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LETTER

Repurposing climate reconstructions for drought prediction in Southeast Asia

A Letter

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Climate information may help smallholder farmers in Southeast Asia take informed risks and reduce their climate vulnerability. Model-based seasonal forecasts are limited in the skill they offer with longer lead times, and in their accessibility to farmers in remote regions. Climate reconstructions derived from tree rings can complement model-based forecasts, providing probabilistic estimates of future climate at an annual resolution. This study demonstrates the skill of PDSI reconstructions derived from the Monsoon Asia Drought Atlas (MADA) to forecast a climate signal several years into the future, and illustrates the advantage of such information vis-à-vis the simple strategy of assuming climate to persist from year to year. This work shows the potential for such climate reconstructions to improve inter-annual decisions on Southeast Asian farms, and highlights the social research necessary to transmute this potential into a valuable climate decision aid.

In much of Southeast Asia the capacity of smallholder farmers to predict and protect against drought is limited. Farmers commonly employ conservative, risk-averse strategies to farm planning and operation that reduce losses to climate-related damages, but that also reduce surpluses in years of favorable climate (Meinke and Stone 2005). Farmers operating close to thresholds of sustenance and self-sufficiency who fail to take advantage of these rents can fall into 'poverty traps' (Holling 2001; Sachs 2005), unable to lift themselves from degraded land conditions and a lack of capital. To help smallholders become informed risk takers and capitalize on the

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opportunities provided by favorable years in an otherwise uncertain climate, tools for climate prediction are of great importance.

Monthly and seasonal climate prediction has been successful in the tropics during ENSO climate anomalies (Kumar et al. 2010; Phelps et al. 2004). Seasonal prediction is generally more successful than monthly prediction, as the averaging process gives an improved signal-to-noise ratio even with a weaker signal overall (Phelps et al. 2004). Even here, however, prediction skill drops with lead times longer than a few months (Lee et al. 2010), dampening the utility of climate models for inter-annual planning. Further, seasonal prediction is a relatively new technology with which only a handful of countries have had significant experience (Hansen 2002). While there is literature documenting experience in the use of climate information in agriculture in Africa (e.g., Roncoli 2006; Klopper et al. 2006; Ziervogel and Calder 2003; Roncoli et al. 2009), North and South America (Lemos et al. 2002; Hu et al. 2006), Australia (e.g., McCrea et al. 2005), and some parts of South Asia (Hansen 2002; Roncoli 2006), we failed to find comparable literature indicating access to, and use of climate information by smallholders in the countries of Southeast Asia upon which this study focuses.

