P3.2 AIR-SEA FLUXES IN NCEP'S GLOBAL FORECAST SYSTEM

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1. INTRODUCTION

The Global Climate and Weather Modeling Branch is responsible for improving operational global numerical weather prediction (NWP) forecasts of weather, such as medium-range forecasts of 3-7 days, and climate, such as seasonal forecasts of up to 7 months. The Global Forecast System (GFS) is also used for short-range aviation forecasts, hurricane forecasts and week-2 forecasts. Of crucial importance, especially for the short- and medium-range forecasts, is data assimilation (GDAS). Forecasts beyond 2 weeks are made with an atmospheric model driven by sea surface temperatures forecast by a coupled atmosphere-ocean system. The branch is currently unifying the atmospheric model used for weather and climate.

Analysis/forecast systems used in NWP have matured to the point that further development requires the direct verification of model physics. Changes in operational NWP systems are designed to improve their synoptic forecast performance; their effect on surface fluxes is often not evaluated as carefully, in part because accurate independent estimates of surface fluxes are more difficult to obtain than measurements of synoptic atmospheric fields. Air-sea surface fluxes are especially important in coupled atmosphere-ocean systems.

The GFS produces global fields of air-sea fluxes at less than 1° resolution every six hours a few hours after observation time; these fields are widely distributed. The GFS carefully checks and assimilates large numbers of different types of observations and uses an atmospheric model based on the laws of physics, including complex parameterizations of physical processes, to interpolate them in space and time. Surface fluxes are obtained from the 0-6 hour forecasts that provide the "first guess" for GDAS. Users, including marine forecasters, continuously monitor the GFS.

Improvements to the GFS are introduced periodically and can cause significant changes, especially in fields, such as surface fluxes, more defined by model physics than by observations. To eliminate the effects of such changes, frozen data assimilation systems have been used to analyze many years of meteorological data. The NCEP-1 reanalysis extends from 1948 to the present and is currently run as the Climate Data Assimilation System (CDAS) (Kalnay *et al.*, 1996; Kistler *et al.*, 2001). It is based on the 1995 operational NCEP global analysis/forecast system. The NCEP-2 reanalysis (Kanamitsu *et al.*, 2002b) corrected mistakes made in the NCEP-1 reanalysis and updated the physical parameterizations used; it extends from 1979 to the present.

The climate records in reanalyses are contaminated by changes in the observational system. The NCEP-1 reanalysis has a discontinuity at the beginning of 1979, when the modern era of satellite data began. ECMWF reanalyses have had problems correcting biases in satellite radiances. The current observational system is moving towards a more space-based system with more and more satellite observations and decreases in traditional ground-based observations such as radiosondes and ship observations.

The performance of the model physics in the NCEP-1 reanalysis has been critically examined by a large number of scientists and compared to many independent estimates from many different periods, often over many years, and is better known than the performance of the physics in the current GFS. NCEP-1's use as CDAS provides a useful benchmark for the current GFS, providing insight into whether changes in the GFS improve the air-sea fluxes.

This paper examines air-sea fluxes from the operational GFS and compares them to other flux estimates. It is motivated by a desire to show that air-sea fluxes from the NCEP global model are the best available global estimates and a desire to find better estimates of air-sea fluxes to use as a basis to improve the GFS.

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Global Mean Balances
Oct. 2001-Sep. 2002

	CDAS	GDAS (May 2000-Apr.2001)	GDAS	K &T	Range	SRB-1
P(mm/day)	2.82	3.00	3.03	2.69	2.69-3.1	
E	2.86	3.02	3.16	2.69		
P-E	-.03	-.02	-.13			
SH (W/m2)	15	12	9	24	16-27	
LH	83	87	92	78	78-90	
Sfc dsw	205	198	211	198		185
usw	45	28	30	30		24
NSW	160	169	180	168	142-174	161
dlw	337	337	331	324		348
ulw	397	398	398	390		396
NLW	60	61	68	66	40-72	48
net rad	100	108	113	102	99-119	113
NHF	+2.2	9.4	13	0		
TOA dsw	342	342	342	342		
usw	117	102	86	107		
ulw	238	243	249	235		
TOA Net	-13	-4	7			
Atm Heat	-15	-13	-6			

Table 1. Global mean surface and top of the atmosphere (TOA) fluxes averaged over May 2000-Apr. 2001 and Oct. 2001-Sept. 2002 from the operational GDAS and over Oct. 2001-Sept. 2002 from CDAS compared to climatological estimates from Kiehl and Trenberth (1997) and from the NASA Langley Research Center Surface Radiation Budget (SRB-1) (Darnell et al. (1992); Gupta et al. (1992)).

