VOLCANIC ASH REMOTE SENSING PRODUCTS AT EUMETSAT FOR NEAR REAL-TIME APPLICATIONS – PRESENT AND FUTURE OUTLOOK

EUMETSAT

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Algorithm Overview: EUMETSAT (Imagers)

- **Overview of Operational F. Prata method**
  - Overview of methodology
  - Most important aspects
  - Strengths, weaknesses and limitations
  - Future work

- **Overview of Cloud Processor OE Method**
  - OE method single layer
  - OE extension to 2 –layers
  - Validation with Met cloud
  - Principles extension to ash cloud
  - Test/example results from Eyjafjallajökull

- **EUMETSAT (Imagers) Ash algorithm planning**
  - Current : Prata algorithm
  - Future: Adaptation to Cloud Processor
  - Detection

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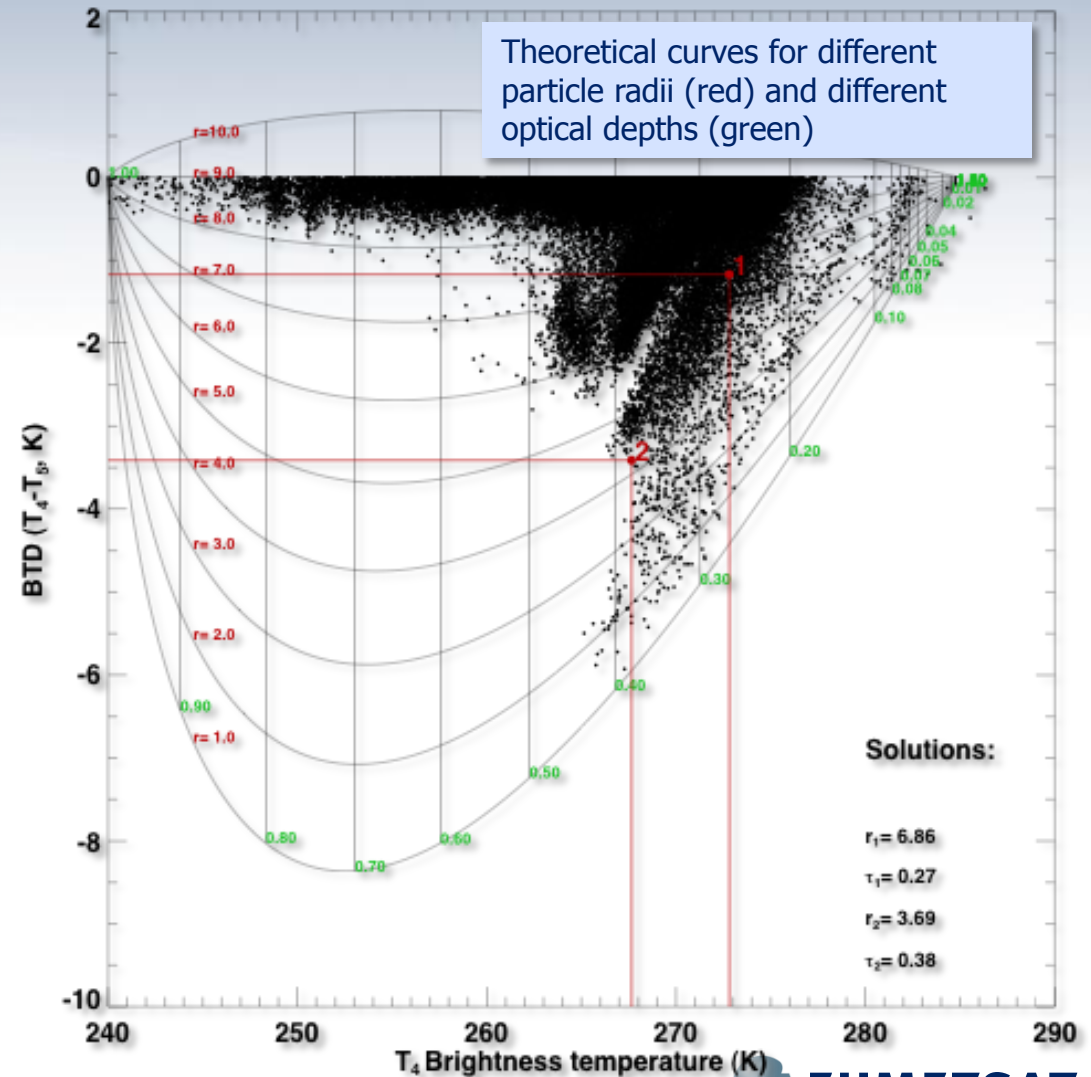# Algorithm Overview: EUMETSAT (Imagers)

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Prata algorithm: summary

1. Mie Code for **spherical** ash particles for polydispersions **with modified-gamma size distribution** and **andesite** spectral complex refractive index data

2. Discrete Ordinates Method (DOM) radiative transfer code (Prata, 1989) run for 16 Gaussian quadrature angles, 11 and 12 μm wavelengths, variable surface and cloud top temperatures, 320 particle size bins, 400 optical depths

3. Large set of LUTs generated for set of Tc's and Ts's in 5 K intervals

4. BTs in Ash pixels **corrected for water vapour** using method of Yu et al. (2004)

5. LUT searched to find r_e and optical depth given measured T_{11} and T_{12}

Theoretical curves for different particle radii (red) and different optical depths (green)

Solutions:

$r_1 = 6.86$

$\tau_1 = 0.27$

$r_2 = 3.69$

$\tau_2 = 0.38$

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F. Prata algorithm: Strengths and weaknesses

Strengths and weaknesses – quote from Fred Prata reporting to EUMETSAT 12 March 2012:

- **Weaknesses:**

  - **Scheme is not optimal estimation – some arbitrariness about estimating cloud top temp and surface temp**

  - **No cloud height estimate**

  - **Problems with identifying ash-affected pixels**

  - **Analysis data not used**

- **Difficult to (cleanly) extend e.g. -**
  - **More channels**
  - **More estimated parameters**
  - **Ash over Met cloud**

- **Strengths:**

  - **Scheme is fast**

  - **Does not require first guess/a priori estimates**

  - **Conservative scheme is fast– few false alarms**

  - **Does not rely on 13.2 channel – uses ubiquitous 11 and 12 µm**

  - **Easily interfaced with dispersion model information**

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Cloud Processor OE: solar and IR fast RTM – $y(x)$
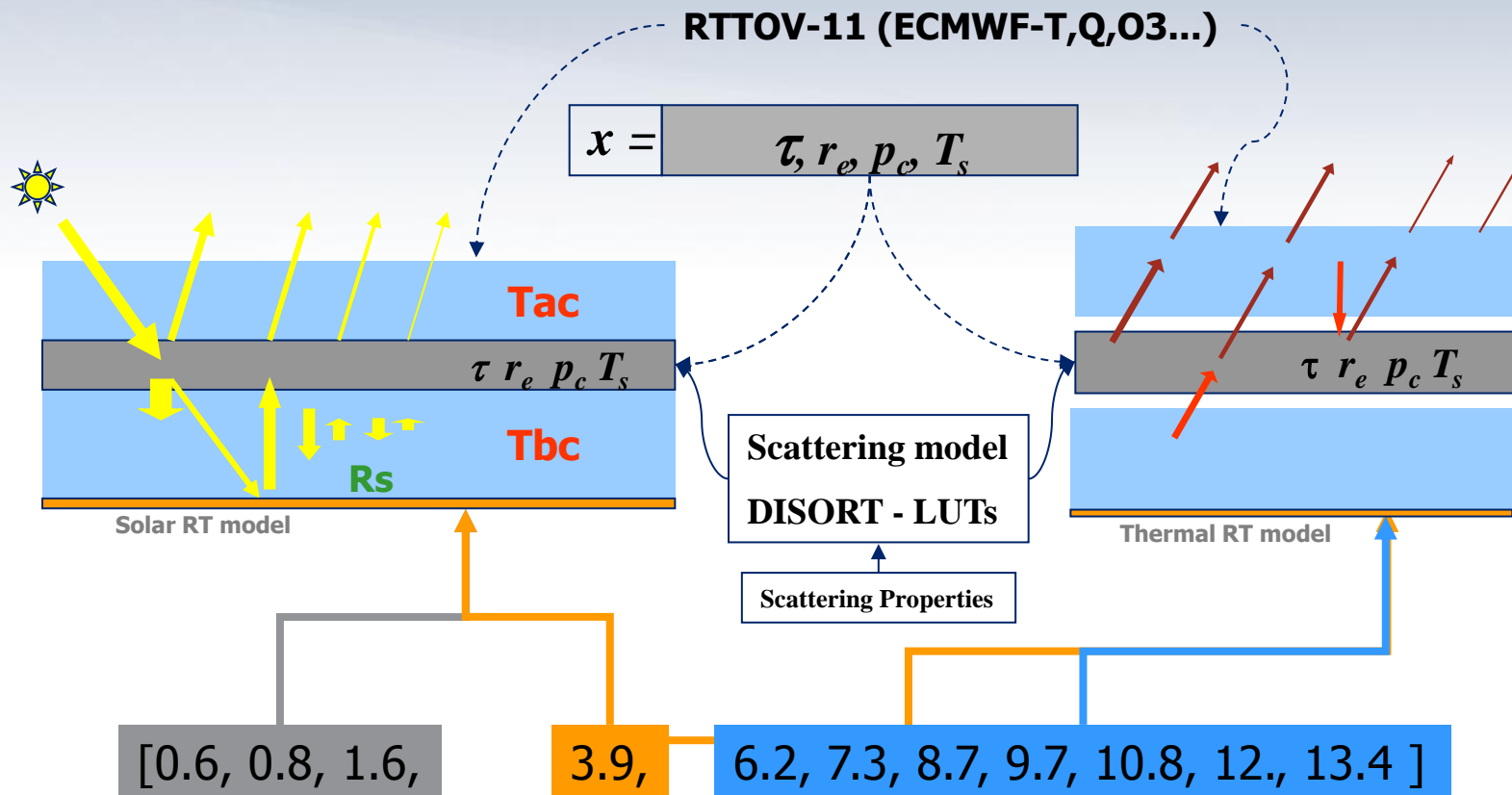
Cloud Processor OE : Inverse model – $x(y)$

$\hat{x} = x_{\min J}$ Obtained by minimising J with respect to x:

