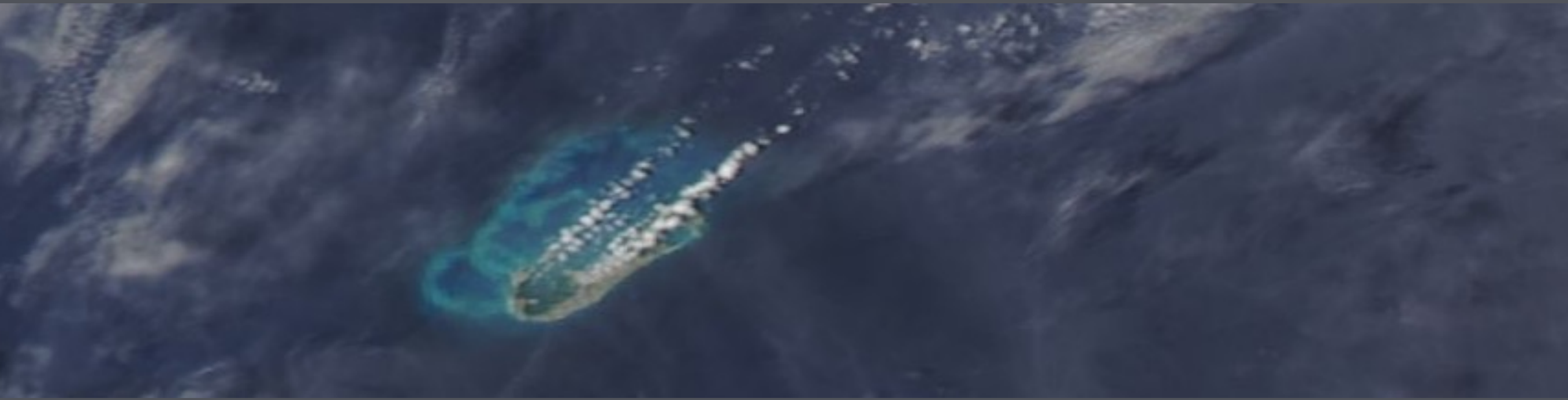
Department of Meteorology

University of Reading

Sensible heat fluxes control cloud trail strength



Michael Johnston, Chris Holloway* and Bob Plant, Univ. of Reading

* presenting author

3rd Workshop on Cloud Organisation and Precipitation Extremes - WCO3

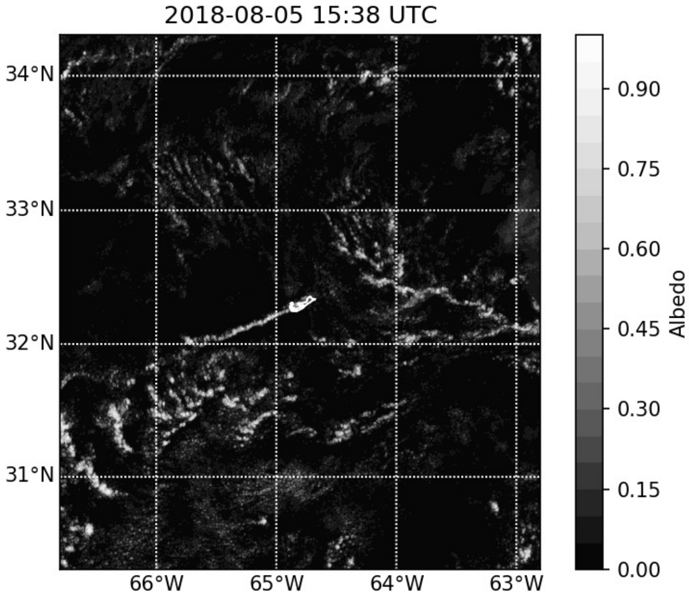
ICTP, Trieste, 8 September 2023

What is a Cloud Trail (CT)?

