Questioning the Importance of the Cloud Lifetime Effect in Marine Stratocumulus

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Introduction

In marine stratocumulus environments with low concentrations of CCN, the cloud lifetime hypothesis postulates in part that more precipitation causes decreased cloud fraction (all other factors being equal). Previous work has highlighted examples of the co-occurrence of open-cellular broken cloud with heavy drizzle and suggests that precipitation is a necessary but not sufficient condition for marine stratocumulus cloud breakup at night. These previous case studies and LES modeling suggest that precipitation frequently causes cloud breakup at night, and thus the suppression of precipitation in a polluted environment (i.e., the second-indirect aerosol effect) would lead to higher cloud fractions. We utilize ship and satellite-based observations to examine the joint diurnal cycles of drizzle, cloud fraction, and cloudiness transitions as a test of the cloud lifetime effect in subtropical marine stratocumulus clouds.

Datasets

- C-Band radar data collected within a 120 km diameter domain during the VOCALS-REx cruises (31 days) by the NOAA ship Ronald H. Brown. Drizzle cells are tracked and analyzed via an automated algorithm (Hall et al. 2015 – *In Preparation*).
- Cloud fraction (CF) is determined from a cloud mask derived from a global merged geostationary satellite 12 µm IR product at 4 km × 4 km spatial resolution and 30 minute temporal resolution (Burleyson and Yuter 2015a – *J. Appl. Meteor. Climatol.*).

