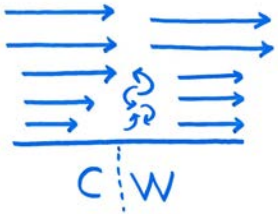
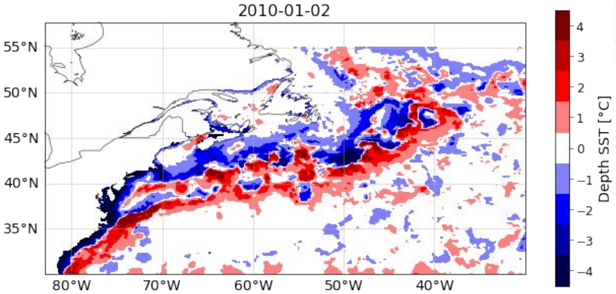
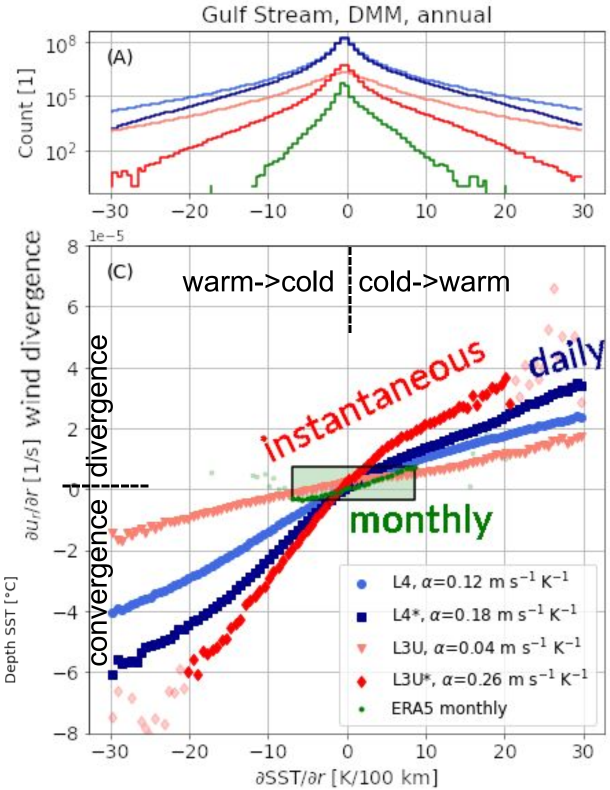
Fast thermal air-sea coupling: the instantaneous wind response and the role of environmental conditions

Agostino N Meroni,
Fabien Desbiolles,
Claudia Pasquero

Sea Surface Temperature mesoscale structures force the lower atmosphere, via, e.g. the Downward Momentum Mixing mechanism:







Data used:

- **ESA CCI SST** at Dx~0.05° (L3U: instantaneous, L4: daily);
- **Ascat** wind field (L2) at Dx~12.5 km;
- **ERA5** monthly at Dx~30 km.

Time frame: Jan 2007-March 2014.

Over all four major Western Boundary Currents we find that:

1) The daily/instantaneous response is found over a **wider range** of forcing and response fields.
2) The **instantaneous coupling is stronger** than the daily one.

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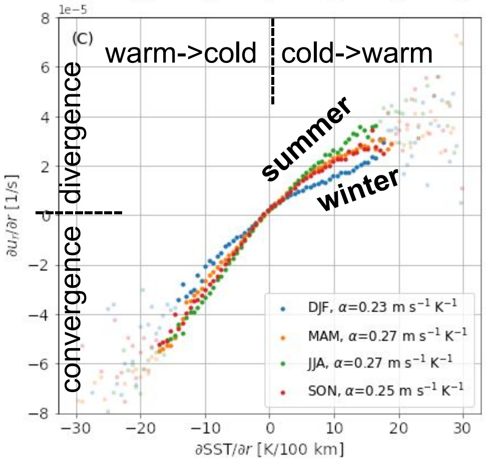
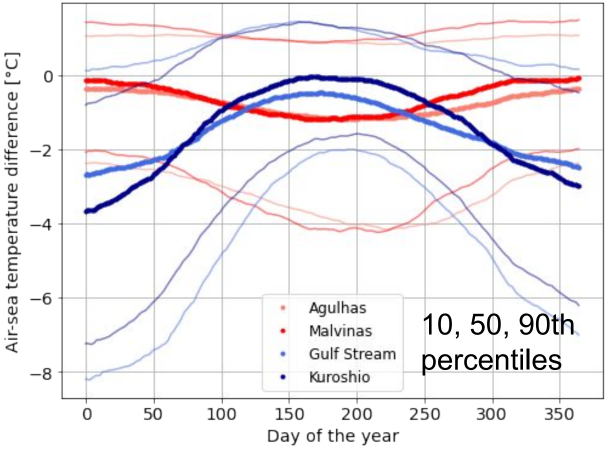
Over **Northern Hemisphere** WBCs, the minimum coupling is observed in **winter.**



In winter the **NH** has **the strongest air-sea temp differences**.

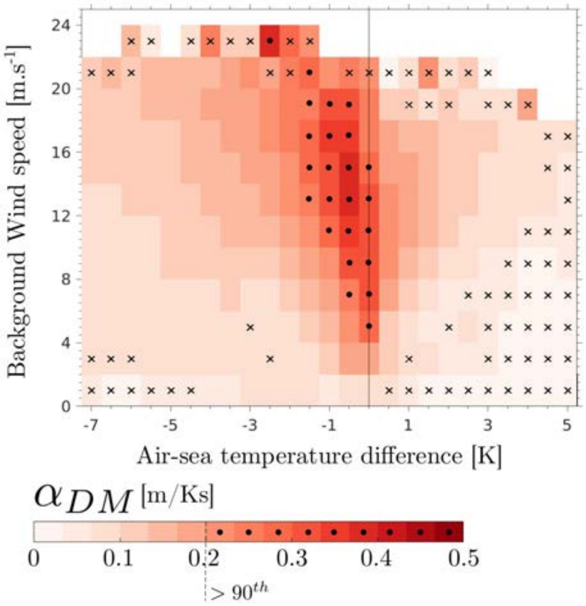


The enhancement and the suppression of the vertical mixing for **very unstable** and **stable** conditions weakens the sensitivity to the surface gradients.

In the Northern Hemisphere, the **winter-time unstable conditions** (due to cold air outbreaks) reduce the DMM efficiency.

The cloud response is also being investigated. TBC…

Five years of global daily ERA5 data are used to evaluate the modulation of **background wind** and **air-sea temperature difference** on the efficiency of the DMM [Desbiolles et al., 2023]: DMM is important for all wind speed in slightly unstable conditions.