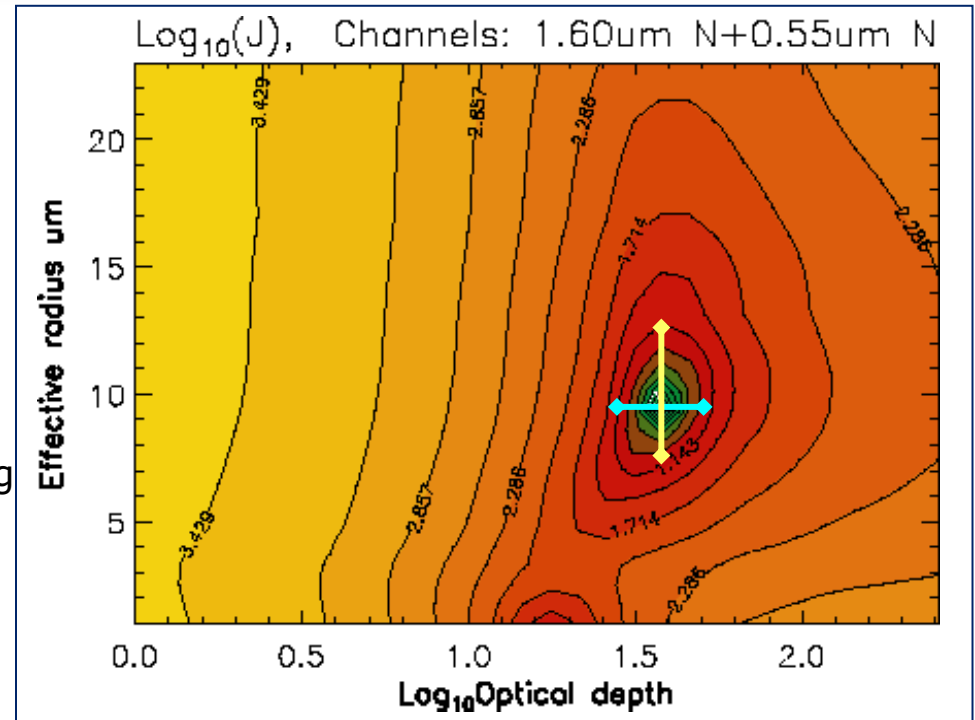$$J = (y_m - y(x))S_y^{-1}(y_m - y(x))^T + (x - x_b)S_x^{-1}(x - x_b)^T$$

$$S = (S_x^{-1} + K^T S_y^{-1} K)^{-1} \qquad (K = \frac{\partial y}{\partial x})$$
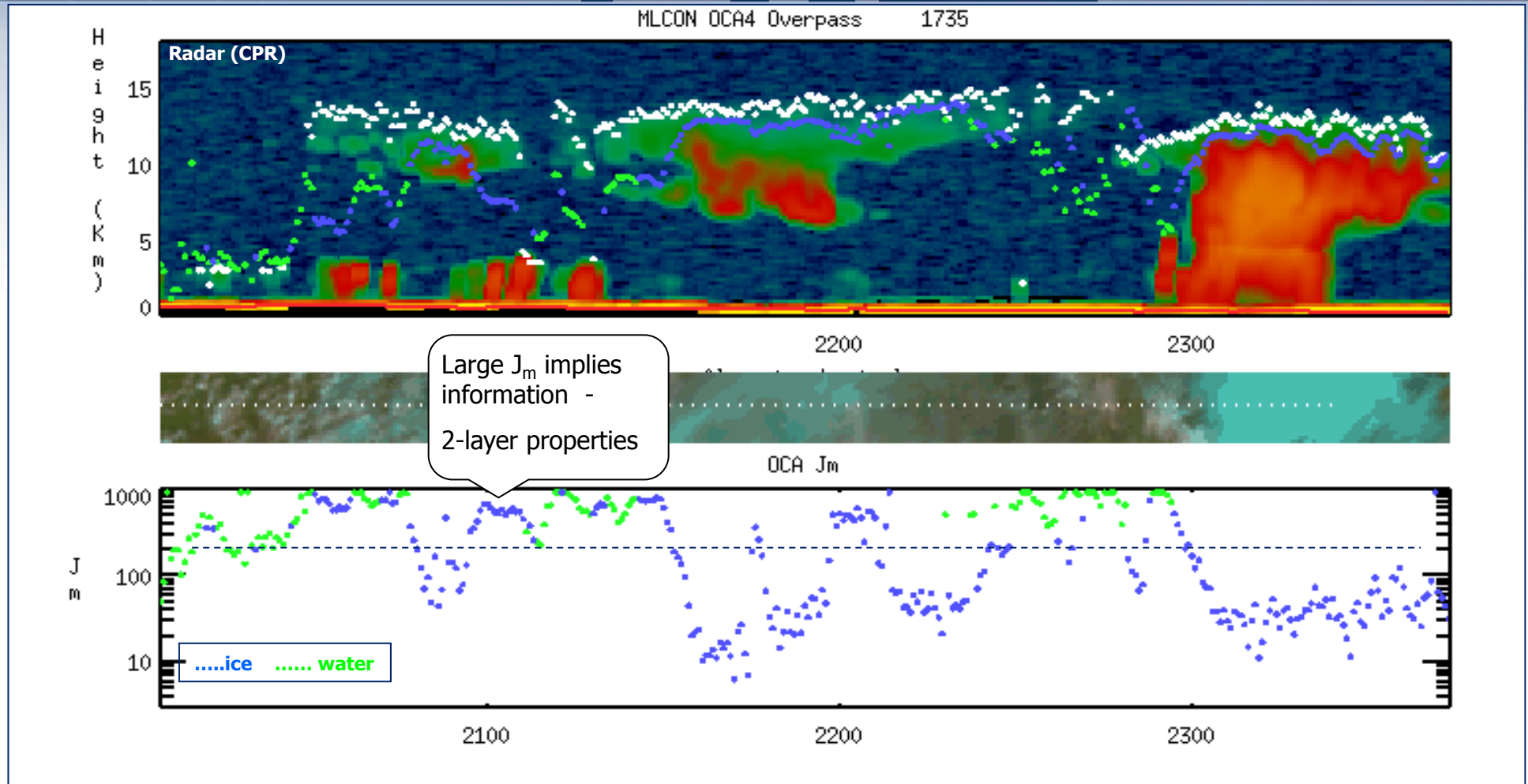
Error estimates
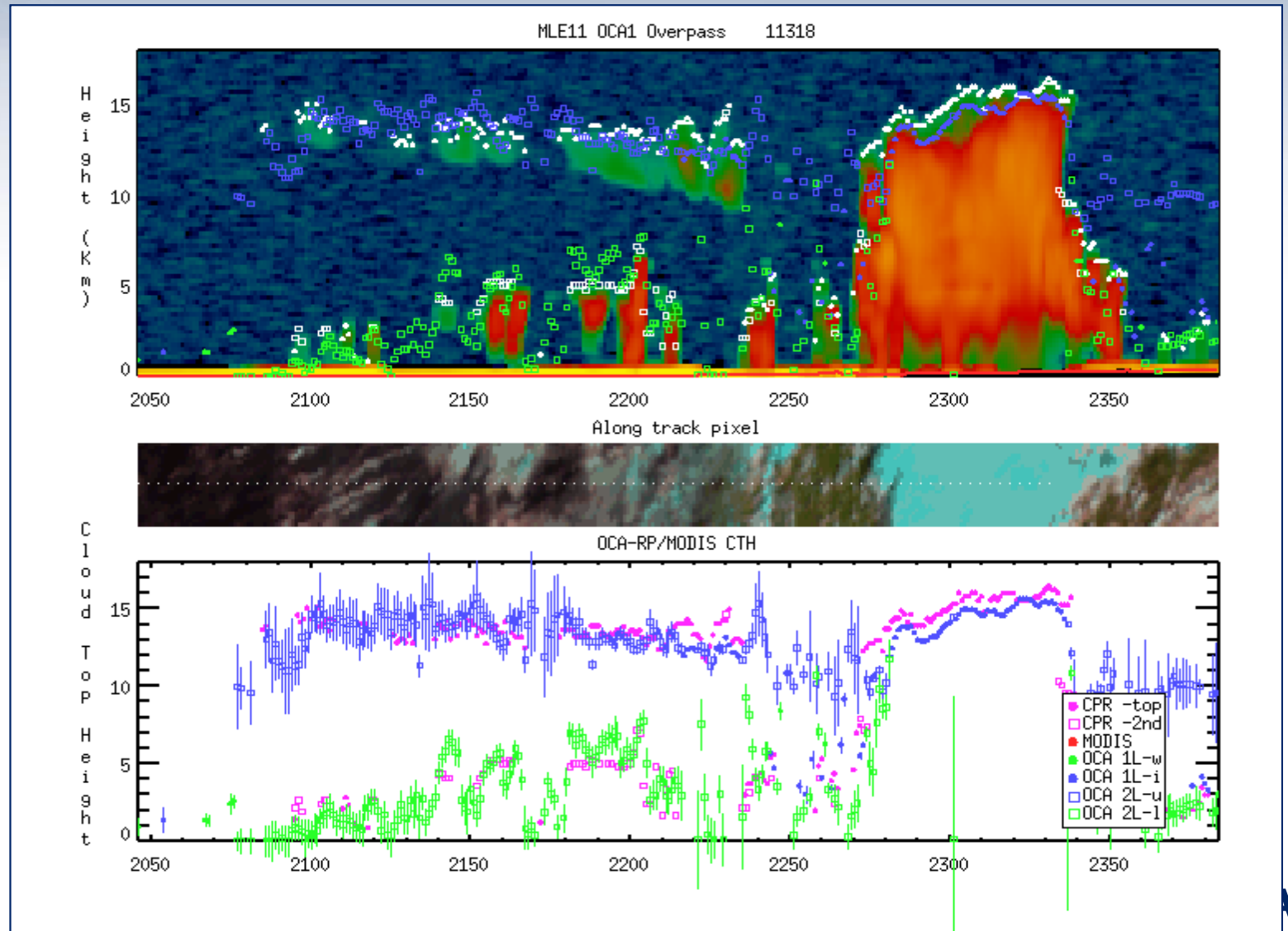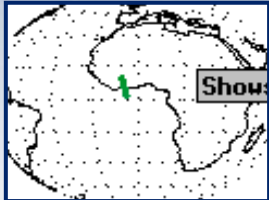
$$\sqrt{S(\tau, \tau)}$$

$$\sqrt{S(r_e, r_e)}$$

Model Quality Control – J_{min} large = something wrong

$Log_{10}(J)$, Channels: 1.60um N+0.55um N

Effective radius um

Log_{10}Optical depth

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Cloud Processor OE : High solution cost often = multi-layer cloud

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Cloud Processor OE : 2-layer cloud retrievals

MLE11 OCA1 Overpass   11318

OCA-RP/MODIS CTH

Legend:
- CPR -top
- CPR -2nd
- MODIS
- OCA 1L-w
- OCA 1L-i
- OCA 2L-u
- OCA 2L-l

Adapting to Cloud + Ash

- Volcanic Ash treated as cloud
    - RT LUTs calculated using relevant ash optical properties
    - Open questions:
        - modified 'first guess' procedures
        - modified / additional (prior) constraints
        - adapt multi-layer detection diagnostic
        - need for / identification of Ash types?
        - ash-specific measurement (modelling) errors?
- Feasibility demonstrated by RAL ORAC processor

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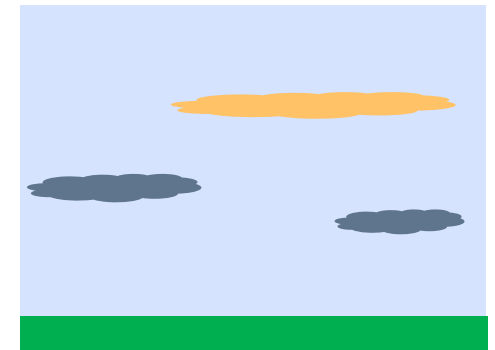
OE Ash: type discrimination?

