Title: Complex system Climate

Abstract:

Complex systems can be found in many places in our daily life. In these complex systems, a small change in one of the variables can have significant impact, resulting in traffic jams, sudden fast stock changes or unpredictable weather and climate phenomena. In recent years, complex systems are being studied with quite general tools independent of their many individual variables or components. In complex systems phenomena emerge that cannot be understood only from the sum of the individual parts; rather, the way in which different components or variables are combined together can provide insight into typical “complex” phenomena.

The climate system as a whole is a classical example of a complex system in physics. It exhibits variability on many different spatial and temporal scales and consists of many nonlinearly interacting subsystems (fast atmosphere, slower ocean, very slow ice sheets). Predicting how the whole system will evolve, therefore requires understanding of processes in the different subsystems, but also how these systems interact.

In this session, some of the highlights of Dutch research into the complex behavior of the climate system will be presented. For example, ocean waves are responsible for mixing, yet exhibit complex spatial patterns, sea level rise is unequally distributed over the globe and inherently difficult to predict. Coupled models of the Earth system are complex in itself, but can we drive them with observations into the correct regime? The Montreal protocol has been in effect since the 1980s, but what effect did it have for the climate?

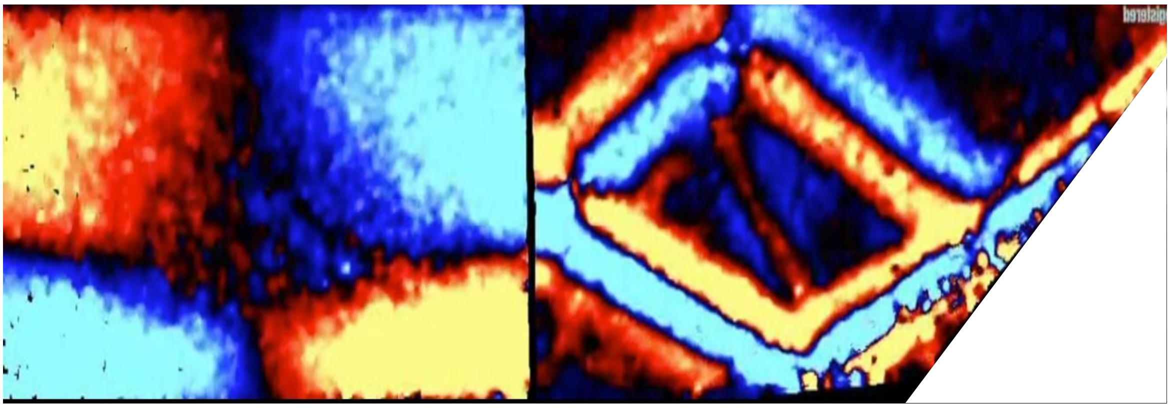
Conveners: Anna von der Heydt and Erik van Sebille

Speakers:

Leo Maas (IMAU/NIOZ)

Title:Wave attractors in anisotropic media

Abstract: Waves in anisotropic media behave quite differently from waves in isotropic media. This applies e.g. to (1) waves in density-stratified and/or rotating media, such as the ocean, atmosphere or planetary and stellar atmospheres, (2) electron-cyclotron waves, in plasma’s subjected to a transverse magnetic field, and (3) electromagnetic waves, in hyperbolic metamaterials. These waves all obey an unusual dispersion relation in which frequency relates only to wave vector *direction*, and not, as for isotropic waves, to its magnitude. Such waves, falling onto sloping boundaries, reflect nonspecularly. During reflection, their wave length decreases and they amplify instantaneously. Ultimately, this leads to indefinite wave focusing at highly predictable locations - ‘hot-spots’ of ocean, atmosphere and stars: ‘wave attractors’. Application to plasma waves, that follow the same unusual dispersion relation, suggests the appearance of wave attractors in stellarators and tokamaks. Similarly, electromagnetic waves in metamaterials, consisting in stacked layers that are conducting within layers but insulating perpendicular to them, are governed by hyperbolic dispersion and might thus also exhibit wave attractors.



Side view of the density perturbation (color) of a uniformly-stratified fluid (salt-concentration decreasing gradually towards surface) in a container that is partitioned into two compartments, and that is weakly oscillated laterally. Depending on the compartment's shape, Internal gravity waves either (left) slosh as a standing wave, or (right) focus, as a propagating wave, onto an attracting periodic orbit (wave attractor).

Aimée Slangen (NIOZ/UU)
Title: Solving the sea-level puzzle
Abstract: Sea-level change is a much-studied topic in the area of climate research. It integrates a number of climate science disciplines and therefore acts as a big thermometer of our climate. Moreover, sea-level change is expected to impact coastal communities around the world. The challenge in sea-level research is that we need to understand many different processes that act on different temporal and spatial scales in order to understand the total sea-level change. Using climate models, global and regional sea-level change can be estimated for the 20th and 21st century. This includes contributions from variations in ocean density and dynamics, cryospheric mass changes, landwater exchange and vertical land movement. For the 20th century the model results are compared to observations and I will show that more than 70% of the observed sea-level change since 1970 is caused by anthropogenic greenhouse gas emissions. For the 21st century, I will show regional sea-level projections for different climate scenarios and discuss the main uncertainties in the projections: what do we need to make even better projections? I will also discuss how the projections can be used to for instance estimate how the frequencies of sea-level extremes will change as a result of sea-level change.

