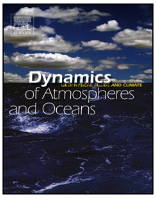
Dynamics of Atmospheres and Oceans 63 (2013) 60–78

Contents lists available at ScienceDirect

Dynamics of Atmospheres and Oceans

journal homepage: www.elsevier.com/locate/dynatmoce



Isolating mesoscale coupled ocean–atmosphere interactions in the Kuroshio Extension region

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ARTICLE INFO

Article history:
Received 15 September 2012
Received in revised form 27 March 2013
Accepted 3 April 2013
Available online 18 April 2013

Keywords:
Mesoscale coupling
Kuroshio Extension
Vertical mixing mechanism
Pressure adjustment mechanism
Scale dependence of ocean–atmosphere coupling
Spatial filtering

ABSTRACT

The Kuroshio Extension region is characterized by energetic oceanic mesoscale and frontal variability that alters the air–sea fluxes that can influence large-scale climate variability in the North Pacific. We investigate this mesoscale air-sea coupling using a regional eddy-resolving coupled ocean–atmosphere (OA) model that downscales the observed large-scale climate variability from 2001 to 2007. The model simulates many aspects of the observed seasonal cycle of OA coupling strength for both momentum and turbulent heat fluxes. We introduce a new modeling approach to study the scale-dependence of two well-known mechanisms for the surface wind response to mesoscale sea surface temperatures (SSTs), namely, the 'vertical mixing mechanism' (VMM) and the 'pressure adjustment mechanism' (PAM). We compare the fully coupled model to the same model with an online, 2-D spatial smoother applied to remove the mesoscale SST field felt by the atmosphere. Both VMM and PAM are found to be active during the strong wintertime peak seen in the coupling strength in both the model and observations. For VMM, large-scale SST gradients surprisingly generate coupling between downwind SST gradient and wind stress divergence that is often stronger than the coupling on the mesoscale, indicating their joint importance in OA interaction in this region. In contrast, VMM coupling between crosswind SST gradient and wind stress curl occurs only on the mesoscale, and not over large-scale SST gradients, indicating the essential role of the ocean mesocale. For PAM, the model results indicate that coupling between the Laplacian of

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http://dx.doi.org/10.1016/j.dynatmoce.2013.04.001

sea level pressure and surface wind convergence occurs for both mesoscale and large-scale processes, but inclusion of the mesoscale roughly doubles the coupling strength. Coupling between latent heat flux and SST is found to be significant throughout the entire seasonal cycle in both fully coupled mode and large-scale coupled mode, with peak coupling during winter months. The atmospheric response to the oceanic mesoscale SST is also studied by comparing the fully coupled run to an uncoupled atmospheric model forced with smoothed SST prescribed from the coupled run. Precipitation anomalies are found to be forced by surface wind convergence patterns that are driven by mesoscale SST gradients, indicating the importance of the ocean forcing the atmosphere at this scale.

1. Introduction

In the western North Pacific Ocean, where major ocean currents meet along the eastern coast of Japan, meandering sea surface temperature (SST) fronts form. From the south, a strong and warm western boundary current hugs the Southeastern coast of Japan and separates around 35° N to form the Kuroshio Extension (KE). Within the KE, pronounced SST fronts produce climatological SST gradients steeper than 3 °C/100 km (Tokinaga et al., 2009), with synoptic fronts that are much stronger, that consequently impact the surface flux exchanges with the atmosphere. The long-term variability of these flux anomalies in the KE region are known to be important in influencing large-scale decadal North Pacific climate feedback processes (Miller and Schneider, 2000; Latif, 2006; Kwon et al., 2010; Frankignoul et al., 2011; Taguchi et al., 2012).

Satellite observation-based studies have shown the strong influence of the mesoscale SST distribution upon the overlying atmospheric wind and wind stress patterns (Xie, 2004; Small et al., 2008; Chelton et al., 2004; Chelton and Xie, 2010). Observations have also indicated coupling between SST and surface heat fluxes (e.g. Thum et al., 2002; Vecchi et al., 2004; Liu et al., 2007; Seo et al., 2008) and models have shown that latent and sensible heat fluxes into the ocean have a negative correlation with mesoscale SSTs in various parts of the World Ocean (e.g. Seo et al., 2007; Haack et al., 2008; Bryan et al., 2010), which suggests SST forcing the atmosphere (Wu et al., 2006) as opposed to the historical atmospheric role in driving large-scale SST anomalies (e.g. Cayan, 1992). It is important to understand the character and mechanisms controlling these regional mesoscale flux anomalies in order to gain further insight into coupling processes controlling large-scale climate variations.

In this study, we execute novel regional ocean–atmosphere coupled modeling experiments that include and exclude the impact of oceanic mesoscale eddies, in order to isolate their effect on the strength of ocean–atmosphere (OA) coupling and local atmospheric response. This is achieved using an interactive 2-D spatial smoother of SST that removes the mesoscale SST structures felt by the atmosphere, while leaving the ocean free to develop mesoscale eddies. The new modeling strategy allows us to quantify the spatial scale over which the coupling processes affect surface fluxes and atmospheric boundary layer fields of winds, vertical velocity, and precipitation. The modeling results are supported by a complementary analysis of observed SST, wind stress, and surface heat flux anomalies that together provide estimates of the seasonal air–sea coupling over the KE region.

The model furthermore allows us to study two prominent mechanisms that have been proposed to explain the response of wind in SST frontal regions, namely the ‘vertical mixing mechanism’ (VMM) and the ‘pressure adjustment mechanism’ (PAM). The VMM suggests that warmer (colder) SST reduces (enhances) the stability of the overlying atmosphere, which enhances (inhibits) the downward transfer of momentum through mixing, that would thus increase (decrease) surface wind stress (Wallace et al., 1989) over the SST anomalies. When winds blow parallel or perpendicular to an SST front, it can lead to wind stress divergence along the downwind, or curl along the crosswind, SST gradients (Chelton