2. GLOBAL BUDGETS

Table 1 displays global water, surface energy and TOA radiation budgets from two versions of the operational GFS GDAS, CDAS or NCEP-1 and climatological estimates by Kiehl and Trenberth (1997) and by SRB-1. The column "Range" is the range of estimates considered by Kiehl and Trenberth (1997) and indicates uncertainty in our current knowledge of global fluxes, as does the large difference in surface downward long wave estimates between Kiehl and Trenberth (1997) and SRB-1. Realistic surface fluxes are essential for useful coupled model forecasts; our current knowledge of surface fluxes is not adequate for that purpose. The hydrological cycle is more intense in GDAS than in the climatological estimate; however, its magnitude lies within the range of independent estimates.

In spite of the large uncertainty in our knowledge of the fluxes, errors are apparent in both CDAS and GDAS. CDAS has too high an ocean surface albedo and too much surface upward short wave radiation; however, the net surface energy budget is much closer to balance than GDAS. GDAS appears to have too little sensible heat flux, possibly due to a new boundary layer parameterization introduced after 1995. GDAS is in better TOA radiative balance than CDAS; GDAS now has less atmospheric cold bias than the earlier GDAS or CDAS.

The differences between the two versions of GDAS reflect to a large extent a major change in cloudiness parameterization. A prognostic cloud liquid water parameterization replaced a diagnostic cloudiness parameterization based on relative humidity in May and August 2001. Significant changes can be seen in surface downward short wave radiation and TOA upward short wave.

3. THE EFFECTS OF CHANGING CLOUDINESS PARAMETERIZATIONS

Fig. 1 and 2 compare surface net short wave radiation and total cloudiness for Jan.-Feb 2000-2001 and Jan.-Feb. 2002 from GDAS with independent climatological estimates for Jan.-Feb. Fig. 3 displays the difference between the two seasons and reflects to a large extent the effects of different cloudiness parameterizations. The changes in 2001 clearly increased downward

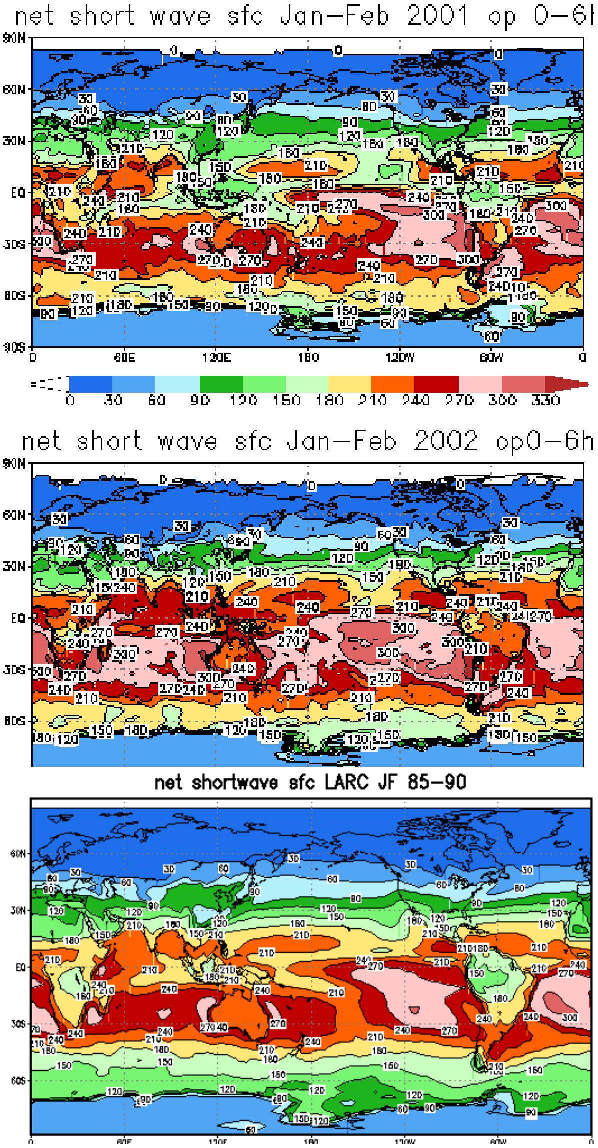

Fig. 1 Surface net short wave radiation from the operational GFS 0-6 hour forecasts (GDAS) (analysis cycle) for (top) Jan.-Feb 2001 and (middle) Jan.-Feb. 2002 and from the SRB-1 climatology for Jan.-Feb. 1985-1990.

short wave radiation at the surface and decreased cloudiness. The new GFS displays increased forecast skill, reduced model biases and offers a more realistic parameterization of cloudiness. However, Figs. 1-3 suggest that the new cloudiness may need to be adjusted.

