The Eastern North Atlantic ARM site: Clouds, aerosols and their interactions in the remote marine boundary layer

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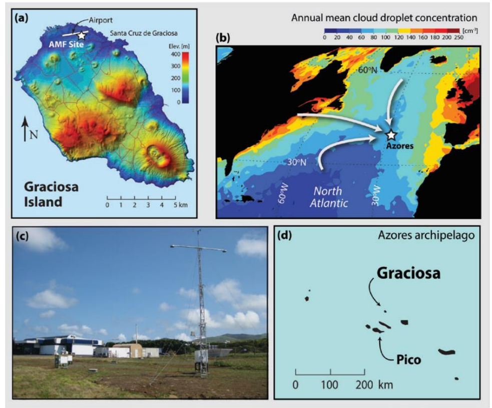
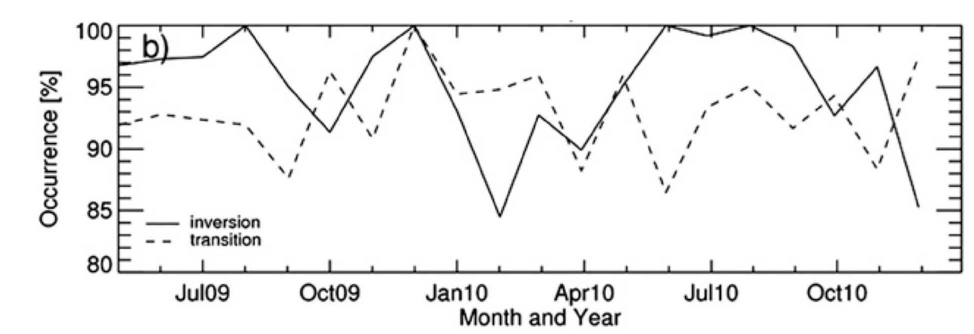
ENA Site Science



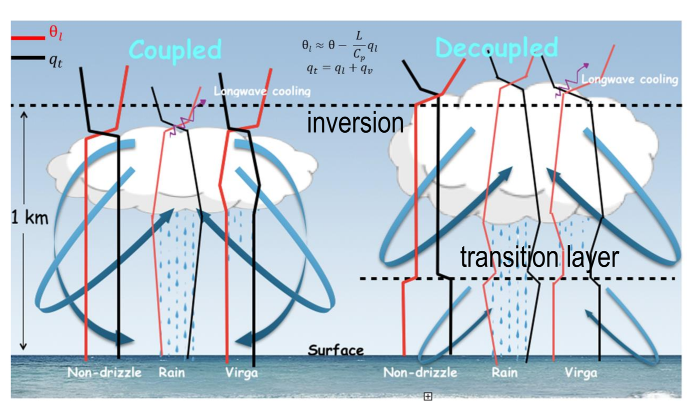
- Theme 1. Acquire process-based understanding of cloud microphysical-macrophysical interactions across scales
- Theme 2. Understand how microphysical-macrophysical interactions depend upon and influence the aerosol and meteorological environment
- Theme 3. Assess and improve process and climate model representations of clouds, aerosols and their interactions.

Cloud droplet concentration and CCN in the coupled and decoupled MBL

- A coupled marine boundary layer (MBL) is defined as one with liquid water potential temperature difference (surface- Sc cloud base) $\Delta\theta_L < 0.5$ K and total water mixing ratio difference $\Delta q_t < 0.5$ g kg^{-1} below the cloud base
- The marine boundary layer at Graciosa is decoupled more than 90% of the time (Rémillard et al. 2012)
- Coupled stratocumulus topped boundary layer (STBL) depths are shallow (typically < 1 km), while decoupled are thicker (typically > 1 km)
- Cloud droplet concentration is much more strongly correlated with surface CCN concentration under coupled conditions

