Cloud microphysics

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WS 2011/2012

Overview of cloud physics lecture

- Atmospheric thermodynamics
  - gas laws, hydrostatic equation
  - 1st law of thermodynamics
  - moisture parameters
  - adiabatic / pseudoadiabatic processes
  - stability criteria / cloud formation
- Microphysics of warm clouds
  - nucleation of water vapor by condensation
  - growth of cloud droplets in warm clouds (condensation, fall speed of droplets, collection, coalescence)
  - formation of rain, stochastical coalescence
- Microphysics of cold clouds
  - homogeneous, heterogeneous, and contact nucleation
  - concentration of ice particles in clouds
  - crystal growth (from vapor phase, riming, aggregation)
  - formation of precipitation, cloud modification
- Observation of cloud microphysical properties
- Parameterization of clouds in climate and NWP models

Cloud-aerosol interactions

- Twomey, 1977: High concentrations of aerosols reduce droplet size and increase cloud albedo for a constant amount of liquid water
- Albrecht, 1989: High aerosol concentrations narrow the size distribution, supressing precipitation and prolonging cloud lifetime
- aerosol-induced changes of cloud microstructure have profound impact on precipitation, dynamic evolution and vertical disposition of latent heat release (e.g. Rosenfeld, 2006)

Figure from Wallace and Hobbs

Cloud-aerosol interactions

- basic processes explaining cloud formation and evolution are well established
- but still many unresolved fundamental issues:
  - temporal and spatial evolution of clouds
  - lack of fundamental understanding of the glaciation of clouds
  - formation of rain in warm clouds
  - convective clouds

Field experiments

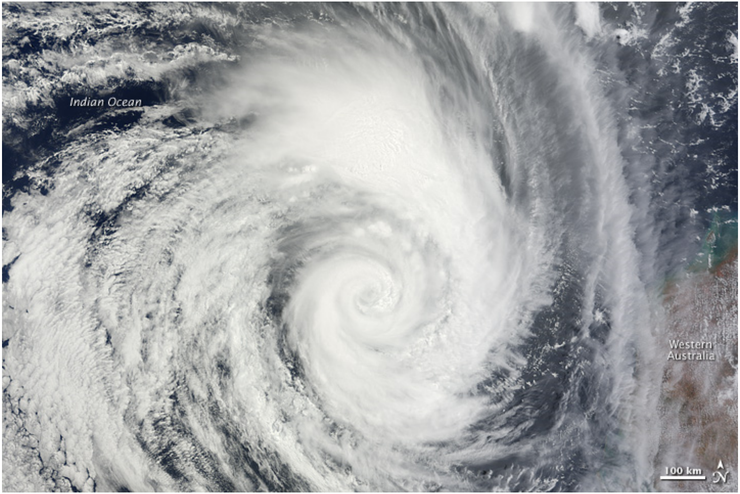
- several field experiments were performed in the last years: e.g. CRYSTAL-FACE, INCA, TC4 ...
- provide information about cloud microphysics at specific points in the cloud, usually no measurements of vertical structure
- can not characterize evolution of cloud microphysics spatial and temporal structure, and link these characteristics to environmental factors (available CCN)

Remote sensing methods

- Precipitation radar: vertical development of precipitation sized droplets in clouds, information on thermodynamic phase of hydrometeors
- Cloud radar (millimeter wavelength): cloud boundaries (bottom and top), small droplets not measured
- Satellite images (visible, NIR): Provide information about optical thickness and particle size (at cloud top).
  - Polar orbit (e.g. MODIS): relatively good spatial resolution (1km), but poor temporal resolution
  - Geostationary orbit (e.g. MSG): good temporal resolution (up to 5 min), but poor spatial resolution (5km)

