Inter-decadal modulations in the dynamic state of the Kuroshio Extension system: 1905-2016

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The Kuroshio Extension is an eastward-flowing, inertial jet in the subtropical western North Pacific after the Kuroshio separates from the coast of Japan. Being the extension of a wind-driven western boundary current, the KE has long been recognized as a turbulent current system rich in large-amplitude meanders and energetic mesoscale eddies. An important feature emerging from the past 25-yr satellite altimeter measurements is that the KE system exhibits clearly-defined decadal modulations between a stable and an unstable dynamic state. The decadally-modulating KE dynamic state exerts a great impact on the regional sea surface temperature, heat content and water mass properties. By clarifying the relationship and physical processes between the basin-scale wind forcing and the KE dynamic state over the altimeter era, we hindcast the KE dynamic state going back to 1905 with the use of ECMWF reanalysis wind stress product. It is found that the low-frequency KE variability modulated in the past century in connection with the mid-1920s, mid-1940s, and mid-1970s' climatic regime shifts in the Aleutian Low pressure system. In addition to the modulations in KE's response to the external wind forcing, the midlatitude ocean's feedback to the overlying atmosphere appeared to have differed within the epochs of the different 20th century regimes.

Keywords: Kuroshio Extension, decadal variability, air-sea interaction

Influence of the Kuroshio Extension and Oyashio fronts on the atmosphere as revealed in the JRA-55 family

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Impact of midlatitude frontal SST gradients on the overlying atmosphere are assessed through comparison between two products of a new Japanese reanalysis (JRA55). One of them is a product called JRA55C in which in-situ observational data have been assimilated in a forecast system with horizontal resolution of ~60km and the COBE SST data with 1-degree resolution is prescribed. The other is an additional product (JRA55CHS) with MGDSST data with a quarter-degree resolution, which can resolve the frontal-scale SST structures. The comparison reveals substantial differences in midlatitude atmospheric processes around the western boundary currents and associated SST fronts. As a typical example, wintertime atmospheric response to variability of the Kuroshio Extension (KE) is examined. The Kuroshio Extension fluctuates between its stable and unstable regimes on (quasi) decadal time scale. In its unstable regime, eastward transport of the KE decreases, and its path tends to be more meandering compared to its stable regime. As in satellite observations, enhancement of cloudiness and precipitation in the mixed-water region east of Japan during the unstable regime of KE relative to its stable regime is represented well in JRA55CHS but not in JRA55C product. The enhancement results from augmented heat/moisture release from the warmer ocean with more active warm-core eddies in unstable KE regimes. This oceanic thermal forcing onto the atmosphere is manifested as positive correlation in anomalies between SST and heat/moisture release, which is represented only in the high-resolution MGDSST but not in the COBE SST. Distinct differences in upward motion and diabatic heating ratio represented in these products are not limited within the atmospheric boundary layer, suggesting the significant impact of the oceanic forcing on the atmospheric circulation in free atmosphere.

Interannual modulations of the influence of North Pacific oceanic fronts on the atmosphere as revealed in the JRA-55 family

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Influence of frontal SST anomalies associated with North Pacific subarctic frontal zone on the overlying atmosphere are investigated through comparison between two sub-products of a new Japanese reanalysis for the global atmosphere (JRA-55). In one sub-product, JRA-55C, all the observational data but satellite data are assimilated on horizontal resolution of ~60km with COBE SST data on 1-degree resolution prescribed over 55 years. The other sub-product, JRA-55CHS, is the same as JRA-55C, but with MGDSST data on a quarter-degree resolution only over 28 recent years.
Atmospheric response to SST anomaly associated with meridional displacement of oceanic frontal zone is investigated as an interannual modulations of the influence of North Pacific oceanic fronts. In JRA-55CHS, SST anomaly is much better collocated with anomalous heat/moisture release in October. Enhancement of convective precipitation over warm SST anomalies is larger and so is area-averaged precipitation anomaly in JRA-55CHS. Anomalous upward motion and convective heating are also enhanced over the warm SST anomaly, not only within the atmospheric boundary layer but also in free troposphere. These results suggest that assimilating high-resolution SST data has a certain impact for global atmospheric reanalysis.

