Elucidating the coupling between clouds and circulation: The EUREC^{4}A field campaign

Sandrine Bony
LMD, CNRS, Paris, France

Bjorn Stevens
MPI, Hamburg, Germany

David Farrell
CIMH, Bridgetown, Barbados

and many more

ECMWF, 11 June 2019

EUREC^{4}A: A field campaign to elucidate the couplings between clouds, convection and circulation

Sandrine Bony · Bjorn Stevens · Felix Ament · Sebastien Bigorre · Patrick Chazette · Susanne Crewell · Julien Delanoë · Kerry Emanuel · David Farrell · Cyrille Flamant · Silke Gross · Lutz Hirsch · Johannes Karstensen · Bernhard Mayer · Louise Nuijens · James H. Ruppert Jr. · Irina Sandu · Pier Siebesma · Sabrina Speich · Frédéric Szczap · Julien Totems · Raphaela Vogel · Manfred Wendisch · Martin Wirth

Surv. Geophysics (2017) www.eurec4a.eu

Outline

- Motivations
- EUREC^{4}A experimental strategy
- How could NWP benefit from EUREC^{4}A?
  How could EUREC^{4}A benefit from NWP?


How sensitive is the Earth's climate?

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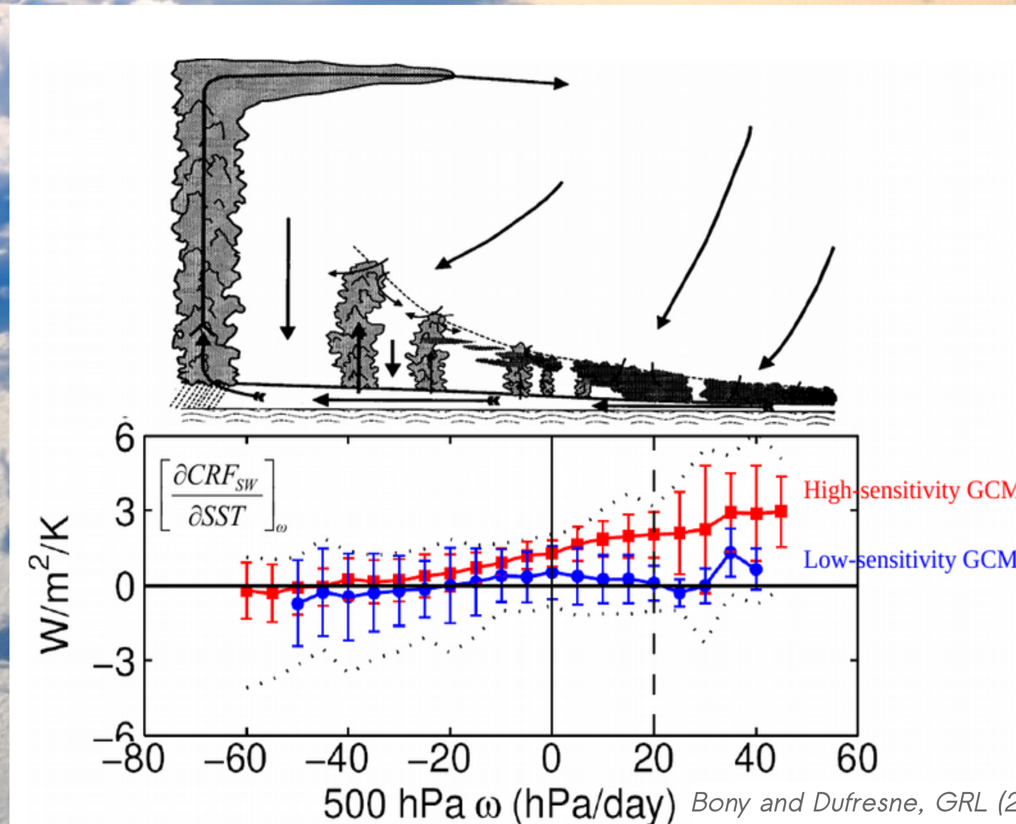

Bony and Dufresne, GRL (2005)

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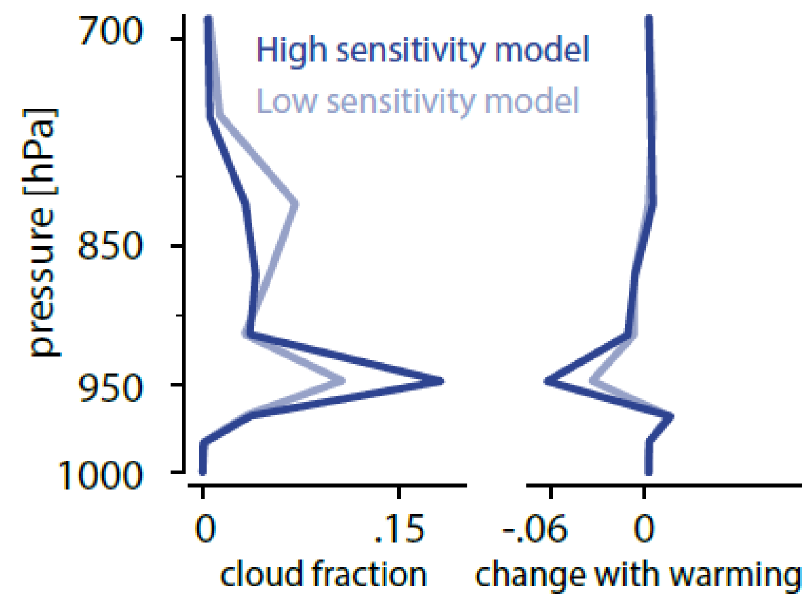
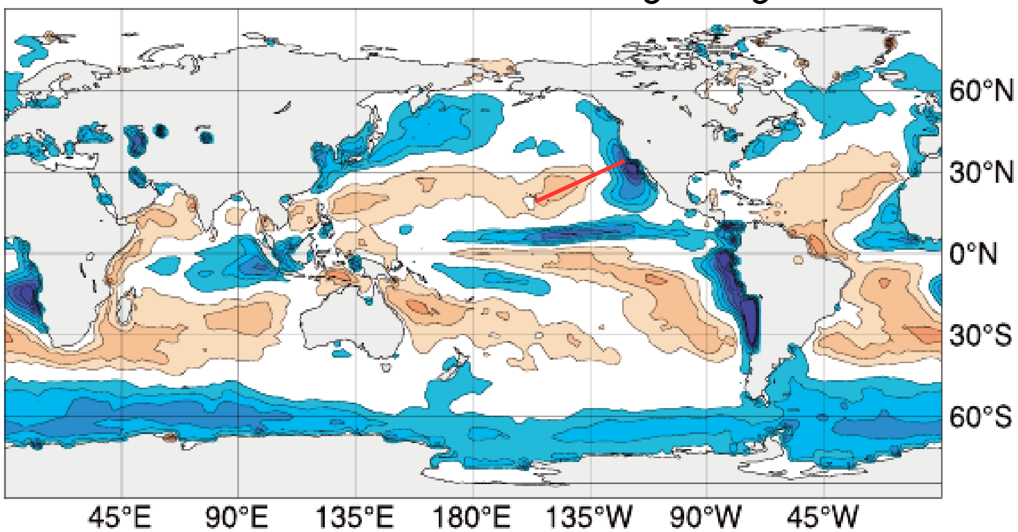


High climate sensitivity models predict a dessication of clouds at their base, that depends on the strength of vertical mixing im the lower troposphere

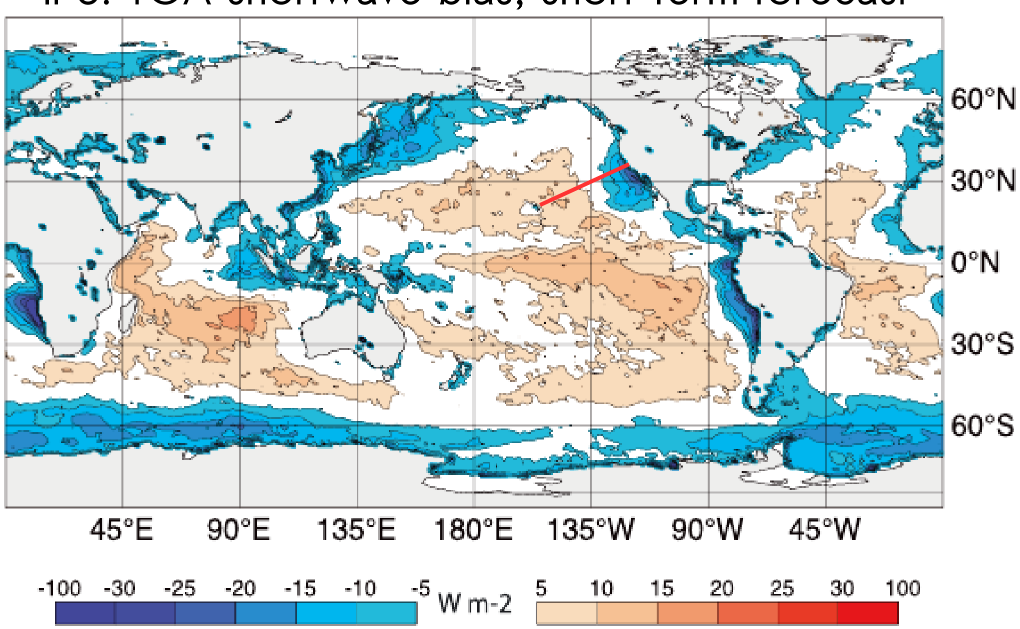
Rieck et al. (2012), Bretherton et al. (2013), Brient and Bony (2013) Sherwood et al. (2014), Zhao et al. (2014), Gettelman et al. (2014), Brient et al. (2016), Stevens et al. (2016), Vial et al. (2016, (2017)

Tradewind clouds: also a challenge for NWP and satellite retrievals

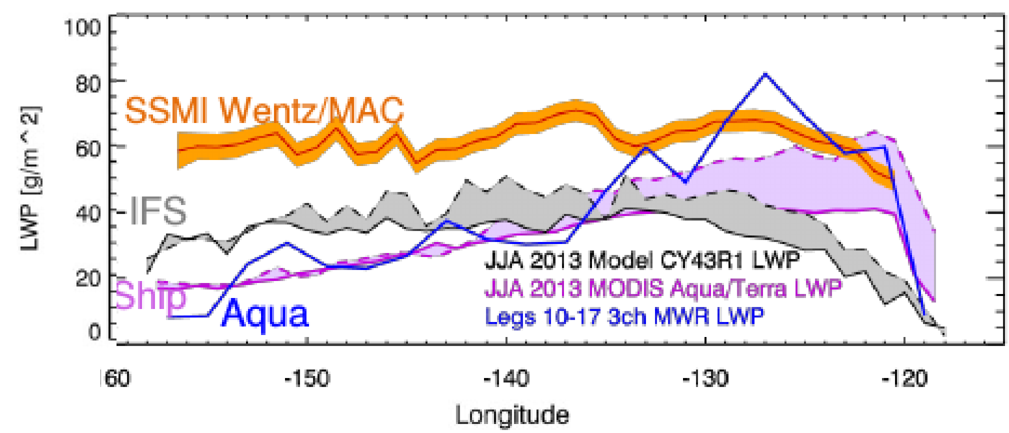
IFS: TOA shortwave bias, long integration



IFS: TOA shortwave bias, short-term forecast

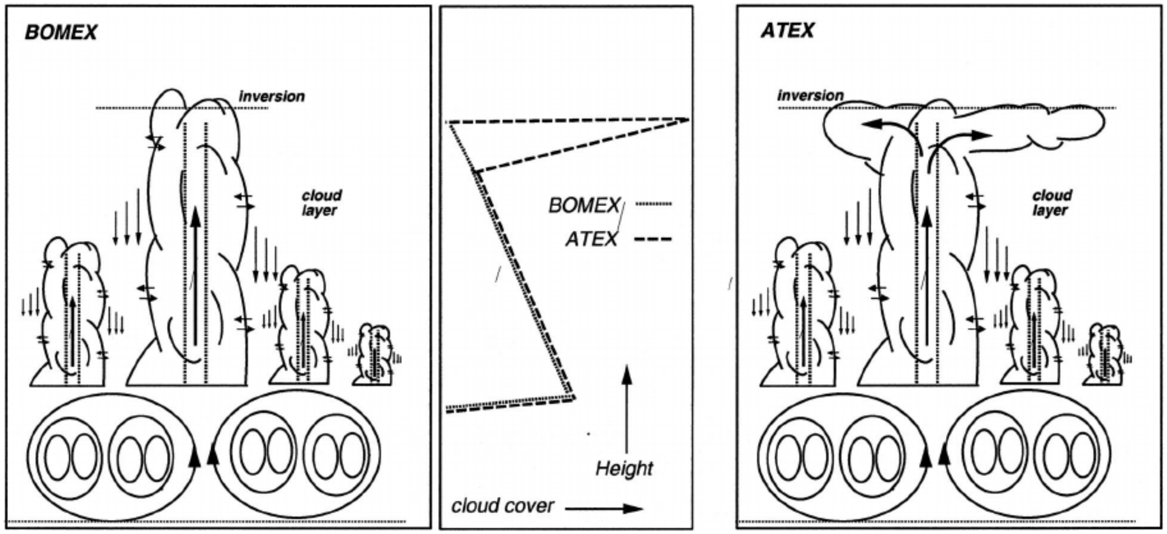


Comparison of IFS LWP with satellite retrievals and ship-based MWR data along the MAGIC ship track

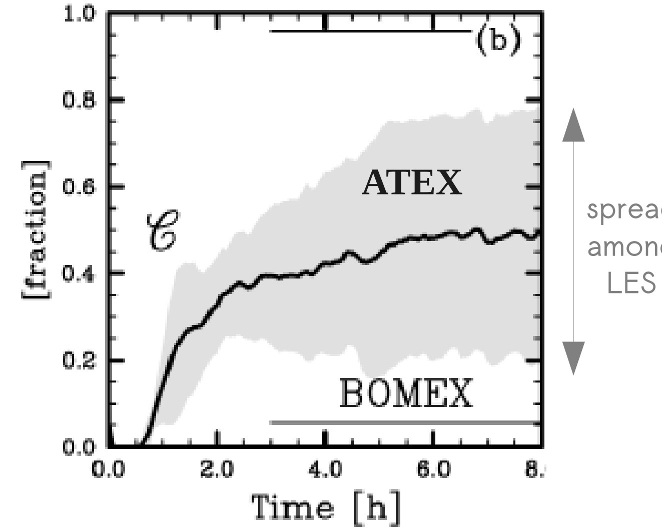


Ahlgrimm, Forbes, Hogan and Sandu, JAMES (2018)

Guides for Progress: Field Campaigns and Large-Eddy Simulations

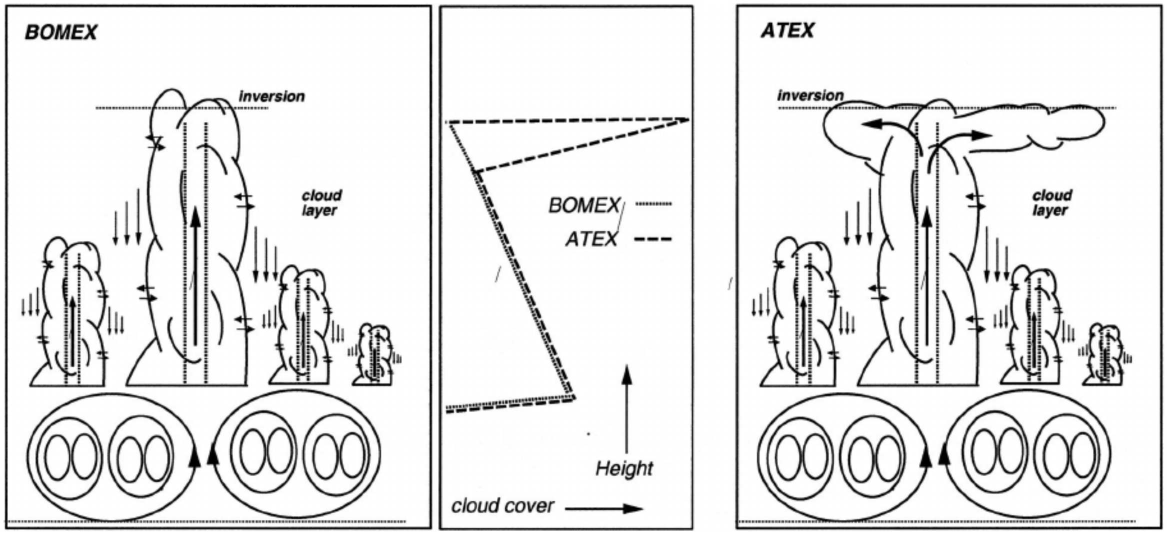


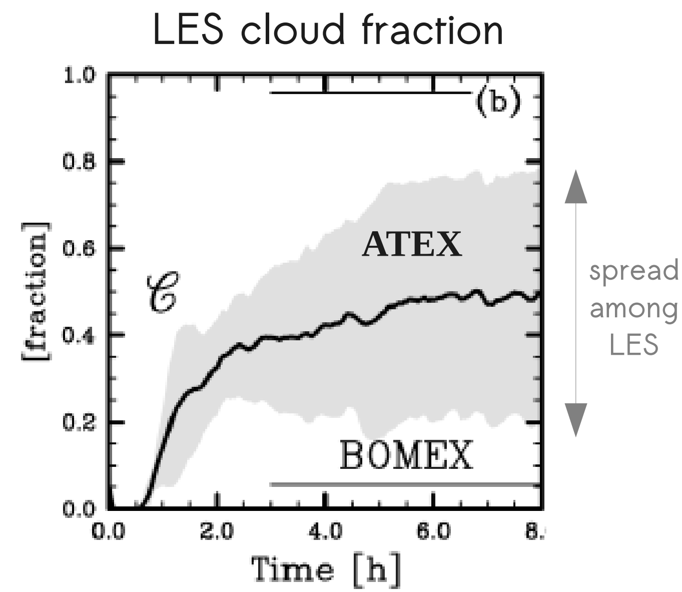
LES cloud fraction



Stevens et al. (2001), Siebesma et al. (2003), van Zanten et al. (2011)

