Improvement of Angular Dependence Models through Multiview Capability Broad-band Radiometers for the Earth Radiation Budget

(In the framework of Contract

ESA-ESTEC AO/1-4139/02/NL/GS)

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TOA Flux Working Group Meeting

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See also: http://asd-www.larc.nasa.gov/Inversion

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See also http://www.sp.ph.ic.ac.uk/gerb

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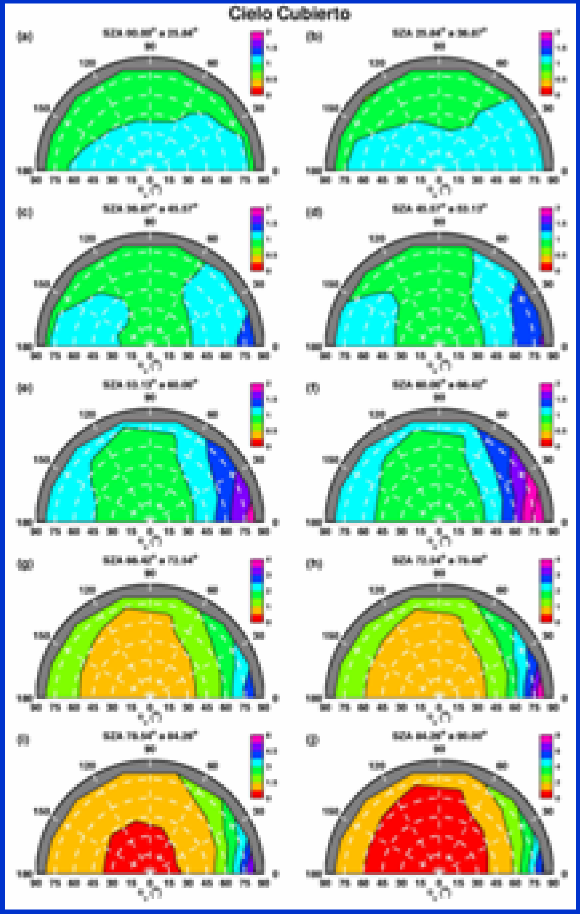
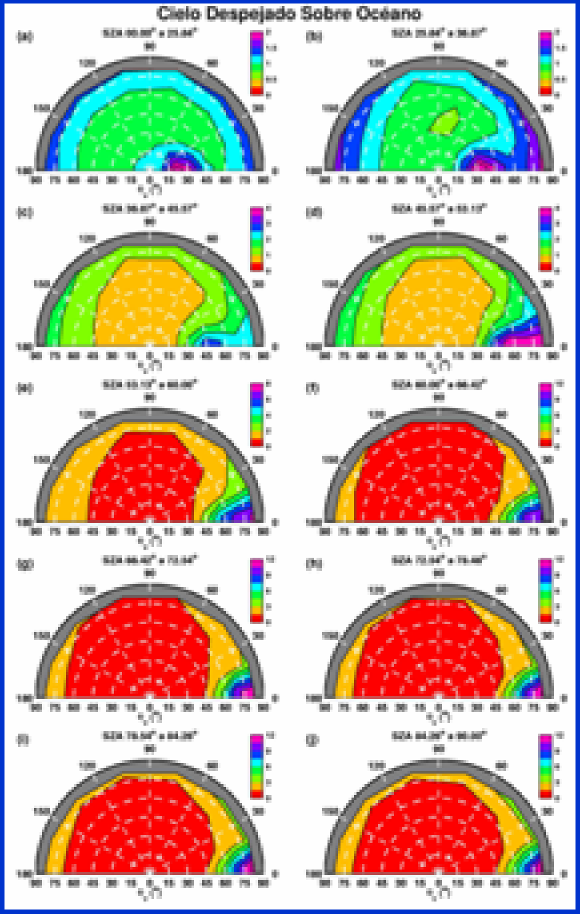
In charge of the inversion of POLDER measurements for cloud and radiative budget analysis.

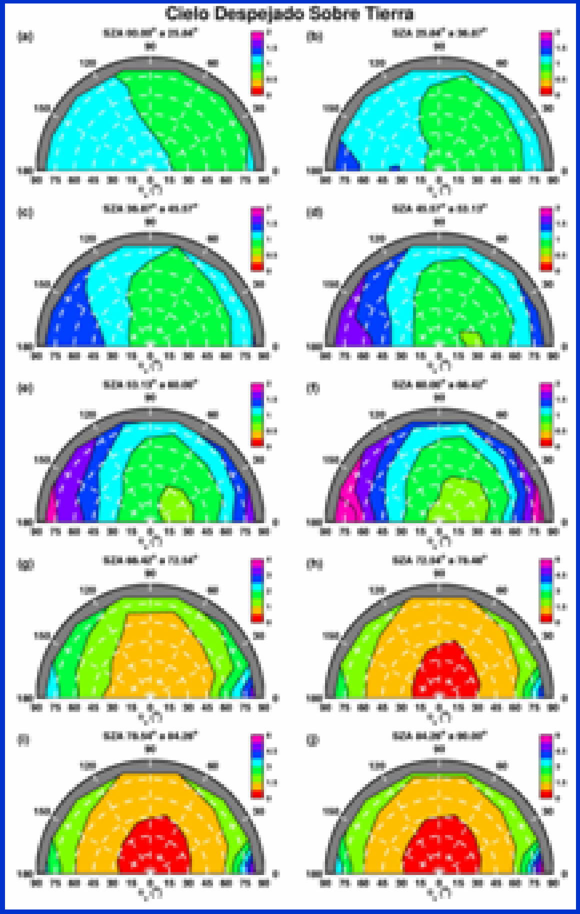
See also http://smsc.cnes.fr/POLDER

Introduction and overview

Examples of SW ERBE ADMs in polar coordinates







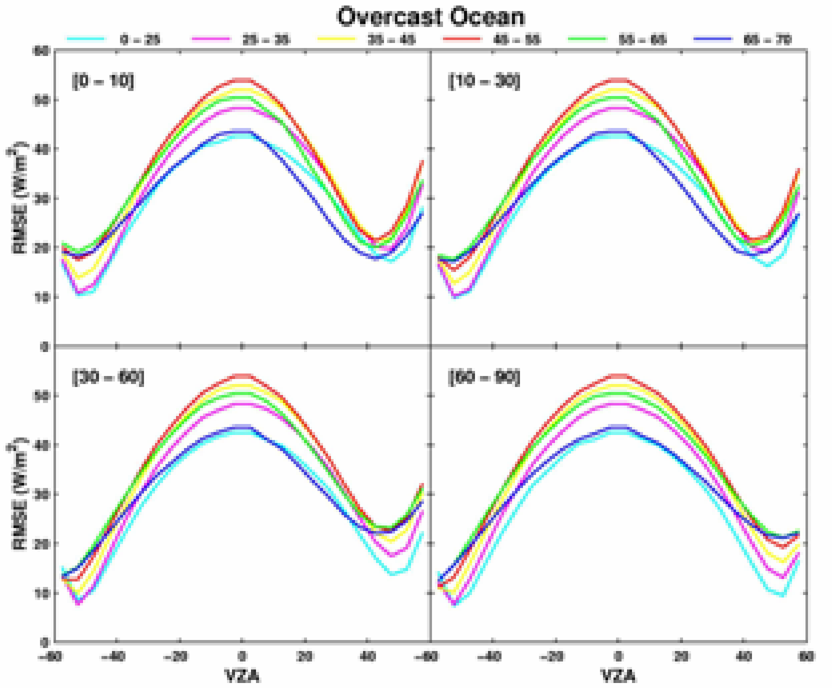
Overcast Sky — Clear-sky over Ocean — Clear-sky over Land

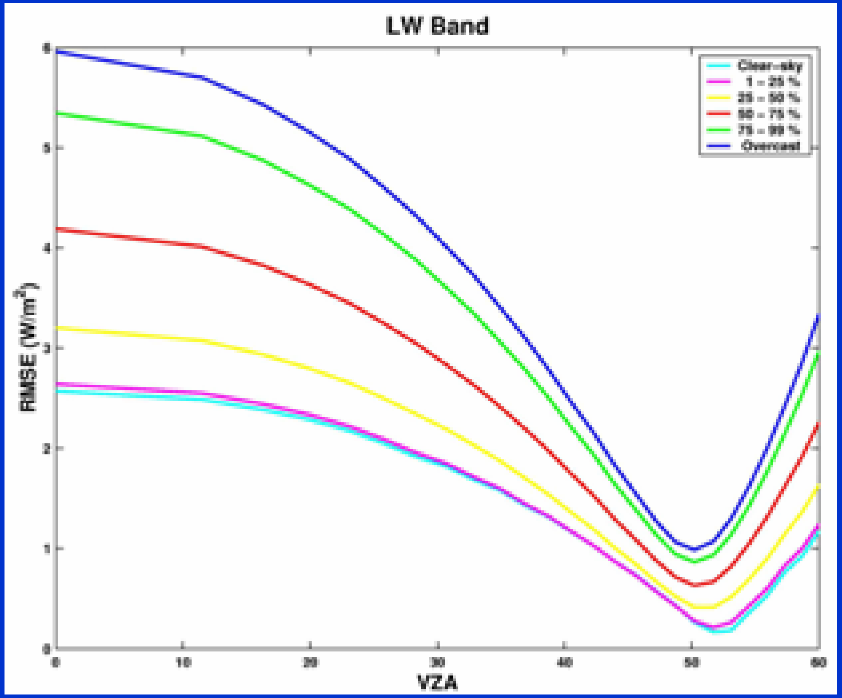
Inversion Error Behaviour

Previous Theoretical Results

Bodas-Salcedo, A., J.F. Gimeno-Ferrer, and E. López-Baeza (2003): Flux Retrieval Optimization with a Nonscanner Along-track Broadband Radiometer, *J. Geophys. Res.*, Vol. 108 No. D2,

for planar clouds, studied several specific methodologies for the flux retrieval with along-track measurements





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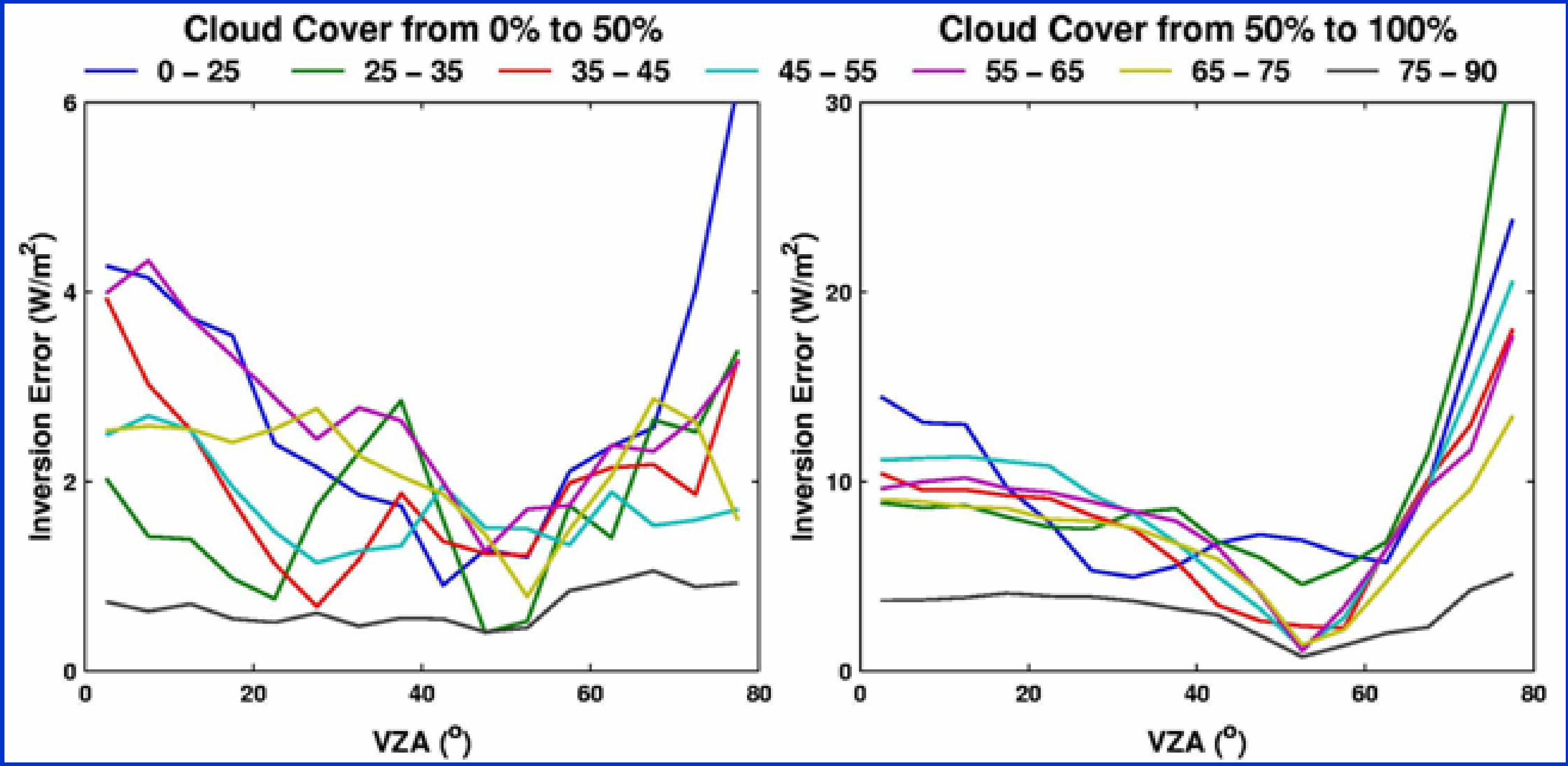
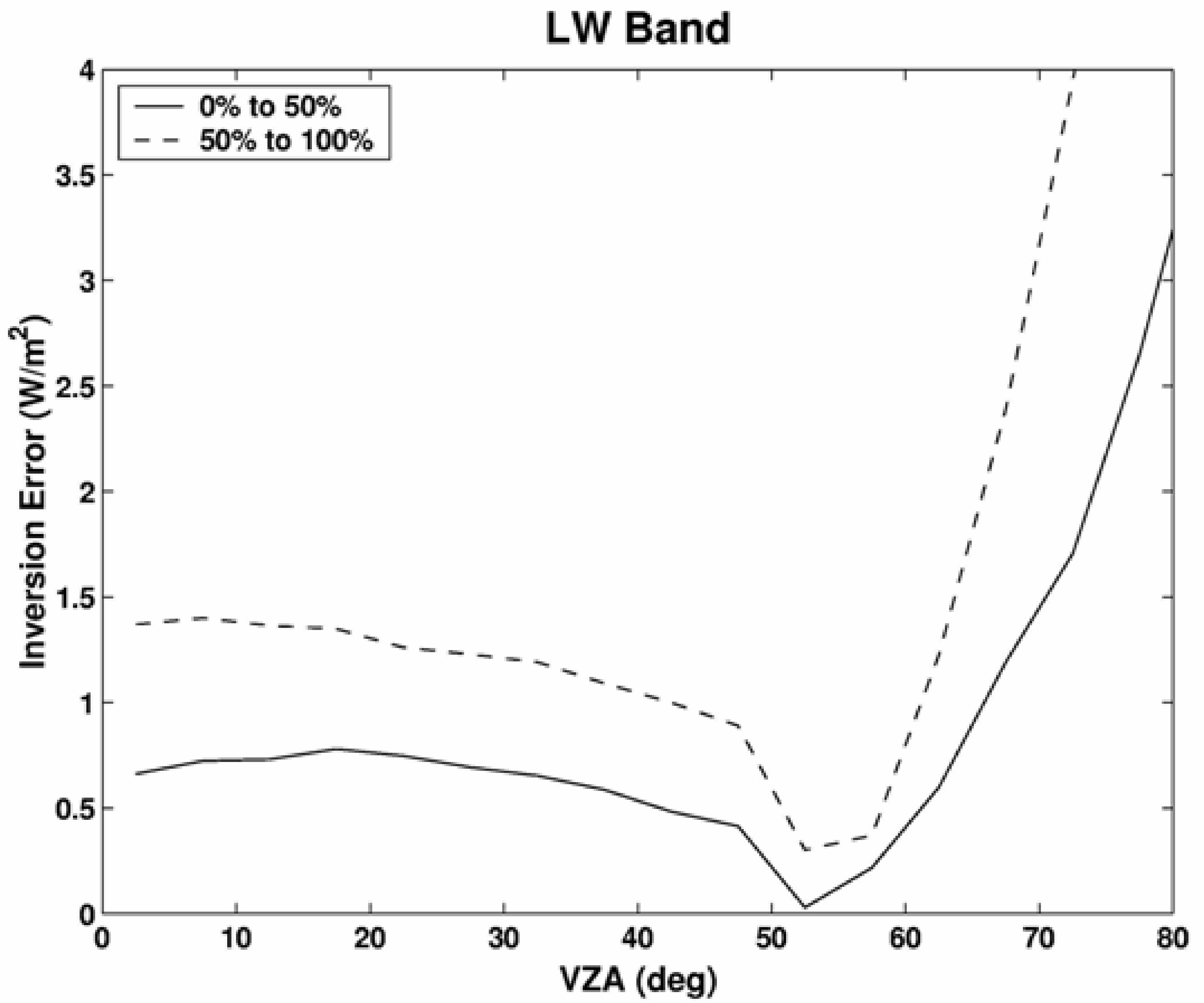
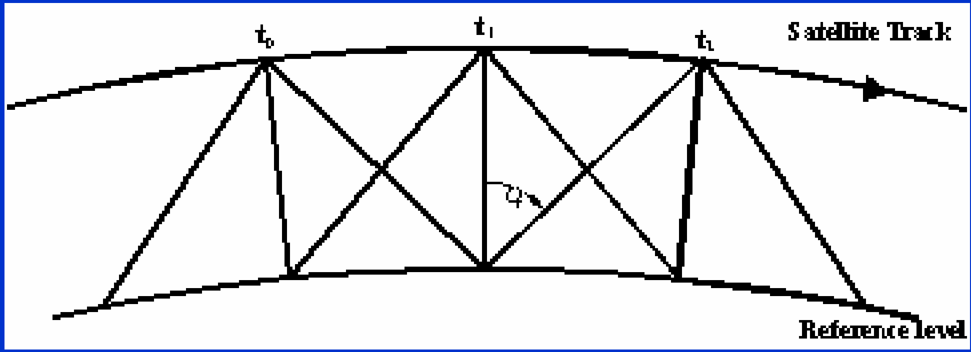
SW Inversion Error Behaviour

