Development & Extratropical Applications of the CYGNSS Surface Heat Flux Product

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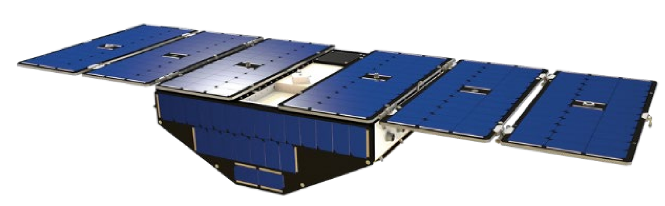
Introduction

- Surface latent (LHF) and sensible (SHF) heat fluxes aid in the transport of heat and energy between the atmosphere and ocean
  - Driven by winds and air-sea temperature/humidity differences
- LHF and SHF increase baroclinicity and instability within the boundary layer, influencing climate/weather systems like:
  - Tropical & Extratropical Cyclones (TCs/ETCs)
  - Atmospheric Rivers (ARs)
  - Tropical Convection (e.g. MJO)



- Remote sensing instruments do not provide consistent estimates of SHF & LHF due to signal attenuation from precipitation and low spatial/temporal frequency
- CYGNSS's dense coverage over tropical/subtropical oceans has been used to estimate surface heat fluxes at higher frequencies
  - A combination of other datasets, like reanalysis for temperature & humidity, are used to estimate LHF & SHF

CYGNSS Flux Algorithm

- Input CYGNSS L2 Wind Speed observations (FDS & YSLF) and ERA5 Reanalysis for temperature and humidity
  - ERA5 is co-located to CYGNSS specular points with a tri-linear interpolation in time and space
  - Previous used MERRA-2 for thermodynamic variables
- Coupled Ocean-Atmosphere Response Experiment (COARE), Version 3.5 is used to estimate LHF and SHF
  - Parameterizes surface heat flux drag coefficients (C_D) as function of gustiness, surface roughness, & atmospheric stability
  - Verified for wind speeds up to 25 m/s (QC flags for wind over 25 m/s)
  - Assume equivalent neutral winds from CYGNSS in upcoming version (SDR V3.2) & make necessary corrections to COARE algorithm
- Output as a Level 2 product with the same number of specular points as their respective Level 2 wind speed product
  - FDS and YSLF ocean surface heat flux estimates

