Characteristics of low cloud variability over the Azores and marine stratocumulus regions

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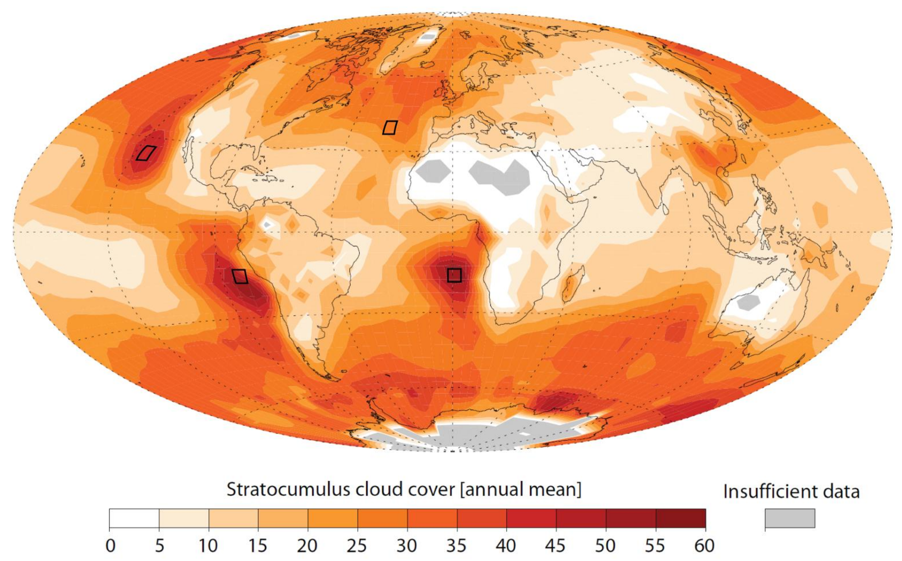

Fig. 1 Annual mean stratocumulus cloud cover with areas of interest outlined (Courtesy of R. Wood).

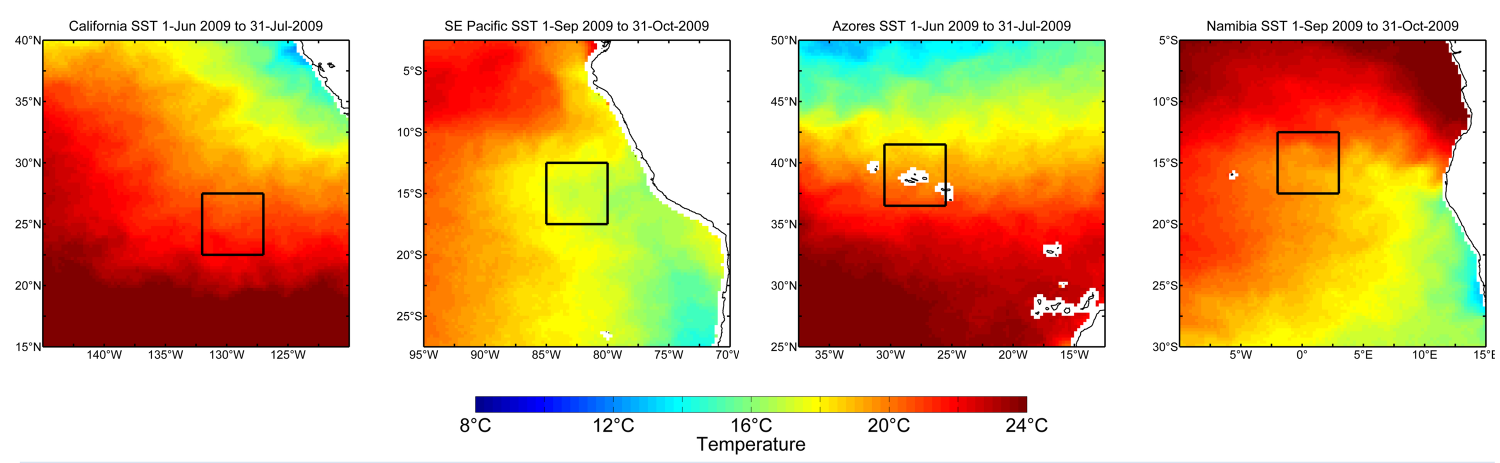

Fig. 2 MODIS mean sea-surface temperature (SST) underneath each of the cloud decks (black boxes indicate the study areas).