Conditional Cloud Fraction Changes

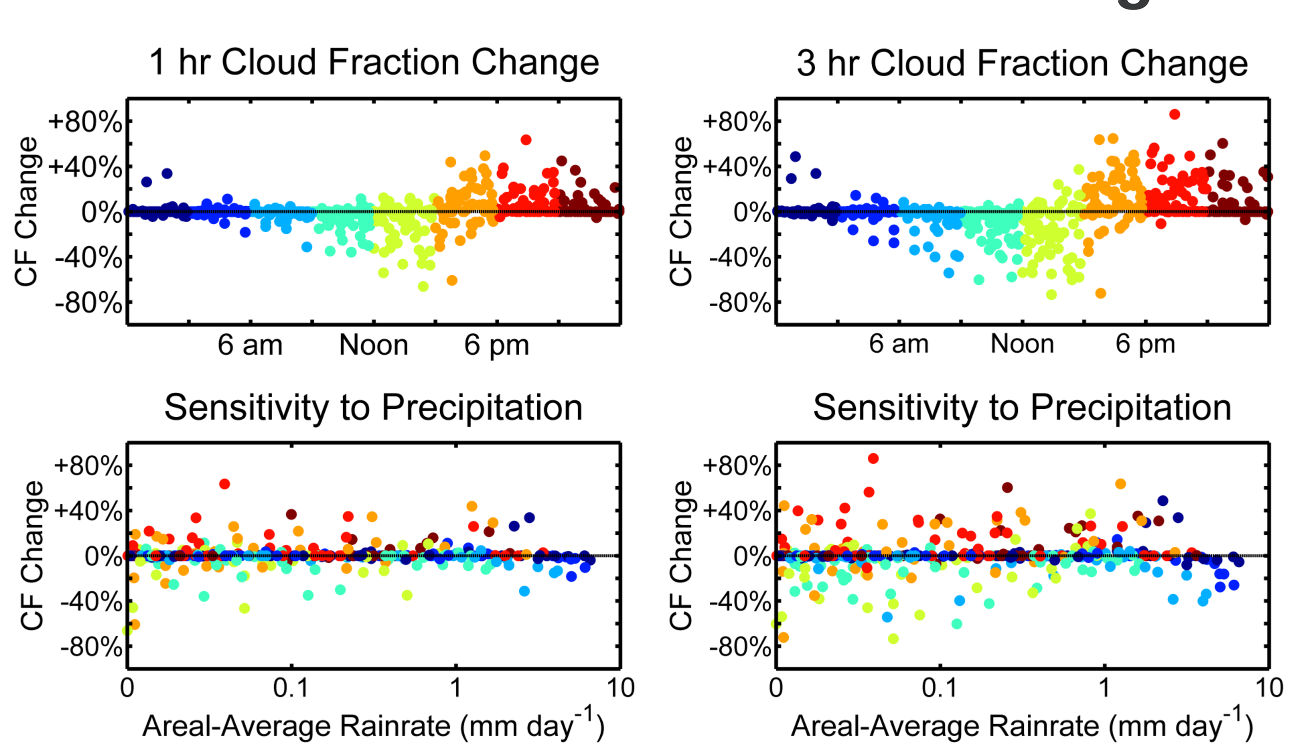


Fig. 1. CF changes over 1-hr (left column; N = 289) and 3-hr (right column; N = 306) as a function of time of day (colors) and average precipitation within 60 km of the ship. CF is closely associated with the solar diurnal cycle. Less than 3% of samples between 6 pm and 6 am have CF decreases larger than 5%. ***High areal-average rain rates and large decreases in cloud amount occur together near sunrise.***

Characteristics of Cloud Fraction Variability

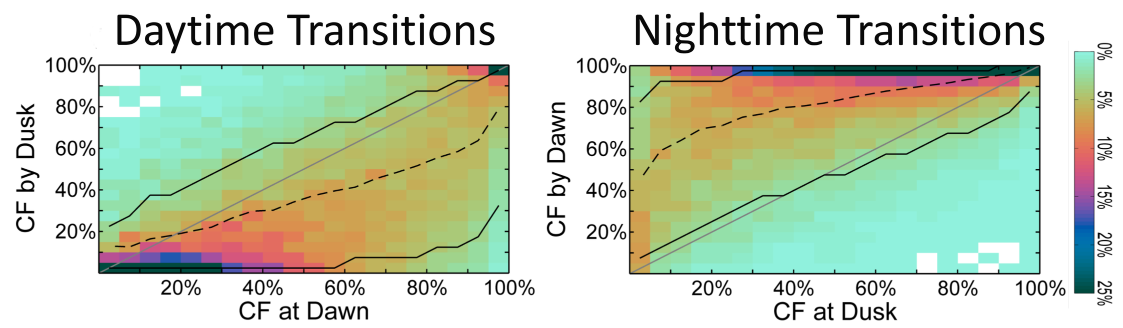
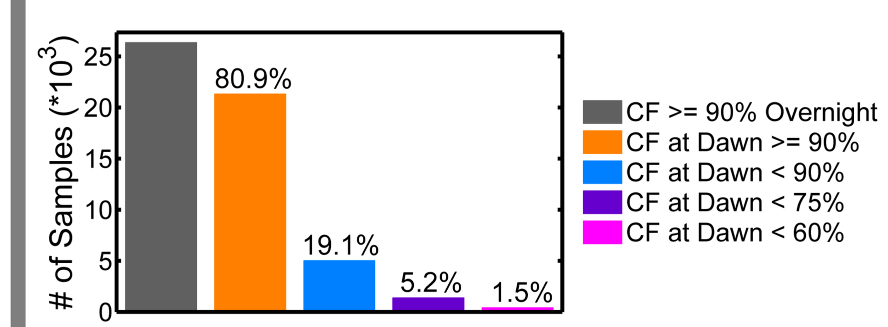


Fig. 2. Data density diagrams showing the change in CF (y-axes) during the day (left panel) and overnight (right panel) conditioned on the CF at dawn and dusk (x-axes). The solid lines show the 10th and 90th percentiles of the CF distribution and the dotted line indicates the mean. ***Cloud fraction decreases overnight only 10-15% of the time.***



If CF is high anytime overnight it is likely to remain high through dawn.

Fig. 3. Relative proportions of the time CF in a 3° x 3° box reaches ≥ 90% overnight and then decreases by various amounts by dawn. Bars to the right of the gray bar are conditional on CF reaching ≥ 90% at some time overnight.

