

A stylized butterfly logo composed of blue and purple lines, positioned to the left of the word "BUTTERFLY".

# 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



AMS Joint Session J10

11 January 2023





# News Wrap: California residents reeling as another winter storm approaches

MAR 8, 2023 8:55 PM EST

COMMENTARY

## California's record winter storms could spawn disastrous floods

BY DAN WALTERS  
MARCH 7, 2023



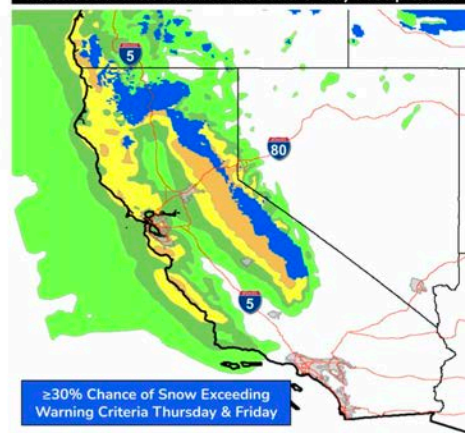
### Key Messages for March 9-10 Winter Storm

Updated Mar 7, 2023  
12:00 PM PST

Winter storm will bring high snow levels and heavy rain to California Thursday Night and Friday

- Strong Winter Storm Arrives Thursday Night**  
 A winter storm will reach the West Coast on Thursday Night and provide a burst of heavy precipitation into Friday.
- Heavy Rain and High Snow Levels Likely**  
 Several inches of rain are expected in the favored upslope areas of the Coastal Ranges and Sierra Nevada in California. This will be a warm storm system with rain falling on existing snowpack up to 8500 feet, with the highest snow levels expected in central California.
- Rain and Snowmelt May Lead to Flooding**  
 The combination of heavy rain and snowmelt may lead to flooding. The most significant snowmelt is expected below 5000 foot elevation, in areas with shallow snowpack. Creeks and streams in the western foothills of the Sierra Nevada will be most vulnerable to flooding from rain and snowmelt.
- Difficult Travel in Snow at High Elevations**  
 Higher elevations in northern California and in the Sierra Nevada are likely to see very heavy snow, which could lead to difficult travel.

#### Potential Winter Storm Areas and 5-Day Precipitation



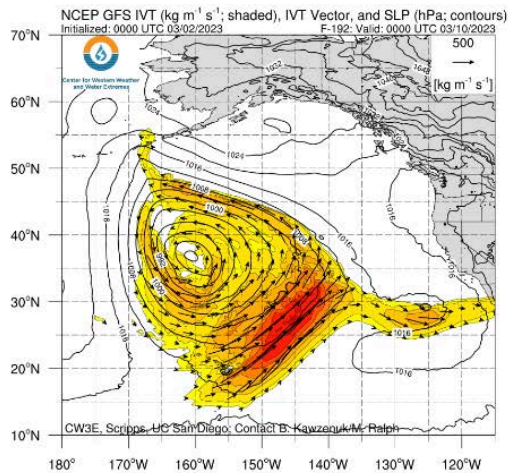
5-Day Precipitation thru Early Sunday, March 12





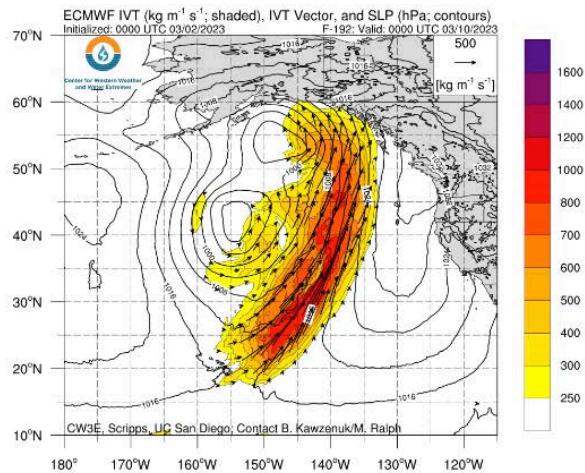
# Long Range Forecast Valid 00 UTC 10 Mar

