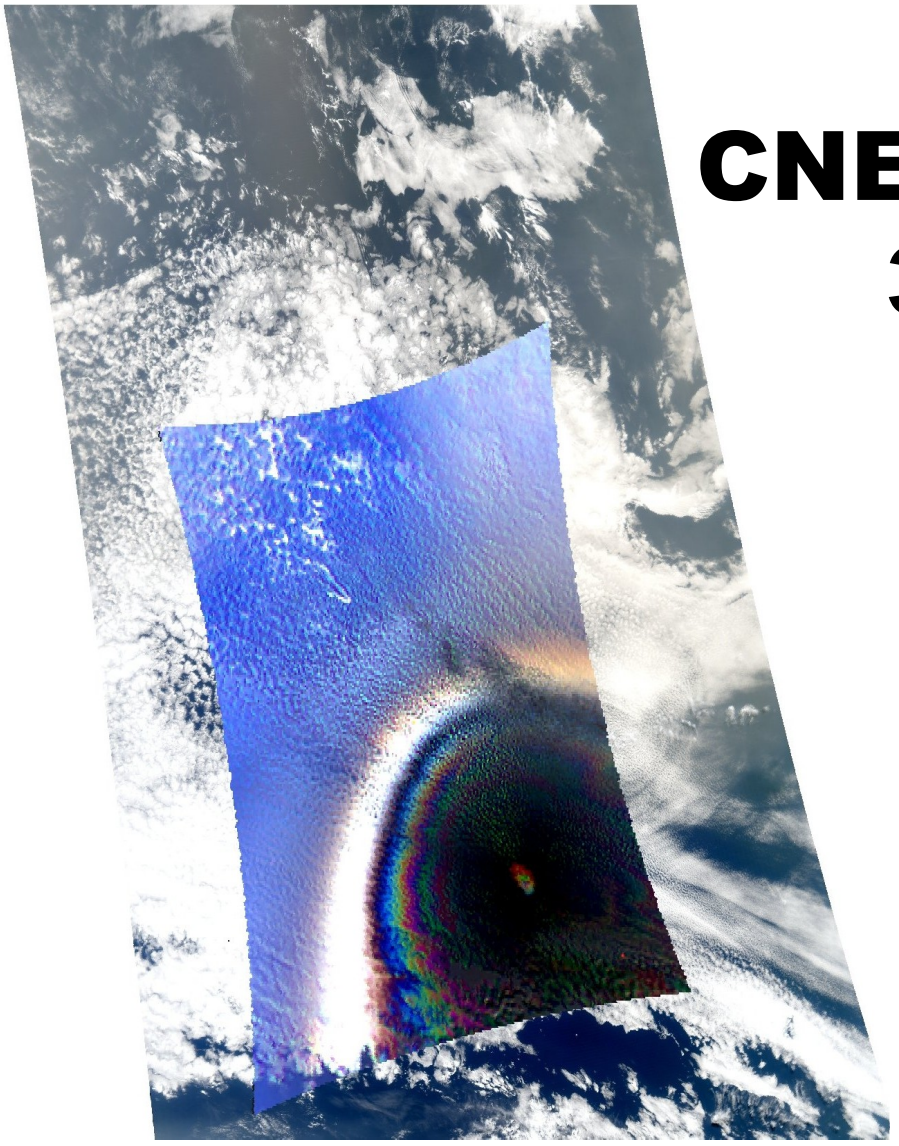

Update on : CNES polarimeter studies 3MI current status

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Outline

1) Summary of CNES phase 0 studies for 3MI

2) A few elements on current 3MI rationale/status from the last Eumetsat Consultation Workshop

3) Questions
Why do we need a polarimeter for PACE ?
What are the requirements ?
Can a 3MI type instrument fulfill those ?
If not, what would it take to make 3MI “PACE compatible” ?

CENTRE NATIONAL D'ÉTUDES SPATIALES

Multi polarization Multi directional Multi spectral 3MI instrument

Phase 0 study Synthesis

FROM POLDER TO 3MI: EVOLUTION OF THE REQUIREMENTS

	POLDER 1-2 (POLDER 3)	3MI
■Altitude (km)	800 (705)	820
■Field of view :	+/- 42° (+/- 51°)	+/- 51°
■Swath (km)	2200 (1600)	2291
■Spectral range :	[443-910 nm] [443-1020 nm]	[340-2200 nm]
■Number of spectral bands	9	12
■Number of polarized bds (nb of polarizations)	3 to 4 (3)	5 (3)
■Spatial resolution	6km	4km , 2km goal
■viewing angles (15 goal)	16	11
■SNR	200	200, 300 goal
■FTM	0.2	0.2

J. Costeraste – C. Le Naour – M-J. Lefèvre *(POLDER 3 on PARASOL)*

PHASE 0 MAIN DRIVERS

- **Enhancements w/c POLDER**

Reduction of straylight

Larger spectral range and better spatial resolution

But cheap, small, light instrument demanding small ressources

Study with 2 phases :

1/ Study of différent concepts based on mirrors, field scanning, linear detectors, splitted field, splitted spectral range….

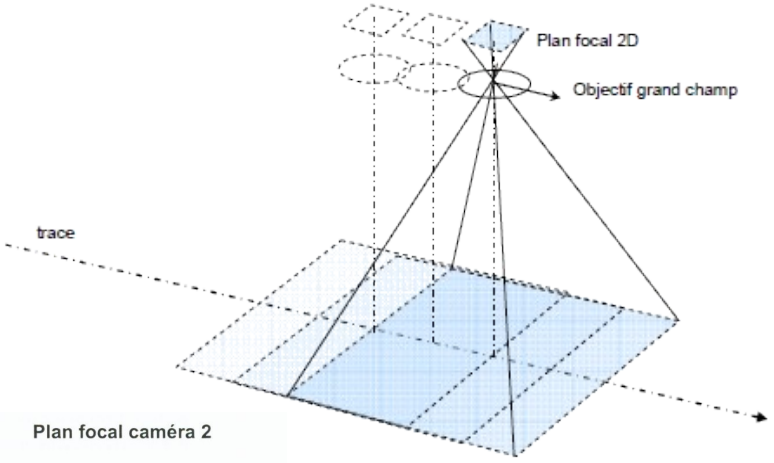
► **trade-off and choice of one or two concepts**

2/ Use of mature detectors (CCD E2V, MCT SOFRADIR) combined with these 2 concepts to obtain the best resolution with low cost

► **instrument definition**

PHASE 0.1 RESULTS

Other concepts than 2D dioptrics lead to great geometric deformation, uncontrolled polarization, technological difficulties on mirrors, linear filters and detectors



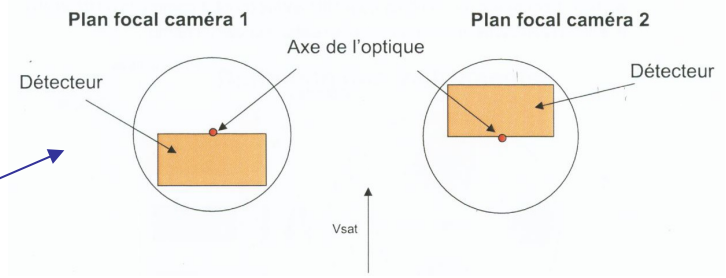
So …

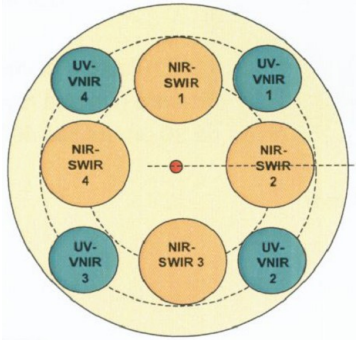
The concept based on dioptric optics, filters wheel, 2D detector array seems today the more efficient.

And it remained …

2 possibilities :

- Full field
- Splitted field by 2 by 4





PHASE 0.2 NEW DIRECTIONS

- To reduce costs and planning: uses of mature technologies including existing and qualified detectors:

  -UV-VIS : E2V detectors, backside-illumination with a broadband AR handling

  CCD 55-20 576 x 770 pxs, 22,5 µm

  ou CCD 47-20 (ASTRIUM) 1024 x 1024 pxs, 13 µm,

  - SWIR : SOFRADIR MCT detectors

  Saturne (ASTRIUM) 1000 x 256 pxs, 30 µm (it comes from PRISMA projet, but with limited disponibility) or Neptune (Thales Alenia Space) 500 x 256 pxs, 30 µm

  In both cases the number of pixels is limited at 256 in one direction (limitation of spatial sampling) and it doesn't exist AR detector processing (for better performance)

  -> but there are other suppliers in USA ...