One RAZ Interval

Real CERES/TRMM data to validate those results (Bodas-Salcedo, A., E. López-Baeza, and G. L. Smith (2002): Study of the Flux Retrieval Error Behaviour with CERES/TRMM Data. *9th International Symposium on Remote Sensing, SPIE, Creete, Greece, 22-27 Sept, 2002.*)




LW Band
0% to 50%
50% to 100%
Inversion Error (W/m^2)
VZA (deg)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
10
20
30
40
50
60
70
80



Introduction and Overview

Along-track configurations

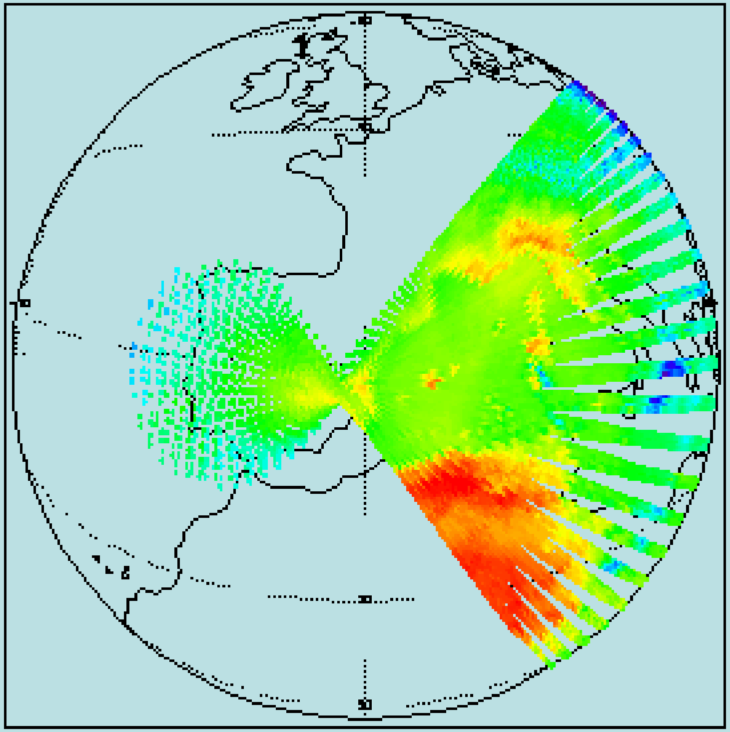
However, accurate determinations on smaller spatial and temporal scales are also needed. In particular, to improve critical parameterisations of cloud-aerosol-radiation interactions in climate models, accurate instantaneous top of the atmosphere (TOA) ERB measurements are needed as constraints to the derivation from other instrumental data of vertical radiative flux profiles in the atmosphere

For this purpose, along-track configurations are very good candidates because the flux retrieval can be optimised by using different views of the same pixel from the same platform. Recent analyses of *Multiangle Imaging SpectroRadiometer* (MISR) data show how the different views along track provide stereo information on cloud heights. Cloud fields are not necessarily plane parallel, and their 3-dimensional effects are a complicating factor in the analysis of satellite data and in particular in determiningn radiative fluxes from radiance measurements. Analysis of multiple views, although complex, is a way to take these factors into account and to improve the flux determinations.

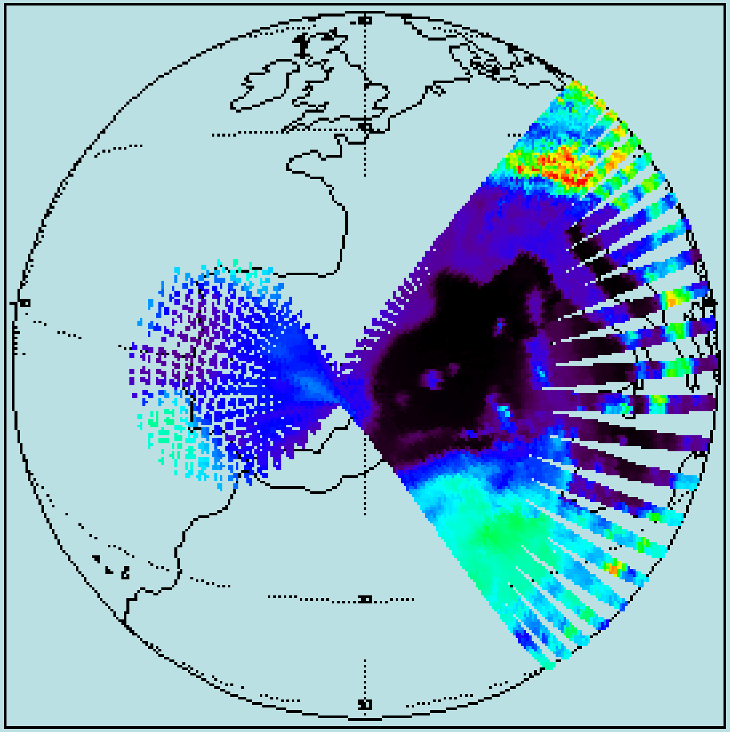
Introduction and Overview

CERES on board TERRA NASA satellite at 10:20 - 10:27 UTC 20 June 2003

LW Radiances



SW Radiances

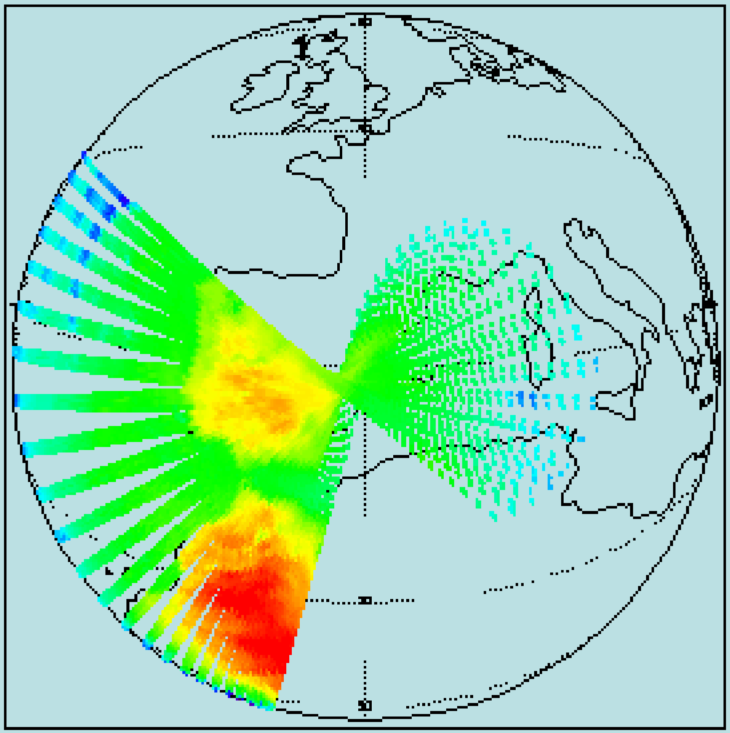


From Z. Peter Szewczyk & G. Louis Smith

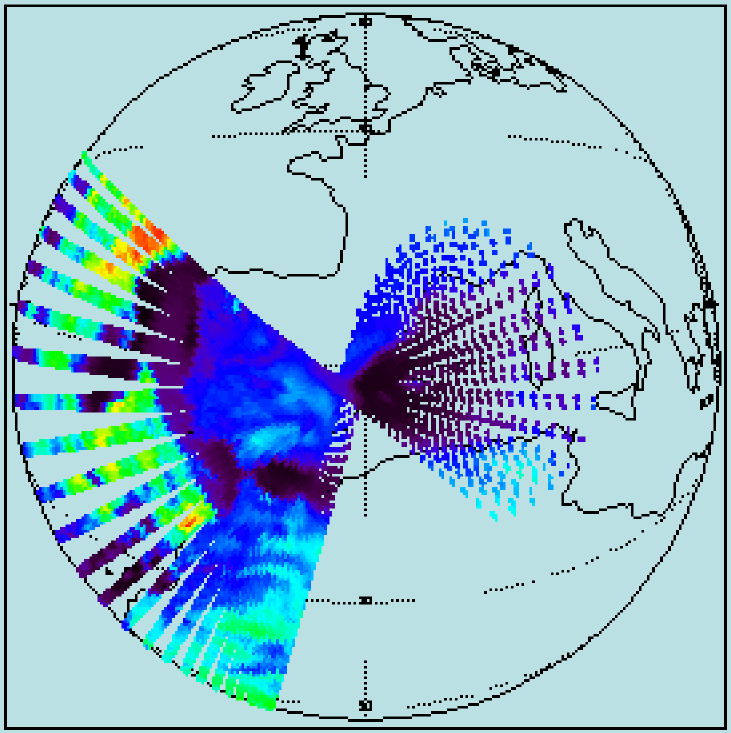
Introduction and Overview

CERES on board AQUA NASA satellite at 13:34 - 13:42 UTC 20 June 2003

LW Radiances



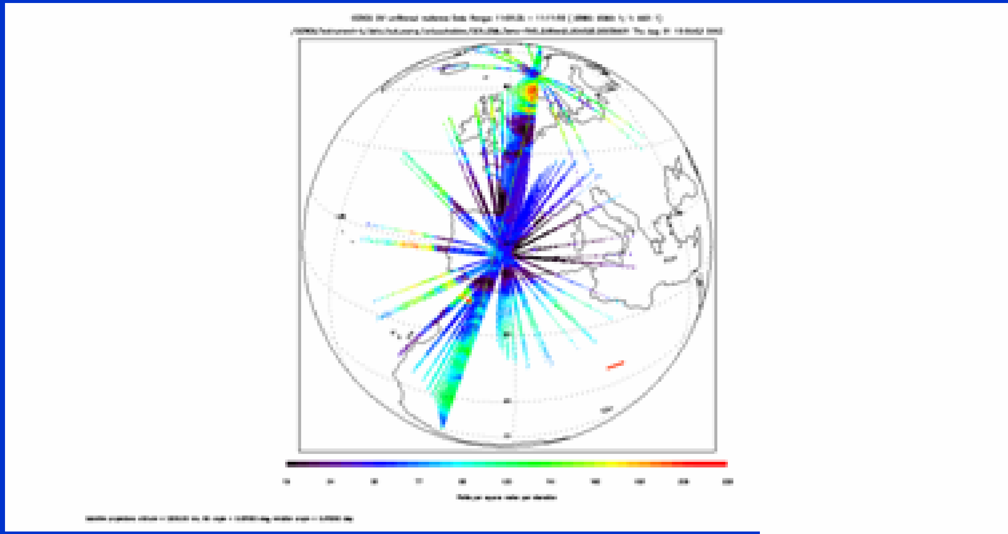
SW Radiances



From Z. Peter Szewczyk & G. Louis Smith

Introduction and Overview

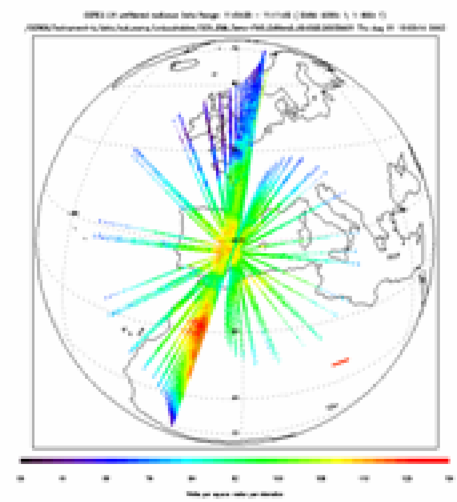
Terra pass at 11:00-11:11 on 06/21/2003; view from 2000km



Longwave radiance

Shortwave radiance

Min VZA = 9.6° !!!

