JRA-55CHS: An Atmospheric Reanalysis Produced with High-Resolution SST

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Abstract

As an additional product of the Japanese 55-year Reanalysis (JRA-55) project, a new global atmospheric reanalysis product, named JRA-55CHS, is under construction. It utilizes quarter-degree sea-surface temperature (SST) as lower-boundary condition with the same data assimilation system as the JRA-55 Conventional (JRA-55C), into which no satellite data is assimilated. The SST data can resolve steep SST gradients along the western boundary currents (WBCs), which are not necessarily well represented in many of the other atmospheric reanalysis products, including the JRA-55C. The present paper briefly documents basic performance of the JRA-55CHS, through comparing it with the JRA-55C and satellite observations in focusing on the major WBC regions. In the JRA-55CHS, mesoscale atmospheric structures along the WBCs are well reproduced in their climatological-mean fields as captured in the satellite observations. Their interannual-to-decadal-scale variations associated with SST variations are also reasonably reproduced. The corresponding atmospheric features are less obvious in the JRA-55C owing to smoother SST prescribed. Furthermore, comparison between the two reanalysis products reveals that the influence of frontal-scale SST distributions can reach into the middle and upper troposphere, especially in summer. The JRA-55CHS will be useful for deepening our understanding of the nature of midlatitude frontal-scale air-sea interactions.

1. Introduction

Recent studies have identified narrow bands of local strengthening and/or weakening of such atmospheric variables as surface wind convergence, ascent and precipitation in their time-mean distributions along the western boundary currents (WBCs), including the Gulf Stream (Minobe et al. 2004, 2010) and the Kuroshio and its extension (Tokinaga et al. 2009; Tanimoto et al. 2011; Masunaga et al. 2015). Similar features have been identified also along the Agulhas Return Current (O’Neill et al. 2005; Shimada and Minobe 2011) and the Brazil/Malvinas Current (Tokinaga et al. 2005). These time-mean atmospheric features have been interpreted as a manifestation of local boundary-layer responses to steep sea-surface temperature (SST) gradients (e.g., Small et al. 2008; Wallace et al. 1989; Hayes et al. 1989; Lindzen and Nigam 1987). Recent studies have argued, however, that they can be a consequence of frequent passage of synoptic-scale atmospheric disturbances since SST fronts act to anchor stormtracks (Nakamura et al. 2008; Parfitt and Czaja 2016; O’Neill et al. 2017). Furthermore, it has been pointed out that SST fronts can modify individual synoptic-scale disturbances (Vannière et al. 2017; Sheldon et al. 2017) and detection frequency of atmospheric fronts tends to increase near the oceanic fronts (Parfitt et al. 2016, 2017).

Most of the global atmospheric reanalyses currently available are generated with one-degree or coarser resolution SST data for the sake of homogeneity of data quality over the entire data periods, even if their forecast models have high resolutions with capability of resolving mesoscale atmospheric features. However, those relatively low-resolution SST cannot adequately resolve steep SST gradients associated with WBCs that can influence the atmosphere. Indeed, through analysis of the ERA-Interim (Dee et al. 2011), Masunaga et al. (2015, 2016) have pointed out that thermal structure and three-dimensional motions in the marine atmospheric boundary layer (MABL) are not well constrained by data assimilation and therefore they are sensitive to SST fields prescribed.

Motivated by the aforementioned studies, the Meteorological Research Institute, under support of the Japanese “Hotspot project” (Nakamura et al. 2015), is constructing an additional product of the Japanese 55-year Reanalysis (JRA-55; Kobayashi et al. 2015; Harada et al. 2016) family, named “JRA-55CHS”. It uses quarter-degree SST data over 30 years, with no atmospheric satellite observations assimilated (“C” of “CHS” stands for “Conventional” observations and “HS” for “High-resolution SST” and “Hot Spot”). Here we briefly report basic performances of the JRA-55CHS for both the Northern Hemisphere (NH) and Southern Hemisphere (SH) through comparing the JRA-55CHS with other JRA-55 products and satellite observations, in focusing on local atmospheric responses to steep SST gradients along the major WBCs, to demonstrate the importance of high-resolution SST in an atmospheric reanalysis for better representation of mesoscale atmospheric features related to SST distributions.

