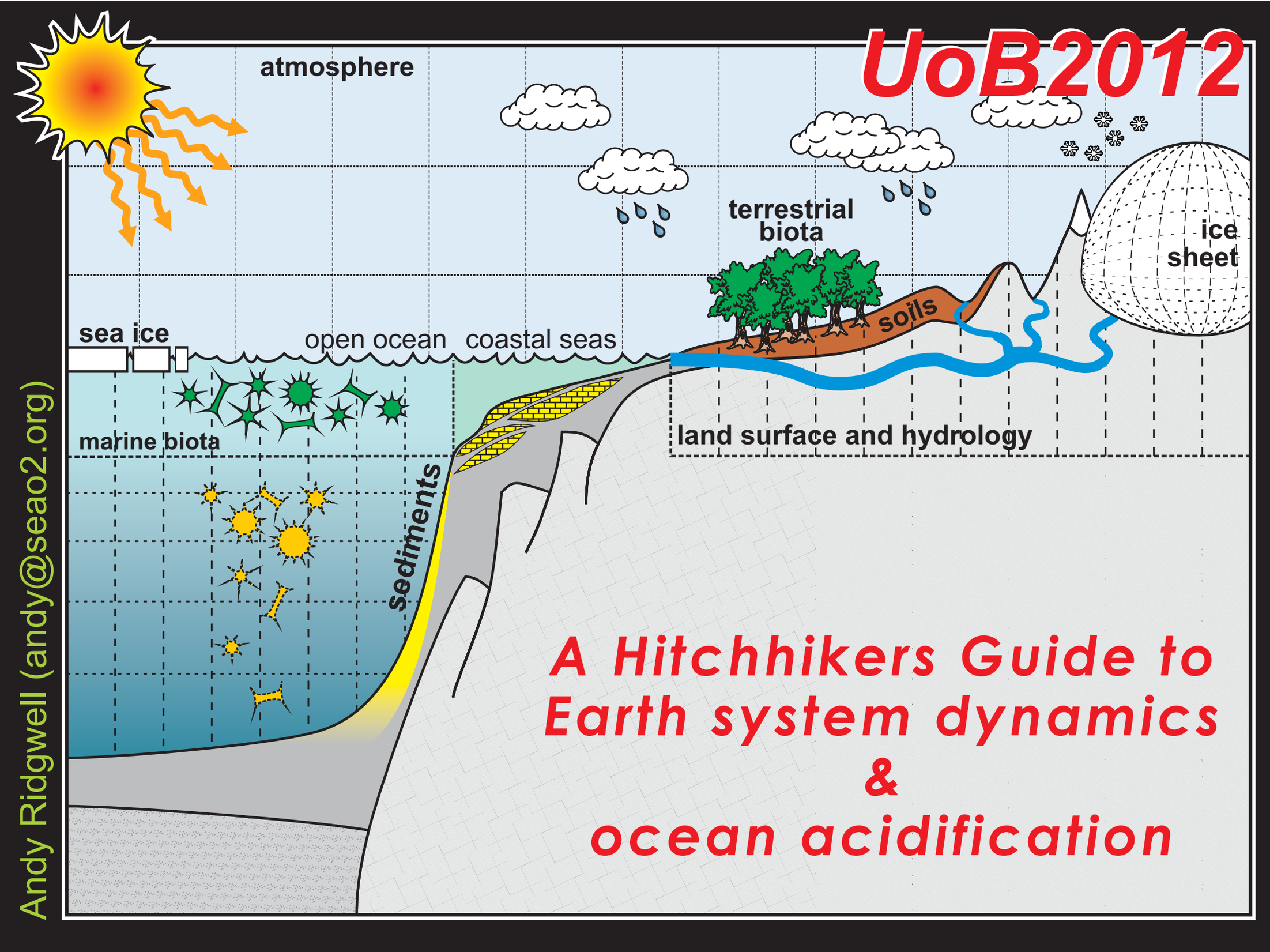

UoB2012
atmosphere
terrestrial biota
ice sheet
soils
sea ice
open ocean
coastal seas
marine biota
sediments
land surface and hydrology
A Hitchhikers Guide to Earth system dynamics & ocean acidification
Andy Ridgwell (andy@seao2.org)

*c*GENIE WORKSHOP:

A Hitchhikers Guide to the Black Arts of Earth system modelling & Ocean Acidification

('or why you should not want know what is in a sausage')

11th-12th September 2012; University of Bristol

Day 1 (Tuesday 11th September) – Earth system modelling for 'newbies'*

START (ca. 11 am)

COFFEE

Presentation – Introduction to (Earth system) modelling and *c*GENIE

Introduction to numerical and Earth system modelling.

Presentation on the *c*GENIE model structure, science components, nomenclature, accessibility to source code, etc.

***Session I* – Getting started**

Accessing the computing cluster; installing and compiling *c*GENIE; *c*GENIE directory structure ('where everything is').

Command-line operation; how to submit jobs to a cluster queue.

Concept of a 'restart'; experiment started from 'cold' vs. from end of previous run.

Time-series, time-slice (2D and 3D) output; integration intervals and specification of frequency of data saving. Panoply and MATLAB visualization resources.

LUNCH (ca. 1-2 pm)

***Session II* – A 'real'(!) experiment**

Setting up experiments: configuration files and setting parameter values.

Exploring the behaviour of the Earth system: Snowball Earth.

END (ca. 5 pm) (+ pub)

*c*GENIE WORKSHOP:

A Hitchhikers Guide to the Black Arts of Earth system modelling & Ocean Acidification

('or why you should not want know what is in a sausage')

11th-12th September 2012; University of Bristol

Day 2 (Wednesday 12th September) – Getting your hands dirty

START (ca. 9:30 am)

***Session III* – 'Poking the climate beast'**

Geochemical 'forcings' of *c*GENIE and tracing ocean circulation.

Exploring the stability of the Atlantic meridional overturning circulation (AMOC).

COFFEE (ca. 11 am)

***Session IV* – Poking the carbon cycle**

CO_2 emissions and future ocean acidification. Pelagic calcification and carbon-climate feedbacks.

LUNCH (ca. 1-2 pm)

***Session V* – How long is forever?**

Long-term controls on atmospheric pCO_2 and ocean carbonate chemistry.

END (ca. 4 pm)

The 1000 Laws of Numerical Modelling

\# 0 Numerical modeling is not just some form of deviant alien sexual activity.

\# 1 Garbage in(side), garbage out.

\# 10 You can put lipstick on a pig, but it's still a pig.

\# 11 Models are not the real World.

#100 All models are wrong.
(Some models are less wrong than others.)

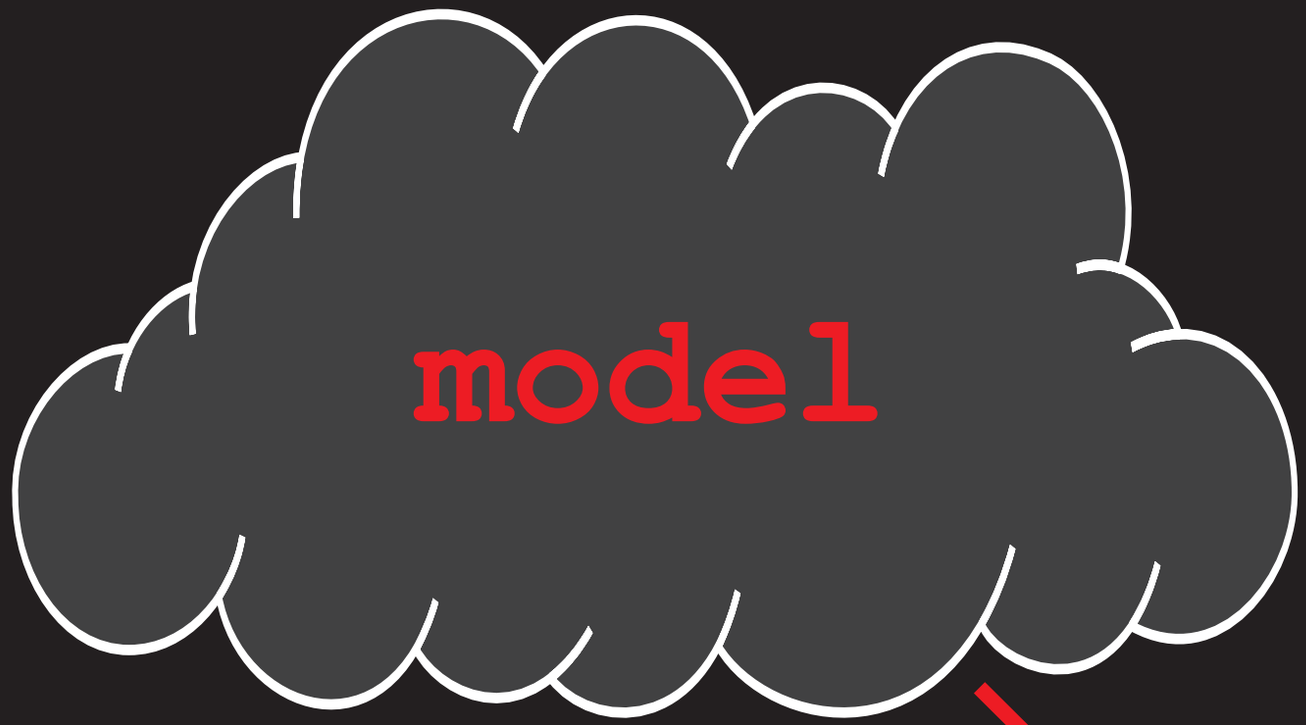
#101 Models are a numerical encapsulation of your preconceptions.

#110 You learn little when a model 'fits' the data.

#111 You can only judge what a model cannot appropriately be applied to.

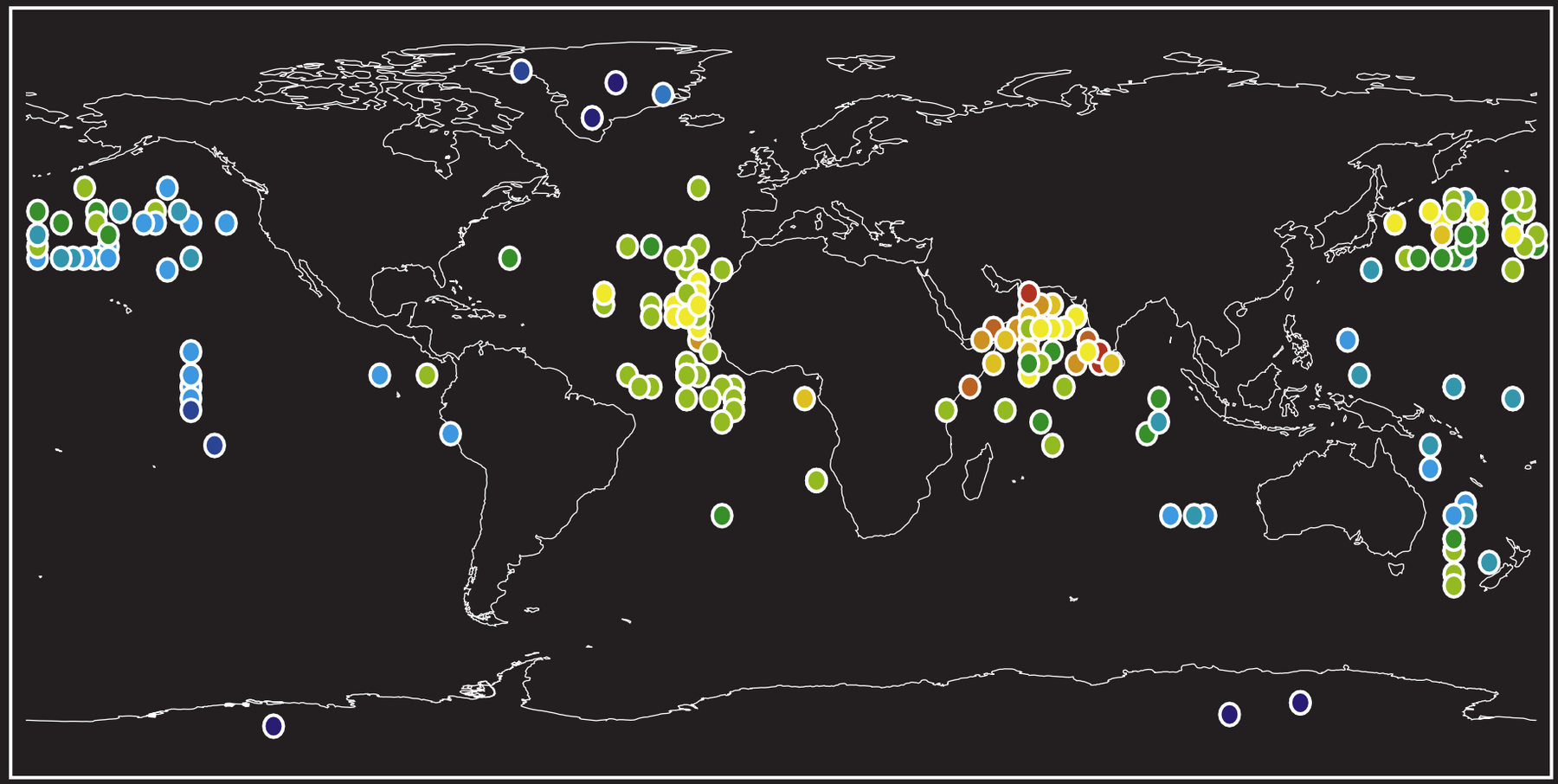
what are models for?

(i) mechanistic 'interpolation' of data, estimating global budgets



Modern global estimates

Global dust (and hence Fe = nutrient) deposition to the ocean

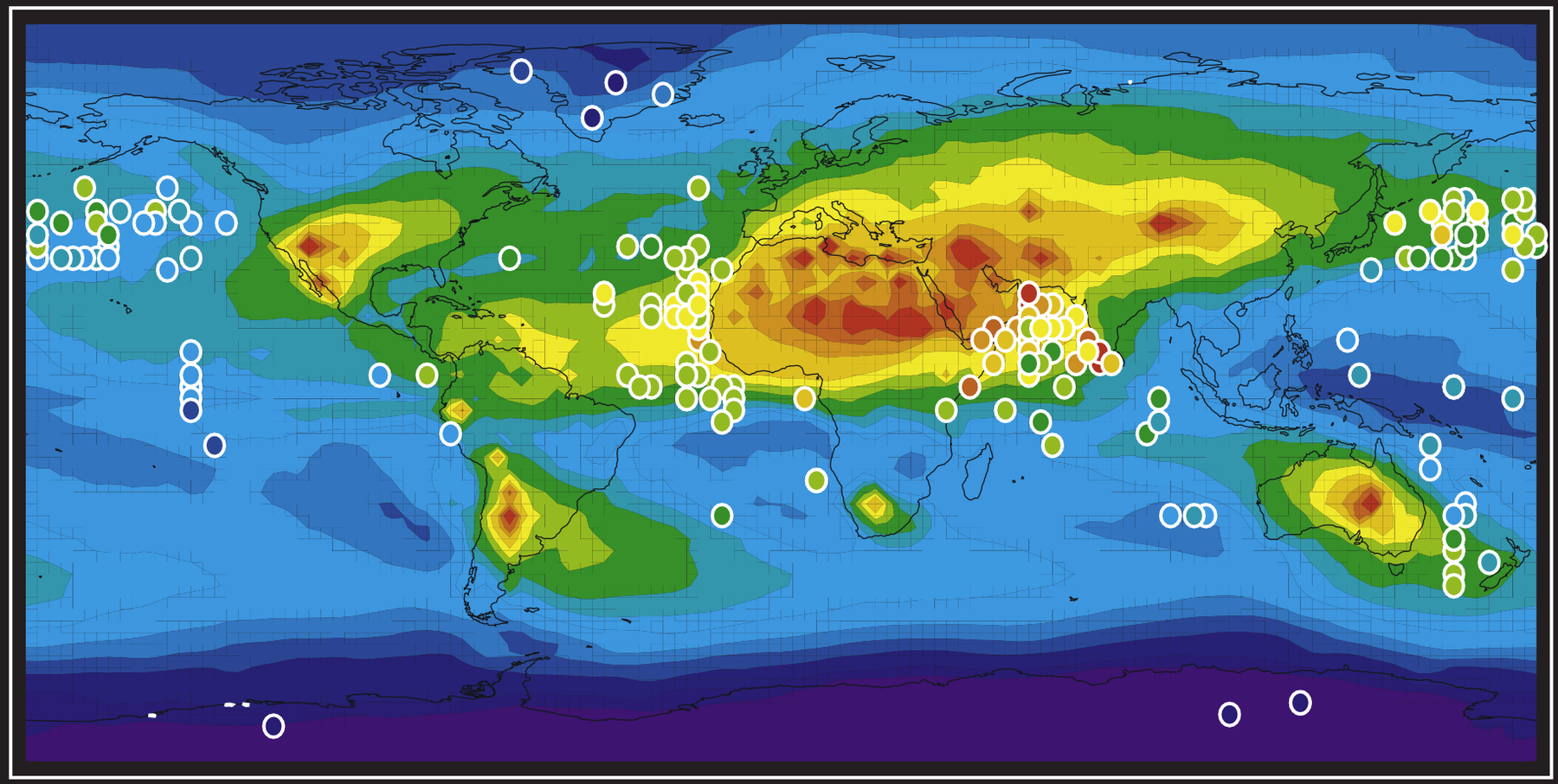


0.0 0.01 0.02 0.05 0.1 0.2 0.5 1.0 2.0 5.0 10 20 50 100 200

Dust deposition (g m^{-2} yr^{-1})

