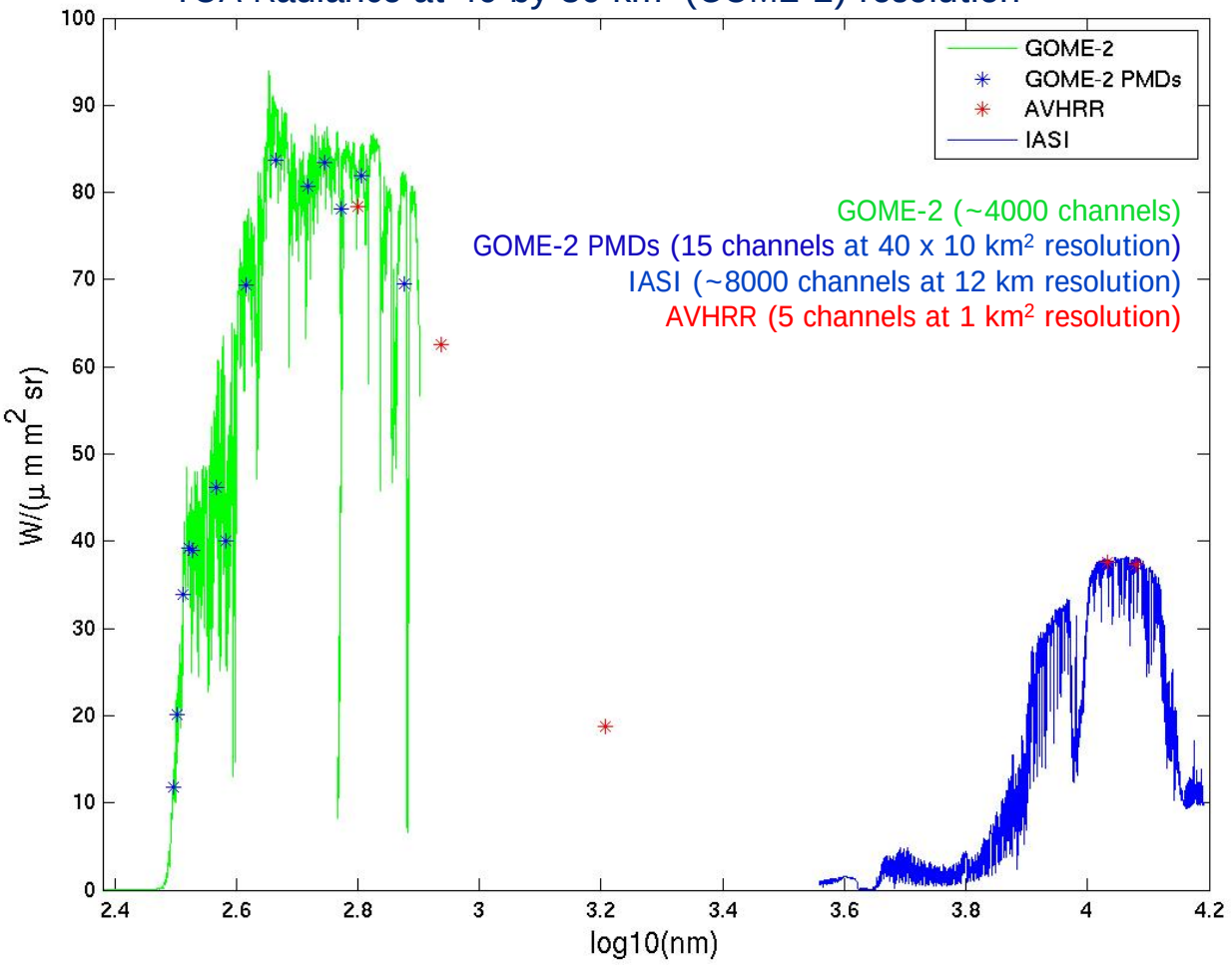
Pro: PMAp is the best AOD information we can get (including its potential) from *Metop*. And its *operational*.

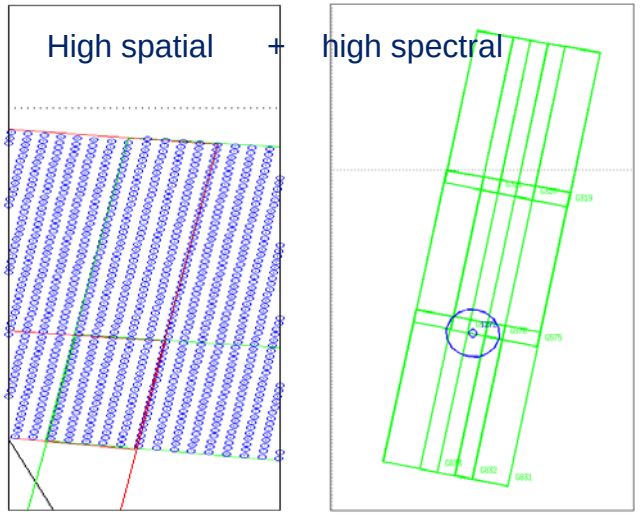
Con: The PMAp product has less information content than products derived from dedicated aerosol missions like polarimeters or LIDAR, however no operational missions of this class are yet available (looking forward to VIIRS and to 3MI on EPS-SG).

PMAp: creating a hyper-instrument

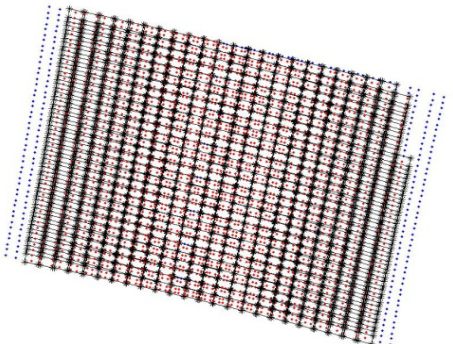
Merging spectral and spatial information from GOME-2 / AVHRR and IASI

TOA Radiance at 40 by 80 km² (GOME-2) resolution





co-location



GOME-2 3-min sample footprint with co-located IASI states

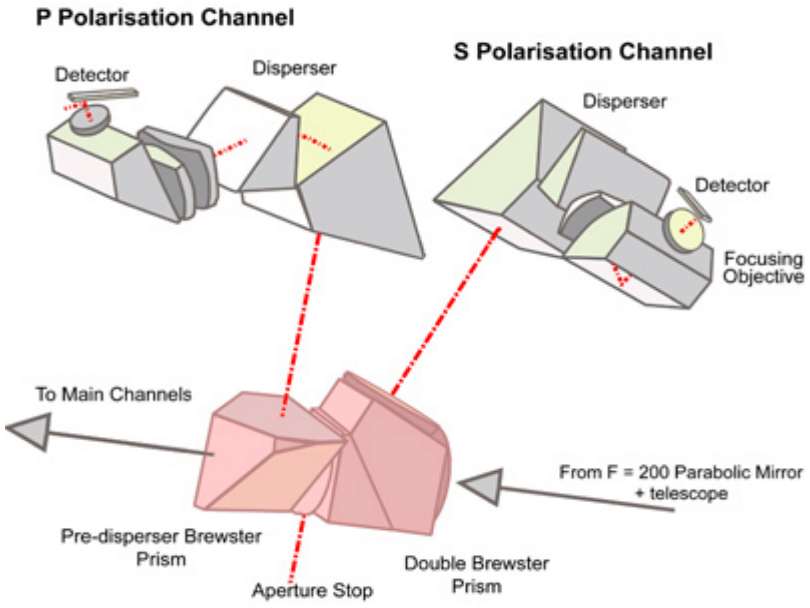
➡ Combining hyper-spectral with hyper-spatial information in a new hyper-instrument

PMAp: the target instrument and its detectors

GOME-2 polarization measurement devices (PMDs)

Band-S				
No.	pix1	pixw.	wav1	wav2
1	22	5	311.709	314.207
2	30	4	316.762	318.720
3	37	12	321.389	329.139
4	50	6	330.622	334.443
5	57	6	336.037	340.161
6	84	17	360.703	377.873
7	102	4	380.186	383.753
8	117	19	399.581	428.585
9	138	27	434.083	492.066
10	165	18	494.780	548.756
11	183	2	552.474	556.262
12	187	11	568.070	612.869
13	198	9	617.867	661.893
14	218	4	744.112	768.269
15	224	2	794.080	803.072

- **Radiances & stokes fraction**
- **better spatial resolution**
- **stokes fraction s = Q / I**



PMAp: multi-mission retrieval

Spatial, spectral and auxiliary data specifications

Instrument		Spatial resolution	Spectral range	comments
GOME	Main science channel	80 x 40 km	240nm -800nm, res. 0.25-0.5nm	AAI, low spatial resolution, not used
	Polarization Monitoring Device	10 x 40 km Metop-B 5 x 40 km Metop-A	311nm-803nm, 15 bands	AOD, aerosol type, AAI Stokes fraction (polarization)
AVHRR	-	1.08 x 1.08 km	580nm-12500nm, 5 bands	Clouds, scene heterogeneity, dust/ash
IASI	-	12km (circular)	3700–15500nm, resolution 0.5 cm^{-1}	desert dust, volcanic ash aerosol heights
Auxiliary data	ECMWF wind speed (forecasting)	Temporal interpolation necessary	-	Required for retrievals over ocean
GOME-2 LER v2	surface albedo	0.25 x 0.25 deg	-	Required for retrievals over land

PMAp: AOP retrieval algorithm design

Retrieval over land & water

Three steps retrieval:

Step1: Pre-classification (Multi-sensor: GOME-2,AVHRR, IASI)

- Clouds detection and cloud corrections, distinguish clouds/dust/ash
- Aerosol pre-classification (volcanic ash, dust, fine/coarse over sea)
- Results are inputs for the GOME-2 retrieval

Step2: Retrieval of a set of candidate AODs (PMD band)

- based on a set of aerosol models from LUT provided by O. Hasekamp (O3MSAF), model selection dependent on step 1.
- over water: Chlorophyll fitted for clear sky pixels (otherwise low chlorophyll assumption)
- over land: surface albedo a-priori (GOME-2 LER DB from G. Tilstra)

Step3: Selection of the best fit

- select the best result of step 2 using least-square minimization for all GOME-2 PMD bands (+ stokes fractions dependent on condition)

PMAp: AOP retrieval algorithm design

Retrieval over land & water

EUMETSAT

Polar Multi-Sensor Aerosol Product:
ATBD

Doc.No. : EUM/TSS/SPE/14/739904
Issue : v3C Draft
Date : 1 June 2016
WBS :

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Documentation:
www.eumetsat.int > Data > Technical documentation > Metop > PMAp

Three steps retrieval:

Step1: Pre-classification (Multi-sensor: GOME,AVHRR, IASI)

- Clouds detection and cloud corrections, distinguish clouds/dust/ash
- Aerosol pre-classification (volcanic ash, dust, fine/coarse over sea)
- Results are inputs for the GOME retrieval

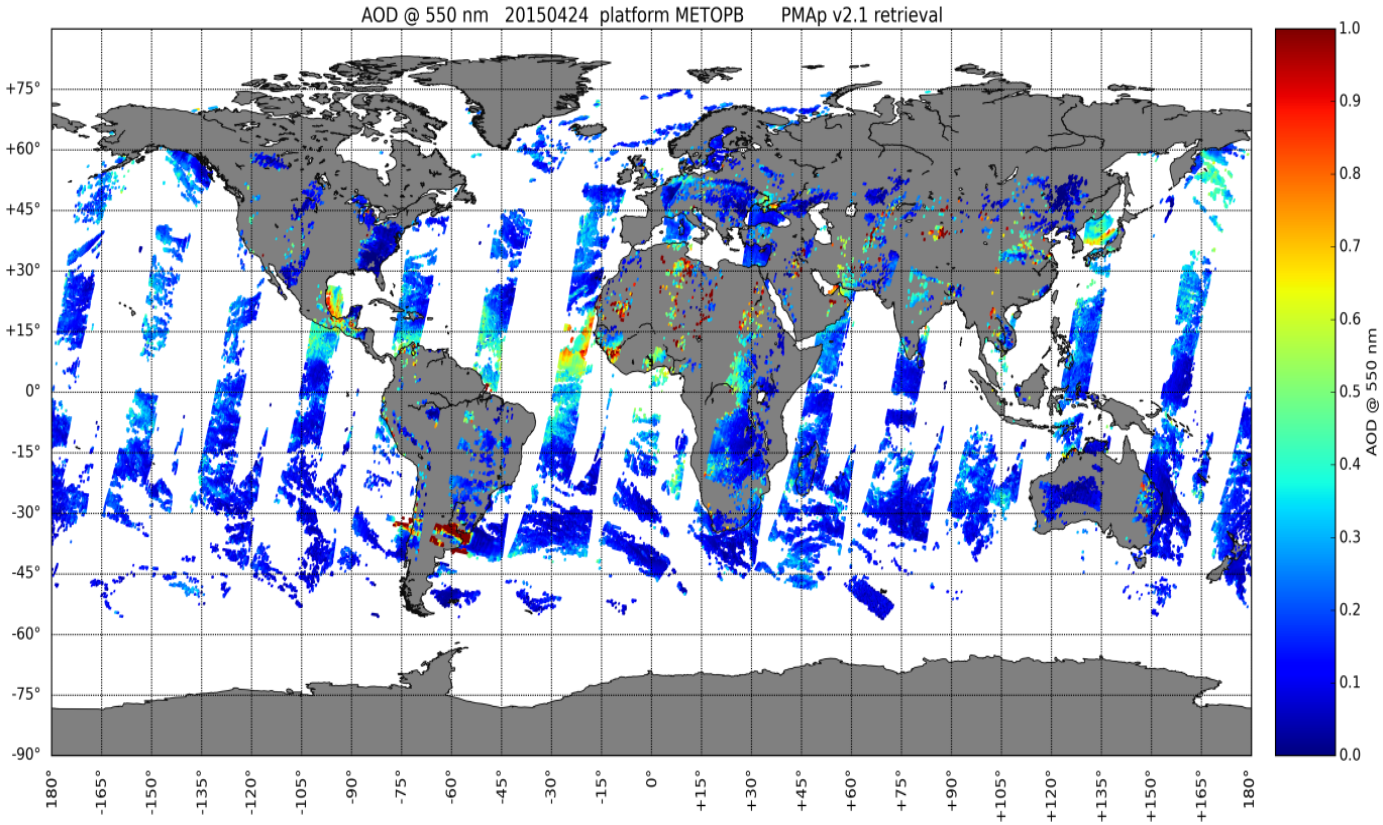
	Class	***Characterization***
0	**No dust/fine mode** (ocean only)	BTD ash tests negative and strong wavelength dependency of the measured signal between 0.6µm and 1.6 µm.
1	**coarse mode** (ocean only)	Desert dust, ash or coarse mode sea-salt without significant BTD signal but weak wavelength dependency in VIS/NIR
2	**Thick biomass burning**	Over ocean: UV index indicate UV absorbing aerosol, coarse mode tests negative, TIR dust/ash tests negative. Over land: Stokes fraction and UV index tests positive.
3	**Thick dust/volcanic ash**	Volcanic ash or thick dust, BTD in TIR indicate dust/ash, weak wavelength dependency in VIS/NIR (ocean) or UV index indicate absorbing aerosol
4	**Volcanic ash with SO_2**	Volcanic ash, IASI ash test positive (including tests with SO2 TIR channels) confirmation by AVHRR VIS/NIR or GOME-2 UV tests
15	No classification	

PMAp: AOD retrieval

Retrieval over land & ocean

24 April 2015

AOD @ 550 nm



Calbuco volcano (South Chile) eruption begun on 22 April 2015

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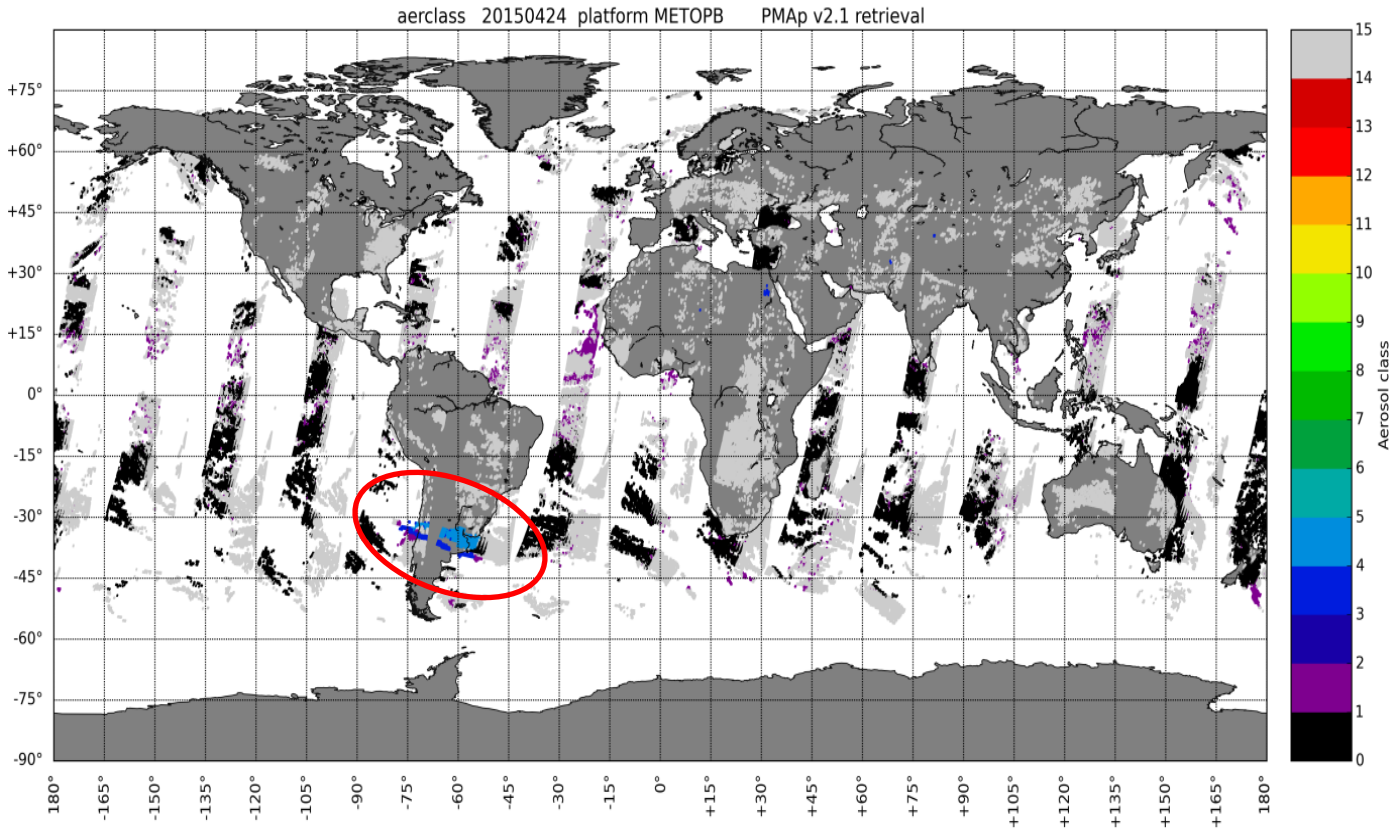
PMAp: AOD retrieval
Retrieval over land & ocean

24 April 2015

aerosol type



0 fine mode
1 coarse mode
3 volcanic ash / thick dust
4 volcanic ash with SO_2

Calbuco volcano (South Chile)
eruption begun on 22 April 2015

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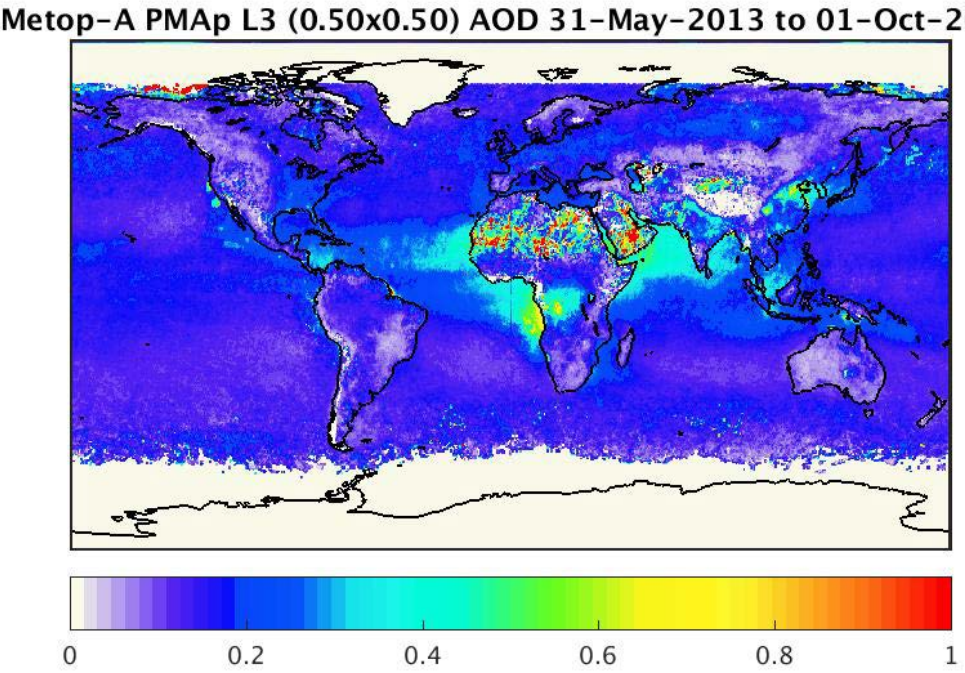
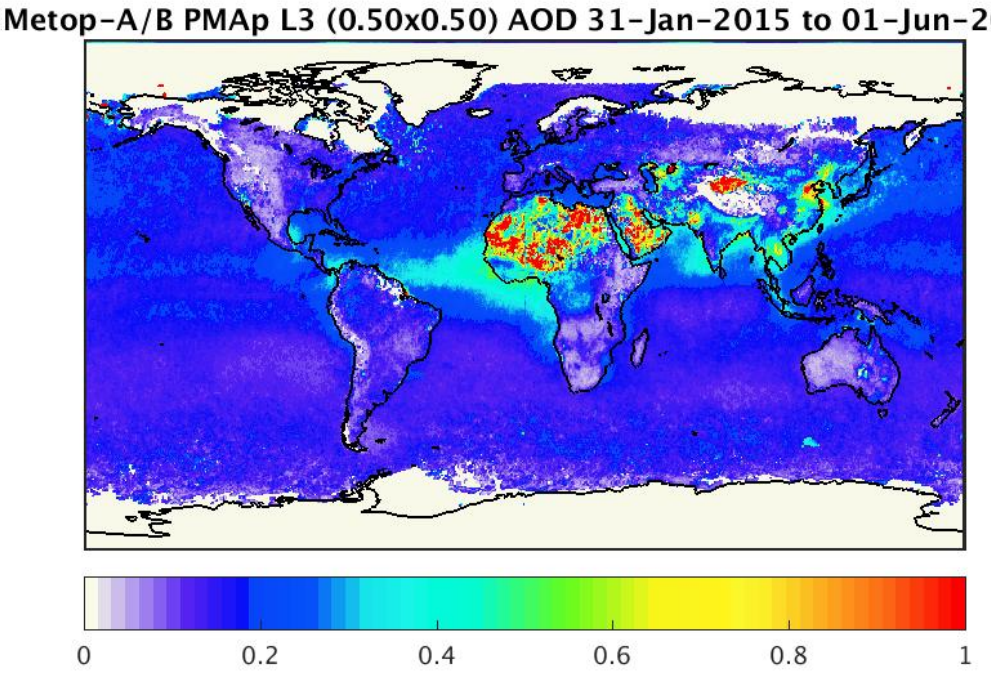
PMAp AOD results

Version 2 L3 gridded results – Summer 2013 and Winter 2015 – Metop-A&B

Summer 2013



Winter 2015



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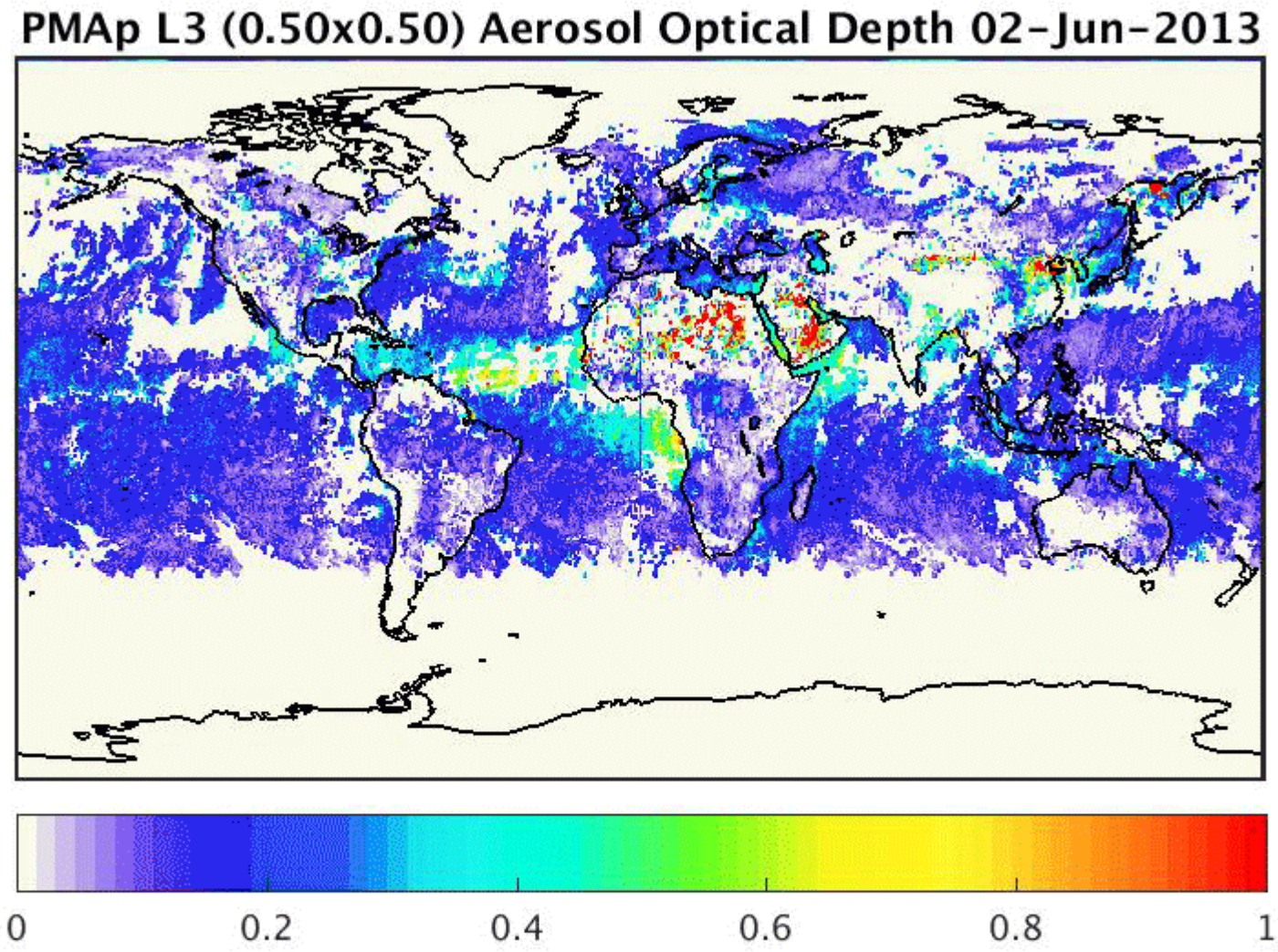
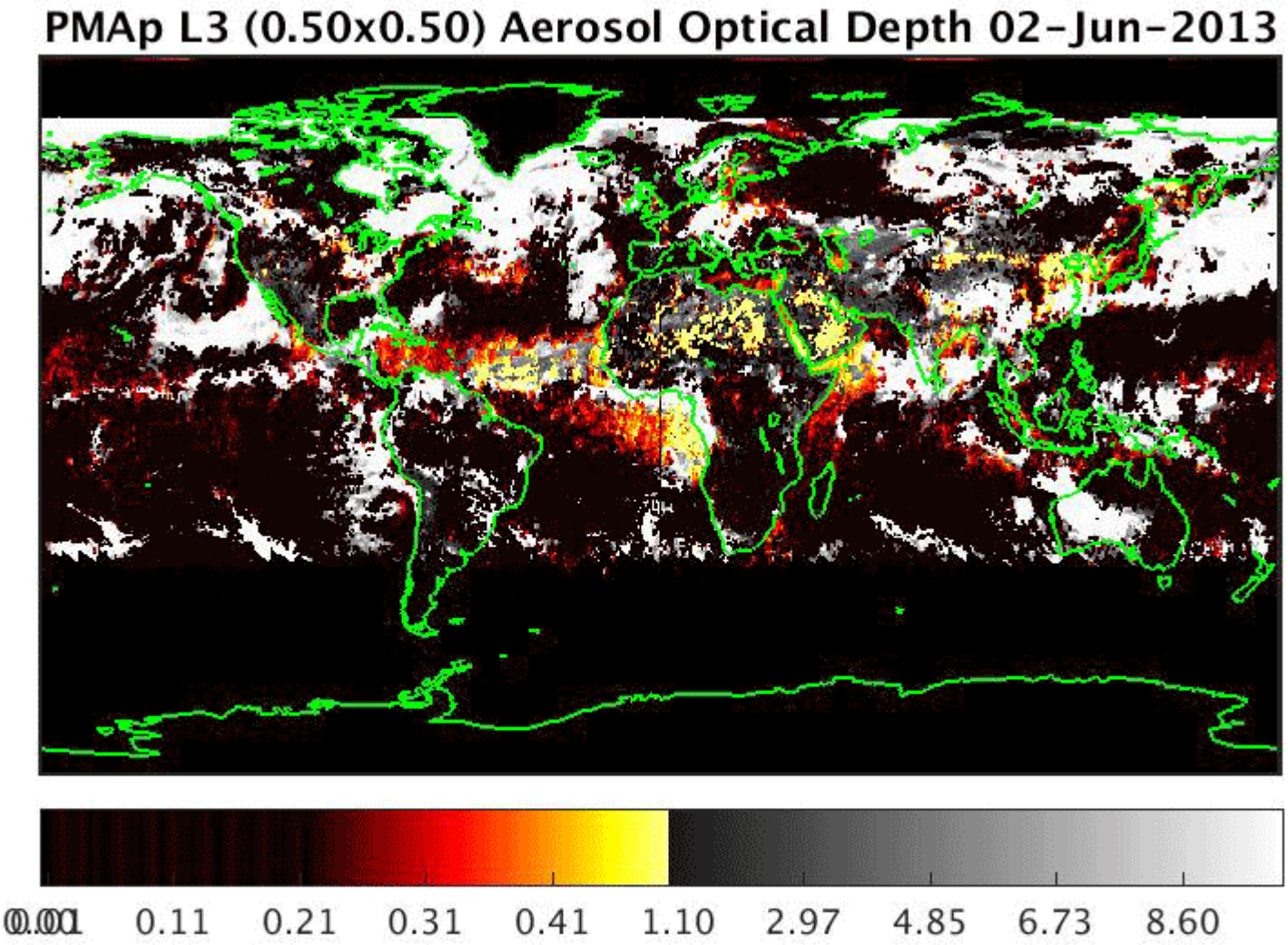
PMAp AOD results

