Preamble

Numerical modelling is important in many aspects of environmental science. It is used to inform decisions and policies and to improve the understanding of natural systems and how they react to changing conditions. For example it can be used to assess the impact of increasing levels of pollution in an area, or the behaviour of the climate system to increasing greenhouse gases.

The processes that occur in the environment are often described by *dynamical models*, which are based on systems of coupled differential equations. Often there are no analytical solutions to these coupled equations and so we have to apply approximate (yet accurate!) algorithms to be solved on a computer.

Let us say a few words about observations in science. Observations are absolutely critical to testing theories and deriving new theories in science. They are often use very effectively if one can control all the variables in one's experiments. However, in the real world this becomes extremely difficult. A purely observation approach to environmental science may therefore not lead very far, because the observations on which you base any theory or new ideas may be based on a limited set of observations (biased data). Where experiments under controlled conditions are impossible in the real world, these become possible in the 'numerical model' world.

Furthermore, some 'experiments' may be subject to ethical considerations. An example here could be the area of geoengineering of the earth's climate to mitigate against rising CO2 levels. One such idea is to seed clouds over the oceans (marine clouds) with sea spray aerosol to increase the amount of solar radiation that is reflected back to space and therefore reduce global temperatures (Latham, 1990). This idea has been given the name 'marine cloud brightening'. The idea, written down on paper, seems like a logical thing to do, but what if it has unintended consequences? Maybe the atmosphere and the climate would compensate to produce less cloud cover with zero net cooling (resulting in a very expensive null experiment!)

Worse still maybe creating brighter clouds in patches, would lead to colder and warmer patches in the cloud tops, which may result in air motions at the edges of clouds that result in the clouds evaporating? This could then leave an unintended effect that the environment warms even further. Hence, before any decisions were made decision-makers usually like to be convinced with a comprehensive set of detailed calculations, which we usually call a model or 'simulation'.

In order to get started on our modelling journey the first week will involve some initial set-up and a requirement to learn a few basic commands to download computer code and 'compile' the code so that it can be run on a computer and generate output. You will also usually need to edit an input file to set the model's initial conditions. Following the set-up you will then run the model and wait for the output to occur. Modern computers are very fast, but equally remember there are usually a large number of calculations required by the model, so please do not be put off if the calculations take a short while. Real model studies usually take much longer, but for this short course we can make do with shorter calculations.

It may seem a lot to remember in the first week, but you will find that each week follows similar principles and the methods you will follow are the same.

Remember! *We are here to help!* Don't worry or feel nervous about approaching us either during classes or out of class time (even during a lecture, if there is something you don't understand—put up your hand in the chat and say so—the chances are that there are others who feel similarly). If there is something you don't understand, keep at it with our help until you do. If you avoid tackling a topic because you are afraid of it or feel you don't like it, you will become lost and demoralised with topics that follow, and we really want to avoid that at all costs.

What will I learn?

In this course you will learn many transferable skills, in addition to some more specific skills that are important for the modern day earth or environmental scientist. Examples of transferable skills are as follows:

- Basic Linux commands
- Downloading and compiling code from GitHub.
- Use of Python to plot your model data.
- Interpretation of complex model output in multi-dimensions.
- Understanding complex relationships between variables and how they are manifest in the real world.
- Basic understanding of parallel computing.

In terms of more specific skills we will learn about the details of how different models work and look at computer code fragments to aid our understanding. In order to aid our understanding further we will change input / set-up files and investigate the effects that different variables have. The specific examples we will use are as follows:

- Finite difference as a means to solve equations.
- The motion of the planets around the sun and the interactions between planets: modelling Milankovitch cycles.
- Cloud formation on aerosol particles.
- Transport of pollutants in the atmosphere.
- What governs the formation of rain from clouds?
- Tsunamis and large-scale dynamics.
- Large-eddy scale fluid dynamics.

What this course is not

This is not intended to be a course in learning how to build your own numerical models. Learning how to build your own models requires experience in programming and numerical algorithms. We will certainly talk about these topics, but we will not cover these topics in great depth. Nevertheless you will be more aware of these topics having completed the module. For those interested in learning more about algorithms to solve equations there are many text books you may consult. One that I have used in the past and found very useful the book by Hoffman (1992).

References

Hoffman, J. D., 1992: *“Numerical methods for engineers and scientists”*. “McGraw-Hill”.

Latham, J., 1990: Control of global warming? **347**, 339–340.