Surface horizontal diffusivity estimated from submesoscale observations of surface currents and passive tracers

Jang Gon Yoo[1], Eun Ae Lee[1], Sung Yong Kim[1]

[1] *Department of Mechanical Engineering, School of Mechanical and Aerospace Engineering, Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea*

KAIST

ENGINEERING FOR MANKIND | KAIST Department of Mechanical Engineering

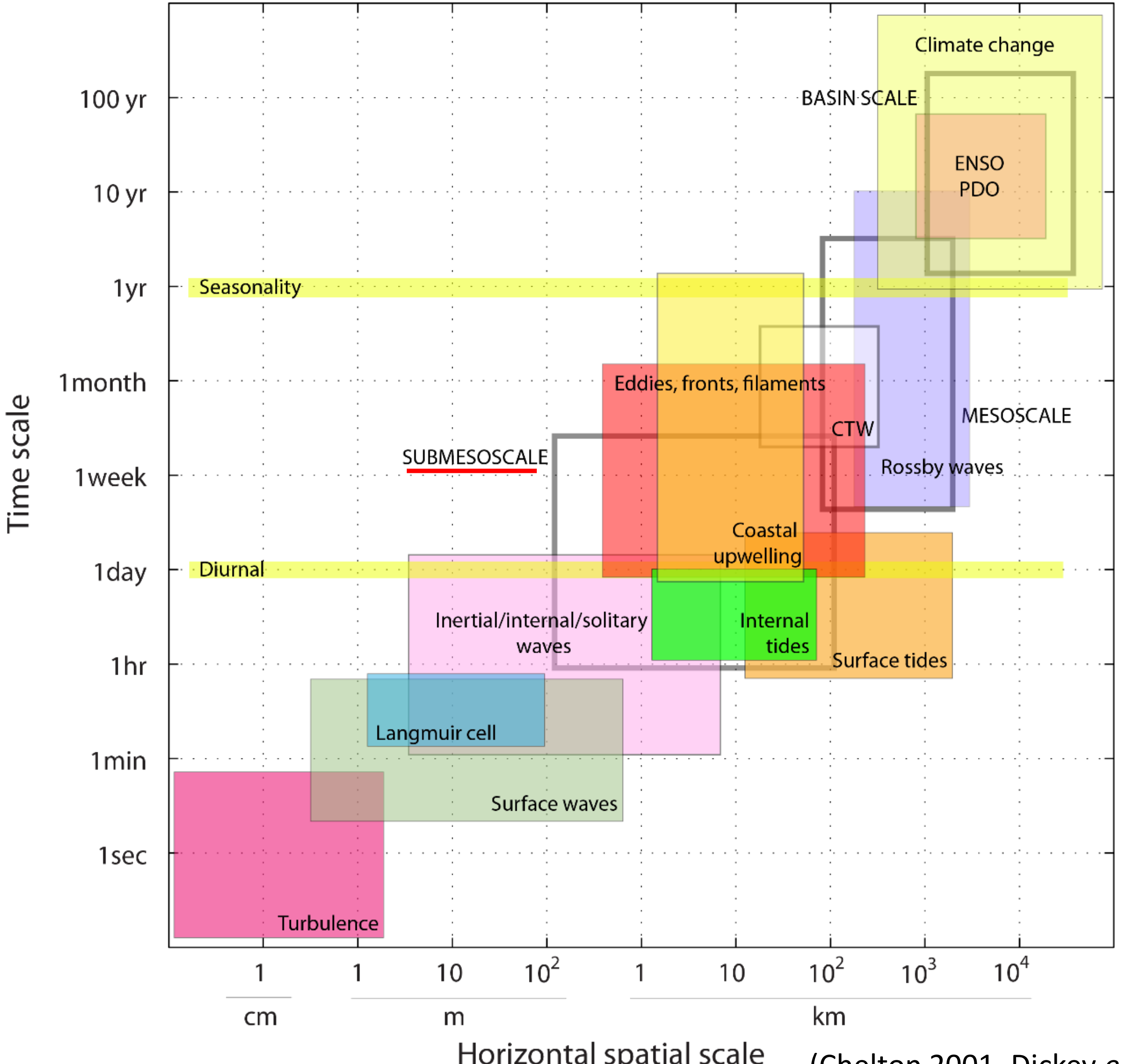
Motivation

- In tracking of water-borne materials (pollutants, search-rescue, larvae, etc), understanding of their advection and diffusion matter.
- Particularly, the physical processes at submesoscale (less than one hour in time and 100 km in space) have got attentions in ocean science community.
- Available observational resources of coastal radar-derived surface currents (km, hourly) and GOCI imagery (km, hourly) can be used to examine the advection-diffusion issue.
- We try to quantify the diffusion based on observations, which can be applicable to tracking water-borne materials with cautions in handling the observational noise and errors....

Outline

- Introduction to oceanic submesoscale processes
- Advection-diffusion equations
- Simulations with idealized currents and density maps
- Conclusion

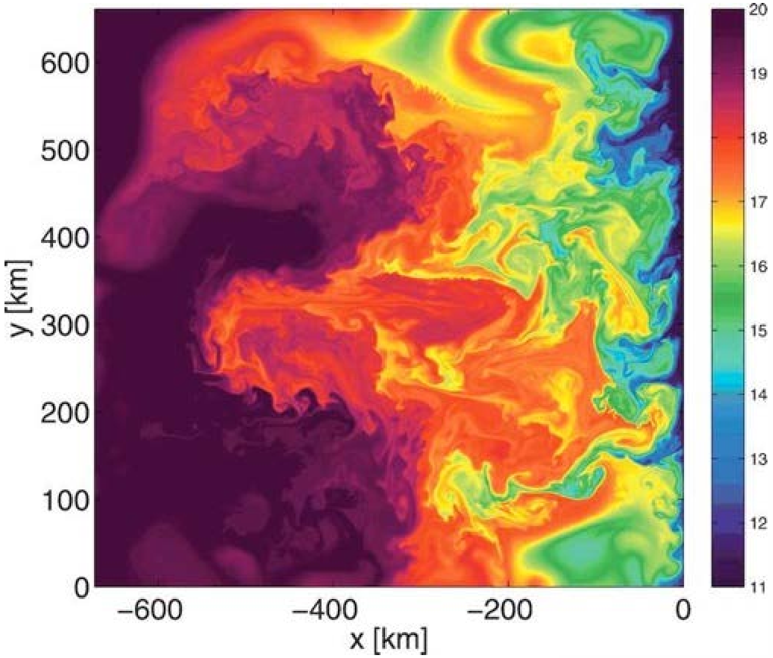
Oceanic processes in time and spatial scales

