The cloud microphysics scheme and the COSP simulator for validation

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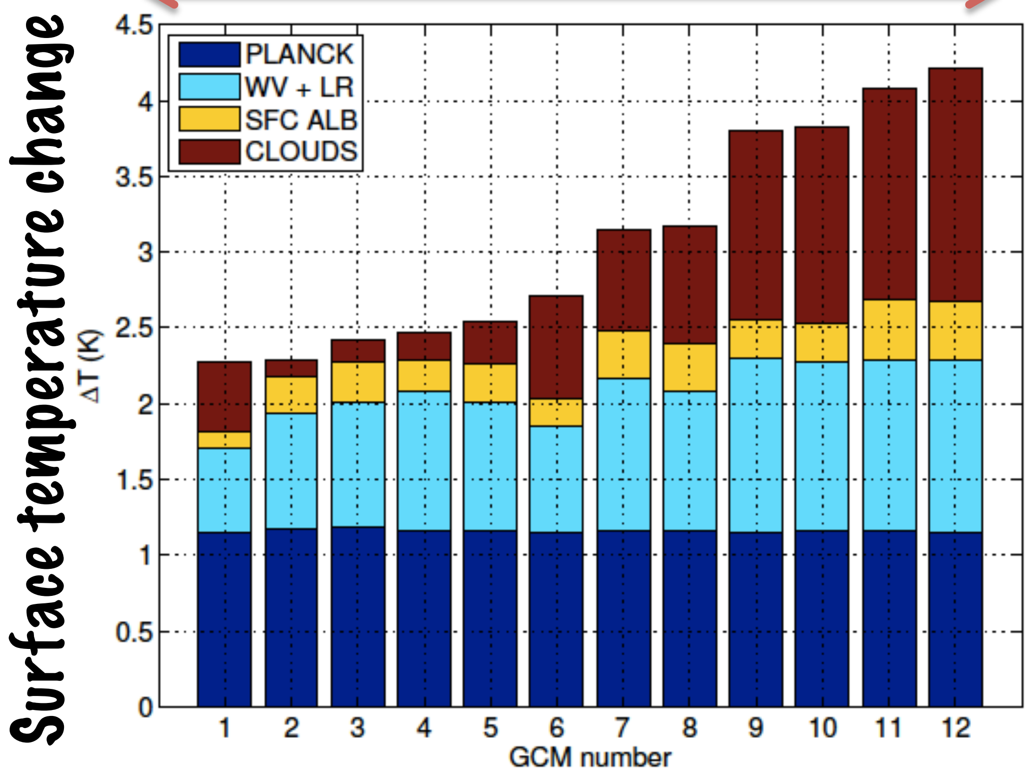
Clouds...

* Clouds are one of the fundemental components of the climate system, and their representation in models is critical

Motivation

12 Different climate models



Dufresne and Bony (2008)

Clouds: highly uncertain feedback...

...relative to other feedbacks.

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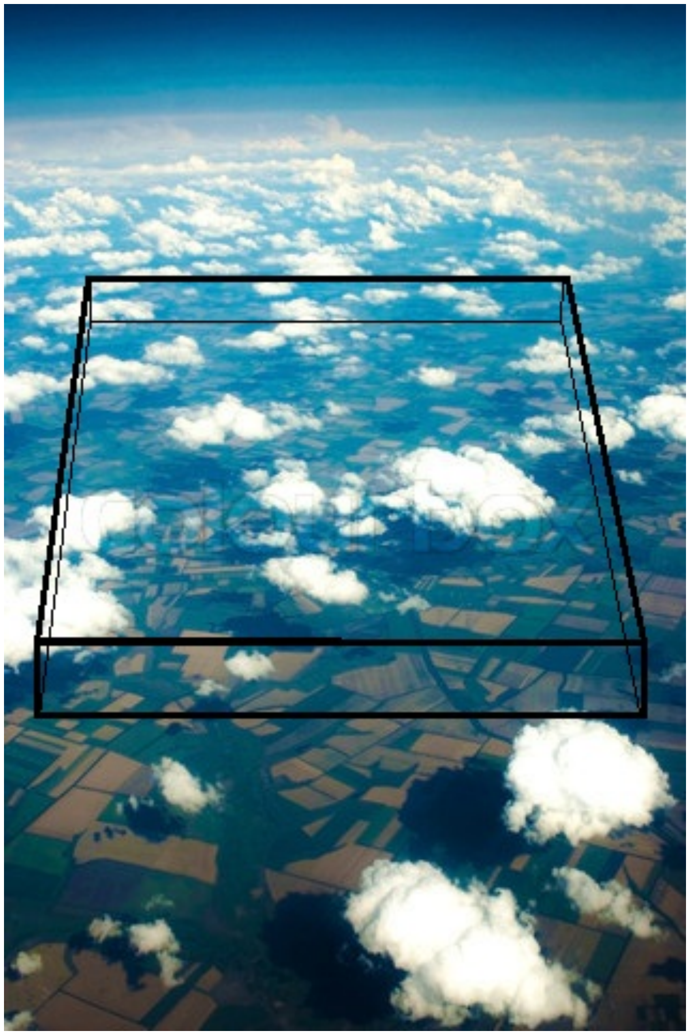
Cloud Parameterizations



In climate models two groups of parameterization schemes:

* CONVECTIVE clouds
  - dynamics

* STRATIFORM clouds
  - microphysics.

CFMIP5 (Vial et al 2013)

show that the spread is associated to how stratocumulus clouds are parameterized

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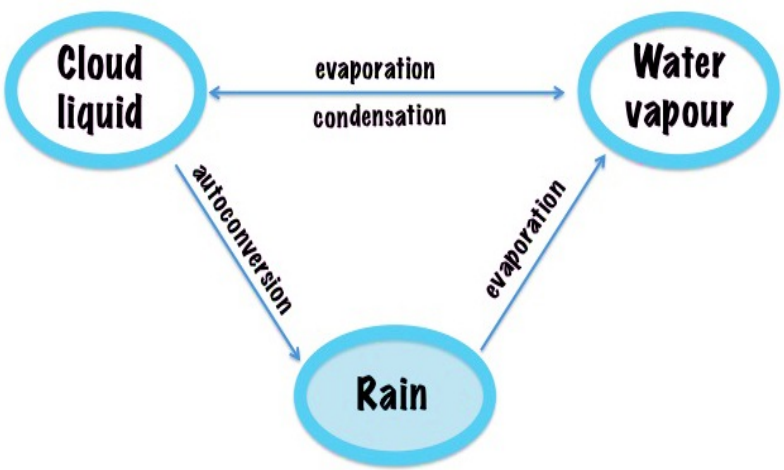
The RegCM4 previous approach

SUBEX



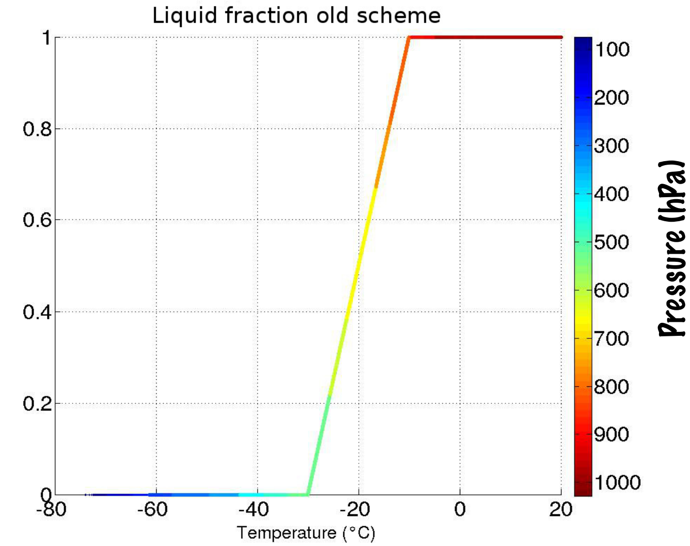
Pal et al (2000)

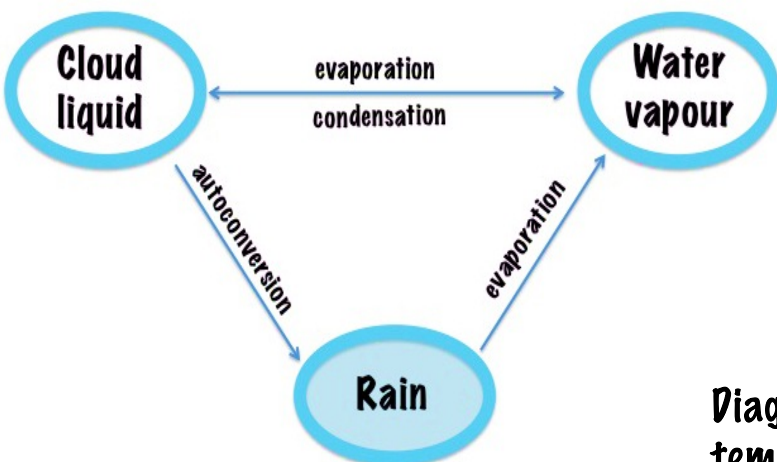
* 1 prognostic variable for cloud water
* 1 diagnostic variable for rain which falls out instantaneously
* no cold clouds microphysics
* divided into ice and liquid according to temperature

The RegCM4 previous approach

SUBEX

Liquid water fraction $= \dfrac{q_l}{q_i + q_l}$





Pal et al (2000)

Diagnostic split of cloud water into liquid and ice according to temperature

- Assumes processes are fast compared to the model timestep
- variables are always in equilibrium

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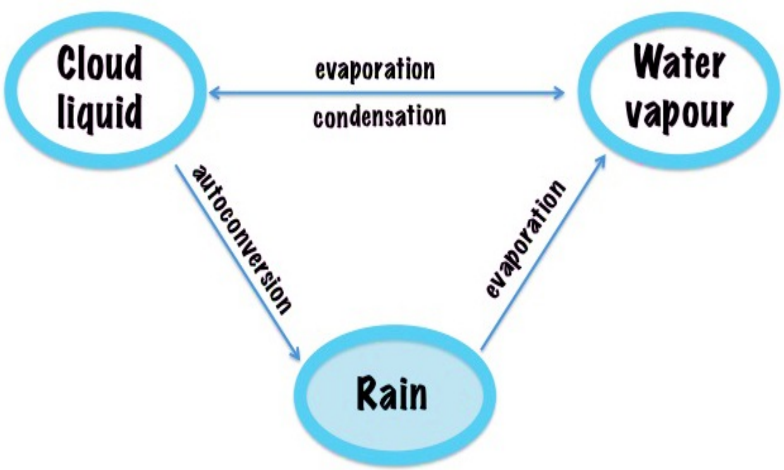
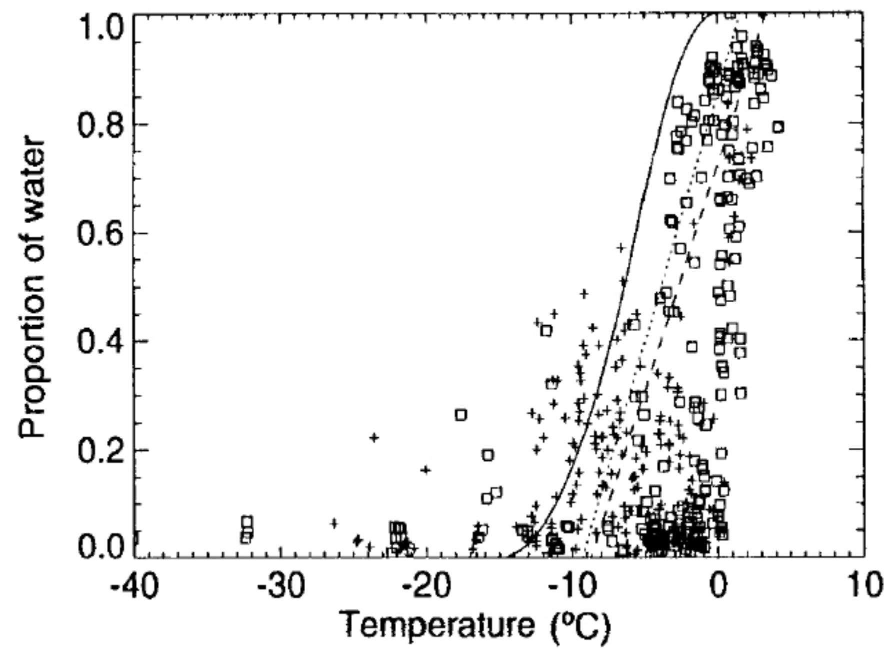
The RegCM4 previous approach

SUBEX



Pal et al (2000)

Is unable to represent temporal variability and evolution of mixed-phase clouds!



(Rotstayn 1996, scatter plot of the liquid water fraction in stratiform clouds as a function of temperature)

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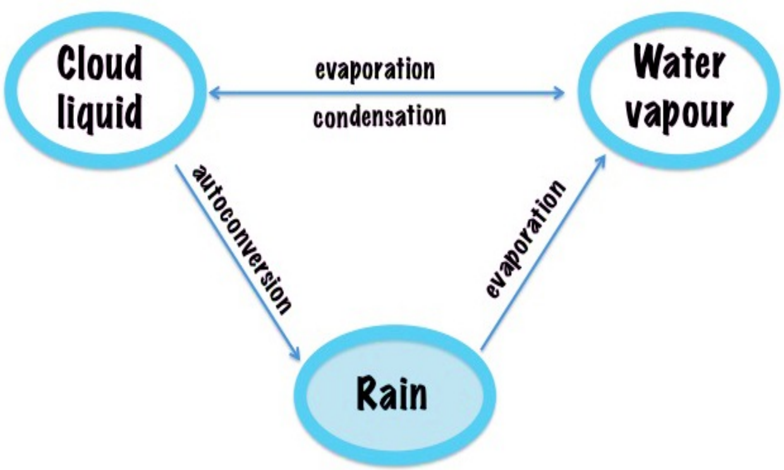
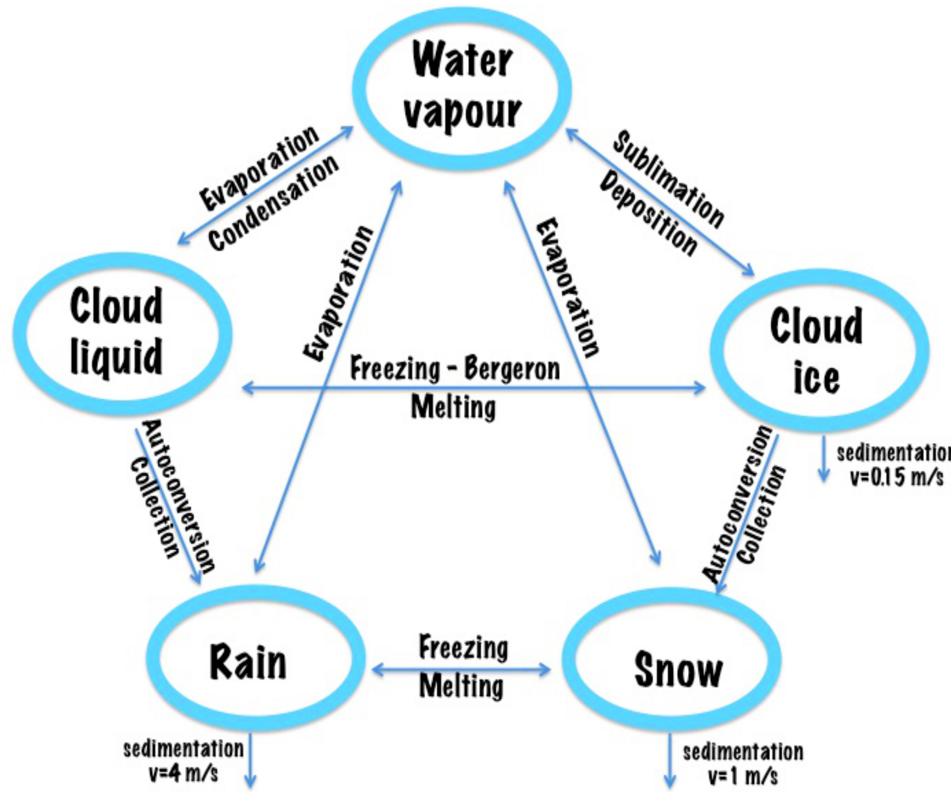
The new Approach

SUBEX

NEW



Pal et al (2000)



