Scale Invariance of Liquid Water Distributions in Marine Stratocumulus. Part I: Spectral Properties and Stationarity Issues

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ABSTRACT

This study investigates the internal structure of marine stratocumulus (Sc) using the spatial fluctuations of liquid water content (LWC) measured along horizontal flights off the coast of southern California during the First ISCCP Regional Experiment (FIRE) in summer of 1987. The results of FIRE 87 data analyses are compared to similar ones for marine Sc probed during the Atlantic Stratocumulus Transition Experiment (ASTEX) in summer 1992 near the Azores. In this first of two parts, the authors use spectral analysis to determine the main scale-invariant regimes, defined by the ranges of scales where wavenumber spectra follow power laws; from there, they discuss stationarity issues. Although crucial for obtaining meaningful spatial statistics (e.g., in climate diagnostics), the importance of establishing stationarity—statistical invariance under translation—is often overlooked. The sequel uses multifractal analysis techniques and addresses intermittency issues. By improving our understanding of both nonstationarity and intermittency in atmospheric data, we are in a better position to formulate successful sampling strategies.

Comparing the spectral responses of different instruments to natural LWC variability, the authors find scale breaks (characteristic scales separating two distinct power law regimes) that are spurious, being traceable to well-documented idiosyncrasies of the Johnson–Williams probe and forward scattering spectrometer probes. In data from the King probe, the authors find no such artifacts; all spectra are of the scale-invariant form $k^{-\beta}$ with exponents β in the range 1.1–1.7, depending on the flight. Using the whole FIRE 87 King LWC database, the authors find power-law behavior with $\beta = 1.36 \pm 0.06$ from 20 m to 20 km. From a spectral vantage point, the ASTEX cloud system behaves statistically like a scaled-up version of FIRE 87: a similar exponent $\beta = 1.43 \pm 0.08$ is obtained, but the scaling range is shifted to [60 m, 60 km], possibly due to the 2–3 times greater boundary layer thickness.

Finally, the authors reassess the usefulness of spectral analysis:

- Its main shortcoming is ambiguity: very different looking stochastic processes can yield similar, even identical, spectra. This problem impedes accurate modeling of the LWC data and, ultimately, is why multifractal methods are required.
- Its main asset is applicability in stationary and nonstationary situations alike and, in conjunction with scaling, it can be used to detect nonstationary behavior in data.

Having $\beta > 1$, LWC fields in marine Sc are nonstationary within the scaling range and stationary only at larger scales. Nonstationarity implies long-range correlations, and we demonstrate the damage these cause when trying to estimate means and standard deviations with limited amounts of LWC data.

1. Introduction and overview

Clouds have a first-order effect on the earth's radiative budget (Ramanathan et al. 1989) and are the major source of uncertainty in climate modeling (Cess et al. 1989). Current climate models assume clear portions according to cloud fraction is used to account for horizontal inhomogeneity when predicting radiative properties. This motivates us to better understand cloud structure. Marine stratocumulus (Sc) are a good starting point. They are one of the