Global River Inflow within the Navy Coastal Ocean Model

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Abstract-**One of the primary concerns driving the development of U.S. Navy global models has been improved performance and nesting support in shelf and nearshore regions with short notice applicability anywhere on the globe. A global implementation of the Navy Coastal Ocean Model (NCOM) is a product of some of the efforts to meet this need. One purpose of Global NCOM is providing a global capability for initializing, nesting, and evaluating fixed and relocatable coastal ocean models. In support of that objective, a database of river flow estimates is needed. Perry et al. (1996) provides a start with estimates of annual mean river discharges for 981 of the largest global rivers. However, many rivers exhibit a strong seasonal variability, which we would like to reflect in our ocean models. Through the use of multiple internet sources and published data sets we have expanded on the Perry (1996) data to provide a global database of monthly mean river discharge and incorporated this data in global and nested NCOM runs. Where sufficient data is unavailable to construct monthly means, a seasonal cycle is imputed from nearby rivers and scaled to the appropriate annual mean. Real time discharge rates are routinely available for almost no rivers outside of the United States, so a monthly mean is likely to be the most appropriate estimate of real time flow for analyses and forecasts in most areas. The monthly river outflow can contribute to more accurate seasonal representation of areas near coastlines. Seasonality particularly affects the polar areas, where river outflow can become quite small during winter months and quite large during the summer melting season. Multiannual daily USGS observations for selected U.S. rivers are used to quantify the improvement in estimation of daily flow by the monthly means versus a multiannual mean. Case studies examine the impact of river input into NCOM.**

I. INTRODUCTION

One of the primary concerns driving the development of U.S. Navy global models has been improved performance and nesting support in shelf and nearshore regions with short notice applicability in regions of possible operations, virtually anywhere on the globe[1]. A global implementation of the Navy Coastal Ocean Model (NCOM) [2] is a product of some of the efforts to meet this need [3]. One purpose of Global NCOM is providing a global capability for initializing, nesting, and evaluating fixed and relocatable coastal ocean models.

A database of river flow estimates is useful to support these objectives. Use of the river database enables the global model to more realistically represent variability and distribution of nearshore salinity in the vicinity of large rivers. It also provides a centralized source for estimates of river discharge of all rivers, even smaller rivers that are insignificant in the resolution of the global model but may be significant in a high-resolution nest. Accurate modeling of salinity is of particular importance in nearshore regimes due to relatively large salinity gradients in the vicinity of riverine or estuarine discharge. These salinity gradients may influence both local dynamics and sensor performance.

Ideally, we would like to incorporate real-time river flow rates into the model. However, real-time river discharge data are difficult to obtain at all, especially in a time frame needed for operational modeling. The most readily available real-time river discharge data are provided by the United States Geological Service (USGS) via their website, http://water.usgs.gov/realtime.html [4]. We have been unable to identify significant open sources of real-time river data outside of the United States.

In the absence of real-time data, climatological databases are a reasonable alternative. Perry et al. [5] provides a comprehensive source, with estimates of annual mean river discharges for 981 of the largest global rivers. However, many rivers exhibit a strong seasonal variability that we would like to reflect in our ocean models. Our hypothesis proposes that a database of monthly mean river discharges will be superior to a database of annual means in its utility for estimating real-time discharge.

Through the use of multiple internet sources and published data sets, we have expanded on the Perry [5] data to provide a global database of monthly mean river discharge. In order to assess the applicability of the monthly means, we use annual means and daily values linearly interpolated from the monthly means to estimate daily streamflow at 28 of the largest rivers in the United States. These estimates are compared with historical USGS daily records over two years to evaluate the conditions under which the use of the monthly means is superior, inconsequential or inferior to use of annual means. We expect that similar conditions in other parts of the world lead to similar representativeness of means. Examples from inclusion of the rivers in global NCOM are shown.

II. DATABASE ASSEMBLY

The NCOM river database contains 986 rivers with a mean annual streamflow value in m^3/s, latitude and longitude of the river mouth, and monthly mean streamflow values in m^3/s. The river mouth location is taken to be approximately the center of the section of coast or delta system through which the discharge enters the sea or a major estuary, such as Chesapeake Bay. For a model on the 5-15 km scales of global NCOM, treating the outflow as a point source should be sufficient for most rivers. As model resolution increases, the river inflow will likely be better represented as a distribution over a range of points across the river mouth or delta system, but these refinements are beyond our present scope.

