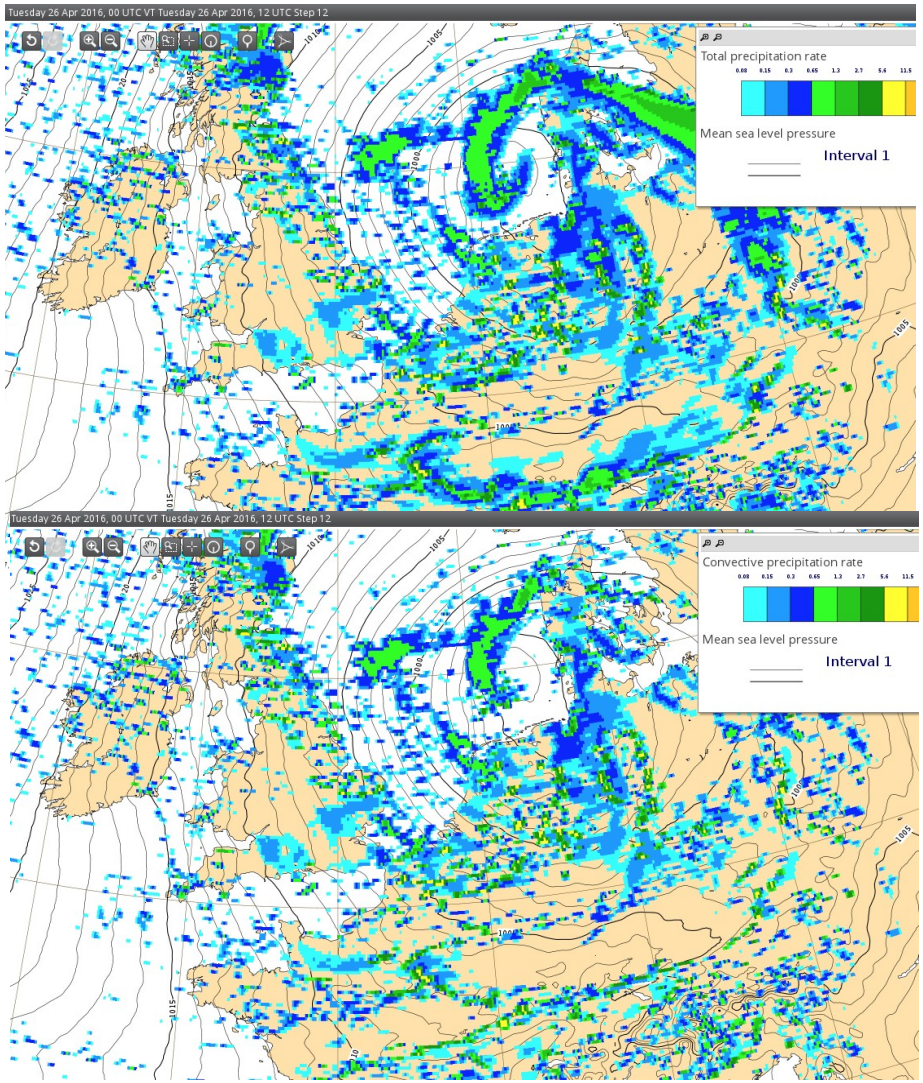
Representation of convection and clouds in the IFS.....20 years and still the same?

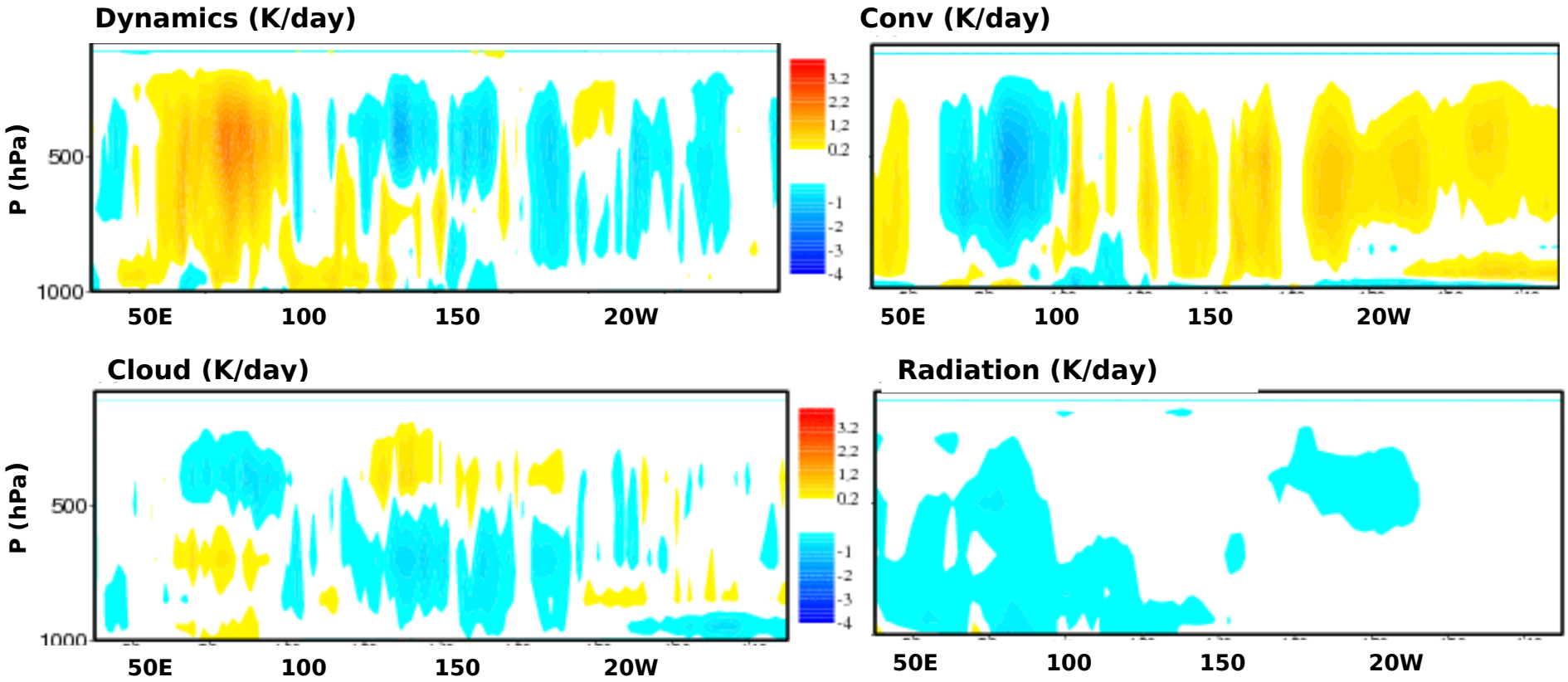
Peter Bechtold with contributions from Richard Forbes and Maike Ahlgrimm

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



TCo1279 26/4/2016

Challenge 2: represent accurate heating profiles and cloud radiation interaction



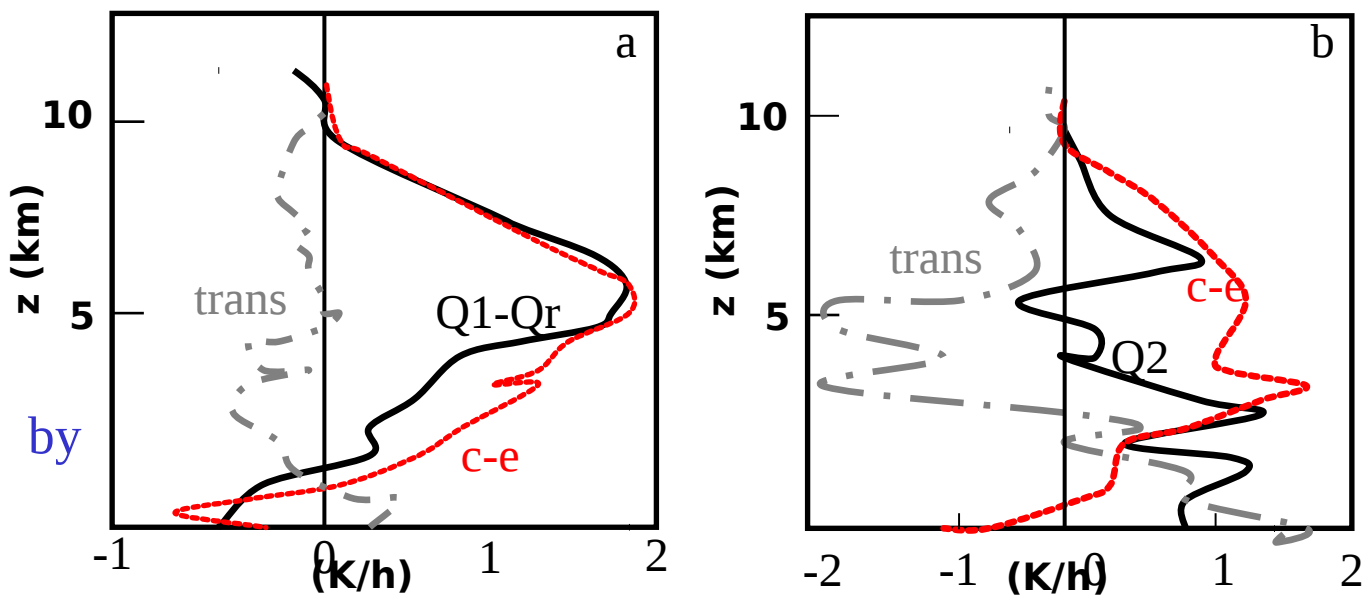
Latitude averaged difference in T-tendency MJO in phase 6/7 – MJO in phase 2/3: Convection over West Pacific - convection over Indian Ocean