MODIS images

http://modis.gsfc.nasa.gov



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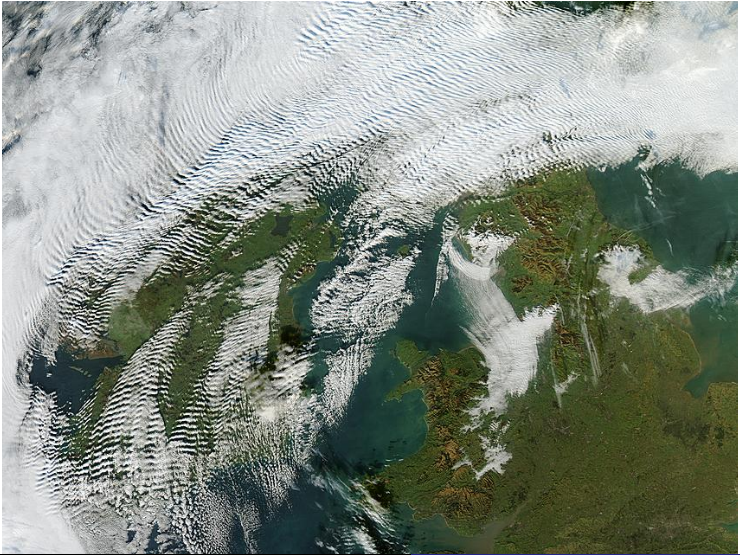
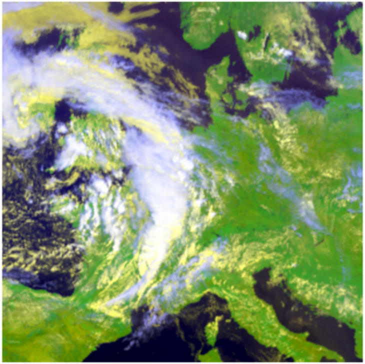
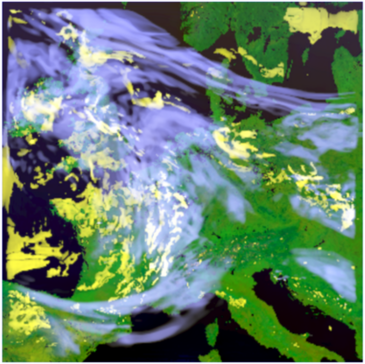


MSG (Meteosat Second Generation) - Simulation of satellite image

MSG-Beobachtung



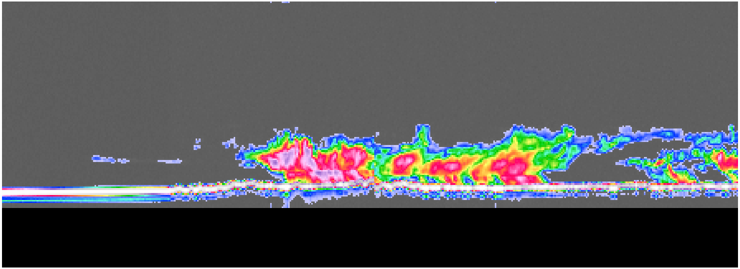
1D (IPA) libRadtran-Simulation



Model atmosphere (pressure, temperature, humidity, water and ice clouds) from weather model “COSMO-EU” of the “Deutscher Wetterdienst” (DWD). Forcast for 2005-08-12.; Surface albedo: MODIS data product. Simulation: Luca Bugliaro

CloudSat

- 94 GHz radar, provides vertical profiles of cloud water content
- not sensitive to droplets smaller than 10 μm or ice crystals smaller than 50 μm.
- effective radius profiles can not accurately be measured



Cloud side scanner

- new approach provides details of vertical, horizontal and temporal microphysical structure in developing cloud
- new cloud spectrometer at MIM: covers solar spectrum from 0.4 to 2.5 μm and the thermal from 8 to 14 *mu*m, will collect (polarized) images of high spatial resolution (50 m) of cloud sides and cloud bottom sides (cirrus). Several spectral camera systems will provide spectral resolutions of $\approx$10 (solar) and $\approx$100 nm (thermal).
- comparable spectrometer on airborne platform (Martins et al. 2011)

