BUTTERFLY

A SATELLITE MISSION TO TRANSFORM OUR UNDERSTANDING OF THE CONTRIBUTION OF AIR-SEA FLUXES TO WEATHER AND CLIMATE

Carol Anne Clayson (PI), Aneesh Subramanian (Deputy PI), Shannon Brown, Tony Lee, Justin Boland, Mark Bourassa, J. Thomas Farrar, Sarah Gille, Kelly Lombardo, Rhys Parfitt, Hyodae Seo

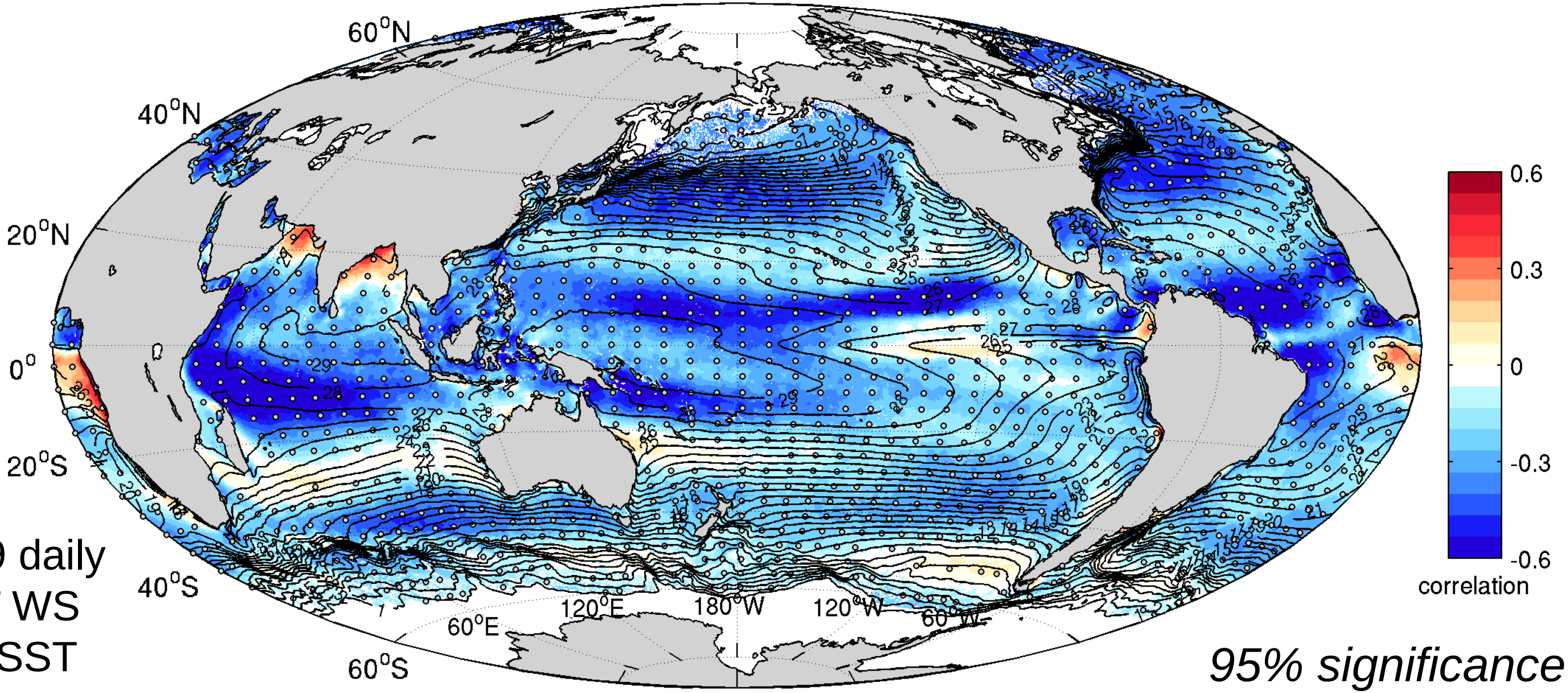
Woods Hole Oceanographic Institution
Scripps Institution of Oceanography
University of Colorado Boulder
PennState
JPL Jet Propulsion Laboratory
Florida State University