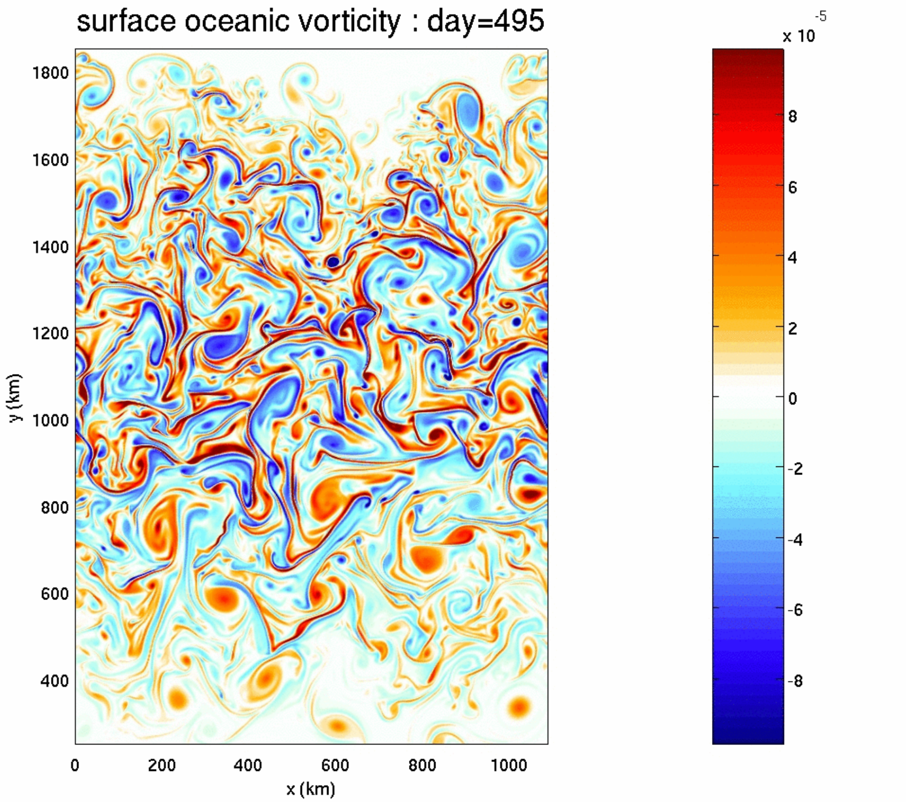


(Chelton 2001, Dickey *et al*, RG 2006; Kim 2015)

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

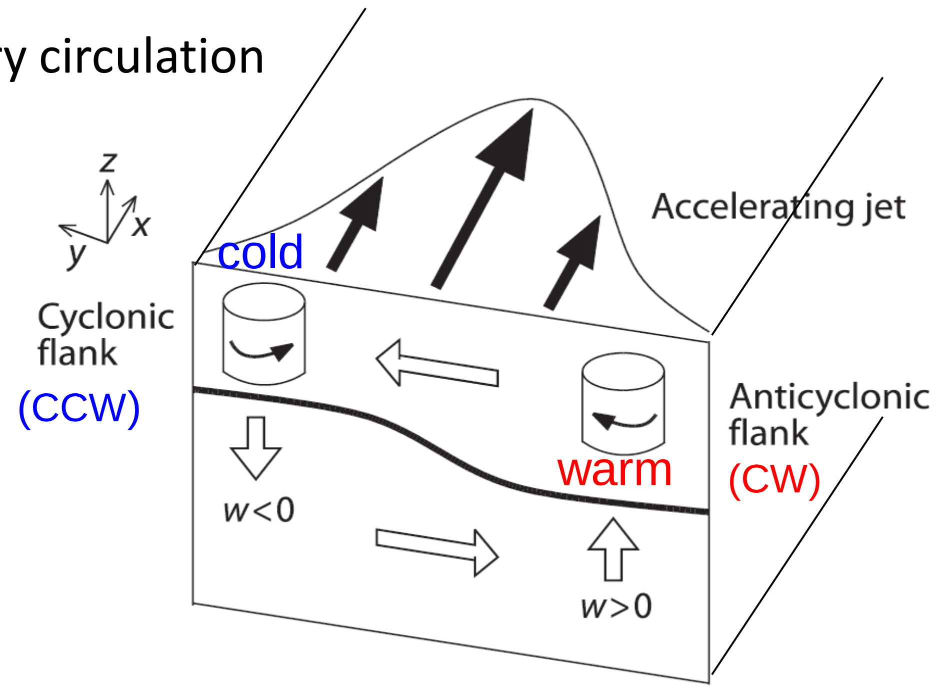




(Courtesy of X. Capet and P. Klein)

Submesoscale processes

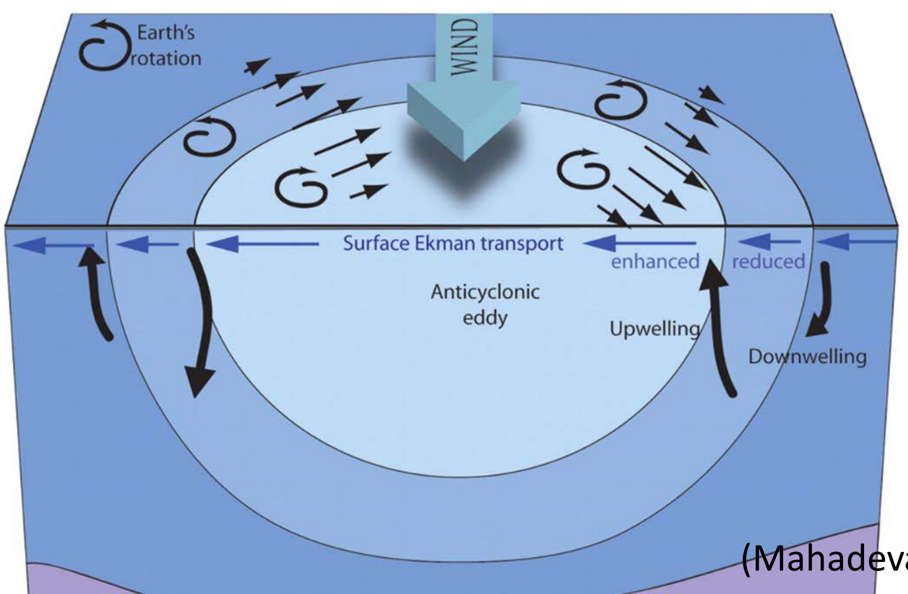
- O(1) Rossby number [Ro = ζ/f]
- A horizontal scale smaller than the first baroclinic Rossby deformation radius; O(1-10) km
- Frequently observed as fronts, eddies, and filaments
- Contribute to the vertical transport of oceanic tracers, mass, and buoyancy and rectify the mixed-layer structure and upper-ocean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



