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Effects of future weather on foraging and farming productivity: Implications for farming's diffusion

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The emergence and spread of farming during the late Pleistocene and Holocene stimulated the evolution of human societies[1,2]. Farming allowed for urbanization and for the emergence of complex societies[3-5]. Farming diffused for several possible reasons[6], including lower weather variability[7,8]. However, the precise path through which lower weather variability affected farming's diffusion remain poorly understood because of a lack of data linking weather with the productivity of farming and its predecessor alternative, foraging (hunting, fishing, and collecting wild plants). Here we use panel data from a contemporary society of forager-farmers in Bolivia's Amazon (Tsimane') to show for the first time that short-term future weather has a greater effect on the amount of farm crops harvested today than on the amount of wildlife collected today. After controlling for total rain and mean hourly temperature today and for mean daily rain and the daily mean of hourly temperature for the previous seven days, we find that a 1%-increase in rain during the next three days lowered the probability of harvesting farm crops today by 0.11% and that a 1%-increase in temperature during the next three days raised the probability of harvesting farm crops today by 0.21%. Future weather did not affect the probability of collecting wildlife today. Since lower weather variability increases the usefulness for farming of short-term weather forecasts based on local knowledge and personal experience[9-12], our findings suggest that the causal mechanism from lower weather variability to farming's diffusion could have worked by enabling better weather forecasts.

Richerson et al.[7] hypothesized that agriculture was impossible during the late Pleistocene but mandatory during the Holocene because of higher weather variability during the Pleistocene[13]. Lower weather variability between years, decades, centuries, and millennia facilitated the accumulation of local farming knowledge. In addition, as weather variability decreased, the usefulness of short-term weather forecasts likely increased. At one extreme, if the weather tomorrow is uncorrelated with previous weather (or with other observed variables), then reliable forecasts of tomorrow's weather are likely impossible to make. At the other extreme, if tomorrow's weather is highly correlated with the weather today and yesterday, then having a forecast of tomorrow's weather is possible, and would benefit foragers and farmers. But are such forecasts of equal value in foraging and in farming?

Short-term weather forecasts benefit farming and foraging, but probably confer more value to farming than to foraging. Unlike the collection of most wildlife, the cultivation of plants is fixed in space and requires choreographing well-defined tasks that take place in a logical and sequential order – planting, weeding, harvesting, threshing, storing. Short-term weather forecasts can inform today's farming's decisions and increase today's farming productivity. For example, if today is sunny but Tsimane' expect rain tomorrow, they will pull up weeds today so weeds dry well and die from exposure to the sun. (See Supplementary Information).

Now contrast the value of a short-term weather forecast in farming with its value in foraging. If today is sunny and Tsimane' expect rain tomorrow, they will hunt or fish today rather than tomorrow, but there is little in that choice that affects the amount of wildlife collected today because the success of today's collection depends chiefly on the skills of the forager, distribution and visibility of wildlife, and other confounders that have little to do with tomorrow's weather[14]. Weather forecasts might be crucial for a successful farming endeavor, but they would at best affect the mere convenience of hunting.

To test the hypothesis that a short-term weather forecast benefits farming more than foraging we use daily weather data and surveys done on days and time blocks chosen at random in which we asked people about the type and amount of wildlife and planted crops collected during the previous 24 hours. Data covers 11 consecutive months (October 2002-August 2003). To measure future weather we took the *(1)* natural log (hereafter log) of the daily mean of hourly temperature and the log of daily total rain of 1, 2, 3, 4, 5, 6, and 7 days after today and *(2)* the mean of log rain and the mean of log temperature for each of the seven future periods (e.g., mean of rain for tomorrow [day 1], tomorrow and the day after tomorrow [days 1+2], … and one week [days 1+2…7]). We used regressions to estimate the simultaneous effects of future rain and future temperature on two outcomes: *(i)* the probability of collecting wildlife (game, fish, or wild plants excluding firewood) today and *(ii)* the probability of harvesting planted farm crops today.

Information comes from all Tsimane' women (n=311) and men (n=326) ≥14 years of age in 13 Tsimane' villages along the Maniqui River, Beni department[15]. Daily mean hourly temperature (C) and daily total rain (cm) refer to the town-airport of San Borja along the Maniqui River. Villages differed in their closeness to San Borja (mean=25.90 km; std. dev.=16.70). Elsewhere[16,17] we show that daily total rain and the mean of daily hourly temperature in San Borja reflect accurately daily weather in the villages. (See Supplementary Information for sources of weather data).

Table 1 shows two noteworthy findings. First, future weather during the next three days had a significant effect on the probability of today collecting planted farm crops but not on the probability of today collecting wildlife. For example, a 1%-increase in the amount of rain tomorrow, tomorrow and the day after tomorrow, and during the next three days from today reduced the probability of harvesting planted farm crops today by 0.03%, 0.05%, and 0.11%. A 1%-increase in mean temperature tomorrow, tomorrow and the day after tomorrow, and during the next three days from today increased the probability of harvesting planted farm crop today by 0.14%, 0.15%, and 0.21%. In contrast, future weather had no significant effect on today's collection of wildlife.

Second, only future weather over the next three days affected the probability of today harvesting planted farm crops; beyond three days into the future, weather no longer affected the probability of harvesting planted farm crops today. This finding buttresses the ethnographic evidence presented in the Supplementary Information that Tsimane' weather forecasts center on the short term, typically 1-3 days. Results of Table 1 stood up well to further analysis.

Since we control for the weather today and for weather during the seven days before today, future weather must affect today's farming harvest through signs that cue Tsimane' on what the weather will be like over the short-run. (See Supplementary Information for discussion of some of the signs).

Our results *(a)* point to one mechanism through which lower weather variability might have aided farming's diffusion in the short run in the past and *(b)* lend support to policies seeking to enhance the accuracy and accessibility of scientific weather forecasts to low-income rural populations[12].

