Satellite Oceanography and Applications 1: Introduction, SST, Ocean color

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Objectives/Goals

✓ To know the basic **methods** of ocean remote sensing (ORS)
✓ To explain the generic **mechanisms** of ORS
✓ To appreciate the **limitations** of ORS
✓ To understand the **processes** which enable ocean parameters to be derived from satellite image data.
✓ To display, enhance and **interpret** image data
✓ To identify and describe **oceanographic observations** which are best made by remote sensing methods.
✓ To appreciate the **synergy** from combining remote sensing and conventional **in situ** observations.
A remote sensing instrument collects information about an object or phenomenon within the instantaneous-field-of-view (IFOV) of the sensor system without being in direct physical contact with it.

The sensor is located on a suborbital or satellite platform.
Remote Sensing: Primary components

- A. Energy Source
- B. Radiation and Atmosphere
- C. Interaction with target
- D. Energy recorded by sensor
- E. Transmission, reception, processing
- F. Interpretation and analysis
- G. Application of information
Satellites and Sensors: A brief history
Remote Sensing: A brief history

Hot-air Balloons
Invented by the Montgolfier Brothers in 1783

1858 Gaspard Felix Tournachon (Nadar) takes first aerial photograph near Paris, using a captive balloon and a collodion plate. Unfortunately, this first aerial photograph did not survive.
In 1903, Julius Neubronner patented a breast-mounted camera for carrier pigeons that weighed only 70 grams.

A squadron of pigeons is equipped with light-weight 70-mm aerial cameras.
Satellites and Sensors: A brief history

1957 – Soviet Union launches first satellite Sputnik

1978 – NASA launches three ocean-observing satellites:

- **TIROS-N** (Television and InfraRed Operational Satellites) on NOAA 6-7 Satellite with AVHRR (Advanced very high Resolution Radiometer) radiometer measuring SST

- **Seasat** Satellite with radar-altimeter measuring sea surface height; microwave scatterometer and synthetic aperture radar (SAR), both measuring ocean roughness;

- **Nimbus-7** Satellite with ocean color sensor - Coastal Zone Color Scanner (CZCS).
Importance of satellite oceanography

- Observes the distribution of certain ocean surface properties in exquisite spatial detail: allows the true spatial structure to be examine

- Captures a “snapshot” of the spatial distribution. “Freezes” the continually changing ocean

- Offers a repeated view: consistent measurements by a single sensor

- Observes part of the ocean other methods miss
  - Shipping routes are concentrated in certain zones
  - Ships tend to avoid poor weather hazardous regions
  - Drifting buoys tend to avoid regions of divergent currents
Limitations of satellite oceanography

- Can observe only some of the ocean's properties and variables
- Measures the ocean only at or near the surface
  -- Although the surface is the most critical place to measure
- Ocean measurements may be corrupted by the atmosphere
- Some satellites/methods cannot see through clouds at all
- Can make measurements only when the satellite is in the right place at the right time
- All measurements require calibration and validation using in situ data
An obvious limitation of remote sensing

**Challenge:** Understand the processes which produce a surface signature for subsurface phenomena

- Remote sensors observe the sea SURFACE
- We often want to observe processes INSIDE the sea
- Subsurface processes can only be detected if they have a *surface signature*
A summary of sensor types & what they measure

**PASSIVE SENSORS**

- **Sensor Class**
  - Visible Waveband sensors
  - Multi-spectral scanners
  - Imaging spectrometers
- **Sensor Type**
  - Infra-red sensors
  - Infra-red imaging radiometers
  - Scanning microwave radiometers

**ACTIVE**

- Radar instruments
- Scatterometer

**Primary measure**

- Ocean colour
- Sea surface temperature
- Surface roughness
- Surface slope

**Derived parameters**

- Chlorophyll Suspended particles
- Bathymetry
- Mixed-layer temperature Skin temperature
- Surface winds Wave height
- Wave spectra
- Internal waves surface slicks
- Geostrophic currents
- Ocean geoid
- Sea-floor bathymetry
Basic physics and principles
Geostationary orbit (Geosynchronous)
These satellites are used for weather obs. The satellite orbits in the same direction as the Earth with a period of one day. The disadvantage of this type of orbit is that since these satellites are very far away, they have poor resolution. Also, have trouble monitoring activities near the poles.

