Scales in the Climate System
An example of interdisciplinary teaching and learning

Main script of the course „Scales in the Climate System“

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* see https://scales-course.cen.uni-hamburg.de/main-script/teaching-scales-in-the-climate-system/
Teaching 'Scales in the Climate System'

An example of interdisciplinary teaching and learning

Climate change is commonly regarded as one of 21st century's grand challenges that needs to be addressed by conducting integrated research combining natural and social sciences. To meet this need, how to best train future climate researchers should be reconsidered.

Here, we present our experiences from the team-taught semester-long course 'Scales in the Climate System' with students of the international master program "Integrated Climate System Sciences" (ICSS) at the University of Hamburg, Germany.

This script presents the summary of three years of course, including background and teaching material (homework, slides, sessions plan). Feel free to download material and use it for your own project.

Here, you can download a PDF version of the main script (chapter 1 to 2.1.4).

This project is authored by Maike Scheffold, Dania Achermann, Jörn Behrens, Michael Brüggemann, Thomas Frisius, Mirjam Gleßmer, Inga Hense, Lars Kaleschke, Lars Kutzbach, Simone Rödder, Jürgen Scheffran and Johanna Baehr. For further information, visit Background lecturers.
The teaching and research project ‘Scales in the Climate System’ was based on the concept of scales. Before exploring our course concept, as one possibility to make interdisciplinarity tangible, we here present our thoughts, ideas and definitions of scales first.

What are scales in the climate system all about?

Climate change is commonly regarded as one of 21st century’s grand challenges, which needs to be tackled by integrated research including natural and social sciences. It is sometimes hailed as nothing less than the “poster child of interdisciplinarity” (Reisinger 2011: 23) and there is little doubt that climate-related knowledge is a body of knowledge in need of integration (e.g., Graybill et al. 2006, Palmer 2005). What then, is the question, can these mechanisms of integration be?

The idea of our graduate course was to employ the concept of scales to transcend disciplinary boundaries and to advance interdisciplinary thinking on the climate system as well as its resonance in social systems (as shown in in the visualization below). In the research practice of most of the lecturers involved in the class, the scale concept is key in theorising, observing and explaining phenomena as diverse as algae bloom, thermokarst, and El Niño. Also, as humans we are used to the idea that the range of scales in the world is much greater than our perception capacities. Yet we know from research on the Nano scale as well as on the universe that we can represent all these scales in abstract mathematical terms and still seek interrelations among them (AAAS 1989: 22).

It has sporadically been noticed, however, that there are different nuances in employing the scales concept that make it hard to transfer experience, conclusions and insights across scales (Clark 1985). It can be assumed that these differences render interdisciplinary collaboration and knowledge integration difficult in general, and with regard to the interaction of the climate system and society in particular. This is problematic not least with regard to teaching undergraduate and graduate courses in integrated climate science. The idea to link fields of knowledge by way of the scales concept arose out of longstanding discussions between some of the lecturers. To rely on a unifying concept, we argue, avoids what has been called the potpourri problem in interdisciplinary curricula “where courses become a little bit of this and a little bit of that without an overall, coherent, structure or scope.” (Jacobs 1989: 2, as quoted in Mathison and Freeman 1997: n.p.).

In the following chapter we present what this unifying concept of scales is all about.
References


About the author
Simone Rödder is an assistant professor of sociology at the University of Hamburg's Department of Business, Economics and Social Sciences and a Principal Investigator in the Cluster of Excellence "Integrated Climate System Analysis and Prediction" (CiSSAP). Her research is located at the intersection of the sociology of science and the science of science communication and applies mainly qualitative methodologies. Her current work focuses on interdisciplinary collaboration in climate research and her major class in the MICSS curriculum is a lecture with practicals, “Introduction to the Social Sciences”. Simone has an academic background in biology, sociology and science communication and holds an interdisciplinary PhD degree (Dr. phil. nat.) from the University of Bielefeld. She has been trained as a journalist and worked for several newspapers and magazines.
A mutual language and understanding is the basis for interdisciplinary teaching and research. We framed our joint understanding by introducing a definition of scales, which is applicable for natural and social sciences.

**How to define scales? We offer a friendly and a math-based (but also friendly) way.**

- 1.1.1 | A friendly introduction to scales
- 1.1.2 | A math-inspired approach to scales
1.1.1 A friendly introduction to scales

This document tries to find a definition and basic terms for the seminar on Scales in the climate system. We define the basic terms and derive a concept that is intended to work across disciplines. The text is structured from coarse to fine. This “friendly introduction” serves as a non-mathematical coarse intro to the theoretical concepts behind our scales approach.

A friendly introduction

In this introductory section, we try to give an outline of the concept of scales, as we will use it in the remainder, without using mathematical nomenclature. Mathematics is basically just a very elegant and simple language, that helps to formulate concepts to some abstraction. Once this abstraction is achieved, the mathematical language reveals structure. And when one understands the structure, it is easy to apply it in different context and to gain new insight. Unfortunately, as with any language, it is a hard and long path to master the language, and not everybody has the privilege to practice it regularly. So, we strive to formulate the basic “mathematics inspired” concepts of scales with common words, instead of definitions, lemmas, propositions and formulas.

We start with those items that are the actors in all the different contexts: gas constituents, liquids, individuals, particles, or aggregate sets of these. We will call them agents. Agents carry properties and attributes that characterize them. A fluid is characterized by its density or temperature; an individual by its state, wealth, educational level, age or others; particles are characterized by their position in space and time and possibly other properties. So, an agent carries a state.

Once agents are in place, they become interesting, when they change. And since we believe in some basic order, we say that agents can change their state under the influence of rules. A rule is an atomistic operation that changes one parameter in the set of states. For example, a particle is moved under gravitational forces, so its position changes. An individual goes to work and earns money, so its wealth increases, and so on. When we look at the reality around us, we are often not able to identify these atomistic rules, and often the changes are more complex. A change of a particle position could easily also mean a change in potential energy level, temperature, pressure, etc. Or an individual earning money might get happy at the same time. So, a combination of rules is often acting on agents, and we will call these combinations a process.

It is important to understand that processes and rules change the states of agents. But of course they can change the states only in a limited way. The speed cannot exceed (as far as we know today) the speed of light, and if a fluid is heated beyond its evaporation point it becomes a gas with different properties. So, we will call the range of useful or allowed states a domain. By default we want to consider space and time to be part of the set of states and therefore a space-time coordinate is part of the domain.

Our next basic concept is crucial to the understanding of scales. In order to define a phenomenon we have to recall, what a process does. A process changes the states of an agent. So, it is a mapping from a former state to a future state. A phenomenon is an identifiable and bounded subset of states. This is very abstract, but let us look at our two examples. A fluid can build a vortex, which can be identified by looking at the velocity vector field of the fluid and computing the vorticity. If the vorticity exceeds a certain threshold, the fluid forms a vortex. An individual can be called poor (or rich) if the income falls below (or exceeds) a certain threshold.

So, a vortex as well as being poor or rich are phenomena. And it is always a process that induces a phenomenon. Sometimes we can identify and describe the process leading to a phenomenon. The Navier-Stokes equations are believed to give a more or less complete description of fluid flow behavior. Under certain influences (shear flow or obstacles in the flow) solutions to these equations lead to areas of high vorticity and therefore form vortices. Sometimes it is not possible to identify the process exactly, since we might not know the rules yet. So, sometimes it is only possible to observe the phenomenon. In any case, the phenomenon is the result of processes acting on agents. Additionally, since the phenomenon is identified by all those agents whose states fulfill the limiting conditions that define the phenomenon, it is formally a subset of the domain of states.

Let us shortly recall:
We have implicitly assumed that we can somehow quantify the states. In particular, will we need a relation smaller or larger than a threshold value for defining phenomena.

We will now start talking about scales, but before doing so, we need to go a little deeper into the quantification. We will need a concept of measuring sizes. The mathematical concept behind measuring is a **metric**. A metric does nothing else than measuring the distance of two objects in an appropriate space. So, let us assume that we can measure distances. For location and time this is simple: the distance between two positions in space is the Euclidean distance. And between two points in time, it is just the time elapsed between these. Measuring the distance between a poor and a rich person can be achieved by comparing their income. So, we will employ an appropriate metric for measuring distances.

By this we can determine the size of a phenomenon: It can be defined as the largest distance between two agents belonging to that phenomenon. For example, a vortex size can be measured as the largest distance between two fluid particles among all particles belonging to the same vortex. The phenomenon “rich” can be measured in different ways, depending on the goal of investigation: It could be measured as the number of agents belonging to the set of rich agents, or it could be measured as the difference between the income level of its agents. After determining the size of a phenomenon, we can compare different phenomena by their sizes. We will call two different phenomena similar with respect to the metric, if they have the same size. For example, a vortex and a wave in the atmosphere can have the same spatial extent and therefore are called similar with respect to their spatial extent. All phenomena of similar size are in the same similarity class.

And this is basically the definition of a scale. We can define the scale of a phenomenon (e.g. a certain atmospheric wave pattern is of regional scale), as the size of this phenomenon with respect to a specified metric. Correspondingly, a scale is the similarity class of all phenomena with the same size. This is a rather static definition, and it does not capture scale interaction yet.

If we want to attribute for scale interaction, we need to measure the extent of a rule. This is a little more demanding, since rules (or processes) acting on the states of agents, can be time-dependent. In other words, if they influence an agent long enough they can have a large impact. So, it will be necessary to control somehow each state of an agent in order to assess the size of a rule (or a process). So, in order to measure the size of a rule, we look at its influence on the agent. We start with the agent’s initial state and measure the distance to its state after the impact of that rule. We will call this distance scale of influence of the rule. With this, the scale of a process is just the largest scale of one of the involved rules.

Since a process is composed of a number of rules, we can decompose it (theoretically) into large scale and small scale components. With this concept, we can even start investigating scale interactions. However, at this point we stop the introduction, because we will need to further investigate and develop our concept in order to make it more useful. And at this point, we want to return to the beauty of abstract mathematical formulations, because they make it much simpler to develop such concepts.
About the author

Prof. Dr. Jörn Behrens. Educated as an applied mathematician with PhD (Dr. rer. nat.) from Bremen University and Habilitation from Technische Universität München, Munich, Jörn develops numerical methods for atmospheric and oceanic simulation. He specializes in adaptive mesh refinement, numerical geophysical fluid dynamics, and high performance computing. In 2006 following the 2004 Sumatra-Andaman Tsunami, he became head of the tsunami modeling group at Alfred Wegener Institute, Bremerhaven, and developed the simulation component of the German-Indonesian Tsunami Early Warning System (GITEWS). After delivering the system, he accepted a professorship for numerical methods in geosciences at the Center for Earth System Research and Sustainability (CEN) of University of Hamburg in 2009. He coordinates the research project ASCETE (Advanced Simulation of Coupled Earthquake Tsunami Events), and serves as Co-Chair of UNESCO Intergovernmental Coordination Group for setting up a Tsunami Early Warning System for the Mediterranean, North-East Atlantic and Connected Seas (NEAMTWS) Working Group 1 (Hazard Assessment and Modeling). Since 2015 he serves as the program director of the special interest group on geosciences for the Society of Industrial and Applied Mathematics (SIAM).
1.1.2 A math-inspired approach to scales

In this section, the same conceptual development of subsection 1.1.1 is described, but explained by a more formal mathematical description for each of the involved terms.

Scales in equations

We start with an attempt to set the framework of basic terms, needed to define scales and in order to derive a concept of scales. The basic constituent, individuals, particles, or aggregated sets of these will be called agents. Agents will be equipped with a number of attributes, like location, status, etc.

Agent

Definition 1

We call \( a = (\mathbf{x}, t; I) \) an agent where \( \mathbf{x} \in \mathbb{R}^3 \) is its location, \( t \in \mathbb{R}^+ \) is its time and \( I \) may be a number of attributes characterizing its state. We may denote a set of agents by \( A = \{a | a \text{ is an agent}\} \).

Remark 1

Note that the characterizing attributes space \( \mathbf{x} \), time \( t \) and other attributes \( I \) may not be important in certain contexts. For example, when looking at communication patterns in the internet, space is of minor relevance.

Example 1

Agents can be quite diverse, depending on the discipline and context of investigation:

1. Density of a constituent \( \rho = \rho(\mathbf{x}, t) \) in a fluid flow may be an agent.
2. Individuals \( i = i(\mathbf{x}, t; I) \) in a population may be agents. \( I \) may be all kinds of attributes, like income, vulnerability, societal status, etc. depending on the scope of investigation.
3. Companies \( c = c(\mathbf{x}, t; I) \) in an economy may be agents, where \( I \) may be a characterization like revenue, number of employees, etc.
4. Cars \( c = c(\mathbf{x}, t; I) \) in a traffic situation may be agents, with \( I \) being attributes like speed, value, size, etc.
5. Groups of species \( s(\mathbf{x}, t; I) \) in an ecosystem may be agents with attributes \( I \) characterizing their size, role (predator/prey), etc.

Agents will interact with each other. This is what we are mainly interested in. So, associated to a set of agents is a set of rules according to which agents can interact. A rule is a mapping that transforms an agent. There may be rules that act only on one agent or on several agents. The result is generally a new combination or new values in the attributes of the agent.

More formally:

Rule

Definition 2

We call \( r : a \mapsto a \) a rule when \( r(a(\mathbf{x}, t; I)) = a(\mathbf{x}, t; I) \).

That means a rule may change the status of an agent.
Usually, it is not just one rule that changes the status of an agent, but a number of rules acting in different ways. So we want to introduce the notion of a process that is formed by a number of rules, and which is the main driving factor of changes to agents.

**Process**

**Definition 3**

Let \( r_i, i = 1 : n \) be a set of \( n \) different rules all applicable to an agent set \( A \). Then we call the map

\[
p(a) = \sum_{i=1}^{n} c_r a_i(a),
\]

with \( c_r \) some weights, a process. Note that the result of \( p \) applied to \( a \) is also a transformation of the attributes, thus

\[
p(a(x, t; 1)) = a(x, t; I).
\]

We have agents and mappings that transform these agents. If we come back to our examples, let us look at examples of processes for these:

**Example 2**

Let us consider again our five arbitrary examples from above:

1. If our agent is density of a constituent \( \rho = \rho(x, t) \), then fluid flow can be a process, described by the Navier-Stokes equations acting on this density. Basically, these are a mathematical formulation of the balance of forces acting on the density.

2. If the agents are individuals \( i = i(x, t; 1) \) in a population, then a process can for example describe the way, how this individual generates income. This may well be comprised by a number of rules. If the individual is a university professor, then there may be a rule that describes how knowledge is gained, another rule describes the way, how knowledge is transferred to other individuals, a third rule may describe how this transfer is accounted for in terms of salary, and thus the sum of all three rules forms the process of generating income.

3. If companies \( c = c(x, t; 1) \) are the agents, then a process may describe how a company generates revenue, or how a company uses resources in order to generate products, etc.

4. If the agents are cars \( c = c(x, t; 1) \) in a traffic situation, then a process may describe how they move in accordance to the traffic rules with stops at red lights, etc.

5. If we consider our agents groups of species \( s(x, t; 1) \) in an ecosystem, then a process can describe how these species depend on each other and how they grow or perish in dependence of each other (the simplest mathematical model being a predator-prey differential system of equations).

Note that in the example 1 and 3, we looked at agents in the context of their environment. So, we will have to define this environment and we will call it a domain and it will be composed of the space-time domain and the space of possible attributes:

**Domain**

**Definition 4**
We call \( D = \{ \Omega, T, \mathcal{L} \} \), a Domain of an agent set \( A \), where \( \Omega \subset \mathbb{R}^d \) is a spatial domain, \( T \subset \mathbb{R}^+ \) is a time interval, and \( \mathcal{L} \) is a domain of possible states/attributes of the agent set \( A \).

Remark 2

We will restrict ourselves to real space and time domains here. Of course we could extend our definition to more general spaces like the complex domain \( \mathbb{C} \).

Remark 3

Note that we will usually also have that the attributes in \( \mathcal{L} \) will form a real vector, since we will strive to map all attributes quantitatively to a real value. Often an index is used for this mapping.

Let us go through our list of examples again:

1. The domain of a fluid flow problem is space and time only. We might consider a third attribute like total energy, vorticity, or enstrophy.
2. The domain of a population of individuals is again space and time -- the location of the individual at any time -- and a range of societal indicators: income range, social class and the like.
3. A company's domain may again have a space and time component, though usually these will be rather static. Additional attribute ranges may be the range of revenues, the range of numbers of employees, etc.
4. The domain of a car is obviously its location in time -- space and time -- but comprises additional attribute ranges like speed range, or gas consumption range.
5. For species the location in time is again characterizing and additionally, attribute ranges like population size.

When we define an agent with a number of attributes in a certain context, then the agent is uniquely determined by the triple \( (x, t, \mathcal{I}) \in D \), where

1. \( x = (x_1, x_2, x_3) \in \mathbb{R}^3 \) is its location in space,
2. \( t \in \mathbb{R} \) is its status in time,
3. \( \mathcal{I} = (I_1, \ldots, I_d) \in \mathbb{R}^d \) is the list of attributes.

Thus, we can identify the agent, with its attributes. Moreover, we can mathematically formulate the action of a rule (and thus of a process) as a mapping of the attributes. More formally, let \( \alpha = (x, t, \mathcal{I}) \) be the triple of attributes corresponding to agent \( a \). Then a rule is a map \( \alpha \mapsto \bar{\alpha} \), where \( \bar{\alpha} = (\bar{x}, \bar{t}, \bar{\mathcal{I}}) \).

Rules and processes can be applied to individual agents, but can also be applied to a whole set of agents. This corresponds to applying the mappings to a whole set of attribute triples. So, let us consider a set of attribute triples \( A = \{ \alpha | \alpha = (x, t, I) \} \). Then obviously a process is a mapping

\[ p : D \rightarrow D, \quad \alpha \mapsto \bar{\alpha}. \]

This makes the definition of a phenomenon relatively straightforward.

**Phenomenon**

**Definition 5**

Let \( D \) be a domain of an agent/attribute set \( A \) and let \( p : D \rightarrow D \) be a process. Then a phenomenon \( P \) is defined as a subset \( U \subset D \) of the image of \( p \):
$P := \{ \bar{\alpha} \mid \bar{\alpha} = p(\alpha), \text{ and } \bar{\alpha} \in U \}.$

**Example 3**

Considering our examples, we look at phenomena with their corresponding processes:

1. For a fluid flow problem a typical phenomenon would be a vortex. The process leading to a vortex is given by the thermodynamical processes (manifested in the Navier-Stokes equations) and the phenomenon is one with arbitrary location and time but a positive vorticity above a certain threshold:

$$P_{vortex} = \{ \rho(x, t, v) \mid v \geq \theta \},$$

where we have (very sloppily) denoted by $v$ the vorticity as an attribute of the density distribution $\rho$ and $\theta$ as the threshold.

