Observational Oceanography II: *in-situ* Process Studies + Goals for the next decade

Meghan Cronin
NOAA Pacific Marine Environmental Laboratory

With slides from Mike Patterson, Director of US CLIVAR

ECCO Summer School 2019 * Friday Harbor Laboratories

What are Observations used for?

From Lecture 1….

- **Observations for mapping fields, initiating or nudging models**
  - Timely (available through the Global Telecommunication System (GTS) in near realtime)
  - Geographically distributed in coherent array, with known uncertainty and quality
- **Observations for validation**
  - Independent obs (e.g. not assimilated)
  - High quality, of known uncertainty that is smaller than error of model.
- **Observations for improving model physics, parameterizations and understanding of processes**
  - Oversampled, high quality observations (e.g. Process Studies)

How many errors can I have?

- Mistakes and Miscalculations
- Mean bias errors & Random uncertainty due to noise
- Systematic biases due to sampling issues
- Systematic biases due to field errors
- Systematic biases dues to calibration errors, model physics errors, etc.
- **Error in representation of a mean value by a spot observations.**

Motivation for Process studies

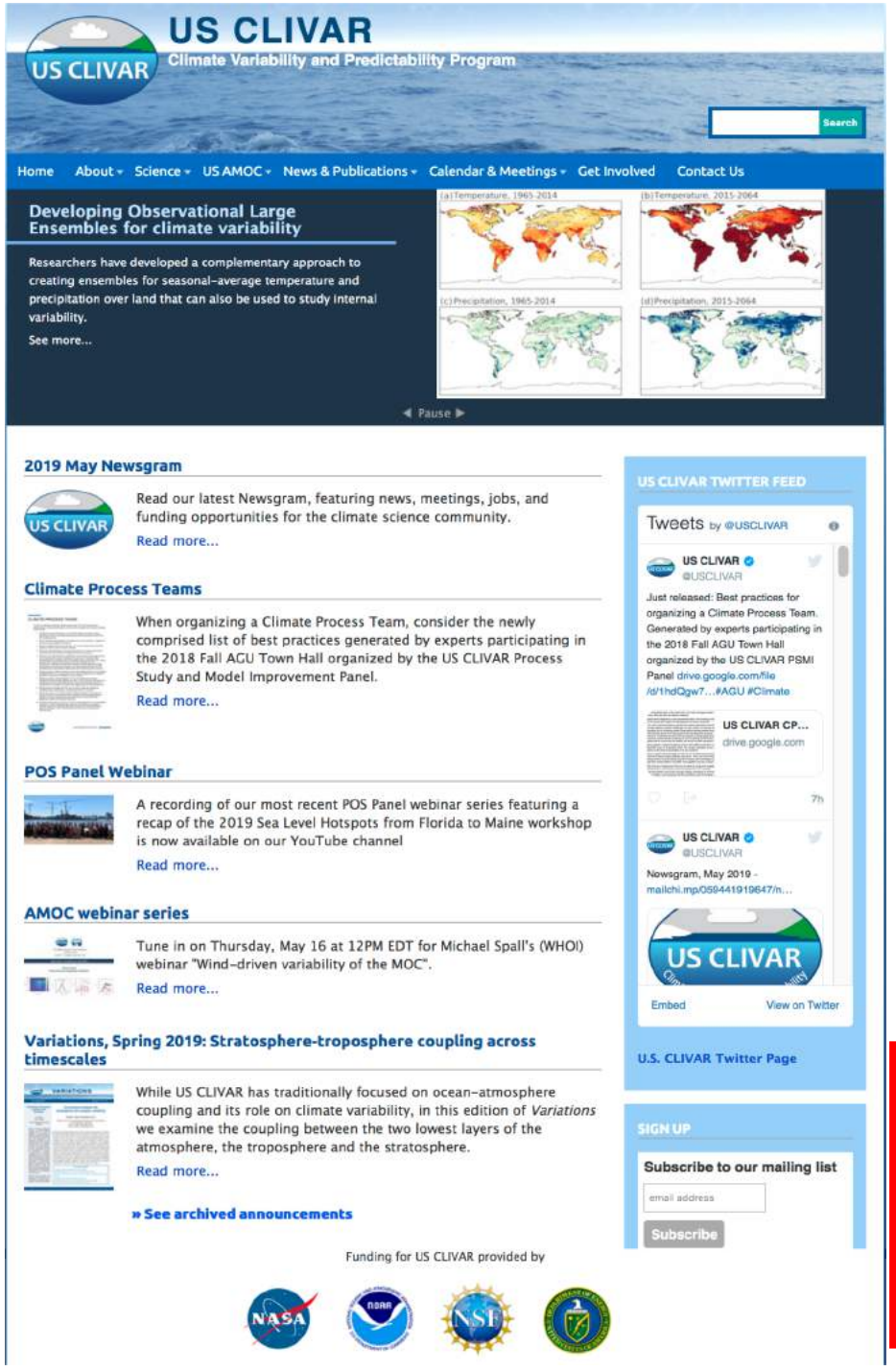
Motivation for Process Studies

What are the key mechanisms and processes controlling the climate system? How are these modulated by large-scale variability and general circulation? *Improved understanding of these processes can lead to better predictability in the climate system.*

If this process cannot be resolved by model, can it be parameterized?

Does the parameterization improve the model state estimates & forecasts?

What are minimum observations/variables needed to resolve and monitor this process? *Improved monitoring of these processes can lead to better predictability in the climate system.*



About US CLIVAR

https://usclivar.org

US Climate Variability and Predictability (CLIVAR) is a national research program with a mission **to foster understanding and prediction of climate variability and change** on intraseasonal-to-centennial timescales, through observations and modeling with emphasis on the role of the ocean and its interaction with other elements of the Earth system, and **to serve the climate community and society through the coordination and facilitation of research on outstanding climate questions.**

…

US CLIVAR research is currently supported by participating programs within five Federal agencies including the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), the Department of Energy (DOE), and the Office of Naval Research (**ONR**). A US CLIVAR Inter-Agency Group of program managers from these five agencies coordinates and targets funding and resources to support the research activities of the program. Four of these agencies, **NASA, NOAA, NSF, and DOE sponsor the US CLIVAR Project Office to work with the SSC and its Panels in coordinating science planning, implementing research activities, communicating research advances and needs, and supporting international engagement and collaboration.**

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Panel Descriptions

Phenomena, Observations, and Synthesis Panel

The Phenomena Observations and Synthesis Panel's (POS) mission is to improve understanding of climate variations in the past, present and future, and to develop syntheses of critical climate parameters while sustaining and improving the global climate observing system.

Predictability, Predictions, and Applications Interface Panel

The Predictability, Predictions and Applications Interface Panel's (PPAI) mission is to foster improved practices in the provision, validation and uses of climate information and forecasts through coordinated participation within the U.S. and international climate science and applications communities.

Process Study and Model Improvement Panel

The Process Study and Model Improvement Panel's (PSMI) mission is to reduce uncertainties in the general circulation models used for climate variability prediction and climate change projections through an improved understanding and representation of the physical processes governing climate and its variation.

Funding for US CLIVAR provided by

US Climate Variability and Predictability Program
1201 New York Ave NW, 4th Floor, Washington DC 20005
202.787.1682 | uscpo@usclivar.org

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Process Study and Model Improvement Panel

The Process Study and Model Improvement (PSMI) Panel's mission is to reduce uncertainties in the general circulation models used for climate variability prediction and climate change projections through an improved understanding and representation of the physical processes governing climate and its variation. The Panel is comprised of up to 12 experts from the scientific community, each serving a 4-year term. New panelists are selected annually by the Scientific Steering Committee based on nominations submitted through an open call for new members each fall/winter.

PSMI PANEL MENU

- PSMI Panel Main Page
- Resources
- Webinars

Process Study and Model Improvement (PSMI) Panel		
Member name	Institution	Term through
Victoria Coles, Co-chair	University of Maryland	Dec. 2020
Kevin Reed, Co-chair	Stony Brook University	Dec. 2020
Amy Butler	NOAA Earth System Research Laboratory/University of Colorado	Dec. 2021
Antonietta Capotondi	University of Colorado/NOAA	Dec. 2022
William Collins	Lawrence Berkeley National Lab/University of California Berkeley	Dec. 2020
Charlotte DeMott	Colorado State University	Dec. 2022
Gregory Foltz	NOAA Atlantic Oceanographic and Meteorological Laboratory	Dec. 2019
Samson Hagos	Pacific Northwest National Lab	Dec. 2020
Taka Ito	Georgia Institute of Technology	Dec. 2019
Hyodae Seo	Woods Hole Oceanographic Institution	Dec. 2019
Janet Sprintall	Scripps Institution of Oceanography	Dec. 2019
Patrick Taylor	NASA Langley Research Center	Dec. 2022
Liping Zhang	Princeton University/NOAA	Dec. 2022

Consider getting on this panel!

