POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

SANTA FE INSTITUTE

Gateways to Emergent Behaviour in Climate and Sustainability Sciences

Four examples of emergent behaviour and its gateways in the context of climate and sustainability sciences.

Author H. J. Schellnhuber

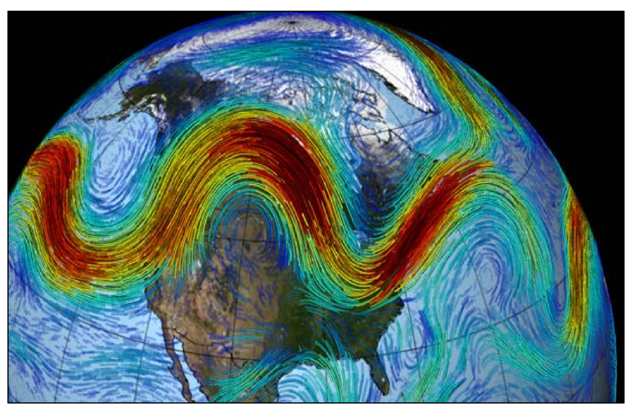
Potsdam Institute for Climate Impact Research, Santa Fe Institute

1. Persistent Planetary Waves and Extreme Events

A recent study (Petoukhov et al. 2013) shows that major extreme events (especially heat waves, droughts and floods) on the Northern Hemisphere in the last few decades might be linked to quasi-resonant amplification of planetary waves with certain frequencies. These "Rossby waves" can be perceived as (northward and southward) bulges of the famous jet stream which separates cold Arctic from warmer mid-latitude air masses.

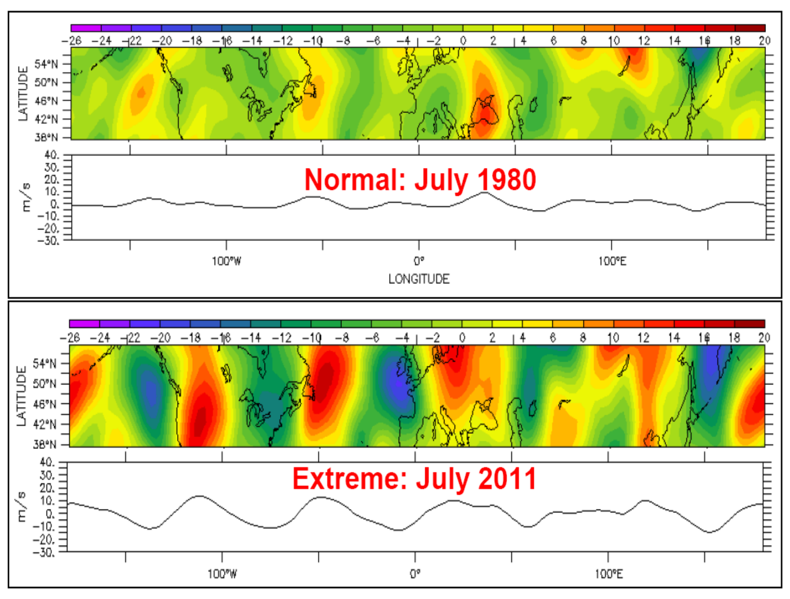
The jet stream is basically a pattern of high winds that is modulated by giant waves, normally travelling from West to East. They bring, alternatively, warmer air from the tropics to the Arctic and cooler air from the North to the lower latitudes. Thus the weather in a given region in the jet-stream domain varies within a few days, and extreme situations rarely occur. However, everything changes once those waves get stuck and the southward/northward anomalies persist for several weeks as has been observed in 1997, 2002, 2003, 2010, 2011 and 2013, for instance.

(a)



Our investigation unravels the physical mechanisms behind this phenomenon or, in other words, the pathway to the emergence of blocked Rossby waves. Data analysis, wave theory and computer simulations together demonstrate that travelling planetary waves with zonal numbers 6, 7 or 8 tend to get trapped by weak standing mid-latitudinal waves of the same frequency. This quasi-resonance then results in a significant mutual amplification of the oscillations involved.