Introduction

Low marine clouds are important sources of cooling within the Earth's radiation budget. Understanding the relative importance of environmental factors that modulate low cloud fraction is fundamental to improving the representation of these clouds within global climate models.

In this study, we utilize satellite data from four marine stratocumulus (Sc) regions (Figs. 1 and 2). Each region has a different set of varying environmental conditions and cloudiness characteristics. We examine and compare time series and diurnal variability in low cloud fraction for each region to establish a starting point for ongoing work in understanding the relative impact of different environmental factors for determining cloudiness conditions.

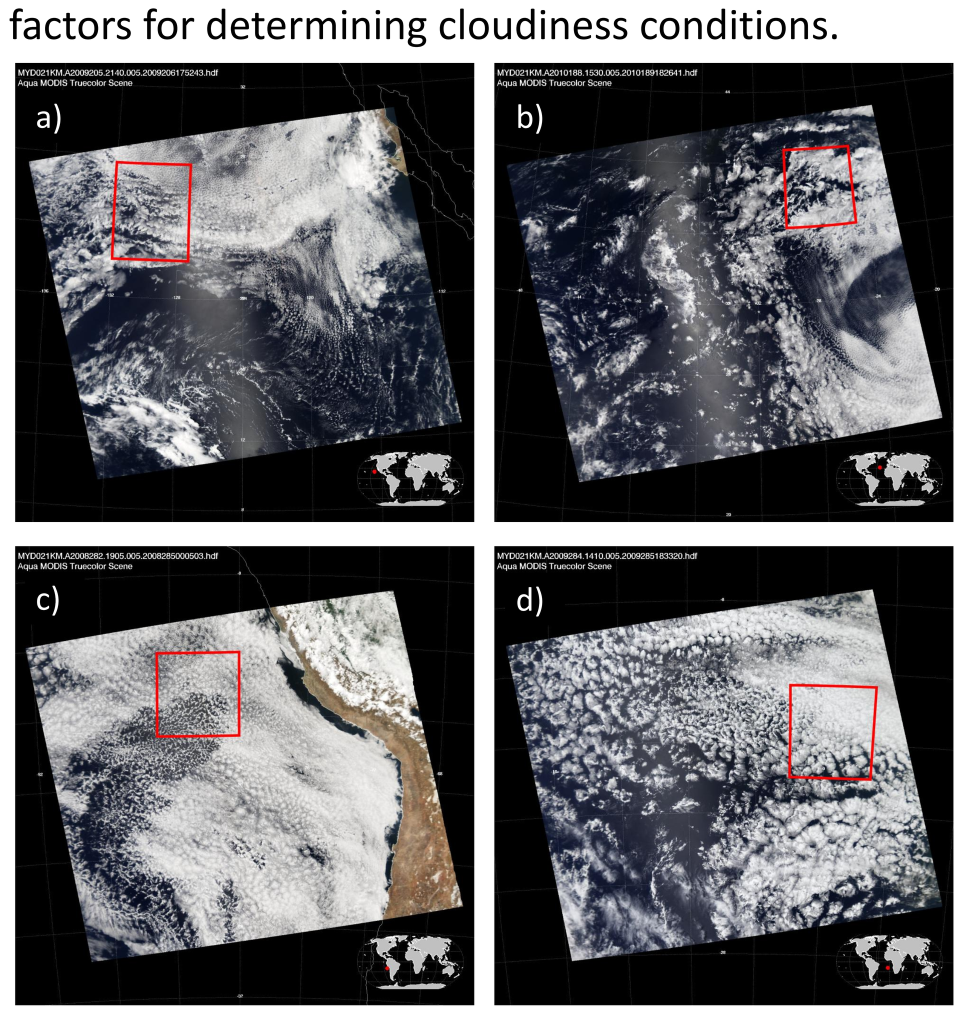

Fig. 3 Visible images of stratocumulus cloud decks in each study area (red boxes). a) off the coast of California on July 24th, 2009 at 21:40 UTC, b) over the Azores on July 7th, 2010 at 15:30 UTC, c) off the coast of Peru on October 8th, 2008 at 19:05 UTC and d) off the coast of Namibia on October 11, 2009 at 14:10 UTC

Background

