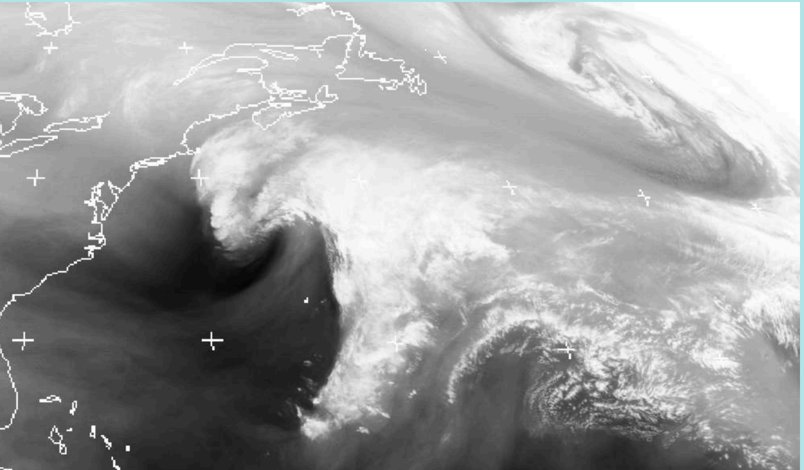
Introduction

Air-sea interaction in the midlatitudes is modulated by the passage of extratropical cyclones and their trailing fronts. Particularly strong ocean heat loss (both sensible and latent) is observed in the post-cold frontal region, where the dry intrusion (DI) airstream descend slantwise from the upper troposphere towards the cold trailing front.

Here we focus on understanding the co-occurrence of DIs, cold trailing fronts and cyclones, and their role in the variability of surface fluxes.

A Life-cycle Perspective on the Cyclone Surface Impact Associated with Dry Intrusions



Vered Silverman[1] and Shira Raveh-Rubin[1], and Jennifer Catto[2]

Contact: vered.silverman@weizmann.ac.il

[1] Weizmann Institute, Israel

[2] University of Exeter, UK

Motivation

Air-sea interaction in the midlatitudes is modulated by the passage of extratropical cyclones and their trailing fronts (e.g, Vanniere et al 2017, Grams et al 2017, Aemisegger and Papritz 2018). Particularly strong ocean heat loss (both sensible and latent) is observed in the post-cold frontal region (Dacre et al., 2019). In this region, airmasses within the dry intrusion (DI) airstream descend slantwise from the upper troposphere towards the cold trailing front (Fig. 1).

As the cyclone case-to-case variability is high, understanding the co-occurrence of DIs, cold trailing fronts and cyclones is important for understanding the variability of surface fluxes, especially in regions not usually associated with frequent frontal activity.

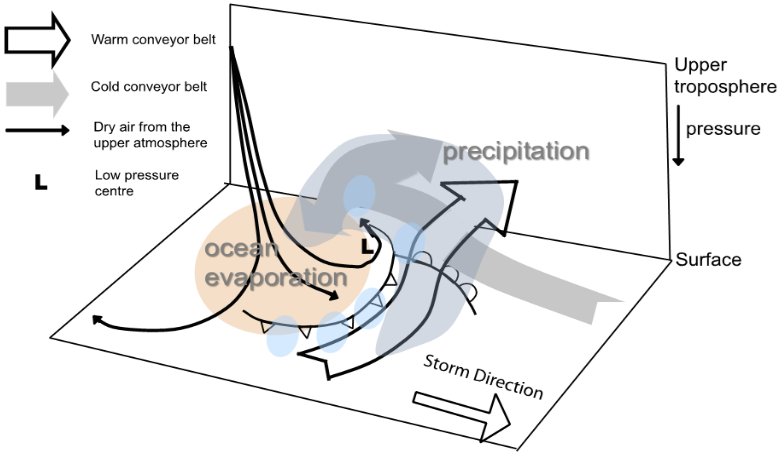


Figure 1: The conceptual model of a cyclone and its associated air streams.

Objectives

A climatological study quantifying the co-occurrence of fronts and DIs (Raveh-Rubin and Catto, 2019) found the presence of DIs to be associated with stronger surface heat fluxes. Here the climatological study is extended to account for the cyclone life-cycle by using feature-based identification and tracking in the ERA-Interim dataset, for the 1979-2014 winters. We focus on the relationship between extratropical cyclone characteristics, DIs and cold fronts, their co-evolution throughout the lifetime of a cyclone, and consequently their impact on air-sea interaction.

