P4.20 A COMPARISON OF FSU2, NCEPR1, AND NCEPR2 WINDS IN THE TROPICAL PACIFIC

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1. INTRODUCTION

Surface wind stress fields are essential for ocean modeling studies of variability at different temporal and spatial scales. Obtaining accurate wind stress over the oceans is difficult; therefore, considerable effort has been made by different institutions to produce accurate surface wind fields based on in-situ and remotely-sensed wind observations. Two widely used and easily available wind products are those from the Florida State University (FSU) and from the National Centers for Environmental Prediction (NCEP). Herein, the wind products, and related quantities, from FSU and NCEP are inter-compared for the tropical Pacific Ocean. The inter-comparison reveals differences in the fields that are important to understand prior to the application of these products in ocean or climate studies.

Three monthly average surface wind products are compared for the tropical Pacific Ocean (29°N-29°S, 122°E-290°E): the objective FSU pseudostress (FSU2; Bourassa et al. 2003), the NCEP/National Center for Atmospheric Research Reanalysis (NCEPR1; Kalnay et al. 1996), and the NCEP/DOE AMIP-II Reanalysis (NCEPR2; Kanamitsu et al. 2002). Previous studies have shown the deficiencies of the NCEPR1 on estimating surface winds and air-sea fluxes (Smith et al. 2001; Goswami and Sengupta, 2003). NCEPR1 tends to underestimate surface wind speeds, especially in the tropical regions. Therefore, an ocean model forced with these winds can produce unrealistic currents. Despite the improvements over the NCEPR1, the NCEPR2 still exhibits some deficiencies in its surface wind stress and flux fields (WCRP/SCOR 2000; Kanamitsu et al. 2002). Preliminary evaluations of the NCEPR2 indicate that the deficiencies may be related to the overestimation of the outgoing longwave radiation over the tropical warm pool and an upper troposphere that is drier in the tropics than was in the NCEPR1. These problems may be related to the new boundary layer formulation and convective schemes in the model. These changes improved the precipitation but inadvertently worsened the radiation budget (Kanamitsu et al. 2002). An advantage of the FSU wind product over the NCEP reanalyses is that it is more dependent on observations than on model parameterization, initialization, and other constraints (Legler 1996).

The paper begins with a brief overview of the datasets in section 2. Section 3 presents the comparisons between the products, and section 4 wraps up the paper with preliminary conclusions.

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2. DATASETS

2.1 *Objective FSU Winds*

The FSU2 surface wind (pseudostress) product is a research quality monthly climatology based on in-situ observations from volunteer observing ships and buoys for the period 1978-2002. These fields are created using an objective technique based on the minimization of a cost function (Bourassa et al. 2003; Pegion et al. 2000). The cost function maximizes information from the observational data and minimizes smoothing.

Although in-situ observations are recorded as winds, gridded fields of pseudostress are produced because the FSU winds are intended for ocean modeling. Ocean circulation is largely driven by wind stress and the curl of wind stress. Wind stress is extremely difficult to measure and estimates rely on a hard to define drag coefficient; therefore, the FSU2 pseudostress is defined as the scalar wind speed multiplied by the vector wind. Both the wind and stress fields can be derived from the pseudostress.

The FSU2 fields have several advantages over the old subjectively analyzed FSU winds. In the new product the height is adjusted to 10 m instead of 20 m, and the ship and buoy observations are weighted independently. The monthly mean FSU2 pseudostress fields are generated on a 2°x2° resolution grid, whereas the old product was analyzed on a 2°x10° grid. The FSU2 winds better resolve convergence zones and curl features and have a reduced month-to-month variability when compared to the subjective product (Bourassa et al. 2003).

