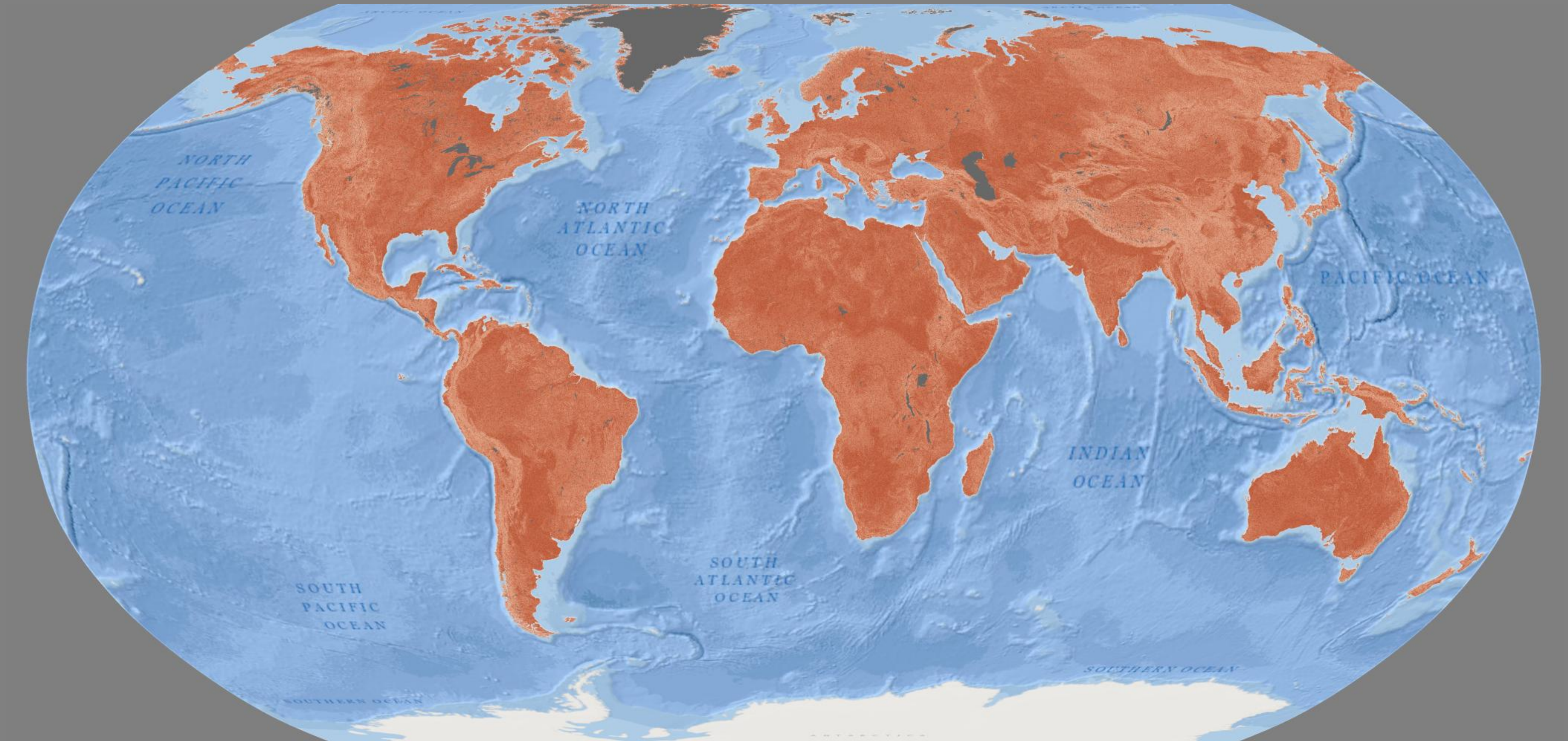
Modelling the Biosphere-Atmosphere System



Ecosystems series

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Modelling the Biosphere-Atmosphere System

A quick tour of the whole field of Ecological Modelling (I'm not here to convince you that this is a field you should go into: this is just a quick and (reasonably) friendly tourist visit).

PART 1: *What kinds of models are there?*

Niche-Based Models (NBMs) and Mechanistic Models

An Example about Wine

Land Surface Models (LSMs)

Applications of LSMs

NBMs vs. Mechanistic Models

PART 2: *How to actually do modelling*

Systems Analysis (System Dynamics)

Coding (inc. a demonstration)

Geographic Information Systems (GIS) (inc. a demonstration)

