Seasonality and linear trend of circulation around Korea derived from multi-platform observations

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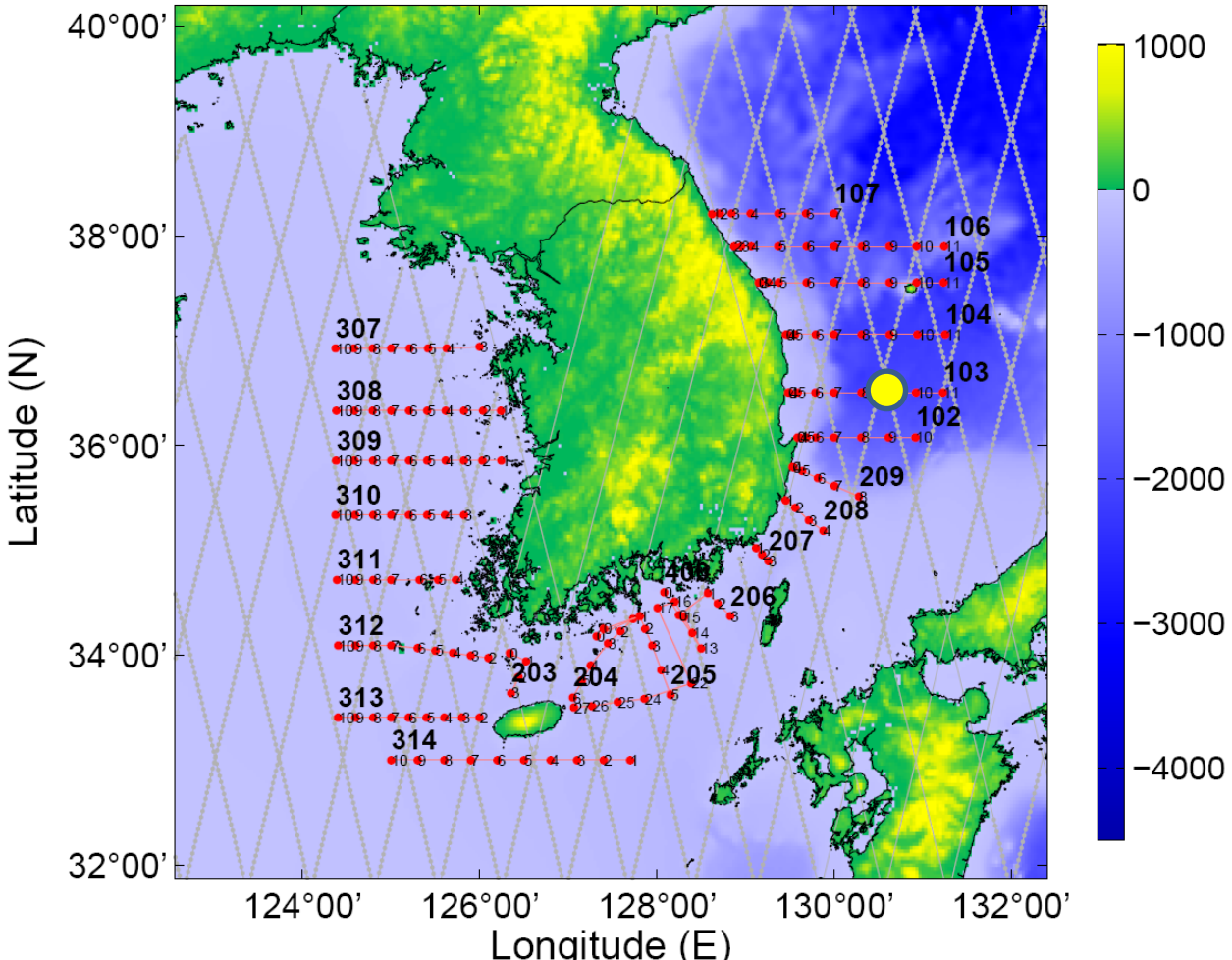
Motivation and study domain

- Seasonal circulation and linear trend based on last 10 years records of CTD (NFRDI; monthly), SST products (NGSST; daily; ~0.05 deg| KISHOU; daily;~0.25 deg), SSHA along-track data (AVISO; 7-daily; ~7km)



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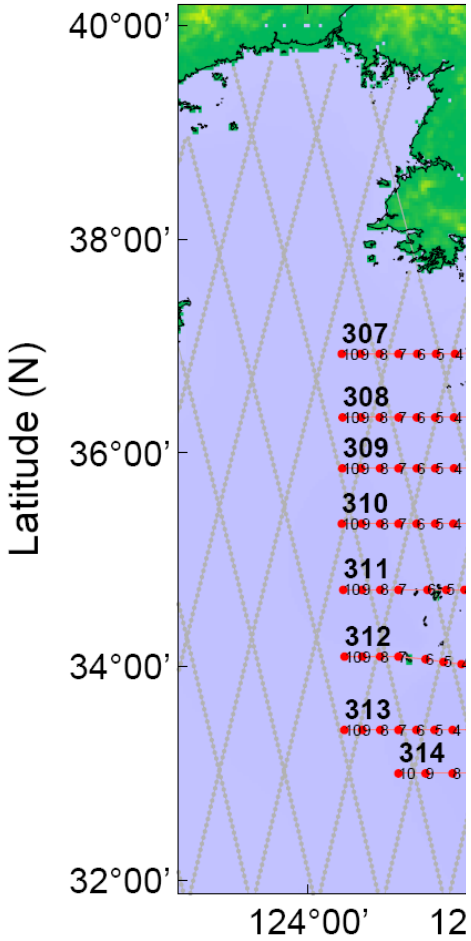
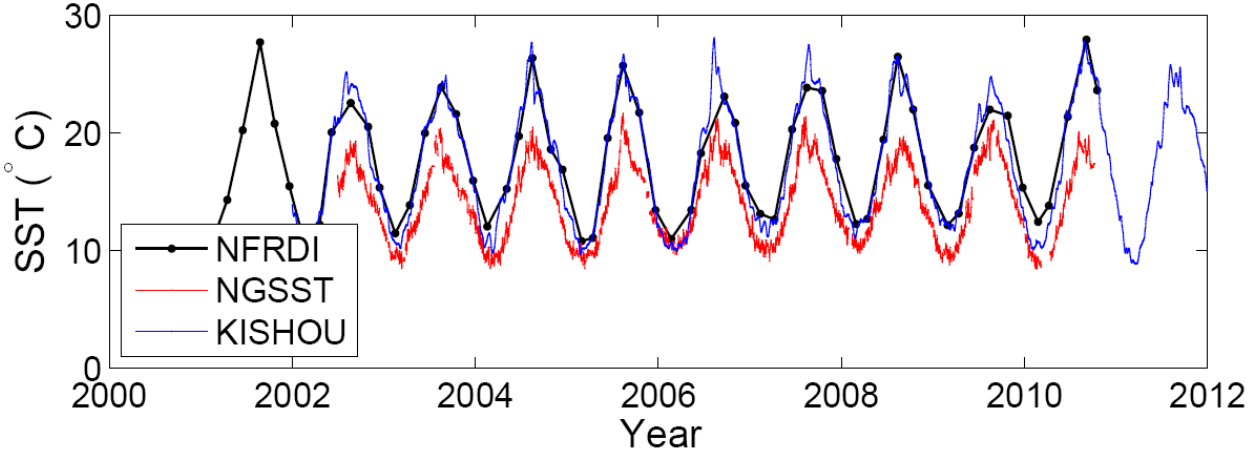
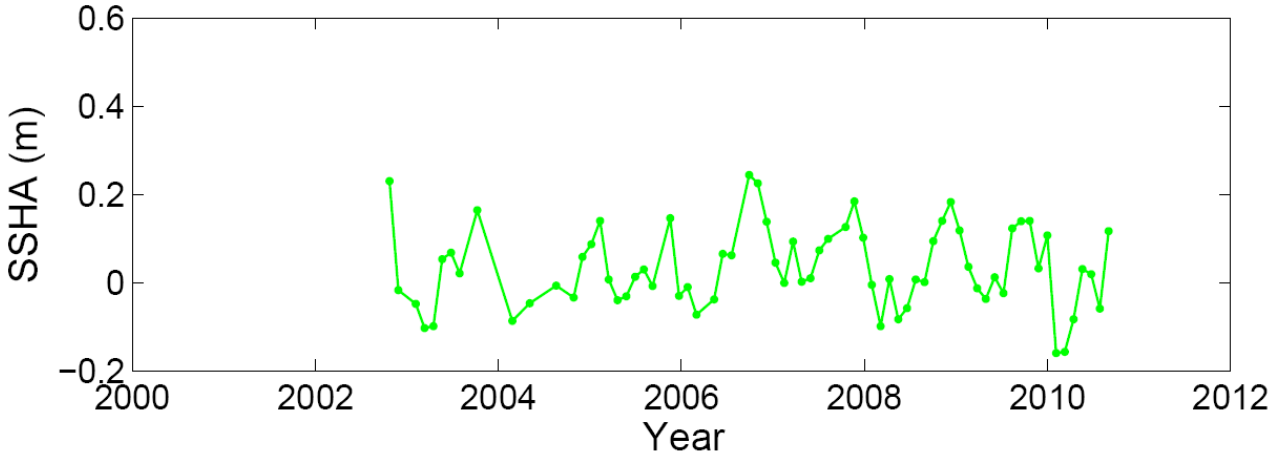