2.2 *NCEPR1*

The NCEP/NCAR reanalysis project uses historical data (1948-present) to produce analyses of atmospheric fields using a frozen state-of-the-art global data assimilation system. Data from in-situ surface and upper air stations, satellites, and aircraft are ingested into the system. The spatial resolution is T62 (~210 km) and 28 levels, and the temporal resolution is 6 hours. Parameterizations of all major physical processes are included: convection, large-scale precipitation, shallow convection, gravity wave drag, radiation with a diurnal cycle and interaction with clouds, boundary layer physics, an interactive surface hydrology, and vertical and horizontal diffusion processes. Optimal averages in time and space are performed over pre-specified areas for temperature, specific humidity, u and v components of the wind, and wind (Kalnay et al. 1996).

For the present comparison, the NCEPR1 monthly means of the 10-m wind components are obtained from the Climate Diagnostics Center (http://www.cdc.noaa.

gov/). The Gaussian gridded NCEPR1 winds are regridded to a 2°x2° resolution grid using a cubic spline, which allows for direct comparisons with the FSU wind fields. Wind divergence, pseudostress, and the curl of the pseudostress are calculated from the regridded NCEPR1 winds.

2.3 *NCEPR2*

NCEP/DOE AMIP-II Reanalysis is a follow-up project to the NCEP/NCAR Reanalysis that fixes the human processing errors discovered in the NCEPR1. The NCEPR2 uses an updated forecast model and data assimilation system, leading to major changes and significant improvements in many of the fields when compared to NCEPR1. The NCEPR2 is a 6-hour global analysis series from 1979 through 2000 that keeps the same spatial resolution and uses most of the same observations as the NCEPR1. The new system components include simple rainfall assimilation over land surfaces and smoothed orography. These changes provide a more accurate picture of soil wetness, precipitation, snow cover and near-surface temperature over land, oceanic albedo and radiative fluxes over ocean, and the land hydrology budget (Kanamitsu et al. 2002).

The NCEPR2 data were obtained from the Data Support Section of NCAR through ongoing funding from NSF. The NCEPR2 underwent the same regridding as the NCEPR1 prior to calculation of wind divergence, pseudostress, and the curl of the pseudostress.

3. RESULTS

The annual, interannual, and monthly variations of the wind, wind divergence, and curl of the pseudostress are compared for the period 1979-2000.

3.1 *Pacific Spatial Averages*

The time series of spatially averaged monthly mean wind magnitudes for the equatorial Pacific Ocean within 11°N-11°S show that the FSU2 winds have larger values during the whole period compared to both the NCEPR1 and NCEPR2 products, and that NCEPR2 has larger values compared to NCEPR1 (Fig. 1a). The annual mean wind magnitudes are 5.6, 4.6, and 4.1 ms^{-1} for the FSU2, NCEPR2, and NCEPR1 products respectively, and the standard deviations are 0.59 ms^{-1} for FSU2 and 0.54 ms^{-1} for both reanalyses. These results show that NCEPR2 improvements in the forecast model and data assimilation system have produced better estimations of the surface winds in this region. When the domain is extended in latitude to 29°N-29°S a similar behavior is observed (Fig. 1b), with annual mean wind magnitudes of 5.9, 4.6, and 4.3 ms^{-1} for the FSU2, NCEPR2, and NCEPR1 products respectively; the standard deviations reduce to 0.44 ms^{-1} for FSU2 and 0.40 ms^{-1} for both reanalyses. However, the difference of annual means between the two reanalyses is smaller in this region (0.2 ms^{-1}) than in the 11°N-11°S region (0.5 ms^{-1}), and the difference between the FSU2 and NCEPR2 products is larger (1.4 ms^{-1}) than in the 11°N-11°S region (1.0 ms^{-1}). The implication is that the improvements in the NCEPR2 are primarily in the Equatorial latitudes in the Pacific.

