Les différentes hypothèses microphysiques et leurs impacts en microondes

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Introduction

La plupart des algorithmes d'inversion des propriétés nuageuses et des précipitations sont basés sur la simulation du transfert radiatif.

- Gprof pour GPM (base de données simulées puis inversion Bayesienne)
- Assimilation variationnelle dans les centres de météorologie opérationnels

=> Nécessité de simuler le transfert radiatif en microonde, avec précision.

Dans la phase liquide des nuages et de la pluie, les processus d'émission dominent.

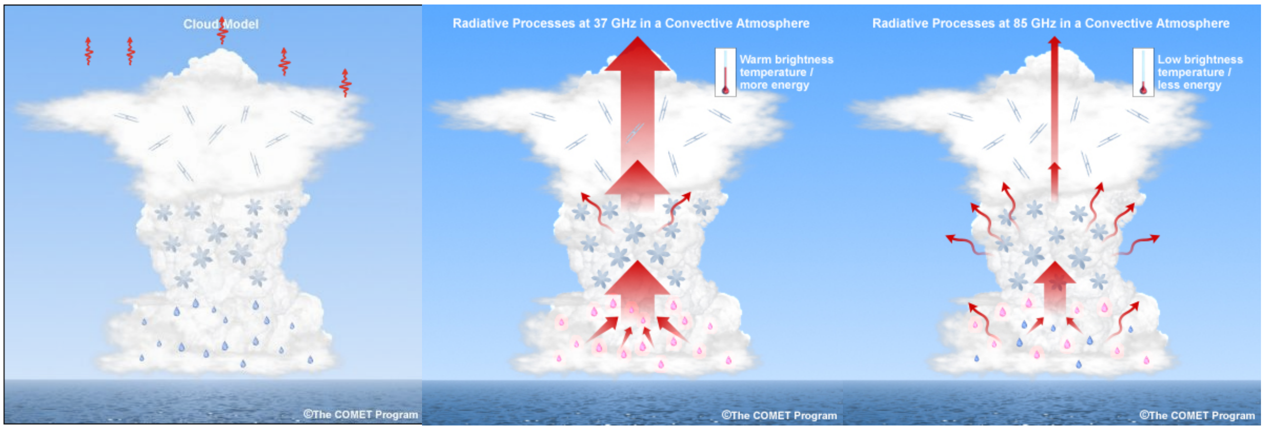
Dans la phase glace, peu d'émission / absorption, mais de la diffusion, plus complexe à modéliser dans le transfert radiatif.

Plus la fréquence augmente et plus les phénomènes de diffusion sont importants.

Introduction

Infrared

Passive microwave



Sense essentially
the cloud top

At **low MW freq**,
water emits strongly
ice is transparent

At **high MW freq**,
water emits and scatters
ice can scatters strongly

Introduction

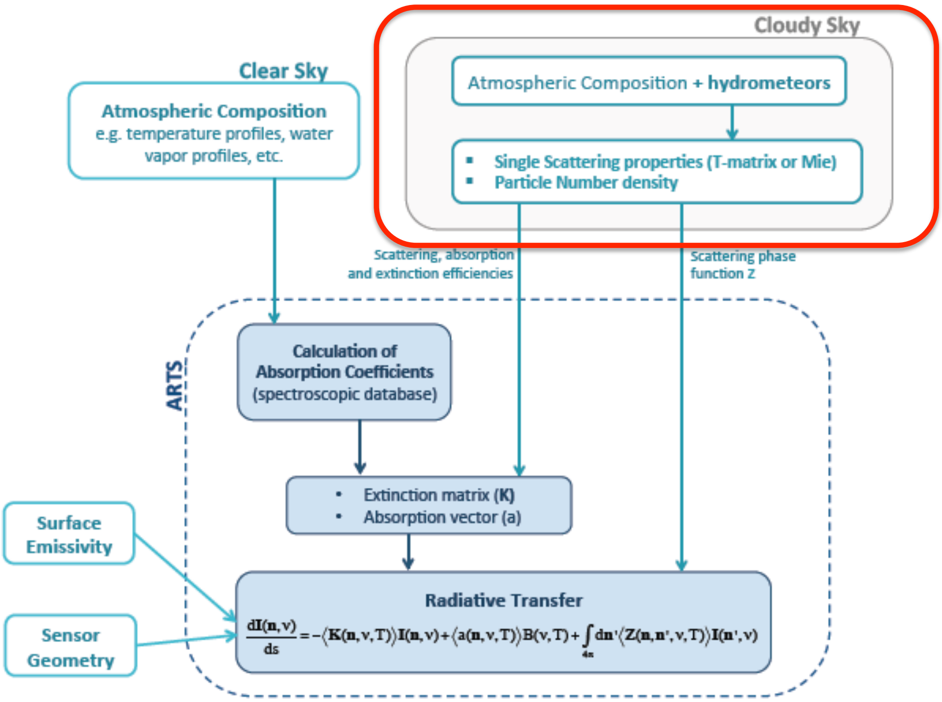
The ingredients of the radiative transfer calculation, in a scattering atmosphere:

- the single scattering properties of the particles
  (function of the dielectric properties of the particle, their size, shape and orientation)
- the particle size distribution

- a radiative transfer code that handles scattering (e. g., ARTS)

… in addition to the other parameters also required for clear sky atmosphere

Introduction



Clear Sky

Atmospheric Composition
e.g. temperature profiles, water vapor profiles, etc.

Cloudy Sky

Atmospheric Composition + **hydrometeors**

- Single Scattering properties (T-matrix or Mie)
- Particle Number density

Scattering, absorption and extinction efficiencies

Scattering phase function Z

ARTS

Calculation of Absorption Coefficients (spectroscopic database)

- Extinction matrix (K)
- Absorption vector (a)

Surface Emissivity

Sensor Geometry

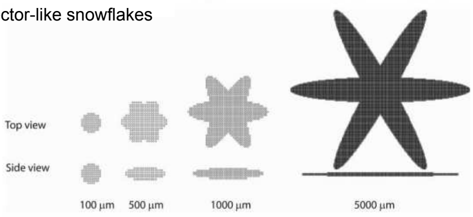
Radiative Transfer

$$\frac{d\mathbf{I}(\mathbf{n},\nu)}{ds} = -\langle \mathbf{K}(\mathbf{n},\nu,T)\rangle \mathbf{I}(\mathbf{n},\nu) + \langle a(\mathbf{n},\nu,T)\rangle B(\nu,T) + \int_{4\pi} d\mathbf{n}' \langle \mathbf{Z}(\mathbf{n},\mathbf{n}',\nu,T)\rangle \mathbf{I}(\mathbf{n}',\nu)$$

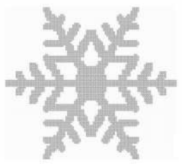
Calculating the single scattering properties

- T-matrix (for spheres, spheroids, cylinders: random and horizontal orientations)
- Other methods e.g. Discrete-Dipole Approximation (DDA): arbitrary shapes
- Practical approach: Liu et al., (2004) approximation
    - Approximate complex non-spherical single scattering properties by a frequency dependent effective density and diameter
    - Allows the use of the T-matrix

Sector-like snowflakes



Dendrite snowflakes



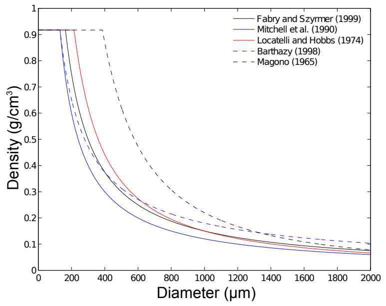
Modeling the hydrometeor microphysical properties

- Particle dielectric properties
  - Pure liquid and pure ice properties: fairly well understood
  - Snow: mixed phase hydrometeors ➔ Mixing formulas e.g. Maxwell Garnett

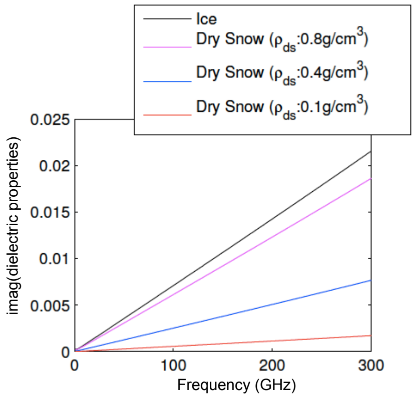
$$\varepsilon_{\mathrm{eff}} = \mathrm{f}(\mathrm{composition}, \mathrm{density})$$

  - Dry snow (ice and air) or wet snow (ice, air and water)

Density



Dielectric properties for different snow densities



➢ Large variability in density and dielectric properties that have an important impact on the scattering properties

