Oceanography from Space

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With invaluable help (and lots of material) from Prof. Ian S. Robinson, Univ. Southampton whose “Measuring the Oceans from Space” (2004) by Springer-Praxis is an excellent reference textbook.
A slightly expanded title....

Oceanography

Study of a component of the Earth System which is vital to mankind and crucial for climate...

from space

...from a very privileged viewpoint!!
Why study the ocean?

- **LOCAL** drivers: fisheries, shipping, transportation, coastal erosion, leisure…
- **GLOBAL** drivers: climate and climate change
Climate change – global warming

Global mean temperature

Period | Rate
--- | ---
50 | 0.128±0.026
100 | 0.074±0.018

Source: IPCC AR4 / P. Lemke
The Greenhouse effect

1. Solar radiation passes through the clear atmosphere. 
   Outgoing solar radiation: 103 Watt per m²
   Incoming solar radiation: 343 Watt per m²

2. Net incoming solar radiation: 240 Watt per m²

3. Some solar radiation is reflected by the atmosphere and earth’s surface.
   Outgoing solar radiation: 103 Watt per m²

4. Solar energy is absorbed by the earth’s surface and warms it... 
   168 Watt per m²
   ... and is converted into heat causing the emission of longwave (infrared) radiation back to the atmosphere

5. Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules. The direct effect is the warming of the earth’s surface and the troposphere.

6. Some of the infrared radiation passes through the atmosphere and is lost in space.
   Net outgoing infrared radiation: 240 Watt per m²

Surface gains more heat and infrared radiation is emitted again.
10000 years of CO$_2$ concentration

today

Equivalent radiative forcing in watt/m$^2$

+1.6 W/m$^2$

Source: IPCC AR4
10000 years of methane concentration

Equivalence of radiative forcing in watt/m²

Source: IPCC AR4
$\text{CO}_2 + \text{methane} \rightarrow \sim 2 \text{ W/m}^2 \text{ in excess}$

Average over entire globe and all seasons, i.e.

*How much is it, in practice?*
1 Electric heater = 1500 Watt
1 football pitch = 7500 sq. meters = 15000 Watt
Climate change – the projections

Source: IPCC AR4
Some of the key questions

• Climate change is here upon us, mainly as an effect of GHG emissions resulting in excess radiative forcing
• … but the oceans are the main heat storage on Earth…
  – Top 3 m contain same heat as whole atmosphere…
  …and oceans’ mean depth > 3000m
• How do they affect climate change (mitigate? Make worse?)
• How are they changing as an effect? Can we predict the future trends?
• How do these changes impact on marine life?
• How do these changes impact on society?

We need a global, privileged viewpoint to provide the observations needed to answer these global questions
Ocean remote sensing: a privileged view

• Spatially detailed
  – Spatial resolution from meters to kms
  – A synoptic picture that is 100 km - 10 000 km wide

• Regularly repeated
  – Revisit intervals between 30 min. and 35 days
  – Continuously repeated over years to decades

• Global coverage
  – Satellites see the parts where ships rarely go
  – Single-sensor consistency - no inter-calibration uncertainties

• Measures parameters that cannot be observed in situ
  – Surface roughness at short length scales (2-50 cm)
  – Surface slope (a few cm over 100s of kilometres)
Spatially detailed overview of mesoscale ocean processes

North Atlantic Sea Surface temperature showing the Gulf Stream meandering
A spatially detailed view of ocean colour

An image of Florida and Cuba captured by the MERIS sensor on ESA Envisat

The light green areas are shallow reef areas
A spatially detailed view of turbidity in coastal seas

2 February 2007
This Envisat image shows Bohai Bay in the People's Republic of China.

False colour composite from full resolution MERIS data (Pixel size 300m)
ESA image
Ocean remote sensing: a privileged view

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Regularly repeated views of the Agulhas retroflection

SST from the AMSR-E Microwave radiometer plotted at 6-day intervals

This is a “choke-point” for the surface flow of warm water from the Indian to the Atlantic ocean.
Kuroshio current from Altimetry: a movie

1 full map every 7 days, from a combination of all available satellite altimeters

Movie by Doug McNeall, NOC (now UK MetOffice)
A quantum leap in sampling!

