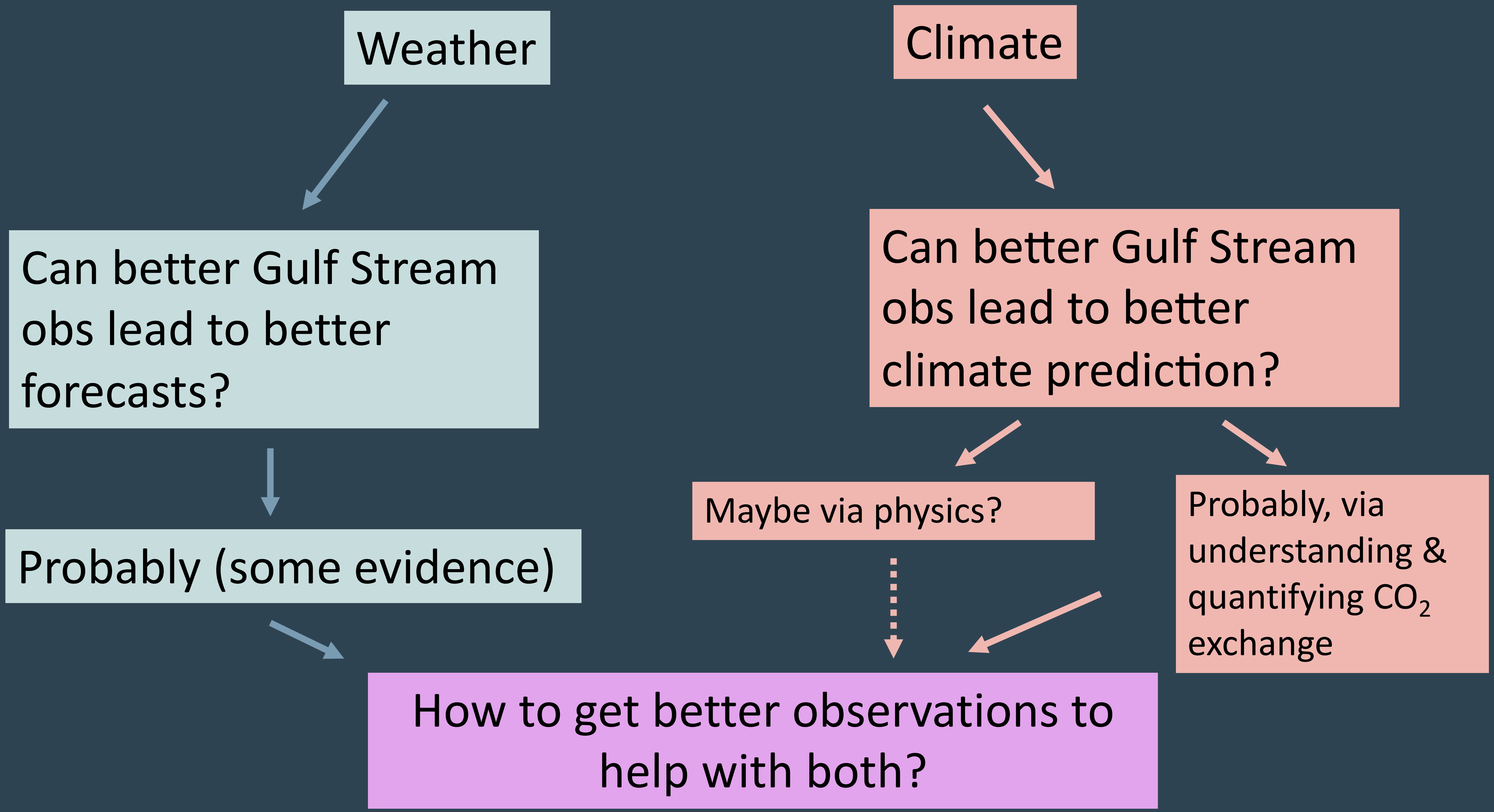
Opportunities and challenges in observing the Gulf Stream for needed insights into weather and climate

Whither the Gulf Stream Clivar Workshop

June 15, 2022

Jaime Palter, University of Rhode Island, with a sea of collaborators
and funding from NSF, NOAA, and Google.org

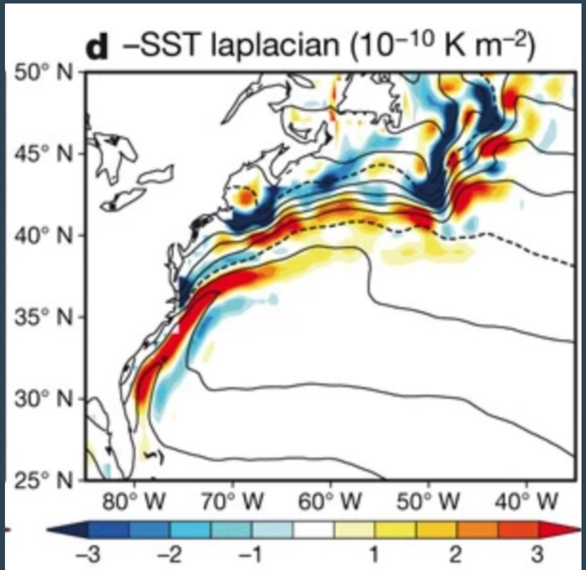

Weather
Climate
Can better Gulf Stream obs lead to better forecasts?
Can better Gulf Stream obs lead to better climate prediction?
Probably (some evidence)
Maybe via physics?
Probably, via understanding & quantifying CO_2 exchange
How to get better observations to help with both?

Weather

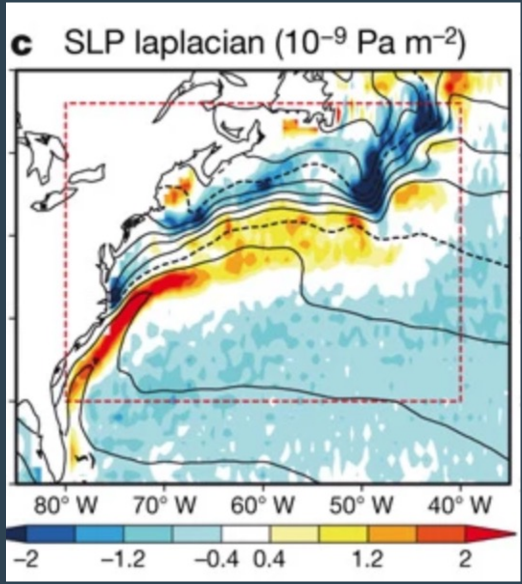
- What is the potential for improved observations of the Gulf Stream to increase skill in weather forecasts, especially at subseasonal to seasonal (S2S) scales?

In 2008, Minobe and colleagues proposed that the Gulf Stream SST anchors upward atmospheric motion and rainfall in winter:

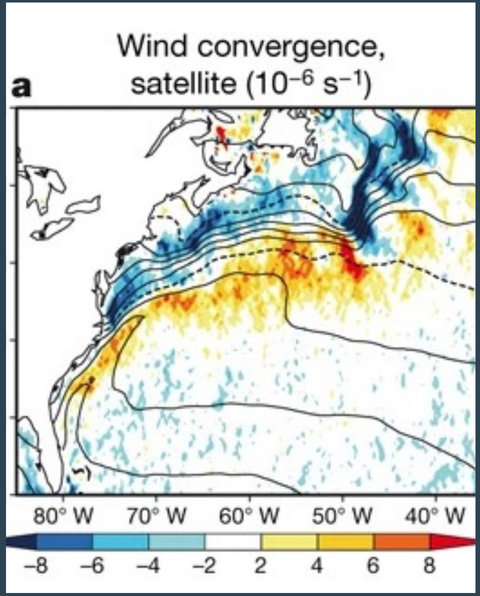
$-\nabla^2 \mathrm{SST}$



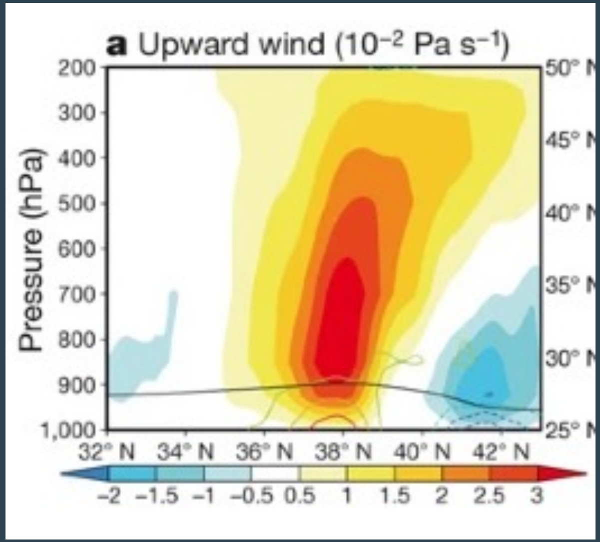
$\nabla^2 \mathrm{SLP}$

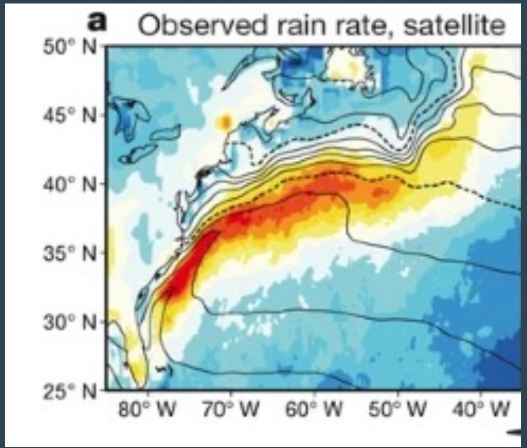


Wind convergence (satellite)