Previous observational and modeling investigations (1) of marine stratocumulus cloud-topped boundary layers (CTBL) have shown that:

- Marine Sc low cloud fraction is well correlated with the strength of the CTBL capping inversion.
- Processes that can reduce marine Sc cloud fraction include: entrainment of warm, dry air from the free troposphere, precipitation, and boundary layer decoupling. Each of these processes varies diurnally.
- Decoupling, such that the clouds near CTBL top are cut off from the surface moisture supply, is more likely during the day.
- Deeper CTBL are associated with warmer SSTs and are more likely to drizzle than shallower CTBL
- Drizzle is more likely to occur at night and is associated with transitions from closed cellular to open cellular clouds. Once drizzle occurs, the CTBL is more likely to be coupled (except when there is strong subcloud evaporation of precipitation). Once the CTBL is coupled, it is more likely to drizzle.

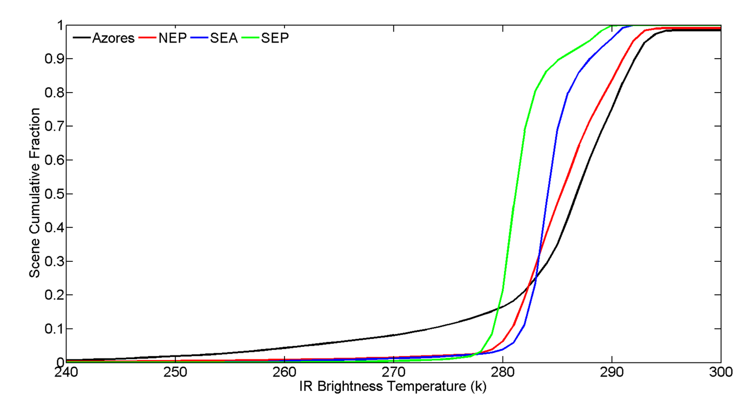

Fig. 4 IR temperature vs. scene cumulative cloud fraction.

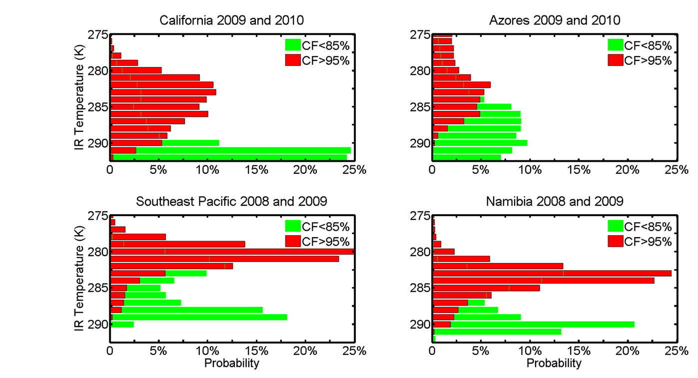

Fig. 5 Distributions of IR temperature for scenes with mean low cloud fraction > 95% (red) and ≤ 90% (green) for each of the four regions.

