CENTRE NATIONAL D'ÉTUDES SPATIALES

Bidirectional Reflectance Distribution Function (BRDF) of Deep Convective Clouds (DCC) Derived from PARASOL Measurements and Compared to Radiative Transfer Computation and Model

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Dave Doelling (NASA-Langley, Virginia)

Audrey Crespin, Bruno Lafrance (CS-SI, France)

Laurent Labonnote (LOA, France)

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DCC BRDF :

Space Measurements and Modeling

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Summary

- Introduction
- The PARASOL instrument
- Methodology to derive the observed BRDF
- BRDF model derived from PARASOL measurements
- Modeling of DCC
- Analysis on the principal plane – comparison Measurements // Computations
- Sensitivity analysis
- Conclusion

Introduction

- DCC are used for many years for calibration purposes
  - not only trending, but also cross-calibration, interband, field-of-view
  - GSICS reference calibration methods
  - that's my powerful white diffuser (see Fougnie et al., IEEE TGARS, 2009)

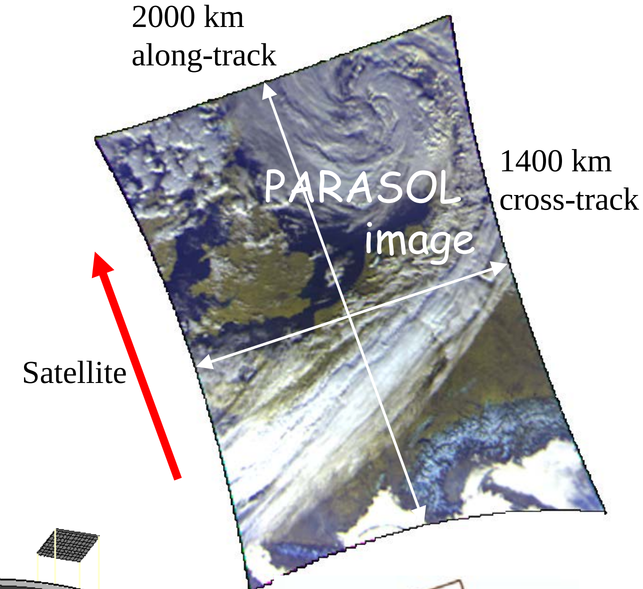
- PARASOL is an instrument allowing a bidirectional characterization of any targets of the Earth-surface system
  - because DCC were used for PARASOL calibration purposes, an archive of CC observations was build and is available (8-years)
  - it can be used to characterized BRDF of DCC

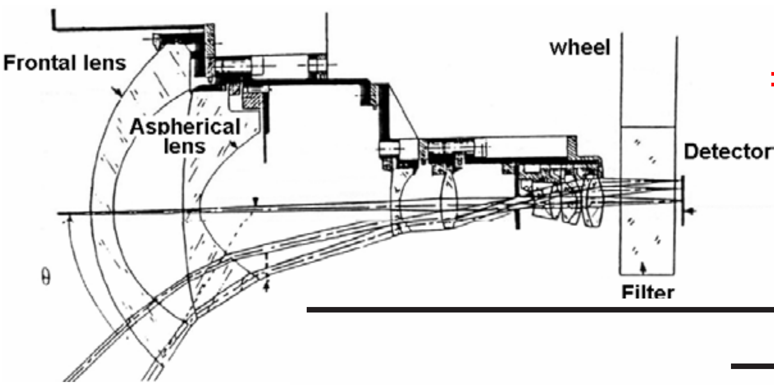
- Model and radiative transfer computations are also possible
  - also developed for calibration purposes
  - can be used to derive BRDF and compare with measurements

The PARASOL Instrument

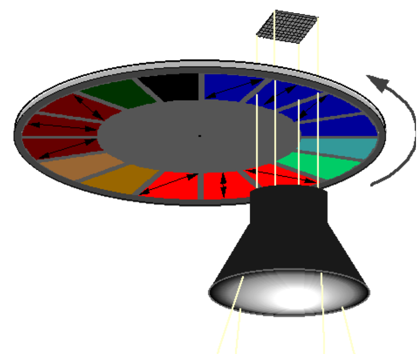
POLDER instrument onboard PARASOL : Dec 04 to Dec 13

- **Camera = wide fov optic + CCD matrix**
  - 2D detector array 274x242 pixels
  - fov : ±50° incident angle (i.e. ±60° viewing angle)
  - Large swath: 2200 km for POLDER, 1400 km for Parasol
  - Moderate resolution : about 6 km
- **Multidirectionality : bidirectional + wide fov**
- **Multispectral and multi-polarisation**





⇒ No on-board calibration device

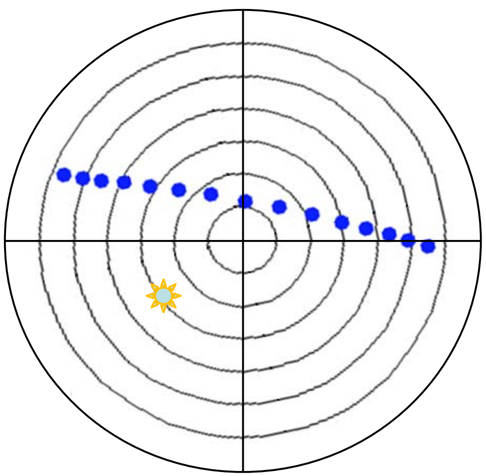


	Spectral Band								
	443	490	565	670	763	765	865	910	1020
Central wavelength (nm)	443.5	490.9	563.8	669.9	762.9	762.7	863.7	907.1	1019.6
Bandwidth (nm)	13.4	16.3	15.4	15.1	10.9	38.1	33.7	21.1	17.1
Polarization	—	yes	—	yes	—	—	yes	—	—
Saturation level (reflectance)	1.28	0.99	1.06	1.01	1.04	0.96	1.00	0.98	1.70

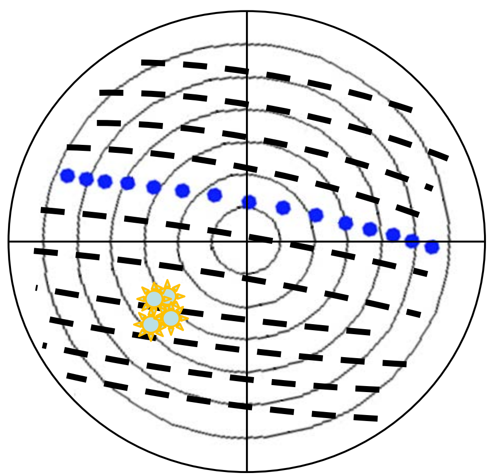
Geometrical sampling

- **Access to bidirectional geometries**
  - **Blue/green = viewing directions**
  - **Yellow = solar directions**