Mahowald et al. [2006]

Global dust (and hence Fe = nutrient) deposition to the ocean

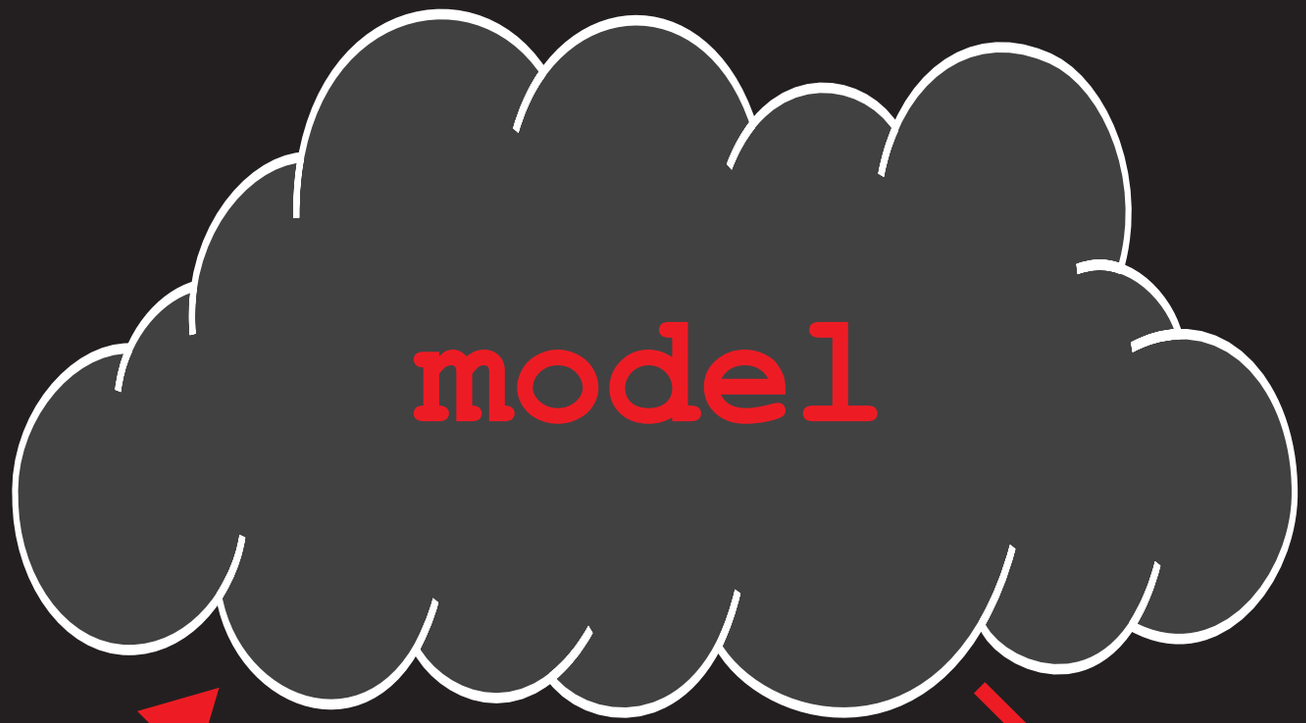


Dust deposition (g m^{-2} yr^{-1})

Mahowald et al. [2006]

what are models for?

(ii) predicting future and past responses to perturbation

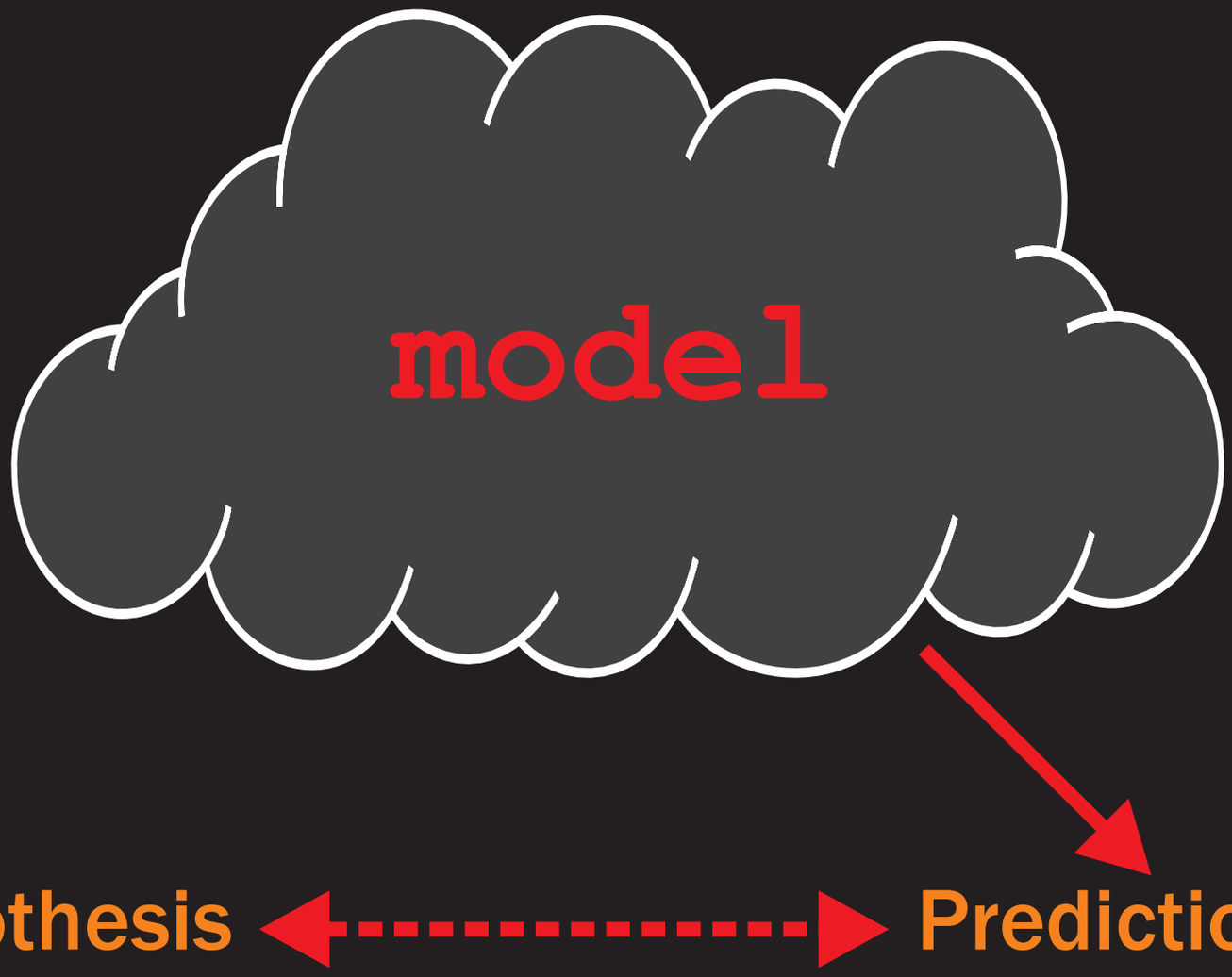


Perturbation

Future/past predictions

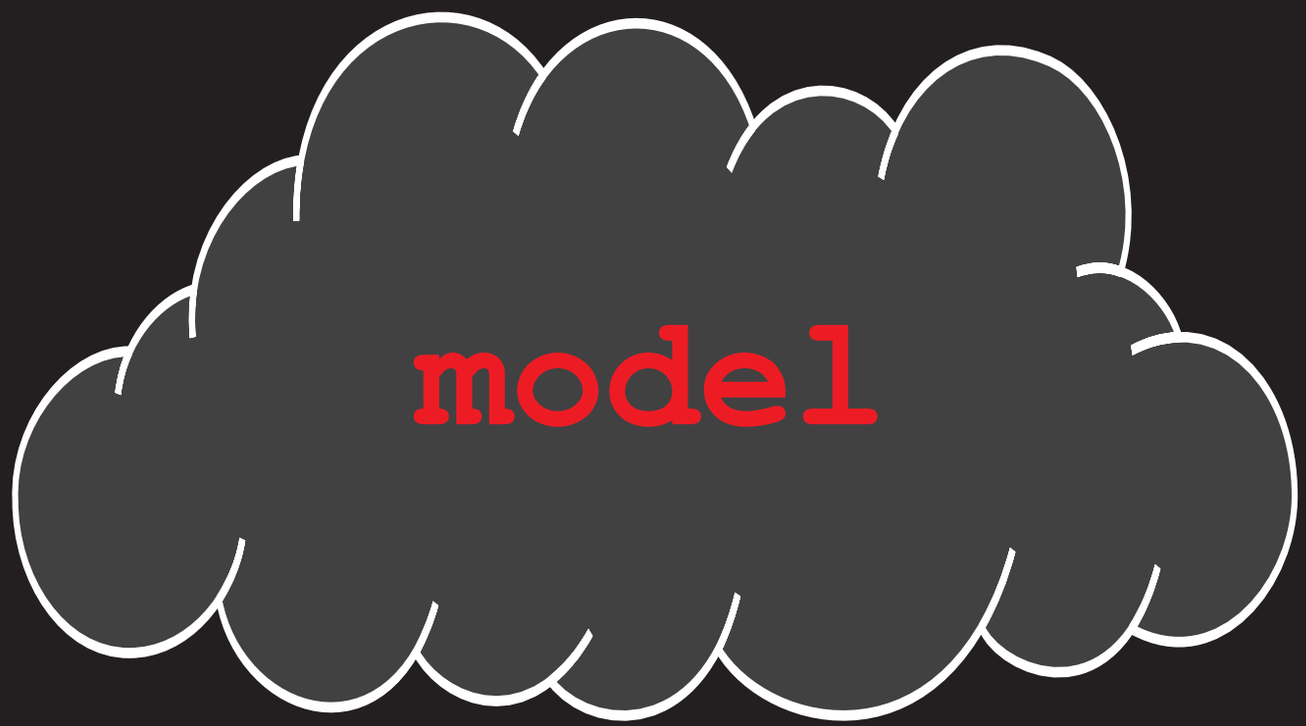
what are models for?

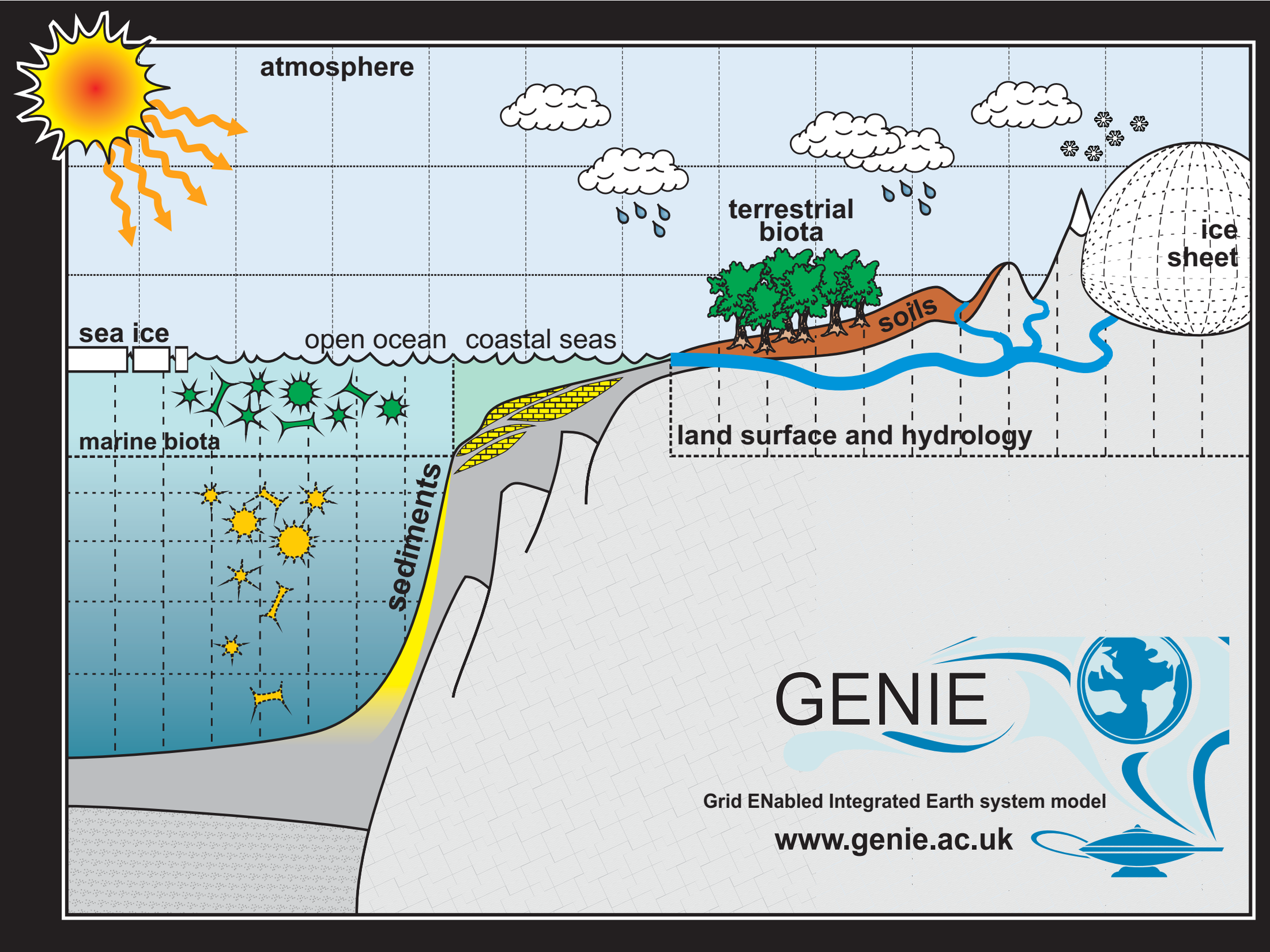
(iii) testing hypotheses



what are models for?