ECMWF

Task of convection parametrisation
total Q1 and Q2

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

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

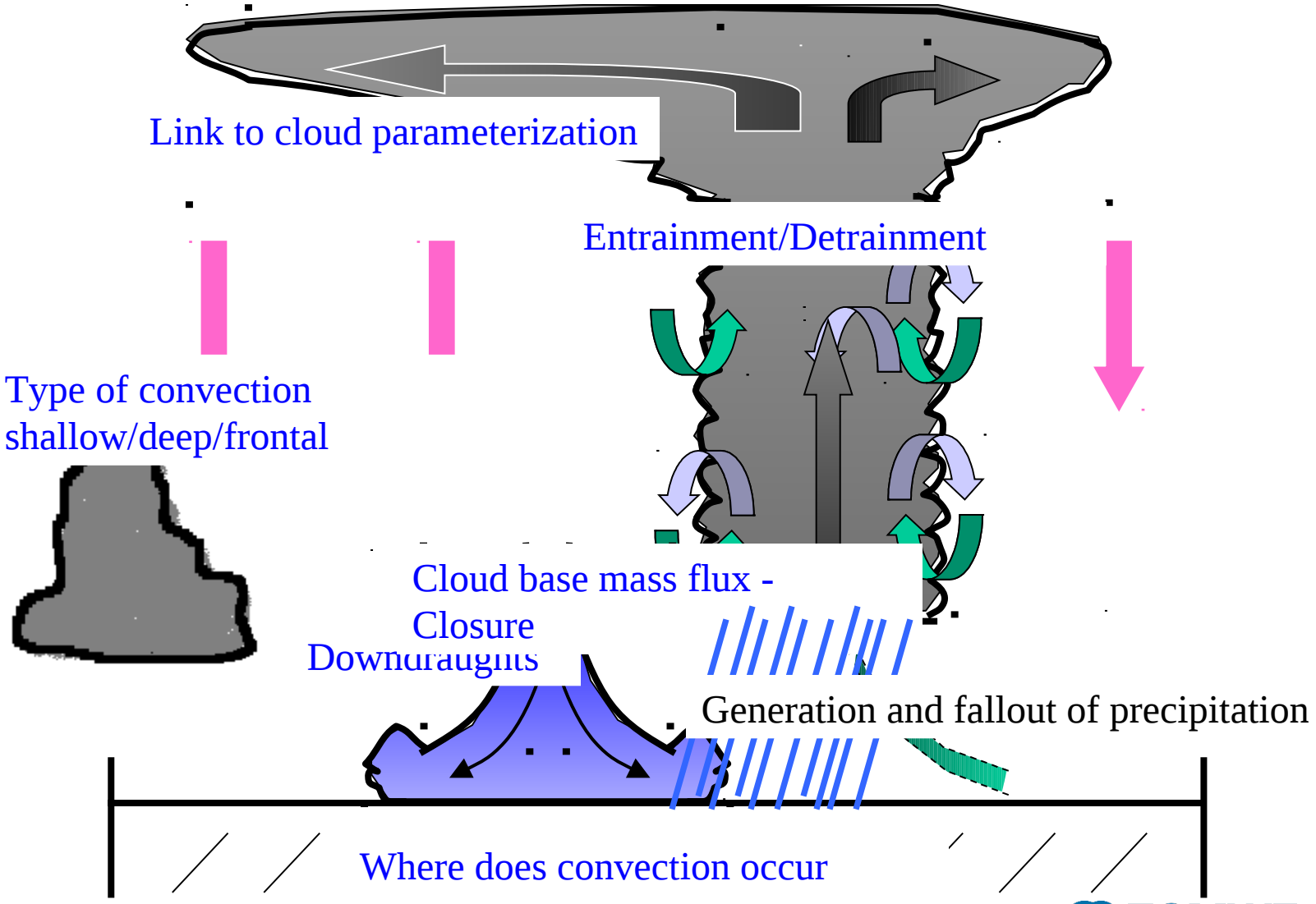


Q1c is dominated by condensation term

but for Q2 the transport and condensation terms are equally important

Caniaux, Redelsperger, Lafore, JAS 1994

The IFS bulk mass flux scheme



Large-scale budget equations: $M=\rho w$; $M_u>0$; $M_d<0$

Heat (dry static energy):

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

Prec. evaporation in downdraughts

Freezing of condensate in updraughts

Mass-flux transport in up- and downdraughts

condensation in updraughts

Prec. evaporation below cloud base

Melting of precipitation

Humidity:

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

ECMWF

Large-scale budget equations

Momentum:

$$\left(\frac{\partial u}{\partial t}\right)_{cu} = g\frac{\partial}{\partial p}\left[M_u u_u + M_d u_d - (M_u + M_d)\bar{u}\right]$$

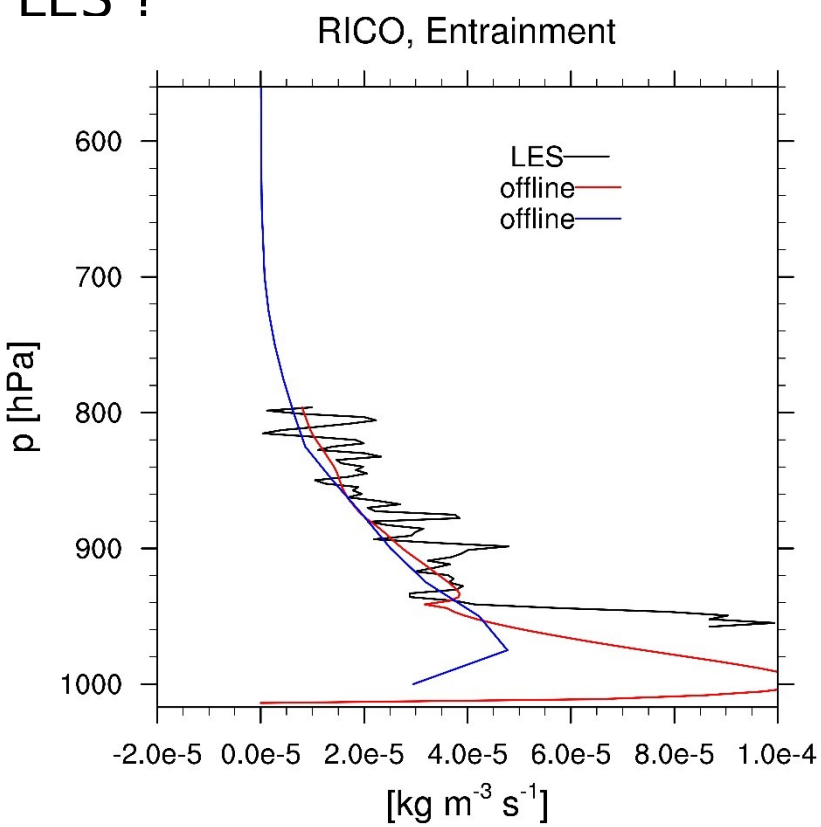
$$\left(\frac{\partial v}{\partial t}\right)_{cu} = g\frac{\partial}{\partial p}\left[M_u v_u + M_d v_d - (M_u + M_d)\bar{v}\right]$$

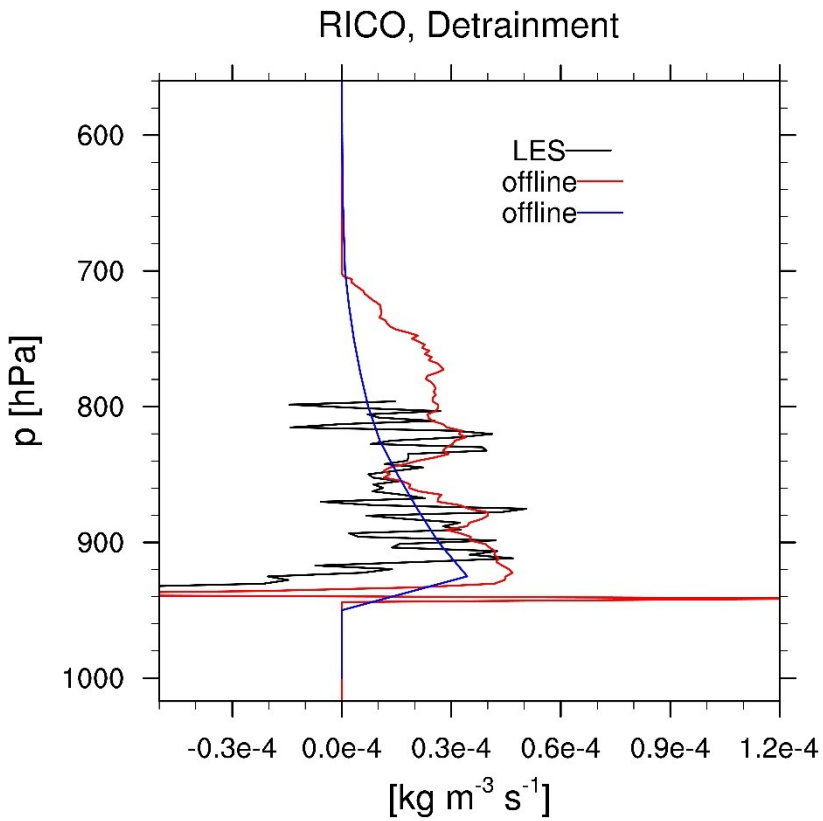
Cloud condensate:

$$\left(\frac{\partial l}{\partial t}\right)_{cu} = D_u l_u$$

Entrainment/Detrainment

Entrainment formulation looks sooo simple: $\varepsilon=1.75\times10^{-3}$ (1.3-RH)f(p) RH=relative humidity, so how does it compare to LES ?

