Ocean and Coastal Remote Sensing in the NOAA Center for Satellite Applications and Research (STAR): Product Development and Transitions between Research and Operations

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NOAA/NESDIS/STAR
College Park, MD

Expanding the "Operational" paradigm

Despite maturity and availability, challenges (real and perceived) remain to achieving more-routine, effective, and sustained uses of satellite oceanographic data.

Challenge: Shifting Perceptions about what "operational" actually means

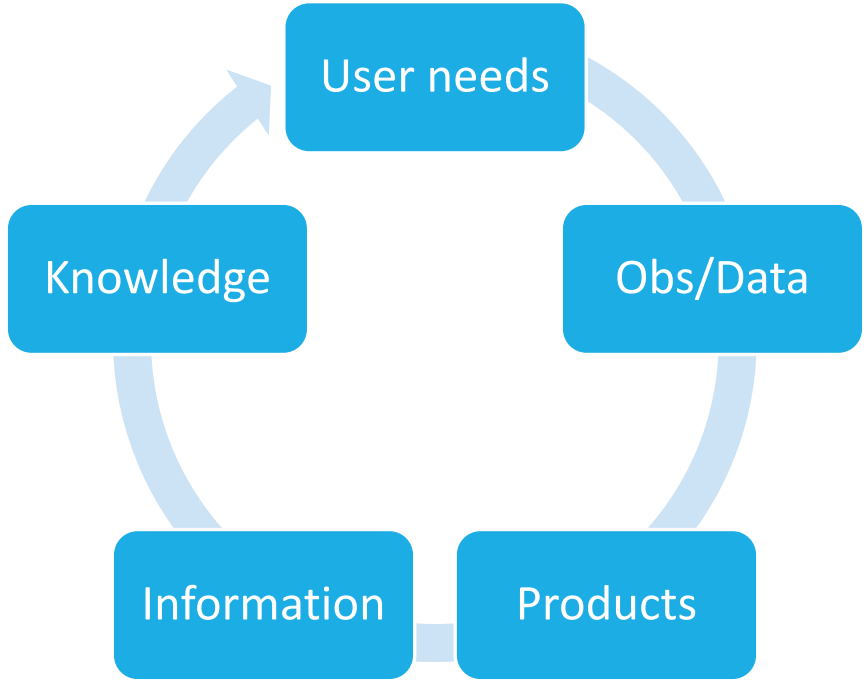
Operational:
= Near-Real Time (NRT)
= 99.99% ground system reliability and operational availability 24x7
= 24x7 human in the loop operations
= Continuity of Operations capability (system redundancy/op backups)
= High-impact IT security

Operational:

- **Routine and sustained provision of accurate, consistent and fit for purpose quality oceanographic satellite observations**
- **Span the different time-scales** (i.e., NRT to climate) of operational mission user interest,
- Can be **high assurance/high-service <u>OR</u> moderate assurance/moderate-service**
- **Consider all applications including research**

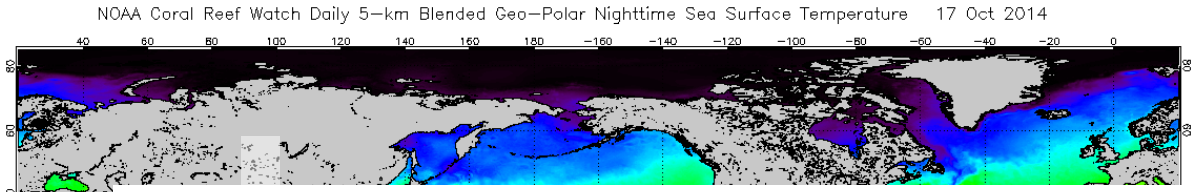
Value Chain: Observations, Data, Products, Information, Knowledge

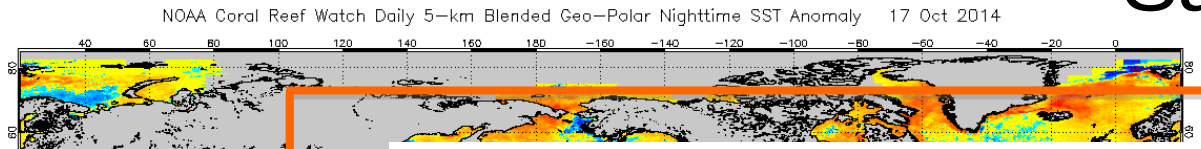
- Satellite Ocean Observations/Data
  - ~from bits & bytes to geophysical parameters
- Satellite Ocean Data Products
  - ~from swath/granule to mapped, merged, anomalies, etc.
- Information
  - combine data types, model output etc, for more complete picture
- Knowledge (***to inform actions***)
- Coral Reef Watch example

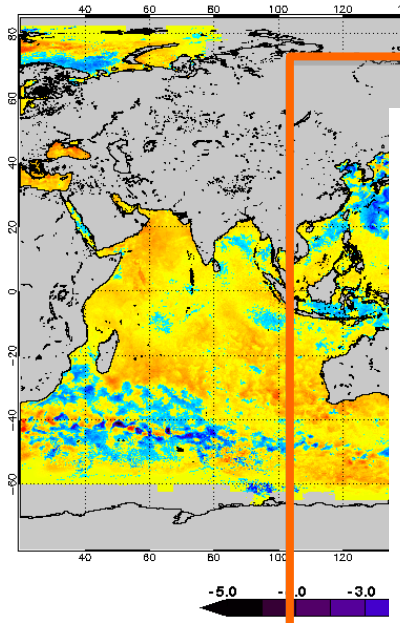


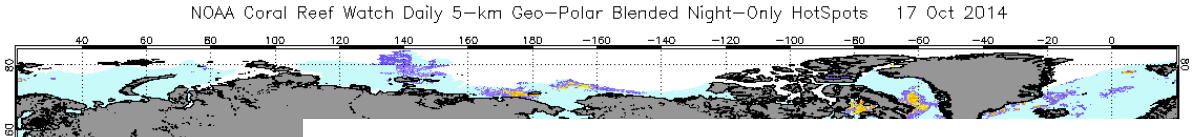
NOAA Coral Reef Watch Satellite-Based Products

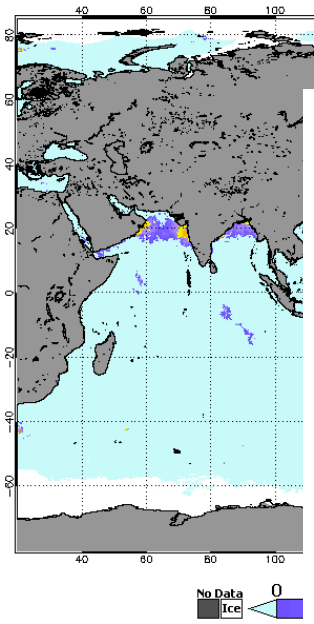
Mark Eakin, Lead

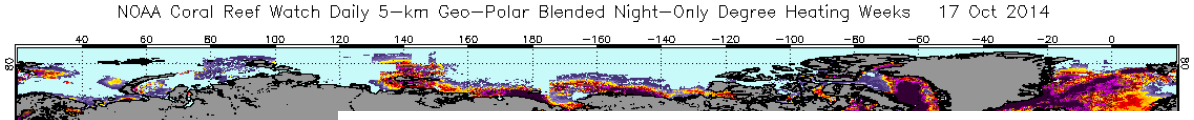


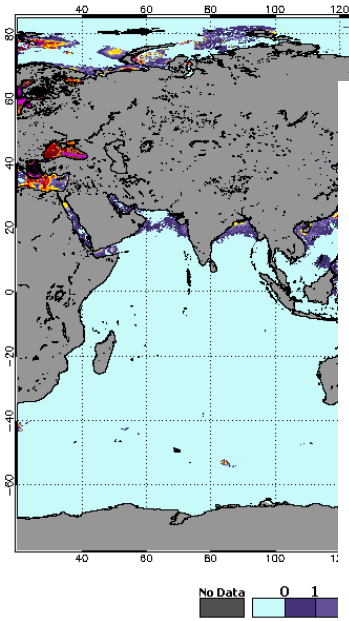


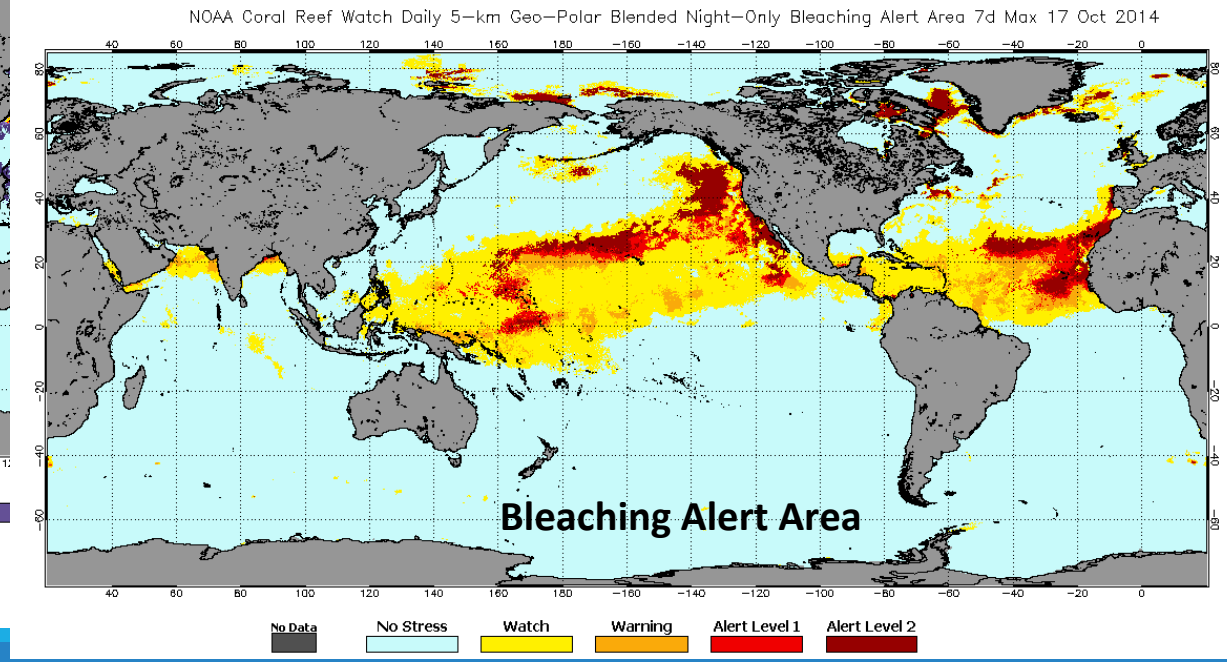












Coral – specific

Ocean Obs and Data Providers & Stewards

NESDIS

Operational Satellite Data
NOAA & non-NOAA assets
STAR (Mod. Assurance/Service)
OSPO (High Assurance/Service)

Archived Satellite Data
NOAA & non-NOAA assets
NCEI

Non-NESDIS Satellite Data Providers

Other Observations & Data
Sub/surface, Airborne, Sub-orbital
NOAA (e.g., IOOS, CPO) & non-NOAA

Ocean Product and Information Generators & Providers

NOAA

Tailored Satellite Products
CoastWatch/OceanWatch
Coral Reef Watch
PolarWatch

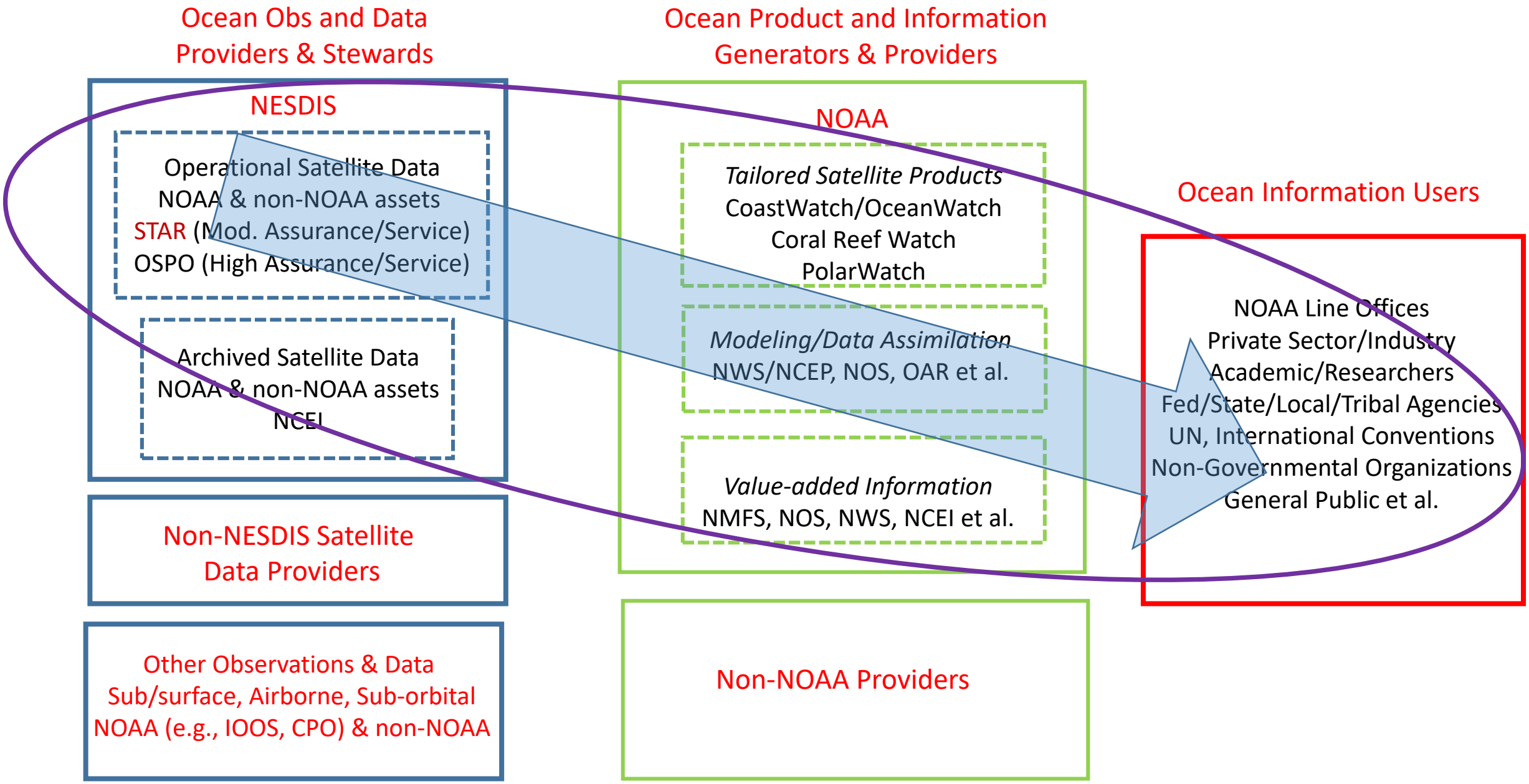
Modeling/Data Assimilation
NWS/NCEP, NOS, OAR et al.

Value-added Information
NMFS, NOS, NWS, NCEI et al.

Non-NOAA Providers

Ocean Information Users

NOAA Line Offices
Private Sector/Industry
Academic/Researchers
Fed/State/Local/Tribal Agencies
UN, International Conventions
Non-Governmental Organizations
General Public et al.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STAR/Satellite Oceanography & Climatology Division (SOCD)

SOCD Organization

SOCD Chief: *Dr. Paul M. DiGiacomo*

Ocean Sensors Branch

Chief: *Dr. Alexander (Sasha) Ignatov*

- Sea Surface Temp, Ocean Winds, Ocean Optics & Water Quality (e.g. Chesapeake Bay)

Marine Ecosystems & Climate Branch

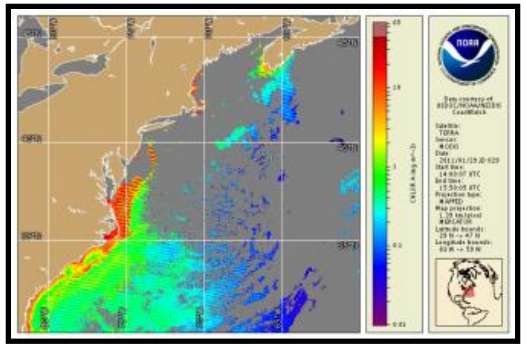
Chief: *Dr. Menghua Wang*

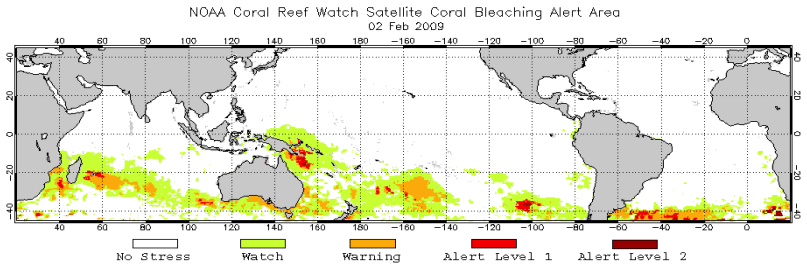
- Ocean Color, Coral Reefs, Sea Ice, Synthetic Aperture Radar, Blended SST

Laboratory for Satellite Altimetry

Chief: *Dr. Eric Leuliette (acting)*

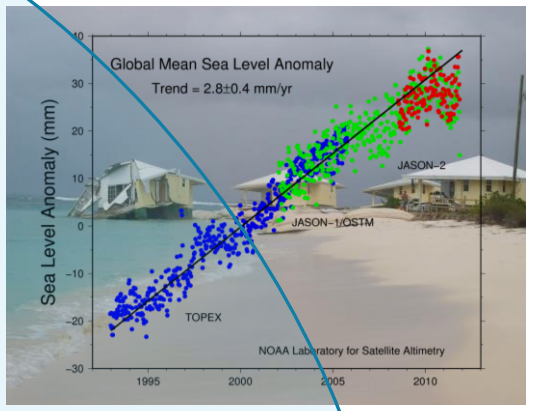
- Sea Level, Bathymetry, Waves, Sea Ice/Climate





Science Teams: R&O

- Sea Ice
- Sea Surface Height
- Sea Surface Roughness
- Sea Surface Salinity
- Sea Surface Temperature
- Ocean Color Radiometry
- Ocean Surface Vector Winds
- CoastWatch/OceanWatch
- PolarWatch
- Coral Reef Watch
- (GEO Blue Planet; AquaWatch)



Major Programs & Activities

- *Users*: All NOAA; extensive inter/national users
- *Approach*: Source-agnostic, measurement-based
- *Fit for purpose*: NRT & science-quality data
- *Enterprise*: Ocean algorithms/processing systems
- Sat ocean data assimilation for environmental modeling
- JASON Satellite Radar Altimeter Program
- JPSS: Ocean Color & SST EDR leads
- GOES-R: SST lead; GCOM-W: Project Lead
- Sentinel-1, 2, 3: Project Lead
- Marine Optical BuoY (MOBY) Project
- National Ice Center support: Chief Scientist et al.

Focusing on the user-driven end-to-end value chain: Observations <> Data <> Products <> Information <> Knowledge

Operational Satellite Oceanography

OPERATIONAL: Routine and sustained provision of mature, fit for purpose quality data and products in support of both near real time and delayed mode research, applications and services...

Linking satellite data providers with intermediate/end users – an iterative process with routine and sustained engagement & feedback:

What are your data/information requirements?

In what ways is your organization using satellite data right now?

How can we support, facilitate and enhance your current usage?

How could/would you like to use these data in the future?