Terms of Reference

- Review, prioritize, and coordinate US scientific plans for, and programmatic support of, relevant process studies, Climate Process Teams and other investigations that lead to improved parameterizations of critical climate processes, better quantification of climate model uncertainties, improved climate model fidelity, and validation of observing systems aimed at increasing their global utility, as necessary to achieve the goals of CLIVAR. Through its review process, US CLIVAR encouragement of nascent process studies does not imply a formal endorsement.
- Develop and encourage mechanisms (e.g. community workshops, commissioned studies, Working Groups) to further the development and implementation of timely and relevant process studies and a research strategy, including filling gaps.

NOWCAST
CLIMATE RESEARCH

BEST PRACTICES FOR PROCESS STUDIES

BY MEGHAN F. CRONIN, SONYA LEGG, AND PAQUITA ZUIDEMA

PROCESS STUDY "BEST PRACTICES"

- Modelers and observationalists should be integrated in the study from the planning stage onward.
- Integrated and synthesized datasets should be generated from the process study observations to provide model-comparable data that can be used as benchmarks for assessing and validating models. Furthermore, diagnostics shown in much-cited published figures should be provided in digital format as "synthesis products."
- Broad use of the data should be encouraged through
  - open data policies;
  - centralized access to all components of the experiment; and
  - data archiving in a user-friendly format, and with sampling information ("metadata") that is necessary for understanding the measurement.

Meghan Cronin was co-chair of the US CLIVAR Process Study and Model Improvement Panel from 2005-2008
Sonya Legg was co-chair of US CLIVAR PSMIP from 2007-2009
Paquita Zuidema was co-chair of US CLIVAR PSMIP from 2009-2011

https://usclivar.org/climate-process-teams

Climate Process Teams

For a decade and a half, US CLIVAR has promoted the concept of Climate Process Teams (CPTs). CPTs improve the fidelity of coupled climate models by facilitating the transfer of knowledge from observational and process-oriented research to the development of physical process representation in component ocean or atmosphere global climate models (GCMs). A CPT, as defined by US CLIVAR, is a:

> funded multi-institutional project that assembles observation-oriented experimentalists, process modelers, process diagnosticians, theoreticians, and climate model developers from two or more modeling centers into a single project that focuses on a specific process or set of processes to assess model sensitivities to process uncertainties, establish observation and model metrics, and develop, test, and implement parameterization improvements.

NSF and NOAA have co-sponsored two rounds of CPT projects, with the latest projects completing in 2015/16.

In 2015, the US CLIVAR Process Studies and Model Improvement (PSMI) Panel organized a review of CPTs to assess the effectiveness and lessons learned from the CPT approach, main sources of errors/biases in models, opportunities for future model improvement, and potential payoff for future CPT projects. The review committee collected input through questionnaires of seven US modeling center and numerous observational programs, process studies, CPT projects, and US CLIVAR Working Groups, followed by an open community workshop held at NOAA GFDL in September 2015. The information collected informed a 2016 US CLIVAR White Paper.

Below are the key findings from the white paper, best practices for a CPT, and how best to propose a CPT project to the US CLIVAR funding agencies.

US CLIVAR has also promoted concept of Climate Process Teams (CPTs).

See their Aug 2016 US CLIVAR CPT White Paper: "**Translating Process Understanding to Improve Climate Models**" and their "**CPT Best Practice Tip Sheet**"

Process Studies vetted by the US CLIVAR panels:

AMOC – Atlantic Meridional Overturning Circulation Program (including SAMBA and OSNAP)

CLIMODE – CLIvar Mode Water Dynamic Experiment

DIMES – Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean

DYNAMO – Dynamics of Madden Julian Oscillation

EPIC – Eastern Pacific Investigation of Climate Processes in the Coupled Ocean-Atmosphere System

IASCLiP – Inter-Americas Study of Climate Processes

KESS – Kuroshio Extension System Study

NAME – North American Monsoon Experiment

SPURS – Salinity Processes in the Upper Ocean Regional Study

VOCALS – VAMOS Ocean-Cloud-Atmosphere-Land Study

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Process studies I was involved in & know well

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Using data from historical process studies

- Learn about process studies by going to US CLIVAR website & process study website.

- Access data from process study website or from national data archive (e.g. NOAA's NCEI, NASA's EOSDIC & PODAAC, NSF's NCAR EOL).

- Reach out to the process study PIs.

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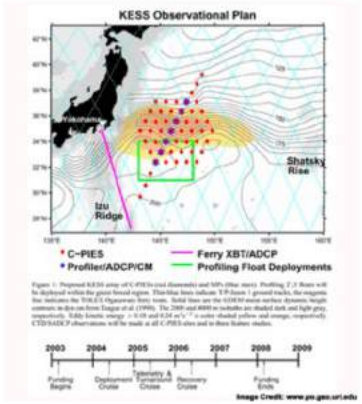
Kuroshio Extension System Study

The warm, northward-flowing waters of the Kuroshio western boundary current leave the Japanese coast to flow eastward into the North Pacific as a free jet — the Kuroshio Extension. The Kuroshio Extension forms a vigorously meandering boundary between the warm subtropical and cold northern waters of the Pacific. A recirculation gyre exists to the south of the Kuroshio Extension. Another may exist to the north. This is also one of the most intense air-sea heat exchange regions on the globe, where the warm Kuroshio waters encounter the cold dry air masses coming from the Asian continent. The Kuroshio Extension system exhibits variations which strongly affect North American climate. Among the diverse fields that will benefit from this work are fisheries and climate research, and understanding storm tracks.



Understanding the processes that govern the variability of and the interaction between the Kuroshio Extension and the recirculation gyre is the goal of this study. Processes coupling the baroclinic and barotropic circulations will be examined by case studies of the local dynamical balances, particularly during strong meandering events. The mechanisms by which water masses are exchanged and modified as they cross the front will be characterized. The objective is to determine the processes governing the strength and structure of the recirculation gyres in relation to the meandering jet.

Science Highlights

KEO Surface Buoy

KEO mooring carries a suite of meteorological sensors to measure winds, air temperature, relative humidity, rainfall, and solar and longwave radiation.

https://uskess.whoi.edu/

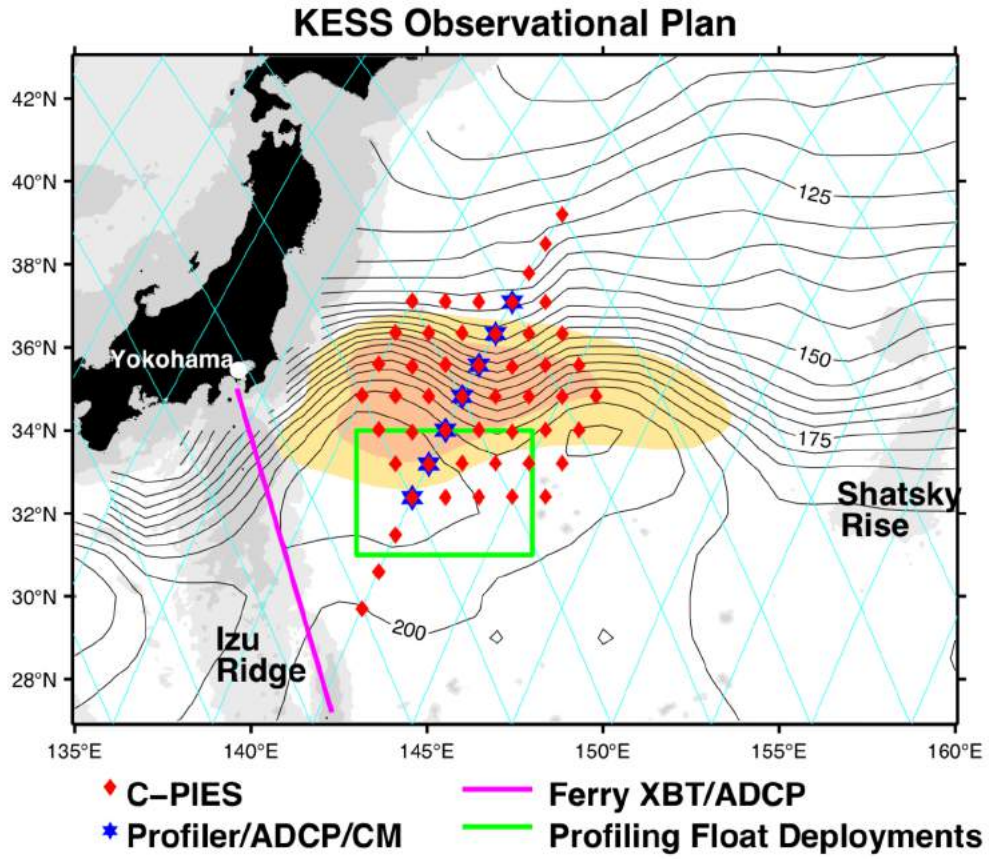
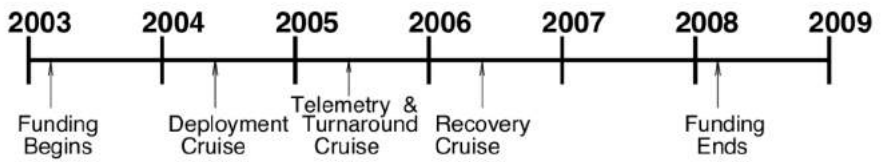


Figure 7: Proposed KESS array of C-PIESs (red diamonds) and MPs (blue stars). Profiling T,S floats will be deployed within the green boxed region. Thin blue lines indicate T/P-Jason 1 ground tracks, the magenta line indicates the TOLEX Ogasawara ferry route. Solid lines are the GDEM mean surface dynamic height contours in dyn cm from Teague et al. (1990). The 2000 and 4000 m isobaths are shaded dark and light gray, respectively. Eddy kinetic energy > 0.18 and 0.24 m^{2}s^{-2} is color shaded yellow and orange, respectively. CTD/SADCP observations will be made at all C-PIES sites and in three feature studies.