Goal: Evaluate climatologically the co-evolution of extra-tropical cyclones and their associated air streams:

- How often cyclones are accompanied by DIs ?
- When during their life-cycle do they match?
- What governs the variability of the remote surface influence of cyclones such as surface sensible and latent heat fluxes?

Methods

1. Atmospheric variables from ERA Interim reanalysis (Dee et al., 2011) are used on an 6-hourly resolution during 1979-2014.
2. Cyclone identification and tracking (Wernli and Schwierz , 2006), according to the outermost closed contours of mean sea level pressure.
3. Fronts are identified using a thermal front parameter (TFP) (Hewson 1998, Berry et al. 2011) based on gradients of wet bulb potential temperature at 850hPa.
4. Dry intrusions are identified using a Lagrangian-based dataset described in Raveh-Rubin (2017) using the Lagrangian analysis tool (LAGRANTO), v2.0 (Sprenger and Wernli, 2015).

Matching Strategy

<u>Matching strategy</u>

Each cyclone track is classified as DI cyclone (Fig. 3, orange line) if its mask (Fig 3., blue contour) was intersected (matched) with an Eulerian object of a cold front (Fig 3., cyan) and a DI outflow object (Fig 3., magenta). Otherwise it is classified as non-DI cyclone, matched with a trailing fronts (isolated cyclones are not considered).

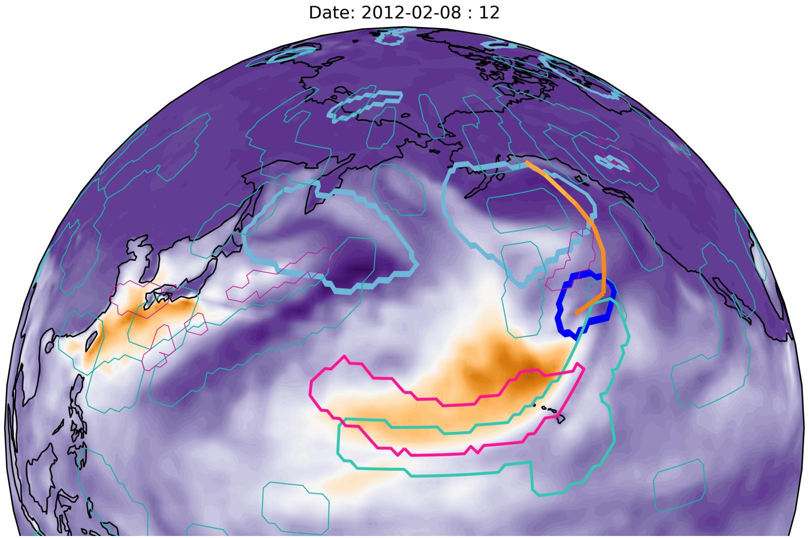
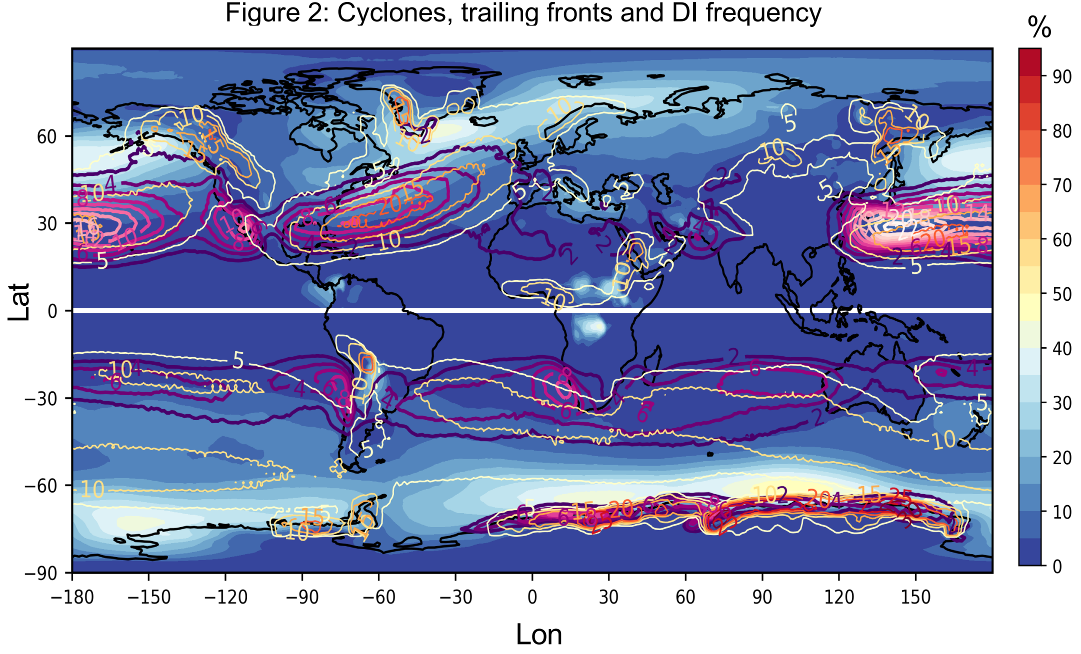


