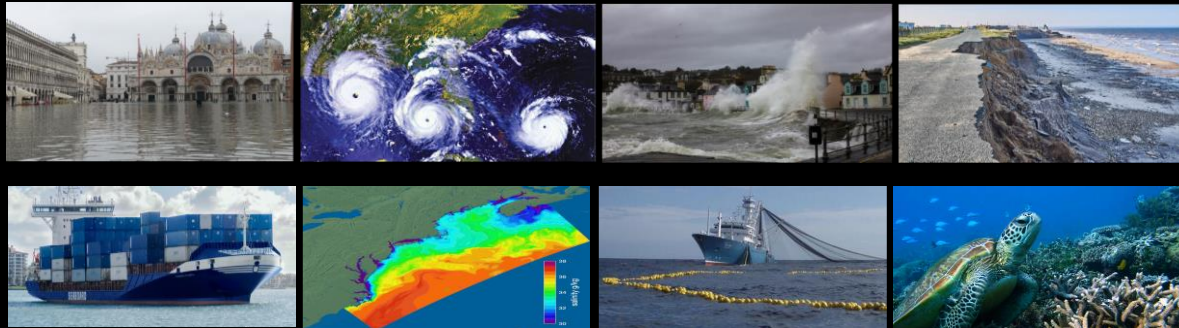# Satellite Altimetry for Ocean and Coastal Applications for Societal Benefit

V. Tsontos & M. Srinivasan

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Review Paper – "Oceans From Space" 2022 Conference Special Issue

remote sensing

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Satellite Altimetry for Ocean and Coastal Applications: A Review

by   Margaret Srinivasan [*]   and   Vardis Tsontos

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

[*] Author to whom correspondence should be addressed.
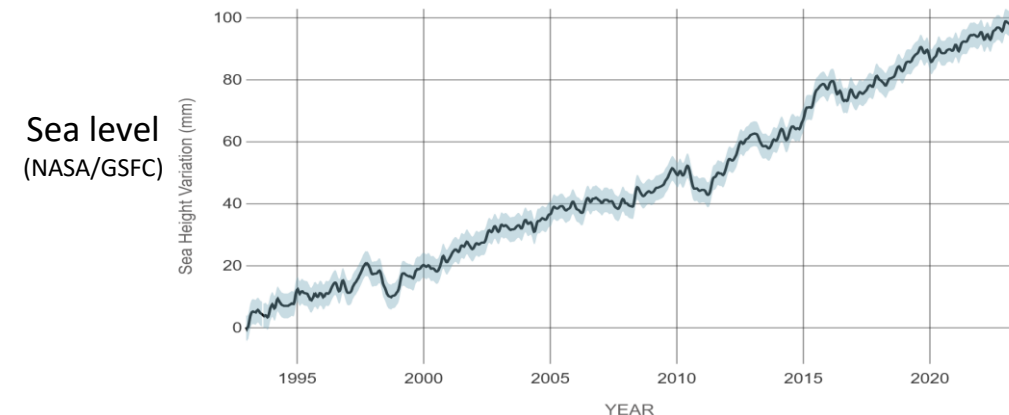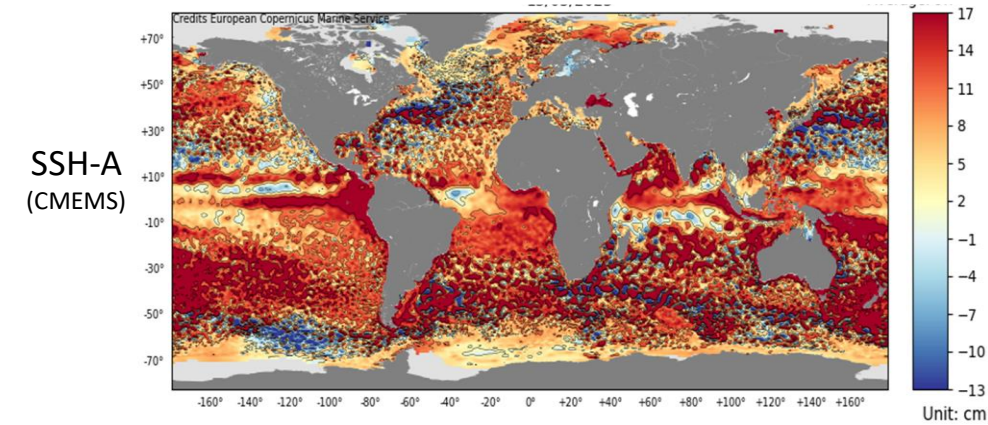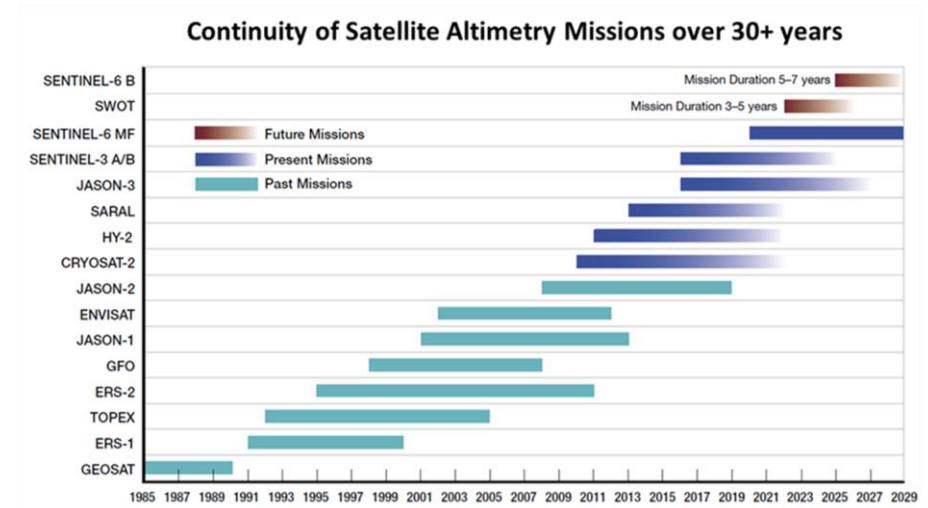
Download ⌄   Browse Figures   Review Reports   Versions Notes

Abstract

More than 30 years of observations from an international suite of satellite altimeter missions continue to provide key data enabling research discoveries and a broad spectrum of operational and user-driven applications. These missions were designed to advance technologies and to answer scientific questions about ocean circulation, ocean heat content, and the impact of climate change on these Earth systems. They are also a valuable resource for the

Continuity & Contributions of Satellite Radar Altimetry

- 30+ years of reference nadir radar satellite altimetry missions

- Continuity via successful partnerships between NASA, NOAA, CNES and other space agencies

- Cross-calibrated, global climate data record of key variables:
    - SSH/A, SWH, Surface wind speed
    - sea ice height/thickness
    - water topography on large lakes and rivers

- Instrumental to improved scientific understanding:
    - global ocean circulation dynamics
    - sea level change
    - water cycle processes

- Enables a growing number practical decision support applications involving operational government agencies and the private sector

Continuity of Satellite Altimetry Missions over 30+ years

SSH-A (CMEMS)

Sea level (NASA/GSFC)

Applications of Earth Observations for Societal Benefit

DATA

Satellite & In-situ
Observation Integration

Analysis

Models
Process, Statistical, ML/AI

Information

Synthesis
Products & Tools

DECISIONS

Operational
Applications
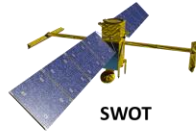
Coastal Hazards: Storm surge, Flooding & Sea Level Rise