Objectives:

https://uskess.whoi.edu/

1) To understand processes coupling the baroclinic and barotropic circulation and variability.

Hypotheses: …

What's needed: Density and velocity time series, with mesoscale resolution to calculate d/dx, d/dy and d/dt of density and velocity. Sufficient vertical resolution to quantify structure of upper-jet baroclinic front and the deep nearly barotropic fields. "Case-studies" of the local dynamical balances, particularly of large-amplitude events.

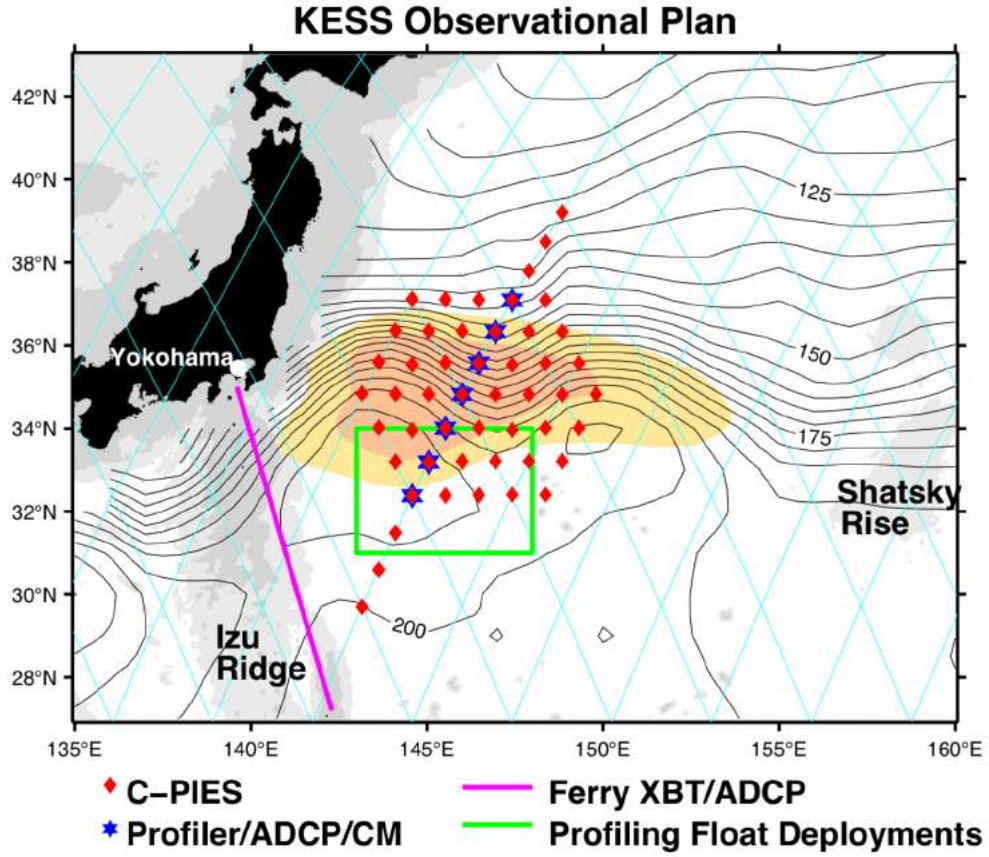
2) To determine and quantify cross-frontal exchange processes in the Kuroshio Extension.

Hypotheses:…

What's needed …

3) To determine the processes that govern the strength and structure of the recirculation gyre – its position, elongation, stratification, and subtropical mode water formation within the gyre.