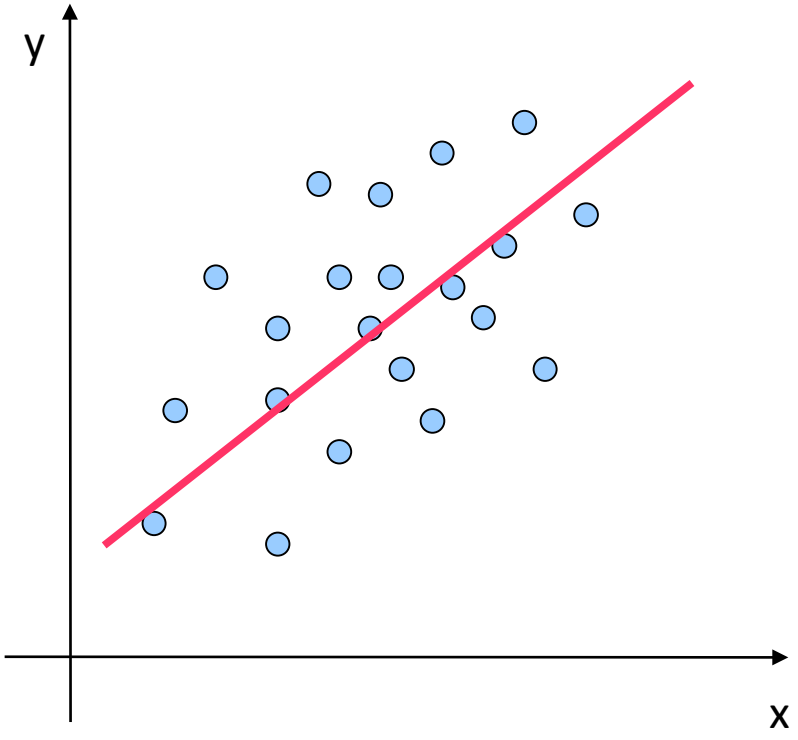
Science questions

- Do the data contain the seasonally modulated signals?
- What's the structure of seasonal circulation around Korea?
- How well would the SST and SSHAs describe the seasonal circulation? More details as well?

Science questions + outline

- Introduction to regression analysis
- Do the data contain the seasonally modulated signals?
- What's the structure of seasonal circulation around Korea?
- How well would the SST and SSHAs describe the seasonal circulation? More details as well?
- Summary

Linear regression



$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{bmatrix} = \begin{bmatrix} x_1 & 1 \\ x_2 & 1 \\ \vdots & \vdots \\ x_n & 1 \end{bmatrix} \begin{bmatrix} a \\ b \end{bmatrix}$$

$$\mathbf{d} = \mathbf{G}\,\mathbf{m}$$

d: Data (observations)
G: Basis functions
m: Regression coefficients

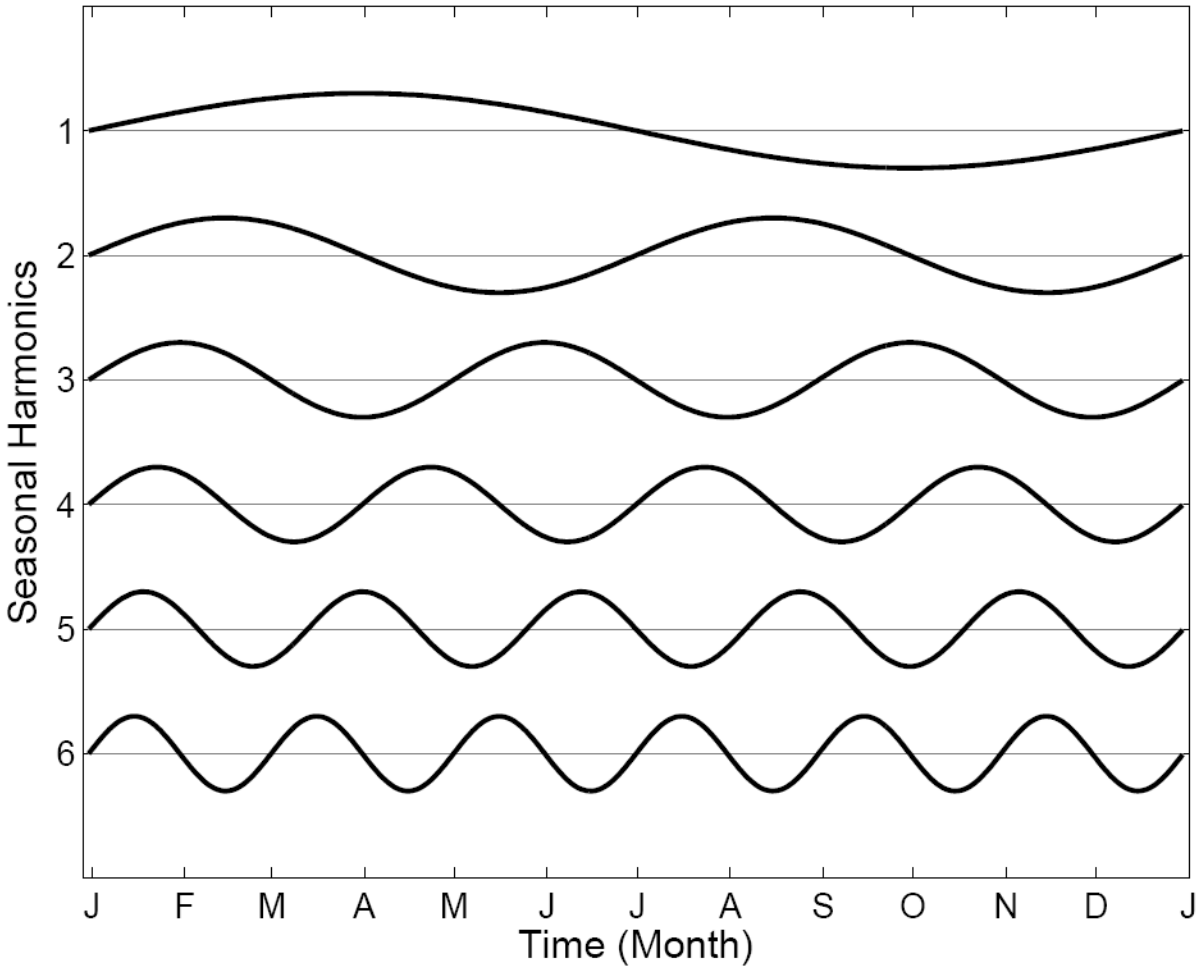
- Least-squares fit for unevenly sampled time series

$$\begin{aligned} \hat{\mathbf{m}} &= \mathbf{P}\mathbf{G}^{\dagger}\left(\mathbf{G}\mathbf{P}\mathbf{G}^{\dagger} + \mathbf{R}\right)^{-1}\mathbf{d}, \\ &= \left(\mathbf{G}^{\dagger}\mathbf{R}^{-1}\mathbf{G} + \mathbf{P}^{-1}\right)^{-1}\mathbf{G}^{\dagger}\mathbf{R}^{-1}\mathbf{d}, \end{aligned}$$

P: model covariance
R: error covariance

Regression basis functions

- SA1 – SA6 (6 harmonics of seasonality)