VZA,SZA in [0-70°], step 10°

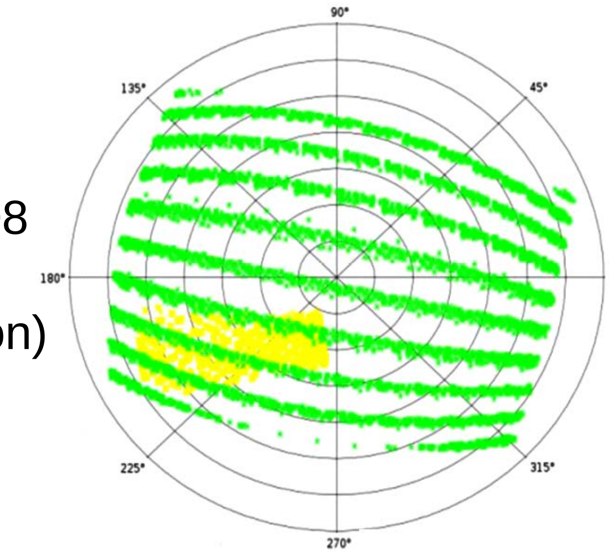


1 daily overpass =
16 viewing angles
1 solar geometry

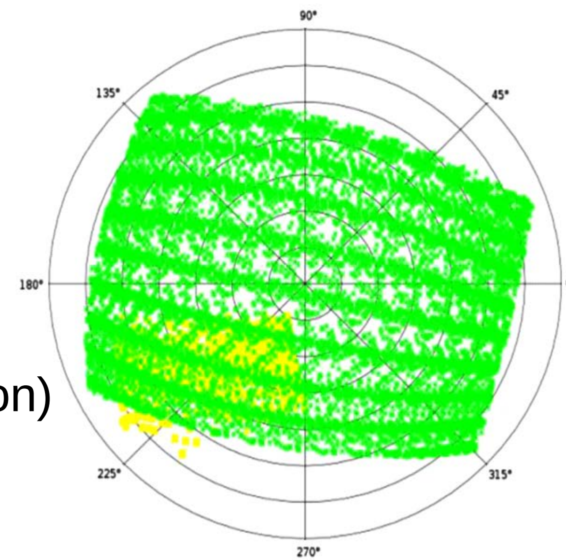


1 cycle = 16 tracks (days)
16x16 viewing angles
16 solar geometries

2005-2008
Archive
(one lat/lon)



2005-2012
Archive
(orbital drift
+ multiple lat/lon)



The Mean DCC

- Database = full archive 2005-2012
- Assume a « mean DCC » :

BRDF depends on :

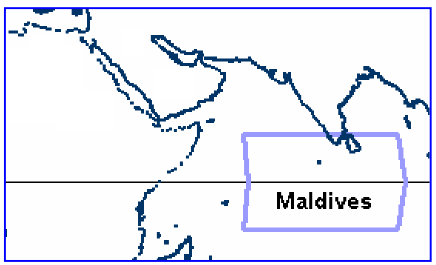
* Cloud particle type
* Cloud optical thickness
* Cloud structure

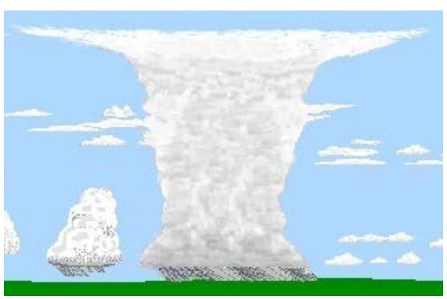
hypothesis = all selected pixels always observe the same « mean DCC »

- All viewing directions are covered
  - 1 pixel = 16 views per track
  - N pixels = Nx16 views per track
  - 16 tracks per cycle
- All solar angles are covered :
  - along the year : from 15 to 45°
  - orbital drift after 2009 = access to large angles, up to 60°

Selection of DCC – The perfect storm

- **How suitable DCC are selected for PARASOL** (not TIR bands) **:**
  - **Operational procedure : every month, acquisitions are collected over**
    - oceanic sites in Guinée et Maldives
    - ρnua>0.7, neighborhood (5x5) < , 400<Papp< 50hPa
    - "nadir/zenith" geometries : θs<30° et θv<40° (avoiding shadow)
      - **This nadir/zenith geometry is for calibration purposes -> here extended to all available angles**

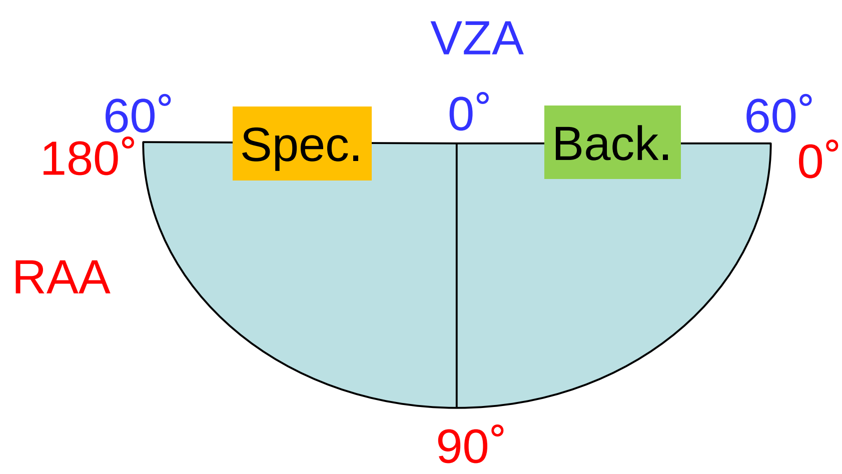




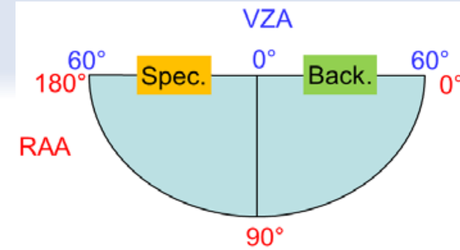
Criteria	Characteristics	Properties
reflectance in band 865 > 0.7	intensive scattering inside the cloud	dense scattered cloud
Inter-tropical sites	favorable areas for the convection mechanism	convective cloud
oceanic site	negligible surface contribution	predominance of the cloud
apparent pressure < 400HPa	top of the cloud > 11km low molecular and aerosol impact	very high cloud
cloud size > 70x70 km²	spatially large cloud structure	large cloud
rms for band 865 < 3% over 30x30km²	homogeneity minimization of structure effect	homogenous cloud
solar angle < 30° viewing angle < 40°	"nadir/zenith" viewing low bidirectional and shadow effects	reference geometry