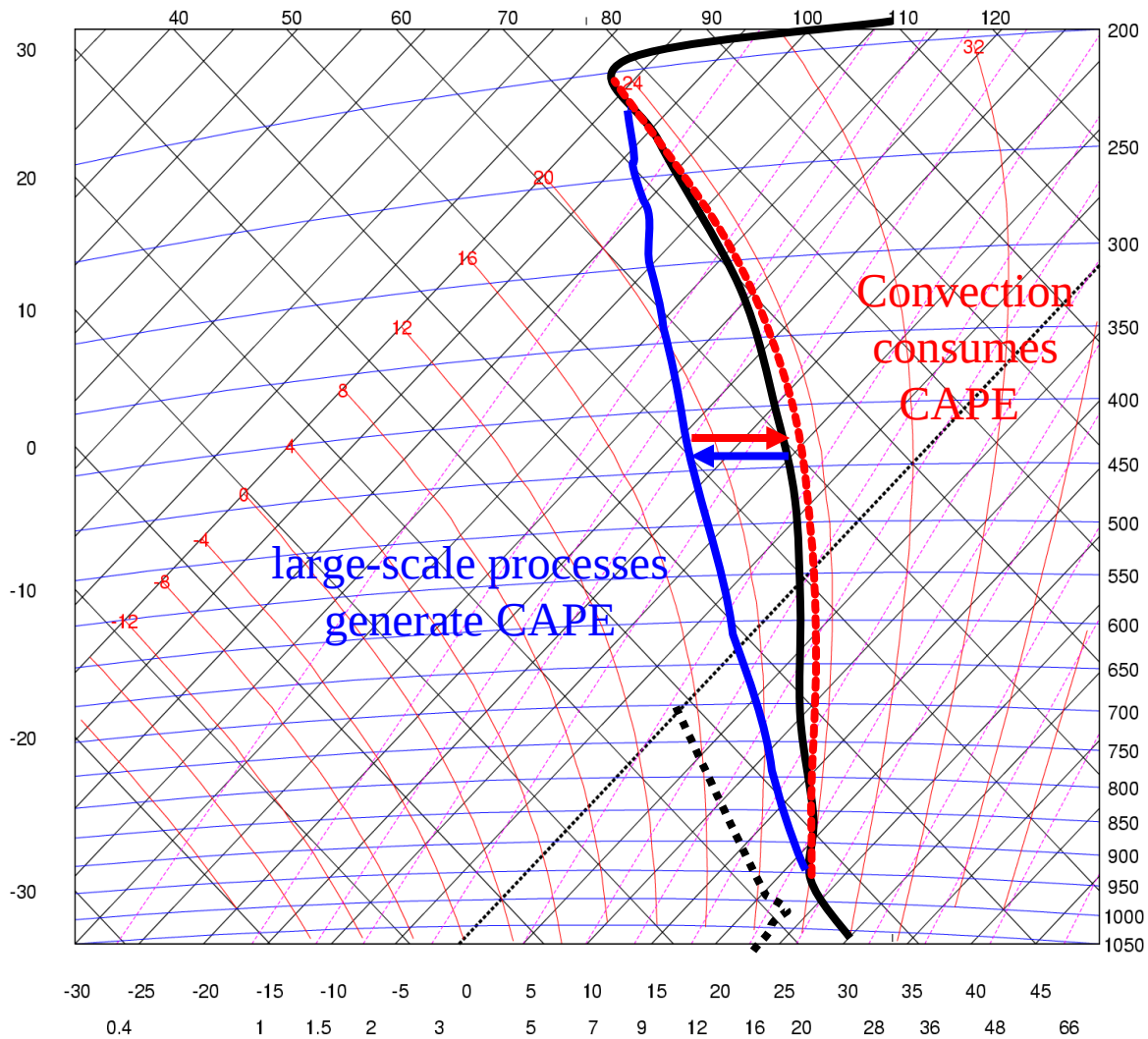




LES (black) IFS IFS formula with LES data

Schlemmer et al. 2017

CAPE closure - the basic idea



Closure - Deep convection

$$CAPE = g \int_{cloud} \frac{T_{v,u} - \bar{T}_v}{\bar{T}_v} dz \approx g \int_{cloud} \frac{\theta_{e,u} - \bar{\theta}_{esat}}{\bar{\theta}_{esat}} dz$$

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

$$PCAPE = -\int_{Pbase}^{Ptop} \frac{T_{v,u} - \bar{T}_v}{\bar{T}_v} dp$$

$$\frac{\partial PCAPE}{\partial t} \approx \underbrace{-\int_{Pbase}^{Ptop} \frac{1}{\bar{T}_v} \frac{\partial \bar{T}_v}{\partial t} dp}_{LS+Cu} \underbrace{- \int_{Pbase}^{Ptop} \frac{1}{\bar{T}_v} \frac{\partial T_{v,u}}{\partial t} dp}_{BL+Cu} + \left. \frac{T_{v,u} - \bar{T}_v}{\bar{T}_v} \right|_{base} \frac{\partial p_{base}}{\partial t} =$$

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

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

$$\partial PCAPE / \partial t = \left. \partial PCAPE / \partial t \right|_{cu}, \left. \partial PCAPE / \partial t \right|_{LS}$$

ECMWF

Closure - Deep convection

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

$$M_{u,b} = M^*_{u,b} \frac{PCAPE - PCAPE_{BL}}{\tau} \frac{1}{\int_{cloud} M^* \frac{g}{\overline{T}_v} \frac{\partial \overline{T}_v}{\partial z} dz}; \qquad M_{u,b} \geq 0$$

$$PCAPE_{BL} = -\tau_{BL} \frac{1}{T^*} \int_{psurf}^{pbase} \left. \frac{\partial \overline{T}_v}{\partial t} \right|_{BL} dp$$

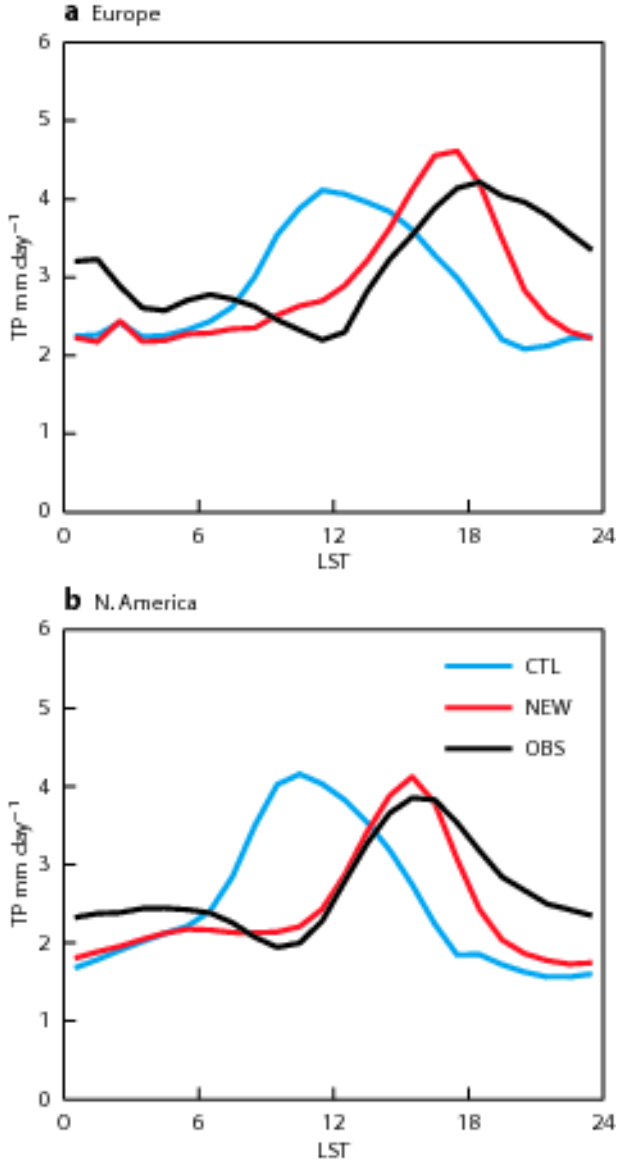
$M^* = M_u + M_d$ Mass flux from the updraught/downdraught computation

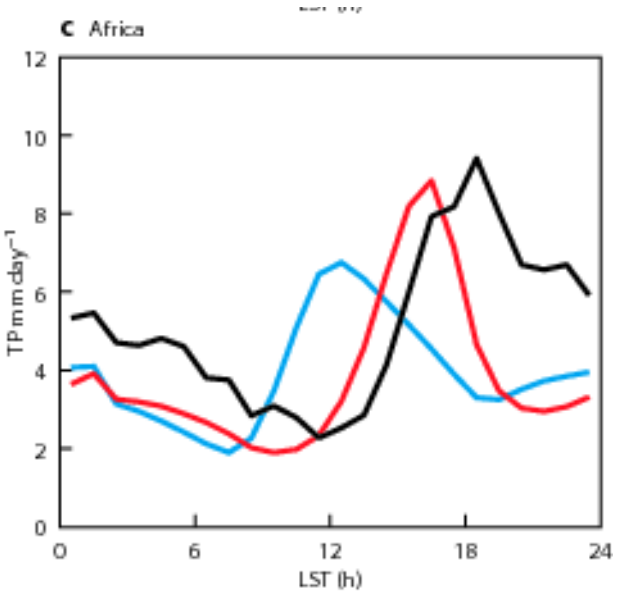
$M^*_{u,b}$ initial updraught mass flux at base, set proportional to 0.1Δp

