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NEW ESTIMATES OF CONTINENTAL DISCHARGE AND OCEANIC FRESHWATER TRANSPORT

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1. INTRODUCTION

Four new estimates of annual and monthly mean values of continental freshwater discharge into the individual and global oceans at 1°resolution have been made (Dai and Trenberth 2002). Simulations using a river transport model (RTM) from the NCAR Community Climate System Model, forced by runoff fields, were used to derive the river mouth outflow from the farthest downstream gauge records. The most accurate estimate is based on results adjusted to match stream-flow data from the world's largest 921 rivers, supplemented with estimates of discharge from unmonitored areas based on the ratios of runoff and drainage areas.

The other estimates utilize RTM simulations forced by different runoff fields (i) based on observed stream-flow and a water balance model (Fekete et al. 2000); (ii) based on estimates of precipitation P minus evaporation E computed as residuals from the atmospheric moisture budget using atmospheric reanalyses from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP) and (iii) the European Centre for Medium Range Weather Forecasts (ECMWF) (Trenberth et al. 2001).

While $P - E$ is a good proxy of runoff over land in a steady state, it may differ because of changes in storage and, in particular, snow accumulation and melt and infiltration of water into the ground. We adopted a simple scheme that melts snow at a rate proportional to how much the climatological mean surface temperature is above 0°C. On a day-to-day basis, runoff depends upon the frequency, sequence and intensity of precipitation and not just amount, as these factors alter the extent to which soils can soak up rain. Changes in soil moisture can be important, and it is only on annual and longer time scales that conditions may approximate a steady state.

Tests have been made using independent estimates of P to infer E and this can be used as a test of the results, since E should be positive. Similarly, there is a requirement that P should exceed E over land except where surface flow allows otherwise, such as in Southern California (owing to irrigation). These results show that the main problems are in regions where the atmospheric data are less reliable, such as Africa, parts of Asia, and South America.

2. DISCHARGE INTO THE OCEAN

When the RTM is forced by the $P - E$ fields derived from the NCEP and ECMWF reanalyses, the simulated station flow rate generally agrees with the observed at most of the major rivers. Substantial differences exist, however, for the world's largest rivers. For example, the simulated flow rate is 3063 and 3833 km^3 yr^{-1} for the Amazon at Obidos in the NCEP and ECMWF cases, and 5083 km^3 yr^{-1} for the Fekete et al. runoff, while the observed rate is 5330 km^3 yr^{-1}. In general, the Fekete et al. runoff resulted in better simulated station flow rates, especially for the world's largest rivers. However, the basin-integrated $P - E$ from the reanalyses generally agree with the Fekete et al. runoff provided that we include the effects of snow accumulation and melt, which are important in middle and high latitudes. The results suggest that the monthly $P - E$ fields are reasonable proxies of monthly runoff as long as the areas are large enough.

The full results are in Dai and Trenberth (2002) and only one figure is shown here. We compare the meridional profile of discharge into the oceans from the best estimate at 1° resolution with the previously widely used values of Baumgartner and Reichel (1975) (BR75). The latter derived global maps of annual runoff and made estimates of annual freshwater discharge largely based on stream-flow data from the early 1960s with rather limited station coverage, and areal integration over 5° latitude zones. The comparison (Fig. 1) shows the 1° values along with the accumulated value integrated from the north southwards from all four estimates.

As expected, the continental discharge is dominated by the peak outflows from the world's largest rivers such as the Amazon (~0.21 Sv at 0.75°S, 1 Sv = 10^6 m^3 s^{-1}), Congo (0.041 Sv at 5.75°S), Orinoco (0.036 Sv at 9.25°N), Changjiang (0.030 Sv at 32.25°N), Brahmaputra/Ganges (0.033 Sv at 24.25°N), Mississippi (0.019 Sv at 30.25°N), and Paraná (0.018 Sv at 34.75°S). The northern mid- to high-latitudes (45–75°N) encompass the largest landmass and many large rivers, such as the Yenisey, Lena, Ob, Amur in Russia, Mackenzie and St. Lawrence in Canada, and Yukon in Alaska. Many of the Russian and Canadian rivers run from south to north and enter the Arctic Ocean. Collectively, these rivers provide a large freshwater discharge into the Arctic, North Atlantic and North Pacific Oceans, thereby affecting the oceanic water budget and circulation, both locally and globally, especially through the thermohaline circulation.