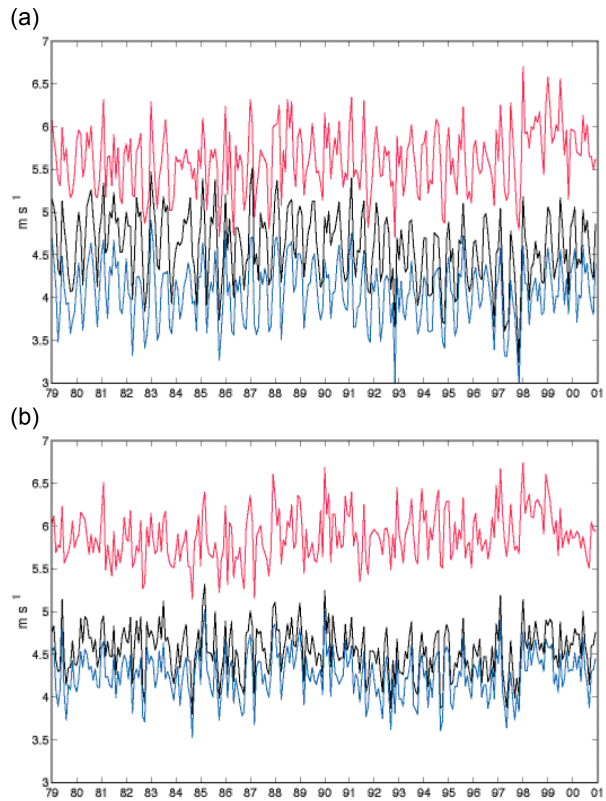


Figure 1. Monthly mean wind speeds (ms^{-1}) for: (a) 11°N-11°S, 122°E-290°E, and (b) 29°N-29°S, 122°E-290°E. FSU2 (red), NCEPR2 (black), NCEPR1 (blue).

3.2 *Annual mean fields*

The mean wind fields for the period 1979-2000 within the equatorial Pacific (29°N-29°S) for the three products (Fig. 2a), and the differences between them (Fig. 2b), show that the FSU2 winds are stronger than NCEPR1 and 2 in most of the basin. Exceptions occur along 11°N-15°N and a region in the southeastern Pacific between 5°S-15°S, 94°W-80°W where the FSU2 winds are weaker than the reanalysis products. Along the Mexican Pacific coast above 19°N (including the Gulf of California), the west coast of South America south of the equator, off the south-southeast coast of New Guinea, and along the northeast coast of Australia, the FSU2 winds are clearly stronger than those from the reanalyses. Also, the FSU2 shows stronger winds around the Hawaiian and Fiji islands. The differences between the two reanalyses clearly show the areas in the central and eastern Pacific where the NCEPR2 has stronger winds, and a relatively small region offshore the Peru-Chile coast where the NCEPR2 winds are significantly weaker compared to the NCEPR1 product.

(a)

(b)

