UNIVERSITY OF EXETER

An introduction to Isca

Dr Stephen I. Thomson

Isca

Plan

- **Part 1:**
  - What are these practical sessions for?
  - What code will we be using? **Isca**
    - What is **Isca** - components, options?
- **Part 2:**
  - How do we **run** Isca / **configure** it / **modify** it?
  - How do we **analyse** the output?
- **Part 3:**
  - A brief introduction to each **project**

What are these practical sessions for?

- Supplement to the lectures - **apply** ideas you've learned
- Climate science relies heavily on **collaborations** - working in teams with diverse set of skills
- Chance to do **meaningful science** - all projects have scope to do new things
- **Do something different** to your PhD / postdoc projects - I would encourage you to do something different to what you normally do.

What code will we be using?

Isca [is-ka]

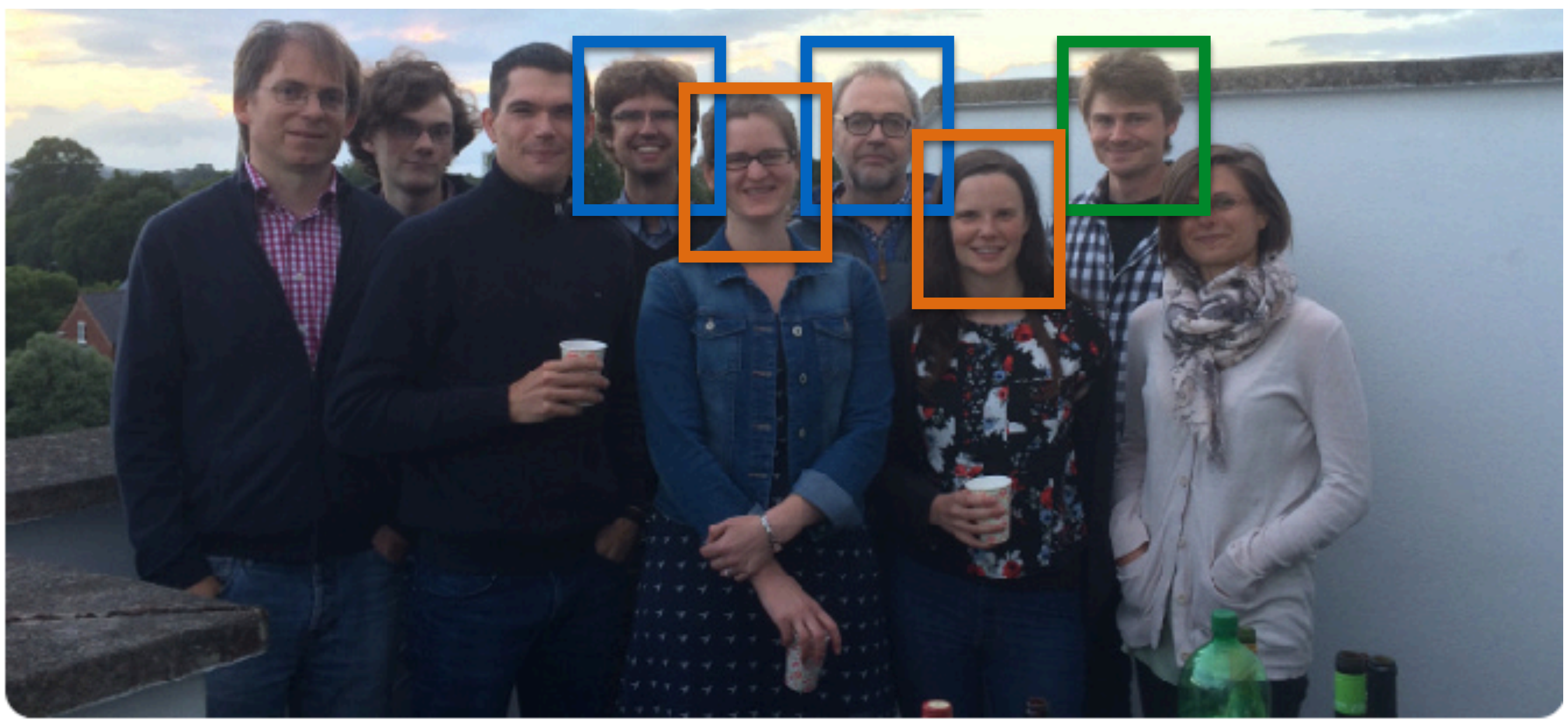
1. a former Roman city located where present day Exeter is,

2. the Latinized Celtic word for running water, and

3. a modelling framework.

Useful contacts:

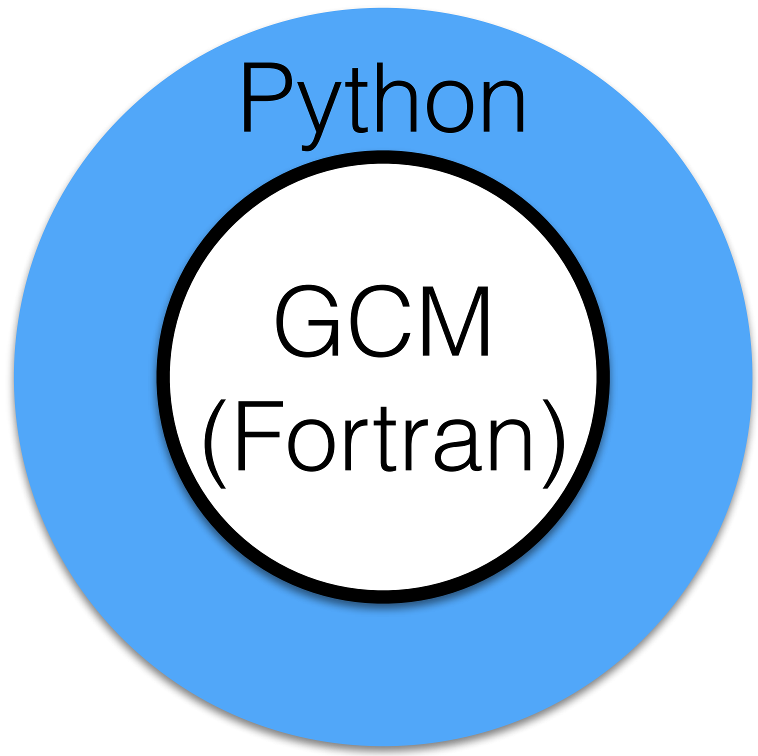
- **Me** (at ICTP this week)
- **Geoff** Vallis (here both weeks)
- **James Penn** (email support)
- **Penny Maher** and **Ruth Geen** (at the workshop next week)



Front (L-R): Greg Colyer, Martin Jucker, Penelope Maher, Ruth Geen, Marianne Pietschnig.
Back (L-R): Alexander Paterson, Stephen Thomson, Geoffrey Vallis, James Penn.

What is Isca ?

- Isca is a **framework** within which a **wide variety** of different model types can be configured
- At the heart of Isca is a **GCM** (based on GFDL's FMS)
- **GCM:**
    - **G**eneral **C**irculation **M**odel
    - **G**lobal **C**limate **M**odel

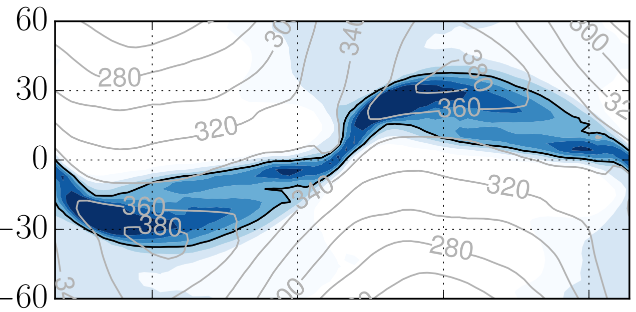


Complicated

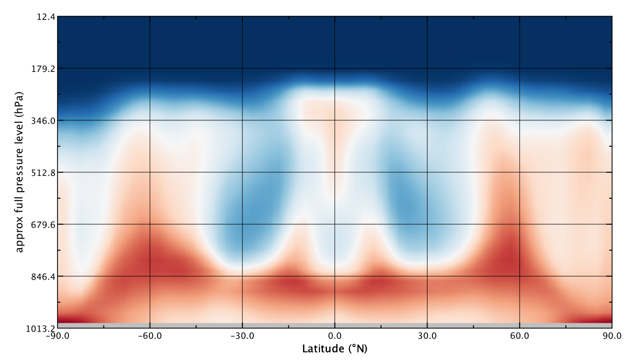
Simple

- **GCM part** is written in **Fortran** - configured and run using **Python**
- **The key** to Isca is that it can be **configured** to create models that are **simple**, and models that are more **complicated** - **a model 'hierarchy'**

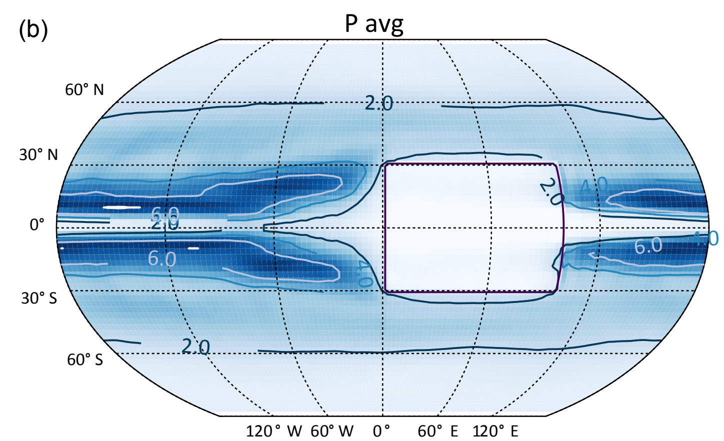
What science has been done with Isca ?



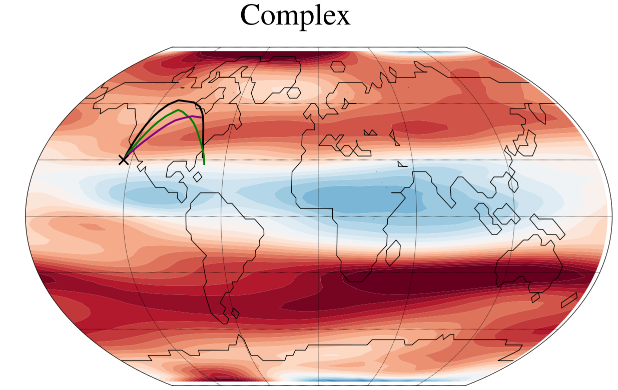
Precip in Aquaplanet - monsoon onset (Ruth Geen - talk next week)



Rel. Humidity in Held-

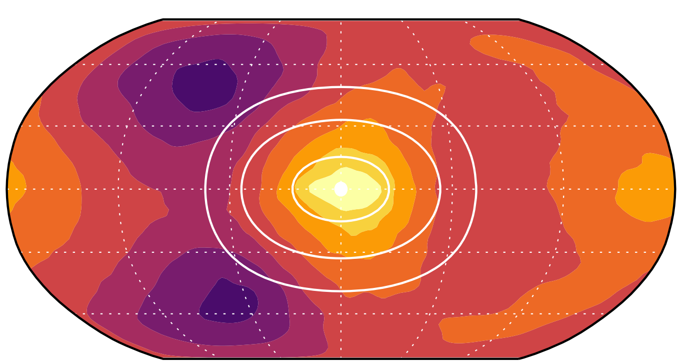


Precipitation response to



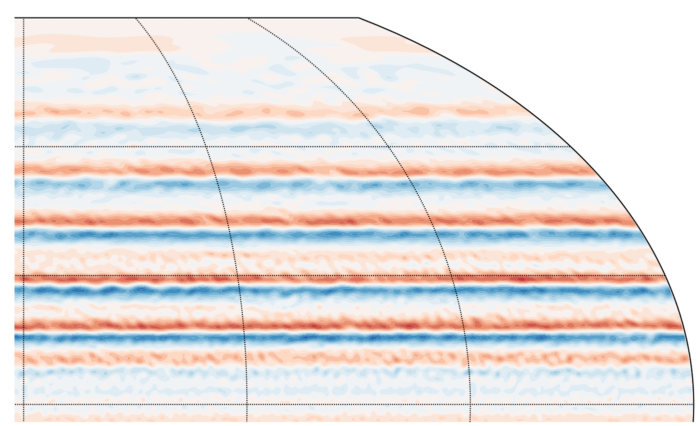
Atmospheric responses to SST anomalies in summer and winter (S.Thomson)