**How assumed composition affects the interpretation of satellite observations of volcanic ash**

Shona Mackie,a * Sarah Millingtonb and I. M. Watsona a School of Earth Sciences, University of Bristol, Bristol, UK b Met Office, Exeter, UK

METEOROLOGICAL APPLICATIONS Meteorol. Appl. 21: 20–29 (2014) Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/met.1445

Experimental Determination of the Complex Refractive Index and Optical Properties of Mineral Dust in the Infrared Spectral Range

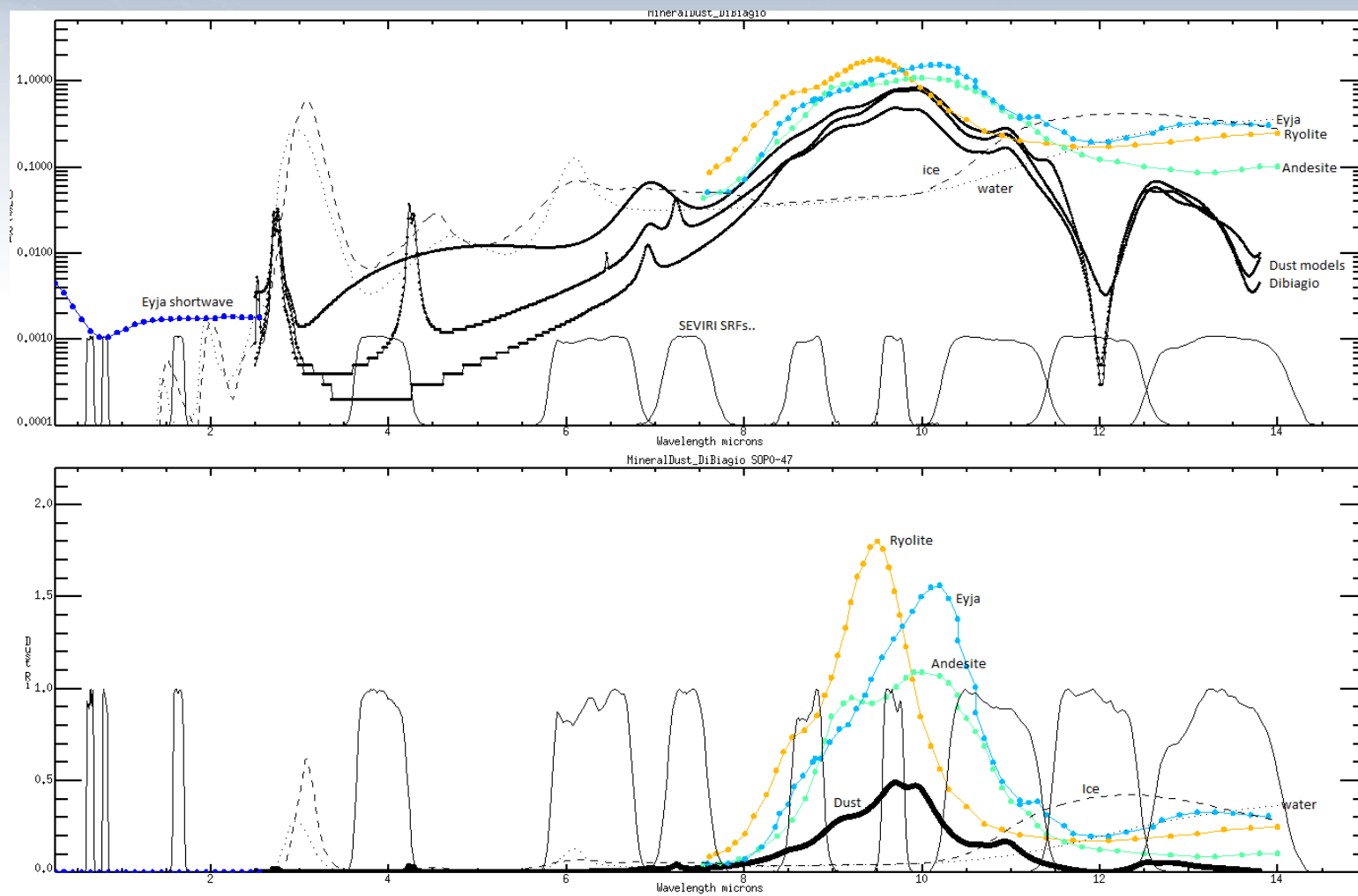C. Di Biagioa,*, H. Boucherb, S. Caquineaub, S. Chevalliera, J. Cuestaa, J.-F. Doussina, and P. Formentia

a LISA, CNRS 7583, UPD and UPEC, IPSL, Creteil, France , b LOCEAN, IRD, Bondy, France
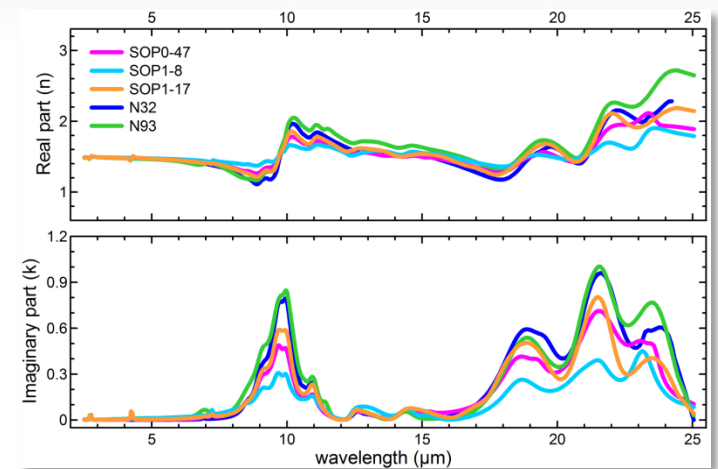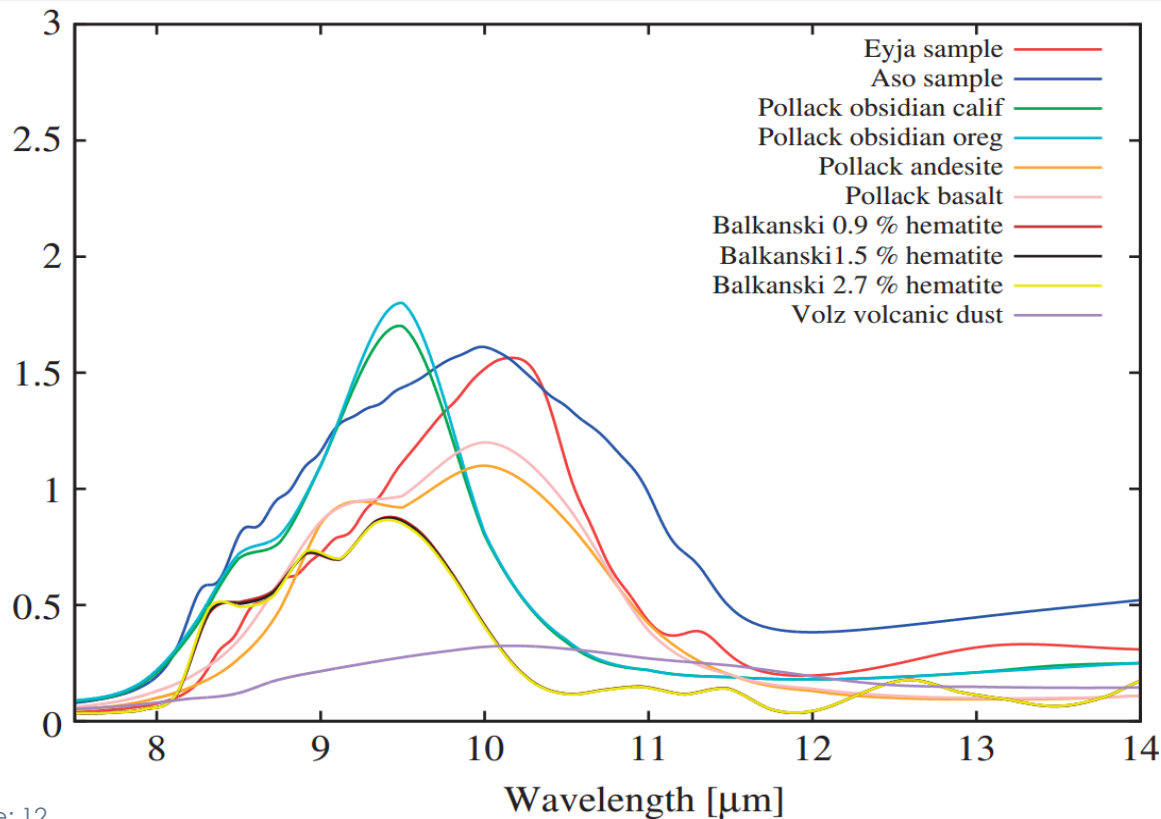
Candiate Ash types:

'Eyja'

Andesite

Rhyolite

N93 dust

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OE Ash: type discrimination?
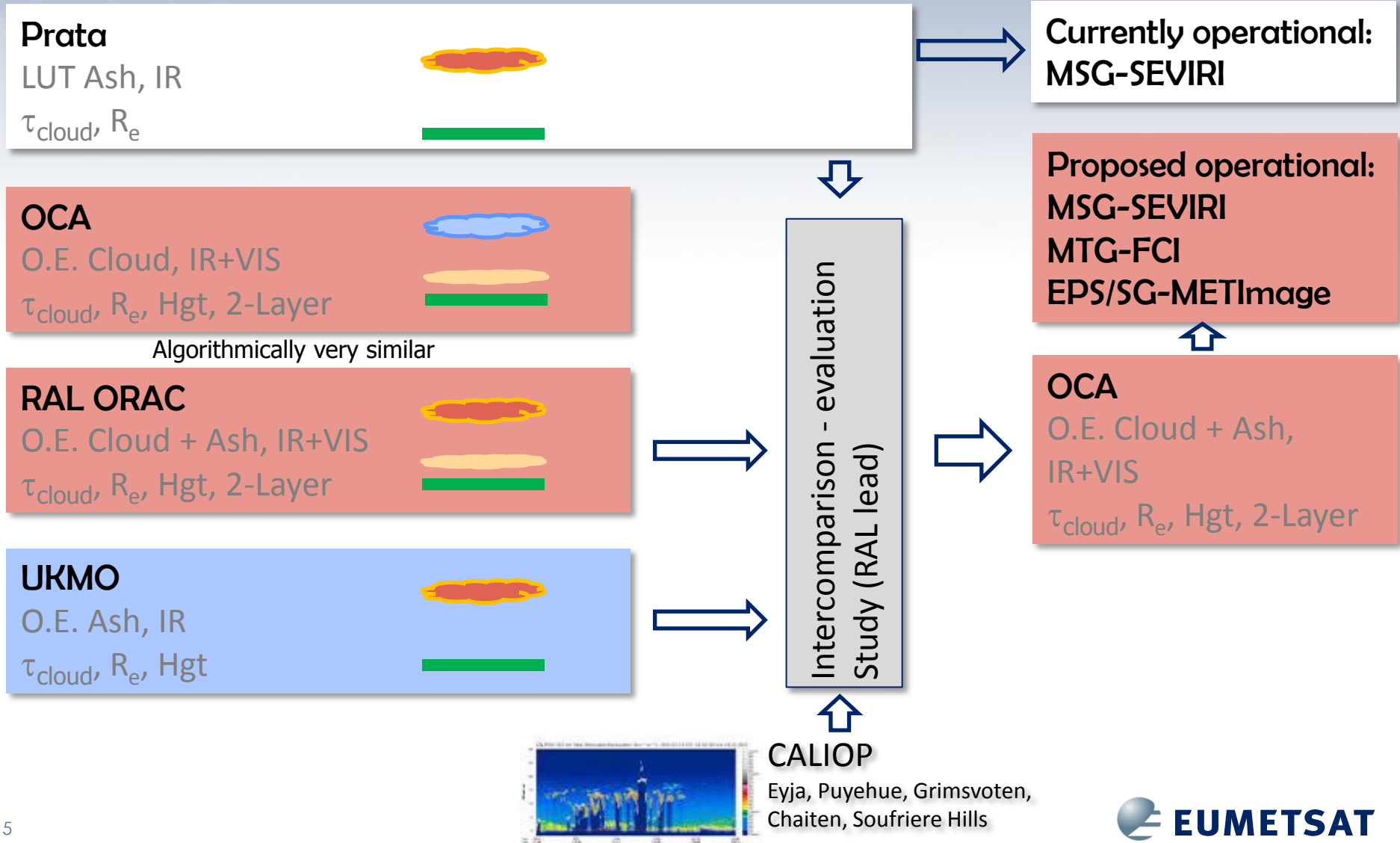
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Algorithm Overview: EUMETSAT (Imagers)