Spatial Planning for Resilience, Early Warning and Disaster Mitigation
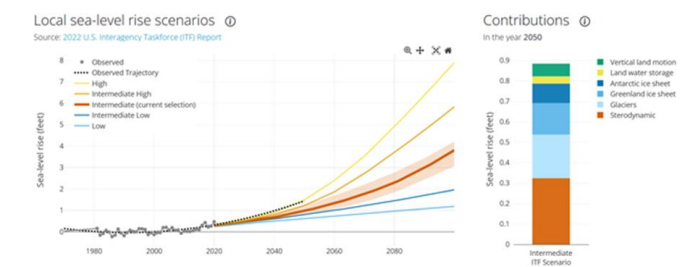
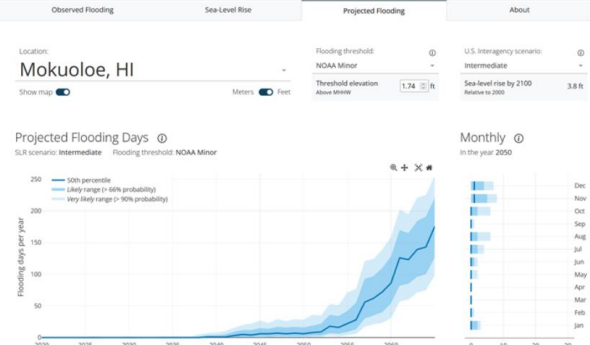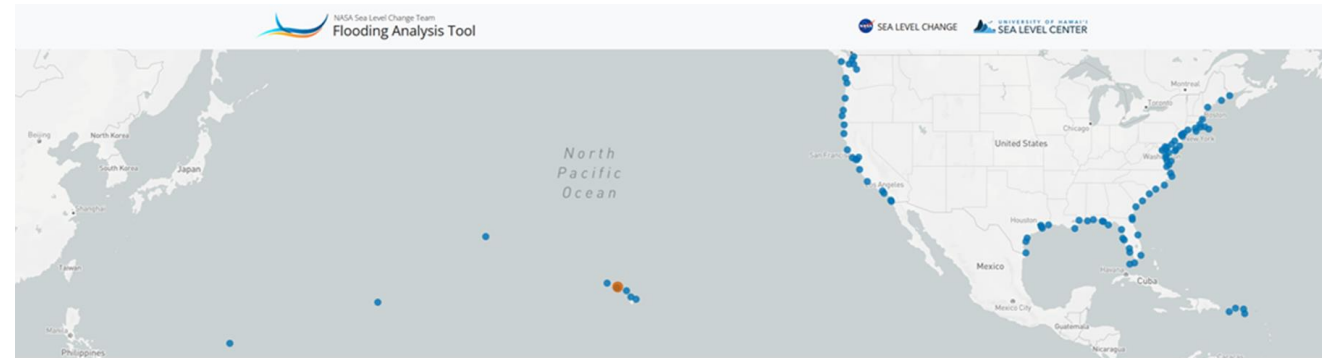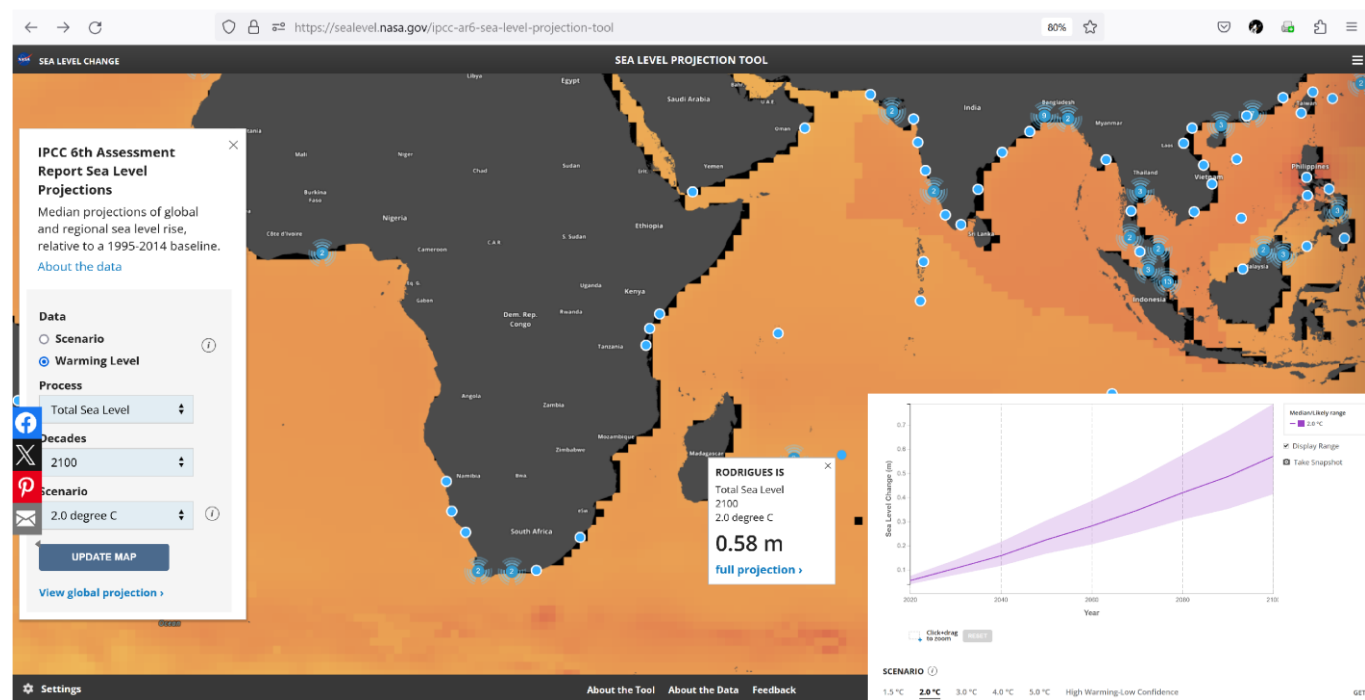# Coastal Flooding & Sea Level Rise (1/4)

- Inclusion of altimetry data in coastal inundation and sea level rise projection models

- Critical for evaluating risk to coastal infrastructure and communities and spatial planning for both government agencies and private sector (eg. insurance industry)

- Importance of tools for communicating projected future states (with uncertainties) and likely coastal impacts under varying scenarios to both managers and the broader public

    https://sealevel.nasa.gov/climate-tools/

    - *IPCC AR6 Sea Level Projection Tool*
    - *Interagency Sea Level Rise Scenario Tool*
    - *Flooding Analysis Tool*

- Simple web-based interfaces for selecting scenarios, exposing model result and charting time series projections at interactively selected mapped point locations

Coastal Flooding & Sea Level Rise
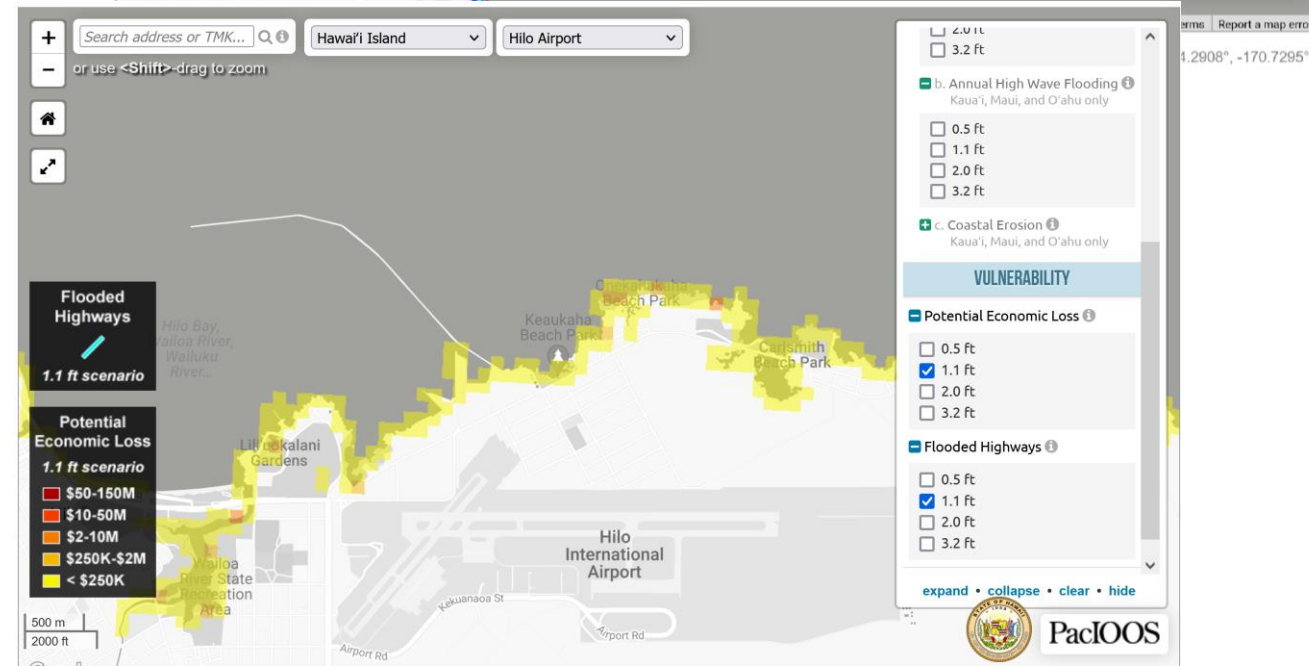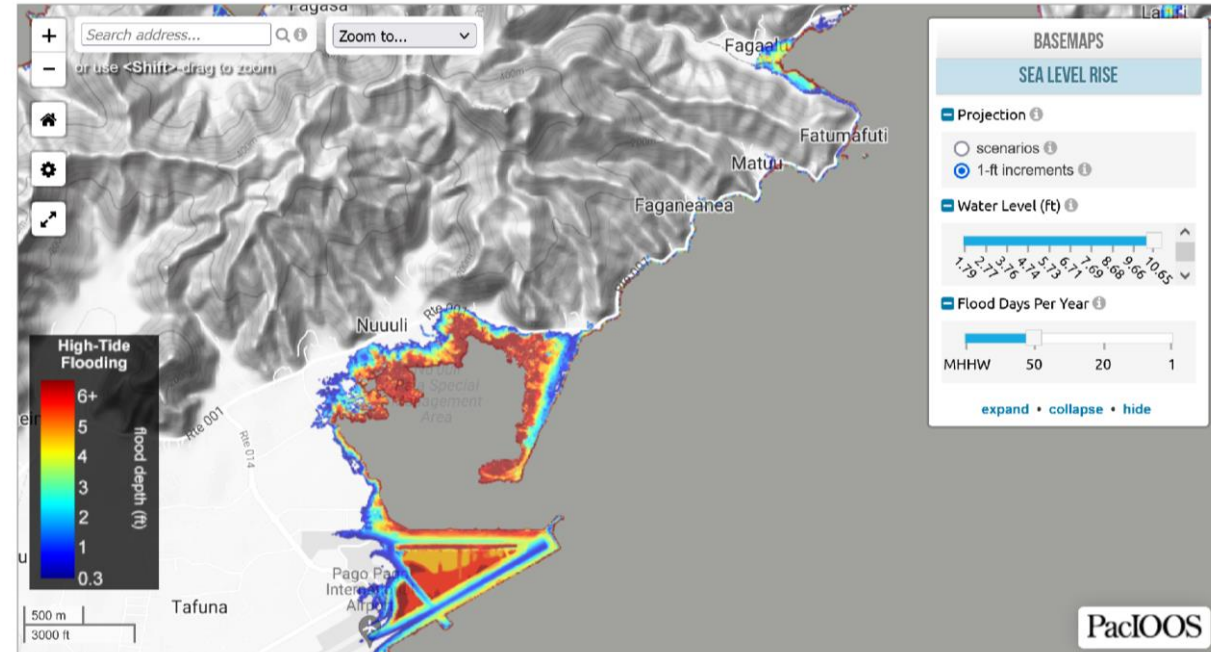
Sea Level Rise Viewer Tool