2. We can describe the phenomenon of poverty in a population of individuals by the subset of individuals $i$ with an income attribute $\$\$ below a certain threshold $\theta$. The corresponding process is the generation of income, which modifies the attribute $\$$, (more or less) independent of space and time:

$$P_{poor} = \{ i(x, t, \$$) \mid \$$ \leq \theta \}.$$

3. The phenomenon of bankruptcy of a company $c(x, t, (I, O))$ with income $I$ and active debt $O$ can be defined as

$$P_{bankrupt} = \{ c(x, t, (I, O)) \mid I < O \},$$

4. The phenomenon of a traffic jam can be characterized by cars $c(x, t, (v, p))$ with velocity $v = 0$, which are not parked ($p = \neg\text{parked}$):

$$P_{jam} = \{ c(x, t, (v, p)) \mid v = 0 \land p = \neg\text{parked} \}.$$

5. The phenomenon of extinction of a species $s(x, t, S)$ can be characterized by the fact that its population size $S$ becomes zero:

$$P_{extinct} = \{ s(x, t, S) \mid S = 0 \}.$$

**Remark 4**

It is important to note that a phenomenon is a subset of the image $I(p) \subset D$ of the mapping represented by the process $p$, which in turn is a linear combination of rules. So, even if we do not know the process in a functional form (and less so the rules), we can still observe and describe the phenomenon, since we can define the subset in a phenomenological way, rather than in a functional way.

Since we have associated the agents with the triple of space, time and attributes (all being real numbers), we can easily measure the size in each of the three components of the triple. But before doing so, we want to formally introduce a metric.

**Norm**

Definition 6

A norm, denoted by $\| \cdot \|$, is a mapping $\| \cdot \| : \mathbb{R}^d \to \mathbb{R}^+$, $x \mapsto \| x \|$ that associates each element $x$ a positive real number. It is defined by the following properties:
1. \( \|x\| = 0 \Rightarrow x = 0; \)
2. \( \|\alpha \cdot x\| = |\alpha| \cdot \|x\| \) for a scalar \( \alpha; \)
3. \( \|x + y\| \leq \|x\| + \|y\| \).

A norm induces a metric \( d \) that measures the distance between two members \( x, y \in \Omega \) by

\[
d(x, y) := \|x - y\|.
\]

**Example 4**

A well-known norm is the length of a vector \( x \) in \( \mathbb{R}^d \), i.e., the Euclidean norm:

\[
\|x\|_2 := \left( \sum_{i=1}^{d} x_i^2 \right)^{\frac{1}{2}},
\]

which induces the metric \( d_2 \) as described in definition 6. With this, we can measure the size of a simply connected subset \( S \subset \mathbb{R}^d \) by

\[
D_2(S) := \max_{x, y \in S} d_2(x, y).
\]

The example above already indicated, how we can measure sizes of sets. We generalize this by defining:

**Size**

**Definition 7**

The size \( D(S) \) of a set \( S \subset \mathcal{D} \) is given by

\[
D(S) := \max_{x, y \in S} d(x, y).
\]

**Similar and similarity class**

A metric associates a unique number to a given set, but several sets may have the same metric. Thus, a metric induces a similarity class of sets. We can define:

**Definition 8**:

Two distinct subsets \( S_1, S_2 \subset \mathcal{D}, S_1 \neq S_2 \), are called similar (denoted by \( S_1 \sim S_2 \)) if \( D(S_1) = D(S_2) \). Consequently, all subsets \( S_i, i = 1, 2, \ldots \) with \( S_i \sim S \) form a similarity class \( S_- := \{ S_i \subset \Omega : S_i \sim S \} \) of \( S \). Note that trivially \( S \sim S \).

We can interpret similarity classes as phenomena of the same size. For example, can we characterize a certain wave length and an eddy size in a fluid dynamics system. Certain wave patterns and mesoscale eddies may fall into the same size class.

With the size of a set and a metric for measuring “distances” between agents defined, we can start investigating scales. We want to measure the size of a rule first. It is our aim to quantify the size of a rule’s influence area.

**Influence of the the rule**

**Definition 9**
Let \( r_\nu : \mathcal{D} \rightarrow \mathcal{D} \) be a rule that acts on one of the attributes \( \nu \in \{ x, t, I \} \). Let furthermore \( \alpha \) be an attribute triple corresponding to the agent \( a \).

Then we denote by \( s(r_\nu) := d(\alpha, r_\nu(\alpha)) \) the **scale of influence** of the rule \( r_\nu \).

**Remark 5**

Rules can act instantaneously (like the splitting of a cell or the collision of two particles) or over time (like nuclear decay or erosion). Furthermore, rules can act on several attributes simultaneously, or just on one of the attributes associated to an agent. Therefore, we want to assume in a rather sloppy way obvious extensions to the previous definition. For example, if the rule is time-dependent, we want to fix the time period in which the rule is active. If the rule acts on several attributes, we may either use a multi-dimensional norm or measure just one attribute's change, or take the maximum.

### Size of influence of process

With this definition we can go on in a straight forward manner to define the size of a process:

**Definition 10**

Let \( p : \mathcal{D} \rightarrow \mathcal{D} \) be a process in the sense of definition 3 and equation 1. In particular \( p \) is composed of the rules \( r_i \), \( i = 1 : n \). Then the **size of influence** of process \( p \) is given by

\[
    s(p) := \max_{i=1}^{n} s(r_i)
\]

It is important to note that our metric allows us to measure sizes of processes as well as phenomena. Since we have introduced the size of a set in definition 7, we can easily determine the size of a phenomenon \( P \) as \( D(P) \). Since we have defined sizes of rules, processes and phenomena, and since we have also defined similarity classes as classes of different phenomena of similar sizes, we are now in the position to state our major definition. But before doing so, we set the frame of reference for all the acting terms.

### System

**Definition 11**

We want to call \( S = (\mathcal{D}, A, r, p) \) a **system**, composed of a domain \( \mathcal{D} \), and agent set \( A \), a rule set \( r \) and a set of processes \( p \).

We can now define a scale as a size class.

### Scale of the phenomenon

**Definition 12**

Let \( S \) be a system, \( p \) a process in that system, and \( P \) a phenomenon triggered by the process, and let \( d \) be a metric in \( A \). Then we can define the **scale of the phenomenon** \( P, S(P) \), by its size:

\[
    S(P) := D(P).
\]

A **scale within the system** \( S(P) \) can be defined as the similarity class of all phenomena with the same scale:

\[
    S_S(P) := P_\ldots.
\]

**Remark 6:**
It is important to note that the term scale is used in different contexts here. The scale of a process is the size of the influence of that process. The scale of a phenomenon is the maximum extent (in any of the attributes) of that phenomenon. And the scale within a system is the similarity class of all phenomena of the same size. Note further, that usually we will not be exact in specifying a size, since there will be no phenomenon of the exact same size two times. So, we will have to define a reasonable range of sizes. In natural sciences it has been common to denote a range of sizes by a logarithmic order description, e.g. \( O(1) \) means all values \( v = c \cdot 1, \) where \( 1 \leq c < 10 \) is an appropriate constant. Thus \( O(10^6) \) is a value \( v \) between \( v = 1 \cdot 10^6 \) (one million) and \( v = 10 \cdot 10^6 \) (ten million).

The definition of a process has a very interesting aspect. With the definition of sizes of rules, we can investigate the scales with more fidelity. We will sort the rules participating to a process in their size, so we can -- from now on -- assume that if \( p(a) = \sum_{i=1}^{n} c_i r_i(a) \) then \( s(r_i) < s(r_j) \) if \( i < j \).

With this understanding, we have rules (or sub-processes) acting on all different scales to form the total effect of a process. By this, we can do a scale decomposition of a process into parts of different scales. Let \( \theta \) be a threshold that defines the difference between micro- and macro-scale, then we can write:

\[
p(a) = p_{\text{micro}}(a) + p_{\text{macro}}(a),
\]

with

\[
p_{\text{micro}}(a) = \sum_{\substack{i=1\ldots n \\ s(r_i) < \theta}} c_i r_i(a),
\]

\[
p_{\text{macro}}(a) = \sum_{\substack{i=1\ldots n \\ s(r_i) \geq \theta}} c_i r_i(a).
\]

With this concept, we have automatically a scale interaction by processes. This takes place if the rules of diverse scales are all involved in the process. If we consider only a part of the scales in composing a relevant sub-process, then we don’t consider scale interaction.

**About the author**

Prof. Dr. Jörn Behrens. Educated as an applied mathematician with PhD (Dr. rer. nat.) from Bremen University and Habilitation from Technische Universität München, Munich, Jörn develops numerical methods for atmospheric and oceanic simulation. He specializes in adaptive mesh refinement, numerical geophysical fluid dynamics, and high performance computing. In 2006 following the 2004 Sumatra-Andaman Tsunami, he became head of the tsunami modeling group at Alfred Wegener Institute, Bremerhaven, and developed the simulation component of the German-Indonesian Tsunami Early Warning System (GITEWS). After delivering the system, he accepted a professorship for numerical methods in geosciences at the Center for Earth System Research and Sustainability (CEN) of University of Hamburg in 2009. He coordinates the research project ASCETE (Advanced Simulation of Coupled Earthquake Tsunami Events), and serves as Co-Chair of UNESCO Intergovernmental Coordination Group for setting up a Tsunami Early Warning System for the Mediterranean, North-East Atlantic and Connected Seas (NEAMTWS) Working Group 1 (Hazard Assessment and Modeling). Since 2015 he serves as the program director of the special interest group on geosciences for the Society of Industrial and Applied Mathematics (SIAM).
1.2 Examples of phenomena

To talk about scales in the climate system, one has to talk about scales of climate phenomena. Here we present some examples of phenomena from natural science, social science and history of science, defined according to our definition of scales in the climate system.

1.2.1 Natural science examples
   - 1.2.1.1 Extratropical cyclone
   - 1.2.1.2 Vortex (e.g. Polar Vortex)
   - 1.2.1.3 El Nino
   - 1.2.1.4 Weddell Sea Polynya
   - 1.2.1.5 Thermokarst
   - 1.2.1.6 Algal bloom

1.2.2 Social science examples
   - 1.2.2.1 Climate skeptical debate about the global warming pause / hiatus / slowdown
   - 1.2.2.2 Social networks in resource use
   - 1.2.2.3 Medialization of Science

1.2.3 History of science example- The Max Planck Institute for Meteorology as a historical phenomenon
1.2.1 Natural science examples

Presented phenomena following the ‘scales’ definition from section 1.1 come from atmospheric, oceanographic, biological and soil as well as geological sciences.

Intertwined natural science components of the climate system.

- 1.2.1 Extratropical cyclone
- 1.2.2 Vortex (e.g. Polar Vortex)
- 1.2.3 El Nino
- 1.2.4 Weddell Sea Polynya
- 1.2.5 Thermokarst
- 1.2.6 Algal bloom
1.2.1.1 Extratropical cyclone

Categories

Component of the climate system
The categorized component of the climate system, or resonance of climate phenomena in social systems
atmosphere

Agents
These are the quantities acting or being modified within the occurrence of the phenomenon. Agents usually own a number of attributes that are changed by rules/processes.
gas, hydrometeors

Rules
These are atomistic rules that change the status of the agent, i.e. modify the attributes.
quasigeostrophic or primitive equations

Processes
These are the general transient modifications of attributes/states of the agents leading to or causing the phenomenon. They are composed of a number of (possibly
unknown) rules.
baroclinic instability (the interplay between vorticity advection, temperature advection and geostrophic adjustment), frontogenesis, occlusion

Domain
These are the values, which can be reached by the attributes/states. It is important to find some quantifiable values, such that comparisons can be made. Time and
space are default attributes; so size and timespan of the phenomenon should be given at least.
space, time (or alternatively wavenumber-frequency domain), central pressure, tilt of the vertical trough axis, deepening rate;

- temporal extent: 1 – 5 days
- spatial extent: 1000 – 2500 km

Description
The description is to be made in terms of conditions on the states of agents that determine/constitute a phenomenon. In mathematical terms a phenomenon is best
described by a sub-set of all possible states.

Extratropical cyclones are the most common synoptic-scale weather systems in the mid-latitudes and they often bring rainy and windy weather. Extratropical cyclones have their origin in regions with a significant north-south temperature contrast as, e.g., observed near the eastern coast of North America where the Gulf Stream warms the overlying atmosphere. Baroclinic instability constitutes the basic mechanism for the genesis of extratropical cyclones. It forms a baroclinic wave along the polar front (line separating polar and subtropical air masses) where low pressure troughs and high pressure ridges have a vertical tilt against the vertical wind shear. In this constellation potential energy of the atmosphere is converted into kinetic energy of the baroclinic wave. Baroclinic instability is a scale-selective process. Baroclinic waves having too short a wavelength cannot grow due to the stable temperature stratification of the atmosphere. On the other hand very long waves cannot grow due to the meridional increase of the Coriolis parameter (the so-called beta effect). The synoptic scale regime (about 1000-2500km) is embedded within these limiting spatial scales. Baroclinic instability comes along with the simultaneous development of cyclones and anticyclones. Later, the anticyclones’ growth slows down relative to that of cyclones because of nonlinear processes. Furthermore, temperature fronts strengthen (frontogenesis) and the warm sector enclosed by warm and cold fronts shrinks. The latter initiates the occlusion process and the halting of the development. The complete life cycle of an extratropical cyclone lasts several days.
References


About the author

Dr. Thomas Frisius is a researcher and lecturer at the University of Hamburg. His research focuses on various Earth-science-related dynamical systems with emphasis on tropical cyclones, baroclinic waves and ocean circulation. A better understanding of these systems can be achieved by simplified and idealized models. Such models often stimulate the formulation of new theoretical concepts and new directions of thought. Thomas Frisius teaches the courses "Introduction to programming of global weather forecast models" and "Conceptual models of complex systems: Development, application and analysis". The first course forms a part of the master study in meteorology and the second one is taught within the interdisciplinary study program "Integrated Climate System Sciences" (ICSS). Thomas Frisius receives funding from the German Science foundation within the Cluster of Excellence "Integrated Climate System Analysis and Prediction" (CiSAP).
1.2.1.2 Vortex (e.g. Polar Vortex)

Categories

Component of the climate system
The categorized component of the climate system, or resonance of climate phenomena in social systems
atmosphere, hydrosphere

Agents
These are the quantities acting or being modified within the occurrence of the phenomenon. Agents usually own a number of attributes that are changed by rules/processes.
gas or fluid (atmosphere over the Arctic)

Rules
These are atomistic rules that change the status of the agent, i.e. modify the attributes.
thermo-dynamics, hydro-dynamics, balance laws, conservation laws, fluid mechanics
(Geophysical Fluid Dynamics [GFD], circum-polar currents, etc.)

Processes
These are the general transient modifications of attributes/states of the agents leading to or causing the phenomenon. They are composed of a number of (possibly unknown) rules.
same as the above.

Domain
These are the values, which can be reached by the attributes/states. It is important to find some quantifiable values, such that comparisons can be made. Time and space are default attributes; so size and timespan of the phenomenon should be given at least.
time (any, depends on regime), space (any, depends on regime), vorticity, flow speed, angular velocity;
  ➢ temporal extent: 1-12 months (life span: months, recurrence rate months)
  ➢ spatial extent: 500-2500 km (also much smaller depending on regime)
  ➢ other axes: angular velocity ?, potential vorticity (≥ 50 PV units...), volume, energy content, ...

Description
The description is to be made in terms of conditions on the states of agents that determine/constitute a phenomenon. In mathematical terms a phenomenon is best described by a sub-set of all possible states.

A vortex is an area in the fluid/gas domain, in which the fluid/gas dominantly flows around an axis of rotation. The vorticity within this domain is large compared to the surrounding area (see figure for the polar vortex).
References


About the author

Prof. Dr. Jörn Behrens. Educated as an applied mathematician with PhD (Dr. rer. nat.) from Bremen University and Habilitation from Technische Universität München, Munich. Jörn develops numerical methods for atmospheric and oceanic simulation. He specializes in adaptive mesh refinement, numerical geophysical fluid dynamics, and high performance computing. In 2006 following the 2004 Sumatra-Andaman Tsunami, he became head of the tsunami modeling group at Alfred Wegener Institute, Bremerhaven, and developed the simulation component of the German-Indonesian Tsunami Early Warning System (GITEWS). After delivering the system, he accepted a professorship for numerical methods in geosciences at the Center for Earth System Research and Sustainability (CEN) of University of Hamburg in 2009. He coordinates the research project ASCETE (Advanced Simulation of Coupled Earthquake Tsunami Events), and serves as Co-Chair of UNESCO Intergovernmental Coordination Group for setting up a Tsunami Early Warning System for the Mediterranean, North-East Atlantic and Connected Seas (NEAMTWS) Working Group 1 (Hazard Assessment and Modeling). Since 2015 he serves as the program director of the special interest group on geosciences for the Society of Industrial and Applied Mathematics (SIAM).
1.2.1.3 El Nino

Categories

Component of the climate system
The categorized component of the climate system, or resonance of climate phenomena in social systems
atmosphere, hydrosphere

Agents
These are the quantities acting or being modified within the occurrence of the phenomenon. Agents usually own a number of attributes that are changed by rules/processes.
gas (air): atmospheric circulation, water: upper ocean (thermocline)

Rules
These are atomistic rules that change the status of the agent, i.e. modify the attributes.
air-sea interaction, thermodynamics and fluid dynamics

Processes
These are the general transient modifications of attributes/states of the agents leading to or causing the phenomenon. They are composed of a number of (possibly unknown) rules.
wind bursts, Rossby and Kelvin wave propagation, Sverdrup transport, wind-driven upwelling

Domain
These are the values, which can be reached by the attributes/states. It is important to find some quantifiable values, such that comparisons can be made. Time and space are default attributes; so size and timespan of the phenomenon should be given at least.

- occurrence: every 2 – 7 yrs, duration: 3 to 18 months, temporal extent: 1 month – 10 yrs
- area: equatorial Pacific, teleconnections: global, spatial extent: 1000 – 100000 km

Description
The description is to be made in terms of conditions on the states of agents that determine/constitute a phenomenon. In mathematical terms a phenomenon is best described by a sub-set of all possible states.

El Nino is a certain state of the atmospheric and oceanic circulation in the equatorial Pacific. Alternative states are La Nina or the neutral state; the three together forming ENSO. El Nino is characterized (in comparison with the other states) by anomalously warm sea surface temperatures in the Eastern Pacific, weaker trade winds and in turn a changed atmospheric (Walker) circulation. Classically, an El Nino is defined as the equatorial Pacific sea surface temperature anomaly (with respect to long-term climatology) is larger than 0.5 K for at least 3 months. While the characterisation of El Nino, and also the separation between the different ENSO states is straightforward, identifying (or even predicting) the trigger(s) for the onset, strength, duration and frequency of individual El Nino events is not.
Sea Surface temperature anomalies (from ERAinterim) averaged over the equatorial Pacific. Anomalies consistently higher than 0.5 K are usually referred to as El Nino, and anomalies consistently lower than -0.5 K are usually referred to as La Nina. (Source: Prof. Dr. Daniela Domeisen)

References


About the author

Johanna Baehr is a professor for ‘climate system data assimilation’ with a background in physical oceanography and experience in climate modelling. Her current research focuses on the predictability of the earth system’s variability on seasonal-to-decadal time scales.
### 1.2.1.4 Weddell Sea Polynya

**Categories**

**Component of the climate system**

The categorized component of the climate system, or resonance of climate phenomena in social systems: cryosphere and atmosphere, hydrosphere.

**Agents**

These are the quantities acting or being modified within the occurrence of the phenomenon. Agents usually own a number of attributes that are changed by rules/processes.

- sea ice, mixed layer, pycnocline, Antarctic Bottom Water (AABW), Maud Rise seamount, wind, currents, eddies, tides, waves, CO2, stratospheric ozone, Southern Annual Mode, ice shelves.

**Rules**

These are atomistic rules that change the status of the agent, i.e. modify the attributes.

- thermodynamics; fluid and ice dynamics.