$PCAPE_{bl}$ 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

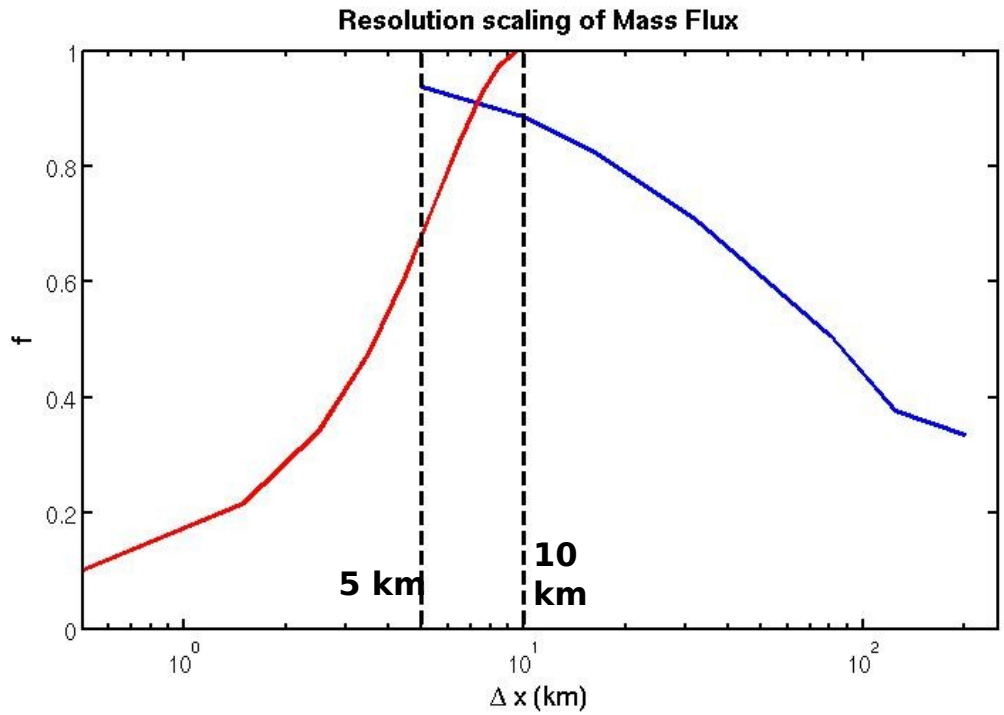
Bechtold et al., 2014, J. Atmos. Sci.
ECMWF Newsletter No 136 Summer 2013

Resolution scaling +absolute mass flux limit

$$\overline{\omega'\Phi'} = \overline{\omega\Phi} - \overline{\omega}\,\overline{\Phi}$$

$$= \sigma\left(1-\sigma\right)\left(\overline{\omega}^{c} - \overline{\omega}^{e}\right)\left(\overline{\Phi}^{c} - \overline{\Phi}^{e}\right) \quad \mathbf{f(\Delta x)}$$

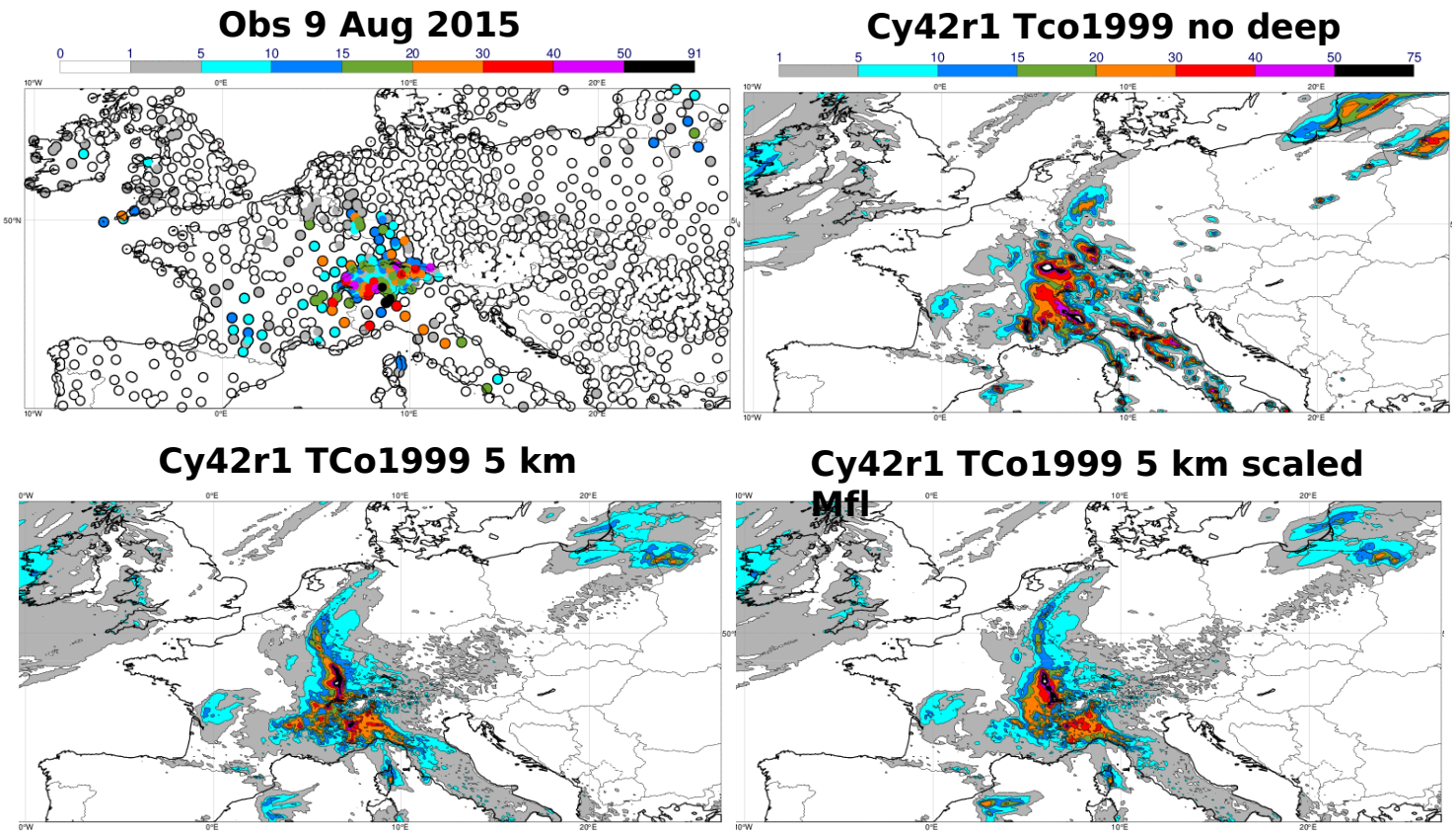
Developed in collaboration with Deutsche Wetterdienst and ICON model



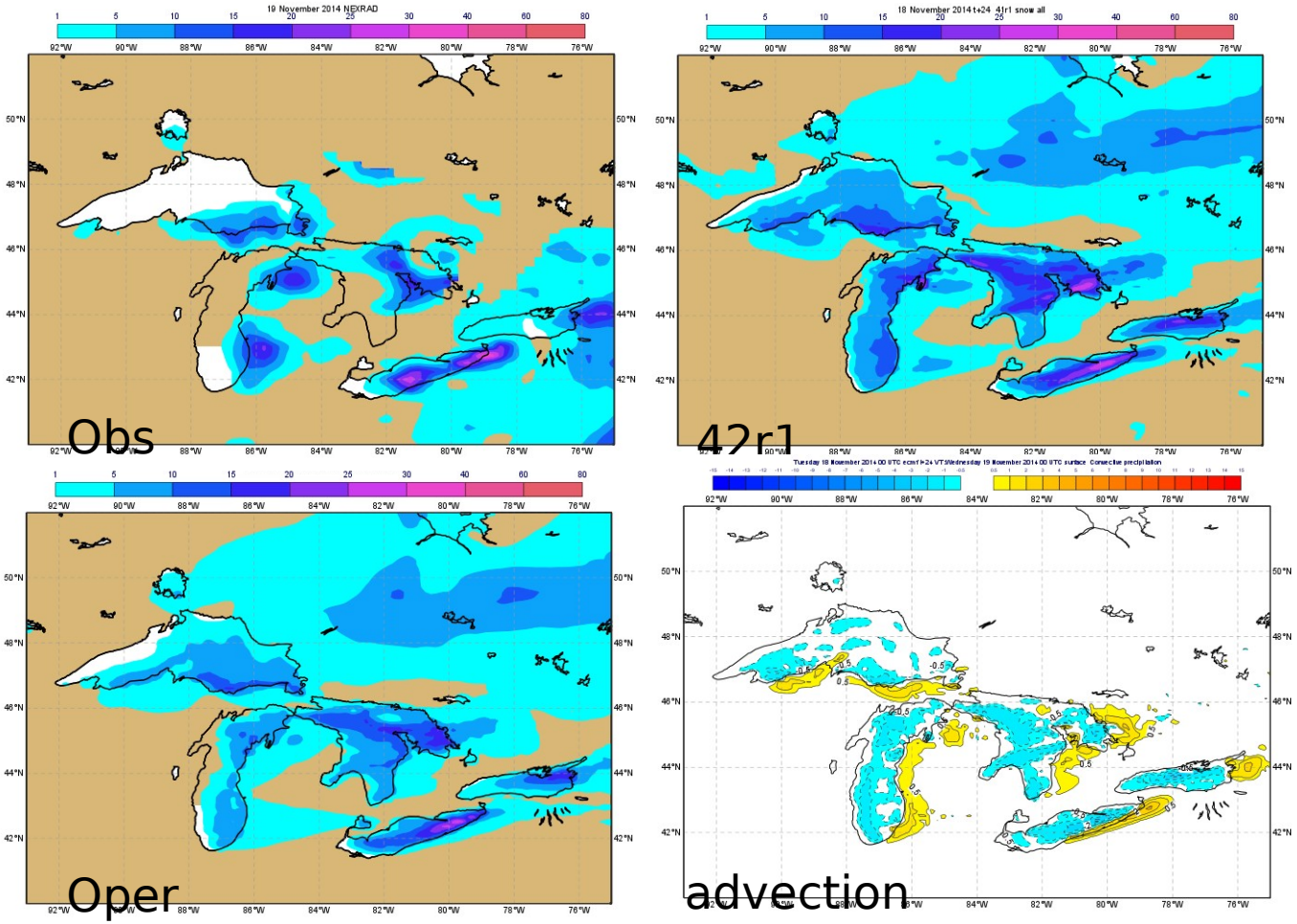
Kwon and Hong, 2016 MWR independently developed very similar relations

