El Niño signature in Alaskan river breakups

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A signature of El Niño-Southern Oscillation is found in the historical dataset of the Alaskan Tanana river breakups where the average ice breaking day is found to anticipate of about 3.4 days when conditioned over El Niño years. This results represents a statistically significant example of ENSO teleconnections on regions remote from tropical Pacific.

The El Niño-Southern Oscillation (ENSO) is the most important recurrent pattern in the interannual climate variability. It corresponds to anomalous warm water in the tropical Pacific ocean (El Niño) coupled to an atmospheric pattern over Indian and Pacific oceans which strongly reduces trade winds. Basic physical ingredients for the appearance of El Niño, occurring irregularly every 2 to 7 years, are now understood, but the extension of its impact is still partially unknown [1]. The effects of El Niño are more consistent in the tropical Pacific areas. At higher latitudes and in remote areas the impact is less deterministic: a single event is mediated by local meteorological conditions and ENSO-related variations are better characterized in a statistical sense. Recent statistical studies have reported effects on a wide spectrum of human and natural activities via the so-called teleconnections. To cite some examples, ENSO signature has been found in forest fire statistics, in disease epidemics and in financial market [1]. Here we report the analysis of ENSO teleconnections on the date of ice breakup in Tanana river in Nenana, Alaska. Thanks to the rather long time dataset (90 years) it is possible to disentangle the imprint of ENSO signal on the local meteorological noise with good statistical significance.

The Tanana data set is an non-conventional time series obtained from the Nenana Ice Classis lottery. Since 1917, participants to the lottery have to guess the day (and minute) of "official" Tanana river breaking, defined as the time at which a wooden tripod frozen into the river moves and stops a clock mechanism at the shore [2]. Nenana is still a small town of about 500 people, and the tripod has been placed in about the same section of the river, therefore we can assume that local conditions are not much changed in the 90 years of record. Moreover, ice breaking in rivers is a complex phenomenon due to both direct thermal (local temperature) and mechanical (snow melting upstream) effects and therefore it is a good indicator of the seasonal climate of the region. For this reason, ice breaking in rivers and lakes has been used to infer trends in climate variation over the past centuries [3]. In particular, the analysis of Tanana dataset revealed a negative (anticipating) trend in the breakup day of about 5.5 days [4]. Our observation of ENSO modulations in the Tanana dataset gives a support to the climatological origin of the observed trend. The 90-year record of Tanana (Fig. 1A) shows large variability with a breakup day ranging from April 20 (in 1940 and 1998) (day $d = 110$ of the year) to May 20 (in 1964) ($d = 140$). Without taking into account trends (but correcting for leap years), the mean breakup day is $< d >= 124.7$, corresponding to May 5th. The underlying distribution is rather wide, with a variance $\sigma_d = 5.97$ days.

El Niño years are classified by a number of different criteria. Mostly used are the an oceanic index based on Sea Surface Temperature (SST) anomalies, and the atmospheric Southern Oscillation Index (SOI) based on pressure difference between Tahiti and Darwin [1]. The present analysis makes use of the NOAA Bivariate EnSo Timeseries (BEST) index [5] which is a combination of Niño 3.4 SST and SOI with a 5-month running mean. El Niño years are defined as those for which the Best index is positive for at least four months between previous October and April. Changes in the details of this definition do not alter significantly the results. According to this definition, there have been 14 El Niño years between 1917 and 2006, the most recent ones in $2002 - 03$ and in $1997 - 98$. In particular, the $1997 - 98$ was a strong El Niño winter followed by one of the two earliest breakup in Tanana (the other, in 1940, also followed an El Niño winter). This coincidence suggests possible connections between ENSO and ice breaking in Tanana river.

We have analyzed the correlation between Tanana dataset and Best index by computing the mean breaking day conditioned to El Niño years. The resulting $< d^* >= 121.3$ significantly differs from the unconditioned mean by a 3.4 day difference. In order to give a statistical meaning to the observed anticipation in breakup, we can make the null hypothesis of no correlation and perform a simple test based on Monte Carlo surrogate data. By taking $N = 14$ random years uniformly distributed between 1917 and 2006, we compute the mean breaking day $\bar{d}$ conditioned over these years. By definition the average value over many realizations is again $< \bar{d} >= 124.7$ with a distribution very close to a Gaussian (thanks to the Central Limit Theorem) with variance of the mean $\sigma_{\bar{d}} = \sigma_d/\sqrt{N} \simeq 1.6$. Conditioning over El Niño therefore gives a mean breakup day $< d^* >$ which is at 2.3 standard deviations below the mean. The probability that such a small value has been obtained by chance is only of 1.1% and we can refute the null hypothesis (no correlation) with a 98.9% of confidence (see Fig. 1B).