Originally, the rivers database used the data from Perry et al.[5] as a starting point, referred to hereafter as the Perry data. The Perry data has an impressive content of river data and global representation, containing a location of river outflow as well as an annual mean streamflow value for 981 rivers. For almost all rivers, the Perry location of river outflow was carried on to the NCOM river database. In some instances we edited locations due to errors in the original database, such as changing the Niger River latitude of 4°S to 4°N. Some modifications were made to adjust river locations to be compatible with the global NCOM grid. In the present NCOM configuration, river streamflow enters the system as a freshwater flux distributed vertically in the water cell that is nearest the river mouth location and adjacent to a land boundary, so long as the location is within the limits of the domain and within a specified number of grid points from the database location. In some instances, the database location falls over a land area in which the nearest water point on the global NCOM grid is ambiguous or incorrect, perhaps because the database indicates an entry point into an estuary or through a peninsula that is not included in the global NCOM grid. For example, the Kalkkinen River in Finland was originally registered to a station location nearest, as calculated in global NCOM grid cells, to the Gulf of Bothnia (northern Baltic Sea), an improper entry location. The Kalkkinen was rereferenced to a point to the southwest, which led to a calculated entry point within the Gulf of Finland (western Baltic). Some rivers were added to or removed from the dataset based on suspected redundancy or a desire for more detail. The Kivchak and Kvichak Rivers in Alaska seemed to refer to the same river, so the Kivchak was removed. The NCOM database adds some minor rivers around Narragansett Bay, between Rhode Island and Massachusetts. It also adds the Atchafalaya River in Louisiana, which discharges about 30% of the water from the Mississippi River, and the Ottowa River, which discharges into the St. Lawrence River below the St. Lawrence gauge. The St. Lawrence, Ottowa, Saint Maurice and Aux Outardes rivers share the share the same discharge location coordinates within the NCOM river database, where the St. Lawrence River opens into the Gulf of St. Lawrence. Vertical flux distribution in NCOM is uniform in the insertion point down to a maximum depth of 50 m.

The complexities surrounding specification of the St. Lawrence inflow are indicative of the discrepancies within the river data between gauge or streamflow estimate location and the location of the river mouth. For purposes of estimating discharge within the NCOM database, we select for each river the gauge with sufficient data that is nearest the river mouth. We typically identify this gauge by comparing area of the upriver basin drained, where available, or by selecting the gauge with the largest annual mean streamflow. If significant changes occur to river streamflow downstream from this station, perhaps due to rainfall, irrigation, damming, or lower tributary additions, then the gauged data may be a poor indicator of discharge into the ocean. For use of real-time data, a time lag might be needed to produce proper timing of discharge fluctuations at the river mouth.

The effort to go extend the NCOM dataset by adding monthly variation to the means began with internet searches for additional data sources. We started with monthly streamflow numbers accessible from the USGS (http://waterdata.usgs.gov/nwis/sw)[4]. The USGS data are tabulated in yearly breakdowns with the monthly means, and then a mean of all years, monthly and annual data. We used the monthly means over all years for our inputs. The number of years used to calculate these means varies greatly river by river.

To be consistent with our data sources for the monthly means, the NCOM river database uses annual means from the USGS data, where available, in preference to the Perry means. For rivers where USGS monthly means are available only for an upstream tributary or only upstream of significant tributaries or other streamflow modification, as discussed above, the Perry annual mean is assumed to be more accurate and the monthly values are scaled to yield an annual mean equal to Perry. For some USGS rivers, we replace the Perry coordinates for the river mouth with coordinates derived from the USGS source.

The largest US river in terms of outflow is the Mississippi River. Unfortunately, the Mississippi also has relatively little available USGS river streamflow data at the mouth near the desired NCOM model domain point of entry. After much consultation with Paul La Violette and NOLA Corps of Engineers, we decided to use Mississippi River data from the Tarbert's Landing Station. This is near the Louisiana and Mississippi border (Pointe Coupee Parish, LA) south of Vicksburg (30 57'39", 91 39'52"). We found no recent complete records of streamflow along the river closer to the Gulf of Mexico.

The USGS site provides ample information on rivers within the United Sates, but additional sources are needed for monthly means over the rest of the globe. Our second major source for river data is the Global River Discharge (RIVDIS) database [6] (http://www.RivDis.sr.unh.edu or http://www.daac.ornl.gov/daacpages/rivdis.html). A third dataset, the Regional, Hydrometeorological Data Network (R-Arcticnet) database (http://www.r-arcticnet.sr.unh.edu) [7] provides most of the information ultimately used on rivers flowing into the Arctic, primarily rivers in Russia and Canada. We matched these data sets to the rivers in the

Perry dataset after significant effort sorting out the various spellings, versions or transliterations of river names.

For all river data downloaded from the internet with multiple stations along a given river, we take the value that is largest (near the river outflow) or very near in location to the largest, but instead the most complete. We define completeness as the longest time series of measurements and/or the least amount of missing values and/or the most recent values.

