Information content analysis of the future Multi-viewing, Multi-channel, Multi-polarisation Imager (3MI) measurements on cloud microphysics parameter

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ABSTRACT

The clouds feedback remains one of the major uncertainties in the climate prediction (IPCC, 2007). In order to reduce these uncertainties it is fundamental to accurately known their properties in order to represent correctly their role in global climate models and to understand their evolution in term of global distribution of physical properties.
Since several decades now, a number of different space borne instrument, with their specific observing characteristics, have been used to get this global vision.

The 3MI (Multiangle, Multichannel and Multipolarisation Imager) instrument developed by EUMETSAT, which is an extension of the POLDER/PARASOL instrument, will allow to measure the total and/or polarized light reflected by the Earth atmosphere system in several spectral bands (from UV to SWIR) and several geometries (from 14 to 16 angles).
The 3MI instrument should provide opportunities to observe the links between the cloud structures and the anisotropy of the reflected solar radiation into space and specifics algorithms will be developed in order to take advantages of the new capabilities of this instrument.

However, prior to this development, we need to understand, through a Shannon information content theory, the limits and advantages of these new instrument for retrieving liquid cloud properties, and especially the amount of information coming from the SWIR channels and how this information is spread out on clouds parameters.
Two pieces of information will be explored to diagnostic this new observing system, e.g. The posterior state vector covariance matrix as well as the total and partial degree of freedom in both measurement and state space.

INFORMATION CONTENT THEORY

■ Model : $y-y_0=K(x-x_0)+\epsilon$

y : measurement vector (length m)
x : state vector (length n)
K : weigthing function (m * n)
ε : errors vector

■ Hypothesis : Gaussian PDFs

Exemple : a priori state PDF

$P(x)=\frac{1}{(2\pi)^{n/2}|S_a|^{1/2}}.\exp\left(\frac{-1}{2}(x-x_a)^T S_a^{-1}(x-x_a)\right)$

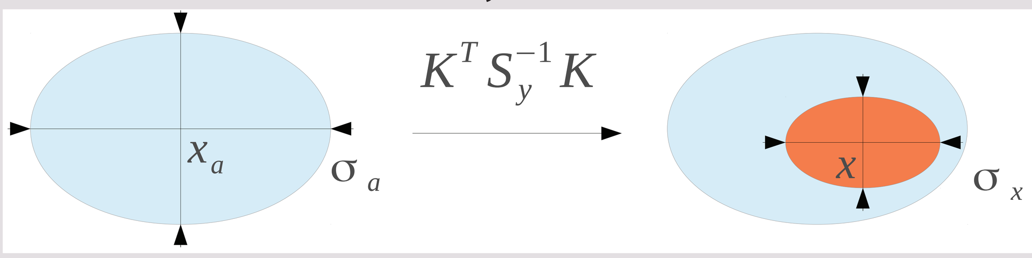
Sa : a priori variance-covariance matrix

‣ We can define the equivalent PDFs for measurements and a posteriori state with :
Sy : measurements and model variance-covariance matrix
Sx : a posteriori variance-covariance matrix

$S_x=(K^T S_y^{-1} K+S_a^{-1})^{-1}$

■ Information content and degrees of freedom :

The information content represents the a priori state volume reduction by the measurements.



Information content H :

$$H=\frac{1}{2}\ln(|S_x^{-1}S_a|)$$

Averaging Kernel Matrix :

$$A=(K^T S_y^{-1} K+S_a^{-1})^{-1} K^T S_y^{-1} K$$

Total degree of freedom (DOF) :

$$ds=E[(\hat{x}-x_a)^T S_a^{-1}(\hat{x}-x_a)]=Tr(A)$$

Represent the number of parameters wich can be retrieved.

Partial degree of freedom (DOFxi) :

$$ds_i=A_{ii}\,(0\leq ds_i\leq 1)$$

If ds_i>0,5 , the parameter xi can be retrieve

Selection order and channel decomposition :

We can classify the measurements by their information intake (H) on the state parameter. It is what we call the selection order hereinafter. To decompose the information content of each channel, we first select the channel which bring the most information. Then we take off the piece of information of this channel and select the second chanel and so on.

STUDIED CASES

Homogeneous plane parallel clouds :

