A NASA Earth Venture Mission - EVM3 - Proposed Mission

EVMs are science driven, competitively selected, low cost satellite missions

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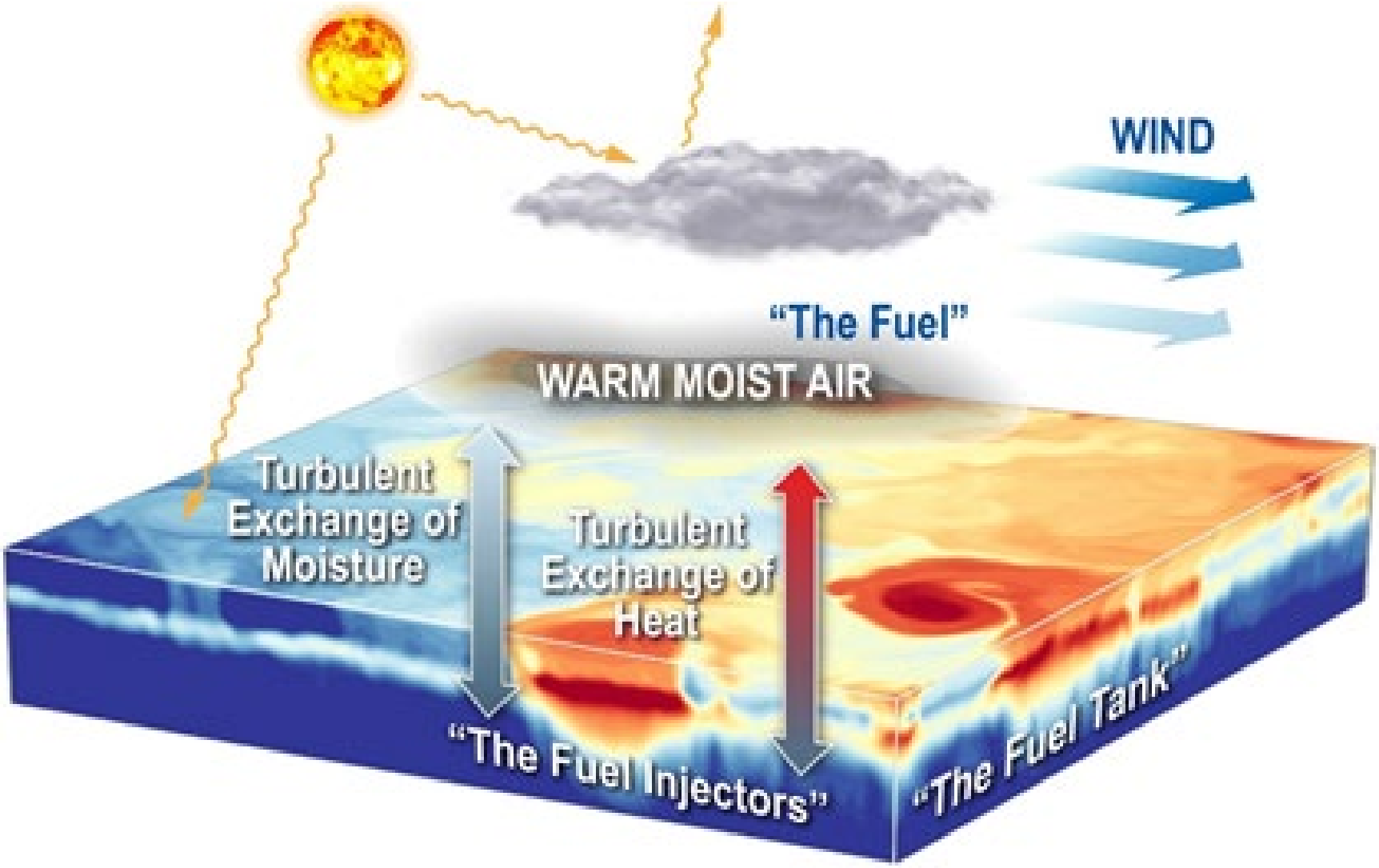
NASA · Farallon Institute · Woods Hole Oceanographic Institution · JPL · Ball · CU · Scripps Oceanography UC San Diego · Penn State

At the ocean surface, the exchange of heat and moisture fuel atmospheric weather and climate *and ocean variability* .

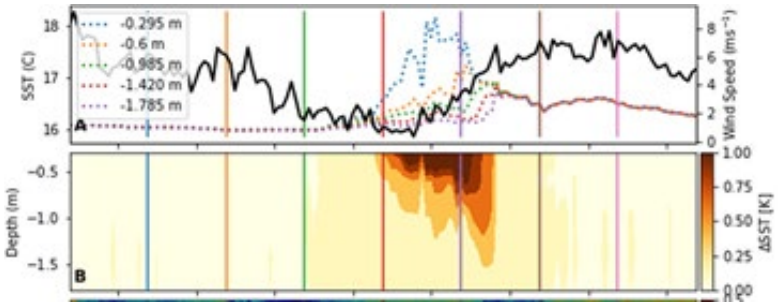


Some examples of …..