Prata

LUT Ash, IR

τ_{cloud}, R_e

OCA

O.E. Cloud, IR+VIS

τ_{cloud}, R_e, Hgt, 2-Layer

Algorithmically very similar

RAL ORAC

O.E. Cloud + Ash, IR+VIS

τ_{cloud}, R_e, Hgt, 2-Layer

UKMO

O.E. Ash, IR

τ_{cloud}, R_e, Hgt

Intercomparison - evaluation Study (RAL lead)

Currently operational: MSG-SEVIRI

Proposed operational: MSG-SEVIRI MTG-FCI EPS/SG-METImage

OCA

O.E. Cloud + Ash, IR+VIS

τ_{cloud}, R_e, Hgt, 2-Layer

CALIOP

Eyja, Puyehue, Grimsvoten, Chaiten, Soufriere Hills

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SEVIRI Ash Detection

Detection used for RAL/MetOffice/EUM inter-comparison study

Cloud detected

AND T10.8 − T12.0 < -0.5 K

AND (T10.8-PT10.8) − (T8.7-PT8.7)   < 0

AND (T10.8-PT10.8) − (T12.0-PT12.0) < -1 K

*Predicted brightness temperatures (PT...) from RTTOV-9 and co-located forecast data
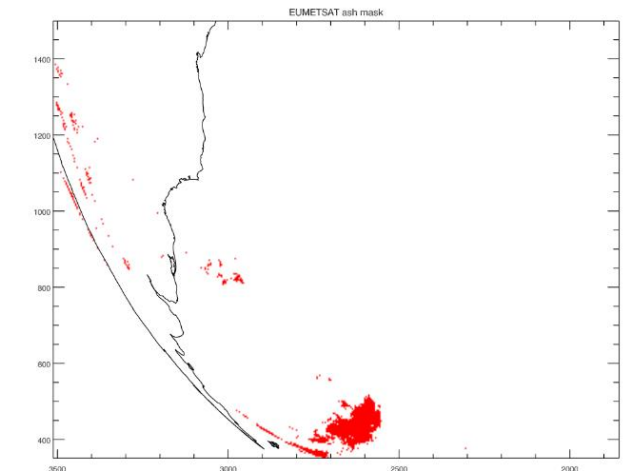
Study showed many false alarms at high view angles.

Thermal false colour: 8.7, 11, 12 microns
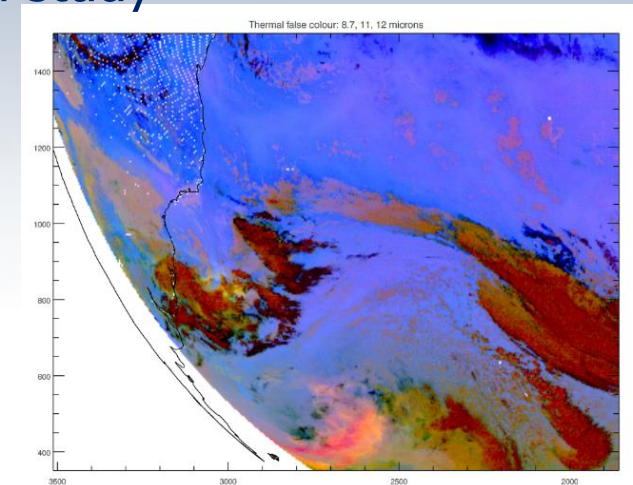
Detection used for SCOPE inter-comparison study

~~Cloud detected~~

(T10.8 − T12.0)/Cosine(θ_{sat}) < -2 K

AND (T10.8-T12.0) < -1 K

Reduced high angle false alarms.

EUMETSAT ash mask

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Algorithm Overview: EUMETSAT (Imagers)

- **Integration with OCA cloud processor for ash detection:**

  - Proven similar performance to alternatives
  - Much greater in-house expertise compared to alternatives
  - Ash and Cloud integrated algorithm across EUMETSAT imagers reduces development / maintenance

  - Potential maybe higher -
    - Multi-layer capability
    - IR + VIS capability

- **Detection stage likely to remain outside inversion algorithm**

  - Signed measurement differences / ratios and spatial tests lie outside OE framework
  - (Same philosophy applies to cloud detection)

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Summary: EUMETSAT Imagers

- Prata algorithm current at EUMETSAT

- Plan to use OE cloud processor adapted for ash, c.f. ORAC

- Initial trial experiment reported here –

    - Tested solution, solution cost and residuals sensitivity to 4 ash types

    - No significant discrimination skill seen

    - AOD and r_{eff} values vary significantly with type

    - Multiple solutions in r_{eff}

    - Ash over Met cloud situation so retrieval under–constrained, as supported by large estimated errors

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Algorithm Overview: EUMETSAT (Imagers)

▸ Dataset

Volcanic Ash Detection (netCDF) - MSG - 0 degree

The ash detection is based on a reversed split window technique, supported by tests in the other IR channels and two VIS channels. The product is disseminated in netCDF classic format, that contains as main parameters the ash mass loading and the mean ash ...
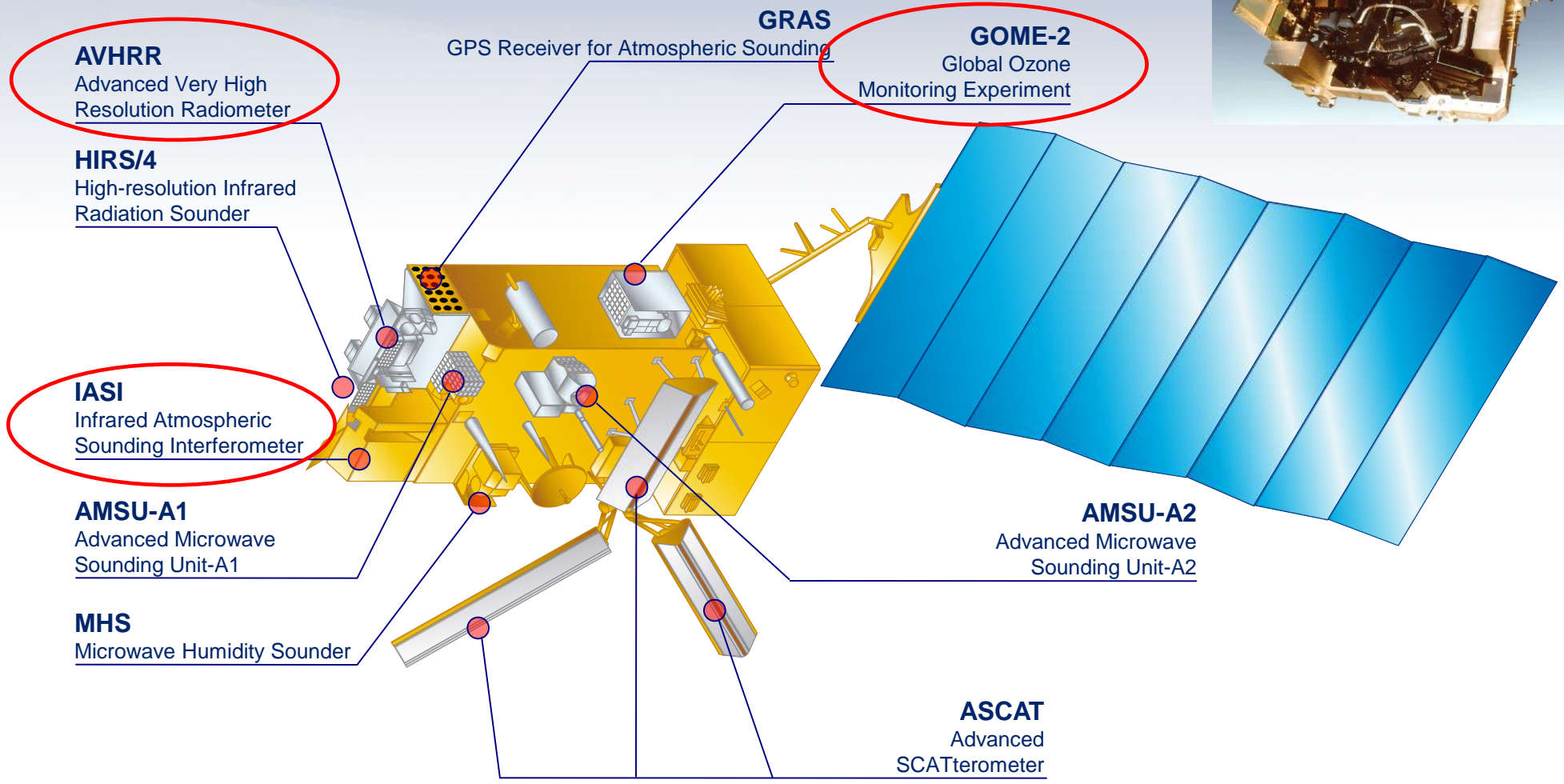
Description | Categorisation | Distribution | Metadata

Collection Reference:	EO:EUM:DAT:MSG:VOLE
Collection Name:	Volcanic Ash Detection (netCDF) - MSG - 0 degree
Acronym:	VOLE, MSGVOLE
Description:	The ash detection is based on a reversed split window technique, supported by tests in the other IR channels and two VIS channels. The product is disseminated in netCDF classic format, that contains as main parameters the ash mass loading and the mean ash particle size. Note that the netCDF files have been compressed with bzip2 and before uncompressing them, the 103 bytes LRIT header must first be removed. After decompression, any reader compatible with netCDF classic format (also known as netCDF-3), written with netCDF library version 4.1.1, can be used to read the data. The navigation data is not supplied within the netCDF product but can be found in the online resources.
Product Status:	Demonstration

Date:	creation:	2012-09-05
	revision:	-

Time Range:	Begin:	2012-09-05
	End:	-

Geographic Bounding Box:	West Bound Longitude:	-65.0
	East Bound Longitude:	65.0
	North Bound Latitude:	65.0
	South Bound Latitude:	-65.0

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Multi-Sensor radiance level-1b/c data input to PMAp
EUMETSAT Polar System - Metop

AVHRR
Advanced Very High Resolution Radiometer

HIRS/4
High-resolution Infrared Radiation Sounder

IASI
Infrared Atmospheric Sounding Interferometer

AMSU-A1
Advanced Microwave Sounding Unit-A1

MHS
Microwave Humidity Sounder

GRAS
GPS Receiver for Atmospheric Sounding

GOME-2
Global Ozone Monitoring Experiment

AMSU-A2
Advanced Microwave Sounding Unit-A2

ASCAT
Advanced SCATterometer

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Algorithm Overview:
PMAp **P**olar **M**ulti-sensor **A**erosol **p**roduct

- AOD with volcanic ash flag (no other ash parametes provided)

- Over ocean only (extended to land in Q1 2016)

- GOME-2 resolution: Metop-A (40x5 km) Metop-B (40x10 km)

- LUT (based on V-RTM Hasekamp et al.)