(b)



There is some evidence that anthropogenic global warming tends to favor the occurrence of this quasi-resonance: Due to the relatively larger increase of Arctic temperatures, the gradients driving the jet stream become smaller. Also, due to differential warming of land and sea, the North-South rims of the continents become more of a barrier for travelling waves. Together, these effects are likely to slow down the easterly motion of air masses, which get more easily "frozen" into a Rossby lattice.

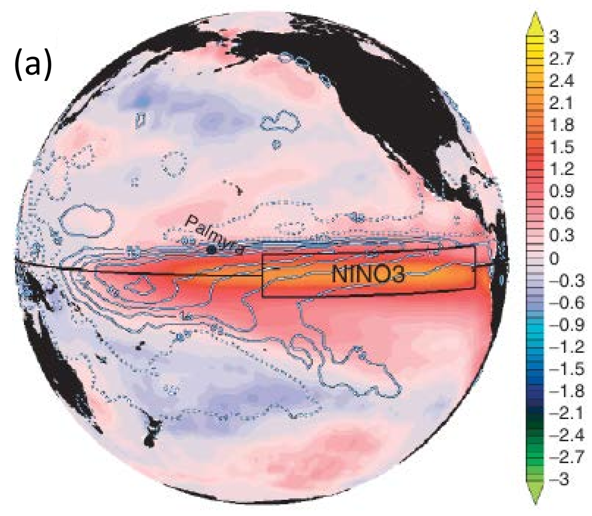
__Fig. 2__ (a) Polar jet stream (fast wind in red, slower wind in blue). Source: NASA's Goddard Space Flight Center. For video see http://tiny.cc/jetstream
(b) Maps of the mid-latitudinal meridional wind (in m s^{-1}) with northward winds depicted in red and southward winds in blue.
Source: http://tiny.cc/planetarywaves, following Petoukhov et al. 2013.

2. Cooperativity Transition Initializing El Niño

"El Niño" is an irregular, large-scale phenomenon in the equatorial Pacific, characterized by a strong rise of sea surface temperatures (often around Christmas) and worldwide knock-on effects (such as heavy droughts in Asia and Australia, floods in Latin America and cold spells in Europe).

New research (Ludescher et al. 2013) demonstrates that the El Niño onset is preceded by a strong growth in cross-correlations between local temperature anomalies throughout the Pacific basin (crucial nodes highlighted in Fig. 1b) at least one year in advance. During the El Niño event itself, the cross-correlations almost collapse. This is reminiscent of hurricane or tornado formation, where large areas get aligned by physical mechanisms (including feedback processes) to provide the collective energy for storm creation. Once these phenomena have gained critical size, they decouple from their wider environment and become violently self-contained.

(a)



The current hypothesis is that something similar happens in the context of El Niño inception. So the gateway to its emergence is probably a cooperativity transition. Deriving its dynamics from first physical principles is a formidable research challenge. However, the analysis performed so far can already be used to considerably improve El Niño forecasting, which is a most important precondition for effective response measures (such as agricultural provision and disaster preparedness).

(b)