The *atmosphere* forcing the ocean

SST/wind ▬ correlation

Diurnal warming: Wind ↓ Ocean Temp ↑



Upwelling: Wind ↑ Ocean Temp ↓

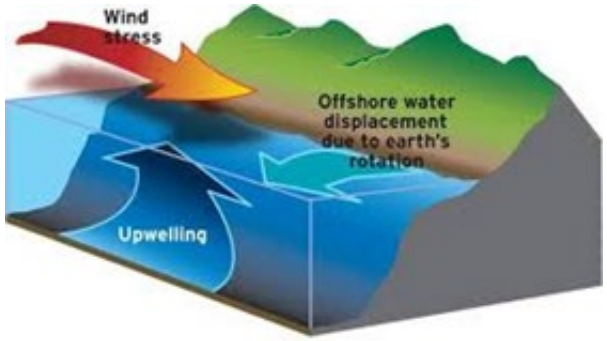


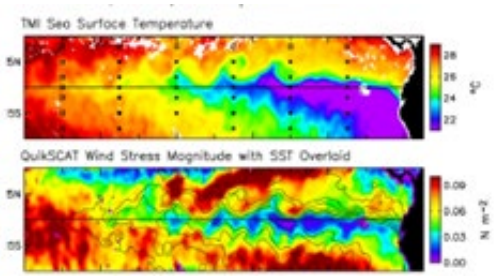
Image: (top) Gentemann et al. 2019; (bottom) NOAA NFSC

The *ocean* forcing the atmosphere

SST/wind ✚ correlation

Boundary layer stability: Wind ↓ Ocean Temp ↓

Boundary layer stability: Wind ↑ Ocean Temp ↑



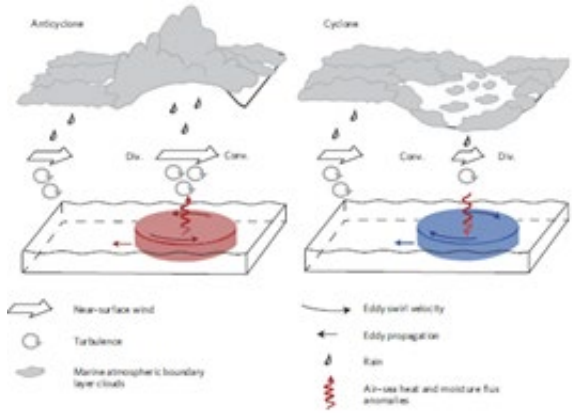


Image: (top) Chelton et al. 2001; (bottom) Frenger et al. 2013

Small -scale air -sea heat & moisture fluxes *appear* to influence both local atmospheric variability and remote weather over land

Wind & SST data show:

At large scales the atmosphere generally drives the ocean.

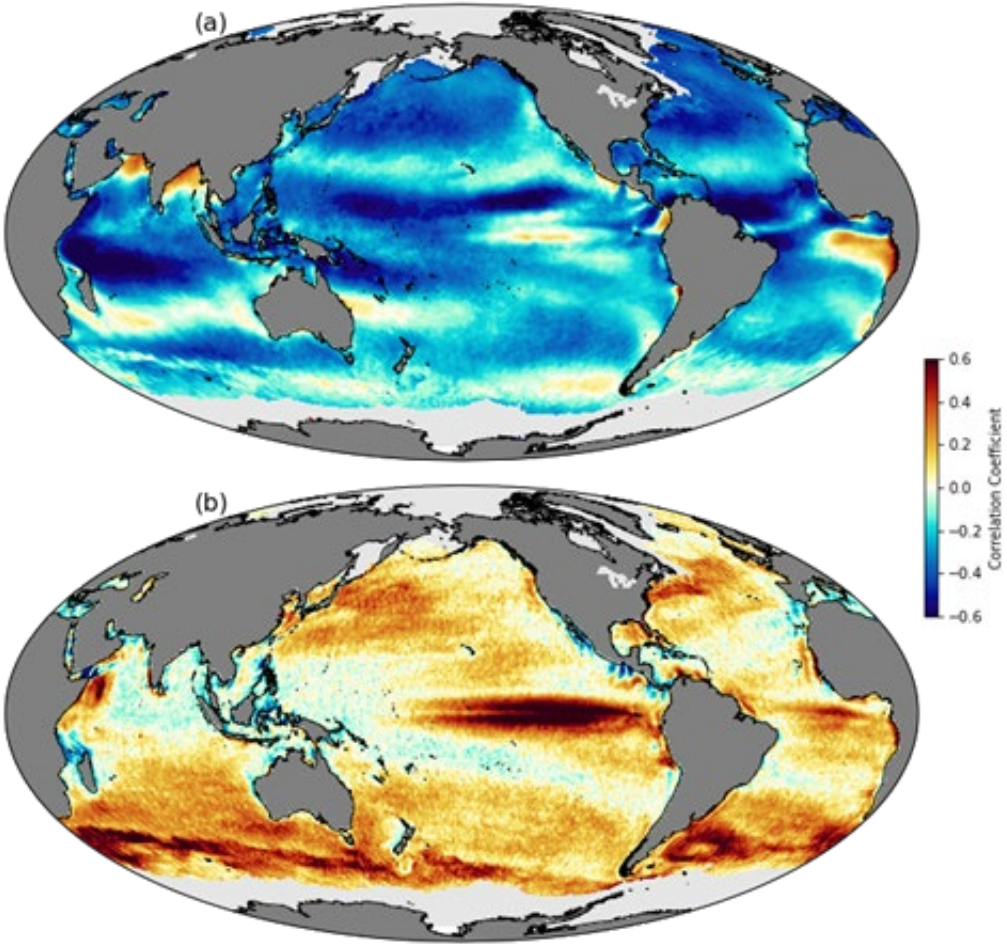
At small scales the ocean drives the atmosphere.

Wind -SST are proxies because we have NO accurate measurements of small -scale air -sea heat / moisture flux data from space

Negative Correlation

High pass filtered data

Positive Correlation



Gentemann et al. (2020)

Air -sea heat & moisture fluxes regulate air -sea interactions, thereby influencing the energy and water cycles

Ocean evaporation is the largest element of the global water cycle. It also has the largest uncertainty.

Are small-scale air-sea interaction an important source of uncertainties for air-sea heat and moisture fluxes on regional to global scales?