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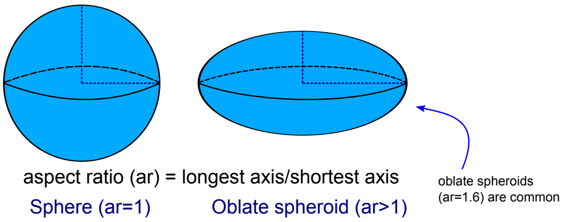
Modeling the hydrometeor microphysical properties

- Particle size
  - Mono-disperse / more realistic parameterizations (e.g., using microphysical scheme in cloud resolving models)
- Particle shape
  - Complex ➔ common approach: spheroids (aspect ratio)



aspect ratio (ar) = longest axis/shortest axis

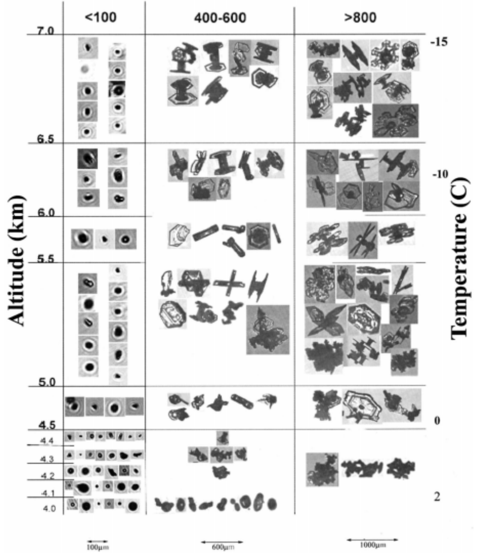
Sphere (ar=1) Oblate spheroid (ar>1)

oblate spheroids (ar=1.6) are common

- Particle orientation
  - Random and horizontally aligned

In-situ observations (field campaign images)

Heymsfield et al. (2002)



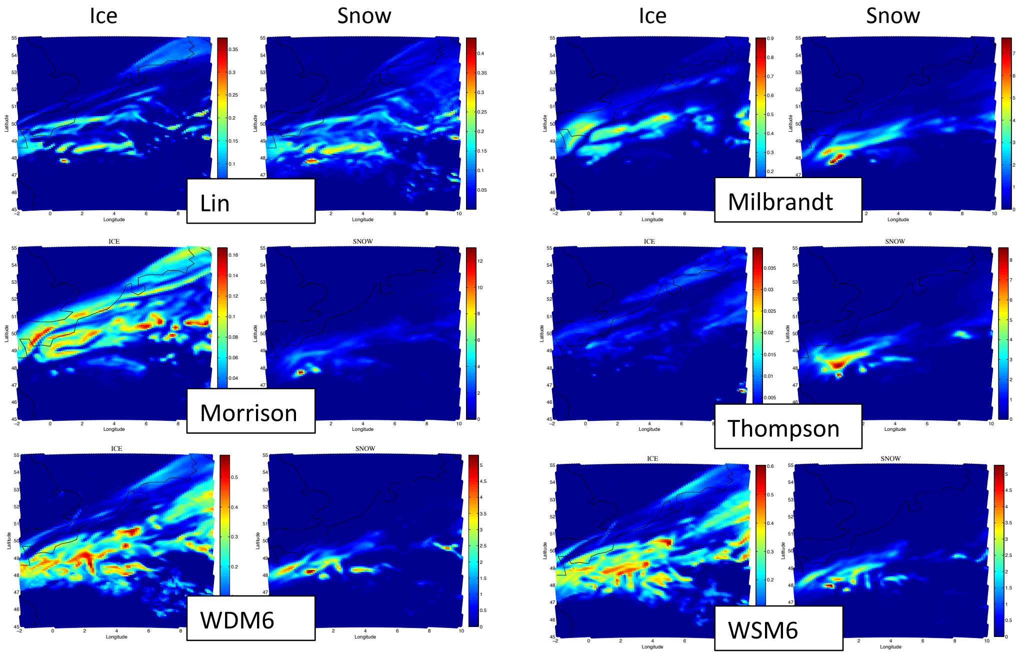
Hydrometeor microphysical properties in cloud resolving models

