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

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Abstract

The surface and subsurface circulations around Korea (East/Japan Sea, Yellow Sea, and southern coast) are investigated with conductivity-temperature-depth (CTD) profiles collected from historical hydrographic surveys, along-track altimeter-derived sea surface height anomalies (SSHA), and satellite sea surface temperature (SST) for recent 10 years (2001 to 2010). The seasonal circulation is enhanced in the surface mixed layer, and their subsurface phase in the East/Japan Sea increases onshore, which may indicate westward propagating seasonal Rossby wave. The timing that both temperature and SSHA at the seasonal frequency reaches their maximum characterizes the complexity of regional circulation in the southern coast of the Korea as a part of interactions of Tsushima currents and outflows from Yellow Sea. The cooling tendency of East/Japan Sea and the warming trend of Yellow Sea are nearly consistent with the linear trend of satellite products, which allows us to infer the subsurface variability at the climate time scale.

Data Analysis

Data

As a part of the periodic hydrographic surveys around Korea, the conductivity-temperature-depth (CTD) data are sampled six times a year for 10 years (2001 to 2010). The surveys have been conducted along the cross-shore lines off eastern (East Sea), western (Yellow Sea), and southern (Jeju and Korea Strait) areas within 200 km from the coast of the Republic of Korea.

Two sets of 7-daily along-track sea surface height anomalies (SSHAs) with respect to the seven-year mean dynamic topography from Envisat and Jason-1 are analyzed. The daily sea surface temperature data are obtained from Kishou (0.25-degree resolution) and NGSST (0.05-degree resolution) for 10 years (2001 to 2010).

Formulation

The time series of in-situ observations are decomposed into a sum of time-mean ($\langle \mathbf{d}(t) \rangle$), seasonal components including six seasonal harmonics ($\mathbf{d}_S$), and linear trend ($\mathbf{d}_L$), and residuals ($\mathbf{d}_R$) [e.g., [1]]:

$$\mathbf{d}(t) = \langle \mathbf{d}(t) \rangle + \mathbf{d}_S(t) + \mathbf{d}_L(t) + \mathbf{d}_R(t), \quad (1)$$

$$= \langle \mathbf{d}(t) \rangle + \left[\mathbf{G}_S \; \mathbf{G}_L \right] \begin{bmatrix} \mathbf{m}_S \\ \mathbf{m}_L \end{bmatrix} + \mathbf{d}_R(t), \quad (2)$$

where $\mathbf{G}_S$ is the basis functions for seasonal and its six harmonic frequencies (SA1, SA2, $\cdots$, and SA6) and $\mathbf{G}_L$ is the linear trend basis function. Their corresponding amplitude are $\mathbf{m}_S$ and $\mathbf{m}_L$, respectively.