Sundry points

PART 3: *Case Study of the Amazon Dieback*

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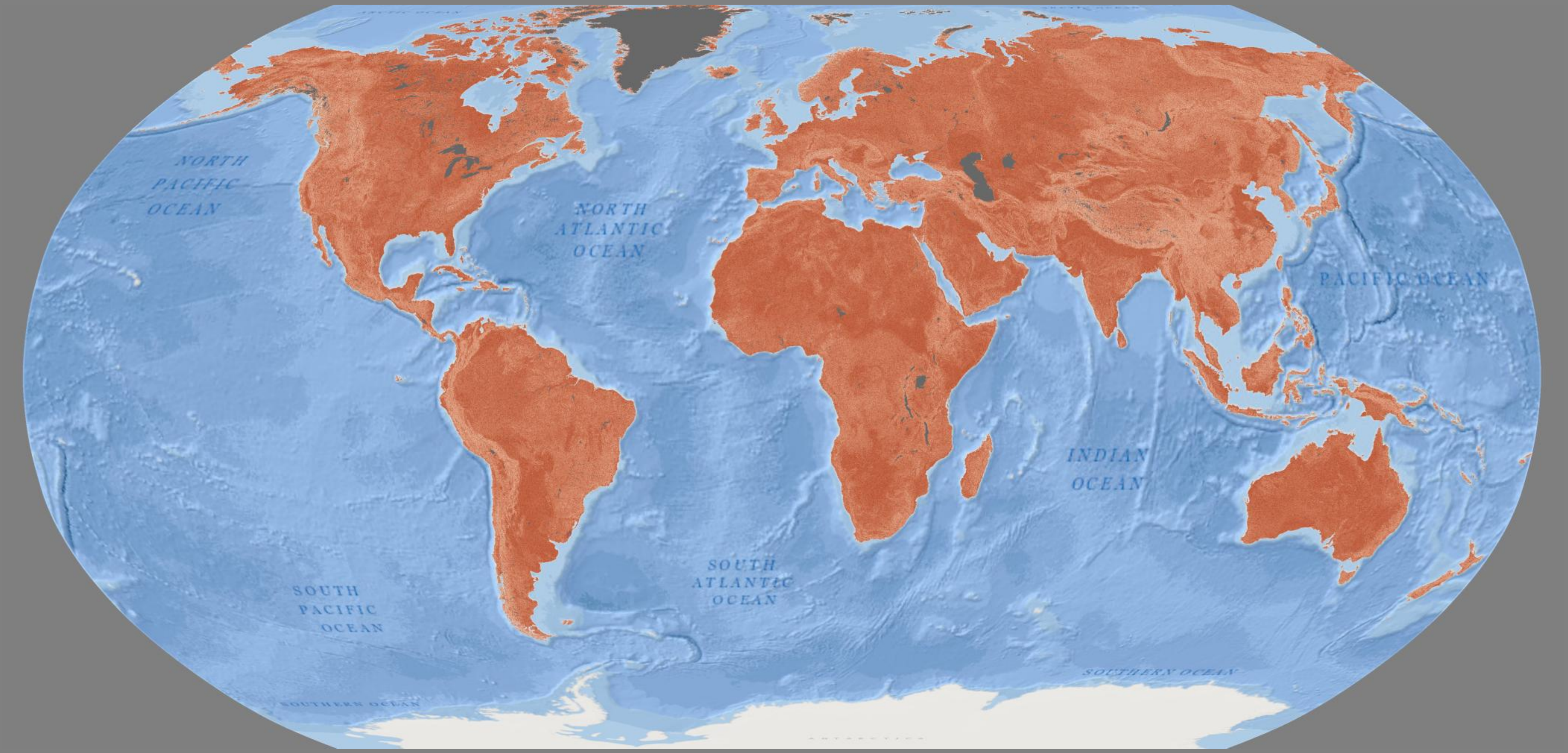

PART 1: Niche-Based Models (NBMs) and Mechanistic Models

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Niche-Based Models and Mechanistic Models

In Ecology there is a major division between two types of **simulation model**:

NICHE-BASED MODELS (NBMs)

Also called EMPIRICAL/DATA-BASED MODELS

(e.g. Climate Envelope models, Bioclimatic Envelope models)