Figure 1: Currently tracked cyclone mask (dark blue) and its track (orange-yellow line), SLHF [W m^{-2}] (shading), cold fronts (cyan), DI outflow mask (magenta), and surrounding cyclones (light blue).

Results – Cyclones, Cold fronts, and DI climatology

Figure 2: Cyclones, trailing fronts and DI frequency



The occurrence frequency (percentage from all 6-hourly data) of cyclones persisting for at least 24 hours (Fig. 2, shading) for DJF/JJA, 1979-2014, shows the ***frequency*** of cyclone occurrence is up to 50% in the storm track regions during this period.

Occurrence frequency of DIs (pink) and trailing fronts (orange) (Fig. 2a), indicate the south-east location of the fronts and the DI outflow behind them in agreement with the conceptual model of a single cyclone.

Results – Cyclones, Cold fronts, and DI climatology

The fraction (%) of cyclones matched with both trailing fronts and DIs (Fig. 3a, colors) is smaller (~ 50%) and are similar in both the Atlantic and North Pacific, with different spatial behavior.

This gives us information about the co-existence of fronts and DIs with cyclones ***instantaneously***.

Figure 3a: Cyclones matched with trailing fronts and DIs

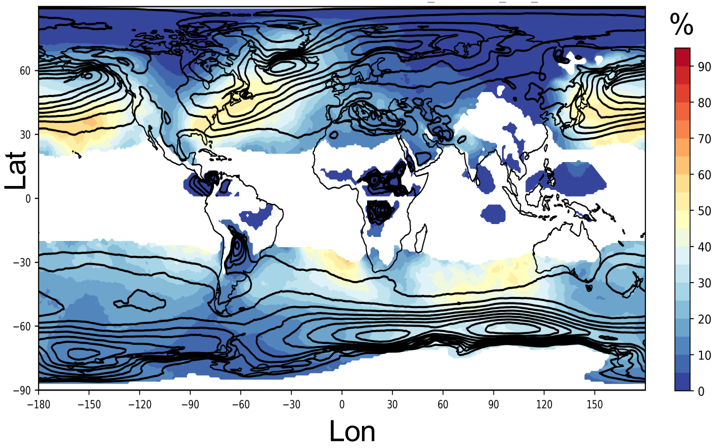
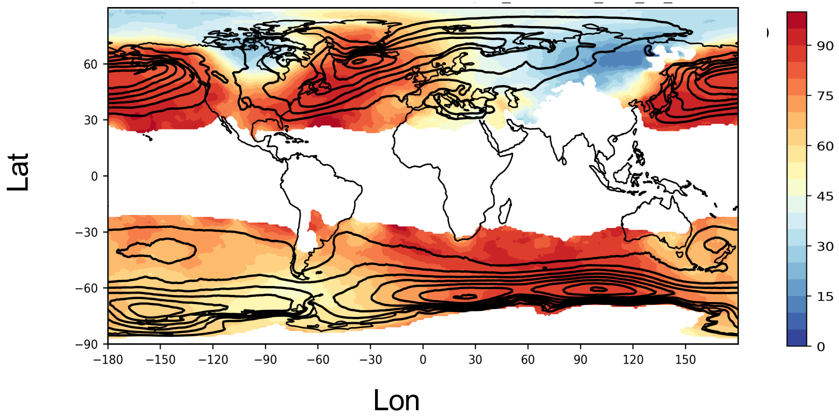


Figure 3b: Cyclones matched with DIs along their track



→ ***How cyclones and DIs co-evolve along the cyclone track?***

If we consider the cyclones that were matched ***somewhere*** along their ***track*** with DIs (Fig. 3b) we see that 65-80% of the cyclones are associated with DIs, while **<u>in the storm track regions most</u>** (80%) of the cyclones are associated with DIs along their track.