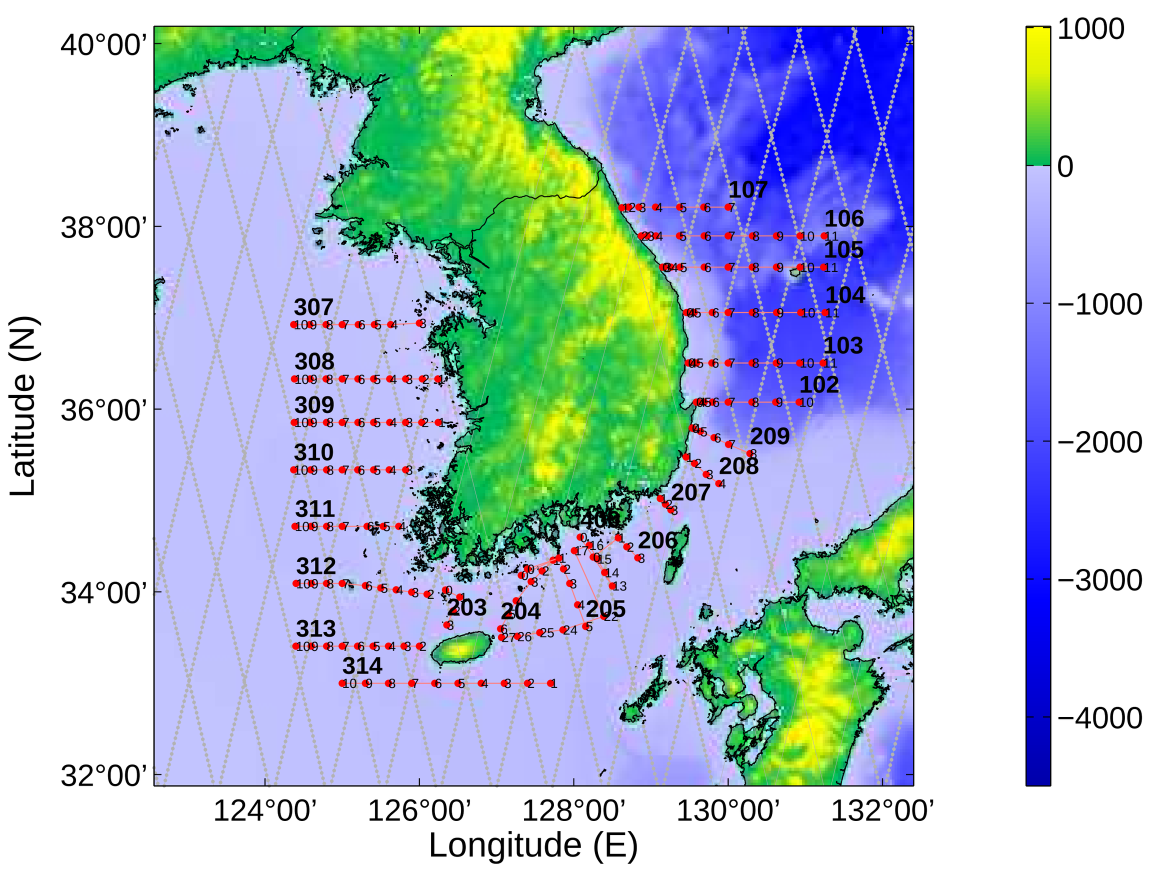

Figure 1: Historical hydrographic survey lines and stations of conductivity-temperature-depth (CTD) casts and the tracks of the satellite altimeter-derived seas surface height anomalies (SLA) sampling are shown as black and gray dots, respectively. The bold number of lines is named in clockwise: east (102 to 107), south (203 to 209), and west (307 to 314). Stations of each line are numbered nearshore to offshore corresponding to 1 to 11 except for the southern area (13 to 26).

Results

The geostrophic currents around Peninsula of Korea flows in counter-clockwise, well captured in horizontal gradients of mean temperature profiles in the cross-shore and along-shore directions. The downward and southward tilts of mean temperature in the upper 300 m depth in east are associated with northeastward geostrophic currents. The flat and downward tiling toward the coast below 400 m appearing 80 –100 km offshore in east implies southward undercurrents (name? and references?). The vertical mean temperature gradients in south is relatively weaker than other areas. In west, there is only southward tilting of mean temperature, which may generate the onshore (eastward) geostrophic currents. The meridional flows in west are mainly driven by tides, so cross-shore structure is nearly uniform. The rms of mean temperature becomes significant in west (8 to 10°C higher than east) and reduced in south and east.

The mean salinity increases in counter-clockwise (west to south, then east) and with depth except for maxima in east between 100 and 300 m depth. Both horizontal and vertical gradients of mean salinity appear in south because of confluence of saltier Kuroshio Currents or its branch flow and relatively fresher water in west driven by dominant tidal pumping. For example, Lines 313, 314, 202, and 204 show horizontal and vertical salinity gradients, presented as fresh water in the upper water column and nearshore and salty water on the lower water column and offshore. Likewise, the rms of salinity is significant in the upper 50 m water column of south (Lines 313, 314, 400, 205, 206, and 207).

