Comments on "Natural Variability and Predictability"

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Madden (1976 hereafter referred to as M) calculated the observed spectra and its low frequency white noise (LFWN) extension to estimate the standard error of monthly mean sea level pressure over Northern Hemisphere. This was referred to as the natural variability, and it was assumed that in the absence of any external or boundary forcings, internal dynamics will produce such a variability. This was indeed a novel approach because it was the first systematic effort to define quantitatively the relative contributions of internal dynamics and possible external forcings. Implicit in the calculations was the assumption that the variability due to internal dynamics is not predictable at long range, and that the variability above the natural variability can be potentially predictable. However, the predictable signal was considered to be only that part of the variance which is on a time scale longer than 96 days and above white noise. The estimates of standard error of monthly means were compared to the observed interannual variability to estimate potential predictability. There is no guarantee that a potentially predictable signal can actually be predicted. However, due to the great importance of the question of predictability of time averages, it is worthwhile to re-examine the assumptions and results of Madden.

The purpose of this note is twofold: 1) to summarize the difficulties in using observed data to calculate natural variability and especially to point out that the method used by Madden overestimates the natural variability and, therefore, underestimates the potential predictability, and 2) to re-emphasize the definition of long range for which Madden's results apply, and to point out the difficulties in interpreting high natural variability as low predictability. It would be argued that the large natural variability of monthly averages does not necessarily rule out the possibility of dynamical or statistical–dynamical prediction of one-month average from a given initial state.

It should be pointed out at the outset that a footnote in Madden's paper defines long range to mean time scales of a year or more. Madden considered the question of predictability of a monthly mean one year in advance, and therefore, his results do not apply to the possibility of dynamical prediction of monthly mean for the next month.

1. Calculation of Natural Variability

a. Inseparability of internal dynamics and boundary forcings

Atmospheric fluctuations are determined by complex interactions between the internal dynamics and slowly changing external forcings due to sea surface temperature, soil moisture, sea ice, and snow etc. The assumption, in M, that the observed spectra for the periods of 48 and 96 days is not affected by changes in the boundary forcings, overestimated the role of internal dynamics in determining the low-frequency spectra. It is not implausible that the slowly varying boundary forcings at the earth's surface contribute significantly to the variability at 48 and 96 day time scales. Even if we assumed that the boundary forcings were quasi-persistent up to a season, the atmospheric response to very low-frequency changes in the boundary forcings will also contribute towards the spectrum at 48 and 96 days.

This assumption is very crucial to the quantitative results of M because if one examines the contribution of different frequency intervals (see Table 1 of M) one finds that almost all of the natural variability is due to the periods beyond 48 days. It should be pointed out that M is frequently referred to in the current literature in support of the notion that day-to-day weather fluctuations (due to passage or intensification of a cyclone, etc.) contribute to the nonpredictability of monthly means. It should be emphasized that in Madden's calculations it is not the high-frequency weather associated with the large day-to-day changes that contribute to the nonpredictability, but the low-frequency component of the weather that makes the monthly means less predictable because the quantitative results of Madden show that unpredictability