Version 2 L3 gridded results – Summer 2013 – Metop-A&B



PMAp AOD results + COD

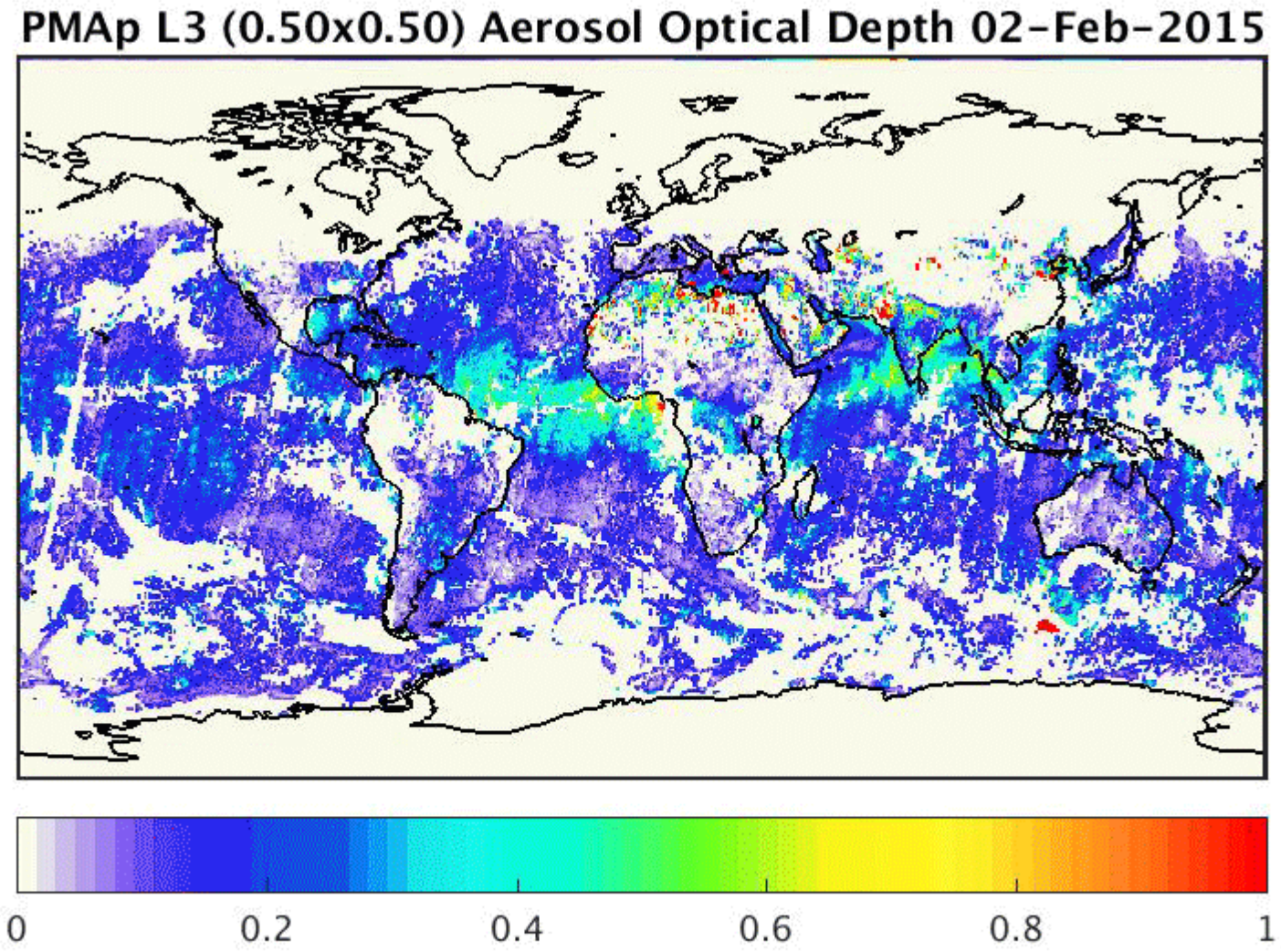
Version 2 L3 gridded results – Summer 2013 – Metop-A&B



COD is demonstrational auxiliary parameter!!!!!

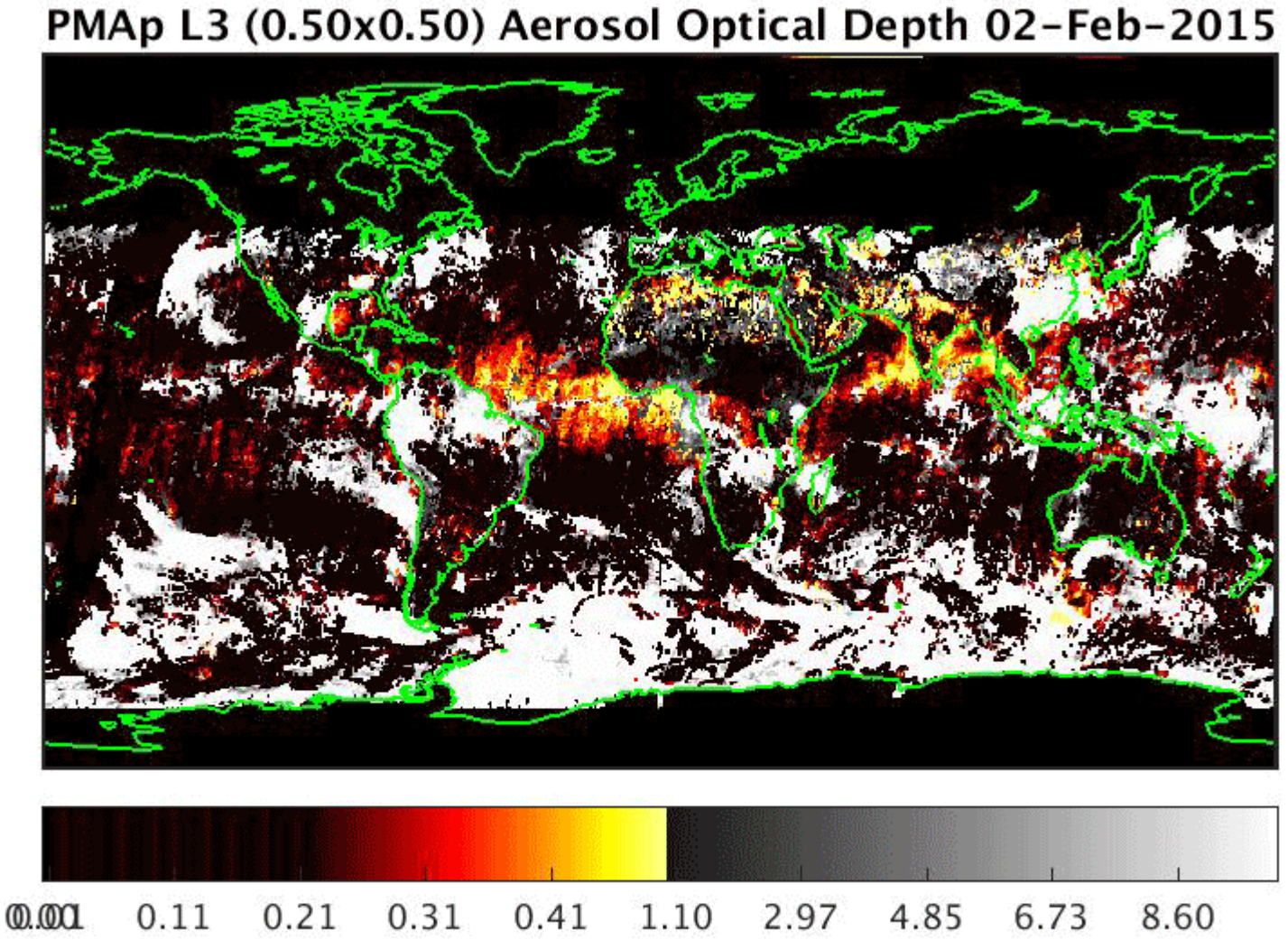
PMAp AOD results

Version 2 L3 gridded results – Winter 2015 – Metop-A&B



PMAp AOD results + COD

Version 2 L3 gridded results – Winter 2015 – Metop-A&B

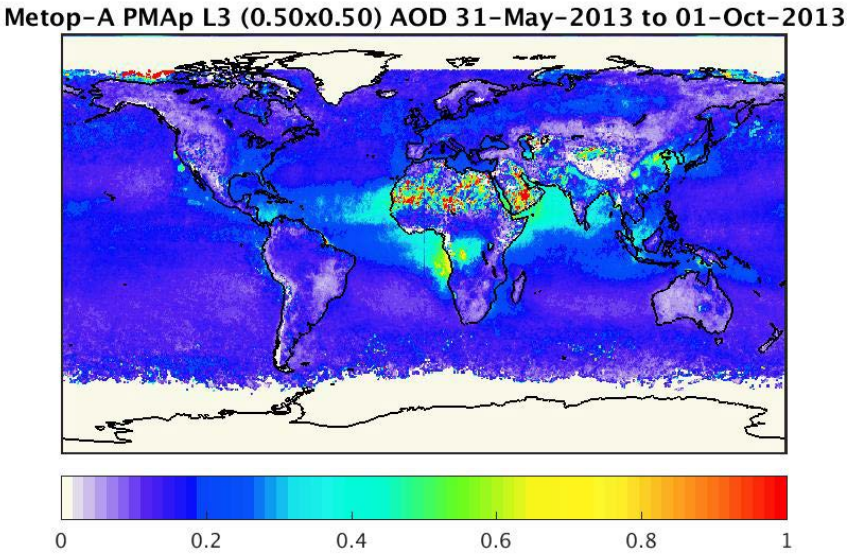


COD is demonstrational auxiliary parameter!!!!!

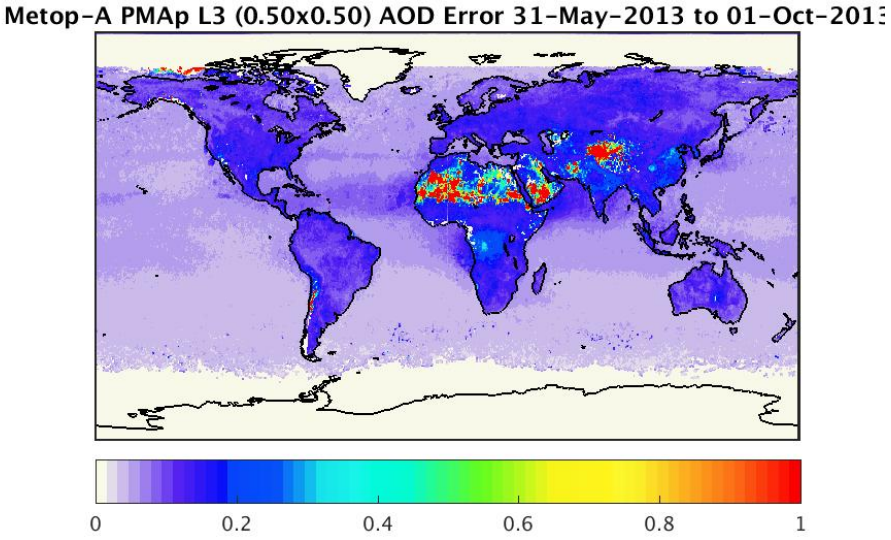
PMAp AOD results and error estimates

Version 2 L3 gridded results – Summer 2013 and Winter 2015 – Metop-A

Version 2.1 AOD



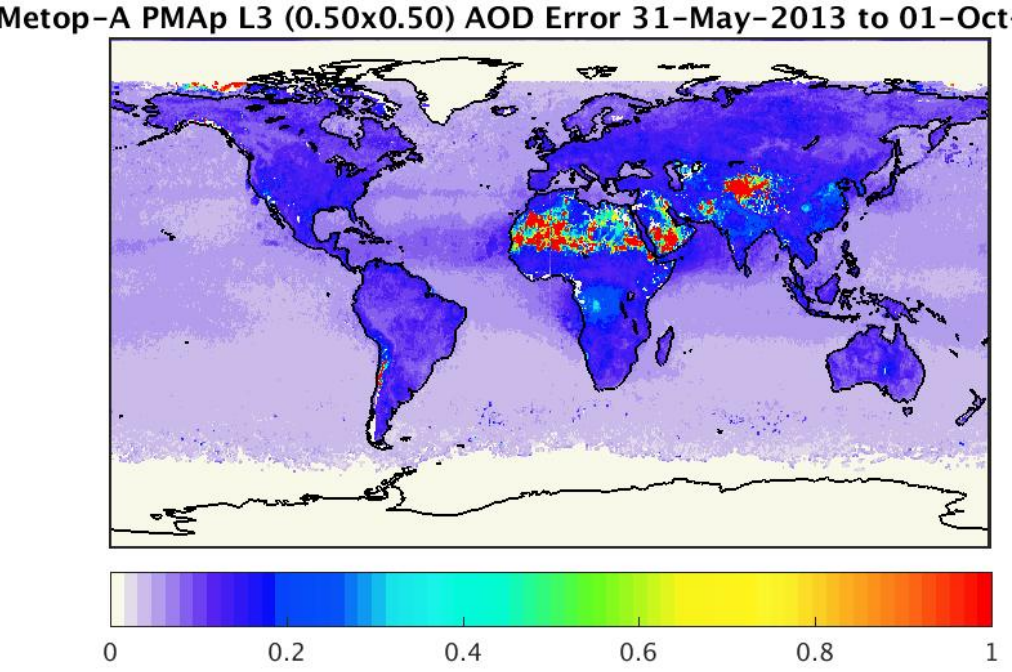
Version 2.1 AOD Error

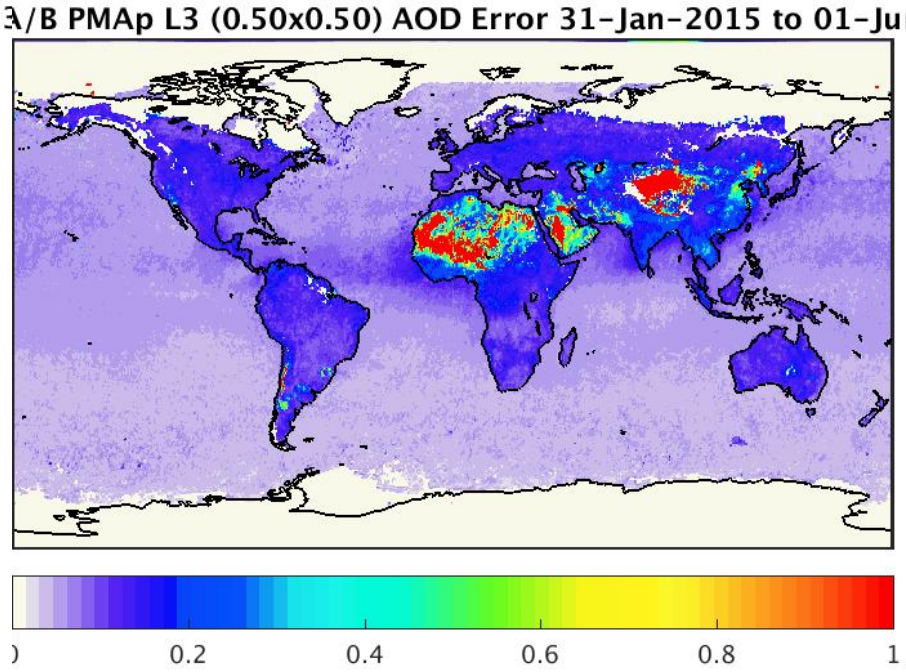


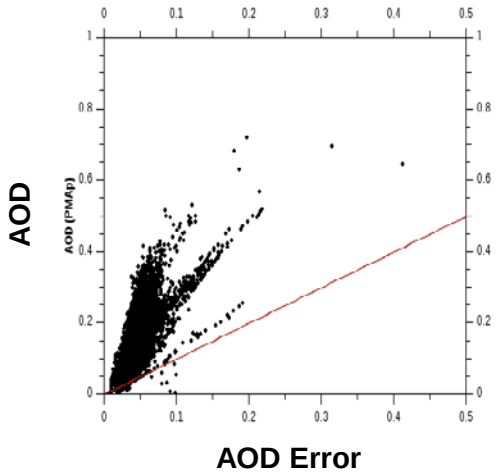
- PMAp does not use optimal estimation methods
  - A set of AOD is calculated using simplified inversion by varying **aerosol type, surface albedo, cloud correction**
  - A standard deviation of these AODs is calculated
  - PMAp calculates a randomized error

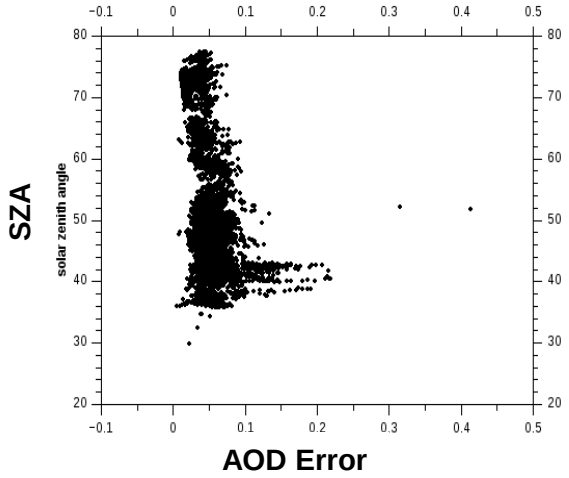
PMAp AOD randomized error estimates

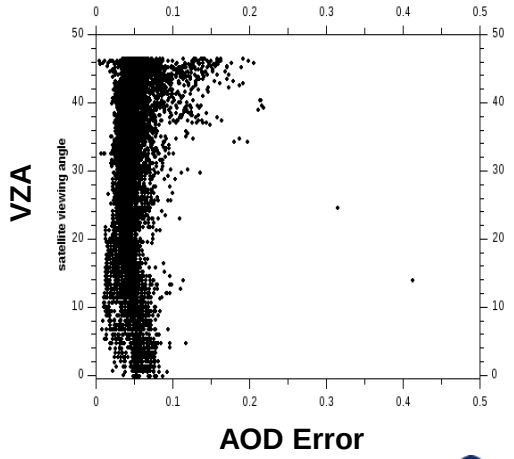
Version 2 L3 gridded results – Summer 2013 and Winter 2015 – Metop-A





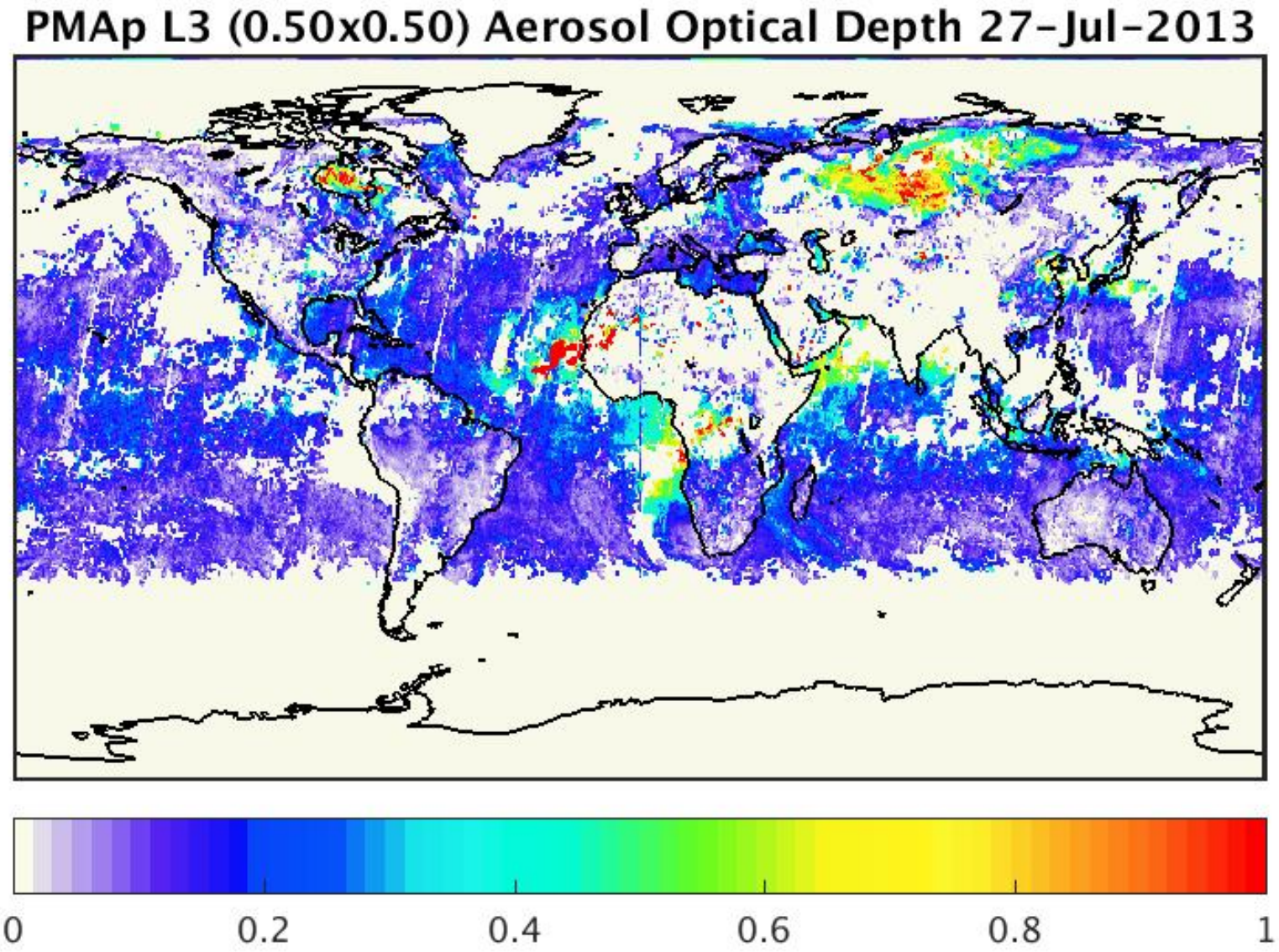






PMAp AOD results

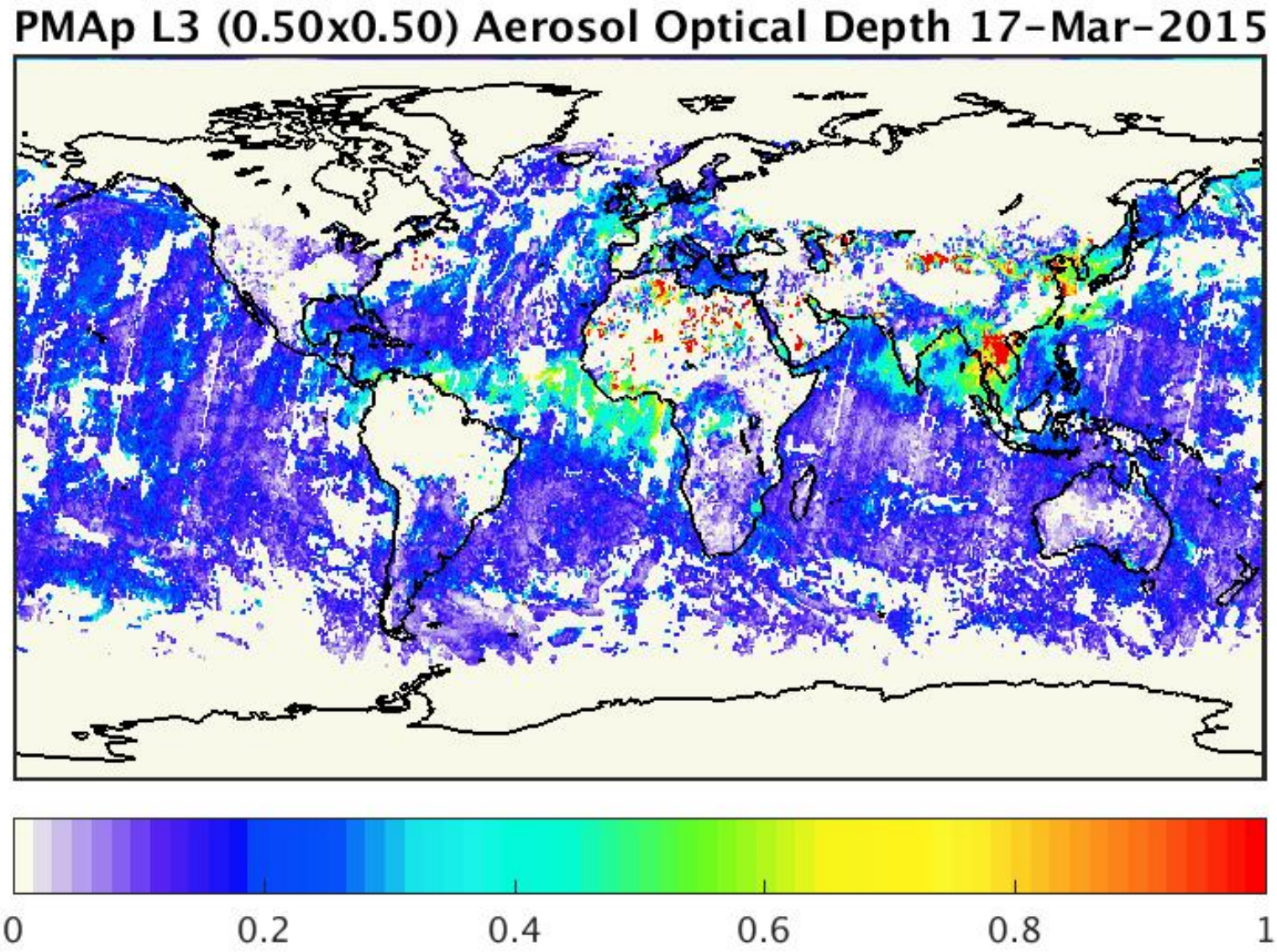
Version 2 L3 gridded results – 1 day Metop-A & B