- This choice drives the optical design, with two spectral domains separed : UV-VIS-NIR and SWIR with an overlap at 875 nm.
- 2 instruments architectures are maintained : full field and splitted fied (see next slide)

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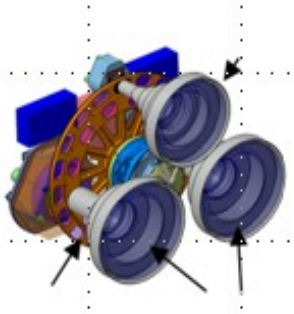
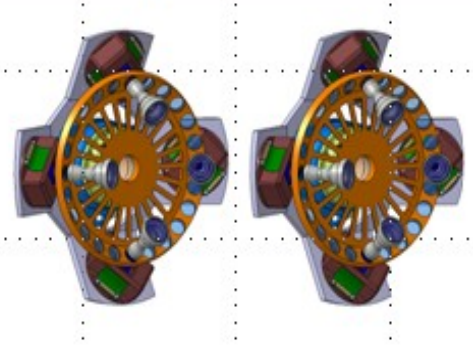
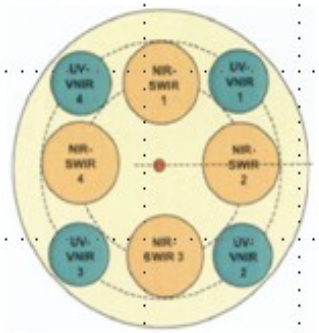
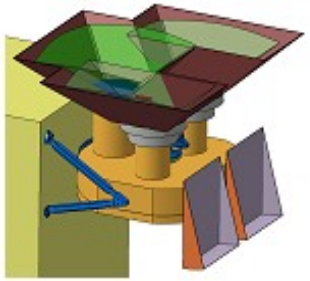
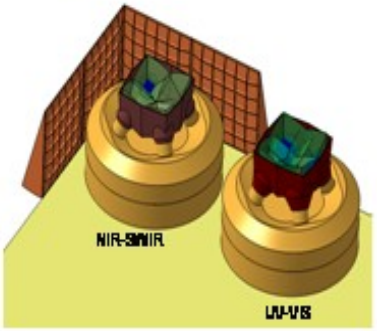
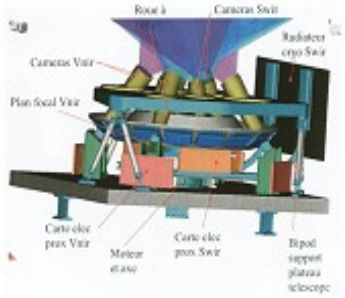
PHASE 0.2 RESULTS (1/2)

Perfos Goal / POLDER	Spatial résolution /2	Spatial résolution /4	
Concept	**Full field**	**Splitted field 1**	**Splitted field 2**
Architecture			
Architecture	UV-VIS: 1 optic, 1 detector (570x576) NIR-SWIR : 2 optics, 2 detectors (500 x 256) 1 filter wheel	UV-VIS: 4 optics, 4 detectors (576x576) NIR-SWIR : 4 optics, 4 detectors (256 x 256) 2 filter wheel	UV-VIS: 4 optics, 4 detectors (576x600) NIR-SWIR : 4 optics, 4 detectors (430 x 256) 1 filter wheel
Spatial resolution	UV- VIS : 3.5 to 6 km NIR- SWIR : 4 à 6.8 km	UV- VIS : 1.2 to 5.7 km NIR- SWIR : 2.64 to 12.8 km	UV- VIS : 1. to 6.2 km NIR- SWIR : 2.7 to 9 km
SNR	>200	>200	>200
FTM	>0.2	>0.2	>0.2

PHASE 0.2 RESULTS (2/2)

Perfos Goal / POLDER	Spatial résolution /2	Spatial résolution /4	
Budgets	**Full field**	**Splitted field 1**	**Splitted field 2**
			
Mass (without margin)	34 kg	45 kg	40 kg
Size (without baffle, electronic box ans radiators)	430 x 385 x 250 mm3	750 x 350 x 200 mm3	400 x 400 x 350 mm3
Power	53W	96 W	82 W
Data rate	4.42 Mbits/s	10 Mbits/s	10 Mbits/s (TBC)

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IN CONCLUSION …

- Innovative concepts with optical mirrors and / or scanning mirrors are potentially less stray light and are more compact but lead to very high sensitivity to geometric distortions increased polarization and points to demonstrate feasibility(mainly on the optics) -> Not selected at this stage

- The concepts with split fields do not greatly reduce stray light because of the size optical field. They lead to a higher spatial sampling but he is not homogeneous. The need for resources is more important and they generate a deterioration in spectral registration spectral and polarization

- The POLDER / PARASOL concept with 4 km/VIS, 4km/SWIR and 8 km/UV spatial sampling seems to be the best compromise in terms of size, technological maturity, performances and cost. It allows a wide spectral range with three optical heads, three "on-the-shelf" sensors and a single filter wheel.

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… AND RECOMMENDATIONS

- **However, some technical points, must be clarified:**
  - **The combination of optics and interfaces**
  - **The anti-reflection treatment of the optics and detector**

- An **optimization of these elements must now be treated as a priority. Is a trade-off between:**
  - **Stray light**
  - **Sensitivity to polarization**
  - **The spectral range over which the radiometric performance is required**
  - **The complexity of the optical system and its cost**

  -> <u>but CNES has the Polder experience</u>

- **No calibration is required on board. Based on the experience CNES POLDER is confident of the ability to find natural sites for calibration in UV and SWIR**

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The 3MI mission

for operational monitoring of aerosols from EPS-SG

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EPS-SG Users Consultation Workshop
Eumetsat, Darmstadt – 29-30 September 2011

Requirements for operational monitoring of aerosols

- Climate record : One of the **E**ssential **C**limate **V**ariable (GCOS, Climate Change Initiative / ESA)
  → global coverage, continuity
  → accuracy for trends detection and radiation budget
- Meteorological application
  → near real time
- Air quality monitoring and forecasting
  → need detailed aerosol properties for assimilation
- Extreme events – security (dust, volcanoes, fires)
  → near real time and details size/composition/load
- Policy control : what are the anthropogenic emissions ?
  → integration within models and links to chemistry

Requirements for operational monitoring of aerosols

GCOS requirements :

Aerosol optical depth	goal	threshold
accuracy	0.01	0.02
stability	0.005 / decade	N/A
resolution	1 km / daily	10 km / weekly

Other aerosol properties to supplement AOD

e.g. single scattering albedo

accuracy 0.02

stability 0.015 / decade

The required level of accuracy is not only depending on calibration – It can not be met without a detailed retrieval of physical properties.

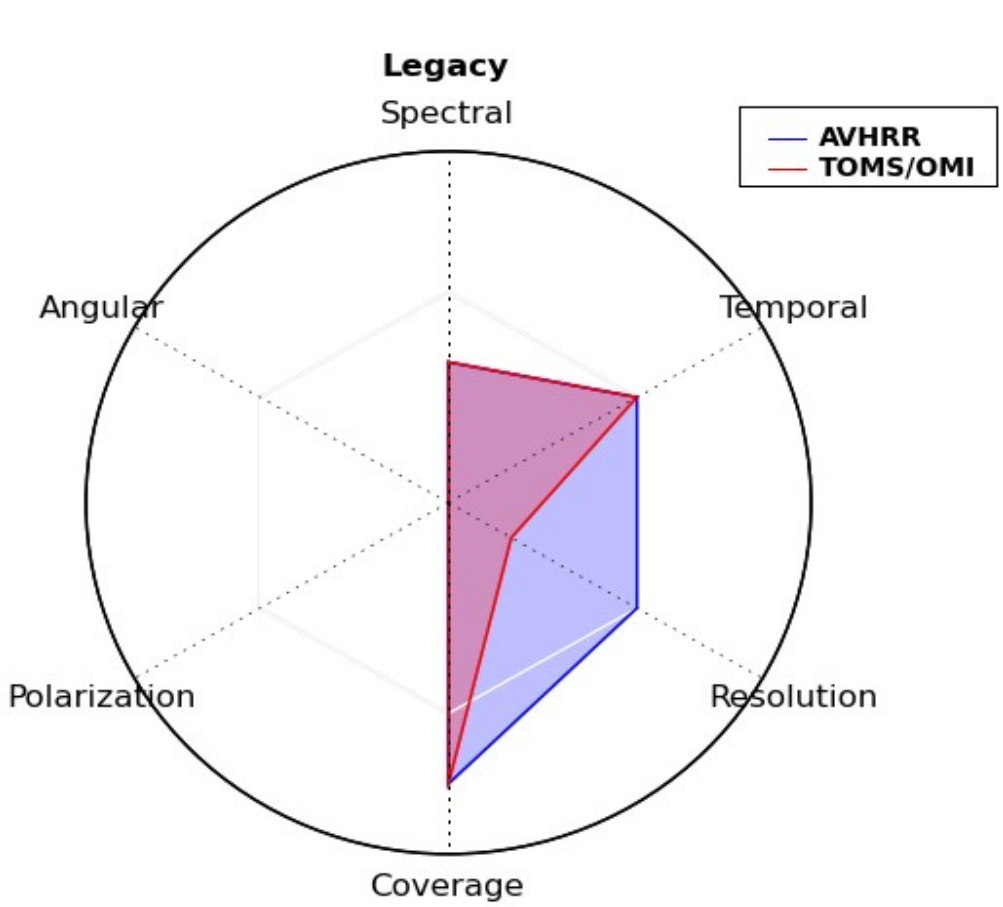
The 3MI mission for operational monitoring of aerosols from EPS-SG