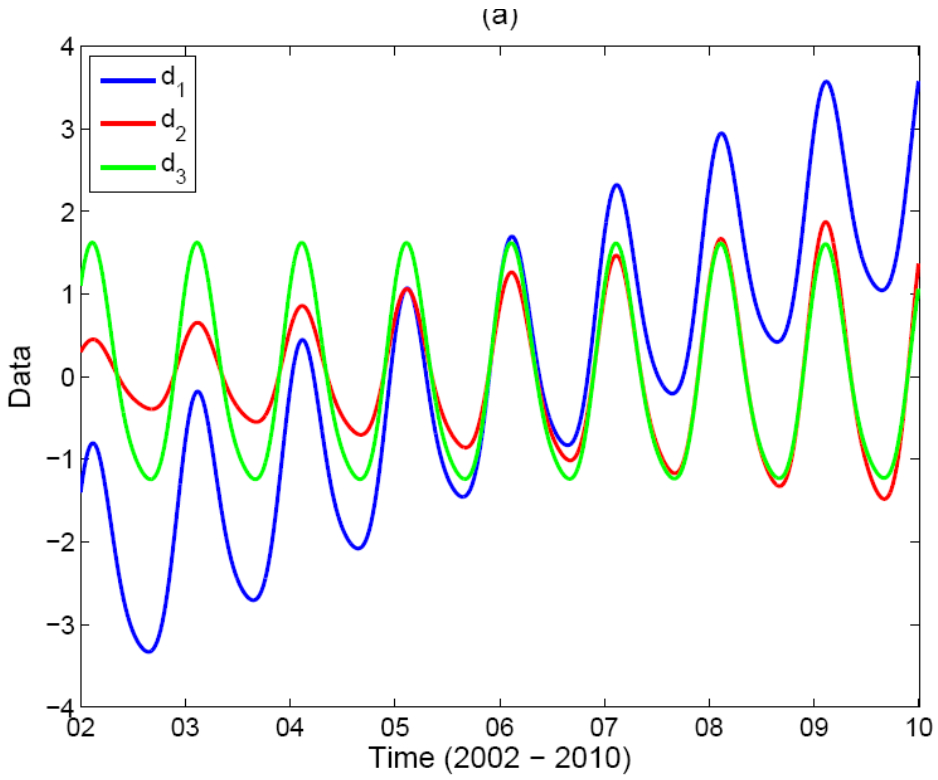


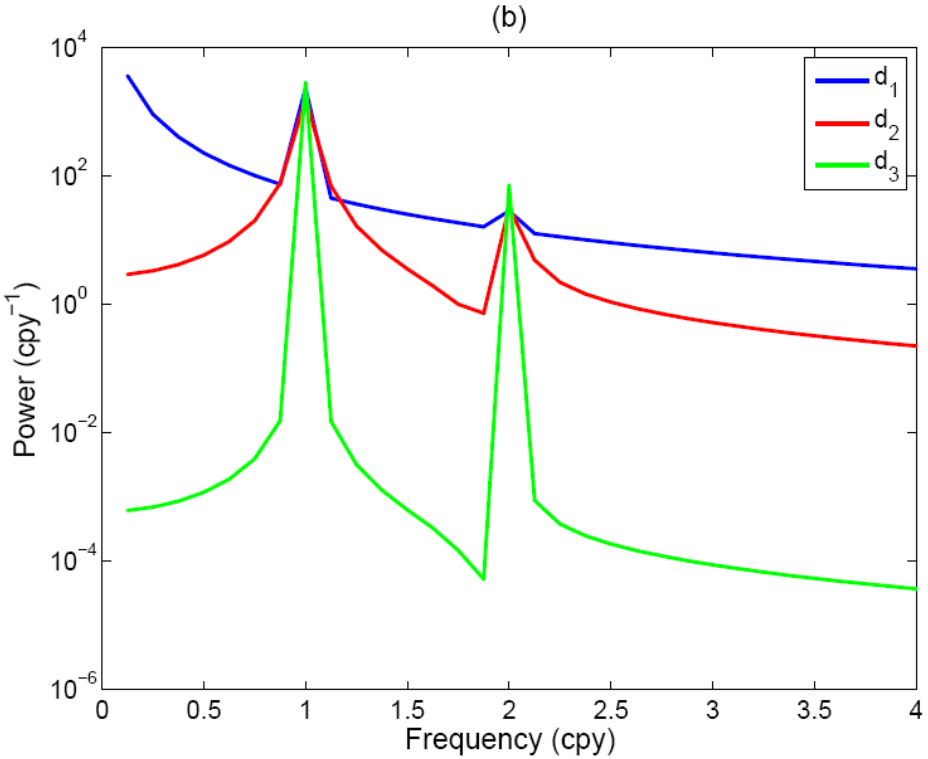
- T = 365.2425 days
- T/2 = 182.6718 days
- T/3 = 121.7812 days
- T/4 = 91.3559 days
- T/5 = 73.0687 days
- T/6 = 60.8906 days

Seasonal modulation

- The variance at the annual cycle modulated by low frequency appears as the cuspate peaks in the power spectrum [Munk et al 1965].
- However, the inter-annual variability that does not interact with the annual cycle should not create any extra energy near the annual cycle.
- The spreading of energy in the Discrete Fast Fourier Transform (FFT) is examined with the pure signal and data.

Seasonal modulation





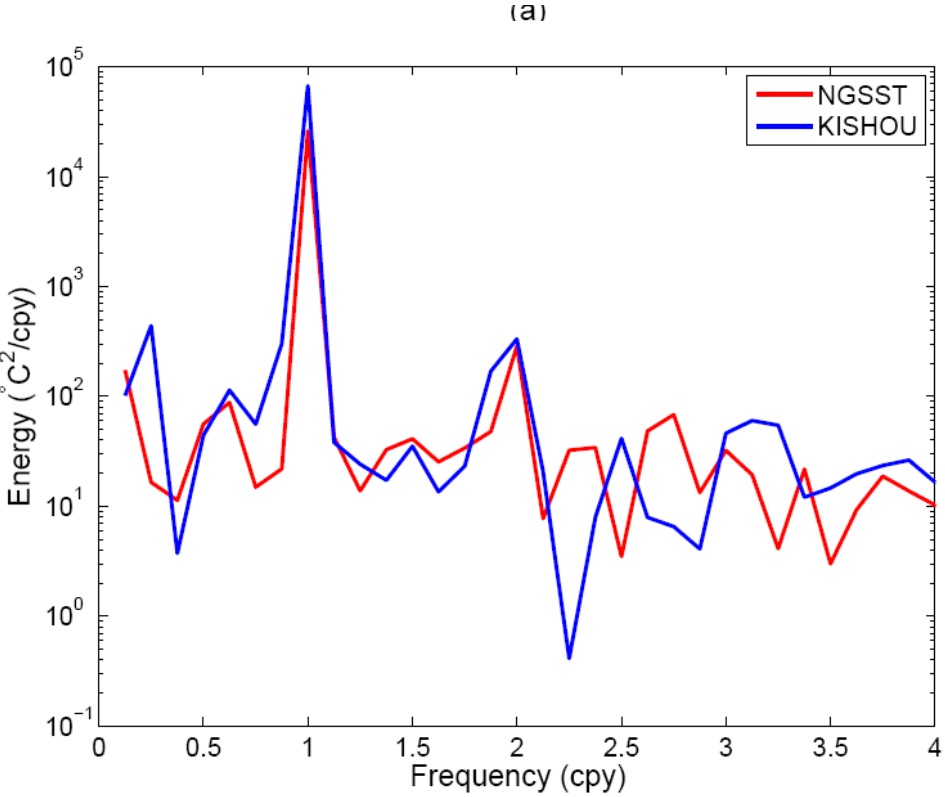
$$g(t) = \cos\sigma_1 t + \sin\sigma_1 t + \frac{1}{10}\cos\frac{\sigma_1}{2}t + \frac{1}{5}\sin\frac{\sigma_1}{2}t$$

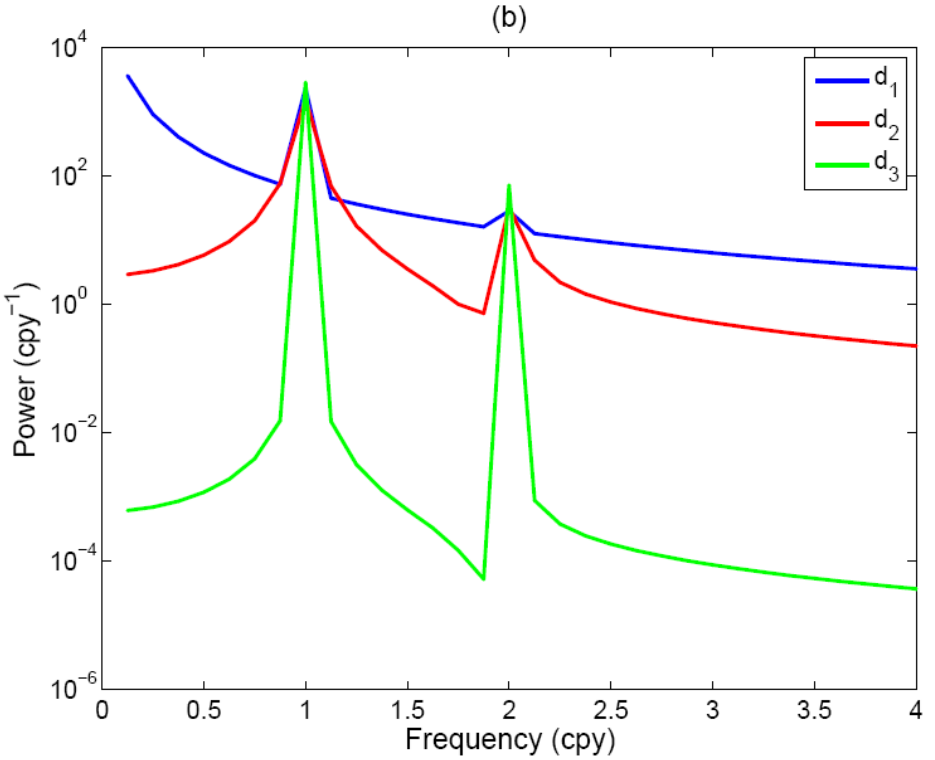
$$d_1(t) = 2.5t + g(t)$$

$$d_2(t) = \frac{1}{2}\left(\frac{t + \langle t\rangle}{\max(t) - \min(t)}\right) g(t)$$

