The variability of clouds, aerosols and precipitation at the Azores from 21 months of AMF sampling

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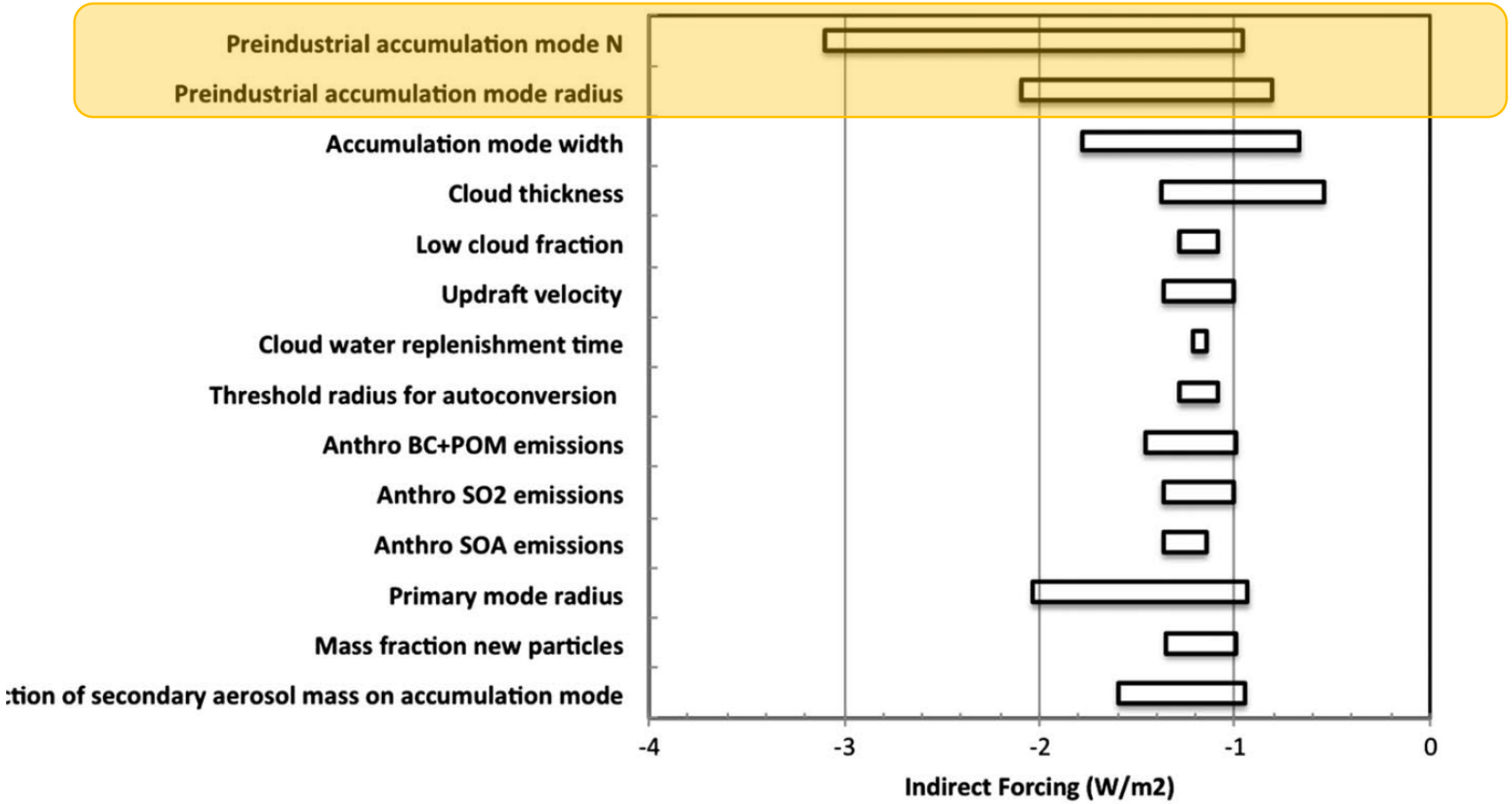
Photograph: Lagoa das Sete Cidades (Lagoon of the Seven Cities), São Miguel, Azores

Why the remote marine environment?

Factors controlling the magnitude and uncertainty of the global AIE



Ghan et al. (*J.Geophys. Res.*, 2013)

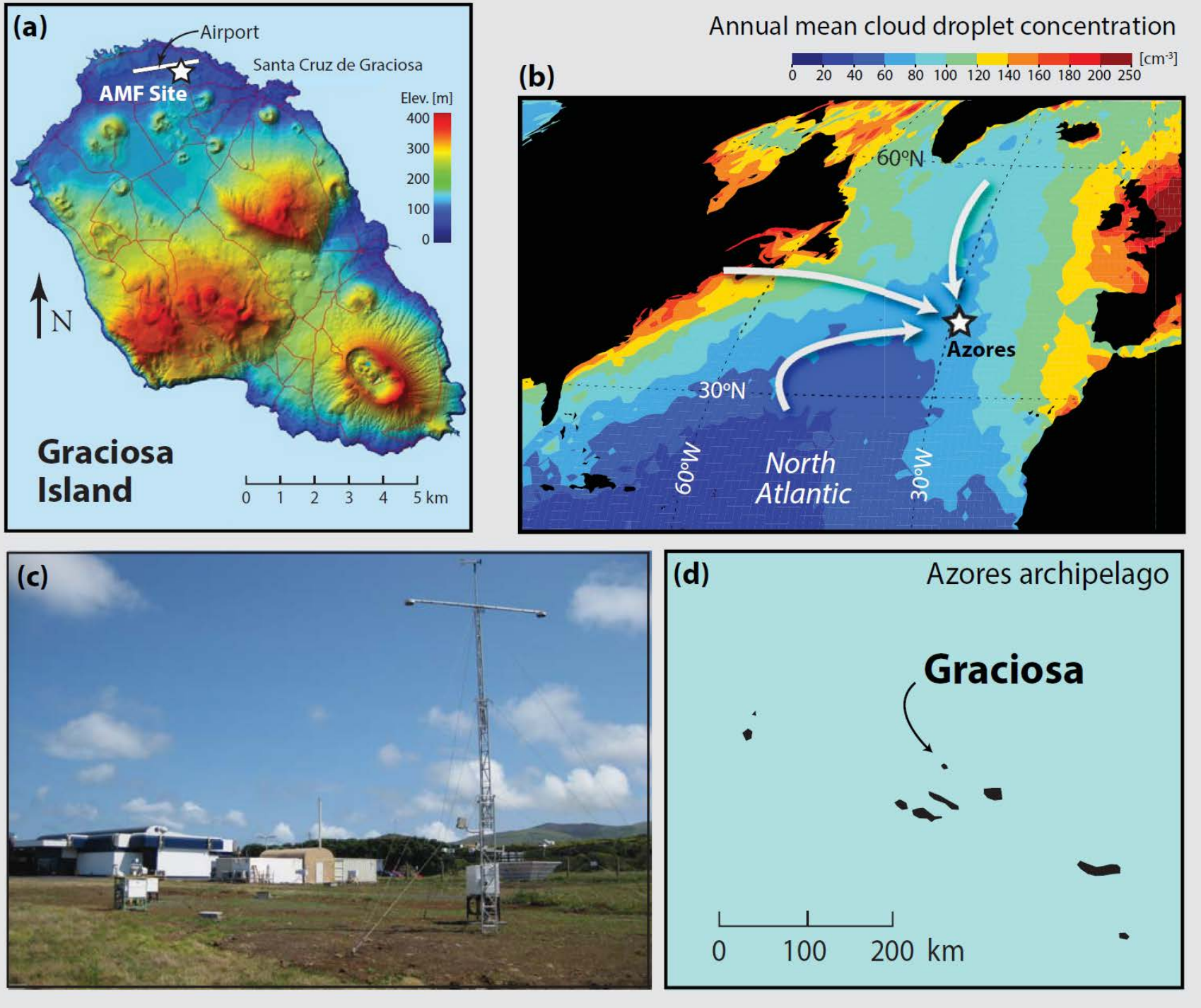
…..also Carslaw et al. (Nature, 2013)

Science questions

Table 1: The primary science questions addressed during CAP-MBL
• Which synoptic-scale features dominate the variability in subtropical low clouds on diurnal to seasonal timescales over the North East Atlantic? • Do physical, optical, and cloud-forming properties of aerosols vary with the synoptic features? • What is the variability in precipitation frequency and strength in the subtropical cloud-topped MBL on diurnal to seasonal timescales, and is this variability correlated with variability in aerosol properties? • Can we find observational support for the Twomey effect in clouds in this region? • Are observed transitions in cloud mesoscale structure (e. g. from closed cellular to open cellular convection) influenced by the formation of precipitation? • How well can state-of-the-art weather forecast and climate models (run in forecast mode) predict the day-to-day variability of cloud cover and its radiative impacts?