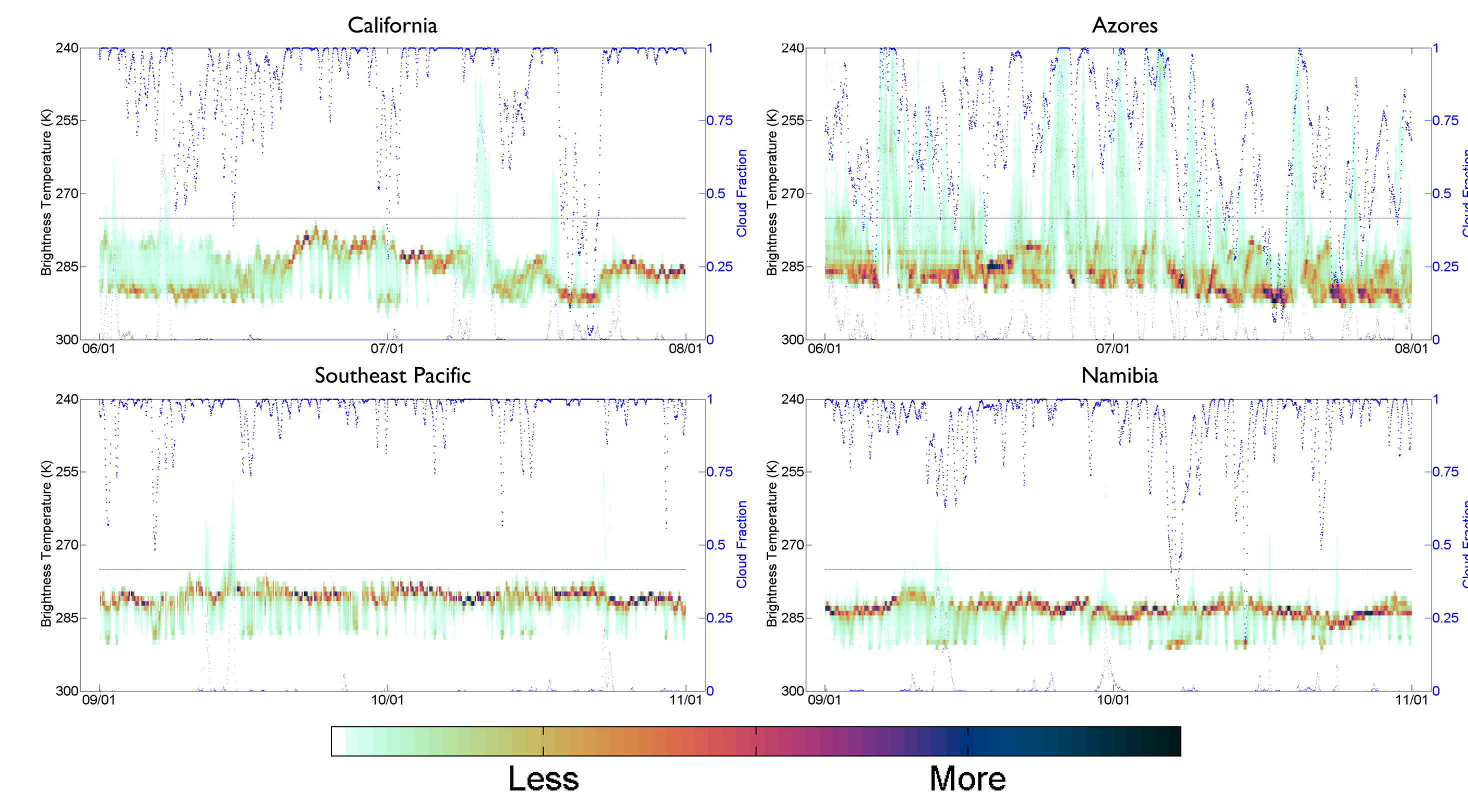

Fig. 6 Time series of IR distribution (shaded) and cloud fraction (blue marks) for each region (in 2009).