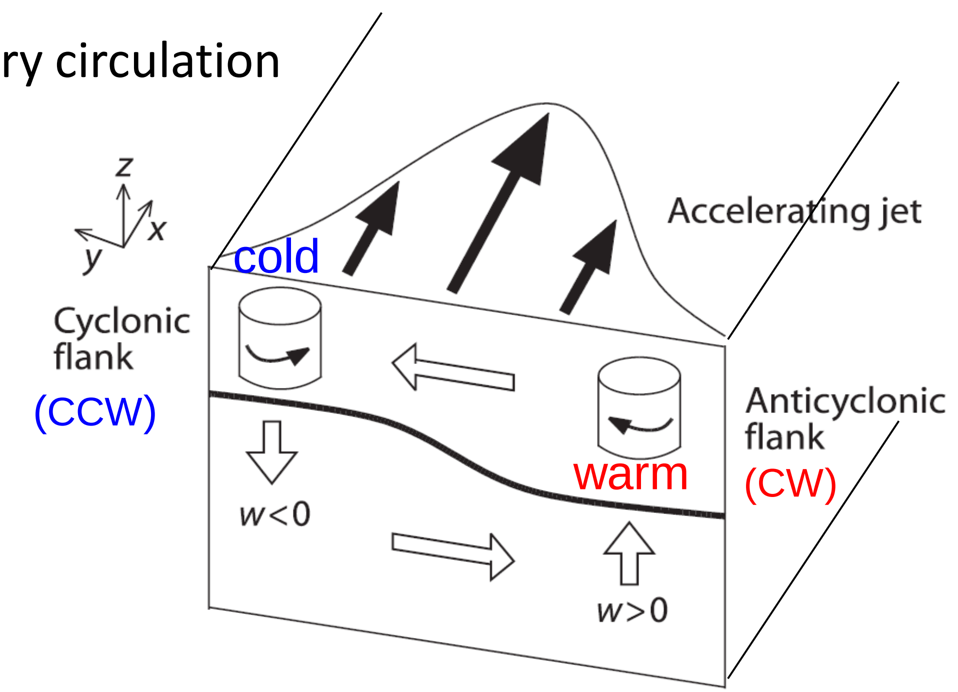
(Williams and Follows, 2003)

Submesoscale processes

- O(1) Rossby number [Ro = 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



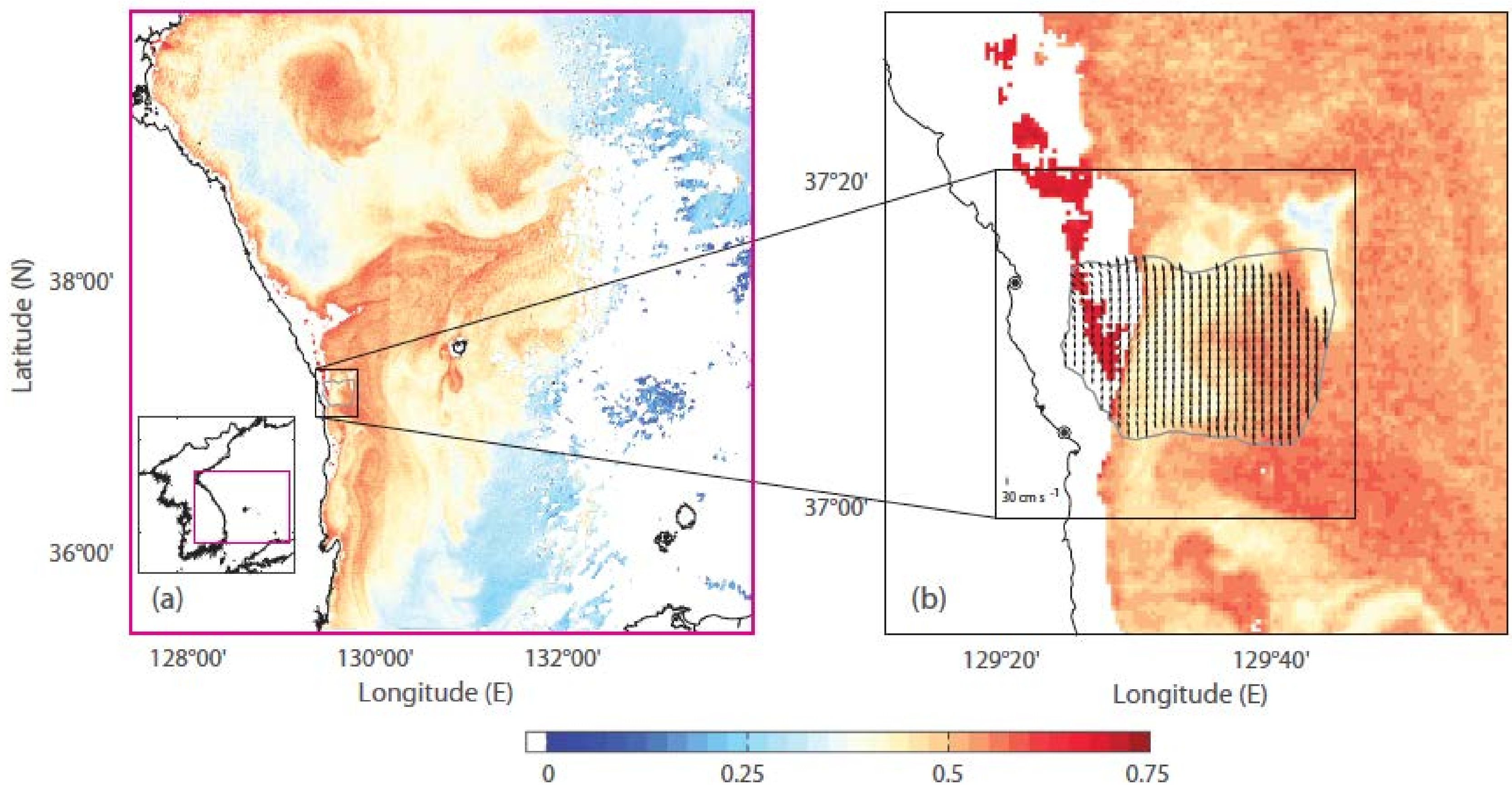
(Mahadevan et al, Science, 2008)