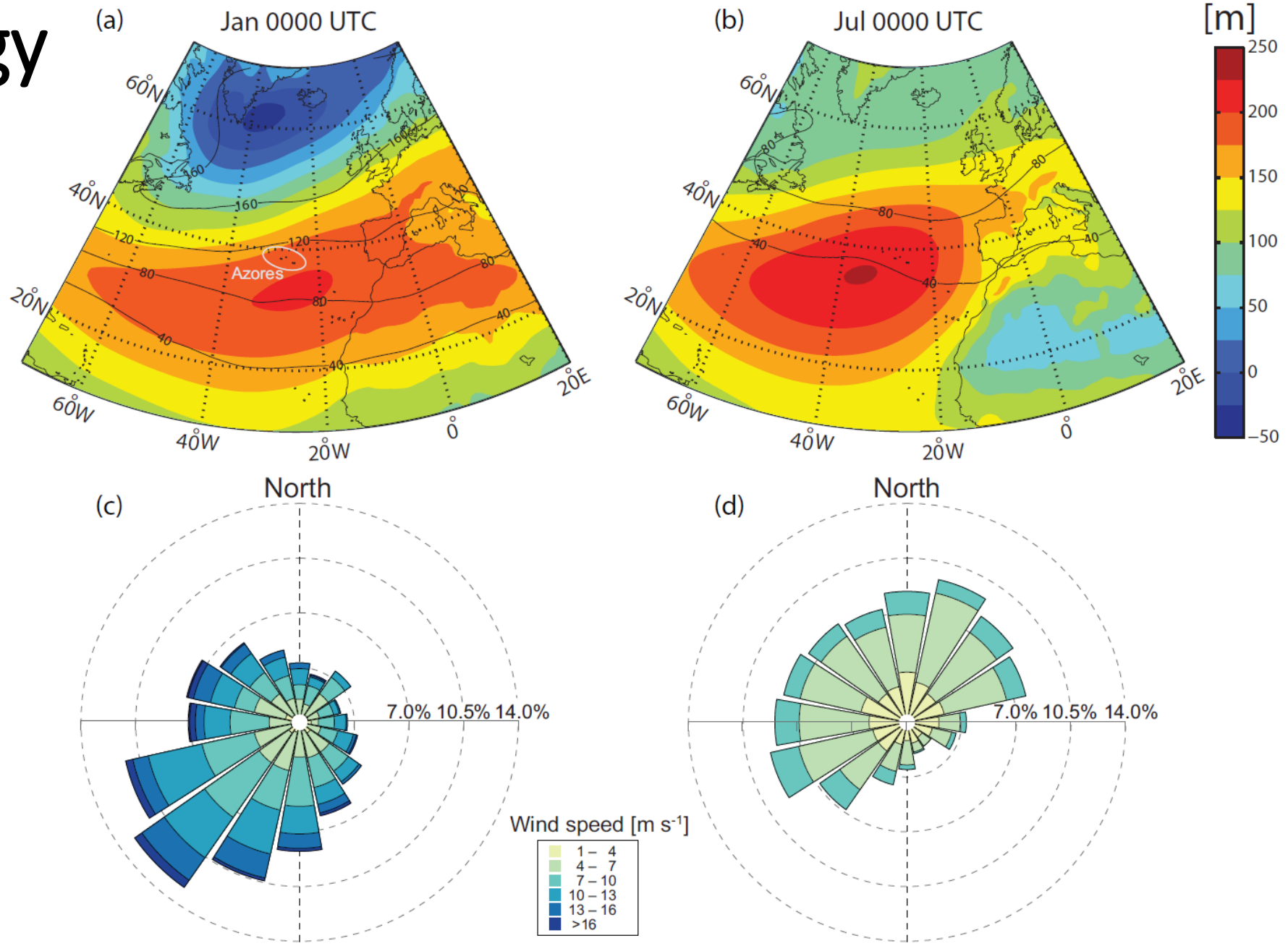
Graciosa

- Situated in the Azores archipelago in the eastern North Atlantic (39°N, 28°W)
- Straddles boundary between subtropics and extratropics
- Remote marine site, receiving air transported from North America, the Arctic, sometimes Europe
- AMF deployed for 21 months – April 2009 to December 2010



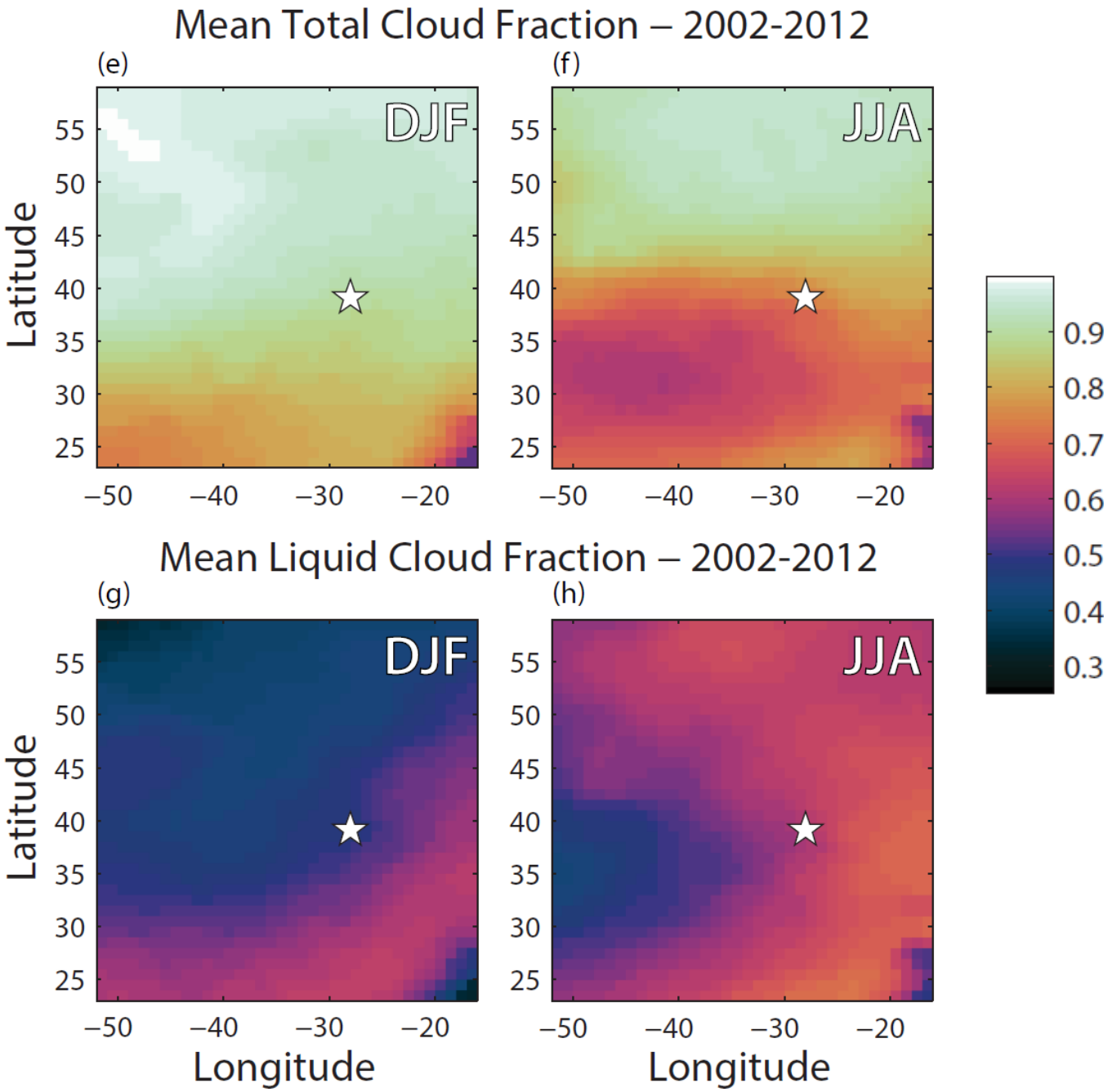
Meteorology

- Azores on southern edge of storm track during winter (left) and within subtropical high during summer (right)
- Winds from W/SW/S (winter); from W/N/NE (summer)
- Winds typically stronger in winter

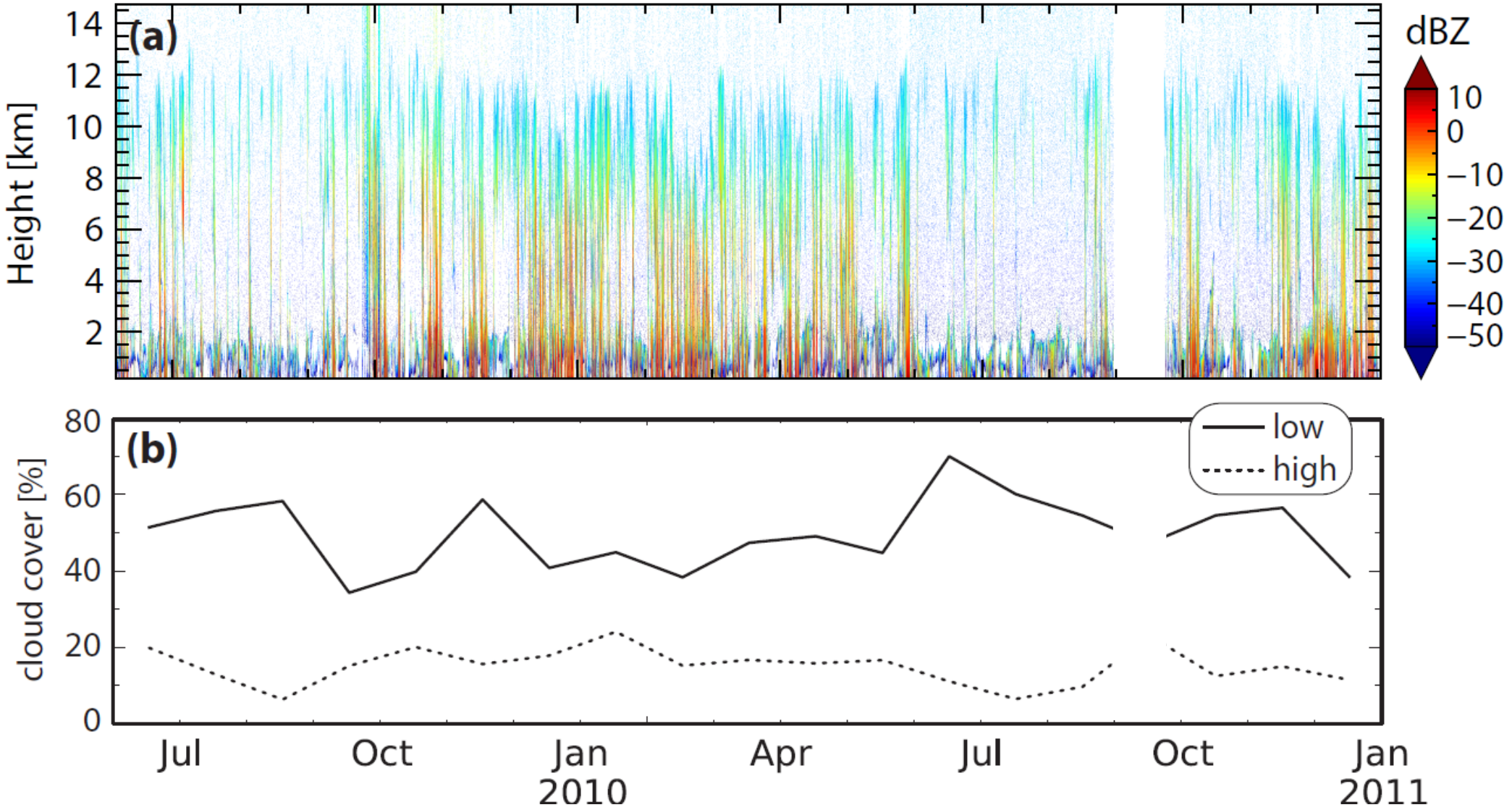


Cloud cover

- Extensive cloud cover all year round
- High clouds peak during winter - mask low clouds and deep clouds with bases in the PBL (Rémillard et al. 2012)
- Single layer low clouds peak during summer (Dong et al. 2014)