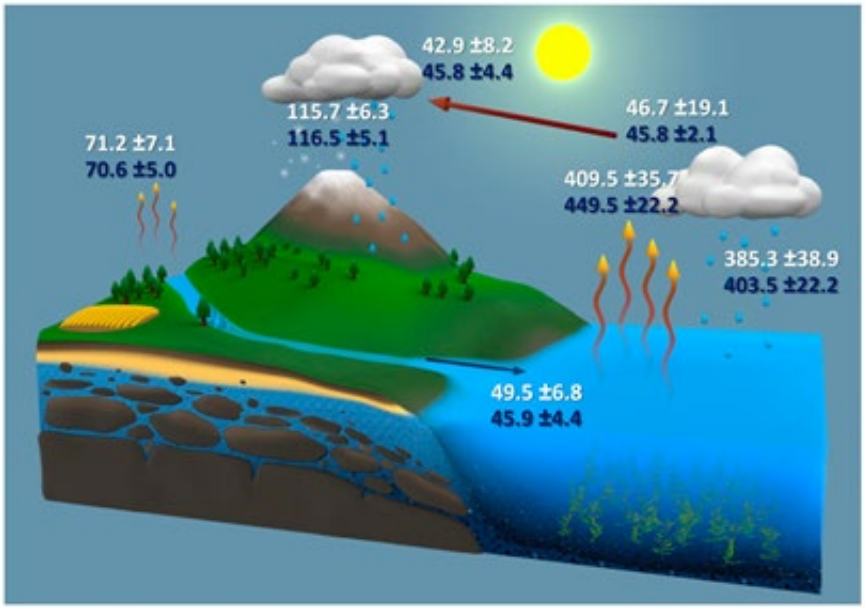
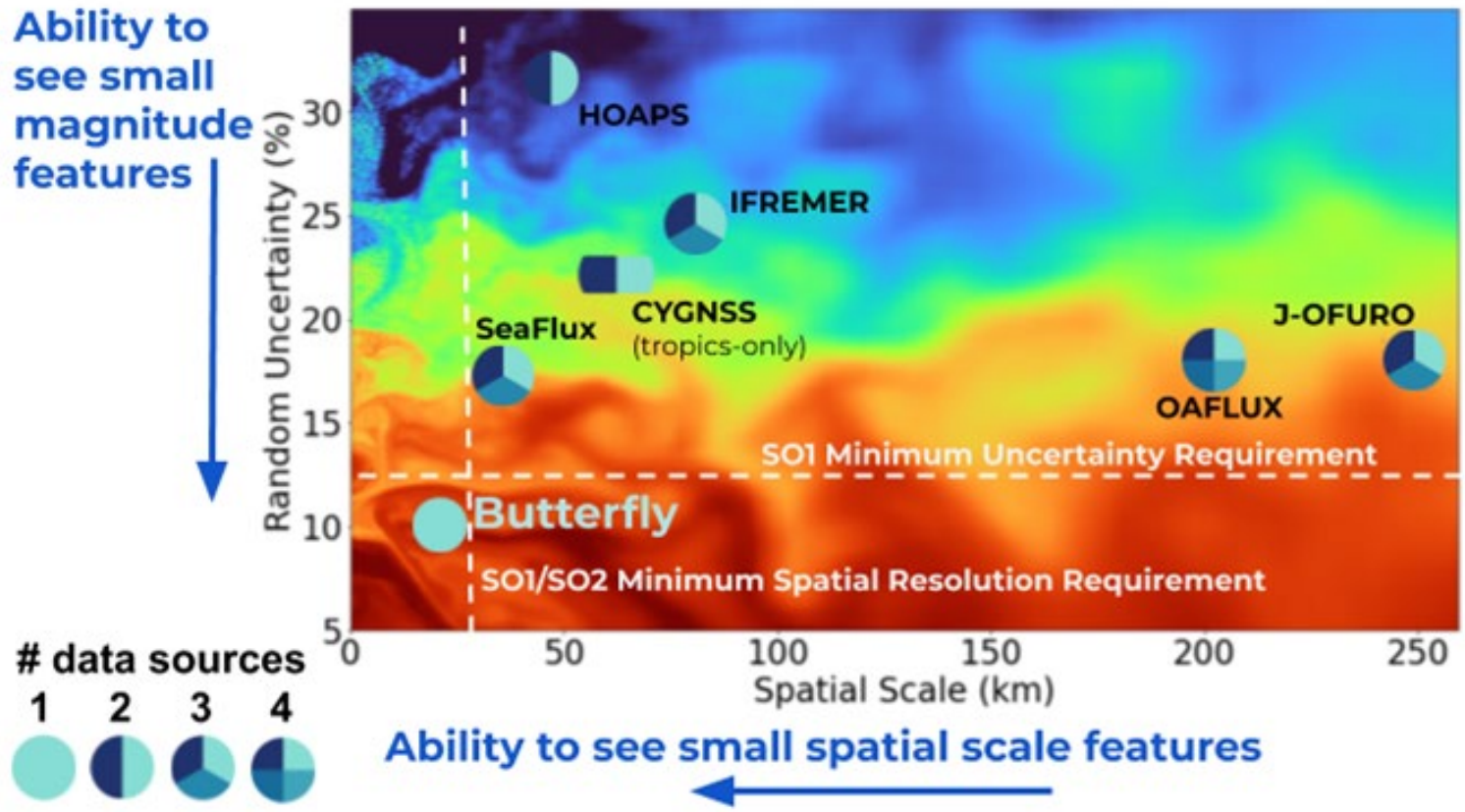


FIG. 2. Mean annual fluxes (10^3 km^3 yr^{-1}) of the global water cycle, and associated uncertainties, during the first decade of the millennium. White numbers are based on observational products and data integrating models. Blue numbers are estimates that have been optimized by forcing water and energy budget closure, taking into account uncertainty in the original estimates.