Current CYGNSS Flux Products and Validation

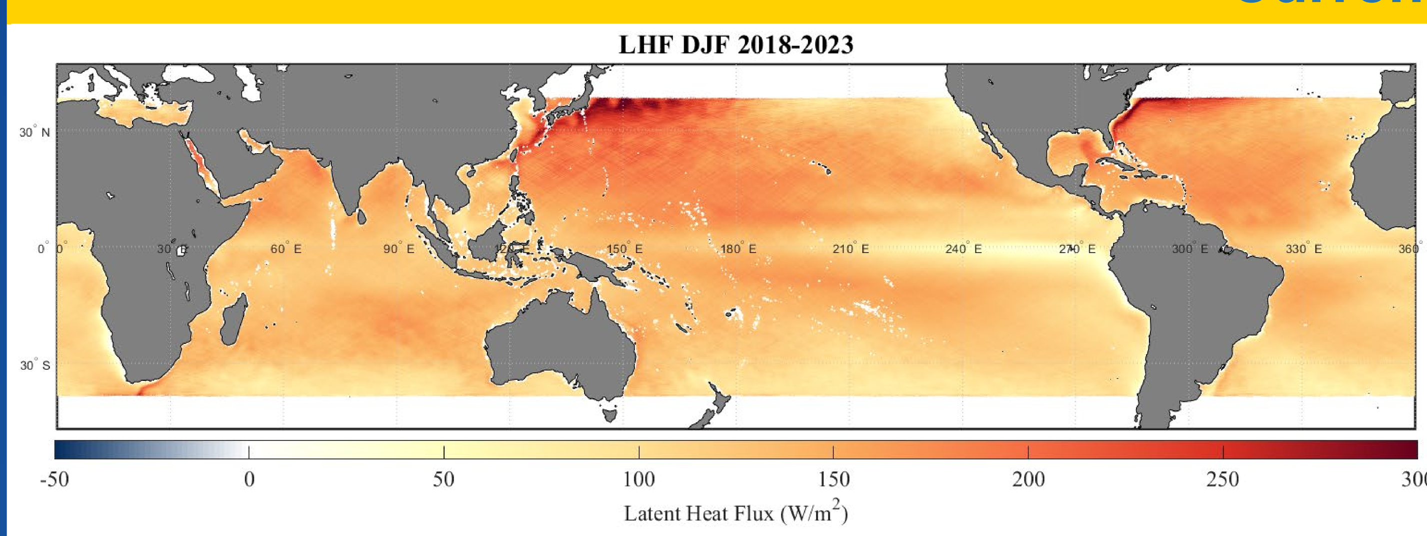
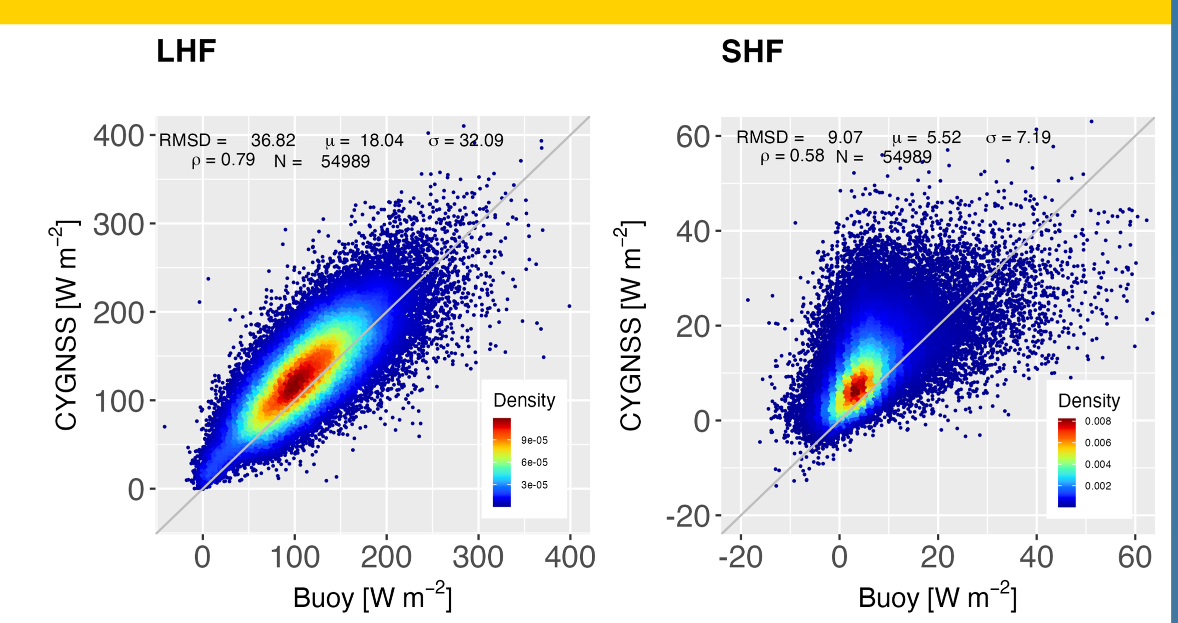


Fig. 1: Mean CYGNSS LHF observations (CDR V1.2) of Dec., Jan., Feb. (DJF) 2018-2023. Units: W/m²

- *Level 2 Science Data Record (SDR) V2.0*
  - CYGNSS L2 SDR V3.1 Winds & ERA5 Reanalysis
- *Level 2 Climate Data Record (CDR) V1.2*
  - CYGNSS L2 CDR V1.2 Winds & ER5 Reanalysis
- *Level 2 SDR V3.2 to be released Summer 2024*
  - CYGNSS L2 SDR V3.2 Winds & ERA5 Reanalysis

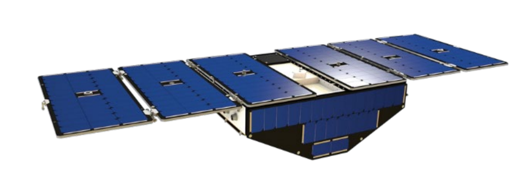
Scan to access CDR V1.2 from the PO.DAAC