Metop A
Metop-B

PMAp AOD results

Version 2 L3 gridded results – 1 day Metop-A & B

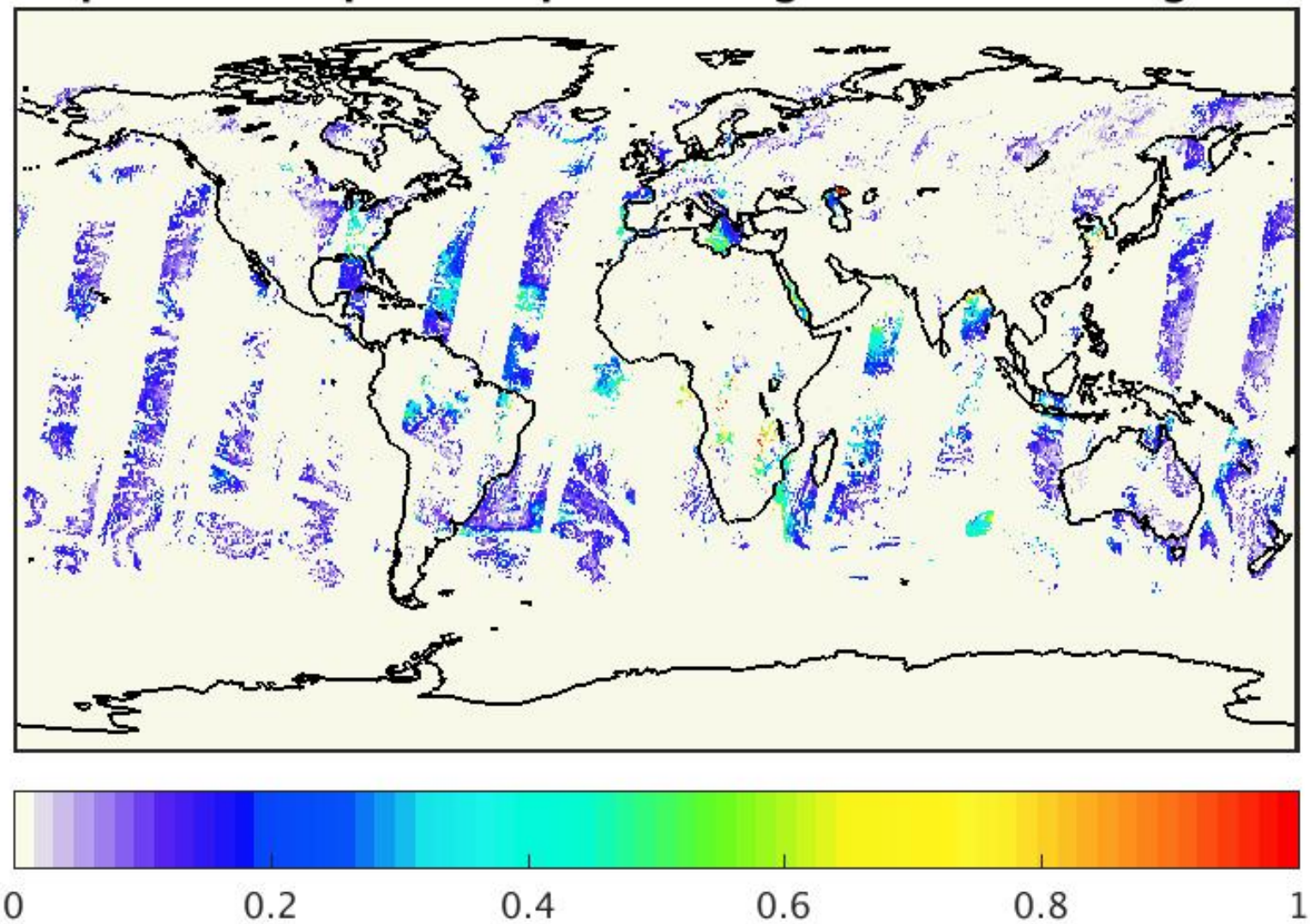


Metop A
Metop-B

PMAp AOD results

Version 2 L2 satellite grid results – 1 day Metop-A - 30 August 2013

Metop-B PMAp Aerosol Optical Depth 30-Aug-2013 to 31-Aug-2013



Operational NRT L2 product

TSAT

PMAp version 2 validation at EUMETSAT
Land & ocean

EUMETSAT

Polar Multi-Sensor Aerosol Product: Validation Report

Doc.No.	:	EUM/TSS/REP/14/745438
Issue	:	v4A e-signed
Date	:	9 February 2017
WBS/DBS	:	

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http://www.eumetsat.int

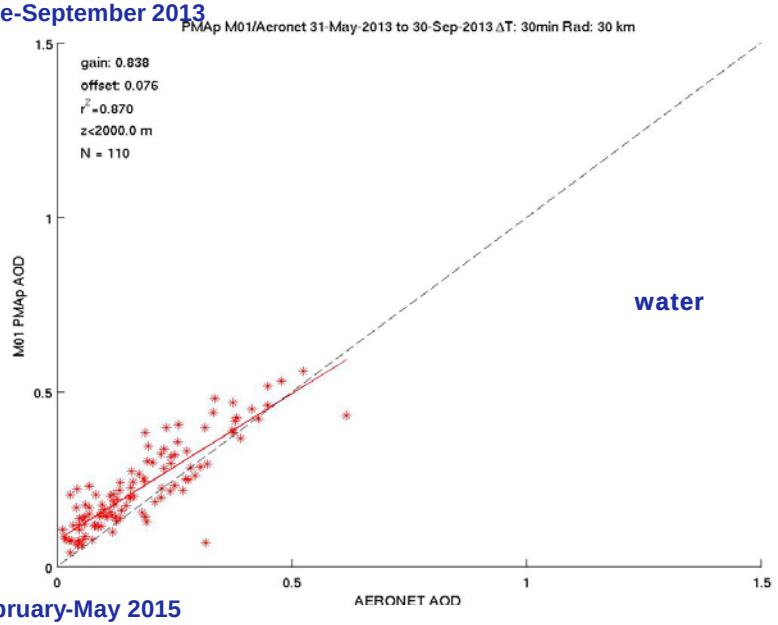
Documentation:

www.eumetsat.int > Data > Technical documentation > Metop > PMAp

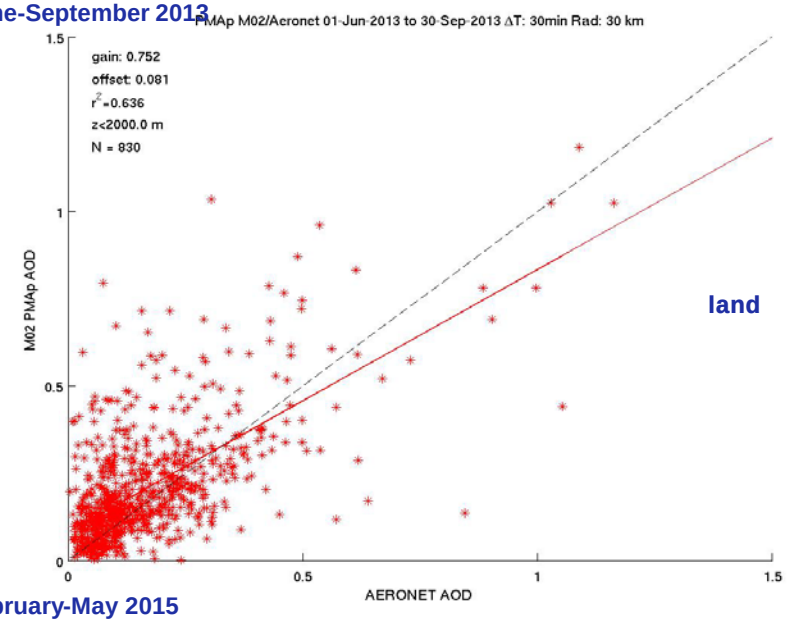
PMAp version 2 validation at EUMETSAT

Operational validation with AERONET 1.5 weekly data

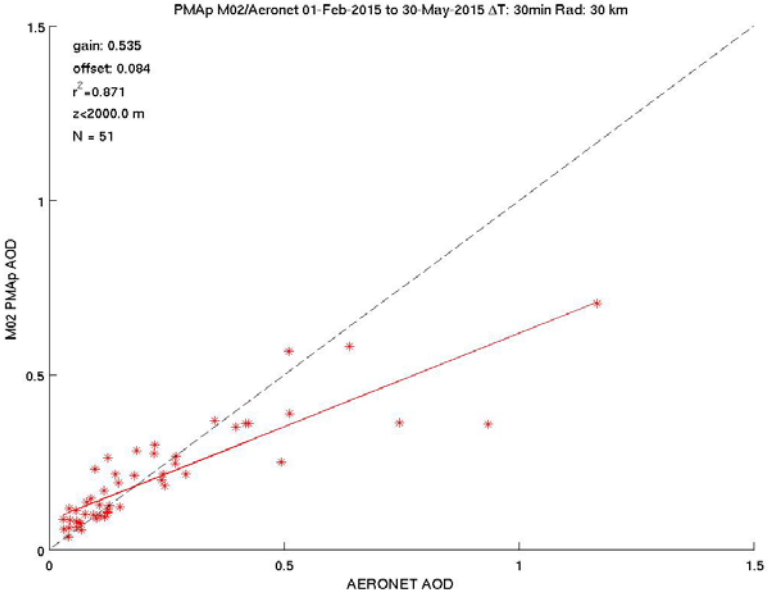
June-September 2013



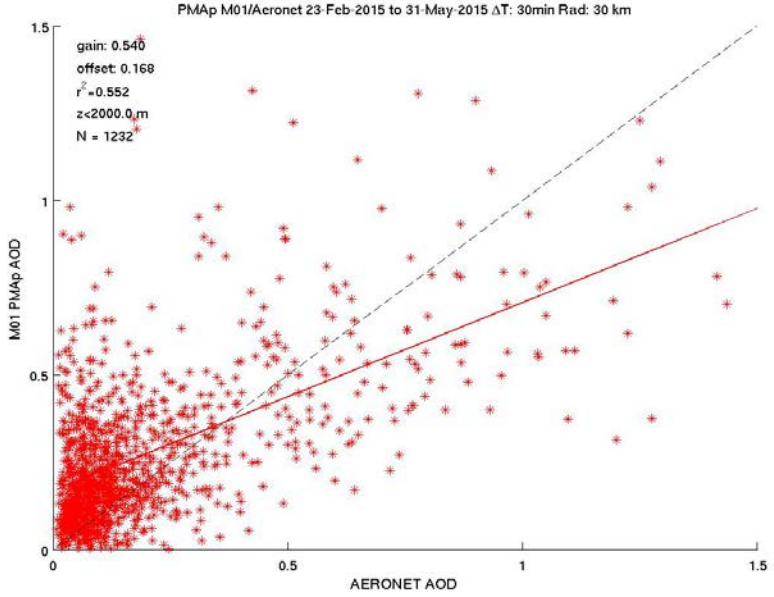
June-September 2013



February-May 2015



February-May 2015

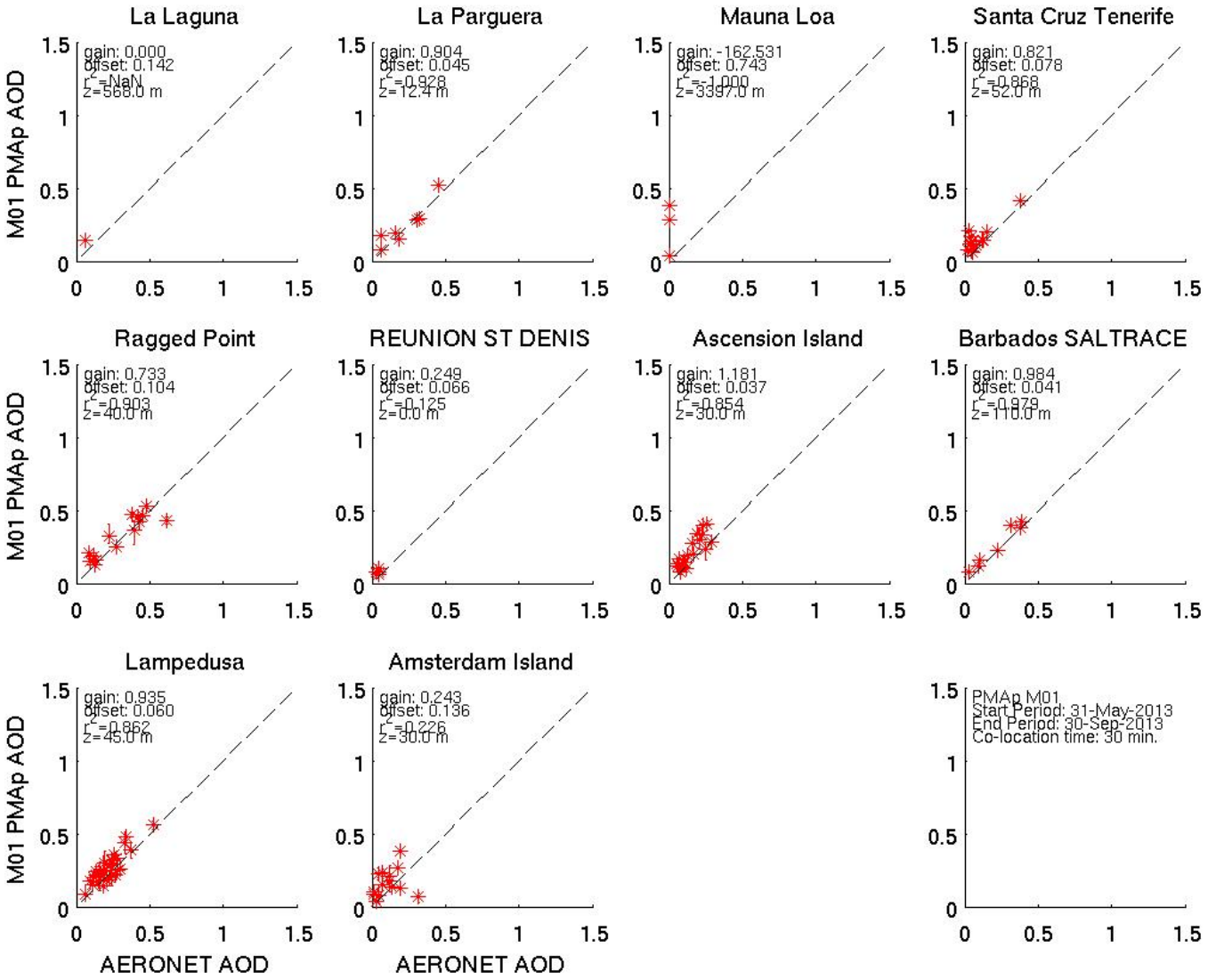


PMAp version 2 validation at EUMETSAT

Operational validation with AERONET 1.5 weekly data

June-September 2013

ocean

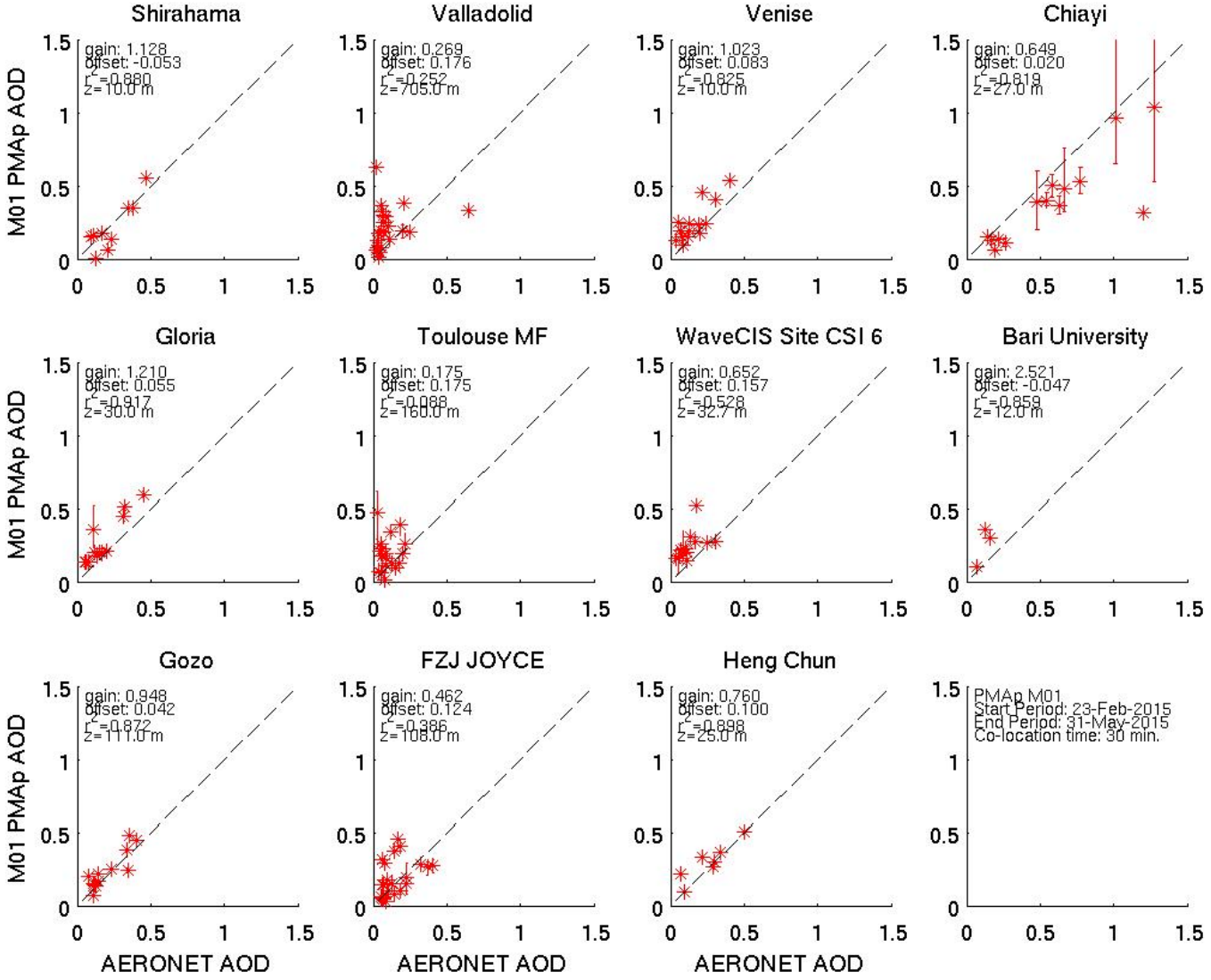


PMAp version 2 validation at EUMETSAT

Operational validation with AERONET 1.5 weekly data

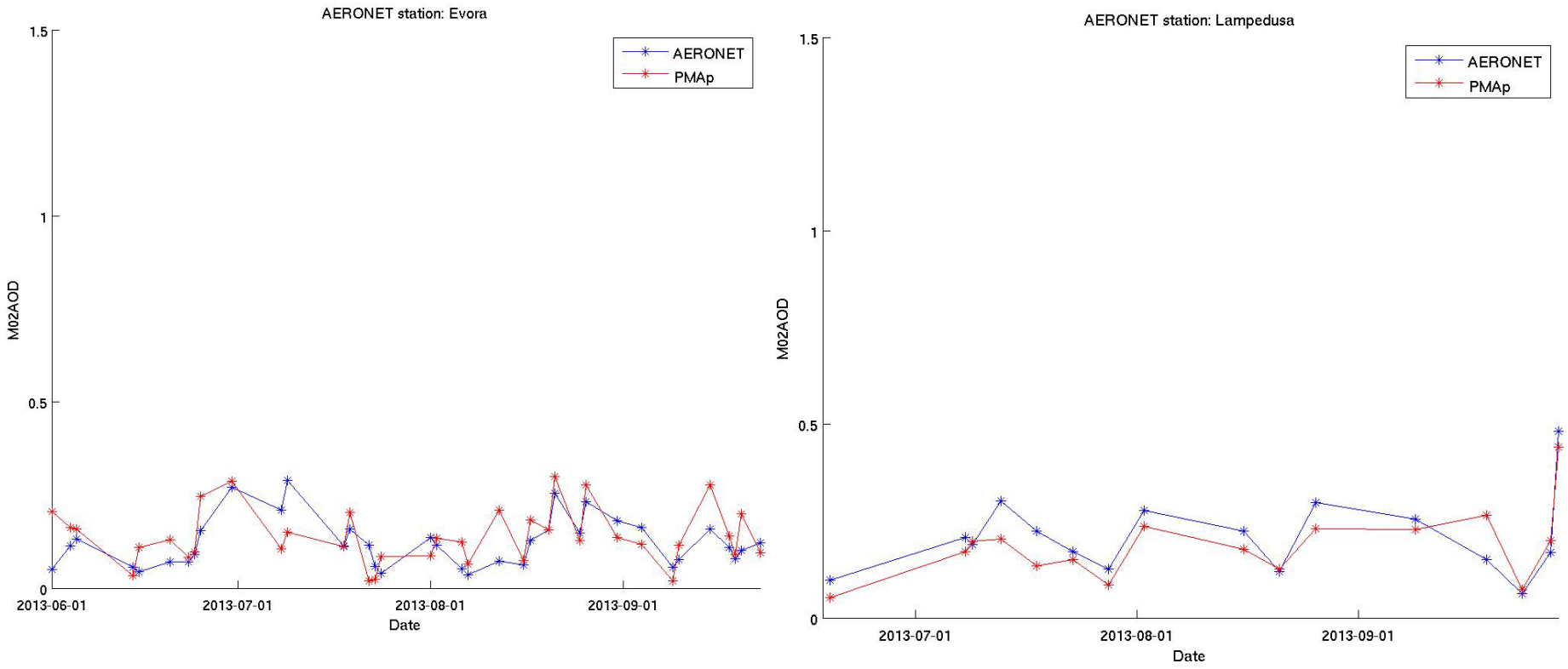
February-May 2015

land



PMAp version 2 validation at EUMETSAT

Operational validation with AERONET 1.5 weekly data



Time series of the AOD at 550 nm for validation period 1 at the Evora AERONET site (left panel) and at the Lampedusa AERONET site (rigth panel) compared to the AOD retrieved from METOP-A.

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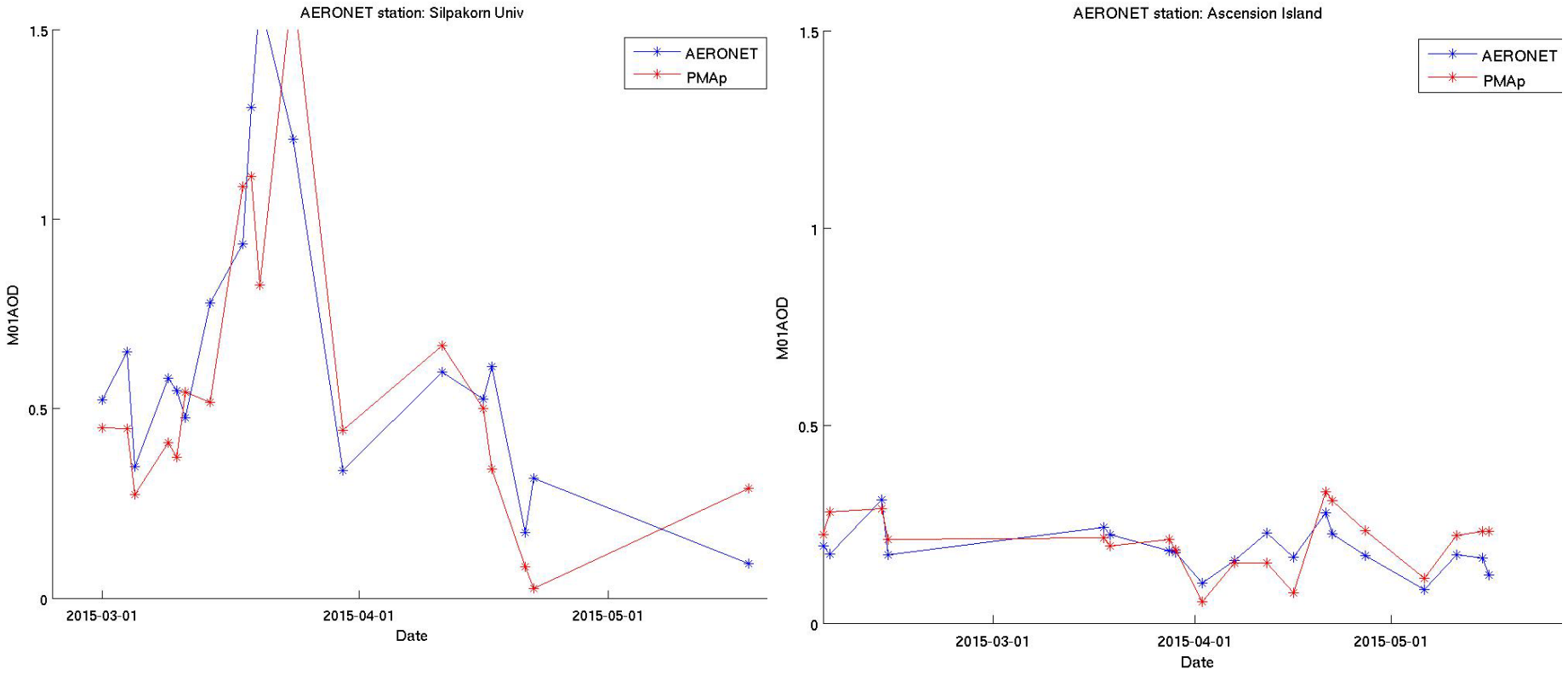
PMAp version 2 validation at EUMETSAT

Operational validation with AERONET 1.5 weekly data



Time series of the AOD at 550 nm for validation period 2 at the Silpakorn University AERONET site (left panel) site and at te Ascension Island AERONET site (right panel) compared to the AOD retrieved from METOP-B.

