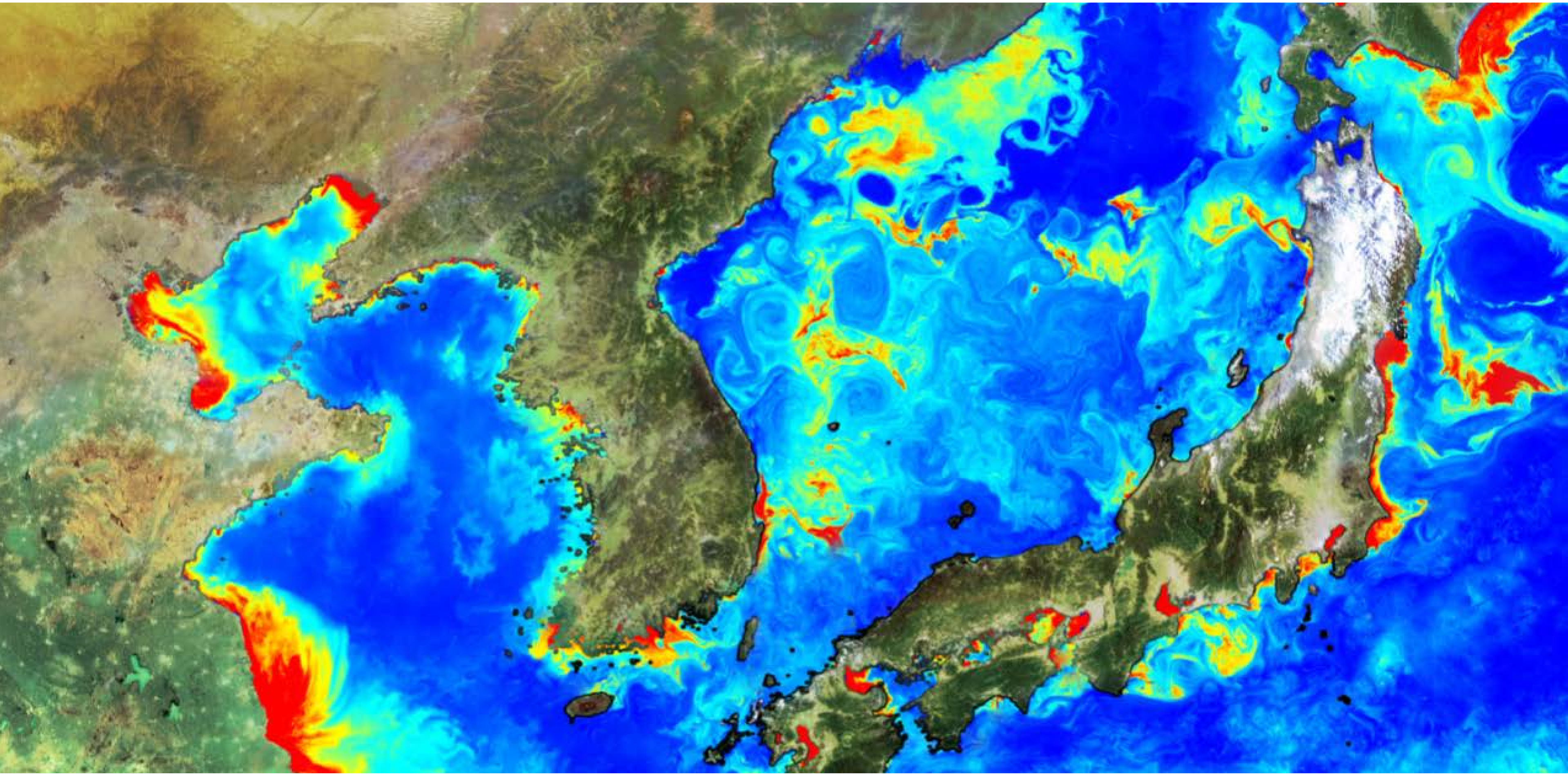
Use of Geostationary Ocean Color Imagery (GOCI) maps for submesoscale oceanic process studies



Sung Yong Kim, Dept. of Mechanical Eng., Korea Advanced Institute of Science and Technology (KAIST)
Collaborators: E. A. Lee (KAIST),Y. J. Park, J. H. Ryu, and J. M. Rhoo (KIOST)

KAIST ENGINEERING FOR MANKIND | KAIST Department of Mechanical Engineering KIOST 한국해양과학기술원

Summary in the beginning…

GOCI is a satellite-derived observational resource to

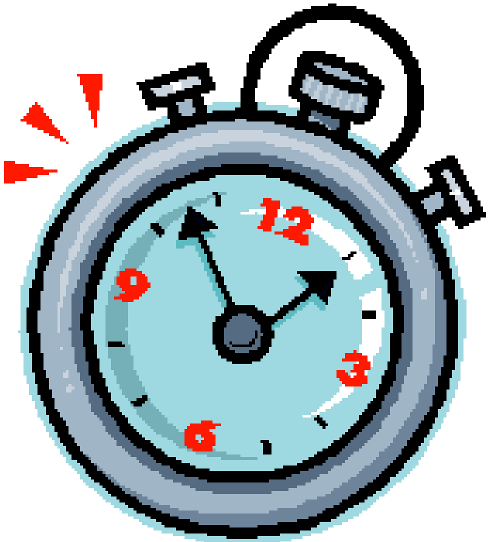
- provide ocean surface passive tracers (CHL, TSS, CDOM, etc) at hourly and 0.5 km resolutions in the operational mode (7-day/week, 8-hour/day)

- Identify the meso-/sub-mesoscale fronts and eddies

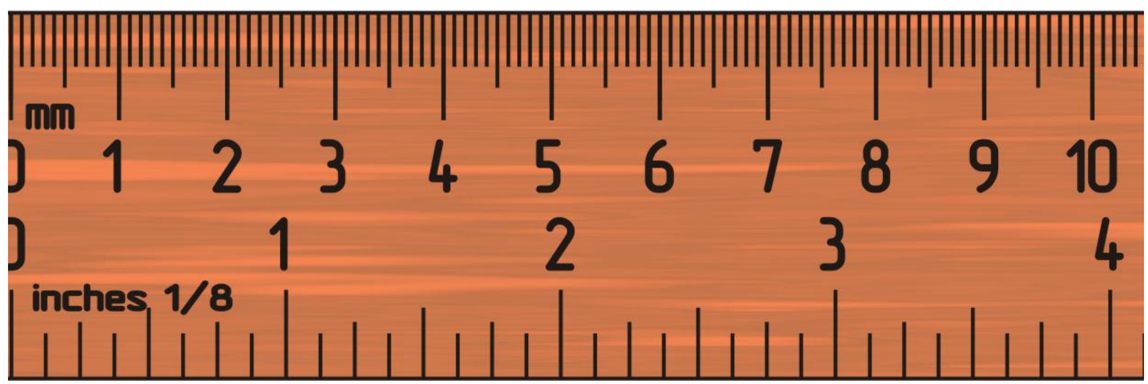
- require (maybe) independent subsurface/in-situ observations for integrated data analysis

Outline

- Definition of scale, mesoscale, and submesoscale
- (Coastal) Oceanic processes
- GOCI examples
- Research topics using GOCI maps
- Conclusion



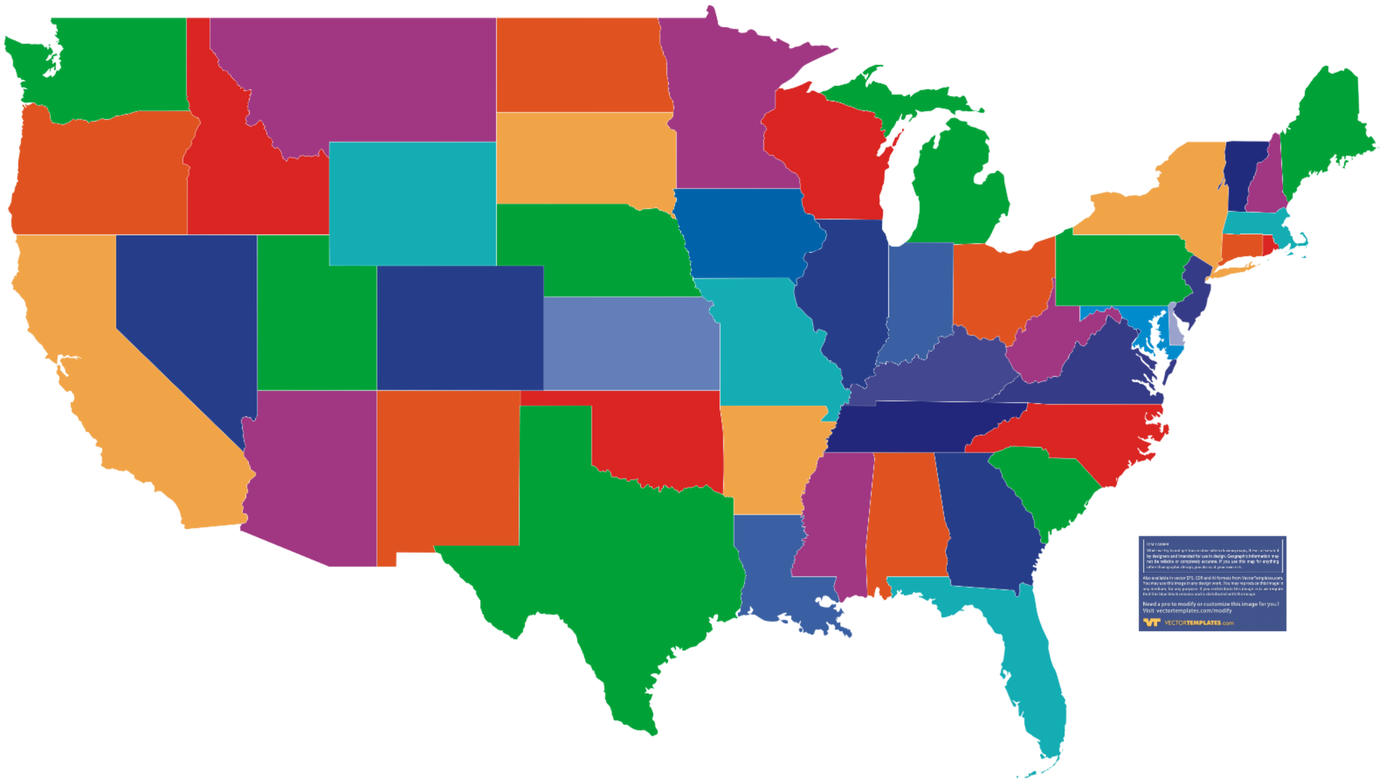
Scales can be defined
in time and space..



Temporal scales

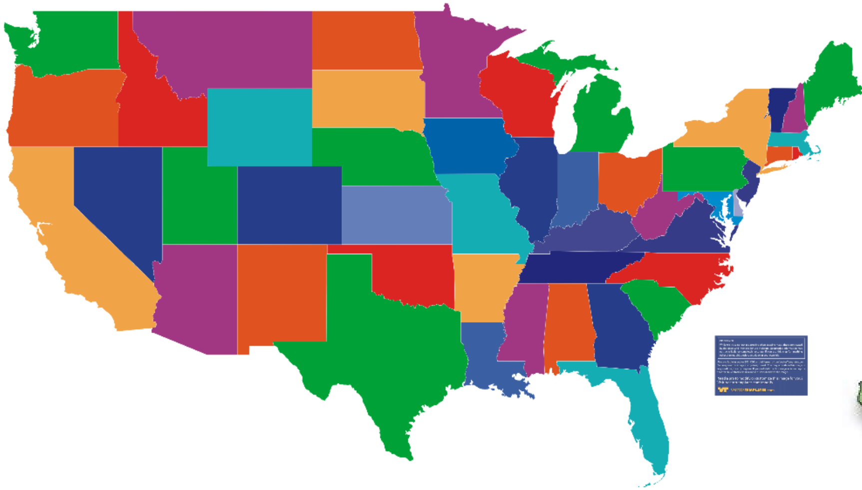
Near the coast, shoaling waves typically have □□ seconds period and land-sea breezes change their directions at every □□□.

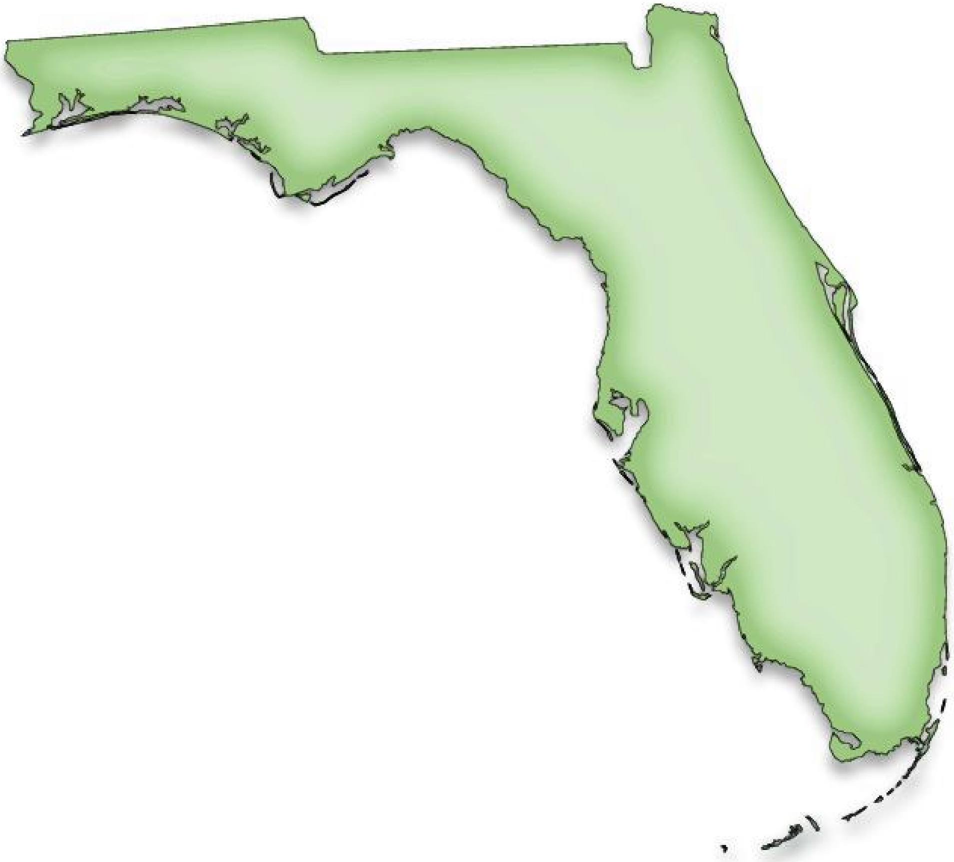
Spatial scales



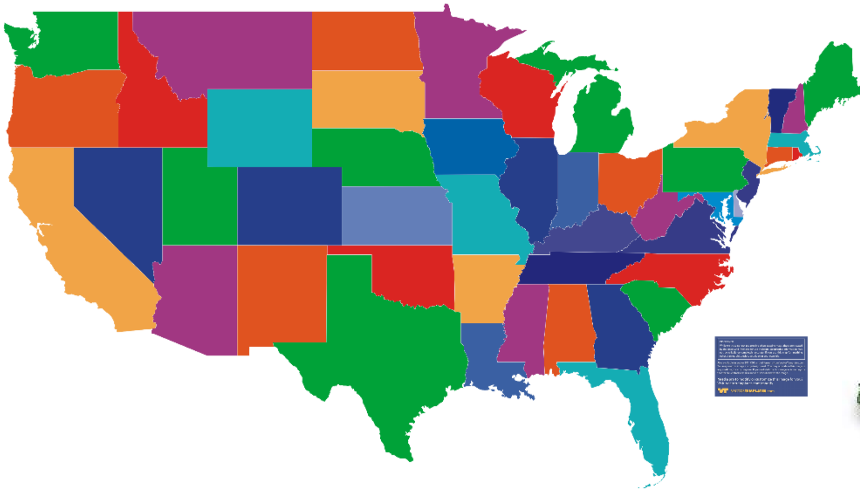
can be used as a nature-deriven-ruler…..