$$d_3(t) = \left(\cos\frac{\sigma_1 t}{300}\right) g(t)$$

Seasonal modulation





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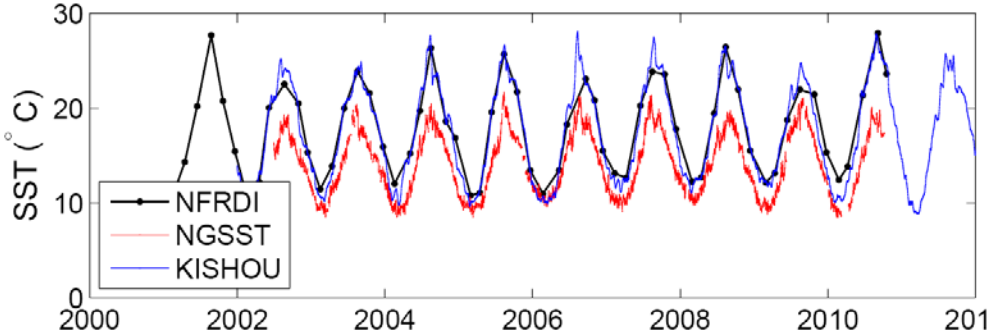
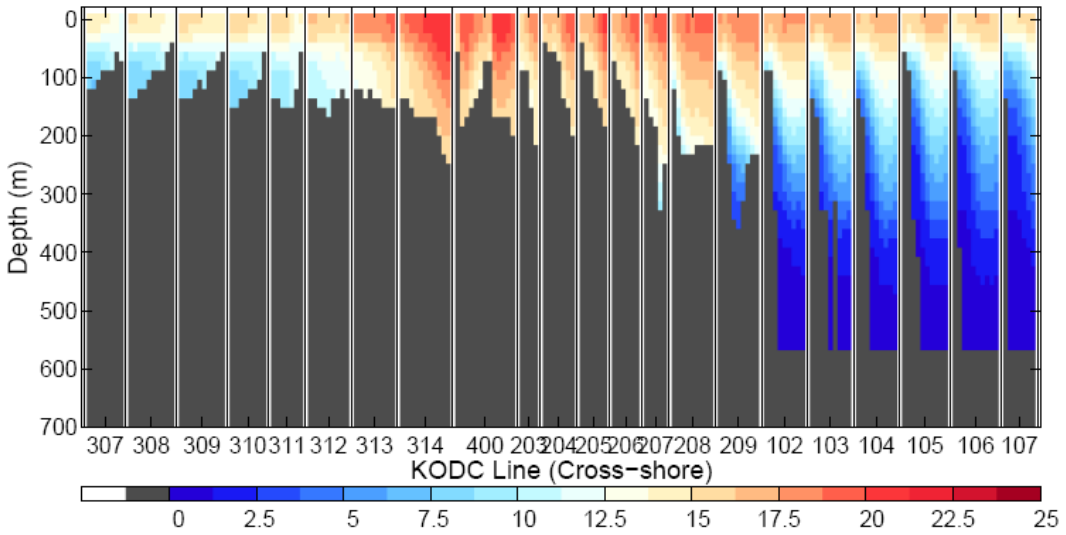
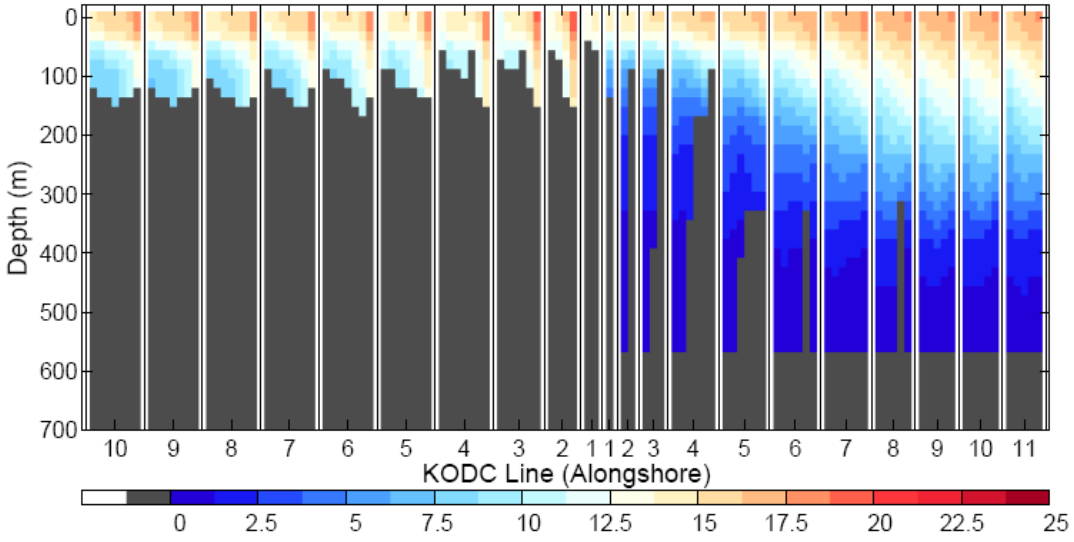


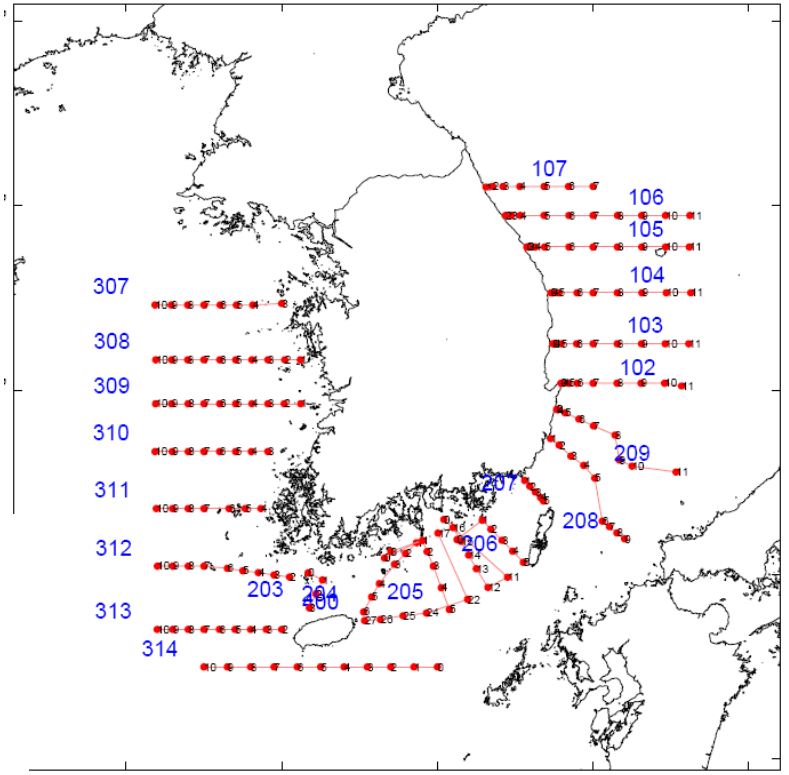
Presentations in cross-shore and alongshore directions

West South (Cross-shore) East



West (Along-shore) East





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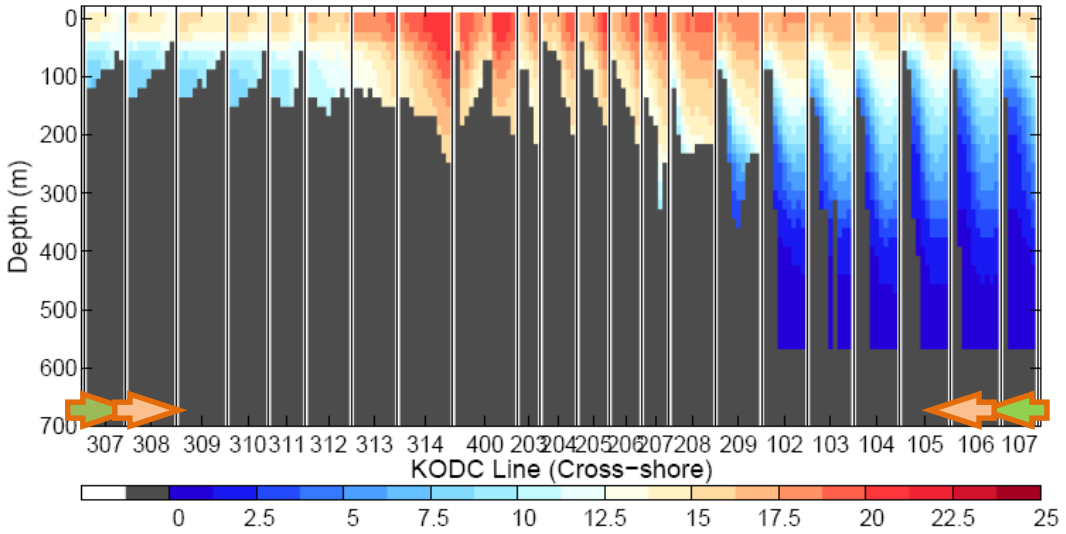

