Journal of Environmental Biology **July 2008,** 29(4) 519-529 (2008)

Spatial variability in long-term changes of climate and oceanographic conditions in Korea

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(Received: February 22, 2007; Revised received: February 26, 2008; Accepted: March 10, 2008)

Abstract: *I evaluated long-term changes in hydrological conditions (temperature, salinity and dissolved oxygen) in Korean sea waters in relation to the regional land climate change (air temperature and precipitation) based on available meteorological and oceanographic data. Regression analyses, spatial patterns and cross-correlations on the climatologic and hydrological factors suggested that industrialization processes and related urban heat-island effects during the past 37 years from 1968 to 2005 in South Korea have increased land surface temperatures by 1.267°C, at least for the urban areas, and subsequently increased sea surface temperatures by 0.975°C and decreased salinities by 0.229. The influence of land surface temperature on the sea water temperature reached at least 75-m depth. Regarding the causality in the land-ocean climate changes, air-temperature changes preceded sea water temperature change by 0-2 months in spring and summer, but the sequence could be reversed, possibly because of potential heat held by the ocean. This study demonstrated that human factors have been driving warming influences on regional sea waters, impacting marine ecosystems and changing dominant fish species in commercial fishery catches of Korea.*

Key words: *Water temperature, Salinity, Air temperature, Urban heat island effect, Climate change, Global warming, Korea*
PDF of full length paper is available with author ***(*sukgeun.jung@gmail.com)***

Introduction

Recently, the Intergovernmental Panel on Climate Change (IPCC) reported that evidence for the warming of the climate system is unequivocal, from rising sea levels to increased temperatures (IPCC, 2007). According to the report, global mean temperature has increased by 0.65°C during the past 50 years, and the average temperature of the global ocean has increased to depths of at least 3,000 m. The report noted that the ocean has been absorbing more than 80% of the heat added to the climate system, suggesting impact of global warming, resulting from modern human activities, on marine systems around the world. Here I report such climate changes and related land-ocean interactions at the local scale for South Korea.

The land mass of Korea covers 220,843 km^2, and extends ca. 1,000 km north-south. Her 'waist' is < 200 km wide (Fig. 1). The Korean peninsula belongs to the temperate zone, but broadleaved evergreen plants and bamboo grow in the south. The peninsula consists of a block of Pre-Cambrian granite covered by later sediments and granitic intrusions, which is tilted down in the westward the Yellow Sea. Approximately 70% of the land surface is mountainous but rarely higher than 1,600 m. The mountain ranges are higher in the north and east. The mountains slope gently toward the south and west, ending in numerous islands and islets in the Yellow Sea. The major rivers also run toward the west and south. People have inhabited the peninsula since the paleolithic, ca. 500 thousand years ago (Nelson, 1993).

The climate of the peninsula is continental, and prehistoric glacial activity is not evident in the Korean peninsula. The winters are cold and dry, while the summers are hot and subject to monsoon rain (McCune, 1956). Large deviations from the mean precipitation are a feature of Korean weather. Compared with the eastern coastal areas of China, changes in coastal lines due to alluvial sediments have been minimal in Korean coastal areas during the Holocene.

The Korean peninsula is surrounded by the three geomorphologically and ecologically distinctive seas, *i.e.*, the East, Yellow and South Seas. The East Sea of Korea is a deep basin (the maximum depth = 4,049 m). The southern portion of the East Sea is influenced by the warm, saline Tsushima Warm Current, a branch of the Kuroshio Current. The North Korea Cold Current, a branch of the Liman Current, flows south along the Korean eastern coast. The Yellow Sea, or the West Sea of Korea, is a shallow, semi-enclosed shelf sea. The mean depth is 44 m. Shallow depths and strong tidal mixing result in high turbidity (Yoo and Park, 2007). Warm, saline water enters from the East China Sea episodically in winter (Lie *et al.*, 2001) and cooler, fresher water originating from rivers dominate the surface distribution of water properties (Chen *et al.*, 1994). The South Sea has intermediate geomorphology and ecology between the Yellow and East Sea. The Tsushima Warm Current enters the South Sea, flowing north east ward through the Korea Strait.

Kim and Kang (2000) investigated relationships of El Nino with hydrological conditions and biota in waters of the South Sea. Zhang *et al.* (2000) and Rebstock and Kang (2003) suggested climatic regime shifts occurred in 1976 and 1988 in the marine ecosystems of Korean waters based on historical climatologic, oceanographic and fisheries data. Seo *et al.* (2006) reported that growth rates of chum salmon (*Oncorhynchus keta*) in the Bering Sea were related to climate changes through zooplankton biomass in the late 1980s.

Special Issue - **Marine Environmental Biology**
Guest Editor - **H.W. Shin, Korea**

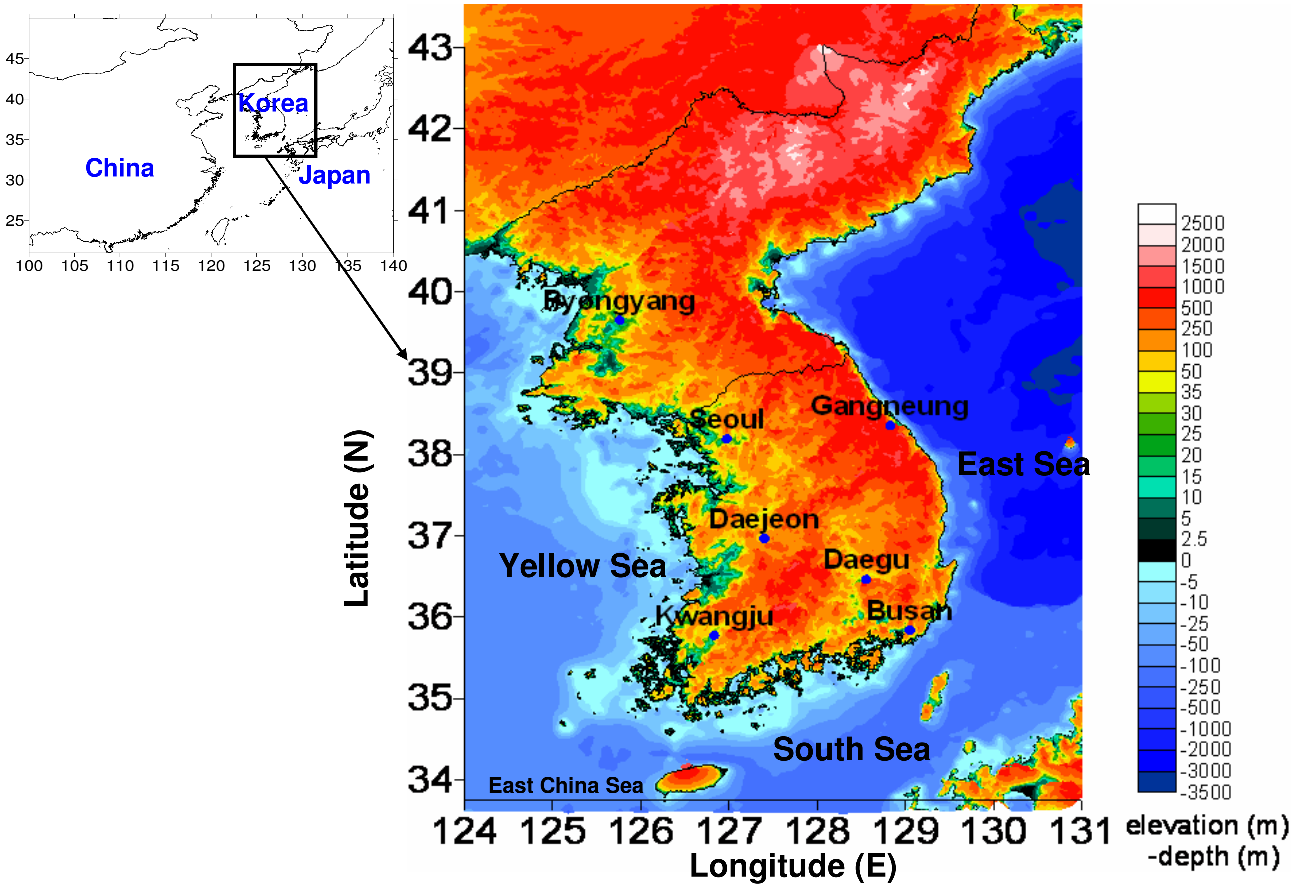

Fig. 1: Geomorphology of Korea (elevation and water depth at m)

