Remote Sensing Basics

Adapted from:
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• Bruce Monger: Cornell University

Last updated: 11/15/2018
Objectives

Establish baseline vocabulary/concepts:
- Satellite vs sensor
- Active vs passive sensor
- Electromagnetic radiation
- Geophysical variable/product
- Atmospheric windows
- Atmospheric correction
- Polar vs geostationary orbit
- Spatial, temporal resolution, swath width
- Wavelength band/channel
- Data levels
- Temporal composites vs cloud cover
- Near-Real Time vs. Science Quality
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Advantages of satellite remote sensing

- Provides information where surface-based measurements are not available and augments existing measurements
- Provides global/near-global coverage with consistent observations
Satellite vs Sensor

- **Satellite**: a space-borne platform holding one or more sensors (instruments) making measurements.

- Some satellites are single-mission, carrying only one sensor: e.g. the SeaWiFS sensor on the GeoEye/OrbImage satellite.

- Other satellites have multiple sensors on them: e.g. MODIS is one of 6 sensors on the Aqua satellite. There is also a MODIS sensor on the Terra satellite.
Satellite vs Sensor

The NASA AQUA satellite

The MODIS instrument/sensor on the NASA AQUA satellite
Satellite vs Sensor: NOAA GOES-R satellite
Sensors can NOT directly measure populations of most fish, whales, turtles, monk seals, etc.

What is measured by the sensors?
What is measured by the sensors?

Satellite data can provide information about oceanic parameters that influence marine resources:
- SST
- Currents
- Wind
- Ocean color
- Salinity
What is measured by the sensors?

- Satellite sensors measure **electromagnetic radiation (EMR)** that is emitted or reflected by the ocean (and land).

- Sensors target specific sets of wavelengths depending on their application.

- After (many) corrections and calibrations, algorithms are used to calculate **geophysical products** (SST, chl a concentration, wind speed, …)
What is measured by the sensors?

From Robinson, Discovering the Ocean from Space
What is measured by the sensors?

Visible and IR (Infrared) radiation is typically measured in wavelengths. Microwaves are measured in frequency. Microwave frequencies are often described by letters, the C-band, the X-band etc.
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What is measured by the sensors?

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Wavelength:
- 0.1 μm
- 1 μm
- 10 μm
- 0.1 mm
- 1 mm
- 1 cm
- 10 cm
- 1 m
- 10 m
- 100 m
Sensor types (active vs passive)

- **Passive sensors** measure electromagnetic radiation that has a natural origin:
  - Solar radiation reflected or scattered from the Earth’s surface
  - Thermal radiation emitted from the Earth’s surface

- **Active sensors** measure electromagnetic radiation generated by the satellite that is:
  - sent down to the Earth’s surface and
  - reflected or scattered back to the satellite
Sensor types (active vs passive)

- **Passive Remote Sensing**: Reception of emitted, reflected or scattered EMR at the satellite sensor, after it travels from the ocean through the atmosphere: used with UV, visible, IR and microwave wavelengths/frequencies.

- **Active Remote Sensing**: Reception of the reflection of a transmitted pulse of EMR, after interacting with the surface of the ocean and travelling through the atmosphere (twice). Examples include: altimeters, scatterometers, lidars, radars.
Electromagnetic radiation (EMR)

- Most solar energy comes to the earth as short wavelength electromagnetic radiation (UV, visible light) and is re-radiated (emitted) back to space as long wavelength electromagnetic radiation (infrared, microwaves)
Electromagnetic radiation (EMR)
The influence of the atmosphere

- All radiation is influenced by the atmosphere in various ways: The sun's radiation is scattered, reflected or absorbed by particles in the atmosphere as is the radiation reflected by the Earth's surface.

- Satellites look at the earth surface through the atmosphere.

- The influence of the atmosphere depends on the wavelength of EMR. The atmosphere is opaque to electromagnetic radiation at many wavelengths, due to absorption by atmospheric gases. There are only certain wavelengths through which radiation may be fully or partly transmitted.