…



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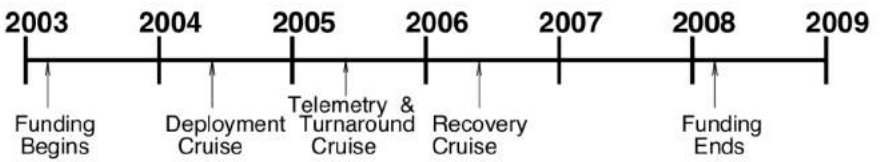
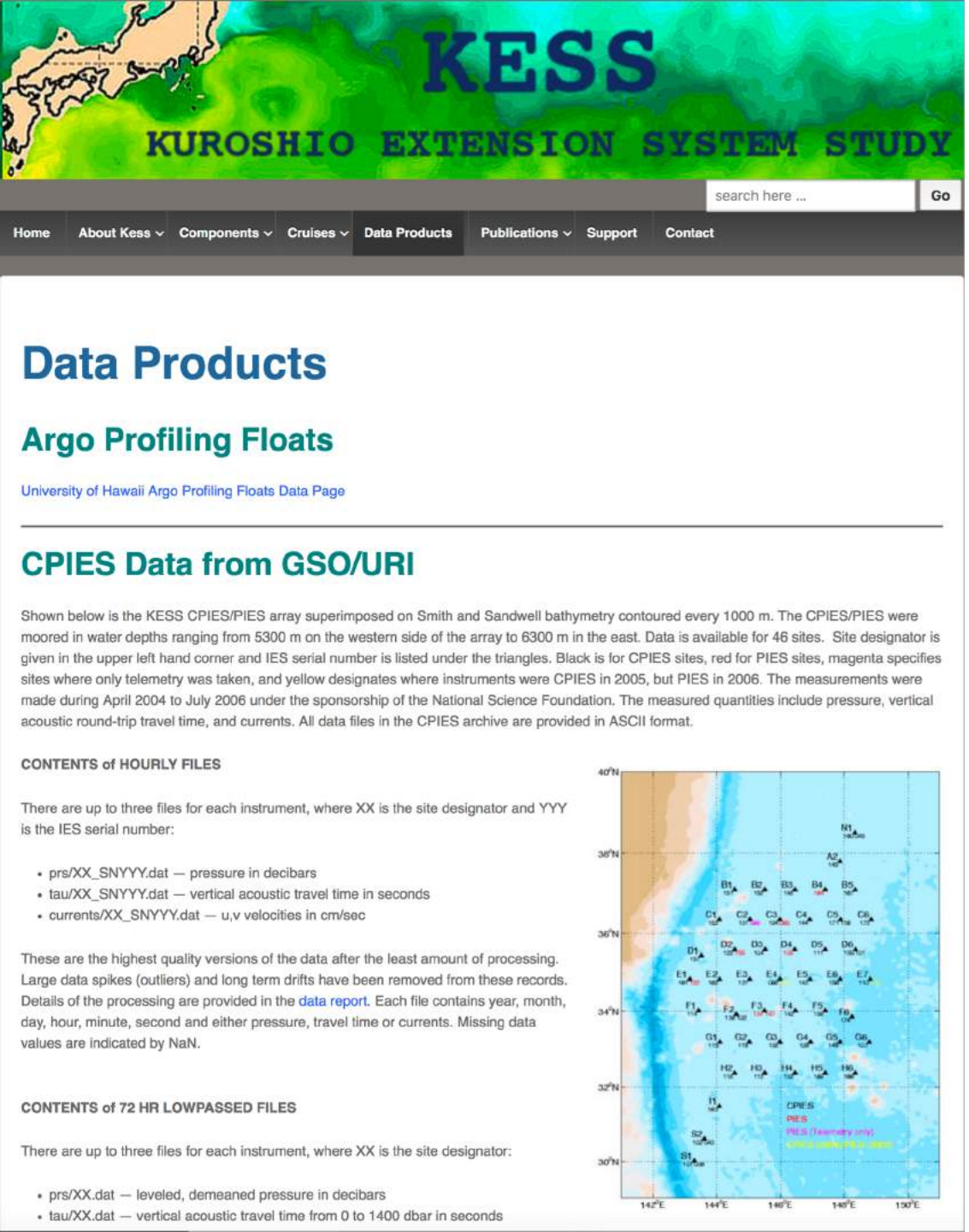
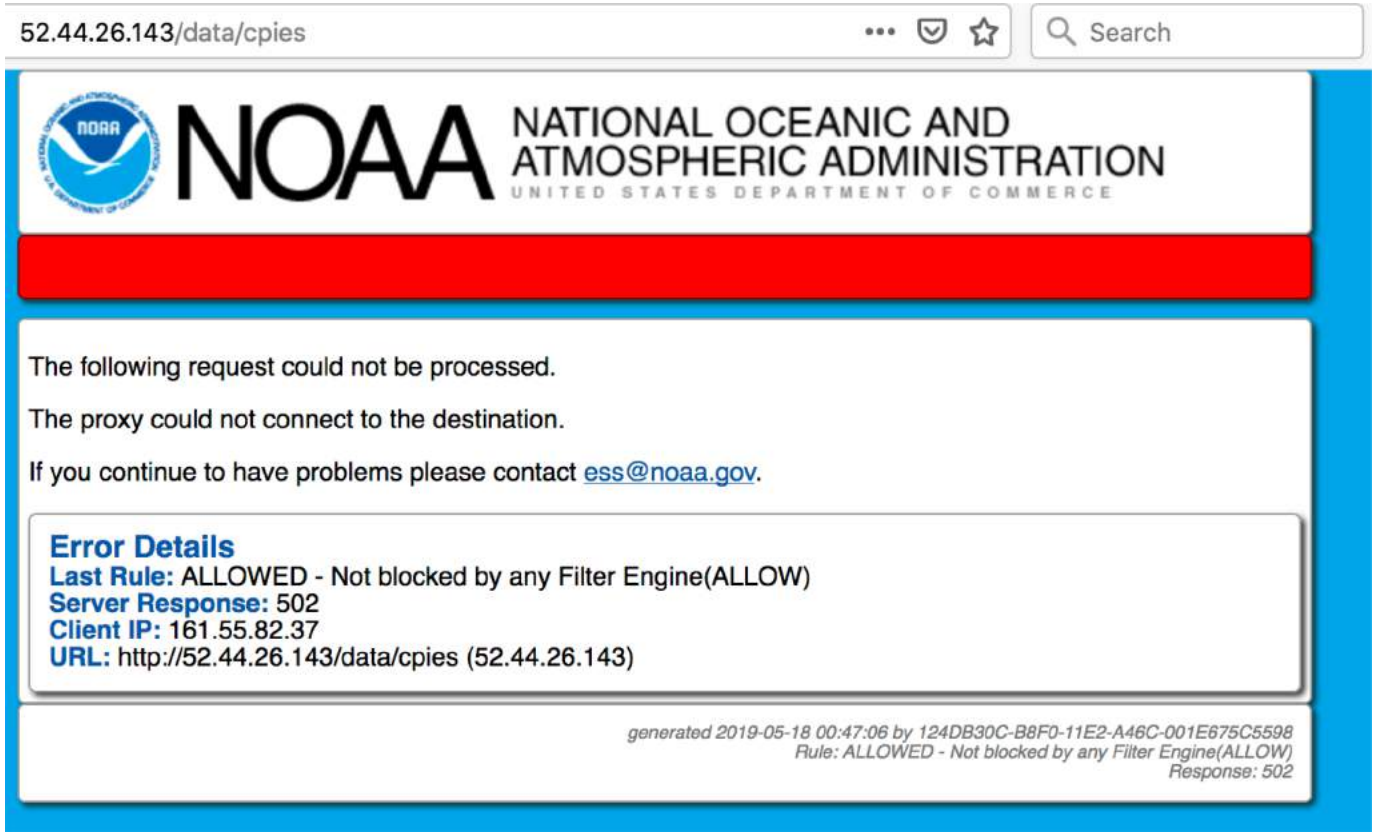
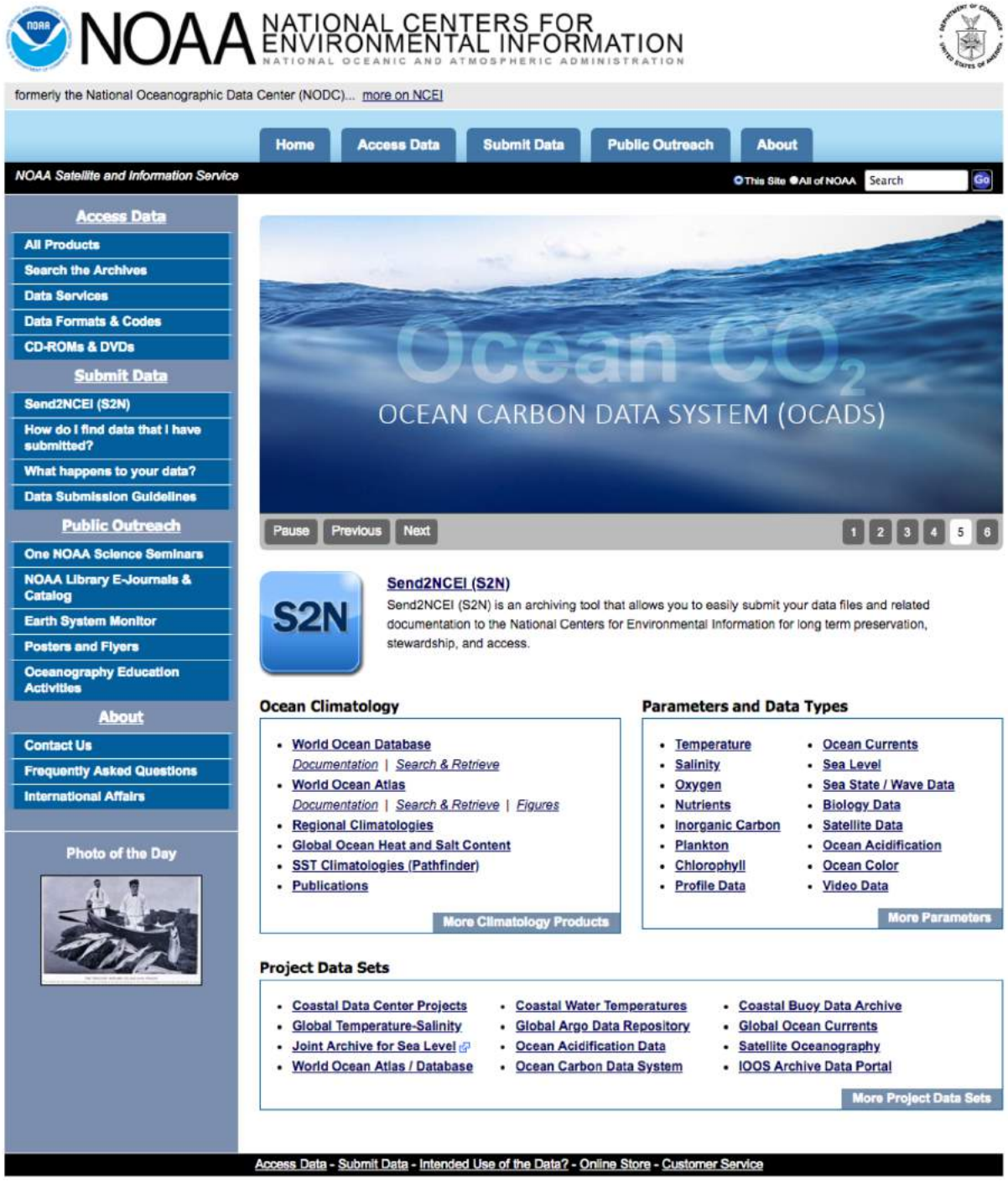


https://uskess.whoi.edu/overview/dataproducts/

Oops! The 2004-2006 process study is done and links to the data on the static website are now broken!







https://www.nodc.noaa.gov/

NOAA National Centers for Environmental Information

The NCEI provides **archival** and access to oceanic, atmospheric, and geophysical datasets from the ocean's bottom to the sun's surface and from million-year-old ice cores to near-real-time satellite retrievals. Limited data from process studies/field campaigns are archived here. Visit https://www.ncei.noaa.gov/

From slide courtesy of Mike Patterson, US CLIVAR director

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formerly the National Oceanographic Data Center (NODC)... more on NCEI

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- Ocean Currents
- Sea Level
- Sea State / Wave Data
- Biology Data
- Satellite Data
- Ocean Acidification
- Ocean Color
- Video Data

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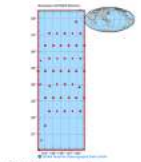
Bottom pressure, vertical acoustic round-trip travel time, and near-bottom currents data collected by Current-and-Pressure-recording Inverted Echo Sounders (CPIES), as part of the Kuroshio Extension System Study (KESS), from 26 April 2004 to 25 June 2006 in the Kuroshio Extension east of Japan (NCEI Accession 0073269)



Preview graphic

This data set contains Current and Pressure recording Inverted Echo Sounder (CPIES) measurements collected during the Kuroshio Extension System Study (KESS) under the sponsorship of the National Science Foundation. The measurements were taken between April 2004 and June 2006. Data are from 46 sites. The measured quantities include bottom pressure, vertical acoustic round-trip travel time and near-bottom currents.