Conceptual diagram of microphysical stages

diagram describes 5 microphysical stages (droplet growth by diffusion, collision-coalescence, warm rainout, ice-water mixed phase, glaciated phase)

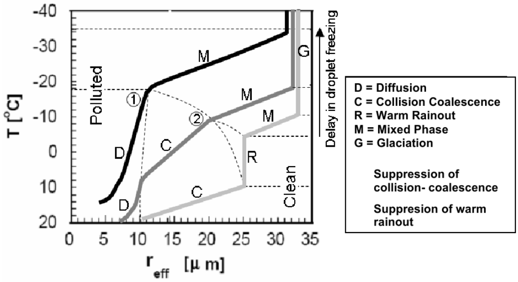


Figure from Martins et al., 2011,
adapted from Rosenfeld and Woodley, 2003

- bottom curve: maritime environment with low CCN concentration (possibility of warm rainout)
- middle curve: continental case, large number of CCN suppress warm rain, glaciation starts at slightly lower T
- top curve: polluted environment where very large number of CCNs produce numerous small droplets at cloud base, supressing collision-coalescence, freezing starts at even lower T

Cloud side remote sensing

- vertical profile of effective radius: very sensitive to aerosol environment
- brightness temperature profile: can directly be associated with thermodynamic phase, provides information on the glaciation temperature
- high temporal resolution: Evolution of cloud microphysics can be observed

Cloud side observations from low altitude aircraft

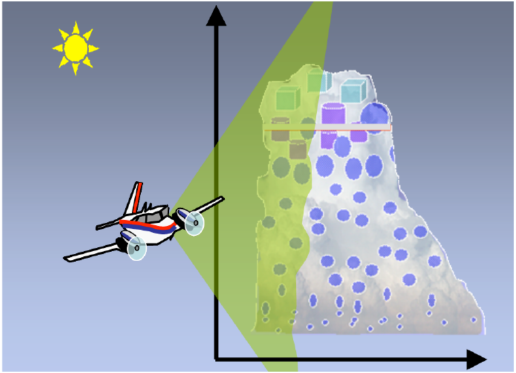


Figure from Martins et al., 2011

Geometry for cloud side remote sensing from aircraft as used by Martins et al., 2011.

Cloud side observations from high altitude aircraft or satellite

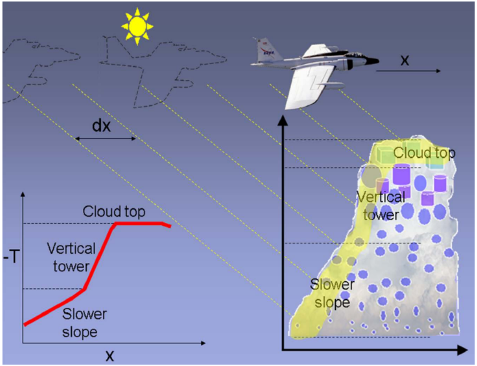


Figure from Martins et al., 2011

Best observation geometry is with sun in back to avoid shadows, all altitudes are observed at the same viewing angle.