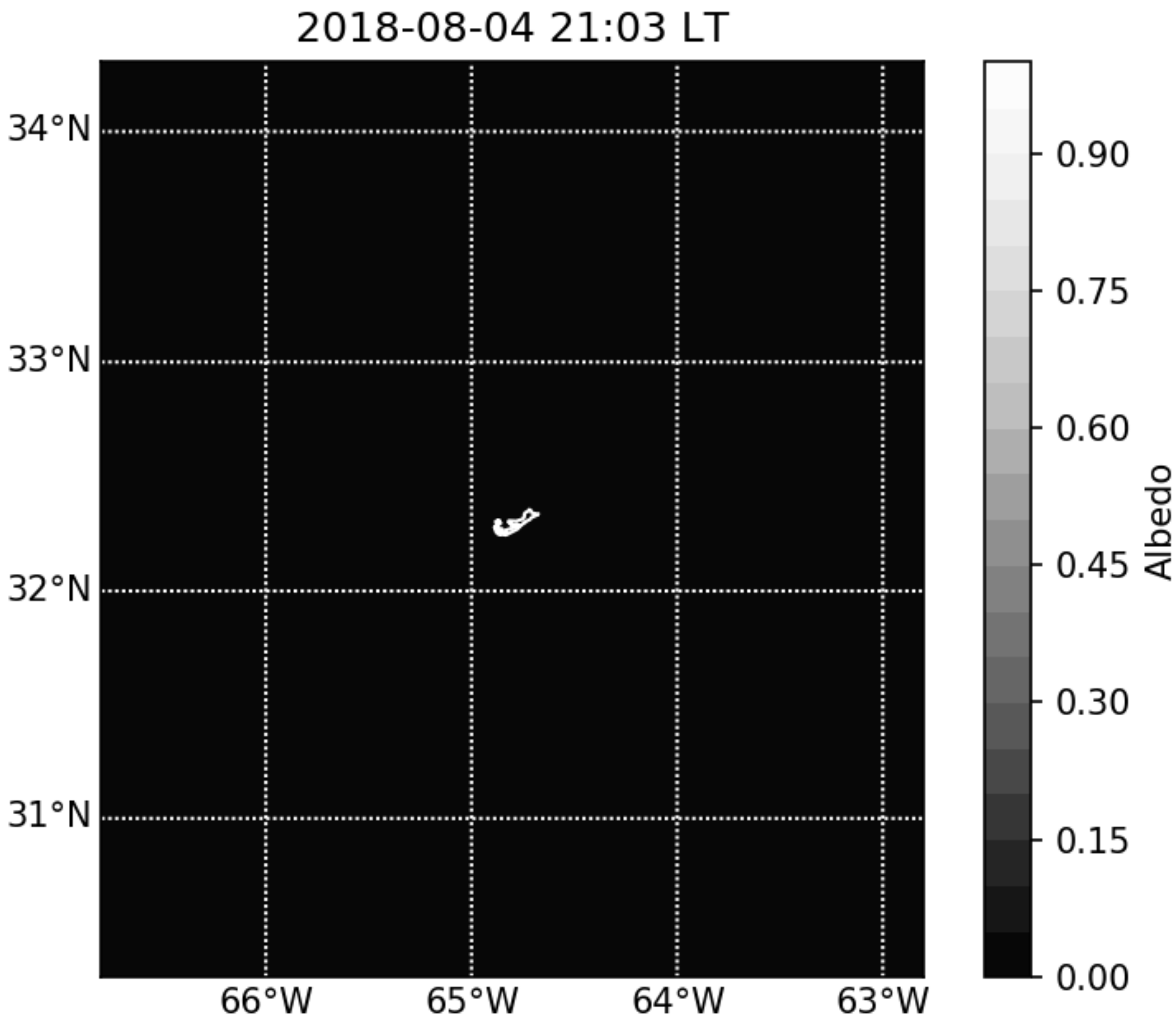
- **One or several cumulus cloud bands**
- **Oriented parallel to the low-level flow**
- **Anchored to a small, heated island**

- **Johnston et al (2018, *MWR*) satellite observations over Bermuda:**

1. CT occurrence follows diurnal & annual cycle of solar heating as expected
2. CT typically grow to ~95 km long, comparable to Nordeen et al. (2001)
3. Warm, humid mixed layer is important to get CT



Here's an example (Bermuda):



Another example (Bahamas)

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Suomi NPP/VIIRS Corrected Reflectance (True Colour)

12 May 2019

Motivation

- **Convection parameterisation:** Convection continues to be a major source of model uncertainty.
  - Coarse grid-spacing = parameterisation required
  - Convection permitting models may not resolve shallow clouds
- **Advance understanding of** convective initiation and organisation across a range of horizontal scales
- **Bermuda = Simple natural lab**
- **Testbed:** Future parameterisation evaluation using a CT reference case

Main question

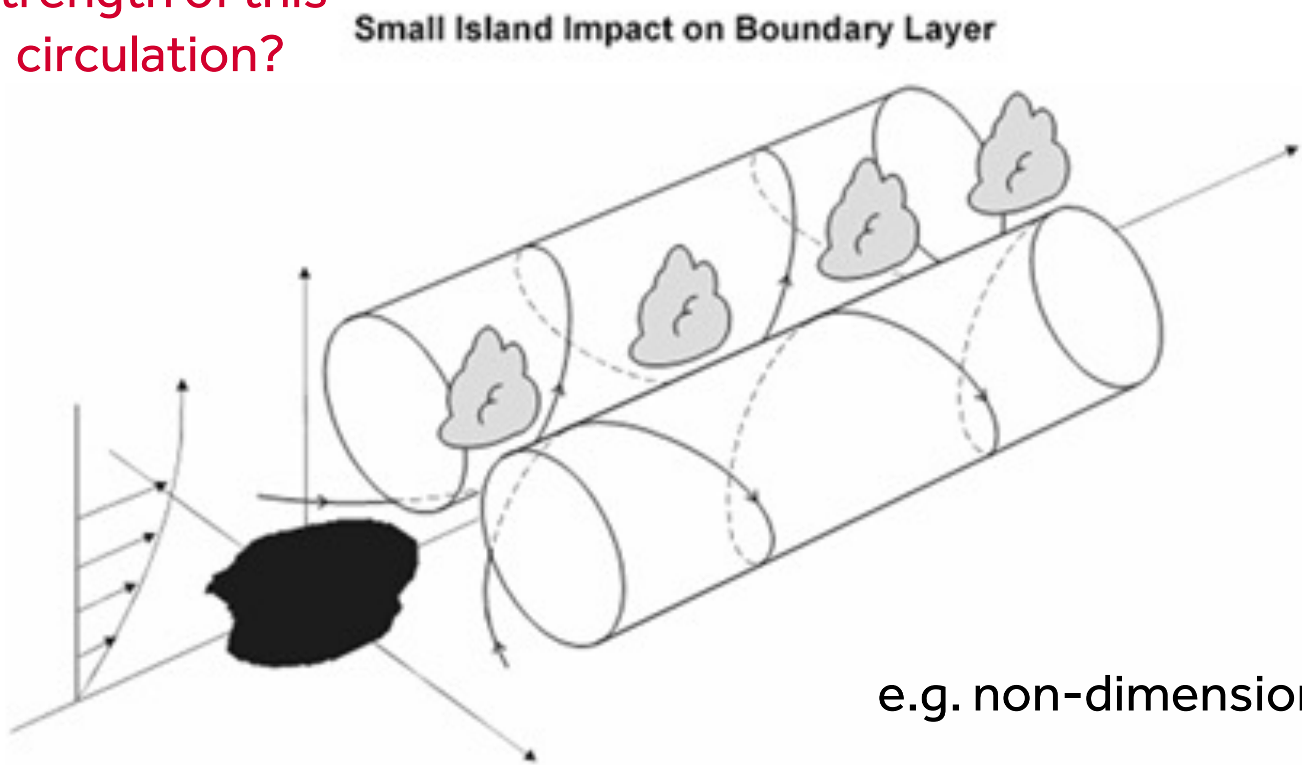
- **What controls the strength of the cloud trail and accompanying circulation?**

