1. Persistent Planetary Waves and Extreme Events

A recent study (Petersilgue 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 colder 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, whenever changes in the jet streams get stuck and the southward/northward anomalies persist for several weeks, as has been observed in 1997, 2001, 2003, 2010, 2011 and 2013, for instance.

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 blocked by weak standing mid-latitude waves of the same frequency. This quasi-resonance often results in a significant modification of the temperatures and precipitation.

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 eastward motion of air masses, which get more easily “frozen” into a Rossby lattice.

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 (Zebiak 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 (cruical nodes highlighted in Fig. 2b) at least one year in advance. During the El Niño event itself, the cross-correlations almost collapse. This is the result of a complex system transition, where large areas get aligned by physical mechanisms (including feedback processes) to provide the collective energy for storm creation. Once these areas are established, the system becomes self-sustaining.

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 computational 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 schemes (such as agricultural provision and disaster preparedness).

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 which was kicked off in Lancashire, England, towards the end of the 18th century. The latter transformation was characterized by several self-organizing 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 cheaply exploiting water power as supplied by rivers and brooks in a hilly landscape all year round. Besides many other social 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 led 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 eastward motion of air masses, which get more easily “frozen” into a Rossby lattice.

As an alternative for the depleting 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 mining areas. The steam engine, invented in 1712, eventually replaced the traditional horse-powered drainage schemes, but with an energy efficiency of just 4.5%.

The only place where such an engine could be employed at all was a coal mine where fossil-fuel-driven power was abundant. This “Industrial Revolution entered through two pathways then:

1. First, James Watt invented a novel engine type with an energy efficiency close to 2%.
2. Second, steam power and mechanical manufacturing were married in Manchester around 1785 in a grand technological unification (see Fig. 3). These developments triggered a very high rate of energy production, culminating – so far – in the exploitation of fossil point sources like oil.

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 new operating point in the “First Law” diagram (see Fig. 4). Since, 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 upfront investments beyond pure public schemes or venture-capital activities.

Amusingly, 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 system 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 institutions 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. Cooperatives 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 interest to be there for the economic benefit on top of the social benefit of the project.

What is the systems narrative behind this exciting development? In essence, this is a tale about bringing together two very different levels of poli-economic preferences – the “volontaires générales” and the “volontaires particuliers” 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, everyday 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 pure public schemes or venture-capital activities.

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 embracing individual movements. For instance, by including individual movements in the context of biodiversity protection, citizens already, often in cooperation with municipalities that constitute important change agents for the German transition to sustainability.

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 diverse 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.