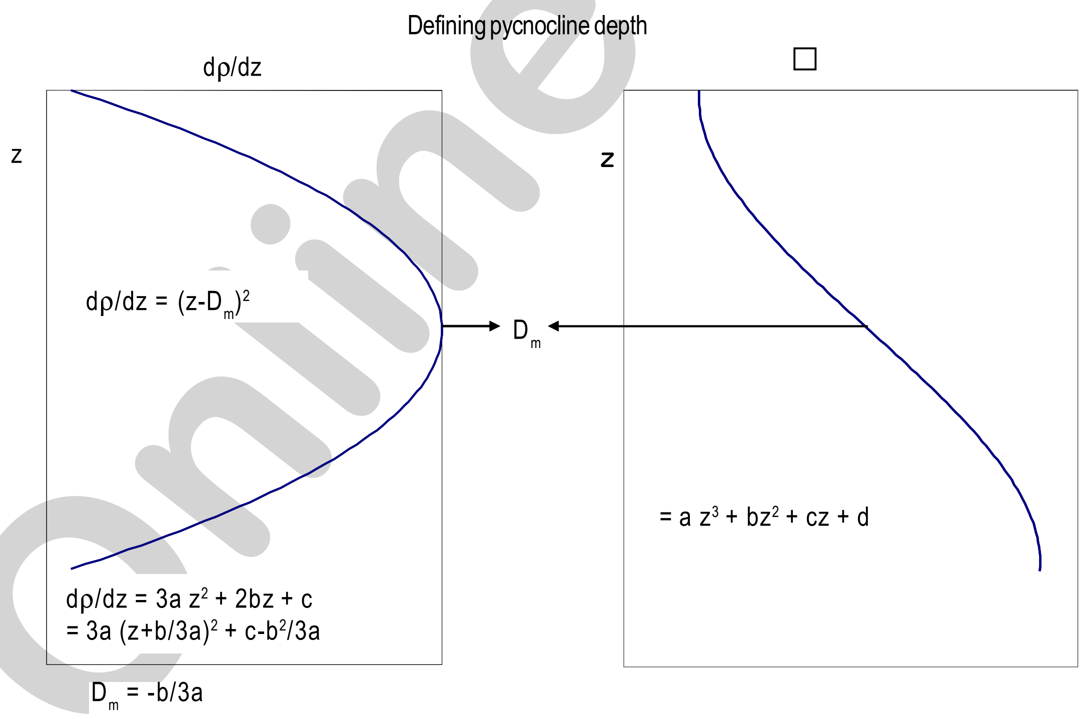

Fig. 2: Scheme of defining pycnocline depth by a third-order polynomial regression on water-density vertical profile used in this study

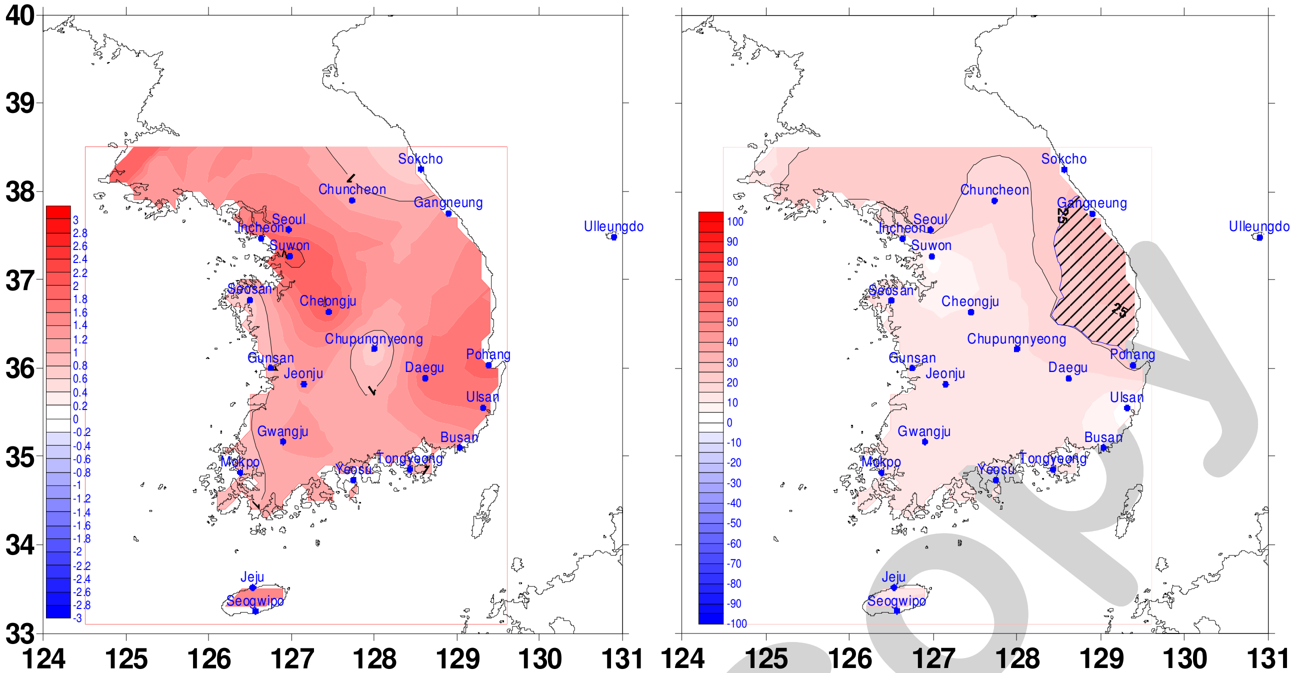

Fig. 3: Spatially-specific, long-term linear changes in (a) air surface temperatures (°C) and (b) precipitations (mm mo^{-1}) in the Korean peninsula from 1968 to 2005. The hatched area in (b) denotes that the precipitation increase was significant at $\alpha = 0.05$