## GFS



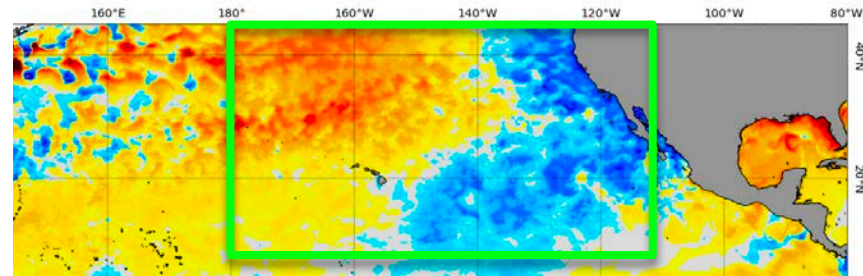
0000 UTC 10 Mar

## ECMWF



0000 UTC 10 Mar

## SST Anomalies (NOAA)

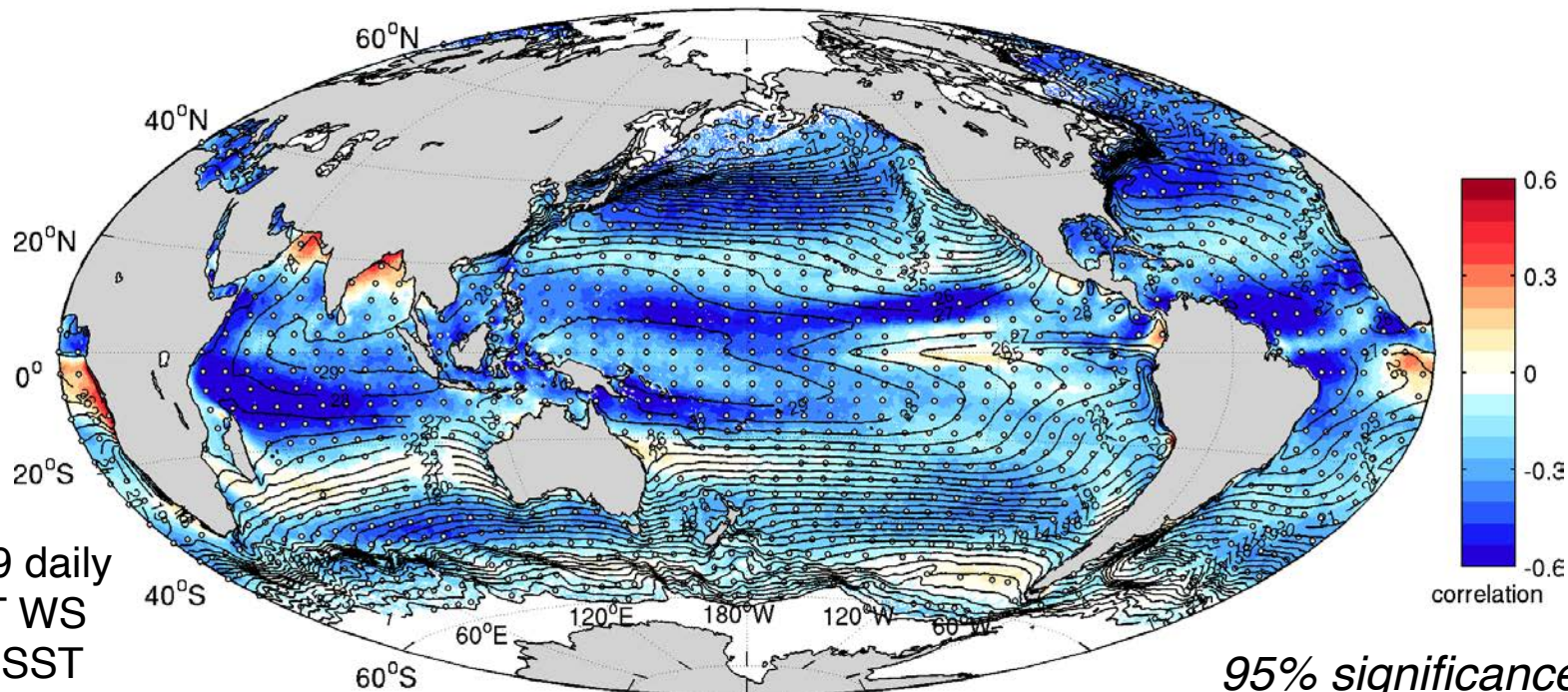


Large inter-model uncertainty in this atmospheric river event in the long range (1 week lead time)!

Atmospheric river event originated in the Tropics and passes over warm SST anomalies in the midlatitude with lots of mesoscale features.