- Comparisons of CYGNSS LHF and SHF estimates to tropical buoys show how well CYGNSS fluxes compare to in-situ observations (Fig. 2)
- CYGNSS fluxes perform well at lower flux values
  - Greater scatter at higher flux values due to wind speed difference (LHF) and Ts-Ta differences (SHF)
- Improvement in surface heat fluxes as the CYGNSS wind speeds improve
  - Improvement in fluxes with corrections to the COARE algorithm to factor in CYGNSS's equivalent neutral wind speed assumptions



	LHF	SHF
RMSD	36.82	9.07
μ	18.04	5.52
σ	32.09	7.19
r	0.79	0.58
N	54,989	54,989

Fig. 2: Comparisons of the upcoming CYGNSS SDR V3.2 flux product to tropical buoy data. Table to the left shows statistical values from the graph above.



CYGNSS Extratropical Cyclone Observations

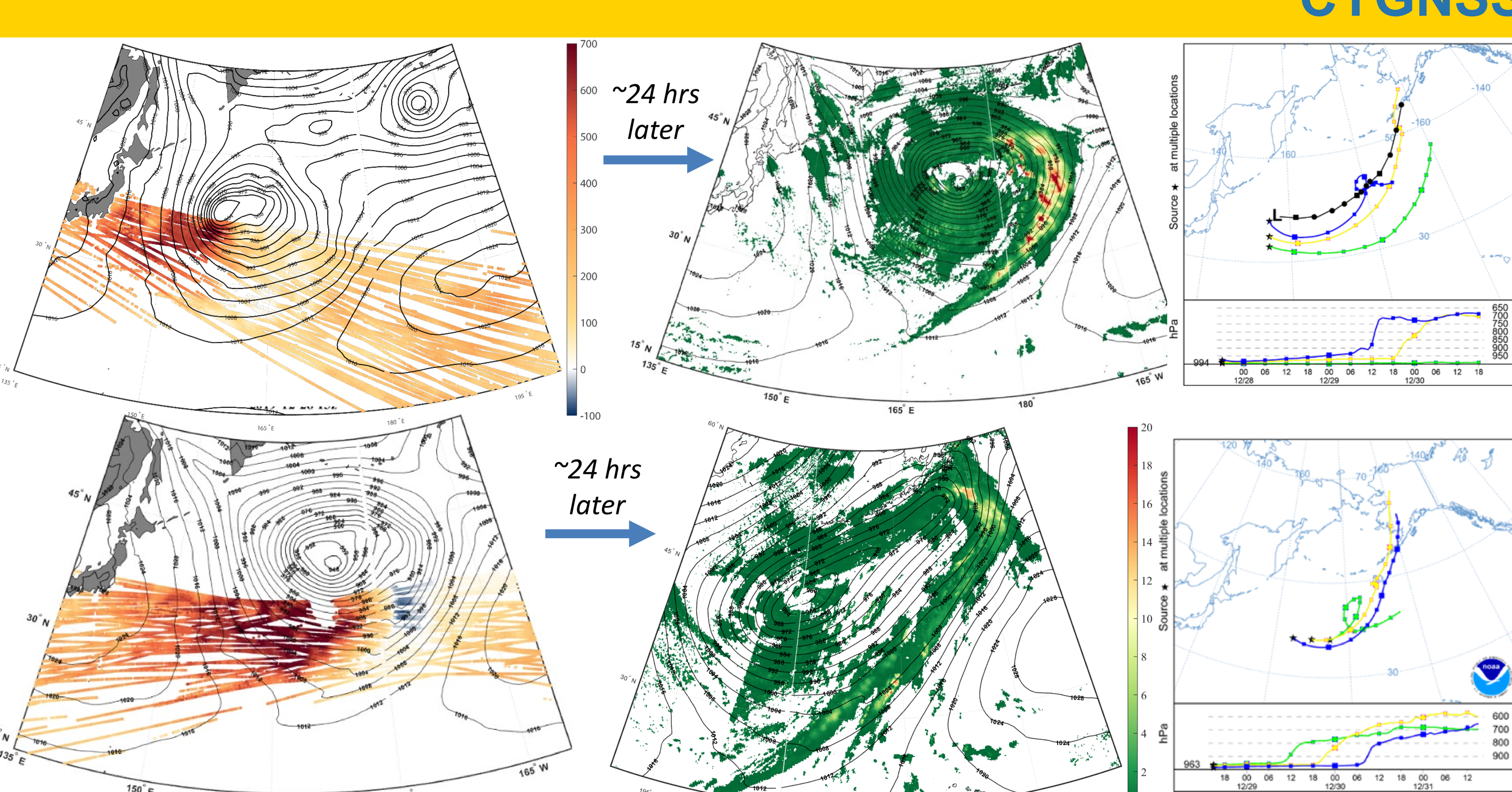


Fig. 3: **Left:** CYGNSS LHF (W/m²) at 2019-12-27 18z & 12-28 15z; **Middle**: IMERG Precip rate (mm/hr) at 2019-12-28 & 12-29 at 18z; **Right**: HYSPLIT forward trajectories from areas of high LHF values observed by CYGNSS.