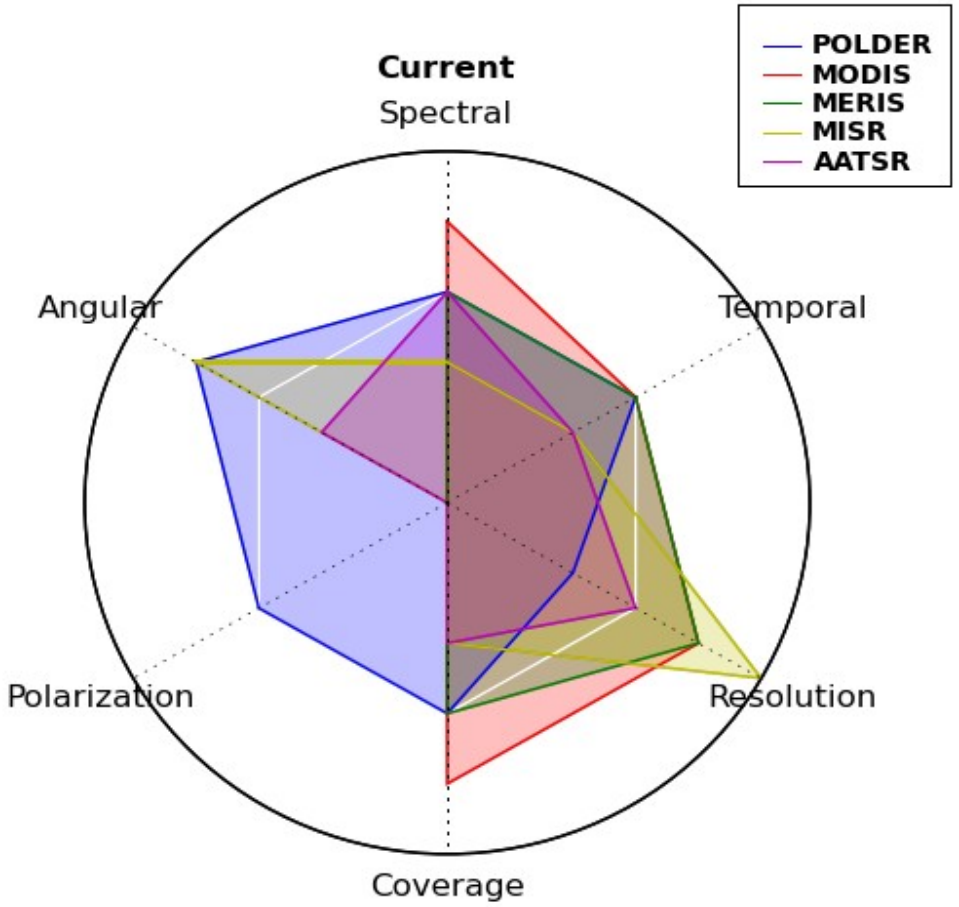
Rationale for a dedicated aerosol sensor

Of all existing or planed sensors only 3MI can provide the required details and accuracy of aerosol properties globally

- global coverage : over **ocean**, **land** and above **clouds**
- **detailed microphysics** for AQ and speciation :
  - **fine** vs **coarse** mode ↔ size distribution
  - **spherical** vs **non spherical**
- physical properties (refractive index → **absorption**) for accurate **radiative forcing calculation** in all sky conditions
- vertical distribution

Sensor capabilities drive aerosol observation skills





We can quantify sensor skills along 6 dimensions contributing to the total information content

Ideal instrument should cover all dimensions

The 3MI mission
for operational monitoring
of aerosols from EPS-SG

Why polarization ? Why multiangle ?

- The angular pattern of polarization is a distinctive “fingerprint” of aerosols.
- Multiangle observations are a powerful constraint on surface BRDF and BPDF
- Multiangle measurements (as opposed to single view) allow to observe, quantify and understand uncertainties
- Polarization is a relative measure, which gives advantage in calibration
- POLDER, thanks to multidirectional polarization, proves powerful for aerosol characterization from space, over ocean and land.

Extending our observation capabilities
SCIENCE RATIONALE

Significant uncertainties in aerosols (and clouds) remote sensing remain due to limited constraints we can impose on atmosphere models, not because of calibration accuracy.

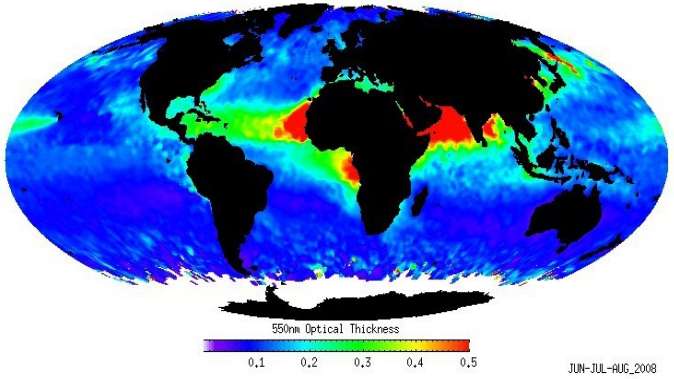
→ **conventional spectral imagers will not allow further progress in observation of aerosols/cloud properties**

At the same time, great progresses have been made recently in methodological development and new generation algorithms are now available to fully take advantage of more constraining observations (*Khokanovsky et al, 2010 - Dubovik et al*, 2011 – *Hasekamp et al*, 2011)

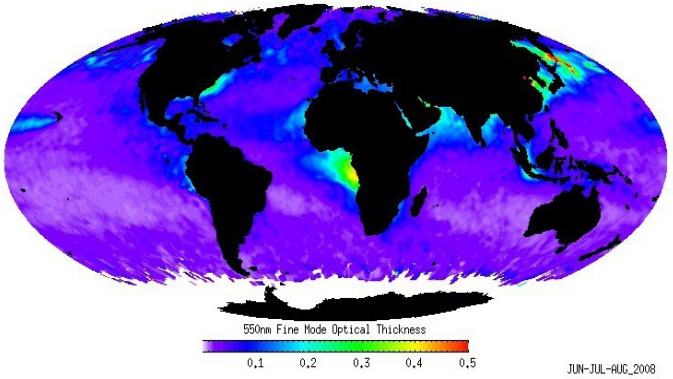
→ **growing consensus (APS reflight report, CCI meetings) that Multiangle, Multispectral and Multipolarisation (3M) observations provide the required breakthrough in aerosol observation and open new perspectives**

What 3M observations can provide
Example products from POLDER

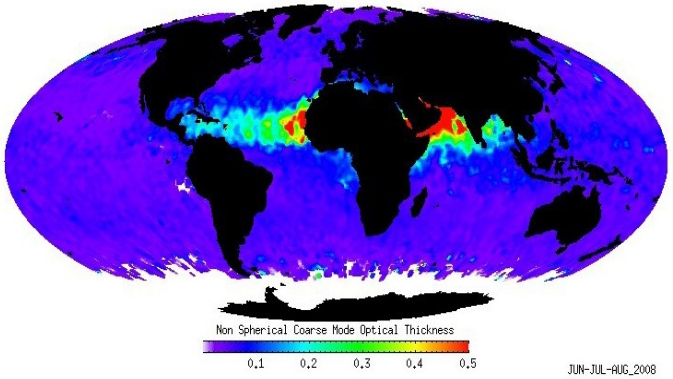
Total Aerosol Optical Depth (AOD) at 550 nm



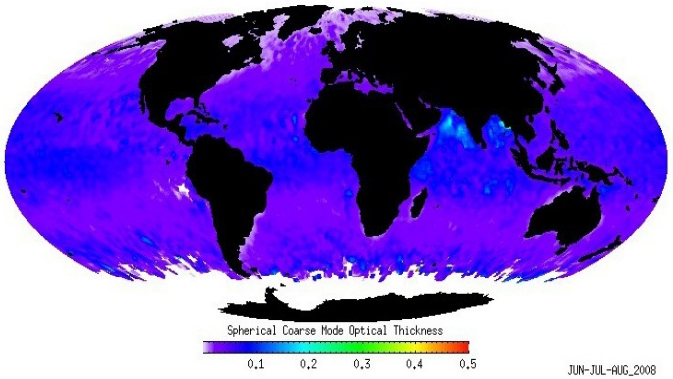
Fine Mode AOD (resulting from particles within the accumulation mode)