Guides for Progress: Field Campaigns and Large-Eddy Simulations





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- Cloud properties from LES are not necessary the truth.
- How do clouds vary with the large-scale environment? (e.g. ω, lower-tropospheric mixing)

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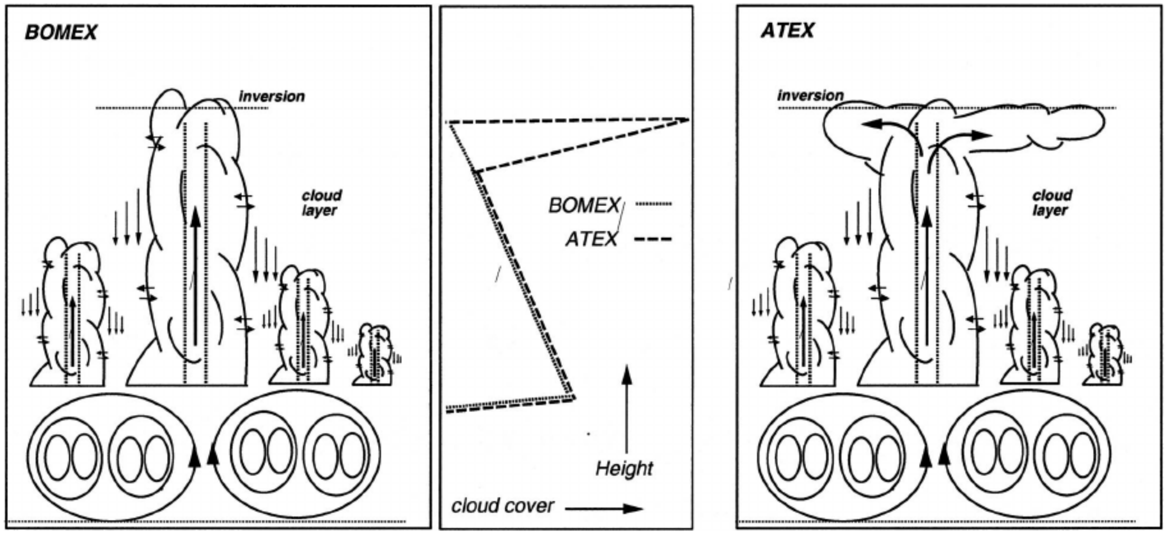

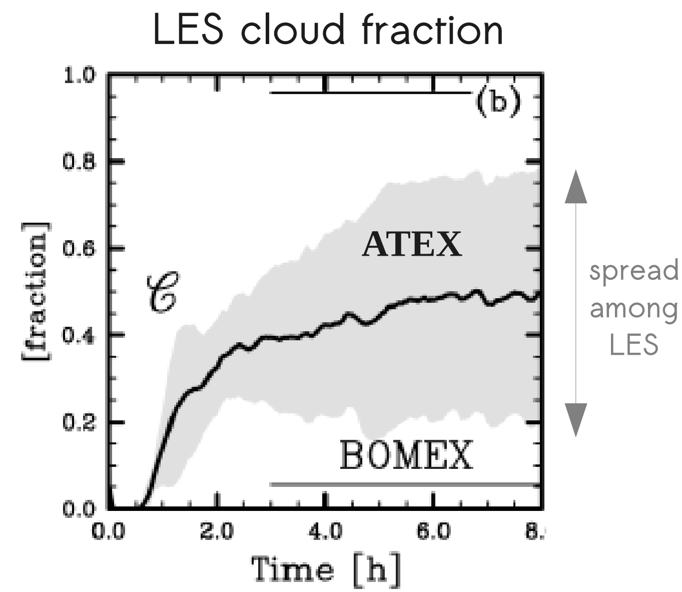

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- characterizes *both* the clouds and the environment in which the clouds form

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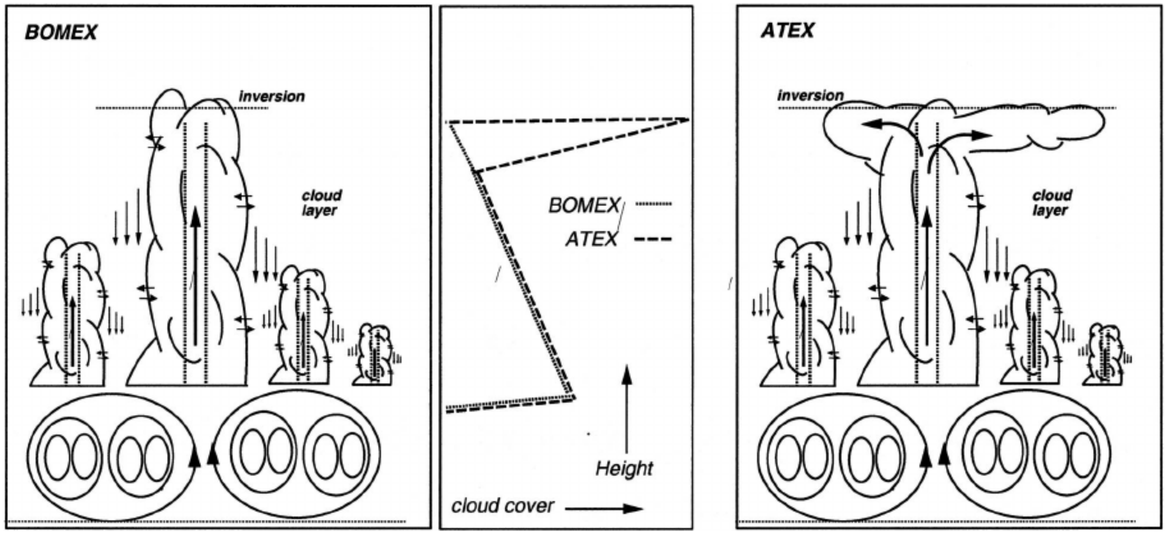

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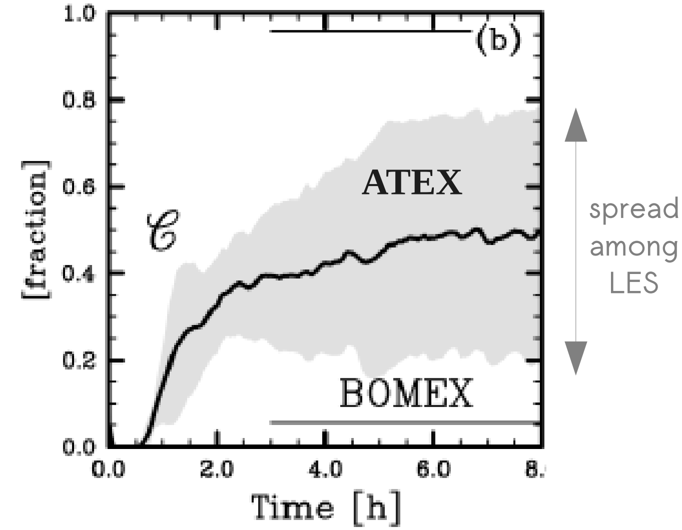

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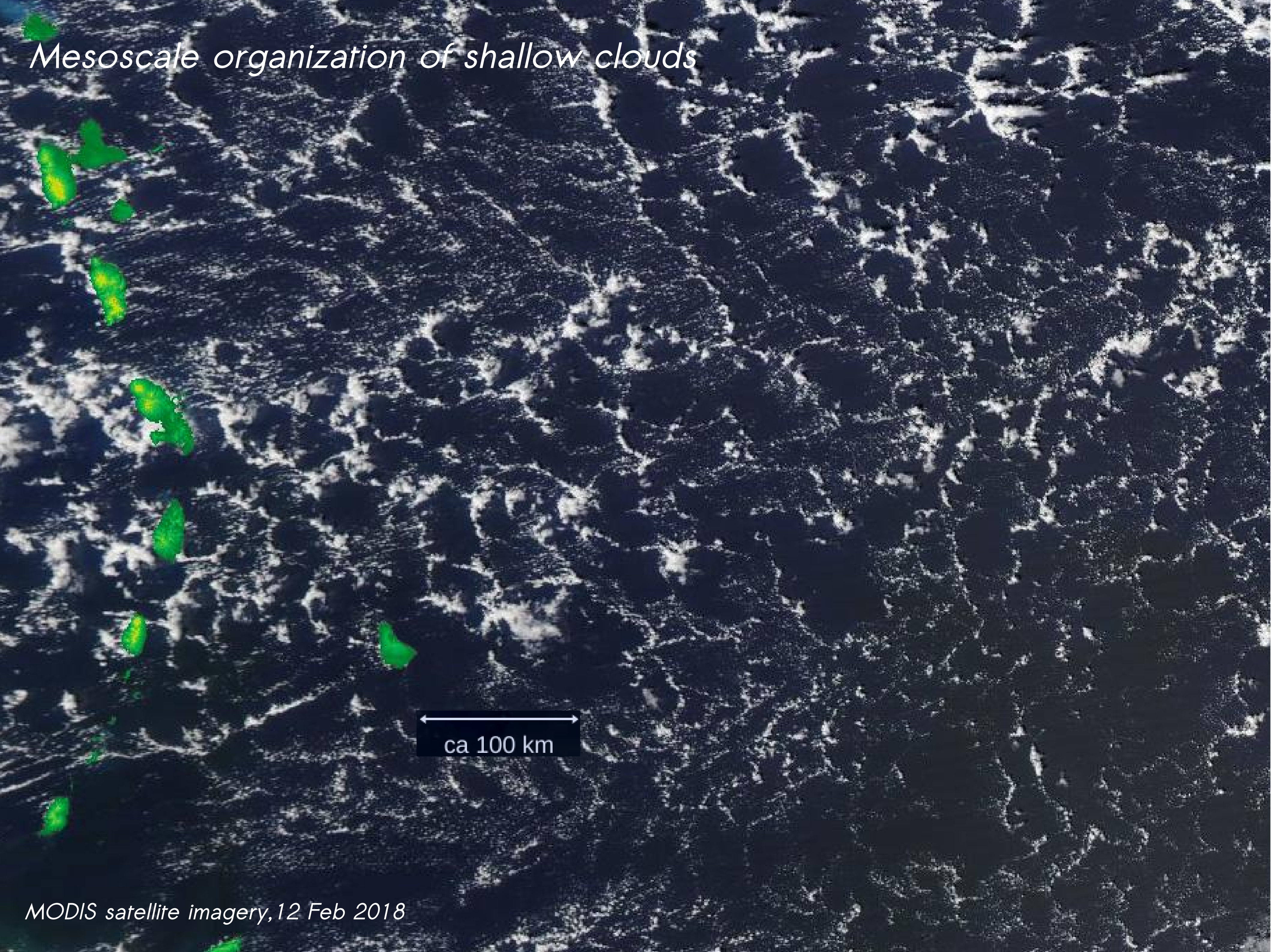
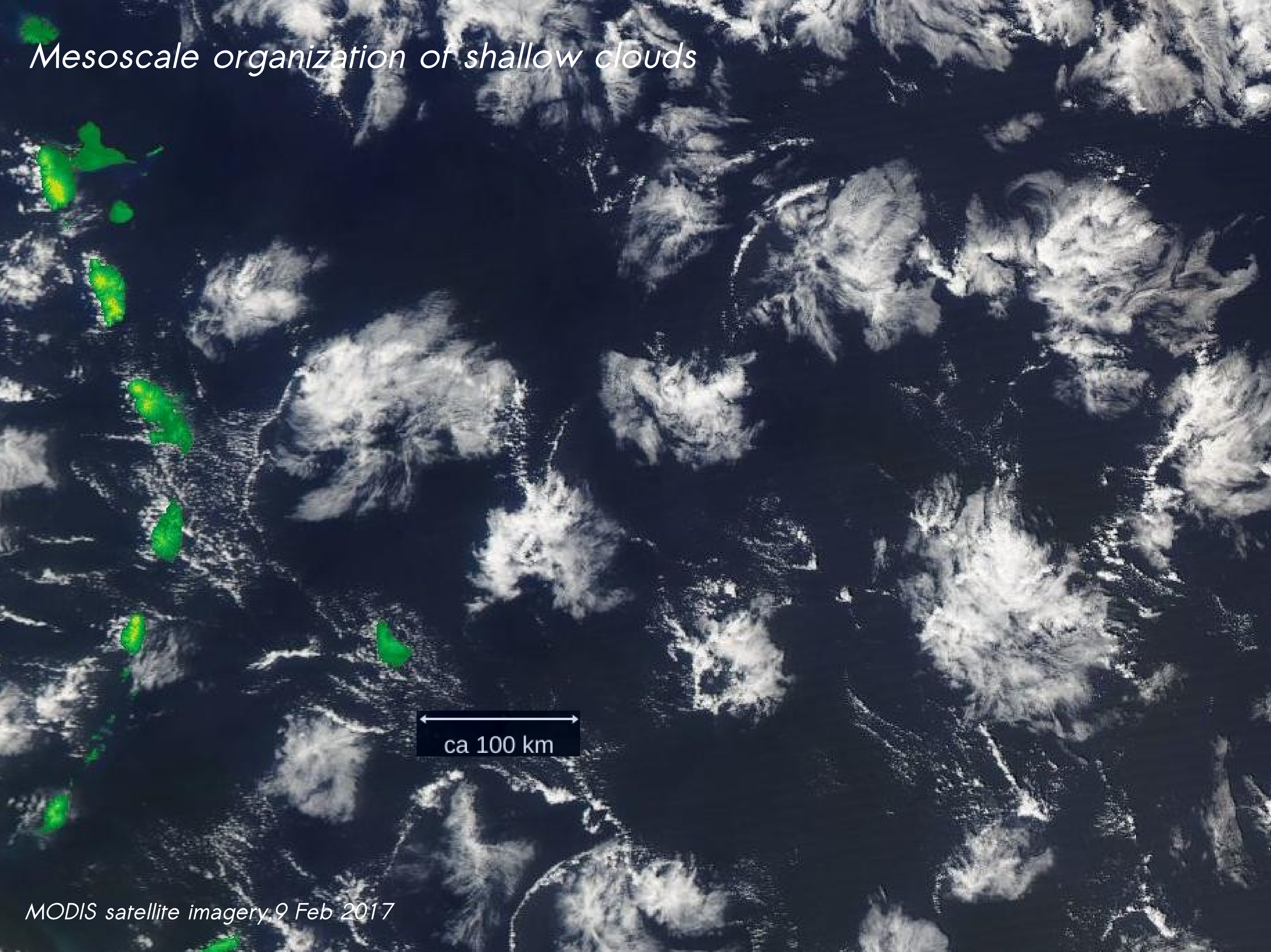
→ Need a field campaign that:

- characterizes *both* the clouds and the environment in which the clouds form
- considers the elephant in the room

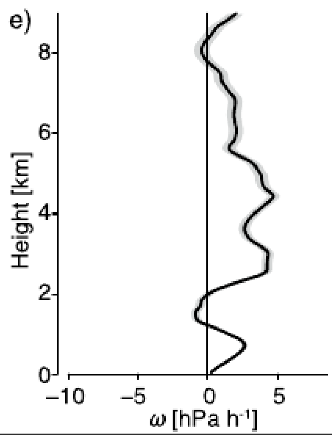

Mesoscale organization of shallow clouds
ca 100 km
MODIS satellite imagery, 12 Feb 2018


Mesoscale organization of shallow clouds
ca 100 km
MODIS satellite imagery,9 Feb 2017

What we want to understand

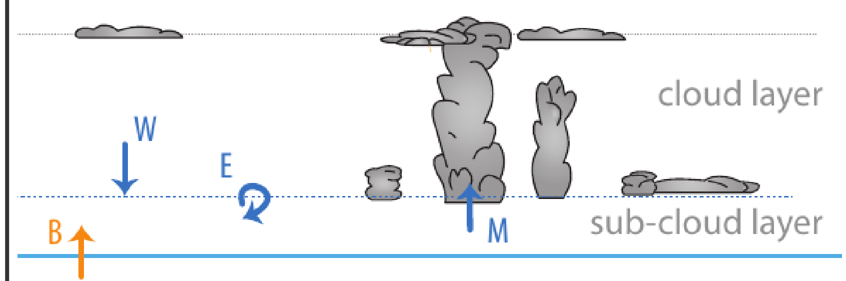
Low-cloud-controlling factors

Lower-tropospheric mixing
Large-scale vertical motion
Inversion strength
Surface wind & turbulence
Free-tropospheric humidity
Sea surface temperature



Cloud properties

(macrophysical, microphysical, radiative)



Mesoscale organization

EUREC^{4}A: Elucidating the role of cloud-circulation coupling in climate

- A French-German-Barbadian initiative endorsed by the World Climate Research Programme (WCRP), that will support the WCRP Grand Challenge on *Clouds, Circulation and Climate Sensitivity*

- The EUREC^{4}A field campaign will occur East of Barbados between 20 January - 20 February 2020

- More information: *Bony, Stevens et al., Surveys in Geophysics (2017)* and *http://eurec4a.eu*

Why is Barbados relevant?