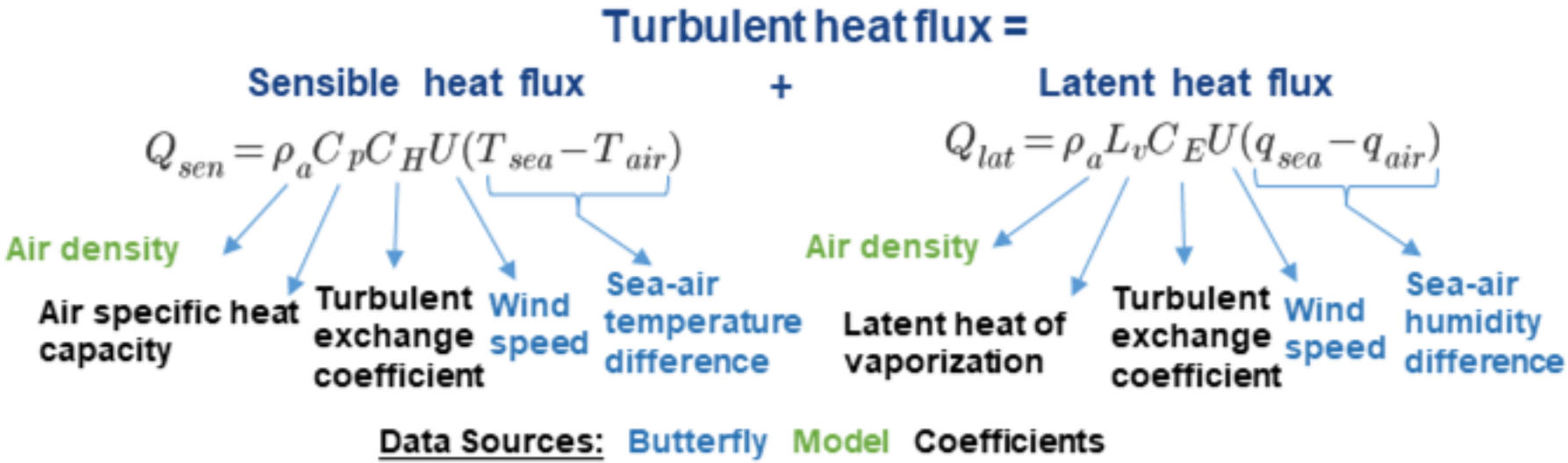
Image Credit: Rodell et al. 2015

No existing satellite is designed to measure the air-sea turbulent heat fluxes.

Existing flux products interpolate multiple data sources in space and time



Estimate the air-sea turbulent heat fluxes:

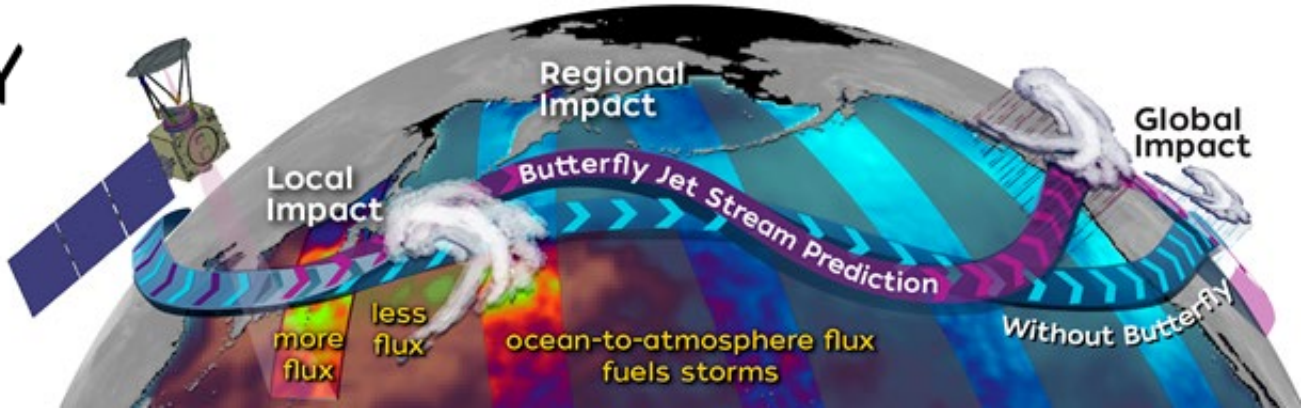


The turbulent heat fluxes include sensible and latent heat fluxes. The latent heat flux is directly related to moisture flux through evaporation.

BUTTERFLY

BUTTERFLY

revealing the ocean's impact on weather & climate



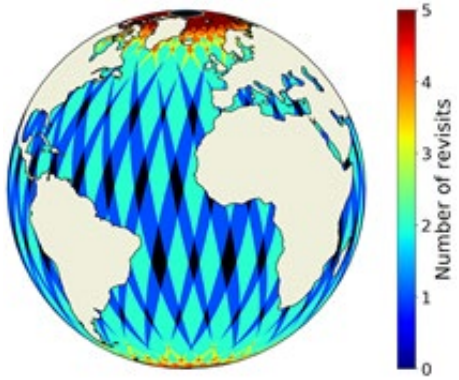
WHAT

Butterfly is 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 able to resolve the impact of small-scale ocean features on large-scale weather and climate.

WHY

The ocean supplies the atmosphere with heat and moisture, fueling local variability, remote weather, and the global climate. No other satellite is designed to estimate this air–sea exchange. **Observing air–sea fluxes will advance Earth system science, improve models, and lead to better daily, seasonal, and climate forecasts.**

2-DAY COVERAGE



Mission	Details
Launch Date	4/2026
Length	2 years
Orbit	sun-sync
Swath Width	640 km

Channel (GHz)	Footprint (km)
7	25x22
11	17x14
19	13x12
24	12x11
37	12x10
110-116	17x14
150-170	12x10
Resampled	20