Both temperature and snowfall contribute to the breaking of ice in a complex way. In the case of lakes, the response to temperature variations is known to be strongly non-linear [6], while the presence of snow has less known net effect as from one side protects ice from melting but, from the other side, increases the water flow below. In order to get more insight on the physical mechanisms of the breakup, we have analyzed the meteorological data of the Alaska Climate Research Center of the University of Alaska at Fairbanks [7]. This remarkable dataset gives the minimum and maximum air temperature, precipitation, snowfall and snow depth with daily resolution for 77 years (1930-2006) in the town of Fairbanks, about 90 km upstream Nenana. We have found that both maximal temperature and snowfall (and snowdepth) are statistically affected by ENSO. The average maximal temperature of the first 120 days (Jan-Apr) rises from $-7.6\ ^oC$ to $-6.3\ ^oC$ if conditioned over the 12 El Niño events of the period while the total snowfall on the same period decreases during El Niño years from an average 75 cm to 55 cm. The probabilities that these variations are due to random fluctuations are comparable and, when evaluated with MonteCarlo surrogates, are around 3%. A direct consequence of reduced snowfall and increased temperature during ENSOs is the acceleration of snow melting on ground, which is one of the known mechanisms for ice breaking. Indeed, we have found that ice breaking days in Nenana are strongly correlated with the "no-snow" days in Fairbanks (defined as the first day without snow on ground). Indeed the correlation coefficient between the two dates on the whole 90 years dataset is $\rho \simeq 0.50$.

In conclusion, the breakup of Alaskan Tanana river is shown to be influenced by El Niño condition in the previous winter. This result supports the extension of ENSO teleconnections to regions remote from tropical Pacific. At these latitudes effects are significant only in a statistical sense and therefore can be resolved on the bases of sufficiently long dataset. Unfortunately, their knowledge is of little use for betting in the next Nenana lottery.

[1] M.J. McPhaden, S.E. Zebiak and M.H. Glantz, *Science*, **314**, 1740 (2006).

[2] See `http://www.nenanaakiceclassic.com/`

[3] J.J Magnuson *et al.*, *Science*, **289**, 1743 (2000).

[4] R. Sagarin and F. Micheli, *Science*, **294**, 811 (2001).

[5] See `http://gcmd.nasa.gov/records/GCMD_NOAA_NWS_CPC_BEST.html`

[6] G.A. Weyhenmeyer, M. Meili and D.N. Livingstone, *Geophys. Res. Lett.*, **31**, L07203 (2004).

[7] Alaska Climate Research Center, see `http://climate.gi.alaska.edu/`

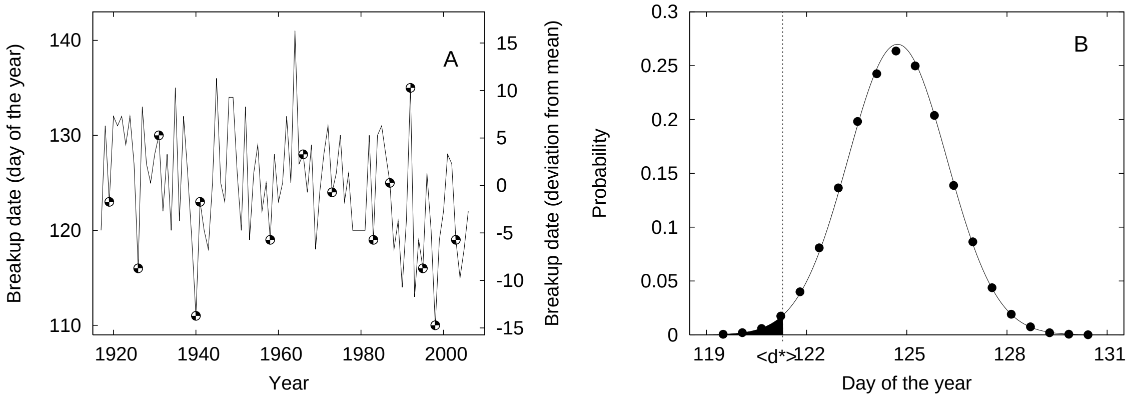

FIG. 1: (A) Breakup date of the Tanana river from the Nenana Ice Classic lottery. Points correspond to El Niño years. (B) Probability density function of 10^6 MonteCarlo realizations of the mean breaking day $\bar{d}$ averaged over $N = 14$ random years in the range 1917-2006. Line represents a Gaussian with the same mean and variance. The vertical line indicates the mean breaking day conditioned over ENSO years, $< d^* >= 121.3$. The probability of a random realization of these years is given by the black area left to the line and is equal to 1.1%.