Resolution scaling and a bit of light in the grey zone

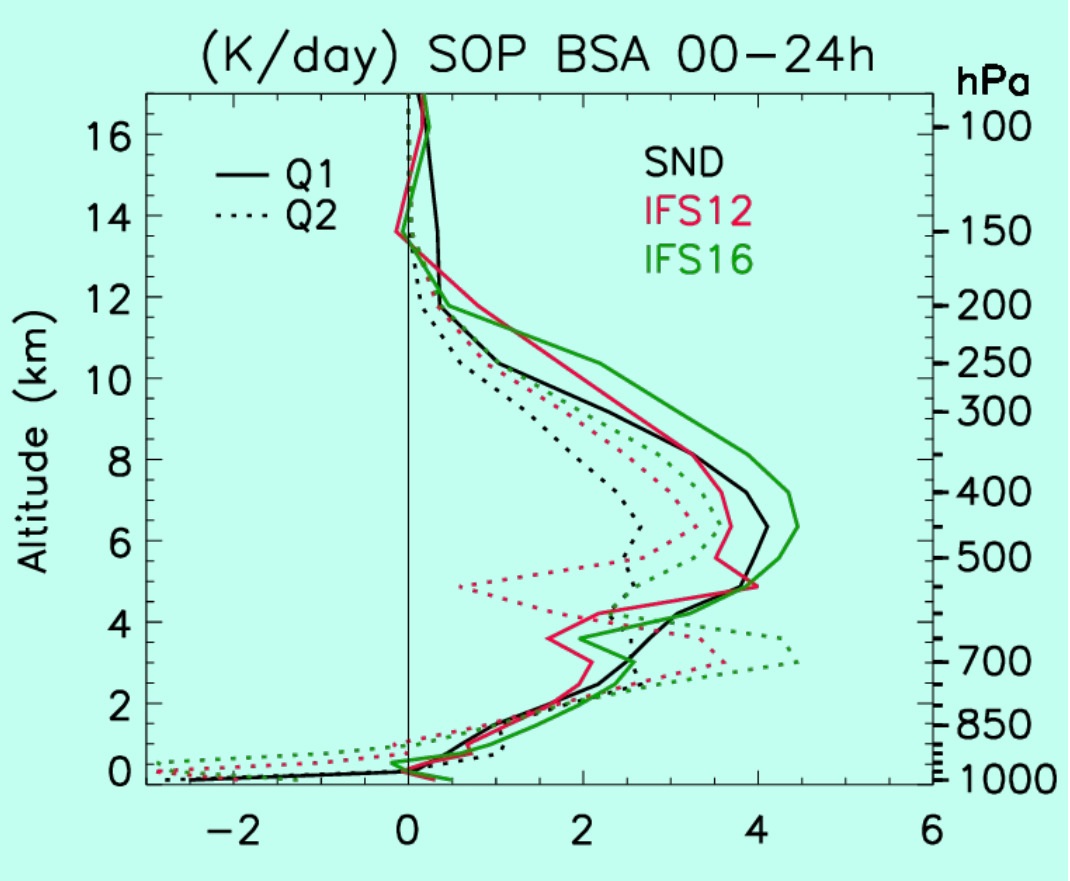
Convection parameterisation at 5km resolution



Convection issue 1: inland penetration of (winter snow) showers



Realism of heating profiles: DYNAMO MJO campaign

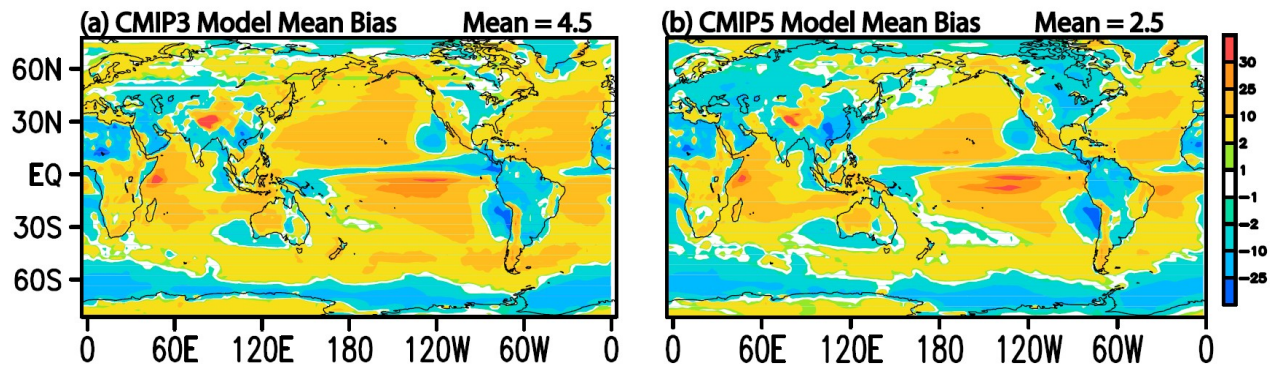


Importance of melting level and mixed-phase microphysics: : green shows smaller discontinuity at the melting level

with J-E Kim and C. Zhang

ECMWF

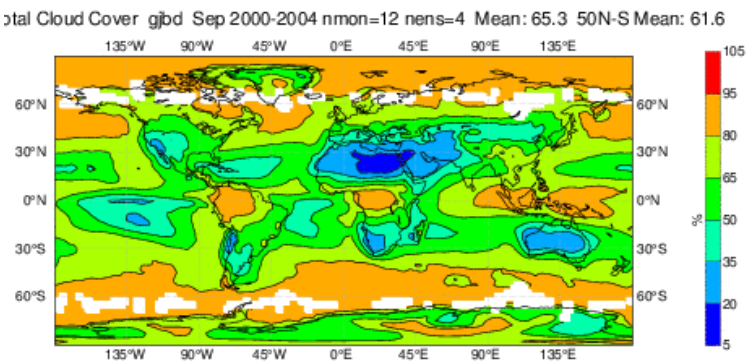
Issue: Global models are not reflective enough over the Southern Ocean, but too reflective over tropical oceans



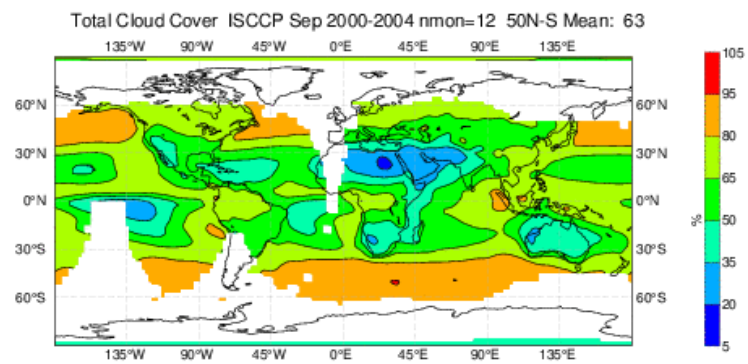
Li et al. 2013
(blue = not reflective enough)

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

IFS



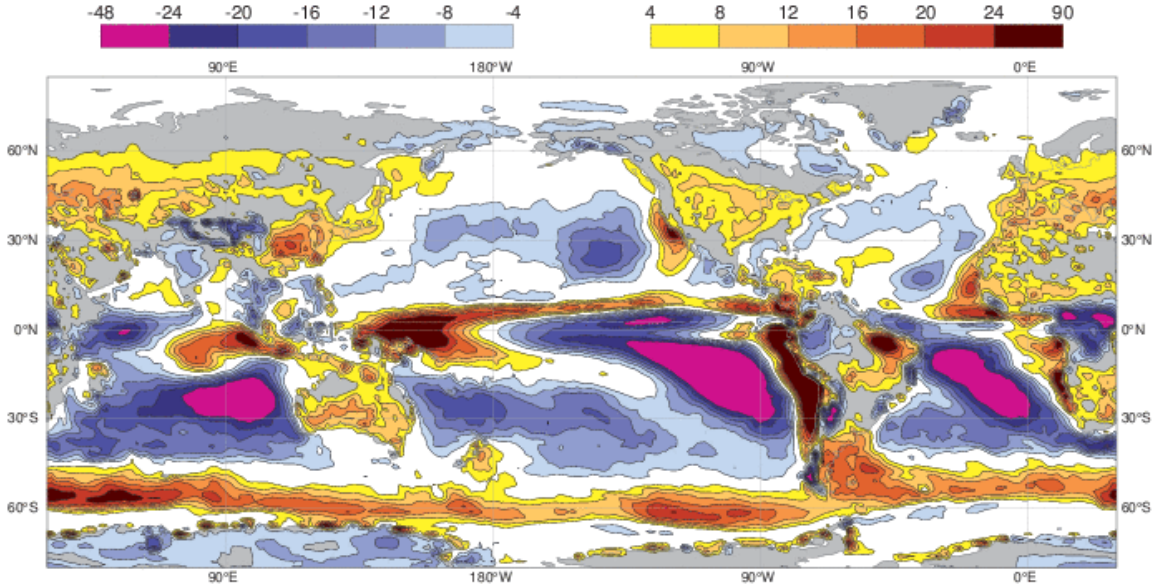
MODIS

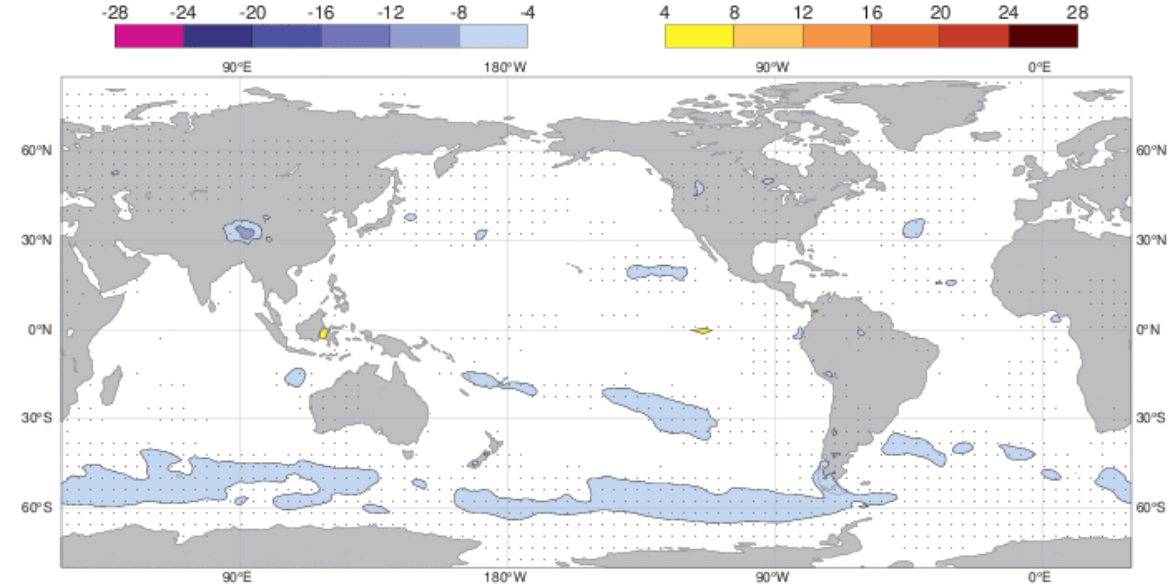


Also true for IFS even if total cloud cover against ISCCP and MODIS looks pretty good