and

MECHANISTIC MODELS

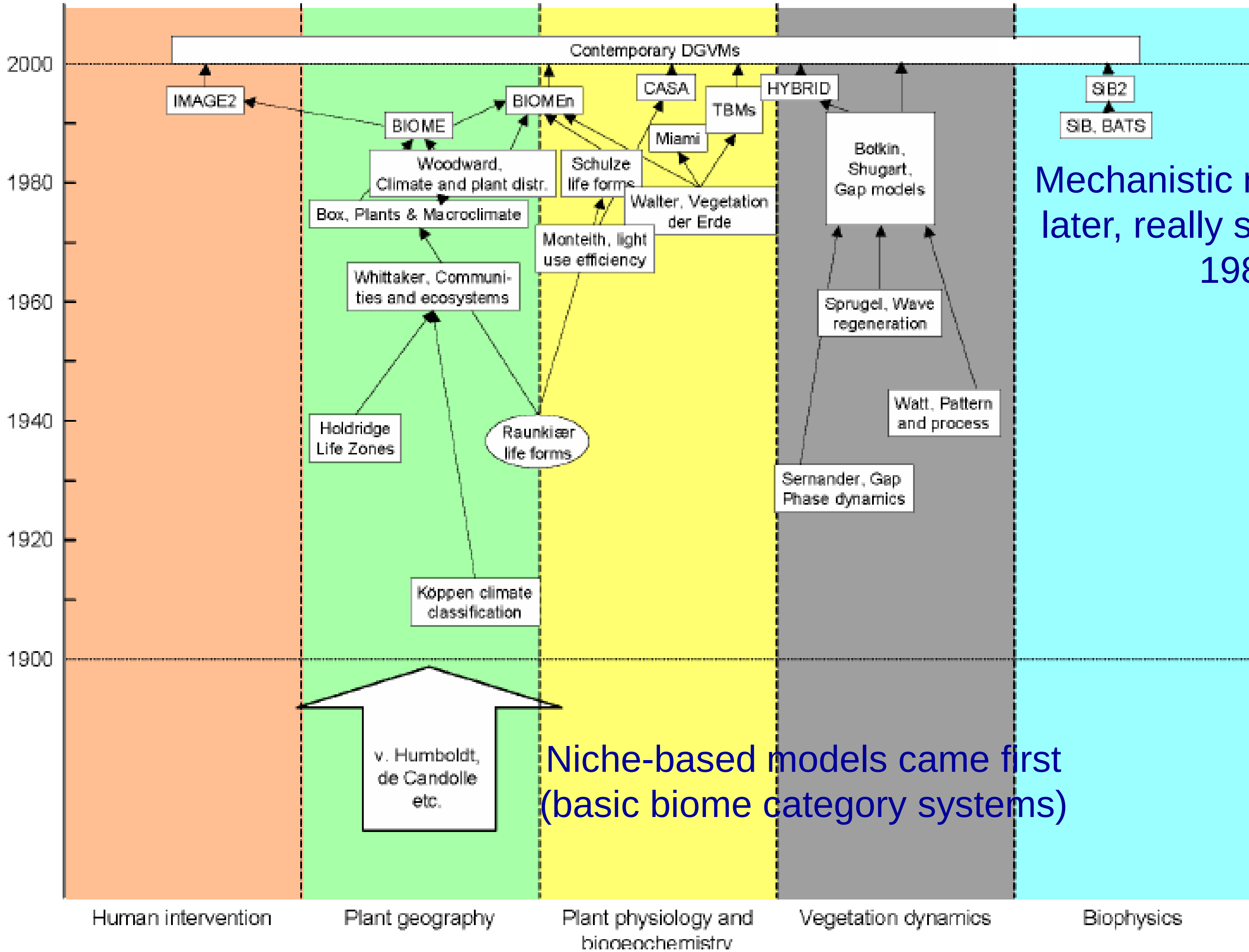
Also called PROCESS-BASED MODELS

(e.g. Land Surface Models (LSMs); Dynamic Global Vegetation Models (DGVMs), Agent-based models, Neutral models)

Both NBMs and mechanistic models can be either **deterministic** or **stochastic**. Deterministic means every time you run it you get the same result, stochastic means there is an element of randomness in the simulation.

Regression fits, **ANOVAs**, **Generalised Linear Models (GLMs)** and **Digital Elevation Models (DEMs)** are also models, but they're not simulation models and won't be discussed here.

The Development of Ecosystem Simulation Models



Mechanistic models came later, really starting in the 1980s

Niche-based models came first (basic biome category systems)

From Prentice *et al.* (2007)

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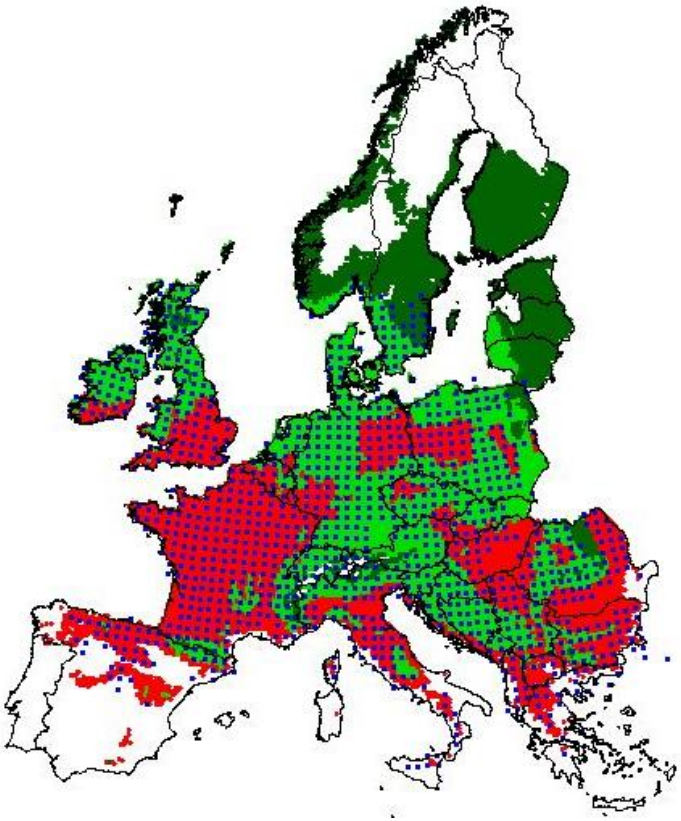
Niche-Based Models (NBMs)

Prediction for sessile oak (*Quercus petraea*) from the niche-based model BIOMOD (Wilfried Thuiller at Grenoble, France: http://www.will.chez-alice.fr/).

BIOMOD works by calculating regressions between current species distributions and climate, then taking future climate predictions and deducing likely future species distributions from them.