For all of the non-US rivers we scale the annual mean streamflow up to the value from the Perry database, if it is smaller than Perry. Alternate values that are larger than those recorded in the Perry dataset are assumed to be derived from data closer to the river mouth. For river streamflow or discharge datasets that record monthly means that average to an annual transport smaller than that of the Perry data, we assumed that:

- The (larger) Perry mean was determined using data downriver of the station used to derive the monthly means and is thus a better estimate of the mean annual transport at the river mouth
- The variability described by the relative size among the monthly means in the additional data source is a good proxy for the variability at the river mouth
- The monthly means at the river mouth should be scaled as (data set monthly mean)*(Perry annual mean)/(data set annual mean)

In the NCOM river database we developed a set of code names to remember the source of each river's monthly mean value (Table 1). We also expanded our set of code names to include summation of available river data and scaling of river data where applicable.

Where sufficient data is unavailable to construct monthly means, a seasonal cycle is imputed from nearby rivers and scaled to the appropriate annual mean.

TABLE 1
DATA CODE NAMES FOR RIVER SOURCE DATA AND PREPROCESSING

Code Name	Source and Preprocessing
Perry96	Mean from Perry 96 for monthly values (smaller rivers, no data on monthly variability)
USGS	http://waterdata.usgs.gov/nwis/sw
RIVDIS	http://www.RivDis.sr.unh.edu or http://www.daac.ornl.gov/daacpages/rivdis.html
RIVDISP	http://www.RivDis.sr.unh.edu or http://www.daac.ornl.gov/daacpages/rivdis.html & scaled up to Perry
Arctic	http://www.r-arcticnet.sr.unh.edu
ArcticP	http://www.r-arcticnet.sr.unh.edu & scaled up to Perry
DervdRD	Annual mean values from Perry 96, monthly cycle from RIVDIS rivers with nearby location, scaled to Perry again
DervdRDP	Annual mean values from Perry 96, monthly cycle from RIVDIS rivers with nearby location
SummRD	Summation of multiple RIVDIS rivers
SummRDP	Summation of multiple RIVDIS rivers and then scaled to Perry 96
SummArc	Summation of multiple R-Arcticnet rivers and then scaled to Perry 96
RVDArc	Summation of R-Arcticnet and RIVDIS rivers
RVDArcP	Summation of R-Arcticnet and RIVDIS rivers, scaled to Perry 96.
ArcRD	R-Arcticnet rivers scaled to RIVDIS
ArcRDP	R-Arcticnet rivers scaled to RIVDIS and then scaled to Perry 96
DervUSGS	Annual mean values from Perry 96, monthly cycle from USGS rivers with nearby location
DervdArc	Annual mean values from Perry, monthly cycle from R-Arcticnet rivers with nearby location

Several of the rivers contained in RIVDIS did not match a corresponding river as named in the Perry data. In some of these cases, a summation of two or more rivers' monthly values, rivers with different names, were used to fill in a river contained in the Perry data. Table 2 lists the Perry name(s) for main rivers and the names of RivDIS source rivers summed to make corresponding estimates of monthly river discharge.

TABLE 2
SUMMED RIVERS TO ESTIMATE MEANS FOR A MAIN RIVER

River Name (Country)	Source Rivers
Pearl/ZhuJiang/Xi (China)	Bei Jiang, Dong Jiang, and Xi Jiang
Shatt-Al-Arab (Iraq)	Tigris and Euphrates
Kola/Tuloma (Russia)	Kola and Tuloma
Harricana (Canada)	Harricana and Kesagami

Several countries have very little representation in the form of data in the RIVDIS database. Mean monthly values of other nearby rivers either in the same country or in neighboring countries are used to calculate the scales of these rivers' monthly means relative to their respective annual means. A mean scale for each month is calculated as the average of scales from all of the nearby rivers. This monthly relative scale is multiplied by the Perry mean for the desired river to estimate the monthly signal.

Two separate programs make these calculations by selecting the rivers either from the original country alone or from a user-supplied neighboring country. We identified RIVDIS monthly data available for each country and then calculated each river's monthly scales relative to its annual mean. All of these relative scales were averaged within each country. Then for any rivers in the same country with Perry annual mean values only, the Perry annual mean was multiplied by the array of monthly scales to provide estimates of monthly river discharges. If monthly means could be identified within a country, the second program applied a similar monthly scaling using weights from one or more neighboring countries. Table 3 identifies countries for which monthly means were not identified and the neighboring countries used to calculate monthly scales.

Monthly temperatures and salinities are also stored in the database, with salinity set to zero and temperature set to surface values in the MODAS temperature climatology [8].