* Figure 3: climatological cyclone frequency indicated by black contours

When along their lifetime do cold fronts and DIs meet? What is their surface impact?

From hereafter we focus on cyclone tracks starting at cyclogenesis hotspots in the North Pacific (NP) and the North Atlantic (NA) (red boxed is Fig.4).

We select only cyclone tracks originating at these locations, and reach their minimum SLP at the ocean.

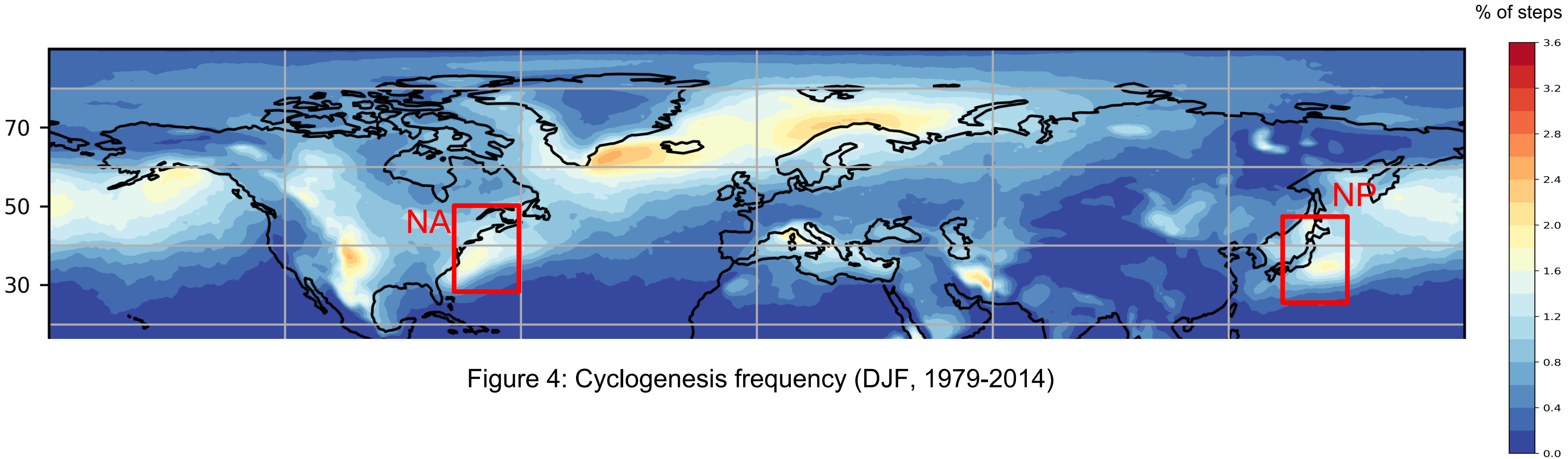


Figure 4: Cyclogenesis frequency (DJF, 1979-2014)

Composite analysis

To understand the temporal development and environmental influence of the cyclone, spatial time-lag composites are centralized around the time of the minimum SLP of each cyclone track. Different variables are gridded to a reference distance of 30deg NS/EW around the equator, relative to the cyclone center.

Strong latent heat flux exists at the south-west quarter (Fig 5. shading), accompanied by a strong DI outflow (pink contours) trailing behind a cold front (blue contours), and a classical comma shaped precipitation pattern (green contours).

The next composites will consider anomalies from climatology instead of the observed field, so we can truly interoperate the evaluation of the cyclone surface influence and its environment.

