Altimetry, Wind, Salinity

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Altimetry

22-year Sea Surface Height Change (cm)

What is altimetry?

- **The surface of the ocean isn’t flat** -- there are high spots and low spots.

- Satellite altimeters measure the ocean surface height in relation to the mean sea level. Altimetry data helps identify areas of upwelling and downwelling and the location of ocean current features and eddies.
• Satellite altimeters are active microwave instruments (-> not affected by cloud cover)

• Altimeters on board the satellites send signals at high frequencies (over 1,700 pulses per second) to Earth’s surface and receive the echoes from the surface.

• The return time of the signal gives a measure of distance to the surface (range, $R$)

https://www.star.nesdis.noaa.gov/socd/lsa/AltBathy/
Basic principle

• However, as electromagnetic waves travel through the atmosphere (twice), they can be decelerated by water vapor or ionization.  
  -> need atmospheric correction for accurate measurements

• The precise position of the satellite is tracked using Doppler shift, GPS or lasers, to determine the satellite altitude, which is the distance to a standard reference (ellipsoid).

https://www.star.nesdis.noaa.gov/socd/Isla/AltBathy/
Basic principle

- The range is subtracted from the altitude of the satellite to give Sea Surface Height (SSH).
- Altimetry data has an accuracy of ~ 3cm.
- Low resolution (~ 25 km), not good close to coasts (20 km).

https://www.star.nesdis.noaa.gov/socd/lsa/AltBathy/
Sea Surface Height

The sea surface height (SSH), is the satellite’s distance at a given instant from the reference surface, so:

$$SSH = Altitude - Range.$$  

For the ocean, the sea surface height integrates effects such as:

- The sea surface height which would exist without any perturbing factors (wind, currents, tides, etc.). This surface, known as the geoid, is determined by gravity variations around the world, which are in turn due to major mass and density differences on the seafloor.

- The ocean circulation, or dynamic topography, which comprises:
  - the permanent stationary component (permanent circulation linked to Earth’s rotation, permanent winds, etc.). The mean effect is of the order of one meter.
  - a highly variable component (due to wind, eddies, seasonal variations, etc.).

http://www.altimetry.info
Sea Surface Height

https://www.star.nesdis.noaa.gov/socd/lsa/AltBathy/
A sea level anomaly (SLA) is the difference between the total sea-level and the average sea-level for a particular time of year.

We look at anomalies because the total level measurement made by the altimeter varies from +/- 100 meters. Most of this is constant, though, and is due to the Earth's gravity (geoid) and the ocean circulation.

Sea level variations caused by El Niño for example account for only 1% of the signals. If the constant part was not removed, the El Niño signal would not be observable.

http://www.tsgc.utexas.edu/topex/activities/elnino/sld005.html
Sea Level Anomalies

- To derive the dynamic topography, the easiest way would be to subtract the geoid height from SSH. In practice, mean sea surface is subtracted instead, to yield the variable part (sea level anomalies) of the ocean signal.

\[ \text{SLA} = \text{SSH} - \text{MSS} \]

MSS represents the mean profile of the SSH over a defined temporal period, also called reference period (currently 1993-2012).

SSH: Sea Surface Height  
SLA: Sea Level anomaly  
MDT: Mean Dynamic Topography  
MSS: Mean Sea Surface

Geostrophic currents

- At large space scales in the ocean, pressure gradients due to gradients in sea level are balanced by the Coriolis force and associated geostrophic currents.

- SLA obtained from satellite altimetry measurements is used to derive surface geostrophic currents.

http://www.seos-project.eu/modules/oceancurrents/oceancurrents-c06-s02-p01.html
Geostrophic currents & SLA

Mean SSH & Geostrophic currents
(2/22 ~ 5/8)

30cm/s

SLA (cm)

Son et al, 2014
Geostrophic currents

Average geostrophic currents – 1992 -2002

Cheng et al, 2014
Eddies can be identified from SLA

Sea Level Anomaly, 07/14/2010, anticyclonic (red) and cyclonic (blue) eddies

The spatial and temporal resolutions of SLA are 25 km and 7 days, respectively, thus an eddy diameter smaller than 50 km or a lifespan shorter than one week can not be detected using altimetry data.

