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Observational Evidence of the Effect of Large-scale Drivers on Marine Boundary Layer Precipitation during Subsidence in the Eastern North Atlantic

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1. Motivations and Goal

Issues with the representation of cloud cover in the Southern oceans in most CMIP5 models has revealed that most model have difficulty representing clouds in extratropical cyclones (*Bodas-Salcedo et al*, 2014), and more specifically in the wake of cold fronts (post-cold frontal region, PCF). This problem is found globally, and is also found in northern hemisphere cyclones in the winter time. Clouds in these dynamical regimes are mostly low-level clouds, driven by shallow convection in conditions of subsidence.

Here we exploit the wealth of observations from the ENA site to explore these PCF conditions. Cloud macroscopic properties were first examined in *Naud et al.* (2018), but so far little is known on the properties of precipitation during these periods.

2. Methods

Collect ARM observations and reanalysis output centered on the ENA observatory between 10-2015 and 09-2018

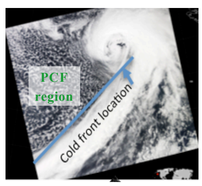
Focus on periods with marine boundary clouds (cloud tops lower than 3km) and identified periods with subsidence associated or not with a cold front.

Estimate precipitation and cloud attributes using 2-s resolution observations then take the hourly average for comparison with coarser resolution large-scale driver datasets.

To overcome scatter emerging from the different time resolutions and measurement uncertainties, establish correlations using observations binned by "driver intensity";

3. Identification of Subsidence and Post-Cold Frontal (PCF) Conditions

$\text{Subsidence}_{\text{North}}$ = subsidence with Northerly wind
$\text{Subsidence}_{\text{South}}$ = subsidence with Southerly wind
$\text{Subsidence}_{\text{PCF}}$ = subsidence after the passage of a cold front



Subsidence: standard definition, $\omega_{500} > 0$ hPa hr^{-1} [MERRA-2 reanalysis]
Fronts require: 1- Extratropical cyclone near ENA [MCMS database]
2- θ gradient and wind dir. changes [MERRA-2]
Effect to ENA verified: 1- wind direction shifts to Northerly as the front passes [Met. Station]
2- wind returns to Southerly as PCF event ends
3 - event lasts > 2hrs

4. Large-Scale Drivers

- Surface relative humidity (RH_{surf}) [Met. station]
- Surface wind speed [Met. station]
- Subsidence rate (ω_{500}) [MERRA-2]
- ΔT_{surf} : T_{skin}-T_{air} [MERRA-2/Met. station]
- Estimated Inversion Strength (EIS): θ_{700}-θ_{surf}-$\Gamma_m^{850}(Z_{700}$-LCL) [Sonde/Met. station]

5. Cloud Attributes/Drivers

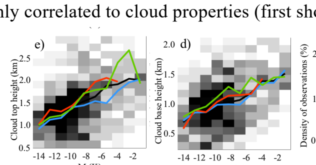
- Cloud base height [KAZR2+Ceilometer]
- Cloud top height [KAZR2]
- Cloud thickness [KAZR2+Ceilometer]

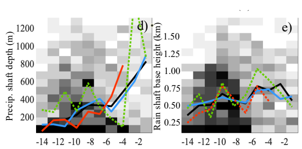
7. Can One Large-Scale Driver Explain it All?

Fletcher et al. (2016) presented the Marine Cold Air Outbreak (MCAO) parameter M
M parameter = θ_{skin}- θ_{800} [MERRA-2/Sonde]

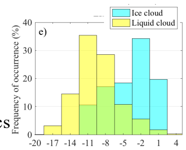
The M parameter was shown to delineate between two common regimes for shallow clouds
Higher M parameter = Higher frequency of open cells (*McCoy et al.*, 2017)

The M parameter was also recently shown to be highly correlated to cloud properties (first shown in *Naud et al.,* 2018):
Higher M parameter = 1) Higher cloud top height,
2) Lower cloud top temp.
3) Higher cloud base height
4) But overall deeper clouds.

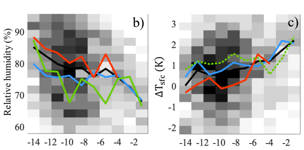




Here we found that the M parameter also correlates with several precipitation attributes, although not as clearly as it does with cloud attributes
Higher M parameter = Deeper rain shafts that do not penetrate as far down



We also found plausible relationship between the M parameter and the microphysical regime where rain is produced
Higher M parameter = Rain produced through mixed-phase microphysics



The success of the M parameter could lie in its relationship to both the sea-air temperature contrast and surface relative humidity which were both found to be highly correlated to several precipitation characteristics in subsidence regimes.