Methodology – construction of a mean DCC

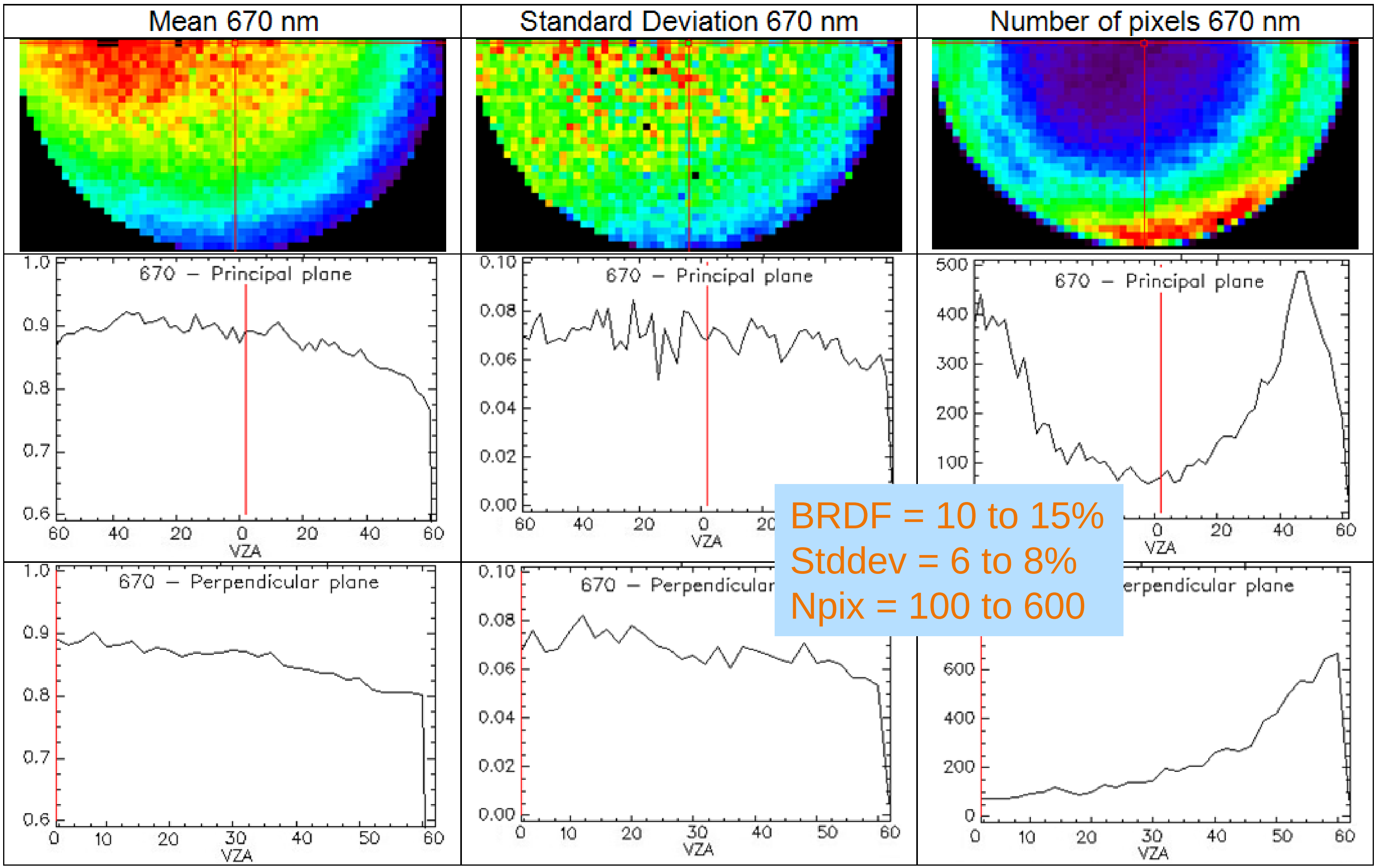
- A BRDF structure is initialized with
  - 2° x2° bins for VZA and RAA
  - 10° range for SZA : [20° ;30°], [30° ;40°], [40° ;50°], [50;60°] (to few for [0° ;20°])
- All Measured reflectance from the archive (all geometries, all dates) is stored in its corresponding (VZA, SZA, RAA) box
  - BRDF assumed to be symetrical to principal plane, i.e. 0° <RAA<180°
- For each box and each wavelength, are computed :
  - mean TOA reflectance
  - standard-deviation
  - number of pixel per bin
- Visualization : polar plot



Exemple for 670nm



- 30° < SZA < 40°

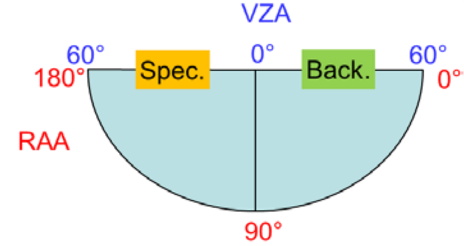


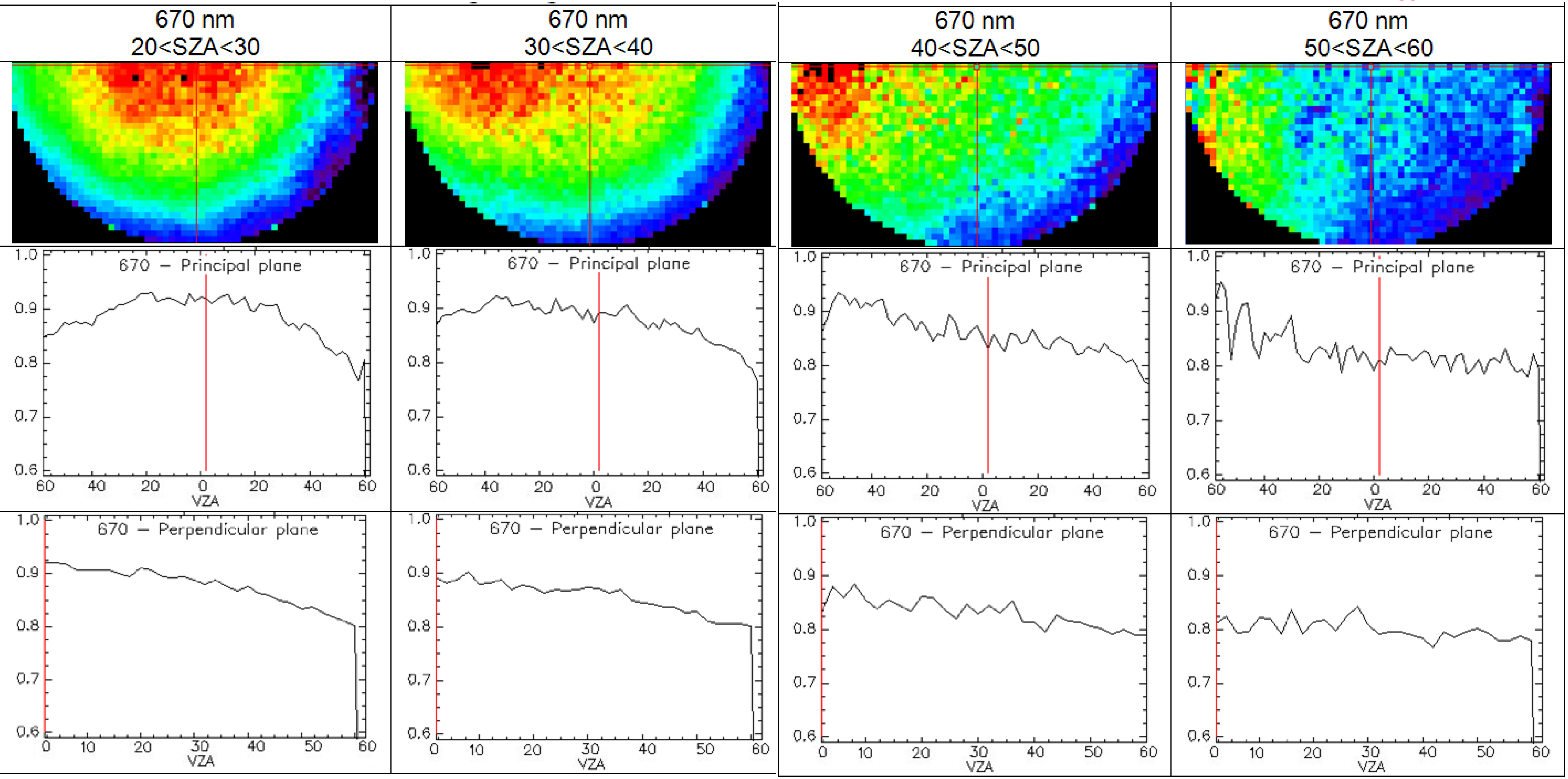
BRDF = 10 to 15%
Stddev = 6 to 8%
Npix = 100 to 600