- Integrated into Regional US-IOOS operational data portal portals (eg. PacIOOS)

- Visualize likely shoreline change from coastal flooding, sea level rise, storm surge and high tides

- Show complimentary information on inundation spatial coverage extent and estimated economic impacts

- Essential component in future planning to assess the short and long-term impacts of rising seas and to minimize the risks to coastal communities and infrastructure
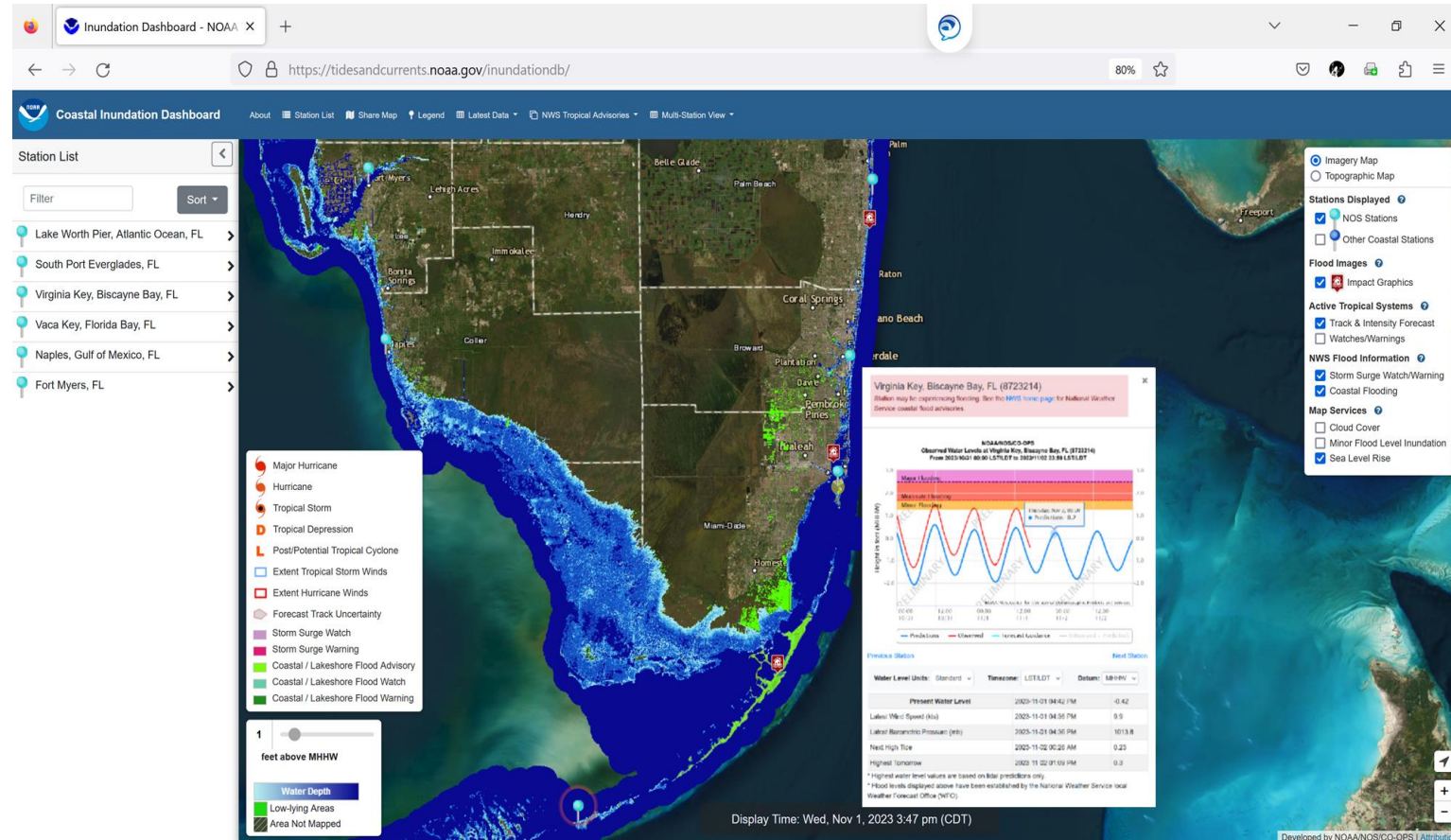
American Samoa Sea Level Rise Viewer
https://www.pacioos.hawaii.edu/shoreline/slr-amsam/

Hawaii Sea Level Rise Viewer
https://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

Coastal Inundation Dashboard

- Provides real-time, forecasted, and historical water level information to understand near-term inundation risks, such as impacts from tropical cyclones, high tide flooding and sea level rise
- Uses NOAA/NWS flood impact thresholds to determine if observed or forecasted water level may result in minor, moderate, or major coastal flooding
- Decision makers can use information to understand/prepare for the effects of coastal flooding sea levels change.
- Access real-time water levels, 48-hour forecasts of water levels for select regions, and historical flooding information at 200+ coastal water level stations
- Monitor water level conditions in the path of a hurricane, nor'easter, or other coastal storm in real time.


https://coast.noaa.gov/digitalcoast/tools/inundation-dashboard.html

Coastal Flooding & Sea Level Rise

USGS
science for a changing world

Coastal Storm Modeling System (CoSMos)

- Dynamic modeling approach for detailed predictions of coastal flooding due to sea-level rise and storms integrated with long-term coastal shoreline evolution

- Models relevant physics of coastal storms (e.g.,tides, waves, and storm surge), and down-scales to local flood projections for use in community-level coastal planning and decision-making.

- Uses wind and pressure from global climate models to project coastal storms under changing climatic conditions.

- Projections of multiple storm scenarios (daily conditions, annual storm, 20-year- and 100-year-return intervals) under a suite of sea-level rise scenarios.