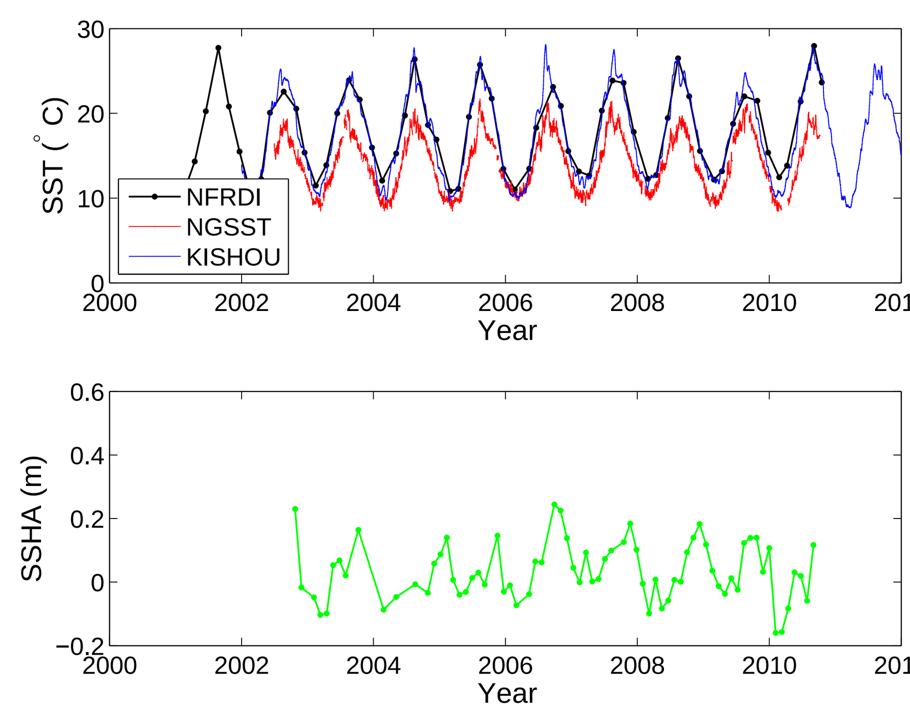

Figure 2: An example of records of (top) temperature and (bottom) SSHA at a KODC (NFRDI) CTD station (Line 18, Station 7, Depth 1).