Isca is a good code for us to do interesting science here at ICTP

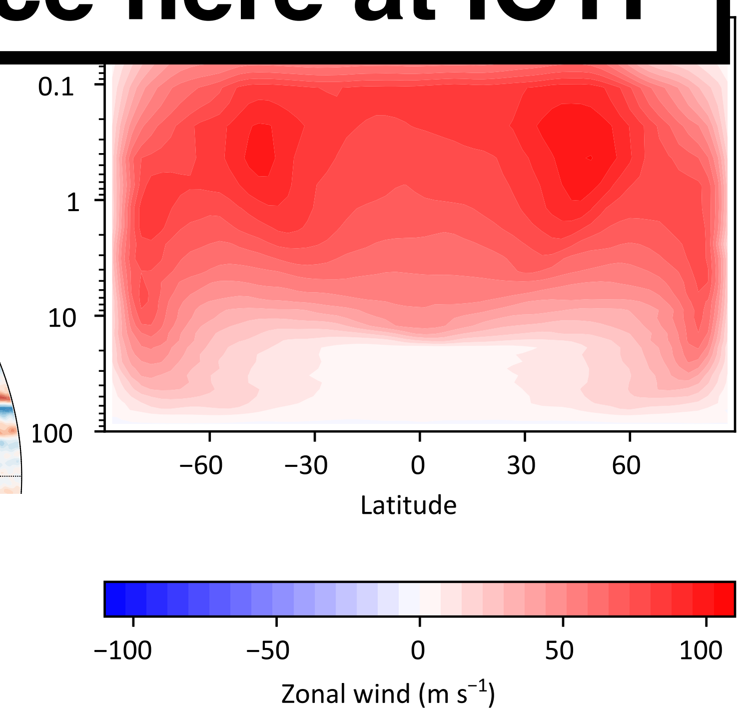


Tidally Locked

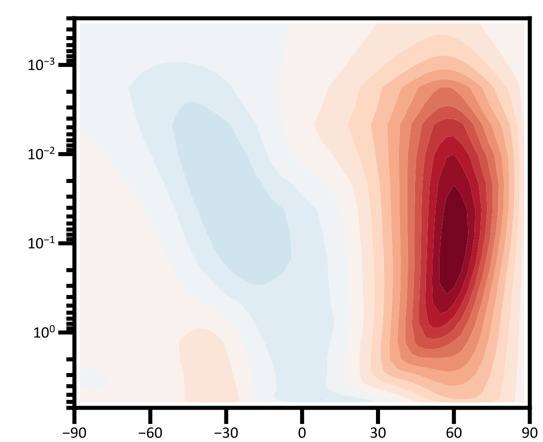
Hotspot position in Tidally-locked exoplanets (James Penn)



Relative Vorticity in Jupiter sim. S.Thomson



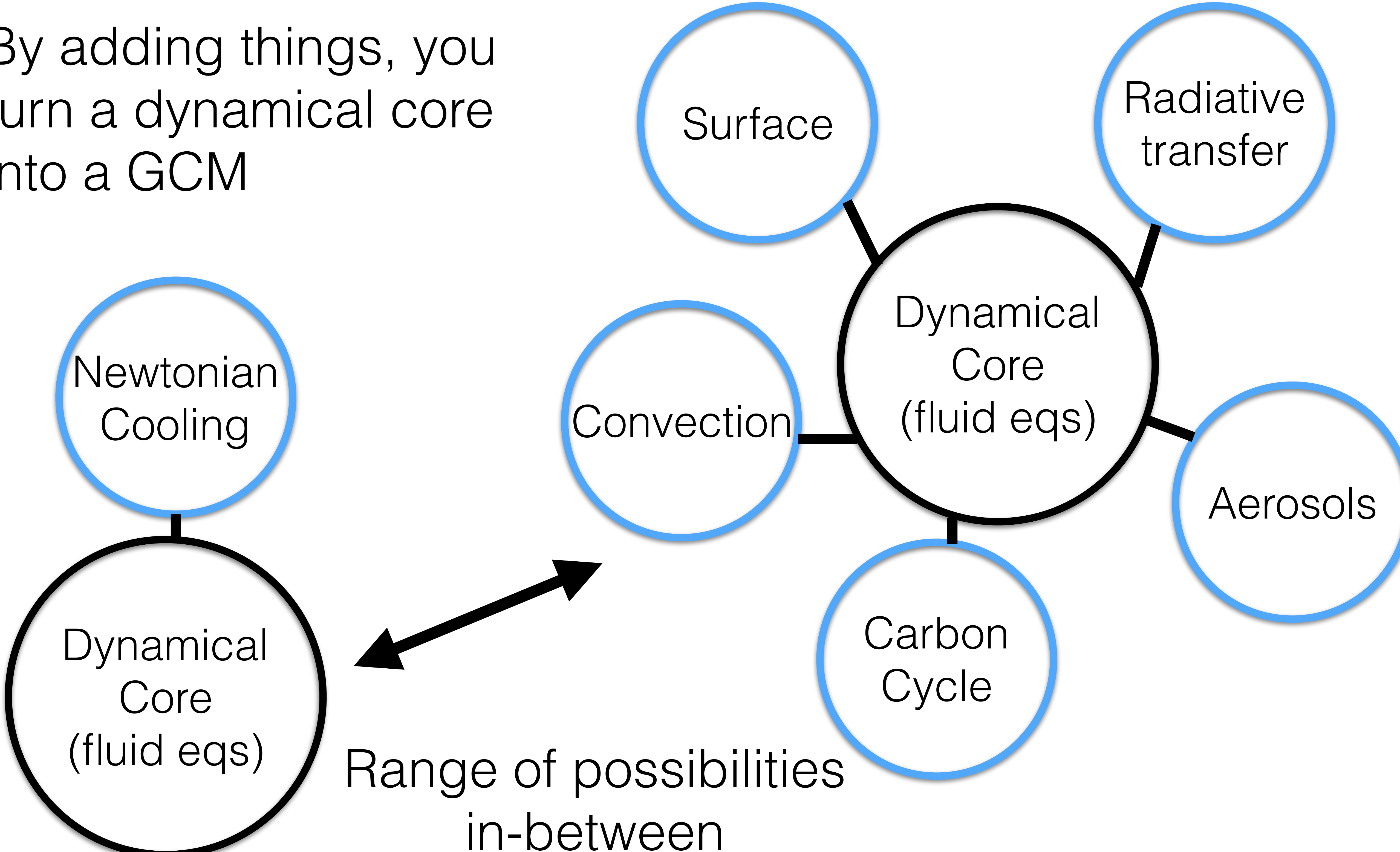
Superrotation in Venus-like atmospheres (Greg Colyer)



Dynamics of Mars' jet streams (S.Thomson)

What is a GCM?

By adding things, you turn a dynamical core into a GCM



Isca allows us to create a range of models between these two

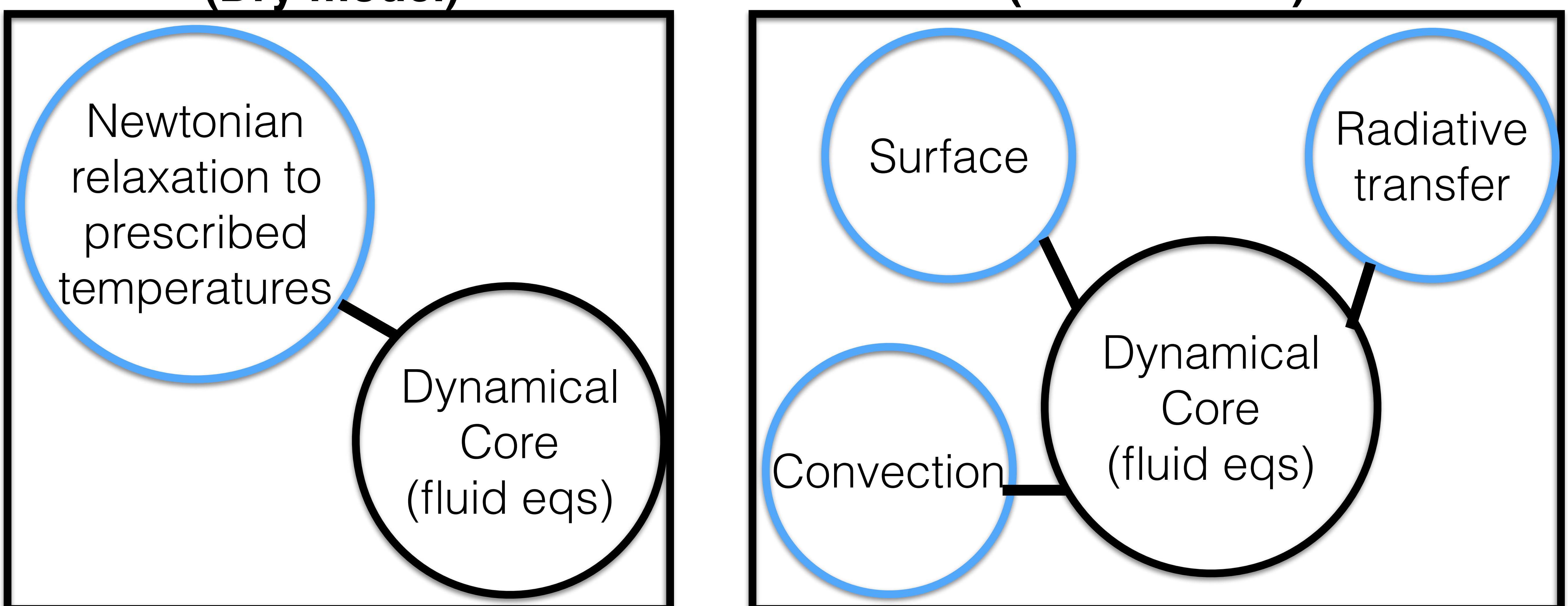
What is Isca ?

When creating a GCM with Isca, the first question to ask is…

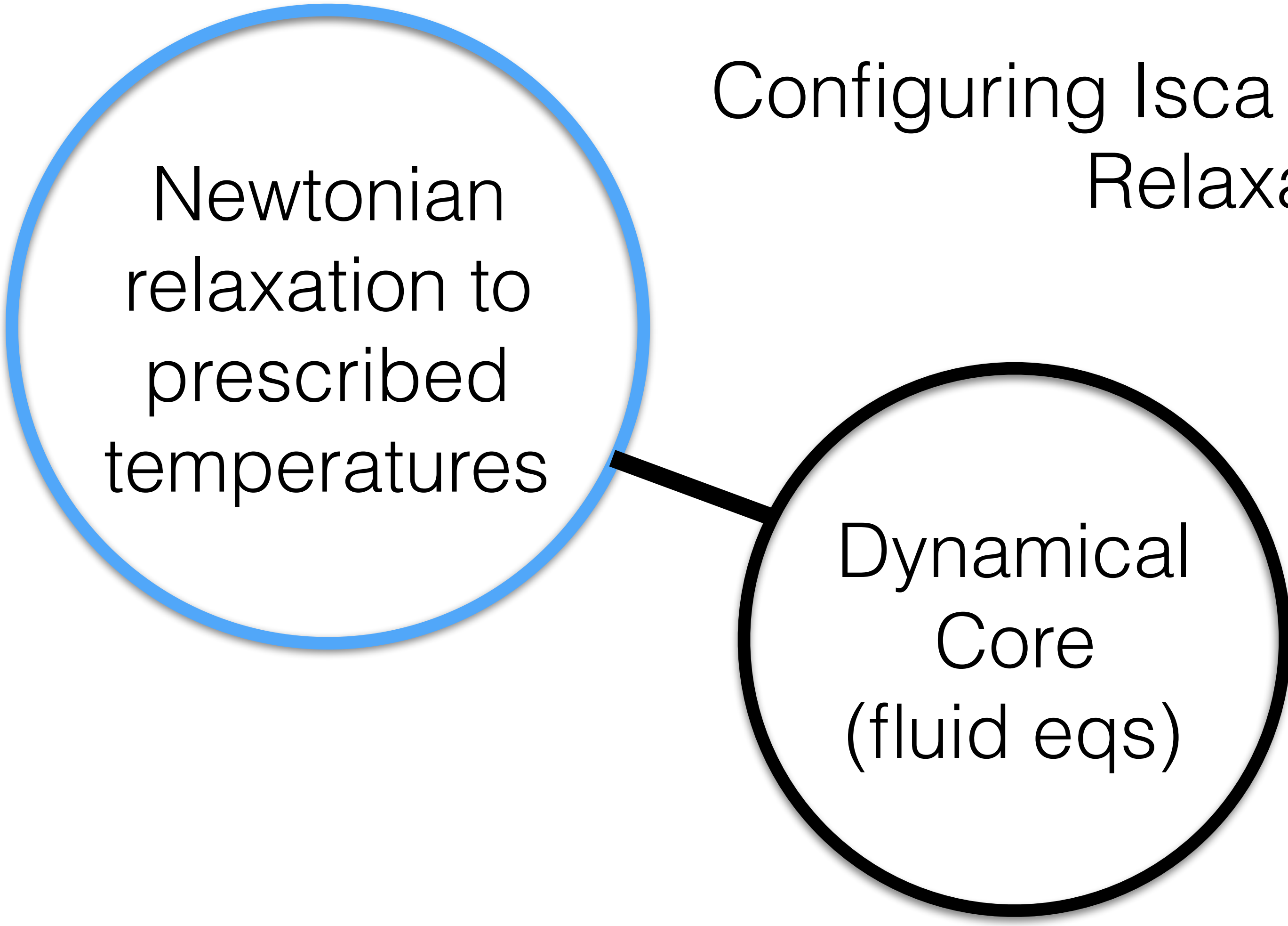
What kind of additional physics will we add to our dynamical core?