Table 1. Effects of future rain and temperature on the probability of today collecting wildlife and planted crops

| Coefficient of future weather includes the mean of the log of total daily rain or the mean of the log of the daily mean of hourly temperature for the following # of days after today: | N | Dichotomous dependent variables for today's collection of: | | | | | |
|---|---|---|---|---|---|---|---|
| | | A. Wildlife – *foraging* | | | B. Planted crops - *farming* | | |
| | | Coefficient of future weather: | | $R^2$ | Coefficient of future weather: | | $R^2$ |
| | | Rain | Temperature | | Rain | Temperature | |
| | | | | | | | |
| 1 day (tomorrow) | 7099 | 0.005 | 0.019 | 0.001 | -0.033* | 0.148* | 0.003 |
| 2 days (tomorrow & day after) | 7235 | 0.019 | 0.008 | 0.002 | -0.050* | 0.158* | 0.005 |
| 3 | 7235 | 0.030 | 0.135 | 0.003 | -0.112* | 0.211* | 0.005 |
| 4 | 7235 | -0.003 | 0.125 | 0.002 | -0.076 | 0.190 | 0.005 |
| 5 | 7235 | -0.027 | 0.149 | 0.002 | 0.015 | 0.023 | 0.005 |
| 6 | 7235 | -0.050 | 0.102 | 0.002 | -0.033 | 0.011 | 0.005 |
| 7 | 7235 | -0.034 | 0.352* | 0.002 | -0.021 | 0.113 | 0.005 |

Table 1 includes 14 regressions for two outcomes: seven for *foraging* (A) and seven for *farming* (B). For each outcome, we run seven regressions, one including the log of tomorrow's rain and the log of tomorrow's temperature (row "1 day"), another including the mean of the log of rain of tomorrow and the day after tomorrow and the mean of the log of hourly temperature of tomorrow and the day after tomorrow (row "2"), etc. for all future periods up to the next seven days from today (row "7"). Regressions include individual fixed-effects with clustering by subject and robust standard errors. Survey data used to create dependent variables: *foraging*=1 if the person reported bringing game, fish, or wild plants (except firewood) to the household during the previous 24 hours and zero otherwise and *farming*=1 if the person reported harvesting a planted farm crop during the previous 24 hours and zero otherwise. Control variables include: *(a)* the log of today's mean hourly temperature, *(b)* the log of today's total rain, *(c)* the log of the mean daily total rain for the seven days before today, *(d)* the log of the daily mean of hourly temperature for the seven days before today, *(e)* body-mass index (weight in kg/height in $m^2$) (measured quarterly), and *(f)* full sets of dummy variables for eight surveyors, 13 villages, 11 months of research, seven days of the week, four three-hour time blocks in a day during which surveys took place, and data quality (1=direct observation, 0=proxy respondent). * significant <1%. $R^2$ is overall.

## Supplementary Information

### Software and sample size of regressions

STATA 10 for Windows was used for the statistical analysis (Stata Corporation, 4905 Lakeway Drive, College Station, Texas 7784). In Table 1, the sample size of the regressions with tomorrow's weather as an explanatory variable (row 1) is smaller (n=7099) than the sample size (n=7235) of the other regressions. The difference arises from the way STATA 10 computes the mean of variables across rows. The STATA command "egen x=rowmean (x1 x2 x3)" produces the mean of x1, x2, and x3; if the value of one variable is missing, STATA estimates a mean for the remaining two variables. Nine days had missing data for tomorrow's rain or for tomorrow's temperature, and for these days the mean rain and mean temperature were set to missing values. There were no days with two or more consecutive future days of missing values for weather variables; therefore, the mean of the weather variables for days 1+2, days 1+2+3, days 1+2+3+4, etc. into the future had more observations than the variable for only tomorrow's weather since the mean of a weather variable for two or more days into the future always produced a non-missing value, even if one of the days in the future had a missing value. Later we show that the results of Table 1 barely change if we exclude the observations with missing data for tomorrow's weather and run all the regressions with the same number of observations.

### Creation of weather variable

We equate daily weather with the daily mean of hourly temperature (C) and with daily total rain (cm). Daily weather refers to the town of San Borja. Elsewhere [16,17] we show that the daily mean of hourly temperature and daily total rain in San Borja reflect accurately daily weather in the villages. The section "Sources of weather data" contains a description of where and how we got the weather data.

Because the weather today, the weather in the immediate past, and the weather in the immediate future are correlated, we control for *(a)* the weather during the seven days *before today* and *(b)* for the weather *today* when estimating the effect of *future* weather on today's collection of wildlife and planted crops. We took the log of daily temperature. We added +1 to daily total rain before taking the log of daily rain to avoid producing missing values for days without rain. We next provide more details on how we constructed the weather variables used in the regression analysis.

*First step: future weather day by day*. We took the log of mean daily hourly temperature and the log of daily total rain for 1, 2, 3, 4, 5, 6, and 7 days *after* today. Day 1 refers to tomorrow, day 2 refers to the day after tomorrow, etc. The first step produced a total of 14 variables for future weather, seven variables capturing daily total rain for the next seven days from today and another seven variables capturing the daily mean of hourly temperature for the next seven days from today.

*Second step: future weather – mean values.* Drawing on the values from the first step we took the mean of log daily rain and the mean of log daily temperature for each of the seven future periods. For example, we estimated the mean amount of total daily rain (in logs) for tomorrow (day 1), the mean amount of total daily rain (in logs) for tomorrow plus the day after tomorrow (days 1+2), or the mean amount of total daily rain (in logs) for the next seven days from today (days 1+2+3+4+5+6+7). This step produced 14 additional variables for the mean of weather variables for different periods of time in the future (e.g., mean temperature of tomorrow and the day after tomorrow; mean temperature of the next seven days, etc.).

*Third step: past weather day by day*. We took the log of mean daily hourly temperature and the log of daily total rain for 1, 2, 3, 4, 5, 6, and 7 days *before* today. Day 1 refers to yesterday, day 2 refers to the day before yesterday, etc. The first step produced a total of 14 variables for past weather, seven variables capturing daily total rain for the previous seven days from today and another seven variables capturing the daily mean of hourly temperature for the previous seven days from today.

*Fourth step: past weather – average of last 7 days before today*. Drawing on the values from the third step, we took the mean of log rain and the mean of log temperature for the seven days before today. The fourth step produced two variables for past weather: the mean daily total rain and the mean daily temperature for the previous seven days before today.

*Fifth step: today's weather.* We took the log of today's total rain and the log of today's mean hourly temperature.

In the regressions we only use the variables from second, fourth, and fifth steps. All the variables from the fourth and fifth step appear in all the regressions; among the variables of the second step, only some are entered in each regression, as shown in the first column of Tables 1 and 3.

**Scans and 24-hour recall surveys**

To estimate the effect of daily weather on the collection of wildlife and planted crops requires an unusual panel or longitudinal data set: contemporaneous, repeated daily observations of *(a)* weather, (*b)* amount of wildlife collected, and *(c)* amount of planted crops harvested. *(b)-(c)* must come from the same people and *(a)* must refer to the locality of the people. Our data meets these requirements.

Since the main text of the article and some of the material presented elsewhere in this Supplementary Information contain a description of how we collected weather data and created weather variables, in this section we describe the use of behavioral spot observations (hereafter scans)[18] and 24-hour recall surveys to collect data on the daily collection of wildlife and planted crops.

