The Emergence of El-Niño as an Autonomous Component in the Climate Network

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Introduction

The temperature and pressure fluctuations of different locations l,r in the same atmospheric layer can be viewed as dynamical systems with interactions. It is possible that l and r have correlated behavior (sometimes with a lag time) due to common forcing mechanisms (such as solar insolation), material flow (salt, dust, water, air) between l and r, direct pressure of l and r on each other, and heat flow between them. These correlations are commonly studied with the aid of eigen-techniques such as principal component analysis, yielding a few fluctutation profiles that are typical.

However these correlations are quite a robust field on their own right, and the profiles of this field, which we call "the climate network" have been the topic of recent studies [A1-4,B1-5]. We have demonstrated [B1-3,A2] that during El-Nino times large portions of this field have a reduced value, corresponding to a less correlated atmosphere. We are now able to pinpoint a peculiar and rich pattern in this effect - the unique autonomous component in the eastern pacific [B4]. We have elaborated a four altitude/two fields (temperature and geopotential heights)/10000 snapshots (corresponding to 10 days reolution over 30 years) survey of the climate network, which presents the behavior of this autonomous component. This includes the distribution of places that strongly correlate with this component, the distribution of its time delays with the environment, and an interesting altitude dependent profile of its interactions with the northern and southern hemispheres. We have also compiled the leading profiles of this information (main principle component), which are shown to be related to the different stages of the El-Nino Southern Oscillations (see an animation of the fields in [A5]).

Methods

We compute for a time shift $\tau \in [-\tau_{\max}, \tau_{\max}]$ days for each pair of sites **l** and **r** on the grid, their cross covariance function

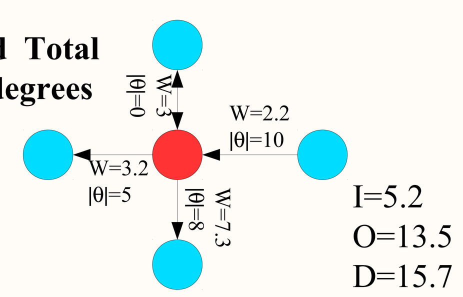
$$X^y_{l,r}(\tau>0)=\frac{\left(\langle T^d_l(\tau)T^d_r(d+\tau)\rangle_d-\langle T^d_l(\tau)\rangle_d\langle T^d_r(d+\tau)\rangle_d\right)}{\sqrt{\langle (T^d_l(\tau))^2\rangle_d-\langle T^d_l(\tau)\rangle^2_d}\sqrt{\langle (T^d_r(d+\tau))^2\rangle_d-\langle T^d_r(d+\tau)\rangle^2_d}}$$

The correlation strength of the link is chosen to be

$$W^y_{l,r}=\max(|X^y_{l,r}|)/\mathrm{std}(|X^y_{l,r}|)$$

Direction: The time shift of the highest peak of the cross covariance function from zero time shift is denoted $\theta^y_{l,r}$. The sign of $\theta^y_{l,r}$ stands for the dynamical ordering of l and r when $\theta^y_{l,r}>0$ the link is regarded as outgoing from node l and incoming to node r.

In,Out,and Total weighted degrees



Results

As seen in Fig.1a, there is a group of nodes, **C**, that have lower values at any time, and are specifically distinct during El-Niño (wide yellow stripes). We find that measuring the dynamics of the interactions of the **C** region with its surroundings yields a sensitive tool to quantify the responses of I and O to El-Niño events. Figs. 1b,c show I^y_C and O^y_C , the in– and out– weighted degree of **C** (which includes 14 nodes), respectively.