**Processes**

These are the general transient modifications of attributes/states of the agents leading to or causing the phenomenon. They are composed of a number of (possibly unknown) rules.

- deep convective overturning circulation, Ekman upwelling, freshening, stratification, ocean ice atmosphere exchange and feedback processes.

**Domain**

These are the values, which can be reached by the attributes/states. It is important to find some quantifiable values, such that comparisons can be made. Time and space are default attributes; so size and timespan of the phenomenon should be given at least.

- time, space:
  - duration: 3 years
  - temporal extent: 1 - 4 years
  - spatial area: 1000 x 300 km
  - spatial extent: 300 – 1500 km

**Description**

The description is to be made in terms of conditions on the states of agents that determine/constitute a phenomenon. In mathematical terms a phenomenon is best described by a sub-set of all possible states.
Polynyas are areas of open water surrounded by sea ice. A particular huge polynya with a size of approximately 200000 km² occurred in the Weddell Sea for a duration of three years in 1974-1976 (Fig. 1). The intriguing phenomenon was observed with one of the first spaceborne microwave radiometers, the Nimbus-5 Electrically Scanning Microwave Radiometer (ESMR). Unlike the frequently occurring wind-driven coastal polynyas, the Weddell Polynya maintained an open water area within the usually sea ice covered deep ocean. It remained a challenging scientific question why the phenomenon persisted despite the complete summer melt of ice, and that since 1976 such a polynya has not been observed again. Various hypotheses have been proposed to explain the phenomenon. Lemke (1987) explained the formation with a combination of divergent sea-ice drift and pycnocline upwelling. Timmerman et al. (1999) studied the importance of a positive atmosphere feedback for the persistence of the phenomenon. Holland (2001) discussed the role of the Maud Rise seamount causing cyclonic eddies and transmitting divergent Ekman stress that leads to an opening of the ice cover. Beckmann et al. (2001) highlighted the importance of periodic tidal forcing modifying the mixed layer above the seamount. Gordon et al. (2007) hypothesized that stratospheric O3 depletion and rising CO2 concentrations leading to a positive phase in the Southern Annular Mode may be responsible for the long quiescence of the phenomenon. Recently, de Lavergne et al. (2014) argued that enhanced surface freshening of the southern ocean since the 1950s suppressed deep convection which was more common in preindustrial times. The disappearance of the phenomenon is thus possibly a result of anthropogenic climate change and linked to the decrease of Antarctic Bottom Water production with important consequences for oceanic heat uptake and carbon storage.

References


de Lavergne, C., Palter, J. B., Galbraith, E. D., Bernardello, R., Marinov, I.,(2014). Cessation of deep convection in the open Southern Ocean under anthropogenic climate change. DOI: 10.1038/NCLIMATE21322.


About the author
Dr. Lars Kaleschke is a professor and head of the CliSAP Sea Ice Remote Sensing Group at the Institute of Oceanography at the University Hamburg. After his diploma in physics he received his PhD (Dr. rer. nat) from the University of Bremen. In 2006 he became a Junior Professor for Oceanography at the University of Hamburg and was involved as a principal investigator for the two phases of the German Excellence Cluster "Integrated Climate System Analysis and Prediction CliSAP" and several other projects. His main research interests can be described with the keywords remote sensing, Arctic and permafrost, the role of sea ice in the climate system, ice-ocean-atmosphere physico-chemical interaction, and sea ice forecasting. His scientific contributions and accomplishments are the development, improvement and validation of retrieval techniques for various sea ice parameters like sea ice concentration, sea ice and snow thickness, melt pond coverage, leads, and frost flowers. He established the relation between frost flowers and atmospheric halogen chemistry and first hypothesized the effect of calcium carbonate precipitation to explain tropospheric ozone depletion events. He coordinated the development and test of a sea ice forecast system for ship route optimization. He serves as a national delegate in the Cryosphere Working Group of the International Arctic Science Committee IASC and as an editor for the journal The Cryosphere. He is member of the ESA SMOS Quality Working Group, NASA SMAP Early Adopter Programme, CNES SMOS-NEXT Science Team, and the DLR Tandem-L Science Team through the HGF Alliance Remote Sensing and Earth System Dynamics (EDA). Lars Kaleschke offers lectures and supervises theses for B.Sc. Geophysics/Oceanography, M.Sc. Oceanography, and Makers of Integrate Climate System Sciences (ICSS).
1.2.1.5 Thermokarst

Categories

Component of the climate system
The categorized component of the climate system, or resonance of climate phenomena in social systems
lithosphere; hydrosphere; biosphere

Agents
These are the quantities acting or being modified within the occurrence of the phenomenon. Agents usually own a number of attributes that are changed by rules/processes.
ground ice bodies in permafrost-affected soils and sediments; mineral and organic soil/sediment constituents; plant individuals

Rules
These are atomistic rules that change the status of the agent, i.e. modify the attributes.
thermodynamics; fluid mechanics; disturbance ecology of plants

Processes
These are the general transient modifications of attributes/states of the agents leading to or causing the phenomenon. They are composed of a number of (possibly unknown) rules.
melting of ground ice; ground subsidence; ponding; dieback of terrestrial vegetation; change of landscape heat capacity; permafrost degradation (all processes together: thermokarst formation, “thermokarstification”)

Domain
These are the values, which can be reached by the attributes/states. It is important to find some quantifiable values, such that comparisons can be made. Time and space are default attributes; so size and timespan of the phenomenon should be given at least.
time, space:

- temporal extent: 10 days to 10000 years
- spatial extent: 1 m to 1000000 m

Description
The description is to be made in terms of conditions on the states of agents that determine/constitute a phenomenon. In mathematical terms a phenomenon is best described by a sub-set of all possible states.

Thermokarst is a land surface configuration that results from the thawing of ice-rich permafrost, leading to subsidence and deformation of the soil surface and formation of specific relief forms and ecosystems. In a thermokarst landform, previously existing ground ice has melted; therefore, there is less ground ice within the thermokarst landform than in the surrounding areas when compared for specific absolute height intervals. The subsidence results in a substantially lower soil surface in the thermokarst landform than in the surrounding areas.

Thermokarst is considered an important phenomenon because it leads to rapid permafrost degradation, mobilization and decomposition of previously frozen soil organic matter and nutrients and release of greenhouse gases. However, the carbon balance of thermokarst formation is very dependent on the time scale: On long time scales, thermokarst depressions are suitable places for peatland development and carbon dioxide sequestration. While the release or uptake of greenhouse gases has global impacts and the mobilization of nutrients has rather regional impacts, the subsidence and destabilization of the ground has also very local direct impacts on buildings and infrastructure.
References


About the author

Lars Kutzbach is a professor at the Institute of Soil Science of the Universität Hamburg and one of the principal investigators of the German Excellence Cluster "Integrated Climate System Analysis and Prediction CliSAP". The main scientific goal of Lars as researcher and teacher is to improve the understanding of the role of soils in the climate system. He focuses his research and education on the interconnected soil and vegetation processes and their coupling to the atmosphere and the hydrosphere. Over the last 16 years, Lars has concentrated his work on permafrost-affected landscapes of the Arctic as well as pristine and anthropogenically degraded peatlands of different climate zones (e.g., in Russia, Finland, Argentina, Northern Germany). His research is based on empirical field measurements and experiments on pedon and landscape scales, and he regularly struggles with the question how process understanding derived on these smaller scales can be used in large-scale Earth system models.
1.2.1.6 Algal bloom

Categories

Component of the climate system
The categorized component of the climate system, or resonance of climate phenomena in social systems
biosphere

Agents
These are the quantities acting or being modified within the occurrence of the phenomenon. Agents usually own a number of attributes that are changed by rules/processes.
phytoplankton cells

Rules
These are atomistic rules that change the status of the agent, i.e. modify the attributes.
physiological and life history "rules"

Processes
These are the general transient modifications of attributes/states of the agents leading to or causing the phenomenon. They are composed of a number of (possibly unknown) rules.
cell growth, cell buoyancy

Domain
These are the values, which can be reached by the attributes/states. It is important to find some quantifiable values, such that comparisons can be made. Time and space are default attributes; so size and timespan of the phenomenon should be given at least.
time, space:

- temporal extent: 1-2 months
- spatial area: 500 x 500 km
- spatial extent: <1m – 1000 km

Description
The description is to be made in terms of conditions on the states of agents that determine/constitute a phenomenon. In mathematical terms a phenomenon is best described by a sub-set of all possible states.

The term "bloom", originally describing the time period of collective flowering of land plants, had been adopted by marine biologists to high phytoplankton cell concentrations in the upper ocean, that occur regularly and simultaneously with the greening of trees in midlatitude spring time. As a precise and quantitative definition of the term "algal bloom" was missing, the term was later also applied in general to "high" phytoplankton abundances as the result of a "significant" increase in cell number. While phytoplankton blooms are often visible by eye, the mechanisms leading to this phenomenon are not always obvious. Algal blooms are usually stimulated by favorable environmental conditions (sufficient light and nutrients) that cause exponential growth of cell populations, but accumulation due to converging flow fields, or upward movement of cells may result in similar features. Typically, algal blooms last days to weeks and extend to an area of square meters to thousands of square kilometers.
About the author

Prof. Inga Hense has longstanding experience in modeling biological processes in marine systems. She uses a range of different numerical ecosystem models to study the effects of climate change on phytoplankton dynamics as well as the consequences of the phytoplankton life cycle on the environment. In particular, she is interested in changes in species composition, biomass and phenological patterns. Inga Hense is lecturer at the interdisciplinary study program “Integrated Climate System Sciences” (ICSS) and Principal Investigator at the German Cluster of Excellence: “Integrated Climate System Analysis and Prediction” (CiSAP) at the University of Hamburg.
1.2.2 Social science examples

Here, each lecturer with a social science background presents a phenomenon following the ‘scales’ definition from chapter 1.1.

Intertwined natural science components and the respective components in social systems.

- 1.2.2.1 Climate skeptical debate about the global warming pause / hiatus / slowdown
- 1.2.2.2 Social networks in resource use
- 1.2.2.3 Medialization of Science
1.2.2.1 Climate skeptical debate about the global warming pause / hiatus / slowdown

Categories

Component of the climate system
The categorized component of the climate system, or resonance of climate phenomena in social systems
Media and Science Communication

Agents
These are the quantities acting or being modified within the occurrence of the phenomenon. Agents usually own a number of attributes that are changed by rules/processes.
IPCC/climate researchers, journalists, contrarians/skeptics

Rules
These are atomistic rules that change the status of the agent, i.e. modify the attributes.
Routines of journalism (balance, search for novelties/news values); communication routines of the IPCC (lack of explanations, passive rather than pro-active communications)

Processes
These are the general transient modifications of attributes/states of the agents leading to or causing the phenomenon. They are composed of a number of (possibly unknown) rules.
Agenda-setting process through the communicative interaction between the agents mentioned above

Domain
These are the values, which can be reached by the attributes/states. It is important to find some quantifiable values, such that comparisons can be made. Time and space are default attributes; so size and timespan of the phenomenon should be given at least.
Space, time (slow level of debate already since 2006; sudden rise in 2013, fall back to lower levels in 2014)

Extent of media coverage claiming that there is a pause in global warming

Description
The description is to be made in terms of conditions on the states of agents that determine/constitute a phenomenon. In mathematical terms a phenomenon is best described by a sub-set of all possible states.

The idea of a global warming pause/slowdown/hiatus arose from questions over whether and why temperature rises appeared to be slowing down in the early 2000s. While recent climate research shows, that actually there was no slowdown of warming in the last 15 years, it has always been a matter of where to set the starting point for creating the image of a hiatus. The year 1998 was used by climate skeptics as point of reference, as that year was exceptionally warm (due to a strong El Nino effect), so that the following somewhat cooler years could be interpreted like a slow down.
Now, my phenomenon is not the hiatus (or its actual absence), but the emergence of a “hiatus” debate that has been strategically promoted by contrarians (outspoken critics of the idea that man-made global warming actually exists) taken up by the media and worsened by the failed PR efforts of the IPCC. Many media outlets, especially in the US have taken up the discourse of the imagined pause in climate change and public beliefs in the US public in the existence of climate change have been shaken as a result. Climate scientists (or to be more precise: the IPCC) are also partly responsible for the emergence of the debate as a leaked draft of an IPCC report from 2013 was formulated in a way that was open to misunderstanding and IPCC authors and representatives were unable to respond to journalists’ in a way to clearly explain that there was no change in climate change.


**References**


**About the author**

Michael Brüggemann (PhD, University of Hamburg) is Professor of Communication Research, Climate and Science Communication at the University of Hamburg and Principal Investigator at the interdisciplinary cluster of excellence CLISAP. His research explores the transformations of journalism, political and science communication from a comparative perspective. For recent publications, see: [www.bruegge.net](http://www.bruegge.net).
1.2.2.2 Social networks in resource use

Categories

Component of the climate system
The categorized component of the climate system, or resonance of climate phenomena in social systems

Agents
These are the quantities acting or being modified within the occurrence of the phenomenon. Agents usually own a number of attributes that are changed by rules/processes.

Community, water, agriculture (crops), livestock, wildlife, health, education, forestry, social development

Rules
These are atomistic rules that change the status of the agent, i.e. modify the attributes.

Resource flows, information flows, financial flows, decisions

Processes
These are the general transient modifications of attributes/states of the agents leading to or causing the phenomenon. They are composed of a number of (possibly unknown) rules.

Resource management, human interaction, conflict, cooperation

Domain
These are the values, which can be reached by the attributes/states. It is important to find some quantifiable values, such that comparisons can be made. Time and space are default attributes; so size and timespan of the phenomenon should be given at least.

Time, space, impact

Description
The description is to be made in terms of conditions on the states of agents that determine/constitute a phenomenon. In mathematical terms a phenomenon is best described by a sub-set of all possible states.

Social network analysis (SNA) focuses on “relationships between actors and on the patterns and implication of these relations” in the transfer or flow of resources (Bodin and Prell 2011). Four principles are relevant: independence of actors; presence of relations or ties in the transfer of resources; the constraining and/or enabling of individual actors by networks; and the generation of long-lasting ties and networks by social structures. Characteristics of the social units arise out of structural or relational processes (Wasserman and Faust 1994). SNA offers tools for mapping and analysing social structures for more stable interactions. Governance networks are created, encouraged, or maintained by certain central steering actors like the government or community.

The social resource network in South Kenya is made up of major cohesive subgroups: water, agriculture (crops), livestock, wildlife, health, education, forestry and social development. The subgroups are interlinked and managed mainly by extension officers and other resource managers employed by the government. Distinctive subgroups are a sign of an active and structured organisation. In-depth network analysis further divided the sectors using the

Source: Ngaruiya 2014
natural and external financial resources driving local ecosystem service utilization (Nagaruiya 2014).

References


About the author

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1.2.2.3 Medialization of Science

Categories

Component of the climate system
The categorized component of the climate system, or resonance of climate phenomena in social systems

Society as the most encompassing social system including major social systems such as mass media, science and politics.

Agents
These are the quantities acting or being modified within the occurrence of the phenomenon. Agents usually own a number of attributes that are changed by rules/processes.

Research institutions such as universities; individual scientists; scientific communication.

Rules
These are atomistic rules that change the status of the agent, i.e. modify the attributes.

“Scientific ethos”, i.e. (normative) ideas about how scientists should behave and communicate (Merton 1942); organisational prerequisites, e.g. outreach staff, media policies (Peters 2012); media logic (rules of media communication), such as selection criteria, ‘sound bite’- and news value orientation (e.g. Luhmann 2000; Galtung and Ruge 1965; Badenschier and Wormer 2012).

Processes
These are the general transient modifications of attributes/states of the agents leading to or causing the phenomenon. They are composed of a number of (possibly unknown) rules.

Media attention, i.e. as measured by quantity of news pieces (in print or digital media) on the work of a scientist, a research group, a climate cluster, or a university. Also quantity of media contacts (resulting or not in news coverage), scientists’ own writings for mass media or social media.

Domain
These are the values, which can be reached by the attributes/states. It is important to find some quantifiable values, such that comparisons can be made. Time and space are default attributes; so size and timespan of the phenomenon should be given at least.

As above, media attention with indicators such as quantity of media contacts, mentions in the news etc., quantity of organizational press events (conferences or press releases), coverage of scientific journals (e.g., Science and Nature) in general mass media.

Description
The description is to be made in terms of conditions on the states of agents that determine/constitute a phenomenon. In mathematical terms a phenomenon is best described by a sub-set of all possible states.

The concept of a medialization of science refers to the mutual relation between the social systems of science and the mass media. It postulates that there is an increasing tendency to orient science towards the interests of the media because their attention for certain topics, scientists and research institutes is perceived as crucial for public support, research funding and/or science outreach and education (Weingart 1998, 2001, 2012). The medialization of science is considered to be an important phenomenon because it might impact (facilitate or impede) processes of scientific knowledge presentation and knowledge production.

The expectation of backlashes of media attention is based on findings of a growing intensity of mass media coverage for science in general, albeit with very different disciplinary shares (e.g., Bauer 1995; Nelkin 1995; Elmer et al. 2008; Bauer 2012; Peters et al. 2012), as well as the rise of digital media (e.g. Scheufele et al. 2014). Media events such as press conferences and press releases, the pre-publication of research results in the mass media prior to their scientific publication, the media orientation of scholarly journals and the appearance of visible scientists have been described as empirical indicators for an orientation of science towards the rationalities of the media system (Weingart 1998, 2001; Rödder et al. 2012).
Because of the highly contested nature of the climate issue, climate science is a case in point. Schäfer and colleagues have demonstrated in several studies that news media attention for climate change is high across the globe (Schäfer et al. 2012; Schmidt et al. 2013; Ivanova et al. 2013). While this attention is welcomed in general and expected to mobilize widespread attitude change among the public, "risks of communication" between science, politics and the mass media in the climate case have long been noticed (Weingart et al. 2000). So with regard to science as a social system, the surge of media reporting about scientific issues in general and climate change in particular is a phenomenon that leads to question the consequences of intense media attention on the production and presentation of climate-related knowledge.

To investigate the relevance of media attention for science requires looking at different scales within the science system: Firstly, at the micro-level scale of individual researchers, one may ask how scientists imagine themselves as public communicators and what their peer community thinks of 'visible scientists' (Rödder 2012). Secondly, at the meso-level scale of research organizations questions include how research institutions react to a perceived (political) expectation to be in the mass media, and whether public relations efforts backlash on scientific practises (Marcinkowski et al. 2014; Peters et al. 2014). At the macro-level scale of scientific communication, the scientific publication system comes into focus. A key question is whether mass media related criteria are anticipated in the presentation of knowledge in scholarly communication (Franzen 2012). Overall, the central research question is if incorporating mass media-related criteria of relevance into communication strategies has an impact on the specific societal function of science, i.e., the production of new and reliable knowledge (Franzen et al. 2012: 5).

By investigating mediationalization on the micro-, meso- and macro scale of social systems, the key issue is how the phenomenon can be measured. In practice, media attention is usually measured by quantities of news pieces (in print or digital media) published on a scientist, a research group, a climate cluster, or a university. Also one may count the quantity of media contacts (resulting or not in news coverage) or of scientists' own writings for mass media or social media. Media orientation might be operationalized by the number of staff in a press department, or the quantity of output such as organizational press events (conferences or press releases). There are, however, a number of problems with a quantitative approach to a complex phenomenon such as mediationalization.