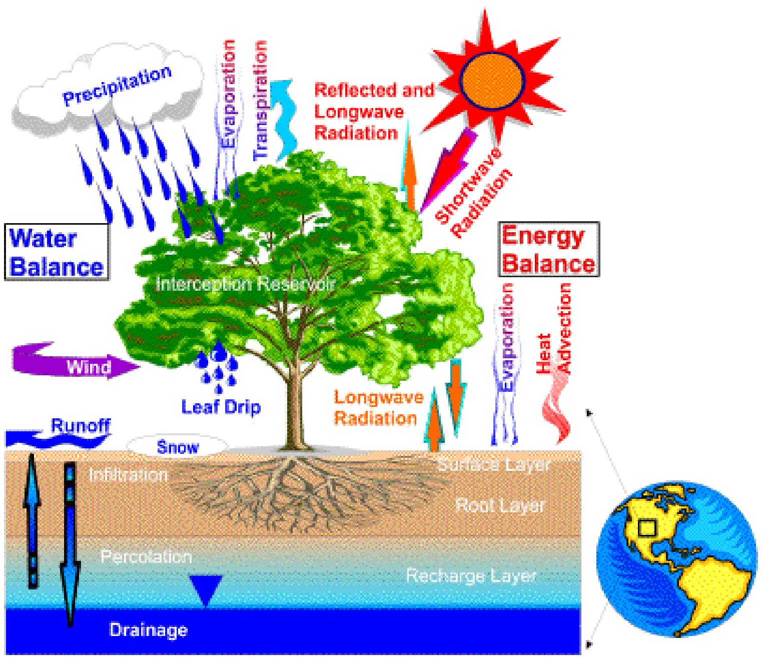
Loss of habitat by 2080

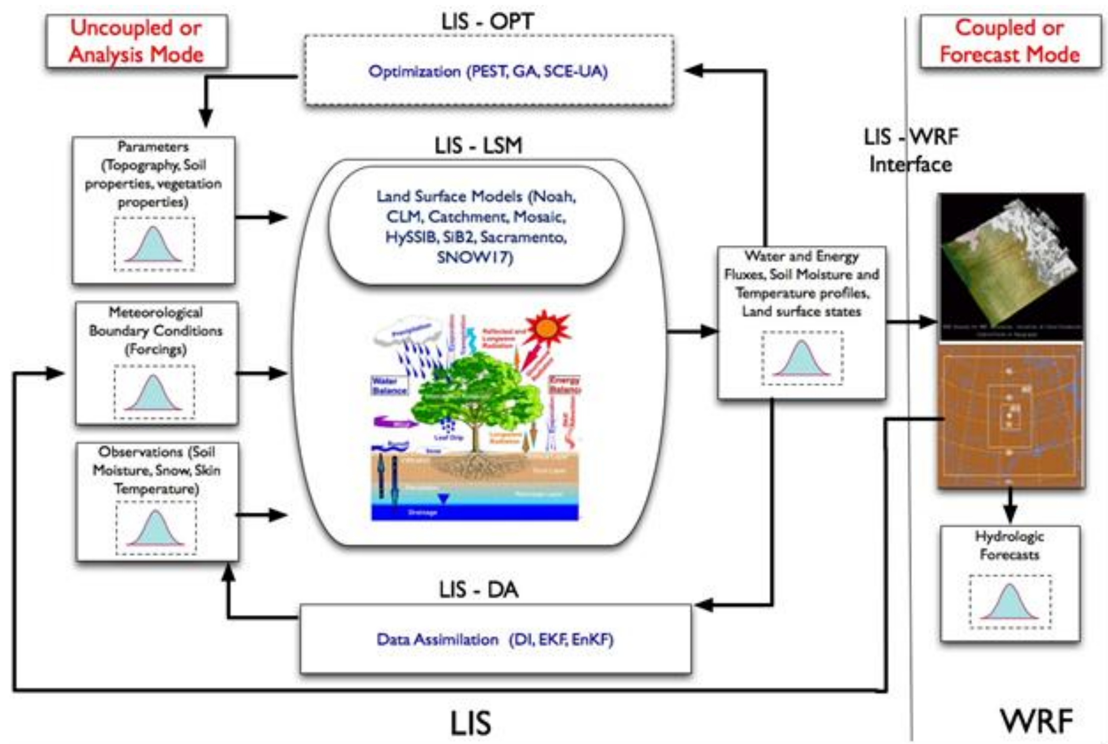
Stable habitat

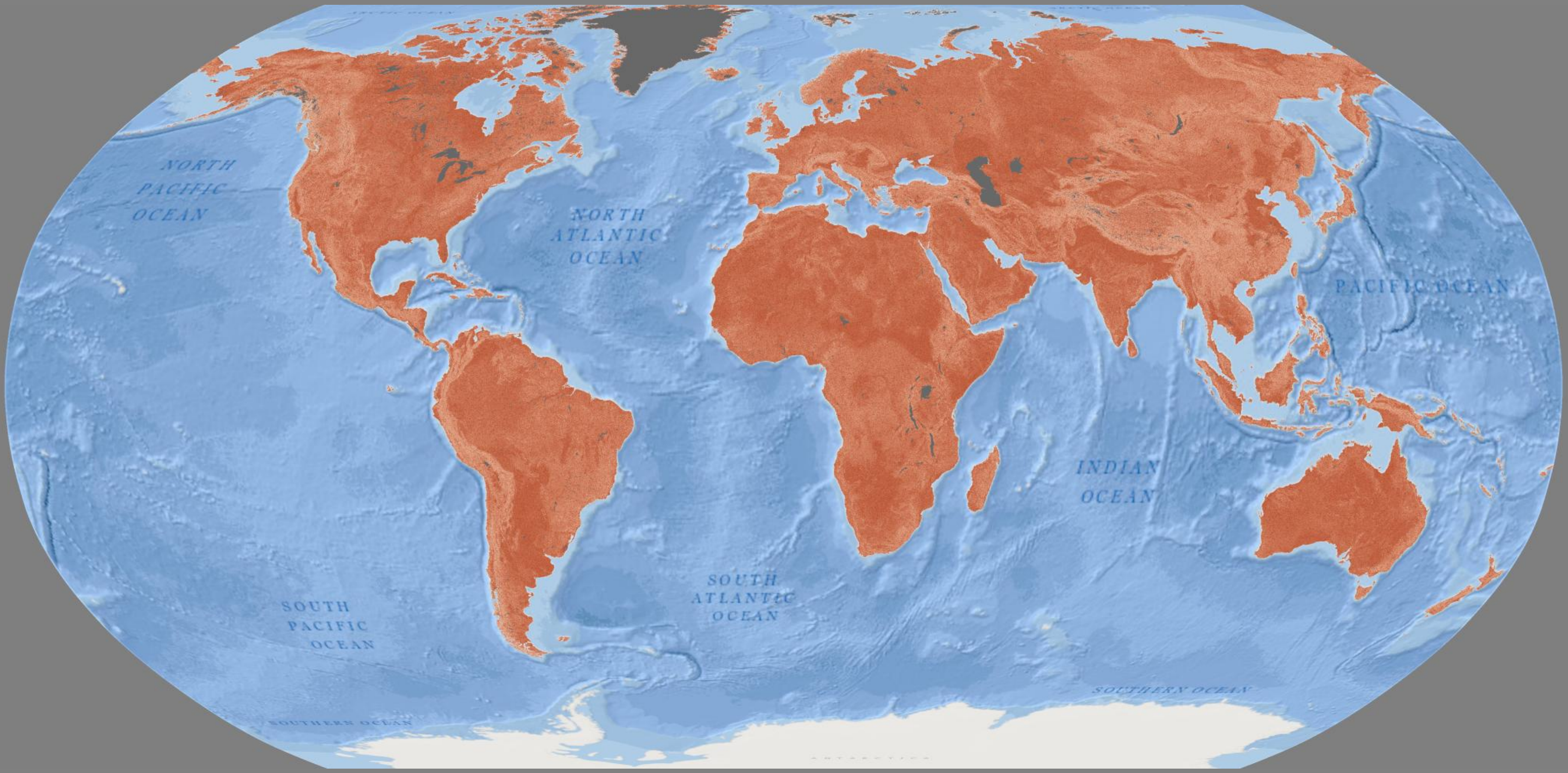
Gain of habitat

Mechanistic Models

The approach here is to break the whole ecosystem down into components and model each process individually.







An Example about Wine

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Niche-Based Models (NBMs): An Example about Wine

Wine quiz

Q1 This grape variety is a black grape used to make full-bodied red wine in Spain. It’s name is a diminutive of the Spanish word for « early » in reference to the fact that it ripens several weeks earlier than most Spanish red grapes. It is the main grape used in Rioja.

