New diagnostics to assess the representation of upper-tropospheric cloud systems in climate models

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Outline

1. High clouds in LMDZ
2. Methodology for new high clouds diagnostics
3. Results for the current version LMDZOR-v6
4. Introducing new parameterizations in LMDZ
5. Conclusions and future work
1. High clouds in the LMDZ GCM
Parameterization of high clouds in the LMDZ GCM (1)

Ice crystals radius:

\[ R_e = (R_{e_{\text{max}}} - R_{e_{\text{min}}}) \frac{T}{81.4} + R_{e_{\text{max}}} \]

\[ (\text{Heymsfield et al. 1986}) \]

Cloud emissivity \( \varepsilon \) as a function of \( R_e \):

\[ \varepsilon = 1 - \exp(-\beta \kappa IWP) \]

\[ \kappa = \alpha + \frac{\gamma}{R_e} \]

\[ (Ebert & Curry 1992) \]
Parameterization of high clouds in the LMDZ GCM (2)

Ice crystal fall velocity:

\[ w_i(IWC) = \alpha \times 3.29 \times (IWC)^{0.16} \]

IWC expressed in kg/m³
w in m/s

Tuning of \( \alpha \)

\[ \frac{d(q_i)}{dt} = \frac{1}{\rho} \frac{\partial}{\partial z} (\rho w_i q_i) \]
Tuning in LMDZ (3)

3 parameters mainly control high clouds in LMDZ:

\(\alpha\) : magnitude of ice crystal fallspeed
epmax : maximum precipitation efficiency in convection scheme
ratqsh : linked to the spread of the distribution of total water content in the mesh in upper troposphere

These parameters are tuned to meet the observational LW and SW Cloud Radiative Forcings
Simulations meet the observational CRF constraints
With tuned parameters epmax, ratqsh
(except for LMDZORf23)

Current version of LMDZ:
LMDZORf01: ctrl experiment
LMDZORf02: smaller fallspeed
LMDZORf12: larger fallspeed

Introducing new parameterizations:
LMDZORf18: DM08 fallspeed
LMDZORf19: H07 fallspeed
LMDZORf23: M11 radius

Other constraints than CRF are needed to fit parameters and improve parameterizations

Need for new high cloud diagnostics
2. Methodology for new high clouds diagnostics using Infrared sounders AIRS and IASI
UT cloud system approach to assess climate models

analyze GCM clouds as seen from AIRS/IASI, via simulator & construct UT cloud systems -> evaluation of GCM convection schemes

nominal fall speed & precipitation efficiency

\[ v_m = f(IWC) \]

\[ v_m \] adapted from Heymsfield 2007

\[ v_m = f(IWC, T) \]

\[ v_m \] adapted from Deng & Mace 2008
3. Results for LMDZOR-v6
Cb cloud cover is too high in midlatitudes in all simulations

alpha and epmax control the proportion of thin cirrus in tropical anvils

Increasing ice fallspeed (+meeting CRF constraints) make anvils too opaque in the Tropics

LMDZORf01: ctrl experiment
alpha=0.6 epmax=0.9985, ratqsh=0.4

LMDZORf12: larger fallspeed
alpha=1 epmax=0.9975, ratqsh=0.25

LMDZORf02: smaller fallspeed
alpha=0.4 epmax=0.999, ratqsh=0.4
Cloud clusters analysis

### Cloud cluster sizes

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*Comparison with ctrl and small fallspeed (02) simulations:*

→ Increase of cluster sizes in 02.

### Thin cirrus / Total anvil ratio

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*Large fallspeed (12) simulation:*

→ Disagrees with data in terms of ThCi/Anv ratio.

Small fallspeed (02) simulations show a better agreement.
4. Introducing new parameterizations in LMDZ
HD90 ice fall speed with alpha = 0.6 as in ctrl simulation:
Average is too low compared to other parameterizations!!

Existing fall speed parameterizations from observations (in-situ small stat./radar retrievals large stat.) differ in terms of mean magnitudes & slopes

All Parameterizations show:
Increase of fall speed with IWC and temperature
- Mean fallspeed and other parameters similar as in ctrl simulation

- Temperature dependency is introduced as in Heymsfield 07 and Deng & Mace 08

→ Lat. distributions are pretty similar
→ Slight increase of anvils in winter hemisphere
Cloud clusters analysis

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Thin cirrus / Total anvil ratio

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→ Introducing temperature dependency in the expression of fallspeed increases cloud cluster sizes and thin cirrus/tot. anvil ratio.

H07 and DM08 simulations show a better agreement.
Ice crystal radius parameterizations

*Ice crystal radius in ctrl simulation*

*(Heymsfield et al. 86)*

*Mitchell 2011: fallspeed = f (Re)*

→ Re = f⁻¹ (fallspeed)

We use DM08 rescaled fallspeed as in simulation 18
The calculated Re is lower than ctrl Re
Decreasing ice radius (LMDZORf23) increases the proportion of opaque clouds, increases LW CRF and makes SW CRF more negative.
Summary...

Ctrl simulation

Existing parameterizations

Ctrl fallspeed is too low

Increasing fallspeed

CRF constraints

Simulation with tuned parameters alpha, epmax, ratqsh

Cb Anv ThCi diagnostics

Cloud clusters diagnostics

Not enough thin cirrus

Adding temperature dependency

Increases thin cirrus

Decreasing radius

decreases thin cirrus

Increases cluster size
... and Outlook

CRF constraints

New simulation with **larger** mean fallspeed (alpha)

Simulation with tuned parameters alpha, epmax, ratqsh

Adding temperature dependency: **synthesis of several existing parameterizations**

Adding $R_e$-fallspeed relationship

Increases ice crystal radius

Cloud cluster analysis provide new diagnostics on the processes of cloud development

Should increase thin cirrus cover, cluster sizes, with simultaneously more realistic ice fallspeed?
Simulator of UT clouds from IR Sounders

(M. Bonazza, C. Stubenrauch)

adapted from Hendricks et al., Meteorol. Z. 2010, Stubenrauch et al., J. Climate 1997

1) Construct clouds from vertically contiguous cloud layers, assuming maximum overlap
2) Assume random overlap for distinct clouds
3) Each cloud divided into sub-sections of similar vertical structure
4) Determine cloud optical depth $\tau_{\text{cl}}^{\text{IR}}$ per cloud

1) Cloud detection if $\Sigma \tau_i > 0.1$ (IR) ($\tau_{\text{vis}} \approx 2 \times \tau_{\text{IR}}$)
2) $p_{\text{cl}} : 0.5 \times (\text{cl} \text{d top + cl} \text{d base} / \text{apparent cl} \text{d base})$
   $\tau_{\text{cl}}^{\text{IR}} < 1.5$ / where cl gets op
-> total & high cloud cover ($p_{\text{cl}} < 440 \text{ hPa}$),
$p_{\text{cl}}$, $T_{\text{cl}}$, $\varepsilon_{\text{cl}}$, $z_{\text{cl}}$ (IWP & De)

also allows to distinguish between:
Cb area ($\varepsilon_{\text{cl}} > 0.98$)
cirrus (anvil) area ($0.5 < \varepsilon_{\text{cl}} < 0.98$)
thin cirrus area ($0.1 < \varepsilon_{\text{cl}} < 0.5$)

spatial resolution: $2.5^\circ \times 1.25^\circ$