AMS Joint Session J10

11 January 2023

Observed air-sea interaction

Correlation between unfiltered wind speed (WS) and SST



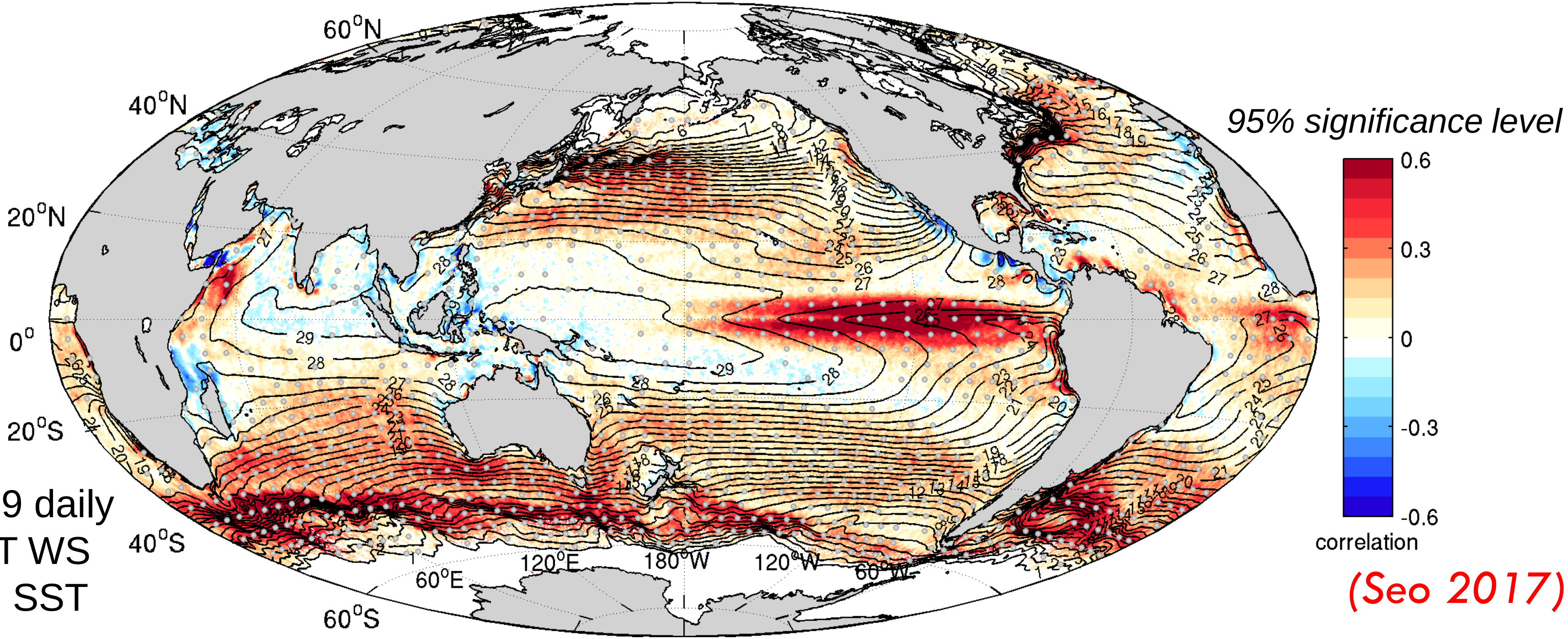
2000-2009 daily
QuikSCAT WS
NOAA-OI SST

95% significance level

Negative correlation: Oceanic response to the atmosphere

Eddy-mediated air-sea interaction

Correlation between high-pass filtered WS and SST