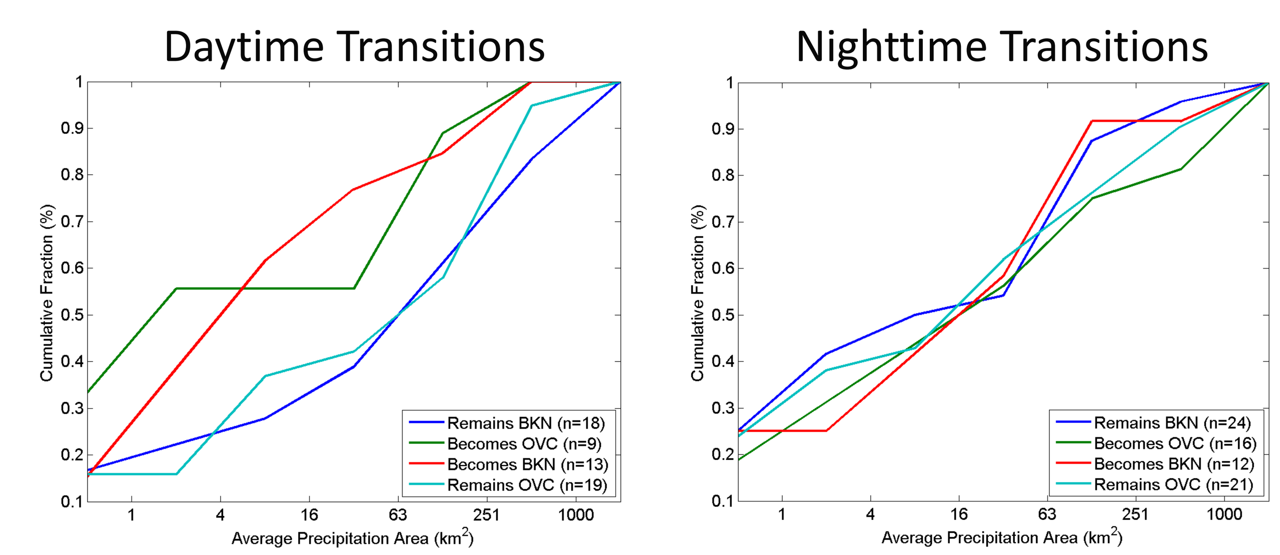


Fig. 4. Cumulative probability distributions of 4 hr average precipitation area trend by cloudiness condition for day (left) and night (right) cases during VOCALS-REx. ***During the night, distributions are similar for all four trends. During the day, cloudiness transitions are more likely to occur at times with less precipitation.***