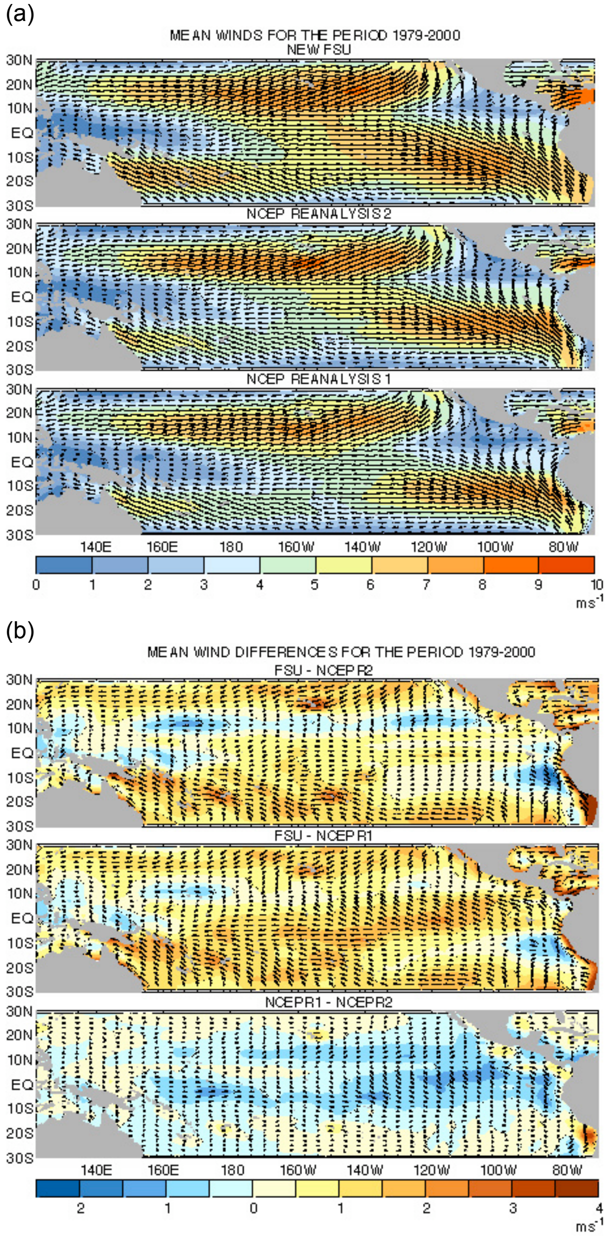


Figure 2. (a) Annual mean wind vectors (arrows) and magnitude (contours) for the three products, and (b) mean wind differences between the three products for the period 1979-2000 (ms^{-1}). Vectors are plotted every 2° in latitude and every 4° in longitude.

The main wind convergence zones of the equatorial Pacific, the Intertropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ), are clearly identifiable in the mean wind divergence fields of the FSU2 and NCEPR2 products, while the NCEPR1 shows a very weak and undulating ITCZ and SPCZ (Fig. 3). Overall, the location and intensity of the ITCZ are similar for the FSU2 and NCEPR2 products. Regional differences occur near the west coast of South America where the ITCZ is stronger in the NCEPR2 versus the FSU2. A second convergence zone in the eastern Pacific, narrower and weaker than the ITCZ, is identifiable in both reanalyses just south of the equator (around 3°S), but is imperceptible in the FSU2. This double ITCZ has been verified with scatterometer data (M. Bourassa, personal communication, 2003). The lack of this feature in the FSU2 may be related to sparse in-situ data coverage.

There are some regions where the divergence fields of the three products show marked differences. The mean wind divergence field in the southeastern Pacific is noisier in both reanalyses, showing patches of more divergent and convergent winds compared to the smooth and weak divergent field of the FSU2. The area of strong divergent winds off the coast of the Baja California peninsula is larger and it is located nearer to the coast in the reanalyses. To the south of the Hawaiian Islands the NCEPR2 product shows more divergent winds than the other two products.

The annual mean pseudostress curl fields show some regional differences between the three products (Fig. 4). The NCEPR2 product shows a band of slightly larger positive values along 10°N, east of 150°E. Both reanalyses show considerably larger positive curl values along the northeast Australian coast. Along the South America west coast the FSU2 shows low positive curl compared with large negative values in the reanalyses. Both reanalyses also show a curl 'dipole' around the Hawaiian islands, which is more intense in the NCEPR2, with northern positive values and southern negative values. The dipole is very weak in the FSU2. Finally, the FSU2 shows a smoother representation of the curl pattern associated with the SPCZ as compared to the reanalyses.