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Global warming effect on oceanic mesoscale eddy energetics

Junghee Yun[1,2], Kyung-Ja Ha[1,2,3] and Sun-Seon Lee[1,4]

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Mesoscale eddies are **ubiquitous** in the global ocean, have a critical role in the mixing and transporting of heat, salt, and biogeochemical properties across the global oceans, and thus, **can regulate the regional and global climate.**

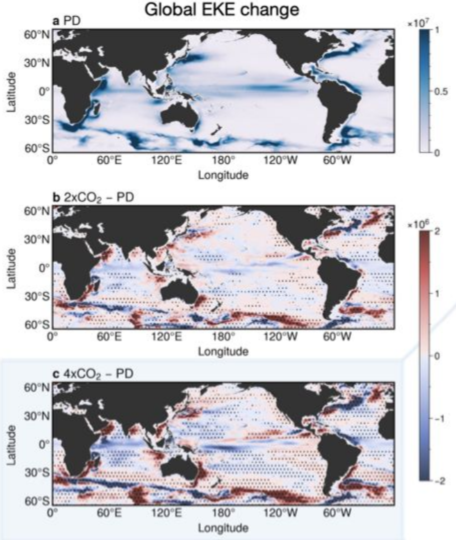
However, it remains unclear how greenhouse warming will alter ocean eddies due to the shortage of observational long-term records and model simulations with high spatiotemporal resolutions.

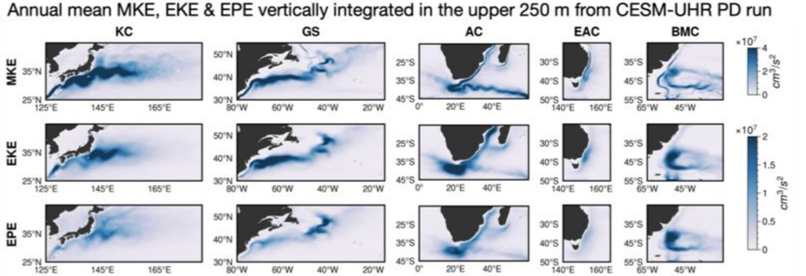
Questions?

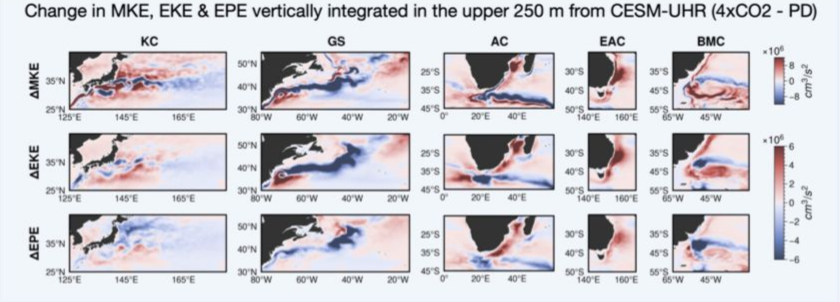
1. *Will mesoscale eddy activity **be enhanced or weakened** under greenhouse warming?*
2. *What is the **key process** underlying it?*

Results

Global eddy energy change


Global EKE change


Annual mean MKE, EKE & EPE vertically integrated in the upper 250 m from CESM-UHR PD run


Change in MKE, EKE & EPE vertically integrated in the upper 250 m from CESM-UHR (4xCO2 - PD)

***CESM-UHR** revealed that CO2-induced global warming brings a complex EKE change across oceans.*

Global warming effect on oceanic mesoscale eddy energetics

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[1]Center for Climate Physics, Institute for Basic Science, Busan, South Korea
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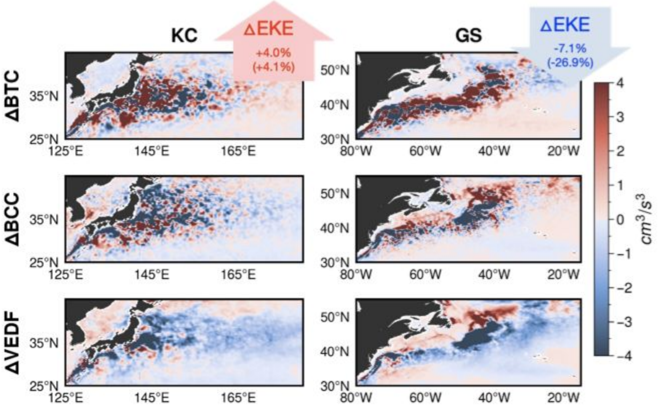
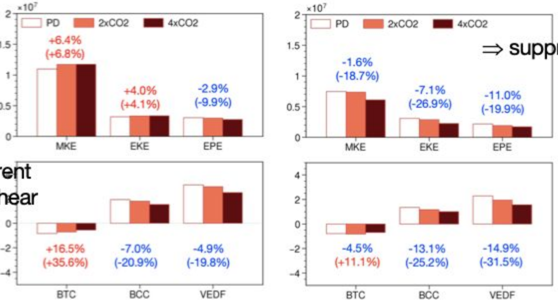
Kuroshio current vs Gulf stream



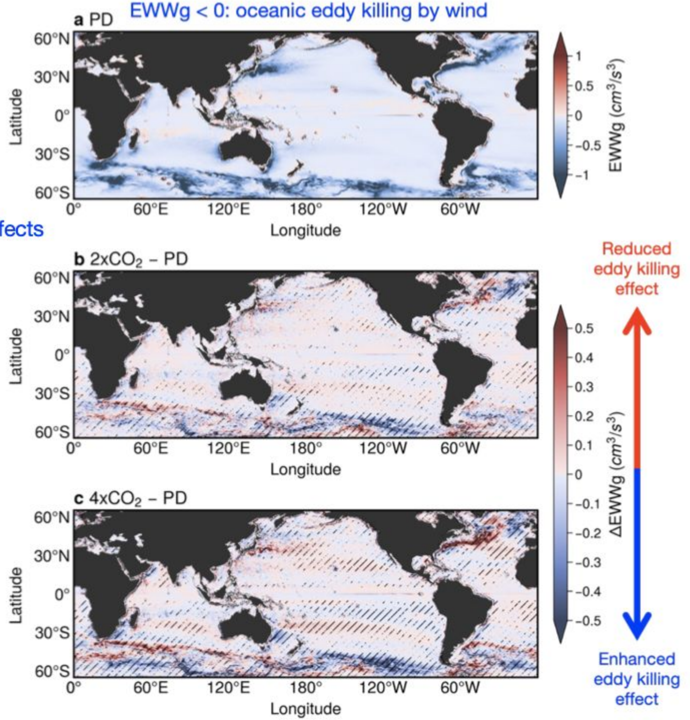


GS: weak AMOC
⇒ suppress vertical buoyancy flux
⇒ reducing EKE

KC: strong surface current
⇒ increase horizontal shear production
⇒ enhancing EKE

How did the effect of current feedback change under global warming?

