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
EUREC4A: 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 • Raphaëla Vogel • Manfred Wendisch • Martin Wirth

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?
How sensitive is the Earth’s climate?
How sensitive is the Earth’s climate?

High climate sensitivity models predict a dessication of clouds at their base, that depends on the strength of vertical mixing in the lower troposphere.
Tradewind clouds: also a challenge for NWP and satellite retrievals

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

Stevens et al. (2001), Siebesma et al. (2003), van Zanten et al. (2011)
Cloud properties from LES are not necessarily the truth.

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

How do clouds vary with the large-scale environment? (e.g. $\omega$, lower-tropospheric mixing)

→ Need a field campaign that:
  • characterizes both the clouds and the environment in which the clouds form
Cloud properties from LES are not necessarily the truth.

How do clouds vary with the large-scale environment? (e.g., $\omega$, lower-tropospheric mixing)

→ Need a field campaign that:
  - characterizes both the clouds and the environment in which the clouds form
  - considers the elephant in the room

Stevens et al. (2001), Siebesma et al. (2003), van Zanten et al. (2011)
Mesoscale organization of shallow clouds

MODIS satellite imagery, 12 Feb 2018
Mesoscale organization of shallow clouds
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
EUREC4A: 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 EUREC4A field campaign will occur East of Barbados between 20 January - 20 February 2020.

Why is Barbados relevant?
Why is Barbados relevant?

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

Brian Medeiros\textsuperscript{a,1} and Louise Nuijens\textsuperscript{b,2}

\textsuperscript{a}National Center for Atmospheric Research, Boulder, CO 80307; and \textsuperscript{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)
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
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)
EUREC4A 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
EUREC4A experimental strategy

Aircraft Operations

- Gulfstream G5 HALO (DLR, DE)
- ATR-42 (SAFIRE, FR)

Barbados

Dropsonde 12x RD94

HALO (560 km, 50 min x 8)

Twin Otter (560 km, 50 min x 8)

RV Meteor

(12.5 N, 57.5 W)

BCO

Barbados

(300 km, 50 min x 6)

20 km

Gulfstream G5 HALO (DLR, DE)

ATR-42 (SAFIRE, FR)
EUREC4A experimental strategy

- Gulfstream G5 HALO (DLR, DE)
- ATR-42 (SAFIRE, FR)
- Twin Otter (BAS, UK)

New!
EUREC4A experimental strategy

- Gulfstream G5 HALO (DLR, DE)
- ATR-42 (SAFIRE, FR)
- Twin Otter (BAS, UK)
- Boreal Drone (CNRM, FR)
- Dropsonde 12x RD94
- HALO (560 km, 50 min x 8)
- Twin Otter (560 km, 50 min x 8)
- RV Meteor
- (12.5 N, 57.5 W)
- ATR-42 (300 km, 50 min x 6)
EUREC4A experimental strategy

- Barbados Cloud Observatory (MPI, DE & CIMH, BB)
- Poldirad C-band radar (DLR, DE)
- R/V Meteor (DE)
- HeliKite (DE)

Aircraft Operations

- HALO (560 km, 50 min x 8)
- Twin Otter
- RV Meteor

BCO

Barbados

(12.5 N, 57.5 W)

20 km

(300 km, 50 min x 6)

90 km
EUREC^4A-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.
Key & novel measurements
What we want to observe

Macro & micro cloud properties

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

ATR-42: up/down looking radar (RASTA) + sideways looking 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

Bony and Stevens, JAS (2019)
The cloud-base convective mass flux can be estimated from the mass budget of the subcloud layer.

Vogel, Bony and Stevens (submitted)
How could NWP benefit from EURECA4?
How could NWP benefit from EUREC4A?

- Hundreds of dropsondes to be assimilated
How could NWP benefit from EUREC4A?

- Hundreds of dropsondes to be assimilated
- Evaluation of vertical profiles of divergence/vorticity/large-scale vertical velocity
How could NWP benefit from EUREC4A?

- Hundreds of dropsondes to be assimilated
- Evaluation of vertical profiles of divergence/vorticity/large-scale vertical velocity

<table>
<thead>
<tr>
<th>Dropsondes</th>
<th>NARVAL2 RF03</th>
<th>ECMWF forecasts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(12 Aug 2016)</td>
</tr>
</tbody>
</table>

C1-C2: good agreement
How could NWP benefit from EUREC4A?

- Hundreds of dropsondes to be assimilated
- Evaluation of vertical profiles of divergence/vorticity/large-scale vertical velocity

<table>
<thead>
<tr>
<th>Dropsondes</th>
<th>NARVAL2 RF03</th>
<th>ECMWF forecasts</th>
</tr>
</thead>
<tbody>
<tr>
<td>(12 Aug 2016)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

C1-C2: good agreement

C3-C4: not so good...
How could NWP benefit from EUREC$^4$A?

- Hundreds of dropsondes to be assimilated
- Evaluation of vertical profiles of divergence/vorticity/large-scale vertical velocity
- Evaluation of columnar water/energy budgets, mesoscale variances and PBL turbulent structures

Ø ~ 180 km
How could NWP benefit from EUREC4A?

- Hundreds of dropsondes to be assimilated
- Evaluation of vertical profiles of divergence/vorticity/large-scale vertical velocity
- Evaluation of columnar water/energy budgets, mesoscale variances and PBL turbulent structures

→ 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 EUREC$^4$A benefit from NWP?

- Before and during the campaign (flight planning):
  - Initialization of high-resolution (CRM/LES) simulations
How could EUREC$^4$A benefit from NWP?

- Before and during the campaign (flight planning):
  - Initialization of high-resolution (CRM/LES) simulations
  - Enhanced collection of process diagnostics?
How could EUREC\textsuperscript{4}A benefit from NWP?

- Before and during the campaign (flight planning):
  - Initialization of high-resolution (CRM/LES) simulations
  - Enhanced collection of process diagnostics?
  - Forecasts of cloud organization patterns?

MODIS imagery 9 Feb 2017

EUREC\textsuperscript{4}A u-blb720 Cloud amount
Thursday 1302 19/02/2017 (t+13h00)

Courtesy A. Lock
(Met Office)
How could EUREC\textsuperscript{4}A benefit from NWP?

- Before and during the campaign (flight planning):
  - Initialization of high-resolution (CRM/LES) simulations
  - Enhanced collection of process diagnostics?
  - Forecasts of cloud organization patterns?

- After the campaign:
  - High-resolution reanalysis of the 20Jan-20Feb period after EUREC\textsuperscript{4}A?
Thank you
The convective mass flux at cloud base can be estimated from the mass budget of the subcloud layer.

\[
\frac{D\eta}{Dt} = E + W - \frac{M}{\rho}
\]
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
**Key EUREC4A measurements:**

Large-scale environment \((u, v, T, q, D, V, \omega)\):
- 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

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

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

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