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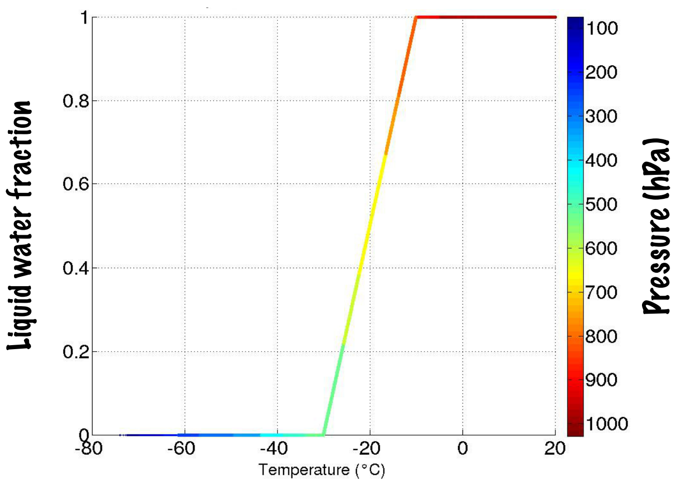
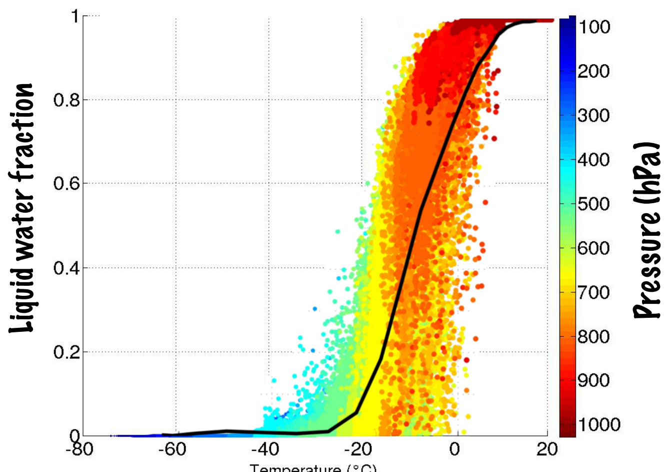
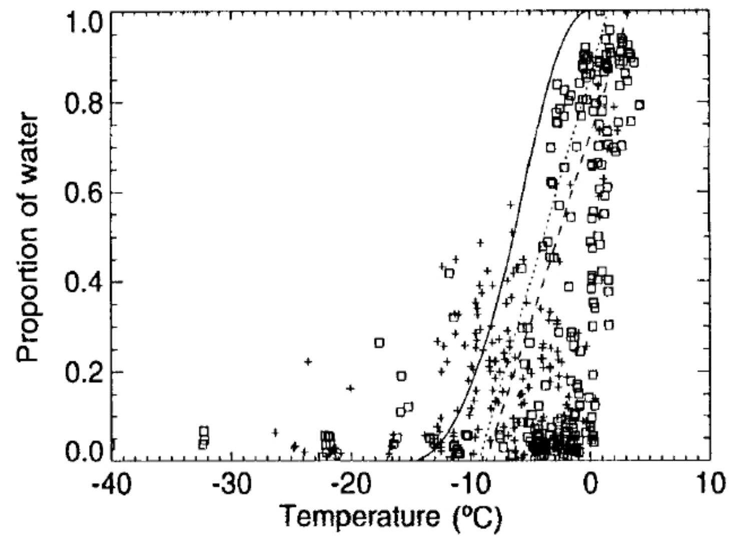
Mixed phase clouds

OLD SCHEME (SUBEX)



NEW SCHEME





Observation in stratiform clouds (Rotstayn 1996)

- No liquid for temperature below the homogeneous nucleation threshold -38°C;
- The new prognostic approach allows the representation of the temporal variability and evolution of mixed phase clouds

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Numerical framework of the new scheme

Numerical framework of the new scheme

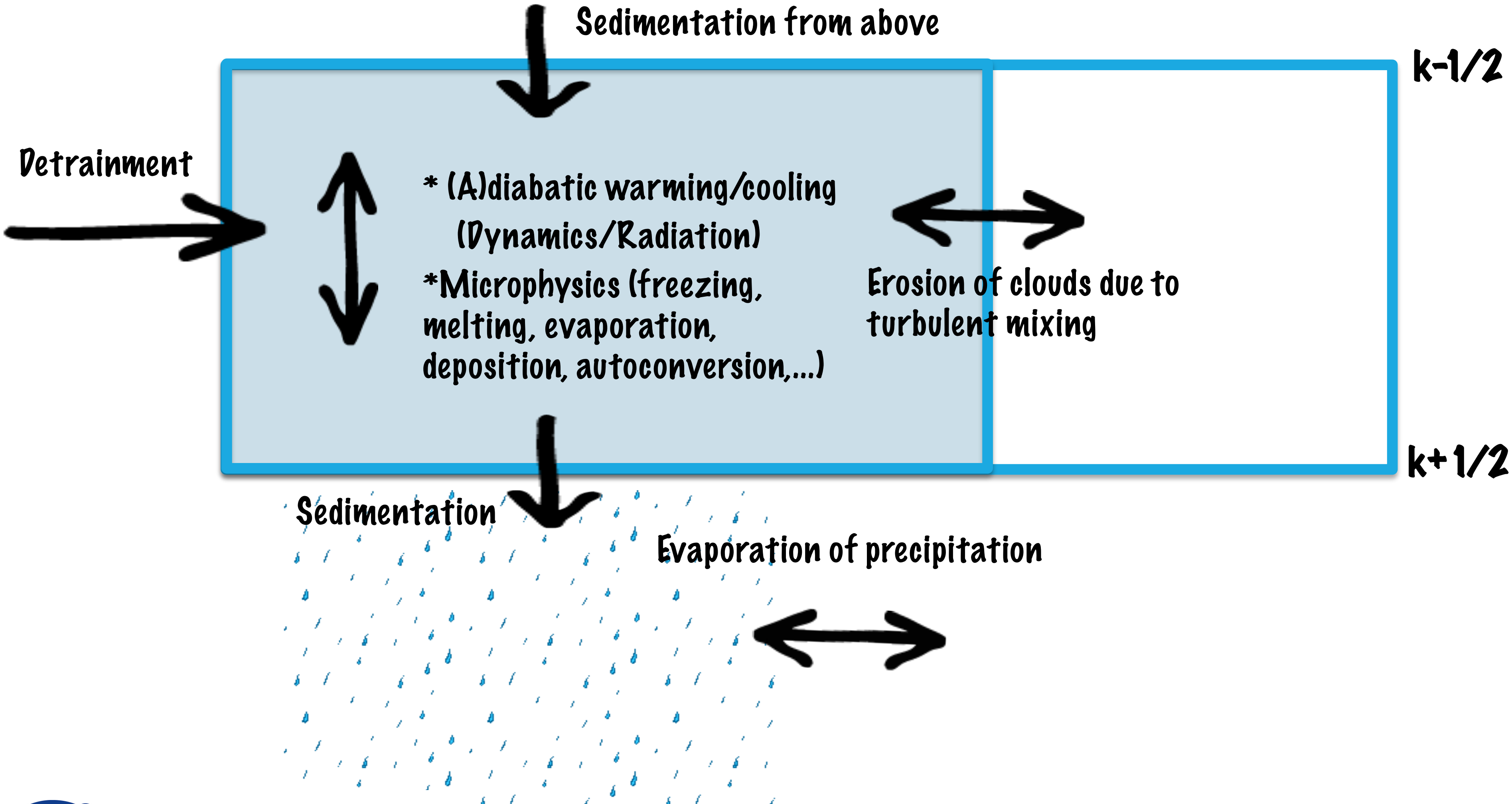
GOOD NEWS!!!

Already explained in the last workshop (May 2014)!

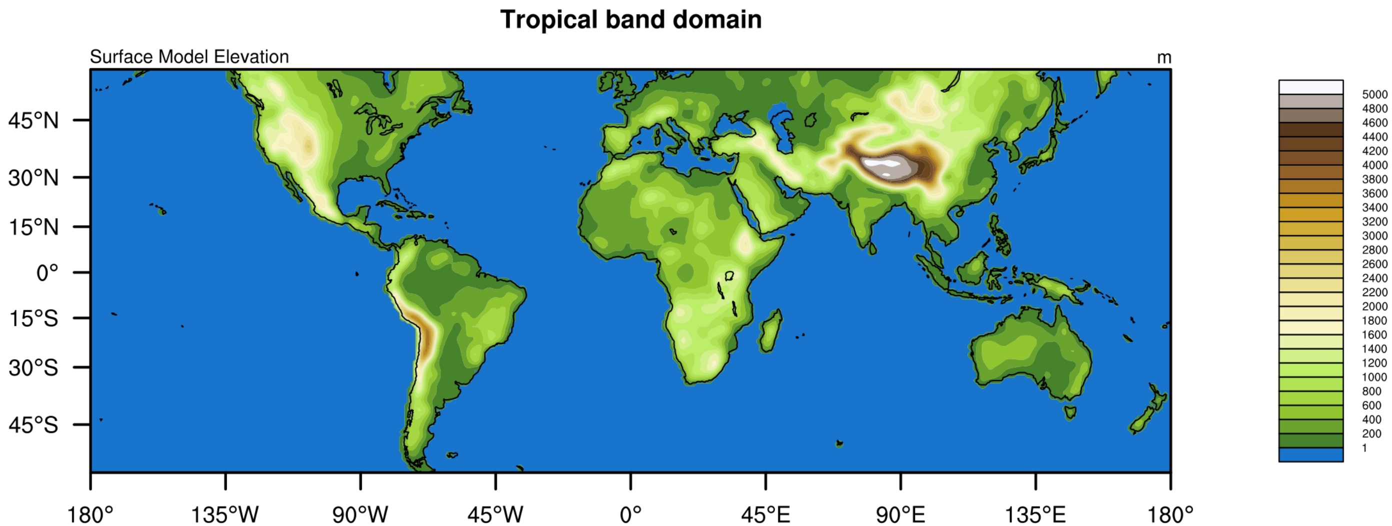
Reference:

Nogherotto, R. et al : **Numerical framework and performance of the new multiple phase cloud microphysics scheme in RegCM4.5: precipitation, cloud microphysics and cloud radiative effects**, *Geosci. Model Dev. Discuss.*, doi:10.5194/gmd-2016-31, in review, 2016.

Schematic of sources and sinks



Sensitivity tests

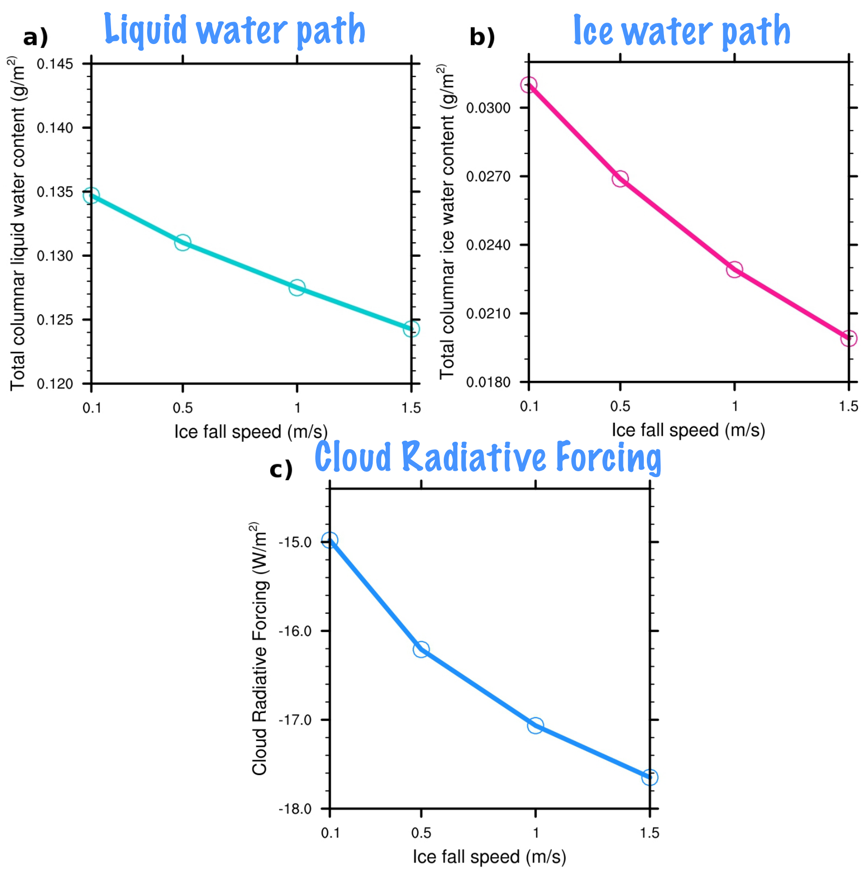


As values of fall speeds are not fixed in nature, we want to determine how the simulated clouds and precipitation depend on the variation of microphysics parameters.

Set of 1-week simulations varying:

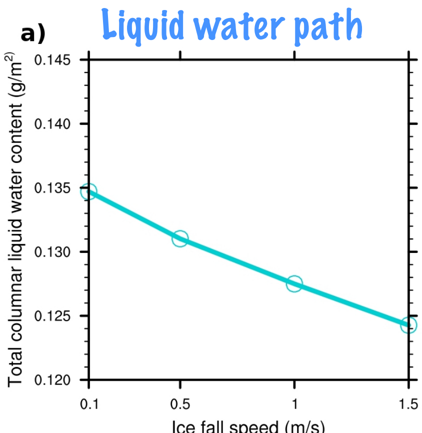
* fall speeds of ice;
* fall speed of rain;
* fall speed of snow;
* autoconversion scheme;

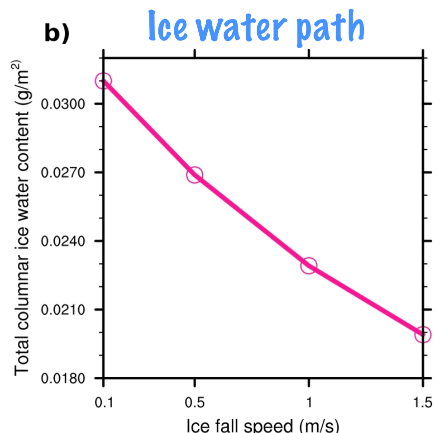
Results : Sensitivity tests

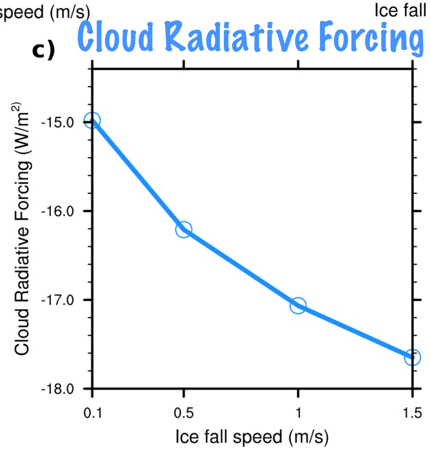


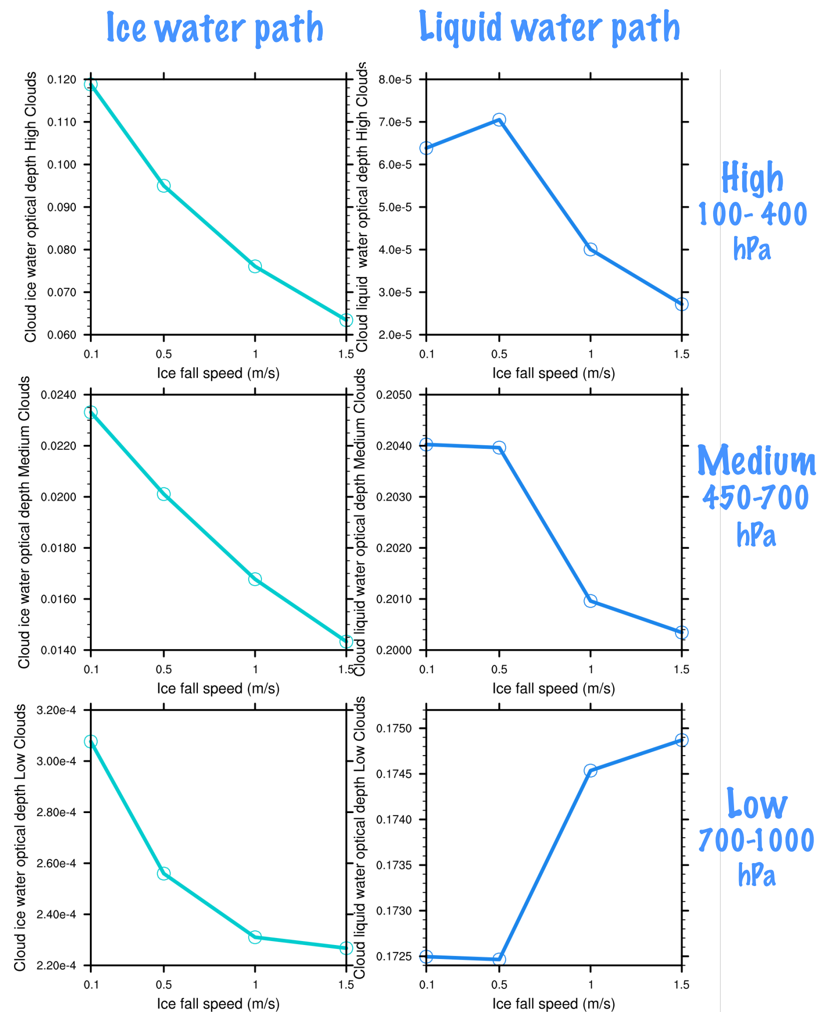
Cloud Radiative Forcing: difference between the radiation budget LW and SW components in cloudy conditions and in clear sky conditions

Results : Sensitivity tests



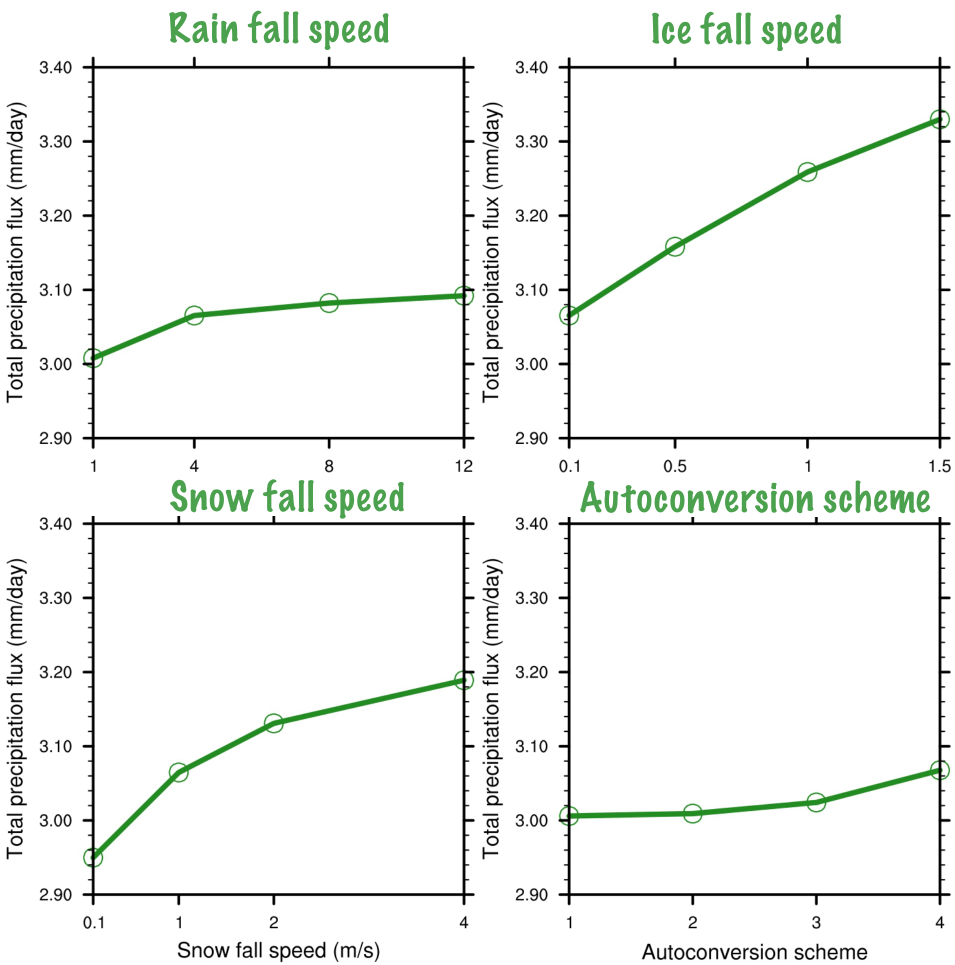






Cloud Radiative Forcing: difference between the radiation budget LW and SW components in cloudy conditions and in clear sky conditions