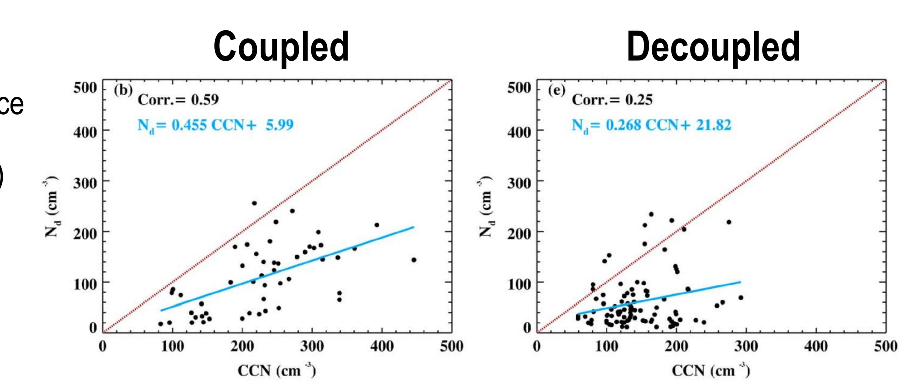


▲ Frequency with which inversions (solid line) and transition layers (dashed line) are found at Graciosa during CAP-MBL



◄ Schematic diagram showing the characteristics of coupled and decoupled boundary layer when stratocumulus cloud is present at the top of the MBL [from Dong et al. 2015]. The presence of a transition layer with jumps in moisture and potential temperature is characteristic of a decoupled MBL.

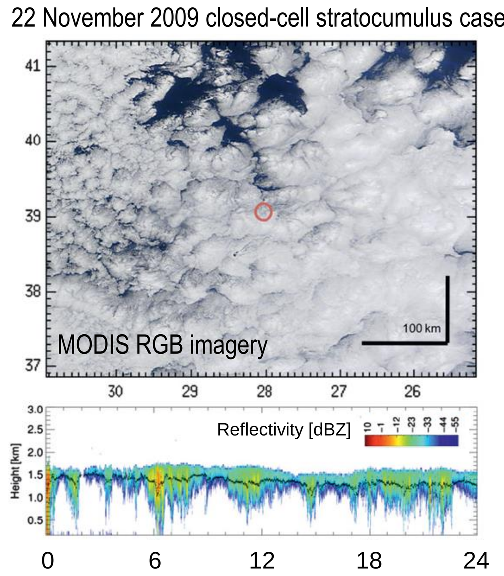
► Cloud droplet concentration vs surface CCN concentration (0.2% supersaturation) for coupled (left) and decoupled (right) stratocumulus-topped boundary layers [from Dong et al. 2015]



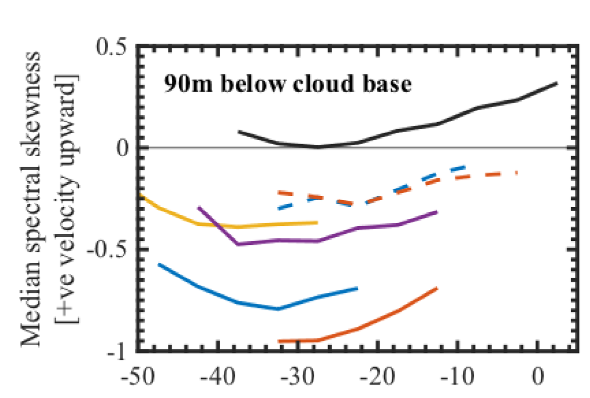
Constraining precipitation in process and large scale models

Using W-band Doppler spectra to confront and improve LES microphysics

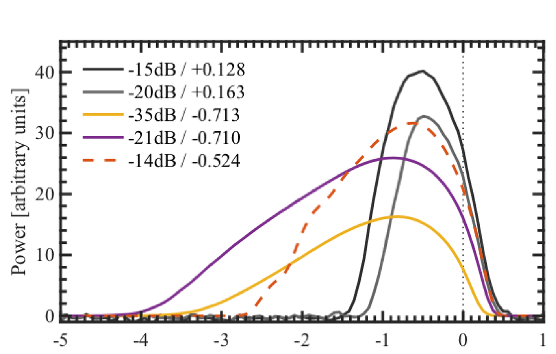
22 November 2009 closed-cell stratocumulus case



► **LES models produce too many large drizzle drops**: Excessive negative skewness just below cloud base in LES model-derived Doppler spectra compared with W-band radar.