ΔEKE vs ΔEWWg
: positive ΔEKE →
enhanced eddy killing effects

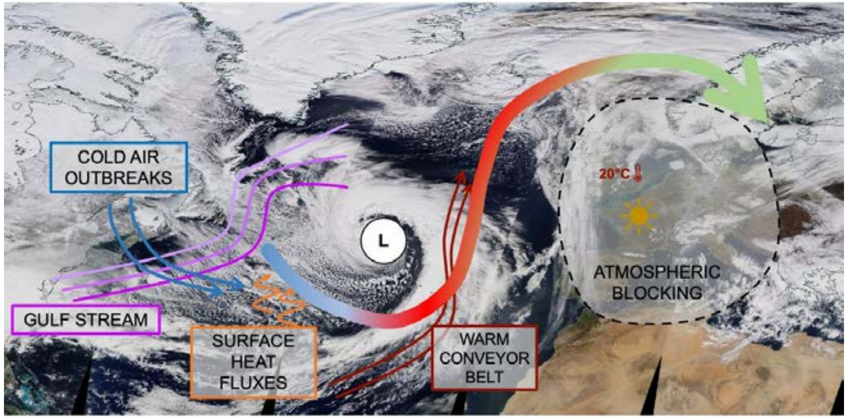


Reduced eddy killing effect

Enhanced eddy killing effect

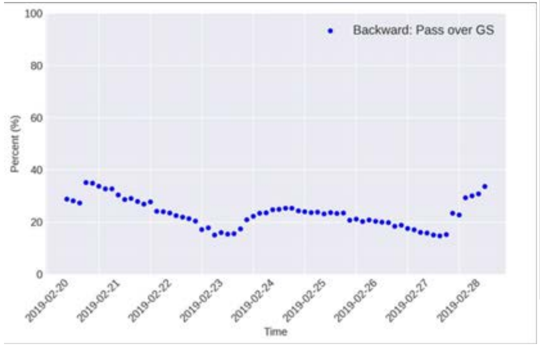
Air-sea interactions and diabatic processes in the Gulf Stream region and their role in the life-cycle of a blocking anticyclone: a case study of European Blocking in Feb 2019.

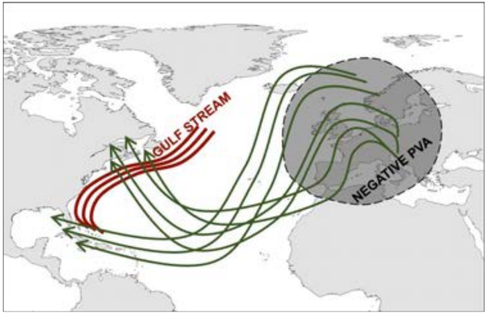
Case Study (20.02.2019 - 27.02.2019)



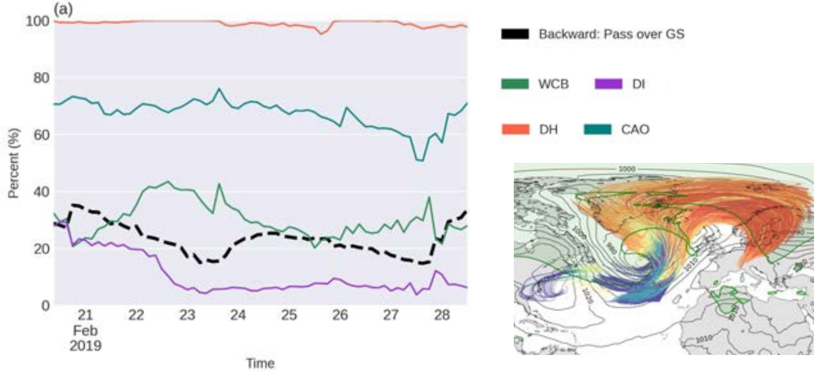
Methods and results

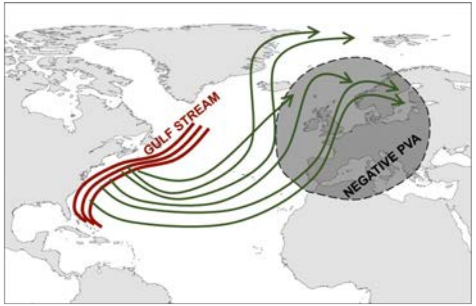
Fraction (%) of 10 days backward trajectories that passed over the Gulf Stream.



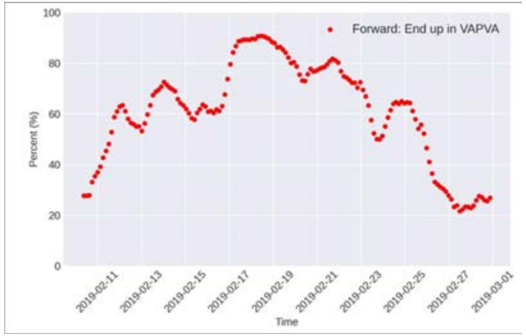


Properties of the trajectories



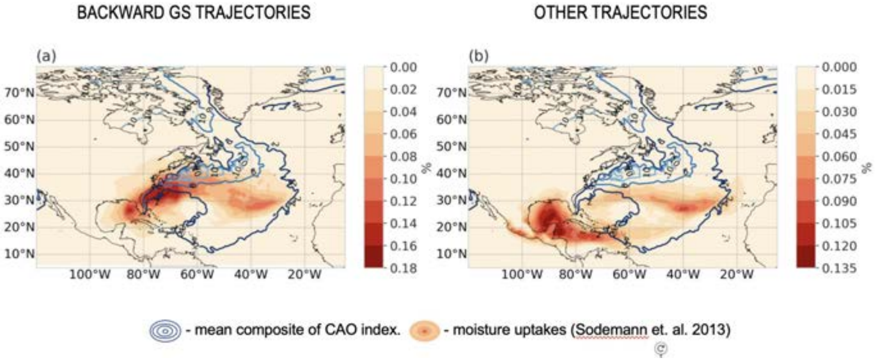


Fraction (%) of 10 days forward trajectories that ended up in the upper-level blocking.

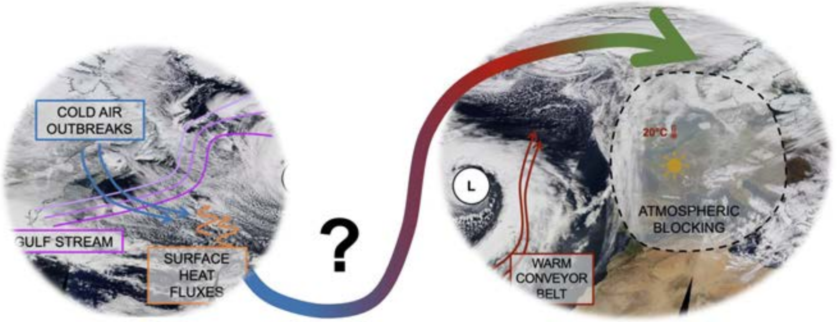


Air-sea interactions and diabatic processes in the Gulf Stream region and their role in the life-cycle of a blocking anticyclone: a case study of European Blocking in Feb 2019.