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Clouds at Barbados are representative of clouds across the trade wind regions in observations and climate models

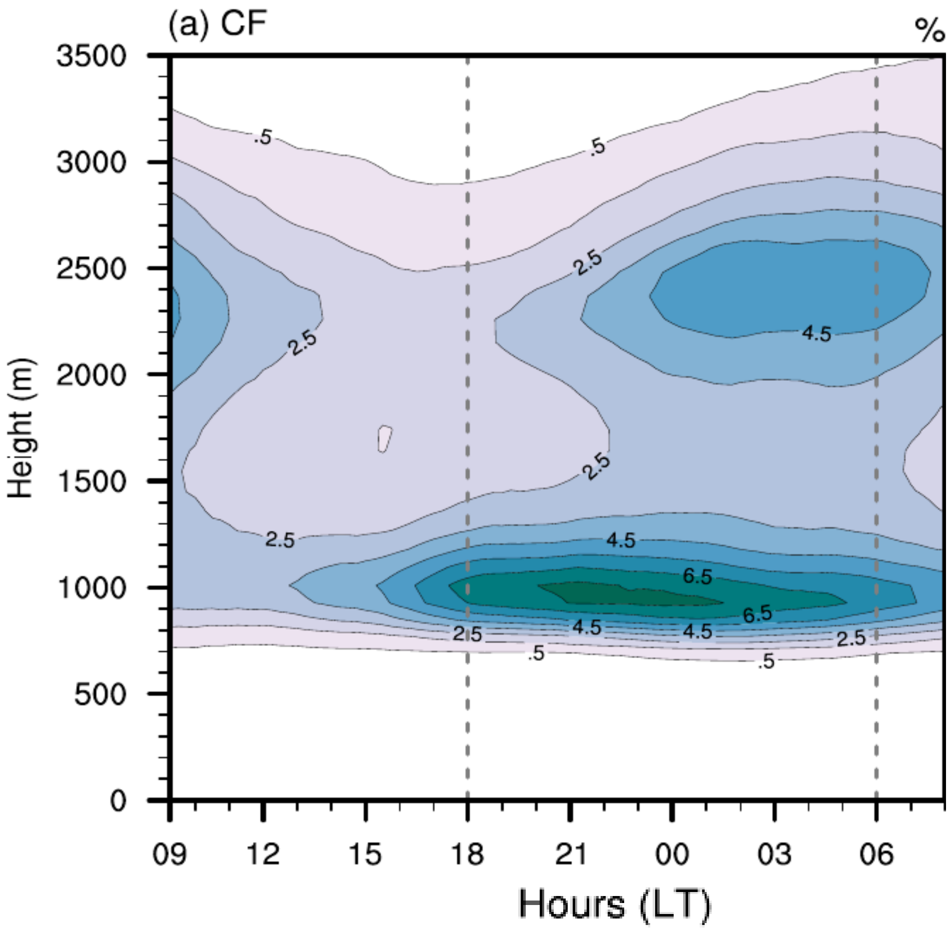
Brian Medeiros[a,1] and Louise Nuijens[b,2]

[a]National Center for Atmospheric Research, Boulder, CO 80307; and [b]Max Planck Institute for Meteorology, 20146 Hamburg, Germany

Edited by Benjamin D. Santer, Lawrence Livermore National Laboratory, Livermore, CA, and approved April 21, 2016 (received for review October 30, 2015)

Max-Planck-Institut
für Meteorologie

Why is Barbados relevant?



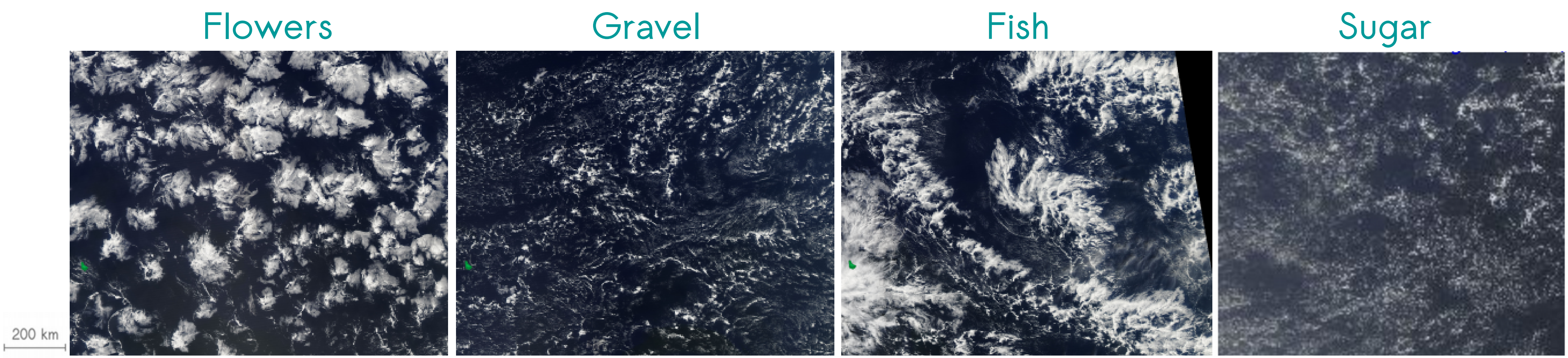
ICON simulations and BCO observations:

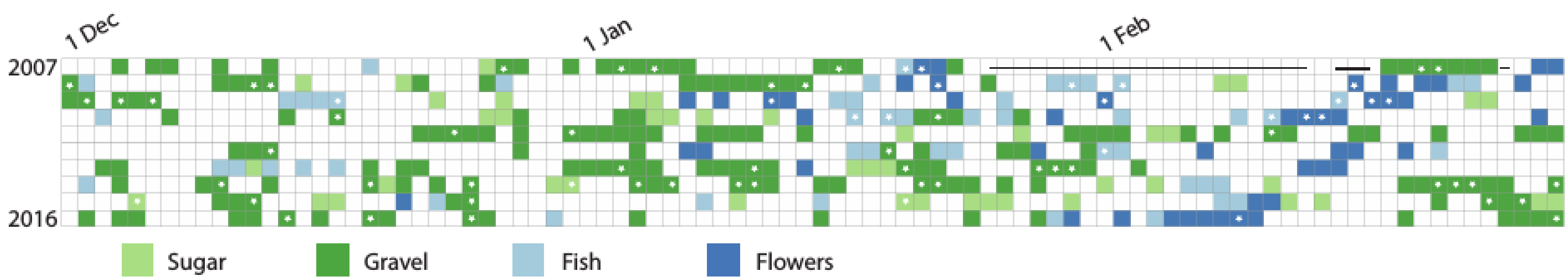
→ diurnal variations of the cloud fraction, especially at cloud base and near the trade inversion

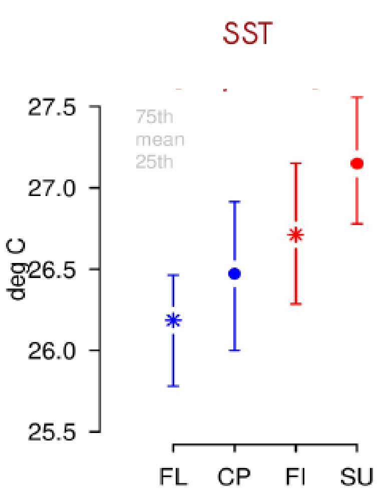
→ opportunity to understand what controls variations in cloudiness

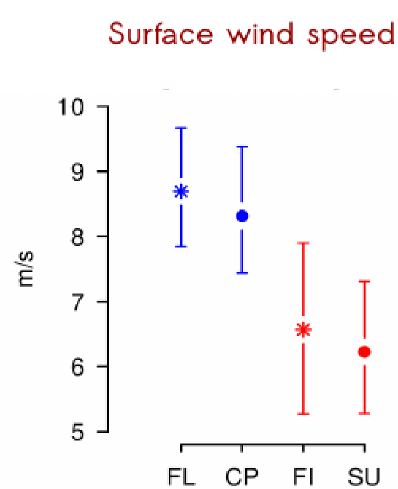
Vial et al., A new look at the daily cycle of tradewind cumuli (submitted)

Why is Barbados relevant?









- Strong day-to-day variability of mesoscale organization
- Some relationship with the large-scale environment

→ Opportunity to investigate the link between LS environment - organization - clouds

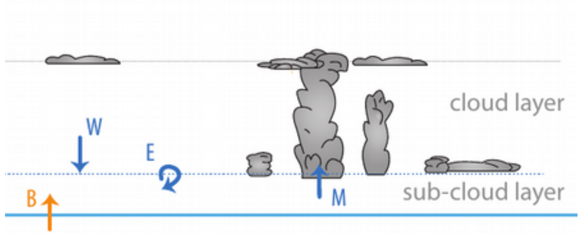
Stevens et al. (in revision); Bony et al. (in prep)

EUREC^{4}A scientific questions & objectives

• How do the clouds depend on environmental conditions in the tradewinds?

→ what controls the cloud fraction at cloud base and aloft?

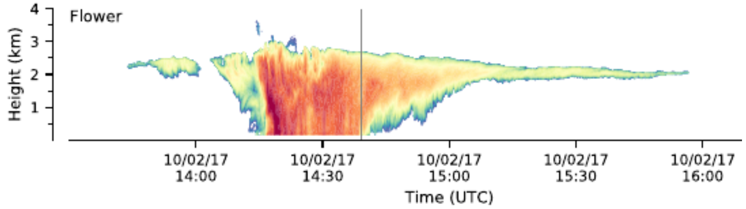
→ role of the mesoscale organization?



• How do radiation and precipitation depend on cloud properties?

→ role of macrophysical vs microphysical properties?

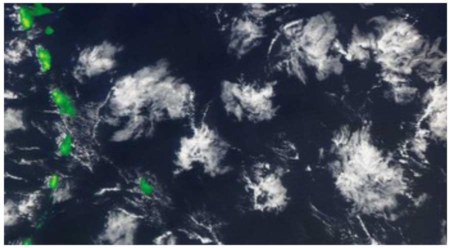
→ role of the mesoscale organization of convection?



• What are the drivers of the mesoscale organization of shallow convection?

→ role of atmospheric processes (turbulence, cold pools, radiation, LS dynamics)?

→ role of ocean mesoscale and sub-mesoscale heterogeneities?

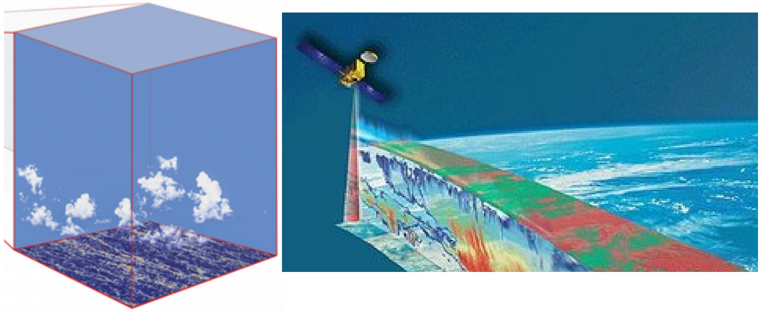


• Provide a benchmark data set for climate/high-resolution models and satellite remote sensing

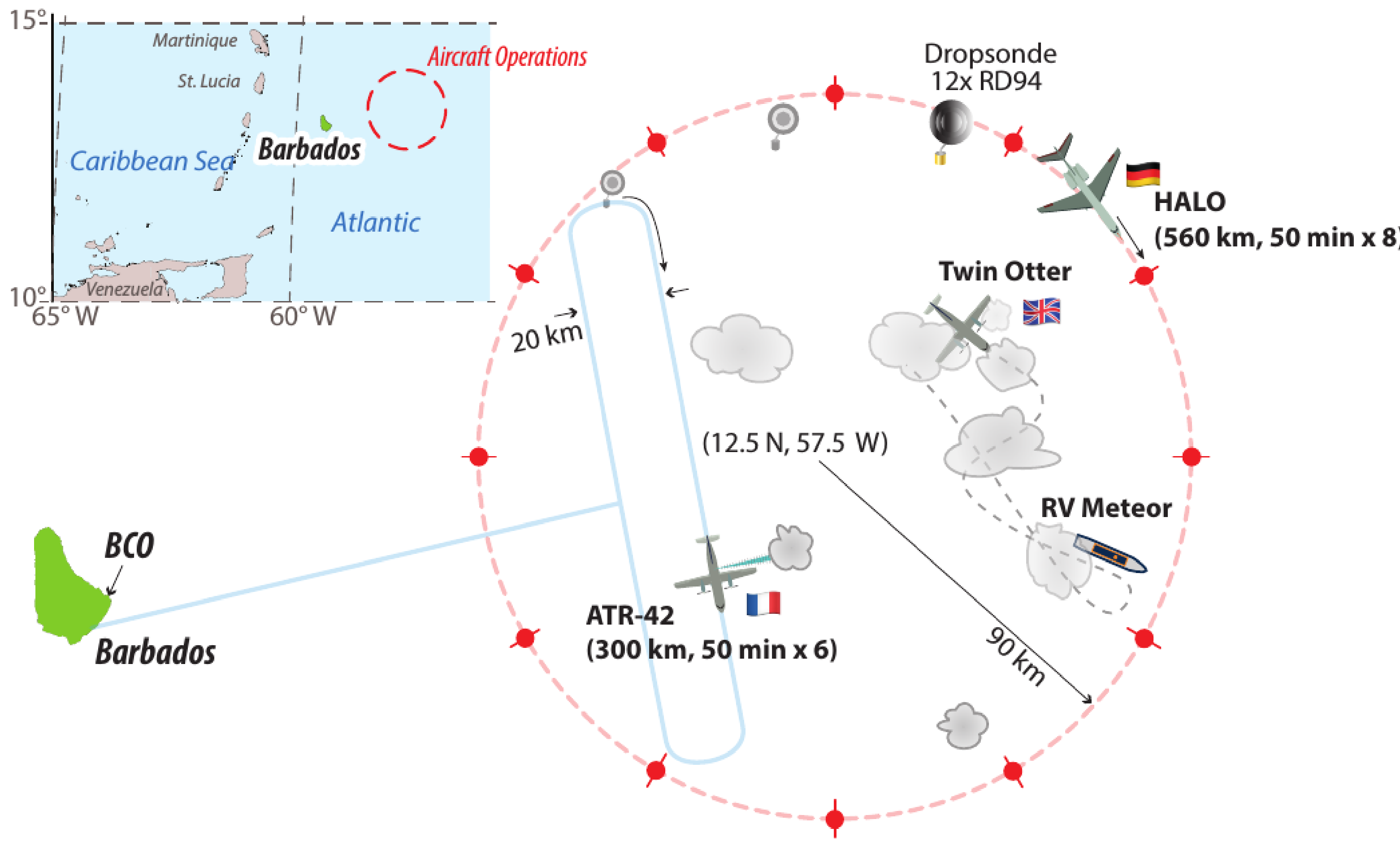
→ representation of diurnal, inter-diurnal variability and mesoscale organization

