Shallow Island Convection: Impact of the Large-scale Environment

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Introduction

Small islands offer an opportunity to focus in on a regularly occurring organised convective system (Cloud Trails) to investigate the convective lifecycle: i.e. initiation, maturation, and decay of convection and associated circulations. This work inspects the convective lifecycle for cloud trails, and tests its sensitivity to changes in the large-scale environment.

What do observations look like?

Cloud trails (CT) are organised bands of convection which are aligned with the low-level flow and anchored to heated islands (e.g. Figure 1). Radiosondes on automatically detected CT days are used to identify environmental differences between days with and without CT (Johnston et al., 2018).

These environmental profiles (e.g. Figure 2) are then used to inform idealised experiments to further explore the mechanisms behind initiation, organisation, and maintenance of convection in CT.

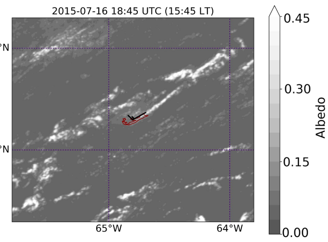

Figure 1. Visible satellite imagery where clouds appear as brighter. The cloud trail can be seen as the cloud line extending from the island. Coastline is marked in dark red, and lat/lon in purple. A wind barb in black.

Environmental profiles:

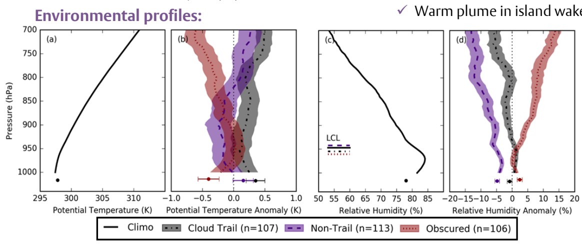

Figure 2 (left). June-July-August composites of the (a) mean potential temperature; (b) potential temperature anomalies from the mean profile in (a); (c) mean relative humidity, (d) anomalies from the mean relative humidity profile in (c). Anomalies on cloud trail days (a CT is present) in **black**, non-trail days (not overcast but no CT observed) in purple, and obscured days (overcast and no CT can be observed) in **dark red**. The shading represents the standard error ($\pm\sigma/\sqrt{n}$). The surface value and its standard error are plotted as a dot in (a) and (c), with error bars in (b) and (d).

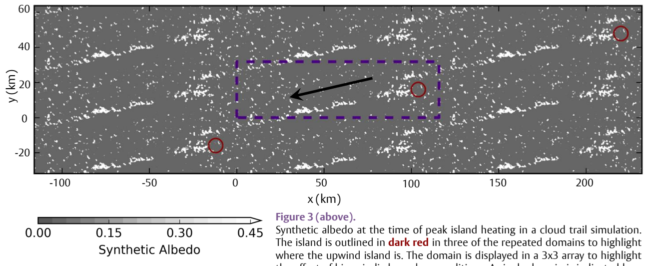

Figure 3 (above). Synthetic albedo at the time of peak island heating in a cloud trail simulation. The island is outlined in **dark red** in three of the repeated domains to highlight where the upwind island is. The domain is displayed in a 3x3 array to highlight the effect of bi-periodic boundary conditions. A single domain is indicated by a purple dashed box. Low-level wind direction is indicated by a **black** arrow.

The Control Experiment

Experiments with the Met Office Unified Model using 100 m horizontal grid spacing are performed.

Idealised initial conditions derived from a case CT day's morning radiosonde profile are used. Large scale subsidence forcing, radiative cooling tendency, and geostrophic wind forcing are applied to the low-levels of the model domain in the style of Large-Eddy Simulations.

Surface turbulent fluxes are prescribed: constant in time/space over sea, and with a 12-hour long diurnal cycle over a 50 km² island. Island Bowen ratio (B = sensible ÷ latent) is set equal to 1 for equally partitioned sensible and latent heat fluxes.

Additional experiments are performed to explore the role of different values of B and relative humidity (RH) in the BL and the free atmosphere.

The high resolution model reproduces the following expected cloud trail qualities.