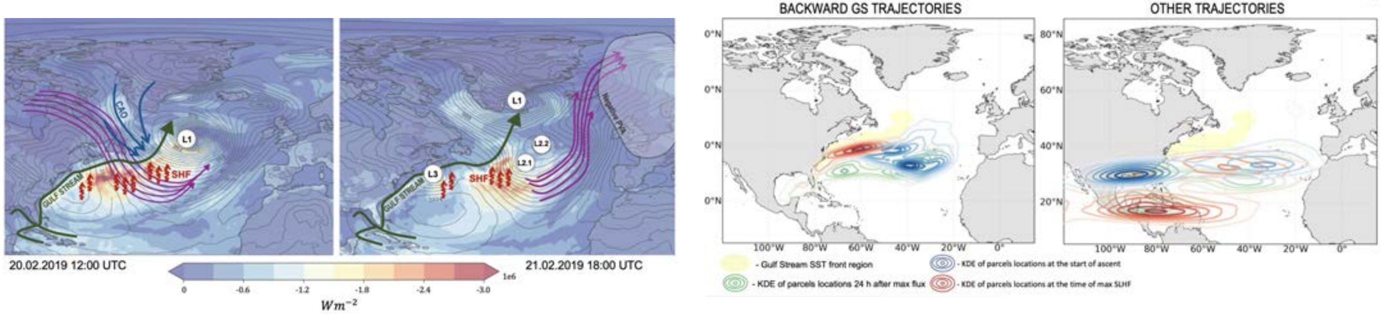
Moisture sources



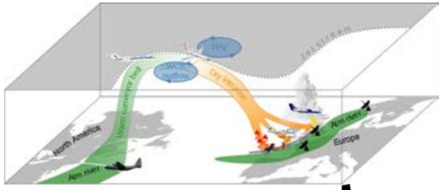
Mechanistic link: Gulf Stream → EuBl



Hand-over mechanism of moisture



NAWDIC (2026)



Authors: Marta Wenta, Christian M. Grams, (Karlsruhe Institute of Technology), Lukas Papritz, Marc Federer (Institute for Atmospheric and Climate Science, ETH Zurich

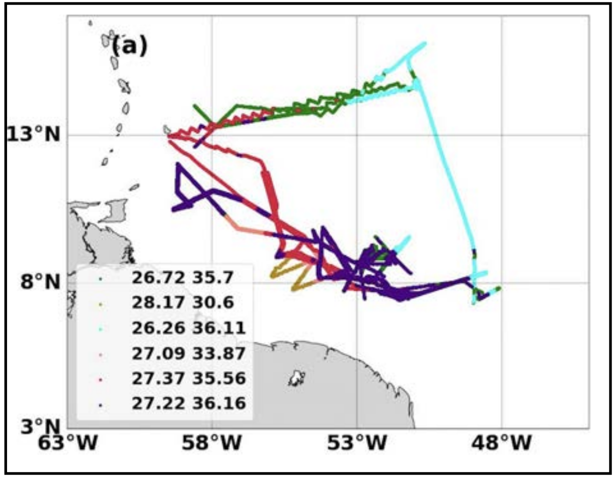
Latent heat flux coupling to the small-scale ocean

Pablo Fernández*, Sabrina Speich, Matteo Borgnino, Agostino N Meroni, Fabien Desbiolles and Claudia Pasquero
*EMAIL: pablo.fernandez@lmd.ipsl.fr

Goals

1) How do ocean small-scale surface features (in SST and SSS) affect latent heat flux (LHF)?

2) Which are the surface ocean - MABL coupling mechanisms driving LHF changes?



Different data sets for different purposes

To evaluate the LHF coupling to the small-scale SST:

- **ERA5** at Dx~25 km (daily averages).
- **SeaFlux** at Dx~25 km (daily averages).
- **MUR-JPL** daily at Dx~0.01º.
- **WRF** daily at Dx~0.03º.

Time frame: DJF 2008-2018.
Spatial domain: 5º-17ºN, 60º-51ºW.

To evaluate the effect of the pair SSS-SST on LHF: *in-situ* data:

- Saildrones
- CTDs, UCTDs, gliders, argo floats, RVs.
- Radiosoundings and lidar.

Time frame: During the EUREC^{4}A-OA campaign, JFMA 2020.
Unprecedented high-resolution sampling of the air-sea interface in the north-west tropical Atlantic Ocean

Latent heat flux coupling to the small-scale ocean

Pablo Fernández*, Sabrina Speich, Matteo Borgnino, Agostino N Meroni, Fabien Desbiolles and Claudia Pasquero

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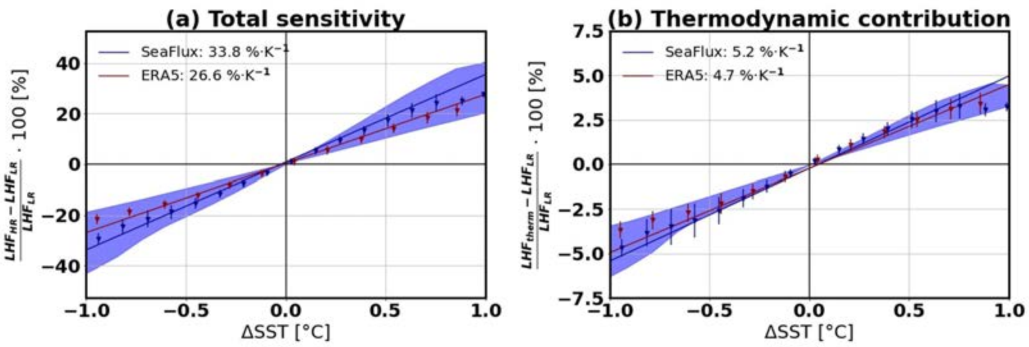
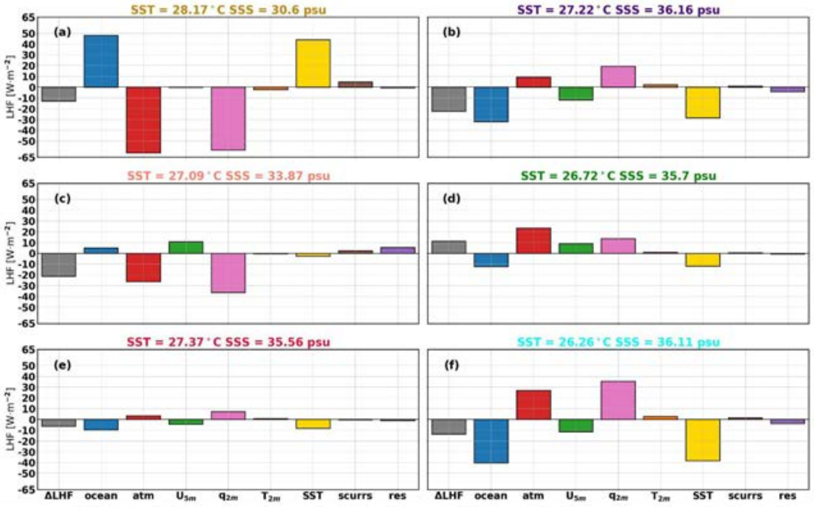