◄ Simulated drizzle DSDs (esp. from DHARMA) produce spurious negative Doppler spectral skewness below cloud base compared with W-band data, indicating systematic errors in simulated DSD shape.

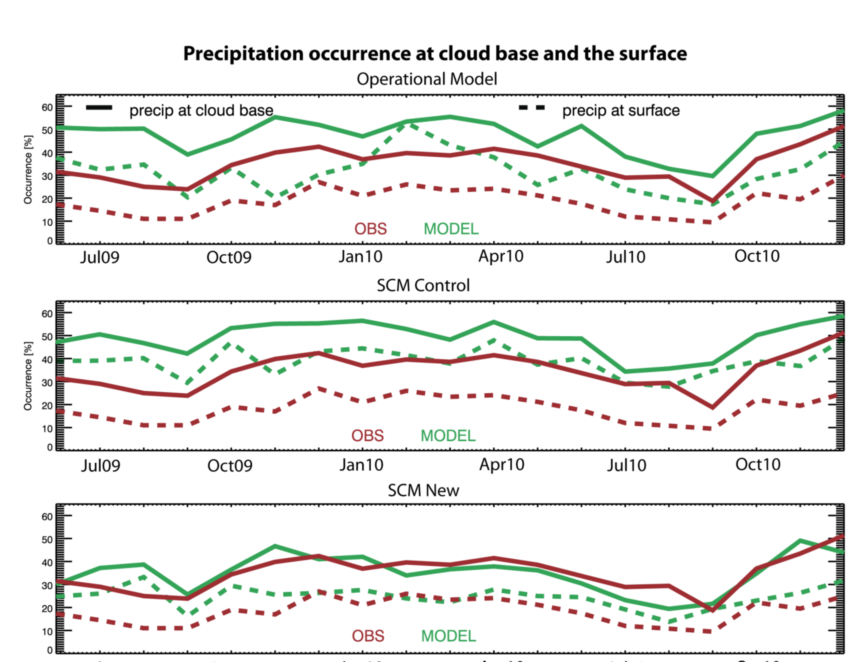


Next Steps:

- Use aircraft DSD measurements (VOCALS, ACE-ENA) to forward model radar Doppler spectra
- Use 1D model framework with LES microphysics to improve DSD evolution

Improving drizzle occurrence statistics in the ECMWF IFS

Many global models overestimate the occurrence of light surface precipitation. Radar retrievals at ENA provide an observational estimate of the frequency of precipitation occurrence that are being used to constrain and improve the ECMWF model

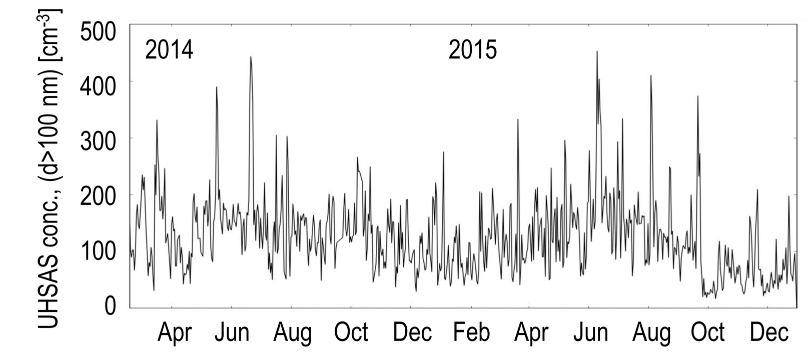


◄ Monthly precipitation occurrence is shown for the CAP-MBL period (observations in red).

