

United States Streamflow Probabilities and Uncertainties based on Anticipated El Niño, Water Year 2003

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BACKGROUND

During the course of spring and summer 2002, tropical sea-surface temperatures in the eastern Pacific Ocean have warmed and the wind and pressure fields have shifted, so that by August, there was considerable confidence that water year (October–September) 2003 will be characterized by a weak to mild El Niño climate (<http://iri.columbia.edu/climate/ENSO/currentinfo/archive/200208/QuickLook.html>). At the same time, the Pacific Decadal Oscillation pattern of sea-surface temperatures in the North Pacific (Mantua et al., 1997) has shifted towards a more neutral state than in the past several years and will not be considered in detail here. Previous studies of the connections between El Niños and streamflow in the United States by the authors (e.g., Redmond and Koch, 1991; Cayan and Webb, 1992; Cayan et al., 1999; Dettinger et al., 2001) indicate that El Niño conditions influence historical streamflow distributions to varying extents. These conclusions, along with those of other researchers, suggest that foreknowledge of El Niño conditions can inform seasonal outlooks for streamflows throughout the Americas and elsewhere. For example, Dettinger et al. (2001), as distilled here into Fig. 1, showed that historical annual streamflow totals have correlated negatively with the Southern Oscillation Index (SOI, which is negatively associated with El Niños) in the U.S. Southwest as well as in the subtropics of South America, and correlate positively in the U.S. Northwest, in much of tropical South America, and, perhaps, in southernmost South America. These interhemispheric bands of El Niño influence are a matter of considerable concern for water- and land-managers throughout the Americas, and expand upon results from previous studies in the western United States (e.g., Redmond and Koch, 1991; Cayan and Webb, 1992), including a recent analysis by Pizarro and Lall (2002), where water availability and hydrologic extremes are particularly pressing issues.

MEAN AND MOST LIKELY STREAMFLOW CONDITIONS

The various studies cited thus far all address El Niño connections to streamflow using composite averaging of El Niño influences on streamflow, or upon correlations of streamflow with El Niño indices. Consequently, they have focused on mean tendencies, the long-term average influences of El Niño on streamflow. A change in mean streamflows associated with El Niño is useful to know, but care may be required in interpreting the change if the variability of streamflows also changes. Thus, it is informative to also consider changes in the shape of the probability distribution of streamflow amounts associated with El Niños. For example, anomalous flow statistics at streamflow gaging stations from the U.S. Geological Survey's Hydroclimatic Data Network (Slack and Landwehr, 1992) are shown in Fig. 2. The panels of this figure show stations at which the frequencies of occurrence, during El Niño years, of annual-maximum daily flows, winter mean flows, and spring mean flows in the historical upper, middle, or lower terciles have differed significantly from 1/3 at 95% confidence. Rivers in the Northwest have historically yielded fewer upper tercile (large) floods and more lower tercile (small) floods during El Niño years than would be expected at random. Some rivers in the extreme Southwest, especially in Southern California, have yielded fewer lower tercile floods. Middle-tercile floods and winter flows are notably less common in the central coastal rivers of California, bearing out the occasional perception that "El Niños bring really dry or really wet winters but few normal ones there." Middle tercile floods are also less common in rivers of North Carolina and in Idaho, and are more common in rivers along the Gulf Coast.

Upper tercile December-March flows are more common in coastal California rivers, in the upper Midwest, and in Florida during El Niño winters, while Northwestern rivers have yielded more lower tercile flows and less upper tercile flows. Lower tercile December-March flows are also more common around the Ohio River region during El Niños. April-July flows in the upper tercile are more common during El Niños in the northern Appalachian Mountains and in some rivers of the southernmost Southwest, and lower tercile flows are more common in Southern California. April-July flows in the lower tercile are more common in the rivers of the extreme Northwest. Generally, frequencies of occurrence of middle-tercile springtime flows change little in the western states with El Niños.

Overall, though, the anomalous probabilities mapped in Fig. 2 are not as large or consistent within the various regions as are changes during La Niña years (Dettinger et al., 1999). This weakness of signal arises even though over two-thirds of the rivers analyzed have long enough records to include 15 or more El Niños. Perhaps most notably, although the mean tendency among El Niño flows in the interior Southwest is toward wetter conditions (e.g., Koch and Redmond, 1991; Cayan and Webb, 1992), the changes in streamflow terciles with El Niño do not appear to be significantly different from random over as large an area. Close to the Mexican border in California and, less so, in Arizona, the snowmelt-driven runoff of April-July have been significantly higher in many rivers. This area is in extreme drought, and both the actual and predicted flows in the upcoming year are of considerable interest.