Methodology

We use MODIS Atmosphere and Ocean data sets as well as the ancillary TRMM merged IR data at 4 km resolution every 30 min. We use two different definitions of cloud fraction:

1) A custom product based on IR data at 30 minute intervals where cloud fraction is defined as the fraction of 4 km x 4 km pixels in the 5 degree square region which have an IR brightness temperature colder than a threshold temperature which is between the IR Tb distribution modes related to the sea surface and to cloud. Additionally, if a scene has IR Tbs ≤ 273 K over a total area >15% of the scene, the cloud fraction for that scene is set to missing.
2) MODIS product: MOD/MYD08_D3 Daily Gridded 1 degree Cloud Fraction via NASA Giovanni.

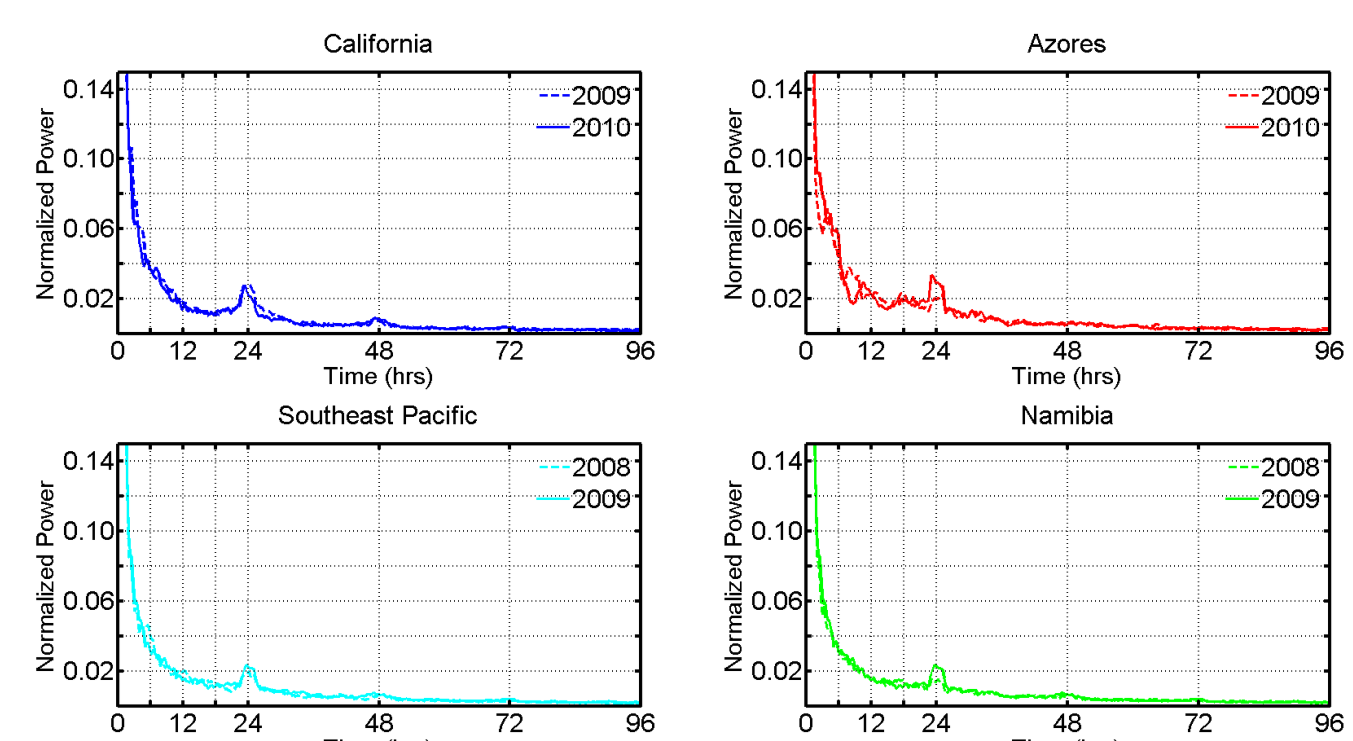

Fig. 7 Normalized power for the time spectrum of low cloud fraction from 0 through 96 hours, created using a Fast Fourier Transform (FFT) function in MATLAB for each of the cloud decks.