Keywords: Oceanic front, Air-Sea interaction, western North Pacific, Atmospheric Reanalysis

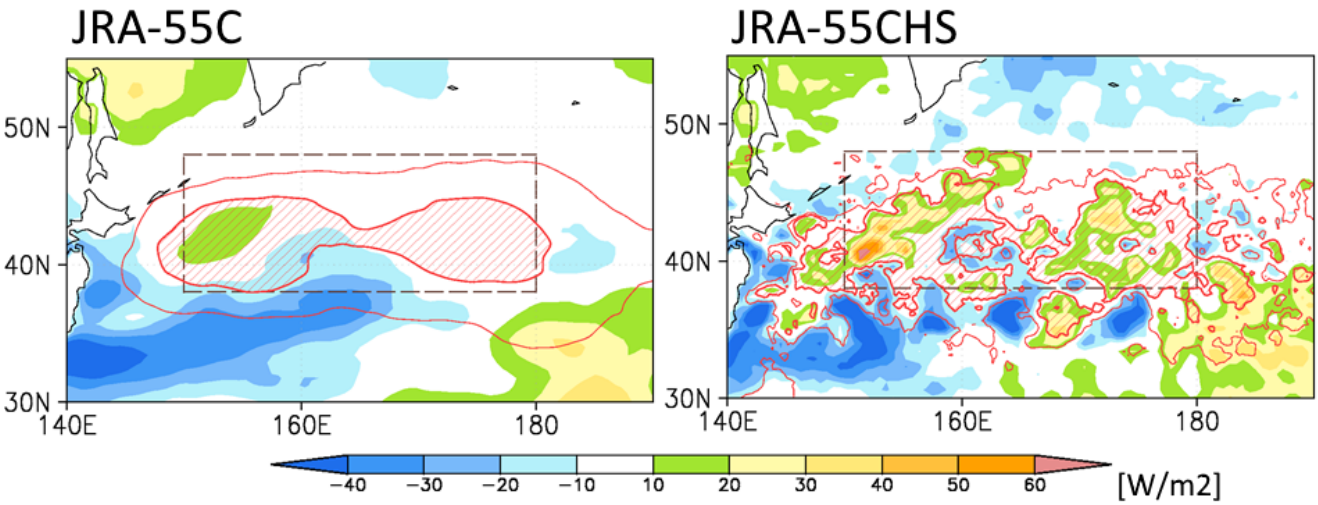

Fig. Anomalous SST (red contours for +0.8K, red hatches for +1.4K) and net turbulent heat flux (color as indicated) in October

Effects of the North Pacific subtropical front on the Baiu/Meiyu rainband in a 60-km AGCM

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Atmospheric effects of the North Pacific subtropical sea surface temperature (SST) front (STF) on the Baiu/Meiyu rainband in late May are investigated using an atmospheric reanalysis and atmospheric general circulation model (AGCM) experiments. The Baiu/Meiyu rainband in the reanalysis is tilted to the northeast with minimum rainfall along the STF, consistent with satellite observations. The reanalysis data and two AGCM experiments based on high-resolution SST and spatially smoothed SST fields identify three effects of the STF. The first is ocean evaporation, which provides a large amount of moisture for the rainband, because of high SST in the STF region. The second is transient eddies, which induce the weak rainfall along the STF. Subsynoptic-scale lows that develop in the atmospheric baroclinic zone anchored by the STF, together with a synoptic high in the main storm track, bring about strong northeasterly winds, which carry dry air to the north of the STF and cause the eddy moisture divergence and the weak rainfall. The third is the mean cyclonic circulation, which forms over the STF and is associated with the intensified subtropical jet in the middle and lower troposphere. The mean cyclonic circulation intensifies the mean moisture convergence by convergent flows and advection, causing the rainband to tilt northeastward. The mechanism of the mean cyclonic circulation is discussed.

