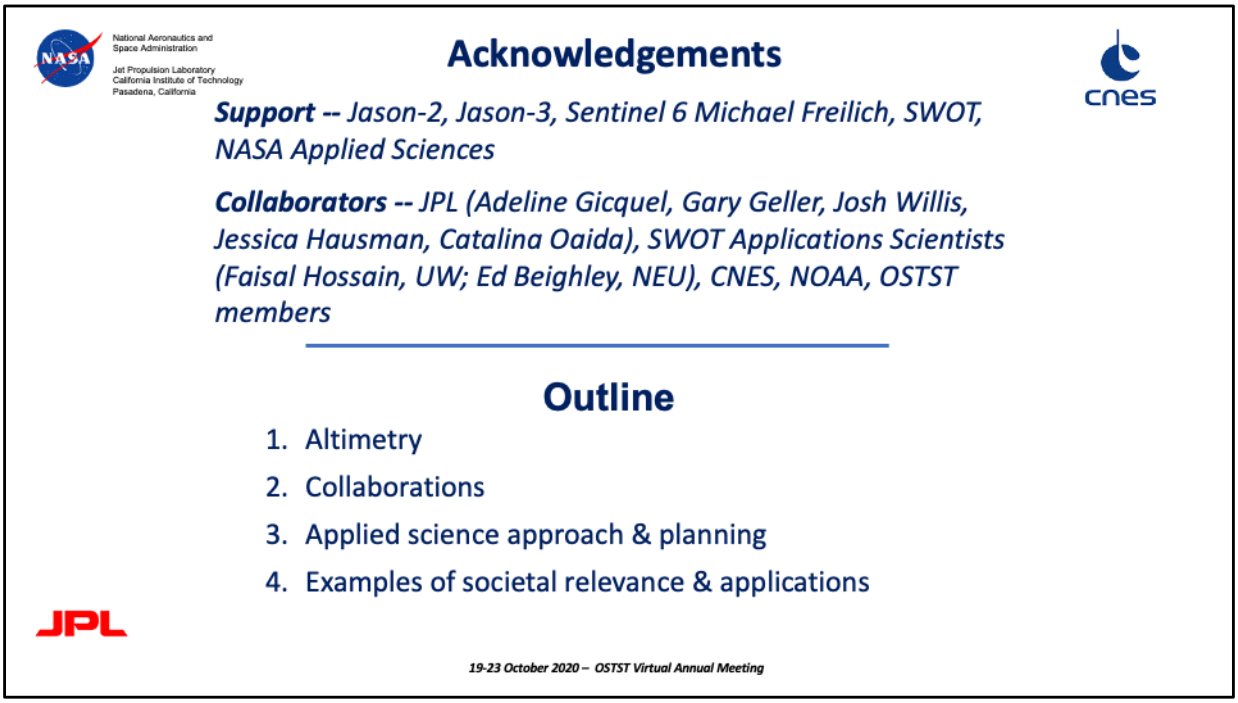
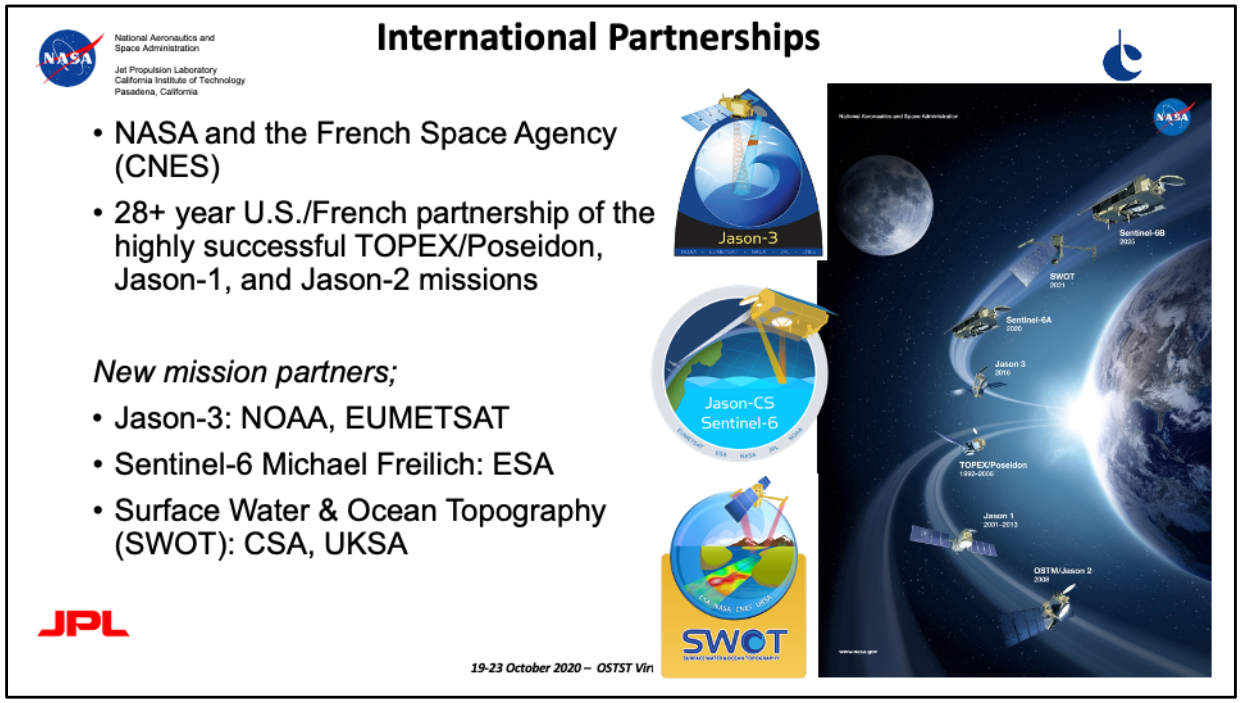
Hello. I am Margaret Srinivasan and I'm the Altimetry Missions Applications Lead for the Jason-series missions at JPL. I am also the Deputy Program Applications Lead for the SWOT mission at NASA HQ. My colleagues in this effort are Dr. Faisal Hossain (U. Washington), and Dr. Vardis Tsontos (JPL). Contributions to this work have also been provided by Dr. Gary Geller (JPL), Dr. Adeline Giquel-Brodke (UMD), and many members of the OSTST and support staff.



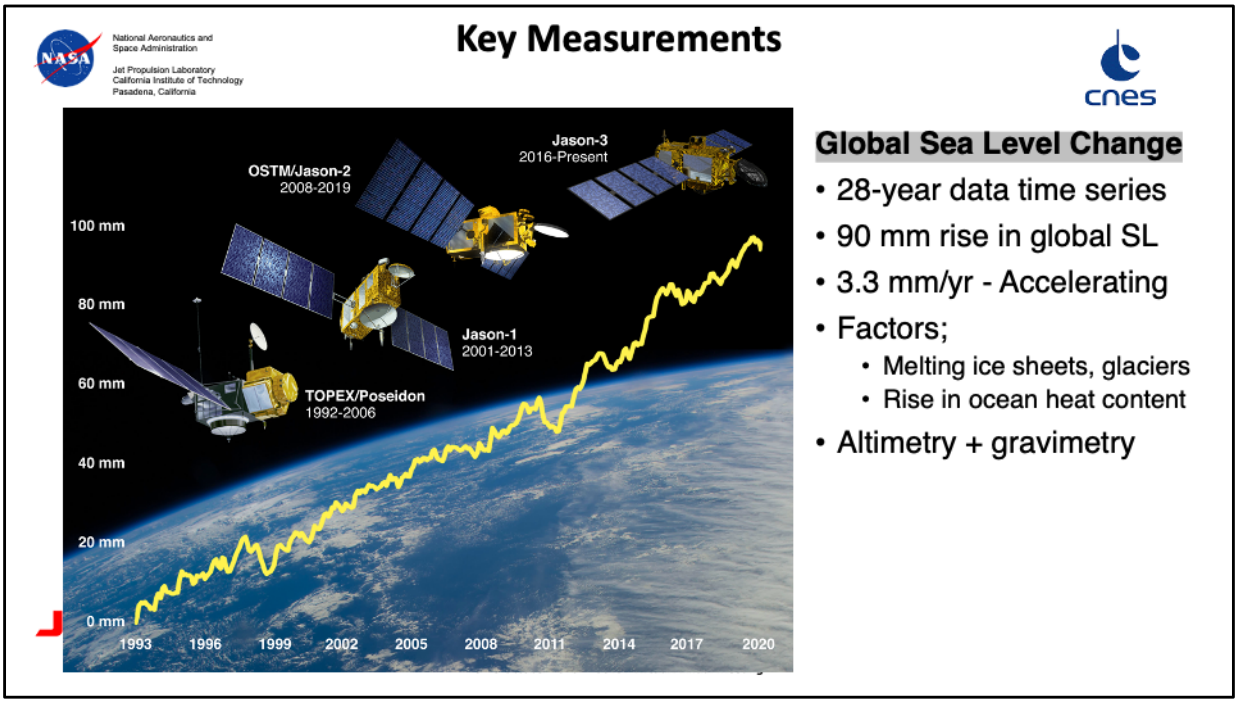
I would like to acknowledge those supporting this effort; the mission Project offices that fund our work, and the NASA Applied Sciences Program. Other collaborators - JPL, UW, NEU, CNES, NOAA OSTST

Outline – this talk will cover;
- Overview of current altimetry missions
- Some details on the collaborative efforts in the Altimetry Applications Program
- Planning & tools used in advancing altimetry applications for societal benefit
- A few examples of the types of Applications we are focusing on