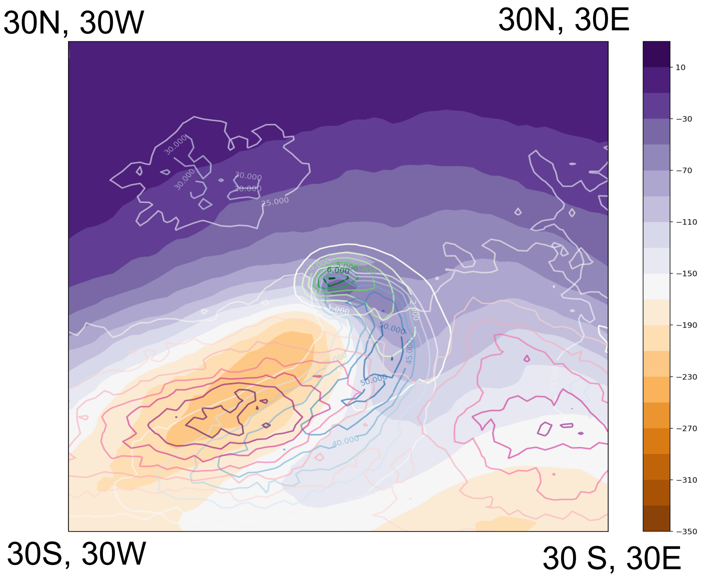
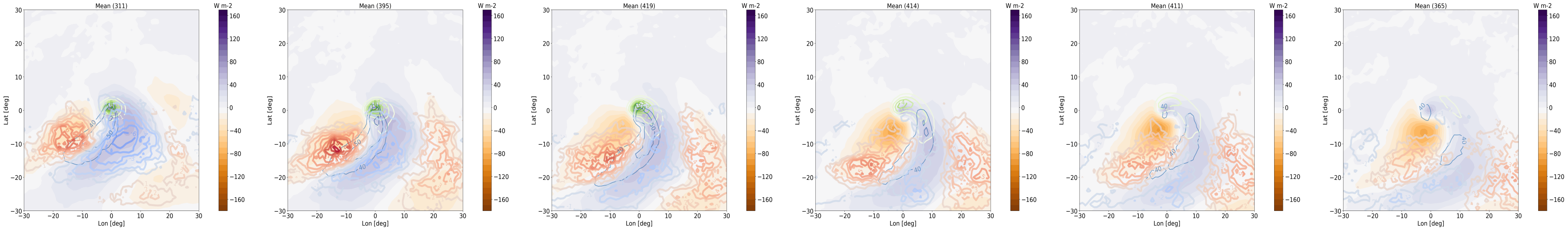


Figure 5:
Composite of 417 tracks in the North Pacific, 6hours prior to reaching minimum SLP.
Latent heat fluxes exist at the south-west quarter (shading, W/m2), DI outflow (trajectory density, pink contours), cold front (blue contours), large scale precipitation pattern (green contours).

A typical life cycle of a cyclone – Latent heat flux, DIs, fronts and precipitation



(a) lag -42h (b) lag -24h (c) lag -12h (d) lag 0h (e) lag 6h (f) lag 18h

Figure 6: time-lag composite for **North Pacific** tracks

Early development:

- Positive latent heat flux anomalies (orange shading) due to ocean evaporation are induced at the west flank of the cyclone where enhanced DI outflow (red contours) is observed, trailing behind the cold front (blue contours). A pronounced sensible heat flux exists also at the south-west flank, accompanied by negative SST anomalies (not shown).
- Precipitation rate is highest at the cyclone center

Reaching cyclone intensity peak:

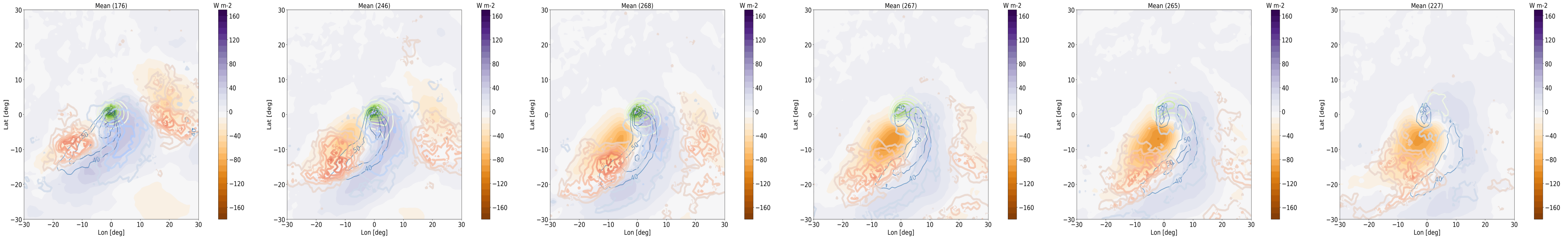
- The anomalous heat flux intensifies, as the DI outflow moves south-east trailing behind the cold front.
- Precipitation extends to a comma shaped pattern.