Q2 This variety of grape originated in the 17th Century in SW France. It was made famous because of its wide use in Bordeaux wines and it is widely planted in Napa Valley, California, Maipo Valley, Chile and Coonawarra, Australia. This grape was the world’s most widely-planted red wine grape before losing its crown to Merlot in the 1990s.

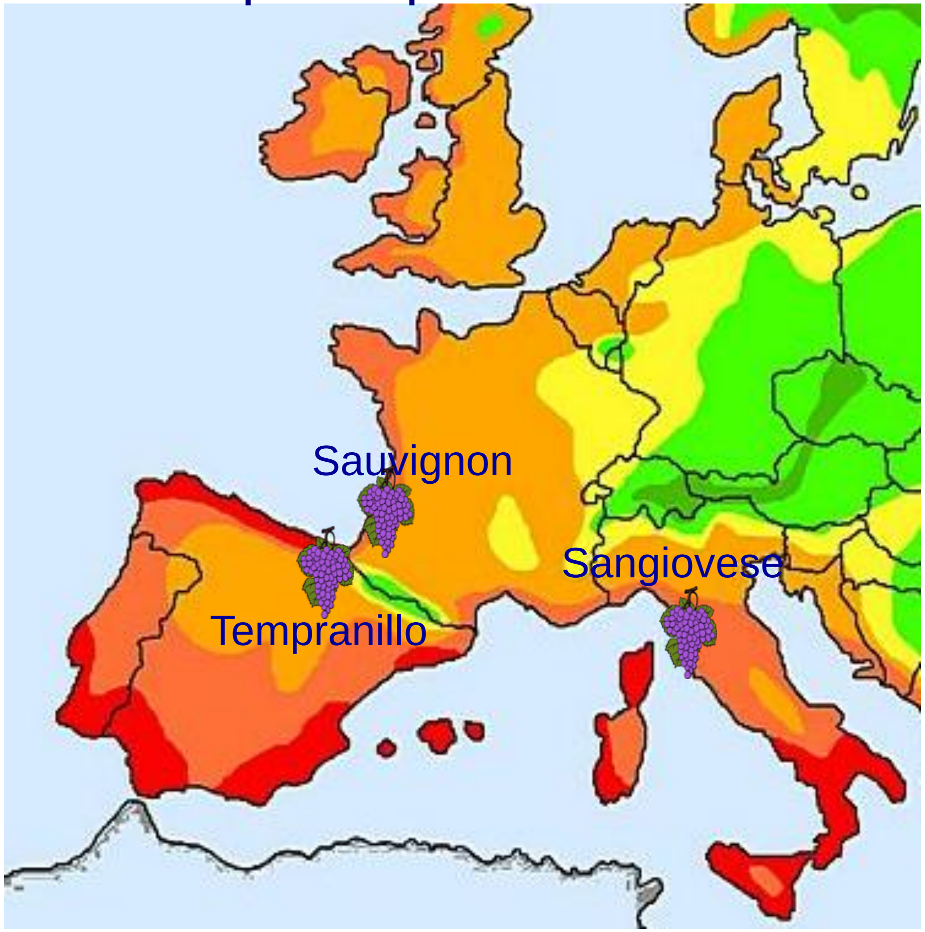
Q3 This Italian red wine grape is the single component of Brunello de Montalcino wine and is the predominant component of Chianti wines. It’s name is from the Latin for « blood of Jove ».

