EUREC^{4}A-UK: Elucidating the Role of Clouds-Circulation Coupling in Climate

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Cloud-circulation interactions are the biggest uncertainty in climate projections

- Trade-wind cumulus clouds are ubiquitous.

  1.5 to 4.5°C spread in climate model projections: about half of this is due to tropical low clouds*.

- Aerosol, cloud and precipitation processes are sensitively coupled to the larger-scale dynamics.

Goal of Research: understand processes controlling response of trade-wind cumulus clouds to changing environmental conditions in our warming climate.

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* e.g. Bony and Dufresne 2005; Vial *et al.* 2013.

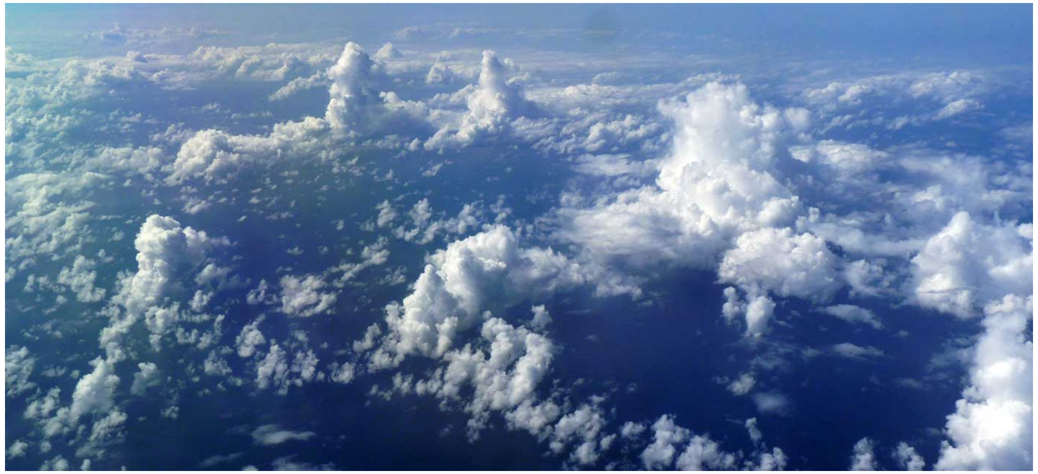
EUREC⁴A is an international initiative in support of the World Climate Research Programme's Grand Science Challenge on Clouds, Circulation and Climate Sensitivity.

How resilient or sensitive is the shallow cumulus cloud amount to variations in the strength of convective mixing, surface turbulence and large-scale circulations?

How do the radiative effects of water vapour and clouds influence shallow circulations and convection?

To what extent do mesoscale patterns of convective organization condition the response of clouds to perturbations?

And what are the implications of all of the above for how clouds respond to warming?



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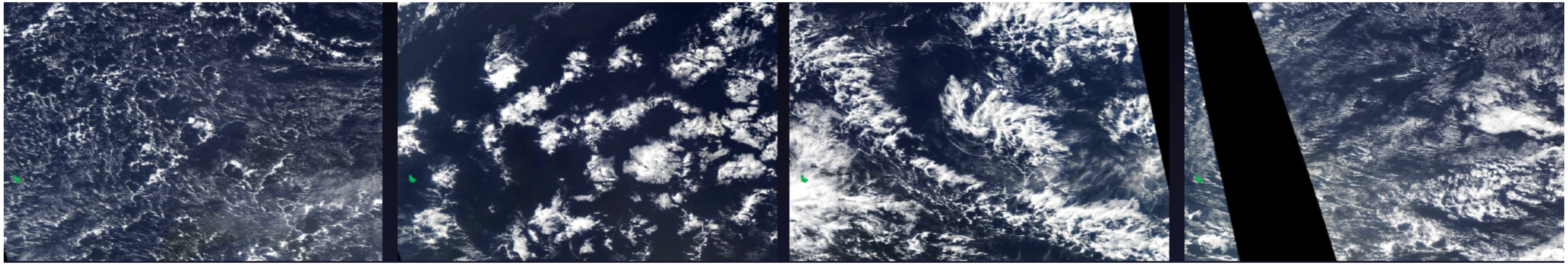
Study of boundary-layer structures and clouds, and large-scale forcing, and the two-way interactions

E.g. Influence on large-scale organisation on depth of clouds, updraft strength, intensity of rainfall and downdraft/gust front strength, and the influence of the downdrafts and gust fronts on large-scale organisation



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1. **BL and convective structures**. a) Characteristics of the structures within the boundary layer, including cold pools. b) Identify different regimes of convective organisation.

