

OBSERVATIONAL EVIDENCE OF REEMERGENCE IN THE EXTRATROPICAL SOUTHERN HEMISPHERE

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1. INTRODUCTION

In this study, observations of subsurface ocean temperatures are used to examine the winter-to-winter “reemergence” of sea surface temperature (SST) anomalies in the extratropical South Pacific basin. Reemergence is the mechanism through which SST anomalies formed in the late winter are sequestered beneath the relatively shallow summer mixed layer and then re-entrained into the deepening mixed layer during the following fall/winter.

Previous studies have examined the reemergence of extratropical wintertime SST anomalies in the North Atlantic and North Pacific (Namias and Born 1970; Namias and Born 1974; Alexander and Deser 1995; Alexander et al. 1999; Timlin et al. 2002; De Coëtlogon and Frankignoul 2003). Reemergence, however, has received only cursory attention in the extratropical Southern Hemisphere (SH), presumably due to lack of subsurface ocean temperature observations there. Hadfield (2000) noted that SSTs in the southeast Tasman Sea recur from spring to the following winter. Hanawa and Sugimoto (2004) noted that SST anomalies also recur in the central South Atlantic, the western Indian and the western South Pacific Oceans. However, these studies relied primarily on satellite-derived SSTs, and to our knowledge, this is the first study to examine reemergence in the SH using subsurface temperature observations.

2. DATA

The primary data used in this analysis are 17 years (1990-2006) of monthly upper ocean temperature profiles obtained from the ENSEMBLES (EN3) dataset provided by the UK Met Office Hadley Centre (Ingleby and Huddleston 2007). Our analysis of the subsurface temperature data is limited by the scarcity of observations in the extratropical SH ocean basins, and is thus restricted to the region 30°-34°S, 170°-180°E, which lies in the western part of the extratropical south Pacific Ocean to the north of New Zealand.

Monthly mean values of SSTs were obtained from the NOAA_OI_SST_V2 data (hereafter referred to as the OI SST data) provided by the NOAA/Office of Oceanic and Atmospheric Research (OAR)/Earth System Research Laboratory (ERSL), Boulder, Colorado, USA, from their web site at <http://www.cdc.noaa.gov/>.

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3. THE REEMERGENCE SIGNAL IN EXTRATROPICAL SOUTH PACIFIC SUBSURFACE TEMPERATURE OBSERVATIONS

The existence of reemergence depends on the amplitude of the seasonal cycle of the depth of the mixed layer: the winter mixed layer must be substantially deeper than the summer mixed layer (Timlin et al. 2002). Figure 1 shows the monthly mean mixed layer depths from the EN3 data (thick solid line) superposed on the pattern of concurrent correlations calculated for each month between temperature anomalies at the surface and temperature anomalies for depths ranging from 0 to 150 m. The EN3 mixed layer depths are defined as the depth at which the temperature differs from the temperature at 10 m by 0.2°C.

The EN3 mixed layer climatology reveal a strong seasonal cycle in the depth of the mixed layer. Relatively strong solar heating and weak surface winds during the SH summer drive mixed layer depths no deeper than ~ 25-30 m. Comparatively weak solar heating and strong surface winds drive mixed layer depths as deep as 100 m in SH winter. For the most part, the seasonal cycle of the mixed layer depth in Fig. 1 is mirrored in the pattern of the correlations. In mid-summer, the correlations between surface temperature anomalies and temperature anomalies at depth exceed 0.8 above ~30 m but decrease to less than 0.4 below 75 m. During winter, the 0.8 correlation contour drops to 100-125 m, which demonstrates that the layer of homogeneous temperatures extends considerably deeper at that time.

