DIGITAL EARTH

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

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Newsletter of the *Digital Earth* Project

Contributions of the Helmholtz-Zentrum Geesthacht

This newsletter presents some specific efforts by the Helmholtz-Zentrum Geesthacht - Centre for Materials and Coastal Research (HZG) regarding activities related to the Show Cases or Work Packages of Digital Earth.

How do floods affect conditions in the German Bight? The Anomaly Detection Workflow

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When weather conditions permit, the Elbe river plume can be detected between Helgoland and the coast. Thanks to regularly operating ferries, such as the "FunnyGirl" between Büsum and Helgoland, data from the Elbe outflow can be collected at locations where it crosses the ferry transect through automated measurement devices mounted on the ferry, the FerryBoxes.

Especially after flood events, it is scientifically interesting to assess the composition and amount of nutrients and pollutants that the Elbe River transports into the German Bight. In addition, the short- and long-term consequences of this deposition require monitoring. A challenge in this context is not only to identify the general location of the Elbe river plume in the German Bight, but also to get a more nuanced idea of its spatial extent. Furthermore, to analyze the substances that the Elbe delivers to the North Sea, information from distributed and diverse datasets must be made available and findable in a convenient way in this context.

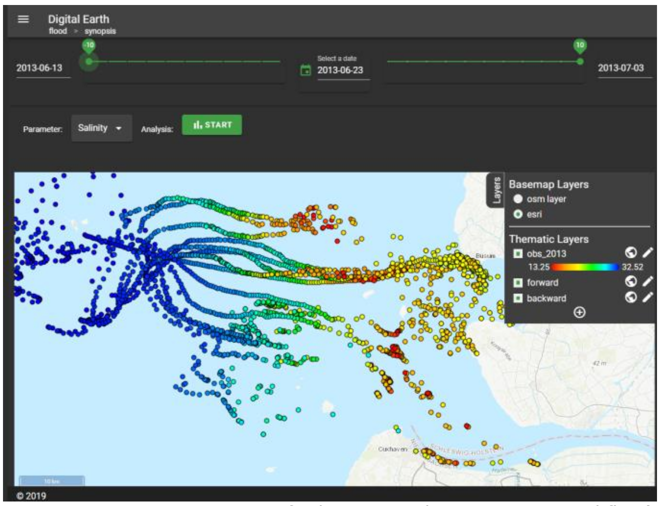

Figure 1: Current state of the Anomaly Detection-Workflow's implementation. After loading FerryBox-data from a test-set of observations made in June 2013 and adding pre-computed synopsis data from a user-defined time interval up to ± 10 days, the user can interactively define a region of interest around a presumed anomaly.

To approach these questions, scientists from HZG and GFZ work together to implement the *Anomaly Detection Workflow* into the Digital Earth Data Explorer. This modular framework will employ several scientific workflows and allow to visually explore diverse data sets and to combine observational and model data to help interpret the state of the system.

In particular, the interface to the Anomaly Detection Workflow (see Fig. 1) aims to equip the user with a comprehensible application to load FerryBox data and complement it with model data, termed synopsis data, to assess the extent and temporal development of the crossing river plume visually. Synopsis plots are assembled from model trajectories starting from the actual measurement positions on the FerryBox transects (see Fig. 2).

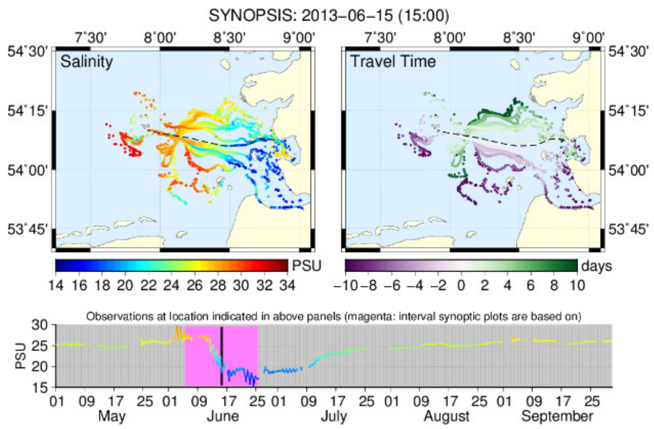

Figure 2: Synopsis plot of FerryBox cruises between Büsum and Helgoland in June 2013. On the left, the modelled positions of the water bodies are colored according to the original measurement's salinity. On the right, the coloring scheme indicates the travel time of water bodies since the model was started. The lower plot shows the time series of observations made on the FerryBox line and, in magenta, the time interval that was used to calculate the modeling results in the top plots.

