# Potential new capabilities for a North Atlantic Hotspot Experiment

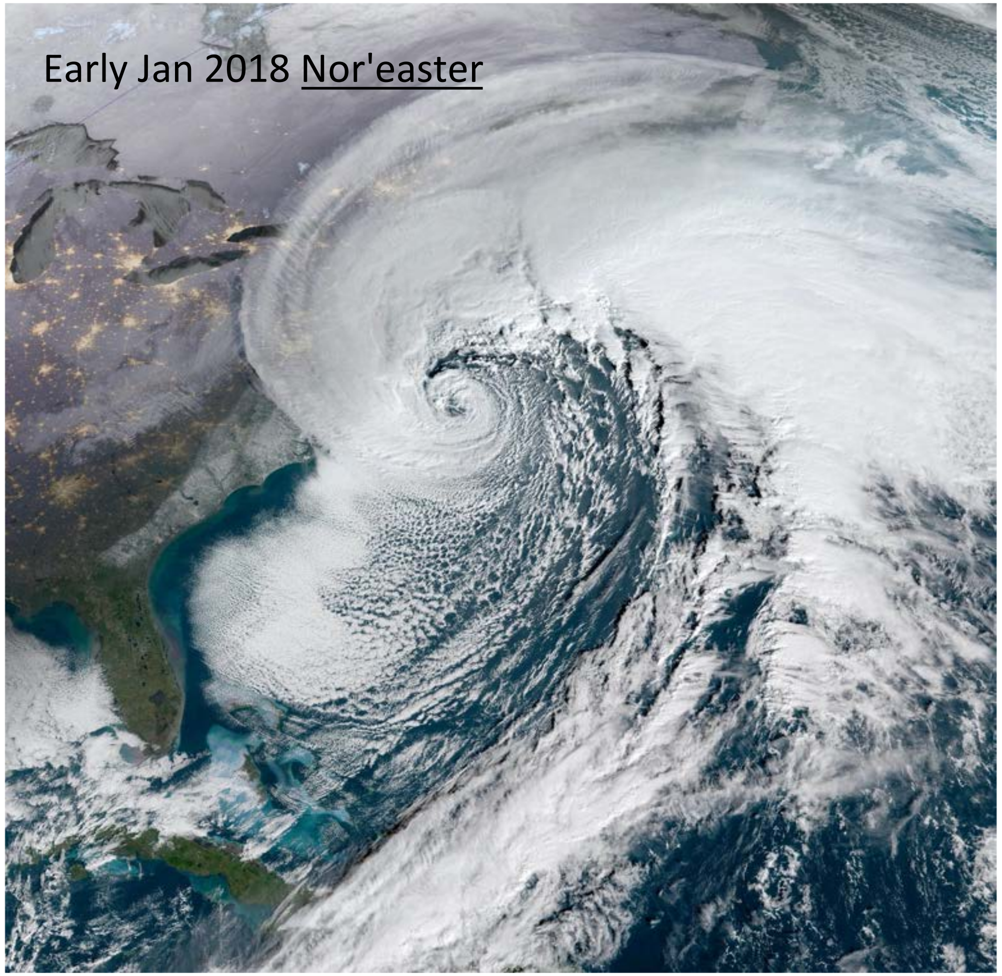
## What kind of in situ observations are needed and possible?

Meghan Cronin (NOAA PMEL)

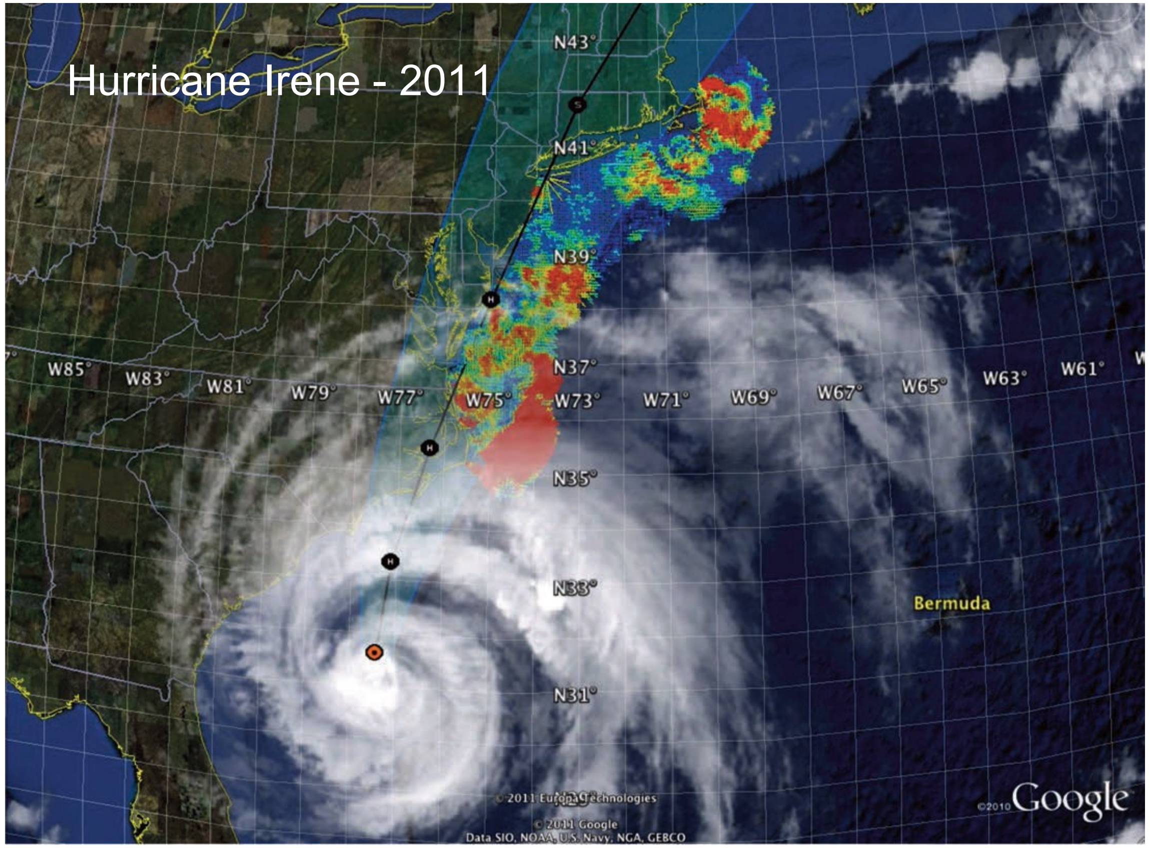
With contributions from:

Raghu Krishnamurthy, Joe Cione, Chidong Zhang, Kathy Donohue, Magdalena Andres, Dongxiao Zhang, Dave Turner, Tony Lee, Seth Zippel, Jack Reeves Eyre, etc

# **North Atlantic HotSpot Experiment** – Gulf Stream influence on Nor’easter “bomb cyclones” and tropical-extratropical transitions




GOES-16 ABI GeoColor image of the Early January 2018 nor'easter. Credit NOAA. Downloaded from Wikipedia




Damage >$16 Billion
Track forecast was accurate, intensity was over predicted

from Travis Miles, Gustavo Goni, Scott Miller, et al NEOTAC Aug 2020 presentation

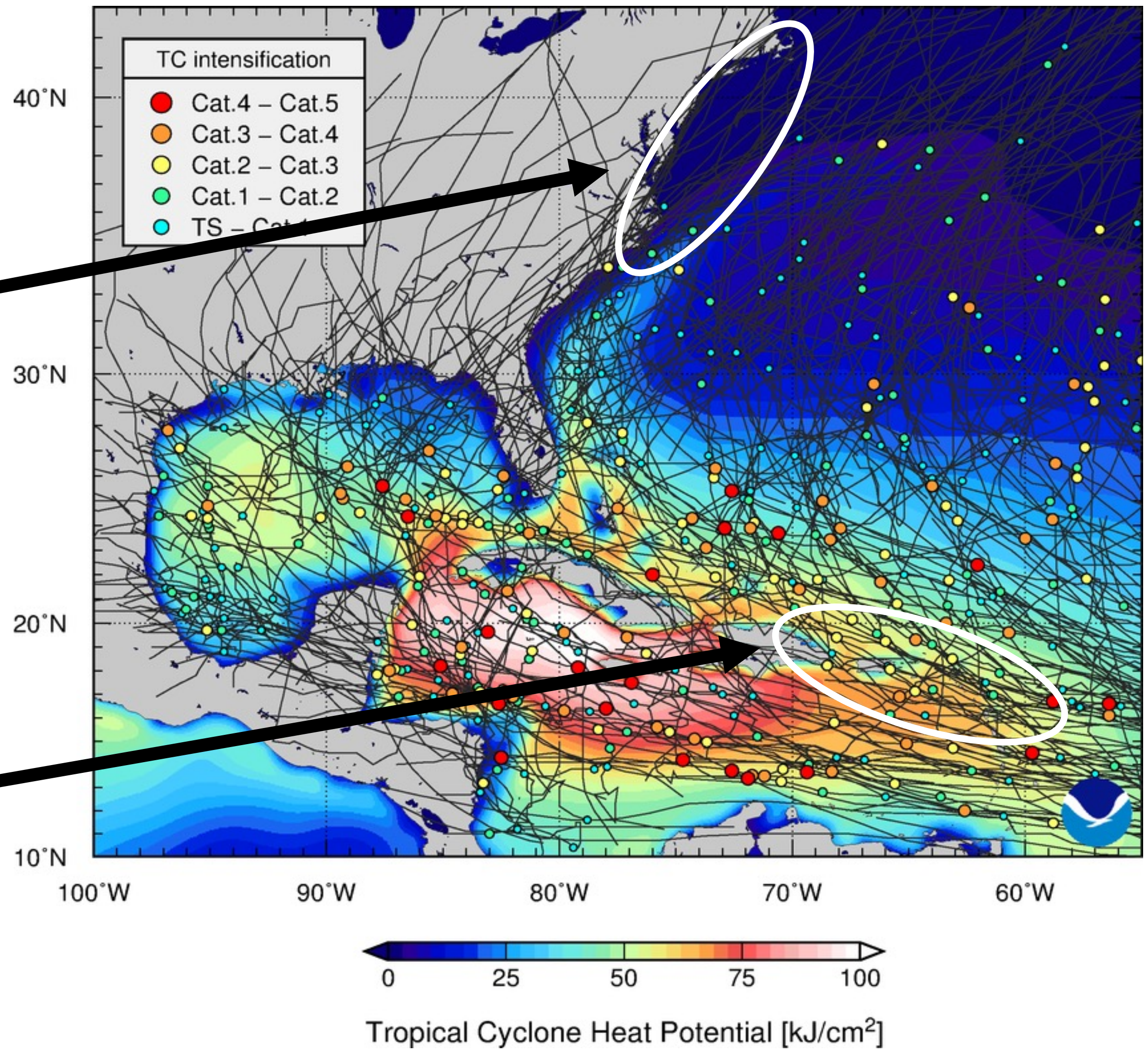
## Disaster Relief Appropriations (2013 Sandy Supplemental)

