Utilizing CYGNSS Surface Heat Fluxes to Understand Air-Sea Impacts on the Development of Extratropical Cyclones and Atmospheric River Clouds and Precipitation Structure

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CYGNSS Ocean Surface Heat Flux Product

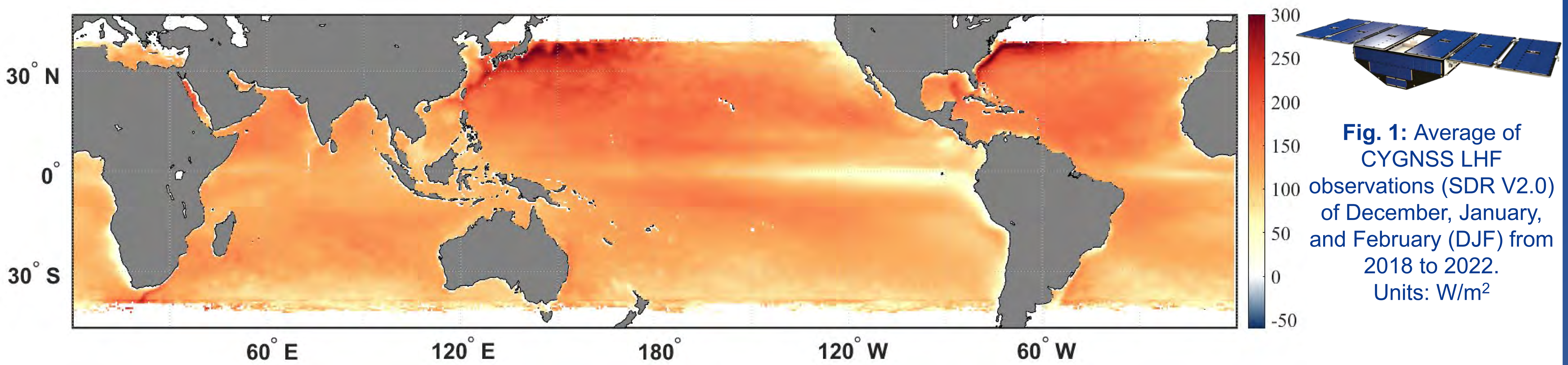
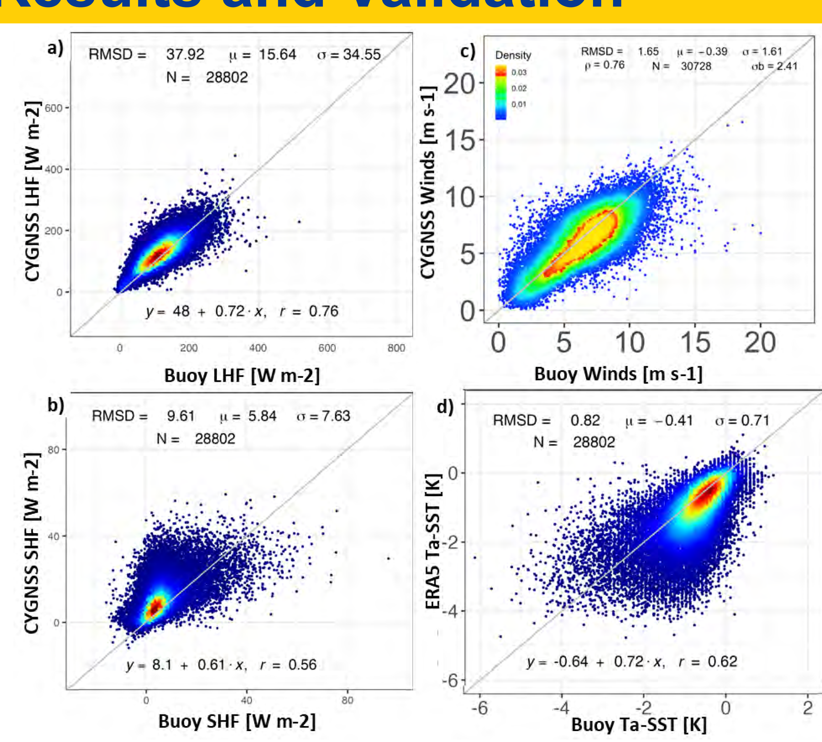


Fig. 1: Average of CYGNSS LHF observations (SDR V2.0) of December, January, and February (DJF) from 2018 to 2022. Units: W/m^2