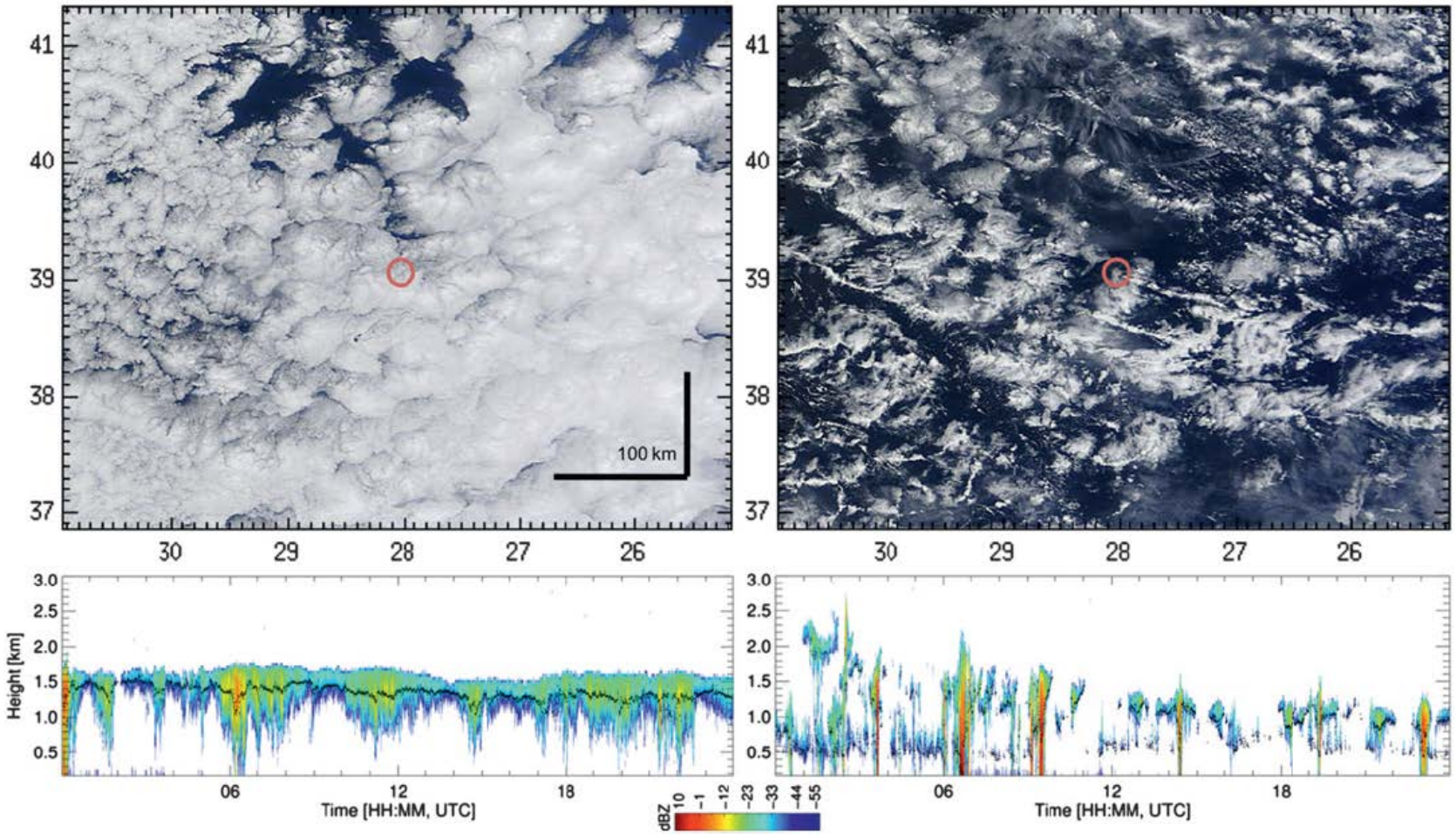
Radar - all 21 months



Low cloud variability

Stratocumulus, 22 Nov 2009

Trade Cu, 30 Aug 2010

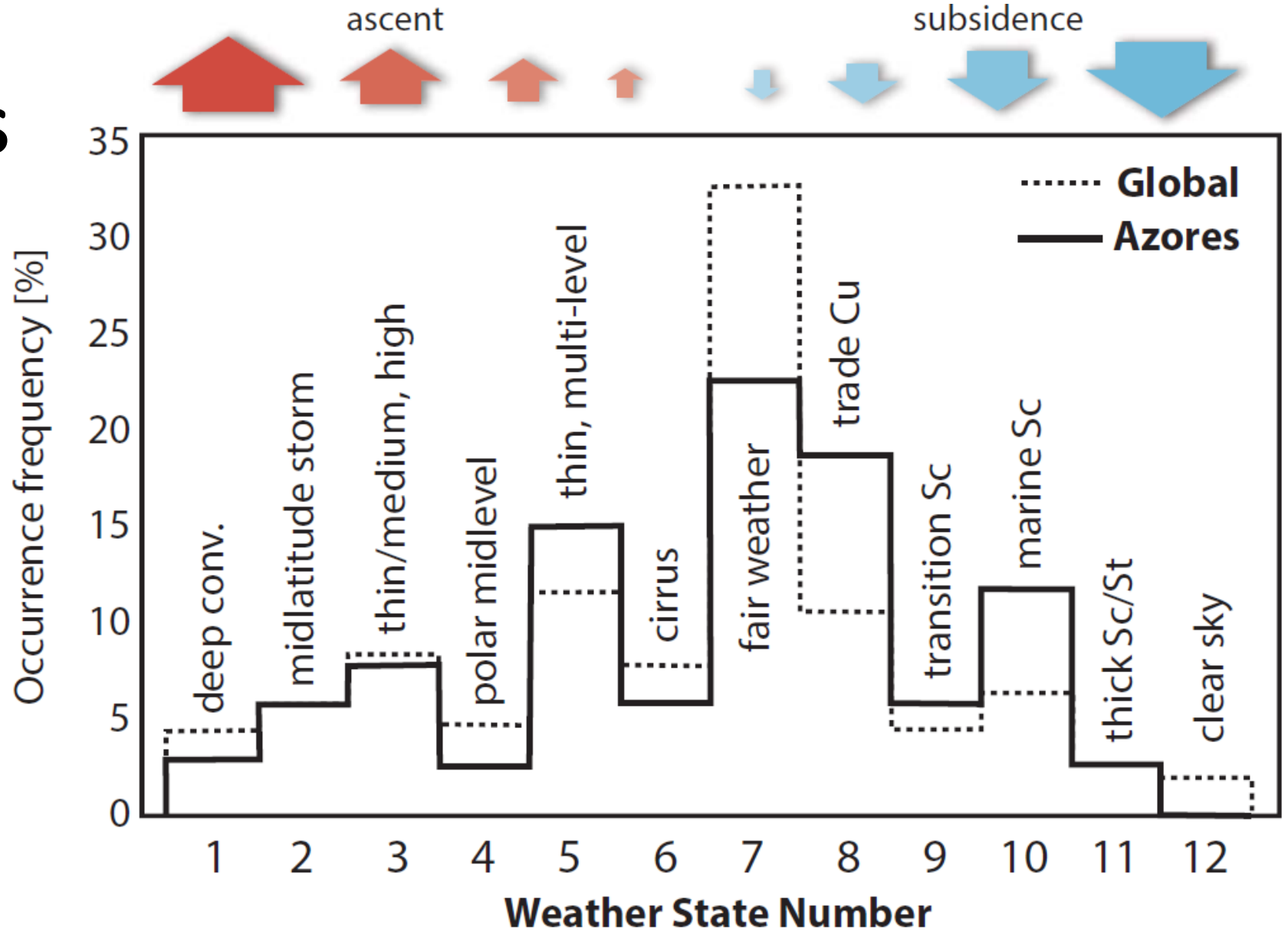


Rémillard et al. (2012, *J. Climate*)