PMAp version 2 validation at EUMETSAT

Operational validation with AERONET 1.5 weekly data

PMAp vs Aeronet Lev2 Over Ocean

	June - Sept 2013		Feb-May 2015	
	MetopB	**MetopA**	**MetopB**	**MetopA**
gain	0.838	0.783	0.493	0.535
bias	**0.076**	**0.045**	**0.115**	**0.084**
correlation	**0.932**	**0.914**	**0.881**	**0.933**
N	110	90	22	51

PMAp vs Aeronet Lev2 Over Land

	June - Sept 2013		Feb-May 2015	
	MetopB	**MetopA**	**MetopB**	**MetopA**
gain	0.597	0.752	0.540	0.503
bias	**0.113**	**0.081**	**0.168**	**0.158**
correlation	**0.767**	**0.797**	**0.742**	**0.782**
N	906	830	1232	1000

Aerosol_CCI

ADV/ASV (AATSR Dual/Single View),
ORAC ((Oxford Ral Aerosol and Cloud Retrieval)
SU (Swansea University)

Metric	Algorithm					
	ADV/ASV		ORAC		SU	
	V1.0	V2.3	V1.0	V3.02	V1.0	V4.21
Over Ocean						
number of points	75	64	65	102	13	52
bias	0.04	0.02	0.07	0.10	0.06	−0.002
RMSE	0.16	0.09	0.15	0.16	0.08	0.06
correlation	0.58	0.89	0.81	0.93	0.89	0.86
GCOS fraction (%)	17	66	46	31	15	58
Over Land						
number of points	306	185	262	262	138	343
bias	−0.005	−0.05	0.03	−0.002	−0.001	−0.01
RMSE	0.16	0.13	0.16	0.08	0.08	0.11
correlation	0.59	0.66	0.59	0.86	0.72	0.82
GCOS fraction (%)	37	54	40	51	46	62

(Popp et al. 2016)

PMAp version 2 validation
MPI for Chemistry study

Comparison of Metop PMAp Version 2 AOD Products using Model Data

Final Report
EUMETSAT ITT 15/210839

Prepared by:

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With contributions from:

Mohamed Abdelkader[2], Klaus Klingmüller, Benedikt Steil and Jos Lelieveld

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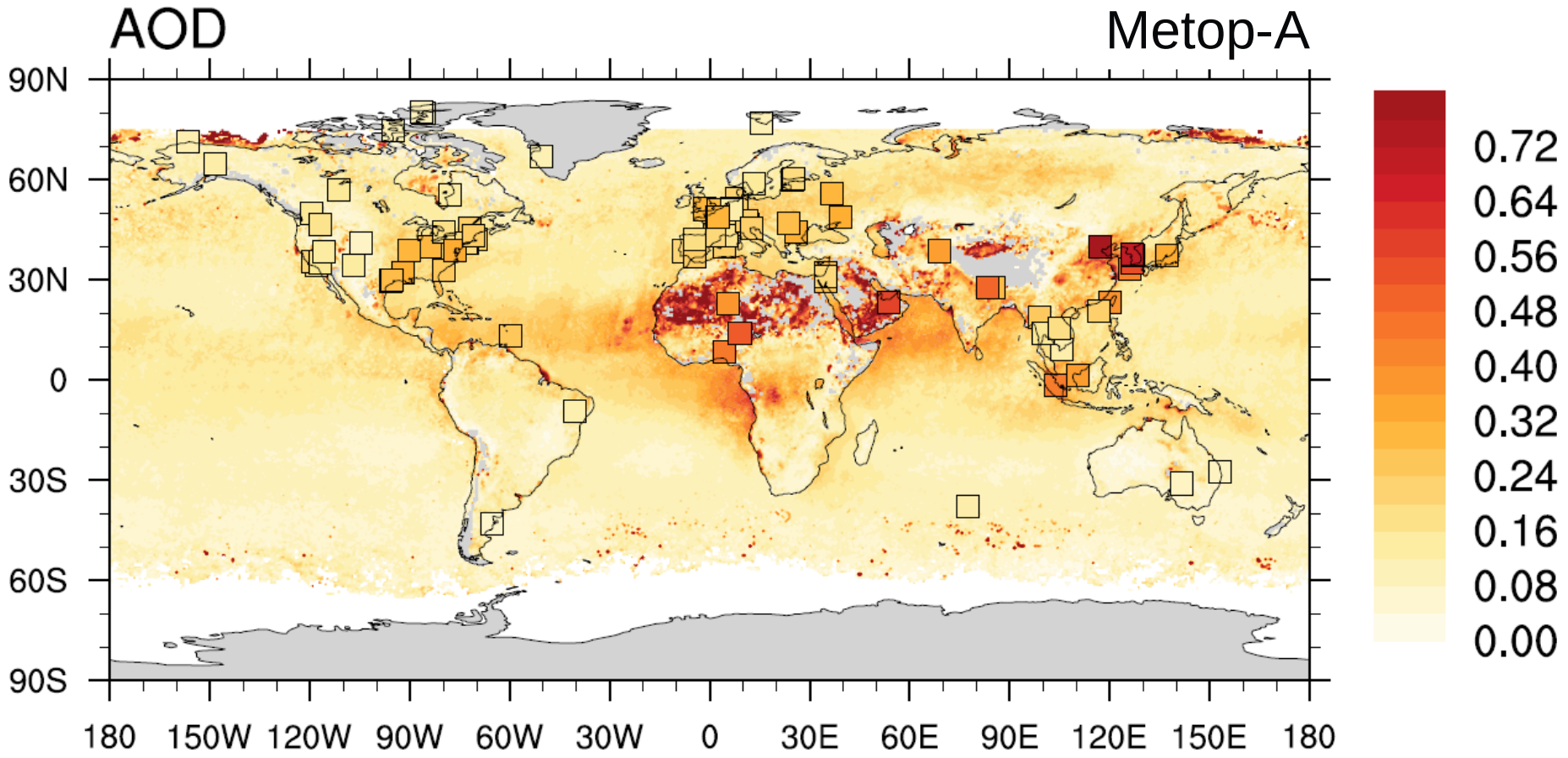
Documentation:
www.eumetsat.int > Data > Technical documentation > Metop > PMAp

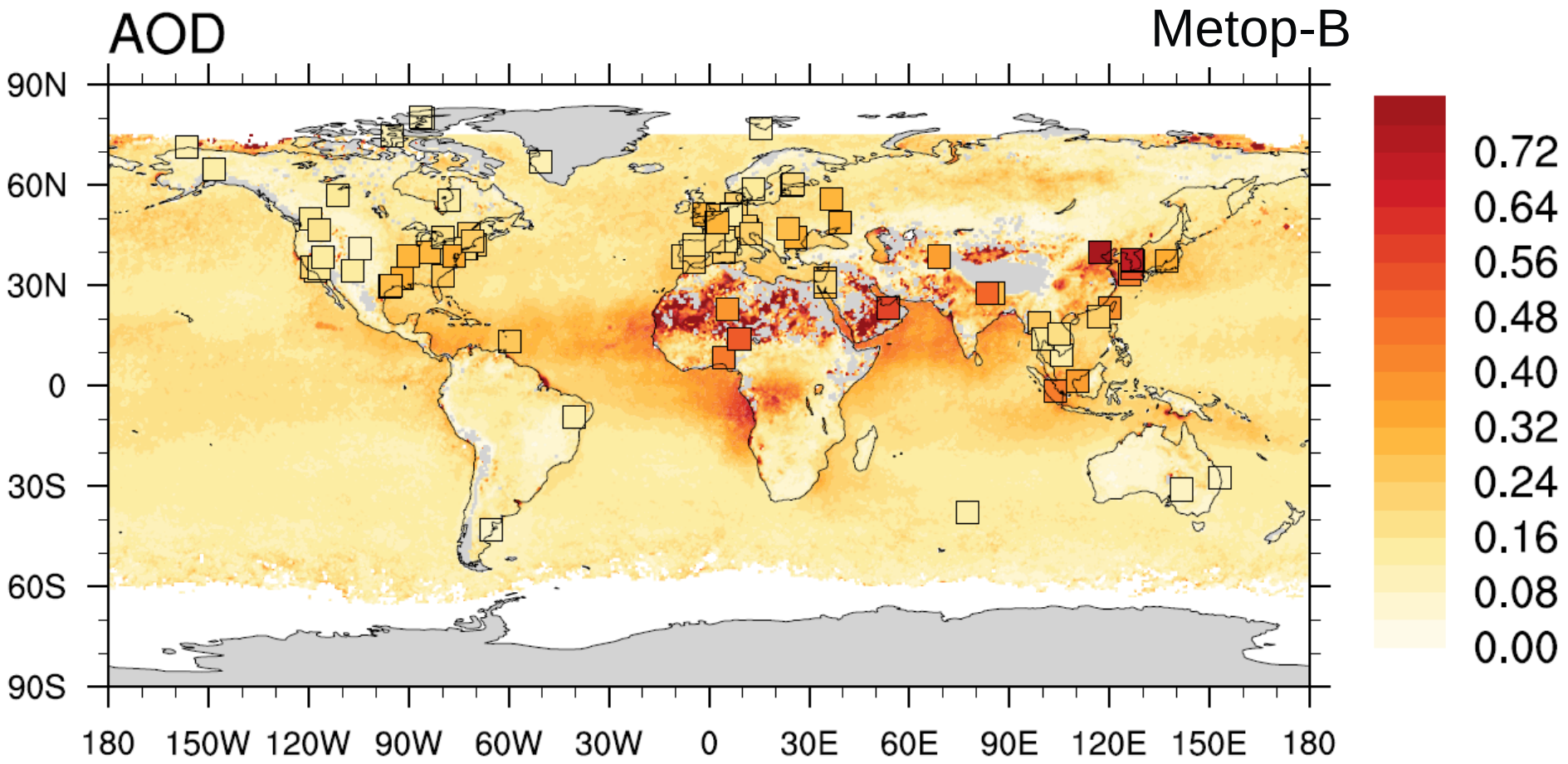
PMAp version 2 validation – MPI Chem.

Validation against Aeronet 2.0 – Metop-A – June to Sep 2013



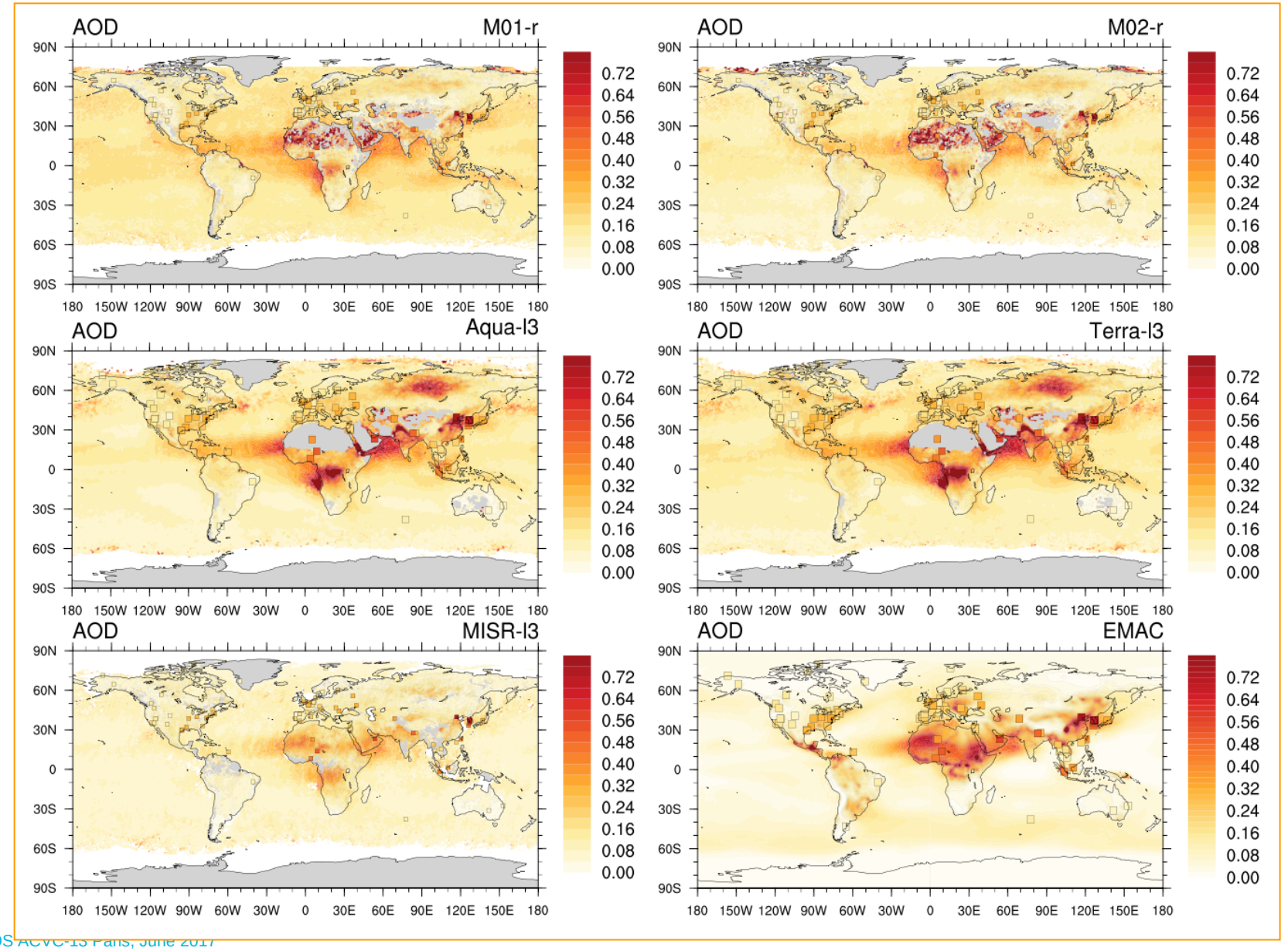
PMAp version 2 validation – MPI Chem.

Validation against Aeronet 2.0 – Metop-B – June to Sep 2013



PMAp version 2 validation – MPI Chem.

Validation against Aeronet 2.0 and other instruments – June to Sep 2013



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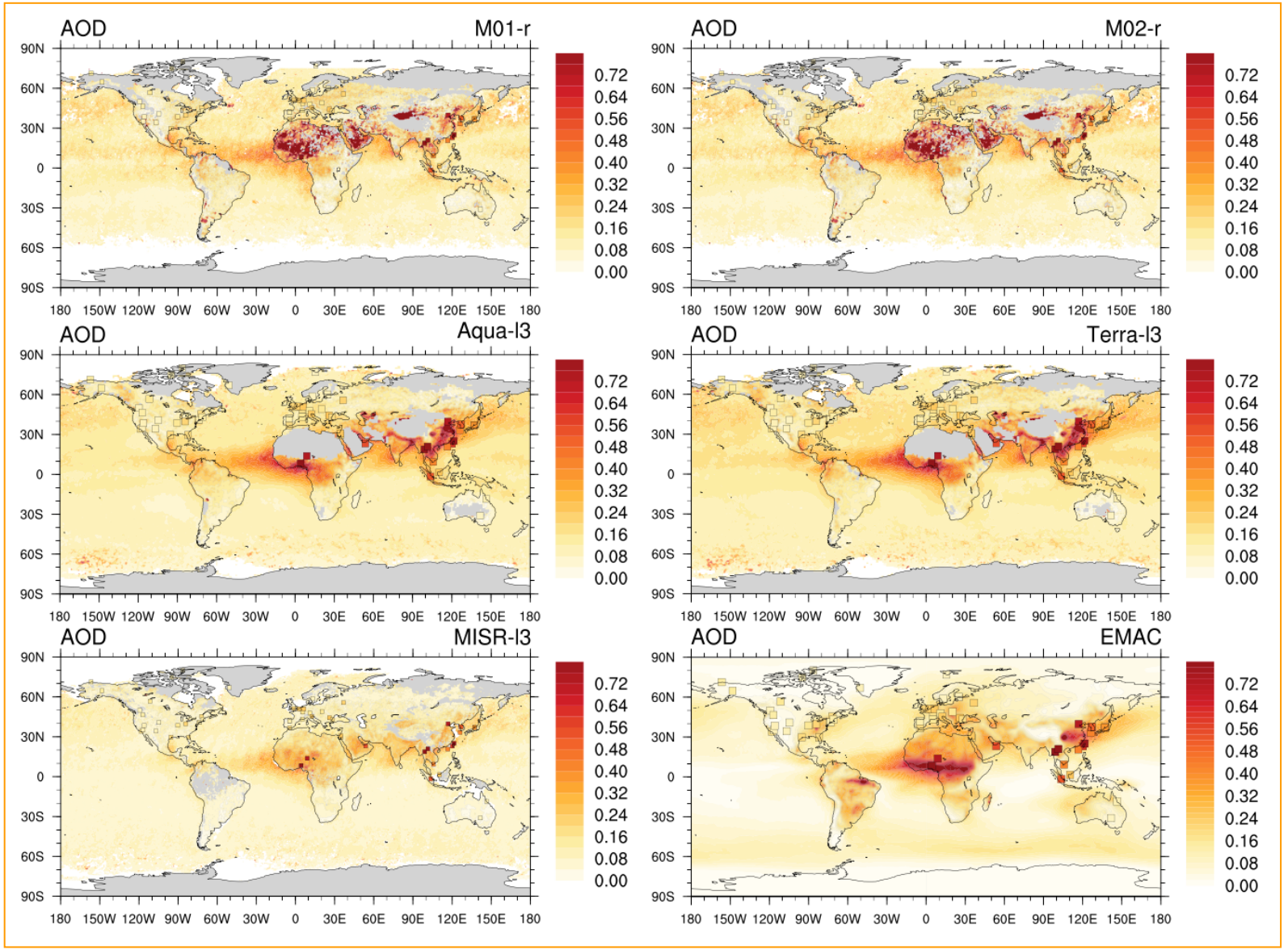
PMAp version 2 validation – MPI Chem.

Validation against Aeronet 2.0 and other instruments – Feb to May 2015



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PMAp version 2
Outlook

Whats next?

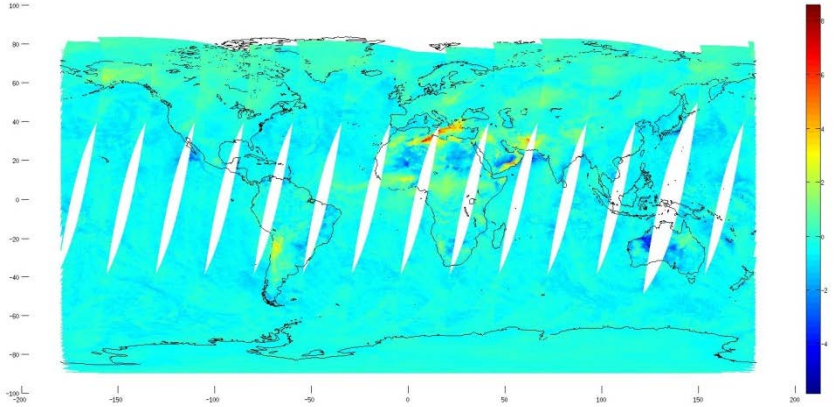
PMAp version 2.2 – release planned for Q1 2018

- Improved dust/ash detection using IASI (Clarisse et al.)

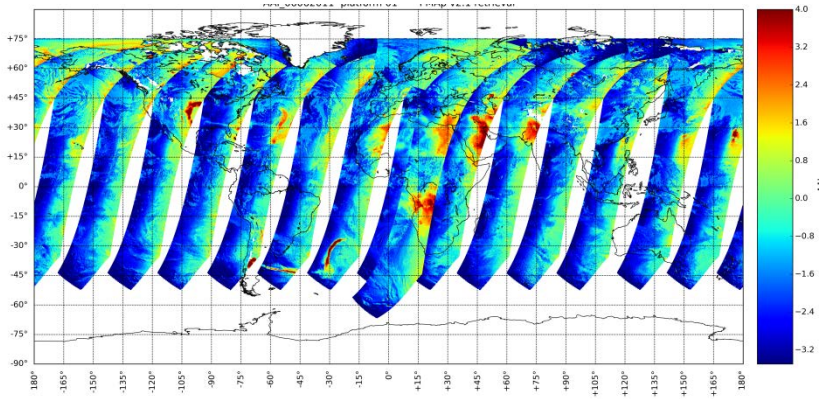
- Include UV information for additional absorbing aerosol detection

- Provide a level-3 gridded daily AOD product (offline TBC)
  - ➢ 0.5x0.5, gap-filled, quality controlled

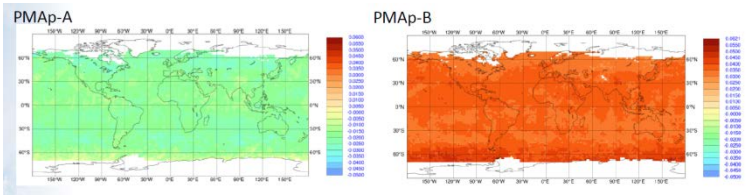
- Degradation correct PMD radiances
  - ➢ reduce overall biases and the biases between Metop-A and B



IASI Dust flag, Clarisse et al, AC SAF



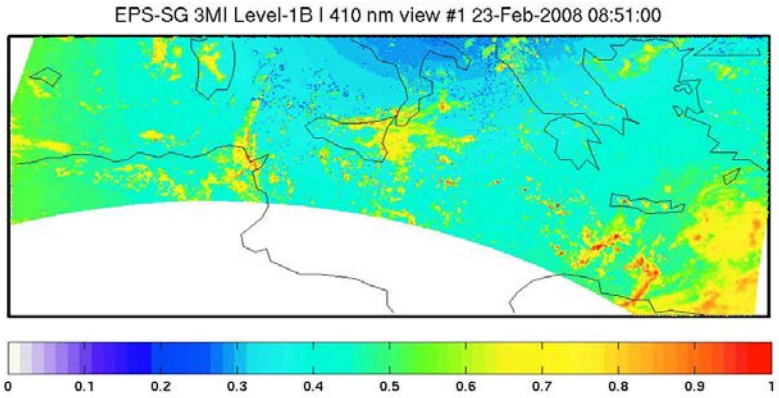
UV absorbing radiances vs background



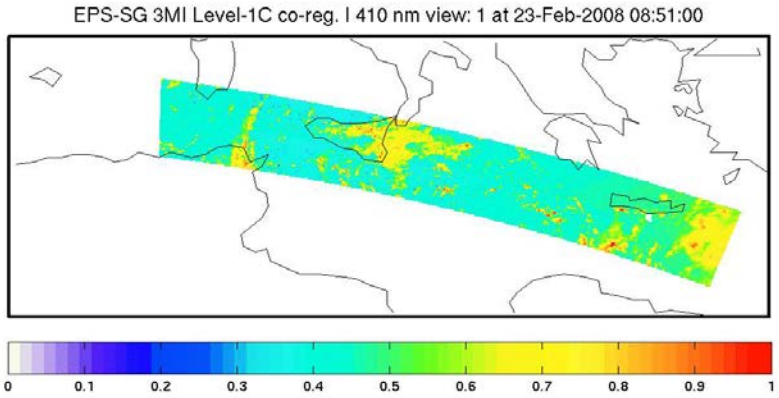
Ades et al., ECMWF

3MI L1C proto-type results

L1C EUM proto-type output – Reflectance $\pi/\cos(\Theta)$ I/R_0 – version 1



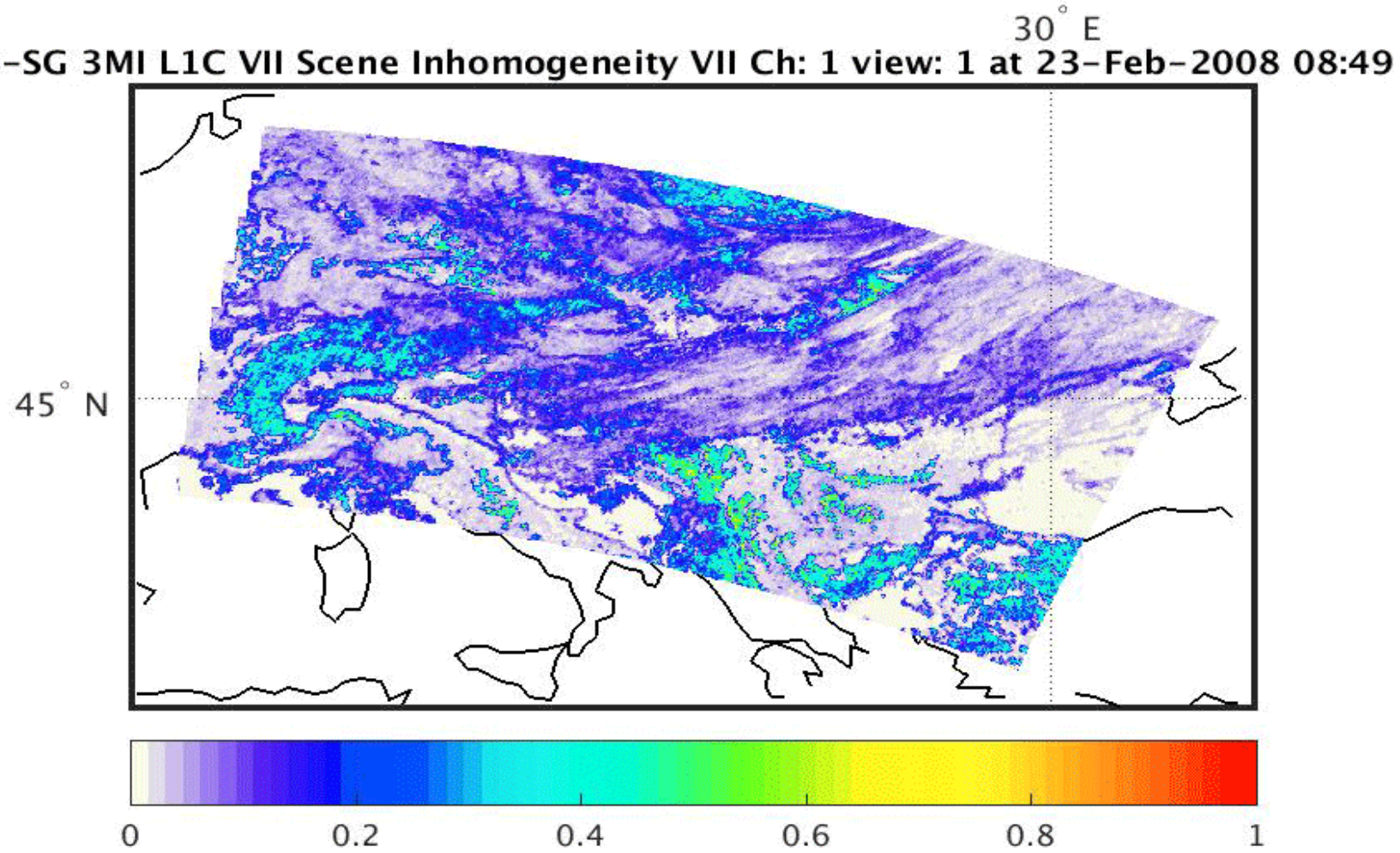
Level 1B
instrument resolution



Level 1C
fixed sinusoidal grid

3MI L1C proto-type version2 results

Co-located VII cloud-information – scene in-homogeneity VII at 555 nm



1st option:

Co-located on the 3MI detector grid per view (14 views of CFR) – presented here!

EPS-SG: Towards an EPS-SG hyper-instrument

3MI/S5/IASI-NG/VII -

Combining co-locations of VII/Sentinel5/IASI-NG observations with co-registered multi-viewing observations (3MI) on 3MI multi-viewing fixed grid.

EPS-SG Platform

Sentinel-5
UV-Vis-SWIR hyper spectral sounder

IASI-NG
IR hyper spectral sounder

VII
Very high spatial resolution,
multi channel imager

3MI
Multi-viewing,
Multi-polarisation,
Multi-channel imager

Co-location and co-registration

EPS-SG
hyper-instrument

0.29 – 15μm
0.5 – 7 km^2
~ 19000 channels

Initial product: Multi-sensor Aerosol product (MAP)

The end

Product delivery features:

- Near real time 3 minutes granules, maximum 3 hours after sensing time

→ *Available via EUMETCast in netcdf4.*

- Full orbit offline data. Available from the EUMETSAT archive

→ http://archive.eumetsat.int *EPS native and netcdf4.*

- AOD, volcanic ash flag

Version1 (water only)
Start of dissemination:
29th April 2014
Version 2.0 (water and land)
Start of dissemination:
17th April 2016
Version 2.1 (water and land)
Start of dissemination:
23rd February 2017

Documentation (user guide):
www.eumetsat.int > Data > Technical documentation > Metop > PMAp

The Polar Multi-sensor Aerosol Product

Product features

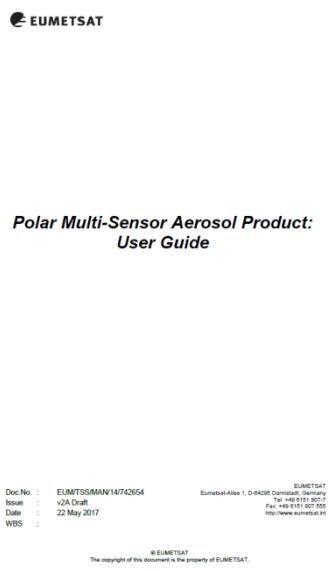
AOD at 550 nm retrieved for the GOME-2 PMD ground pixel	
Error on the retrieved AOD	
Aerosol class	0: no dust / fine mode (ocean) 1: coarse mode (ocean) 2: thick Biomass burning 3: volcanic ash/thick dust 4: volcanic ash with SO_2 15: no classification
flag_ash	0: no ash 1: ash 15: no classification
pmap_geometric_cloud_fraction	
chlorophyll_pigment_concentration	
retrieval_flags_aerosol	
retrieval_algorithm	
avhrr_geometric_cloud_fraction	
flag_sun_glint	
flag_snow_ice	
split_window_btd	
wind_speed	
land_fraction	
reflectance_inhomogeneity	

- **Near Real Time 3min-granules**
  maximum 3 hours after sensing time

  Available via EUMETCast in EPS native and netcdf4

- **Full orbit offline data**

  Available from the EUMETSAT archive in EPS native and netcdf4


EUMETSAT

Polar Multi-Sensor Aerosol Product: User Guide

Doc.No. : EUM/TSS/MAN/14/742654
Issue : v2A Draft
Date : 22 May 2017
WBS :

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EUMETSAT

Polar Multi-Sensor Aerosol Product: Factsheet

Doc.No. : EUM/TSS/DOC/14/776541
Issue : v2E e-signed
Date : 28 February 2017
WBS :

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Concluding remarks

Regional comparison

- PMAp AOD is in good agreement, in most part of the evaluated regions, with ground-based observations from many AERONET stations