Cyclone decay:

- The DI outflow is still pronounced at the decay stage although it is located farther away.
- Precipitation weakens

Figure 6:
Time lag composite of 417 tracks in the North Pacific. Surface latent heat fluxes exist at the south-west quarter (shading, W/m2), DI outflow (red contours, trajectory density), cold front (blue contours, frequency occurrence), large scale precipitation pattern (green contours, mm).

A typical life cycle of a cyclone – Latent heat flux, DIs, fronts and precipitation



(a) lag -42h (b) lag -24h (c) lag -12h (d) lag 0h (e) lag 6h (f) lag 18h

Figure 7: time-lag composite for **North Atlantic** tracks

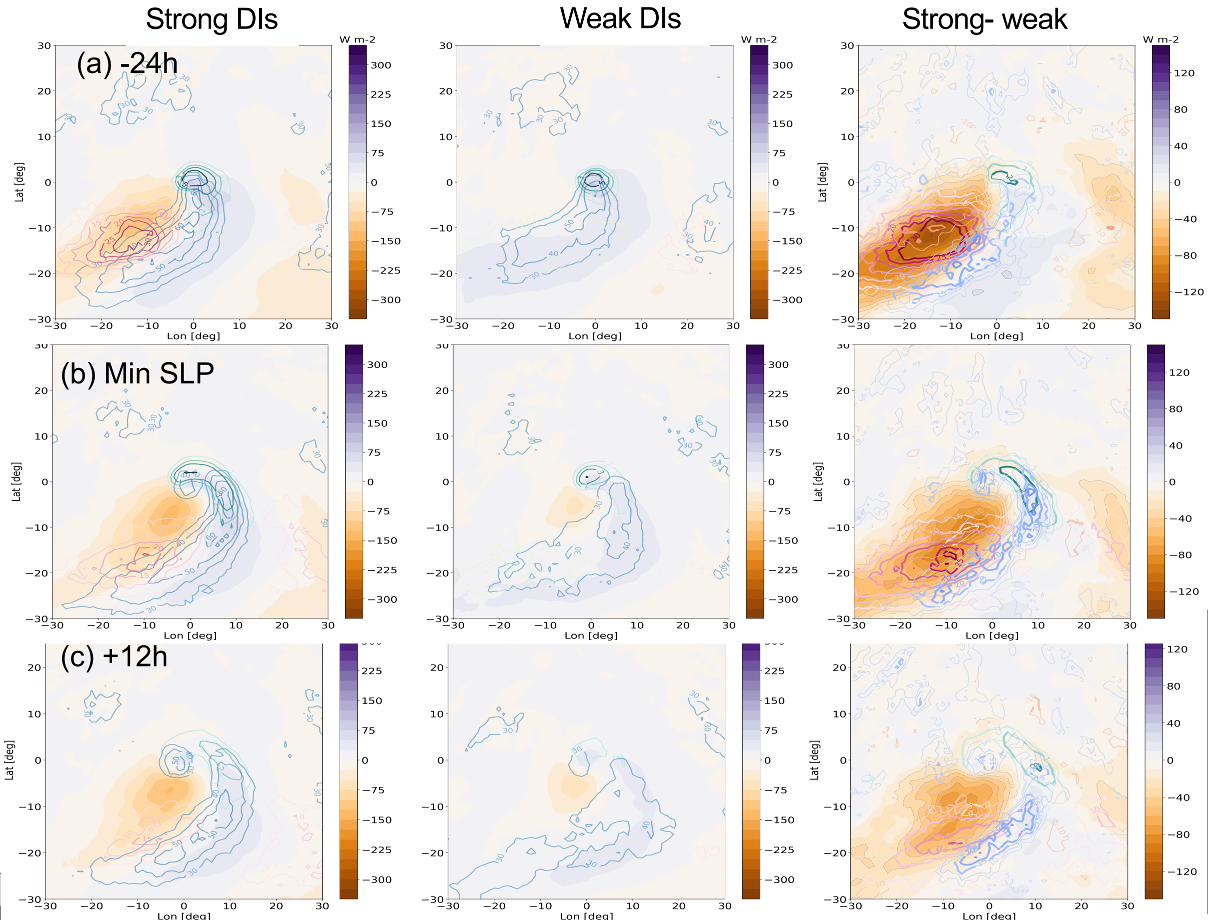
→ Similar cyclone evolution is found in the North Atlantic.