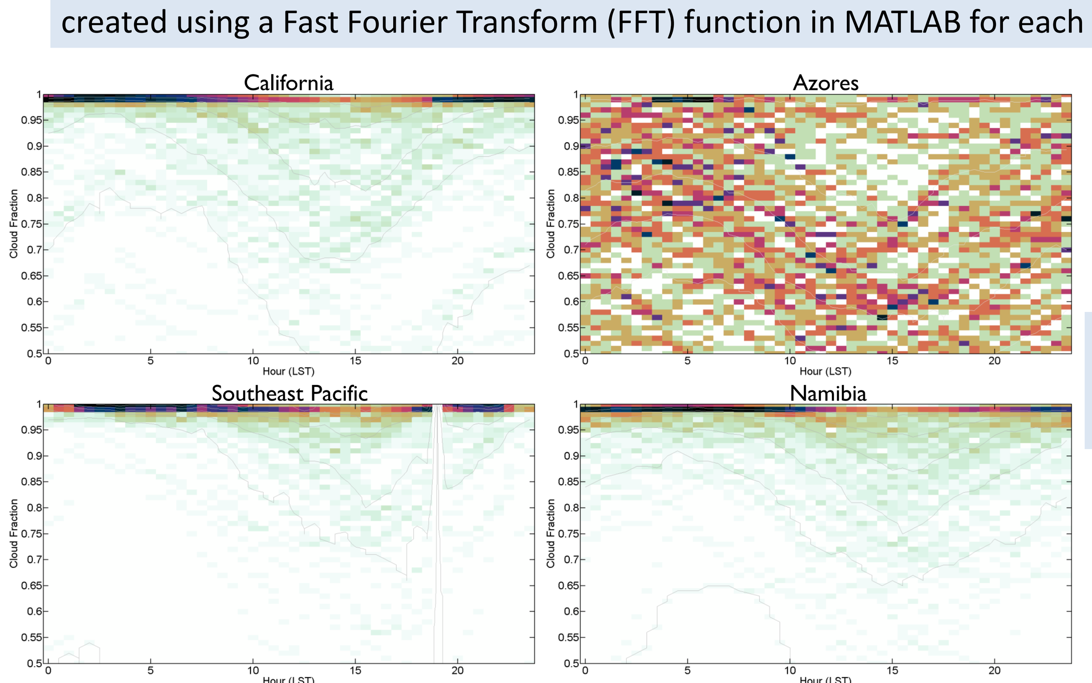

Fig. 8 Diurnal distribution of cloud fraction for each of the four regions.