# Observed air-sea interaction

Correlation between unfiltered wind speed (WS) and SST

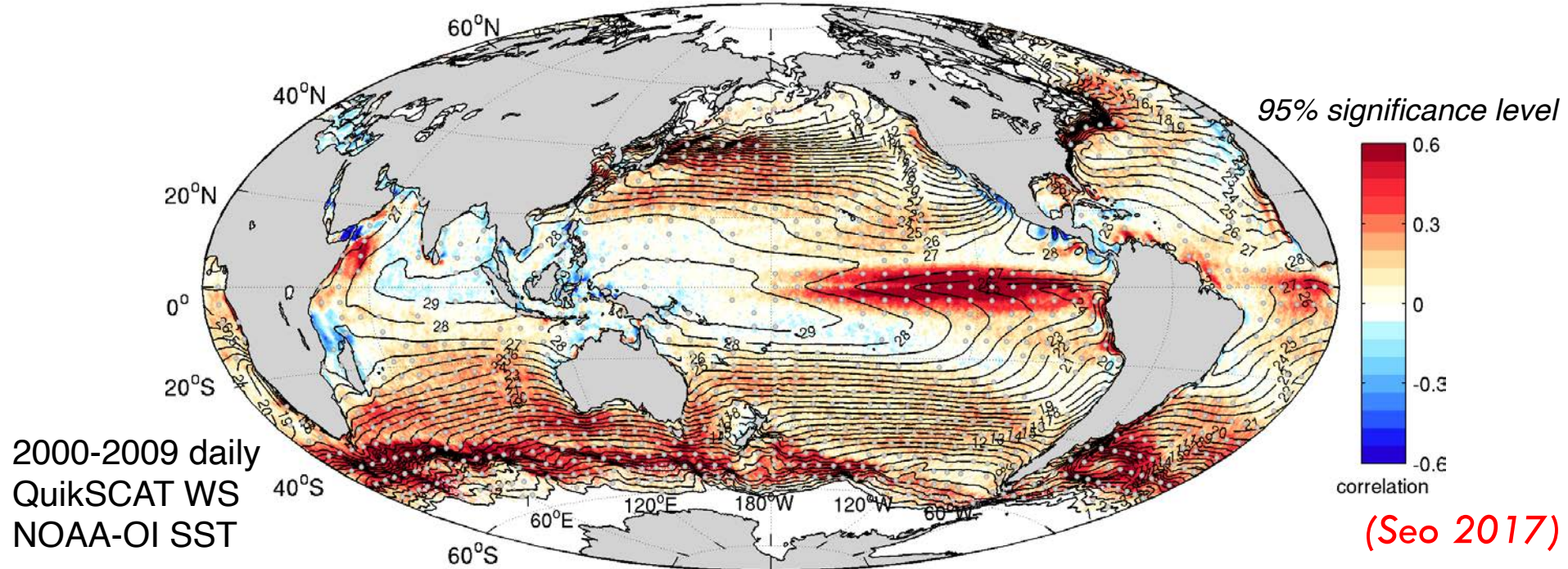


Negative correlation: Oceanic response to the atmosphere



# Eddy-mediated air-sea interaction

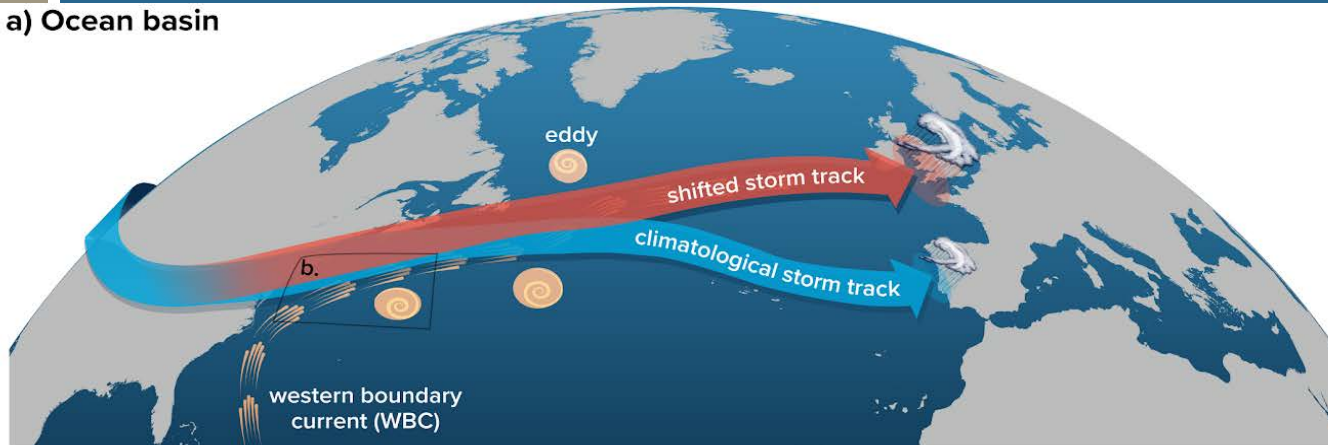
Correlation between high-pass filtered WS and SST



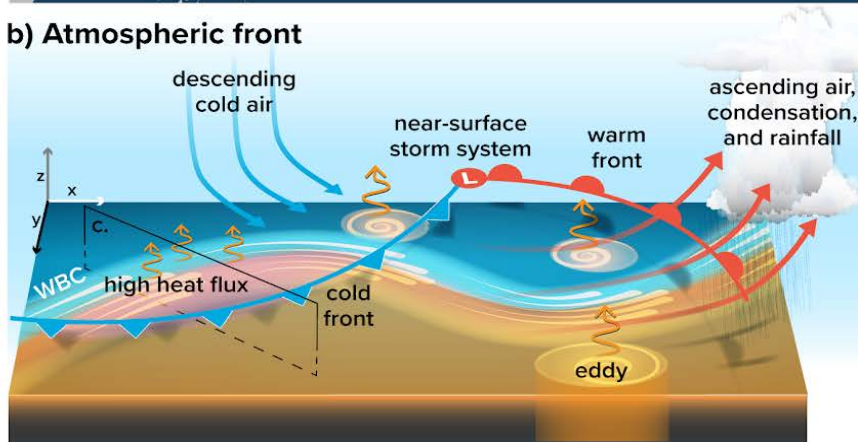
Oceanic forcing of the atmosphere on frontal and mesoscales