Microphysical Sensitivity tests



* Precipitation is not sensitivite to rain fall speed and to different autoconversion schemes;
* Precipitation is more sensitive to ice and snow fall speeds;

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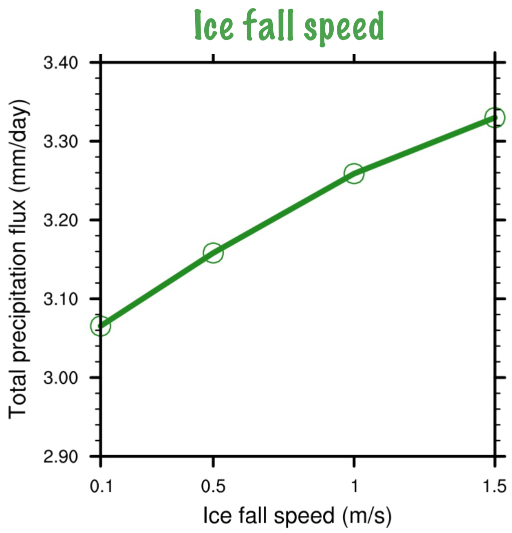
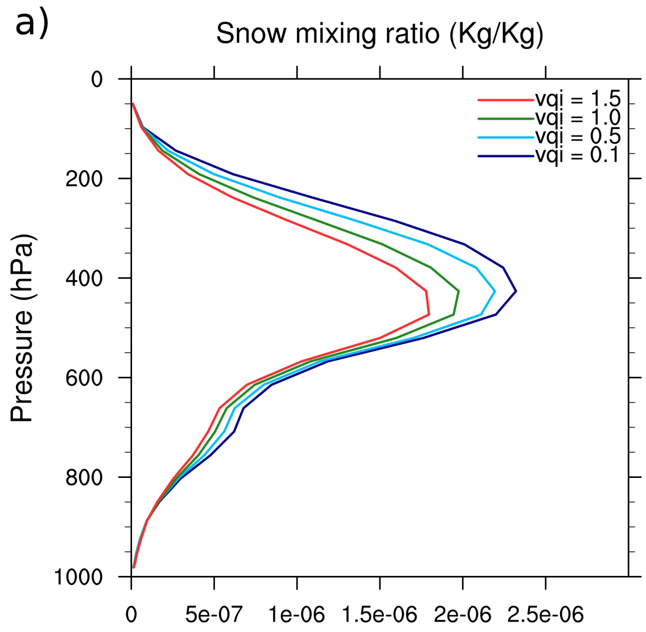
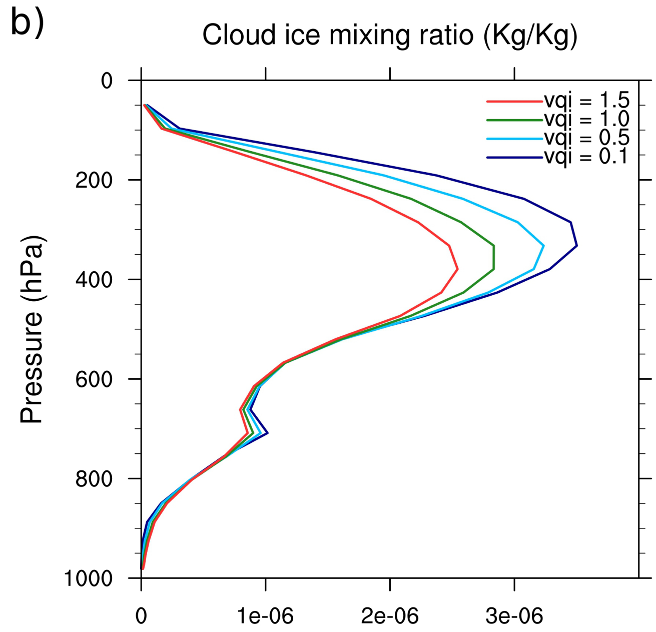
Sensitivity to ice fall speed







- Ice fall speed increases;
- Cloud ice mixing ratio decreses;
- Cloud snow mixing ratio decreases;
- Total precipitation flux increases;

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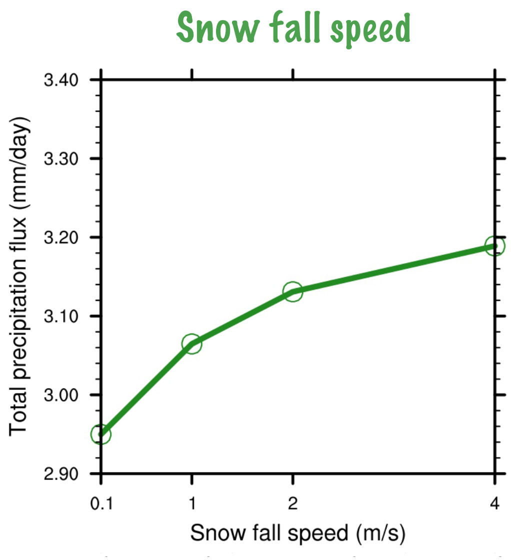
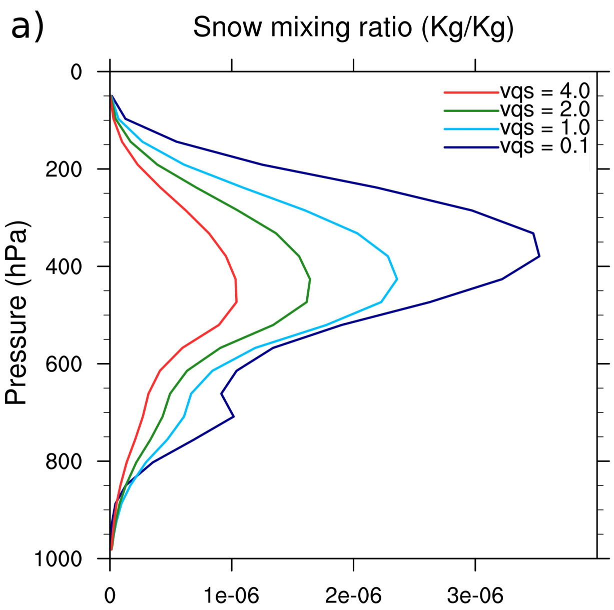
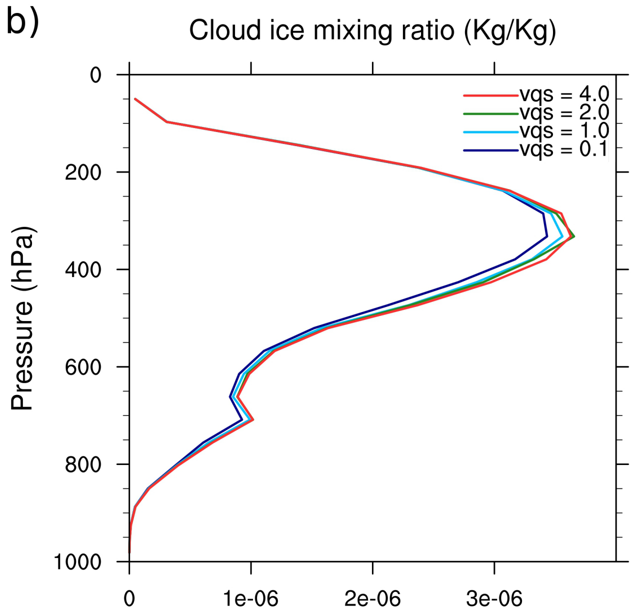
Sensitivity to snow fall speed







* Snow fall speed increases;
* Cloud snow mixing ratio decreses;
* Cloud ice constant;
* Total precipitation flux increases;

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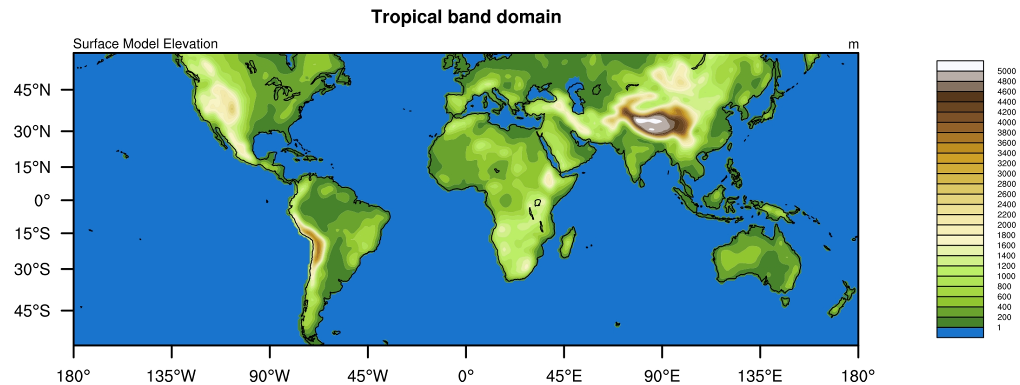
Validation

- 10-years simulation (JJA - DJF 2000-2010)
- SUB - SUBEX scheme + Simulator
- MIC - Microphysics scheme + Simulator
- OBServations



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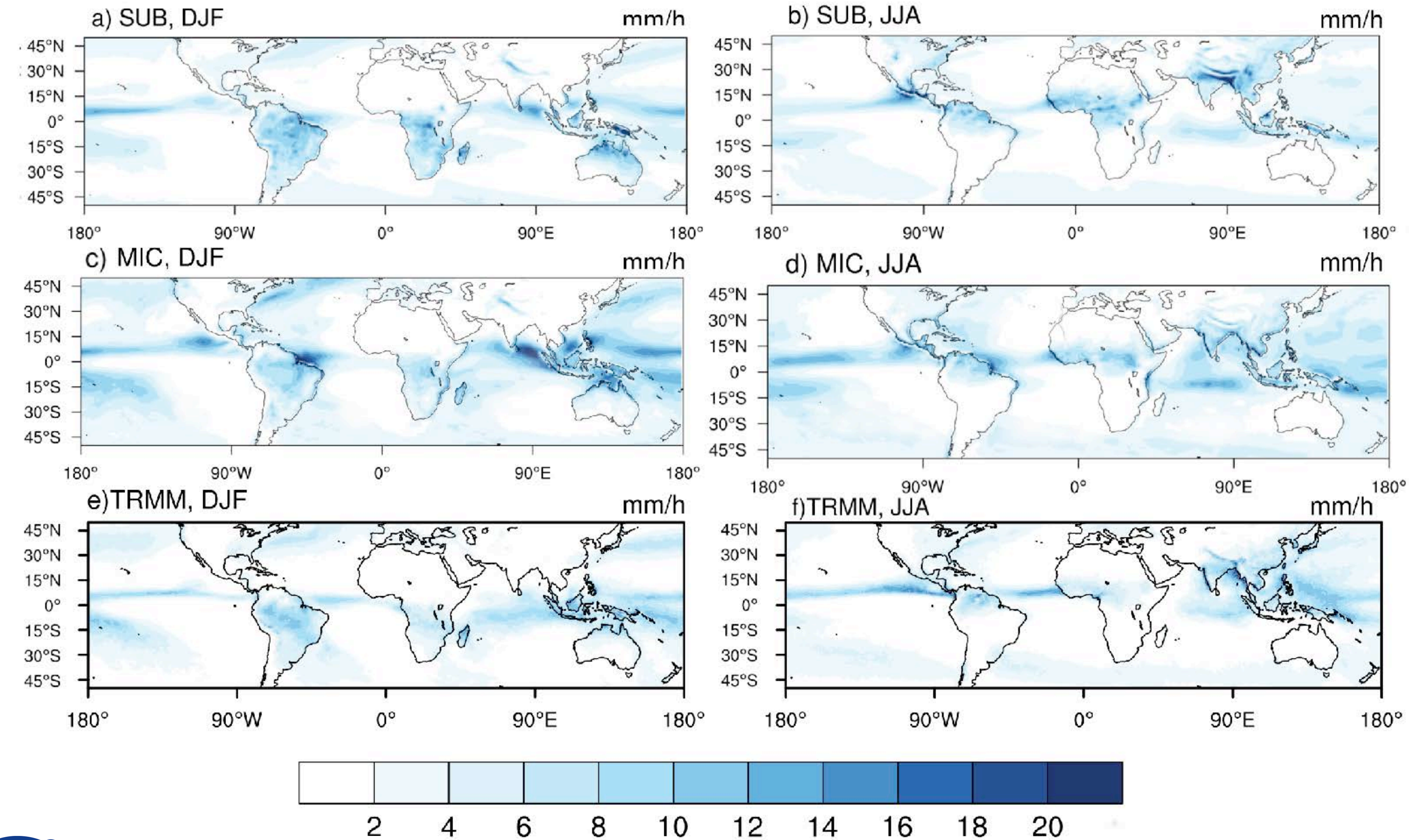
Precipitation



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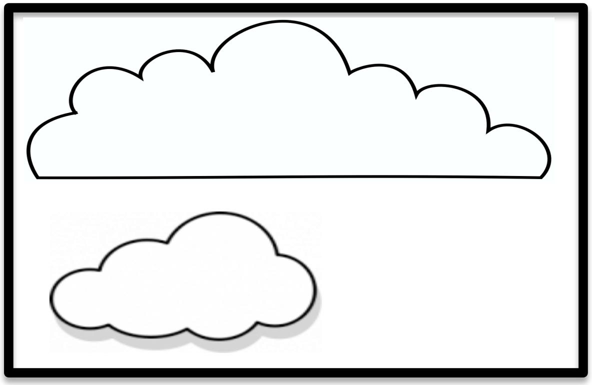
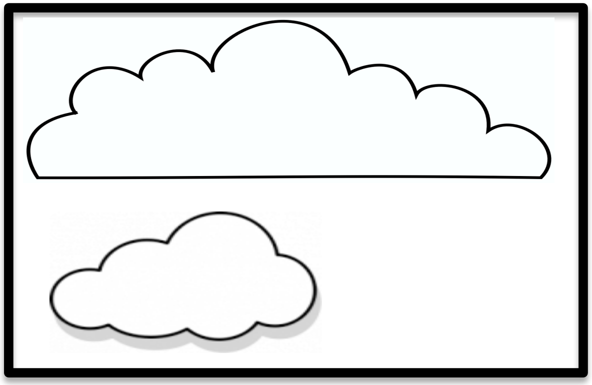
Validation of clouds



Real Clouds

Validation of clouds



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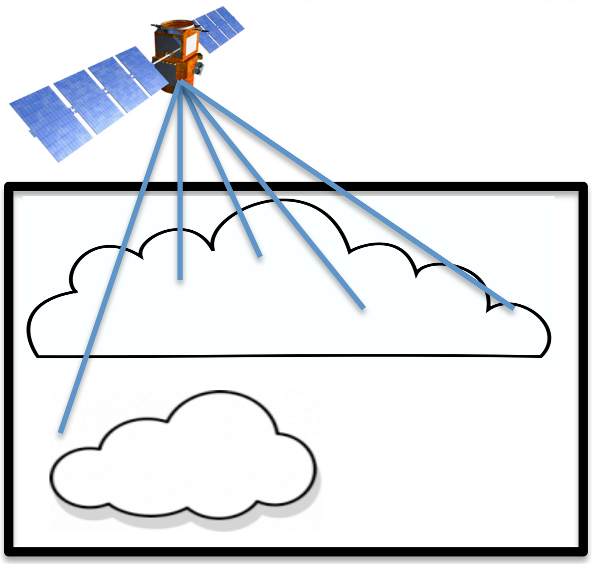