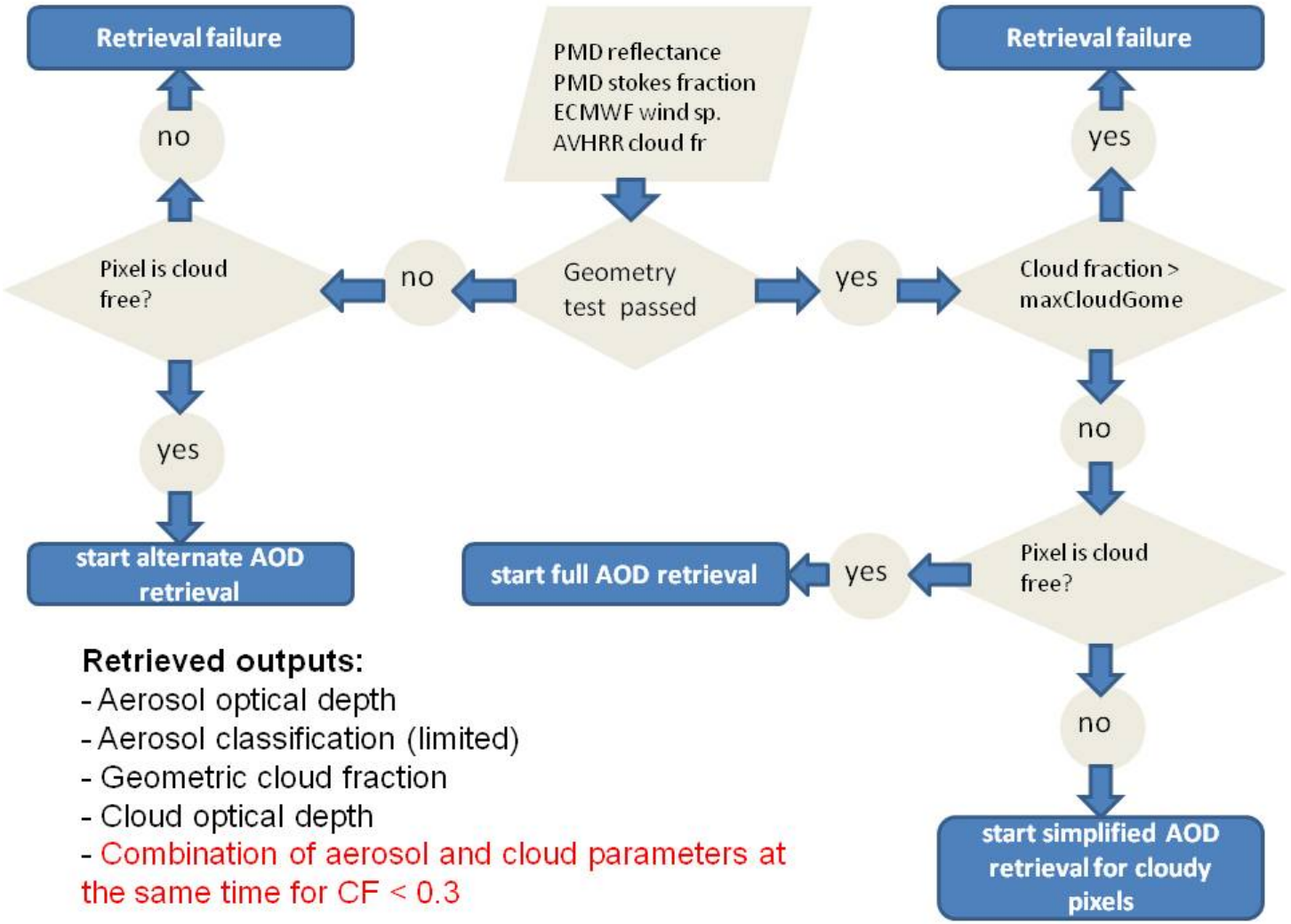
- MPIC validation – vs Aeronet
  PMAp M02 r (-0.28 * - 0.950) with RMSE (0.06 - 0.5)
  PMAp M01 r (-0.66 * - 0.62) with RMSE (0.06 - 0.32)
  * r < 0 for M01 in 3 regions (EMME, Arabian Gulf, North Africa; N < 8, high reflectance areas)
  for M02 in 1 region (Indian Ocean, N = 4)

- still critical NW America and Australia - critical for MODIS as well
  - Rayleigh scattering correction not included in the data provided to MPIC
  - high reflectance area

- complementary in-house AERONET comparison

	PMAp v 2.1.0				PMAp v 2.0	
	July 2013		March 2015		29/02 – 9/03 2016	
	M01	M02	M01	M02	M01	M02
gain	0.522	0.958	0.765	0.651	0.820	0.804
offset	0.106	0.049	0.163	0.136	0.208	0.204
r	0.74	0.74	0.79	0.86	0.66	0.78
N sites	60	60	65	90	--	--

PMAp: AOD retrieval algorithm



Retrieved outputs:
- Aerosol optical depth
- Aerosol classification (limited)
- Geometric cloud fraction
- Cloud optical depth
- Combination of aerosol and cloud parameters at the same time for CF < 0.3

- Geometry dependent test with intercomparison of:
  - calculated surface signal
  - calculated wind speed dependence
  - calculated aerosol signal
- Cloud filter:
  - AVHRR/VIS
  - AVHRR/IR

PMAp: AOD retrieval
Volcanic ash detection

Algorithm 1 - AVHRR & GOME-2 -

<u>over OCEAN & LAND</u>

- **BT(10.8 µm – BT(12 µ) < - 2.2 °K**
  coarse absorbing particles

<u>over OCEAN</u>

- **R(AVHRR_chVIS) / R(AVHRR_chNIR) > ths**
  relative spectral flatness

<u>over LAND (in-progress)</u>

- GOME UV Absorbing index

Algorithm 2 - IASI -

<u>over OCEAN & LAND</u>

BT(10µm) – BT(12µm) < - 1.0 °K

AND

BT(IASI_bckg ch) – BT(IASI_ν_3 SO_2 abs ch) > 2.0 °K

volcanic ash / thick dust

volcanic ash with SO_2

Flag ASH

PMAp: AOD retrieval – Outlook for PMAp 2.2

Additional dust/ash detection using IASI and UV data

Unified approach to detect aerosol type exploiting the IR spectral range

Distance approach

L. Clarisse et al., Unified approach, ACP 2013

set of clear spectra
(i.e. not affected by aerosol)

$\boldsymbol{\mu_c}$ mean spectra,
$\mathbf{S_c}$ clear covariance matrix

set of 'polluted' spectra
(ash, dust, … set of same type aerosol target species)

$\boldsymbol{\mu_p}$ mean spectra;
by RTM simulation μp = K + μ_c ; or measured

$$R_N = \frac{(\mu_p - \mu_c)^T S^{-1}}{\sqrt{(\mu_p - \mu_c)^T S^{-1} (y - \mu_c)}} (y - \mu_c) \leq \text{thrs}$$

$$R_N = G\ (y - \mu_c) + C \leq \text{thrs}$$

dust

Y = analysed spectra
G = f (ch, surf_type)
μ_c = f (surf_type)
C = f (surf_type)
thrs to be manually tuned

+ GOME-2 absorbing aerosol UV information bewteen 360 to 400 nm.

PMAp: AOD retrieval – Outlook for PMAp 2.2

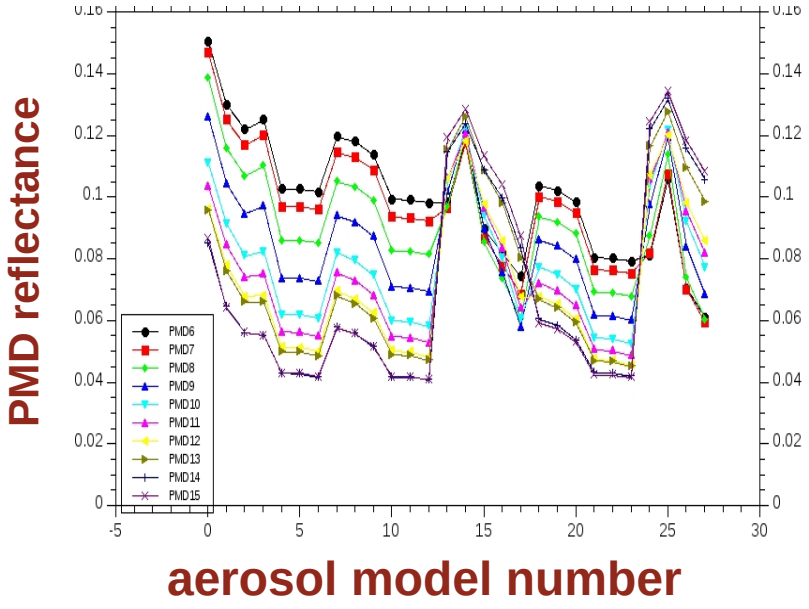
Retrieval of one AOD per class

Three steps retrieval:

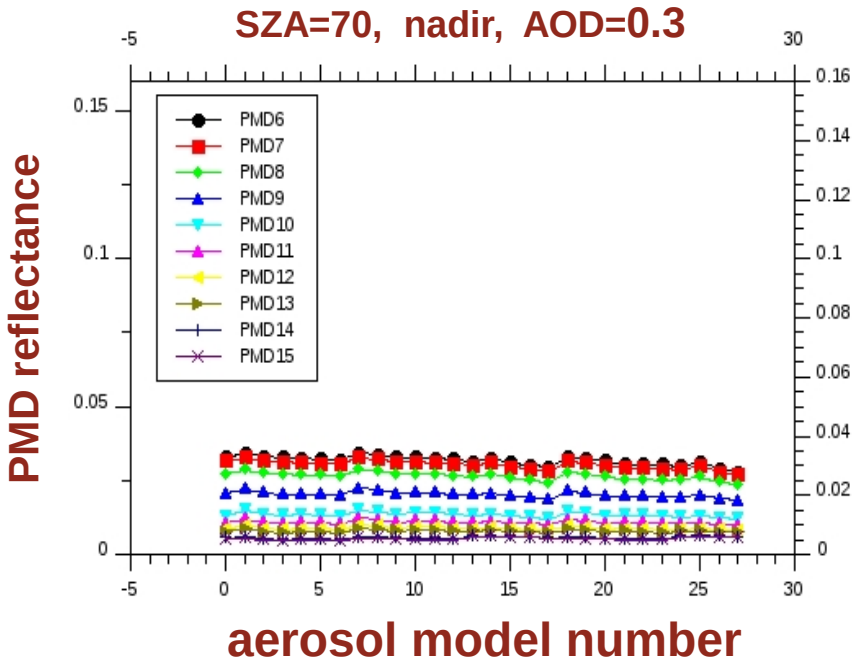
Step2: Retrieval of a set of candidate AODs (type)

$$\chi^2 = \frac{\sum_O \frac{\left(R_{PMD} - R_{modelled}\right)^2}{R_{modelled}} + \sum_P \frac{\left(q_{PMD} - q_{modelled}\right)^2}{q_{modelled}}}{O + P}$$

SZA=40, cos(RAZI)=-1, VZA=45, AOD=4



SZA=70, nadir, AOD=0.3



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Three steps retrieval:

Step3: Selection of the best fit

Select the best result of Step2 using least-square minimization for all GOME PMD bands (+ stokes fractions dependent on condition)

→ microphysics fit:

χ^2 minimization providing the best (AOD, aerosol type)

where χ is a measure of the distance between measured and modeled Reflectances (and Stokes fractions) at GOME PMD wavelengths

→ AOD error calculation:

std dev of a set of AODs calculated using variations in the input data

(e.g. wind speed, aerosol models, max-min of the cloud correction factor, …),

statistical approach to provide an error suitable for assimilation purposes

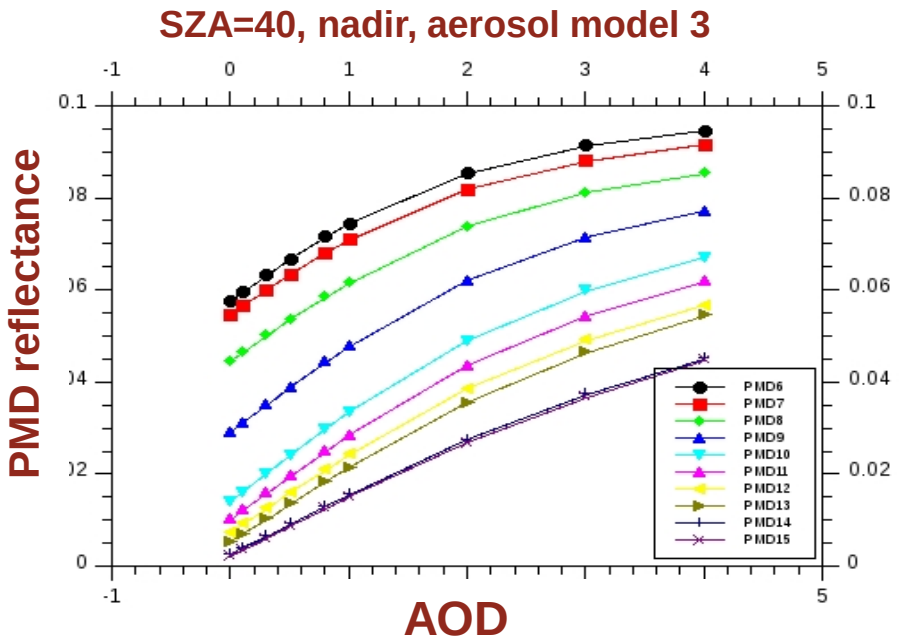
PMAp version history

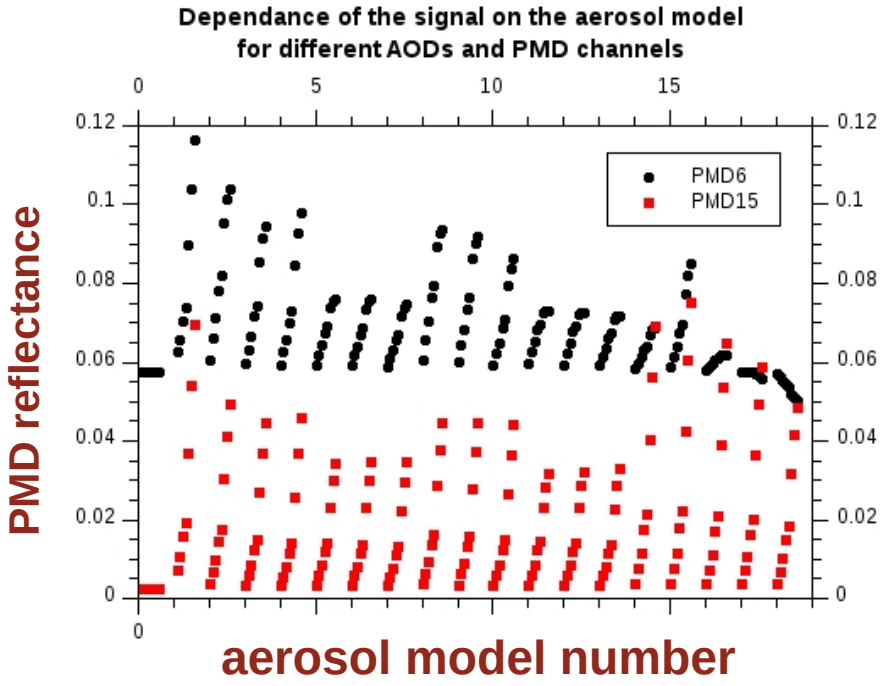
Retrieval over land & water – version 2

- **Release 2.0.2 (March 2016)**
  - Implementation of the PMAp retrieval over land surfaces
    - land fraction threshold test (from AVHRR)
    - LUT interpolation (geometric conditions, surface albedo, surface elevation)
  - New set of quality flags on the retrieval
- **Release 2.1.0 (Feb 2017)**
  - Surface homogeneity test
  - Surface elevation correction function for Rayleigh scattering calculation
  - Surface reflectance database (LER v2 0.25x0.25) statically masked for more accurate land/water areas partition
  - Volcanic Ash/SO_2 class using thermal IR IASI measurement
- **Next Release - foreseen Q4/2017**
  - Improved detection of thick desert dust and discrimination wrt to water clouds (IASI spectrum / Clarisse dust/ash detection scheme)
  - Add more GOME-2 UV information to support the pre-classification for absorbing aerosol (dust and ash)

Case 1 & 2: Geometry/Surface test passed

- A set of AODs (for all AVHRR preselected models) and chlorophyll corrections is estimated:
  - **Clear sky**: **UV [380 nm]**, **VIS/green [520 nm]**, **VIS/red [640 nm]**
  - **Cloudy**: **VIS/red [640 nm],** a priori chlorophyll, AVHRR cloud correction





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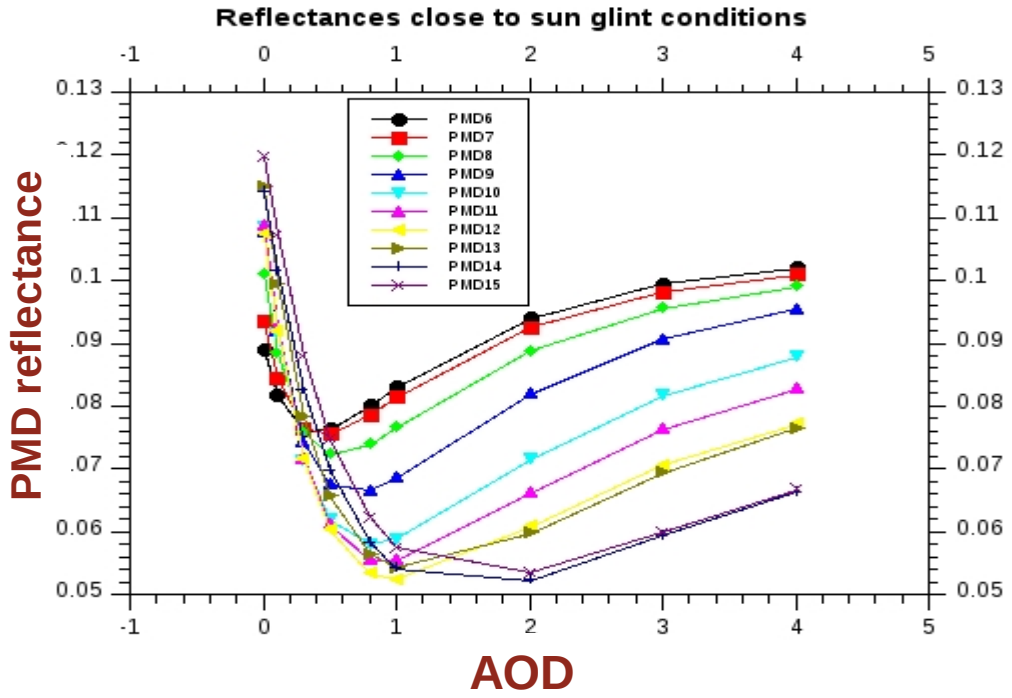
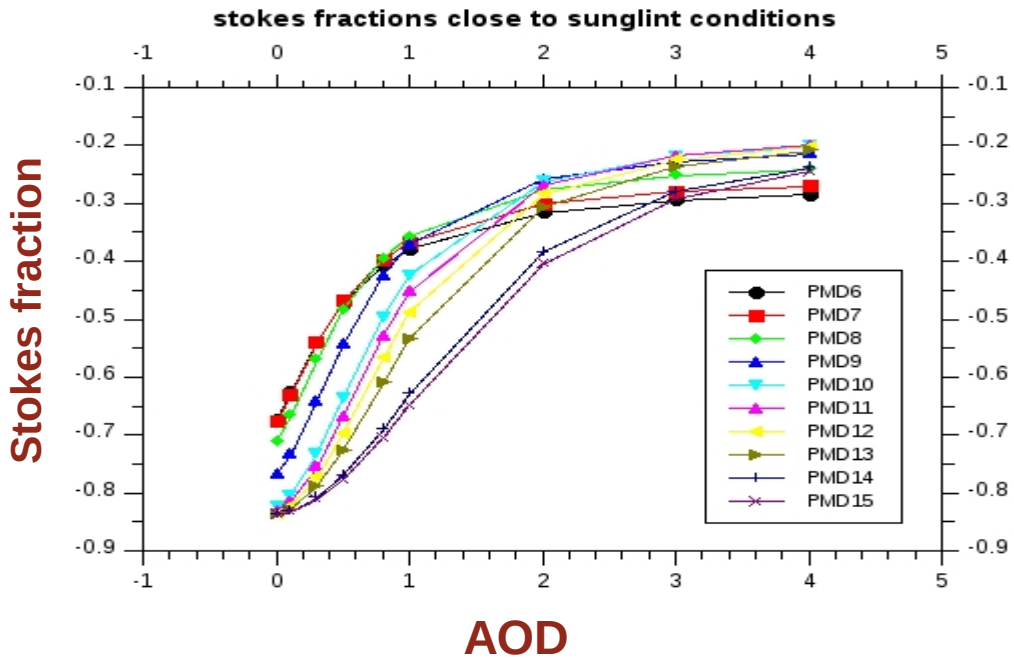
Case 3: Alternate retrieval combining reflectances & stokes fractions

- Guess an AOD using one channel (reflectance or stokes fraction) using different aerosol models and a priori surface
- Check reliability: $\chi^2 = \sum_N \frac{(R_{PMD} - R_{modelled})^2}{R_{modelled}} + \sum_M \frac{(q_{PMD} - q_{modelled})^2}{q_{modelled}} < chi2max$

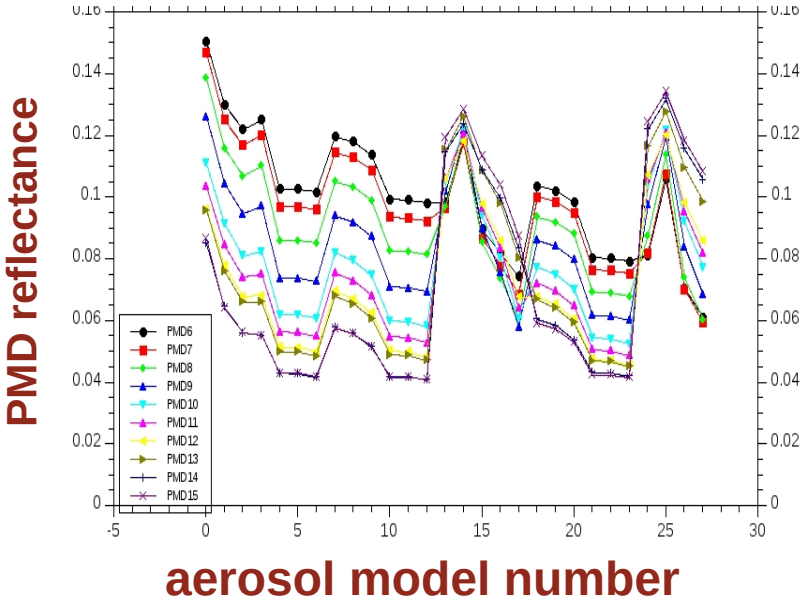




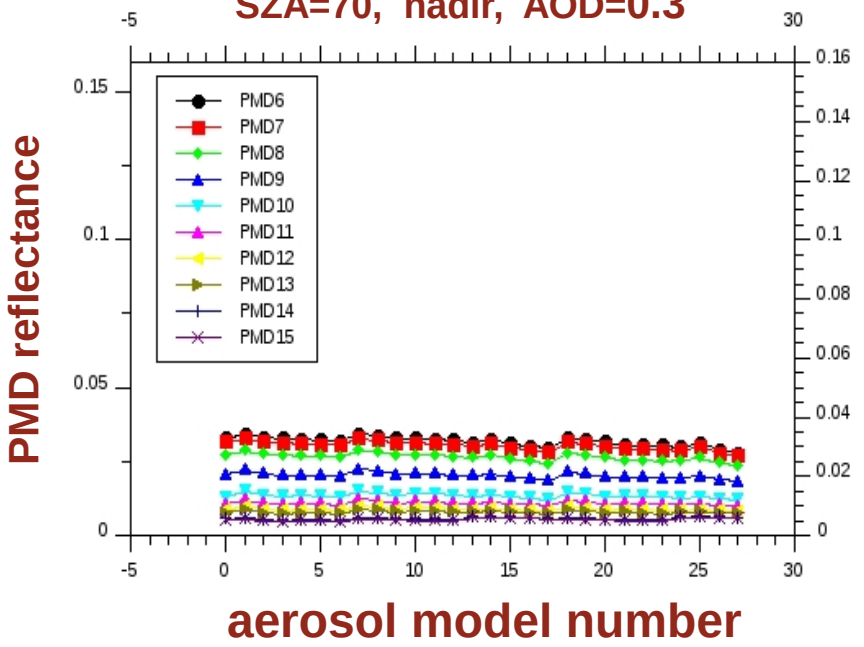
Selection of the aerosol model: Reflectances ...

$$\chi^2 = \frac{\sum_O \frac{(R_{PMD} - R_{modelled})^2}{R_{modelled}} + \sum_P \frac{(q_{PMD} - q_{modelled})^2}{q_{modelled}}}{O + P}$$

SZA=40, cos(RAZI)=-1, VZA=45, AOD=4



SZA=70, nadir, AOD=0.3



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Validation process
MPIC external study & complementary in-house validation

Validation periods 1. June – September 2013 2. February – May 2015

Correlative data-set

- ground-based reference data AERONET lev2
- satellite-based data
- EMAC model data

Sensor	Platform	Data Level	Spatial resolution	version
MODIS	Terra	Lev2	10 km x 10 km	6.0
		Lev3	1° x 1°	6.0
MODIS	Aqua	Lev2	10 km x 10 km	6.0
		Lev3	1° x 1°	6.0
MISR	Terra	Lev3	0.5° x 0.5°	8.31

Spatio – temporal co-location (Interpolation module, MPIC Evaluation Framework)

- EMAC model output sampled close to local MetOp satellites sensing time
- Co-location window
  - -> 30 min span wrt to MetOp overpass
  - -> 30 km radius around the AERONET station
- EMAC model grid used as reference in the comparison

Validation process
MPIC external study & complementary in-house validation

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MODIS	Aqua	Lev2	10 km x 10 km	6.0
		Lev3	1° x 1°	6.0
MISR	Terra	Lev3	0.5° x 0.5°	8.31

Validation procedure

- global scale

-> satellite inte-rcomparison: global maps & meridional means

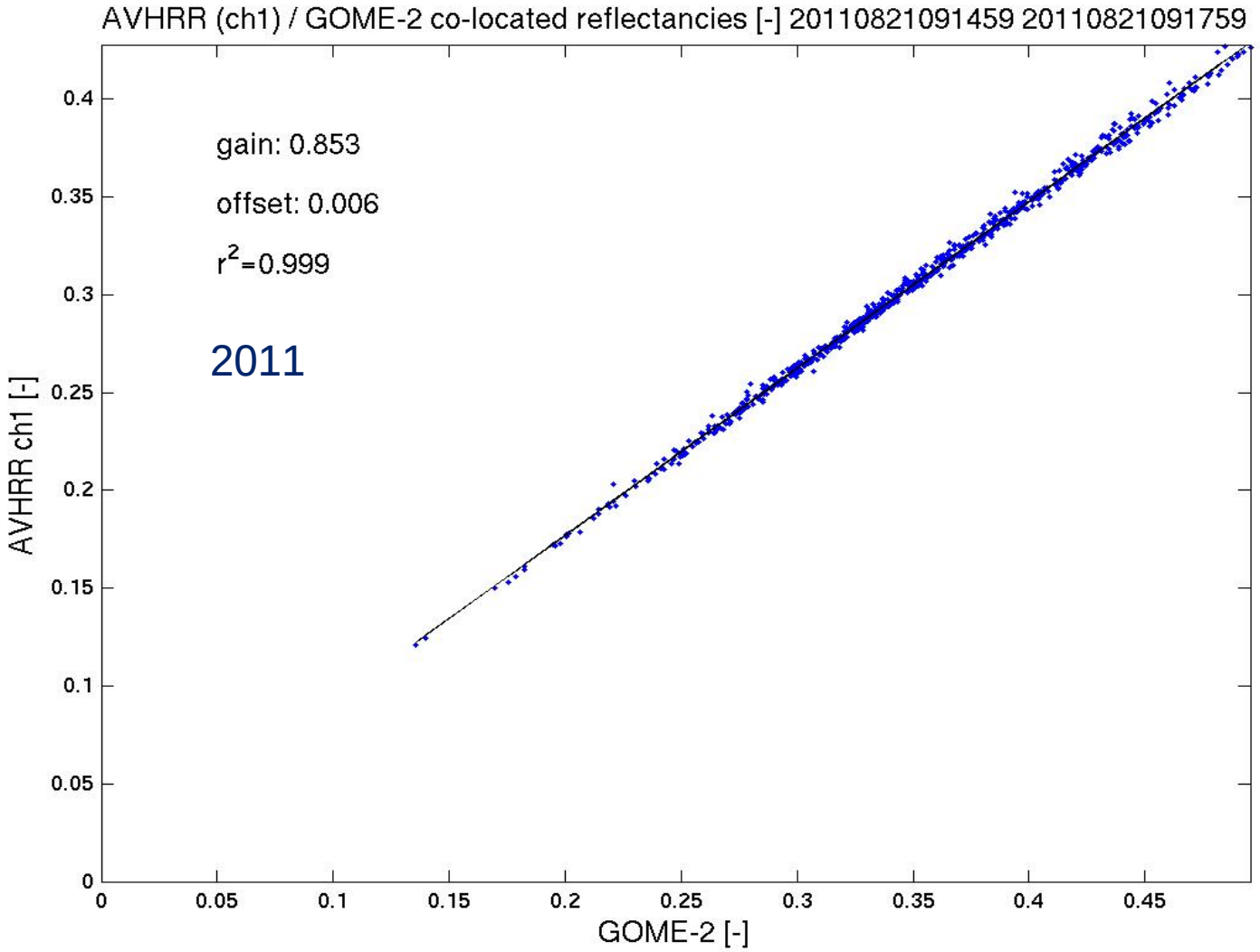
-> scatter and Taylor plots: PMAp vs AERONET and EMAC data