1. Newtonian Relaxation (Dry model)

2. 'Full'-physics (Moist model)



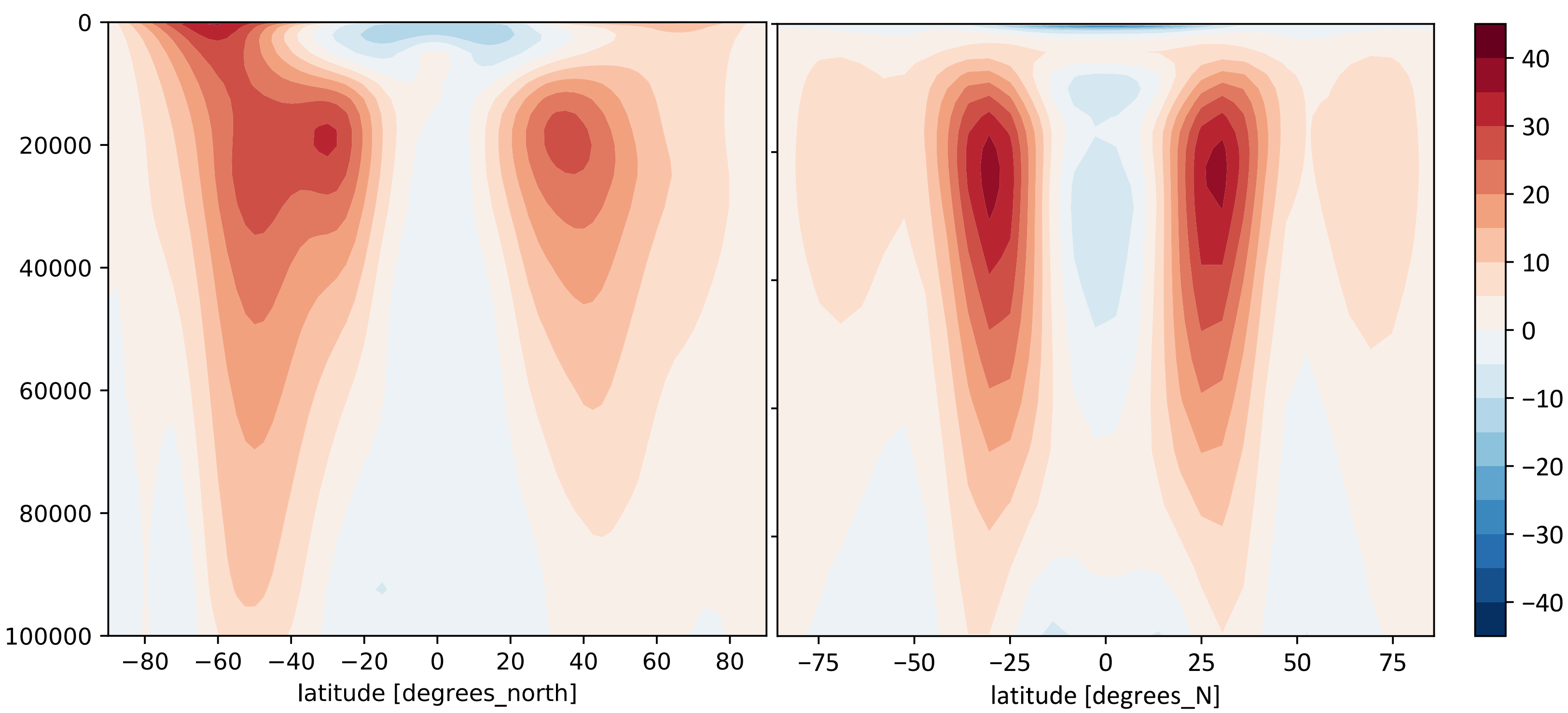
Configuring Isca with Newtonian Relaxation



$$\frac{\partial T}{\partial t} = \cdots - k_T(\phi,\sigma)\left[T - T_{eq}(\phi,p)\right]$$

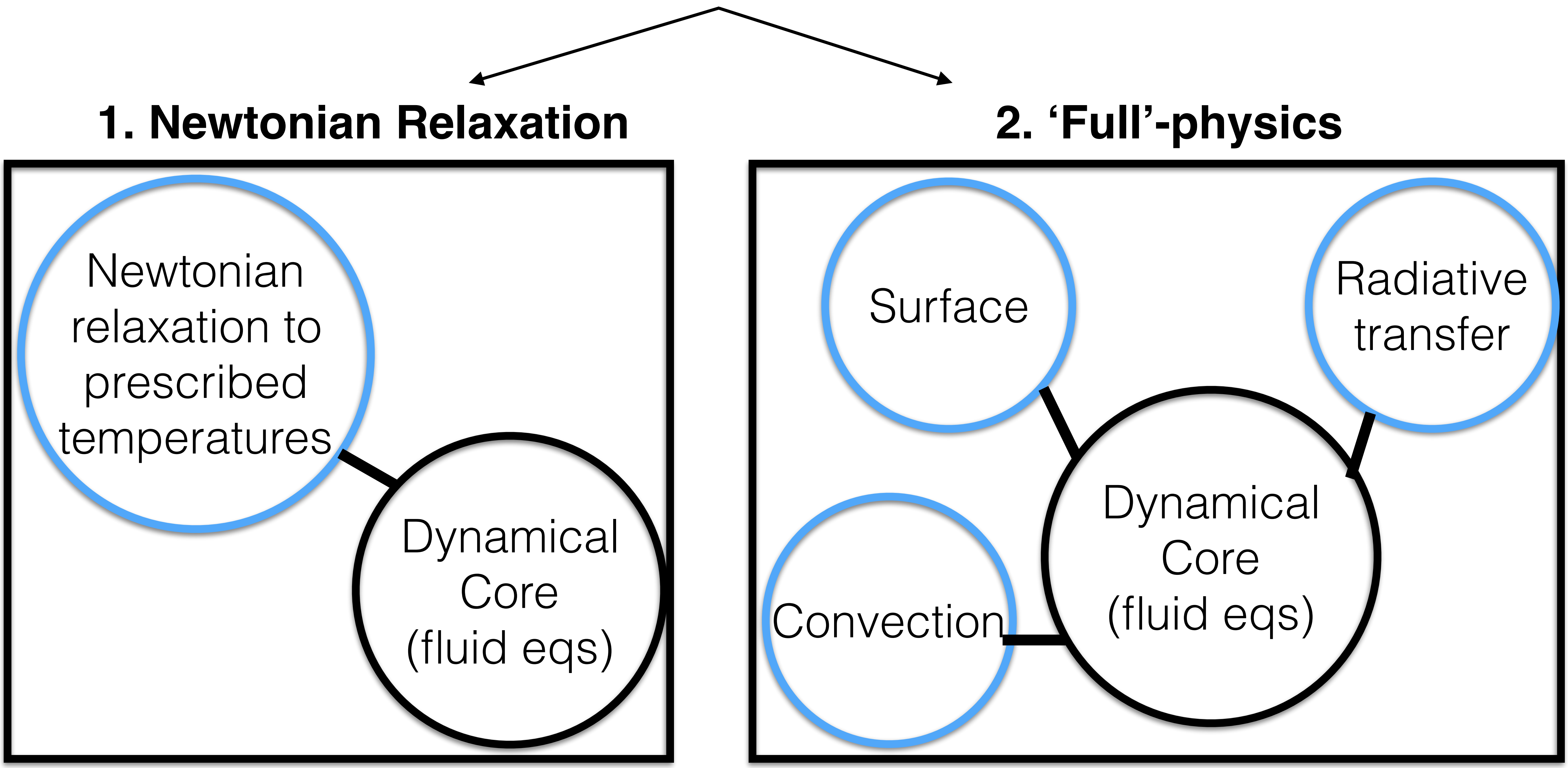
- This is (arguably) the simplest global model of the atmosphere
- ‘Held-Suarez’ model of 1994 is setup in this way
- Inputs are the equilibrium temperatures (T_eq) and the associated timescales (k_T)
- Sometimes referred to as a ‘**dry**’ model, as it doesn’t directly include moisture (is included implicitly in Held-Suarez)

JRA-55 Ubar   Held-Suarez Ubar

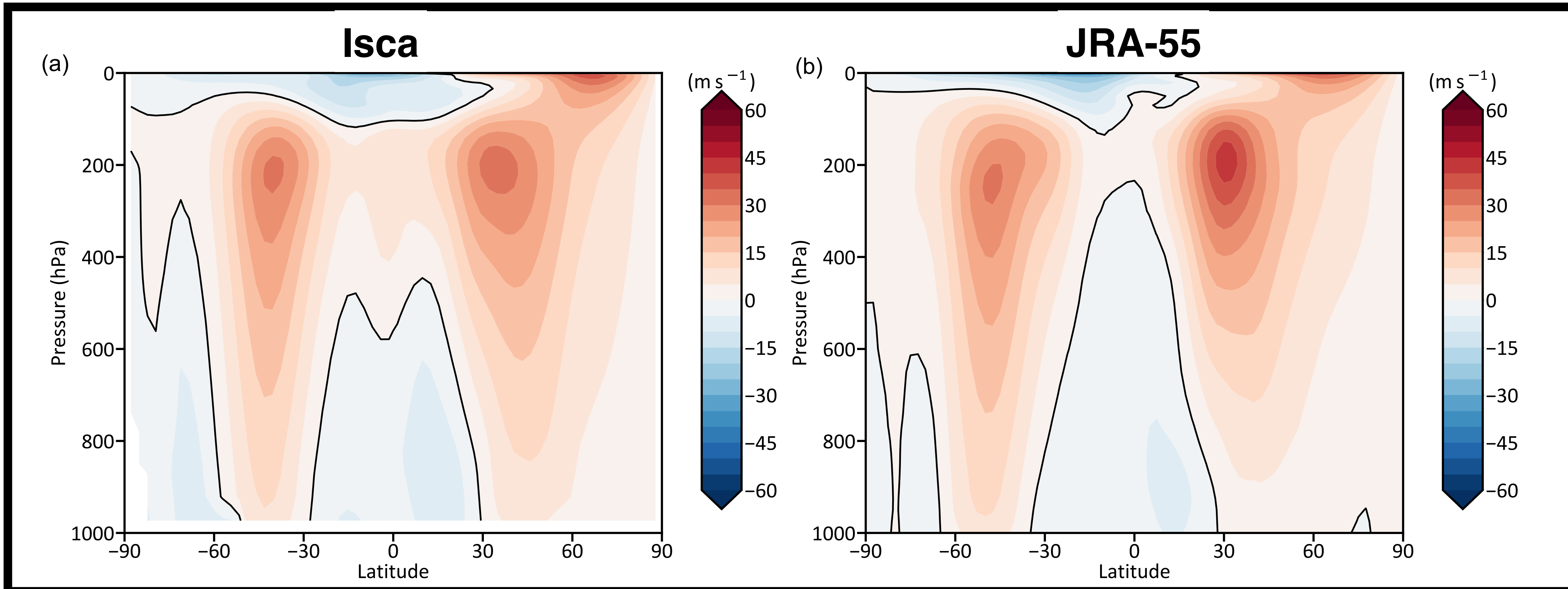


What is Isca ?

What kind of additional physics will we add to our dynamical core?



