# Towards a Marine Stratus Climatology on Drizzle Occurrence from CALIPSO

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## ABSTRACT

Marine stratus are a predominant feature of our planet with the annual mean coverage exceeding 20%. They strongly reflect sunlight yet exert only a modest effect on outgoing infrared radiation, providing a significant net cooling to the Earth's radiative balance. Their formation is coupled to boundary layer circulations that are driven, in part, by cloud top radiative cooling and evaporative cooling from precipitation in downdrafts. Understanding how these cloud systems evolve as the climate changes is a key question that requires additional information on their lifecycle and microphysical properties to accurately represent their behavior in global circulation models.

From a large-scale perspective, insight into the microphysical properties of marine stratus at cloud top can be realized through estimates of the effective radius ($R_e$) of the droplet size distributions derived from MODIS observations. Estimates on the occurrence of rain/drizzle are available from CloudSat. Together these observations indicate that precipitation frequently occurs in clouds with higher cloud top $R_e$. This relationship is consistent with the well documented shift in cloud top droplet size distributions towards fewer, yet larger droplets prior the onset of precipitation.

Here we report on a new and complementary set observations from the CALIPSO mission. The approach derives an extinction-to-backscatter ratio ($S_c$, also known as the cloud lidar ratio) using an established relationship that depends on observations of the lidar attenuated backscatter and volume depolarization ratio within the cloud. Because $S_c$ is strongly and inversely related to $R_e$, a change in the derived $S_c$ from higher to lower values corresponds to a change in the droplet size distribution as seen by MODIS. This change in the lidar signals at cloud top clearly identifies clouds that are capable of precipitation.

This presentation provides a brief overview of the approach for deriving $S_c$ and compares CALIOP-derived $S_c$ with observations from other techniques. CALIOP classifications of drizzling clouds, based on the retrieved values $S_c$, depolarization etc. are compared to independent, collocated assessments of drizzle occurrence reported in the standard CloudSat data products. Regional, seasonal and annual anomaly comparisons highlight the strengths and weaknesses of the two data records. A machine learning approach that combines information from both CALIOP and CloudSat showcases possible improvements in the global identification of scenes likely to contain rain-bearing clouds.


## Drizzle Case

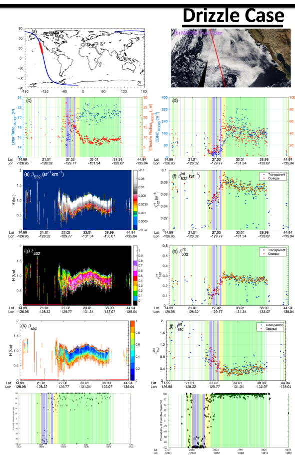

Fig. 1: Drizzle properties for one-half Orbit starting at 21:37:17 UTC on September 22nd 2009

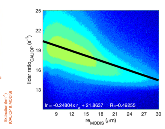


Fig. 2: Sc-re relationship

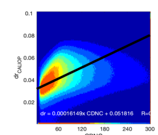


Fig. 3: depolarization ratio (dr) to cloud droplet number concentration (cdnc) relationship

**when transitioning from cloud droplets to rain**

- ❑ particle size distributions are broadening which lead to low cloud lidar ratios;
- ❑ droplet number concentrations are decreasing, resulting in reduced in-cloud signal attenuation, smaller backscatter coefficients, lower depolarization ratios, and deeper signal penetration into clouds
- ❑ cloud inhomogeneity increases, arising from large spatial variabilities in droplet size and number concentrations that yield concomitant variability in lidar backscatter signal intensities.

## Statistical Distributions

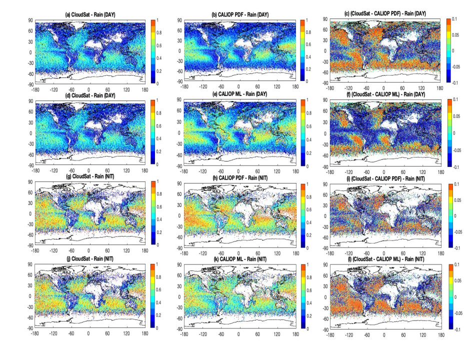


Fig 4: Geographical Distribution of drizzle occurrence

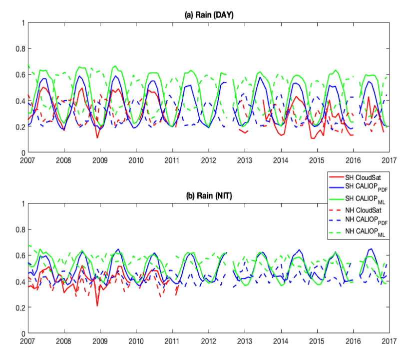


Fig 5: Seasonal variations of drizzle occurrence

❑Similar geographical distributions: higher occurrence offshore compared to near shore

❑Similar seasonal distributions: lower occurrence in summer while higher occurrence in winter.

## Anomalous Changes of Drizzle and Clouds Micro-Macro Physics Between El Niño and La Niña Years

During **El Niño**, the warm pool of water moves eastward and the slope of the thermocline flattens.
During **La Niña**, the warm pool moves westward, and the slope of the thermocline steepens.