2. **Warm rain**. Determine if the warm rain process can be modelled

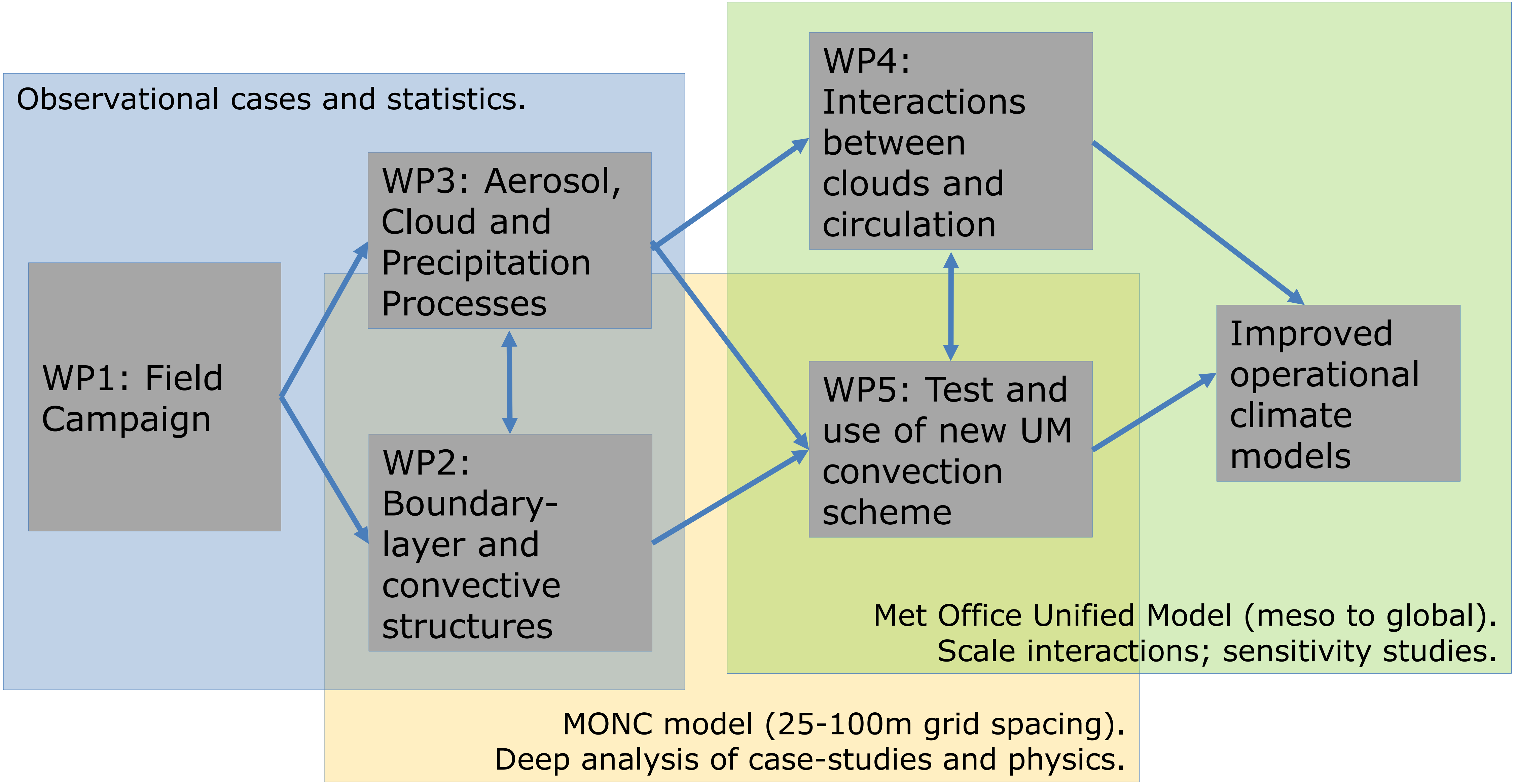
3. **Downdraughts**. Understand and model the process of formation and development of downdraughts, cold pools and gust fronts, and the production of new convection at the head of the gust front.

4. **Detrainment layers**. Quantify and simulate the geometrical shapes of cloud detrainment regions, and determine the reasons for the differences in different environmental conditions. Calculate the visible reflectance and compare with satellite measurements.

5. **Interactions between clouds and larger scales**. Determine how the cloud amount in cumulus layers responds to changes in the large-scale circulation and equally, how the cloud-scale processes influence the large-scale circulation.

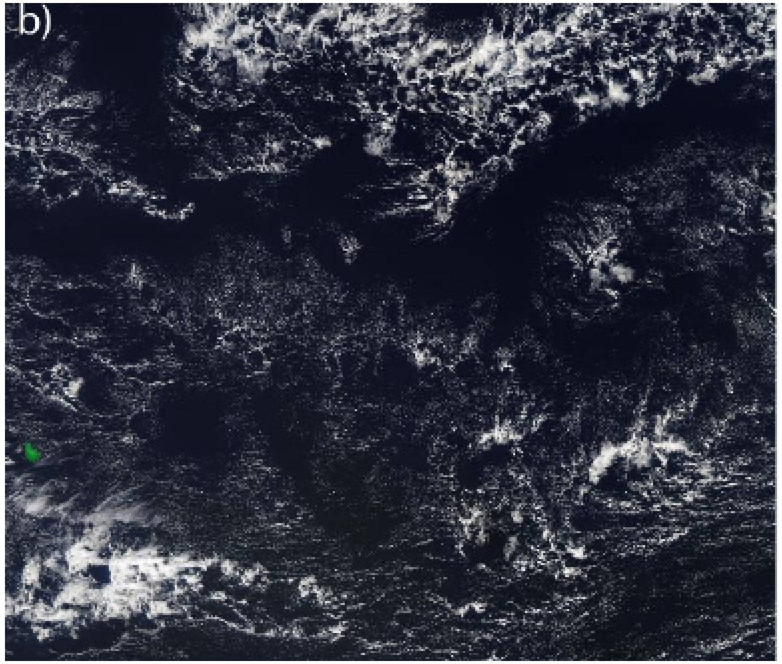
6. **Dominant physical controls of cloud fields**. Test the UM convection scheme (CoMorph) against new observations, improve parametrisations and determine the dominant physical controls on the modelled cloud fields.