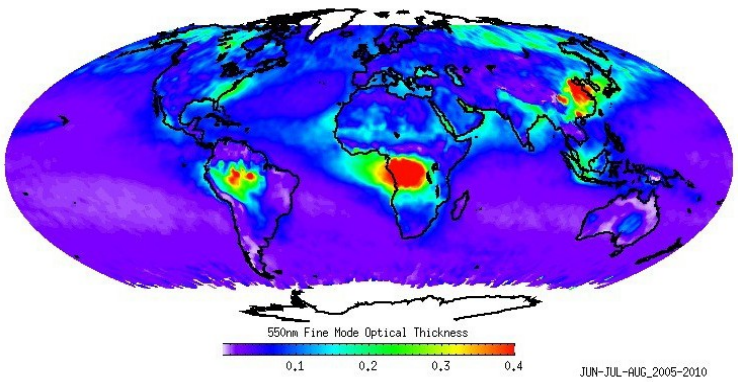
AOD resulting from non-spherical particles within the coarse mode



AOD resulting from spherical particles within the coarse mode



5-Year Global Seasonal Fine Mode Aerosol Optical Depth



2005 Anomalies

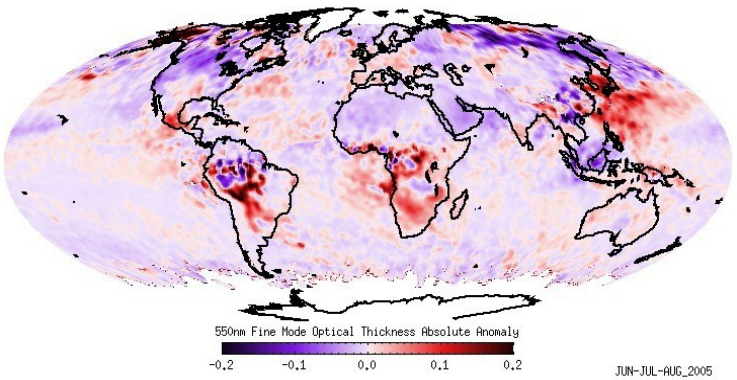
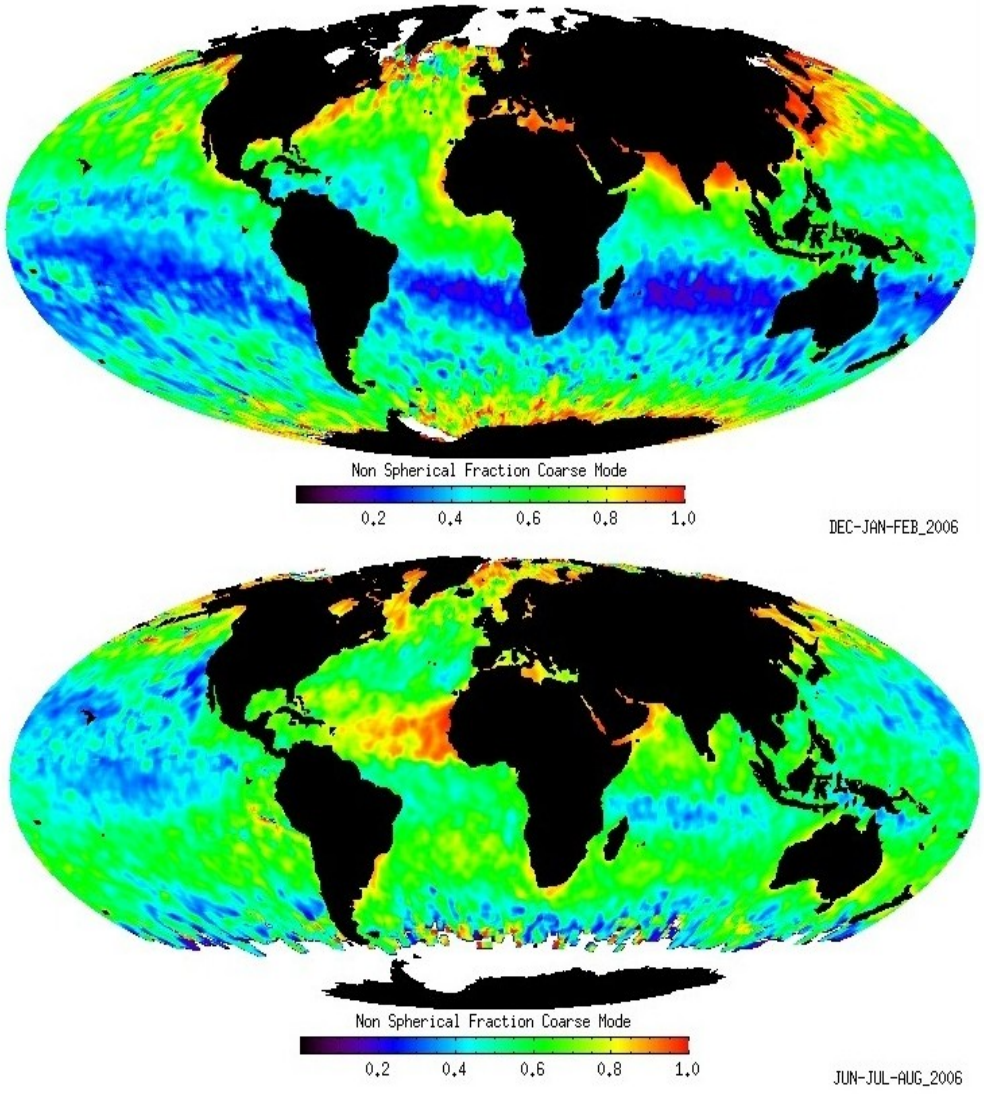


Image Credits : ICARE Data and Services Center

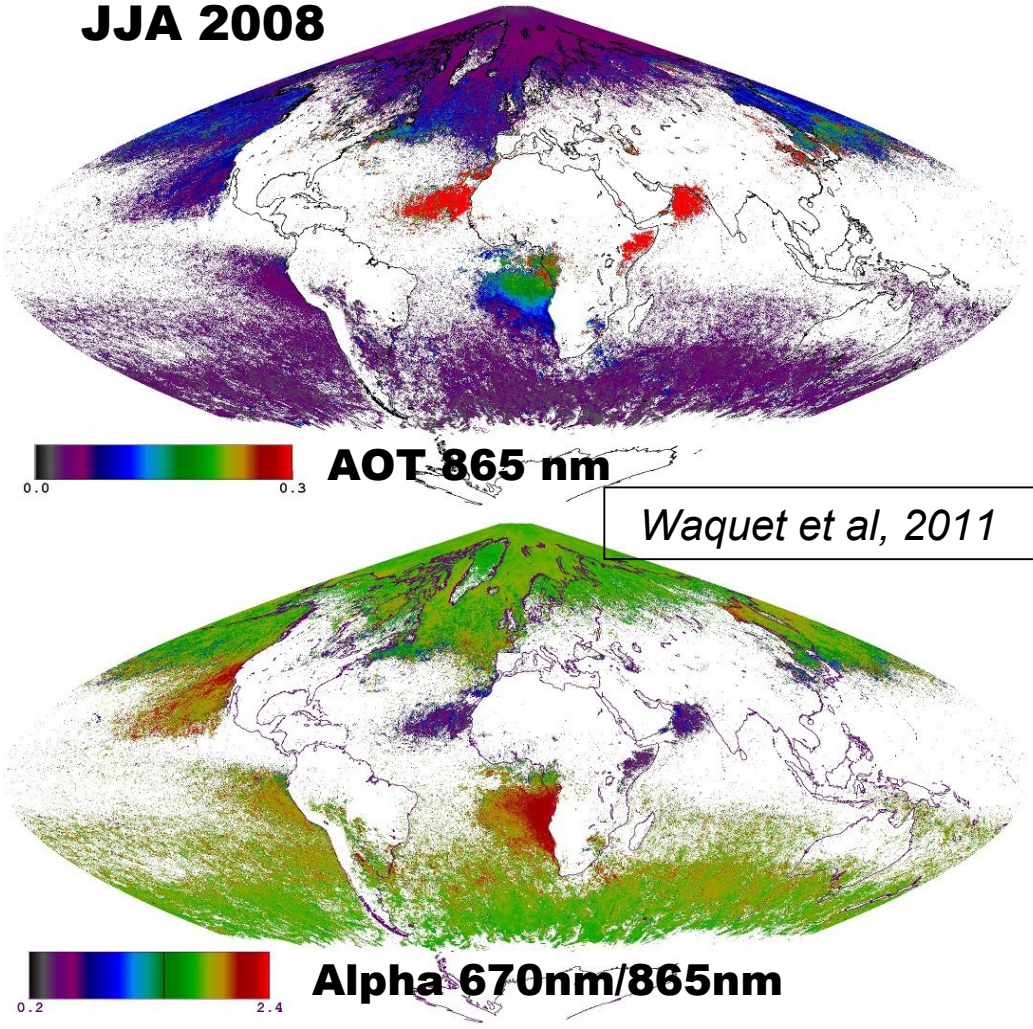
The 3MI mission
for operational monitoring of aerosols from EPS-SG

What 3M observations can provide
Example products from POLDER

Non spherical fraction of coarse mode



Aerosols above clouds



3MI : Lessons learned from POLDER
SPECTRAL COVERAGE

The spectral coverage of POLDER is a clear limitation (for coarse particles over land esp.).