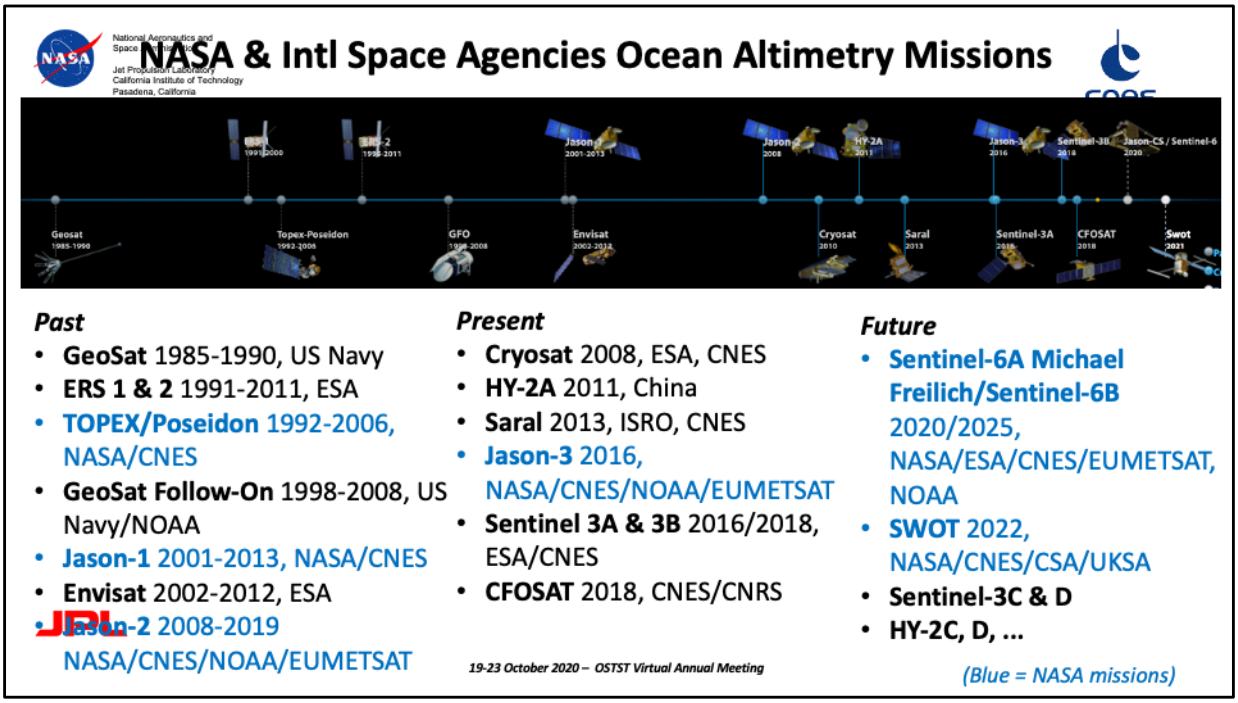
In 1992, the TOPEX/POSEIDON (TP) mission was the first international collaboration between NASA & CNES, on what would exceed a 28 year partnership. After TP, came Jason-1 and OSTM/Jason-2 (launched in 2001 and 2008, respectively).

New mission partners joined for;
- Jason-3, launched in 2016, and currently in Phase E extended mission operations
- Sentinel 6 Michael Freilich will launch 10 Nov 2020, and was recently renamed by our European colleagues to honor the former NASA Director of Earth Sciences
- SWOT will launch in 2022, -- a revolutionary new technology including a wide swath altimeter, interferometric SAR



Nearly 28 years of ocean altimetry measurements from the TOPEX/Poseidon and Jason satellite series has provided researchers and operational users an unprecedented time series of data. This continuous record is the result of an enduring partnership between NASA, CNES, and other U.S. and international organizations and it continues to support operational, commercial, and environmental applications. With the launch of Sentinel-6 Michael Freilich next month, and more planned missions into the next decade, this resource of valuable data will be used by researchers and operational users across the globe to monitor ocean circulation and to improve our understanding of the role of the ocean in climate and weather.

Sea level rise is caused primarily by two factors related to global warming: 1) the added water from melting ice sheets and glaciers and 2) the expansion of seawater as it warms.



WHAT'S OUT THERE.....

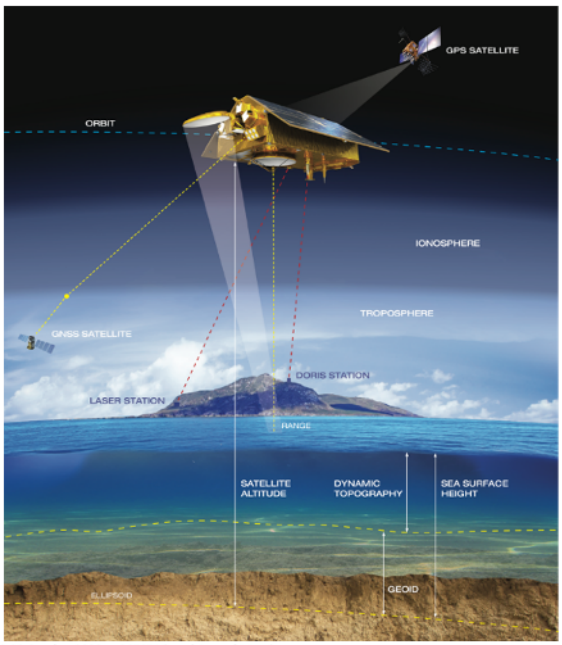
- NASA missions continuing a 28-year legacy
- Longstanding international partnerships

The Altimetry Applications Program, which focuses on the NASA-CNES missions, will engage existing ocean altimetry data users, as well as the community of potential altimetry data users, to provide information about the uses of the observations from these missions and emerging community needs.

This presentation will focus on efforts to identify and highlight applications and opportunities to provide data and information products to existing and new users, and to highlight the value of this resource for societal benefit.

How Altimeters Work

- Range – nadir altimeter
- Position – Known geoid (GRACE); DORIS; Laser Ranging (LRA); GPS
- Wet path delay – Advanced Microwave Radiometer (AMR)
- Precise sea surface height measurements; 2-3 cm



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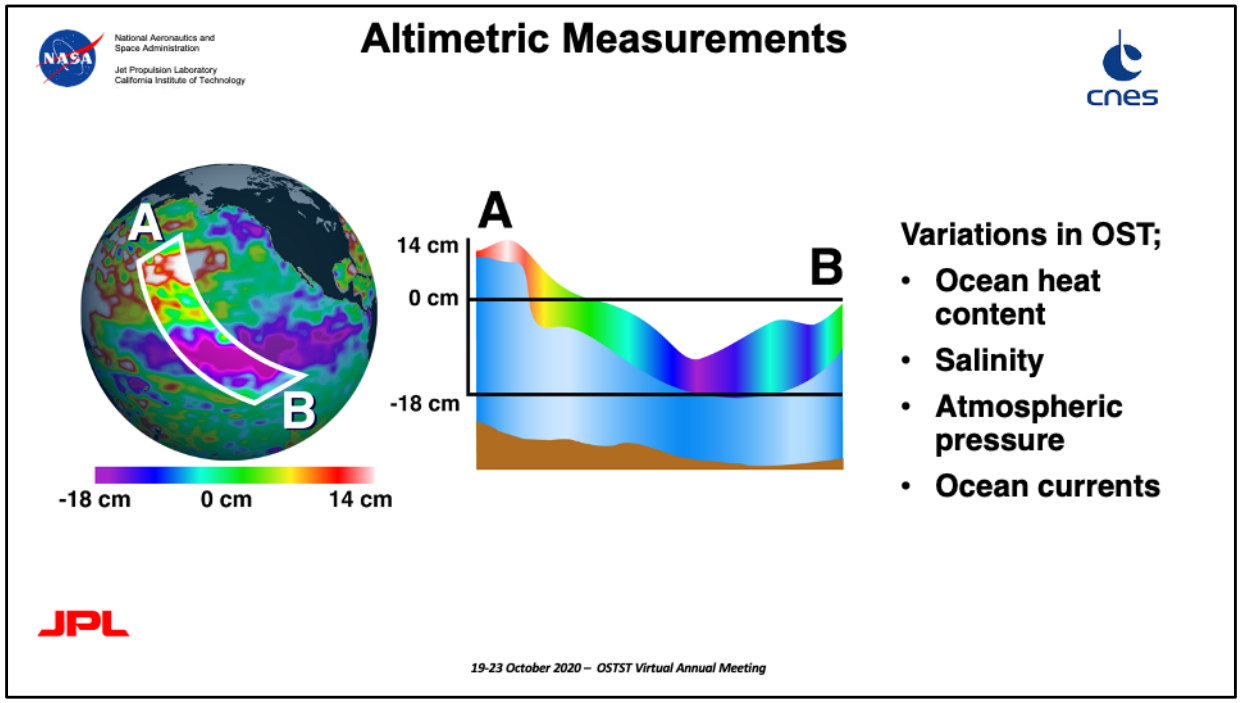
Source: J. Willis, JPL

HOW THEY WORK…Just like its predecessors,S6MF will have a radar altimeter, an instrument that measures sea surface height by precisely knowing the satellite's position in its orbit and by measuring the distance between it and the top of the ocean.