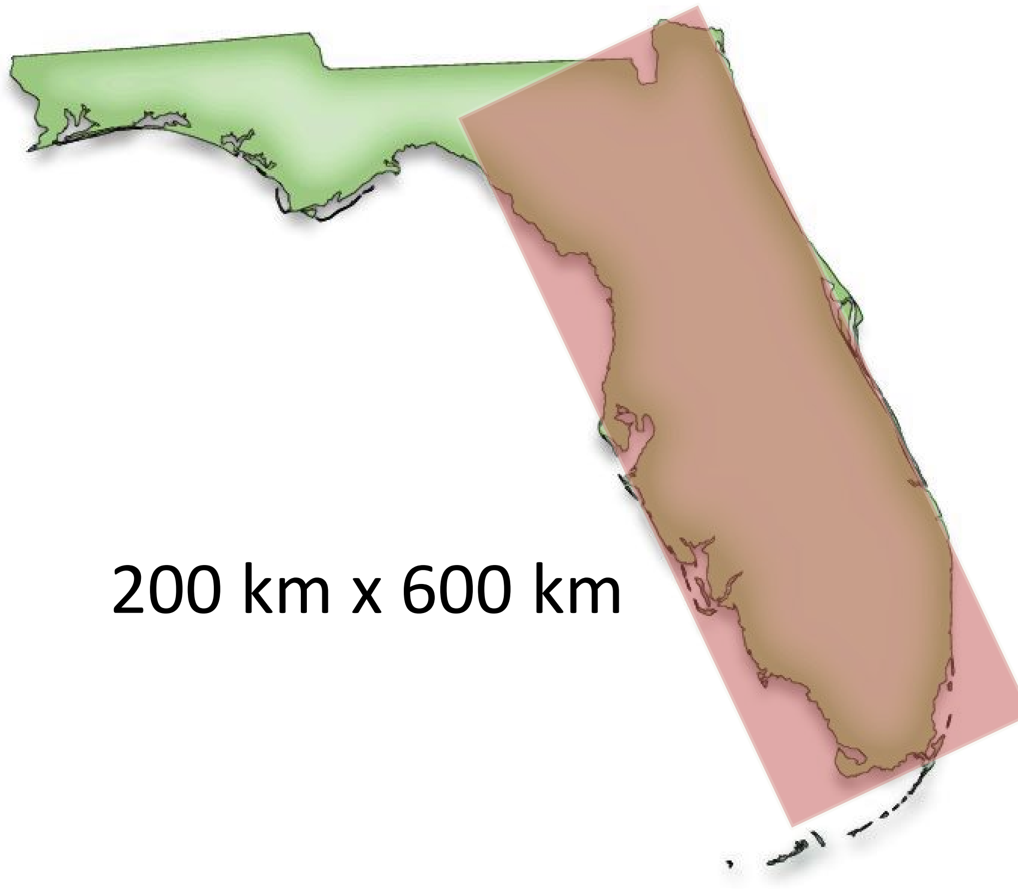
Spatial scales





Spatial scales

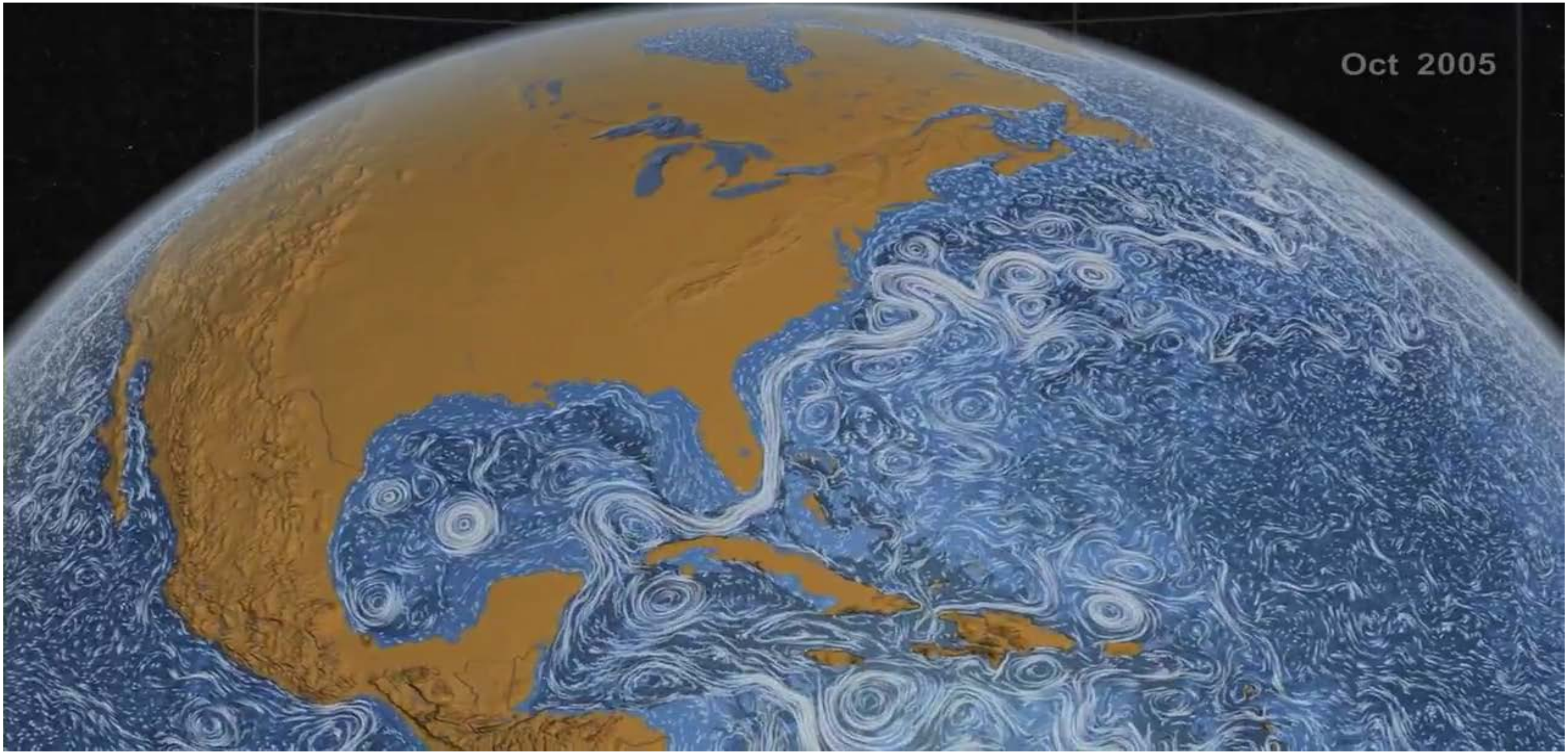




200 km x 600 km

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.



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.

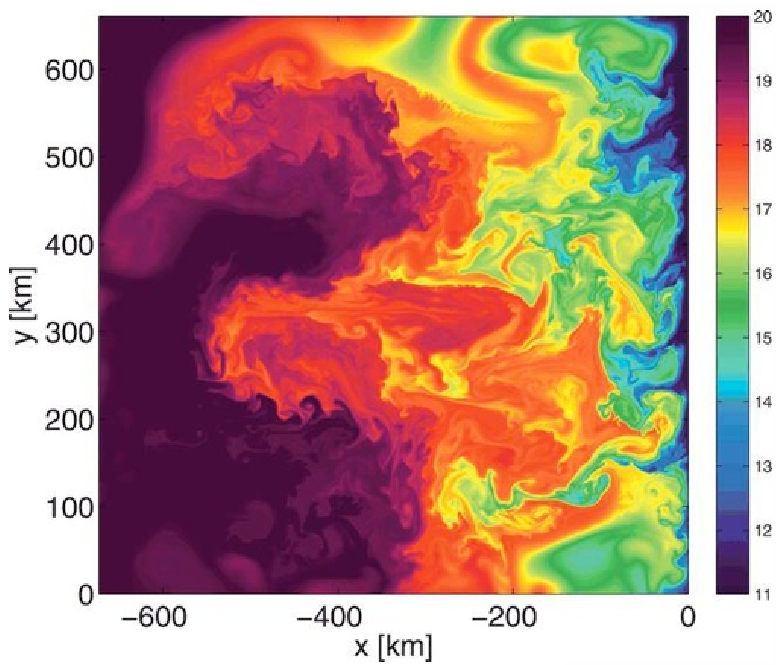
?

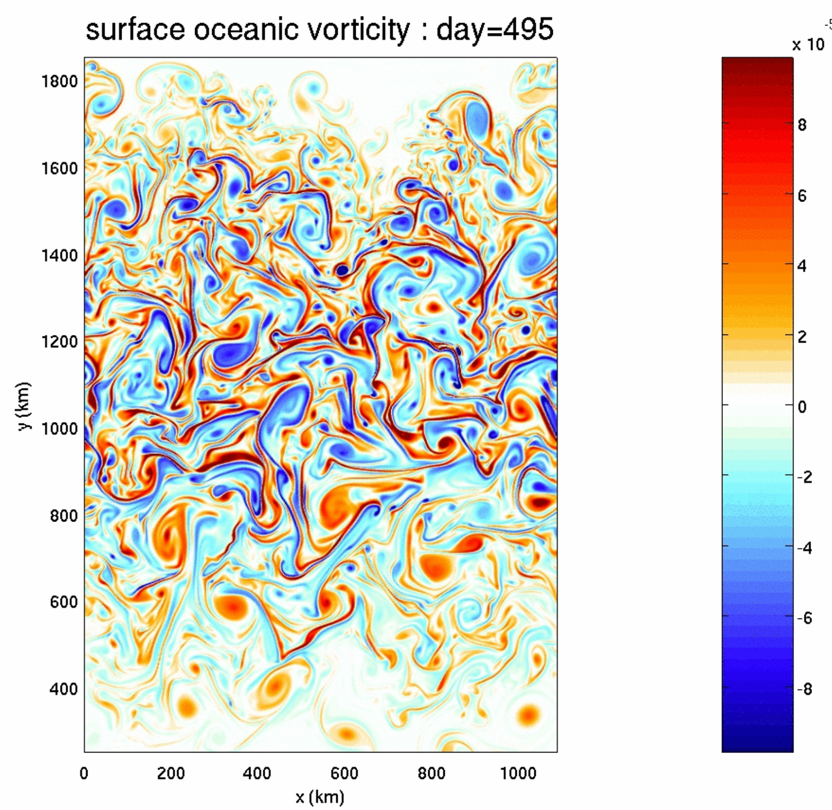
Spatial scales - Submesoscale

Influence of earth rotation (a moving object on a rotating frame) becomes equal or small compared with rotational tendency (relative vorticity) of an object.

Spatial scales - Submesoscale

Influence of earth rotation (a moving object on a rotating frame) becomes equal or small compared with rotational tendency (relative vorticity) of an object.

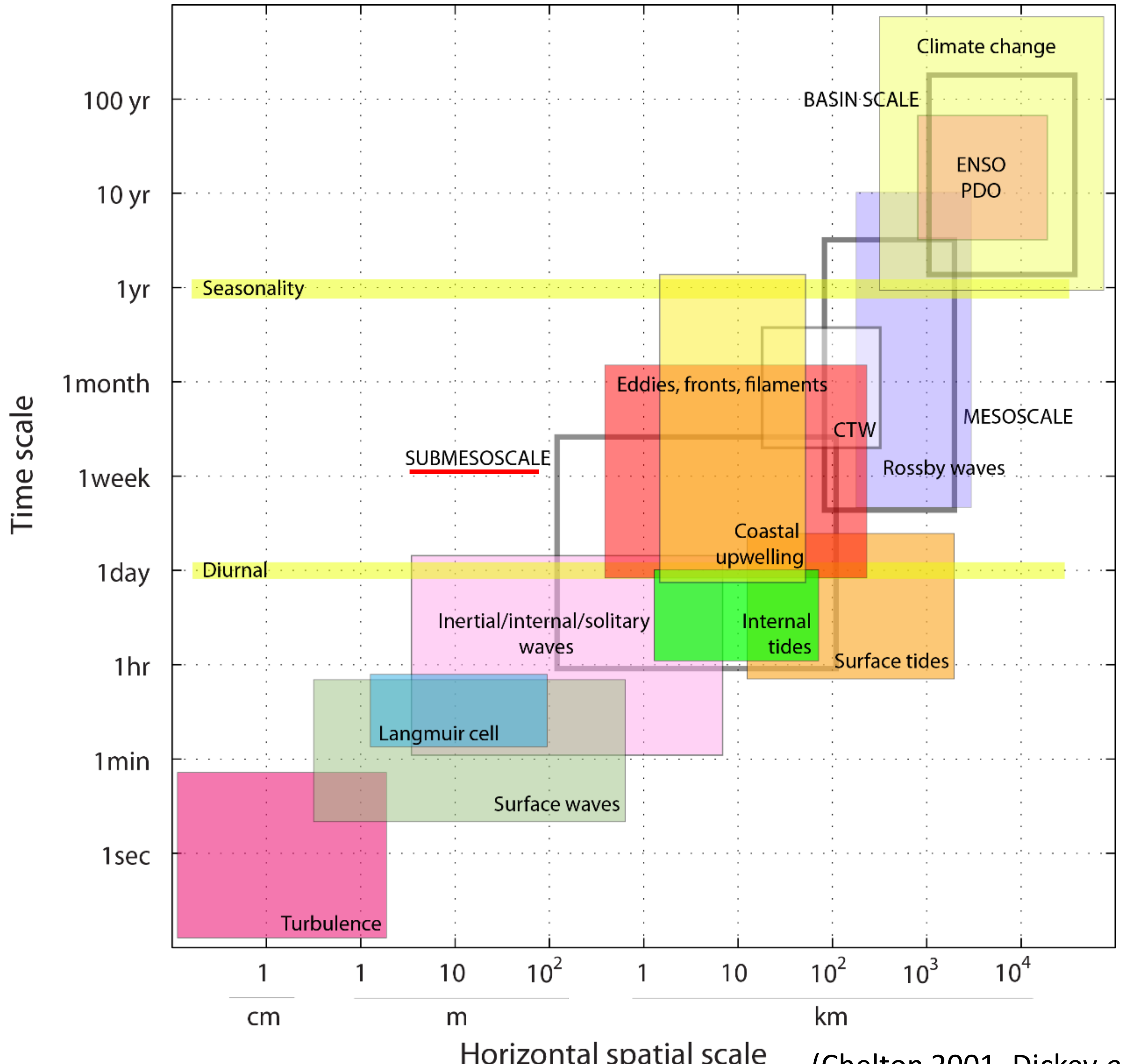




O(1) Rossby number [$Ro = \zeta/f$]

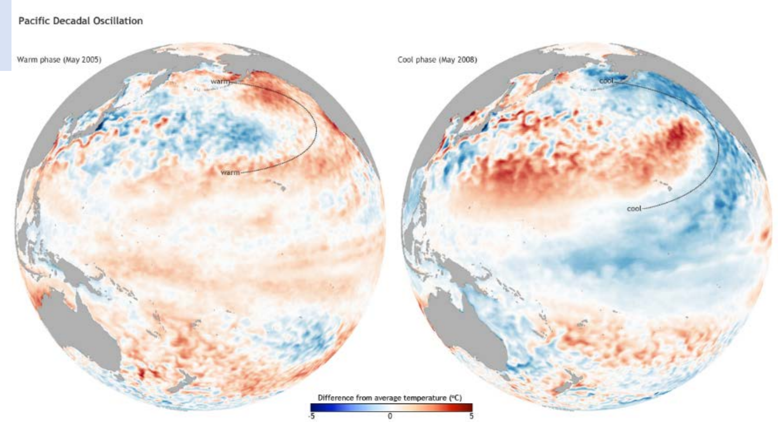
(Courtesy of X. Capet and P. Klein)

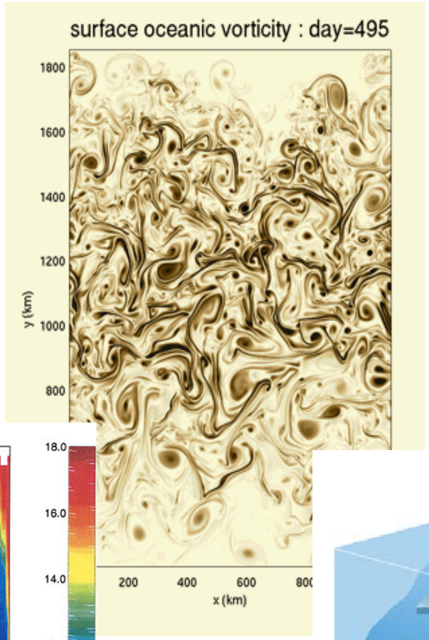
Oceanic processes in time and spatial scales

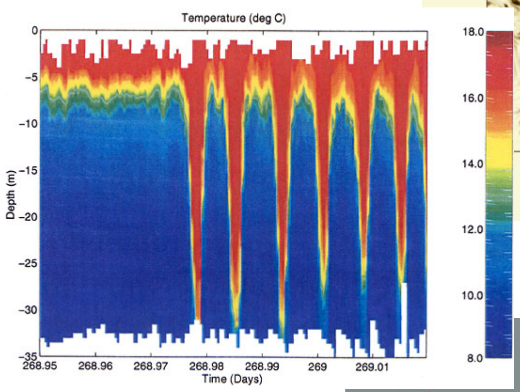


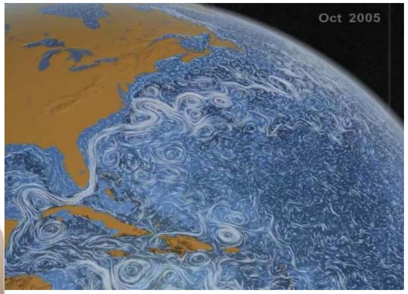
(Chelton 2001, Dickey *et al*, RG 2006; Kim 2015)

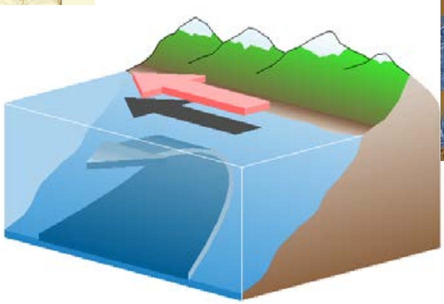
Examples of oceanic processes

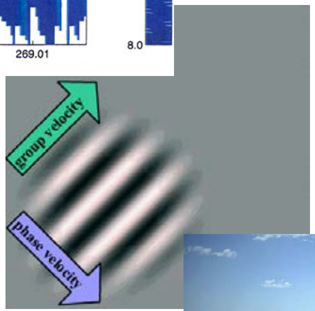


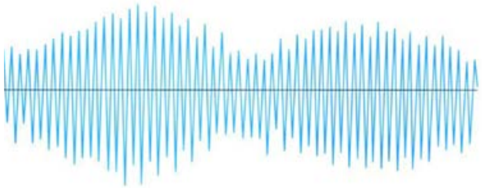


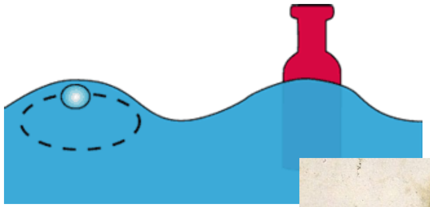


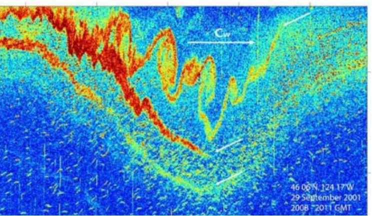


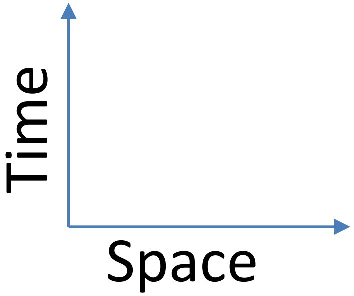






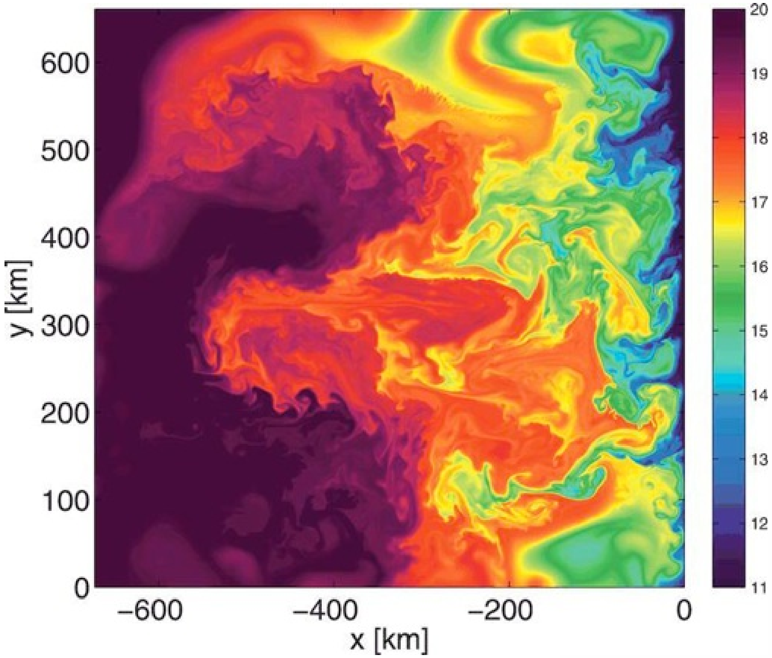


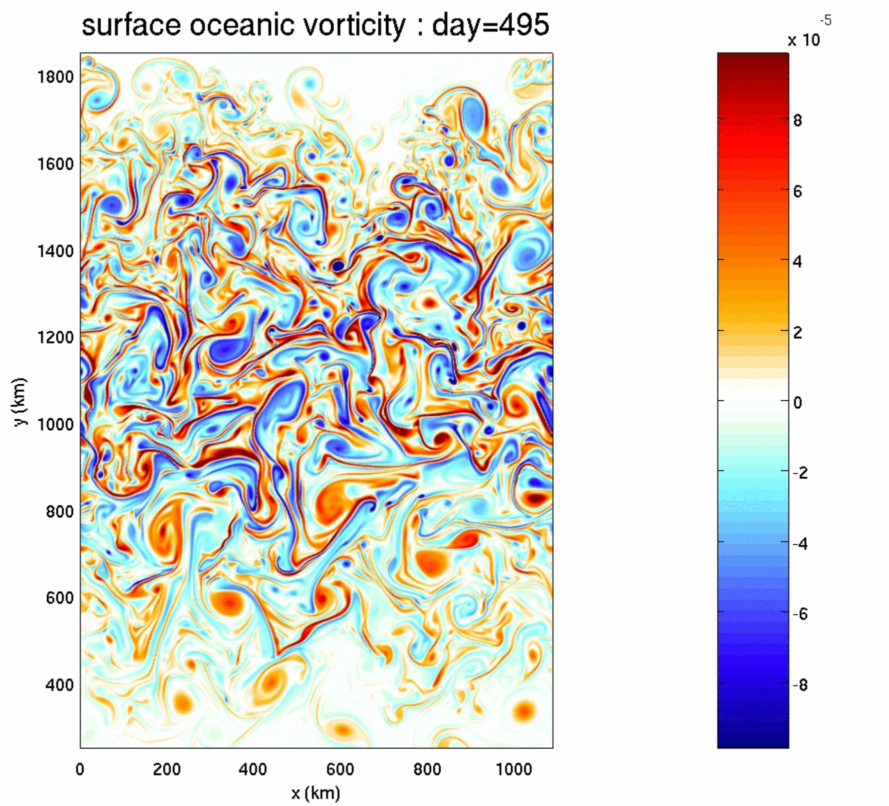




Submesoscale processes

- O(1) Rossby number [Ro = ζ/f]
- A horizontal scale smaller than the first baroclinic Rossby deformation radius; O(1-10) km
- Frequently observed as fronts, eddies, and filaments