Fig. 2 shows that ISCCP (International Satellite Cloud Climatology Project) estimates of cloudiness are generally higher than estimates in GDAS. Cloudiness in the GFS system has generally been tuned to Air Force nephanalyses, operational cloud analyses that give lower cloud amounts than ISCCP and that use ground-based estimates of cloudiness, unlike ISCCP.

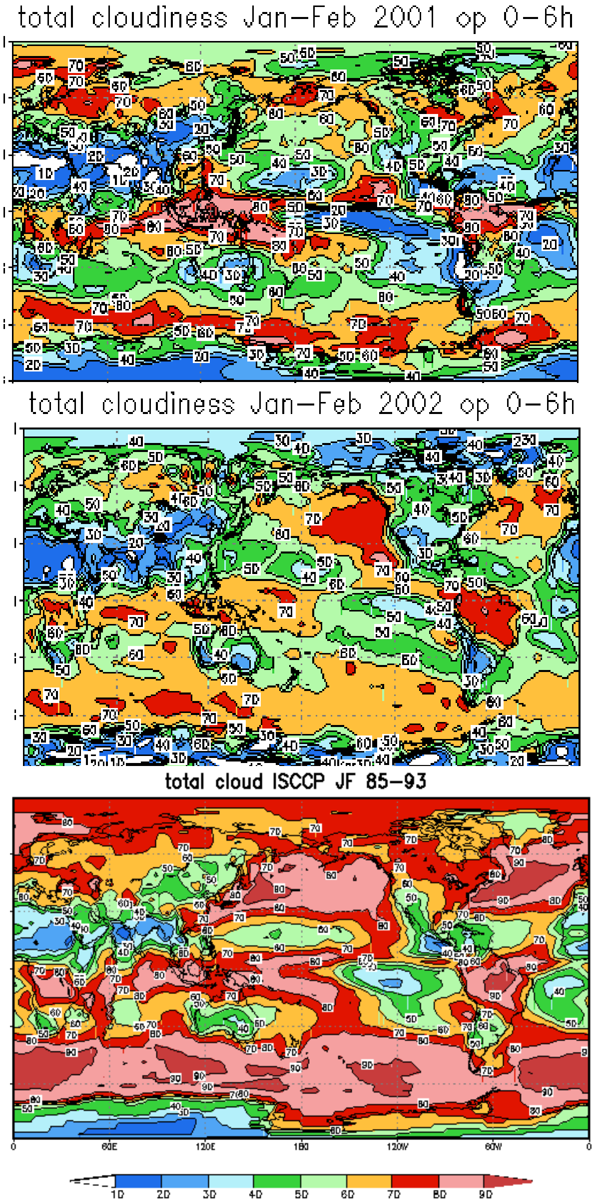

Fig. 2. Total cloudiness from the operational GFS 0-6 hour forecasts (analysis cycle) for (top) Jan.-Feb 2001 and (middle) Jan.-Feb. 2002 and from ISCCP climatology for Jan.-Feb. 1985-93.

Fig. 3 indicates that not all changes in surface short wave radiation are due to changes in total cloudiness. It also indicates that surface radiative fluxes in NWP still have major shortcomings, reflecting largely problems and uncertainties in cloudiness and atmospheric moisture.

