Importance of the Low-level Diabatic Heating on the Formation of the Summertime Subtropical Highs: Sensitivity to Diabatic Heating Data Set

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INTRODUCTION

Summertime subtropical highs exist over the eastern portions of the subtropical oceans. The equatorward along-shore winds along the eastern flanks of the highs act to maintain cool sea-surface temperatures (SSTs) underneath by enhancing surface evaporation, mixing and coastal upwelling. The presence of the cool SSTs and a mid-tropospheric subsidence favors the local development of marine stratus in the planetary boundary layer.

The formation mechanisms of the summertime subtropical highs have been investigated through numerical experiments. Rodwell and Hoskins (2001), in which a primitive-equation planetary-wave model was forced with diabatic heating at all vertical levels in some regions, emphasized an effect of monsoonal convective heating on the formation of the summertime subtropical highs. Shaffrey et al. (2001) supported the conclusion of Rodwell and Hoskins (2001) through AGCM experiments forced with modified boundary conditions such as topography, albedo and SST. However, it may be problematic that marine stratus was poorly reproduced in their model. Importance of marine stratus on the formation of the summertime subtropical highs is suggested by Miyasaka and Nakamura (2005) through numerical experiments forced with diabatic heating of the National Centers for Environmental Prediction (NCEP)-the Department of Energy (DOE) reanalysis (Kanamitsu et al. 2002). They concluded that the summertime subtropical highs are formed mainly by low-level land-sea heating-cooling couplets, which are associated with sensible heat flux over dry continents and radiative cooling due to marine stratus. However, diabatic heating of reanalysis may have uncertainty quantitatively. Therefore, to confirm the conclusion of Miyasaka and Nakamura (2005), similar numerical experiments are performed with diabatic heating of the JRA-25 reanalysis (Onogi et al. 2007).

DATA AND A MODEL

The model used in this study is same as in Miyasaka and Nakamura (2005); a global primitive-equation planetary-wave model (T42L30) with simplified physical processes such as Newtonian cooling, Rayleigh friction and horizontal hyper-diffusion. In this model, zonal-mean state in the model is fixed to zonal mean of NCEP-DOE reanalysis. Diabatic heating is taken from the NCEP-DOE or JRA-25 reanalyses. Diabatic heating and zonal-mean state in experiments for the Northern and Southern Hemispheres are climatology (1979-1998) in July and January, respectively.

SLP RESPONSES TO DIABATIC HEATING

A control run forced with diabatic heating of the JRA-25 reanalysis assigned at all vertical model levels globally and global topography indicates that the summertime subtropical highs in the Northern Hemispheres can be reproduced realistically as well as counterpart forced with diabatic heating of the NCEP-DOE reanalyses (Figure 1). When diabatic heating is assigned only at lower tropospheric layers ($0.667 < \sigma < 1$) in the land-sea heating-cooling

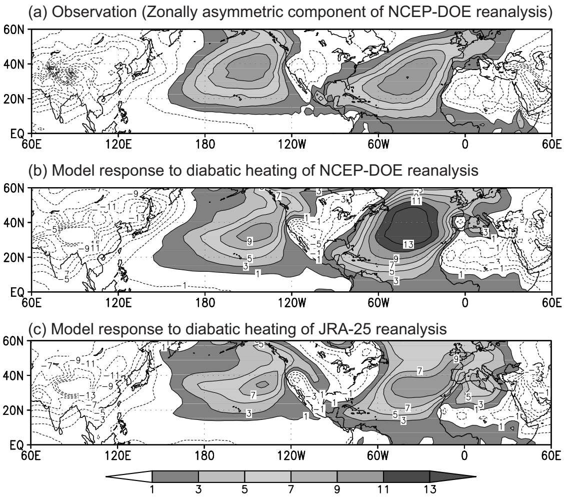

Figure 1: (a) Zonally asymmetric component of climatological sea-level pressure (SLP) in July. (b) SLP response of the control run for July forced with global topography and global diabatic heating at all vertical levels. Diabatic heating is taken from the NCEP-DOE reanalyses. (c) As in (b) but for diabatic heating of the JRA-25 reanalyses.