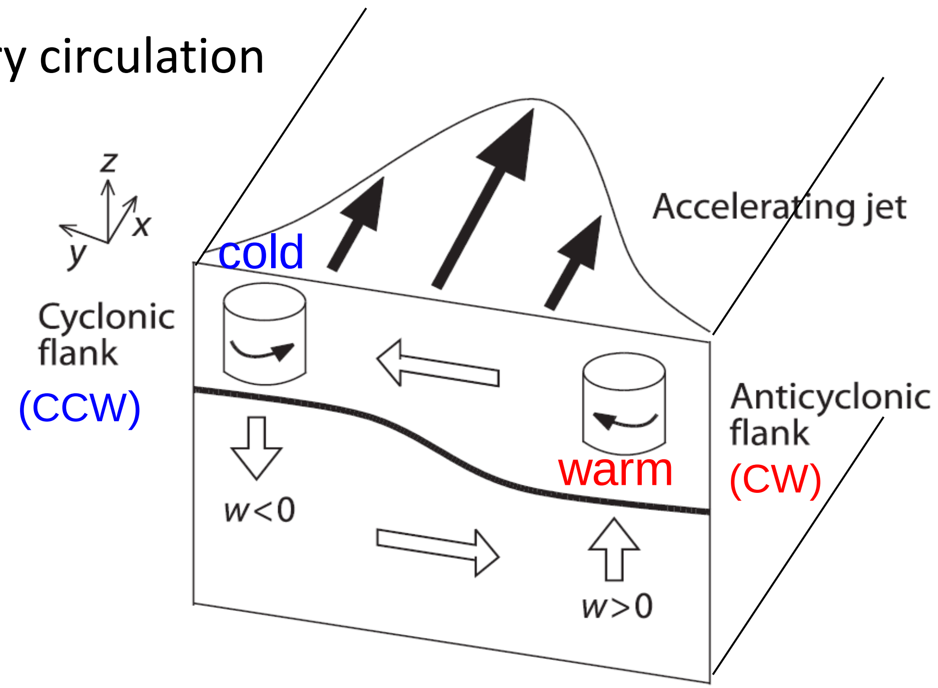




(Courtesy of X. Capet and P. Klein)

Submesoscale processes

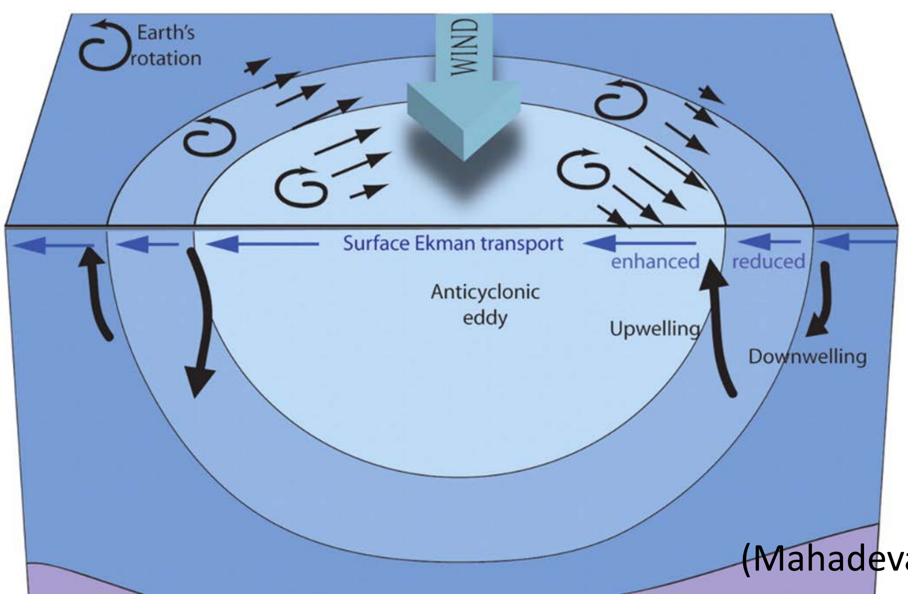
- O(1) Rossby number [Ro = ζ/f]
- A horizontal scale smaller than the first baroclinic Rossby deformation radius; O(1-10) km
- Frequently observed as fronts, eddies, and filaments
- Contribute to the vertical transport of oceanic tracers, mass, and buoyancy and rectify the mixed-layer structure and upper-ocean stratification
  - e.g., vertical frontal scale secondary circulation



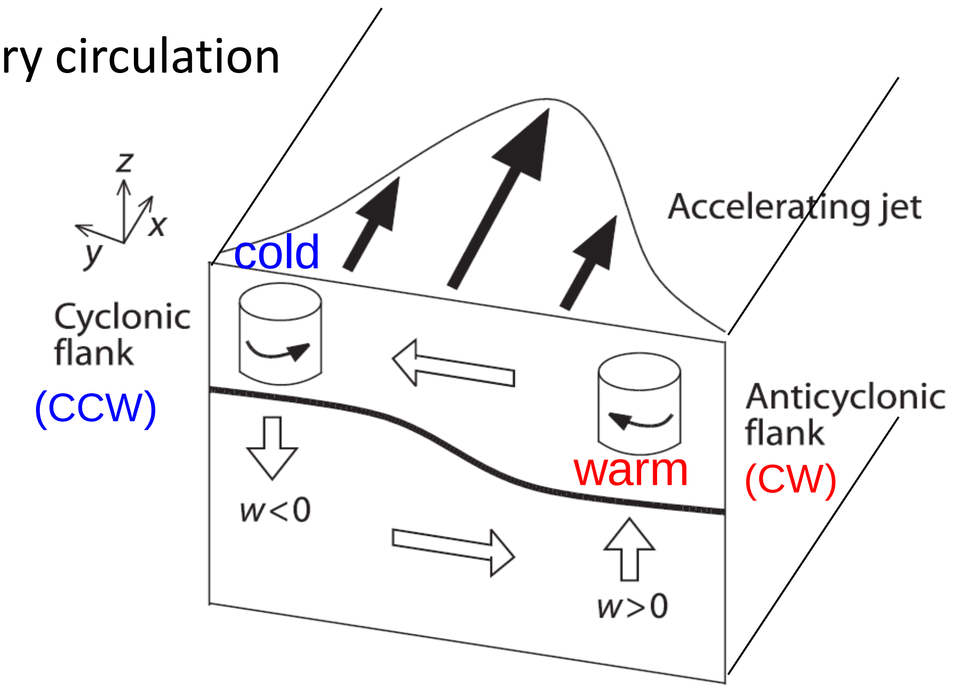
(Williams and Follows, 2003)

Submesoscale processes

- O(1) Rossby number [$Ro = \zeta/f$]
- A horizontal scale smaller than the first baroclinic Rossby deformation radius; O(1-10) km
- Frequently observed as fronts, eddies, and filaments
- 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



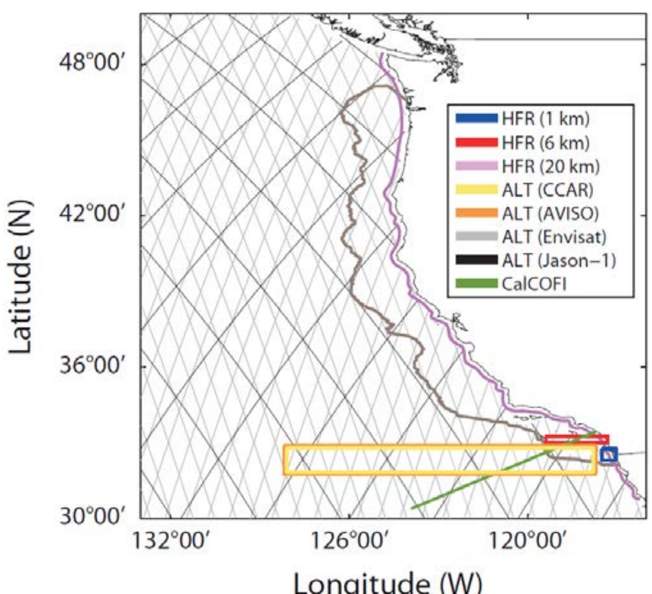
(Mahadevan et al, Science, 2008)



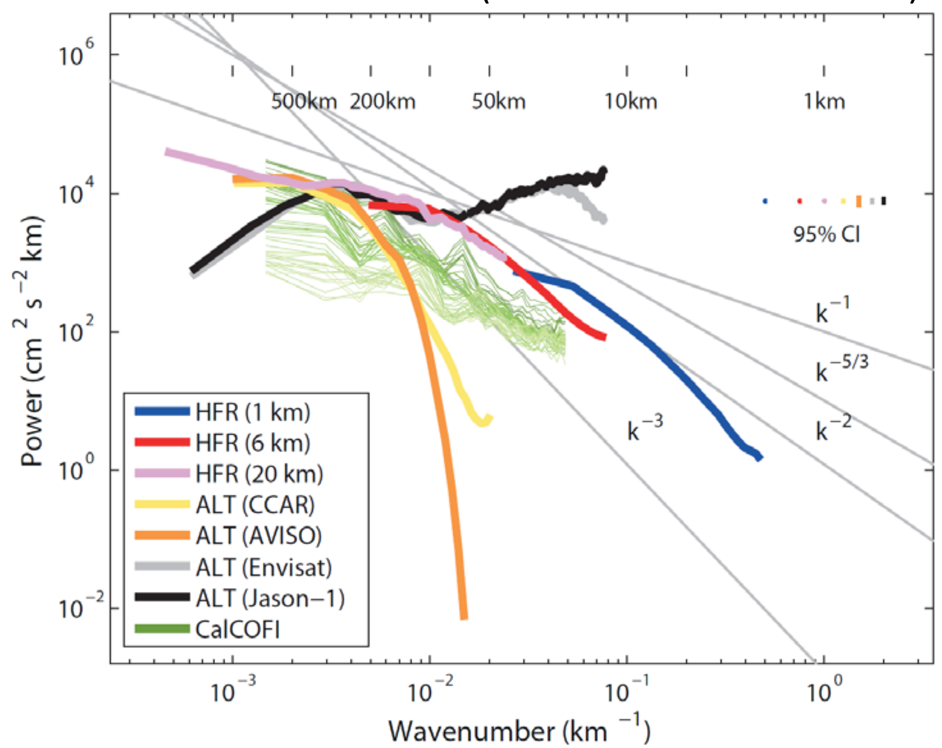
(Williams and Follows, 2003)

Submesoscale processes

- O(1) Rossby number [Ro = ζ/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)

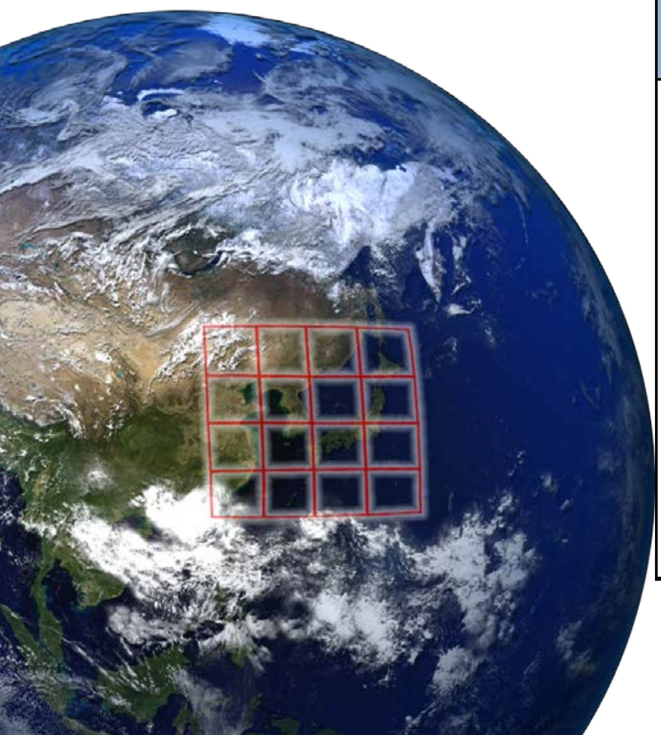


Summary of submesoscale processes

- O(1) Rossby number [Ro = ζ/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 km × 0.5 km
  - Target Area : 2,500 km × 2,500 km (Center : 130°E 36°N)
  - Included Nations : Korea, China, Taiwan, Japan, Russia, etc.
  - Temporal Resolution : 1 hour (8 times / day)
- Spectral Bands Characteristic and Requirements of GOCI



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

(Courtesy of KOSC)

GOCI data products and applications

PRODUCTS	DESCRIPTION
Water-leaving Radiance (Lw)	The radiance assumed to be measured at the very surface of the water under the atmosphere
Normalized water leaving radiance	The water leaving radiance assumed to be measured at nadir, as if there was no atmosphere with the Sun at zenith
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

Applications

Earth Environment Climatic Change

Long & Short term Ocean Environment Monitoring

Atmosphere & Weather

Land & Disaster Prevention

Military Application

Secret Intelligence Community

(Courtesy of KOSC)

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

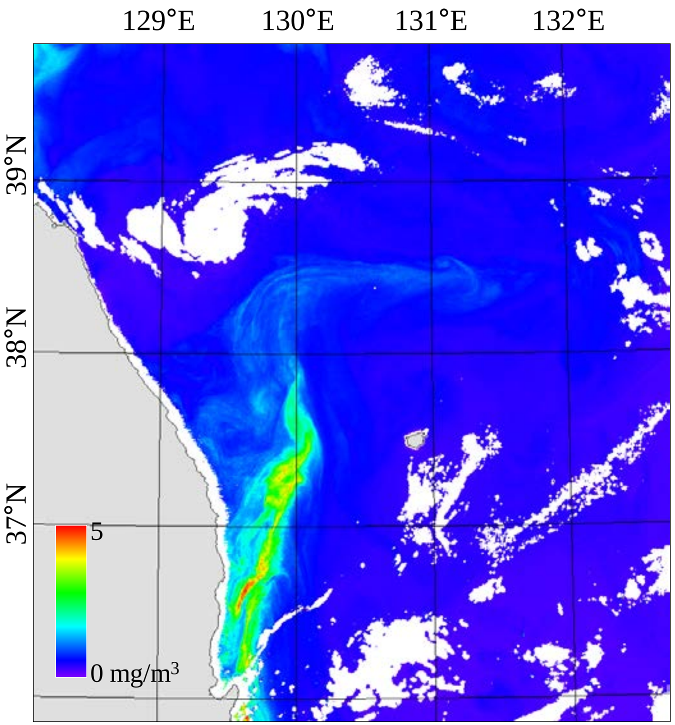
(temporal, global/local, short-term, operational
+ high spatial(250m), multi-sensor)

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

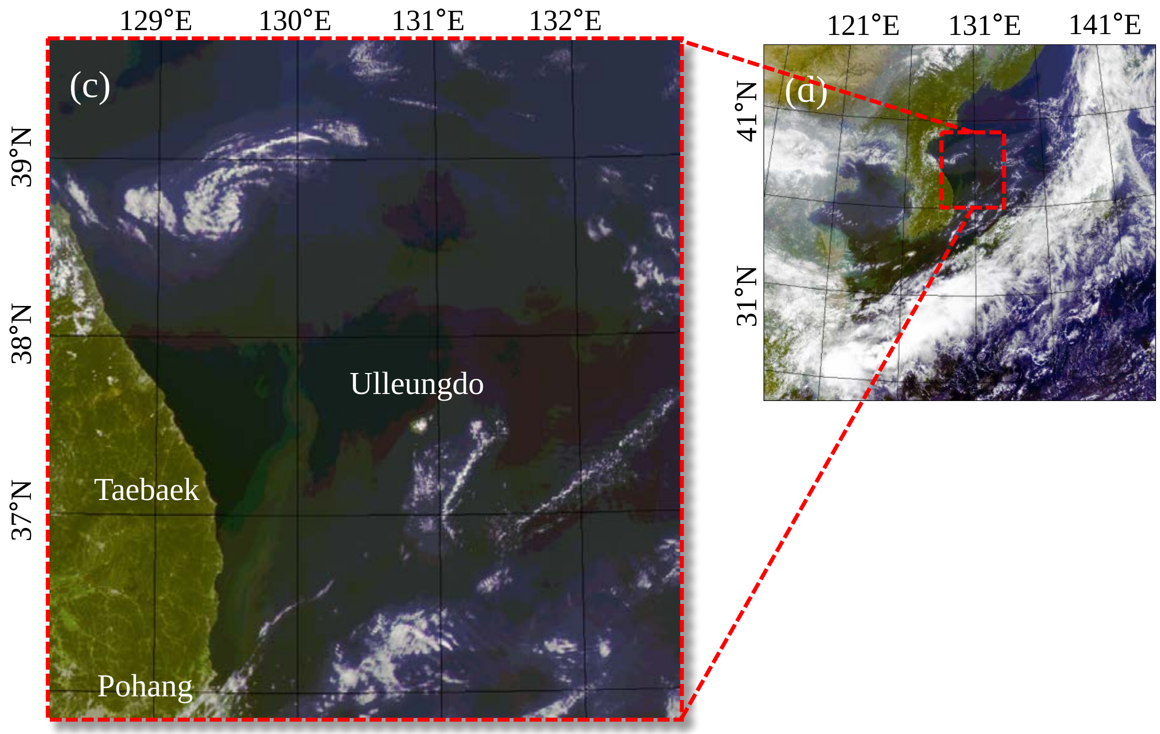
(Courtesy of KOSC)

GOCI examples: Fronts captured in Chlorophyll (CHL)

(Courtesy of KOSC)



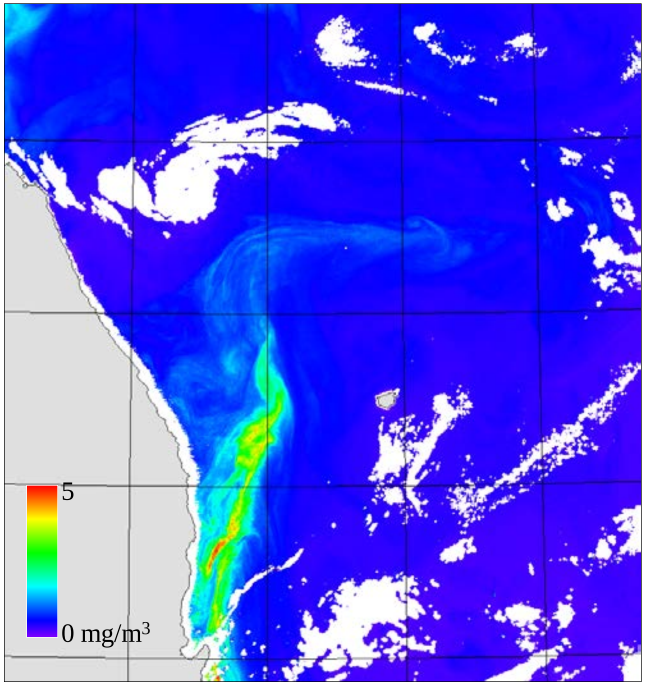
Chlorophyll concentration (CHL)