(iv) playing, exploring, & understanding; asking: 'what if?' questions




atmosphere
terrestrial biota
ice sheet
soils
sea ice
open ocean
coastal seas
marine biota
sediments
land surface and hydrology
GENIE
Grid ENabled Integrated Earth system model
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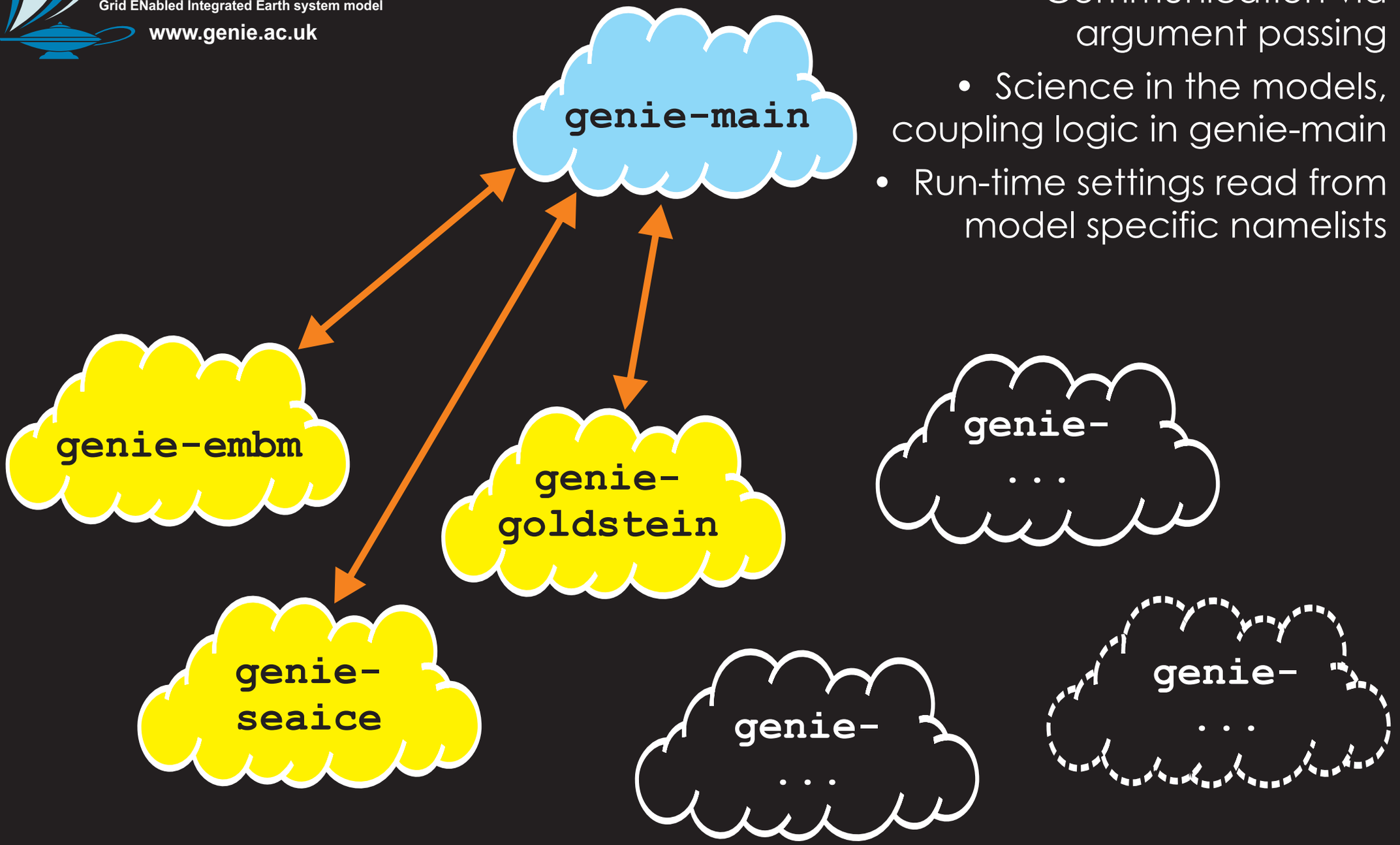
GENIE

Grid ENabled Integrated Earth system model

www.genie.ac.uk

Modular, Hierarchical

- Communication via argument passing
- Science in the models, coupling logic in genie-main
- Run-time settings read from model specific namelists



GENIE

Grid ENabled Integrated Earth system model

www.genie.ac.uk

Modular, Hierarchical

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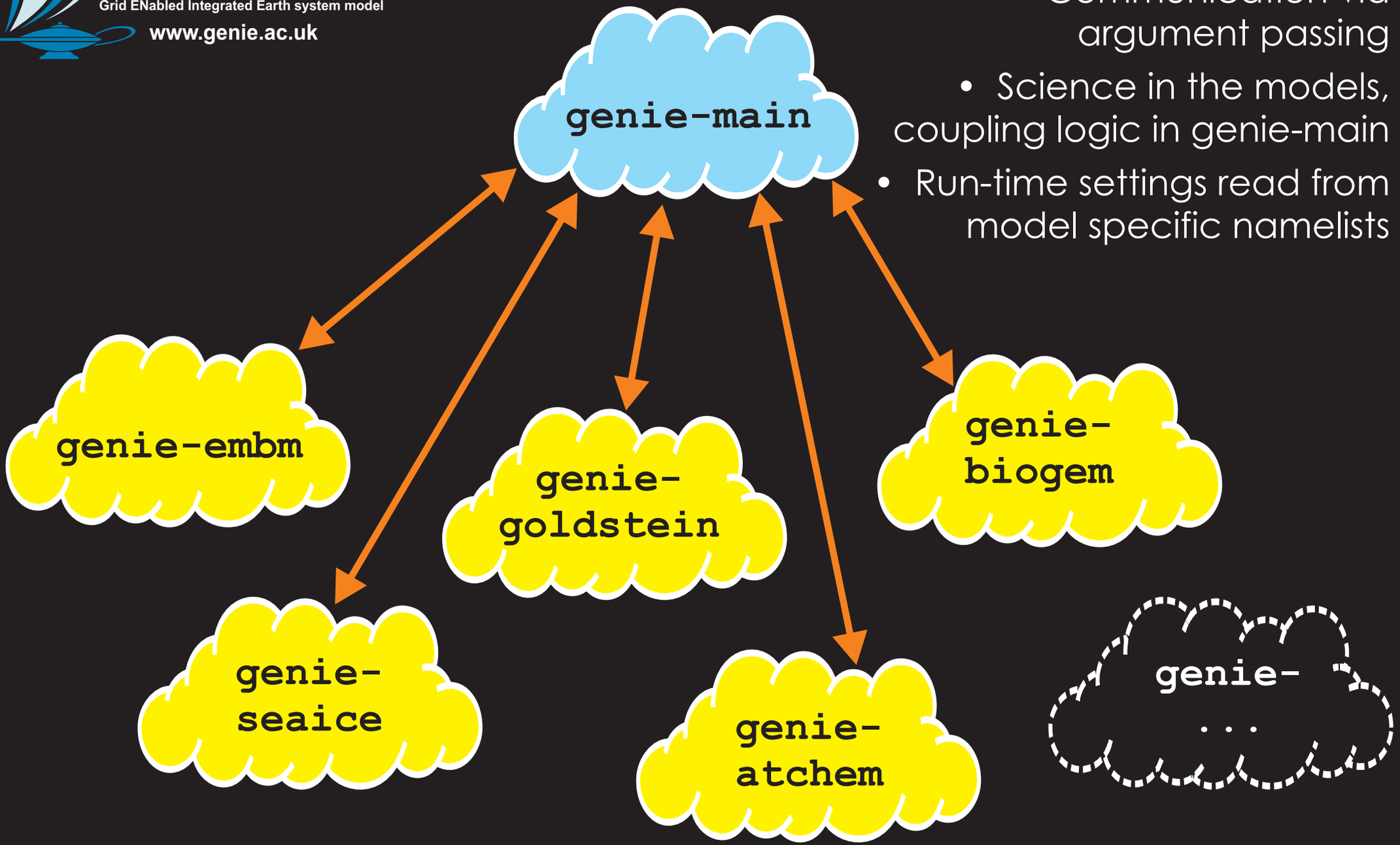
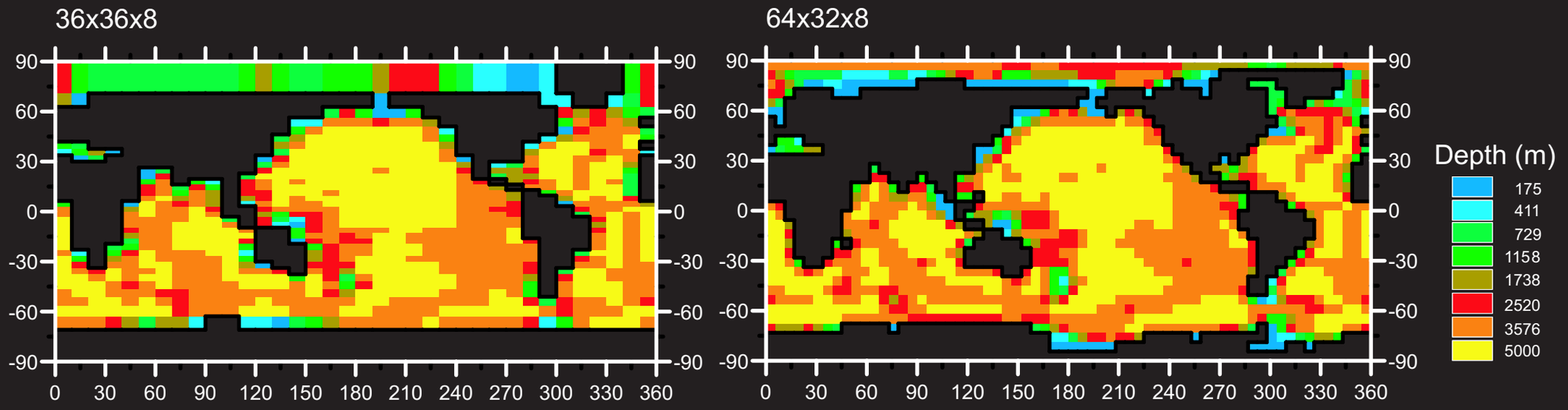


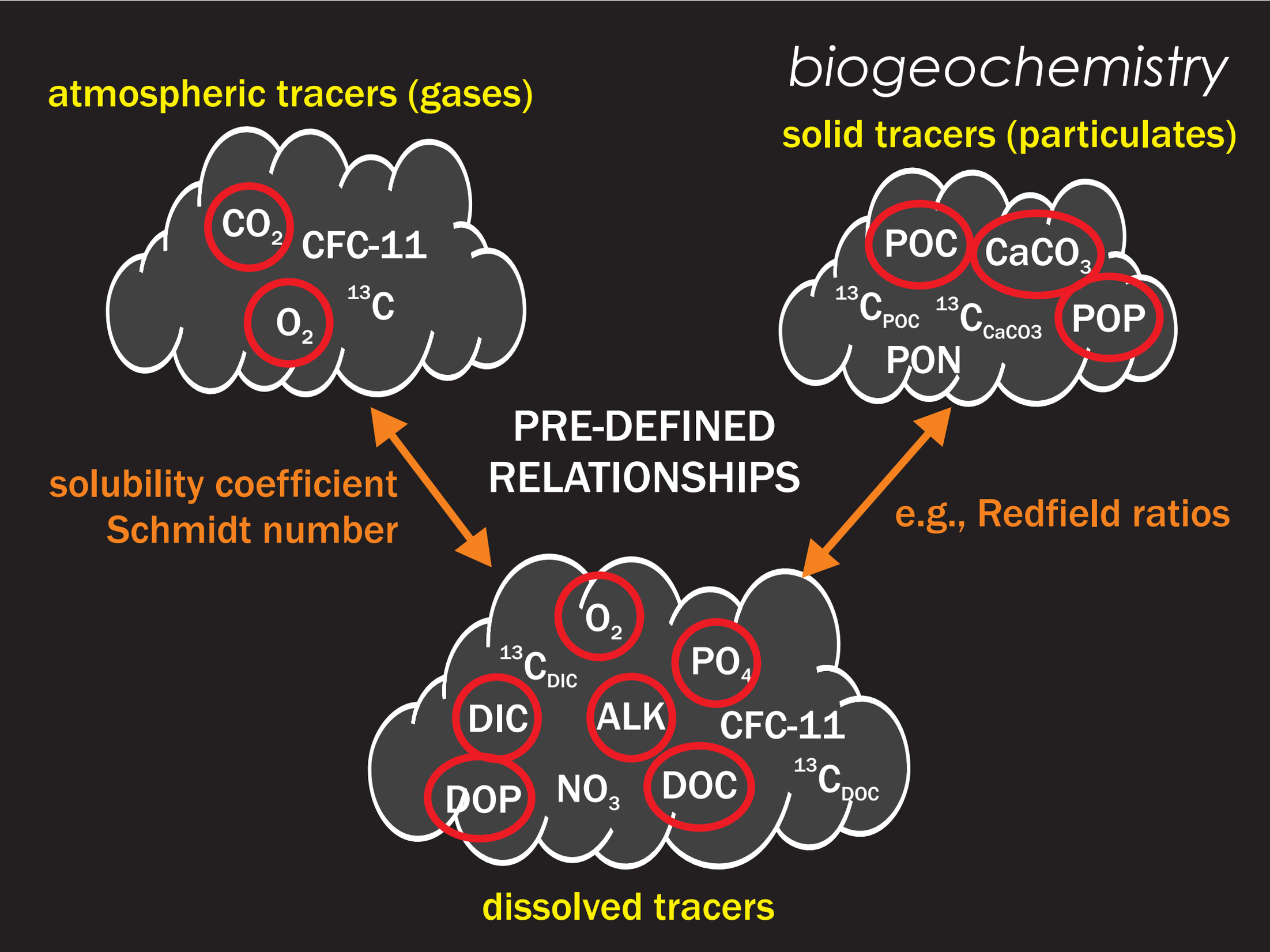
GENIE science modules

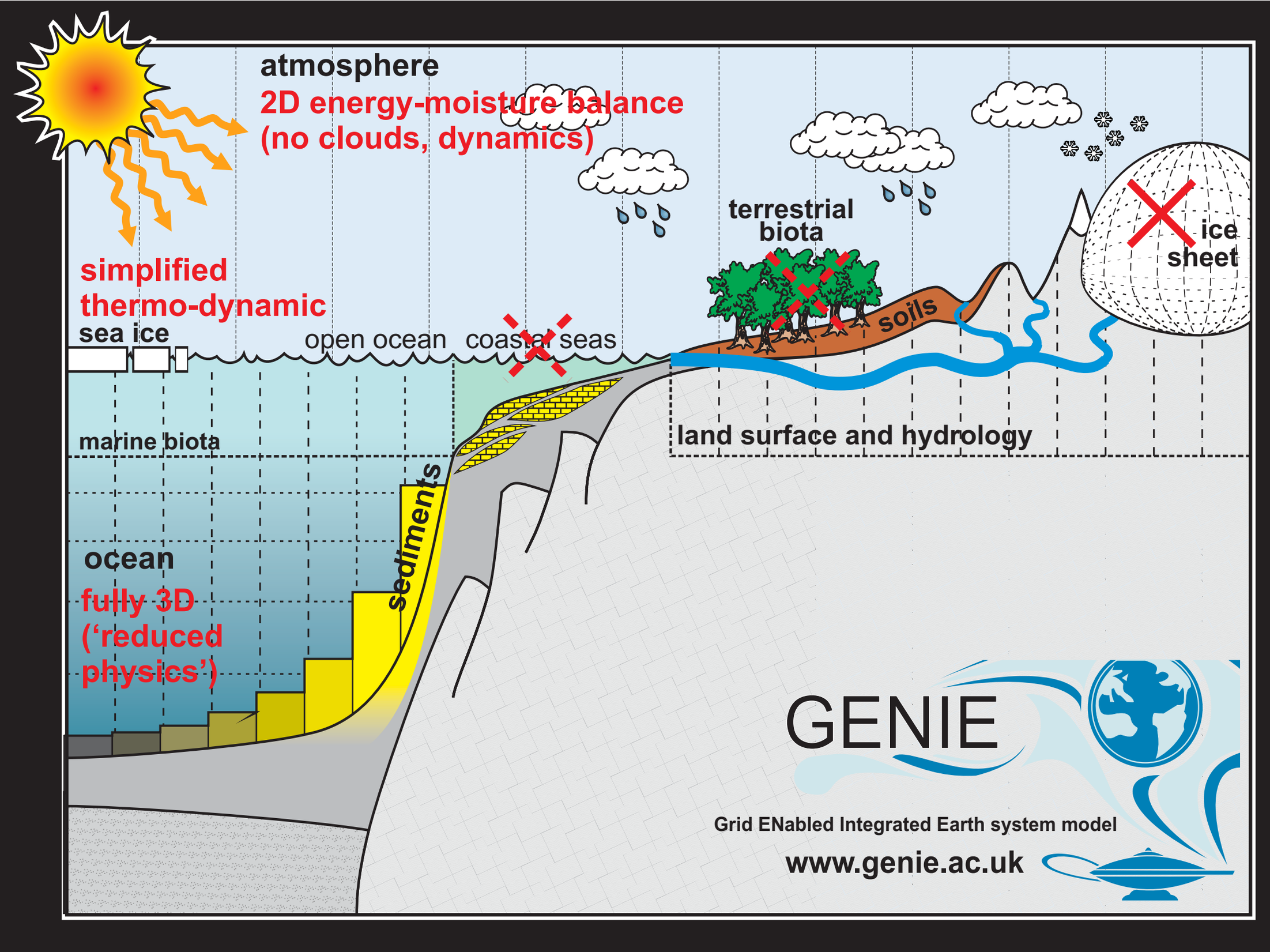
Component	Abrv.	?	Model	Reference
Atmosphere	ig eb fa	⊗	IGCM (3-D AGCM) EMBM (2-D) Fixed	*de Forster et al.* [2000] *Fanning and Weaver* (1996)
Ocean	go so fo	⊗	GOLDSTEIN Slab Fixed	*Edwards and Marsh* (2005) *de Forster et al.* [2000]
Sea-ice	gs ss fs	⊗	GOLDSTEIN (multi-option) Slab Fixed	*Edwards and Marsh* (2005) *de Forster et al.* [2000]
Land surface	 ml el fl		GENIE-land IGCM-land ENTS Fixed	*Meissner et al.* (2003) *de Forster et al.* [2000] *Williamson et al.* [2006]
Ice-sheets	gi fi		GLIMMER Fixed	*Payne* (1999)
Vegetation			TRIFFID ENTS Fixed	*Cox* [1998] *Williamson et al.* [2006]
Ocean biogeochemistry	bg	⊗	BIOGEM	*Ridgwell et al.* [2007a]
Deep-sea sediments	sg		SEDGEM	*Ridgwell and Hargreaves* [2007]
Atmospheric chemistry	ac	⊗	ATCHEM	*Ridgwell et al.* [2007a]
Terrestrial weathering	rg		ROKGEM	