VARIANCE OF EL NIÑO STREAMFLOWS

Some of this apparent unreliability of the El Niño signal in the interior Southwest can be understood from the example of a river in which floods have a strong response, in the mean, to El Niño episodes. The distribution of annual maximum-daily floods in the Salt River of Arizona as a function of the SOI is shown in Fig. 3. The mean annual flood during El Niño years is 585 cms, in La Niña years is 226 cms, and in years that are neither it is 630 cms. A regression line would project a notable decrease in the (mean) flood size as a function of SOI, which might be interpreted as indication that “floods are bigger during El Niños (negative SOI).” However, at least as notable as the increase in the mean flood size is the dramatic increase in the historical range of flood sizes in El Niño years, compared to the narrow range of sizes during La Niña years. Clearly, historically, El Niños yielded a much greater scatter of flood sizes; some El Niños are quite wet, others are remarkably dry.

Thus in addition to considering the average effects of El Niños on flows (as in Figs. 1 and 2) and floods or mean flows, the influence of El Niños on the uncertainty of flows should be examined. How widespread is the tendency towards enhanced variability during El Niño, illustrated for a particular river in Fig. 3? First, note in Fig. 3 that this spreading of outcomes in El Niño years is not a response to decadal fluctuations of the climate or of teleconnections, as measured by the PDO index (Mantua et al., 1997, Gershunov et al., 1998; McCabe and Dettinger, 1999). More likely, the answer is associated with El Niño/La Niña differences in the distributions of the atmospheric circulations that bring precipitation to North America. Yarnal and Diaz (1986) found greater ranges of precipitation variability associated with El Niños than with La Niñas along much of the West Coast, and attributed this to the greater sensitivity of West Coast precipitation to the geographic, east-west placement of the meridional wave form of the Pacific-North America atmospheric circulation pattern, which is common during El Niños, than to the details of a more zonal circulation, which is common during La Niñas. If, in fact, El Niños primarily bring more variable weather to an otherwise dry setting like the Salt River basin, then one consequence—given the fact that river flows can not be negative—is a larger mean; that is, in order to spread the flow distribution as much as is in Fig. 3, the wider distribution inevitably ends up having a larger mean unless the changes in the distribution are tuned unrealistically carefully.

In order to simply and widely evaluate the historical extent of El Niño influences on the ranges of streamflow, a simple measure used herein are comparisons of the standard deviation of seasonal flows and floods during El Niño years with those during La Niña years (like those in the past several years), which are mapped in the upper panels of Fig. 4. In many rivers along the southernmost conterminous U.S., and in many rivers of the eastern half of the country, annual floods have been twice or more variable during El Niño years than in La Niña years (Fig. 4a). For example, floods in the Salt River (Fig. 3) are four times more variable during El Niño years. Rivers along the West Coast, along with a prominent cluster of rivers in the middle Atlantic seaboard, are notable for smaller ranges of flood variability during El Niño years. Ratios of the standard deviations of seasonal flow totals during El Niño years to those from La Niña years are shown in Figs. 4b and 4c. In these maps, the tendency for Southwestern-streamflow uncertainties to be enhanced during El Niños, relative to La Niñas, is even clearer. By April-July, the standard deviations of flows in many river in southern California and Arizona are many times larger during El Niños than during La Niñas. Rivers clustered around Iowa also display notable (and geographically consistent) increases in variance during El Niños. Between winter and spring, the influence of El Niños on streamflow variance change signs in several regions (e.g., around Virginia, in Texas/Louisiana, and in northern Minnesota). Elsewhere, such as in the Northwest, the influence of El Niño on the variance of seasonal-scale flows is not statistically significant.