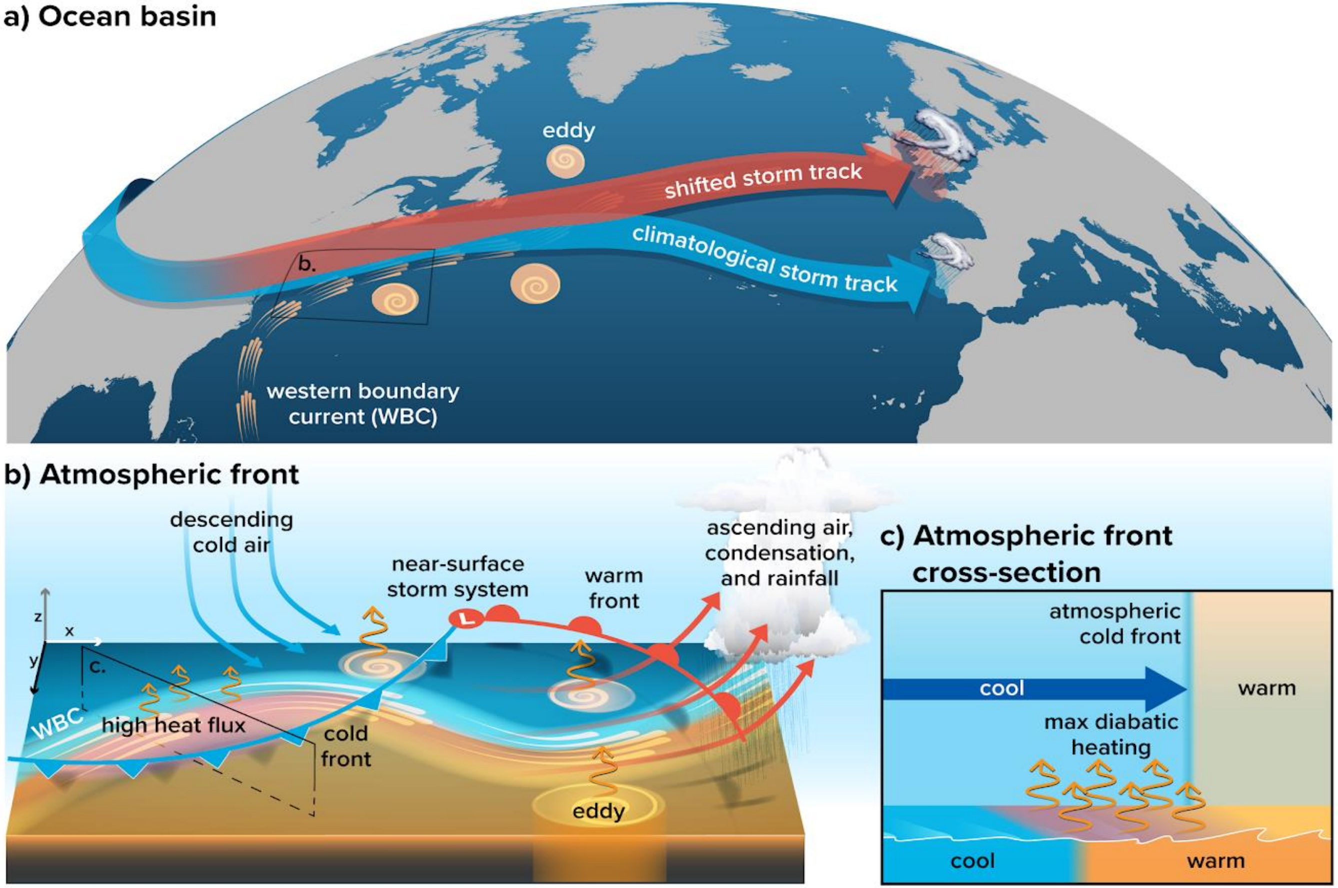


2000-2009 daily
QuikSCAT WS
NOAA-OI SST

(Seo 2017)

Oceanic forcing of the atmosphere on frontal and mesoscales

Ocean and atmospheric fronts and impact

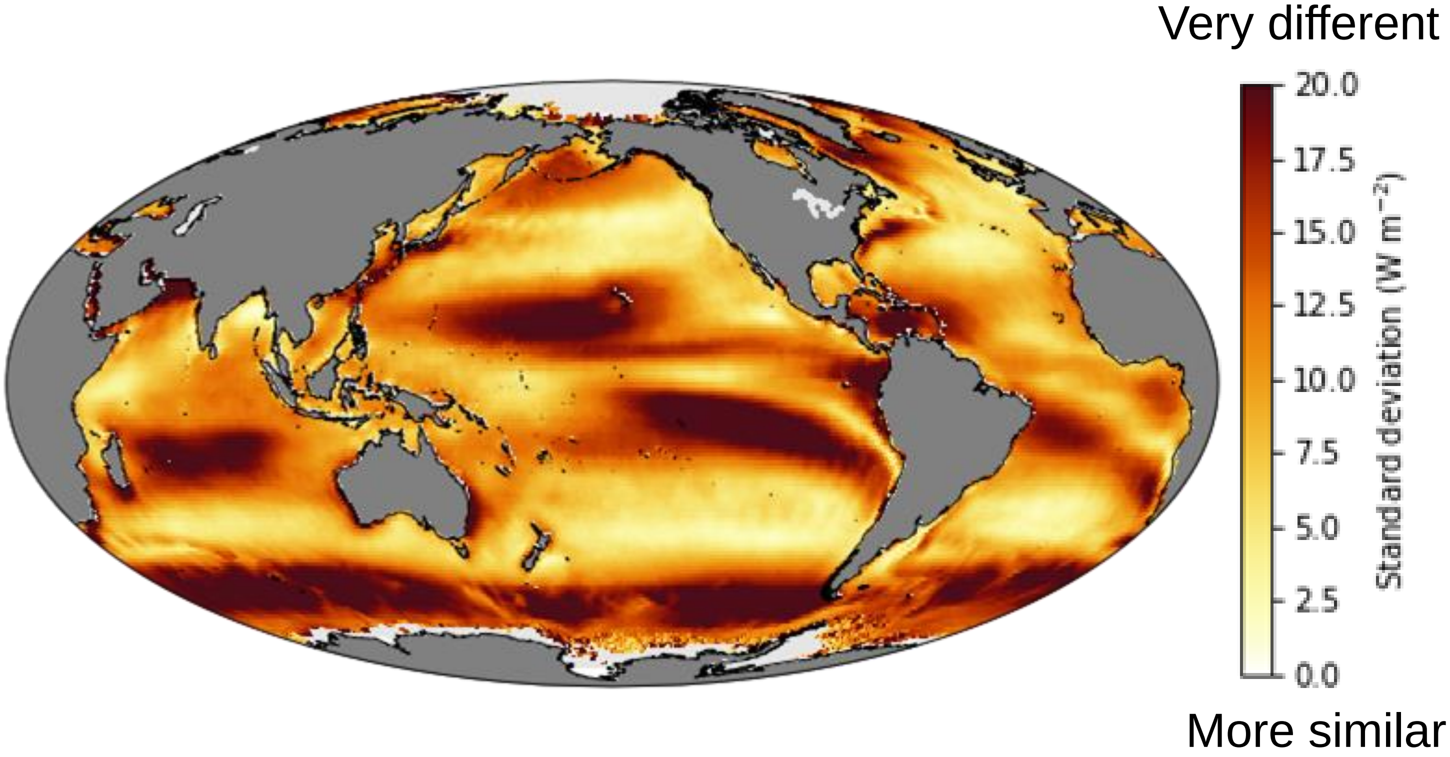


US CLIVAR Working Group on Mesoscale and Frontal-Scale Ocean-Atmosphere Interactions and Influence on Large-Scale Climate