First cloud side measurements

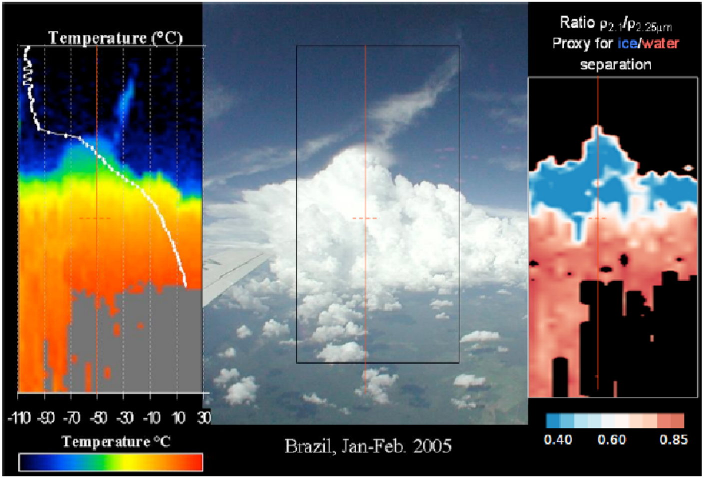


Figure from Martins et al., 2011

Retrieval of effective radius and cloud phase

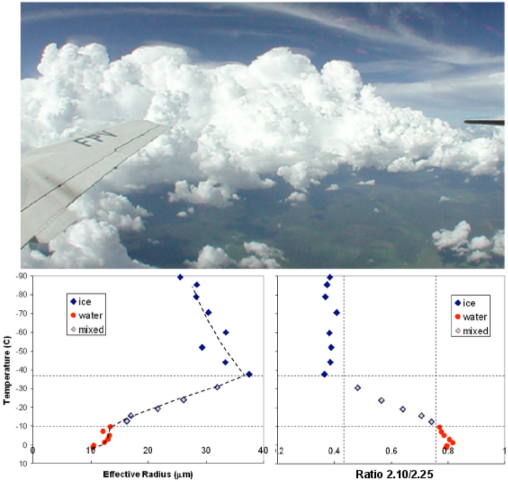


Figure from Martins et al., 2011

3D retrieval of cloud particle profiles

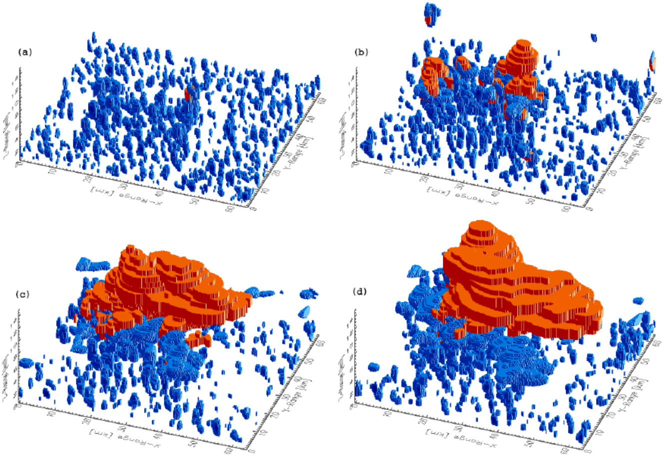


Figure from Zinner et al., 2008

Cloud scenes from LES model.

MYSTIC simulation of cloud scanner observation

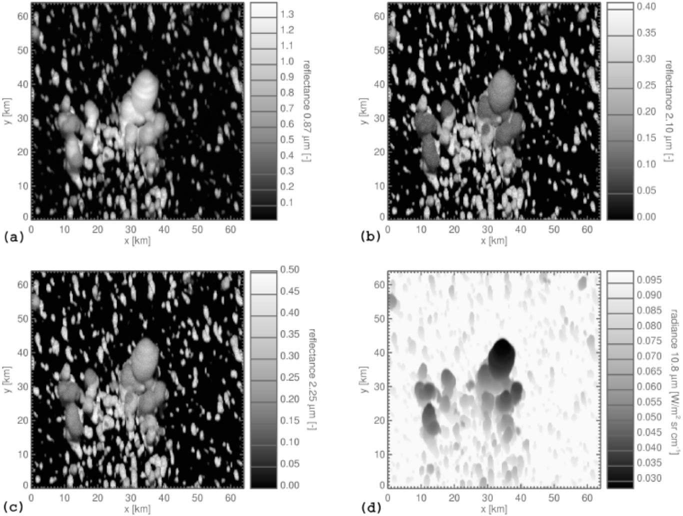


Figure from Zinner et al., 2008

Imaginary part of refractive index of water and ice

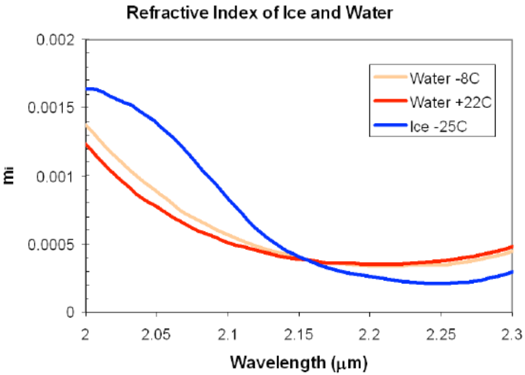


Figure from Martins et al., 2011

Imaginary part of refractive index is related to absorption. This explains 2.10μm/2.25μm ratio is measure for thermodynamical phase of cloud.