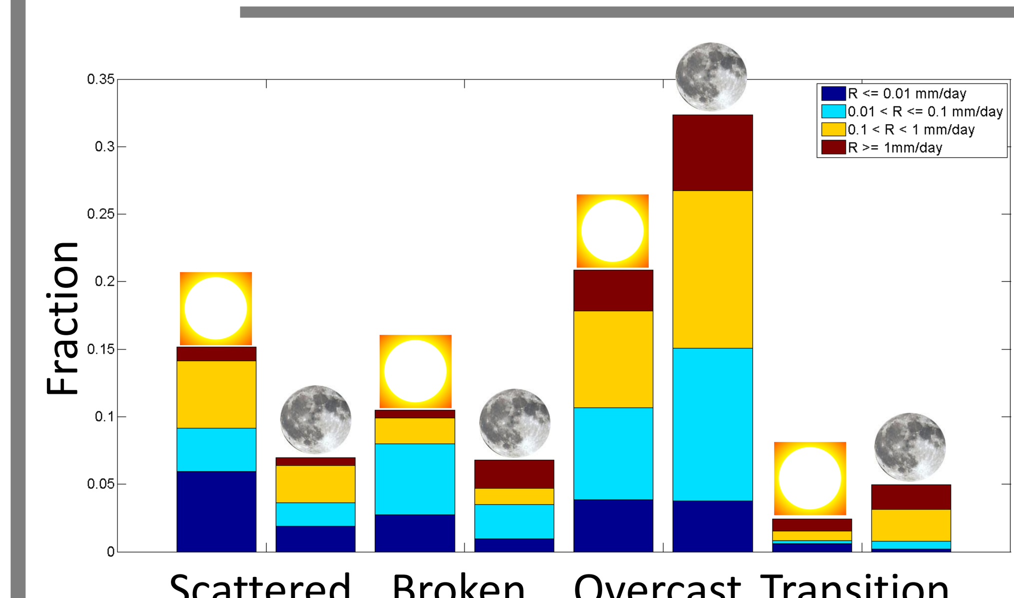


Fig. 5. Precipitation distributions for different cloudiness conditions. ***Heavy rain (R ≥ 1 mm day^{-1}) occurs more frequently overnight in overcast conditions compared to regions where the cloud fraction is transitioning.***

Conclusions

Contrary to the hypothesis that precipitation reduces cloud fraction, we found that increased precipitation increases the probability of maintaining a given cloud fraction. Our statistical analysis (as opposed to a case-study approach) of two distinct observational datasets suggests that the impact of precipitation on stratocumulus cloud fraction has been generally overstated.

1) Anecdotal examples can be found for a variety of cloud fraction transitions and precipitation area conditions.
2) At night:
   - Overcast conditions with or without precipitation usually do not break up; Cloud fraction typically increases.
   - Overcast cloud breakup can occur without precipitation.
3) During the day:
   - Clouds with larger precipitation areas tend to maintain their existing cloud fraction (likely thicker clouds).
   - Clouds with smaller precipitation areas are more likely to co-occur with a cloudiness transition (likely thinner clouds).
   - The rate of cloud fraction decrease is closely associated with changes in the magnitude of the downwelling SW flux.
4) At 100-300 km and < 5 hr scales:
   - Drizzle and cloud fraction co-vary with the diurnal cycle of solar radiation.
   - Drizzle is neither necessary nor sufficient for reducing cloud fraction overnight.

Revisiting POC Cases From the Literature

Many of the pockets-of-open cells (POCs) examples coincidentally occur near sunrise. This makes it impossible to cleanly separate the relative importance of precipitation and the diurnal cycle.

Paper and Relevant Figures/Tables	Basin	Date	Time Analyzed (A) or Formed (F)	Data Sources
Stevens et al. 2005 - Fig. 2	SEP	19 Oct 2001	A 0600-1200 LT	GOES Visible Reflectance, Cloud Radar
Stevens et al. 2005- Fig. 3	NEP	11 Jul 2002	A ~0730 LT	GOES Visible Reflectance, Lidar
Sharon et al. 2006 - Fig. 1a	NEP	30 Jun 1987	A ~1030 LT	GOES Visible Reflectance
Sharon et al. 2006 - Fig. 1b	NEP	16 Jul 1999	A ~0845 LT	GOES Visible Reflectance
Comstock et al. 2007 - Figs. 13	SEP	18 Oct 2001	F 0345 to 0645 LT	GOES IR, Precipitation Radar
Wood et al. 2008 - Figs. 4 and 5	SEP	17 Oct 2001	F 0500 to 0600 LT	GOES IR, Ceilometer, Cloud Radar
Wood et al. 2008 - Figs. 6 and 7	SEP	16 Nov 2003	F ~0315 LT	GOES IR, Ceilometer, Cloud Radar
Wood et al. 2011b - Fig. 2 (RF06)	SEP	27 Oct 2008	F 2330 to 0530 LT	GOES IR

Table 1. A summary of some of the existing POC cases in the literature and the characteristics of when and where they were observed. Where possible, we note the time of POC formation given in the paper or otherwise estimate the time of formation from the data presented in the paper. Many of the cases do not have sufficient evidence to determine exactly when the POC formed.