Representation of convection and clouds in the IFS......20 years and still the same?

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Challenge 1: Convective vs stratiform (grid-scale) precipitation

TCo1279  26/4/2016
Challenge 2: represent accurate heating profiles and cloud radiation interaction

Latitude averaged difference in T-tendency MJO in phase 6/7 – MJO in phase 2/3: Convection over West Pacific - convection over Indian Ocean
Task of convection parametrisation

total Q1 and Q2

Parameterization needs to describe the collective effects of a cloud ensemble: Condensation/Evaporation and Transport

\[ Q_{1C} \equiv Q_1 - Q_R \equiv L(c - e) - \frac{\partial \omega s'}{\partial p} \]

\( Q_{1C} \) is dominated by condensation term

But for \( Q_2 \) the transport and condensation terms are equally important

Caniaux, Redelsperger, Lafore, JAS 1994
The IFS bulk mass flux scheme

- Entrainment/Detrainment
- Type of convection: shallow/deep/frontal
- Cloud base mass flux - Closure
- Downdraughts
- Generation and fallout of precipitation
- Where does convection occur
- Link to cloud parameterization
Large-scale budget equations: 
\( M = \rho w; \ M_u > 0; \ M_d < 0 \)

Heat (dry static energy):

\[
\left( \frac{\partial s}{\partial t} \right)_{cu} = g \frac{\partial}{\partial p} \left[ M_u s_u + M_d s_d - (M_u + M_d)\bar{s} \right] + L(c_u - e_d - e_{subcl}) - L_f(M - F)
\]

Humidity:

\[
\left( \frac{\partial q}{\partial t} \right)_{cu} = g \frac{\partial}{\partial p} \left[ M_u q_u + M_d q_d - (M_u + M_d)\bar{q} \right] - (c_u - e_d - e_{subcl})
\]
Large-scale budget equations

Momentum:

\[
\begin{align*}
\left( \frac{\partial u}{\partial t} \right)_{cu} &= g \frac{\partial}{\partial p} \left[ M_u u_u + M_d u_d - (M_u + M_d) \bar{u} \right] \\
\left( \frac{\partial v}{\partial t} \right)_{cu} &= g \frac{\partial}{\partial p} \left[ M_u v_u + M_d v_d - (M_u + M_d) \bar{v} \right]
\end{align*}
\]

Cloud condensate:

\[
\left( \frac{\partial l}{\partial t} \right)_{cu} = D_u l_u
\]
Entrainment/Detrainment

Entrainment formulation looks sooo simple: \[ \varepsilon = 1.75 \times 10^{-3} \times (1.3 - \text{RH}) f(p) \]  
RH=relative humidity, so how does it compare to LES?

Schlemmer et al. 2017
CAPE closure - the basic idea

large-scale processes generate CAPE

Convection consumes CAPE
Closure - Deep convection

\[ \text{CAPE} = g \int_{\text{cloud}} \frac{T_{v,u} - \overline{T_v}}{\overline{T_v}} \, dz \approx g \int_{\text{cloud}} \frac{\theta_{e,u} - \overline{\theta}_{\text{esat}}}{\overline{\theta}_{\text{esat}}} \, dz \]

Use instead density scaling, time derivative then relates to mass flux:

\[ \text{PCAPE} = - \int_{P_{\text{base}}}^{P_{\text{top}}} \frac{T_{v,u} - \overline{T_v}}{\overline{T_v}} \, dp \]

\[ \frac{\partial \text{PCAPE}}{\partial t} \approx - \int_{P_{\text{base}}}^{P_{\text{top}}} \frac{1}{T_v} \frac{\partial \overline{T_v}}{\partial t} \, dp - \int_{P_{\text{base}}}^{P_{\text{top}}} \frac{1}{T_v} \frac{\partial T_{v,u}}{\partial t} \, dp + \frac{T_{v,u} - \overline{T_v}}{\overline{T_v}} \left| \frac{\partial p_{\text{base}}}{\partial t} \right| \]