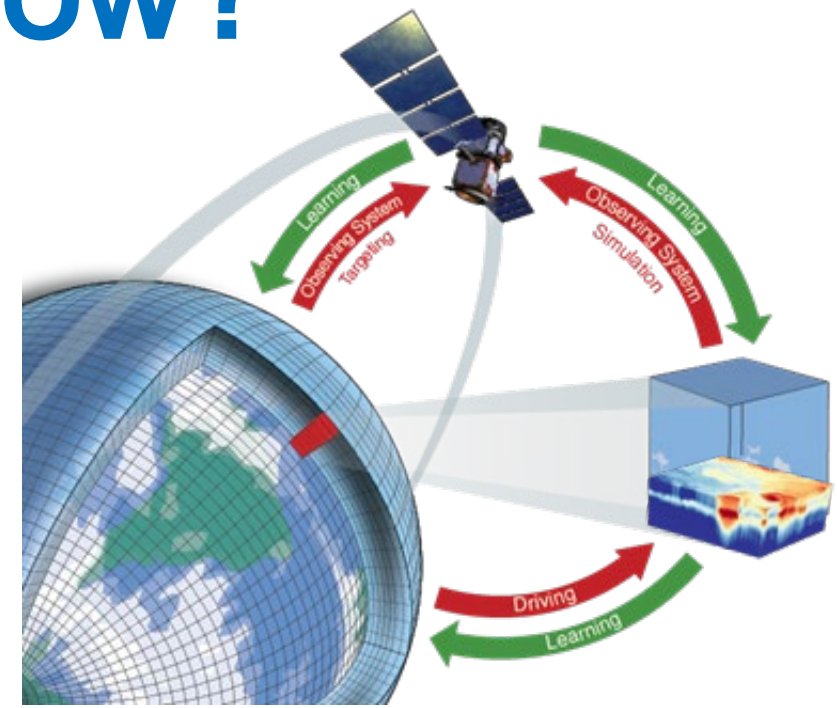
HOW

Building on NASA technology, Butterfly combines a passive microwave radiometer (7, 11. 19, 24, and 37 GHz), hyperspectral sounder (110-118, 160-183 GHz), two spinning reflectors, and a digital backend to generate RFI-robust data.

Why now?

Operational centers are all moving to coupled models

….but the coupling mechanism details are still highly uncertain and coupled data assimilation development is still in an experimental phase.



Butterfly will collect **the exact data** needed to advancing coupled modeling and data assimilation, accelerating operational model development, making a step change in coupled forecasts, and improving predictive skill across scales.

Image credit: https://climate-dynamics.org/earth-system-modeling-2-0/

How?

Butterfly combines:

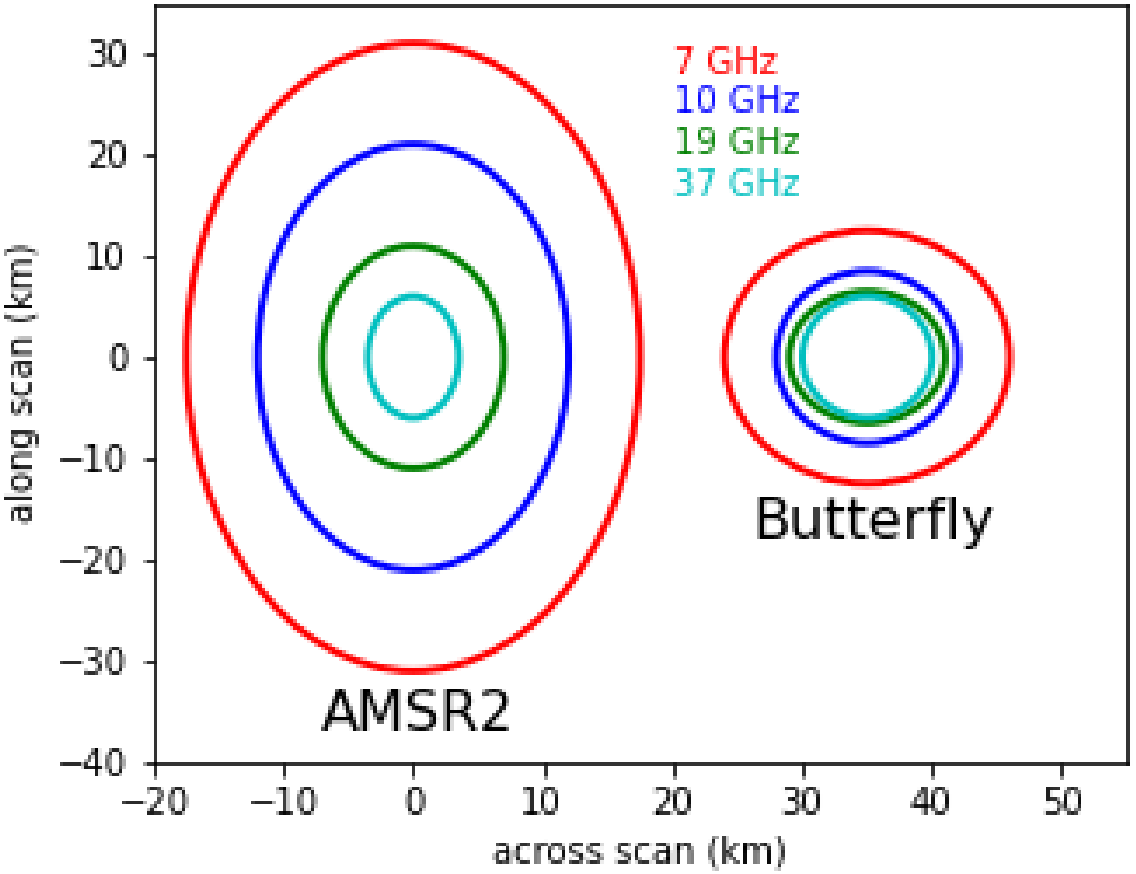
Passive microwave imager
- 6.8, 10.7. 18.7, 23.8, and 37 GHz
- Measures sea surface temperature & wind speed

Near-surface sounder
- 110-116, 150-170 GHz
- Measures near-surface air temperature & humidity