cnes

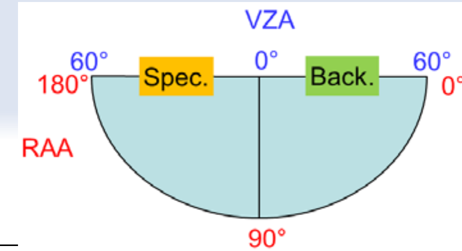
Solar range

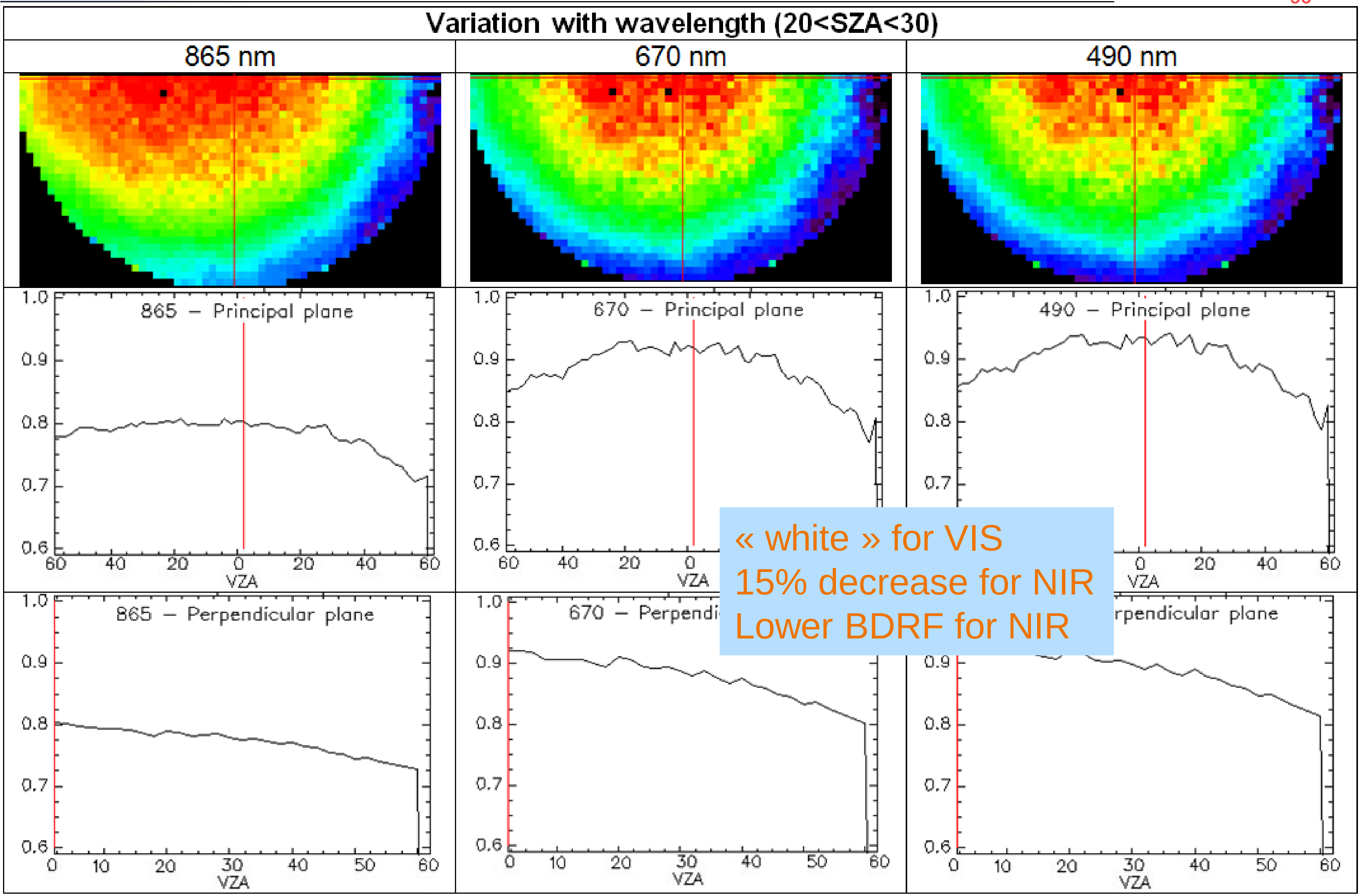
Maximum moves with SZA





Spectral



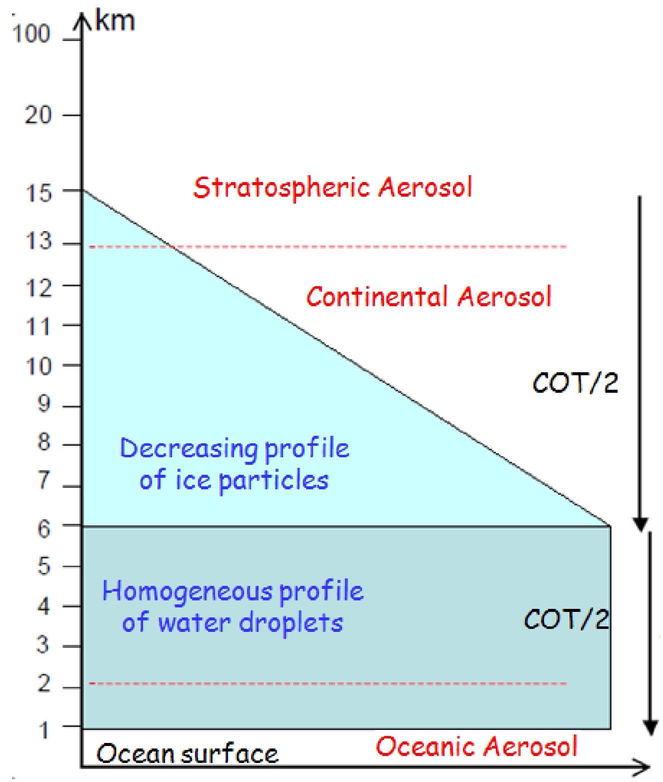


« white » for VIS
15% decrease for NIR
Lower BDRF for NIR

Modeling DCC

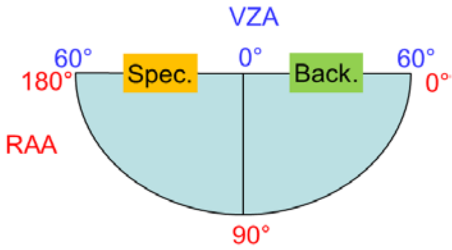
- **Hu et al. model (2004) : used by GSICS for cross-calibration over DCC**
  - **based on broadband CERES data collection**
  - **extrapolated to narrowband using a non linear regression neural network**
  - **paramaters are taken from hualb.data file (reference GSICS)**