Weather states

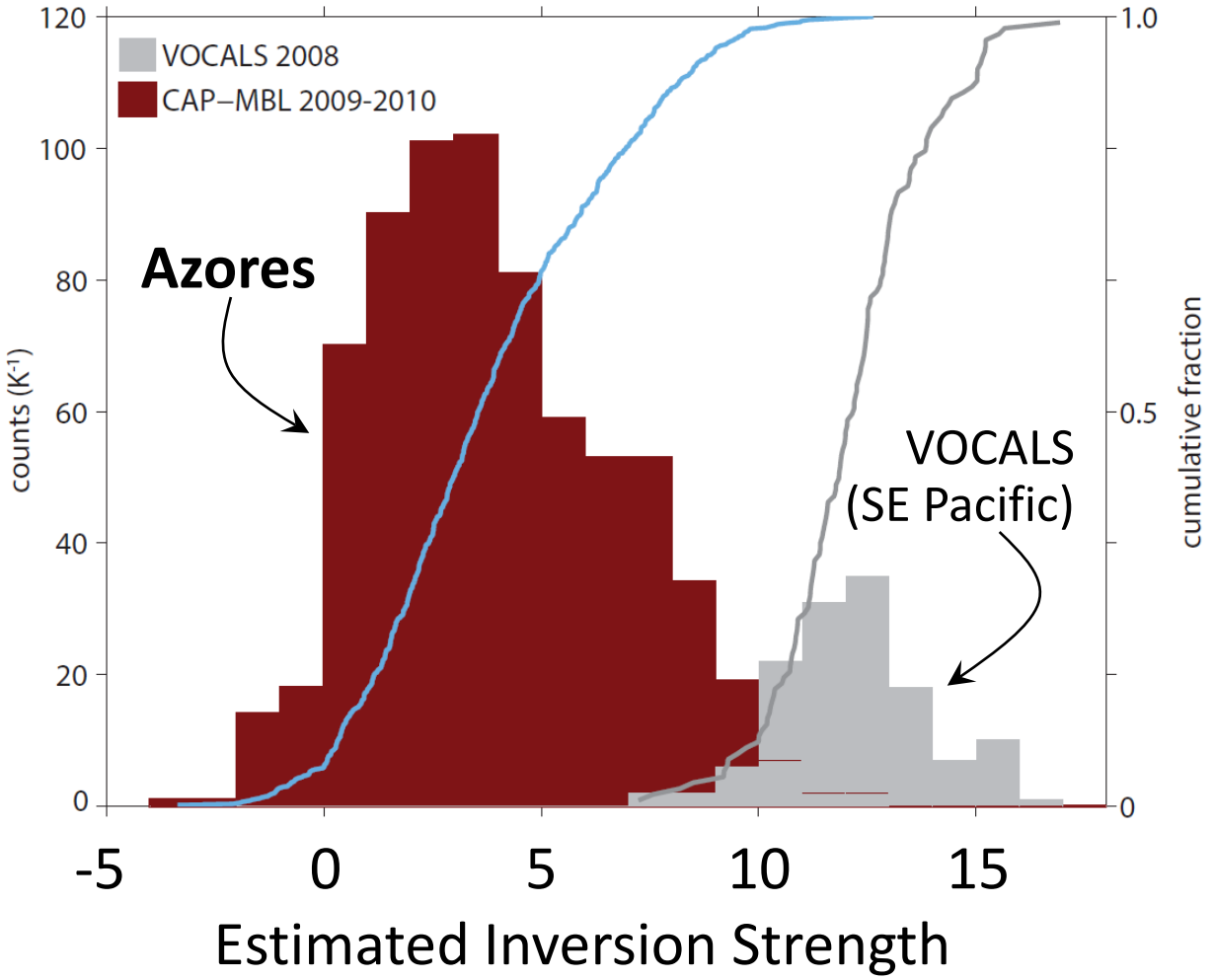
Azores states remarkably representative of the global weather states….

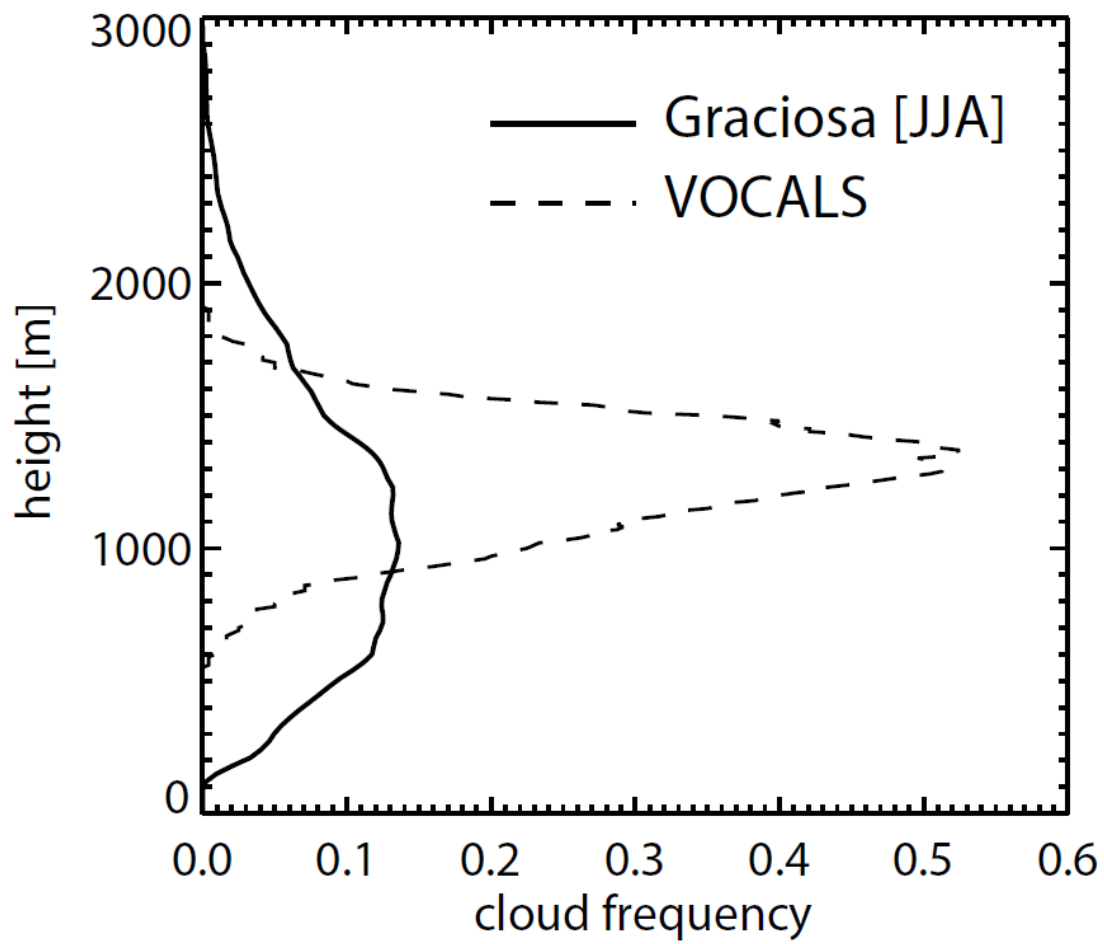
….but with more marine Sc and trade Cu



Tselioudis et al. (2014)

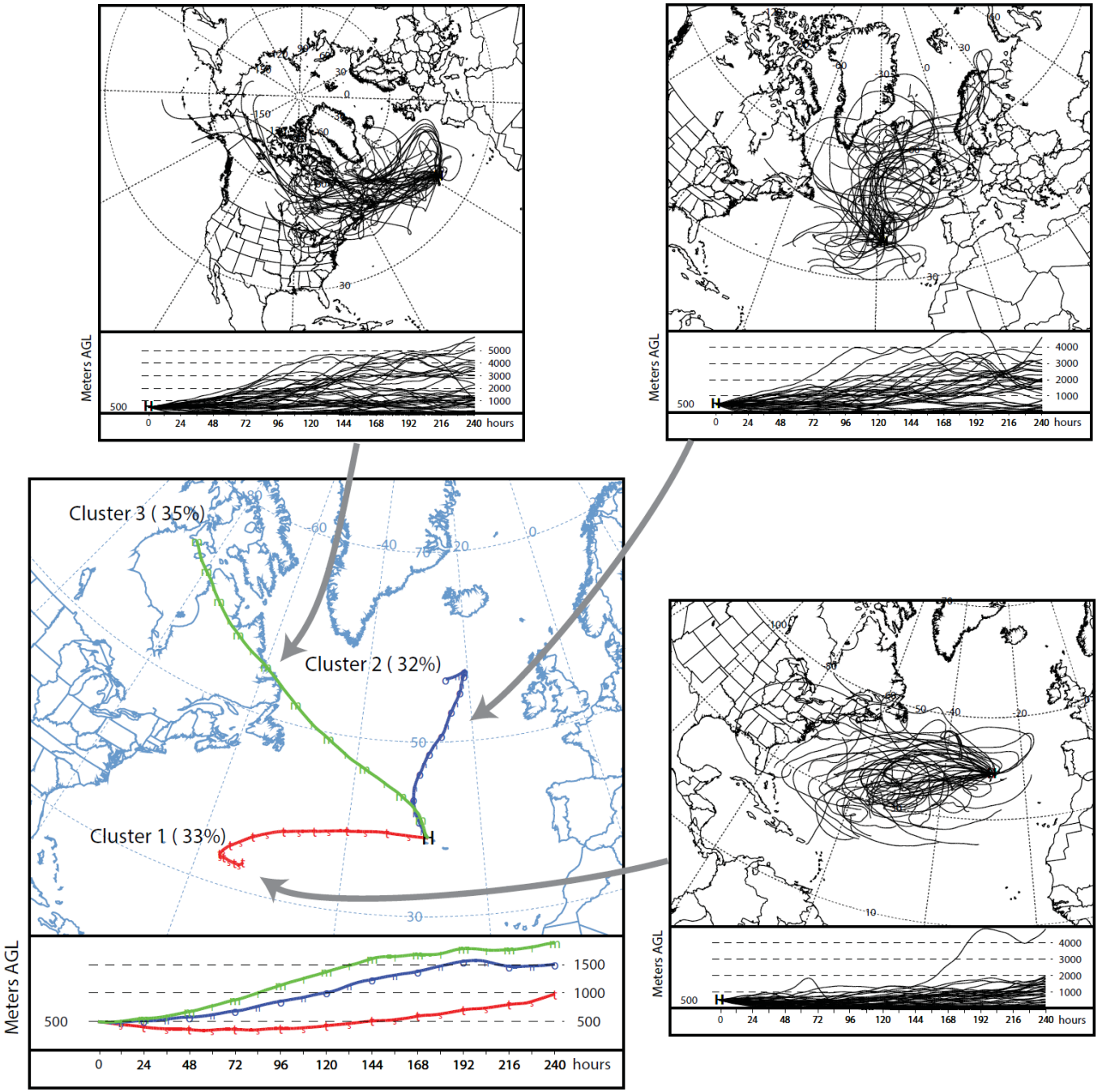
Much greater variability than “classical” subtropical stratocumulus regions