- regional scale

selected areas: scatter plots, Taylor plots, time-series

PMAp vs AERONET and EMAC data

EPS: Instrument calibration
GOME-2/AVHRR reflectivity inter-calibration



AVHRR channel 1 to GOME-2/Metop-A gain in reflectivity <8% (AVHRR < GOME-2)

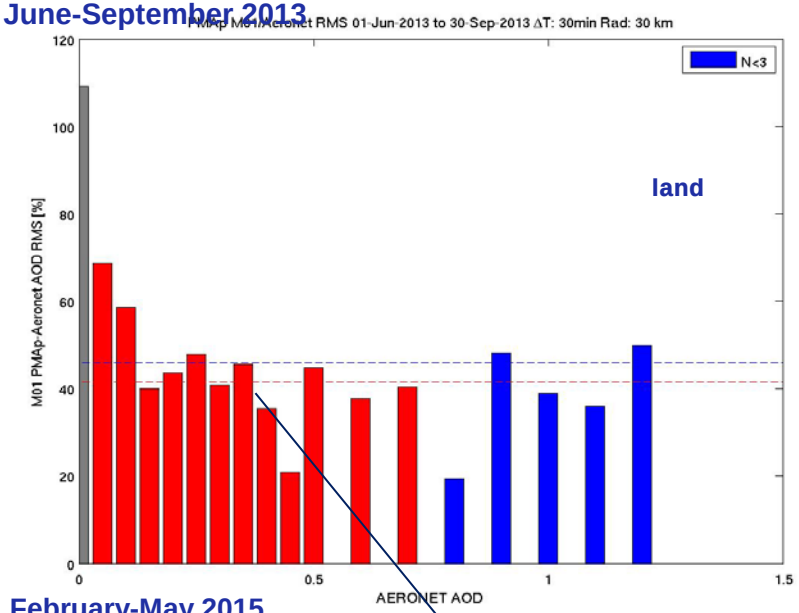
2011

see GSICS Quarterly Newsletters, vol 5, number 3, *Latter et al.*

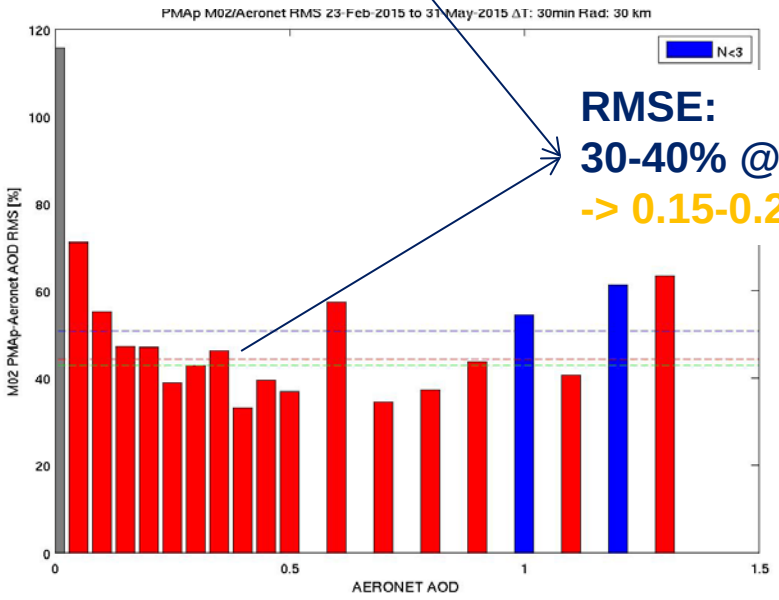
PMAp version 2 validation at EUMETSAT

Operational validation with AERONET 1.5 weekly data

June-September 2013



February-May 2015



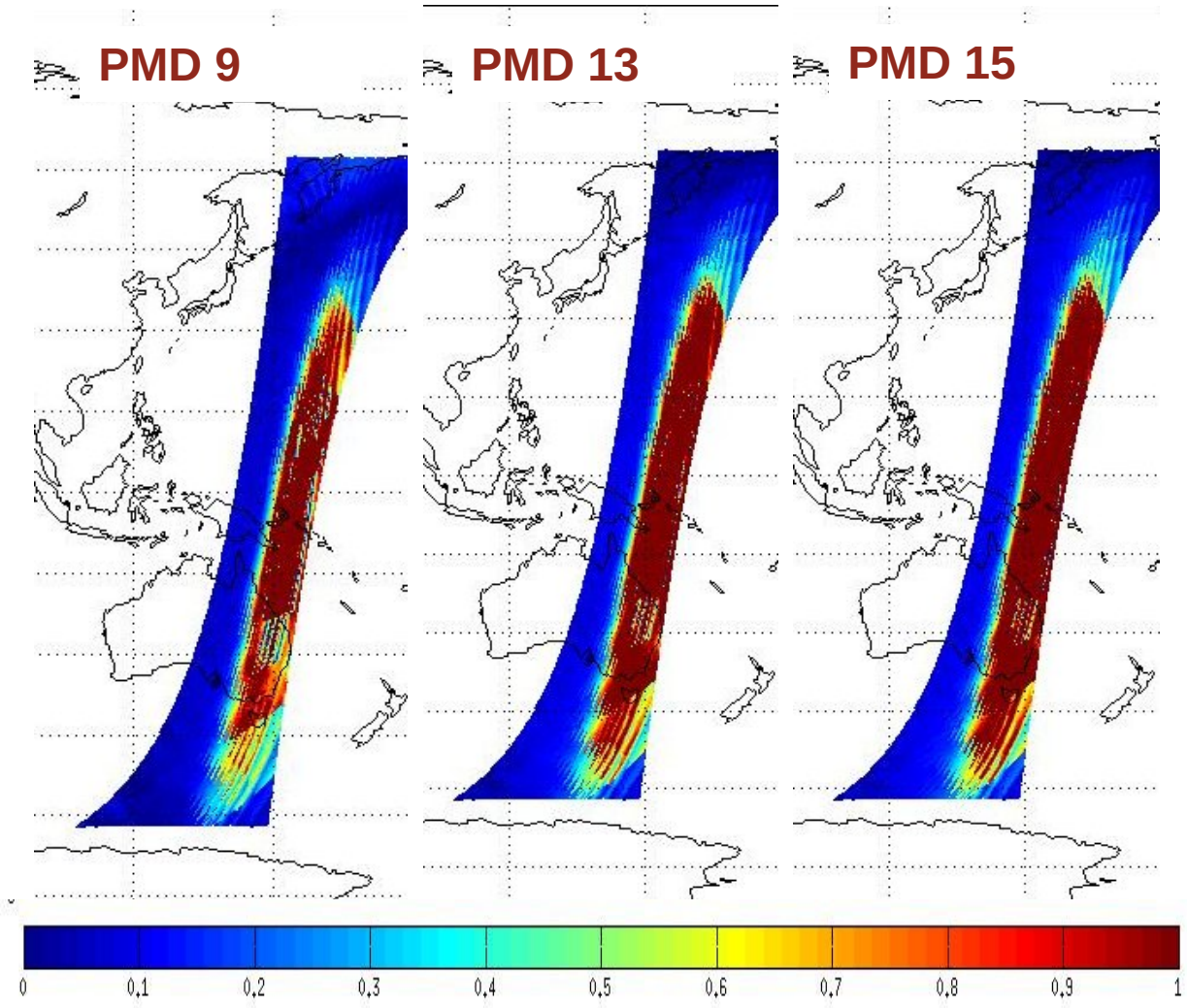
RMSE:
30-40% @0.5 AOD
-> 0.15-0.2

Aerosol_CCI

ADV/ASV (AATSR Dual/Single View),
ORAC ((Oxford Ral Aerosol and Cloud Retrieval)
SU (Swansea University)

Metric	Algorithm					
	ADV/ASV		ORAC		SU	
	V1.0	V2.3	V1.0	V3.02	V1.0	V4.21
	Over Land					
mber of points	306	185	262	262	138	343
bias	−0.005	−0.05	0.03	−0.002	−0.001	−0.01
RMSE	0.16	0.13	0.16	0.08	0.08	0.11
correlation	0.59	0.66	0.59	0.86	0.72	0.82
GCOS fraction (%)	37	54	40	51	46	62

PMAp: estimating the surface contribution
Over ocean



- Variablility of the surface reflectance with wind speed can be as large as the signal of an aerosol (AOD=0.3) :

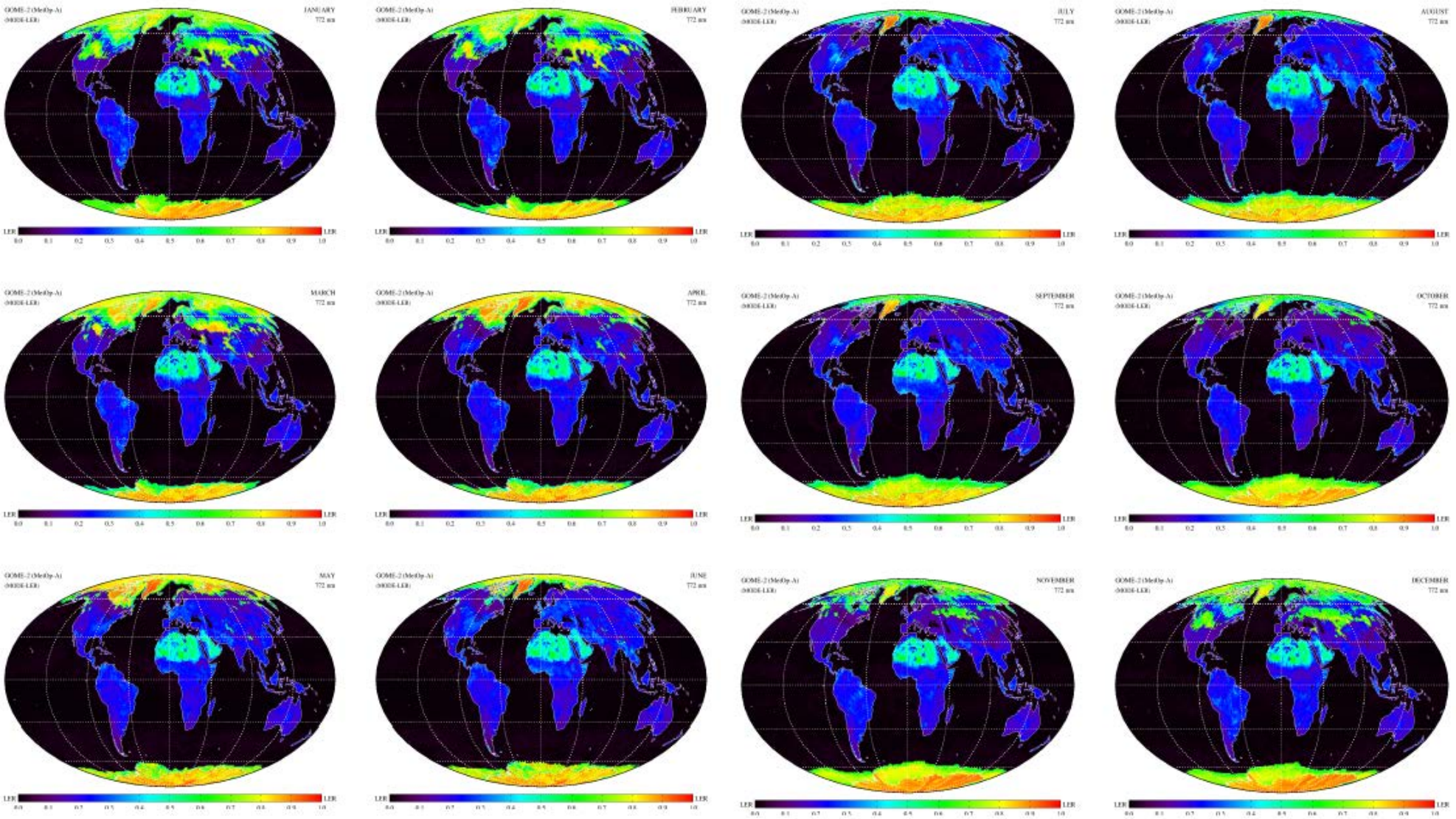
$$\frac{\left|R_{clear}(12m/s) - R_{clear}(3m/s)\right|}{R_{aerosol} - R_{clear}}$$

- AOD retrieval will depend on a surface test comparing:
  - calculated clear-sky signal
  - calculated wind speed dependence
  - calculated aerosol signal

PMAp: estimating the surface contribution

Over land: Use of AC SAF LER surface reflectance database.

PMD	λ (nm)	application / relevance
09	460	LER, aerosol, NO_2, O_2-O_2
10	519	LER, aerosol
11	554	LER, aerosol
12	589	LER, aerosol
13	639	LER, aerosol, H_2O
14	756	affected by O_2 absorption
15	799	LER, aerosol



Tilstra et al. 2017, KNMI

PMAp cloud correction for CF <0.3

Correcting GOME-2 radiances using AVHRR sub-pixel information

- AVHRR cloud tests:
  - Albedo test
  - T4 test
  - Uniformity test
  - T4T5 test
- Clear sky PMD reflectance for cloudy pixels:
  - Spectral overlap required

AVHRR Channel	Central wave-length[µm]	Wavelength range [µm]
1	0.630	0.580 - 0.680
2	0.865	0.725 - 1.000
3A	1.610	1.580 - 1.640
3B	3.740	3.550 - 3.930
4	10.800	10.300- 11.300
5	12.000	11.500- 12.500

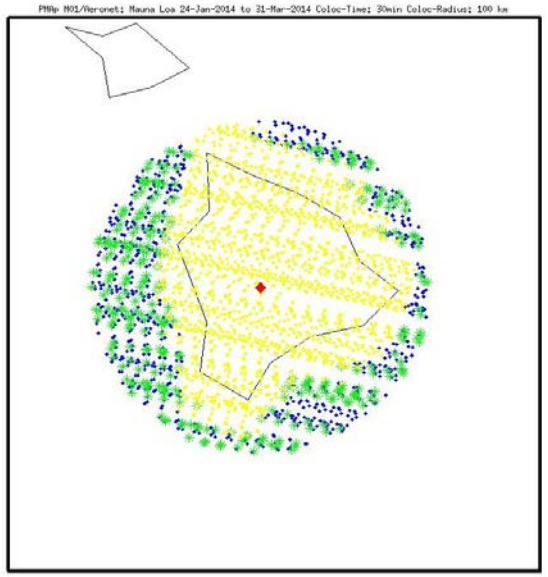
- Geometric cloud fraction:

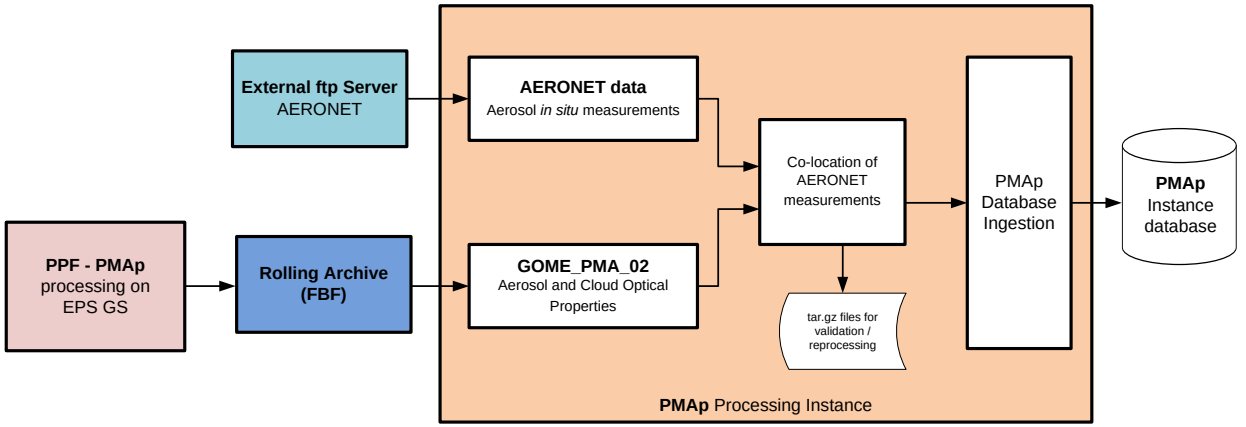
$$CF(GOME) = \frac{n_{cloudy}(AVHRR)}{n_{collocated}(AVHRR)}$$

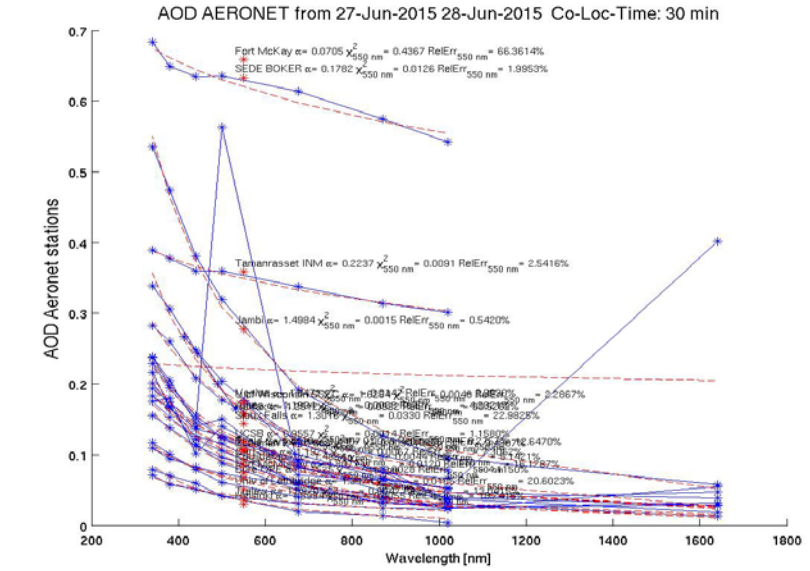
$$R_{corrected}(cloudfree) = R_{PMD}\frac{\tilde{R}_{AVHRR}(cloudfree)}{\overline{R_{AVHRR}(all)}}$$

PMAp version 2 validation at EUMETSAT

Operational monitoring



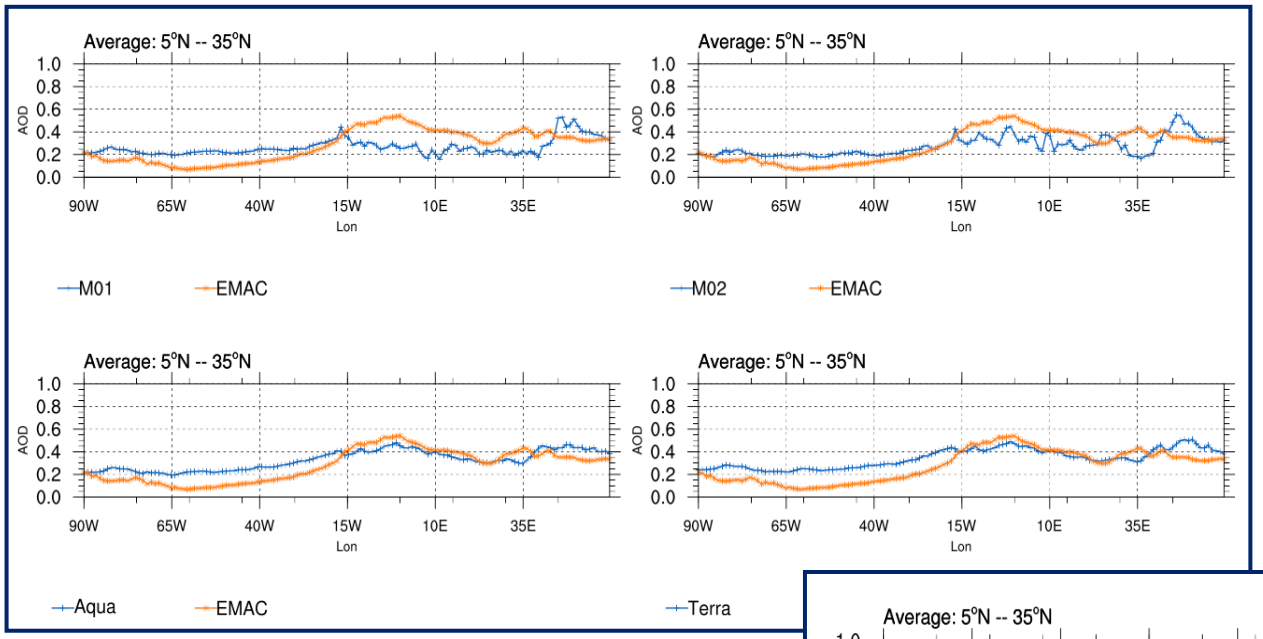




- Ocean:
  - Stations on islands and selected coastal stations
  - Continuous monitoring since January 2014 (ocean)
  - Max spatial difference: 60km; max temporarily difference: 30min
- Land:
  - Stations on continents (including coastal stations)
  - Two weeks period, 80 stations around the world
  - Max spatial difference: 30km; max temporarily difference: 30min

Global scale satellite inter-comparison

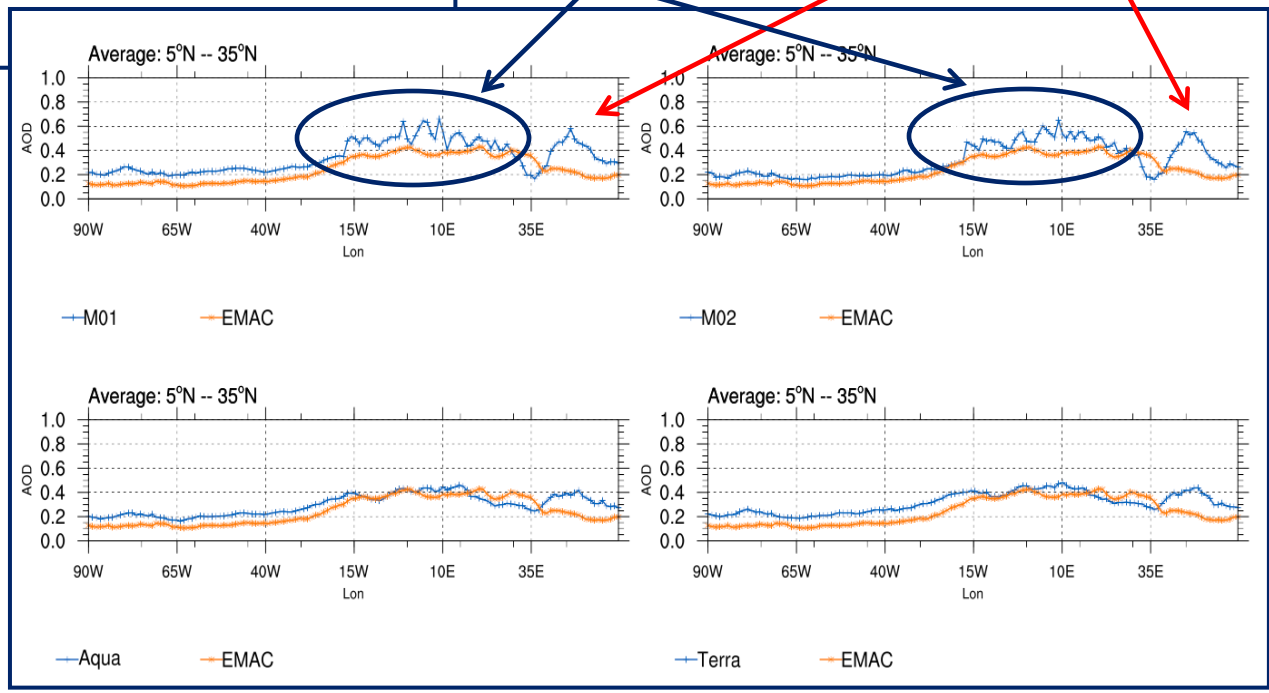
Meridional means PMAp M01&M02 - MODIS Terra&Aqua - vs EMAC



validation period 1

Arabian Peninsula high values

Sub Saharan biomass burning activity

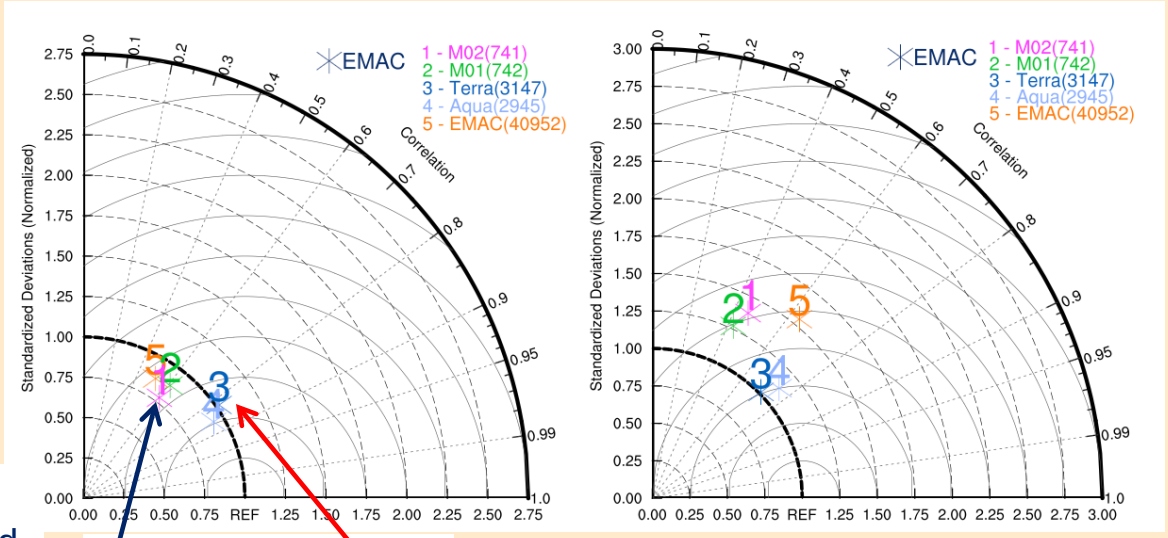


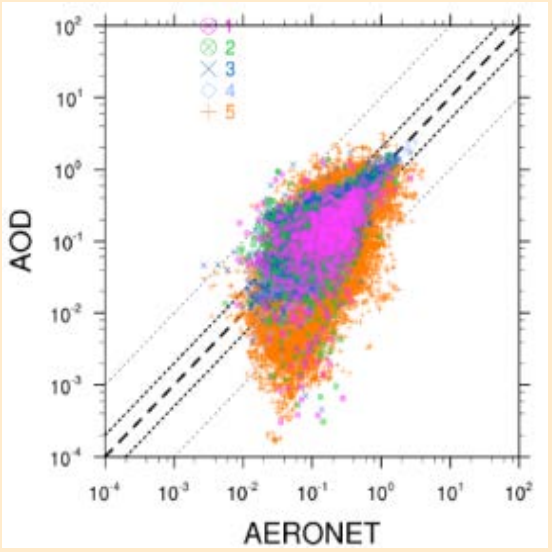
validation period 2

PMAp version 2 validation – MPI Chem.