GENIE configuration

Model		Longitude cells	res.	Longitude cells	res.	Vertical levels
Ocean GOLDSTEIN	⊗	36	10°	36	sin(π/36)	8
		72	5°	72	sin(π/72)	16
		64	5.625°	32	5.625°	8
		72	10°	60	3°	8
Atmosphere 2-D EMBM	⊗	36	10°	36	sin(π/36)	1
		72	5°	72	sin(π/72)	1
		64	5.625°	32	5.625°	1
		72	10°	60	3°	1
Atmosphere 3-D IGCM	⊗	64	5.625°	32	5.625°	7




biogeochemistry
atmospheric tracers (gases)
CO_2
CFC-11
^{13}C
O_2
solid tracers (particulates)
POC
$CaCO_3$
$^{13}C_{POC}$
$^{13}C_{CaCO3}$
POP
PON
PRE-DEFINED
RELATIONSHIPS
solubility coefficient
Schmidt number
e.g., Redfield ratios
O_2
$^{13}C_{DIC}$
PO_4
DIC
ALK
CFC-11
DOP
NO_3
DOC
$^{13}C_{DOC}$
dissolved tracers


atmosphere
2D energy-moisture balance
(no clouds, dynamics)
terrestrial
biota
ice
sheet
simplified
thermo-dynamic
sea ice
open ocean
coastal seas
soils
land surface and hydrology
marine biota
sediments
ocean
fully 3D
('reduced
physics')
GENIE
Grid ENabled Integrated Earth system model
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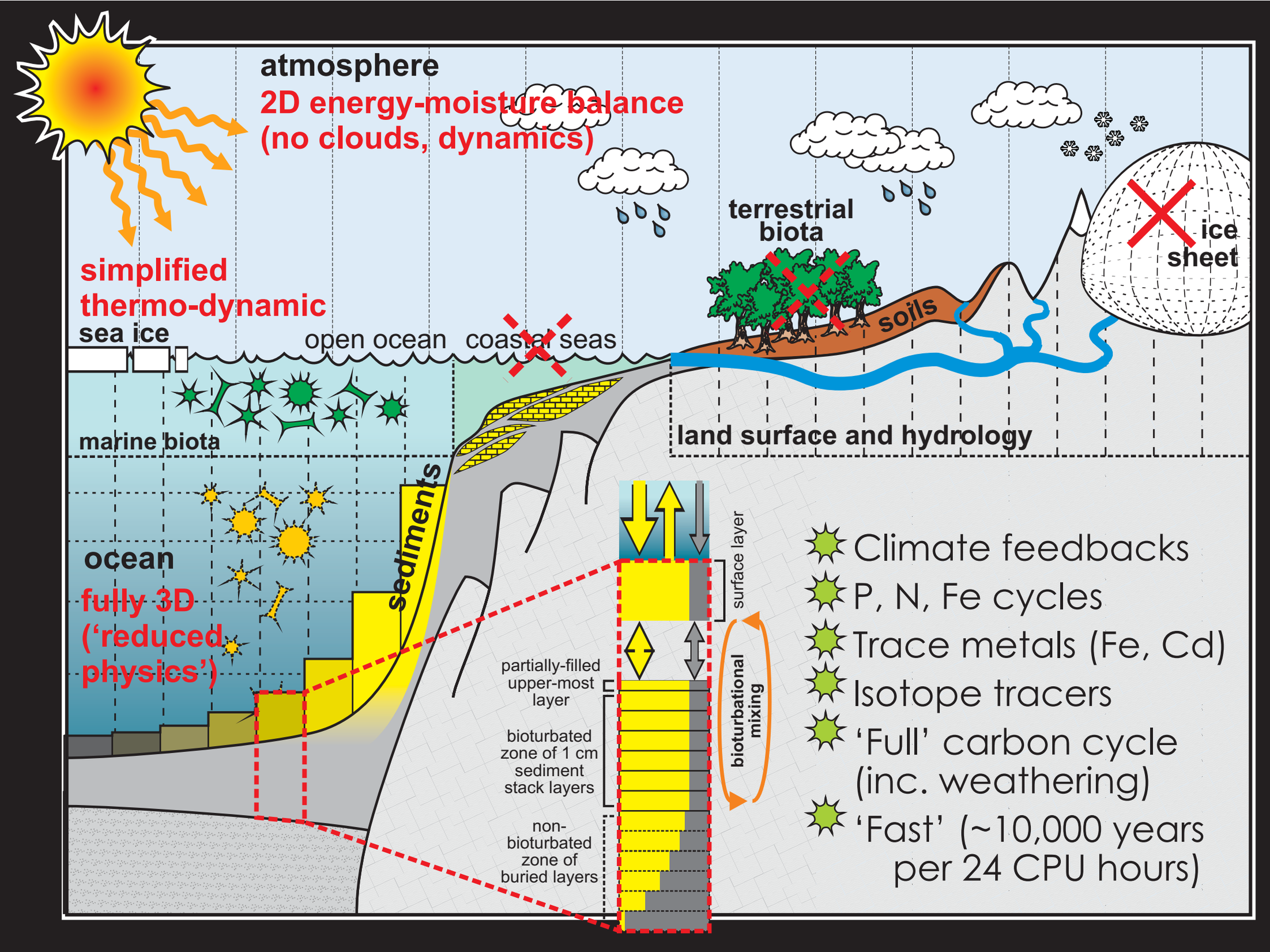
atmosphere
2D energy-moisture balance
(no clouds, dynamics)
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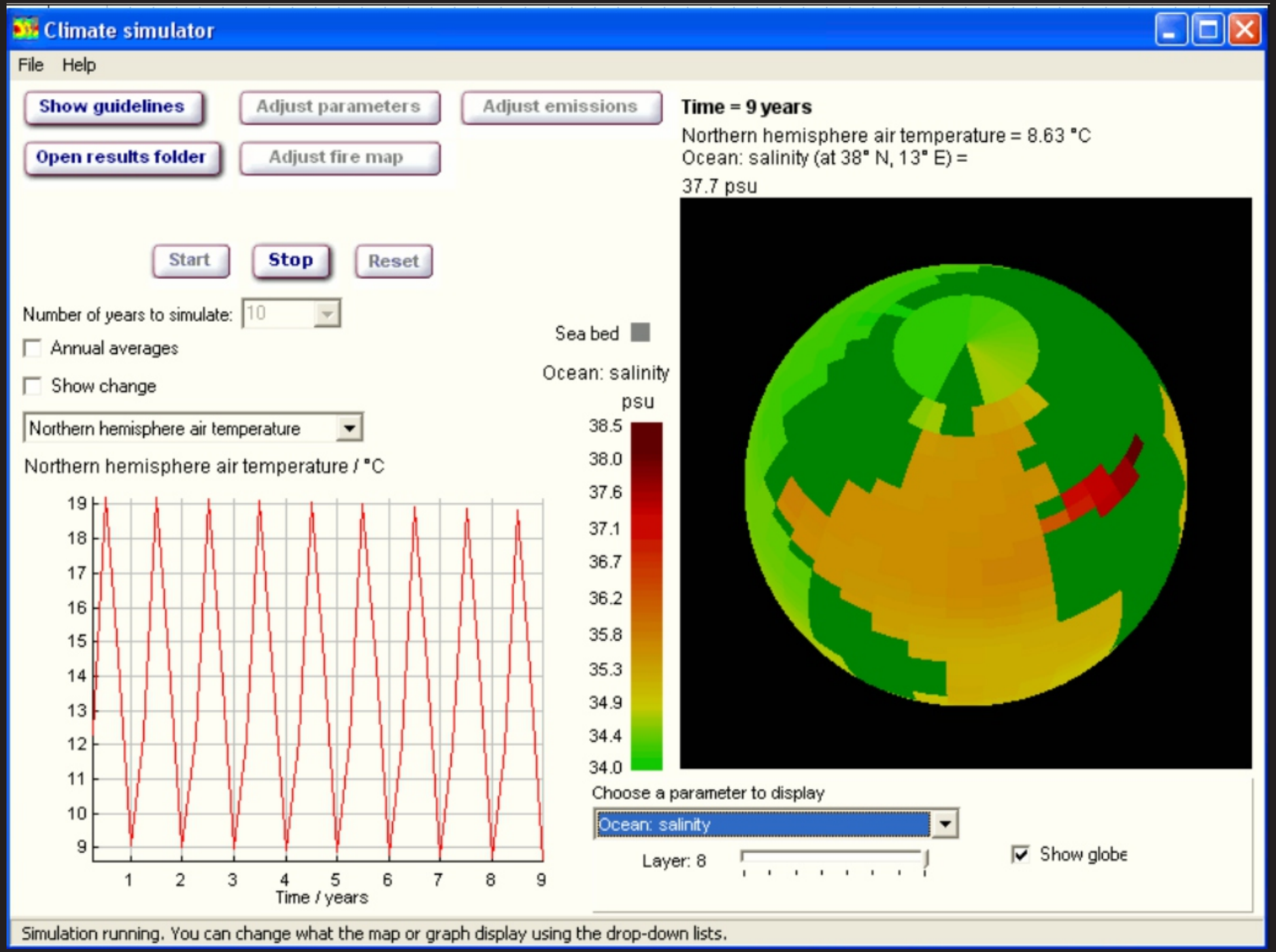
sea ice
open ocean
coastal seas
terrestrial
biota
soils
ice
sheet
marine biota
land surface and hydrology
sediments
ocean
fully 3D
('reduced
physics')
surface layer
partially-filled
upper-most
layer
bioturbated
zone of 1 cm
sediment
stack layers
non-
bioturbated
zone of
buried layers
bioturbational
mixing
Climate feedbacks
P, N, Fe cycles
Trace metals (Fe, Cd)
Isotope tracers
'Full' carbon cycle
(inc. weathering)
'Fast' (~10,000 years
per 24 CPU hours)

Using cGENIE



Using cGENIE

1:almond.ggy.bris.ac.uk - mushroom@almond - SSH Secure Shell

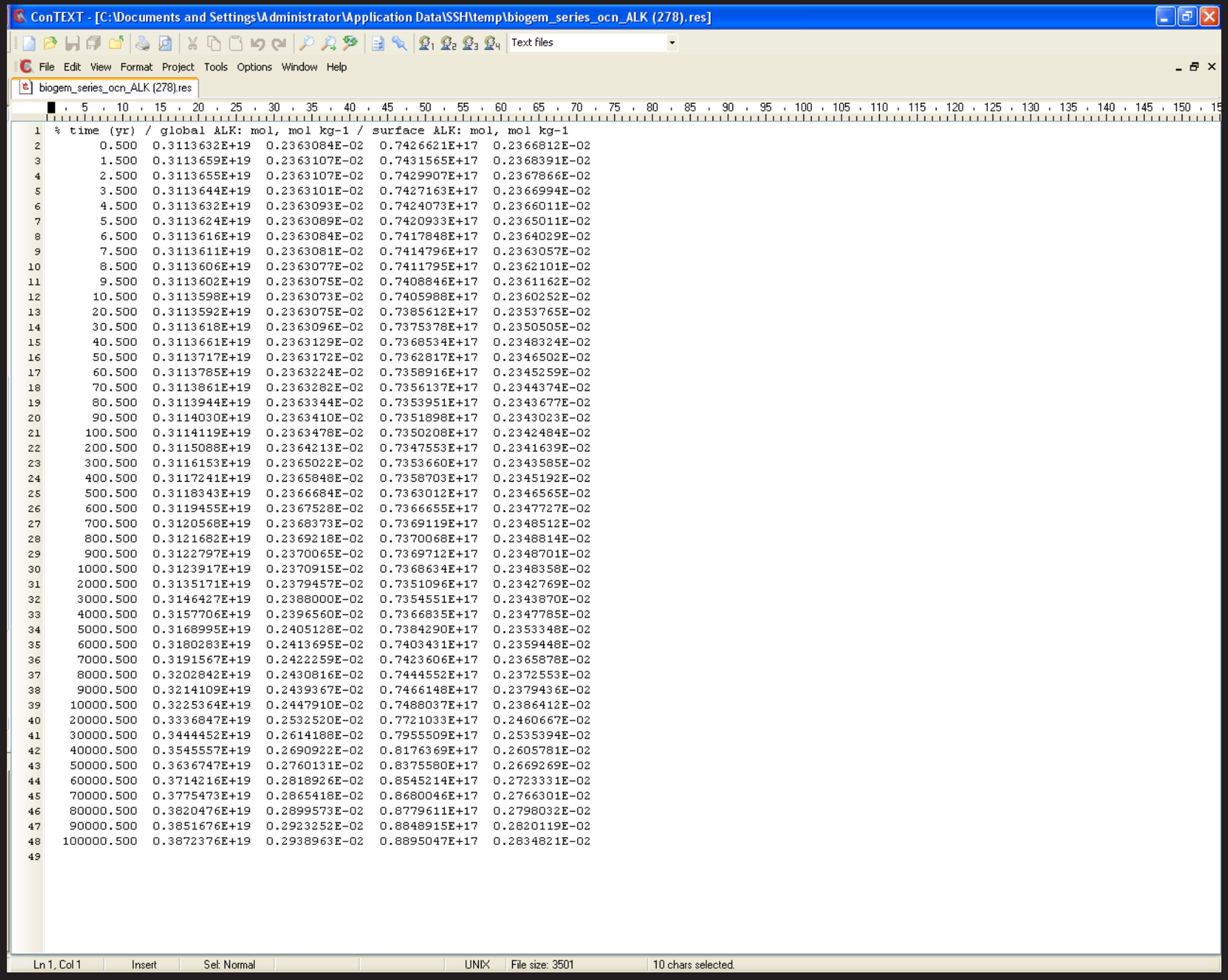
File Edit View Window Help

Quick Connect Profiles

```
 Filename for restart input                        : atchem
 Filename for restart output                       : atchem
 =====================================================
  Initialisation of ATCHEM module complete
 =====================================================

 Check for weightings from genie atm =   0.999999999999993
 Check for weightings from genie ocn =   0.999999999999993

 *****************************************************
  Initialisation complete, simulation starting
 *****************************************************

 do the looping.....

                                 model year  * pCO2(uatm)   d13CO2  *  AMO(Sv)  ice(%)   <SST>   <SSS>  *  <DIC>(uM)  <ALK>(uM)

 >>> SAVING BIOGEM TIME-SERIES @ year       0.50       285.160   -6.812      17.359   0.211   1.393  34.901      2242.457   2363.077
     temp             / min = 0.2713E+03 (19,36, 8) / max = 0.2774E+03 (27,20, 8)
     sal              / min = 0.3488E+02 ( 6,18, 8) / max = 0.3496E+02 (19,36, 8)
     DIC              / min = 0.2203E-02 (34,12, 8) / max = 0.2249E-02 ( 4,16, 7)
     DIC_13C          / min = 0.3334E+00 ( 4,16, 7) / max = 0.8790E+00 (35,12, 8)
     DIC_14C          / min = -.1917E+00 ( 4,16, 7) / max = 0.1239E+01 (35,12, 8)
     PO4              / min = 0.1968E-05 (36,19, 8) / max = 0.2203E-05 ( 4,16, 7)
     O2               / min = 0.1641E-03 ( 4,16, 7) / max = 0.3378E-03 (34,11, 8)
     ALK              / min = 0.2363E-02 ( 4,16, 7) / max = 0.2365E-02 (21,22, 8)
     DOM_C            / min = -.3186E-07 (17,25, 6) / max = 0.1155E-04 (31,20, 8)
     DOM_C_13C        / min = -.1000E+20 ( 1,13, 1) / max = -.2874E+02 (21,25, 4)
     DOM_C_14C        / min = -.1000E+20 ( 1,13, 1) / max = -.2505E+02 (21,25, 4)
     DOM_P            / min = -.3006E-09 (17,25, 6) / max = 0.1090E-06 (31,20, 8)
     Ca               / min = 0.1025E-01 (25,21, 8) / max = 0.1025E-01 (19,36, 8)
     CFC11            / min = 0.0000E+00 ( 1, 3, 2) / max = 0.0000E+00 ( 1, 3, 2)
     CFC12            / min = 0.0000E+00 ( 1, 3, 2) / max = 0.0000E+00 ( 1, 3, 2)
     Mg               / min = 0.5281E-01 ( 8,33, 8) / max = 0.5283E-01 (19,36, 8)
 >>> SAVING BIOGEM TIME-SLICE @ year  0.500000000000000
 >>> SAVING BIOGEM TIME-SERIES @ year       1.50       295.241   -7.277      17.955   2.247   3.545  34.901      2240.918   2363.122
     temp             / min = 0.2712E+03 (19,36, 8) / max = 0.2831E+03 (27,20, 8)
     sal              / min = 0.3483E+02 (25,21, 8) / max = 0.3516E+02 (19,36, 8)
     DIC              / min = 0.2168E-02 (31,19, 8) / max = 0.2258E-02 ( 4,16, 7)
     DIC_13C          / min = 0.2156E+00 ( 4,16, 7) / max = 0.1296E+01 (34,11, 8)
     DIC_14C          / min = -.5418E+00 ( 4,16, 7) / max = 0.2424E+01 (34,11, 8)
     PO4              / min = 0.1736E-05 ( 3,16, 8) / max = 0.2288E-05 ( 4,16, 7)
     O2               / min = 0.1543E-03 ( 4,16, 7) / max = 0.3343E-03 (13,29, 8)
     ALK              / min = 0.2362E-02 (10,34, 8) / max = 0.2369E-02 (18,36, 8)
     DOM_C            / min = -.1272E-06 (17,25, 6) / max = 0.1772E-04 (31,20, 8)
     DOM_C_13C        / min = -.1000E+20 ( 1,12, 1) / max = 0.6187E+01 (27,16, 1)
     DOM_C_14C        / min = -.1000E+20 ( 1,12, 1) / max = 0.3613E+02 (27,16, 1)
     DOM_P            / min = -.1200E-08 (17,25, 6) / max = 0.1672E-06 (31,20, 8)
     Ca               / min = 0.1024E-01 (25,21, 8) / max = 0.1028E-01 (18,36, 8)
     CFC11            / min = 0.0000E+00 ( 1, 3, 2) / max = 0.0000E+00 ( 1, 3, 2)
     CFC12            / min = 0.0000E+00 ( 1, 3, 2) / max = 0.0000E+00 ( 1, 3, 2)
     Mg               / min = 0.5276E-01 (25,21, 8) / max = 0.5296E-01 (18,36, 8)
 >>> SAVING BIOGEM TIME-SERIES @ year       2.50       302.269   -7.580      17.161   4.377   5.279  34.901      2240.016   2363.147
     temp             / min = 0.2712E+03 (19,36, 8) / max = 0.2857E+03 (31,20, 8)
     sal              / min = 0.3479E+02 (25,21, 8) / max = 0.3526E+02 (19,36, 8)
     DIC              / min = 0.2143E-02 (31,19, 8) / max = 0.2265E-02 ( 4,16, 7)
     DIC_13C          / min = 0.1340E+00 ( 4,16, 7) / max = 0.1540E+01 (22,25, 8)
     DIC_14C          / min = -.8203E+00 ( 4,16, 7) / max = 0.3046E+01 (11,27, 8)
     PO4              / min = 0.1575E-05 ( 3,16, 8) / max = 0.2352E-05 (26,29, 7)
     O2               / min = 0.1463E-03 ( 4,16, 7) / max = 0.3331E-03 (13,30, 8)
     ALK              / min = 0.2360E-02 (25,21, 8) / max = 0.2371E-02 (18,36, 8)
```

