Spatial Distribution of Turbulent Heat Fluxes in the Western North Pacific: Ocean Current Constraint for Hot Spot of Mid-Latitude Air-Sea Interaction

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ABSTRACT

Climatological mean distributions of turbulent heat fluxes (i.e., latent plus sensible heat fluxes) have been documented using an operational analysis dataset, whose spatial resolution is about one order higher than the resolution of widely used reanalysis datasets. It is revealed that mean oceanic currents and associated Sea-Surface Temperature (SST) fronts, i.e., the Kuroshio, the Kuroshio Extension, and the subpolar front (also sometimes called the Oyashio extension), strongly affect the heat fluxes. Such close constraints are not discernible in the reanalysis dataset. The present results indicate that the narrow ocean currents and associated sharp SST fronts are essential for the interaction between the atmosphere and ocean.

Keywords: Kuroshio, Air-sea interaction, Heat fluxes

INTRODUCTION

Western boundary currents and associated fronts of Sea Surface Temperature (SST) attract large attention of researchers studying both climate and marine ecosystems. The Kuroshio brings a large amount of heat from low latitudes to mid-latitudes, and turbulent heat fluxes from the Kuroshio and the Kuroshio Extension to the atmosphere exhibit a prominent maximum. The subpolar front is known by its sharp, year-round, SST front, whereas the SST front over the Kuroshio Extension is less prominent in summer season. The Kuroshio Extension and the subpolar front were not well separated by most of numerical models, and these two oceanic features are often called "Kuroshio-Oyashio Extension" or KOE. The potential role of KOE in climate variations, particularly those on decadal-to-centennial timescales, has been described in a substantial number of publications (e.g., Refs. 1–2). KOE has been considered to play important roles also in marine ecosystems. In particular, Ref. 3 hypothesized that the SST around the south of the KOE controls decadal variability of sardine population. Co-variability of sardines in both sides of the North Pacific with climate variability such as Pacific Decadal Oscillation or changes in Aleutian low strength has been important research area in the last two decades [e.g., 4].

DATA AND METHODS

We use two datasets in the present study. One dataset is an operational product of atmospheric model provided by European Centre for Midrange Weather Forecast. Using a data assimilation technique, observed data are incorporated into the atmospheric model. Since the datasets are produced as operational basis, the products are called "operational analysis". We obtained the dataset for the period from

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January 2002 to February 2006. During this period, the atmospheric model uses a spectral dynamical core with TL511 resolution, equivalent to a grid resolution of approximately 38 km, or higher in the last month (February 2006). Combined with this high model resolution, the use of high-resolution Real-Time, Global (RTG) SST [5] since February 2001 substantially improves the representation of the near-surface atmospheric response to SST variations [6]. Therefore, the ECMWF operational analysis can provide information with the unprecedented high spatial resolution.

The other dataset is NCEP/DOE reanalysis [7]. This dataset is an updated and error-corrected version of an NCEP/NCAR reanalysis [8], which is probably the most widely used dataset for climate studies about parameters of the atmosphere and those at the atmosphere/ocean interface. These datasets were produced by a data assimilation technique using the same atmospheric model throughout the analysis period. Such a method is generally termed as "re-analysis", in contrast to the aforementioned operational analysis, for which numerical models are continuously changed in time. Therefore, a re-analysis product has a better temporal continuity than an operational analysis, and this is the reason why re-analysis is preferred in climate studies. On the other hand, operational analysis has an advantage of continuous improvements in the spatial resolution and in the model physics compared to a re-analysis.