Issue: not reflective enough storm tracks

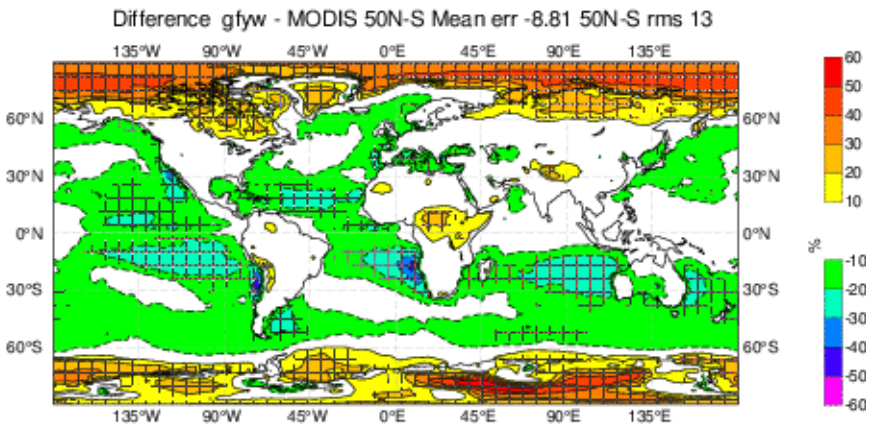
Effect of detraining more liquid phase condensate to cloud scheme corrects SW radiation error in SH storm tracks (during cold air outbreaks) by around 5 W/m2 or 20%



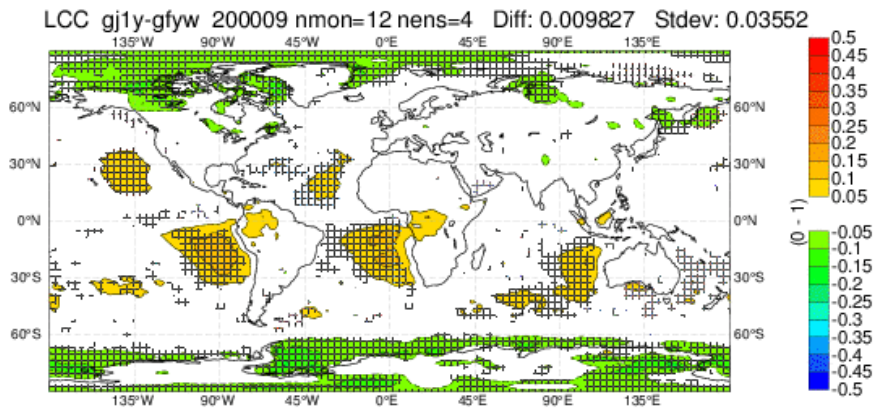


future tests: producing only liquid for shallow, but requires more technical developments and might produce biases

Issue too reflective subtropics: sensitivity to shallow detrainment

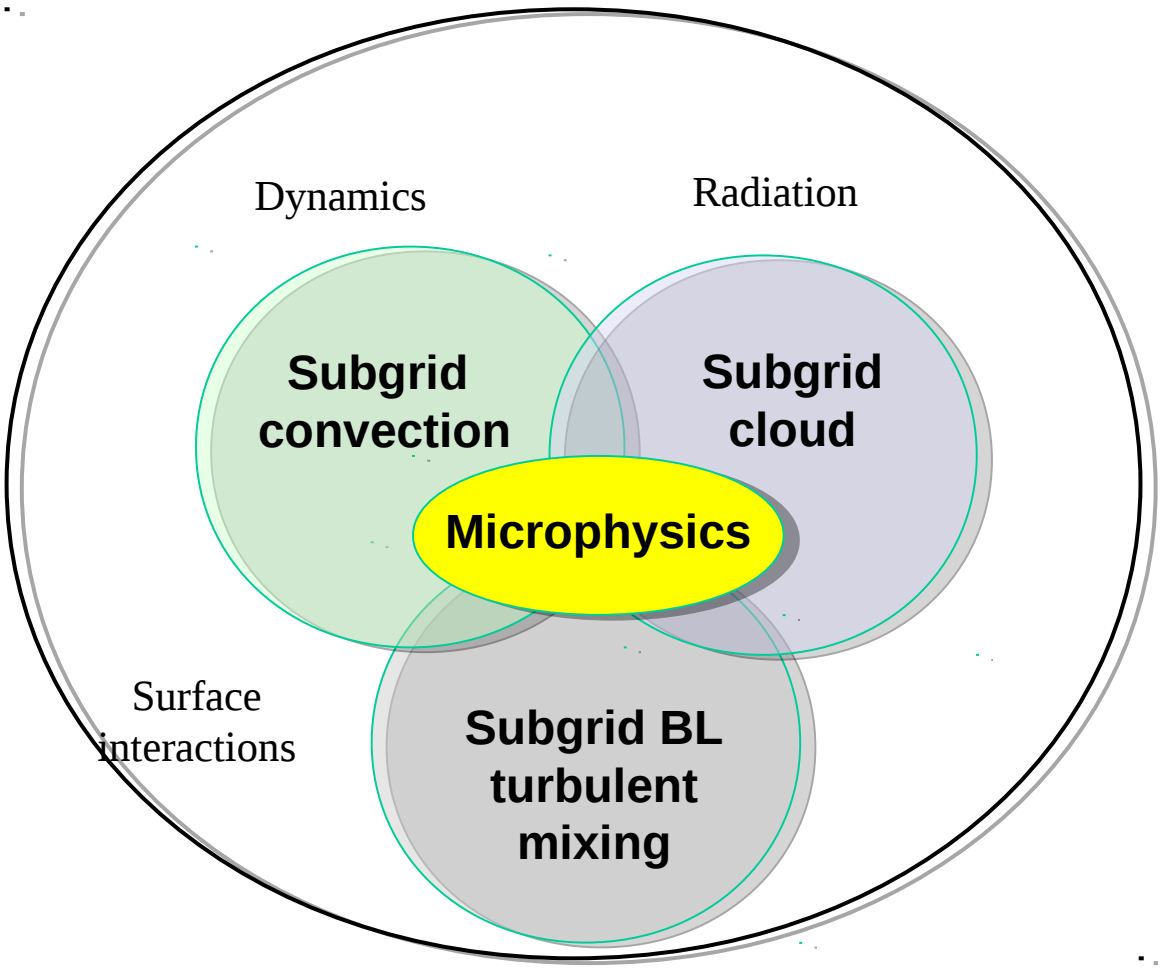


C42r1- MODIS low cloud cover: annual mean



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)

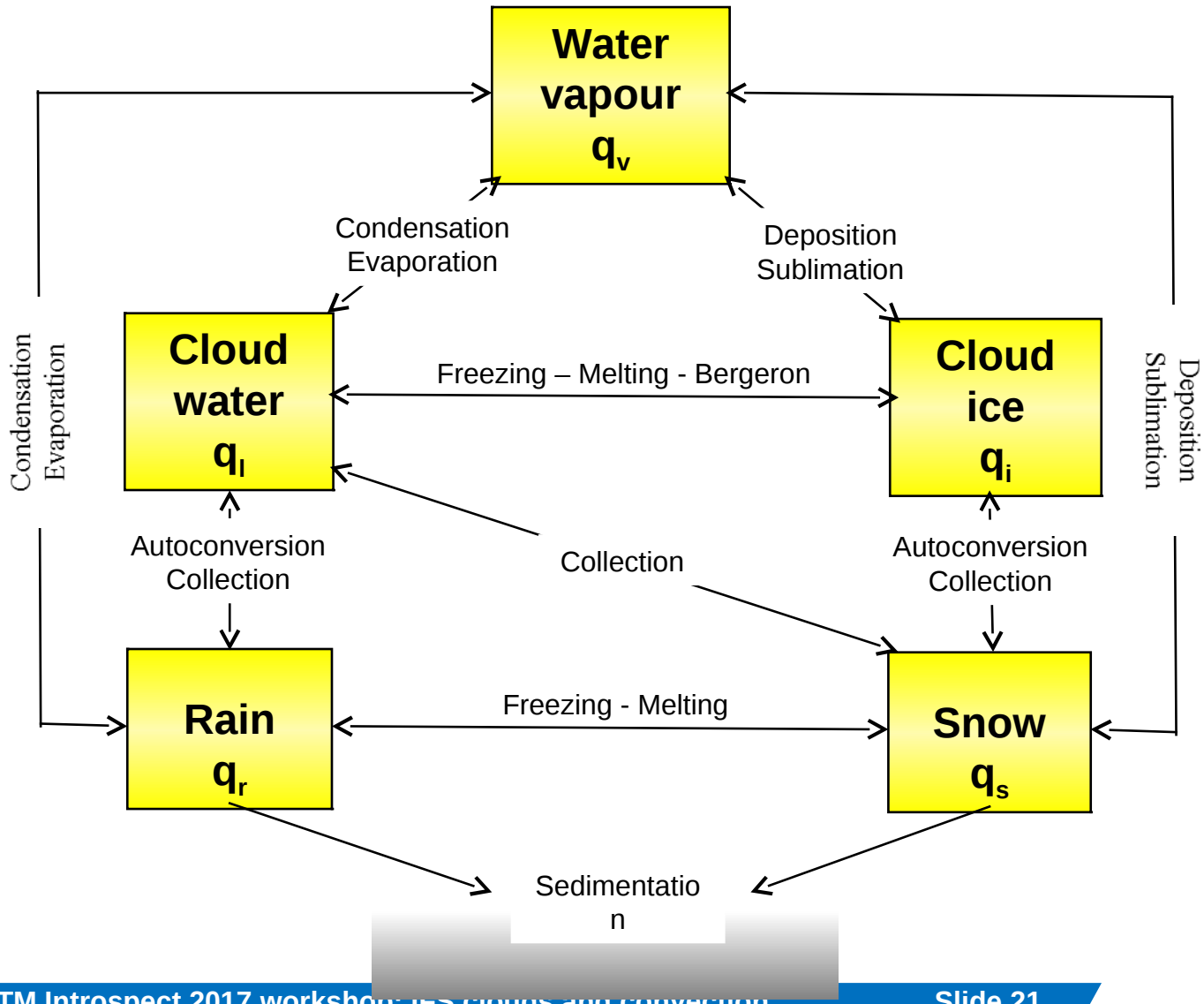
Eddy-diffusivity + multiple mass flux plumes (e.g. EDMF Dual-M)