In the following I will exemplify limitations of the approach of, firstly, identifying indicators of mediationalization, and secondly, quantifying them in line with the general idea of the "scales" concept (see also Chapter 1.1.4 on "Advancing integrated thinking"). I will discuss two indicators of a media orientation within science that – while promising in the first place – turn out to not be complex enough to capture the phenomenon of mediationalization (cf. for the following Rödder and Franzen 2014).

The first indicator is the quantity of media coverage. This indicator is at the heart of mediationalization theory and has been widely used to support the idea that there is mediationalization going on at all. A number of studies have provided evidence for a rise in the media coverage of science (especially the life sciences) since the 1990s (Bauer et al. 1995; Hampel et al. 1998; Görke et al. 2000; Schäfer 2007; Weingart et al. 2008; Elmer et al. 2008, Bauer 2012, and for climate science Schäfer et al. 2012; Schmidt et al. 2013). The absolute quantity of media coverage – while being indicative of an increased media interest in science and technology – is often equally taken as an indicator of the degree of media orientation within science, and namely of research institutions.

This conclusion, however, does not take into account that the professional mandate of every press office is twofold: To induce media coverage which is affirmative of the organisation (the so called agenda setting function) and to try to prevent coverage of those issues that an organisation does not want to be out in the public sphere (the so called agenda cutting function). The sheer quantity of media coverage can thus not be taken as an indicator of institutional changes within research organizations (such as the establishment of a press office). Rather, agenda setting as well as agenda cutting must be seen (and analyzed) as a result of a media orientation of research institutions. As an effect of a very professional, media-oriented press office’s work, the quantity of media coverage may actually decrease.

A second indicator is the quantity of press releases. At first sight, the number of press releases that for instance accompany a scientific paper seems to be a viable indicator for the intensity of organizational media work, and therefore media orientation. This indicator, however, deserves a closer look, too. A case in point is the sequencing of the platypus genome (Warren et al. 2008), published as cover story in the journal Nature in 2008. It is characteristic for big genome science that the sequencing of entire genomes is jointly accomplished in large international consortia, and resulting in multi-authorship publications. In the case of the platypus paper, more than 100 contributing authors are listed who are affiliated to 32 institutions. When we researched all accompanying press material from relevant electronic archives (including EurekAlert!, Informationsdienst Wissenschaft e.V. (idw), the research institutions and the publisher involved), we ended up with eight press releases for the scientific paper. Five were issued by research institutions (including three US-American, one German, and the European Molecular Biology Laboratory EMBL) and two by US-American funding agencies. A final release was issued by the journal Nature that also bundles all press information in form of its embargoed news service. It is plausible to assume that the intensity of press work in the platypus case had to do with the anticipation of media selection criteria: The cute and curious animal lends itself perfectly to news values such as the surprise-factor (Badenschier and Wormer 2012) and is as such easily identified by professional PR as a potential Nature as well as media cover, as well as longer or shorter news story. Research organisations regularly use new publications to demonstrate their scientific success (Kallfass 2009: 116; Friedrichsmeier et al. 2013). In this particular case, the PR effort lead to news articles in all of the three press outlets that we studied, Frankfurter Allgemeine Zeitung, Süddeutsche Zeitung and DIE ZEIT. The publication of the platypus genome therefore is a case in point of successful media agenda setting by the high-impact journal Nature, seconded by press work out of research institutions. This can now be considered the routine case in the coverage of the life sciences (Franzen 2012).
But how do we have to evaluate the quantity of eight press releases that we found? Are eight releases few or many if four times more institutions are involved in the research? A comparatively high amount of press releases first of all indicates an increased supply (and maybe enhanced competition) on the science side. It is exactly this competition that leads other press departments to reduce the quantity of their press releases (Kallfass 2009). We can thus conclude that indicators, which favor a quantitative comparison between cases, have to be used with great care, and often are by themselves of little validity.

References


About the author

Simone Rödder is an assistant professor of sociology at the University of Hamburg’s Department of Business, Economics and Social Sciences and a Principal Investigator in the Cluster of Excellence “Integrated Climate System Analysis and Prediction” ( CliSAP). Her research is located at the intersection of the sociology of science and the science of science communication and applies mainly qualitative methodologies. Her current work focuses on interdisciplinary collaboration in climate research and her major class in the MICSS curriculum is a lecture with practicals, “Introduction to the Social Sciences”. Simone has an academic background in biology, sociology and science communication and holds an interdisciplinary PhD degree (Dr. phil. nat.) from the University of Bielefeld. She has been trained as a journalist and worked for several newspapers and magazines.
1.2.3 History of science example- The Max Planck Institute for Meteorology as a historical phenomenon

Categories

Component of the climate system
The categorized component of the climate system, or resonance of climate phenomena in social systems

Science

Agents
These are the quantities acting or being modified within the occurrence of the phenomenon. Agents usually own a number of attributes that are changed by rules/processes.
human/institutional: MPG senate, Fraunhofer Society, individual scientists, politicians, science manager
non-human: climate change/environment, technology (climate models)

Rules
These are atomistic rules that change the status of the agent, i.e. modify the attributes.
Constitution of research institutions (scientific problem, research programme, research groups, research questions), research funding traditions. (MPG "rule": Harnack Principle was disregarded!)

Processes
These are the general transient modifications of attributes/states of the agents leading to or causing the phenomenon. They are composed of a number of (possibly unknown) rules.
scientific (development of climate modelling, competition), institutional (communication between various institutions), social (rise of environmental awareness), political and economic processes... And everything we don’t yet know before doing historical research.

Domain
These are the values, which can be reached by the attributes/states. It is important to find some quantifiable values, such that comparisons can be made. Time and space are default attributes; so size and timespan of the phenomenon should be given at least.
Space (between local and international), time (between months and decades)

Description
The description is to be made in terms of conditions on the states of agents that determine/constitute a phenomenon. In mathematical terms a phenomenon is best described by a sub-set of all possible states.

The Max Planck Institute for Meteorology (MPI-M) in Hamburg is operated by the Max Planck Society (MPG), a state-funded research institution beyond university walls. It was officially inaugurated in February 1975. The major goal of the new institute was to develop climate models, integrating ocean-atmosphere interaction, and investigate climatic change.

The fact that this institute exists today is the result of past decisions and choices, which were made under specific conditions and scopes. Hence, the existence of the MPI-M is the consequence of historical processes and can, as such, be seen as a historical phenomenon – in other words, it cannot be taken for granted. It is therefore reasonable to ask “Why is there a Max Planck Institute for Meteorology in Hamburg?” In order to find an answer we need to analyse the context in which these choices and decisions were made. That includes all areas of society that influence the decision-making process, such as science itself, as well as political, economic, social and technological factors.

The main actors in historical processes are human beings. However, in recent years an increasing number of historians include non-human actors and consider, for example, technology, “the environment”, or animals also as having an agency in historical processes. Following this in the context we discuss here, in addition to scientists, managers, politicians and other people, we can also identify a rising awareness of environmental problems from the 1960s onwards (air pollution, climate change etc.) and the development of climate modelling as a major research technology as important drivers of the founding process of the MPI-M.
But human beings as crucial actors in the development of historical phenomena tend not to behave according to strict rules like, for example, physical processes. Every historical situation in which a choice is made is unique. In addition to that, every human being acts according to his/her own individual experience, character and emotions. Consequently, such processes are hardly reproducible. The question of “what can we learn from history?” is therefore tricky. Having said this, we may identify some patterns that influence the founding process of a scientific institution in the 1970s. This may be funding structures of the organisation of a scientific community.

Analysing the historical processes that resulted in the existence of the MPI-M can help us understand why the production of climate knowledge is organised in a particular way today and what factors have influenced the way current scientific knowledge is generated.

About the author

Dania Achermann is a historian of science and was a guest researcher at the Cluster of Excellence “Integrated Climate System Analysis and Prediction (CliSAP)” from April to August 2017. She holds a Master’s degree in history and geography from Zurich University (Switzerland) and a dual degree PhD in history of science and technology from both Ludwig-Maximilians-University Munich (Germany) and Aarhus University (Denmark). Her main field of interest is the history of atmospheric and climate sciences in the 20th century, history of ice and snow research, environmental history and interdisciplinarity.
Now that we have introduced our definition of scales and related terms and described some climate system phenomena according to our definition, we start presenting and discussing scale diagrams, commonly used tools to visualise scale-depending analyses.

Looking at scales- the art of scale diagrams

- 1.3.1 | History of scale diagrams
- 1.3.2 | Theory of scale diagrams
1.3.1 History of scale diagrams

Scale Diagrams in climate sciences

Scale diagrams are widely used in climate sciences, predominantly to illustrate climate phenomena or processes in a particular time-space domain. The idea for this type of diagram comes from Stommel (1963) in ocean and Smagorinski (1974) as well as Orlanski (1975) in atmospheric sciences. The original purpose to generate these scale diagrams was to guide future studies, specifically observational field studies or modeling activities and to raise awareness for the scale perspective.

In social sciences, scale diagrams were used, too. However, the focus is less on phenomena or processes but on environmental impacts. Thus, it is not surprising that such diagrams are designed in a different way with time (Burton 1978) or numbers (e.g., of affected people) on the x-axis and social science categories or costs on the y-axis (e.g., Burton 1978; White and Haas 1975).

At a time, before IPCC was first established, Clark (1985) picked up the concepts of the different disciplines. His work was pioneering, because phenomena from both natural and social sciences found the way into the scale diagram (see Fig. 1). To derive this diagram he gathered information from 15 disciplines (see Fig. 2). This integration of the different disciplines is still unique today and there is no scale diagram which is more comprehensive and advanced.

References


About the author

Prof. Inga Hense has longstanding experience in modeling biological processes in marine systems. She uses a range of different numerical ecosystem models to study the effects of climate change on phytoplankton dynamics as well as the consequences of the phytoplankton life cycle on the environment. In particular, she is interested in changes in species composition, biomass and phenological patterns. Inga Hense is lecturer at the interdisciplinary study program "Integrated Climate System Sciences" (ICSS) and Principal Investigator at the German Cluster of Excellence: "Integrated Climate System Analysis and Prediction" (CiSAP) at the University of Hamburg.
1.3.2 Theory of scale diagrams

How to get a scale diagram? one possible way

Phenomena exist in a finite volume of space-time. In many cases one can describe it by a set field of fields \( \Phi_i(r,t) \) \( (i=1,...,N) \), where \( r \) denotes the position vector and \( t \) the time. Therefore, a phenomenon can also be represented by its Fourier-transform

\[
\Phi_i(k, t) = \int \int \Phi_i(r, t) e^{-i k \cdot r} \, dr
\]

where \( k=(k_x, k_y, k_z) \) denotes the wavenumber vector. The power spectrum of this spectral field becomes

\[
P[\Phi_i] = \frac{1}{2} |\Phi_i(k, t)|^2
\]

and describes the importance of the spectral ranges for the phenomenon. A reasonable measure for the spatial scale \( L_S \) of the phenomenon can be deduced for the wavenumber vector \( k_m \) where the power spectrum maximizes in amplitude. It could just be defined by half of the maximum wavelength \( L_S=\lambda_m/2=p /\min(k_x, k_y, k_z) \). [1]

In a more thorough way one can represent the phenomenon in a wavenumber-frequency spectrum involving both wavenumbers and frequencies:

\[
\Phi_i(k, \omega) = \int \int \Phi_i(r, t) e^{-i(k \cdot r - \omega t)} \, dr \, dt
\]

where \( \omega \) denotes the frequency. Now, also a temporal scale \( T_S = \omega /|\omega_m| \) arises by a local maximum of

\[
P[\Phi_i(k, \omega)] = \frac{1}{2} |\Phi_i(k, \omega)|^2
\]

at \( k=k_m \) and \( \omega=\omega_m \).

Multiple extrema may occur in a certain field giving rise to several scales. This may even happen for a single phenomenon but it appears more likely by the existence of several phenomena in the same field. A suitable approach to restrict the scale analysis is to consider only a subvolume of the complete space-time \( \Re^4 \). E.g., for meteorological applications it is sufficient to analyze the atmosphere only and leave all other spheres out. Furthermore, we have only limited information about the field. Values of the field quantity \( \Phi_i \) are only available at discrete points in space-time. Therefore, for the practical analysis one must apply the discrete Fourier transform (DFT) instead:
where the discrete points \( x_j, y_k, z_l \) and \( t_n \) have equal distances \( \Delta x, \Delta y, \Delta z \) and \( \Delta t \) to each other, respectively. The resulting spectrum is only meaningful between the fundamental frequency \( \omega_F = \frac{2\pi}{J \Delta t} \) and the Nyquist frequency \( \omega_N = \frac{\pi}{\Delta t} \). The discrete approach limits the wavenumber ranges likewise.

In the following we demonstrate the technique for the simpler case where the field depends only on one spatial coordinate. This applies, e.g., for the analysis of a physical field along a latitude circle at a certain level. Then, the field \( \phi_i(\lambda, t) \) depends only on longitude \( \lambda \) and time \( t \). The graphical presentation of such a field in two-dimensions is known as Hovmöller diagram. In this diagram it is often feasible to identify wave packets, phase speeds and group velocities. Since this field is periodic in the spatial dimension it is straightforward to apply the DFT in longitudinal direction. However, the atmosphere does not exhibit periodic behaviour in time and it is not justified to define a fundamental frequency giving rise to a line spectrum including only the subharmonics. Therefore, for a given finite time series one must estimate the spectrum with a more sophisticated method. The Blackman-Tukey method has been established for estimating time-spectra (see Jenkins and Watts 1969). By this method the space-time power spectrum can be determined as follows:

\[
P[\Phi_i(\mathbf{k}, \omega)] = \frac{1}{2\pi^2} C_0 + \sum_{m=1}^{M} \left[ 1 + \cos\left(\frac{\pi m}{M}\right) \right] C_m \cos(\omega m)
\]

where \( M \) denotes the lag window width and \( C_m \) the autocorrelation function given by

\[
C_m = \frac{1}{N - m} \sum_{n=1}^{N-m} \Phi_i(\mathbf{k}, t_n) \Phi_i(\mathbf{k}, t_n + m \Delta t)
\]

A suitable size for the window is between \( M = N/6 \) (for \( N \) about 100) and \( N = N/10 \) (for \( N \) about 1000).

The power spectrum does not always indicate the frequencies of various oscillations correctly. For example the Fourier transform of a Gaussian bell yields another Gaussian bell having its maximum at zero frequency. This result would lead to the wrong interpretation that the time scale is infinite. To overcome this problem Zangvil (1977) suggested multiplying the resulting power spectrum with the frequency \( \omega \). This problem can be resolved likewise for the dependency on wavenumber.

To demonstrate the suitability of the method we consider three examples which are all based on reanalysis data from the National Center for Environmental Prediction (NCEP). For a documentation of this data-set see Kalnay et al. (1996).

1. Example: Extratropical weather systems
In the first example the geopotential height of the atmospheric 500hPa pressure surface for the winter 2004/05 season from December 2004 to February 2005 (DJF) is analysed. Fig. 1 displays isolines of geopotential height at the latitude 45°N as a function of latitude and time. Such a graph is called Hovmöller diagram. In essence, we see three types of waves: Short waves with a large phase speed, long waves with a slow wavespeed and long quasi-stationary waves. The former two wave types form due to baroclinic instability and are called baroclinic waves which in general travel towards the east. On the other hand, quasi-stationary waves typically result from nonlinear interactions with baroclinic waves and move very slowly. Sometimes, they even travel westward which is known as retrogression. All these fluctuations superimpose a very long stationary wave that results from the orography and the heterogeneous land-sea distribution. The stationary wave is connected with the Icelandic and Aleutian lows. It has a large projection on zonal wavenumber 2 (the latitude circle comprises two wavelengths). The separation into the various wave types becomes evident in the wavenumber-frequency representation.

Fig. 2 displays the power spectrum of geopotential height at 45°N as a function of time scale π/|ω| and length scale π/λl. These maxima arise which can be assigned to the various wave phenomena. The short baroclinic waves have a length scale that corresponds to zonal wavenumber 7 (LS=2000km) and a time scale of about 1.6 days. The long baroclinic wave adopts zonal wavenumber 5 (LS=2800km) and maximum spectral density at a time scale of about 4 days. The quasi-stationary wave having zonal wavenumber 4 (LS=3500km) reveals a time scale of about 20 days and can be regarded as a low frequency wave. It is responsible for persistent weather situations like atmospheric blocking. It is notable that Fraedrich and Böttger (1978) found the same classification of waves in a similar analysis.

2. Example: Quasi-Biennial Oscillation (QBO)
The Quasi-Biennial Oscillation (QBO) emerges in the tropical stratosphere in the form of alternating zonal winds with a period of about 28 months. The oscillation results from a downward propagating zonally constant zonal flow that is forced by the momentum flux of upward propagating inertia-gravity and Rossby waves (Baldwin et al. 2001). Fig. 3 displays the Hovmöller diagram of 10hPa zonal wind at the equator. We see indeed an oscillation of zonal mean zonal wind with a period of about two years. In contrast to the midlatitude analysis (Fig. 1), anomalies of the zonal mean have small amplitude. Due to these reasons the space–time diagram shown in Fig. 4 reveal a clear signal at a time scale of 14 months and a length scale of 40000km which corresponds to zonally constant flow along the equatorial great circle. Surprisingly, the diagram does not contain a maximum at the annual time scale. Therefore, the annual cycle does not play an important role in the zonal wind field of the tropical stratosphere.

3. Example: El Niño Southern Oscillation (ENSO)

El Niño Southern Oscillation (ENSO) describes a coupled atmosphere-ocean circulation phenomenon in the tropical Pacific. The atmospheric Walker cell and the sea surface temperature (SST) in the East Pacific vary in conjunction with ENSO at an interannual time scale. In the tropical Pacific, anomalous low surface pressure is correlated with anomalously high SST. The pressure anomaly causes equatorial zonal winds which in turn accelerates the upper ocean water by the wind stress. Then, the resulting oceanic flow modifies the sea surface temperature and, consequently, the surface pressure anomaly. By these processes a feedback loop arises which lead to the ENSO phenomenon (for a detailed introduction see Enfield 1989). ENSO modifies the global atmospheric circulation and, therefore, this phenomenon has an impact on the atmospheric conditions in remote regions which in turn are important for agriculture and the economy. ENSO also influences the ocean basin ecosystem (Enfield 1989).
Fig. 5 displays the time anomaly of surface temperature at the equator in a Hovmöller diagram for the period from 1948 to 2013. We can clearly see the annual cycle that has in some regions several degrees in amplitude. Beside the annual cycle an irregular interannual oscillation becomes evident in the Pacific region. The resulting warm anomalies give rise to an El Niño event while the cold anomalies are associated with a La Niña event. The prominent El Niño events from 1982/83 and 1997/98 are highlighted by corresponding arrows.

In the space-time diagram (Fig. 6) the power spectrum is dominated by the annual cycle which extends over various length scales. The ENSO phenomenon reveals a much weaker signal at zonal wavenumber 1 (20000km length scale) and 2 (10000km length scale). It has two maxima at 14 months and 24 months. This corresponds to time periods between 2 and 4 years. Recall that ENSO exhibits irregular time behaviour and, therefore, it cannot be associated with a single time scale.