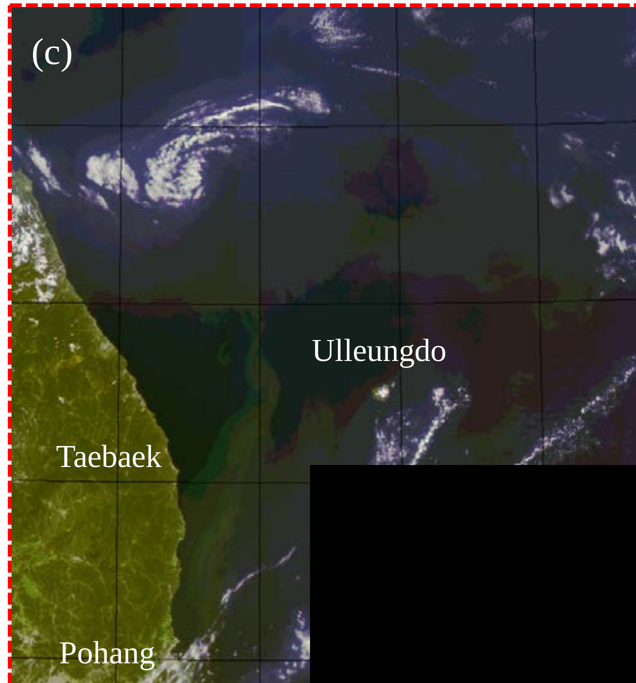
Natural color composite

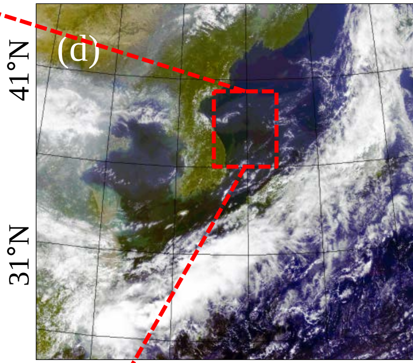
GOCI examples: Fronts captured in Chlorophyll (CHL)

(Courtesy of KOSC)

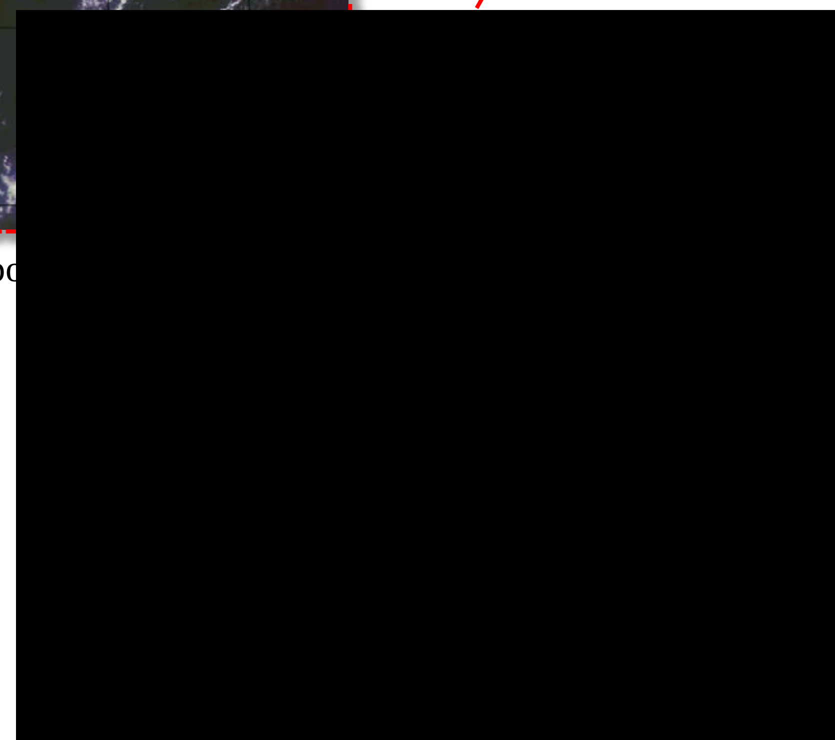


Chlorophyll concentration (CHL)





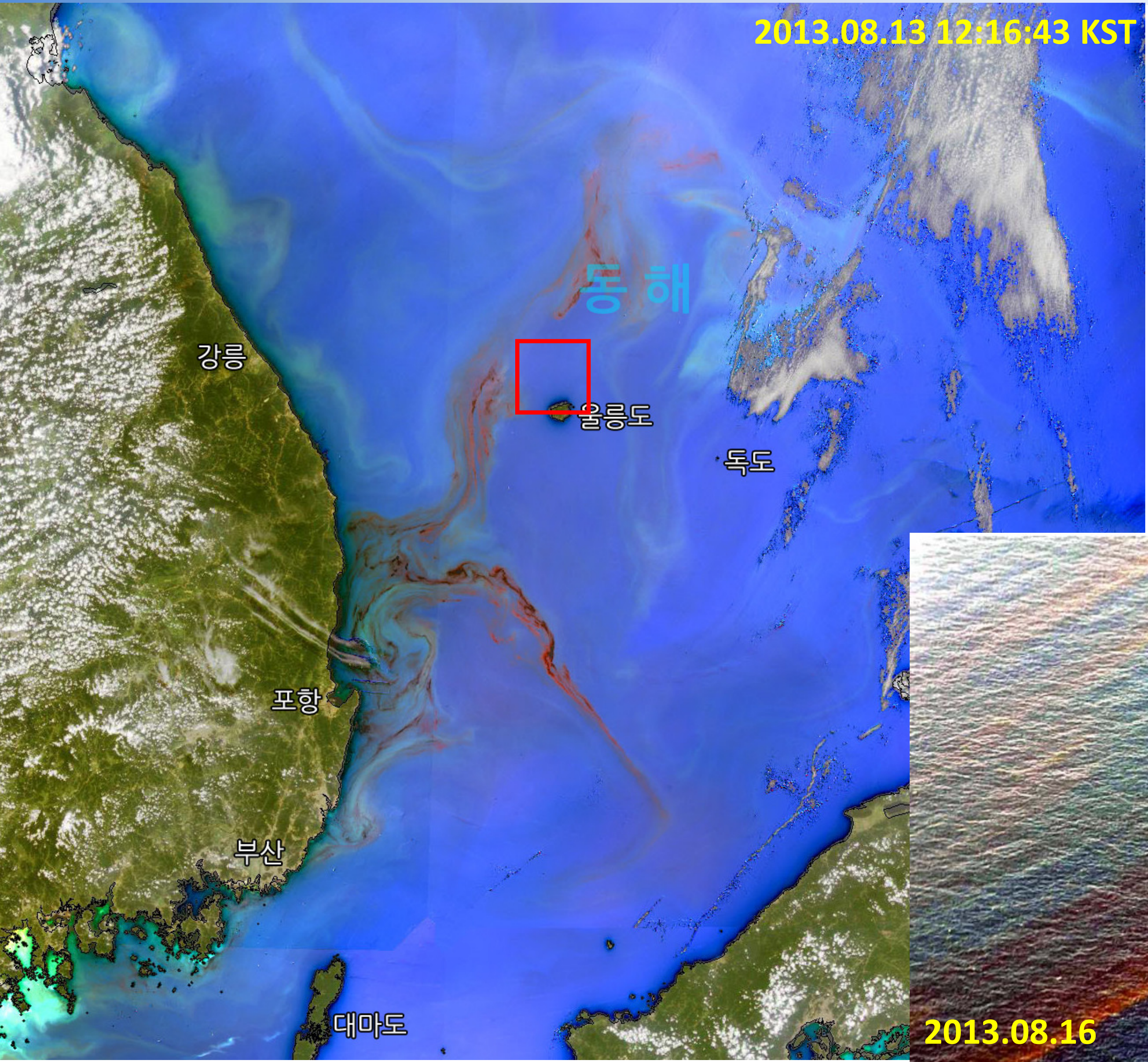
Natural color compo



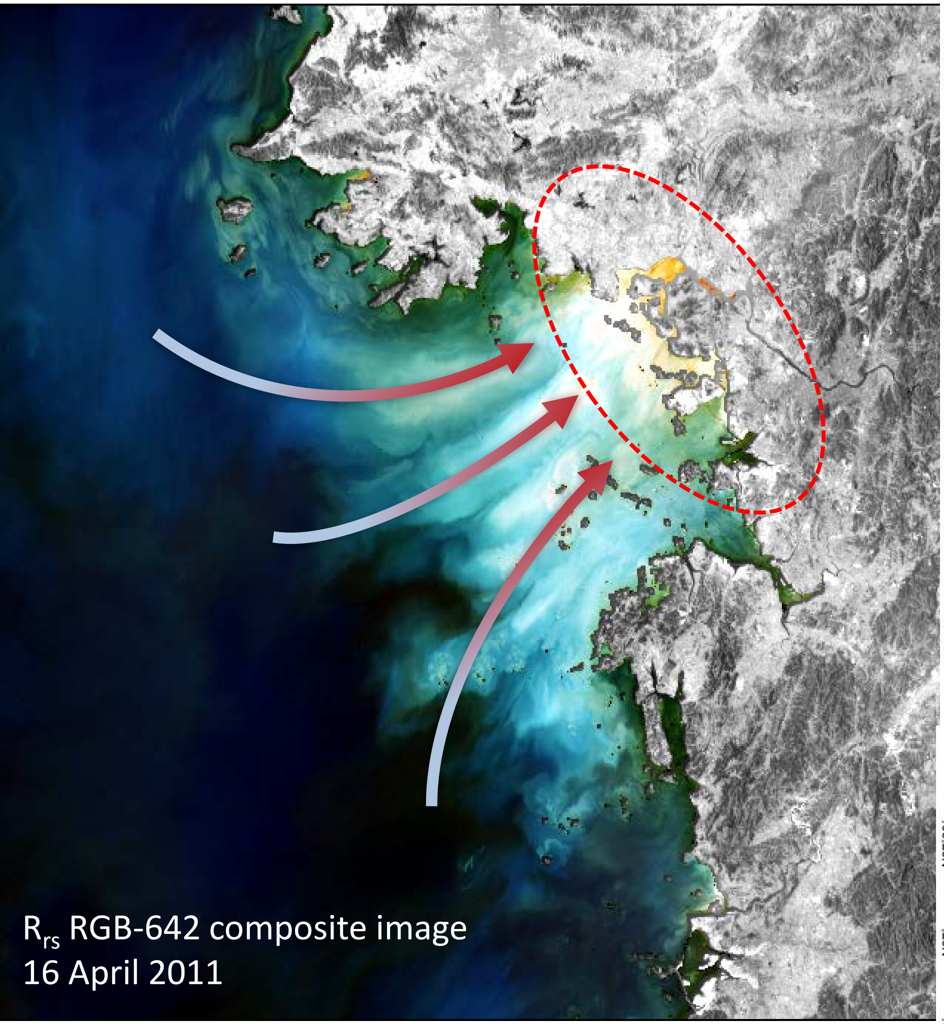
Examples of CHL-derived Ocean Fronts

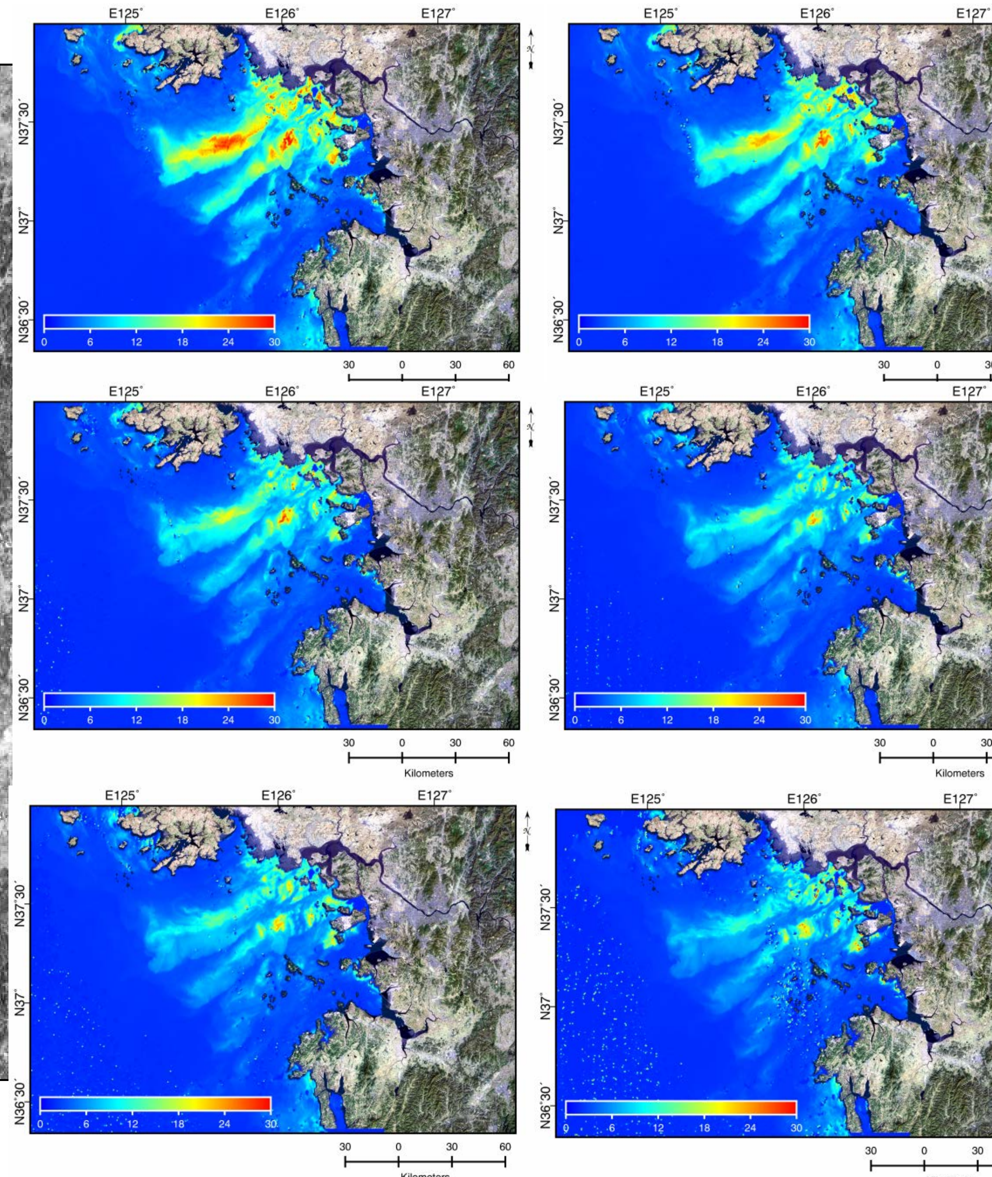
GOCI examples: Red-tide monitoring

(Courtesy of KOSC)



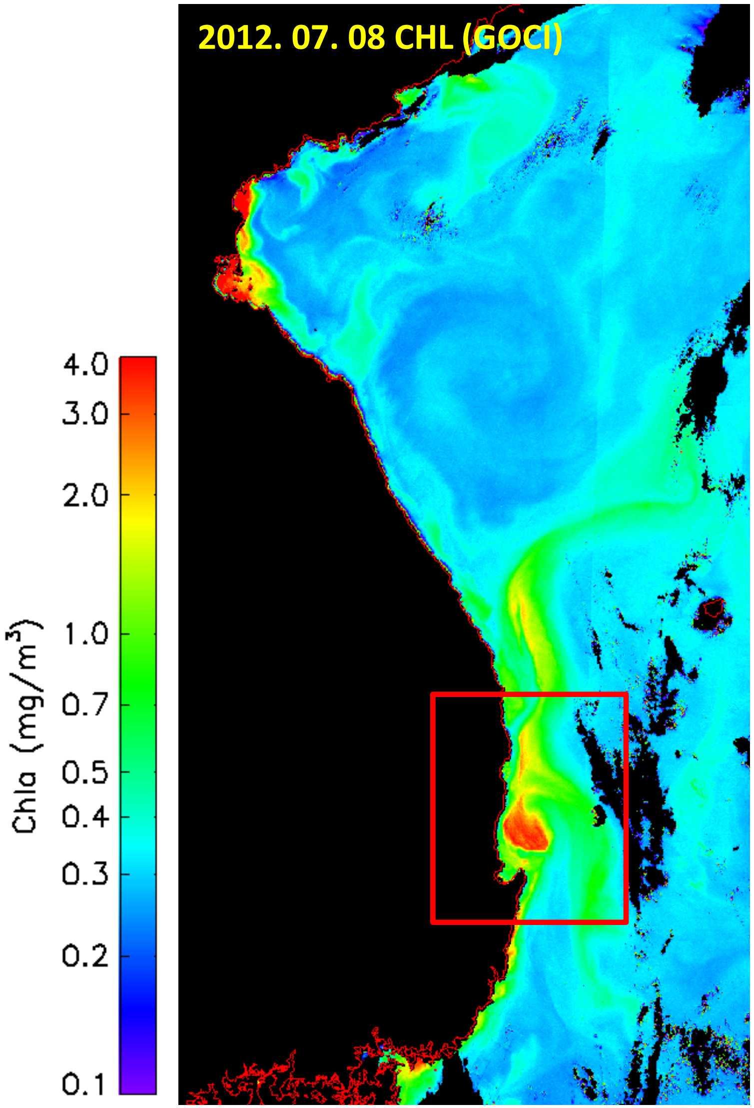
GOCI examples: Footprints of shallow-water tidal mixing

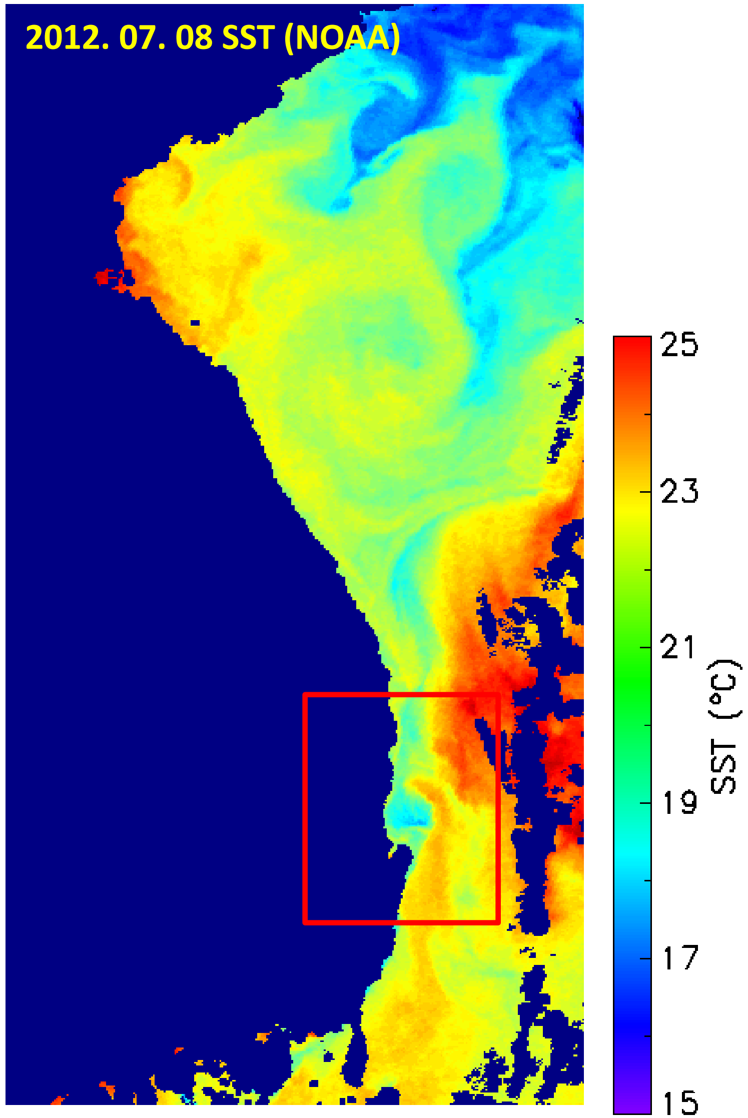




(Courtesy of KOSC)