(Williams and Follows, 2003)

Submesoscale process studies

- Have been 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.



Advection-diffusion equations (2D)

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

where

- C(x,t): Concentration of harmful algae and pollutants. In-situ observations, satellite-derived maps of passive tracers (e.g., Chlorophyll; TSS; CDOM) [e.g., GOCI, AVHRR products]
- u(x,t): (Geostrophic) current field [e.g., HFR surface current maps; AVISO geostrophic currents]
- κ(x, t): Diffusion coefficients [Unknowns]

Known current fields and concentration maps

- A spectral model is built based on spectra of observed surface currents.

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

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

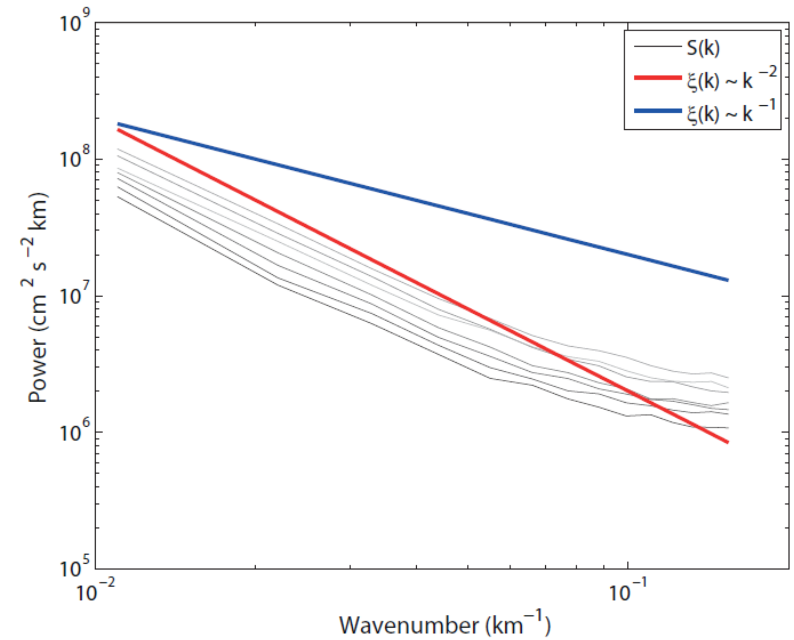
$$\vartheta_{mns} = 2\pi \left(k_m x + l_n y - \sigma_s t\right) = 2\pi \left(\frac{m}{L_x} x + \frac{n}{L_y} y - \sigma_s t\right)$$

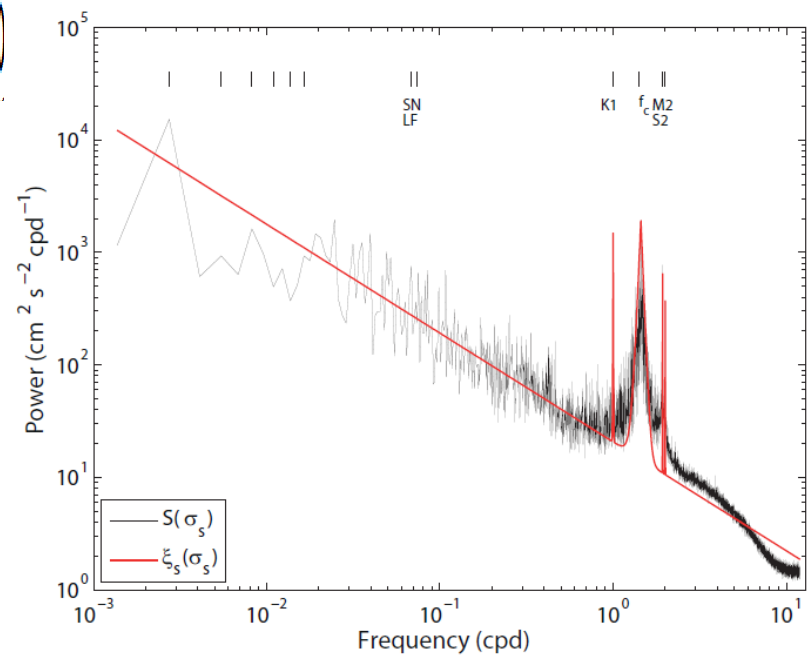
$$\hat{A}_{mns} = \left(\xi_{mn}\right)^{\frac{1}{2}} \xi_s \mathrm{N}(0,1),$$