- LHF & SHF increase the baroclinicity/instability within the boundary layer, influencing climate/weather systems like: *Tropical/Extratropical Cyclones (TCs/ETCs), Atmospheric Rivers (ARs), and Tropical Convection (e.g. MJO)*
- Remote sensing instruments do not consistently provide estimates of SHF & LHF due to signal attenuation from precipitation and low spatial/temporal frequency
- CYGNSS (Cyclone Global Navigation Satellite System) provides improved wind speed observation coverage over the tropical and subtropical oceans
  - Combined with other datasets, like reanalysis, for temperature/humidity, can be used to estimate LHF & SHF
  - Utilizes GPS L1 Channel (1575 MHz, 19-cm wavelength), which does not attenuate with precipitation
- CYGNSS Surface Heat Flux Product was initially released in August 2019, with the latest versions (Climate Data Record (CDR) V1.1 and Science Data Record (SDR) V2.0) being released in 2021 & 2022, respectively (**Fig. 1**).
  - Provides LHF & SHF observations throughout the entire CYGNSS mission (2018-08-01 to Present)
  - Distributed by the Physical Oceanography Distributed Active Archive Center (PO.DAAC)
  - Utilizes COARE 3.5 algorithm to estimate LHF and SHF at every specular point
  - ERA5 reanalysis (previously MERRA-2) for temperature & humidity; co-located with CYGNSS specular points

Buoy Results and Validation

- Comparisons of flux estimates between CYGNSS and Global Tropical Moored Buoy Array show how CYGNSS compares to buoy data (Fig. 2a-b)
  - CYGNSS fluxes perform well at lower flux values
  - Some greater scatter at higher fluxes
- CYGNSS wind speed observations compare well with buoy observations (Fig. 2c)
- Differences in air-sea temperature between ERA5 and buoy likely main reason for discrepancies in fluxes (Fig. 2d)

