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Deliverable D5.3

Software package for the identification of tipping points (based on network properties) associated with a rapid Atlantic MOC change

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EXECUTIVE SUMMARY

Deliverable 5.3 is a set of computer codes which construct the correlation network associated to the Atlantic Overturning Meridional Circulation (MOC), and then calculates (and plots) the associated degree distribution. This document is a short description and guide to use such codes. An example file is provided to illustrate the use of the software. It contains a time series of twodimensional streamfunction data, obtained from computer simulations of the ocean circulation model FAMOUS. The companion deliverable 5.4 "*Report on early warning signals and identification of tipping points with the MOC change as a particular example*" explains how the network quantifiers computed by the present software can be used to identify climatic tipping points, and to give early-warning signals of the approach to them, thus completing the main goals of Workpackage 5 (WP5) of the LINC project "Tipping Points in the Climate System".

Besides WP5, this deliverable is linked to WP3 and WP4, since the identification of climatic tipping points needs to take into account both natural climatic variability and climatic changes, of which the MOC is a particularly relevant example.

Deliverable Identification Sheet

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Abstract (for dissemination)	This deliverable consists on a set of computer codes to build a climatic correlation network from streamfunction data of the Atlantic circulation. From it, the degree distribution is computed, which provides useful indicators to identify and to anticipate the Atlantic Meridional Overturning Circulation tipping point. Example files are provided, coming from computer runs of the FAMOUS model.	
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1 Introduction

This document describes deliverable 5.3 “*Software package for the identification of tipping points (based on network properties) associated with a rapid Atlantic MOC change*”. The deliverable itself is a set of computer codes and example files that can be obtained from the LINC web site: <http://www.climatelinc.eu/results/deliverables/>. The computer codes are the ones used to produce the results in Deliverable 5.4 “*Report on early warning signals and identification of tipping points with the MOC change as a particular example*”. Thus, please refer to that deliverable to get additional details on the scientific results and interpretation of the output of the software presented here.

2 Requirements

The software will run under Linux, Windows and Mac OSX, provided there is in the system a working installation of Python 2.7 or higher, with the package NumPy installed. NumPy is freely available from <http://www.numpy.org/>. The plotting routine `PlotDegreeField.m` will also need a working installation of Matlab (<http://www.mathworks.com/products/matlab>).

3 Software description and operation

The software provided computes the degree field of the correlation network associated to streamfunction data obtained from a simulation of the Atlantic circulation with the model FAMOUS (see details in Feng *et al.* (2014)), but it can be easily adapted to any other set of geophysical time-series obtained at different spatial locations. After computing the network and its degree field, it is immediate to calculate other more global indicators such as the variance or the kurtosis of the degree distribution (Mheen *et al.*, 2013; Feng *et al.*, 2014). Monitoring the increase of these indicators is an efficient signaling method of the approach to the MOC collapse tipping point (Mheen *et al.*, 2013; Feng *et al.*, 2014).

The components and operation of the software package are as follows:

1. **Input file.** It should contain a two-dimensional set of time series, one for each spatial location. The format of the file `data_filename` should be such as the one produced by the Matlab commands

```
Moc = reshape(MOC,nlatitude*ndepth,ntimes);
dmlwrite(data_filename,Moc,'delimiter','\t');
```

where `MOC` is a three-index (latitude, depth, and time) array containing two-dimensional snapshots (of sizes `nlatitude` and `ndepth`) of the zonally averaged annual mean Atlantic meridional transport (i.e. the MOC streamfunction) at `ntimes` consecutive years. As an example we provide in the package the file `CNTRL_AMOC_p22Sv.txt` which contains streamfunction data for `ntimes=100` years from the FAMOUS equilibrium simulation #6 described in Feng *et al.* (2014). Streamfunction data in Sv ($1 Sv = 10^6 m^3 s^{-1}$) are present for `nlatitude=42` latitude values and `ndepth=21` depth values. The corresponding latitude (in degrees) and depth (in meters) values are in files `LAT_L.txt` and `DEP.txt`, respectively.

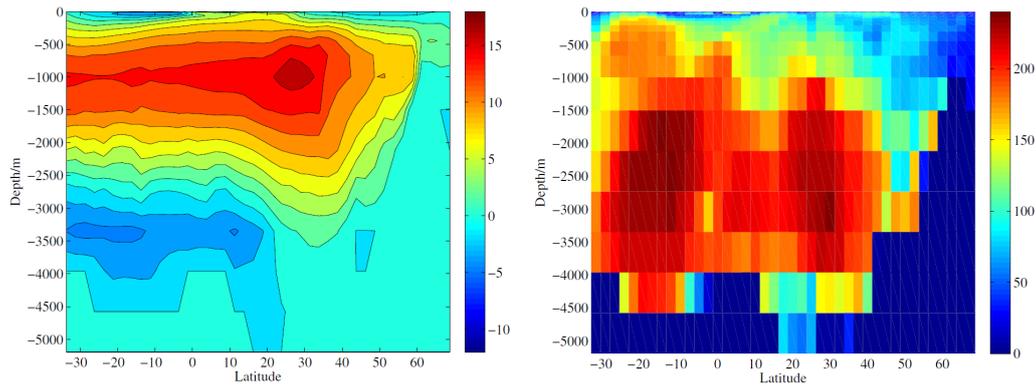


Figure 1: Left: Annual mean for year 100 of the MOC streamfunction (in Sv) from the simulation of the FAMOUS model contained in the example input file `CNTRL_AMOC_p22Sv.txt`. Right: the degree field in file `C_degree_p22Sv.txt`, as computed from the input data by the script `MOC_Section.py`, and plotted by `PlotDegreeField.m`. For details and interpretation of these example data, see Deliverable 5.4 *“Report on early warning signals and identification of tipping points with the MOC change as a particular example”*.

2. **MOC_Section.py** The main Python script that reads-in the streamfunction data in the **input file** and writes a text file (in the example, `C_degree_p22Sv.txt`; to change the output filename edit it in the last line of the script) containing the values of the degree field. It calls the routines contained in the file `netmath.py`, which compute cross-correlations (and can also be used to compute mutual information) between the time series at the different locations. The name of the input file should be provided in line 17 of the script. The correlation threshold to build the network from correlation data is set to 0.5. This can be changed in the script at line 21.
3. **PlotDegreeField.m**. This is a simple `Matlab` script that reads-in the degree-field file, together with the latitude and depth coordinates, and plots the degree field (as in Figure 2 of Deliverable D5.4 and in Feng *et al.* (2014)). Modifications of this script can be used to calculate statistical properties of the degree field, such as variance and kurtosis, which are efficient indicators of the approach to the MOC collapse tipping point (Mheen *et al.*, 2013; Feng *et al.*, 2014).

Figure 1 shows the MOC streamfunction corresponding to year 100 in the FAMOUS equilibrium run contained in the file `CNTRL_AMOC_p22Sv.txt`, as well as the degree field computed by the software codes described above. Deliverable 5.4 analyzes this kind of results and describes how they are used as warning signals of approaching climatic tipping points.

References

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