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Seasonal Two-way Relationships among the Sea Surface Net Heat Flux in the Kuroshio Extension Region and the North Pacific Climate Indices during 1989 – 2006

Hiroshi ICHIKAWA
RIGC, JAMSTEC, Yokosuka City, Kanagawa, 237-0061, Japan
E-mail: ichikawah@jamstec.go.jp

Background:

In mid- and high-latitude regions, the seasonal variations of oceanic and atmospheric variables are much more dominant than the interannual variations and are closely related to each other based on the seasonal timescale land-atmosphere-ocean interaction processes. Among them, the sea surface net heat exchange is the key components. Newman et al. (2003) examined the seasonal cycle of correlations among the North Pacific Index (NPI), the Pacific Decadal Oscillation index (PDO) and the El Nino - Southern Oscillation (ENSO) index from 1950 to 2001, and indicated that the NPI leads the PDO not only on monthly timescales but also on annual timescales during the winter. The ENSO index also leads the PDO index by a few months throughout the year, most notably in the winter and summer. However, they did not discuss on the NPI response to PDO and the ENSO response to PDO.

Objectives:

The interannual variations of oceanic variables are conjectured to respond to those of atmospheric variables through seasonal timescale interactions among their interannual annual signal changes, and vice versa. For examining this possible two-way response, the seasonal relationship among the satellite-derived sea surface net heat flux from the ocean (HFN) in the Kuroshio Extension region, the North Pacific Index (NPI), PDO index and NINO3.4 index from 1989 to 2006 are estimated together with the relationship among NPI, PDO and NINO3.4 for the data duration period from 1951 to 2006.

Data (Fig. 1):

Monthly mean HFN used in this study is area mean of satellite-derived HFN at 10 x 6 grid points with 1-degree interval in the Kuroshio Extension region of 32.5N-38.5N and 142.5E-152.5E, in the data set called J-OFURO2 over the global ocean during 20 years from January 1988 to December 2007 (Tomita et al, 2010). 3-month running mean monthly HFN time series from January 1989 to December 2006 is calculated from the anomaly time series of monthly mean HFN from its 20-year monthly means. NPI and PDO time series is calculated by the same method as for HFN. 5-month running mean NINO3.4 time series is the anomaly time series from its 20-year monthly means.

Method (Fig. 2):

The dominant relations between two variables, X and Y, are identified by comparing the statistically significant ($p< 0.01$) lagged correlations RXY(L, m) and RYX(L, m) in the range of lags from -36 to 36 months. Here, for example, the lagged correlation, RXY(+14, 1), between X in January and Y in March after 14 months, coincident with RYX(-14, 3), is calculated as a covariance between X in January from 1989 to 2005 and Y in March from 1990 to 2006.

Results:

The HFN is found to have two-way relationship with NINO3.4 and NPI, but one-way relationship with PDO (Table 1). While this result is limited in the duration of the data period from January 1989 to December 2006, it should be noted that the September HFN has the highest correlation with the NPI in December after 15 months, and the high correlation with NPI before 36 months.

The PDO and NINO3.4 are found to have two-way relationship with each other, but the NPI has one-way relationship with PDO and NINO3.4 for the 1989-2006 data (Table 2), but the PDO, NPI and NINO3.4 are found to have two-way relationship with each other for the 1951-2006 data (Table 3). It is confirmed that, while the winter NPI leads the PDO by 1 month, the September PDO leads NPI by 5 months. While the summer and winter NINO3.4 leads the PDO by 2 months, the September PDO leads NINO3.4 by 4 months. The winter NPI delays NINO3.4 by a few months, but the summer NPI leads NINO3.4 by a few months.

While the correlation analysis does not explain the mechanism underlying the obtained relations, the existence of dominant relations among HFN, NPI, PDO and NINO3.4 in the observed data give us valuable information for the prediction and general understanding of oceanic and atmospheric variability over the North Pacific.