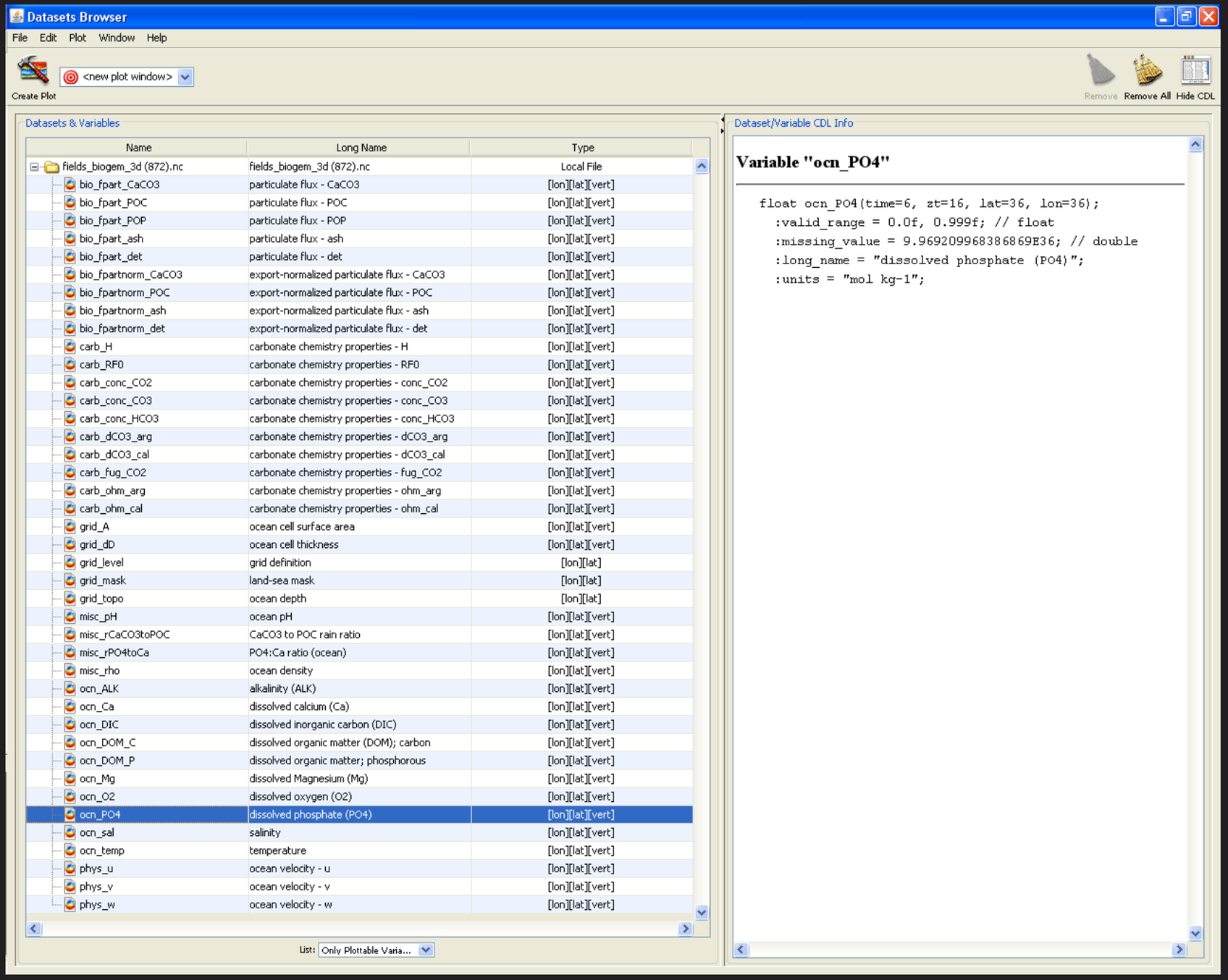
Connected to almond.ggy.bris.ac.uk SSH2 - aes128-cbc - hmac-md5 - none 178x61 NUM

Using cGENIE

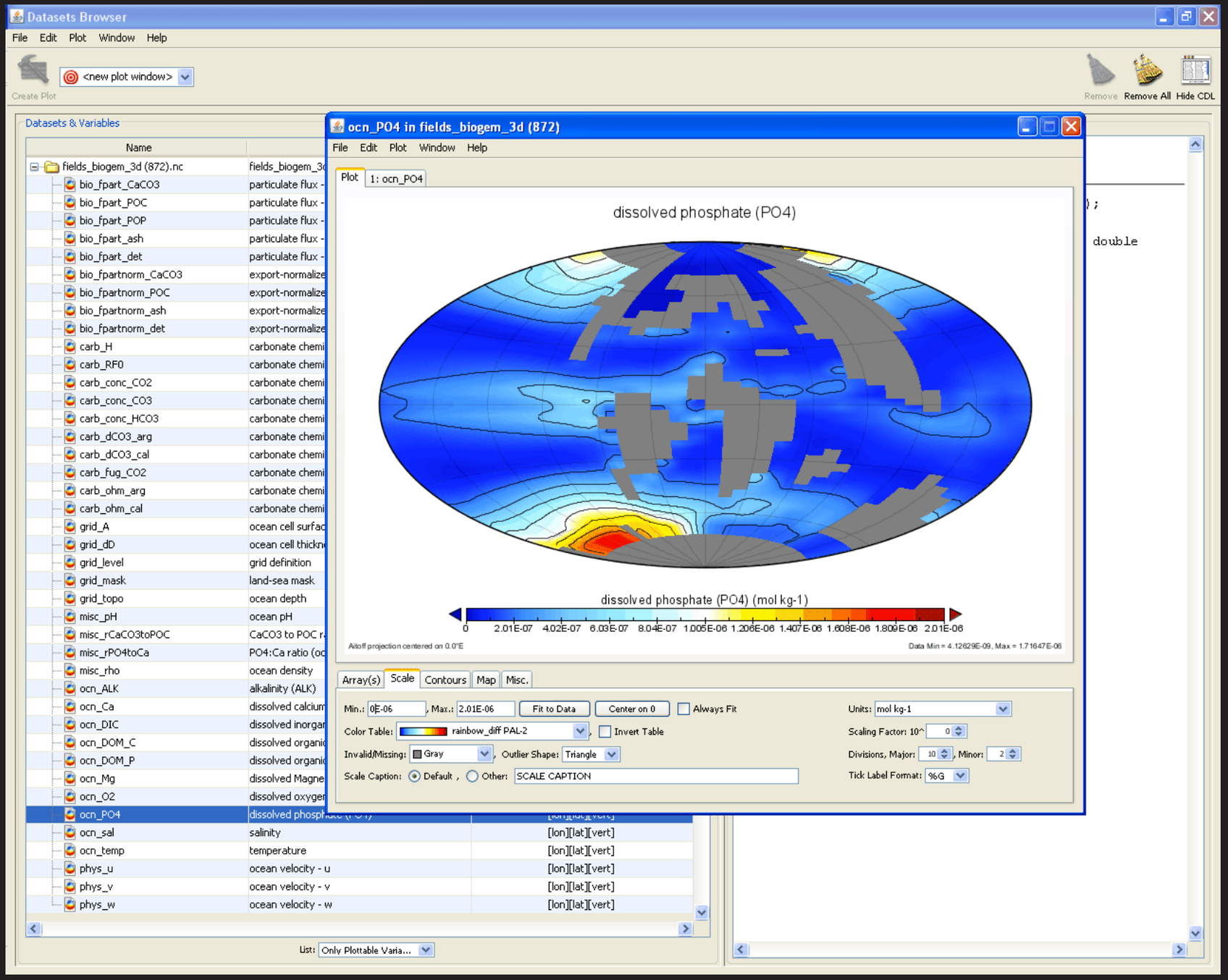



```
% time (yr) / global ALK: mol, mol kg-1 / surface ALK: mol, mol kg-1
       0.500  0.3113632E+19  0.2363084E-02  0.7426621E+17  0.2366812E-02
       1.500  0.3113659E+19  0.2363107E-02  0.7431565E+17  0.2368391E-02
       2.500  0.3113655E+19  0.2363107E-02  0.7429907E+17  0.2367866E-02
       3.500  0.3113644E+19  0.2363101E-02  0.7427163E+17  0.2366994E-02
       4.500  0.3113632E+19  0.2363093E-02  0.7424073E+17  0.2366011E-02
       5.500  0.3113624E+19  0.2363089E-02  0.7420933E+17  0.2365011E-02
       6.500  0.3113616E+19  0.2363084E-02  0.7417848E+17  0.2364029E-02
       7.500  0.3113611E+19  0.2363081E-02  0.7414796E+17  0.2363057E-02
       8.500  0.3113606E+19  0.2363077E-02  0.7411795E+17  0.2362101E-02
       9.500  0.3113602E+19  0.2363075E-02  0.7408846E+17  0.2361162E-02
      10.500  0.3113598E+19  0.2363073E-02  0.7405988E+17  0.2360252E-02
      20.500  0.3113592E+19  0.2363075E-02  0.7385612E+17  0.2353765E-02
      30.500  0.3113618E+19  0.2363096E-02  0.7375378E+17  0.2350505E-02
      40.500  0.3113661E+19  0.2363129E-02  0.7368534E+17  0.2348324E-02
      50.500  0.3113717E+19  0.2363172E-02  0.7362817E+17  0.2346502E-02
      60.500  0.3113785E+19  0.2363224E-02  0.7358916E+17  0.2345259E-02
      70.500  0.3113861E+19  0.2363282E-02  0.7356137E+17  0.2344374E-02
      80.500  0.3113944E+19  0.2363344E-02  0.7353951E+17  0.2343677E-02
      90.500  0.3114030E+19  0.2363410E-02  0.7351898E+17  0.2343023E-02
     100.500  0.3114119E+19  0.2363478E-02  0.7350208E+17  0.2342484E-02
     200.500  0.3115088E+19  0.2364213E-02  0.7347553E+17  0.2341639E-02
     300.500  0.3116153E+19  0.2365022E-02  0.7353660E+17  0.2343585E-02
     400.500  0.3117241E+19  0.2365848E-02  0.7358703E+17  0.2345192E-02
     500.500  0.3118343E+19  0.2366684E-02  0.7363012E+17  0.2346565E-02
     600.500  0.3119455E+19  0.2367528E-02  0.7366655E+17  0.2347727E-02
     700.500  0.3120568E+19  0.2368373E-02  0.7369119E+17  0.2348512E-02
     800.500  0.3121682E+19  0.2369218E-02  0.7370068E+17  0.2348814E-02
     900.500  0.3122797E+19  0.2370065E-02  0.7369712E+17  0.2348701E-02
    1000.500  0.3123917E+19  0.2370915E-02  0.7368634E+17  0.2348358E-02
    2000.500  0.3135171E+19  0.2379457E-02  0.7351096E+17  0.2342769E-02
    3000.500  0.3146427E+19  0.2388000E-02  0.7354551E+17  0.2343870E-02
    4000.500  0.3157706E+19  0.2396560E-02  0.7366835E+17  0.2347785E-02
    5000.500  0.3168995E+19  0.2405128E-02  0.7384290E+17  0.2353348E-02
    6000.500  0.3180283E+19  0.2413695E-02  0.7403431E+17  0.2359448E-02
    7000.500  0.3191567E+19  0.2422259E-02  0.7423606E+17  0.2365878E-02
    8000.500  0.3202842E+19  0.2430816E-02  0.7444552E+17  0.2372553E-02
    9000.500  0.3214109E+19  0.2439367E-02  0.7466148E+17  0.2379436E-02
   10000.500  0.3225364E+19  0.2447910E-02  0.7488037E+17  0.2386412E-02
   20000.500  0.3336847E+19  0.2532520E-02  0.7721033E+17  0.2460667E-02
   30000.500  0.3444452E+19  0.2614188E-02  0.7955509E+17  0.2535394E-02
   40000.500  0.3545557E+19  0.2690922E-02  0.8176369E+17  0.2605781E-02
   50000.500  0.3636747E+19  0.2760131E-02  0.8375580E+17  0.2669269E-02
   60000.500  0.3714216E+19  0.2818926E-02  0.8545214E+17  0.2723331E-02
   70000.500  0.3775473E+19  0.2865418E-02  0.8680046E+17  0.2766301E-02
   80000.500  0.3820476E+19  0.2899573E-02  0.8779611E+17  0.2798032E-02
   90000.500  0.3851676E+19  0.2923252E-02  0.8848915E+17  0.2820119E-02
  100000.500  0.3872376E+19  0.2938963E-02  0.8895047E+17  0.2834821E-02
```

Using cGENIE



Using cGENIE



1.0 You are going to be installing the model from scratch – why? Why not? Hell, it saves me installing it a dozen times! Actually, having gone through the install and testing procedure once, you should be able to install cGENIE 'for real' another time. (If you dare ever use it again ...)

1.1 Having logged into the PC terminal, log in to the account that has been created for you on the almond computing cluster. To do this – first start the SSH Secure Shell program (you can find this via the All Programs menu tree from the Start icon in Windoz). Run the Secure Shell Client (rather than the Secure File Transfer Client) to start off.
Click on the Quick Connect icon in the main Secure Shell Client window. A 'Connect to Remote Host' dialogue box will appear. In the first box, 'Host Name', enter:

iwan.ggy.bris.ac.uk

and your computing cluster user-name on the line below this ('User Name').

When (and only when) you click on the Connect button will you be asked for your password in a new dialogue window that will appear.

You should now have a dull, blank-look window with the command prompt (`$`) (see previous page).

For displaying directory contents and transferring model results files we are going to be using the SSH file transfer program. One of the icons towards the middle of the icon bar in the SSH terminal window you have opened is called 'New File Transfer Window' (it should be the 2nd icon to the right of the search (binoculars) icon). Click on this to open a file transfer window.

Or: Again from the All Programs menu tree of Windoz `Start`, select `Secure File Transfer Client`.

You should now have TWO windows open – a 'shell' window (lines of text on an otherwise blank screen) and a file manager (transfer) window. Ensure that you have both these before moving on. It is recommended that you maximize both these windows to full screen. (But no-one will die horribly for not doing so. Probably.).