- CYGNSS observations show higher LHF values as the ETC develops in WPAC (Fig. 3)
  - HYSPLIT preliminary trajectories show parcels from high flux areas following the ETC, vertical movement as well
  - Parcel locations correlate with strong precipitation ~24 hours later
- Stronger surface heat fluxes when ETC matures
  - HYSPLIT trajectories show a similar pattern but do not line up with the precipitation observed
  - Precipitation rates 24 hours after LHF maxima weaker than before
  - If fluxes play a role, fluxes earlier or before development likely play a larger role than fluxes when the ETC has matured
- Composite analysis of strong and weak fluxes in the area of the Warm Sector (WS) 24 hours prior to arrival (Fig. 4) suggests that fluxes before ETC arrival play a significant role in ETC development.

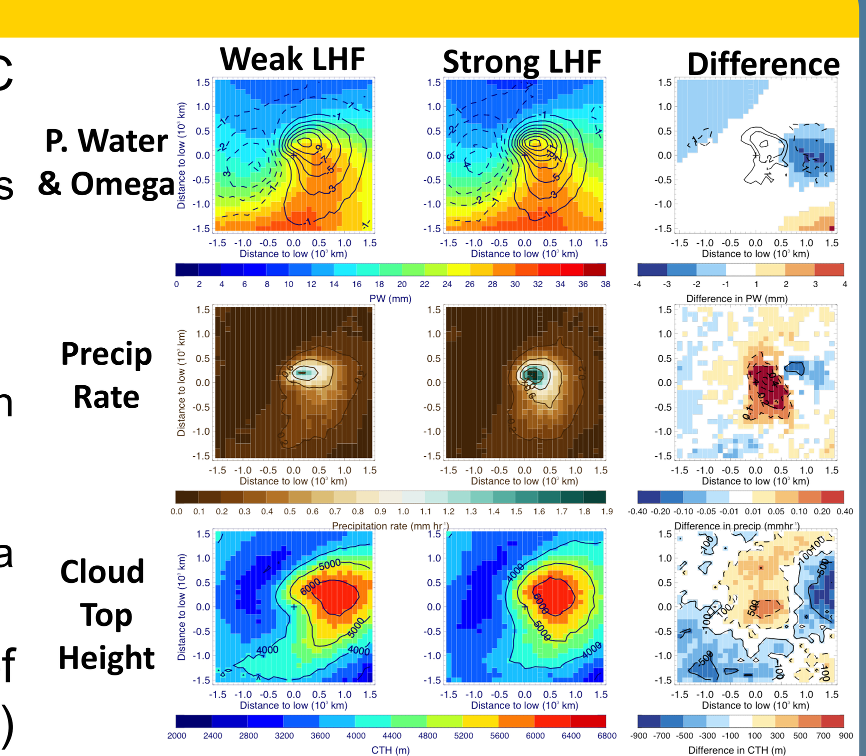


Fig. 4: Cloud and precipitation variables (top to bottom: Precipitable water/ascent strength, Precipitation rate, Cloud Top Height) between ETCs with weak and strong LHF values in the Warm Sector 24-hours prior to ETC arrival.