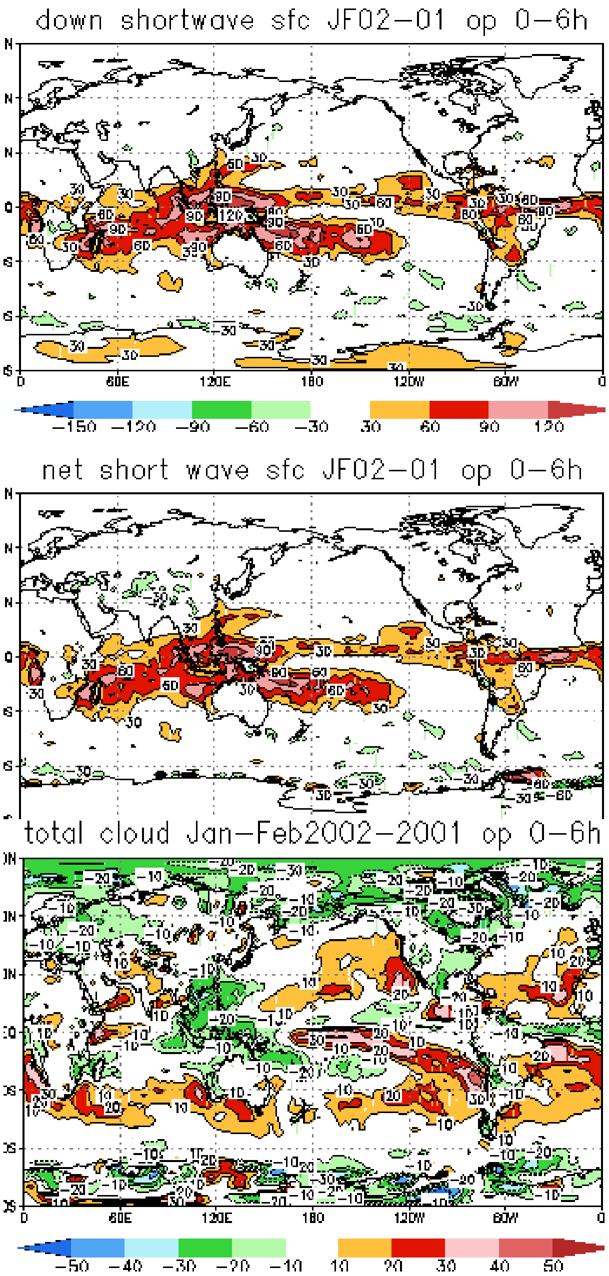

Fig. 3 Changes in surface (top) downward and (middle) net short wave radiation and in (bottom) total cloudiness from Jan-Feb. 2001 to Jan.-Feb. 2002 in operational GFS 0-6 hour (analysis cycle) forecasts.

4. ZONAL SURFACE STRESS IN AMIP INTEGRATIONS

S. Saha and W. Wang recently performed AMIP simulations, extended integrations with observed SST, with different versions of the NCEP global atmospheric model, to investigate which version is the most suitable for seasonal forecasts and to examine more fully systematic biases in the GFS. Of particular relevance to coupled ocean-atmosphere model forecasts is the surface wind stress.

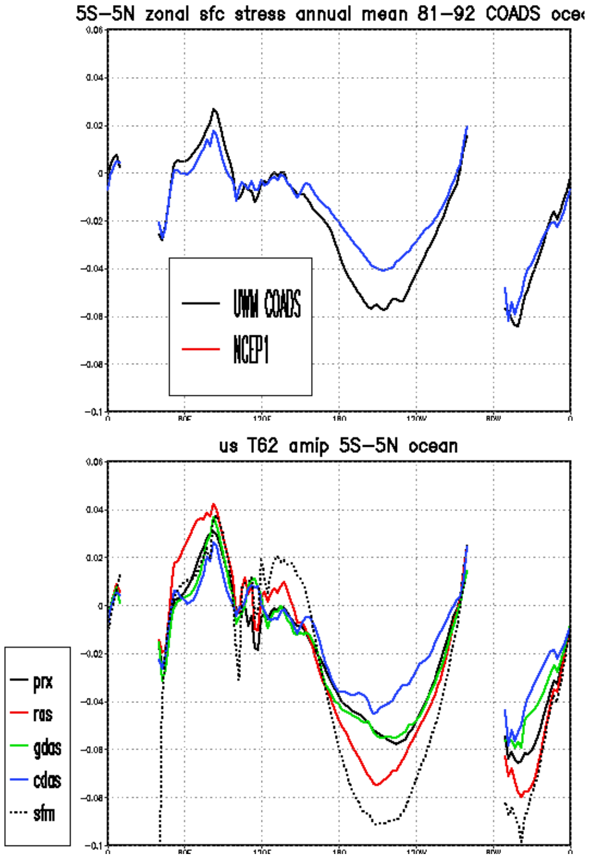

Fig. 4 Zonal surface stress averaged over 5S-5N from (top) NCEP1 (blue line) and the da Silva *et al.* (1993) COADS-based climatology for 1981-92 and (bottom) GDAS, CDAS and 3 AMIP integrations from mid-Dec. 2000 for 2001.

Fig. 4 compares surface zonal wind stress near the equator from climatologies and from analyses and AMIP runs for 2001. The top panel displays a well-known problem in the NCEP1 reanalysis (CDAS): too weak wind stress in the eastern equatorial Pacific.