# Ocean and atmospheric fronts and impact

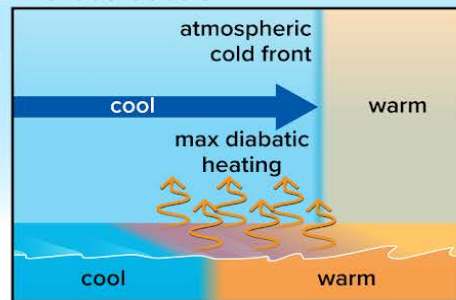
a) Ocean basin



b) Atmospheric front



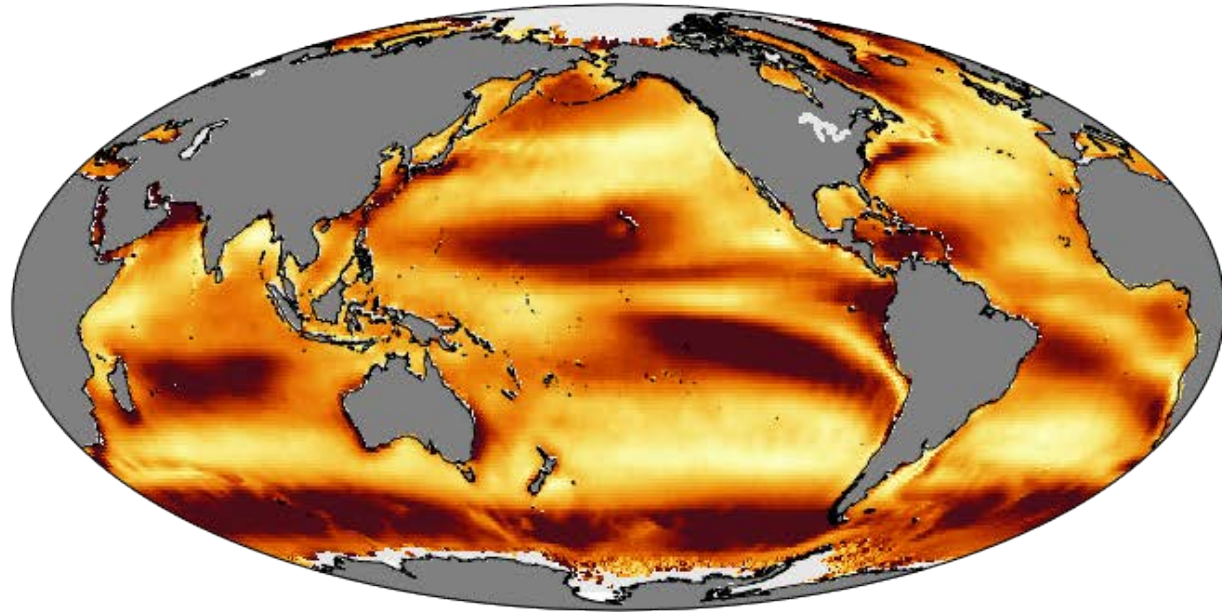
c) Atmospheric front cross-section



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