Michael Johnston

Johnston, M.C., Holloway, C.E. & Plant, R.S. (2023). Sensible heat fluxes control cloud trail strength. *Quarterly Journal of the Royal Meteorological Society*, 149(753), 1165–1179

CT Circulation

What controls the strength of this circulation?



COMET (DOE/ARM), based on ideas in Matthews et al. 2007

e.g. non-dimensional buoyancy gradient

$$\Pi_2 = \frac{gHl_x^3}{\rho c_p T_0 U_{sc}^3 l_y^2}$$

Kirshbaum and Fairman (2015)

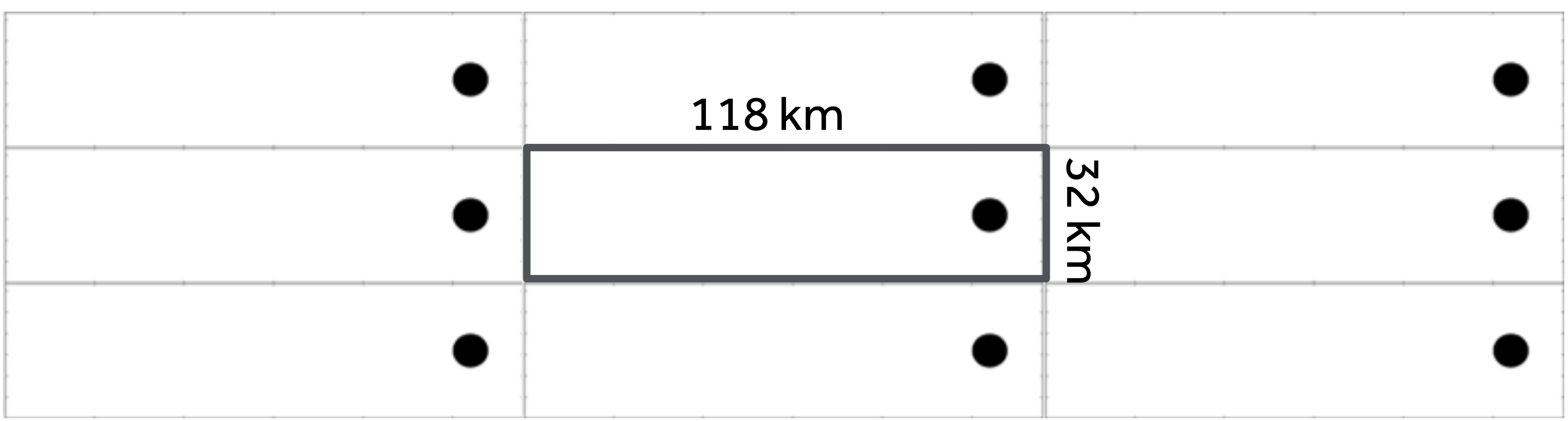
Idealised Simulation Design

Met Office Unified Model vn 10.9 (UM)

- Domain and Resolution
  - 100 m grid spacing
  - 140 vertical levels stretched to 40 km top
  - 50 km^2 flat island
  - 118 x 32 km domain (x, y)
  - Periodic boundary conditions (see figure below)

- Idealisations
  - Geostrophic forcing
  - Subsidence
  - Prescribed surface fluxes
  - Radiative cooling