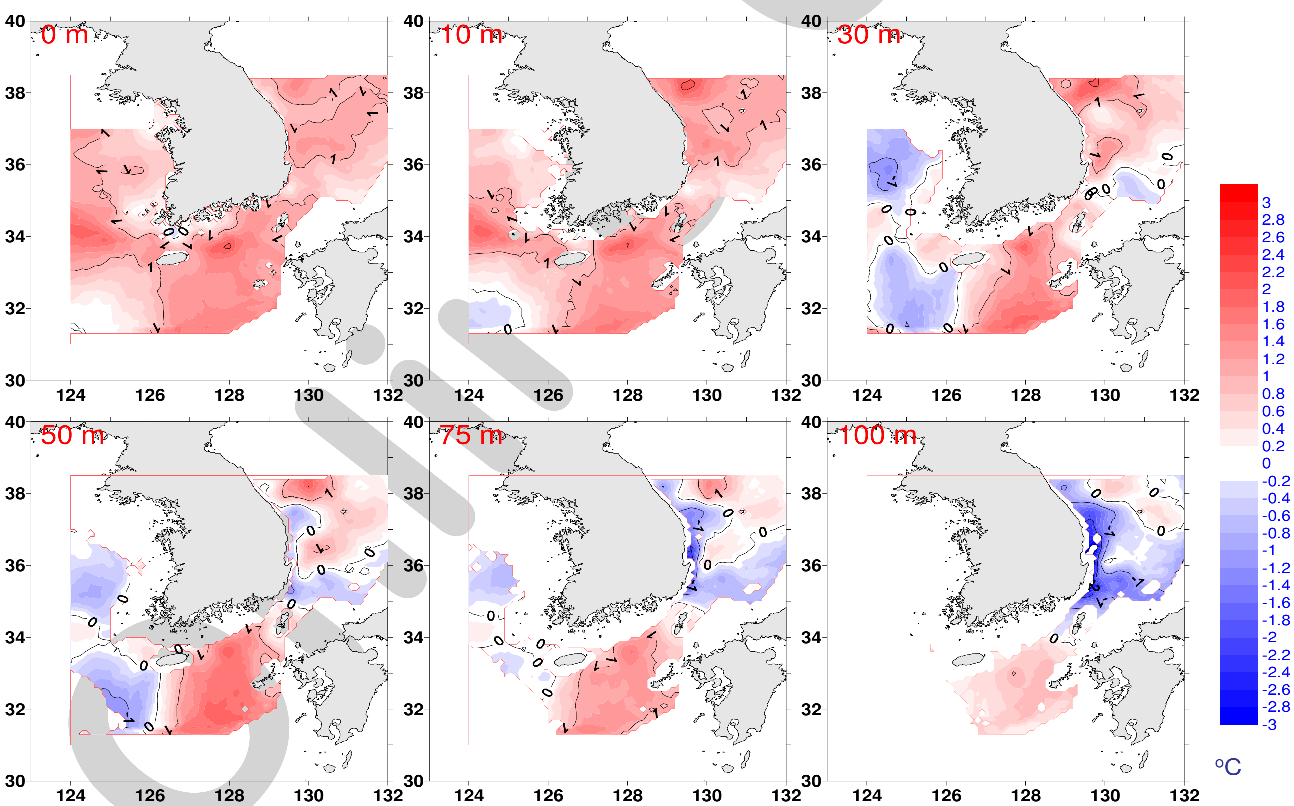

Fig. 4: Spatially-specific, long-term linear changes in water temperatures (°C) at each standard water depth in sea waters off South Korea from 1968 to 2005. The color red denotes an increase whereas the blue denotes a decrease

However, Korean meteorological data have not yet been utilized enough to be related to hydrological and ecological changes in Korean waters. Admittedly, oceanographic conditions of Korean waters could respond remotely to global climate processes such as El Niño (Kim *et al.*, 1997, Kim and Kang, 2000, Suh *et al.*, 2003), the East Asian Monsoon Index (Rebstock and Kang, 2003) and the Pacific Decadal Oscillation (PDO) (Zhang *et al.*, 2000). However, proximate effects of regional climate changes in the Korean peninsula on its adjacent sea waters have not yet been investigated. Without examining regional terrestrial climate changes, it would be difficult to understand causal relationships and interactions among various local and global processes regarding climate changes. As a first attempt to understand responses of local marine ecosystems to global climate change, I correlated regional, long-term climate changes in the Korean peninsula with hydrological changes in marine ecosystems adjacent to the peninsula.

The objectives of this study are 1) to describe spatially-explicit, long-term climate changes in the Korean peninsula during the past 40 years, 2) to investigate land-ocean interactions with respect to the local climate changes, and 3) to identify distinctive features in the regional climate changes when compared with global climate changes.

Materials and Methods

Data source: The Korea Meteorological Administration (KMA-http://www.kma.go.kr) provided me with daily time-series of air temperature and precipitation that have been measured from up to 41 stations covering the South Korea since 1904, but I included only data since 1968 when the nationwide number of stations reached 22. The meteorological variables were averaged or summed monthly for each station to compare with oceanographic variables. At these 22 stations, monthly means of temperature and precipitation were available without any single missing value from 1968 to 2006, ruling out possibility of potential biases due to differences in stations.

Oceanographic factors (temperature, salinity, and dissolved oxygen) have been measured bimonthly for the water columns at 175 fixed stations along 22 oceanographic lines in Korean waters since 1961 by the National Fisheries Research and Development Institute (NFRDI-http://www.nfrdi.re.kr), but I included only the 1968-2005 data to match with the period of the meteorological data. For consistency, I selected the data for the standard water depths of 0, 10, 20, 30, 50, 75 and 100 m. To exclude the effect of water temperature on gas solubility, DO saturation levels were also calculated based on the potential full saturation level estimated based on temperature and salinity using the following equation (EPA, 2003):

DO saturation = 14.6244 - 0.367134*WTEMP + 0.0044972*WTEMP*WTEMP - 0.0966*SALIN + 0.00205*SALIN*WTEMP + 0.0002739*SALIN*SALIN;

Pycnocline depth: I estimated pycnocline depths from derivatives of third-order polynomial regression equations for each station (Fig. 2):

$$\rho = a z^3 + b z^2 + c z + d$$

where ρ : density; z: depth (m). The first-order derivative is

$$d\rho/dz = 3a z^2 + 2 b z + c$$

The first-order derivative will be a dome-shaped curve for a typical density profile in the sea, because the $d\rho/dz$ increases from surface to the pycnocline depth, decreasing thereafter to the bottom (Fig. 3). This means that $a < 0$, $b > 0$. Thus *ds/dz* will be maximized at (Pycnocline depth) = $-b/3a$

because $d\rho/dz = 3a z^2 + 2 b z + c = 3a (z + b/3a)^2 + c - b^2/3a$, which is maximized at $z = -b/3a$ because $a < 0$. For those destabilized stations where the regression failed to fit, mean pycnocline depth for the region was assigned. Because the polynomial equations fit poorly for the cold seasons, I estimated the pycnocline depths only for Aug. to estimate the long-term trend.

Kriging: Anisotropic (both latitudinal and longitudinal) linear variogram functions without 'nugget' effect (Cressie, 1993) were used to estimate the meteorological and oceanographic variables including the Aug. pycnocline depth by interpolation of values for unsampled 10 x 10 nautical-mile grids to generate distribution maps. The variogram functions were derived by applying proc VARIOGRAM of SAS version 9, and the grid data files were generated by proc KRIGE2D to produce distribution maps (SAS, 1996).

Trend of change: The trend of long-term change from 1968 to 2005 of the meteorological and hydrological variables were estimated by a seasonal analysis using proc GLM of SAS version 9 (SAS, 1989) for each grid. The seasonal analysis estimated the slope of a regression line after removing seasonality (an exception is the Aug. pycnocline depth). Depth-specific, monthly means of water temperature, salinity and dissolved oxygen, which were averaged for the sea area adjacent to the Korean peninsula (124^o-132^o E, 31^o -38^o 30' N), were used as the independent variable in the seasonal analysis. Additionally, linear trend of changes were estimated by linear regression analysis after estimating annual means of the three hydrological variables from 1968 to 2005.

