The Future of Remote Sensing

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1993-2011: Jet Propulsion Laboratory
2012-present: Remote Sensing Solutions, Inc.

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California Institute of Technology

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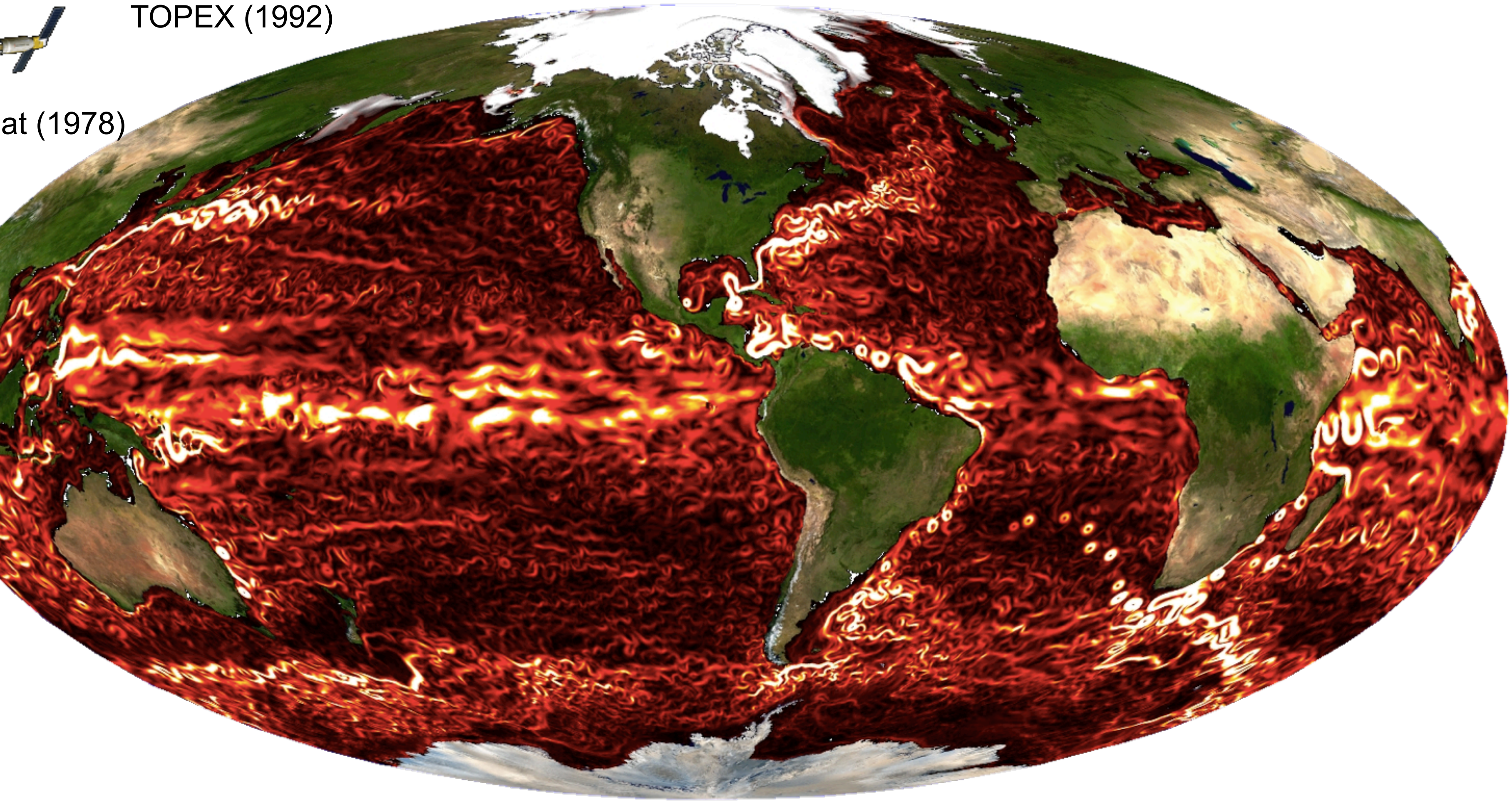
- Current state-of-the-art
- Future challenges and mission concepts
- Remote sensing data integrated with in situ data and assimilative/forecasting models

Emerging Field of Satellite Oceanography

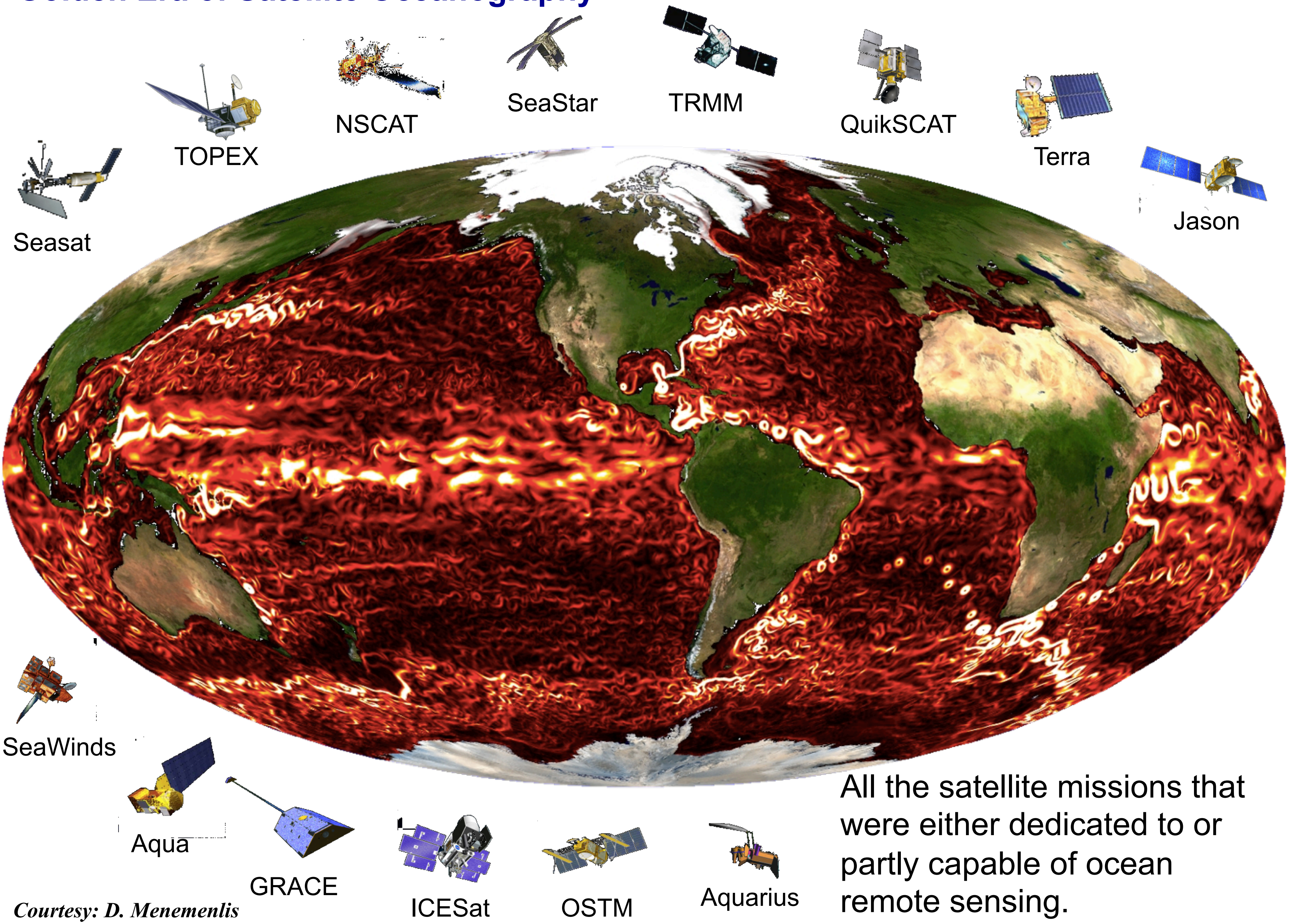
TOPEX (1992)

Seasat (1978)



Courtesy: D. Menemenlis

Golden Era of Satellite Oceanography

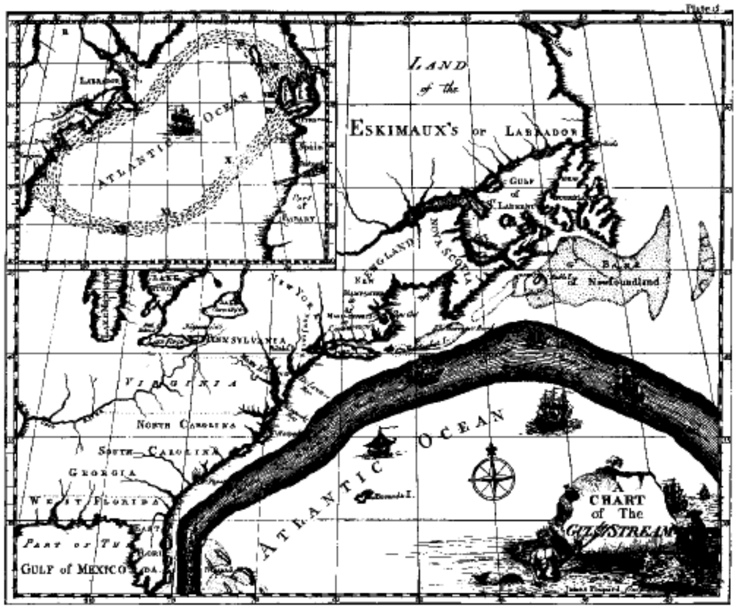


All the satellite missions that were either dedicated to or partly capable of ocean remote sensing.

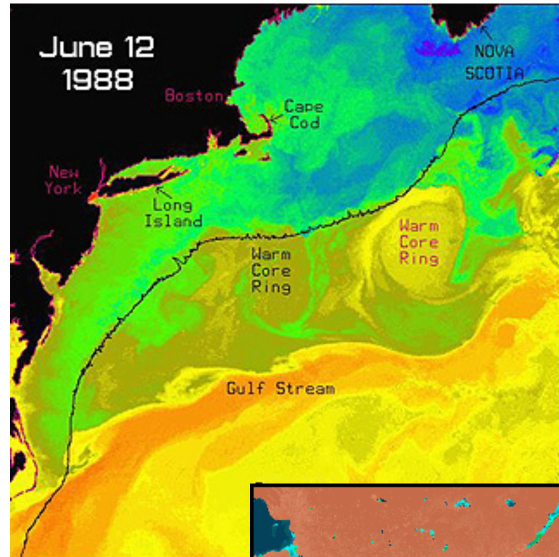
Courtesy: D. Menemenlis

1st Weather (Meteorological) Satellite (1960)

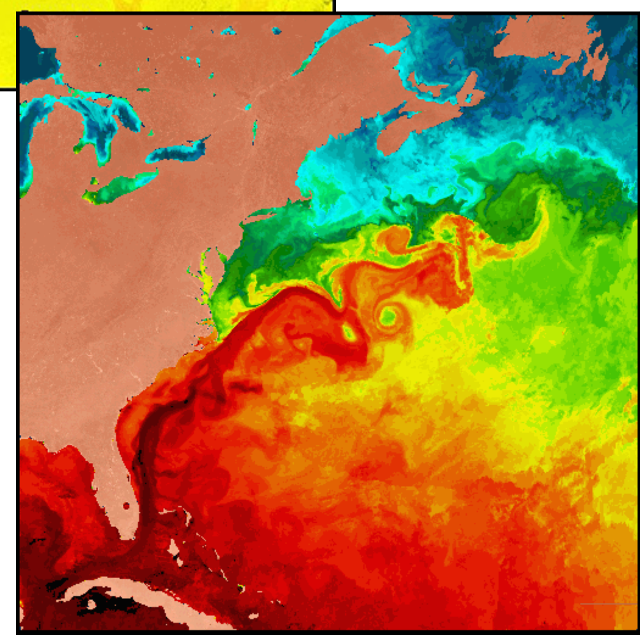
1st Oceanographic Satellite (1978)