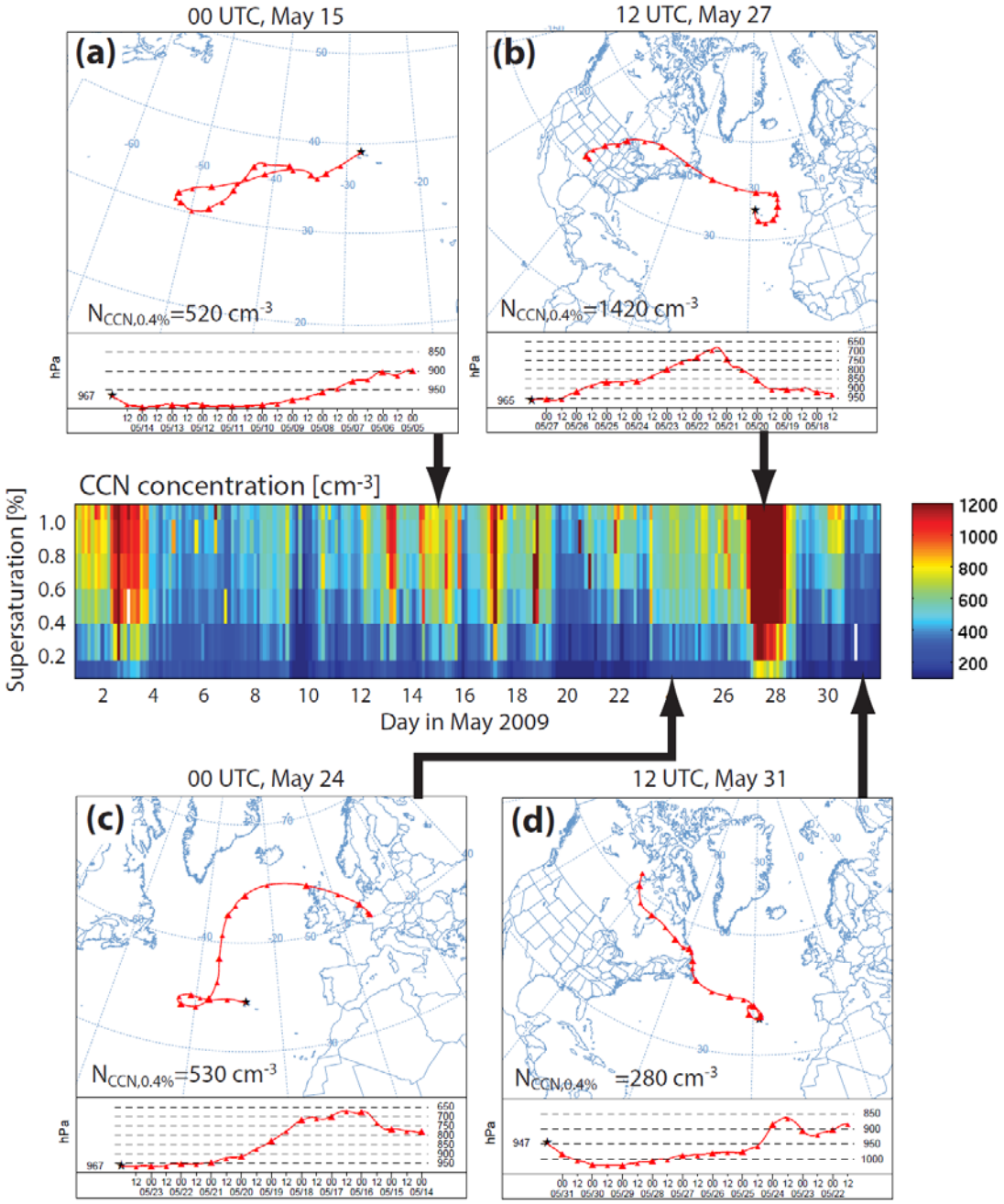
Air mass origins

- Back trajectory analysis (here shown for summer 2009 only) indicate dominant clusters of air mass origins from (a) North America; (b) recirculation around the subtropical high; (c) the Arctic

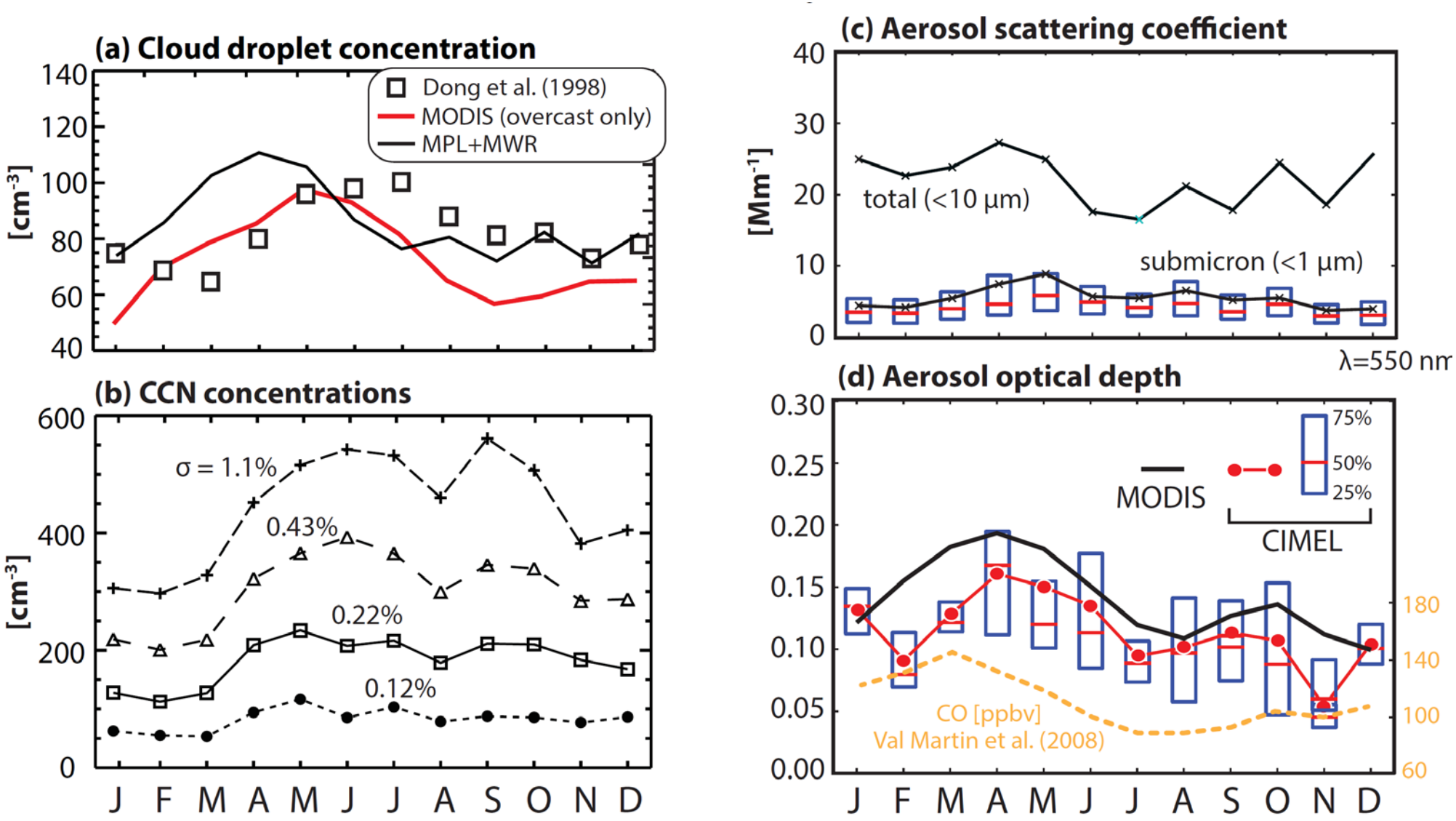


Example trajectories

- Difficult to connect CCN population observed at Graciosa with trajectory history in a straightforward way

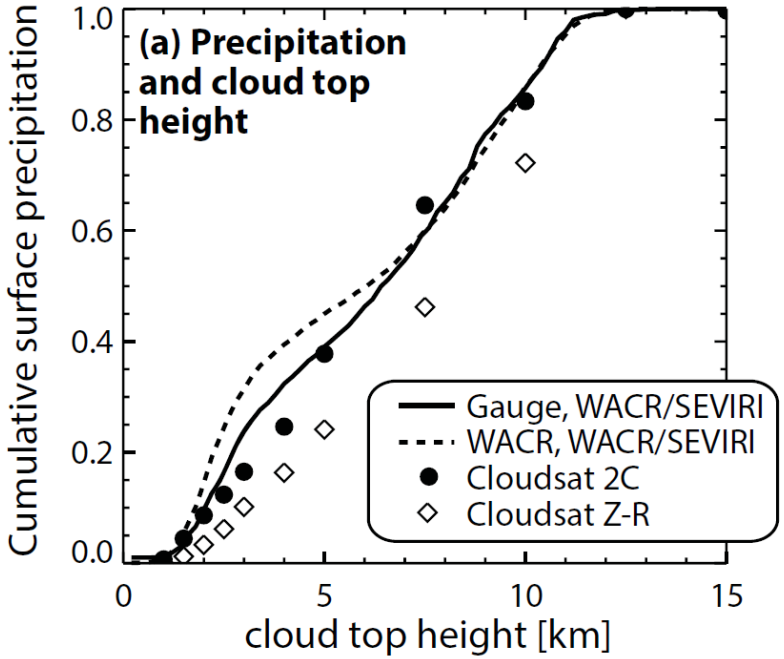


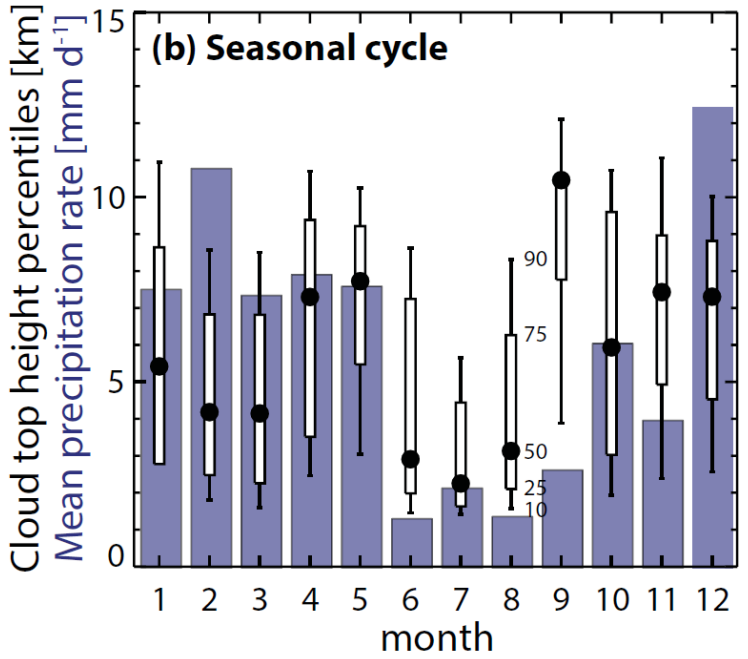
Seasonal cycle, aerosol and cloud microphysics