Extension of polarization capabilities to both SWIR and shorter wavelength (410 nm, 388 if possible) will enable better characterization of aerosol properties :

- **provide similar performance over land and ocean**
- **enhance retrieval of coarse mode**
- **improve retrieval of layer altitude**

- SWIR extension is critical and improves retrieval of all parameters including (somehow surprisingly) layer altitude and spectral absorption because coarse mode is much better constrained

- polarisation at shorter wavelength (388nm if possible, or 410 nm) is also critical for disentangling layer altitude and single scattering albedo, further constraining spectral variation of absorption

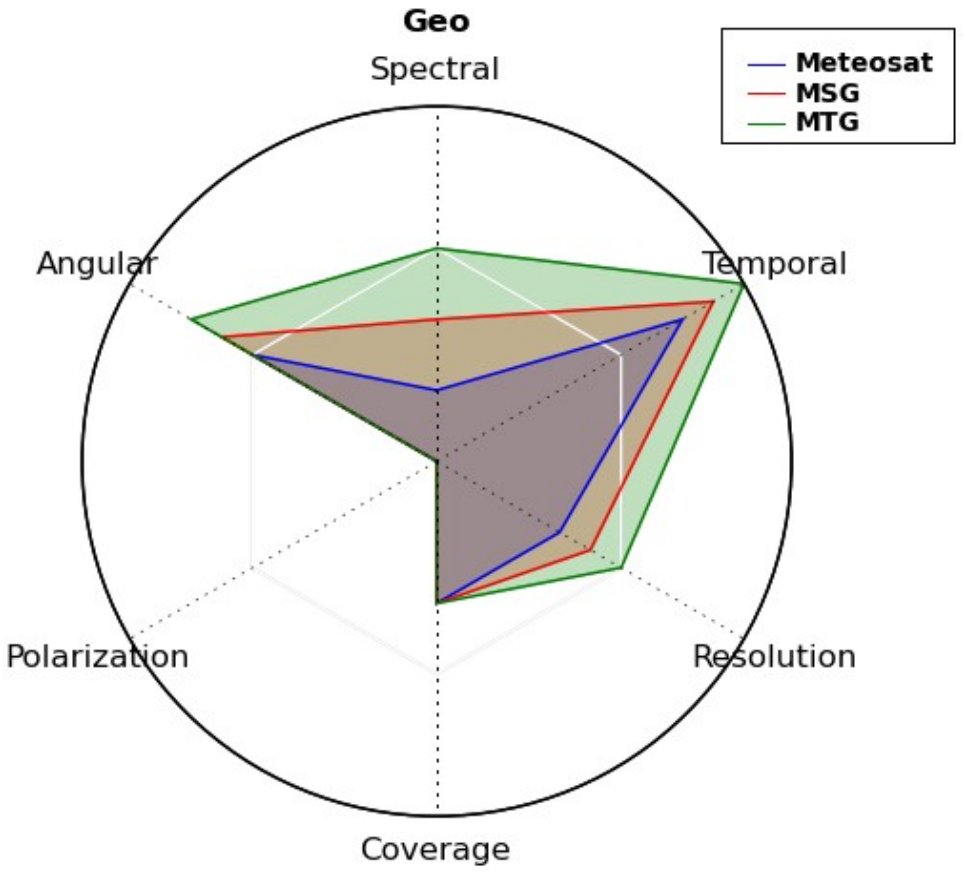
3MI : Lessons learned from POLDER
SPATIAL RESOLUTION

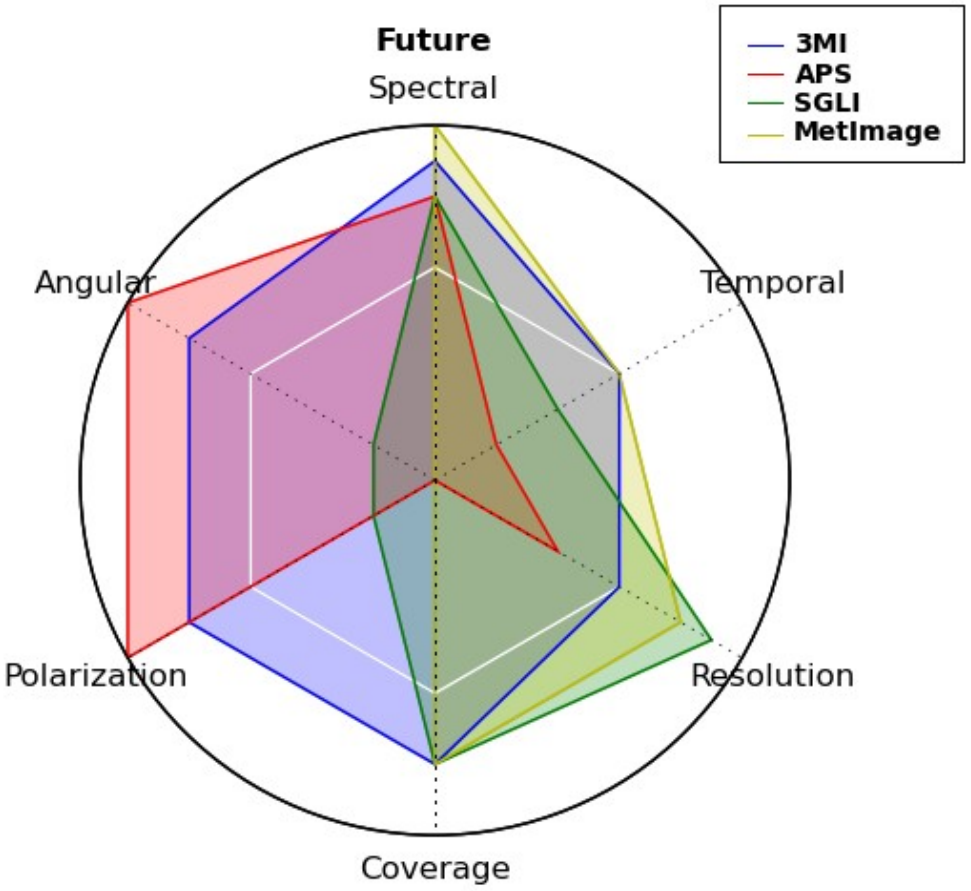
Rationale : Users requirements define the product resolution BUT the retrieval requirements define the instrument resolution and **must account for aerosols and clouds spatial variability scales** : 50% of all clear MODIS pixels are located 5km or closer to cloudy pixels (Marshak et al, 2010)

Aerosols and clouds do appear as a continuum, so higher resolution compared to POLDER would :
- maximize the probability of getting clear sky (non cloudy) pixels
- allow for understanding processes at the transition zone

Constraints :
1) SWIR and VIS resolution need to be consistent
2) High. res. in some VIS channels would be useful but synergy with MetImage will compensate
3) High. Res. is more demanding as it requires multiangle registration at layer altitude

Future sensors capabilities





Only 3MI will cover all dimensions of the information content space

Conventional spectral imager won't bring the necessary breakthrough

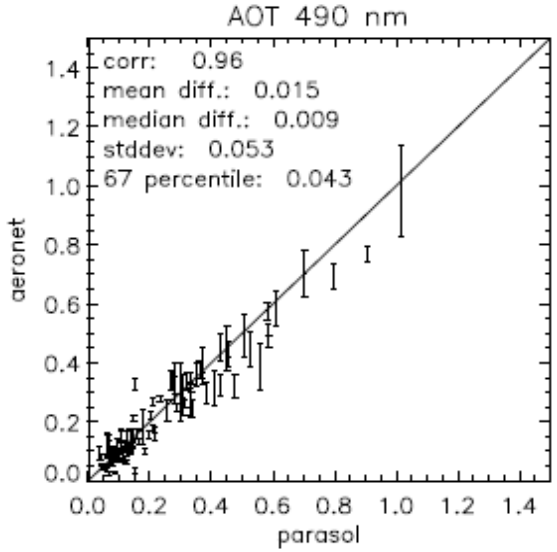
GEOs will remain essential to provide the temporal dimension