- COSMOS-GW (Groundwater) additionally integrates USGS 3D-MODFLOW results to model scenario impacts to Groundwater

- Available: San Francisco Bay, southern California, central and north-central California coast.

https://www.usgs.gov/centers/pcmsc/science/
coastal-storm-modeling-system-cosmos
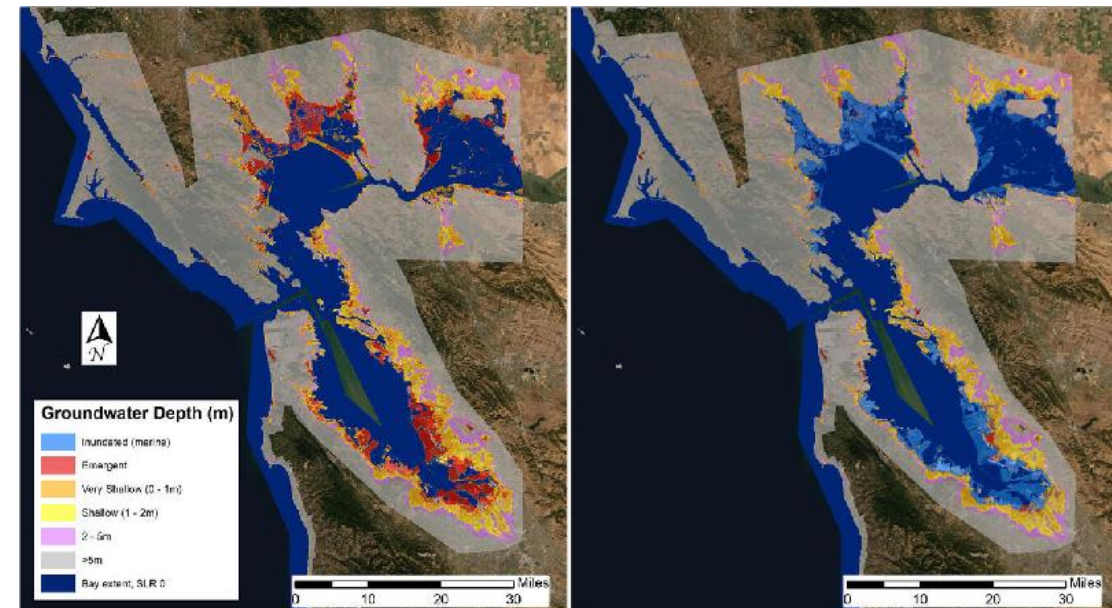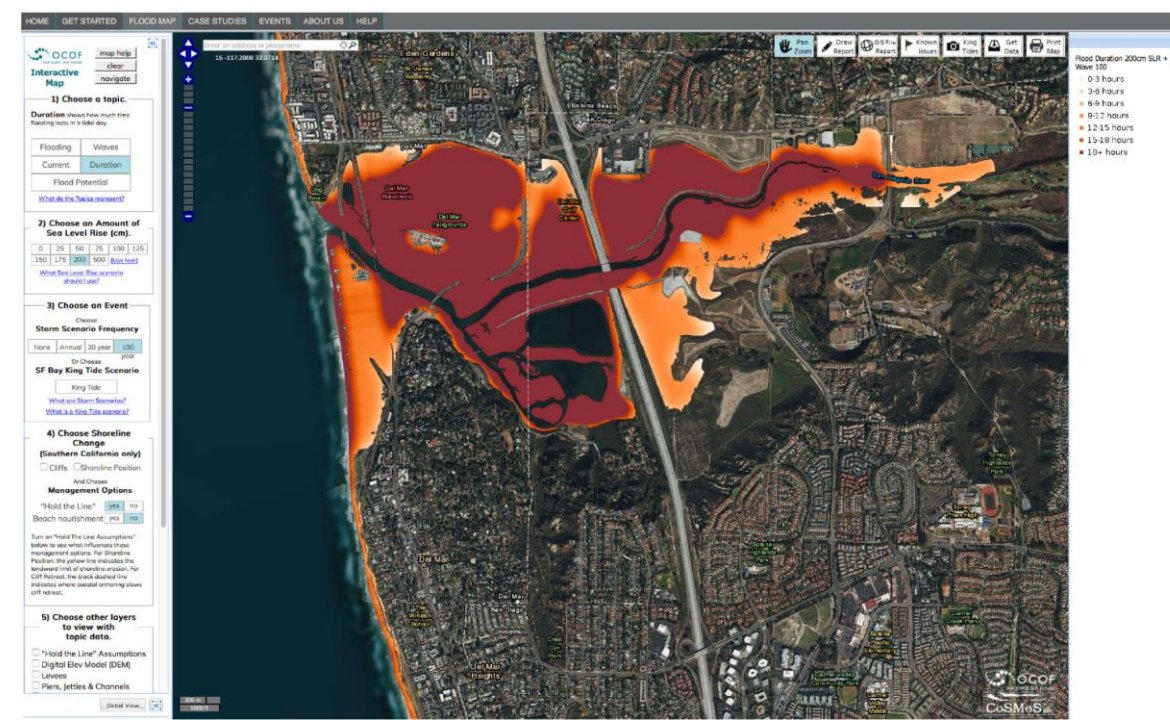
Tropical Cyclone Forecasting

Early Warning for Emergency Response

NWS/NCEP Operational Hurricane Forecast System Ocean Data Assimilation

- Hurricane Weather Research and Forecasting (HWRF)- Hybrid Coordinate Ocean Model (HYCOM) and Wave Watch III coupled modeling systems

- Assimilate multi-mission Nadir-Altimeter data in addition to Satellite SST, SSS and in-situ observations

- Short term forecasts of the strength and trajectory of individual hurricanes

- Longer-term seasonal forecasts of expected numbers and strengths of hurricanes

- Basis of agency emergency response planning and public advisories

Sea Surface Height
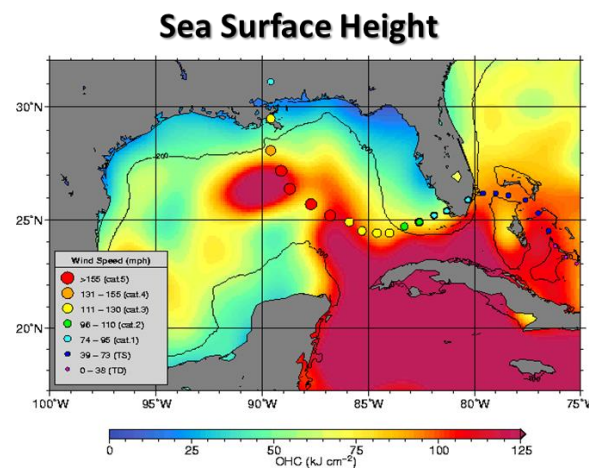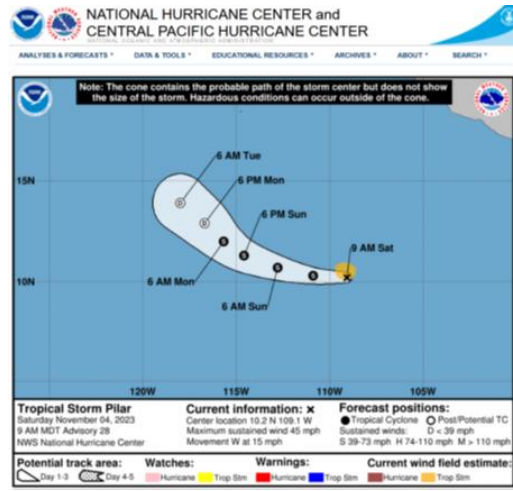
SST:
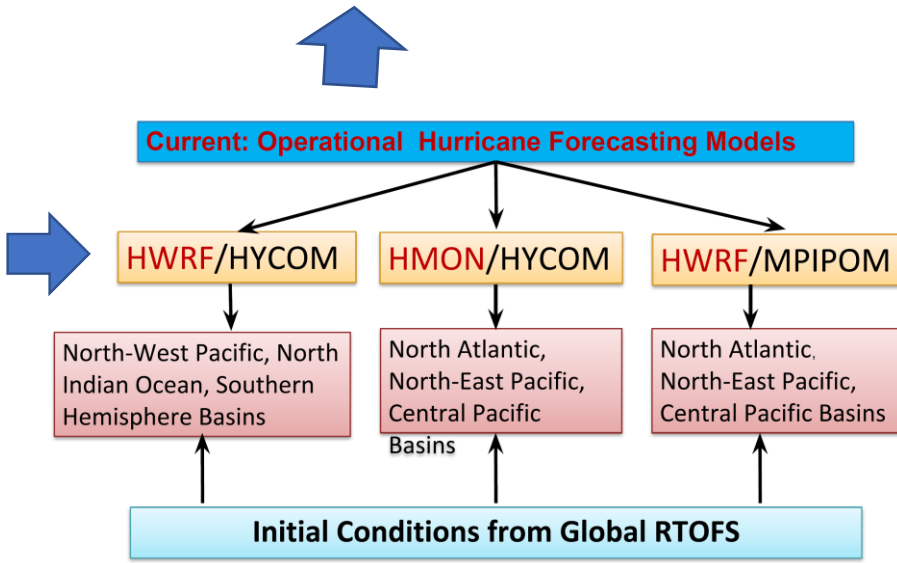METOP, NPP, JPSS, GOES, HIMAWARI, Ship, Buoy
SSS:
SMAP, SMOS, Buoy
Profile Temp/Salt:
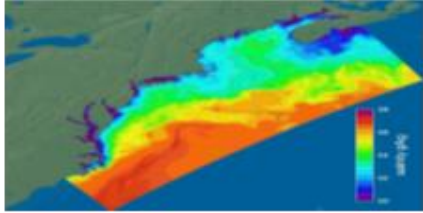XBT, CTD, Argo Floats, Buoy, Gliders, ALAMO, Animal-borne sensors, Saildrone
Altimeter SSH:
Jason, CryoSat, Altika, Sentinel
Sea Ice:
SSMI/S, AMSR
Velocity:
ADCP, Drifters, Gliders