Two mechanisms control LHF sensitivity to SST

Dynamic: As a consequence of the thickening/shallowing of the MABL (~28%·K^{-1}). **Only present when the small-scale coupling is considered.**

Thermodynamic: As a result of the dependence of water vapour saturation pressure on SST (~5% ·K^{-1}).

Lower SSSs imply a **reduced water entrainment** from the deep ocean and an **increased heating rate** of the ocean mixed layer.

↓

These two ingredients increase LHF but **a decrease is observed over the freshwater plume.**

Small-scale variability of air-sea momentum and heat fluxes in the tropical Atlantic trade wind region

Suneil Iyer[1,*], Kyla Drushka[1], Jim Thomson[1], Elizabeth Thompson[2]
[1]Applied Physics Laboratory, University of Washington; [2]NOAA Physical Sciences Laboratory
[*]Now at College of Earth, Ocean, and Atmospheric Sciences, Oregon State University

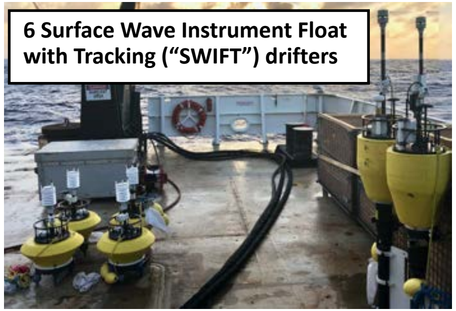
Research Questions

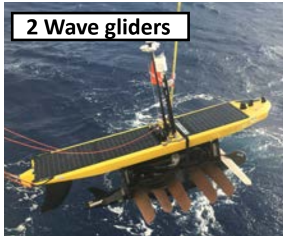
1) Do variations in the surface current direction and magnitude influence waves and momentum flux?

2) Do sea surface temperature (SST) variations influence air-sea heat and buoyancy flux?

Observations from the ATOMIC field campaign

- **January-February 2020 in the NW tropical Atlantic**


6 Surface Wave Instrument Float with Tracking ("SWIFT") drifters


2 Wave gliders

Data:

Air : T, humidity, wind, P, clouds

Fluxes: heat, vapor, buoyancy, momentum

Ocean: T, S, currents, wave parameters, wave spectra, TKE dissipation rate

*SWIFTs (WGs) deployed for 21 (30 and 34) days

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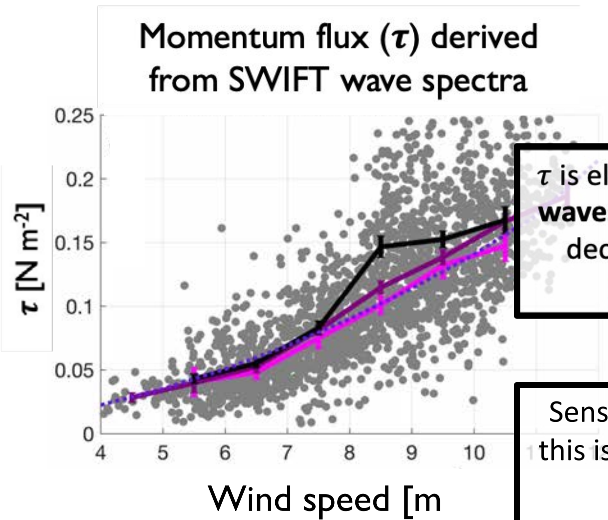
US CLIVAR Mesoscale and Frontal-Scale Air-Sea Interactions Workshop
March 6, 2023

Small-scale variability of air-sea momentum and heat fluxes in the tropical Atlantic trade wind region

Oregon State University
College of Earth, Ocean, and Atmospheric Sciences

Suneil Iyer[1,*], Kyla Drushka[1], Jim Thomson[1], Elizabeth Thompson[2]
[1]Applied Physics Laboratory, University of Washington; [2]NOAA Physical Sciences Laboratory
[*]Now at College of Earth, Ocean, and Atmospheric Sciences, Oregon State University

Waves and momentum flux are modified by surface current variability



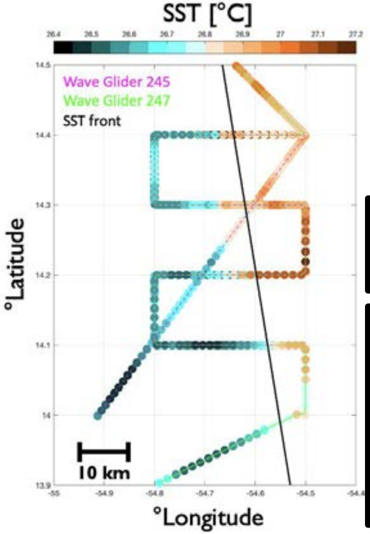
Strongly wave-following currents (>0.2 ms^{-1})
Weakly wave-following currents (<0.2 ms^{-1})
Wave-opposing currents

τ is elevated (by 15%) **when waves oppose currents** and decreased **when waves follow currents**.

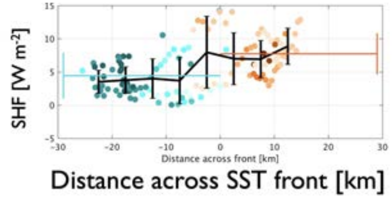
Sensitivity tests show that this is due to a combination of changes in the current-relative wind and wave-current interactions.

Sea surface temperature variability modifies air-sea heat fluxes

Sea surface temperature (SST) from Wave Gliders from 2-6



Sensible heat flux (SHF) across the SST gradient observed on 2-6 Feb.



SST varies by 0.7°C across 25 km, typical of 10-100 km fronts in the region.

Sensible heat flux is on average 3.6 W m^{-2} higher on the east (warm) side of the gradient. Because SST and SHF gradients were correlated throughout the campaign, SST likely modulates the spatial variability of sensible heat flux.