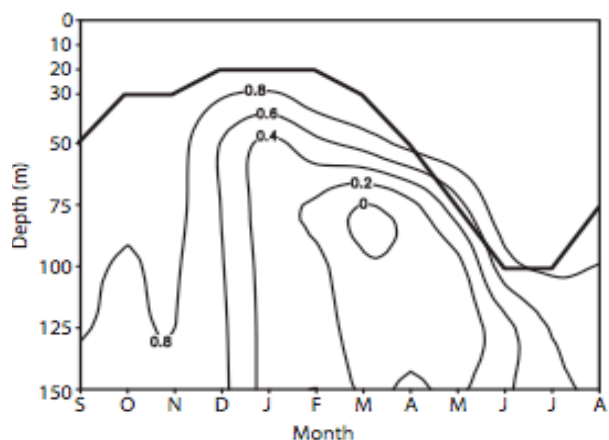


Figure 1. Concurrent correlations between temperature anomalies at 0m and temperature anomalies at 0 m down to 150 m for each month. For example, the correlation coefficient between temperature anomalies at 0 m and temperature anomalies at 50 m in January is 0.4.

The most notable difference between the pattern of the correlations in Fig. 1 and the mixed layer depths from the EN3 climatological mean temperatures is found in the spring months (September–November) when the climatological mean mixed layer depth is only ~30–50 m but surface temperature anomalies are strongly correlated down to 125–150 m. A similar result was noted in Alexander and Deser (1995), who hypothesized that the depth of the correlations is determined by the scale of the vertical mixing during periods of enhanced springtime storm activity, whereas the depth of the mean mixed layer depth reflects an average over stormy and calm periods. An alternative explanation is that since the temperature anomalies at all levels exhibit substantial persistence, then the depth of the correlations during spring are determined by the depth of the vertical mixing during the previous winter.

To evaluate the reemergence signal in the subsurface data, we examine the temporal evolution of thermal anomalies in the upper ocean from one winter to the next. Studies that have investigated the reemergence signal in the Northern Hemisphere (NH) have done so by examining lag correlations of thermal anomalies from one winter to the next. Here we adopt a similar methodology.

Figure 2 shows the lag correlations between temperature anomalies at 0 m in September and at 0 m–150 m for 0–13 month lags within the region 30°–34°S, 170°–180°E. In practice, qualitatively similar results are derived for correlations based on August and October temperature anomalies (not shown). The thick black line corresponds to the depths at which correlations with surface temperature anomalies exceed 0.8 (i.e., the 0.8 contour from Fig. 1), i.e., the layer of homogenous temperature anomalies.

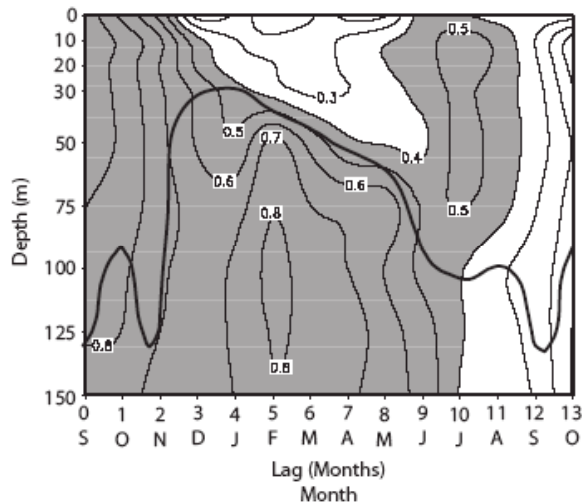


Figure 2. Lag correlations between temperature anomalies at 0 m in September and at standard depths for 0–13 month lags. For example, the correlation coefficient between September surface temperature anomalies and January temperature anomalies at 100 m is 0.7. Correlations that exceed 0.4 are shaded. The thick black line corresponds to the 0.8 contour line from Figure 1.

As shown in Fig. 1, temperature anomalies in September are highly coupled throughout the top 125–150 m of the ocean. At the surface, the correlations decrease as a function of lag such that by December the surface temperature anomalies are not significantly correlated with surface temperature anomalies from the previous September (Fig. 2), and are correlated with temperature anomalies below the mixed layer (Fig. 1). The decay of the surface temperature anomalies from September to December is consistent with damping by anomalous heat fluxes at the ocean surface. In contrast, the temperature anomalies at depth in December are insulated from atmospheric influences. Hence the temperature anomalies below about 50 m remain significantly correlated throughout the summer season with the subsurface and surface anomalies formed during the previous September.