Dataset Citation | Dataset Identifiers | ISO 19115-2 Metadata

Access | Time & Location | Documentation | Description | Credit | Keywords | Constraints | Lineage

Download Data	HTTPS *(download)* Navigate directly to the URL for data access and direct download. FTP *(download)* These data are available through the File Transfer Protocol (FTP). You may use any FTP client to download these data.
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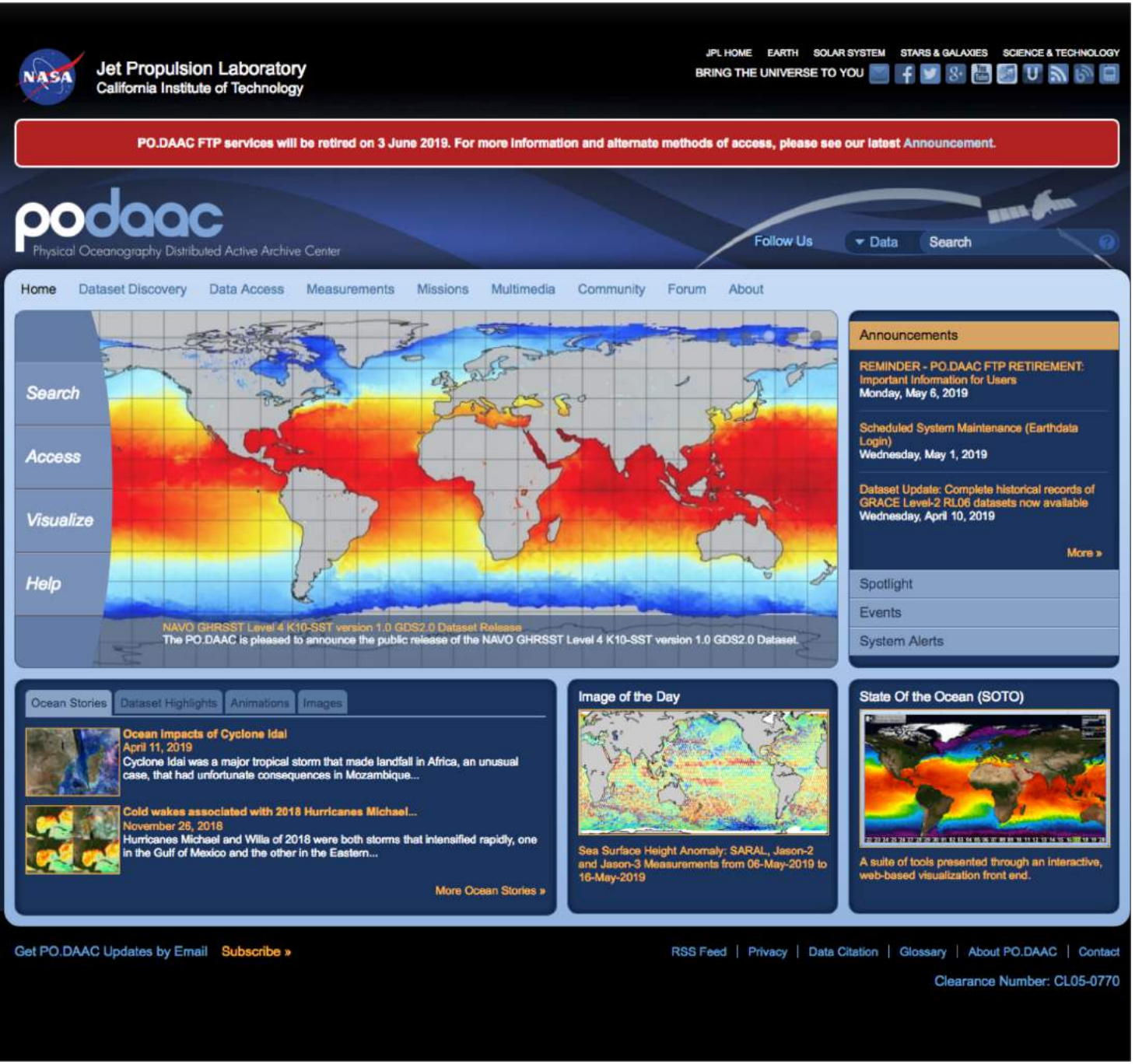
KESS | Highlight All | Match Case | Whole Words | 1 of 3 matches

Let’s see if we can get to the SPURS data….



NASA Earth Observing System Data and Info Service (EOSDIS) and the Physical Oceanography Distributed Active Archive Center (PODAAC)

NASA PO.DAAC preserves and provides access to NASA’s ocean and climate data. Data from NASA-sponsored process studies/field campaigns (e.g., SPURS) are archived here. Visit https://podaac.jpl.nasa.gov/

From slide courtesy of Mike Patterson

Searching on “SPURS” in PODAAC brings up 3 pages of data from SPURS-1 and SPURS-2. Notice nice organization of data in left bar !

podaac
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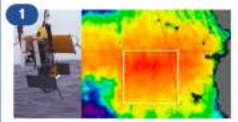
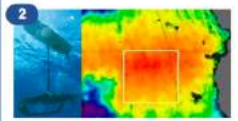
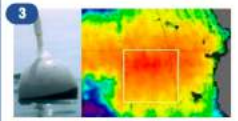
1 

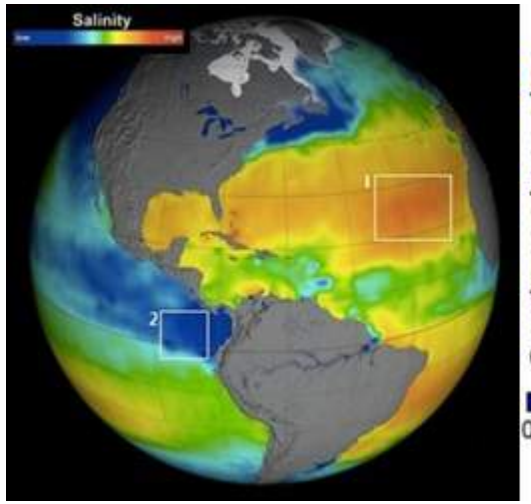
Seasoar CTD data for the SPURS-1 N. Atlantic field campaign (SPURS1_SEASOAR)
Ocean Temperature, Salinity/Density, Salinity/Density
Platform/Sensor: Seasoar/CTD
Processing Level: 2
Along/Across Track Resolution: 0 km x 0 km
Start/End Date: 2013-Mar-22 to 2013-Apr-8
Description: The SPURS (Salinity Processes in the Upper Ocean Regional Study) project is an oceanographic process study and associated field program that aim to elucidate key mechanisms responsible ... more

