Use of Geostationary Ocean Color Imagery (GOCI) maps for submesoscale oceanic process studies

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Outline

• Definitions of scale, mesoscale, and submesoscale
• (Coastal) Oceanic processes
• GOCI examples
• Research topics using GOCI maps
• Conclusion
Scales can be defined in time and space.
Near the coast, shoaling waves typically have □□□ seconds period and land-sea breezes change their directions at every □□□□.
Spatial scales can be used as a nature-driven-ruler.....
Spatial scales
Spatial scales

200 km x 600 km
Spatial scales - Mesoscale

How big are the eddies?
Spatial scales - Mesoscale

Influence of earth rotation (a moving object on a rotating frame) becomes dominant compared with rotational tendency (relative vorticity) of an object.
Influence of earth rotation (a moving object on a rotating frame) becomes **dominant** compared with rotational tendency (relative vorticity) of an object.
Influence of earth rotation (a moving object on a rotating frame) becomes equal or small compared with rotational tendency (relative vorticity) of an object.
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\[ O(1) \text{ Rossby number } [\text{Ro} = \frac{\zeta}{f}] \]
Oceanic processes in time and spatial scales

- Seasonality
- Inertial/internal solitary waves
  - Langmuir cell
  - Surface waves
- Eddies, fronts, filaments
- Coastal upwelling
- Internal tides
- Surface tides
- Rossby waves
- CTW
- ENSO PDO
- Climate change

Time scale:
- 100 yr
- 10 yr
- 1 yr
- 1 month
- 1 week
- 1 day
- 1 hr
- 1 min
- 1 sec

Horizontal spatial scale:
- cm
- m
- km

Examples of oceanic processes
Submesoscale processes

- O(1) Rossby number \([\text{Ro} = \frac{\zeta}{f}]\)
- A horizontal scale smaller than the first baroclinic Rossby deformation radius; \(O(1-10)\) km
- Frequently observed as fronts, eddies, and filaments (Courtesy of X. Capet and P. Klein)
Submesoscale processes

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- Contribute to the vertical transport of oceanic tracers, mass, and buoyancy and rectify the mixed-layer structure and upper-ocean stratification
  - e.g., vertical frontal scale secondary circulation

(Williams and Follows, 2003)
Submesoscale processes

- O(1) Rossby number \([\text{Ro} = \zeta/f]\)
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Submesoscale processes

- O(1) Rossby number \([\text{Ro} = \zeta / f]\)
- A horizontal scale smaller than the first baroclinic Rossby deformation radius; \(O(1-10)\) km
- Frequently observed as fronts, eddies, and filaments
- Energy spectra with a slope of \(k^{-2}\) at \(O(1)\) km scale
  - Quasi Geostrophic theory (QG; \(k^{-3}\))
  - Surface QG (sQG; \(k^{-5/3}\))
  - Semi-geostrophic theory (SG; \(k^{-8/3}\))

(Kim JGRC 2015 submitted)
Summary of submesoscale processes

- \( O(1) \) Rossby number \([\text{Ro} = \frac{\zeta}{f}]\)  
- A horizontal scale smaller than the first baroclinic Rossby deformation radius; \( O(1-10) \) km 
- Frequently observed as fronts, eddies, and filaments 
- Contribute to the *vertical transport* of oceanic tracers, mass, and buoyancy and rectify the mixed-layer structure and upper-ocean stratification 
  - e.g., vertical frontal scale secondary circulation 
- Energy spectra with a slope of \( k^{-2} \) at \( O(1) \) km scale
Geostationary Ocean Color Imagery (GOCI)

**Specification**
- GSD (Ground Sampling Distance): \(0.5 \text{ km} \times 0.5 \text{ km}\)
- Target Area: \(2,500 \text{ km} \times 2,500 \text{ km}\) (Center: \(130^\circ \text{E} 36^\circ \text{N}\))
- Included Nations: Korea, China, Taiwan, Japan, Russia, etc.
- Temporal Resolution: 1 hour (8 times / day)

