Detecting Historical Ocean Climate Variability

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While ocean observations of temperature and salinity extend back to the 19th century, their observation count, as well as geographical and vertical distributions all changed dramatically between successive decades. Similarly, atmospheric observations were unevenly distributed in space and time. This study is designed to address the question of the extent to which massive climate anomalies such as the 1997/8 El Niño, the 1997 shift of the Indian Ocean dipole, and the 1998/2000 La Niña would have been represented had these events occurred during other decades in the past century.

Our approach is to begin with a numerical simulation of the ocean that spans the four year period 1995-1998, which we refer to as the Nature Run. We then carry out a set of observing system simulation experiments attempting to reconstruct the results of the Nature Run by applying data assimilation, but beginning with erroneous initial conditions and using inaccurate forcing. In our first set of experiments we sample the Nature Run at the locations where historically observations were collected. We assimilate these synthetic observations into a model driven by climatological monthly surface forcing. Thus in this set of experiments all information about year-to-year climate variability comes from the assimilation of observations rather than from initial conditions or surface forcing. In a second set of experiments we use both assimilation and historically varying surface forcing (degraded consistent with meteorological error estimates).

In the first set of five experiments synthetic observations from five decades (1925-8, 1945-8, 1965-8, 1995-8, and 2005-8) are assimilated. Each successive experiment has more observations which extend to deeper levels reflecting the growth of the observing system over time. The results show that by the 1960s the ocean surface and subsurface observing system is sufficiently extensive that the major features of the warm and cold phases of ENSO and shifts in the Indian dipole can be reproduced even in the absence of information from surface forcing. In the northern subtropics/midlatitudes the comparison of basin-average quantities such as temperature and salinity in the upper 300m suggests that even as far back as the 1940s the historical observational coverage can allow us to estimate temperature anomalies with an accuracy of 0.2^{o}C, but that basin-averaged salinity remains unconstrained. From the 1960s forward basin-averaged temperature errors are less than 0.2^{o}C throughout the upper 300m and salinity errors are generally less than 0.2psu except within the mixed layer. The salinity errors increase somewhat in the late-1990s due to a shift towards observing systems that measure temperature, but not salinity, and then decrease as a result of the introduction of Argo.

In the second set of experiments the 1920s and 1990s experiments described above are repeated, but now including historical surface forcing (from 20CRv2), but forcing which is degraded consistent with meteorological error estimates. The results of these more realistic experiments show that historical representation of surface meteorological forcing is sufficiently accurate that phenomena of the magnitude of the 1997/8 El Niño and associated 1997 Indian dipole and 1998 La Niña could have been described qualitatively at least as early as the 1920s and likely even earlier. This result is extremely encouraging for the application of data assimilation to historical ocean climate studies in the first half of the 20th century (e.g. Giese et al., 2010).

The current study comes with a number of qualifications. It focuses on phenomena resembling the climate anomalies of the late-1990s which had their largest expression in the tropics. By focusing on this extraordinary era and the tropics, we likely overestimate the ability of an ocean reanalysis to track more usual climate events and those outside of the tropics. Simplifying assumptions in this study include the assumption that the ocean observations are perfect (no observation error). The use of the same numerical simulation model for the Nature Run and for the experiments eliminates deleterious effects of model error and unresolved physical processes. The study also accepts, without any attempt to verify, the error estimates that accompany 20CRv2. Additional studies are needed to explore all of these qualifications.

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