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Read more at:
Iyer et al. (2022), JGR Oceans, doi: 10.1029/2021JC018003 (waves, momentum flux)
Iyer et al. (2022), JGR Oceans, doi: 10.1029/2022JC018972 (heat flux)

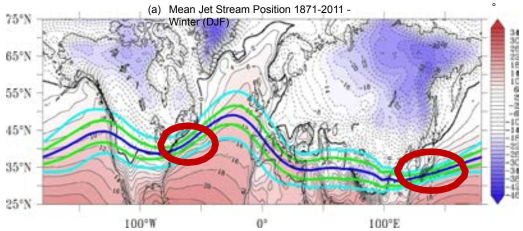
Source of funding: NOAA CPO CVP Award NA19OAR4310374

A land-ocean comparison of the variability of the northern hemisphere jet stream 1871 – 2011

Samantha Hallam[1], Simon Josey[2], Gerard McCarthy[1], Joel Hirschi[2]

1.Irish Climate Analysis Research Units, Maynooth University, Ireland 2. National Oceanography Centre, Southampton, UK

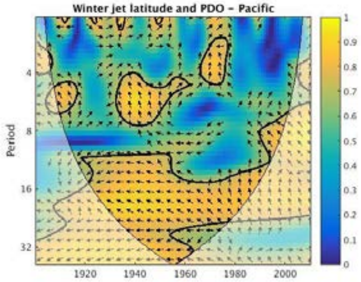
1. Seasonal Variability



Mean Seasonal Jet Stream Position overlaying the 2 m air temperature for the period 1871 -2011

Winter Jet range at a minimum where SST gradients greatest

3. Interannual variability and the Pacific Decadal Oscillation (PDO)



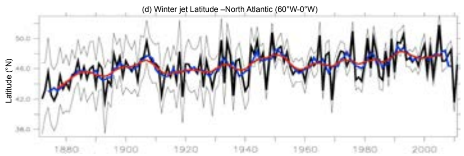
Wavelet coherence for Jet Latitude for North Pacific. Colour bar indicates correlation. Black contours indicate statistically significant features (95% confidence level)

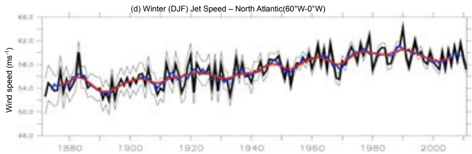
The Pacific Decadal Oscillation (PDO) explains 50% of the winter variance in jet latitude since 1940. The direction of the arrows indicates the PDO and jet stream are anti correlated, and the PDO leads.

2. Decadal Trends

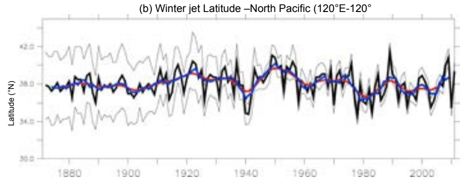
Jet Latitude

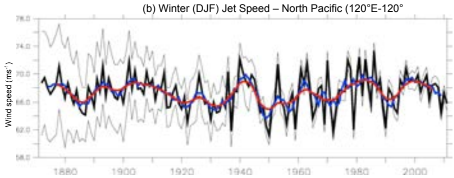
Jet Speed





Atlantic +3°N, +4.5ms^{-1}





Pacific No changes

Download our paper here

Hallam et al., Climate Dynamics 2022

https://link.springer.com/article/10.1007/s00382-022-06185-5

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Global Warming Effect on Ocean Horizontal Stirring Characterized by Finite-Size Lyapunov Exponents

IBS Center for Climate Physics

Gyuseok Lee (gyuseok@pusan.ac.kr)[1,2], June-Yi Lee[1,2], Axel Timmermann[2,3], Karl Joseph Stein[2,3], Eun Young Kwon[2,3], Sun-Seon Lee[2,3], and Myeong-Hyeon Kim[1,2]

[1] Pusan National University, Department of Climate System, Busan, South Korea, [2] Center for Climate Physics, Institute for Basic Science, Busan, South Korea,
[3] Pusan National University, Busan, South Korea

Ocean Horizontal Stirring

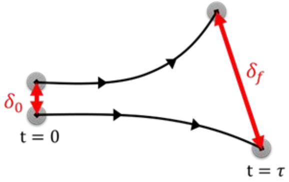
- Stirring is a turbulent phenomenon that promotes mixing speed by deforming the fluid into an elongated shape.
- It is almost everywhere accompanied by other dynamical oceanic processes such as eddies, meandering, currents, and fronts.

“How will ocean horizontal stirring respond to greenhouse warming?”

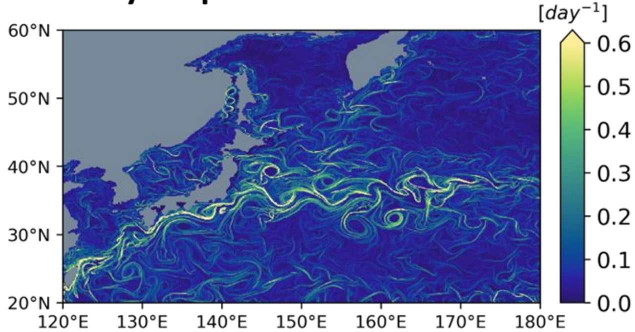
Methods: Finite-Size Lyapunov Exponents (λ)

- It is a Lagrangian metric that characterizes the dispersion rate of two infinitesimally separated particles as an exponential function in a chaotic system.

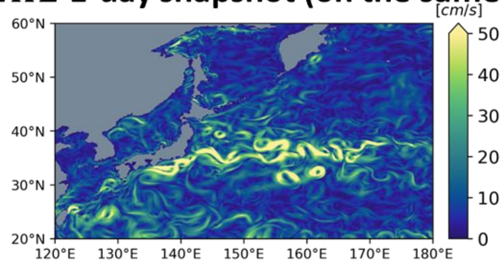
$$\lambda(x,y,t) = \frac{1}{\tau}\ln\frac{\delta_f}{\delta_0}$$



FSLE 1-day snapshot



$\sqrt{EKE}$ 1-day snapshot (on the same day)



Global Warming Effect on Ocean Horizontal Stirring Characterized by Finite-Size Lyapunov Exponents

Gyuseok Lee (gyuseok@pusan.ac.kr)[1,2], June-Yi Lee[1,2], Axel Timmermann[2,3], Karl Joseph Stein[2,3], Eun Young Kwon[2,3], Sun-Seon Lee[2,3], and Myeong-Hyeon Kim[1,2]