Integrated structure to deliver

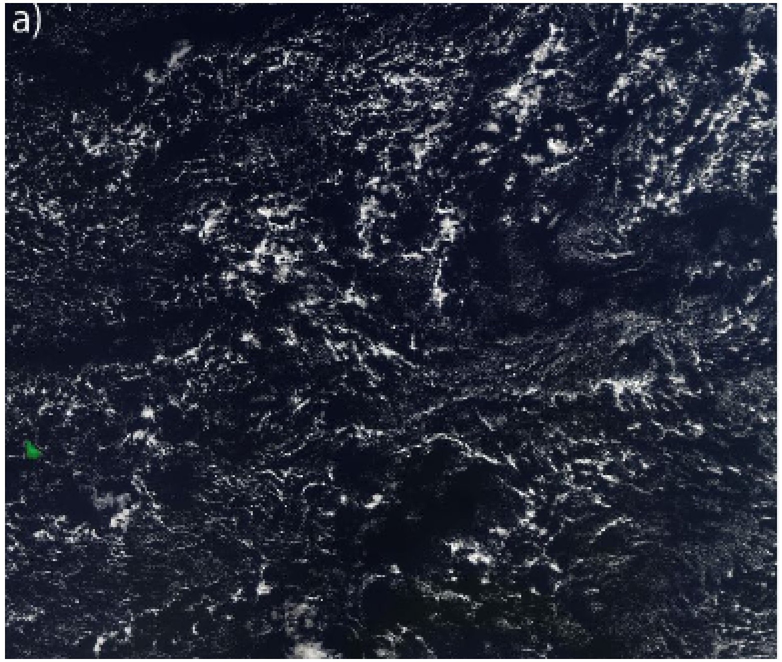


Sugar, Gravel, Fish, and Flowers: Mesoscale cloud patterns in the Tradewinds

Stevens et al, Submitted to QJ.



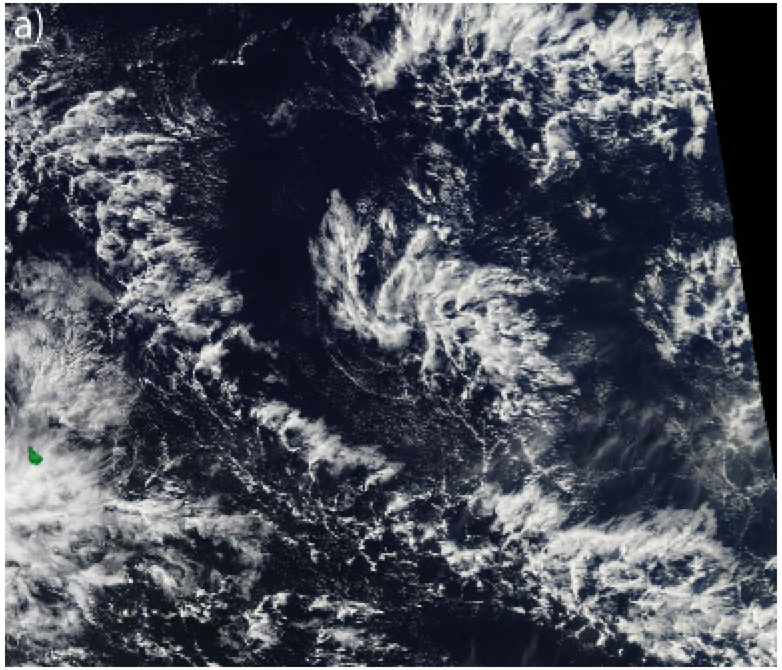
Sugar: Dusting of very fine scale clouds with small vertical extension and little evidence of self-organisation (by cold-pools or gust fronts).



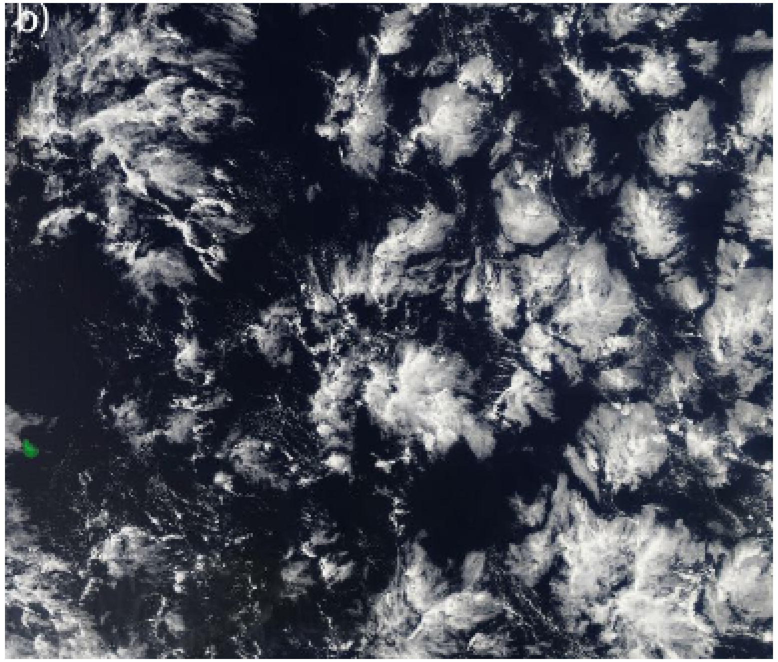
Gravel: Cloud fields patterned along meso-β (20 km to 100 km) lines or arcs defining cells with intermediate granularity, and brighter cloud elements (as compared to Sugar), but with little evidence of accompanying stratiform cloud veils.