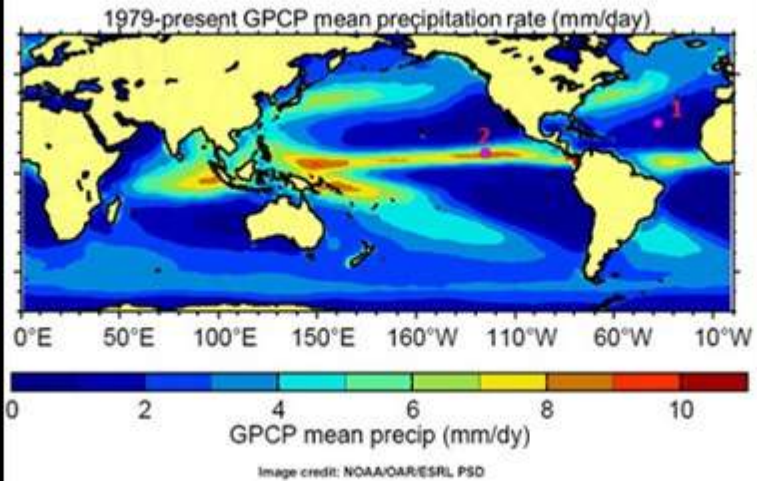
2 

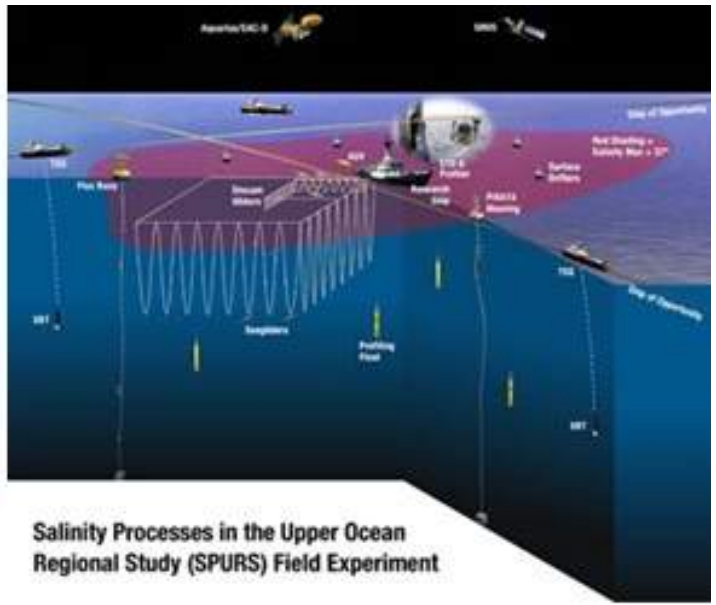
Waveglider data for the SPURS-1 N. Atlantic field campaign (SPURS1_WAVEGLIDER)
Ocean Winds, Ocean Temperature, Ocean Temperature, Salinity/Density, Ocean Circulation, Ocean Pressure, Salinity/Density
Platform/Sensor: Waveglider/MMS , Waveglider/CURRENT METERS , Waveglider/CTD
Processing Level: 2
Along/Across Track Resolution: 0 km x 0 km
Start/End Date: 2012-Sep-1 to 2013-Mar-25
Description: The SPURS (Salinity Processes in the Upper Ocean Regional Study) project is an oceanographic process study and associated field program that aim to elucidate key mechanisms responsible ... more

3 

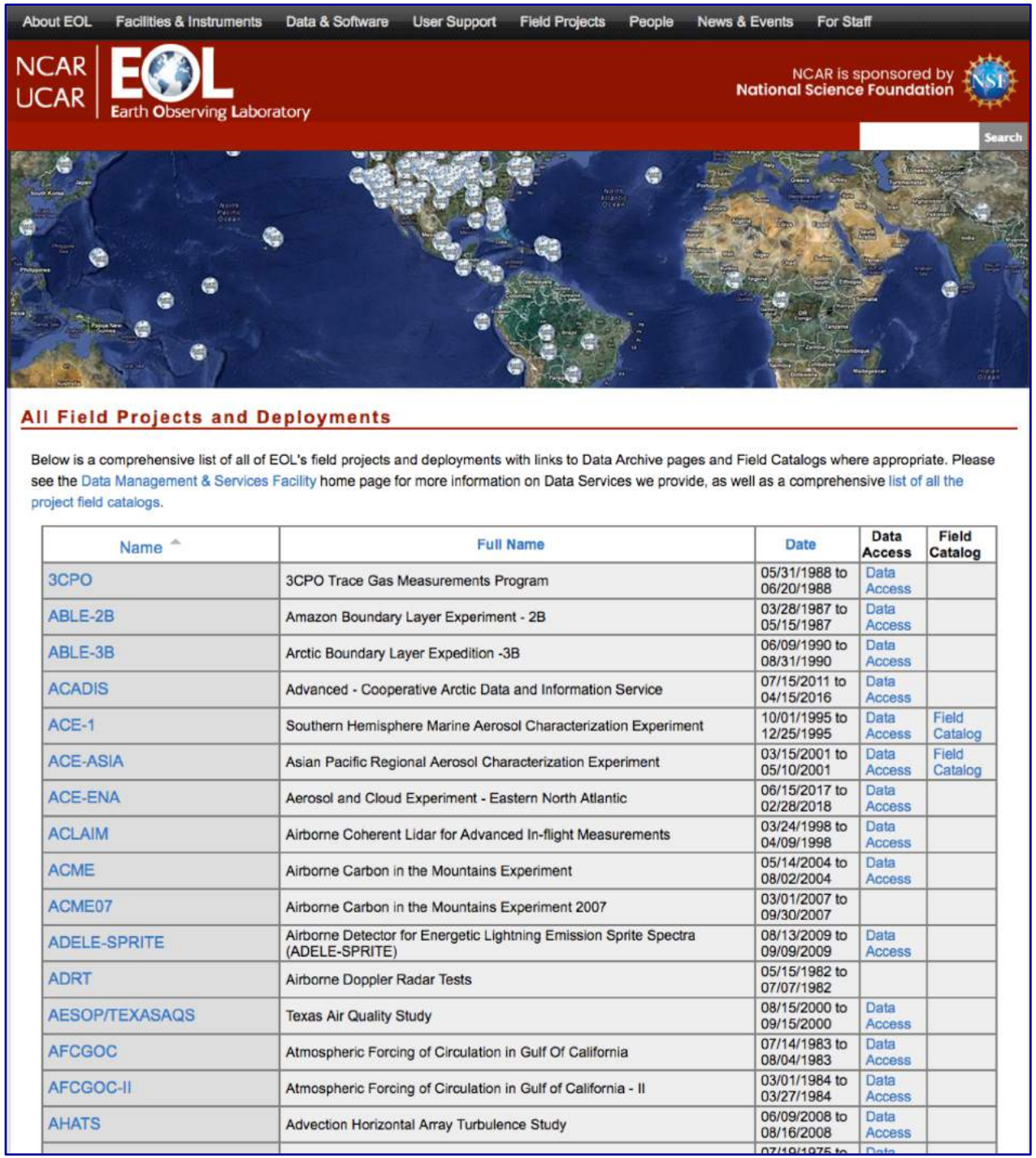
Drifter data for the SPURS-1 N. Atlantic field campaign (SPURS1_DRIFTER)
Ocean Temperature, Salinity/Density
Platform/Sensor: Drifter/CTD
Processing Level: 2
Along/Across Track Resolution: 0 km x 0 km
Start/End Date: 2011-Oct-19 to 2014-Apr-10
Description: The SPURS (Salinity Processes in the Upper Ocean Regional Study) project is an oceanographic process study and associated field program that aim to elucidate key mechanisms responsible ... more







SPURS (Salinity Processes in the Upper Ocean Regional Study) aimed to resolve key mechanisms responsible for near-surface salinity variation.



NCAR Earth Observing Laboratory

The EOL Data Archive provides archival and access to atmospheric, oceanographic, and other geophysical datasets from scientific process studies/field campaigns for which NCAR/EOL has provided data management support.

Visit https://www.eol.ucar.edu/all-field-projects-and-deployments

From slide courtesy of Mike Patterson, US CLIVAR director

DYNAMO 2011-2012

DATA BY CATEGORY

- Accompanying Archives
- Aerosols
- Aircraft
- Ancillary
- Chemistry
- Cloud Properties
- Flux
- Hydrology
- Intercomparison
- Land Based
- Lightning
- Model
- Oceanography
- Photography
- Radar
- Radiation
- Satellite
- Ship Based
- Upper Air

DATA BY SITE

- Diego Garcia
- Maldives

Back to DYNAMO

Email comments & questions to *codiac@ucar.edu*

Oceanography		
DYNAMO SeaSoar (Leg 1) Data [Lien, Moum (APL, UnivOfWashington, OSU)]		
IMD Kalpana SST Imagery [(NCAR-EOL)]	2012-11-20	
Microwave/Infrared Satellite-Derived 9km Sea Surface Temperature Data [(REMSS)]	2012-09-28	Document
MODIS Ocean Color and Sea Surface Temperature Products [(NASA)]	2012-04-24	Document
NESDIS Ocean Surface Products [(NESDIS-STAR)]	2012-04-24	Document
NOAA P-3 Airborne eXpendable Bathythermographs (AXBT's) [Wang, Q. (NPS)]	2013-09-23	Document
NOAA P-3 Airborne eXpendable Conductivity Temperature and Depth Probe (AXCTD) Data [Wang, Q. (NPS)]	2013-09-23	Document
NOAA P-3 Corrected Radiometric SST Data [D. Khelif (University of California-Irvine)]		
NOAA POES SST and Anomaly Imagery [(NCAR-EOL)]	2012-11-20	
OSCAR Ocean Surface Current Data [(NASA-PO.DAAC)]	2012-08-30	Document
R/V Baruna Jaya SST Data [Yoneyama, Kunio (JAMSTEC)]	2012-08-02	Document
R/V Mirai ADCP Shipboard Data [Katsumata, M. (JAMSTEC)]	2013-02-19	Document
R/V Mirai ADCP Sub-surface Mooring Data [Katsumata, M. (JAMSTEC)]	2013-02-28	Document
R/V Mirai Biogeochemical Sampling Data [Yoneyama, K. (JAMSTEC)]	Updated 2013-06-06	Document
R/V Mirai CTD Data [Yoneyama, K. (JAMSTEC)]	2013-02-28	Document
R/V Mirai LADCP Data [Richards, K. (IPRC-UH)]	2013-02-28	Document
R/V Mirai MBES Bathymetry Data [Yoneyama, K. (JAMSTEC)]	2013-05-29	Document
R/V Mirai Oceanic Microstructure Profiling Data [Katsumata, M. (JAMSTEC)]	2013-02-28	Document
R/V Mirai Sea Surface Water Data [Yoneyama, K. (JAMSTEC)]	2013-02-28	Document
R/V Mirai XCTD Data [Katsumata, M. (JAMSTEC)]	2013-02-28	Document
R/V Roger Revelle CTD Data [Moum, J. (Oregon State University)]	2013-03-13	
R/V Roger Revelle Expendable Bathythermograph (XBT) Data [Moum, J. (Oregon State University)]	2015-09-04	
R/V Roger Revelle Flux, Near-Surface Meteorology, and Navigation Data [Edson, Jim, Chris Fairall, Simon De Szoeke (U. Conn, ESRL-PSD, OSU)]	2012-08-07	Document
R/V Roger Revelle Seaglider Data [Matthews, A. J. (UEA)]	2012-08-02	
R/V Sagar Kanya CTD Data [Kumar, S. Prasanna (NIO)]	2013-02-28	Document
Shipboard Automated Meteorological and Oceanographic System (SAMOS) Data Center [(FSU)]		Document
Oceanography: Buoy		
Argo Float Data [Yamada, H (JAMSTEC)]	2012-08-02	Document
DYNAMO Moorings Surface and Subsurface Data [Lien, Moum (APL, UnivofWashington, OSU)]	2013-02-19	
GTS LDM Ship and Buoy Observation Data (Global, ASCII) [(NCAR-EOL)]	2012-08-09	Document