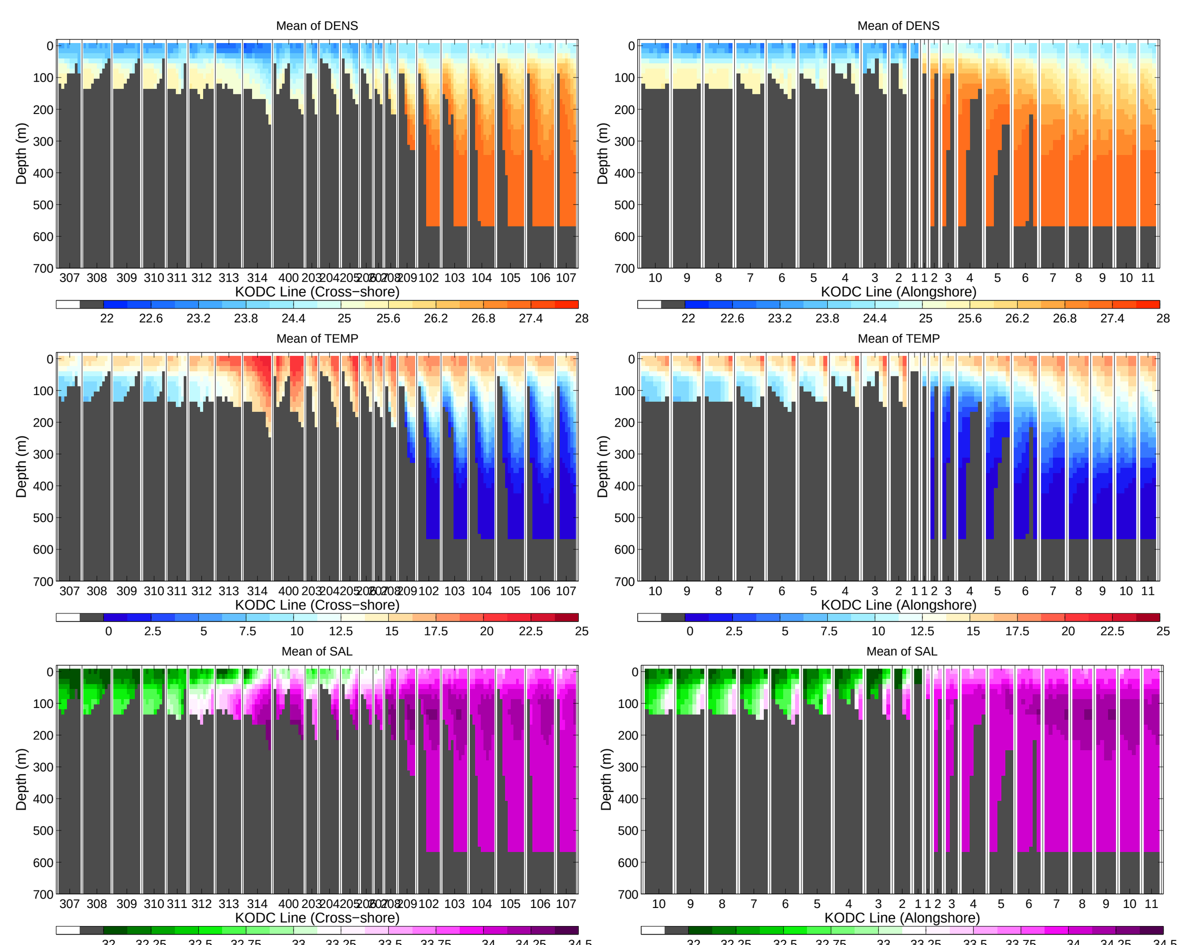

Figure 3: Mean of KODC density anomalies ($\mathrm{kg/m^3}$), temperature (°C), and salinity profiles in the cross-shore and along-shore directions.

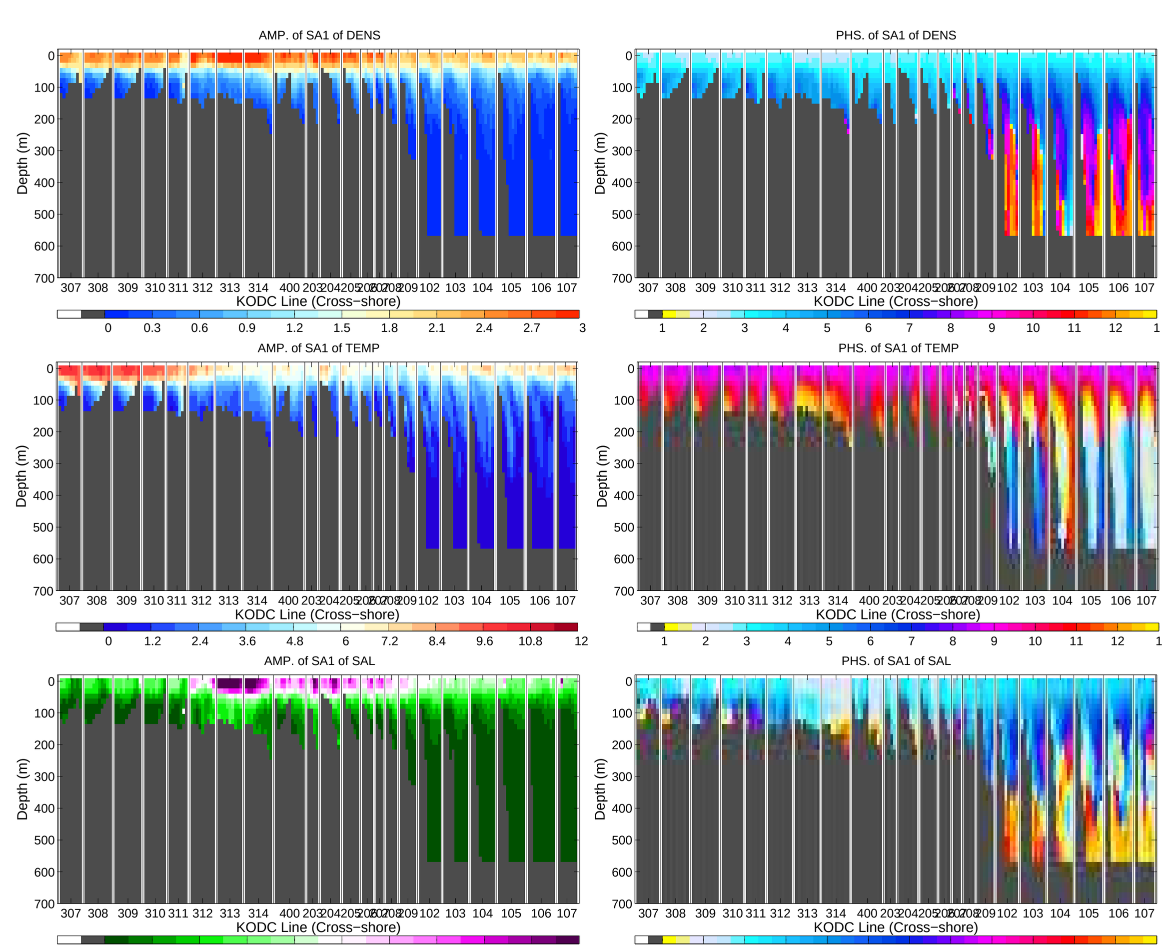

Figure 4: SA1 amplitudes and phase of KODC density anomalies ($\mathrm{kg/m^3}$), temperature (°C), and salinity profiles.