The bottom panel shows a more realistic wind stress in the operational analyses (GDAS) for 2001 and in an AMIP run with a version of the GFS scheduled to be implemented in late 2002. AMIP integrations with a different convection parameterization (RAS) and the currently operational seasonal forecast model (SFM) (Kanamitsu *et al.*, 2002a) both yield too strong wind stress in the eastern equatorial Pacific.

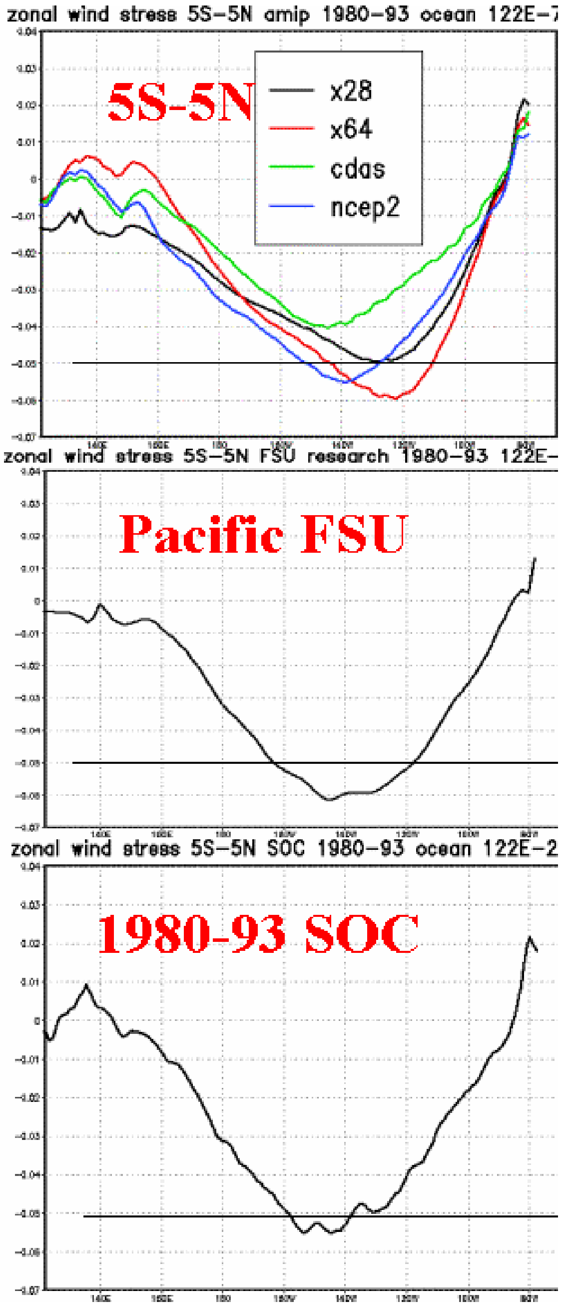

Fig. 5 Zonal surface stress averaged over 5S-5N for 1980-93 from (top) CDAS, NCEP2 and 2 AMIP runs with different vertical resolution, (middle) Florida State Univ. and (bottom) Southampton Oceanography Centre (Josey *et al.*, 1998).