microphysics schem	Water Species	Particle size distribution function (m^{-3})	Intercept Parameters (m^{-4})	Slope parameter (m^{-1})	Density (kg/m^3)	References
Lin (2)	Rain Snow Graupel	$N_r(D)=n_{or}\exp(-\lambda_r D_r)$ $N_s(D)=n_{os}\exp(-\lambda_s D_s)$ $N_g(D)=n_{og}\exp(-\lambda_g D_g)$	$n_{or}=8*10^6$ $n_{os}=3*10^6$ $n_{og}=4*10^4$	$\lambda_r=(\pi\rho_w n_{or}/\rho q_r)^{0.25}$ $\lambda_s=(\pi\rho_s n_{os}/\rho q_s)^{0.25}$ $\lambda_g=(\pi\rho_g n_{og}/\rho q_g)^{0.25}$	1000 100 917	Rutledge and Hobbs (1983) Lin et al (1983)
WSM6 (6)	Cloud Rain Snow Graupel Ice	Mono[illegible]$*10^8$ $N_r(D$[illegible] $N_s($[illegible] N_g[illegible] $N_i(D)=5.38$[illegible]	$n_{or}=8*10^6$ $n_{os}=2*10^6\exp(0.12(T-T_0))$ $n_{og}=4*10^6$	$\lambda_r=(\pi\rho_w n_{or}/\rho q_r)^{0.25}$ $\lambda_s=(\pi\rho_s n_{os}/6\rho q_s)^{0.25}$ $\lambda_g=(\pi\rho_g n_{og}/\rho q_g)^{0.25}$	1000 1000 100 500	Hong et al (2006) Hong et al (2004)
WDM6 (16)	Cloud Rain Snow Graupel Ice	$N_c(D)= 3\lambda c^3 n_c D_c^2\exp(-\lambda_c D_c$[illegible] $N_r(D)= \lambda r^2 n_r D_r\exp(-\lambda_r D_r)$ $N_s(D)=n_{os}\exp(-\lambda_s D_s)$ $N_g(D)=n_{og}\exp(-\lambda_g D_g)$ $N_i(D)=5.38*10^7(2.08*10^{22}D^8)^{0.75}$	[illegible]	$\lambda_c=(\pi\rho_w\Gamma(2)n_c/6\Gamma(1)\rho q_c)^{1/3}$ $\lambda_r=(\pi\rho_w\Gamma(5)n_r/6\Gamma(2)\rho q_r)^{1/3}$ $\lambda_s=(\pi\rho_s n_{os}/6\rho q_s)^{0.25}$ $\lambda_g=(\pi\rho_g n_{og}/\rho q_g)^{0.25}$	1000 1000 100 500	Lim and Hong (2010)
Thompson (8)	Cloud Rain Snow Graupel Ice	$N_r(D)=n_{or}\exp(-\lambda_r D_r)$ $N_s(D)=M_2^4/M_3^3(490.6\exp(-20.78 M_2D/M_3+17.46$ $\exp(-3.29DM_2/ M_3)(M_2D/M_3)^{\mu 8}))$ $N_g(D)=n_{og}\exp(-\lambda_g D_g)$	$n_{or}=(9*10^9-2*10^6)\tanh(($[illegible] $M_2= \int D^2 N_s(D)dD$ $M_3= \int D^3 N_s(D)d$[illegible] $n_{og}=\max(10^4,\min(200/q_g,5*10^6))$	[illegible]	1000 1000 [illegible]	Thompson et al (2008)
Milbrandt (9)	Cloud Rain Snow Graupel Ice (rosettes) Hail	$N_c(D)=3n_c\lambda^6D^5\exp(-\lambda_r D_r)^3$ $N_r(D)=n_{or}\exp(-\lambda_r D_r)$ $N_s(D)=n_{os}\exp(-\lambda_s D_s)$ $N_g(D)=n_{og}\exp(-\lambda_g D_g)$ $N_i(D)=n_{oi}\exp(-\lambda_i D_i)$ $N_h(D)=n_{oh}\exp(-\lambda_h D_h)$	$n_{oc}=n_c\lambda_c^2/\Gamma(2)$ $n_{os}=n_s\lambda_s^2/\Gamma(2)$ $n_{og}=n_g\lambda_g^2/\Gamma(2)$ $n_{oi}=n_i\lambda_i^2/\Gamma(2)$ $n_{oh}=n_h\lambda_h^2/\Gamma(2)$	$\lambda_c=(\pi\rho_w\Gamma(5)n_c/6\Gamma(2)\rho q_c)$ $\lambda_r=(\pi\rho_w\Gamma(4)n_r/6\Gamma(1)\rho q_r)^{1/3}$ $\lambda_s=(\pi\rho_w\Gamma(4)n_s/6\Gamma(1)\rho q_s)^{1/3}$ $\lambda_g=(\pi\rho_w\Gamma(4)n_g/6\Gamma(1)\rho q_g)^{1/3}$ $\lambda_i=(440\rho_w\Gamma(4)n_i/\Gamma(1)\rho q_i)^{1/3}$ $\lambda_h=(\pi\rho_w\Gamma(4)n_h/6\Gamma(1)\rho q_h)^{1/3}$	1000 1000 100 400 500 900	Milbrandt and Yau (2005)
Meso-NH	Cloud Rain Snow Graupel Ice	$N_c(D)= 3\lambda c^9 n_c D_c^6\exp(-\lambda_c D_c)^3/\Gamma(3)$ $N_r(D)=n_{or}\exp(-\lambda_r D_r)$ $N_s(D)=n_{os}\exp(-\lambda_s D_s)$ $N_g(D)=n_{og}\exp(-\lambda_g D_g)$ $N_c(D)= 3\lambda c^9 n_c D_c^6\exp(-\lambda_c D_c)^3/\Gamma(3)$	$n_{or}=8*10^6$ $n_{os}=2.5*10^6S^{-0.94}$ $n_{og}=5*10^5((\rho q_g/19.6*5*10^5\Gamma(2.8))^{-1/3.3})^{0.5}$	$\lambda_r=4.1R^{-0.21}*10^3$ $\lambda_s=2.29S^{-0.45}*10^3$ $\lambda_g= (\rho q_g/19.6*5*10^5\Gamma(2.8))^{-1/3.3}$	1000 1000	Pinty and Jabouille (1998)