NCAR Earth Observing Laboratory

Selecting a specific field project takes you to the list of accessible data sets by category, platform, data type, lead scientist, and institution.

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This example shows data from DYNAMO (Dynamics of Madden Julian Oscillation) process study that took place in the tropical Indian Ocean in 2011-2012.

From slide courtesy of Mike Patterson, US CLIVAR director

Using data from historical process studies

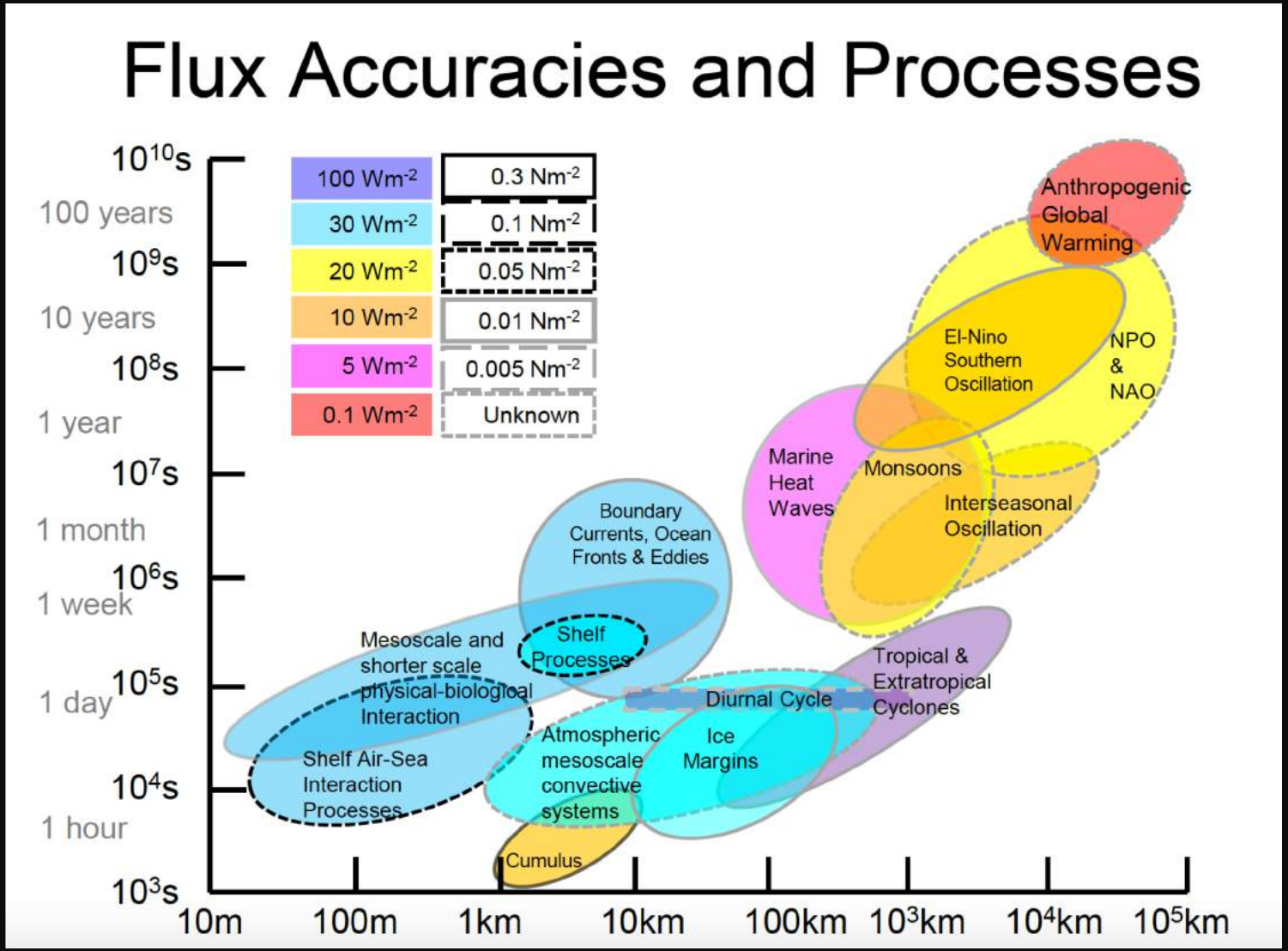
- Learn about process studies by going to US CLIVAR website & process study website.

- Access data from process study website or from national data archive (e.g. NOAA's NCEI, NASA's EOSDIC & PODAAC, NSF's NCAR EOL).

- Reach out to the process study PIs.

Air-Sea Fluxes with a focus on Heat and Momentum

Meghan F. Cronin, Chelle L. Gentemann, James Edson, Iwao Ueki, Mark Bourassa, Shannon Brown, Carol Anne Clayson, Chris Fairall, Tom Farrar, Tatsuya Fukuda, Sarah Gille, Sergey Gulev, Simon Josey, Seiji Kato, Masaki Katsumata, Elizabeth Kent, Marjolaine Krug, Peter Minnett, Rhys Parfitt, Rachel T. Pinker, Paul Stackhouse, Sebastiaan Swart, Hiroyuki Tomita, Douglas Vandemark, Robert Weller, Kunio Yoneyama, Lisan Yu, Dongxiao Zhang



Goals for 2030:

Gridded Air-Sea fluxes with 1-day random uncertainties of:

15 W m^{-2} (5%) & 0.01 N m^{-2} (5%)

And Biases less than:

5 W m^{-2} & 0.005 N m^{-2}

For: 3-hourly at 25 km

Aspirational goal: 1-hrly at 10km

Flux EOV/ECV	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Bulk SST	Partially met												Adequate
Skin Temperature	Partially met												Adequate
Wind Speed and Direction	Partially met												Adequate
Air Temperature	Not met												Adequate
Humidity	Not met												Adequate
Bulk Surface Currents	Partially met												Adequate
Skin Surface Currents	Not met												Adequate
Surface Solar Radiation	Partially met												Adequate
Surface Longwave Radiation	Partially met												Adequate
Albedo	Partially met												Met
Sea State	Requirement Unknown												Requirement Known

	Requirement not met / inadequate
	Requirement partially met / threshold
	Requirement adequately met / breakthrough
	Requirement fully met / ideal goal

Need more than 10 essential ocean & climate variables to compute air-sea heat fluxes.

$$Q_{net} = Q_{SW} - Q_{LW} - Q_{lat} - Q_{sen}$$

Sensible heat flux

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

Air density; Air specific heat capacity; Turbulent exchange coefficient; Wind speed rel. sfc; Sea-air temperature difference

Latent heat flux

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

Air density; Latent heat of vaporization; Turbulent exchange coefficient; Wind speed rel. sfc; Sea-air humidity difference

OCEAN OBS'19

Air-Sea Fluxes with a focus on Heat and Momentum

Two Big Asks:

(1) Improved space-based near-surface retrievals of surface humidity and air temperature.