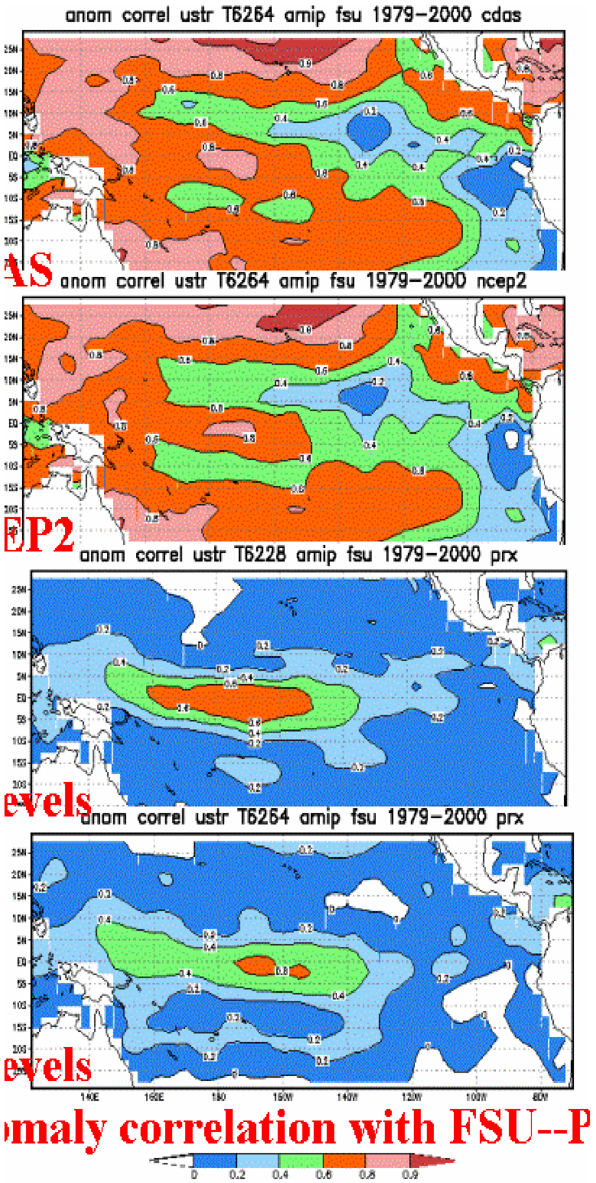

Fig. 6 Anomaly correlations with FSU zonal surface stress for monthly mean anomalies for 1979-2000 from (top) NCEP1, (second from top) NCEP2, (second from bottom) an AMIP integration with 28 vertical levels and (bottom) an AMIP integration with 64 vertical levels. Anomalies of each are from that data set's 22-year mean annual cycle of zonal wind stress.

Fig. 5 compares the zonal surface stress in the equatorial Pacific for 1980-93 from the two NCEP reanalyses with two independent estimates and with two AMIP runs at T62 spectral resolutions, but different vertical resolutions: 28 and 64 levels. The FSU estimate (Bourassa *et al.*, 2001) is slightly stronger than NCEP2 or the SOC COADS-based estimate, while the AMIP runs' wind stress is strongest 30^o east of the others.

Fig. 6 displays the correlation of monthly mean anomalies in zonal wind stress from the two reanalyses and two AMIP runs with FSU wind stress over 22 years. The two AMIP integrations display significant correlations only in a narrow

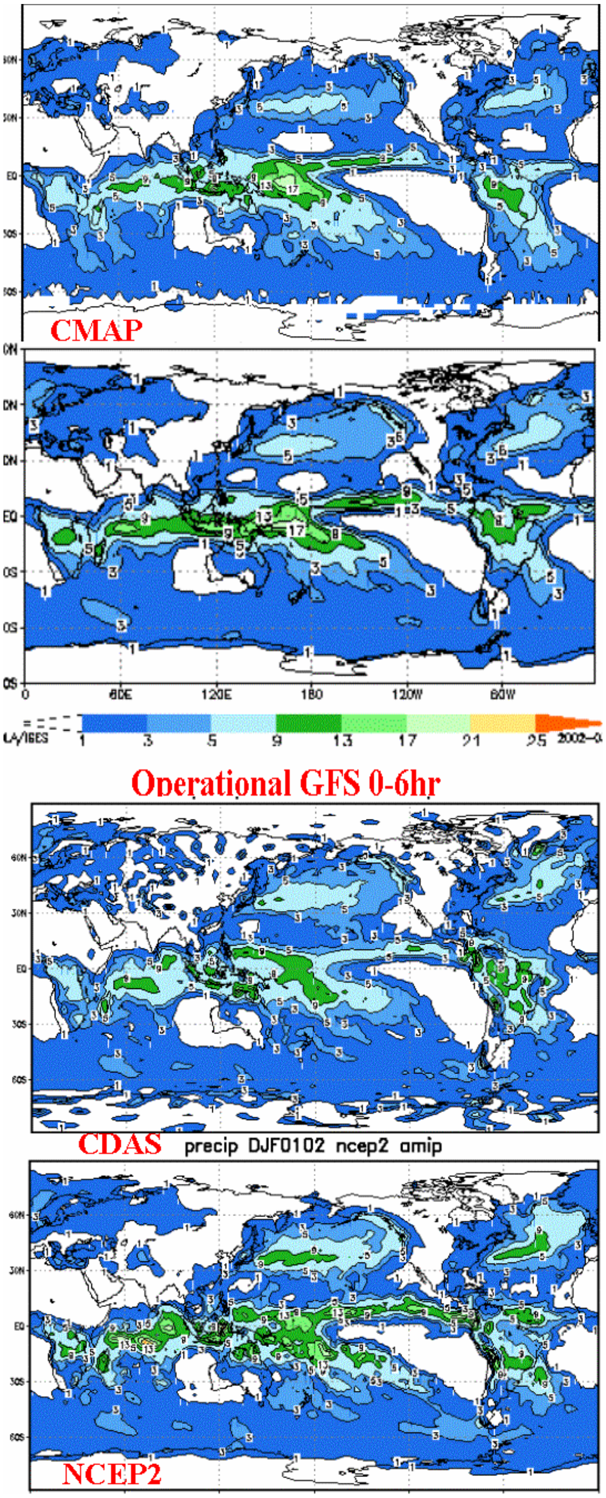

Fig. 7 Preciptation for Dec.2001-Feb. 2002 from (top) CMAP, (second from top) operational GFS 0-6 hour fcsts (GDAS), (second from bottom) NCEP1 (CDAS) and (bottom) NCEP2