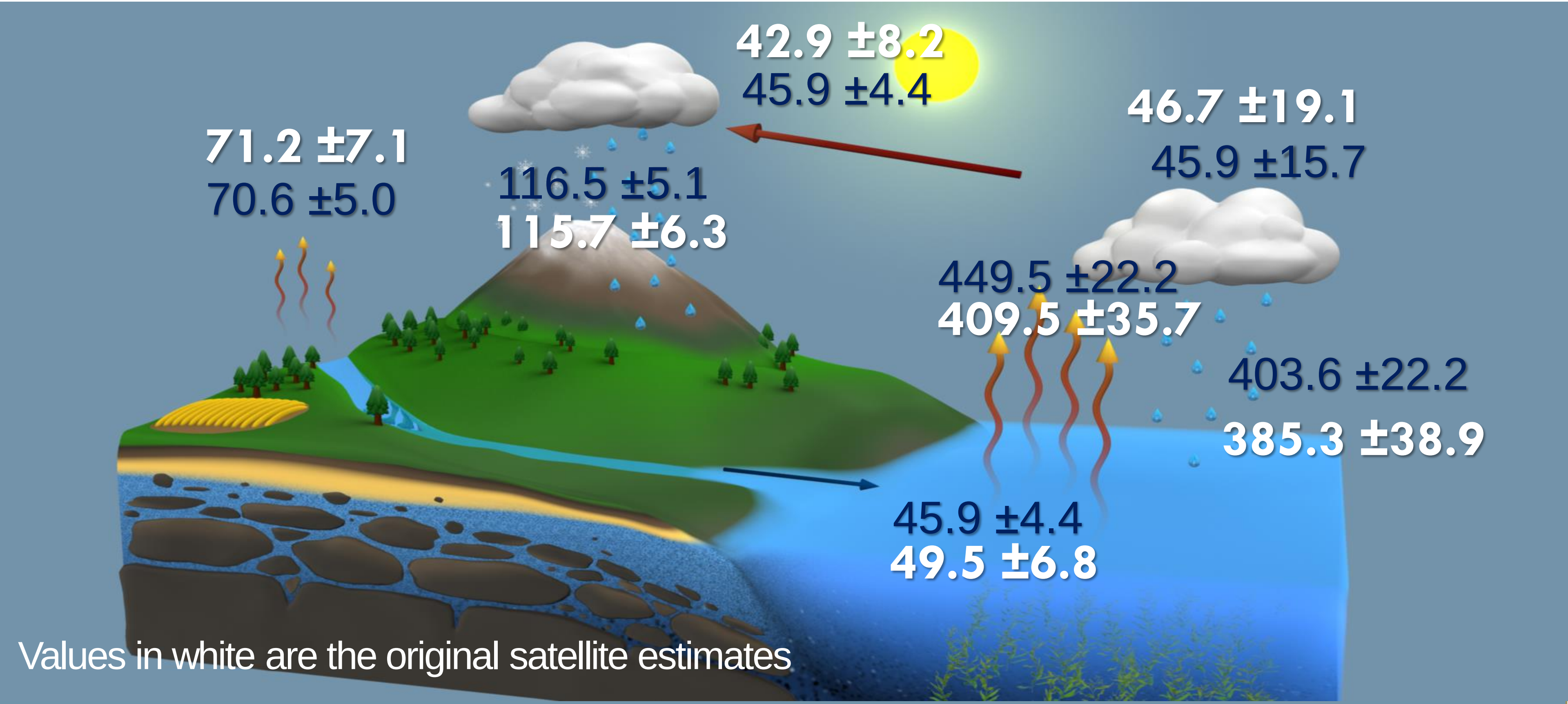
Seo et al., 2022

Current flux products have large discrepancies

- **Not designed for near surface air/humidity measurements**
- **Different instruments / resolutions**
- **Aliasing due to mixing measurements from different times**