**Spectral Bands Characteristic and Requirements of GOCI**

<table>
<thead>
<tr>
<th>Band</th>
<th>Central Wavelengths</th>
<th>Band Width</th>
<th>SNR</th>
<th>Type</th>
<th>Primary Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>412 nm</td>
<td>20 nm</td>
<td>1,000</td>
<td>Visible</td>
<td>Yellow substance and turbidity</td>
</tr>
<tr>
<td>B2</td>
<td>443 nm</td>
<td>20 nm</td>
<td>1,090</td>
<td>Visible</td>
<td>Chlorophyll absorption maximum</td>
</tr>
<tr>
<td>B3</td>
<td>490 nm</td>
<td>20 nm</td>
<td>1,170</td>
<td>Visible</td>
<td>Chlorophyll and other pigments</td>
</tr>
<tr>
<td>B4</td>
<td>555 nm</td>
<td>20 nm</td>
<td>1,070</td>
<td>Visible</td>
<td>Turbidity, suspended sediment</td>
</tr>
<tr>
<td>B5</td>
<td>660 nm</td>
<td>20 nm</td>
<td>1,010</td>
<td>Visible</td>
<td>Baseline of fluorescence signal, Chlorophyll, suspended sediment</td>
</tr>
<tr>
<td>B6</td>
<td>680 nm</td>
<td>10 nm</td>
<td>870</td>
<td>Visible</td>
<td>Atmospheric correction and fluorescence signal</td>
</tr>
<tr>
<td>B7</td>
<td>745 nm</td>
<td>20 nm</td>
<td>860</td>
<td>NIR</td>
<td>Atmospheric correction and baseline of fluorescence signal</td>
</tr>
<tr>
<td>B8</td>
<td>865 nm</td>
<td>40 nm</td>
<td>750</td>
<td>NIR</td>
<td>Aerosol optical thickness, vegetation, water vapor reference over the ocean</td>
</tr>
</tbody>
</table>

(Courtesy of KOSC)
<table>
<thead>
<tr>
<th>PRODUCTS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-leaving Radiance (Lw)</td>
<td>The radiance assumed to be measured at the very surface of the water under the atmosphere</td>
</tr>
<tr>
<td>Normalized water leaving radiance</td>
<td>The water leaving radiance assumed to be measured at nadir, as if there was no atmosphere with the Sun at zenith</td>
</tr>
</tbody>
</table>
| Optical properties of water                       | K-coefficient  
Absorption coefficient  
Backscattering coefficient                                                                                                                                      |
| Chlorophyll                                       | Concentration of phytoplankton chlorophyll in ocean water                                                                                                                                                   |
| TSS                                               | Total suspended sediment concentration in ocean water                                                                                                                                                        |
| CDOM                                              | Colored dissolved organic matter concentration in ocean water                                                                                                                                              |
| Red tide                                          | Red tide index information                                                                                                                                                                                  |
| Fishing ground information                        | Fishing ground probability index, fishing ground prediction                                                                                                                                                 |
| Underwater visibility                             | Degree of clarity of the ocean observed by the naked eye                                                                                                                                                     |
| Sea surface current vector                        | Sea surface current direction/speed                                                                                                                                                                           |
| Atm. & earth environment                          | Yellow dust, Vegetation Index                                                                                                                                                                                 |
| Water quality level                               | Coastal water quality level estimation                                                                                                                                                                        |
| Primary productivity                              | The production of Organic compounds from carbon dioxide, principally through the process of photosynthesis                                                                                                 |
Paradigm in satellite-borne ocean observations

Polar Orbit Satellite
(spatial, global, long-term, environmental)

- CZCS (1978)
- OCTS (1996)
- POLDER (1996)
- MOS (1996)
- SeaWiFS (1997)
- OCM (1998)
- MODIS AM (1998)
- OCI (1999)
- OSMI (1999)
- MERIS (2000)
- GLI (2000)
- POLDER-2 (2000)
- MODIS PM (2000)

Stationary Orbit Satellite
(temporal, local, short-term, operational)

- GOCI (2010)

Next-generation Stationary Orbit Satellite
(temporal, global/local, short-term, operational + high spatial (250m), multi-sensor)

- HR-GEO (2015)
- GOCI-II (2019)
- GEO-CAPE (2020 ~)

(Courtesy of KOSC)
GOCI examples: Fronts captured in Chlorophyll (CHL)

Chlorophyll concentration (CHL)

Natural color composite

(Courtesy of KOSC)
Examples of CHL-derived Ocean Fronts
GOCI examples: Red-tide monitoring

2013.08.13 12:16:43 KST

(Courtesy of KOSC)
GOCI examples: Footprints of shallow-water tidal mixing

R_s RGB-642 composite image
16 April 2011

(Courtesy of KOSC)
GOCI examples: Daily composite mean of CHL maps

(Courtesy of KOSC)
GOCI examples: Upwelled water (Chlorophyll bloom)
GOCI examples: Sea-ice

(Courtesy of KOSC)
GOCI examples: Coastal Fog
GOCI examples: Yellow Dust

(Courtesy of KOSC)
GOCI examples: Aerosol optical depth

(Courtesy of KOSC)
GOCI II (Phase II)

- GOCI-II is focused on the coastal and global ocean environment monitoring with better spatial resolution and spectral performance for the succession and expansion of the mission of GOCI.