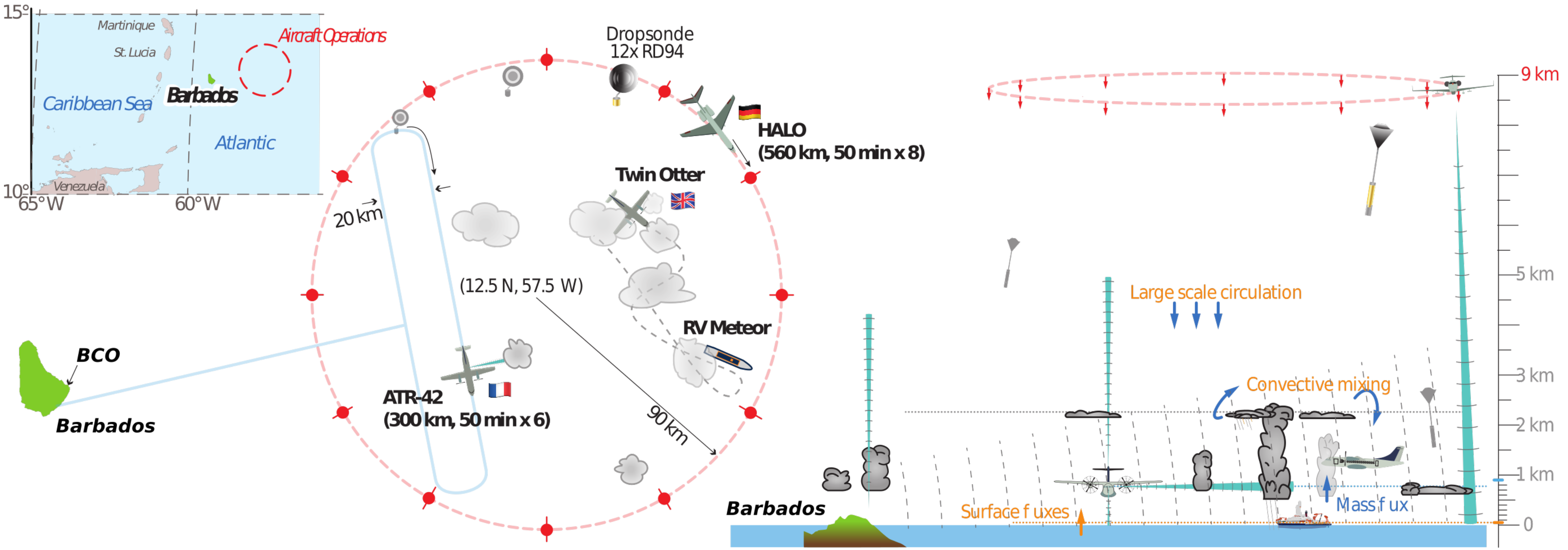
Sugar, Gravel, Fish, and Flowers (cont)

Fish: Meso-ɑ scale (200 km to 2000 km) skeletal networks (oftenfishbone-like) of clouds separated from each other, or from other cloud forms, by well defined cloud free areas and sometimes accompanied by a stratiform cloud shield.

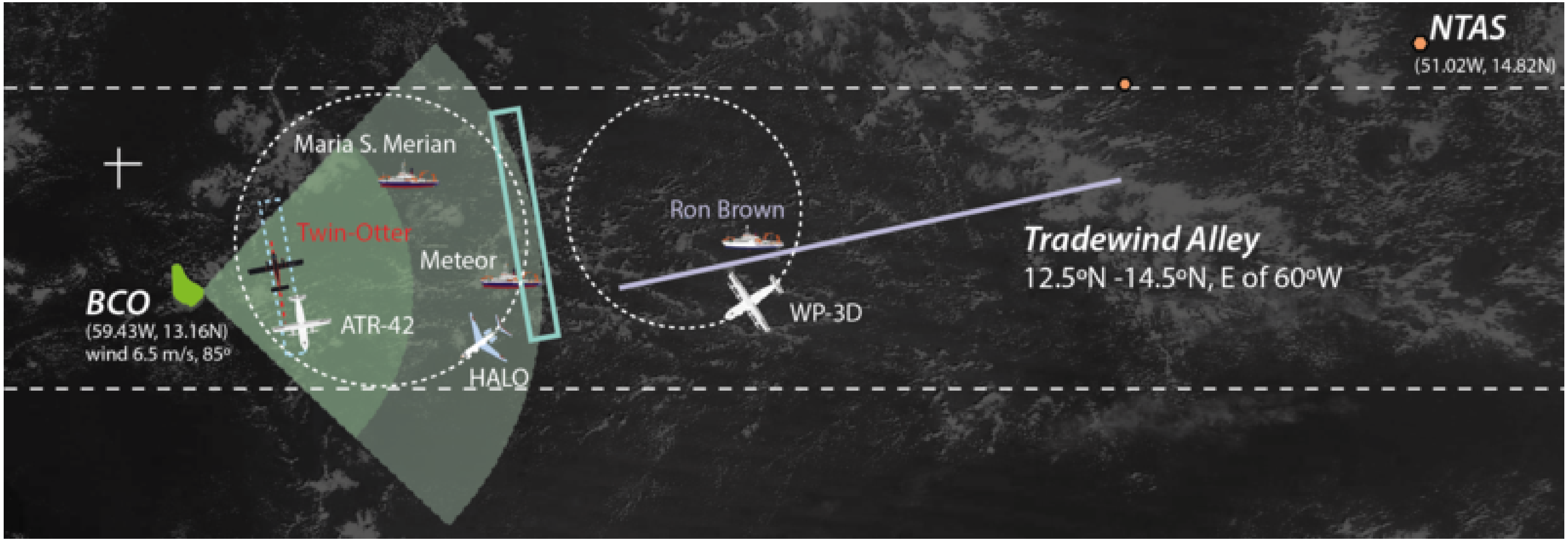


Flowers: Irregularly shaped meso-β scale (20 km to 200 km) stratiform cloud features, often with higher reflectivity cores, and appearing in quasi-regular spaced bunches (hence the plural) with individual features well separated from one another by regions devoid of clouds.