1.2 The next step is to download a copy of the source code for the *c*GENIE model as follows (all this is done in the shell window of your `iwan` computer account):

(1) To get a (read-only) copy of *c*GENIE: from the home directory (`~`), type:

```
$ svn co https://svn.ggy.bris.ac.uk/subversion/genie/branches/cgenie
 --username=genie-user cgenie
```

All this must be on a continuous line, with a S P A C E before '`--username`', and before `cgenie`.

(If you get asked about a 'certificate' – enter '`p`' to accept 'permanently'.)

Depending on the weather and phase of the moon, you may (or may not!) be asked for a password. If so – it is: `g3n1e-user`. Again – don't mix up the ONE ('`1`') with an 'el' ('`l`'). (The mystery character in question is a 'one' if you must know …)

Some of the files that are installed are quite large, and at times, it may appear like it is 'stuck'. Be patient! Installation should be complete within about 2-3 minutes (longer if everyone else is trying to do this at exactly the same time …)

(2) Change directory (see: Appendix I) to `~/cgenie/genie-main` and type:

```
$ make testbiogem
```

(3) At this point, the science modules are currently compiled in a grid and/or number of tracers configuration that is unlikely to be what you want for running experiments. Clean up (remove) all the compiled cGENIE modules, ready for re-compiling afresh from the source code by typing:

```
$ make cleanall
```

(4) That is almost it as basic installation goes. However, for running cGENIE using the '`runcgenie.sh`' script you will need to create the following directories in your home directory

```
cgenie_archive
cgenie_log
```

(Refer to Appendix I for the relevant linux commands if you need to, and note that you will have to change directory from where you currently are, which is currently: `cgenie/genie-main`, to your account 'home', by typing e.g. `cd` .)

1.3 You should now have the following the following files and directories (command: `ls` to list):

`cgenie`	[a directory containing model source code and **experiment configuration**]
`cgenie_archive`	[a directory containing **archived model results**]
`cgenie_output`	[a directory containing the **results of the model experiments**]
`cgenie_log`	[a directory containing redirected run-time output and error messages]

[The *c*GENIE *User Manual* contains a fuller but rather more tedious explanation of the directory structure and file locations.]

1.4 Later on you will be editing some configuration files. So now might be a good time to check that you can use the editor! (You will also be using the same editor to view some of the model output.)

You have two alternative options for editing and viewing text files, depending on whether you are a UNIX nerd with no life, or prefer anything to do with computers to be wrapped in cotton wool and covered with dollops of treacle.

EITHER: Use the linux `vi` application (or similar) if you are familiar with it. I think that this pretty much sucks as a text editor and life is far too short and brutal … so I will not *make* you ;)

OR ... Use a suitable linux-friendly text editor (NOT Micro$oft Notepad) in conjunction with the Secure File Transfer Client. For example: '`SciTE`' http://www.scintilla.org/SciTEDownload.html is suitable (note that you need to download from the link under the heading 'Windows Executables'). `Notepad++` (http://notepad-plus-plus.org/) is also good.

To set SciTE to automatically open the model configuration files: in the Secure File Transfer Client – go to Edit, then Settings… and from the SECOND File Transfer section of the list in the left-hand panel (there are TWO File Transfer section entries and you are after the one near the bottom of the lest), click on the button for If a file association is missing, use this application to open the file. Then from `Program Files` on the C drive of the Windoz machine, find the SciTE editor directory (called: Scintilla Text Editor) and its program executable inside (`SciTE.exe`). Click on `OK` to close the `Settings` dialogue box. Then under `File` in the main menu: `Save Settings`.

It should now be possible to double-click on a file in the Secure File Transfer Client and it will open like magic (almost)! Try opening `runcgenie.sh` (directory: `cgenie/genie-main`) in this way. If you edit and save the file, you will be asked whether you want to transfer it back to the remote machine and also whether you want to over-write the original file. Simply click `Yes` to both.

If you log out of Windoz then you may have to re-do these settings …

2. Running the model ('interactively', in a shell window)

2.1 The strategy for running the model is as follows:
At the command-line (`$`) in the `genie-main` directory (not your home directory), you will be entering in a command (`runcgenie.sh`) together with a list of parameters that will be passed to the model, and as if by magic the model will run (or sometimes not):

```
$ ./runcgenie.sh #1 #2 #3 #4 (#5)
```

You must list at least 4 parameters after `./runcgenie.sh`, separated by S P A C E S and on a single continuous line (even if it 'wraps' around across 2 lines of the screen). For example:

```
$ ./runcgenie.sh cgenie_eb_go_gs_ac_bg.worbe2.ANTH LABS exp1_modern 10
```

parameter number = ↑ #1 ↑ #2 ↑ #3 ↑ #4

(Take care not to confuse an el ('`l`') with a one ('`1`') when typing this in ... (it is a 'one' here).)

These parameters are:

#1 … is the name of the required base (or 'basic') configuration ('*base-config*') of the model.

Initially, we will mostly be using the base config: **`cgenie_eb_go_gs_ac_bg.worbe2.ANTH`**, which specifies the cGENIE climate model components: GOLDSTEIN ocean (`go`) + (GOLDSTEIN) sea-ice (`gs`) + EMBM atmosphere (`eb`) together with ocean (`bg`) and atmosphere (`ac`) carbon cycle modules (and a FULL-ish selection of ocean geochemical tracers). The ocean circulation component is configured with 8 vertical levels and is forced with annual average insolation. This configuration is basically as described in *Ridgwell et al.* [2007].

#2 … is the name of the subdirectory (if any) containing the user configuration ('*user-config*') file (i.e., the file containing the specification of a particular experiment). In the particular file structure adopted here, it will be: **`LABS`**. (If a *user-config* to be used does not live in a subdirectory of `cgenie/genie-userconfigs`, then a '`/`' is passed as this parameter (a blank or space will be hideously mis-interpreted …).)

#3 … is the name of the experiment itself. There must be a file in the directory specified by parameter #2 (`cgenie/genie_userconfigs/LABS`) with exactly the same name as you enter here for parameter #3. i.e. the actual experiment is defined by the *user-config* file. Here, the experiment is called: **`exp1_modern`**.

#4 … is the run length of the experiment in years – this must be entered as an integer (even though cGENIE will actually be treating it as a real number). In this example, we are running for only **`10`** years.

There is also one optional (5th) parameter (not used in this particular example and so left out (blank)):

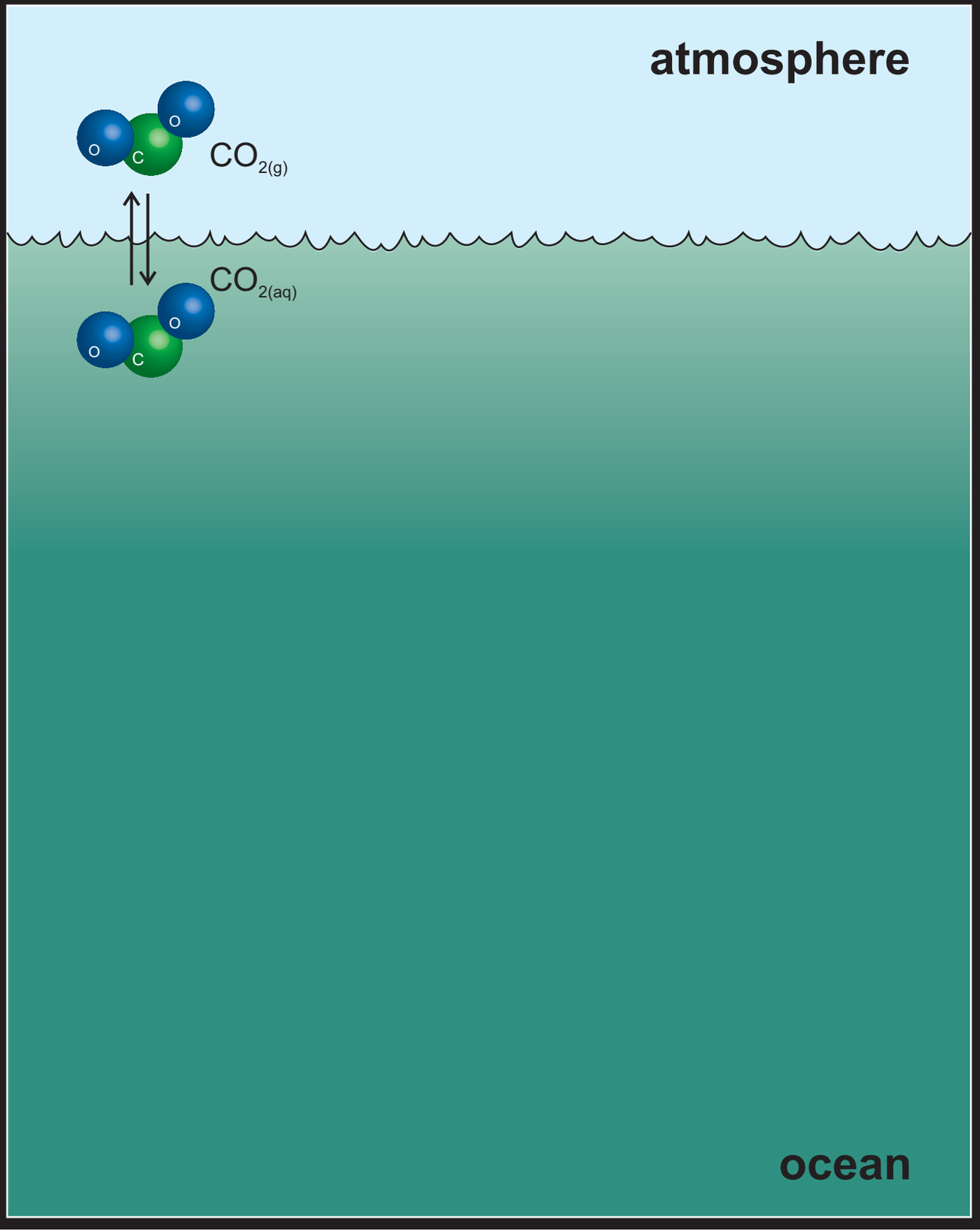
#5 … is the full path (and name) of any model experiment that you wish to continue on from the end of (called a '*restart*' file). If the 5th (optional) parameter is not passed then cGENIE will run from 'cold'. If the 5th parameter is present then cGENIE will attempt to run from a previously generated (*restart*) state. *Restarts* will be discussed later ...

atmospheric CO_2 concentration (ppm)

390
380
370
360
350
340
330
320
310

1950
1960
1970
1980
1990
2000
2010

year

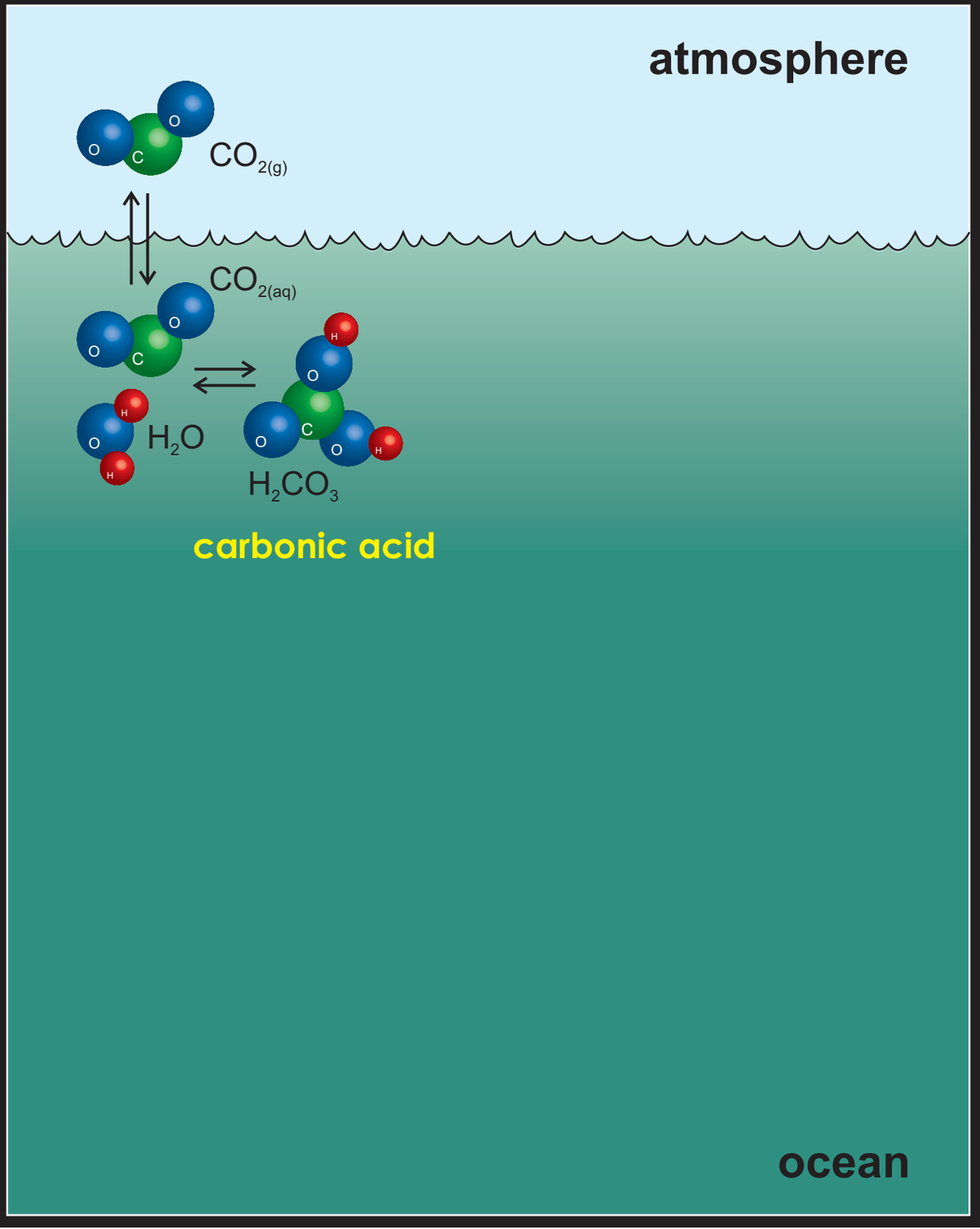


CO_2 chemistry in seawater

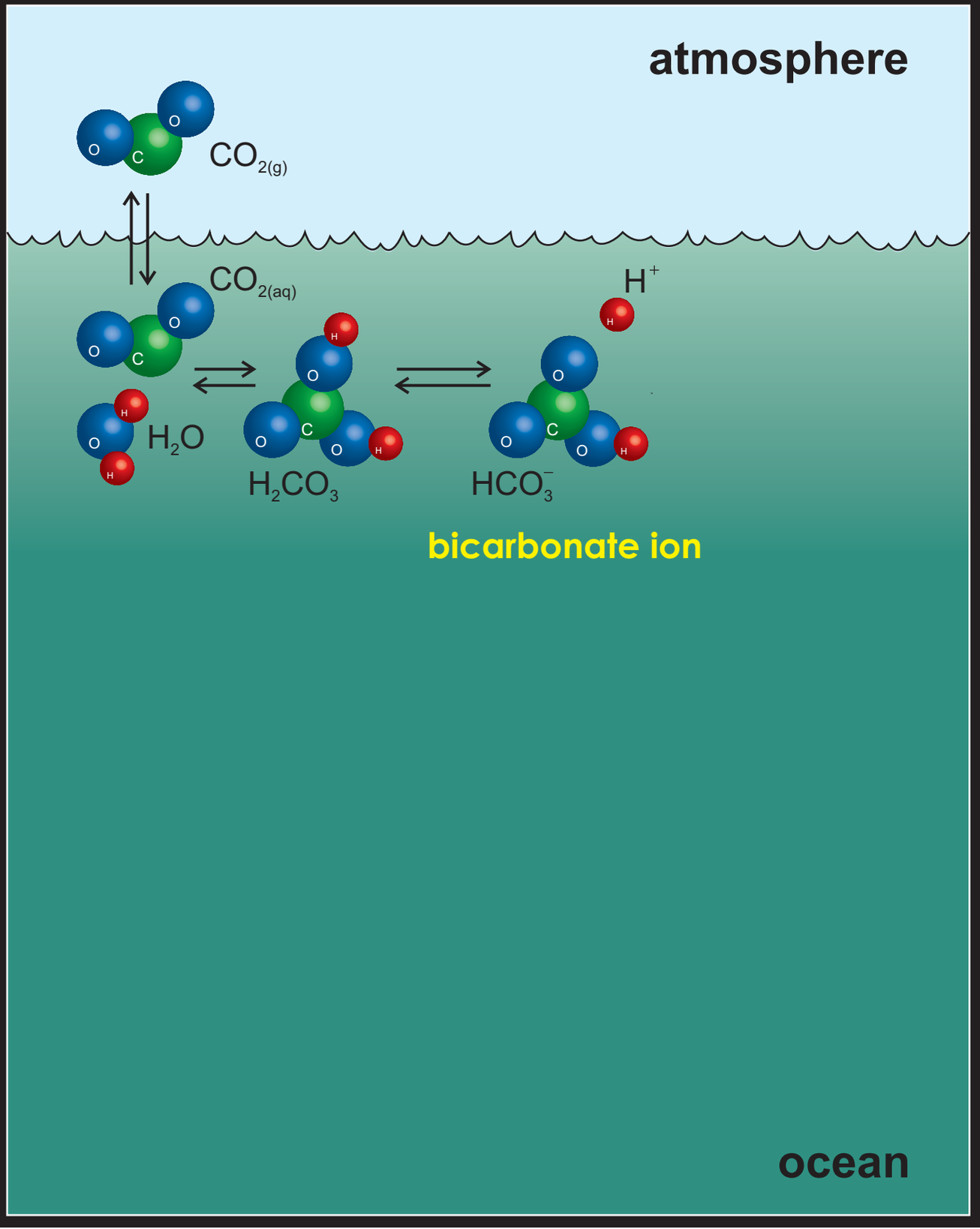
From: *Barker and Ridgwell* [2012]