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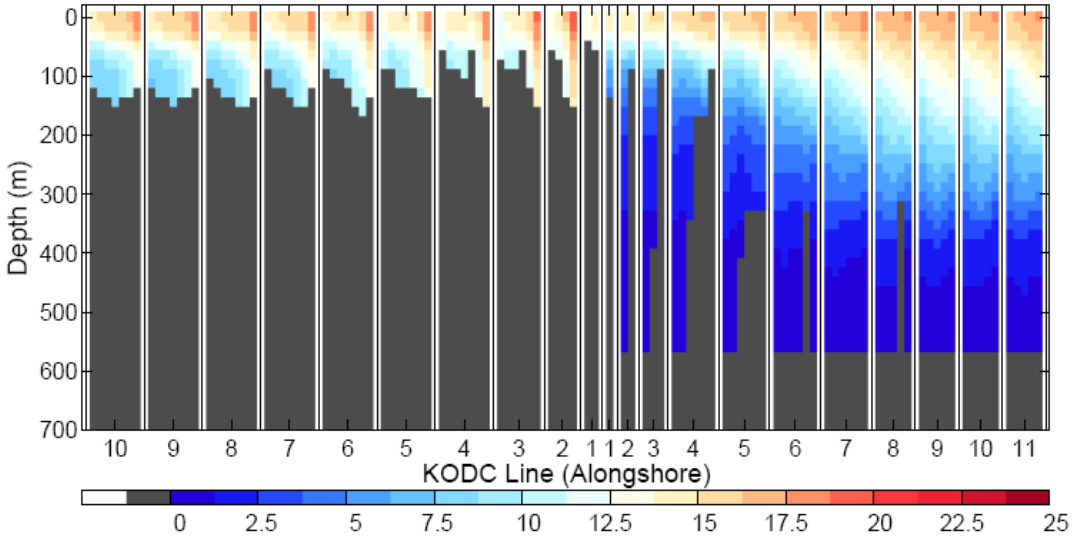
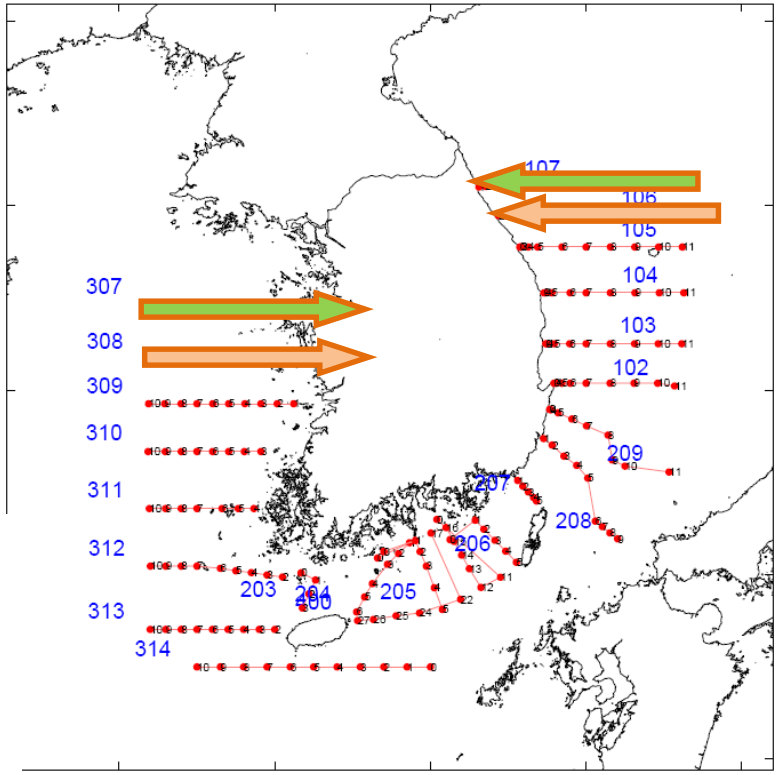
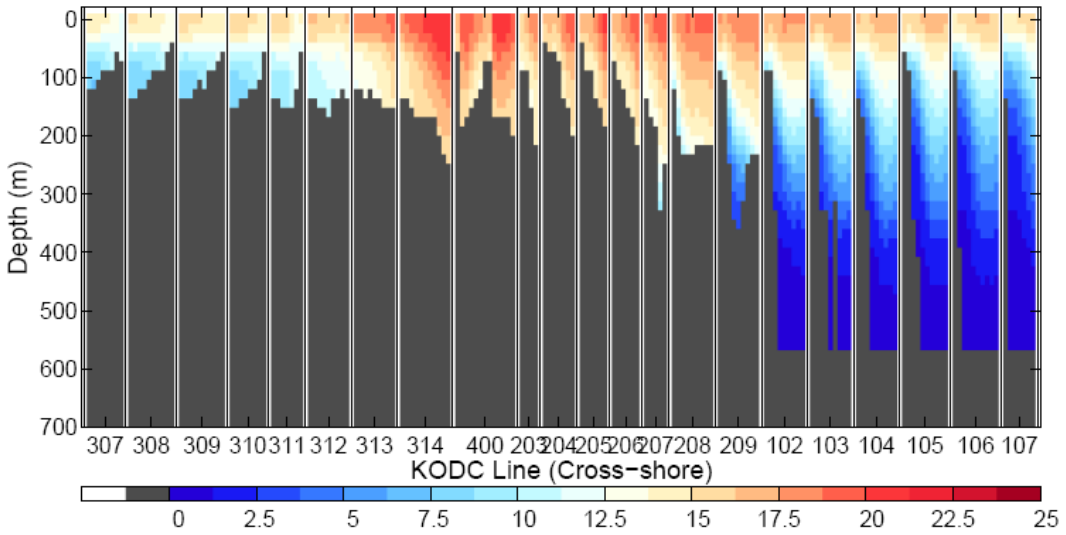


To show W, S, and E

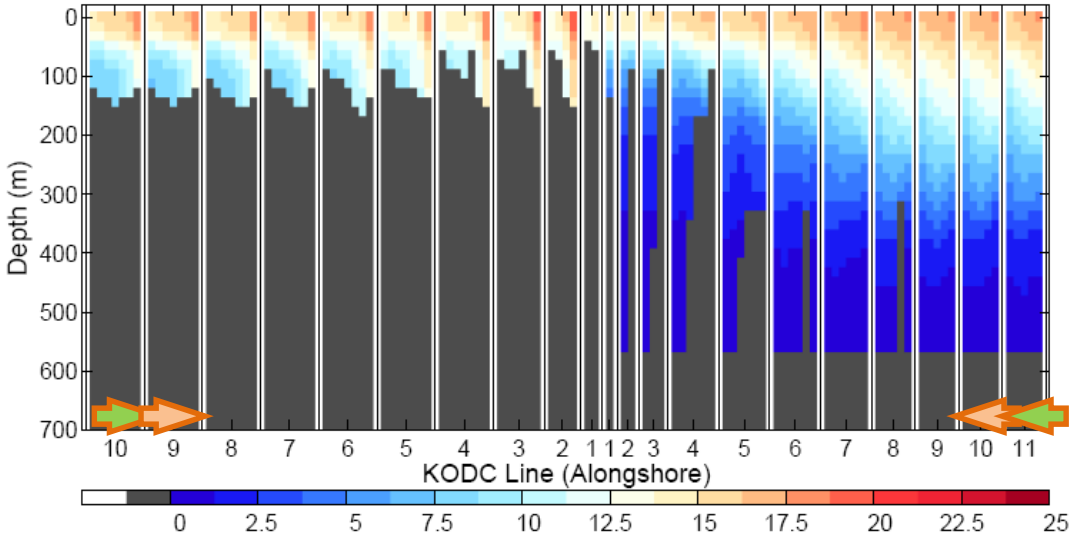


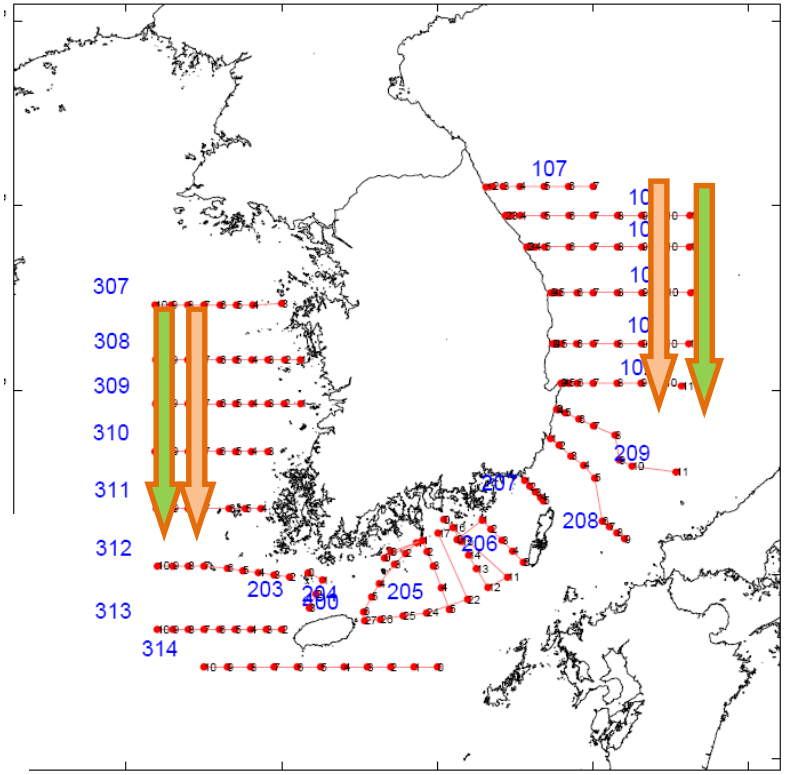
Presentations in cross-shore and alongshore directions