→ towards a new generation of ocean-atmosphere coupled models

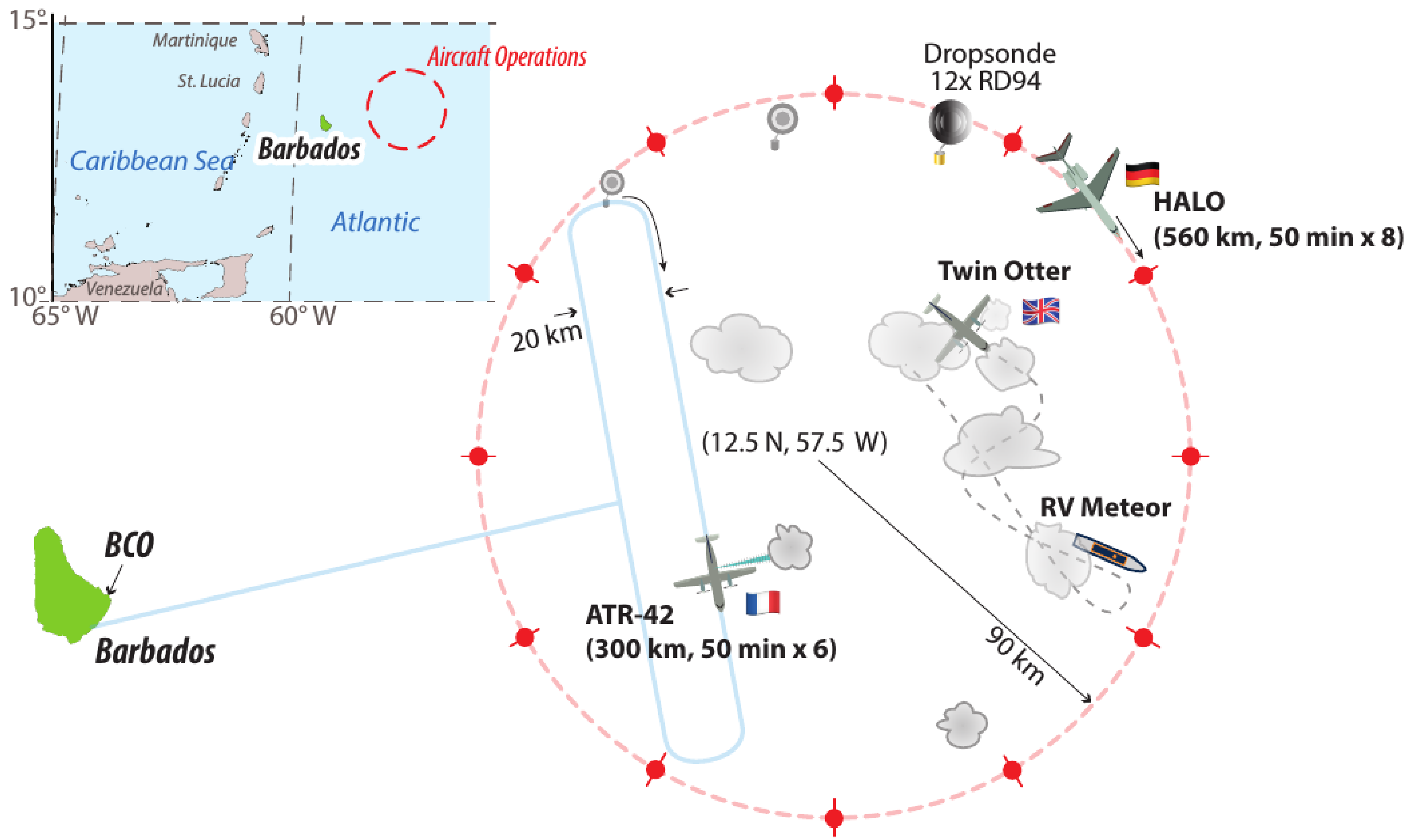
→ retrievals of WV, clouds, winds and energy budget



EUREC^{4}A experimental strategy



EUREC⁴A experimental strategy



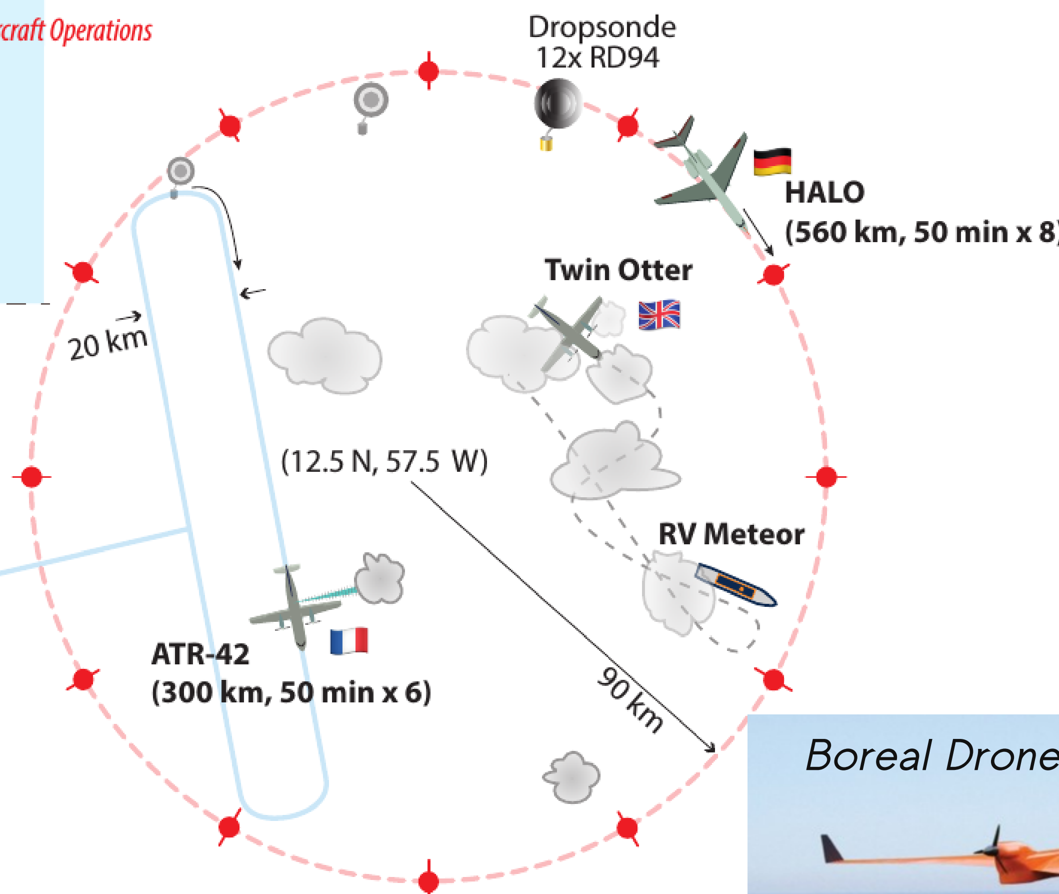
New!


Gulfstream G5 HALO (DLR, DE)


ATR-42 (SAFIRE, FR)


Twin Otter (BAS, UK)

EUREC⁴A experimental strategy



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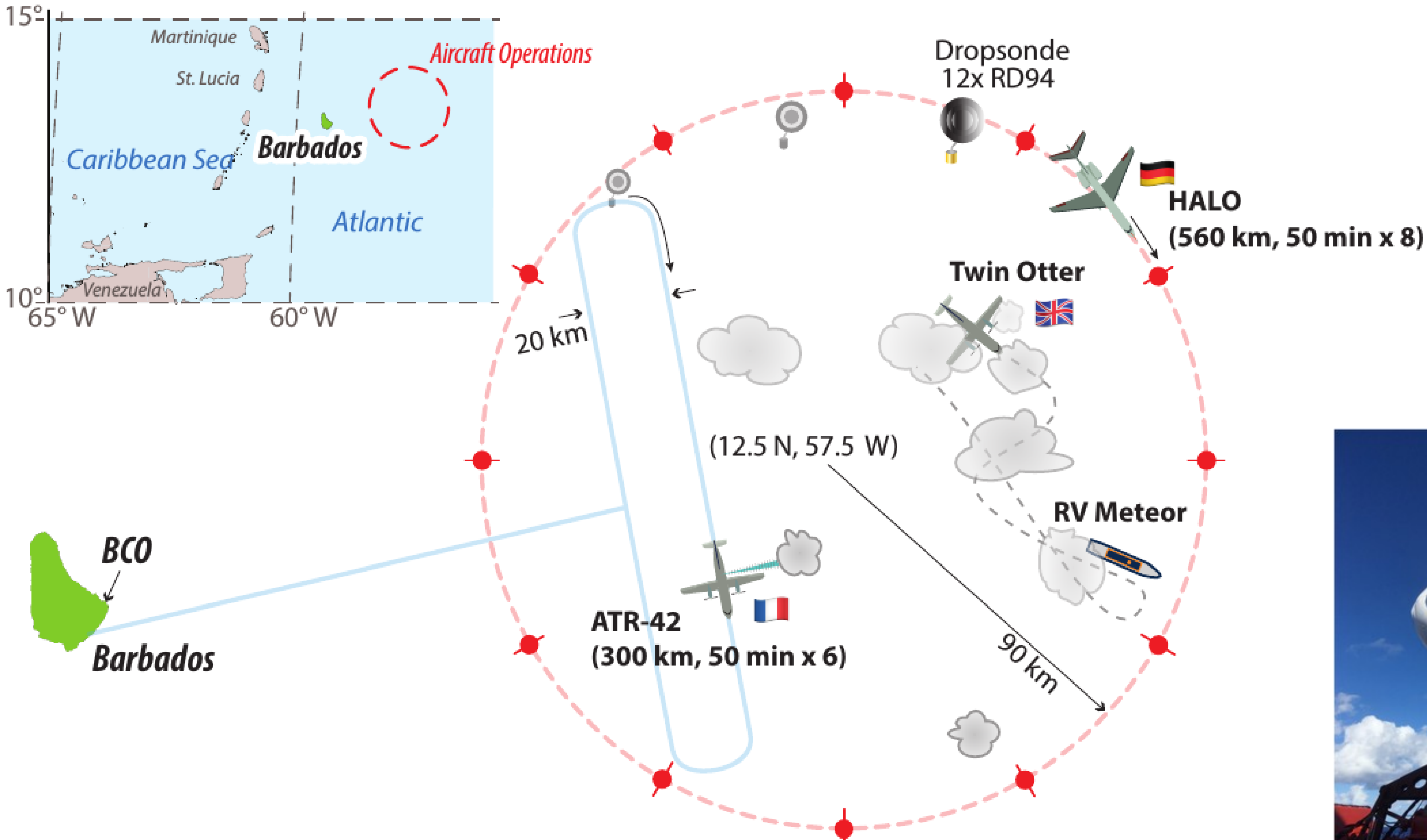
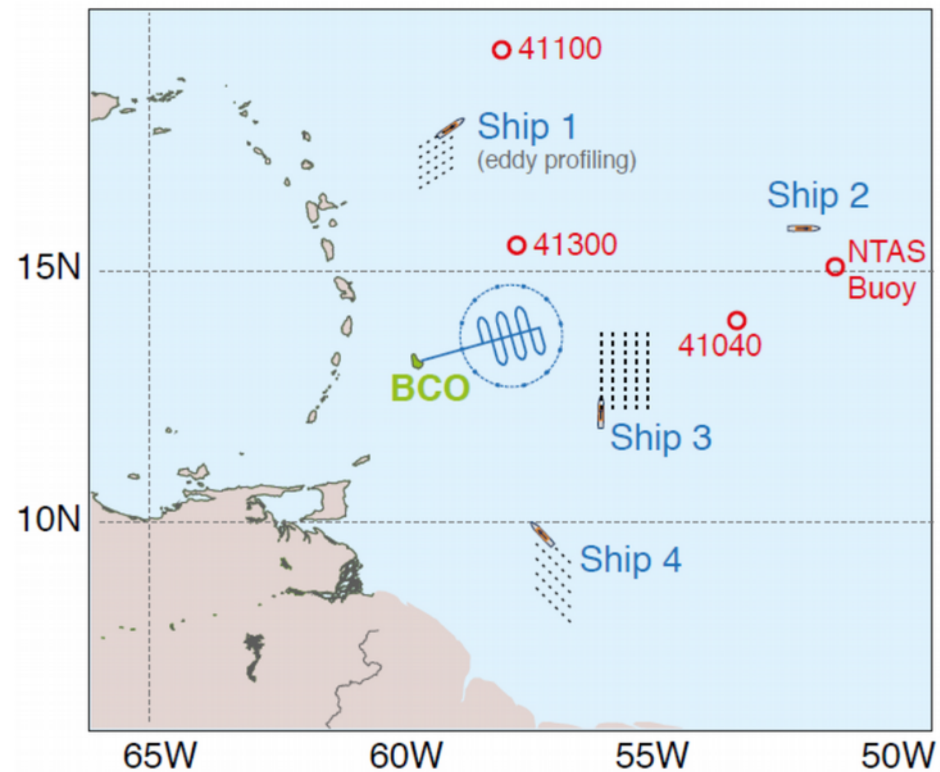
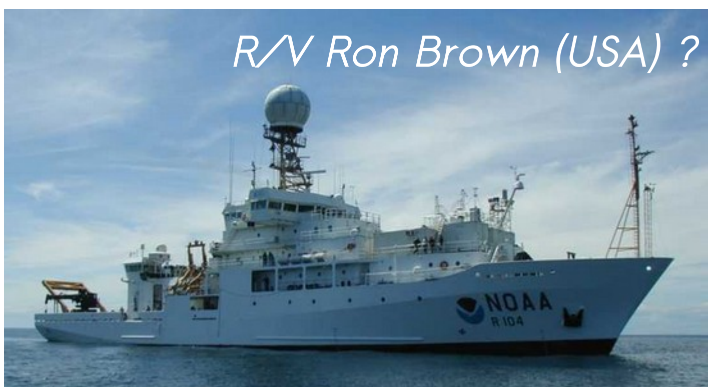


EUREC^{4}A-OA (Europe) / ATOMIC (US) initiatives

An opportunity to better understand
the role of mesoscale processes
(ocean eddies, atmospheric organization)
in air-sea interactions
+
to characterize the diurnal cycle of
the coupled ocean-atmosphere system



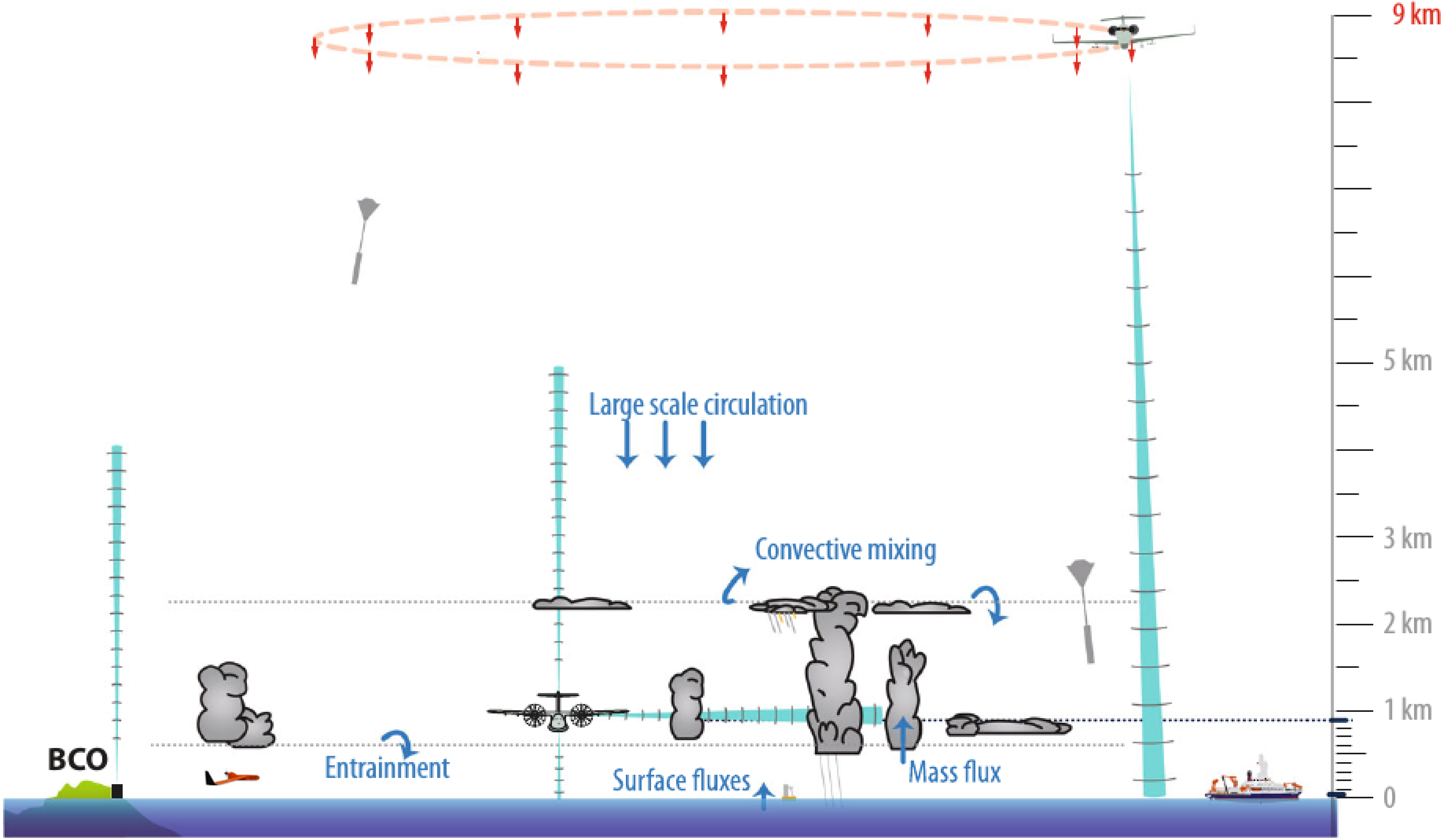

R/V Ron Brown (USA) ?