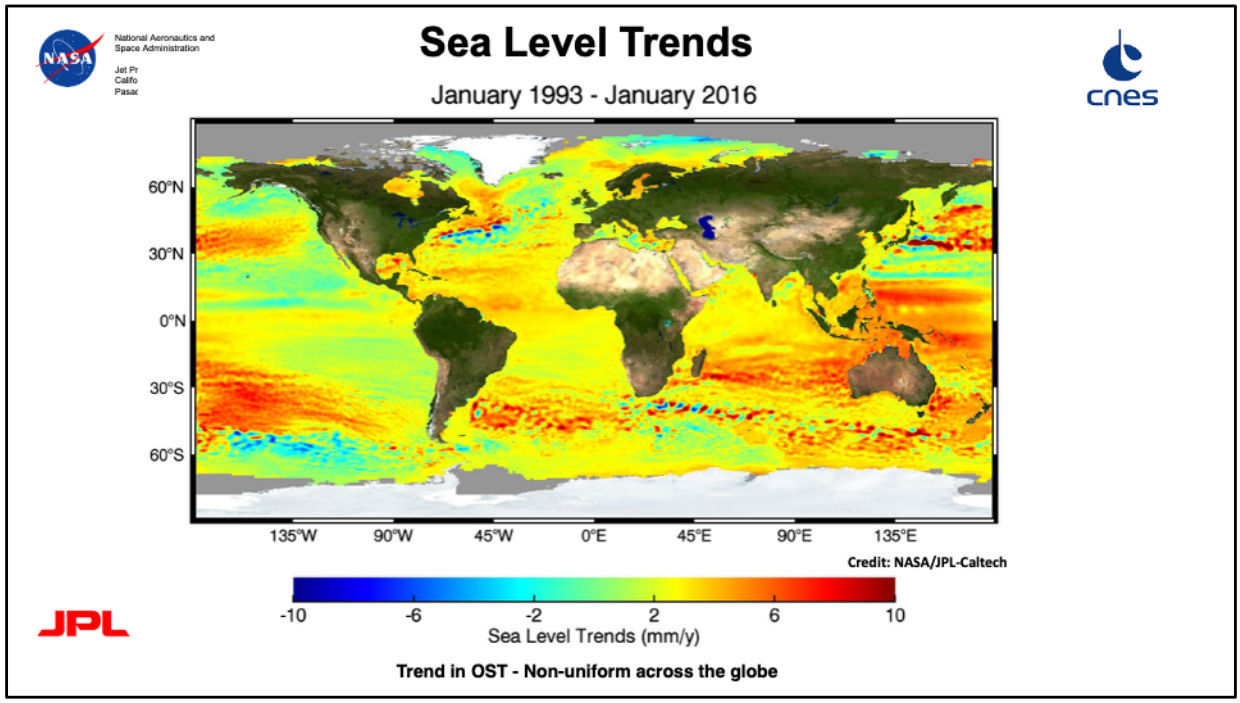
BASIC OBSERVATIONS from these measurements: Ocean currents and ocean heat content

The ocean surface is constantly changing, from waves, to tides, to El Niño, to sea level rise. Increased global warming causes the ice sheets & glaciers to melt into Earth's ocean, and at the same time, it heats the ocean surface, causing the warmed water to expand. It is absolutely crucial to have highly accurate, continuous global sea level measurements.

Since the majority of Planet Earth is covered by ocean, and since water is exceptionally good at storing heat, the ocean will continue to play an enormous role in Earth's long-term climate. That's why it's so important to have an uninterrupted stream of satellite data that extends far into the future.

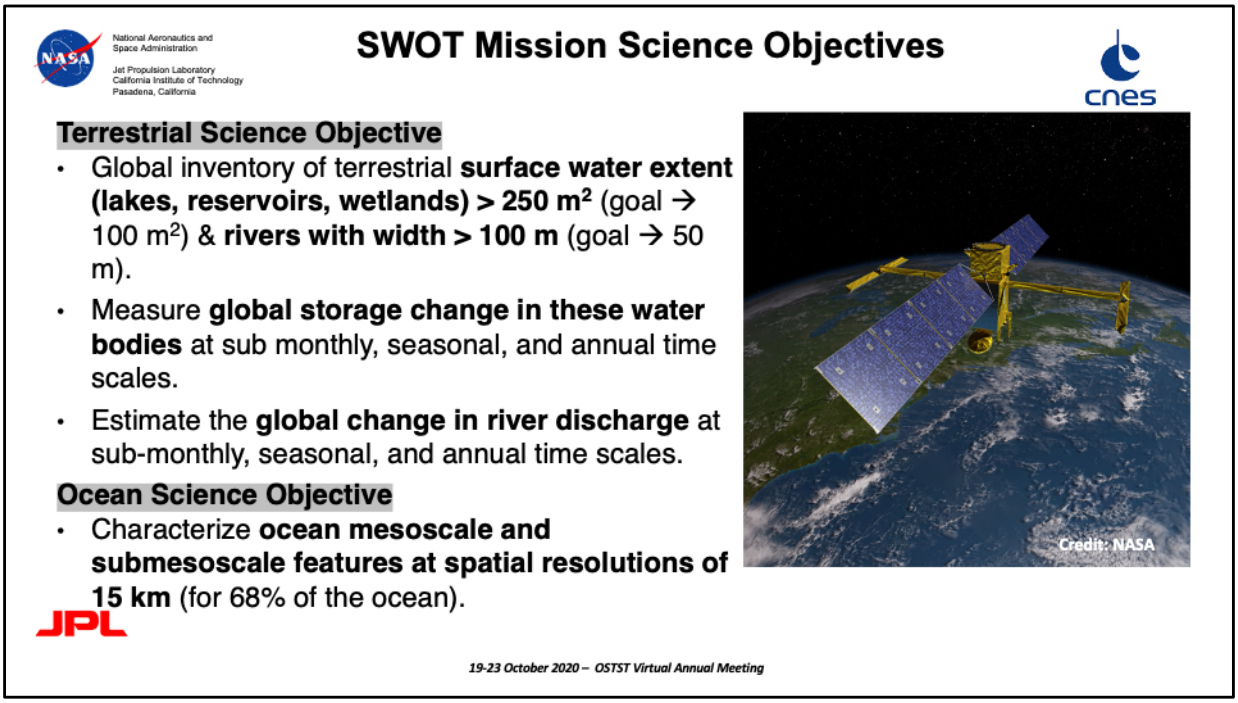


This illustration graphically shows the key measurement - the topography of the ocean surface. Variations in OST are the result of temp of the water, salinity, atmospheric pressure, and ocean currents.



This image shows the 23-year trend of changing sea levels across the globe from 1993 to 2016. Most of these 20-to-30 centimeter changes in sea level on the open ocean are cyclic, from natural things like El Niño and La Niña, or ocean currents speeding up or slowing down," What really matters is what's happening in coastal regions where long-term changes in relative sea level – is caused by the overall rise due to global warming, and the movement of the land.

This means that although sea level rise affects coastal areas all over our ocean planet, some regions feel its effects sooner and more severely than others. This is reflected in future projections of sea level rise, with many cities in Asia expected to be among the hardest hit localities. Here in the United States, cities expected to see the worst impacts include New York, Miami and New Orleans, to name but a few.



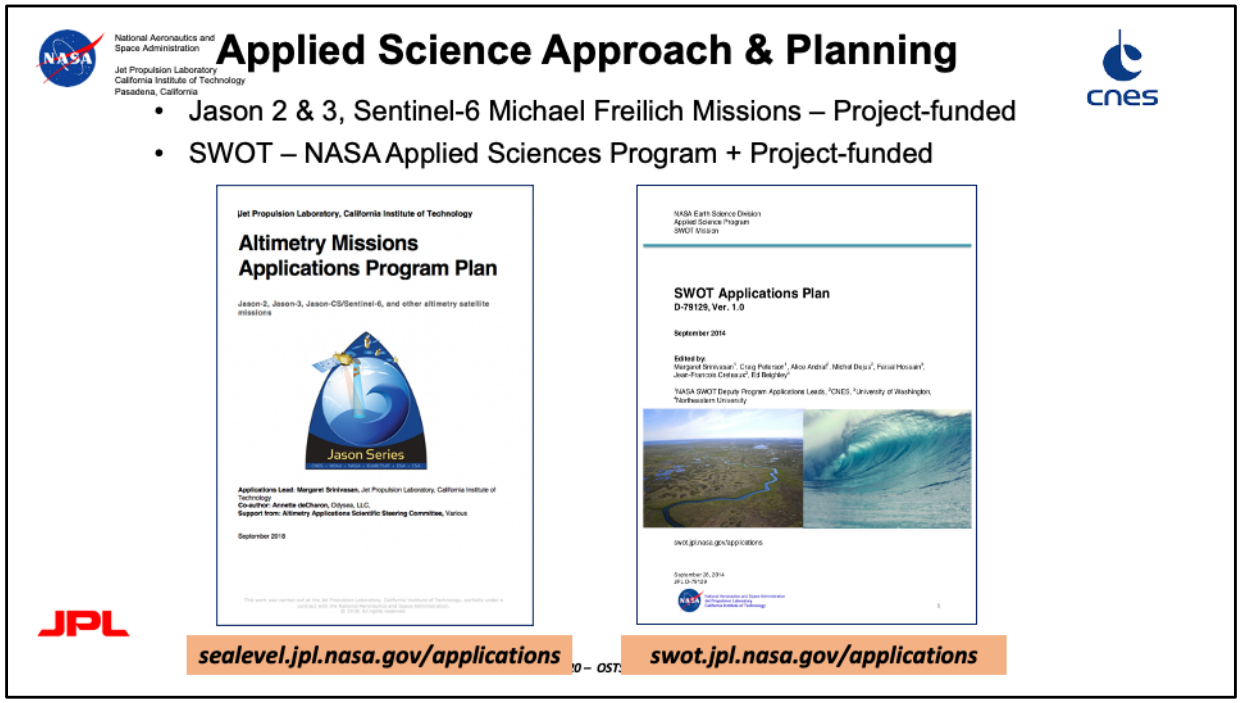
The Surface Water and Ocean Topography mission (SWOT) will provide a quantum improvement for oceanography and hydrology with a 'next generation' measurement system—the KaRIn interferometric SAR instrument.