2. Outline of JRA-55CHS and satellite observations for verification

The model specification, data assimilation system and input observations for the JRA-55CHS are the same as those used for the “JRA-55 Conventional” (JRA-55C; Kobayashi et al. 2014) except for SST specification. The horizontal resolution of the forecast model is TL319 (equivalent to ~55km resolution) with 60 sigma-pressure hybrid vertical levels. To ensure homogeneity of data quality over the 55 years, no satellite observations for the atmosphere are assimilated and the Centennial Observation-Based Estimates of SST (COBE-SST; Ishii et al. 2005), with one-degree resolution, is used for the JRA-55C. In place of COBE-SST, the JRA-55CHS uses the Merged Satellite and In-situ data Global Daily Sea Surface Temperature (MGDSSST) data (Kurihara et al. 2006), which is available only from 1982. The JRA-55CHS has been produced for the period from January 1985 through December 2012, and the production will go back to January 1982. The MGDSSST with quarter-degree resolution is capable of resolving steep SST gradients associated with the WBCs.

The main product of the JRA-55 project used widely hereafter, is noted as “the main JRA-55C” or “JRA-55CCHS” and all available atmospheric observations, including satellite data, while its model setting and SST data are the same as for the JRA-55C. Kobayashi...
et al. (2014) have indeed identified gradual improvement of data quality in the main JRA-55. Therefore, the JRA-55CHS is compared with the JRA-55C in the most straightforward manner.

For the verification of the atmospheric distributions represented in the JRA-55CHS, several satellite observations are utilized as listed in Table 1. Though relying partly on atmospheric reanalysis products, the J-OFURO3 are based mainly on satellite observations (Tomita et al. 2017 submitted; https://j-ofuro.scc.u-tokai.ac.jp/) and certainly independent from the JRA-55CHS.

3. Preliminary results of JRA-55CHS performance

3.1 Horizontal structures in annual climatologies

Annual climatologies of SST and its horizontal gradients based on the satellite observation (OISST; Reynolds et al. 2007; Banzon et al. 2016), MGDSST for JRA-55CHS and COBE-SST for JRA-55C are shown for the four WBC domains: the Kuroshio-Oyashio Extension (KOE) region (Figs. 1a, 1b, 1c, and 1d), Gulf Stream region (Figs. 2a, 2b, 2c, and 2d), Agulhas Return Current region (Figs. 3a, 3b, 3c, and 3d) and Brazil/Malvinas Current region (Figs. 4a, 4b, 4c, and 4d). Compared to the COBE-SST for JRA-55C (panels c of Figs. 1, 2, 3, and 4), MGDSST for JRA-55CHS (panels b of Figs. 1, 2, 3, and 4) indicates stronger SST gradients along the WBCs, whose strength is comparable to that derived from the independent satellite data (panels a of Figs. 1, 2, 3, and 4). The differences between MGDSST and COBE-SST (panels d of Figs. 1, 2, 3, and 4) overall exhibit distinct differences along the WBCs, but they are slightly less pronounced for the KOE region, probably reflecting the relatively high performance of the COBE-SST around Japan.