w, Full troposphere



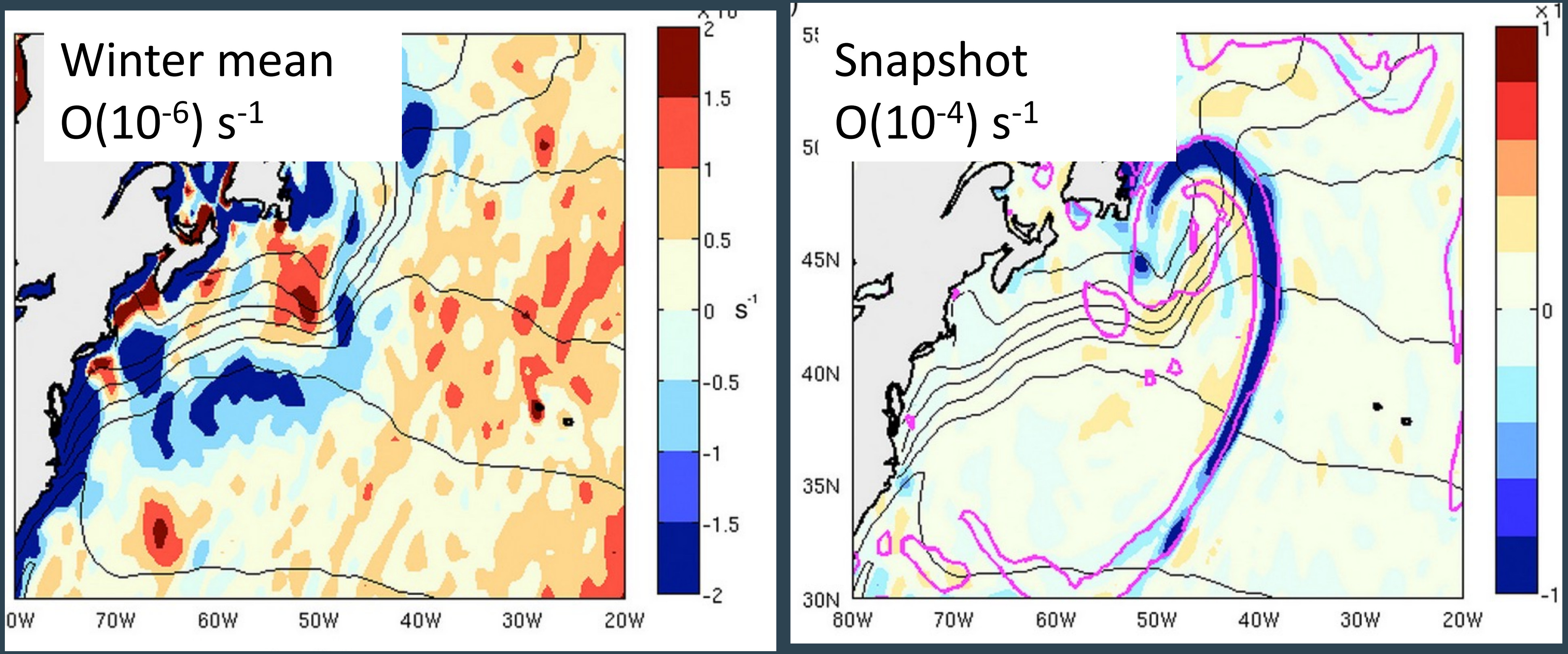


Influence over entire Northern Hemisphere weather and cimate

The averages obscure the dynamics:

Atmosphere-Gulf Stream relationships arise from the aggregated impact of extratropical cyclones crossing sharp SST gradients

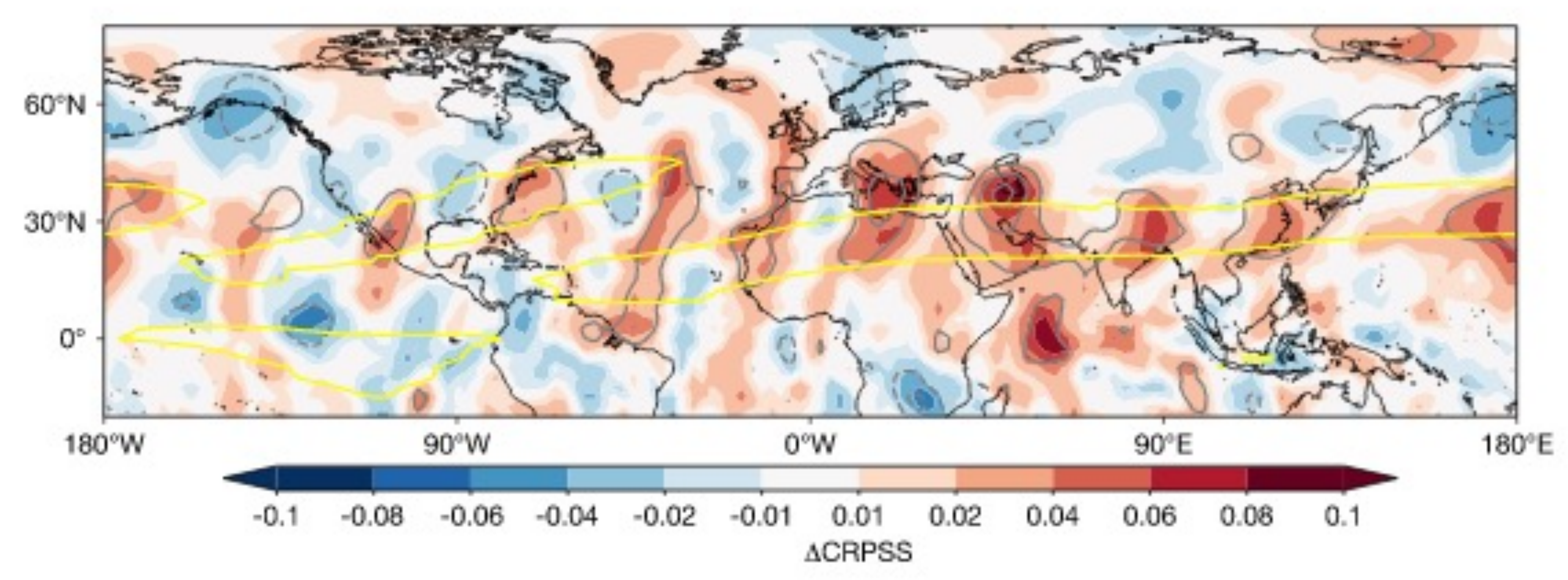
- Time-mean wind divergence pattern over Gulf Stream disappears when anomalous events are filtered
- No time-mean Gulf Stream "anchor"
- **Key air-sea dynamics are at the storm scale**



Wind divergence from Parfitt and Seo 2018. Wind divergence a factor of 50 greater under atmospheric front than background mean. (Fronts present >50% of the time)

Ideas also from O'Neill et al., 2017; Parfitt and Czaja 2016

Reducing SST bias increases wintertime subseasonal forecast skill



Shading = Change in forecast skill for wind at 200 hPa from forecast days 26-32 after North Atlantic SST bias correction

Increased skill circumnavigates the globe with a spatial structure characteristic of stationary wave activity propagating along the northern hemisphere subtropical waveguide (yellow contour).


Geophysical Research Letters

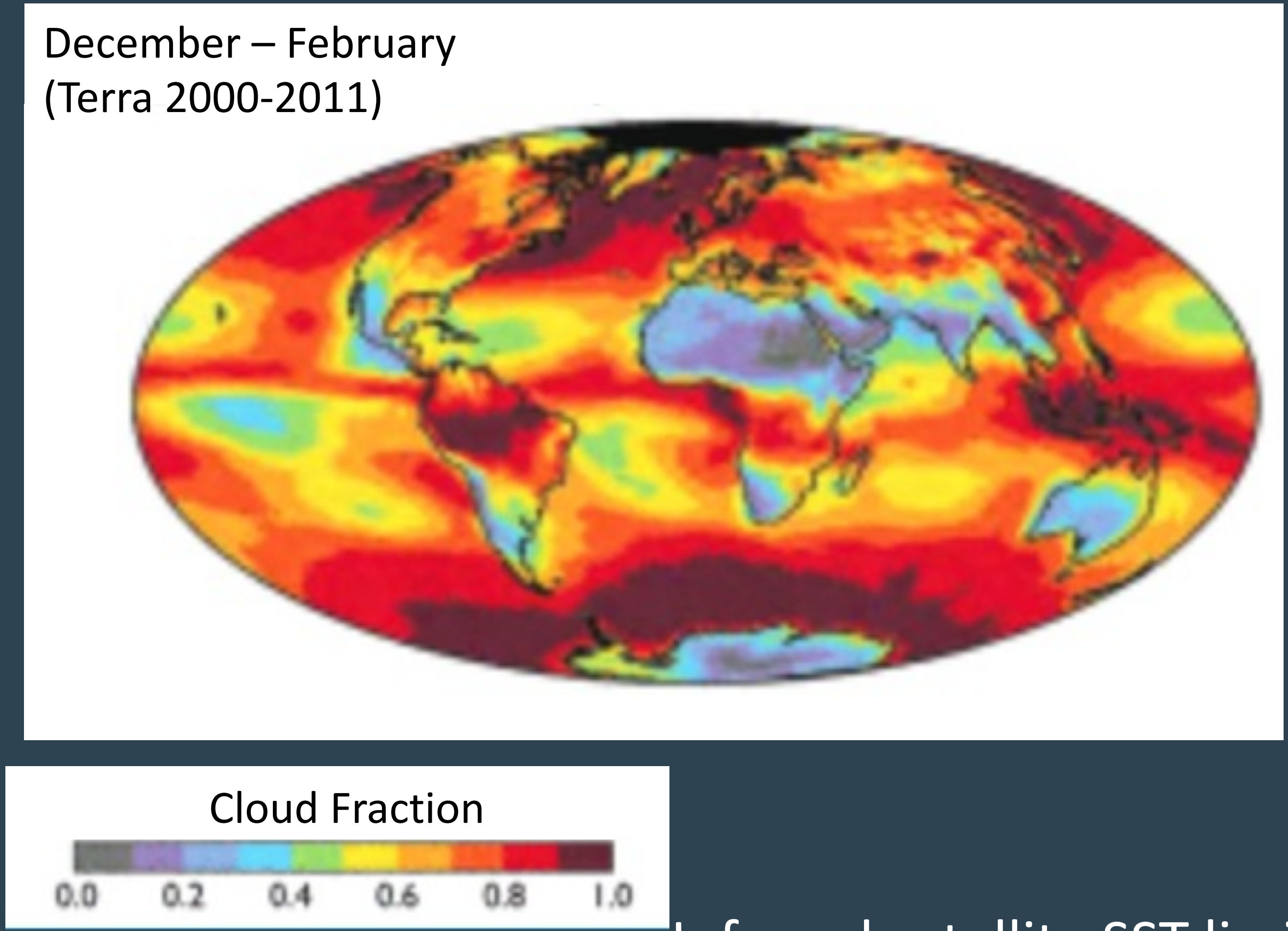
Research Letter | Full Access

Hemispheric Impact of North Atlantic SSTs in Subseasonal Forecasts

C. D. Roberts, F. Vitart, M. A. Balmaseda

2022

Forecast skill improves despite that the bias correction is based on sparse satellite observations



Infrared satellite SST limited by clouds

- Clear sky conditions are required for the derivation of SST from IR measurements
- Cloud masking is especially difficult near ocean thermal fronts like the Gulf Stream