- Global (SZA<78°) – but only one overpass per day (dayside)

- Operational at EUM and disseminated in NRT

- Error estimate per AOD retrieval value

- Ash detection using AVHRR in T4-T5 (10.8 – 12 μm) plus VIS/NIR criteria (0.6, 0.8, 1.6 μm)

- If the volcanic ash test is positive, the heterogeneity within a GOME-2 PMD pixel is analyzed (using AVHRR 1km resolution) for partly discrimination of clouds and aerosols. No cloud models used.

- A(sh)OD retrieval in the VIS/NIR GOME-2: 400 to 800 nm plus Stokes fractions based on dust models

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Three step retrieval:

Step1: Pre-classification by AVHRR

- Cloud detection and cloud corrections, distinguish clouds from dust/ash

- Aerosol type pre-classification (no dust, dust, ash, no classification)

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

- based on a set of aerosol models from LUT provided by O. Hasekamp (O3MSAF), model selection dependent on step 1.

- Chlorophyll fitted for clear sky pixels (otherwise a priori)

Step3: Selection of the best fit

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

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PMAp Operational version 1:
AOD: Metop A (June+July 2013)

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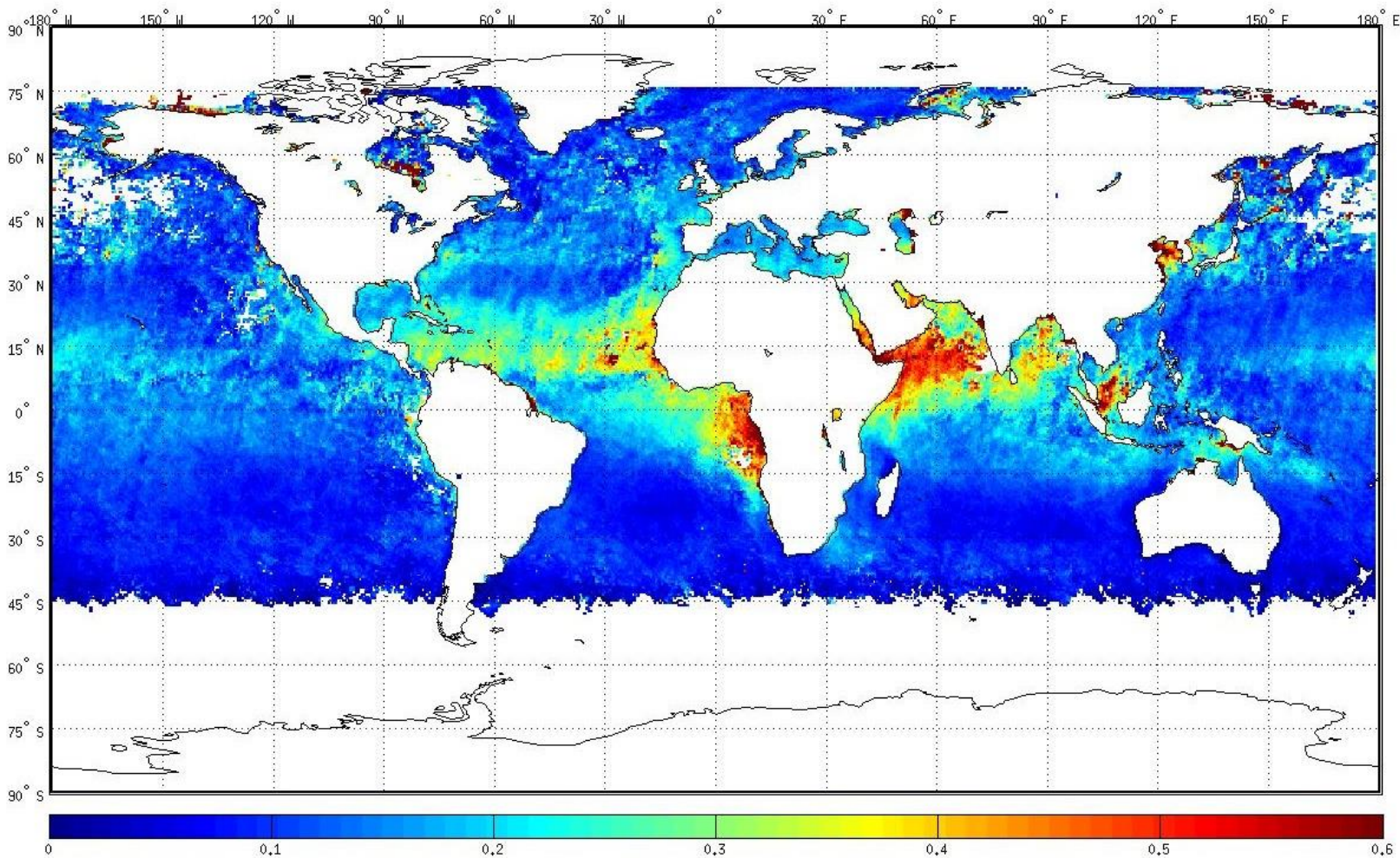
PMAp AOD: Metop A & B combined

AOD (PMAp – METOP A & B)

Ocean = operational retrieval
Land = test retrieval in development

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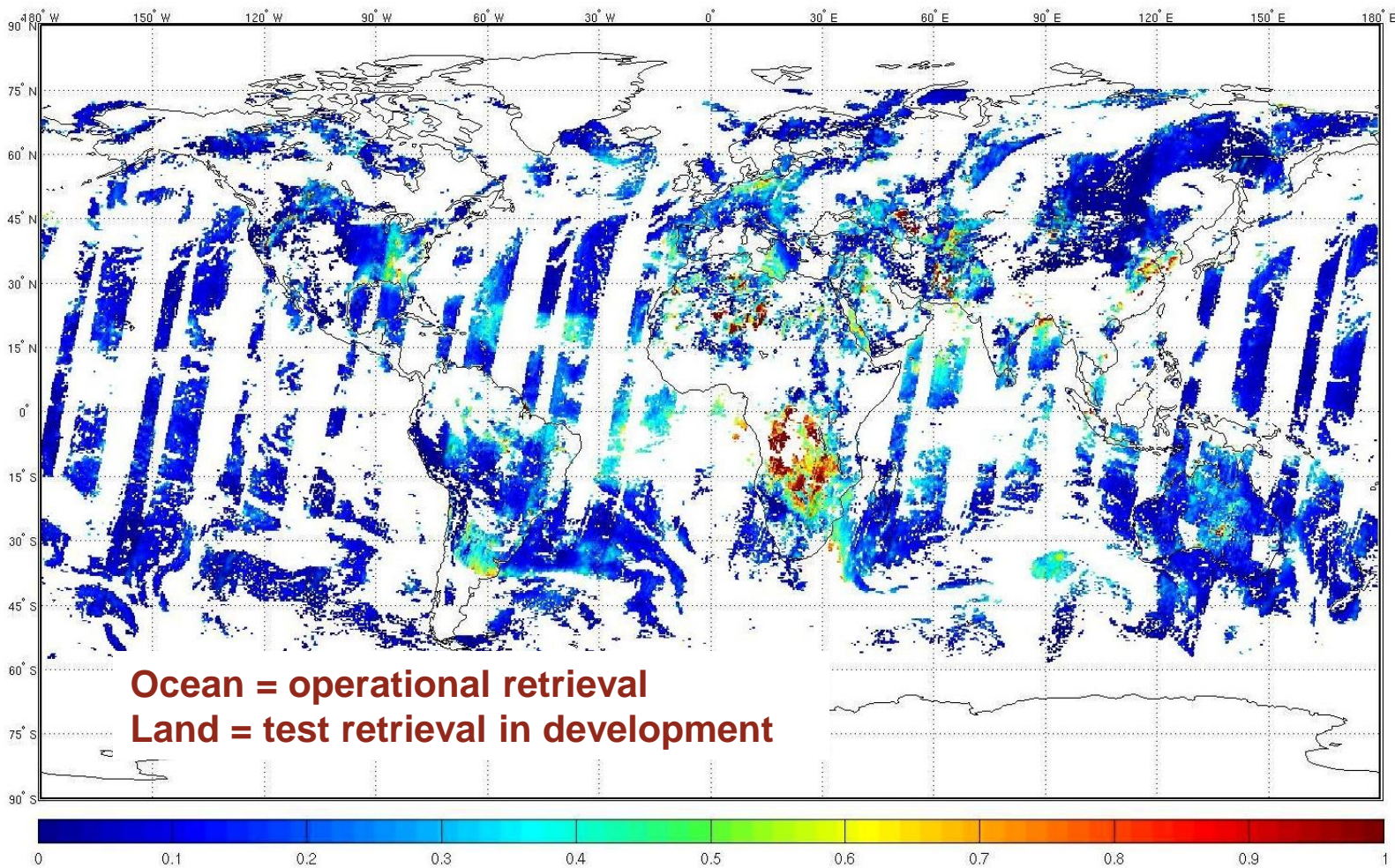
Aerosol type pre-classification I: Volcanic ash

- Distinguish clouds & thick dust from volcanic ash using AVHRR

    - Brightness temperature difference T4-T5 (10.8 µm – 12 µm) < threshold

    - Thresholds in AVHRR-VIS and NIR to detect false alarms (T3A/T2 & T3A/T1 & T2/T1 > threshold)

    - Homogeneity test at T4 > threshold

    - AVHRR Cirrus test < threshold

$$R_{corrected}(ash) = R_{PMD} \frac{R_{AVHRR}(\min(T4-T5))}{R_{AVHRR}(all)}$$

+ Weighted GOME-2 pixel radiances

ATBD available at: www.eumetsat.int > Data > Technical documentation > Metop > PMA