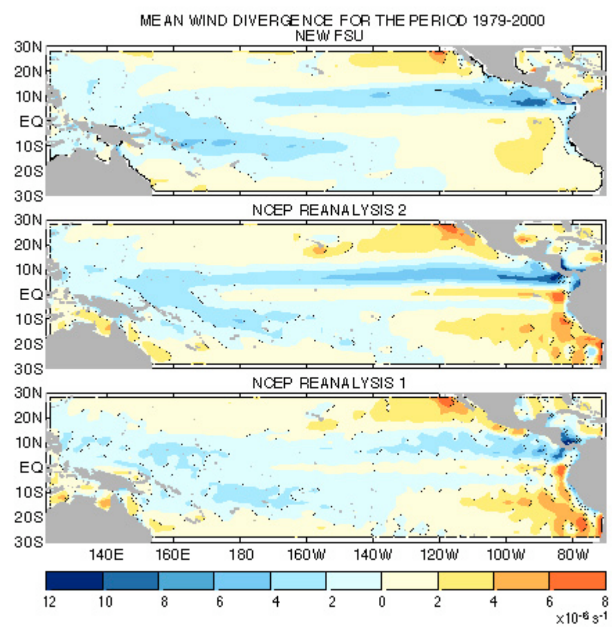


Figure 3. Annual mean wind divergence (x10^{-5} s^{-1}) for the period 1979-2000.

3.3 *Seasonal Variability*

The monthly mean wind fields over the analyzed period show the FSU2 to have stronger wind magnitude overall than the reanalysis products. In addition, many of the regional differences mentioned above appear, with some features being more evident during certain months (not shown). In general, all three products show the seasonality in the wind magnitude of the Trades that are stronger during the winter months (December-March for the northern hemisphere and June-September for the southern hemisphere) than in summer. They also show the strong seasonal variations in wind direction over the western equatorial Pacific, west of 150°E, where the winds reverse in April and October of each year.

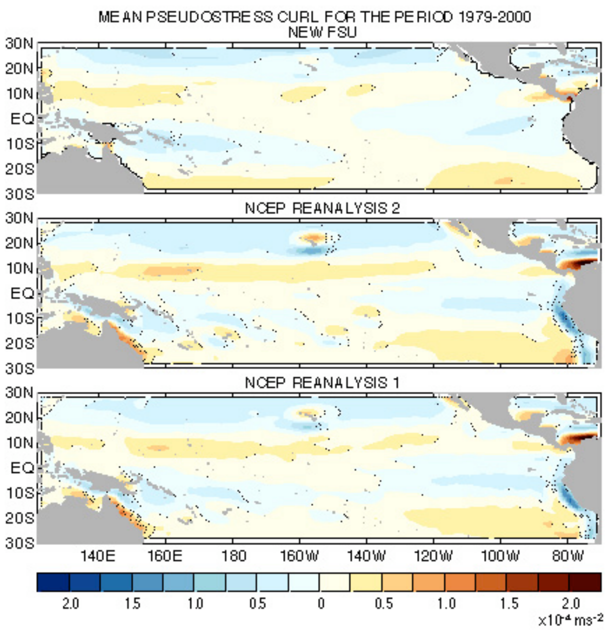
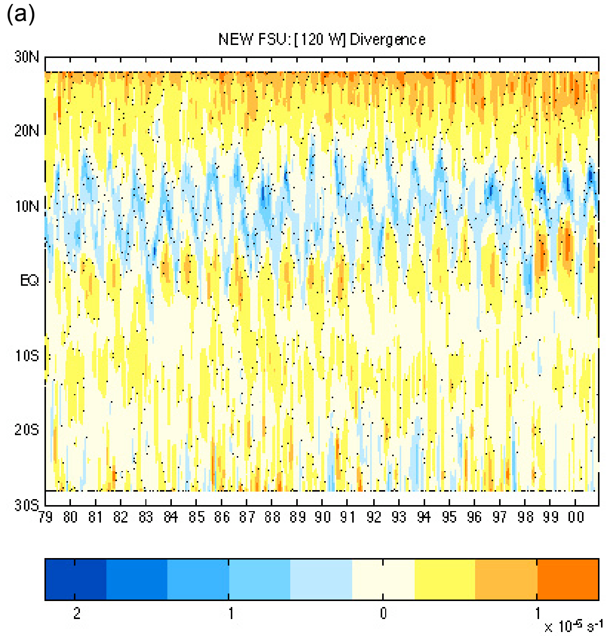


Figure 4. Annual mean pseudostress curl (x10^{-4} ms^{-2}) for the period 1979-2000.