CINAR – Cooperative Institute for the North Atlantic Region

Woods Hole Oceanographic Institution
Rutgers, The State University of New Jersey
University of Maryland – Horn Point
University of Maine
Gulf of Maine Research Institute

NOAA's Atlantic Oceanographic and Meteorological Laboratory
U.S. Department of Commerce

NOAA AOML Physical Oceanography Division
University of Puerto Rico Mayaguez

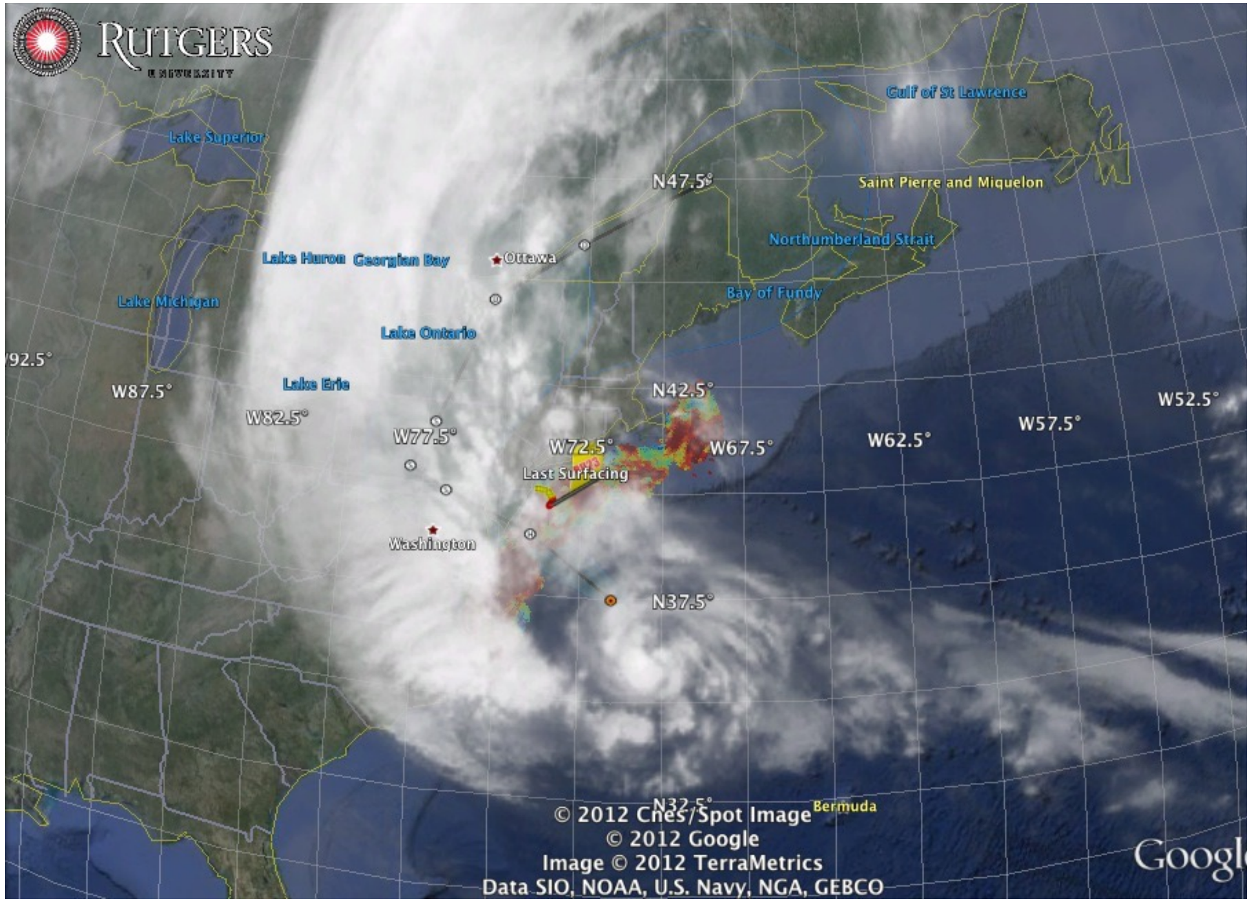



from Travis Miles, Gustavo Goni, Scott Miller, et al NEOTAC Aug 2020 presentation

As sea level rises,

we will become ever

more vulnerable




Sandy – 2012

Damage > $70 Billion
Track and intensity were accurate ~5 days in advance

from Travis Miles, Gustavo Goni, Scott Miller, et al NEOTAC Aug 2020 presentation

# What observations are Needed?

# What might be possible?

**Crewed Platforms:** Aircraft, Ships

**Autonomous Platforms:** Moorings, barges, floats, drifters

**Uncrewed Systems:** Gliders, Unmanned Airborne Systems, Uncrewed surface vehicles

# What Kind of Observations are Needed?

- **Ocean and Atmospheric State Estimates Mapping**
  - **Analysis:** Assimilation into NWP models, Optimal Interpolation Mapping,..
  - **Want:** Spatially coherent network -- “overlapping bulls-eyes of information”

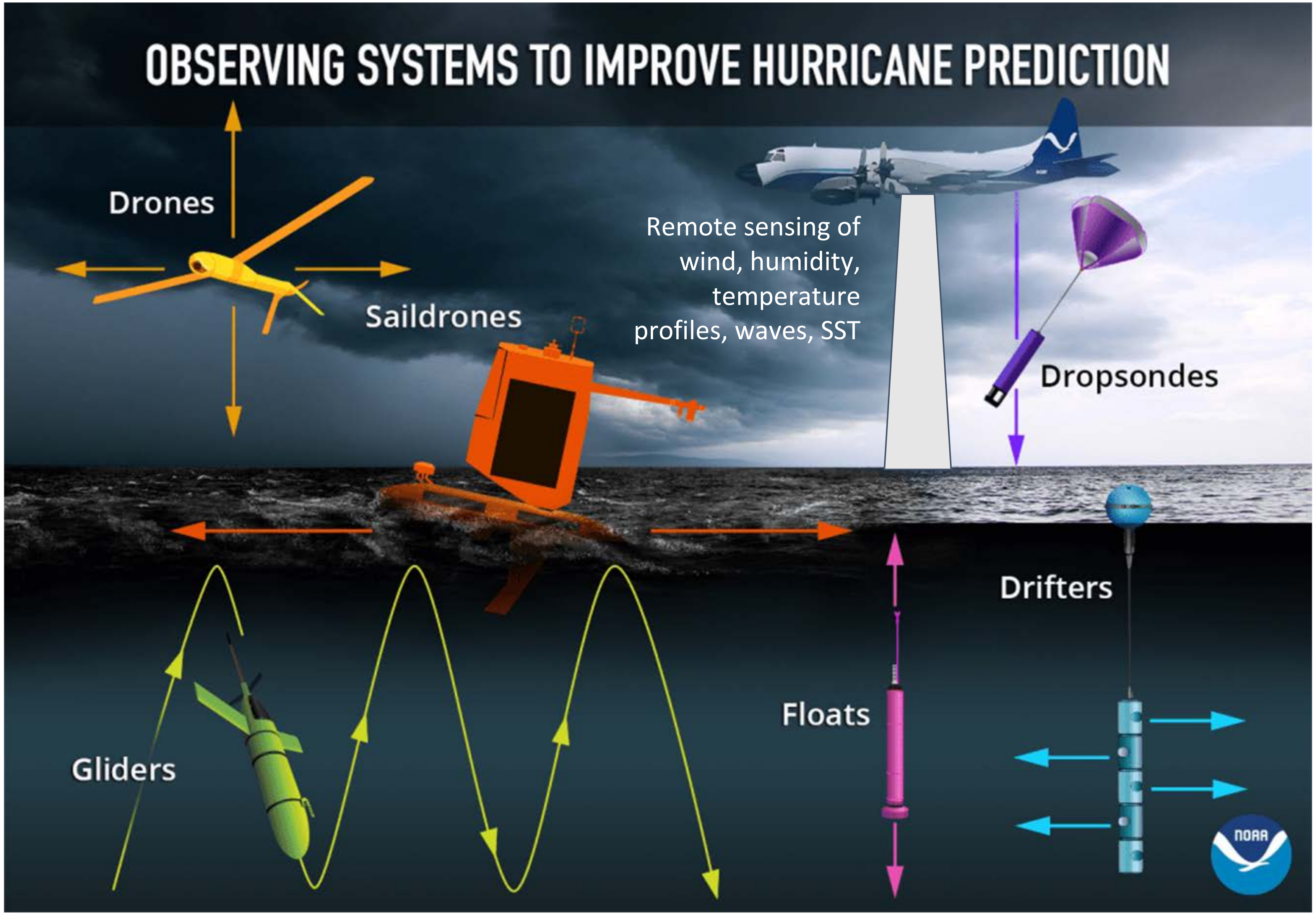
- **Models and Satellite Products Validation**
  - **Analysis:** Intercomparisons
  - **Want:** Ability to Bin data into different regimes (e.g. seasons, regions, phenomena,..)