For scans, we selected at random one day each week and, within the chosen day, we selected at random one block of time of three hours to do the scan. For data collection, we split the chosen day into four three-hour blocks of time: *(1)* 7am-9am, *(2)* 10am-12noon, *(3)* 1pm-3pm, and *(4)* 4pm-6pm. The hours in a block were inclusive; for example, the 7am-9am block went from 7:00am until 9:59am. Of the four blocks of time in a day, we selected at random one block of time to do the scan. During the scan we walked the village at a constant pace and, following standard practice [18], coded what people were doing at the instant we first spotted them. Half of the village was scanned one day and the other half was scanned on a different day. We did 7.27 days of scans each month (median=7.00 days; standard deviation=1.73; total=80 days of scans for the 11 months of research) during 11 consecutive months, so we were able to capture variation in activities throughout the year. Note that the total number of days in which we did scans, 80, is about twice as high as the number of scans one would have from doing scans only one day a week during 11 months (44=11*4); the discrepancy arises because half of a scan in a village was done one day and the other half of the scan in the same village was done next day. After coding the behavior of the person, we asked the person about the type, provenience, and quantity of goods the person had brought to the household during the previous 24 hours. If the person was absent at the time of the scan, we asked a proxy respondent about the current activity, collection of wildlife, and harvest of planted crops by the absent person during the 24 hours before the interview. Later we test whether limiting the analysis to direct observations by the researchers (and excluding answers from proxy respondents) affected the results of Table 1.

**Background on the Tsimane': Subsistence, weather, seasons, and weather forecasts**

Subsistence. The Tsimane' number ~8000 people and live in over 100 villages along riverbanks and logging roads, mostly in the Beni department. Subsistence centers on hunting, collection of wild plants, fishing, and slash-and-burn farming[19]. Because they do not have irrigation to water their planted farm crops, Tsimane' depend on rain to produce their crops. Rain also affects the availability of edible wild plants, and the likelihood of fishing, hunting, and collecting wild plants. Except for some who work as schoolteachers, or who work for logging firms, most Tsimane' make their living from farming their own plots and from foraging. Elsewhere[20] we document the low personal daily income (US$2.35-3.25) and the economic self-sufficiency of the Tsimane'.

The share of observations indicating that people had brought wildlife or planted farm crops to their household on a given day were very similar: 16.93% of observations indicated that people had brought wildlife and 15.69% of observations indicated that people had brought planted farm crops. This result suggests that the absence of an effect of future weather on today's collection of wildlife does not hinge on the low variance of the dependent variable *foraging*; both dependent variables, *foraging* and *farming*, had almost exactly the same share of zeros and ones.

*Foraging* and *farming* had a Pearson correlation coefficient of 0.001 (p=0.909), suggesting that time spent in foraging does not deflect from time spent in farming (and vice versa) and that Tsimane' carry out the two activities independent of each other.

Weather. Figure 1 shows the mean total amount of rain for each month during 1943-2005 (the longest weather record available for San Borja) and for the period of this study (October 2002-August 2003). Both data sources show two seasons: a dry season between May and September and a wet season between October and April. The figure also shows that rain during the study period conformed to long-run trends, except for two months: December (2002) and January (2003). During December (2002) and January (2003), total monthly rain levels were 75.21% and 62.13% below the long-run average for those months.

INSERT FIGURE 1 ABOUT HERE

Figure 2 (A) shows that mean monthly temperature during the study period tracked the long-run (1943-2005) trend of mean monthly temperature. The mean monthly temperature during the study period was 27.36 C, only 1.07 C or 4.06% higher than the mean monthly temperature during 1943-2005 (26.30 C). Figure 2 (B) shows that the mean of the minimum monthly temperature during the study period was higher than the mean of the minimum monthly temperature during 1943-2005. The mean of the minimum monthly temperature during the study period was 20.41 C, 4 .00 C or 24.38% higher than the mean of the minimum monthly temperature during 1943-2005 (16.41 C). Figure 2 (C) shows that the mean of the maximum monthly temperature during the study period was lower than the mean of the maximum monthly temperature during 1943-2005. The mean of the maximum monthly temperature during 1943-2005 was 33.85 C, 2.23 C or only 6.58% higher than the mean of the maximum monthly temperature during the study period (31.62 C).

INSERT FIGURE 2 ABOUT HERE

The weather data suggests that rain and temperature during the study period tracked closely local long-run trends in rain and temperature. The partial exception was minimum temperature.

Seasons. Tsimane' clear the forest during the dry season and let the underbrush and logs dry before burning[19]. They burn the debris and then plant plantains and annual crops such as rice, maize, and manioc amid the dry debris. Planting takes place between August and December, toward the end of the dry season and toward the beginning of the rainy season. If they cut the forest too early or if they wait too long to cut (or if rains arrive early), the debris burns poorly to: *(a)* deposit nutrients into the soil, *(b)* maximize the amount of space available for crops to grow, and *(c)* minimize the amount of labor required to prepare the field for planting[21,22]. *(a)-(c)* affects crop yields. Tsimane' plant perennial crops (e.g., fruit trees) on fallow farm plots or on fallow forests.

Starting in May with the onset of the dry season, many edible fruits in the forest ripen; this is the time when wild animals gain weight and provide ideal prey. The onset of the dry season corresponds with greater frequency and duration of hunting expeditions. Some of the hunting expeditions are done in groups and take many days to finish. The dry season is also the time when Tsimane' use plant poison to fish, which they often do in a group.

In Table 2 we show the percent of observations of people who were foraging or farming during scans (columns A-B) or who had brought wildlife or planted crops to the household during the previous 24 hours (columns D-E). Columns A-B suggest that during May-July people were more likely to be foraging than farming, but with the onset of the planting season from about September until November, the share of people farming surpassed the share of people foraging. For example, during June, 13.51% of the observations from scans showed that people were foraging, compared with only 6.46% of observations showing that people were farming. By October, the share of people foraging during scans was 11.30%, but the share of people doing some type of farm work had risen to 21.53%. The information in columns D-E suggests that dependence on foraging and farming varied across months. During October-December when Tsimane' prepare their farm plots, the probability of bringing wildlife was much higher than the probability of bringing planted crops. For instance, during November and December, 23.96% and 20.62% of people brought wildlife, whereas only 12.42% and 14.50% of people brought planted crops. During February and March when Tsimane' start to harvest annual crops (e.g., rice), the share of people bringing planted crops into the household rises to 19.35% and 17.36% whereas the share of people bringing wildlife into the household drops to 14.17% and 10.83%.