Current: Operational Hurricane Forecasting Models

HWRF/HYCOM	HMON/HYCOM	HWRF/MPIPOM
North-West Pacific, North Indian Ocean, Southern Hemisphere Basins	North Atlantic, North-East Pacific, Central Pacific Basins	North Atlantic, North-East Pacific, Central Pacific Basins

Initial Conditions from Global RTOFS

Source: A. Mehra NOAA/NWS/EMC

Marine Safety & Navigation
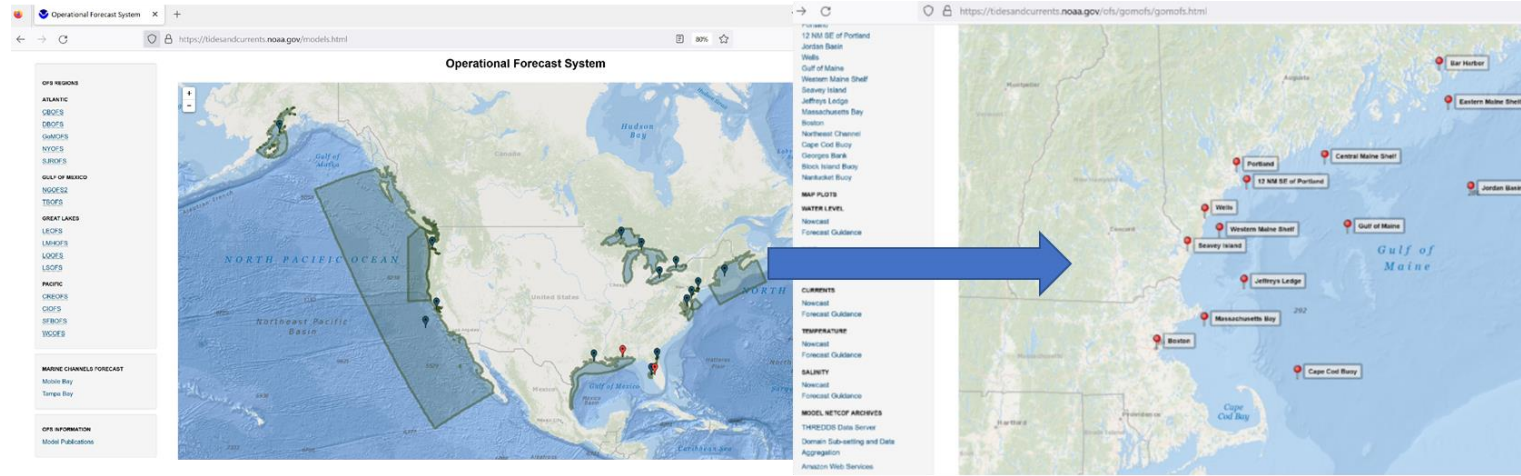
Circulation and Wave Model-based Systems

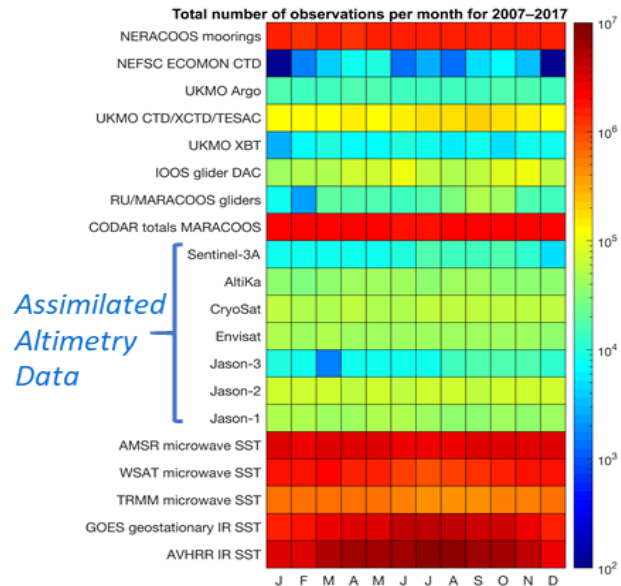# National network of Operational Nowcast & Forecast Hydrodynamic Model Systems (OFS).

- State-of-the-art regional hydrodynamic models driven by real-time observing system data (meteorological, oceanographic, river flow rate) and satellite observations.
- Delivers nowcast & short-term (0 hr. - 72 hr.) forecast predictions of key parameters (e.g., water levels, currents, salinity, temperature, waves).
- GoMOFS based on Rutgers University's Regional Ocean Modeling System (ROMS).
- Forecasts support the maritime user community in navigation, emergency response, ecological applications
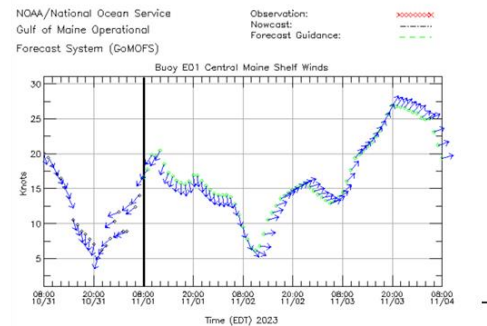
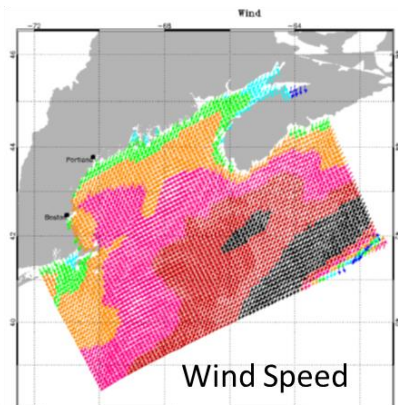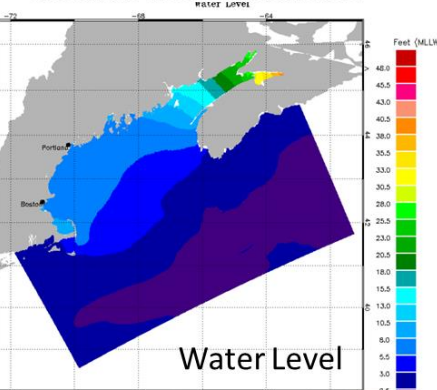**NOAA Operational Forecast System (OFS)** **Gulf of Maine OFS – Rutgers ROMS Model**

https://tidesandcurrents.noaa.gov/models.html

Total number of observations per month for 2007–2017

Gulf of Maine (GOMOFS)