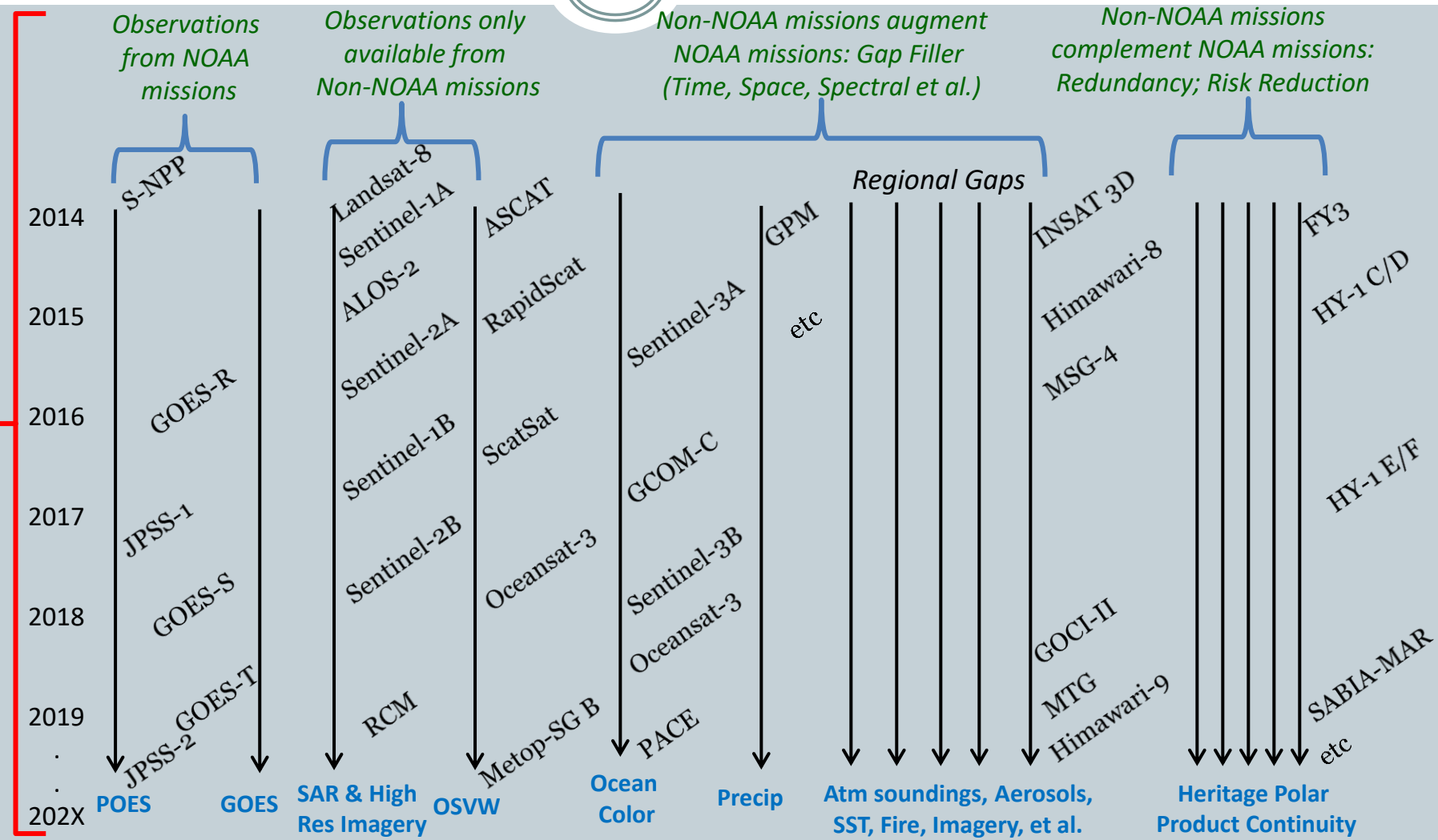
Where do you see big data, product or information gaps?

What barriers to access and use of satellite data do you perceive?

Are you familiar with all the new satellite capabilities coming in the next decade and how they might add value to your mission skill?

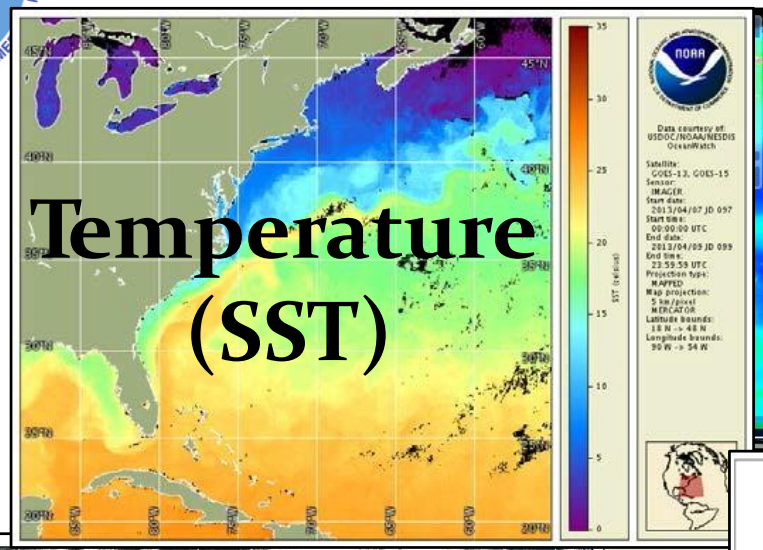
Source Agnostic, Measurement-based, enterprise approach in support of users: Ensuring continuity, coverage & consistency

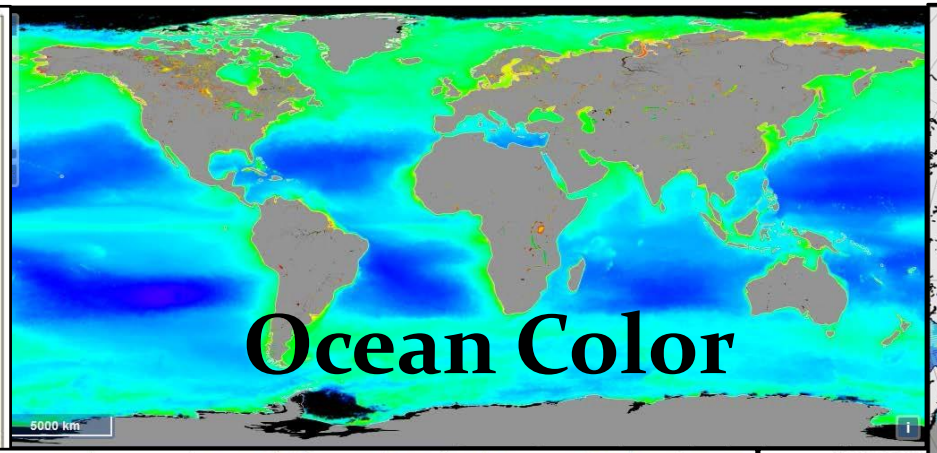
Scientific enterprise approach along observing system "highways": Cal/Val; Algorithm & Product Development; Data Distribution, Application Development; User Engagement

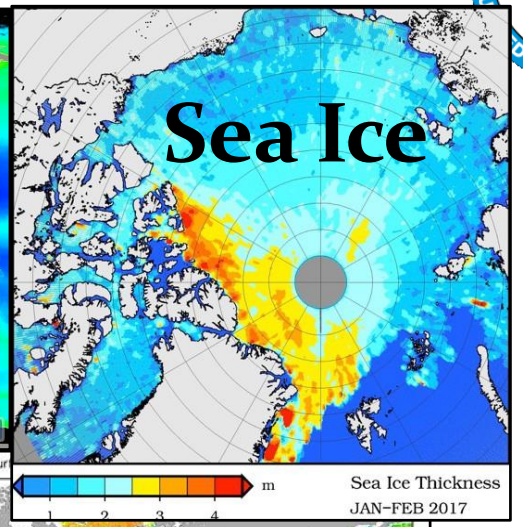


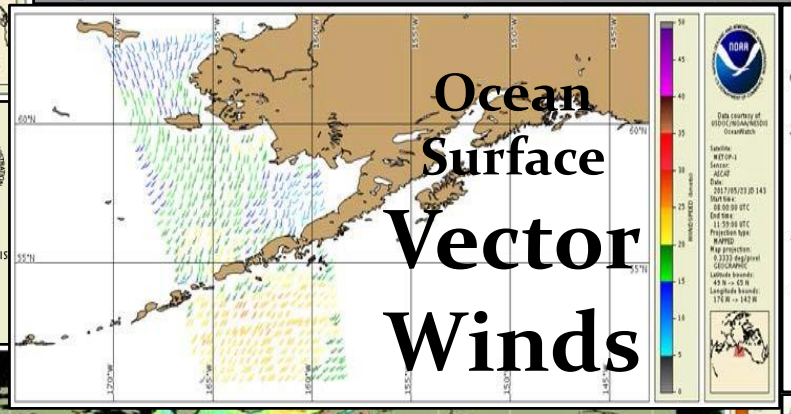
Courtesy: Paul DiGiacomo & Paul Chang

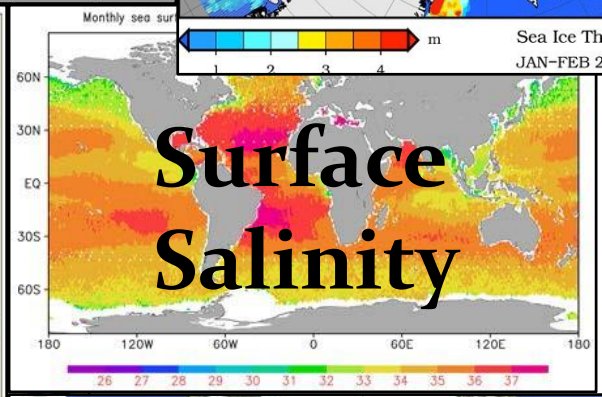
Ocean Parameters from SPACE

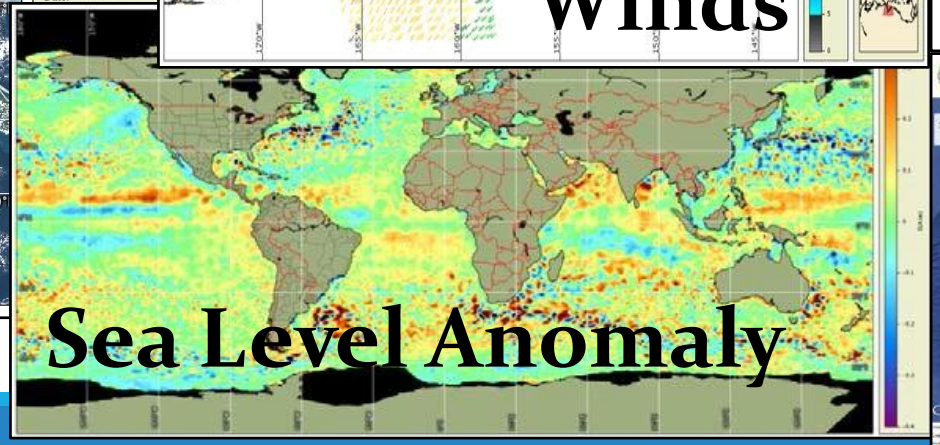


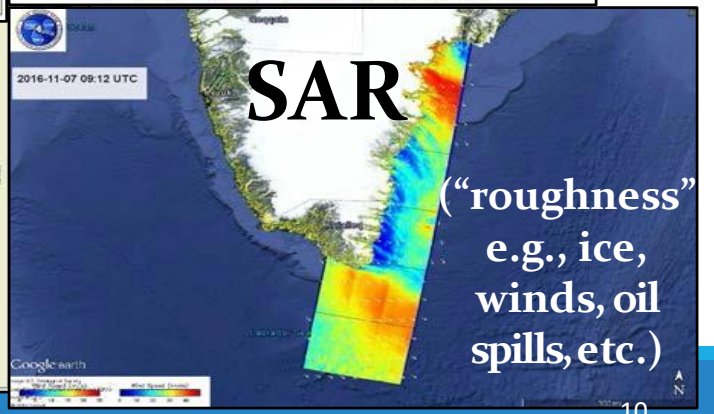




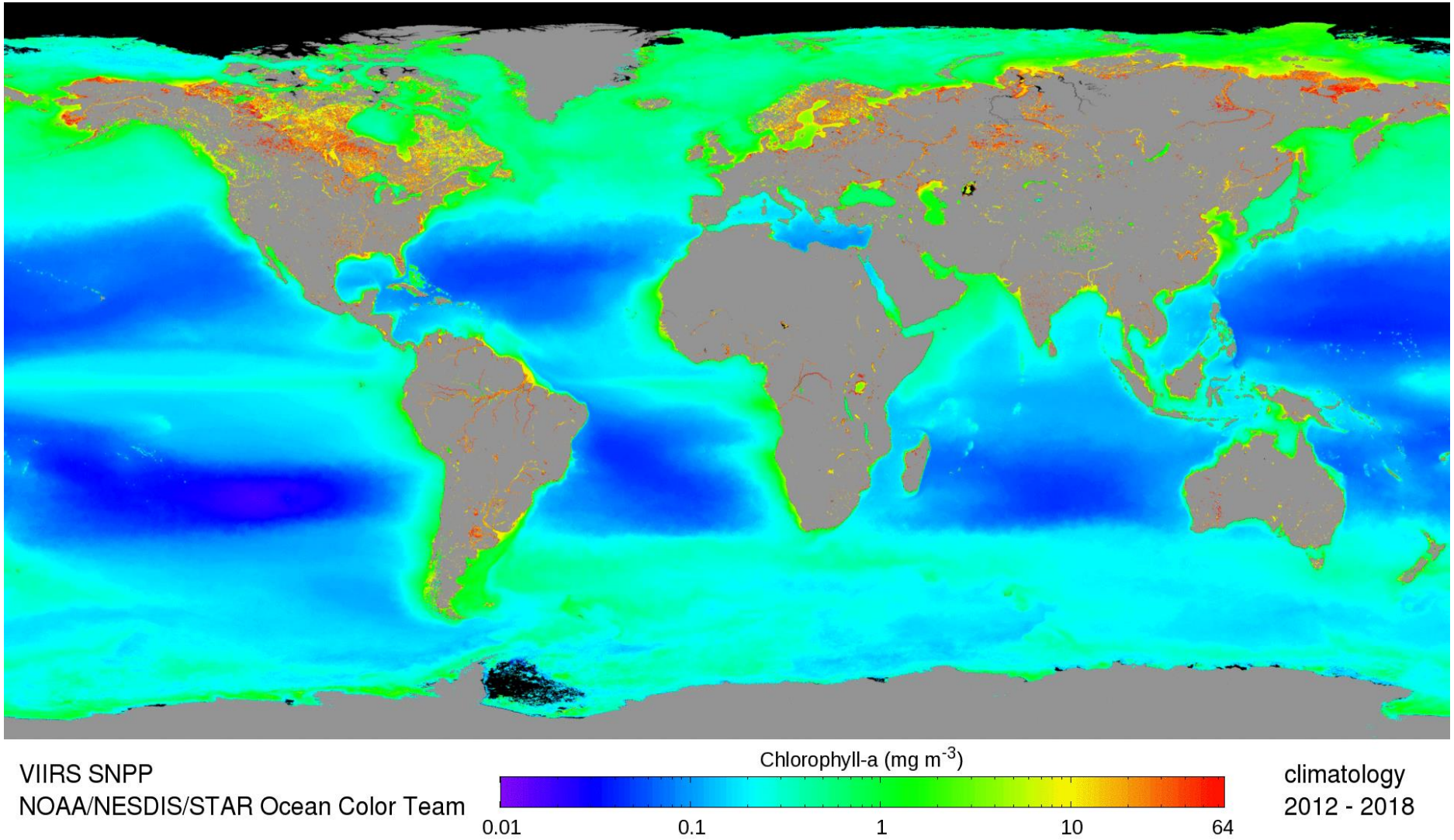








VIIRS Climatology Ocean Color Product Image
SNPP (2012–2018)



MSL12 with the NIR-SWIR data processing system is used for VIIRS

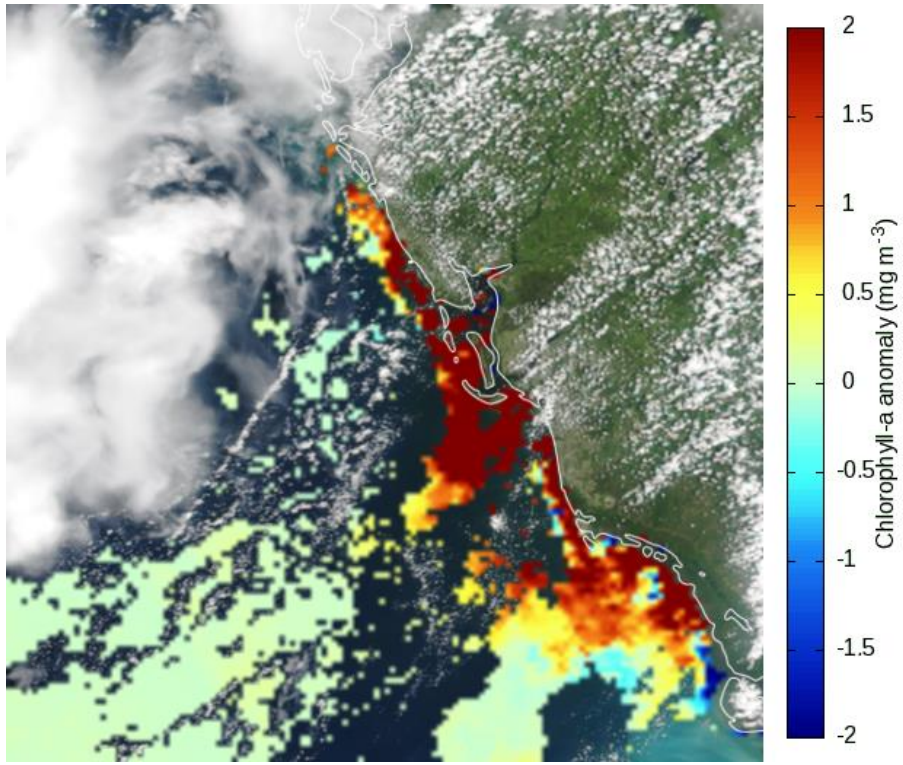
Menghua Wang, NOAA/NESDIS/STAR

Summary of VIIRS Ocean Color EDR Products (Updates-Based on Users Input)

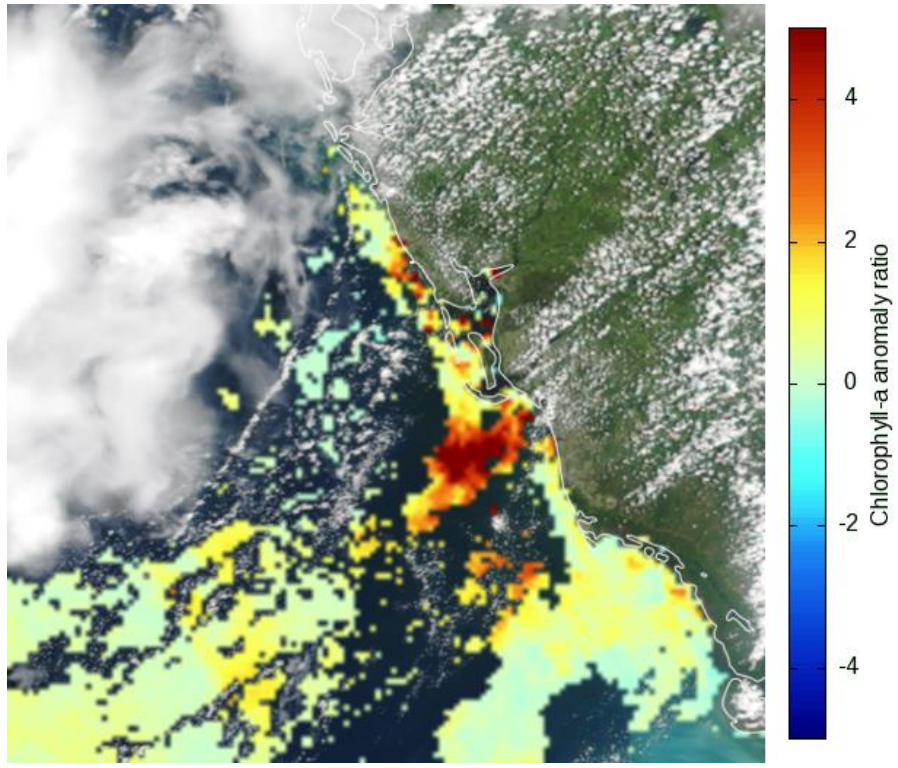
- **Inputs**:
  - VIIRS M1-M7, I1, and the **SWIR** M8, M10, and M11 bands SDR data
  - Terrain-corrected geo-location file
  - Ancillary meteorology and ozone data
- **Operational (Standard) Products (10)**:
  - Normalized water-leaving radiance (nL_w's) at VIIRS visible bands M1-M5, and **I1 (638 nm)**
  - Chlorophyll-a (Chl-a) concentration
  - Diffuse attenuation coefficient for the downwelling spectral irradiance at the wavelength of 490 nm, $K_d(490)$
  - Diffuse attenuation coefficient of the downwelling photosynthetically available radiation (PAR), $K_d(PAR)$
  - **QA Score** for data quality ($nL_w(\lambda)$ spectra) (*Wei et al.*, 2016)
  - Level-2 quality flags
- **Experimental Products (29):**
  - Inherent Optical Properties (IOP-a, IOP-a_{ph}, IOP-a_{dg}, IOP-b_b, IOP-b_{bp}) at VIIRS M2 or other visible bands (M1-M5) from the Quasi-Analytical Algorithm (QAA) (*Lee et al.*, 2002)
  - Photosynthetically Available Radiation (PAR) (*R. Frouin*)
  - Chl-a from ocean color index (OCI) method (*Hu et al.*, 2012; *Wang and Son*, 2016)
  - Others, e.g., user specific products (e.g., **Chl-a anomaly** and **Chl-a anomaly ratio**)

➢ Data quality of ocean color EDR are extremely sensitive to the SDR quality. It requires **~0.1%** data accuracy (degradation, band-to-band accuracy…)!