The general science objectives of SWOT are;

Hydrology: First global inventory of fresh water storage and its change on a global basis. SWOT will provide measurements of lake & reservoir height change, river slope & discharge

Oceanography: First global determination of the ocean circulation, kinetic energy and dissipation at high resolution; scales ~15 km

Planned launch: February 2022



The Altimetry Mission Applications Program Plan is available at https://sealevel.jpl.nasa.gov/applications/overview/

Products and services have been developed for a wide range of applications. Some of those enabled by altimeter data and information products include:

- International ocean forecasting systems,
- Ship routing and sport sailing,
- Precision marine operations: cable-laying, oil production, shipping
- Naval operations,
- Fisheries assessment and management,
- River, lake, and reservoir monitoring,
- Flood forecasting,
- Marine mammal habitat monitoring,
- Hurricane forecasting and tracking,
- Debris tracking, and
- Coastal applications

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Key Applications Questions

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- What are the specific applications that water stakeholder agencies/users oversee that can benefit from high frequency mapping of water elevations?
- What are the specific latency requirements of data products for that application?
- What does each stakeholder agency see as potential roadblocks to sustainable uptake of data in their agency environment?
- What type of support would stakeholders like the missions to provide in terms of training and incubation of potential application ideas?

JPL

→Surveys → Workshops →Early Adopters/User Support

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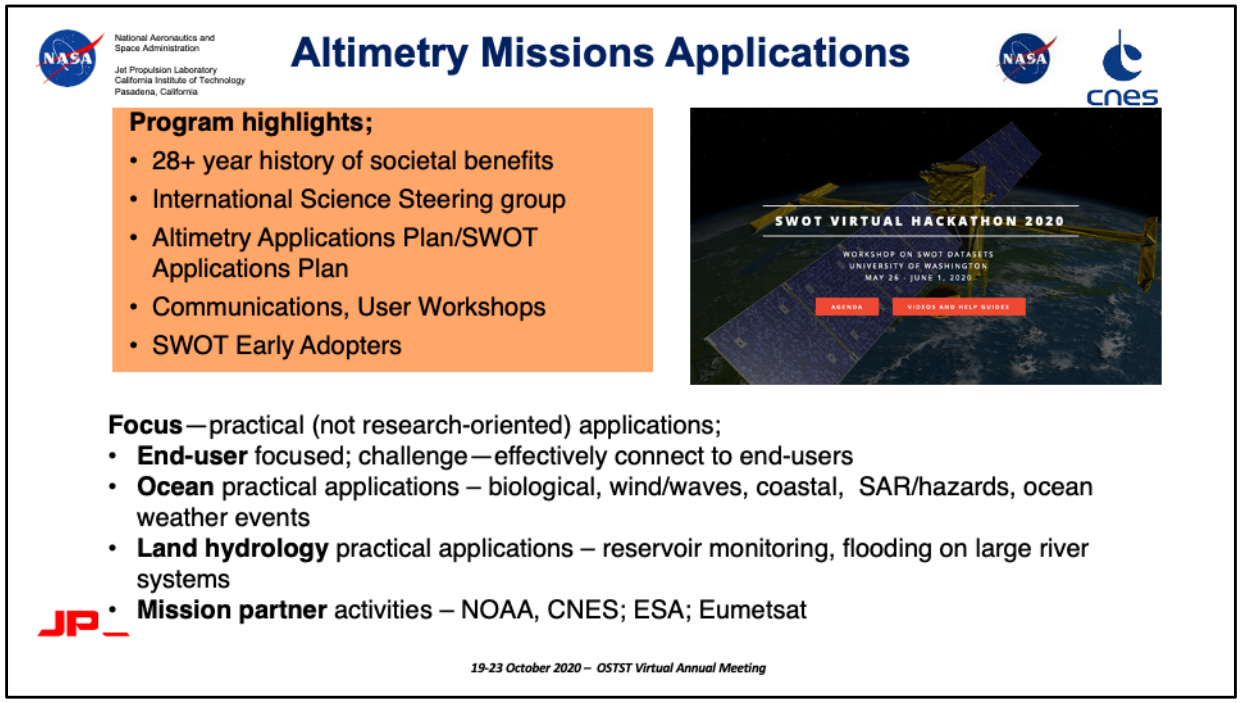
The focus od these plans is to address key appl questions;

ASecific applications
latency reqs
roadblocks?
type of support -- training, technology, skillsets, modeling



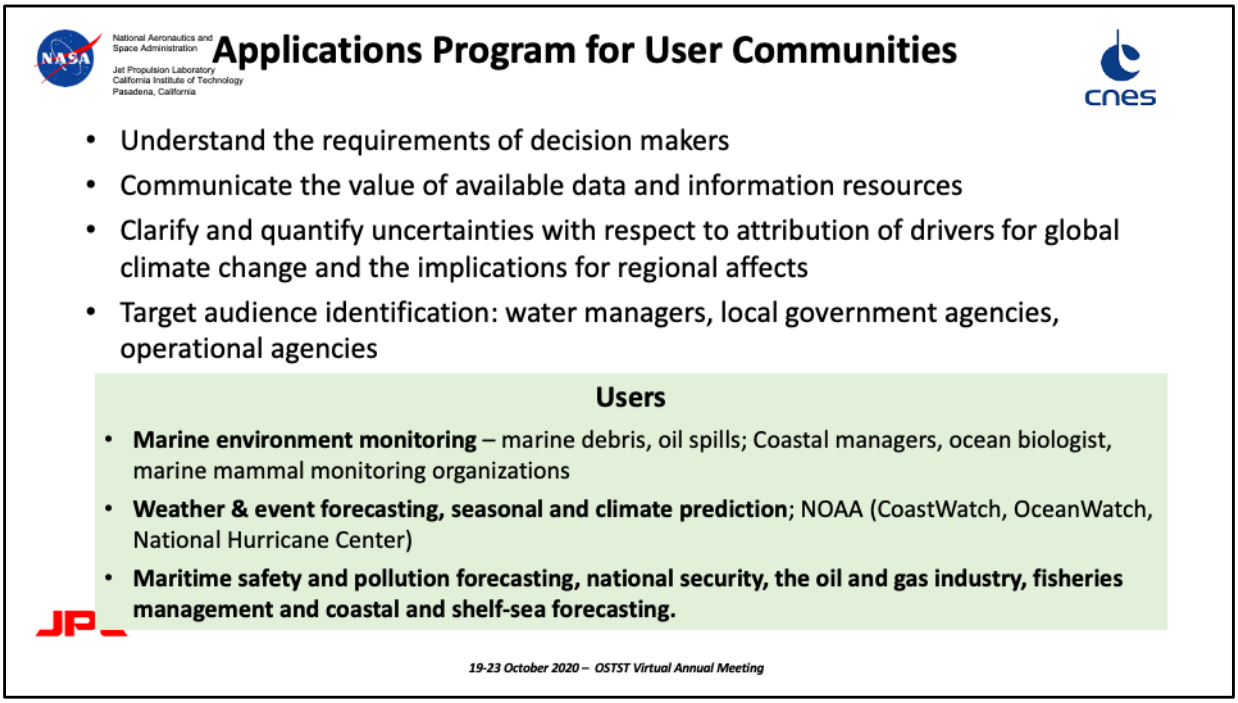
The Altimetry Applications program is intended to identify existing users and to engage new users of alt data

TheObjectives of the Steering Committee:

- To provide inputs from altimetry science and Project people who have an interest in applied uses of the mission series data products, or are working with users outside of traditional research capacities;
- To provide guidance and direction on topical focus areas for an Applications Working Group;
- To help formulate a “road map” for development of future information products and training events that are aligned with an Applications focus from the altimetry mission time series; and
- Provide advice on expansion of or support for altimetry data product users/user communities.

Besides significant research contributions of altimetry time series, it has also contributed valuable information and services to decision makers and national-regional organizations focused on addressing global disaster risk reduction, and potential science-based mitigation activities for water resources challenges. This new

effort will highlight these valuable contributions of societal benefits in a systematic and structured way, including updated web access to information and data products, training, and participation at key meetings and conferences.



With respect to our user communities...these are the elements we focus on.

Products and services have been developed for a wide range of applications. Some of those enabled by altimeter data and information products include:

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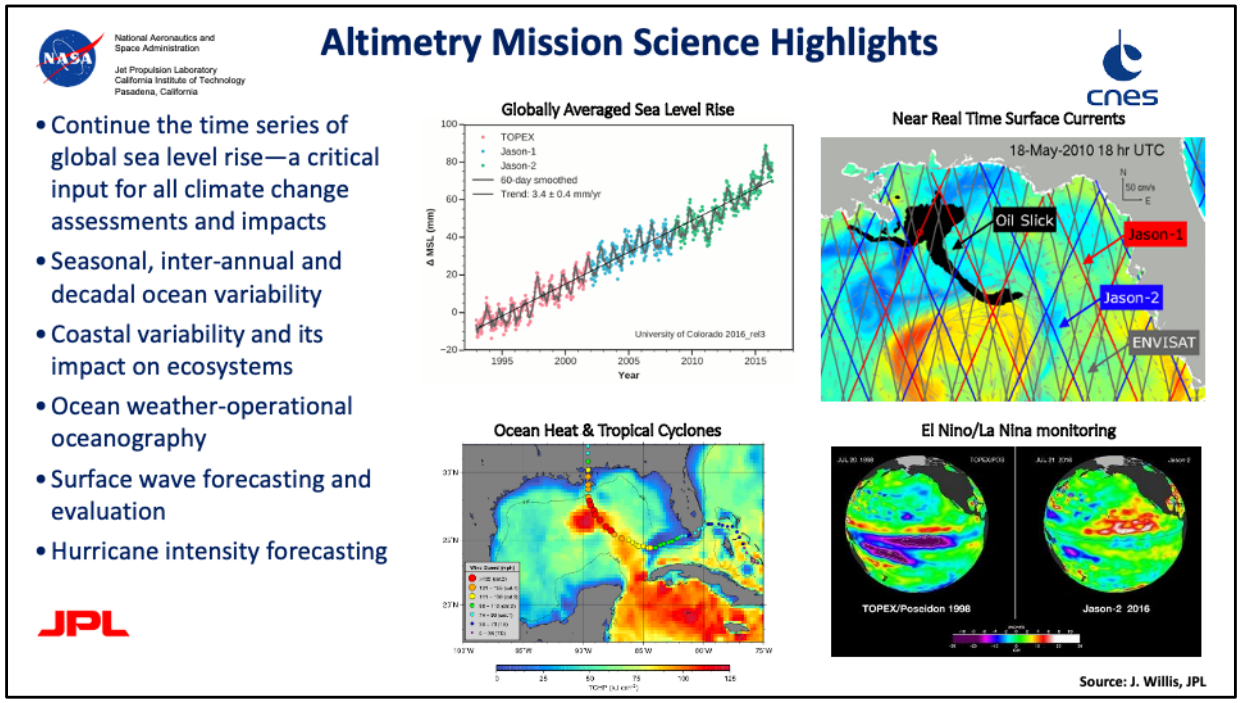
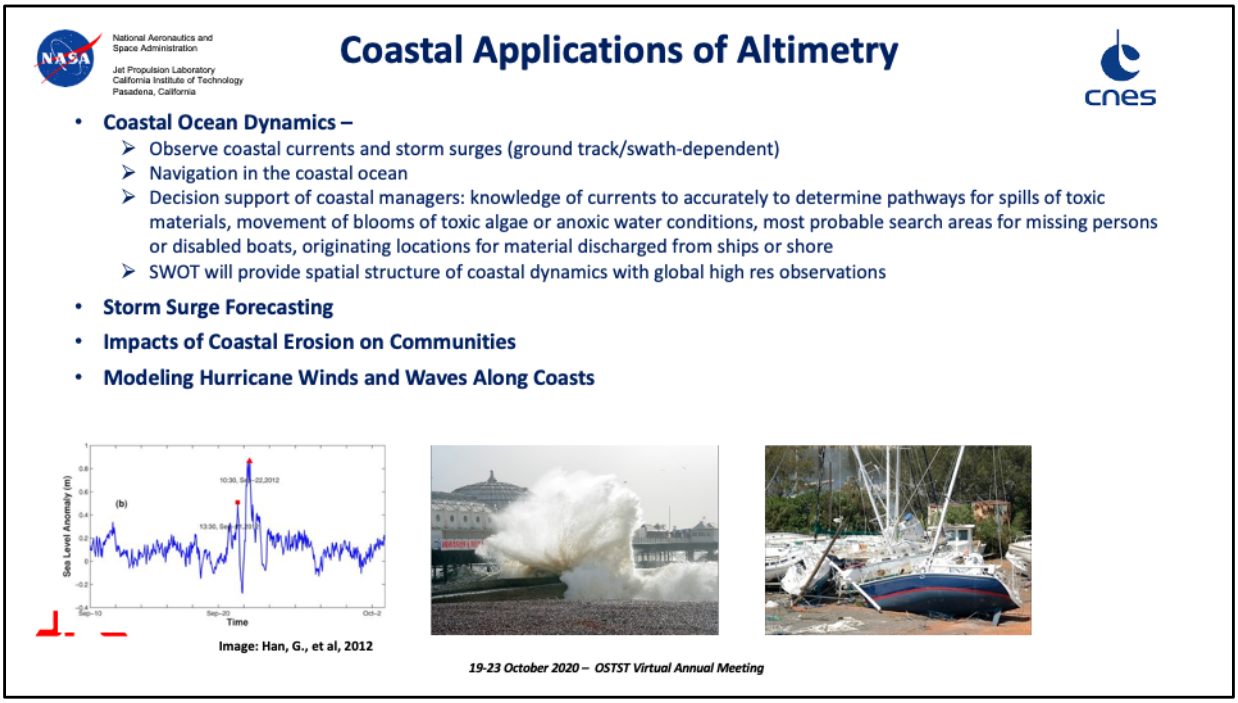
- Coastal applications



- **Observes global sea level rise -** Averaging sea level across the global tells us how much global sea levels have been affected by the warming climate. Global sea level rise from altimeters is a key input for both US and Intergovernmental Climate Assessments (NCA, IPCC, etc.).

- Discovered acceleration of sea level rise
- El Nino and it's global impact
- Global forecasting and hindcasting of ocean currents
- Charting the shape and depth of the sea floor globally



There are about 620,000 kilometers (372,000 miles) of coastline. Over one-third of the total human population, nearly 2.4 billion people, lives within 100 km (60 miles) of an oceanic coast (NASA Science; https://science.nasa.gov/earth-science/oceanography/living-ocean).

USEFULNESS of these measurements SPECIFIC TO APPLICATIONS-

Coastal Ocean Dynamics: Currents in coastal transport systems move substances 10–100 km/day (6–60 miles/day), both in the alongshore and onshore-offshore directions.

Storm surge forecasting

Changes in coastal currents brings different water properties to a region, affecting the growth and survival of kelp beds and larval/juvenile coastal fish and benthic invertebrate species, as well as populations of aquacultured fish and shellfish, etc. The currents also create the patterns of SST that affect the creation of local fog and coastal weather.

Improved coastal resolution:
The proposed SWOT altimeter, with horizontal resolution of 0.5–1.0 km, will help to resolve these small-scale coastal currents within each 120 km-wide swath, extending to within 0.5–1.0 km of the coast.

S6 - Experimental high frequency radiometer (90, 130 & 168 GHz) integrated into classical AMR (18, 23, 34 GHz) structure sharing the main AMR-C 1-m reflector

Objective: Measure wet tropospheric Path Delay to better than 1 cm with ~5x smaller spatial footprint (compared to AMR)

Complements S6 high-resolution radar altimeter for improved characterization of important coastal processes

Operational Reservoir Monitoring in the Mekong Basin

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Outflow, *O*
- Estimate from satellite data

Inflow into Reservoir, *I*
- Upstream Reservoirs
- Satellite derived streamflow

Evaporation, *E*
- Estimated from weather data or general trends

Storage Change, *ΔS*
- Improved lake/reservoir levels
- Water extent from visible & infrared (Jason-3, Landsat, Sentinel-1)

Challenges
- Computational feasibility
- Ease of access to data by users
- Coordination with other altimeter missions like Sentinel series

Credits: F. Hossain, UW

Reservoir Mass Balance $O = I - E - \Delta S$

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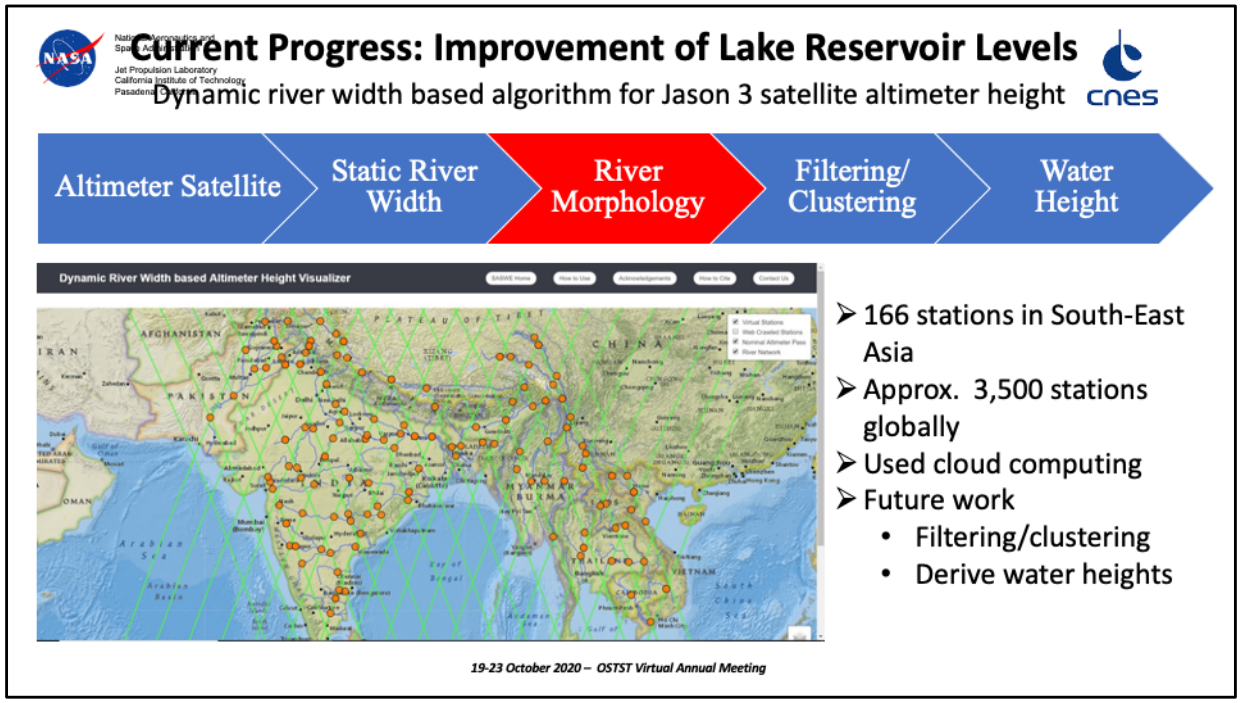
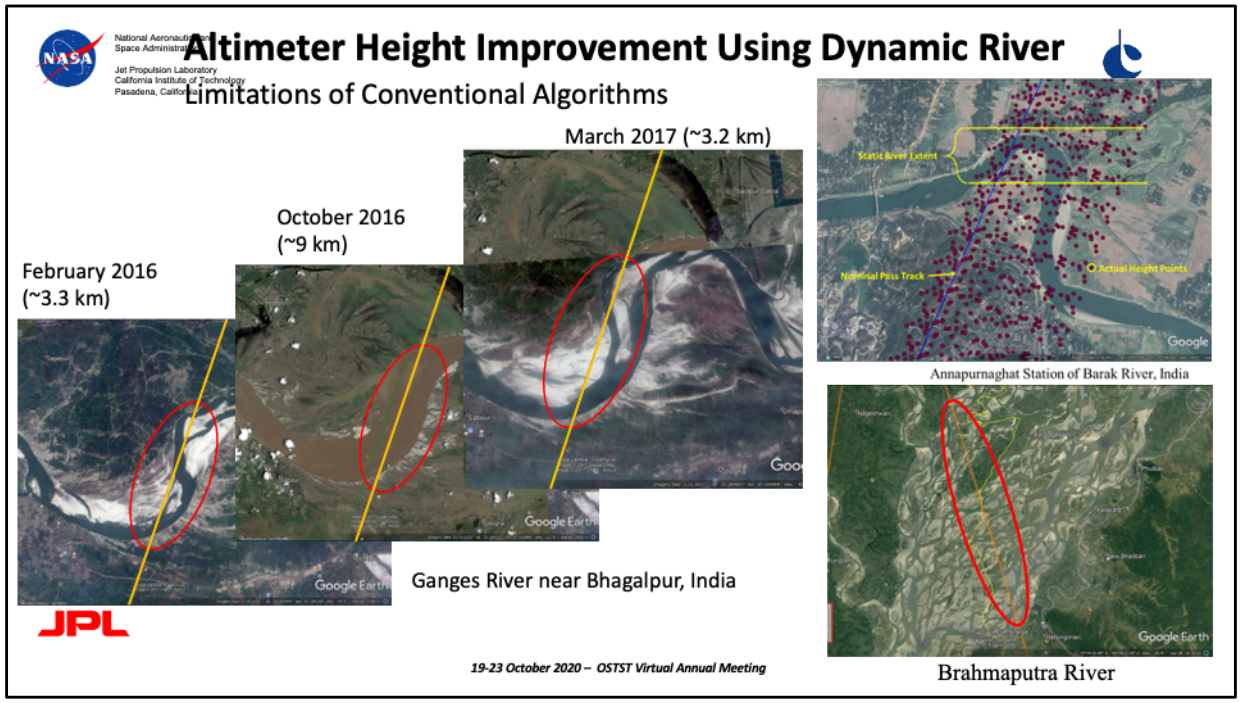
- This system is operational at http://depts.washington.edu/saswe/vietnam/ and http://forecasting.vaci.org.vn/
- The system uses 'operational' and 'real-time' satellite data (from Landsat/MODIS and Jason-3 altimeter when available) to estimate reservoir storage change.
- Reservoir storage change is used to estimate outflow or understand reservoir operating patterns which then gets used for decision making by the downstream stakeholder nation/agency.