Cheng et al, 2014
Altimetry missions

Past missions
- SPOT2
- Topex-Poseidon
- SPOT3

Current missions
- SPOT4
- Jason-1
- Envisat
- SPOT5

Future missions
- Jason-2/OSTM
- Cryosat-2
- HY-2A
- HY-2B
- Saral/AltiKa
- Jason-3
- Sentinel-3A
- Sentinel-3B
- Sentinel-CS
- Jason-CS
- SWOT

CLS/CNES
Current missions

Jason-2 (2008)
Cryosat (2010)
SARAL (2013)

Jason-3 (2016)
Sentinel-3A (2016)
Sentinel-3B (2018)

Slide from Eric Leuliette
Current constellation coverage

Jason-2, Jason-3, Sentinel-3A, AltiKa, Cryosat-2

Much of the ocean surface is interpolated: low spatial resolution ~ 25km, 7 days

Slide from Eric Leuliette
Data products

- **AVISO data.** Distributed by CMEMS (Europe). Free for research purposes but need to register to get access.  

- **NOAA CW/OW product:**
  - For now, only SLA, 2014 – present
  - FY19: SLA and geostrophic currents for 1993-present
NOAA CW/OW product

- Daily gridded **near-real time** (5-hour latency) sea level anomaly product (2017 – present)
  
  [https://coastwatch.noaa.gov/cw_html/SSH_SeaLevelAnomaly.html](https://coastwatch.noaa.gov/cw_html/SSH_SeaLevelAnomaly.html)

Slide from Eric Leuliette
Delayed mode (Science quality) daily $\frac{1}{4}^\circ$ multiple altimeter optimal interpolation sea level anomaly gridded product
• Years: 2014–2018
(soon to be on OW ERDDAP)

<table>
<thead>
<tr>
<th>Year</th>
<th>Missions</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>sa, c2, j2</td>
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<tr>
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<td>2016</td>
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<tr>
<td>2017</td>
<td>sa, c2, j2, j3, 3a</td>
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</tbody>
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SLA variability (cm²)

Slide from Eric Leuliette
Ocean Surface Winds

QuikSCAT, 01/03/2004

noaa.gov/datasets/ocean-surface-winds/
Ocean Surface Winds

- Ocean wind is defined as the motion of the atmosphere relative to the surface of the ocean.

- Typically, ocean winds are measured very close to the ocean surface by buoys, platforms, and ships. The most common reference height for near-surface ocean wind measurements is **10 meters above sea level**.

- Satellite ocean wind measurements are done using both passive and active instruments.

- Today, the combination of all available satellite wind measurements can provide **global coverage** over the ice-free oceans at **multiple times per day**.

https://podaac.jpl.nasa.gov/OceanWind
Ocean Surface Winds

- Sensors operate at microwave frequencies -> can make measurements day and night and under nearly all-weather conditions.

- Both active (radar scatterometers) and passive (radiometers) microwave instruments are capable of retrieving the ocean surface wind speed.

- Active microwave instruments are also capable of retrieving the wind direction.

- Microwave measurements are inaccurate in regions of heavy rain and close to coasts.

- Typical spatial resolution is ~ 25km.
Passive sensors – basic principle

- The ocean surface responds quickly to the motion of the air above, which provides a distinct roughness pattern depending on the relative speed and direction of the wind with respect to the ocean surface.
- The roughness of the ocean surface provides a specific “brightness” which can only be observed using passive microwave radiometers;
- With the right combination of specific microwave wavelengths and processing algorithms, the brightness of the ocean surface can be accurately translated to a near-surface wind speed.
Active sensors – basic principle

The backscatter of scatterometer pulses is sensitive to sea surface roughness.

**No wind**
- Sea surface is flat
- Most energy is reflected away from the sensor

**Light wind**
- Sea surface roughens
- Some energy is backscattered to sensor

**Strong wind**
- Sea surface roughness increases
- More energy is backscattered toward sensor
Active sensors – basic principle

The backscatter is also sensitive to the pulse direction relative to the wind direction.

For any wind speed, the backscatter returned to the sensor is

- maximal with the pulse pointed upwind
- minimal with the pulse pointed crosswind

**Problem**

A suite of speeds and directions could explain a single measurement
Active sensors – basic principle

Scatterometry uses surface roughness and pulse angle to get wind direction and speed.