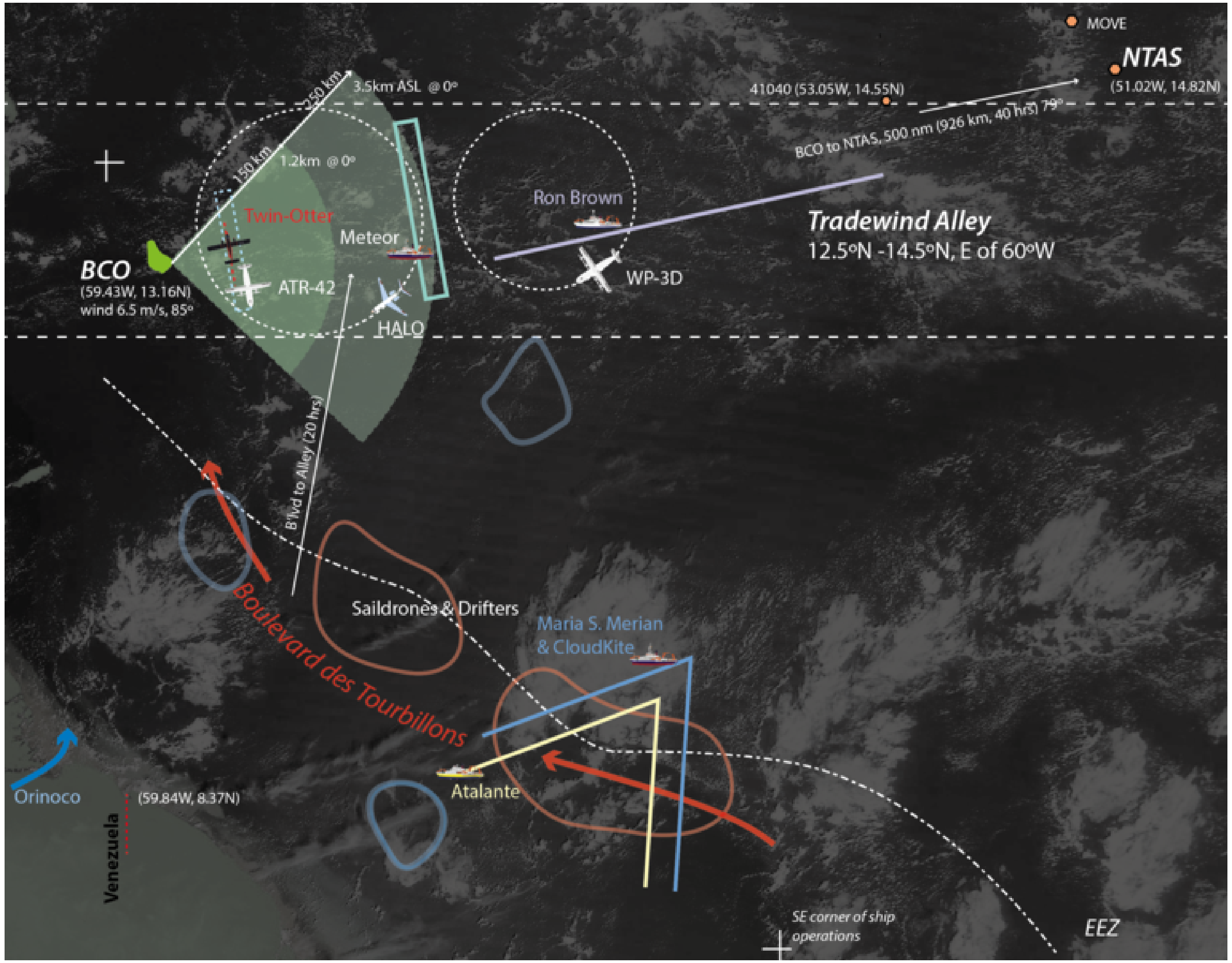


- Microscale processes observed.
- Statistical sampling of many clouds.
- All scales will be well constrained: for the first time.



Area of field operations, showing 'Tradewind Alley' the central measurement area in a semi-circle defined by the Barbados-based Polarized C-Band Radar, PolidiRad.

Project builds on a decade of measurements in the tropical Atlantic at the Barbados Cloud Observatory, and on two aircraft campaigns with HALO: NARVAL in December 2013, and NARVAL2 in August 2016



The measurements will be complemented by additional ship-board measurements from the R/V L'Atalante abd R/V Maria S. Merian, as well as a wide array of auntonomous vehicles (drones). Both the NOAA WP-3D and the R/V Ron Brown will participate as part of the NOAA funded ATOMIC project.

Flight plans. Points to consider.

1. Include a profile except perhaps in the BL-focus flights. Time is a factor.

2. Divide flights into two categories of sampling and three vertical regions. Suggest we focus on one region per flight.

3. It may be possible to have two flights per day: e.g. first of 4 hrs and second 3 hrs.

Categories.

