SKILL OF MONTHLY/SEASONAL CPC OUTLOOKS BASED ON CONSTRUCTED ANALOGUE ON US SOIL MOISTURE
1981-2001

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Note 1: A more complete article (Van den Dool et al 2003) on this subject will appear in the GCIP issue of JGR-D.

Note 2: Real time forecasts based on soil moisture can be found at: http://www.cpc.ncep.noaa.gov/soilmst/index_jh.html

1. Introduction

We have conducted an experiment to assess the real time skill in monthly and seasonal predictions based solely on patterns of antecedent hydrological information over the limited domain of the United States. The hydrological information is contained in a proxy for soil moisture at 102 locations over the lower 48 states. This soil moisture is calculated over the years 1931-present from a local hydrological equation taking monthly precipitation (P) and temperature (T) as input, and producing soil moisture (w), evaporation (E), runoff and loss to groundwater as output. The initial condition (IC) for the forecast procedure is soil moisture at the end of the month (w30). We constructed an analogue, the so-called CA method (Van den Dool 1994), to the w30 fields, i.e. made linear combinations of soil moisture fields in the same months in years past so as to reproduce the IC to within a small tolerance. The coefficients assigned to the years past are then persisted and the subsequent developments in the historical years are linearly combined to form a forecast. This CA method has been running at CPC for soil moisture (acronym CAS is also used) in real time since 1998, and we added 1981-1997 in 'retroactive real time' mode to form a large enough sample. In total we considered both seasonal and monthly forecasts at leads -1 to +6 months for 1981-2001, for the elements w30, E, T and P. From the outset we wanted to investigate non-local forecast methods, considering local effects, on evaporation and temperature mainly, as being established already and well documented (Huang et al 1996). In a non-local method we entertain the possibility of precipitation (the response) falling downstream of a soil moisture anomaly (forcing).

2. Results

We found, see Fig.1, that we have about a 0.6 correlation in forecasting monthly soil moisture with a lead of one month (i.e. July at the end of May). This figure is higher in spring and somewhat lower in the early fall. The capability to forecast evaporation anomalies, see Fig.1 as well, is very seasonal. During the cold half of the year, when E anomalies resemble T anomalies, the correlation is only 0.2-0.3, but in summer, when E anomalies resemble w anomalies, the skill of forecasts goes up to 0.6. We thus have some insight in patterns of anomalous water vapor input from the land surface into the atmosphere on a continental scale. During summer we are able to forecast E anomalies with skill considerably higher than persistence, see Fig.2.

Skill of forecasting T, see Fig.3, is modest, reaching 0.2-0.3 in many month and seasons, but no clear seasonal dependence that relates unambiguously to the presumed physics of land atmosphere interactions. Skill in forecasting P is quite low, barely 0.1 in correlation, but +ve in all months and seasons.

In Fig.4 we show the scores for 1 month lead JJA T&P forecasts for each year during 1981-2001. As is common with all forecast methods, the skill fluctuates wildly (understanding this would be desirable, but beyond the scope of this paper) from case to case, especially for temperature. A good aspect of CA is that real terrible forecasts (highly negative correlations) are rare. JJA in 2000, a forecast that was available in real time, worked out very well, both for P and T. Famous years from a hydrological standpoint include 1993 and 1988. In neither year did we do well on P, but T in 1988 was one of the best. The forecast for summer 1998, the first we made in real time, was interesting because it followed the El Nino winter 1997/98. During 1998 the 66 weights continued to be positive, on average, for historical El Nino years all the way through August, thus suggesting a degree of determinism in the forecast and reasonable skill as well. The physics appear to be that the soil moisture condition in spring, left behind by a prominent winter

El Nino winter precipitation anomaly pattern, gets carried over into summer by land surface feedbacks.

3. Discussion and conclusion

We did alternative experiments where the constructed analogue was built on E, T or P instead of w, and verified the forecast of all elements likewise. We found initial w to be the best for forecasting w itself and indeed for forecasting the other fields as well! This is important testimony that soil moisture is indeed the key!, as has been suspected by many for ages.