- GOCI-II project started the development in 2012, and will be launched in 2019.

- The user requirements of GOCI-II will have higher spatial resolution, \(300m \times 300m\), and 13 spectral bands to fulfill GOCI’s user requests, which could not be implemented on GOCI for technical reasons.

- GOCI-II will have a new capability, supporting user-definable observation requests such as clear sky area without clouds and special-event areas, etc. This will enable higher applicability of GOCI-II products. GOCI-II will perform observations 8 times daily, the same as GOCI’s.

- The main difference between GOCI-II and GOCI is the global-monitoring capability, which will meet the necessity of the monitoring and research on the long-term climate change. Daily global observation once is planned for GOCI-II.

<table>
<thead>
<tr>
<th>Items</th>
<th>GOCI Specs</th>
<th>GOCI-II Specs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Increased</strong> band number</td>
<td>8 bands</td>
<td>13 bands</td>
</tr>
<tr>
<td><strong>Improved</strong> spatial resolution</td>
<td>500m</td>
<td>300m</td>
</tr>
<tr>
<td><strong>More</strong> observations</td>
<td>8 times/day</td>
<td>10 times/day</td>
</tr>
<tr>
<td><strong>Pointable &amp; Full Disk</strong> coverage</td>
<td>Local Area</td>
<td>Local Area + Full Disk</td>
</tr>
</tbody>
</table>

(Courtesy of KOSC)
Summary of GOCI maps

- 0.5 km spatial and hourly temporal resolutions
- Ocean surface passive tracer maps (CHL, TSS, CDOM, etc)
- 8 band signals (raw data) can be incorporated.
- Atmospheric corrections are required
- Missing data on the cloud-covered areas
- Orthographic projection (and bilinear interpolation)

Chlorophyll concentration (CHL)
Submesoscale process studies

- have benefited from primarily idealized numerical models and theoretical frameworks because they require the use of high-resolution observations of less than one hour in time and \( O(1-10) \) km in space.
Submesoscale process studies

- have benefited from primarily idealized numerical models and theoretical frameworks because they require the use of high-resolution observations of less than one hour in time and $O(1-10)$ km in space.

- Available observational resources are
  - Dynamic variables
    - Shipboard ADCPs-derived subsurface current profiles and CTD (T/S)
    - High-frequency radar-derived surface current maps
  - Passive tracers
    - GOCI....

(Hosegood et al., JGRC 2013)
Potential research topics

• Tracking of water-borne materials at submesoscale
  • Pollutants; red tides; oil spills; larvae transports
  • Particle trajectory model (e.g., random walk/flight models)
  • Estimates of diffusion coefficients using 1D/2D advection-diffusion equations

• Bio-physical interactions at submesoscale
  • Finite-size/Finite-time Lyapunov Exponents (FSLE/FTLE) using current field (AVIOS; HFR; model)
  • Comparison with concentration maps (e.g., CHL/CDOM)

• SST and CHL fronts and eddies at submesoscale
  • Upwelling fronts; Submesoscale eddies and fronts
  • Reynolds flux estimates
  • Instability due to horizontal density gradients; feature extractions and energy spectra
Advection-diffusion equations

\[
\frac{\partial C(x, t)}{\partial t} + u(x, t) \frac{\partial C(x, t)}{\partial x} = \kappa \nabla^2 C(x, t)
\]

where

• \(C(x,t)\): Concentration of harmful algae and pollutants. In-situ observations, satellite-derived maps of passive tracers (e.g., Chlorophyll; TSS; CDOM) [potential sources: GOCI, AVHRR products]

• \(U(x,t)\): (Geostrophic) current field [potential sources: HFR surface current maps; AVISO geostrophic currents]

• \(\kappa(x, t)\): Diffusion coefficients [Unknowns]
Advection-diffusion equations

\[ x(t) = \int_{t_0}^{t} (u(t') + \varepsilon^u) dt' + x(t_0) \approx \sum_k (u(t_k) + \varepsilon^u_k) \Delta t + x(t_0) \]