INSERT TABLE 2 ABOUT HERE

Weather forecasts. Most of the rules of thumb Tsimane' use to forecast weather center on the short term or 1-3 days into the future. During open-ended, informal ethnographic interviews Tsimane' said that the following signs today cue them that rains will arrive in the next 1-3 days: *(a)* one or more previous hot days, *(b)* cloud formation (e.g., color, shape, proximity, movement), *(c)* behavior of some wild and domesticated animals, *(d)* halo around stars called *cava'vare*, *(e)* a burial during the previous 1-2 days, and *(f)* holes on the ground made by ants.

During May-July, the *sur* – rains and unusually cold temperatures from the south -- hit the Bolivian lowlands. Tsimane' use the flowering of some wild plants and the singing of some birds to forecast the *sur*'s arrival. During May-July, some Tsimane' listen to reports of current weather from the department of Santa Cruz (which lies to the south-east of the Tsimane' territory) and, based on the arrival of the *sur* in Santa Cruz, estimate the *sur*'s approximate arrival in the Maniqui River. Tsimane' say that depending on wind velocity, the *sur* arrives in the Maniqui River between six hours and one day after it reaches Santa Cruz. Villagers with radios listen to weather reports from Santa Cruz about the *sur* and share the information with other villagers. During 2002-2003, 255 households or 54.14% of the sample of households had a radio.

Except to forecast the *sur*, Tsimane' do not rely on weather reports from radio or from television stations to forecast the weather because stations transmit current weather (rather than forecasts) for departments (rather than for smaller areas). The weather information supplied by radio and television stations is too general to be of use in the Maniqui River because the information refers to the entire department of Beni and because rain in the Amazon can vary within small areas[12].

Tsimane' do not forecast the onset of the rainy season nor the amount of rain they expect during the coming agricultural cycle. We found no evidence that Tsimane' use the position of starts to forecast weather for the coming year, as done by farmers in the Andean highlands[9]. Some Tsimane' said they expected inter-annual weather oscillations.

For example, they expected warm weather one year to be counterbalanced by cooler weather the next year, just as they expected an unusually rainy year to be followed by a dry year.

Tsimane' say that their expectation of tomorrow's weather informs what they will do today. For example, if they expect rain tomorrow, then today they would weed so weeds dry well and die from exposure to the hot sun, wash clothes so clothes dry well, collect firewood, harvest, plant, forage, and take day trips to nearby towns or villages. On rainy days, Tsimane' prefer to rest, prepare home-brewed alcoholic beverages, remove maize husks and grains from cobs, separate rice grains from chaff, do handicrafts, harvest plantains and manioc, and visit other households in the village.

Tsimane' say a rainy day discourages hunting because it: *(a)* hampers a hunter's ability to see or hear wild animals, *(b)* undermines the smelling acuity of hunting dogs, and *(c)* erodes the hunter's ability to move through the forest since the sun's ray cannot bicker through the foliage to help hunters guide their movements. On rainy days, many wild animals hide, making it hard for hunters to spot their prey. Tsimane´ said they could fish during a rainy day, but prefer not to do so because of the discomfort.

**Robustness and limitations**

Robustness. In Table 3 we show the results of additional analysis to ensure the robustness of Table 1. The regressions of Table 3 are identical to the regressions of Table 1 except for the changes noted in the sub-headings of Table 3. For Table 3 we re-estimated the regressions of Table 1 using: *(a)* the day-to-day measures of rain and temperature for the previous seven days from today instead of the mean temperature and the mean rain for the previous seven days from today, *(b)* minimum daily temperature and *(c)* maximum daily temperature instead of the mean of daily hourly temperature, *(d)* only the four main planted crops (rice, maize, manioc, and plantains) instead of any planted crop, *(e)* only fish and wild game and not wild plants, *(f)* only the months when the *sur* does not strike, *(g)* only observations with complete data for future weather, and *(h)* only direct observations (i.e., exclude answers from proxy respondents). We next explain the rationale for introducing these changes.

INSERT TABLE 3 ABOUT HERE

We do *(a)* to ensure that our results are indeed driven by future weather, rather than by an aspect of past daily weather that may be predictive of future weather but lost when we aggregate data on weather for a week. Recall from the previous discussion that Tsimane' use warm weather to predict rain, so it is possible that today's collection of planted crops or today's collection of wildlife responds more to maximum or to minimum daily temperature than to mean daily temperature. For this reason we do *(b)* and *(c)*. We do *(d)* and *(e)* because some so-called wild plants may have been planted long ago[23], and some planted crops may have been planted so long ago that they could be considered wild. Limiting the analysis to the four main planted crops that are unlikely to be harvested in their wild state, and limiting the analysis to fish and wild game allows us to obtain sharper results for *farming* and for *foraging*. Excluding the months when the *sur* strikes (May-July, inclusive) *(f)* allows us to remove the potential effect of weather reports from radio stations because Tsimane' are most likely to listen to such reports during the months when the *sur* strikes. The results of Table 1 could be biased by the missing observations for tomorrow's weather and rain. As Table 1 shows, and as discussed earlier, the number of observations is lower for the first regression (row 1 day) than for all other regressions because of the missing values for tomorrow's weather. To address this issue, we re-estimate the regressions of Table 1 using the same observations (n=7099) for all the regressions *(g)*. Last, proxy respondents may have provided inaccurate answers about the absent person, and results could change if we limit the analysis only to events directly observed by the researchers *(h)*.

With two exceptions, the results of Table 3 support the findings of Table 1. Using maximum temperature (C), limiting the analysis to the four main planted crops (D) and to fish and wild game (E), or using only observations without missing data for tomorrow's weather (G) confirmed the previous results that weather during the next three days from today had a significant effect on the harvest of planted crops but not on the collection of wildlife. Excluding the months when the *sur* strikes (F) made four of the six coefficients under *farming* that were statistically significant in Table 1, statistically insignificant at the 99% confidence level or higher in Table 3 because of the reduction in sample size, but the sign of the weather coefficients under *farming* remained the same and the size of these coefficients did not change much. For instance, the effect of a 1%-increase in rain tomorrow lowered the probability of collecting planted farm crops today by 0.03% in Table 1 (p=0.007); if we limit the analysis to the months without the *sur*, the coefficient drops to 0.02% (p=0.085). Limiting the analysis to direct observations (H) reduces the sample size for most regressions by 42% (from 7235 to 4190) and makes four of the six coefficients under *farming* that were statistically significant in Table 1, statistically insignificant at the 1% level in Table 3, but the size of coefficients for temperature for tomorrow, for the day after tomorrow, and for the two days from today increased considerably – from 0.148, 0.158, and 0.211 in Table 1, to 0.180, 0.225, and 0.294 in Table 3 (H). Thus, though statistically weaker, the size of the effect of future weather on the collection of planted crops increases.