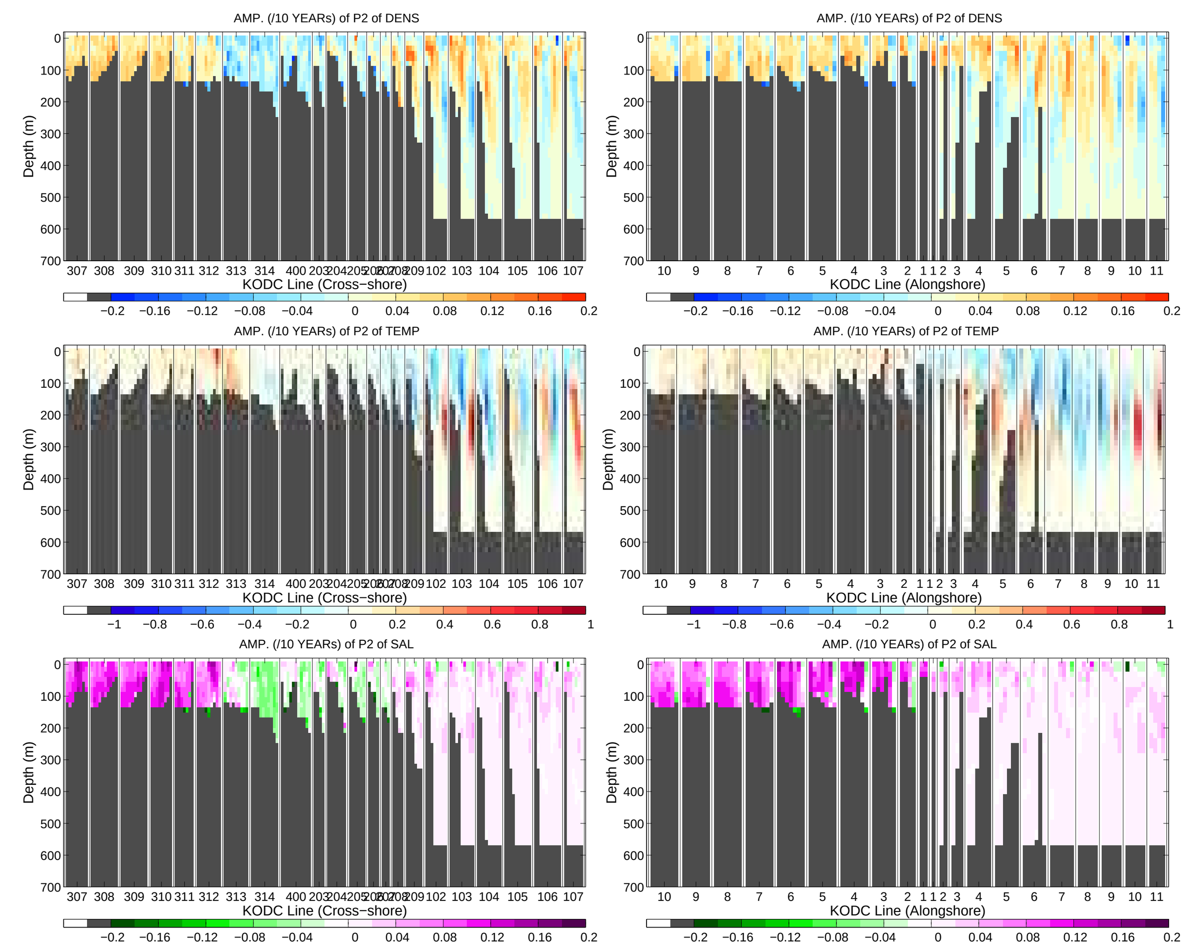

Figure 5: Linear trend off KODC density ($\mathrm{kg/m^3}$), temperature (°C), and salinity profiles.