The deepening mixed layer throughout the fall allows the thermal anomalies sequestered within the seasonal thermocline to be re-entrained into the mixed layer. Thus in June and July, temperature anomalies throughout the mixed layer are impacted by the entrainment process and become significantly correlated with surface temperature anomalies formed during the previous September. By July, the mixed layer encompasses the entire top 100 m of the ocean and the SST anomalies that were formed 11 months earlier (and stored beneath the summertime mixed layer) are finally damped to the overlying atmosphere. The structure of the reemergence signal is also clearly evident if temperature anomalies below the summer mixed layer are used as a basis for the correlations (not shown).

4. THE SURFACE SIGNATURE OF REEMERGENCE

In this section, monthly OI SST anomalies are used to more closely examine the robustness of reemergence in the region 30°–34°S, 170°–180°E. Figure 3 shows the lag correlations between area-averaged SST anomalies for three start months (August, September, and October). Note that the x-axis in Fig. 3 is a function of lag relative to the basis month for the correlations. For example, lag 4 corresponds to correlations between August and December SST anomalies (solid line), September and January SST anomalies (dashed line), and October and February SST anomalies (dotted line).

The results in Fig. 3 demonstrate that the reemergence signal in the region 30°–34°S, 170°–180°E is robust to small changes in the start month. Whether the SST anomalies are formed in August, September, or October, they are only weakly correlated with February SST anomalies but are significantly correlated with June SST anomalies when mixed layer depths are deepest (see Fig. 1). In all three cases, the correlations between wintertime SST anomalies and June SST anomalies are statistically significant at the 95% confidence level and are also broadly consistent with the subsurface results in Fig. 2. Analysis of the OI SST data also reveals a widespread reemergence signal across the western extratropical South Pacific basin but is less discernible in the eastern part of the basin (not shown).

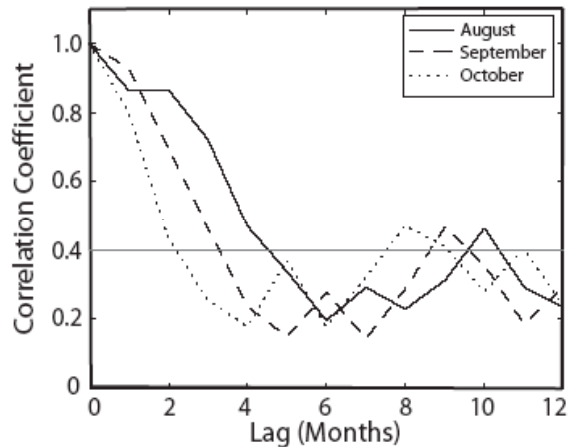


Figure 3. Lag correlations of OI SST anomalies averaged over the region 30°-34°S, 170°-180°E based on a starting month of (solid line) August, (dashed line) September, and (dotted line) October. For example at lag 6, the solid line corresponds to a correlation between August and February SST anomalies of ~0.2. The gray line corresponds to the 95% confidence level.

5. CONCLUSIONS

The results of this study demonstrate that, consistent with the reemergence mechanism, extratropical western South Pacific SST anomalies formed in the late winter/ early spring are significantly related to SST anomalies observed in the following fall/winter but are unrelated to SST anomalies in the intervening summer. The reemergence of SH SST anomalies explains ~21% of the year-to-year variance in the June SST field over the western South Pacific and are generally consistent with the behavior of reemergence observed in the NH (Alexander and Deser 1995; Alexander et al. 1999; Timlin et al. 2002).

The reemergence of SST anomalies in the extratropical South Pacific yields predictability in anomalous SSTs out to ~8-10 months, which is longer than the known predictability associated with most other physical phenomena. It is unclear if the reemerging SST anomalies impact the extratropical atmospheric circulation, but if they do, reemergence may prove to be important for seasonal forecasting.

6. REFERENCES

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