I investigated causality in land-ocean climate interactions in Korea by correlation and cross-correlation analyses using SAS version 9 proc CORR and ARIMA (SAS, 1989). To evaluate possible responses of Korean local climate systems to the global climate change, I compared the regionally-obtained time-series with available global climate indices such as the East Asian Summer Monsoon Index (EASMI-http://web.lasg.ac.cn/staff/ljp/data/EASMI.htm) and the El Nino/Southern Oscillation Index (ENSO-http://www.cdc.noaa.gov/people/klaus.wolter/MEI/mei.html). Correlation analyses were used for this purpose.

Results and Discussion

Air temperature and rainfall: Seasonal analysis for each city showed that air temperature has increased during the past 37 years without exception in South Korea (Table 1). The long-term temperature-increase trend was most pronounced in Suwon, a city near Seoul and Cheongju areas (ca. 2^{o}C), followed by the Incheon, Pohang and Daegu (Table 1). In overall, the temperature increase

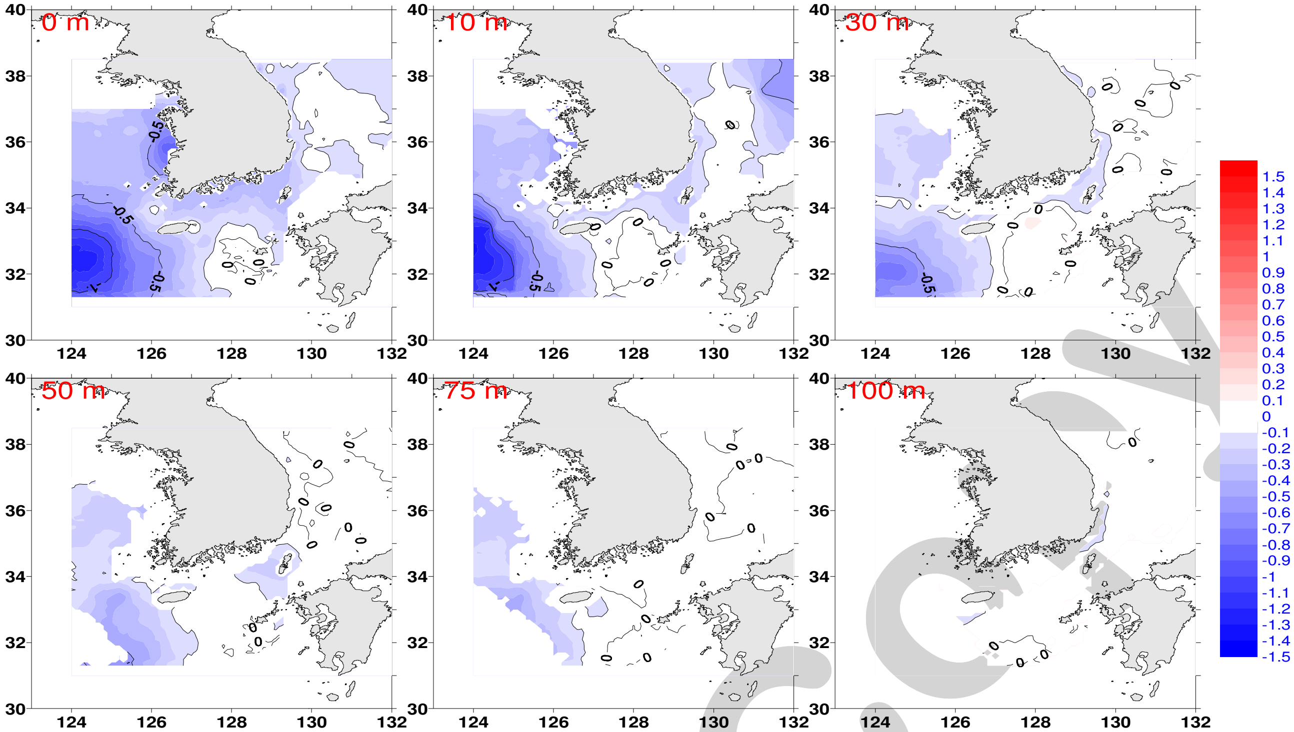

Fig. 5: Spatially-specific, long-term linear changes in salinities at each standard water depth in sea waters off South Korea from 1968 to 2005. The color red denotes an increase whereas the blue denotes a decrease

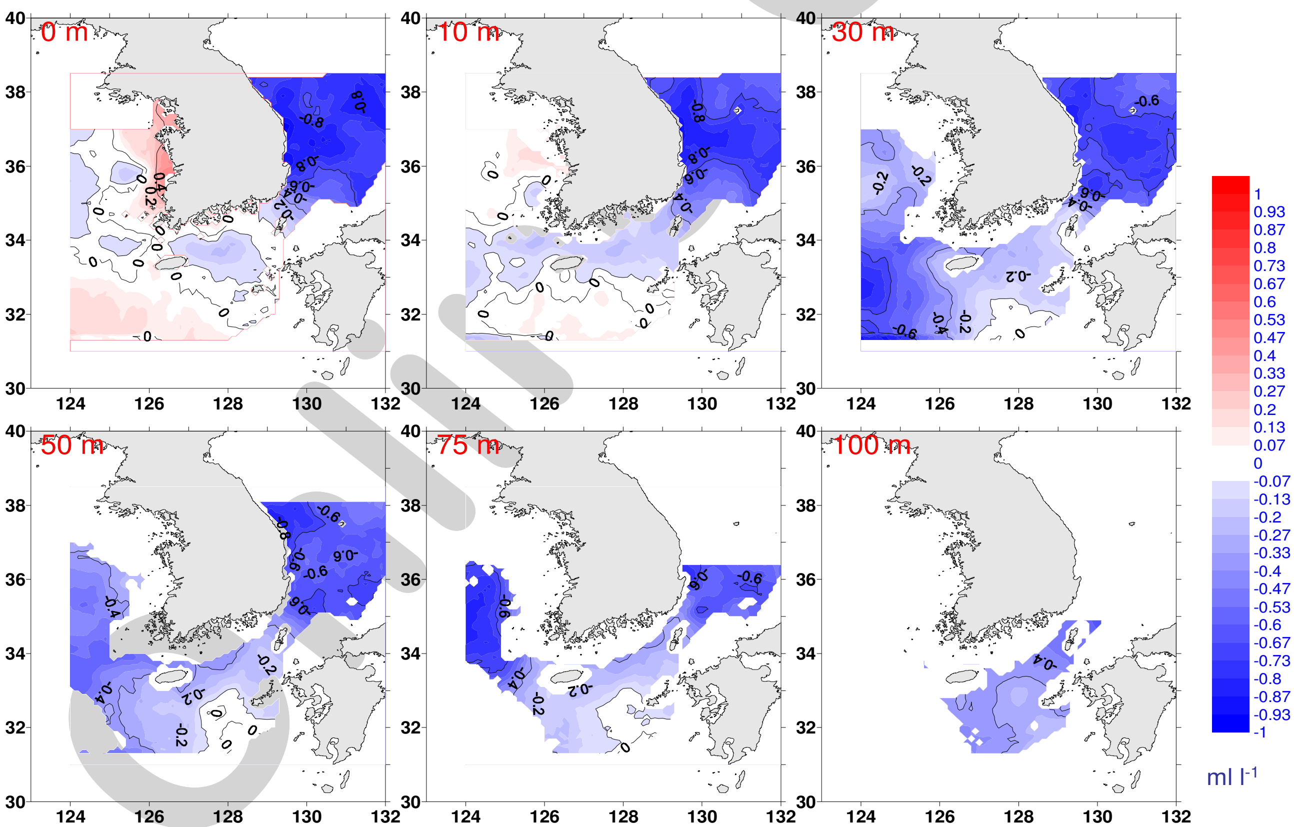

Fig. 6: Spatially-specific, long-term linear changes in dissolved oxygen amounts (ml l^{-1}) at each standard water depth in sea waters off South Korea from 1968 to 2005. The color red denotes an increase whereas the blue denotes a decrease