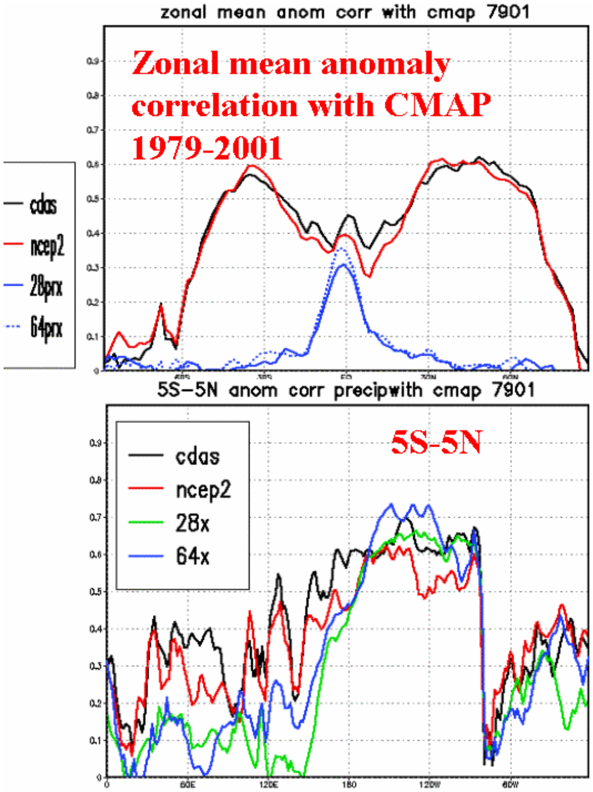

Fig. 8 Correlation of monthly mean anomalies or precipitation with CMAP over 1979-2001 for NCEP1, NCEP2, and two AMIP integrations. (Top) Zonal mean, (bottom) Integrated over 5S-5N.

region along the equator. The reanalyses display significant correlations except just north of the equator in the eastern Pacific and near South America. The AMIP run with 64 levels does not produce better wind stress than the run with 28 levels.

5. PRECIPITATION

Fig. 7 shows four estimates of time-mean precipitation for Dec. 2001-Feb. 2002: CMAP (Xie and Arkin, 1997) (from rain gauges and satellite-based estimates), GDAS, and the two NCEP reanalyses. GDAS has the most similar pattern to CMAP, suggesting that a new reanalysis with the operational analysis might provide a better estimate of the atmospheric hydrological cycle than the NCEP1 and NCEP2 reanalyses, reflecting higher spatial resolution as well as several years of improvements to model physics.

Fig. 8 displays correlations of monthly precipitation anomalies from the two reanalyses and the two AMIP integrations with different vertical resolutions with CMAP. The AMIP forecasts display significant correlations with CMAP only in the eastern equatorial Pacific,

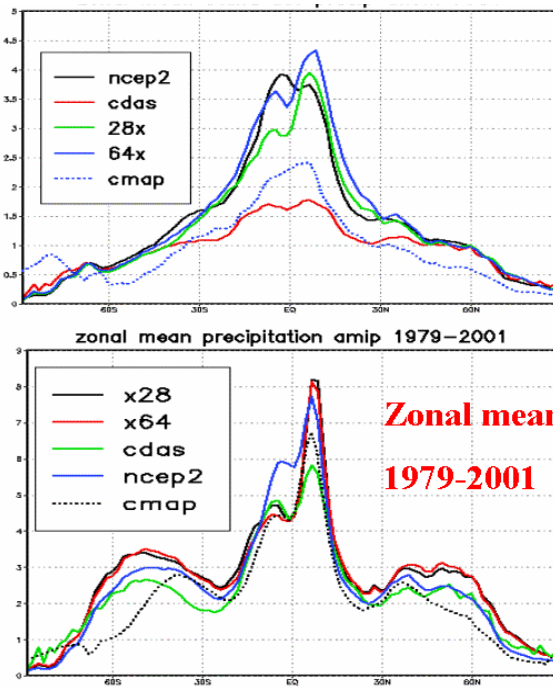

Fig. 9 Zonal mean (top) standard deviation of monthly mean anomalies of precipitation and (bottom) time-mean precipitation for 1979-2001 for CMAP, NCEP1 and 2, and two AMIP integrations.

where they actually have higher correlations with CMAP than the reanalyses do. The AMIP run with 64 levels displays slightly higher correlations with CMAP than the 28 level run. The reanalyses are best correlated with CMAP in mid-latitudes.