- 10-day small-domain spin-up with interact. surf. fluxes for initial state



Experimental Design

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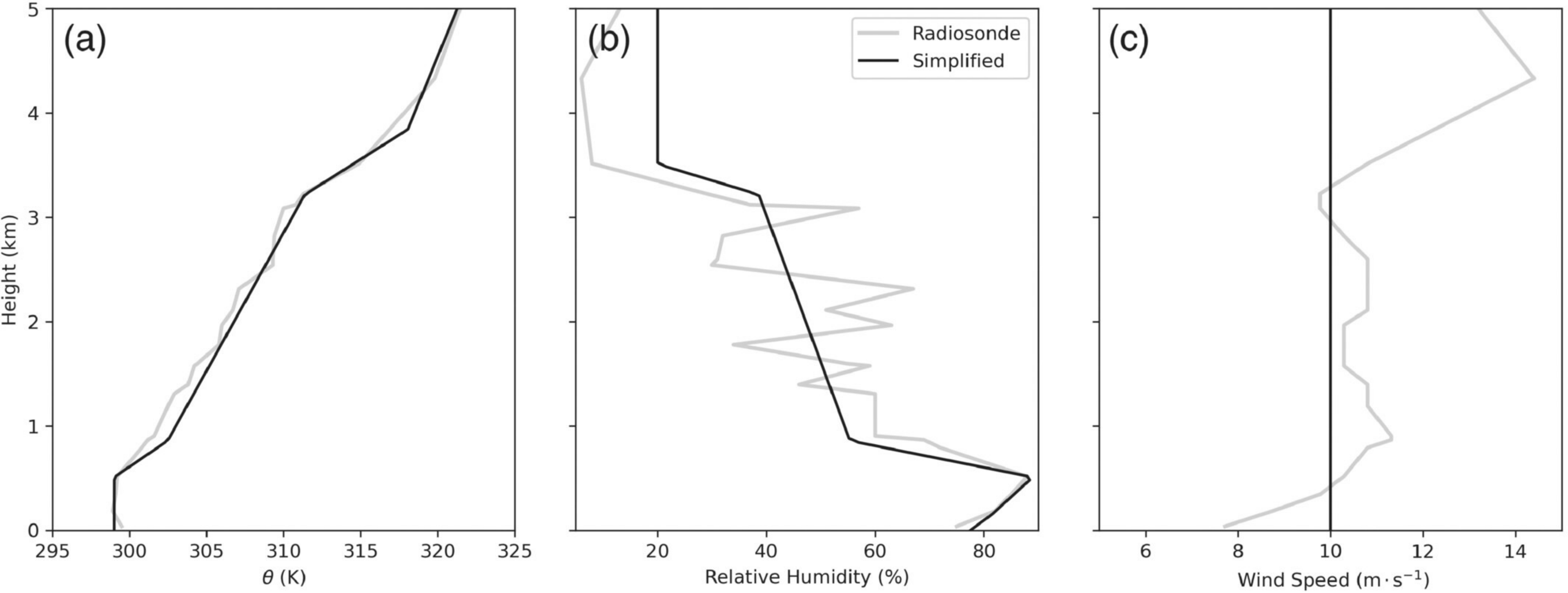
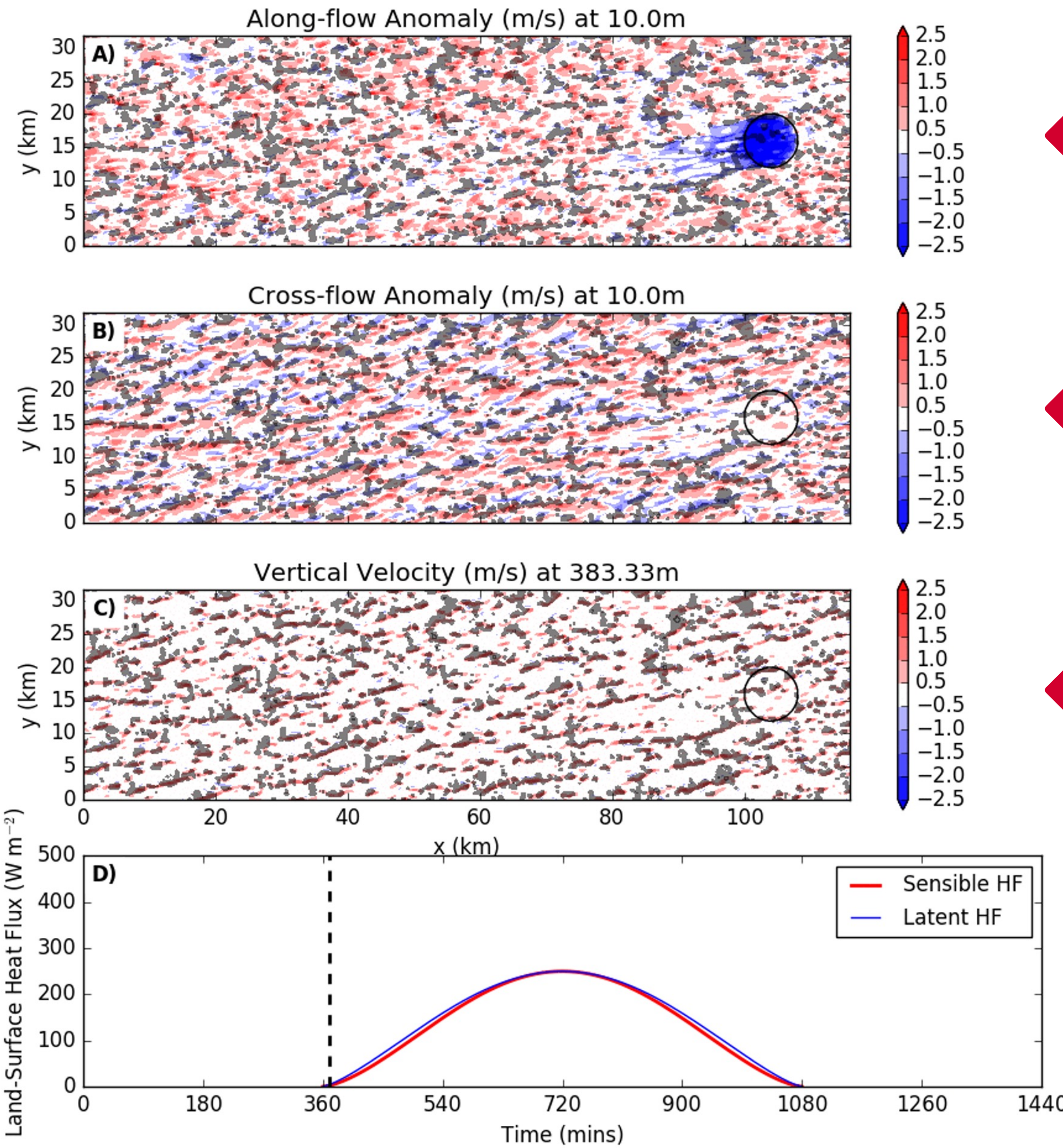