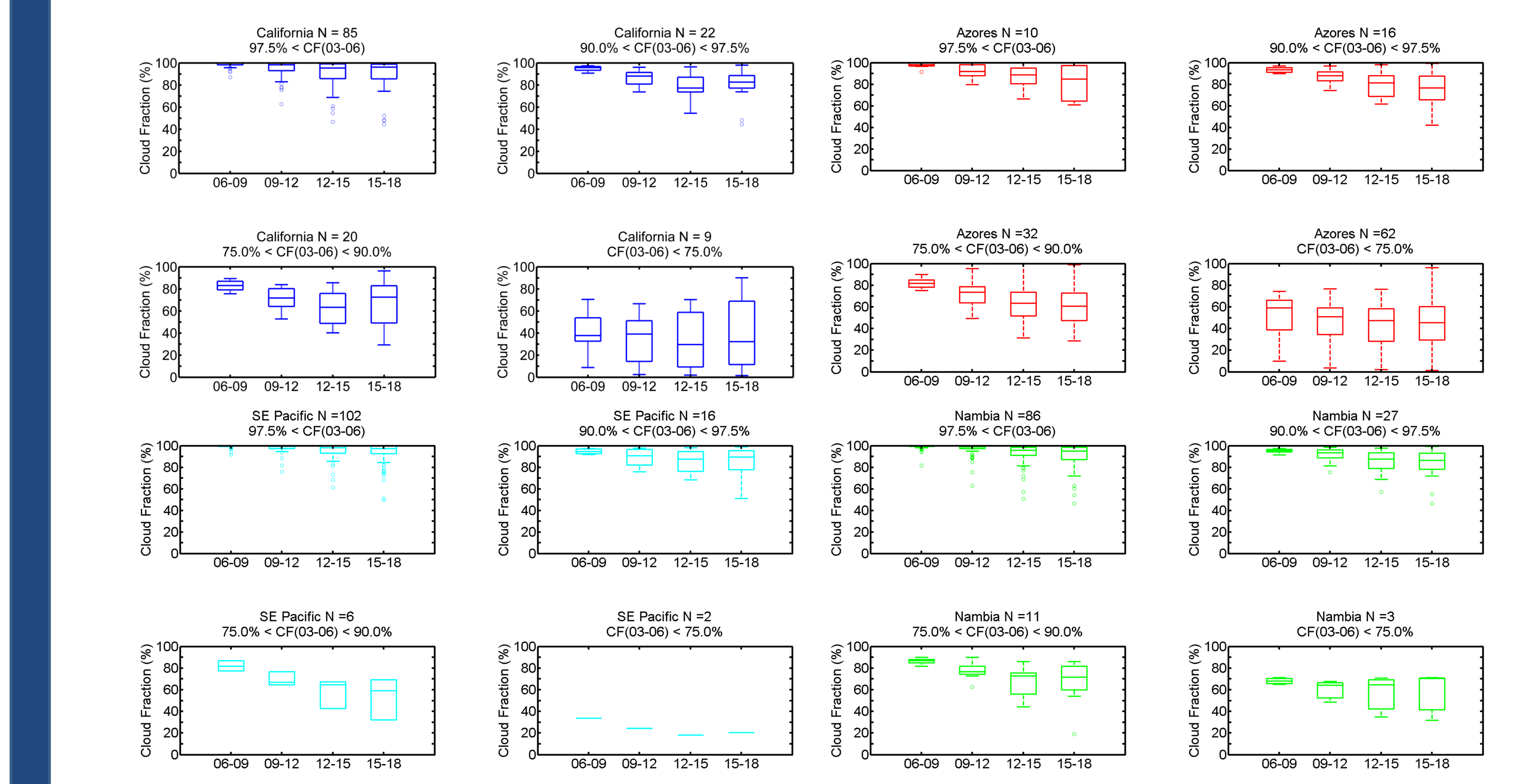

Fig. 9 Distributions of mean cloud fraction conditioned on cloud fraction at dawn. Boxes show means and quartiles, whiskers indicate two standard deviations, and dots are outliers.