The SST differences exert distinct impacts on representation of turbulent sensible and latent heat fluxes from the ocean. The satellite observations capture narrow bands of the vigorous heat fluxes just over the warm WBCs (panels e of Figs. 1, 2, 3, and 4), which are highlighted by applying meridional high-pass filtering defined as local departures from meridional ~7° running-mean values (Supplement 3). Compared to the J-OFURO3, both the JRA-55CHS (panels f of Figs. 1, 2, 3, and 4) and JRA-55C (panels g) tend to overestimate the total turbulent heat fluxes over the WBC regions. Still, reproducibility of the high-pass-filtered field is much higher in the JRA-55CHS than in the JRA-55C (Supplement 3). Indeed, the differences in the turbulent heat fluxes (shaded in panels h in Figs. 1, 2, 3, and 4) are clearly related to the SST differences (contoured). Note that these and the following results for the JRA-55C/JRA-55CHS products are based on statistics for the period from 1985 through 2012, while most of the satellite counterparts are constructed only for ~10 recent years. Nevertheless, we have checked that essential features are qualitatively insensitive to an analysis period chosen (not shown).

In the satellite observations, surface wind convergence is enhanced locally over the warm WBCs with divergence slightly to the poleward where SST gradient maximizes (panels i of Figs. 1, 2, 3, and 4). Accordingly, satellite-observed cloud liquid and ice path combined (CL+CI, panels q) and precipitation (panels m) tend to be augmented locally along the warm WBCs. Indeed, local maxima and minima in their high-pass-filtered components well correspond to local maxima and minima, respectively, in the high-pass-filtered SST along the WBCs (Supplement 5 for CL+CI and Supplement 4 for precipitation; color conventions are different among the panels).

These mesoscale features in surface wind convergence are reproduced reasonably in the JRA-55CHS (panels j of Figs. 1, 2, 3, and 4), while they are substantially weakened in the JRA-55C (panels k) especially in the SH. The high-pass-filtered SH distributions of CL+CI and precipitation represented in the JRA-55CHS are consistent with satellite observations, with hints of their local augmentation over the warm WBCs even in their unfiltered fields (panels r and n of Figs. 3 and 4). These features are, however, indistinct in the JRA-55C and their high-pass filtered maxima are shifted equatorward slightly. In the NH, local enhancement in precipitation along the WBCs is well reproduced in both the JRA-55CHS (panels n of Figs. 1 and 2) and JRA-55C (panels o of Figs. 1 and 2), partly because of relatively small inconsistencies in their SST. Nevertheless, they are more distinct in the JRA-55CHS associated with higher SST along the WBCs. The situations are similar in CL+CI (panels r and s), while their absolute values are substantially underestimated and their local maxima along the WBCs are not as distinct as satellite observations. In all the WBC regions, the differences between the JRA-55CHS and JRA-55C (panels p and t, of Figs. 1, 2, 3, and 4) well reflect their SST differences. Since the SST fronts undergo seasonal-to-decadal variations (e.g., Kelly et al. 2010; Qiu et al. 2014), the differences depicted in Figs. 1, 2, 3, and 4 as annual climatologies must be underestimated, and the corresponding differences should be even greater for a specific month or week.

These results suggest that improvements in SST resolution can exert significant local impacts on the atmospheric reanalysis. As anticipated, higher-resolution SST leads to better representations of mesoscale atmospheric fields. Even in the main JRA-55, in which satellite observations for the atmosphere are assimilated, the corresponding mesoscale atmospheric features are quite similar to the JRA-55C rather than the JRA-55CHS (not shown). This is even the case for the 21st century, when abundant satellite observations are available for assimilation. Note that precipitation in the JRA-55 family is known to be oversensitive to underlying SST anomalies, and the aforementioned impacts of the SST resolution change may therefore be overestimated. Indeed, peaks of
Fig. 1. Annual climatologies over the western North Pacific domain. (a) SST (contoured every 2°C) and its horizontal gradient [°C (100 km)−1] for the period from 1985 through 2012 based on OISST. (e) SST (contoured every 2°C) and upward sensible and latent heat fluxes combined (W m−2) based on J-OFURO3 for 2002−2012. (i) SST (contoured every 2°C) and surface wind convergence (10−5 s−1) based on SCOW for September 1999−October 2009. (m) SST based on OISST (contoured every 2°C) and total precipitation (mm day−1) based on CMORPH for 2003−12. (q) SST based on OISST (contoured every 2°C) and column-integrated cloud liquid plus ice combined (g m−2) based on MODIS for 2003−12. (b), (f), (j), (m), (q), (r) As in (a), (e), (i), (m), (q), respectively, but for the JRA-55CHS for the period from January 1985 through December 2012 and (c), (g), (k), (o), (s) for JRA-55C and (d), (h), (l), (p), (t) their differences (JRA-55CHS − JRA-55C; contoured every 0.4°C). Grey hatches are applied where the differences for shadings are statistically significant at the 95% confidence level.