Table - 1: List of meteorological observation stations and the linear rates of temperature increase from 1968 to 2005

	Longitude	Latitude	Annual rate			Linear increase
	Decimal	Degree	(°C yr⁻¹)	S.E.	p	(1968-2005) (°C)
Suwon	126.98	37.27	0.056	0.006	<.0001	2.055
Cheongju	127.45	36.63	0.052	0.006	<.0001	1.939
Pohang	129.38	36.03	0.050	0.005	<.0001	1.868
Incheon	126.63	37.47	0.049	0.005	<.0001	1.817
Daegu	128.62	35.88	0.048	0.005	<.0001	1.762
Seogwipo	126.57	33.25	0.046	0.004	<.0001	1.715
Seoul	126.97	37.57	0.044	0.006	<.0001	1.621
Ulsan	129.32	35.55	0.043	0.005	<.0001	1.592
Gangneung	128.90	37.75	0.036	0.006	<.0001	1.333
Jeju	126.53	33.52	0.036	0.004	<.0001	1.319
Busan	129.03	35.10	0.033	0.005	<.0001	1.211
Gwangju	126.90	35.17	0.032	0.005	<.0001	1.196
Yeosu	127.75	34.73	0.032	0.005	<.0001	1.174
Jeonju	127.15	35.82	0.031	0.005	<.0001	1.152
Chuncheon	127.73	37.90	0.029	0.006	<.0001	1.068
Ulleungdo	130.90	37.48	0.027	0.005	<.0001	0.984
Tongyeong	128.43	34.85	0.025	0.005	<.0001	0.934
Gunsan	126.75	36.00	0.024	0.005	<.0001	0.901
Mokpo	126.38	34.82	0.021	0.005	<.0001	0.782
Sokcho	128.57	38.25	0.017	0.006	0.0019	0.641
Seosan	126.50	36.77	0.017	0.005	0.0007	0.636
Chupungnyeong	128.00	36.22	0.016	0.005	0.0024	0.585

trend was higher in the Capital area around Seoul and the Yongnam area covering Daegu, Pohang and Ulsan where industrialization has been most active in Korea during the past 40 years (Fig. 3a). From 1968 to 2005, the nationwide mean temperature has increased by 1.267°C (0.034 +/- 0.007°C yr^{-1}, $p < 0.0001$) (Table 2), which is 2.6 times higher than the linear warming trend at the global scale of 0.013°C yr^{-1} reported for the past 50 years by the IPCC (2007).

The increasing trend of air temperatures in the Korean peninsula shown in the seasonal analysis (Fig. 3a) could be overestimated, because most of the 22 meteorological observation stations are located within the downtown areas where industrialization and population increase has been most active during the past 40 years in South Korea (urban heat island effect). In other rural areas, where the urban heat island effects are minimal, the increasing trend of air temperature could be less than the trend reported in this study.

Based on the pattern of spatial distribution of air-temperature increase (Fig. 3a), it could be conclude that the magnitude of the temperature changes generally corresponded to regional population and degree of industrialization, and was high in the capital area around Seoul and the southeast area around Pohang and Ulsan, the center of modern industrialization during the past 40 years.

Although the nationwide monthly mean precipitation has not increased significantly (19.9 mm mo^{-1} from 1968 to 2006, $p = 0.15$), the area linking Gangneung and Pohang in the east of the Korean peninsula showed significant increase in precipitation by > 25 mm mo^{-1} (Fig. 3-b).

Oceanographic conditions: Seasonal analysis showed that, in Korean coastal sea waters, depth-specific, monthly-averaged water temperatures, averaged for the entire sea areas included in the analysis , has significantly increased in the entire water column from 0 to 75-m depth for the 1968 to 2005 period, but the magnitude of increase dwindled with water depth and became statistically not significant at 100-m depth (Table 2, Fig. 4). The IPCC (2007) also reported that the average temperature of the global ocean has increased to depths of at least 3,000 m. The annual increase rate ranged from 0.026 +/- 0.005°C yr^{-1} at surface to 0.011 +/- 0.006 at 75 m. In overall, the sea surface temperature has increased by 0.975°C from 1968 to 2005 (Table 2).

Spatially, the warming trend was most prominent in the East and South Sea (Fig. 4), suggesting additional warming influence from the tropical Pacific via the Kuroshio current (McPhaden and Zhang, 2002). At 0 and 10 m depths, water temperatures have increased for the entire ocean area off Korea. However, in some areas of Korean part of the Yellow Sea, water temperatures have decreased at 20-50 m depths. In the East Sea, water temperatures have decreased at some areas at < 30 m depths, and the area of decreasing trend expanded with water depths up to 100 m (Fig. 4), suggesting that the warming sea surface layer could strengthen the pycnocline, reducing heat transport by vertical mixing to deep water.

For the 1968 to 2005 period, depth-specific monthly salinity, averaged for the entire sea areas, has decreased at depth layers ≤ 10 m (Table 2; Fig. 5). The annual decrease rate was 0.006 +/- 0.002 at the surface and 0.005 +/- 0.002 at 10-m layer. Below 20-m