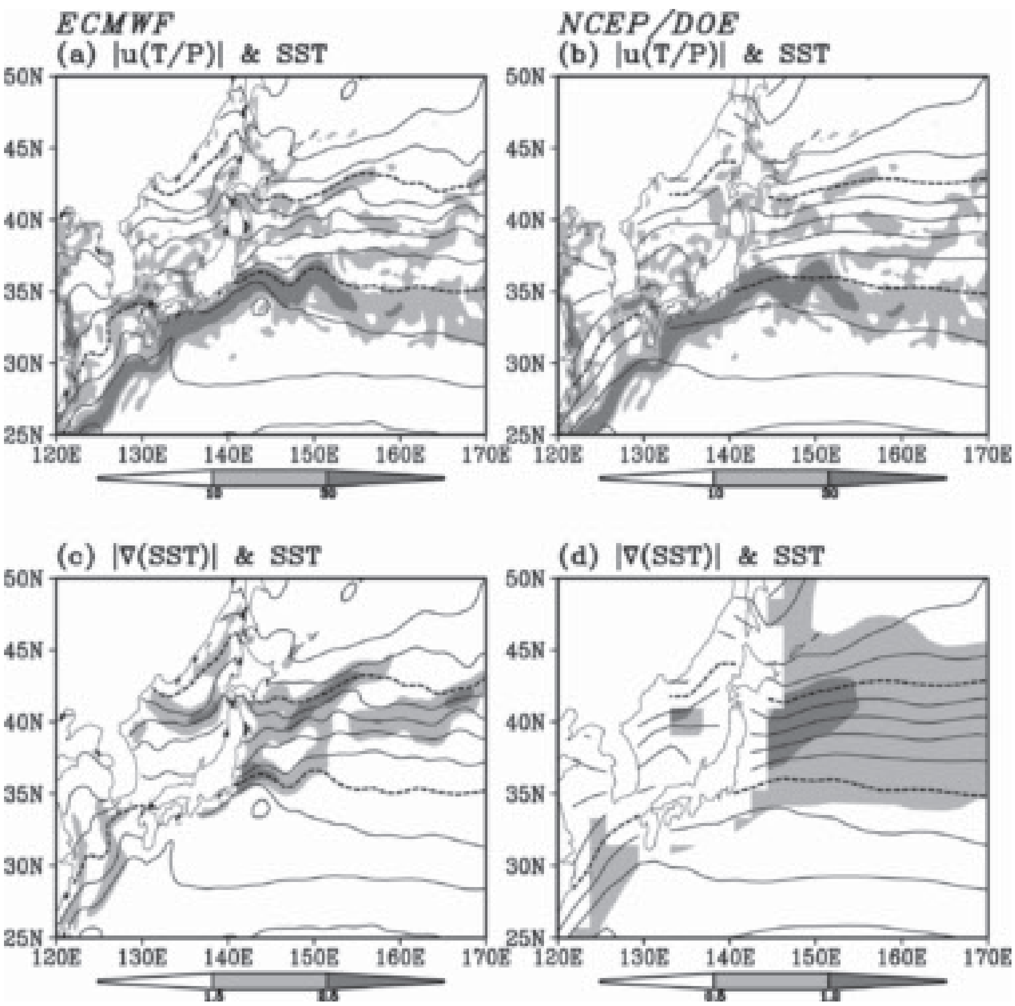

Fig. 1 Top: Surface geostrophic current velocities (shade, cm s^{-1}) and SST (contour, ºC). Bottom: absolute value of SST gradient (shade, 10^{-5} ºC m^{-1}) and SST (contour, ºC). The contour interval is 2ºC with thick dashed contours for 10ºC and 20ºC. SST data are based on ECMWF operational analysis (left) and NCEP/DOE reanalysis (right).