- Remote sensing focuses on those transmissive ranges, the so-called atmospheric windows.
The influence of the atmosphere

Source: NASA
The influence of the atmosphere

Source: NASA
The influence of the atmosphere

Where satellites can “see”:

[Graph showing atmospheric transmittance and EMR intensity bands]
The influence of the atmosphere

Where satellites can “see”:
## Atmospheric windows

The atmospheric windows are categorized into UltraViolet, Visible, Infrared, Microwave, Radio, VHF, and HF bands, each with specific wavelengths ranging from 0.1 μm to 100 m.

### Wavelengths

- **0.1 μm**
- **1 μm**
- **10 μm**
- **0.1 mm**
- **1 mm**
- **1 cm**
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- **1 m**
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### Sensor and Application

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Atmospheric windows

In the visible, where the sun emits at the highest intensity, the atmospheric transmittance is high.
Atmospheric windows

At higher wavelengths, transmittance is reduced to narrow bands. This includes the optical windows in the thermal infrared, where the Earth's surface emits radiation.
Atmospheric windows

In the microwaves, the atmosphere is nearly transmissive, but the sun and earth's radiation are weak (need large antennas to collect enough radiation)
Atmospheric windows

Wavelengths shorter than the ultraviolet are nearly totally absorbed by the atmosphere and are therefore less relevant for remote sensing.
Atmospheric Pathways

Ray 1 - the useful signal
Ray 2 - the radiation leaving the sea that is absorbed by the atmosphere
Ray 3 - the radiation that is scattered by the atmosphere out of the sensor field of view
Ray 4 - the energy emitted by the constituents of the atmosphere
Ray 5 - the energy reflected by scattering into the field of vision of the sensor
Ray 6 - the energy that left the sea surface but from outside the field of view.

-> Even at “window” wavelengths, atmospheric correction of the satellite data is necessary to derive accurate satellite data products.

Atmospheric pathways of EMR between the ocean and the satellite.
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Atmospheric pathways of EMR between the ocean and the satellite.
Atmospheric Correction

The ocean area **within** the sensor’s field of view emits rays $1+2+3$

Rays 4, 5, and 6 reach the sensor from outside of the sea surface in the field of view, and therefore constitute extraneous "noise" on top of the signal.

The sensor receives rays $1+4+5+6$

The complete atmospheric correction should result in the sum of rays $1+2+3$. 

Atmospheric pathways of EMR between the ocean and the satellite.
What is measured by the sensors?

- Satellite sensors measure the intensity of EMR at specific wavelengths using a telescope to focus the EMR onto a series of light detectors (radiometers).
- The configuration of the light detectors and telescope varies between sensor types, but in the end, all sensors produce a set of equally spaced boxes/pixels (i.e., a 2-D array of measured values) where each individual box/pixel contains the value of the intensity of EMR (Watts m\(^{-2}\)) for a specific wavelength from each location on earth covered by the satellite.
What is measured by the sensors?

- The resulting 2-D array can be displayed as an image or it can be analyzed as a 2-D array of numbers.

- The size of the rectangular region on earth over which the instrument averages the EMR onto a single light detector is referred to as the instrument resolution. For example, 1-km resolution sensor averages EMR intensity over a 1-km by 1-km region on the earth (at nadir, i.e. when the satellite is directly at the vertical).

EMR intensity at a specific wavelength, over a region.
What is measured by the sensors?

- Multispectral radiometers measure EMR intensity at a few discrete wavelength regions. Each wavelength region is defined by a central wavelength and a small range of wavelengths around it (a bandwidth).

- The intensity of EMR at each wavelength region is stored separately in a stack of digital images. Each separate image is called a wavelength band or a wavelength channel.

- Each band or channel can be referred to by its central wavelength value or by sequential numbering (1, 2, 3, ...) of each band from shortest to longest wavelength.
Higher order products

Example of Using Band Combinations to Make Higher Order Products
In this case making a true color image from the addition of separate R, G and B bands.

