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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Motivation and Goal

Issues with the representation of cloud cover in the Southern oceans in most CMIP5 models related to issues representing clouds in post-cold frontal regions

Problem is also present 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

*Naud et al.* (2018) reported that post-cold frontal regions exhibit distinct cloud attributes related to the intensity of large-scale drivers

but so far little is known on the properties of precipitation during these periods

Here we exploit ENA observations to explore the relationship between precipitation attributes and large-scale drivers during Post-Cold Frontal conditions.
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.

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

using MCMS database, MERRA-2 and Met. Station

*Subsidence*: standard definition, \( \omega_{500} > 0 \) hPa hr\(^{-1} \)
Methods

Establish correlation between \textbf{hourly-averaged precipitation attributes} and large-scale or cloud drivers:

\textbf{Larger-scale drivers}

- Surface relative humidity (RH\textsubscript{surf}) [Met. station]
- Surface wind speed [Met. station]
- Subsidence rate (ω\textsubscript{500}) [MERRA-2]
- ΔT\textsubscript{surf} : T\textsubscript{skin} - T\textsubscript{air} [MERRA-2/Met. station]
- Estimated Inversion Strength (EIS): \(\theta\textsubscript{700} - \theta\textsubscript{surf} - \Gamma_m^{850}(Z\textsubscript{700} - \text{LCL})\) [Sonde/Met. station]

\textbf{Cloud drivers}

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

To overcome scatter emerging from the different time resolutions and measurement uncertainties, establish correlations using observations binned by “driver intensity”
Estimate precipitation base height using 2-s resolution observations then take the hourly average.
Subsidence\textsubscript{Post-Cold Front} have rain that does not reach as far down especially in the fall.
Subsidence$_{\text{Post-Cold Front}}$ have rain that does not reach as far down especially in the fall.

Sub$_{\text{PCF}}$ also presents: 1) lower RH$_{\text{sfc}}$, 2) higher CBH and 3) somewhat deeper clouds.

From the correlations, only the RH$_{\text{sfc}}$ and CBH trends are consistent with the rain trend suggesting that RH$_{\text{sfc}}$ and CBH play a more important role in determining the lowest height where rain can penetrate.
Precipitation Shaft Vertical Extent

KAZR2 radar reflectivity (dBZ)

Estimate distance between precipitation top and precipitation base height using 2-s resolution observations then take the hourly average.
**Subsidence**<sub>Post-Cold Front</sub> have deepest rain, especially in spring
Subsidence of the Post-Cold Front have deepest rain, especially in spring. Sub_{PCF} also presents: 1) higher sea-air temperature contrast ($\Delta T_{surf}$), 2) lower RH_{sfc} and 3) somewhat higher cloud top height.

Only changes in $\Delta T_{surf}$ and CTH are consistent with the rain trend suggesting that $\Delta T_{surf}$ and CTH play a more important role in determining the depth of precipitation shaft.
Rain rate PI product from radar-lidar

Average the rate of only rain shafts reaching 0.5 km during the hour
In-rain Rain Rate 0.5 km a.g.l.

No distinction across subsidence regimes and seasons
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$\text{Sub}_{\text{PCF}}$’s lower $\text{RH}_{\text{sfc}}$, 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.
In an hour, \#profiles with precip. divided by \# profiles with cloud
Subsidence Post-Cold Front have higher rain to cloud fraction, highest in winter and spring
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Sub$_{PCF}$ also presents: 1) higher sea-air temperature contrast ($\Delta T_{surf}$) and somewhat higher cloud top height

Both changes in $\Delta T_{surf}$ and CTH are consistent with the rain trend suggesting that $\Delta T_{surf}$ and CTH are both related to cloud propensity to precipitate.
Can One Large-Scale Driver Explain it All?

Fletcher et al. (2016) presented the Marine Cold Air Outbreak (MCAO) parameter $M$

$M = \theta_{\text{skin}} - \theta_{800\text{hPa}}$ [MERRA-2/Sonde]

Higher $M = \text{Higher frequency of open cells}$ (McCoy et al., 2017)
Higher $M = \text{Higher cloud top height}$ (Naud et al., 2018)
Higher $M = \text{Higher cloud base height}$ (Naud et al., 2018)
Higher $M = \text{Deeper clouds}$ (Naud et al., 2018)

Here we found:

Higher $M = \text{Deeper rain shafts that do not penetrate as far down}$
Higher $M = \text{Rain produced through mixed-phase microphysics}$

While relationships are significant they are not as clear as with clouds
**Conclusions**

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.

**Post-Cold Frontal conditions** relative to general subsidence
- rain that does not reach as far down especially in the fall
- deepest rain shafts, especially in spring
- higher rain to cloud fraction, highest in winter and spring
- no distinction in intensity of rain reaching 0.5 km across subsidence regimes and seasons

**Drizzle PI product available in the ARM archive**
For the Eastern North Atlantic Observatory
For the period 2015-10-01 and 2018-09-29

**Retrievals of:**
- Rain Rate with its uncertainty
- Melting layer height
- Drizzle water content with its uncertainty
- Drizzle diameter (D₀) and its uncertainty
- Drizzle number concentration (N) with its uncertainty
- Shape of drizzle drop size distribution (Mu)
- Drizzle fall velocity with its uncertainty
- Eddy dissipation rate with its uncertainty