Global Mean Water Budget

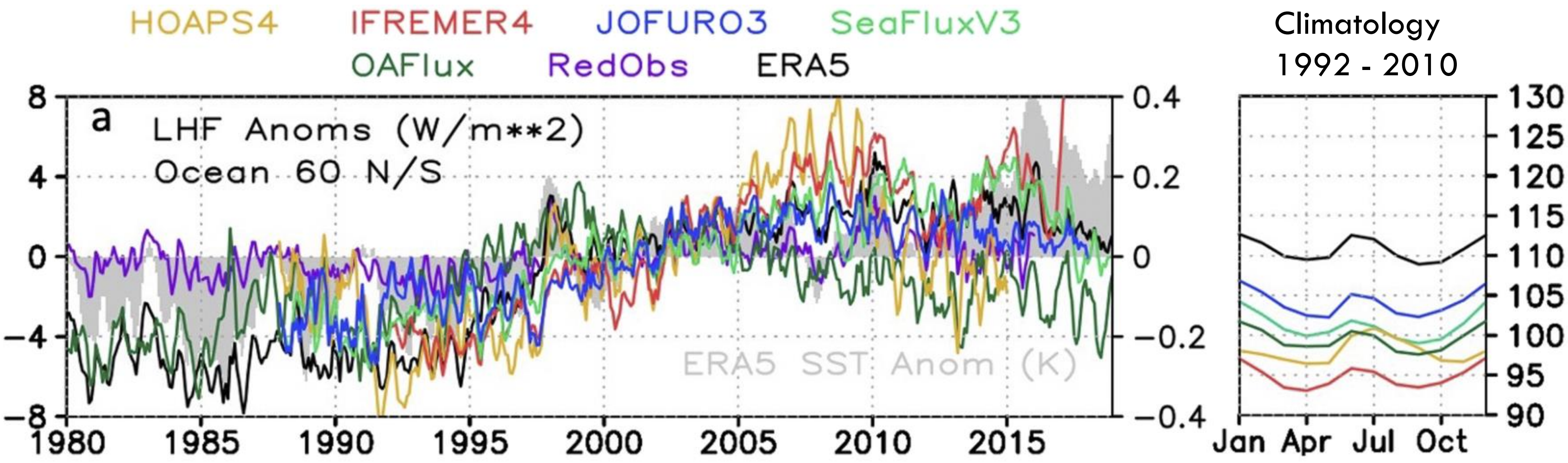


Global mean water fluxes (1,000 km^3/yr)

Rodell et al. 2015

What is the global trend in ocean evaporation?

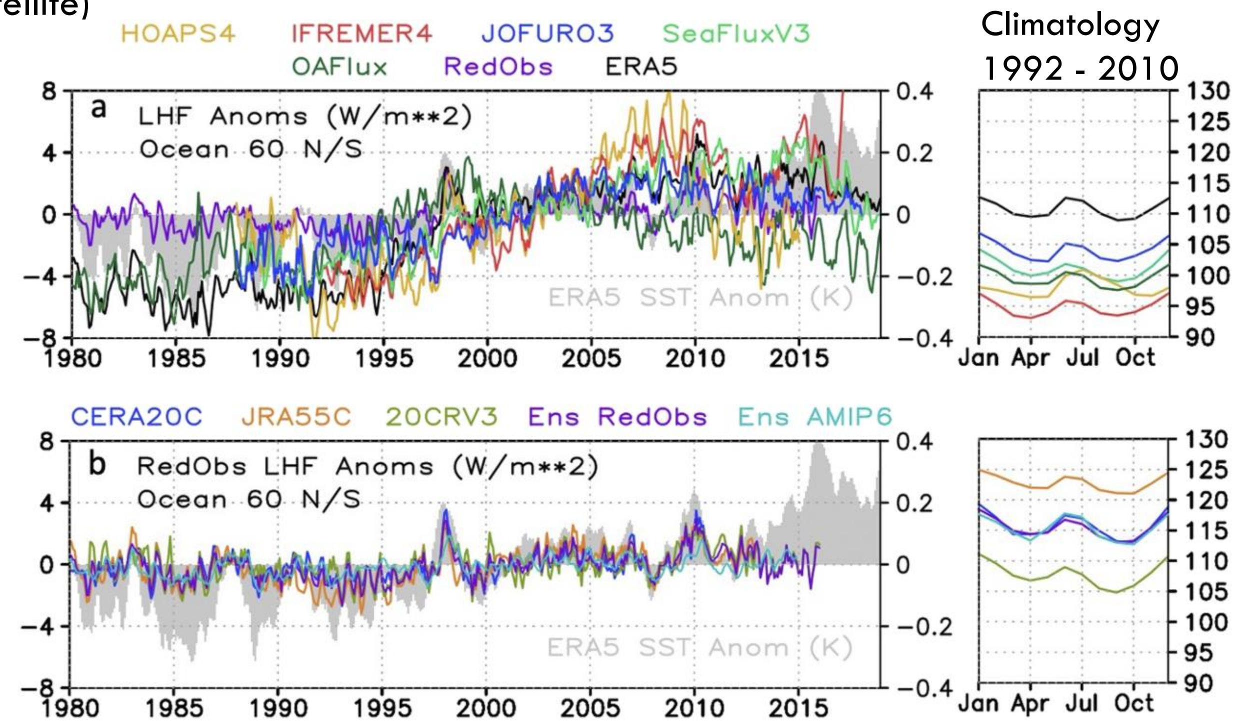
- Globally different satellite products have varying ocean evaporation trends



(Robertson et al. 2020)

How does this differ from model estimates?