TABLE 3
COUNTRIES PROVIDING MONTHLY SIGNAL

Country without monthly signal data	Country(ies) with monthly signal data
Myanmar	Thailand and India
Indonesia	New Guinea and Malaysia
Vietnam	Thailand and available Vietnam
Norway	Sweden
Angola	Zaire
Guadeloupe	Dominican Rep
Guam	New Guinea
Kenya	Tanzania
Latvia	Lithuania
Martinique	Dominican Republic
Mauritius	Madagascar
Reunion	Madagascar
Sao Tome	Gabon
Sardinia	Italy
Singapore	Malaysia
Somalia	Tanzania
Tahiti	New Zealand
Taiwan	China
Togo	Ghana
Trinidad&Tobago	Dominican Republic

III. EVALUATION

Comparing derived estimates with corresponding archived USGS daily streamflow data (Table 4) allows us to evaluate NCOM river database monthly means.

TABLE 4
RIVERS WITH USGS DAILY STREAMFLOW FOR EVALUATION OF NCOM RIVER DATABASE

River Name	Latitude	Dates	Mean m^3/s	Sdev. m^3/s
Alsek	59.1°N	19980930-20000930	832.0	870.2
Alamaha	31.3°N	19990930-20010930	215.8	251.0
Apalachicola	29.7°N	19980930-20000930	414.3	246.3
Columbia	46.3°N	19990930-20010930	5265.1	2100.9
Colville	70.3°N	19770609-19770930	1015.4	1295.5
Connecticut	41.3°N	19990930-20010930	509.7	469.9
Copper	60.5°N	19930930-19950930	1824.7	1987.4
Delaware	39.2°N	19990930-20010930	303.1	242.0
Hudson	40.6°N	19990124-20000618	1027.8	590.0
James	37.0°N	19990930-20010930	133.9	144.5
Klamath	41.6°N	19980930-20000930	581.0	571.7
Kobuk	67.0°N	19980930-20000930	367.2	479.4
Kuskokwim	60.0°N	19980930-20000930	1209.5	974.8
Kvichak	58.5°N	19850930-19870930	542.7	180.7
Mississippi	29.0°N	19960930-19980930	20235.1	10104.2
Noatak	67.0°N	19690930-19710930	481.0	679.3
Nushagak	59.0°N	19910930-19930930	632.5	383.6
Pascagoula	30.2°N	19980930-20000930	137.7	252.3
Pearl	30.1°N	19980930-20000930	145.2	219.2
Penobscot	44.5°N	19940930-19960930	424.2	364.9
Potomac	38.1°N	19980930-20000930	207.2	203.8
Sacramento	37.8°N	19980930-20000930	783.6	532.0
Savannah	32.0°N	19990930-20010930	176.5	43.8
Skagit	48.3°N	19980930-20000930	520.0	241.6
Stikine	56.5°N	19980930-20000930	1528.9	1506.2
Susquehanna	39.5°N	19990930-20010930	849.9	791.9
Taku	58.2°N	19980930-20000930	357.7	365.2
Yukon	63.0°N	19940930-19960930	6065.7	4741.6

Four potential estimates of river discharge are evaluated: the true mean over the evaluation period, the Perry annual mean, the NCOM database annual mean (from USGS) and interpolated daily values from the NCOM database monthly mean. Flow rates are interpolated by assigning the monthly means to the fifteenth day of each month and linearly interpolating in time between adjacent months. Mean |% error| is calculated as the mean absolute error divided by true mean, (true mean)*(1/n)*Σ|est-obs|, and multiplied by 100 to give a number in percent. Thus mean error is nonnegative. Results are in table 5.

TABLE 5
MEAN |% ERROR| FOR ESTIMATES OF DAILY STREAMFLOW

River Name	True Mean m3/s	True Mean |% Error|	Perry Mean |% Error|	NCOM Ann Mean |% Error|	NCOM Mon Mean |% Error|
Alsek	832.0	89.4	89.9	90.4	24.8
Alamaha	215.8	71.8	121.3	122.4	100.3
Apalachicola	414.3	48.8	73.3	87.9	88.1
Columbia	5265.1	32.8	51.7	47.2	39.5
Colville	1015.4	73.1	59.3	86.3	67.3
Connecticut	509.7	61.1	58.8	58.4	38.7
Copper	1824.7	92.0	86.7	91.2	24.5
Delaware	303.1	57.0	75.4	60.4	45.3
Hudson	1027.8	48.1	58.5	63.4	56.3
James	133.9	63.3	92.0	93.4	85.8
Klamath	581.0	73.9	71.2	71.0	38.5
Kobuk	367.2	92.4	94.9	98.6	52.0
Kuskokwim	1209.5	71.4	74.1	71.3	21.6
Kvichak	542.7	28.5	29.5	29.0	15.2
Mississippi	20235.1	41.2	43.0	47.0	34.8
Noatak	481.0	80.5	73.6	73.6	95.7
Nushagak	632.5	51.9	63.7	52.8	26.8
Pascagoula	137.7	91.2	183.6	166.3	152.1
Pearl	145.2	87.2	142.5	155.9	129.0
Penobscot	424.2	62.0	59.3	60.8	49.3
Potomac	207.2	67.2	93.1	98.2	85.8
Sacramento	783.6	51.1	46.9	46.1	31.4
Savannah	176.5	16.1	94.1	91.6	91.2
Skagit	520.0	34.4	33.9	34.0	25.0
Stikine	1528.9	84.9	81.5	85.8	26.7
Susquehanna	849.9	69.3	76.4	84.5	59.1
Taku	357.7	84.1	110.1	86.2	34.0
Yukon	6065.7	72.2	72.5	72.5	22.3
average		64.2	79.0	79.5	55.8