R/V Atalante (FR) ?


R/V Maria S. Merian (DE)


R/V Meteor (DE)

Key & novel measurements



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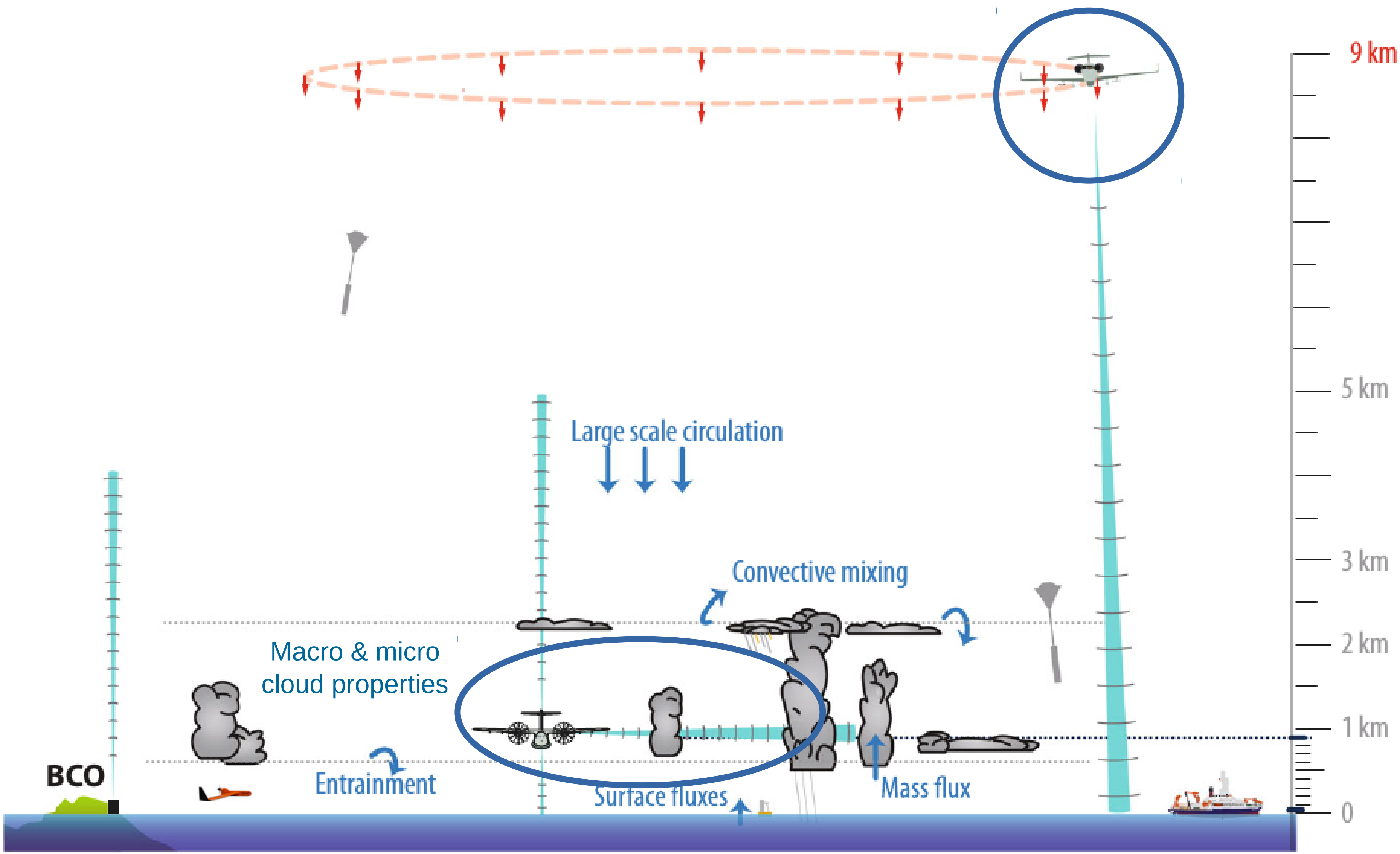
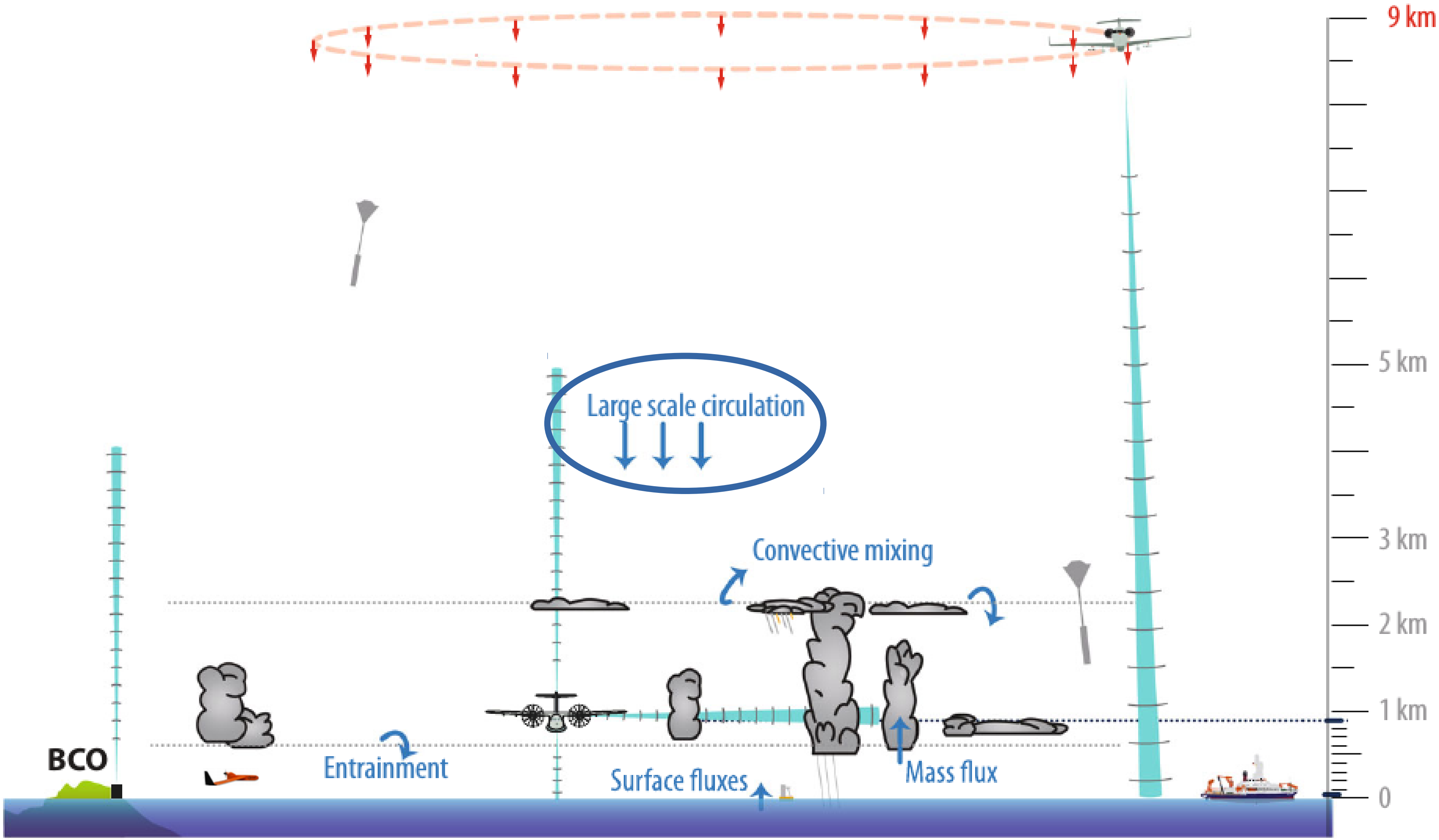


HALO: downward looking lidar & radar (WALES, Ka-band), radiometers (HAMP, SpecMACs, SMART), dropsondes

ATR-42: up/down looking radar (RASTA) + <u>sideways looking</u> lidar & radar (Alias, BASTA) + in-situ (turb, micro, radiation, isotopes)

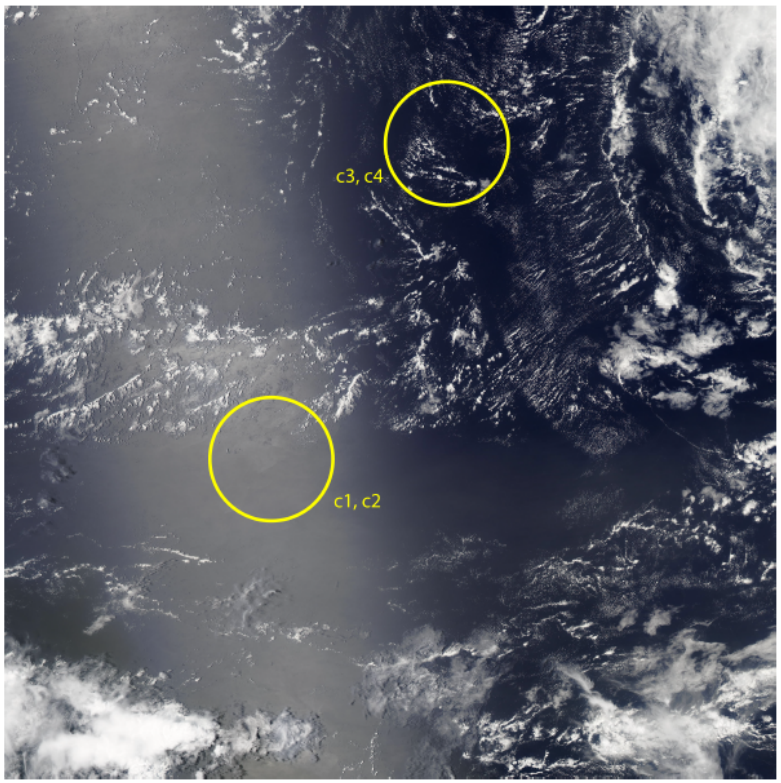
Key & novel measurements



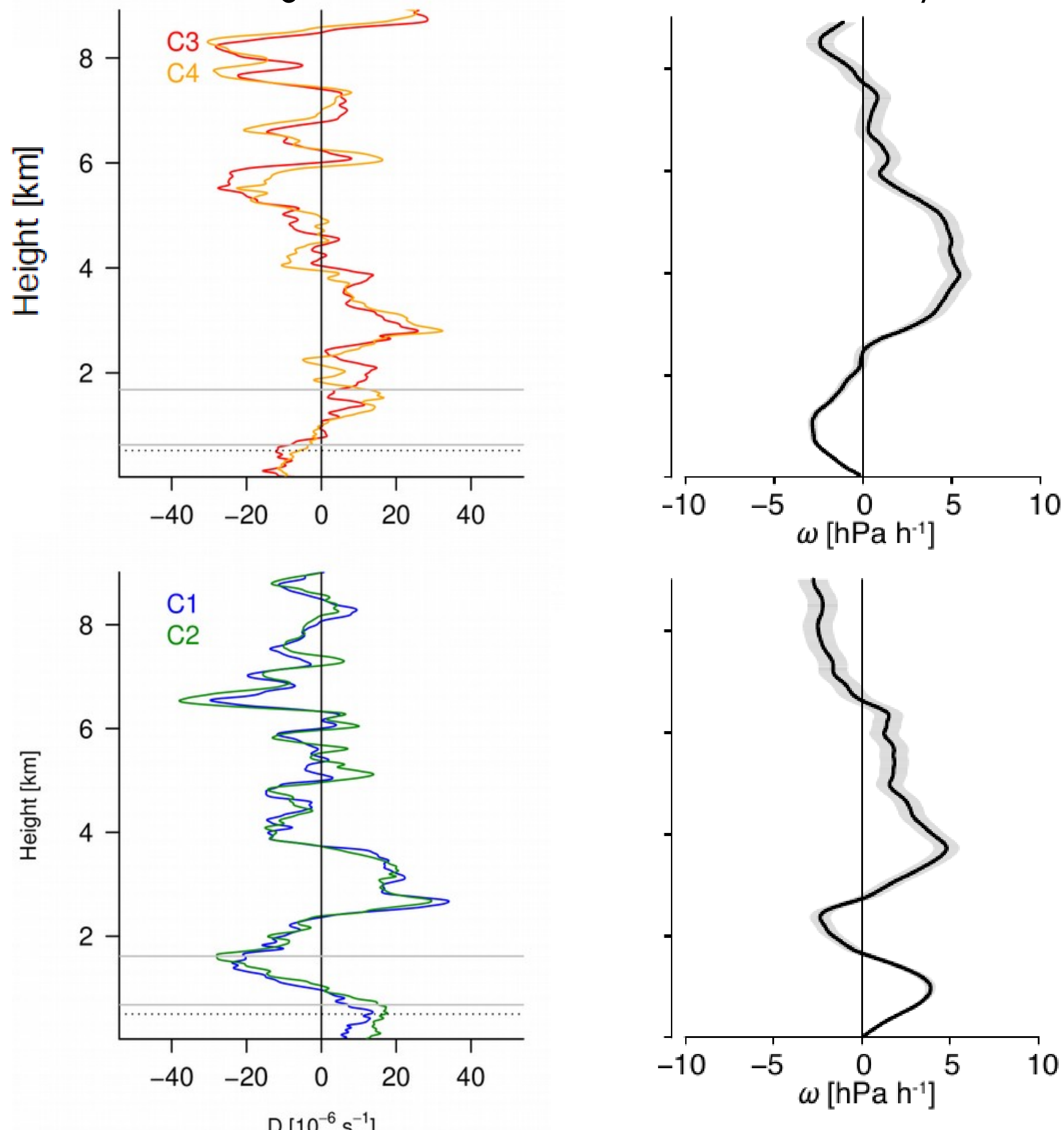
Can we measure large-scale mass divergence and vertical motions by using dropsondes ?