Configuring Isca with ‘full-physics’



In its most complex form, it can get pretty close to the real atmosphere (Thomson & Vallis, 2018a)

Convectio

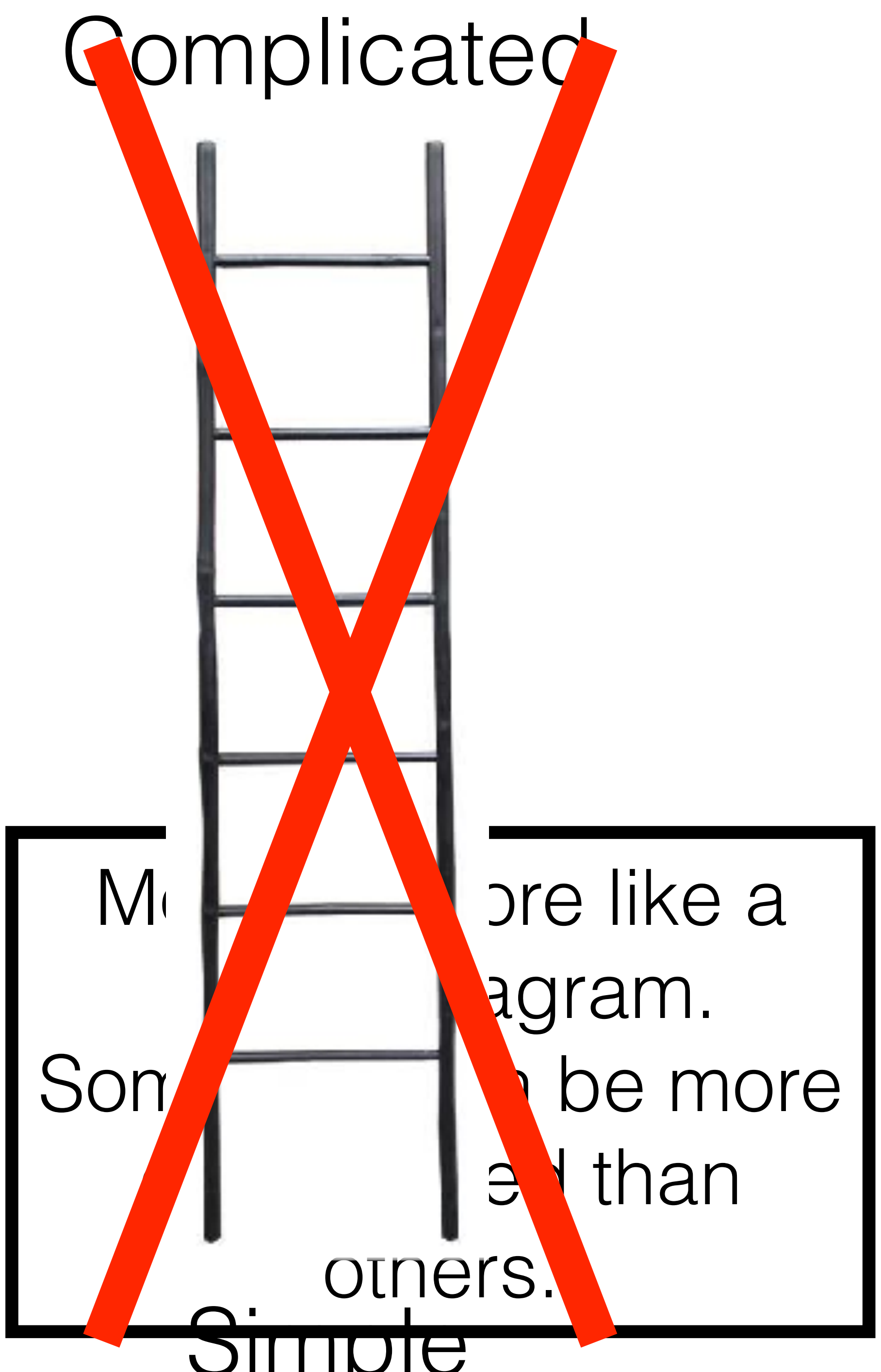
ns for each of

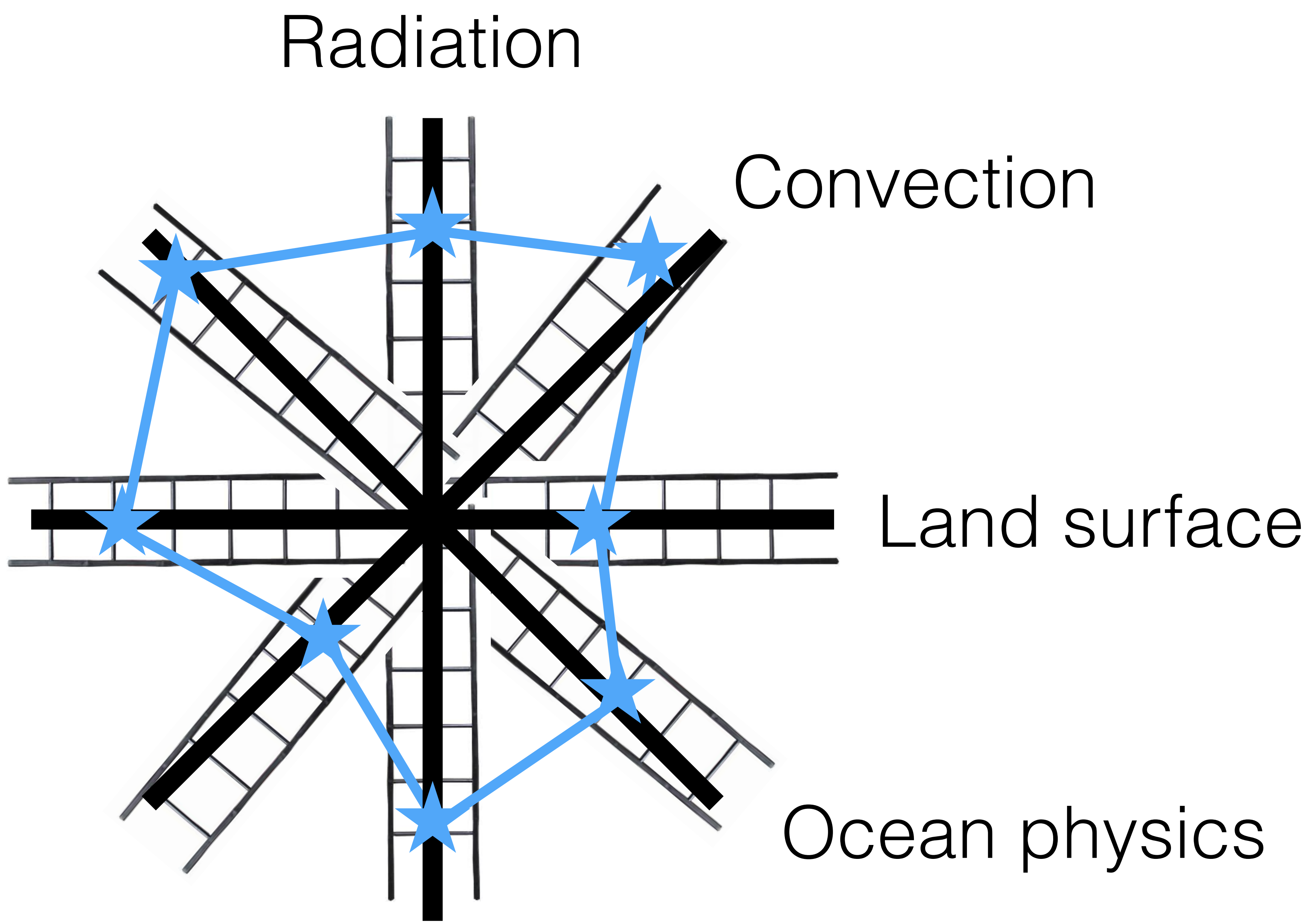
complex convection

- There is a hierarchy of complexity within each of these processes

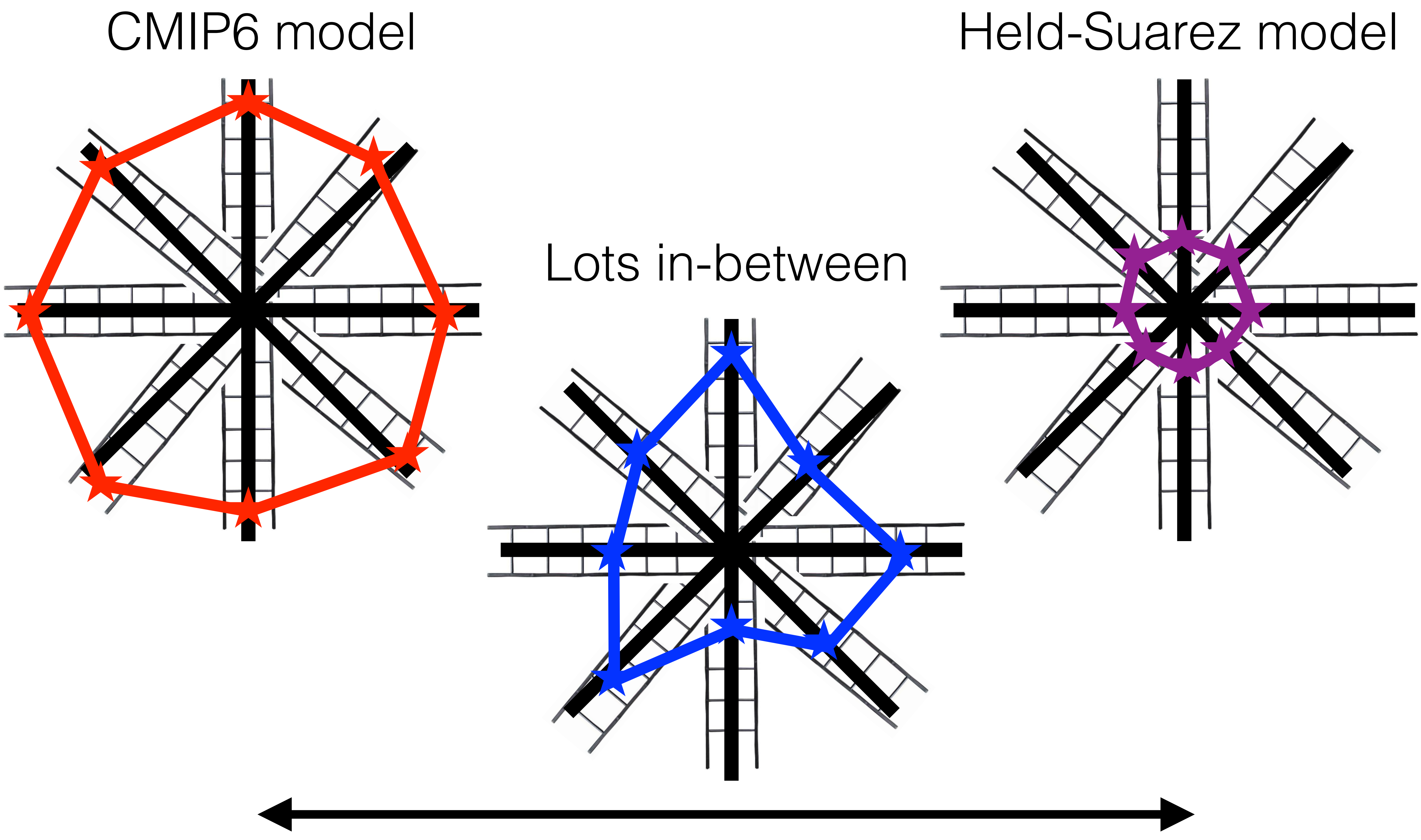
What is Isca?

- When creating a **GCM** with lots of choices about the **complexity** of each process, deciding whether the whole GCM is ‘simple’ or ‘complicated’ is **ambiguous**



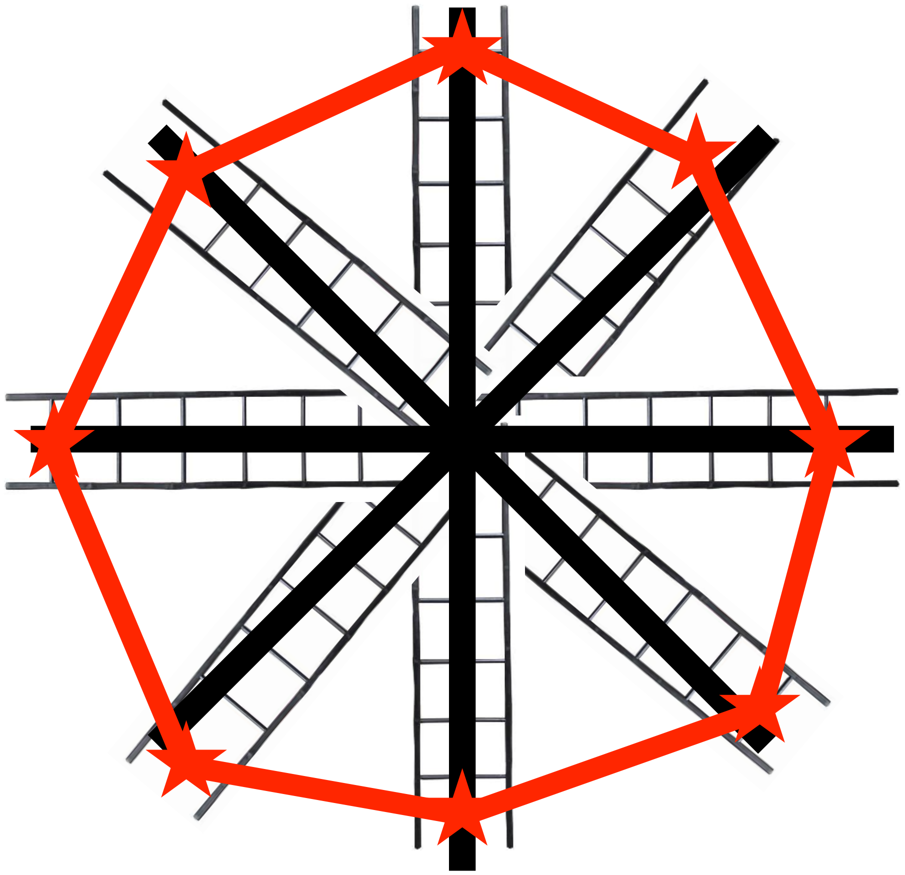


What is Isca?