Figure 7:
Time lag composite of 268 tracks in the North Atlantic. Surface latent heat fluxes exist at the south-west quarter (shading, W/m2), DI outflow (red contours, trajectory density), cold front (blue contours, frequency occurrence), large scale precipitation pattern (green contours, mm).

How does the DI intensity influence these features?

Next we inspect the different evolution of cyclones with strong and weak DIs, selected as those below or above the the 30th and 70th percentiles of the mean trajectory density at the south west flank of the cyclone at lag -24h

Influence of DI intensity - Pacific



Cyclones with strong DIs are associated with:

→ Enhanced ocean evaporation and cooling (Fig 8a, shading)

→ Stronger precipitation at the cyclone center (Fig8a, green contours) at the early stages

→ Stronger precipitation at the north east flank WCB region at the decaying stage (Fig 8b,c , green contours).

→ The DI outflow is pronounced even at the decaying stage of the cyclone, along with a longer lived cold front (Fig 8b,c , pink and blue contours correspondingly).

In the Atlantic, the cold front and associated precipitation are less significant at the decaying stage (not shown).

Figure 8: Strong vs Weak DIs (24hours prior to minSLP)
Time lag composite (-24h, 0, +12h) for strong (left), and weak (mid) DIs, and their difference (right), selected as those below or above the the 30th and 70th percentiles of the mean trajectory density at the south west flank of the cyclone at lag -24h, for the North Atlantic. Surface latent heat fluxes exist at the south-west quarter (shading, W/m2), DI outflow (pink-green contours, trajectory density), cold front (blue contours, frequency occurrence), large scale precipitation pattern (green contours, mm).
The statistical significance is indicated at the difference shown for SLHF (grey contours), precipitation and DI outflow (thick contours).

Relationship between DI intensity and cyclone intensity and upper levels

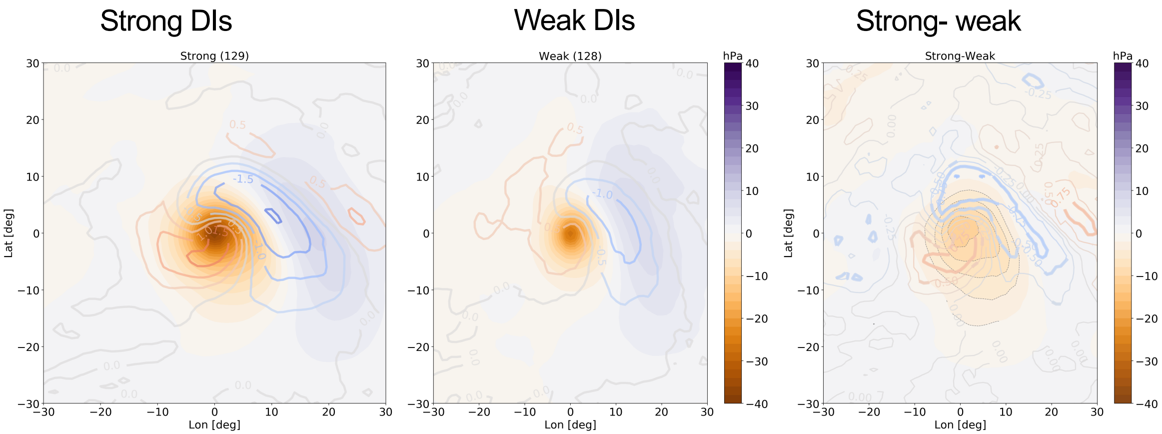


Figure 9: Composite for cyclones with strong (left), and weak (mid) DIs, and their difference (right), showing SLP anomalies (shading, hPa), and PV anomaly at 330K isentrop (red-blue contours, PVU). Statistical significance is indicated at the difference shown for SLP (grey contours), and PV at 330K (thick contours).

Cyclones associated with stronger DIs at the early development stages:

→ Are stronger and larger (Fig 9 shading, showing SLP anomalies)

→ Supported by a stronger upper level positive PV anomaly, tilted westwards with height at negative time lags (not shown), while breaking cyclonically (Fig 9, right pane) poleward to the jet maxima (not shown).