Some of these increases in the variability of streamflow are the result of a general scaling of the flows, especially in the Southwest where flows typically exhibit nearly exponential distributions. In these

rivers, mean and variances of flow scale up or down together. In other areas, where flows are generally smaller during El Niños, such scaling will suggest that variances also decline. To determine where the variances of flow decline in relative terms, ratios of the standard deviations of the logarithms of flows and flood sizes are mapped in the lower panels of Fig. 4. The patterns of these relative changes in standard deviation of logarithms (e.g., standard deviations as percentages of the El Niño means) are different from those of the standard deviations of absolute flow magnitudes. Notably, the relative variance of floods and spring flows in the Northwest—where El Niño mean flows are smaller—are larger during El Niños than during La Niñas. Relative variations of flows in the Appalachians are also larger during El Niños. To some extent, the increases in relative variations (bottom panels, Fig. 4) fill in the regional gaps left among the increases in absolute variations (top panels, Fig. 4). Thus, in either absolute or relative terms (but rarely both), El Niños bring greater streamflow variability to most regions of the U.S.

Do increases in the range of streamflows (e.g., in the Southwest) during El Niños develop because there are simply fewer “normal” El Niño years? That is, do El Niños bring very wet or very dry years but fewer near-normal years? An examination of the frequencies of occurrence of middle-tercile flows during El Niño years, in the middle panels of Fig. 2, indicates that this is not generally the case in many rivers across the U.S., with notable local exceptions like the winter floods of the Central California coastal rivers. Elsewhere, the frequency of occurrence of middle-tercile flows during El Niño years is even greater than would be expected during a year selected at random.

In summary, historical El Niños may have been most notable for the variability that they impart to U.S. streamflows in many regions. The range of streamflow conditions during past El Niños have been anomalously large in absolute terms in the Southwest, upper Midwest, and parts of the Southeast. The ranges have been large in relative terms in Northwest and Appalachian rivers. In the midst of these uncertainties, there are nonetheless important regional signals. Historically, El Niño years have brought, on average, increases in mean flows (and flood sizes) in the Southwestern U.S. and east-central states, and decreases in the Northwest and parts of the Southeast (excluding Florida). Thus, drought conditions that currently exist in the Southwest could see some relief but there is reason for concern in the interior Northwest and in the mid-Atlantic states.

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CORRELATIONS of - SOUTHERN OSCILLATION INDEX, 1915-1988,
with OCT-SEPTEMBER STREAMFLOW

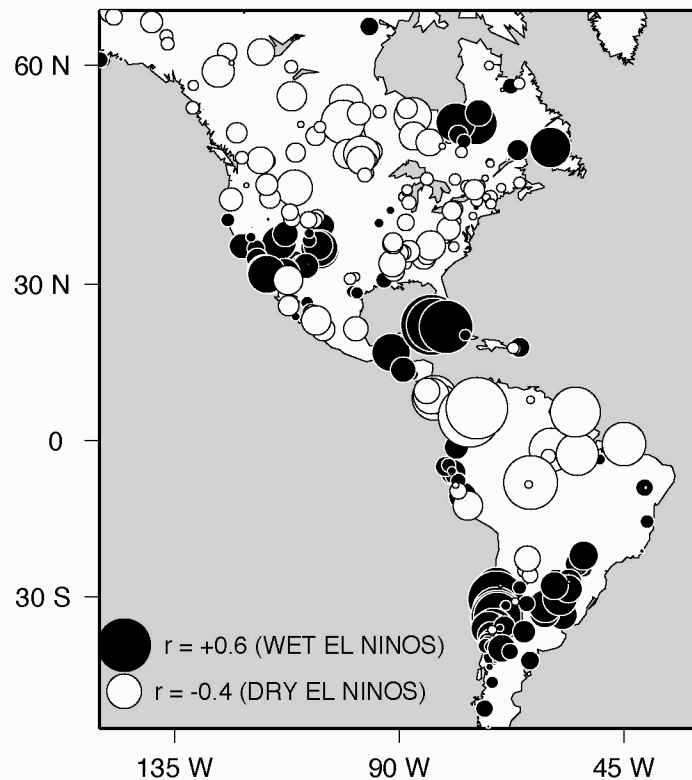


Fig. 1 – Correlations between October-September streamflow totals and the negative of the concurrent Southern Oscillation Index, 1915-1988; radius of circle indicates strength of correlation, color indicates wet or dry relation to El Niño conditions (see also Dettinger et al., 2001).