# 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



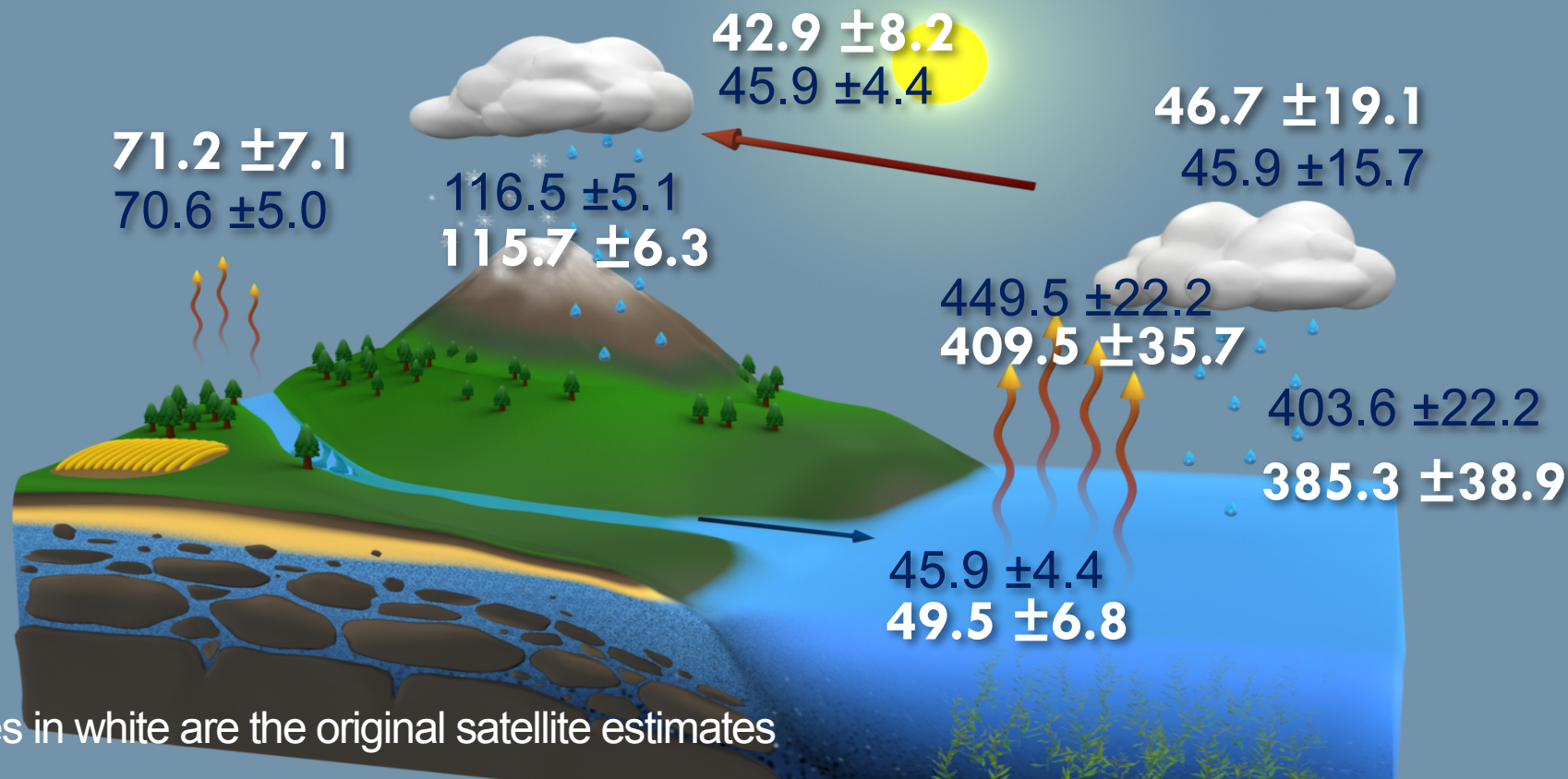
Very different

Standard deviation ( $\text{W m}^{-2}$ )

More similar



# Global Mean Water Budget

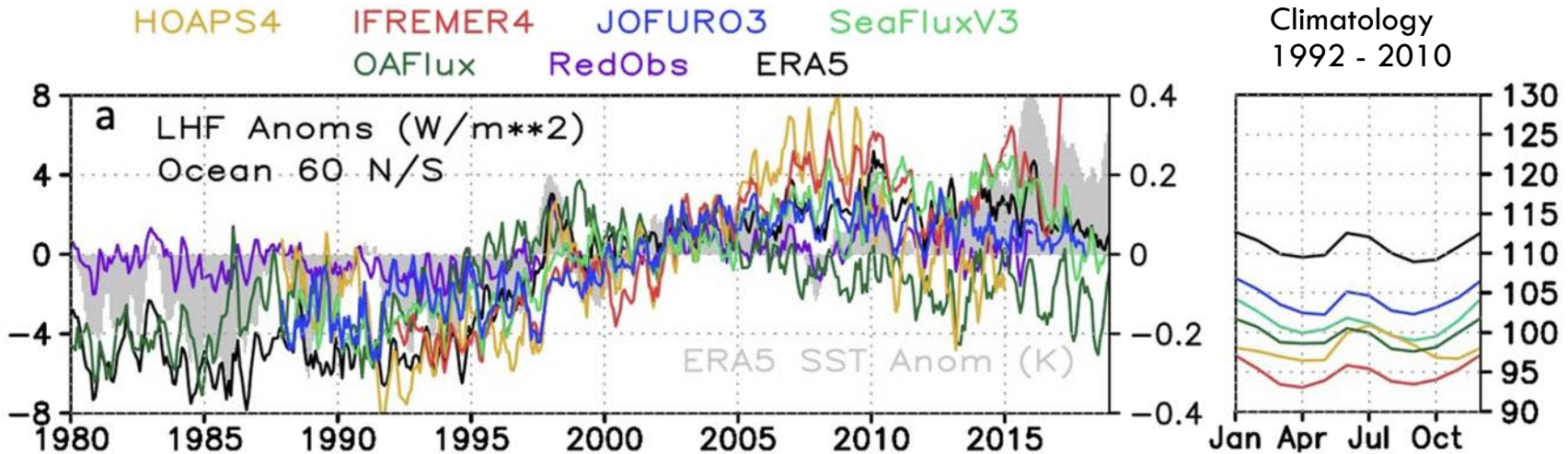


Global mean water fluxes (1,000 km<sup>3</sup>/yr)