Aerosol optical depth
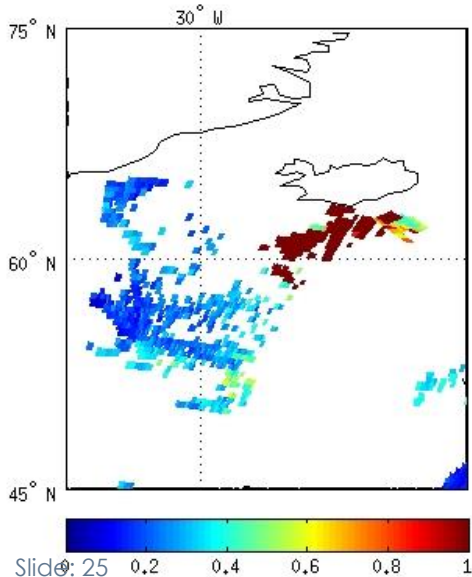
Volcanic ash flag
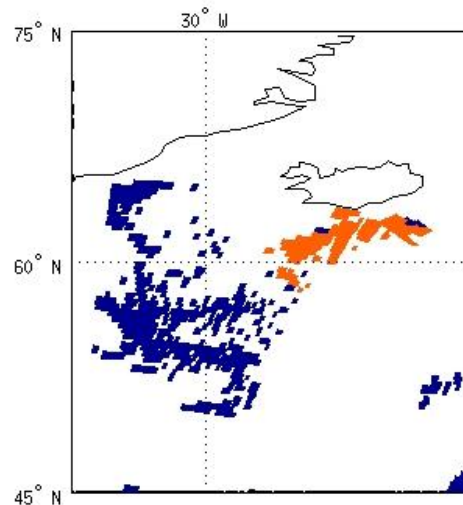
Orange: Strong ash test positive, cloud tests ignored

Blue: cloud fraction < 0.3, AOD retrieved

White:
- no retrieval or
- cloud fraction > 0.3 and negative ash test

23/05/2011

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Aerosol type pre-classification II: Dust / ash & fine mode

- Aerosol type pre-classification for negative cloud but including positive ash tests
  - desert dust tests: weak wavelength dependency VIS/NIR
  - no dust/fine mode: strong wavelength dependency VIS/NIR

Red: Volcanic ash
Green: Desert dust
Blue: no dust/fine mode

Eyjafjällajökull 23/05/2011

AT
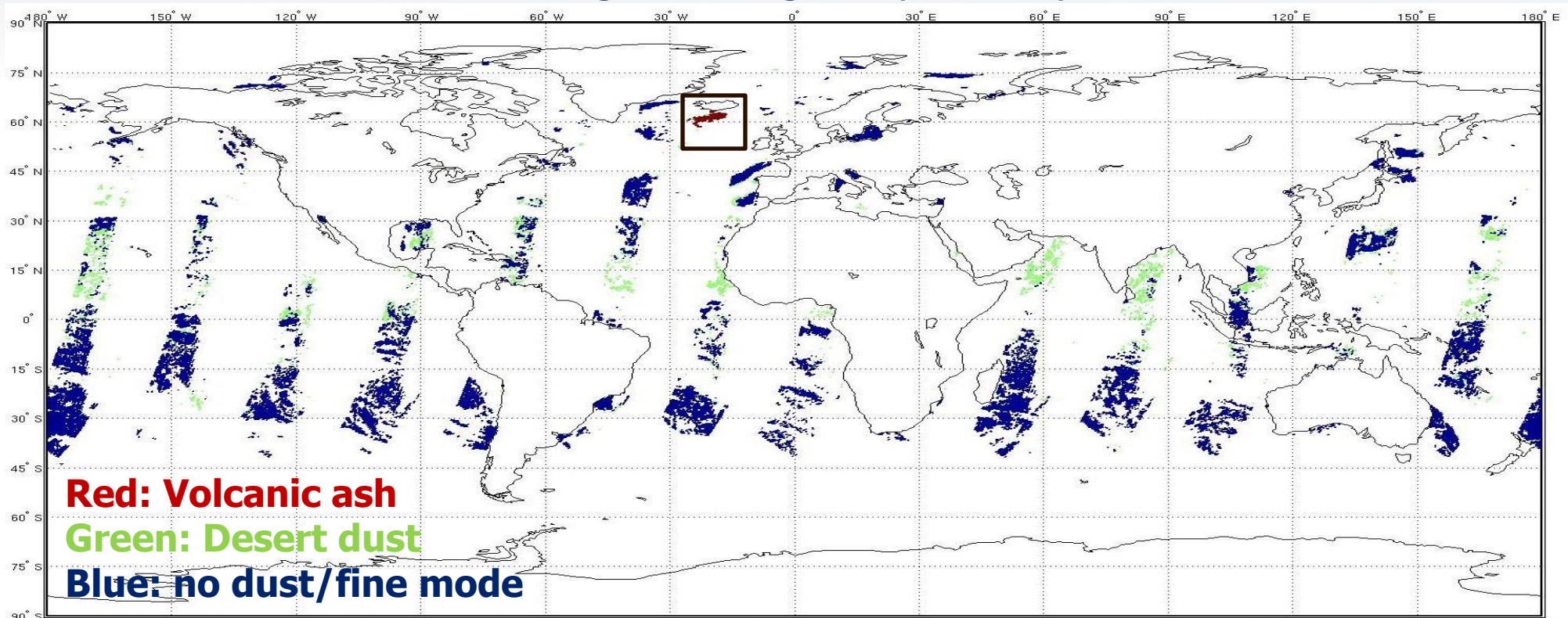
Aerosol type pre-classification III: Transport of volcanic ash

06/06/2011

13/06/2011
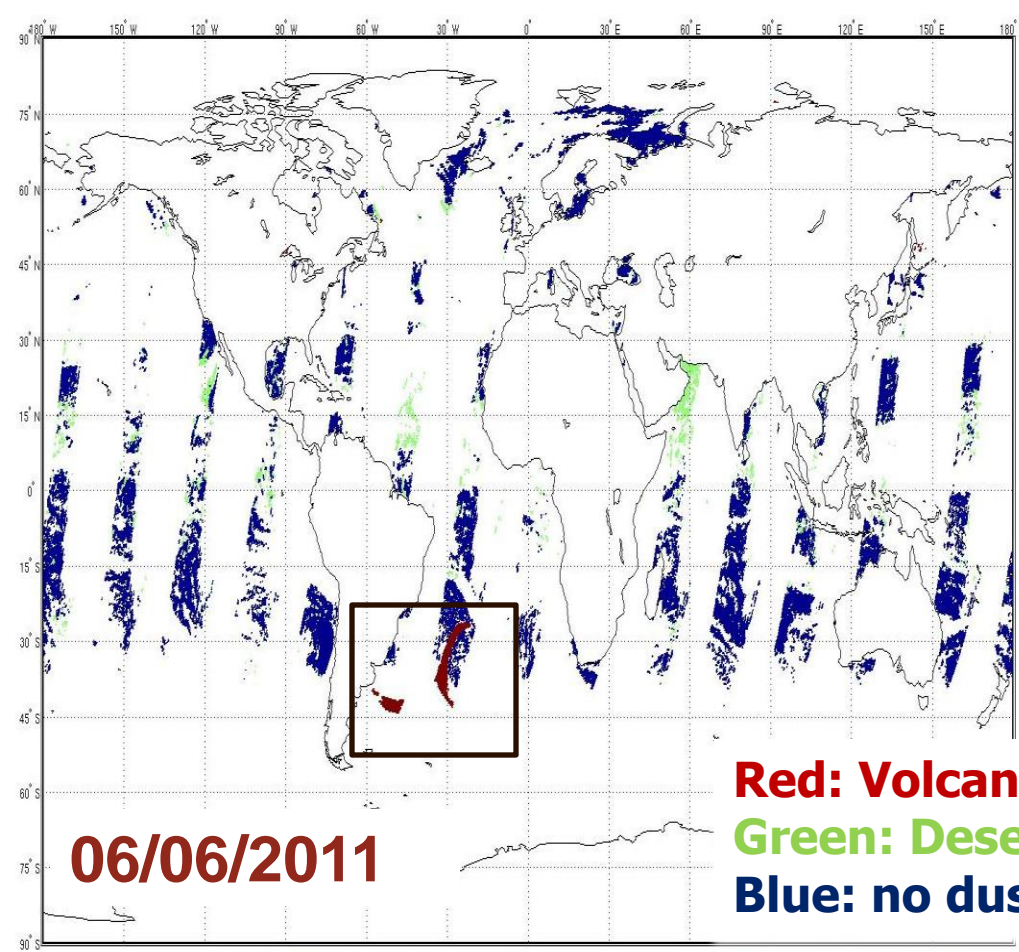
Red: Volcanic ash
Green: Desert dust
Blue: no dust/fine mode
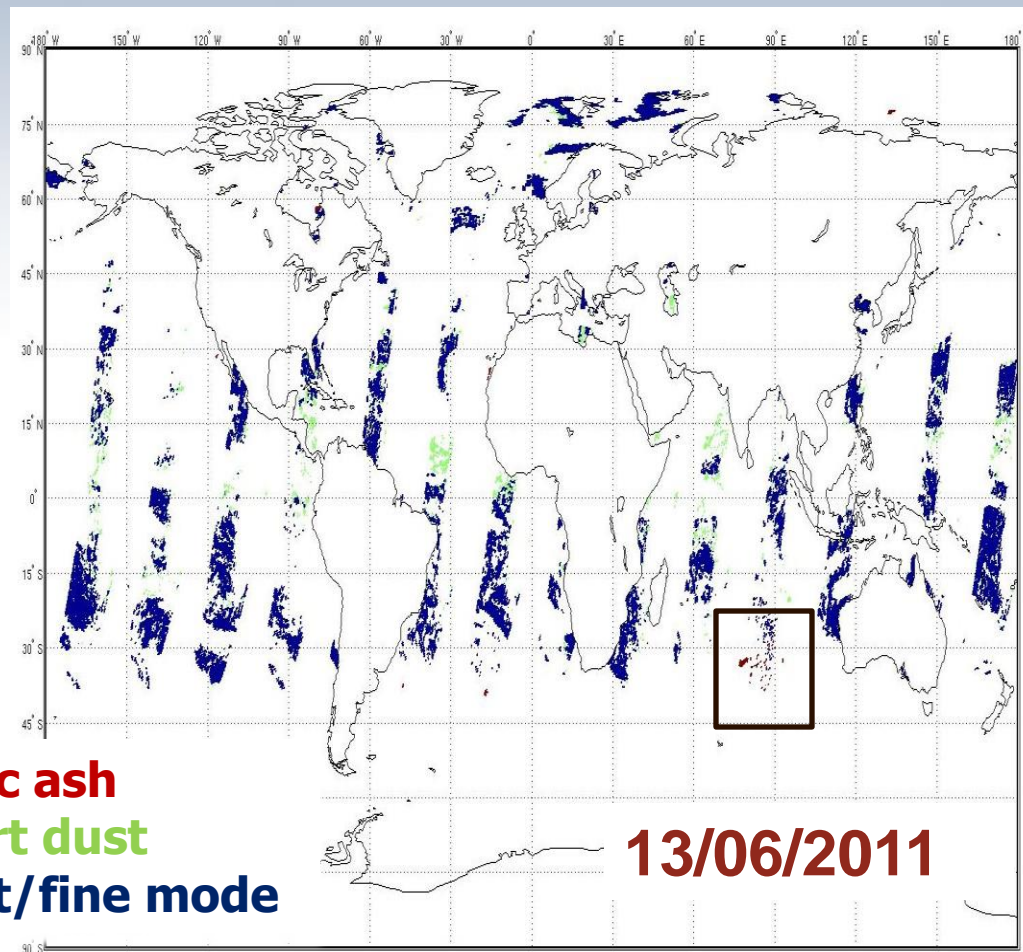
Puyehue-Cordon Caulle