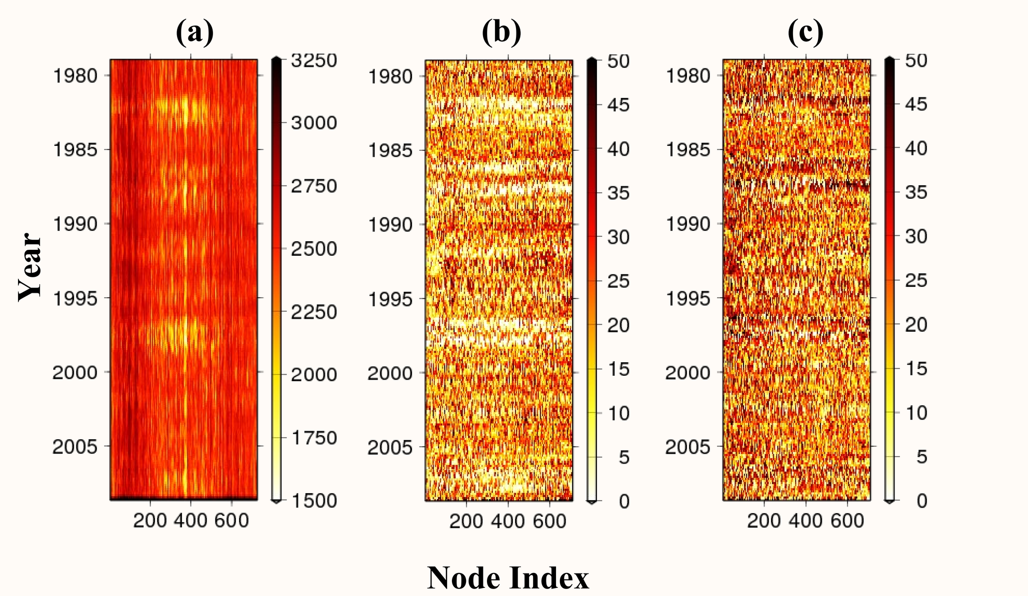


Fig. 1 Weighted degrees as a function of time (y axis) and the node index (x axis). (a) Total weighted degree D^y_l . (b) The microscopic contributions to the weighted incoming degree of C, I^y_C. (c) The microscopic contributions to the weighted outgoing degrees, O^y_C. One should bare in mind that each point is compiled from records of 565 days : 365 days + 200 days of shifts. The representative point in all figures for each 565 period is the beginning date of the period.

