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
• 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

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

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1st Weather (Meteorological) Satellite (1960)
1770 Benjamin Franklin (postmaster) collected information about ships sailing between New England and England, discovering and mapping 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

36,000 km
Geostationary orbit

Global
GOES+MTSAT+SEVIRI

Jul 10 2012

℃

JPL
TRMM Microwave Imager (TMI) & AMSR-E
(cloud-free, but coarse resolution $\Delta \sim H\lambda/D \approx 25$-km)
Microwave Radiometer on the Aquarius satellite: The first NASA satellite to measure salinity

Launched in June 2011 (0.2 psu accuracy)

Two decades from lab to aircraft and satellite
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
Satellite Altimetry (Active sensing): Climate data record for global sea level rise

(Gold standard: 2~3 cm accuracy!)
Future Challenges: Ocean Mesoscale and Submesoscale 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 (Light Detection and Ranging)
- Backscattered beam
- Sea surface
- Particulate profile
- Turbulence profile
- Incident beam

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

Graph showing averaged global Lidar (490 nm) penetration depth [m] - Year 2006
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)
Known constraints (slow 0.5 knot, Battery, shipping lanes)
Uncertain constraints (time-varying 3D currents)
Operate autonomously & replan daily
Real-time glider data are used to improve the model forecast

(Wang et al., 2013)
Gliders and Satellite Formation Flight

Science Agents

Science Alerts

Science Event Manager
Processes alerts and
Prioritizes response observations

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

ASPEN
Schedules observations on EO-1

Observation Requests

Scientists

Science Campaigns

Updates to onboard plan

Hyperion on EO-1

(Schofield et al., 2010)
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