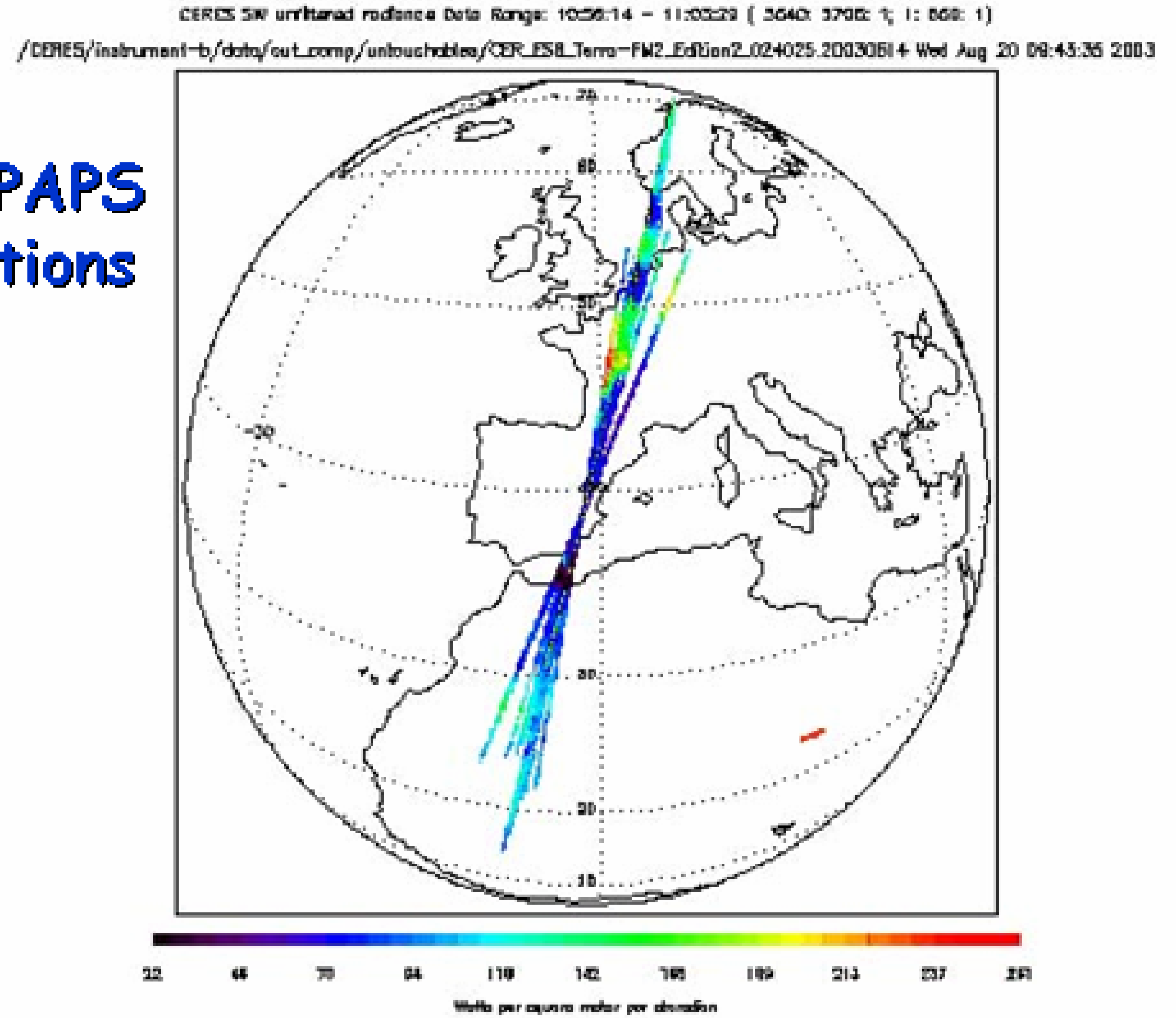


From Z. Peter Szewczyk & G. Louis Smith

Introduction and Overview

Along-track configurations

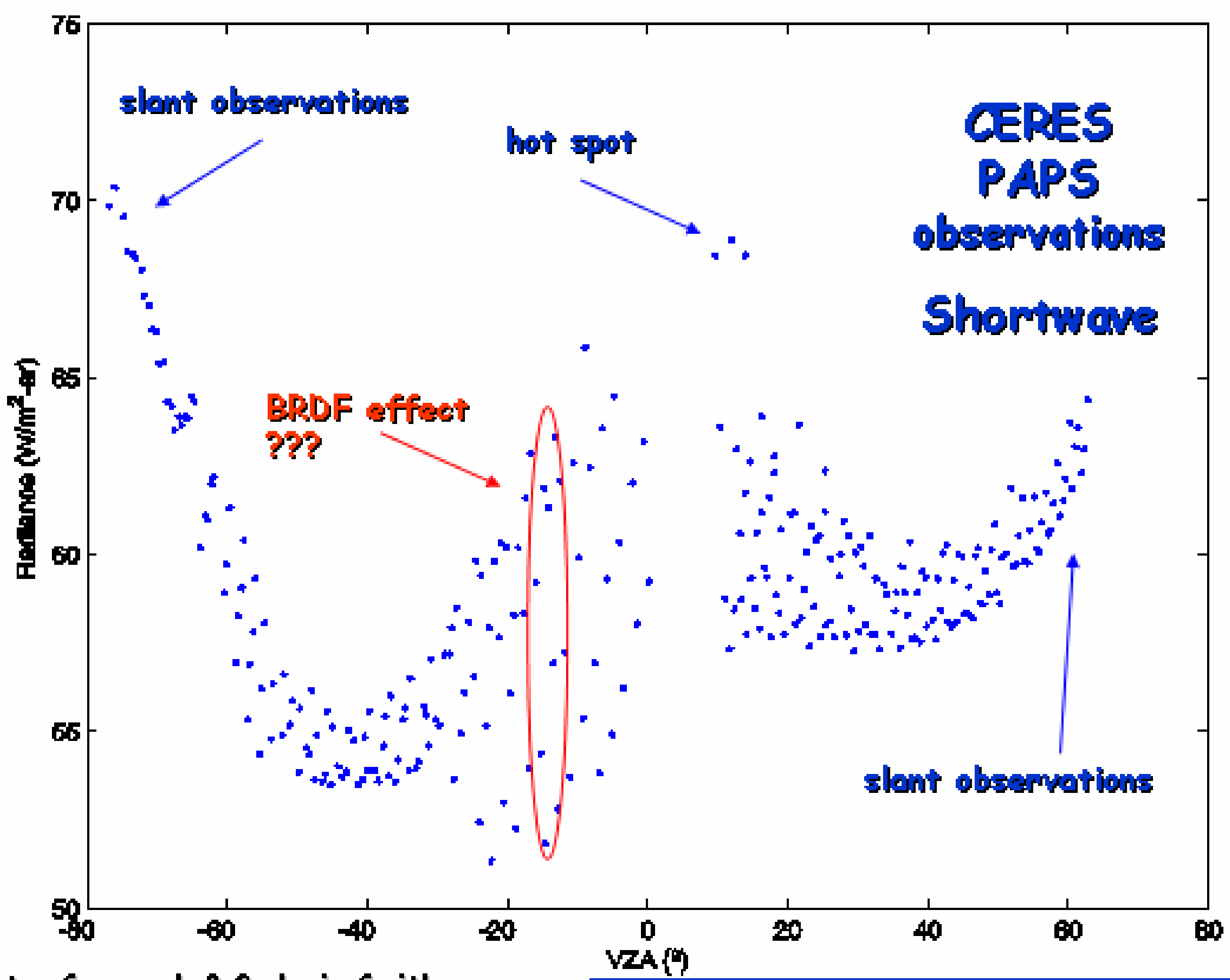
CERES PAPS observations



From Z. Peter Szewczyk & G. Louis Smith

Introduction and Overview

Along-track configurations



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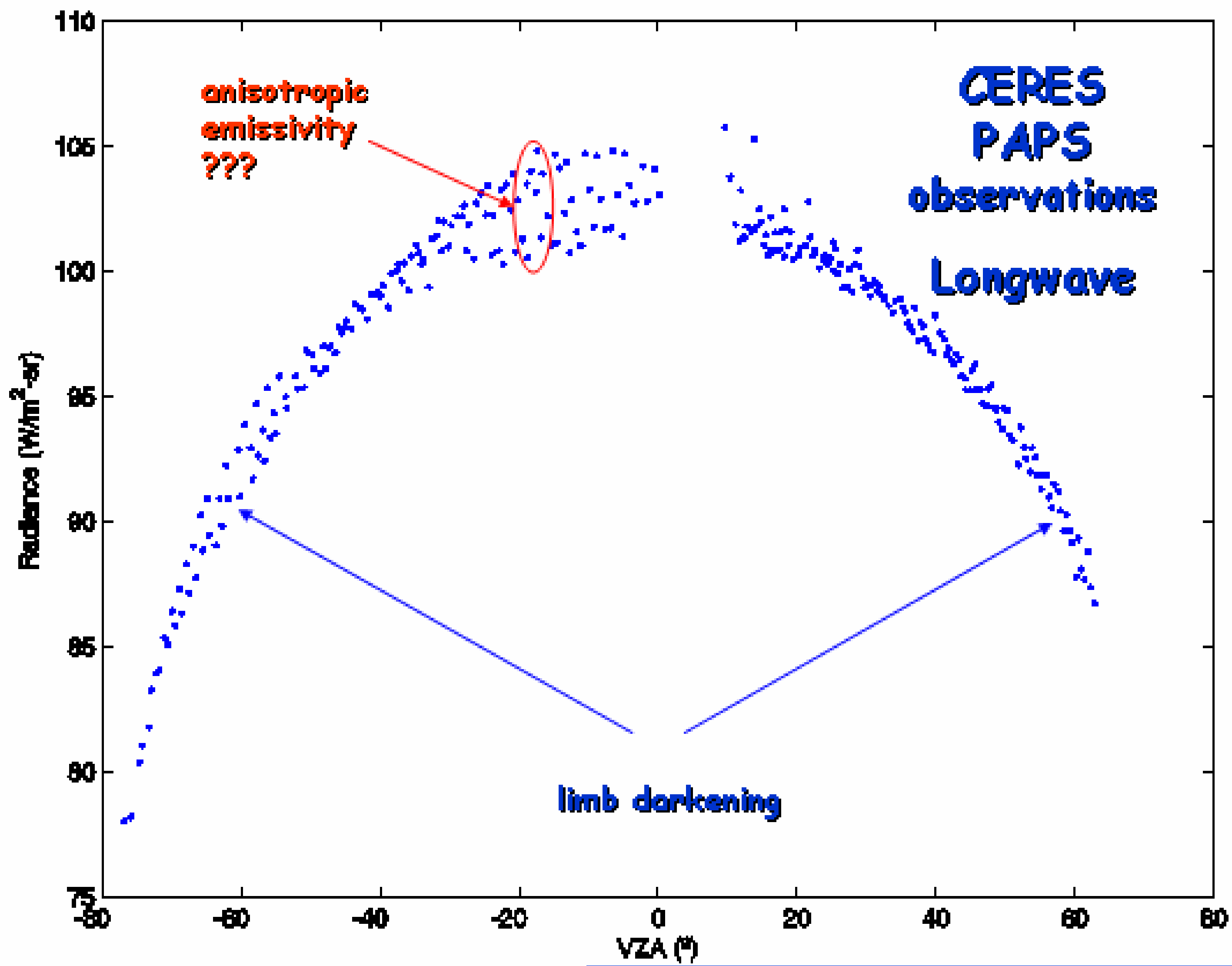
Along-track configurations



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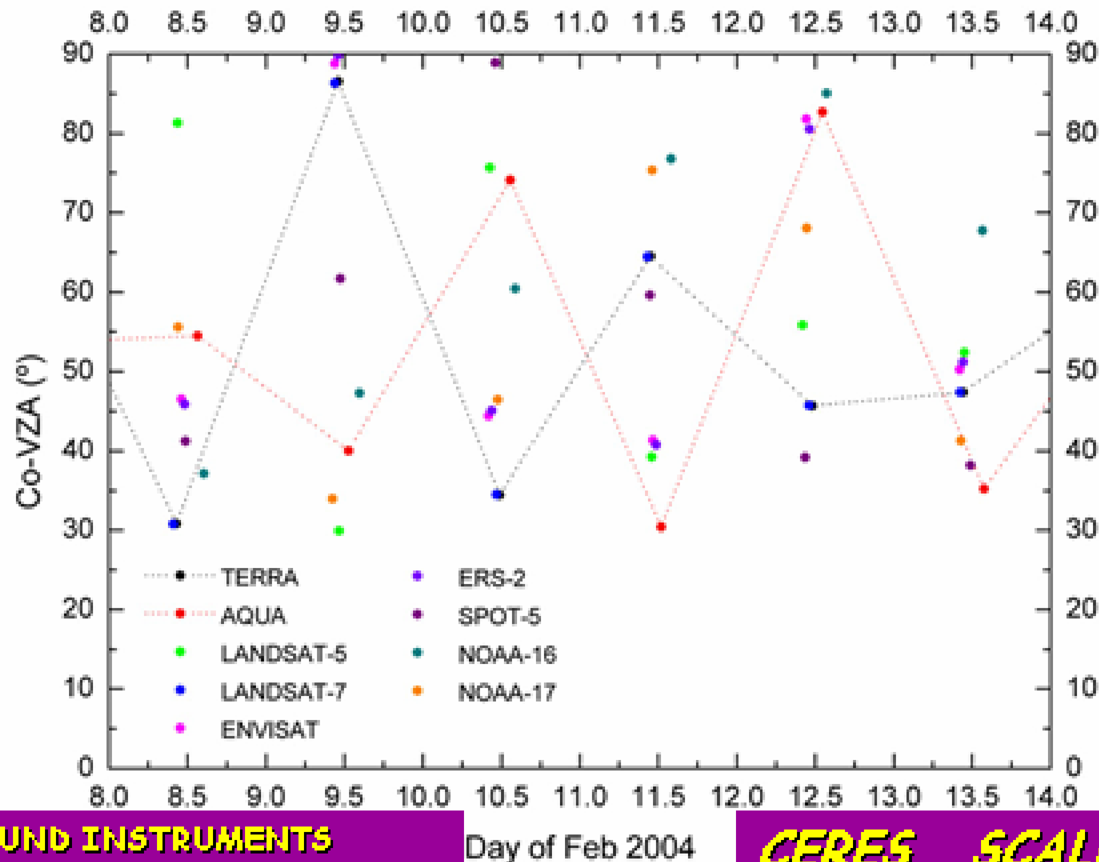


SATELLITE SENSORS IMPLIED

MSG
- GERB
- SEVIRI

TERRA & AQUA
- CERES
- ASTER
- MISR
- MODIS

ENVISAT
- MERIS
- AATSR
- MOPITT
- MIPAS
- SCIAMACHY

NOAA-16 & -17
- AVHRR

SPOT-5
- VEGETATION

LANDSAT
- LADSAT-7 ETM
- LANDSAT-5 TM

ERS-2
- ATSR-2

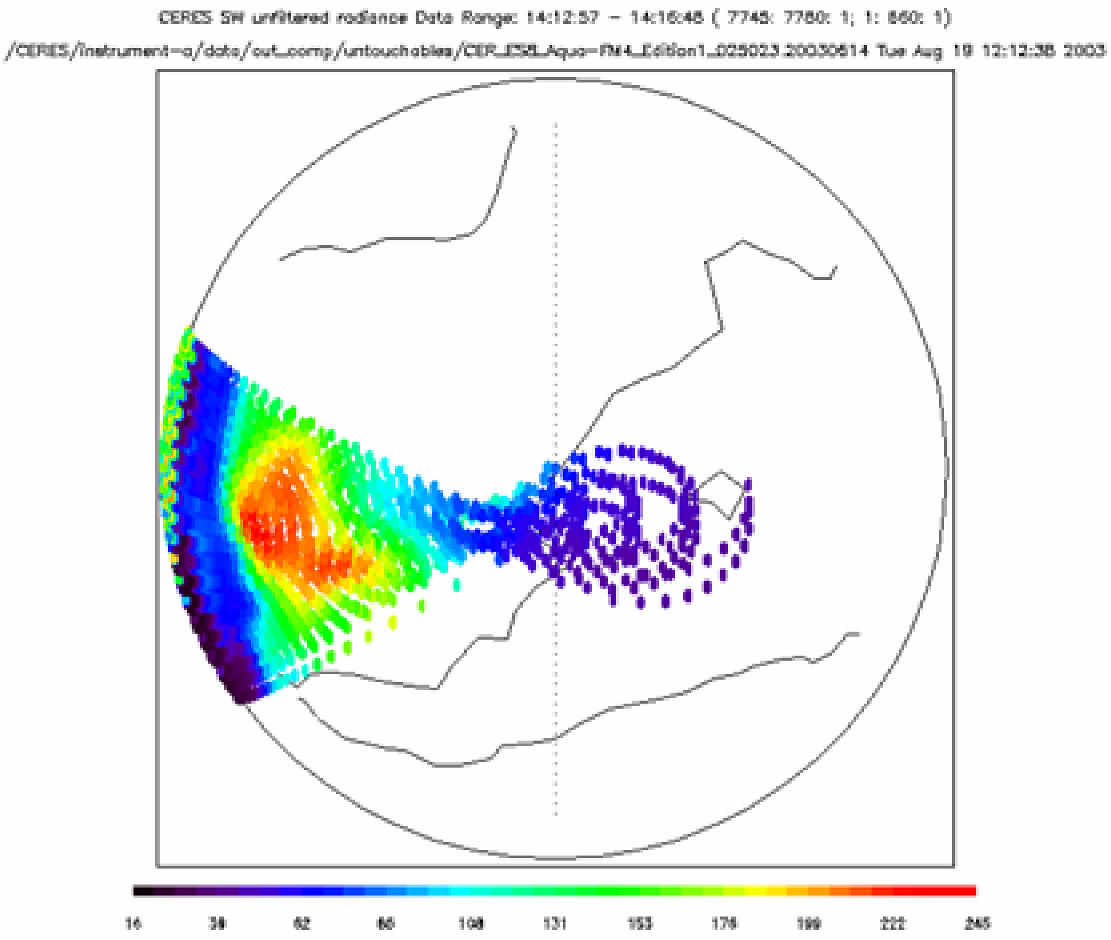
GROUND INSTRUMENTS

- VALENCIA ANCHOR STATION, MOBILE MET. STATIONS
- FULLY-EQUIPPED AIR-QUALITY STATION
- RADIOSOUNDING ASCENTS
- GPS
- SUN-PHOTOMETER
- DELTA-T THETA PROBES AND SOIL PROFILE PROBE

CERES SCALES Winter Campaign, 2004 (February 2004). 2nd GERB Ground Validation Campaign

Introduction and Overview

Along-track configurations



From Z. Peter Szewczyk & G. Louis Smith

FM4 scanning pattern

Aqua pass at 14:13-14:17 on 06/14/2003

view from 100 km

Shortwave Radiance

TOA

Objectives of the Study

- To develop improved ADMs to retrieve instantaneous TOA radiative fluxes, specially for broad-band radiometers with a footprint in the order of 10 km and multi-view capability, and

- To evaluate the expected error introduced by the statistical nature of ADMs and three-dimensional radiative effects, mainly due to cloud fields, in the accuracy of the derived TOA fluxes.

Tasks from the SoW

- Task 1: Selection of a representative dataset
- Task 2: Scene definition
- Task 3: ADMs, BRDFs and surface albedo
- Task 4: Conclusions and recommendations

Task 1: Selection of a representative dataset

The overall objective

- to improve the radiance to flux conversion
- a prospective broad-band radiometer (BBR)
  - relative small footprint (around 10 km)
  - multi-view capabilities
    - (3-views along track, nadir and 53° fore and aft)

For the representative data set

- the best candidate is the 5-instrument CERES dataset
  - RAPS and PAPS modes
  - 10 km (TRMM) or 20 km resolution (Terra and Aqua)
- POLDER
  - 14-view capability and its 6-km resolution (nb-bb)
- GERB (40 km and 15 min sampling) with SEVIRI
  - a given area of the Earth is always observed with the same VZA
- Other instruments
  - MISR, ATSR-2 and AATSR
  - historical ERBE and ScaRaB

Find how the 3 directions of the prospective BBR are representative of the radiance field for different cloudiness and cloud type.

Imager information from MSG/SEVIRI, MODIS and NOAA-AVHRR will also be obtained for different periods, which will provide horizontal cloud field structures for different selected cloud systems.

Task 2: Scene definition

The second task defines the scenes upon which the angular models will be built, by taking into account information provided by the statistical analysis of real data, and realistic 3D radiative transfer simulations

By scene definition we understand the classification of any radiance in one and only one group of observations of targets with similar anisotropic behaviour. Each group is defined by a set of surface and atmosphere parameters

This task has two main objectives

- to establish the classification of scenes that will be used in the angular models generated from the database produced in Task 1,
- to generate representative radiance fields from 3D radiative transfer simulations for each of the scenes selected

Task 3: ADMs, BRDFs and surface albedo

The objective is the construction of ADMs specifically suitable to along-track measurements

ADMs employed in ERBE, ScaRaB and CERES missions make use of only one radiance in the inversion process

With the along-track configuration, 3 almost simultaneous radiances will be available for the same target, thus providing more information on the anisotropy of the observed scene

It is assumed that surface bidirectional reflectance distribution functions (BRDFs) and surface albedo are input parameters for the simulation. TOA BRDFs and TOA albedo are outputs either from the BBR representative data base or from the radiative transfer calculations.

Main problems and proposed solutions

Practical Problems

Task 1: Selection of a representative dataset

Each satellite data set taken separately responds only partially to the needs of the study

POLDER-1 (November 1996 to June 1997, period with no NFOV BBR in space)

Overlap of CERES/TRMM and CERES/Terra (March 2000, only)

Better perspectives for the coming years

'pre-validated' POLDER-2 and GERB data (?)

Angular Sampling

Even the 14 observation views of POLDER are far from providing a complete angular coverage. Furthermore only VZAs smaller than 60° are recorded.

Combination of complementary satellite data sets. But...

Co-registration of data coming from different platforms is not perfect

Start with CERES

Enrich with POLDER, GERB, MISR, AATSR,...

Additionally NOAA-AVHRR to determine horizontal cloud field structures for different selected cloud systems (convective cloud fields, stratiform cloud fields...)

SESAT (Berger, 2001) allows the determination of cloud properties (cloud cover, cloud top temperature and reflectance as well as cloud optical depth and cloud droplet radii and/or cloud ice crystal sizes.

Main problems and proposed solutions

Task 2: Scene definition

Two main problems to overcome:

- Sampling
- Specific characteristics of the platform/sensor

As regards to sampling

The starting point for this study will be the scene definition adopted in the construction of CERES/TRMM ADMs, which include 592 scenes in SW, and 1036 in LW (Loeb et al., 2002).

CERES/TRMM flew in a 35º inclined orbit, and therefore it only provides sampling measurements for the tropical region. That means that the conclusions of the study would only be valid for those conditions. However, as planned in Task 1, the database will be updated and implemented with measurements from CERES/Terra, GERB, and POLDER, which cover the climatological regimes not included in CERES/TRMM data.

Main problems and proposed solutions

Task 2: Scene definition

Regarding the sensor spatial resolution, there are several issues to deal with

Spatial noise: the pixel size changes when VZA increases

The reference level: changes in the scenes observed by nadir and off-nadir views.

In order to study these issues, full 3D radiative transfer simulations for the conditions of each scene will be carried out. These theoretical results will help to evaluate the impact of 3D effects in the radiance to flux inversion depending on the scene.

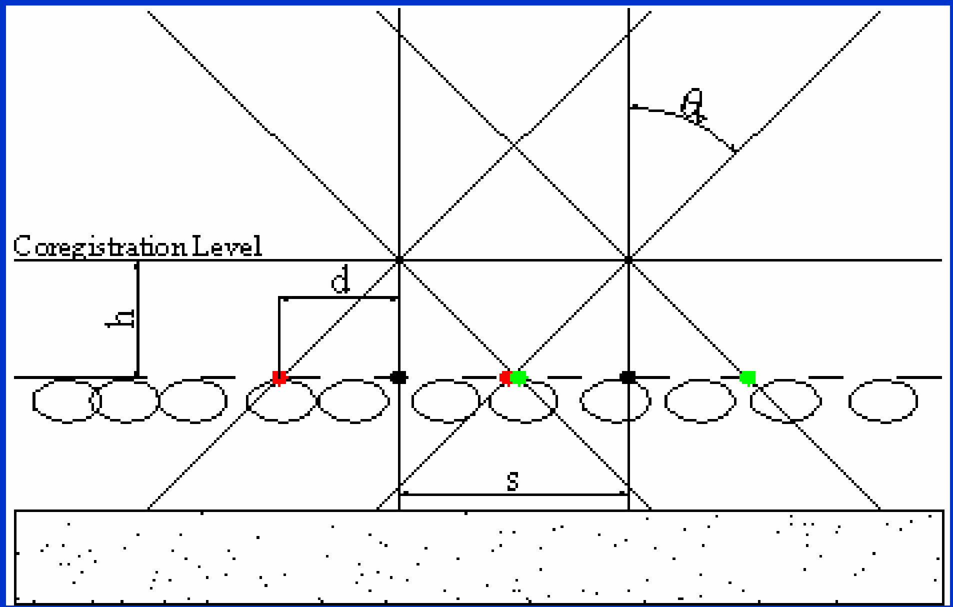
Another general issue concerning along-track measurements is the spatial coverage. Along-track data typically leave many gaps between measurements and, therefore, the spatial sampling is worse than for cross-track measurements, and this becomes an error source when computing regional means. However, since our interest is flux retrieval on an instantaneous pixel basis, the spatial coverage is not a problem, and will not be considered in this study.

