Determination of Optical and Microphysical Properties of Ice Clouds from ATSR/POLDER Synergy

Main Optical Characteristics
Co-incidences between the 2 instruments
Measurements Data processing
Modeling Ice cloud reflectivities
Model-Measurements adjustments

WP 2
E. Pachart, F. Parol, G. Brogniez
**POLDER (Polarisation and Directionality of Earth Reflectances)**

- Wide field-of-view optics
- 9 spectral bands: visible – near IR: 443 nm to 910 nm
- Polarisation capabilities at 443, 670, and 865 nm
- Up to 14 ≠ viewing angles per pixel for a single satellite over pass
- Spatial resolution: 6x6 km

**ATSR (Along Track Scanning Radiometer)**

- 7 spectral bands
  - 4 visible–near IR bands: Reflectance measurements at:
    - 0.55 µm, 0.65 µm, 0.87 µm, and 1.6 µm
  - 3 thermal bands: 3.7 µm, 11.0 µm, and 12.0 µm
- 2 viewing geometries: nadir and 52° forward
- Spatial resolution: nadir 1x1 km, forward 2x1.5 km
• ATSR-2 and POLDER orbits were compared at the descending nodes (latitude = 0)

• The criteria which have been retained are:
  \[ \Delta \text{Longitude} \leq 5^\circ \]
  \[ \Delta t \leq 15 \text{ min} \]

• The time criterion has been favoured

only 8 months of POLDER-1 data
6-12 co-incident days per month
Cirrus scenes have been selected by using retrieved products from POLDER measurements.

Example for POLDER orbit 4059, 18 December 1996, latitude between 28° and 52°

Cloud cover

Cloud phase
1: Liquid
2: Solid
3: Mixed

Cloud optical thickness at 670 nm

This way 60 zones have been processed
• ATSR Data extraction
  - By using the SADIST-2 soft package which provide:
    - Gridded Brightness Temperature/reflectance products (GBT)
      - 512x512 km geolocated, collocated nadir and forward-view brightness temperature and/or images reflectance at 1 km resolution
      - Additional images (cloud cover, land-flagging, thin and gross cirrus test)
  - GBT Products are regridded at POLDER resolution (6x7 km)
    - ATSR pixels corresponding to the same POLDER pixel are averaged

• POLDER Data Extraction (Orbit Co-incidences)

• Ice Clouds are identified by using POLDER phase algorithm

• Quality control tests (to ensure that co location processing works properly)

• Optical and Microphysical retrieved products
Regridding on POLDER resolution

- ATSR latitude and longitude are used to calculate the corresponding POLDER coordinates (3240x6480 pixels)
- ATSR pixels corresponding to the same POLDER pixel are averaged

Example of co-location between ATSR and POLDER at 670nm

POLDER-ATSR comparisons at 865 nm
- Quality control test to ensure that the co-location processing works properly
- Up to 14 viewing direction for POLDER
  The nearest direction according to ATSR is selected
Signature of Polarised reflectances for ice crystals and liquid droplets (*Riedi et al …*)
This processing is applied for each POLDER pixel

Example over France, 10 Nov 1996
LEVEL 1 PRODUCTS (1)

Reflectance at 1.6 µm versus 0.865 µm combined to POLDER phase

- Due to mean particle size, ice and liquid particles have different behaviour

Temperature histograms combined to POLDER phase

- High probability to observe ice pixels with high brightness temperature
  presence of thin cirrus
Additional criterion based on POLDER phase

Rejection of:

- Pixels at the frontier of ice and liquid clouds
- Pixels which are not surrounded by pixels with the same phase
• The 60 available regions have been processed

• Database for all cloudy pixels (ice crystals and liquid droplets), including all the necessary information for the continuation of our study:

  - POLDER orbit number
  - POLDER coordinates
  - ATSR Viewing geometry (nadir and forward viewing direction)
  - Brightness temperature at 11 µm
  - Brightness temperature difference between 11 and 12 µm
  - Reflectance at 0.865 µm
  - Reflectance at 1.6 µm
  - Ocean-land flag
  - Others ATSR flags (thin cirrus tests …)
Ice cloud Database
- Inhomogeneous Hexagonal Monocrystal (IHM) Model

- Why this crystal model?

- Sensitivity tests
IHM Model

- Calculation of the scattering light by randomly oriented hexagonal ice crystals containing spherical impurities of soot and air bubbles
- Combination of ray tracing and Lorenz-Mie theory
- Calculation of the 6 independent elements of the scattering matrix

Main input parameters of our IHM code

- Wavelength of incident beam
- Ice refractive index
- Equivalent sphere volume radius
- Aspect ratio L/2R
- Air bubbles/soot refractive index
- Mean free path length
- Percentage of soot and air bubble
- Effective radius and variance of soot and air bubble
Combination between POLDER bidirectional measurements and simulation using the discrete-ordinates method

- Cloud optical thickness at 670 nm is retrieved and expressed in term of spherical albedo (Buriez et al ...)
- The best adapted ice crystal model minimize the differences between « directional » value of the cloud spherical albedo and the average value over all available directions for any scattering angle