- Globally different satellite products have varying ocean evaporation trends
  - Models with no satellite data (RedObs) have quite similar trends to each other (but not necessarily to satellite)



(Robertson et al. 2020)

Turbulent heat flux calculations

Estimate the air-sea turbulent heat fluxes:

Turbulent heat flux =

Sensible heat flux + **Latent heat flux**

$$Q_{sen} = \rho_a C_p C_H U (T_{sea} - T_{air})$$

- ρ_a: Air density
- C_p: Air specific heat capacity
- C_H: Turbulent exchange coefficient
- U: Wind speed
- $(T_{sea} - T_{air})$: Air-sea temperature difference

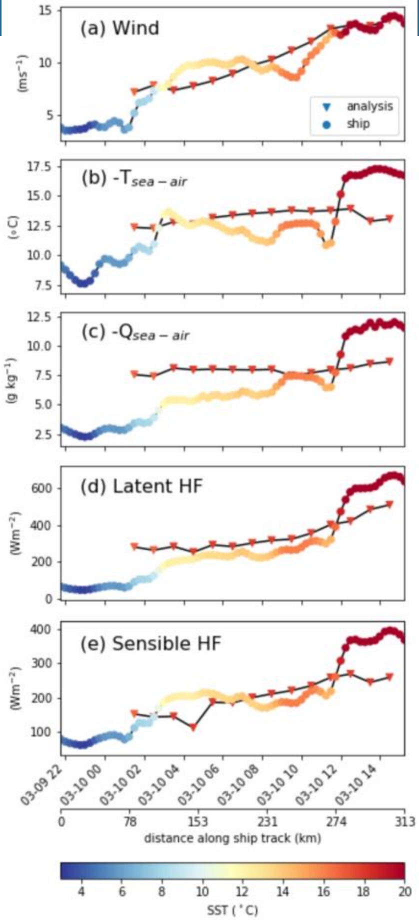
$$Q_{lat} = \rho_a L_v C_E U (q_{sea} - q_{air})$$

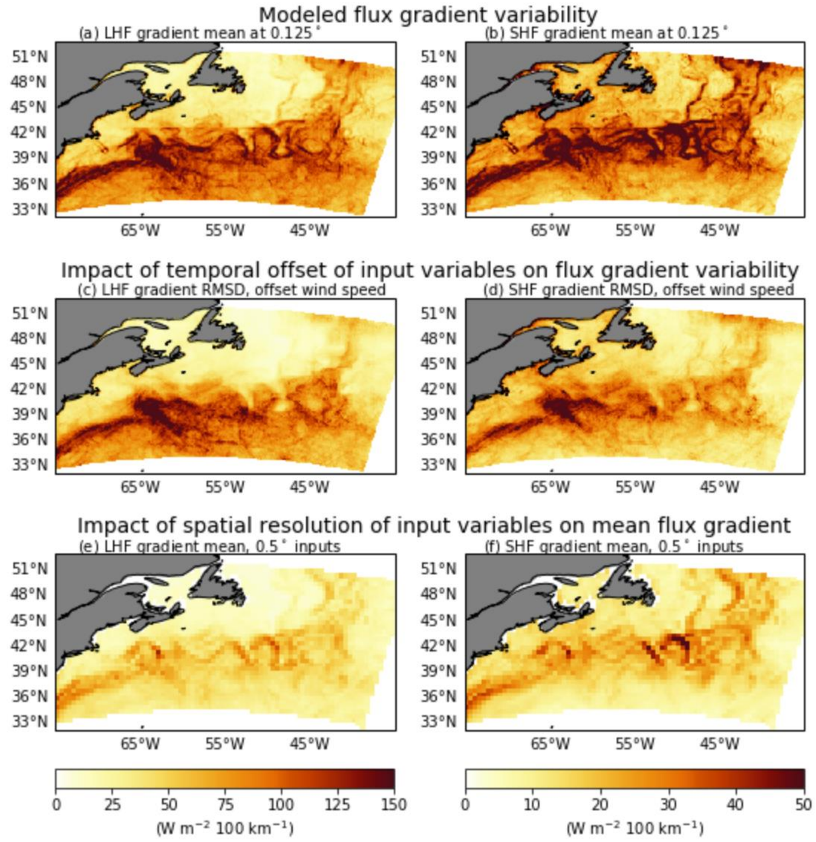
- ρ_a: Air Density
- L_v: Latent heat of vaporization
- C_E: Turbulent exchange coefficient
- U: Wind speed
- $(q_{sea} - q_{air})$: Air-sea humidity difference

<u>Data Sources:</u> Butterfly Model Coefficients

The turbulent heat fluxes include sensible and latent heat fluxes. The latent heat flux is directly related to moisture flux through evaporation.