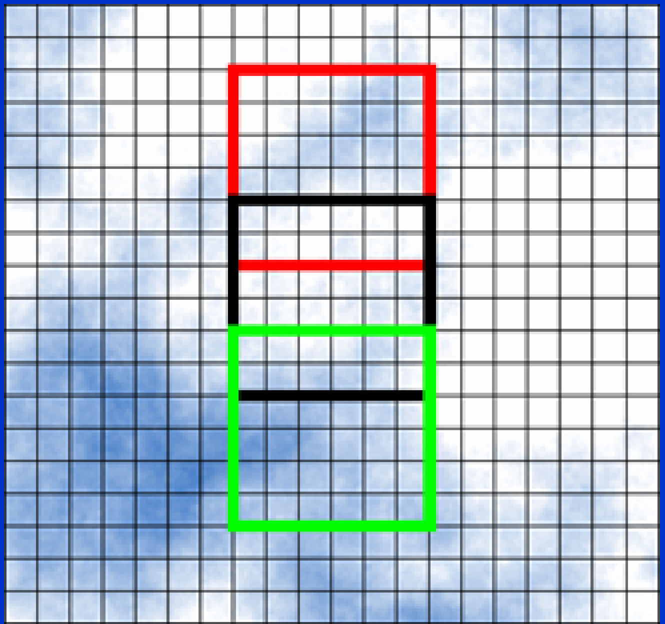
Main problems and proposed solutions

Task 3: ADMs, BRDFs and surface albedo

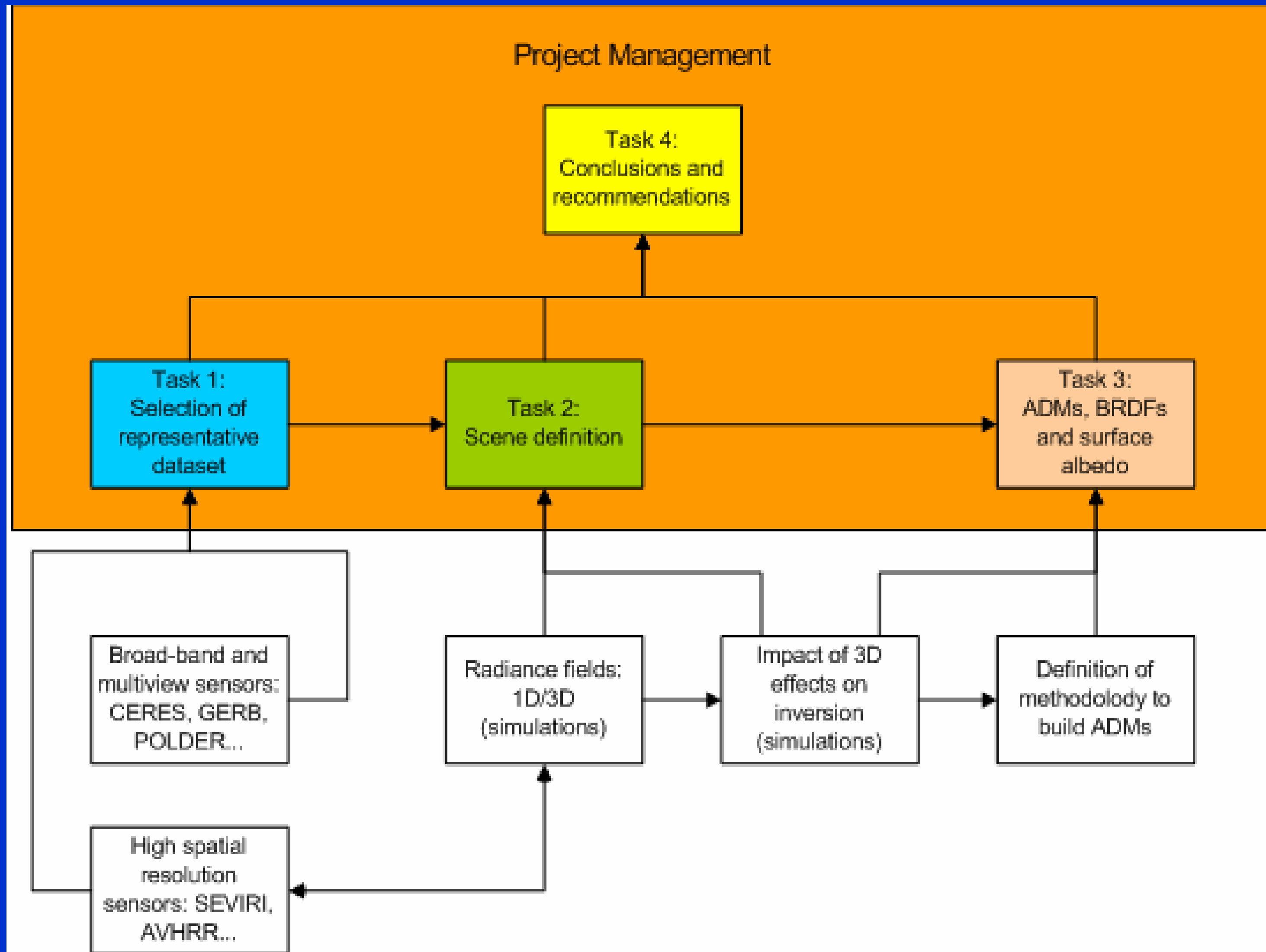
The main problem of making use of the along-track capability to develop angular models is the collocation between the different views of the same pixel

Due to the fact that these problems only arise on scenes with a high degree of spatial variability, they will be studied only in a subset of the scenes defined in Task 2, with the aid of the simulations also generated in Task 2.



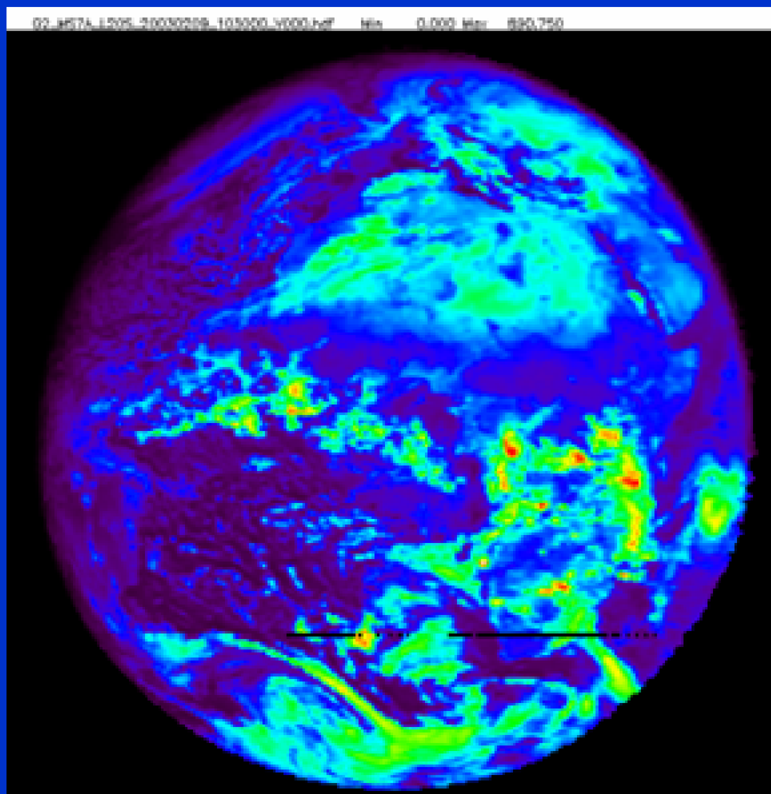


Overall Structure of the Study Plan

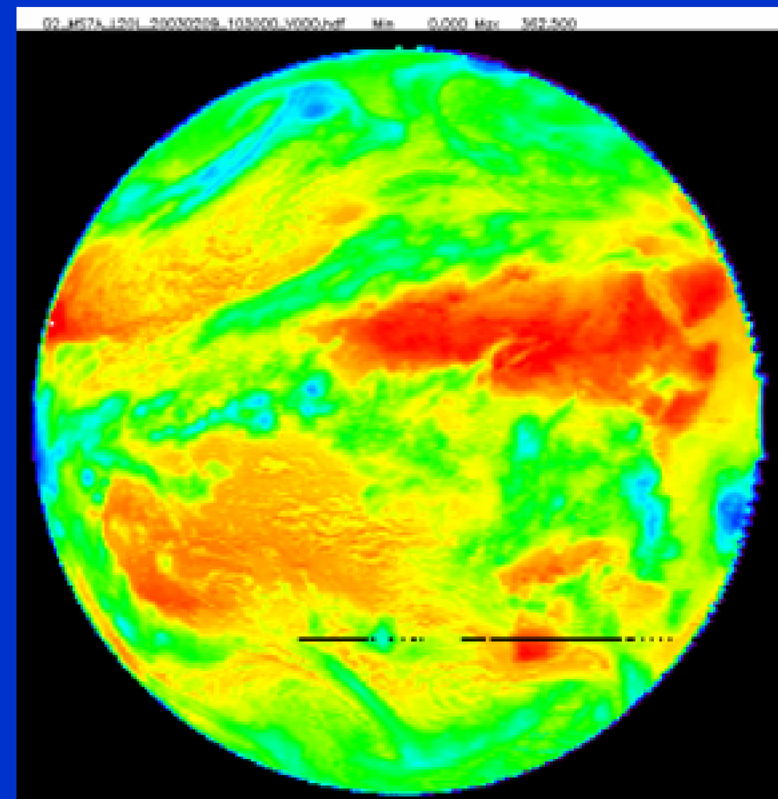


Task 1: Selection of a representative dataset

4 GERB / MSG



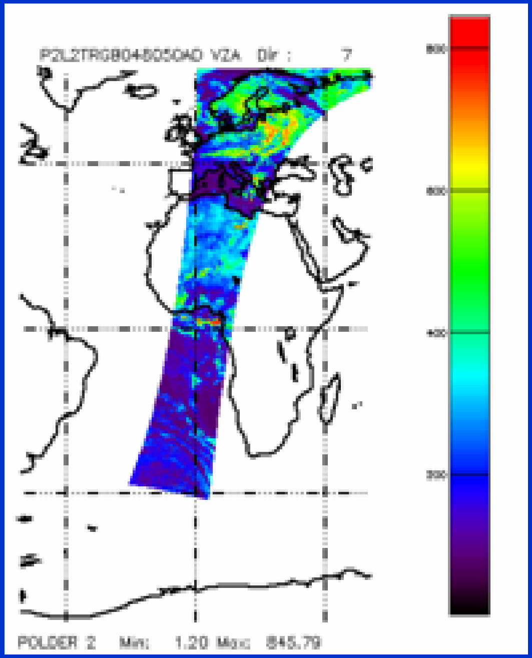
SW

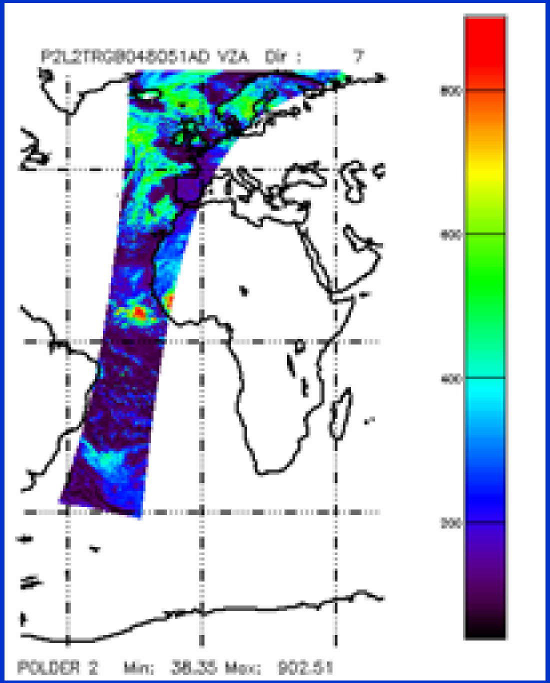


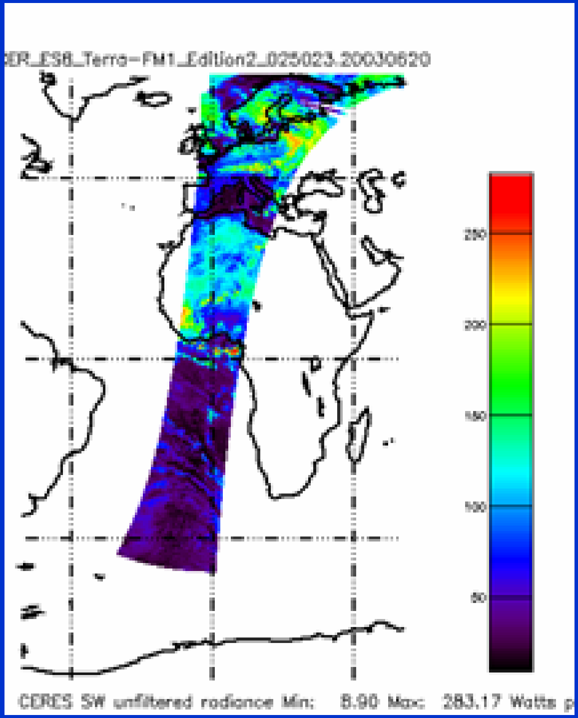
LW

9 fév. 2003 10:30. Resolutions: 40 km, 15 min. fixed VZA

2003, JUNE 20, during SCALES experiment





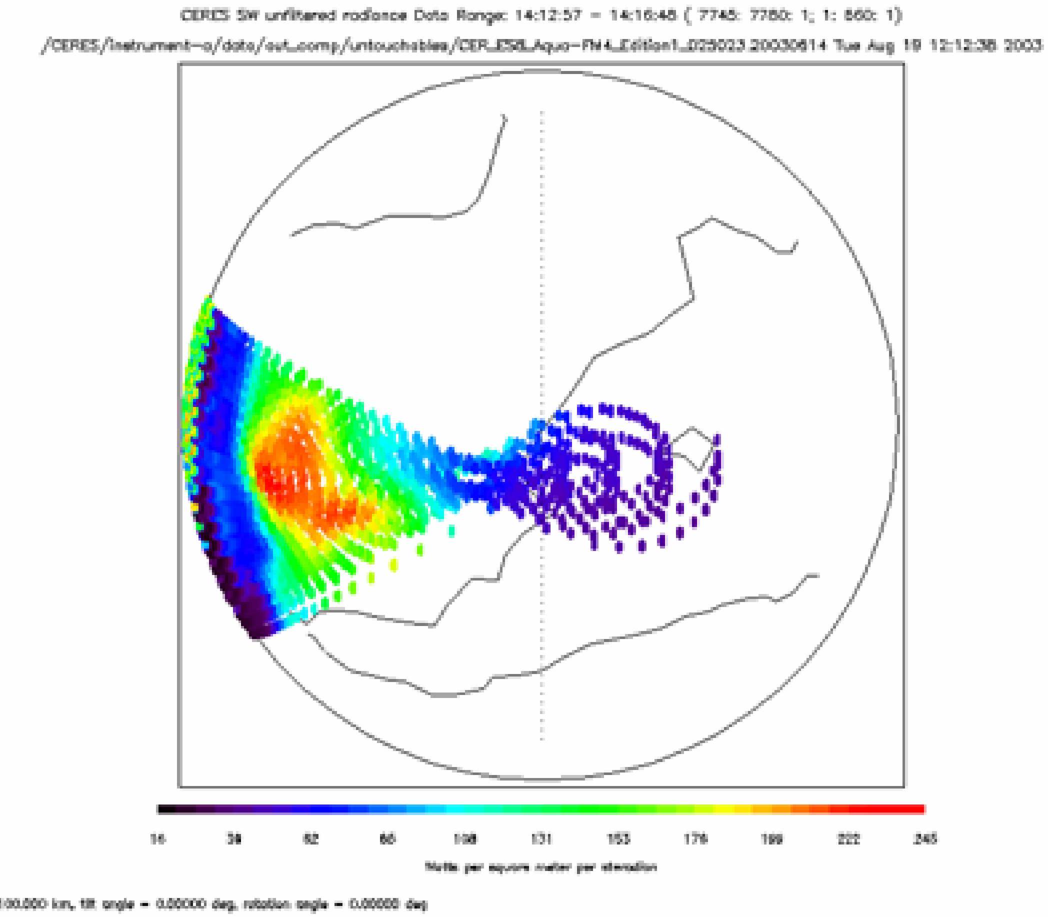


POLDER

CERES

Task 2: Scene definition. Surface BRDF

Surface anisotropy is a main error source in ADMs development



Task 2: Scene definition. Surface BRDF

Kernel-driven BRDF models are generally employed to account for surface reflectivity anisotropy:

$$\rho(\theta_s,\theta_v,\phi)=\sum_{m=1}^{m=M}\beta_m f_m(\theta_s,\theta_v,\phi)$$

Usually, three physically meaningful kernels are distinguished:

$$\rho(\theta_s,\theta_v,\phi)=\beta_{iso}f_{iso}+\beta_{geo}f_{geo}(\theta_s,\theta_v,\phi)+\beta_{vol}f_{vol}(\theta_s,\theta_v,\phi)$$

Isotropic term

Optical-geometrical (surface scattering) term

Radiative transfer (volume scattering) term

Task 2: Scene definition. Surface BRDF

Roujean's BRDF model is wide spread in the modelling of surface reflectivity anisotropy. This model has an isotropic, a geometric scattering and a volume kernel:

$$\rho(\theta_s,\theta_v,\phi)=\beta_0+\beta_1 f_1(\theta_s,\theta_v,\phi)+\beta_2 f_2(\theta_s,\theta_v,\phi)$$

Geometric-scattering kernel

Volume kernel

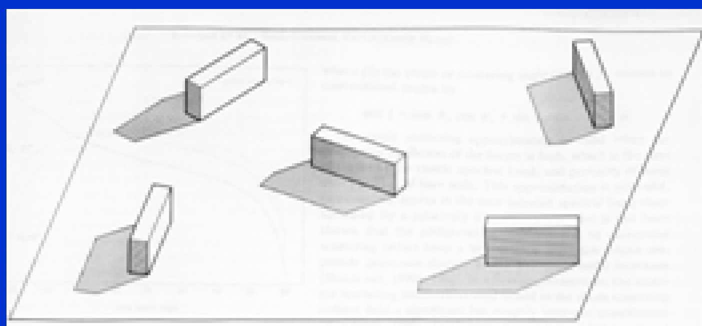


Fig. 1. Random distribution of protrusions inside a subpixel surface.