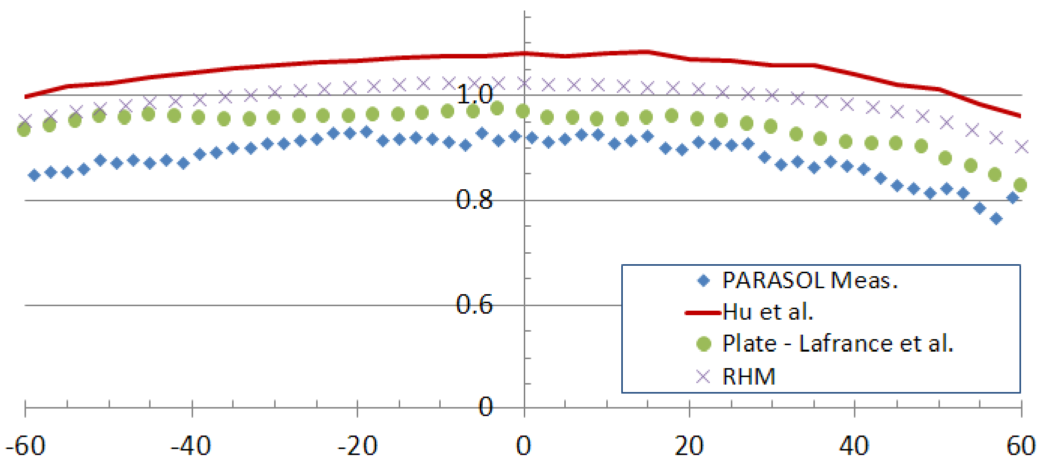
- **Lafrance et al. model (2002) : used by CNES for calibration over DCC**
  - **based on Discrete Ordinate Code – narrowband**
  - **16 layers, droplet in 1-6km, ice in 6-15km, molecular scattering + aerosol background**
    - DCC are very white for VIS (most of contributors are minor)
    - cloud particle type (CPT) and cloud optical thickness (COT) are the dominant parameters
  - **CPT**
    - Historical CPT : plate and hexogonal crystals based on Macke et al. (1996)
    - Revised CPT : RHM (Rough Hexagonal Monocrystals) derived by Labonnote et al. and based on Hess et al. reference (1998)

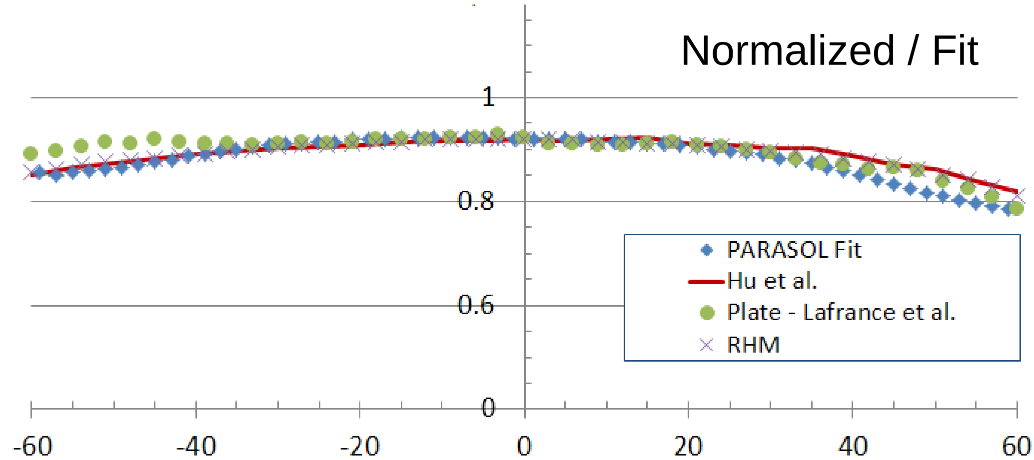


Analysis on the principal plane

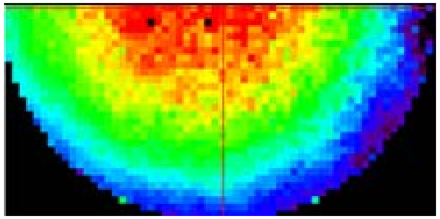
■ SZA=25° (largest effect) for 670nm
- PARASOL measurements : BRDF from the mean DCC
- Plate and RHM for a COT=140
- Hu model





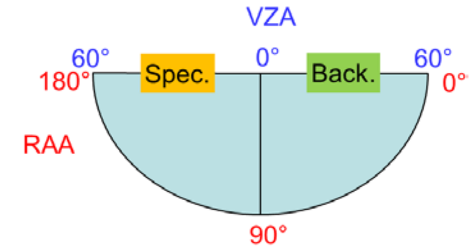


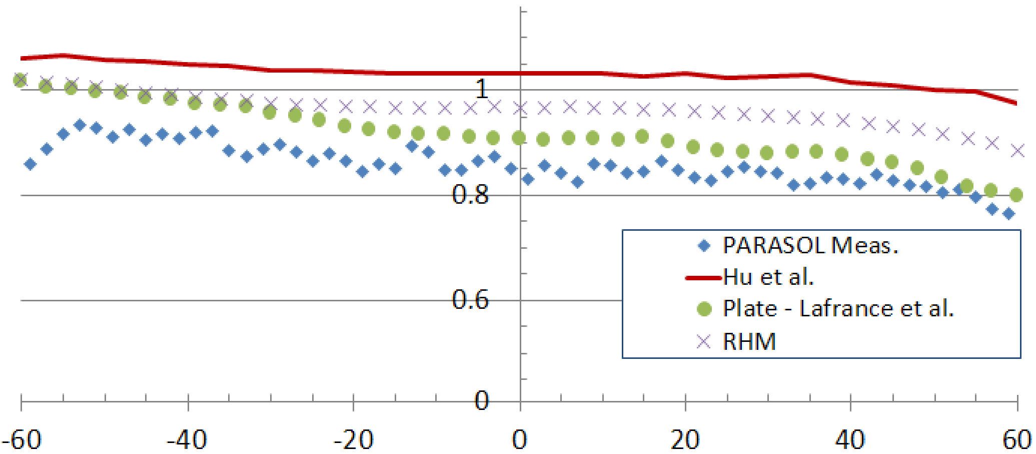
- Excellent consistency between RHM and Hu
- Good consistency with measurements for VZA>45°
- Some differences for large angles