While CA is a powerful exploratory method, a potential drawback is that one needs to truncate data in EOF space in order to find solutions. With about 70 years of data we feel comfortable retaining about 30 EOFs, which generally explain from 90% (summer) to 93% of the soil moisture variance. EOF truncation deleted many mainly local features. So, in pursuing a remote response method we shaved off a lot of the local information, which, as we know (Huang et al 1996), contributes to forecast skill also. The linearity of CA in combination with EOF truncation may pose a particular problem if large amplitude wet anomalies occur on tiny spatial scales. Some merging of local and non-local forecast methods may have to be considered in practice.

It is not clear as to why the low skill in T and P especially is due to a low predictability ceiling in general or a particular weakness in any of the building blocks used here. Among the potentially weak points we should include that soil moisture over the US only is an unrealistic limitation from a physical point of view. Certainly land conditions over Canada and Mexico should be included, and it may even be that a proper evaluation of the role of soil moisture can only be made when the lower boundary condition over the (nearby or global) oceans are also included. Progress can be made along many lines. The most obvious one is to improve the estimate of soil moisture. Various land Reanalyses are underway, yielding much more detailed and physically realistic soil moisture in some cases over many decades (Maurer et al 2002; Fan et al, 2003). The LDAS experiments (Mitchell et al 2000) are geared towards making model consistent soil moisture, so using full blown GCMs for a real time forecast is an obvious alternative to CA. Ultimately global land surface conditions will be prepared for the whole world, including a true assimilation of soil data (Walker and Houser 2001) but this may be a few years away. Merging lower boundary condition over the ocean and land, in the context of the CA method, is another point to consider. Anomalies in evaporation over land near the ocean need to be merged with E anomalies over the ocean itself, for the system to make physical sense. Of course, if predictability is fundamentally limited to start with, none of these improvements may yield much new forecast skill. A recent study (Koster et al 2002) found empirical evidence of feedback of soil moisture onto precipitation over the US to be only in July, and only in the center of the country.

There is no question that the CA forecast is non-local and this aspect may well be realistically modeled by CA, but this does not prove that the forecast is, or should be, skillful. If the forecast is too sensitive to the details of the initial soil moisture distribution we may not have any skill at all, no matter how well we model the physics. This could be a problem of the just CA method (i.e. maybe CA is too sensitive), or for all methods, we do not know. One has to realize that the notion of predictability of the first kind, i.e. sensitivity to uncertainty in the IC, has to be extended here to uncertainties in the initial lower boundary condition as well. The question as to how accurately we will ever know soil moisture is well beyond current insights.

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Figures:

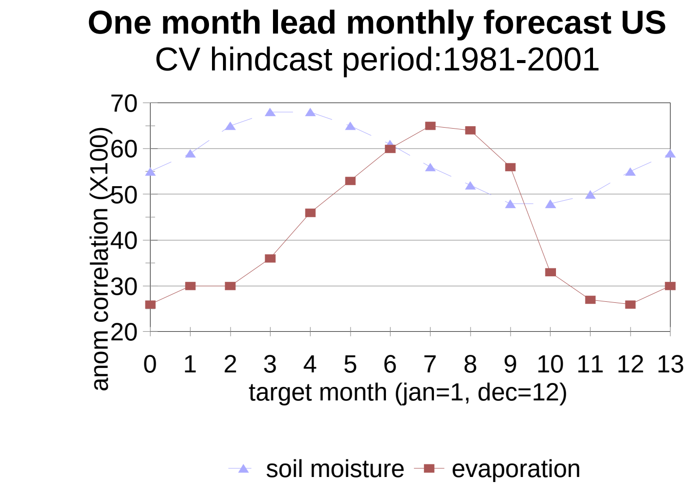

Fig.1 The skill of the one month lead monthly forecast of w30 (triangles, dashed line) and E (squares, full line), as a function of the target month (1 = Jan, 12 = Dec). For a better representation the December value (at 0) and January value (at 13) are repeated. Skill is expressed as correlation (times 100), which ranges from 0 to 100 (dimensionless). The period is 1981-2001.