1. Study of "single cloud": e.g. for flowers, but also for developing clouds in other regimes
2. Quasi-statistical flying, in more-or-less straight line, but diverting to target clouds

Flight plans. Points to consider.

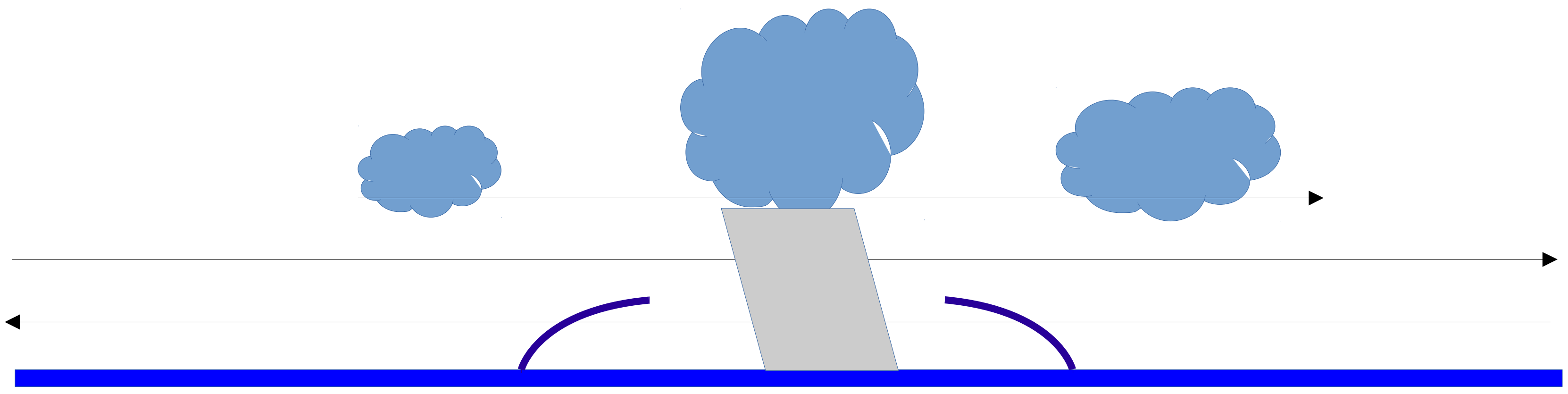
Regions.

1. **Sub-cloud layer** for BL structures, precipitation shafts and gust fronts; include 1 leg just above cloud base to determine concentration of cloud drops.

2. **Cloud layer** for the development of warm rain, the development of downdrafts and general properties of the clouds (e.g updraft structure, vertical profile of lwc and Nd); include one leg just below cloud base for aerosols (CCN) and information on cloud base.

3. **Detrainment layers** -- include a leg just below cloud base, and one leg just above for aerosols and Nd, respectively. Also include 1 leg just below the detrainment layer if possible, near to cloud top to measure drop size distribution.

Sub-Cloud layer



1. Profile ascent out of Barbados followed by descent to lowest level. (30 mins?) [Suggest missing out sounding since there will be so many soundings made and aerosol profile not so important for this region. Time is precious.]

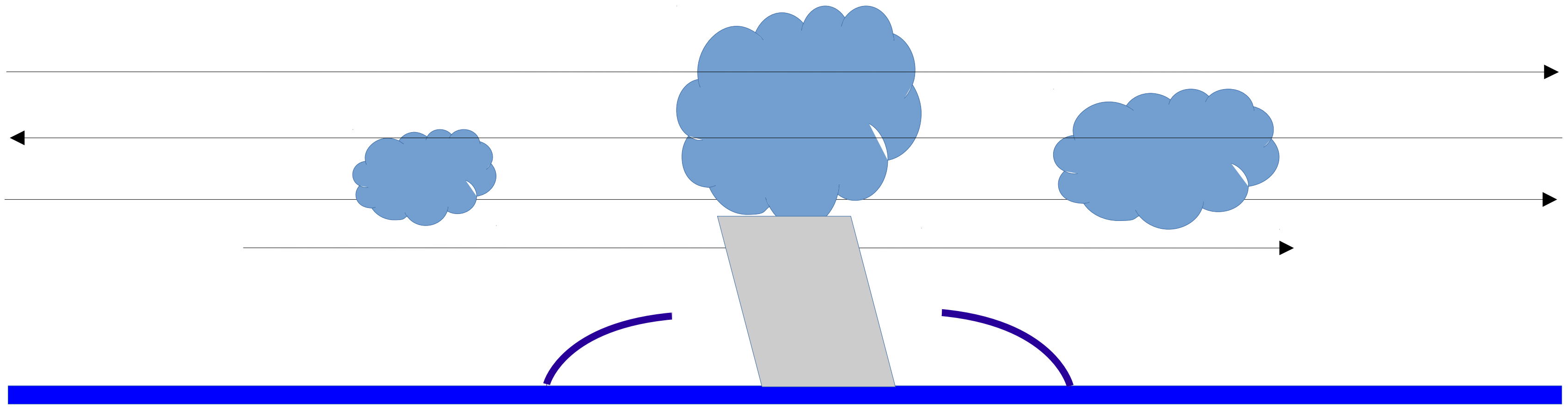
Choose appropriate direction... e.g. perpendicular to fish direction, or with prevailing wind. Distances below can vary, of course.

2. 100-km leg just below cloud base (30 mins; 1 hr)
3. 50-km leg just above cloud base (15 min; 1 hr 15 mins)
4. 100-km leg just above the sea surface -- lowest level (30 mins; 1 hr 45 mins)
5. 100-km leg at mid-level of BL (30 mins; 2 hrs 15 mins)

Repeat BL passes perpendicular to the wind? (1 hr 15 mins; 3 hrs 30 mins).

