Detecting precipitation vs. mixing in shallow cloud marine boundary layers

Oregon State University College of Earth, Ocean, and Atmospheric Sciences

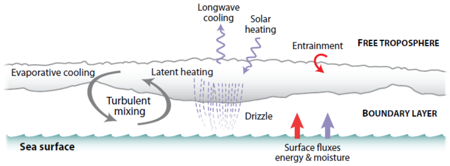
Dean Henze - College of Earth, Ocean, and Atmospheric Science, Oregon State University, OR USA

David Noone - Department of Physics, Waipapa Taumata Rau (The University of Auckland), Auckland NZ

The University of Auckland Te Whare Wananga o Tamaki Makaurau New Zealand

Introduction

Marine shallow cloud representation and cloud-aerosol interactions are two primary sources of uncertainty in climate models. Stratocumulus clouds are a key shallow cloud type and cover large portions of eastern ocean basins. In the case of the southeast Atlantic, biomass burning aerosols from central/southern Africa seasonally mix into the cloud deck.



Schematic showing the key processes in stratocumulus topped boundary layers (from Wood, 2012).

Stratocumulus formation is connected with marine boundary layer moisture and energy budgets. These budgets include cloud-top entrainment mixing and precipitation. Because isotope ratios are sensitive to precipitation, they provide a unique constraint to supplement traditional thermodynamic variable budget analyses.

Detecting/constraining precipitation can be useful to cloud-aerosol research. For example, wet scavenging is the primary removal mechanism for some aerosols. Conversely, it is possible that high aerosol loads suppress precipitation.

Acknowledgments

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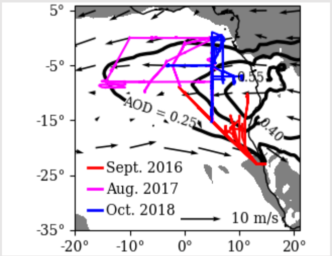
References

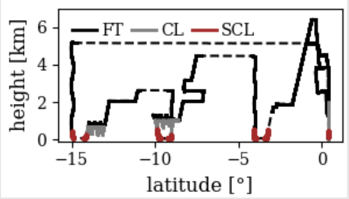
Wood, R. Stratocumulus clouds. Review paper, *Mon. Wea. Rev.*, 140, 2373-2423, 2012.

Merlivat, L., and Jouzel, J. (1979), Global climatic interpretation of the deuterium-oxygen 18 relationship for precipitation, *J. Geophys. Res.*, 84(C8), 5029– 5033

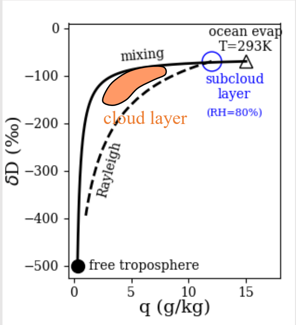
Methods



Flight tracks during ORACLES, with MERRA aerosol optical depth and 500 hPa winds.



Example aircraft height vs latitude for the flight on Aug. 15th 2017.



q-dD diagram showing simple mixing and precipitation processes.

Aircraft sampling

The NASA ORACLES campaign included in-situ meteorological, aerosol, and total water isotope ratio measurements.

Three observation periods (IOPs): Sept. 2016 (14 flights), Aug. 2017 (12 flights), and Oct. 2018 (13 flights). Flights were within 7a to 5:30p local time.

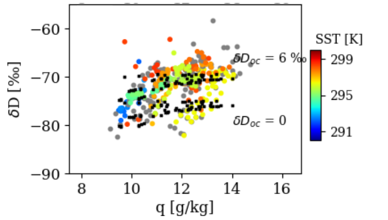
Cloud layer (CL) and sub-cloud layer (SCL) data taken from (1): level legs or saw-tooth patterns deliberately through the CL and SCL, or (2): vertical profiles where SCL and CL boundaries were inferred from temperature and relative humidity.

Profiles were also used to identify free troposphere (FT) airmasses just above (200 – 400 m) the CL.

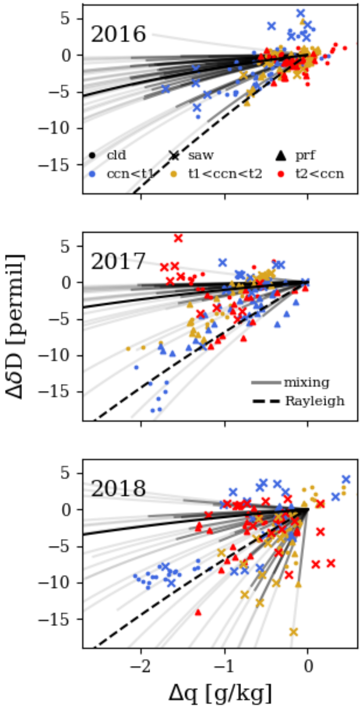
Mixing vs. precipitation on a q-dD diagram

The airmass total water concentration (q) and its HDO isotope ratio (δD) take different relationships depending on the hydrologic processes occurring. In two simple cases for the CL, it can be considered a simple mixture of SCL and FT airmasses, or SCL air which has precipitated with 100% condensate removal (Rayleigh).

Results and Conclusions



SCL data for 2017 sampling period as 60 s means.



CL deviations from SCL. cld = in-cloud level leg 90 s means; saw = sawtooth pattern 90 s means; prf = vertical profiles 100 m means.

Sub-cloud layer data

- SCL data for the 2017 IOP demonstrate q, δD values in this region.
- Merlivat & Jouzel 1979 closure (black) is shown for comparison.

Detecting cloud layer mixing vs precip

- CL data shown as deviations from the mean of the nearest SCL sampled, with the goal of highlighting CL hydrology and subtracting variations in SCL state.
- 2016 and 2017 IOPs: most data fall between (1) a mixing line between the SCL and very dry FT air, and (2) a Rayleigh curve.
- Mixing models between the SCL and observed air masses 200 m above the cloud tops also show possible reasons for deviation from the dry FT mixing case.
- However, results suggest that at least some of the signal is due to precipitation.
- 2018 IOP: more convoluted, due to the variety of FT q-δD values above cloud top.

Possible cloud-aerosol interactions

- There is some evidence that relatively lower SCL cloud condensation nuclei concentrations (CCN, colors) correlate with isotope signatures of precipitation.
- Further work is needed to test the above hypothesis, and determine if scavenging or precipitation suppression is occurring.