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

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

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

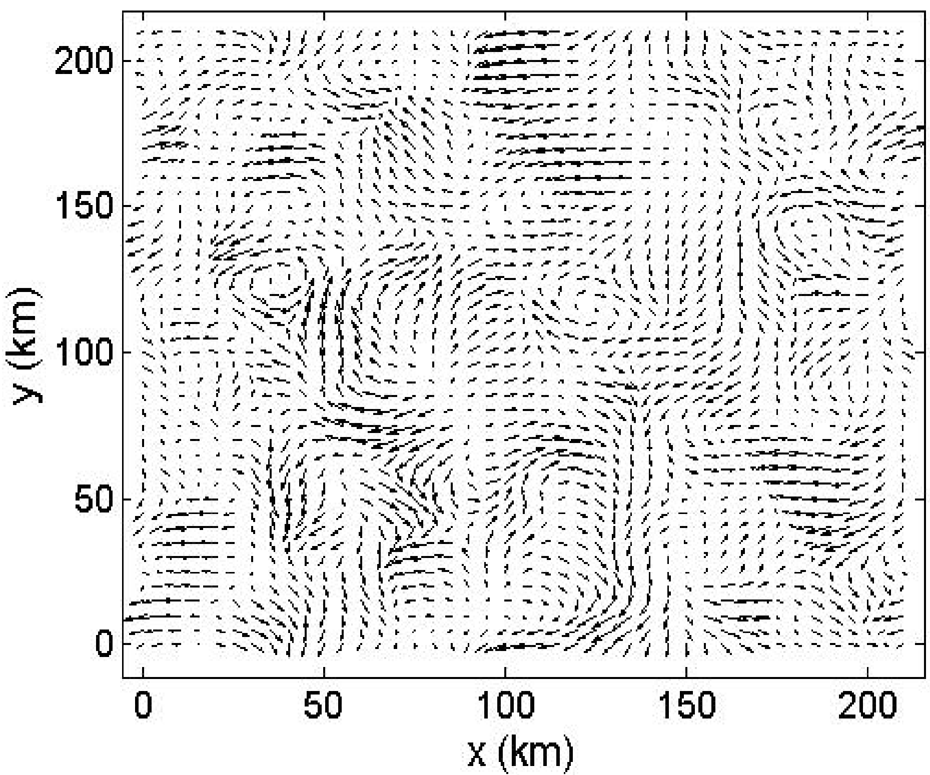


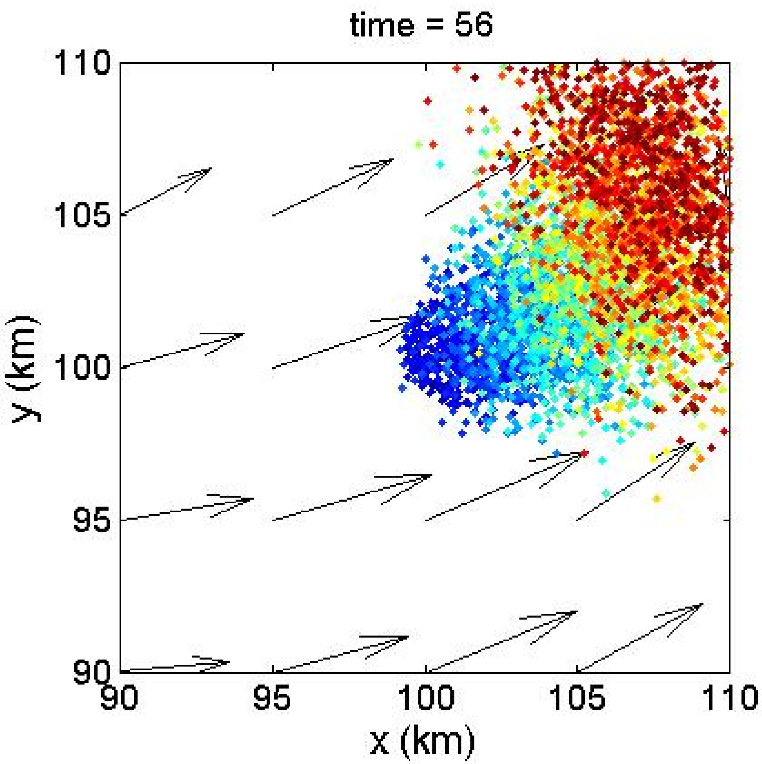


Known current fields and concentration maps

- A spectral model, built based on spectra of observed surface currents, generates current fields in space and time.
- From particle tracking using a random walk scheme, we generate the concentration map of tracer.

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



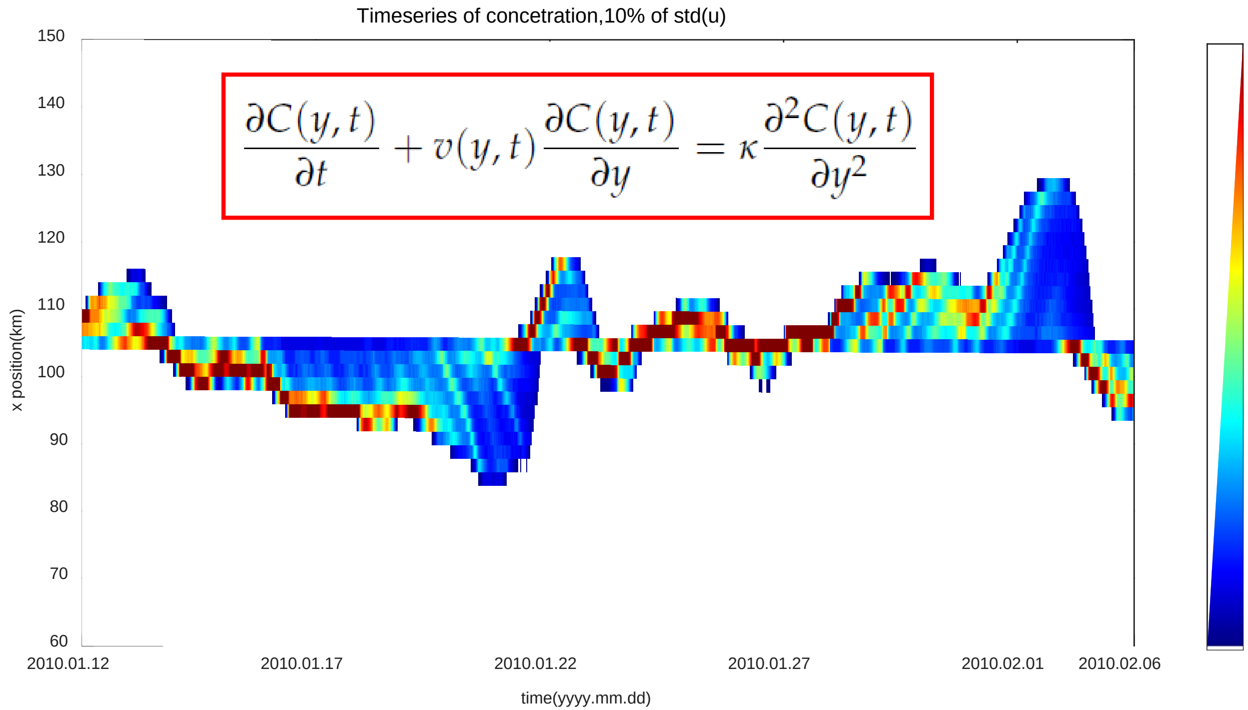


Known current fields and concentration maps

- A spectral model, built based on spectra of observed surface currents, generates current fields in space and time.
- From particle tracking using a random walk scheme, we generate the concentration map of tracer.