http://www.nature.com/scitable/knowledge/library/ocean-acidification-25822734

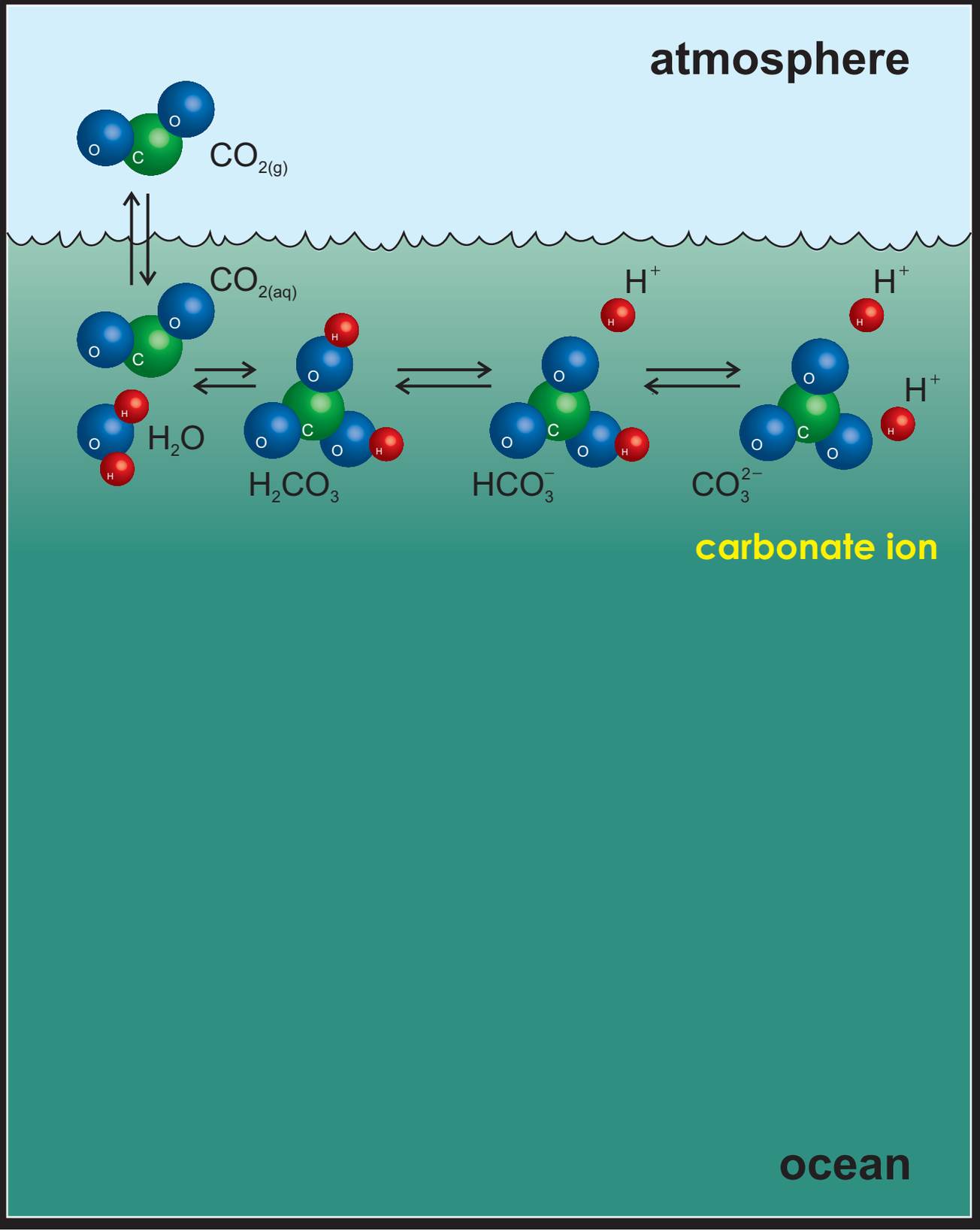
CO_2 chemistry in seawater

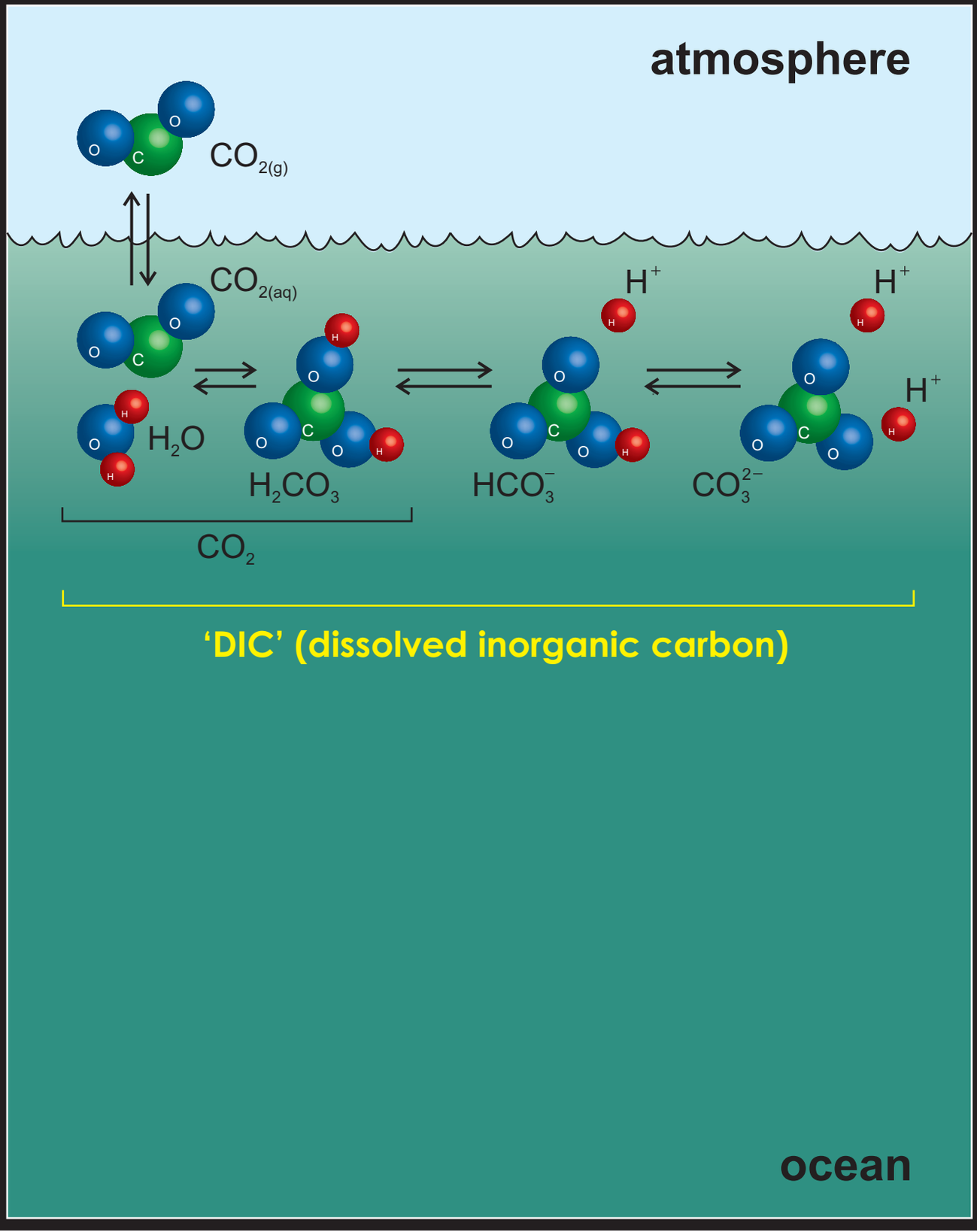


CO_2 chemistry in seawater



CO_2 chemistry in seawater





CO_2 chemistry in seawater

So ... when CO_2 dissolves in seawater, the complex equilibrium distribution of dissolved carbon between $CO_{2(aq)}$, HCO_3^-, and CO_3^{2-}, is perturbed.

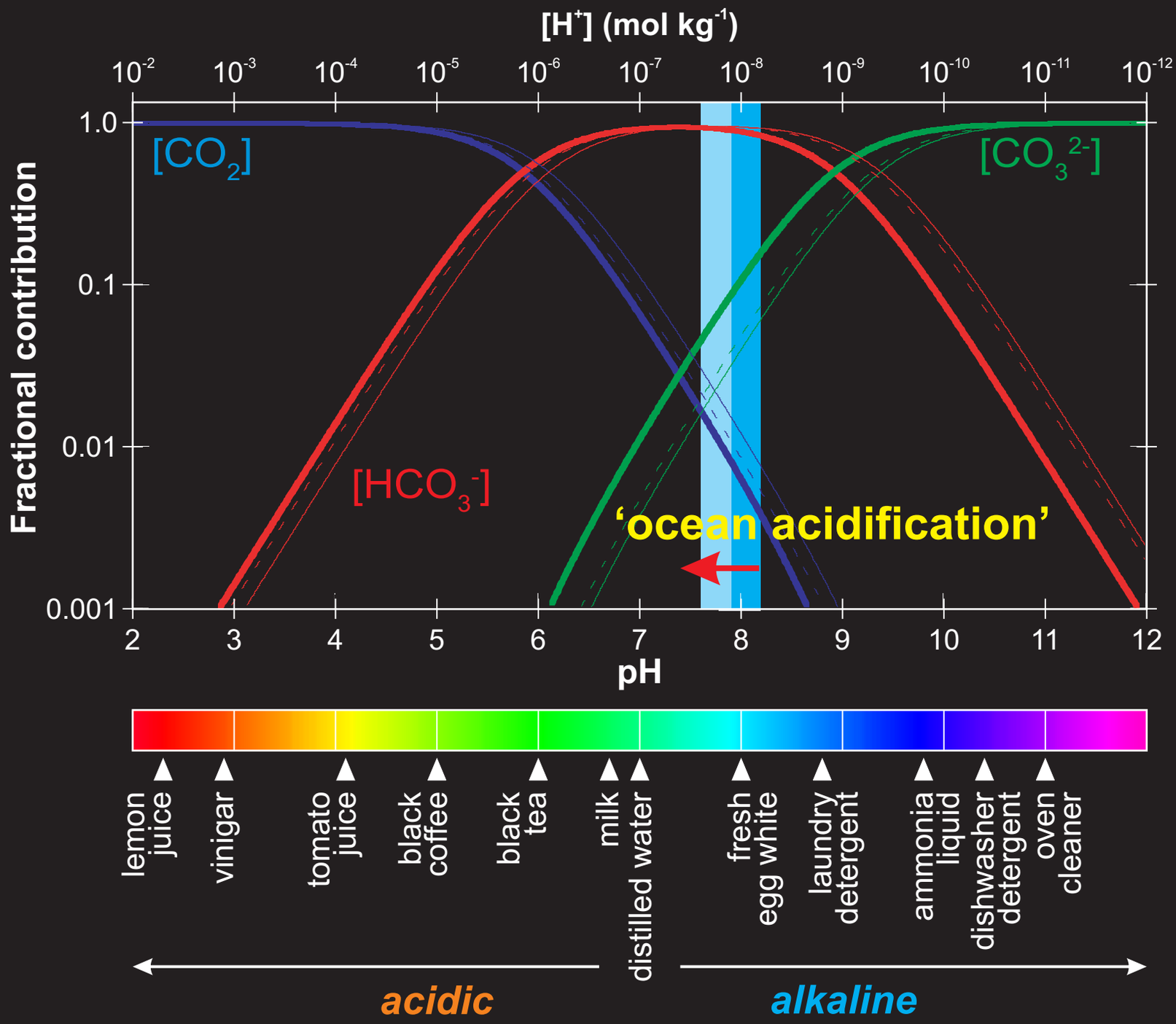
While there is more total dissolved carbon, carbonate ion (CO_3^{2-}) concentrations do not increase because the hydrogen ion (H^+) equilibrium is also perturbed.

To a first approximation, the net outcome can be written:

$$CO_{2(aq)} + CO_3^{2-} + H_2O \rightarrow 2HCO_3^-$$

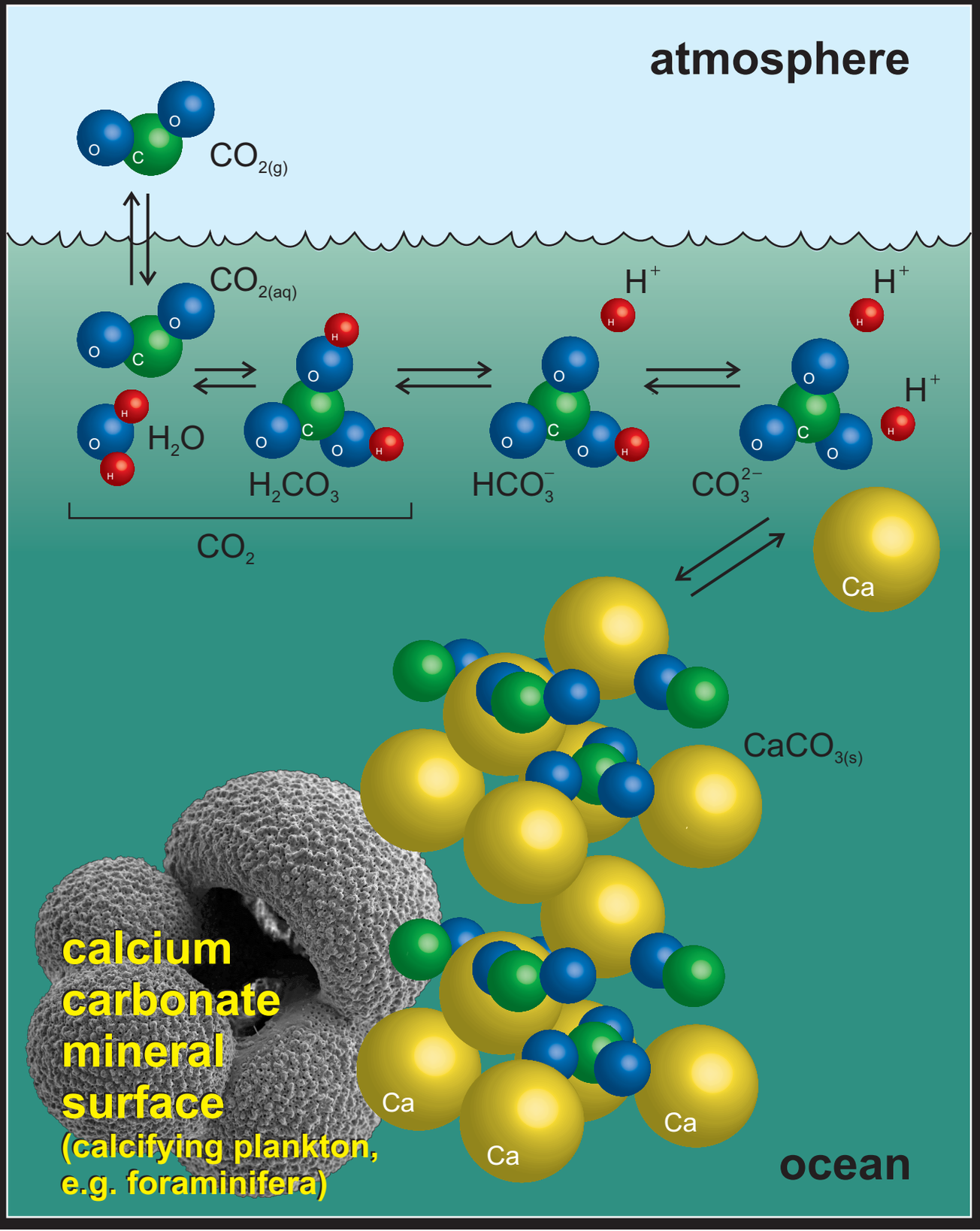
(However, a small part of the resulting HCO_3^- dissociates into CO_3^{2-} and H^+, which is where the 'acidification' in ocean acidification comes from.)