Intensity of the 8 Visible and Near-Infrared Bands from the SeaWiFS Sensor for the East Coast of the United States:
Higher order products

True-Color Image
Created from bands 2, 5, and 6 corresponding to wavelengths 443, 555 and 670 nm (±10 nm)

Final Color Image = $C_1 \cdot \text{band}2 + C_2 \cdot \text{band}5 + C_3 \cdot \text{band}6$
Types of Applications

PATHS OF SENSORS

Sensor class
- Visible waveband sensors
  - Multispectral scanners
  - Imaging spectrometers

Sensor type
- Infrared sensors
- Microwave sensors
- Scanning microwave radiometers

Primary observable quantity
- Ocean colour
- Sea surface temperature
- Salinity
- Surface roughness
- Surface slope

Derived variables
- Chlorophyll
- Suspended particulates
- Bathymetry
- Mixed-layer temperature
- Skin temperature
- Surface winds
- Wave height
- Wave spectra
- Internal waves
- Surface slicks
- Geostrophic currents
- Ocean geoid
- Sea floor bathymetry

From Robinson, Discovering the Ocean from Space
Resolution

- **Spatial resolution** is defined as the pixel size of an image representing the size of the surface area being measured on the ground and is determined by the sensors' instantaneous field of view (IFOV).

- **Temporal resolution** is defined by the amount of time that passes between imagery collection periods.

- **Swath width** of the satellite refers to the width of the area observed by the satellite. Satellites with larger swath widths will take less time to acquire global spatial coverage.
Satellite orbits

The two major types of satellite orbits are:

- **Polar orbiting**: a single polar orbiting satellite can view the entire earth once a day

- **Geostationary**: a single geostationary satellite can view a limited region of the earth, but can do so continuously throughout the day
Polar Orbiting

- Altitude: 700 - 800 km
- ~ 14 orbits a day
- Depending on the width of the swath, will cover almost the whole Earth in a day
- Global coverage
- High spatial resolution (< 1 km)
- Low temporal resolution (≥ 1 day)

Credit: EUMETSAT
Geostationary orbit

- Altitude: 35,800km
- Always sees same part of the Earth (no global coverage)
- Lower spatial resolution (2-4 km)
- High temporal resolution (every minute!)
- Poor coverage of the poles

Credit: Omega Open Course
Geostationary orbit – GOES-East

Credit: http://rammb-slider.cira.colostate.edu/
Geostationary orbit: e.g. weather satellites

GOES-West (US), GOES-East (US), MeteoSat x2 (Europe), Himawari (Japan)
-> 5 satellites for global coverage
A note on satellite names …

• NOAA assigns a letter to the satellite before it is launched and a number once it has achieved orbit.

• For the geostationary constellation, before being launched, GOES satellites are designated by letters (A, B, C, etc.).
  • Once a GOES satellite is launched successfully, it is redesignated with a number (1, 2, 3, etc.).
  • GOES-R, the first in NOAA's GOES-R series of satellites, was designated GOES-16 when it reached geostationary orbit. GOES-S became GOES-17.

• Same for the polar-orbiting constellation:
  • ITOS-A became NOAA-1.
  • JPSS-1 was designated NOAA-20 when it reached its orbit.
A note on satellite names ...

Whyyyyy??
A note on satellite names ...

- GOES-A to GOES-F became GOES-1 to GOES-6.

- Because GOES-G was a launch failure, it never received a number. GOES-H to GOES-R became GOES-7 to GOES-16 (skipping GOES-Q, which was not built).

- The switch from pre-launch to on-orbit names allows to keep the name series intact for the on-orbit constellations.
Levels of Data

- **Level 0**: Raw data received from satellite, in standard binary form
- **Level 1**: Unprocessed data in sensor’s geographic coordinates, containing calibration information
- **Level 2**: Derived geophysical variables atmospherically corrected and geolocated, but presented in sensor’s geographic coordinates (granules). Also sometimes referred to as “along-track” data.