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PMAp aerosol events: Volcanic ash plume Calbuco April 2015
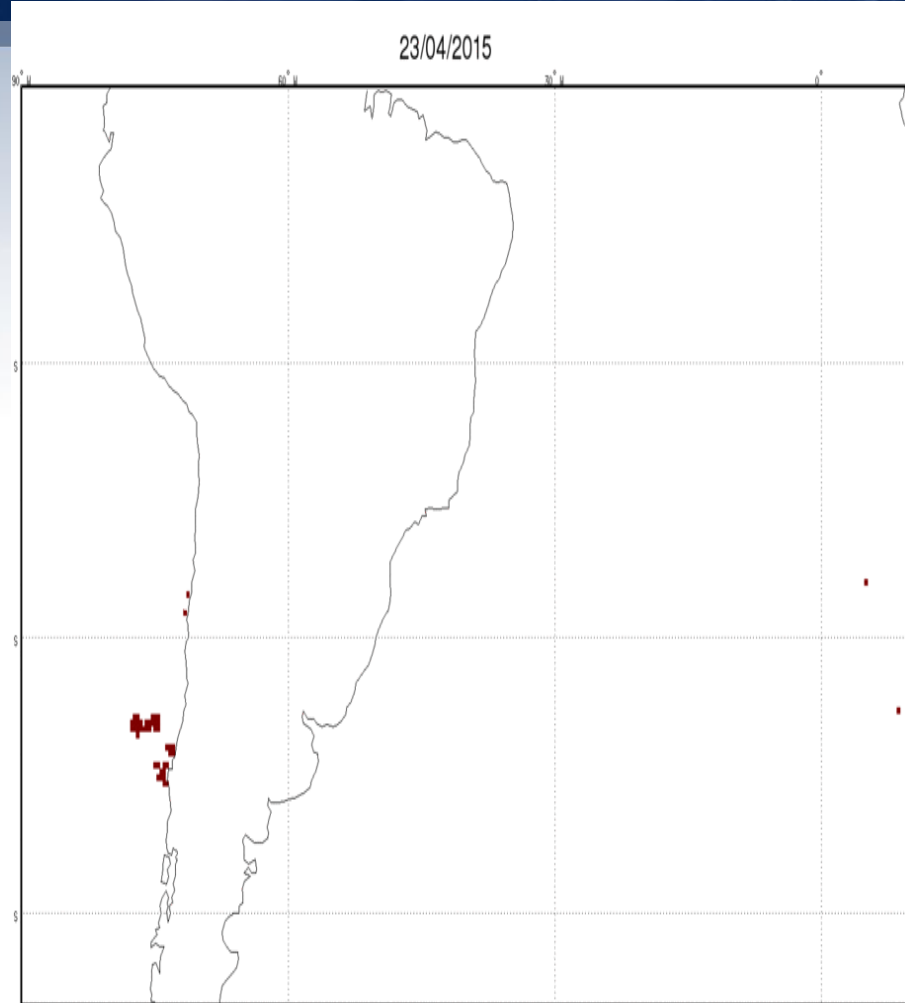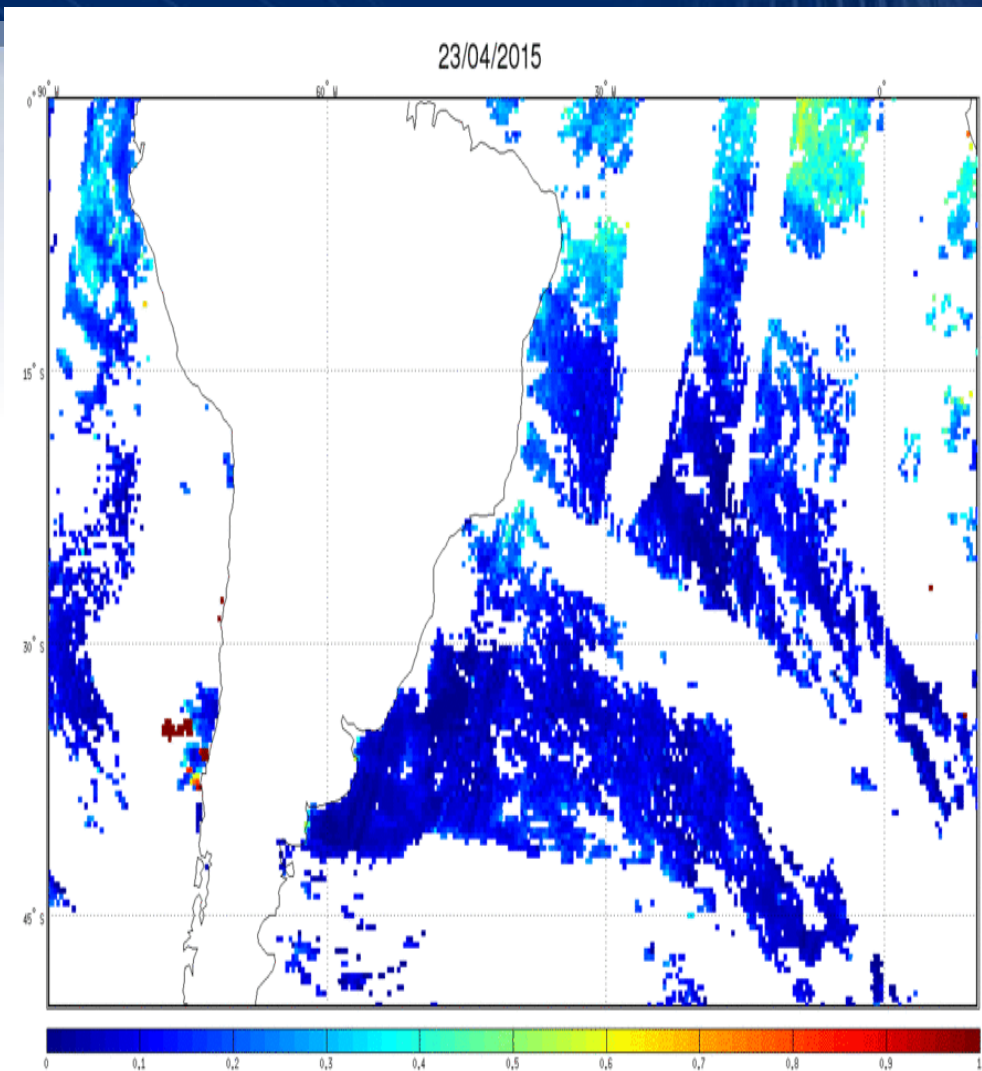
Calbuco 23-27/04/2015

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SO2 monitoring from Metop (GOME-2 / IASI)
Observing volcanic eruption and dust events for aviation control

Cap Verde eruption

November 2014

GOME-2 Metop-A/B

GOME-2 Metop-A/B [DU] SO2 GDOAS 2014-11-22

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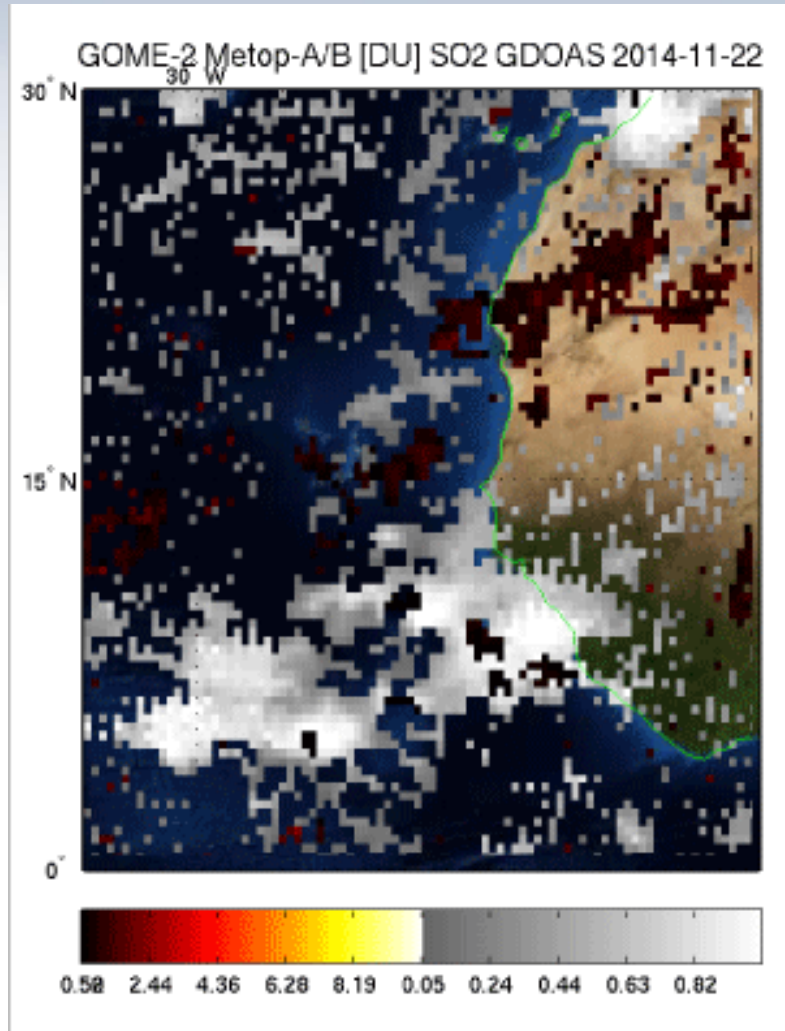
GOME-2 SO₂ courtesy of University of Bremen (Andreas Richter & colleagues)