Polar orbit (Sun-Synchronous)
These satellites are good for Chl, SST. Scans from north to south over one face, and Reverse in other face. A period of 1-2 hours.

Nearly polar sun-synchronous orbit
These satellites are used for TRMM. Near Equatorial low inclination orbit. This orbit covers half of the globe.
Sources of energy for remote sensing

- **The Sun**
  - Visible waveband
  - Near Infra red waveband

- **Thermal emission by the ocean surface**
  - Thermal infra red
  - Microwaves

- **Energy source on the satellite**
  - Microwaves (Radar)
  - Visible (Lidar)
Energy-matter interactions in the atmosphere, at the study area, and at the remote sensor detector

**Electromagnetic Energy Interactions**

Energy recorded by remote sensing systems undergoes fundamental interactions:

Eg., if the energy being remotely sensed comes from the Sun, the energy:

- is radiated by atomic particles at the source (the Sun),
- propagates through the vacuum of space at the speed of light,
- interacts with the Earth’s atmosphere,
- interacts with the Earth’s surface,
- interacts with the Earth’s atmosphere once again, and
- finally reaches the remote sensor where it interacts with various optical systems, filters, or detectors.
Energy may be transferred 3 ways: *conduction*, *convection*, and *radiation*:

(a) **conduction**: one body (molecule or atom) transfers its kinetic energy to another by colliding with it (direct contact).

(b) **convection**: the KE of a body is transferred from one place to another by physically moving the bodies. E.g. the convectional heating of air in the atmosphere in the early afternoon

(c) Electromagnetic energy in the form of *electromagnetic waves* (*radiation*) transmitted through the vacuum of space from the Sun to the Earth.
Electromagnetic Spectrum

The Sun produces a continuous spectrum of energy from gamma rays to radio waves that continually bathe the Earth in energy.

The visible portion of the spectrum may be measured using wavelength (micrometers or nanometers) or electron volts (eV).

All units are interchangeable.
Electromagnetic Spectrum

1. IR device
2. Bare eyes
3. X-ray
4. Microscope

A man detected by different instruments
Once electromagnetic radiation is generated, it is propagated through the earth's atmosphere almost at the speed of light in a vacuum.

- Unlike a vacuum in which nothing happens, however, the atmosphere may affect not only the speed of radiation but also its wavelength, intensity, spectral distribution, and/or direction.

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**Scattering**

**Atmospheric Scattering**

**Rayleigh Scattering**
- Gas molecule

**Mie Scattering**
- Smoke, dust

**Nonselective Scattering**
- Water vapor
Absorption

• *Absorption* is the process by which radiant energy is absorbed and converted into other forms of energy.

• An *absorption band* is a range of wavelengths (or frequencies) in the electromagnetic spectrum within which radiant energy is absorbed by substances such as water (H₂O), carbon dioxide (CO₂), oxygen (O₂), ozone (O₃), and nitrous oxide (N₂O).

• The cumulative effect of the absorption by the various constituents can cause the atmosphere to *close down* in certain regions of the spectrum. This is bad for remote sensing because no energy is available to be sensed.

~ 40% of sunlight is reflected by clouds
~ 20% of sunlight is absorbed by the atmosphere
~ 40% of sunlight is absorbed by the Earth’s surface
Reflectance: radiation “bounces off” an object like a cloud or the terrain.

- Reflection exhibits fundamental characteristics that are important in remote sensing:
  
  (a) First, the incident radiation, the reflected radiation, and a vertical to the surface from which the angles of incidence and reflection are measured all lie in the same plane.

  (b) Second, the angle of incidence and the angle of reflection are equal.
Remote Sensor Resolution Considerations

- **Spatial** - the size of the field-of-view, e.g. 10 × 10 m.

- **Spectral** - the number and size of spectral regions (or frequencies) the sensor records data in, e.g. blue, green, red, near-infrared, thermal infrared.