Fig. 2. The same as in Fig. 1, but for the western North Atlantic.
Fig. 3. The same as in Fig. 1, but for the South Indian Ocean.

Fig. 4. The same as in Fig. 1, but for the South Atlantic.
high-pass-filtered precipitation in the JRA-55CHS can be twice as large as those in the satellite observations (not shown) if they are compared for their overlapped period (2003–2012).

3.2 Meridional-vertical structure

Significant impacts of higher SST resolution in the JRA-55CHS are not limited to the MABL. Upper panels of Fig. 5 show meridional sections of vertical motion (as sign-reversed pressure vertical velocity) and potential temperature for longitudes at which differences in 700 hPa upward motion maximize within the individual ocean basins (Supplement 1). In the JRA-55CHS (left column), upward motion exhibits distinct maxima on the warmer flanks of the SST fronts (black lines in lower panels), accompanying local maxima in precipitation (blue lines in lower panels) and shallow downward motion on the cooler sides of the fronts. Consistent with weaker surface wind convergence and less precipitation in the SH (Figs. 3 and 4) than in the NH (Figs. 1 and 2), upward motion is weaker and shallower in the SH. In the JRA-55C, however, these features are less discernible or virtually missing (middle column). The difference between the JRA-55CHS and JRA-55C (right column) features local enhancement of upward motion over locally warmer SST and that of precipitation.

The comparison between the JRA-55CHS and JRA-55C reveals that distinct differences in potential temperature are confined into the MABL (contours in Figs. 5c, 5f, 5i, and 5l), while notable differences in upward motion tend to reach even into the upper troposphere. These deep structures in both their climatological means and differences basically reflect convective features in summer (e.g., Minobe et al. 2010). Nevertheless, the climatological differences in upward motion are most distinct in winter near the MABL top, where the differences reach as much as ~20% of its seasonal climatology. At this stage, no independent
observational climatology of vertical motion is available that can be regarded as the “truth”. Nevertheless, the vertical motion represented in the JRA-55CHS reflects more realistic SST distribution than its JRA-55C counterpart. The above results demonstrate that improved SST resolution for an atmospheric reanalysis can yield significant impacts on MABL processes and even on the free troposphere.

3.3 Impacts of regime changes of the Kuroshio Extension

The KE is known to fluctuate between its different dynamical regimes on (quasi-) decadal scales. In its stable (unstable) regime, the KE jet is intensified (weakened) and less (more) meandering.
(Qui et al. 2005). In this subsection, we briefly examine how mesoscale atmospheric structures are modulated under the regime changes of the KE. On the basis of the KE regime index proposed by Qui et al. (2014), we identify 14 winters (1989−94, 2001−05, and 2010−12) for the stable KE regime and 10 winters (1995−2000 and 2006−09) for the unstable regime.