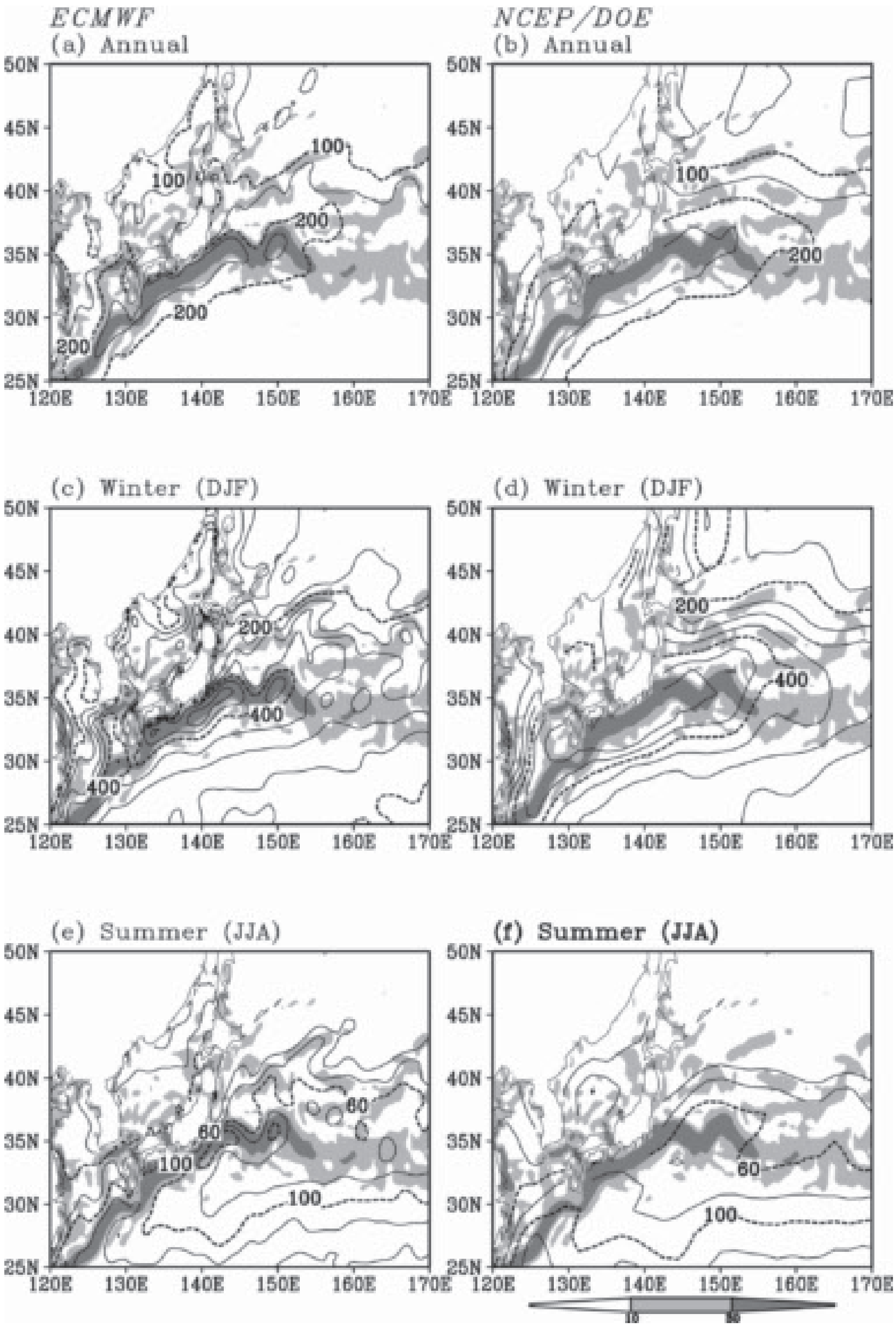

Fig. 2 Climatological turbulent heat fluxes (contour, W m^{-2}) for annual mean (top), for winter mean (December-February) (middle) and for summer mean (June-August) (bottom), along with annual mean surface geostrophic current velocities (shade, cm s^{-1}) also shown in Fig. 1. The contour intervals are 50, 50, and 20 W m^{-2} for the top, middle and bottom rows, respectively, with thick contours for 100 and 200 W m^{-2} for the top panels, 200 and 400 W m^{-2} for the middle panels, and 60 and 100 W m^{-2} for the bottom panels. Turbulent heat fluxes are based on ECMWF operational analysis (left) and on NCEP/DOE reanalysis (right).

RESULTS

Figure 1 shows SST and its gradient along with surface geostrophic current velocities. The geostrophic currents are strong along the axis of the Kuroshio in the East China Sea and south of Japan and also along the axis of the Kuroshio Extension to the east of Japan. The quasi-steady meandering of the Kuroshio Extension from 140°E to 155°E is apparent. The contours of the ECMWF SST are parallel to the Kuroshio and its extension including the steady meandering to the east of Japan. Contours of NCEP SSTs are also generally parallel to the surface currents, but the contours no longer follow the meandering of the Kuroshio Extension.

Gradients of the ECMWF SST exhibit strong amplitudes along the subpolar front about 40°N to the east of Japan and also in the Japan Sea (Fig. 1). The gradient is also strong over the Kuroshio Extension and the Kuroshio in the East China Sea. However, such dependency of the gradient strength on mean currents is not reproduced in NCEP SST, whose gradient is strong broadly over the region from the Kuroshio Extension to the subpolar front to the east of Japan (roughly 35°–45°N).