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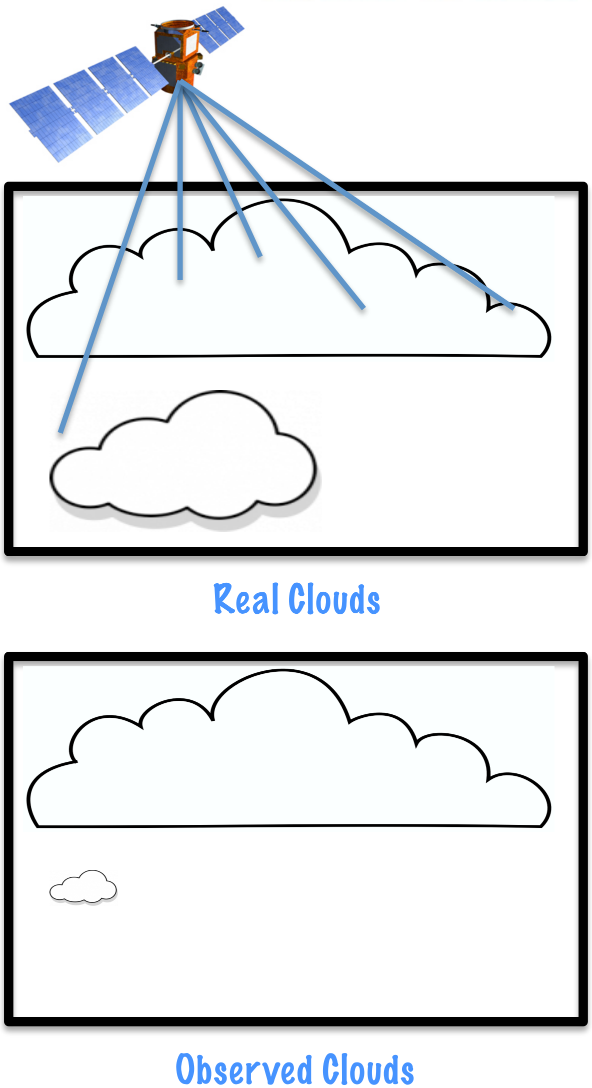

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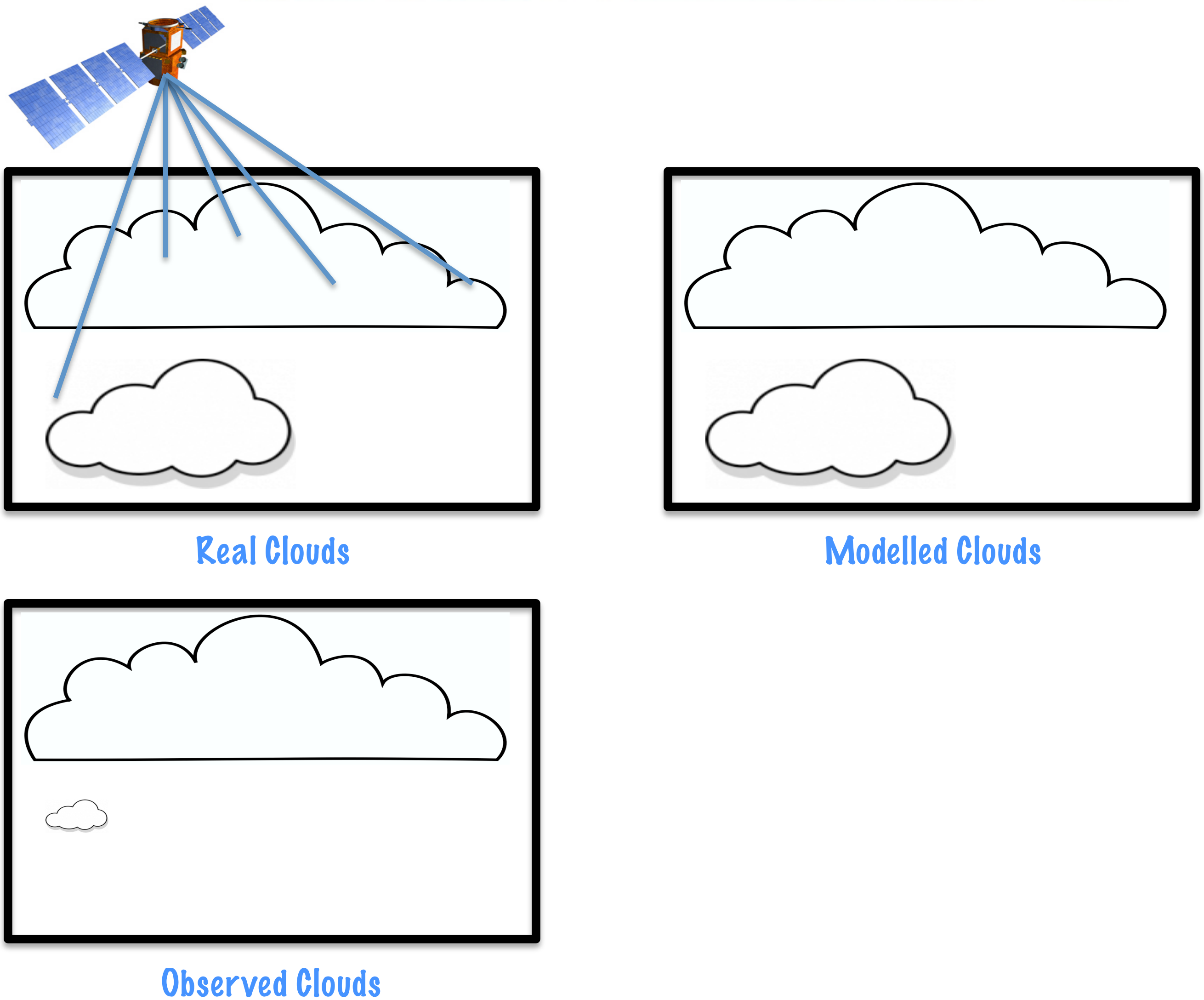

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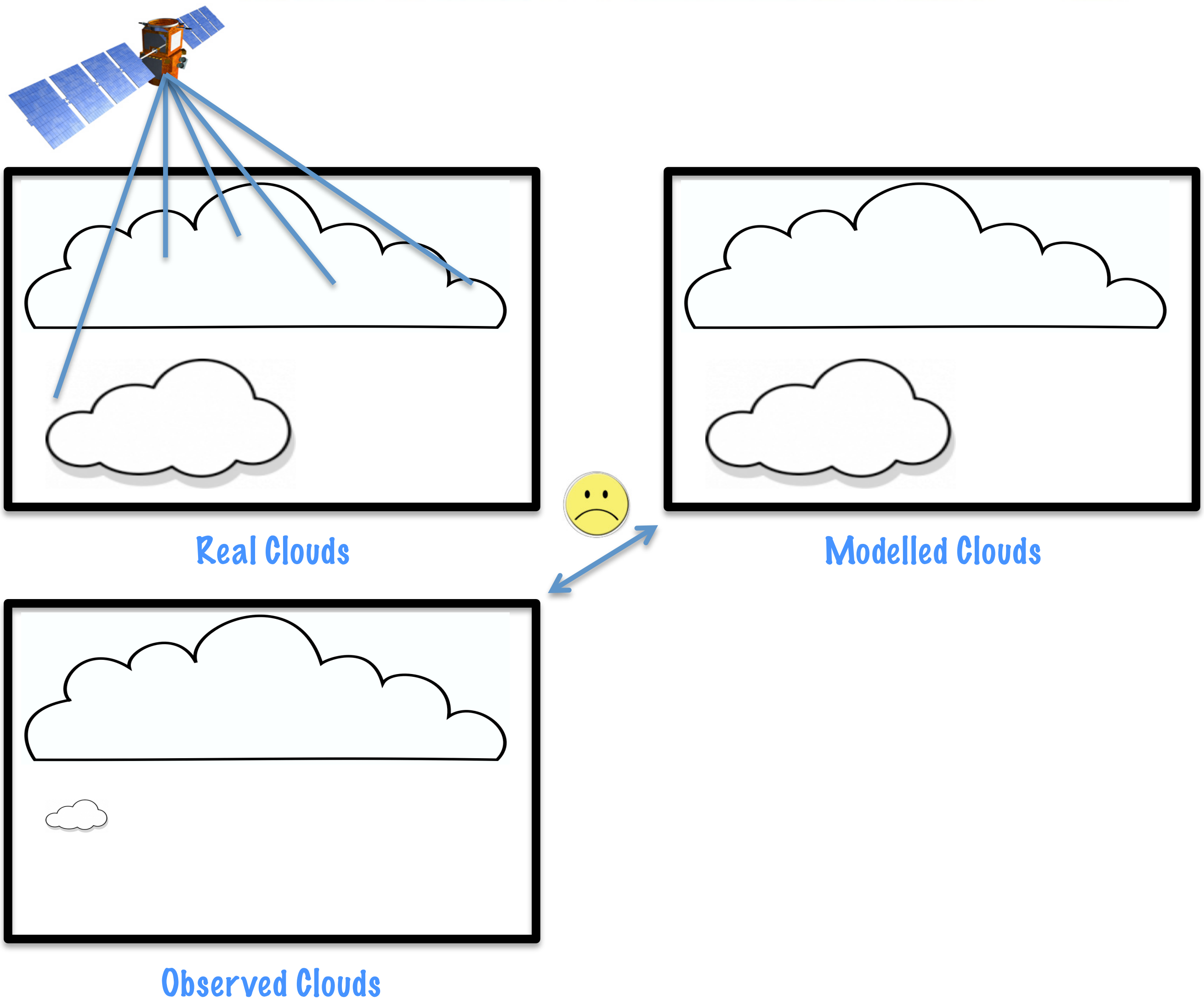

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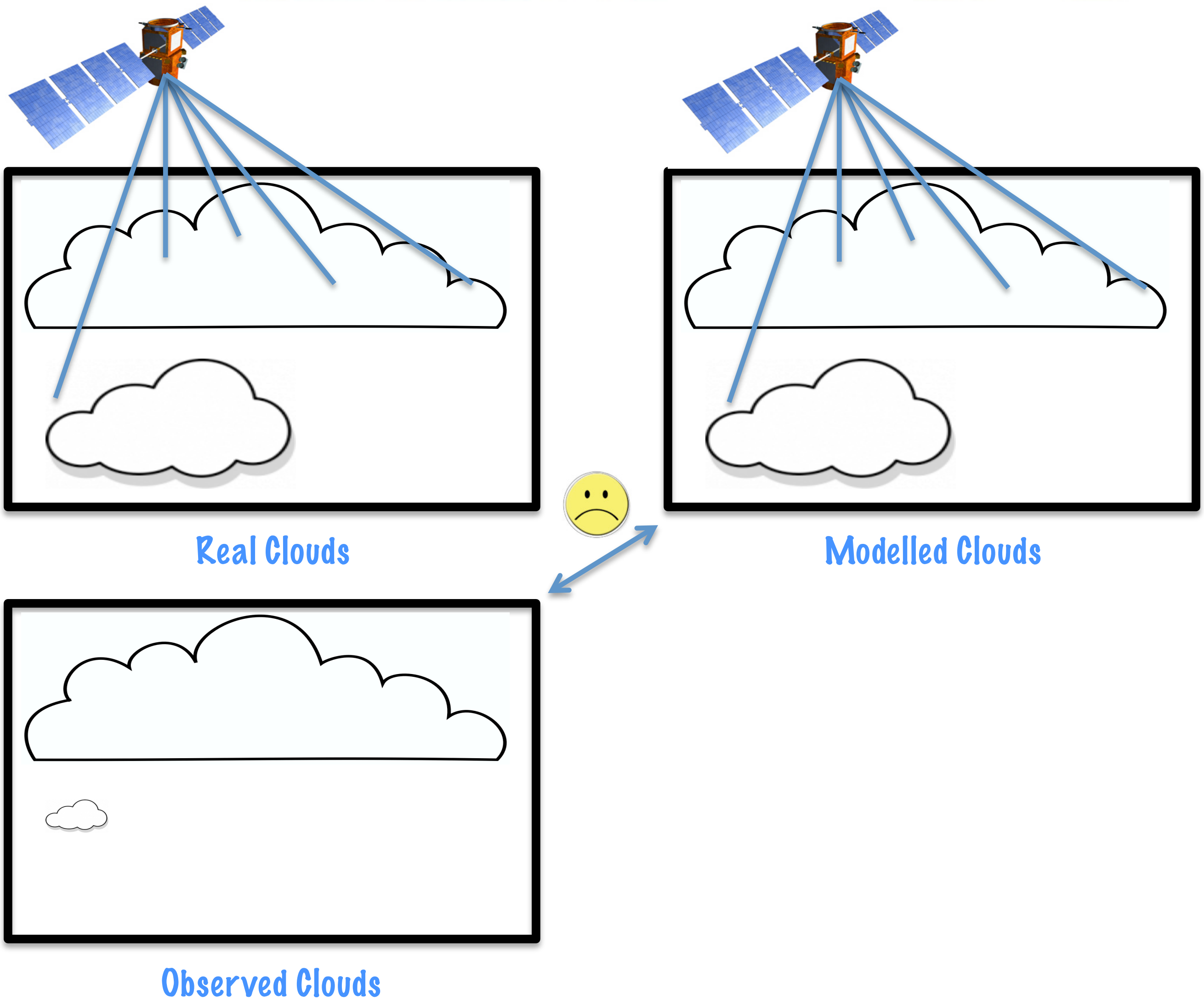

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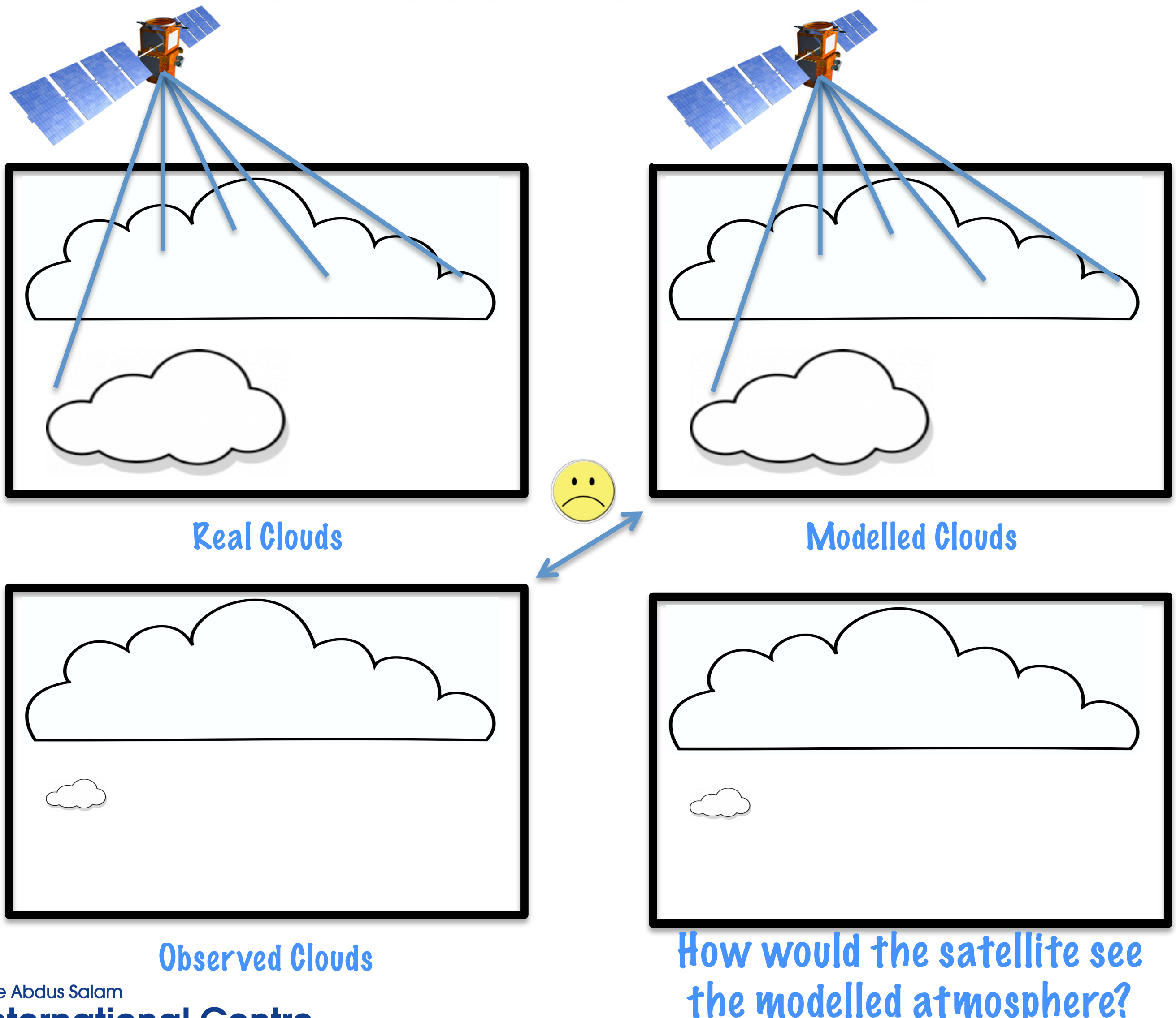