In Fig. 6, wintertime DJF-mean composite maps of selected variables separately for the unstable (left column) and stable (middle column) regimes of the KE and their differences (right column). In the JRA-55CHS (Figs. 6a and 6b), the KE front substantially weakens in the unstable regime than in the stable regime. Indeed, their difference is characterized by negative SST anomaly along the climatological KE and stronger positive SST anomaly to its north (Fig. 6c), which accompany negative and positive anomalies in upward heat fluxes, respectively (not shown). In the stable regime, the JRA-55CHS represents stronger surface wind convergence over the KE with stronger divergence to the north (Fig. 6d) than in the unstable regime (Fig. 6g), which can be interpreted as results of enhanced vertical mixing of momentum and/or adjustment of sea-level pressure through hydrostatic balance (Masunaga et al. 2016). Accordingly, a precipitation band is confined meridionally into the climatological KE in its stable regime (Fig. 6a), while meridionally broadened in the unstable regime (Fig. 6m). Thus, the JRA-55CHS represents statistically significant anomalies in surface wind convergence (Fig. 6i) and precipitation (Fig. 6o) associated with the significant SST anomalies along the climatological KE and to its north with opposing polarities. The corresponding variations seem consistent with satellite observations (Supplement 2), although their straightforward comparison is difficult due to the limited data period for the latter. The atmospheric variations associated with the KE regime changes are, however, less obvious or even missing in the JRA-55C due to its insufficient SST resolution (Figs. 6d, 6e, and 6f). Compared to the JRA-55CHS, representation of surface wind convergence is slightly improved in the main JRA-55 thanks to assimilated satellite observations (not shown), although the signature is still much weaker than in the JRA-55CHS. Furthermore, the features in the JRA-55CHS are consistent with ERA-Interim for 2002−2012 (Masunaga et al. 2016) and the Climate Forecast System Reanalysis (CFSR; Saha et al. 2010; not shown), and therefore the JRA-55CHS is likely to be more realistic than JRA-55C. These results add another suggestion for the importance of high-resolution SST for an atmospheric reanalysis.

4. Concluding remarks

As a new additional product of the JRA-55 project, the JRA-55CHS is under construction, for which SST with quarter-degree resolution is prescribed as the lower-boundary condition of the forecast model for 30 recent years. With the JRA-55CHS, we can investigate climatic influence of frontal SST gradients along the WBCs on the overlying atmosphere concerning their seasonality, regionality and temporal variations. The present study suggests that JRA-55CHS is advantageous over other JRA-55 products with respect to the representation of those fine atmospheric features. Since large-scale atmospheric features, especially observable quantities in the free atmosphere, are constrained by assimilated data, exploring remote atmospheric responses to oceanic fronts in this framework may not necessarily be relevant. In the JRA-55CHS, this constraint tends to be weaker in the SH, where fewer in-situ observations are available. Still, over both the NH and SH, no large-scale climatological differences are apparent in the free-tropospheric circulation between the JRA-55CHS and JRA-55C, although detailed investigation is left for our future work.

Cautions must be exercised in using the JRA-55CHS. Specification of sea ice is different between the JRA-55CHS and other JRA-55 products, and surface temperature therefore exhibits distinct differences around sea-ice margins. The sea-ice differences may affect representation of atmospheric circulations, including stormtrack activity (Nakamura and Shimpo 2004). Furthermore, the JRA-55 family tends to represent local maxima and minima in high-pass-filtered low-cloud cover on the cooler and warmer side, respectively, of the SST fronts, while satellite observations and the ERA-Interim indicate the opposing features. In addition, the JRA-55 family, as some other atmospheric reanalyses, tends to underestimate midlatitude low-cloud cover, especially in the SH, which can affect the radiative balance and MAIRP processes. Nevertheless, the JRA-55CHS, together with other JRA-55 products, will contribute to deepening our understanding of the nature of frontal-scale air-sea interaction, with some important implications for a future atmospheric reanalysis. Hopefully, this introductory paper can motivate potential users to explore still-unrevealed impacts of fine SST distribution, not only in the extratropics but also in the tropics, on the atmosphere.

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Supplements

Supplement 1 shows climatological-mean upward motion (i.e., sign reversed pressure vertical velocity) at 700hPa based on the JRA-55CHS and the JRA-55C.

Supplement 2 shows wintertime composites for the KE variability based on satellite observations

Supplement 3 shows high-pass-filtered upward surface sensible and latent heat fluxes combined

Supplement 4 shows high-pass-filtered total precipitation

Supplement 5 shows high-pass-filtered cloud liquid and ice path combined

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