Retrieval of thermodynamical phase

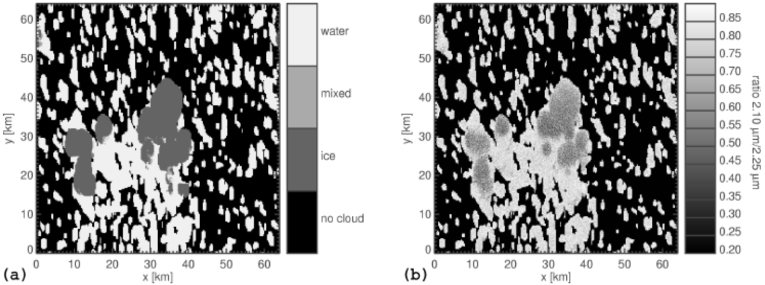


Figure from Zinner et al., 2008

Effective radius retrieval of cloud particle profiles

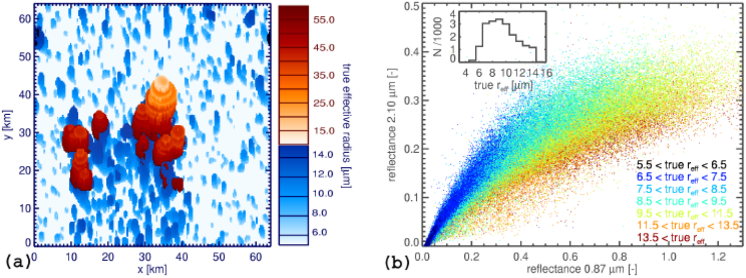


Figure from Zinner et al., 2008

Simulated reflectance with known effective radius profile.

Effective radius retrieval of cloud particle profiles

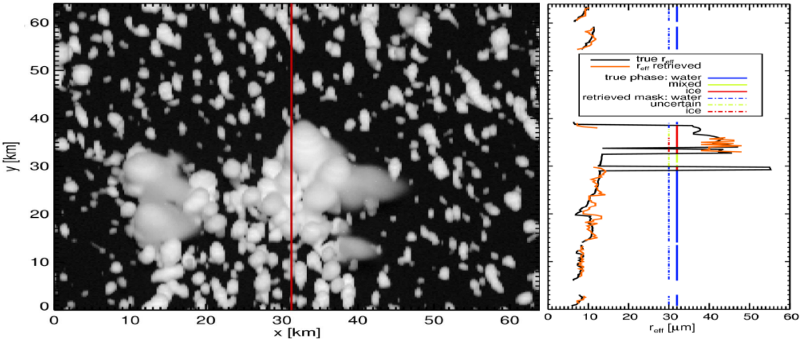


Figure from Zinner et al., Poster EGU 2009

Cloud observation system at MIM

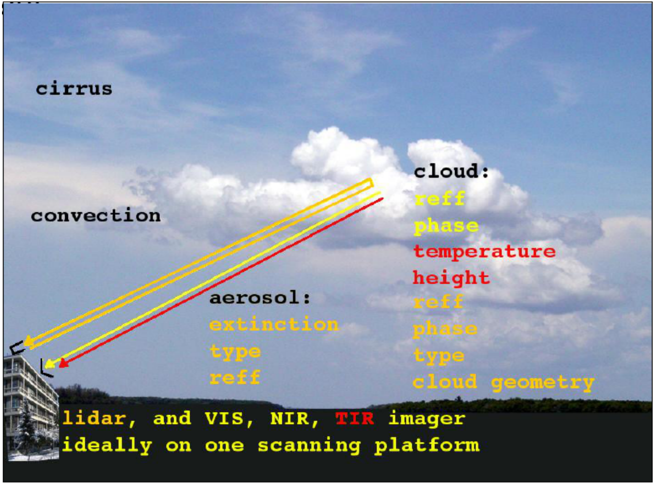


Figure from Zinner et al., Poster EGU 2009

Polarization

- Radiation becomes polarized when scattered at cloud particles, polarization signal includes information about particle size and shape distribution