6. Precipitation Attributes : Variability + Relation to Large-scale Drivers and Clouds

Precipitation shaft base [KAZR2+Ceilometer] :

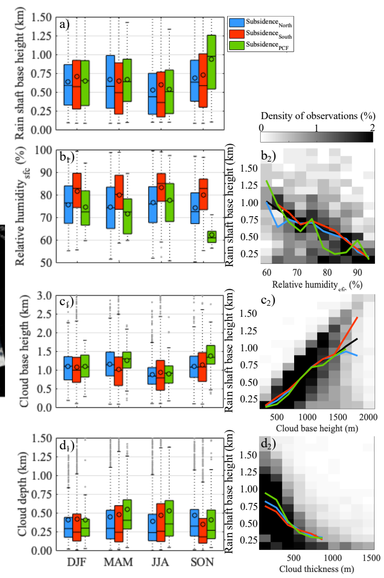
Sub_{PCF} characterized by rain that does not reach as far down especially in the fall
Sub_{PCF} also presents: 1) lower RH_{sfc}, 2) higher CBH and 3) somewhat deeper clouds

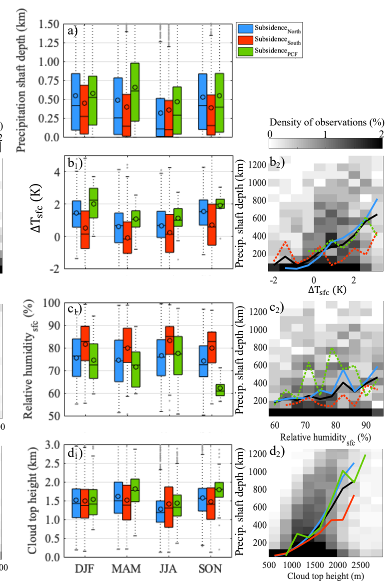
From the correlations, only the RH_{sfc} and CBH trends are consistent with the rain trend suggesting that RH_{sfc} and CBH play a more important role in determining the lowest height where rain can penetrate.

Precipitation shaft vertical extent [KAZR2]: (Max height with Z >-15dBZ) – (Min height with radar echo)

Sub_{PCF} characterized by deepest rain, especially in spring
Sub_{PCF} also presents: 1) higher sea-air temperature contrast (ΔT_{surf}), 2) lower RH_{sfc} and 3) somewhat higher CTH

Only changes in ΔT_{surf} and CTH are consistent with the rain trend suggesting that ΔT_{surf} and CTH play a more important role in determining the depth of precipitation shaft.





"In-rain" rain rate at 0.5 km [Drizzle PI product]: Rate of rain reaching 0.5 km not accounting for clear sky

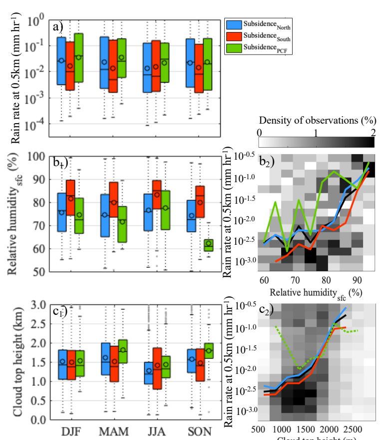
No distinction across subsidence regimes and seasons

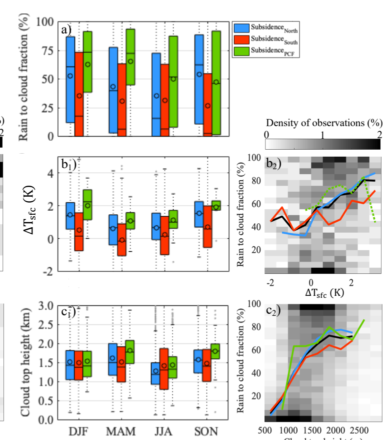
Sub_{PCF}'s lower RH_{sfc} , which is related to a reduction in rain rate at 0.5 km, seems balanced by the presence of higher cloud tops (i.e., deeper clouds) which tend to produce more intense rain at 0.5 km.

Precipitation to cloud fraction [KAZR2+Ceilometer]: In an hour, #profiles w/ precip. divided by # profiles w/ cloud

Sub_{PCF} characterized by higher rain to cloud fraction, highest in winter and spring
Sub_{PCF} also presents: 1) higher sea-air temperature contrast (ΔT_{surf}) and somewhat higher CTH

Both changes in ΔT_{surf} and CTH are consistent with the rain trend suggesting that ΔT_{surf} and CTH are both related to cloud propensity to precipitate.





* *Significant correlation (p<0.05) in solid lines and random correlations in dashed lines.*
* *Black line represents all subsidence conditions.*