Gulf of Maine OFS Water Level Nowcast

Water Level

Wind Speed

Assimilation of SOFAR Spotter Buoy Network & Satellite Altimetry Data for Marine Weather Model forecasting & Operational Ship Routing Optimization
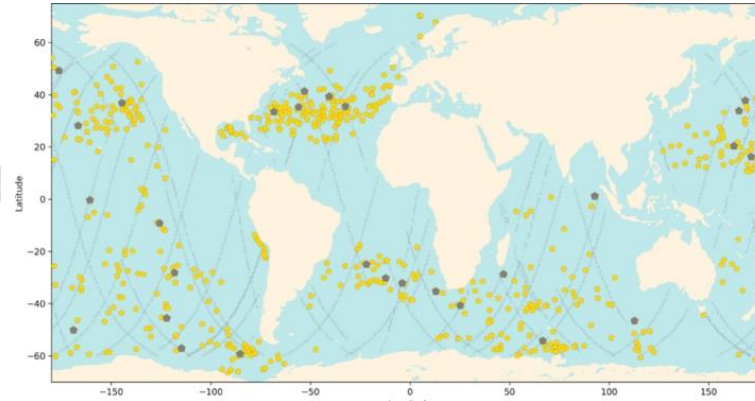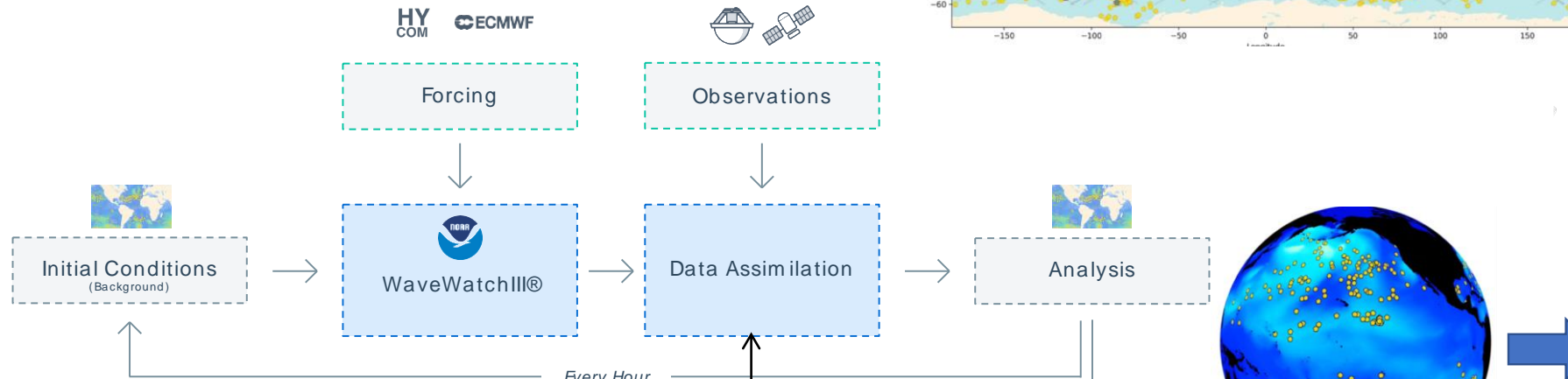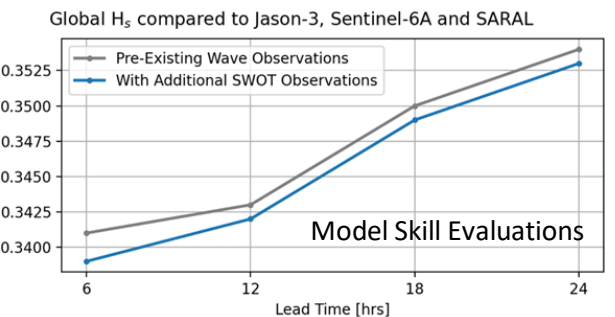
SOFAR Ocean

A SWOT Early Adopter

SOFAR Met-Ocean Buoys (network of 1000+)
SWH, Wave Period/Direction, Wind Speed/Direction
SST, Barometric Pressure

Satellite Altimetry: Jason 3, Sentinel-6A, Altika, SWOT
SWH, SSH

Cost of trip [USD]

Emissions [MT CO2]

↓$13,464

↓88.82 MT   • 1603.73 MT   • 1514.91 MT

Wayfinder Service/Tool

Process flow

Forcing (HYCOM, ECMWF)

Observations

Initial Conditions (Background) → WaveWatchIII® → Data Assimilation → Analysis → 10 Day Forecast

Vessel Performance Data

Every Hour

Every 6 Hours

Model Skill Evaluations

Global H_s compared to Jason-3, Sentinel-6A and SARAL

- Pre-Existing Wave Observations
- With Additional SWOT Observations

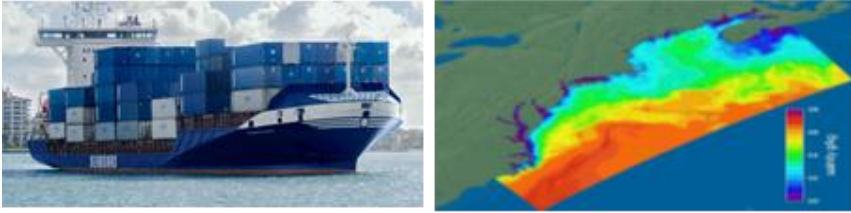RMSE [m] vs Lead Time [hrs]

2019-12-26 5:00 UTC
Bunker Savings: -$556
TC Opportunity: $34,399
Net Voyage Gain: $33,843

Dynamic route updating

Great Circle Route 9.6 kts 51% MCR
Optimized Route 11.9 kts 52% MCR

Marine Fisheries & Ecological Conservation

Fishing Advisories, By-catch limitation, Marine Protected Area Designation

Fishing Advisories for Optimized Fleet Operations

- Synergistic use of Altimetry with other satellite observations for identification of fisheries habitat & productivity hotspots associated with dynamic mesoscale oceanographic features (fronts, eddies)

  SSH/A, EKE, current velocity, Lagrangian fronts, filaments, gradients, SST, CHL-A, SSS, Winds

- Habitat Suitability Index (HSI) and Statistical analyses (GAM, Regression Tree)

- Successfully applied to a range of large and small pelagic species in several ocean areas

- "Potential Fishing Zone" (PFZ) fishing advisory map products used operationally to better direct spatial fishing effort and reduce fleet operational costs (fuel, CO_2)
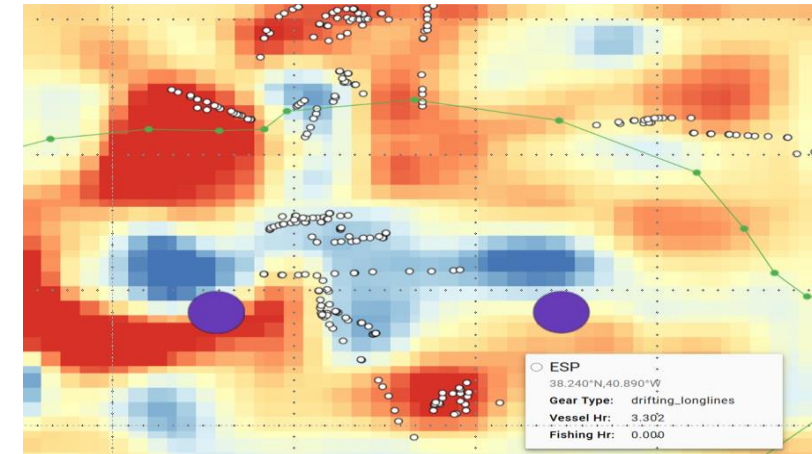
  eg. NOAA-ECOCAST, Andaman PFZs, AIS integration

- Commercial services:
  - ROFFS (Roffers Ocean Fishing Forecasting Service)
  - FishTrack
  - Terrafin
  - Hiltons near-realtime Navigator