Two spinning reflectors
- Achieves 20 km spatial resolution

Digital backend
- Improves accuracy and provides RFI-robust data

20 km data, 640 km swath width, and 91% global coverage in 2 days



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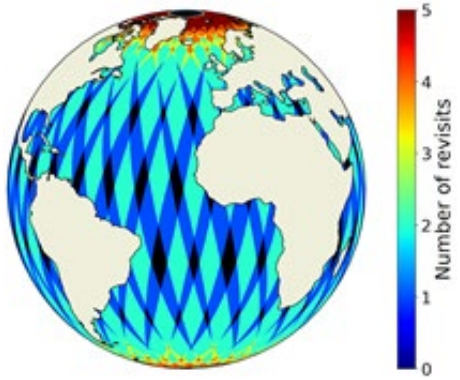
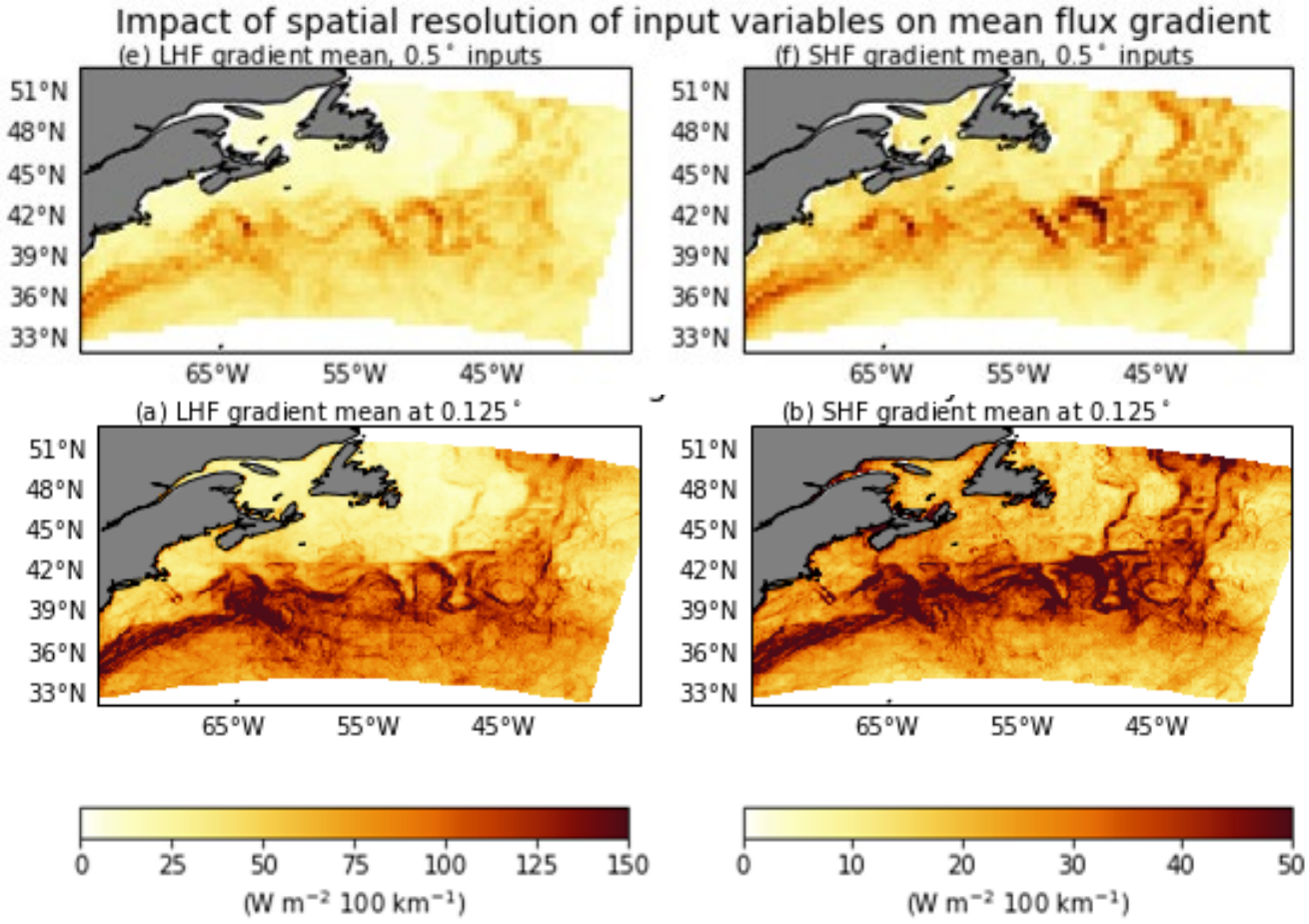


A new view of fluxes



A WRF-based assessment

Now

Butterfly

~50% reduction of errors

Instantaneous observational random errors for each input variable and the flux errors for current missions and Butterfly based on error propagation.

Variable	Observational Random Error		Latent Flux Uncertainty ($W\ m^{-2}$)		Sensible Flux Uncertainty ($W\ m^{-2}$)	
	Current	FluxSat	Current	FluxSat	Current	FluxSat
q_{sea} ($g\ kg^{-1}$)	0.47 [1]	0.4	6.8	6.1	-	-
q_{air} ($g\ kg^{-1}$)	1.3 [2]	0.6	23.2	10.8	-	-
T_{sea} (K)	0.5 [3]	0.6	-	-	5.1	4.6
T_{air} (K)	1.6 [4]	0.7	-	-	14.6	7.2
u ($m\ s^{-1}$)	0.8 [5]	0.6	5.9	4.4	1.5	1.1
pressure (mb)	5.0	5.0	0.5	0.5	0.1	0.1
total [6]	-	-	24.9 →	13.2	15.5 →	8.6

[1] Calculated using COARE 3 using uncertainties from pressure and T_{sea}. [2] Average error from range given in [33]. [3] [57,58]. [4] Average error from range given in [64,65]. [5] Average error from range given in [55,56]. [6] Calculated as the square root of the sum of each error source squared.