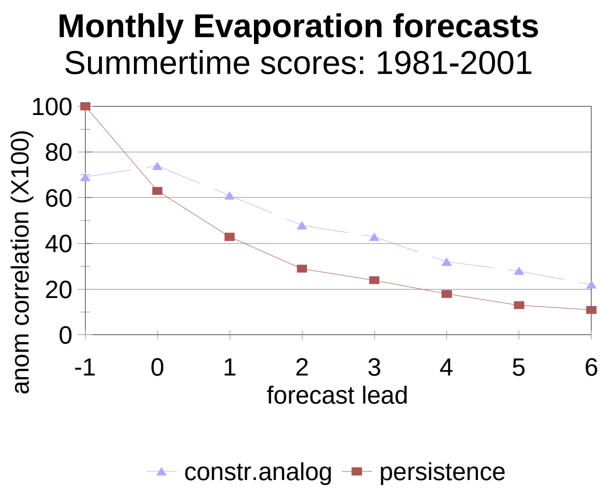

Fig.2: The skill of monthly E forecasts verifying from May to September, as a function of lead. Line for persistence has squares and for Constructed Analogue triangles. Skill is expressed as correlation (times 100), which ranges from 0 to 100 (dimensionless). The period is 1981-2001.

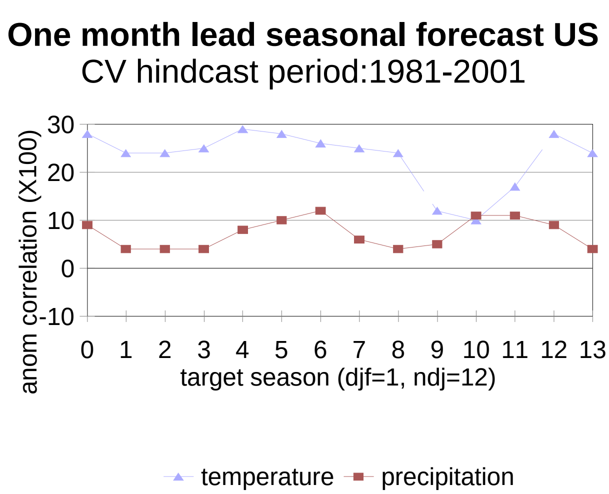

Fig.3: The skill of 1 month lead seasonal forecasts of temperature (triangle) and precipitation (squares), as a function of target season (1 = DJF, 12 = NDJ). For a better representation the NDJ value (at 0) and DJF value (at 13) are repeated. Skill is expressed as correlation (times 100), which ranges from 0 to 100 (dimensionless). The period is 1981-2001.

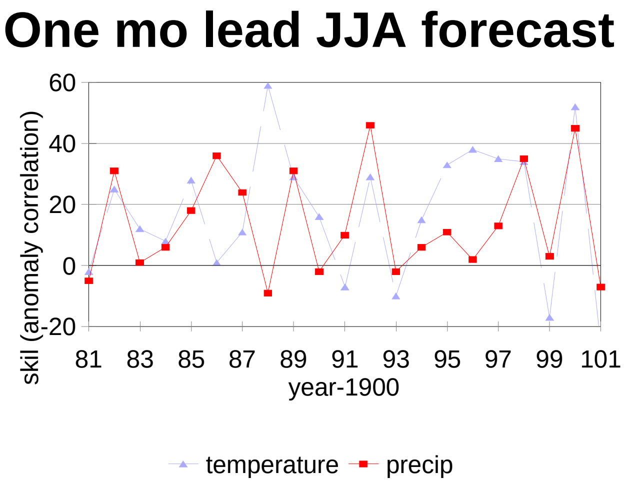

Fig. 4: The skill of 1 mo lead seasonal forecasts of temperature (triangle) and precipitation (squares) for JJA, year-by-year for 1981-2001. Skill is expressed as correlation (times 100), which ranges from 0 to 100 (dimensionless). The year is indicated as year-1900, i.e. 81 means 1981.