Weather

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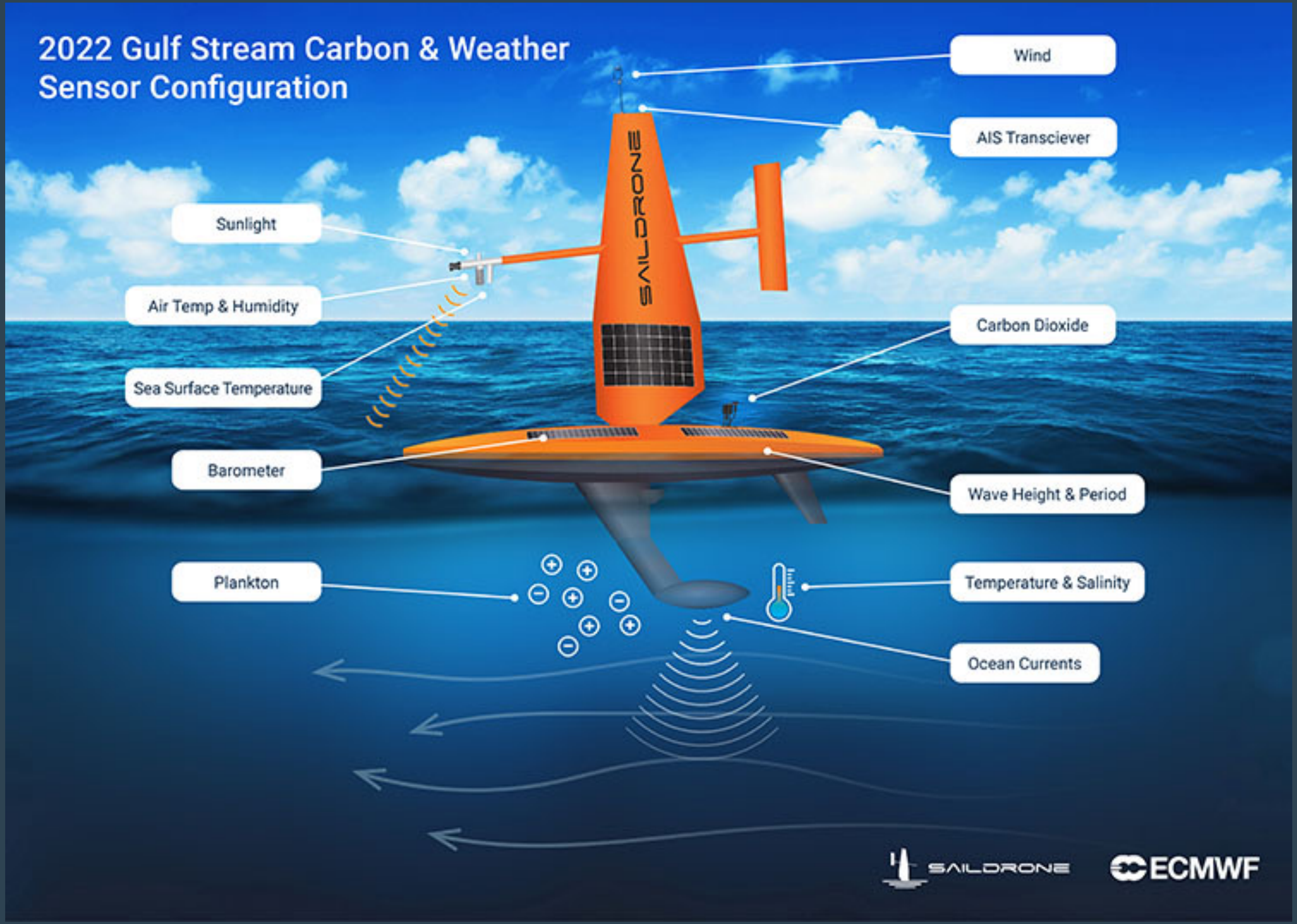
Probably (some evidence)

How to get better observations?

Uncrewed Surface Vehicles (USVs) may fill gaps created by days or weeks without a cloud-free view of the Gulf Stream



- *In situ* measurements can help fill the gap
- Time/space variability is extremely challenging, but there is hope in Uncrewed Surface Vehicles (USVs)

Two Saildrone missions to the Gulf Stream

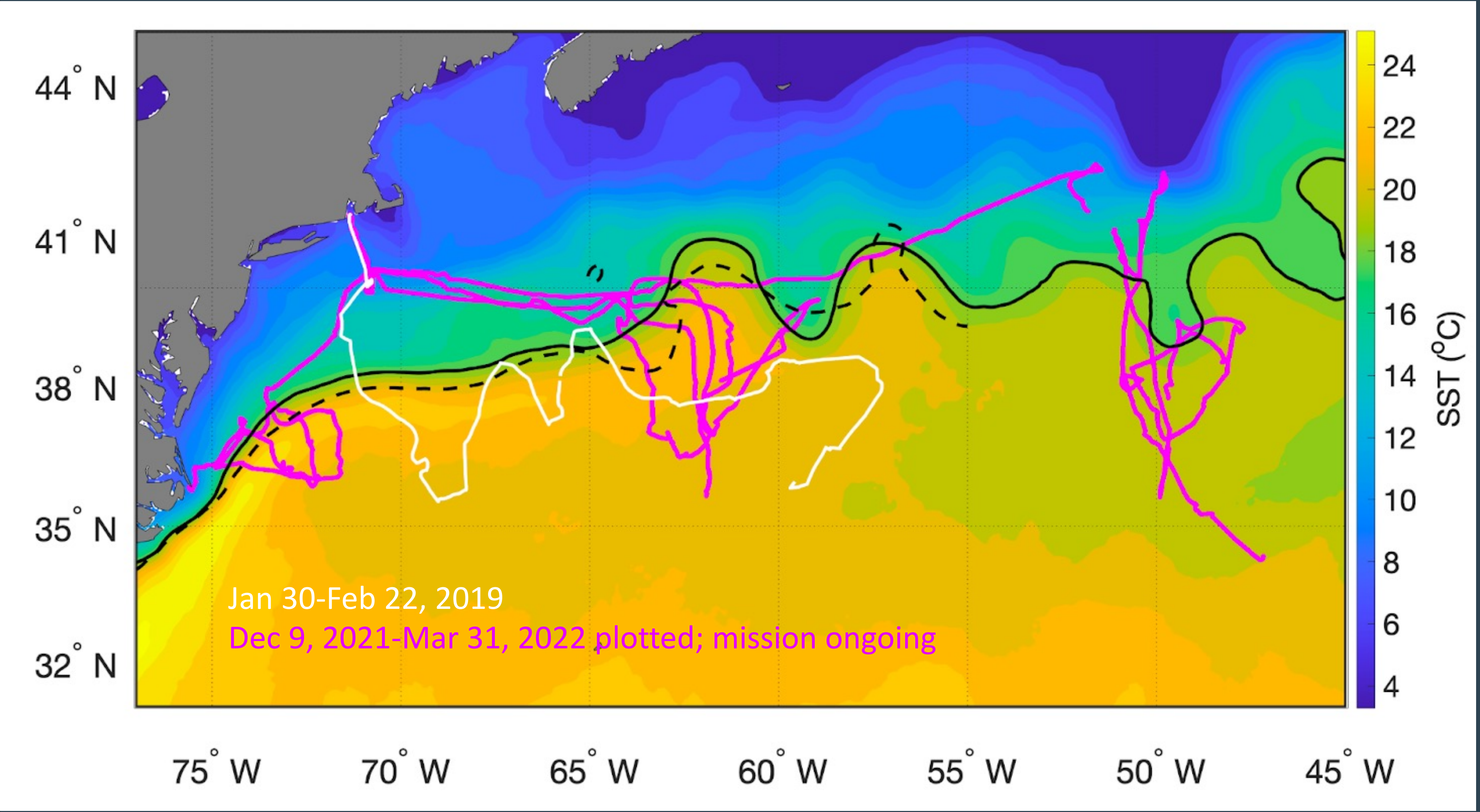
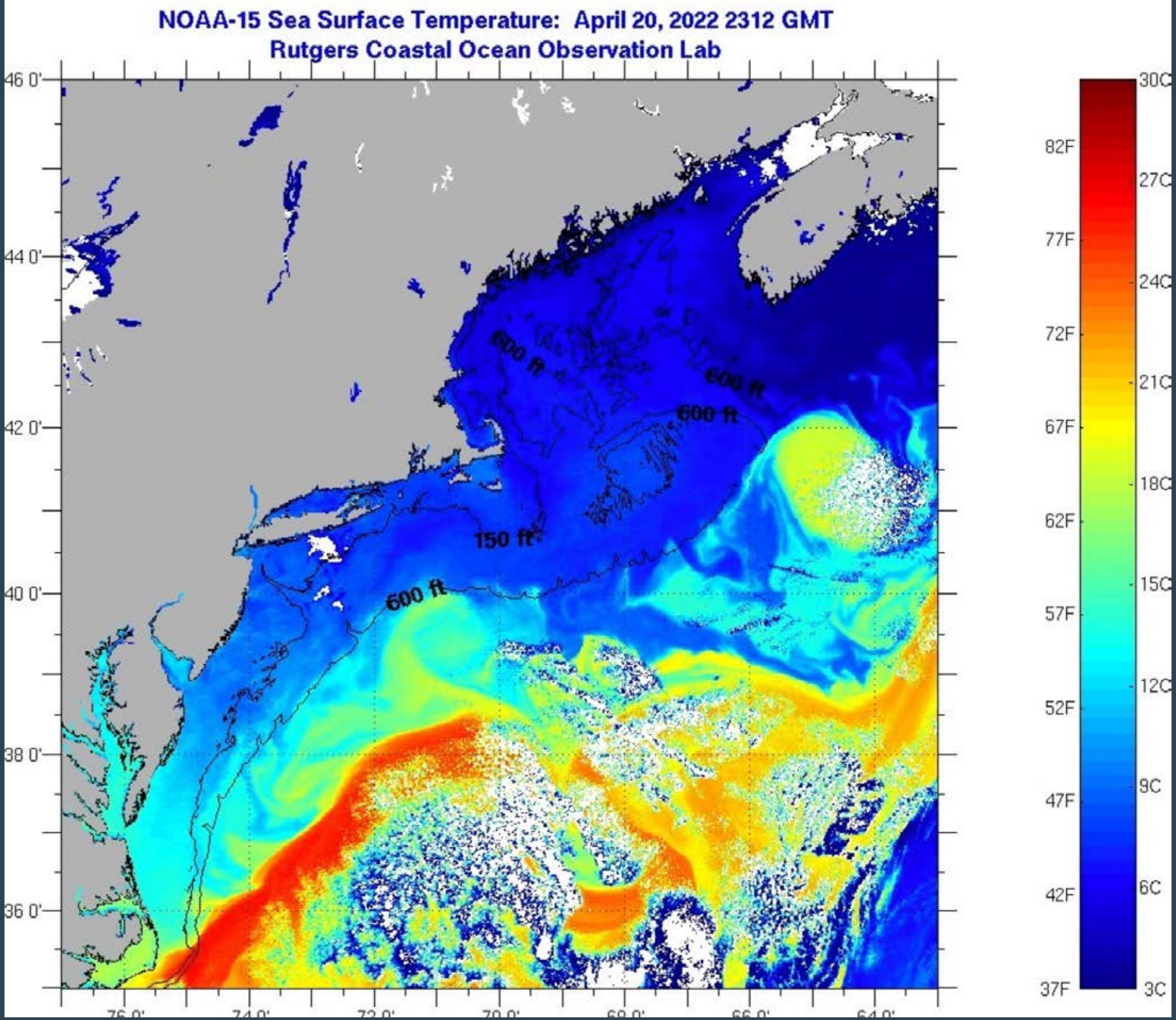
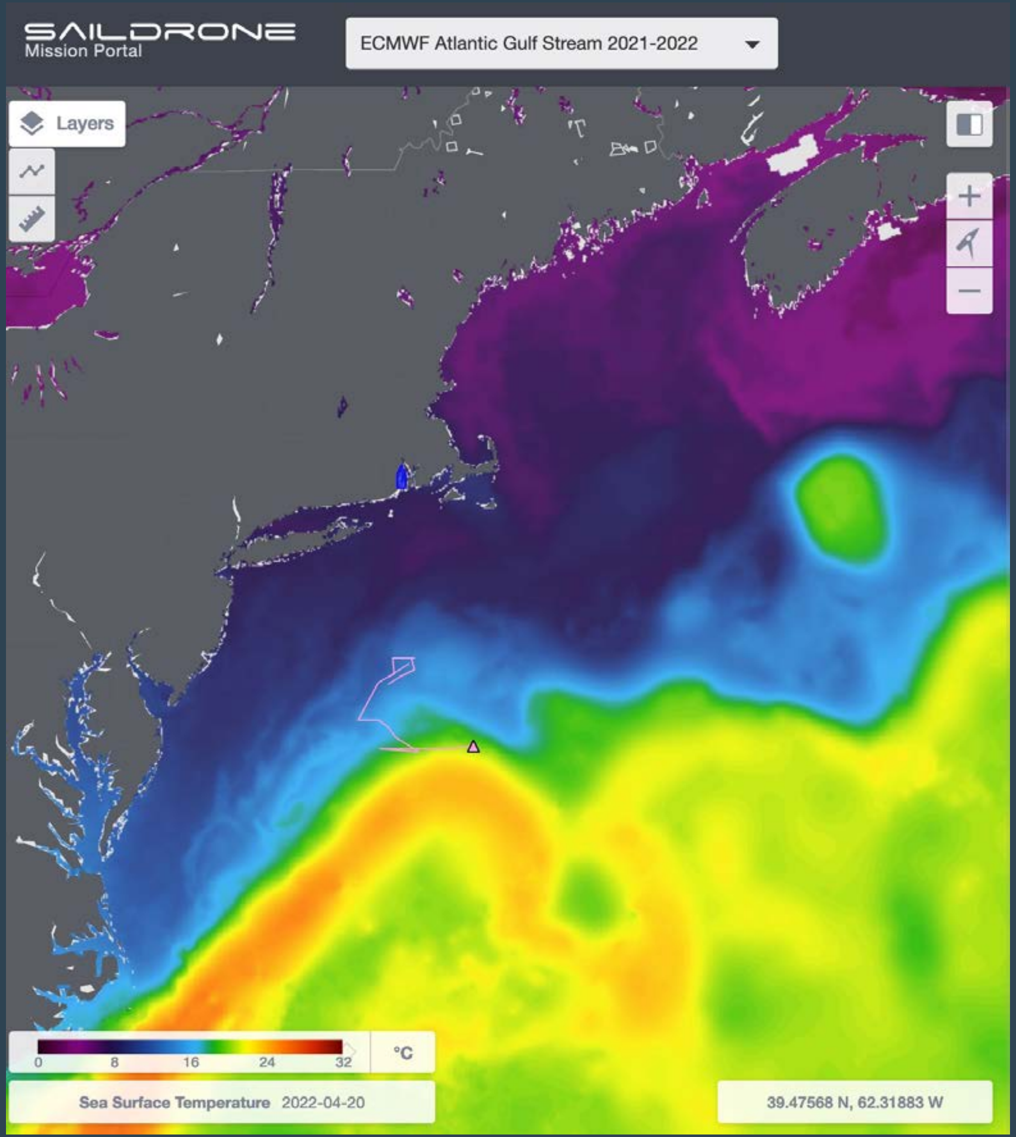


