The 7 to 9 September 2006 AMMA Anvil-cirrus cloud case study : Numerical Simulation of the Dynamics, Cloud Microphysics and Synthetic observations

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1. Introduction

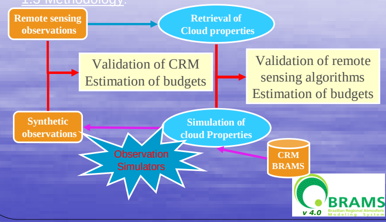
1.1 Problematic:

Intensive convection (isolated or organised) associated with African monsoon produces a large amount of high level clouds
- –How many ?
- –Which is their lifespan ?
- –Which are their roles on monsoon ?
  - » Radiative impacts,
  - » Water vapor transport,
  - » Feedback on convection and monsoon circulation

1.2 Objectives :

- Constrain cloud model to represent life cycle of stratiform clouds produced by deep convection
- Optimize tools to investigate remote sensing observations of stratiform clouds
  - Synthetic Observations calculated with 3-D model outputs
- Quantify radiative and water budgets of MCS with a better accuracy for the stratiform parts

1.3 Methodology:



2. Tools

2.1 Model:

Brazilian version of the Regional Atmospheric Modelling System (RAMS[1]) is used:
- ***Dynamics*** : tailored for tropic convection
- ***Radiation*** : Harrington[2] two-stream parameterization scheme for short and long-wave radiation (interacts with liquid and ice hydrometeor size spectra + water vapor)
- ***Microphysics*** :Two moments bulk microphysical scheme for 7 hydrometeor species
  For each microphysical species :
  - Mixing ratios are prognosed
  - Number concentrations are prognosed
  - Mass = $\alpha.D^{\beta}$ and falling velocity $V=\gamma.D^{\delta}$
  - Each Particle Size Distribution is parameterized with a generalized gamma function
  - Pristine and snow crystal shapes are diagnosed with respect to temperature and ice super saturation (column, plate, needles, bullet, dendrite)

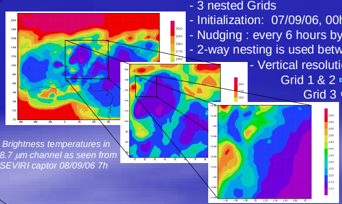
2.2 Synthetic observations: Simulators

- *95 GHz Radar*: **Equivalent Reflectivity factor** Z_e*(dBZe)* and **Doppler Velocity** V_d *(m.s*$^{-1}$*)*
  Mie + attenuation effects
- *532 nm Lidar*: **Backscattering coefficient** β *(m*$^{-1}$*.sr* $^{-1}$*)*
  Multiple scattering effects (calculated with Fast Lidar Forward Model[3])
- *Infrared Radiometer*: **Brightness Temperatures** *BT(K)*
  Multiple scattering + absorption effects
  (calculated with fast radiative transfer code FASDOM[4])

As measured by IIR (Imaging Infrared Radiometer) onboard CALIPSO and SEVIRI (Spinning Enhanced Visible & InfraRed Imager) onboard MSG **in 3 channels** (8.7, 10.6 and 12 µm).

⇨ *Optical properties* for each microphysical species are derived from:
- RADAR : Mie theory (because of radar wavelength λ= 3.15 mm) depending on
  - Size of particles
  - Equivalent density of ice hydrometeors (density that would have a sphere with the same maximum diameter than ice crystal)
- LIDAR + IR Radiometer : Ping Yang[5] theoretical calculations depending on
  - Shapes of particles
  - Effective radius of particles : $R_{eff} = \frac{3}{2}\frac{V}{S}$

3. Simulation protocol

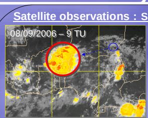


Brightness temperatures in 8.7 µm channel as seen from SEVIRI captor 08/09/06 7h

- 3 nested Grids
- Initialization: 07/09/06, 00h with ECMWF fields
- Nudging : every 6 hours by ECMWF fields at domain's limits
- 2-way nesting is used between grids
- Vertical resolutions :
  - Grid 1 & 2 ⇨ 34 levels from Δz= 500 m to 1 km
  - Grid 3 ⇨ 115 levels stretched from Δz = 100 m (between 10-15 km) to 1 km
- Horizontal resolution :
  - Grid 1 = 25 km (133 x 109 pts)
  - Grid 2 = 5 km (207 x 207 pts)
  - Grid 3 = 1 km (207 x 207 pts)

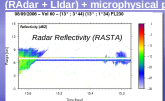
4. Case Study

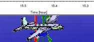
Satellite observations : SEVIRI (MSG)



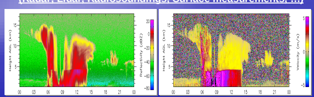
MCS was born September, 7, near 12 a.m. (blue circle), and then moved westward during the day to reach Niamey region September, 8 at approximately 3 a.m. Then it stayed several hours over Niamey, reached its maximum intensity at 6 a.m., and then dissipated until 7 p.m.