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

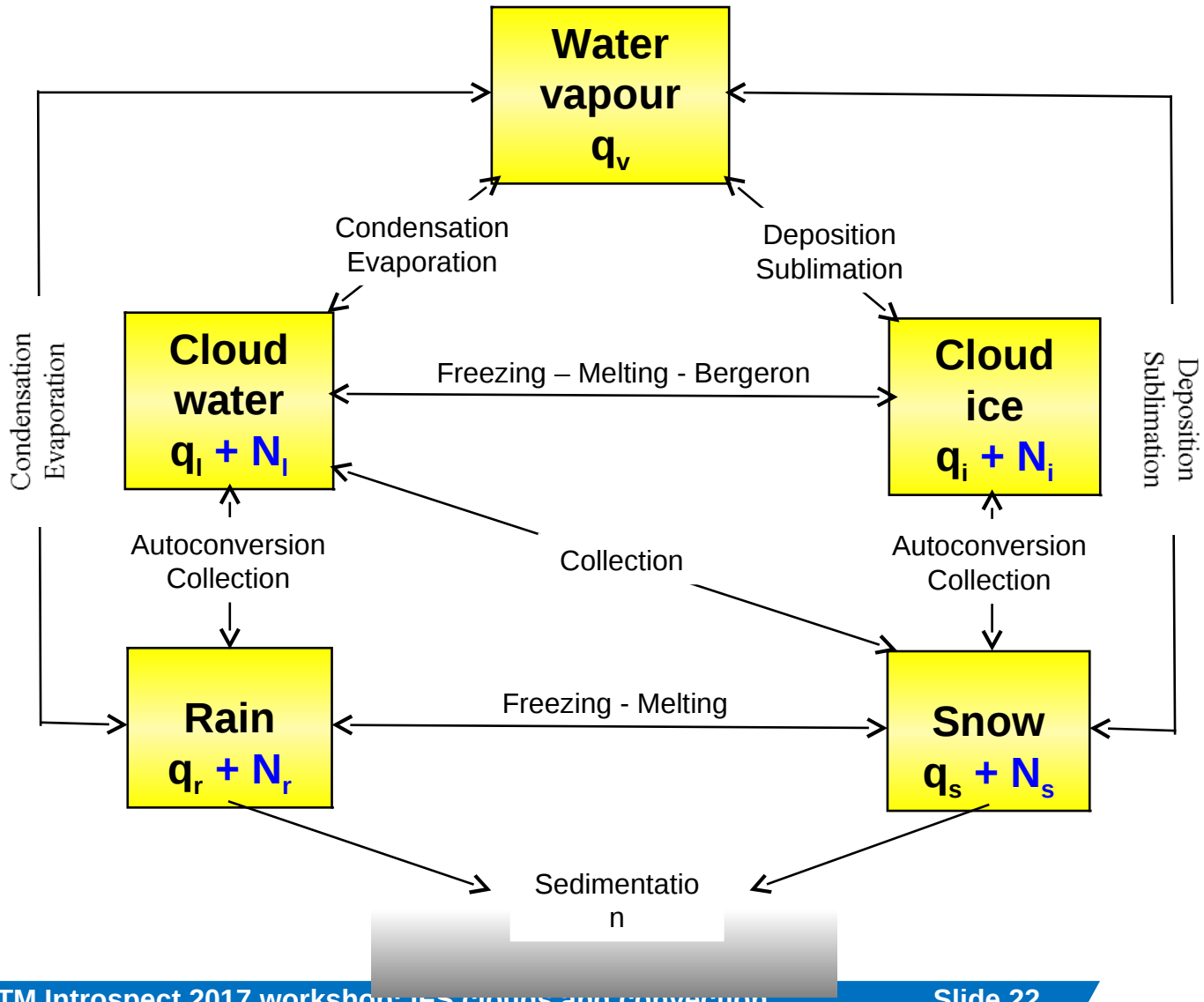


Rutledge and Hobbs (1983)

ECMWF

Microphysics Parametrization: The “category” view

Double moment schemes



e.g.

Ferrier (1994)

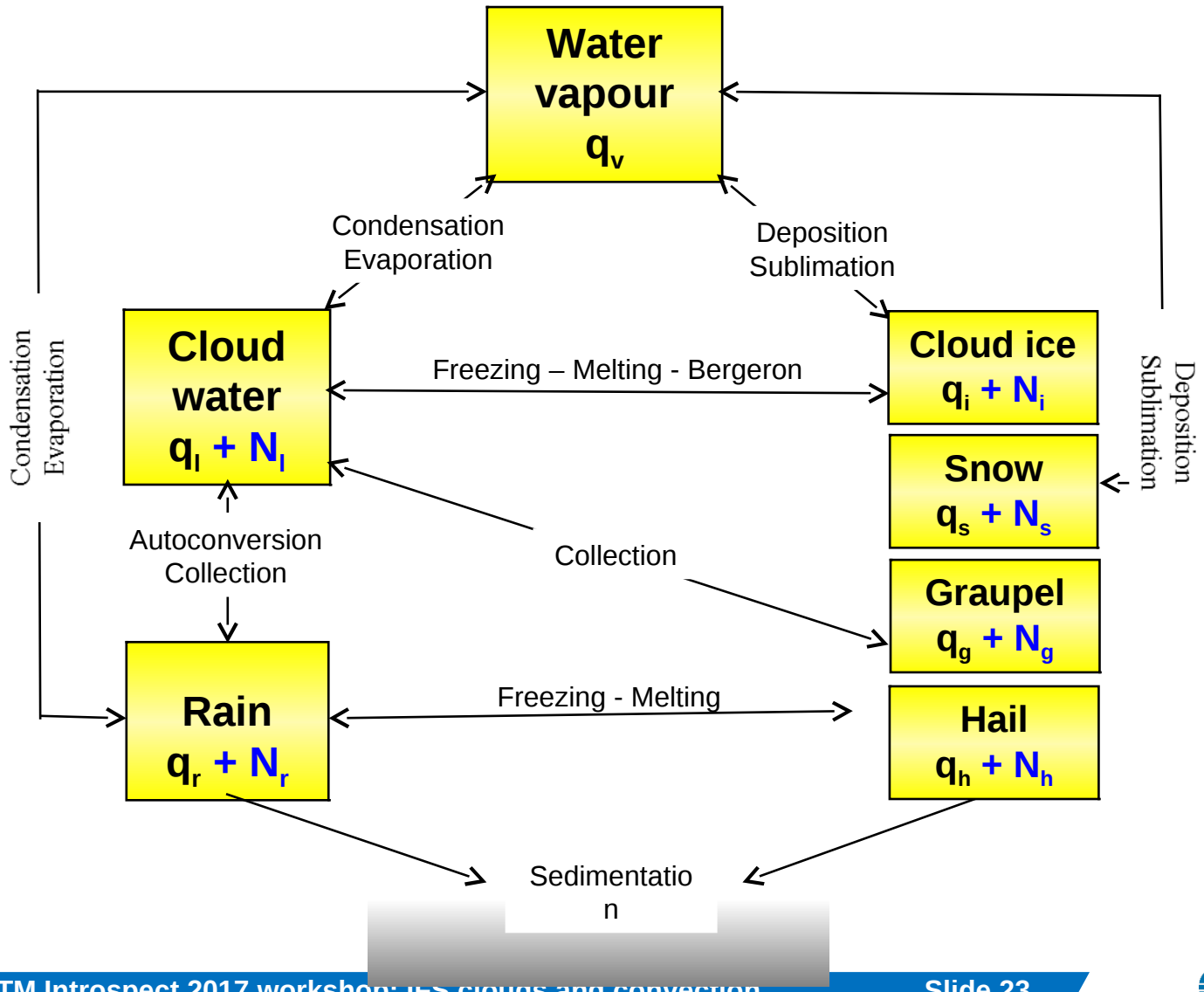
Seifert and Beheng (2001)

Morrison et al. (2005)

ECMWF

Microphysics Parametrization: The “category” view

Double moment schemes – multiple ice categories



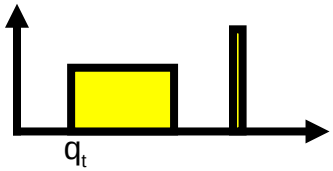
e.g.