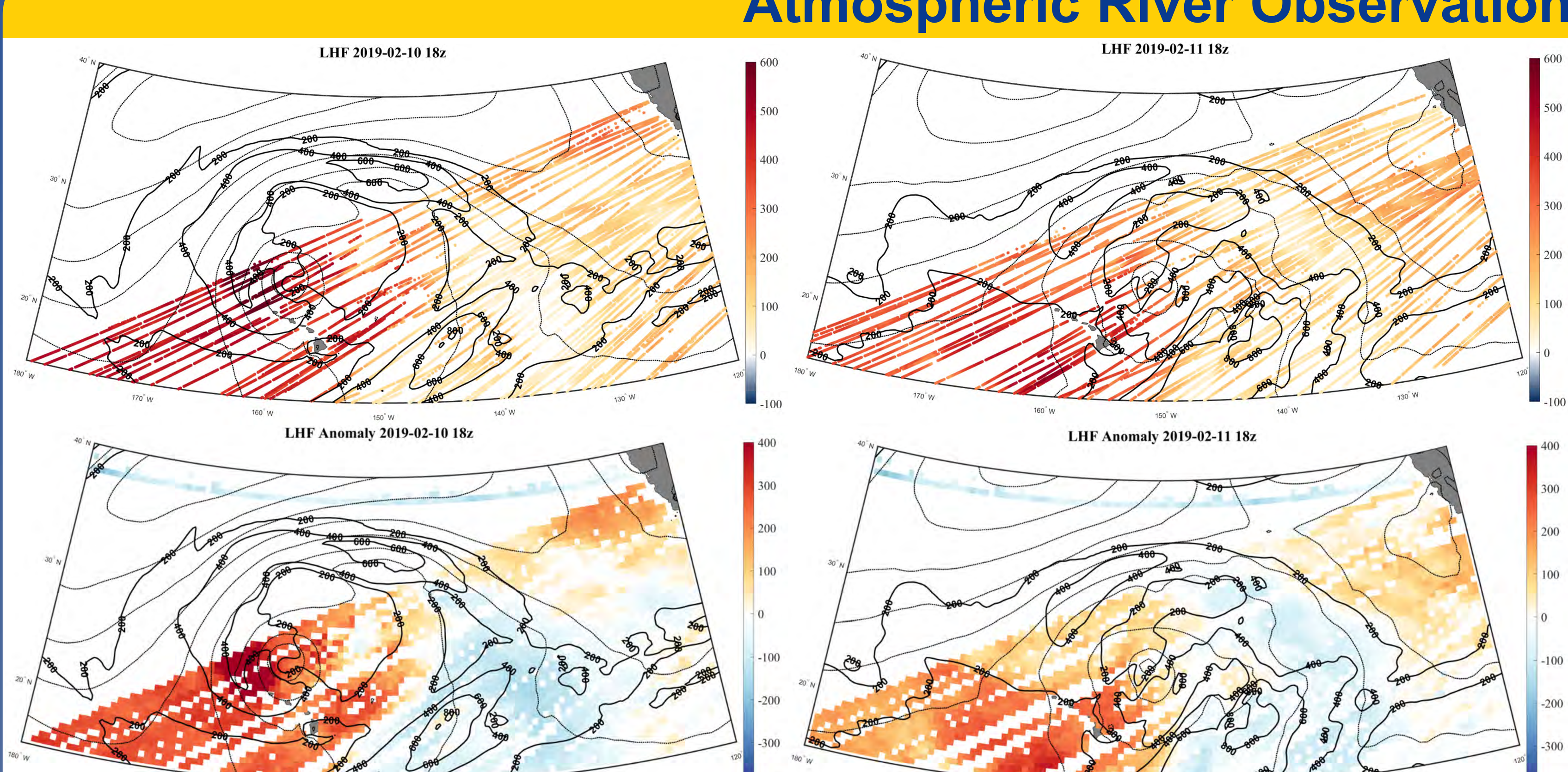


	LHF	SHF	Wind	Ta-SST
RMSD	37.92	9.61	1.65	0.82
μ	15.64	5.84	-0.39	-0.41
σ	34.55	7.63	1.61	0.71
r	0.76	0.56	0.76	0.62

Table: Values shown in Fig. 2

Fig. 2: Density plots of collocated (a) CYGNSS and buoy LHF [W m^{-2}], (b) CYGNSS and buoy SHF [W m^{-2}], (c) CYGNSS and buoy winds [m s^{-1}], (d) ERA5 (interpolated to CYGNSS specular points) and buoy air-sea temperatures