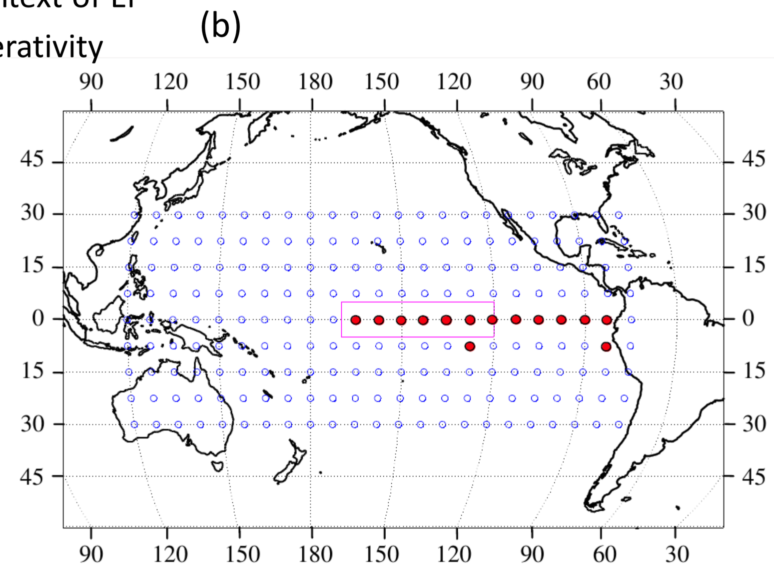


__Fig. 1__ (a) Anomalies of sea surface temperature (shaded, in °C) and precipitation (contours, in mm d^{-1}) during El Niño years averaged from June to December. Source: Vecchi & Wittenberg 2010.
(b) Crucial nodes for El Niño forecasting used in the new approach of Ludescher et al. (2013) that indicate an El Niño event by increasing cross-correlations of temperature anomalies one year before the event. Source: Ludescher et al. 2013.

3. Emergence and Diffusion of the Industrial Revolution

Two "Great Transformations" propelled the human enterprise and eventually brought about the modern world: the Neolithic Revolution that started in independent locations in the Near and Middle East some 9000 years ago, and the Industrial Revolution that was kicked off in Lancashire, England, towards the end of the 18th century. The latter transformation was characterized by several self-amplifying and self-proliferating innovation processes which were fully unleashed, however, only by breaking through a specific efficiency barrier.

Northwest England has a long tradition of cleverly exploiting water power as supplied by rivers and brooks in a hilly landscape all year round. Besides many other causal chains, one crucial gateway to the emergence of a new industrial metabolism was a series of topical mechanical inventions in the textile sector like the water-powered loom (1772). This made spinning and weaving much more efficient and increased the demand on cotton, which was imported from the English colonies in the West Indies. As a drive-out consequence of this (and other demands resulting from sea warfare and piracy), shipbuilding activities exhausted the domestic forest resources.