The analysis approach presented in this chapter has some limitations and can, therefore, not applied to all phenomena in the climate system. These limitations result from the following circumstances:

1. Some phenomena do not have a pronounced scale

In the scale diagram we assume that the phenomenon has pronounced amplitude at a certain scale. However, this does not necessarily be true. Turbulence, for example, reveals a spectrum where the power declines at a certain rate with increasing wavenumber. The time spectrum can also be devoid of any maximum. E.g., a monotonic decrease of power with increasing frequency is widely known as red noise.
2. Lack of data

In many cases data sets are insufficient to apply a wavenumber frequency analysis. This is especially true for paleoclimatology data which typically are derived from tree rings, ice cores, corals, ocean sediments and lake sediments. Therefore, these data exist in the form of time series and one can only estimate the spatial pattern of the reconstructed field quantity. Spectral analysis of the time series and guessing the corresponding length scales would be a passable compromise in these cases.

3. The field approach could be dubious

The presented method assumes the existence of continuous fields that describes the phenomenon under consideration. However, many cases exists which cannot represented by fields. For example, it would be misleading to analyse volcanic eruptions by a field since the events appear rather as point sources in the climate context. Furthermore, consideration of fields is useless for nearly phenomena in the social sciences. Also in this case one can overcome this problem by estimating the spatial scale intuitively and analysing only the me behaviour.

4. Assignment of a length scale could be fatuous

Many phenomena in social sciences have no obvious length scale. For example, the rebound effect in the consumer society is a phenomenon that arises in different countries on the earth. Therefore, we can deduce that it acts out on a global scale but it would be erudite to state that the rebound effect has a length scale of 40000km. Sometimes, the word “scale” refers to other things than length or time. For example, in economic science scale has usually to do with the aggregated physical volume of material throughput (Daly 1992). Consequently, in context with social sciences we should think about another quantity that describes the scale of a phenomenon.

These limitations show that still more thoughts are necessary to treat the issue “scale in the climate system” from an interdisciplinary perspective. In the next chapter a third axis in the scale diagram is introduced that could possibly resolve the limitation of the last paragraph.

References


About the author
Dr. Thomas Frisius is a researcher and lecturer at the University of Hamburg. His research focuses on various Earth-science-related dynamical systems with emphasis on tropical cyclones, baroclinic waves and ocean circulation. A better understanding of these systems can be achieved by simplified and idealized models. Such models often stimulate the formulation of new theoretical concepts and new directions of thought. Thomas Frisius teaches the courses "Introduction to programming of global weather forecast models" and "Conceptual models of complex systems: Development, application and analysis". The first course forms a part of the master study in meteorology and the second one is taught within the interdisciplinary study program "Integrated Climate System Sciences" (ICSS). Thomas Frisius receives funding from the German Science foundation within the Cluster of Excellence "Integrated Climate System Analysis and Prediction" (CliSAP).
The concept of scales and scale diagrams are used in a wide range of disciplines. Space and time are the common denominator in natural sciences. However, aiming to find scale diagrams, which integrate natural and social sciences, we need to see beyond space-time-diagrams.

**Why do we need other axes?**

The main promise but equally one of the crucial challenges of the concept of scales is the integration of the natural sciences and social sciences. Natural science phenomena might be easier to measure with spatial and temporal scales but social science phenomena, which are normally not quantified on a spatial or temporal scale or are not quantified at all, do not easily fit into the 2D-concept of scales. Another aspect to be considered is the difficulty to interpret the temporal and spatial scale of all phenomena regarding the impact of these phenomena on humans or the public awareness and activity these phenomena trigger. One can easily imagine that even a phenomenon with a high spatial and temporal scale might not be considered of high public interest, when other characteristics, e.g. the visibility of the consequences of that phenomenon, are diminishing this large temporal and spatial extent. To be more precise the knowledge about the connection between spatial and temporal scales and another third dimension such as public awareness or interest, is unsatisfying and should be deepened. The scales concept developed in this class might be a good candidate to do so.

- **1.4.1 | Google Trends' Search Interest: example for a third axis**
  - **1.4.1.1 | Advantages and disadvantages of Google Trends**
  - **1.4.1.2 | How to use Google Trends**
  - **1.4.1.3 | Example diagrams with Google Trends**

- **1.4.2 | Possible other axes**
  - **1.4.2.1 | Scientific interest**
  - **1.4.2.2 | Event-related deaths**
  - **1.4.2.3 | Controllability**
  - **1.4.2.4 | People-affected**
New scales/axes are challenging and come with a lot of discussions and problems. Spatial and temporal scales were already hard to define in an inclusive way for all phenomena. However, all proposed new scales, e.g. media coverage and social impact indicated by e.g. death rates, are additionally based on hardly predictable and often inaccessible data. So far, we only generated accessible and reproducible data by Google Search with Google Trends, which displays the search interest of a certain search item by counting how often this term is entered relative to the sum of all searches over a chosen geography and time period. Although this seems to be an appealing way to display public awareness, Google Trends does not reveal how its algorithms work and the search conditions of Google Trends are not as straightforward as it might look at first glance.

1.4.1 Google Trends' Search Interest: example for a third axis

- 1.4.1.1 | Advantages and disadvantages of Google Trends
- 1.4.1.2 | How to use Google Trends
- 1.4.1.3 | Example diagrams with Google Trends
1.4.1.1 Advantages and disadvantages of Google Trends

There are several disadvantages, methodical complications, interpretation traps but also advantages, which should be considered and kept in mind to use Google Trends in an appropriate way.

Google Trends or not Google Trends—that is one of the questions

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google Trends is easily accessible and freely available.</td>
<td>Google Trends only gives relative numbers and there is no way to get absolute numbers. Therefore, a compared search needs to be done to get results which can be compared.</td>
</tr>
<tr>
<td>The data can be easily exported and is useful in comparing research.</td>
<td>People which might be affected the most by some of the phenomena might not have internet access.</td>
</tr>
<tr>
<td>There is no survey with data each week and over language and geographical borders. The data Google Trends collects is valuable because of its continuity and global data collection.</td>
<td>The context of the search is not clear. There are very many reasons for people to type in a term in Google Search. Interest is by far not the only reason. There is no information about the person searching for the term and therefore this cannot be excluded.</td>
</tr>
<tr>
<td>Because Google Search is the mostly used search engine Google Trends can represent a good percentage of all people with free access to the Internet.</td>
<td>The context of the content needs to be validated. There are not only a few words which can have different meanings. To exclude the ones you do not want to have in your search interest Google Trends is offering the possibility to search in Categories. But how these categories are formed and which algorithm is matching searches together is not clear.</td>
</tr>
</tbody>
</table>

Methodical Complications

Because Google Trends only displays relative values comparing analyses need to be based on the compared search of Google Trends. With this search, up to 5 search items can be compared in one search. Note that all search interests are normalized to the highest search interest of the group. In case there are more than 5 terms, the term with highest or maximum search interest needs to be included in the next searches as well to guarantee reproducibility and comparability. In cases where no item of a group can be identified as the item with the highest maximum search interest, another item with a clear highest maximum search interest has to be found and included in all searches.

The longer the search terms the lower is the chance that someone searches them exactly like that. But the more a search term is shortened the more information might get lost. Then again a validation of the right content of the search is necessary.

Interpretation Traps

The results seduce to interpret them without considering that these are only relative values. The results of a compared search show how the search interests of the different search terms differ from each other. Within this group comparison and ranking is possible but not more.

Google Trends uses a percentage of randomly chosen Google Web Searches. So the values differ each time a search is done, particularly in the weekly values. The calculated mean and max can be used to show the magnitude but do not, by any means, represent stable values.
In the end, or at least for the year 2016, Google Trends was arguably the best of all investigated possibilities of a third axis.

The main and most important advantage is that the data is easily and freely available. The time spent to increase the reproducibility and the validation of the context might be quite long and the results should not be over interpreted. But as long as there is no other option the search interest calculated by Google Trends is the only data based possibility for a third axis.

About the author

Maike Scheffold is research assistant in the teaching project 'Scales in the Climate System'. She finished her Master degree in 'Integrated Climate System Sciences' at SICSS with a Master Thesis topic in biological oceanography. Her background is geology/geophysics. As part of the ICSS curriculum she attended the Scales class in the year 2015, when it was first taught, and supported the class the year after as a student assistant. As a student assistant she also worked with Simone Rödder within the project “Reassessing an assessment: A study of the IPCC process”.
1.4.1.2 How to use Google Trends

Step 1
Visit the website of Google Trends.

Step 2
Log in via the button in the upper right corner. It is necessary to log in if you want to export the data later. If you don’t have an account yet, you have to create one.

Step 3
Set All Categories to Science-Earth Sciences-Atmospheric Science-Climate Change and Global Warming (Fig. 1). Keep all other parameters as they are (Web Search, Worldwide...).

Step 4
Look at your list of phenomena and pick the one phenomenon (P) that you assume to have the highest maximum search interest. Since all search interest are normalized to the phenomenon with the maximum search interest, you need to find that phenomenon (called Norm-P) and include in all your searches to equally normalize your values. Since this choice influences your results immensely, you have to carefully pick your Norm-P. Conduct several rounds of search to assess your choice. Because of the statistical differences of all searches, phenomena with similar maximum search interests might alternately be the phenomena with the highest maximum search interest. If this is the case in your group of phenomena and no clear Norm-P can be found, you must choose an additional phenomenon as a Norm-P. Keep in mind that the maximum search interest of a Norm-P should always be highest but not too high compared to the rest of the search items.

Once you found your Norm-P, use it as the standard first search item. Group your phenomena around in groups of 5 phenomena including the Norm-P and do the compared search on Google Trends (only possible for 5 items per search, see Fig. 2). Depending on the number of P’s chosen you have to do several compared searches (Fig. 3). While doing this it might happen that you find that your Norm-P is has not the highest search interest of all your P’s. In this case you have to change the Norm-P to the one with the higher interest and do it again.

If the search terms are too long, Google Trends will not find any searches. In this case, you have to find a shorter but matching search term. Example: “Violence” might be an appropriate search term for "climate induced violence" because the connection to climate change is supposedly guaranteed by the selection of the category (Tab. 1).

<table>
<thead>
<tr>
<th>Phenomena</th>
<th>Search Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAO</td>
<td>NAO</td>
</tr>
<tr>
<td>Tropical Cyclones</td>
<td>Tropical Cyclones</td>
</tr>
</tbody>
</table>
Table 1: Examples of phenomena and related search terms.

<table>
<thead>
<tr>
<th>Term</th>
<th>Related Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Droughts</td>
<td>Coral bleaching</td>
</tr>
<tr>
<td>Coral bleaching</td>
<td>New deserts in Asia</td>
</tr>
<tr>
<td>New deserts in Asia</td>
<td>Switch to Renewable</td>
</tr>
<tr>
<td>Switch to Renewable</td>
<td>Climate Justice Protests</td>
</tr>
<tr>
<td>Climate Justice Protests</td>
<td>Climate change denial</td>
</tr>
<tr>
<td>Riots occurred after a sudden natural disaster</td>
<td>Violence</td>
</tr>
<tr>
<td>Heat (wave) induced violence</td>
<td>Climate change denial in politics</td>
</tr>
<tr>
<td>Climate change denial in politics</td>
<td>EL Nino</td>
</tr>
<tr>
<td>Land use change caused by climate change</td>
<td>Land use change</td>
</tr>
</tbody>
</table>

Table 2: Search tips (modified after [1](https://support.google.com/trends/answer/4359582?hl=en&ref_topic=4365530)).

<table>
<thead>
<tr>
<th>Search term</th>
<th>Type of results you'll see</th>
</tr>
</thead>
<tbody>
<tr>
<td>tennis shoes</td>
<td>Results can include searches containing both tennis and shoes in any order. Results can also include searches like red tennis shoes, funny shoes for tennis, or tennis without shoes. No misspellings, spelling variations, synonyms, plural or singular versions of your terms are included.</td>
</tr>
<tr>
<td>“tennis shoes”</td>
<td>Results include the exact phrase inside double quotation marks, possibly with words before or after, like red tennis shoes.</td>
</tr>
<tr>
<td>tennis + squash</td>
<td>Results can include searches containing the words tennis OR squash.</td>
</tr>
<tr>
<td>tennis -shoes</td>
<td>Results will include searches containing the word tennis, but exclude searches with the word shoes.</td>
</tr>
<tr>
<td>center + centre + centere</td>
<td>Results will include alternative spellings like &quot;centre&quot; or &quot;centere&quot; and common misspellings like &quot;centere.&quot; Trends considers each version of a word a different search, including misspellings.</td>
</tr>
<tr>
<td>cat + Katze</td>
<td>Results will include different languages</td>
</tr>
</tbody>
</table>

In the following example, the five P’s of suspected highest search interest were chosen and El Nino was chosen as the Norm-P (Fig. 2). Two more searches were conducted to include six more P’s (Fig.3 and Fig. 4). The labels of the P’s were changed to shorter ones. Obviously this increases vagueness and you should try to validate that the terms you take will lead to similar phenomena as originally planned.
Figure 2: First search with the Norm-P. Data Source: Google Trends (www.google.com/trends)[17/05/2017]

Figure 3: Second search with the Norm-P. Data Source: Google Trends (www.google.com/trends)[17/05/2017]

Figure 4: Third search with the Norm-P. Data Source: Google Trends (www.google.com/trends)[17/05/2017]
Step 5

Download the timeseries of each search round as CSV-file. To do this, click on the three points in the upper right corner and choose „Download as CSV“. Using the CSV-file with Excel might lead to complications with the format. If you do not know how to deal with this, use Google Sheets: https://www.google.com/sheets/about/ . You have to sign in with your Google account again. Click on the folder shaped button in the right upper corne r and download your CSV-file (Fig. 5-6).

Step 6

Calculate the max and mean interest (Fig. 7). In the header of the CSV-file you find information about search terms and parameters. Below you find the time period in the first column, a value for the interest of the first search term in the second column, a value for the interest of the second search term in the third column and so on. There is one value for every search term for every week starting on 2004-01-04.

As Google Trends uses a certain percentage of randomly chosen Google Web Searches you have to be aware that your values might differ each time you search. This will be especially visible in the weekly values but is not tremendous in the mean and the max values. Since this is a statistical procedure the values you obtain are “house-numbers” and should only be interpreted that way.

Step 7

As always in scientific work, you have to cite your source. Make sure that all your values derived with Google Trends data are marked in an appropriate way by using e.g. “Data Source: Google Trends (www.google.com/trends) [17/05/2017]”.

Since Google Trends renews its data weekly you should mark the date of your search.

About the author

Maike Scheffold is research assistant in the teaching project ‘Scales in the Climate System’. She finished her Master degree in ‘Integrated Climate System Sciences’ at SICSS with a Master Thesis topic in biological oceanography. Her background is geology/geophysics. As part of the ICSS curriculum she attended the Scales class in the year 2015, when it was first taught, and supported the class the year after as a student assistant. As a student assistant she also worked with Simone Rödder within the project ”Reassessing an assessment- A study of the IPCC process”.

Figure 5: Folder button in the upper right corner

Figure 6: Upload your CSV-file.

Figure 7: Calculate the mean and the max. Data Source: Google Trends (www.google.com/trends) [17/05/2017]
Here, we present example diagrams using some phenomena from the students’ database (2015/2016). The first diagram shows the mean search interest on the third axis displayed via the transparency of the ellipse: the phenomenon with the lowest interest appears darkest, while the phenomenon with the highest search interest appears lightest. The second diagram displays the categorized search interest. Categories of search interest are defined based on the minimum and maximum search interest values. In this diagram the categorized space axis is set as the third axis.

Figure 1: Phenomena from the students database. The mean search interest is displayed via the transparency of the ellipse: the phenomenon with the lowest search interest appears darkest, while the phenomenon with the highest interest appears lightest.

Data Source: Google Trends (www.google.com/trends)[17/05/2017]
Figure 2: Phenomena from student's database. The categorized search interest, defined based on the minimum and maximum Google Search interest, is displayed on the y-axis. The categorized space axis is set as the third axis, displayed with a colormap ranging from blue (lowest spatial extent) to red (highest spatial extent).

Data Source: Google Trends (www.google.com/trends)[17/05/2017]

About the author

Maike Scheffold is research assistant in the teaching project ‘Scales in the Climate System’. She finished her Master degree in ‘Integrated Climate System Sciences’ at SICSS with a Master Thesis topic in biological oceanography. Her background is geology/geophysics. As part of the ICSS curriculum she attended the Scales class in the year 2015, when it was first taught, and supported the class the year after as a student assistant. As a student assistant she also worked with Simone Rödder within the project “Reassessing an assessment: A study of the IPCC process”.

Based on homework and plenum discussions in class, students proposed following new axes in 2017.

**Other possible axes**

### Summary of student's third axes

<table>
<thead>
<tr>
<th>Axis Name</th>
<th>Phenomena</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scientific Interest</strong></td>
<td>El Nino, NAO, Sandstorm, Switch to Renewables, City Adaptation to Climate Change</td>
<td>1=0</td>
</tr>
<tr>
<td><strong>Event-related deaths</strong></td>
<td>Tropical cyclones, Drought, Riots occurring after a sudden natural disaster, Wildfire, El Nino</td>
<td>Very low=0</td>
</tr>
<tr>
<td><strong>Controllability</strong></td>
<td>Wildfire, EL Nino, Illegal CFC trading, Switch to Renewables, Climate Change denial in politics <em>With new method: Switch to Renewables</em></td>
<td>Absolute no control=0</td>
</tr>
<tr>
<td><strong>People affected</strong></td>
<td>Tropical cyclones, Heat wave, Weddell-Polynya, Adaptation of metropolitan area to climate change, Cod fishery collapse</td>
<td>individual=1</td>
</tr>
</tbody>
</table>
1.4.2.1 Scientific interest

Our third axis describes the scientific interest in the phenomena. As an indicator we used the number of scientific articles published on the phenomenon. We used google scholar as a tool and just included articles which have the name of the phenomenon in the title. In this way we exclude articles which do not deal primarily with the phenomenon. However, the individual words of the name do not need to appear in the right order in the title. We also excluded citations and patents. To be sure to include all articles, we used different spellings. We also limited the search to English articles so we do not accidentally include articles on other topics due to insufficient language skills in other languages. And since we are interested in the total interest over all times, we did not set a time period for the search.

We set up nine categories according to the span of hits. We set the upper limit close to the number of hits we got for “climate change” since this is the phenomena of highest scientific interest that we found. The lower limit is zero since we got zero hits for “Climate justice protests”. The categories are:

1=0|50, 2=51|200, 3=201|500, 4=501|1000, 5=1001|5000,
6=5001|10000, 7=10001|50000, 8=50001|200000, 9=200001|inf

Of course there are a number of limitations to this axis which have to be investigated for a further use of this axis. However, the axis fulfills our goal to get verifiable numbers for all possible phenomena.

About the authors

Meike Schickhoff, Markus Ritschel, Ana Luevano de la Cruz, Suman Halder and Pia Freisen are students of the ‘Master of Integrated Climate System Sciences’ taking part in the course ‘Scales in the Climate System’ in 2017.
1.4.2.2 Event-related deaths

The United States Environmental Protection Agency (EPA) mentions that climate change has influenced on climate system components (physical, biogeochemical and social) in a complex way and the development of appropriate indicators is challenging and still emerging. Those indicators should be clear, measurable and timely to better understand the link between climate change and human effects. Therefore, our third axis, "event-related death", is based on cause-specific mortality rate, which is a measure of the frequency of occurrence of death in a defined population during a specified interval (U.S Department of Health & Human Services, 2012).

The formula for the even-related death is:
\[
\text{(the number of deaths attributed to a specific cause)} / \text{(the size of the population at the midpoint of the time period)} \times 10^5
\]

The categories of the event-related death are very low (<5%), low (5-10 %), medium (10-15%), high (15-20%) and very high (20% >).