PFZ Maps Andaman & Nicobar Islands, India
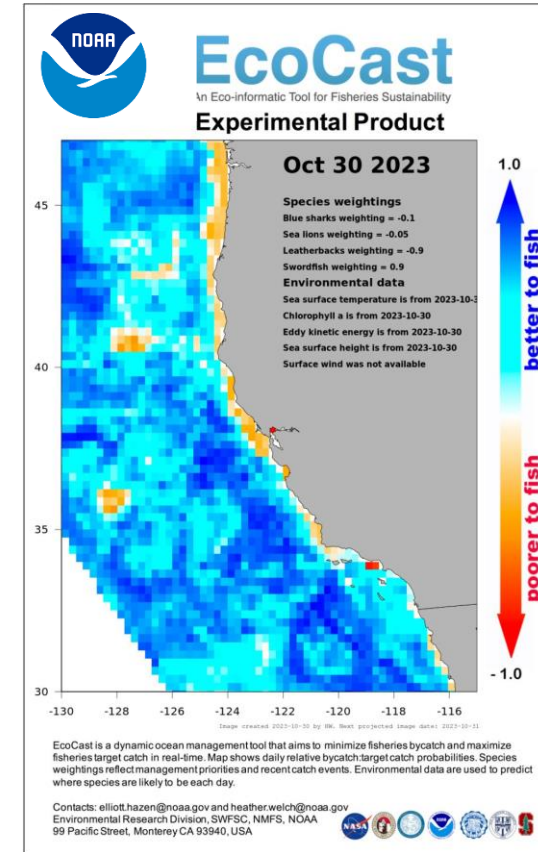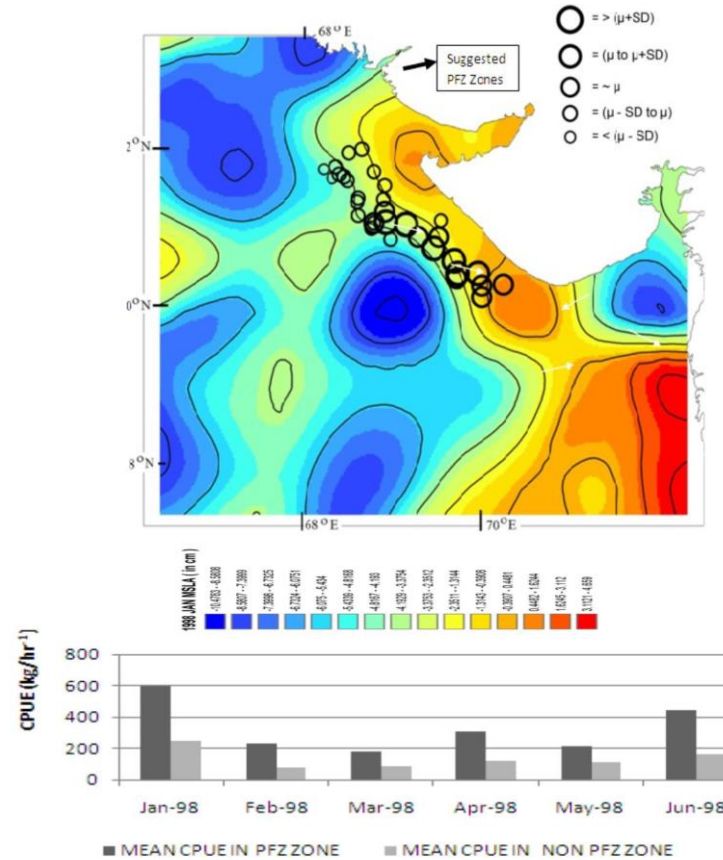
Longline fishing vessel distributions from AIS in relation to eddies from SSHA, N. Atlantic

Fishery By-catch Mitigation

- Satellite-based habitat model products
  eg. NOAA Whale Watch & Turtle Watch

- Minimize fishery and commercial shipping interactions
  with protected species

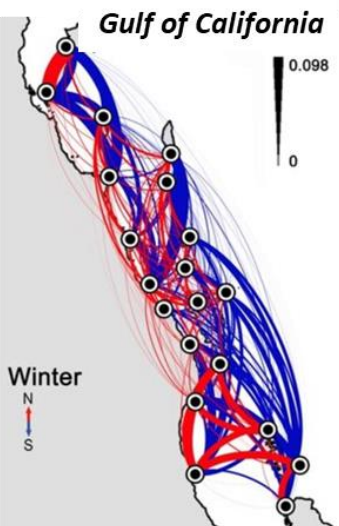## Design of Marine Protected Areas

- Assimilating ROMS modeling of fish metapopulation reproductive
  subsidy and larval distributions

- Critical to understanding fish recruitment dynamics & the designation
  of fishery closed areas/MPAs for marine biodiversity conservation

- Tools supporting UN BBNJ Treaty

EXPERIMENTAL PRODUCT
Avoid fishing between solid black 63.5°F and 65.5°F lines to help reduce loggerhead sea turtle interactions

Sea Surface Temperature : 2023/10/29
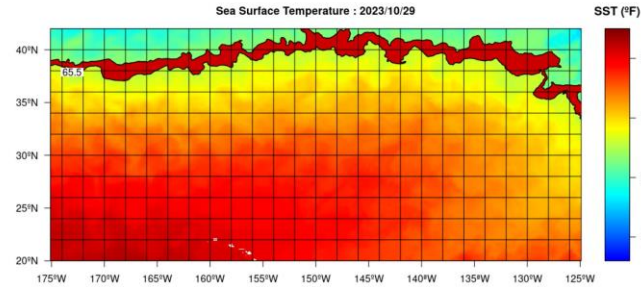
PACIFIC ISLANDS FISHERIES SCIENCE CENTER
ECOSYSTEM SCIENCES DIVISION
1845 Wasp Blvd, Honolulu, HI 96818
http://www.pifsc.noaa.gov/eod/turtlewatch.php
contact: melanie.abecassis@noaa.gov
Data provided by the OceanWatch - Central Pacific node
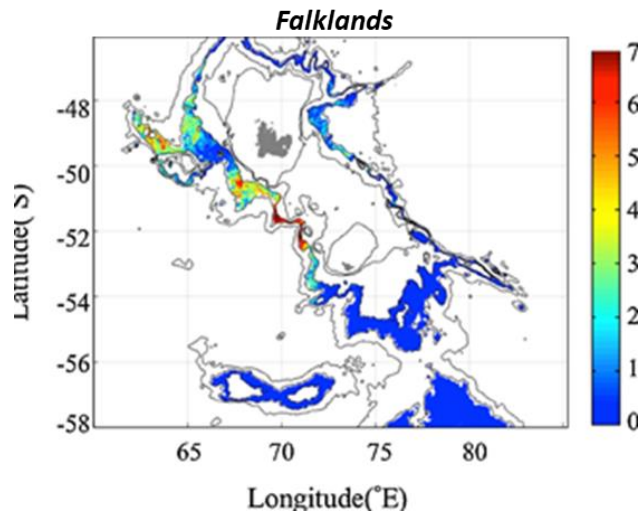
TurtleWatch

Whale Watch Product

BBC 5 March 2023

Ocean treaty: Historic agreement reached after decade of talks

The High Seas Treaty aims to help place 30% of the seas into protected areas by 2030, to safeguard and recuperate marine nature.
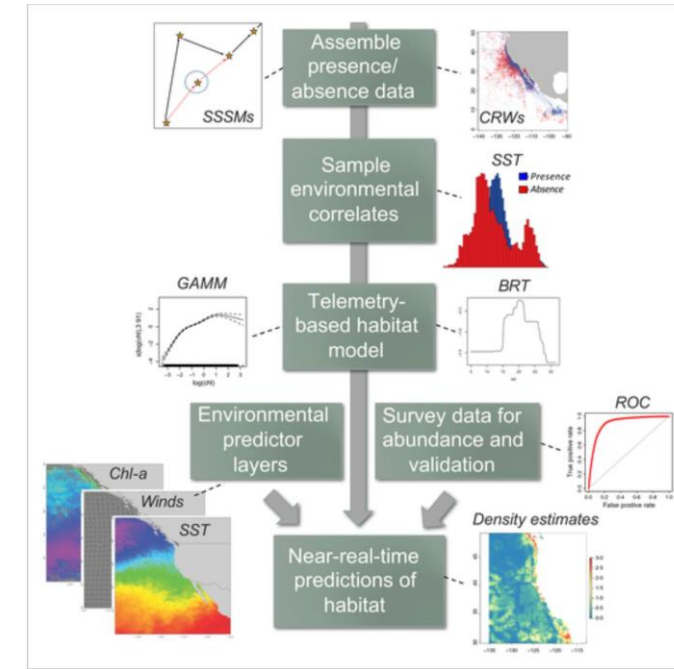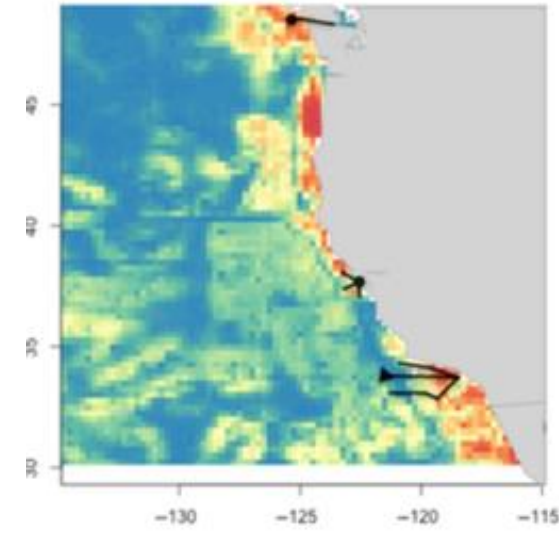
Red Snapper larval transport
Gulf of California