- **Temporal** - how often the sensor acquires data, e.g., every 30 days.

- **Radiometric** - sensitivity of detectors to small difference in electromagnetic energy.
Spatial Resolution

Imagery of Harbor Town in Hilton Head, SC, at Various Nominal Spatial Resolutions

a. 0.5 x 0.5 m.  
b. 1 x 1 m.  
c. 2.5 x 2.5 m.  
d. 5 x 5 m.  
e. 10 x 10 m.  
g. 40 x 40 m.  
h. 80 x 80 m.

Variations of IFOV (spatial resolution) with view angle

Nadir IFOV  
Oblique IFOV
Ocean scale

The diagram illustrates the relationship between time scale, spatial scale, and various oceanic phenomena. It shows how different processes and events occur at various scales, from short-term, high-frequency events to long-term, low-frequency phenomena.
Radiometry: Infrared
Thermal infrared energy is emitted from all objects that have a temperature greater than absolute zero. Radiometry is the techniques of measuring electromagnetic radiation.

Humans sense thermal energy primarily through the sense of touch. Our eyes cannot detect differences in thermal infrared energy because they are primarily sensitive to short wavelength visible light from 0.4 µm to 0.7 µm. Our eyes are not sensitive to the reflective infrared (0.7 - 3.0 µm) or thermal infrared energy (3.0 - 14 µm).
Why SST from space?

• From satellite SST we can identify and monitor surface disturbances that cross entire ocean basins, track ocean eddies and map ocean fronts

• It can also reveal striking features such as ‘storms’ in the upper ocean, known as eddies.
  
  – These are typically ~100 km wide and carry large amounts of energy around the globe. They play an important role in ocean circulation and climate.
Why SST from space?

• Space-borne IR sensors estimate SST by measuring heat radiation from the ocean surface.
  – This gives the temperature of the surface ‘skin’, the top mm or so, rather than the bulk of the water.
  – The skin temperature is critical. It controls the exchange of heat and moisture between the ocean and atmosphere.
SST is measured using a radiometer (like “night vision goggle”)
  - Infrared (mainly)
  - microwave

Spectral bands used are near the peak of surface emission — the peak ones aren’t used due to atmospheric effects

It is measured by:
  - taking the intensity of radiation at top of atmosphere
  - removing the atmospheric contribution
  - results in the brightness temperature ($T_B$) at the surface. $T_B$ is approximately equal to the SST
• Popular SST products:
  – NOAA Multi-channel (MC)/Pathfinder SST global. AVHRR sensor has been available since 1978
  – ATSR ASST (Along-Track Scanning Radiometer Average Sea Surface Temperature Products) on ERS-1 & ERS-2
  – TRMM (Tropical Rainfall Measuring Mission) TMI (TRMM Microwave Imager) SST
Cloud detection

• Temperature thresholds

• Visible waveband threshold (daytime only)
  – various things in image - land sea cloud have different spectral characteristics - different intensities in different spectral bands

• spatial coherency testing
• multi-spectral tests
• problems with sub-pixel clouds
### Applications of satellite-measured SST