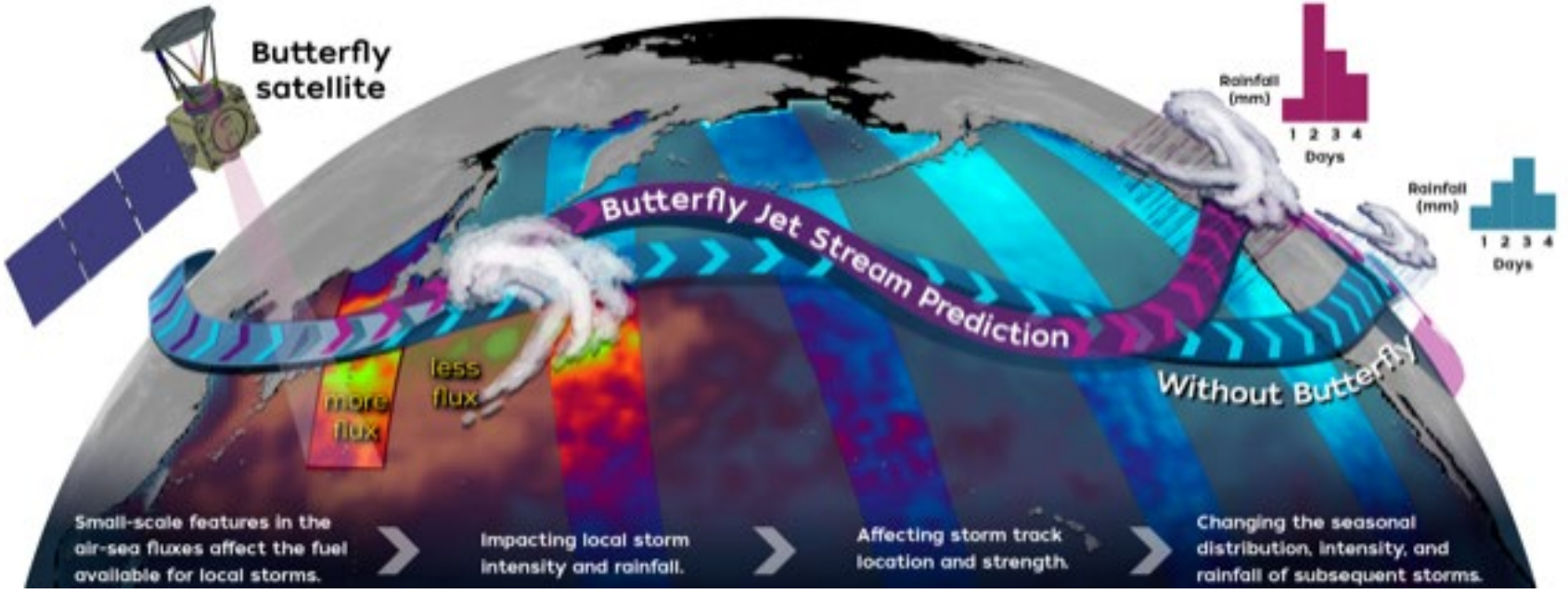
The errors of current flux products due to temporal/spatial mismatch of input variables have not been included. Butterfly is not affected by such mismatch because of its simultaneous measurements of input variables.

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: Do small -scale spatial variations in air –sea fluxes near warm ocean currents affect large -scale storm evolution and improve prediction of long -term weather?

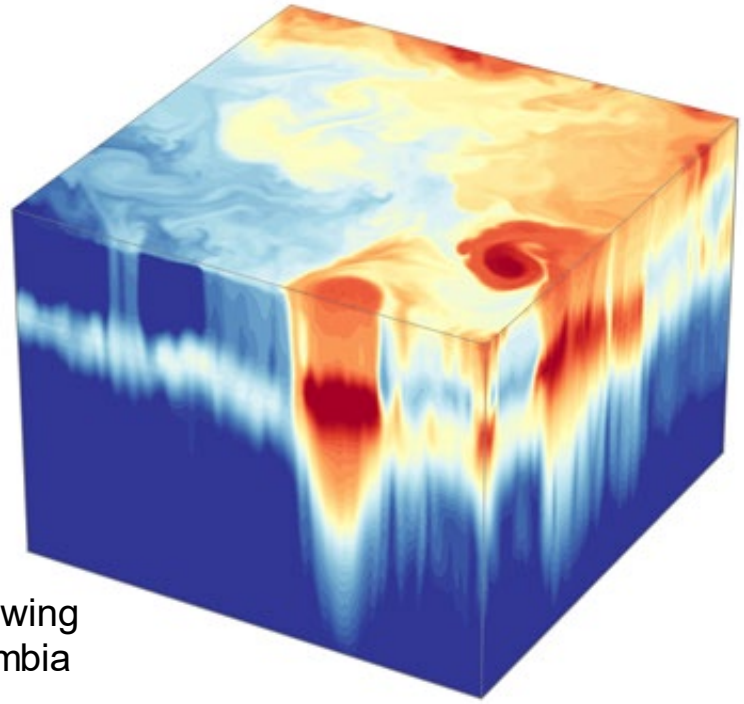


Butterfly Science

Local to Global

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

Science Objective 2: Do small -scale variations in the air –sea boundary layers contribute significantly to the large -scale air –sea exchange of heat and moisture?