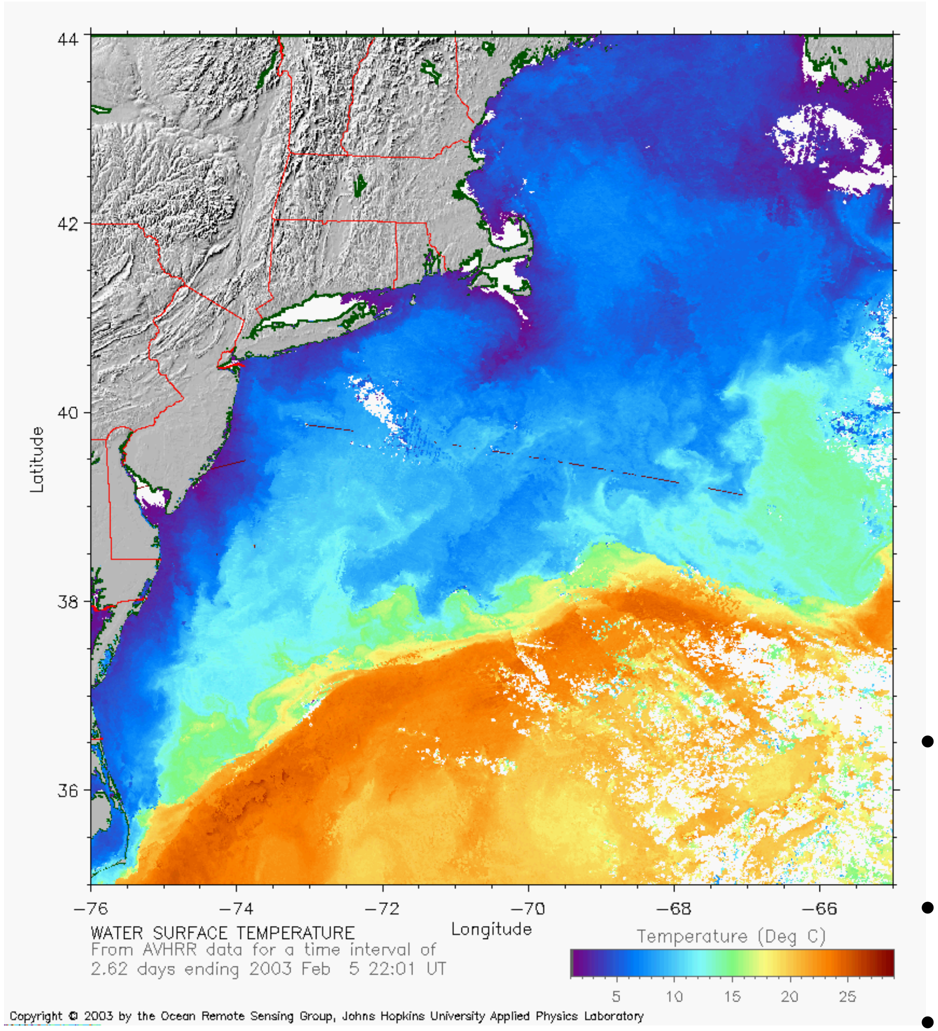
1770 Benjamin Franklin (postmaster) collected information about ships sailing between New England and England, discovering and mapping the Gulf Stream

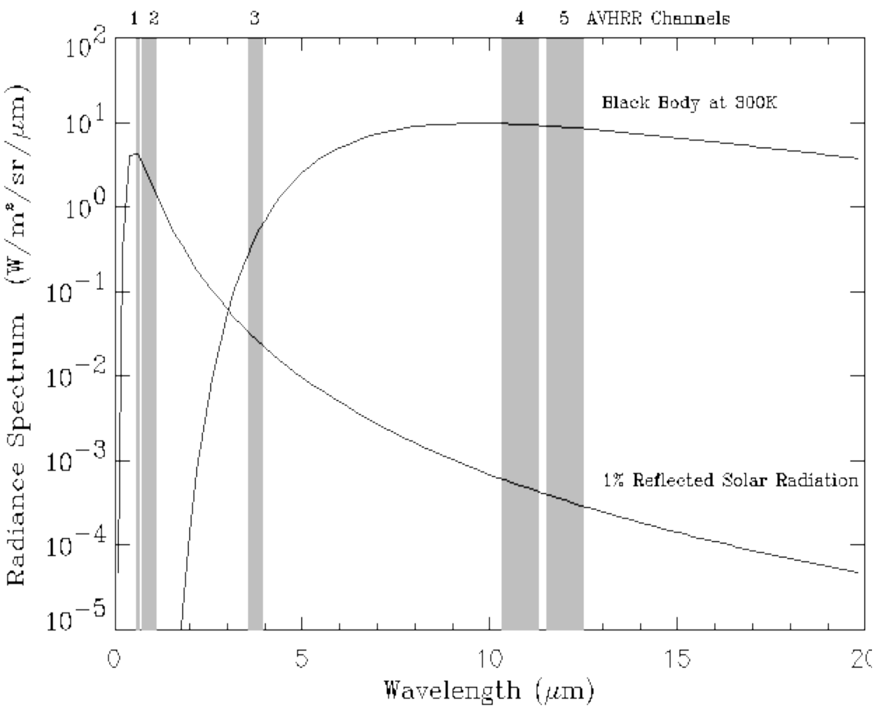


Satellite's view of the Gulf Stream



Sea Surface Temperature as measured by thermal infrared sensor via multi-channel

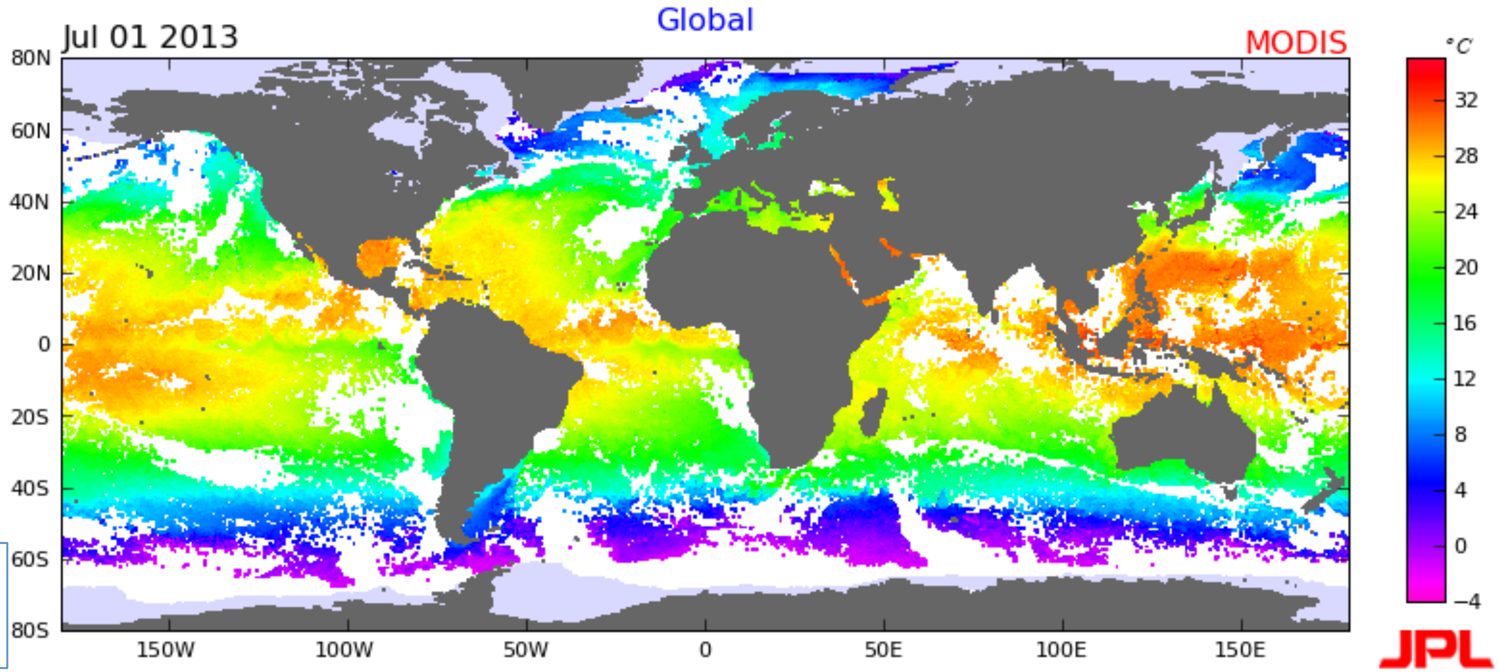


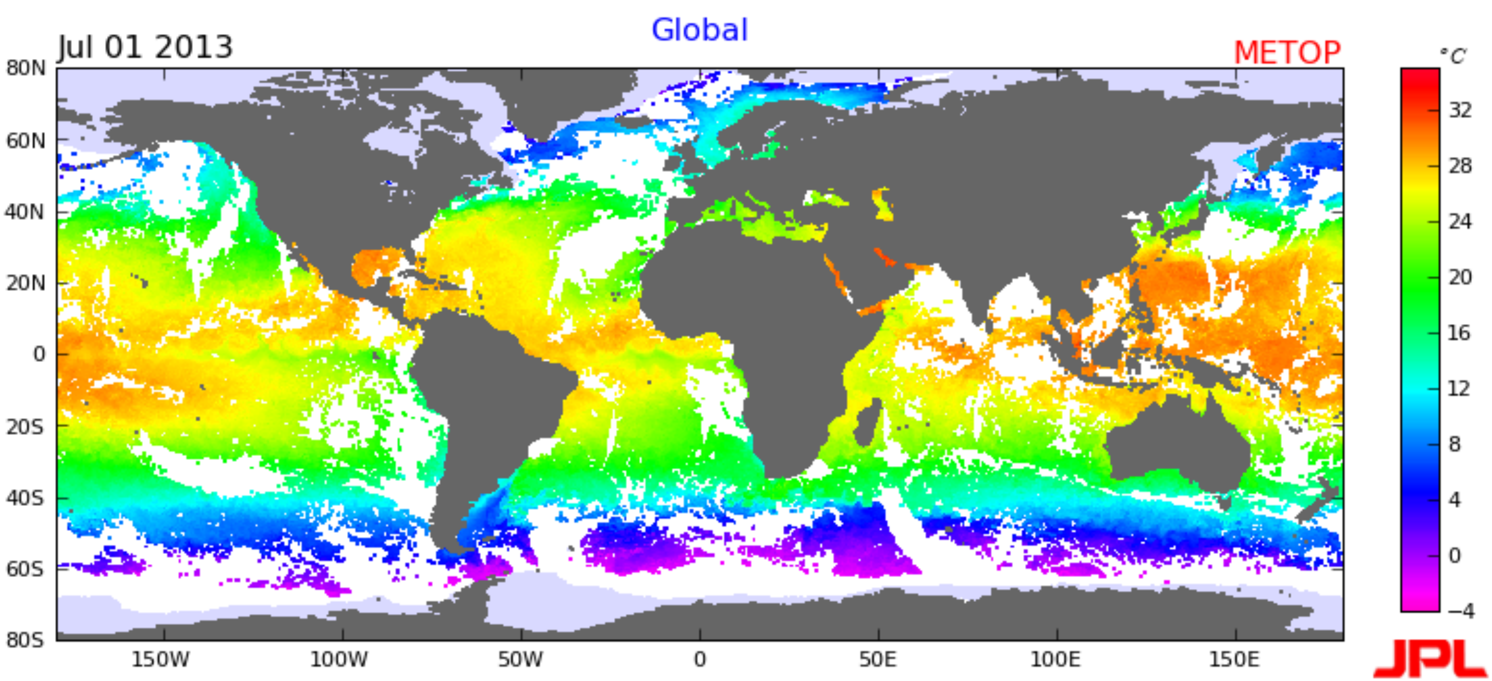


- Atmosphere absorbs and emits radiation (wavelength dependent, use multi-channel)
- Reflection of solar radiation (avoid solar radiation band)
- ~0.5°C accuracy