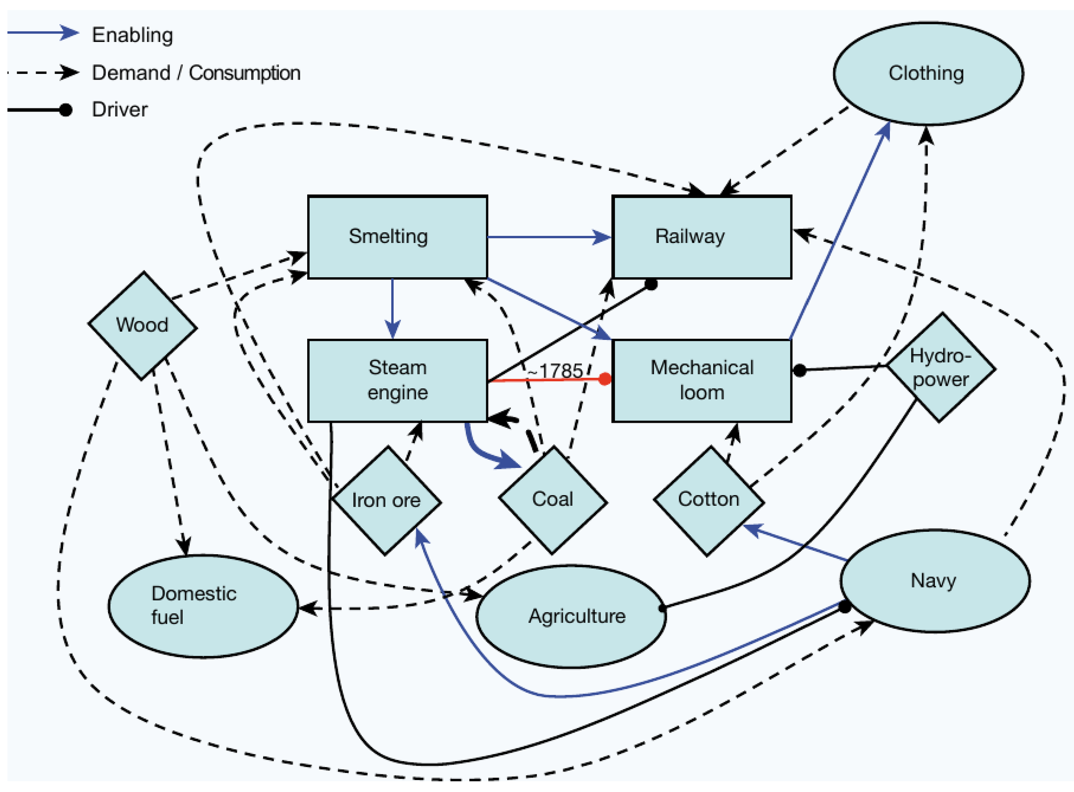


__Fig. 3__ Illustration on the driving, interdependent factors of the acceleration of the Industrial Revolution. Source: WBGU.

As an alternative for the dwindling supply of firewood for cities like London, coal had to be mined, which was a non-trivial technical task due to the perpetual intrusion of water into the deepening pits. The steam engine, invented in 1712, eventually replaced the traditional horse-powered drainage schemes, but with an energy efficiency of just 0.5 %. The only place where such an engine could be employed at all was a coal mine where fossil-fuel debris was abundant. The Industrial Revolution entered through two pathways then:

First, James Watt invented a novel engine type with an energy efficiency close to 2 %. This was sufficient to "delocalize" steam power, i.e., to emancipate its use from the mines, and coal-driven locomotion became the name of the game. Second, steam power and mechanical manufacturing were married in Manchester around 1785 in a grand technological unification (see Fig. 3). These developments triggered a number of self-amplifying supply & demand processes and innovation loops, boosting, in particular, the textile and the steel industries. The emerging network of techno-economic interactions was finally pushed into a new mode of operation by the invention of the railway in the early 19th century, allowing for a much wider and faster distribution of industrial products and thereby expanding the revolution across the British Isles and to continental Europe.

It must not be forgotten, however, that the emergence of the new industrial metabolism was favored by unique sociopolitical circumstances such as long-lasting inner peace in England, liberal economic thinking, public and private interest in inventions, and sufficient capital as well as resources originating from the British colonies. Therefore, the Industrial Revolution was instigated by a regional technocultural singularity, that allowed to tap and harness a huge resource of free energy.

4. Crowd Financing of Sustainability Transition

A major signature of global development through all types of historical innovations (see Sec. 3) is the per-capita use of energy in relation to the required land area. A rough functional estimate based on a disperse data set is given in Fig. 4, delivering a hyperbola in log-normal units. This tells us that the story of human progress has been essentially a tale about the densification of energy production, culminating – so far – in the exploitation of fossil point sources like oil wells.

As the negative externalities of the incumbent energy system, such as global warming and respiratory diseases, become ever more apparent, a massive switch to renewable energy sources seems not only desirable, but necessary. This would introduce a turning point in the "life line" depicted in Fig. 4, since sun, wind and biomass require much more land (per energy unit generated) than traditional fossil fuels. This is an interesting phase transition in its own respect, but we will focus here on a related aspect, namely how to organize adequate up-front investments beyond pure public schemes or venture-capital activities.

Amazingly, observations from Germany – which has embarked on the so-called "Energiewende" after the Fukushima disaster, implying rapid decarbonization without nuclear power assistance – point to an emerging option based on crowd funding. This approach, which is somewhat related to the concept of cloud computing, aims to bring about *systemic* change as a phenomenon emerging from thousands (or even millions) of *individual* contributions.