We find that in terms of the mean |% Error|, use of the NCOM monthly means provides, on average, an estimate of daily river discharge that is superior to any of the annual means, including the true mean over the two year period. The difference between using the NCOM or Perry annual means is negligible. By this standard, using the true mean is usually better than using either of the other annual means, but in ten of the 28 rivers, at least one of the other annual means measures better, though perhaps not significantly better, than the true mean. Of course, for real-time application, the true mean is not available. The best we can hope for in terms of an annual mean is a multi-year annual mean such as those in Perry or USGS databases, the latter for the U.S. only. The NCOM river database follows the USGS annual means inside the U.S. and the Perry annual means outside the U.S., unless otherwise noted by the data codes.

Using the NCOM database monthly means is superior to using the NCOM annual mean in all cases, and superior to the Perry annual means in all but three cases: Apalachicola, Colville and Noatak. The Colville and Noatak are in the extreme north, where variations in the timing of the spring thaw may throw off the timing of estimates based on a monthly mean seasonal cycle. Based on these statistics, the NCOM monthly means provide the best overall estimates of daily river discharge.

The data indicate general regions where the representation of daily river discharge by monthly means show trends of higher or lower relative accuracy. Of the 11 rivers with NCOM monthly mean |% error| less than 35%, all but the Mississippi and the Sacramento are north of 48°N. Only 3 rivers north of 47°N do not fall in this low |% error| category: the Colville, Kobuk and Noatak. These are the three northernmost rivers in the evaluation, all north of 65°N. With the exception of the Mississippi and Sacramento Rivers, all of the rivers that evaluate better than average when using the |% error| statistic with the monthly means lie within the 39°N - 67°N band, and only the extreme north Noatak falls in this band but has |% error| higher than 4 percentage points above the mean; the Hudson and Susquehanna fall within four percentage points of the average.

The two rivers most difficult to estimate on a percentage error basis are the Pearl and Pascagoula; these also have the highest ratio of standard deviation to mean over the test periods. These perhaps reflect the impact of random events such as tropical storm activity, which may be difficult to average out in a two-year window. Of the ten rivers with standard deviations in streamflow higher than the mean, three fall within the low mean % error latitude band: the Alsek, Copper and Taku. These are modeled well by the monthly means, which show at least 50% improvement over using annual means. The three highest latitude rivers all have standard deviation larger than their mean, probably indicating the extreme variations between Arctic summer and winter.

A similar evaluation of the daily flow estimates is done using a root mean squared error (RMSE) statistic (Table 6). For easier comparison among rivers of different transport, the RMSE are normalized by the corresponding true means and multiplied by 100, producing % normalized root mean squared error (NRMSE). This statistic reveals no overall preference between using the Perry or NCOM (USGS) annual means to estimate daily river discharge, although individual rivers agree more closely with one or the other. If the true mean were known, it would produce average NRMSE approximately 10% lower than either of the other annual means. In a comparison of annual means, a true mean has the lowest RMSE in estimates of daily streamflow for any of the individual rivers.