Keywords: SST front, Rainband

Response of the early summer (baiu) rain to interannual sea surface temperature variability in the East China Sea

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The East China Sea is the region where deep atmospheric response to warm western boundary currents is the strongest along with the Gulf Stream region. Atmospheric response, especially response of early summer (baiu) rain, to interannual variability of sea surface temperature (SST) front associated with the Kuroshio in the East China Sea is examined using by observational data and regional atmospheric model simulation. It is revealed from observational data that the strong (weak) SST front is accompanied by the heavy precipitation and large cloud liquid water over the northern East China Sea and south of Japan. The heavy precipitation is likely associated with the strengthening of storm activity over the SST front. These observational results are confirmed by the regional atmospheric model simulation. That is, when the SST front is intensified (reduced) by adding negative (positive) SST anomalies over the continental shelf, the storm activity is intensified (weakened) over the SST front. Because the interannual variability of the SST front intensity is largely governed by SST anomalies over the continental shelf, and because these SST anomalies persist at least from a month earlier, the results in the present study imply potential predictability of precipitation over south of Japan in early summer.

Keywords: Baiu rainband, Kuroshio, East China Sea

The Cloud Top Heights of Marine Low Clouds and the Frequency of Marine Fog over Mid-Latitudes, and their Controlling Environment

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While cloud amount of marine low-clouds is mainly controlled by a stability of a lower troposphere, which is substantially determined by the difference between SST and temperature of a mid-troposphere, low-cloud amount has a significant influence on SST through an interruption of solar insolation. It means that there is a strong interaction between marine low-clouds and the ocean.

Though marine low clouds over subtropics have been studied extensively, those in the mid-latitudes have received less attention than subtropical ones. Studies associated with cloud top height is very few, although we can find several studies related to low-cloud amount over the mid-latitudes. Therefore, the cloud top height of marine low-clouds in the mid-latitudes is investigated here in detail using cloud mask data, which are based on observations from the CALIPSO satellite. It became possible to reveal cloud top heights globally only after CALIPSO satellite was launched.

This study provides a comprehensive overview of the observational characteristics of variations in cloud top height of marine low-clouds and fog frequency over the mid-latitudes. Seasonal variations in the cloud top height of mid-latitude marine low-clouds were determined, as well as the differences in these seasonal variations between the Northern and Southern hemispheres. While clear seasonal variations in the frequency of fog occurrence are found over the North Pacific and the northwest Atlantic, the fog frequency over the Southern Ocean is almost constant irrespective of the season. Furthermore, controlling meteorological fields, including SST, which cause these characteristics and variations, were investigated. High correlations were found between the low-cloud top height and stability indexes, and between the fog frequency and some surface parameters including temperature difference between the surface air and the sea surface (Fig. 1).

Keywords: mid latitude, marine low clouds, marine fog

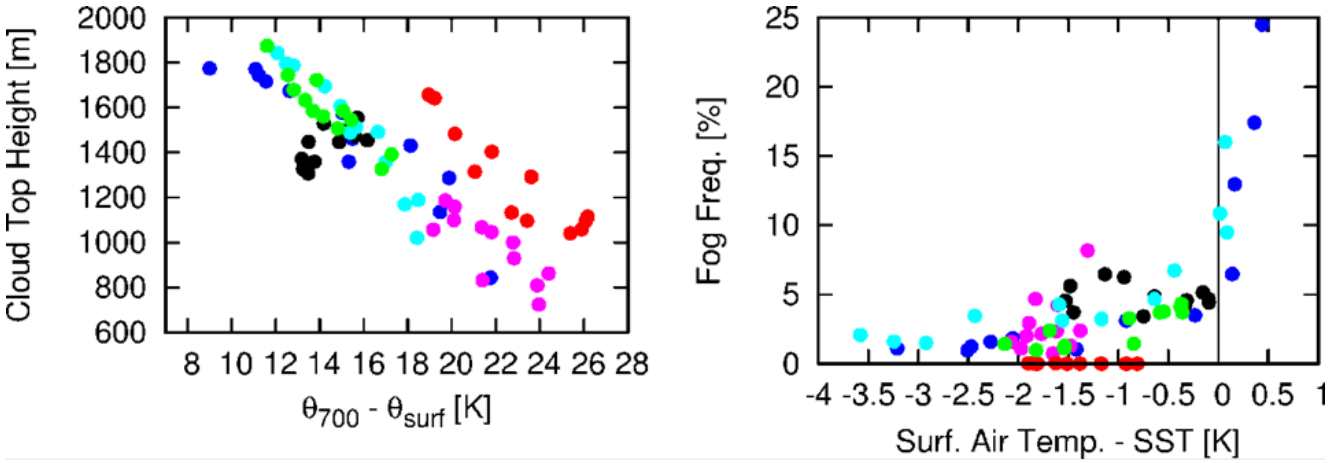

Fig. 1. The relationship between cloud top height and a potential temperature difference $\theta_{700}-\theta_{surf}$ (left), and the relationship between fog frequency and temperature difference between the surface air and the sea surface (right). Areas investigated in the present study: the North Pacific (blue), the Southern Ocean (black), the northwest Atlantic (light blue), the northeast Atlantic (green), off California (pink), and off Peru (orange).