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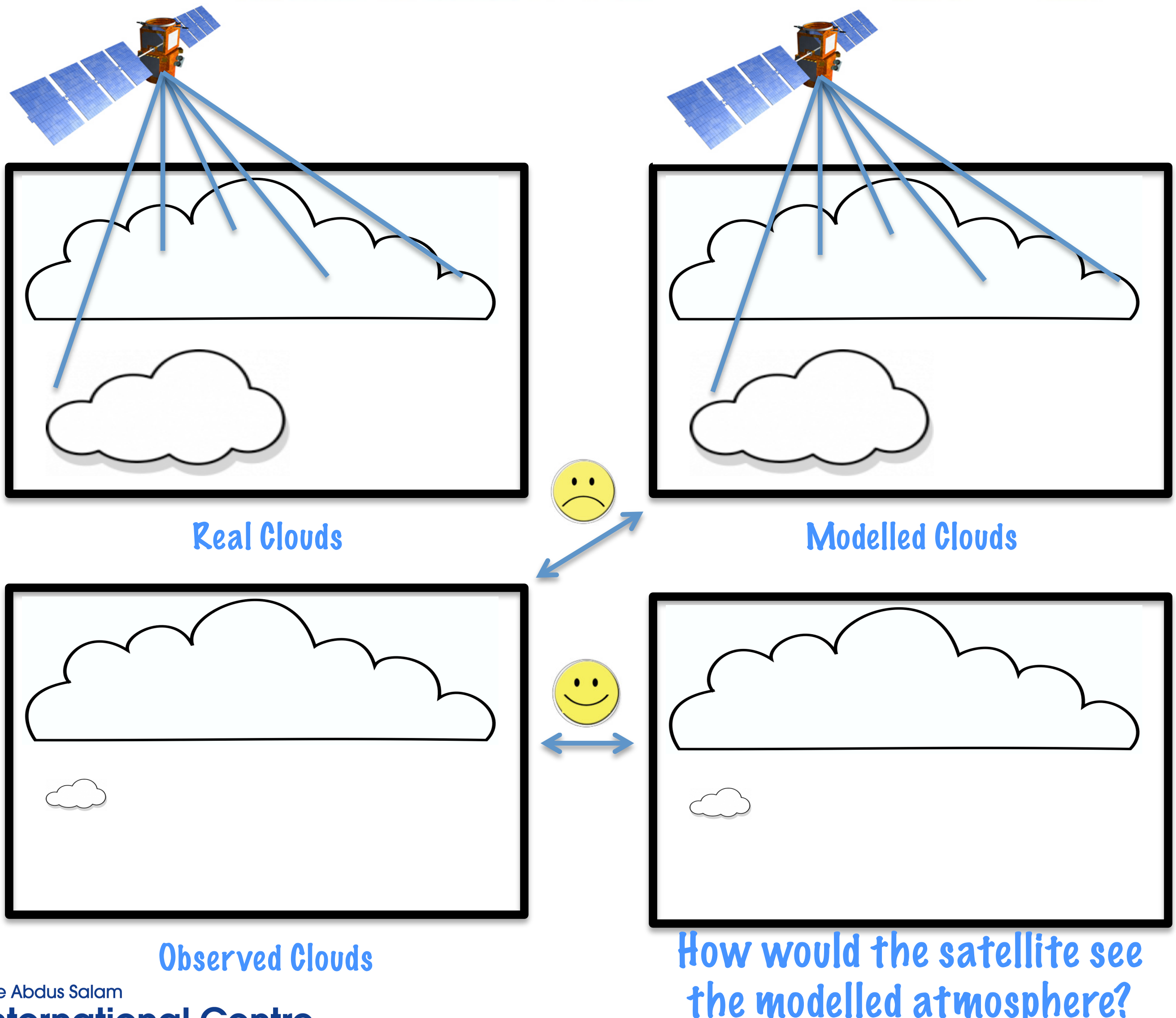
Validation of clouds



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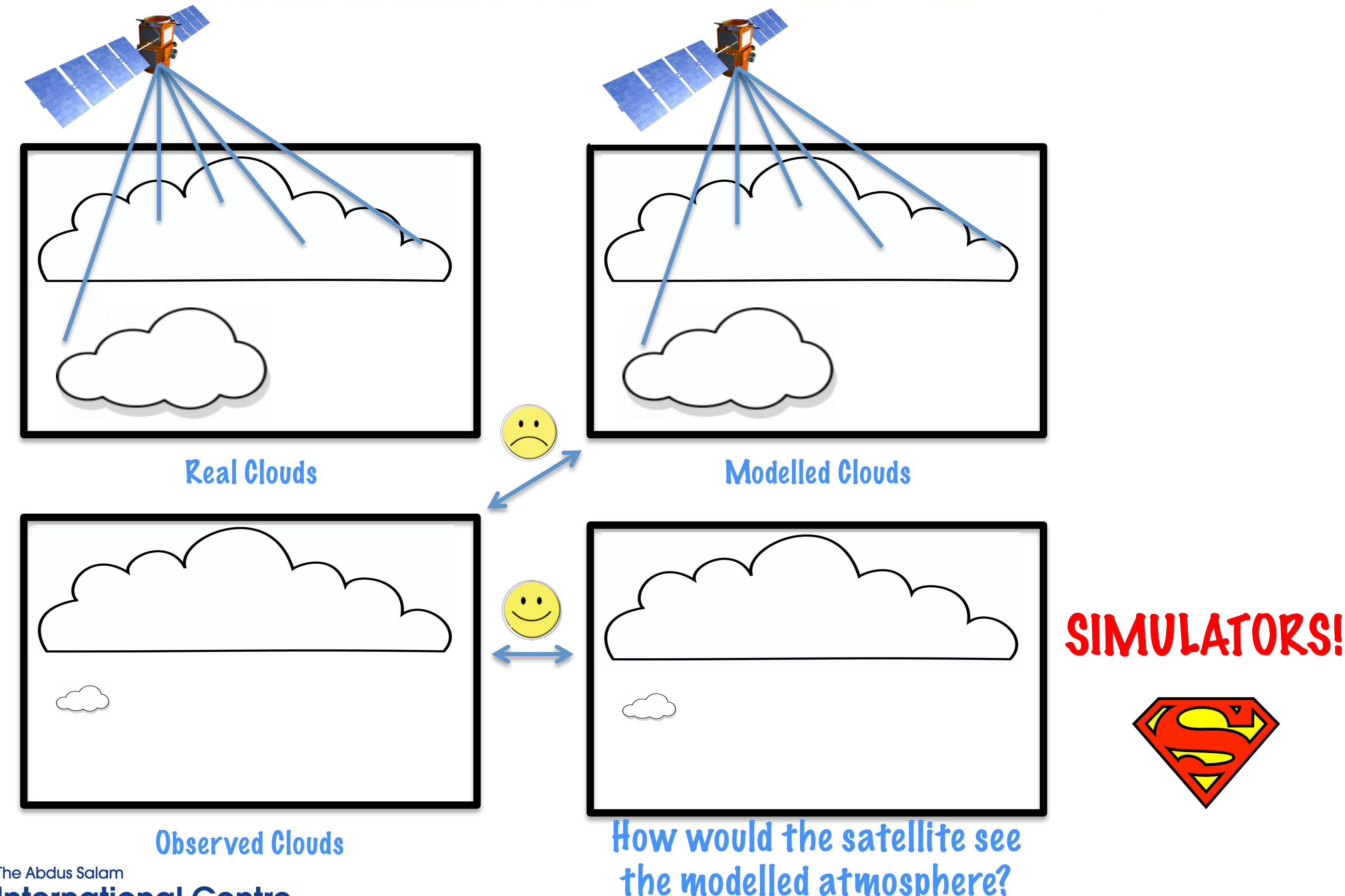

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Instrument simulators

Basic idea: Rewrite model outputs miming the observational processes taking into account instrument's biases.

The CFMIP Observation simulator Package (COSP): Software used for the validation of cloud properties

Met Office
Hadley Centre

EUCLIPSE

European Union CLoud Intercomparison, Process Study and Evaluation Project

Bodas-Salcedo et al. (2011)

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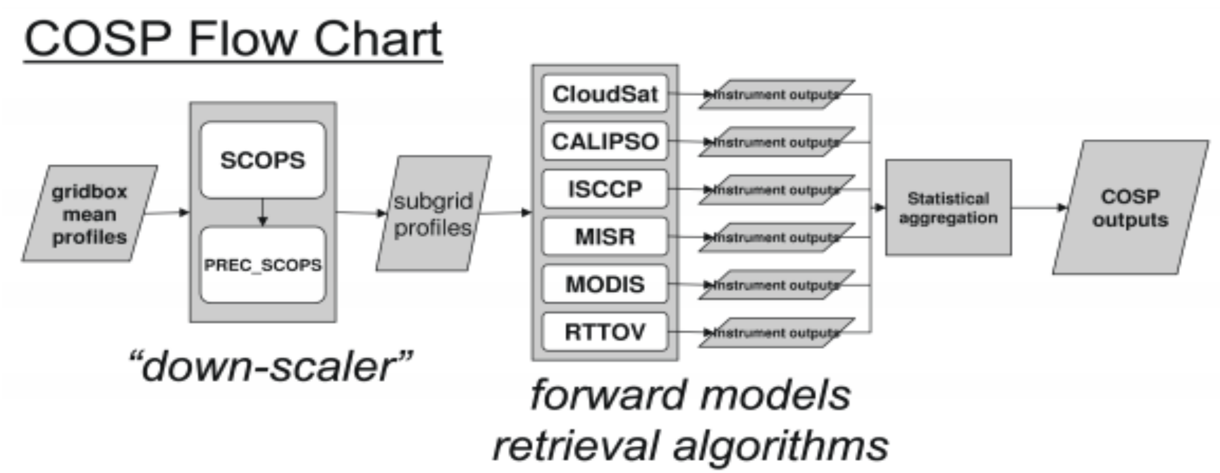

European Union CLoud Intercomparison, Process Study and Evaluation Project

Bodas-Salcedo et al. (2011)

Met Office Hadley Centre

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Validation of clouds

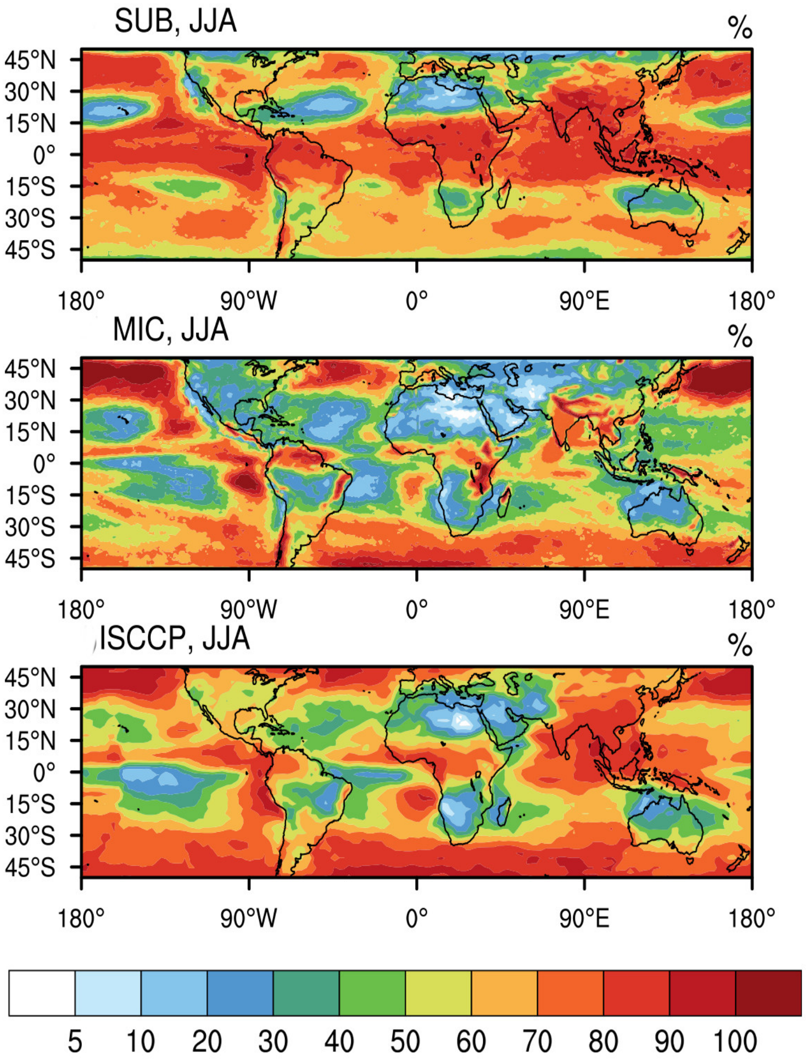
* We implemented the COSP package to be used for RegCM4 (available online on gforge : http://gforge.ictp.it/gf/download/frsrelease/251/1556/cosp_regcm.tar.gz)

* First evaluation of RegCM4 clouds using the simulators;

* Tropical band domain to have a general overview of the model's ability in representing different types of clouds ;

Cloud fraction

International Satellites Cloud Climatology Project (ISCCP)

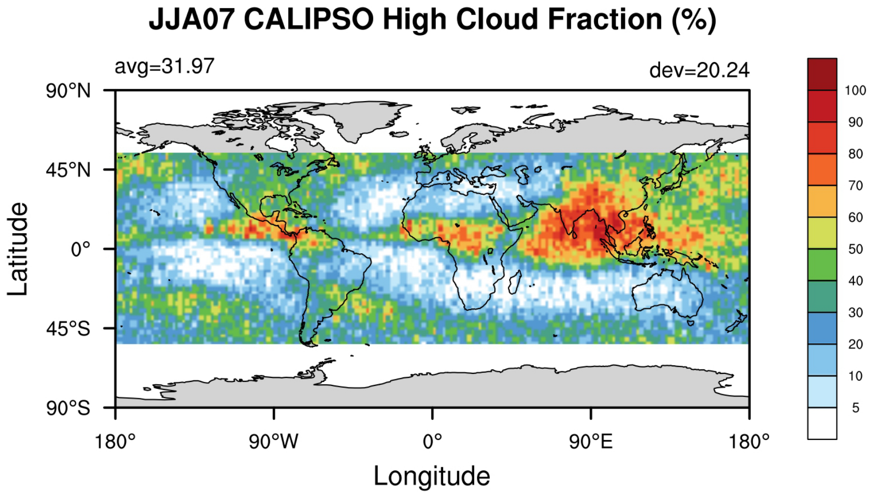


SUB + ISCCP Simulator
(cloud fraction= 67,35 %)

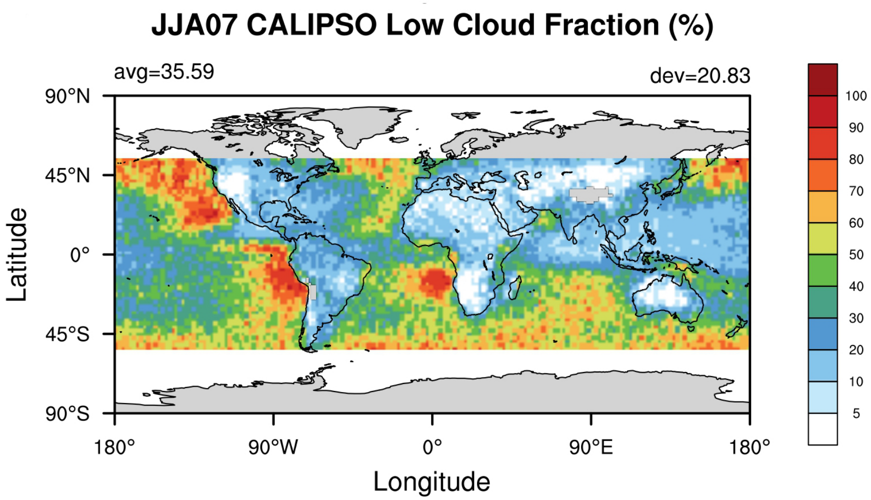
MIC + ISCCP Simulator
(cloud fraction= 60,04 %)

ISCCP OBS
(cloud fraction= 64.66%)

Tropical band clouds



- High clouds – InterTropical Convergence Zone
- Convection due to ascending branches of the Hadley cells



- Low clouds – Eastern sides of oceans basins
- Descending branch of Walker circulation
- Dry warm air from above meets cold and moist air at the surface

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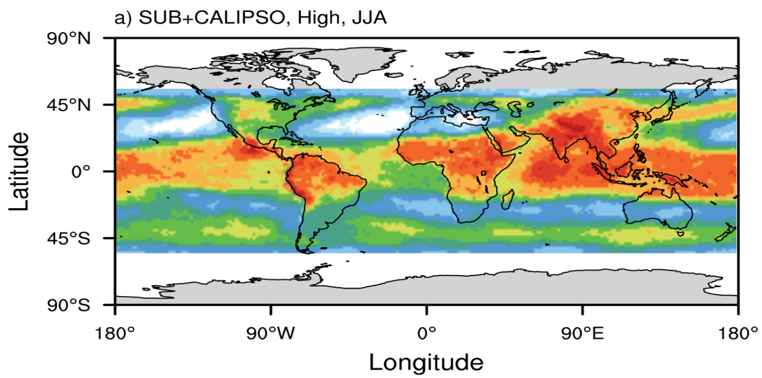
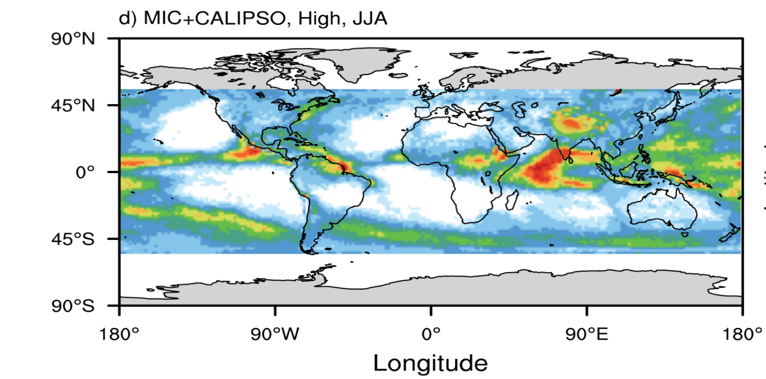
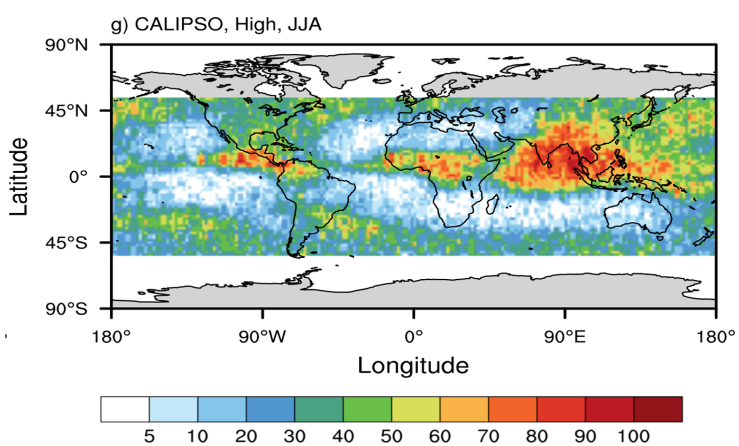
High Clouds (CTP < 440 hPa)



SUB + CALIPSO Simulator
(cloud fraction= 64,33 %)