One of the regions with marked differences in wind magnitude and direction between the FSU2 and the reanalyses is the Gulf of Carpentaria (northern Australia) where the FSU2 winds are stronger than the reanalyses throughout the year. Another region with noticeable differences is off the west coast of South America below 15°S where the FSU2 shows relatively strong southeasterly winds throughout the year, while the reanalyses, mainly the NCEPR2 product, show very weak winds with variable direction. These two regions also show marked differences in the monthly mean divergence and curl fields. Along the Mexican Pacific coast, north of 20°N, the winds from the reanalyses are lighter and their direction is more along-coast than the FSU2 winds.

The monthly composites of the wind divergence field (not shown) from the FSU2 and NCEPR2 show a strong ITCZ from June to November. As noted in the annual means, the ITCZ is not well defined in the NCEPR1. Both the FSU2 and NCEPR2 also capture the seasonal north-south migration of the ITCZ, which moves northward during the boreal summer months. This migration is clearly seen in the time-latitude diagram of the divergence at 120°W (Fig. 5). The NCEPR2 better resolves and captures the seasonality (peak convergence from December to May) of the southern branch of the ITCZ at 5°S than does the FSU2. During this period, the ITCZ in the FSU2 product looks broader.

(a)



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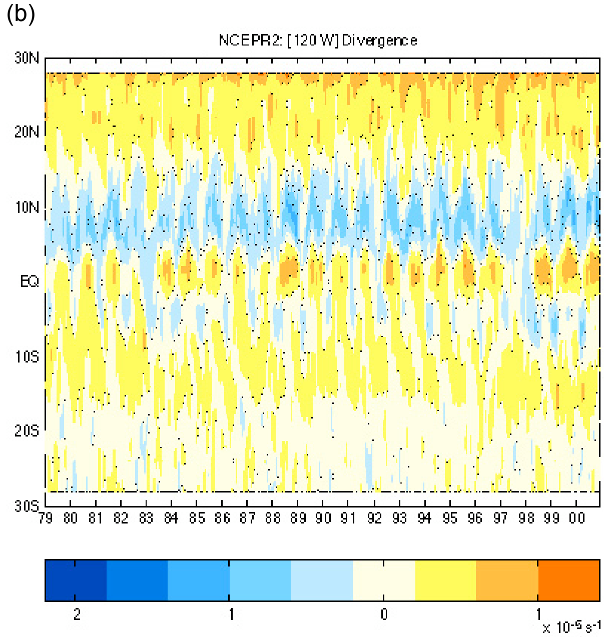


Figure 5. Time-latitude diagrams for the wind divergence (x10^{-5} s^{-1}) analyzed at 120°W for (a) the FSU2 product, and (b) the NCEPR2 product.

The SPCZ shows a weaker seasonal signal than the ITCZ, being slightly stronger from December to March. The time-latitude diagram of the divergence at 180°E (Fig. 6) shows more monthly variability in FSU2 than in NCEPR2.

The monthly composites also show a very different seasonal pattern of the divergence field north of Australia. The NCEPR2 product shows very strong divergent winds, mainly during September to November, while the FSU2 winds are slightly convergent during most of the year.