TABLE 6
ROOT MEAN SQUARED ERROR FOR ESTIMATES OF DAILY DISCHARGE. NRMSE ARE % NORMALIZED BY TRUE MEAN

River Name	True Mean NRMS Err	Perry Mean NRMS Err	NCOM Ann Mean NRMS Err	NCOM Mon Mean NRMS Err	NCOM Mon Mean RMS Error m^3/s
Alsek	104.5	104.5	104.6	38.2	317.5
Alamaha	116.2	140.5	141.4	123.0	265.4
Apalachicola	59.4	83.2	98.5	102.3	424.0
Columbia	39.9	57.7	52.5	49.5	2608.0
Colville	127.0	133.4	153.6	152.2	1544.9
Connecticut	92.1	92.3	92.3	64.5	328.6
Copper	108.8	112.0	108.9	48.3	881.7
Delaware	79.8	88.9	80.3	64.0	194.0
Hudson	56.9	79.4	84.1	75.1	772.2
James	107.9	118.5	119.4	118.2	158.3
Klamath	98.3	99.1	99.3	71.9	417.7
Kobuk	130.5	130.7	131.6	91.4	335.6
Kuskokwim	80.5	84.1	80.6	34.9	422.4
Kvichak	33.3	34.4	33.9	17.6	95.6
Mississippi	49.9	53.6	60.4	46.6	9424.9
Noatak	141.0	143.6	143.5	137.5	661.5
Nushagak	60.6	72.7	60.9	37.0	234.0
Pascagoula	183.1	222.5	211.4	204.2	281.2
Pearl	150.9	170.4	179.3	168.2	244.2
Penobscot	86.0	87.1	86.1	75.4	319.9
Potomac	98.3	111.9	115.9	103.7	214.9
Sacramento	67.8	68.7	69.1	49.4	386.7
Savannah	24.8	96.9	94.4	102.0	180.1
Skagit	46.4	47.2	47.3	39.1	203.4
Stikine	98.5	100.0	98.5	40.2	614.0
Susquehanna	93.1	94.9	99.8	75.3	639.7
Taku	102.0	122.5	102.4	53.2	190.2
Yukon	78.1	78.3	78.3	34.8	2113.3
average	89.8	101.0	101.0	79.2	874.1

As in the case of mean error, estimating daily river discharge by linear interpolation of the NCOM database monthly means is, on average, clearly preferable to use of any of the annual means. For individual rivers, one or more of the Perry and NCOM annual means is preferable to the NCOM monthly means only for the Apalachicola and Savannah Rivers in the southeastern U.S. and the Colville River in the extreme north.

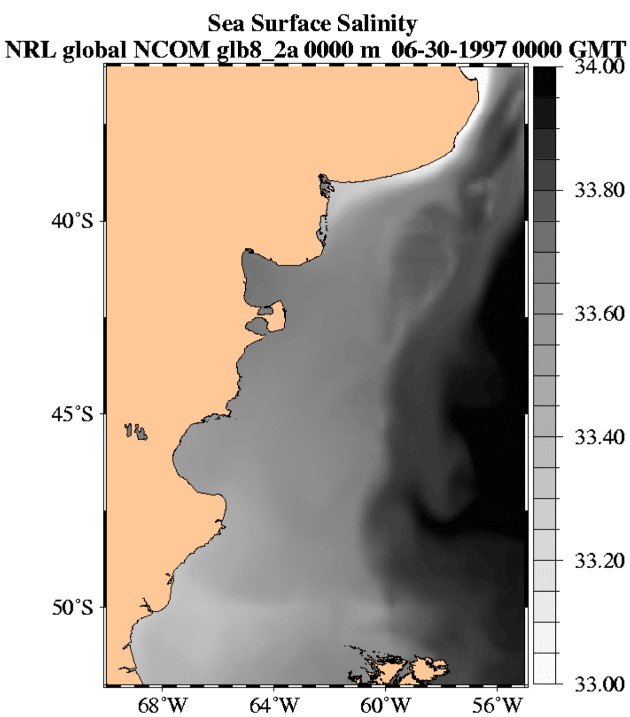
Daily streamflow estimates using the monthly means evaluate worse than the 79.2 average normalized RMS error for 10 of the 28 rivers: the three northernmost rivers starting at 67°N and all the rivers south of 39°N with the exception of the Mississippi and the Sacramento. All the rivers in the 39°N-66°N band have below average normalized RMS errors. The Sacramento and Mississippi may follow the trends of 39°N-66°N bands because most of their respective watersheds lie within this band. These two, along with all in the 45°N-65°N range, are the only cases where NRMS monthly mean error is less than 55%.

IV. DISCUSSION

Examination of the inclusion of rivers in global NCOM is in its beginning stages. For more information on global NCOM, see Rowley et al., this issue. Comparisons between two hindcast runs are included here. Both cases are forced with ECMWF wind stresses and heat fluxes, internally calculate latent and sensible heat flux, and assimilate historical MODAS [8] dynamic climatology surface and 3D temperature and salinity [3]. The difference between 2a and 2f is 2f includes the river database while 2a does not. Both will have some salinity information from relaxation to the MODAS surface salinity.

Figs. 1a and 1b show the impact along the coast of Argentina. Both cases show a freshwater plume along the coast originating from the Plata at roughly 35°S, indicating that the MODAS climatology captures a nearshore salinity signal here. Without explicit rivers, the simulation produces somewhat of a plume northward from 41°S, probably representative of outflow from the Negro or Colorado as reflected in the climatology. However, after rivers are explicitly input (Fig. 1b), the simulation shows enhanced plumes from the Negro and Colorado along with a northward moving freshwater plume from the Santa Cruz, near 50°S. All plumes exhibit a trend to remain trapped near the coast and extend toward the north, as expected.