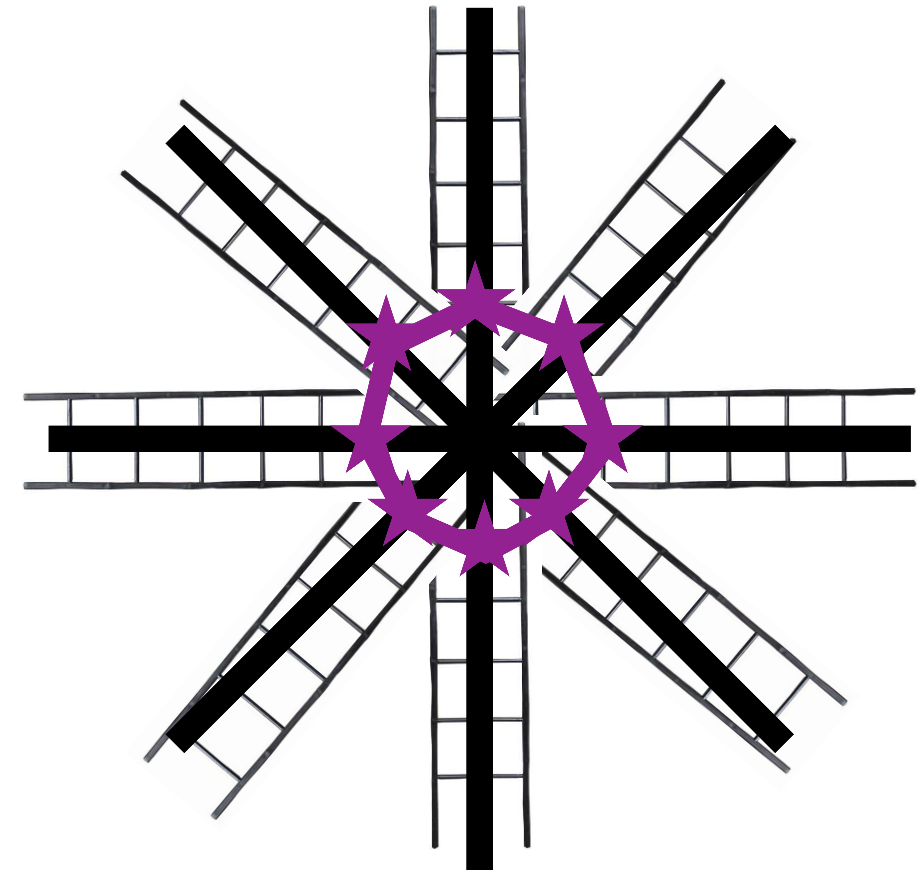


What is Isca?

CMIP6 model



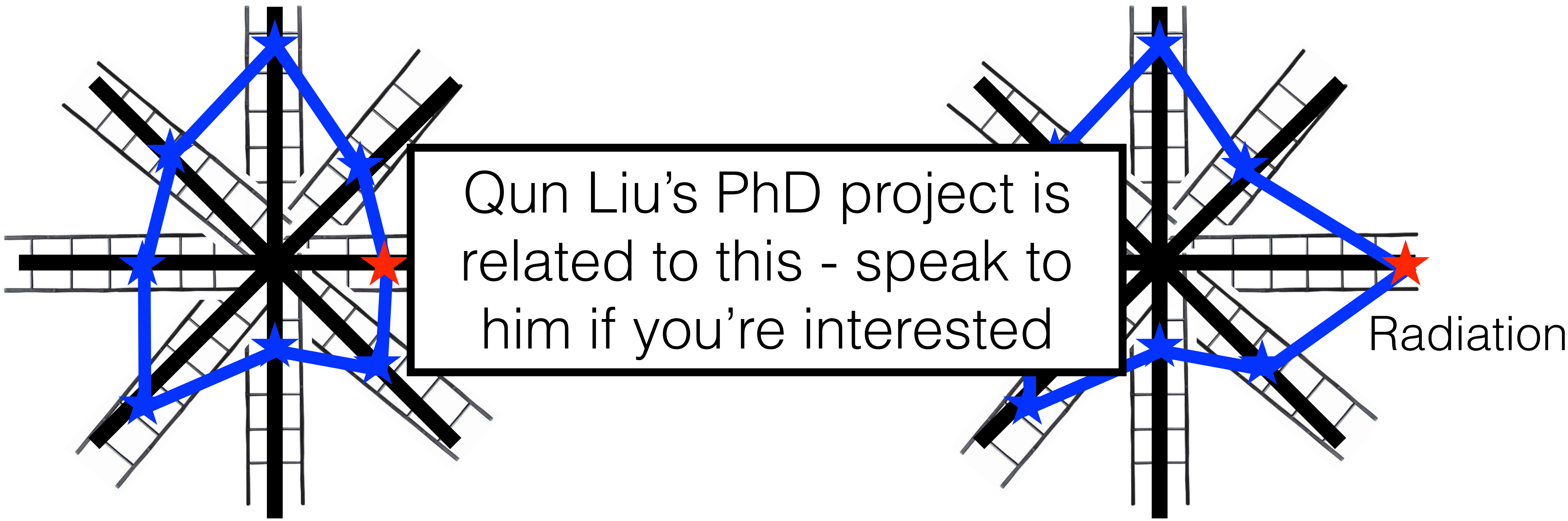
Held-Suarez model



- The **advantage** of **Isca** is that it has **many options** for all of the different model components
- This means you can compare results with different schemes
- This can be useful when considering science questions

An example…

- Hypothesis - ‘the increase in long-wave optical depth due to increased **water vapour** is important for understand surface temperature responses to **climate change**’



Model with **simple** radiation scheme that **doesn’t** include **water-vapour feedback**

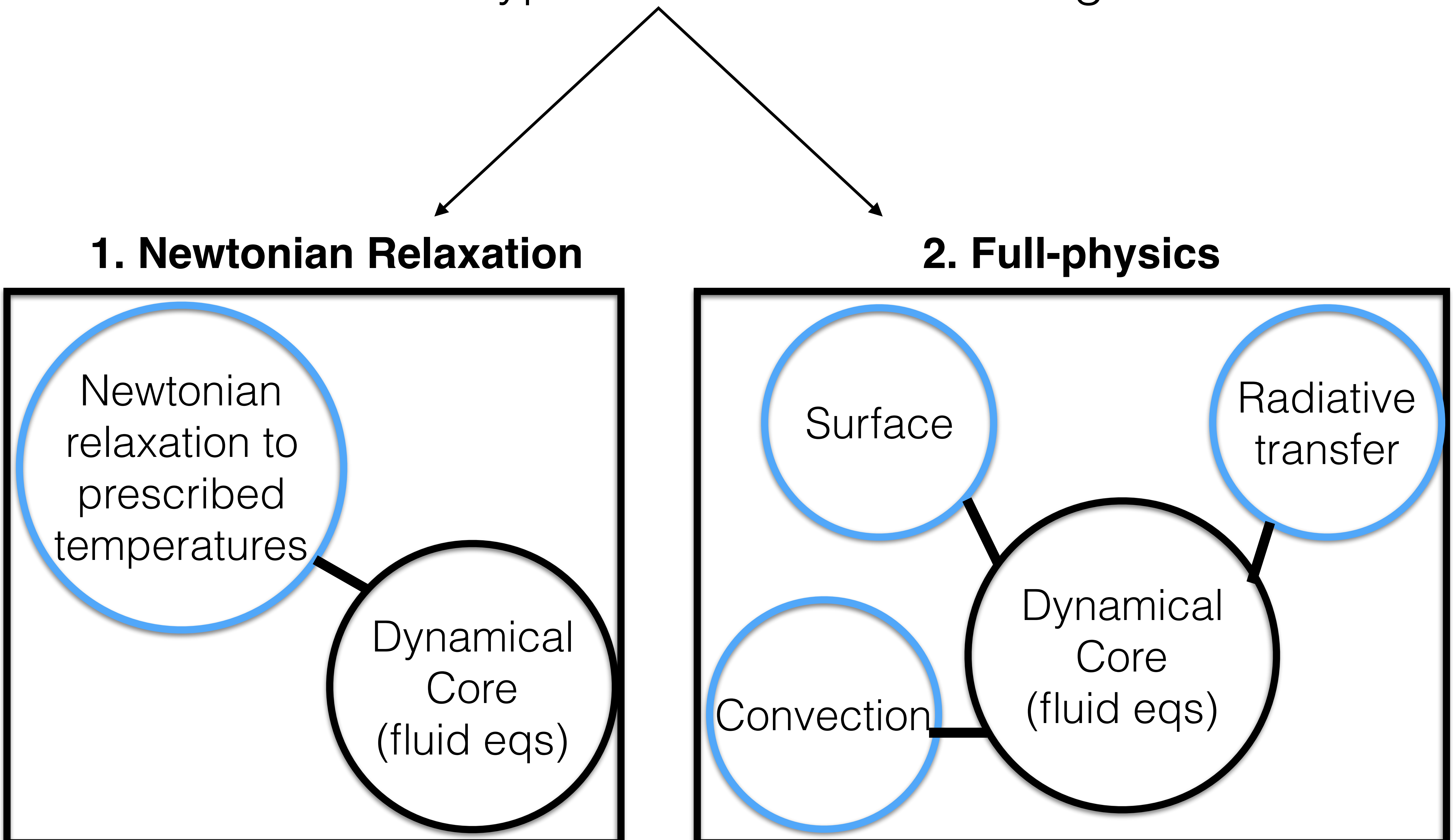
Model with **complex** radiation scheme that **does** include **water-vapour feedback**

What kind of model is Isca? - Summary

- Isca is **framework** containing a GCM, which has many options for its different components
- This means it can be used to run simple and complex models, as the user chooses
  - Although it's difficult to measure complexity in absolute terms
- **Two big questions:**
  - What options are there for each of the components?
  - How do I configure the model to use those different options?

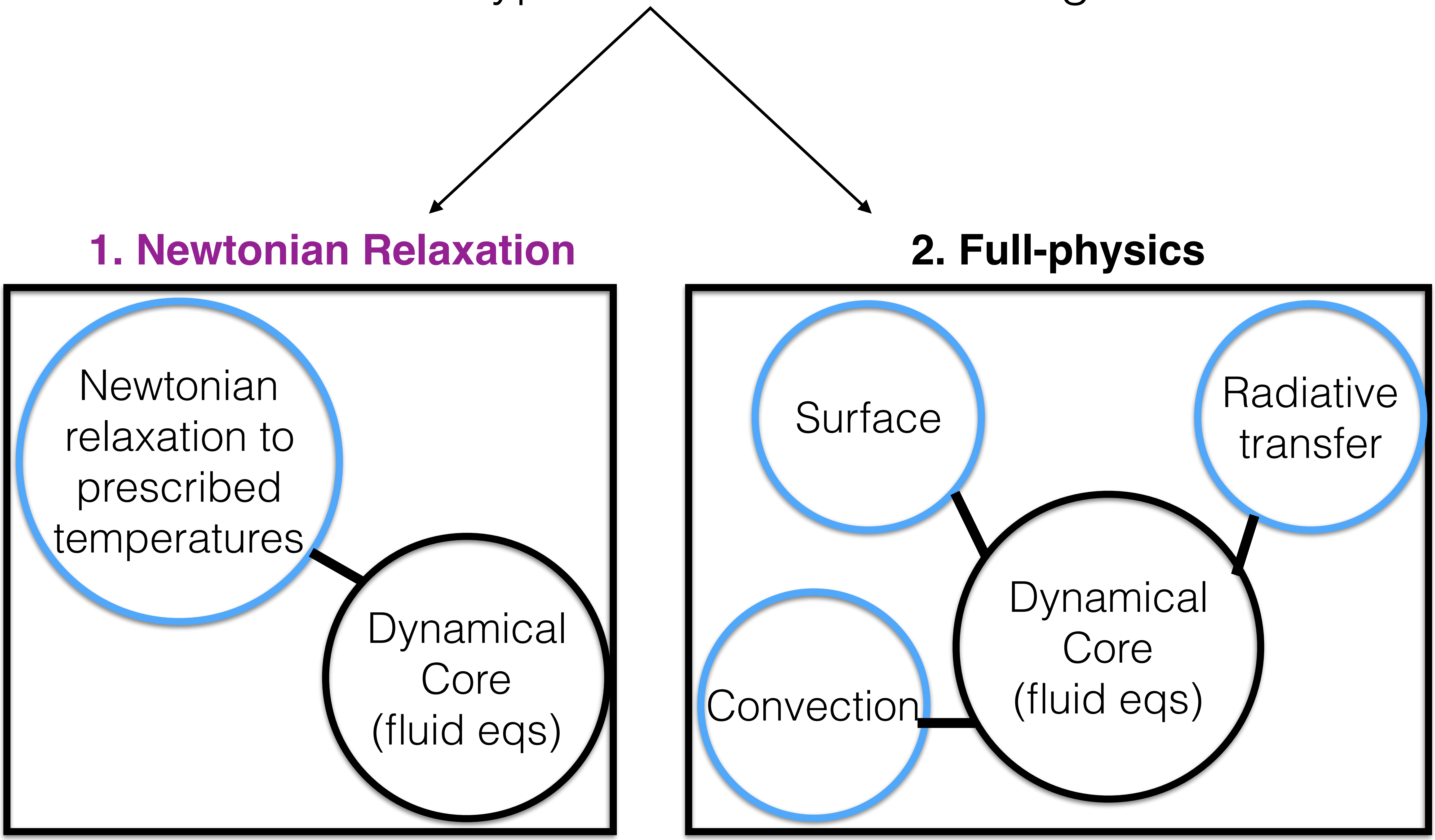
What options are there for the different components?