The accumulated discharge for the NCEP $P - E$ case is considerably lower than the others, whereas the BR75 case agrees remarkably well with our estimates based on the

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stream-flow data, Fekete et al. runoff and ECMWF $P-E$. However, the latitudinal distribution from BR75 at 5° resolution is too smooth and quite unrealistic, as even after smoothing the 1°discharge data using 5°lat running-mean, large differences still exist between the BR75 and our estimates, whereas the agreement among our four different estimates is improved. Further, the distribution of BR75 among ocean basins also differs considerably.

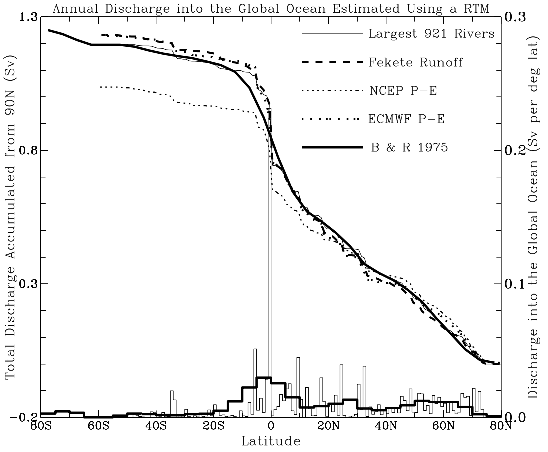

Fig. 1. Estimates of annual mean continental freshwater discharge into the global oceans for each 1°latitude zone (right ordinate and lower stepwise lines) and the cumulated discharge starting from 90°N (upper curves). Each line pattern represents an estimate based either on the largest 921 rivers (thin solid line) or on a runoff field (dashed lines), which was used to force a river transport model to derive the discharge. Also shown is an estimate from Baumgartner and Reichel (1975, thick solid line).

3. OCEAN FRESH WATER TRANSPORTS

The new continental discharge estimates and the oceanic P-E fields derived from the reanalyses, along with other estimates including those based on marine observations (Josey et al., 1998), are then used to derive meridional freshwater transport within each ocean basin and by the global oceans.

Fig. 2 compares various estimates of northward freshwater transport by the global oceans. Using the 921-river based discharge, the various oceanic P-E fields result in large differences in the oceanic freshwater transport. In particular, the Southampton Oceanographic Centre (SOC) P-E product (Josey et al. 1998), which was derived based on marine observations, and the mean of GPCP and CMAP precipitation, minus SOC E case produce essentially southward transport at all latitudes, which is physically unrealistic. The P-E fields derived from the ECMWF and NCEP reanalyses result in similar transports at most latitudes. These transports are generally lower than those of Wijffels et al. (1992) and the inferred oceanic transports by the atmospheric moisture transport in the reanalyses. This is especially true around 5-10°S and south of 35°S. As a result, these estimates have a small (0.15 Sv for the ECMWF case and 0.31 Sv for the NCEP case) southward transport south of 70°S, where oceanic transports should approach zero. These biases, which represent the accumulated errors in deriving the transport starting from the North Pole, result from the imbalances between the 921-river based continental discharge and the reanalysis based oceanic P-E fields.

Fig. 3 compares the oceanic freshwater fluxes at selected latitudes estimated by us (based on the ECMWF P-E and 921-river based discharge) and by Wijffels et al. (1992). In both cases, the transport at the Bering Strait was assigned a value of 0.79 Sv based on observations (see Wijffels et al. 1992), and the integration starts from the Arctic Ocean to the North and South Atlantic Oceans. Current estimates of the Indonesia Throughflow (Fp) are very uncertain, probably in the range of 5-10 Sv (Wijffels 2001). It can be seen that our estimated southward transports in the Atlantic Ocean and northward transports in the South Pacific Ocean are considerably higher than those of Wijffels et al.(1992). Furthermore, our eastward transports by the Antarctic Circumpolar Current (ACC) are higher than those of Wijffels et al. (1992) at most longitudes.

Comparisons with available direct, basin-wide estimates of oceanic transports suggest that our estimate is generally closer than that of Wijffels et al. (1992). This is especially true at southern latitudes of the Atlantic where Holfort and Siedler (2001) obtain -0.55 Sv at 30°S versus -0.58 from our estimate and -0.13 from Wijffels et al. (1992). Because of this and the errors in the widely used BR75 discharge, we believe our estimate is likely to be more reliable than current published estimates.