This way, the approximate position of the phenomenon is calculated for times before and after the actual observation date and will be used in the Anomaly Detection-Workflow to investigate the anomaly in other datasets with observation times close to the original detection time. By finding and analyzing additional observational datasets with the computed position and timestamp of the synopsis data, scientists will be able to observe the phenomenon in more detail and include more parameters than could be gathered by just using the FerryBox data. Furthermore, modeled trajectories of the FerryBox data allow making assumptions about an anomaly's origin. Using them enables scientists to support claims such as that an observed anomaly could indeed have its origin in the Elbe estuary.
In the Digital Earth Data Explorer, these features of the Anomaly Detection-Workflow are implemented in an intuitive and interactive application, and will be enhanced by the ability to load additional observational data comfortably

from the COSYNA (*Coastal Observing System for Northern and Arctic Seas*) data portal. The implementation allows to visually explore the Elbe River plume across time, space and parameters. In addition, it employs a function to determine the anomaly's statistical properties in comparison to the surrounding waters and enables a thorough understanding of the influence of a flood event on the conditions in the German Bight.

Flood Event Explorer: The Change Toolbox

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During extreme rainfall and flood events, cascading effects can lead to complex, and poorly understood event-chains affecting across compartments in a non-linear, time-delay manner. For instance, combinations of high groundwater and soil moisture levels combined with heavy rain can lead to high runoff. Future changes in such combinations and cascades, and ways to model these, are still poorly understood. As such, floods have been identified as Show Case in the Digital Earth project.

At GERICS, we use our in-house state-of-the-art high-resolution Regional Climate Model simulations of Europe to determine the extent which **severe precipitation events**, which contribute to floods, will change in future climate projections in order to support governments, administration, and businesses in their efforts to adapt to climate change.

Users of climate model simulations, as with earth observations, demand efficient and effective transformation of big data into timely, reliable, and user relevant information. Some common **challenges** in developing Climate Services include:

1) Transformation petabytes of data from physical quantities (e.g. precipitation, temperature, wind)

- to user applicable quantities, such as return periods of heavy precipitation for legislative and construction design frequency,
- for the identification of unknown relationships between physical quantities and societal concerns (e.g. flooding & population health),
- for the combination of these physical quantities with socio-economic data.

2) Technical & physical barriers in the use and interpretation of climate data

- is often difficult for users to explore, analyse, and extract locally relevant information efficiently.
- include data volume, unfamiliar software & data formats, technical infrastructure, and technical background knowledge.
- Requires scientific background knowledge, including assumptions, which can limit or influence interpretation of results.

Working closely with Digital Earth partners at the GFZ, we are tackling these challenges by developing the Flood Event Explorer's 'Change Toolbox' and applying innovative data analytical technologies to Regional Climate Data. In this first phase of Digital Earth, the 'Change Toolbox' is designed for climate scientists allowing for faster processing and interpretation of projected climatic change and uncertainties over a given region. Ultimately, the 'Change Toolbox' is intended to be useful for local stakeholders too.

The Flood Event Explorer - Change Toolbox is composed of two parts.

- Part I of the 'Change Toolbox' will provide a general **overview of the projected changes in precipitation** over a user-defined region of interest. It will convey the bandwidth, the minimum/maximum range projected by an ensemble of regional climate models, of future precipitation scenarios alongside expert judgement on the robustness and significance of regional changes based on a very wide range of different models and projections.

- Part II of the 'Change Toolbox' will provide a **detailed analysis of changes in heavy precipitation events and their properties**, such as duration, intensity, and frequency. Ultimately it will address the **scientific question**: "Is there an increased likelihood of sequences of heavy precipitation events, as well as an increase in the combinations of prolonged wet/dry periods followed by heavy precipitation events in a warmer climate?" These scenarios increase likelihood of flood runoff generation as they influence initial soil moisture & high ground water conditions and are combined with heavy rainfall.