- **Improved understanding / model development through Process Studies**
  - **Analysis:** Governing Equations budget analysis – e.g. d/dy <v’T’>
  - **Want:** All of the above

- **Monitoring indicators (“Context”)**
  - **Want:** Long timeseries of timely data for validation, budget analyses and understanding

**Want:** Spatially coherent surface & subsurface observations

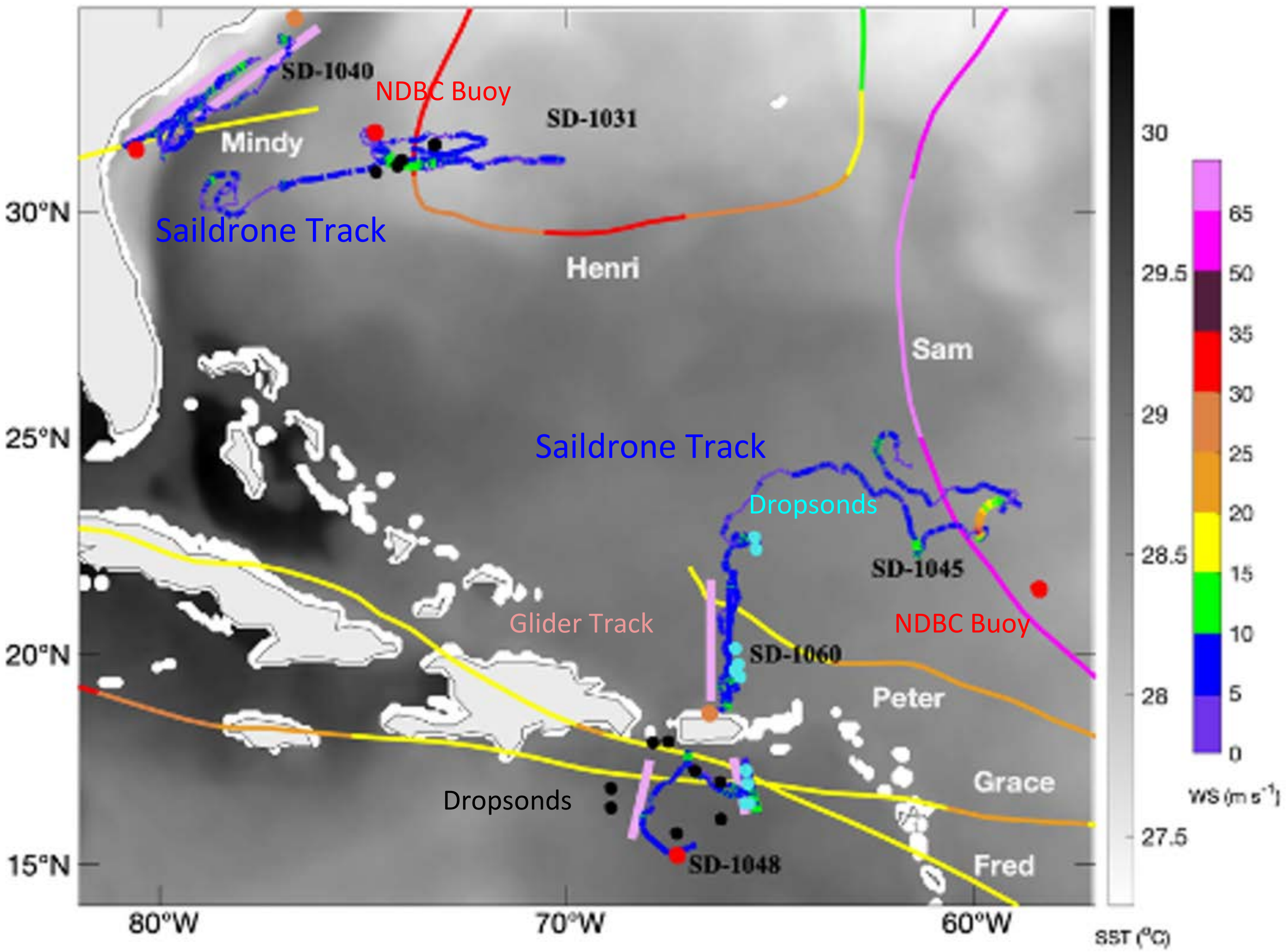
**Mapping Example**




Courtesy: Chidong Zhang

**Want:** Spatially coherent surface & subsurface observations along expected hurricane path






# Lessons Learned:

**Saildrone can be used in Hurricanes** (would need to test this in a strong current environment)

**Can make coordinated observations with different type of uncrewed systems** (Saildrones, gliders). Still need to test this with Airborne Uncrewed Aerial Vehicles (UAV) + USV + glider

**Pilot studies are Important !!**

**Example: NOAA Saildrone-Glider Hurricane Observation Mission in 2021**

**Composite Map of Assets** (not complete list of all obs used for assimilation)

Courtesy: Chidong Zhang

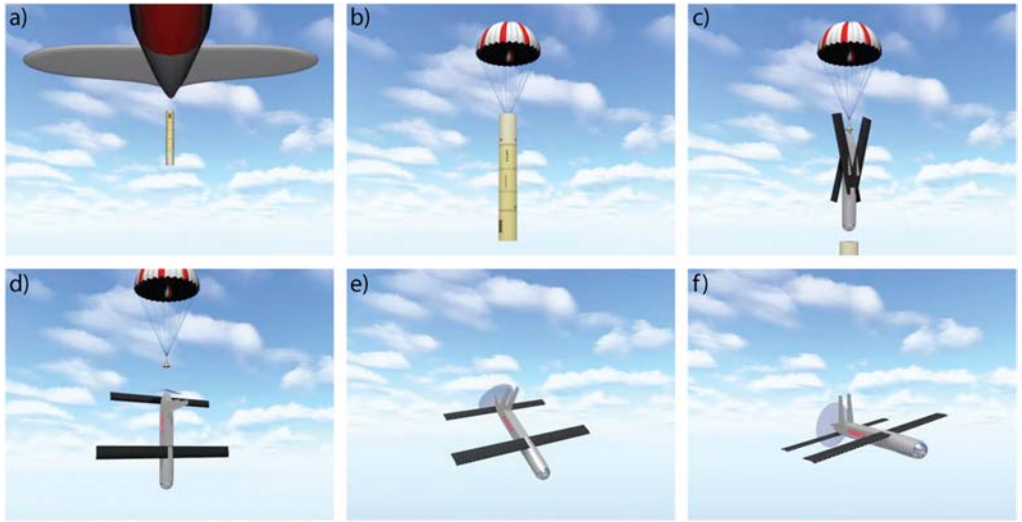
**Want:** Model vs. Observation Intercomparison across different regimes **Validation Example**


**Example:** New and Improved Observing Technologies And Enhanced Concept of Operations Working Group (NEOTAC) – Courtesy Joe Cione

Downloaded from NEOTAC August 6 2020 meeting with permission from Joe Cione and from Cione et al. (BAMS 2020)

**Want:** Model vs. Observation Intercomparison across different regimes **Validation Example**


Deployment of sUAS from Aircraft allows use over open ocean. sUAS are not recovered




## Coyote small Unmanned Aircraft System (sUAS)

**Raytheon's Coyote sUAS:**

**Wingspan: 1.5 m (~5 ft)**
**Length: 0.9 m (~3ft)**
**Weight: 6 kg (~13 lb)**

**Meteorological Measurements:**

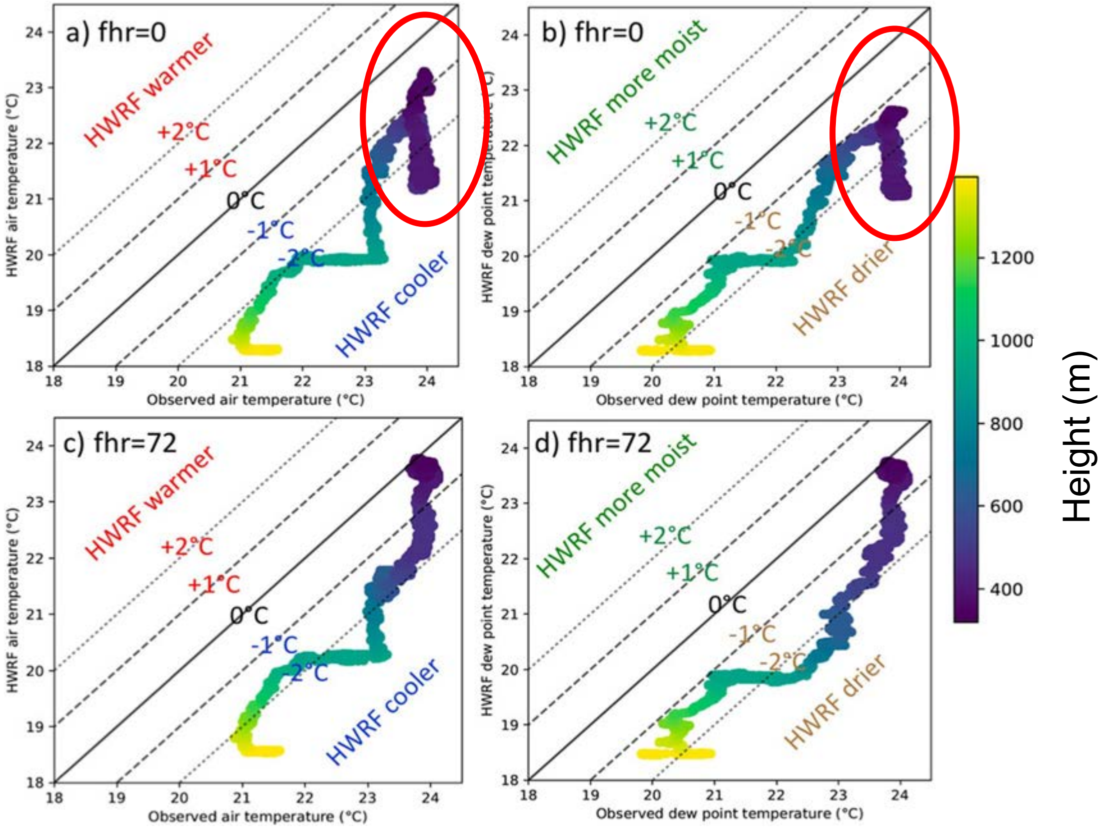
- **Wind speed and direction (up to 1-10 Hz)**
- **Temperature, relative humidity, pressure**
- **Sea surface temperature (SST) and cloud top temperature (IR)**
- **Future: laser altimeter, turbulence gust probe**

**Example:** New and Improved Observing Technologies And Enhanced Concept of Operations Working Group (NEOTAC) – Courtesy Joe Cione

**Want:** Model vs. Observation Intercomparison across different heights **Validation Example**


Coyote sUAS hurricane observations show HWRF was too cool & dry in boundary layer. Potentially unstable bias.