Anomalous Probabilities of US Streamflows during an El Niño Year

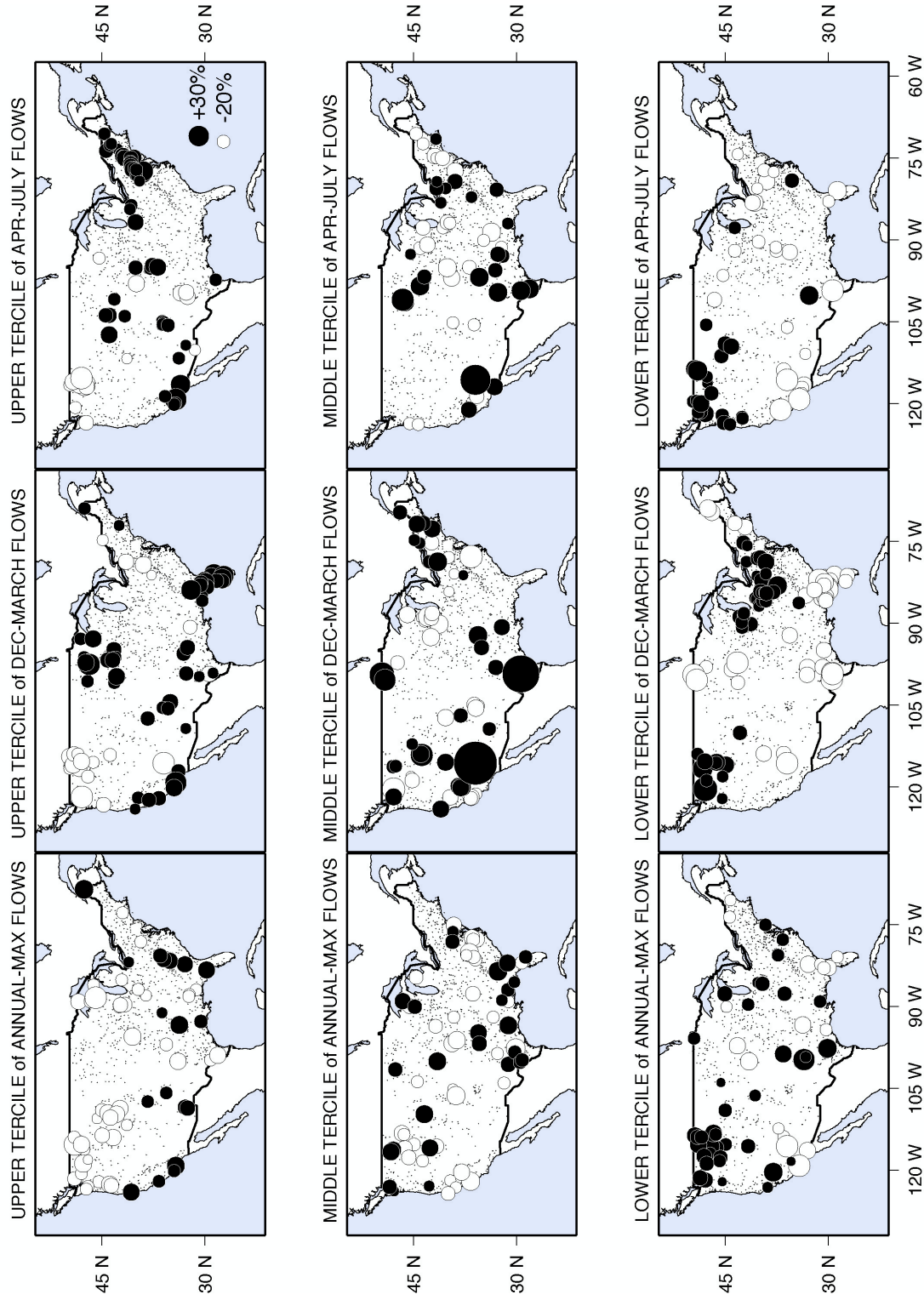


Fig. 2 – Anomalous probabilities of occurrence of floods and seasonal flows in upper, middle, and lower terciles of historical flows during El Niños (based on water-year Southern Oscillation Index, with SOI < -0.5). Black circles indicate greater than random historical frequencies of occurrence, white circles indicate lower than random frequencies. Only frequencies significantly different from 0.33 at 95% level are indicated.