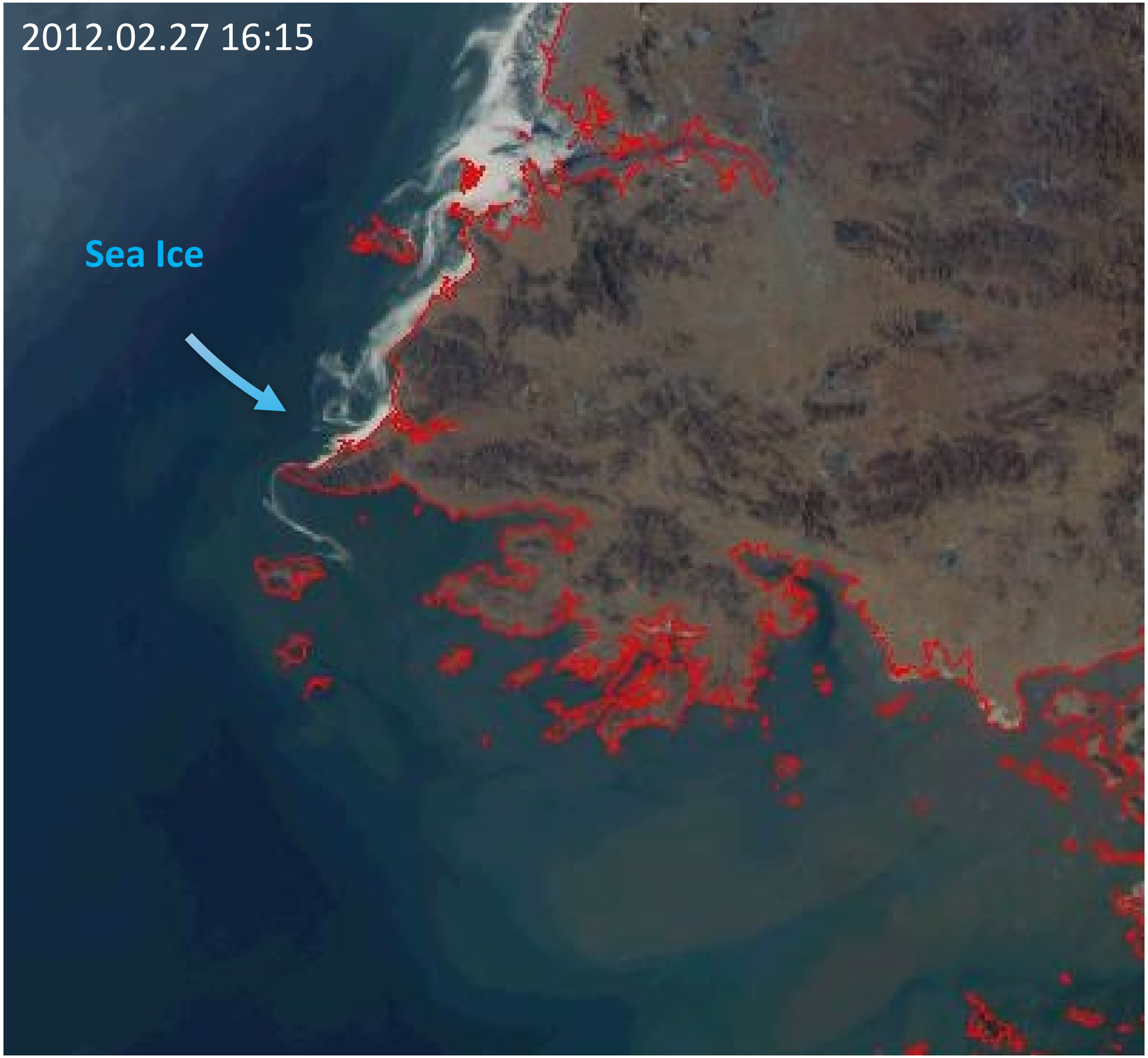
GOCI examples: Upwelled water (Chlorophyll bloom)





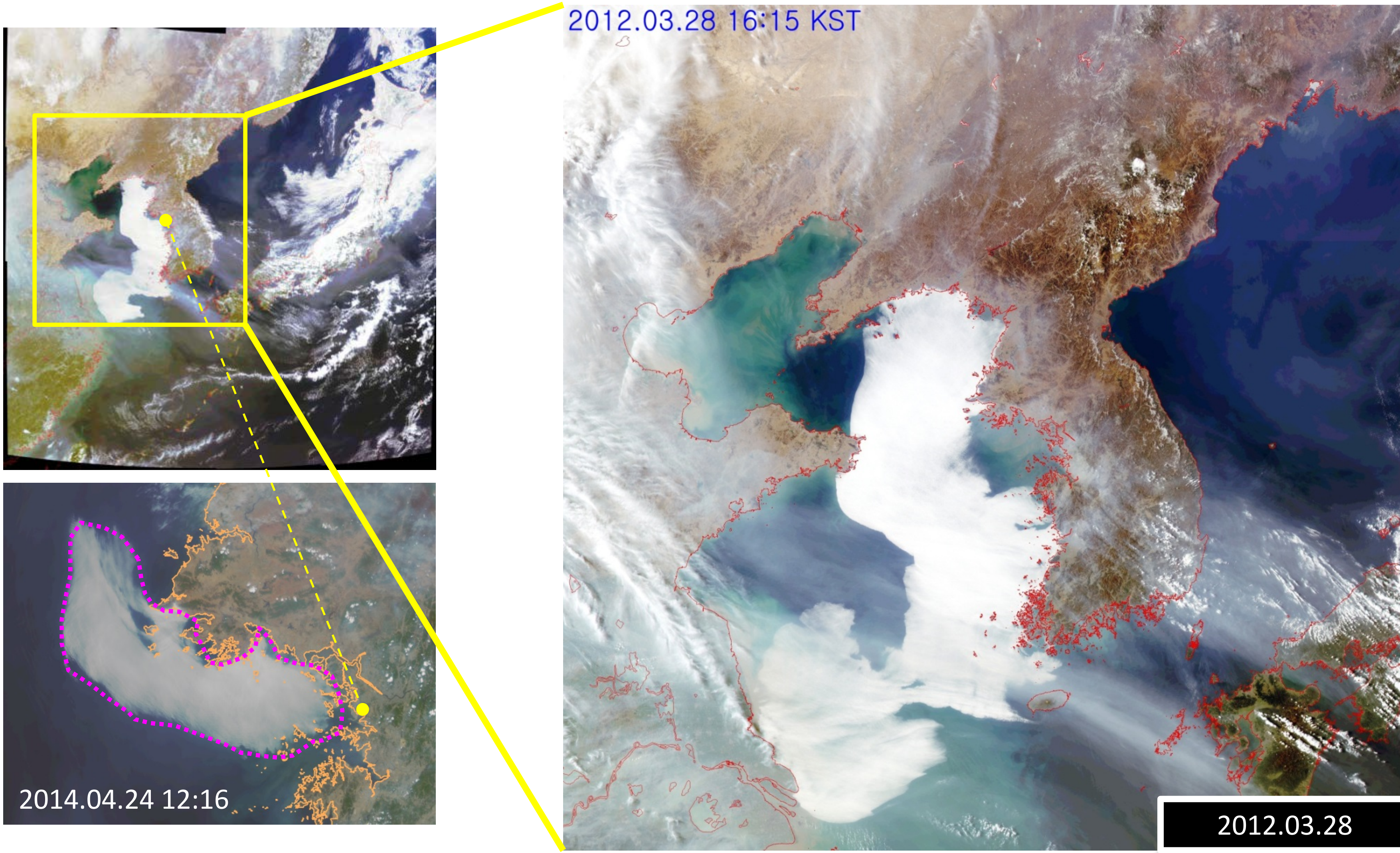
(Courtesy of KOSC)

GOCI examples: Sea-ice



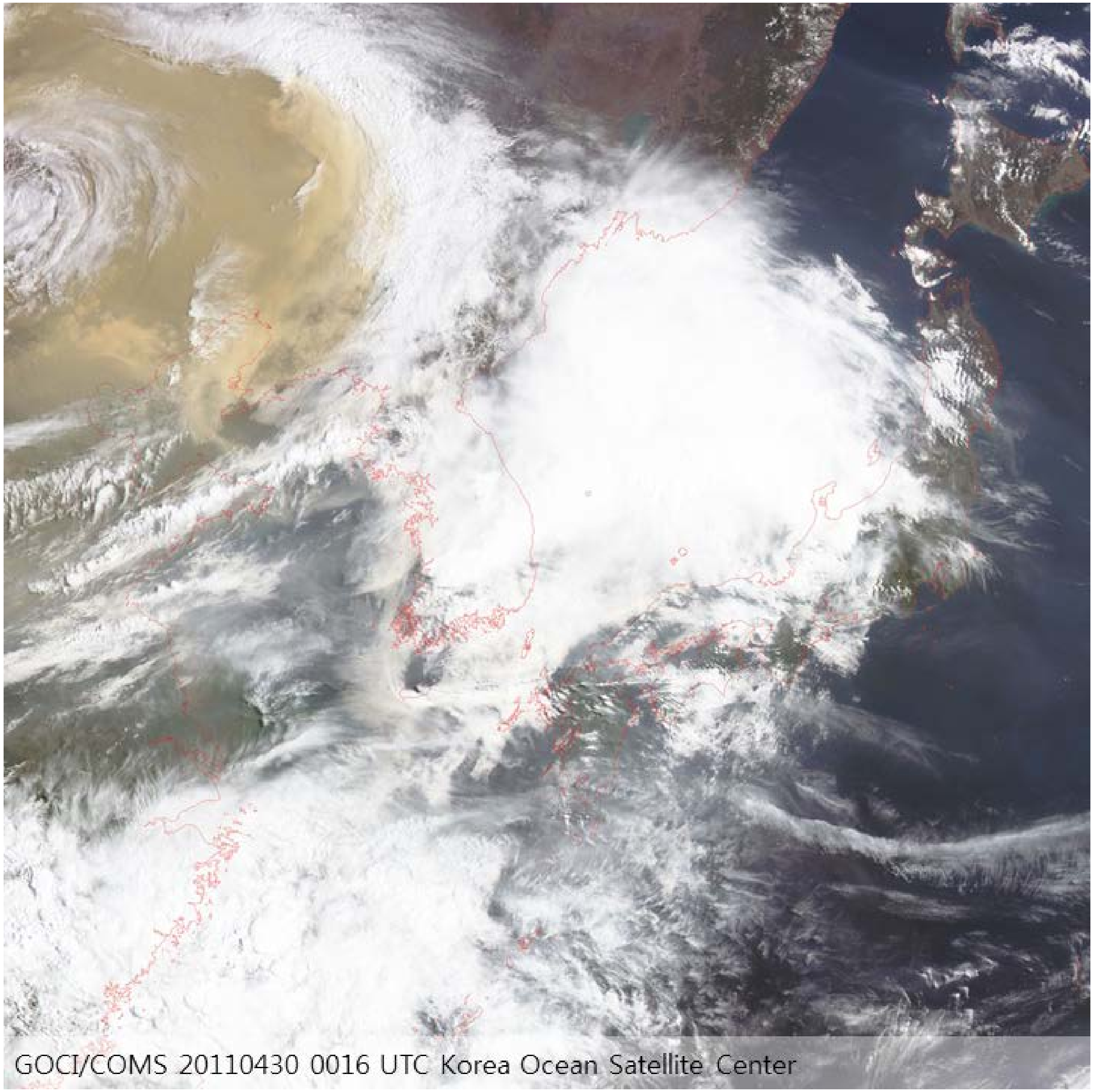
(Courtesy of KOSC)

GOCI examples: Coastal Fog



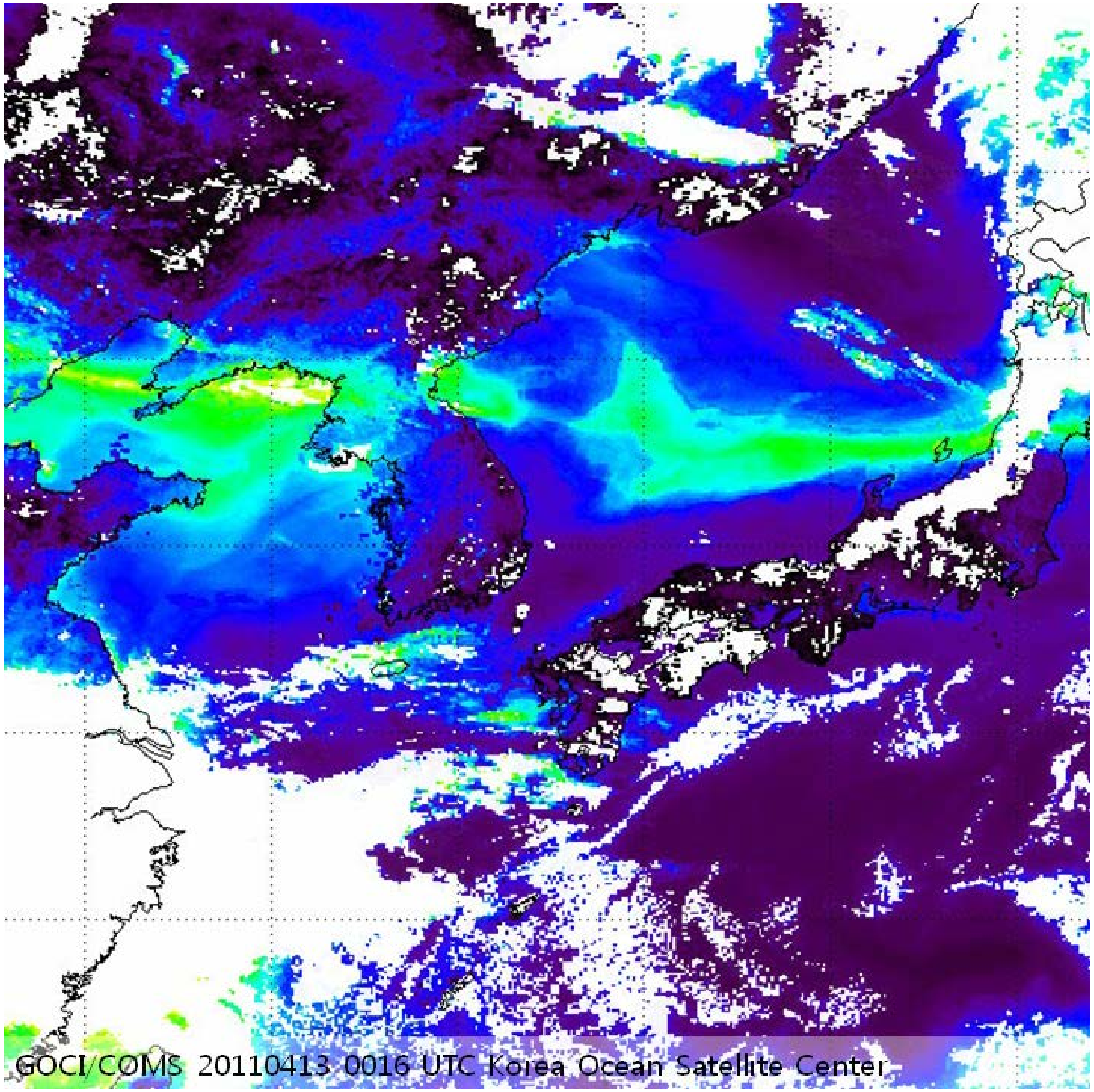
(Courtesy of KOSC)

GOCI examples: Yellow Dust



(Courtesy of KOSC)

GOCI examples: Aerosol optical depth

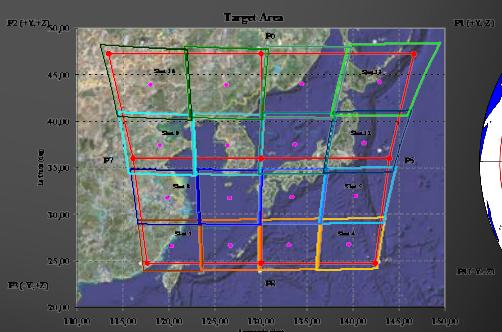


(Courtesy of KOSC)

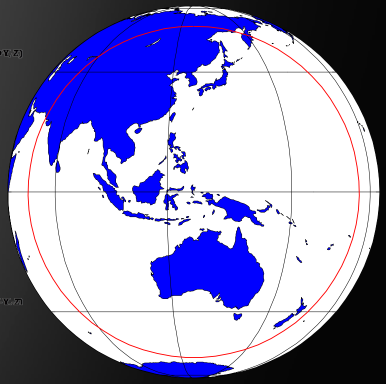
GOCI II (Phase II)

- 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×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.