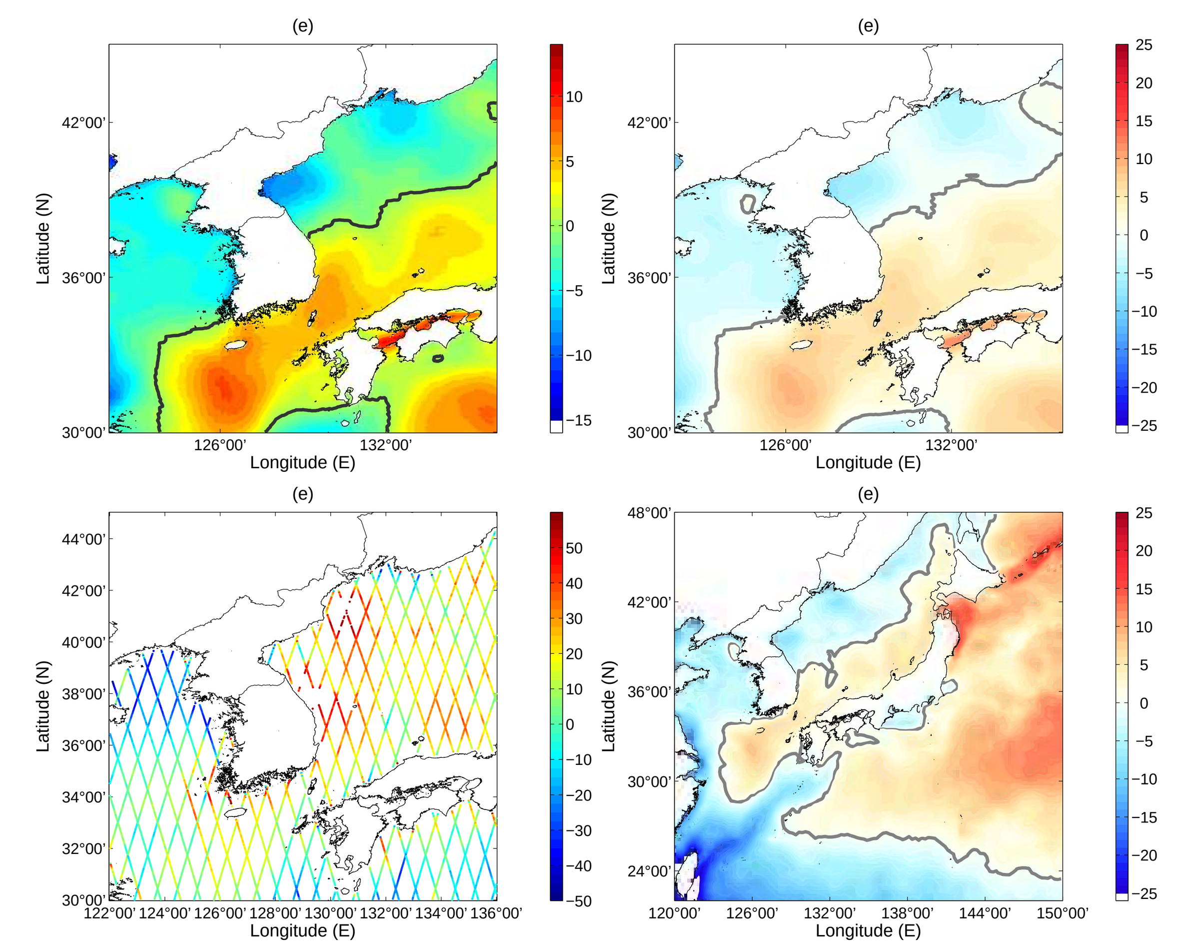

Figure 6: (Top) Time lags (days) to have the maximum SST. Gray contours indicates the zero lag. Two different color scales from the same JMA NGSST (Hiroshi Kawamura; 5 km resolution); (Bottom left) Time lags to have maximum SSH. AVISO alongtrack SSHA. (Bottom right) Time lags (days) to have the maximum SST. Kishou SST (25 km resolution)

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References

[1] S. Y. Kim and B. D. Cornuelle. Coastal ocean climatology in the Southern California Bight: Seasonal variability, climate indices-coherent signals, and linear trend. *Prog. Oceanogr.*, 2014. submitted.