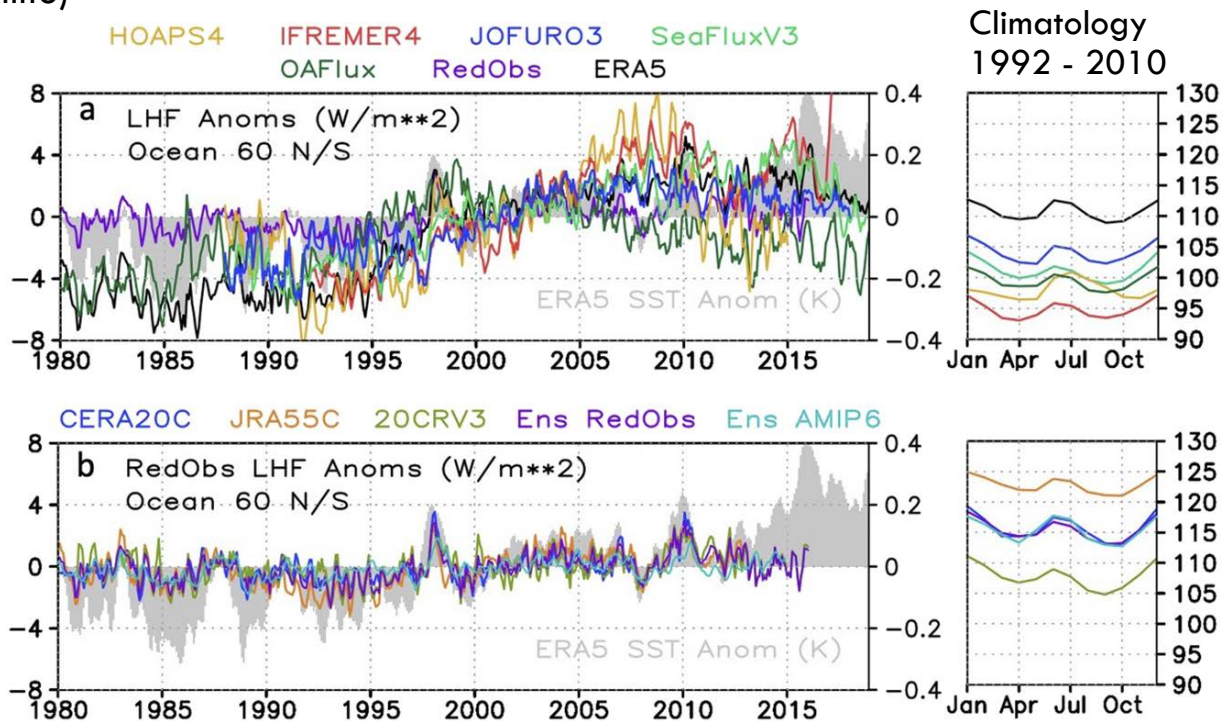
# What is the global trend in ocean evaporation?

- Globally different satellite products have varying ocean evaporation trends



# 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

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

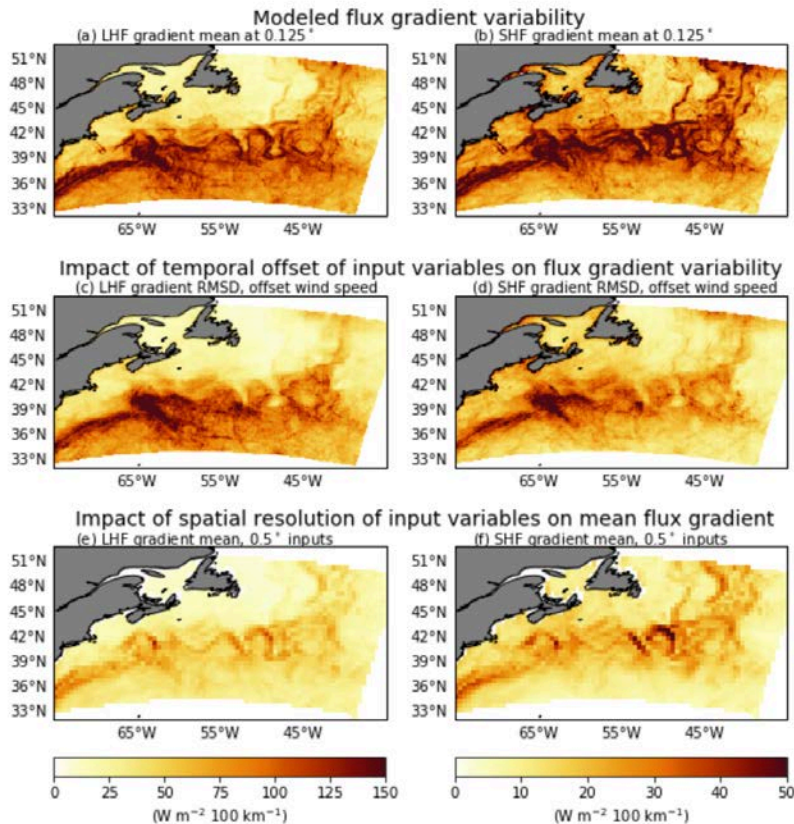
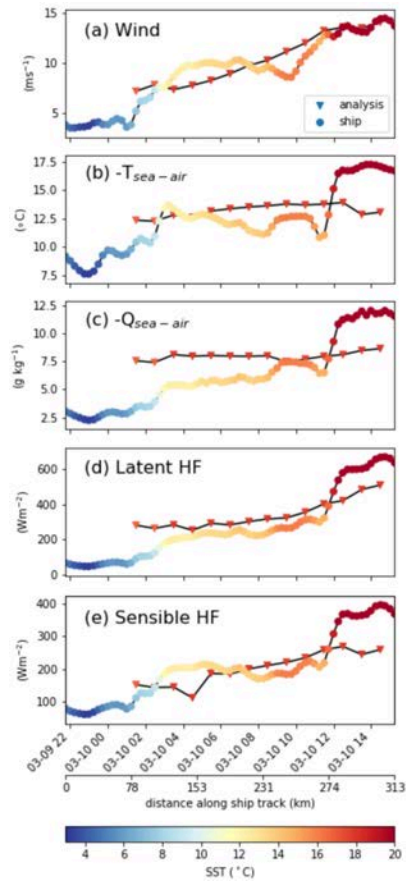
$Q_{lat} = \rho_a L_v C_E U (q_{sea} - q_{air})$