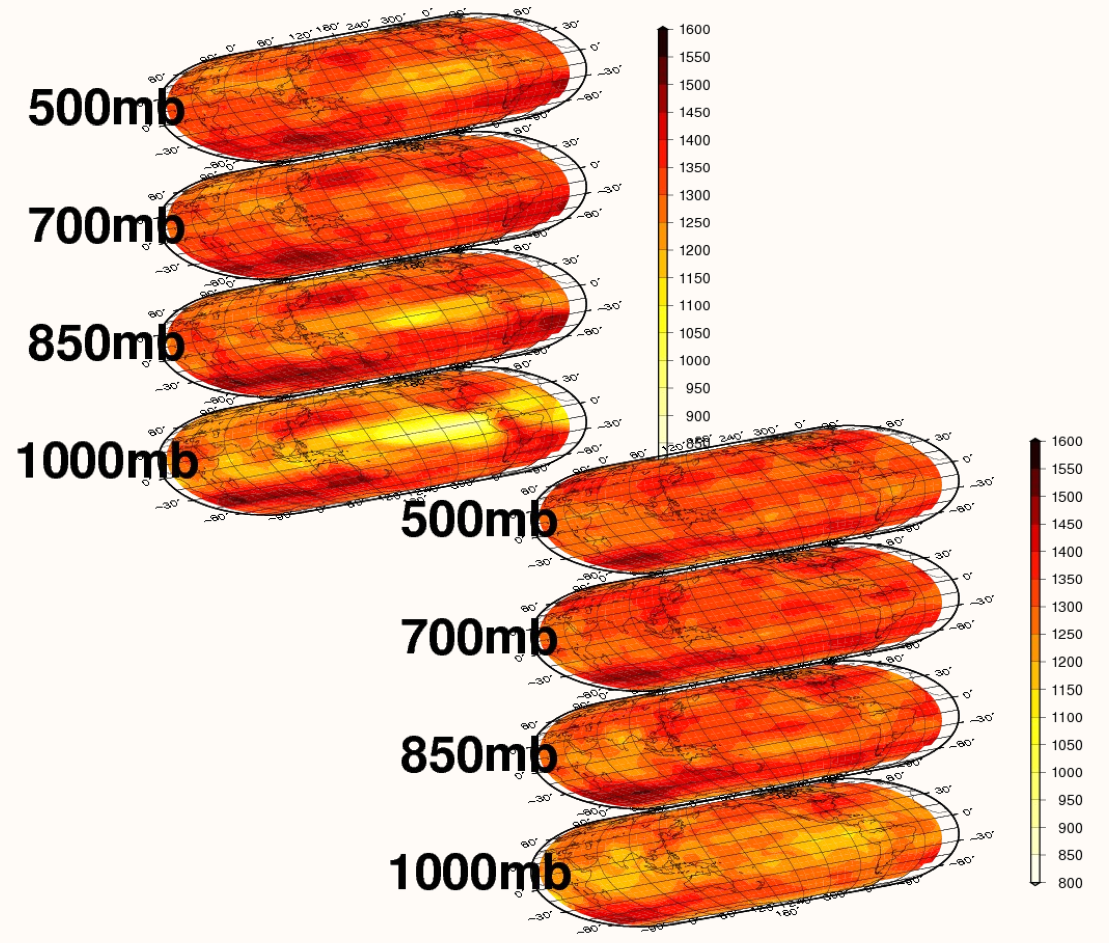


FIG. 2: Spatial distribution of the weighted degrees of nodes (in and out, upper and lower panels respectively) averaged over El-Niño times.

The interaction of the autonomous cluster **C** with its environment is highly asymmetrical with respect to the equator. This might have several explanations, mostly regarding the asymmetrical distribution of the lands. However, this asymmetry is reversed in high altitudes as shown in Fig. 3.

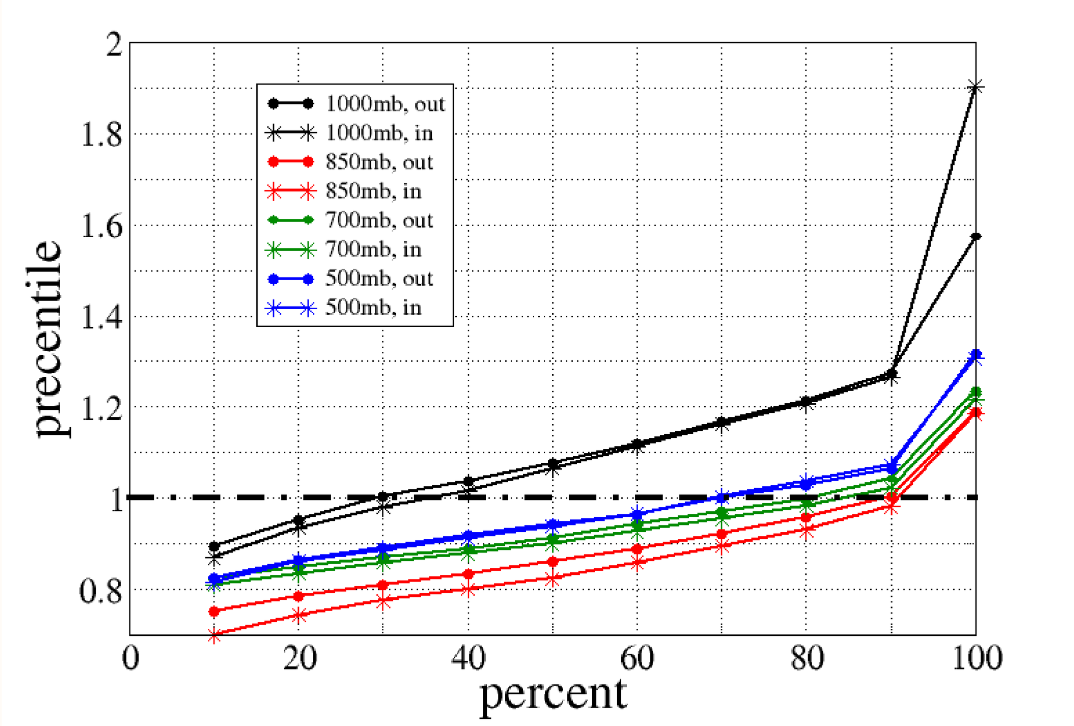


FIG. 3: (1000mb) Percentiles of the ratio of north to south (south to north) in– weights (out–weights). This shows quantitatively that links incoming to (outgoing from) C mainly come from the north (south), since most of the values are well above 1. The two lines, representing the asymmetries of the two fields, show a remarkable similarity, while reflects a mirror relation between the asymmetry parameters of the two fields. For higher altitudes we see an opposite behavior.