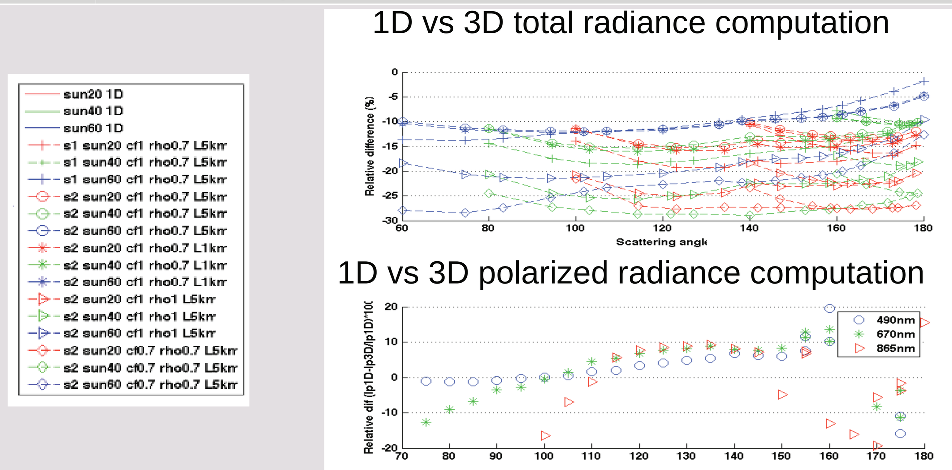
$$\tau=(2;10),\ r_{eff}=10\,\mu m,\ v_{eff}=0{,}02$$

Prior and posterior state vector :

$$x=\begin{pmatrix}\tau\\ r_{eff}\\ v_{eff}\end{pmatrix}\quad x_a=\begin{pmatrix}10\\ 10\\ 0{,}1\end{pmatrix}\quad S_a=\begin{pmatrix}10^2 & 0 & 0\\ 0 & 10^2 & 0\\ 0 & 0 & 0{,}1^2\end{pmatrix}$$

Measurements end associated errors (B. Fougnie, 2007)

errors \ y	$I_{670\,nm}$	$Lp_{670\,nm}$	$I_{2{,}2\mu m}$	$Lp_{2{,}2\mu m}$
Calibration noise	2 %	2 %	2 %	2 %
White noise	0,005 W/m2/sr	0,005 W/m2/sr	0,0025 W/m2/sr	0,0025 W/m2/sr
3D effects	Lp : 10 % for $130°<\theta_v<145°$ else 5 % I : 10 % everywhere			



2 cases :

mono-angular measurements

$$y=\begin{pmatrix}I_{670nm}(\theta_v,\varphi_v)\\ I_{2{,}2um}(\theta_v,\varphi_v)\\ Lp_{670nm}(\theta_v,\varphi_v)\\ Lp_{2{,}2um}(\theta_v,\varphi_v)\end{pmatrix}$$

with : $Lp=\sqrt{(U^2+V^2)}$

multi-angular measurements

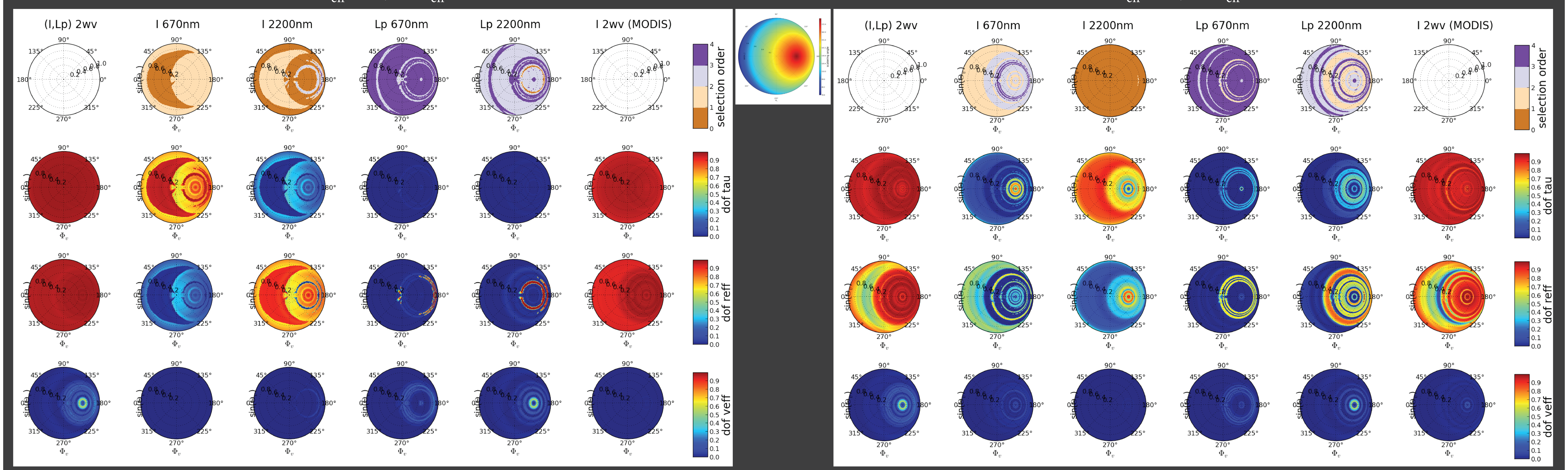
$$y=\begin{pmatrix}I_{670nm}(\theta_v(i),\varphi_v(i))\\ I_{2{,}2um}(\theta_v(i),\varphi_v(i))\\ Lp_{670nm}(\theta_v(i),\varphi_v(i))\\ Lp_{2{,}2um}(\theta_v(i),\varphi_v(i))\\ .\\ .\\ .\end{pmatrix}$$