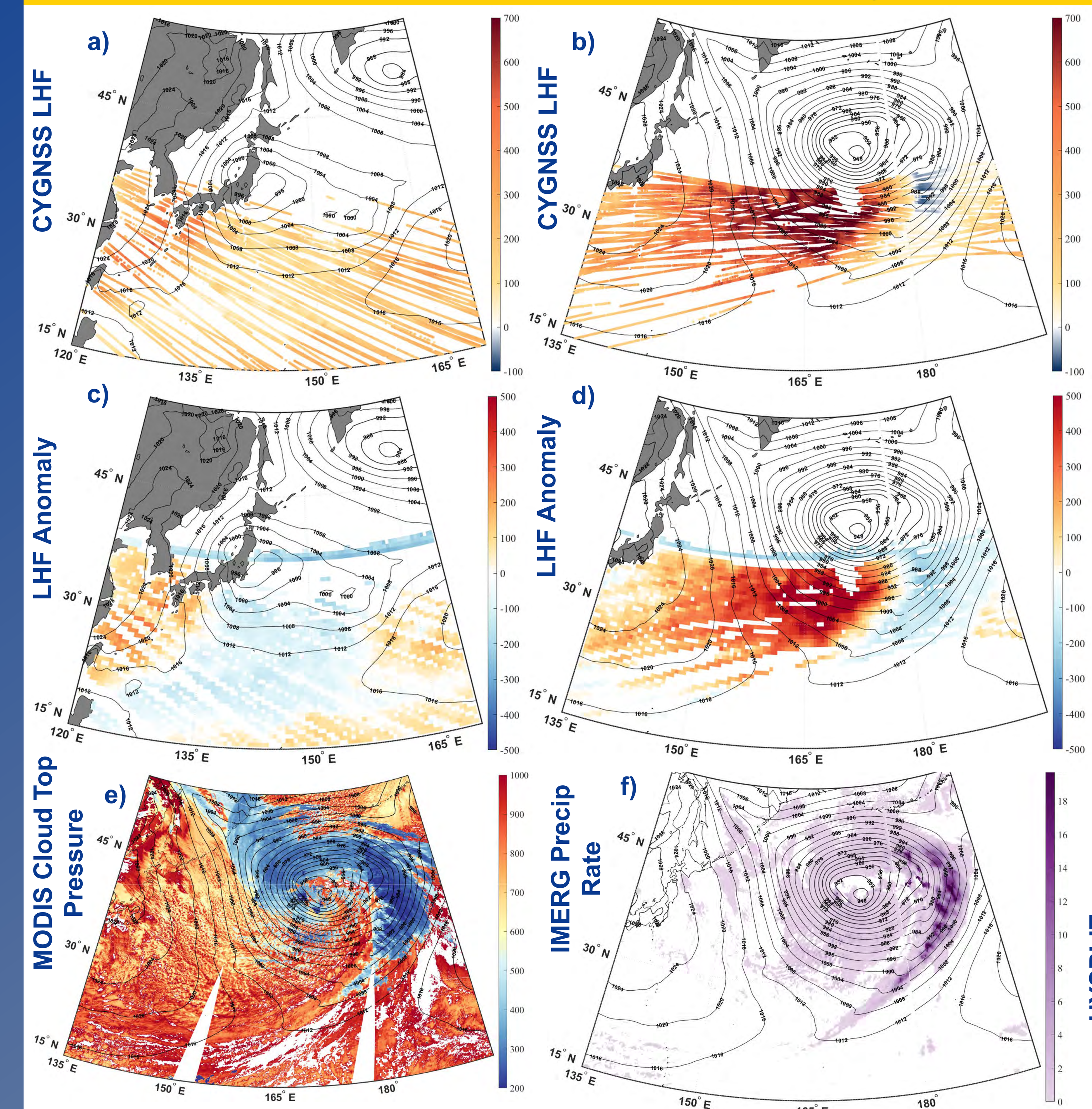
Atmospheric River Observations



- Significantly greater LHF values associated with low pressure system 24 to 48 hours before AR formation
- Higher LHF fluxes at moment of classification, but lower compared to the previous day
- Subject of ongoing investigation: Do these higher fluxes before and at genesis contribute to AR development and possible convection?

Fig. 3: LHF observations (top) and anomalies compared to DJF averages (bottom) of 2019 Valentine's Day AR before formation (Left: 2019-02-10 18z) and when it was initially categorized as an AR (Right: 2019-02-11 18z). Black solid lines: Integrated Water Vapor Transport (IVT). Dashed Lines: Mean Sea Level Pressure

Extratropical Cyclone Case Studies



- As ETC initially forms, LHF is weak
  - Below DJF averages around the low pressure area (Figure 4a,c)
- Strong surface heat fluxes observed as ETC develops, low pressure deepens (Fig. 4b,d)
- Strong surface heat fluxes correlate with:
  - Greater formation of mid-to-lower level clouds in post-cold frontal (PCF) region
  - Larger footprint of upper level cloud cover (Fig. 4e)
  - Higher precipitation rates, localized cells along cold frontal region (Fig. 4f)
- Are actually impacted by surface fluxes, or is it just a correlation?
  - Simple forward trajectory analysis hints that parcels in high flux areas become entrained into ETC, but…
  - Parcels stays close to surface
  - Highly dependent on starting location (Fig. 4d)
- Composite analysis could help us better understand the correlations

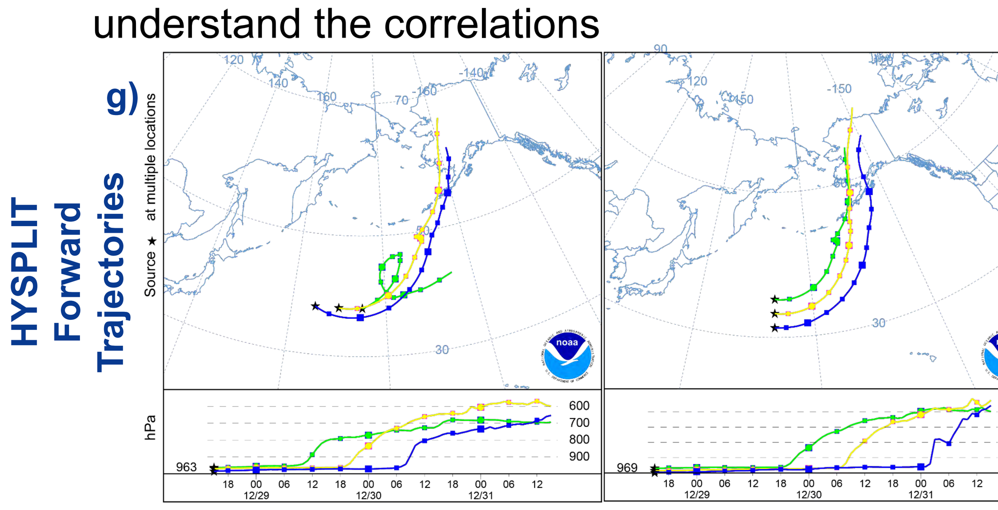


Fig. 4: Observations of ETC on 2019-12-26 21z (a,c) and 2019-12-28 15z (b,d,e,f) with forward trajectories (g) starting from area of high fluxes in 4b.