Harmful Algal Bloom Detection and Prediction



Chl-a Anomaly



Chl-a Anomaly Ratio

High chlorophyll-a anomaly linked to HAB presence in waters off the Gulf Coast of Florida. Global NRT Chl-a anomaly and anomaly ratio are routinely produced

Example: Experimental product development

Phytoplankton Functional Types – research & algorithm development

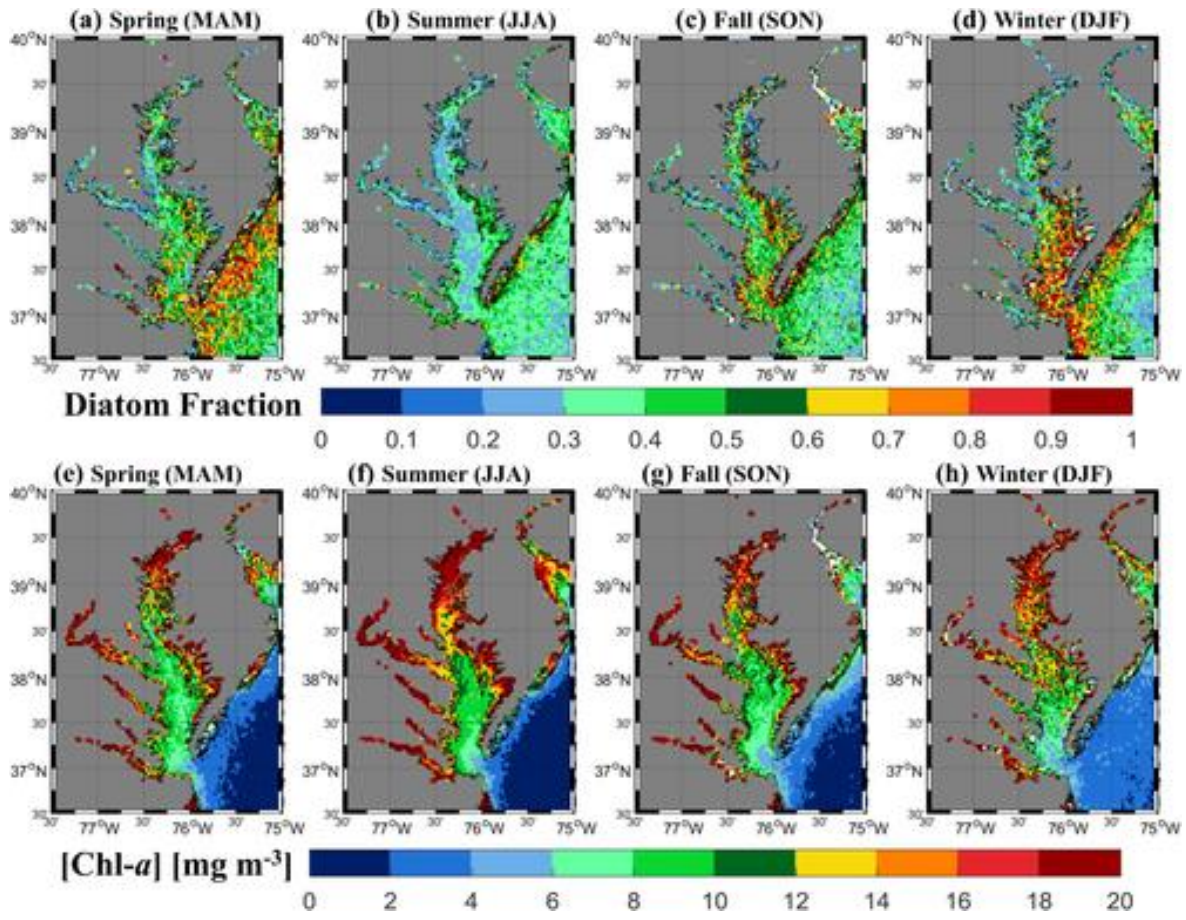
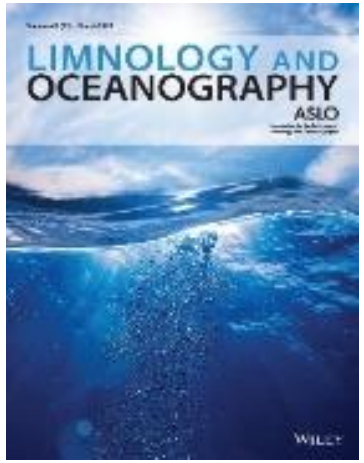
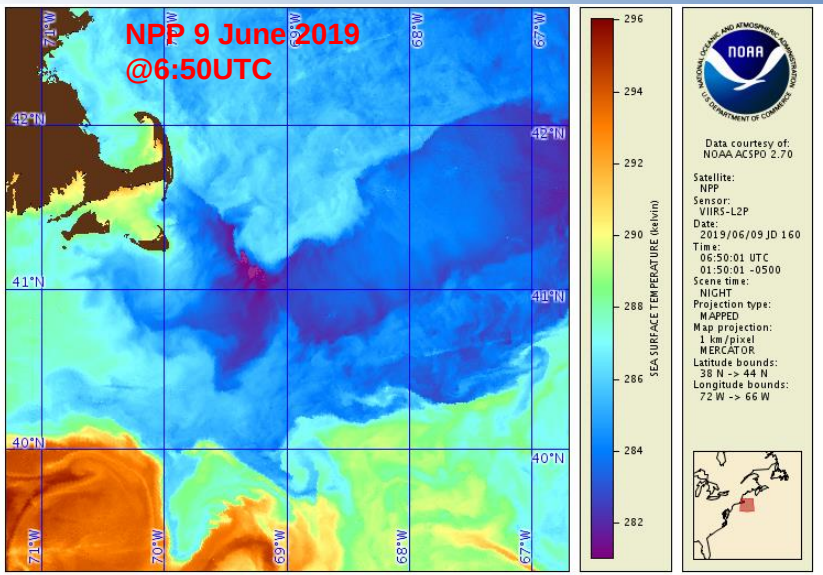
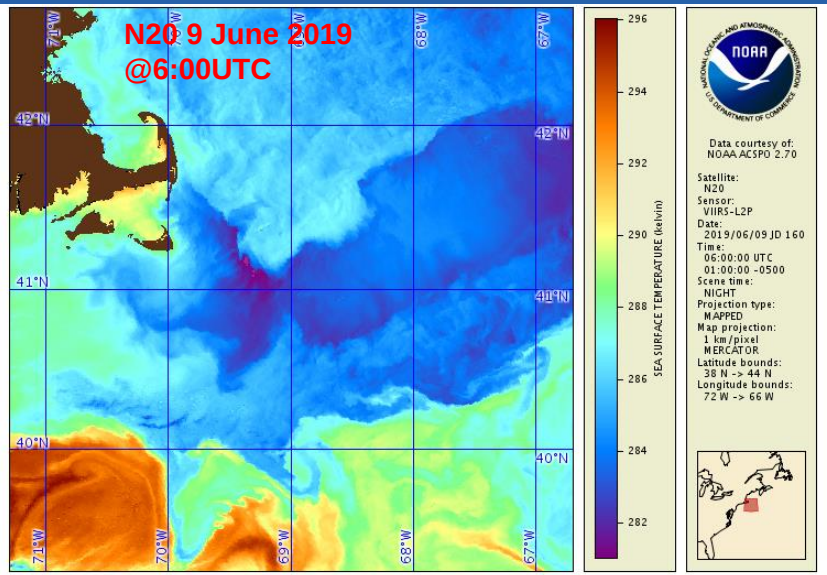


Fig. 5 from Zheng and DiGiacomo, Detecting phytoplankton diatom fraction based on the spectral shape of satellite-derived algal light absorption coefficient, March 2018 Volume: 63, Issue: S1, S85-S98, DOI: (10.1002/lno.10725)
Limnology & Oceanography



New NOAA Polar Constellation, JPSS, is in orbit
Work is underway on super-collated VIIRS SST product (L3S)

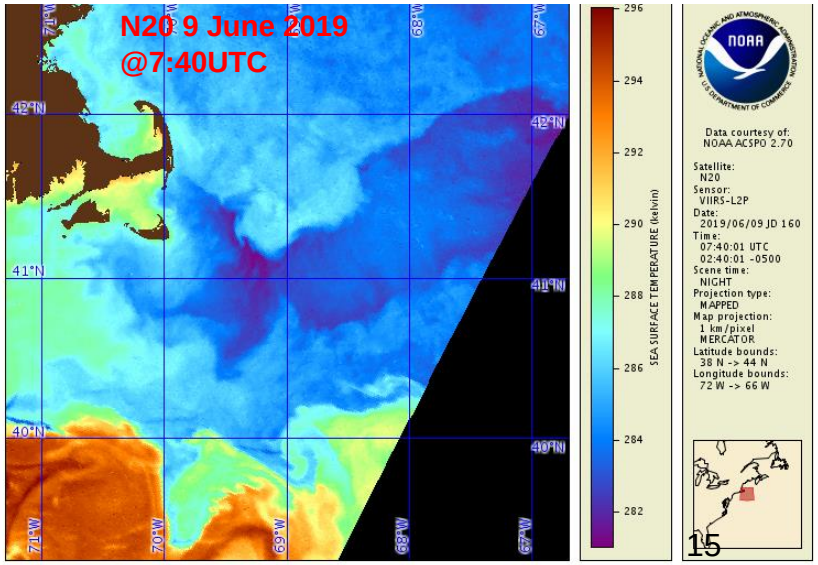




NPP & N20 SSTs are operational, fully validated, highly accurate, consistent & archived at PO.DAAC, NCEI & CW

Users want super-collated SST. Initial focus is on two VIIRSs.

3 AVHRR FRACs (Metop-A/B/C) & 2 MODISs (Terra/Aqua) will be added later



New NOAA Geostationary Constellation, GOES-R, is in orbit
Will conduct G17 Provisional Review Jul 2019, go operational & archive

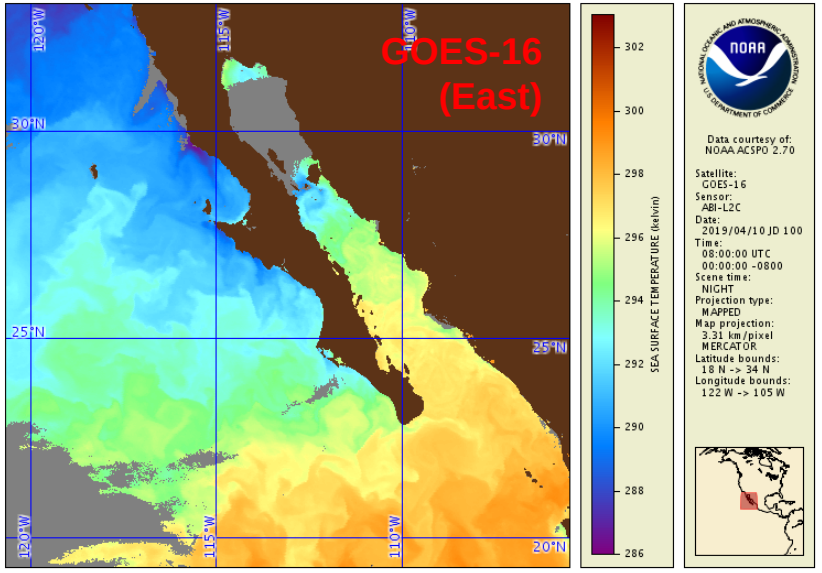
Launch G16/East
19 November 2016

G16 is operational, validated, accurate & archived at PO.DAAC, NCEI & CW

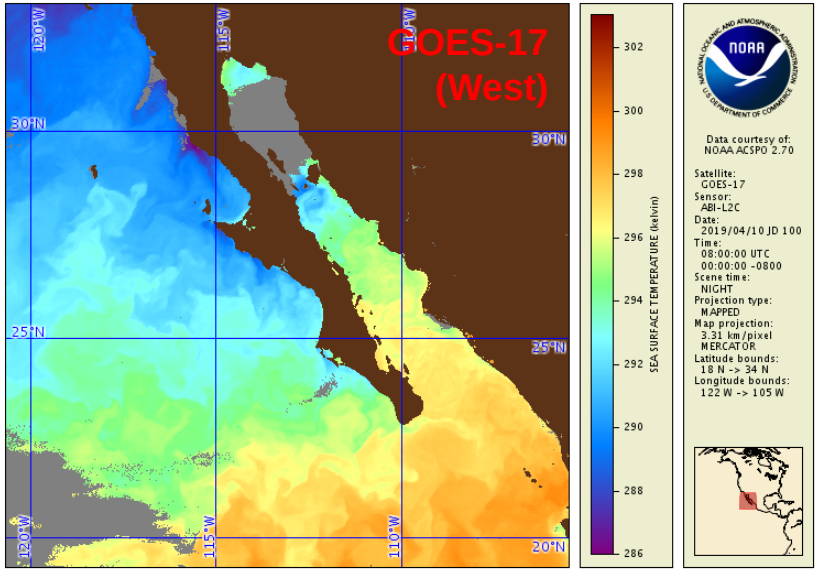
G17 ABI experiences sensor issues. Product is generated only for 13hrs out of 24

Work on provisional review is underway. Then product will become operational & archived at PO.DAAC, NCEI, CW

Launch G17/West
March 1, 2018

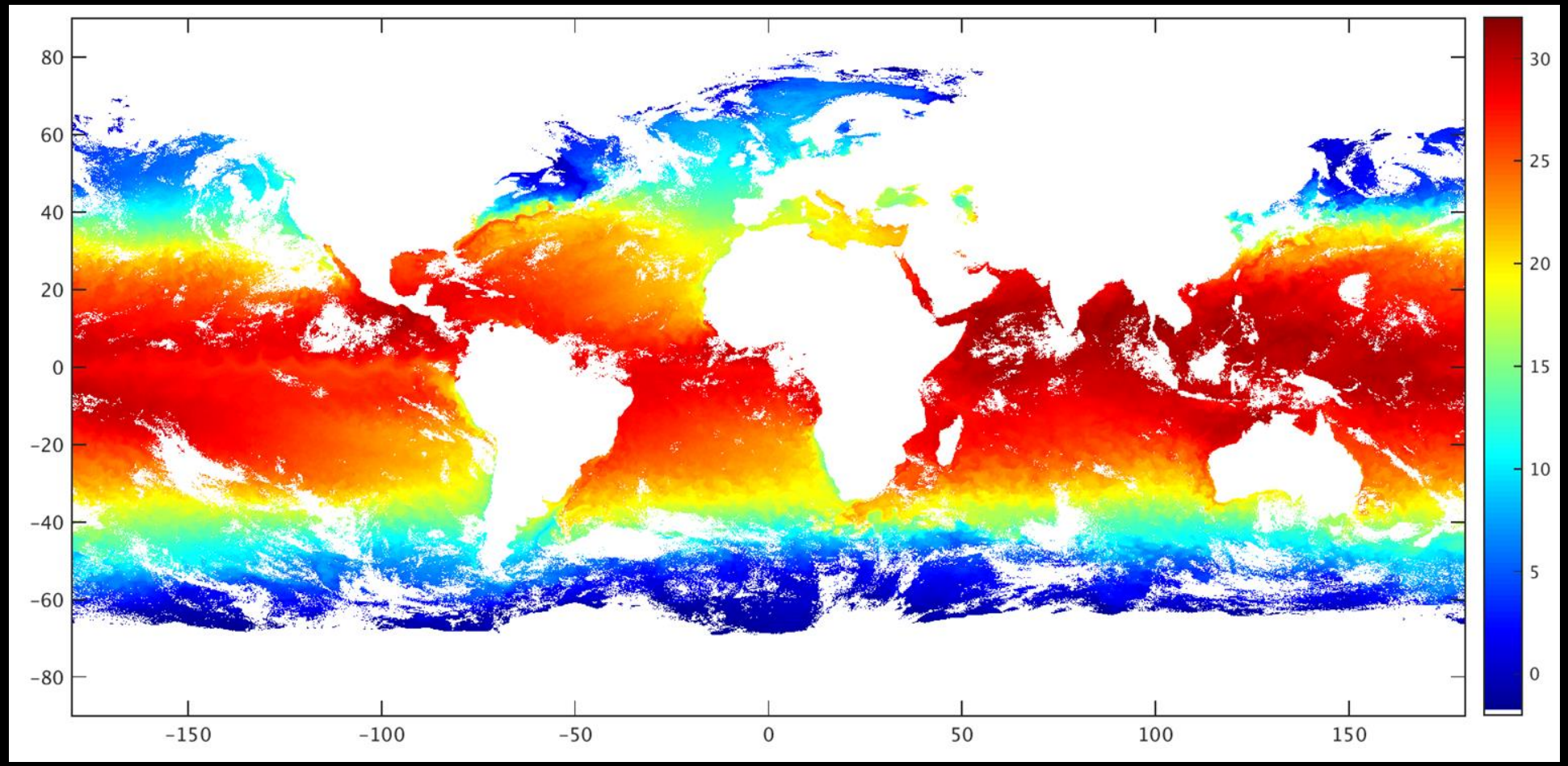


When observed from both G16 & G17, two SSTs are consistent



ABI (GOES-16) & SEVIRI (Met-11/8)

S-NPP NOAA-20 MetOp-B



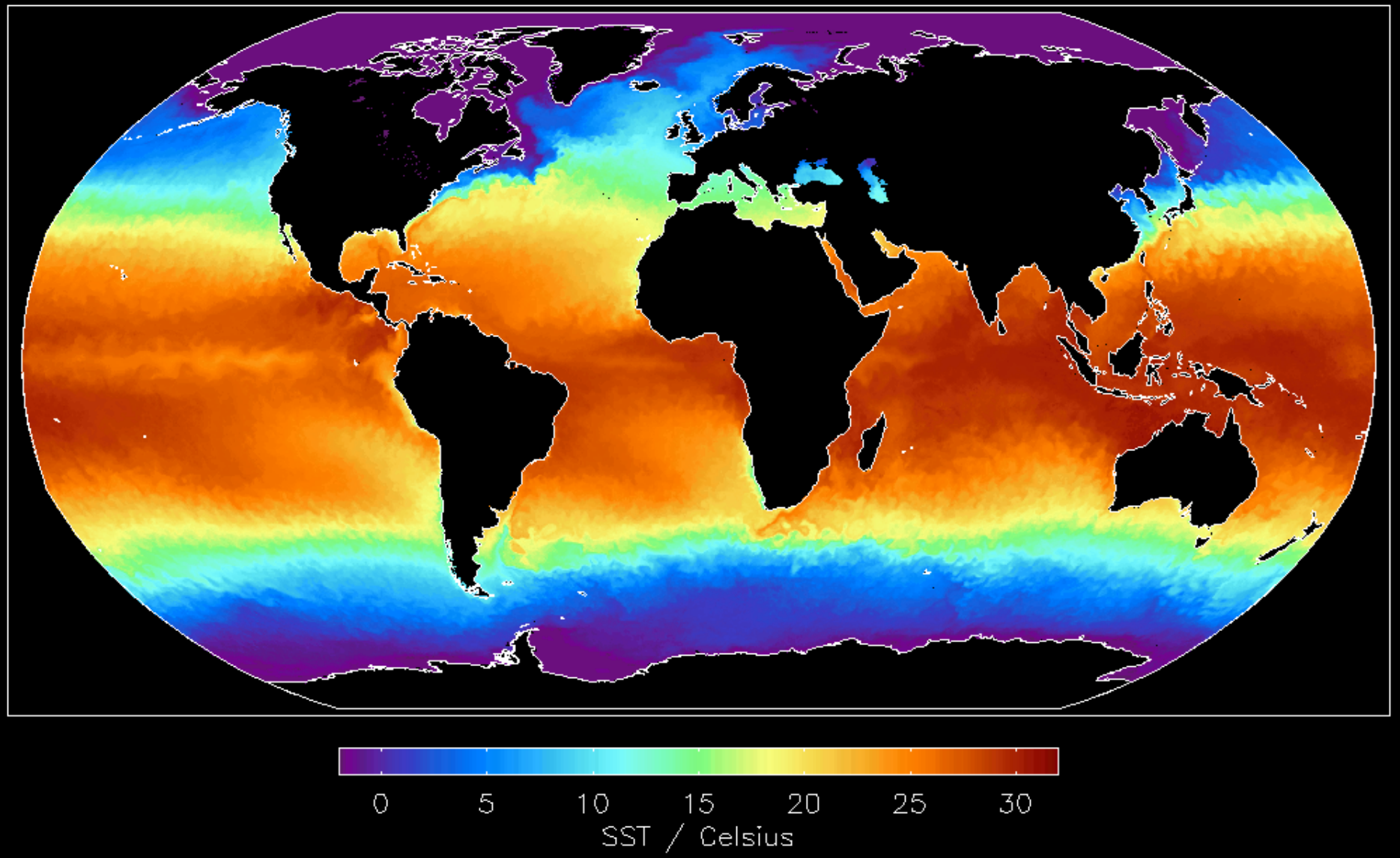
GOES-15 GOES-16 Met-11 Met-8 Himawari-8

Each dataset (day & night) is **individually bias-corrected** prior to the analysis step