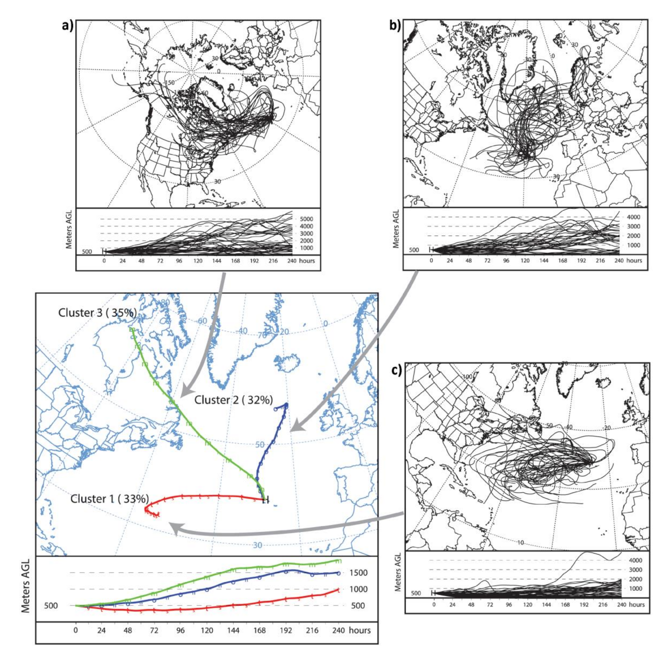
Both the operational and SCM version of the ECMWF model (green) overestimate precipitation occurrence at the cloud base and the surface, indicating that too much drizzle is generated in-cloud, and not enough evaporates below cloud base.

Changes to the autoconversion, accretion and evaporation schemes lead to a better agreement with observations in a modified version of the SCM [Ahlgrimm and Forbes 2014].

Aerosol variability



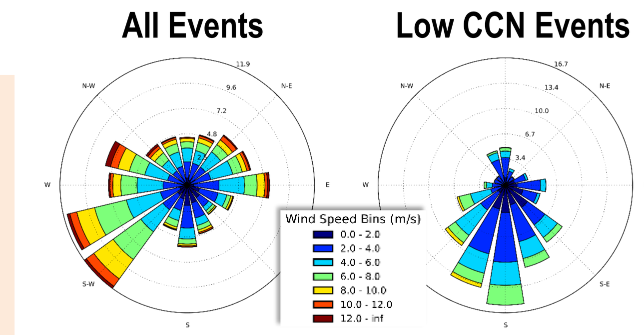
▲ Daily median accumulation mode concentration (UHSAS) at the ENA site during 2014-2015 shows robust seasonal cycle with maximum concentration during summer months and minimum in winter



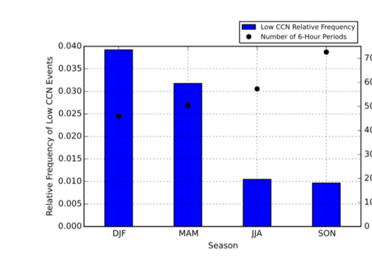
◄ Clusters of trajectories arriving at Graciosa during the summer period (May–Aug 2009) showing the three primary clusters representing (a) North American, (b) Arctic/northern European, and (c) recirculating Azores high flow. Daily HYSPLIT trajectories (NCEP GDAS meteorological data) determine trajectory motion. A cluster analysis was then performed on the resulting back-trajectory set and a three-cluster solution was found to capture most of the variance (Wood et al. 2015)