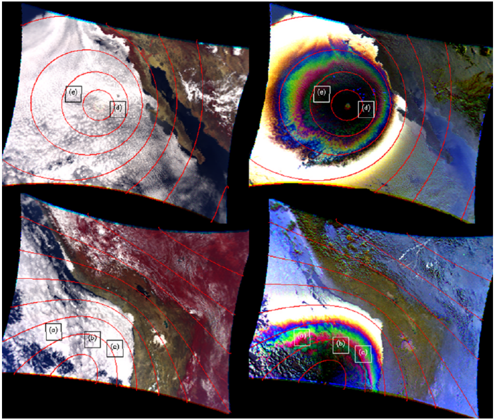
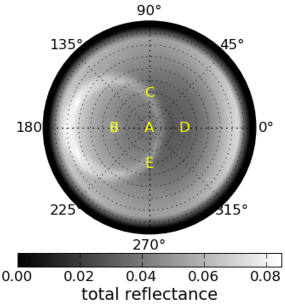


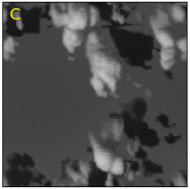
Figure from Breon et al., 2005



1D cloud layer

Cumulus Clouds

$\phi_v = 90^\circ$

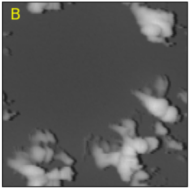


solar zenith angle: 30°

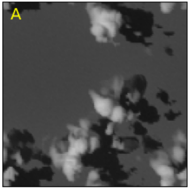
viewing zenith angle: 30°

wavelength: 500 nm

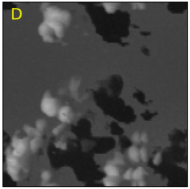
$\phi_v = 180^\circ$



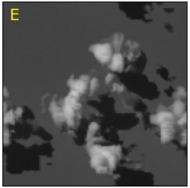
$\phi_v = 10^\circ$, $\theta_v = 0^\circ$



$\phi_v = 0^\circ$

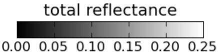


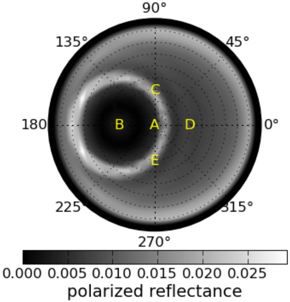
$\phi_v = 270^\circ$



cloud resolution: 60 m

sample resolution: 47 m





1D cloud layer

Cumulus Clouds

solar zenith angle: 30°

viewing zenith angle: 30°

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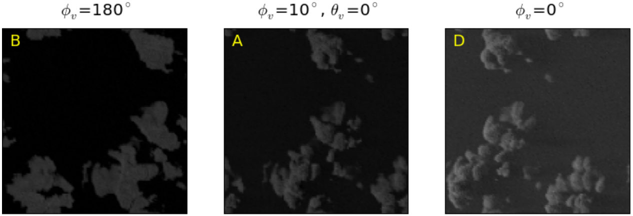

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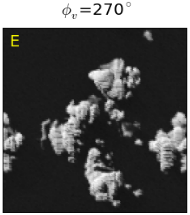

Summary

- several fundamental cloud microphysical processes, in particular cloud-aerosol interactions are not yet well understood
- clouds and aerosols are main source of uncertainty in future climate predictions
- observations of cloud microphysics (in-situ, remote sensing) can help to improve our understanding of basic processes