Very different schemes available in WRF

Hydrometeor microphysical properties in cloud resolving models

- Very different schemes -> resultant frozen phase outputs vary widely

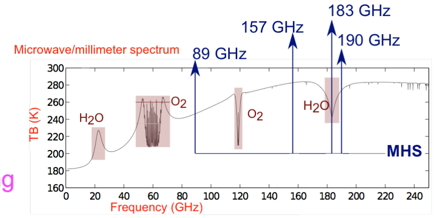


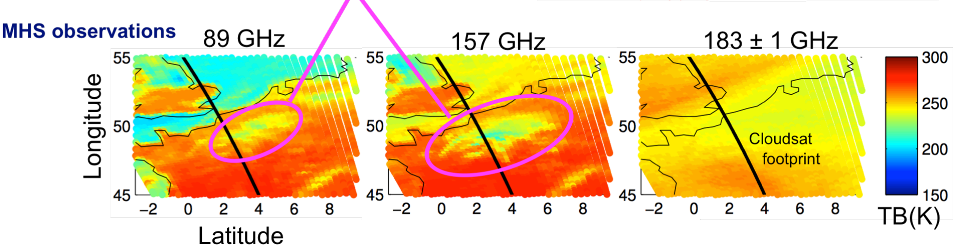
Which ones are representative of observations?

Microphysical assumptions: impact on microwave and millimeter frequencies

- Evaluation of passive and active radiative transfer simulations of real snowfall scenes: A heavy snowfall scene over France with Meso-NH

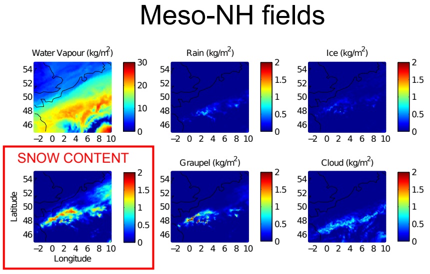
  - France, 8 December 2010: Passive/active coincident observations
    - Microwave humidity sounder radiometer (MHS): 89, 157, 183±1, 183±3, 190 GHz
    - Cloud radar CloudSat: 94 GHz
  - Exploit synergy (multi-frequency passive observations and active observations)

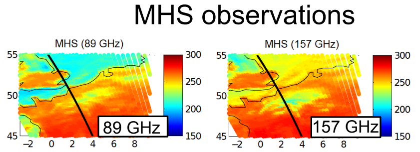




Microphysical assumptions: impact on microwave and millimeter frequencies

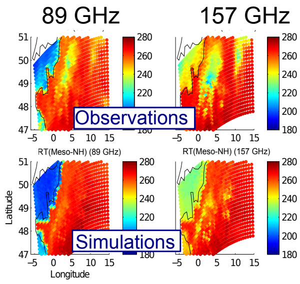
- Study coupling radiative transfer model ARTS with cloud resolving model Meso-NH to simulate microwave instruments
  - ➢ Evaluation of radiative transfer simulations and microphysical assumptions
- 1st step: Meso-NH scheme (intrinsic particle size distribution and mass-size relationship)
  - Assume most basic shpae: spheres and derive density
  - Dielectric properties (snow, graupel with mixing formulas)