MODIS Terra & Aqua Satellites

Infrared cannot penetrate cloud

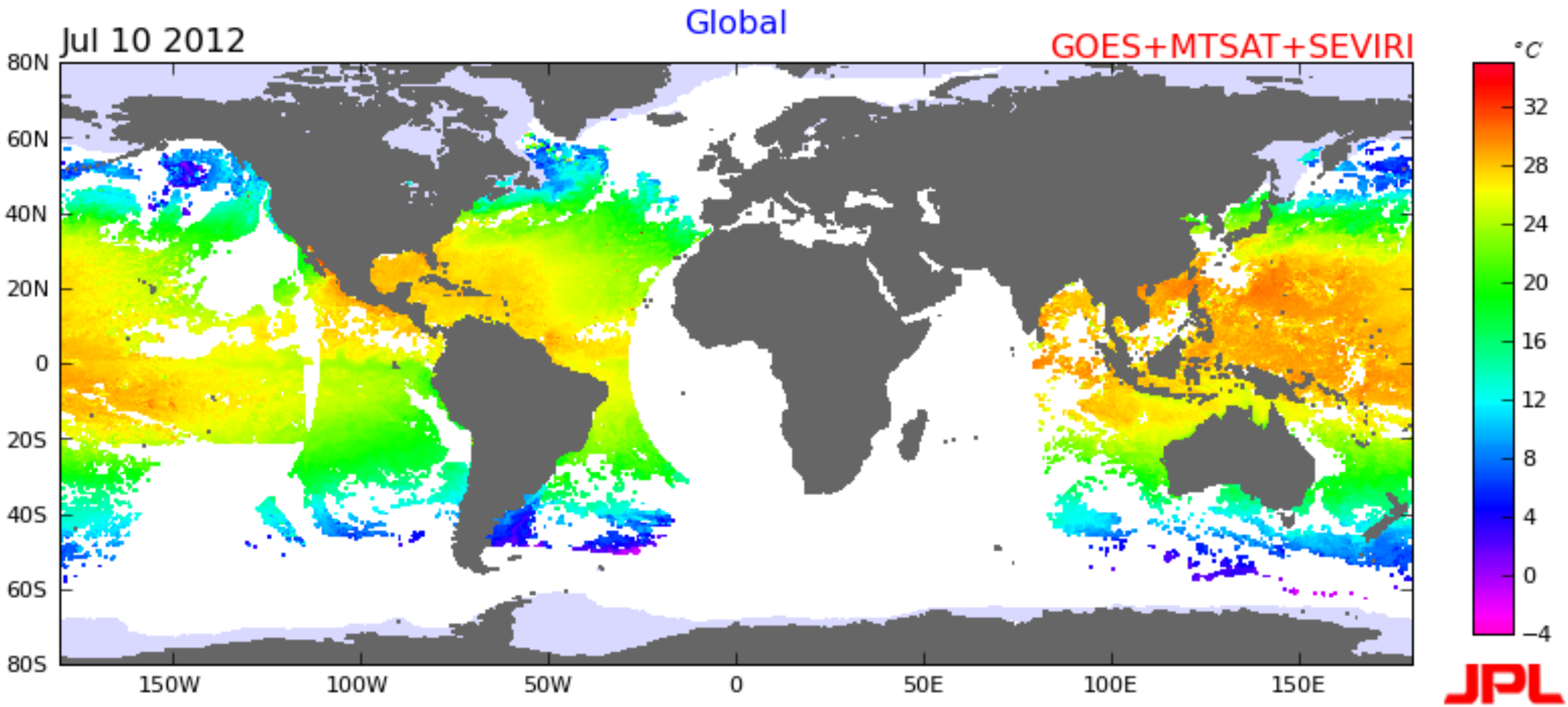


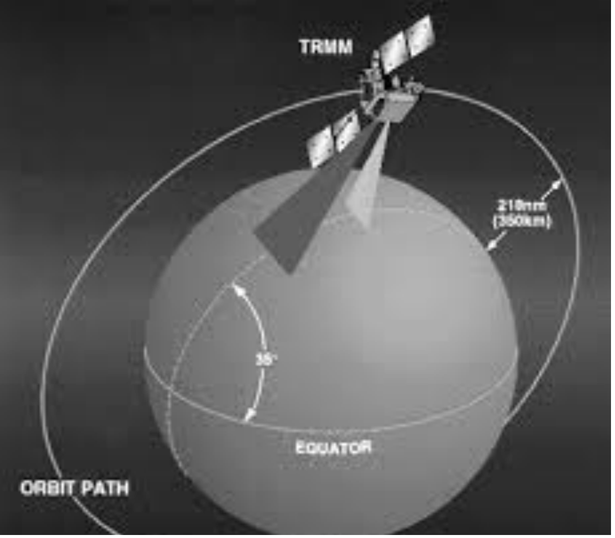


MetOp Satellites by EUMETSAT

(VIIRS on NPP)

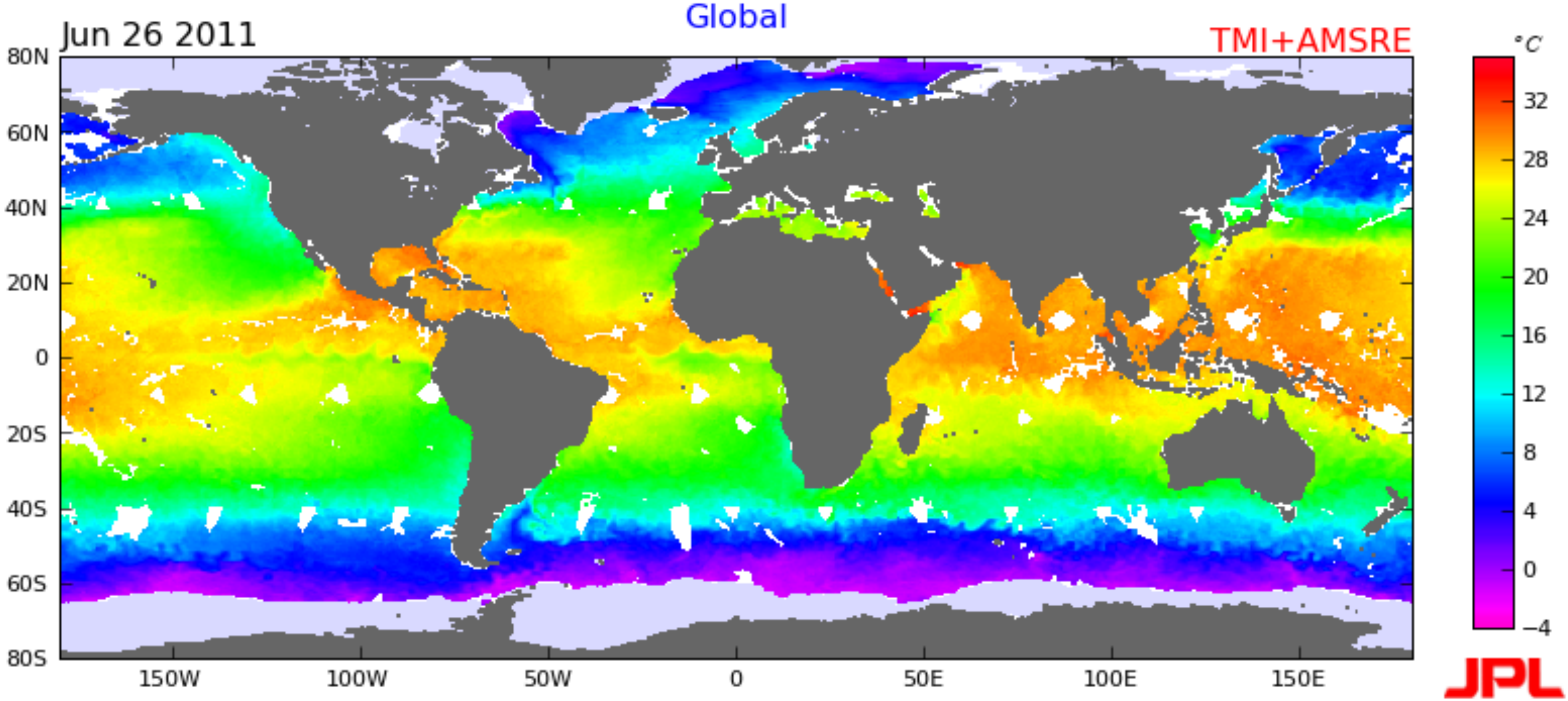
Geostationary Satellites



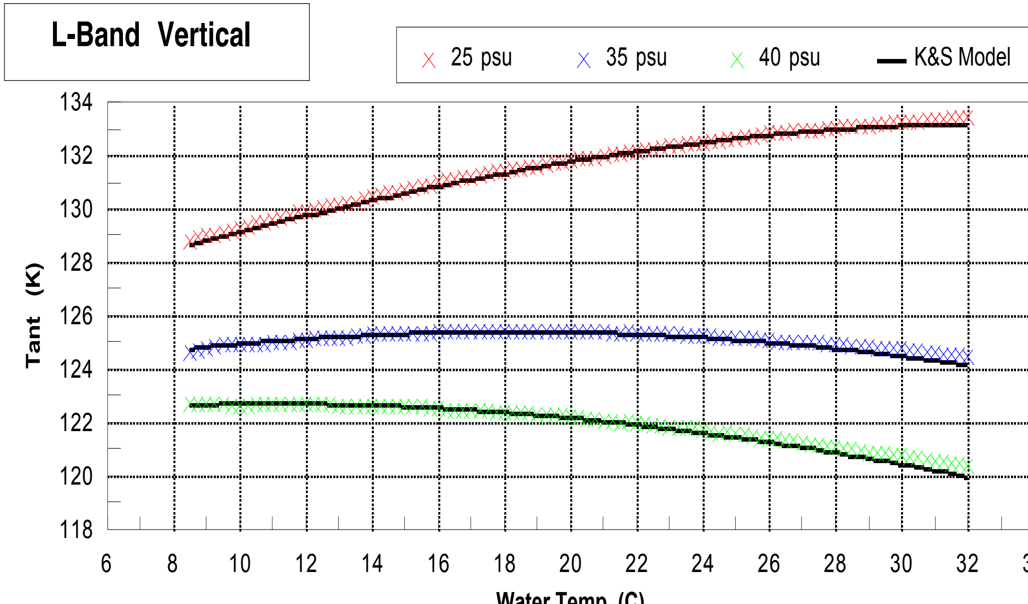


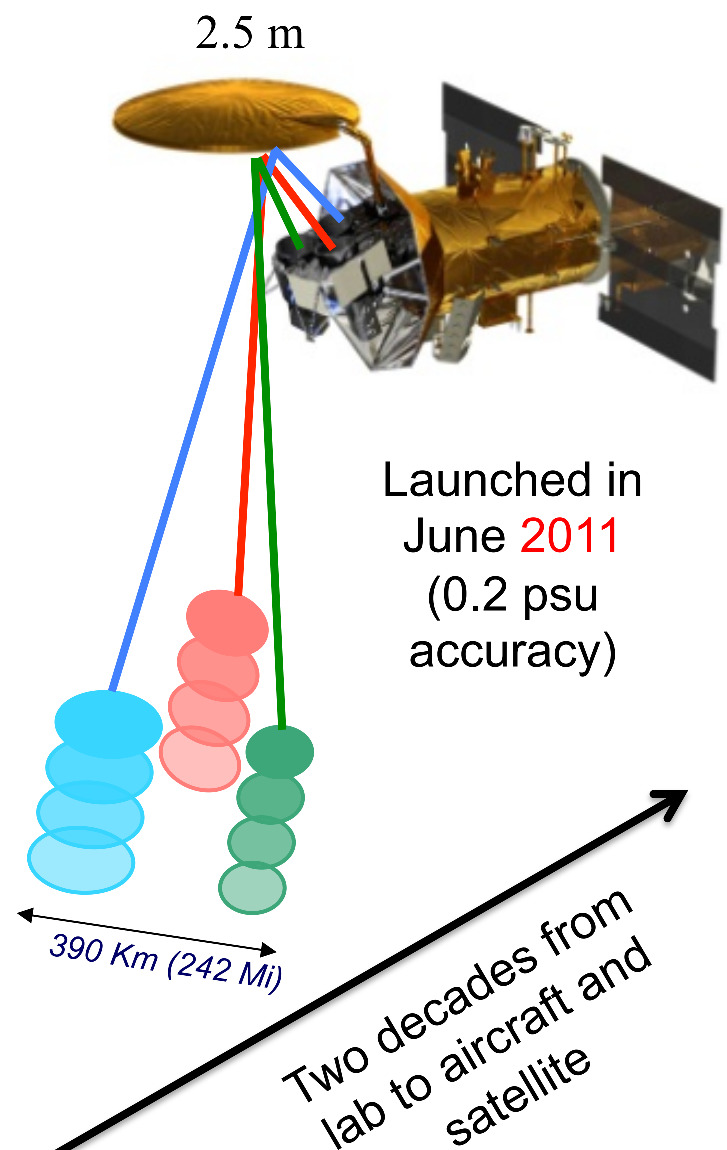
TRMM Microwave Imager (TMI) & AMSR-E

(cloud-free, but coarse resolution Δ ~ Hλ/D ~ 25-km)