Section (A) of Table 3 produced weaker results and section (B) of Table 3 produced unexpected results compared with the results of Table 1. Using day-to-day measures of total rain and the mean of hourly temperature for the seven days before today (A) reduced the size of the coefficients for future weather in both *farming* and *foraging* and made them statistically insignificant. A comparison of the coefficients for future rain and temperature for one, two, and three days from today (rows 1-3) between Table 1 and Table 3 (section A) shows that the coefficients for rain fell by an average of 41.04% and that the coefficients for temperature fell by an average of 23.73%. The reduction in the size of the coefficients suggests that the *(i)* sign of the indirect effect from excluding day-to-day weather variables for the seven days before today in Table 1 is positive and *(ii)* that the loss of statistical significance likely could have resulted from the multicollinearity of including 14 additional regressor and reducing the sample size from about 7235 observations to 6909 observations.

The use of minimum temperature (B) suggests that future minimum daily temperature 2-6 days from today has a significant positive effect on the collection of wildlife; on average, an increase of 1% in minimum temperature during the next 2-6 days from today increased the probability of collecting wildlife today by 0.16-0.29%. In the regression with *farming* as a dependent variable the use of minimum daily temperature made the coefficients for the mean of daily minimum temperature for the next one, two, and three days from today (rows 1-3) about 70% smaller than the coefficients for the mean of daily temperature for the next one, two, and three days from today in Table 1. In the regressions with *farming* as a dependent variable the use of minimum daily temperature did not affect the coefficients for future rain during the next two and three days from today; these coefficients remained essentially unchanged from Table 1 and statistically significant.

Limitations. The study contains at lest two limitations. First, our data is not refined enough to allow us to estimate how future weather might affect different stages of the farming or foraging cycle. The dependent variables in Table 1 refer only to the collection of wildlife or to the harvest of planted farm crops and come from 24-hour recall surveys. Foraging requires several steps, such as pursuit and collection. Farming also requires several steps, such as cutting and burning the forest, planting, weeding, and harvesting. Future weather might have different effects on these steps. Second, it is possible that weather forecasts for the next 1-3 days have an impact on the harvest of planted farm crops, but only in areas with abundant perennial farm crops (e.g., plantains, tree crops), such as the Amazon. The effect of short-run weather forecasts on the harvest of planted farm crops might be weaker in areas without (or with less) perennial crops or in areas that depend heavily on planted annual crops.

**Notes**

The Cultural and Physical Anthropology Programs of the National Science Foundation, USA, provided funding for the research. The Institutional Review Board for research with human subjects of Northwestern University approved the study protocol. The Great Tsimane’ Council also approved the study. Before enrollment in the study we obtained assent from participants. Xia Meng and Wu Zeng provided computational assistance. Thanks to P. Richerson, K. Bawa, J. Morduch, and E. Moran for commenting on earlier drafts.

Table 2. Percent of observations of people foraging or farming at the time of scan or who had collected wildlife or planted crops during the 24 hours before the scan: monthly data, October 2002-August 2003

| | | During scan person was: | | | In 24-hour recall, person brought: | | |
|---|---|---|---|---|---|---|---|
| Year | Month | Foraging | Farming | Obs | Wildlife | Planted crops | Obs |
| | | ***[A]*** | ***[B]*** | ***[C]*** | ***[D]*** | ***[E]*** | ***[F]*** |
| 2002 | | | | | | | |
| | October | 11.30 | 21.53 | 469 | 13.48 | 9.05 | 519 |
| | November | 11.74 | 13.10 | 954 | 23.96 | 12.42 | 1014 |
| | December | 15.66 | 6.92 | 664 | 20.62 | 14.50 | 703 |
| 2003 | | | | | | | |
| | January | 11.46 | 7.31 | 916 | 15.43 | 15.33 | 1004 |
| | February | 7.76 | 13.48 | 927 | 14.17 | 19.35 | 1023 |
| | March | 5.91 | 21.11 | 947 | 10.83 | 17.36 | 1071 |
| | April | 7.74 | 17.58 | 813 | 15.31 | 18.81 | 914 |
| | May | 11.01 | 6.13 | 554 | 17.11 | 16.93 | 555 |
| | June | 13.51 | 6.46 | 866 | 19.73 | 16.90 | 917 |
| | July | 11.57 | 5.57 | 950 | 17.58 | 14.68 | 1103 |
| | August | 6.80 | 4.25 | 235 | 20.26 | 11.76 | 306 |

Notes:

Obs = observations
Column A: Person was hunting, fishing, or collecting feral plants other than firewood.
Column B: Person was planting, harvesting, weeding, or processing any planted farm crop.
Column C: Person brought fish, game, or feral plants other than firewood
Column D: Person brought a planted crop into the household