Validation against Aeronet 2.0 and other instruments

validation period 1





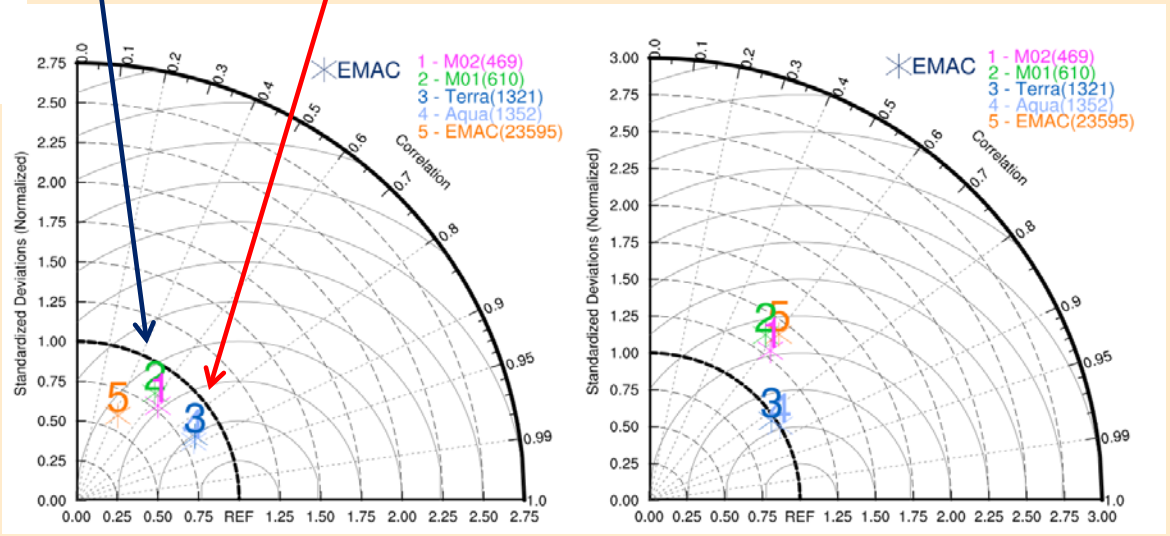
Lev 3 regridded data

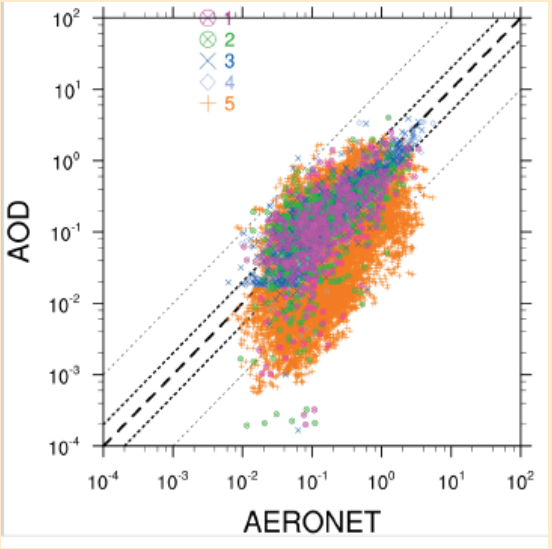
similar std dev

PMAp

MODIS

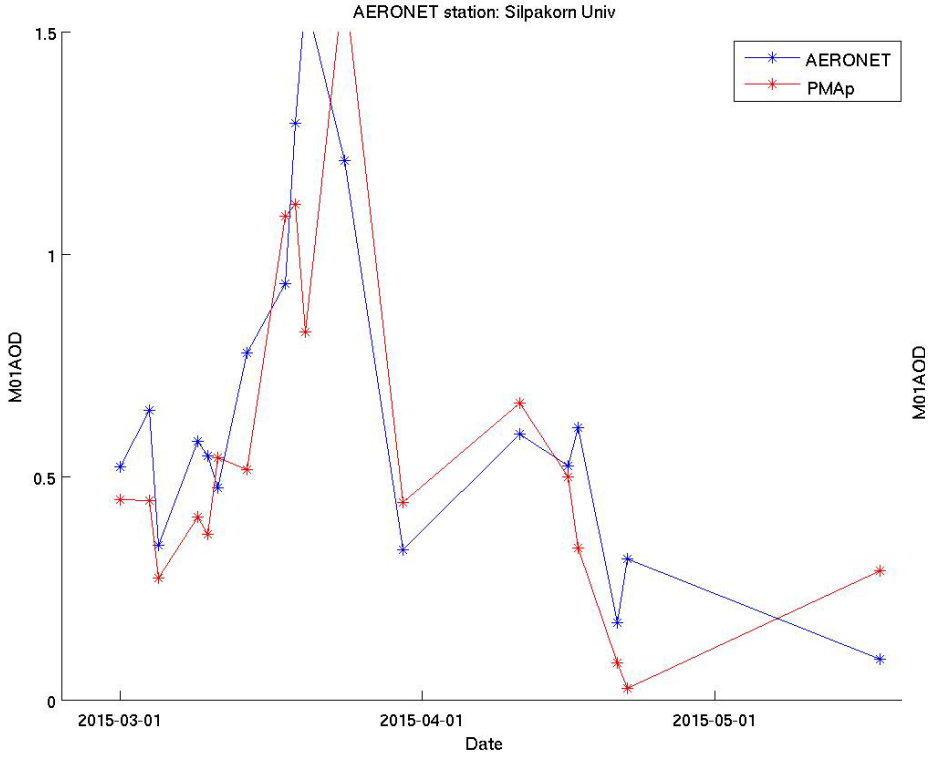
validation period 2



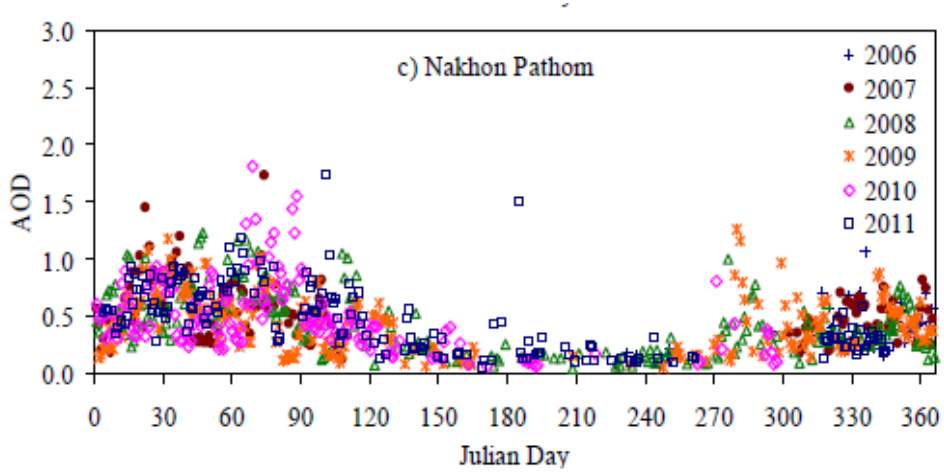


PMAp version 2 validation at EUMETSAT

Operational validation with AERONET 1.5 weekly data



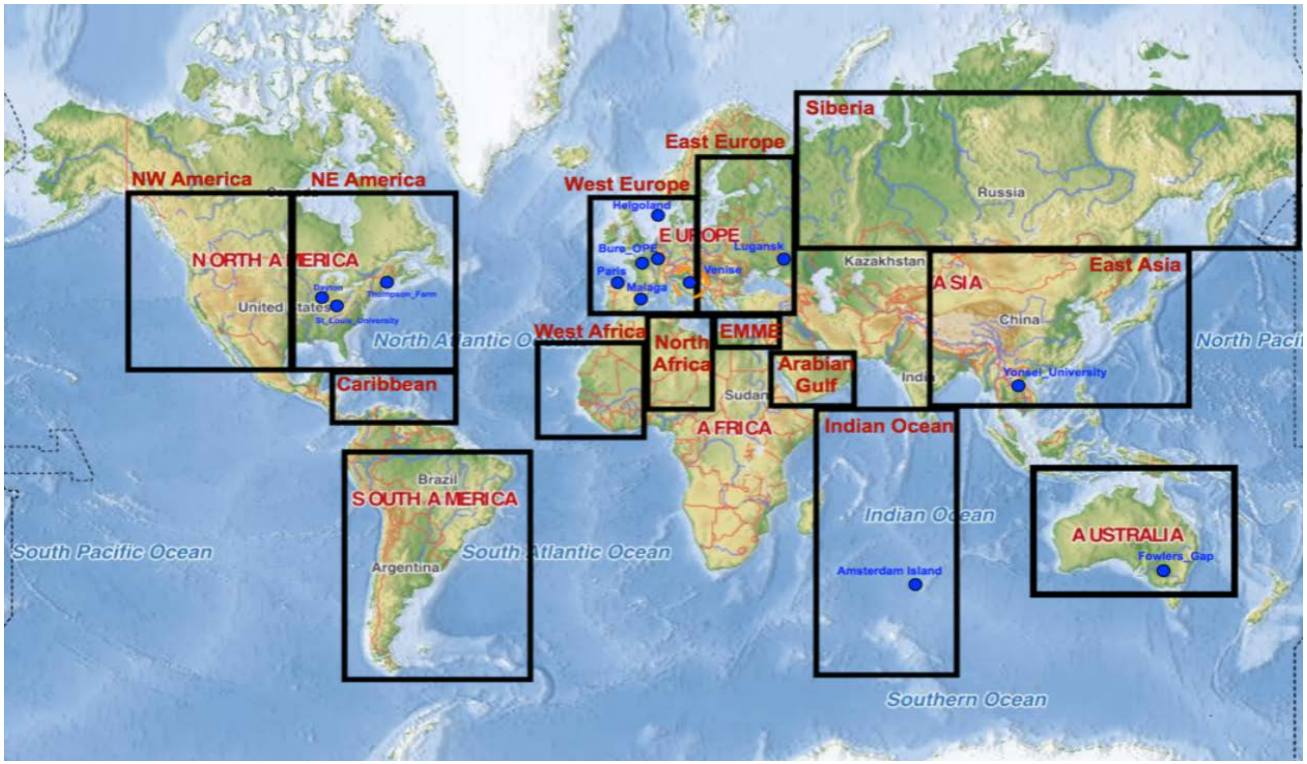
Time series of the AOD at 550 nm for valid AERONET site (left panel) site and at te Asc compared to the AOD retrieved from METOP-B.



the Silpakorn University, the AOD has a strong seasonal dependence with maxima in the dry season - from November to April – and minimum values from May to October. This is mainly due to the typical biomass burning activities carried out in the northern part of the country from January to April combined with the northeasterly winds dominating the measurements area
[Bridhikitti and Overcamp, 2011; Janjai et al. 2012].

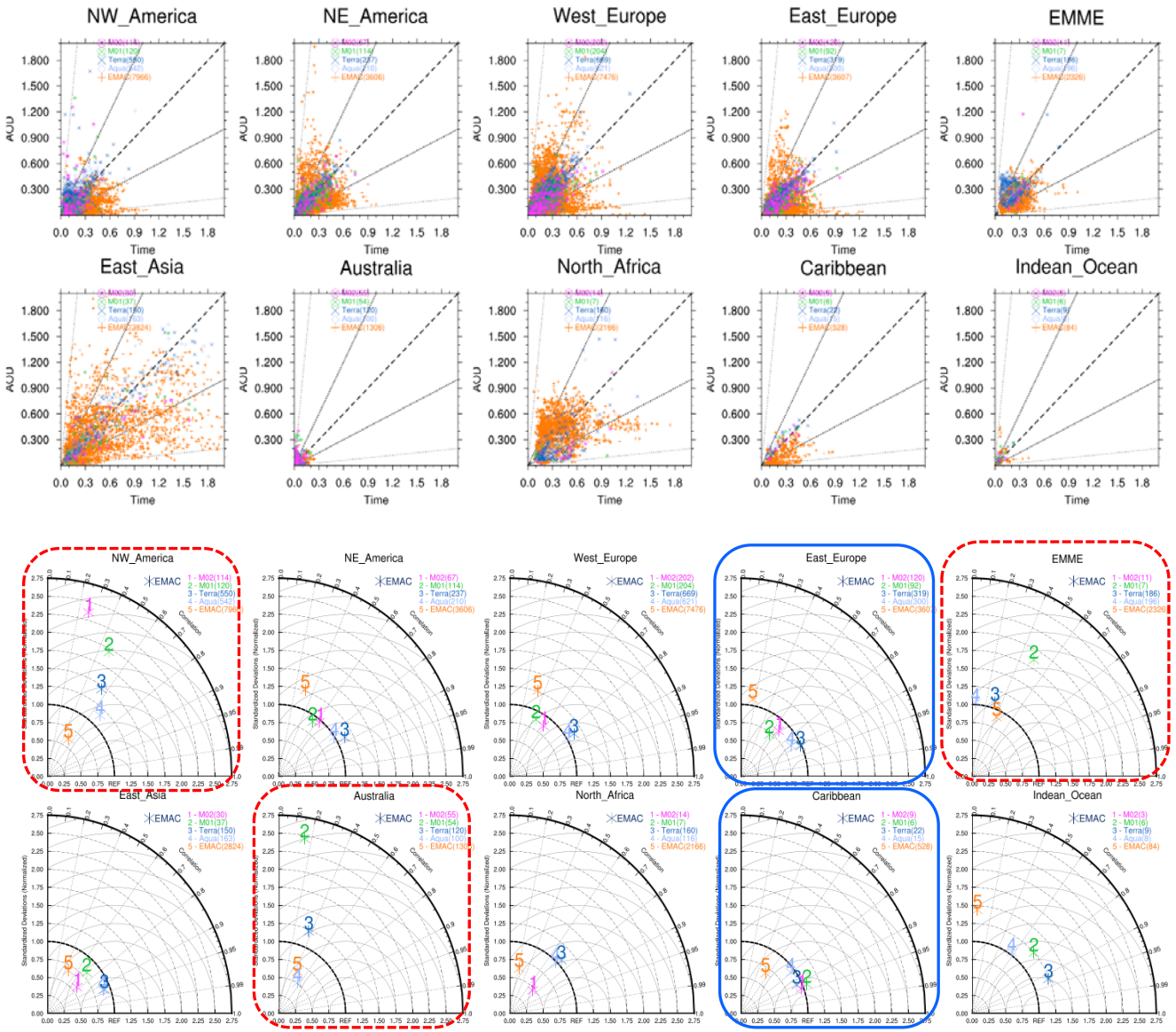
PMAp version 2 validation – MPI Chem.

Validation against Aeronet 2.0 and other instruments – regional scale



PMAp version 2 validation – MPI Chem.

Validation against Aeronet 2.0 and other instruments – regional scale – Jun to Sep 2013



PMAp M01, M02
MODIS/Terra, Aqua
EMAC
versus
AERONET

PMAp M02
0.3 < r < 0.93
PMAp M01
-0.1 < r < 0.92

0.06 < RMSE< 0.7

MODIS/Terra
0.32 < r < 0.93
MODIS/Aqua
0.05 < r < 0.93

0.03< RMSE< 0.2

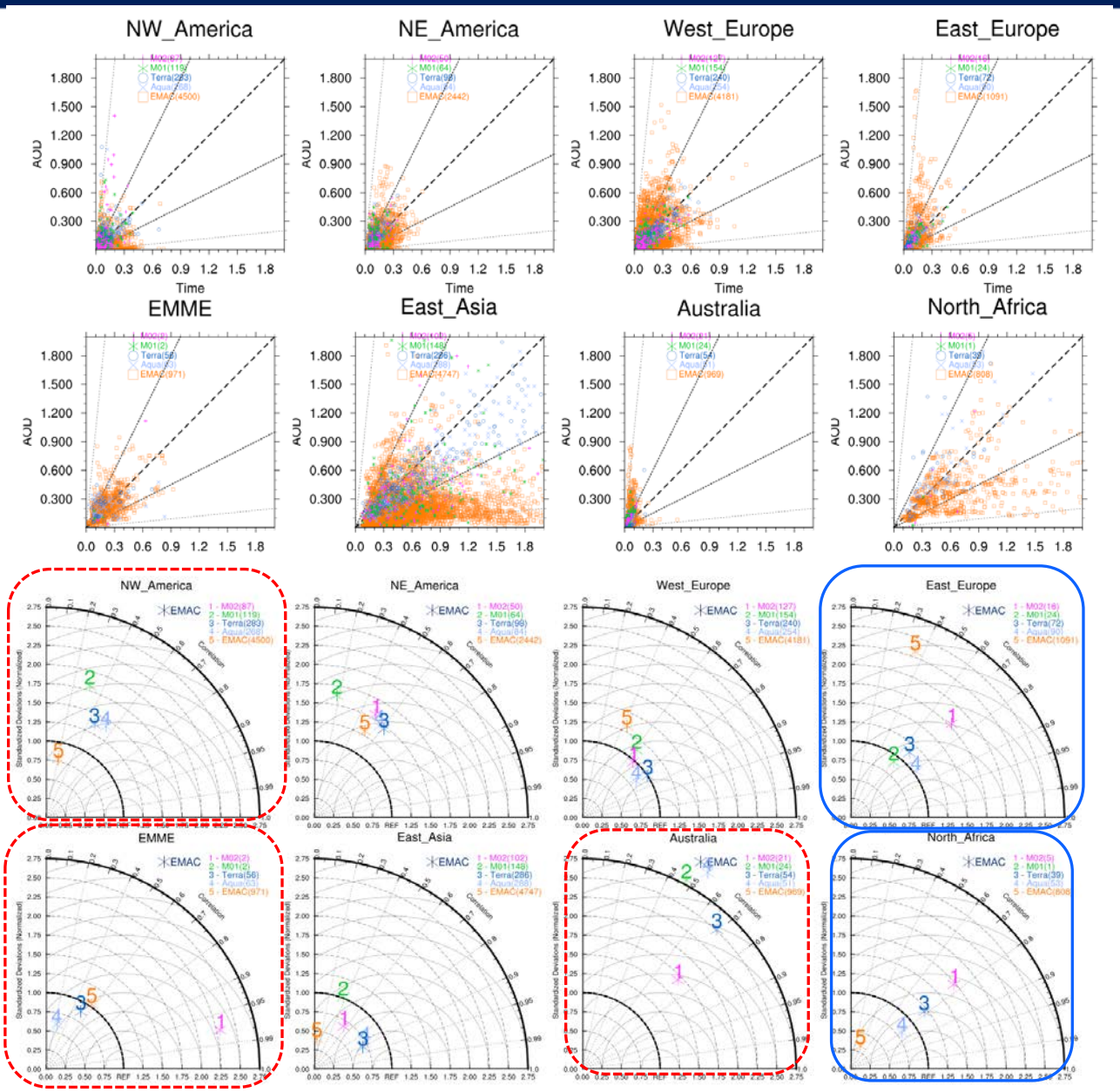
PMAp most critical areas
- NW_America for MODIS critical too
- Australia for MODIS critical too

- EMME: few co-locations

EUMETSAT

PMAp version 2 validation – MPI Chem.

Validation against Aeronet 2.0 and other instruments – regional scale – Feb to May 2015



PMAp M01, M02
MODIS/Terra, Aqua
EMAC
versus
AERONET

PMAp M02
0.4 < r < 0.95
PMAp M01
0.43 < r < 0.5

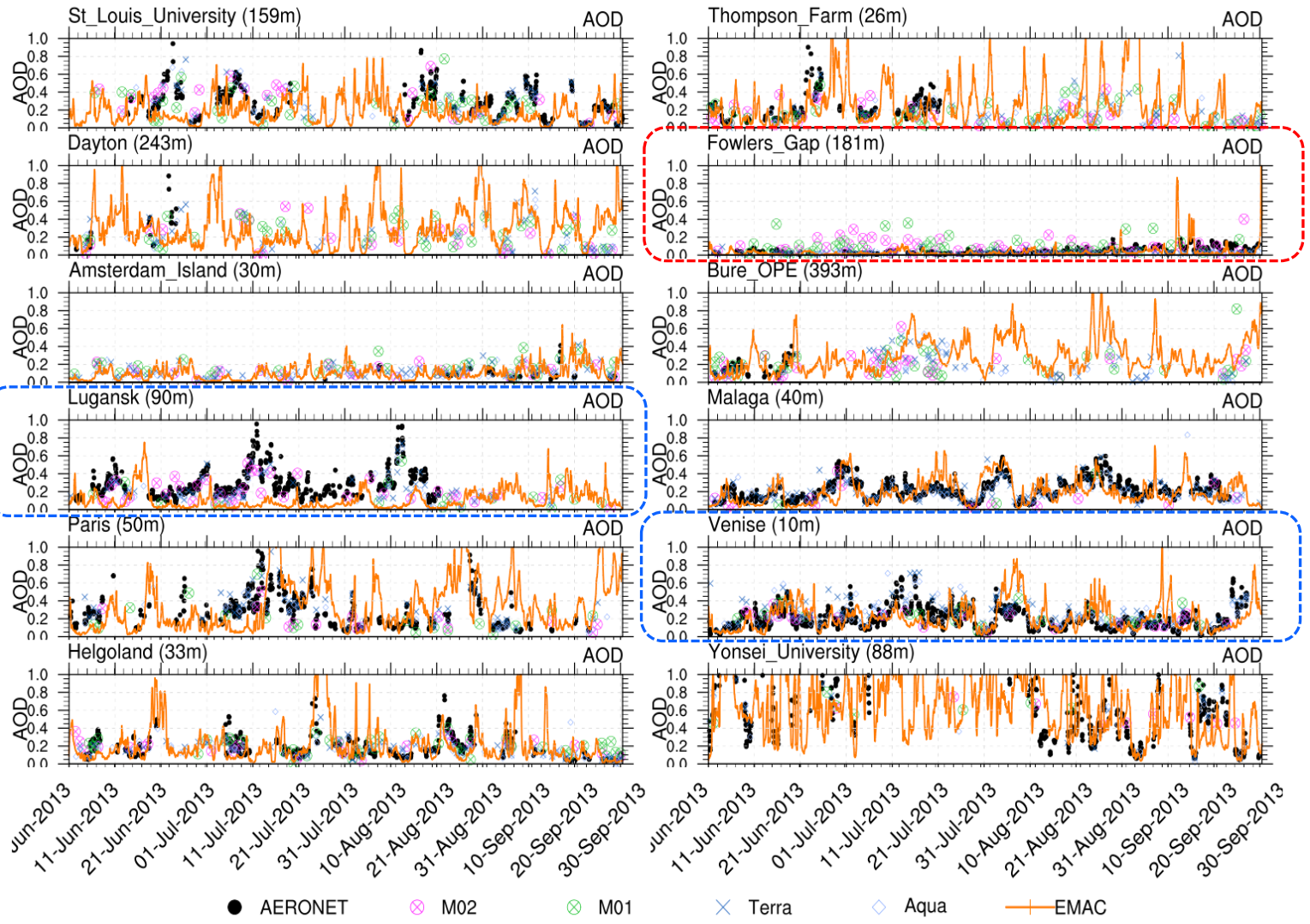
0.06 < RMSE< 0.6

MODIS/Terra
0.46 < r < 0.91
MODIS/Aqua
0.23 < r < 0.88

0.07< RMSE< 0.34

PMAp version 2 validation – MPI Chem.

Validation against Aeronet 2.0 and other instruments – regional scale – Feb to May 2015

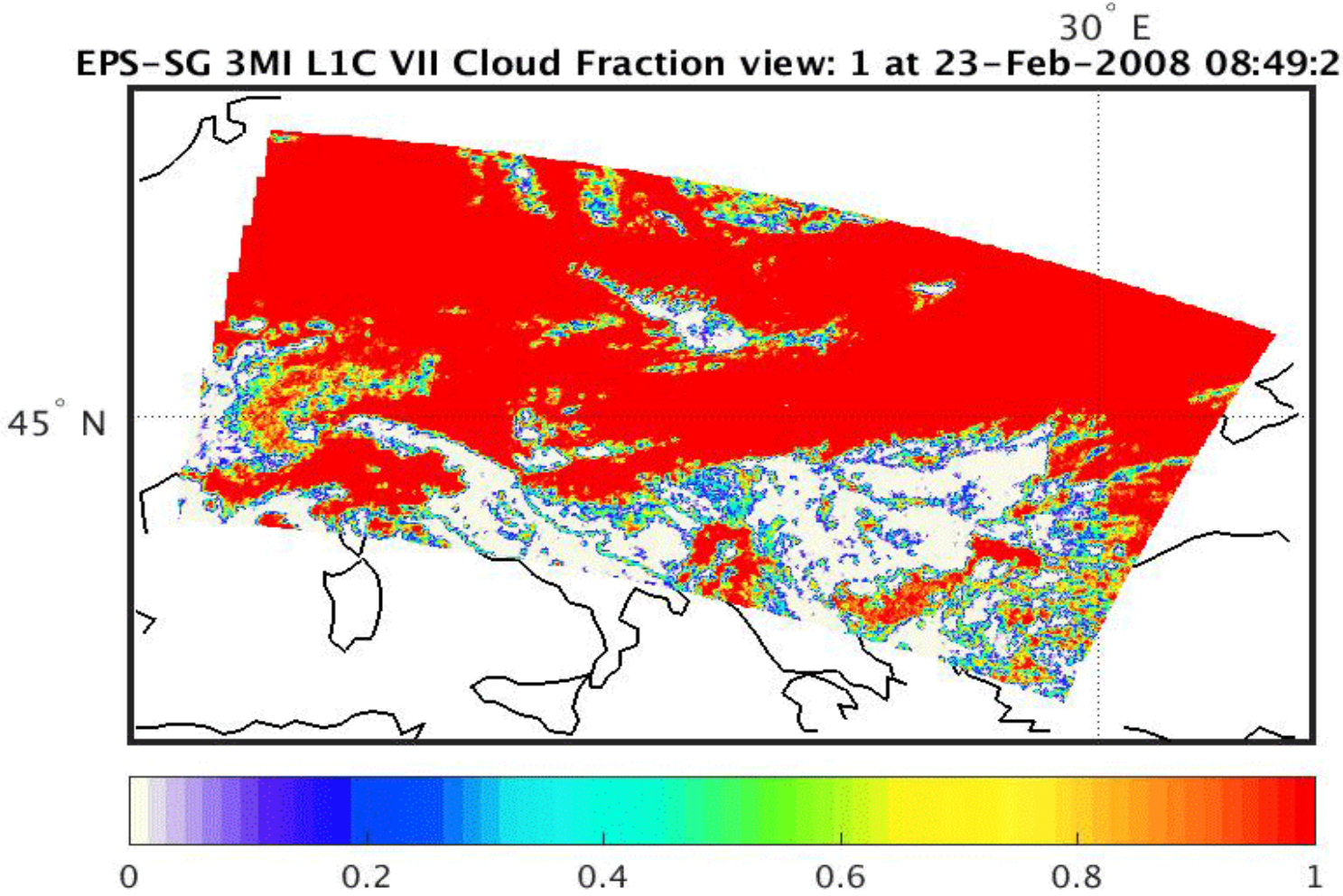


East Europe

Australia arid area

EUMETSAT

3MI L1C proto-type version2 results
Co-located VII cloud-information - CFR

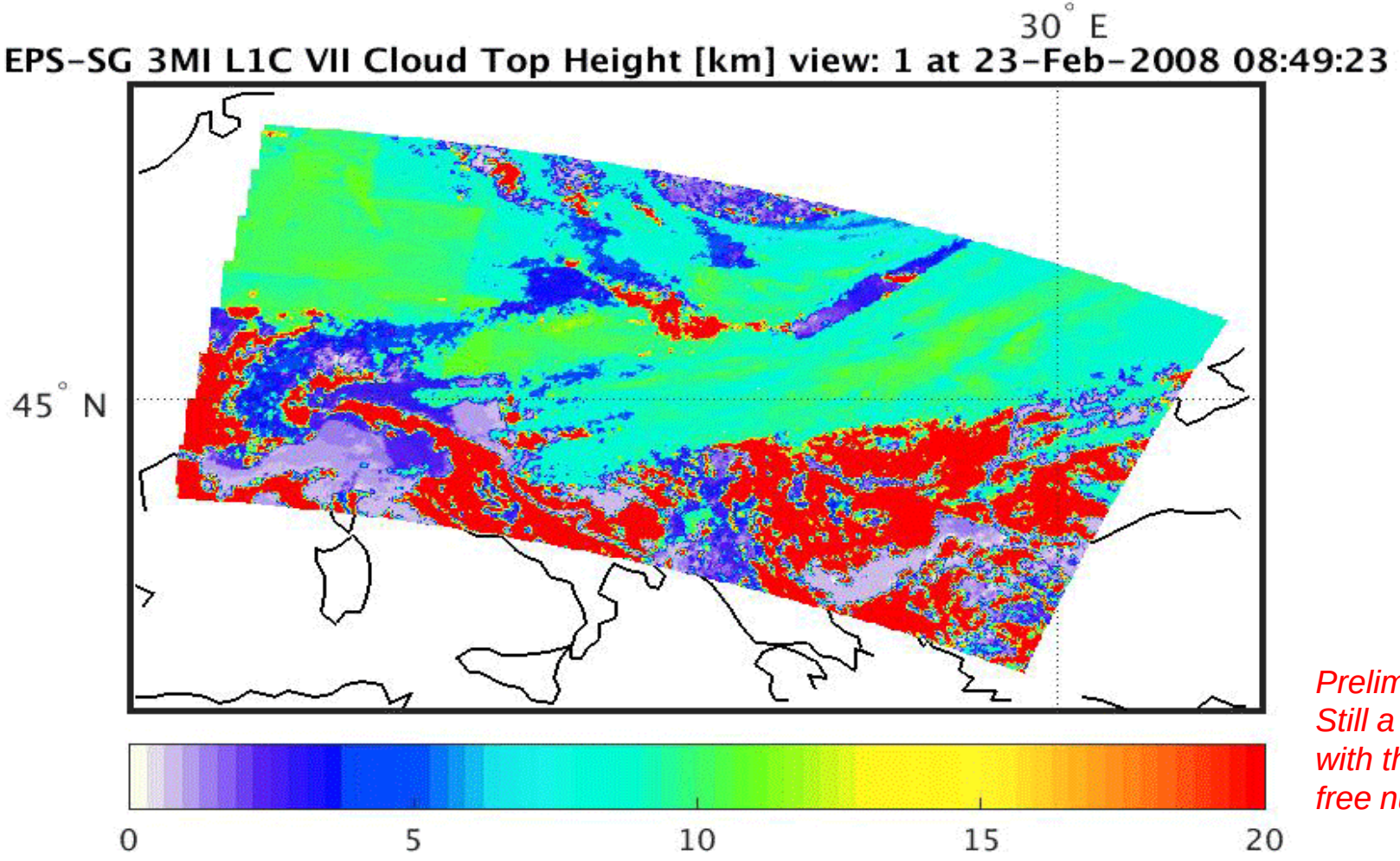


1st option:

Co-located on the 3MI detector grid per view (14 views of CFR) – presented here!