ECCO ocean model data showing ocean eddies off British Columbia

Butterfly will provide us with the first observational opportunity to test major hypotheses about mesoscale air -sea interaction mechanisms affecting both ocean and atmospheric variability

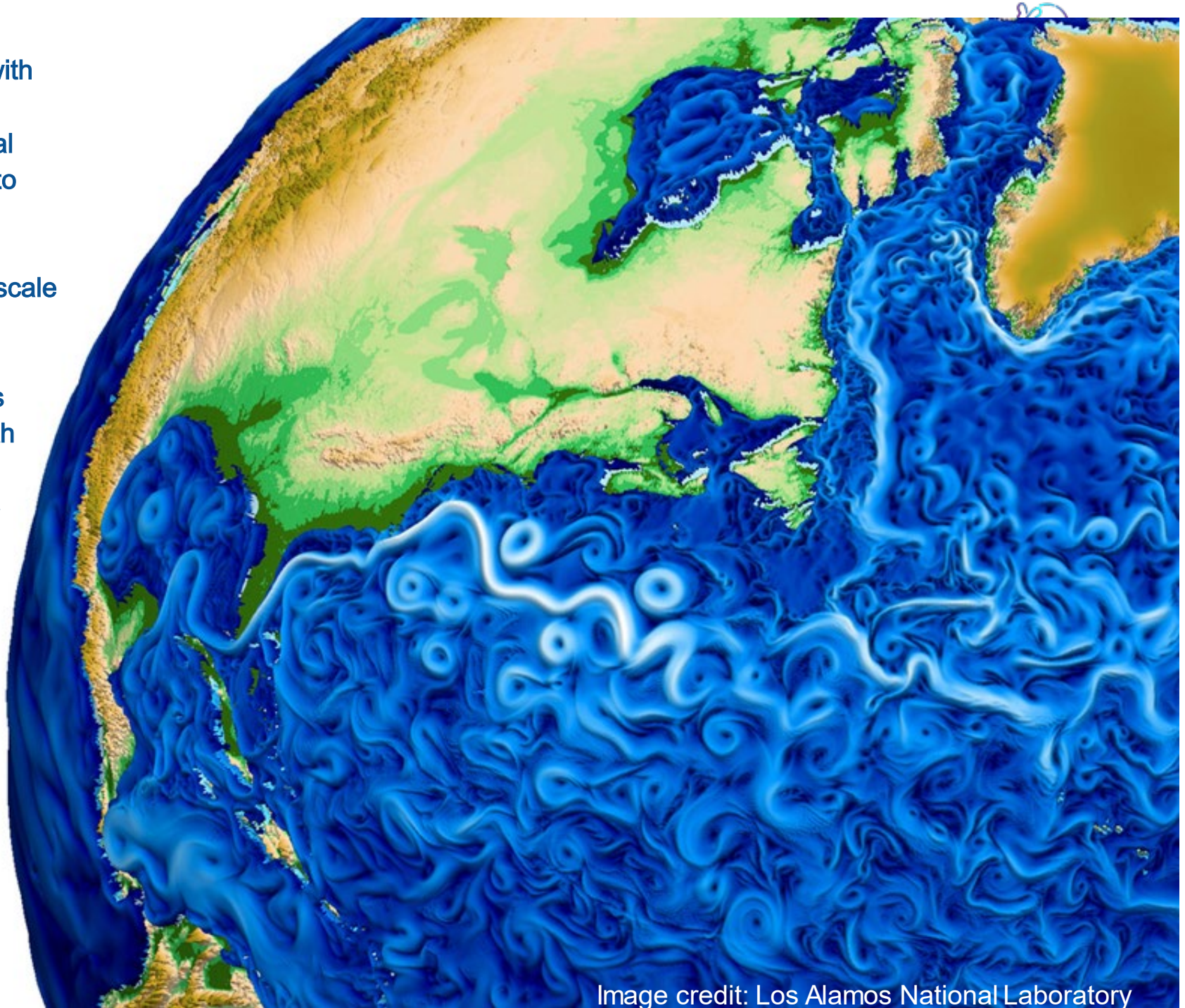


Image credit: Los Alamos National Laboratory

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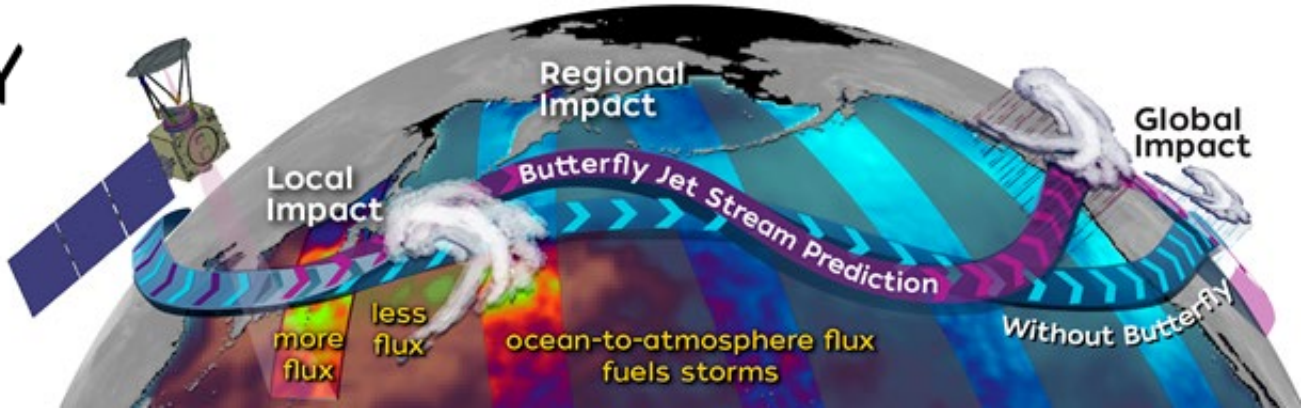

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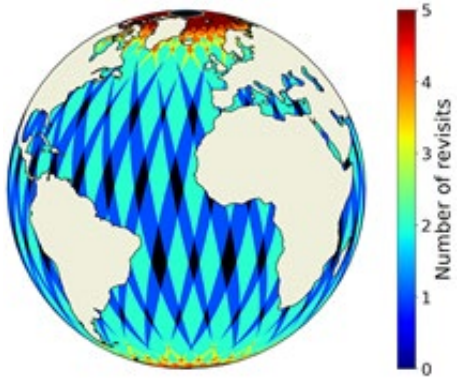

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