About the authors

Alejandro Uribe, Maria Caballero Espejo, Ram Poudel and HyunJu Jung are students of the 'Master of Integrated Climate System Sciences' taking part in the course 'Scales in the Climate System' in 2017.
The third axis we propose is „controllability“. By that we mean a measure for how much mankind (be it the society or individuals) are able to manipulate the magnitude, frequency or any other parameter of interest of a phenomenon. This control could be achieved by behavioral change, technology or any other kind of influencing the parameter.

The controllability in this sense is defined here by a desired rate of change of a parameter \( \frac{dx}{dt} \)aim and the observed change of rate \( \frac{dx}{dt} \)obs due to the effort for control.

C-value of C=1 indicates a full controllability. The target is achieved in this case (or will be achieved in future). A C-value of C=0 indicates no controllability. If the desired rate of change is a minimum target, every C>1 also indicates full control. For example if the aimed target is an increase in the share of renewable energy of at least 1% per year and the observed change is 2% per year, the phenomenon would be considered as fully controllable. If the aim is to control the magnitude of an algal bloom, so that the bloom is neither stronger nor weaker, both a C-value of C<1 and C>1 would indicate a reduced controllability.

This method of defining the controllability has however a number of limitations. The method is only applicable if a target is set. For many phenomena, that might be in theory at least partly controllable, there is no target set. That could be either because there is no incentive to control the phenomenon or because the chance of control is very little and the effort would be very big, so that there is no effort done. There are also phenomena which are (partly) controllable but there is no concrete target set. The target set is often only a qualitative target. For example reducing the unemployment rates. Another problem is that the definition of the controllability used here can result in arbitrary results since a target can be chosen arbitrarily.

Finally one must distinguish between natural changes and controlled changes. It is possible that a target is achieved at least partly due to natural variations in the parameter. This change contributes to the apparent controllability but it might in fact be uncontrollable.

These limitations reduce the amount of phenomena which can be scaled on a controllability axis. However an appropriate definition of the examined phenomenon helps to overcome some of the limitations. Nevertheless we argue that a variety of phenomena from all components (atmosphere, socio-economics, science etc.) can be scaled with the controllability. This universal applicability makes the controllability an interesting third axis especially for an interdisciplinary comparison of phenomena, despite the strong limitations. It might be interesting to examine roughly the controllability of rather wide classes of phenomena and to investigate differences in the controllability of several classes. As an example one could elucidate the question whether biological phenomena have higher controllability than atmospherical phenomena. Also a comparison of the controllability of socio-economical phenomena in development countries with those in developed countries is possible.

Categories:

Absolute no control=0|1, virtually no control= 2|20, little control=21|39, about as controllable as not=40|60, Some control =61|79, significant control=80|98, Full control =99|100

About the authors

Johanna Markkanen, Lucas Schmitz, Igor Prado and Tatjana Klisho are students of the 'Master of Integrated Climate System Sciences' taking part in the course 'Scales in the Climate System' in 2017.
We believe studying scales on this axis goes a good way towards answering the course question: "On which scales do climate phenomena occur and affect human experiences and social responses?"

"Affected" in our case would mean to have their state significantly altered by the occurrence of the phenomenon. It should be noted that we are counting only direct effects—those where the phenomenon is not further removed from the person affected by more than one level of influence, for example, the people who donate to relief efforts in the aftermath of a tropical cyclone. So, on our axis the number of people affected by the \( i \)th occurrence of a phenomenon is given as:

\[
N_i = \text{Number of people killed} \cup \text{Number of people injured} \cup \text{Number of people rendered homeless} \cup \text{Number of people located in the geographical area where the phenomenon occurs} \cup \text{Number of participants in the phenomenon}
\]

The reasoning behind including the fourth quantity is that anyone located in an area where a climate phenomenon occurs can be said to have been affected by it.

The number used on the axis is then:

\[
N = \frac{\text{Max}\{N_i\} - \text{Min}\{N_i\}}{2}
\]

This method is used to gain an average number for phenomena that occur repeatedly, and the involved quantities are easier to measure than having to take into account every single instance of the phenomenon. So, only the extreme values of people affected by the phenomenon are used to calculate the mean.

The indicators will vary across phenomena, as the axis and quantities are chosen so as to apply to a wide range, across the natural and social sciences.

### 1.4.2.4 People-affected
About the authors

Alon Azoulay, Josephine Wong, Shubhankar Sengupta and Wenlin Xiao are students of the 'Master of Integrated Climate System Sciences' taking part in the course 'Scales in the Climate System' in 2017.
1.5 Coupling

In this section, we introduce an important - if not the most important - aspect of scales, namely scale interaction. Eventually, this is what we are interested in: how do small scale processes or phenomena interact with large scale processes or phenomena. Since this is so important, we want to dedicate a whole section on this theoretical concept, starting again with a friendly (formula-free) introduction, and moving then to a mathematical description.

How do phenomena of different scales interact?

- 1.5.1 | A friendly introduction to scale interaction
- 1.5.2 | Formal interaction of scales
- 1.5.3 | Scale interaction
### 1.5.1 A friendly introduction to scale interaction

Let us consider three different examples for deriving our concept:

1. **El Nino Southern Oscillation (ENSO)**: This phenomenon occurs every five to ten years, characterized by a certain pattern of tropical Pacific sea surface temperature. In principle, the sea surface temperature in the tropical Pacific oscillates with the seasonal cycle, yielding warm surface waters in summer and colder temperatures in winter. Every now and then, a strong anomaly in this pattern occurs such that the surface temperature in a large region is up to 3°C warmer than normal, triggering a whole cascade of subsequent processes commonly called the El Nino Phenomenon. It is important to realize that this phenomenon is linked to the seasonal oscillation of sea surface temperature and therefore only occurs around November/December, a reason why it is called el Nino – the Spanish expression for the (Christ) Child.

2. **Media hype**: A media hype is characterized by a large number of articles, screencasts, radio broadcasts, etc. on one particular topic within a short timeframe. When looking at its genesis, in particular in context of climate sciences, then usually a scientific result is published in a highly renowned journal, causing the originating institute’s public relations department to issue a press release with a slightly bolder conclusion than in the original scientific publication. This PR material is then taken by the sciences section of a serious newspaper, just leaving the boldest statements, which in turn is copied by other media, amplifying and sometimes even negating the original scientific findings. The processes involved are propagation of information, amplification and simplification.

3. **A children’s swing** or rather the phenomenon of a swinging child: This is characterized by a child sitting on a specially designed pendulum, which is triggered by a deliberate movement of legs and arms of a child at the eigenfrequency of that pendulum. The child is swinging, if the pendulum deviates from its balanced state by a certain amount.

What do these examples have in common? They are all characterized by a certain phenomenon, and processes that trigger this phenomenon. However, the processes triggering the phenomenon are of quite distinct size as the phenomenon itself. Seasonal cycling, as in the El Nino case, can be formulated as a phenomenon itself; it has a period of one year. The El Nino phenomenon is again a cyclic event, but with a less regular and less frequent occurence.

The media hype is triggered by small scale (basically one-to-one) communication schemes, but leads to a large scale mass communication phenomenon. And finally, the swing’s movement and deviation from balanced state is triggered by inserting (at the right frequency) small amplitude/low energy momentum into the system.

This suggests to use the analogy of resonance as a concept for our scale interaction. In the previous section, we already introduced the notion of several processes acting together with different strengths to form the total effect of forces leading to a phenomenon. We will employ this here again. So, depending on the frequency and strength of each individual process, the interaction of different scales can lead to large scale behavior or just noise. In analogy to the swing we can see: If the child triggers the swing at the right rate (basically an integer multiple of the eigen frequency) then it can swing higher and higher. If the child does not sense this amplifying frequency, then it will never take off and the movement of the swing appears erratic.

This will be formalized in the following section.
Prof. Dr. Jörn Behrens. Educated as an applied mathematician with PhD (Dr. rer. nat.) from Bremen University and Habilitation from Technische Universität München, Munich, Jörn develops numerical methods for atmospheric and oceanic simulation. He specializes in adaptive mesh refinement, numerical geophysical fluid dynamics, and high performance computing. In 2006 following the 2004 Sumatra-Andaman Tsunami, he became head of the tsunami modeling group at Alfred Wegener Institute, Bremerhaven, and developed the simulation component of the German-Indonesian Tsunami Early Warning System (GITEWS). After delivering the system, he accepted a professorship for numerical methods in geosciences at the Center for Earth System Research and Sustainability (CEN) of University of Hamburg in 2009. He coordinates the research project ASCETE (Advanced Simulation of Coupled Earthquake Tsunami Events), and serves as Co-Chair of UNESCO Intergovernmental Coordination Group for setting up a Tsunami Early Warning System for the Mediterranean, North-East Atlantic and Connected Seas (NEAMTWS) Working Group 1 (Hazard Assessment and Modeling). Since 2015 he serves as the program director of the special interest group on geosciences for the Society of Industrial and Applied Mathematics (SIAM).
### 1.5.2 Formal interaction of scales

#### Introduction to Resonance

We want to use the notion of resonance in order to understand and somehow formalize the interaction of scales. A forced resonance is given by a differential equation that basically represents first Newton's principle, i.e. force balances mass times acceleration. We mention the equation here for reference:

\[ m \ddot{x} + c \dot{x} + kx = F(t) \]

We have used \( m \) as the mass of a body, \( x \) as its location, \( c \) as the damping factor (e.g. by friction), \( k \) the spring constant (we assume the body to be attached to a spring that tries to move it back into its original position), and \( F \) the forces acting on the body.

Let us now assume that we can express all the forces as oscillations (i.e. we have a periodic behavior – everything is waves), and let us also consider for the moment that we can neglect the second term (damping) by setting \( c \equiv 0 \), then we can solve the resulting differential equation

\[ m \ddot{x} + kx = F_0 \cos(\omega t) \]

where \( F_0 \) is the amplitude of the forcing and \( \omega \) the wave length. The solution reads

\[ x = C_1 \cos(\omega_0 t) + C_2 \sin(\omega_0 t) + \frac{F_0}{\omega_0^2 - \omega^2} \cos(\omega t) \]

with \( \omega_0 \) the eigenfrequency of the system, \( C_1 \) and \( C_2 \) constants to be determined from the system constants. So, the solution is a modulated wave. Depending on the system parameters, different behaviour can be observed. We give two examples:

1. For \( m = 0.5 \), \( k = 8 \), and \( F_0 = 10 \), and initial conditions \( x(0) = \dot{x}(0) = 0 \), we obtain the solution
   \[ x = \frac{20}{16} (\cos(\omega t) - \cos(4t)). \]

2. For \( m = 1 \) (normalized mass), \( k = \omega^2 \), and \( F_0 = \frac{F_1}{m} \) we obtain a system that is forced with its eigenfrequency.

In this case, the solution can be given as

\[ x = C_1 \cos(\omega t) + C_2 \sin(\omega t) + \frac{F_1}{2m} \cos(\omega t). \]

The two solutions are visualized in Figure 1 in order to make the two regimes visible.

For case 2, we assume \( C_1 = C_2 = 0 \) and \( m = 1 \), \( F_0 = 2 \), \( \omega = \pi \).
Interpretation

The two cases above demonstrate a typical behavior of resonances. The oscillation of the force on the right hand side interacts with the eigenfrequency of the system. In the first case (Fig. 1, blue line) the system has a different eigenfrequency as the force. Therefore, the behavior of the forced system is somehow oscillatory, but stable. In the second case (Fig. 2 green line) the force triggers an amplification of the system’s oscillation, because it acts in the same frequency. Eventually, the signal will be amplified to infinity, blowing up the solution.

Generalization

We want to generalize the idea of a forced resonance for our idea of scale interaction. So, regardless of the original differential equation and its solution, we can now just state that we consider two different (wave-like) phenomena, characterized by their characteristic size (wave length), interacting by their amplitudes. Mathematically this can be expressed by the following formula:

\[ x(t) = C_1 \cos(\omega_1 t) + C_2 \cos(\omega_2 t). \]

where \( C_1 \) and \( C_2 \) are the strengths (amplitudes) of the two phenomena and \( \omega_1 \) and \( \omega_2 \) correspond to the wave lengths. For simplicity, we consider \( \omega_i \) to be multiples of \( \pi \) here.

Note that this notation is very similar to the notation in equation (2.2). Here the \( \omega_i \) indicate the size of the process.

Examples

Let us consider a few examples to demonstrate this idea:

1. Consider two different wave lengths, say \( \omega_1 = 3\pi \) and \( \omega_2 = 5\pi \). And let \( C_1 = 1 \) be normalized and \( C_2 = 0.5C_1 \). Thus, frequencies and strengths are different but of the same order of magnitude.
2. Consider a large difference in frequencies, but still relatively equal strengths:
   \[ \omega_1 = 2\pi, \omega_2 = 20\pi, C_1 = 1, \text{ and } C_2 = 0.5C_1. \]
3. Consider equal frequencies: \( \omega_1 = 2\pi, \omega_2 = 2\pi, C_1 = 1, \text{ and } C_2 = 0.5C_1. \)
4. Finally, consider time-dependency of one of the strengths with different wave lengths:
   \( \omega_1 = 2\pi, \omega_2 = 3\pi, C_1 = 1, \text{ and } C_2 = 0.5t. \)
These cases are visualized in figure 2.

Case (1) showcases a situation in which two different but not too distinct scales with different (but again not too distinct) strengths interact. This results in a funny shape of the resulting signal. The interaction of a fast and a slow wave, as showcased in case (2), results (obviously) in the slow long term signal modulating the fast small scale signal. If the two signals have the same wave length (case (3)), then it is clear that the two swing in perfect harmony, so none is distinguishable in the final signal.

Finally, in case of a time dependent strength as in case (4), an amplification can be observed. Additionally, the influence of the short wave becomes more and more visible. In the first “bump” the modulation is minimal, in the second it already ‘bites a dent” and in the third it is almost indistinguishable from the overall modulation.

Figure 2: Examples of wave interactions, serving as prototypical templates for scale interaction. Explanations are given in the text.

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1.5.3 Scale interaction

The previous observations motivate us to propose the following formulation for scale interaction. First, we need to understand that the interaction of scales can only be initiated by processes. Processes drive the whole machine and lead to phenomena. Thus, phenomena can only be linked by processes. For simplicity, we will not distinguish between rules and processes at this point, since they both have the same effect and act in the same domains (i.e. the agent’s states).

So, let us assume there are processes \( p_1, p_2, \ldots, p_n \) that are to some extent relevant for two phenomena \( P_1 \) and \( P_2 \). Then the total effect of those processes can be written as

\[
p(a) = \sum_{i=1}^{n} c_i r_i(a).
\]

Think of \( C_k \) as the strengths and \( p_k \) as the waves (as above). If the \( p_k \) are caused by a phenomenon \( P_1 \) then if \( p \) leads to a threshold above the definition level for phenomenon \( P_2 \) the first phenomenon can cause/trigger the second.

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1.6 Discussion on the concept of scales

Throughout the years of ‘Scales in the Climate System’ we experienced successes, challenges and limits of scales and scale diagrams as a potential tool for the integration of climate sciences. Here, we discuss on the concept of scales particularly with regard to the social sciences.

Scales and social sciences- a promising match?

- 1.6.1 | Social sciences and scales
- 1.6.2 | Advancing integrated thinking & research through interdisciplinary team teaching
1.6.1 Social sciences and scales

The very idea of anthropogenic climate change indicates that the climate system can no longer be researched by ignoring an important factor: humanity. Talking about the “anthropocene” (Crutzen 2002) further emphasizes this idea that nature, today, is as much a product of human influences as human life is also a product of natural processes. Therefore, analyzing human behavior is a fundamental challenge for climate sciences.

Yet, humans do not shape nature in their capacity as individuals but through the dynamics of their collective behavior: only the sum of individual actions is so powerful as to shape current and future climates, only collective patterns of actions of many human beings have an influence as opposed to individual idiosyncratic behavior that may indeed neither save, nor damage the global climate system. It is therefore the study of human society that is of prime importance for everyone who tries to understand the climate system. This is the domain of the social sciences, understood broadly as the whole range of disciplines that try to describe and explain different aspects of society, including sociology, but also economics, politics, communication research, geography etc. (Hunt and Colander 2011).

The future trajectory of the climate system will depend on how society will react to the challenge of climate change. It is therefore rather odd that the reports of the Intergovernmental Panel on Climate Change (IPCC) so far have hardly covered society in a comprehensive way and that traditional climate models have treated society as a big black box (Brulle and Dunlap 2015). The challenge to integrated climate sciences is to unpack this box: Society is not just one additional variable in climate models. It is a configuration of variables that is no less complex than the climate system itself. This is why the social sciences can hardly provide the data that can easily be fed into climate models: social dynamics are determined by a multitude of different influences and resist predictability. Also, culture and interpretive frameworks are important drivers of human actions, they cannot easily be measured in a way so that they can be translated into numbers and statistics. If we want to research which interpretations guide people’s actions and interactions with other people, qualitative case studies are a powerful tool. They can reveal broader patterns of social action but it is not easy to feed these findings back into models about the future of the climate system. Thus, the added value of the social sciences to the climate systems is a new and relevant topic that is not studied by the natural sciences: society. Yet, this object of study is much broader and more complex than just one additional variable.

Furthermore, there is another value of social sciences for climate sciences: the former highlight a blind spot of the latter: the influence of the researcher and the way he or she does climate science. Social sciences study e.g. how climate scientists work, how they deal with uncertainties in their research, how value questions do impact on their research questions, methods and results. Thus, social sciences provide reflexivity (Giddens 2001, p. 680): they describe and reflect on how climate sciences proceed as a part of society. From this perspective, the professional practices of climate scientists are not only the result of technical needs on how research on the climate has to be conducted. Ways of doing climate sciences are also the product of society, of belief systems (e.g. in the power of the scientific method or statistics) and other structural factors such as the reward system in place for conducting a certain type of research and for presenting it in a certain format. Scientific practices are rooted not only in technical necessities but also in history. By analyzing these social contexts of climate sciences, social sciences can be the source of self-reflection and creativity: the specific conduct of climate sciences that you learn at University is the outcome of a particular historical development. It is contingent, as sociologists say: it may also be done in a different (and possibly better) way. Thus, besides adding social influences to climate models, reflexivity is another treasure that social sciences can offer to climate sciences.

How the social sciences could contribute to researching the roles of scales in climate-society interaction

Both arguments also apply to the question of how the social sciences can add to the debate about scales in climate research: They offer new phenomena, processes, dimensions to be measured, and they can set off a more conscious reflection about the role of scales in society. Time and space as the most important dimensions that guide climate scientists’ reconstructions of climate change are relevant for the social sciences as well, but different phenomena might ask for different dimensions along which questions related to scales arise. The most important new dimension relevant for phenomena researched in the social sciences is probably the social reach of a phenomenon: How many people are involved, to what degree and how?
At the same time, the study of society also provides specific challenges due to the different scales on which human behavior and climate change develop. As Clark (1985) observes, the actions of a human being often take place on a much smaller scale (in time and space) than the processes of climate change. Global warming is thus not directly observable by individual people: they do not feel increasing global average temperature increases that occur over several decades. Also, the horizon of human behavior is often short-term: Politicians’ concerns are heavily influenced by election cycles, consumer decisions may often be taken on a day-to-day horizon or with a certain monthly budget in mind, but not always with much thought about what will happen to the climate in several decades or even centuries away or what the effects of our actions may be for the Arctic or small islands far away.