Figure fromSarah Nickford

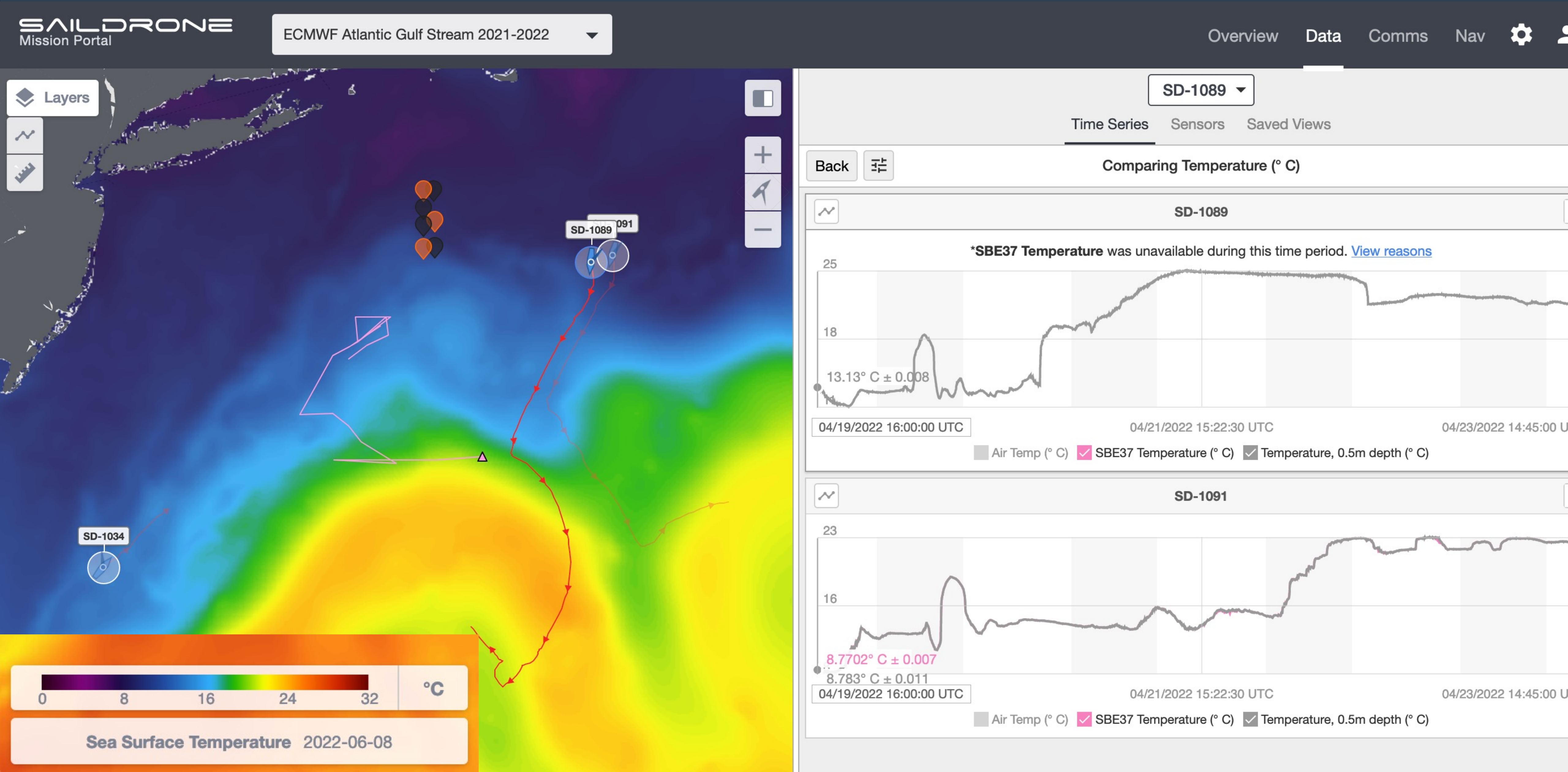
Sampling in a sea of variability beneath nearly ubiquitous clouds





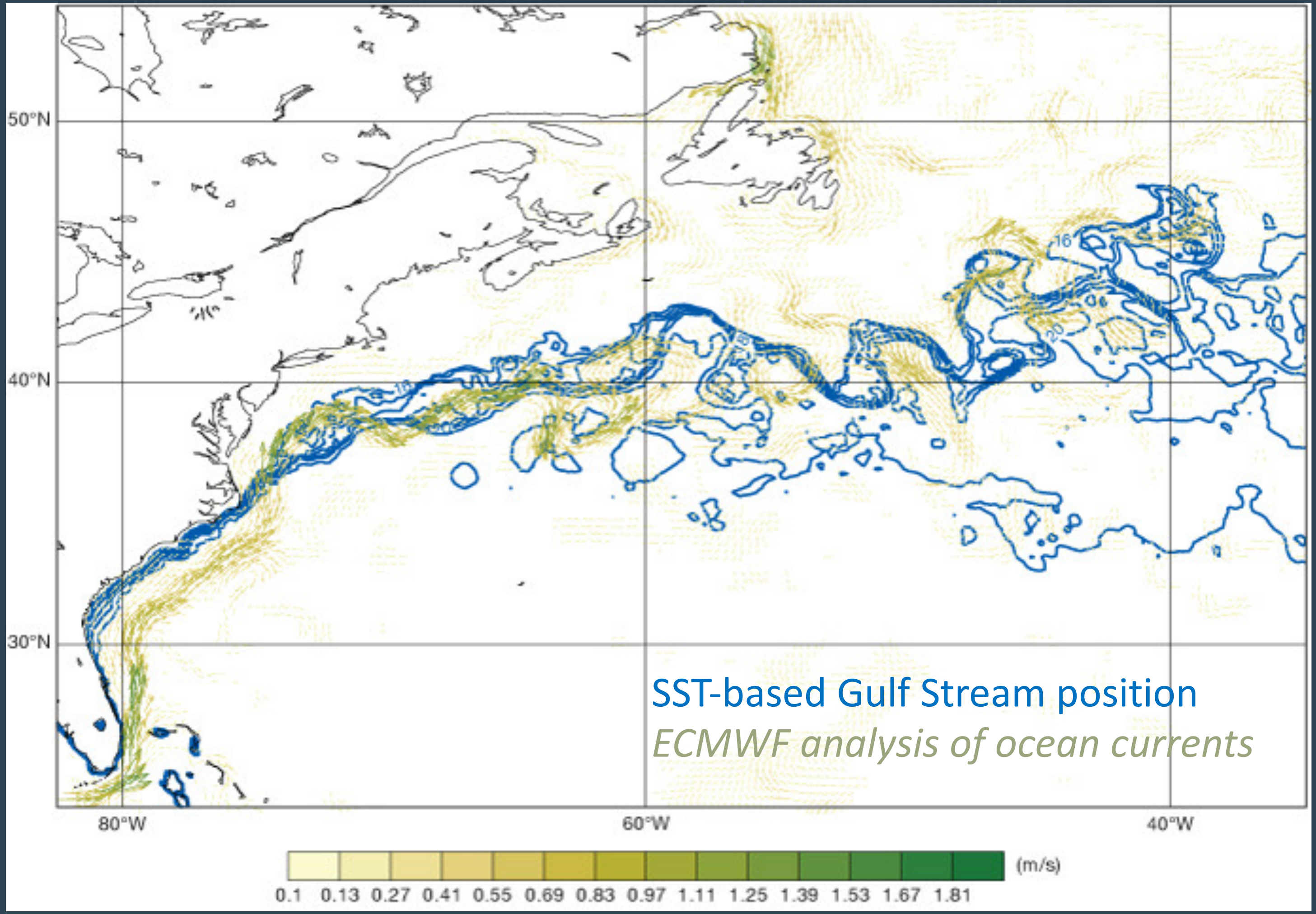
Example: April 2022

Sampling in a sea of variability. 2 USVs side-by-side:



ECMWF is assimilating these data and will study the impact on forecasts

- The goal is to improve weather forecasts at all timescales, from medium-range to extended-range forecasts
- Motivated by the ever-increasing need for accurate/long forecasts given the energy transition to wind and solar



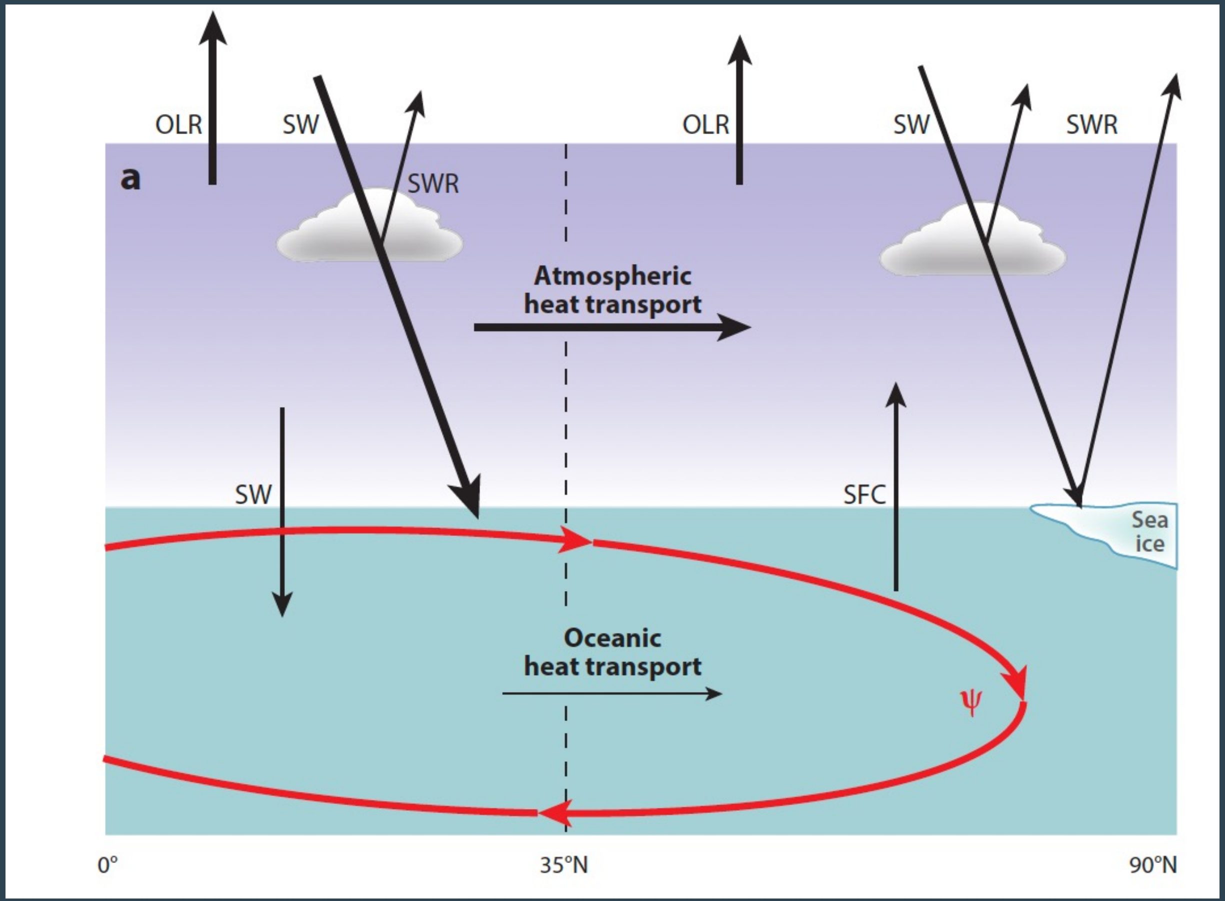
Lead PI Phil Browne. https://www.ecmwf.int/en/newsletter/

Climate

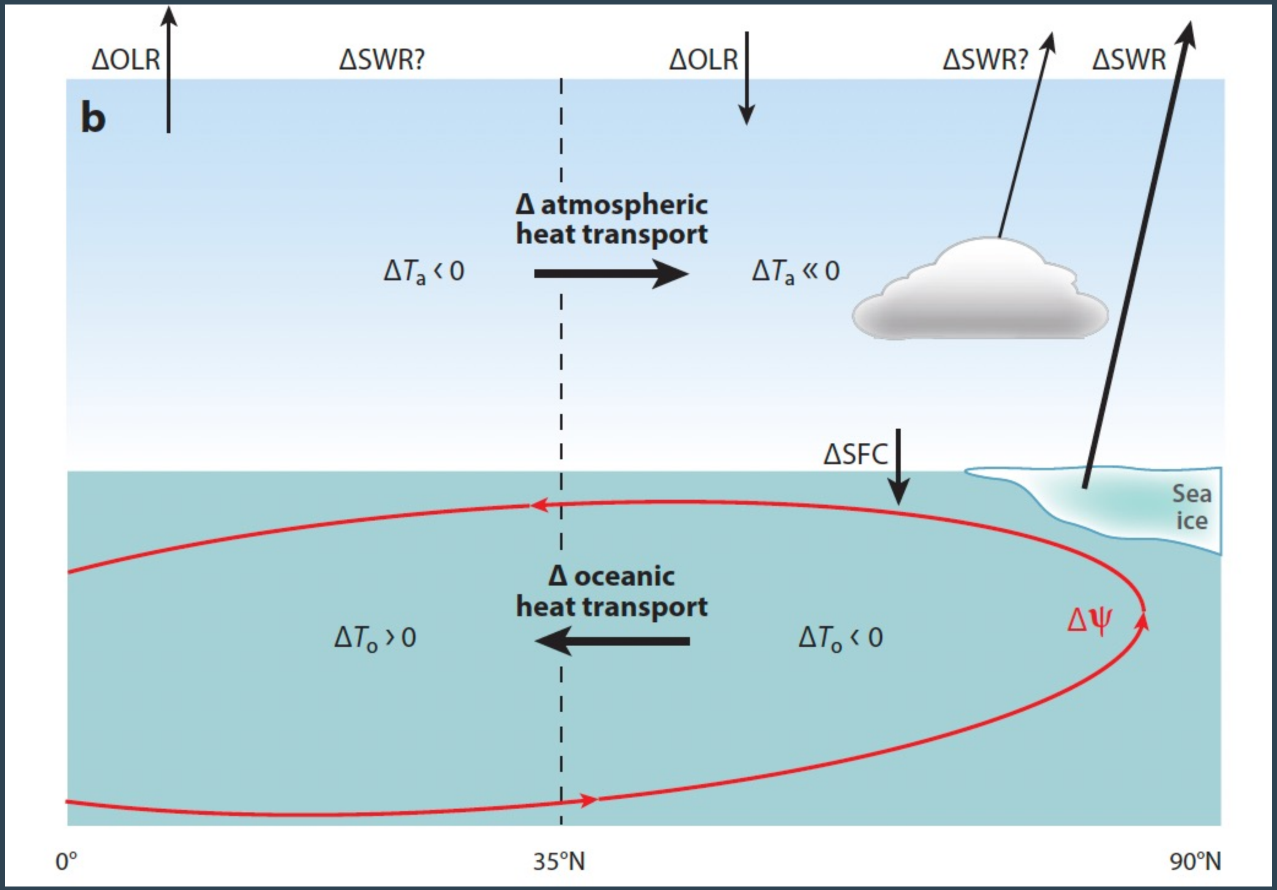
Can better Gulf Stream obs lead to better climate prediction?

Maybe via physics?

Gulf Stream heat transport is a key climate driver



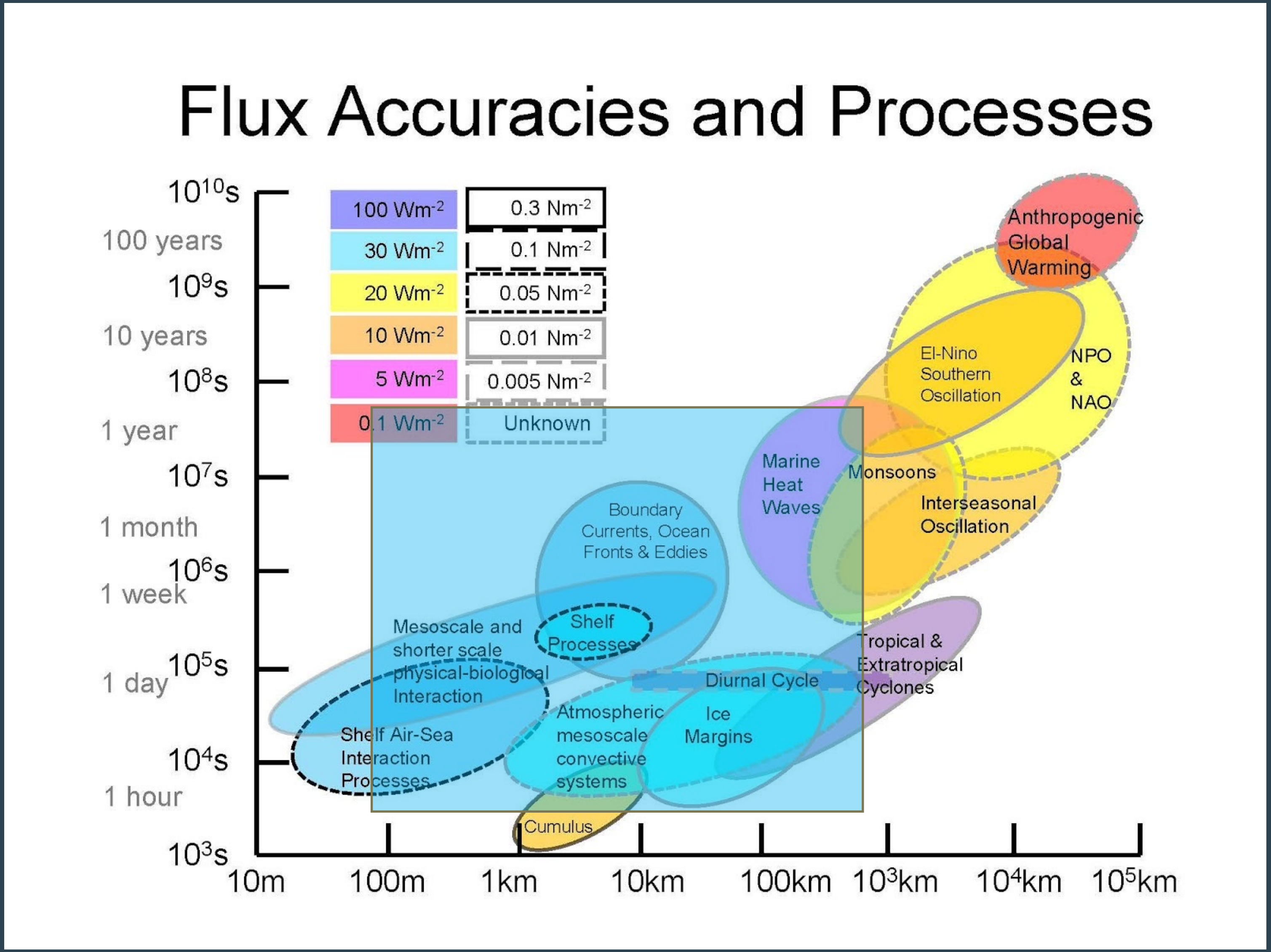
Mean state



Anomalies under a AMOC slowdown

Palter 2015, Annual Review

Thinking about a Gulf Stream observing system



Cronin et al. (2019) "Air-sea fluxes with a focus on heat and momentum"