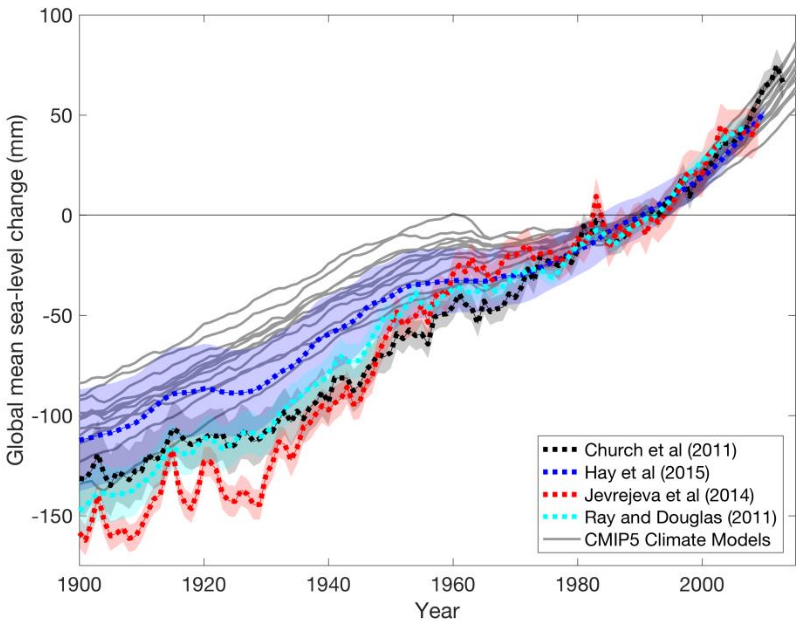


Figure 1: Global mean sea-level change from CMIP5 climate models compared to observational reconstructions (mm) relative to a baseline period of 1980-2000. Shading indicates 1□ uncertainty. Adapted from Slangen et al (2017), Journal of Climate.

Femke Vossepoel (TU Delft)

Title: Assimilation of subsidence observations in an integrated Earth model

Abstract: By extracting fluids such as gas, oil and water from the subsurface, and injecting water and gas into it, human activity affects the lives of those living on the Earth's surface. Estimation and forecasting of land mo- tion, whether caused by human activity or natural processes, requires an understanding of the physics of these processes and their interaction. Re- versely, observations of land motion can improve the understanding of the processes and unravel their interaction. This presentation presents how assimilation of observations of subsidence into coupled flow-geomechanical models of the integrated subsurface can be used to improve the parametri- sation of these models.

Various data assimilation techniques can be used for this purpose. Se- quential Monte Carlo methods have the advantage that they do not require the gradient of the model dynamics to be calculated, can be applied for non-linear systems, and are relatively straightforward to implement. Ex- periments with models with increasing levels of complexity demonstrate the effectiveness of this method for low-dimensional systems, and its cur- rent limitations when applied to high-dimensional systems.

Eventually, data assimilation in integrated Earth models is expected to lead to a better estimate, understanding and eventually forecast of the effects that subsurface processes have on the surface.

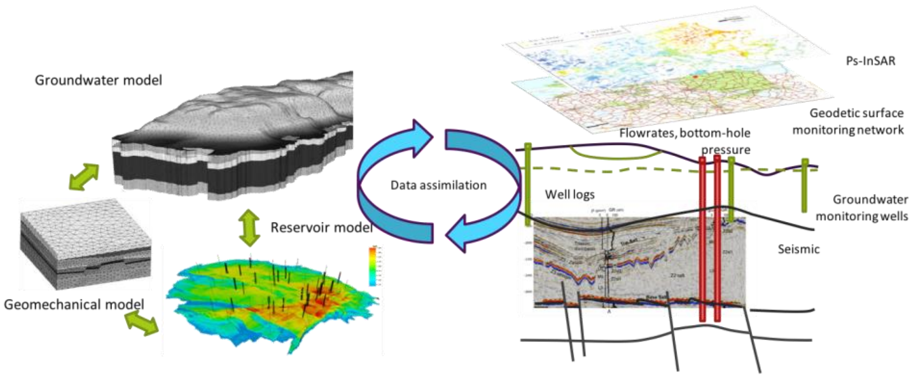


Figure 1: Integrated approach for subsidence estimation.

Guus Velders (RIVM/IMAU)
Title: Climate impact of the Montreal Protocol
Abstract: The Montreal Protocol has reduced the use of ozone-depleting substances by more than 95% from its peak levels in the 1980s. As a direct result the use of hydrofluorocarbons (HFCs) as substitute compounds has increased significantly. National regulations to limit HFC use have been adopted recently in the European Union, Japan and USA to substantially reduce growth in HFC use. In October 2016 in Kigali, the parties to the Montreal Protocol agreed to amendment the protocol to include HFCs and phasedown their consumption and production in the coming decades. The effects of the national regulations and Kigali amendment on climate forcings and surface temperatures will be presented. Without global regulations the HFC emissions could reach 4.0-5.3 GtCO$_2$-eq yr^{-1} in 2050, which corresponds to a projected growth from 2015 to 2050 which is 9% to 29% of that for CO_2 over the same time period. This yields a contribution of HFCs to the global average surface warming of 0.3-0.5 ^{o}C by 2100. With the Kigali amendment the emissions are reduced significantly and the surface warming from the HFCs is limited to less than 0.1 ^{o}C by 2100.