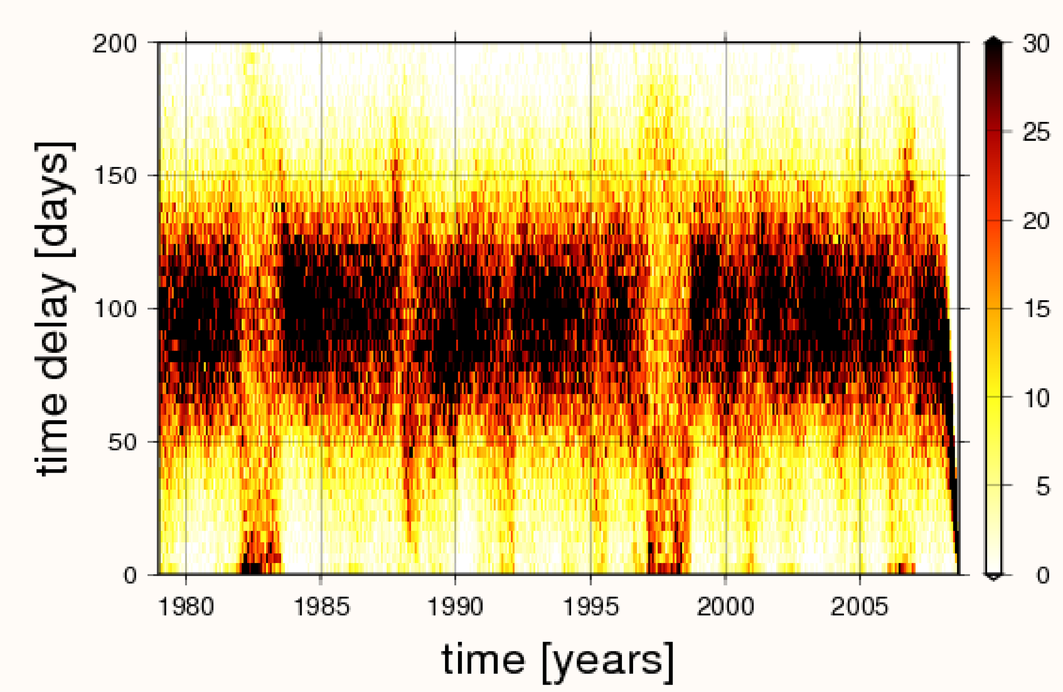


Figure 4. Time dependent distribution of the time delays between C and the rest of the world, as a function of time, for the 500mb layer. The measures of time delays is very noisy, but one might see that delays related to El Niño times are shorter, and the significant delays are between 0 and 60-70 days. This has the fingerprint of ocean scales, even for this high altitude.

Conclusions

We have found a new dynamical pattern that reflects the coupling between the El-Niño basin (ENB), and the rest of the world. ENB becomes significantly more autonomous during El-Niño, losing a large fraction of its in–links, while still having out–links. This kind of topology is reminiscent of pacemakers in network models [A6]. The major impact of events inside ENB on world climate on one hand, and the weakened correlations during El-Niño episodes on the other hand , are thus not contradicting. In fact, the uni–directional interaction of ENB with large parts of the climate network might suggest the origin for its significant dynamical role in the global climate.

The autonomous property of ENB exists even in high altitudes, but the detailed structure, and the interactions of this component with its environment *is* altitude dependent.

One of the most pronounced detailed altitude behavior is the north south asymmetry. Near sea surface, ENB is forced more by the northern hemisphere than by the southern, and forces the southern hemisphere more than it forces the northern. In higher altitudes this asymmetry is reversed. Since the annual cycle in the two hemispheres is opposite, this north–south asymmetry might be related to the known (not yet fully understood) partial phase locking of the ENSO cycle with the annual cycle (see e.g. [A7,A8]).

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For further information

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Our results were summarized in four papers:

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B2. A. Gozolchiani, K. Yamasaki, O. Gazit, S. Havlin, EPL 83, 28005 (2008)
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B5. http://technology.newscientist.com/channel/tech/mg19926675.600-software-predicts-where-el-niño-will-strike-next.html