West South (Cross-shore) East



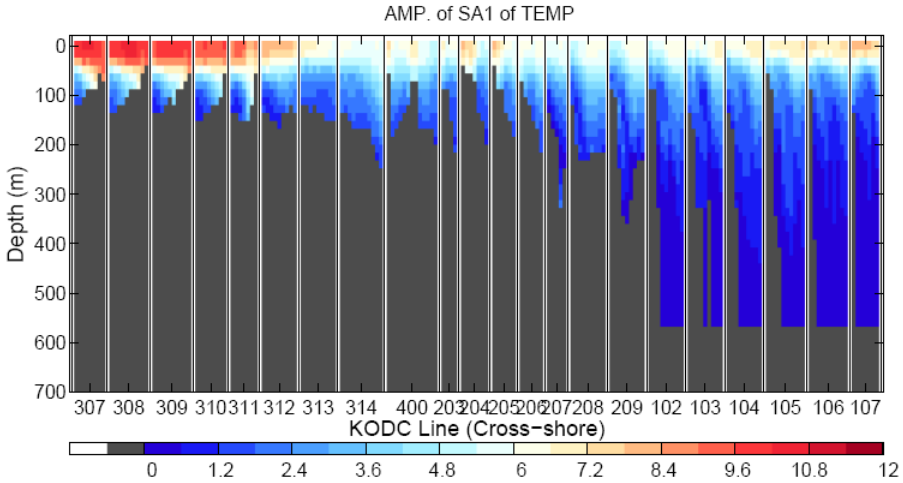
West (Along-shore) East

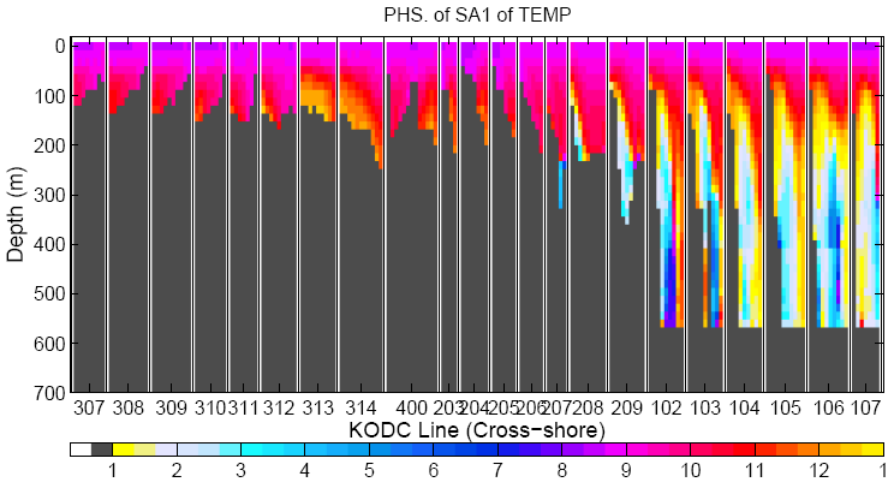


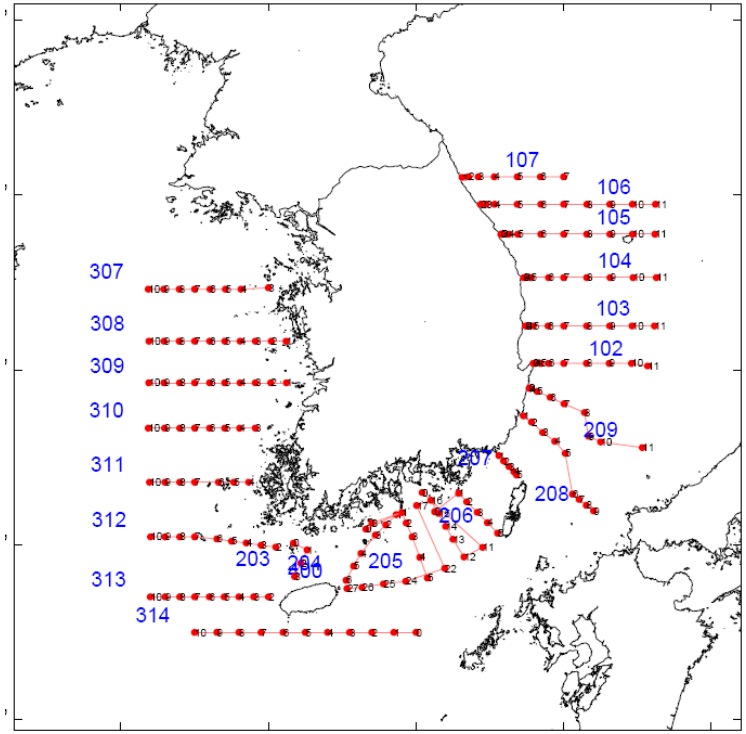


To show cross-shore structure in W & E

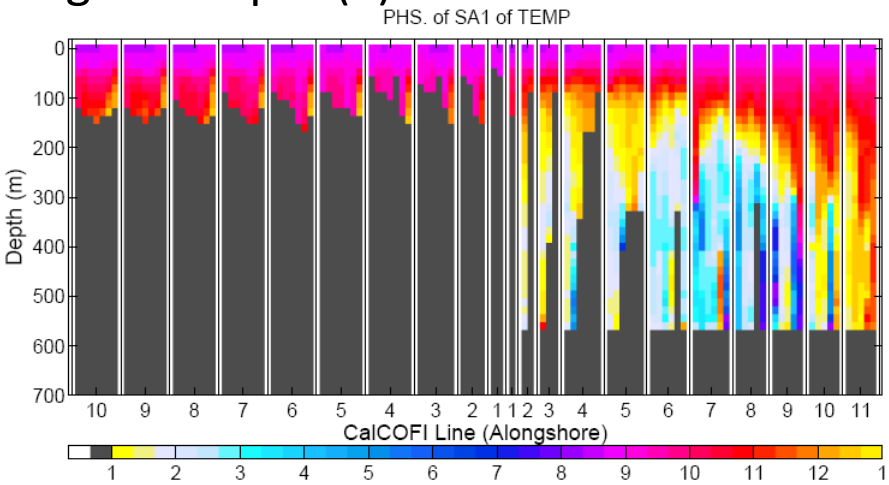
Seasonal amplitudes of T





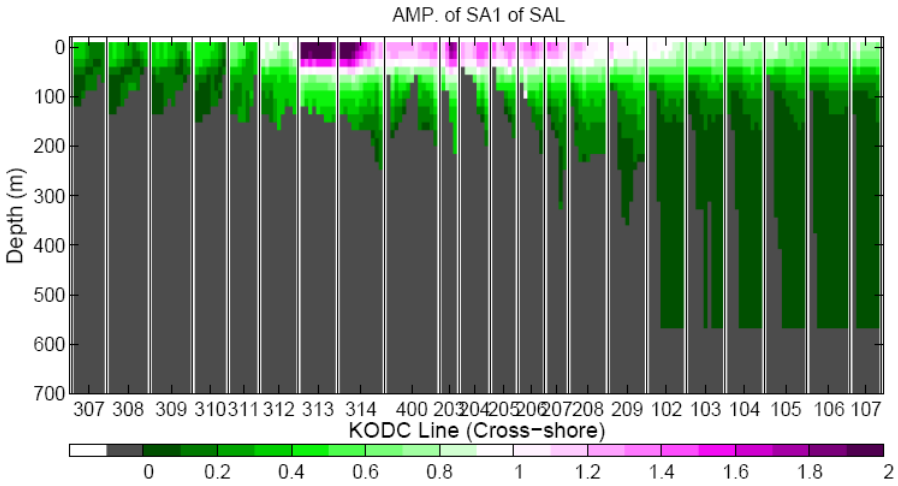


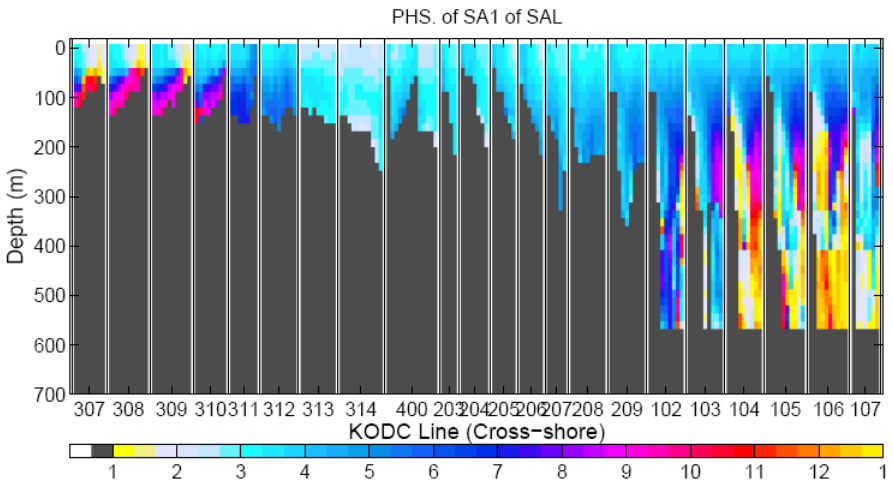
- Seasonal mixing or penetration depth gets deeper (E)