IHM crystal with L/2R = 2.5 is one of the best appropriated model (Labonnote et al ...)
• Simulation of reflectance at 1.6 µm versus reflectance at 0.865 µm by using the adding-doubling method

• Scattering phase functions of ice crystal have been calculated by the IHM model and the aspect ratio has been fixed to 2.5

• Sensitivity tests to different parameters have been conducted
  • Solar zenith angle
  • ATSR viewing angle (nadir and forward)
  • Relative azimuth angle
  • Ice cloud optical thickness (from 0 to 80)
  • Effective radius of ice particle (from 8 to 85 µm)
Sensitivity tests

Nadir Viewing Direction

IHM – ADDING : Reff = 8 µm, SZA = 30°

IHM – ADDING : Reff = 35 µm, SZA = 30°

IHM – ADDING : Reff = 60 µm, SZA = 30°

IHM – ADDING : Reff = 8 µm, SZA = 60°

IHM – ADDING : Reff = 35 µm, SZA = 60°

IHM – ADDING : Reff = 60 µm, SZA = 60°
Sensitivity tests

Forward Viewing Direction

IHM – ADDING: Reff = 8um, SZA = 30°

IHM – ADDING: Reff = 35um, SZA = 30°

IHM – ADDING: Reff = 60um, SZA = 30°

IHM – ADDING: Reff = 8um, SZA = 60°

IHM – ADDING: Reff = 35um, SZA = 60°

IHM – ADDING: Reff = 60um, SZA = 60°
Sensitivity tests

Summary: Nadir & Forward Viewing Direction

SZA = 30° (solid lines)
SZA = 60° (dashed lines)
Sensitivity tests

Estimated errors on retrieved Reff
(preliminary to model measurements adjustments)

Nadir viewing direction

• Thick clouds: A case of study
  ⇒ Asymptotic range of reflectance
  at 1.6 µm

  ⇒ Weak sensitivity to viewing
  direction for a given solar zenith
  angle

  ⇒ For a given solar zenith angle:
  A simple interpolation of
  reflectivities simulated at 1.6 µm lead
  to the retrieved Reff +/− 5 µm

Forward viewing direction

• Taking into account all angles involved
  in the viewing geometry is necessary

  ⇒ high sensitivity to viewing nadir angle
  and relative azimuth angle

No possibility to retrieve basically Reff!
Sensitivity tests

Sensitivity to Reff
L/2R value is 2.5

Sensitivity to L/2R
Reff value is 25 µm
Determination of the microphysical properties of ice clouds from measurements and simulations

- Determination of ice crystals effective size and optical thickness
- Correlation between temperature and ice particles effective size
Basical Analysis

• Model Measurements comparisons for 2 solar zenith angles
• Reflectances simulated at 1.6 \( \mu m \) versus 0.865 \( \mu m \) are averaged for different viewing angles
• All ATSR reflectance measurements available are superposed

The dominating effective size of ice particles is about 40 \( \mu m \)
ATSR brightness temperature versus reflectance at 1.6 µm and 0.865 µm. Solar zenith angles range between 28° and 32°.

- Highest temperature correspond to thinnest cloud according to simulation results.
- Our study is restricted to thicker cloud ($\delta > 5$).
- For those cases, by using the combination of measurements and simulations: On average, the higher the temperature, the higher the effective size.
The interest of the study of thick ice clouds is also the asymptotic behaviour of reflectance at 1.6 µm versus 0.865 µm, as showed in the simulations results (for a given solar angle and a given effective size of ice particle).

For those cases, only reflectance at 1.6 µm need to be considered to retrieve the effective size of ice particle.

For thick ice clouds:

On average, the lower the reflectance at 1.6 µm the higher the temperature.
Retrieved effective size of ice particles versus brightness temperature

- All available ATSR data have been processed for thick cloud
- On average:
  the higher the cloud temperature, the higher the ice particle effective size
General study (thick and thin ice cloud)

- LUTS (viewing geometry, cloud optical thickness, Reff and reflectivities)
  => multi-linear interpolation (5 parameters)
- Retrieval Reff are rejected if the corresponding algorithm error < 1 %
- Instable retrieval Reff due to error measurements are also rejected
• Our last inversion method also allows to retrieve ice clouds optical thickness
  => Comparisons with POLDER C2 algorithms lead to
  $\langle \text{differences} \rangle < 1\%$ with retrieved optical thickness from ATSR-2
  (co incident orbits)
  => Highest temperatures correspond to the thinnest retrieved optical
  thickness (Correction of emissivity need to be take into account)
• Retrieved products have been recently compared between nadir and
  forward viewing directions
  => Additional rejection for some retrieved Reff
  => For those pixels, changing L/2R lead to a better agreement
  between nadir and forward viewing directions
• ATSR and POLDER measurements combined to simulation (IHM) are well adapted to retrieve the microphysical properties of icy clouds
• Simulations combined to POLDER bidirectional reflectance measurements have allowed the determination of the best radiatively equivalent crystal model
• Sensitivity tests have been performed to determine the main parameters useful to model-measurements adjustments
• Simulations combined to ATSR measurements led to retrieve the effective size of ice particles
• Correlation between cloud temperature and the effective size of ice crystals has been established