Large-scale vertical motions can be measured with dropsondes

NARVAL2, RF06, 19 Aug 2016

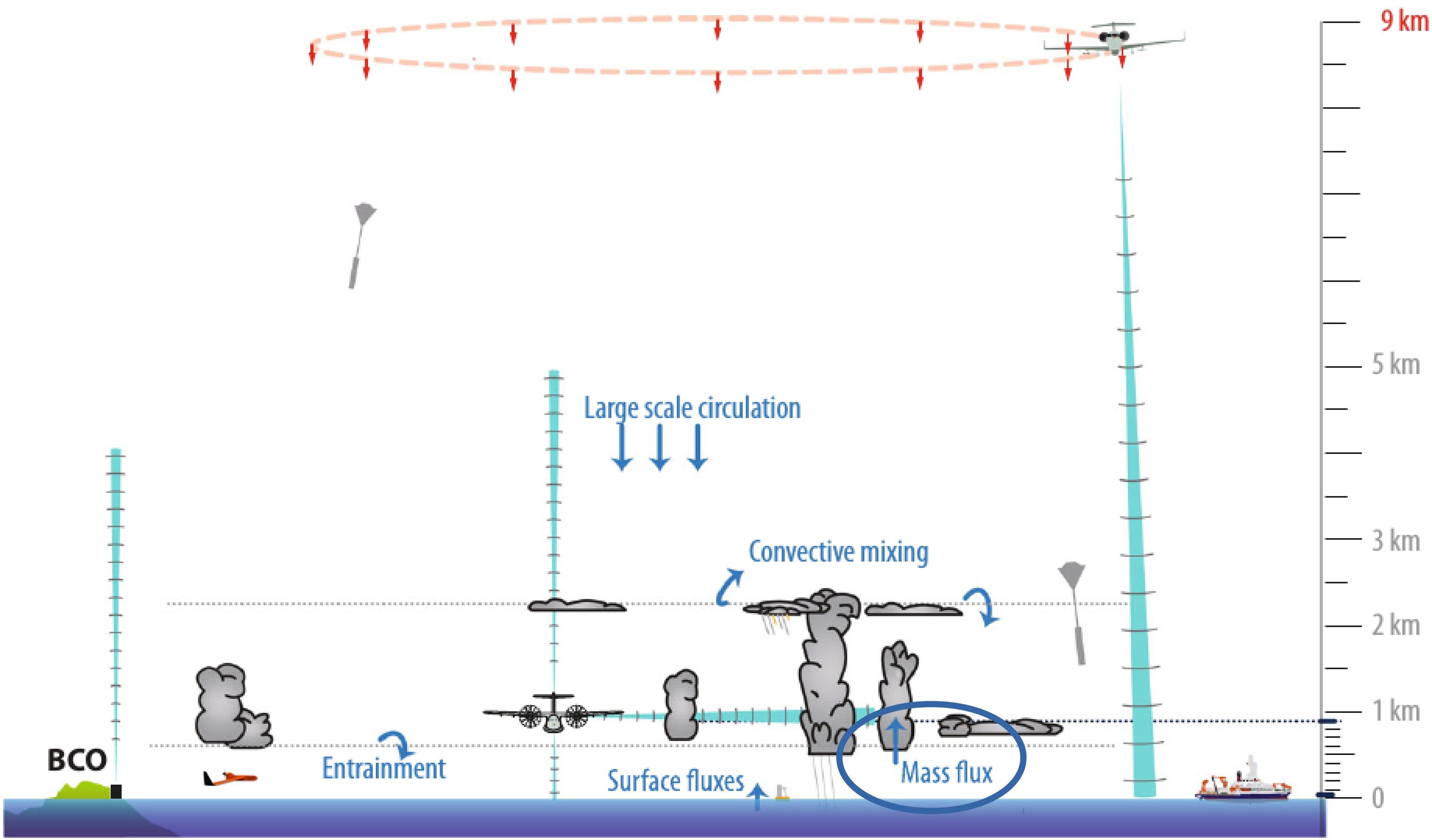


divergence (10^{-6} s^{-1}) vertical velocity ω (hPa h^{-1})



Bony and Stevens, JAS (2019)

Key & novel measurements



The cloud-base convective mass flux can be estimated from the mass budget of the subcloud layer.

Vogel, Bony and Stevens (submitted)

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- Hundreds of dropsondes to be assimilated

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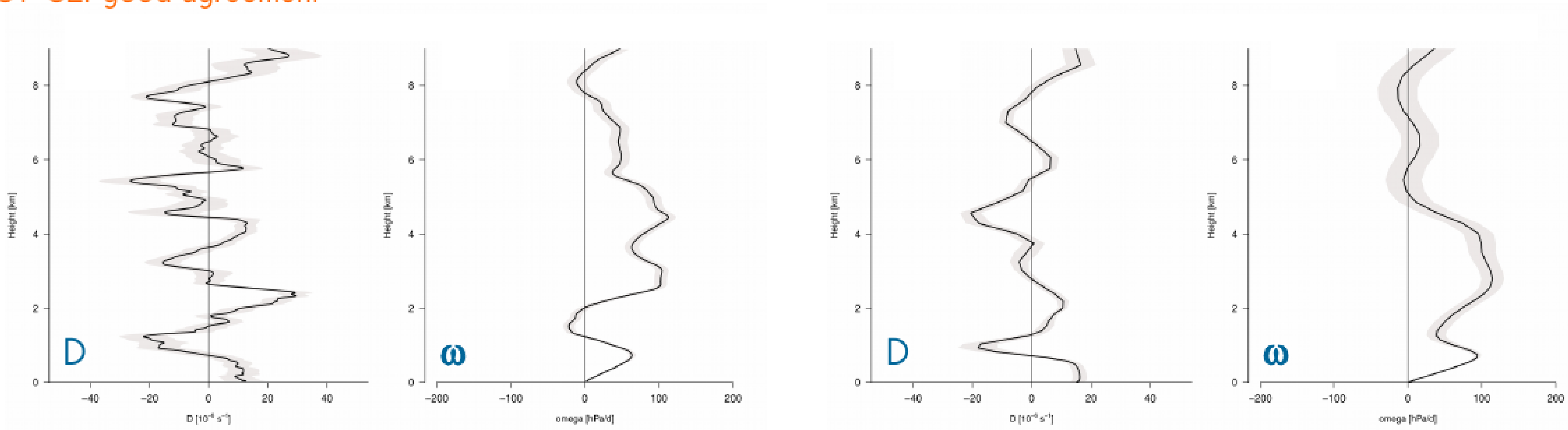
Dropsondes | NARVAL2 RF03 (12 Aug 2016) | ECMWF forecasts

C1-C2: good agreement



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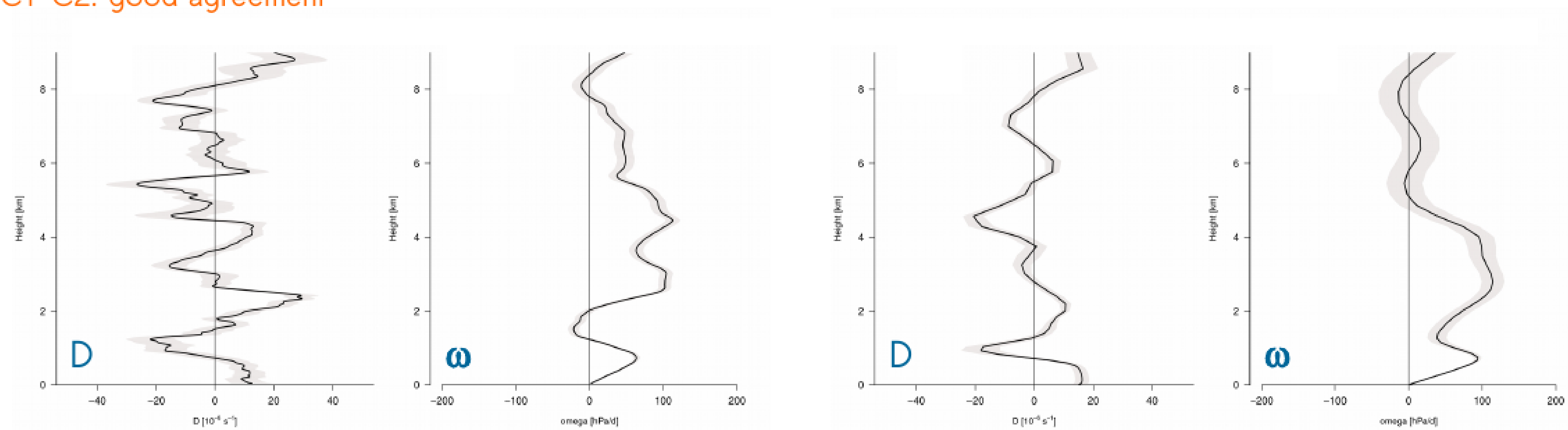
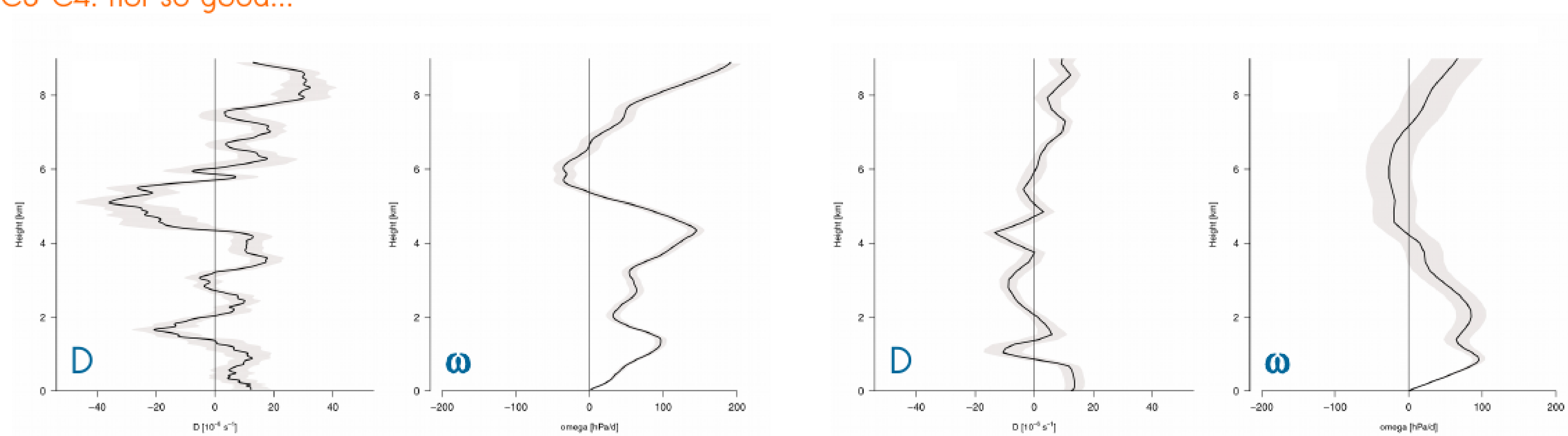


C3-C4: not so good...



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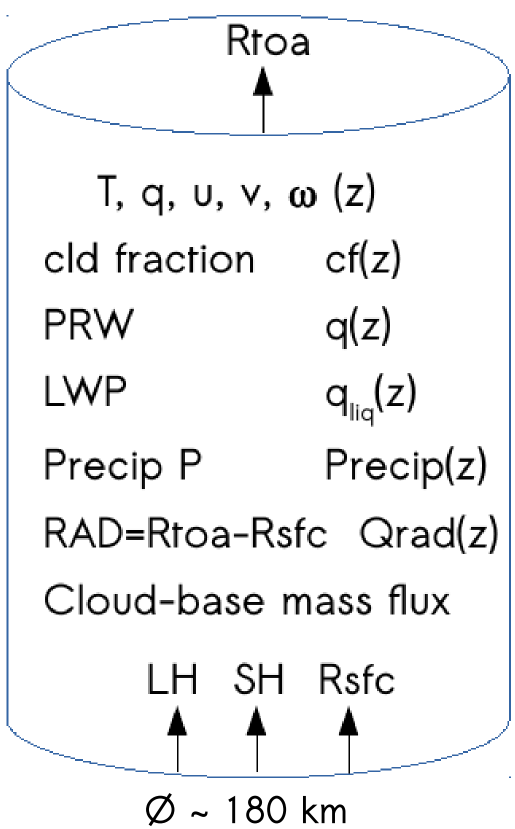
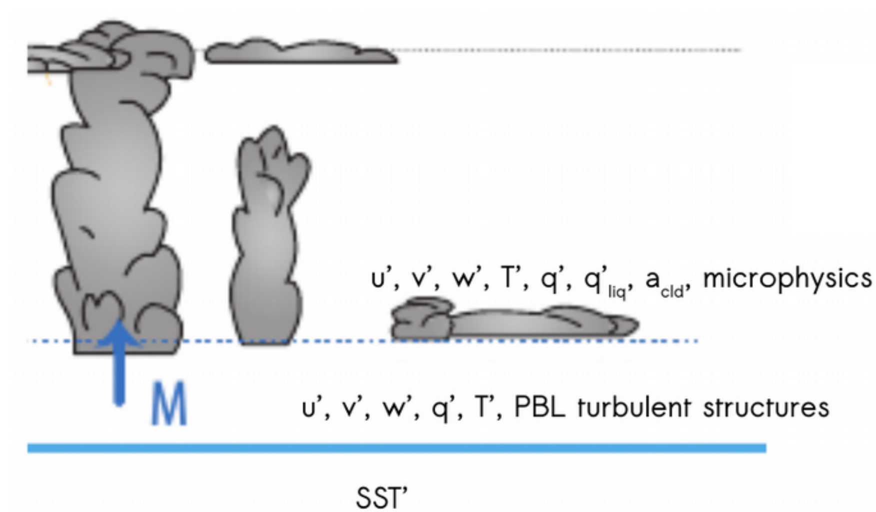
- Evaluation of columnar water/energy budgets, mesoscale variances and PBL turbulent structures





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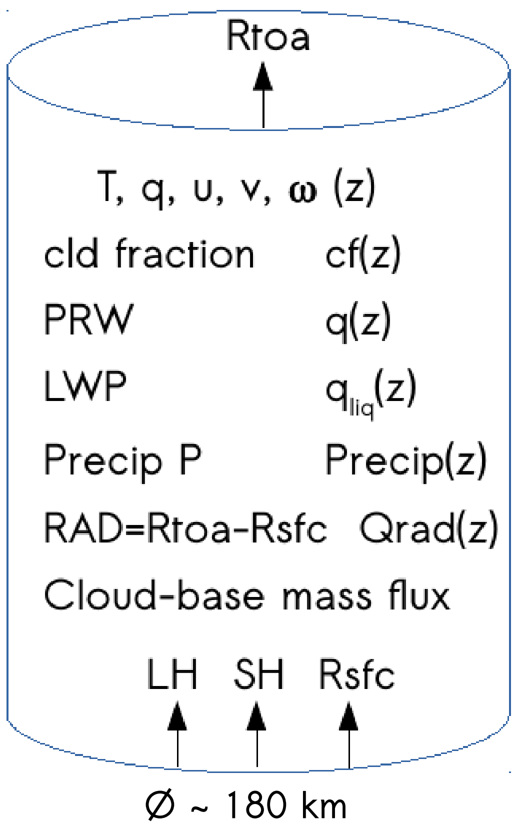
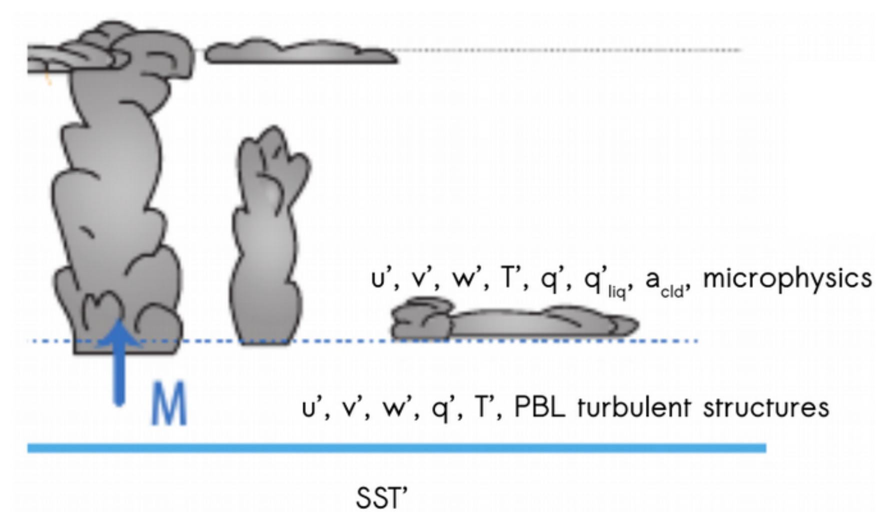




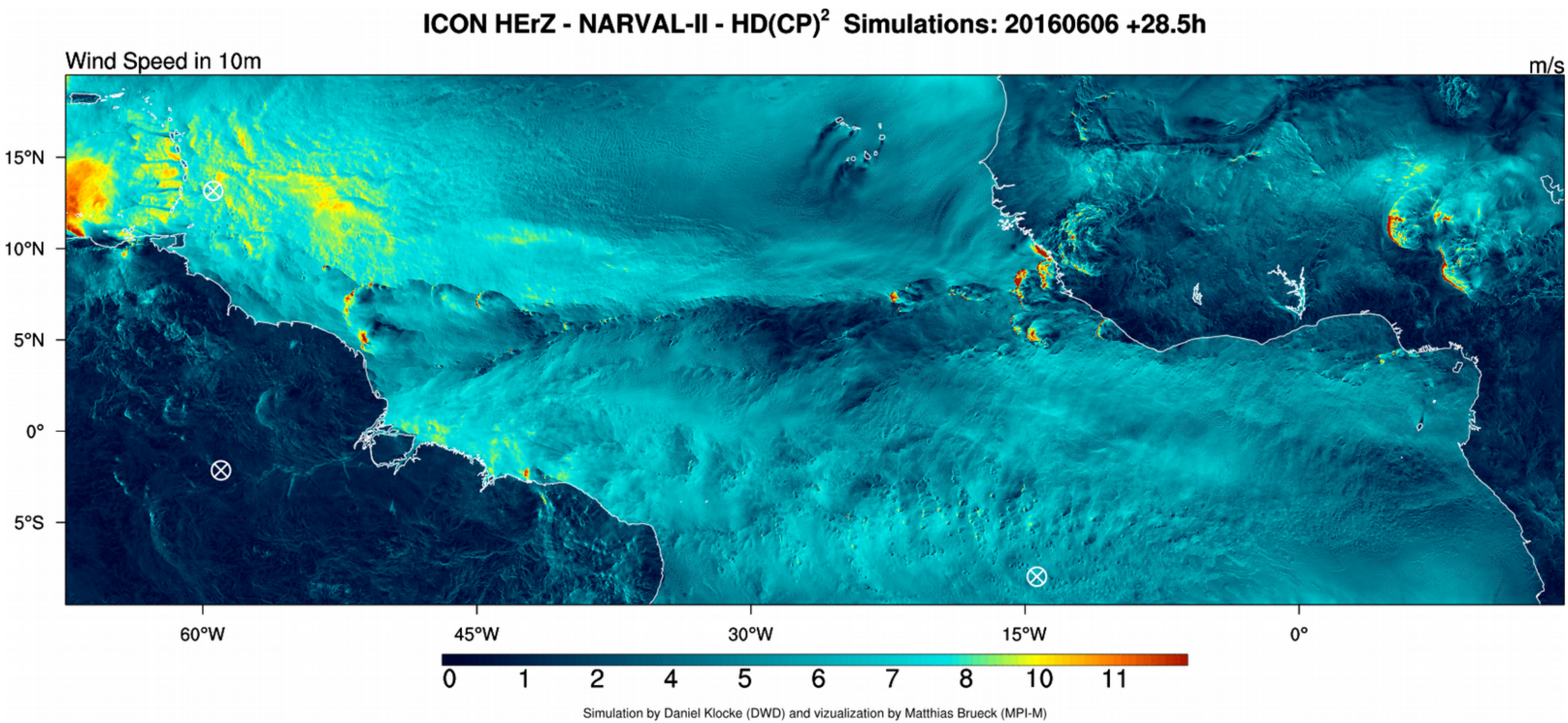
→ Testing and development of parameterizations

→ (indirectly) Improvement of satellite remote-sensing algorithms (e.g. LWP)

→ Test of the ability of high-resolution models to predict mesoscale organization patterns

How could EUREC⁴A benefit from NWP?