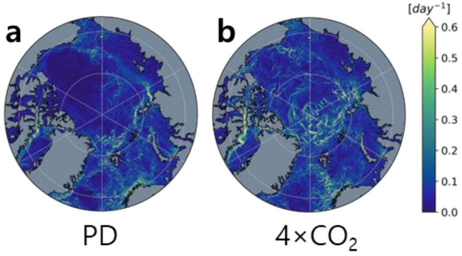
[1] Pusan National University, Department of Climate System, Busan, South Korea, [2] Center for Climate Physics, Institute for Basic Science, Busan, South Korea,
[3] Pusan National University, Busan, South Korea

Model Experiments

- High-resolution experiments based on the fully-coupled Community Earth System Model (CESM) version 1.2.2.
  - Present-day (367 ppm)
  - 2×CO_2 (734 ppm)
  - 4×CO_2 (1,468 ppm)
- Ocean model: POP2 (62 levels)
- Data: daily u, v at 15 m depth (lev=2)
- Horizontal resolution: 25 km (atm), **10 km (ocean)**
- Analysis period: 10 years for each condition

Arctic Ocean Changes

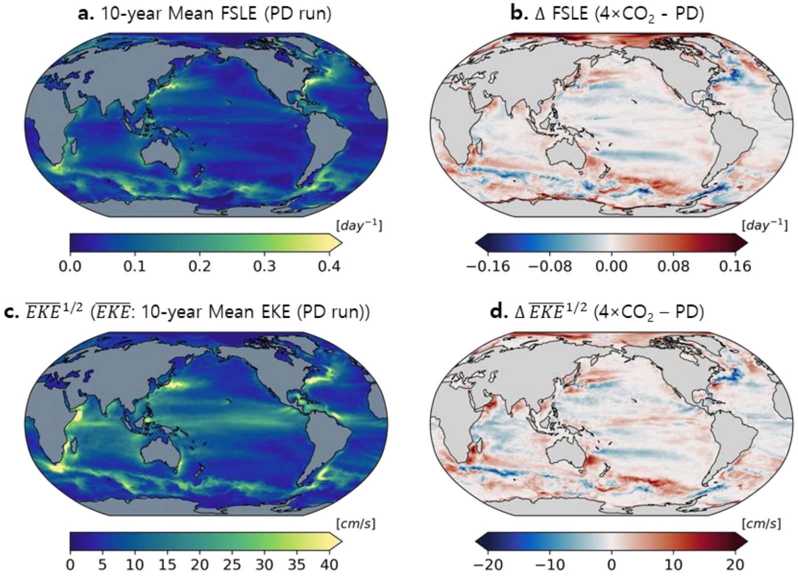
Here we present possible mechanisms for FSLE changes in the Arctic Ocean, where the change is most pronounced due to sea ice decline.



PD

4×CO_2

FSLE and EKE changes in the global surface ocean



Lamont-Doherty Earth Observatory
Columbia University | Earth Institute

Using Ship-Deployed High-Endurance Uncrewed Aerial Vehicles for the Study of Ocean Surface and Atmospheric Boundary Layer Processes

Christopher J. Zappa[1], Scott M. Brown[1], Nathan J. M. Laxague[1], Tejendra Dhakal[1], Ryan A. Harris[1],
Carson Witte[1], Aaron Farber[2] and Ajit Subramaniam[1]
[1] Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY, USA; zappa@ldeo.columbia.edu
[2] L3 Latitude, Tucson, AZ 85701, USA

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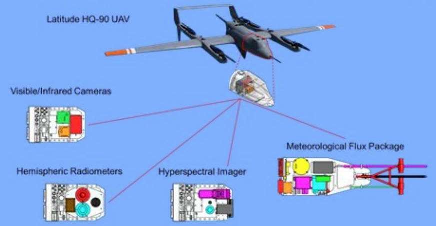
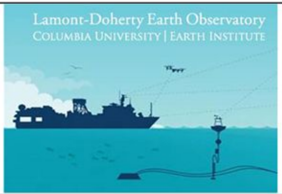
- **Complete autonomous takeoff, flight and landing from ships**
- **Dual-UAV aircraft continuous flight operations.**
  - 3 aircraft utilized
- **High endurance flights for > 8-hours.**

- **Routine Flights (>40) with Payloads (242 hours)**
  - MET, RAD, ATOM, VNIR payloads



- **Long-range capability (50+ nm) with high bandwidth data link (100+ Mbps)** for **real-time mission control and tasking.**
  - Primary UAV with squadron at further distance or lower altitude…. Coordinated with AUV and ASV.
- **Demonstrated 24-hour operations.**
- **zappa@ldeo.Columbia.edu**



Using Ship-Deployed High-Endurance Uncrewed Aerial Vehicles for the Study of Ocean Surface and Atmospheric Boundary Layer Processes

Christopher J. Zappa[1], Scott M. Brown[1], Nathan J. M. Laxague[1], Tejendra Dhakal[1], Ryan A. Harris[1],
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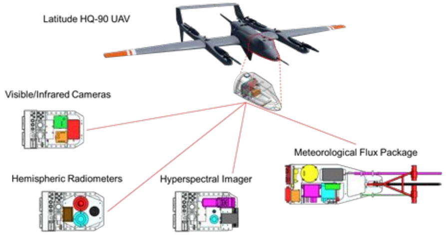
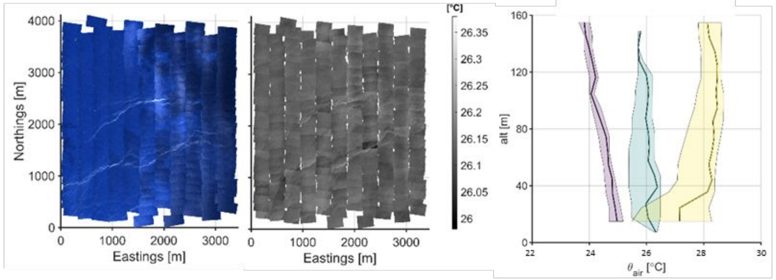


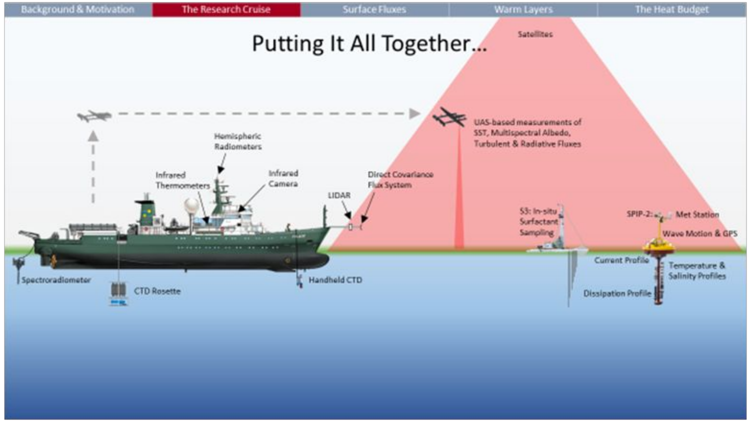
Eyes Over the Horizon

UAS Mission Control on R/V Falkor

UAS Reconnaissance of Cyanobacteria Front

Observing Cyanobacteria in Infrared and Hyper-Visible & BL Response





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Direct Measurement of the Air-Sea Momentum Flux, Near-Surface Ocean Currents, and Wave Hydrodynamics Using a Hybrid Imaging System