Aircraft observations : RALI (RAdar + Lidar) + microphysical probes

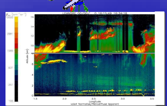




Ground observations (Niamey): ARM mobile facility (Radar, Lidar, Radiosoundings, Surface measurements, …)



Radar Refectivity — Doppler velocity

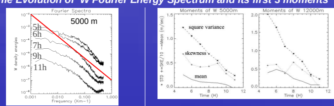


Lidar backscattering coefficient (LNG)

5. Results

5.1 Test on BRAMS dynamics:

Time Evolution of $\vec{W}$ Fourier Energy Spectrum and its first 3 moments

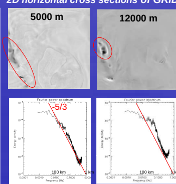


- Small scales (1-10km) are filtered in the model.
- Larger scales (10 -100km) are close to the -5/3 slope representing classical turbulence energy dissipation.

-Square variance is decreasing linearly at 5 km = OK with 3D turbulent convection theory in well mixed layers.

-Faster decrase at 12 Km due to buoyancy effects in more stratified regions.

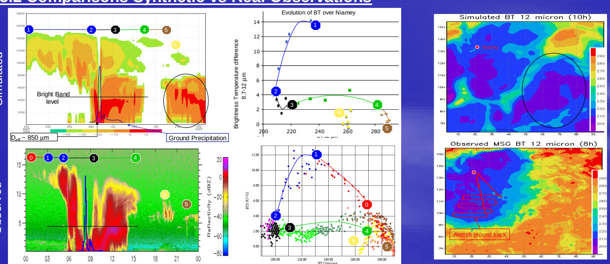
2D horizontal cross sections of GRID 3 $\vec{W}$ field at 9 h



Vertical velocity at 5000 m shows an organized squall line moving westward. Main convective core is well localised on the 12000 m cross section.

During active (deep) convection more energy is available at 12000m than 5000m
⇨ Standard Result

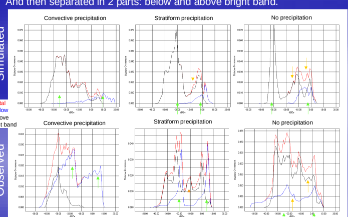
5.2 Comparisons Synthetic vs Real Observations



Simulated MCS has 2 hours late and globally too much clouds are simulated over the whole domain. MCS is well represented in space. One way to investigate this comparison is to plot Brightness Temperature Differences between 2 IR-channels (8.7-12 µm) vs BTs at 12 µm. Evolution of BTD is very similar. Higher BT Differences in the front of MCS can be explain by the presence of small particles. Once MCS is well developped, larger particles (smaller BTD) are observed and as optical depths increase, BTs at 12 µm decrease. We finally obtain arches which are very similar.

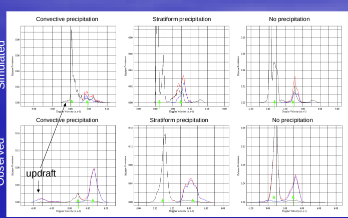
5.3 Statistical Comparisons: PDF approach

PDFs of ARM Reflectivities and Doppler velocities have been analysed in terms of ground precipitations : *convective, stratiform* and *none*
And then separated in 2 parts: below and above bright band.



-Both total PDFs of synthetic and real observations underline 2 main modes (model always simulate only one below bright band)
⇨ 2 different convective regimes
In aggrement with various observations realized during deep convection events (Niamey, Benin and Darwin, Australia) with cloud top height PDFs.

-Transition between these 2 modes:
- Ground convective precipitation: fast transition between large modes (composed of multiple shifted peaks due to attenuation effects)
- Ground stratiform precipitation: slower transition between narrow modes (*intermediate mode* appears above bright band in obs.)
- No precipitation: slow transition between larger peaks (presence of small *secondary modes)*



- 2 modes : Cloud and Precipitation

- Model underestimate doppler velocity.
- Observations show a peak representing updraft below bright band which is not simulated

- Cloud mode : - Contribution in both case is mainly due to hydrometeors above bright band.
  - Splitted in the model between 0-1 m.s^{-1}

- Precip. mode : - Obs: only below bright band
  - Synthetic obs: 50% comes from above bright band

6. Conclusion and outlooks.

- Simulated MCS is late by 2 hours but spatially well situated.
- Expected dynamical structures of MCS and African Monsoon dynamics (not shown) are captured by BRAMS
- Similar brightness temperatures arches between observations and synthetic ones.
- PDF of reflectivity underline 2 convective modes with different transitions - Too much contribution of high levels to precipitation in model.

- Comparisons with RASTA and In-Situ reflectivities (µφ measurements + simulator) ⇨ Sensibility tests on power laws
- Investigate the different contributions of hydrometeor species to the signal ⇨ Constrain model microphysics
- Test of retrieval algorithms
- Water and radiative budgets analysis

7. Acknowledgement.

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8. Selected References.

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