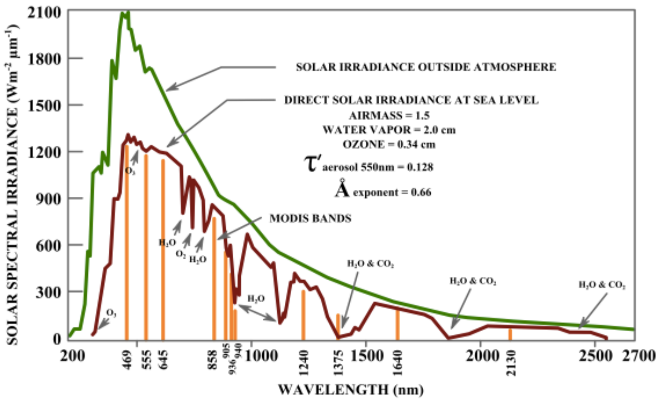
Microwave Radiometer on the Aquarius satellite: The first NASA satellite to measure salinity





Launched in June 2011 (0.2 psu accuracy)

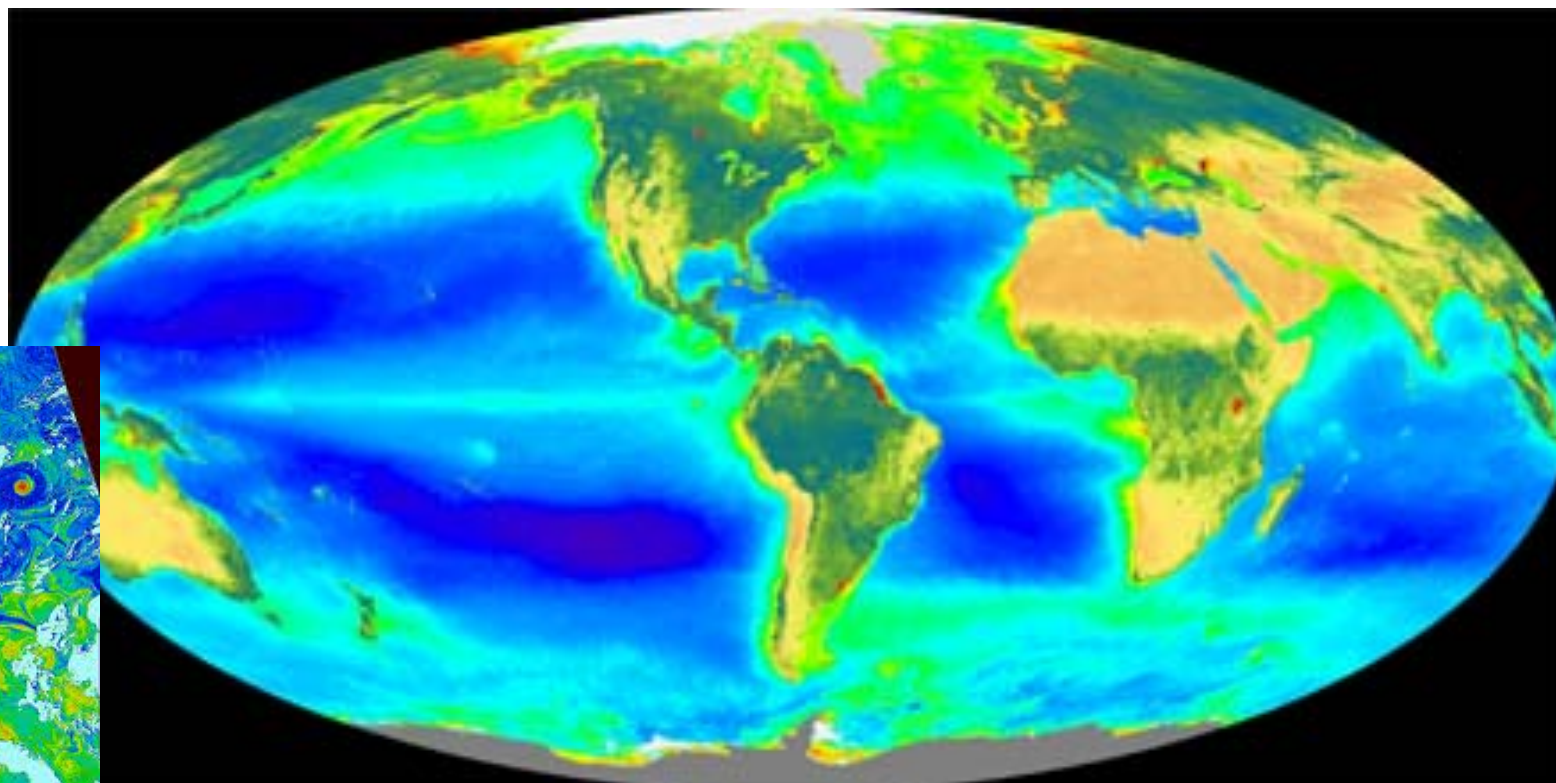
Ocean Color Radiometry: Biogeochemistry & Ecosystem

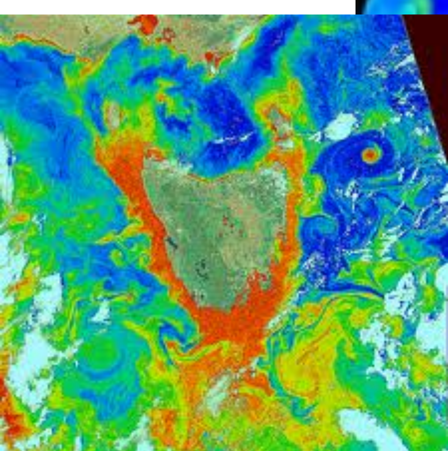


Coastal Zone Color Scanner (or CZCS) on Nimbus 7 satellite, 1978-1986

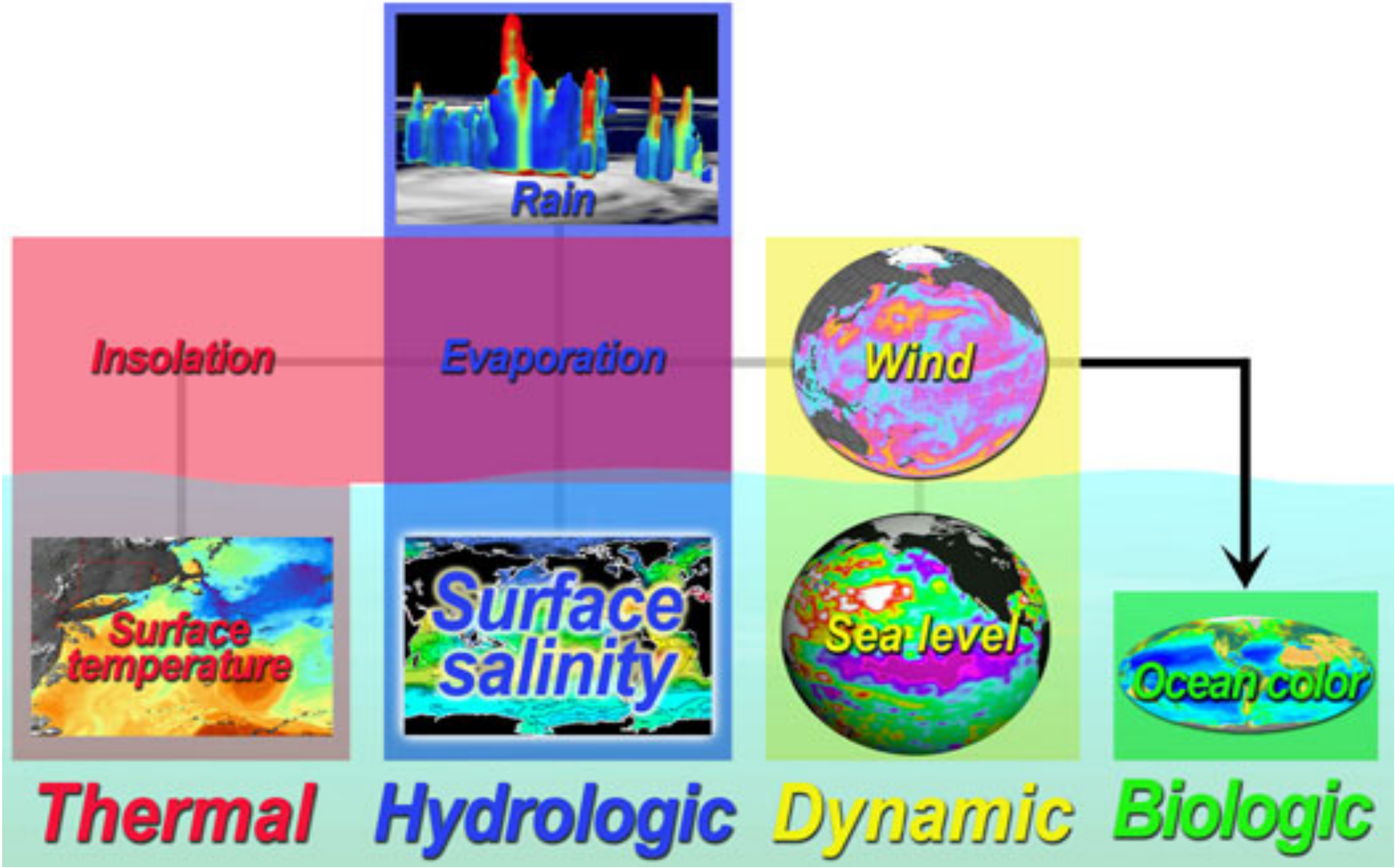
Sea-viewing Wide Field-of-view Sensor (SeaWiFS) on SeaStar, 1997-2010

Moderate-resolution Imaging Spectroradiometer (MODIS) on Terra (1999-) and Aqua (2002-) satellites





Carbon Cycle via Satellite Remote Sensing



Satellite Scatterometry (Active sensing): Marine weather and storms

Centimetric Roughness: Gravity-Capillary Waves

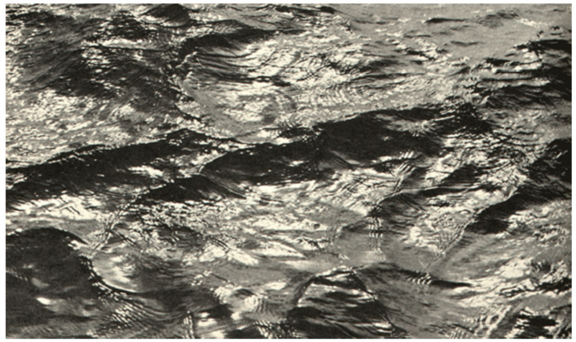
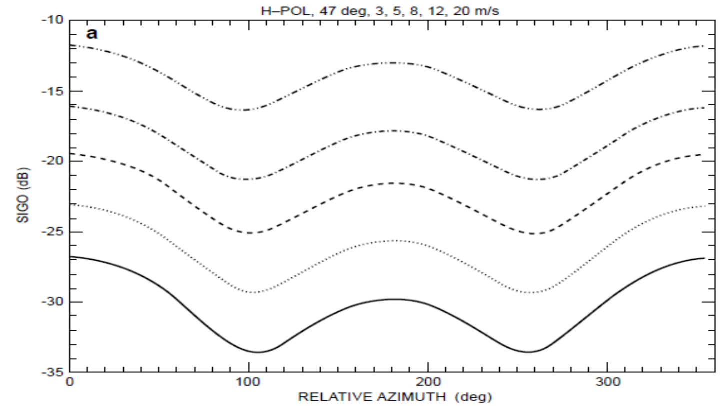
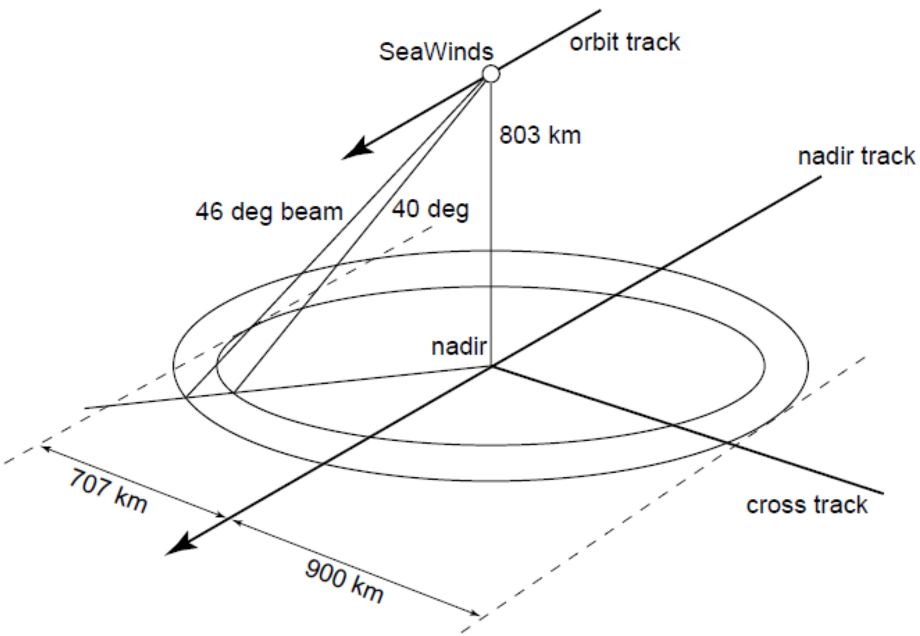
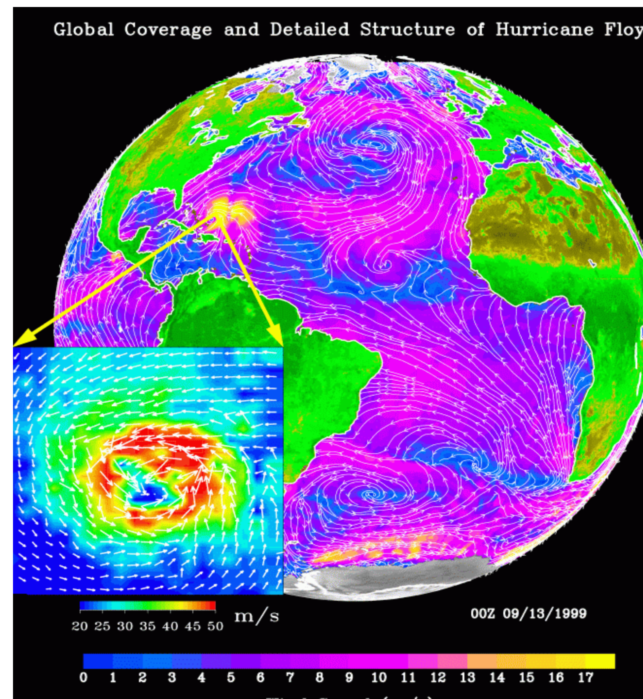