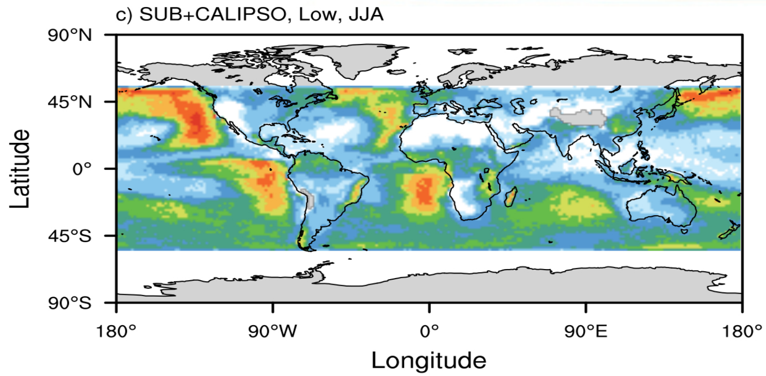


MIC + CALIPSO Simulator
(cloud fraction= 24,85 %)



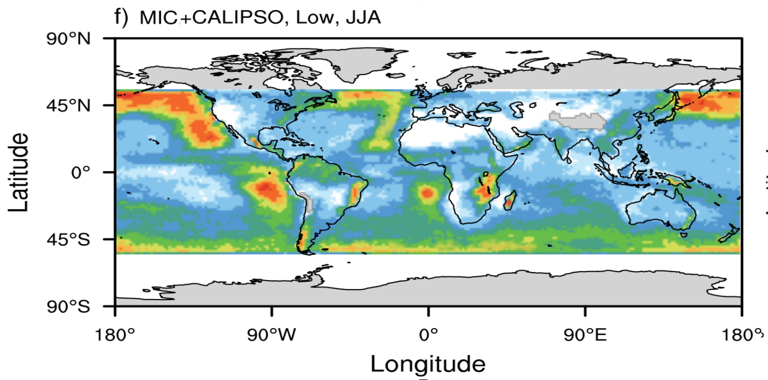
CALIPSO OBS
(cloud fraction= 31,97%)

Low clouds (CTP > 680 hPa)



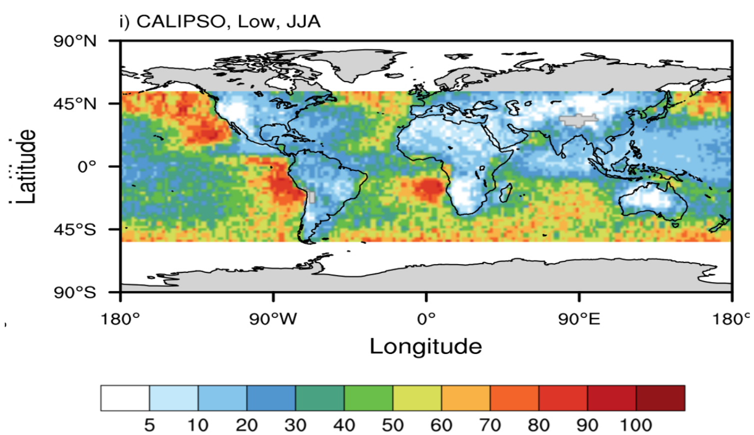
SUB + CALIPSO Simulator

(cloud fraction= 29,22 %)



MIC + CALIPSO Simulator

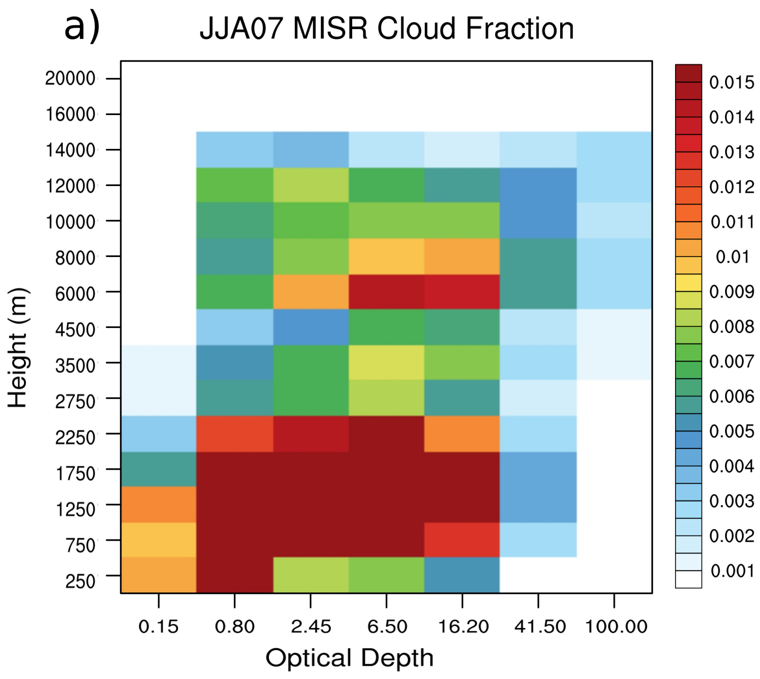
(cloud fraction= 29,10 %)



CALIPSO OBS

(cloud fraction= 35,59%)

Multi-angle Imaging SpectroRadiometer (MISR)



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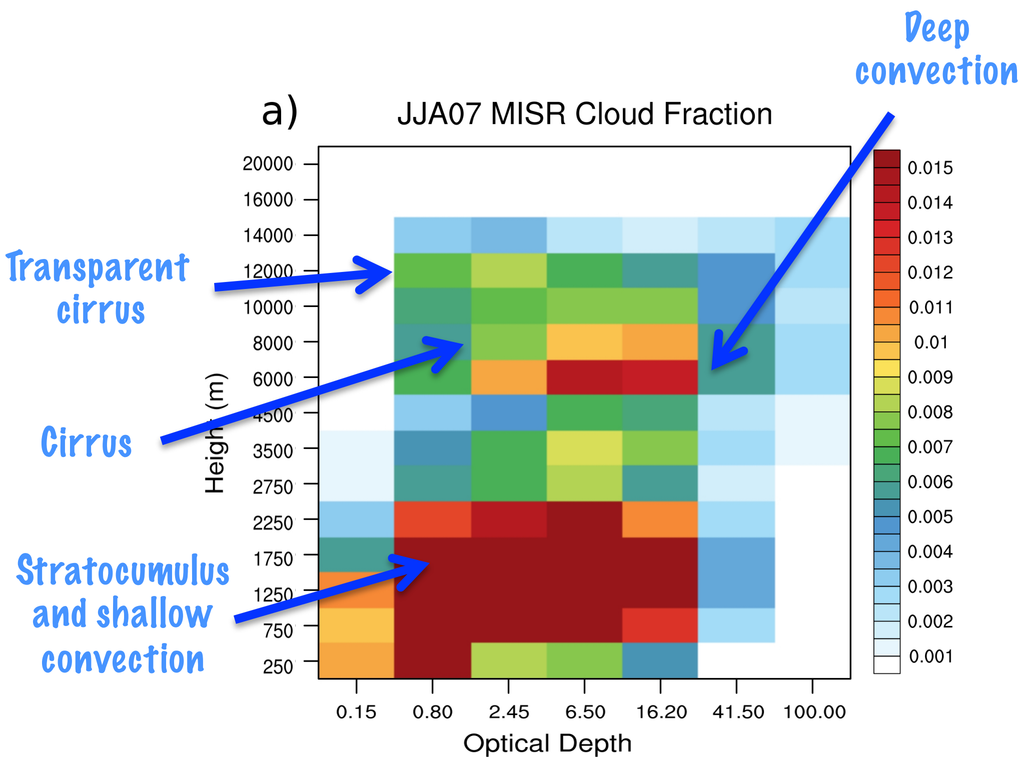
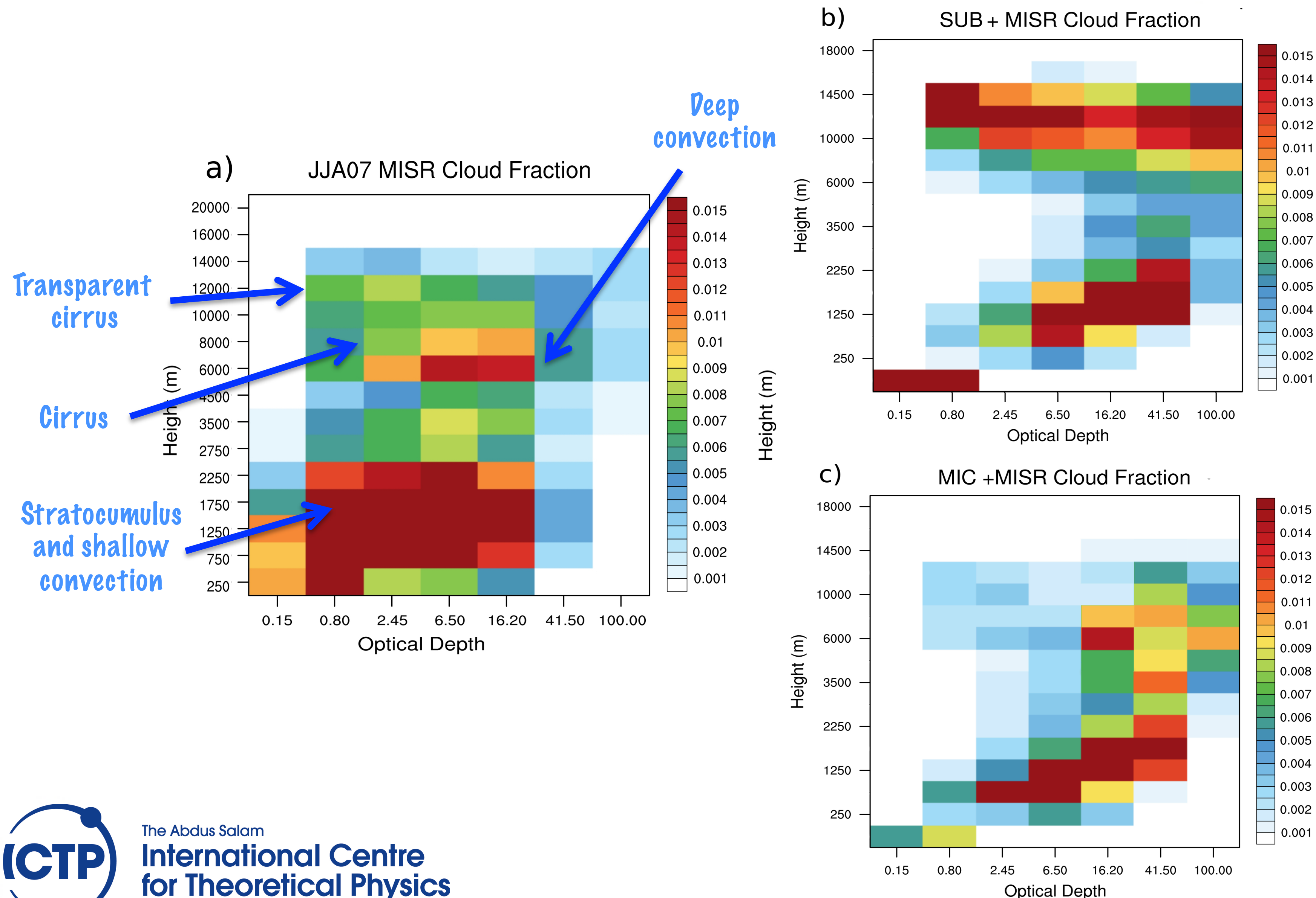
Multi-angle Imaging SpectroRadiometer (MISR)



MISR simulator



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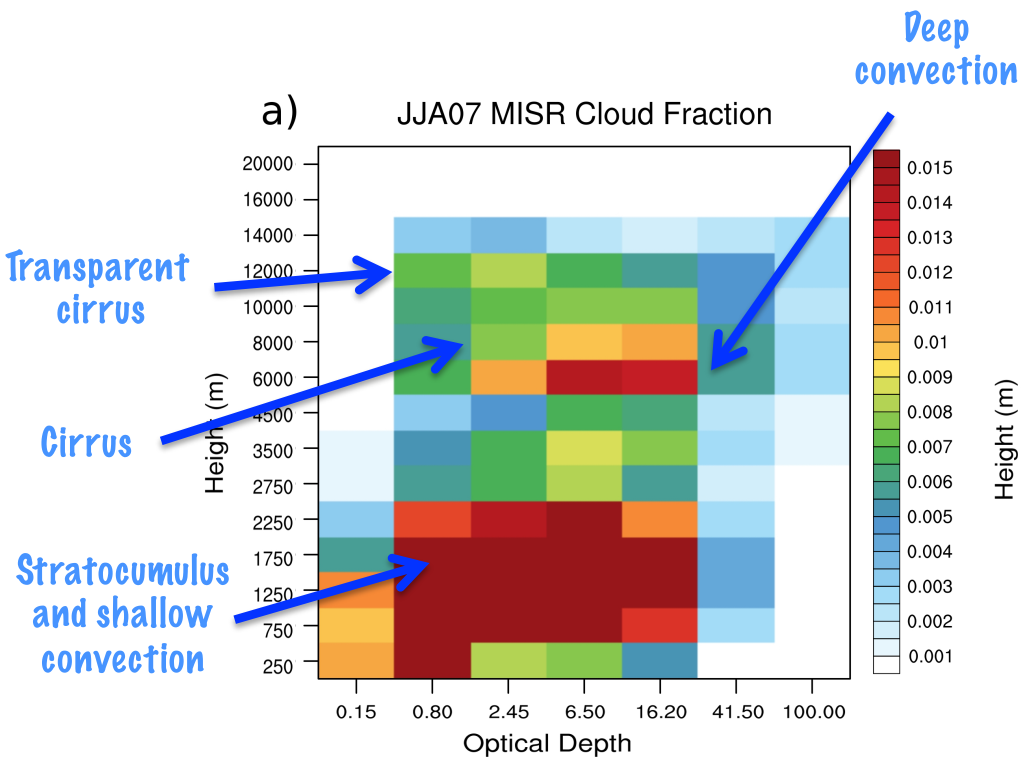
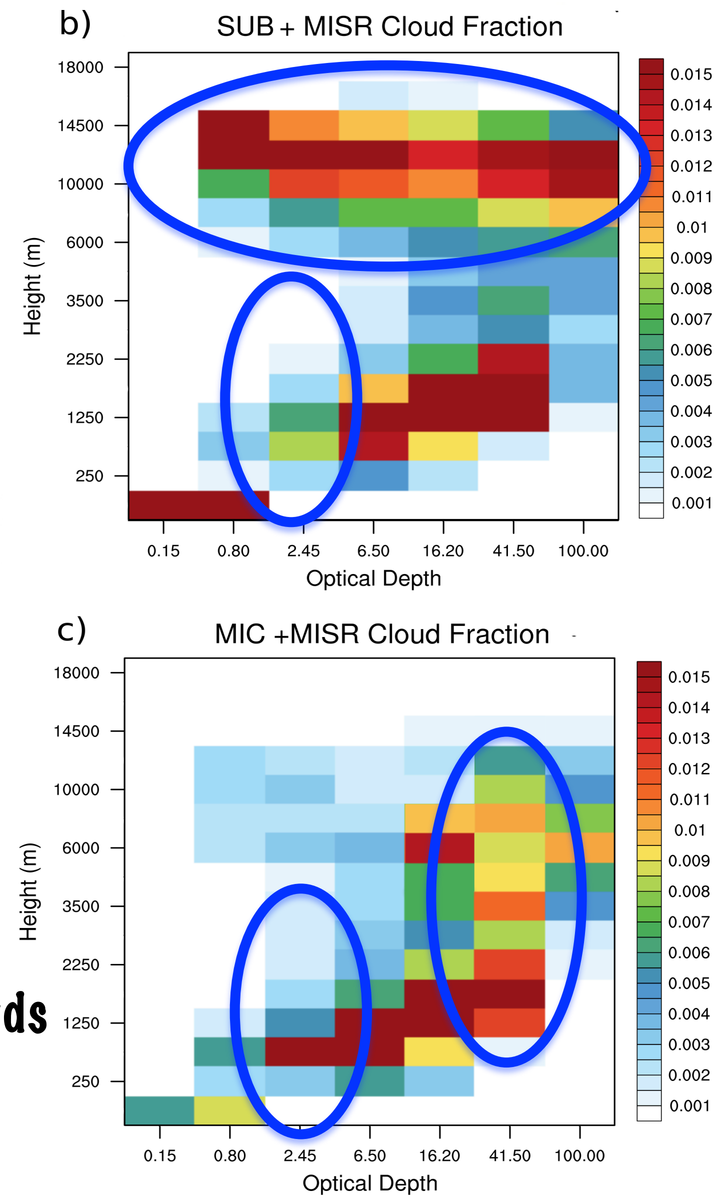
MISR simulator





* Underestimation of low optical thin clouds
* Overestimation of optically thick high clouds

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Radiation fields - Cloud Radiative Forcing