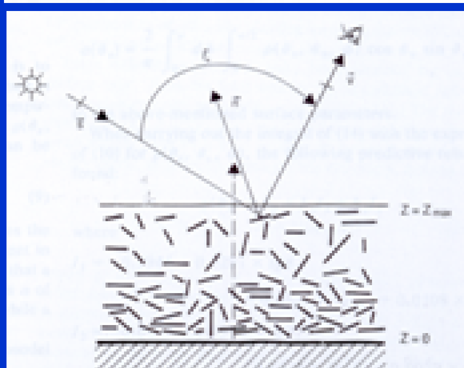


Fig. 3. Single scattering on an infinite discrete medium made of randomly distributed facets.

Task 2: Scene definition. Surface BRDF

Roujean geometric-scattering kernel:

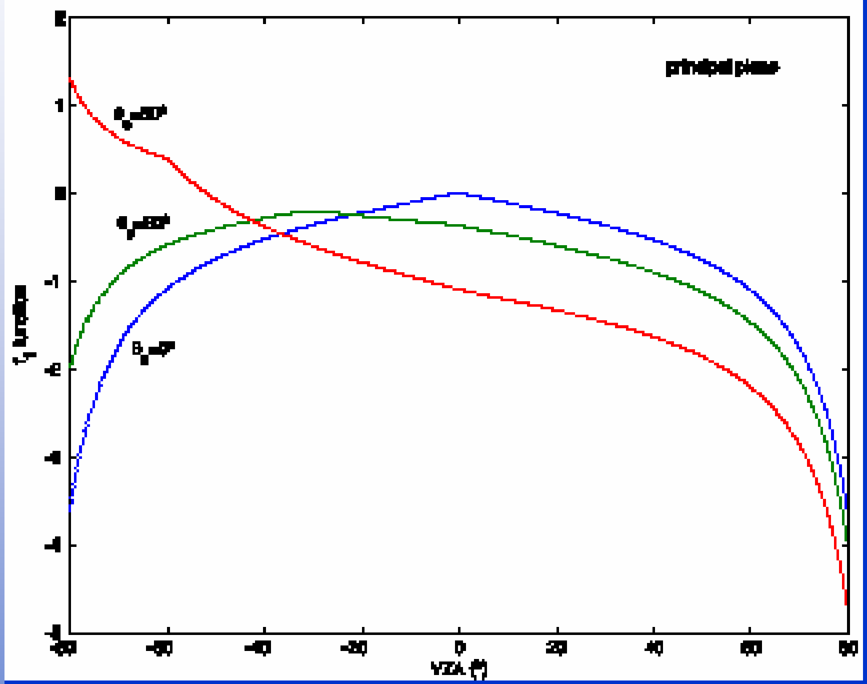
$$f_1(\theta_s,\theta_v,\phi)=\frac{1}{2\pi}\left[(\pi-\phi)\cos\phi+\sin\phi\right]\tan\theta_s\tan\theta_v-\frac{1}{\pi}\left(\tan\theta_s+\tan\theta_v+\sqrt{\tan^2\theta_s+\tan^2\theta_v-2\tan\theta_s\tan\theta_v\cos\phi}\right)$$

Roujean volume kernel:

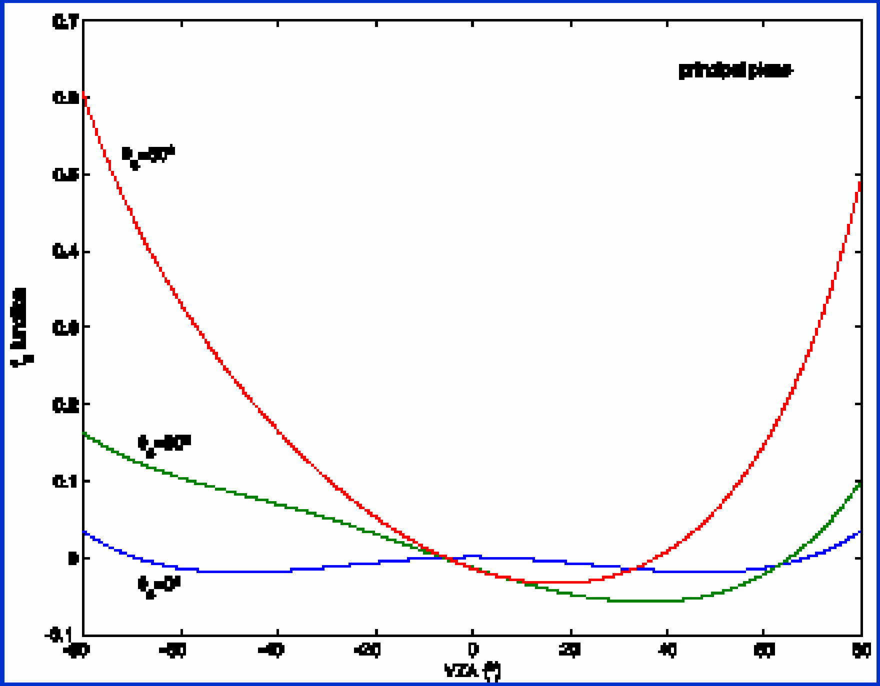
$$f_2(\theta_s,\theta_v,\phi)=\frac{4}{3\pi}\frac{1}{\cos\theta_s+\cos\theta_v}\cdot\left[\left(\frac{\pi}{2}-\xi\right)\cos\xi+\sin\xi\right]-\frac{1}{3},$$

$$\cos\xi=\cos\theta_s\cos\theta_v+\sin\theta_s\sin\theta_v\cos\phi$$

Task 2: Scene definition. Surface BRDF



Roujean geometric-scattering kernel



Roujean volume kernel

TOA Flux Working Group Meeting

Task 2: Scene definition. Surface BRDF

Also other alternative non-linear BRDF models have been proposed, such as

- RPV (Rahman, Pinty and Verstraete)
- MRPV (MISR version of RPV, suggested by Martonchik)
- Staylor and Suttles
- Reciprocal Li models

Task 2: Scene definition

Characteristics of radiation calculations in EarthCARE sumulator

- gaseous attenuation: CKD method (Correlated K distribution)

- 4 types of ice crystals
- liquid droplets
- 5 types of aerosols

} scattering properties are tabulated in 1 μm bins

- 10 surface types + ocean

- SW and LW narrowband and broadband fluxes and radiances

Task 2: Scene definition

Clouds and the EarthCARE simulator

- typically, the simulator operates on cloud fields produced by cloud-resolving models

- can use idealized scenes too (e.g., slabs, cubes, etc...)

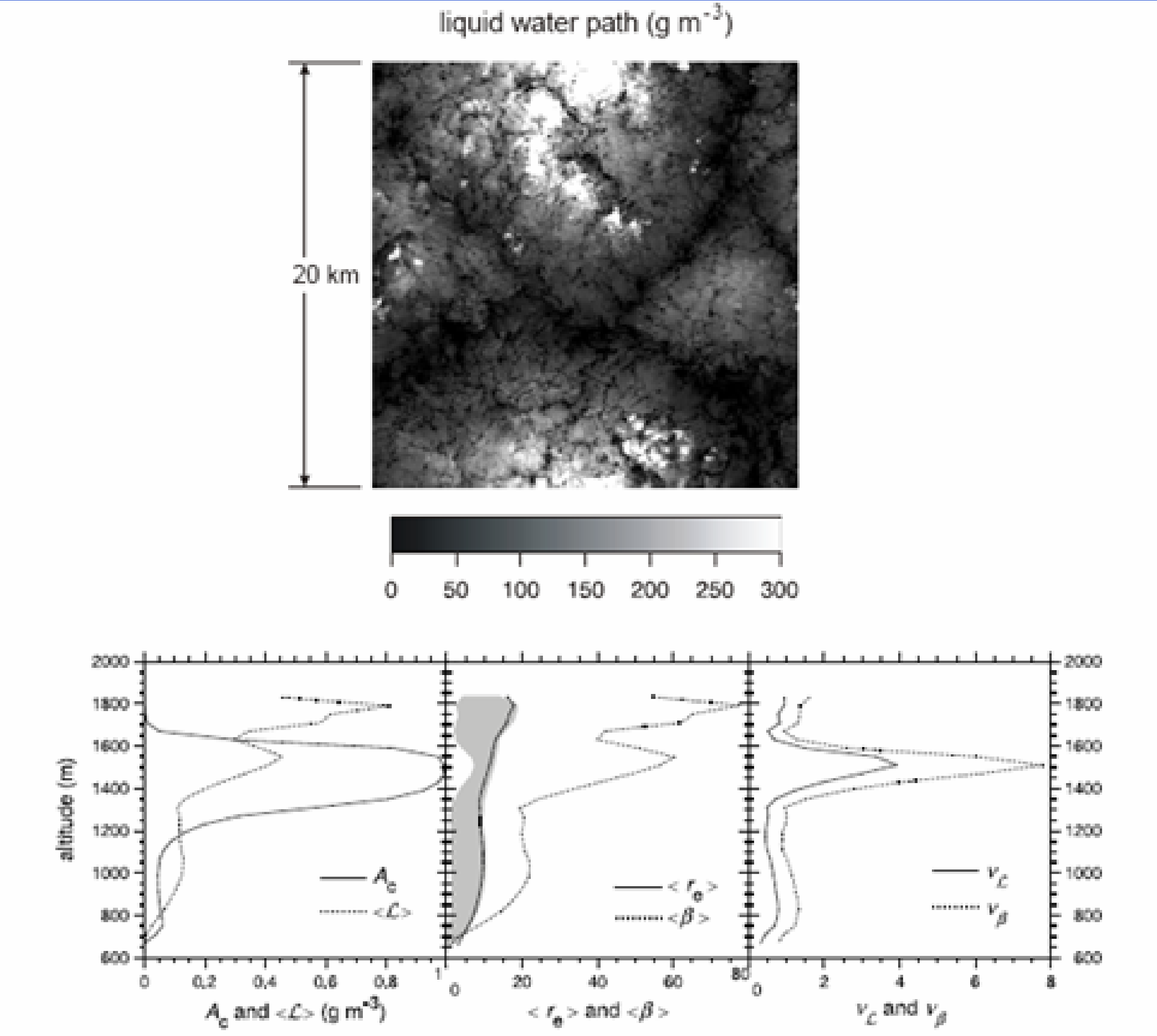
Task 2: Scene definition

Example: Numerical simulation of MODIS radiances

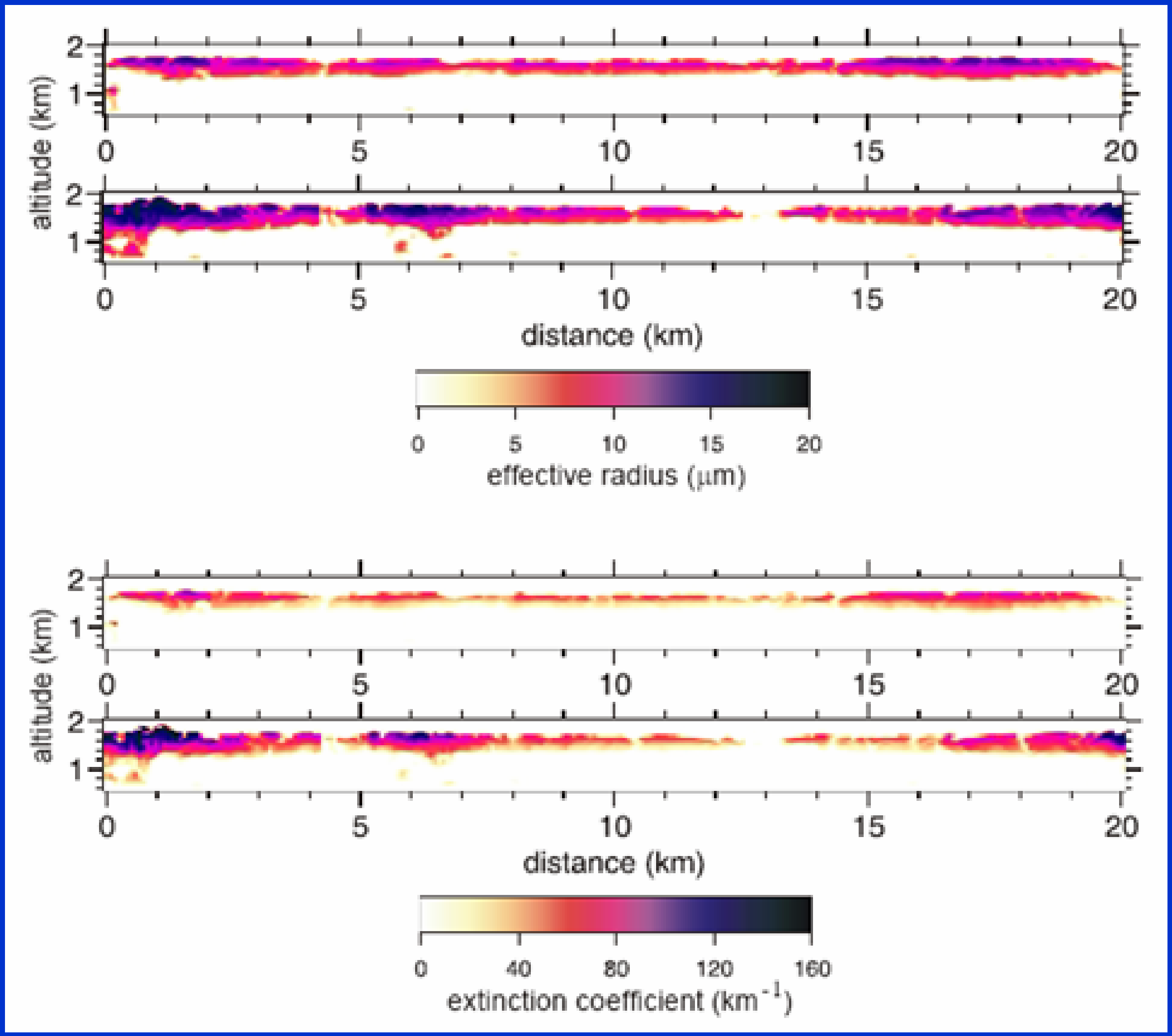
- 3D cloud field from cloud system resolving model
- nadir radiances (MODIS: 2, 6, 7, 20) simulated by Monte Carlo algorithm

- CRM data : D. Stevens et al. (2002)... ATEX - trade Cu beneath marine StCu
    - grid-spacings: 40 m x 20 m domain size: 20 km x 20 km x 4 km
- gamma droplet size distribution
    - $N_{cld} = 100\ cm^{-3}$; $v_{eff} = 0.1$
- no other attenuators
- black surface (ocean)

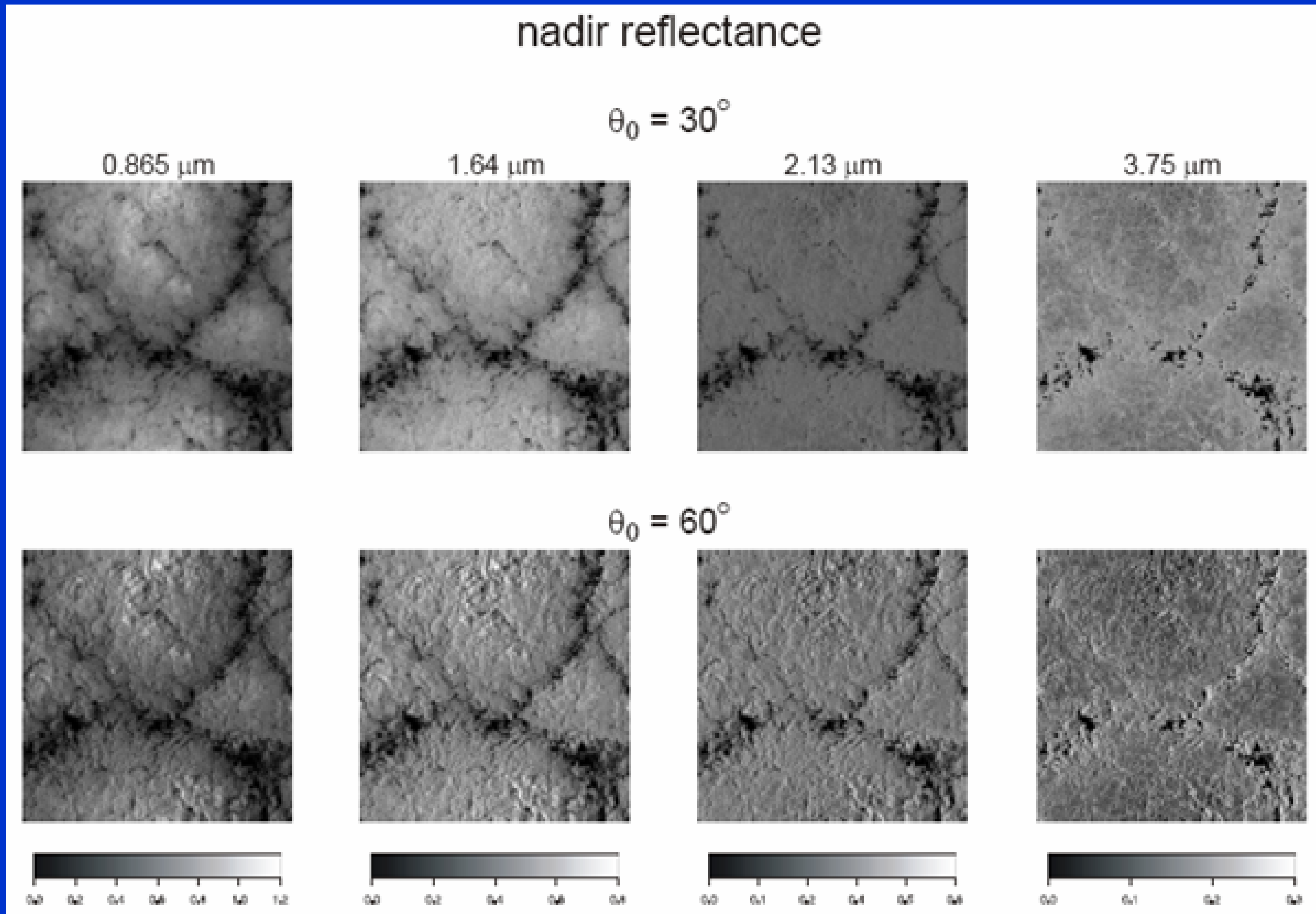
Task 2: Scene definition



Task 2: Scene definition



Task 2: Scene definition



Task 2: Scene definition

Simulated radiances (looking towards the Sun) for clouds associated with cold air advecting over warm ocean