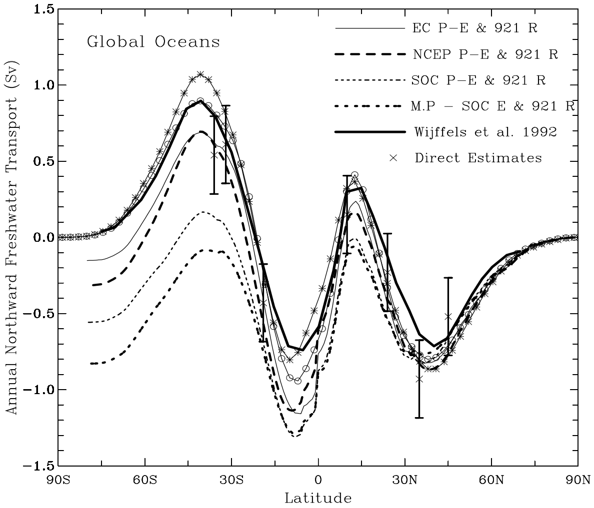

Fig. 2. Latitudinal distribution of annual freshwater transport (Sv, positive northward) by the global oceans estimated using various oceanic P-E (see text for more details) and continental runoff estimated based on streamflow data of world largest 921 rivers. The thin-solid line with circles and stars are inferred oceanic transport of freshwater from atmospheric moisture transport in the ECMWF and NCEP/NCAR reanalyses, respectively. The thick solid line is an estimate by Wijffels et al. (1992) based on BR75. Also shown are some direct estimates (crosses) adopted from Wijffels (2001).

4. CONCLUSIONS

The continental discharges into the oceans within each 1°latitude band implied by the Fekete et al. runoff and reanalysis $P-E$ fields agree reasonably well with the river-based estimates, which we regard as the closest to the truth. This is particularly true for the Fekete et al. runoff and ECMWF $P-E$ cases and for the global oceans and the Atlantic Ocean. In general, the NCEP $P-E$ underestimates continental discharge at many latitudes for all the ocean basins except for the Arctic Ocean. Snow accumulation and melt have large effects on the annual cycle of discharge into all the ocean basins except for the Indian Ocean and the Mediterranean and Black Seas. The new discharge estimates combined with $E-P$ estimates over the ocean provide new global estimates of freshwater transports within the ocean that agree with some direct local basin estimates.

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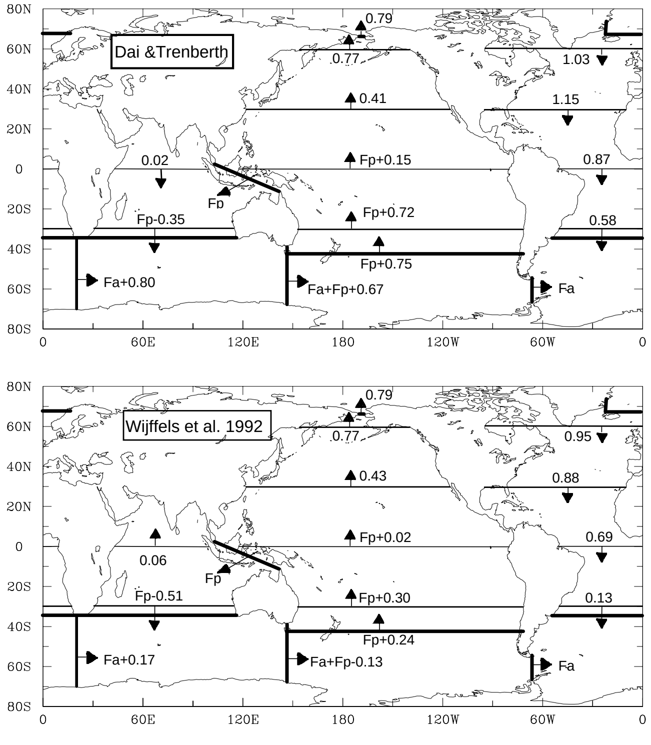

Fig. 3. Top: Oceanic freshwater flux (Sv) at selected latitudes estimated by this study using the 921-river based discharge and the ECMWF reanalysis based oceanic P-E. The solid lines are ocean basin boundaries. Bottom: Same but from Wijffels et al. (1992).