Cyclone and DI impact on ocean Air-Sea interaction

Fig 10a: SLHF [W/m2] DJF 1979-2014 climatology

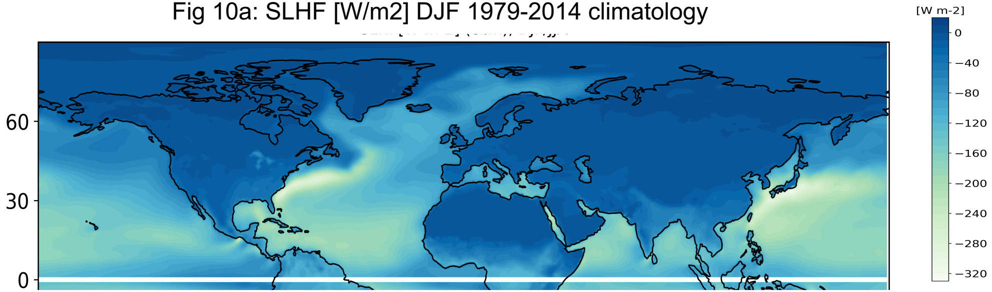


Fig 10b: Fraction of SLHF [W/m2] masked by DIs

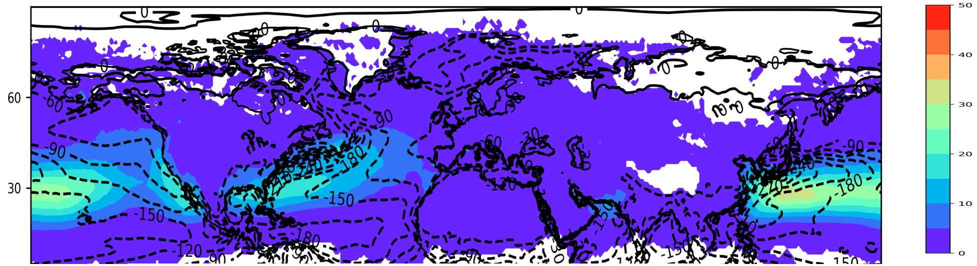
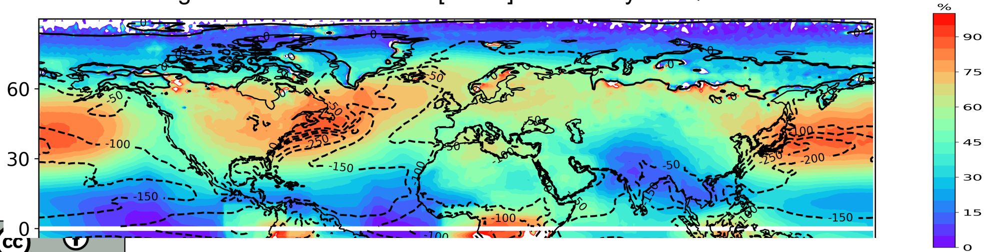


Fig 10c: Fraction of SLHF [W/m2] masked by SWQ



What is the contribution of the surface fluxes induced by DIs associated with etratoropical cyclones to the Air-Sea interaction?

The surface latent heat flux is calculated by masking the latent heat flux climatology with DI objects and the south-west quarter (SWQ) 30-0S, 30-0W to the cyclone center and its fraction in the entire climatology (Fig. 10a, shading, and black contours in Fig.10b-c).

→ SLHF masked by DIs (Fig 10b) contribute up to 40% of the observed climatology, stronger influence in the pacific ocear and around the gulf stream.

→ SLHF [W/m2] masked by SWQ (Fig.10c), contribute up to 80%

Conclusions and Outlook

By objective Lagrangian identification and tracking of DIs we evaluated a typical life cycle of extratropical cyclones, and quantified the surface impact of their associated DIs.

We find that 65-80% of extratropical cyclones are matched with DIs, mostly during the intensification period. Closely inspecting oceanic cyclones shows that stronger DIs are associated with stronger cyclones, supported by an upper level PV anomaly in a cyclonic wave-breaking synoptic system, induce stronger precipitation at the WCB region, and enhanced evaporation in the region of enhanced DI outflow.

The evaporation induced by DIs account for up to 40% in the observed climatology, and the entire south-west quarter of the cyclone center accounts for up to 80%, showing how transient weather systems contribute to the air-sea interaction significantly, through a fairly remote influence of the cyclones.

The large database we produced will serve us in studying in more detail the surface impact of cyclones. Specifically, we will study the cyclones impact on SST, on short and longer time scales, and compile a budget analysis to quantify the influence of the observed features to the cyclone development and air-sea heat transfer.

Thanks you