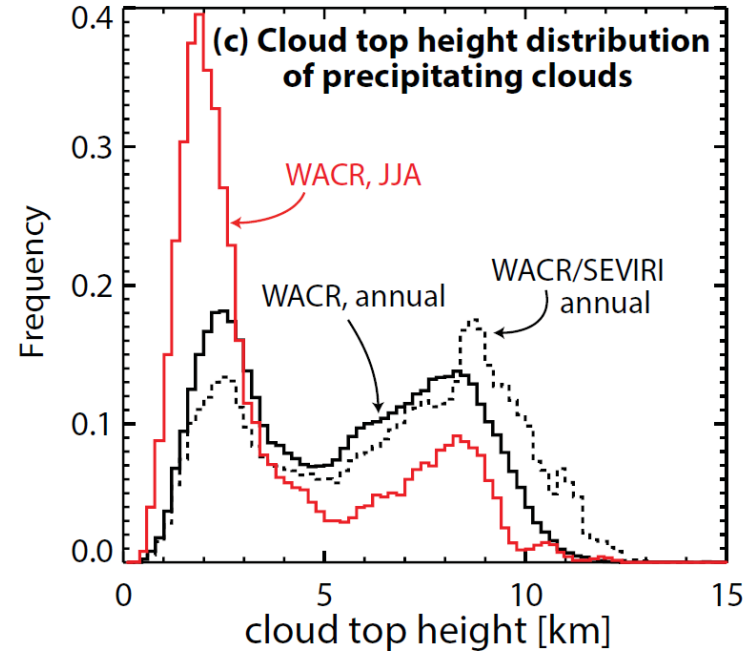


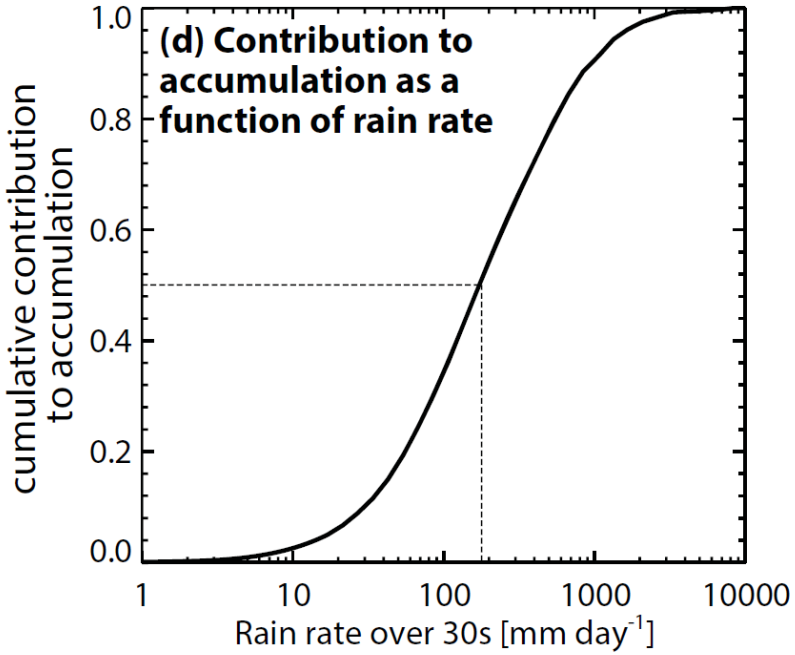
Precipitation

- Roughly equal contribution to precipitation from clouds with tops at all heights from 2-11 km
- Precipitation dominated by low clouds during summer
- Approximately half of all clouds are precipitating (Rémillard et al. 2012)



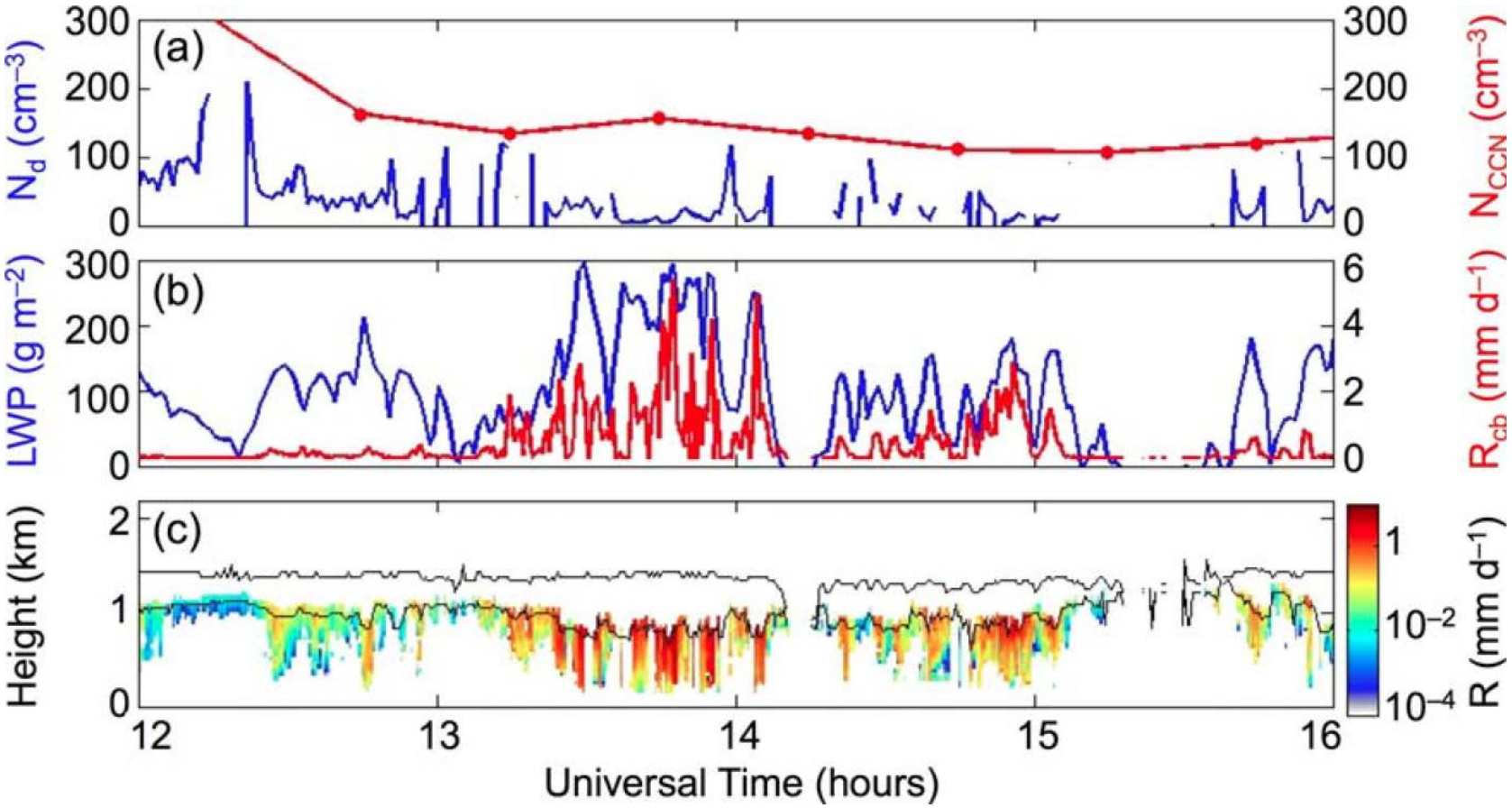






Warm rain from stratocumulus

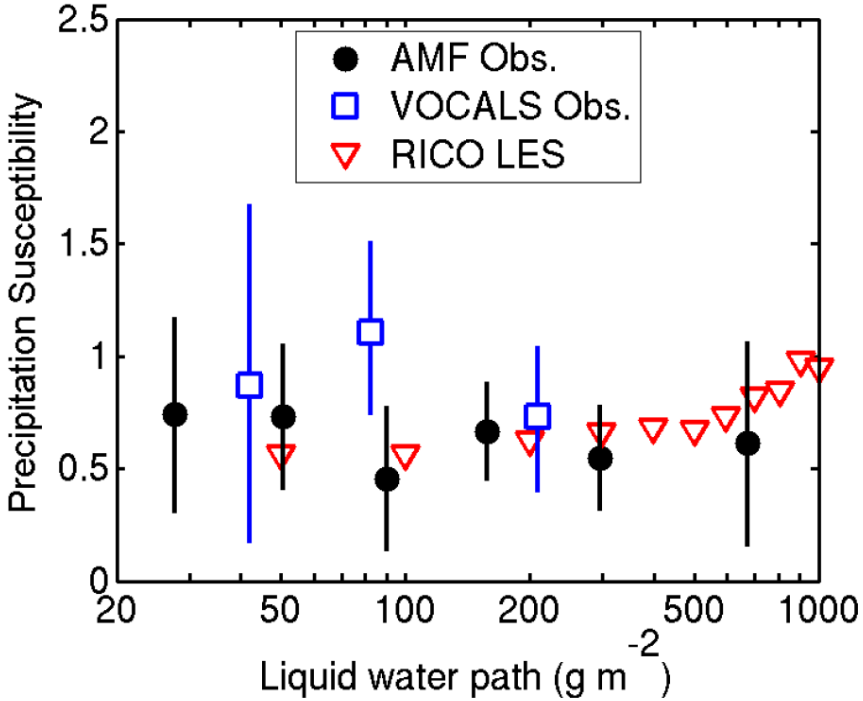
- Warm rain controlled by both LWP and aerosol concentration (Mann et al. 2014)