with : i=1 to 14

MONO-ANGULAR MEASUREMENTS INFORMATION CONTENT ANALYSIS

Cloud studied : $\tau=10, r_{eff}=10\mu m, v_{eff}=0{,}02$ with sza=30°

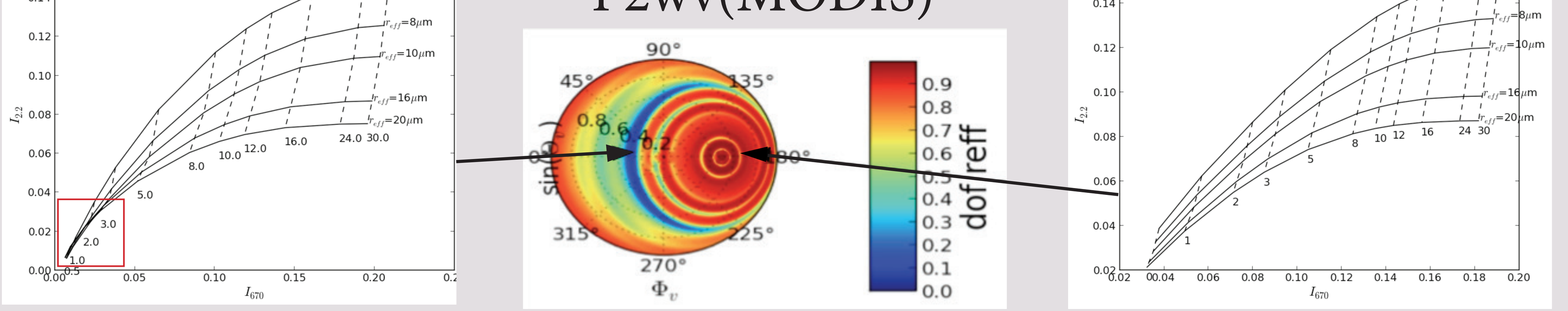
Cloud studied : $\tau=2, r_{eff}=10\mu m, v_{eff}=0{,}02$ with sza=30°



■ The τ and reff retrieval should be possible.
■ The veff retrieval is not.
■ As expected, information on τ comes from I_{670nm} and information on r_{eff} comes from $I_{2{,}2um}$ (bi-spectral method).

■ r_{eff} is no longer retrievable behind the bows where the radiances are weak.
■ Information of total radiances is not sufficient anymore.
■ Polarized radiances complete total radiances but not sufficiently for some geometries.

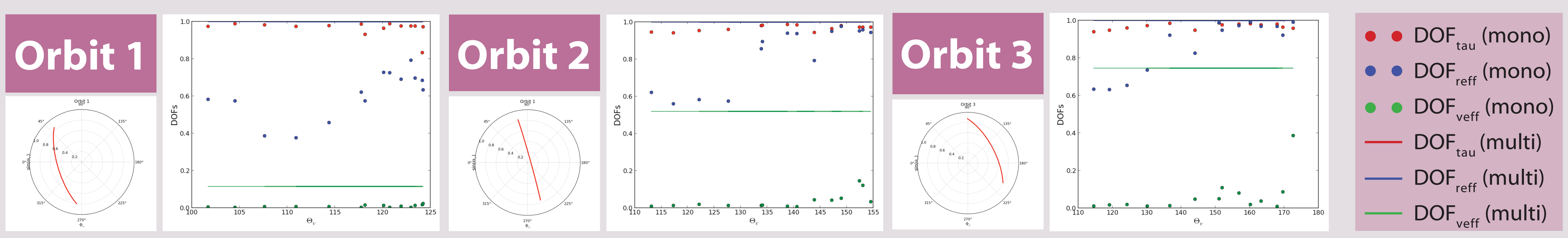
τ=10,reff=10μm,veff=0,02
I 2wv(MODIS)



In the "blue zone" and for weak optical thicknesses, the effective radius sensibility is weaker than in the "red zone" (The curves are tightened).
It is why the degree of freedom is weaker.

MULTI-ANGULAR MEASUREMENTS INFORMATION CONTENT ANALYSIS

■ We performed this study for three different orbits (14 angles for each orbit)



■ The τ and r_{eff} retrievals are feasable for the three orbits. The multi-angular measurements bring more information on reff than mono-angular measurements
■ Multi-angularmeasurements allow also the v_{eff} retrieval when the satellite aims for the bows.

CONCLUSION

■ Conclusion

‣ r_{eff} is not retreavable with the bi-spectal method for several view angles when τ is weak.
‣ Multi-angular measurements bring more information on the particle size distribution.

■ Prospects

‣ We could do the same information content study for inhomogeneous clouds. We will begin by the study of vertically inhomogeneous clouds. In this case, we will study the information content of a effective radius profile from 3MI measurements.

■ Bibliography

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