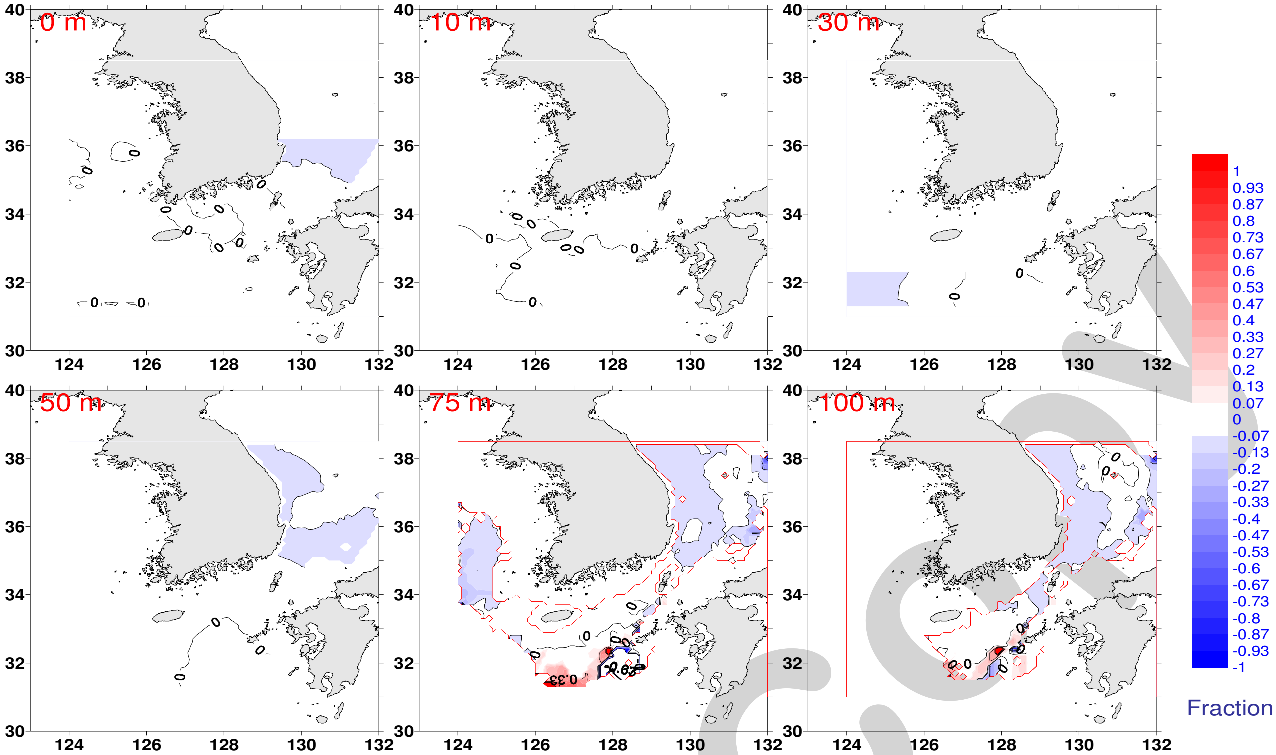

Fig. 7: Spatially-specific, long-term linear changes in dissolved oxygen saturations (fraction) at each standard water depth in sea waters off South Korea from 1968 to 2005. The color red denotes an increase whereas the blue denotes a decrease

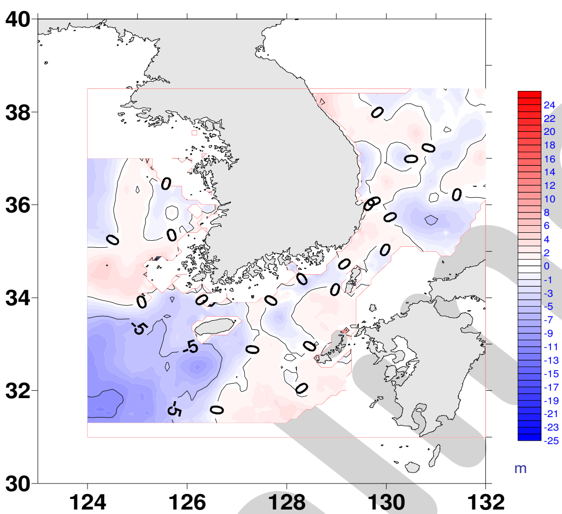

Fig. 8: Spatially-specific, long ong-term linear changes in Aug. pycnocline depths (m) in sea waters off South Korea from 1968 to 2005. The color red denotes an increase whereas the blue denotes a decrease

depth, it has ostensibly decreased, but the decreasing trend was statistically not significant. Spatially, the decreasing trend of salinity was most visible in the northern East China Sea, probably related to the annual variations in Changjiang diluted water (Chen *et al.*, 1994) (Fig. 5).

Depth-specific, monthly-averaged dissolved oxygen (DO) level, averaged for the entire sea areas, has decreased significantly from 1968 to 2005 at all of the standard depths from 0 to 100 m (Table 2; Fig. 6), suggesting reduced gas solubility by increased water temperature. DO saturation levels, which exclude the effect of water temperature on gas solubility, also have decreased significantly for the entire water column, at least up to 100 m (Fig. 7). The degree of decrease generally increased with water depth (Table 2). Although water temperatures have increased most in the South Sea, spatial distributions of the DO and its saturation levels showed that DO decreased most in the East Sea (Figs. 6 and 7).

The Aug. pycnocline became generally shallower during the past 37 years, but the spatially-explicit linear trends were statistically significant only in the northern East China Sea (124°-127° E, 31° 5'-34° N) where showed a deepening trend by 5-10 m (Fig. 8).

The linear change in depth-specific water temperature, salinity, and DO, which were estimated by a linear regression based on annual means (Figs. 9-11), slightly differed from those estimated by seasonal analysis based on monthly means.

Land-ocean interactions in local climate changes in Korea: Regarding the causality of land-ocean climate interactions, cross-correlation analyses indicated that water temperatures change generally followed air temperature change with time lags of 0 to 12 months, although they could precede air temperature changes by up to 3 months, possibly because of potential heat held by the sea.

Table - 2: The linear rates of land climate and depth-specific hydrological factors in the sea waters (124°-132° E, 31° -38° 30' N) adjacent to the Korean peninsula from 1968 to 2005

Factors	Depth (m)	Annual rate (yr^{-1})	S.E.	p-value	Linear increase (1968-2005)
Climate factors					
Air temperature (°C)		0.034	0.007	<.0001	1.267
Precipitation (mm mo^{-1})		0.537	0.375	0.1531	19.869
Hydrological factors					
Water temperature (°C)	0	0.026	0.005	<.0001	0.975
	10	0.025	0.004	<.0001	0.918
	20	0.014	0.005	0.0054	0.500
	30	0.013	0.005	0.0188	0.470
	50	0.012	0.006	0.0274	0.454
	75	0.011	0.006	0.0479	0.411
	100	0.001	0.007	0.9117	0.028
Salinity	0	-0.006	0.002	0.0014	-0.229
	10	-0.005	0.002	0.0133	-0.176
	20	-0.003	0.002	0.1009	-0.094
	30	-0.002	0.001	0.1332	-0.071
	50	-0.002	0.001	0.0915	-0.060
	75	-0.001	0.001	0.4492	-0.021
	100	0.000	0.001	0.9295	0.002
Dissolved oxygen (ml l^{-1})	0	-0.006	0.002	0.0001	-0.238
	10	-0.008	0.002	<.0001	-0.299
	20	-0.011	0.002	<.0001	-0.418
	30	-0.013	0.002	<.0001	-0.490
	50	-0.012	0.002	<.0001	-0.460
	75	-0.013	0.002	<.0001	-0.490
	100	-0.015	0.002	<.0001	-0.549
Dissolved oxygen saturation	0	0.000	0.000	0.0498	-0.015
	10	-0.001	0.000	0.0046	-0.022
	20	-0.001	0.000	<.0001	-0.040
	30	-0.001	0.000	<.0001	-0.045
	50	-0.001	0.000	<.0001	-0.039
	75	-0.001	0.000	<.0001	-0.035
	100	-0.001	0.000	<.0001	-0.047