Alternatively:
1. Possibility of targetting gust fronts or precipitation shafts and making repeated passes. Decision for doing this should be taken when a good phenomenon is encountered, rather than chase the rainshaft for example.
2. Same orientation but adding more levels in the BL

Cloud layer



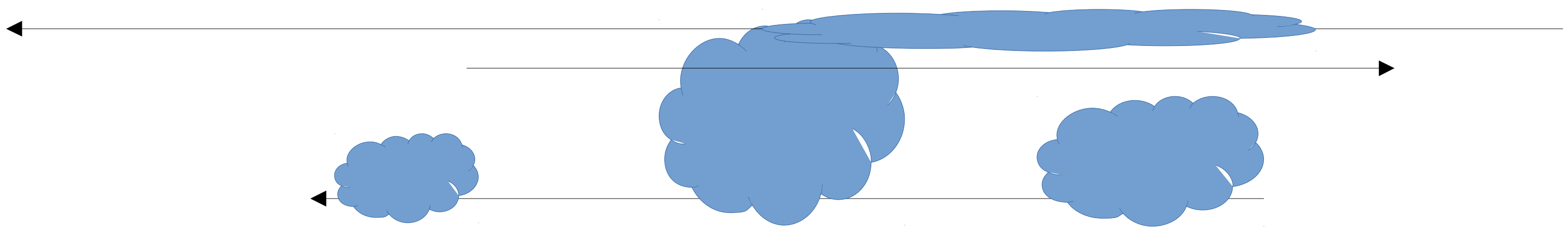
1. Profile ascent out of Barbados followed by descent to lowest level. (30 mins?)

2. 50-km leg just below cloud base (15 mins; 45 mins)
3. 100-km leg just above cloud base (30 min; 1 hr 15 mins)
4. 100-km leg at mid-levels (30 mins; 1 hr 45 mins)
5. 100-km leg near cloud top (30 mins; 2 hrs 15 mins)

Repeat mid-level and cloud top passes perpendicular to the wind? (1 hr 15 mins; 3 hrs 30 mins).

Alternatively:
1. Possibility of targetting specific clouds and making repeated passes; developing clouds. Decision for doing this should be taken when a good phenomenon is encountered, as above), rather than chase the clouds.
2. Descend to work in BL

Detrainment layers



1. Profile ascent out of Barbados. (15 mins?)

2. 50-km leg just below cloud base (15 mins; 30 mins)
3. 50-km leg just above cloud base (15 min; 45 mins)
4. 50-km leg just below detrainment layer (15 min; 1 hr)
5. Legs in detrainment layers (2 hrs 30 min; 3 hrs 30 mins) as below:

a. Flowers:
Target individual cloud -- multiple passes through the detrainment layer and in clear region in several directions to measure geometry

b. Fish:
Make passes almost perpendicular to the arc, zig-zagging down the spine

c. Gravel:
Target clouds and make multiple passes in several directions; if there are many clouds -- possibly do quasi-statistical flying

EUREC4A-OA

Both shallow convection and its mesoscale signature are thought to influence and be influenced by their interaction with the ocean.

Ocean mesoscale eddies strongly affect the ocean surface heat budget and therefore SST.

They are ubiquitous in the ocean - increasing evidence that associated dynamical processes drive SST anomalies

These in turn impact the air-sea exchanges and the overlying atmosphere (wind, clouds, rainfall).

Preliminary results from satellite and in-situ data: in Tropical Northwest Atlantic, ocean eddies are massive heat reservoirs that capture the fresh waters of the Amazon and Orinoco rivers.

EUREC^{4}A–iso

The aim is to investigate the distinct isotope signature associated with different boundary-layer moistening and drying processes and their relation to the macroscale cloud properties under different large-scale flow configurations.

Complete characterization with isotope measurements in water vapour, precipitation and ocean water using ship, aircraft and ground-based instrumentation.

The complementing modelling efforts involve isotope-enabled numerical model simulations at the global, regional and LES scales.

EUREC^{4}A - Wind

The trade winds are important because they modulate e.g. turbulent fluxes at the ocean surface and SSTs

The winds in turn can be modulated by clouds and convection, via momentum transport, or via cloudiness and the surface energy fluxes, which regulate turbulence near the surface. These processes may act to slow down large-scale winds -- CloudBrake!

-- better understanding of the coupling of winds, convection and clouds and their importance for weather and climate prediction

-- tackles the lack of wind profile and wind flux measurements over open ocean

-- foster collocated wind, cloud and solar radiation measurements to address offshore renewable energy potential.

ATOMIC -- Atlantic Tradewind Ocean–Atmosphere Mesoscale Interaction Campaign

Investigate atmospheric shallow convection and air-sea interaction needed to improve understanding and prediction of the impacts of shallow convection on weather and climate conditions on the U.S.