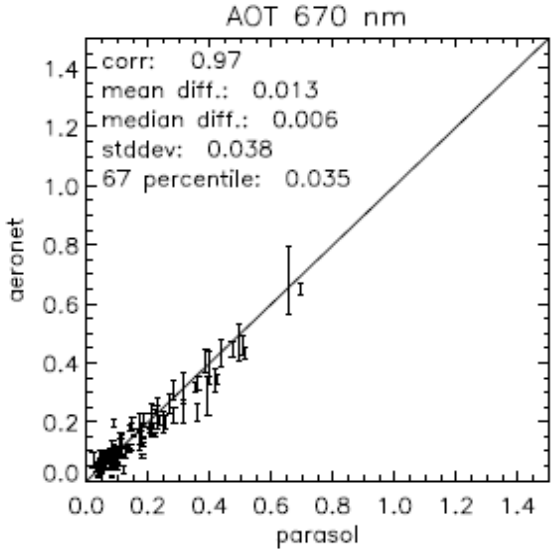
The 3MI mission
for operational monitoring
of aerosols from EPS-SG

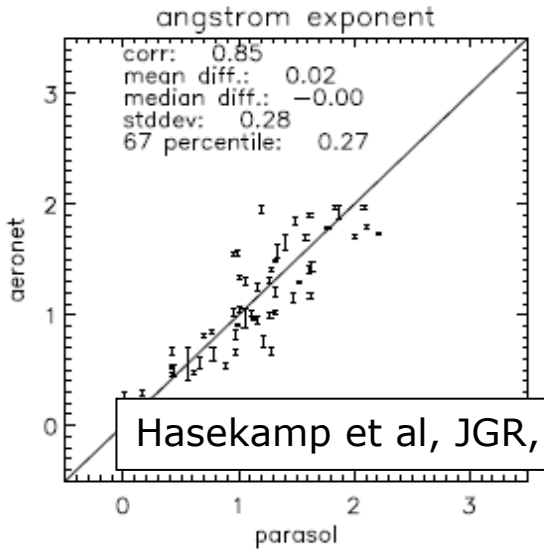
Advanced retrieval of aerosols from 3M information

- Recent algorithm development demonstrate that new aerosol information can be retrieved. **Multiple efforts are providing evidences** that enhanced 3M observations would allow for the retrieval of detailed aerosols properties (Waquet et al, 2010; Dubovik et al, 2011; Hasekamp et al, 2011)
- No restriction to prescribed aerosol models, but retrieval of aerosol physical properties: ***size distribution, refractive index and number of particles (AOT).***
- Simultaneous retrieval of surface properties
  → **retrievals are now possible over ALL types of land surfaces** and also above clouds !
  → forget distinctions between bright and dark target

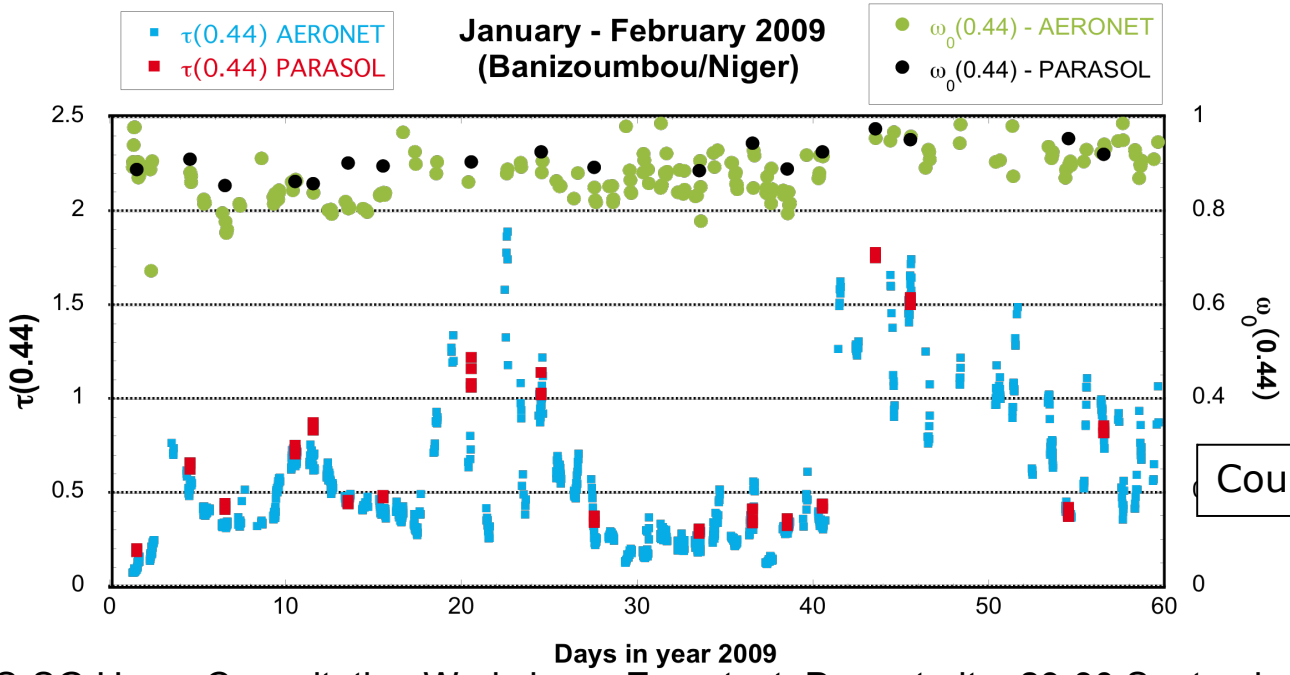
Advanced retrieval of aerosols from POLDER







Hasekamp et al, JGR, 2011



Courtesy O. Dubovik

The 3MI mission
for operational monitoring
of aerosols from EPS-SG

Retrieval Errors (POLDER obs.)

Fine mode

	0.1<τ<0.3	τ > 0.3	prior
reff (μm)	0.021	0.02	0.2
veff	0.071	0.052	0.5
mr	0.055	0.036	0.2
mi	0.018	0.013	0.02
AOT	0.036	0.044	-

Coarse mode

	0.1<τ<0.3	τ > 0.3	prior
reff (μm)	0.24	0.38	2.0
veff	0.30	0.39	0.5
mr	0.016	0.021	0.2
mi	0.02	0.02	0.02
AOT	0.05	0.058	-

An order of magnitude in retrieval accuracy can be achieved through new retrieval approaches using POLDER data