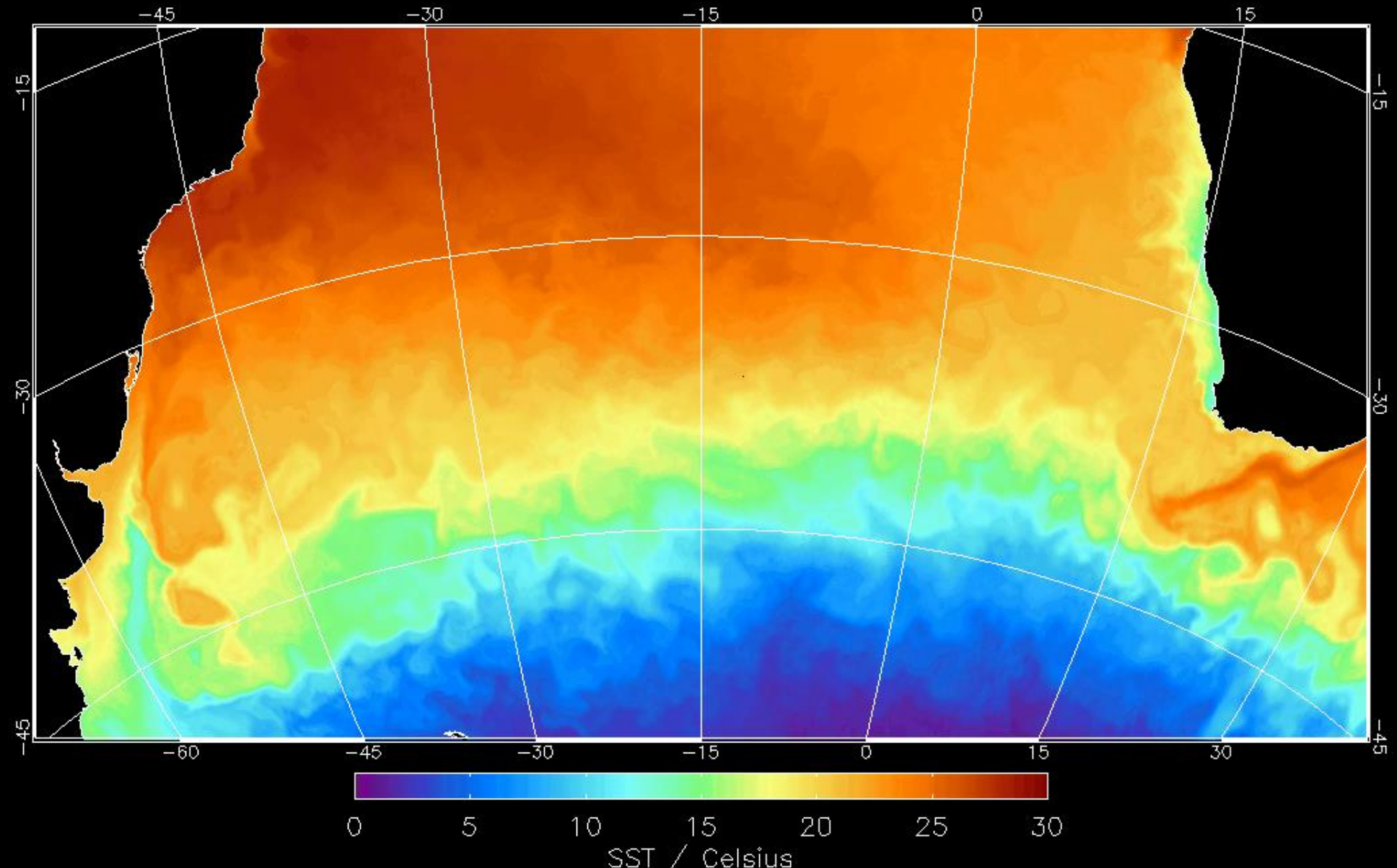
Geo-Polar Blended SST

MetOp-B S-NPP

GOES-15 GOES-16 Meteosat-11 Meteosat-8 Himawari-8

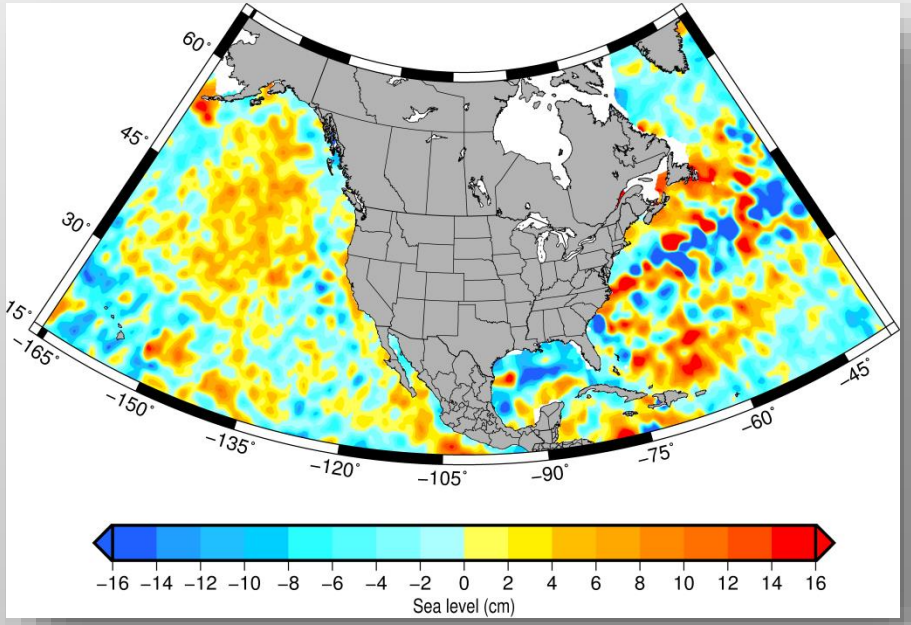


Brazil-Malvinas Confluence, Agulhas Retroflection, Benguela Current & Antarctic Circumpolar Current



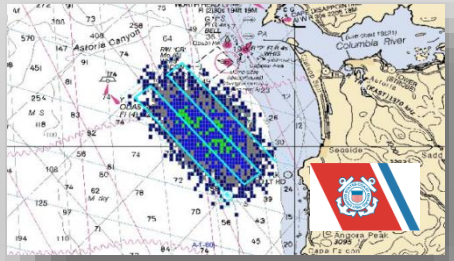
Jason Altimetry Applications & End Users

Sea Level Anomaly –"Ocean Weather"- Feb 3-13, 2014

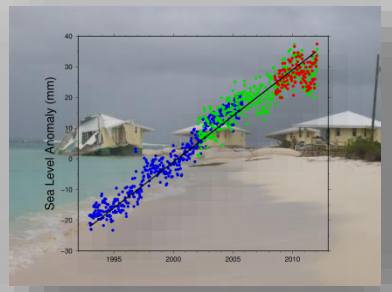


High Wave Forecasting

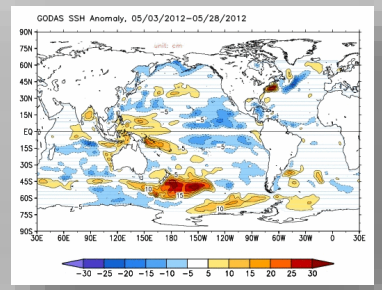
Coast Guard Search & Rescue



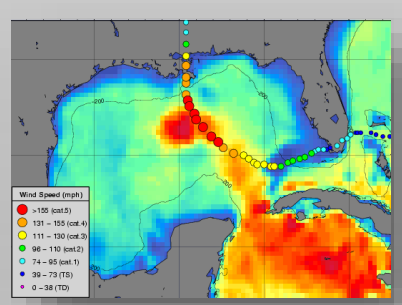
Global & Regional Sea Level Rise



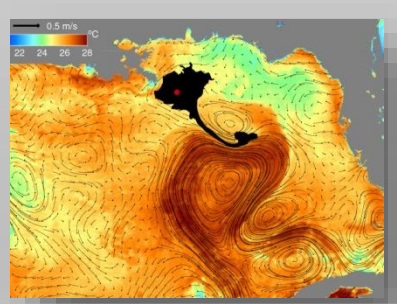
El Nino Forecasting



Hurricane Intensity Forecasting



Oil Spill Monitoring



RADS: operational altimetry products

Radar Altimeter Database System (RADS)

- Jointly developed and maintained by NOAA, EUMETSAT, and TUDelft
- RADS serves as an analysis tool and as a product generating platform for expert users
- NOAA produces and distributes CryoSat-2 Interim Geophysical Data Records with RADS

RADS-based products for operational users

- Along-track NRT dynamic topography for data assimilation at NWS/EMC and via NCODA

RADS-based products for intermediate users

- Along-track sea surface heights, winds, and waves via STAR ftp and CoastWatch

RADS-based products for general users

- Multiple-mission gridded sea level anomalies and geostrophic currents via STAR ftp and CW/OW

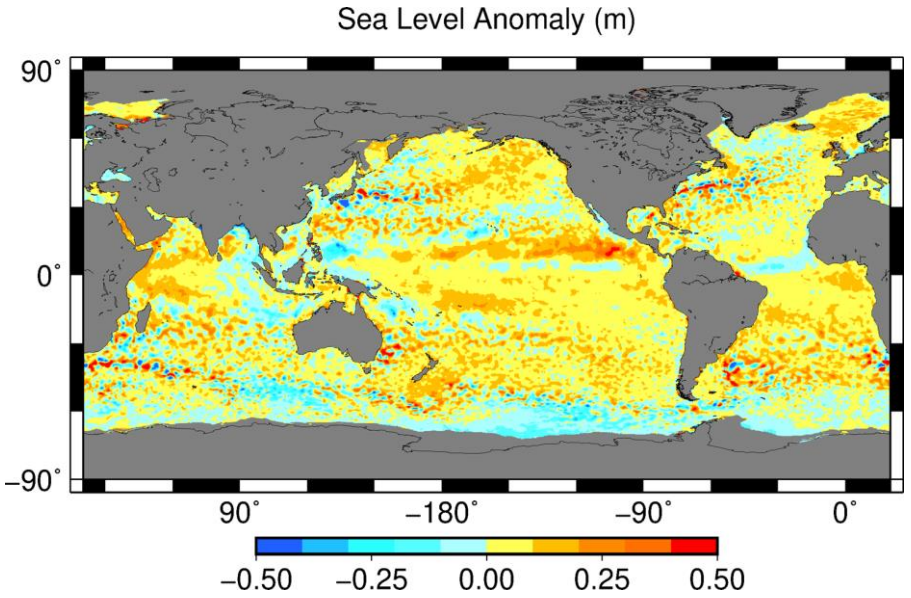
RADAR ALTIMETER DATABASE SYSTEM

RADS

EUMETSAT

NOAA Laboratory for Satellite Altimetry NOAA-NESDIS-STAR

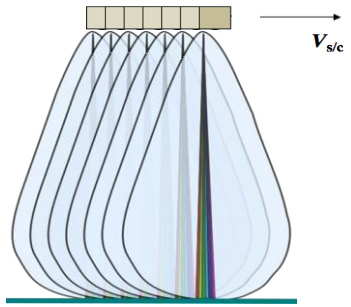
TU Delft Delft University of Technology



Plans for future altimetry products

1. Fully-Focused SAR processing

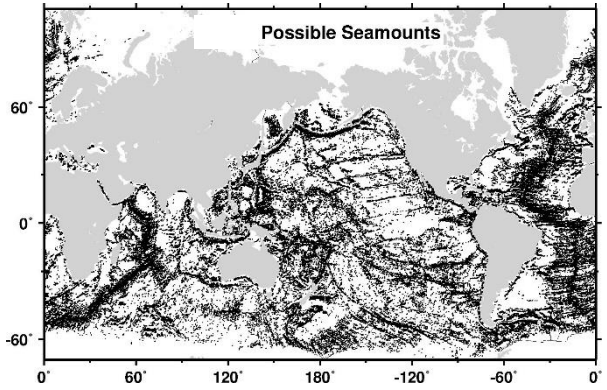
- Improved open ocean products
- Coastal altimetry applications
- Lake and river water levels
- Sea ice freeboard



- Coherent processing ~2 s
- Along-Track Resolution ~0.5m
- Pulse limited across-track
- Closed Burst
- Significantly more independent observations of the surface

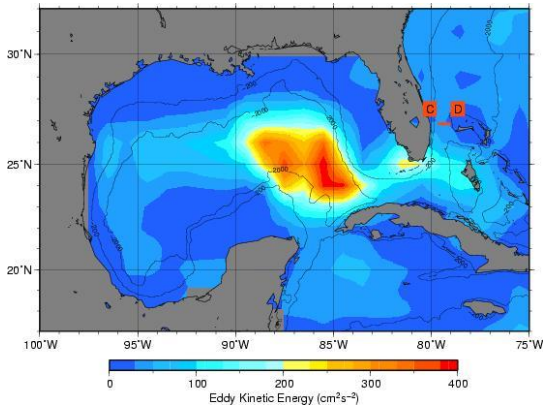
2. Stacked altimetry for seamount detection/mapping