HWRF-Simulation




Coyote sUAS Observations

# Challenges & Lessons Learned:

Drones launched from landbased operator must stay within visual range

Expanded range of P3 Aircraft observing through use of sUAS; Aircraft must stay within 5-km of drone.

Not recovered – Cannot diagnose problems

Work needed to:

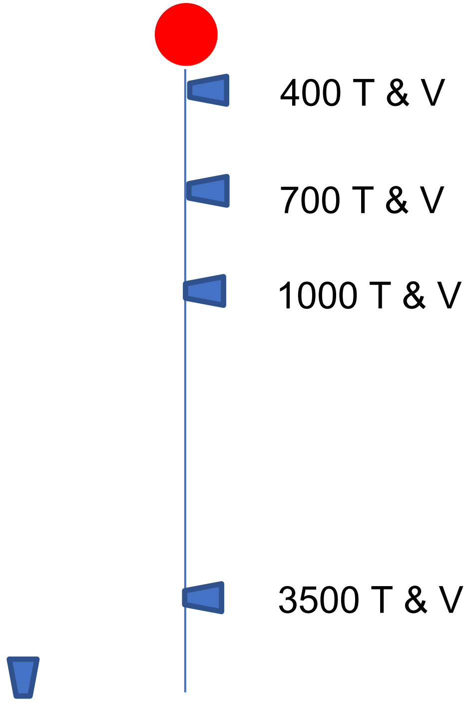
- enhance payload,
- augment battery life,
- increase transmission range and permitting so NOAA P-3 is not required to loiter nearby.

**Want:** Sustained "horiz & vertical mapping" of multiple variables

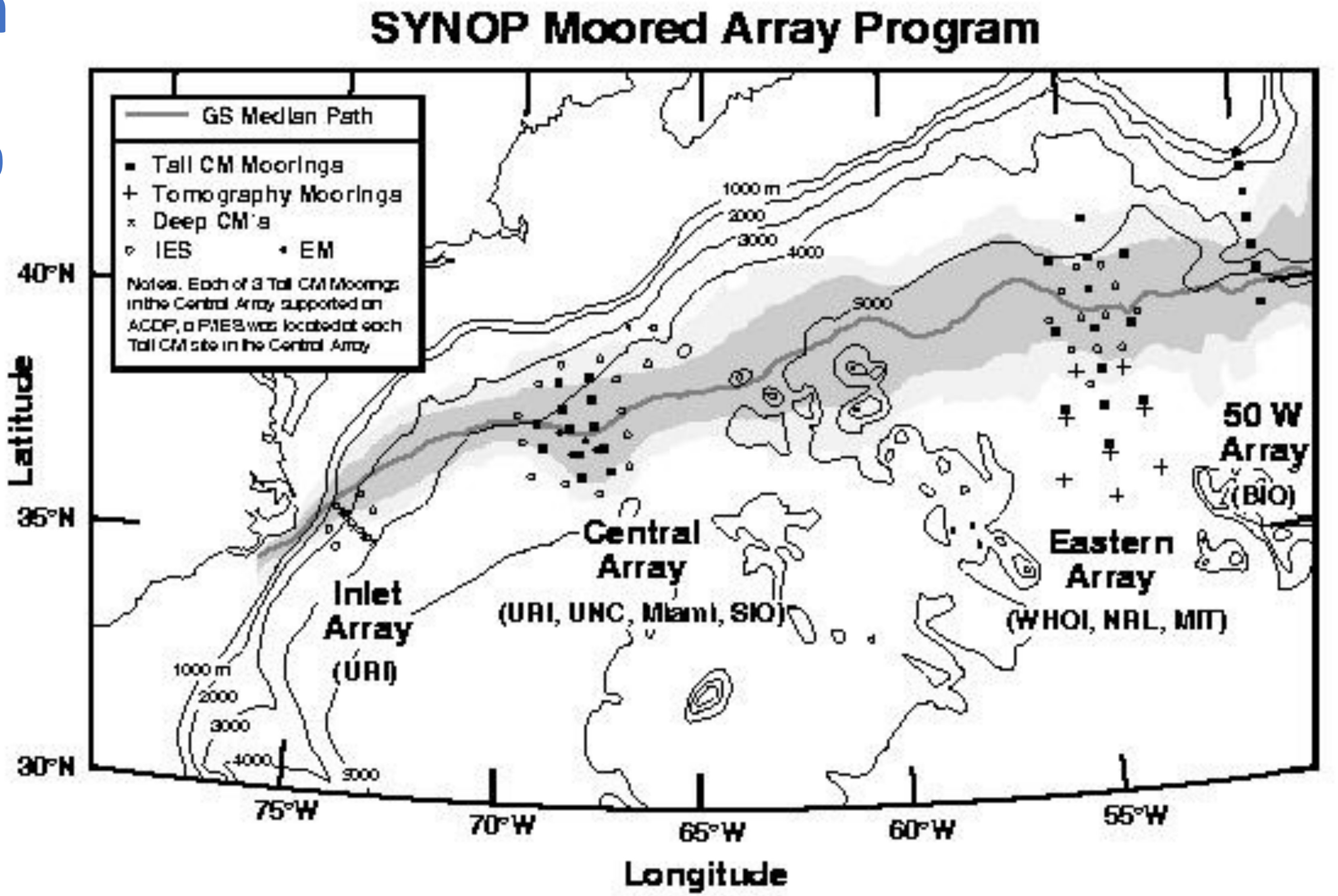
Process Study Example

# SYNOP – Ocean Weather Maps

## May 1988-August 1990




Bottom Inverted Echo Sounded with P & V (C-PIES)



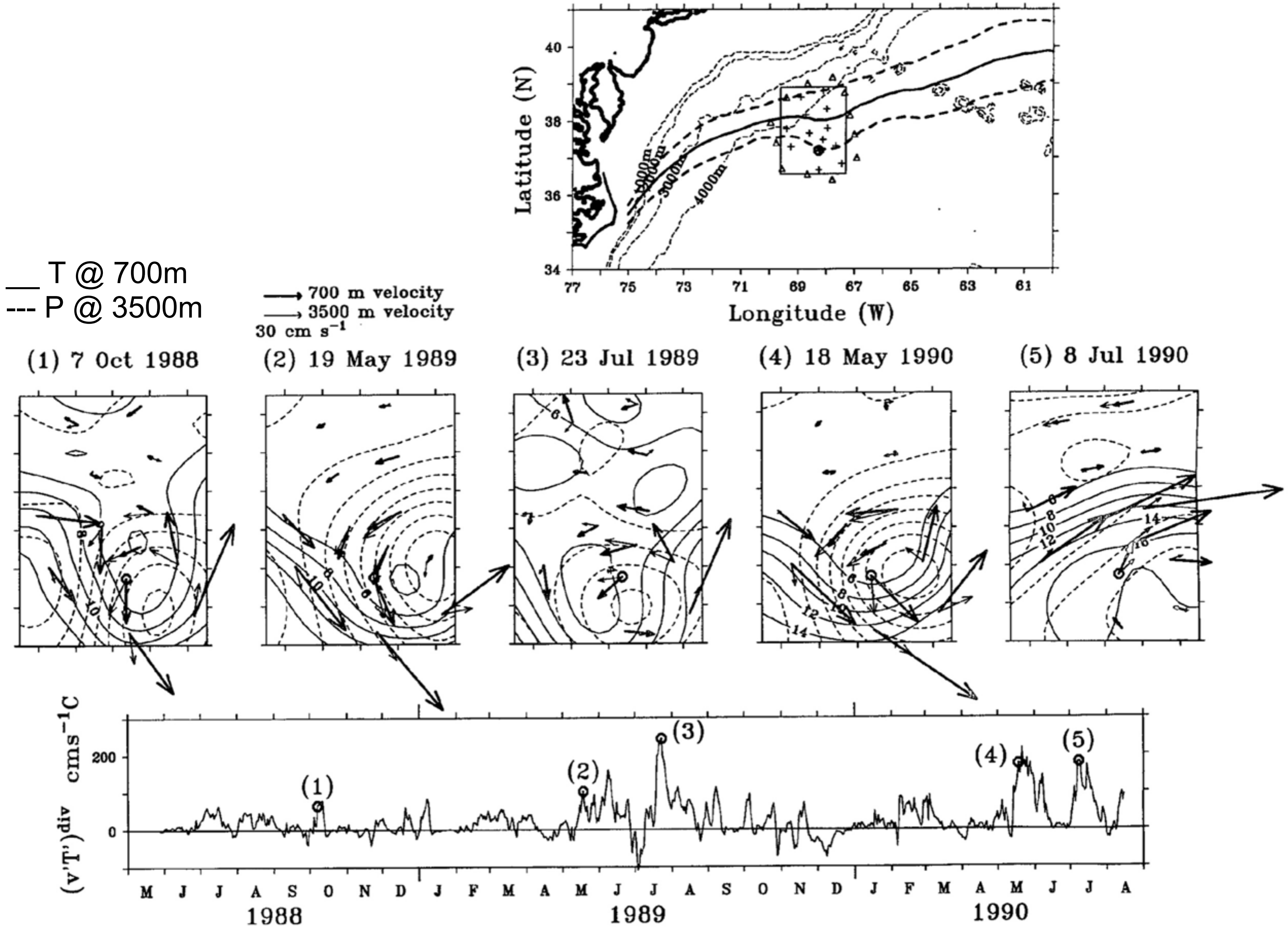
**Want:** Sustained “horiz & vertical mapping” of multiple variables **Process Study Example**

# SYNOP – Ocean Weather Maps

## May 1988-August 1990

Computation of eddy energy conversion rates: $-\langle v'T' \rangle^{div} \, dT/dy$

Shows intensification of Gulf Stream upper and deep lows occur through baroclinic instability




Cronin & Watts, 1996: Eddy-mean flow interaction in the Gulf Stream at 68W: Part I. Eddy energetics, *JPO*.