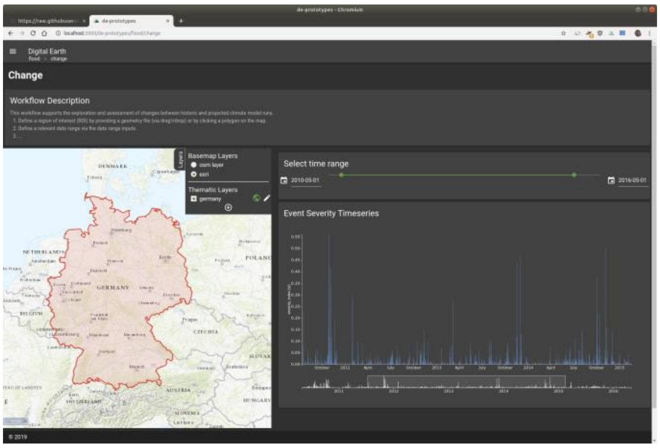

Figure 2: Prototype of Part II of the Change Toolbox – A Work in Progress!

Estimation of chemical substances in the atmosphere using neural network

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Problem formulation. Chemical substances of anthropogenic and natural origin released into the atmosphere affect the air quality and thereby the health of the population. As a result, there is an instantly increasing demand for reliable assessments of air quality and its dependence on emissions and prevailing atmospheric conditions. The analysis of existing air pollution modelled data allows retrieving some information. Where and when are the concentrations of a certain air pollutant expected to be particularly high? How representative are measurements from an existing monitoring network? How will air pollution change with reduced emissions? What will be the consequences of climate change that might affect relative frequencies of certain weather situations?

Answering such questions needs comprehensive model simulations. However, computational costs of such simulations using numerical atmospheric chemical models are very high. Therefore, in this project we try to replace a detailed air quality model by a much simpler surrogate model, fitted to existing numerical simulations. For that purpose, methods of artificial intelligence are used. The much more efficient (in terms of computation time) surrogate model can then easily be run in different setups defined, for instance, in agreement with specific emission or climate change scenarios.

Given detailed numerical model simulations based on emissions, atmospheric conditions and known physical/chemical equations, artificial intelligence methods represent dependencies between inputs and outputs empirically in a most efficient way. At present, artificial intelligence offers a large number of techniques where the neural networks (NN) are among the most popular. NNs can approximate any continuous and bounded function with any rate of accuracy, determine the nonlinear dependencies, and analyze the temporal context between the two dependent data sets.

Current state. We develop a neural network that computes chemical concentrations in the atmosphere based on weather conditions (temperature, humidity, pressure gradient). The NN is trained on the Community Multiscale Air Quality (CMAQ) model outputs. A technical advantage of model simulations is that they have no gaps, which are often intrinsic to observations. In our study, we treat the model simulations as being 'perfect', disregarding any simulation errors.

At present, our NN is able to compute daily mean surface concentrations of NO2, SO2, and ozone on a European scale for the period from late spring up to the middle of autumn. Results are in good correspondence with CMAQ simulations. The average correlation between NN and CMAQ outputs equals 0.88 and 0.84 for NO2 and SO2, respectively. The root-mean-square differences equal 0.47 and 0.53 standard deviations, respectively. Figure 1 shows the example of a NO2 concentration simulated with CMAQ (left panel) and approximated with the NN (right panel). The spatial correlation between these patterns is 0.97.

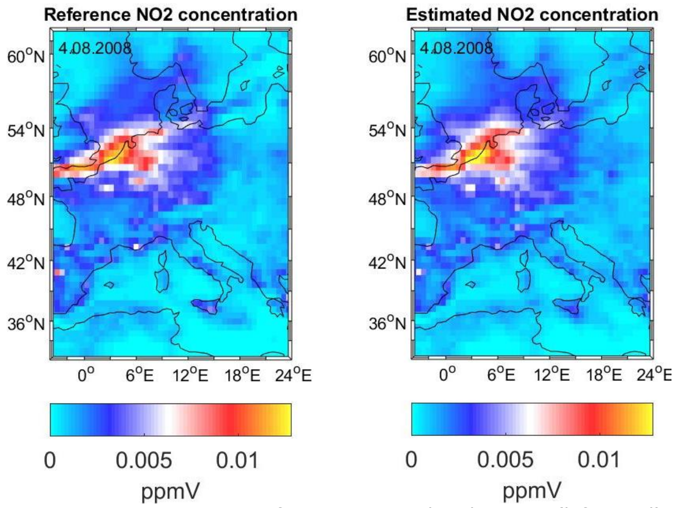

Figure 2: Concentrations of NO2 estimated with CMAQ (left panel) and NN (right panel).

Next steps. The comparison of NN estimates with CMAQ model computations shows the good potential of the NN. As the next step, we will train the NN to predict the anomalies in atmospheric and water methane concentration, which is one of the tasks in the Digital Earth project.