- AltiKa completed
- Currently processing Sentinel-3A

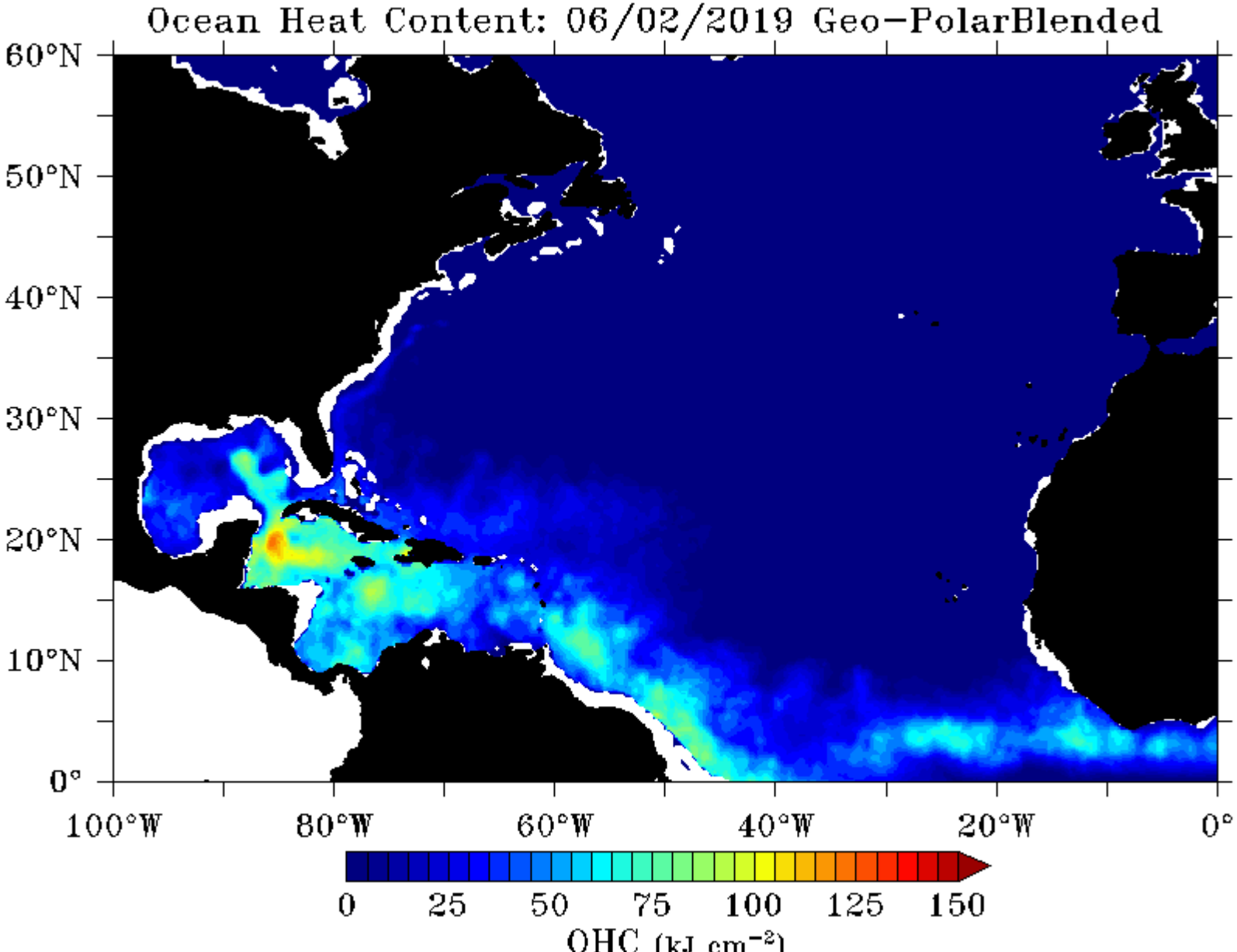


3. New multi-mission gridded products

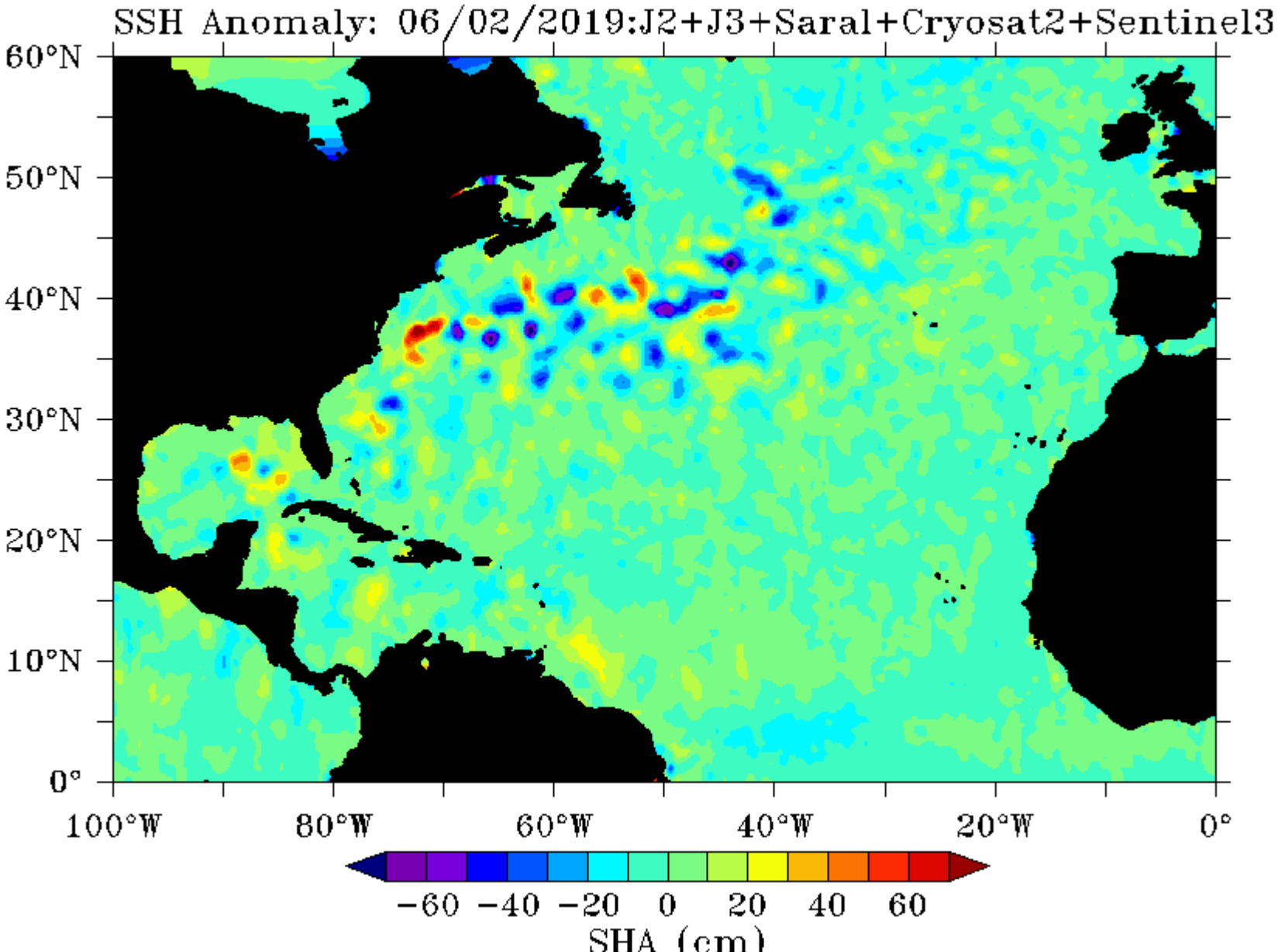
- Daily eddy kinetic energy



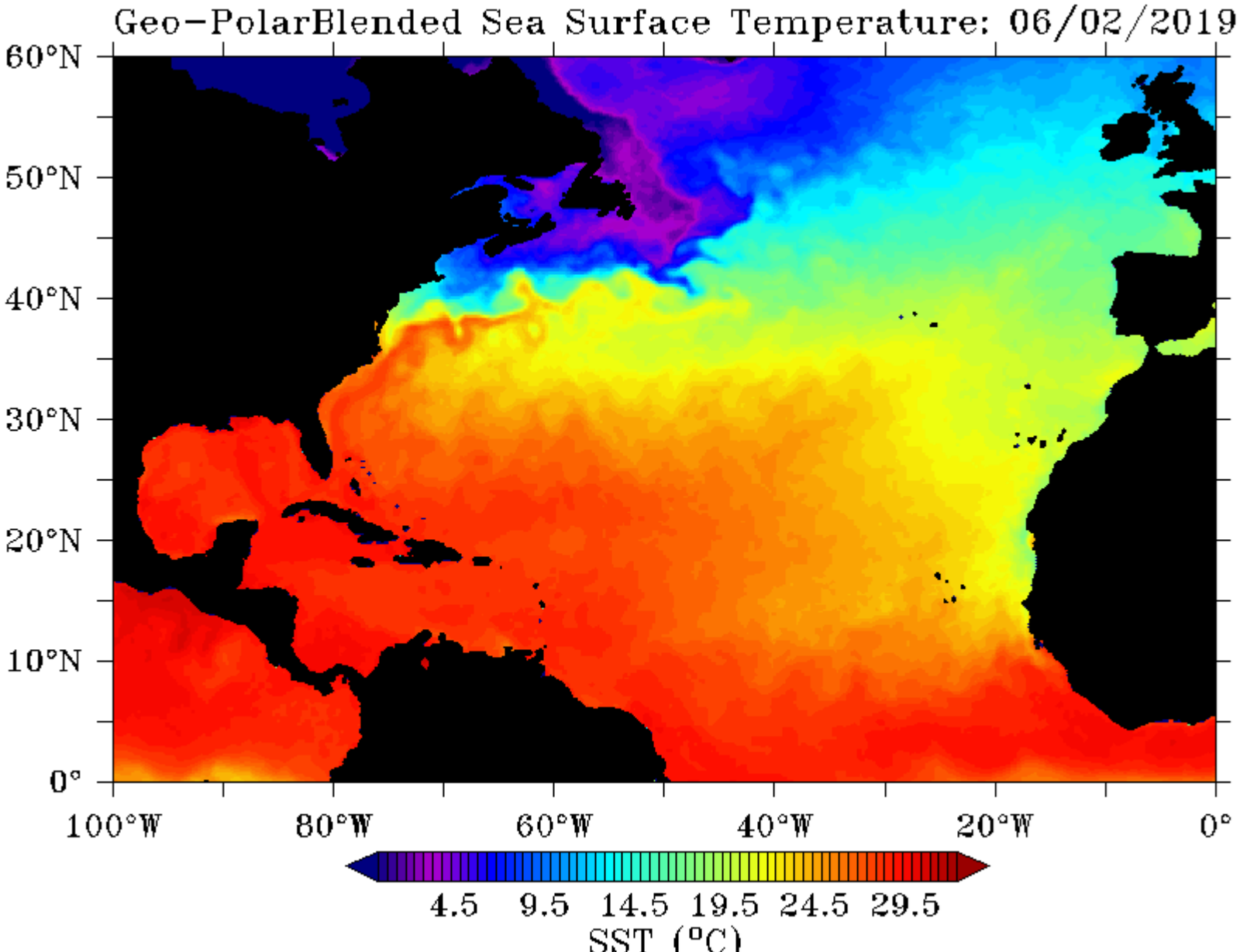
Applications - Ocean Heat Content



Applications - Ocean Heat Content

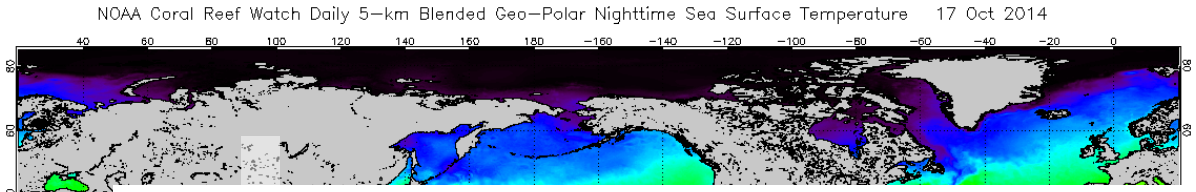


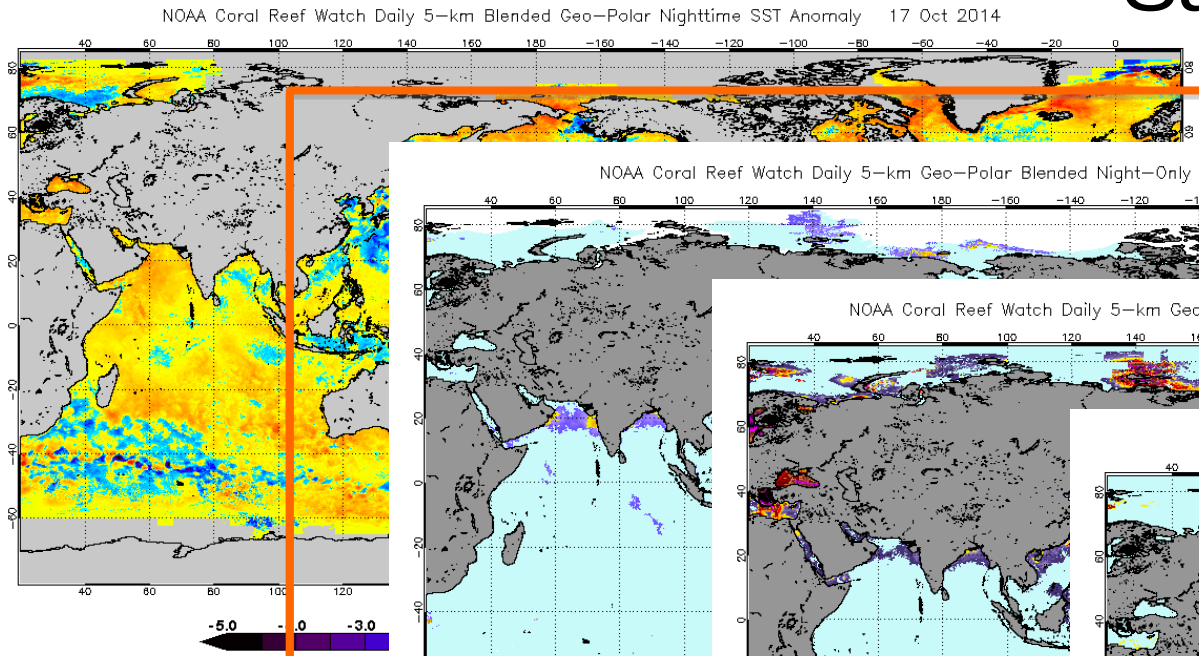
Applications - Ocean Heat Content

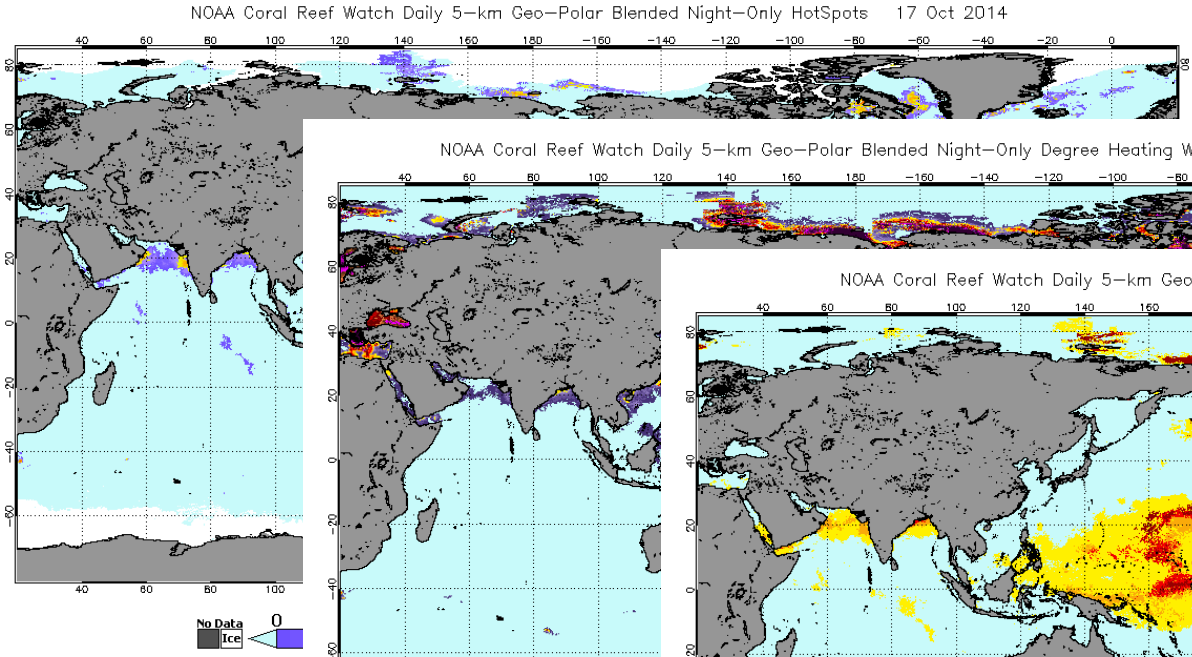


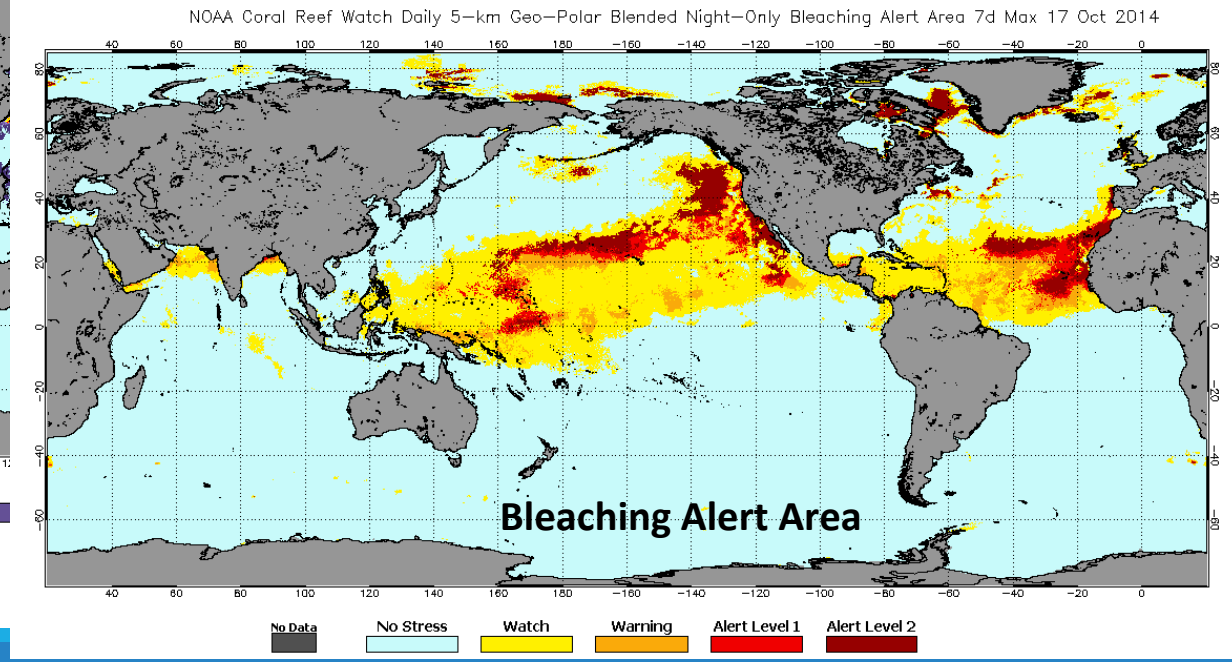
NOAA Coral Reef Watch Satellite-Based Products

Mark Eakin, Lead



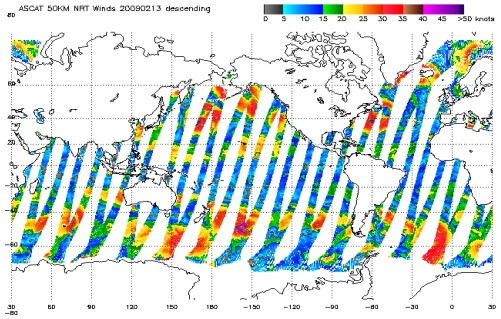




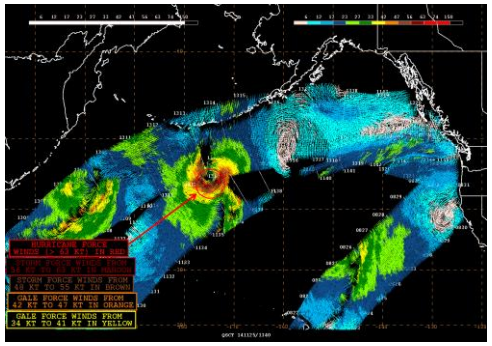


Coral – specific

NOAA Ocean Winds Science Team



Daily descending ASCAT passes



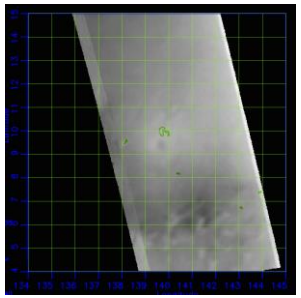
Scatterometer NAWIPS display

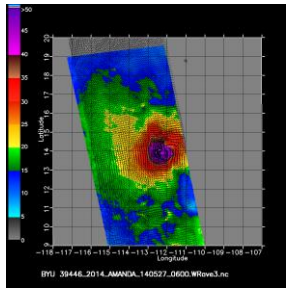
Activities:

- Product improvement/development
- Instrument and product calibration and validation
- Investigating new remote sensing techniques and products
- Investigating air-sea interactions in extreme winds (hurricanes and ocean winter storms)
- End user engagement/training
- In-situ (aircraft flight program) to validate and understand the extreme winds (tropical and extratropical cyclones)

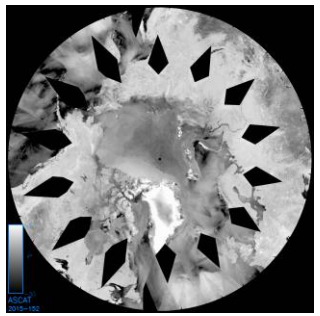
Missions Supported

- Scatterometry
  - ASCAT A, B and C
  - SCATSAT-1
- GNSS-R (CYGNSS)
- CFOSAT (winds and waves)
- SMAP (winds)
- WindSAT
- AMSR2
- SCA (risk reduction for cross-pol)

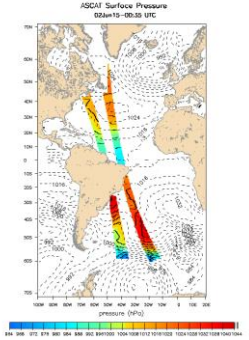




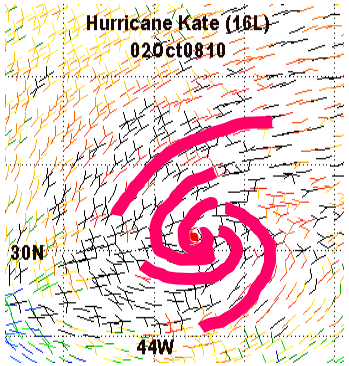
Ultra high resolution processing products



Daily Sea Ice



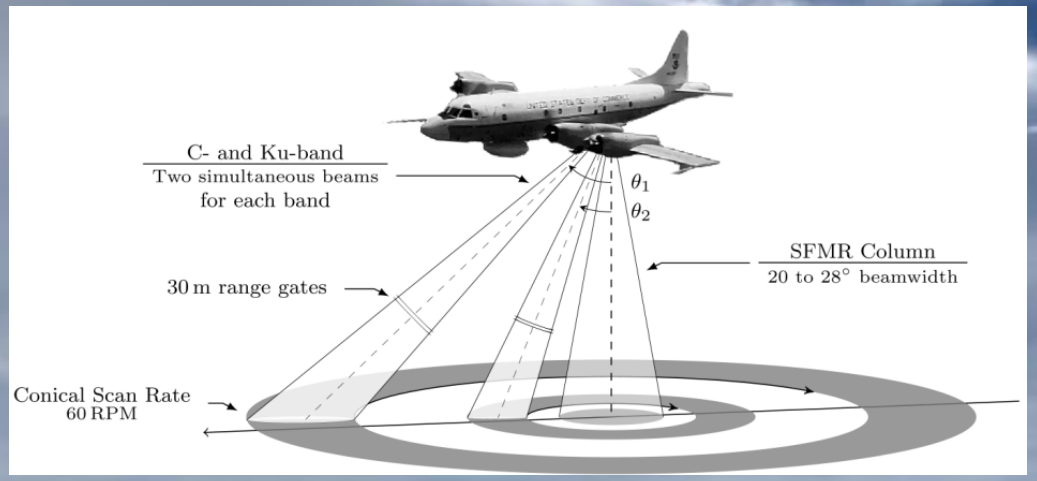
Surface Pressure



Ambiguity Analysis

NOAA/NESDIS OCEAN WINDS HURRICANE AND WINTER STORMS AIRCRAFT FLIGHT EXPERIMENT PROGRAM

Imaging Wind and Rain Airborne Profiler (IWRAP)
C- and Ku-band profiling radar systems



Ka-band Interferometric Altimeter

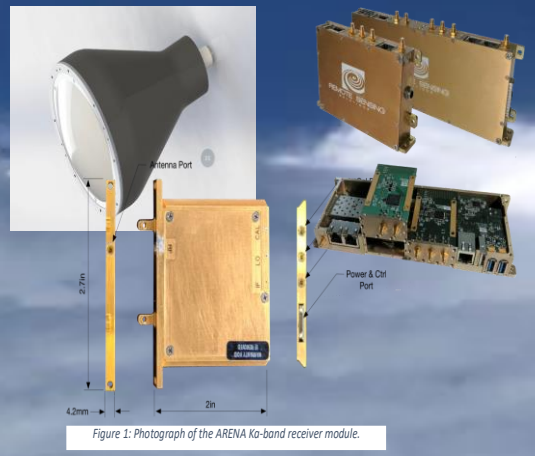


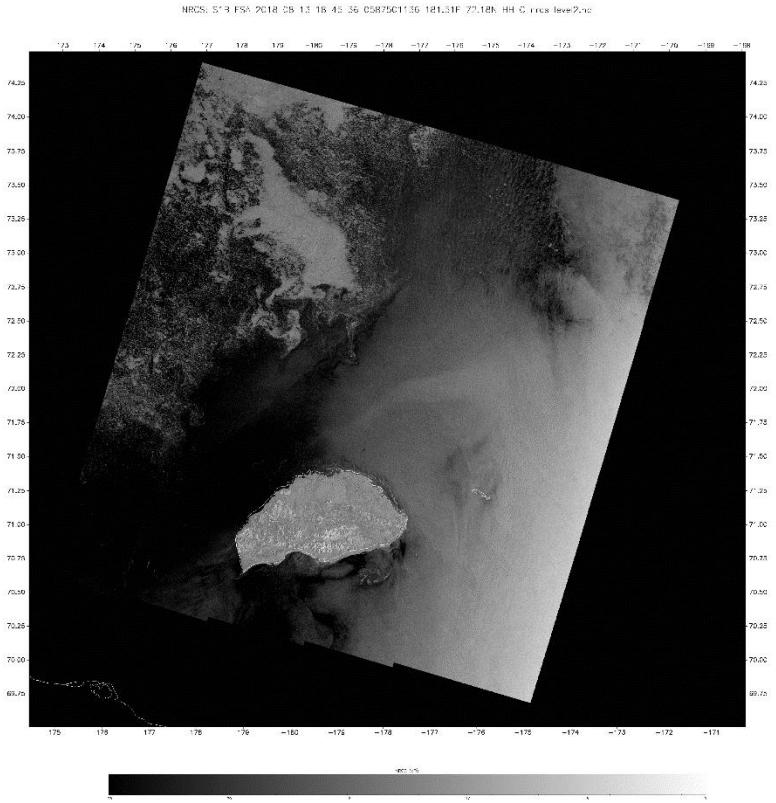
Figure 1: Photograph of the ARENA Ka-band receiver module.