Niche-Based Models (NBMs): An Example about Wine

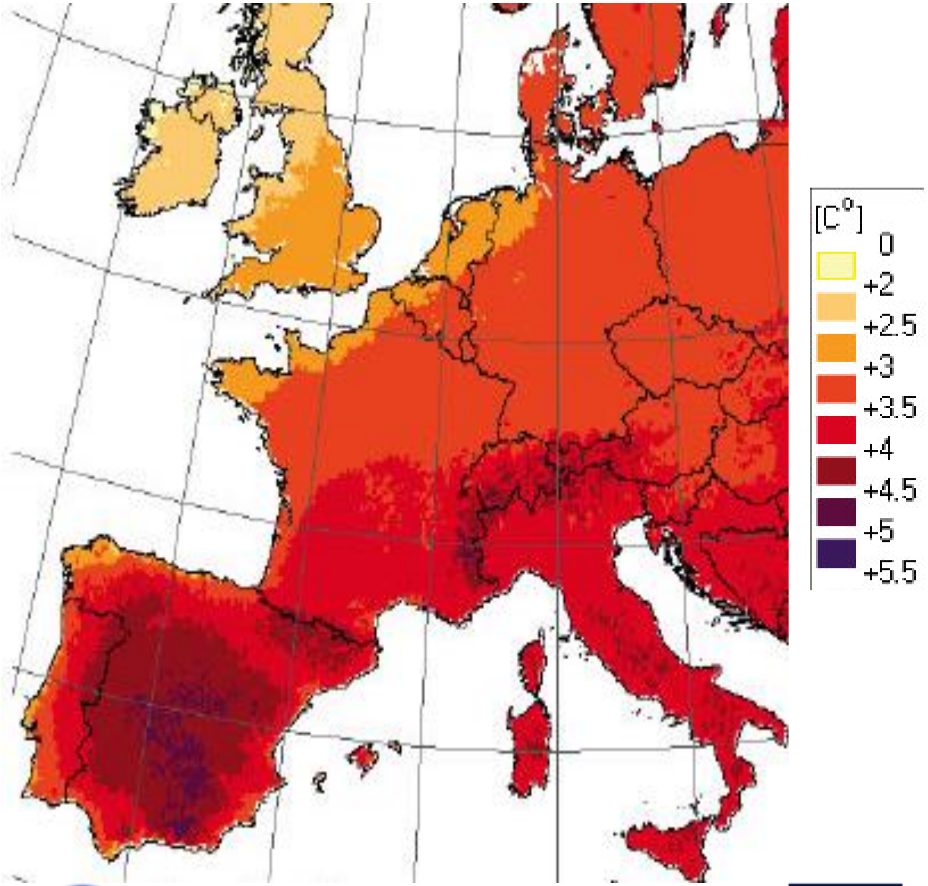
These grape varieties grow in well-known locations in Europe.

If climate change makes Europe ~4°C warmer, what will happen to the grapes?

Current European temperatures



Future temperature change



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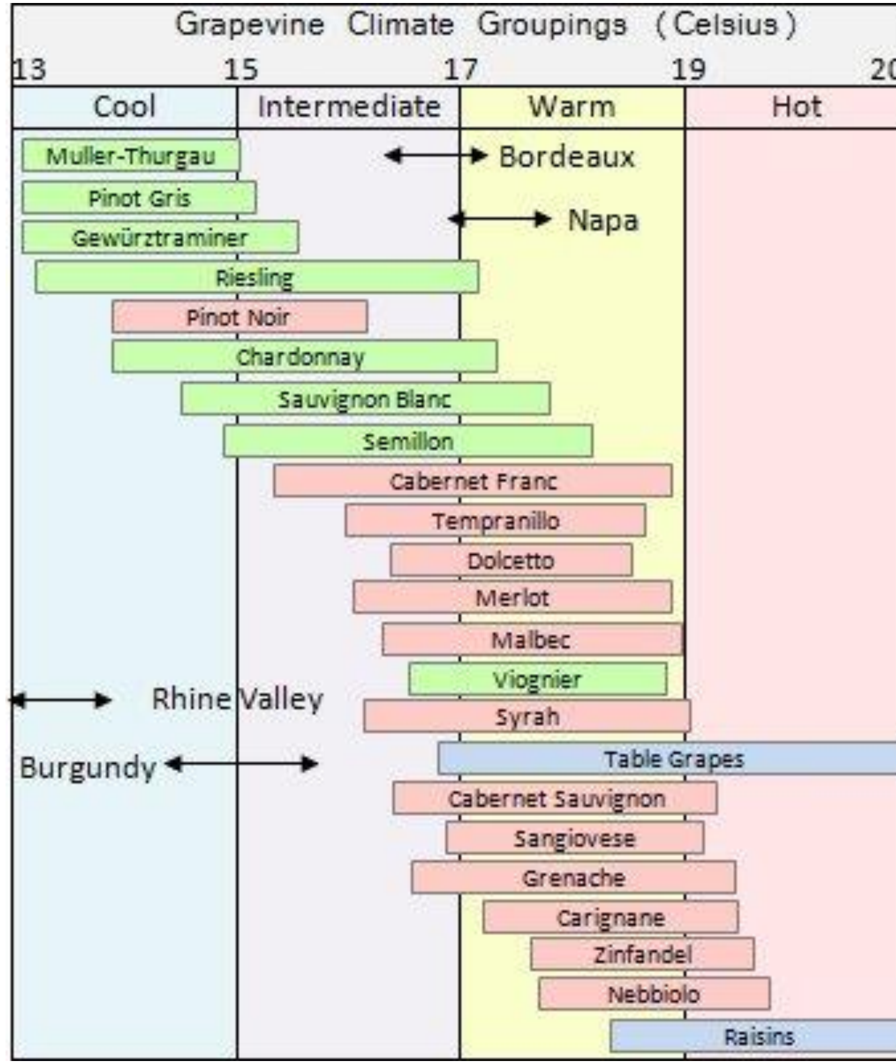
Niche-Based Models (NBMs): An Example about Wine

Next, we collect together data on the climatic tolerances of these grape varieties.

Grapes are well-known to have very well-defined temperature tolerances.

Effectively, we are assuming here that the bioclimatic niche of these grape varieties is defined wholly by temperature.