Winter
N
S

Patagonian Toothfish larval sources/sinks
Falklands

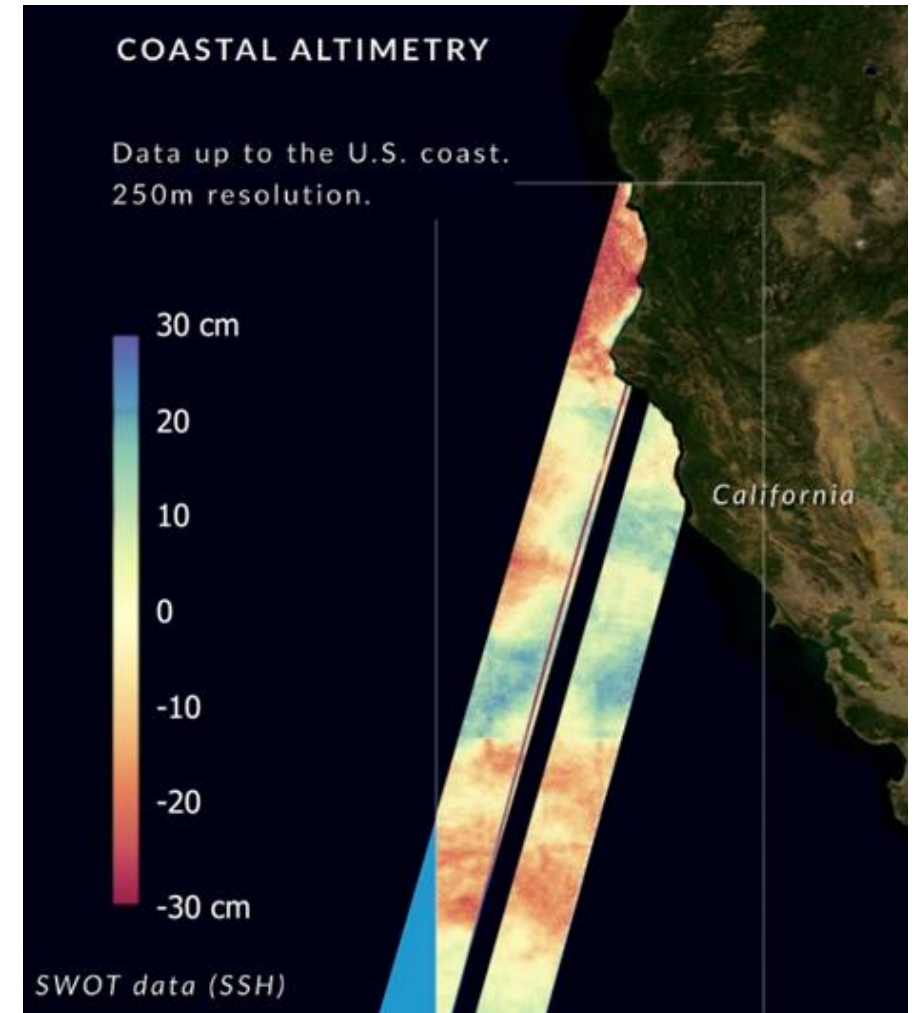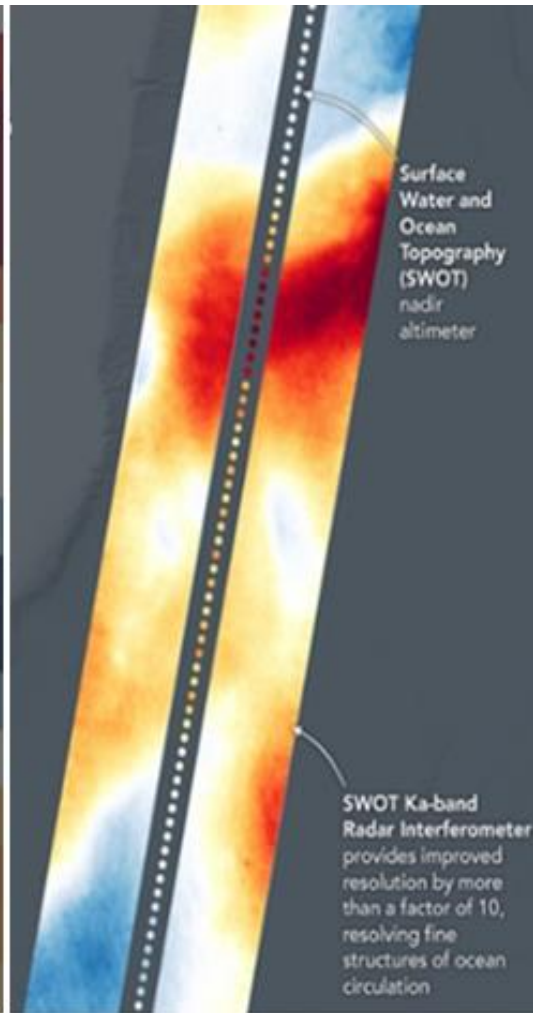# SWOT Potential to Further Enable Marine & Coastal Altimetry Applications
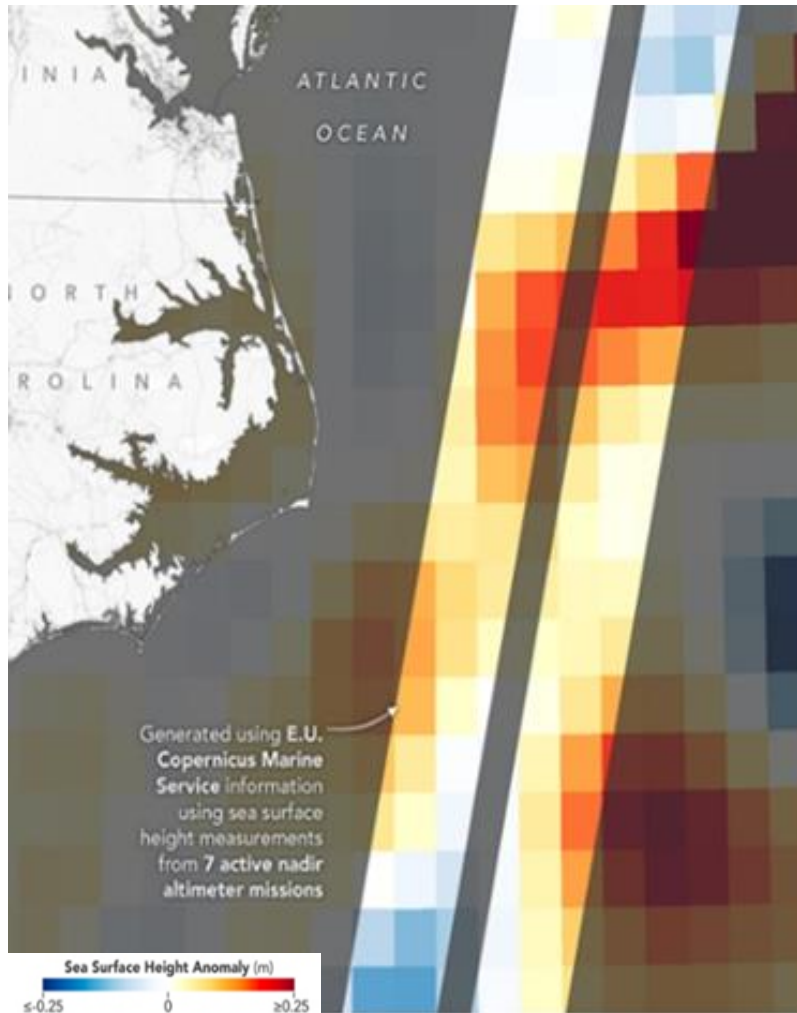
Enhanced Spatial Resolution for sub-mesoscale feature detection & Wide-swath coverage

High Res. Data 3km from Shoreline

25 km AVISO/CMEMS merged multi-mission product

SWOT LR Ocean data (2km)

SWOT HR data (250m)

Conclusions

Topex-Poseidon OSTM/Jason-2 Jason-3 Sentinel 6-MF SWOT

- Continuity in Satellite Altimetry Observations for 30+ years has enabled a range of coastal and marine decision support applications for societal benefit in a growing number of areas

  - Coastal Hazards: Storm surge, Flooding & Sea Level Rise
  - Tropical Cyclone Forecasting
  - Marine Safety & Navigation involving assimilating ocean circulation & wave models
  - Marine Fisheries & Ecological Conservation: Fishing advisories, By-catch mitigation, MPA design

- Government agency but increasingly private sector involvement providing value-added data/analysis services

- Improved distribution/access to decision-support information products via a proliferating number of Web portal tools

- Higher resolution, wide-swath coverage also closer to coastlines from SWOT will further catalyze such applied uses

- Altimetry Applications & SWOT Early Adopters Program dedicating to promoting and helping to advance such efforts