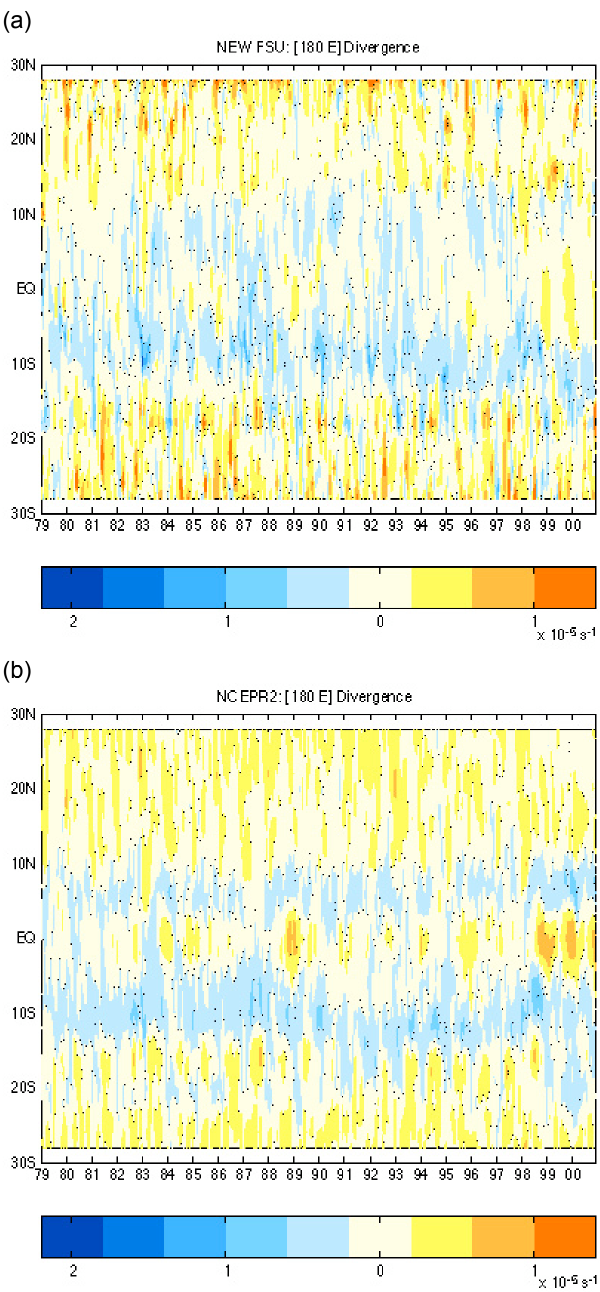


Figure 6. Time-latitude diagrams for the wind divergence ($x10^{-5}$ s^{-1}) analyzed at 180°E for (a) the FSU2 product, and (b) the NCEPR2 product.

All seasonal composites of the pseudostress curl (not shown) show similar differences between the FSU2 and the reanalyses. The reanalyses show large negative values (anticyclonic winds) along the west coast of South America during the whole year (stronger from June to August) compared to the near zero values in the FSU2 product. The curl 'dipole' around the Hawaiian Islands in the reanalyses is identifiable during most of the year, being weaker during the winter months, but is almost absent in the FSU2. As in the divergence fields, the regions between New Guinea and Australia and off the northeast coast of Australia show marked differences between the products, mainly from March to August when the reanalyses show large negative values south of New Guinea and large positive values along the northern Australian coasts.

3.4 *Interannual Variability*

The longitude-time diagrams of the zonal wind component anomalies at 5°N to 5°S for 1979-2000 (Fig. 7) show larger values in the FSU2 product than in the NCEPR2 product. During El Niño years (1982, 1986, 1987, 1991, and 1997 according to the JMA SST index; Hanley et al. 2003) there is the expected propagation of positive anomalies (westerly winds) from the west to the central and eastern Pacific, reaching as far as 100°W during the 1982-83 and 1997-98 events. Since the beginning of 1998 until middle 2000 a strong negative anomaly is observed in the western Pacific that propagated eastward, reaching as far as 150°W, associated with the 1998 and 1999 La Niña events that is more evident in the FSU2 product. Also the negative anomalies associated with La Niña of 1988 are identifiable. There is also a strong negative anomaly in the FSU2 product approximately between 122°E and 160°E that lasted from the end of 1982 through middle 1984. Overall, the tendency is for 1-3 ms^{-1} stronger easterly anomalies (west of 170°E) in the FSU2 during La Niña events as compared to NCEPR2. Westerly anomalies during El Niño are also stronger in the FSU2 (~2 ms^{-1}), but the region of largest differences changes with the strength of the warm phase. Largest differences occur around 170°W for the strong events of 1982-83 and 1997-98 and near 170°E for the weaker 1986-87 and 1991-92 warm events.