Having said that, it might also be misleading to regard social processes as having a fixed scale. Social processes are changing over time. Models “assuming constant social structures [...] are likely to be extremely misleading” (Clark 1985, p. 19). Human beings as social and cultural animals can act upon considerations well-beyond their personal life span or the space they inhabit and have first-hand experiences with. A religious person might act with eternity in mind: thus acting with regards to a very large scale ‘phenomenon’. People may take revenge for things that happened generations ago or they might act with future considerations such as ‘responsibility for the lives of our children’.

Social action transcends scales also by means of media: invented to allow human communication across time and space, they also allow to transcend the typically narrow scales of traditional human life. Mediated communication provides us with the means to orient our actions on scales that are beyond our first-hand experiences. They make the long-term process of climate change salient to the individual and define it as a problem with an urgency to act. Media reports might as well ignore climate change or make it seem as something that is beyond the scales of relevance for our lives. Particularly, global digital networks are challenging the traditional scales of our social lives: the internet can store information (about the present and the past) permanently and allows us to expand the scale of our attention into the past. This latter feature has always been part of the function of rather ‘old’ media like books. At the same time, the web enables us to communicate at much faster time frames. Forwarding a Tweet takes less than a second. Thereby, information may spread around the world in seconds. The same process used to take hours a decade ago, weeks a century ago and years a millennium ago. New digital communication networks like the internet partly render the space dimension irrelevant: people may co-orient their behavior with people living at a totally different place. Consequently, phenomena such as hype on Twitter cannot always clearly be assigned a geographical size. Nevertheless, social life still tends to have a geographical center: some topics trend on Twitter, but only in a specific country or region.

Still, the cognitive capacities of human beings to process information have not changed substantially, thus fast global communication about e.g. climate change does not necessarily lead to fast growing individual knowledge or global action. The very speed of journalism with its news factors (criteria of selection and emphasis in producing the news), focusing on novelty, surprise and short-term events is at odds with the scale of long-term processes like climate change. Resulting from this difference of relevant scales is the attempt of journalism to connect short-term and locally delineated events, such as an extreme summer heat or a flood to climate change. Climate scientists are unwilling and unable to do just that since the processes they study are located mostly at a different scale. This leads to mutual misunderstanding and a confusion of audiences who might conclude that climate science is very contested and uncertain and therefore no immediate action seems needed.

Researching these questions goes beyond the social sciences’ role to provide additional dimensions and challenges for scale construction. In studying e.g. how journalists and scientists deal with scales in a different way, the social sciences provide reflexivity about the role of scales in society. There is not much research on these questions yet. One example of this kind of research is a case study analyzing the transcripts from a recent IPCC press conference (Hollin and Pearce 2015): In order to fill the gap between the grand scale of climate change and the shorter scales of human perceptions of changes in their environment, IPCC lead authors mentioned the extraordinary warm years after 2001 as evidence of global warming. At the same time they discounted questions about the so called ‘global warming pause’ as not being relevant to climate change since the presumed ‘pause’ of global warming refers to a shorter time scale than the scale of phenomena defined as climate change. The authors of the study argue that this caused confusion and ultimately negative press coverage about the IPCC press conference. The incident is an example of how scales in climate sciences clash with the scales deemed relevant in everyday life. With these kinds of studies, social sciences can not only use scales but also research scales as social phenomena.

Finally, we will go deeper into the question of how society and the climate system interact and how this happens across and on different levels. Levels, a term that has a similar status in the debates in the social sciences as scale in the climate sciences, are understood as different locations along a scale (Gibson et al. 2000).
Multi-actor and multi-level interactions in climate-society relations

Multiple actors are shaping the interaction between the climate and society as they can choose targets as well as actions across different levels, from micro to macro scales (see Figure). As explained in Clark (1985: 21): “The relevant social phenomena range from the individual farmer’s planting decisions to global patterns in the development and wealth of nations.” Different political levels distinguished in Gibson et al. (2000) are international national regional, community and household levels. At international or global levels of decision-making main actors are usually governments of nation states or groupings among them, often clustered along regional boundaries and connected via different kinds of media. At local levels individual citizens are key players who affect or are affected by global warming. The multi-level process between local and global decision-making passes through several layers of aggregation (from billions of citizens to a few diplomats representing their countries), with each layer having its own decision procedures for setting targets, implementing them into real actions and communicating them through media (Scheffran 2008, 2015). The multi-level structure represents different social functions and does not necessarily imply a hierarchy where lower levels are part of higher levels. For instance, companies can act at local levels as well as global levels (such as multi-national corporations). Similarly, citizens, communities and municipalities as well as nations are embedded into cross-cutting local and glocal structures (Cash et al. 2006; Brondizio et al. 2009). The outcomes for actors at each level are dependent on the actions of actors at the same or other levels. Given these complexities, a crucial issue is how actors can act together and cooperate on climate change across levels, managing the transition from competition to cooperative action (Hooghe and Marks 2001). Multi-actor and multi-level interaction and governance can follow a top-down approach where global decision-making bodies define global targets for emission reductions based on scientific assessment and an evaluation of which degree of dangerous climate change is tolerable. The task is to implement these targets at lower, in particular national levels. In a bottom-up approach local actors such as citizens, consumers and companies pursue their individual interests, having an impact on higher levels, e.g. by electing municipal and national governments or by selecting products with more or less environmental impacts. In reality both approaches interfere with each other at each level and could potentially lead to scale mismatches and conflict (Cumming et al. 2006; see Figure). If GHG concentrations cannot be stabilized at tolerable levels, mankind may face potentially disastrous consequences. The dangers will be geographically dispersed, across different temporal, spatial and impact scales, and depend on the vulnerability and adaptive capacity of actors. Citizens, decision-makers and negotiators will have to address the question which scale of regional and temporal disruptions are acceptable and how to bridge unequally distributed climate impacts which may be positive in some regions and negative in others, giving less weight to “remote” times and places which are outside of the windows of attention of the respective actors, taking spatial, temporal or social dimensions of “distance” into consideration.

Temporal and spatial scales of action and interaction
A crucial issue are the timescales. There can be a considerable time lag between emission reductions and their impact on the climate system. Temperature effects may be expected 20 to 50 years after peak emissions of CO2 whereas sea level changes may occur hundreds of years after concentrations have stabilized. This problem is aggravated by the fact that due to inertia of the socio-economic system the effect of policies will be delayed, too. This concerns in particular the replacement of infrastructure and technology, such as buildings, power stations or transport systems, which can take several decades or even more. As a consequence, considerations of time lags seem to be essential for adequate political decisions. Time discounting represents the degree to which decision-makers take the present or near-term value into consideration compared to future time horizons that are ‘discounted’. How far this horizon reaches into the future or into the geographic environment depends also on ethical criteria and precautionary principles that can shape control strategies. Discounting provides a quantitative measure for comparing decisions with consequences occurring at different times. Because of the uncertainties of the distant future, choosing an appropriate discount rate for impacts spread out over decades or even centuries is controversial. High discount rates represent “wait and see” policies and short-term investment priorities, spending on immediate social needs consistent with market realities. The prescriptive approach favors investments for climate mitigation policies, corresponding to low discount rates. Social scale dimensions also matter, e.g. due to social stratification or social network structures which prevent exchange, communication and cooperation between different actors, following the poor-rich classification or different religious beliefs.

Thus, issues related to different scales and cross-scale interactions are no less complex and important to research from the perspective of social sciences than in the natural sciences. The interaction of scales in society and in ‘natural’ processes remains a challenge for further research that can best be tackled by close cooperation between researchers from both strands of research.

References


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Conclusions for the scales approach

In this chapter I look at some limitations of the scales approach in advancing an integrated view on the climate system and its resonance in social systems from the perspective of a scholar working with a qualitative methodology, frankly of someone who never uses the concept of scales explicitly in her research and teaching.

Limitations of the scales concept as a tool to advance an integrated view of the climate system and its resonance in social systems

An everyday understanding and all the more so, scientific concepts of scale presuppose a quantitative understanding of the world, or, as we have labelled it, “a mathematics inspired approach to scales” (subsection 1.1.2). The concept is therefore inherently closer to certain epistemologies and fields than to others, an important aspect in the context of interdisciplinary teaching and learning. A basic limitation of the scales approach lays in that any phenomenon to be analysed must lend itself to a description in quantitative terms i.e. where one can meaningfully measure a spatial, a temporal and a third axis (cf. subsection 1.3.2). A mathematics inspired approach by definition assumes a number of formal principles to be applicable, such as transitivity (if A is larger than B and B larger than C than A is larger than C). While this holds true for physical, chemical or biological phenomena – we can measure the speed of light, the pH value of a solution and the size and number of cells in a tissue – it does – arguably– not adequately and entirely capture the resonance of climate phenomena in social systems.

That the scale concept has different distances to the disciplines represented by the lecturers was clearly visible in class with the (qualitative) social sciences being much more reluctant to embrace the approach than the physical and biogeochemical sciences. Evaluating the scales approach in its usefulness to promote an integrated view of the climate system comes down to the question whether every aspect in the resonance of social systems to climate phenomena is measurable. Several debates in class revolved around the question of in how far time and space are meaningful dimensions with regard to social phenomena such as media hypes, armed conflict, example from student course work and the communication of uncertainty. We also tried to evaluate the soundness of tools such as Google Trends to measure the scale of phenomena such as media debates.

In my view, we achieved a tremendous amount of insight in the course by clarifying everybody’s approach to integrated climate science in society. We were able to distinguish (at least) three different models of the resonance of climate phenomena in social systems, or shortly, in society as the most encompassing social system.

1. The first model is a model of society as computable, or we could also say “a mathematics inspired approach to society”. This approach is close to the natural sciences as well as mathematics and economics whereby only the latter field deals with society as its object under study. This approach applies a physicists' methodology to society, assuming that – in principle – society can be quantified, modelled and simulated as a set of differential equations.

2. A second model of society appears in the way geographers go about it. In geographical thinking, society is conceptualised as a spatial order, i.e. that it is the spatial dimension that makes for important differences and has to be varied and investigated for social analysis.

3. A third conceptual model, eventually, assumes that society is a social order. This is the model of social theorists who have long argued that social reality needs to be thought of as a reality sui generis (Durkheim 1982), implying that the social sciences cannot be pursued as a sort of ‘social physics’. While the latter view is held by some schools in the social sciences, and most notably in economics, the field has established ways of looking at society and its various subsystems in social terms (power, conflict, gender, organisation, differentiation) rather than in terms of time and space.
A case in point is the raw between climate researchers and climate deniers on whether there is anthropogenic climate change or not. These debates have been scientifically informed by assessment reports from the Intergovernmental Panel on Climate Change (IPCC) since 1990. In its repeated reports, the IPCC (i.e., the thousands of scientists who are its intellectual backbone) has suggested that there is sound scientific evidence for an anthropogenic component in the current global warming and that furthermore the scientific confidence in this circumstance increases from report to report. The question now is why this evidence base seems to not resonate with the deniers’ defeat of anthropogenic global warming. It has been observed that the public and policy debate between advocates and deniers of climate change has long turned into an ideological battle (e.g., von Storch und Krauss 2013). In this situation, the reduction of uncertainty or a better quality of observational data do not make any difference to an opponent’s position. Rather than focusing on more persuasive communication strategies or such like, the situation has to be analysed as a conflict system, following the rules of a conflict system: Everything the conflict party argues is not rejected on factual grounds but on social grounds, i.e. precisely because it is the other party who says it.

A key axiom in most general social theories is that society is characterised by differentiation in major social spheres such as politics, science or the market, and it has been argued that this disunity on the societal level (the non-existence of a “global we”) is consequential for the resonance of social systems to ecological threats (Luhmann 1989). Another implication of this theorising is that relations between social systems such as science and politics are best characterised as discontinuities (Interdependenzunterbrechungen) which arguably defy linear or probabilistic modelling. A lay model of the relation of science and politics often assumes that more scientific knowledge leads to more political negotiation or even more policymaking with regard to the climate issue. General social theory in contrast would not expect a somewhat linear relationship between the quality of the scientific evidence on climate change and policy outcomes. Much rather, discontinuities need to be expected: Politically successful policy negotiations can be based on utmost erroneous climate data while a sound model simulation does in no way make the success of a policy negotiation more likely. With regard to bodies such as the IPCC, a social analysis needs to take into account a genuinely political function of an assessment report rather than buying into a linear model of ‘evidence-based policy making’. "Policy-makers view the IPCC reports mainly as a source of quotes with which to legitimise their preferences." (Geden 2015: 28). In general, the goal of these kinds of analyses is less to explain social reality by way of establishing cause-effect relations but by understanding it in its functional set-up. This can imply looking at scale interactions such as between the temporal scales of science and policy in the IPCC reports: The IPCC process has a set temporal framework of six years with a fixed cut-off-date for publications to be considered in the forthcoming report. This does not necessarily match the temporal scale of scientific knowledge production. The latter is, in general, much longer than political terms of office and may, at times, interfere with the temporal scale of knowledge production (the same holds true for research funding which comes in junks that do not necessarily match the logic of knowledge production (a further example is the ‘rise and fall of social problems’; see Hilgartner und Bosk 1988).

To sum up, I conclude that the scales approach accomplished at least two things. Firstly, it enabled conversation across a wide range of disciplines in an educational setting and resulted in original student course work as well as in joint work on publications by the lecturers. Secondly, the scale concept – in a nutshell – suggests a much more general epistemological divide in “integrated climate system sciences”. This divide neatly separates disciplines and fields which think of their objects as computable, i.e. as perfectly representable in mathematical terms, and causal relations, from disciplines and fields that do not. Examples of the first group include physics, oceanography, meteorology, biology, soil sciences, geology, biogeochemistry, geography and economics. Among the latter group count the fields of (qualitative) sociology, ethnography, history and qualitative approaches to communications and media studies. In terms of teaching and learning, the scales program thus speaks directly to the question of the possibility of an integrated Earth System Model and provides the whole spectrum of perspectives in science of whether this is feasible or not.

While this is a challenging endeavour the course provided evidence that most of the students were able to cope with the methodological and epistemic diversity of the perspectives presented and overcome initial confusion to result in overall very good student course work. We therefore conclude that all parties dealt with the challenge of creating and sustaining an interdisciplinary course in an educationally valuable way: The lecturers had the chance to firstly, learn something climate-related about areas in which they have limited expertise and to reflect their own teaching styles in the light of collaborative practice. The students succeeded in reflecting limitations of their scale diagrams in the light of different disciplinary perspectives, and by describing diverging perspectives in example phenomena.

References


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An example of interdisciplinary teaching and learning

'Scales in the Climate System' was a teaching and research project, funded by the cluster of excellence CliSAP (2015-2016) and the Universitätskolleg Hamburg (2017). The course was created in 2014 by a group of lecturers with different backgrounds in physical, mathematical, biogeochemical and social sciences and became a mandatory class for the students of the 'Integrated Climate System Sciences' Master between 2015 and 2017.

In the 'class-experiment', the concept of scales was used to spread the concept of scales, to improve the overall understanding as well as an interdisciplinary language of all involved parties as a stepping-stone to encourage interdisciplinary discussions and a joint integration of gained knowledge. The idea behind the course was not just about the scale concept itself, but also about creating a place for interdisciplinary exchange. That is why the course was mostly taught through team-teaching with the discussion among the lecturers becoming an important aspect of the course.

The trustful team-teaching without aiming for immediate own "gain" became an example of lived and successful interdisciplinarity for all involved parties and promoted an open critical as well as constructive scientific confrontation. All contributing students were actively involved in the development and success of the course, since an essential part of the course was the students' work on their own research questions and scale diagrams. The participation of students and lecturers, as well as their will to take part in controversial discussions, made the course a challenging but worthwhile experience. We recommend you to go through the provided information to see whether and how you can adapt our concept for your teaching.

The presented information present a summary of three years of course, including an example script, the eScript of the course 2017 (background and teaching material (homework, slides, sessions plan) as well the Diagram Generator, a tool developed for the class to visualize scale diagrams.
2.1 | The course concept
   2.1.1 | Motivation
   2.1.2 | Learning outcomes
   2.1.3 | Educational perspective
   2.1.4 | Sociological perspective

2.2 | Teaching materials
   2.2.1 | Sessions plan 2017
   2.2.2 | Example eScript 2017
   2.2.3 | Publication on 'Scales in the Climate System'
2.1 The course concept

The foundation of the course is the use of the concept of ‘scales’ – climate varying on different temporal and spatial scales. We developed and used a joint definition of ‘scales in the climate system’, that is applicable in both the natural sciences and in the social sciences.

By applying our interdisciplinary definition of ‘scales’ to phenomena from all components of the climate system and its socio-economic dimensions, we aim for an integrated description of the climate system.

Following the concept of inquiry based/research-driven teaching and learning and using a variety of teaching techniques, the students designed their own scale diagram to illustrate climate-related phenomena in different disciplines. The highlights of the courses were the presentations of individually developed scale diagrams by every student to both lecturers and students.

In the summer term 2017, we offered the course for the third time. Given the interdisciplinary nature of the course, and the inquiry based/ research-driven style, we largely considered the course in an experimental stage. We incorporated the experience from previous years in our teaching, thus, to be more explicit with the aims of the course. Apart from the intrinsic experience of interdisciplinary understanding of the climate system, we also formulated an overall question - which should both guide through the course as well as be helpful to assess the final results of the course:

On which scales do climate phenomena occur and affect human experiences and social responses?

- 2.1.1 | Motivation
- 2.1.2 | Learning outcomes
- 2.1.3 | Educational perspective
- 2.1.4 | Sociological perspective
2.1.1 Motivation

The Hamburg graduate school “School of Integrated Climate System Sciences” (SICSS) offers a two-year masters and a three-year doctoral program in the field of integrated climate system sciences, i.e. covering a wide range of natural sciences and climate-relevant aspects of social and economic sciences. The graduate school aims to prepare students for a ‘career in an interdisciplinary field of science’ improving their ‘ability to communicate with colleagues from different disciplines, to apply a diverse suite of methods from various subject areas to climate-related research questions, as well as the generation, interpretation and combination of scientific results’ (SICSS MSc Module Handbook winter term 2017/18). The students enrolled in the MSc programme ‘Integrated Climate System Sciences’ have backgrounds in diverse fields such as physics, geo- and atmospheric sciences. The MSc curriculum has three tracks: a physical track (P), a biogeochemistry track (B), and an economics & social sciences track (ES). In these three tracks, the curriculum is primarily integrated by combining courses to modules, with a joint oral exam at the end of each term. In the latest years, the programme also promoted more experimental course settings within the different disciplines as starting points for interdisciplinary understanding (cf. Frank et al. 2017) and team-taught classes. However, as of 2015, there were some team-taught classes in the master curriculum, but none with a cross-track approach trying to integrate the physical, biogeochemistry and economics & social sciences tracks. [1]

In this context, Scales in the Climate System was offered for the first time in summer 2015 as a mandatory class for second semester MSc students. [2] The course embraced a broad interdisciplinary, cross-track approach. The class was team-taught by ten lecturers, all from different fields - spanning oceanography, meteorology, mathematics, biogeochemistry, marine biology, soil science, geography, communications and sociology. The lecturers strived for a common understanding of the scales concept through joint preparation of the sessions and co-presence in class. At least four lecturers were present in any session. [3]

References


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Simone Rödder is an assistant professor of sociology at the University of Hamburg’s Department of Business, Economics and Social Sciences and a Principal Investigator in the Cluster of Excellence “Integrated Climate System Analysis and Prediction” (CISSAP). Her research is located at the intersection of the sociology of science and the science of science communication and applies mainly qualitative methodologies. Her current work focuses on interdisciplinary collaboration in climate research and her major class in the MICSS curriculum is a lecture with practicals, “Introduction to the Social Sciences”. Simone has an academic background in biology, sociology and science communication and holds an interdisciplinary PhD degree (Dr. phil. nat.) from the University of Bielefeld. She has been trained as a journalist and worked for several newspapers and magazines.
2.1.2 Learning outcomes

As described before, this course is nothing like the lectures or seminars students and lecturers are used to. Instead, everyone who participates in the course had to embark on a joint interdisciplinary journey and to develop new content together.