The diagram illustrates the components of the turbulent heat flux equations. For the sensible heat flux equation,  $Q_{sen} = \rho_a C_p C_H U (T_{sea} - T_{air})$ , the variables are:  $\rho_a$  (Air density),  $C_p$  (Air specific heat capacity),  $C_H$  (Turbulent exchange coefficient),  $U$  (Wind speed), and  $(T_{sea} - T_{air})$  (Air-sea temperature difference). For the latent heat flux equation,  $Q_{lat} = \rho_a L_v C_E U (q_{sea} - q_{air})$ , the variables are:  $\rho_a$  (Air Density),  $L_v$  (Latent heat of vaporization),  $C_E$  (Turbulent exchange coefficient),  $U$  (Wind speed), and  $(q_{sea} - q_{air})$  (Air-sea humidity difference).

Data Sources: 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

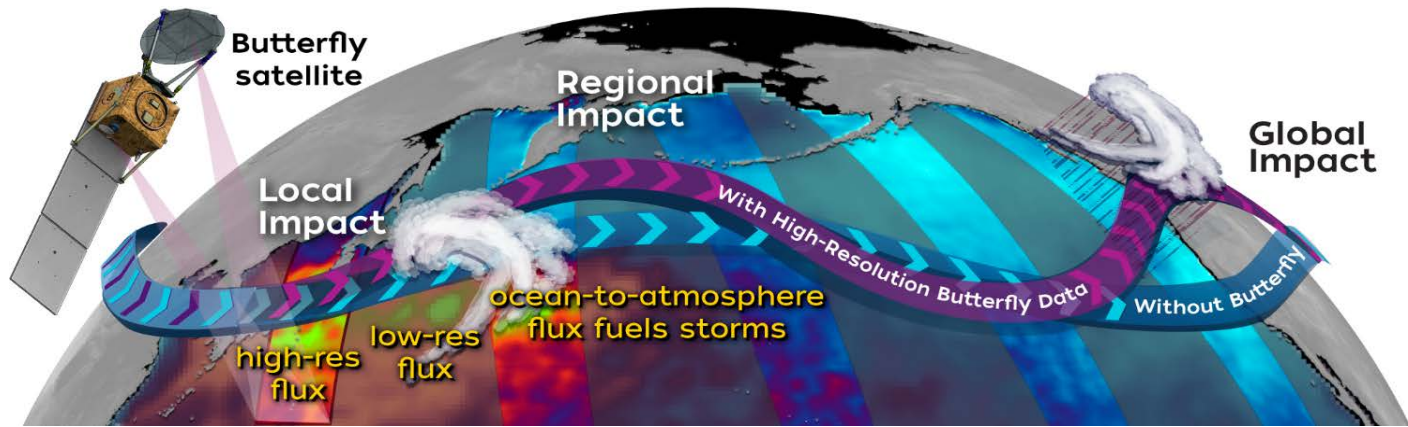


Gentemann, Clayson et al., 2020





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

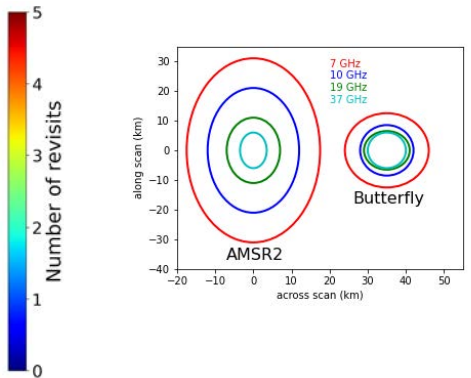
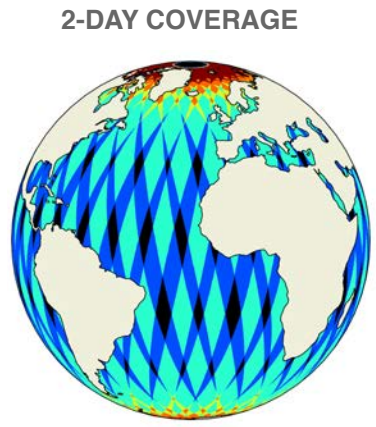


**Science Team:**  
Mark Bourassa, Hyodae Seo, Kelly Lombardo, Sarah Gille, Tom Farrar, Rhys Parfitt

# 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



**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).

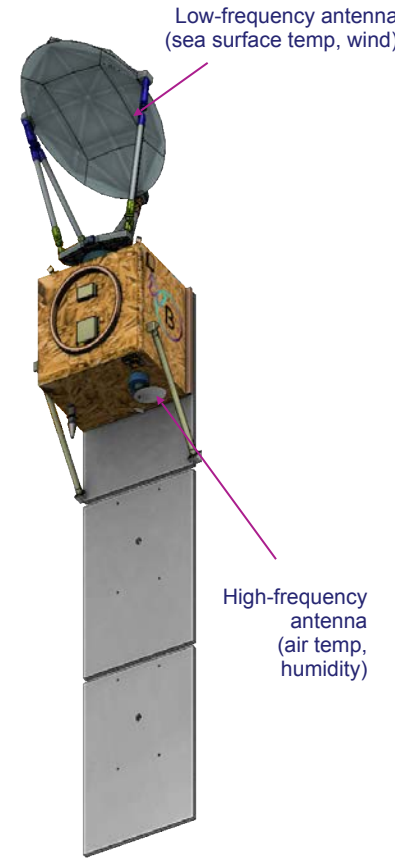
- Single-string architecture with functional redundancy in safe mode using backup ADCS components
- Solar electric propulsion for orbit transfer and maintenance
- Zero net momentum ADCS