Items	GOCI Specs	GOCI-II Specs
Increased band number	8 bands	**13 bands**
Improved spatial resolution	500m	**300m**
More observations	8 times/day	**10 times/day**
Pointable & Full Disk coverage	Local Area	**Local Area + Full Disk**



Selected LA

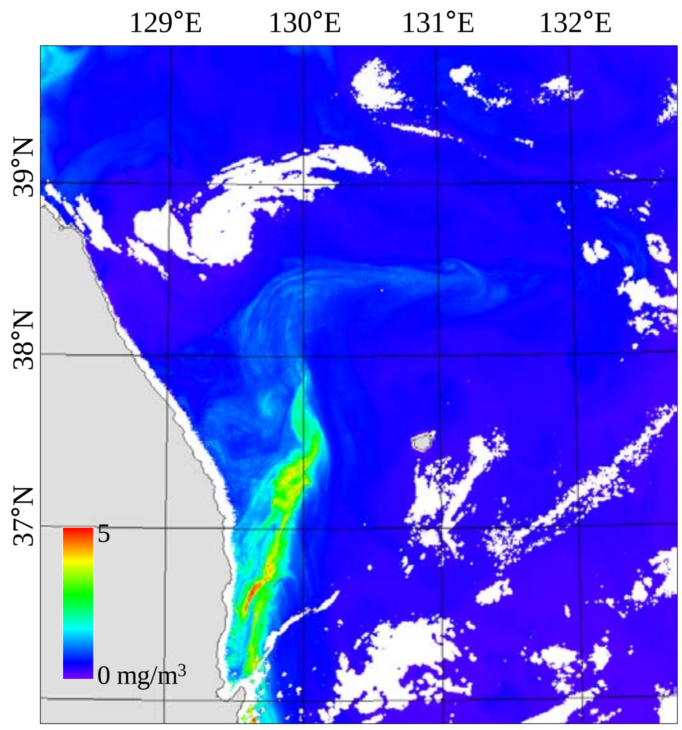


FD (Red Circle)

(Courtesy of KOSC)

Summary of GOCI maps

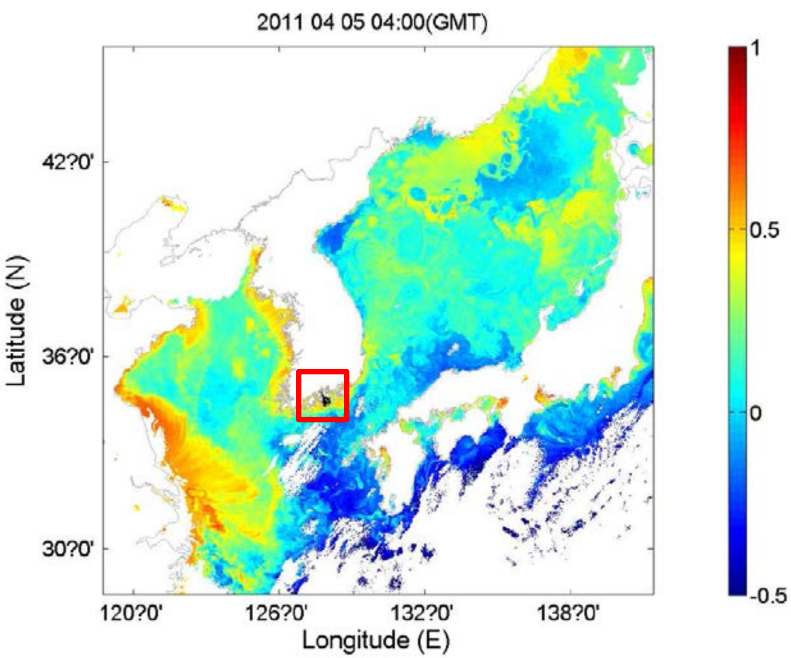
- 0.5 km spatial and hourly temporal resolutions
- Ocean surface passive tracer maps (CHL, TSS, CDOM, etc)
- 8 band signals (raw data) can be incorporated.
- Atmospheric corrections are required
- Missing data on the cloud-covered areas
- Orthographic projection (and bilinear interpolation)

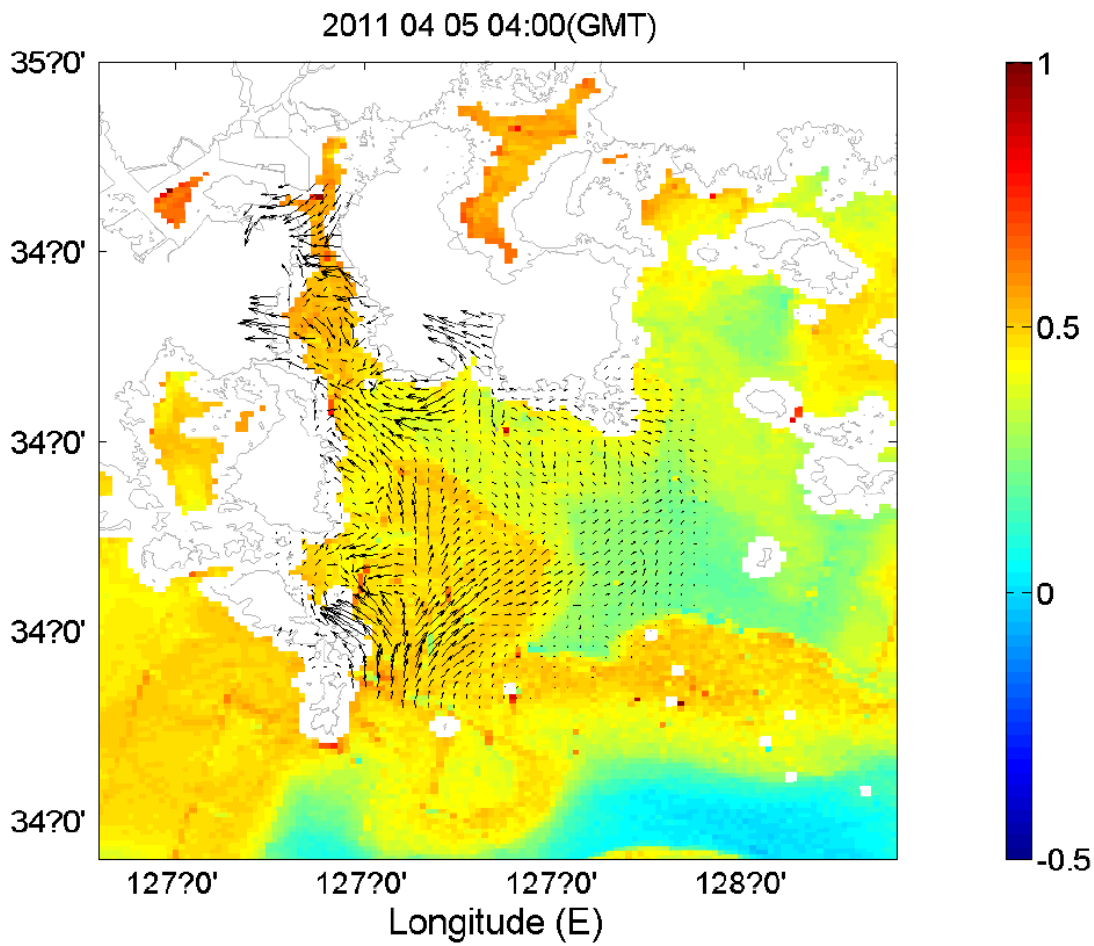


Chlorophyll concentration (CHL)

Submesoscale process studies

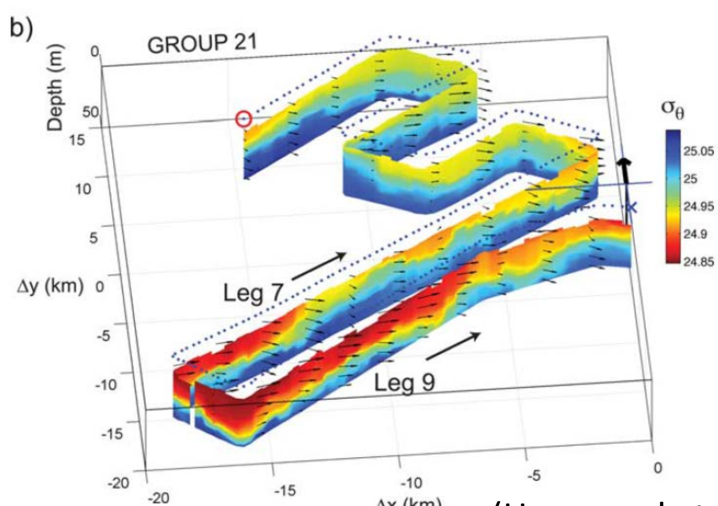
- have benefited from primarily idealized numerical models and theoretical frameworks because they require the use of high-resolution observations of less than one hour in time and O(1-10) km in space.



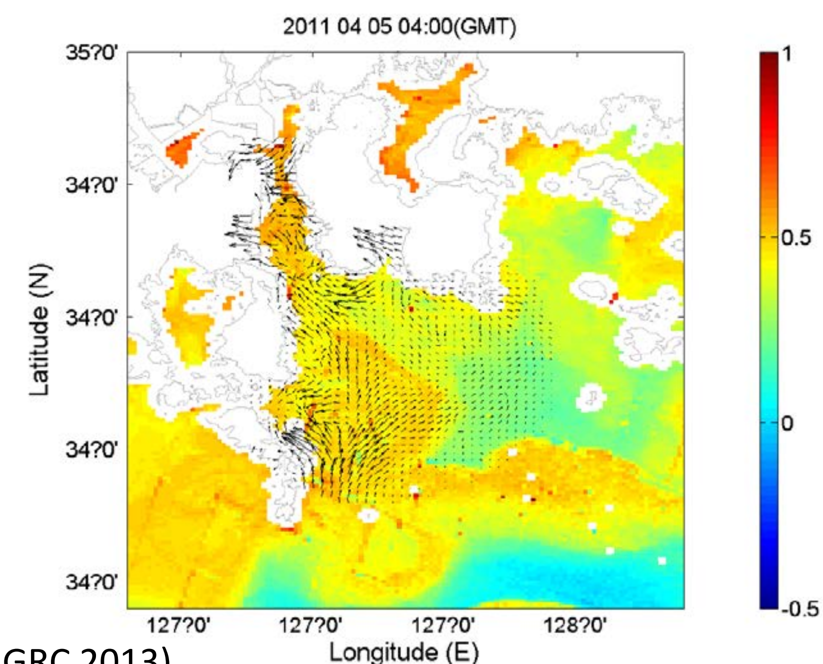


Submesoscale process studies

- 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, 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

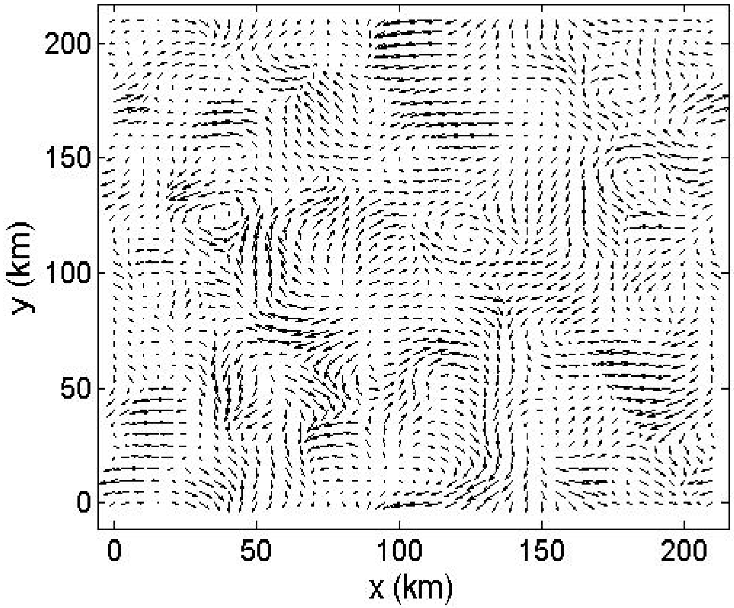
Advection-diffusion equations

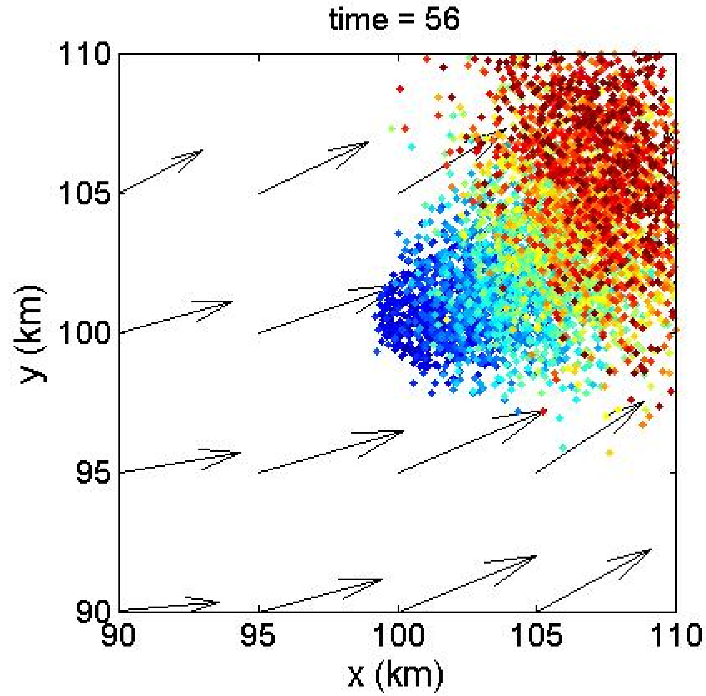
$$\frac{\partial C(\mathbf{x},t)}{\partial t} + \mathbf{u}(\mathbf{x},t)\frac{\partial C(\mathbf{x},t)}{\partial \mathbf{x}} = \kappa \nabla^2 C(\mathbf{x},t)$$

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]
- κ(x, t): Diffusion coefficients [Unknowns]

Advection-diffusion equations





$$x(t) = \int_{t_0}^{t} (u(t') + \varepsilon^u)\mathrm{d}t' + x(t_0) \approx \sum_k (u(t_k) + \varepsilon_k^u)\Delta t + x(t_0)$$

- 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

$$u(x,y,t) = \sum_{m=-M^*}^{M^*} \sum_{n=-N^*}^{N^*} \sum_{s=-S^*}^{S^*} \hat{A}_{mns} \cos \vartheta_{mns} + \hat{B}_{mns} \sin \vartheta_{mns}, \tag{A1}$$

$$v(x,y,t) = \sum_{m=-M^*}^{M^*} \sum_{n=-N^*}^{N^*} \sum_{s=-S^*}^{S^*} \hat{C}_{mns} \cos \vartheta_{mns} + \hat{D}_{mns} \sin \vartheta_{mns}, \tag{A2}$$

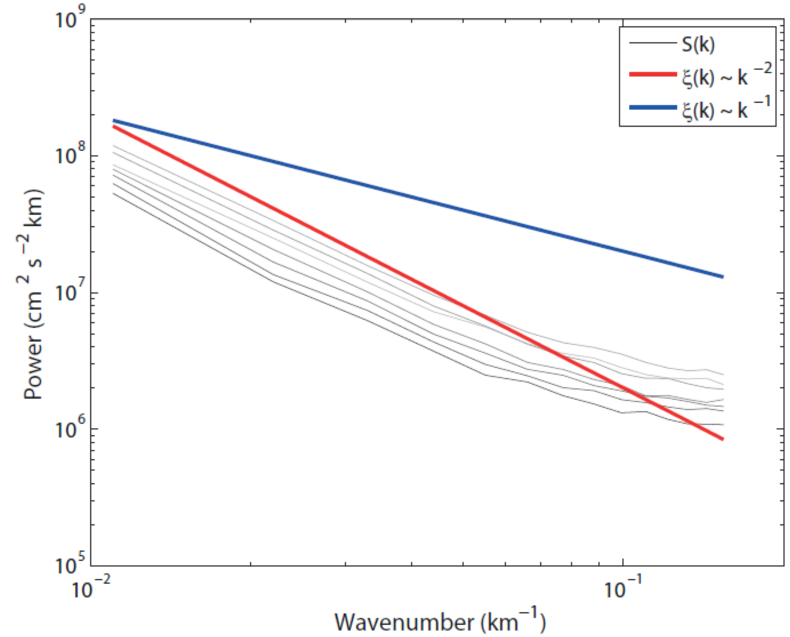
$$\vartheta_{mns} = 2\pi\left(k_m x + l_n y - \sigma_s t\right) = 2\pi\left(\frac{m}{L_x}x + \frac{n}{L_y}y - \sigma_s t\right)$$

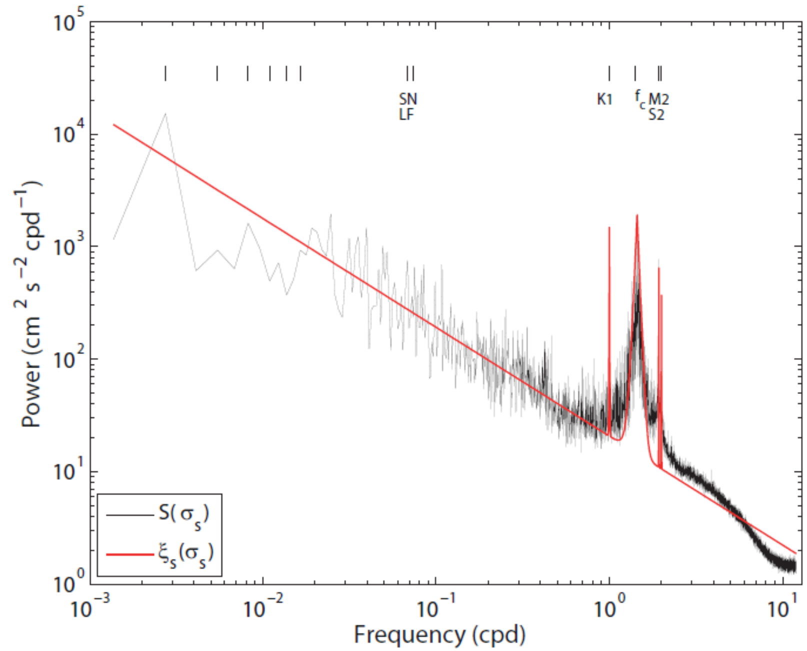
$$\hat{A}_{mns} = \left(\xi_{mn}\right)^{\frac{1}{2}} \xi_s \mathrm{N}(0,1),$$

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

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

$$\xi_s(\sigma_s) = A\sigma_s^{-\alpha} + \sum_{n=1}^{N} B_n \exp\left(-\frac{|\sigma_s - \nu_n|}{(\lambda_t)_n}\right),$$