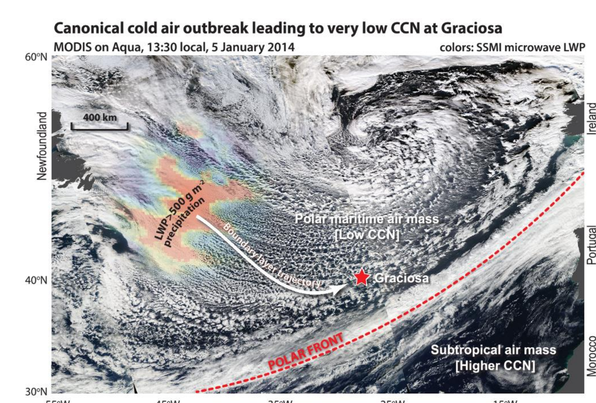
Low CCN events

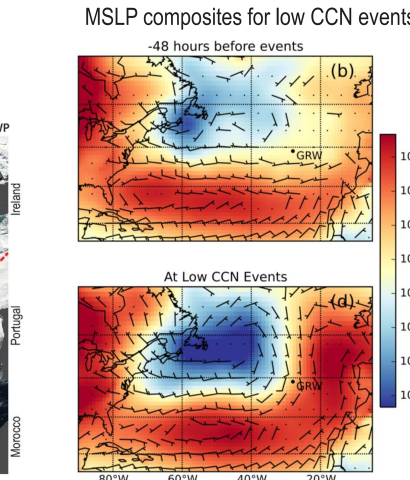
- Defined as 6 hr mean CCN concentrations (0.1% supersaturation) below 20 cm^{-3}.
- Low CCN events occur more often in winter and spring, have low cloud droplet concentrations (not shown), and are often associated with cold air outbreaks.
- Upstream, satellite data show high LWP regions that may be responsible for cleaning the MBL before arrival at Graciosa.



▲ Wind roses for low CCN events show weaker winds and southerly flow. However, SLP composite maps ▼ indicate that low CCN events occur when synoptic lows are present to the west and north of Graciosa. Trajectories show preference for association of low CCN events with continental and marine cold air outbreaks upstream



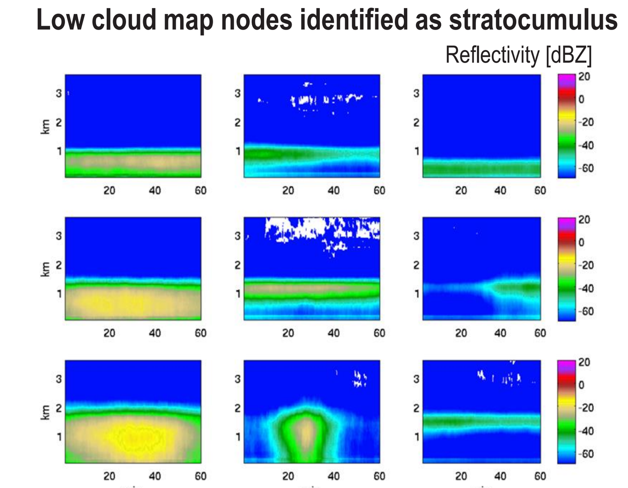




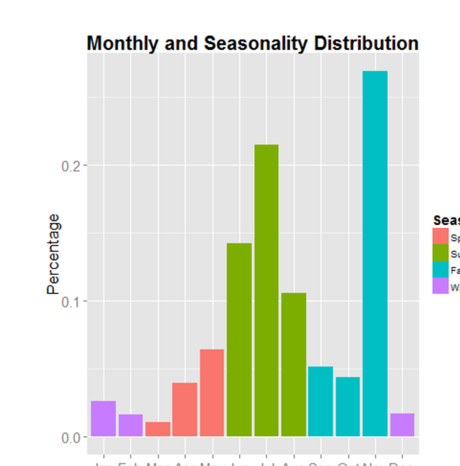
Cloud Classification via Self-Organizing Map Algorithm

The ultimate goal is to objectively identify stratocumulus cloud types using WACR radar data

