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

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California’s record winter storms could spawn disastrous floods

BY DAV WALTERS
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**Key Messages for March 9-10 Winter Storm**

- **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.
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

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

Oceanic forcing of the atmosphere on frontal and mesoscales

(Seo 2017)
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

Values in white are the original satellite estimates

Global mean water fluxes (1,000 km³/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:

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

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

The 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

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Science Team: Mark Bourassa, Hyodae Seo, Kelly Lombardo, Sarah Gille, Tom Farrar, Rhys Parfitt
Mission info (EVM3)

### 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
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 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

- 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
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.