<table>
<thead>
<tr>
<th>Application</th>
<th>Area covered</th>
<th>Spatial resolution (km)</th>
<th>Time span of data</th>
<th>Sampling Interval</th>
<th>Sensitivity °C</th>
<th>Accuracy K</th>
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<tbody>
<tr>
<td>Climatological database</td>
<td>Global</td>
<td>50</td>
<td>30 years</td>
<td>5-10 days</td>
<td></td>
<td>0.2</td>
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<tr>
<td>Global SST for CO₂ monitoring</td>
<td>Global</td>
<td>200</td>
<td>&gt; 5 years</td>
<td>15 days</td>
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<td>Weather forecasting</td>
<td>Global</td>
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<td>2-5 days</td>
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<tr>
<td>Ocean heat flux</td>
<td>Ocean basin</td>
<td>50</td>
<td>5 years</td>
<td>2 days</td>
<td></td>
<td>0.2</td>
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<tr>
<td>Deep convection</td>
<td>Regional (500-1000km)</td>
<td>5</td>
<td>10-60 days in late winter</td>
<td>1 day</td>
<td>0.1</td>
<td>0.1</td>
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<td>Dynamical processes:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Equatorial long waves</td>
<td>Ocean basin</td>
<td>50</td>
<td>1 year</td>
<td>1-5 days</td>
<td>0.3</td>
<td>1</td>
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<tr>
<td>Mesoscale eddies</td>
<td>Regional</td>
<td>5</td>
<td>1 year</td>
<td>1 day</td>
<td>0.2</td>
<td>1</td>
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<tr>
<td>Fronts</td>
<td>Regional</td>
<td>1</td>
<td>10-100 days</td>
<td>1 day</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td>Upwelling</td>
<td>Regional</td>
<td>1</td>
<td>10-100 days</td>
<td>1 day</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Coastal discharges and pollution</td>
<td>Local (200-500km)</td>
<td>0.3-1</td>
<td>10 days</td>
<td>hours</td>
<td>0.1</td>
<td>1</td>
</tr>
</tbody>
</table>
Visible waveband: Ocean color
What is the color of the ocean?

• The color of the ocean appears BLUE in clear water.

• But it changes due to:
  -- Phytoplankton patchiness
  -- Inorganic/Organic matter
What is the color of the ocean?

- Clean ocean water absorbs red light, i.e., sun radiation of long wavelength and transmits and scatters the light of short wavelength. That is why ocean surface looks blue.

- Phytoplankton cells contain chlorophyll that absorbs other wavelengths and contributes green color to ocean water.

- In coastal areas suspended inorganic matter backscatters sunlight, contributing green, yellow and brown to water color.
Why ocean color from space?

- Locates and enables monitoring of regions of high and low bio-activity. Synoptic Scales of Pigments
- Food–primary production (phytoplankton linked with chl); marine fisheries
- Climate (phytoplankton, possible CO$_2$ sink-carbon budget)
- Seasonal influences; phytoplankton blooms; upwelling
- River and Estuary plumes and influences
- Boundary currents. Reveals current structure & behavior.
- Reveals Anthropogenic influences (pollution); oil spills
- Remote sensing reveals large and small scale structures that are very difficult to observe from the surface.
Major Ocean Color Data Products

✓ Chlorophyll
✓ Suspended Sediments
✓ Yellow Substances
✓ Aerosol
Principles of satellite measurements of ocean color

Visible Spectrum - Wavelengths in nanometers

- Ultraviolet (UV)
  - Violet 400-450nm
  - Blue 450-500nm
  - Green 500-570nm

- Infrared (IR)
  - Red 610-700
  - Orange 590-610
  - Yellow 570-590

Relative transparency to wavelengths:

- Only 45% remains of energy incident on the surface
- Only 16% remains of energy incident on the surface
- Only 1% remains of energy incident on the surface

Distance sunlight travels in the ocean:

- Sunlight (euphotic) zone: Sunlight penetrates beyond this zone.
- Twilight (dysphotic) zone: Sunlight decreases rapidly with depth. Photosynthesis is not possible here.
- Midnight (aphotic) zone: Sunlight does not penetrate at all. This zone is bathed in darkness.

Sea surface
Basic principles of satellite measurements of ocean color
Principles of satellite measurements of ocean color

Ocean color can be measured on the basis of the spectrum of visible light emitted from the study object.

Clean ocean water (A) has maximum in short (blue) wavelength and almost zero in yellow and red.

Higher is phytoplankton (i.e., chlorophyll and other plant pigments) concentration, more is contribution of green color (B).

In coastal zones with high concentration of dead organic and inorganic matter light spectrum has maximum in red (C).
Sources of ocean color change

• Phytoplankton and its pigments

• Dissolved organic material
  -- Colored Dissolved Organic Material (CDOM, or yellow matter, or gelbstoff) from decaying vegetable matter (land) and phytoplankton degraded by grazing of photolysis.