10 years
WOCE Hydrographic Survey Lines

10 years
Observations from Volunteer Observing Ships

10 days
TOPEX/POSEIDON 10-Day Repeat Ground Track

1 day
QuikSCAT Coverage in 24 Hours (1 February 2000)
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Global measurements for global science

The distribution of ocean chlorophyll measured from MODIS

August, 2008
Global sea surface temperature

Ensemble of SST analyses derived from satellite data from several sensors, for 14 Sept 2013

SST anomaly compared to Climatology

Anomalies for 14 Sept 2013
North Pacific winds from Quikscat

Source: http://www.ssmi.com/qscat/qscat_browse.html
Scatterometers are fully operational
Salinity from Space

- L-band (1.4GHz) has a small dependence on salinity
- Much stronger dependence on surface temperature
- Strongly influenced by surface roughness
- Also impacted by surface foam, external noise...

L-band TB against SST and SSS (Swift, 1980)

0.7 K/psu at 30° C
cf 0.2 K/psu at 0° C
Salinity from Space

- **Soil Moisture and Ocean Salinity (SMOS)**
  - synthetic aperture (interferometric radiometer)
  - 35km resolution
  - 3 day repeat

- **Aquarius**
  - Passive radiometer
  - 100km resolution
  - 7 day global coverage
Salinity from Space: Aquarius

Aug. 25 – Sept. 11, 2011

NASA/GSFC/JPL-Caltech

3rd ESA ADVANCED TRAINING ON OCEAN REMOTE SENSING
23–27 September 2013 | NMCI | Cork, Ireland
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Texture over land shows fields etc.

Rough sea shows bright and smooth shows dark, revealing slicks, waves, and other dynamical features.

This SAR image over the Isle of Wight is from ESA’s ERS-1 satellite.
A possible oil seepage slick observed in ERS SAR imagery.

Mediterranean ERS SAR image shows signatures of (a) katabatic winds, (b) convective atmospheric cells, (c) low winds, (d) ocean eddies and (e) internal waves.
Envisat ASAR monitors the GoM spill
SAR currents

13 September, 2007

View direction (range)

Flight direction (Azimuth)

16 September, 2007

$U_D$, Doppler surface radial velocity, m/s (Positive towards satellite)
Satellite Altimetry

• one of the most successful EO techniques
  • synoptic, sustained view of surface ocean dynamics (currents, eddies, planetary waves)
  • accurate, long-term global and regional sea level monitoring
Computed from Envisat cycle 50 SSHA + Rio05 Mean Dynamic Topography

Geostrophic currents (m/s), Envisat cycle 50 + Rio05
Chelton et al., 2011, have identified **35891 eddies** (with lifetimes $\geq 16$ wks) in 16 years of two-mission altimeter data

- **averages:**
  - lifetime 32 weeks
  - propagation distance 550 km
  - amplitude 8 cm
  - radius 90 km

D. Chelton et al., 2011
Great synergy possible in all studies of bio-phys interactions when altimetry is combined with SST, ocean colour.
SEA LEVEL RISE - global

Overall trend: 2.7 mm/yr
No GIA correction (add 0.3 mm/yr)
Seasonal tides removed

Remko Scharroo, NOAA/Altimetrics LLC
(now at EUMETSAT)
Sea Level component on dedicated ESA programme, the “Climate Change Initiative”

Regional MSL trends from Oct–1992 to Mar–2010 (mm/year)
Satellites trace sea level change

Scientists have reviewed almost two decades of satellite data to build a new map showing the trend in sea levels. Globally, the oceans are rising, but there have been major regional differences over the period.

Annual average sea-level rise, 1993-2010
Coastal Altimetry

Standard altimetry does not quite go all the way to the coast!
Traditionally, data in the coastal zone are flagged as bad and left unused (coastal zone: as a rule of thumb 0-50 km from coastline, but in practice, any place where standard altimetry gets into trouble as radar waveforms are non-standard and/or corrections become inaccurate)

20+ years of data in the coastal strip can be recovered!