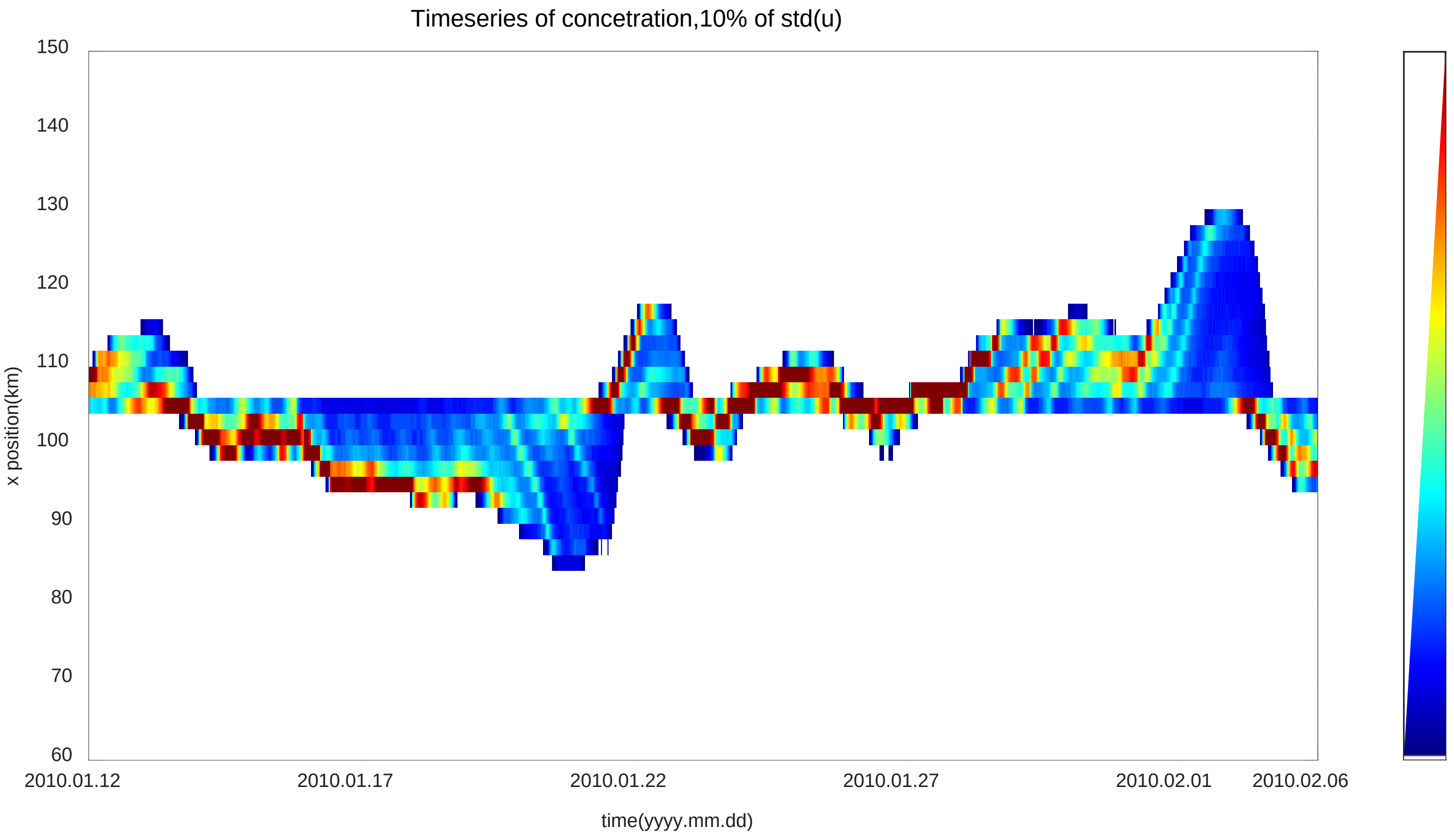




2D->1D advection-diffusion equations

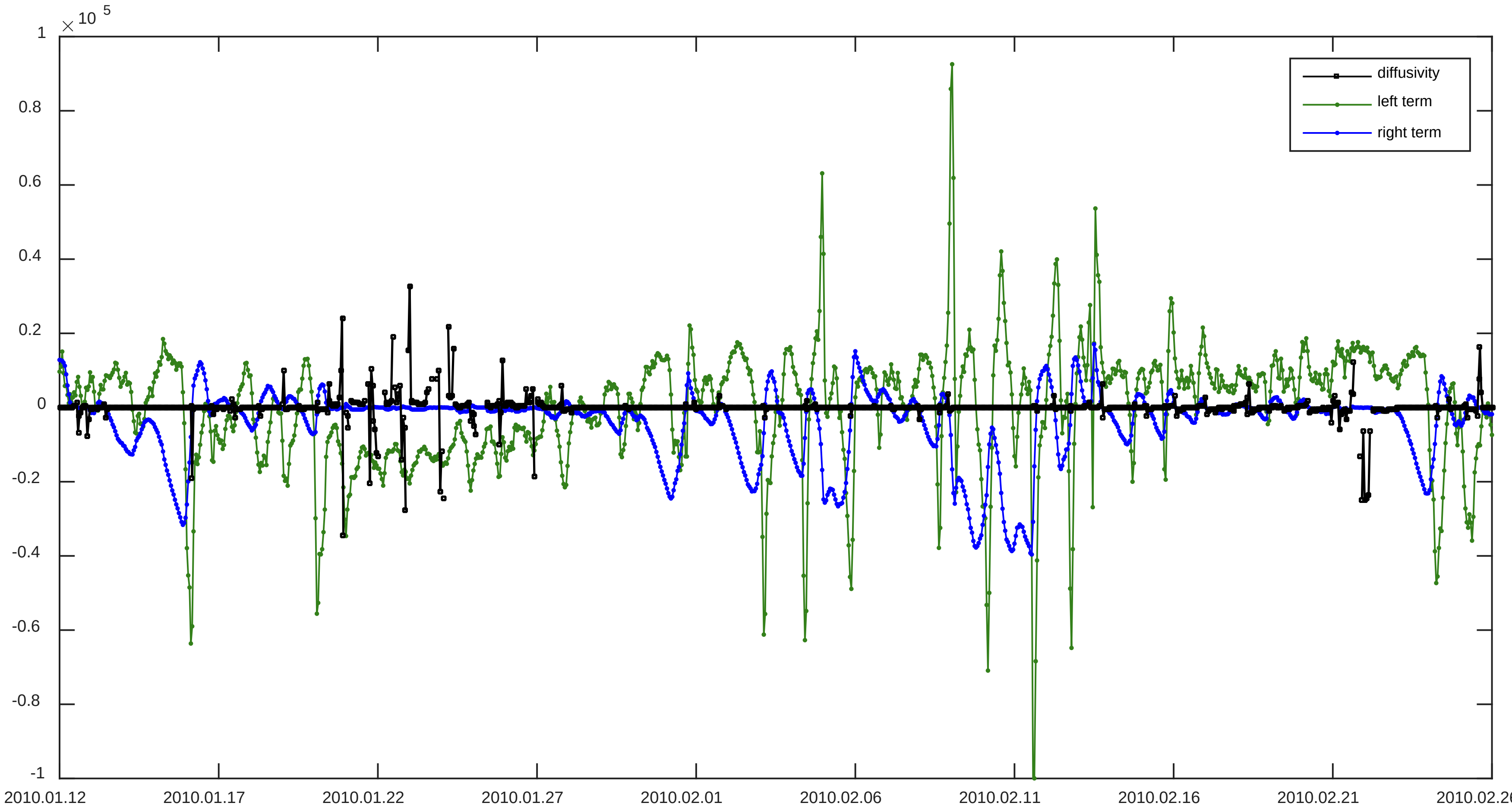
$$\boxed{\frac{\partial C(\mathbf{x},t)}{\partial t} + \mathbf{u}(\mathbf{x},t)\frac{\partial C(\mathbf{x},t)}{\partial \mathbf{x}} = \kappa \nabla^2 C(\mathbf{x},t)}$$

$$\Rightarrow \boxed{\frac{\partial C(y,t)}{\partial t} + v(y,t)\frac{\partial C(y,t)}{\partial y} = \kappa \frac{\partial^2 C(y,t)}{\partial y^2}}$$



Estimates of diffusion coefficients

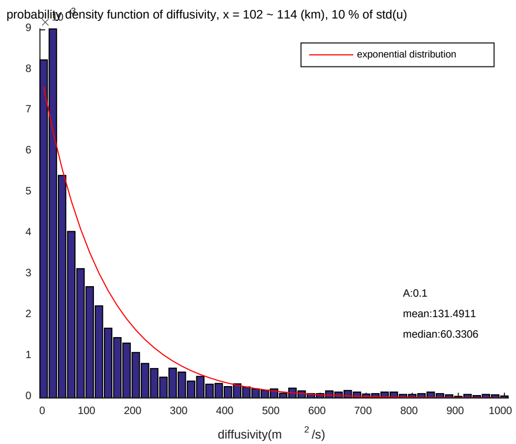
$$\frac{\partial C(y,t)}{\partial t} + v(y,t)\frac{\partial C(y,t)}{\partial y} = \kappa \frac{\partial^2 C(y,t)}{\partial y^2}$$



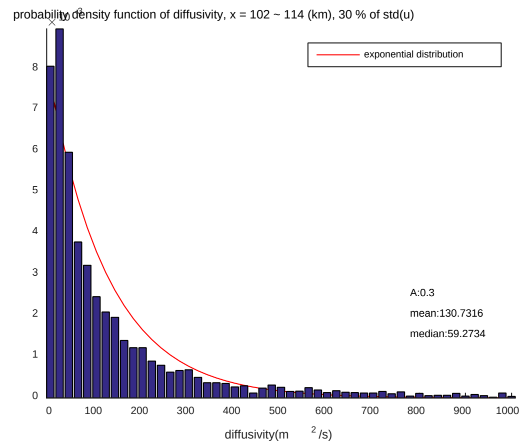
Distribution of diffusion coefficients

Condition: 1) particle 20, life span:50h

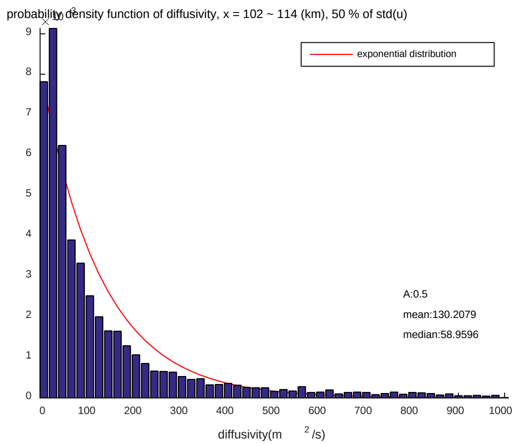
2) abnormally large diffusivity is removed (>1000)



Random parameter:10 %



Random parameter:30 %



Random parameter:50 %

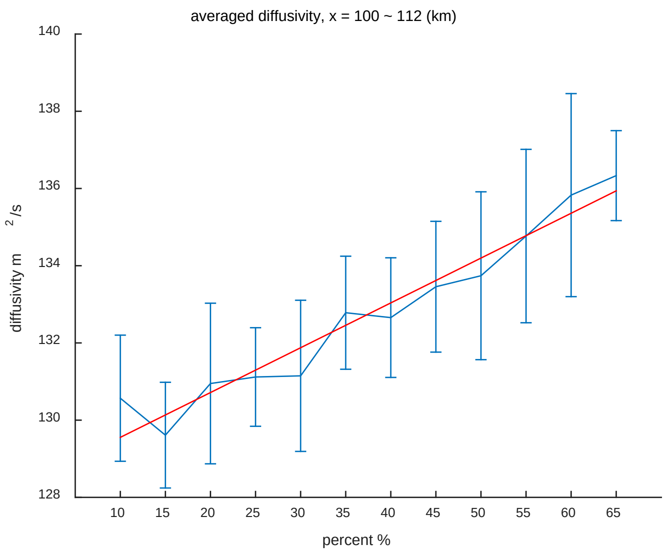
Exponential distribution

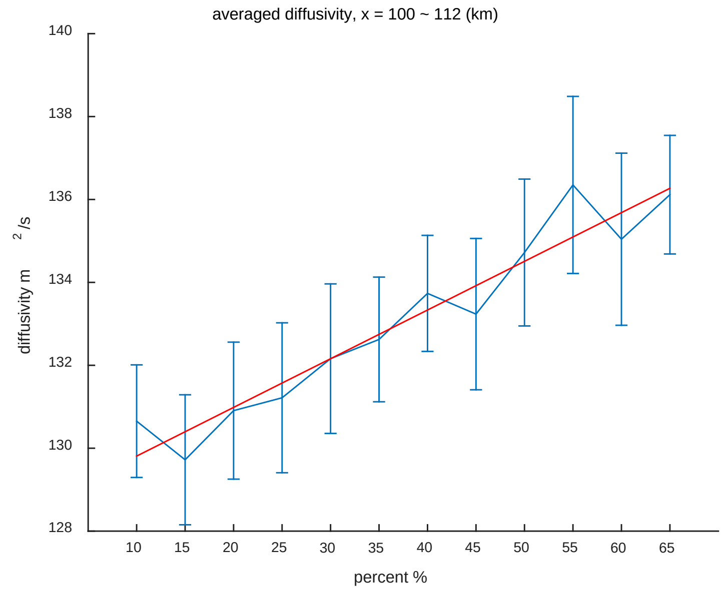
$$f(x) = \lambda e^{-\lambda x}$$

Diffusion coefficients and unceratinty

a: random parameter

b: diffusivity





b=0.1161a+128.3934

residual = 1.6680

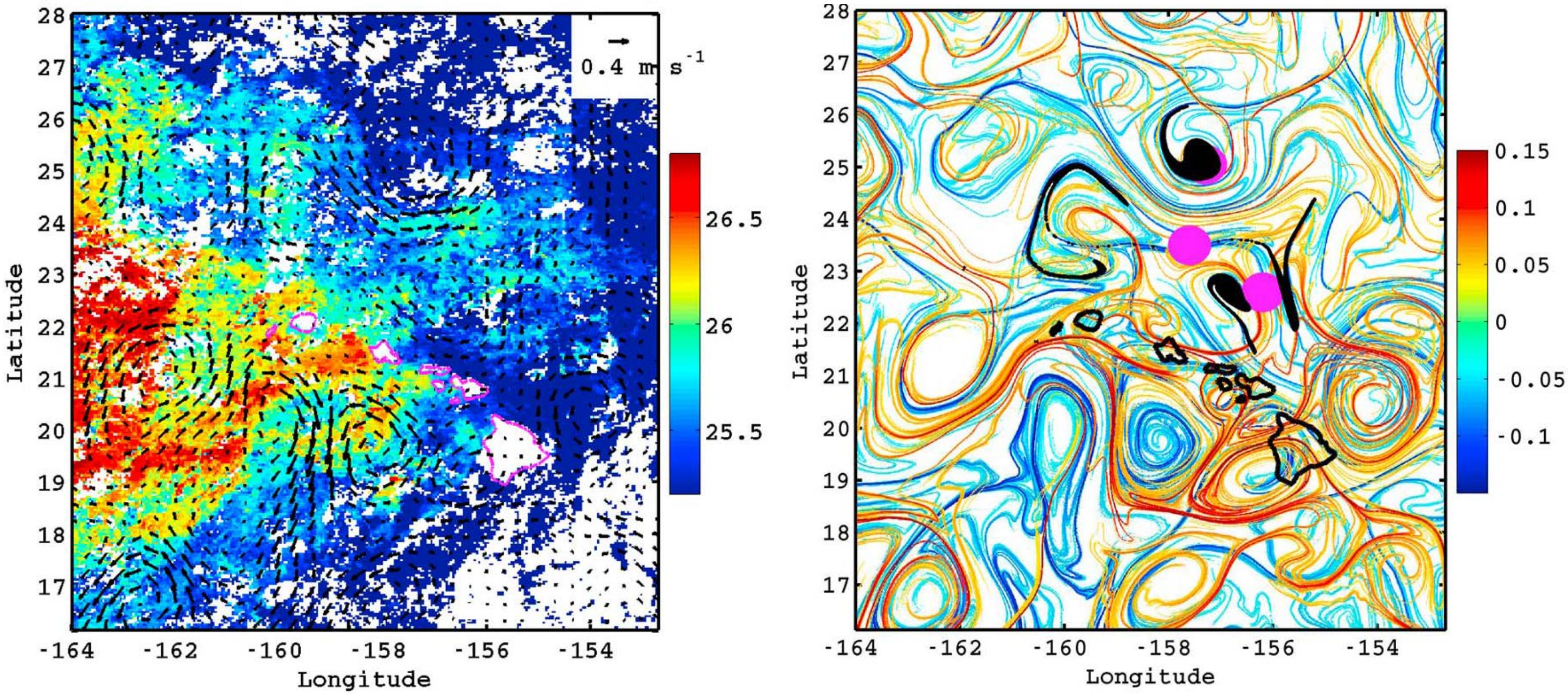
b= 0.1174 a+ 128.6356

residual = 2.0005

Potential research topics

- Tracking of water-borne materials at submesoscale
  - Pollutants; red tides; oil spills; larvae transports
  - Particle trajectory model
  - 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

SST w/ current fields and FSLE

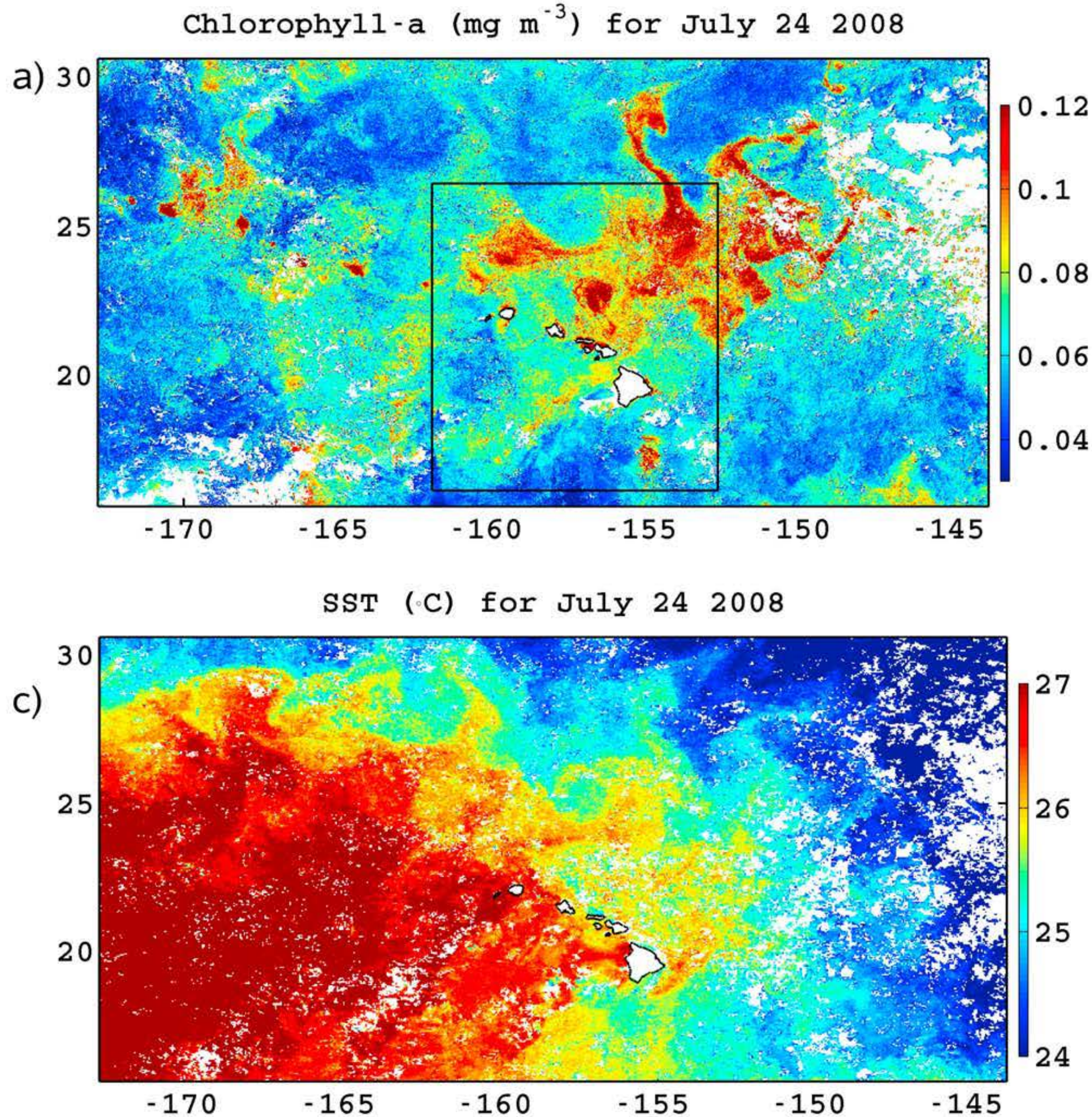


- SST with AVISO geostrophic currents off Hawaii
- Manifolds obtained from FSLEs
- Limitations on spatial and temporal scales

(Calil et al JGRC 2011)

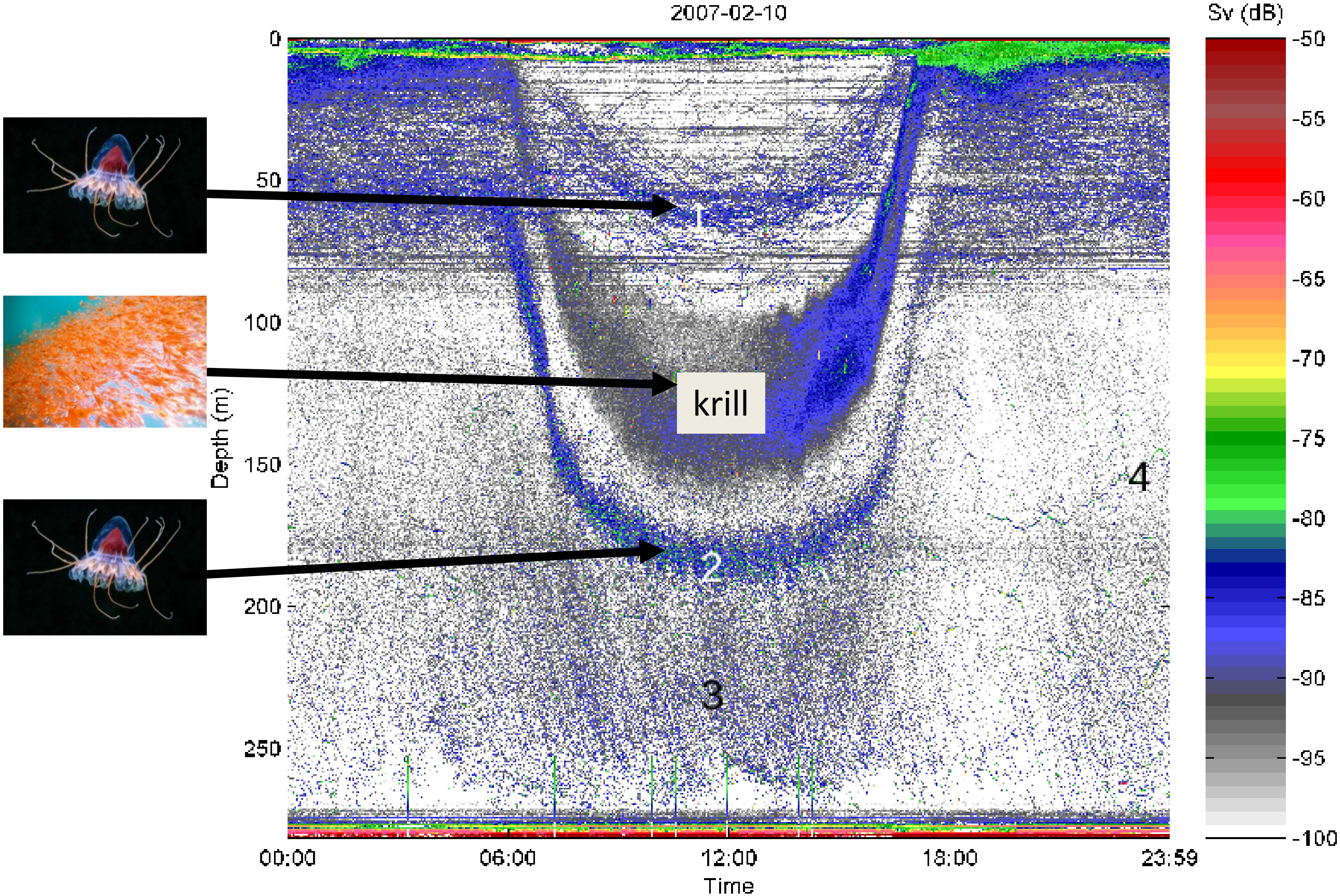
CHL and SST

- Cross-validation with satellite CHL maps and SST.