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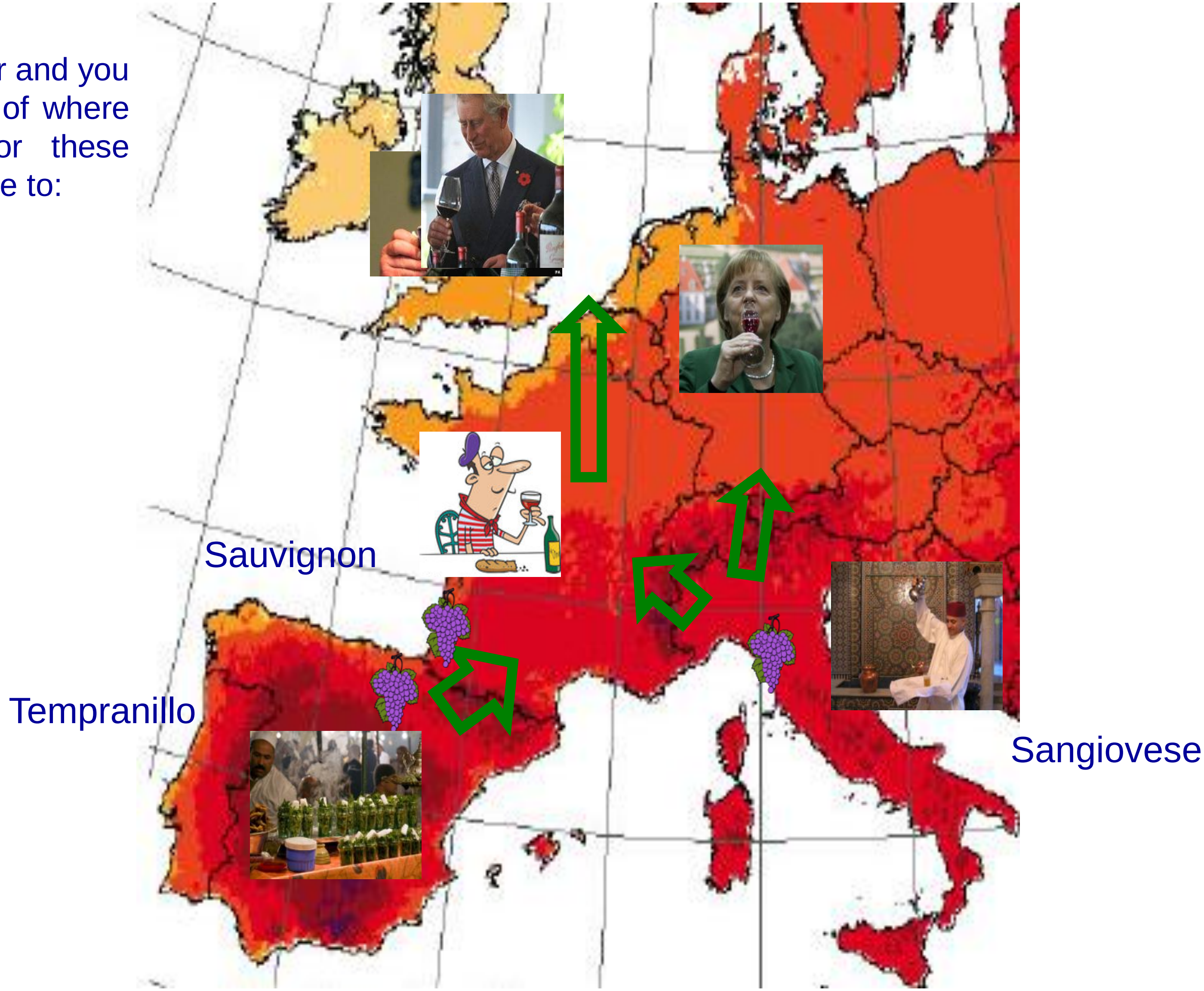
Niche-Based Models (NBMs): An Example about Wine

Now put this all together and you can make a prediction of where the growing areas for these grapes are likely to move to:



Niche-Based Models (NBMs): An Example about Wine

OK, maybe the mint tea will never replace wine, but this kind of analysis gets British wine-growers very excited (see this map where even the Scots are dreaming of vineyards ... !).

The wine industry in Europe is extremely concerned about what may happen to their grapes over the course of the next century and large amounts of money are at stake. Not only are they concerned about it: they are responding already to what these models predict will happen. For more, see the Oct 2012 article: http://qz.com/6578/what-is-global-climate-change-doing-to-our-wines/ .

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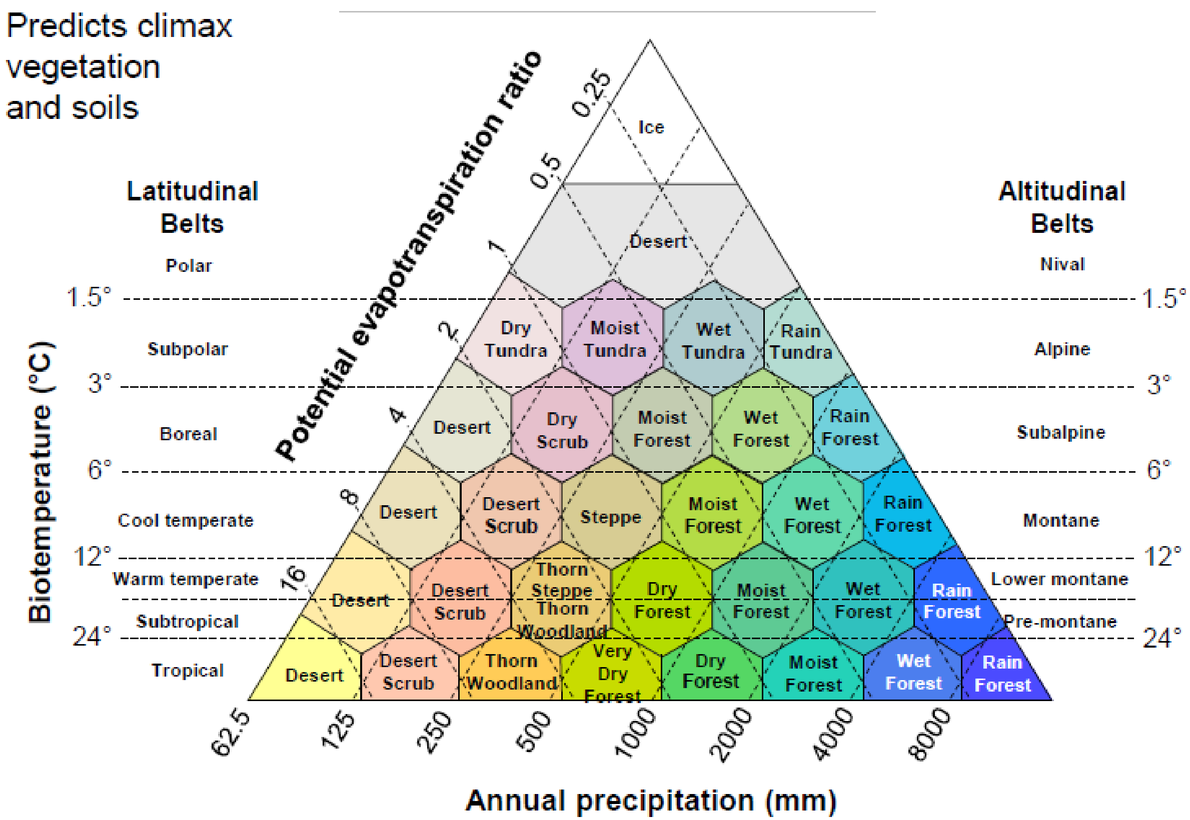
Niche-Based Models (NBMs)