Aircraft

HALO -- (17 Jan - 17 Feb; 12 9-hr flights); large (200 km diameter) circle patterns over a fixed spatial location, upwind of the BCO to define the environment of the shallow convection; 72 dropsondes per flight; continuous remote sensing will characterize the large-scale environment and cloud field. Cloud Radar; radiometers; Lidar; SMART (radiation); specMACS; IR Imager; Dropsondes; Broadband radiometers; Aircraft state variables

ATR-42 -- 2 4-hr flts per day; low-level legs (~100 km) in sub-cloud layer and cloud layer, especially just above cloud base (~ 1 km). Legs spaced by about 20 km.
Sideways and vertical-pointing lidar and radars -> cloud fraction at cloud base.
Characterize turbulence structures in subcloud-layer.
Microphysics; RASTA Radar (up and down); BASTA Radar (side looking bistatic FMCW); AliAS Lidar (10 km range); CLIMAT CE332 (SST); upwelling and downwelling long and short-wave radiation; high-resolution side-looking camera; Picarro (isotopic ratios of Oxygen-18 and Deuterium)

Aircraft (cont)

WP-3D Orion (NOAA; ATOMIC) -- 100 flight hours, 15 Jan - 15 Feb to provide atmospheric and oceanic context to the observations of the Ron Brown; link the upwind environment being sampled by the ship and NTAS buoy, to the nearer-shore measurement area.
AXBT (ocean tempr); tail Doppler X-band radar; dropsondes; microwave radiometer; cloud probes; Ku-band wave radar; W-band cloud radar; Stable water isotopologue measurements; Radiometer (SST)

Ships

Research Vessel L'Atalante -- south of Barbados in the North Brazil Current eddy corridor; E.g
Met, 2-6 soundings per day, cloud camera, ceilometer, UAVs (e.g. BC)

Research Vessel Maria S Merian -- in regions where strong mesoscale ocean eddies are identified; a second objective is to use state-of-the art Largrangian cloud measurements with a CloudKite carrying advanced microphysical instrumentation; E.g. UVP (particles and plankton), X-band radar, cloud radar (W, FMCW), micro-rain radar, disdrometer, met, sondes

Ships

Research Vessel Meteor -- eastern (upwind-edge) of the HALO circles; track will consist of a 2-day, wind-perpendicular, race-track patterns across Tradewind Alley. E.g. Met and cameras, Soundings 6-12 times per day, cloud radar, radiometer, Raman lidar, Cloud kite, wind lidar, eddy covariance, uavs (particle sizing)

Research Vessel Ronald H. Brown -- ATOMIC; 6 Jan -13 Feb; focus on air-sea interaction with an emphasis on the mesoscale, primarily operating in the area between the R/V Meteor (upwind of Barbados) and the NTAS buoy near 51 ºW. Soundings 4 times per day. E.g. Doppler lidar, air-sea fluxes, radiometers, unmanned aerosol systems, cloud radar, ceilometer, in-situe aerosol

Ground-based measurements

Barbados Cloud Observatory -- Raman lidar, upward-looking Ka-band and W-band radars, two Doppler wind lidars, microwave radiometer, micro-rain radar, ceilomoter, disdrometer, CCN and aerosols, radiation (Pyranometer, Pyrgeometer and Pyrheliometer), pressure, temperature, humidity, precipitation, wind speed and wind direction, fish-eye camera and webcam movies.

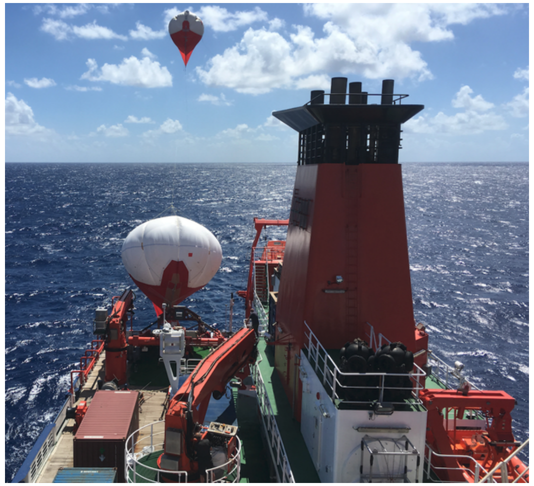
Ragged Point Observatory -- Manchester aerosol measurements (Keith)

Miscellaneous

PoldiRad Radar -- will be installed approx 8 km WNW of the BCO in December 2019 and will operate throughout the EUREC4A field campaign until July 2020.

CloudKite -- Two Max Planck CloudKites (MPCK) to probe atmospheric boundary layer, clouds and cloud-turbulence interactions (up to 2 km).

MPCK+ from R/V Maria S. Merian to measure cloud microphysical and turbulence properties.



The mini-MPCK will be flown from the R/V Meteor and focus on cloud and sub-cloud layer profiling. E.g. LWC, CDP, 3D-winds, and MPIDS Holographic system -- 3D particle position and size distribution, 75Hz

Miscellaneous (cont)

Boréal UAV -- one six-hour flight per flight day; multi-hole 3D wind and turbulence probe, particle counter and number size distribution, altimetry radar (wave height), temperature of sea surface, downwelling broadband solar radiation, pressure / temperature / humidity and real-time video

Caravela, an Autonaut (piloted remotely from UEA) -- determine air-sea fluxes of heat and momentum.
Three Seagliders will be deployed, one from Caravela and two from R/V Meteor, to measure vertical fluxes throughout the ocean boundary layer.
Met instruments
- incoming longwave radiation between 5 µm and 30 µm;
- wind speed and direction and air temperature
- humidity and temperature

Impact Plan

EUREC^{4}A-International

EUREC^{4}A-UK

Field campaign

IPCC and community

Met Office Hadley Centre
NCAS

Governments
Business
NGOs
Public

Operational forecasting

Caribbean Meteorological Agency (CMO)

Improved models

Workshops:

- High-impact weather prediction.
- Increased resilience to climate change.
- Forecaster training resources .

Dominica: Christmas Eve flooding, 2013: A warm-rain event.