- What can we observe in the lower left quadrant to inform the upper right?
- I hope to have lots of good conversations about this question here
- I've been focused on better observing CO_2

Climate

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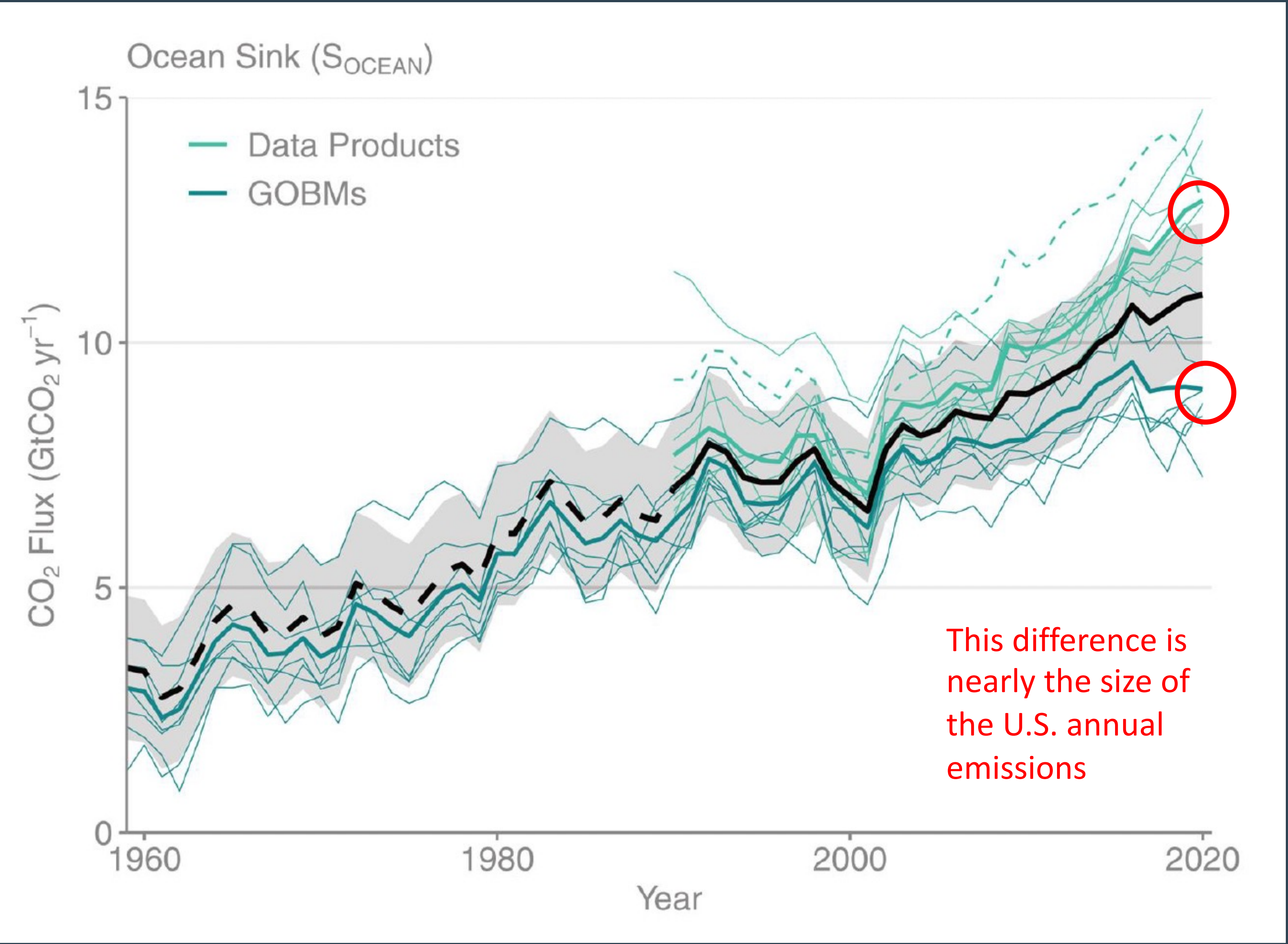
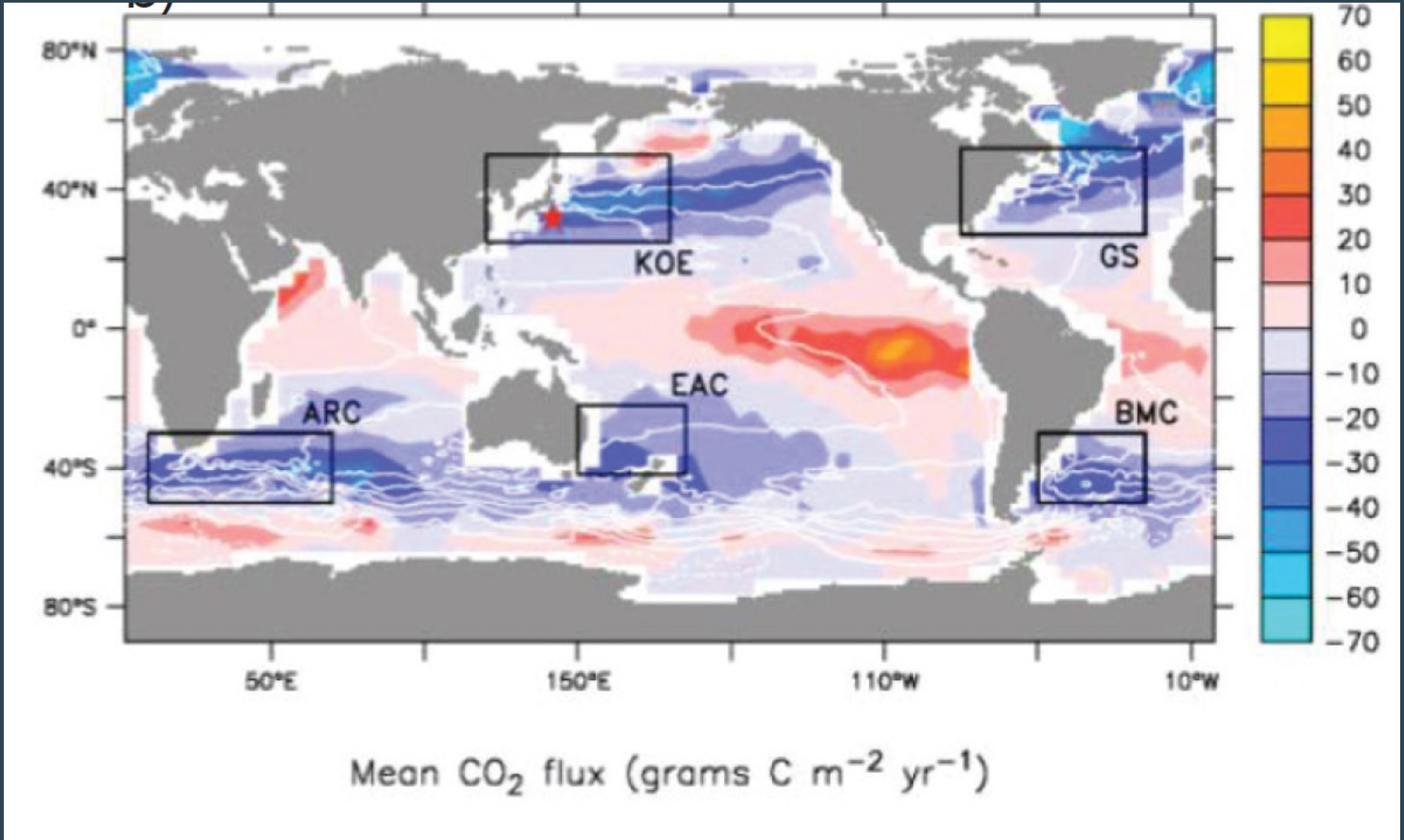
Probably, via understanding & quantifying CO_2 exchange

- The ocean absorbs about a quarter of anthropogenic CO_2 emissions, but uncertainty is high
- Data products and models drifting further apart!



Global Carbon Budget 2021

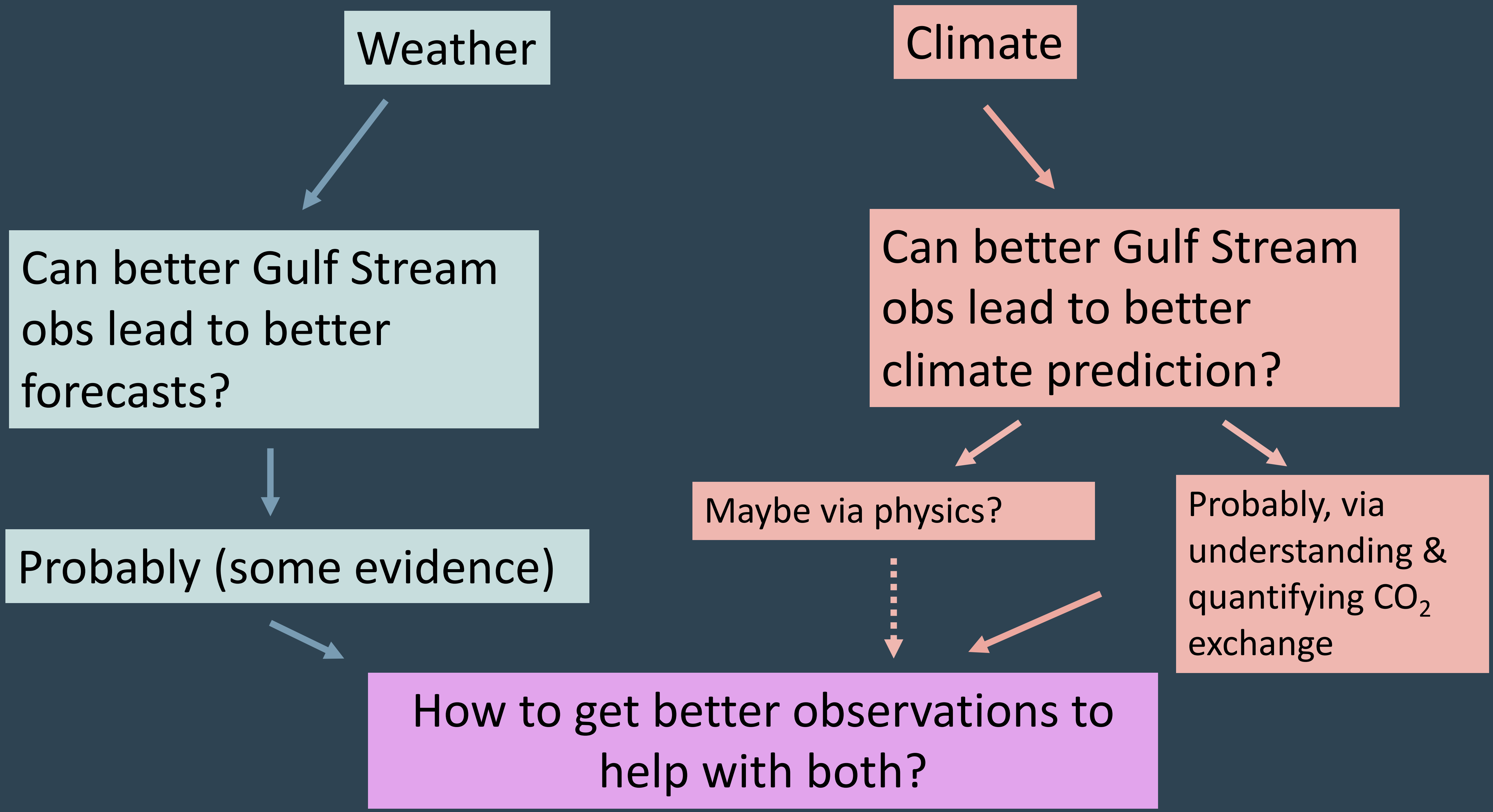
The Gulf Stream is a hotspot for ocean carbon uptake



Progress in understanding the global ocean carbon sink necessitates … a game-changing increase in high-quality pCO_2 observations.

