A detailed look at the cumulus-valve mechanism and its potential implications for cloud-base cloudiness

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Uncertain warming response of cloud-base cloudiness in trades

Discrepancy in warming response between GCMs and Large-eddy simulations (LES) near cloud base, where cloud amount largest (Vial et al. 2017, Nuijens et al. 2014)

> GCMs: very sensitive to warming, controlled by convective mixing (Sherwood et al. 2014)


Cumulus-valve mechanism:

> convection acts like a valve that maintains the mixed-layer top h close to the lifting condensation level (LCL) (Betts 1976, Albrecht et al. 1979, Neggers et al. 2006)

> negative feedback on humidity, and pot. cloudiness near cloud base (Neggers et al. 2006, Nuijens et al. 2015)

> could explain larger cloud fraction with increasing mass flux

→ opposite to what many GCMs do
purpose:

Use ICON-LEM simulations to study the premises of the valve mechanism and its potential implications for cloud-base cloudiness

research question:

Does cloud-base cloudiness increase with increasing mass flux?
ICON-LEM simulation over tropical Atlantic

> ICON-LEM simulations run by Matthias Brueck at MPI
> Smagorinsky turbulence, binary cloudiness, fixed SST
> initialization and lateral boundary conditions from ECMWF IFS (nudged every hour)
> 150m, 300m & 600m resolution, 155 vertical levels

used here:
> 150 m resolution on 1° x 2° domain upstream Barbados
> 6 days in December 2013, from 12 LT – 8 LT
Does cloud-base cloudiness increase with increasing mass flux?
Mostly yes...

\[ M = a_{co} \cdot w_{co} \]

> The mass flux \( M \) explains a lot of the variations in cloud-base cloud fraction \( a_{cid} \).
Mostly yes...

\[ M = a_{co} \cdot w_{co} \]

> The mass flux \( M \) explains a lot of the variations in cloud-base cloud fraction (\( a_{cid} \))
Mostly yes...

The mass flux $M$ explains a lot of the variations in cloud-base cloud fraction ($a_{cld}$)

Positive daytime and negative nighttime relationship between $M$ and $a_{cld}$ on some days

\[ M = a_{co} \cdot w_{co} \]
M and RH\textsubscript{max} together explain cloud-base cloudiness very well

\[ M = a_{co} \cdot w_{co} \]

> Maximum relative humidity at mixed-layer top (RH\textsubscript{max}) important additional control
> From mass budget perspective, M controlled by entrainment rate and large-scale vertical velocity

(Vogel, Bony, Stevens, in review)

> What controls RH\textsubscript{max}?
$\text{RH}_{\text{max}}$ controlled by surface RH and sub-cloud layer depth (h)

> Sub-cloud layer thus well mixed!
\( \text{RH}_{\text{max}} \) controlled by surface RH and sub-cloud layer depth (h)

> Sub-cloud layer thus well mixed!
$R_{\text{max}}$ controlled by surface RH and sub-cloud layer depth ($h$)

$R_{\text{max}} \sim -0.06 + 1.06 \cdot R_{\text{H}_10m} + 2 \times 10^{-4} \cdot h$

1. constant $h$: 
2. constant $R_{\text{H}_10m}$:

- Sub-cloud layer thus well mixed!
- Cumulus valve: Decrease in $h$ in response to increase in $M$ reduces $R_{\text{max}}$ and cloudiness, which reduces $M$
- GCMs tend not to resolve variations in $h$ and unphysically compensate the increasing $M$ by entrainment
Summary

> Combination of M and RH_{max} explains cloud-base cloudiness very well (R=0.95)
> M controlled by entrainment rate and large-scale vertical velocity (Vogel, Bony, Stevens, in review)
> RH_{max} controlled by surface RH and sub-cloud layer depth

How to think about the cumulus valve mechanism?

Coupling between mass flux and RH_{max} through mass budget crucial for capturing cloud response

>> to be tested during the EUREC^4A campaign <<