- Improving our understanding of ocean surface microwave remote sensing measurements in extreme conditions found in hurricanes and extratropical cyclones
- Improving and validating satellite wind products
- Investigating future remote-sensing measurement systems and methodologies
- Improving our understanding of the geophysical factors (winds, waves and sea spray) occurring in extreme conditions

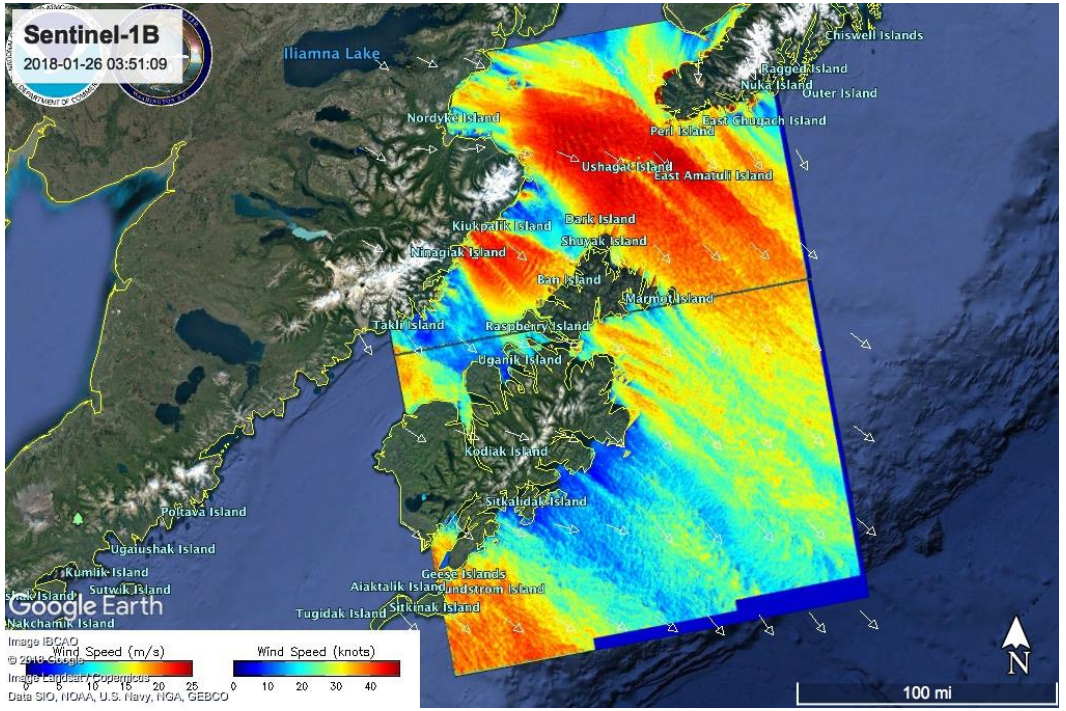
SCA breadboard antenna on loan from ESA integrated with IWRAP for risk reduction

Operational SAR products from Sentinel 1 and RadarSat 2

Normalized Radar Cross Section (NRCS): The NRCS provides analysts the ability to generate products from the image



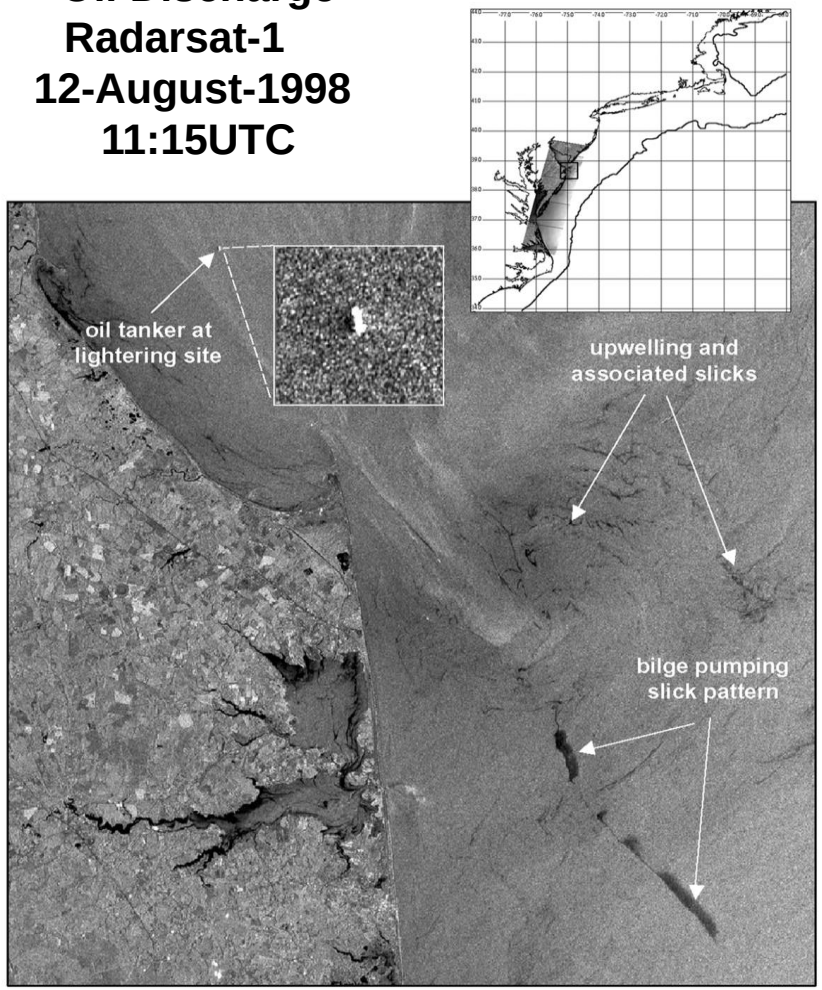
Winds: The higher the wind the higher the roughness and the higher the cross section.



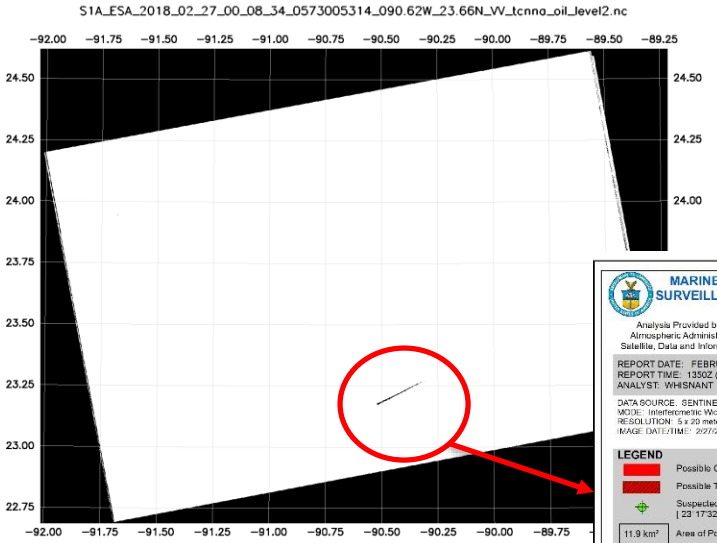
Operational Oil Monitoring SAR products

Oil smooths the surface and decreases radar cross section.

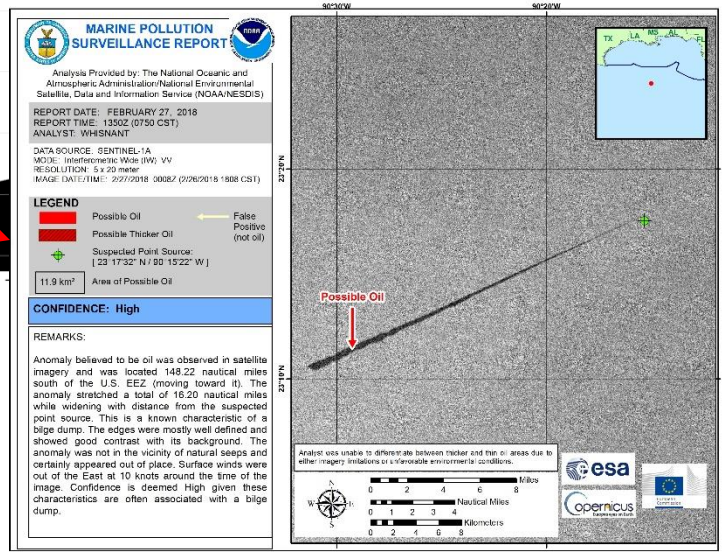
Oil Discharge
Radarsat-1
12-August-1998
11:15UTC



NOAA's Automated Oil Spill Detection using SAR



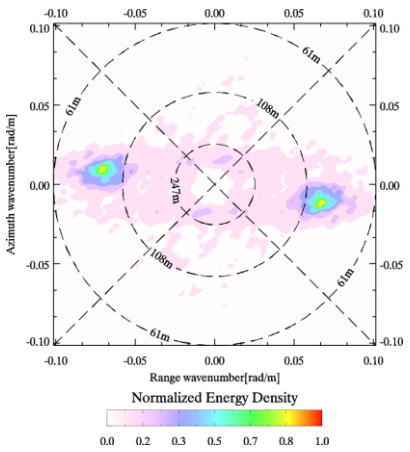
Gulf of Mexico (outside EEZ), 27 Feb 2018



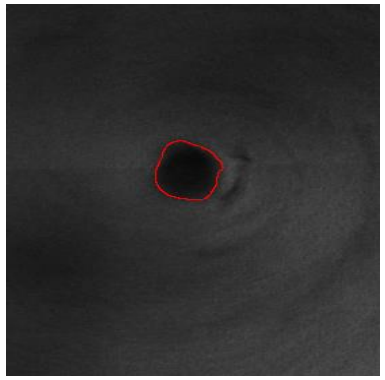
Upcoming SAR Based Ocean Products

CYCLONE BOUNDARY LAYER DATA

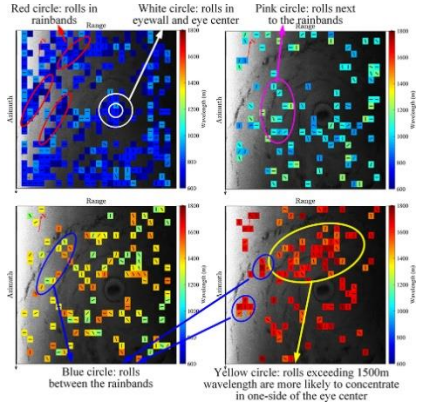
Hurricane Wave



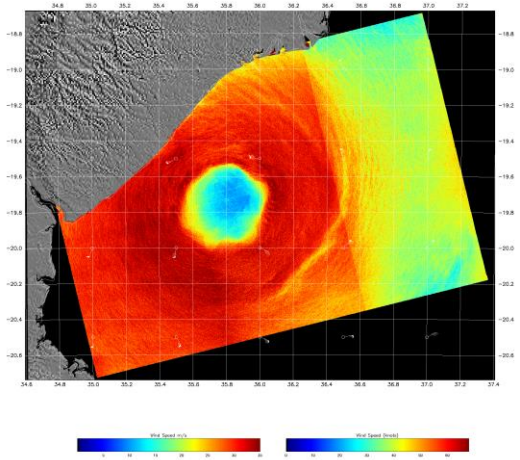
Hurricane eye Morphology



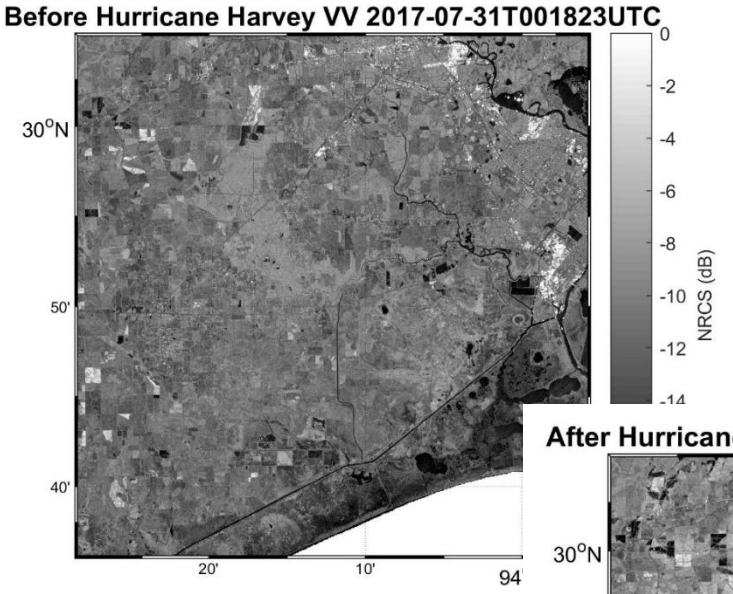
Hurricane Boundary-Layer Rolls

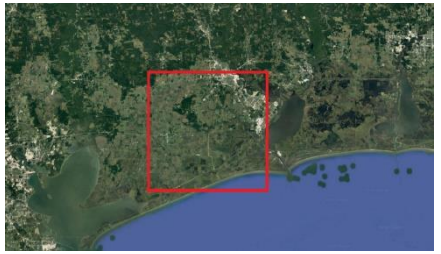


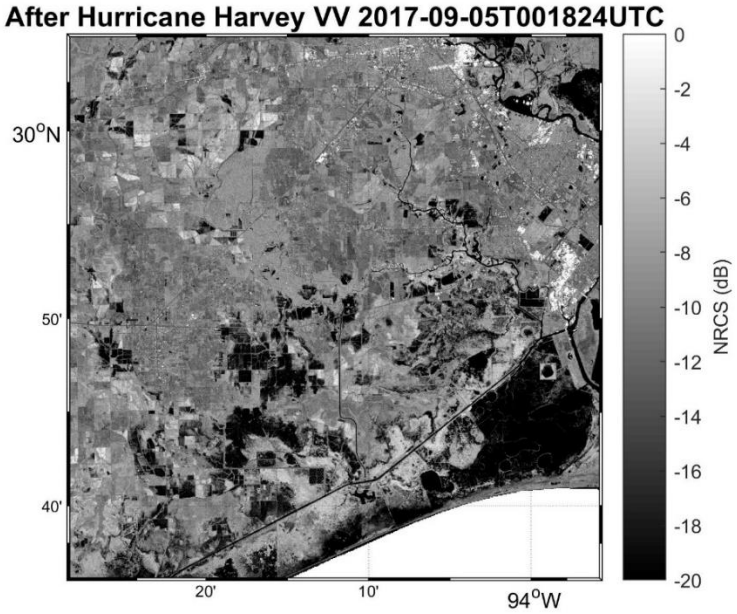
Hurricane Winds



COASTAL FLOOD MAPPING



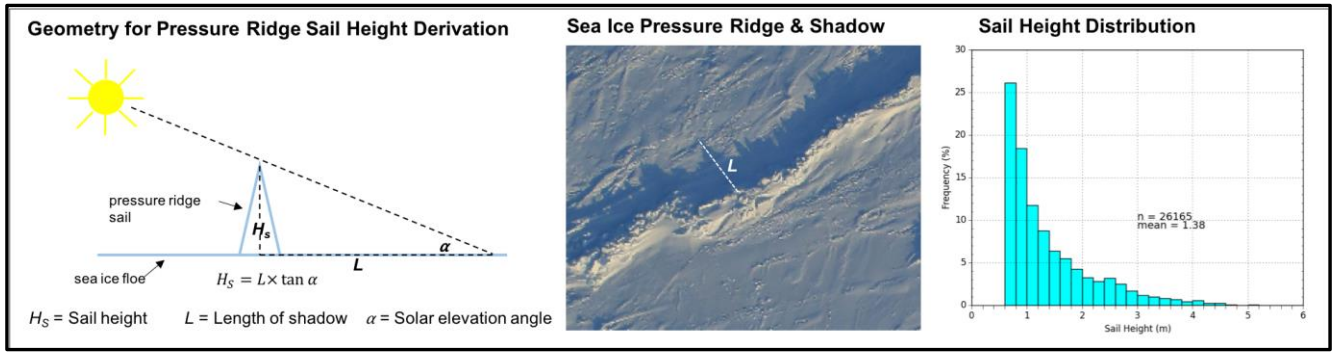




Sea Ice and Polar Dynamics Product Development

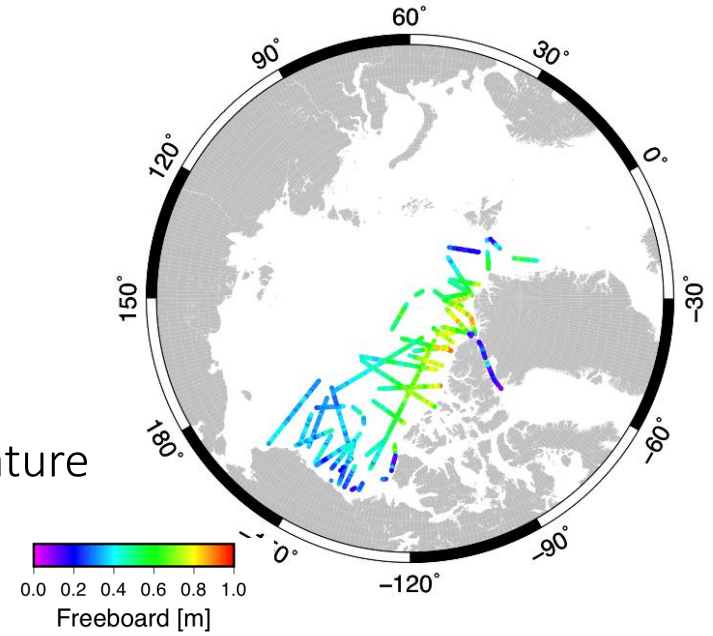
Airborne (2-D) Sea Ice Products

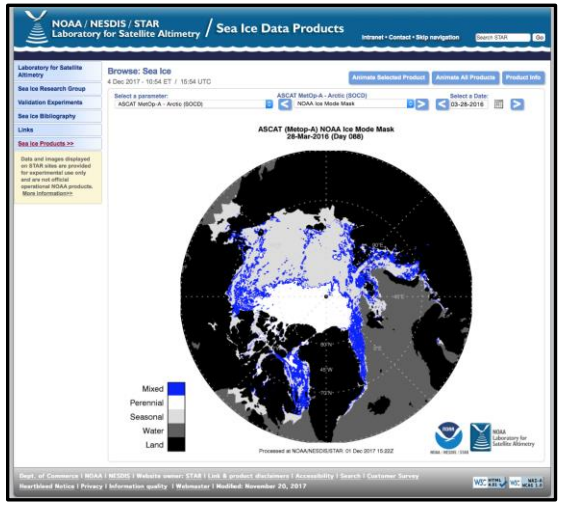
- Pressure Ridge Sail Height
- Surface Roughness
- Snow depth on sea ice
- Sea ice freeboard
- Sea ice thickness