- Hauck et al., 2020

Cronin et al., 2010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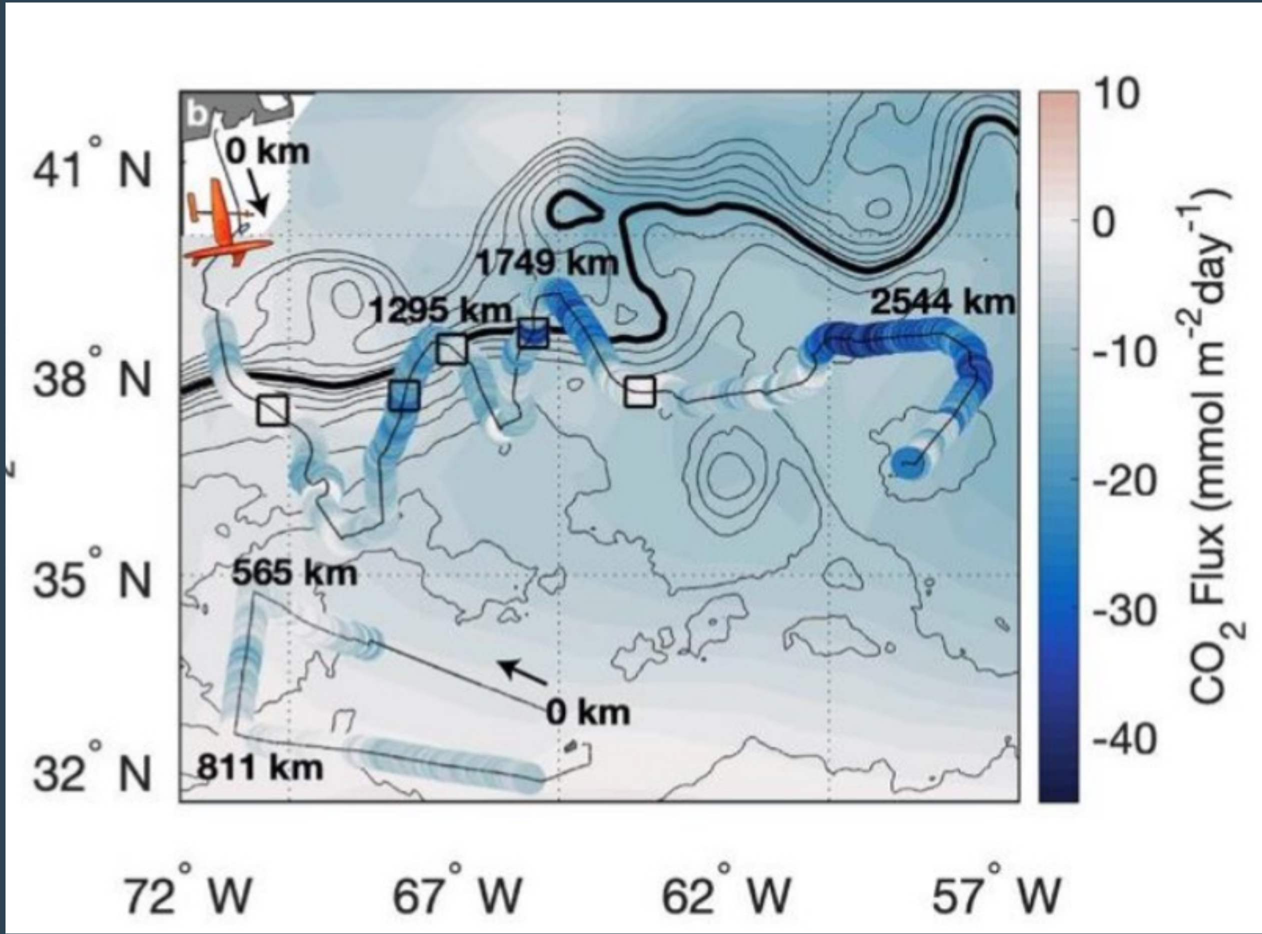
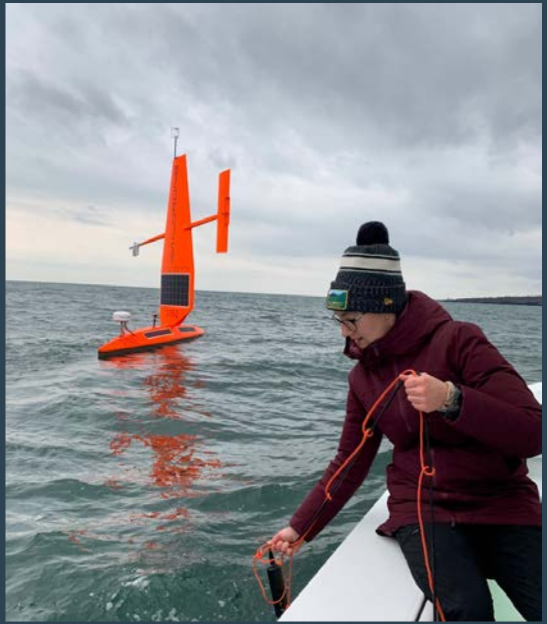
Autonomous Wintertime Observations of Air-Sea Exchange in the Gulf Stream Reveal a Perfect Storm for Ocean CO_2 Uptake

S. Nickford[1], J. B. Palter[1], K. Donohue[1], A. J. Fassbender[2], A. R. Gray[3], J. Long[4], A. J. Sutton[2], N. R. Bates[5,6], and Y. Takeshita[4]

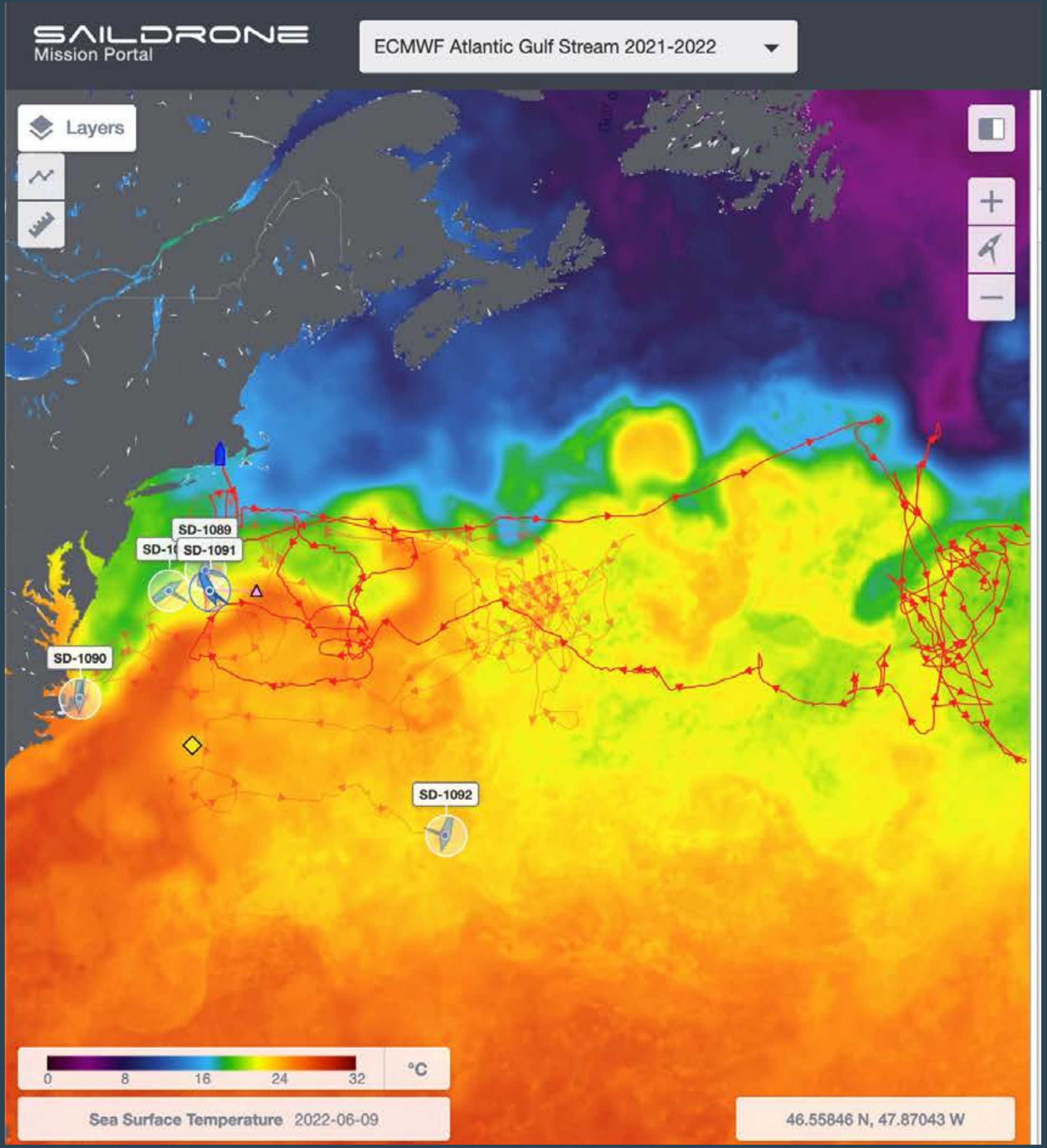




Sarah Nickford, PhD student

GRL, 2022

Opportunities and challenges using USVs in the Gulf Stream



Opportunities:

- Sample gradients at the time/space scales of interest
- Long-duration (single vehicle can sample for 6+ months)
- Large sensor payload, highly adaptable
- NOAA-PMEL ASVCO2 system, a game changer for pCO_2 observations
- Wind- and solar-powered, zero CO_2 emissions to operate