FIGURE 1A
NCOM WITHOUT RIVERS ALONG ARGENTINA



The impact of including rivers in the South China Sea is shown in Figs. 2a and 2b. Without rivers, a climatological freshening is evident in the Gulf of Thailand and nearshore in the Gulf of Tonkin. Addition of rivers produces no clear changes to the solution in the Gulf of Thailand (Fig 2b).

FIGURE 1B
NCOM WITH RIVERS ALONG ARGENTINA

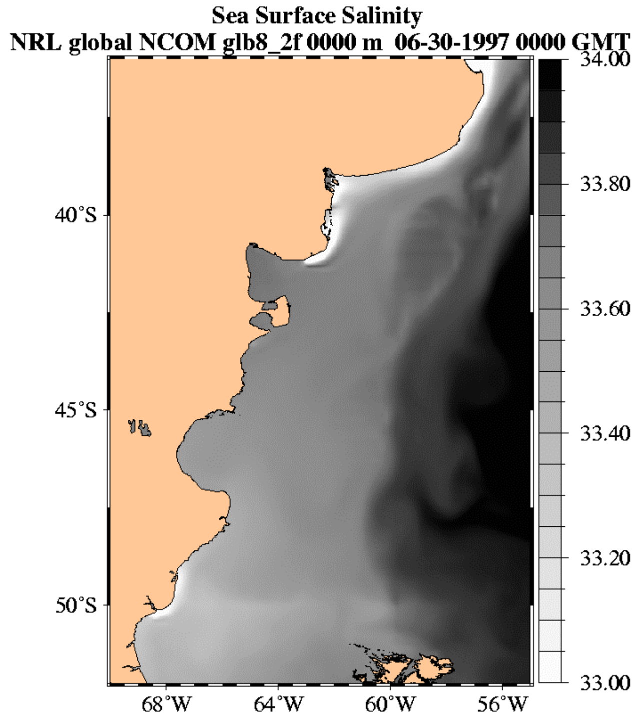
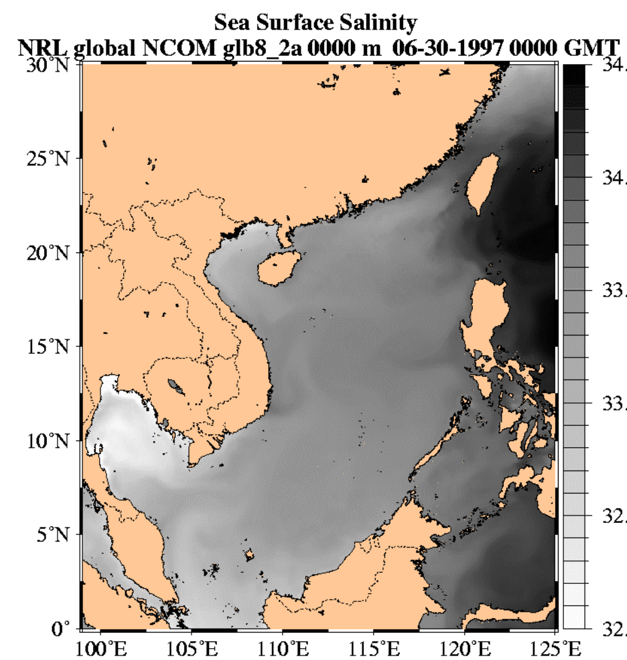
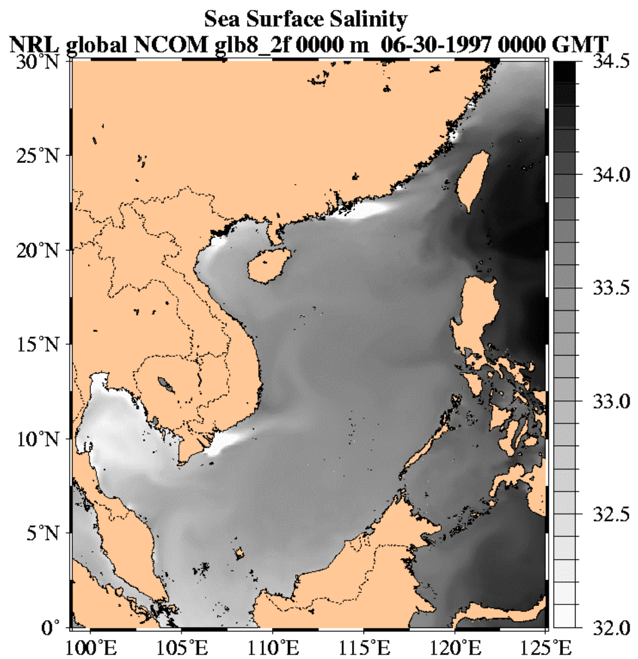


FIGURE 2A
NCOM WITHOUT RIVERS IN SOUTH CHINA SEA



The Hungho River plume is distinguishable as the 20°N source of freshwater into the Gulf of Tonkin. At the southern tip of Vietnam, a plume extends east and north from the Mekong River, wrapping around a low-salinity feature that is detectable in both runs. A large freshwater plume also extends westward from the Xi (Pearl) River in China, near 113°E, and some minor rivers can be identified along the Chinese coast.