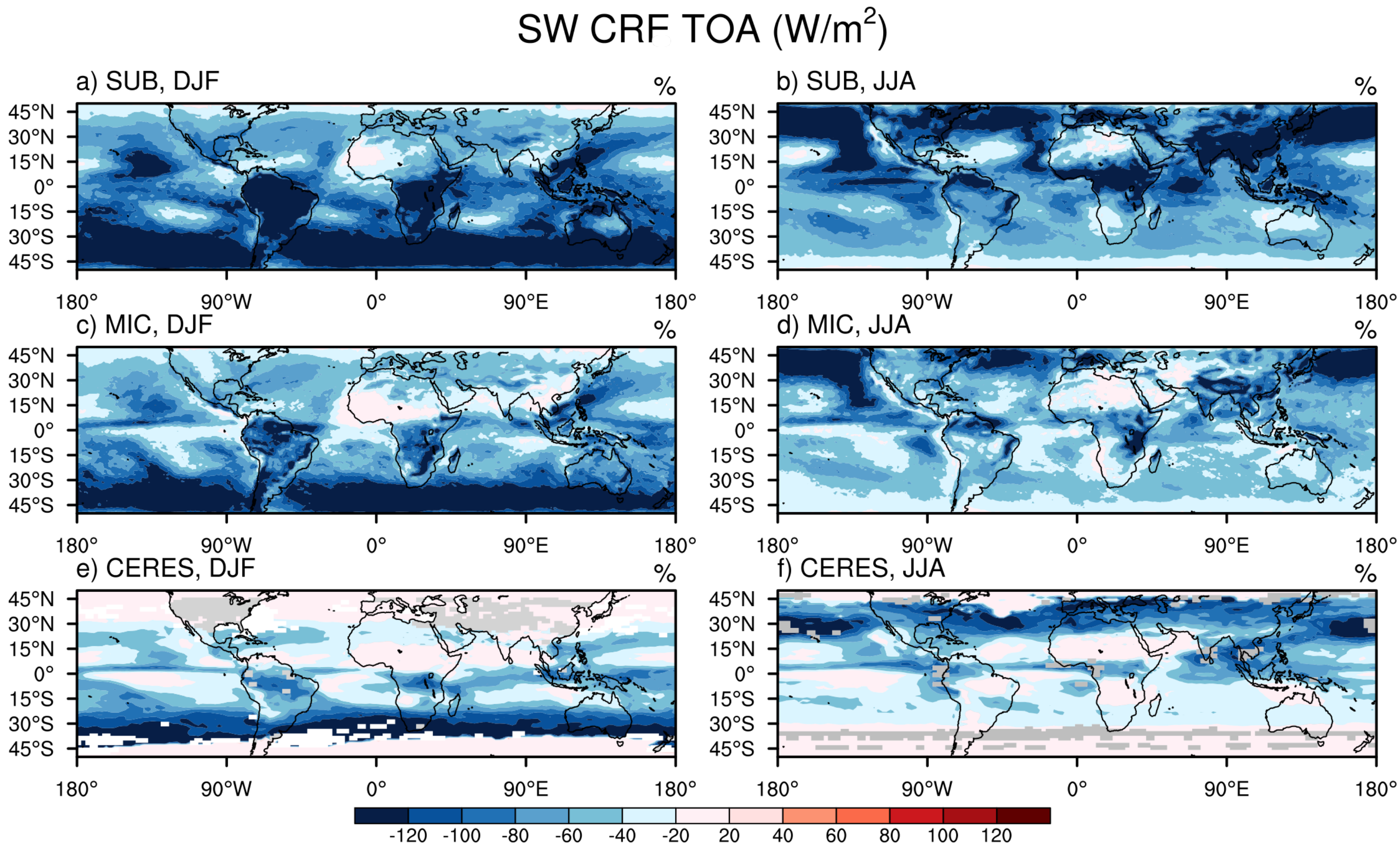
* The effect of clouds on the Earth's radiation balance is measured as the difference between clear-sky and all-sky radiation results

$$CRF^{X}(cloud) = CRF^{X}(cld) - CRF^{X}(clear)$$

$$CRF^{Net}(cloud) = CRF^{SW}(cloud) + CRF^{LW}(cloud)$$

* where X= SW or LW

TOA - CRFsw



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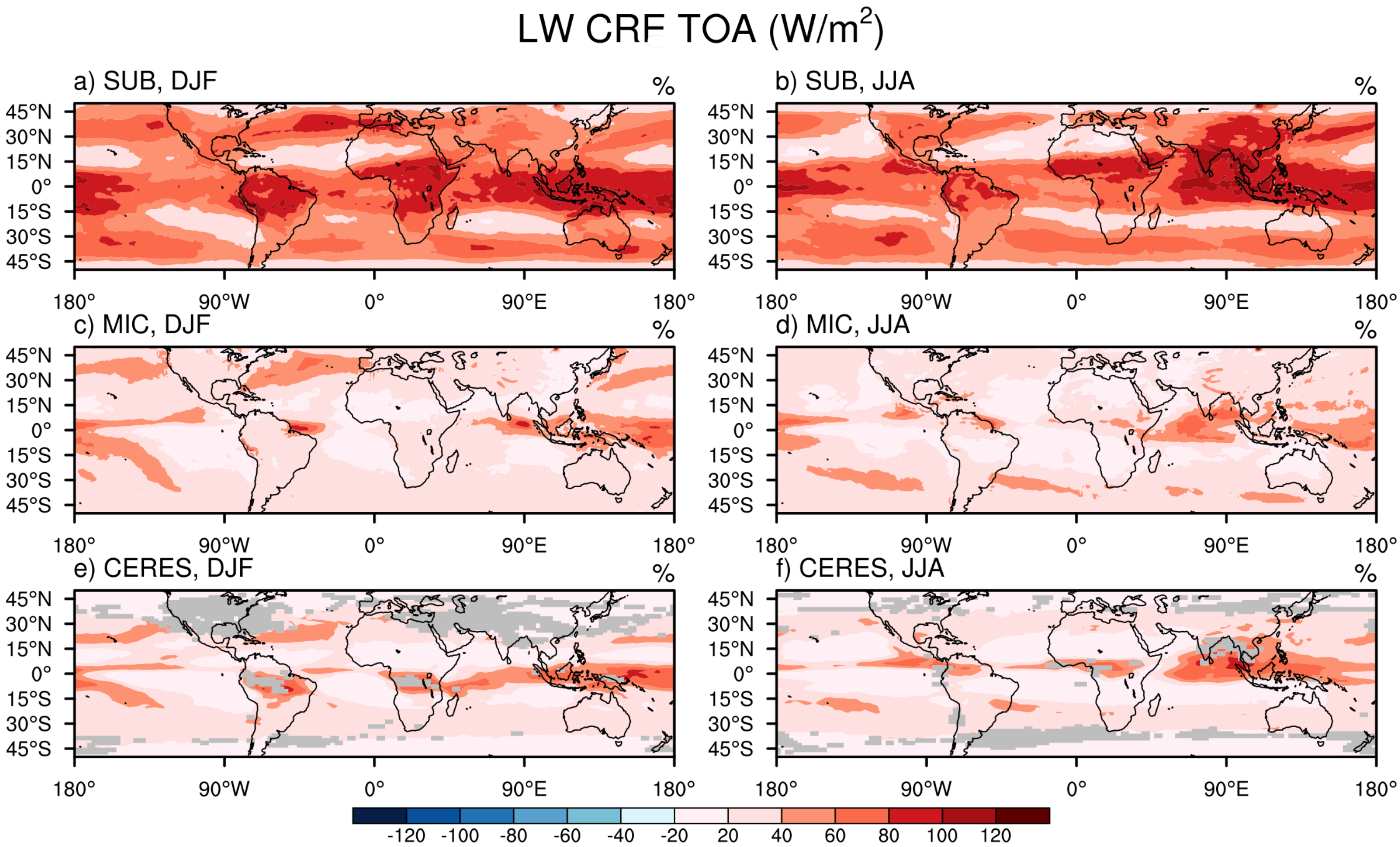
TOA - CRFLW



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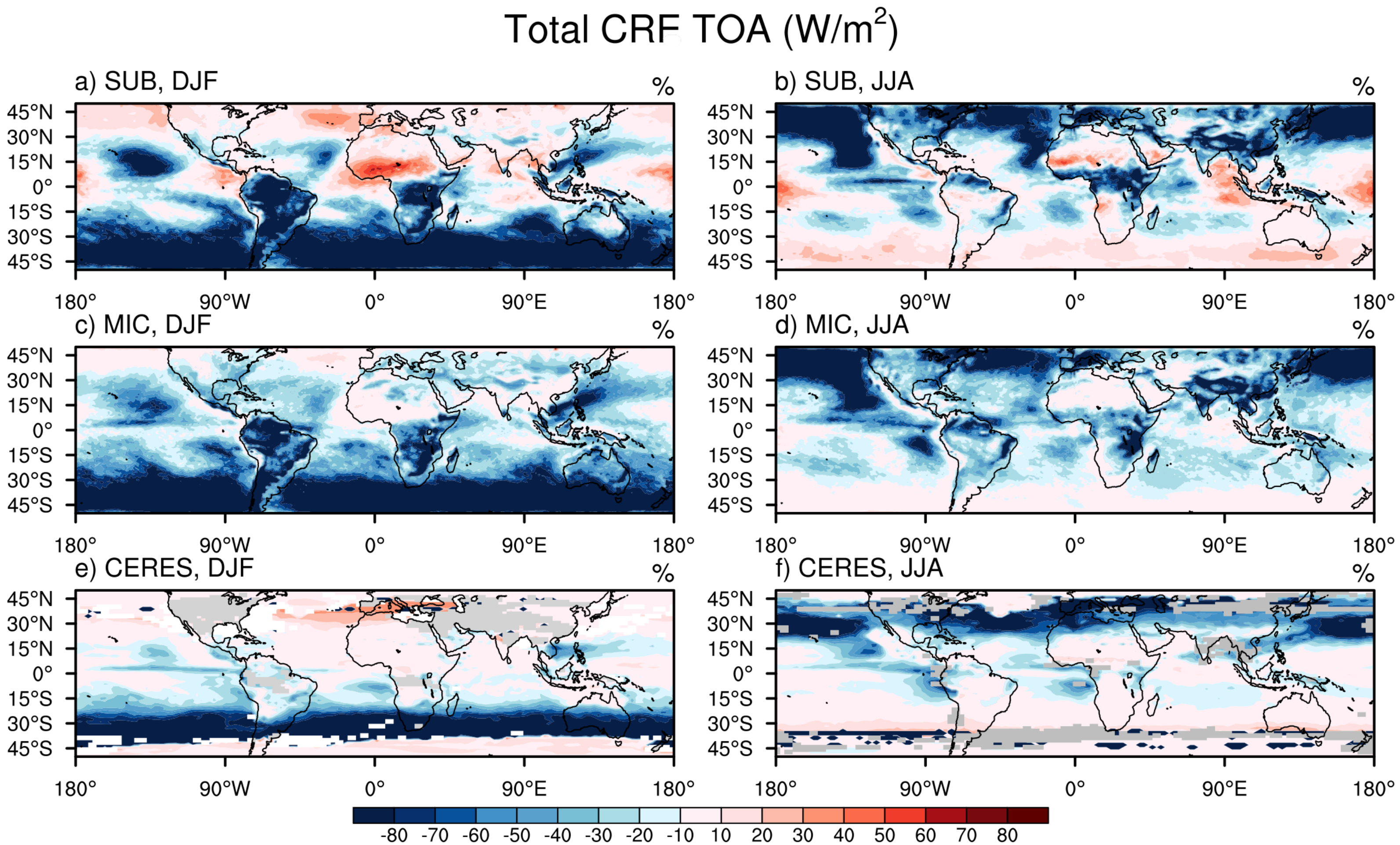
TOA Total CRF = $CRF_{SW} + CRF_{LW}$



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Summarizing

Fields	RegCM4: MIC	RegCM4: SUB	Obs: CERES
TOA CRF$_{LW}$ JJA (W m^{-2})	28.8	58.3	20.6
TOA CRF$_{LW}$ DJF (W m^{-2})	29.9	59.6	21.2
TOA CRF$_{SW}$ JJA (W m^{-2})	-50.1	-82.4	-40.8
TOA CRF$_{LW}$ DJF (W m^{-2})	-53.4	-85.3	-40.6
TOA CRF$_{tot}$ JJA (W m^{-2})	-21.3	-24.1	-20.2
TOA CRF$_{tot}$ DJF (W m^{-2})	-23.5	-25.7	-19.3

* SUB strongly overestimates the TOA CRFLW and CRFSW
* MIC strongly improves the CRF representation
* Small effect on total CRF

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Conclusions

* First evaluation of RegCM's using SIMULATORS;
* MIC compared to the original SUBEX scheme reduces precipitation amounts over land and increases them over ocean (ok and not ok);
* MIC has a strong effect on the simulation of cloudiness. Decrease in simulated upper level thin cirrus clouds, which increased agreement with observations;
* Despite having a small effect on the total CRF, the new scheme considerably improves its partitioning into longwave and shortwave component

References

* Nogherotto, R., A.M. Tompkins, G. Giuliani, E. Coppola, F. Giorgi: Numerical framework and performance of the new multiple phase cloud microphysics scheme in RegCM4.5: precipitation, cloud microphysics and cloud radiative effects, *Geosci. Model Dev. Discuss.*, doi:10.5194/gmd-2016-31, in review, 2016.
* Forbes, R. M., A.M. Tompkins & A. Untch, 2011: A new prognostic bulk-microphysics scheme for the IFS. *ECMWF Tech. Memo. No. 649.*
* Tompkins, A.M., April 18, 2005: The parameterization of cloud cover, *Moist Processes Lecture Notes Series, Research Department ECMWFune the new scheme using the sensitivities;*

Sources and Sinks – Precipitation Melting

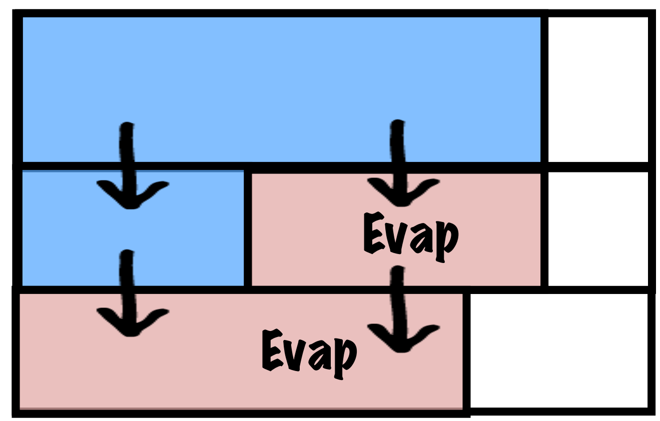
* Melting occurs when T > 0 °C
* Freezing occurs when T< 0 °C

Sources and Sinks – Precipitation Evaporation

* **Evaporation (Kessler 1969)**

  is proportional to the saturation deficit and dependent on the rain mass in the clear air fraction of the grid box.

  Evaporation reduces the precipitation.



Sorces and Sinks - Autoconversion

Large cloud droplets collect small ones and become embryonic raindrops

1. **Kessler (1969)**

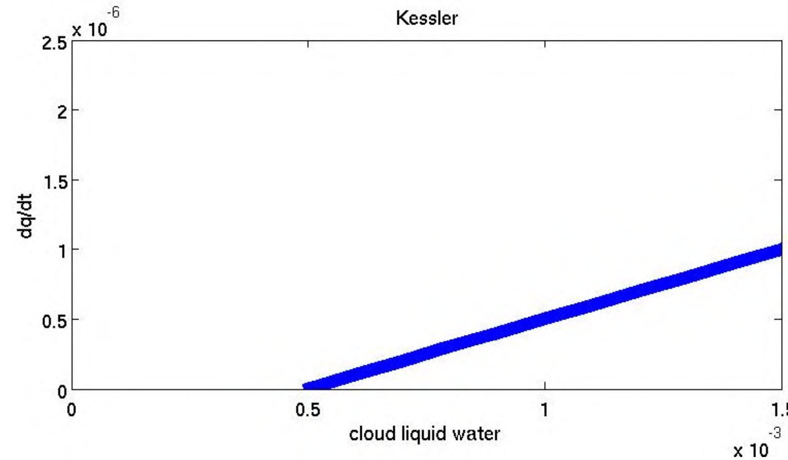
$$\frac{\partial q_l}{\partial t} = \begin{cases} c_0\left(q_l - q_l^{crit}\right) & \text{if } q_l > q_l^{crit} \\ 0 & \text{otherwise} \end{cases}$$

