Sensibilité des nuages d’enclume à la température de surface et à l’agrégation de la convection & Projet de campagne EUREC4A

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Anvil clouds & temperature: Iris effect?
Anvil clouds & convective aggregation

For given domain-averaged precipitation and large-scale forcings:

more convective aggregation \rightarrow more clear-sky
less anvil clouds

Bretherton, Blossey and Khairoutdinov, JAS (2005)
Anvil clouds & convective aggregation

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Stein, Holloway, Tobin and Bony (in revision)
Tobin et al., JAMES (2013)

Bretherton, Blossey and Khairoutdinov, JAS (2005)
May convective aggregation influence climate change?

Easier convective aggregation at high surface temperatures

Atmospheric drying, less anvil clouds, enhanced OLR

Impact on Climate Sensitivity and Hydrological Sensitivity?

Khairoutdinov and Emanuel, AMS (2010); Khairoutdinov and Emanuel, JAMES (2013); Wing and Emanuel, JAMES (2014); Emanuel et al., JAMES (2014); Wing and Cronin, QJRMS (2015); Coppin and Bony, JAMES (2015); Bony et al., Nat Geosci. (2015); Mauritsen and Stevens, Nat Geosci. (2015);

Fig adapted from Muller and Held, J. Climate (2012)
May convective aggregation influence climate change?

Easier convective aggregation at high surface temperatures → Atmospheric drying, less anvil clouds, enhanced OLR → Impact on Climate Sensitivity and Hydrological Sensitivity?

Missing iris effect as a possible cause of muted hydrological change and high climate sensitivity in models

Thorsten Mauritsen* and Bjorn Stevens

Khairoutdinov and Emanuel, AMS (2010); Khairoutdinov and Emanuel, JAMES (2013); Wing and Emanuel, JAMES (2014); Emanuel et al., JAMES (2014); Wing and Cronin, QJRMS (2015); Coppin and Bony, JAMES (2015); Bony et al., Nat Geosci. (2015); Mauritsen and Stevens, Nat Geosci. (2015); Fig adapted from Muller and Held, J. Climate (2012)
GCMs run in Radiative-Convective Equilibrium (RCE)

- IPSL-CM5A-LR, ECHAM6 and CAM5 GCMs
- Aqua-planet configuration
- Spatially uniform insolation, prescribed surface temperature, no rotation
- Convective self-aggregation occurs
GCMs run in Radiative-Convective Equilibrium (RCE)

Increasingly so at high surface temperature
The clustering of convection reduces the anvil-cloud amount

- IPSL climate model
- Non-rotating Radiative-Convective Equilibrium
- Uniform prescribed SST (here: 305K)
Global warming as well

- As the climate warms: anvil clouds rise... and their coverage falls.
- A consequence of convective aggregation or global warming?

→ Both, but primarily global warming. Mechanism?
Constraints on upper-level cloudiness

The altitude of tropical anvil clouds is well constrained by upper-tropospheric convergence computed from the mass and energy budget of the clear-sky atmosphere

\[ D_r = \frac{\partial \omega}{\partial P} \quad \text{with} \quad \omega = -\frac{Q_r}{S} \]

\[ S = -\frac{T}{\theta} \frac{\partial \theta}{\partial P} = \left( \frac{R_d}{c_{pd}} \right) \frac{T}{P} (1 - \gamma) \]
Thermodynamic control on anvil-cloud amount

\[ D_r = \frac{\partial \omega}{\partial P} \quad \text{with} \quad \omega = -\frac{Q_r}{S} \]

- The anvil-cloud fraction varies linearly with the upper-level mass divergence \( D_r \) (convective outflow).
- As the climate warms, the upper-level mass divergence decreases (even in the absence of convective aggregation).
- Results from changes in upper-tropospheric static stability: Stability Iris
A mechanism rooted in basic thermodynamics (moist adiabats)

Moist adiabatic temperature profiles associated with different cloud-base temperatures:

Static stability: \[ S = -\frac{T}{\theta} \frac{\partial \theta}{\partial P} = \left( \frac{R_d}{c_{pd}} \right) \frac{T}{P} (1 - \gamma) \]

In a warmer climate, the anvil-clouds rise and remain at nearly the same temperature, but find themselves at a lower pressure and thus in a more stable atmosphere.

It reduces the convective outflow (less mass divergence required to balance the vertical gradient in radiative cooling), leading to less anvil clouds: a stability iris effect.
The same mechanism explains the variation of the anvil cloud amount with convective aggregation.
Robustness of the stability Iris mechanism?
**Robustness of the stability Iris mechanism?**

RCE simulations from a CRM run over a large domain (from Wing and Cronin 2016) exhibit the same effect.
Robustness of the stability Iris mechanism?

AMIP simulations (i.e. realistic configuration) run with the same GCMs also exhibit a stability Iris
Robustness of the stability Iris mechanism?

The tropically-averaged (30S-30N) anvil cloud fraction simulated by GCMs in AMIP simulations (1979-2005) also exhibit a stability Iris.

...observations too (Zelinka and Hartmann 2011)
Conclusion

- La couverture des nuages d’enclume diminue lors d’un réchauffement du climat ou d’une plus grande agrégation de la convection.