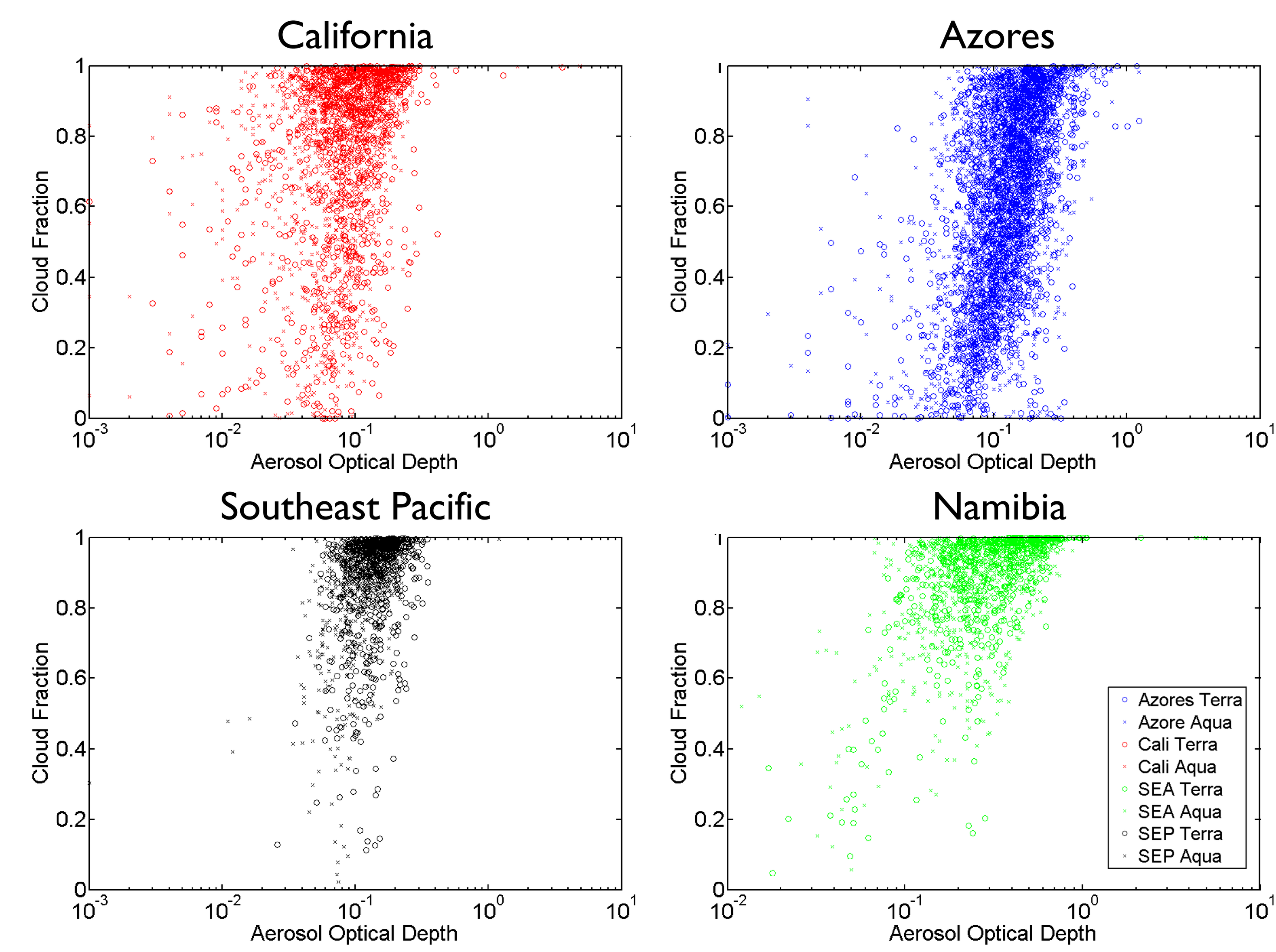

Fig. 10 MODIS Daily Cloud Fraction versus Aerosol Optical Depth for each region.

Conclusions

a) Spectral analysis indicates that the diurnal signal in total cloud fraction can vary considerably year to year during the peak marine stratocumulus season for a given geographic region. All four regions show a clear diurnal cycle.

b) There is an association between cloud fraction at dawn and cloud fraction variability later during the day. The SE Pacific and SE Atlantic stratocumulus decks are least likely to have broken clouds in the afternoon given overcast conditions at dawn (cloud fraction > 97.5%). In every region, if the cloud is broken at dawn (cloud fraction < 75%), cloud fraction is likely to decrease until mid-afternoon.

c) Of the four regions, the Azores are most likely to have mixed phase and ice clouds, which is not surprising since that location has the highest latitude.

d) There are multi-day variations in low cloud fraction and IR temperature distributions. One possibility is that these variations are related to extratropical cyclones occurring at higher latitudes.

References (1)
Comstock et al. 2005; Comstock et al. 2007; deSzoeke et al. 2012; Klein and Hartmann 1993; Leon et al. 2008; Mechem et al. 2012; Stevens et al. 2008; Wood and Bretherton 2004; Wood 2011; Zuidema et al. 2009.

Acknowledgements: This work is supported by DOE ASR grant # DE-SC0006701.