Satellite (gridded) Sea Ice Products

- ASCAT sea ice type mask
- ASCAT 10-day backscatter variability
- ASCAT daily normalized radar cross-sections
- VIIRS & GCOM (AMSR-2) Ice Concentration
- VIIRS & GCOM (AMSR-2) Ice Surface Temperature





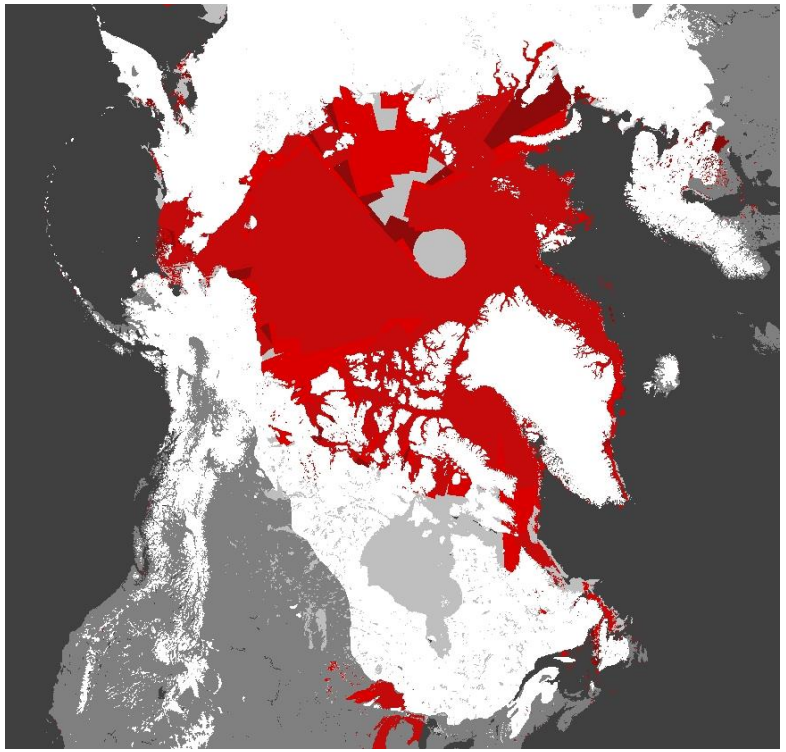
Web Link:
https://www.star.nesdis.noaa.gov/sod/lsa/SeaIce/DataProducts/products_SeaIce.php

LSA sea ice team – products website

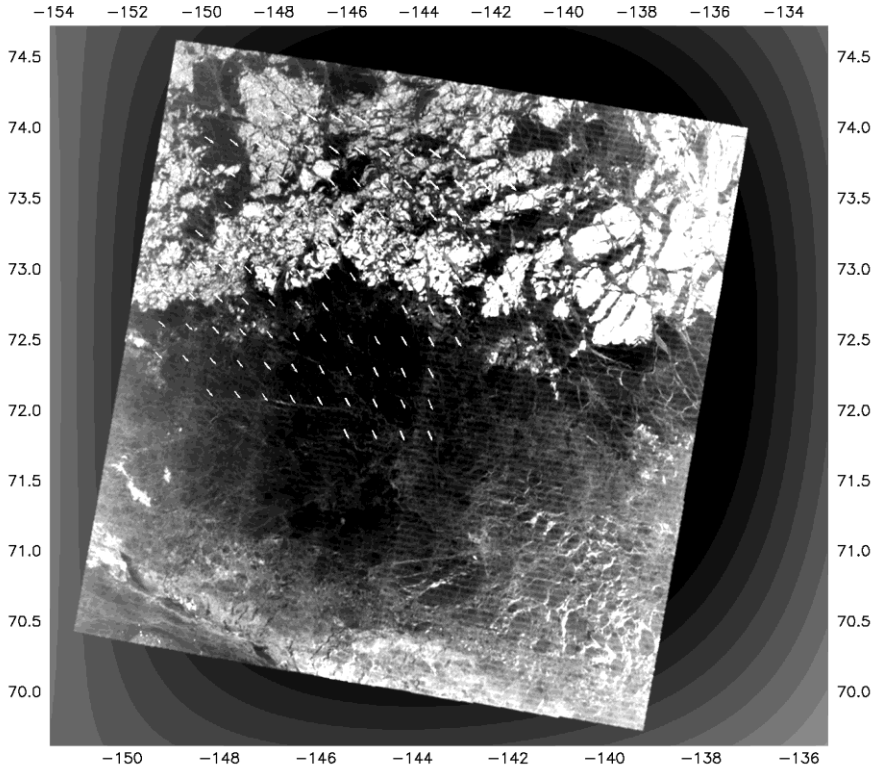
FTP Data Access Link:
ftp://ftp.star.nesdis.noaa.gov/pub/socd/lsa/SeaIceProducts/

SAR Operational Ice Support Products

3 Day Ice Extent – 20 - 22 April 2019

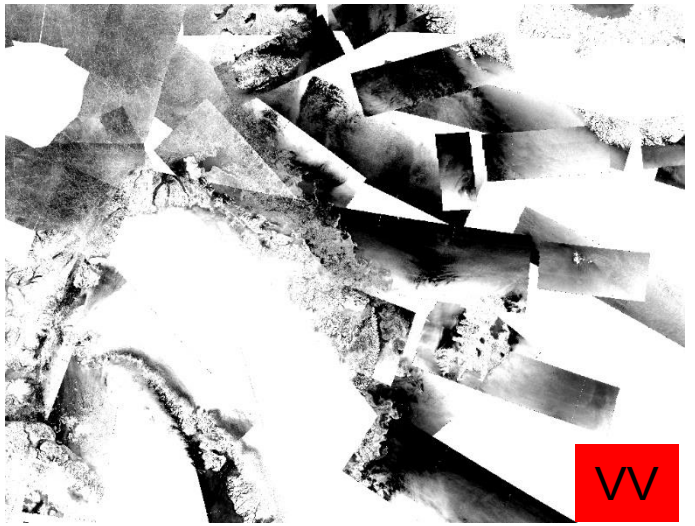


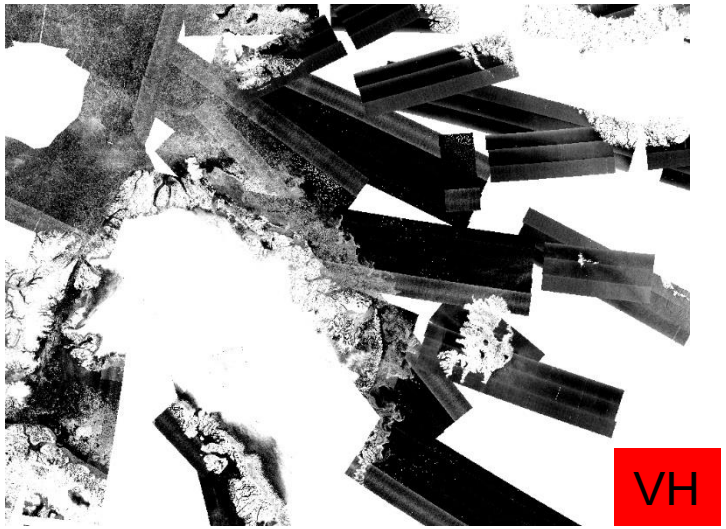
RSAT2 1day Ice Motion Vectors



2019-02-14

S1 + RSAT2 1day Mosaics





Future Sea Ice Products and Activities

- **ICESat-2**
  - **ATLAS**: Advanced Topographic Laser Altimeter
  - 6 beams, photon counting
  - Laser Freeboard

- **ICESat-2/CryoSat-2**
  - Future overlapping orbits
  - Derived snow depth

- **Fully-Focused SAR processing**
  - Enhanced lead detection
  - Radar Freeboard

- **NOAA P-3 Sea Ice Missions**
  - Sea Ice product cal/val and development
  - Sea Ice Processes: multi-agency collaboration

ICESat-2

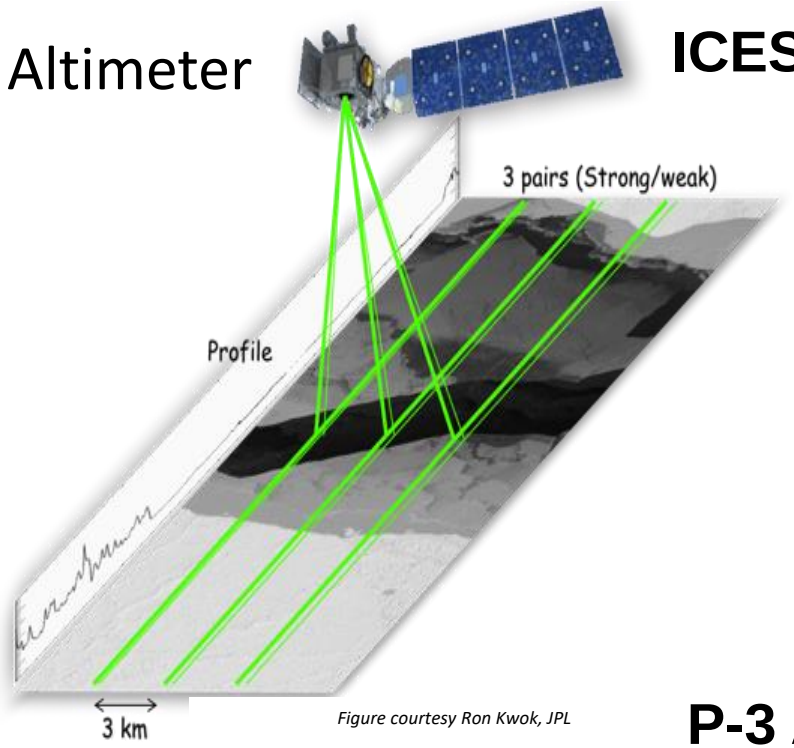


Figure courtesy Ron Kwok, JPL

P-3 Aircraft

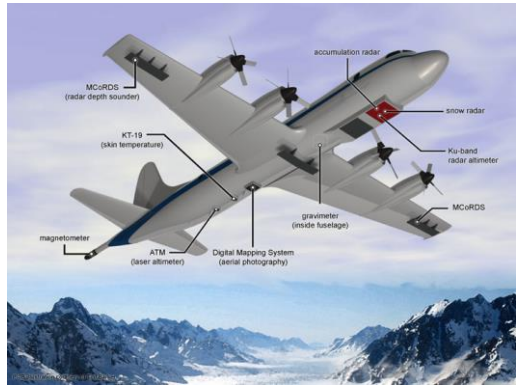
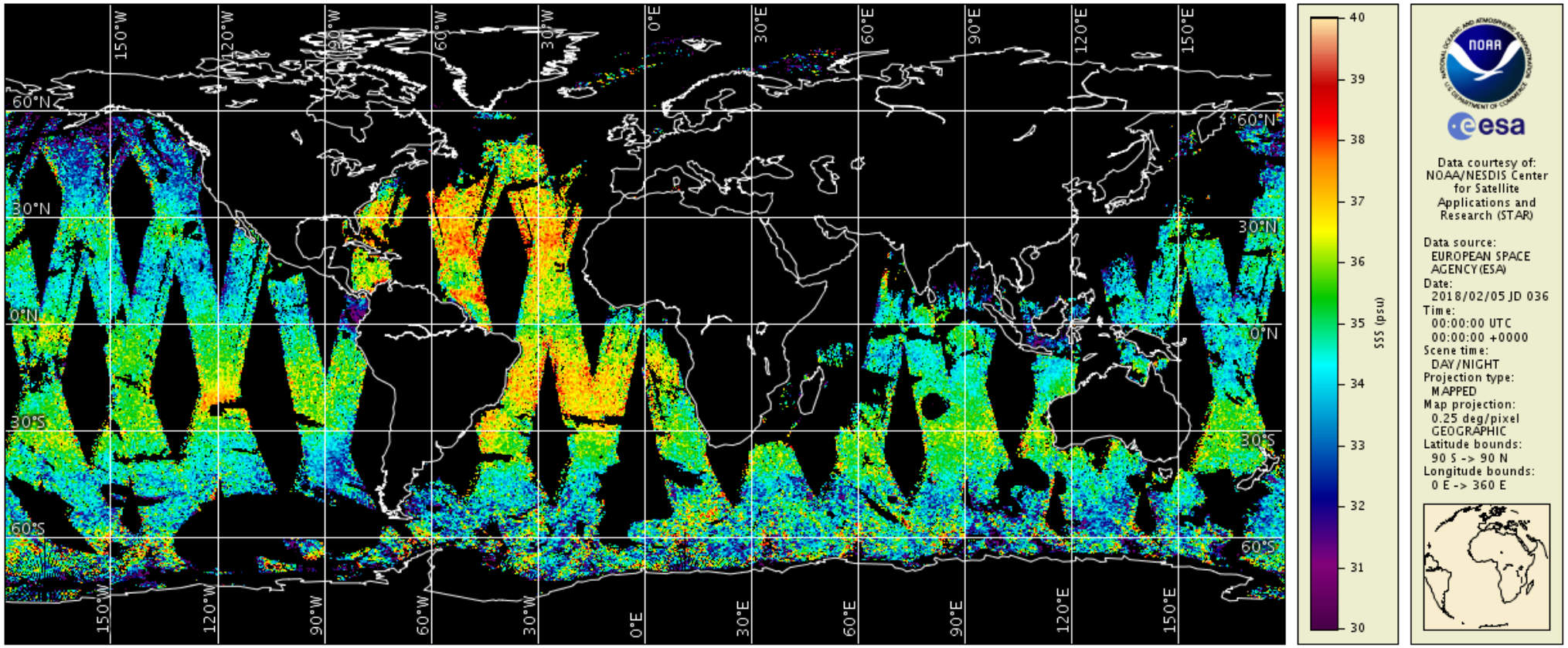


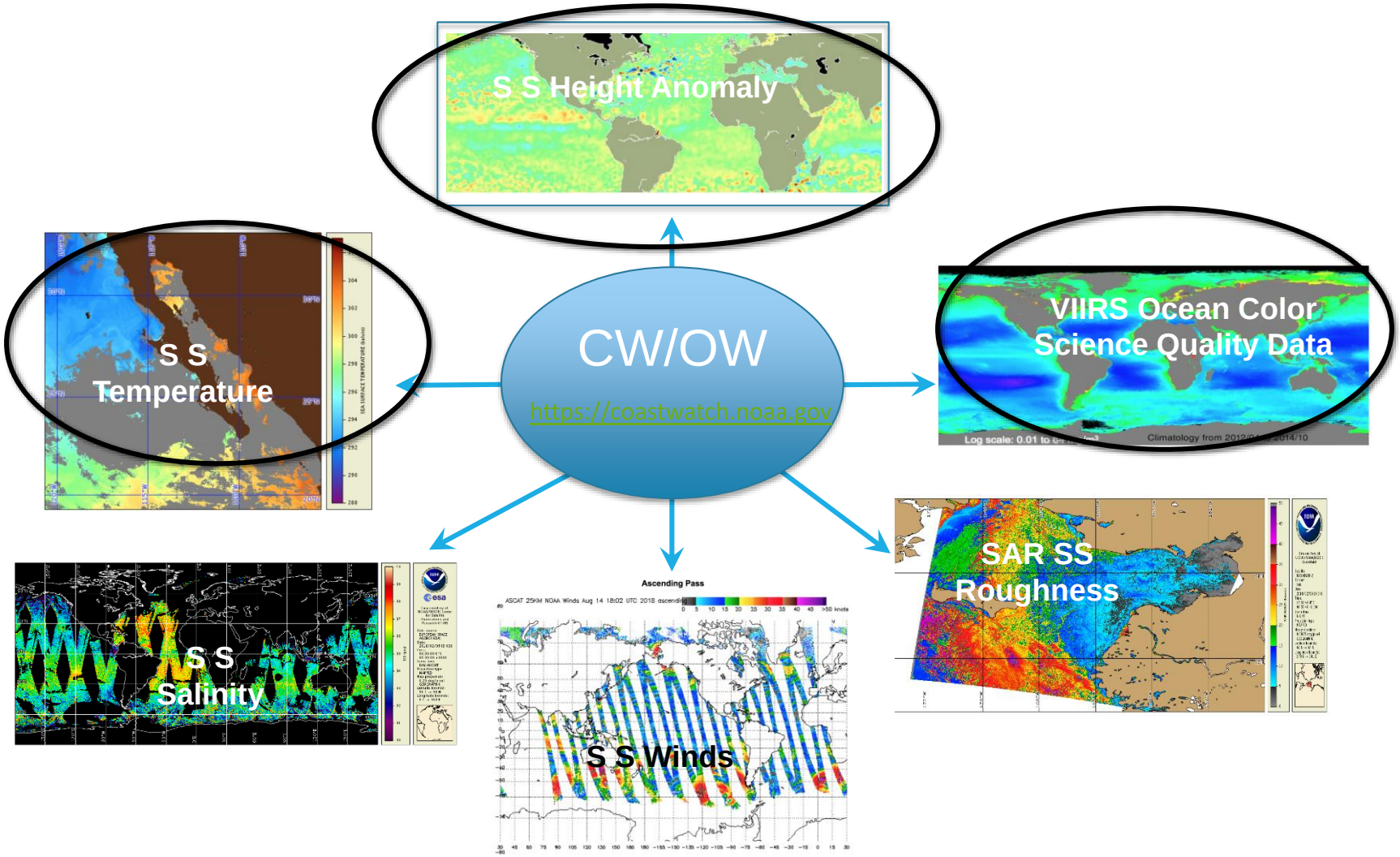
Figure courtesy of Operation IceBridge

Sea Surface Salinity

Lead: Eric Bayler & CoastWatch in collaboration with NWS/CPC/OMB

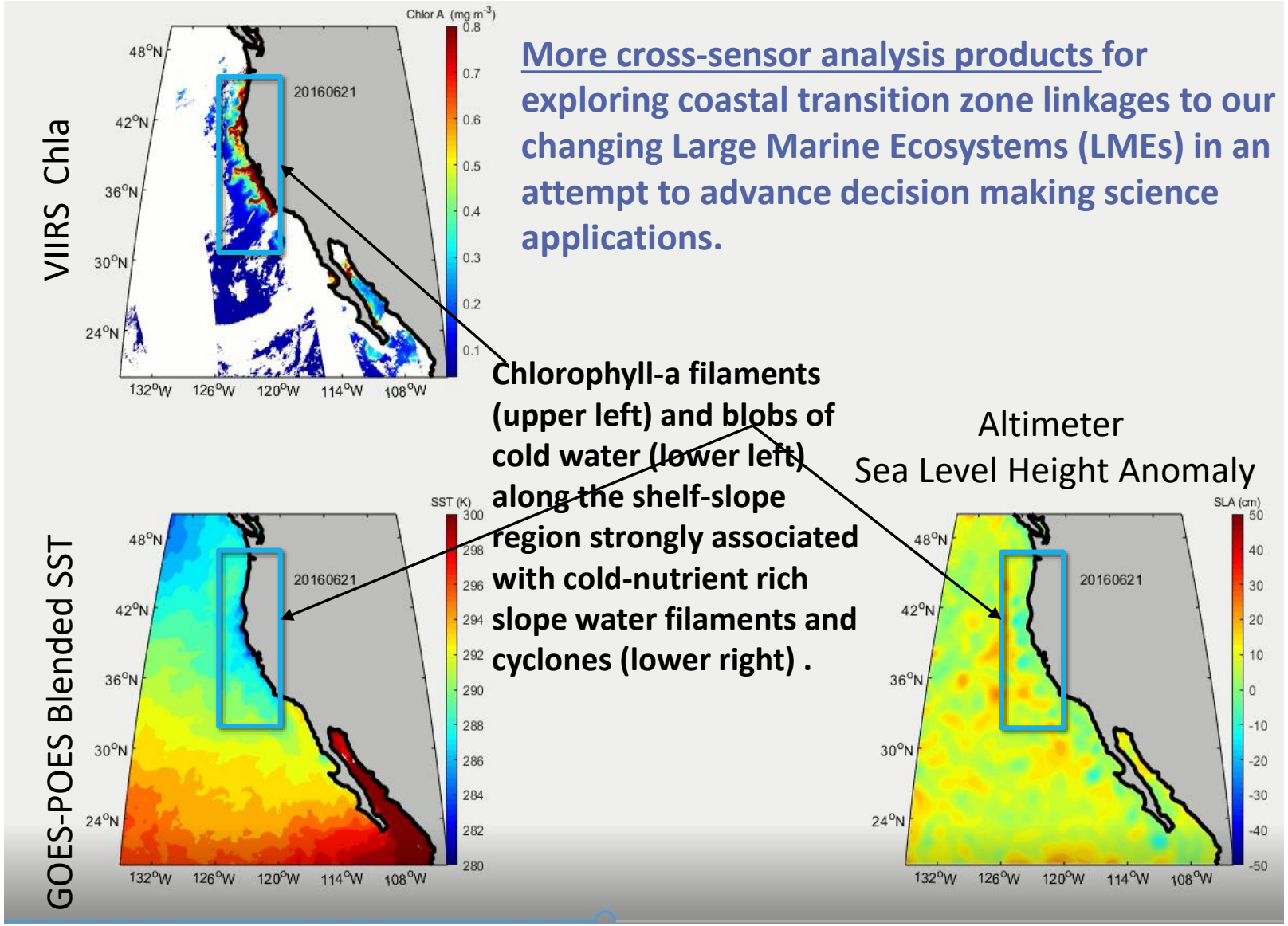


On the Need for Combined Cross-Sensor Analysis



Data from CW/OW through STAR Science Teams

Ongoing & Further Applications using multi-sensor satellite data



More cross-sensor analysis products for exploring coastal transition zone linkages to our changing Large Marine Ecosystems (LMEs) in an attempt to advance decision making science applications.