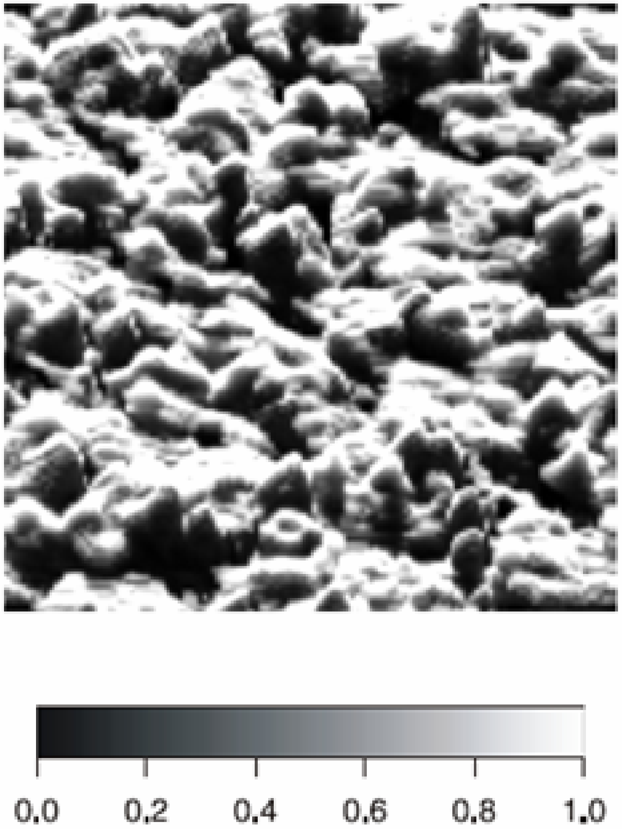
CRM data : Anderson et al. 1997

390 m x 50 m

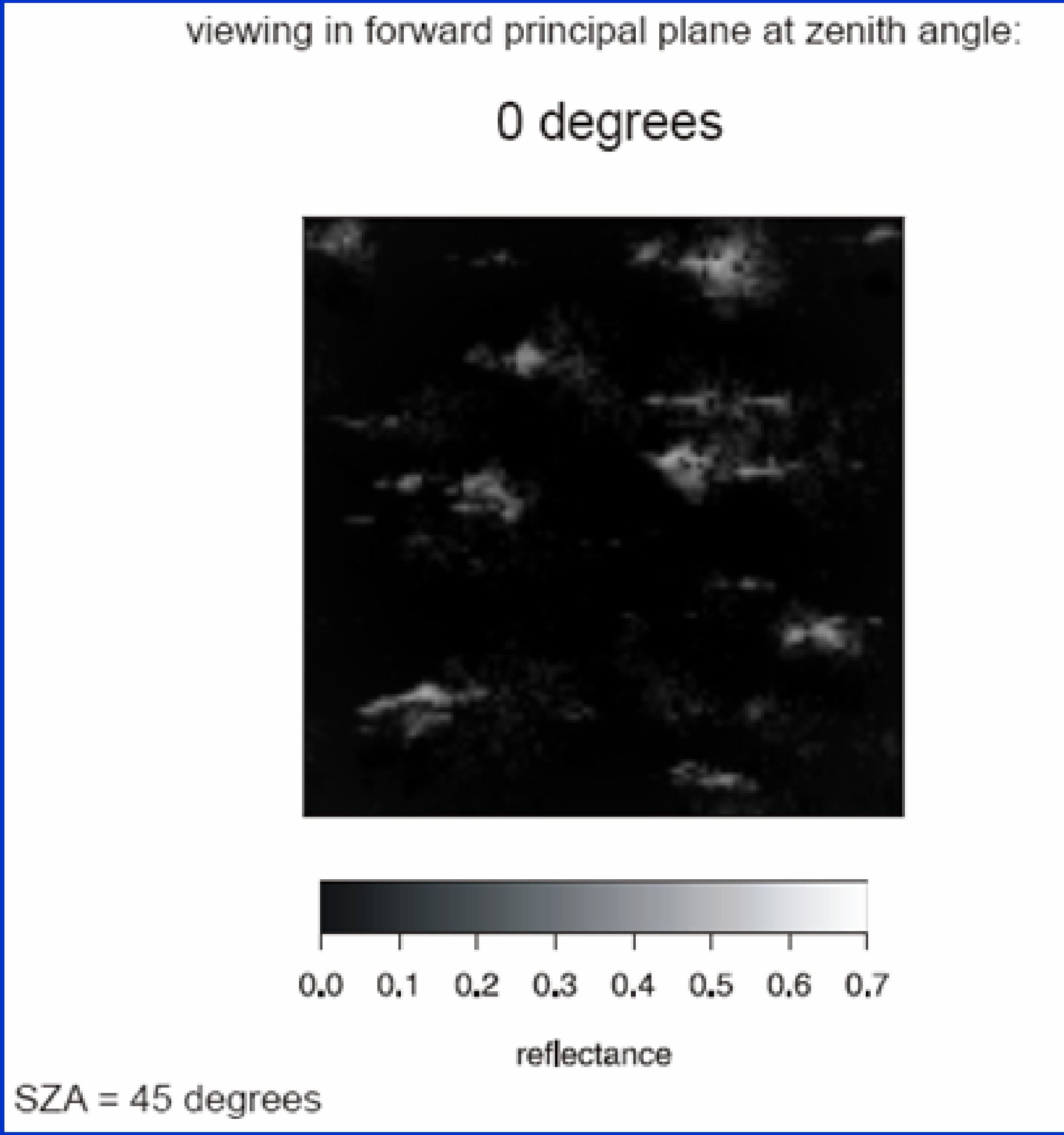
CCD = 100 cm^{-3}

v_c = 0.1

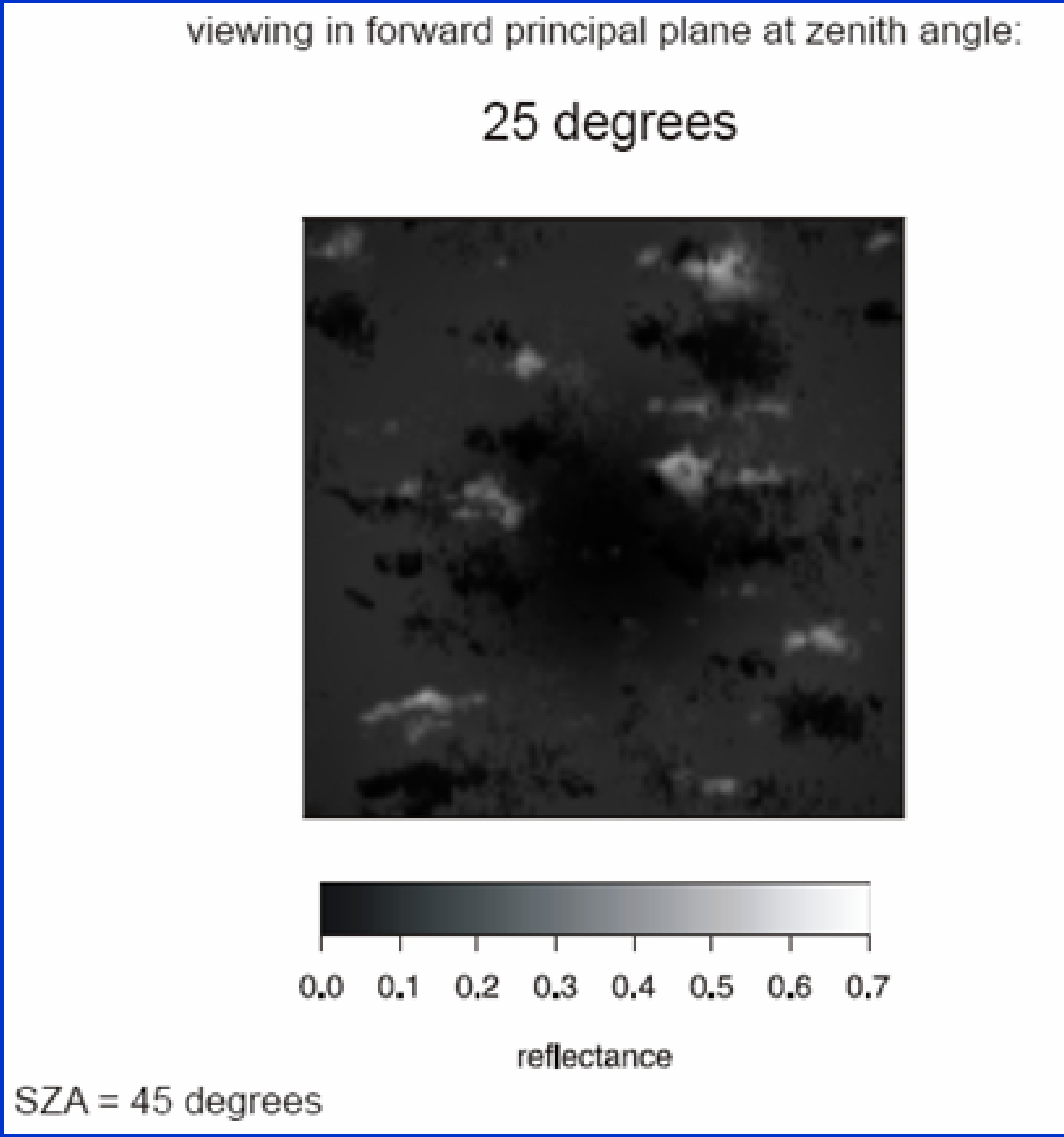
black surface



Task 2: Scene definition



Task 2: Scene definition



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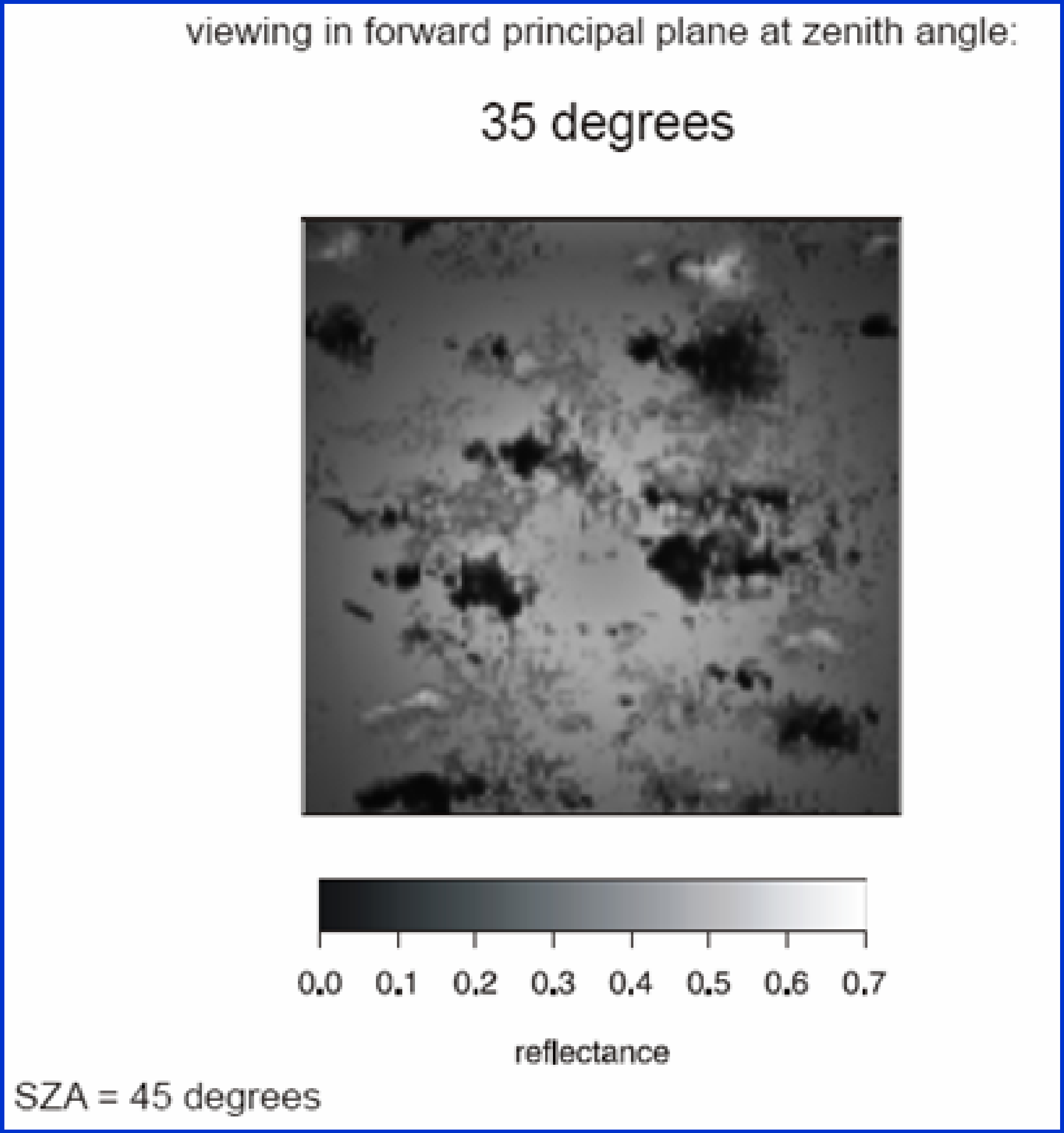
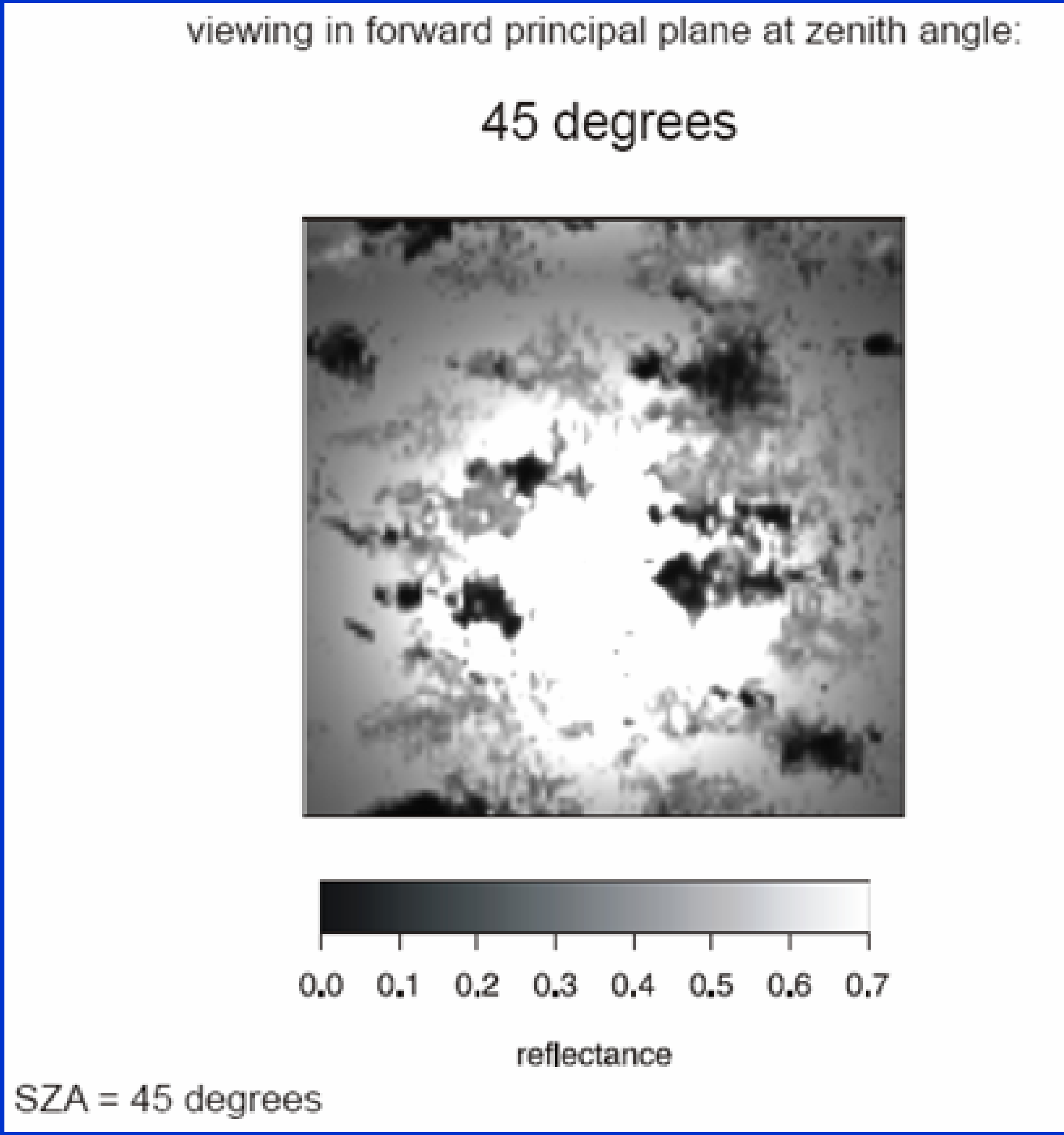
Task 2: Scene definition