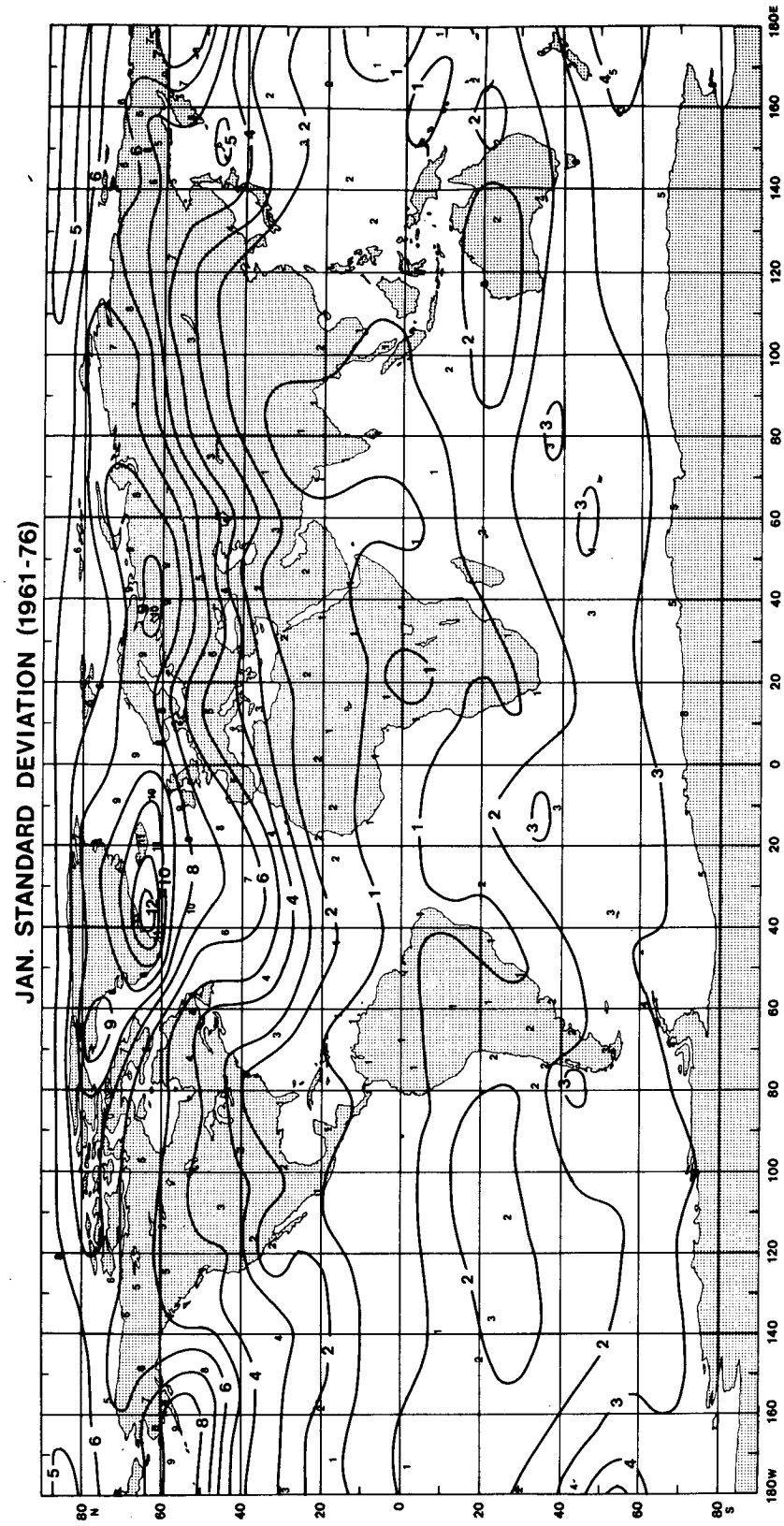

FIG. 1a. Standard deviation of sea level pressure (mb) for January.