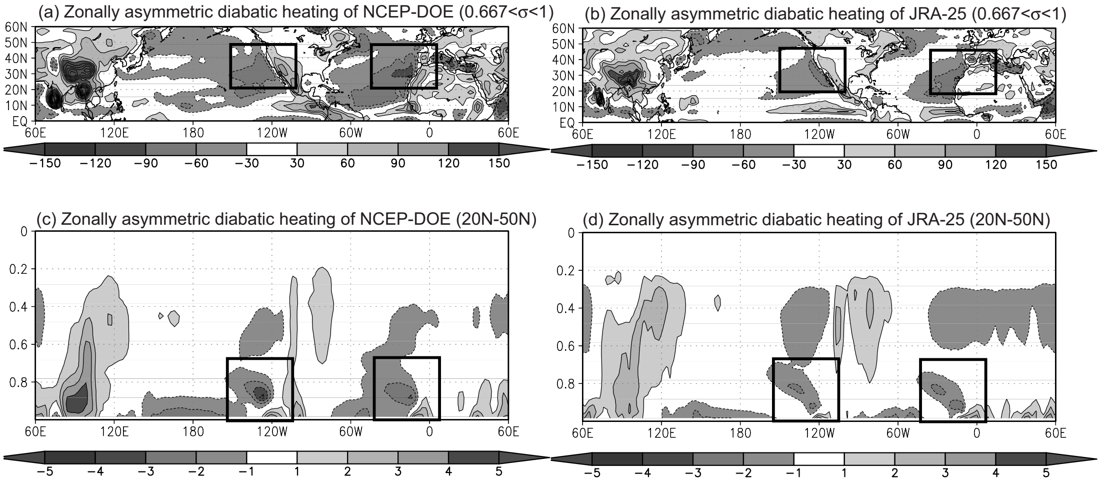

Figure 2: Zonally asymmetric July diabatic heating of (a and b) the NCEP-DOE and (b and d) JRA-25 reanalyses. (a and b) Diabatic heating is averaged (a and b) in the lower troposphere (0.667<σ<1) and (c and d) in subtropics (20°~50°N). Thick rectangles signify forcing domains for model simulations for the local low-level diabatic heating experiments.

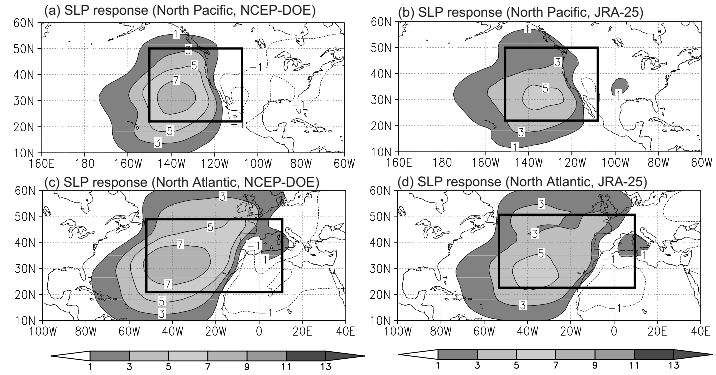

Figure 3: SLP response to diabatic heating of (a and c) the NCEP-DOE and (b and d) JRA-25 reanalyses in (a and b) the North Pacific and (c and d) Atlantic. Thick rectangles signify forcing domains for model simulations for the local low-level diabatic heating experiments.

couplet regions (indicated by rectangles in Figures 2 and 3), subtropical highs over the North Pacific and Atlantic can be reproduce with ~67% and ~60% strengths of the control run, respectively (Figures 3). Diabatic heating of the JRA-25 reanalyses shows that the land-sea heating-cooling couplet is comprised of sensible heating over dry continent and radiative cooling due to marine stratus (Figure 2). These results are similar to the counterparts in Miyasaka and Nakamura (2005), therefore their conclusion is confirmed. Also in the Southern Hemisphere, it is confirmed that the summertime subtropical highs can be reproduced mainly by the local low-level land-sea heating-cooling couplet of both reanalysis diabatic heating (Table 1).