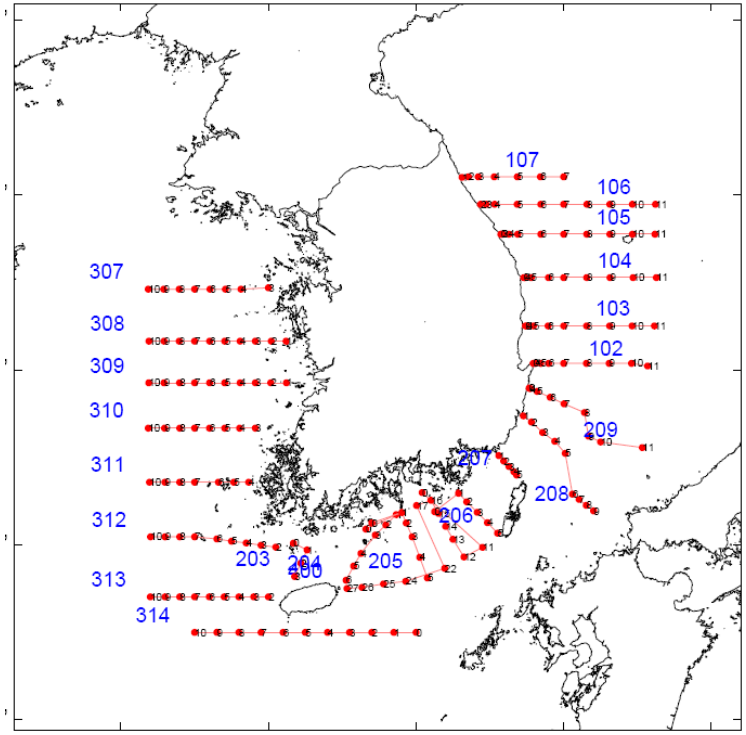


- Increasing phase toward the coast (E) Rossby wave or intrusion of deep water

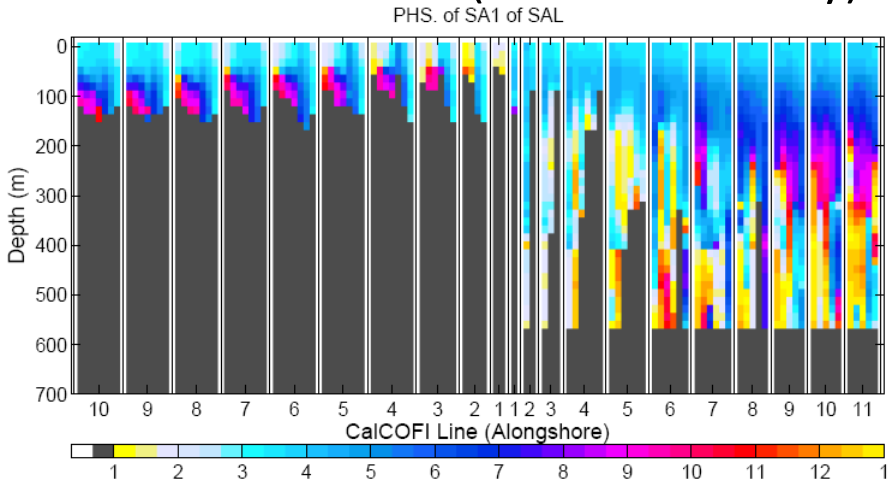
Seasonal amplitudes of S





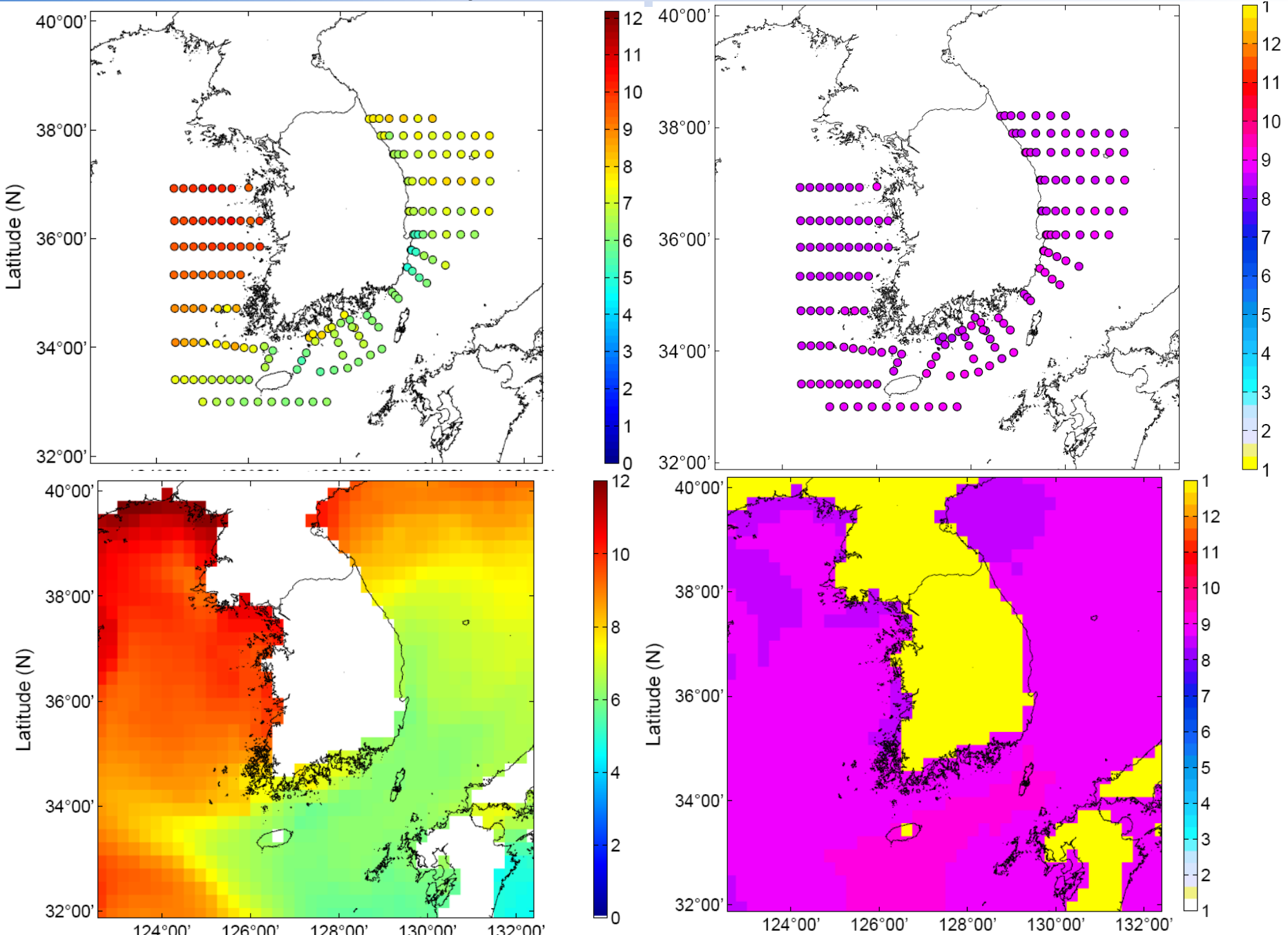


- Salinity maximum in upper 100m moves from S to E (from Feb to May).