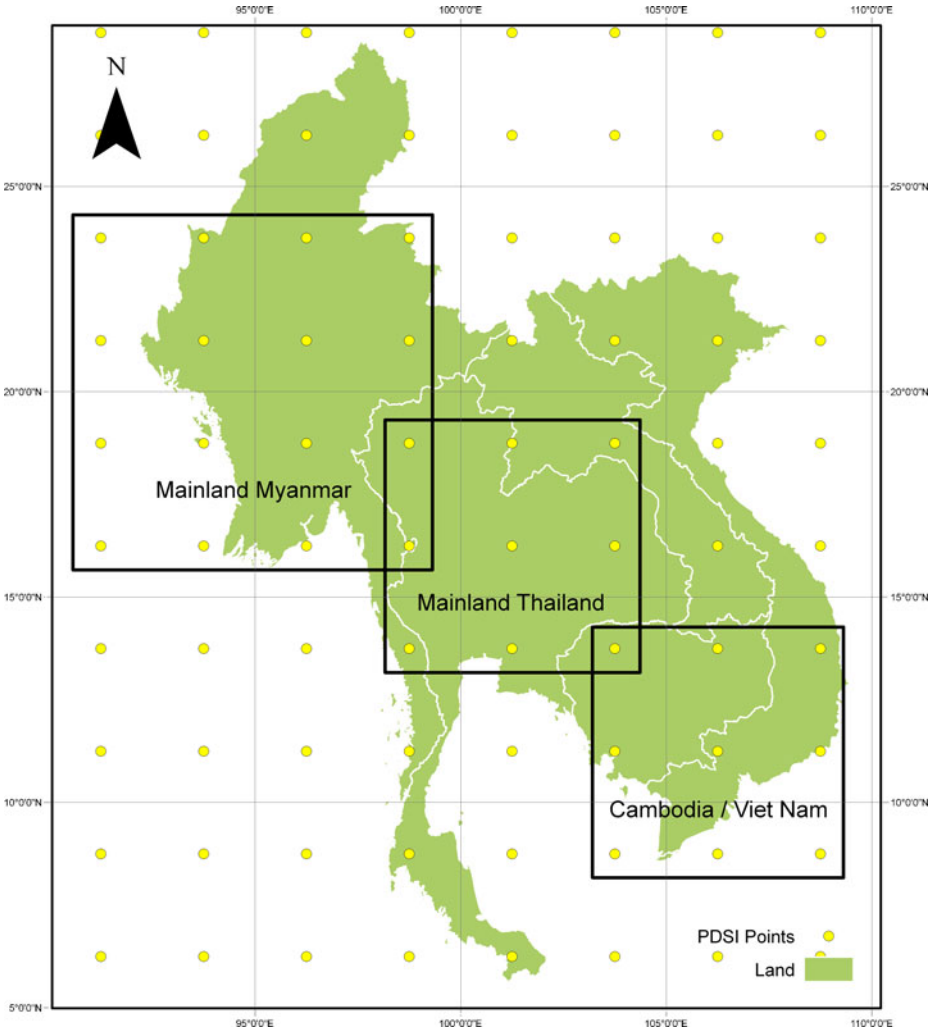
Climate reconstructions derived from tree-ring studies can be a valuable and accessible complement to model-based predictions of future climate for Southeast Asia. Inter-annual autocorrelation of climate, particularly during climate anomalies, means that climate in the current year can be indicative of what might happen in the following year, and even in the year after; climate reconstructions can be easily repackaged to express this in probabilistic terms. In the realm of proxy climate reconstructions, tree rings are considered a high-resolution proxy due to an absolute annual (and potentially sub-annual) dating control. Though for purposes of this study, where seasonal forecasting is the goal, we consider this resolution to be low, it must be noted that tree-ring climate reconstructions offer several advantages vis-à-vis climate models. Firstly, through their biology trees reflect an integrated signal of climate—specifically, temperature and precipitation translated into effective soil moisture—that may be more intuitive for smallholder producers to work with. Secondly, being derived from actual climate events and being constructed through sets of assumptions that are easier to explain and demonstrate, these histories may be given greater legitimacy and face-validity than is granted to model outputs. Finally, because they are based on events in the past, climate reconstructions derived from tree rings can be made much more accessible in smallholder households. A simple booklet, for example, based on the last 100 or 200 years or more of reconstructed climate will remain relevant for years following its production and dissemination, becoming a valuable aid where the costs of reaching remote communities and translating current predictions for their use is difficult. Probabilistic guides based on historical climate are not new (e.g., Podestá et al. 2002; Hansen et al. 2006), but the use of tree rings extends their applicability to points in time and space where reliable climate records may not exist, especially when multiple chronologies can be constructed from a region.

In this study we demonstrate several approaches to repurposing tree-ring climate reconstructions of seasonal drought indices into forms that more intuitively express serial autocorrelation in climate, in three regions of mainland Southeast Asia. We demonstrate the skill of the climate information contained in these reconstructions by evaluating how well they are able to predict future climate and compare these against the baselines of random guesses at climate, and a simple 'persistence' (next

year will be the same as this year) approach. Finally, we draw on these results to highlight other research steps necessary to make tree-ring climate reconstructions a valuable decision aid alongside modeled climate predictions.

1 Methods

We used as a basis for this work the gridded 2.5° Palmer Drought Severity Index (PDSI) reconstructions from the Monsoon Asia Drought Atlas (MADA), which is based on tree-ring data from more than 300 sites across Monsoon Asia and provides a well-calibrated, validated history for much of the last millennium (Cook et al. 2010).



Map 1 PDSI grid points and regions for area-averages

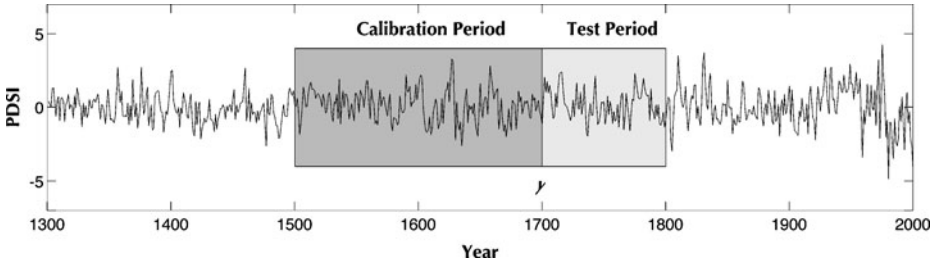


Fig. 1 PDSI history for Mainland Myanmar and example of calibration and test periods

The PDSI is a drought measure, expressed as a normalized departure from a local mean moisture balance, that is used widely to express drought in the US (Heim 2002), and globally (Dai et al. 2004). We obtained area-averaged PDSI histories for three regions in the grid representing Mainland Myanmar, Mainland Thailand, and Cambodia/Southern Viet Nam (Map 1). For each of these three PDSI histories, we quantize the continuous PDSI values into m classes; in the examples shown in the Electronic Supplementary Material we use $m = 5$.