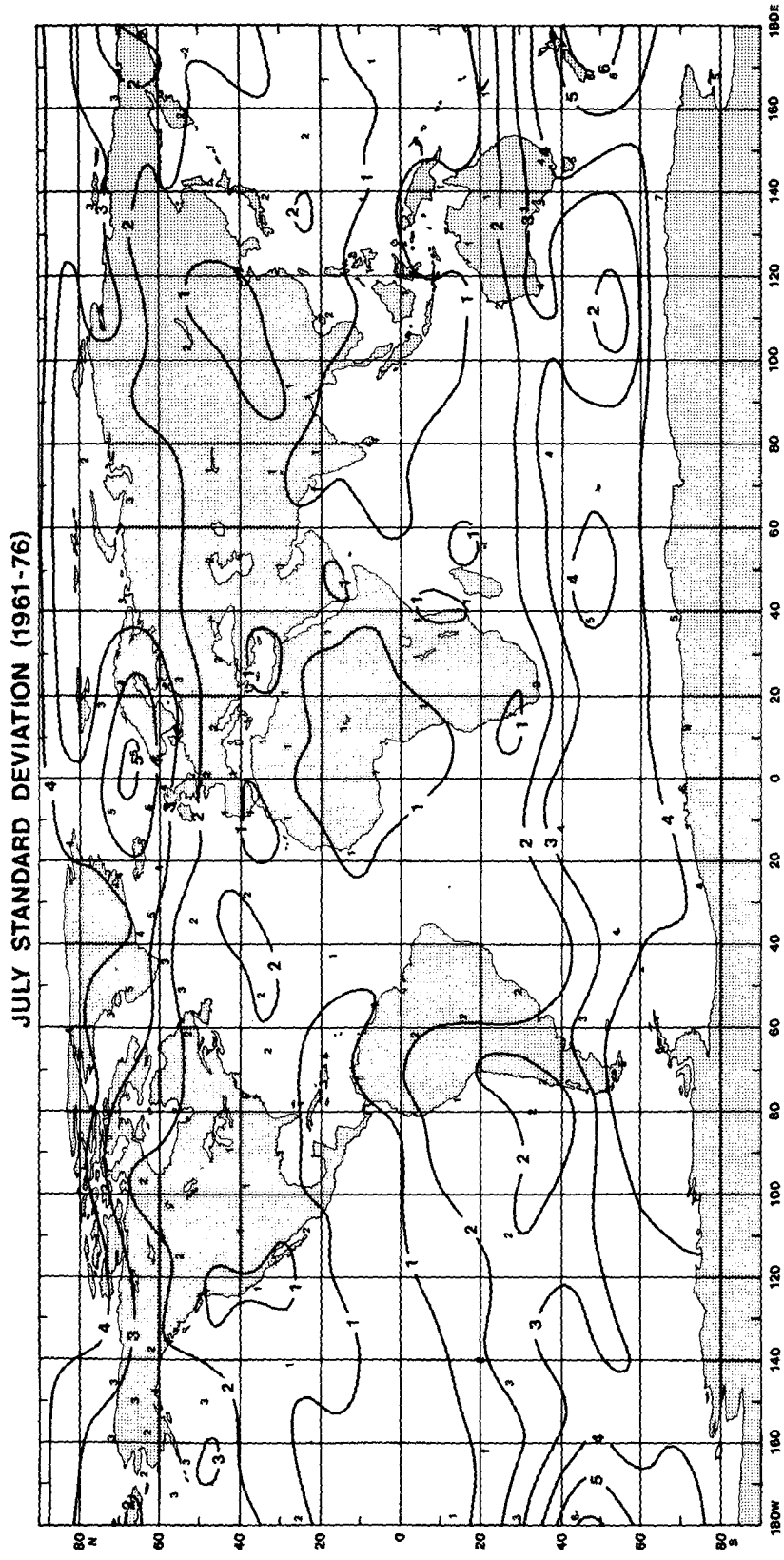

FIG. 1b. Standard deviation of sea level pressure (mb) for July.

of monthly means comes mostly from fluctuations of 96 days or more. It is assumed that these long period fluctuations are solely due to unpredictable weather fluctuations. Examination of Table 1 in M shows that more than 97% of the natural variability was accounted for by periods longer than 48 days. If similar calculations were made to estimate the natural variability of seasonal means using season length data, almost all the contribution would be due to the assumed LFWN.

b. Low-frequency white noise (LFWN) extension

It is assumed in M that the spectral power at zero-frequency is the same as that at 96 days. This is a reasonable assumption. However, if power for the 96-day spectrum were overestimated due to nonseparability of the effects of boundary forcings, so were the spectrum at zero-frequency. We suggest that the 96-day spectrum is overestimated because fluctuating boundary forcings also contribute to spectra *within* 96 days, and therefore the observed spectra up to 96 days cannot be attributed entirely to internal dynamics. Since the spectrum at zero-frequency is the second largest contributor to the natural variability of the monthly means, the assumption of LFWN extension further overestimates the value of natural variability.

c. Removal of trend and seasonal cycle from observed data

The spectrum at 96 days can be sensitive to the way the trend and the seasonal cycle is removed from the 96-day long time series. In M, no trend was removed from the data and the seasonal cycle was defined as the ensemble mean of the observed values on each calendar day for a 74-year period. This way of defining the seasonal cycle is appealing because of its simplicity and its consistency with respect to the solar forcing; however, it does open the possibility of overestimating the 96 day spectrum due to very low frequency components which might be present due to slow changes in the external forcings. If the seasonal cycle were removed by fitting a parabola to the ensemble mean time series for 96 days, it is quite likely that the 96-day spectrum would be lower, and it would be lowered further if the parabola was fitted separately for each year. We cannot comment on how much quantitative differences would occur in Madden's results, but we can safely state that Madden did not underestimate the natural variability because of his choice of method for removing the seasonal cycle.