Which type of model are we using?



What options are there for the different components?

Which type of model are we using?



What options are there for the different components?

Newtonian Relaxation of temperature

Complicated

Radiative-convective equilibrium temperatures with seasons

(If you want references for all of these, they are in the Isca paper - *Vallis et al 2018*)

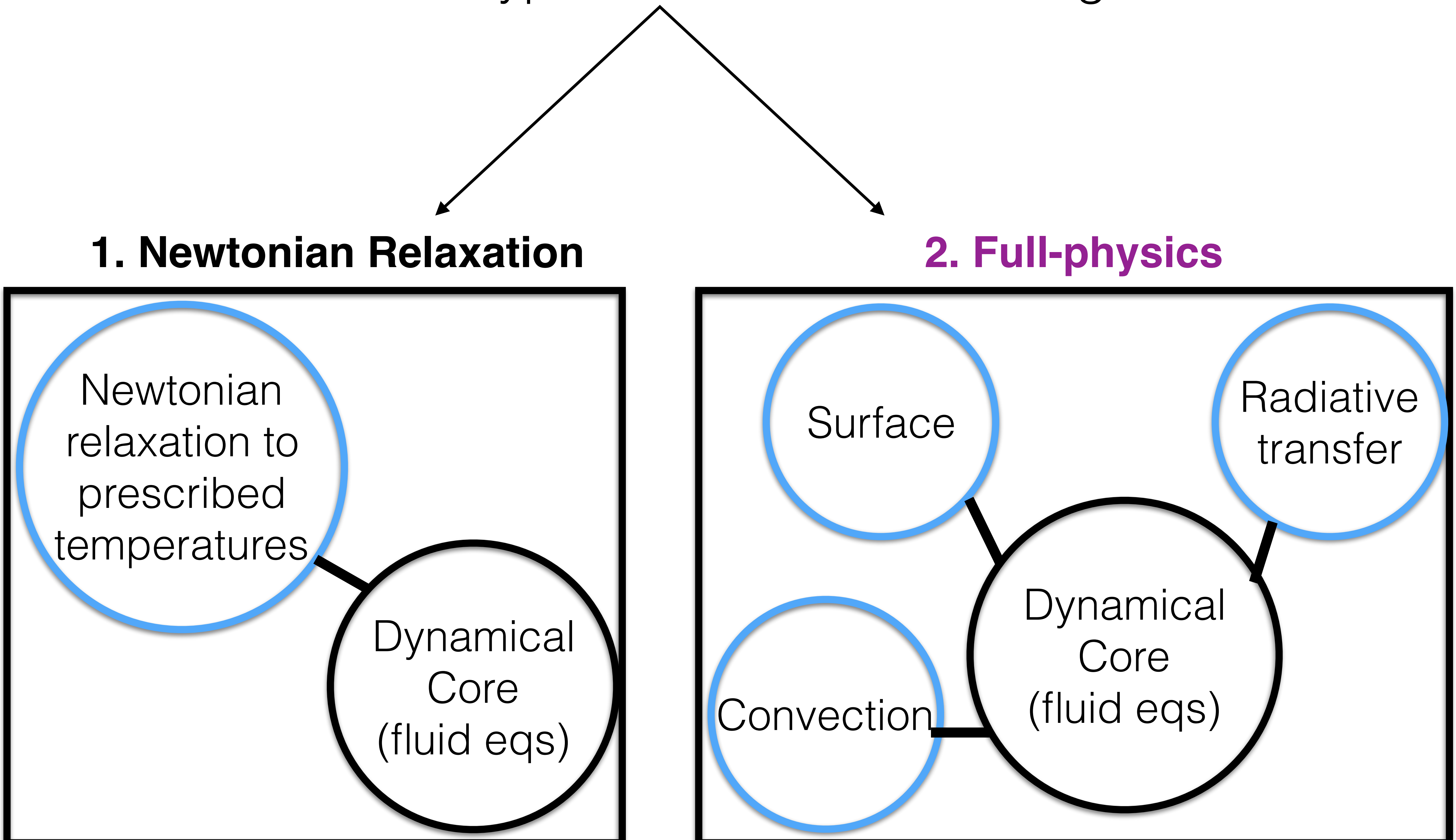
Held Suarez

Simple

Relevant Fortran file - hs_forcing.f90

What options are there for the different components?

Which type of model are we using?



What options are there for the different components?

Radiative transfer

Complicated

Simple

Socrates (ask me…!)

RRTM

Geen

Byrne & O'Gorman

(Schneider & Liu)

Frierson

Relevant Fortran files:

'idealized_moist_phys.F90'

'two_stream_gray_rad.F90'

'rrtm_radiation.f90'

What options are there for the different components?

Orbital Parameters

Complicated

Obliquity, eccentricity and diurnal cycle

Relevant Fortran files:
‘astronomy.f90’

Zero obliquity, circular orbit with no diurnal cycle

Simple

What options are there for the different components?

Convection scheme

Complicated

Relaxed Arakawa-Schubert

‘Full’ Betts-Miller

Simple Betts-Miller

Dry Convection

Simple

Relevant Fortran files:

‘idealized_moist_phys.F90’

‘ras.f90’

‘betts_miller.f90’

‘qe_moist_convection.F90’

‘dry_convection.f90’

What options are there for the different components?

Ocean

Complicated

Simple

Full dynamical ocean (don’t have this)

Mixed-layer ocean with empirical q-fluxes

Mixed-layer ocean with analytic q-fluxes

Mixed-layer ocean with no horizontal heat transfer

Relevant Fortran files:
‘mixed_layer.f90’

What options are there for the different components?

Land surface

Complicated

Bucket hydrology (finite evaporation from land)

Land-sea contrast (contrast in albedo, heat-capacity, surface roughness)

No land (aquaplanet)

Simple

Relevant Fortran files: 'mixed_layer.f90'

What options are there for the different components?

Primitive equation dynamical core

Complicated

Full 3D dynamics with variable horizontal and vertical resolution

Zonally-symmetric dynamics (no eddies)

Relevant Fortran files:
'spectral_dynamics.f90'

Simple

What options are there for the different components?

Clouds…

Complicated

Simple

There are no clouds in Isca,
because we never have any clouds in the UK…

How can I find these different options within the fortran?

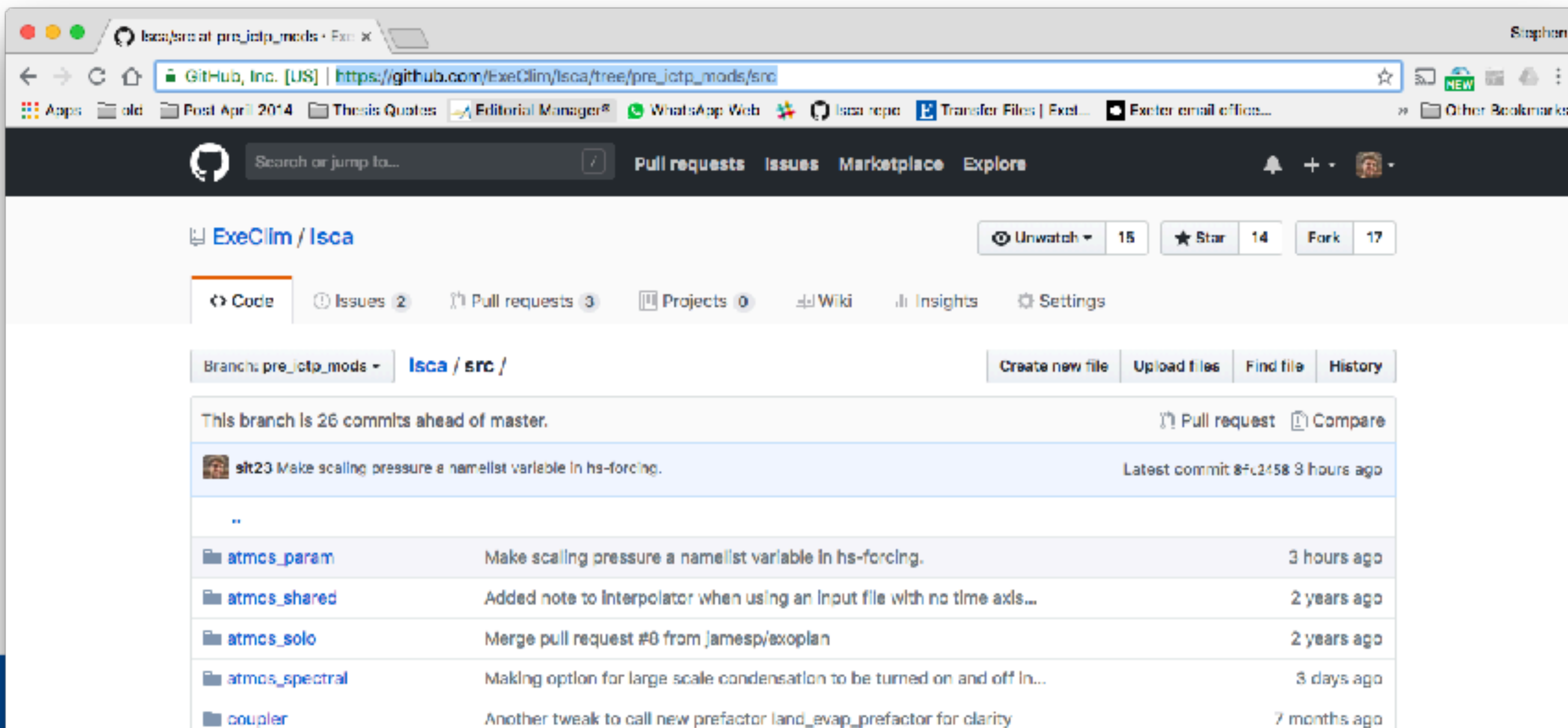
Let's explore Isca on GitHub (what is GitHub?)