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

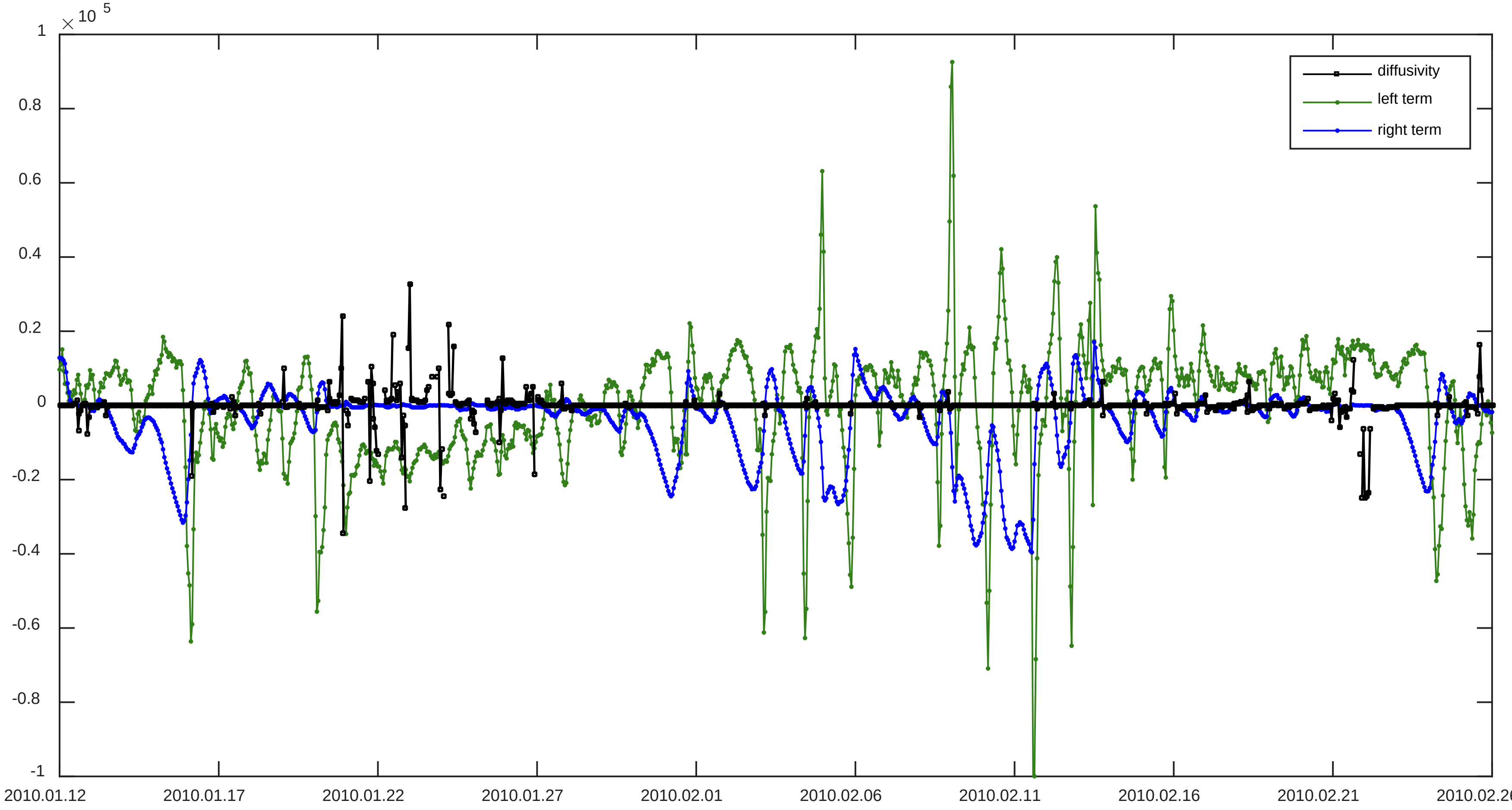
- Find a relationship between a random parameter (ε) and diffusion coefficient (κ) in the equation (2D->1D).



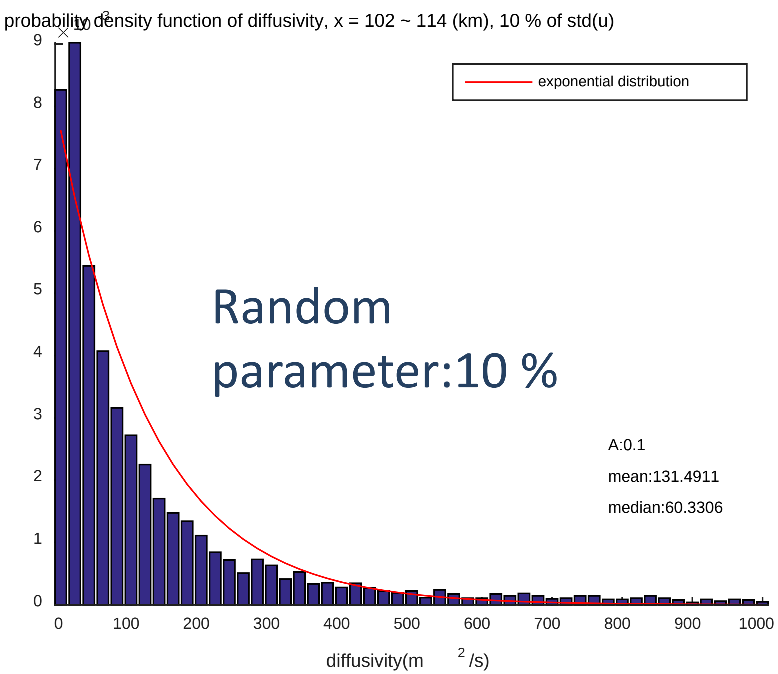
$$\frac{\partial C(y,t)}{\partial t} + v(y,t)\frac{\partial C(y,t)}{\partial y} = \kappa \frac{\partial^2 C(y,t)}{\partial y^2}$$

