Multi-scale flows in the presence of various shallow cloud organization patterns
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(Where) do shallow clouds decelerate or accelerate the wind?

1. Analysis of the momentum budget using EUREC4A observations
2. The near-surface wind vector balance
3. Wind balance throughout the lower troposphere (in observations and IFS forecast)
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Stronger trade-winds - in response to stronger pressure gradients - drive deeper, larger clouds, which may reduce cross-isobaric wind turning and large-scale wind convergence in the ITCZ
Central to EUREC4A were circular sounding arrays that allow us to revive early budget studies.

Holland & Rasmusson (1973): Ship array during BOMEX “where the air meets the ocean”

The residual in the momentum budget is interpreted as eddy momentum flux divergence (a friction)

* JOANNE: circular dropsonde arrays (85 circles, 13 flight days): meso-scale divergence, pressure gradients and winds are used to construct the momentum budget

* In-situ turbulence measurements:
  - profiles: the French ATR Safire aircraft legs within the circle
  - profiles: the Unmanned Airborne Vehicle CU RAAVEN
  - near-surface: the NOAA Saildrone in the trade-wind alley

* Flights sample mesoscale variability in divergence
Near the surface, what is the wind vector balance?

Near the surface, what is the wind vector balance? (Nuijens et al. 2022, in review)

\[\begin{align*}
\text{Textbook cross-isobaric flow} \\
\frac{1}{\rho} \frac{\partial}{\partial p} \left( \rho \frac{\partial F_s}{\partial p} \right) - f u_s + p_+ = p_- 
\end{align*}\]
Near the surface, what is the wind vector balance?

Textbook cross-isobaric flow:

\[
-fu_s \quad \frac{1}{\rho} \frac{\partial}{\partial p} \frac{\partial u_s}{\partial p}
\]

EUREC4A mean:

\[
F_s \quad p_+ \quad -\rho^{-\frac{3}{2}} \nabla p
\]

Nuijens et al (2022, in review)
Near the surface, what is the wind vector balance?

Wind veering with height, vertical transport introduces momentum with positive $v$-component.

Wind veering is small ($2.7^\circ$ up to cloud base), vertical transport efficient!

Textbook cross-isobaric flow

$$\frac{1}{\rho} \frac{\partial}{\partial p}$$

EUREC4A mean: cross-isobaric flow

$$\nabla \cdot \mathbf{u}$$

A component of friction that veers the wind - opposing cross-isobaric wind turning - is most pronounced during a period of stronger trade-winds and convection.

Nuijens et al (2022, in review)
Convective, mesoscale flows create a deeper layer of easterly flow

layer with acceleration of easterly flow

frictional layer

Nuijens et al. (2022, in review)
Convective, mesoscale flows create a deeper layer of easterly flow

See Poster Alessandro Savazzi:
CO63 – Convective Momentum Transport in Organised Shallow Cumulus Fields
Differences in wind tendencies linked to weak zonal wind bias in IFS

no convective tendency above 1.5 km

compensating physics/dynamics errors

Savazzi, Nuijens, Sandu, George and Bechtold (in review)
Trade winds convection accelerates flow near surface and cloud tops: Frictional layer is ~ 1.5 km deep, convection contributes to friction in the upper mixed-layer and lower cloud layer. Weak wind turning!

Highlights and implications

- **Trade winds convection accelerates flow near surface and cloud tops:** Frictional layer is \( \sim 1.5 \text{ km} \) deep, convection contributes to friction in the upper mixed-layer and lower cloud layer. Weak wind turning!

- **A brake on the circulation?** Convection plays a role in veering the wind, opposing friction-induced cross-isobaric flow (Ekman pumping), which may impact the structure of the ITCZ

> **EUREC4A Large Eddy Simulations show an increase in the role of physics to veer the wind as winds strengthen**
Highlights and implications

✦ **Acceleration near surface and cloud tops:** Frictional layer is about 1.5 km deep, convection contributes to that friction in the upper mixed-layer and lower cloud layer.

✦ **A brake on the circulation?** Convection plays a role in veering the wind, opposing friction-induced cross-isobaric flow (Ekman pumping), which may impact the structure of the ITCZ.

✦ **Break-out group discussion tomorrow:** Shallow convective momentum transport, impact on the large-scale circulation and persistent wind biases in GCMs.