Table 3. Robustness analysis of Table 1

| Coefficient of future weather includes the mean of the log of total daily rain or the mean of the log of the daily mean of hourly temperature for the following # of days after today: | N | Dichotomous dependent variables for today's collection of: | | | | | |
|---|---|---|---|---|---|---|---|
| | | A. Wildlife – *foraging* | | | B. Planted crops - *farming* | | |
| | | Coefficient of future weather: | | $R^2$ | Coefficient of future weather: | | $R^2$ |
| | | Rain | Temperature | | Rain | Temperature | |
| A. Log of daily rain and log of daily temperature for previous 7 days entered separately day by day | | | | | | | |
| 1 day (tomorrow) | 6909 | -0.006 | -0.026 | 0.020 | -0.015 | 0.089 | 0.009 |
| 2 days (tomorrow & day after) | 6909 | -0.019 | -0.010 | 0.020 | -0.030 | 0.119 | 0.009 |
| 3 | 6909 | -0.006 | 0.062 | 0.021 | -0.080* | 0.197 | 0.010 |
| 4 | 6909 | -0.016 | -0.017 | 0.021 | -0.059 | 0.214 | 0.009 |
| 5 | 6909 | -0.021 | -0.037 | 0.003 | 0.015 | 0.042 | 0.008 |
| 6 | 6909 | -0.040 | -0.121 | 0.019 | -0.028 | -0.048 | 0.008 |
| 7 | 6909 | -0.057 | 0.159 | 0.022 | -0.027 | 0.156 | 0.009 |
| B. Minimum daily hourly temperature instead of average daily hourly temperature | | | | | | | |
| 1 day (tomorrow) | 7099 | 0.003 | 0.115 | 0.001 | -0.025 | 0.044 | 0.003 |
| 2 days (tomorrow & day after) | 7235 | 0.003 | 0.163* | 0.002 | -0.047* | 0.035 | 0.005 |
| 3 | 7235 | 0.035 | 0.260* | 0.005 | -0.101* | 0.079 | 0.006 |
| 4 | 7235 | -0.009 | 0.296* | 0.004 | -0.071 | 0.110 | 0.005 |
| 5 | 7235 | -0.062 | 0.281* | 0.002 | 0.013 | 0.153 | 0.005 |
| 6 | 7235 | -0.089 | 0.258* | 0.001 | -0.025 | 0.245 | 0.005 |
| 7 | 7235 | -0.086 | 0.223 | 0.001 | -0.021 | 0.317* | 0.005 |
| C. Maximum daily hourly temperature instead of average daily hourly temperature | | | | | | | |
| 1 day (tomorrow) | 7099 | 0.001 | -0.106 | 0.001 | -0.028 | 0.189* | 0.003 |
| 2 days (tomorrow & day after) | 7235 | 0.014 | -0.071 | 0.003 | -0.056* | 0.200* | 0.005 |
| 3 | 7235 | 0.027 | 0.049 | 0.003 | -0.121* | 0.260* | 0.006 |
| 4 | 7235 | -0.023 | 0.064 | 0.002 | -0.086* | 0.221* | 0.005 |
| 5 | 7235 | -0.061 | 0.110 | 0.002 | -0.008 | 0.256* | 0.005 |
| 6 | 7235 | -0.083 | 0.083 | 0.001 | -0.074 | 0.287* | 0.005 |
| 7 | 7235 | -0.070 | 0.104 | 0.001 | -0.062 | 0.305 | 0.005 |

Table 3 - continued

| Coefficient of future weather includes the mean of the log of total daily rain or the mean of the log of the daily mean of hourly temperature for the following # of days after today: | N | Dichotomous dependent variables for today's collection of: | | | | | |
|---|---|---|---|---|---|---|---|
| | | A. Wildlife – *foraging* | | | B. Planted crops - *farming* | | |
| | | Coefficient of future weather: | | $R^2$ | Coefficient of future weather: | | $R^2$ |
| | | Rain | Temperature | | Rain | Temperature | |
| D. Farming limited to four main planted crops: maize, rice, manioc, and plantains | | | | | | | |
| 1 day (tomorrow) | 7099 | Not applicable | | | -0.035* | 0.125* | 0.002 |
| 2 days (tomorrow & day after) | 7235 | | | | -0.053* | 0.139 | 0.005 |
| 3 | 7235 | | | | -0.113* | 0.188* | 0.005 |
| 4 | 7235 | | | | -0.080* | 0.170 | 0.005 |
| 5 | 7235 | | | | 0.004 | 0.022 | 0.004 |
| 6 | 7235 | | | | -0.040 | 0.020 | 0.005 |
| 7 | 7235 | | | | -0.029 | 0.113 | 0.005 |
| E. Wild plants excluded from foraging; only fish and wild game included | | | | | | | |
| 1 day (tomorrow) | 7099 | -0.0008 | 0.00008 | 0.006 | Not applicable | | |
| 2 days (tomorrow & day after) | 7235 | 0.007 | 0.027 | 0.001 | | | |
| 3 | 7235 | 0.004 | 0.132 | 0.001 | | | |
| 4 | 7235 | -0.032 | 0.129 | 0.001 | | | |
| 5 | 7235 | -0.044 | 0.091 | 0.001 | | | |
| 6 | 7235 | -0.048 | 0.051 | 0.001 | | | |
| 7 | 7235 | -0.052 | 0.160 | 0.001 | | | |
| F. Limited to August-April (inclusive), the months without *sur* | | | | | | | |
| 1 day (tomorrow) | 5355 | 0.002 | 0.030 | 0.008 | -0.027 | 0.134 | 0.006 |
| 2 days (tomorrow & day after) | 5355 | 0.031 | -0.012 | 0.009 | -0.057* | 0.192 | 0.006 |
| 3 | 5355 | 0.051 | 0.158 | 0.008 | -0.135* | 0.175 | 0.008 |
| 4 | 5355 | 0.025 | 0.038 | 0.008 | -0.095 | 0.214 | 0.007 |
| 5 | 5355 | 0.004 | 0.126 | 0.009 | -0.002 | -0.047 | 0.006 |
| 6 | 5355 | -0.057 | -0.009 | 0.008 | -0.076 | -0.147 | 0.006 |
| 7 | 5355 | 0.013 | 0.200 | 0.009 | -0.063 | -0.079 | 0.006 |