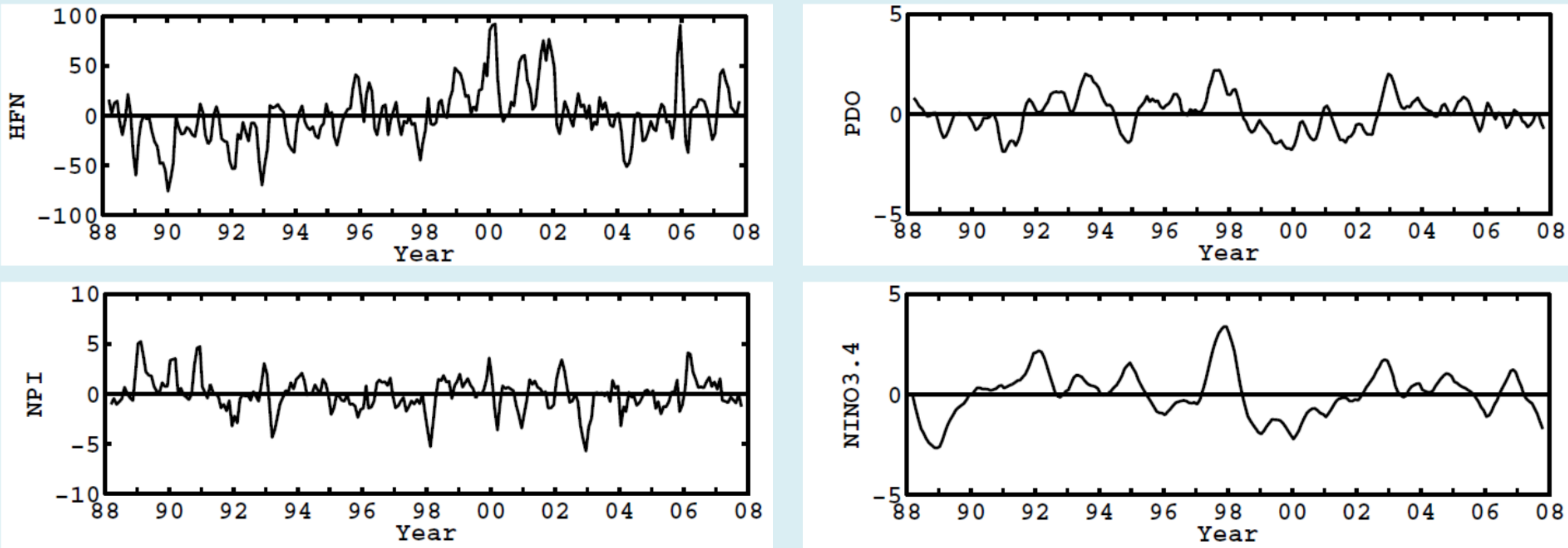

Fig. 1 Variations of HFN, NPI, PDO and NINO3.3

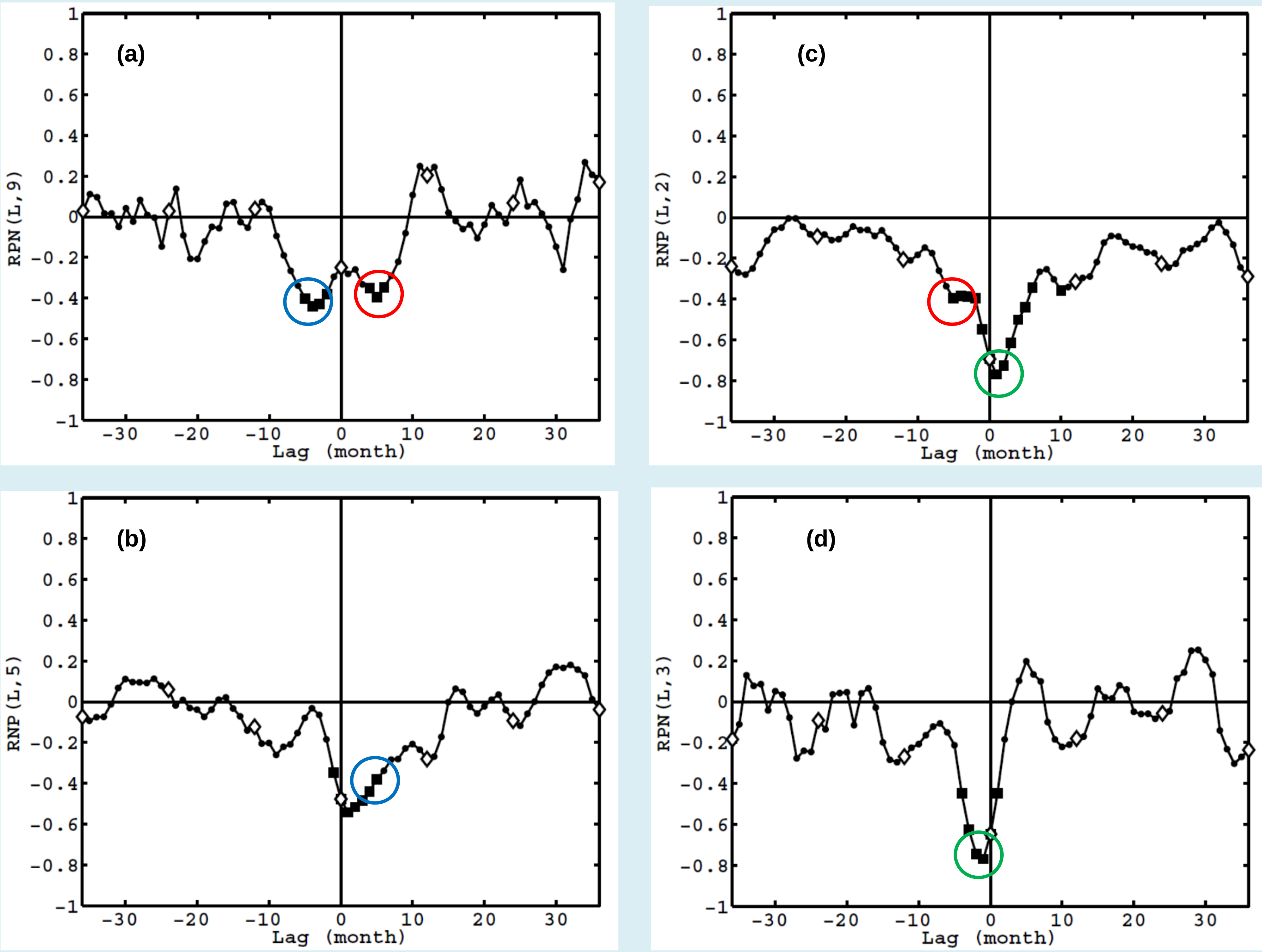

Fig. 2 Seasonal lagged correlations between PDO and NPI. The RXY(L, m) indicates the correlation of X in moth of m with Y after L months. Statistically significant ($p < 0.01$) correlations are indicated by squares. Diamonds indicate the values at lags of 12-month intervals from -36.

RPN(L, 9) in (a) has two correlation minima at L = -4 (May) and +5 (Feb.).
RNP(L, 5) in (b) indicates that RPN(-4, 9)=RNP(+4, 5) is not a dominant relation.
RNP(L, 2) in (c) has a significant correlation maximum at L = -5, indicating that RPN(+5, 9)=RNP(-5, 2) is a dominant relation.
The highest correlation at RNP(+1, 2) in (c) and RPN(-1, 3) in (d) indicate that it is the dominant relation.

TABLE 1. Dominant relations of HFN with NPI, PDO and NINO3.4 (NIN) from January 1989 to December 2006. A positive lag number indicates the number of months by which the index in the first column leads the index in the second column.

Month of HFN	Month of NPI, PDO or NIN	Lag	Correlation	P-value
September	December NPI	+15	-0.7032	0.0016
September	September NPI	-36	+0.6544	0.0081
December	April NPI	+4	+0.6420	0.0055
April	August NPI	+4	+0.6409	0.0042
November	September PDO	-2	-0.6651	0.0026
December	February PDO	-34	+0.6304	0.0088
December	April NIN	+4	-0.6864	0.0023
November	March NIN	+4	-0.6819	0.0026
April	December NIN	-4	-0.6214	0.0078
November	December NIN	+1	-0.6010	0.0083

TABLE 2. Dominant relations among NPI, PDO and NINO3.4 (NIN) from January 1989 to December 2006. A positive lag number indicates the number of months by which the index in the first column leads the index in the second column.