Satellite analysis across Gulf Stream

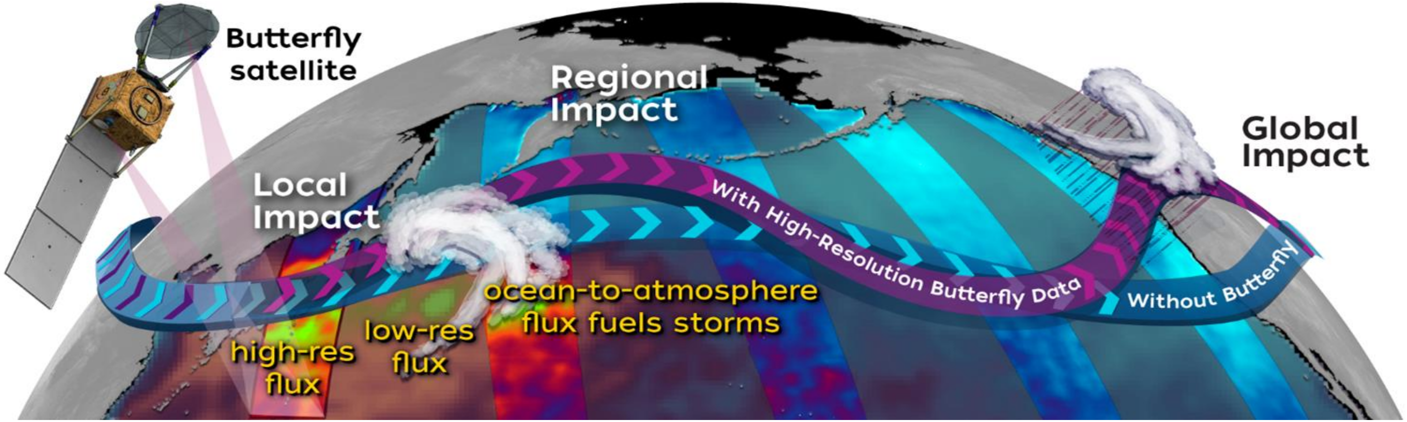




Gentemann, Clayson et al., 2020

BUTTERFLY

revealing the oceans' impact on weather & climate



Principal Investigator: Dr. Carol Anne Clayson
Deputy Principal Investigator: Dr. Aneesh Subramanian
Project Scientist: Dr. Tony Lee
Deputy Project Scientist: Dr. Shannon Brown

Science Team:
Mark Bourassa, Hyodae Seo, Kelly Lombardo, Sarah Gille, Tom Farrar, Rhys Parfitt

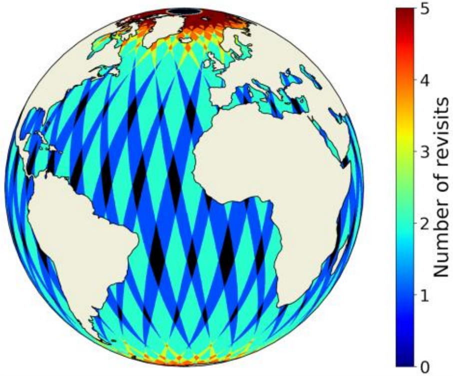
Mission info (EVM3)

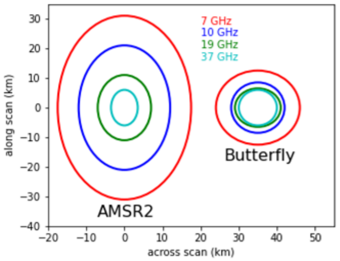
2021	2022	2023	2024	2025	2026	2027	2028
Butterfly Phases: Ph A (8mo)		Ph B (9mo)	Ph C (18mo)	Ph D (14mo)		Ph E (24mo)	F
Major Reviews: KDP-A	KDP-B, SRR/MDR	KDP-C, PDR 6/2023	CDR 1/2024	KDP-D, SIR	PSR, KDP-E, Launch 3/2026		KDP-F

Funded Schedule Reserve = 22 weeks

Mission Characteristics

2-DAY COVERAGE





Butterfly's single instrument combines:

Passive microwave channels: 7, 11, 19, 24, 37 GHz

Measures sea surface temperature & wind speed

Near-surface sounding channels: 109-117, 150-175 GHz

Measures near-surface air temperature & humidity

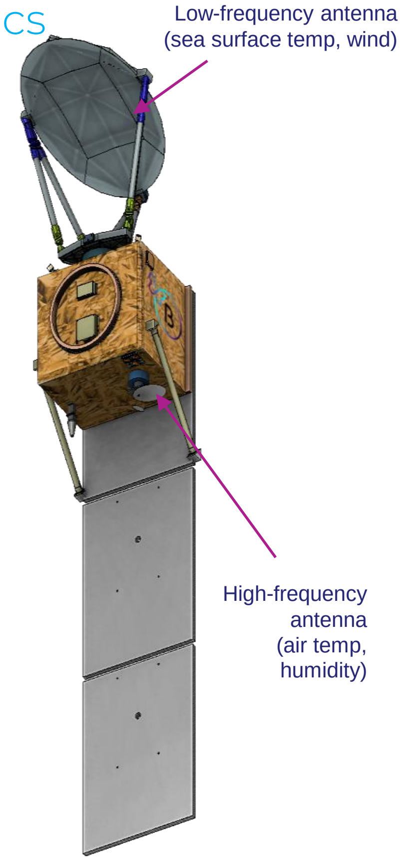
Two spinning reflectors: Achieves 20 km spatial resolution

Digital backend: Improves accuracy and provides RFI-robust data

Key Spacecraft Characteristics

Butterfly leverages Ball's high-heritage spacecraft product line (GPIM, STPSat-3) and experience accommodating rotating reflectors (QuikSCAT & WSF-M).