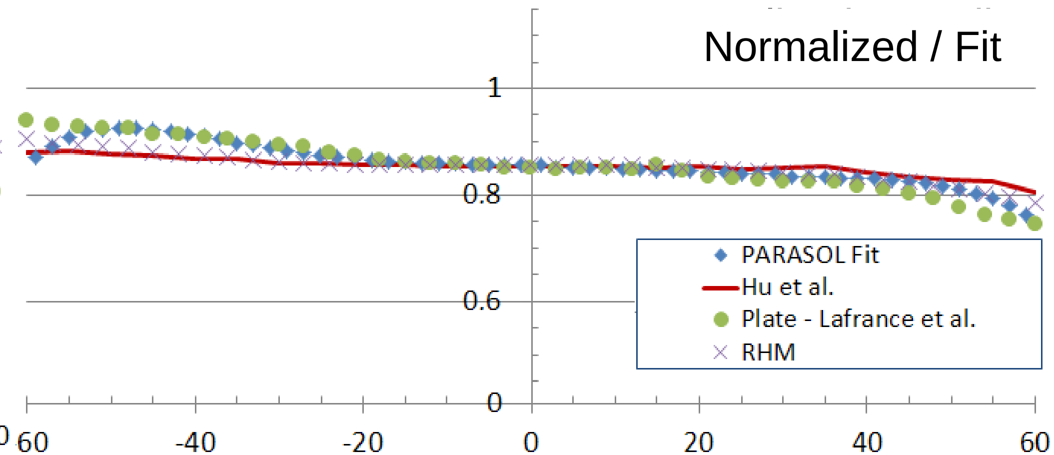


Analysis on the principal plane

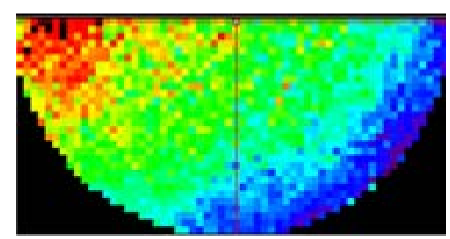
- **SZA=45° for 670nm**
  - **PARASOL measurements : BRDF from the mean DCC**
  - **Plate and RHM for a COT=140**
  - **Hu model**







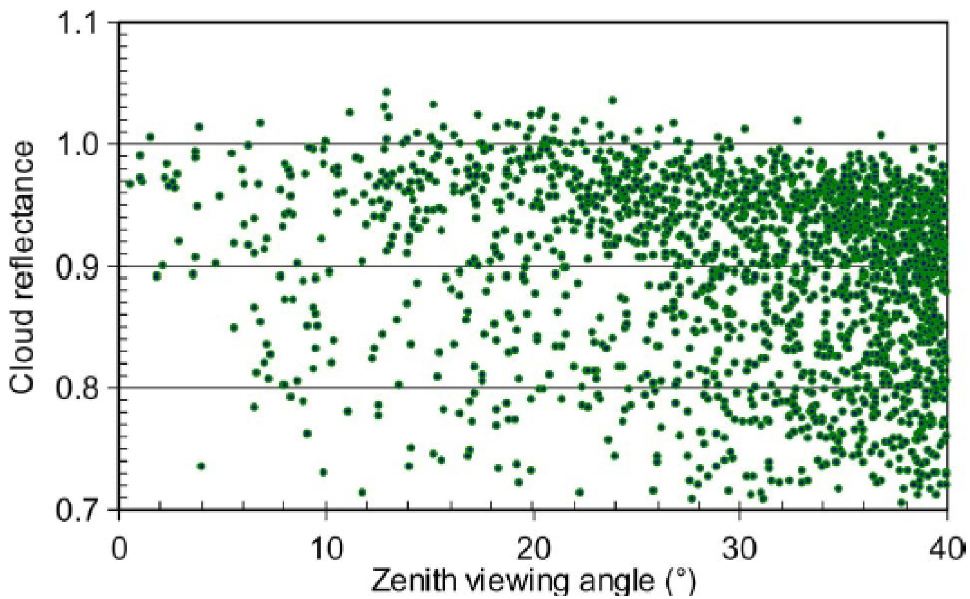
- **Excellent consistency between RHM and Hu**
- **Good consistency with measurements for VZA<40°**
- **Some differences for large angles**

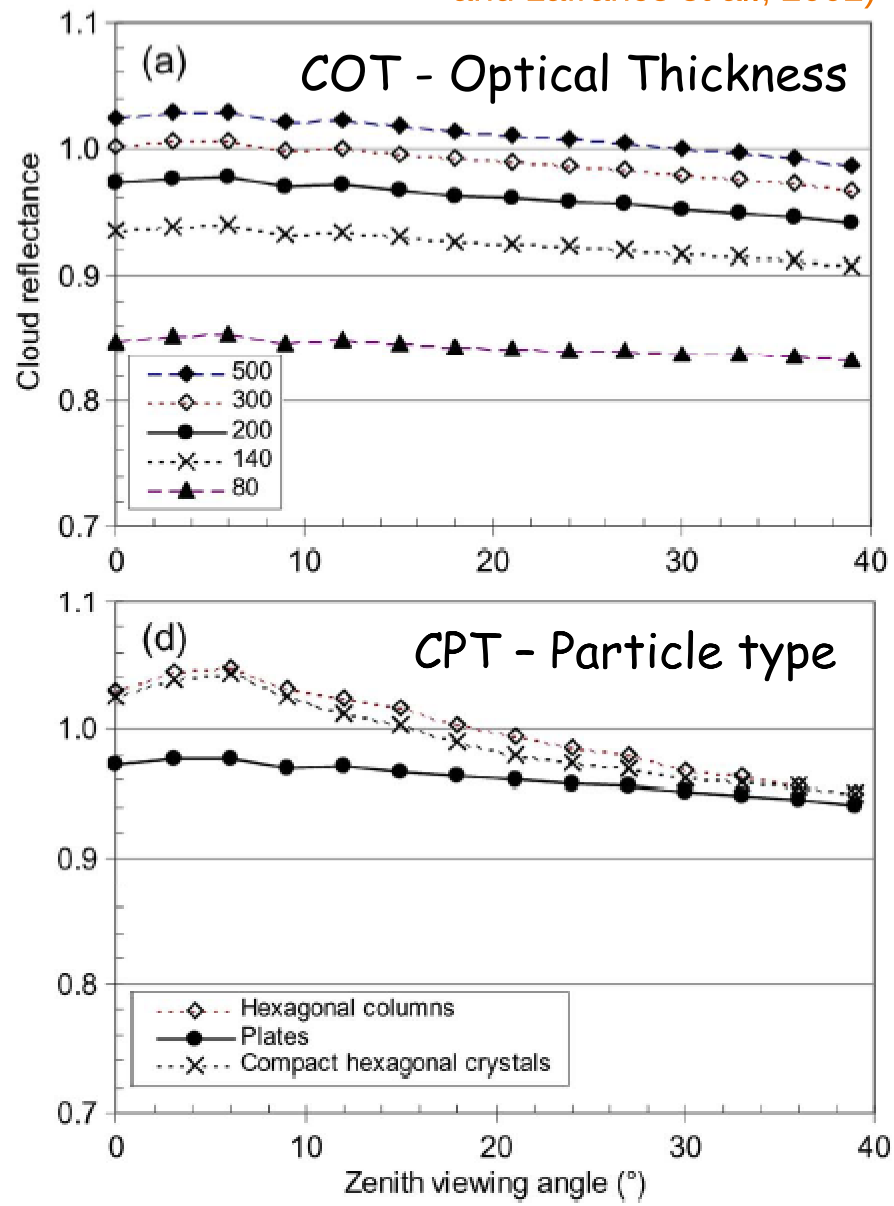


Sensitivity analysis

(from Fougnie and Bach, 2009 and Lafrance et al., 2002)