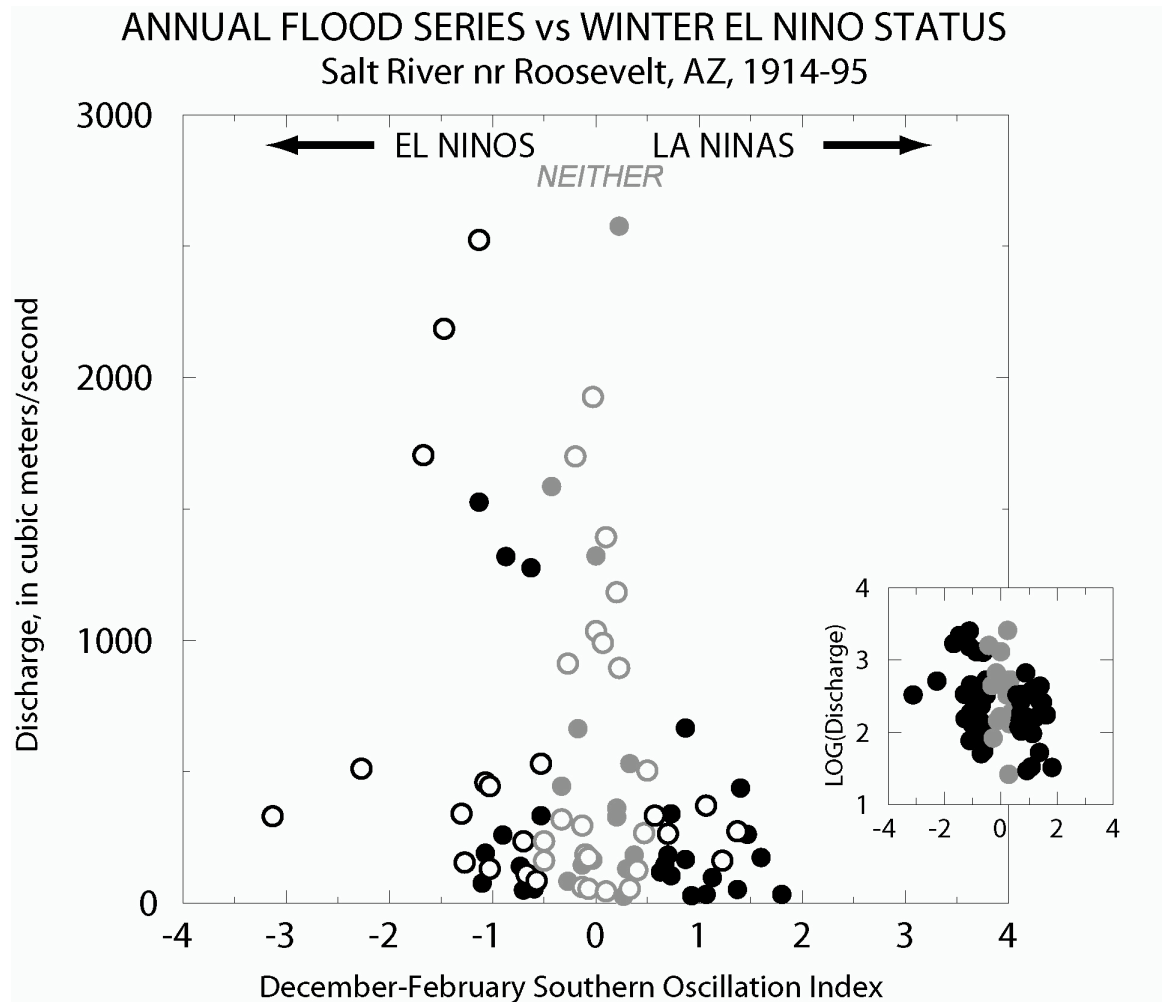


Fig. 3 – Historical relations between the largest daily flow each water year (October-September) and the concurrent winter (December-February) Southern Oscillation Index for the Salt River in Arizona; open circles indicate years with positive Pacific Decadal Oscillation (PDO) indices, filled circles are negative PDO years. Years that are neither El Niños nor La Niñas are shaded grey. Inset shows relation between logarithm of flood magnitudes and SOI.