Most useful for PIFSC research:

- **Level 3**: Derived geophysical variables mapped on uniform space-time grid scales. Spatial and temporal composites.
- **Level 4**: Model output or results from analyses of lower-level data (e.g., variables derived from multiple measurements, like primary productivity), or interpolation to provide cloud-free product
Levels of Data

From Robinson, Discovering the Ocean from Space
Levels of Data: L0 -> L3 examples

<table>
<thead>
<tr>
<th>Level 0 parameter</th>
<th>→ Level 1 parameter</th>
<th>→ Level 2/3 (geophysical variable)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness temperature for two or three infrared wavelengths</td>
<td>Calibration, inversion of Plank's law, cloud masking, atmospheric correction (split-window algorithm)</td>
<td>SST (°C)</td>
</tr>
<tr>
<td>Normalized water-leaving radiances at six wavelengths</td>
<td>Calibration, band combination, cloud masking</td>
<td>Chl a (mg m⁻³)</td>
</tr>
<tr>
<td>Surface backscatter coefficient (σ)</td>
<td>Cox and Munk (1954) model (σ = aWb)</td>
<td>Windspeed and direction (if multidirectional measures)</td>
</tr>
<tr>
<td>SSH</td>
<td>Pseudogeoid (average signal) subtraction</td>
<td>SLA</td>
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Chassot et al. 2011
Level-2 vs. Level-3 data

The sensor views the earth in a swath of individual scan lines as the satellite is moving.

L2: Swath
- View is “distorted”, pixels geolocated along scan line

L3: Earth-Projected
- Pixels resampled to regular grid (lat/lon)
Levels of Data – Additional types of Level 3

• **Level 3C**: Level 3 Collated: Data from different time periods from the same sensor are collated together to create a more complete image. For example, GOES-16 collects data every 15 mins, a daily L3C product would collate all data from one day. This helps with cloud cover.

• **Level 3S**: Level 3 Super-collated: Data from various sensors are collated together. For example, data from geostationary and polar-orbiting sensors to take advantage of the strengths of both (higher resolution vs less impact from clouds).
Level-3 data – Temporal composites

GOES West Imager – SST – 1 hour, 09/15/2018
Level-3 data – Temporal composites

GOES West Imager – SST – 1 day, 09/15/2018
Level-3 data – Temporal composites

GOES West Imager – SST – 1 week, 09/12/2018 – 09/18/2018
Level-3 data – Temporal composites

GOES West Imager – SST – 1 month, 09/01/2018 - 09/30/2018
GOES footprint
Level-3 vs. Level-4 data: Puerto Rico SST

L3 Terra-MODIS 2:55
L3 N-20-VIIRS 05:20
L3 SNPP-VIIRS 06:10
L4 MUR
L4 Geo-Polar blended
L3C G-16-ABI

Slide from Irina Gladkova
Levels of Data: \( L_3 \rightarrow L_4 \)

<table>
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<tr>
<th>Input geophysical variables</th>
<th>Processing scheme</th>
<th>→ Level 4 metavariable</th>
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<td>Convolution (e.g. Sobel operator)</td>
<td>Local SST gradient (°C km(^{-1}))</td>
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<td>SST</td>
<td>Determination of limits between water masses</td>
<td>Frontal positions</td>
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<tr>
<td>Chl α, photosynthetically available radiation (PAR), photosynthetic efficiency curve</td>
<td>Equation of water attenuation and photosynthetic efficiency relationship</td>
<td>Primary production (mg C m(^{-2}) d(^{-1}))</td>
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<td>SLA</td>
<td>Application of baroclinic instability</td>
<td>Geostrophic currents</td>
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Chassot et al. 2011
NRT vs Science Quality

• For some purposes, data is needed in near-real time (NRT), i.e. as quickly after being measured as possible. For many datasets, it is possible to obtain yesterday’s data (or from a few hours ago).

• However, the processing of NRT data is a little on the “quick & dirty” side, to ensure fast through-put. To look at trends over time, or for data used in publications, Science Quality data, which has been processed more carefully for more accuracy, might be more adequate.

• Different agencies have different definitions of NRT vs. Science Quality (or Climate Quality) data.
  • Some science quality data are available several days after NRT, others perhaps only when the entire mission data is reprocessed.
US Satellite Agencies

NASA
National Aeronautic and Space Agency
Responsible for satellite research and development

NOAA
National Oceanic & Atmospheric Administration
Responsible for operational satellites (routine uses, such as weather forecasting)

DOD
Department of Defense
Responsible for military satellites
When a satellite application (developed by NASA) is mature, NOAA takes over the operational acquisition. E.g. SST, SSH, ocean color and surface winds.

To secure continued support for data streams, NOAA needs to demonstrate the **operational use of the data** within the agency.