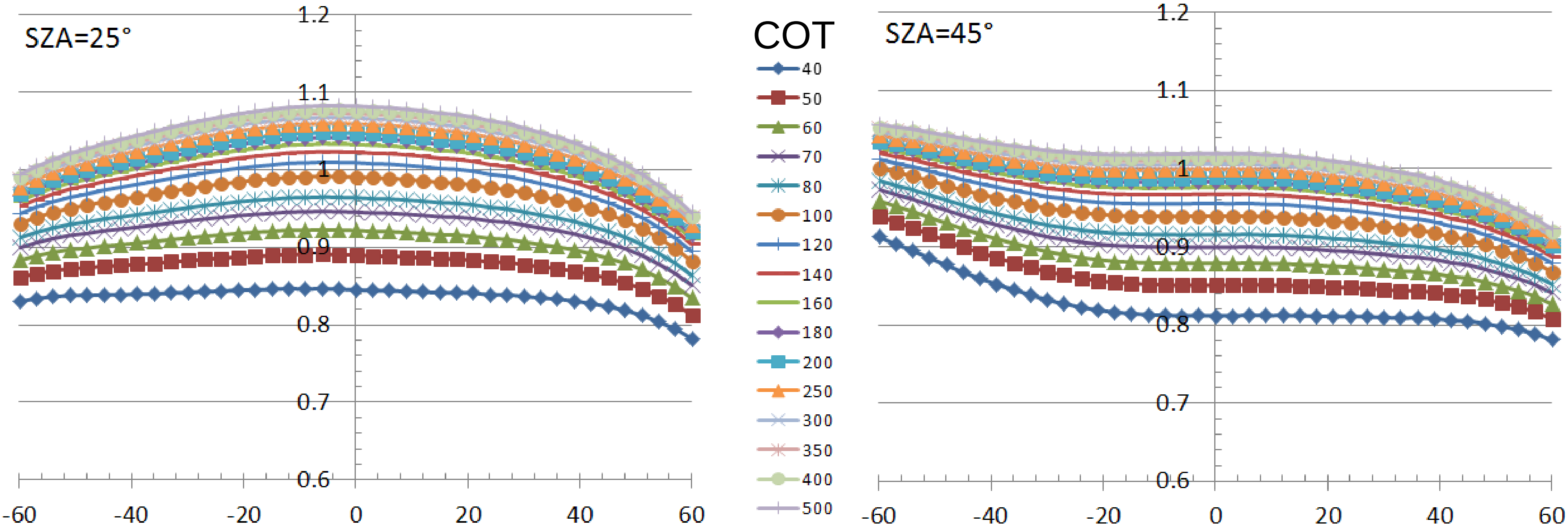
- **The reflectance and BRDF properties may vary with :**





Sensitivity analysis

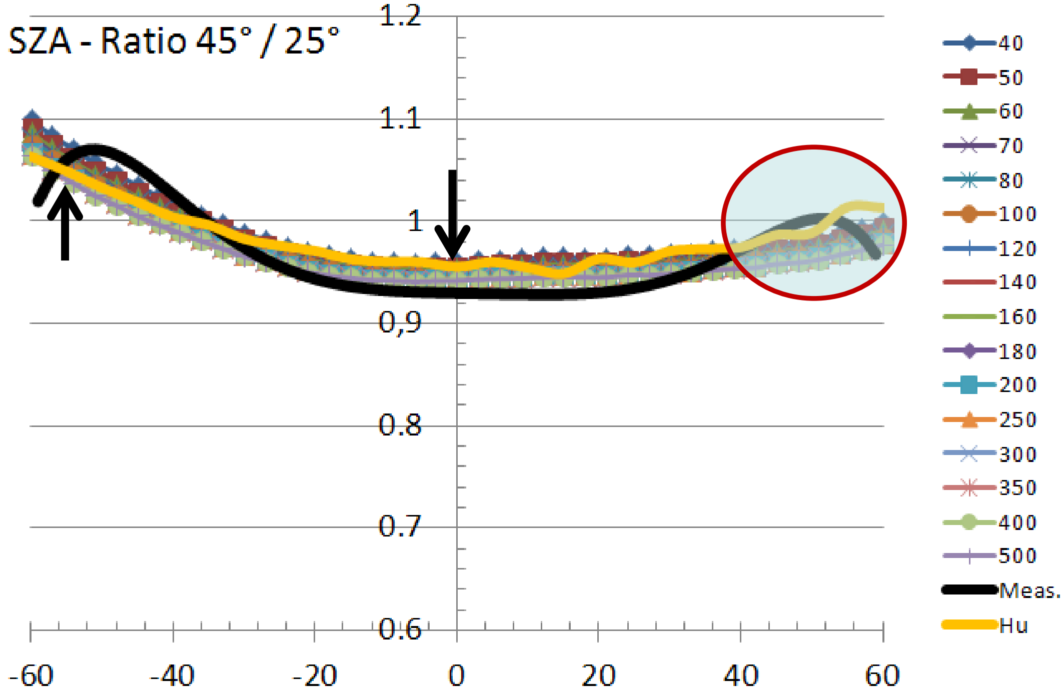
- **Cross-calibration strategy :**
  - at a given date & geolocation // COT and CPT are given by the actual geophysics
  - exact simultaneity, i.e. solar and viewing geometries, is not always possible
- **Behavior versus VZA for SZA=25° and 45°and for 16 COT**
  - computed at 670nm for CPT=RHM (principal plane)



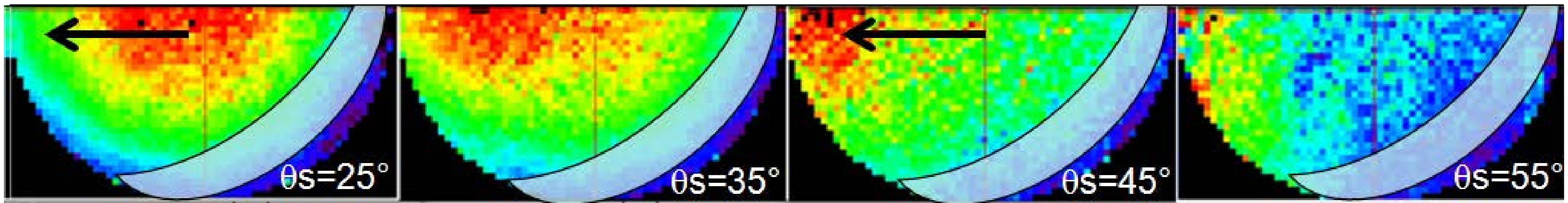
Sensitivity analysis – The Crescent BRDF