3MI L1C proto-type version2 results

Co-located VII cloud-information - CTH



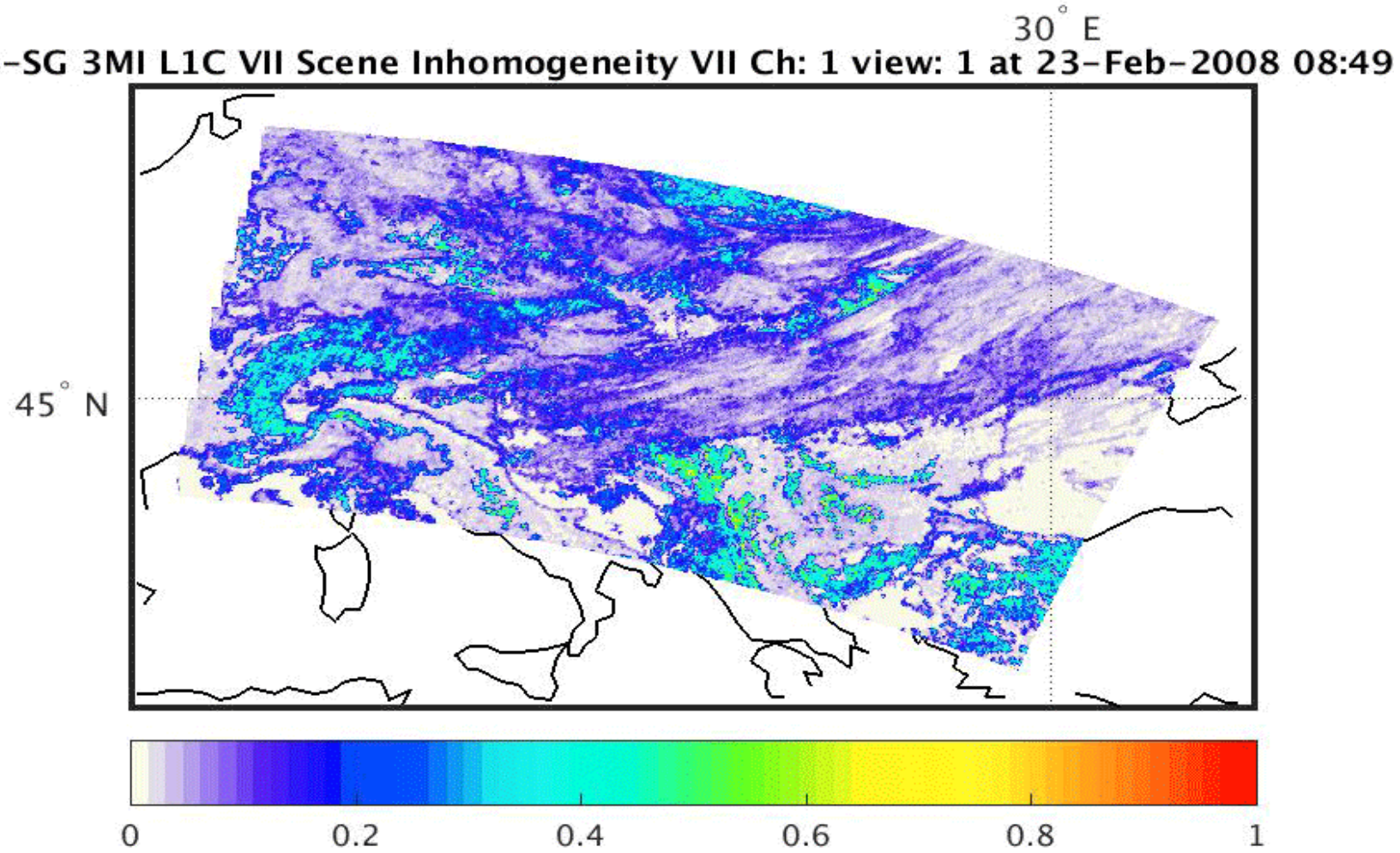
Preliminary. Still a problem with the cloud-free numbers!

1st option:

Co-located on the 3MI detector grid per view (14 views of CFR) – presented here!

3MI L1C proto-type version2 results

Co-located VII cloud-information – scene in-homogeneity VII at 555 nm



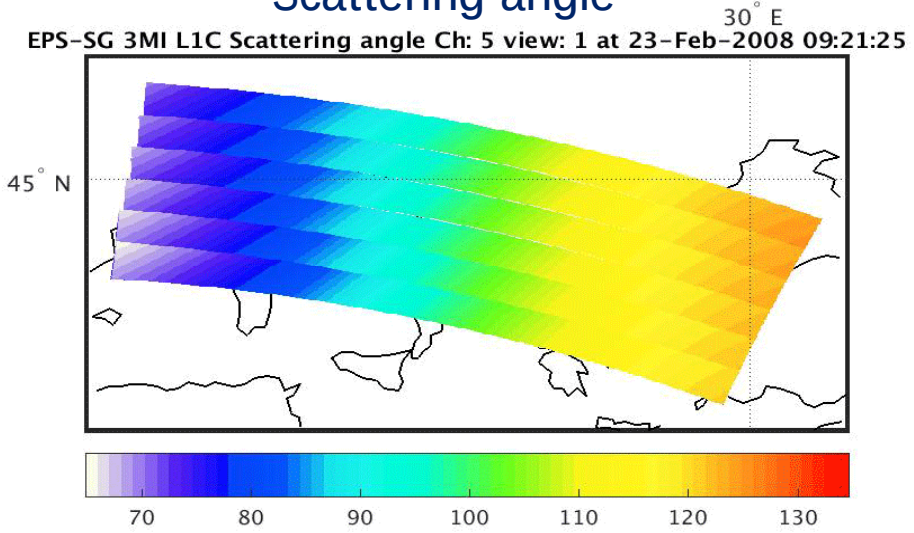
1st option:

Co-located on the 3MI detector grid per view (14 views of CFR) – presented here!

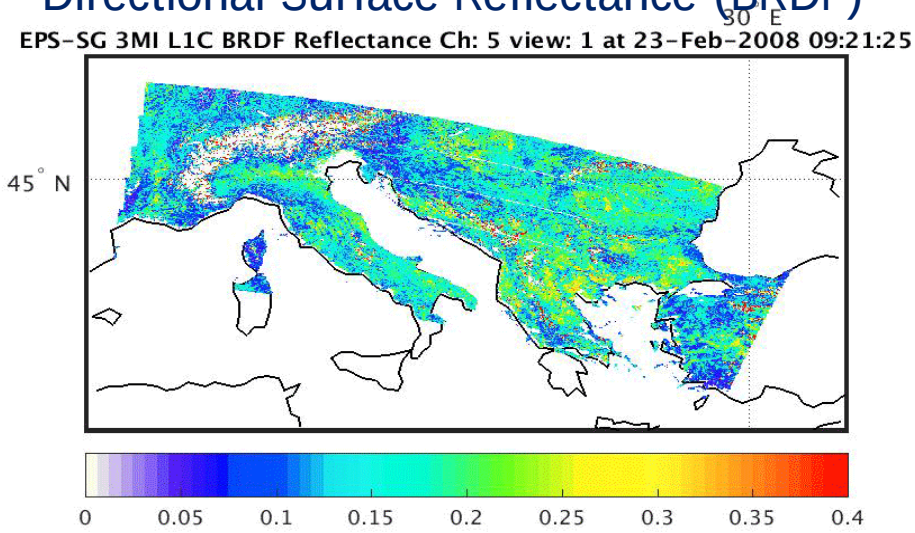
3MI level 2 surface (BRDM) product

RSP – AC team prototyping activities – Breon and Maignon EUM study

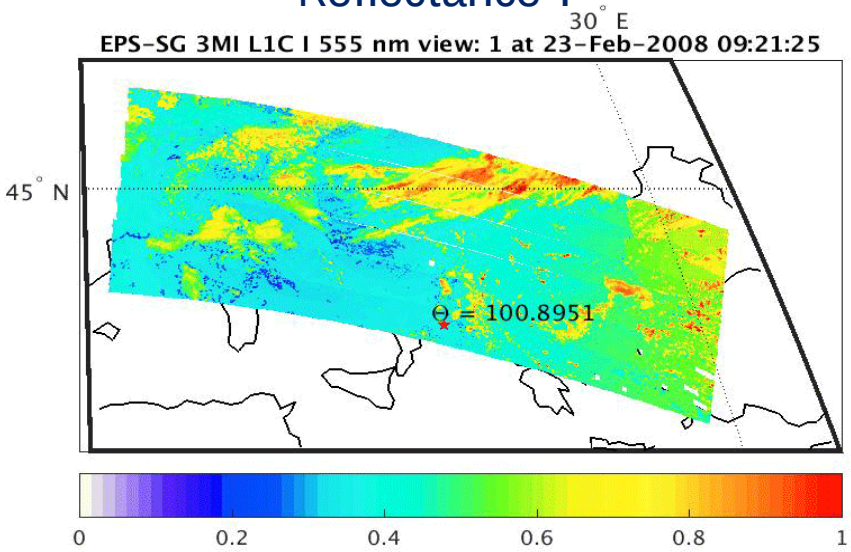
Scattering angle



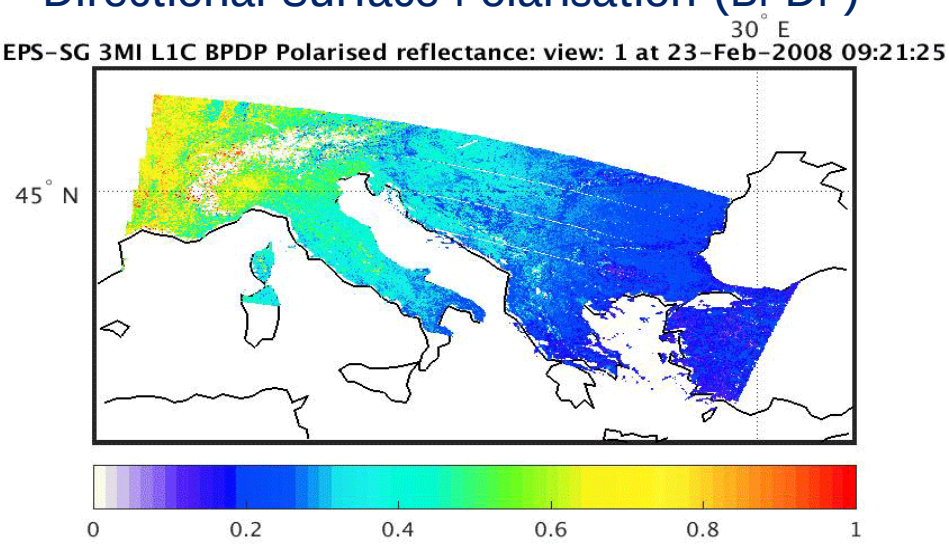
Directional Surface Reflectance (BRDF)



Reflectance I



Directional Surface Polarisation (BPDF)

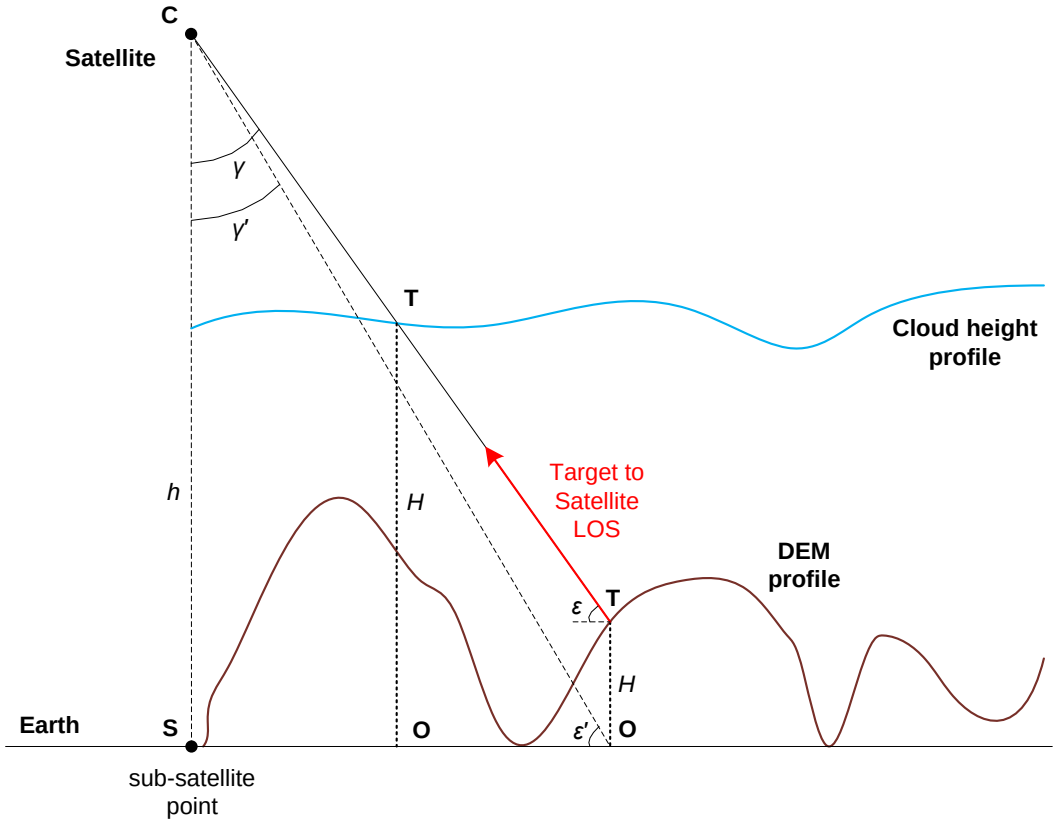


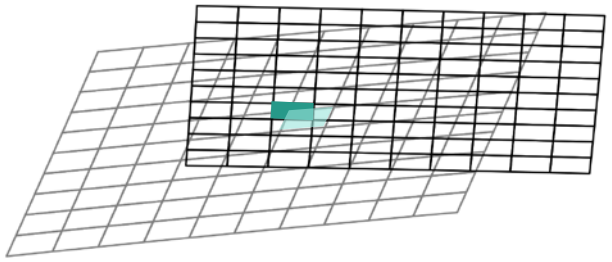
3MI Level 1C proto-type results, v2

3MI Level 2 BRDM proto-type results, v2

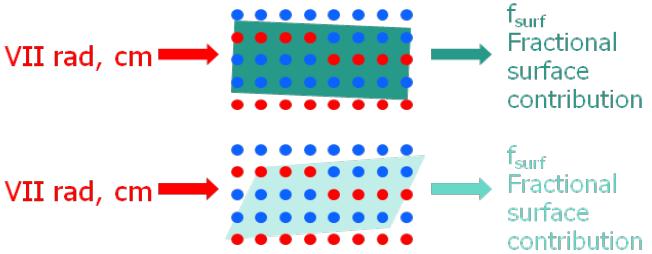
3MI L1C proto-type version2 results
Parallax correction

Parallax correction is done using VII ch. 555, 865 and 2300 radiance and cloud mask information:
Calculation of dominant signal surface/cloud in 3MI pixel (threshold 50%; default)
3MI to VII ch mapping as for inhomogeneity is [0 0 0 0 1 1 1 2 2 2] (default)





Input:
VII radiance and cloud mask information



Fractional surface contribution of signal per 3MI ground pixel

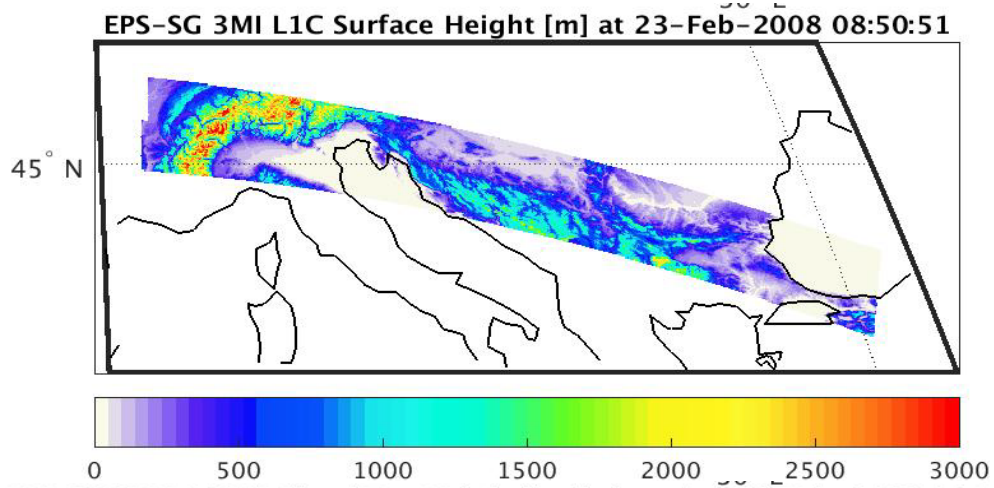
If f_{sub} < 50% use CTH
If f_{sub} > 50% use DEM

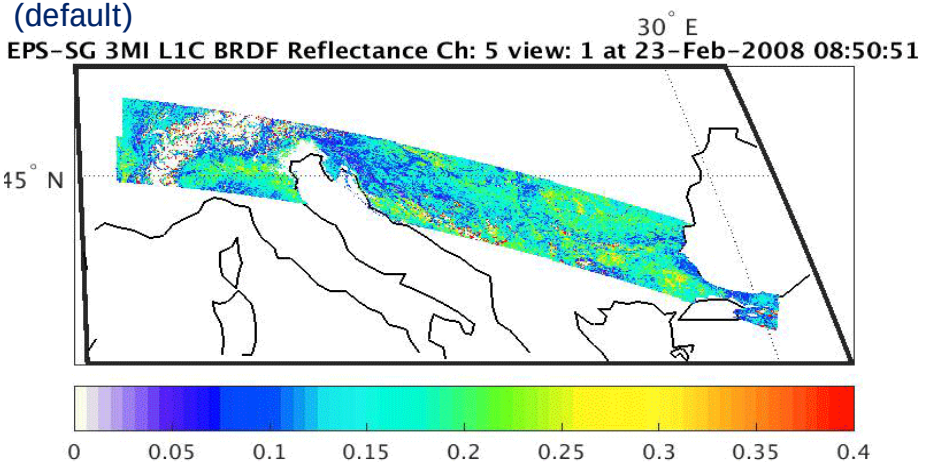
3MI L1C proto-type version2 results
Parallax correction

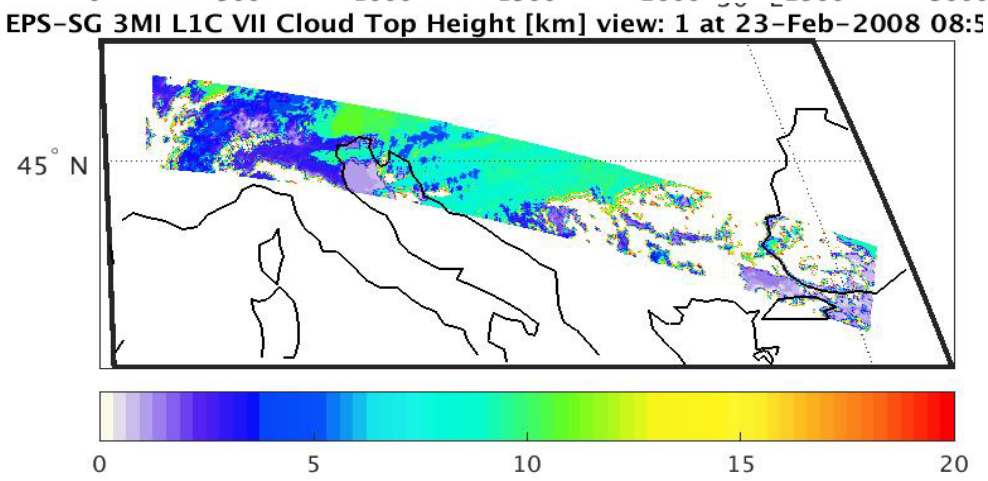
Parallax correction is done using VII ch. 555, 865 and 2300 radiance and cloud mask information:

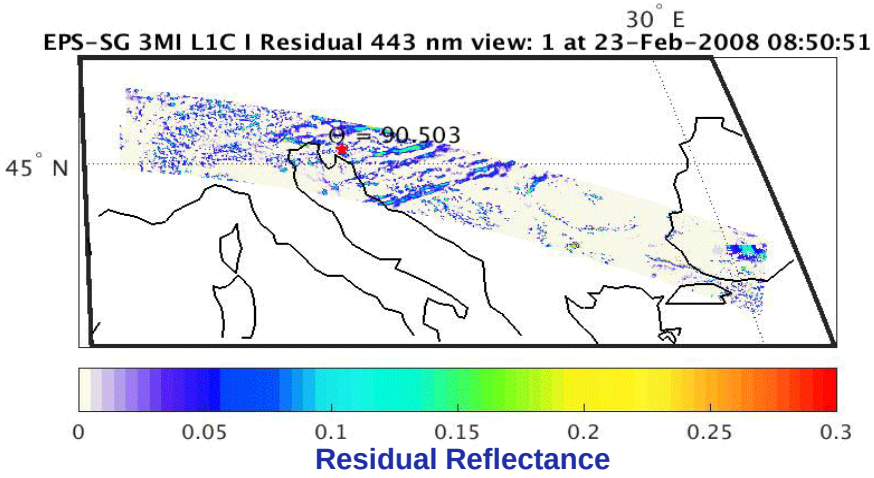
Calculation of dominant signal surface/cloud in 3MI pixel (threshold 50%; default)

3MI to VII ch mapping as for inhomogeneity is [0 0 0 0 1 1 1 2 2 2] (default)



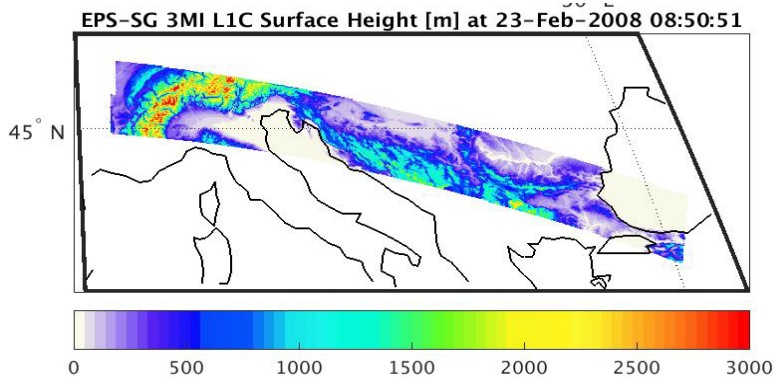


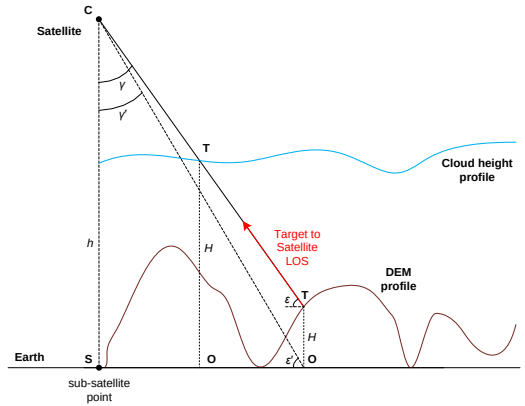




3MI L1C proto-type version2 results

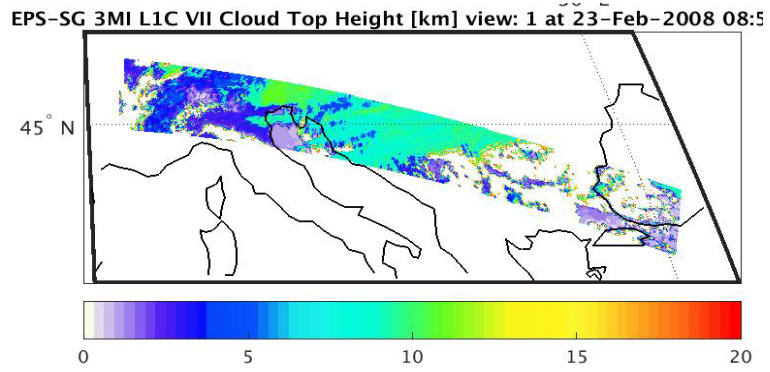
Parallax correction

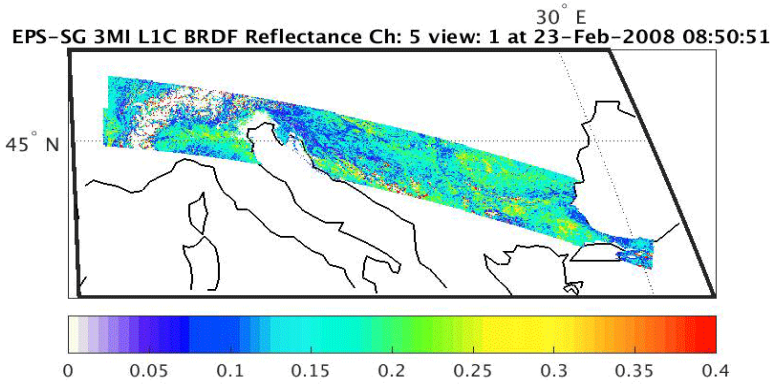


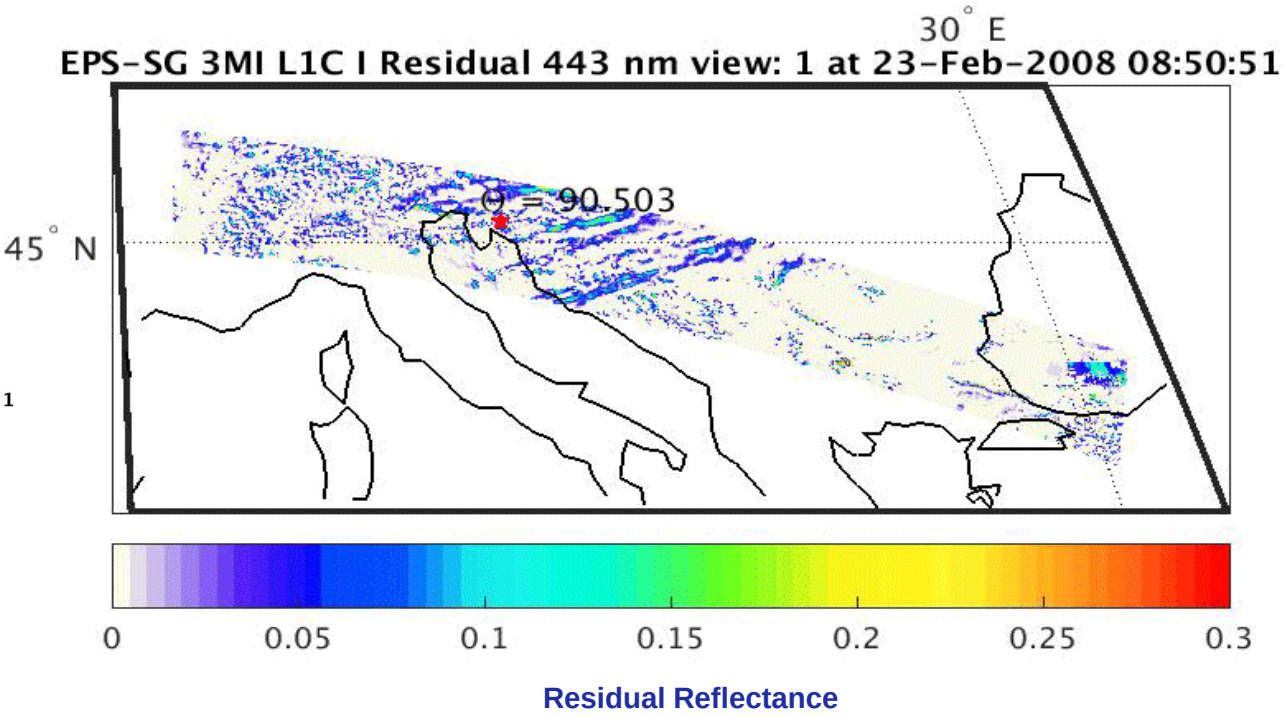


Fractional surface contribution of signal per 3MI ground pixel using VII radiances and cloud mask information

If f_{sub} > 50% use CTH
If f_{sub} < 50% use DEM







Residual Reflectance