The influence of the Gulf Stream on wintertime European blocking and North Atlantic jet

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The influence of Gulf Stream over the North Atlantic and Europe sector are investigated by analyzing NCEP-CFSR dataset and conducting a pair of 20-year integrations of 50-km grid-spacing AGCM (AFES). For the boundary condition, observed SSTs are used for control experiment (CNTL) and spatially smoothed SST for the other experiment (SMTH) over the Gulf Stream region. Between these experiments, substantial differences are found in European blocking and in North Atlantic eddy driven jet. For both phenomena, CNTL reproduces better the observed features than SMTH, which misses some of essential features of each phenomenon. This indicates that the realistic SSTs and high-resolution atmospheric models are important in reproducing these phenomena, including cold spells, long-lasting low surface air-temperature condition, resulted from European blockings. In the presentation, we will show that how these phenomena are related to meridional heat flux of the lower atmosphere and other atmospheric processes. Also, we would like to introduce HighResMIP in CMIP6, because HighResMIP can provide us very-near-future opportunities for the first time to investigate consistencies of mid-latitude atmospheric responses to the oceanic fronts and eddies are consistent among numerical. How robust consistencies we can find for what phenomena will affect our future trajectories of mid-latitude air-sea interaction studies.

Keywords: high-resolution model, eddy heat flux, precipitation heating

To what extent do oceanic frontal zones affect mid-latitude weather and climate?

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This talk introduces the mechanism of “Thermal Damping and Strengthening” and discusses why understanding this process is key to determining the influence of oceanic frontal zones, such as the Gulf Stream and the Kuroshio Extension, on mid-latitude weather and climate. Specifically, we argue this mechanism is key because it is the interaction of oceanic frontal zones with individual atmospheric fronts that is primarily responsible for the local as well as basin-scale ocean-to-atmosphere feedback in the seasonal mean and longer time scale. As a result, it is suggested that the influence of these oceanic frontal zones on climate can only be properly realised in general circulation models of sufficiently high resolution (i.e. horizontal grid size of 25km or less). The current implications for both general circulation models and reanalysis datasets are also addressed.

Keywords: Frontal air-sea interaction, Mid-latitude climate variability

Links of wintertime climate variability in Eurasia to ocean temperature anomalies in the preceding seasons

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Several recent studies indicate that wintertime extreme weather events and climate variability over Eurasia are related to anomalies of sea ice cover in the Barents Sea region even though casual mechanisms behind this relation remain uncertain. Here we will first review our previous investigations of this problem, based on a regression analysis between oceanic observations and atmospheric (NCEP/NCAR) reanalysis for the period 1982-2006, which show that: (i) a large fraction (70% of the variance explained) of the total sea ice cover variability in the Barents and Greenland Seas in winter is related to Atlantic water temperature (AWT) anomalies at the entrance to the Barents Sea in the preceding summer, (ii) these local AWT anomalies are representative of, at least, a regional mode of subsurface ocean temperature anomalies which reemerge on the surface in the following autumn-to-winter season, (iii) these anomalies affect not only the sea ice cover but, consequently, also the local atmospheric conditions up to the tropopause level in the Barents Sea region, (iv) they influence also the large-scale atmospheric circulation in the Northern Hemisphere extratropics by perturbing the storm tracks. The large-scale surface air temperature anomalies related to warm AWT anomalies form a kind of the “warm Arctic-cold Eurasia” pattern with a negative lobe in the latitude band of a significant reduction of the upper-tropospheric storm track activity and lower-tropospheric poleward transient eddy heat flux. This pattern is uncorrelated with the corresponding anomalies related to the North Atlantic Oscillation, which increases the potential for seasonal prediction of wintertime climate variability in middle latitudes based on summer AWT anomalies. Finally, we will present some preliminary results on the robustness of the proposed scenario based on a statistical analysis of links between wintertime surface atmospheric variability in Eurasia (data from the ERA-Interim reanalysis) to the sea surface temperature in the Barents Sea and North Atlantic during preceding seasons in whole era of satellite observations (1979-2016).