As can be seen in Fig. 9 (bottom), the AMIP integrations tend to have more precipitation than CDAS and CMAP, especially in higher latitudes. The NCEP-2 reanalysis has more precipitation at and just south of the equator than the other estimates. It is not certain what the correct magnitude of tropical precipitation is. CMAP precipitation anomalies display considerably less month-to-month variability than other estimates, except for CDAS in the tropics.

A common problem in atmospheric models occurs over Indonesia, where the models tend to have too little precipitation. Fig. 10 shows that this problem is in the GFS, although it is reduced with 64 levels.

Increasing the number of vertical levels from 28 to 64 levels improves the GFS model's ability to simulate precipitation in AMIP integrations.

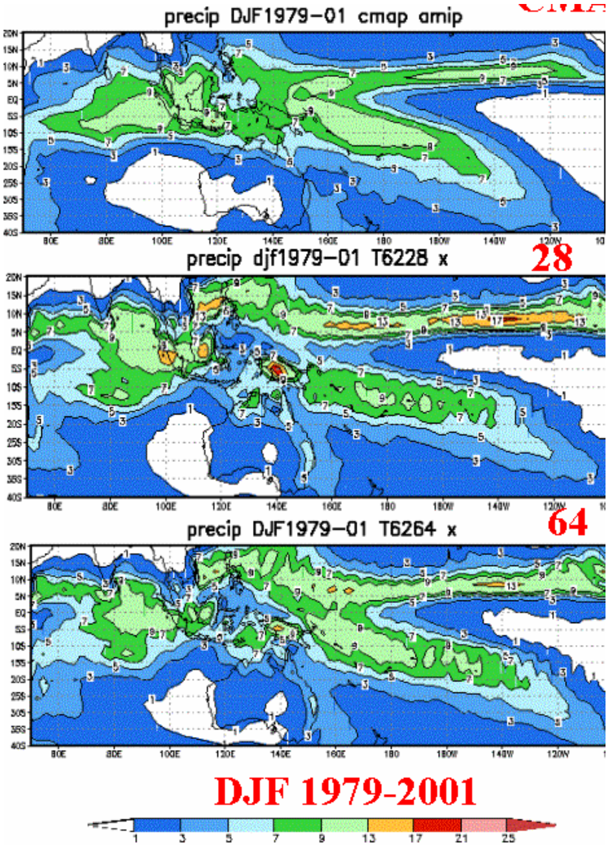

Fig. 10 Precipitation for Dec.-Feb. 1879-2001 from (top) CMAP, (middle) an AMIP run with 28 levels and (bottom) an AMIP run with 64 levels.

6. SUMMARY

This paper has attempted to show the importance of accurate global air-sea fluxes in evaluating and improving numerical weather prediction in every aspect from data assimilation to seasonal forecasts. Accurate air-sea fluxes are required to evaluate the performance of model physics; our current knowledge of fluxes is not adequate.

Information on our current knowledge of air-sea fluxes can be obtained online. The World Climate Research Programme (WCRP)/ Scientific Committee on Oceanic Research Working Group on Air-Sea Fluxes recently published a report on air-sea fluxes (Taylor, ed., 2001). It is available at http://www.soc.soton.ac.uk/JRD/MET/WGASF, as are the proceedings of a recent workshop sponsored by the working group. The WCRP Global Energy and Water Cycle Experiment (GEWEX) sponsors SEAFLUX, the ocean surface turbulent flux project, which can be seen at (http://paos.colorado.edu/~curryja/ocean).

Information on the GFS can be found at http://wwwt.emc.ncep.noaa.gov/

This paper has shown that NWP needs to improve its treatment of cloudiness. Satellite-based estimates of surface radiation still have discrepancies from ground-based measurements (Rossow and Zhang, 2001), but are probably more accurate than NWP estimates. More accurate measurements of atmospheric moisture and the magnitude of the hydrological cycle are needed to validate and improve model physics.

Air-sea fluxes such as surface stress and sensible and latent heat fluxes whose parameterizations depend directly on near-surface fields appear to be handled better by NWP; NWP estimates of these fields may be as accurate as any global estimates. The magnitude of latent heat flux appears to be uncertain and needs to be measured more accurately.

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