1. This is the front end of the system at http//depts.Washington.edu/saswe/jason3 that runs entirely on cloud computing.
2. It uses Jason-3 height and improves it using SAR data from Sentinel-2
3. The system has relevance for PODAAC and its SWOT data hosting effort due to the use of cloud computing architecture.
4. See - http://depts.washington.edu/saswe/jason3/
5. Generous support of J3 program.



- **This work was supported by the JASON-3 project – 2017-2019**
- **In the first phase – by UW, they sought to understand how much Jason-3 altimeter heights estimates can be improved for dynamic rivers by using SAR or optical (Landsat) data.**
- Once it was proven that SAR data was more effective for these often-changing rivers to improve river height in South and Southeast Asian environments, **a system was operationalized using cloud computing by Nishan Biswas, UW.**
- **This system used Google Earth Engine and then demo'ed to PODAAC. The system can be availed at http://depts.washington.edu/saswe/jason3/**
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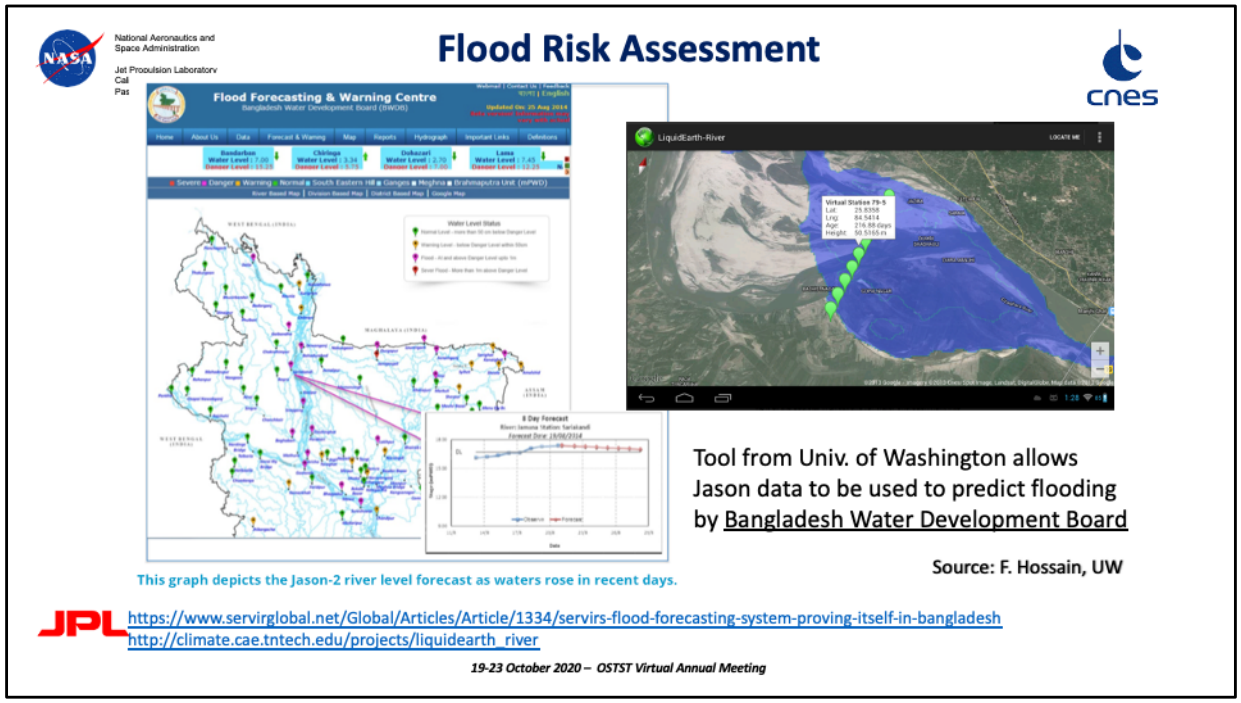


Summary: The university of Washington, under contract with the Jason-2 Project at JPL, has developed a mobile platform for the dissemination of flood risk in developing nations. The system can use multiple altimeter inputs (incl. ICESat-2, Sentinel 3, Cryosat-2). River levels upstream are obtained by altimeters, and used to model downstream virtual stream gauge levels. Flood forecast times are improved from 5 to 8 days advanced notice, compared to 3 or so without this system.

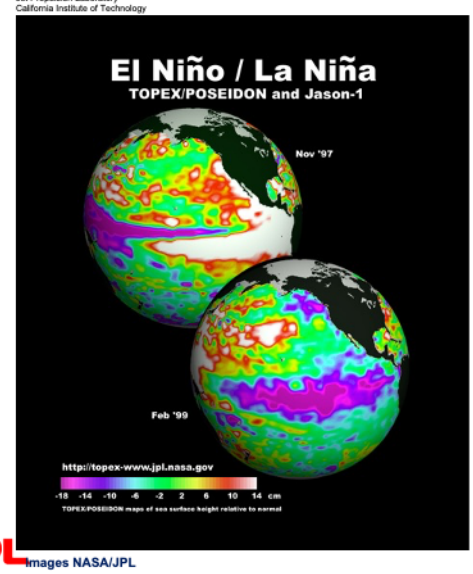
Users: Flood Forecasting and Warning Center (FFWC), Bangladesh Water Development Board; NASA's SERVIR

Lea, D., Martin, M., Oke, P. 2014. Demonstrating the complementarity of observations in an operational ocean forecasting system. Qtly Jour. Of the Royal Met. Soc. 140:2013-2049 (https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/qj.2281)

El Nino & La Nina

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology



- Monitoring El Niño and La Niña
- NOAA long term climate forecasts: flood control, agricultural strategy, water and energy use planning
- Media use to explain weather and climate to the public
- TOPEX/POSEIDON data have become familiar to more than a billion people worldwide