Table 3. Robustness analysis of Table 1

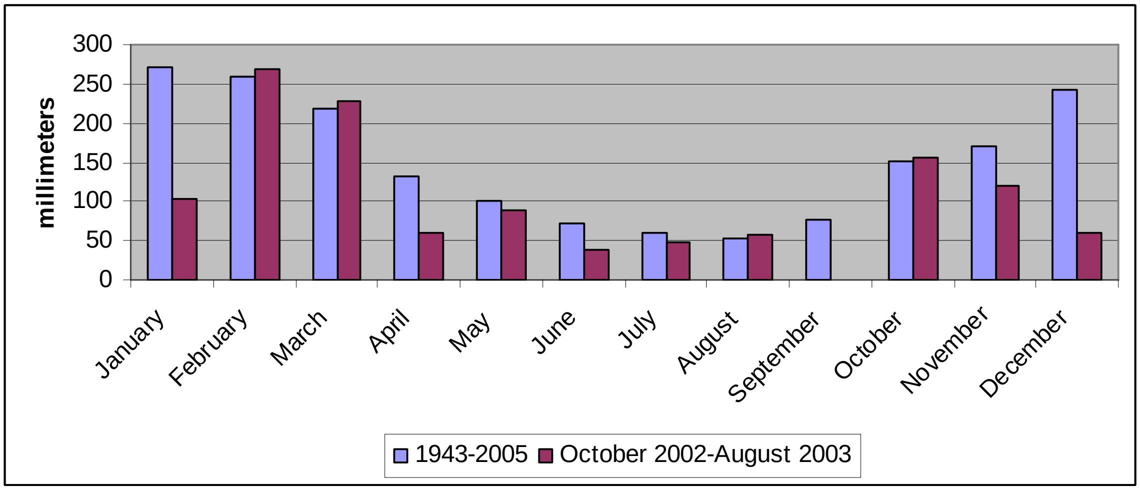
| Coefficient of future weather includes the mean of the log of total daily rain or the mean of the log of the daily mean of hourly temperature for the following # of days after today: | N | Dichotomous dependent variables for today's collection of: | | | | | |
|---|---|---|---|---|---|---|---|
| | | A. Wildlife – *foraging* | | | B. Planted crops - *farming* | | |
| | | Coefficient of future weather: | | $R^2$ | Coefficient of future weather: | | $R^2$ |
| | | Rain | Temperature | | Rain | Temperature | |
| G. Excluding days with missing weather for tomorrow to equalize the sample size of observations across regressions | | | | | | | |
| 1 day (tomorrow) | 7099 | 0.005 | 0.019 | 0.001 | -0.033* | 0.148* | 0.003 |
| 2 days (tomorrow & day after) | 7099 | 0.024 | -0.011 | 0.001 | -0.055* | 0.169* | 0.003 |
| 3 | 7099 | 0.037 | 0.109 | 0.001 | -0.118* | 0.225* | 0.003 |
| 4 | 7099 | 0.002 | 0.085 | 0.001 | -0.082* | 0.212 | 0.003 |
| 5 | 7099 | -0.018 | 0.118 | 0.001 | 0.008 | 0.037 | 0.003 |
| 6 | 7099 | -0.038 | 0.058 | 0.001 | -0.041 | 0.035 | 0.003 |
| 7 | 7099 | -0.025 | 0.309* | 0.001 | -0.032 | 0.151 | 0.003 |
| H. Analysis limited to direct observations by researchers (excludes data from proxy respondents) | | | | | | | |
| 1 day (tomorrow) | 4130 | 0.021 | -0.051 | 0.014 | -0.021 | 0.180 | 0.001 |
| 2 days (tomorrow & day after) | 4190 | 0.040 | -0.067 | 0.001 | -0.052 | 0.225 | 0.001 |
| 3 | 4190 | 0.045 | 0.069 | 0.007 | -0.108* | 0.294* | 0.001 |
| 4 | 4190 | 0.019 | 0.041 | 0.007 | -0.045 | 0.279 | 0.001 |
| 5 | 4190 | -0.008 | 0.088 | 0.001 | 0.067 | 0.138 | 0.001 |
| 6 | 4190 | -0.037 | 0.052 | 0.007 | 0.002 | 0.155 | 0.001 |
| 7 | 4190 | -0.024 | 0.402* | 0.001 | 0.035 | 0.280 | 0.001 |

*Notes*

Same notes and definitions as Table 1

A. Instead of using the log of the mean hourly temperature and the log of mean daily total rain for the seven days before today, we introduce the log of mean daily hourly temperature and the log of daily total rain for each of the seven days before today; this produces 14 additional explanatory variables.

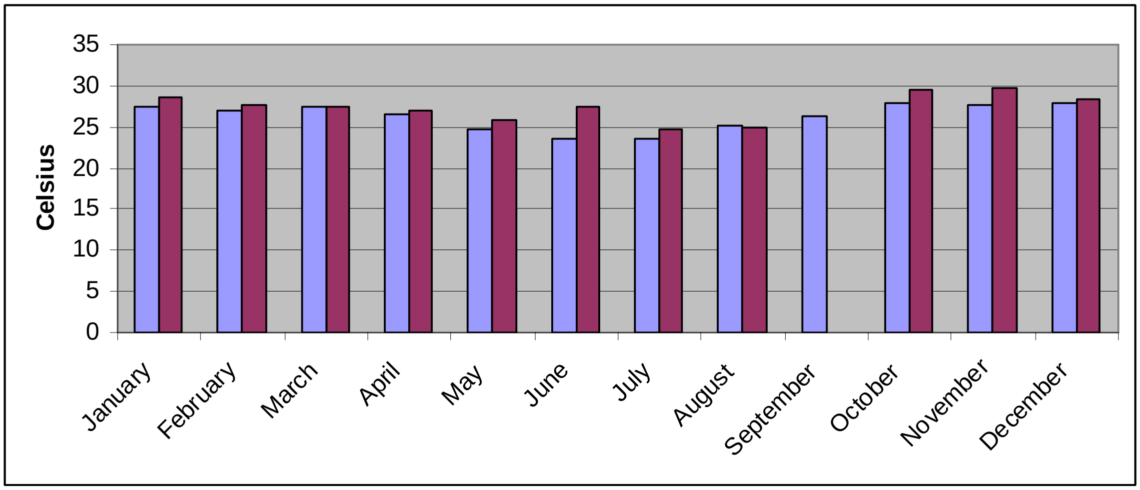
Figure 1. Average total monthly rain in the airport in the town of San Borja: 1943-2005 and October 2002-August 2003



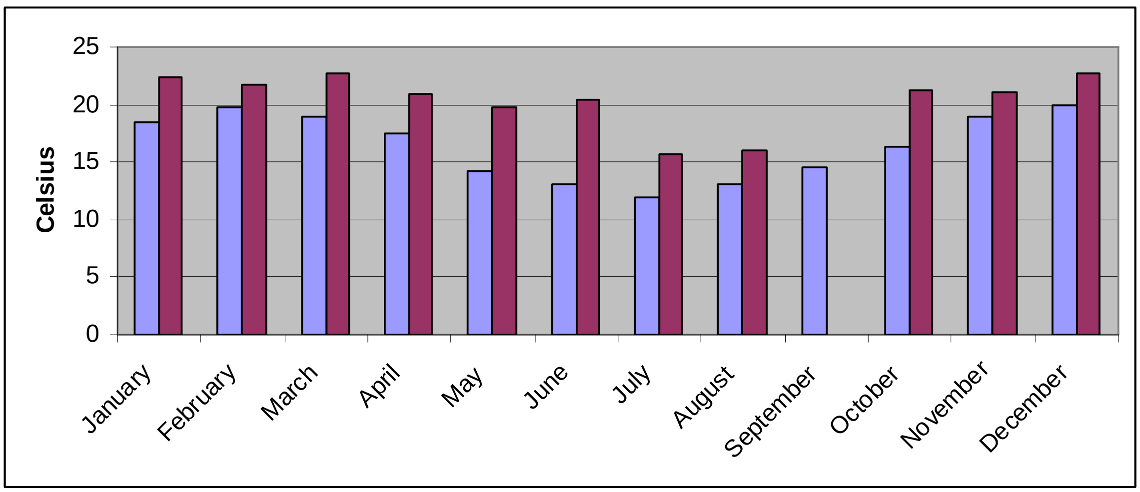

Source for Figures 1-2: [17] and section "Sources for weather data"

Figure 2. Monthly temperature in the airport in the town of San Borja: 1943-2005 and October 2002-August 2003