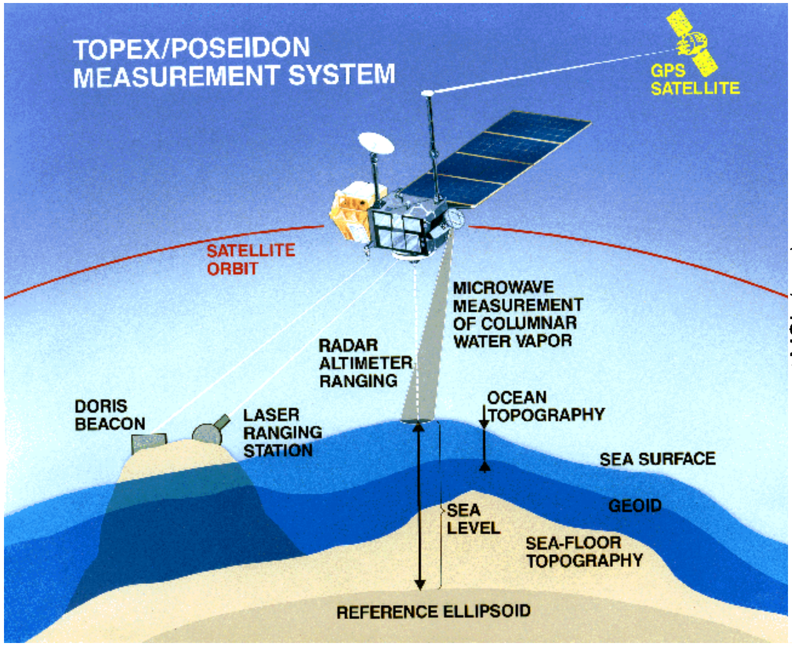
Figure courtesy of M. Freilich

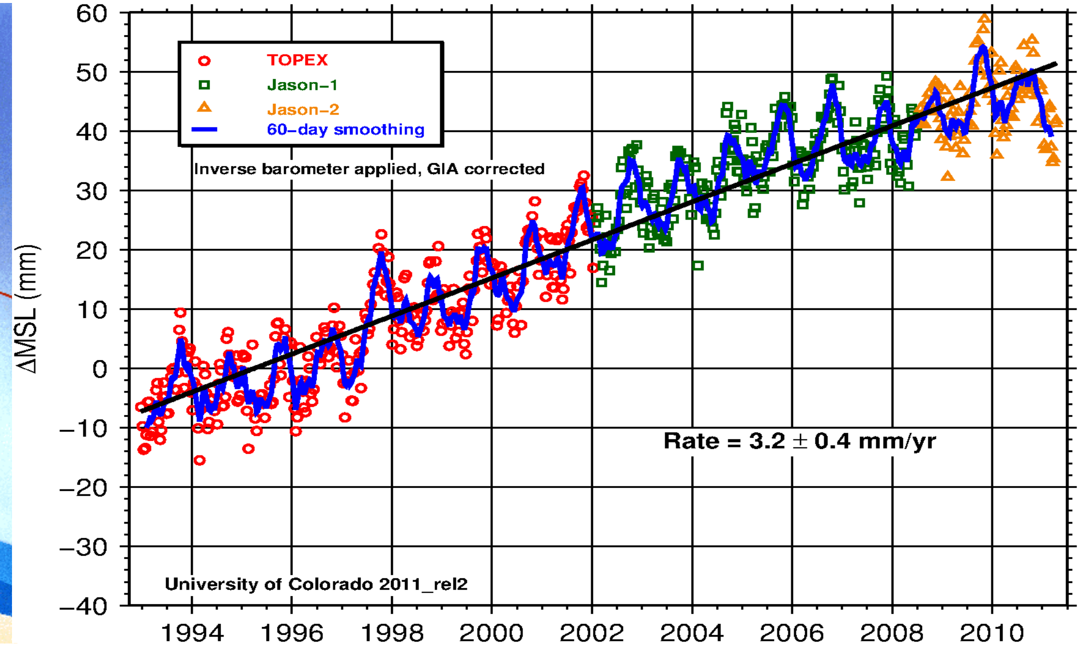


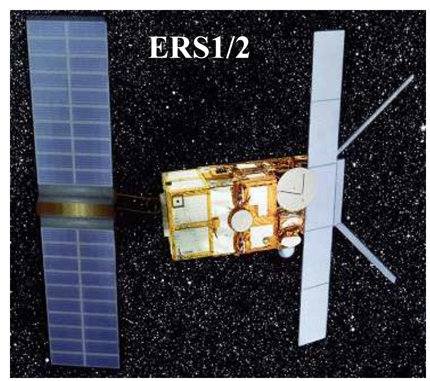


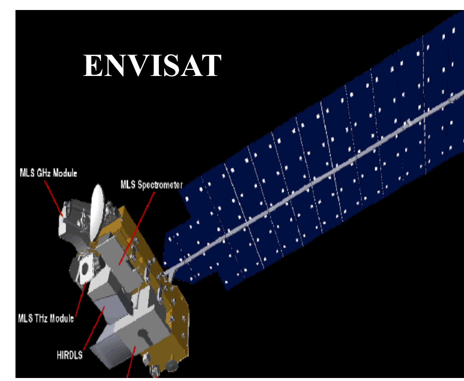


Satellite Altimetry (Active sensing): Climate data record for global sea level rise



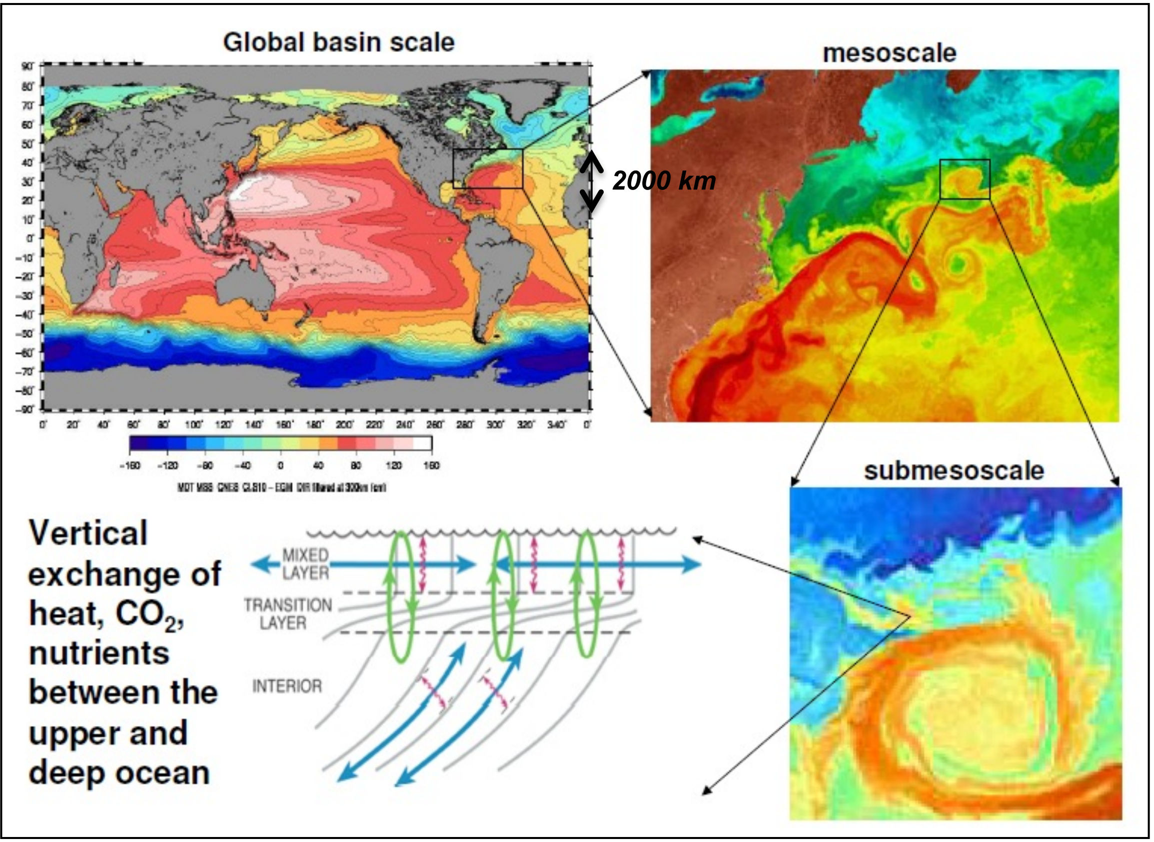


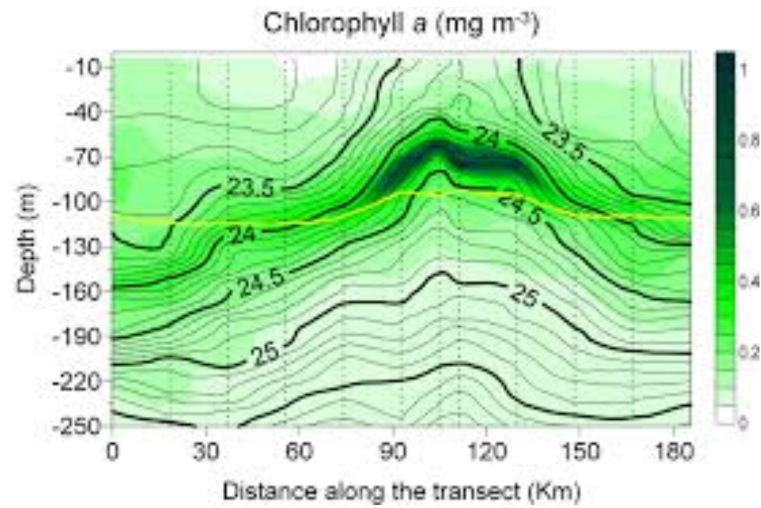


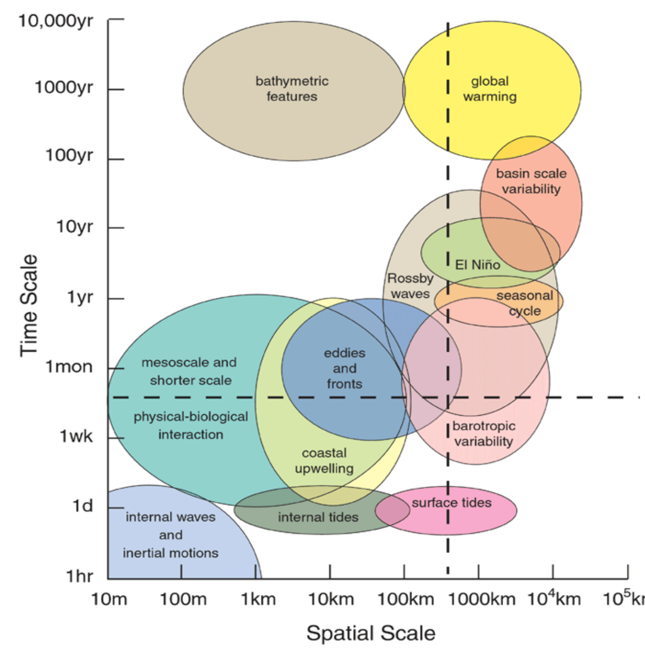


(Gold standard: 2~3 cm accuracy!)