Observed profiles

Flow Relative Anomalies at T+370mins

Cloud shown in grey



Turbulent momentum transfer increases wind speed downwind

Circulation forms at leeward island edge and advects downwind

Mid-BL ascent along band coincides with the cloud band (clouds are mainly passive, not causing this ascent)

Cloud Trail Sections

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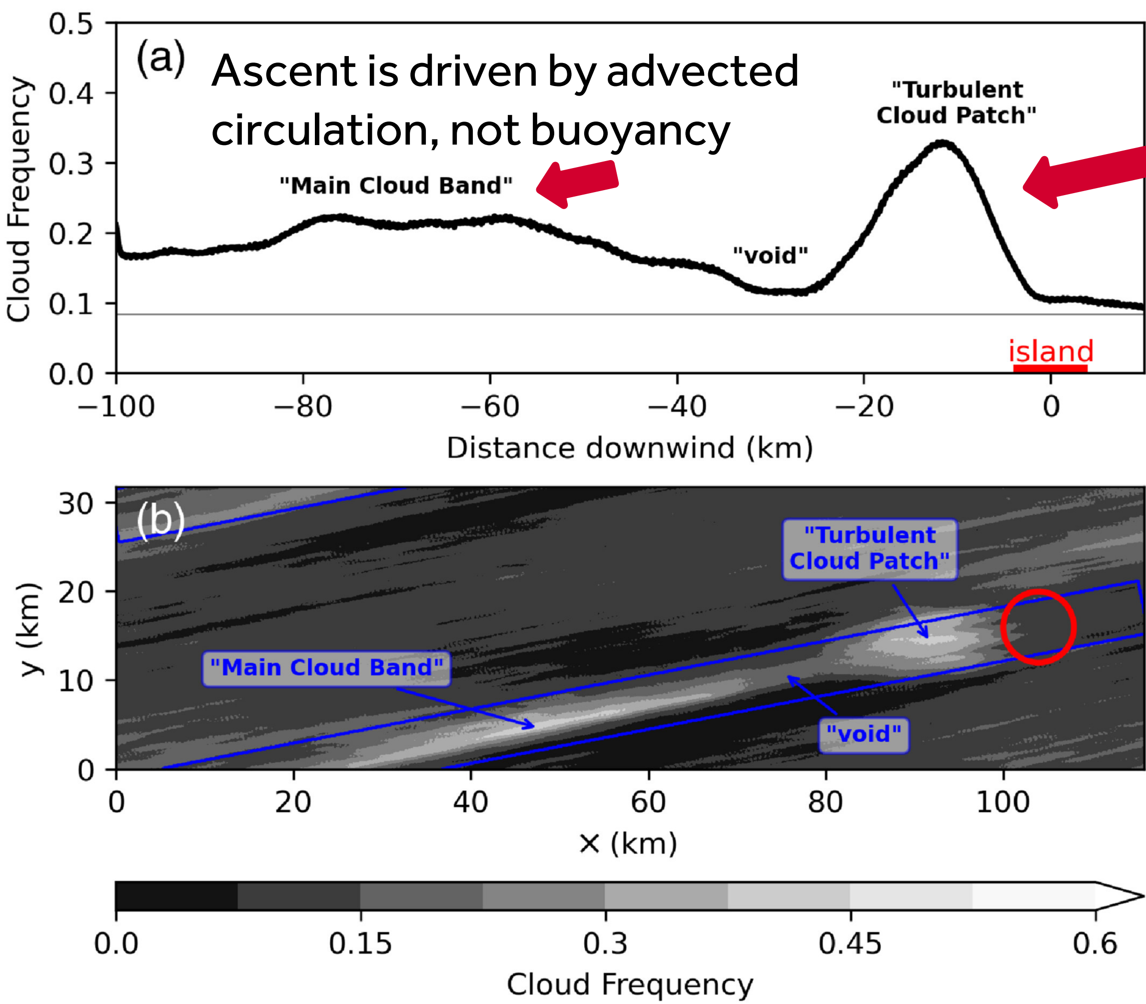
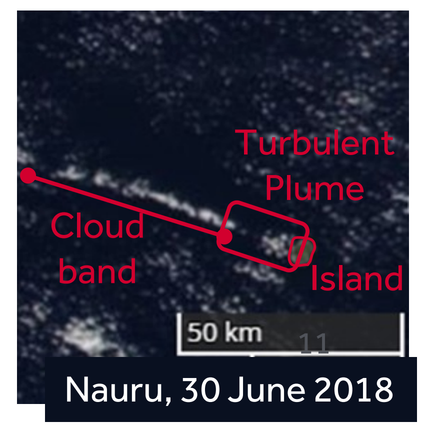
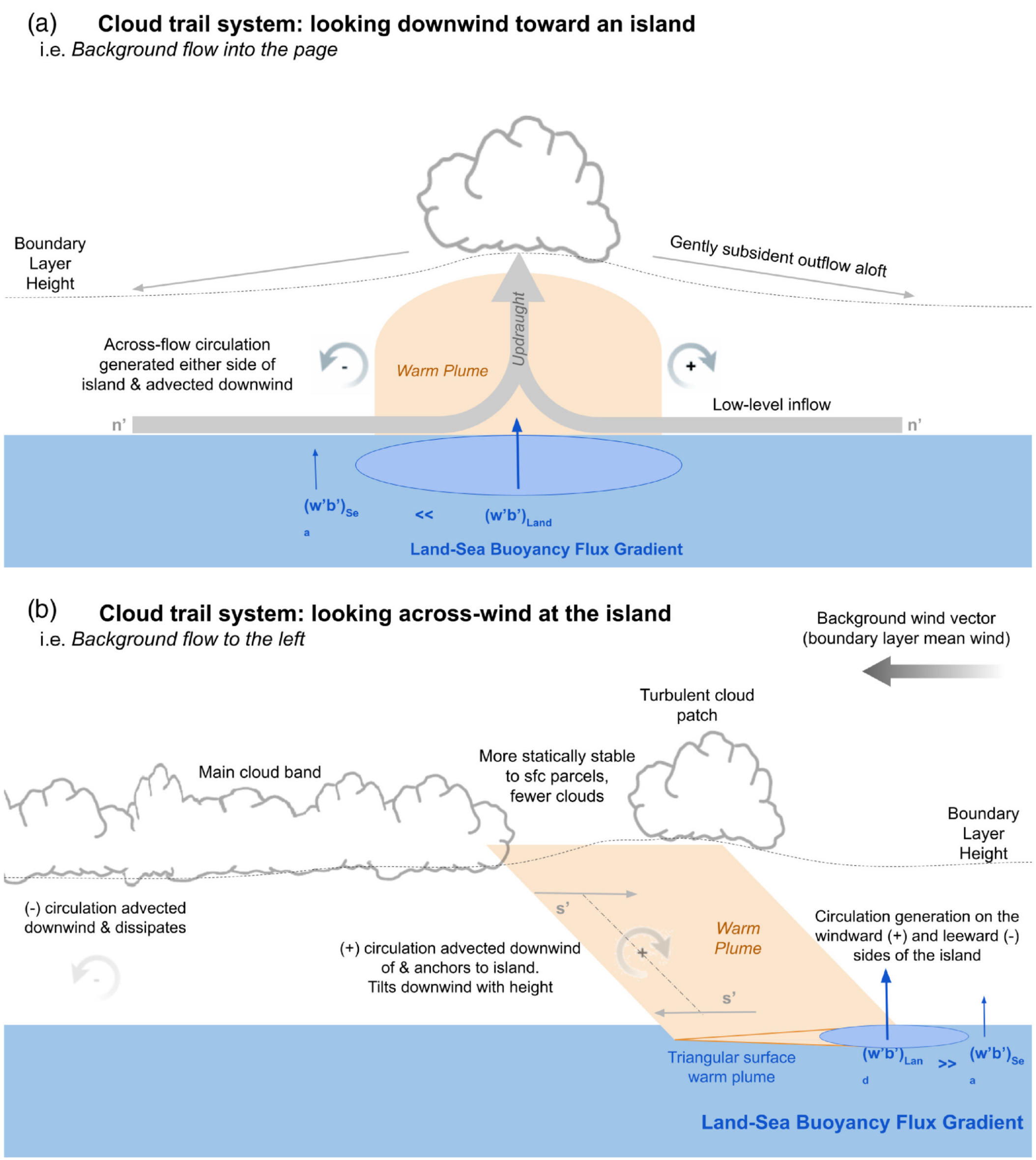