We are aware that this type of learning was possibly new and maybe scary to both, lecturers and particularly students, as they are depending on grades and proves of qualifications. Therefore, we stated exactly what learning outcomes are envisioned for this class at the beginning of the class.

What will be learned in this course? - learning outcomes

The course focused on skills that the participants developed during the course, whereas the actual content was not clearly defined before and was jointly developed throughout the class.

We used the framework of the "Deutscher Qualifikationsrahmen", the German Qualifications Framework, to formulate the learning outcomes.

Knowledge

Upon completion of the course, students were able to

1. reproduce a definition of scales that is applicable to both natural and social sciences;
2. explain specialized terms in the context of the course (e.g. "scale", "agent", "rule", "phenomena"...); and
3. give an overview of relevant processes and phenomena in the climate system, from both within their discipline as well as all other disciplines present in the course.

Skills

Upon completion of the course, students were able to

1. apply the definition of scales to phenomena and processes of the climate system, even those that were not explicitly discussed in the course;
2. compare scales between processes or phenomena, and parts of the climate system; and
3. design a diagram that includes relevant processes and phenomena in the climate system - sorted by their relevant scale on relevant axes.

Social competence

Upon completion of the course, students were able to

1. develop joint solutions in heterogeneous, interdisciplinary groups with fellow students and present them; and
2. reflect on the team's collaboration and their own individual contribution towards it.
Autonomy

Upon completion of the course, students were able to

1. assess their own state of learning in specific terms and to define further work steps on this basis guided by the instructors
2. assess possible consequences of their professional activity
As described before, this course started in 2015 as an experiment in interdisciplinary teaching and learning. But not only were the instructors and students from many different fields related to climate sciences, we also wanted to engage in "inquiry-based learning" -- meaning that it was not a priori defined what exactly students were to know in the end. Instead, we started out by asking a question and jointly worked on finding the answer throughout the semester. And the same thing -- which a slightly different question -- is going to happen again this year.

This might seem like a risky course for students and also some lecturers to take if so many things are not well defined beforehand. How will students know what the expectations are for a good grade if we don't even know exactly what this course will be about? And what exactly is going to happen throughout the semester?

To answer these questions and doubts, we reassured following aspects.

We have defined the learning outcomes (see 2.1.2) so the students knew exactly what our expectations were. There were a couple of "facts" that they needed to be able to explain, listed under the heading "knowledge". But those are well defined and were taught within the first few weeks of the semester. All the other learning outcomes do not depend on what content we actually ended up working on, rather, they are skills that can be developed (almost) independent of content.

And what might sound like a random course design ("ask a question and see where you end up with it") is not that random, after all. Inquiry-based teaching and learning has a long history and is actually a well-established teaching method. It is born out of constructivist thinking: content that is lectured does not enter everybody's brains in similar ways and leads to the same thoughts and memories. On the contrary: everybody needs to construct knowledge for themselves, and knowledge is constructed individually. Based on the Humboldtian model of higher education, calls for a holistic combination of research and studies in higher education has recently become more and more prominent (BAK 2009). For students, the advantage is that they can follow their intrinsic motivation and research a question much more autonomously than in most other teaching formats. For instructors, inquiry-based learning provides the opportunity of closely combining teaching and research activities. Inquiry-based learning is thus well suited to learn about and practice the research process. In fact, it is not about learning about the research process, it is about engaging in it. Inquiry-based learning can span a wide spectrum of different approaches. Classified along the axes "student activity" and "focus of the content", one can distinguish several different approaches (Rueß et al. 2013). Student activity can range from being a passive recipient of whatever is being taught to taking active part in the research process. The content of a course can range from looking at results of previous research, looking at individual research methods, or really focusing on the research process.

In our course, we somewhat moved around in this space and students sometimes were in a passive role, listening to others talking about their results, but most of the time they were actively doing research yourself, using the scientific process to solve their own research question. While actively engaging in the research process, they closely interacted with the instructors and their peers and thereby learned to think like a researcher as they are working in an interdisciplinary research team in a real research environment. Students were allowed to make mistakes in a safe space and learned how to learn from them in the context of this course and their future career. Most researchers will tell you that more than 90% of their ideas turn out to be nonsense, so knowing how to learn from mistakes is one of the most important skills to master during studies! Students are also well advised to learn to take responsibility for their own learning and structure it in a purposeful way (Reimann and Mandl 2006).

Another important aspect of inquiry-based learning, especially when led by a team of interdisciplinary instructors as in this course, is that students have the opportunity to engage with a diverse group of researchers, which can be both extremely motivating and also helpful for figuring out possible paths as a researcher, as the course provided a pool of role models who were eager to support the students in their learning and development (Gillen and Knutzen 2014). Of course, the drawback with inquiry-based learning is that it is really hard to predict how much time each step will take, as students and lecturers are conducting real research and the research process itself is unpredictable (Mooraj and Pape 2015). But since research is what students are doing in their Master thesis and possibly beyond in their future career, this is the perfect opportunity to practice it in a safe space.
References


About the author

Dr. Mirjam Glessmer is a physical oceanographer turned educational developer. After a postdoc on sources of observed and modelled freshwater in the Nordic Seas, she is now mainly interested in how people learn about the ocean and climate, and how understanding how people learn can be used to improve education and design better teaching materials. Read about her work here: mirjamglessmer.com
2.1.4 Sociological perspective

The course is designed as a ‘live’-experiment in “real” interdisciplinary teaching and research-based learning, and we used the metaphor of “experiment” throughout the course to refer to our approach. To kick off class discussions, a mathematical definition of scales was presented (cf. subsection 1.1.2), additionally, all lecturers were asked to define and present the scales concept from their respective disciplinary perspective [1]. For short presentations in 2015, which also served the purpose of introducing the lecturers, we chose the topic of hurricanes as a common theme and integrating element across presentations. While all lecturers took on the challenge of linking their work to the scale concept as well as the hurricane topic, these presentations were also arenas for inter-disciplinary boundary work [2], through which they could ensure that their disciplinary perspective was ‘properly’ presented (cf. Mathison and Freeman 1997).

To explore the potential of the scale concept for advancing integrated thinking in an educational setting comes with an built in tension: On the one hand, there was an innovative conceptual approach that had not previously been considered (for an exception see Clark 1985) and on the other hand, there is the practice that predefined goals, work packages and learning objectives are formalised and presented at the beginning of a new class. In this regard, the course opted for a research-driven approach to education, in which “knowledge is not viewed as information to be ‘covered’ but as multidimensional, highly personalized schemas ‘owned’ and used to create generalizations, analogies, explanations, and connections” (Maurer 1994: 7, as quoted in Mathison and Freeman 1997). It is not easy to work with such a framework of uncertainties in class and it, at times, clashes with the students’ preference for orientation. The 14 participants indeed oscillated between the role as student, in which they wanted to know exactly what to do for their assignment, and the role as researcher, in which one learns something new by thinking and doing something for the first time, such as coming up with one’s own scale diagram. In the course of the term, there was some unease with regard to what “the lecturers want” (personal communication, June, 26, 2015) and the students worried about the basis for their grading. They were told that “confusion and controversy are expectable and the experiment might even fail”, but at the same time, reassured that “your grading will depend on your effort and engagement, and not on the result achieved (because we all do not know yet whether a synthesis is possible)” (Quote from presentation slides lecture 5 2015).

The lecturers on their part faced some ambiguity between the role of teacher and the role of the learning researcher. As teachers we generally have specialised knowledge on the class’s contents; while in the role of researcher, we ask new, as yet unexplored questions and can thus not a priori know a great number of answers. These roles tend to be held mutually exclusive in most of an academic’s everyday life: In the classroom, she is a teacher while in the laboratory, library or field she acts as a researcher (Sorenson 2002: 3 as quoted in Blanchard 2012: 339). The potential as well as the challenge of bringing these two roles together should not be underestimated for both students and instructors; it implies “acknowledging our own limitations” (Blanchard 2012: 339) and it takes time and effort to feel comfortable with and trust new roles, goals and interactions (Mathison and Freeman 1997: np). A related issue was a tension between maximal openness for ways of re-thinking scales and scale interactions, and the need to define basic concepts to allow for shared understanding at all. In a small group discussion among the lecturers, it became evident that there were not only no overarching definitions of terms such as “climate system” and “coupling”, but also no consensus on definition within fields, e.g. on whether speaking of “coupling” presupposes mutual influences or mere one-way influences (such as in some ‘coupled’ climate models). This lead to a debate in how far meaningful debates across disciplinary boundaries depend on exact definitions of key concepts or if a certain vagueness in their use can be a chance to open up to new ways of thinking. The latter indeed seem to come more naturally to the less ‘disciplined’ students than to most of the lecturers. However, the disparate understanding of key concepts at times lead to divergent or even contradictory advice to the class, for example during a “speed dating” session in which every student got short individual feedback on their coursework from a number of lecturers. Collaborative teaching thus invited instructors “to be more deliberatively reflective about disciplinary assumptions, learning styles and pedagogies” (Blanchard 2012: 338).
Early in the course, the students were asked to come up with an interdisciplinary description of climate-related phenomena, i.e. phenomena in the climate system or phenomena describing the resonance of climate phenomena in social systems, and to name a third axis in addition to time and space to characterise their phenomenon. One presentation induced a vivid debate on the definition of such characteristics in the social world. The case in point was that the student proposed “number of people affected by a particular G7 summit” as a possible axis to quantify the political event’s social reach. The question what a journalist has in mind when he reports that “xy people are affected” by the event sparked a discussion on how to operationalise such an indicator. Suggestions on how to specify “affected by a political event” included mentally, physically, badly, positively, directly, indirectly, and if it brings or costs you money. The example shows that a specific definition is a prerequisite of a meaningful analysis but obviously loses the all-inclusiveness that was hoped for.

In sum, the students of the 2015 class faced the challenge that the class posed with intellectual curiosity and enthusiasm. As one student wrote in a feedback form: “The course was successful in triggering new ways of thinking and while pushing the understanding of ‘the scales’ further we stumbled about other things we didn’t think about before.” (Quote from feedback session 2015). In their final evaluation, the students embraced the course as an ambitious attempt to do something innovative and more integrated than most of their classes, and especially valued the multiplicity of perspectives: “I think the course achieved the stated goals especially because of the many discussions that were fueled by the different views of all lecturers and students.” (Quote from feedback session 2015). This is in line with previous studies that report an increased sensitivity to and respect for other points of view in learning situations with more than one teacher (as summed up in Blanchard 2012: 345ff). All students recommended that the course should be kept in the master program's curriculum.

References


About the author

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"It's your human environment that makes climate" - Mark Twain

Here we present the lecturers' biographies to give a face to the content of this e-learning unit.
Maike Scheffold

Maike Scheffold is research assistant in the teaching project 'Scales in the Climate System'. She finished her Master degree in 'Integrated Climate System Sciences' at SICSS with a Master Thesis topic in biological oceanography. Her background is geology/geophysics. As part of the ICSS curriculum she attended the Scales class in the year 2015, when it was first taught, and supported the class the year after as a student assistant. As a student assistant she also worked with Simone Rödder within the project "Reassessing an assessment- A study of the IPCC process".

Dania Achermann
Dania Achermann is a historian of science and was a guest researcher at the Cluster of Excellence "Integrated Climate System Analysis and Prediction (CiSAP)" from April to August 2017. She holds a Master’s degree in history and geography from Zurich University (Switzerland) and a dual degree PhD in history of science and technology from both Ludwig-Maximilians-University Munich (Germany) and Aarhus University (Denmark). Her main field of interest is the history of atmospheric and climate sciences in the 20th century, history of ice and snow research, environmental history and interdisciplinarity.

Jörn Behrens

Educated as an applied mathematician with PhD (Dr. rer. nat.) from Bremen University and Habilitation from Technische Universität München, Munich, Jörn develops numerical methods for atmospheric and oceanic simulation. He specializes in adaptive mesh refinement, numerical geophysical fluid dynamics, and high performance computing. In 2006 following the 2004 Sumatra-Andaman Tsunami, he became head of the tsunami modeling group at Alfred Wegener Institute, Bremerhaven, and developed the simulation component of the German-Indonesian Tsunami Early Warning System (GITEWS). After delivering the system, he accepted a professorship for numerical methods in geosciences at the Center for Earth System Research and Sustainability (CEN) of University of Hamburg in 2009. He coordinates the research project ASCETE (Advanced Simulation of Coupled Earthquake Tsunami Events), and serves as Co-Chair of UNESCO Intergovernmental Coordination Group for setting up a Tsunami Early Warning System for the Mediterranean, North-East Atlantic and Connected Seas (NEAMTWS) Working Group 1 (Hazard Assessment and Modeling). Since 2015 he serves as the program director of the special interest group on geosciences for the Society of Industrial and Applied Mathematics (SIAM).

Michael Brüggemann

Michael Brüggemann (PhD, University of Hamburg) is Professor of Communication Research, Climate and Science Communication at the University of Hamburg and Principal Investigator at the interdisciplinary cluster of excellence CiSAP. His research explores the transformations of journalism, political and science communication from a comparative perspective. For recent publications, see: www.bruegge.net .

Thomas Frisius

Dr. Thomas Frisius is a researcher and lecturer at the University of Hamburg. His research focuses on various Earth-science-related dynamical systems with emphasis on tropical cyclones, baroclinic waves and ocean circulation. A better understanding of these systems can be achieved by simplified and idealized models. Such models often stimulate the formulation of new theoretical concepts and new directions of thought. Thomas Frisius teaches the courses “Introduction to programming of global weather forecast models” and “Conceptual models of complex systems: Development, application and analysis”. The first course forms a part of the master study in meteorology and the second one is taught within the interdisciplinary study program “Integrated Climate System Sciences” (ICSS). Thomas Frisius receives funding from the German Science foundation within the Cluster of Excellence “Integrated Climate System Analysis and Prediction” (CiSAP).

Mirjam Gleßmer

Dr. Mirjam Glessmer is a physical oceanographer turned educational developer. After a postdoc on sources of observed and modelled freshwater in the Nordic Seas, she is now mainly interested in how people learn about the ocean and climate, and how understanding how people learn can be used to improve education and design better teaching materials. Read about her work here: mirjamglessmer.com.

Inga Hense
Prof. Inga Hense has longstanding experience in modeling biological processes in marine systems. She uses a range of different numerical ecosystem models to study the effects of climate change on phytoplankton dynamics as well as the consequences of the phytoplankton life cycle on the environment. In particular, she is interested in changes in species composition, biomass and phenological patterns. Inga Hense is lecturer at the interdisciplinary study program "Integrated Climate System Sciences" (ICSS) and Principal Investigator at the German Cluster of Excellence: "Integrated Climate System Analysis and Prediction" (CiSAP) at the University of Hamburg.

**Lars Kaleschke**

Dr. Lars Kaleschke is a professor and head of the CiSAP Sea Ice Remote Sensing Group at the Institute of Oceanography at the University Hamburg. After his diploma in physics he received his PhD (Dr. rer. nat) from the University of Bremen. In 2006 he became a Junior Professor for Oceanography at the University of Hamburg and was involved as a principal investigator for the two phases of the German Excellence Cluster "Integrated Climate System Analysis and Prediction CiSAP" and several other projects. His main research interests can be described with the keywords remote sensing, Arctic and permafrost, the role of sea ice in the climate system, ice-ocean-atmosphere physico-chemical interaction, and sea ice forecasting. His scientific contributions and accomplishments are the development, improvement and validation of retrieval techniques for various sea ice parameters like sea ice concentration, sea ice and snow thickness, melt pond coverage, leads, and frost flowers. He established the relation between frost flowers and atmospheric halogen chemistry and first hypothesized the effect of calcium carbonate precipitation to explain tropospheric ozone depletion events. He coordinated the development and test of a sea ice forecast system for ship route optimization. He serves as a national delegate in the Cryosphere Working Group of the International Arctic Science Committee IASC and as an editor for the journal The Cryosphere. He is member of the ESA SMOS Quality Working Group, NASA SMAP Early Adopter Programme, CNES SMOS-NEXT Science Team, and the DLR Tandem-L Science Team through the HGF Alliance Remote Sensing and Earth System Dynamics (EDA). Lars Kaleschke offers lectures and supervises theses for B.Sc. Geophysics/Oceanography, M.Sc. Oceanography, and Masters of Integrate Climate System Sciences (ICSS).

**Lars Kutzbach**

Lars Kutzbach is a professor at the Institute of Soil Science of the Universität Hamburg and one of the principal investigators of the German Cluster of Excellence "Integrated Climate System Analysis and Prediction CiSAP". The main scientific goal of Lars as researcher and teacher is to improve the understanding of the role of soils in the climate system. He focuses his research and education on the interconnected soil and vegetation processes and their coupling to the atmosphere and the hydrosphere. Over the last 16 years, Lars has concentrated his work on permafrost-affected landscapes of the Arctic as well as pristine and anthropogenically degraded peatlands of different climate zones (e.g., in Russia, Finland, Argentina, Northern Germany). His research is based on empirical field measurements and experiments on pedon and landscape scales, and he regularly struggles with the question how process understanding derived on these smaller scales can be used in large-scale Earth system models.

**Simone Rödder**

Simone Rödder is an assistant professor of sociology at the University of Hamburg's Department of Business, Economics and Social Sciences and a Principal Investigator in the Cluster of Excellence "Integrated Climate System Analysis and Prediction" (CiSAP). Her research is located at the intersection of the sociology of science and the science of science communication and applies mainly qualitative methodologies. Her current work focuses on interdisciplinary collaboration in climate research and her major class in the MICSS curriculum is a lecture with practicals, "Introduction to the Social Sciences". Simone has an academic background in biology, sociology and science communication and holds an interdisciplinary PhD degree (Dr. phil. nat.) from the University of Bielefeld. She has been trained as a journalist and worked for several newspapers and magazines.

**Jürgen Scheffran**
Jürgen Scheffran is Professor at the Institute of Geography and the Center for Earth System Research and Sustainability (CEN) of the University of Hamburg in Germany and head of the Research Group Climate Change and Security (CLISEC) in the CliSAP Cluster of Excellence. Until summer 2009 he held faculty positions at the Departments of Political Science and Atmospheric Sciences at the University of Illinois at Urbana-Champaign (UIUC) where he also was a researcher in the Program in Arms Control, Disarmament and International Security, and the Center for Advanced BioEnergy Research. After his PhD at Marburg University, he worked in research positions in the IANUS Research Group at Technical University Darmstadt, the Potsdam Institute for Climate Impact Research, and the University of Paris (Sorbonne). His research and teaching interests include: climate change and energy security; environmental conflict and human migration; complex systems analysis, agent-based modelling and human-environment interactions; sustainability science, technology assessment and international security.

Johanna Baehr

Johanna Baehr is a professor for 'climate system data assimilation' with a background in physical oceanography and experience in climate modelling. Her current research focuses on the predictability of the earth system's variability on seasonal-to-decadal time scales.

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