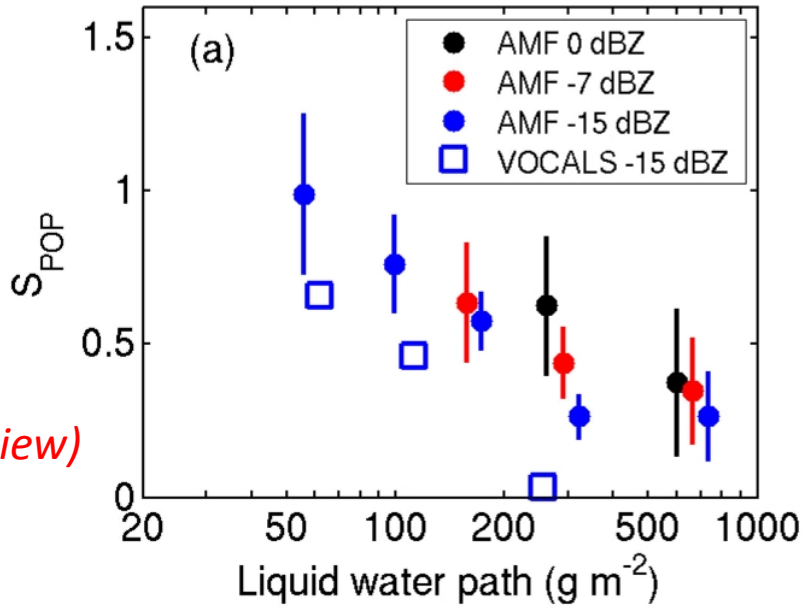
Precipitation susceptibility $(-d\ln R/d\ln N_{CCN})_{LWP}$

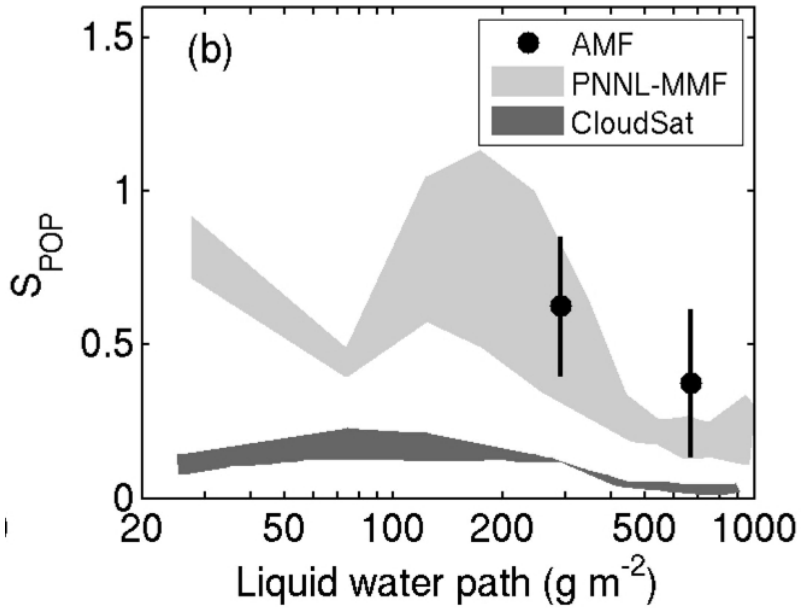
- Precip. susceptibility is in range 0.5–0.9, and generally agrees with values from models and aircraft for LWP<300 g m^{-2}
- S_{POP} exceeds that from satellites, but is similar to estimates from aircraft and the PNNL MMF

Mann et al. (2014, JGR, under review)



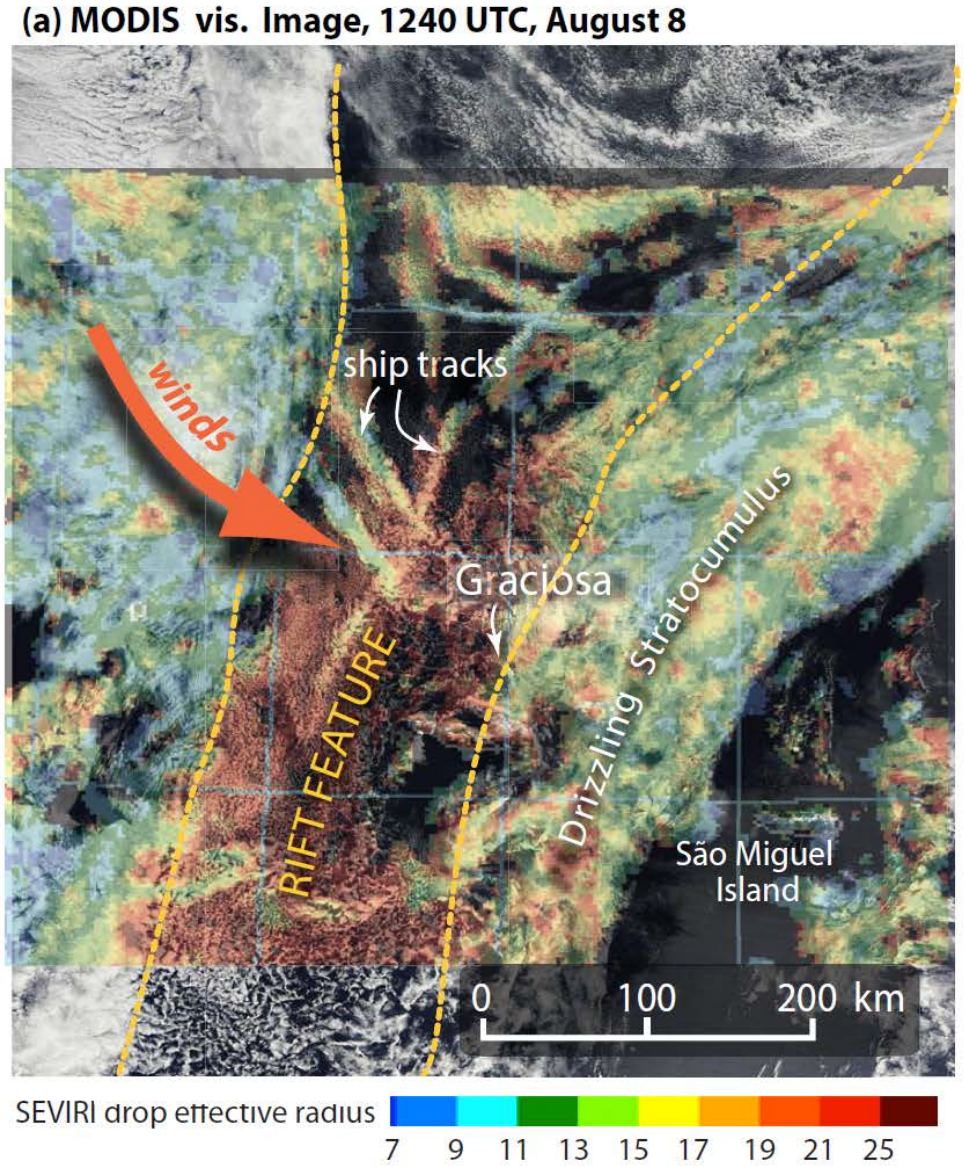
Terai et al. (201) for VOCALS; Sorooshian et al. (2009) for LES