Month of NPI or PDO	Month of PDO or NIN	Lag	Correlation	P-value
September PDO	June NIN	-3	+0.7546	0.0003
March PDO	August NIN	-7	+0.6708	0.0032
September PDO	January NIN	+4	+0.6089	0.0095
March PDO	January NIN	-2	+0.6068	0.0076
June NPI	June NIN	0	-0.7108	0.0009
February NPI	January NIN	-1	-0.6730	0.0022
December NPI	August NIN	-28	+0.6712	0.0044
January NPI	October NIN	-3	-0.6157	0.0085
July PDO	May NPI	-2	-0.7597	0.0003
January PDO	November NPI	-2	-0.7497	0.0005
April PDO	April NPI	0	-0.7347	0.0005
March PDO	January NPI	-2	-0.6849	0.0017
March PDO	May NPI	-10	-0.6328	0.0064
February PDO	June NPI	-8	-0.6307	0.0066

TABLE 3. Dominant relations among NPI, PDO and NINO3.4 (NIN) from January 1951 to December 2006. A positive lag number indicates the number of months by which the index in the first column leads the index in the second column.

Month of NPI or PDO	Month of PDO or NIN	Lag	Correlation	P-value
Augast PDO	June NIN	-2	+0.6263	0.0001>
September PDO	July NIN	-2	+0.6215	0.0001>
February PDO	July NIN	-7	+0.5396	0.0001>
September PDO	January NIN	+4	+0.5265	0.0001>
March PDO	JanuaryNIN	-2	+0.5005	0.0001
February NPI	January NIN	-1	-0.5057	0.0001
February NPI	November NIN	-3	-0.4985	0.0001
August NPI	September NIN	+1	-0.3563	0.0070
August NPI	November NIN	+3	-0.3475	0.0087
October NPI	January NIN	-33	+0.3527	0.0089
March PDO	February NPI	-1	-0.7684	0.0001>
February PDO	Janaury NPI	-1	-0.7550	0.0001>
January PDO	December NPI	-1	-0.7449	0.0001>
May PDO	April NPI	-1	-0.6401	0.0001>
September PDO	February NPI	+5	-0.3973	0.0027
December PDO	March NPI	-9	-0.3684	0.0052