CYGNSS Atmospheric River Observations

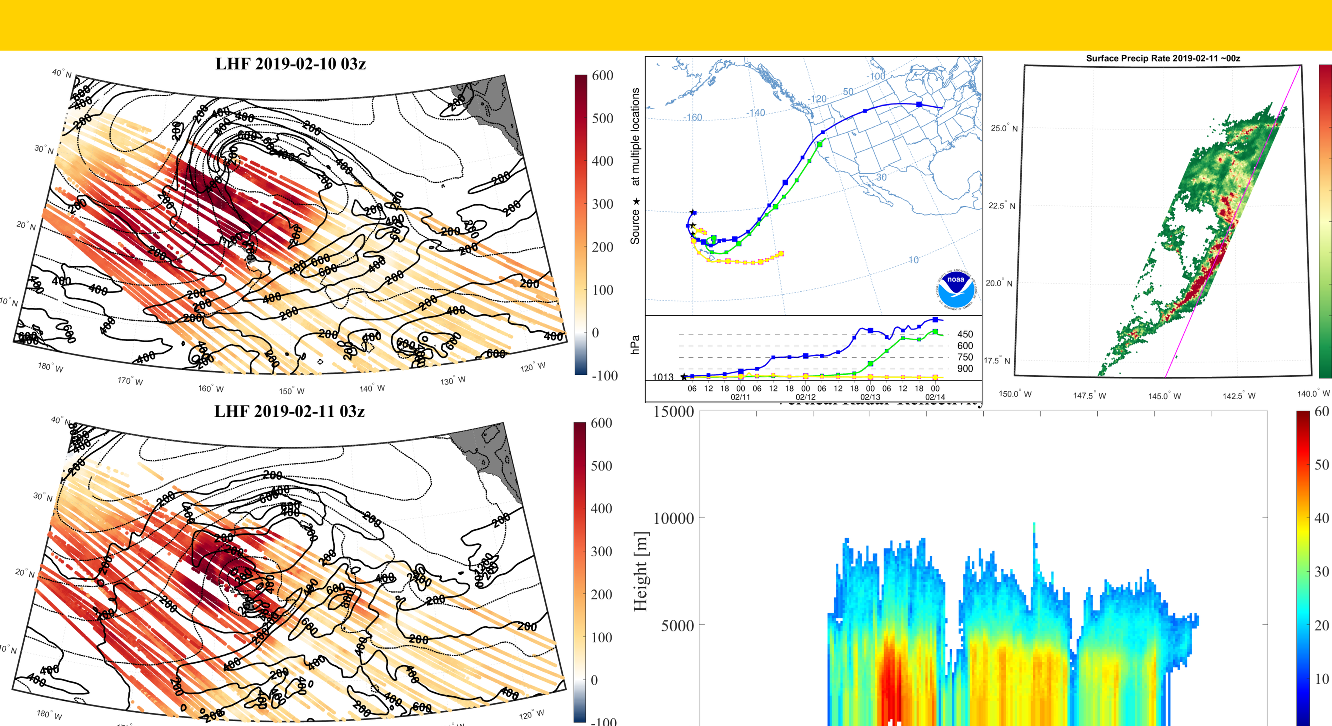


Fig. 5: CYGNSS LHF (W/m²) at 2019-02-10 & 02-11 at 03z (left) as the Valentine's Day Atmospheric River begins to form. GPM Precipitation Radar observations (right) of the AR on 2019-02-11 at 00z, with HYSPLIT forward trajectories (top) linking them to observed LHF.

- CYGNSS observations show high LHF values associated with developing and matured ARs in the Northern Pacific Ocean
- Strong LHF values present near Hawai'i associated with a Kona Low (Fig. 5) before developing into the 2019 Valentine's Day AR
  - HYSPLIT trajectories from areas of high LHF show parcels following the path of the AR, lining up with landfall and early precipitation development
  - GPM PR observations show significant mesoscale structure within the AR as it forms, lining up with some of the parcel trajectories
- AR Family in January 2023 impacted the US West Coast, with most of the ARs having strong LHF values (Fig. 6)
  - Trajectories from areas of high fluxes show energy being transported upstream to the other ARs, possibly strengthening them
  - Some parcels (just a degree apart) follow the path of the AR, suggesting that the location and timing of the fluxes are highly important