\[ = \left. \frac{\partial \text{PCAPE}}{\partial t} \right|_{\text{LS}} + \left. \frac{\partial \text{PCAPE}}{\partial t} \right|_{\text{BL}} + \left. \frac{\partial \text{PCAPE}}{\partial t} \right|_{\text{Cu=shal+deep}} \]

this is a prognostic CAPE closure: now try to determine the different terms and try to achieve balance

\[ \partial \text{PCAPE} / \partial t = \left. \partial \text{PCAPE} / \partial t \right|_{cu} , \left. \partial \text{PCAPE} / \partial t \right|_{LS} \]
Closure - Deep convection

Solve now for the cloud base mass flux by equating 1 and 2

\[ M_{u,b} = M^*_u + M_d \]

Initial updraught mass flux at base, set proportional to 0.1Δp

contains the boundary-layer tendencies due to surface heat fluxes, radiation and advection

see Bechtold et al. 2014 JAS and work bei Saolo Freitas
Impact of closure on diurnal cycle
JJA 2011-2012 against Radar

Obs radar
NEW=with PCAPEBbl term

ECMWF Newsletter No 136 Summer 2013
Resolution scaling + absolute mass flux limit

\[ \omega' \Phi' = \omega \Phi - \bar{\omega} \Phi \]

\[ = \sigma (1 - \sigma) (\overline{\omega}^c - \bar{\omega}) (\overline{\Phi}^c - \bar{\Phi}) f(\Delta x) \]

Developed in collaboration with Deutsche Wetterdienst and ICON model

Kwon and Hong, 2016 MWR independently developed very similar relations
Resolution scaling and a bit of light in the grey zone

Convection parameterisation at 5km resolution
Convection issue 1: inland penetration of (winter snow) showers
Realism of heating profiles: DYNAMO MJO campaign

Importance of melting level and mixed-phase microphysics: green shows smaller discontinuity at the melting level

with J-E Kim and C. Zhang
Issue: Global models are not reflective enough over the Southern Ocean, but too reflective over tropical oceans

Li et al. 2013
(blue = not reflective enough)

Annual mean 10-20 Wm$^{-2}$ difference from CERES-EBAF

IFS

MODIS

Also true for IFS even if total cloud cover against ISCCP and MODIS looks pretty good
Issue: not reflective enough storm tracks

Effect of detraining more liquid phase condensate to cloud scheme corrects SW radiation error in SH storm tracks (during cold air outbreaks) by around 5 W/m² or 20%.

future tests: producing only liquid for shallow, but requires more technical developments and might produce biases.
Issue too reflective subtropics: sensitivity to shallow detrainment

C42r1- MODIS low cloud cover: annual mean

43r1-42r1 change in low cloud cover
Moist process parametrizations: The integrated view

Examples:
- Increased consistency between existing parametrizations
- Prognostic cloud PDF schemes (e.g. Tompkins et al 2002)
- Eddy-diffusivity + multiple mass flux plumes (e.g. EDMF Dual-M)
- Higher order closure (e.g. CLUBB)

How the different parametrizations interact can be as important as the parametrizations themselves.
Microphysics Parametrization: The “category” view

Single moment schemes

- Water vapour $q_v$
  - Condensation
  - Evaporation
  - Deposition
  - Sublimation

- Cloud water $q_l$
  - Autoconversion
  - Collection
  - Freezing – Melting - Bergeron

- Rain $q_r$
  - Freezing - Melting
  - Sedimentation

- Cloud ice $q_i$
  - Autoconversion
  - Collection
  - Deposition

- Snow $q_s$
  - Rutledge and Hobbs (1983)
Microphysics Parametrization: The “category” view
Double moment schemes

- Water vapour $q_v$
- Cloud water $q_i + N_i$
- Cloud ice $q_i + N_i$
- Snow $q_s + N_s$
- Rain $q_r + N_r$