- S’interprète par un mécanisme énergetique et thermodynamique basique.

- Ce comportement semble robuste (GCMs en RCE, RCE+slab, AMIP, OAGCM) CRMs avec/sans rotation, observations).
Implications

- Atmospheric circulations:
  - The stability iris constitutes a positive feedback on convective aggregation
  - With cloud-radiative effects: contributes to the narrowing of rainy areas as the climate warms

- Climate sensitivity?
  - Anvil clouds affect both infrared and solar radiation
    → Changes in anvil cloud amount might be neutral regarding to high cloud feedbacks
  - Less anvil clouds & more low clouds
    → Low-clouds increasingly influence the Earth radiation budget
  - The three climate models examined here exhibit a positive global cloud feedback under climate change and their differences in climate sensitivity mostly relates to differences in low-cloud feedback
Implications

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  - The stability iris constitutes a positive feedback on convective aggregation
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Bony, Stevens, Coppin, Becker, Reed, Voigt and Medeiros, 2016
Low-cloud feedbacks remain the primary cause of uncertainty in model estimates of climate sensitivity

Key processes:  
- surface turbulent fluxes  
- lower-tropospheric mixing (by shallow convection and large-scale circulations)  
- atmospheric cloud-radiative effects (Vial et al. submitted)  
+ mesoscale organization?
EUREC$^4$A (Elucidating the role of cloud-circulation coupling in climate)
**EUREC$^4$A (Elucidating the role of cloud-circulation coupling in climate)**

EUREC$^4$A est une campagne d’observation franco-allemande qui se déroulera au large des Barbades (13N, 59W) fin 2019 ou début 2020 (financement ERC + Max-Planck Society + DFG).

Contribution au Grand Challenge du WCRP sur *Nuages, Circulation et Sensibilité Climatique*.

**Deux objectifs principaux:**

- **Mieux comprendre les facteurs dynamiques et thermodynamiques qui contrôlent les propriétés macrophysiques des cumulus d’alizés (e.g. fraction nuageuse à la base)**
  

- **Produire un jeu de données le plus complet possible pour l’évaluation et l’amélioration**
  
  → de la représentation des shallow cumulus dans les modèles LES, CRM et GCM

  → des retrievals satellite dans les zones de shallow convection (notamment EarthCare, ADM-Aeolus, surface fluxes, water vapor profiling)
EUREC$^4$A (Elucidating the role of cloud-circulation coupling in climate)

Field of operations:

Atlantic trades, East of Barbados (13N, 59W), late 2019 or early 2020
EUREC$^4$A (Elucidating the role of cloud-circulation coupling in climate)
- A sideways-staring lidar on board the ATR-42 will measure the cloud fraction near cloud base (Cyrille Flamant, Julien Delanoe & co)

- Large-scale vertical velocity from the surface to the mid-troposphere will be measured by launching a dense array of dropsondes along the HALO circles and measuring the divergence profile of the horizontal wind (NARVAL team, preliminary tests during NARVAL2 this summer)

- The convective mass flux at cloud base will be inferred from the mass budget of the mixed subcloud layer.
Statut & développements

- **Timing:**
  Feb 2020? (compromis shallow cumulus / ADM-Aeolus / EarthCare)

- **Préparation / tests de la stratégie expérimentale EUREC4A:**
  - measure de $\omega$ à partir de dropsondes – Campagne NARVAL2 (Aug 2016)
  - estimation du flux de masse convectif par l’analyse du bilan de masse de la subcloud-layer (LES)
  - analyse d’observations spatiales & in-situ (Narval, RICO, Barbados Cloud Observatory..)
  - application de simulateurs lidar/radar à des simulations LES – collaboration LATMOS (Julien Delanoë, Cyrille Flamant) et LAMP (Frederic Szczap)

- **Renforcement possible des moyens d’observation:**
  - Falcon du DLR (lidar vent) – validation d’ADM-Aeolus dans les tropiques

- **Opportunité pour aborder une plus grande gamme de questions scientifiques, e.g.:**
  - influence processus micro sur macrophysique des nuages (e.g. aerosols) – Alan Blyth, Leo Donner
  - formation et dynamique des poches froides – Paquita Zuidema
  - test des théories de quasi-équilibre de la convection – Kerry Emanuel
  - expériences de lachés de traceurs au large des Barbades (mélange oceanique) – Rafaele Ferrari
  - interactions entre l’atmosphere et les tourbillons océaniques – Sabrina Speich

- **Préparation, réalisation, exploitation de la campagne:**
  - forte connection au projet HD(CP)2 (High Definition Clouds and Precipitation for Climate Prediction)
  - connection à ECCLAT & DEPHY?
Merci
Radiative-Convective Equilibrium simulations

The altitude of anvil clouds is well constrained by upper-tropospheric convergence diagnosed from the mass and energy budget of the clear-sky atmosphere.

The anvil cloud amount too.
Robustness of the stability Iris mechanism?

Observations of the tropically-averaged anvil-cloud fraction at the interannual time scale (Zelinka and Hartmann 2011) show the same effect.
Anvil clouds & convective aggregation

Calipso/CloudSat observations

Rain Rate = 5 mm/day

Rain Rate = 10 mm/day