Can you find some of the options discussed above?

https://github.com/ExeClim/Isca/tree/pre_ictp_mods

https://bit.ly/2lsYojA

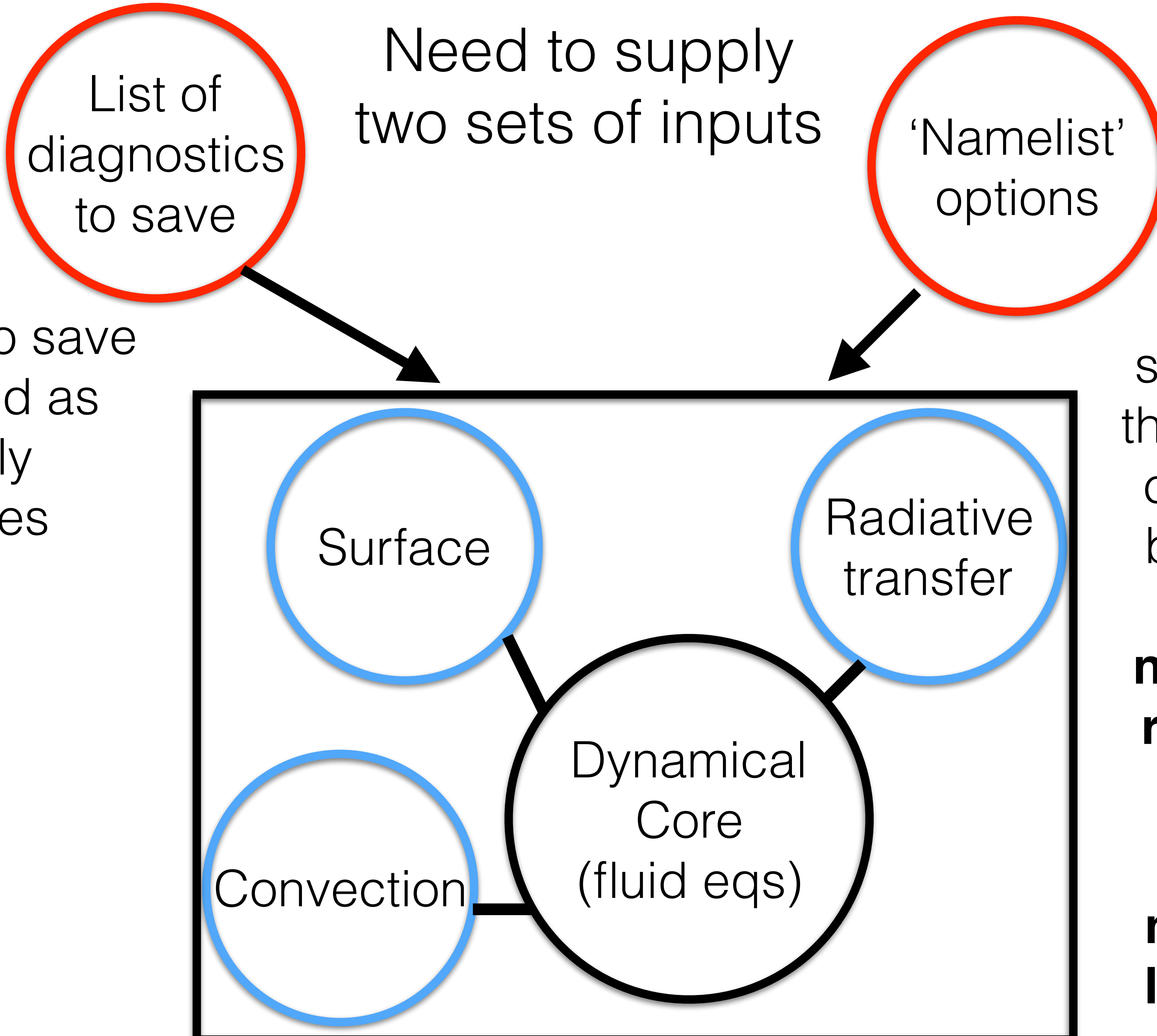
'FIND FILE' -> 'idealized_moist_phys.F90'



Part 2: How do I run and configure the model?

Need to supply two sets of inputs

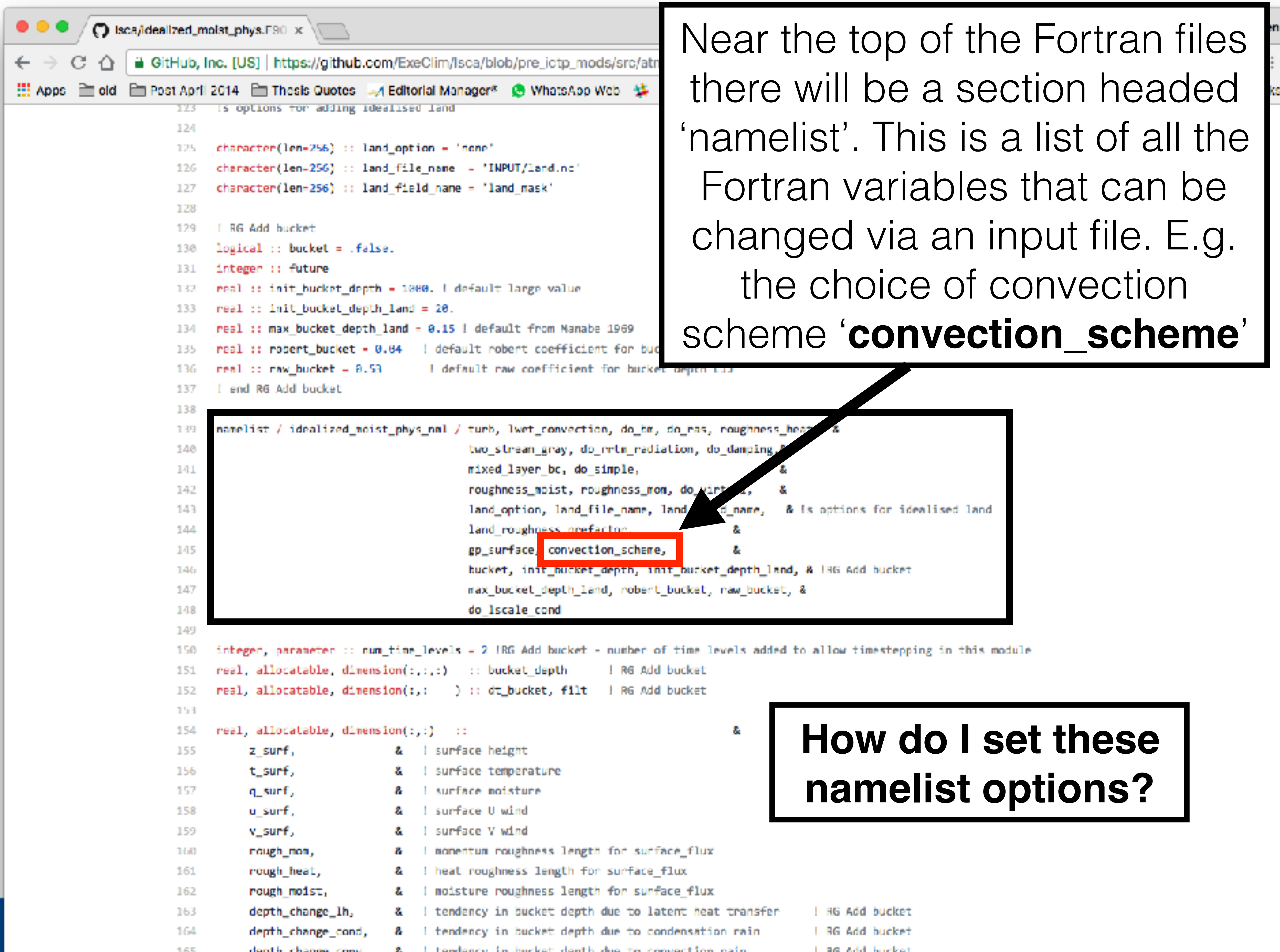
e.g. want to save zonal-wind as monthly averages



A list of options supplied to the model to change its behaviour, **without needing to recompile**

What do namelists look like?

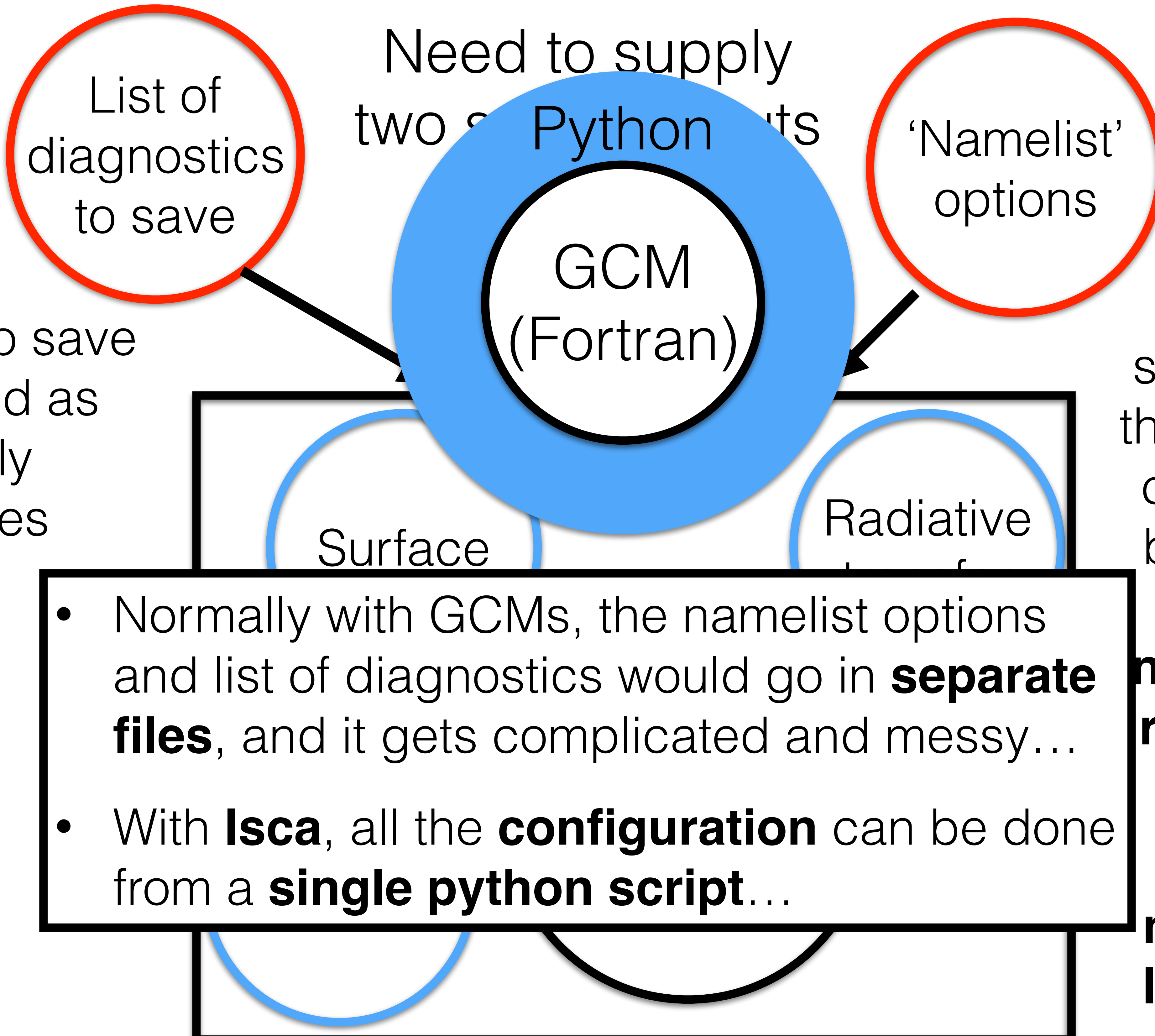
What do namelists look like in the Fortran?



Near the top of the Fortran files there will be a section headed 'namelist'. This is a list of all the Fortran variables that can be changed via an input file. E.g. the choice of convection scheme '**convection_scheme**'

How do I set these namelist options?

Part 2: How do I run and configure the model?



e.g. want to save zonal-wind as monthly averages

A list of options supplied to the model to change its behaviour, **without needing to recompile**

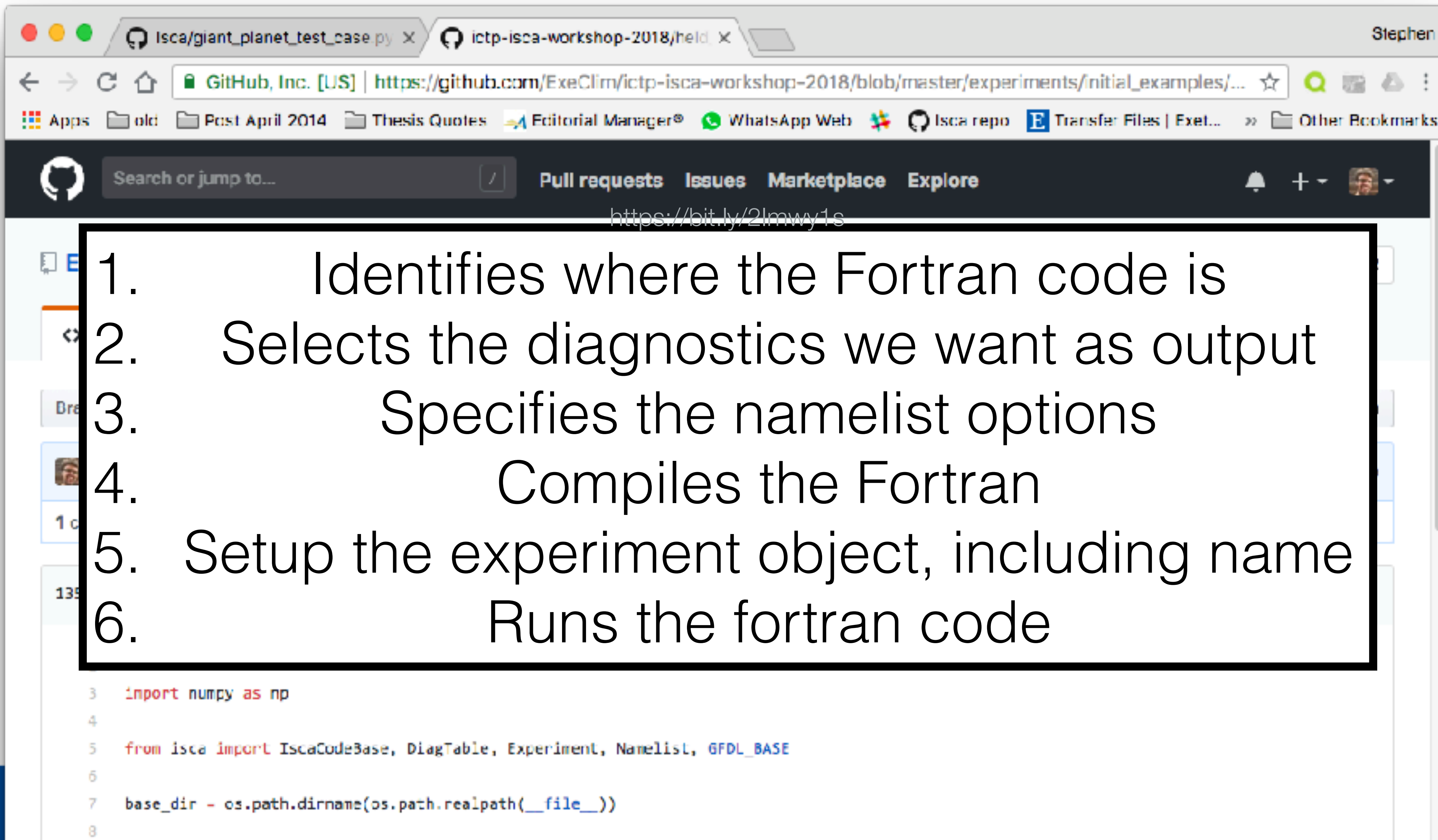
- Normally with GCMs, the namelist options and list of diagnostics would go in **separate files**, and it gets complicated and messy…
- With **Isca**, all the **configuration** can be done from a **single python script**…

What do namelists look like?