- Single-string architecture with functional redundancy in safe mode using backup ADCS components
- Solar electric propulsion for orbit transfer and maintenance
- Zero net momentum ADCS



Alternative Access to Space

- SpaceX Falcon 9 dedicated rideshare to 500-600 km altitude
- JPL procurement compliant with NASA insight and approval policies

Operational Orbit

- > 80º inclination
- 425 ±25 km altitude

Butterfly Science: Local to Regional

Addressing <u>Decadal Survey Question W-3</u> "*How do spatial variations in surface characteristics modify transfer between domains and thereby influence weather and air quality?***"**

<u>Science Objective 1:</u> Determine the degree to which sub 25-km resolution turbulent heat and moisture fluxes influence midlatitude storm evolution and long-term weather.

Butterfly Science: Local to Global

Addressing <u>Decadal Survey Question C-4</u> ***"How will the Earth system respond to changes in air-sea interactions?"***

Science Objective 2: Balance the global ocean turbulent heat and moisture flux contributions to the energy and water cycles to within 5%.

Why now?

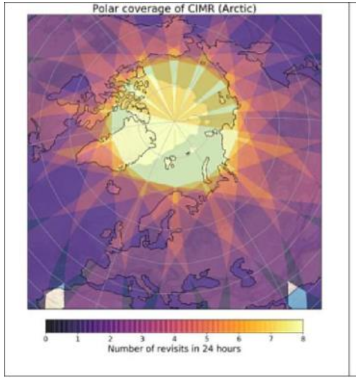
Prediction systems are moving towards high-resolution coupled ocean-atmosphere models.

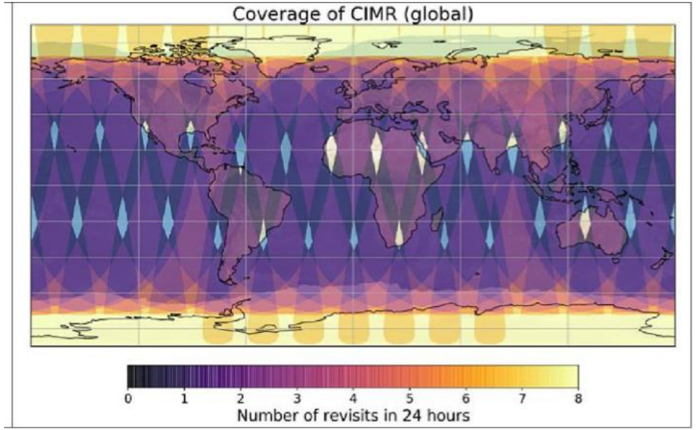
We don't have high-resolution air-sea heat and moisture flux measurements needed to evaluate and improve these models.

Butterfly fills a major gap in our knowledge of how small-scale air-sea exchange of heat and moisture affect large-scale weather and climate, potentially improving forecast accuracy from days to a season by providing global measurements of the air-sea turbulent heat and moisture fluxes.

Synergies with other community efforts

- CIMR (Copernicus Imaging Microwave Radiometer, conically scanning)
  - SST at 15 km (55 km salinity, 5 km sea ice concentration). Currently Phase B2, with view to launch in 2027. 10 years (2 systems)
  - Butterfly could fly in similar orbit Gain larger swath, could drop our other retrieval resolution to 10 km



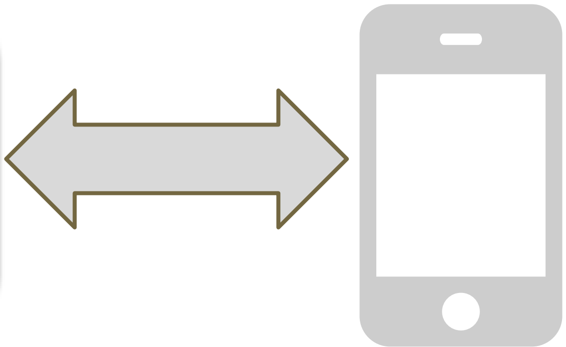


Synergies with other community efforts

- ESA Harmony, selected 10th Earth Explorer mission
  - Multibeam thermal-infrared instrument, receive-only SAR, 2 satellites
  - Will provide cloud movements, SST, winds, waves, and currents
- NASA ODYSEA mission concept
- NASA PBL, currently in incubation
  - Science team meetings etc. to be more broadly open to develop larger boundary layer community

Current and planned Butterfly activities

- Synthetic data for "early adopters"
- Hackathon & making code available on github
- Simulator
- Webinars
- *Need a few early career science team members*



Take a picture to go to the Butterfly project page

BUTTERFLY

Butterfly would be the first satellite mission to **simultaneously** measure sea surface temperature, wind, & near-surface air temperature & humidity in order to estimate air–sea turbulent heat and moisture fluxes at a spatial resolution and accuracy sufficient to resolve the impact of small-scale ocean features on large-scale weather and climate.