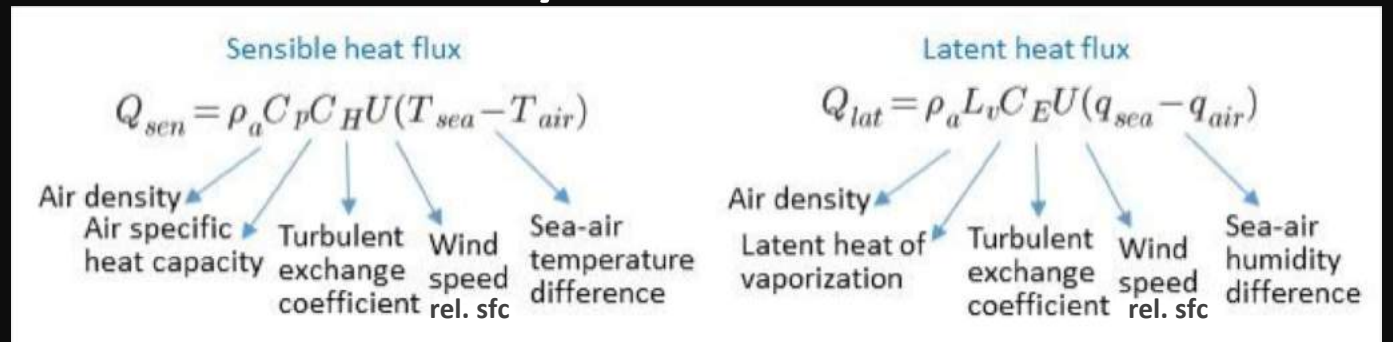
(2) Regionally distributed in situ network of flux observations, built around an expanded OceanSITES network of reference stations.

(1) Improved space-based near-surface retrievals of surface humidity and air temperature.

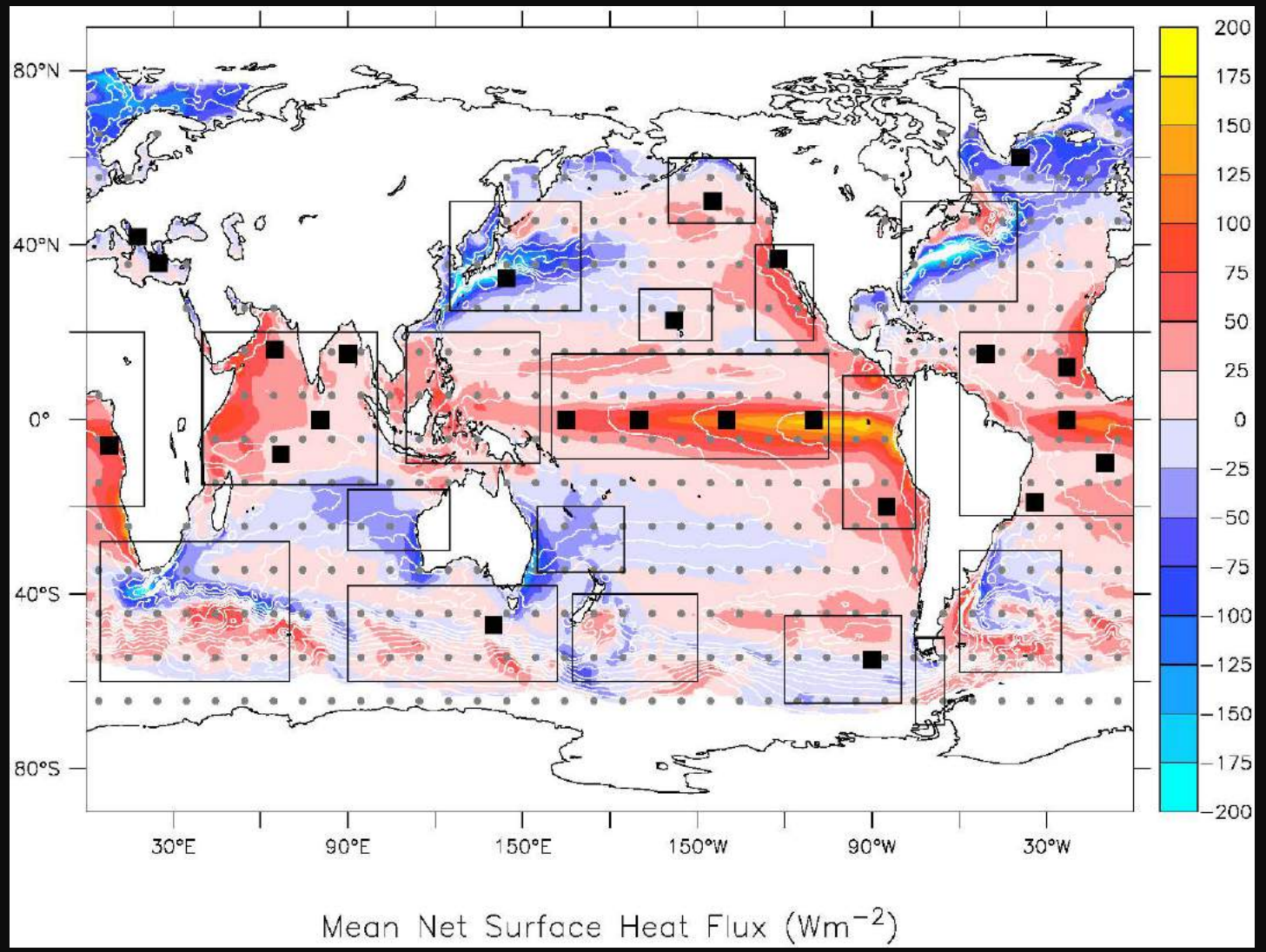
Improved vertical resolution and accuracy of temperature and humidity profiles. *This could be done for example by combining a 5-channel C- to Ka-band digital radiometer with a 50 and 183 GHz hyperspectral digital sounder.*

Improved algorithms relating near-surface retrievals to surface humidity and air temperature.

Simultaneous retrievals of SST, surface wind speed and direction, and profiles of near-surface air temperature and humidity (as well as rain, water vapor, soil moisture, sea ice concentration).



(2) Regionally distributed in situ network of flux observations, built around an expanded OceanSITES network of reference stations.



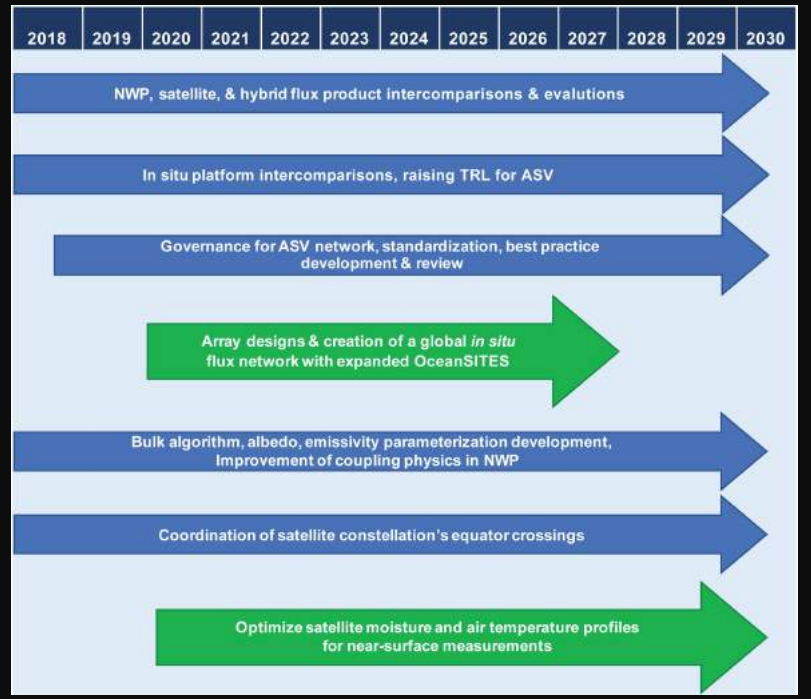
Cronin et al. OO'19 Community Whitepaper

Roadmap for Expansion of *in situ* Array

- Evaluate **cross-platform**, **cross-product**, & **ocean vs. land-based** comparisons to quantify uncertainties and **improve best practices** and **model physics and parameterizations**.
  - Ocean & Land **Baseline Surface Radiation Network (BSRN)?**
- Form an international **Autonomous Surface Vehicles (ASV) expert group** to coordinate data stream, evaluate data, and develop best practices and standardizations.
- Perform **array design studies** and **pilot studies** to raise Technical Readiness Levels for flux platforms.
- **Improve bulk algorithms**, including role of sea state, and parameterizations of albedo and emissivity.
- Improve **coupling physics in NWP**.

Roadmap for Optimization of Satellite Retrievals

- Improve **resolution of satellite retrievals, time coincidence** of remotely-sensed flux EOVs/ECVs, and **algorithms** relating retrievals to near-surface conditions.
- Improve parameterizations for transforming bulk EOV/ECV into bulk algorithm state variables.



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