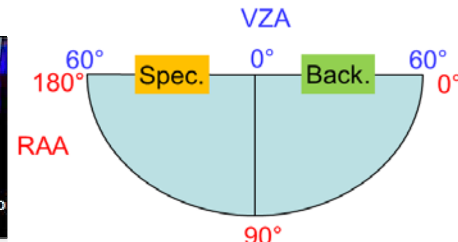
■ Optimisation for Cross-calibration

- **A crescent (RAA//VZA) could to be preferred**



- moderate variation with both SZA and VZA
- toward the backscattering half-space and/or large viewing angles
- doesn't simply correspond to the backscattering direction





Conclusion

- A first DCC BRDF characterization based on the mean TOA observation by PARASOL was derived
- Comparison with reference model (Hu) and computations show :
  - A very good consistency between measurements and computation
  - This is a statistical mean observation, BDRF may depend on various parameters
  - Here 490/670/865 are presented
    - 565, 763, 765, 910, 1020 available but sensitive gaseous absorption, straylight for 443
- Main difference between measurements & modeling
  - MODEL : Assumption of a flat homogeneous level for cloud
  - MEASU : roughness of the DCC, shadowing effects
  - SZA variation can be correlated to seasonal change of microphysics (CPT)
- Recommandation for cross-calibration purposes is to select the most isotropic part of the BRDF
  - avoid geometries around the specular direction, ideally prefer « the crescent » (large angles on the backscattering half space)

Thank you !

References

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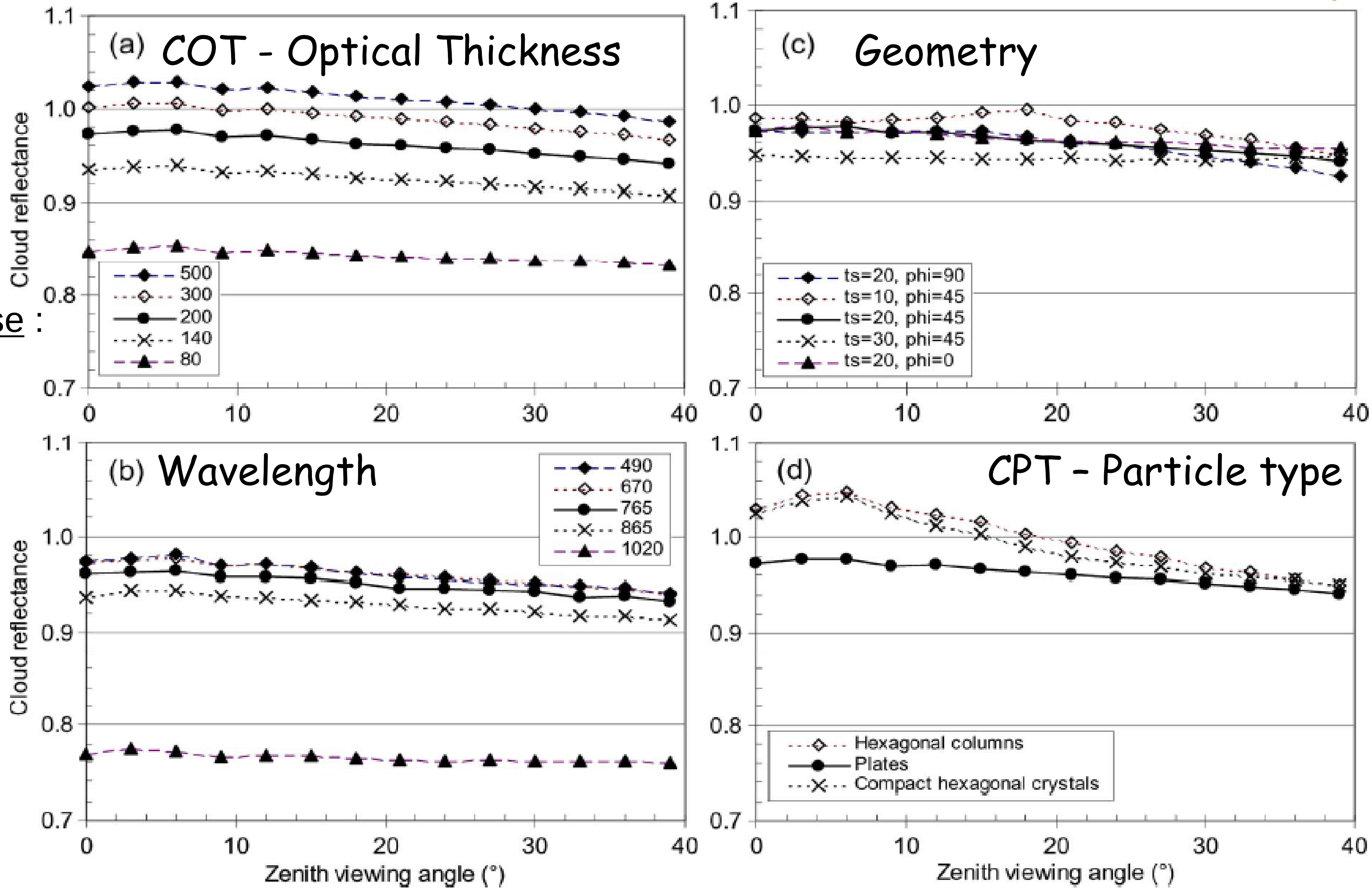
- **Hess et al., *J. Quant. Remote-Sensing. Tech*., 1998**
  Scattering Matrice of Imperfect Hexagonal Ice Crystals
- **C.-Labonnote et al., *J. Geophys. Res*., 2001**
  Polarized Light Scattering by Inhomogeneous Hexagonal Monocrystals. Validation with POLDER.
- **Lafrance et al., *IEEE TGARS*, 2002**
  Interband Calibration Over Clouds for POLDER Space Sensor
- **Hu et al., *IEEE TGARS*, 2004**
  Application of DCC Albedo Observation to satellite-based Study of the Terrestrial Atmosphere
- **Fougnie et al., *IEEE TGARS*, 2009**
  Monitoring of Radiometric Sensitivity Changes of Space Sensors Using DCC – Operational Application to PARASOL
- **Fougnie et al., *CALCON*, 2011**
  Adding an On-board Diffuser in Front of the PARASOL Instrument
- **Fougnie et al., *CALCON*, 2013**
  Definition, Adjustment and Validation of a Physical Model to Describe the PARASOL Radiometric Tending

Backup Slides

Computation using Discrete Ordinate Code

(from Fougnie and Bach, 2009 and Lafrance et al., 2002)



<u>Reference case</u> :

CPT=Plate

COT=200

ts=20°

Phi=45°

670nm

How lambertian are DCC – Spectral Ratio

Spectral ratio = λ/670

Computation using Discrete Ordinate Code

<u>Reference case</u> :
CPT=Plate
COT=200
ts=20˚
Phi=45˚
670nm

<u>VIS :</u>
→ no effect

<u>NIR :</u>
→ sensitive to COT & CPT but no angular variation