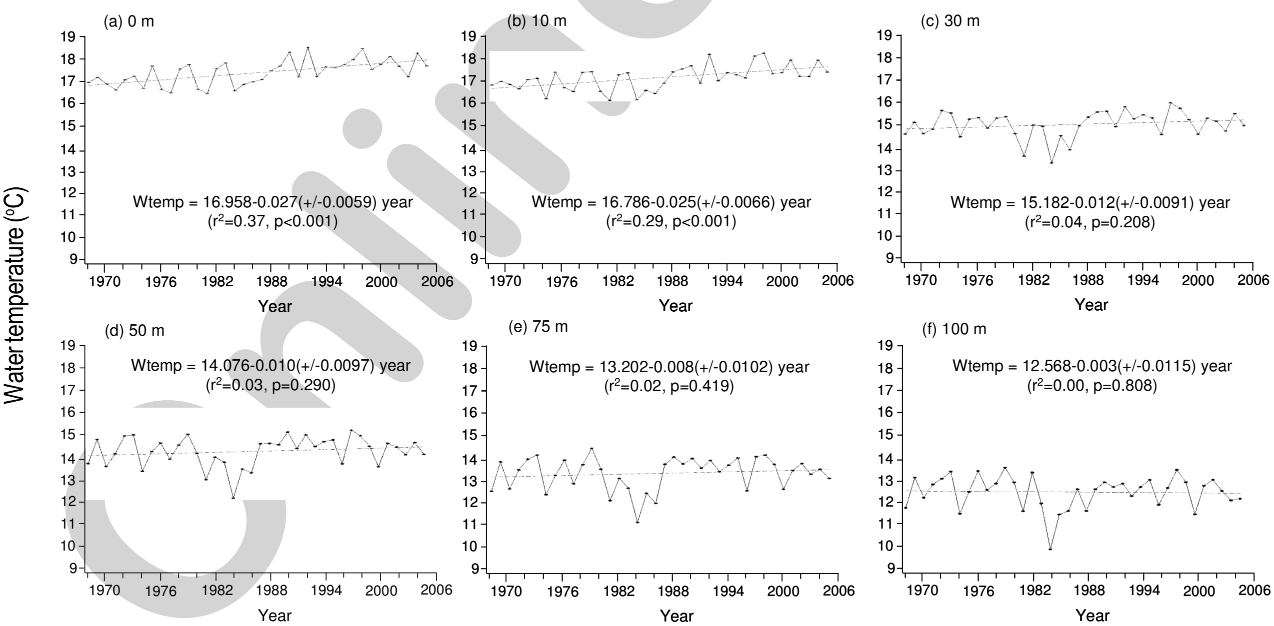

Fig. 9: Long-term linear changes in annually-averaged water temperatures (°C) at each standard water depth in sea waters off South Korea from 1968 to 2005. Water depths are (a) 0 m, (b) 10 m, (c) 30 m, (d) 50 m, (e) 75 m, and (f) 100 m

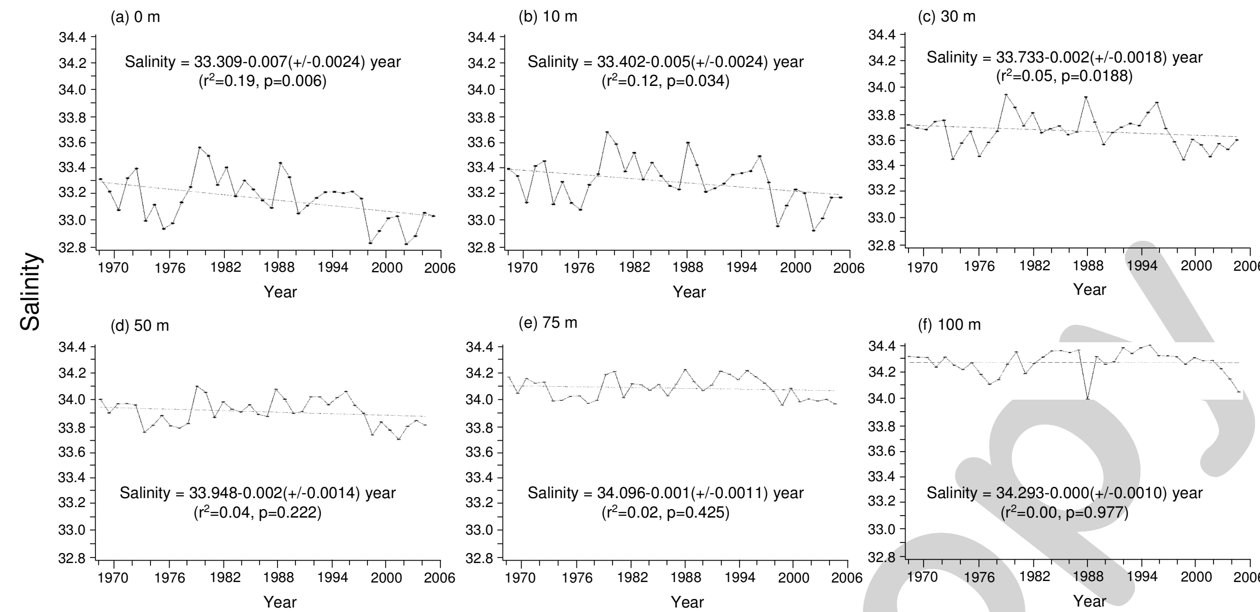

Fig. 10: Long-term linear changes in annually-averaged salinities at each standard water depth in sea waters off South Korea from 1968 to 2005. Water depths are (a) 0 m, (b) 10 m, (c) 30 m, (d) 50 m, (e) 75 m, and (f) 100 m

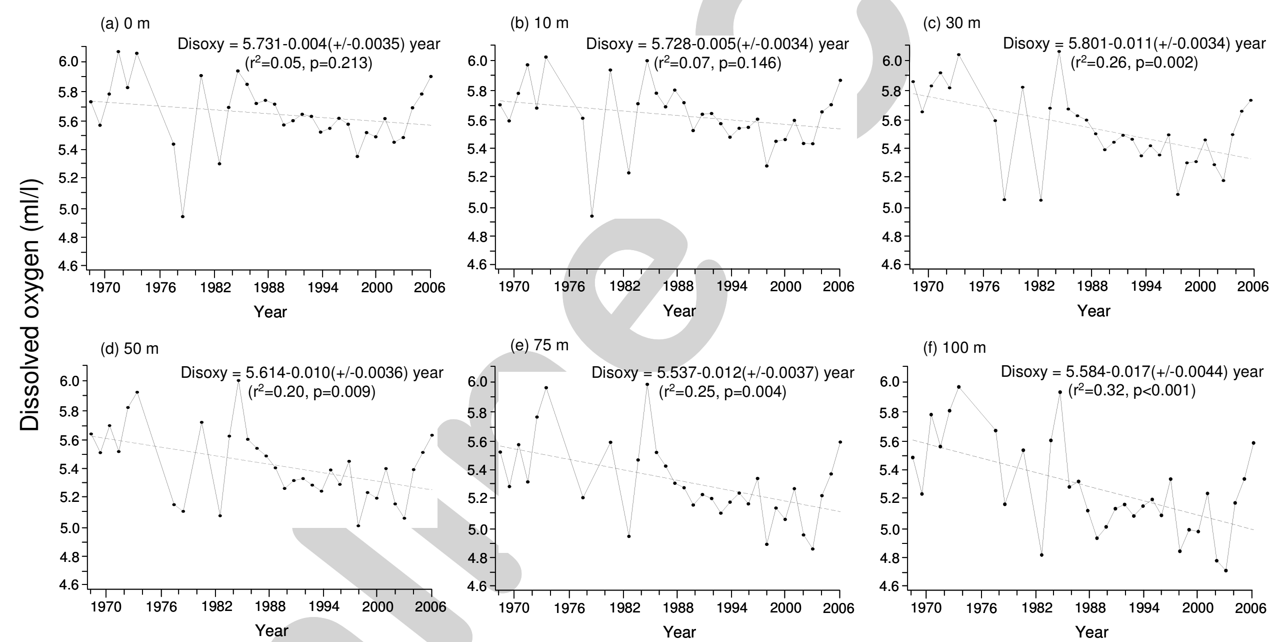

Fig. 11: Long-term linear changes in annually-averaged dissolved oxygen amounts (ml l^{-1}) at each standard water depth in sea waters off South Korea from 1968 to 2005. Water depths are (a) 0 m, (b) 10 m, (c) 30 m, (d) 50 m, (e) 75 m, and (f) 100 m