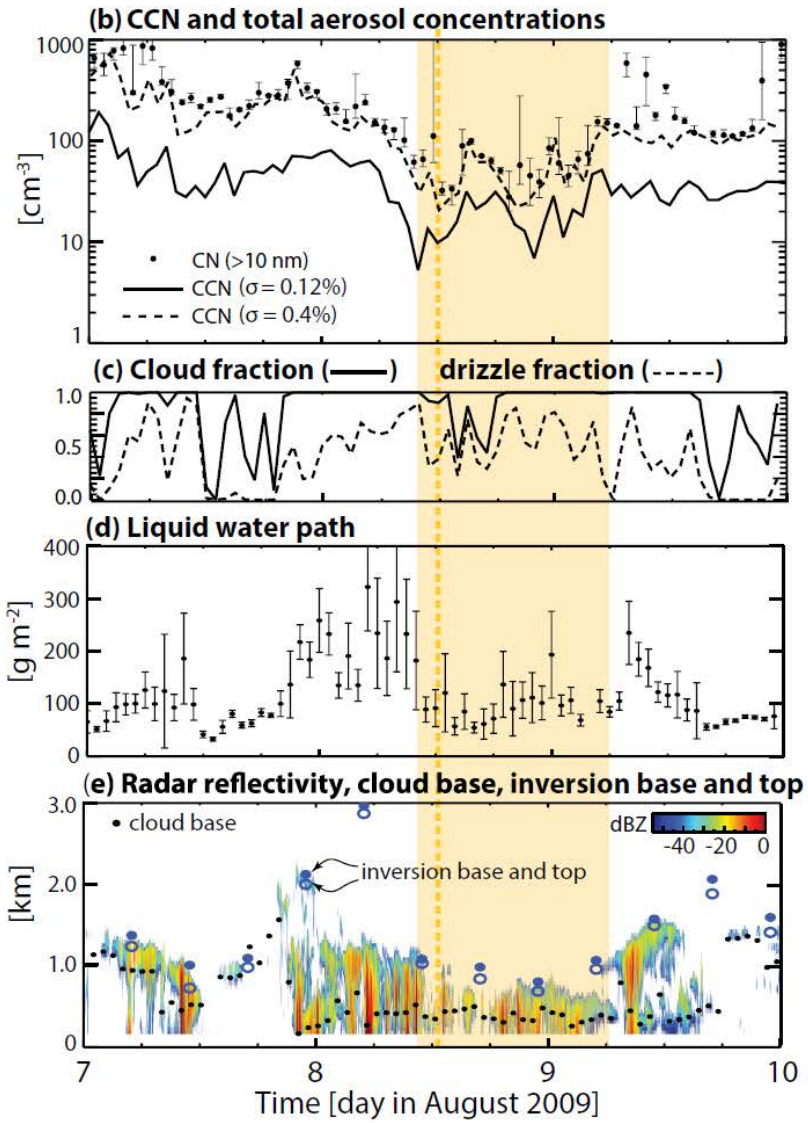




Depleted aerosol events

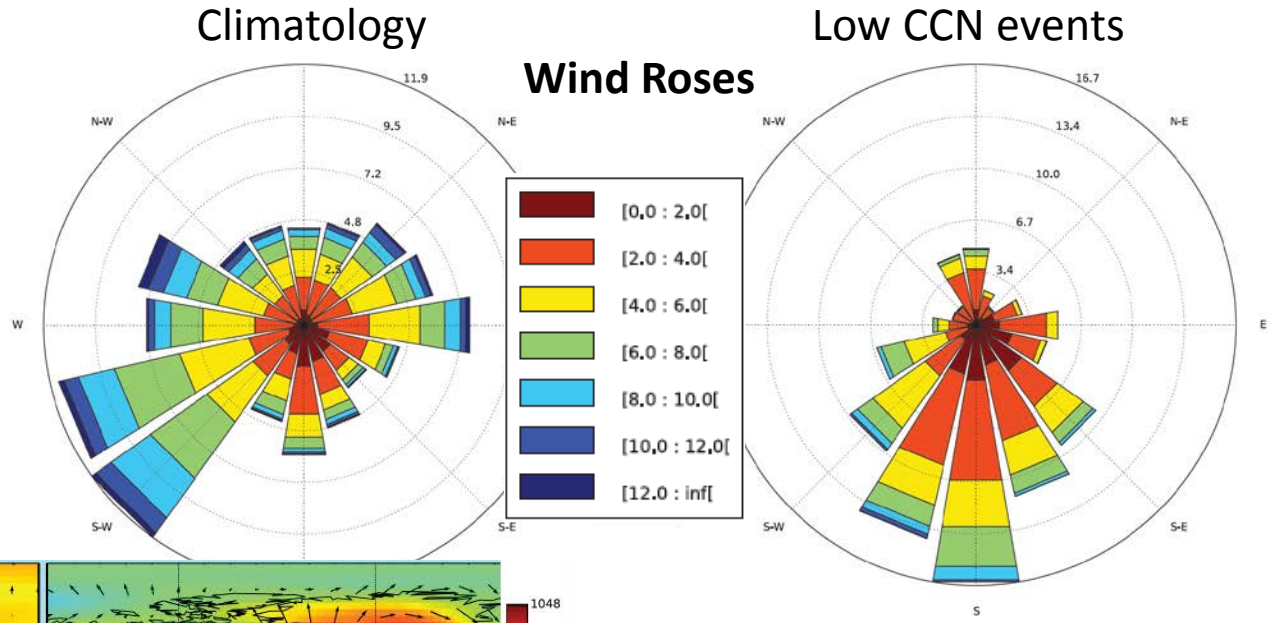
- Low CCN events (6 hourly mean $N_{CCN,1\%} < 20\ cm^{-3}$) occurred on 36 days)
- Sometimes associated with open cell structures over Graciosa

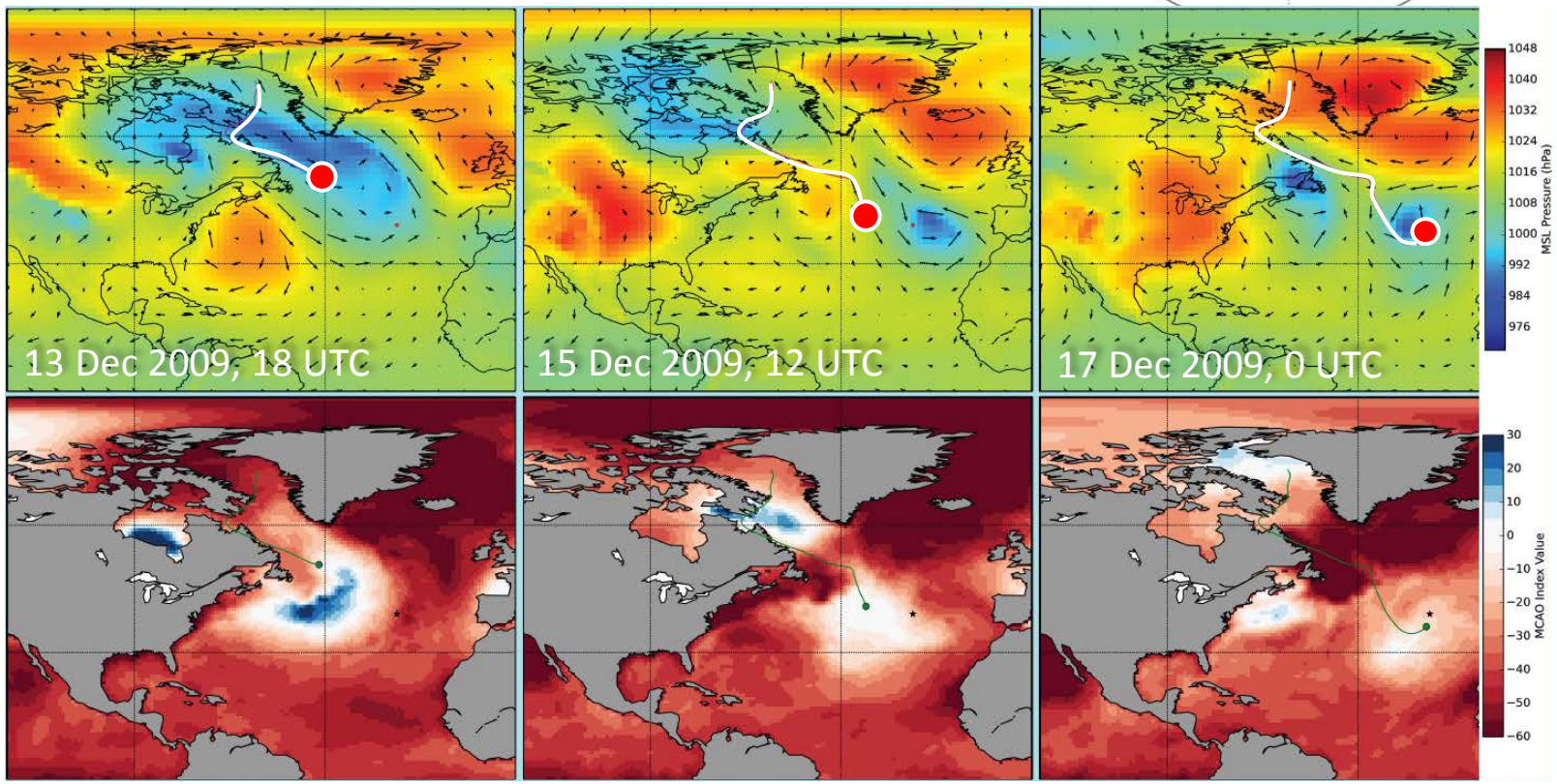




Low CCN events

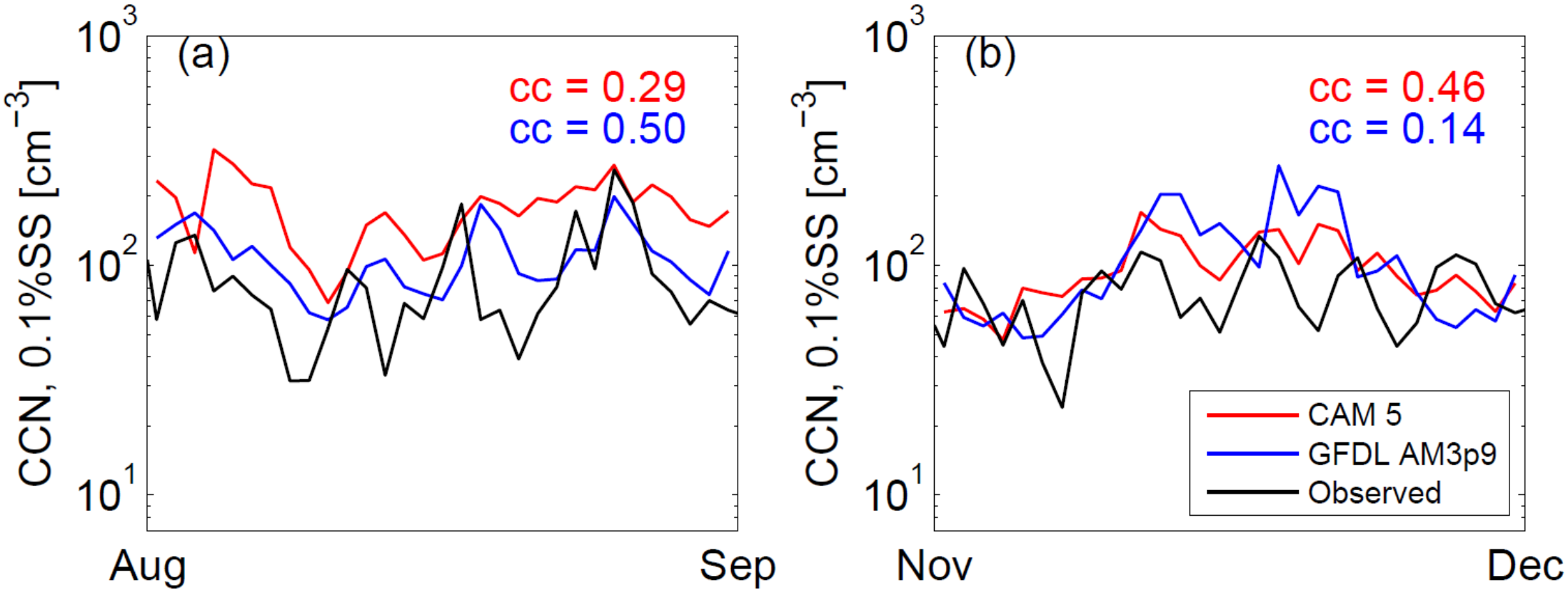
- Weak southerly flow associated with most events
- Favored during winter
- Link with marine cold air outbreaks





Stemmler et al. (2014), see also poster

Model representation of CCN



- Models in the right ballpark, but observed and modeled CCN only modestly correlated

Summary

- The observations collected during the 21-month AMF deployment on Graciosa Island in the Azores comprise the longest dataset of its type collected to date in an extratropical marine environment.
- Strong seasonality. Diverse range of air mass histories. Strong synoptic meteorological and cloud variability compared with other low-cloud regimes.
- Scratching the surface at important bidirectional interactions between aerosols, clouds and precipitation.
- Excellent choice for continued measurements by the ARM program.
- Ground-based measurements and retrievals require validatation by aircraft *in situ* measurements

Clouds, Aerosol, and Precipitation in the Marine Boundary Layer: An ARM Mobile Facility Deployment

paper in revision for the Bulletin of the American Meteorological Society

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