Future Challenges: Ocean Mesoscale and Submesocale Eddies; Frequent Sampling

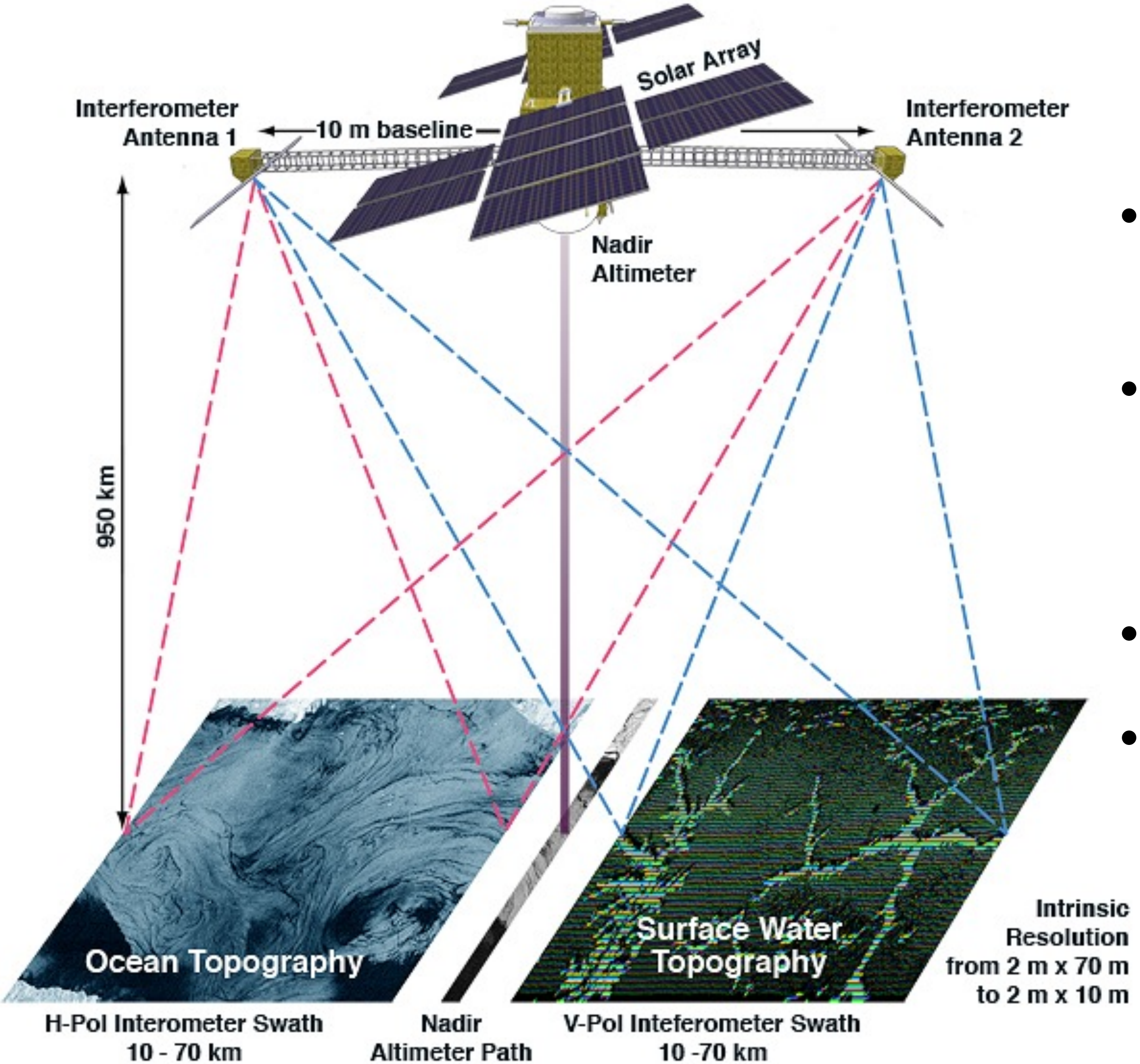






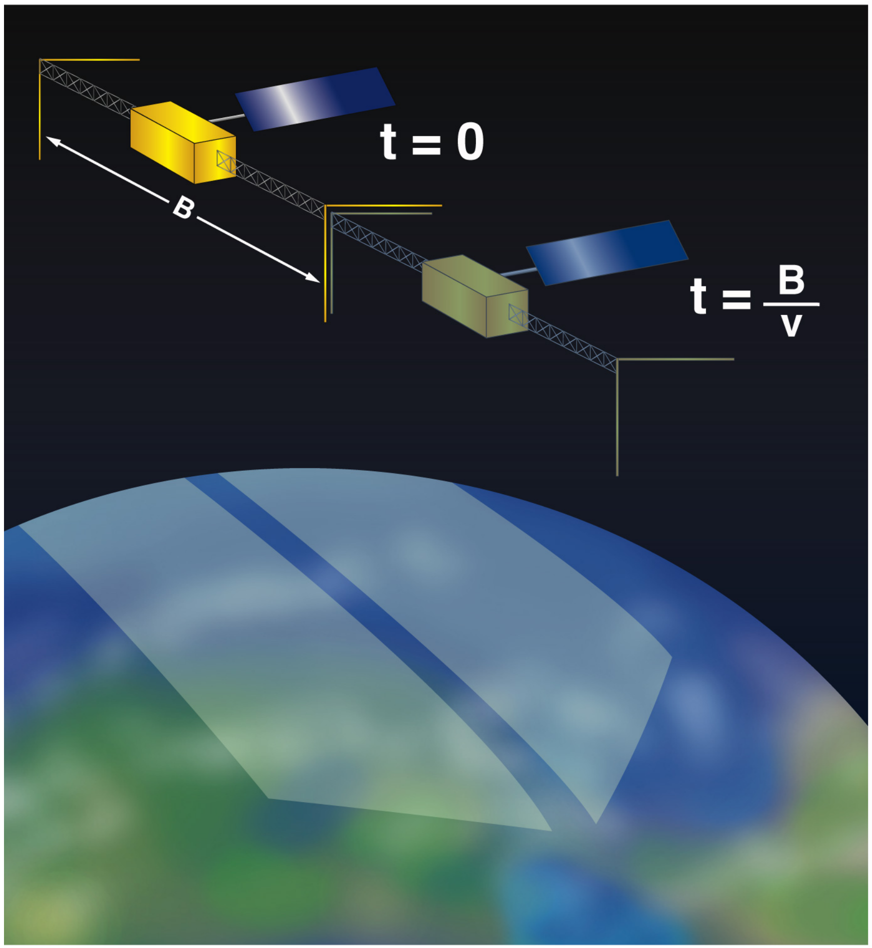
Regional scale
From mesoscale to submesoscale eddies
3D vertical process via upwelling/downwelling
Subsurface maximum

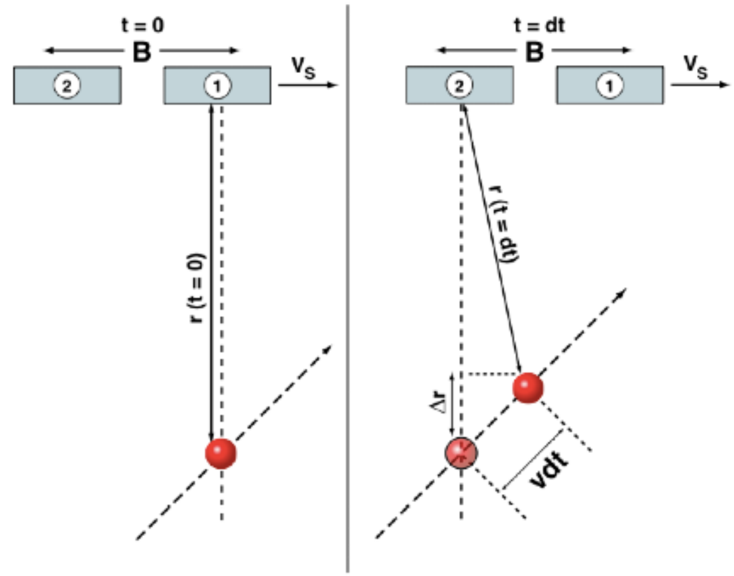
SWOT (Surface Water Ocean Topography) satellite to be launched in 2020

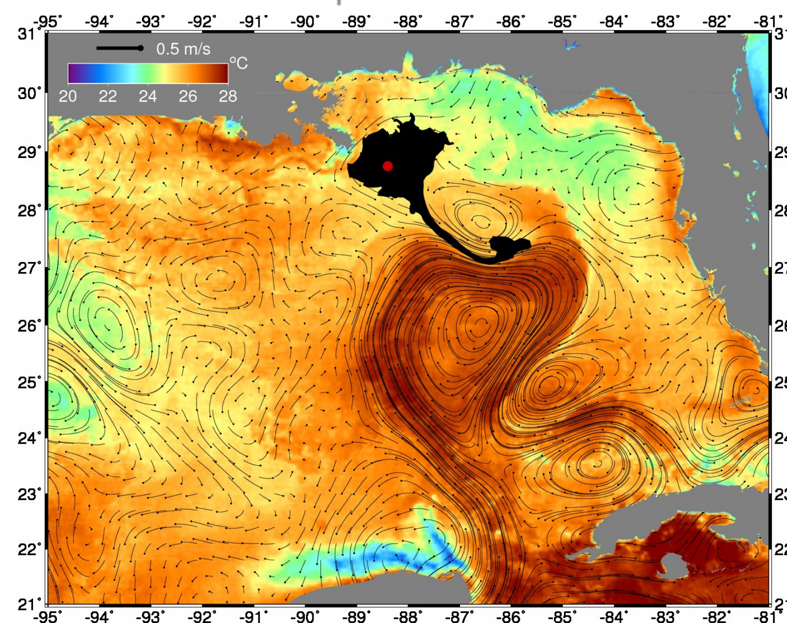


- Ka band (0.85 cm wavelength)
- Extremely high resolution: 10-70 m & 5 m
- 21-day repeat cycle
- 1~3 TB per cycle (Max:620 Mb/s)

Mission Concept beyond 2020: Along-Track Interferometry to measure surface current