Configuring Isca using Python

https://github.com/ExeClim/ictp-isca-workshop-2018/blob/master/experiments/initial_examples/held_suarez.py

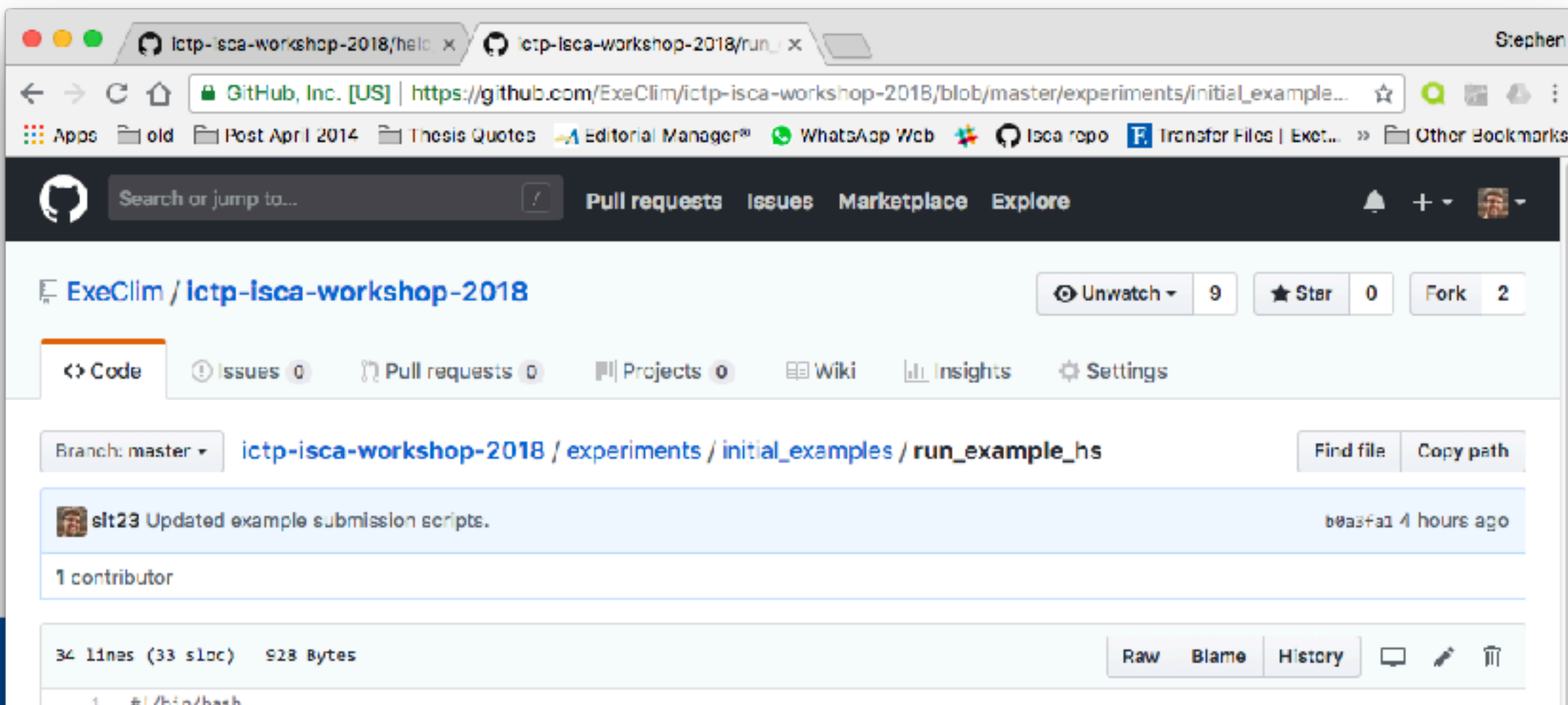
https://bit.ly/2Imwy1s



1. Identifies where the Fortran code is
2. Selects the diagnostics we want as output
3. Specifies the namelist options
4. Compiles the Fortran
5. Setup the experiment object, including name
6. Runs the fortran code

How do I run Isca at ICTP?

- We will be running all our experiments on ICTP's supercomputer '**Argo**'
- We have ~150 cores reserved between now and Saturday evening (30th June)
- To run an experiment on Argo **we can't just run the python script**, we have to submit it to the queuing system using a **submission script (e.g. run_example_hs)**



Let's get onto Argo

- **At this point, please sit in your project groups**
- 9 groups, each of which have 1 account on Argo
  - To access Argo, open a terminal on your machine (easy on linux or mac, if you're using **Windows** you'll need to install **Putty** (https://www.putty.org/) or similar)
  - (From now on, all commands you should execute will be in **bold**)
  - I will now switch to a PDF document that I will scroll through.
    - This PDF is part of the ictp-isca-workshop-2018 repo:
    - https://github.com/ExeClim/ictp-isca-workshop-2018/blob/master/experiments/getting_onto_argo.pdf
    - An alternative guide, written by an Exeter student (Neil Lewis) is also available for reference:
    - https://github.com/ExeClim/ictp-isca-workshop-2018/blob/master/experiments/isca_help_ictp.pdf

Part 3: Introducing the projects

- At this point, I'd like to go through the individual projects, and discuss the example experiments we have put together for each

- **Good** for you to listen to all of the project descriptions, as then you'll have an idea of who to ask if you want to e.g. change the rotation rate, or add land, etc.

- We have put together a short list of papers related to each project - might be a good idea to start reading some of them:

    - https://github.com/ExeClim/ictp-isca-workshop-2018/blob/master/experiments/ictp_project_reading.pdf

Introducing the projects

- **Project 1: Climate Sensitivity and climate variability**

- Goal - How climate sensitivity and natural variability are related, and how robust this is across different model formulations.

- Experiments to do:

  - Run two or more versions of the models with different radiation or convection schemes

  - Compare their natural variability and their response to increased CO_2

- Analysis to do:

  - Climate sensitivity seasonal variability, jet latitudes, tropopause height, etc

- Example experiments provided:

  - Aquaplanet with grey radiation, shallow mixed layer and CO_2 350, 700 and 1400ppmv

  - Aquaplanet with RRTM radiation, shallow mixed layer with CO_2 350, 700 and 1400ppmv

Introducing the projects

- **Project 2: Hadley Cell, Moisture and Eddies**

- Goal - Understand how the Hadley Cell is affected by moisture and eddies.

- Experiments to do:

    - Simple moist model with fully 3D dynamics and compare with zonally-symmetric dynamics (no eddies)

    - The same but with a 'dry' model

- Analysis to do:

    - Changes in strength and width of the Hadley Cell with and without moisture and with and without eddies.

- Example experiments provided:

    - Aquaplanet with grey radiation, shallow mixed layer with 3D and zonally-symmetric dynamics

    - Held-Suarez model with 3D and zonally-symmetric dynamics

Introducing the projects

- **Project 3: Storm tracks, continents and reversed rotation**
- Goal - Understand how the location of the storm tracks depends on the location of continents, and how they would change if rotation was reversed.
- Experiments to do:
  - Moist model with full radiation scheme and realistic continents
  - Reverse the rotation and run to equilibrium
- Analysis to do:
  - Storm track diagnostics, jet position
- Example experiments provided:
  - Earth-like planet with continents and topography, with RRTM radiation, and normal and reversed rotation.

Introducing the projects

- **Project 4: Seasonal cycle, hysteresis and mixed-layer depth**

- Goal - Understand how seasonal lags are affected by continents, mixed-layer depth, length of season.

- Experiments to do:

  - Configure the moist model with two different arrangements of idealized continents and mixed layer depths

- Analysis to do:

  - Seasonal amplitude, lag with respect to insolation

- Example experiments provided:

  - Aquaplanet with RRTM radiation and a seasonal cycle, with mixed-layer depths of 20 metres and 5 meters.

Introducing the projects

- **Project 5: Oceanic heat transport effects on atmospheric circulation**

- Goal - Understand if and how the atmospheric circulation is affected by ocean heat transport (Q-fluxes), with and without continents, with and without seasons.

- Experiments to do:

    - Lots of different ones…

    - Easiest thing - look at the effect of ocean heat transport on an aquaplanet, change the spatial form, amplitudes, etc.

- Analysis to do:

    - Atmospheric heat transport vs oceanic heat transport

    - Hadley cell strength, ITCZ position, etc

- Example experiments provided:

    - Aquaplanet with RRTM radiation with perpetual equinox radiation, run with and without a q-flux, which is read from an input file.

    - Python script provided to create q-flux input files from analytic form.

Introducing the projects

- **Project 6: Obliquity changes**

- Goal - Understand how the climate would change at higher or lower obliquity, varying from small (realistic) changes to large idealized changes.

- Experiments to do:

    - Control aquaplanet experiment at Earth-like obliquity, then at higher and lower obliquities

- Analysis to do:

    - Temperature distribution, heat transport, Hadley Cell strength, etc

- Example experiments provided:

    - Aquaplanet with RRTM radiation with seasonal cycle, shallow mixed-layer depth, and two obliquity values, Earth and double Earth.

Introducing the projects

- **Project 7: Ice-albedo feedback and snowball Earth**

- Goal - Explore the effects of ice-albedo feedback on the climate of the model, with and without continents and seasons. ***Note,* this experiment will require the user to make changes in the Fortran code.**

- Experiments to do:
  - Implement a temperature dependent surface albedo in the model (mixed_layer.f90)
  - Obtain stable climate, then change the solar constant / CO2 levels to see what you need to push it for a snowball Earth.

- Analysis to do:
  - Surface temperature as a function of albedo, etc.

- Example experiments provided:
  - Aquaplanet with RRTM radiation with perpetual equinox, without ice-albedo feedback

Introducing the projects

- **Project P1:Effects of rotation rate and size of the planet**
- Goal - Understand the basic effects of changing planetary parameters and the power of non-dimensionalization.
- Experiments to do:
  - Change one or more of the rotation rate, radius, surface pressure with simple and more complex models
- Analysis to do:
  - Zonal winds, angular momentum, etc
- Example experiments provided:
  - Held-Suarez experiment with Earth-like rotation rate, then double and half the rotation rate

Introducing the projects

- **Project P2:Effects of gravity in dry and moist atmospheres.**
- Goal - Understand how gravity changes an atmosphere (or not) with and without moisture
- Experiments to do:
  - Run a model without moisture with 1 and 2 * Earth gravity
  - Run a model with moisture with 1 and 2 * Earth gravity
- Analysis to do:
  - Demonstrate the truth of the premise that g does not affect a dry model, but that it does affect a moist model
- Example experiments provided:
  - Held-Suarez experiment with 1 and 2 * g
  - Aquaplanet with grey radiation without a seasonal cycle with 1 and 2 * g.

Introducing the projects

- These projects are for you to make your own - start with our suggestions, but think up your own ideas and experiments

- Talk to me and the other lecturers, as they will be happy to help with discussing experiment and analysis ideas

- If you want to compare with **reanalysis** - monthly **JRA-55** data is on **Argo**, and an example script is available in the **analysis** folder. The same is true for the **HadISST** dataset.

- **Before you leave today, make sure somebody runs your group's example experiments. Then you'll have something to analyse tomorrow.**

- Split up the work within your group:

    - Who wants to run the model first?

    - Who wants to do some analysis of my example experiments so that they are ready for the real results later?

    - Who wants to read a related paper?

    - **Make sure you have a go at a variety of tasks - good opportunity to do that!**