- Before and during the campaign (flight planning):
  - Initialization of high-resolution (CRM/LES) simulations



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  - Enhanced collection of process diagnostics?

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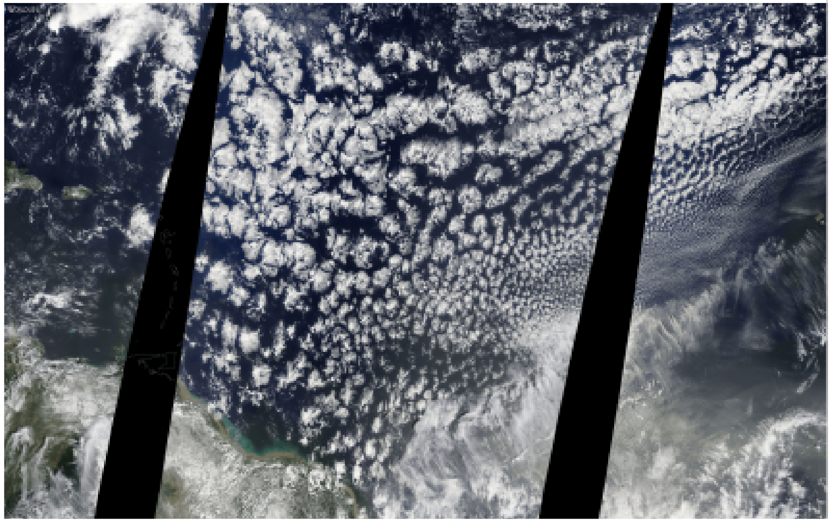
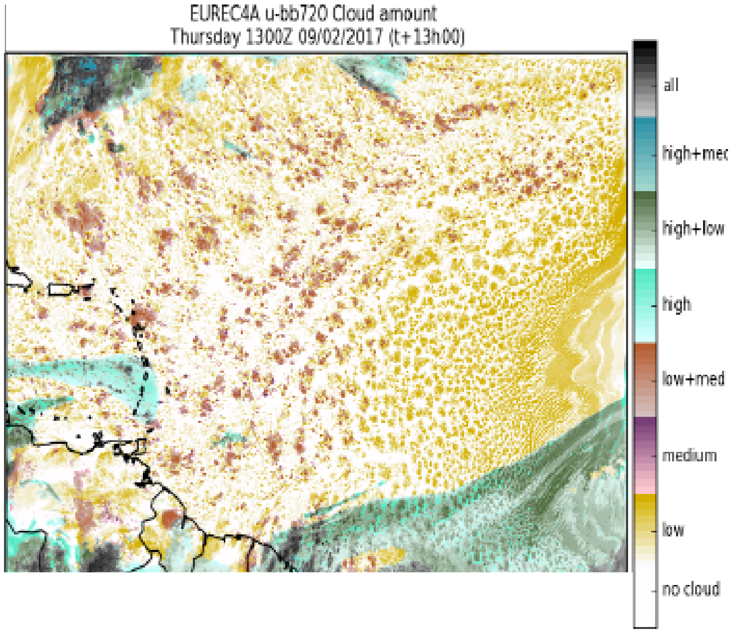
  - Enhanced collection of process diagnostics?
  - Forecasts of cloud organization patterns?

MODIS imagery 9 Feb 2017





Courtesy
A. Lock
(Met Office)

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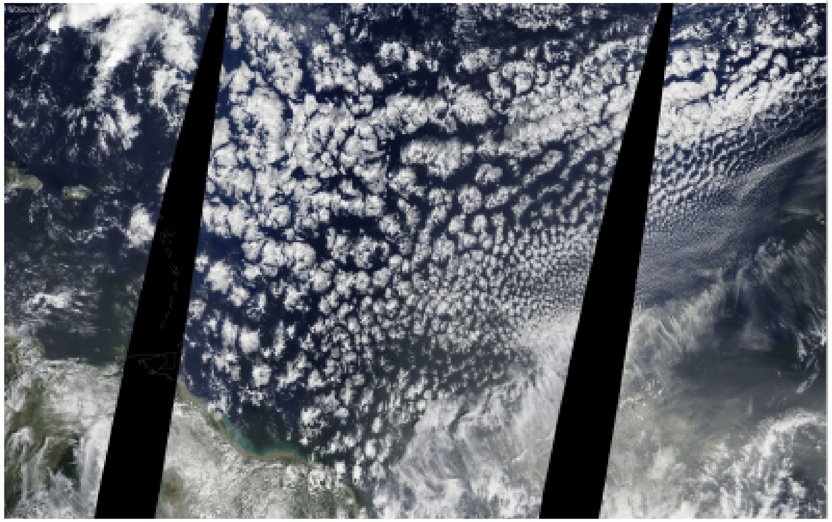
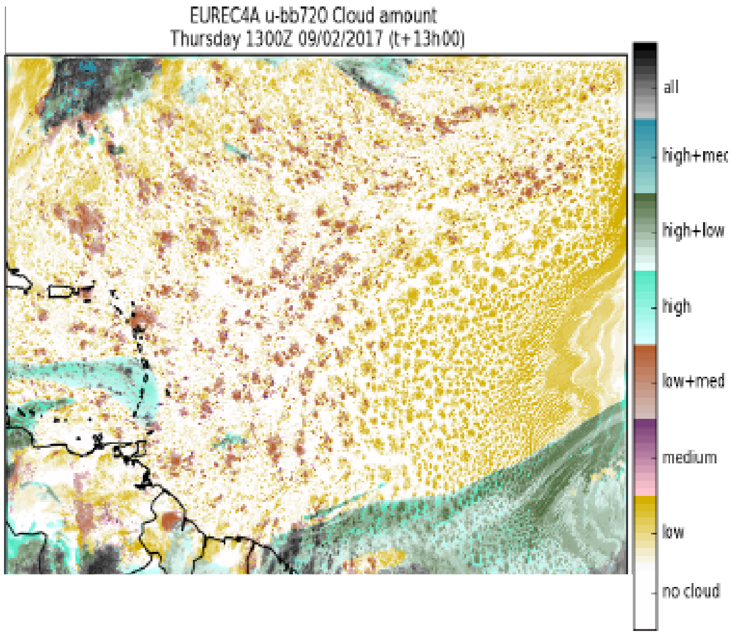


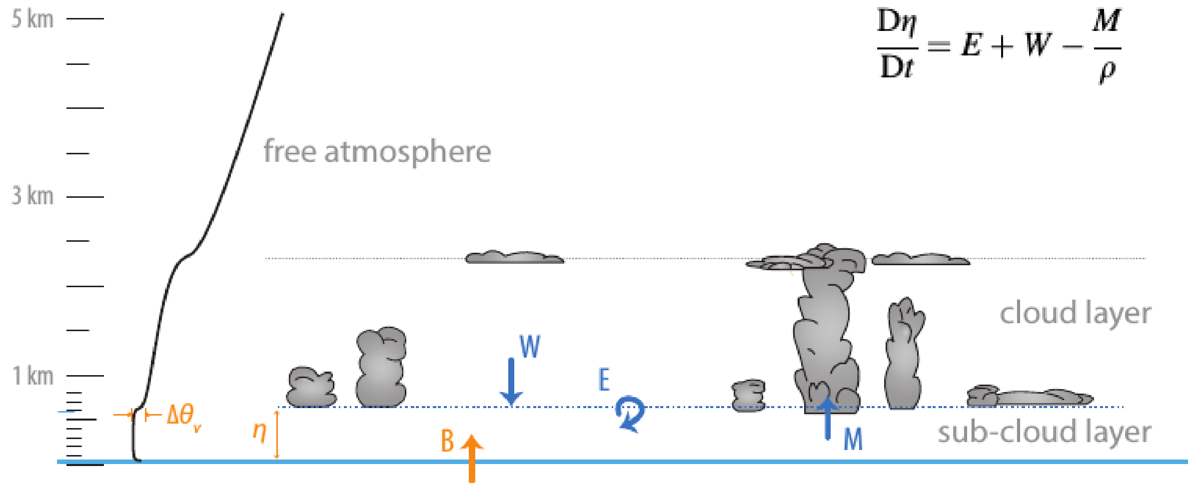


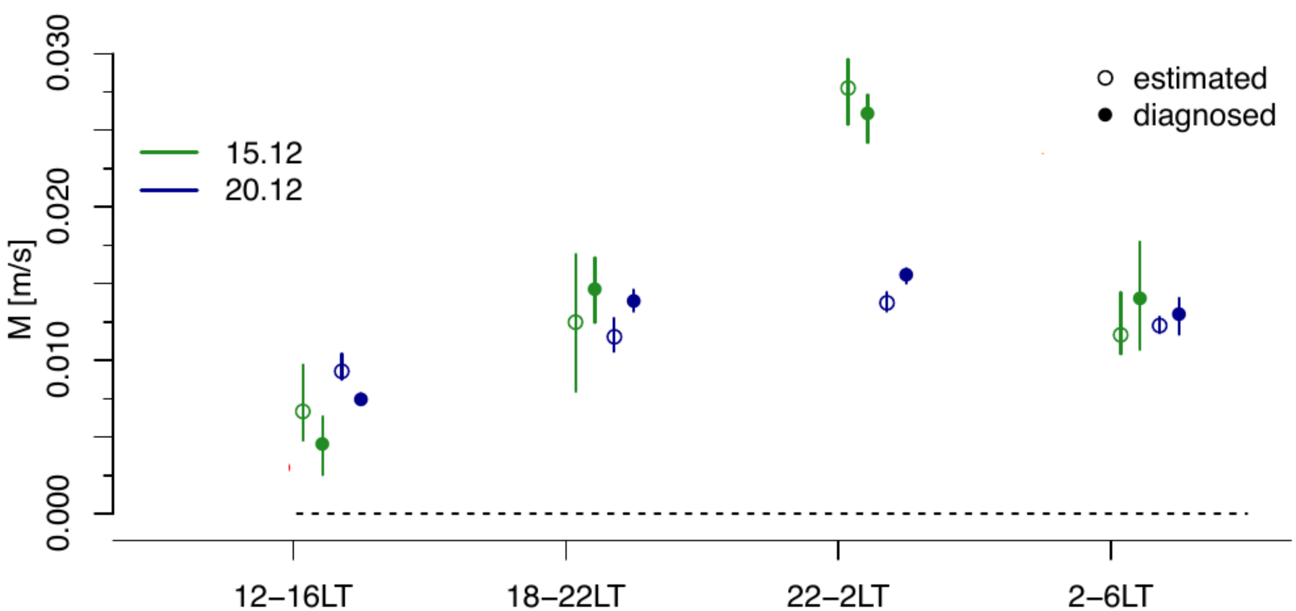
Courtesy A. Lock (Met Office)

- After the campaign:
  - High-resolution reanalysis of the 20Jan-20Feb period after EUREC^{4}A?


Thank you
EUREC4A
20 Jan - 20 Feb 2020

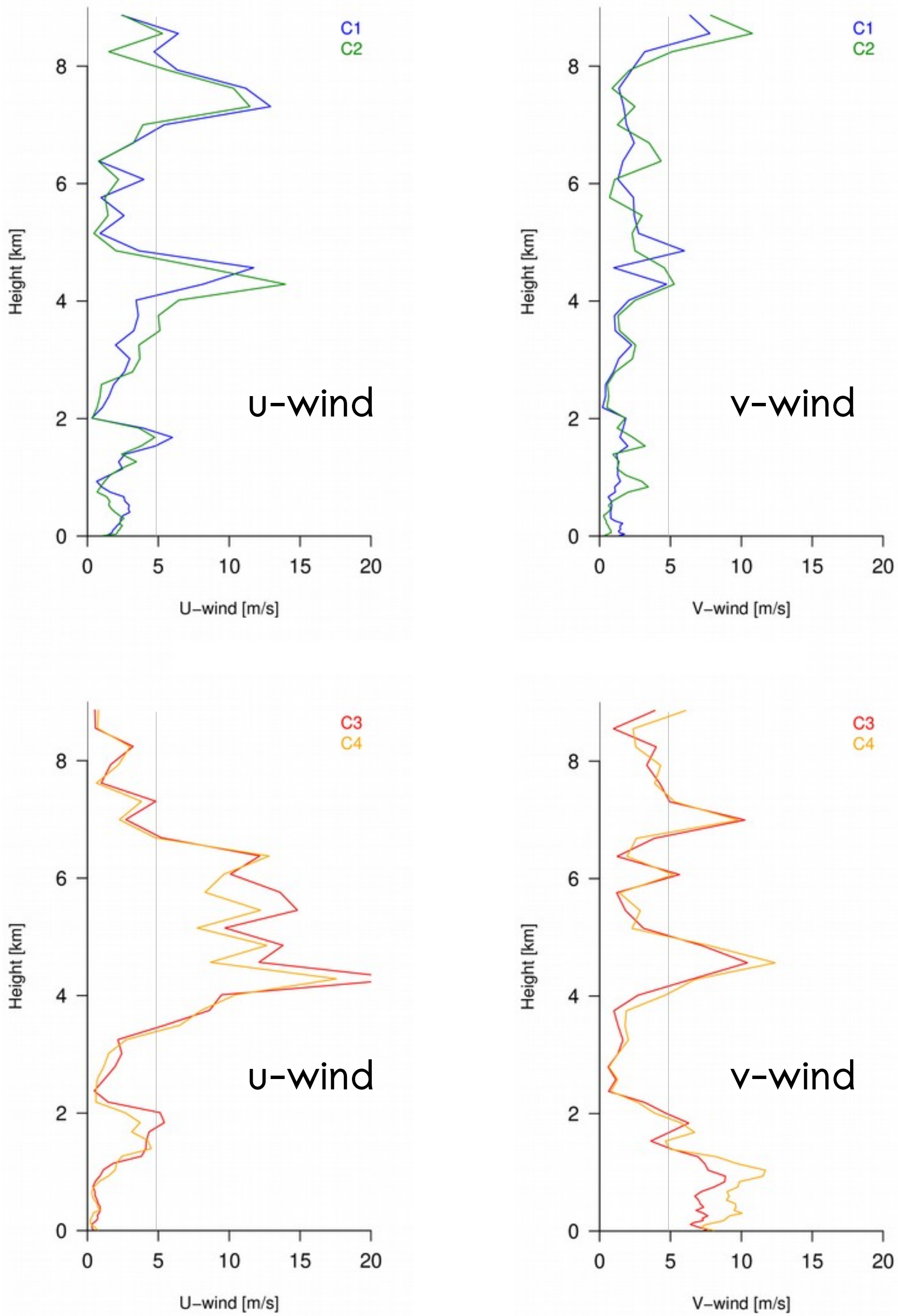
The convective mass flux at cloud base can be estimated from the mass budget of the subcloud layer