Near-surface buoyant air over island leads to clouds which are advected here



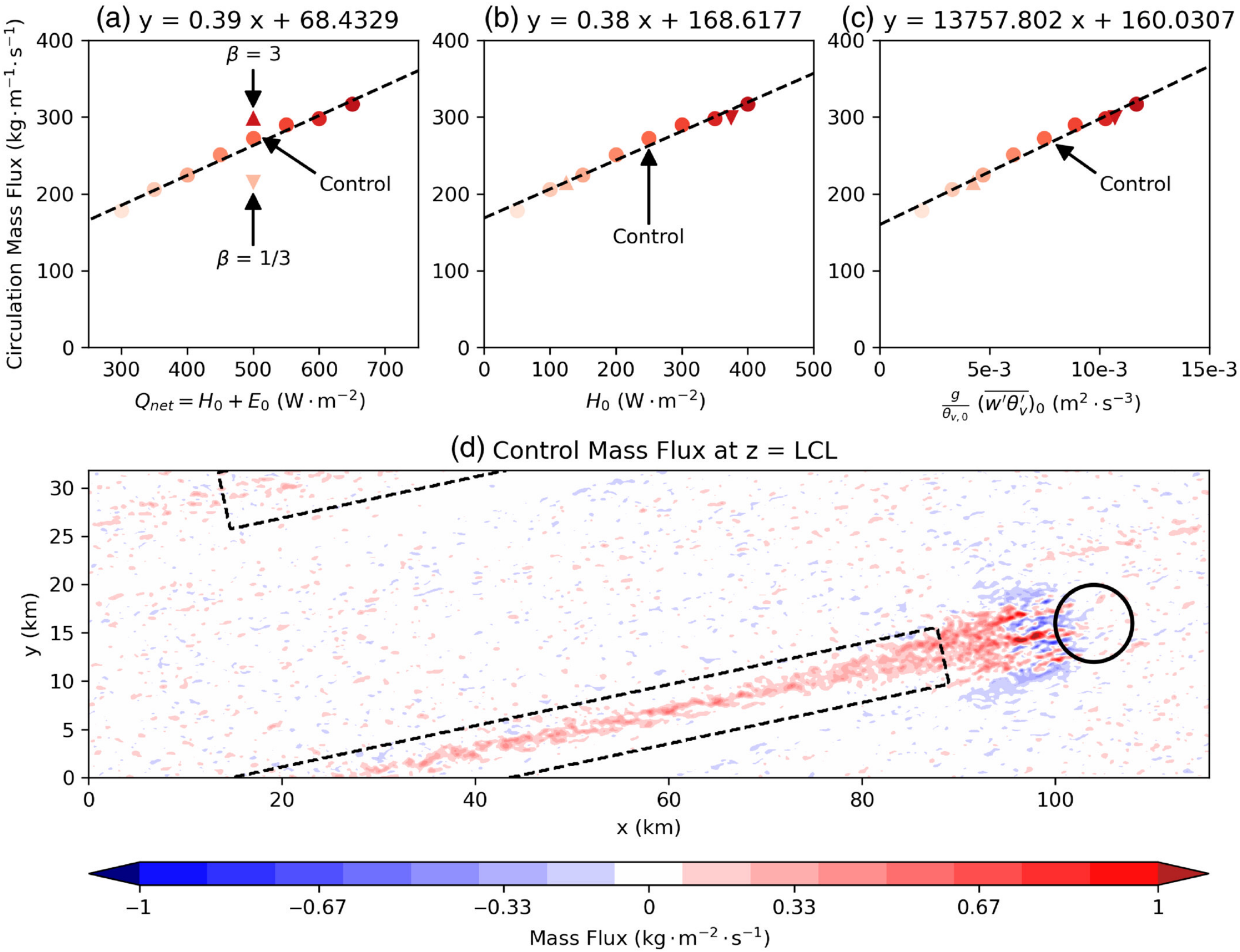
Johnston et al 2023

Cloud Trail Schematic



Johnston et al 2023

Cloud Trail strength vs. sf. flux



Johnston et al 2023

Mass flux: scaling arguments

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$$w \propto b' \Delta t = \frac{g H l_x^2}{\rho c_{pd} z_h T_0 U^2},$$

w (and mass flux) scale linearly with *H*

where H is the sensible heat flux, l_x is the island width in the along-wind direction, z_h is the boundary layer depth, ρ is the air density, c_{pd} is the specific heat capacity of dry air at constant pressure, and U is the ambient wind speed. This reflects the heating input at the surface ($H / \rho c_{pd}$) being distributed through the depth of the boundary layer (z_h) over the residence time of air over the island ($\Delta t = l_x / U$).

Note: Kirshbaum and Fairman (2015) find *w* scales with $H^{0.5}$ for Dominica, but we speculate that our assumption of a constant BL depth may not hold for larger, mountainous islands

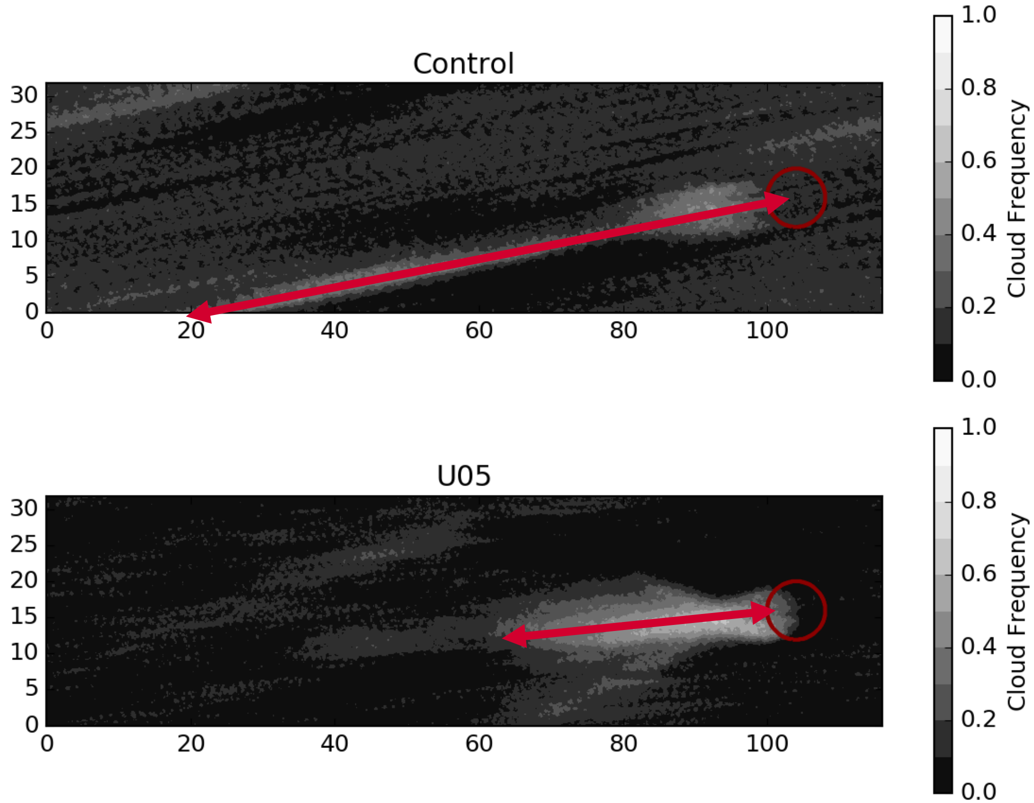
Experiments decreasing u

Initial expectations

Decreasing u increases the land-sea buoyancy contrast
- CT shorter in length
- stronger circulation
- deeper clouds

(see also: Kirshbaum and Fairman 2015)