**Want:** Sustained “horiz & vertical mapping” of multiple variables

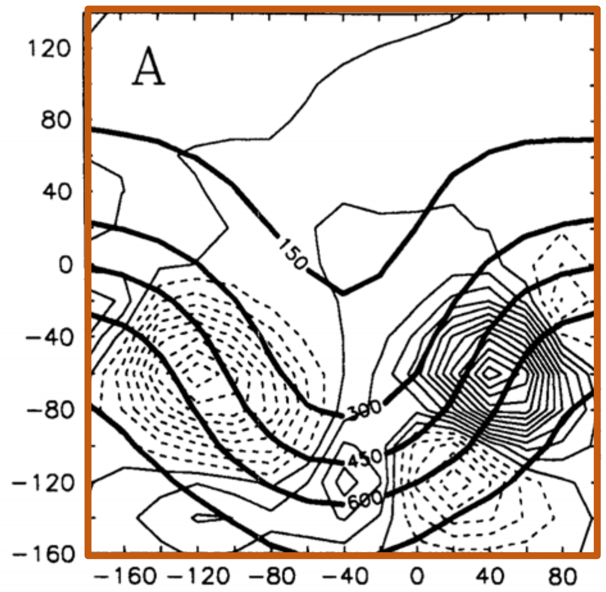
**Process Study Example**

# SYNOP – Ocean Weather Maps

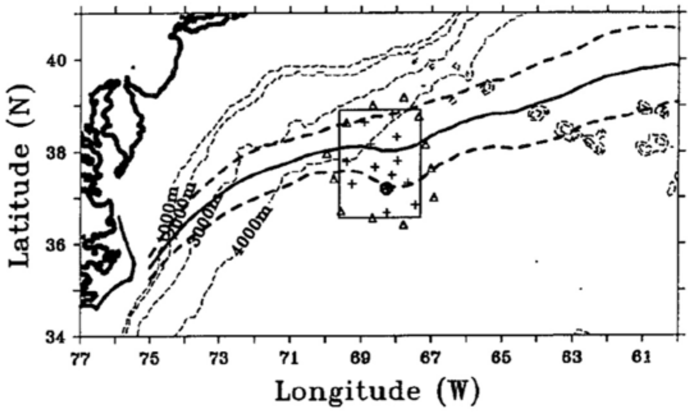
## May 1988-August 1990

__ Z12
--- w

19 May 1990

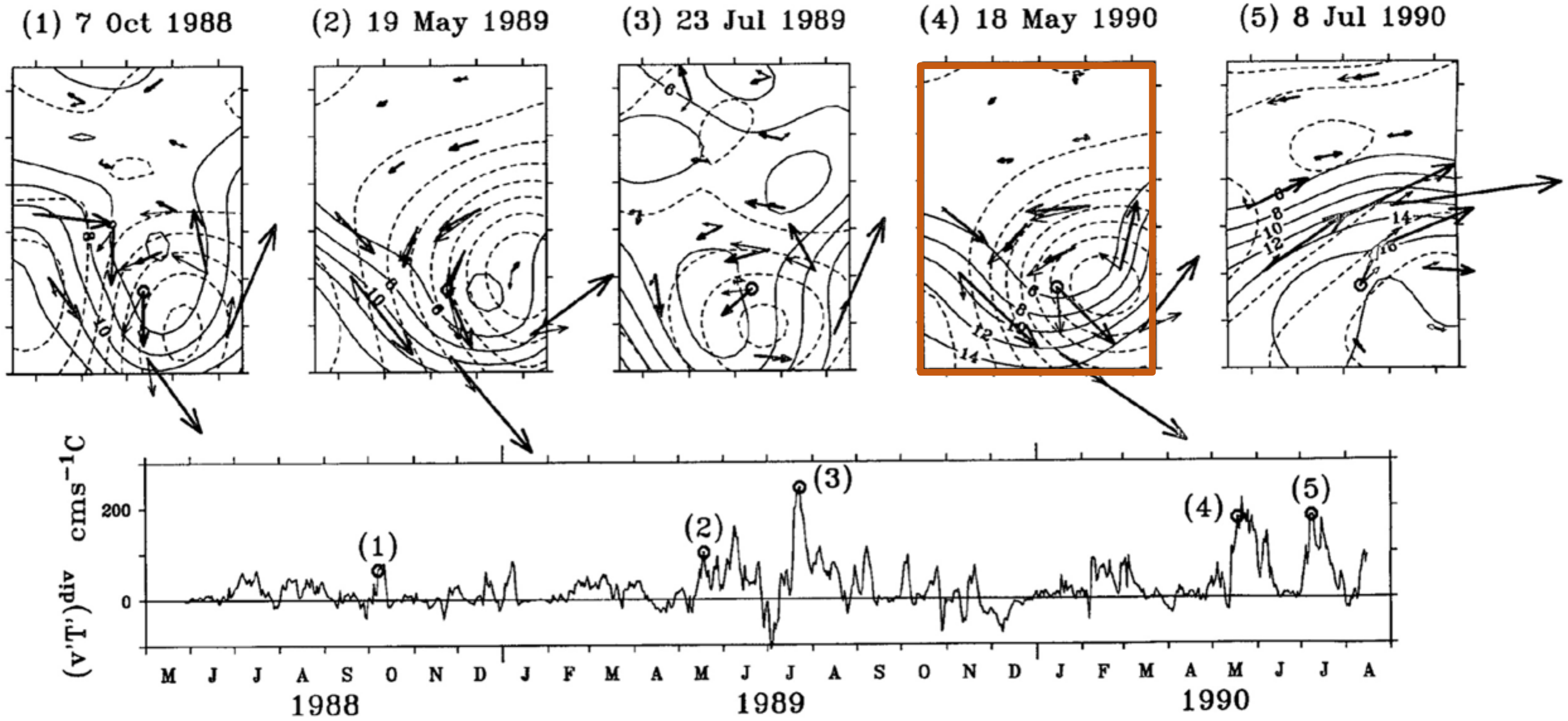



Lindstrom & Watts, 1994: Vertical motion in the Gulf Stream near 68W … *computed from the “Omega-Equation”.*




__ T @ 700m
--- P @ 3500m

→ 700 m velocity
→ 3500 m velocity
30 cm s$^{-1}$

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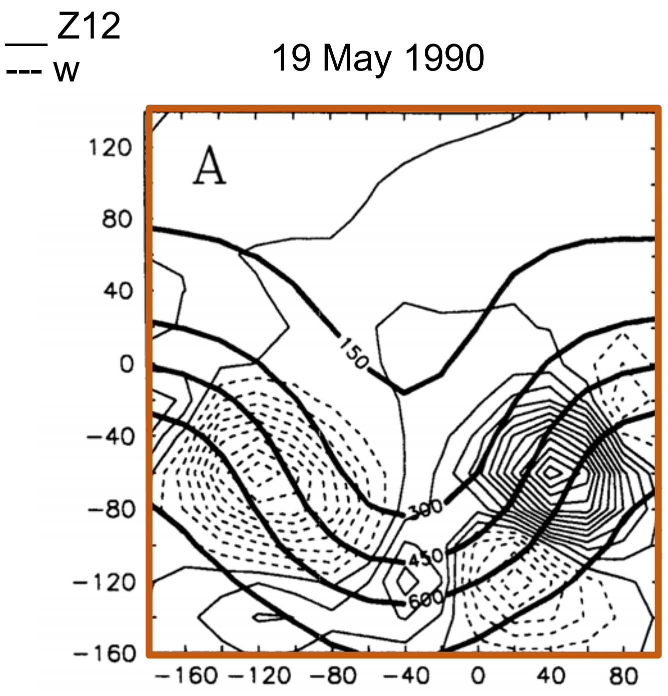
**Want:** Sustained “horiz & vertical mapping” of multiple variables **Process Study Example**