- ✓ Downwind/anchored cloud band (Figure 3/4a)
- ✓ Cloud trail circulation (in-up-out) (Figure 4b)
- ✓ Warm plume in island wake (Figure 4c)

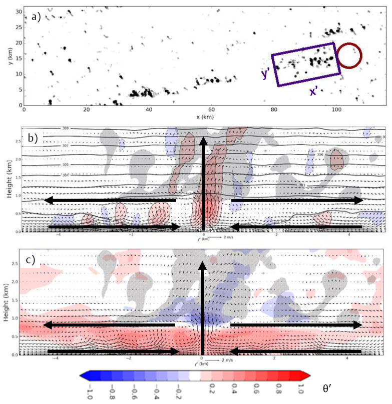

Figure 4 (above).
(a) Cloud mask with region of interest highlighted. Cloud appears **black** here. Region is rotated so that the long axis of the rectangle is aligned with the mean mixed-layer flow, i.e. x'-y' coordinates.
(b) y'-z averages over the rectangular region of interest in (a) along the x' direction following the flow. Plotted are: potential temperature (solid **black** lines), wind vector in the plane (**black** arrows), vertical velocity (red/blue shading), and cloud mask (grey).
(c) Averages as in (b) of potential temperature anomaly (red/blue shading), wind vector in the plane (**black** small arrows), exaggerated flow marked by large **black** arrows, and cloud mask (grey).

References

1. Johnston, M. C., C. E. Holloway, R. S. Plant, 2018: Cloud Trails Past Bermuda: A 5-year Climatology from 2012-2016. *Mon. Wea. Rev.*, **146**, 4039-4055.

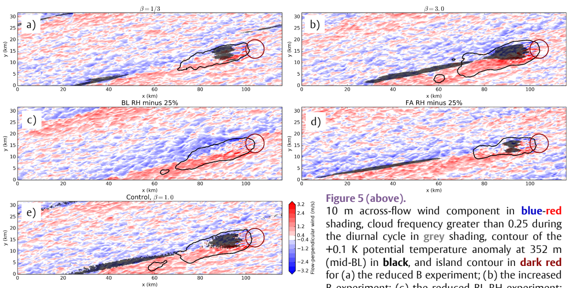

Figure 5 (above). 10 m across-flow wind component in blue-red shading, cloud frequency greater than 0.25 during the diurnal cycle in grey shading, contour of the +0.1 K potential temperature anomaly at 352 m (mid-BL) in **black**, and island contour in **dark red** for (a) the reduced B experiment; (b) the increased B experiment; (c) the reduced BL RH experiment; (d) the reduced free-atmosphere RH experiment; and (e) the control experiment.

Environmental Sensitivity:

Changes to Bowen ratio :

Cloud trail characteristics are largely controlled by the strength of the sensible heating.

Decreasing B to 1/3 in Figure 5a reduces the size and intensity of the warm plume, and low-level convergence is weaker compared to the control (Figures 5e). Similarly, increasing B to 3 in Figure 5b increases the size and intensity of the warm plume, and low-level convergence is stronger. However, rain evaporation (not shown) is a suspected limiting factor.

Changes to Relative Humidity:

BL circulation is present for all heated islands, but requires sufficient low level RH for cloud and cloud trail .

Severely reducing the BL RH in Figure 5c produces very little cloud, yet the BL convergent structure is strongly evident. Reducing the free-atmosphere RH in Figure 5d reduces the warm plume extent/intensity, and the cloud trail extent. Low-level circulation is otherwise comparable to the control.

Conclusions

- Stronger surface sensible heating over the island relates to a stronger low-level circulation. Secondary factors (e.g. precipitation) weaken circulation

$$\uparrow H_{sfc} = \uparrow \text{Circulation}$$

- Strongly reducing low-level humidity prevents cloud from forming across the domain, including in the cloud trail region
  - BUT the low-level circulation is still present

$$\text{No Cloud} \neq \text{No Circulation}$$

- Cloud latent heating also contributes to the circulation, ongoing analysis seeks to quantify this.

$$\text{Circulation} \propto H_{sfc} + L_v \Delta q_{con} + \ldots$$