GOME-2 SO₂ (Jabal al-Tair): 2007/09/30
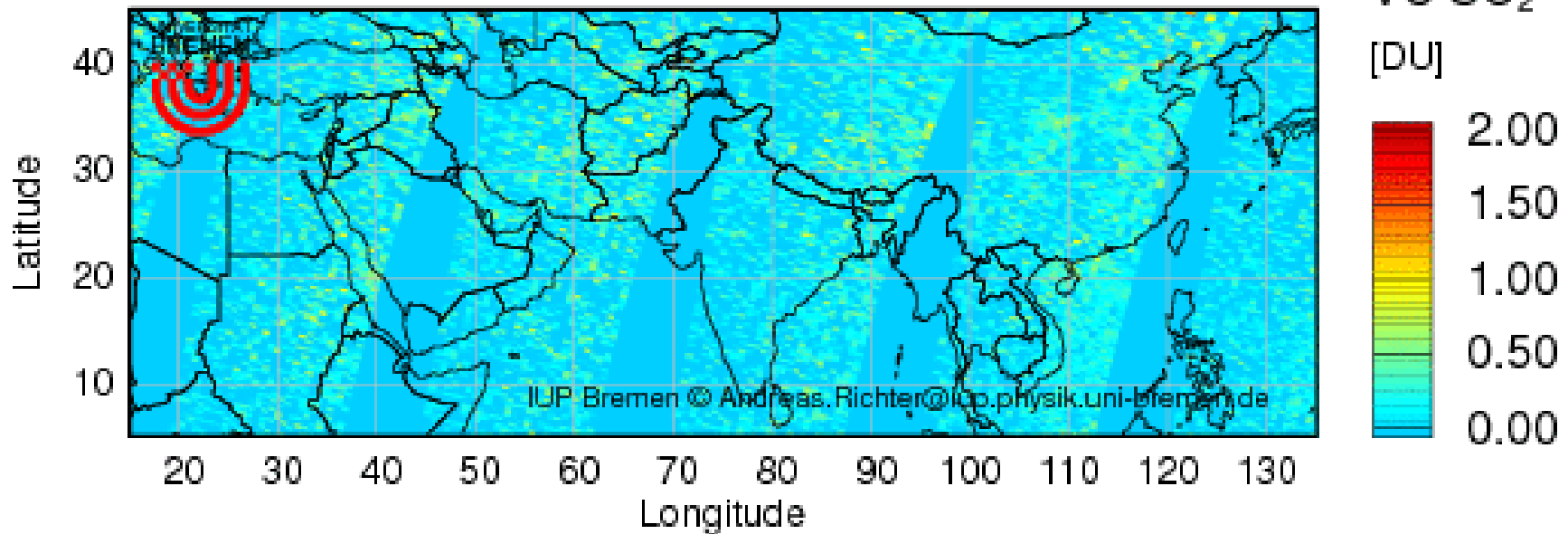
Aerosol and SO2 monitoring from Metop
Observing volcanic eruption and dust events for aviation control

Cap Verde volcanic SO2 emissions

Dust signal

30. November 2014

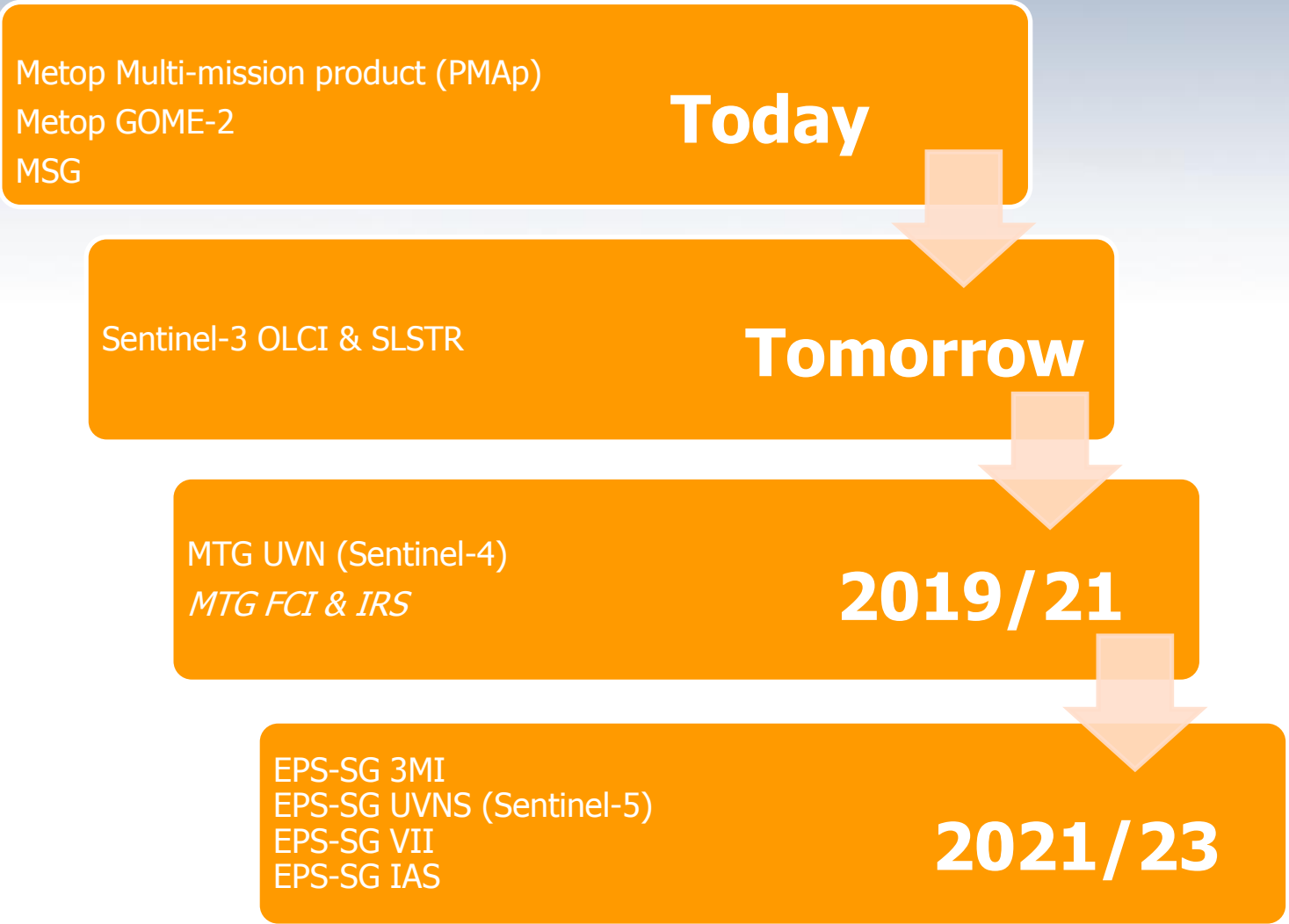**http:/sacs.aeronomie.be**

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Summary: PMAp

- A new aerosol product <u>over ocean</u> from METOP instruments (PMAp) is delivered to our users
  - GOME-2 product using a multi-sensor approach
  - Pre-Operational since April 2014
  - Fully validated with operational status since 14th October 2014

- PMAp provides AOD, aerosol classification (fine,coarse, thick-dust/ash), as well as a volcanic ash flag.

- A new PMAp release providing AOD over land is in development
  - First results look promising
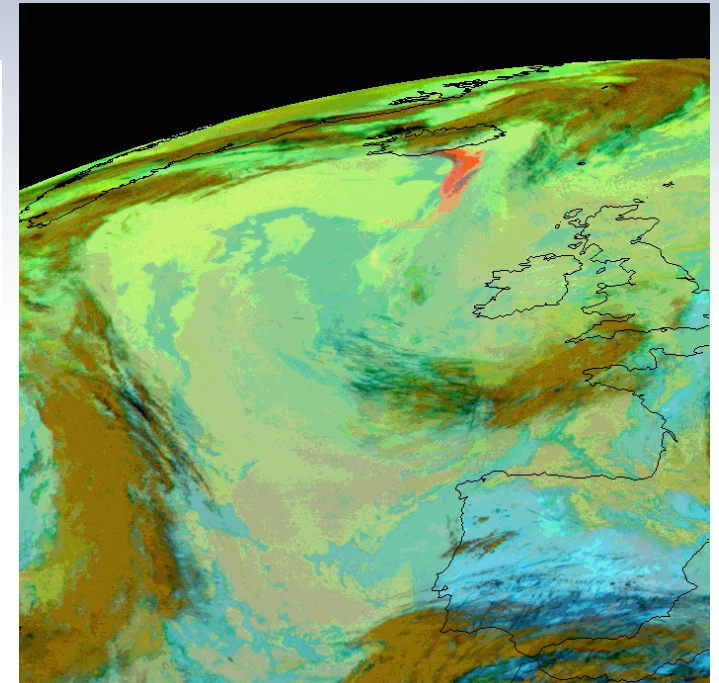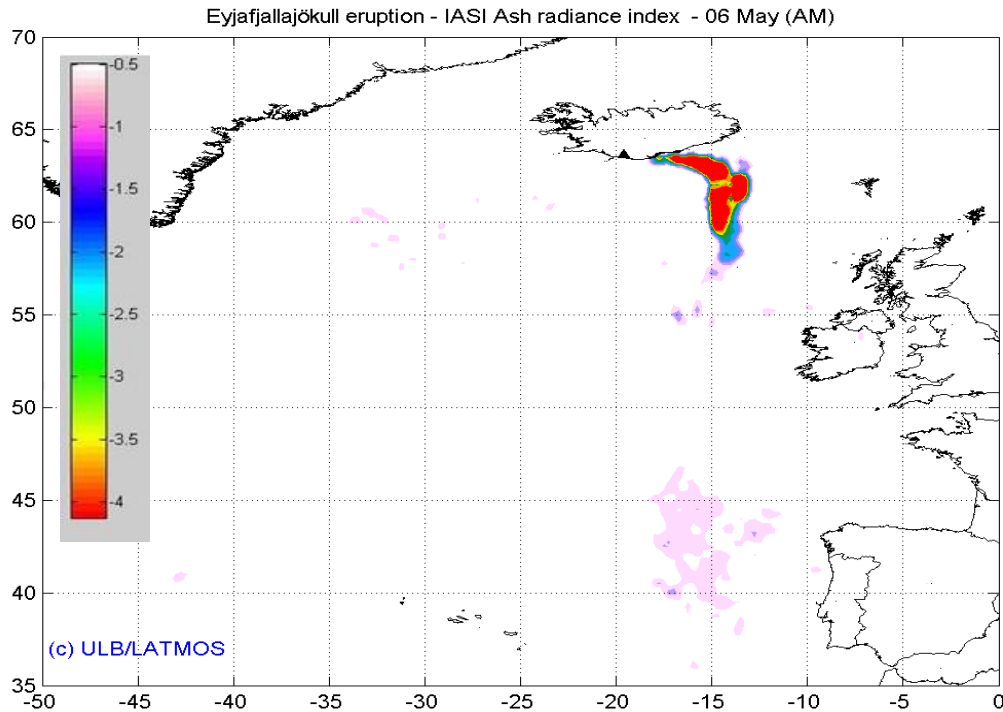 - Start of pre-operations expected in Q1/2016

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Missions Providing Aerosol and Volcanic Ash Products

Metop Multi-mission product (PMAp)
Metop GOME-2
MSG

Today

Sentinel-3 OLCI & SLSTR

Tomorrow

MTG UVN (Sentinel-4)
MTG FCI & IRS

2019/21

EPS-SG 3MI
EPS-SG UVNS (Sentinel-5)
EPS-SG VII
EPS-SG IAS

2021/23

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Eyjafjallajökull eruption - IASI Ash radiance index - 06 May (AM)

(c) ULB/LATMOS

06 MAY 2010 1100 UTC

Qualitative Volcanic Ash RGB - MSG

Aerosol absorbing index derived from IASI overpasses:

Higher index – larger particles

Courtesy C. Clerbaux et al., LATMOS/ULB

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Conclusions

- New products on their way

- Novel ideas to use (e.g. tracking ash-cloud, trajectories, geo/leo combination

- New instruments already there (AHI,ABI)

- New instruments/capabilities coming, e.g. MTG IRS, Sentinel-4

- New technologies into operations; Lidar?

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