Tripole precipitation pattern and SST variations linked with extreme zonal activities of the western Pacific subtropical high

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Using the daily variables of NCEP reanalysis 1 from 1981 to 2014, this study first constructs a new index to describe the western Pacific subtropical high (WPSH) zonal activities by the normalized relative vorticity (RV) series averaged over a three-dimensional (3D) core domain (112.5°–142.5°E, 10°–30°N, 925–500 hPa). Its horizontal scope is referred to as core region. Ten positive and six negative extreme episodes lasting from 10 to 17 days were identified based on the new index. They demonstrated prominent variabilities in intraseasonal and interannual timescales. Composite results show a tripole precipitation pattern with a wet (dry) zone over the tropical western Pacific (TWP) separating two dry (wet) zones in the meridional direction. The northern one covers the mei-yu belt while the southern one extends along the tropical Indian Ocean (TIO) and the Maritime Continent (MC). The activities of WPSH and monsoon trough form the height anomalies over the core region, while its northern height anomalies are due to the westerly trough in middle latitudes. Further, the three systems exert joint effects on the tripole dry-wet pattern.
Within the biweekly evolution of positive composite, a weaker WPSH displays first an eastward and then a westward track. Negative composite indicates that a stronger WPSH first retreats eastward, then strides westward, and finally moves northeastward during around two weeks. The sea surface temperature (SST) anomalies over TIO and TWP are crucial for the extreme WPSH episodes. Concretely, the SST anomalies over TIO largely influence the overall intensity and location of WPSH and are especially important in the early stages of WPSH episodes. Locally, the SST anomalies over the core region are passive responses of atmospheric forcing in the early stages of WPSH episodes and then exert effect on the WPSH in their later stage.

Keywords: western Pacifc subtropical high, extreme episode, relative vorticity, geopotential height, precipitation, sea surface temperature

Role of mixed layer depth in surface frontogenesis of the Kuroshio Extension region: Interannual variability

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Using the JRA-55 reanalysis data and Argo observation dataset from 2004 to 2015, we examine how meridional variations in the mixed layer depth across the sea surface temperature (SST) front in the Kuroshio Extension region affects the surface frontogenesis. A mixed layer heat budget analysis shows that the surface heat flux term generally strengthens the SST front despite the stronger net surface heat loss on the equatorward side, because the surface mixed layer is much deeper on the equatorward side, and the SST is less sensitive to the surface heat flux.

Keywords: Kuroshio Extension, sea surface temperature front, mixed layer depth, surface heat flux

Frontogenesis in the Agulhas Return Current region simulated by a high-resolution CGCM

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Detailed mechanisms for frontogenesis/frontolysis of the sea surface temperature (SST) front in the Agulhas Return Current (ARC) region in the southwestern Indian Ocean are investigated using outputs from a high-resolution coupled general circulation model (CGCM), the Community Earth System Model (CESM; Small et al. 2014), which has good skill in simulating the main features of the SST front and mixed layer depth in the ARC region. The SST front is maintained throughout the year due to approximate balance between frontolysis by surface heat flux and frontogenesis by horizontal advection. Although a southward (northward) cross-isotherm flow on the northern (southern) side of the front is weaker than a strong eastward along-isotherm current in the frontal region, this cross-isotherm confluent flow advects warmer (cooler) temperature toward the SST front north (south) of the front and acts as the dominant frontogenesis mechanism. In addition, stronger (weaker) frontogenesis in austral summer (winter) is attributed to the stronger (weaker) cross-isotherm confluence, which may be linked to seasonal variations of the Agulhas Current, ARC, and Antarctic Circumpolar Current.
On the other hand, the contribution from entrainment is relatively small, because frontolysis by larger (smaller) entrainment velocity on the northern (southern) side opposes frontogenesis by less (more) effective cooling associated with a thicker (thinner) mixed layer and smaller (larger) temperature difference between the mixed layer and entrained water in the northern (southern) region.

Keywords: frontogenesis/frontolysis, Agulhas Return Current, high-resolution coupled general circulation model, horizontal advection, entrainment