Different spatial resolutions between the operational analysis and re-analysis also influence turbulent heat fluxes. Figure 2 shows annual, wintertime and summertime turbulent heat fluxes in ECMWF operational analysis and NCEP/DOE reanalysis. ECMWF heat fluxes are strongly constrained by mean currents and SST gradients. The heat fluxes are large over the Kuroshio and its extension, and the meandering of the Kuroshio Extension results in heat fluxes, which tend to enlarge at the northward ridge of the meander. Also, heat fluxes are strong along the Kuroshio in the East China Sea and south of Japan. Concentrated heat flux along the Kuroshio in the East China Sea is consistent with an atmospheric meso-scale model study for the winter season [9]. Furthermore, it is interesting to note that heat flux concentration along the Kuroshio is still found in summer season in this region. Although heat flux amplitudes around the subpolar front east of Japan are about half or less than those in the Kuroshio and its extension, the subpolar front gives the maxima of heat fluxes in the zonal direction.

The close relation between the heat fluxes and mean current and/or SST gradient found in ECMWF is much less prominent in NCEP heat fluxes (Fig. 2). NCEP heat fluxes still capture the general tendency that the heat fluxes are large over the Kuroshio and its extension. However, the detailed spatial correspondences between the heat fluxes and the oceanic currents or SST fronts are not found in the NCEP heat fluxes; the influence of the steady meander of the Kuroshio Extension is absent in heat fluxes, and relative maximum of the heat fluxes associated with the subpolar front is also not reproduced.

DISCUSSION

The strong constraints found in the turbulent heat fluxes in the ECMWF operational analysis exert substantial implications in the air-sea interaction. It was known that the near surface wind distribution is affected by SST distribution in the Kuroshio south of Japan and Kuroshio extension [10], but detailed structures of the turbulent heat fluxes, which may act as agents to connect the atmosphere and ocean, was not documented in previous studies with a spatial resolution as high as presented in this study. The validity of the operational heat fluxes, however, is not yet examined by a comparison with observations, and such examination should be an important research topic for the air-sea interaction. At the moment, two surface buoy moorings are maintained by Japan Agency for Marine-Earth Science and Technology and by National Oceanic and Atmospheric Administration. It should be a matter of interest to compare the heat fluxes and other parameters associated with air-sea interaction between operational analysis and buoy observations.

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REFERENCES

1. Latif, M. and Barnett, T.P., 1994. Causes of decadal climate variability over the North Pacific and North America. Science, 266, 634–637.
2. Minobe, S., 2002. Interannual to interdecadal changes in the Bering Sea and concurrent 1998/99 changes over the North Pacific. Progr. Oceanogr., 55, 45–64.
3. Noto, M. and Yasuda, I., 1999. Population decline of the Japanese sardine, Sardinops melanostictus, in relation to sea surface temperature in the Kuroshio Extension. Can. J. Fish Aquat. Sci., 56, 973–983.
4. Chavez, F.P., Ryan, J., Lluch-Cota, S.E. and Niquen, C.M., 2003, From anchovies to sardines and back: multidecadal change in the Pacific Ocean. Science, 299, 217–221.

5. Thiébaux, J., Rogers, E., Wang, W. and Katz, B. 2003. A new high-resolution blended real-time global sea surface temperature analysis. Bull. Amer. Meteor. Soc., 84, 645–656.
6. Chelton, D.B. and Wentz, F.J. 2005. Global microwave satellite observations of sea surface temperature for numerical weather prediction and climate research. Bull. Am. Met. Soc., 86, 1097–1115.
7. Kanamitsu, M., Ebisuzaki, W., Woollen, J., Yang, S.-K., Hnilo, J.J., Fiorino, M. and Potter, G.L., 2002. NCEP-DOE AMIP-II Reanalysis (R-2). Bull. Am. Met. Soc., 83, 1631–1643.
8. Kalnay, E. and coauthors, 1996. The NCEP/NCAR 40 year re-analysis project. Bull. Amer. Meteor. Soc. 77, 437–471.
9. Xie, S.-P., Hafner, J., Tanimoto, Y., Liu, W.T., Tokinaga, H. and Xu, H., 2002. Bathymetric effect on the winter sea surface temperature and climate of the Yellow and East China Seas. Geophys. Res. Lett., 29, 2228, doi: 10.1029/2002 GL015884.
10. Nonaka, M., and Xie, S.P., 2003. Covariations of sea surface temperature and wind over the Kuroshio and its extension: Evidence for ocean-to-atmosphere feedback. J. Climate, 16, 1404–1413.