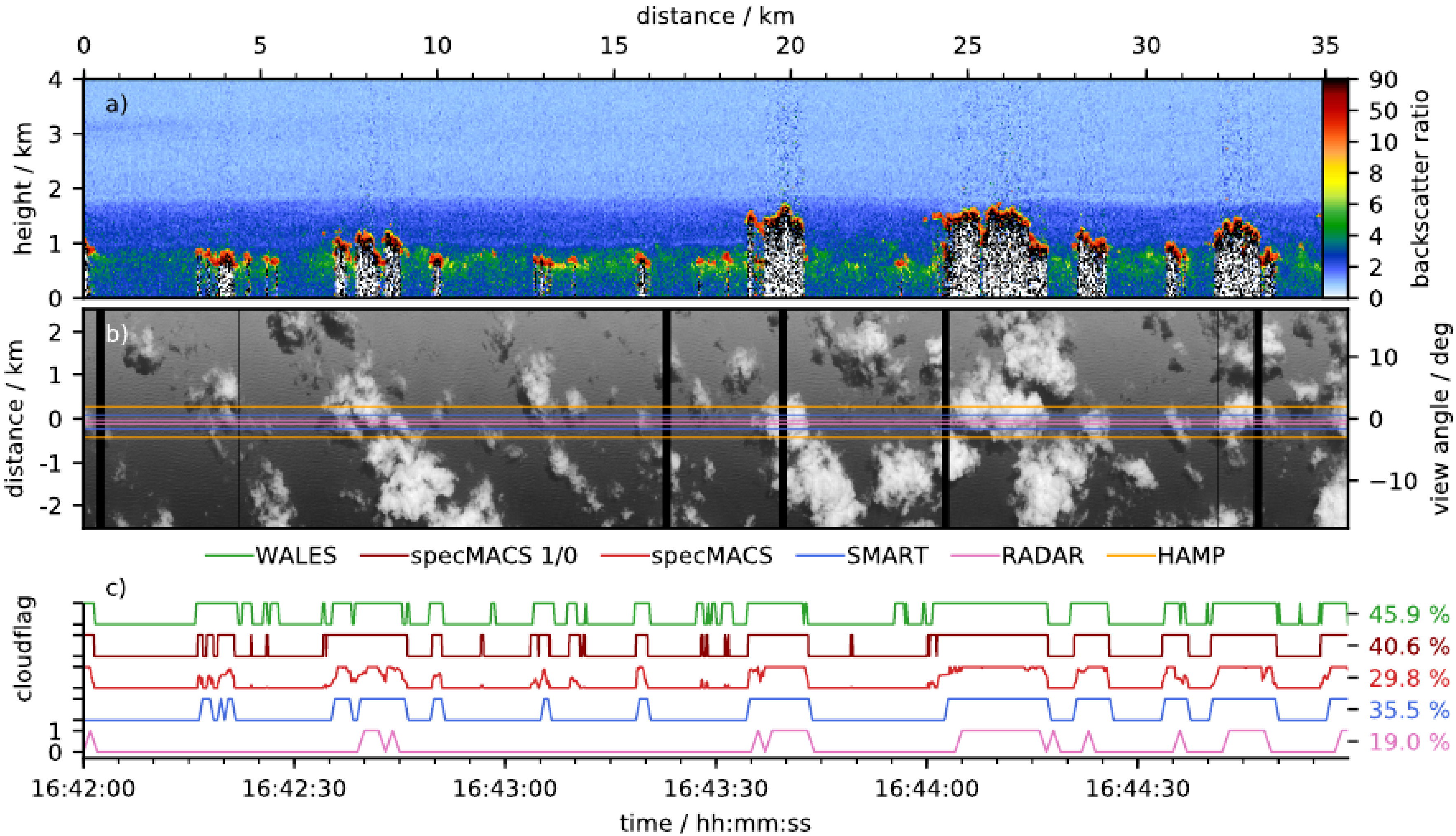
Vogel et al. (submitted)

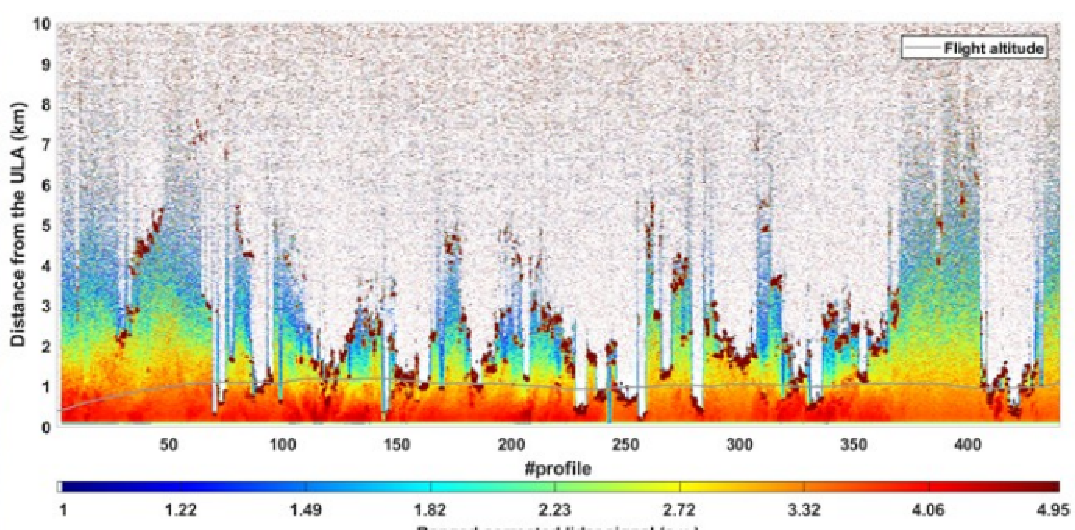
RMS error of ECMWF forecasts

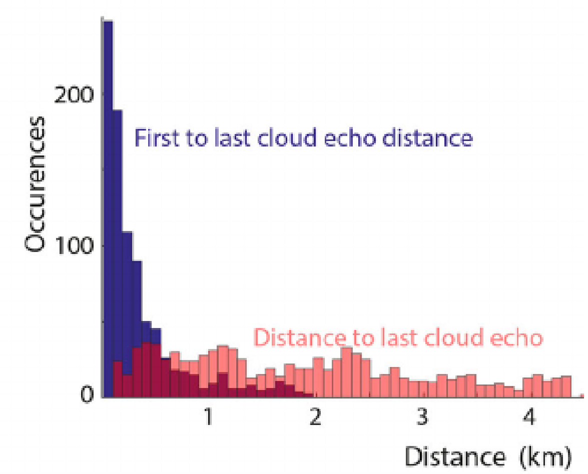


u-wind and v-wind in good agreement with observations

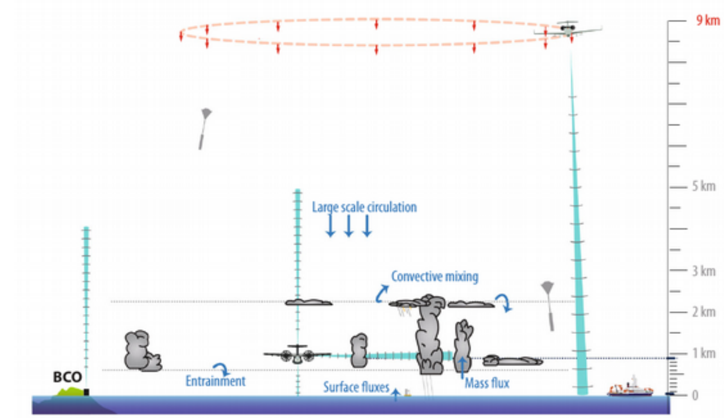
u-wind biased in the mid-troposphere
v-wind biased in the PBL


distance / km
0
5
10
15
20
25
30
35
height / km
a)
backscatter ratio
90
50
10
8
6
4
2
0
b)
distance / km
view angle / deg
WALES
specMACS 1/0
specMACS
SMART
RADAR
HAMP
c)
cloudflag
45.9 %
40.6 %
29.8 %
35.5 %
19.0 %
16:42:00
16:42:30
16:43:00
16:43:30
16:44:00
16:44:30
time / hh:mm:ss


Flight altitude
Distance from the ULA (km)
#profile
1
1.22
1.49
1.82
2.23
2.72
3.32
4.06
4.95
Ranged corrected lidar signal (a.u.)


Occurences
First to last cloud echo distance
Distance to last cloud echo
Distance (km)

Key EUREC^{4}A measurements:



Large-scale environment (u, v, T, q, D, V, ω):
- → vertical profiles (HALO: dropsondes + Dial WV lidar;
  BCO & Ships: soundings; meteorological analyses)
- → precipitable water (BCO + Ships: GPS; HALO: microwave)
- → in-situ at flight level (ATR, HALO)

Clouds:
- → cloud amount and vertical distribution cloud layers (HALO: cloud radar + lidar + radiometers; ATR: radar, BCO)
- → cloud-base cloud fraction (ATR: sideways-looking doppler cloud radar + lidar)
- → cloud water content (ATR: in-situ + radar; HALO: microwave)
- → cloud particles size (ATR: in-situ + radar; HALO: radiometers; Ship: Helikite)

Radiative profiles (upward and downward LW and SW fluxes):
- → TOA (satellites: CERES, Megha-Tropiques)
- → upper troposphere (HALO: radiometers)
- → subcloud and cloud layer (ATR: radiometers; Drone?)
- → surface (BCO & Ships: radiometers)

Convective mass flux at cloud base:
- → from mass budget (dropsondes + turb. fluxes)
- → from doppler cloud radar (ATR)

Turbulent fluxes:
- → PBL (ATR: T, q, V at 25 Hz + Doppler spectrum from radar)
- → surface (Ships; Buoys?)

Mesoscale organization:
- → satellite imagery (GOES-16, MODIS, ASTER?, HR)
- → ATR: cloud wind above the aircraft from doppler radar
- → Boreal drone? other platforms (e.g. saildrones)?

Precipitation:
- → scanning C-band radar (on Barbados)
- → others?

Aerosols:
- → in-situ (ATR: in-situ from 60 nm; Ships)
- → vertical profiles: (HALO: lidar, radiometers;
  Ships: Helikite)

Water isotopes (laser spectrometry):
- → subcloud-layer and just above (ATR)
- → surface (BCO; Ships)
- → free troposphere (satellites)

Sea surface temperature:
- → ATR; HALO; Ships; satellites
- → autonomous vehicles

HALO:

- Ka-band Doppler radar
- WALES (aerosol and DIAL WV lidar)
- SMART
- SpecMACS
- Dropsondes
- HAMP (26 radiometers)
- Thermal imager
- Up and downward broadband irradiances
- Split window radiometric SST

ATR-42:

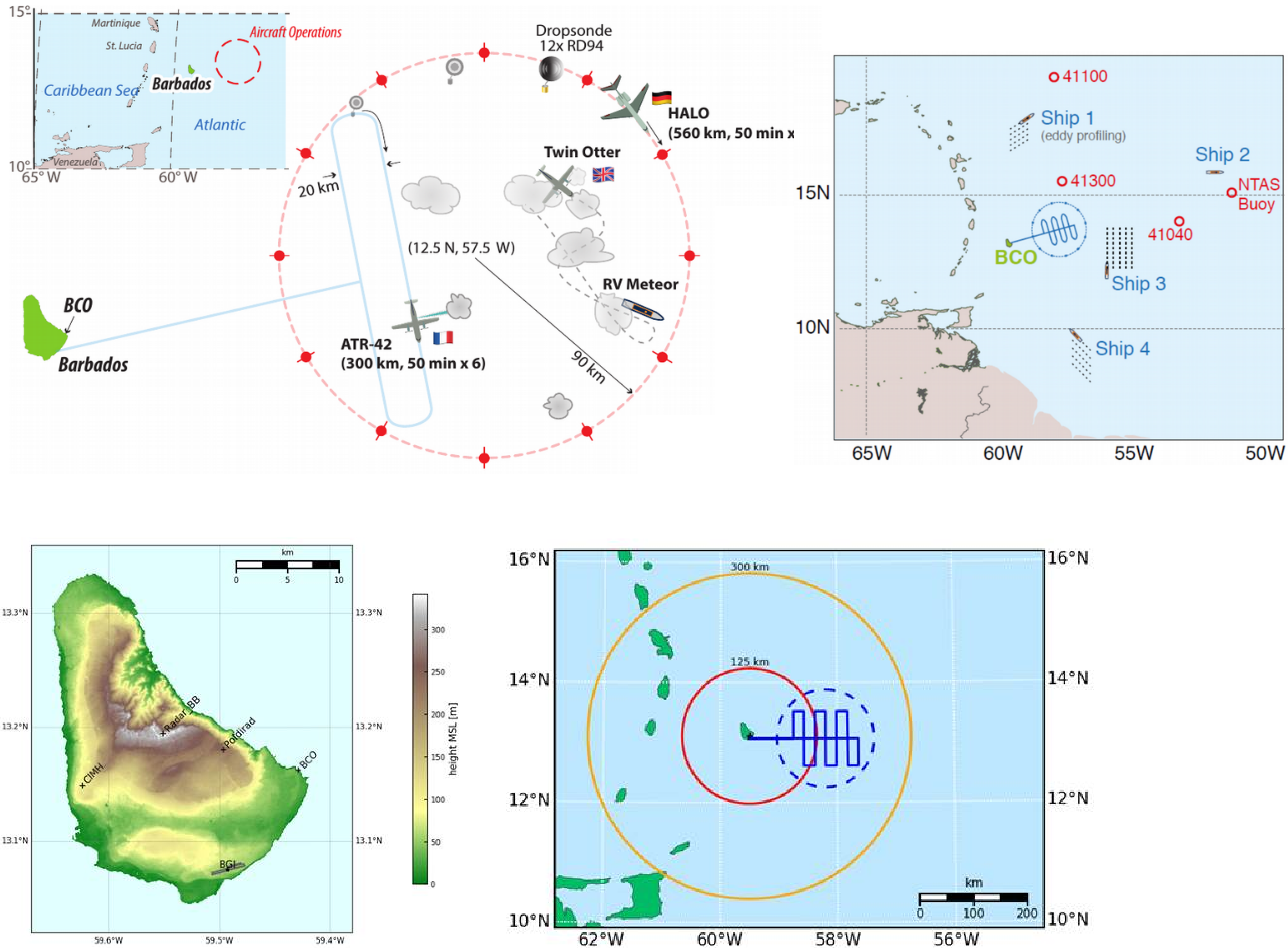
- RASTA (95 GHz Doppler cloud radar, -30 dBZ@1km)
- BASTA (95 GHz Doppler radar, sideward staring, -35dBZ@1km)
- AliAS backscatter 355 nm lidar, sideward staring
- Fast sensors (q, T, u, v, P @ 25Hz) for turbulent fluxes
- U, V, T, q, P + liquid water content
- Upward and downward broadband radiative fluxes
- Particle size (50 nm to several mm)
- Laser spectrometer for water isotopes
- Three-channel infrared radiation for SST measurement

BCO:

- Ka, W, and scanning C-band radar
- Water vapor Raman lidar
- Wind lidar
- Surface radiation
- Microwave radiometer
- Optical disdrometer
- Ceilometer
- Surface meteorology

Meteor:

- Heli-Kite with cloud probe
- Raman lidar
- Wind lidar
- Ceilometer
- 94 GHz cloud radar
- Precipitation radar?
- Microwave radiometer (MWR)
- Cloud LWP and precipitable water
- Laser spectrometer for water isotopes
- UV-VIS-NIR transmission, sunphotometer
- Soundings
- Air-Sea flux and gas exchange



Martinique
St. Lucia
Aircraft Operations
Caribbean Sea
Barbados
Atlantic
Venezuela
15°
10°
65° W
60° W
BCO
Barbados
Dropsonde
12x RD94
HALO
(560 km, 50 min x
Twin Otter
20 km
(12.5 N, 57.5 W)
RV Meteor
ATR-42
(300 km, 50 min x 6)
90 km
41100
Ship 1
(eddy profiling)
Ship 2
41300
NTAS
Buoy
15N
41040
BCO
Ship 3
10N
Ship 4
65W
60W
55W
50W
km
0
5
10
13.3°N
13.2°N
13.1°N
Radar BB
Poldirad
BCO
CIMH
BGI
59.6°W
59.5°W
59.4°W
height MSL [m]
300
250
200
150
100
50
0
16°N
14°N
12°N
10°N
300 km
125 km
km
0
100
200
62°W
60°W
58°W
56°W