Lower u, shorter CT



Weaker wind results in shorter CT

Lower u, more precipitation

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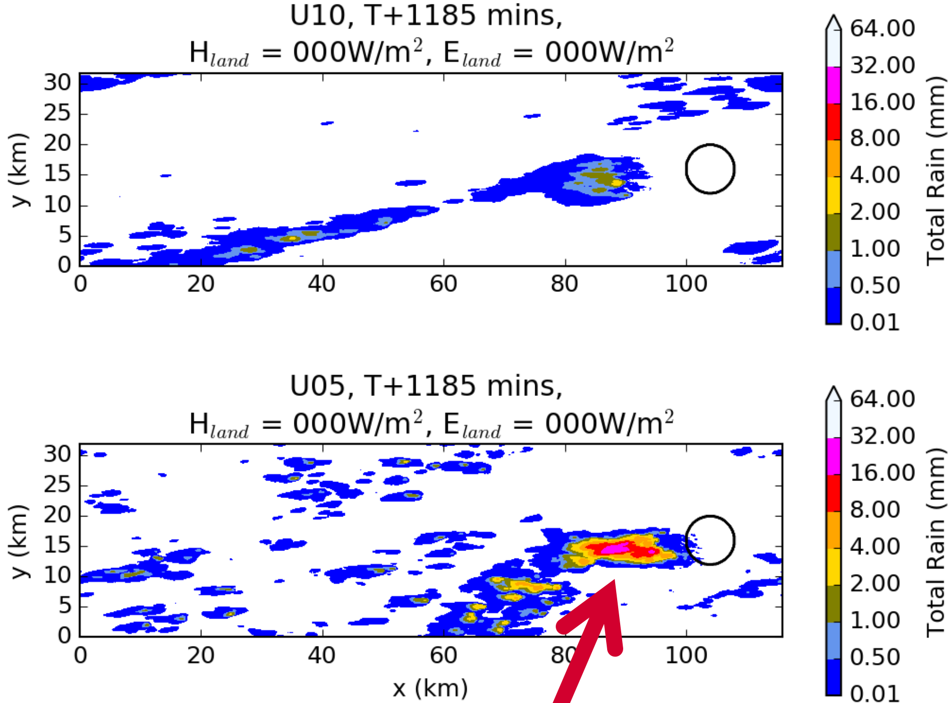

Max = 2.7 mm

Max = 31.6 mm

Nearly stationary precipitating cell leads to higher precipitation totals + cold pool

Cold pool shortens CT

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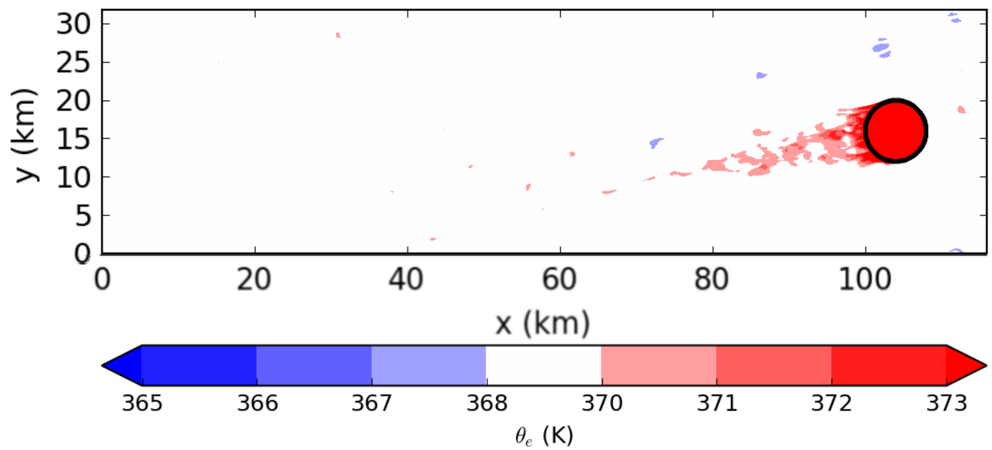
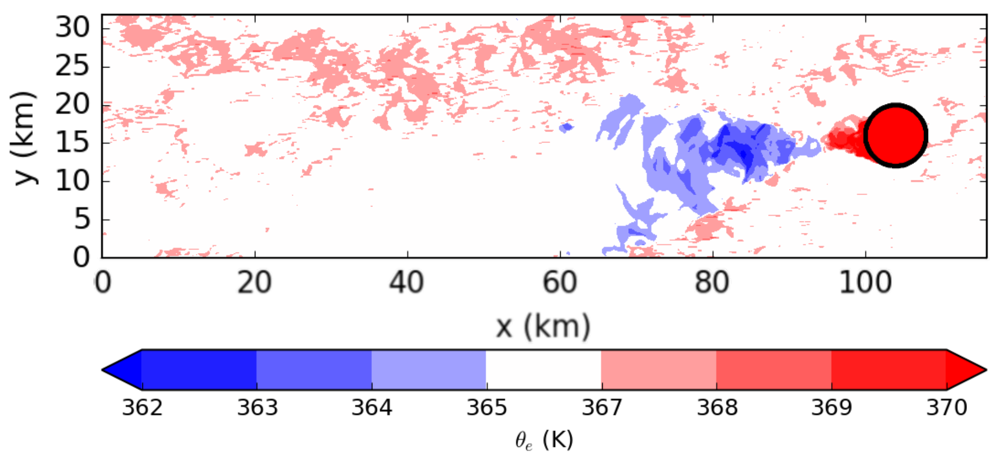
Control:
No significant cold pool



(Half mean wind) U05:
Significant cold pool



2m Equivalent Potential Temperature at 12 PM

Summary

- The cloud trail (CT) **circulation** is advected downwind (not the clouds per se).
- The CT circulation is controlled by the strength of the integrated excess heating of the flow as it passes over the island.
- This excess heating is in turn controlled by the strength of the island sensible heat fluxes, with a linear relationship between CT circulation strength and the island surface heat flux.
- The cloud contribution to circulation is generally small (clouds are passive). When there is significant precipitation, this is no longer valid.
- Lighter winds = stronger circulation + precipitation (and cold pool) which results in shorter CT.

Thank you!

Questions?