Multi-Model Evaluation of Cloud Phase Transition Using Satellite and Reanalysis Data

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Why does the Cloud Phase matter?

• Different radiative properties (e.g. Twomey, 1977)
• Cloud lifetime
• Precipitation
• In GCMs, clouds, climate sensitivity & radiation are sensitive to the treatment of the cloud phase (e.g. Li & LeTreut 1992, Forbes and Ahlgrimm 2014).
Cloud Phase in GCMs

**T-Dependent**
Diagnose and split as a function of the T

- condensation/evaporation
- autoconversion

**Complex Microphysics**
Prognose using more complex processes

- Water vapor
- Cloud Liquid/Ice
- Precipitation

*e.g.* Tiedtke, 1993

*e.g.* Rotstayn et al., 2000
Goals of the study

- Develop a method to compare obs and models
- Evaluate the cloud phase representation in the models
- Evaluate T-dependent vs. complex microphysics for cloud phase representation
Since no lidar simulator is used in this part of the study, we developed another method to evaluate the models in a consistent way.
Method: Phase Ratio at 90% (PR90)

Model

\[
\text{MPR} = \frac{\text{IWC}}{\text{IWC} + \text{LWC}}
\]

Phase Ratio at 90% (PR90) vs. Temperature (°C)
**Method: Phase Ratio at 90% (PR90)**

**Model**  
$$\text{MPR} = \frac{\text{IWC}}{\text{IWC} + \text{LWC}}$$

**Obs or Model+Sim**  
$$\text{FPR} = \frac{\text{Ice}}{\text{Ice} + \text{Liq}}$$  
Cloud Frequency Phase Ratio

**At 90%, Mass Phase Ratio (Model) ≈ Frequency Phase Ratio (Obs)**  

$$\Rightarrow \text{PR90 allows a consistent evaluation of the models while no simulator is used.}$$
Results

16 Models (GASS-YOTC & CMIP5)
- 2.5x2.5 and 40 temperature levels
- Daily frequency
- Annual Mean
- AMIP-like

Obs
- 2.5x2.5 and 40 temperature levels
- Daily frequency (Nighttime only)
- Annual mean (7 years)
Zonal mean of the Mass Phase Ratio
Zonal mean of the Mass Phase Ratio

Large diversity in the model’s behavior.
Few models are able to reproduce the observed zonal variations at PR90.
Global Average of the Temperature at PR90

Temperature (°C)

-45
-40
-35
-30
-25
-20
-15
-10
-5
0
-33.7
-31.9

Obs
Multi-Model
Global Average of the Temperature at PR90

Inter-Model spread very large
In 13/16 models, the temperature at PR90 is too warm compared to Obs.
Conclusions

Using the Phase Ratio at 90% in both CALIPSO-GOCCP observations (FPR90) and 16 GCMs (MPR90), we showed that:

• **Very few models are able to reproduce the observed zonal variations of the cloud phase at PR90.**

• **Transition from mixed-phase to ice clouds occurs at too warm temperature in most models (13/16).**

• **Apart from observations, models demonstrate a wide variation in Mass Phase Ratio across all latitudes/temperatures.**
Cloud Phase Evaluation: 
*Obs vs. Model*

- **Obs: CALIPSO**
- **Models**
  - **CMIP5: 4 GCMs**
  - **MPR**: Ice & Liq Water Content
  - **Lidar Simulator**
  - **FPR**: Ice & Liq Cloud Frequency

**CONSISTENT**

**OK at 90%**

- Using the simulator allows a consistent evaluation of the cloud phase at every temperature and for every height level (not only at PR90)
Zonal mean of the Phase Ratio

- CAM5
- Can
- CNRM
- IPSL

MPR (Model)

Temperature (°C)

Latitude (°N)

LIQ
ICE

Phase Ratio (%)

T-Dependent
Zonal Mean of the Phase Ratio (SIM)

- **Cam5**
- **Can**
- **CNRM**
- **IPSL**

**Variables:**
- **Temperature (°C)**
- **Latitude (°N)**
- **Phase Ratio (%)**
- **LIQ**
- **ICE**
- **T-Dependent**

**Models:**
- **MPR (Model)**
- **FPR (Model + SIM)**
Only complex microphysics models can reproduce realistic zonal variation of the cloud phase.
Temperature / Phase + Simulator

Phase Ratio (%)

Temperature (°C)

ICE

Can

CNRM

IPSL

MPR (Model)

LIQ
Temperature / Phase + Simulator

ICE

MPR (Model)

FPR (Model + SIM)

LIQ

Temperature (°C)

Frequency of Occurrence (%)
Not enough supercooled liquid clouds at very low T
The observed cloud phase – temperature relation is more complex than a simple linear relation.
Summary

Using CALIPSO-GOCCP observations, we assessed the cloud phase representation in several GCMs (GASS-YOTC and CMIP5).

- **Without simulator**, we can still evaluate some aspects of the cloud phase using the phase ratio at 90% method:
  - The zonal variations of the cloud phase (barely reproduced by few models)
  - The transition temperature (height) from mixed-phase to ice clouds (too warm in 13/16 models)

- **With the simulator**, we can fully evaluate the cloud phase at every temperature and height level:
  - $T$-dependent cloud phase partitioning is not realistic
  - Not enough supercooled liquid clouds at temperature colder than -30°C

Overall, complex microphysics cloud schemes are needed to better reproduce observations.