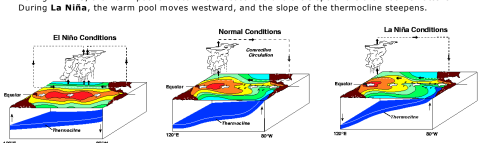


Fig 5. Schematic of anormal atmosphere-ocean circulations among El-Niño, La-Niña and normal years. This carton is from NOAA website https://www.pmel.noaa.gov/elnino/schematic-diagrams, provided by the Tropical Atmosphere-Ocean (TAO) Project Office, Pacific Marine Environmental Laboratory (PMEL), National Oceanic and Atmospheric Administration (NOAA).

Cth: cloud top height
Ccm: cloud cover from Modis
Lcc: liquid cloud cover
Lcth: liquid cloud top height

lr: lidar ratio
dr: depolarization
re: effective radius from Modis
CDNC: cloud droplet number concentration

### High + Low clouds

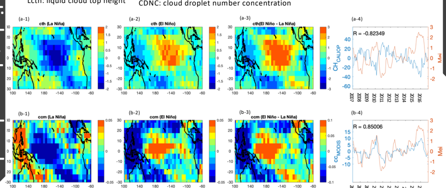


Fig. 6: Anormal of all cloud macro-micro physics (1st row cloud top height and 2nd row cloud fraction) between El-Niño (ENSO MEI values > 0.5) and La-Niña years (ENSO MEI values < -0.5), MEI index are from NOAA website https://psl.noaa.gov/enso/mei/

### Low Liquid clouds

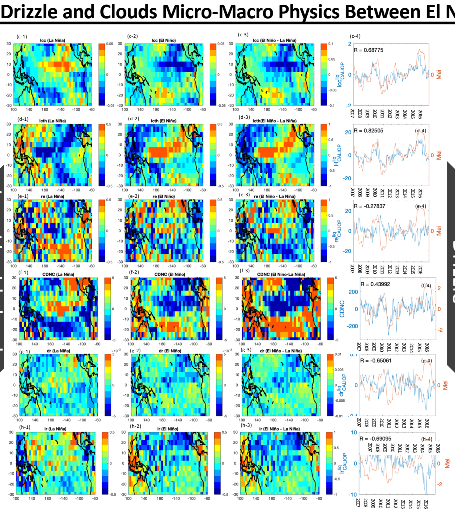


Fig. 7: Anormal of water cloud macro-micro physics El-Niño (ENSO MEI values > 0.5) and La-Niña years (ENSO MEI values < -0.5) , MEI index are from NOAA website https://psl.noaa.gov/enso/mei/

### Drizzle

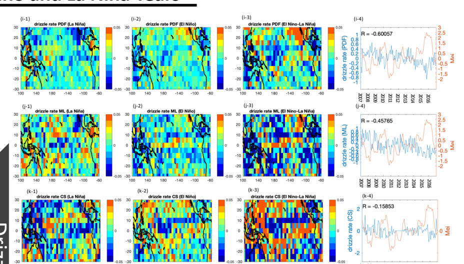


Fig. 8: Anormal of drizzle occurrence frequencies El-Niño (ENSO MEI values > 0.5) and La-Niña years (ENSO MEI values < -0.5)

### ❑ High and low clouds react to El Niño and La Niña in quite different ways

### ❑ During El-Niño years over West of Peru:

- Water clouds are lower and wider
- Water cloud effective radius are smaller and number concentrations are larger
- There are less drizzle associated with those water clouds
- Lidar ratio and depolarization are both larger

### ❑ During El-Niño years to the West of California:

- Water clouds are higher and lesser
- Water cloud effective radius are larger and number concentrations are smaller
- There are less drizzle associated with those water clouds
- Lidar ratio and depolarization are both smaller

**Conclusion** Drizzle can be inferred from CALIPSO from changes of cloud microphysics at cloud top. These changes include (a) the broadening of particle size distributions when transitioning from cloud droplets to rain, as evidenced by a pronounced decrease in the cloud extinction-to-backscatter ratios; (b) lower droplet number concentrations, resulting in reduced in-cloud signal attenuation, smaller backscatter coefficients, lower depolarization ratios, and deeper signal penetration into clouds; and (c) increased cloud inhomogeneity, arising from large spatial variabilities in droplet size and number concentrations that yield concomitant variability in lidar backscatter signal intensities. The CloudSat and CALIPSO drizzle products agree in over 84% of drizzle cases within low water clouds. Drizzle from both instruments and two different methods show similar geographical distributions: higher occurrence offshore compared to near shore, and similar seasonal distributions: lower occurrence in summer while higher occurrence in winter. During El Nino years, weak ocean updraft near Peru leads to rising sea surface temperature and possible changing the circulation structure and the base height of the thermal inversion layer. Liquid water clouds thus become shallower but wider covered. Consequently, cloud droplets become smaller and more numerous and suppress the formation of drizzle.