MARITIME COOLING IN TWO REANALYSES

It is noteworthy that the responses to diabatic heating of the JRA-25 reanalyses are weaker than counterpart of the NCEP-DOE reanalyses (Table 1), although low-level cloud of the JRA-25 reanalyses is grater than of the NCEP-DOE reanalyses (Figures 4a and 4d). This relation seems to be conflicted because it is thought that the more marine stratus develops the stronger radiative cooling is. Radiative heating components of both reanalyses in the North Pacific are shown in Figures 4b and 4e. Consistently with grater cloud cover in the JRA-25 reanalyses than in the NCEP-DOE reanalyses, radiative cooling in the JRA-25 reanalysis is stronger than in the NCEP-DOE reanalyses (Figures 4b and 4e). However, vertically diffusive heating component of diabatic heating in the JRA-25 reanalyses shows strong heating in marine stratus unlike in the NCEP-DOE reanalysis (Figures 4c and

Table 1. SLP responses to the local low-level diabatic heating and their percentages to response in the control runs

	NCEP-DOE diabatic heating	JRA-25 diabatic heating
North Pacific	8 hPa (~80%)	6 hPa (~67%)
North Atlantic	8 hPa (~57%)	6 hPa (~60%)
South Pacific	4 hPa (~80%)	3 hPa (~75%)
South Atlantic	4 hPa (~80%)	3 hPa (~75%)
South Indian Ocean	3 hPa (~100%)	2 hPa (~50%)

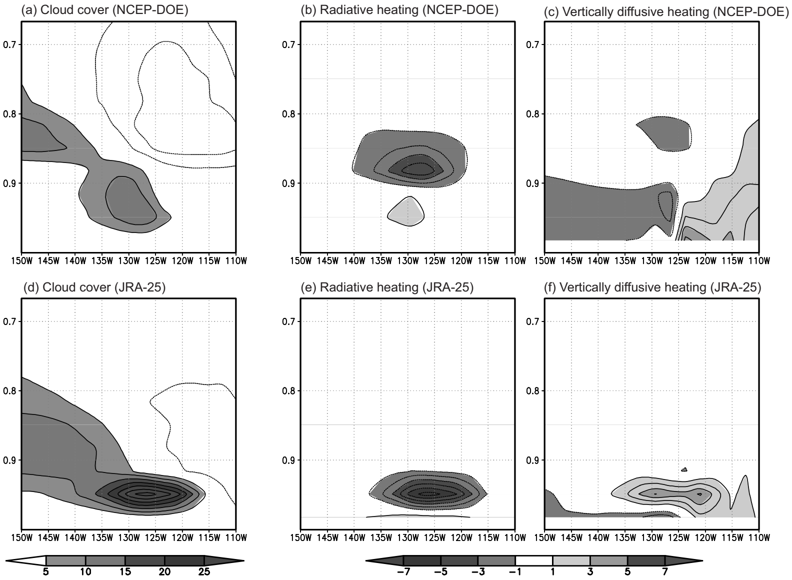

Figure 4: Longitude-height cross sections of zonally asymmetric component averaged for 20~50N in the Northeastern Pacific. (a and d) Cloud cover. (b and e) radiative and (c and f) vertically diffusive heating component of diabatic heating. (a, b and c) The NCEP-DOE and (d, e and f) JRA-25 reanalyses.

4f). As a result, total maritime cooling in the JRA-25 reanalyses is weaker than in the NCEP-DOE reanalyses, and SLP responses to diabatic heating of the JRA-25 are weaker than counterpart of the NCEP-DOE reanalyses.

SUMMARY

It is confirmed that the summertime subtropical highs are mainly formed by the local land-sea heating-cooling couplets through numerical experiments forced with diabatic heating of the JRA-25 reanalysis as well as Miyasaka and Nakamura (2005), in which similar experiments performed with diabatic heating of the NCEP-DOE reanalyses. However, diabatic heating of the JRA-25 reanalyses shows stronger radiative cooling associated with grater marine stratus and stronger vertically diffusive heating in marine stratus unlike in the NCEP-DOE reanalysis. These differences suggest that diabatic heating of reanalyses have negligible uncertainty quantitatively and a quantitative discussion on the formation mechanisms of the summertime subtropical highs is difficult.

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