Extratropical Cyclone Composite Analysis

- Strong and weak LHF categories based on LHF in Post-Cold Frontal (PCF) region (Fig. 5)
  - ETCs from August 2018-September 2021
- When higher LHF is observed in PCF region:
  - Higher rain rates are observed near the ETC center and warm front
  - Higher cloud top heights ahead of the warm front
  - Low-level clouds dominate behind the cold front/PCF sector
- ETCs with strong LHF in PCF region are much more vigorous in the ascent region
  - Stronger subsidence in wake of the cold front
  - Actual size of ETC is also bigger with strong LHF observations
  - Decrease of Precipitable Water (PW) in PCF

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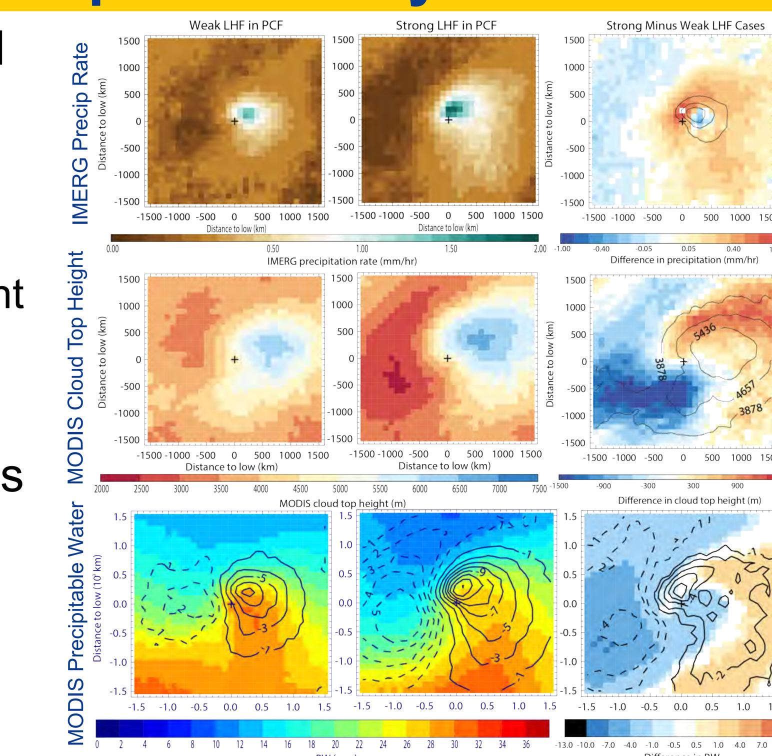

Fig. 5: ETC-centered composites of IMERG Precipitation (top), MODIS cloud top height (middle), and MODIS precipitable water (colored)/ascent strength (lines) (bottom) when LHF in PCF is weak (left), strong (middle), and the differences between ETCs with strong and weak LHF values (right)

Conclusions

- CYGNSS provides reliable observations of LHF & SHF over the tropical and subtropical oceans
  - Improvements to wind speed estimates have improved flux estimates.
  - Area for improvement lies with air-sea temperature and humidity observations.
- In AR case, we observe strong surface heat fluxes 24-48 hours before AR is officially identified
  - Are these surface heat fluxes contributing to AR genesis and possible embedded convection?
- In ETC case, strong surface heat fluxes are not present until the ETC has developed
  - Fluxes below DJF averages in Western Pacific Region
  - Strong flux observations with ETC development did correlate with changes in cloud and precipitation structure within the ETC
- Future modeling studies and advanced trajectory analysis is needed to determine if fluxes do make an impact on ETC evolution, or if it's just a correlation
  - This work can be expanded into AR studies and the fluxes observed before and during formation

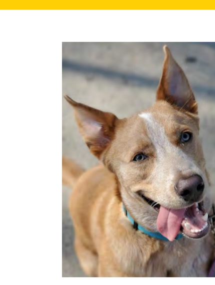

Fig. 6: A good boy named Coriolis.