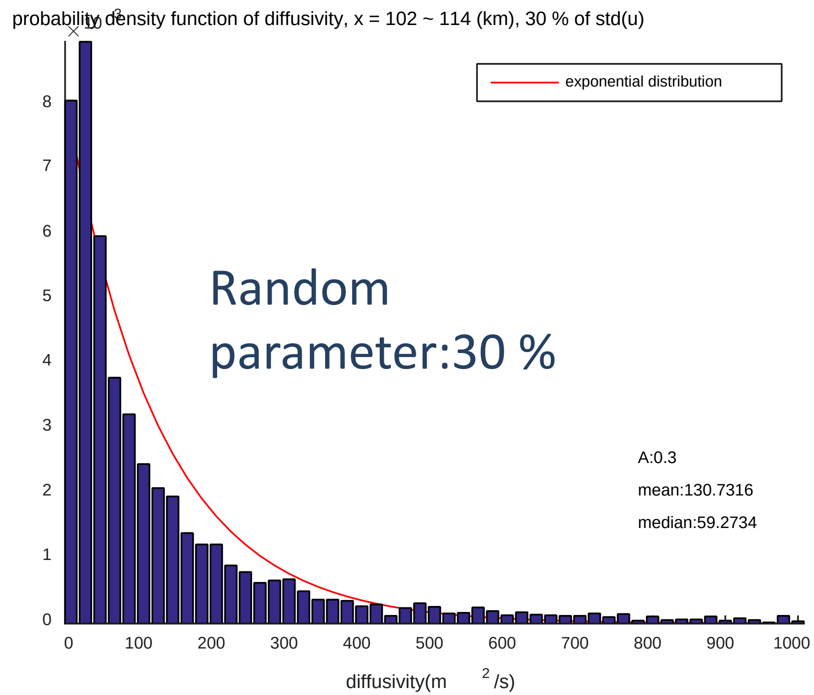
An example of time series in AD equations

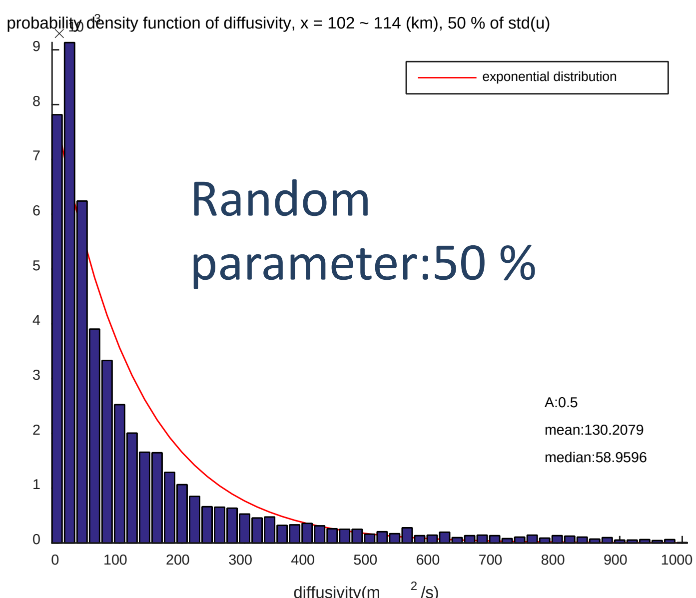
$$\frac{\partial C(y,t)}{\partial t} + v(y,t)\frac{\partial C(y,t)}{\partial y} = \kappa \frac{\partial^2 C(y,t)}{\partial y^2}$$