With the PDSI histories re-expressed as a series of classes from 1 to m, we 'repurpose' them by calculating (1) the probability of PDSI falling into class i in the jth year following the current year, given current conditions; (2) the probability of PDSI remaining persistently at or below class i, as well as persistently above class i, for the j years following the current year; and (3) the distribution of drought lengths in years given a drought threshold i. Each of these quantities provides a different lens into the autocorrelation occurring between years in the PDSI histories that gives them skill as predictive tools. Mathematical derivations of these three quantities are given in the Electronic Supplementary Material.

Finally, we develop a simple test of the skill of the PDSI histories. First, we derive probabilities as described above in (1) for a 200-year calibration period starting in year $y-200$ and ending in year $y-1$ (Fig. 1). We then evaluate the skill of the tool by predicting the climate for each year in a 100-year test period that follows immediately after the calibration period (years y to $y+99$). For each year j in the test period, the climate in years $j+1$, $j+2$, and $j+3$ is predicted as the climate bin with the highest probability given the climate in year j. For comparison, the results are compared against (1) a random guess at climate, and (2) a 'persistence' approach—assuming that climate in year $j+1$, $j+2$, or $j+3$ will be the same as that in year j. To look at how the potential for present to be predicted from past has shifted over time, we vary y (the start date of the test period) from 1500 to 1900, making full use of the climate histories available through the MADA.

2 Results and discussion

The first result of interest is that using the climate information provided by the PDSI reconstructions has significant skill in predicting climate for the following year (compared against a baseline random guess) (Fig. 2). The skill is similar to the simple 'persistence' approach for making predictions into the next year, which is not unexpected—much of the effectiveness of the PDSI-based predictions derives

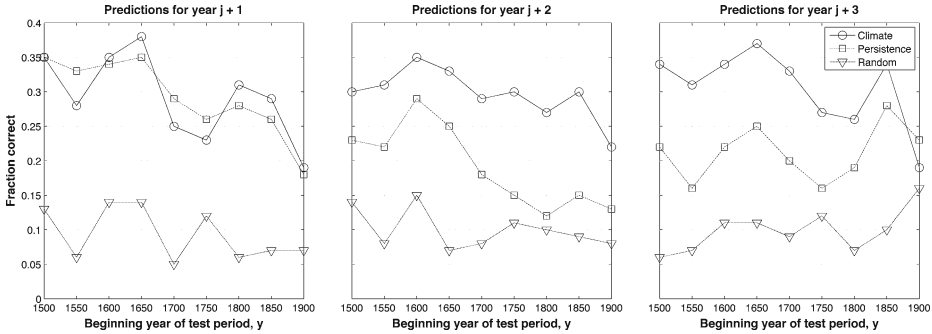


Fig. 2 Fraction of correct predictions of climate for first (*left*), second (*middle*), and third (*right*) years after current year for all years within 100-year test period, across temporal periods in the climate reconstruction for the case of $m = 11$ bins for Mainland Myanmar. Success rates reflect only the correct predictions, and no 'nearly' correct predictions (i.e., 7 or 9 when the actual quantized climate bin is 8), and are roughly analogous to the rates of correctly predicting the roll of a somewhat-weighted, 11-sided die. Results for $m = 3$ and $m = 5$ bins, for all regions, are tabulated in Tables ESM.1–3

from their detection of persistence (Figures ESM.1–6). However, the PDSI-based predictions retain greater skill into the second and third years following the current year (Fig. 2; Tables ESM.1–3), suggesting potential for their use in farm structural planning at the multiannual scale (Meinke and Stone 2005) beyond what is possible with the simple 'persistence' approach.

It is notable that these results emerge using only a portion of the information contained in the climate records. There are at least two simple characteristics of a current climate condition—what state the climate is in, and how long it has been in that state (i.e., how long it has persisted below, above, or at a normal state)—and in this example we use only the former characteristic for prediction. Thus, the approach we have taken to use the reconstructions may not be the optimal use of the data, and there may be significantly more useful information contained in the climate records. An additional note is that these results do not incorporate any aspects of agricultural decision-making or farm production that would allow us to evaluate the potential economic benefits of using climate information in these regions. Rather, the results in Fig. 2 are important simply in that they demonstrate that there is significant mathematical potential in the PDSI reconstructions to predict future climate.