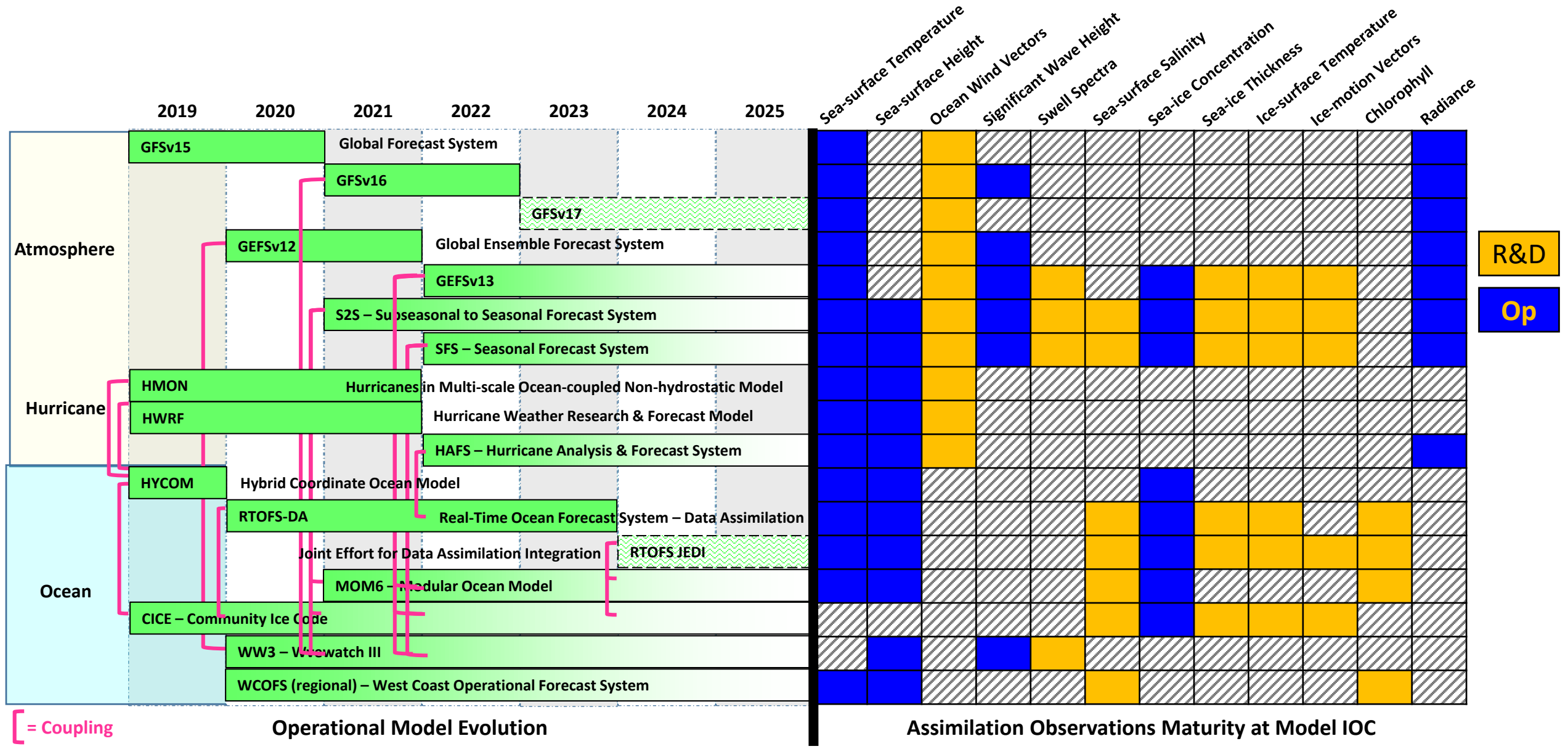
Chlorophyll-a filaments (upper left) and blobs of cold water (lower left) along the shelf-slope region strongly associated with cold-nutrient rich slope water filaments and cyclones (lower right) .

Satellite Observations in Numerical Prediction

- **Current NOAA ocean prediction operations:**
  - Sea-surface temperature
  - Sea-surface altimetry (sea-surface height anomaly)
  - Sea-ice concentration/edge
  - Sea-surface roughness (ocean vector winds, ocean wind speed)

- **Research and development (R&D) targeting ocean prediction:**
  - Sea-surface salinity
  - Sea-ice thickness
  - Ice-surface temperature
  - Ice-motion vectors
  - Ocean radiometry (color)
  - Swell spectra
  - Significant wave height
  - Radiances

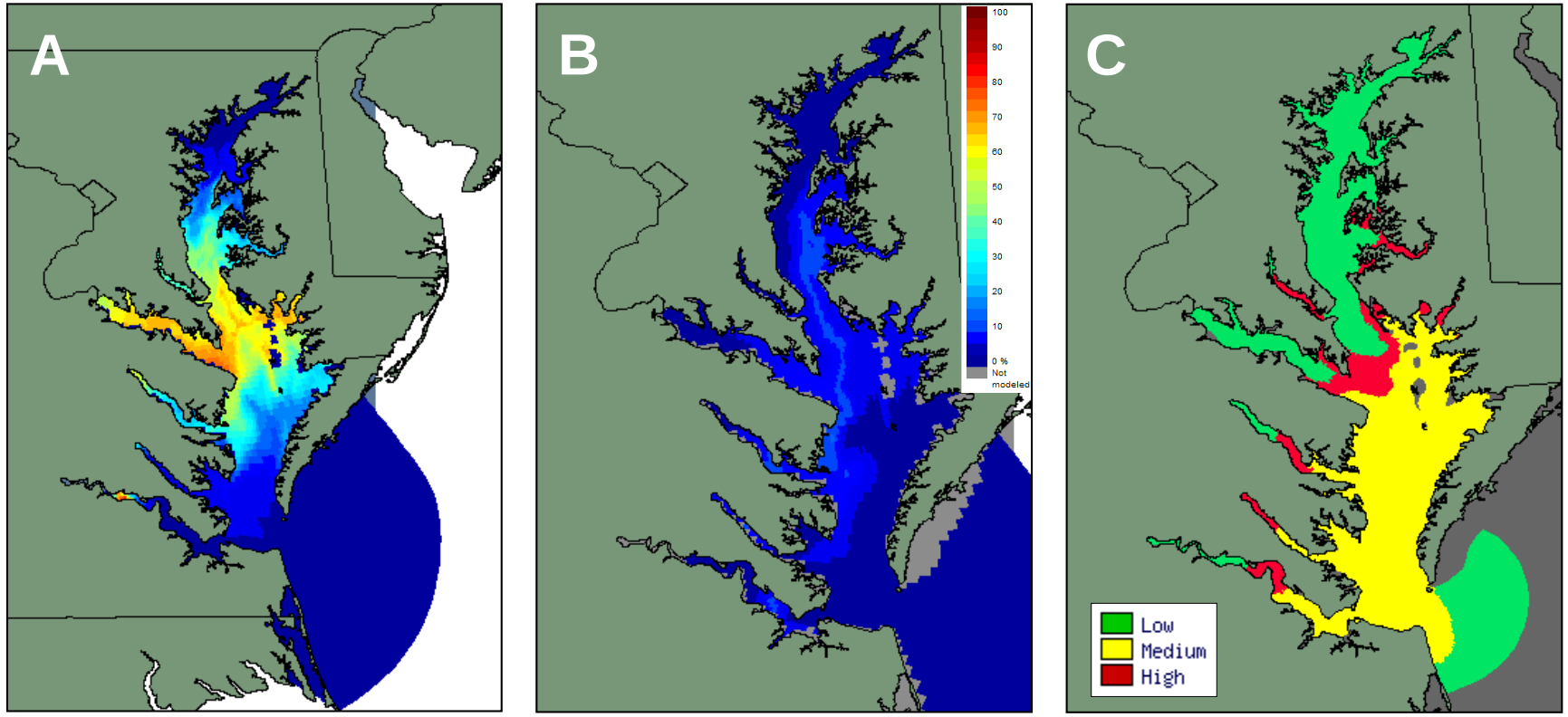
Satellite Ocean Data for Operational Environmental Modeling



Ecological Forecasting

- **Data Assimilation**
  - Satellite-derived chlorophyll, Kd_{PAR}, and bio-optically-active reflectance for improving HAB, biogeochemical, and SST model predictions
    - Component development effort for pending NOAA operational West Coast regional model
    - California-Harmful Algae Risk Mapping (C-HARM)
    - NOAA's EcoCast, which provides fishing guidance to minimize bycatch
  - Neural network methodology demonstrated for filling data spatial/temporal gaps and providing forecasted values
- **Habitats**
  - **NOAA Coral Reef Watch Program provides:**
    - Current and upcoming reef environmental conditions using POES-GOES Blended SST product to provide to quickly identify areas at risk for coral bleaching
    - Weekly predictions of the likelihood of coral bleaching heat stress based on NOAA's Climate Forecast System to up to four months in the future
- **Water Quality**
  - **NOAA's Ocean Service generates operational and experimental Harmful Algal Bloom (HAB) Forecasts** using satellite ocean color derived products (chl-a anomaly; cyanobacterial index) and associated wind/transport forecasts
    - Includes New product development efforts are underway to optically discriminate water mass constituents using satellite ocean color data
    - Improved detection, tracking and forecasting of coastal plumes and blooms
    - Discrimination of phytoplankton functional taxa and size in support of fisheries management and other applications
  - **NOAA CoastWatch/OceanWatch satellite ocean observations and tools support monitoring:**
    - Risk index for bacteria (multiple health issues, including seafood contamination)
    - Turbidity and visibility
    - Floating algae index
    - Ocean acidification

Ecological Forecasting



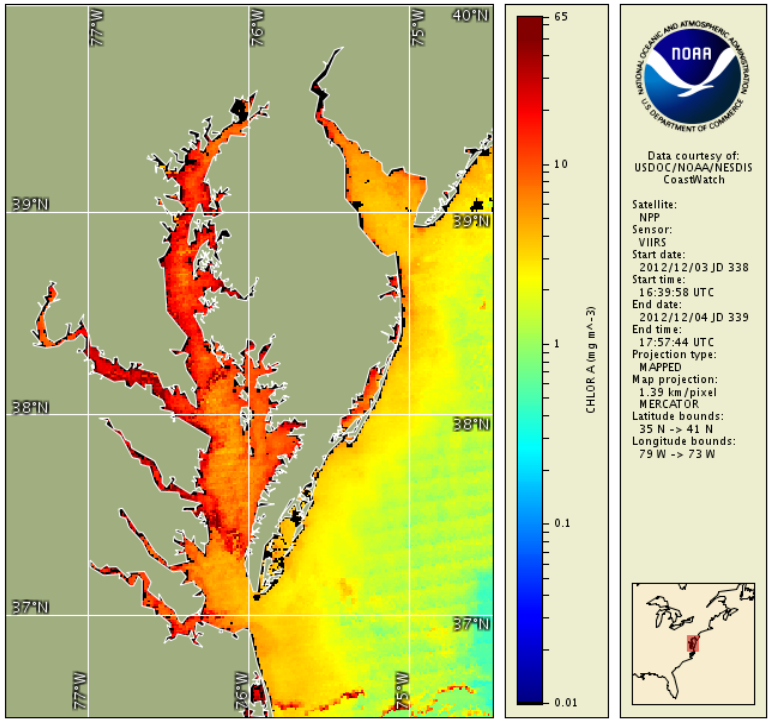
Examples of species forecasts generated by the Chesapeake Bay Ecological Prediction System. (A) Likelihood of encountering sea nettles, *Chrysaora quinquecirrha* on 17 August 2007. (B) Likelihood of *Vibrio vulnificus* on 20 April 2011. (C) Relative abundance of *K. veneficum* on 20 April 2005. Legend: low: 0-10, med: 11-2000 cells/ml, high: > 2000 cells/ml. Color bar for likelihood is the same for both A and B.

Incorporating Satellite Observations into Fisheries Ecosystem Model

Test satellite chlorophyll as a model input

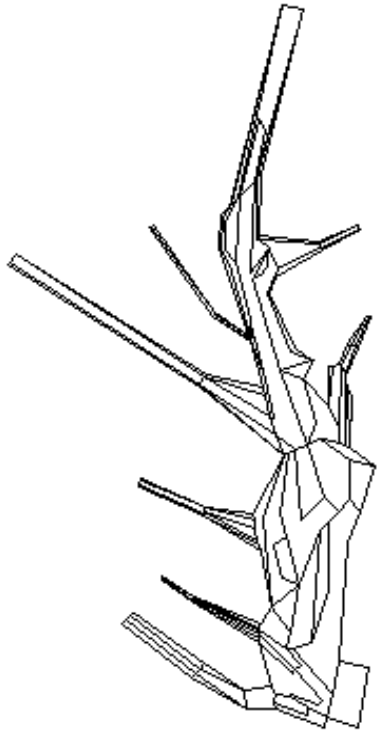
Conversion of chlorophyll to the polygonal model grid:

VIIRS satellite chlorophyll → **Georeferenced grid** → **Ecosystem model grid**



S-NPP VIIRS chlorophyll CoastWatch 2-day avg (Dec 3-4, 2012) Raster data: UTM coordinates

Chesapeake Bay Program Georeferenced polygonal grid; 8,282 polygons



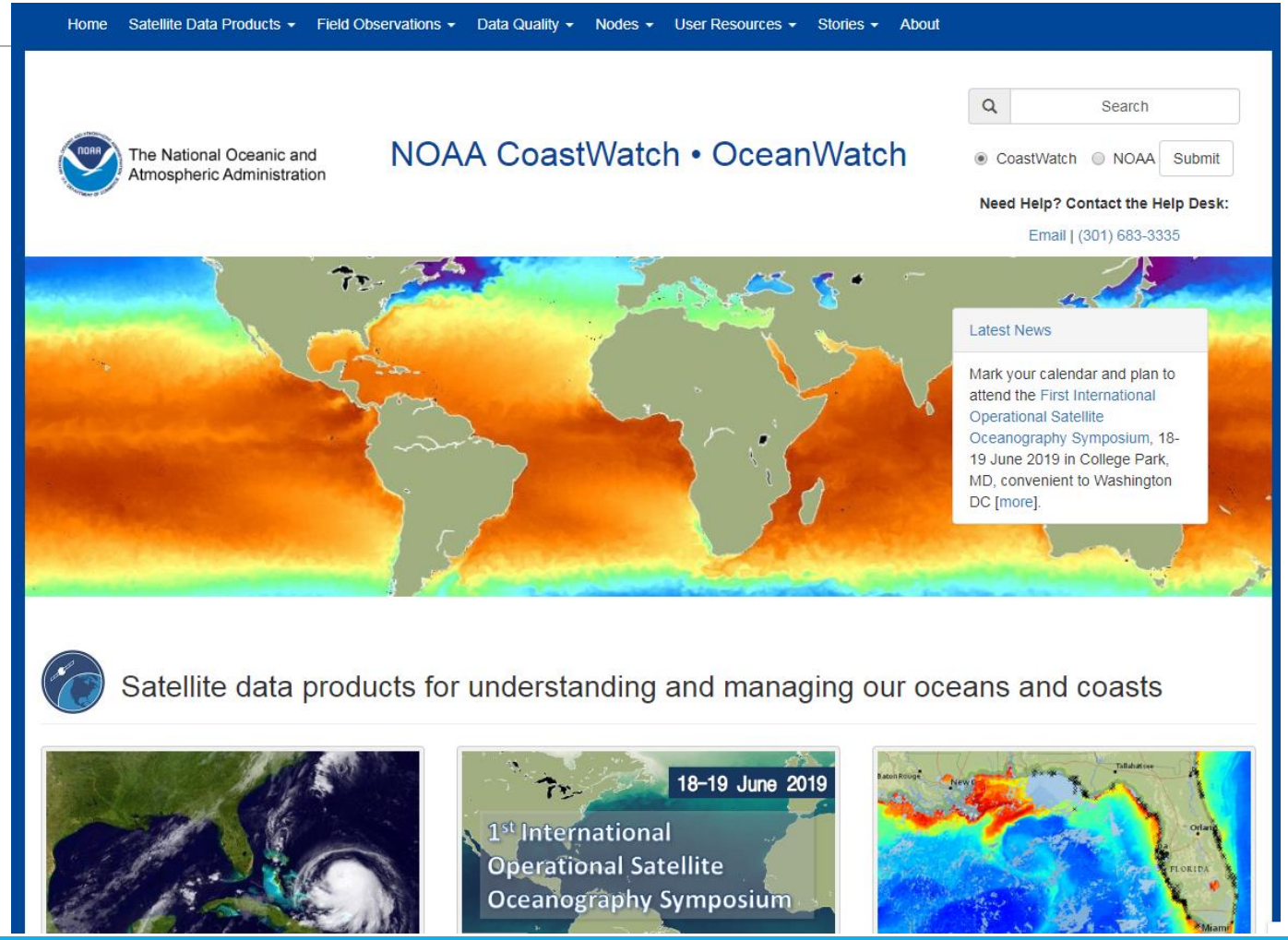
NOAA/NMFS/NCBO Atlantis Ecosystem Model 97 polygons aggregated from 8,282

NOAA CoastWatch/OceanWatch/PolarWatch

CoastWatch.NOAA.gov

Facilitating the use of ocean & aquatic satellite data along the value chain from observations to decision-making

- Multi-sensor data discovery and access
- Tailored products (regions, formats etc.)
- Product assurance and quality monitoring
- Value-added product distribution (nodes)
- User engagement and training
- Outreach and education
- Feedback to science/product developers



Take Home Messages

- Now entering a "golden-age" of ocean remote sensing, particularly a significant expansion and availability of satellite oceanography data for operational utility, supporting diverse applications, services & research – Blue Economy et al.
- As data providers we are actively reaching out to users to demonstrate, facilitate and expand usage of fit for purpose operational satellite oceanography data & derived-products
- Given the rapid evolution of modeling and data assimilation for operational forecasting et al. needs, ocean satellite data are becoming increasingly important to improve skill/benefits
- Significant improvements are still to come with recent and upcoming satellite sensors and associated new and improved satellite-based and integrated sat-in situ-model products

Thank you!

Questions?