Distribution of diffusion coefficients

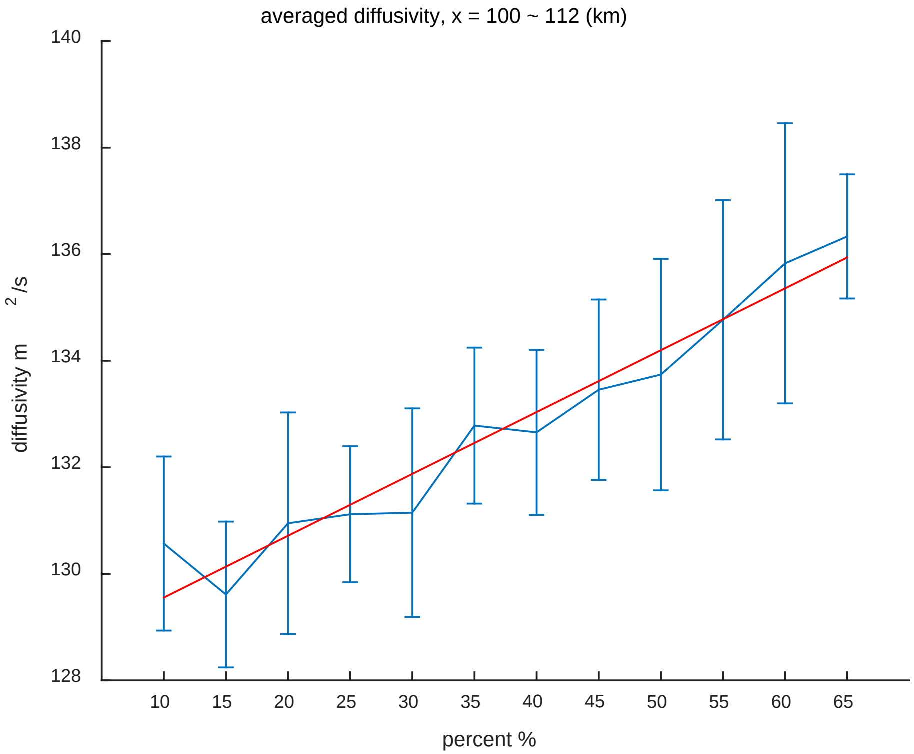


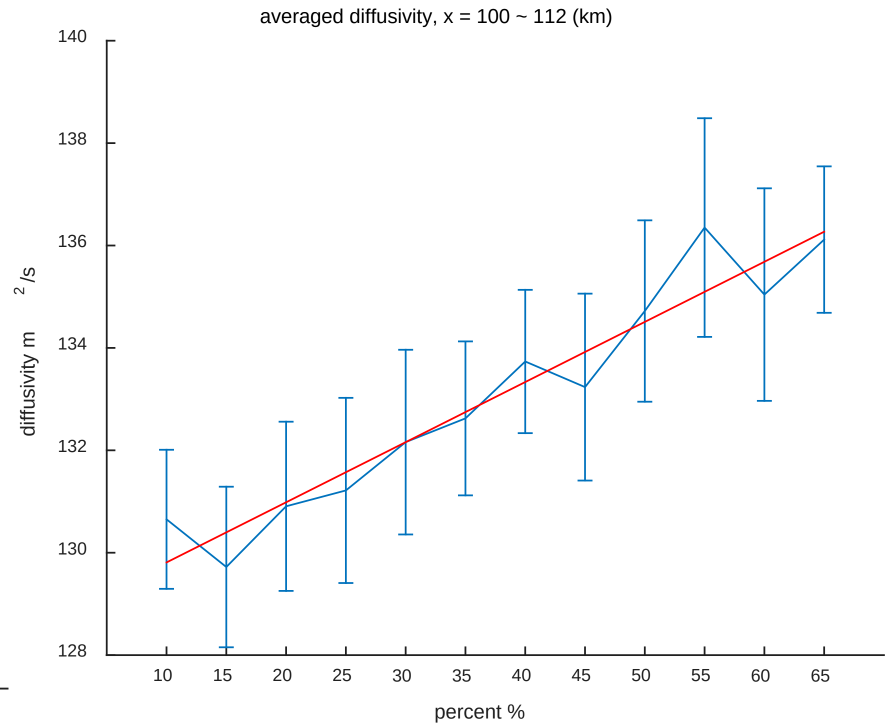




1) particle 20, life span:50h
2) abnormally large diffusivity is removed (>1000)

Random parameter and diffusion coefficient





b=0.1161a+128.3934
residual = 1.6680

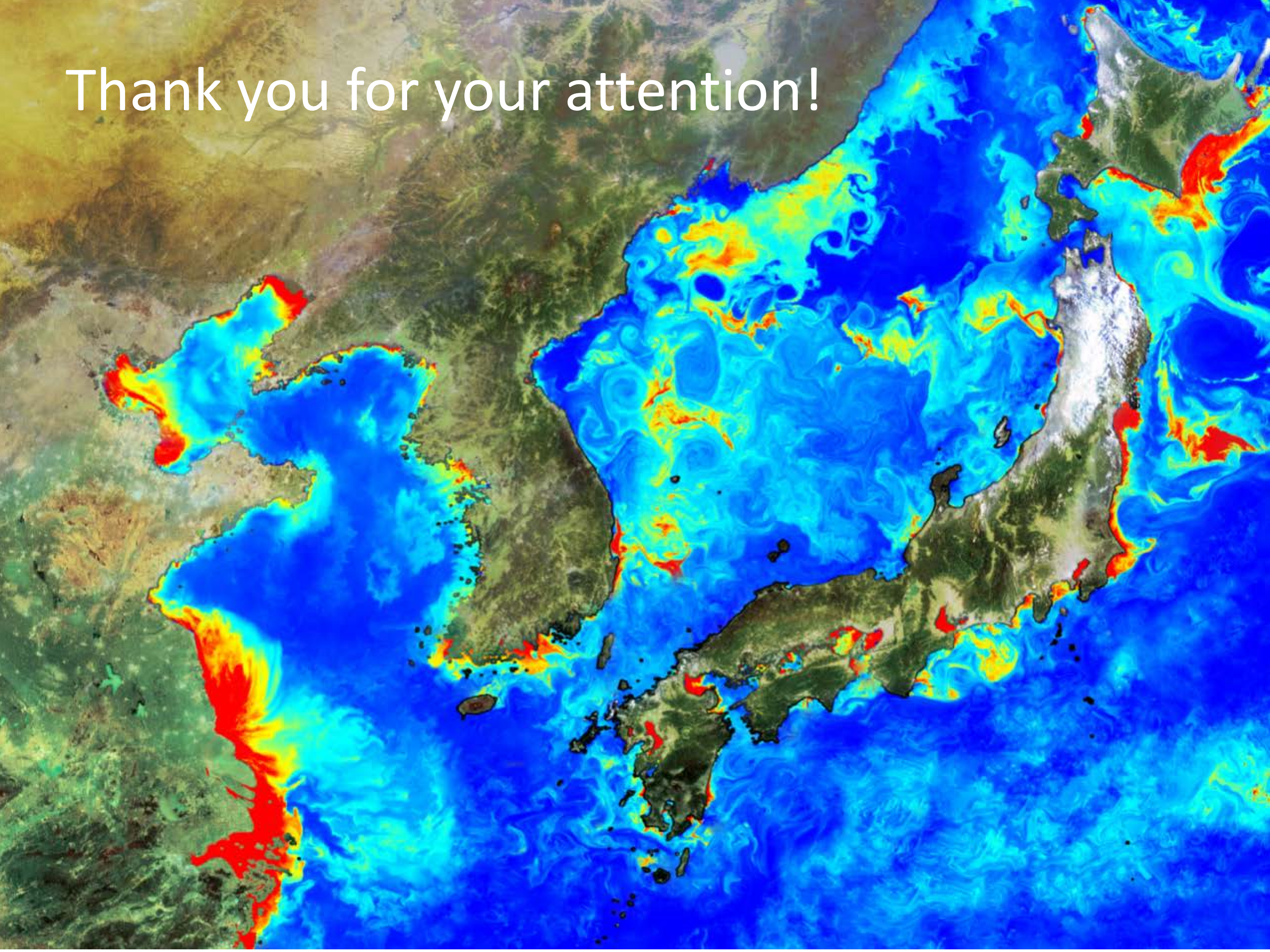
b= 0.1174 a+ 128.6356
residual = 2.0005

a: random parameter

b: diffusivity

Conclusion

- Given observations of surface currents and GOCI Chlorophyll maps, diffusivity at submesoscale can be investigated
- Using idealized current fields and concentration maps, diffusion coefficients are estimated based on advection-diffusion equations (1D).
- Simulations using random walk scheme and estimate diffusion coefficients are quantified.
- Diffusion coefficients estimated from observations can be implemented with a random walk model for tracking water-borne contaminants.


Thank you for your attention!