- Generate concentration maps using assumed uncertainty and current field
- Estimate diffusion coefficients using advection-diffusion equations
- Estimate a relationship between assumed uncertainty and diffusion coefficients for tracking applications
Generation of background current field

\begin{align}
  u(x, y, t) &= \sum_{m=-M^*}^{M^*} \sum_{n=-N^*}^{N^*} \sum_{s=-S^*}^{S^*} \hat{A}_{mn}s \cos \theta_{mn}s + \hat{B}_{mn}s \sin \theta_{mn}s, \\
  v(x, y, t) &= \sum_{m=-M^*}^{M^*} \sum_{n=-N^*}^{N^*} \sum_{s=-S^*}^{S^*} \hat{C}_{mn}s \cos \theta_{mn}s + \hat{D}_{mn}s \sin \theta_{mn}s,
\end{align}

(A1)

\[ \theta_{mn}s = 2\pi (k_m x + l_n y - \sigma_s t) = 2\pi \left( \frac{m}{L_x} x + \frac{n}{L_y} y - \sigma_s t \right) \]

\[ \hat{A}_{mn}s = (\xi_{mn})^{1/2} \xi_s N(0, 1), \]

\[ \xi(k_m, l_n) = \pi \lambda_x \lambda_y \exp \left( -\pi^2 k_m^2 \lambda_x^2 - \pi^2 l_n^2 \lambda_y^2 \right) \]

\[ \xi(k_m, l_n) = \frac{4 \lambda_x \lambda_y}{(1 + 4\pi^2 k_m^2 \lambda_x^2 + 4\pi^2 l_n^2 \lambda_y^2)^{3/2}}, \]

\[ \xi_s(\sigma_s) = A\sigma_s^{-\alpha} + \sum_{n=1}^{N} B_n \exp \left( -\frac{|\sigma_s - \nu_n|}{(\lambda_t)_n} \right), \]
2D->1D advection-diffusion equations

\[
\frac{\partial C(x, t)}{\partial t} + u(x, t) \frac{\partial C(x, t)}{\partial x} = \kappa \nabla^2 C(x, t)
\]

\[
\frac{\partial C(y, t)}{\partial t} + v(y, t) \frac{\partial C(y, t)}{\partial y} = \kappa \frac{\partial^2 C(y, t)}{\partial y^2}
\]
Estimates of diffusion coefficients

\[ \frac{\partial C(y, t)}{\partial t} + v(y, t) \frac{\partial C(y, t)}{\partial y} = \kappa \frac{\partial^2 C(y, t)}{\partial y^2} \]
Condition: 1) particle 20, life span: 50h 
2) abnormally large diffusivity is removed (>1000)

Exponential distribution

\[ f(x) = \lambda e^{-\lambda x} \]

Random parameter: 10% 

Random parameter: 30% 

Random parameter: 50%
Diffusion coefficients and uncertainty

a: random parameter
b: diffusivity

\[ b = 0.1161a + 128.3934 \]
residual = 1.6680

\[ b = 0.1174a + 128.6356 \]
residual = 2.0005
Potential research topics

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  - Particle trajectory model
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  - Reynolds flux estimates
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SST w/ current fields and FSLE

- SST with AVISO geostrophic currents off Hawaii
- Manifolds obtained from FSLEs
- Limitations on spatial and temporal scales

(Calil et al JGRC 2011)
CHL and SST

- Cross-validation with satellite CHL maps and SST.

(Calil et al JGRC 2011)
Echo sounder image of vertically migrating zooplankton

www.oceanobservatory.com
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• SST and CHL fronts and eddies at submesoscale
  • Upwelling fronts; Submesoscale eddies and fronts
  • Reynolds flux estimates
  • Instability due to horizontal density gradients; feature extractions and energy spectra
• As a **passive tracer**, 0.5 km and hourly GOCI maps can be an important resource in the submesoscale process studies along with in-situ high-resolution observations (e.g., shipboard ADCP subsurface profiles, HF radar surface current maps, etc).

• **Bio-physical interactions and ocean submesoscale turbulent studies** using GOCI maps are promising.

• The integrated data analysis using **independent observations** at submesoscale (including cross-validation) can provide various aspects and complete understanding of oceanic submesoscale processes.

• **Corrections of atmospheric signals** are required.

• Please stay tune...!
Thank you for your attention!