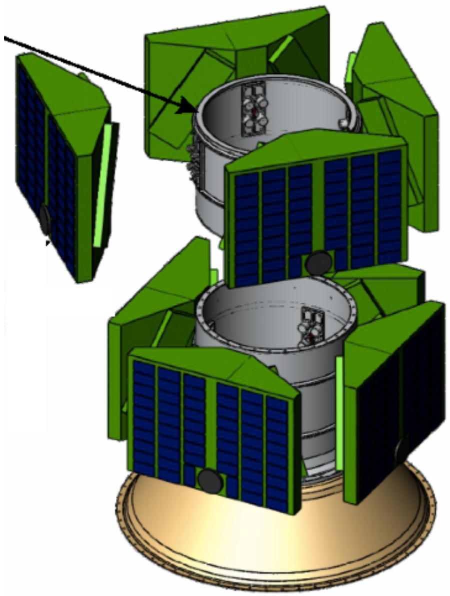




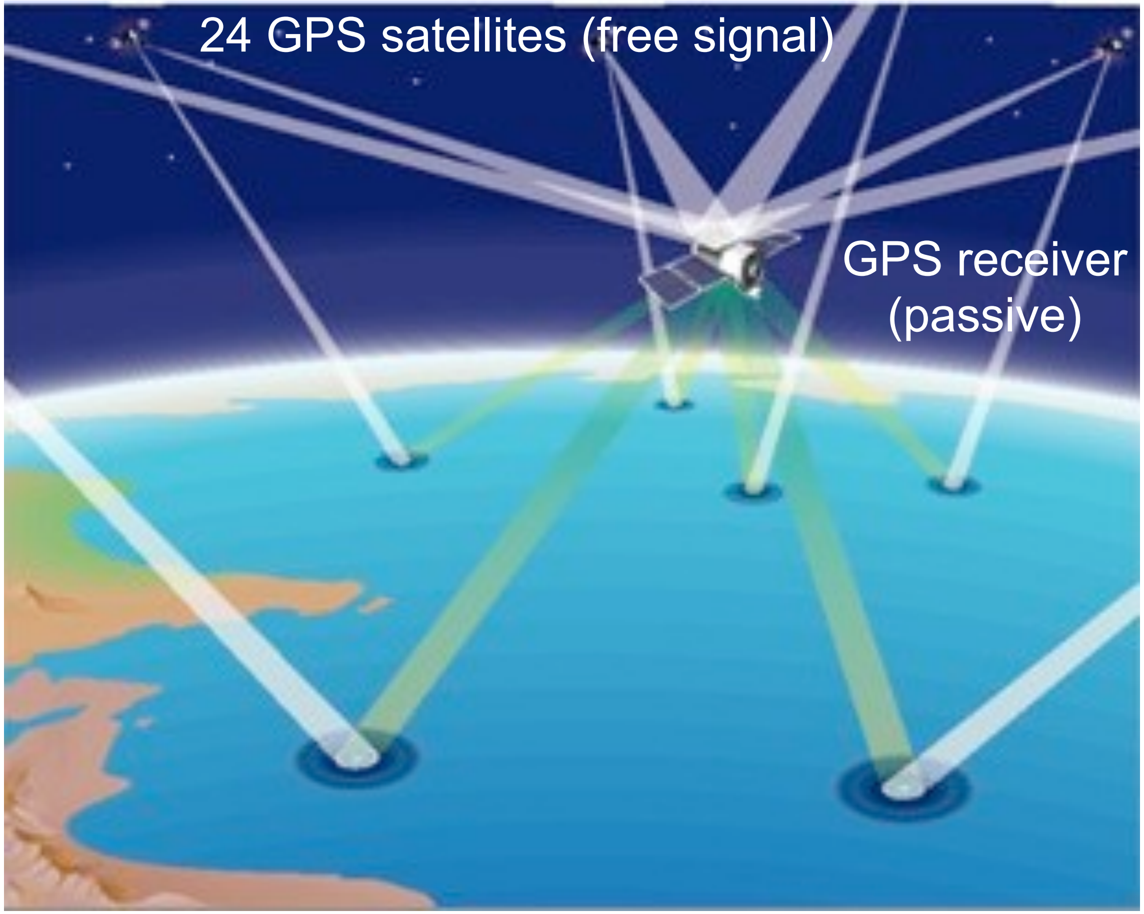
GPS (Global Positioning System) Reflectometry: Altimetry and Scatterometry (Fast sampling)

GPS Scatterometry to derive winds: Cyclone Global Navigation Satellite System (CYGNSS) to be launched in 2016

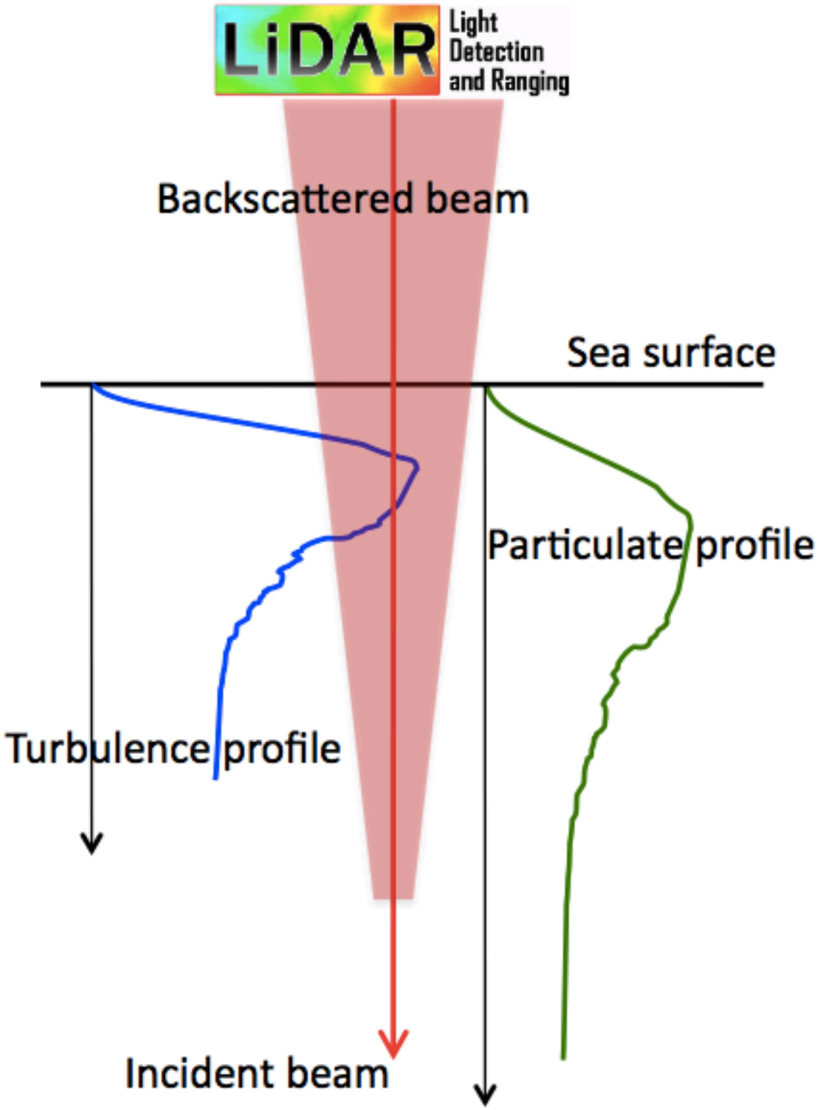
Mission concept: GPS Altimetry to derive sea level



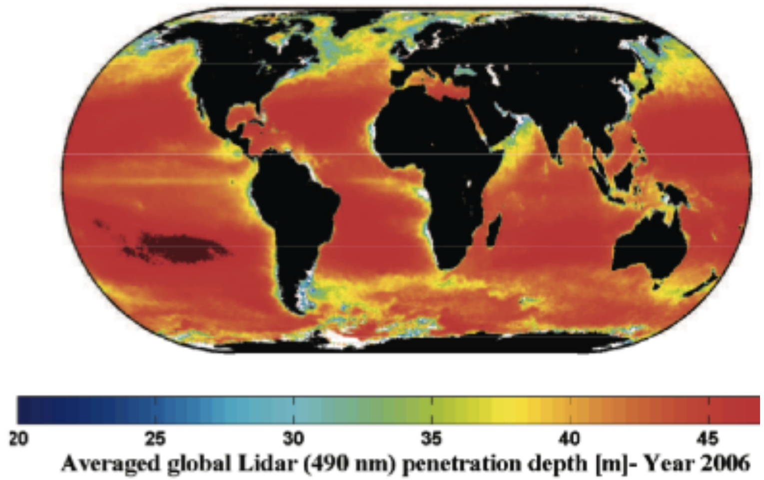
A constellation of 8 GPS receivers from a single satellite launch

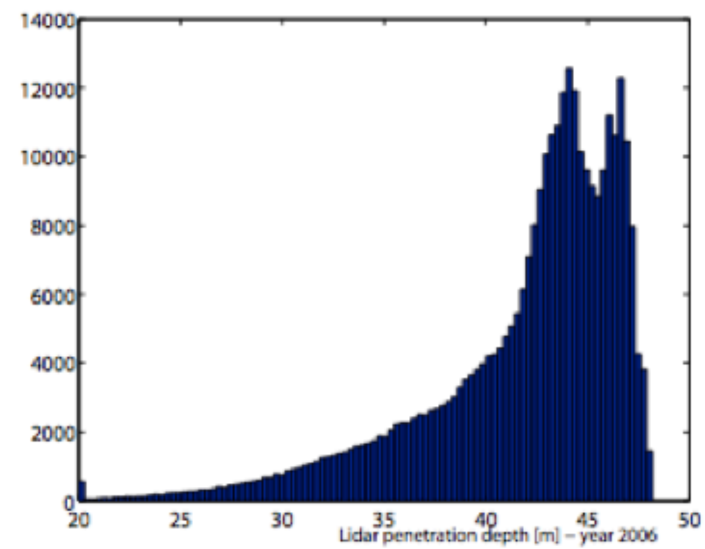


Mission Concept: Remote Sensing of the Mixed Layer Depth

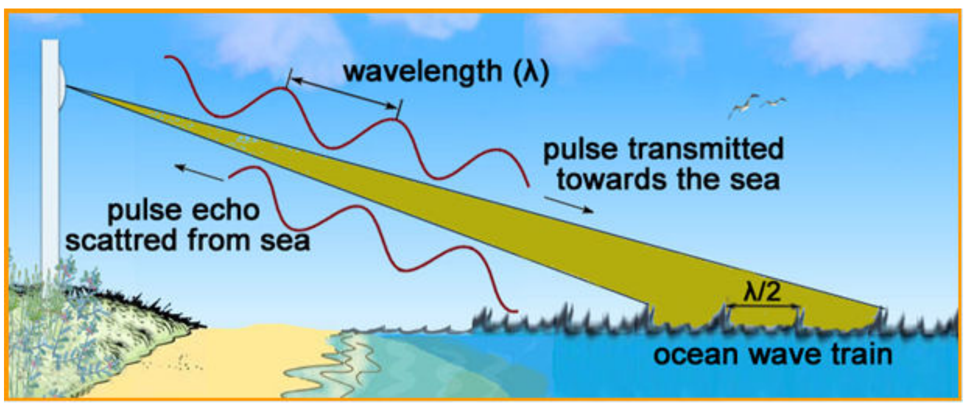


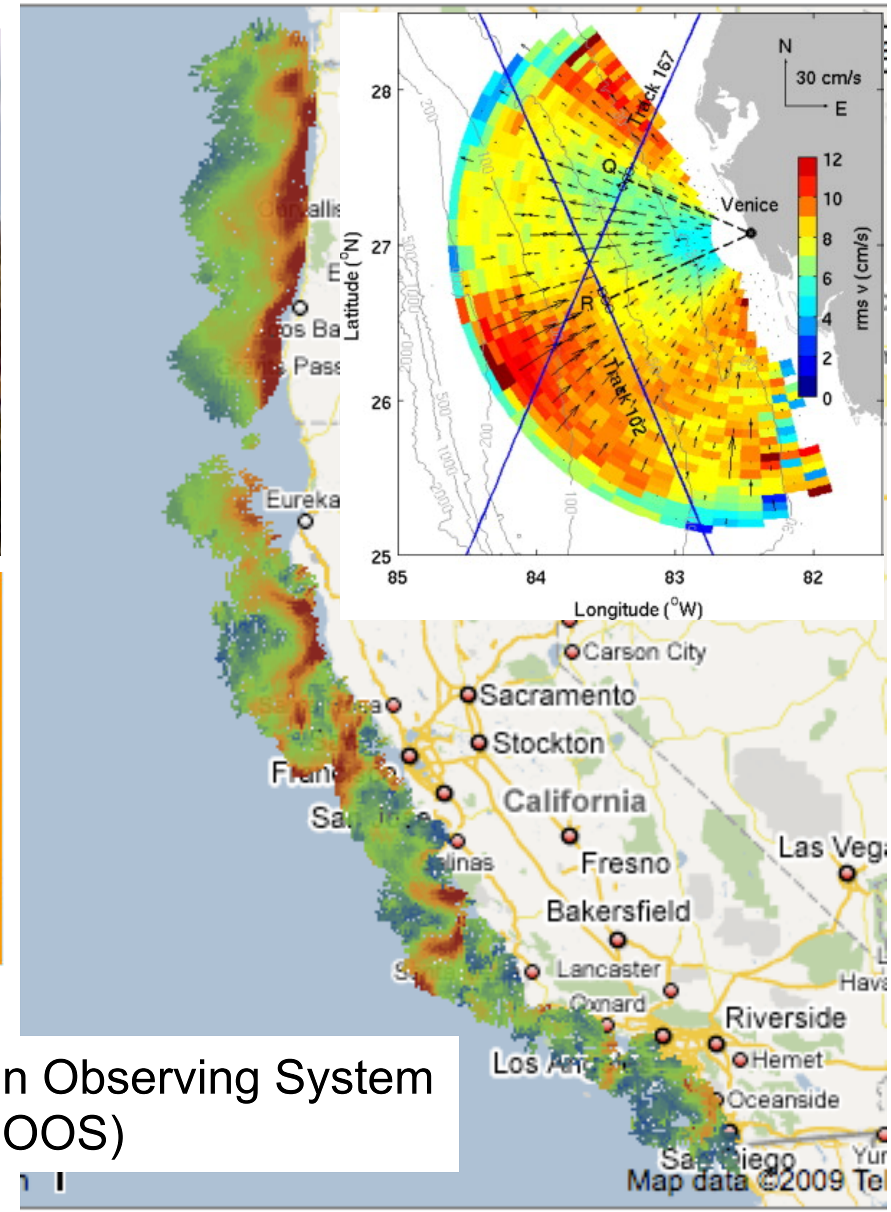
Lidar penetration map using lidar specifications in Churnside et al. 1998