Challenges:

- Gulf Stream sea state is formidable (3 wings damaged over the two missions with 6 vehicles)
- Sensors can fail or fatigue (2 out of 6 SeaBird SBE37s failed within a month of deployment; 1 ASVCO2 pump failed within a month, another 2 fatigued after several months)
- Battery charge is a challenge requiring active monitoring and problem-solving
- Optimization studies needed

Thank you

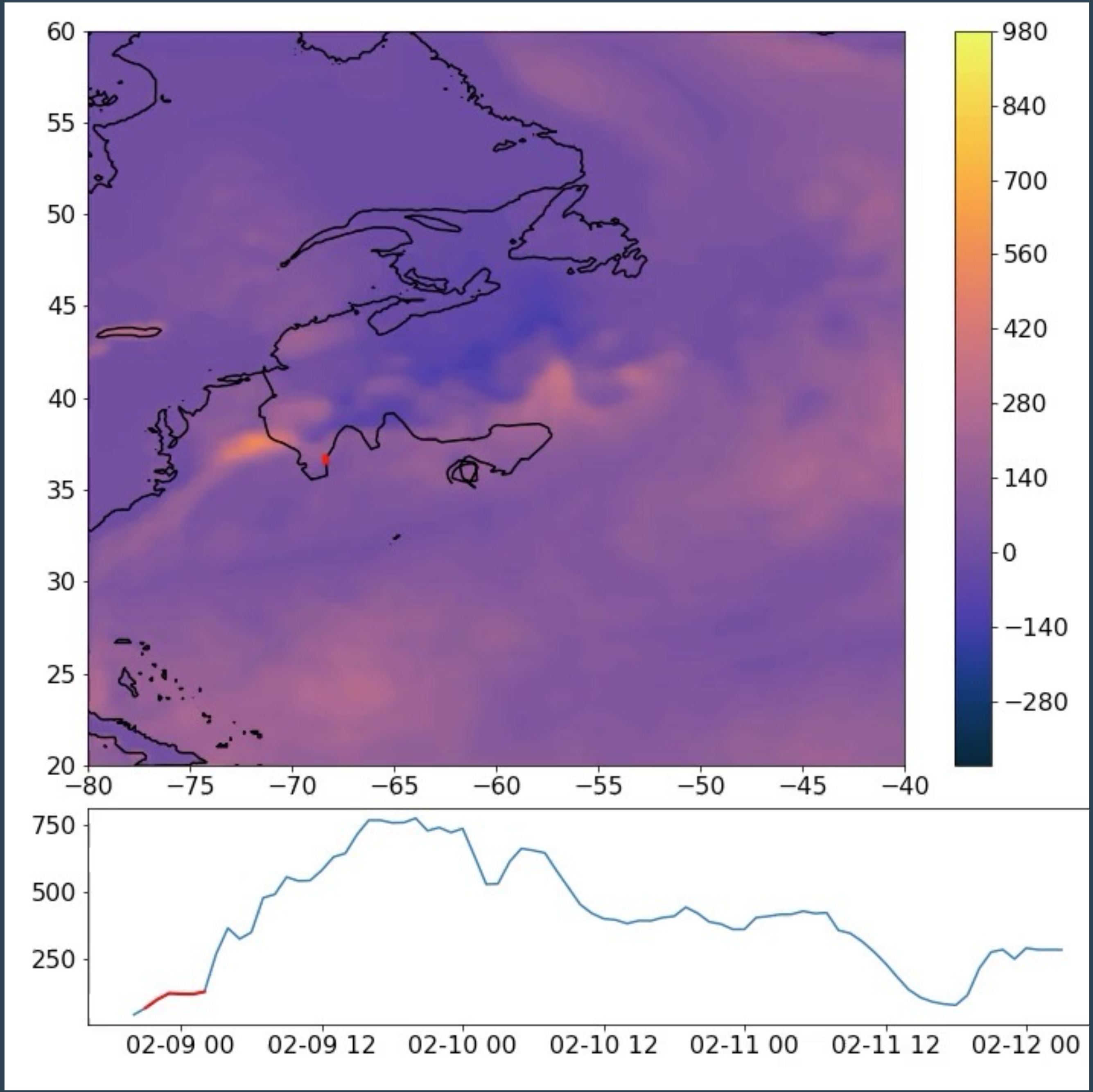
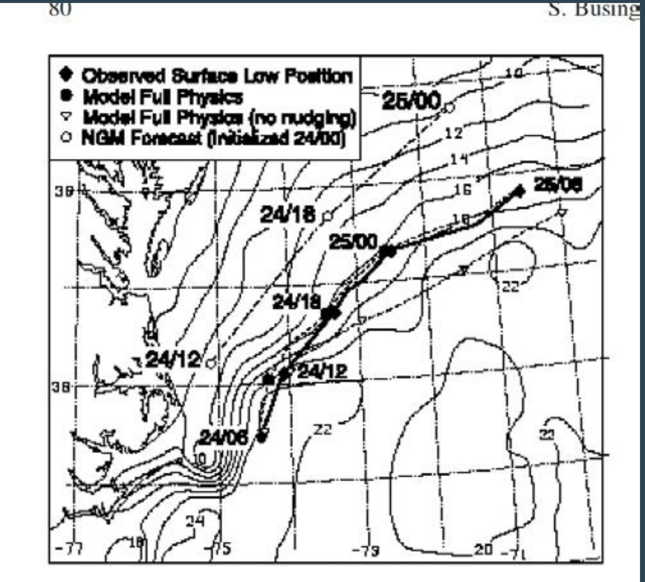


Figure by Marc Diard

Example of storm-Gulf Stream interaction influencing forecast skill

- On 24–25 February 1989 a storm brought high winds and moderate to heavy snow to the U.S. East Coast.
- The storm is noteworthy for its rapid mesoscale development within a polar air mass at relatively low latitudes and for the difficulty experienced by operational NWP models and forecasters in predicting the storm's impact.
- Accurate simulation of the storm track required a high-resolution, full-physics run that included high-resolution SST data in the initial condition and moisture nudging during the early hours of the simulation. (weekly composite 18 km AVHRR data for 18-24 Feb 1989)



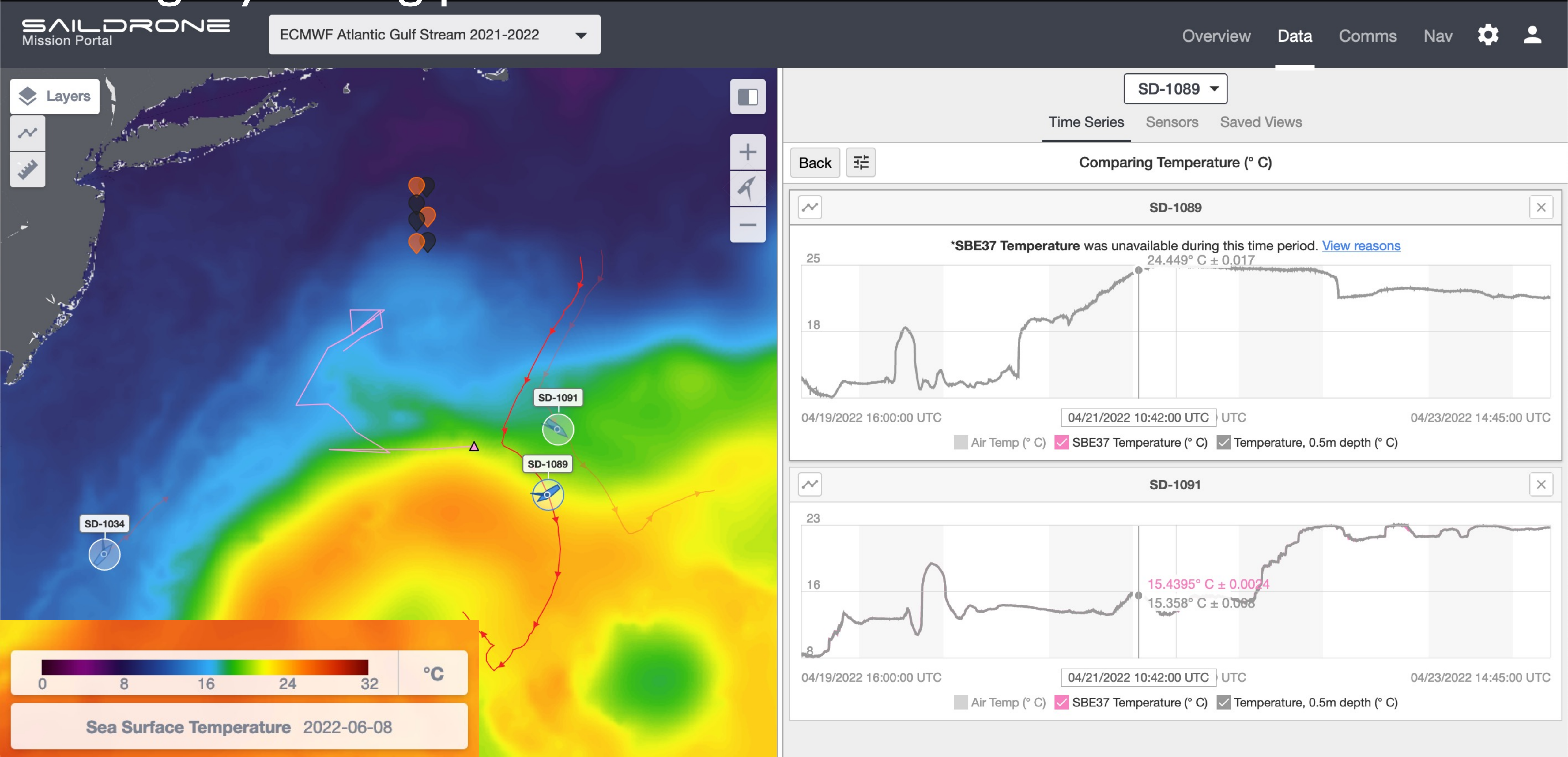
Published: 24 May 2004

Cold-air cyclogenesis along the Gulf-Stream front: investigation of diabatic impacts on cyclone development, frontal structure, and track

S. Businger, T. M. Graziano, M. L. Kaplan & R. A. Rozumalski

Meteorology and Atmospheric Physics **88**, 65–90 (2005) | Cite this article

Gridded SST products are too smooth and put gradients in slightly wrong positions.



Paper exploring climate prediction skill

- The separate role of resolved ocean and atmosphere dynamics in shaping the atmospheric circulation is still largely unknown.
- Here we demonstrate for the first time, by using coupled seasonal forecast experiments at different resolutions, that resolving meso-scale oceanic variability in the Gulf Stream region strongly affects mid-latitude interannual atmospheric variability, including the North Atlantic Oscillation.

nature > scientific reports > articles > article

Article | Open Access | Published: 16 September 2019

Sensitivity of winter North Atlantic-European climate to resolved atmosphere and ocean dynamics

Reindert J. Haarsma, Javier García-Serrano, Chloé Prodhomme, Omar Bellprat, Paolo Davini & Sybren Drijfhout

Scientific Reports **9**, Article number: 13358 (2019) | Cite this article