RATIOS of STD DEVS during El Nino years to STD DEVS during La Nina years
 ANNUAL-MAXIMUM FLOWS DEC-MARCH FLOWS APRIL-JULY FLOWS

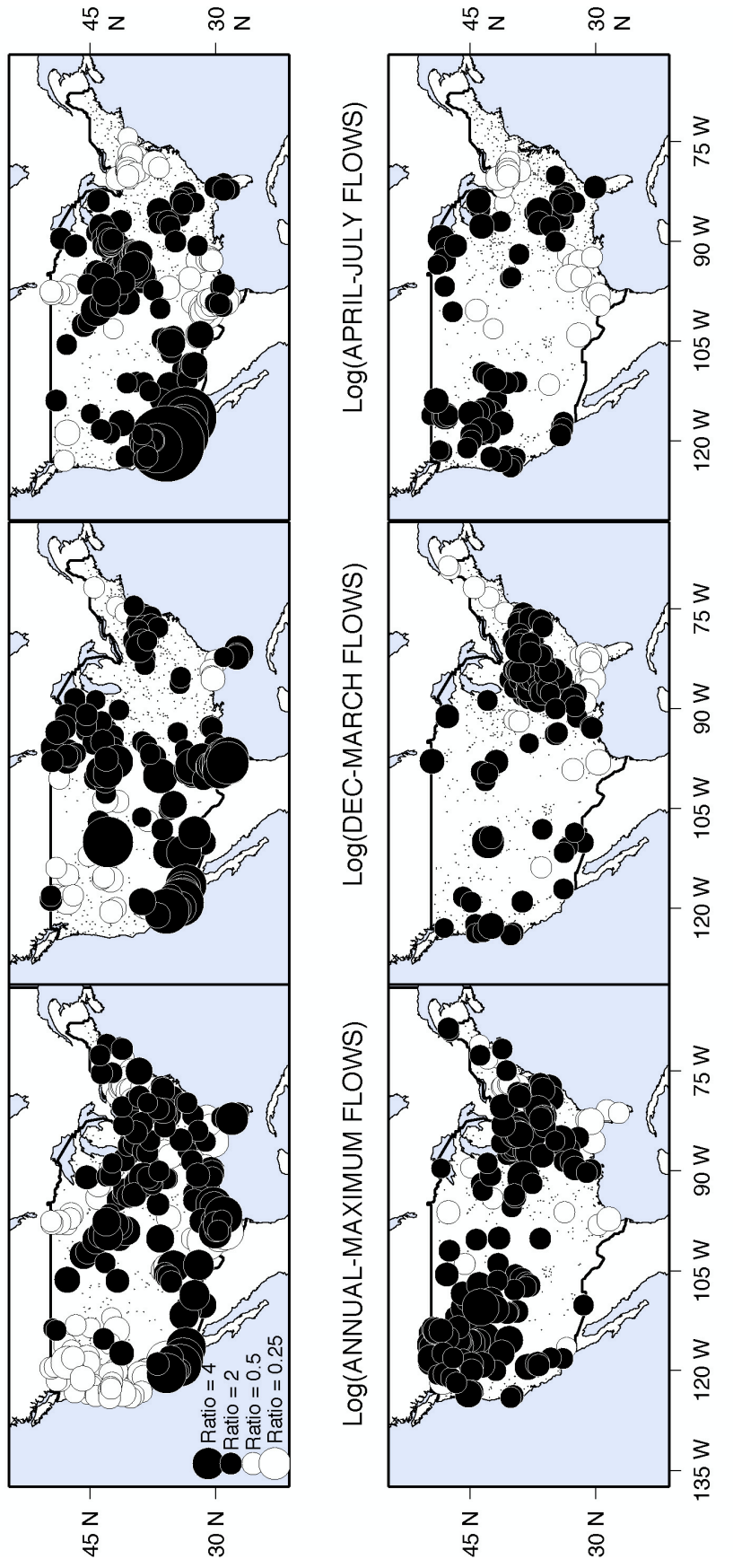


Fig 4.—Ratios of standard deviations of flood sizes and seasonal flows (top panels) and the logarithms of flood sizes and seasonal flows (bottom panels) during El Niño water years to those during La Niña water years (identified as in Fig. 2); size of circles indicates size of ratio, color indicates whether El Niños (black) or La Niñas (white) had more variable outcomes. Only stations where the ratio is significantly different from unity (F test) are indicated with circles.