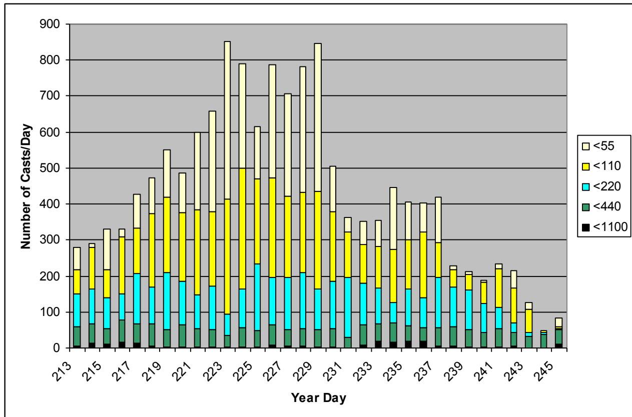
Land-Based High-Frequency (HF) Radar to measure surface current (hourly, 1-km)

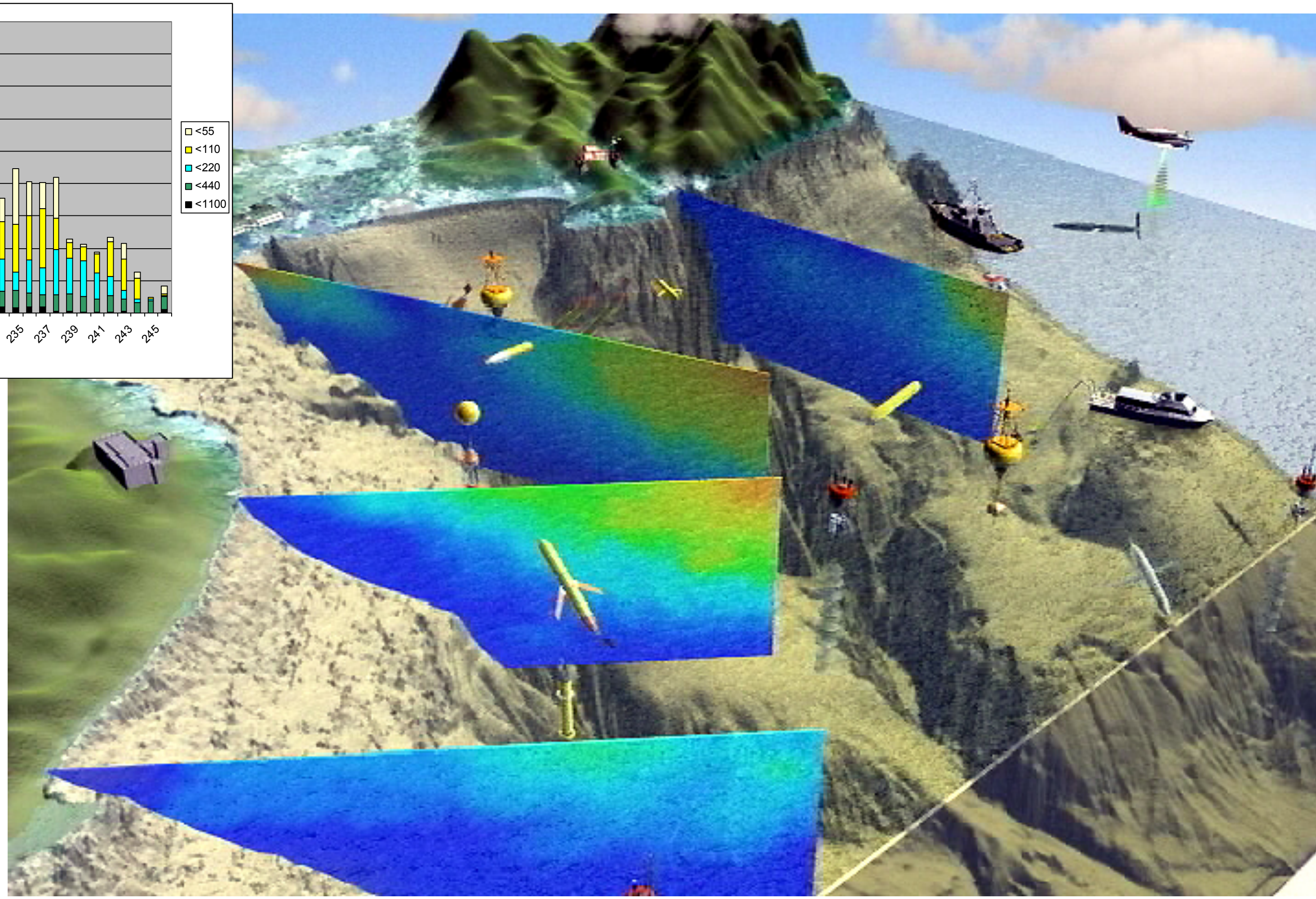




Integrated Ocean Observing System (IOOS)

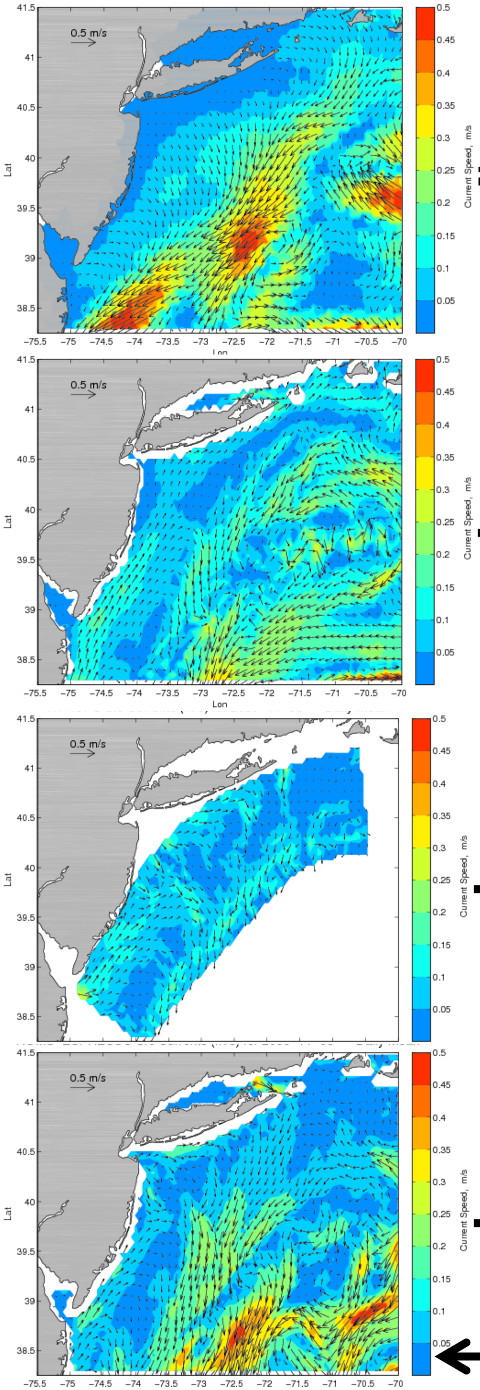
Integrating Ocean Observing and Forecasting Modeling: Field Experiments



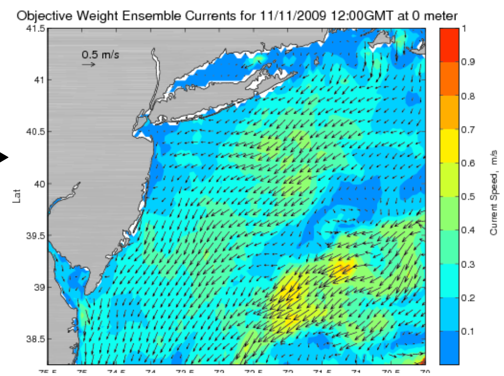


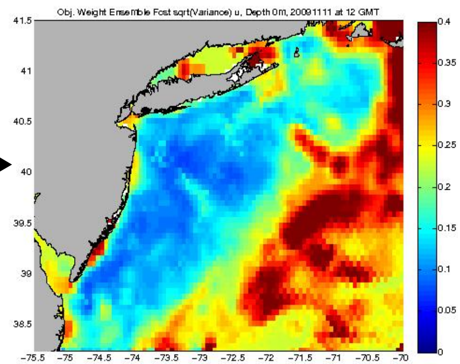
2003 Monterey Bay Experiment
Adaptive Sampling Ocean Network (AOSN-2)

Ensemble Prediction & Glider Path Planning



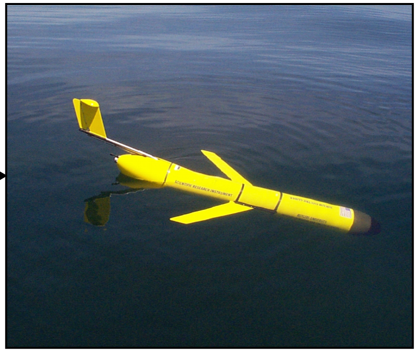
Multi-Model Ensemble





Error Estimation

Glider Planning



Known constraints (slow 0.5 knot, Battery, shipping lanes)

Uncertain constraints (time-varying 3D currents)

Operate autonomously & re-plan daily

Real-time glider data are used to improve the model forecast

(Wang et al., 2013)

Gliders and Satellite Formation Flight

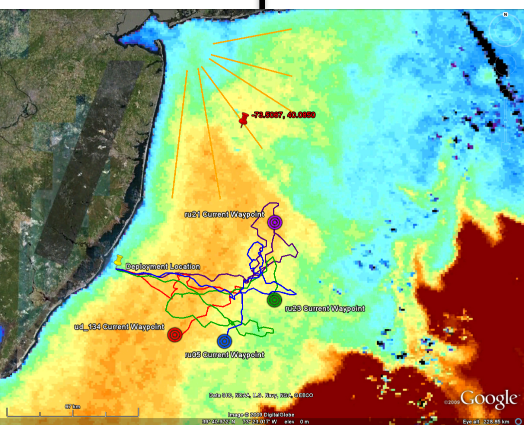
Science Alerts

Scientists

Science Campaigns

Science Agents

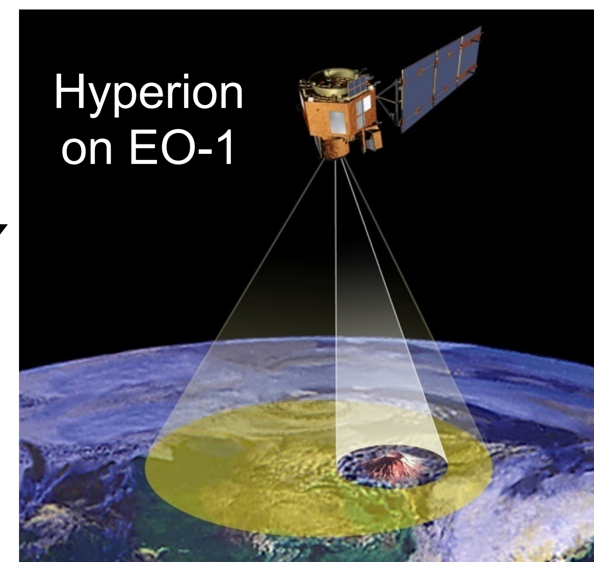
Science Event Manager
Processes alerts and
Prioritizes response observations



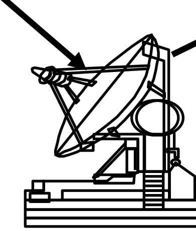
Observation Requests

EO-1 Flight Dynamics
Tracks, orbit, overflights,
momentum management

ASPEN
Schedules observations on EO-1



Updates to onboard plan



(Schofield et al., 2010)

Contact Information

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