3MI observations will bring even higher accuracy

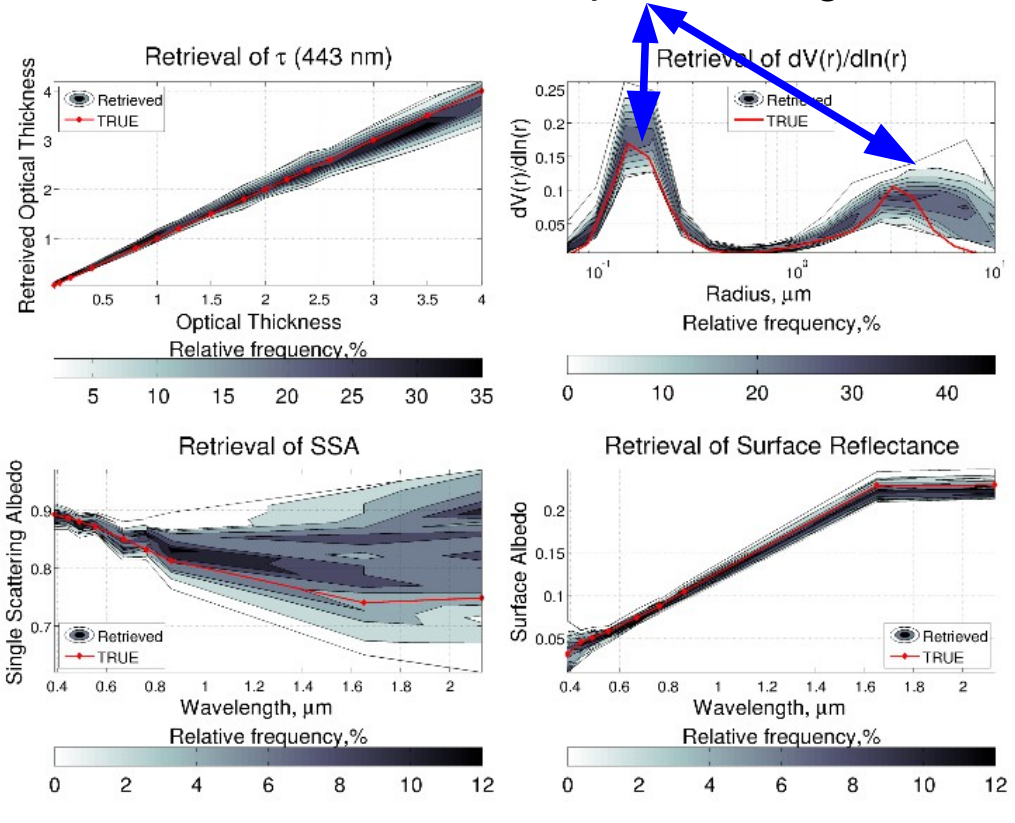
Hasekamp et al, JGR, 2011

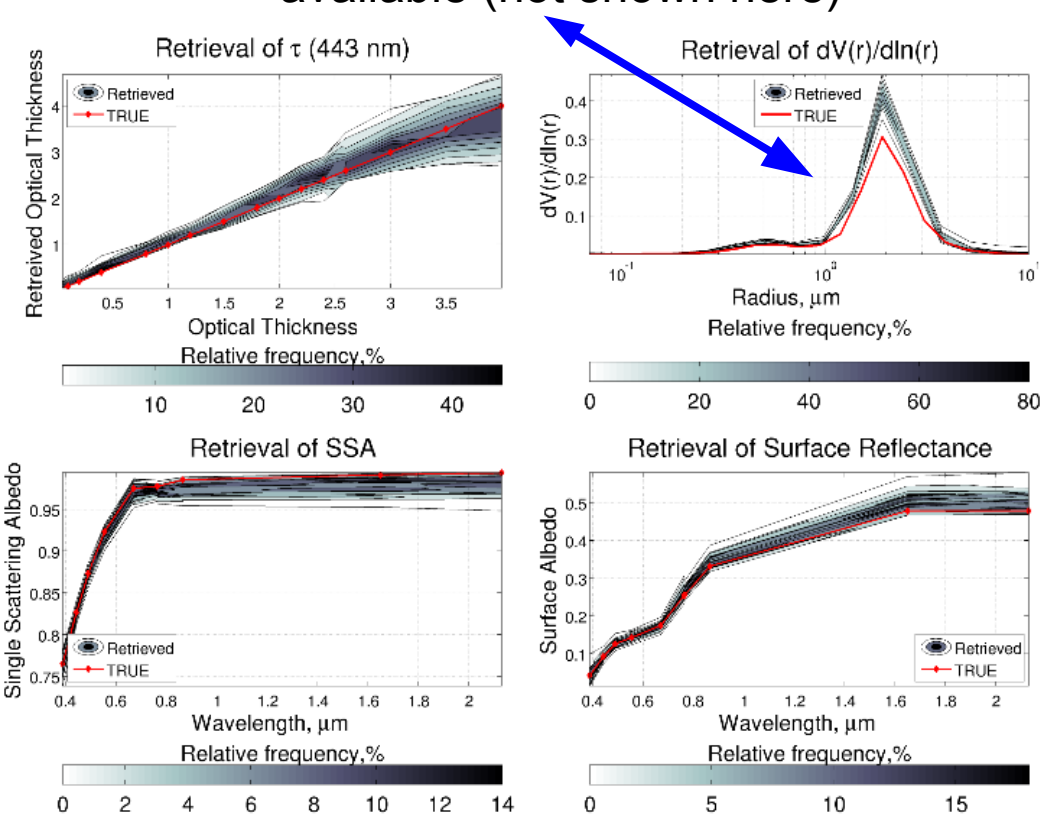
Advanced retrieval of aerosols

3MI performance analysis using synthetic obs.

Performances linked to spectral range available

Information on non sphericity also available (not shown here)





Biomass aerosols over vegetation

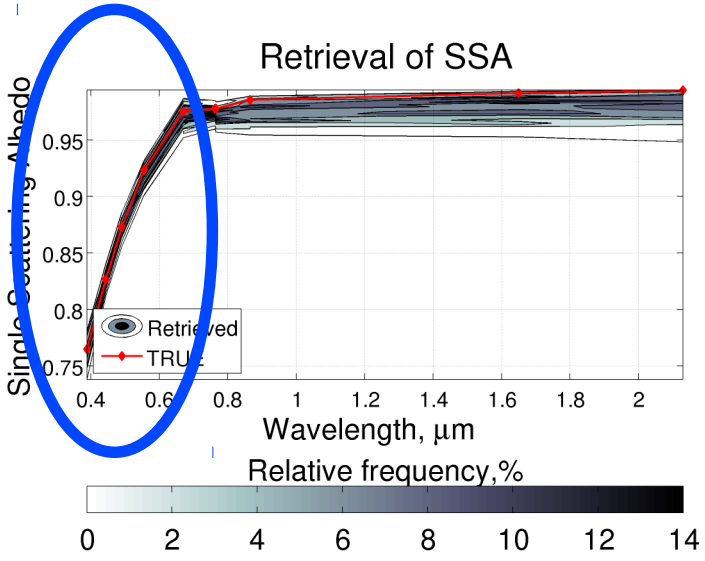
Dust aerosols over bright surface

Dubovik et al – LOA/CNES

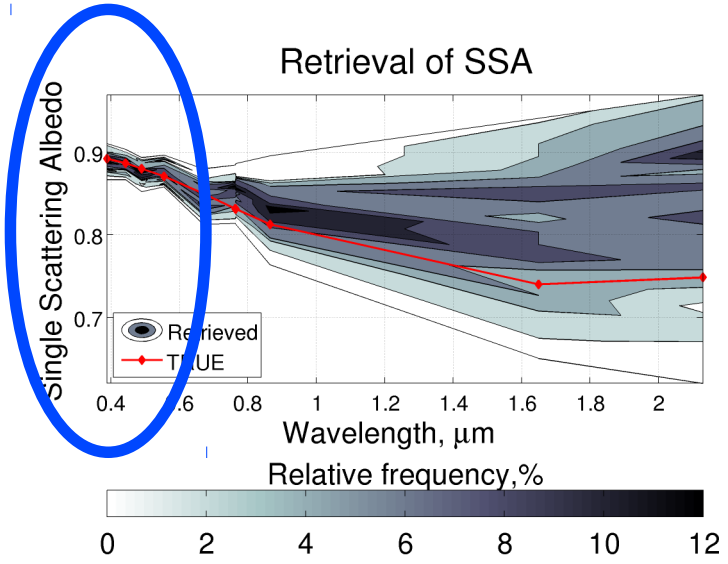
The 3MI mission
for operational monitoring
of aerosols from EPS-SG

Advanced retrieval of aerosols

3MI performance analysis using synthetic obs.



SSA retrievals for dust aerosols



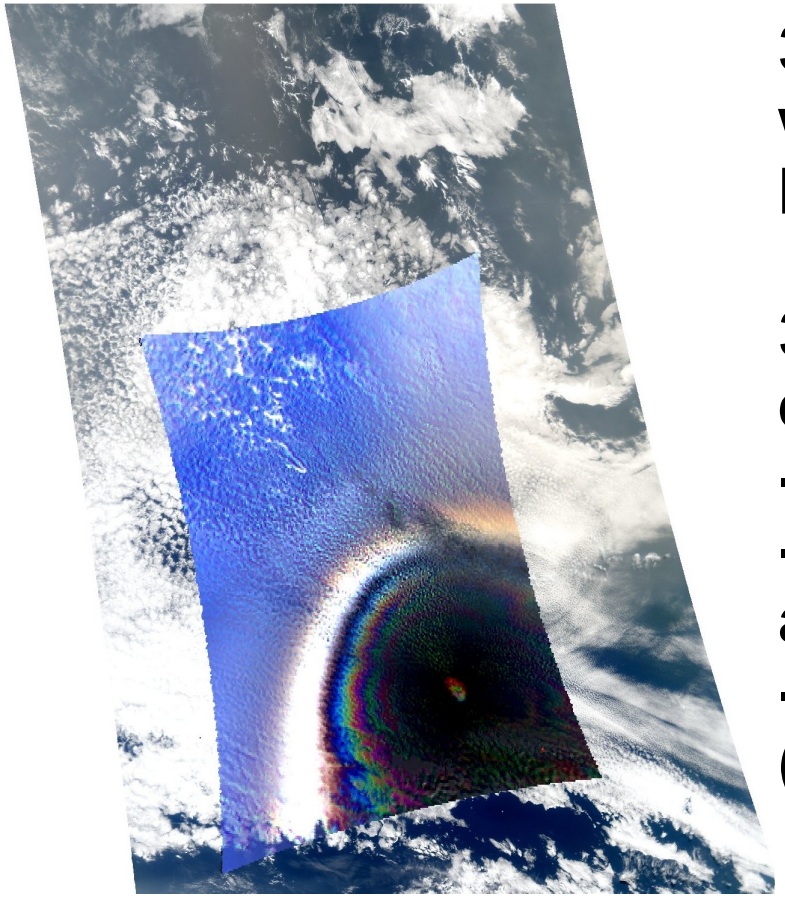
SSA retrievals for biomass aerosols

Spectral variation of SSA towards short wavelength (deep blue 410nm, or further down) is a critical information for aerosol speciation.