In recent years a vibrant community of researchers has started to believe that most of those coastal data can be recovered and that coastal altimetry can be a legitimate component of coastal observing systems!
Based on TOPEX altimeter. High-pass filtered to emphasise the sea floor topography influence.
Geoid from GOCE
Global Currents from GOCE and altimetry

Global ocean currents
Centimetres per second

Source: Bingham et al
Wave Climate from Space

Wave height (metres), January

Wave height (metres), July

NOC Southampton
GNSS (GPS/Galileo) Reflectometry

HOW GNSS-R WORKS
Sea Ice cover and extension

**Envisat ASAR image** A large iceberg, C-16, rammed into the well-known Drygalski Ice Tongue, a large sheet of glacial ice and snow in the Central Ross Sea in Antarctica, on 30 March 2006, breaking off the tongue’s easternmost tip and forming a new iceberg. (Image is ~200 km square)

Sea-ice concentration based on microwave radiometry (from NSIDC)

Source http://earth.esa.int/earthimages/
Arctic sea ice is shrinking from various sensors (now AMSR2)

![Arctic Sea Ice Extent (Ver.2) chart](chart.png)
Propagating features:
Eddies and planetary waves

25 South

34 South
FACT: We see planetary waves and eddies in chlorophyll data.


QUESTION: What causes the observed signature in the chlorophyll field?
Synergy between different data types

In 2007 Satellites showed that the sea ice retreated in summer far further than ever before - almost to the N. Pole.

Interesting link with satellite data records of the temperature north of Bering Strait.

The temperatures were up to 8 K warmer than climatology.
SSS and altimeter currents

Ifremer: N Reul and J Tenerelli
SSS and altimeter currents
The Observing and Forecasting System

Remote Sensing

In situ:
- research ships,
- VOS,
- Drifters, buoys, tide gauges, ARGO floats

Models
- (Circulation and Climate)
- Forecasting
Synergy with Argo

- Descent to cruising depth:
  - Approx. 10 cm/s (~6 hours)

- Cruising depth:
  - 1500 db (1500m)
  - Drift approx. 9 days

- Total cycle time: 10 days

- Salinity & Temperature profile recorded during ascent:
  - Approx. 10 cm/s (~6 hours)
• SP-1304 Science Strategy for ESA’s Living Planet Programme, issued in 2006 after broad user consultation

The Challenges of the Oceans

Challenge 1: Quantify the interaction between variability in ocean dynamics, thermohaline circulation, sea level, and climate.

Challenge 2: Understand physical and bio-chemical air/sea interaction processes.

Challenge 3: Understand internal waves and the mesoscale in the ocean, its relevance for heat and energy transport and its influence on primary productivity.

Challenge 4: Quantify the temporal, spatial, and biogeochemical impacts of the Earth System

Challenge 5: Understand land-ocean interactions in terms of natural and anthropogenic forcing.

Challenge 6: Provide reliable model- and data-based assessments and predictions of the past, present and future state of the ocean.

Available from [http://esamultimedia.esa.int/docs/SP-1304.pdf](http://esamultimedia.esa.int/docs/SP-1304.pdf)
So many scales in the ocean...!

With remote sensing we measure all these!
In summary…

- **Oceans are crucial** – to man & the climate system
- Remote sensing allows us to measure a range of oceanic parameters in a *synoptic* and *repeated* way like no other technique does; and the remotely-sensed parameters are useful in countless applications from the coastal/local/regional scale to the large/global scale (and to monitor climatic trends)
- The complexity of the techniques for remote sensing of the ocean call for a *new breed of scientists, specially trained to exploit the richness of information* in ocean remotely sensed data and the many *synergies* with in situ data and numerical models, using oceanographic knowledge and signal processing and statistics skills
- **Those scientists are you!**

Comments? Ideas? Get in touch: cipo@noc.ac.uk