# SYNOP – Ocean Weather Maps

## May 1988-August 1990

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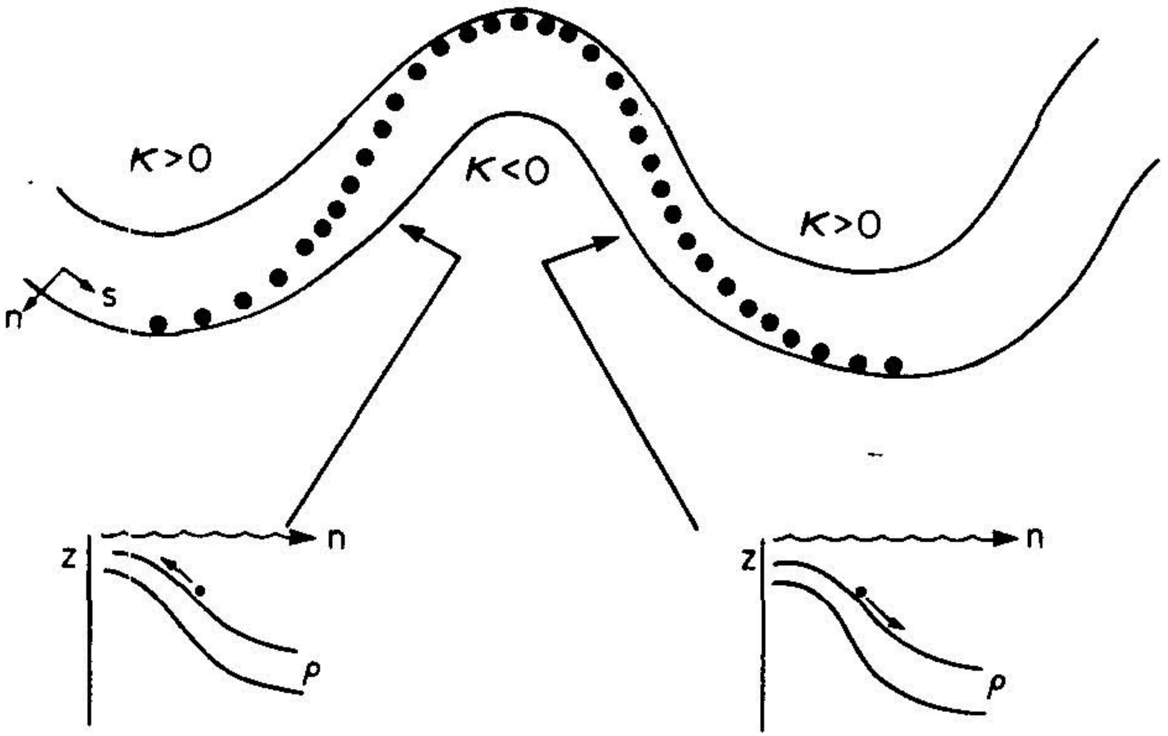
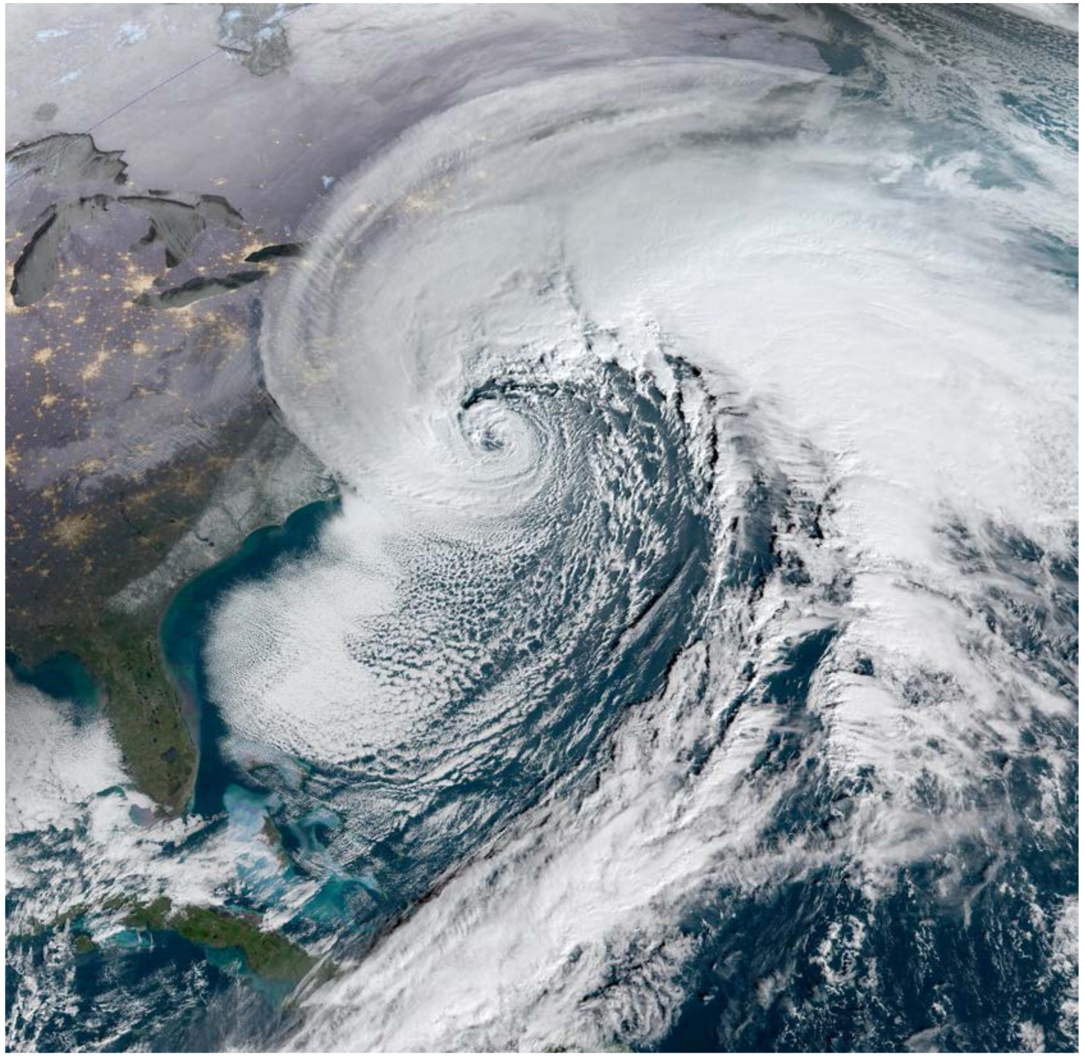



FIG. 4. Schematic view of three-dimensional motion of RAFOS floats. Dots indicate trajectory of a float through a Gulf Stream meander.

Bower and Rossby 1989: Evidence of cross-frontal exchange processes in the Gulf Stream based on isopycnal RAFOS Float data, *JPO.*

# **North Atlantic HotSpot Experiment** – ocean-land-atmosphere interactions associated with tropical-extratropical transitions and nor'easter "bomb cyclones"



**Want:** Sustained ABL and OBL observations over full region of storm and storm development area

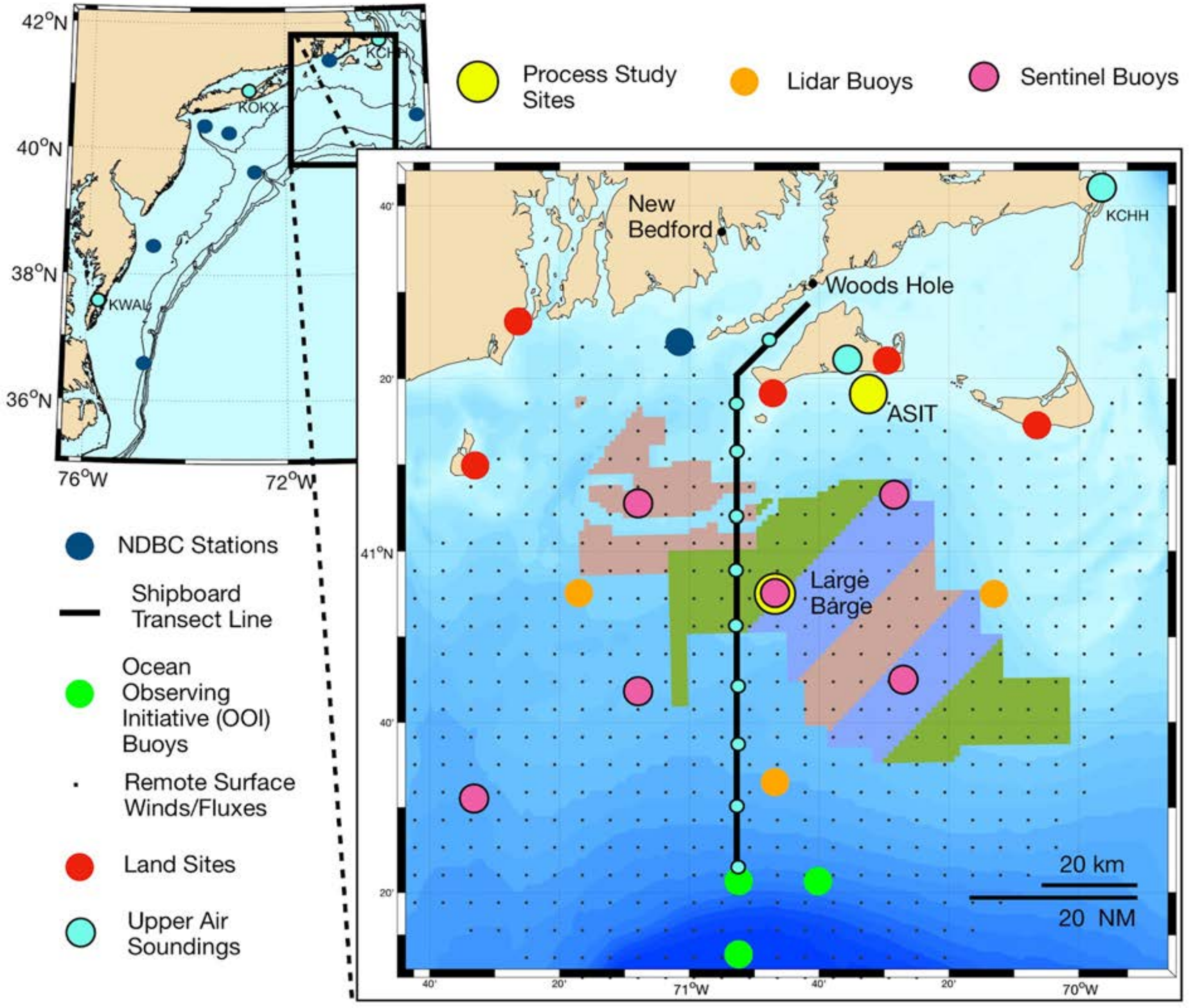
- Atmospheric observations are probably sufficient over land
- Atmospheric observations in coastal areas could be leveraged from offshore wind energy observing assets.
- Would need to enhance observing capabilities over broad region of shelf and deep ocean, resolving Gulf Stream system
- Need technology development for marine atmosphere boundary layer profiling

GOES-16 ABI GeoColor image of the Early January 2018 nor'easter. Credit NOAA

Pacific Northwest NATIONAL LABORATORY

# Wind Forecasting Improvement Project 3 (WFIP3)

- Objective: Our goal is to drive down the cost of energy from offshore wind farms by improving wind resource assessments and forecast models and reducing the uncertainty in energy yield and design load assessment
- Model developments within WFIP3 will be be implemented within NOAA's operational forecasting model (Rapid Refresh Forecast System)
- Engage with wind energy industry to support their needs in observations and model development
- Planned Highlights:
  - 12-18 month field campaign
  - Large barge platform with remote sensing instruments
  - 9 offshore buoys
  - 6 coastal stations with remote sensing
  - Industry partners and overlap with NSF, NASA, and NOAA resources




Key project partners: PNNL, WHOI, NOAA, LLNL, ANL, NREL, NCAR, CU, UTD, Tufts, DNV GL (industry)

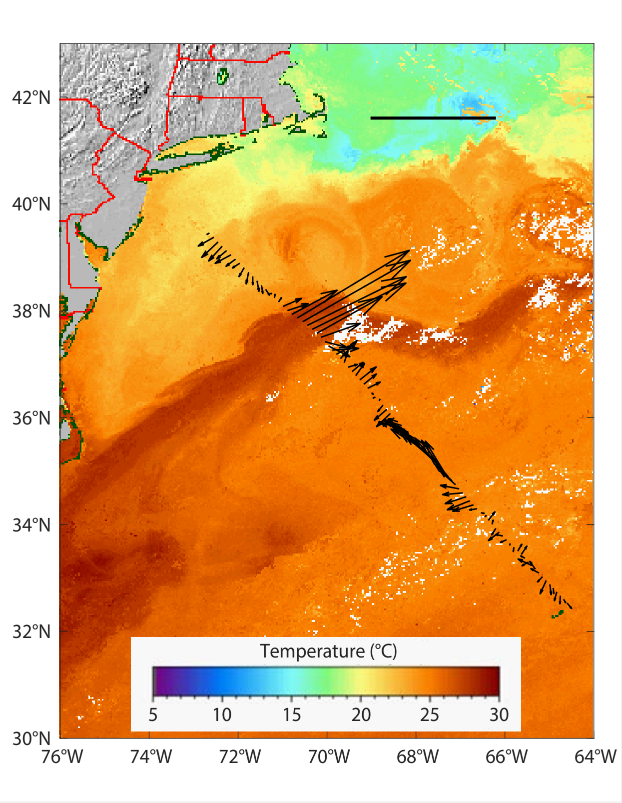
PI contact: Raghu Krishnamurthy (raghu@pnnl.gov) or Anthony Kirincich (akirincich@whoi.edu)