In Germany, there is an increasing number of local or regional initiatives which try to enhance the decentralized supply of renewable energy by creating energy cooperatives and collectively purchasing public infrastructures like power grids. More than half of the renewable energy facilities currently operated in the country are owned by citizens already, often in cooperation with municipalities that constitute important change agents for the German transition to sustainability. Crowd funding works like this, for instance: Members joining a cooperative contribute a self-chosen amount of money until the necessary capital for building, e.g., a solar park supporting the energy services for the neighborhood, is raised. Since the excess electricity can be fed into the regional or national grid, there is an extra benefit guaranteed by law ("feed-in tariff regulations " or, briefly, "EEG").

What is the systems narrative behind this exciting development? In essence, this is a tale about bringing together two very different levels of polit-economic preferences – the "volonté générale" and the "volonté particulière" in the words of the moral philosopher Jean-Jacques Rousseau. The German public has an overwhelmingly positive attitude towards climate protection and renewable energy, and an overwhelmingly negative attitude towards nuclear power. On the other hand, every-day life decisions are dominated, as in most parts of the world, by benefit maximization and short-term thinking. This antagonism can be overcome by appropriate boundary conditions, set by the state or other authorities, that allow to combine philanthropic sentiments with private profit. This was actually achieved by the EEG, which boosted renewable energy beyond nuclear power within a decade.

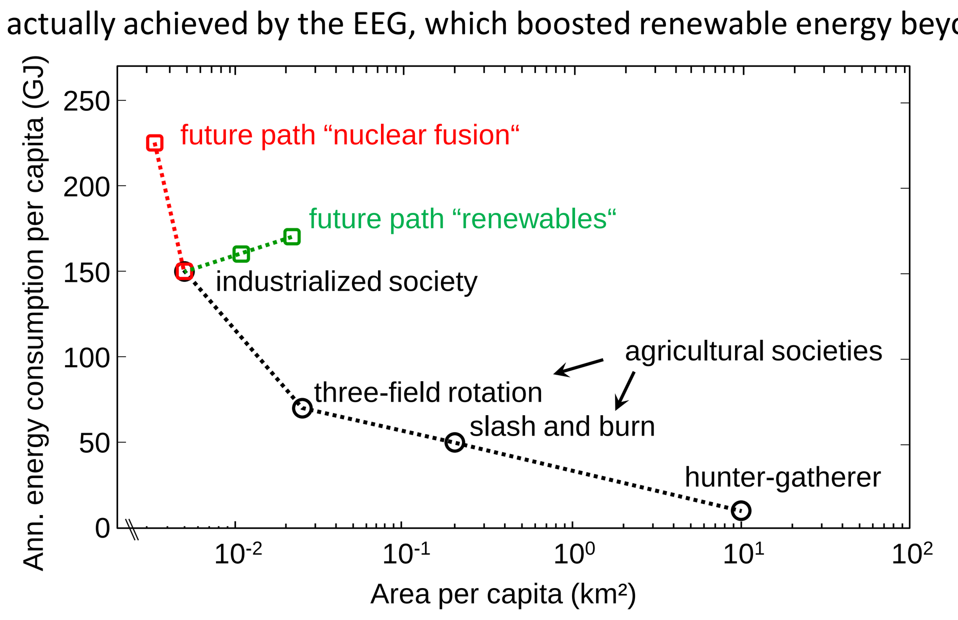


__Fig. 4__ Annual per capita energy consumption over required area per capita for past and future societies. Source: following Sieferle et al. 2006.

From the point of view of complexity science, legislation of the EEG-type acts like a (more or less weak) background field, amplifying a collective motion in the right direction by biasing individual movements. That's the gateway to emergent behavior in this context. The German government currently plans to extend the crowd financing strategy by guaranteeing private shareholders of sustainable infrastructure projects something like 5 % return on investment for at least 10 years.

Contact H. J. Schellnhuber
Telegrafenberg A31 | D-14473 Potsdam
director@pik-potsdam.de