Previous month's air temperatures (m-1) explained 93% of the variance in monthly means of coastal sea surface temperatures (m) off the peninsula (Fig. 12), but contemporaneous air temperatures (m) explained only 66% of the variance. This pattern of significant cross-correlation between sea-water temperature and previous month's air temperature was consistently observed for up 30-m water depths, but below 30-m, the correlation tended to be less significant for the Jun.-Aug. period. For 50-100 m water depths, Jul. and Aug. water temperature showed negative cross-correlation with the previous month's air temperature (graphics not shown), suggesting that shallow sea waters interact more instantly with the air temperature of the peninsula than deep waters. The degree of response to the annual mean air temperature also dwindled with water depths, but the correlation of annual mean water temperature with the air temperature was still statistically significant even at 100-m depth (r = 0.38, p = 0.0176), implying warming influences could

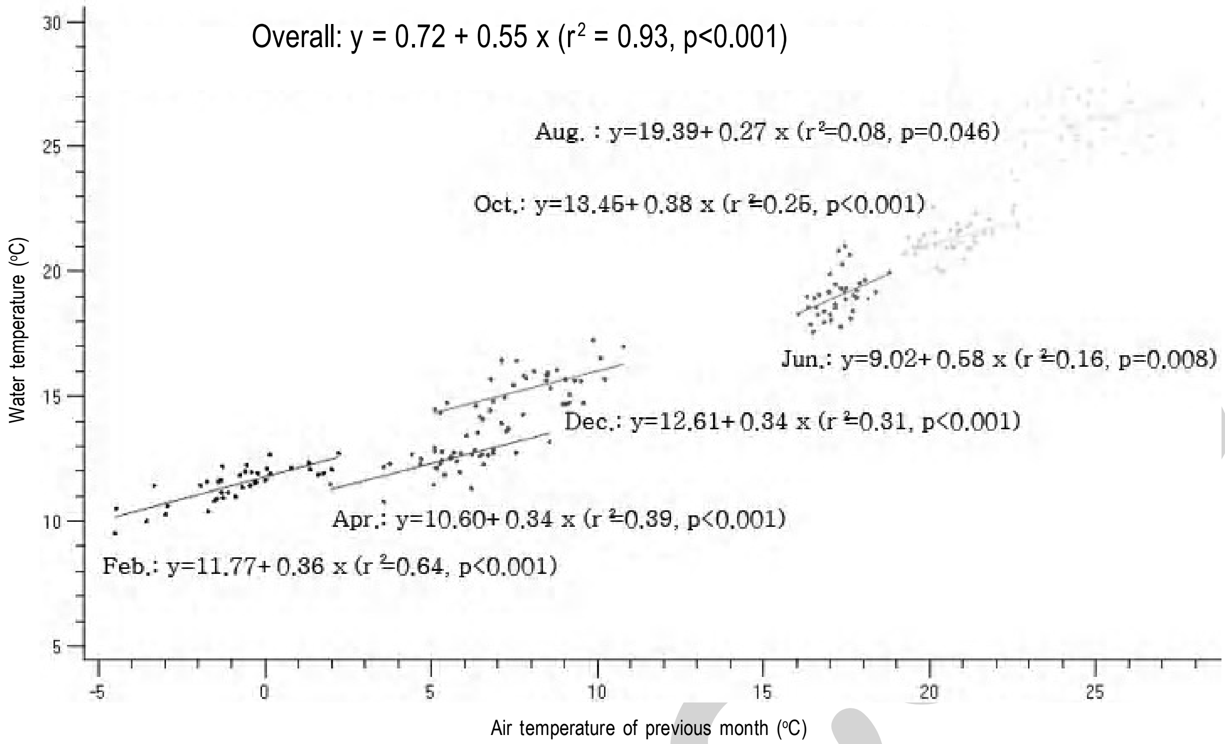

Fig. 12: Month-specific regression analyses of mean sea surface temperatures with respect to mean air surface temperatures of the previous month from 1968 to 2005. Each point represents a year (n= 38, from 1968 to 2005). The equation denotes the overall regression line for all of the 6 months (n = 38 x 6)

reach 100-m depth in Korean coastal, impacting marine ecosystems and changing dominant species in fishery catches (Brinda and Bragadeeswaran, 2005).

Depth-specific, annually-averaged mean salinity was generally negatively correlated with annual precipitation in South Korea, but the correlation was statistically significant only for surface to 20-m water depths ($p < 0.05$), suggesting the influence of precipitation on coastal water is restricted to the mixed layer.

Dissolved oxygen (DO) level and its saturation level, averaged for the year and the entire sea area off South Korea, were significantly negatively correlated with annual, nationwide mean air temperatures for all of depths ranging from 0 to 100 m (r = 0.58~ 0.44, p<0.01). The magnitude of DO response to the mean air temperature change increased with increasing water depth, ranging from -0.165 ml l^{-1}/°C air temperature at the surface to -0.289 ml l^{-1}/°C air temperature at 100-m depth, implying that global warming could decrease DO more drastically in deeper layers in Korean coastal waters. The increasing trend with water depths in the magnitude of DO response to air temperature was the same for DO saturation levels, suggesting that global warming could impact benthic organisms in deep Korean coastal waters through extending hypoxia (Chen *et al.*, 2007).

Relationships of local climate systems to the global climate change: Annually-averaged air temperature for the entire Korean peninsula did not show significant correlations with the El Nino-Southern Oscillation (ENSO) index (p = 0.69) or with the East Asian Summer Monsoon Index (p = 0.48). Annual, nationwide total precipitation also did not show significant correlations with the ENSO index (p = 0.75) or with the East Asian Summer Monsoon Index (p = 0.81). However, the ENSO and East Asian Summer Index were significantly correlated with each other ($p < 0.001$).

Cross-correlation analysis showed that some of depth-specific, monthly-averaged water temperatures, salinity and DO were significantly correlated with ENSO index with time lags of up to 1 yr, suggesting that oceanic hydrological conditions, rather than the terrestrial climate system of the Korean peninsula, could respond more to ENSO. Further detailed regional analyses are required to investigate the relationships of local climate and hydrological conditions in Korea in relation to global climate indices.

Prospect of climate change in Korea: My estimate of linear trend of air temperature in South Korea for the past 37 years is 2.6 times higher than the linear warming trend of 0.013°C yr^{-1} estimated for the past 50 years by the IPCC (2007).

Compared with the status of the regional climate in 2005, I anticipate that air-temperature in South Korea could increase by 0.82°C in 2030 and by 3.12°C in 2100, if the current trend continues. Under the same assumption, the projected sea surface temperatures around the Korean peninsula could increase by 0.63° and 2.48°C in 2030 and 2100, respectively. The magnitude of the linear trend of surface water temperature corresponds to 77% of that of air temperature in the Korean peninsula.

This cumulative data analysis demonstrated that human factors such as industrialization, green gas and urban heat island effects, could drive warming influences on regional sea waters, impacting marine ecosystems (Axenrot and Hansson, 2003, Beamish *et al.*, 2004, Blanchard *et al.*, 2005, Friedland *et al.*, 2003, Petit *et al.*, 1999, Rose, 2004) and changing dominant fish species in commercial fishery catches of Korea (Gong *et al.*, 2007, Wood *et al.*, 2004). The baseline data and their long term changes interpreted in this study can be used to assess the impacts of global and local climate changes on Korean marine ecosystems, ranging from eutrophication (Govindasamy *et al.*, 2000) and secondary production to fish community structure and fishery yield.

Acknowledgments

I thank the Korea Meteorological Administration for providing historical meteorological data of South Korea. Special thanks to all the crew members and scientists of NFRDI who have participated in KODC cruises since 1961. This is Contribution No. RP-2008-ME-001 of NFRDI.

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