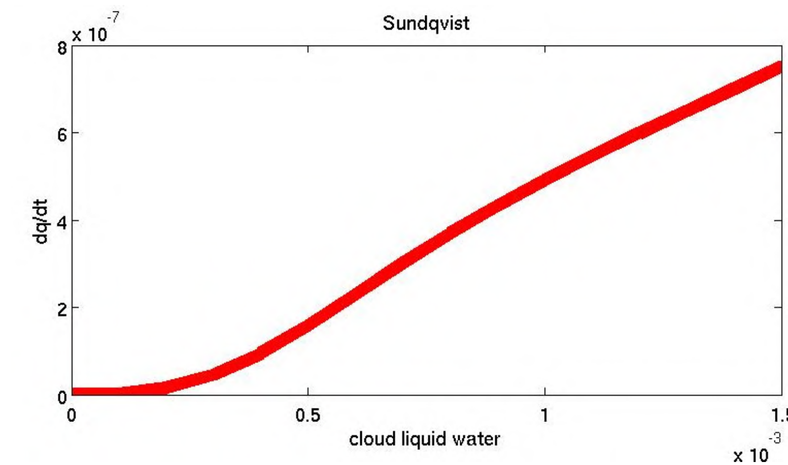
2. **Sundqvist (1978)**

$$\frac{\partial q_l}{\partial t} = c_0\, q_l \left(1 - e^{-\left(\frac{q_l}{q_l^{crit}}\right)^2}\right)$$

$$c_0 = 5 \cdot 10^{-4}\ \text{s}^{-1}$$

3. **Klein and Pincus (2000)**
4. **Khairoutdinov and Kogan (2000)**





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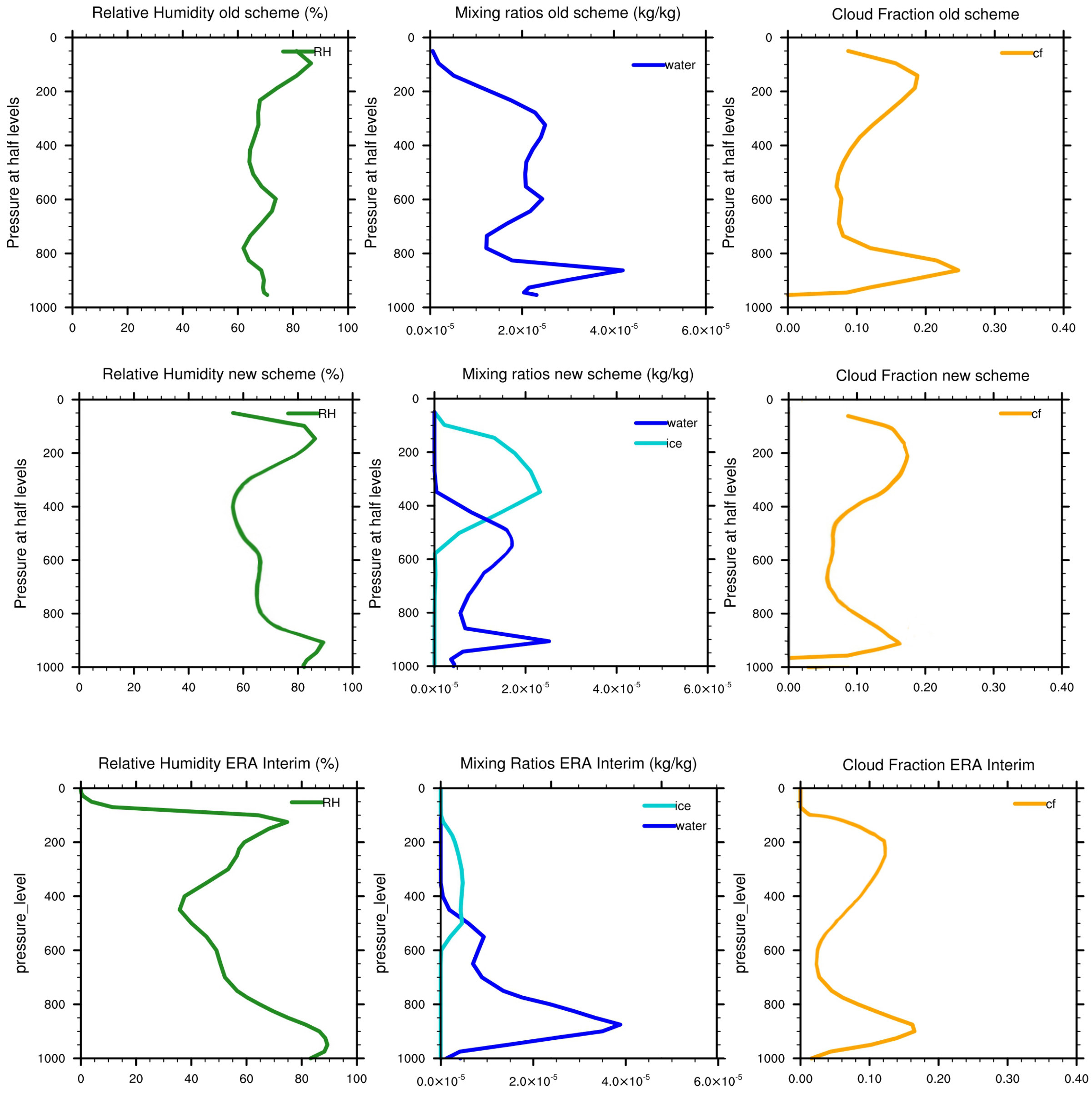
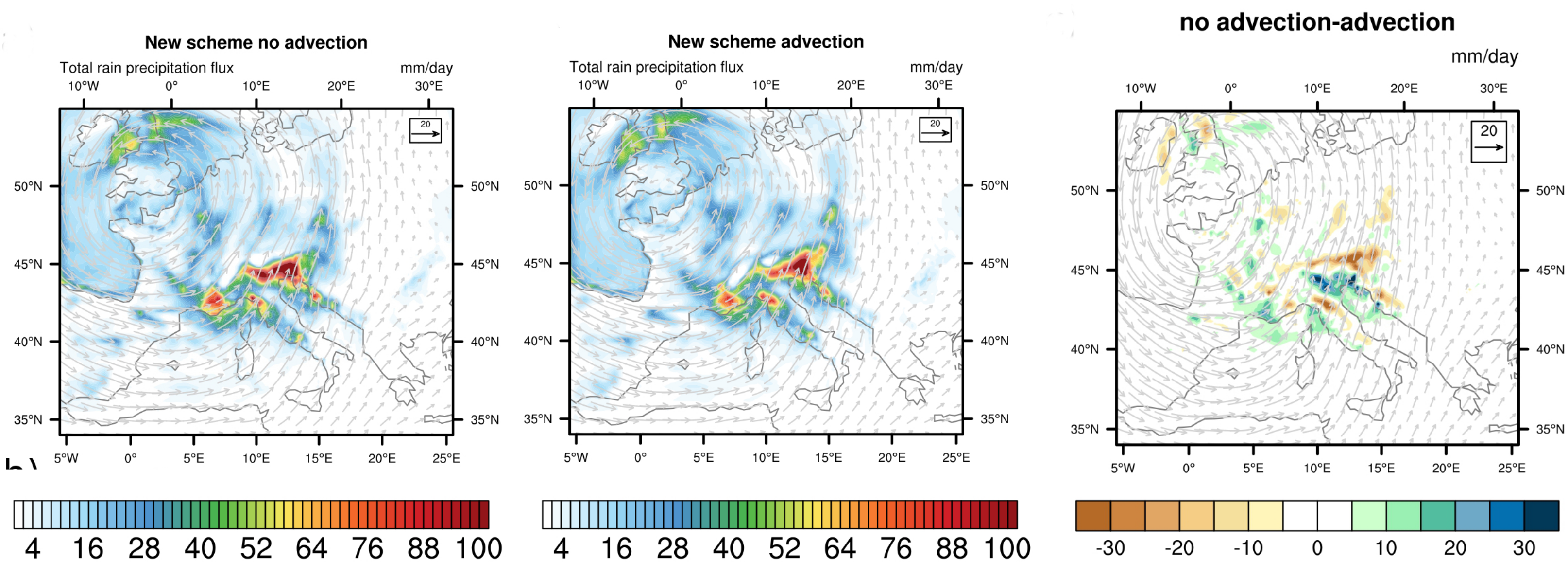
Vertical profiles



Results : Advected precipitation



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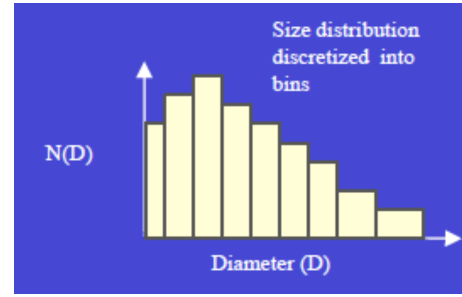
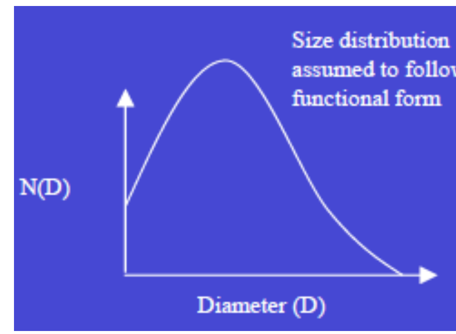
Cloud Microphysics Parameterizations

* **Spectral (bin) parameterization schemes** – divide microphysical particles into bins for different sizes and compute evolution of each bin separately – particle size distribution (PSD)



* **Bulk parameterization schemes** predict one or more bulk quantities (e.g. mixing ratio) and assume some functional form for the particle size distribution



1-moment scheme: mixing ratio

2-moments schemes: mixing ratio + concentration of hydrometeors

Cloud Microphysics Parameterizations

* Spectral (bin) parameterization schemes - divide microphysical particles into bins for different sizes and compute evolution of each bin separately - particle size distribution (PSD)

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1-moment scheme: mixing ratio

2-moments schemes: mixing ratio + concentration of hydrometeors

Cloud Microphysics Parameterizations

Focus on the prediction of one or more species of cloud water.

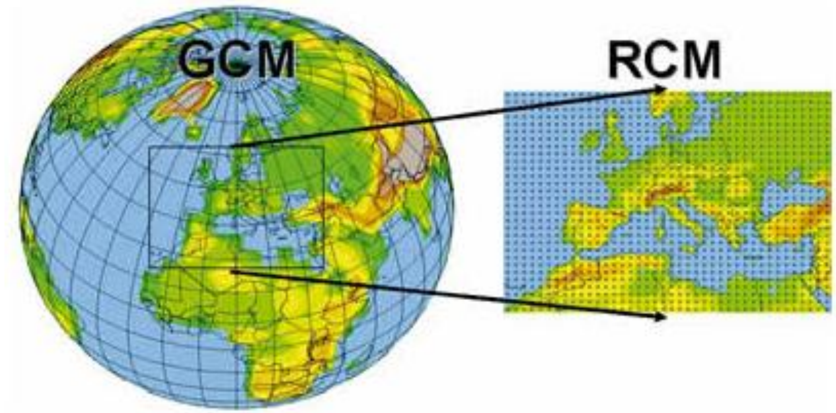
* Diagnostic equations (Rotstayn 1997, Pal et al 2000, ...)
* Prognostic equations (Fowler 1996, Lohmann and Roeckner 1996, Tiedtke 1993, ..)

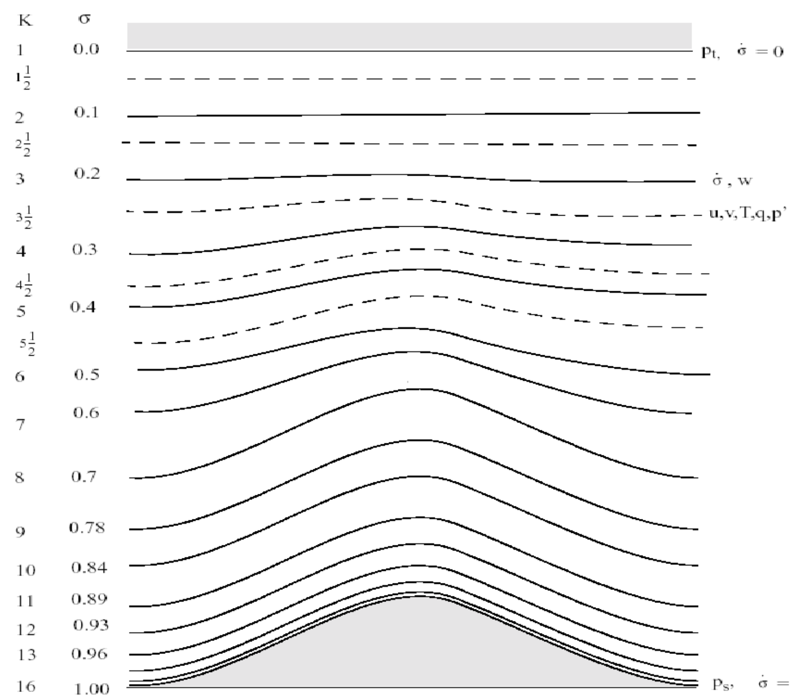
Advantages of the prognostic scheme:

* ice and liquid undergo different microphysical and thermodynamical processes;
* precipitate with different fall speeds;

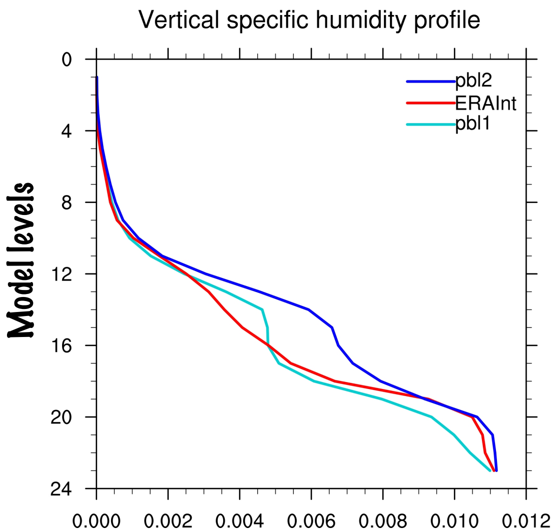
RegCM4

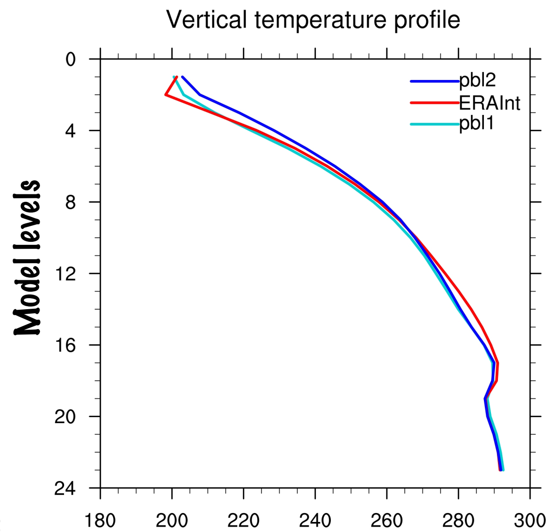
* Regional Climate Model initially developed at NCAR (Giorgi 1990)
* Hydrostatic, compressible, sigma vertical coordinates model
* Split-explicit time integration system
* ERA-Interim ICBC

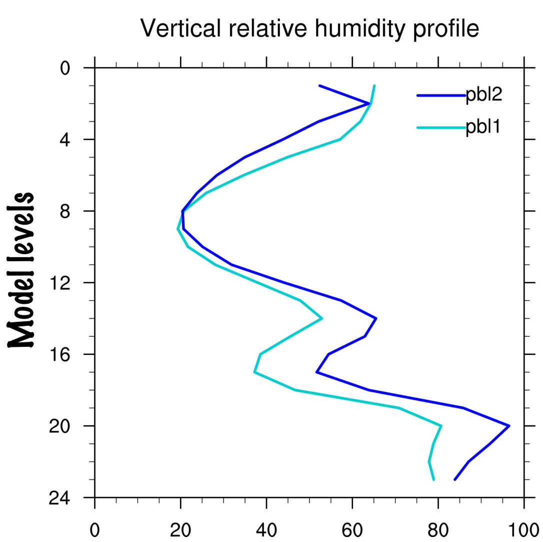


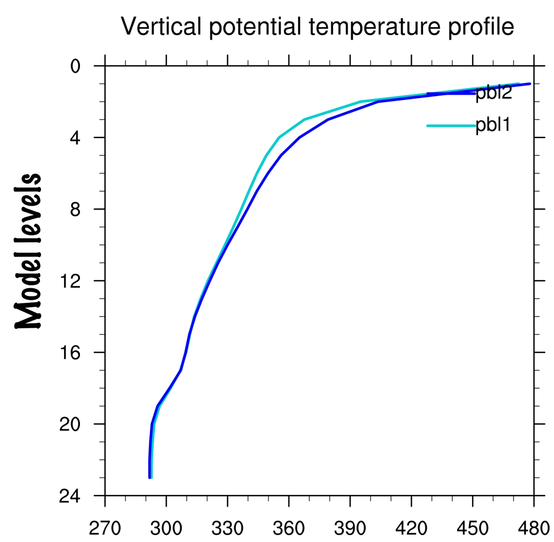


pbl1 vs pbl2









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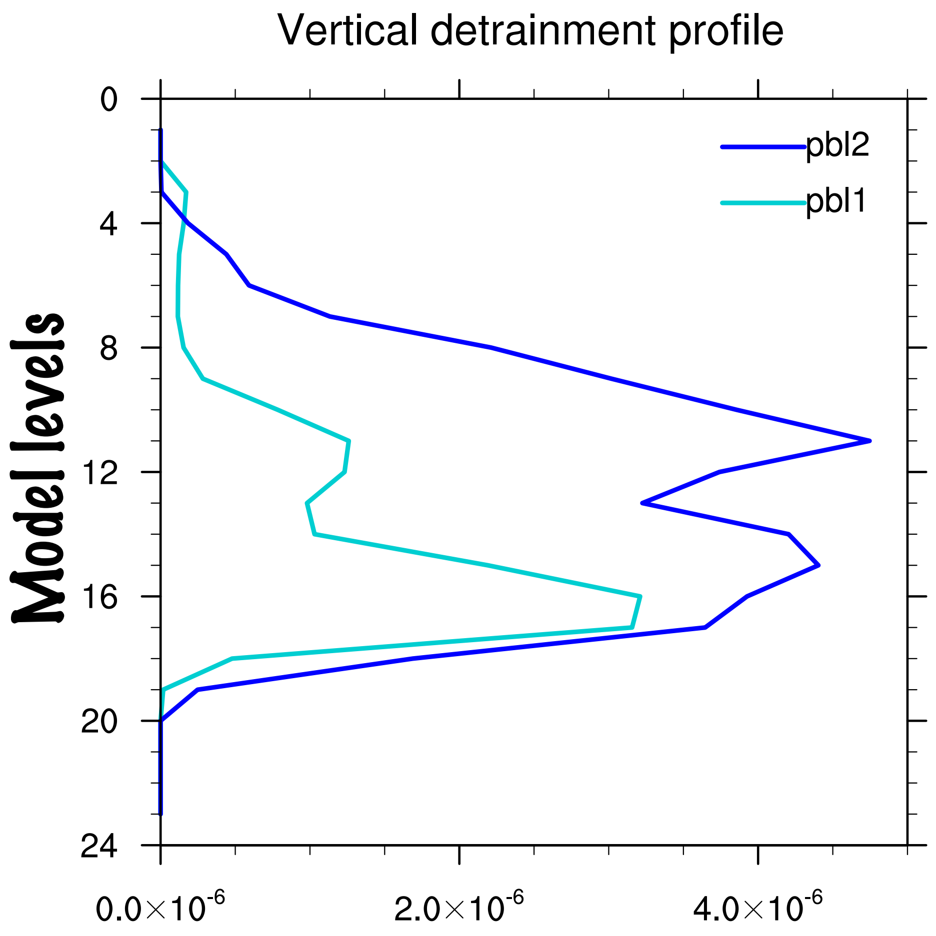
pbl1 vs pbl2



Vertical detrainment profile
Model levels
0
4
8
12
16
20
24
0.0×10⁻⁶
2.0×10⁻⁶
4.0×10⁻⁶
pbl2
pbl1