Solution

- Measure backscatter at several pulse directions
- Then solve for the wind speed and direction that best fits all of the measurements
Ocean Surface Winds - sensors

Satellite observations
Active instruments (green) and passive instruments (red)

http://www.remss.com/measurements/ccmp/
Ocean Surface Winds - CCMP

- The Cross-Calibrated Multi-Platform (CCMP) gridded surface vector winds are produced using satellite, moored buoy, and model wind data, and as such, are considered to be a Level-4 ocean vector wind analysis product.

- The V2 CCMP processing now combines Version-7 RSS radiometer wind speeds, QuikSCAT and ASCAT scatterometer wind vectors, moored buoy wind data, and ERA-Interim model wind fields using a Variational Analysis Method (VAM) to produce four maps daily of 0.25 degree gridded vector winds.

- Data is provided every 6 hours, and as monthly composites.

- Spatial resolution is 0.25º

- From 1987 – 2017. (data is not provided in NRT).

- Available on OW ERDDAP.

http://www.remss.com/measurements/ccmp/
Wind stress & Wind stress curl

- **Wind stress** is the shear stress exerted by the wind on the surface of the ocean.

- It is the force component parallel to the surface, per unit area, as applied by the wind on the water surface.

- **Wind stress curl** is a measure of the rotation of wind: \( \text{curl} = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \)

- In the northern hemisphere, positive curl is associated with upwelling of water, negative curl with downwelling.

- Wind stress and wind stress curl are available for QuikSCAT and ASCAT data.
Sea Surface Salinity  
SMOS, 2010

grams per kilo

http://www.salinityremotesensing.ifremer.fr/

NOAA FISHERIES
Sea Surface Salinity

- The ocean is roughly 3.5% salt and the concentration of dissolved salts in the ocean is referred to as salinity, which varies across the globe and over time.

- Salinity plays an important role in how the Earth system functions and is critical to many aspects of the ocean, from circulation to climate to the global water cycle.

- The concentration of salt on the ocean surface — the part of the ocean that actively exchanges water and heat with Earth's atmosphere — is a critical driver of ocean processes and climate variability.

- Because ocean surface salinity varies from place to place and over time, it is used to trace the ocean's role in Earth's water cycle. About 86% of global evaporation and 78% of global precipitation occur over the ocean. By measuring changes in ocean surface salinity caused by these processes, as well as changes caused by melting ice and river runoff, satellites provide important information about how the Earth's freshwater moves between the ocean and atmosphere and around the globe.

https://aquarius.oceansciences.org/cgi/ov_salinity.htm
Thermohaline circulation

Together with temperature, salinity controls the density of seawater, determining whether it sinks or floats. Salinity has a major effect on the flow of deep ocean currents that move heat from the tropics to the poles and affect global climate.
Basic principle

- The relationship between conductivity and salinity allows for remote sensing of salinity from space. As the conductivity of ocean surface waters changes (with salinity) there are minute detectable changes in the “brightness” of the surface in microwave emissions which are detectable by microwave radiometer.

- For accurate measurements, it’s necessary to make adjustments for the sea surface temperature and roughness, the intervening atmosphere and ionosphere, and galactic signals reflected off the sea surface.
Basic principle

• Steps for salinity retrieval:
  a) evaluation of brightness temperature (i.e. apparent temperature) at the sea surface by correcting for ionosphere, atmosphere and extra-terrestrial radiations
  b) correction of roughness and sea surface temperature contributions
  c) retrieval of salinity from brightness temperature

• Microwave radiometers measure salinity within 1-2 cm of the surface

• Spatial resolution: between 0.25° and 1°, depending on the sensor.

• Not close to the coasts.

• Global coverage: in 3 to 10 days.
Salinity Missions

- **Aquarius** on SAC-D (NASA): 2011 – 2015, 1°x1°
  v.5:
  [https://coastwatch.pfeg.noaa.gov/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=Aquarius+%22Version+5%22](https://coastwatch.pfeg.noaa.gov/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=Aquarius+%22Version+5%22)

- **MIRAS** on **SMOS** (Europe): 2010 – present, 1°x1°
  Soon to be on ERDDAP.

- **SMAP**-Radiometer on SMAP (NASA): 2015 – present, 0.25°x0.25°
  [https://coastwatch.pfeg.noaa.gov/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=SMAP](https://coastwatch.pfeg.noaa.gov/erddap/search/index.html?page=1&itemsPerPage=1000&searchFor=SMAP)