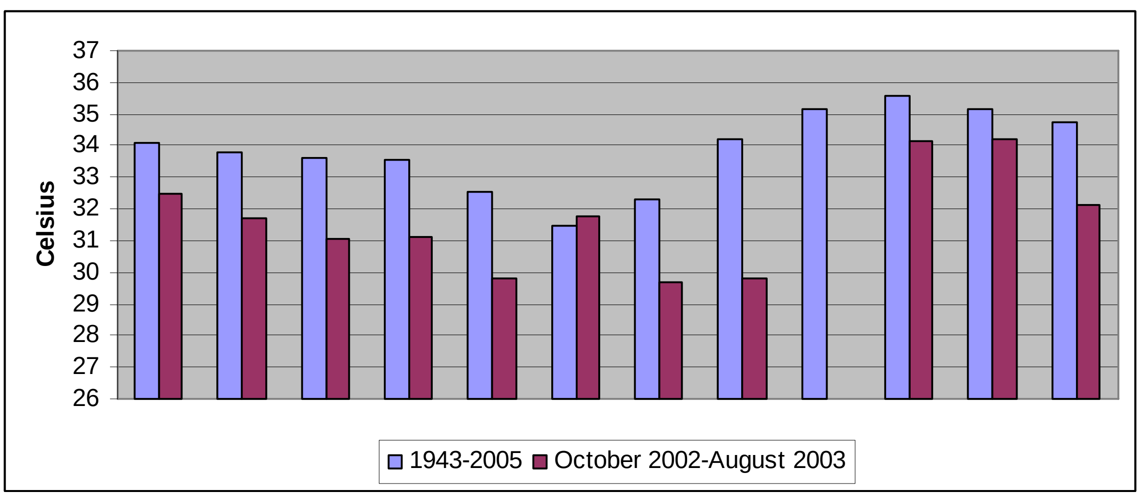
A. Mean




B. Minimum




C.Maximum



**Sources for weather data**

1) Source: National Oceanic & Atmospheric Administration (NOAA); US department of Commerce

a) Home page. http://www.noaa.gov/

b) Data downloaded from this link. http://www.ncdc.noaa.gov/oa/ncdc.html (Data link)

c) For free data. http://www.ncdc.noaa.gov/oa/mpp/freedata.html

d) Scroll down to free data J- Surface data- Global summary of the day.

- Select the country
- Choose the station of interest (in this case San-Borja, Rurranbaque, and Trinidad)

e) Data from Jan 2002 to Dec 2003 was downloaded.

2) **Address:**

National Climatic Data Center
Federal Building
151 Patton Avenue
Asheville NC 28801-5001
1-828-271-4800
FAX: 1-828-271-4876
**Email: ncdc.info@noaa.gov**

All contact information for various departments can be access through this link
**http://www.ncdc.noaa.gov/oa/about/ncdccontacts.html**

**3) Coding**

First record-- header record.
All ensuing records--data records as described below.
All 9's in a field (e.g., 99.99 for PRCP) indicates no report or insufficient data.

| FIELD | POSITION | TYPE | DESCRIPTION |
|---|---|---|---|
| STN | 1-6 | Int | Station number (WMO/DATSAV3 number) for the location. |
| WBAN | 8-12 | Int | WBAN number where applicable--this is the historical "Weather Bureau Air Force Navy" number - with WBAN being the acronym. |
| YEAR | 15-18 | Int | The year |
| MODA | 19-22 | Int | The month and day |
| TEMP | 25-30 | Real | Mean temperature for the day in degrees Fahrenheit to tenths. Missing = 9999.9 (Celsius to tenths for metric version.) |
| MAX | 103-108 | Real | Maximum temperature reported during the day in Fahrenheit to tenths--time of max temp report varies by country and region, so this will sometimes not be the max for the calendar day. Missing = 9999.9 (Celsius to tenths for metric version.) |
| Flag | 109-109 | Char | Blank indicates max temp was taken from the explicit max temp report and not from the 'hourly' data. * indicates max temp was derived from the hourly data (i.e., highest hourly or synoptic-reported temperature) |
| MIN | 111-116 | Real | Minimum temperature reported during the ay in Fahrenheit to tenths--time of min temp report varies by country and region, so this will sometimes not be the min for the calendar day. Missing = 9999.9(Celsius to tenths for metric version.) |
| Flag | 117-117 | Char | Blank indicates min temp was taken from the explicit min temp report and not from the hourly' data. * indicates min temp was derived from the hourly data (i.e., lowest hourly or synoptic-reported temperature) |
| PRCP | 119-123 | Real | Total precipitation (rain and/or melted snow) reported during the day in inches and hundredths; will usually not end with the midnight observation--i.e., may include latter part of previous day.<br>.00 indicates no measurable precipitation (includes a trace).<br>Missing = 99.99 (For metric version, units = millimeters to tenths & missing = 999.9.<br>Note: Many stations do not report '0' on days with no precipitation--therefore, '99.99' will often appear on these days. Also, for example, a station may only report a 6-hour amount for the period during which rain fell. See Flag field for source of data. |
| Flag | 124-124 | Char | A = 1 report of 6-hour precipitation amount.<br>B = Summation of 2 reports of 6-hour precipitation amount.<br>C = Summation of 3 reports of 6-hour precipitation amount.<br>D = Summation of 4 reports of 6-hour precipitation amount.<br>E = 1 report of 12-hour precipitation amount.<br>F = Summation of 2 reports of 12-hour precipitation amount.<br>G = 1 report of 24-hour precipitation amount.<br>H = Station reported '0' as the amount for the day (e.g., from 6-hour reports), but also reported at least one occurrence of precipitation in hourly observations--this could indicate a trace occurred, but should be considered as incomplete data for the day.<br>I = Station did not report any rain data for the day and did not report any occurrences of precipitation in its hourly observations--it's still possible that rain occurred but was not reported. |

The NCDC Climate Services Branch (CSB) is responsible for distribution of NCDC products to users. NCDC's CSB can be contacted via the following phone number, internet address, or fax number:

Telephone Number: 1-828-271-4800
Fax Number: 1-828-271-4876
Internet Address: ncdc.orders@noaa.gov

4) Methods used to impute the missing values

- Daily temperature comes from hourly records of temperature. Daily temperature was converted to centigrade using the following formula,
  T in C= [(T in F-32)/9]*5
- Rain data refers to the total for a given day and was given in inches; multiplied by 2.54 to convert into centimeters
- If San Borja had a missing value, we imputed the mean value from Trinidad and Rurrenabaque, two nearby towns. Recent publications contain discussion of imputation methods for missing weather data[16,17].

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