The second result of interest is that the effectiveness of the climate information in predicting future climate shifts over time. In the example shown, there is a visible decreasing trend in the capacity for the calibration period (the 200 years prior to y) to predict climate in the test period (the 100 years after y). The PDSI reconstruction for this region has visible loss of stationarity over the twentieth century (Fig. 1) helping to explain this drop in effectiveness. This result highlights that the extent to which past conditions could have informed decision-making has shifted over time. Points in Southeast Asia's history where even the potential for agricultural choice to be informed by the past would have been limited may help inform not only our understanding of previous collapses and famines (Buckley et al. 2010), but also the potential for climate information to be of value moving forward in agriculture and resource decision-making (Milly et al. 2008). In particular, the anthropogenic climate

forcing we have begun to experience, and expect to experience in future (IPCC 2007), is a source of variability we would not find in the paleoclimate record.

These results demonstrate prediction skill in the climate reconstructions, and expand the potential for historical analog approaches to be of value alongside modeled forecasts for the region. However, alongside any mathematical exploration there are social research questions whose answers will be critical to making this or any other tool valuable to farmers making planning decisions in Southeast Asia. Predictability in climate alone does not lead to livelihood improvements for rural peoples—there must exist an important decision whose outcome can be shaped by climate information in the form (Klopper et al. 2006) and the scale (Ziervogel and Downing 2004) at which it is available. Farmers in Lesotho, for example, felt they could benefit much more from predictions of rain onset and seasonal distribution than predictions of total rainfall; as well, the capacity for any information to improve decisions varied from poor to well-off farmers (Ziervogel and Calder 2003). In Burkina Faso, the relative values of knowing rainfall onset and distribution versus total rainfall differ, for example, from cotton production in the Southwest to millet production in the Sahel (Ingram et al. 2002).

Thus, one important line of social research accompanying our drought prediction work must be an investigation of how climate is conceptualized locally (Roncoli 2006; Roncoli et al. 2009). That is, we must map out the locally relevant conceptions of climate, and link them to the standardized indices such as PDSI through which the research community interprets climate. As noted in the introduction, there is yet a dearth of literature discussing the use of climate information by smallholders in Indochina, and documenting this—what kinds of information are of value, in what forms, and what capacity local smallholders have to make use of them—is a critical, context-specific foundation for any climate-related decision aid. A further consideration in the use of probabilistic tools is that while they can lead to better outcomes in the long term, they are often wrong in the short term, and there is need for research specific to Indochina into how best to communicate the long-term benefits of probabilistic tools (Roncoli 2006) as part of the decision-making process and encourage their use by farmers even when in a given year they might not point to the best option. Having demonstrated skill in prediction, the results of the current study can first be of value as a 'pre-' product within this process, as a focal point alongside other climate information products (such as model-based seasonal or decadal forecasts) in participatory exercises aimed at understanding what forms and sources of information have the most potential to be understood, trusted, and of value.

Next, the set of options available to local farmers needs to be documented and understood. Climate information is valuable when it has the potential to lead farmers to make different choices than they might reach without it, as has been the experience in smallholder farming in Africa and elsewhere (Amissah-Arthur 2003; Stern and Easterling 1999). Here, 'options' can be interpreted strictly as strains of crops with different climate performance, different choices of crop, or as broadly as the decision to invest in fertilizer, livestock, or to send children away to school (Ziervogel and Calder 2003). The ability to respond to climate and improve conditions by choosing among such options is an important driver of adaptive capacity (Smit and Wandel 2006), which in turn can be very location- and context-specific. Research undertaken to inventory the set of choices farmers in rural Southeast Asia make or are able to make in response to climate would, in the first place, provide a detailed lens

into adaptive capacity in these rural landscapes. Secondly, by establishing a yield–climate relationship for these choices similar to those generated in this study, such research would produce a valuable database for use by this or any other climate decision aid.

In summary, we have demonstrated the potential for climate reconstructions derived from tree rings to make useful probabilistic annual forecasts of climate in three regions in Southeast Asia. We have highlighted, however, at least two areas of social research that will be critical to making these or any other such forecasts into tools useful for farmers in the region: (1) research on the way in which climate is framed by farmers in the region, what kinds of climate information are of value, and in what form; and (2) research into the set of options employed by, or available to farmers in these regions, and the relationships these options have with climate. Advances along these lines of research, incorporating 'pre-' products such as that developed in the current study, will allow the production of climate-related decision aids tailored to the needs of local farmers in Southeast Asia, and improve the linkages between climate research and rural development within the context of Indochina.

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