Dubovik et al – LOA/CNES

POLDER/MODIS prefiguring 3MI/MetImage

In addition to aerosol monitoring, a number of studies from POLDER/MODIS prefigure the added value of 3MI on EPS-SG for clouds :
- cloud phase : Riedi et al, ACP, 2010, Zeng, 2011 (PhD)
- ice cloud microphysics : Zhang et al, ACP 2009
- liquid cloud microphysics : Bréon et Doutriaux-Boucher, IEEE TGRS 2005
- cloud vertical struct. from O2 A-Band : Ferlay et al, JAMC 2010



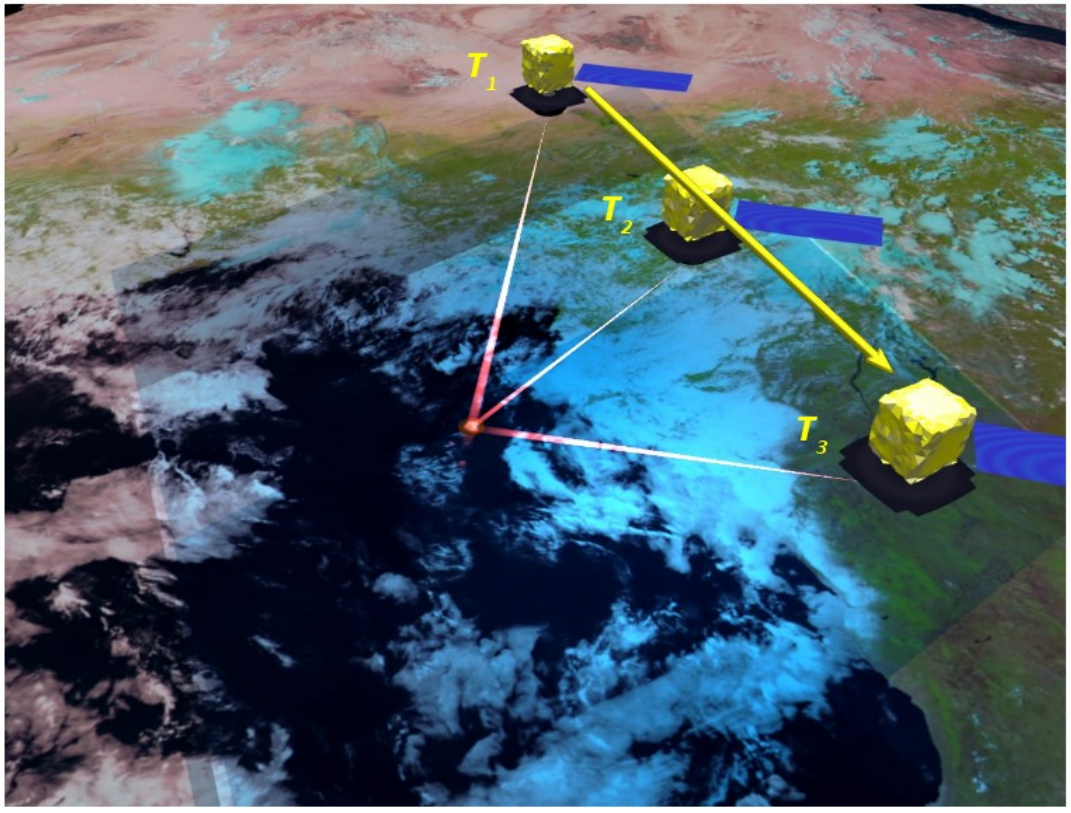
3MI will provide additional skills which will complement and strengthen MetImage cloud analysis.

3MI products will be instrumental in better describing and understanding :
- clouds/aerosols interactions,
- radiation budget, including effect of aerosols over clouds
- links between cloud microphysics (phase, size) and precipitations

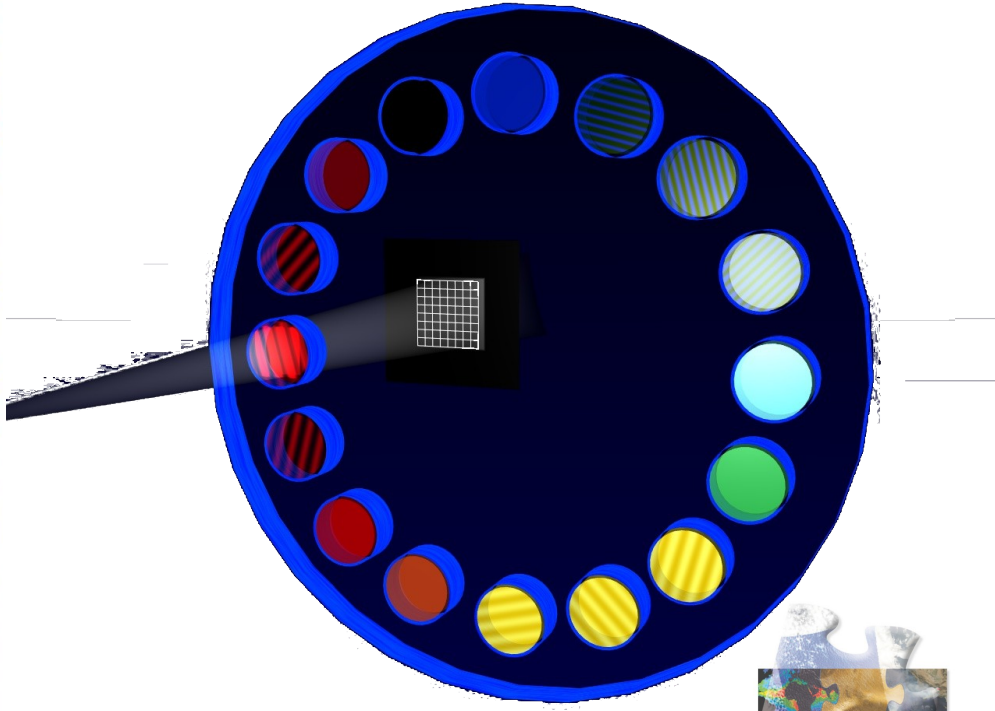
3MI implementation in a nutshell

Instrument design : No need to change the instrument concept
That's the beauty of it !!! 3MI will remain a small and simple instrument which reliability has been proven over the course of 3 POLDER missions

Wide field of view optics for multiangle imaging as satellite moves



Rotating filter wheel for spectral and polarization acquisition



The 3MI mission
for operational monitoring of aerosols from EPS-SG

3MI implementation in a nutshell

Instrument requirements

- large field of view of 114°
- 10 to 14 different angles per ground pixel
- 13 optical channels – 8 of them in 3 polarization → 29 channels
- Polarization sensitivity > 96% for polarized channels
- Polarization sensitivity < 5% for non polarized channels
- Bandwidth from 10 nm to 40 nm
- co-registration of ~7 sec max between all channels for one direction
- ground resolution between 2km (goal) and 6km (threshold) – current status being 4km for all channels

Mission band	Wavelength [nm]	FWHM [nm]	Polar.
3MI-1	354	10	Y
3MI-2	388 / 410	20	Y
3MI-3	443	20	Y
3MI-4	490	20	Y
3MI-5	555	20	N (T)
3MI-6	670	20	Y
3MI-7	763	10	N
3MI-8	765	40	N
3MI-9	865	40	Y
3MI-9a	910	20	N
3MI-10	1370	40	Y (G)
3MI-11	1650	40	Y
3MI-12	2150	40	Y

3MI synergy on EPS-SG

Synergy in retrieval:

- 3MI multidirectionality and polarization improves METimage single view detection of cirrus, aerosols over clouds, and volcanic ash plumes
- 3MI aerosol information improves light path correction of trace gas retrievals from UVNS and IASI-NG
- 3MI multidirectionality improves radiant energy retrieval from RER
- 3MI O2 A-band optical cloud height is complementary to METimage infrared cloud height
- 3MI cloud masking will be improved with METimage high resolution

Synergy in calibration:

- Radiometric and spectral calibration of 3MI, UVNS and METimage
- 3MI polarization information improves correction of polarization effects in UVNS and METimage

SUMMARY

- Need for aerosols operational monitoring is here and clearly defined
- Of all existing or planed sensors only 3MI can provide the required details and accuracy of aerosol properties globally
- Retrieval methodology is available
- 3MI relies on proven, reliable and simple concept
- Synergistic potential is high within EPS-SG

Open questions …

3MI implementation resulted from a trade-off cost/capability → some specifications could be revisited in the framework of a dedicated polarimeter for PACE :

- Spectral bands can be easily adjusted within the current range (400 nm → 2150 nm)
- Depending on (simple) data rate consideration :
  - Spatial resolution (availability of SWIR detectors)
  - Angular sampling resolution → increase frame rate
- Depending on more demanding developments :
  - Polarization measurements : currently filters – other possibilities ?

Open questions …

3MI implementation resulted from a trade-off cost/capability → some specifications could be revisited in the framework of a dedicated polarimeter for PACE

But it will eventually depend on our answers to the followings :

Why do we need a polarimeter for PACE ?
What are the requirements ?
Can a 3MI type instrument fulfill those ?
If not what would it take to make 3MI “PACE compatible” ?