Processes:
- Condensation
- Evaporation
- Freezing – Melting
- Bergeron
- Autoconversion
- Collection
- Deposition
- Sublimation
- Condensation
- Evaporation
- Autoconversion
- Collection
- Freezing
- Melting
- Evaporation
- Deposition
- Sublimation
- Condensation
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- Evaporation
- Deposition
- Sublimation
- Condensation
- Evaporation
- Autoconversion
- Collection
- Freezing
- Melting
- Evaporation
- Deposition
- Sublimation

References:
- Ferrier (1994)
- Seifert and Beheng (2001)
- Morrison et al. (2005)

IITM Introspect 2017 workshop. IFS clouds and convection
Slide 22
Microphysics Parametrization: The “category” view
Double moment schemes – multiple ice categories

- Condensation
- Evaporation
- Freezing – Melting - Bergeron
- Autoconversion Collection
- Deposition Sublimation
- Collection
- Freezing - Melting
- Sedimentation

- Cloud water: $q_i + N_i$
- Rain: $q_r + N_r$
- Cloud ice: $q_i + N_i$
- Snow: $q_s + N_s$
- Graupel: $q_g + N_g$
- Hail: $q_h + N_h$

References:
- Lin et al. (1983)
- Meyers et al. (1997)
- Milbrandt and Yau (2005)
Microphysics Parametrization: The cloud fraction

- The ECMWF global NWP model has **prognostic water vapour, cloud water** and **cloud fraction**. With a uniform function for heterogeneity in the clear air and a delta function (homogeneous) in-cloud.

- The UK Met Office global NWP model (PC2 scheme) also has **prognostic water vapour, cloud water** and **cloud fraction**.

- Many other operational global NWP/climate models have **diagnostic sub-grid cloud schemes**, e.g. NCEP GFS: Sundquist et al. (1989)

- Research is ongoing for **statistical schemes with prognostic PDF moments** (e.g. Tompkins scheme tested in ECHAM, CLUBB tested in CAM).
Mixed-phase clouds: Observed supercooled liquid water occurrence

Observations:
• Colder than -38°C, no supercooled liquid water.
• Supercooled liquid water increasingly common as approach 0°C.
• Often in shallow layers at cloud top, or in strong updraughts associated with convection
• Often mixed-phase cloud – liquid and ice present
• Convective clouds with tops warmer than -5°C rarely have ice.
Parametrizing cloud phase
Diagnostic vs prognostic

• Many (global) models with a single condensate prognostic parametrize ice/liquid phase as a diagnostic function of temperature (see dashed line for ECMWF model pre-2010 below).

• Models with separate prognostic variables for liquid water and ice, parametrize deposition allowing a wide range of supercooled liquid water/ice fraction for a given temperature (see shading in example below).

\[
\frac{\partial m}{\partial t} = \frac{4\pi sCF}{\left(\frac{L_s}{RT} - 1\right) L_s + \frac{RT}{\chi e_{si}}}
\]

PDF of liquid water fraction of cloud for a diagnostic mixed phase scheme (dashed line) and prognostic ice/liquid scheme (shading)
Why represent heterogeneity?
Important scales of cloud cover & reflectance

- Contribution to global cloud cover (solid), number (dotted) and SW reflectance (dashed) from clouds with chord lengths greater than L (based on MODIS, aircraft and NWP data).

- Map of the cloud size for which 50% of cloud cover comes from larger clouds (from 2 years of MODIS data)

- Larger scales dominate mid-latitude storm tracks
- Small scales dominate over subtropical ocean

(from Wood and Field 2011, JClim)
Cloud heterogeneity in radiation and microphysics (autoconversion): using fractional standard deviation FSD

E.g.:
- Enhanced heterogeneity in winter storm tracks, summertime NH continent
- Detrainment ratio highlights areas with enhanced variability
- Apparent height dependence in zonal mean CALIPSO observed FSD → Parameterized

Parameterized ice FSD, Model

Current assumption in radiation: FSD=1

Observed ice FSD, 2C-ICE retrieval