The nature of pH (and acidity vs. alkalinity)



From: *Barker and Ridgwell* [2012]
http://www.nature.com/scitable/knowledge/library/ ocean-acidification-25822734

CO_2 chemistry & mineral phases



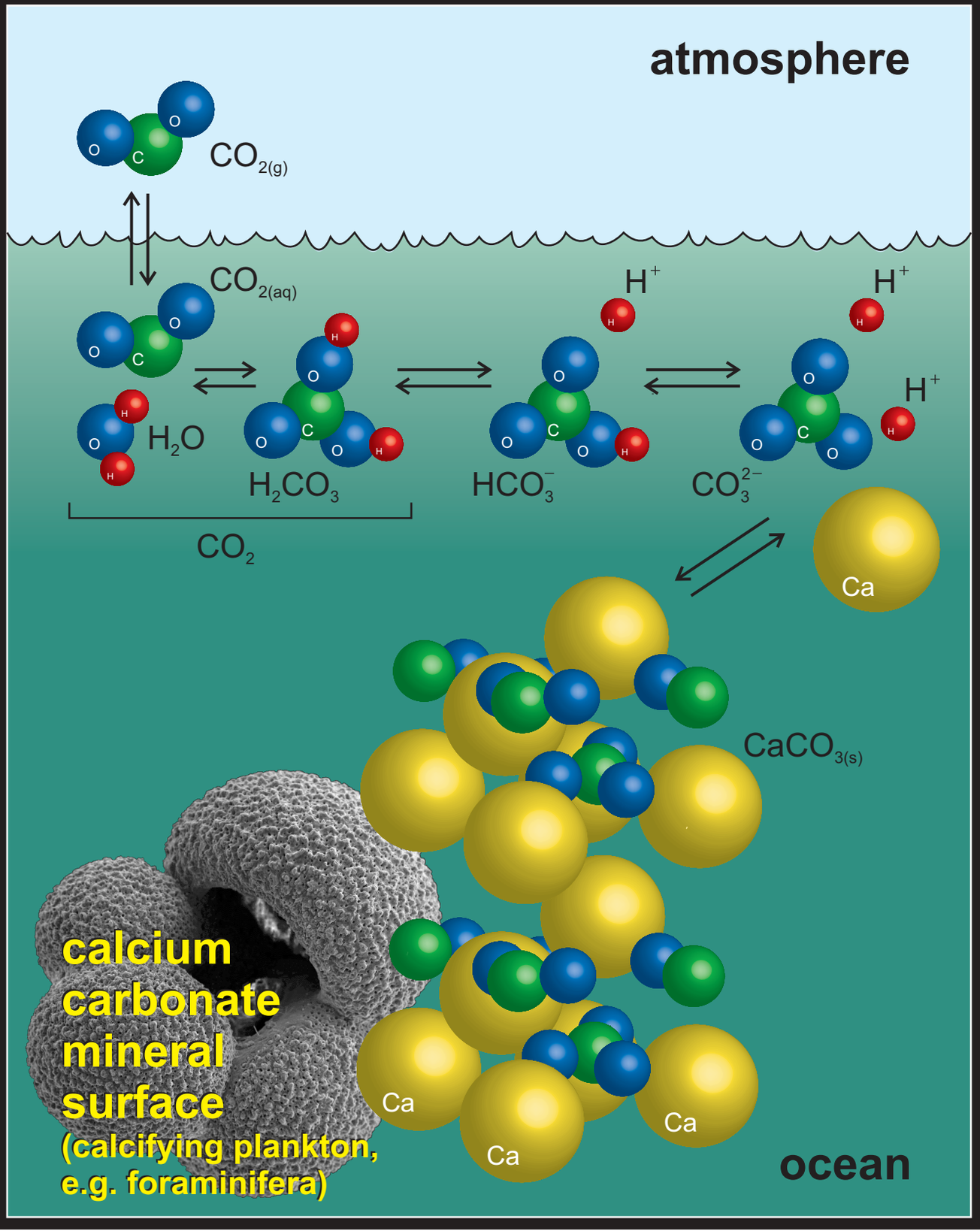
Aragonite: less stable

orthorhombic polymorph (e.g., many corals, pteropods)

Calcite: more stable

(and more abundant) trigonal polymorph (e.g., coccolithophorides, foraminifera)

CO_2 chemistry & mineral phases

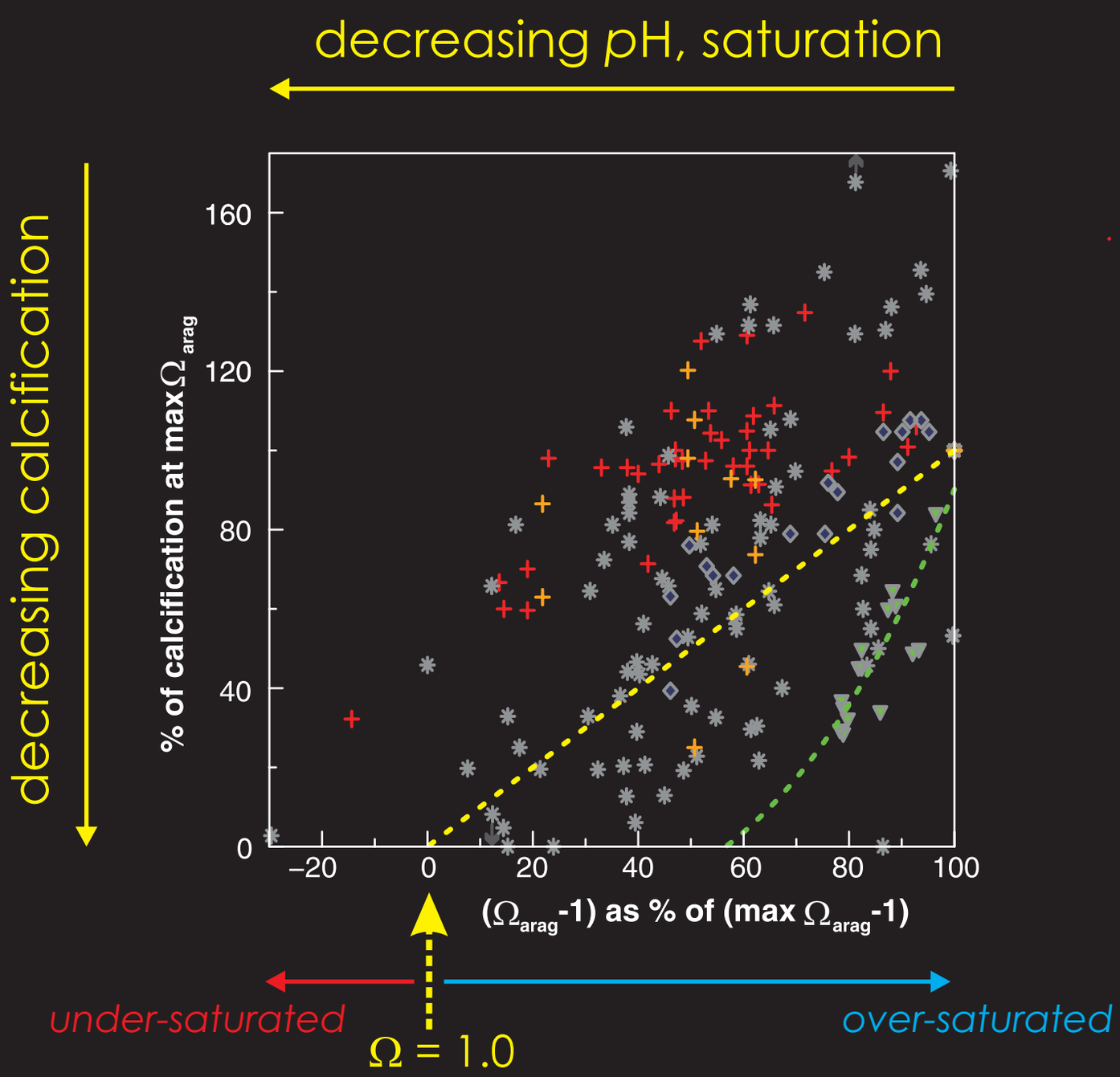


The addition of (fossil fuel) CO_2 to seawater results in a decrease in carbonate ion (CO_3^{2-}) concentration and 'ocean acidification'. A decrease in CO_3^{2-}, in turn, suppresses the stability of $CaCO_3$, defined by its *saturation state*:

$$\Omega = [Ca^{2+}] \times [CO_3^{2-}] / k$$

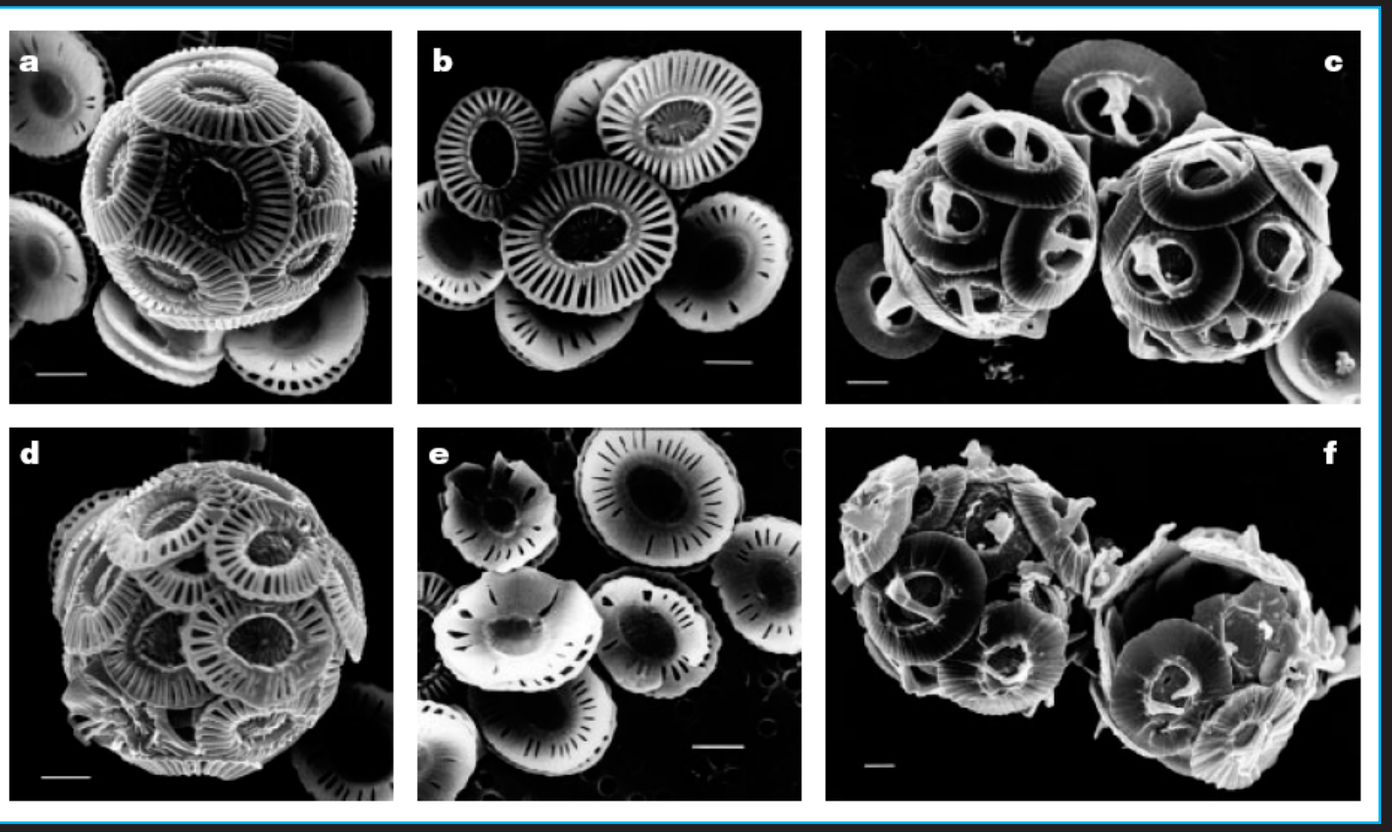
⇒ The thermodynamic efficiency of precipitating $CaCO_3$ is a function of $[CO_3^{2-}]$ (and carbonate 'saturation').

Ocean biological consequences(?)



Pandolfi et al. [2011] (*Science*)

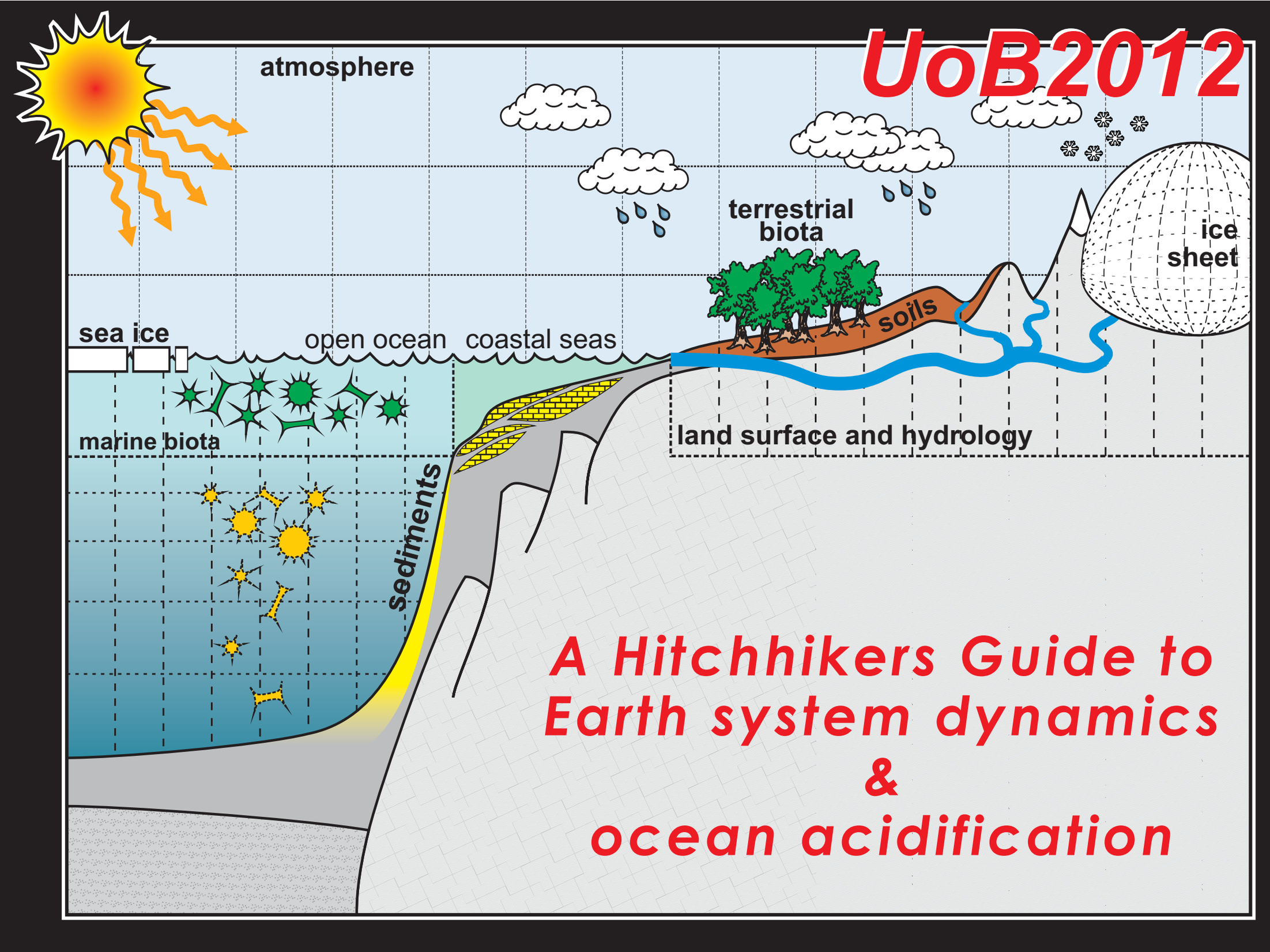
Ocean biological consequences(?)



low CO_2 (high pH)

high CO_2 (low pH)

SEM micrographs of coccolithophorids under different CO_2 conditions
Riebesell et al. [2000] (*Nature* 407)


UoB2012
atmosphere
terrestrial biota
ice sheet
soils
sea ice
open ocean
coastal seas
marine biota
sediments
land surface and hydrology
A Hitchhikers Guide to Earth system dynamics & ocean acidification