## 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

- > 80° inclination
- 425 ±25 km altitude





## Butterfly Science: Local to Regional

**Addressing Decadal Survey Question W-3** “*How do spatial variations in surface characteristics modify transfer between domains and thereby influence weather and air quality?*”

**Science Objective 1:** 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 Decadal Survey Question C-4** “*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?

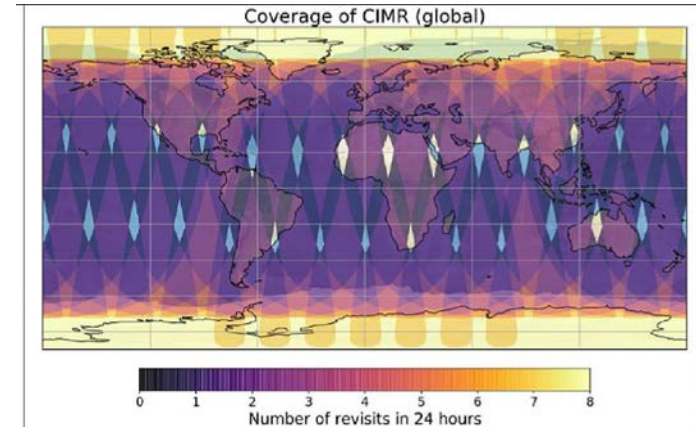
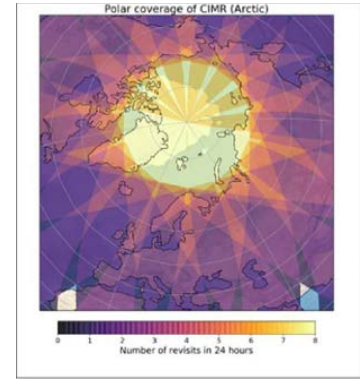
Prediction systems are moving towards high-resolution coupled ocean-atmosphere models.

***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 10<sup>th</sup> 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

- Satellite Simulator: Synthetic data for “early adopters”
- Hackathon & making code available on github
- Webinars
- *We seek qualified individuals to serve on its science team.*
  - ***Expertise in Socioeconomic research, Tools development for Butterfly applications, Use of scientific data for societal weather/ climate solutions***



Take a picture to go to the Butterfly project page

A stylized butterfly logo composed of overlapping blue and purple lines, positioned to the left of the title. The word "BUTTERFLY" is written in white, uppercase, sans-serif font on a dark olive green horizontal bar.

# 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.