Causal discovery algorithms for the study of climate change impacts on the global water cycle

Lead Supervisor: Michaela I. Hegglin, University of Reading, Department of Meteorology
Email: m.i.hegglin@reading.ac.uk

Co-supervisors: Varun Ojha, University of Reading, Department of Computer Science**; Marlene Kretschmer,** University of Reading, Department of Meteorology**; Brian Kerridge,** Rutherford Appleton Laboratory, STFC Harwell

The water cycle plays a critical role in shaping the global environment and supporting life on Earth. Climate change is predicted to lead to changes in the water cycle, affect available water resources, and as a consequence endanger the livelihoods of societies especially in the developing world. Characterising the local to regional variability and long-term changes in the water cycle is therefore crucial to aid adaptation measures. Currently, our knowledge of changes in the water cycle is limited. While the fifth IPCC assessment report (2013) reported changes in the water cycle to be robust and of high confidence over the ocean, past changes over land are only stated with medium confidence. However, it is over land that changes in the water cycle matter most in terms of impacts.

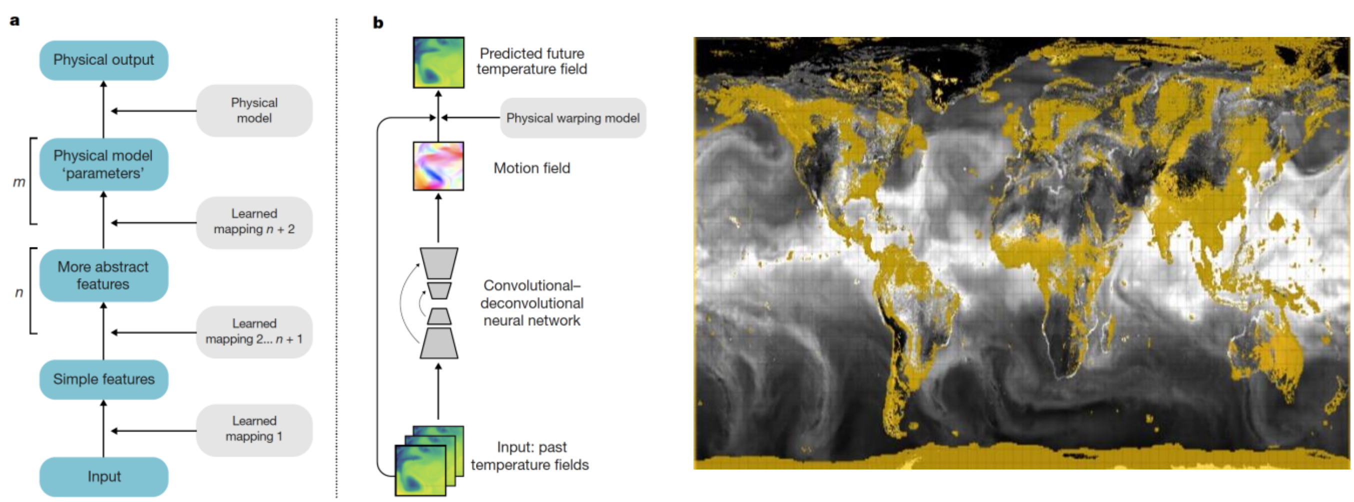

Figure 1: (left) Schematic of how theory-driven approaches can be joined with data-driven approaches to make a neural network model physically more realistic (*from Reichstein et al., Nature 2019*). **(right)** Daily snapshot of atmospheric water vapour from the ESA Water Vapour Climate Change Initiative (*courtesy Brockmann consult*).

This PhD project will use a combination of novel observations and analysis tools to revisit the question of how the water cycle may have changed over the recent past. For observations, newly established observational data records from the European Space Agency's Climate Change Initiative (ESA CCI http://cci.esa.int/objective) that aim at achieving highest standards of observational quality will be used as basis for the conducted evaluations. **Figure 1 (right)** shows an example of water vapour from the ESA Water Vapour CCI project.

For analysis tools, the project will take advantage of novel machine learning (ML) techniques. ML techniques feature algorithms and statistical models that computer systems use to perform a specific task without using explicit instructions, relying on patterns and inference instead. ML has recently attracted much attention, especially because of its potential to identify patterns in complex systems that are too complex to be identified by the human brain (or traditional analysis approaches). Combined with physical knowledge (see **Figure 1 (left)**), ML is expected to help gain new insights into the processes that drive changes in the climate system.

An approximate outline for the project is:

1) Literature review to learn about potential drivers of observed variability and long-term trends in global water vapour fields, available observational climate data records, ML algorithms, and other data analysis tools.
2) Analysis of atmospheric water vapour changes based on novel climate data record with a focus on (i) general patterns and (ii) the relevant drivers of variability and change using ML techniques identified in 1).
3) Multivariate data analysis using different variables relevant to the water cycle and exploration of connections between them.
4) Use the findings from the observations to test weather forecast models.
5) Addition of surrogates of socio-economic drivers (population numbers and economic parameters such as GDP) to capture non-physical drivers of environmental change.

Training opportunities:

The project offers the possibility to visit the project's industrial partner, STFC-RAL, over an extended time period to learn alongside retrieval specialists the theory behind Earth observation science. It also provides the unique opportunity to work along an international project, the ESA Water Vapour Climate Change Initiative, with opportunities to gain international contacts through attending conferences and project meetings.

Student profile:

The project would be suitable for students with a degree in meteorology, mathematics, physics, computational sciences or a closely related environmental or physical science. A high level of numeracy and strong computer and programming skills are necessary in order to allow for efficient progress in the project. Applicants should hold a 1st class or upper 2nd class degree or equivalent.

Funding particulars:

None.

References: (optional)

If required, put in any relevant recent publications.

http://www.reading.ac.uk/nercdtp