Slide credit: M. Andres

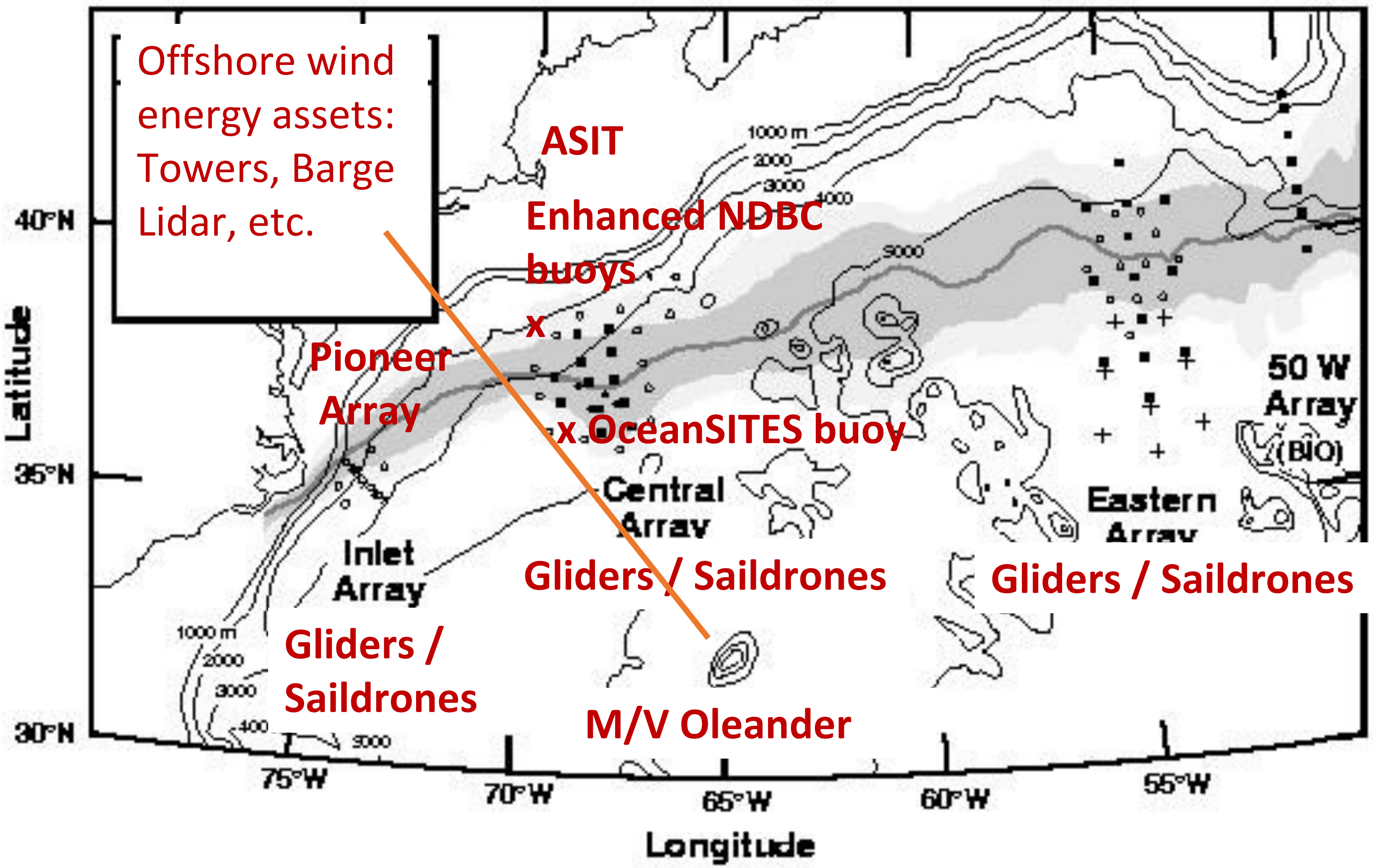
# Repeat sections with commercial ships: MV Oleander, Nuka Arctica & Norröna




- Direct measure of Gulf Stream velocity structure and transport (Rossby et al., 2019).
- Gulf Stream studies (Sanchez-Frank et al., 2014; Andres et al., 2020).
- Estimates of volume, heat and fresh water flux divergence across the subpolar gyre (Chafik & Rossby, 2019).
- Comparisons with models (Chi et al., 2018; Levin et al. 2018), with altimetry (Worst et al., 2014). Ingesting velocities into models (Levin et al., 2020; 2021).
- Accelerated warming of the Middle Atlantic Bight, changes in Shelfbreak Jet, influence of Warm Core Rings (Forsyth et al., 2015; 2021; 2022); diagnosing warming (K. Chen et al., 2014) and Marine Heatwaves (E. Perez et al., 2021).



# North Atlantic Hot Spot Process Study




**What might be sustained as legacy monitoring observations ?**

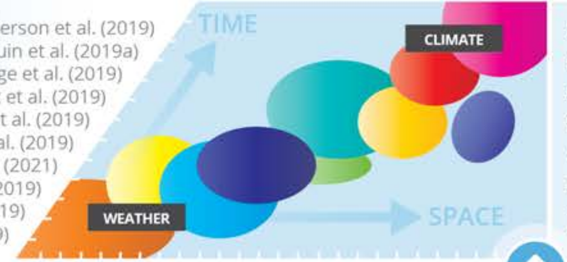
OASIS

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

# Observing Air-Sea Interactions Strategy (OASIS) is harmonizing community recommendations from OceanObs'19 and UN Decade Laboratories...

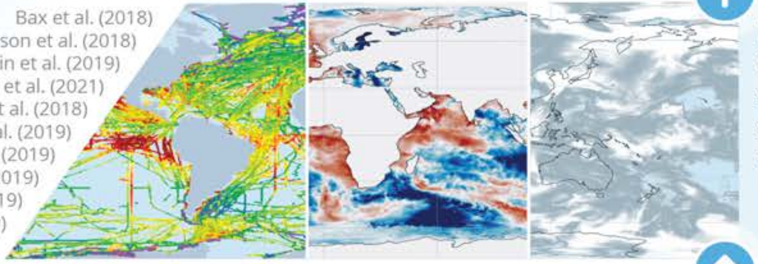
## ...into three **"Big Asks"**

Anderson et al. (2019)
Ardhuin et al. (2019a)
Bange et al. (2019)
Bax et al. (2019)
Canonico et al. (2019)
Domingues et al. (2019)
Estes et al. (2021)
Penny et al. (2019)
Pinardi et al. (2019)
Powers et al. (2019)



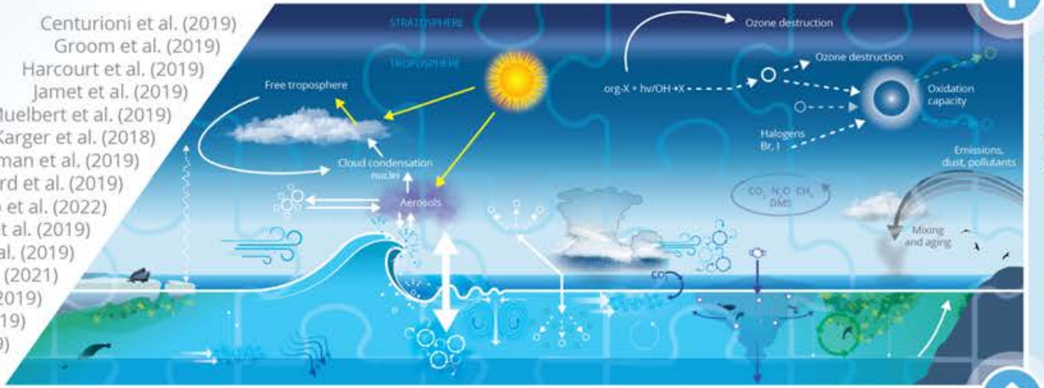

Improved Earth system *(including ecosystem)* forecasts for a predicted, clean, accessible, healthy, safe & productive ocean

Bax et al. (2018)
Benson et al. (2018)
Cronin et al. (2019)
Cronin et al. (2021)
Fennel et al. (2018)
Foltz et al. (2019)
Hermes et al. (2019)
Maximenko et al. (2019)
Smith et al. (2019)
Speich et al. (2019)
Wanninkhof et al. (2019)



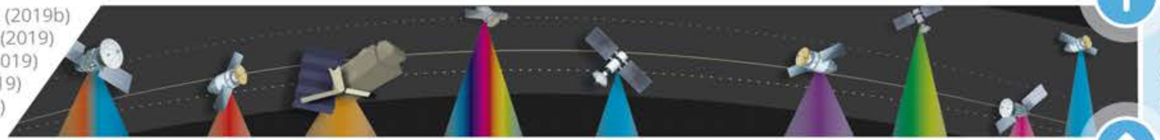
Improved ocean information serving stakeholders around the world

Centurioni et al. (2019)
Groom et al. (2019)
Harcourt et al. (2019)
Jamet et al. (2019)
Muelbert et al. (2019)
Muller-Karger et al. (2018)
Newman et al. (2019)
Lombard et al. (2019)
Marandino et al. (2022)
Kent et al. (2019)
O'Carroll et al. (2019)
Sequeira et al. (2021)
Steinhoff et al. (2019)
Subramanian et al. (2019)
Swart et al. (2019)
Villas Bôas et al. (2019)