Christopher J. Zappa[1] and Nathan J. M. Laxague[2]

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Observations of mean and wave orbital flows in the ocean's upper centimetres

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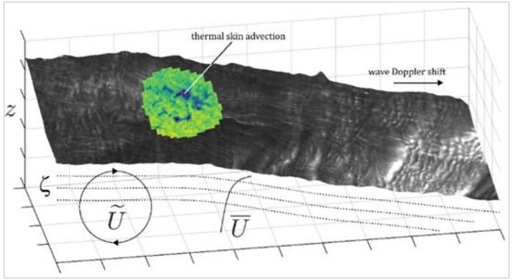
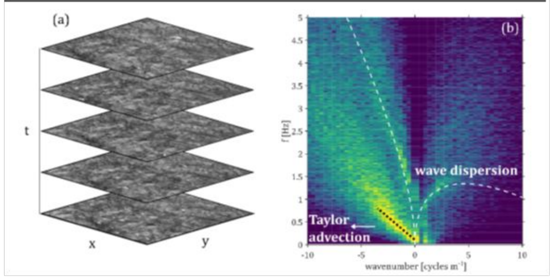
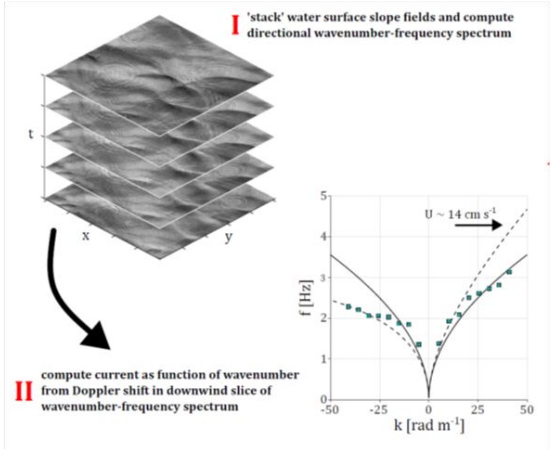


Ocean Surface Velocity from Infrared Imagery



By invoking Taylor's frozen turbulence hypothesis, it is possible to remotely infer the mean advective velocity of a fluid through quantification of the spatiotemporal evolution of turbulent eddies at a single depth (Dugan et al., 2012).

Near-Surface Velocity Profiles from Polarimetry

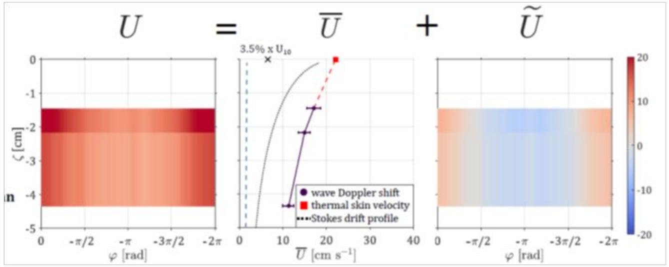


I 'stack' water surface slope fields and compute directional wavenumber-frequency spectrum

II compute current as function of wavenumber from Doppler shift in downwind slice of wavenumber-frequency spectrum

Mean and Orbital Wave-Coherent Velocity Profile

IV decompose current into mean and wave orbital profiles



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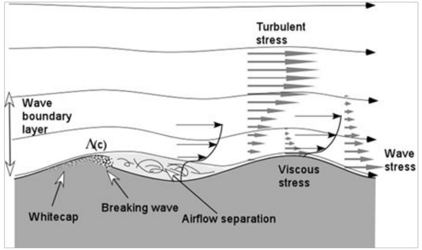
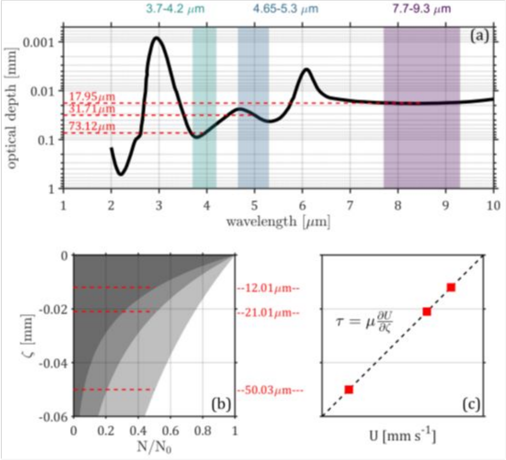
Wave-Boundary Layer



Conceptual schematic of the constant stress and wave boundary layers above the ocean surface where surface waves break, create whitecaps, and induce flow separation. At the surface, the total turbulent stress is partitioned to the surface tangential viscous stress and the form drag.

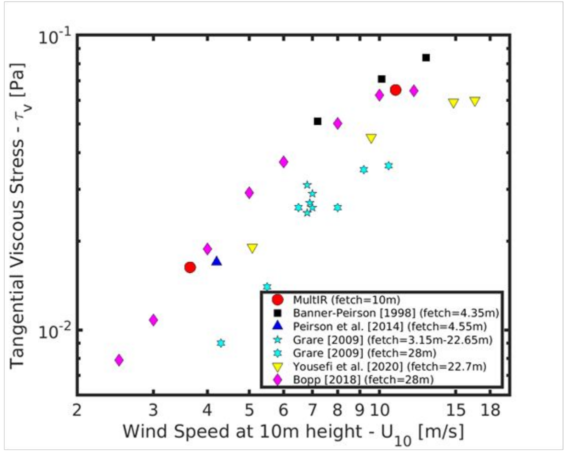
Multi-Spectral Infrared (MultIR) Imaging System



$$\rho u_*^2 = \tau_v + \tau_{form}$$

Our central hypothesis is that measurements of the velocity profile from thermal infrared (TIR) imagery within the top 100 µm of the water surface will provide a robust estimate of the surface ocean viscous stress. To test this hypothesis, we will conduct detailed measurements of the tangential stress structure beneath the air-water interface compared to form drag and the total stress in the wind tunnel using a recently developed infrared imaging technology under a range of wind-wave regimes.

SUSTAIN Laboratory Experiments



The detailed structure of the tangential stress beneath the air-water interface was investigated using the recently-developed infrared imaging technology. The new multi-spectral TIR camera system (MultIR) provides remotely sensed skin friction measurements within 10-100 µm of the water surface.