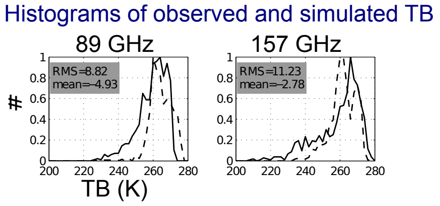




➢ Distribution of simulated TB: shifted to warmer temperatures than observations

➢ Basic interpretation of Meso-NH outputs failing to reproduce the observed intense scattering





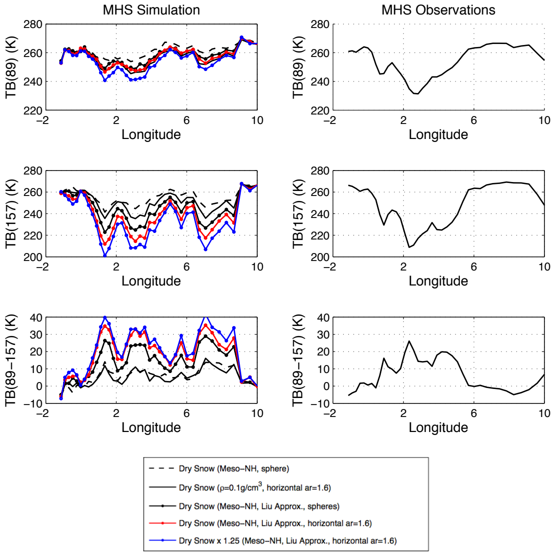
Microphysical assumptions: impact on microwave and millimeter frequencies

- Passive observations: sensitivity analysis
  - Basic interpretation of Meso-NH outputs: very little scattering
  - Tested different sizes, densities, dielectric properties, single scattering properties
  - Tested sensitivity to snow content

➢ High sensitivity to density

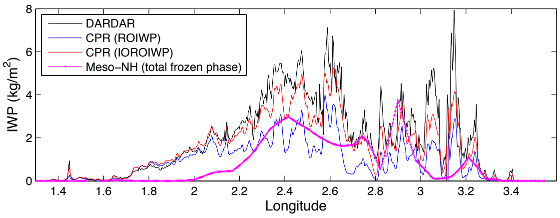
➢ Liu et al. (2004) approximation matches observations

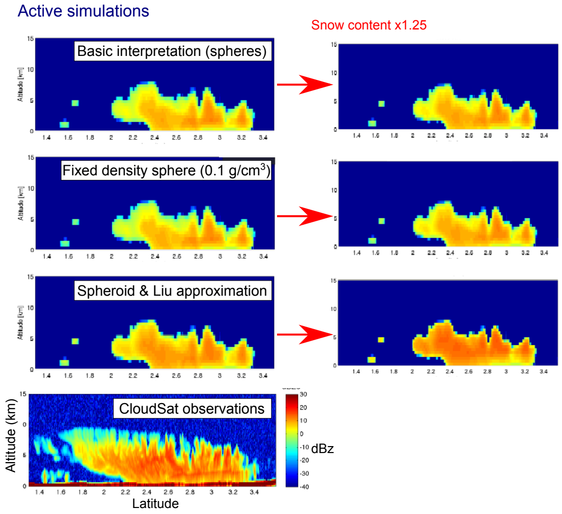
➢ Similar results for other real scenes



Microphysical assumptions: impact on microwave and millimeter frequencies

- Active observations: sensitivity analysis
  - Same microphysical assumptions
  - CloudSat retrievals vs. Meso-NH snow content





Synergy: passive multi-frequency simulations and active

➢ Better constrain (e.g. active sensitivity to mass content)

➢ Consistent assumptions about microphysical parameters, we can reasonably simulative active and passive simulations

Conclusions

Very large sensitivity of the microwave observations to the ice phase, above 80 GHz.

It increases with the frequency
=> interest of the millimeter waves for ice characterization (ICI on MetOp-SG)

Importance of realistic estimates of the microphysical properties of the ice and snow for accurate radiative transfer simulations, and as a consequence, accurate ice and snow retrievals with passive microwaves.

Work to be continued with cloud modelers, with evaluation with satellite observations.

Interest of passive / active microwave synergy to help constrain the problem