(Calil et al JGRC 2011)

Echo sounder image of vertically migrating zooplankton



www.oceanobservatory.com

Potential research topics

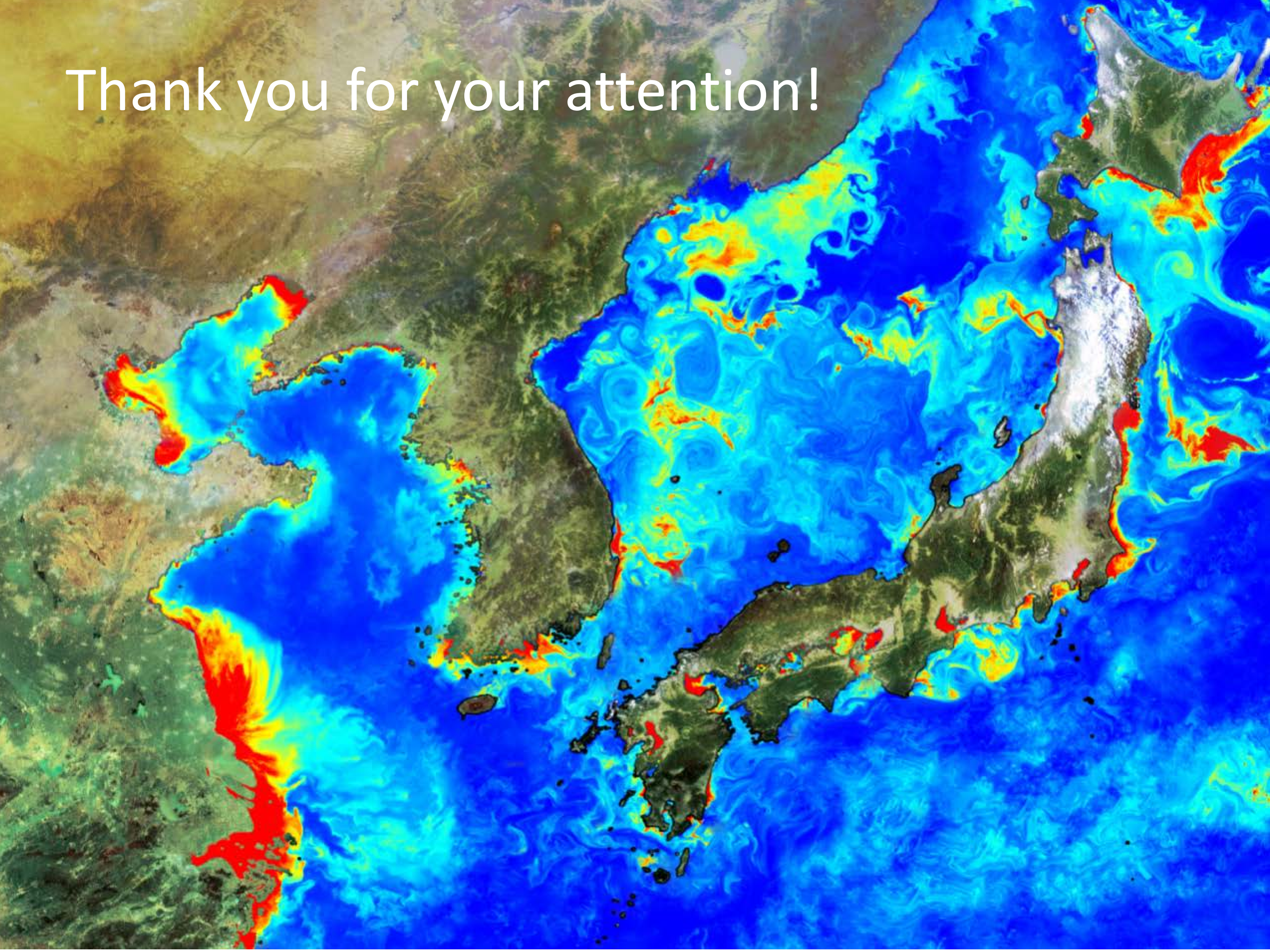
- Tracking of water-borne materials at submesoscale
  - Pollutants; red tides; oil spills; larvae transports
  - Particle trajectory model
  - Estimates of diffusion coefficients using 1D/2D advection-diffusion equations
- Bio-physical interactions at submesoscale
  - Finite-size/Finite-time Lyapunov 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

Conclusion

- 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 submesocale processes.
- Corrections of atmospheric signals are required.

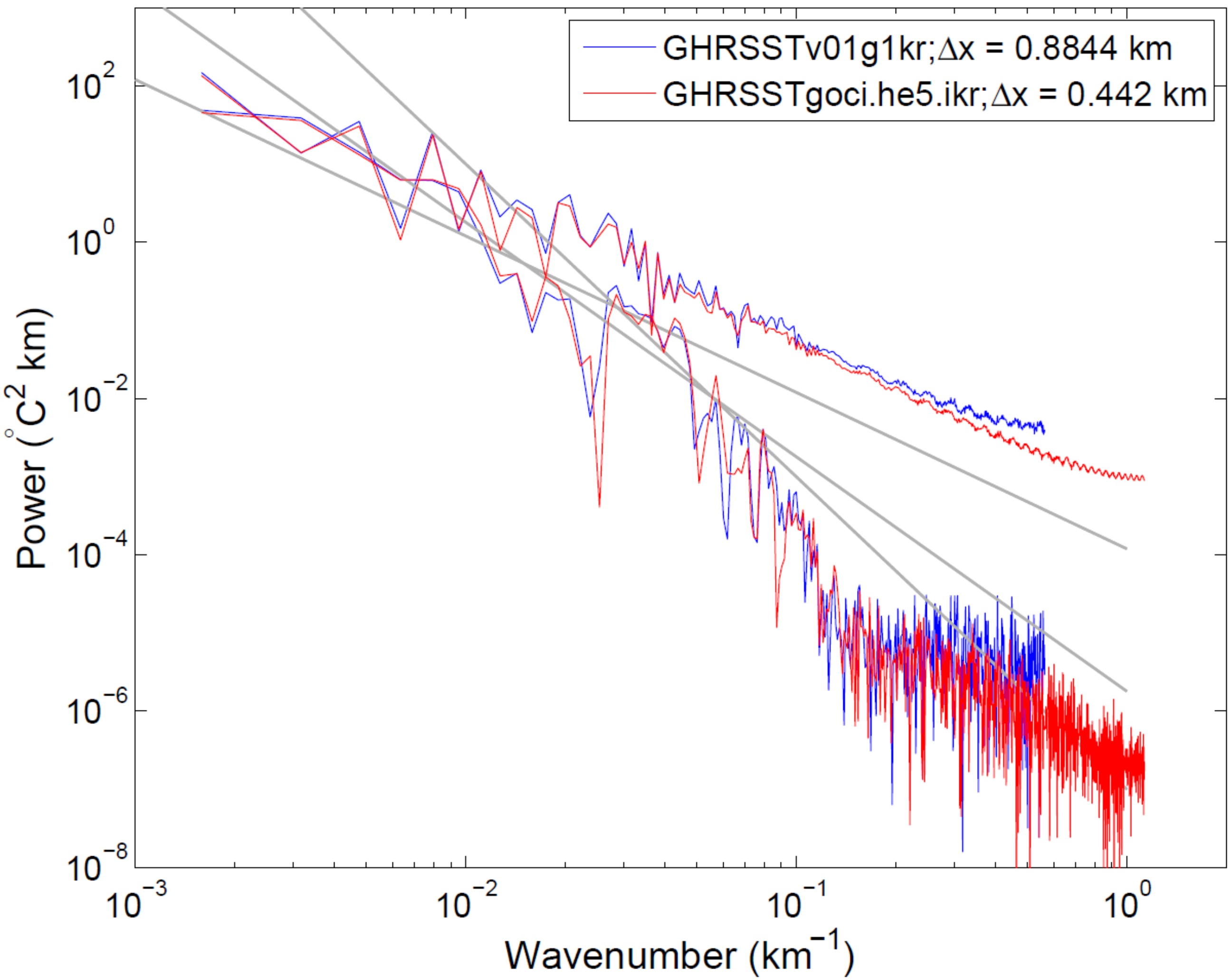
- Please stay tune…!

Thank you for your attention!



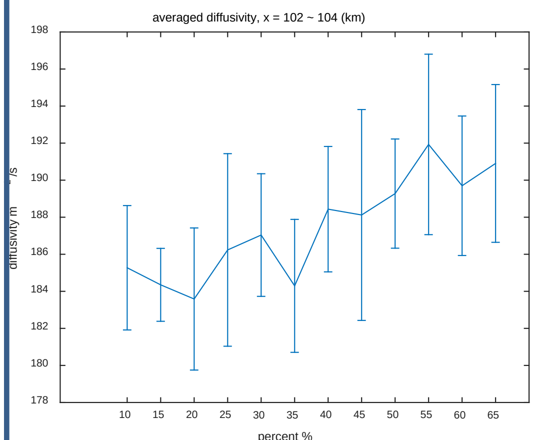
Projection in GOCI data

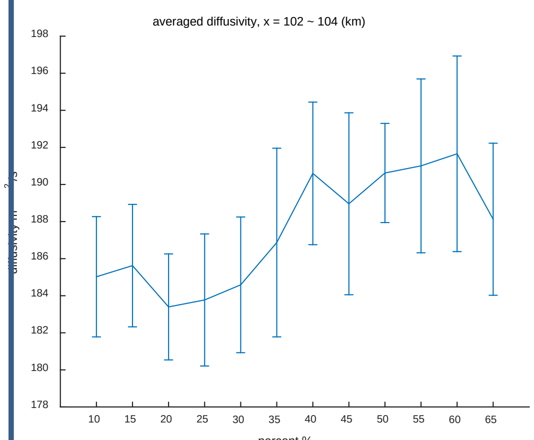
- 0.5 km resolution; orthographic projection and bilinear interpolation



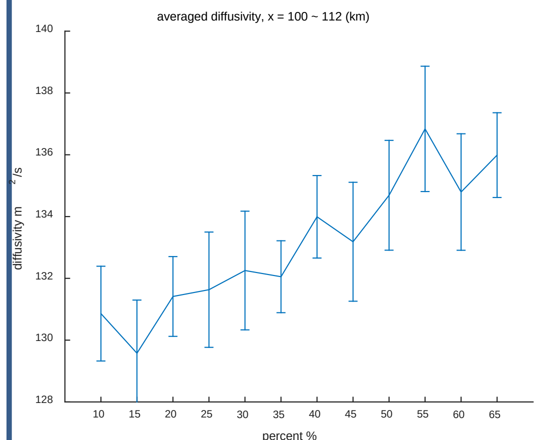
Averaged diffusion coefficients

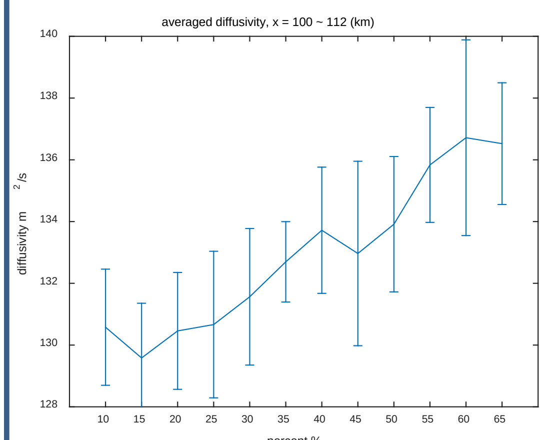
(a) x: 102~104km





(b) x: 100~112km





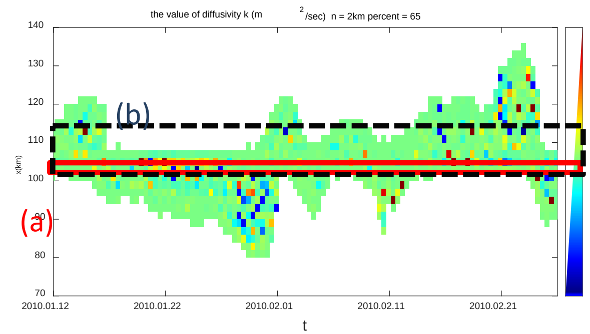
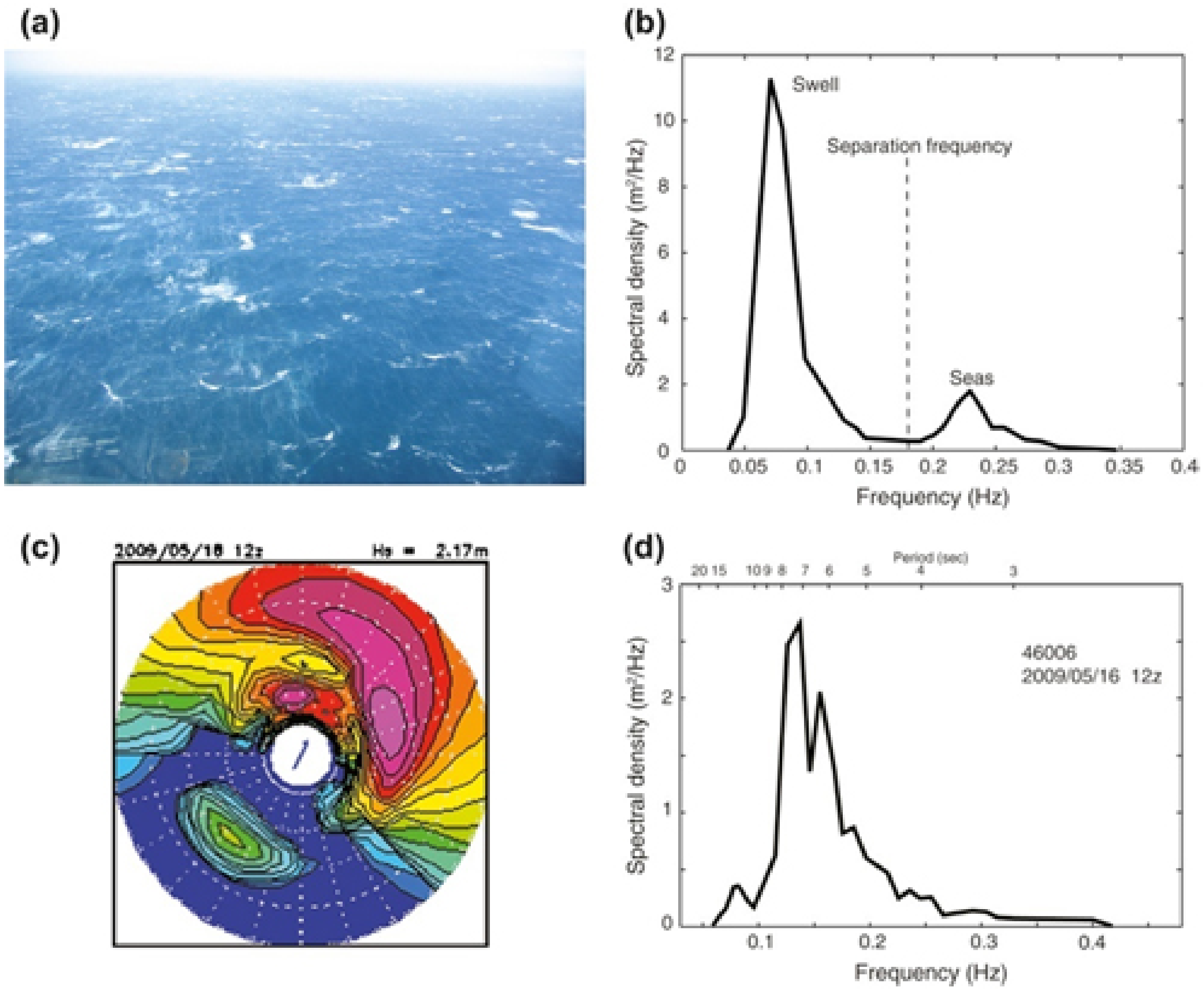


Figure2. For indicating position of (a) and (b)

Before we start....

Aha~

used when something is suddenly seen, found, or understood



(a)
(b)
Swell
Separation frequency
Seas
Spectral density (m²/Hz)
Frequency (Hz)
0
2
4
6
8
10
12
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
(c)
2009/05/18 12z
Hs = 2.17m
(d)
Period (sec)
20
15
10
9
8
7
6
5
4
3
46006
2009/05/16 12z
Spectral density (m²/Hz)
Frequency (Hz)
1
2
3

Outline

- What’s the submesoscale processes?
- An overview on Geostationary Ocean Color Imagery (GOCI) products?
- How can we use the GOCI maps for relevant submesoscale studies?
  - Energy spectra of passive tracers
  - Submeoscale horizontal mixing and diffusion (?)
- Lessons

Submesoscale processes

- An easy definition? Secondary circulation at the front?
- An easy example (as shown in GOCI data)?
- Passive tracer snapshots and zoom-in