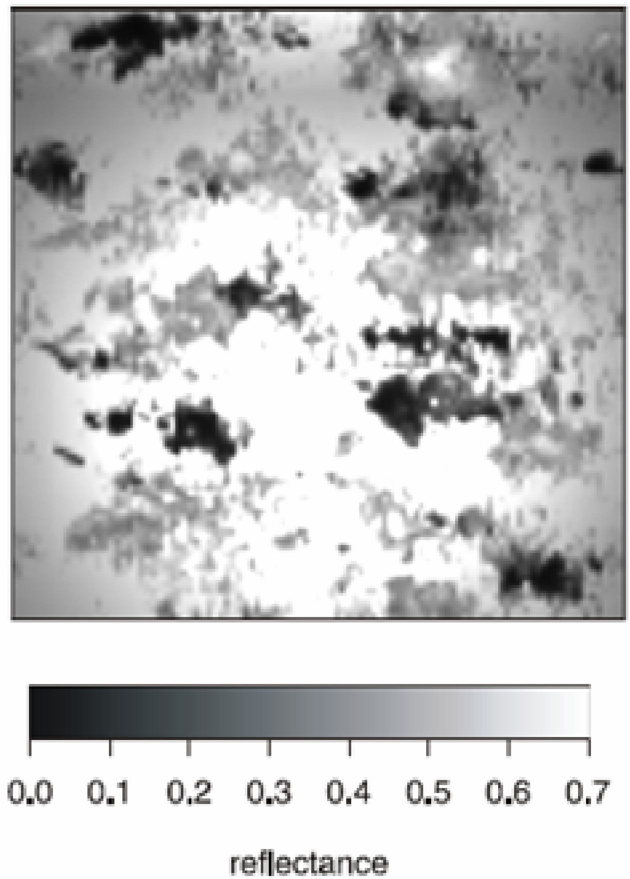
Task 2: Scene definition



Task 2: Scene definition

viewing in forward principal plane at zenith angle:

55 degrees



SZA = 45 degrees

Selection of representative data sets

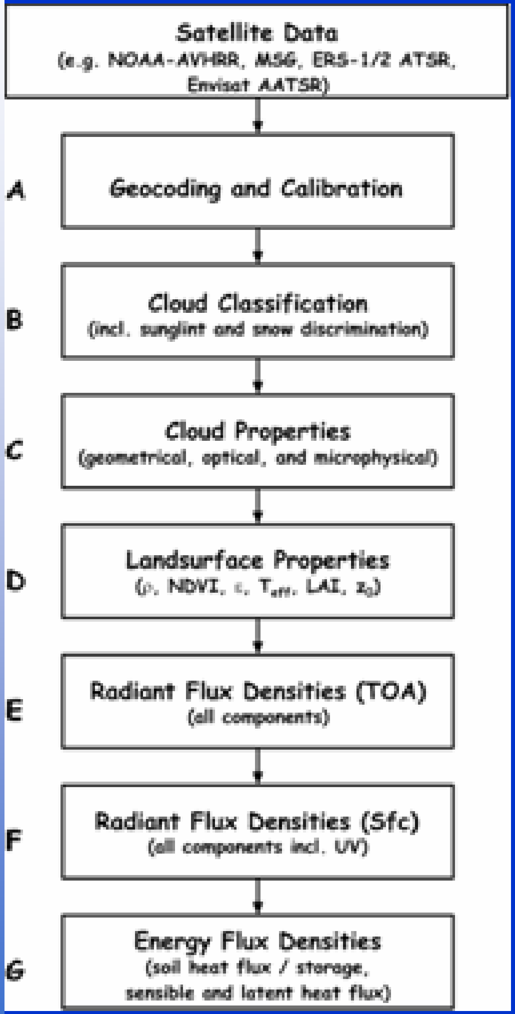
WP 1.2: High resolution data selection

1. Adaption of SESAT (satellite data analysis scheme) to *Meteosat-8* (former *MSG*-1) SEVIRI data

2. Scene definition for *Meteosat-8* SEVIRI and GERB data and selection of representative data

3. Scene analysis with *Meteosat-8* SEVIRI data (SESAT)

4. Scene analysis with NOAA-16/17 AVHRR data (SESAT)



SESAT (Berger, 2001)

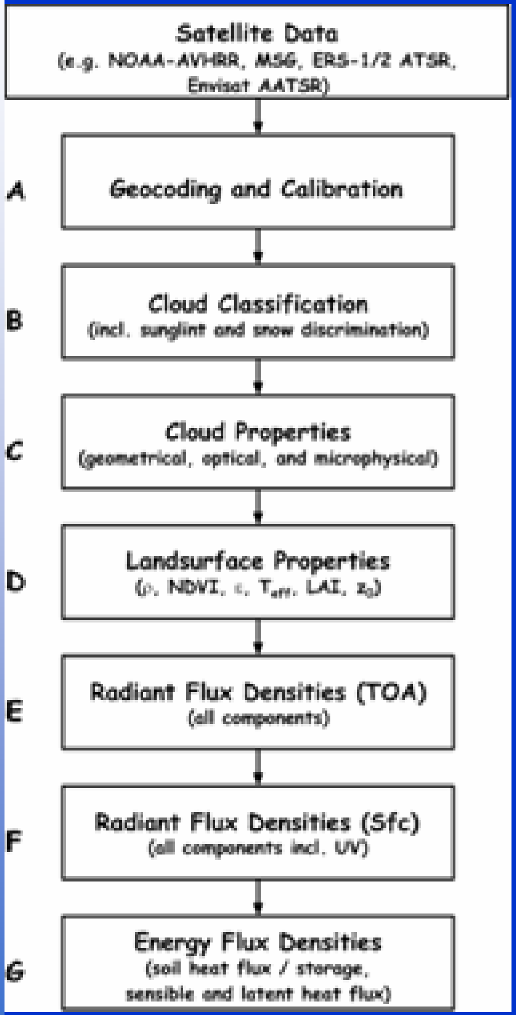
(**S**trahlungs- und **E**nergieflüsse aus **Sat**ellitendaten)

1. **developed for NOAA-AVHRR, ERS-1 ATSR, MSG SEVIRI and Envisat AATSR data** (all using highest available spatial resolution)

2. **and tested with more than 1000 AVHRR data sets (Baltic Sea, Central Europe, worldwide)**

3. **partly tested (cloud classification / cloud forcing) with more than 600 AVHRR data sets (North Sea) / LAC/GAC data** (Berger, 1995)

SESAT – Overview



complex, modular scheme

⇒ calibration and geocoding

⇒ cloud classification incl. snow and sunglint detection

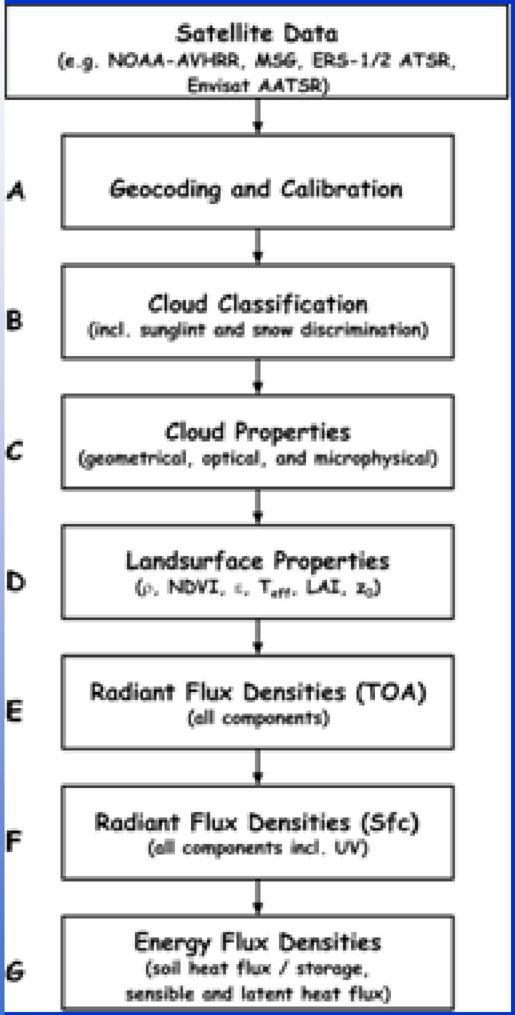
⇒ cloud properties (geometrical, optical and microphysical)

⇒ landsurface properties (reflectance, emissivity, effective, surface temperature, LAI, roughness length)

⇒ radiant flux densities (TOA – all components)

⇒ radiant flux densities (surface – all components, incl. UV)

⇒ energy flux densities (heat storage / soil and canopy, sensible and latent heat fluxes)



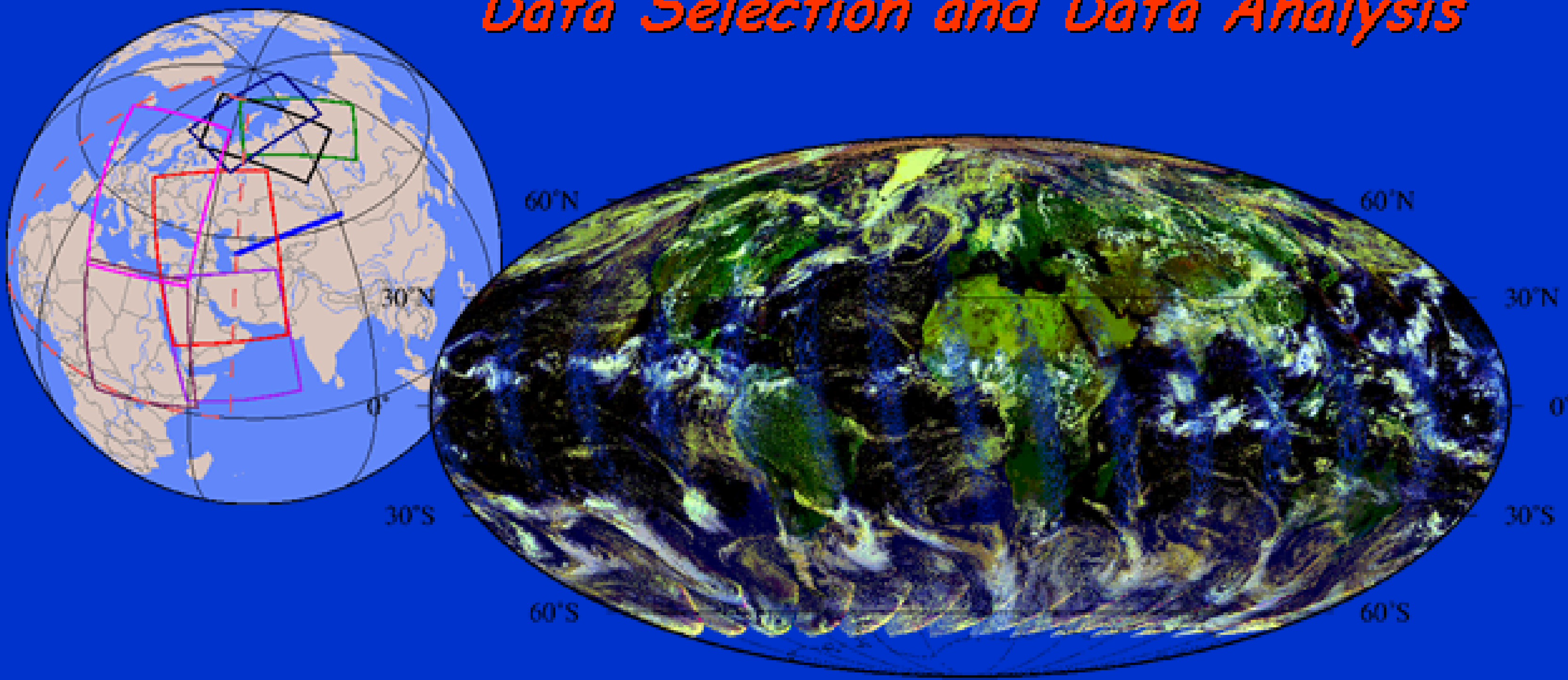
Cloud types, optical and microphysical cloud properties

1. cloud classification incl. sunglint and snow detection (all available channels)

2. cloud optical thickness (0.6 mm channel) – inverse remote sensing technique

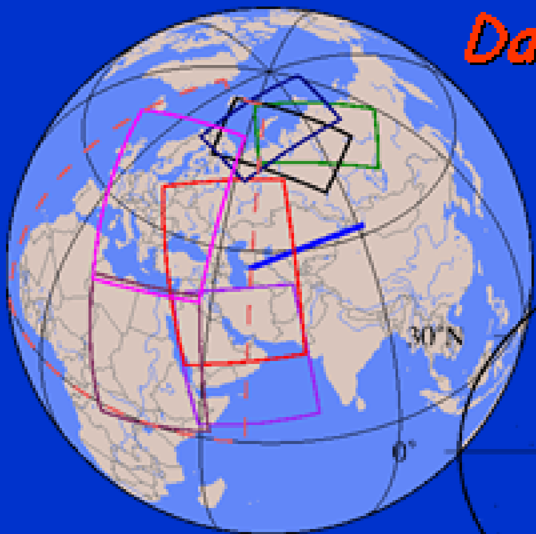
3. Effective cloud droplet radius / ice crystal diameter (1.6 mm) – inverse remote sensing technique