FIGURE 2B
NCOM WITH RIVERS IN SOUTH CHINA SEA



Perhaps the most obvious modifications resulting from inclusion of riverine inflow are seen along the west coast of Africa. Fig. 3a shows a simulation without rivers, indicating relatively salty water just south of the equator bordered by zones of fresher water north and south. Waters adjacent to the coast are relatively fresh only in the northern zone. Addition of rivers (Fig. 3b) reveals the river sources of the northern freshening: from roughly 1°S to 4°N, the Ogooue (Gabon), the Ntem, Nyong, Sanaga and Wouri (Cameroon) and the Cross (Nigeria). Major low-salinity plumes not found in the earlier simulation discharge from the Congo (6°S) and Niger (6°E) rivers.

FIGURE 3A
NCOM WITHOUT RIVERS, WEST OF AFRICA

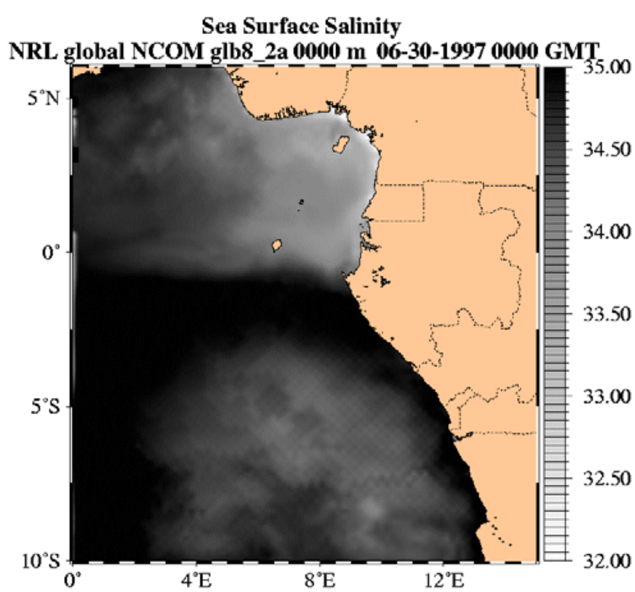
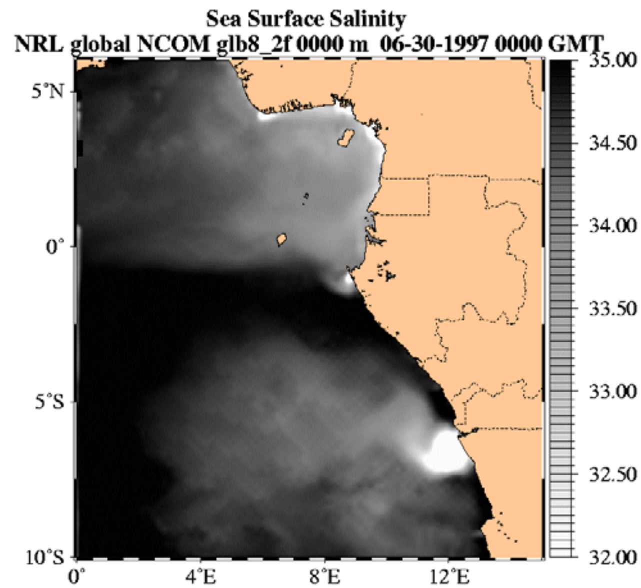


FIGURE 3B
NCOM WITH RIVERS, WEST OF AFRICA



What are the implications of the evaluation regarding use of the river database outside of the United States? Data quality and representativeness for both the annual and monthly means are likely to be worse outside the U.S., particularly in less developed countries, which likely devote few resources to monitoring and disseminating such information. As Perry [5] noted, significant rivers are doubtlessly missing from this database. For example, no rivers are present for some major islands of Indonesia, a tropical nation with relatively large rainfall [5]. Based on these results and assuming zonal similarity and meridional symmetry, we would expect the monthly river climatologies to be most beneficial in the latitude bands 39°N-66°N and 39°S-66°S. The very high latitude and subtropical zones may still benefit from the monthly variations, but random events, such as tropical storms or variable spring thaws, may lead to significant aseasonal variations in river discharge.

Future work includes expansion and refinement of the river database and more detailed examination of the impact of the rivers on global and regional ocean models.

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