Low cloud map nodes identified as stratocumulus

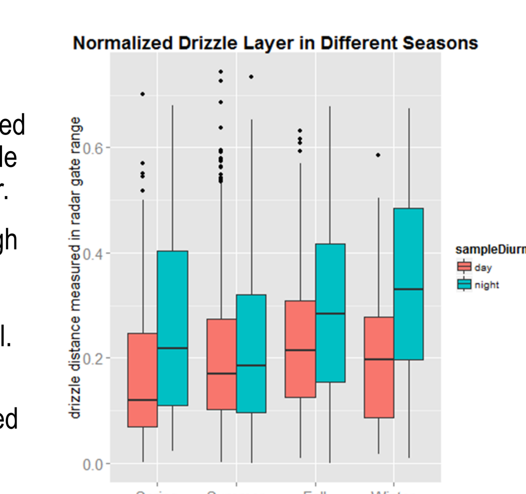


- CAP-MBL data were divided into 1-hour-long segments and introduced into a modified unsupervised clustering algorithm known as a Self-Organizing Map (SOM).
- The second round of SOM (shown at left) produced refined map nodes and successful in differentiating stratocumulus from other cloud modes.
- SOM is a possible mechanism for automated cloud classification at ENA.



▲ Seasonality of SOM-classified stratocumulus frequency showing clear preference for summer

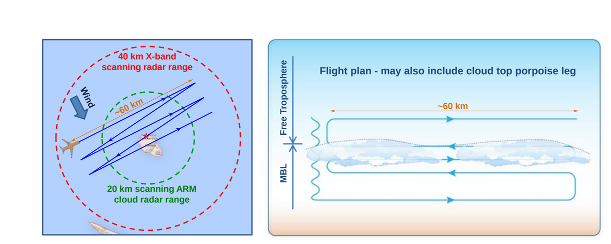
- Diurnal distribution of subcloud drizzle layer thickness in stratocumulus identified using SOM and normalized with respect to the height of cloud top (MBL Depth).
- Interpretation: For example, 0.4 means that 40% of the total MBL depth is occupied by evaporating drizzle in the subcloud layer.
- Depth of MBL through which falling drizzle evaporates is seasonal and diurnal.
- Largest diurnal difference is observed in stratocumulus during winter.



Aerosol and Cloud Experiments in Eastern North Atlantic (ACE-ENA)

Science Themes

- Budget of MBL CCN and its Seasonal Variation
- Effects of Aerosol on Clouds and Precipitation
- Cloud Microphysical and Macrophysical Structures, and Entrainment Mixing
- Advancing Retrievals of Turbulence, Cloud, Drizzle
- Model Evaluation and Processes Studies



Flight Plans

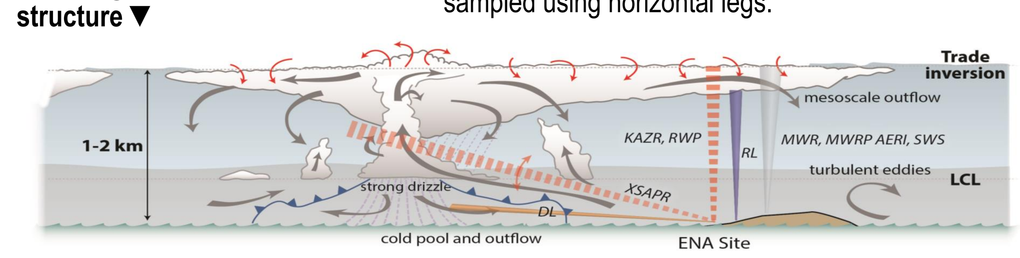
Lagrangian drift to characterize the vertical structure and mesoscale variation of thermodynamics, aerosol, cloud, and precipitation

Repeated spirals near the ENA site and straight and level runs at multiple altitudes, ~20-30 km in length

Aerosol profiling in FT - vertical profile up to 5000 m to identify potential elevated aerosol layers in the FT, which will be sampled using horizontal legs.

PI: Jian Wang (BNL)
DOE G-1 Aircraft
1st IOP (summer): 80 flight hours, June 15-July 25, 2017
2nd IOP (winter): 80 flight hours, January 11 – February 20, 2018

G-1 will complement ENA sampling of mesoscale structure ▼



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