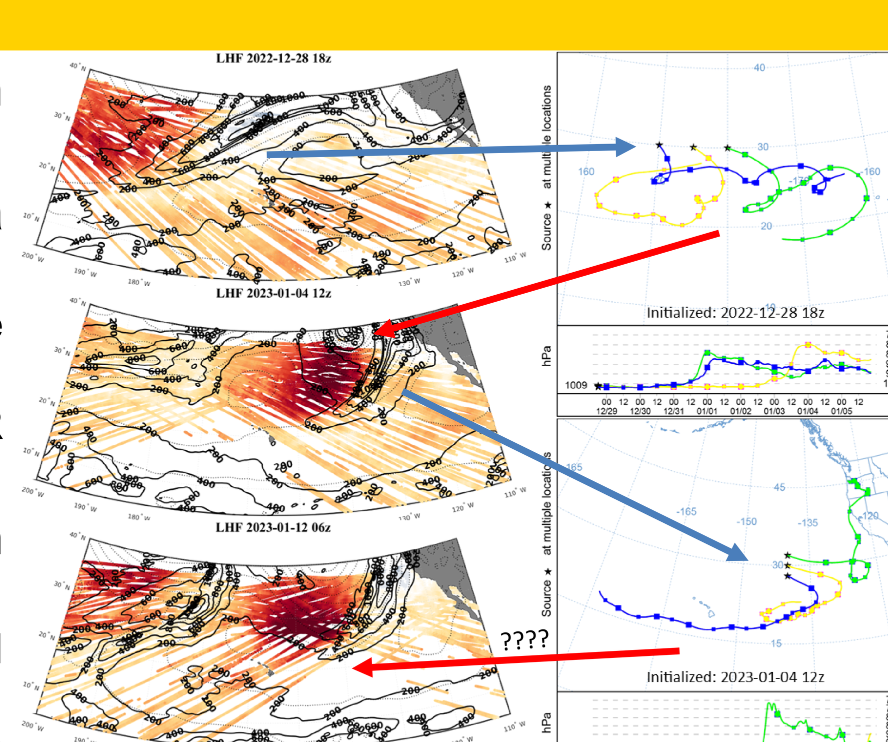


Fig. 6: LHF observations (left) from an AR Family in January 2023, with HYPLIT forward trajectories from areas of high LHF.

Conclusions

- CYGNSS Ocean Surface Heat Fluxes have become a valuable tool for observing and understanding air-sea processes over the tropical and sub-tropical oceans.
- CYGNSS provides valuable flux observations as ETCs and ARs develop in the lower midlatitudes
  - Fluxes earlier in their lifecycles likely play a role in cloud and precipitation development, but when matured, the fluxes (though stronger) do not.
  - Fluxes associated with ARs and ETCs may be transported upstream, strengthening other ETCs/ARs in a family. But more tests are needed.

Future Developments

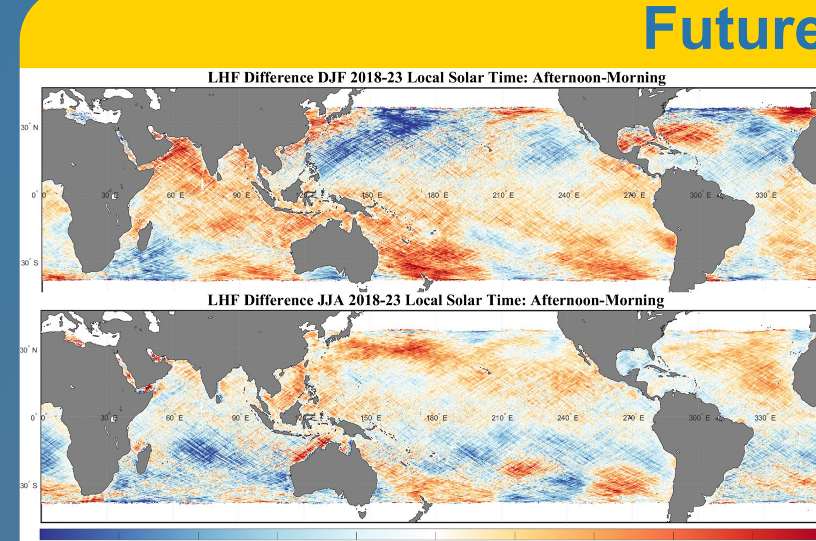


Fig. 7: Mean LHF differences between local afternoon and morning in DJF (top) and JJA (bottom) from 2018-2023.

- Future CYGNSS flux products will include Local Solar Time (LST), which will allow us to factor in diurnal cycles in ETCs and ARs on longer time scales (Fig. 7)
- Further trajectory analysis is needed through HYSPLIT or LAGRANTO in order to better analyze the link between air-sea interactions and mesoscale cloud/precipitation formation in ETCs and ARs.
  - Location and timing are important