JPL

Images NASA/JPL

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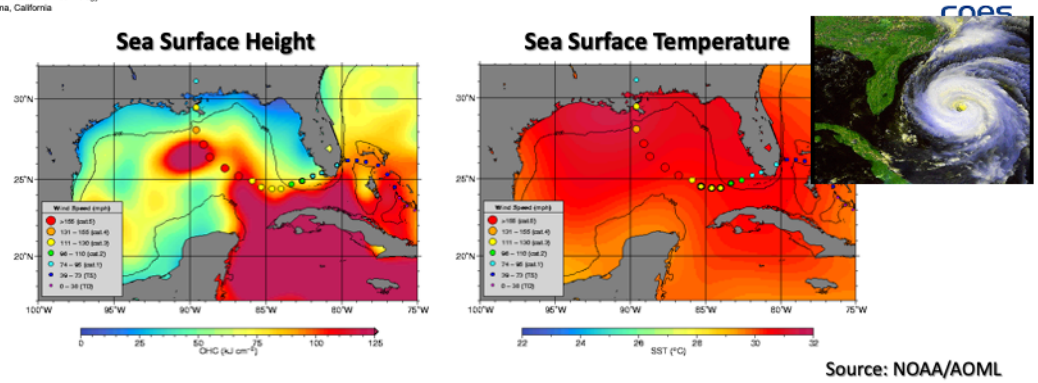
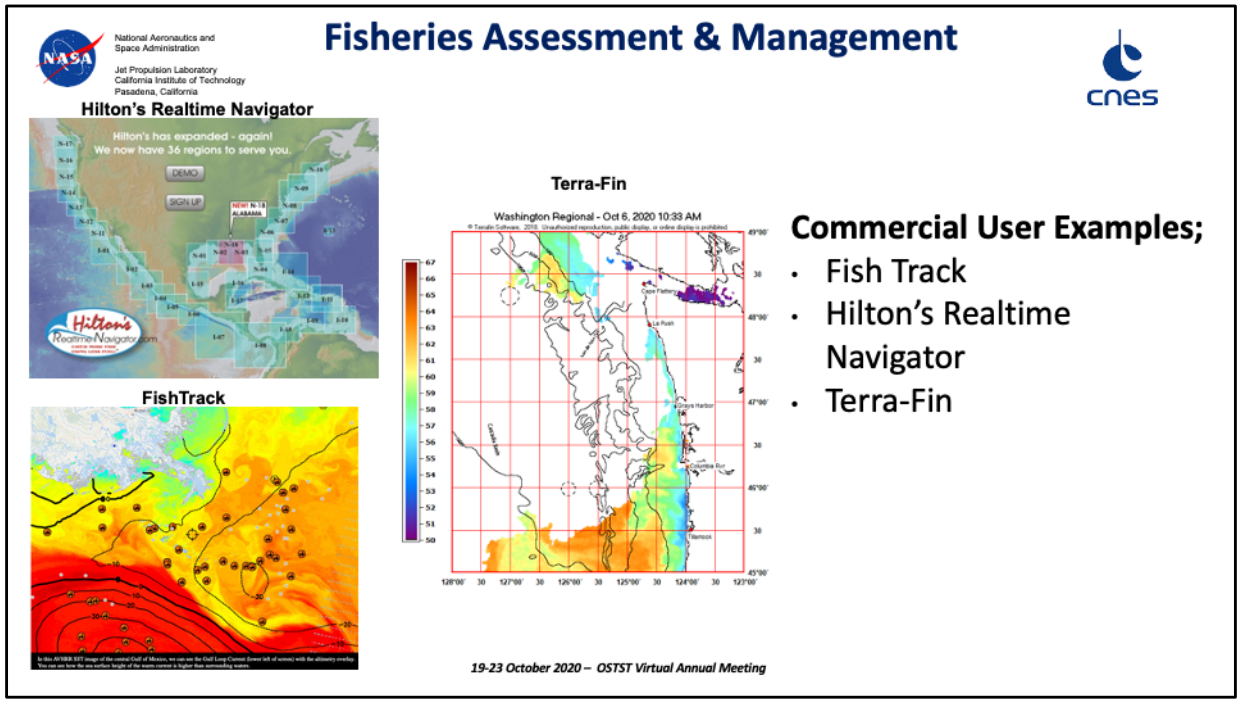
Hurricane Forecasting



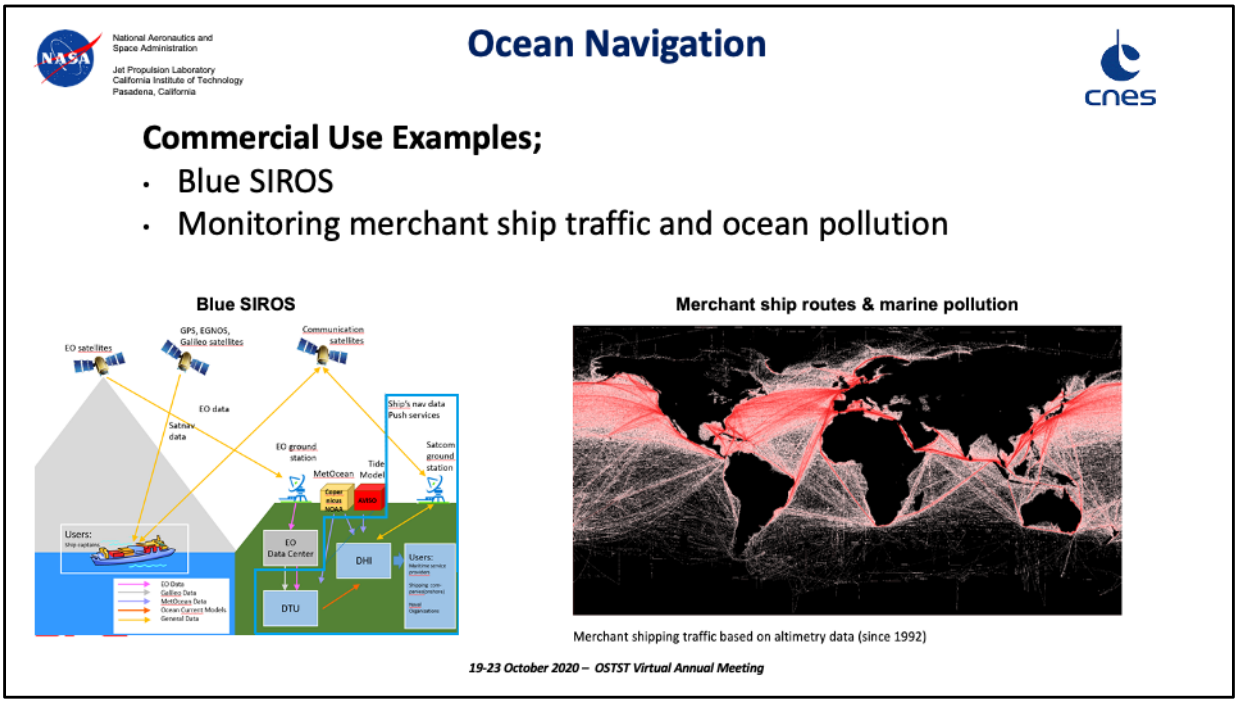
Source: NOAA/AOML

- National Hurricane Center
- Ocean heat content shows heat available over to increase intensity of tropical cyclones.
- Long-term seasonal forecasts of the numbers and strengths of hurricanes expected in a given hurricane season
- Short term forecasts of the strength of individual hurricanes



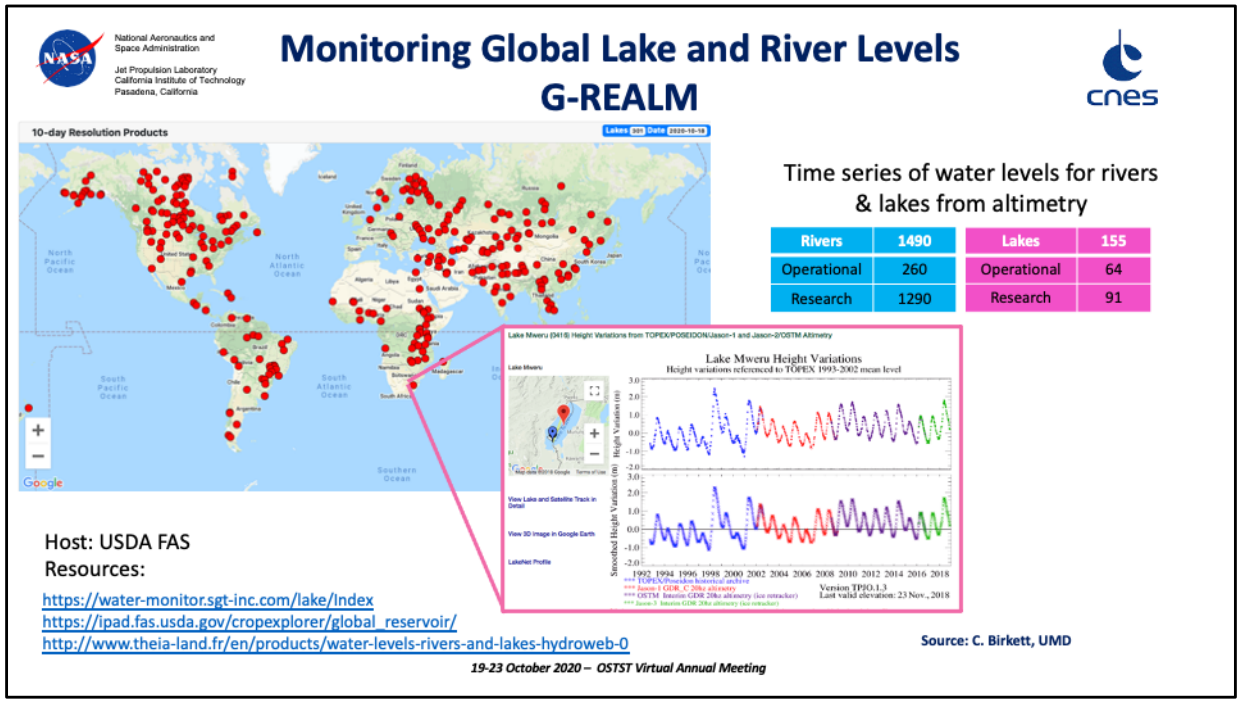
Some examples of operational and practical applications in the commercial sector include;

- **FishTrack**; (http://www.fishtrack.com/features/how-to-altimetry-maps_132784) – combines sea surface temperature (SST), chlorophyll with altimetry to identify potential fish feeding zones
- **Hilton's Realtime Navigator**; (http://realtime-navigator.com) combines SST, chlorophyll and altimetry to generate fishing charts
- **Terra-Fin**; uses similar data assets to provide information to anglers and divers



Some examples of operational and practical applications in the commercial sector include;

- **Blue SIROS**; (https://business.esa.int/projects/blue-siros) for marine route optimization which integrates modelling and forecasts of ocean currents based on near-real time satellite altimetry data
- **Merchant ships and pollution**; (https://news.agu.org/press-release/worldwide-ship-traffic-up-300-percent-since-1992/) Using altimetry, merchant ship traffic can be monitored with unprecedent accuracy. A comprehensive study using altimetry revealed a 300% increase in merchant shipping since 1992



Summary: The U.S. Department of Agriculture's Foreign Agricultural Service (USDA-FAS), in co-operation with the NASA and the University of Maryland, are routinely monitoring lake and reservoir height variations for many large lakes around the world. The program utilizes NASA/CNES/ESA/ISRO radar altimeter data over inland water bodies operationally. Surface elevation products are produced via a semi-automated process and placed on a web site for USDA and public viewing. Initial real-time products from this project have been in operation since December 2003.