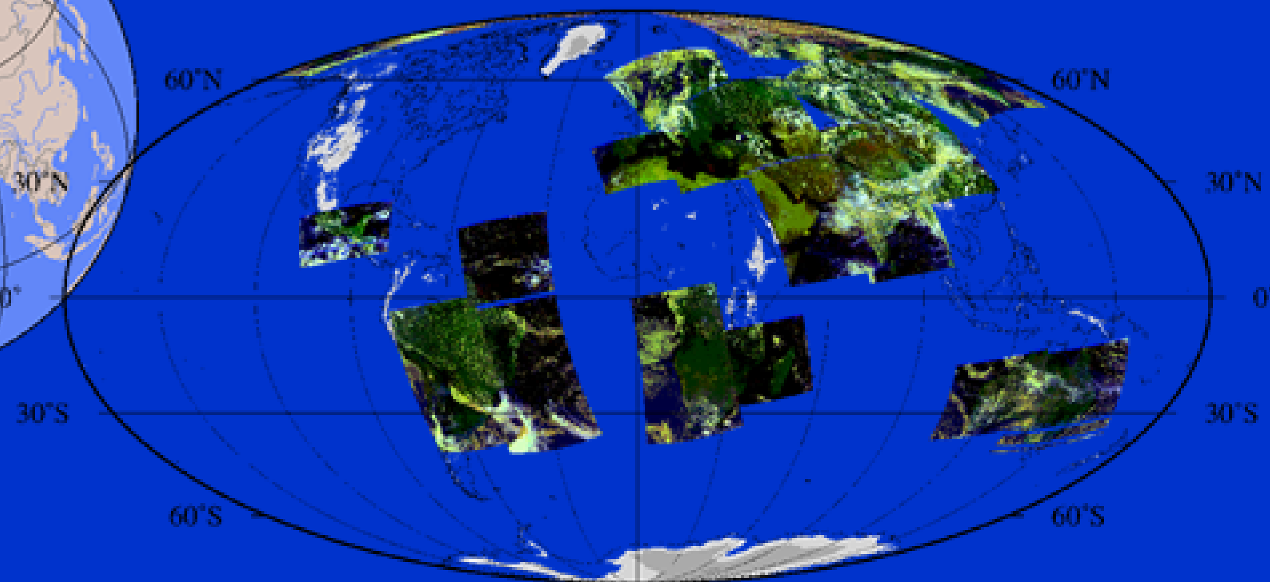
Data Selection and Data Analysis



GAC data – 20 July 2001

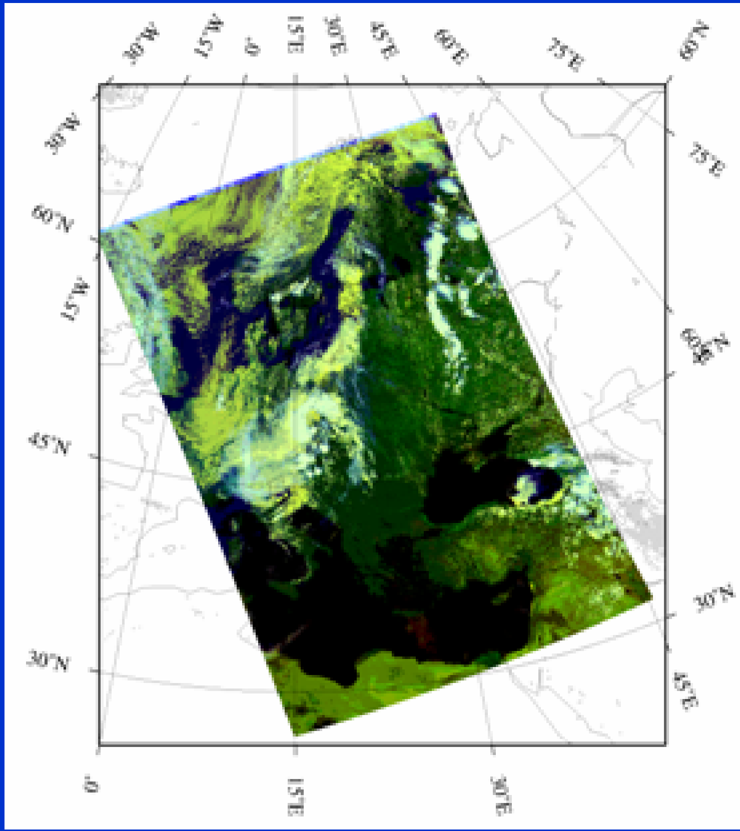
Data Selection and Data Analysis

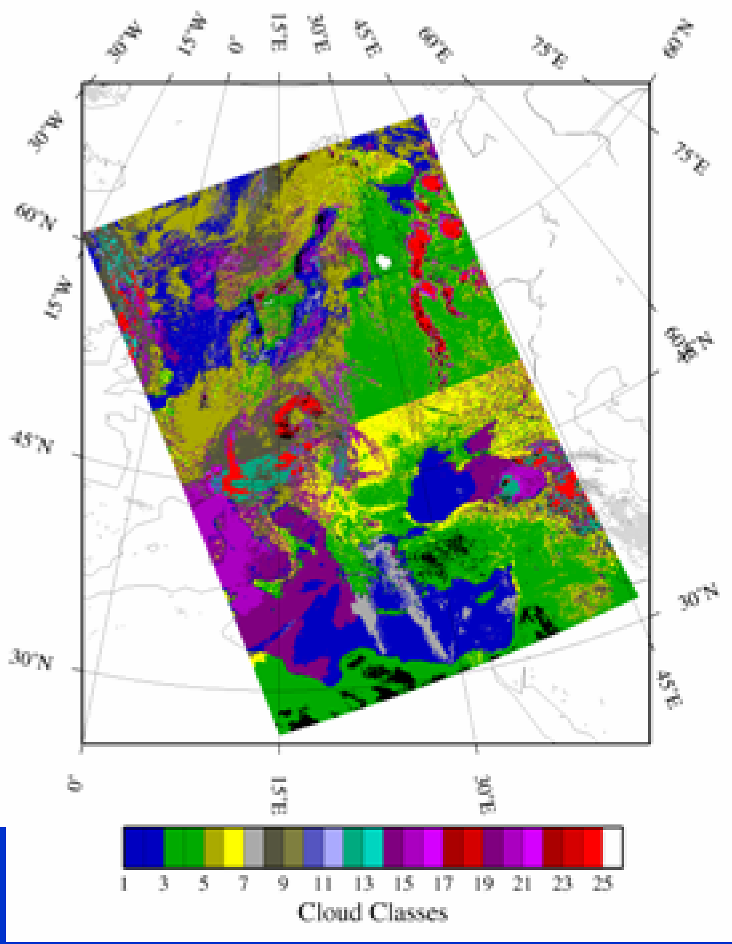




LAC data – 20 July 2001

Previous Results

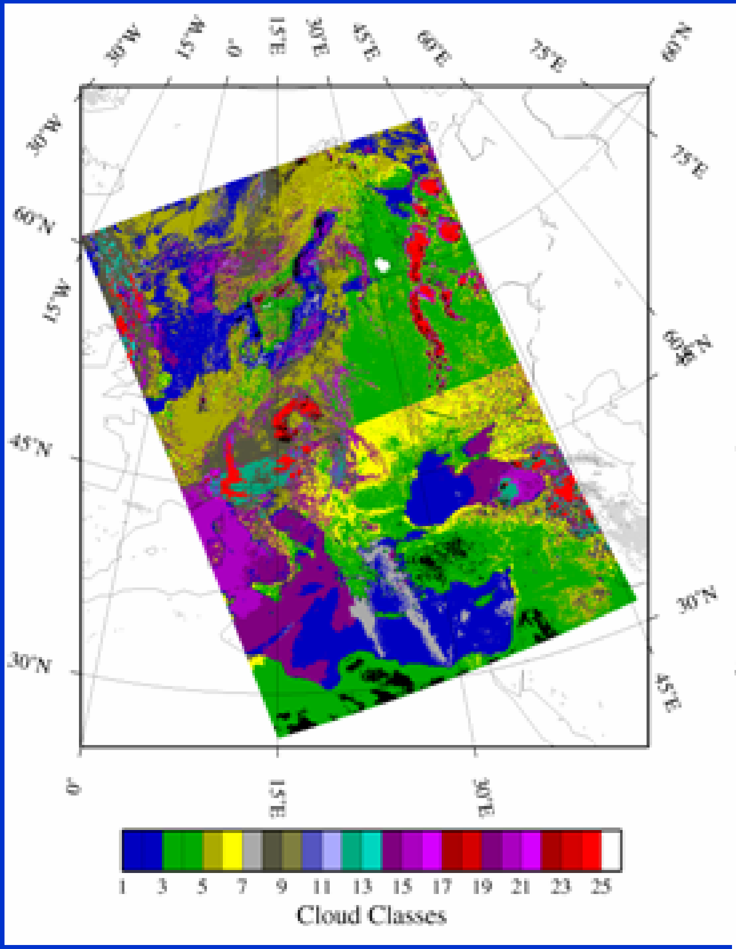


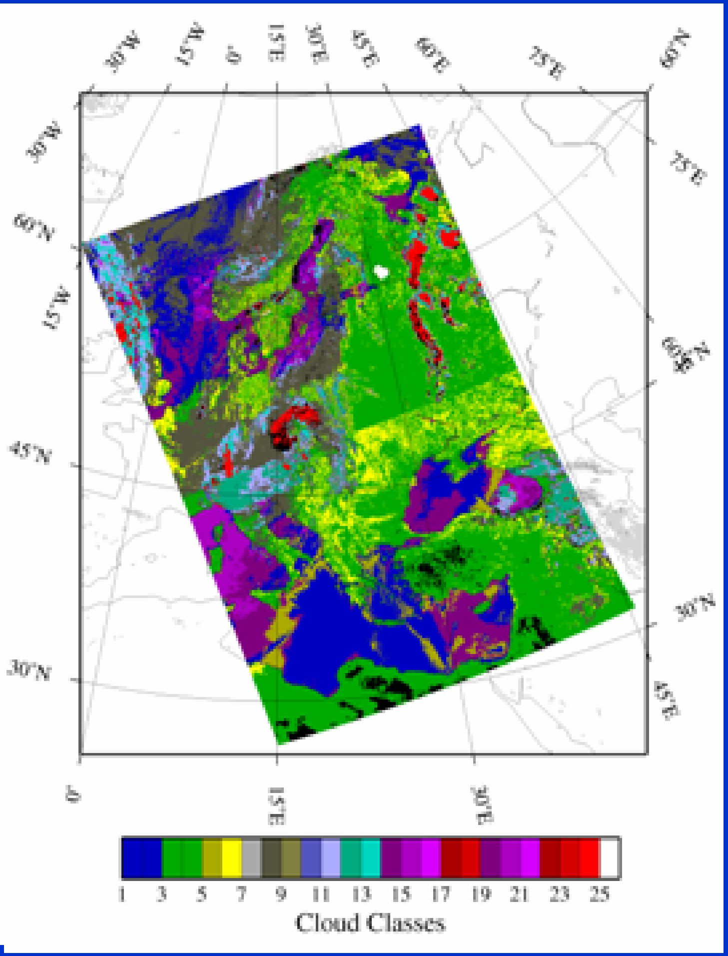


LAC - 20 July 2002
(4260)
Europe

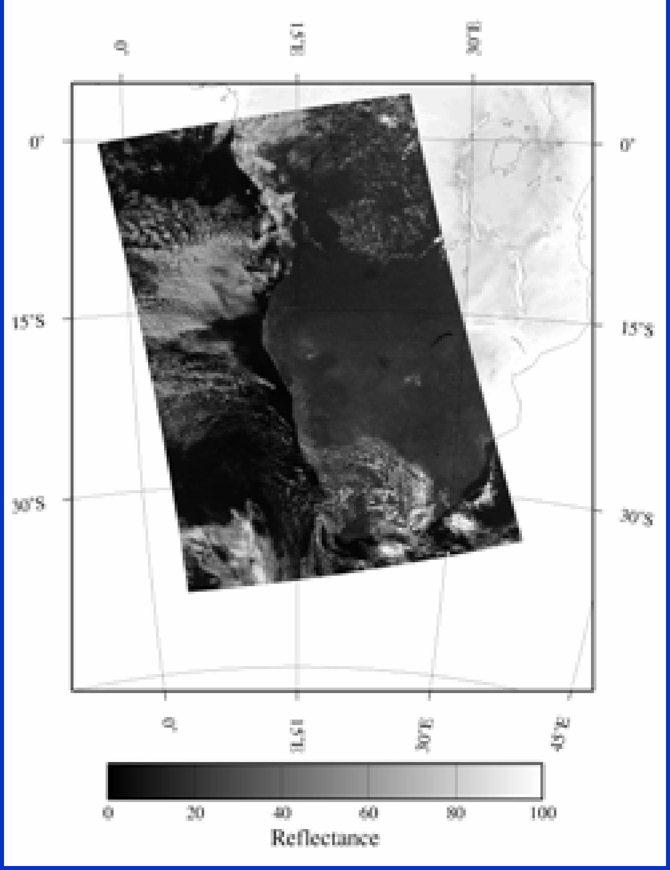
LAC

Previous Results





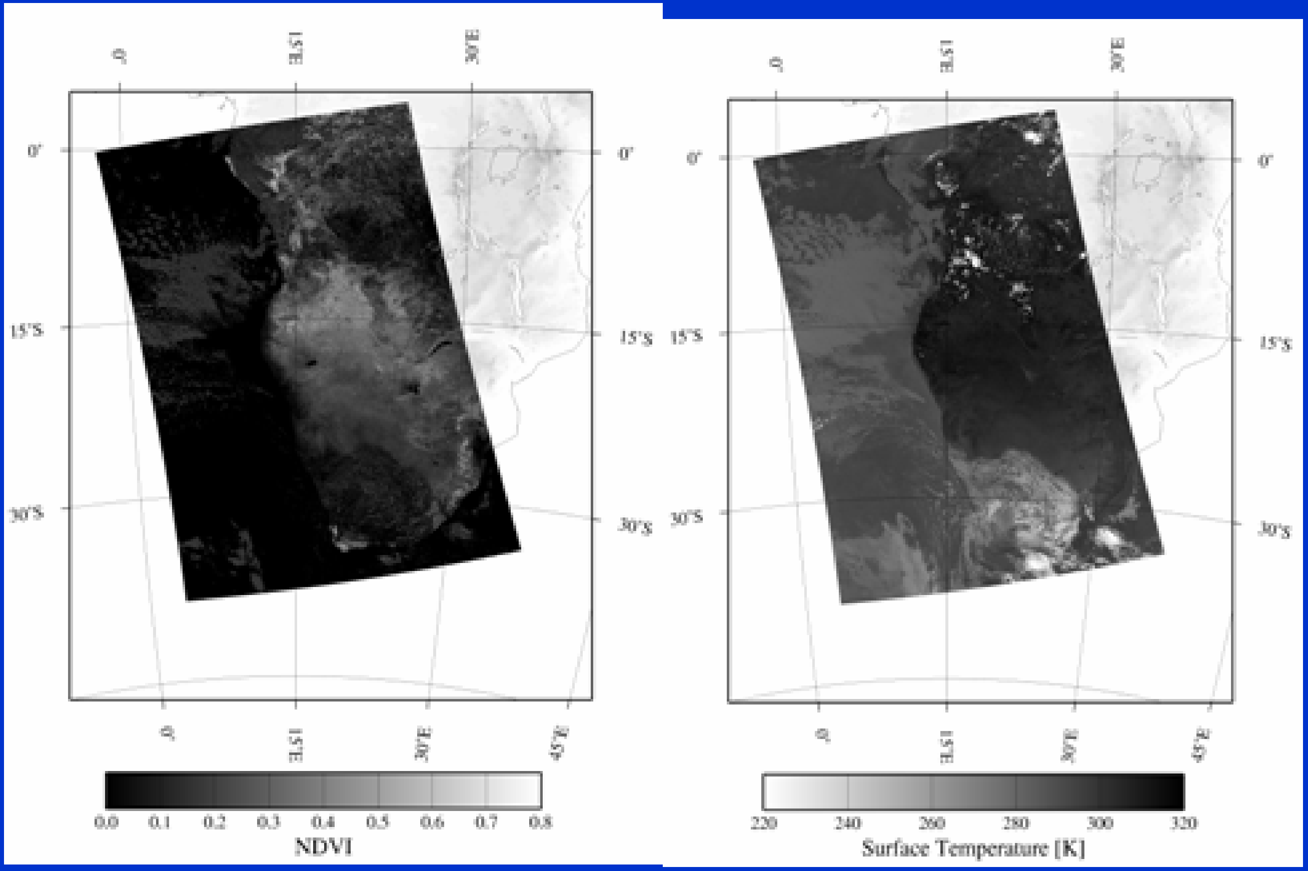
Previous Results - TOA Broadband Reflectance



LAC - 20 July 2001 (4260) - South Africa

TOA Flux Working Group Meeting

Previous Results - NDVI / Surface Temperature



LAC - 20 July 2001 (4260) - South Africa

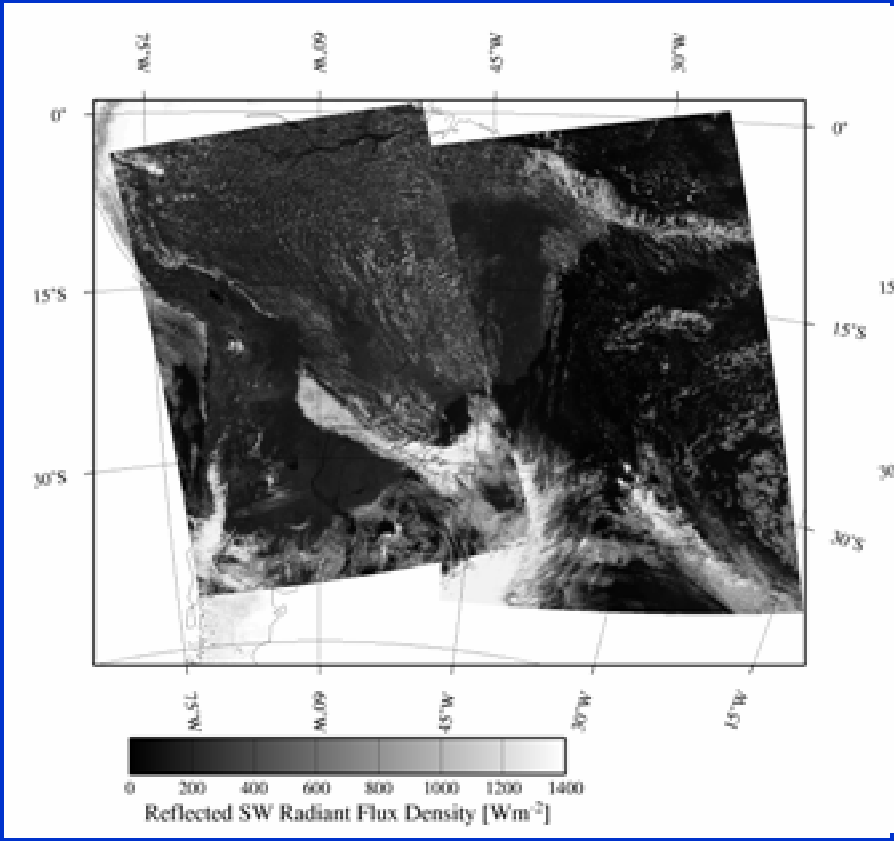
ADM BRDF

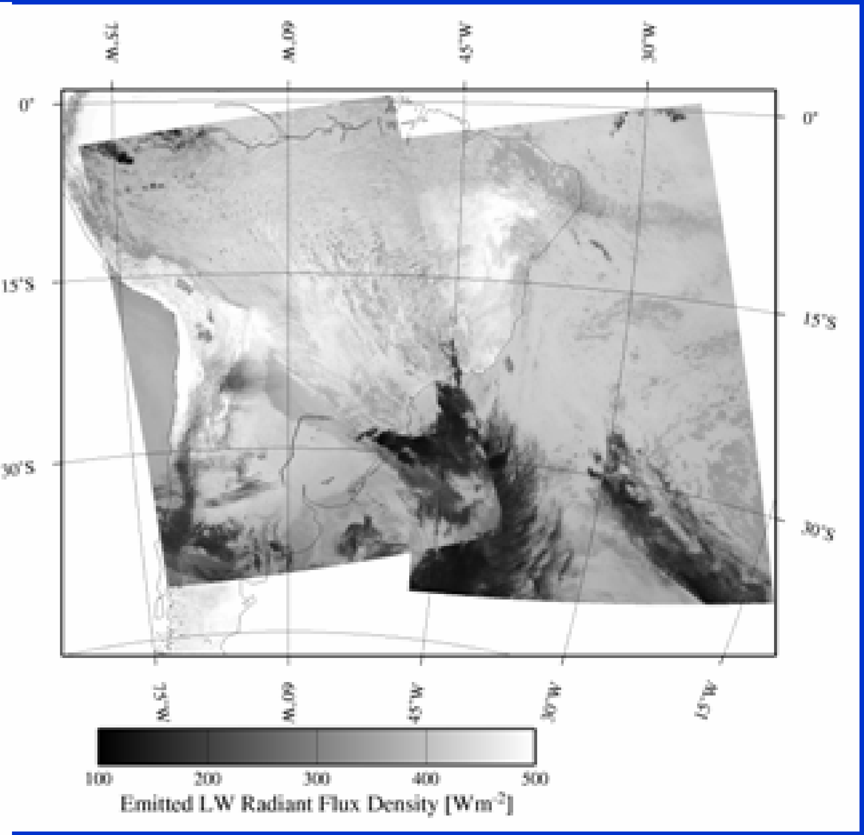
CERES-GERB Meeting. NCAR, Mesa Lab, Boulder, Colorado, USA

March 29 - April 2, 2004

TOA Flux Working Group Meeting

Previous Results - TOA Flux Densities





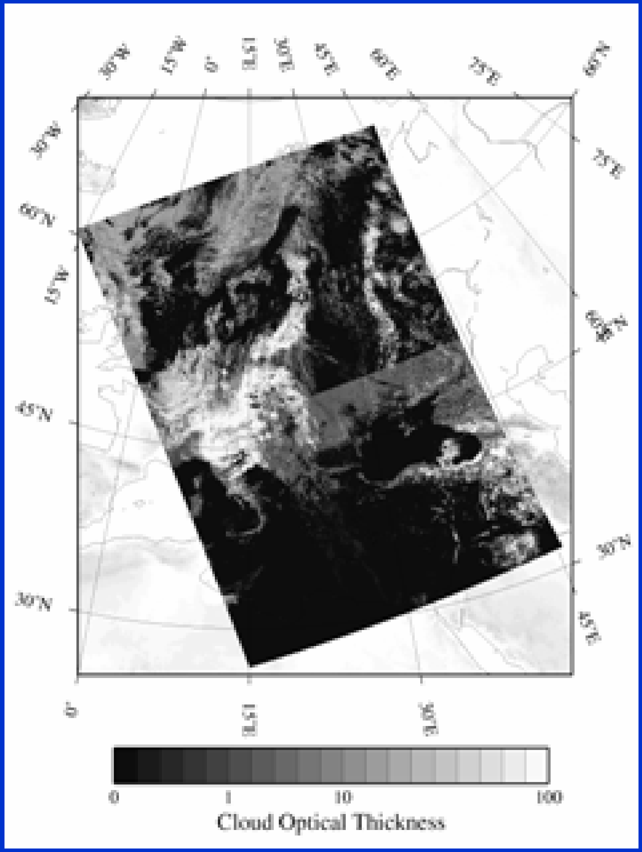
LAC - 20 July 2001 (4262/4263) - South America

Vniversitat de València Facultat de Física LMD/CNRS MSC SMC Technische Universität Dresden

ADM BRDF

TOA Flux Working Group Meeting

Previous Results - Cloud Optical Thickness



LAC - 20 July 2001 (4260) - Europe

First Meteosat-8 / MSG-1 Image

4 December 2002
12:30 UTC