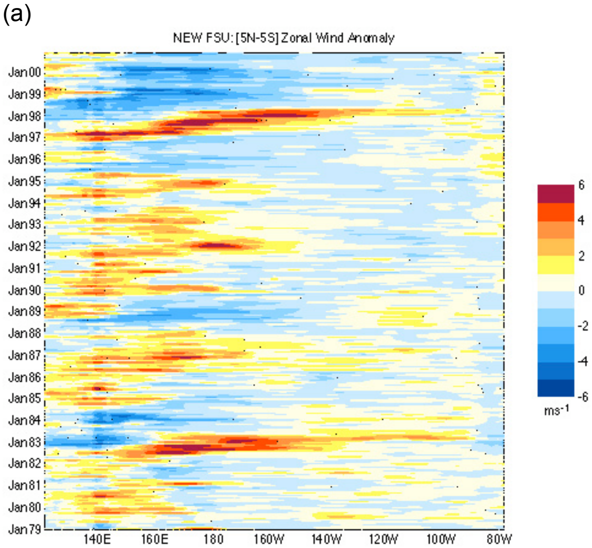
4. SUMMARY

Inter-comparisons of the FSU2, NCEPR1, and NCEPR2 tropical Pacific winds reveal differences that may yield vastly differing ocean circulations when the winds are used to force ocean models. Overall, the FSU2 and NCEPR2 compare favorably for many of the large-scale features of the Pacific (e.g., ITCZ), but a number of differences exist at regional scales. Many of the regional differences occur near islands or coastlines.

The NCEPR2 is a substantial improvement over the NCEPR1. Winds in the tropics are stronger in the NCEPR2, offsetting to some degree the previously documented underestimation of the tropical winds in the NCEPR1 (Smith et al. 2001; Goswami and Sengupta

2003). The ITCZ and SPCZ are well defined in the NCEPR2 as opposed to the highly variable pattern of divergence for the NCEPR1. The NCEPR2 does have higher spatial variability in the Southern Hemisphere that does not appear in the FSU2.

(a)



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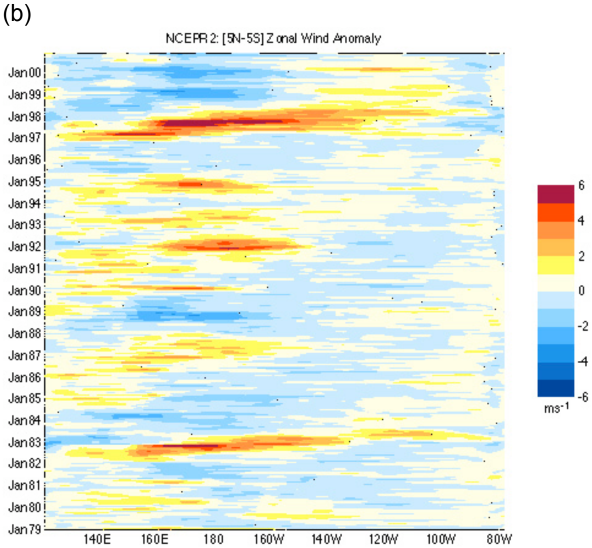

Figure 7. Longitude-time diagrams for the zonal wind component anomaly (ms^{-1}) averaged at 5°N-5°S for (a) the FSU2, and (b) the NCEPR2 product.

The reasons for the identified differences have not been determined. They may be partially related to differences in the input data for each product. For example, near land, the FSU2 only ingests in-situ ship and buoy data, while the NCEPR2 uses both data over the ocean and from the nearby landmass. One would expect some influence from the overland data to propagate over the ocean in the NCEPR2. In addition, the winds from the NCEPR2 are linked to the input data through a series of model physics and near surface parameterizations in the assimilation system that are absent in the FSU2. Isolating the cause of large-scale and regional differences is a complicated task and the authors plan to collaborate with NCEP scientists.

ACKNOWLEDGEMENTS

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