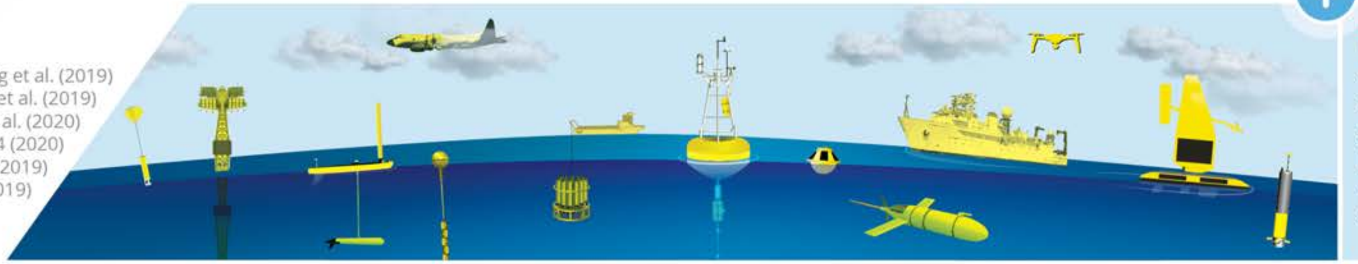

**Big Ask #3**
Improved models & understanding of air-sea interaction processes

Ardhuin et al. (2019b)
Bourassa et al. (2019)
Gommenginger et al. (2019)
Morrow et al. (2019)
Rodríguez et al. (2019)
Vinogradova et al. (2019)



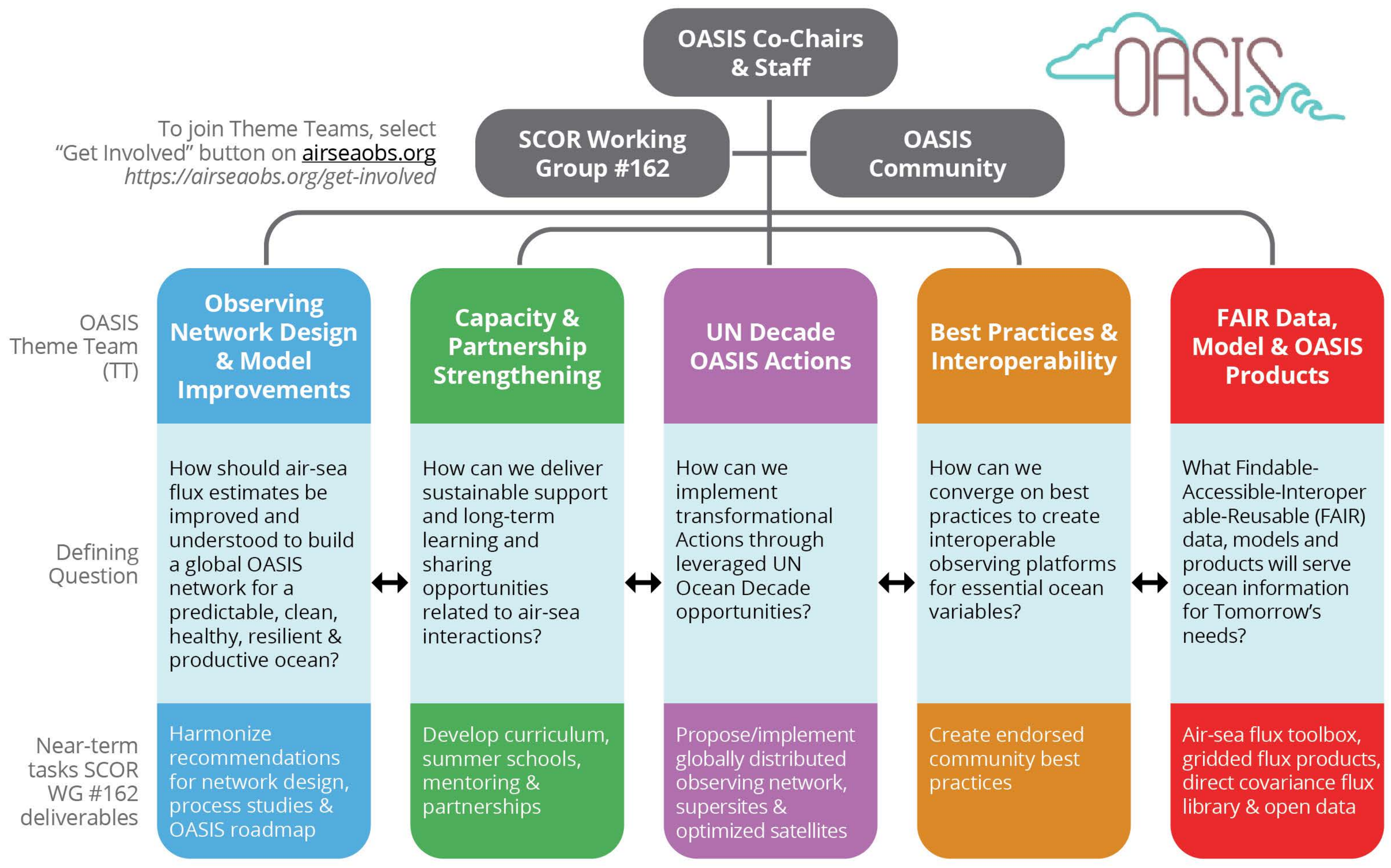
**Big Ask #2**
A constellation of optimized satellites

Meinig et al. (2019)
Pearlman et al. (2019)
Sabine et al. (2020)
SCOR Working Group 154 (2020)
Smith et al. (2019)
Wang et al. (2019)



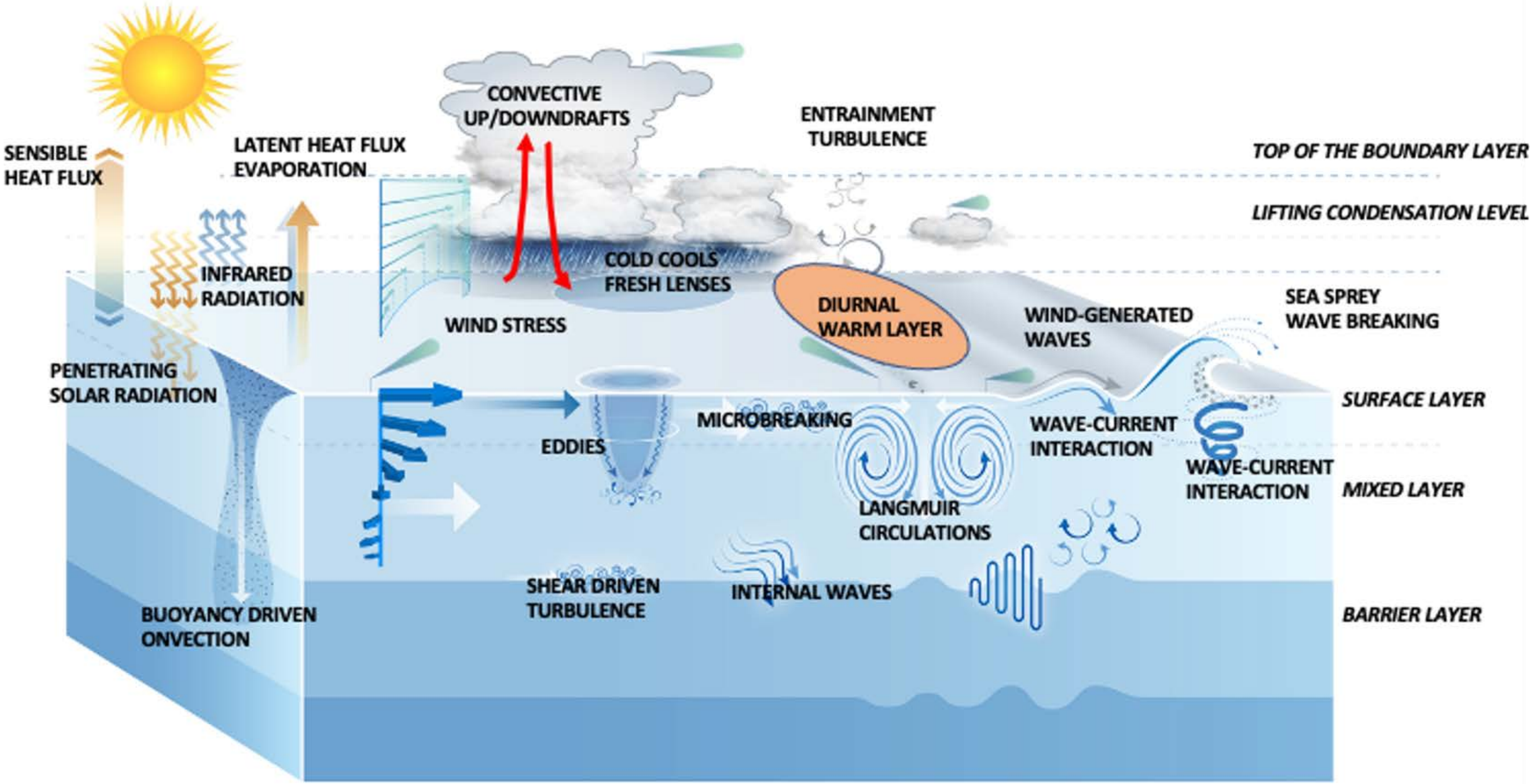
**Big Ask #1**
A globally distributed in situ air-sea observing network built around an expanded time series station array

Image: Sarah Battle/NOAA visit: airseaobs.org


OASIS Co-Chairs & Staff
SCOR Working Group #162
OASIS Community
To join Theme Teams, select “Get Involved” button on airseaobs.org
https://airseaobs.org/get-involved
OASIS Theme Team (TT)
Defining Question
Near-term tasks SCOR WG #162 deliverables
Observing Network Design & Model Improvements
How should air-sea flux estimates be improved and understood to build a global OASIS network for a predictable, clean, healthy, resilient & productive ocean?
Harmonize recommendations for network design, process studies & OASIS roadmap
Capacity & Partnership Strengthening
How can we deliver sustainable support and long-term learning and sharing opportunities related to air-sea interactions?
Develop curriculum, summer schools, mentoring & partnerships
UN Decade OASIS Actions
How can we implement transformational Actions through leveraged UN Ocean Decade opportunities?
Propose/implement globally distributed observing network, supersites & optimized satellites
Best Practices & Interoperability
How can we converge on best practices to create interoperable observing platforms for essential ocean variables?
Create endorsed community best practices
FAIR Data, Model & OASIS Products
What Findable-Accessible-Interoperable-Reusable (FAIR) data, models and products will serve ocean information for Tomorrow’s needs?
Air-sea flux toolbox, gridded flux products, direct covariance flux library & open data

# EXTRA SLIDES

## Air-Sea Transition Zone & Associated Processes




Courtesy: Chidong Zhang