Lin et al. (1983)

Meyers et al. (1997)

Milbrandt and Yau (2005)

Microphysics Parametrization: The cloud fraction

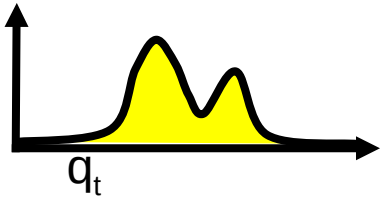


Uniform-delta:
Tiedtke (1993)

- 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)

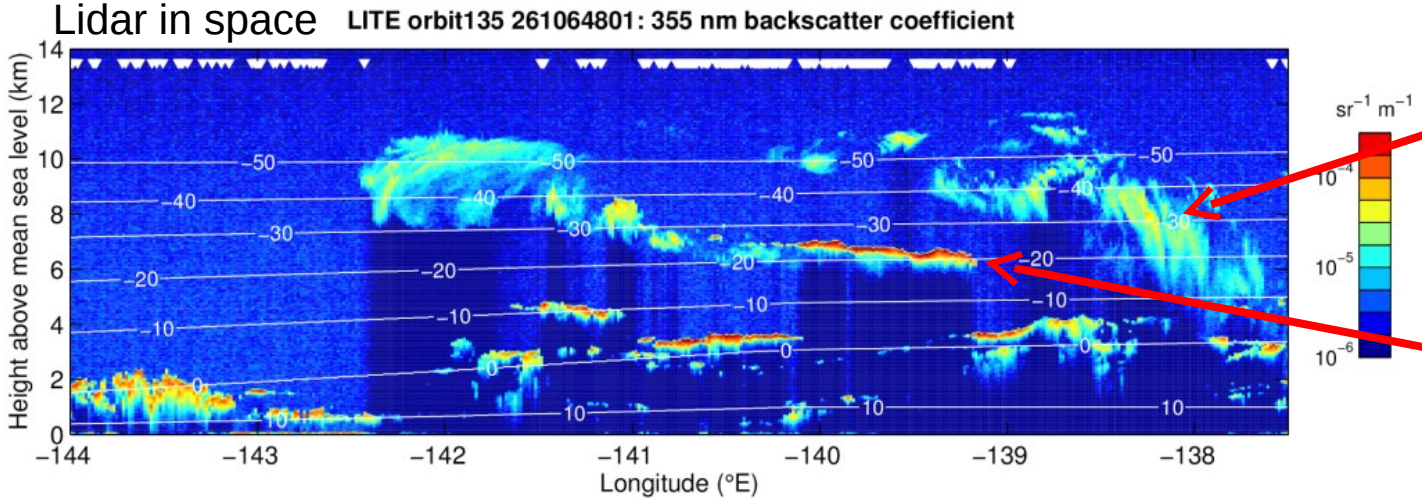


Double-Gaussian
(CLUBB)

- 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

Lidar in space



Lidar: lower backscatter from ice cloud

Lidar: high backscatter from liquid water layers

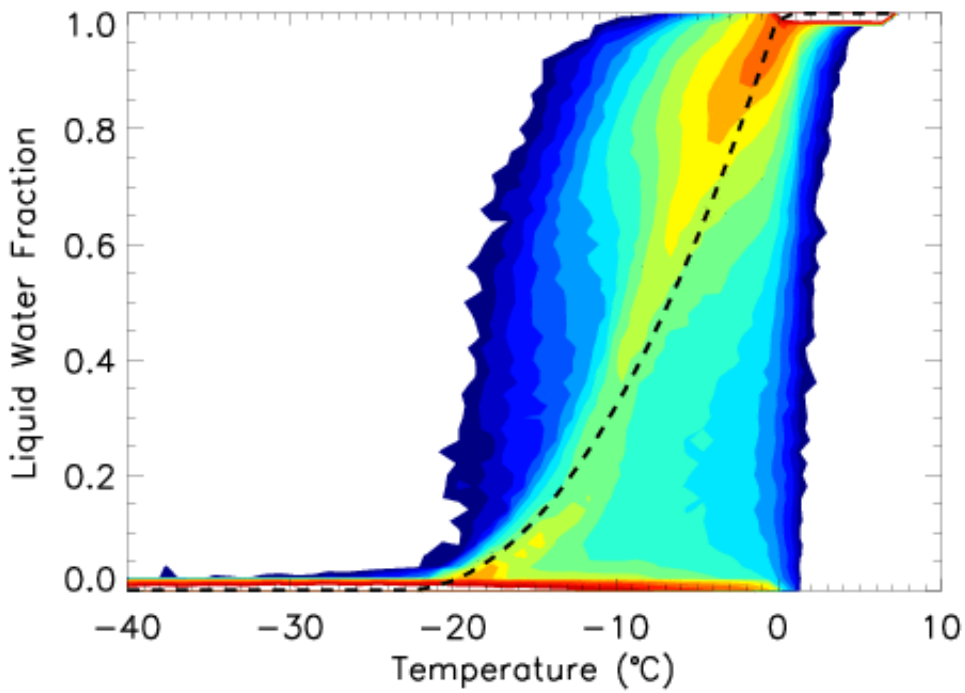
Observations:

- 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

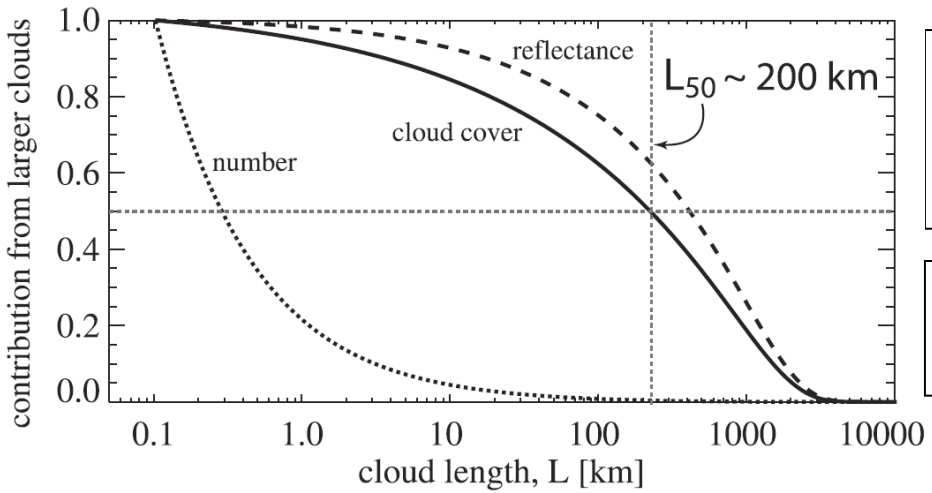
- Many (global) models with a single condensate prognostic parametrize ice/liquid phase as a diagnostic function of temperature (see dashed line for ECMWF model pre-2010 below).
- Models with separate prognostic variables for liquid water and ice, parametrize deposition allowing a wide range of supercooled liquid water/ice fraction for a given temperature (see shading in example below).

$$\frac{\partial m}{\partial t} = \frac{4\pi s C F}{\left(\frac{L_s}{RT} - 1\right)\frac{L_s}{k_a T} + \frac{RT}{\chi e_{si}}}$$



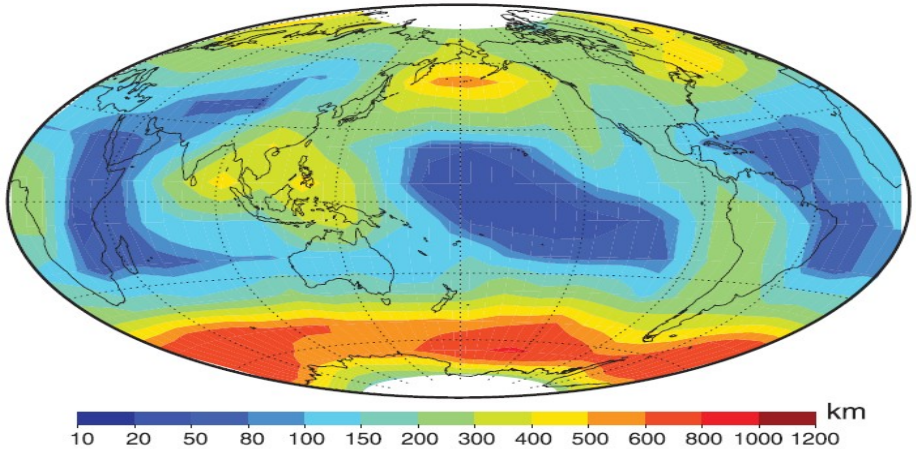
PDF of liquid water fraction of cloud for a diagnostic mixed phase scheme (dashed line) and prognostic ice/liquid scheme (shading)

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).

50% of cloud cover is from clouds with scale > 200 km
85% of cloud cover is from clouds with scale > 10 km
15% of cloud cover is from clouds with scale < 10 km



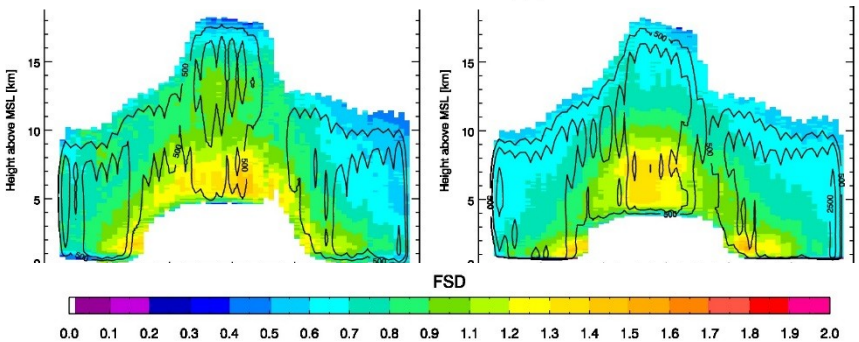
Map of the cloud size for which 50% of cloud cover comes from larger clouds (from 2 years of MODIS data)

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

CALIPSO observed FSD Parameterized



E.g.:

- Enhanced heterogeneity in winter storm tracks, summertime NH continent
- detrainment ratio highlights areas with enhanced variability
- apparent height dependence in zonal mean

current assumption in radiation: FSD=1