Users: USDA FAS, farmers, water managers - quickly locate regional droughts, as well as improve crop production estimates for irrigated regions located downstream from lakes and reservoirs;

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Private Sector: Operational Ocean Forecasting

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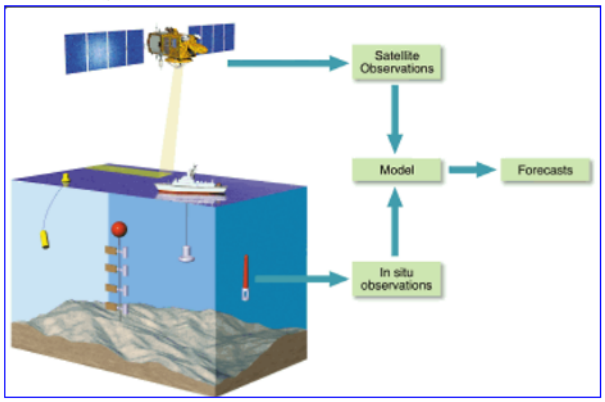

Source: www.myocean.eu

Mercator Ocean

- EU-based
- Ocean monitoring indicators (OMIs)
  - Health
  - Heat content
  - Sea level rise
  - Sea Ice
  - Climate Variability
- Global, regional trends data

Application: Realtime ocean charts for general marine consulting using infrared, satellite altimetry, and surface isotherm data. Oceanographic analyses are produced and available for the Gulf Stream area and all major global currents.

Operation: Using near real-time altimeter data with sea surface temperature imagery to evaluate currents affecting offshore operations. Waypoints are also provided for taking advantage of favorable currents and for avoiding unfavorable ones.

Ocean Monitoring Indicators (OMIs) are free downloadable trends and data sets covering the past quarter of a century. These are key variables used to track the vital health signs of the ocean and changes in line with climate change.

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Private Sector: Operational Ocean Forecasting

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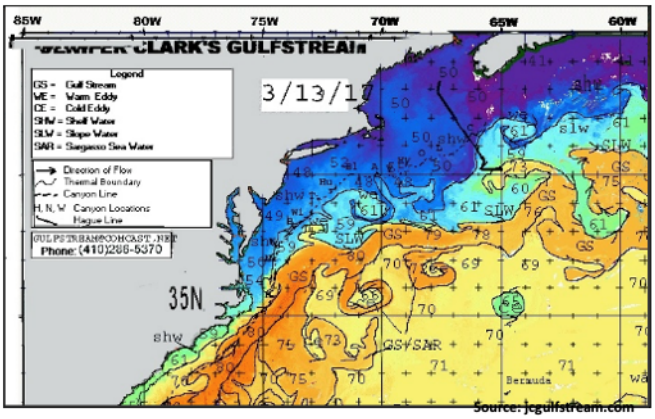


Jenifer Clark's GulfStream

- Charts of surface height
- Eddies and swift moving currents can be identified
- Transatlantic ship routing, cable laying, and oil exploration use these maps to increase safety and economic return.
- Recreational boating

Application: Realtime ocean charts for general marine consulting using infrared, satellite altimetry, and surface isotherm data. Oceanographic analyses are produced and available for the Gulf Stream area and all major global currents.

Operation: Using near real-time altimeter data with sea surface temperature imagery to evaluate currents affecting offshore operations. Waypoints are also provided for taking advantage of favorable currents and for avoiding unfavorable ones.

Altimeter Product Used: Near-real time data SSH and geostrophic velocity data viewers.

Private Sector: Offshore oilfield operational support

Data User: Capt. Karl Greig, captain of a large anchor handling tug boat owned by Edison Chouest Offshore, a petroleum industry service company, uses NRT Jason data from CCAR to optimize routes while towing semi-submersible drilling rigs used in deepwater oil and gas exploration between lease blocks.

Example Operation: Moving a rig from Mississippi Canyon block 68 to Mustang Island block 68, a total of 425 nautical miles. Typical towing speeds are 3 to 4 knots so avoiding and/or using eddy currents significantly reduces transit times, in this case by over 50 hours.

Altimeter Product Used: Overlays of geostrophic velocity vector on colored magnitudes values accessed on CCAR website by satellite phone.

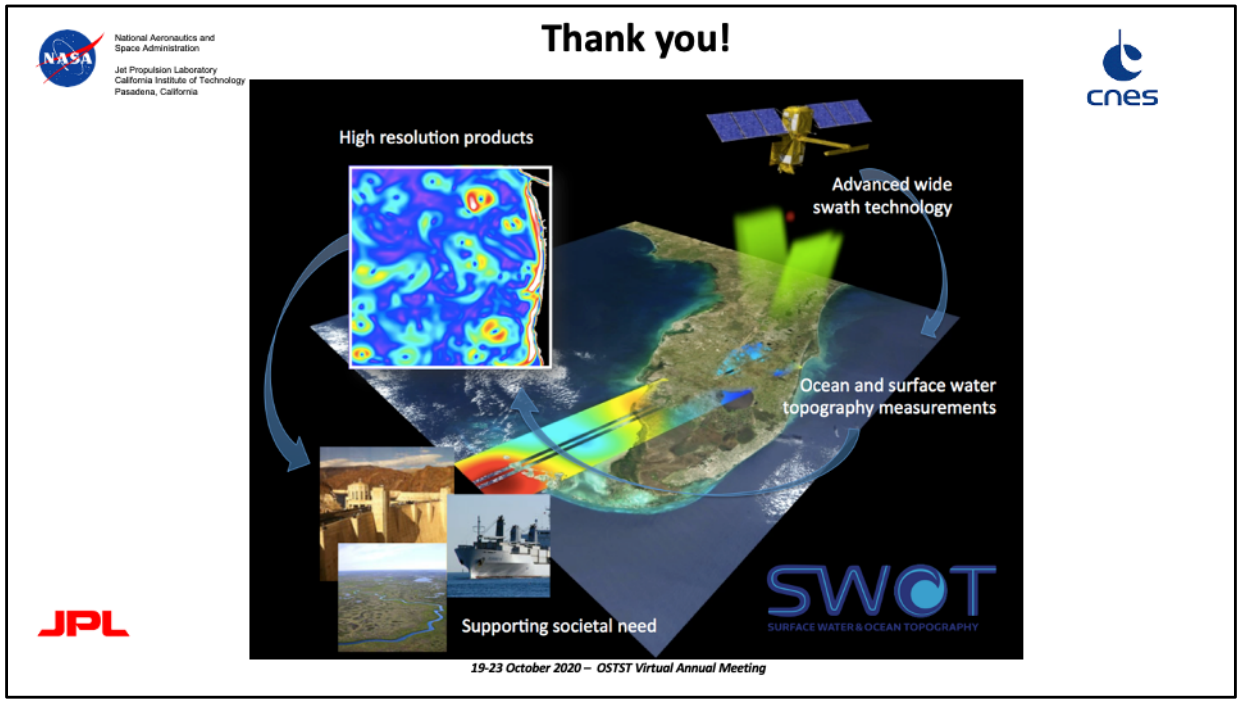
Estimated Savings: $650,000 in rig downtime and towing costs for one event.

A 2003 communication to the Univ. Colorado, who provided images, analysis and information products to altimetry users for over 20 years, much of that time on contract to the NASA projects that provided the data, came from Capt. Karl A Greig of the Edison Chouest Offshore company. This use of data illustrates the high value potential use of altimetry data when users are able to access and understand the data and information products provided.

Captain on a Large Anchor Handling Towing Supply boat that belongs to Edison Chouest Offshore of Galliano, Louisiana and we work in the oil and mineral industry. This is to explain exactly why I asked if you could develop such a site, and how we use it. First of all The equipment we use: **The A.H.T. Supply boats:** Are 240 to 300 ft long, 40 to 72 feet wide, draft 8 to 30 feet, Horsepower is from 5000 to 33,000 brake. We have winches and storage capacity for app. 60,000 feet of 3.5 inch diameter wire. the winches have a lifting capacity of 500 metric tons, our ship has a bollard pull of over 200 Metric tons. These ships are growing in size and power as the water depth increases and the rigs and equipment get larger. **The Tug boats:**Are generally 7000 to 12,000 horsepower with 80 to 150 ton bollard pull. **The Drilling Rigs**: Average Deepwater Semi Submersible Stabilized Column unit: Length 400ft. Breath

240ft. Height 150ft. Draft 25 to 80ft. These rigs are moored in position by 8 to 12 anchors on the ocean bottom, with chain and steel cables connecting them. Normally in slack water we can tow a rig with one tug and 2 anchor boats at 3 to 5 knots Now that you see what we are working with it may be easier to see why the current velocity site helps us. The average cost to move a rig is $12,000.00 to $13,000.00 per hour. This includes: Rig downtime, Anchor Handling and Tug Boats, Towing time to new location, Rig move Anchor crews, transportation for equipment and personnel. In August of 2003, I made a rig move from Mississippi Canyon block 68 (Lat. 28 55N Lon. 88 45W) to Mustang Island block A18 (Lat.27 21N Lon. 96 33W) We had approximately a 425 mile tow from one location to the next. By using the Velocity site I was able to adjust my courses to avoid towing into the loop currents and to get one astern of us and increase our tow speed by almost two knots. By using the website that you and your department developed, this enabled me to shorten our towing time by over fifty hours on a four hundred and twenty mile tow, saving the company chartering the equipment a considerable amount of money. I will highly recommend this site to all my coworkers and anyone working in this industry, and I imagine you will be getting quite a few hits on this site in the future. Thanks again to you and your group.

Capt. Karl A. Greig



Many other examples of the operational, private sector, and societal benefits of altimetry data will be forthcoming as our new collaboration with U. Washington, and new team members at JPL take on the Altimetry Applications program into the next decade!

Thank you. Please contact me with any questions;

Margaret Srinivasan
NASA/Jet Propulsion Laboratory
Phone: 818 393 3974
margaret.srinivasan@jpl.nasa.gov