It would be reasonable to conclude that the whole procedure of calculation used in M does not suggest any possibility of underestimating the value of natural variability, but it does raise several possibilities of overestimating it.

2. Interpretation of natural variability

a. Internal dynamics is not necessarily completely unpredictable

In M, all the observed variance up to 96 days, and white noise extension beyond 96 days, is considered to be due to unpredictable weather fluctuations. It is further assumed that any variability due to internal dynamics is unpredictable beyond a few days. We believe that there is not sufficient evidence to rule out the potential predictability of space and time averages of internal dynamics.

It has been shown (Shukla, 1981) that even with constant boundary forcings, the persistence and evolution of long waves remains sufficiently predictable up to one month so that the combined effects of their own non-predictability and their depredictabilization by synoptic-scale instabilities is not large enough to degrade the dynamical prediction of monthly means. Diagnostic calculations of the atmospheric energetics have shown that wave–wave energy transfers are not found to be the dominant energy source in the energy budget of long waves. Long waves can grow and decay due to their own instability with respect to the prevailing flow, and because of their slow growth rates, may be more predictable than synoptic scale baroclinic instabilities. Presence of stationary forcings in the earth's atmosphere may also contribute to the potential predictability because as shown in Fig. 1, the standard deviation of monthly mean sea level pressure for January and July calculated from 16 years (1961–76) of data of ~1500 stations over the globe shows large interannual variability in the Northern Hemisphere compared to the Southern Hemisphere (Godbole and Shukla, 1981).

b. Persistence anomalies like blocking appear to be dynamically more predictable

It is seen in M that larger values of natural variability occur over the regions of most frequent occurrence of persistent anomalies known as blocking. There is growing evidence from numerical weather prediction models that compared to fast changing flows, the blocking events are more likely to be deterministically predictable with a realistic dynamical model. The occurrence of blocking events produces slow decay of the autocorrelation function and large values of natural variability and therefore reduces the estimate of predictability in M. This apparent contradiction between the results of current dynamical forecasting models and the conclusion of M arises because predictability, as defined in M, does not refer to the predictability of a one-month mean obtained from the dynamical evolution of a given initial state, but to a one-month mean after time range of one year or beyond.

3. Summary

In M, the definition of natural variability includes all observed fluctuations up to 96 days and white noise extension beyond 96 days. Therefore, what is left to be considered as predictable signal is the variance above the white noise for periods longer than 96 days. Thus, it is not relevant to the predictability of 30-day means from a given initial state. Madden's results apply to the predictability of monthly means for one year in advance.

We have pointed out some of the intrinsic difficulties in calculating the natural variability from the observed data which arise due to nonseparability of internal dynamics and boundary forcings. We have looked for but found no reason that Madden could have underestimated the value of natural variability; however, we have pointed out several reasons why he overestimated the value of natural variability. We therefore conclude that Madden's results should be considered only as the lower bound of the potential predictability of the monthly means of the atmosphere.

We have also pointed out the difficulties in the interpretation of high natural variability as low predictability, because the areas of high natural variability are the areas of high persistence, which are likely to be more predictable with a realistic nonlinear dynamical model.

The purpose of this note was only to point out that the potential predictability of monthly means is larger than that implied by Madden, and it is yet to be seen how much of the potential predictability can actually be realized. However, the dynamical predictability of low-frequency long waves and the additional predictability due to slowly varying boundary forcings at the earth's surface suggest a more optimistic possibility of dynamical (or statistical–dynamical) prediction of monthly means.

Acknowledgments. The author is extremely grateful to Dr. R. Madden for the benefit of several illuminating discussions on the question of predictability. I would also like to acknowledge several other people who, after my lectures on dynamical predictability of monthly means asked, in one way or the other, the following question: "Hasn't Madden shown that monthly means are not predictable?" Although it was clear that this impression is largely based on an insufficient understanding of Madden's paper, it suggested the idea of writing this note because the topic is of sufficient importance to warrant a discussion and possible clarification.

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