• Suspended particulate matter
  -- The organic particulates (detritus) consist of phytoplankton and zooplankton cell fragments and zooplankton fecal pellets.
  -- The inorganic particulates consist of sand and dust created by erosion of land-based rocks and soils. These enter the ocean through:
    -- River runoff.
    -- Deposition of wind-blown dust.
    -- Wave or current suspension of bottom sediments.
# Current ocean color sensors

<table>
<thead>
<tr>
<th>SENSOR</th>
<th>AGENCY</th>
<th>SATELLITE</th>
<th>OPERATING DATES</th>
<th>SWATH (km)</th>
<th>RESOLUTION (m)</th>
<th>NO. OF BANDS</th>
<th>SPECTRAL COVERAGE (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOS</td>
<td>DLR (Germany)</td>
<td>IRS – P 3 (India)</td>
<td>21-Mar-1996</td>
<td>200</td>
<td>500</td>
<td>18</td>
<td>408-1600</td>
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<td>SeaWiFS</td>
<td>NASA (USA)</td>
<td>OrbView – 2 (USA)</td>
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<td>2806</td>
<td>1100</td>
<td>8</td>
<td>402-885</td>
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<td>OCI</td>
<td>NEC (Japan)</td>
<td>ROCSAT – 1 (Taiwan)</td>
<td>Jan 1999</td>
<td>690</td>
<td>825</td>
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<td>OCM</td>
<td>ISRO (India)</td>
<td>IRS – P4 (India)</td>
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<td>350</td>
<td>8</td>
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<td>MODIS-TERRA</td>
<td>NASA (USA)</td>
<td>EOS – Terra (USA)</td>
<td>18-Dec-1999</td>
<td>2330</td>
<td>1000</td>
<td>36</td>
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<td>MISR</td>
<td>NASA (USA)</td>
<td>EOS – Terra (USA)</td>
<td>18-Dec-1999</td>
<td>360</td>
<td>250</td>
<td>4</td>
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<td>OSMI</td>
<td>KARI (Korea)</td>
<td>KOMPSAT (Korea)</td>
<td>20-Dec-1999</td>
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<td>850</td>
<td>6</td>
<td>400-900</td>
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<td>MERIS</td>
<td>ESA (Europe)</td>
<td>ENVISAT – 1 (Europe)</td>
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<td>1150</td>
<td>300/1200</td>
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<td>412-1050</td>
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<td>MODIS-AQUA</td>
<td>NASA (USA)</td>
<td>EOS – Aqua (USA)</td>
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<td>1000</td>
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<td>OCTS</td>
<td>CNSA (China)</td>
<td>Hai Yang – 1 (China)</td>
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<td>1400</td>
<td>1100</td>
<td>10</td>
<td>402-12500</td>
</tr>
</tbody>
</table>
CZCS -- Coastal Zone Color Scanner (1978 - 1986)

- was a multispectral line scanner developed by NASA to measure ocean color.
- Sun-synchronous, near polar
- CZCS was launched aboard Nimbus-7 satellite platform in October 1978

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelength (nm)</th>
<th>Property</th>
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<tr>
<td>1</td>
<td>433-453</td>
<td>chlorophyll absorption</td>
</tr>
<tr>
<td>2</td>
<td>510-530</td>
<td>chlorophyll concentration</td>
</tr>
<tr>
<td>3</td>
<td>540-560</td>
<td>Gelbstoffe concentration</td>
</tr>
<tr>
<td>4</td>
<td>660-680</td>
<td>aerosol absorption</td>
</tr>
<tr>
<td>5</td>
<td>700-800</td>
<td>land and cloud detection</td>
</tr>
</tbody>
</table>
The SeaWiFS program was started in 1980s, immediately after the end of the CZCS mission.

- Sun Synchronous orbit
- launched on August 1, 1997 by SeaStar Space Craft.
MODIS--Moderate Resolution Imaging Spectroradiometer

- Two MODIS sensors:
  - **Terra** satellite launched December 18th, 1999
  - **Aqua** satellite launched May 4th, 2002.

- Both have sun-synchronous near-polar orbit.

- Terra's orbit around the Earth is timed so that it passes from N to S across the equator in the morning (10:30 a.m., descending node)

- Aqua passes S to N over the equator in the afternoon (1:30 p.m., ascending node).