- Seasonal intrusion of saline water (S)

Details of seasonal phases obtained from SST



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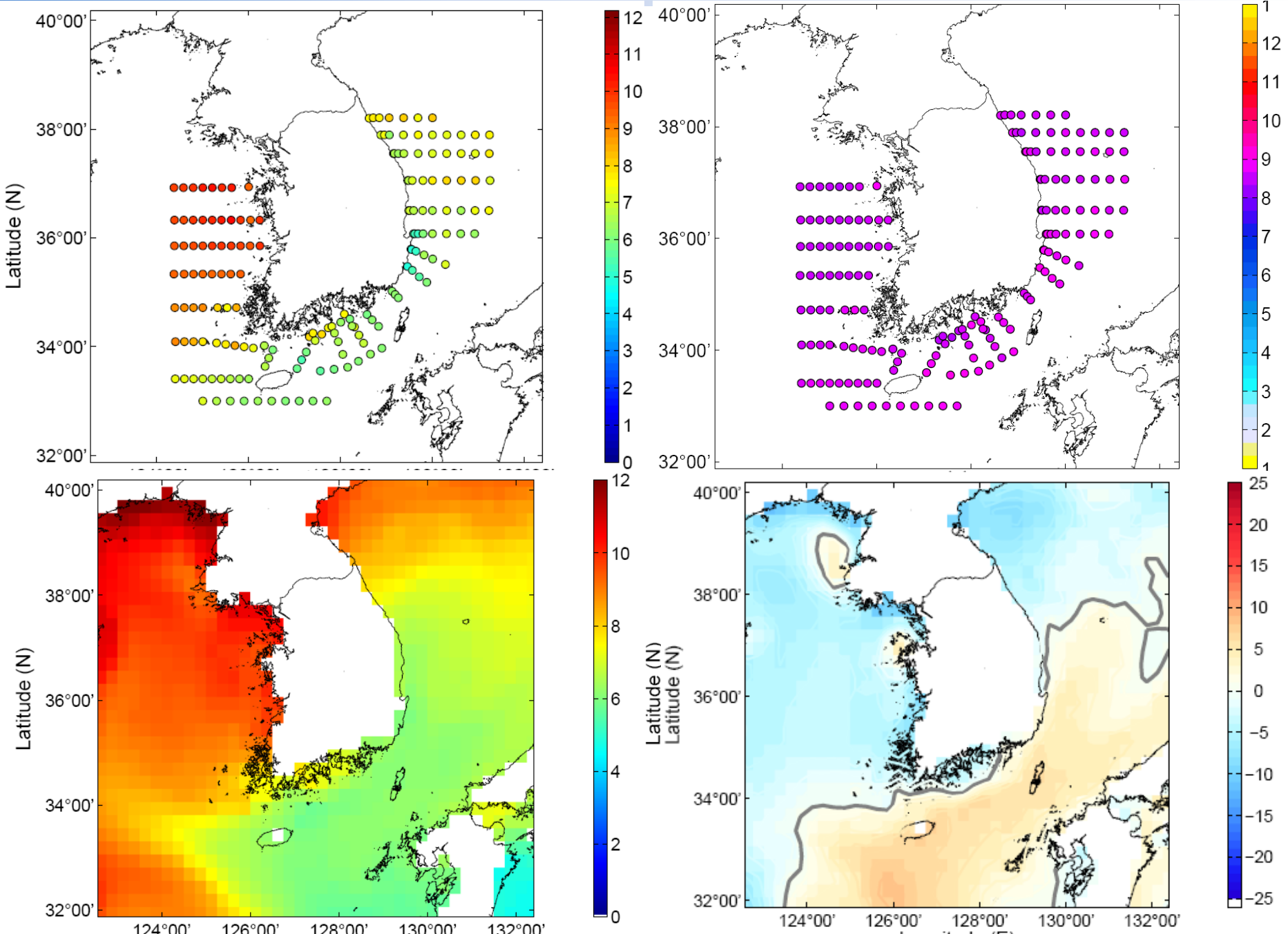
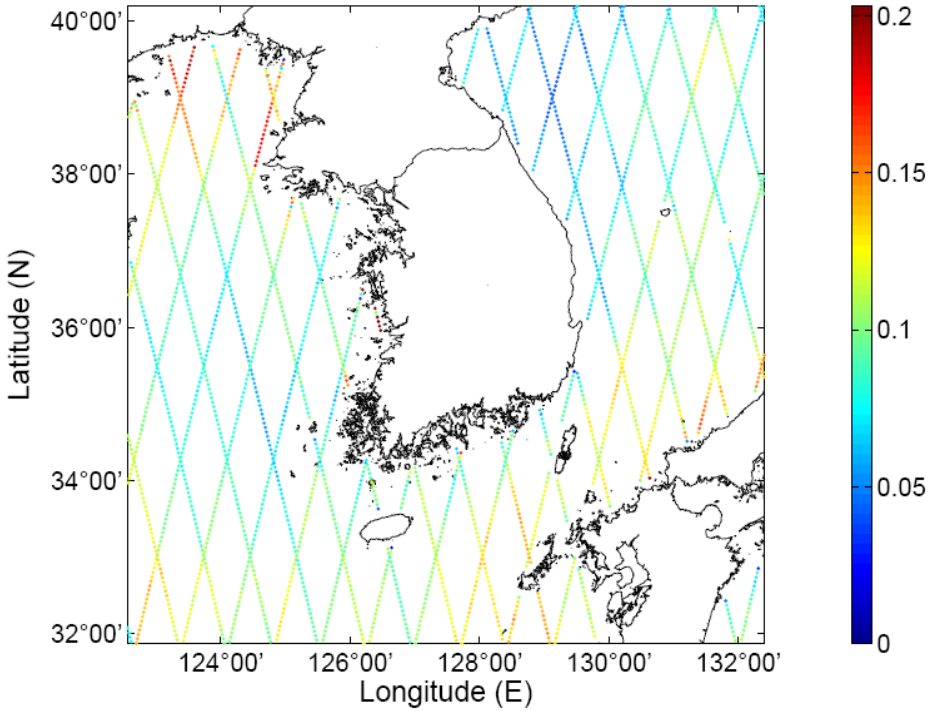
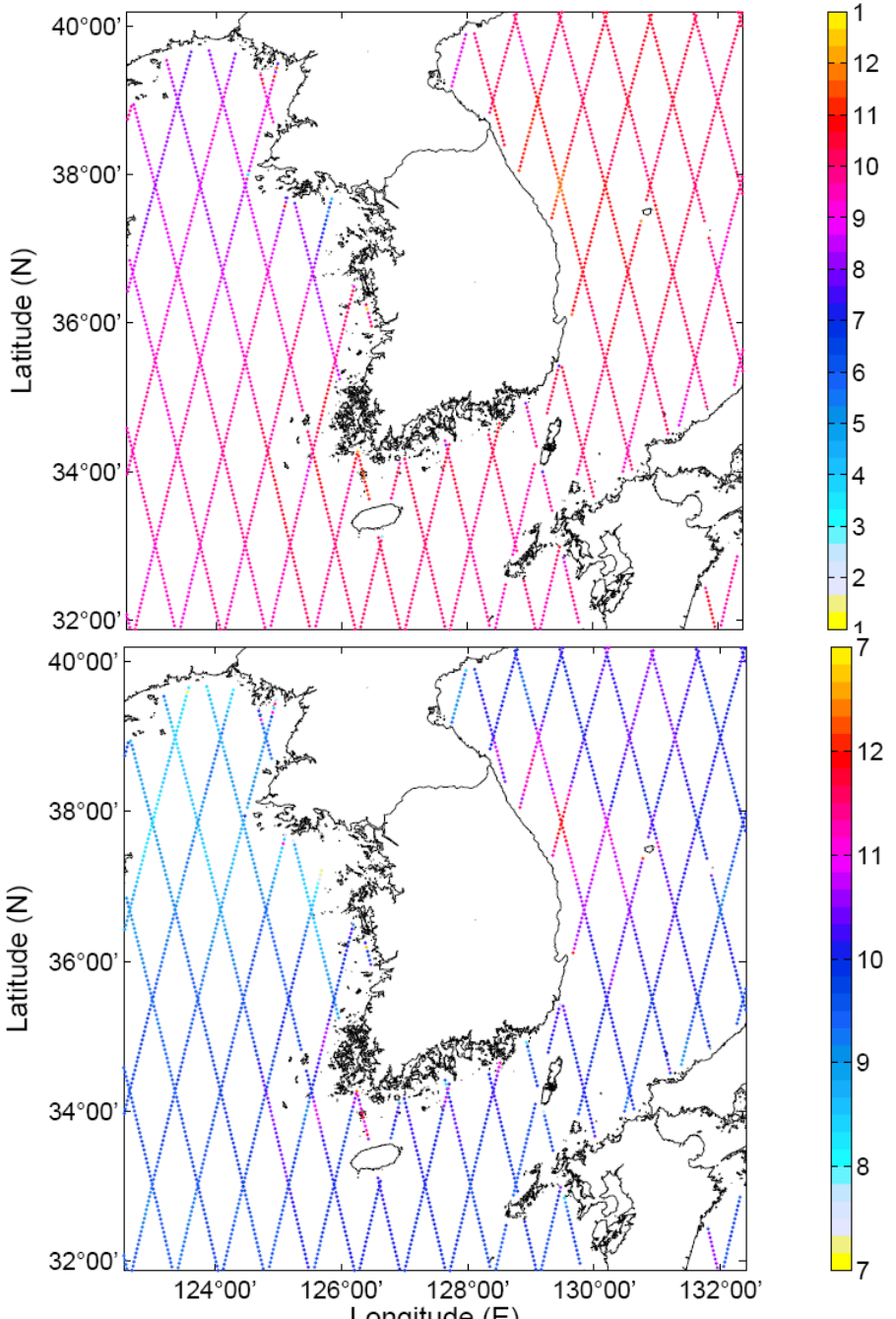


Seasonal amplitudes and phases of SSHAs





Summary

- CTD, SST, and SSHAs (along-track) are fitted with seasonal cycle and its five harmonics and linear trend.
- SST and CTD at the surface complement the interpretation of variability at the ocean surface. However, the seasonal modulation may be enhanced with depth, so the seasonal fitting may have limitation.
- Amplitudes and phases of SSHAs at the seasonal frequency exhibit different spatial structure compared with CTD (at surface) and SST.