This approach can be applied globally, of course. For that, you need to consider more habitat variables than just temperature, which means using a bioclimatic zones system. The most widely used in the tropics are Holdridge (below) and Köppen-Geiger.



Niche-Based Models (NBMs)

Application of an NBM to assess the likelihood of climate-driven conversion of Amazon rainforest to savanna (Malhi *et al.* 2009, PNAS).

Note that model no. 2 here predicts this Eastern Amazonian rainforest changing into savanna (=dieback). We'll return to this in the Case Study shortly.

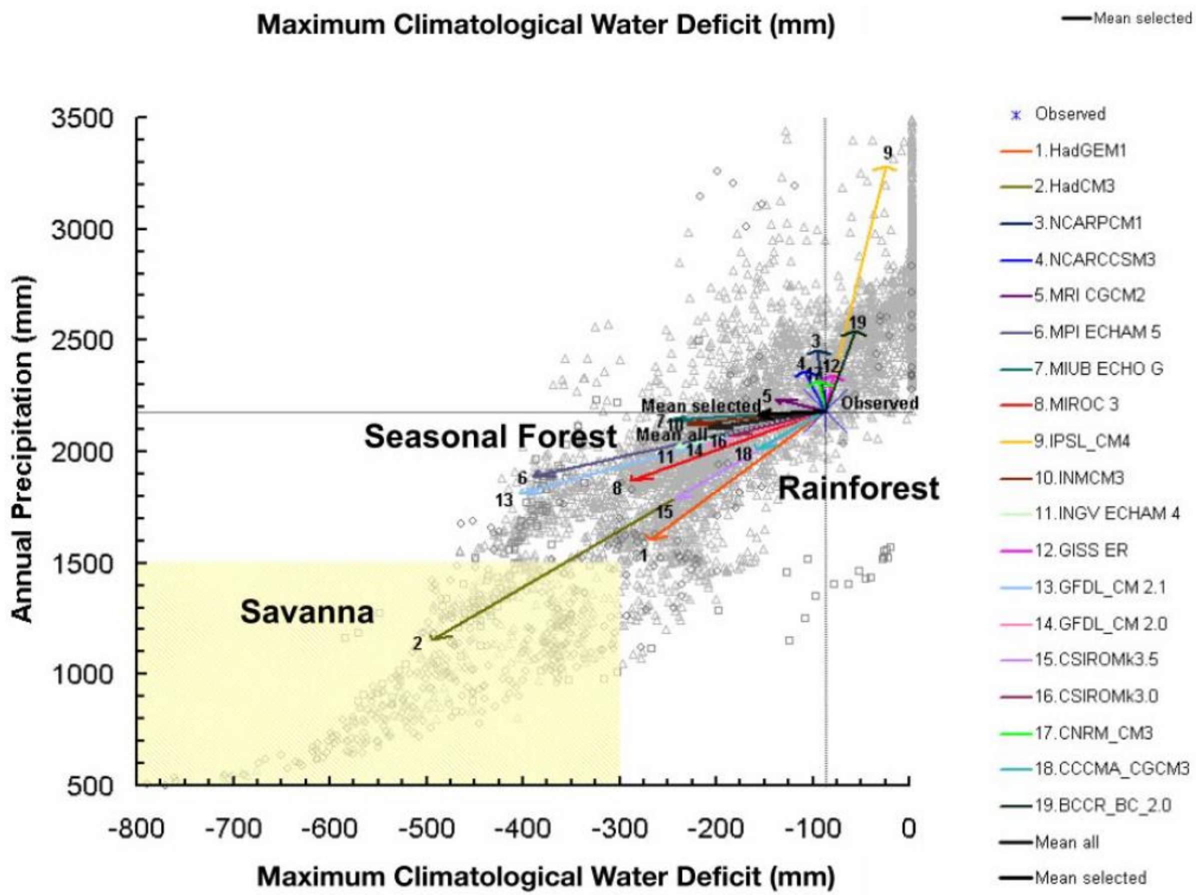


Fig. 2. An evaluation of GCM simulations in change of rainfall regime in E. Amazonia.
(*B*) The trajectories of changes in GCM rainfall regime when recalculated as relative changes forced to start from the CRU observed climatology. The tip of the arrow indicates the late 21st-century rainfall regime. Our suggested savanna zone is shaded (MCWD < -300 mm, AP < 1500 mm).

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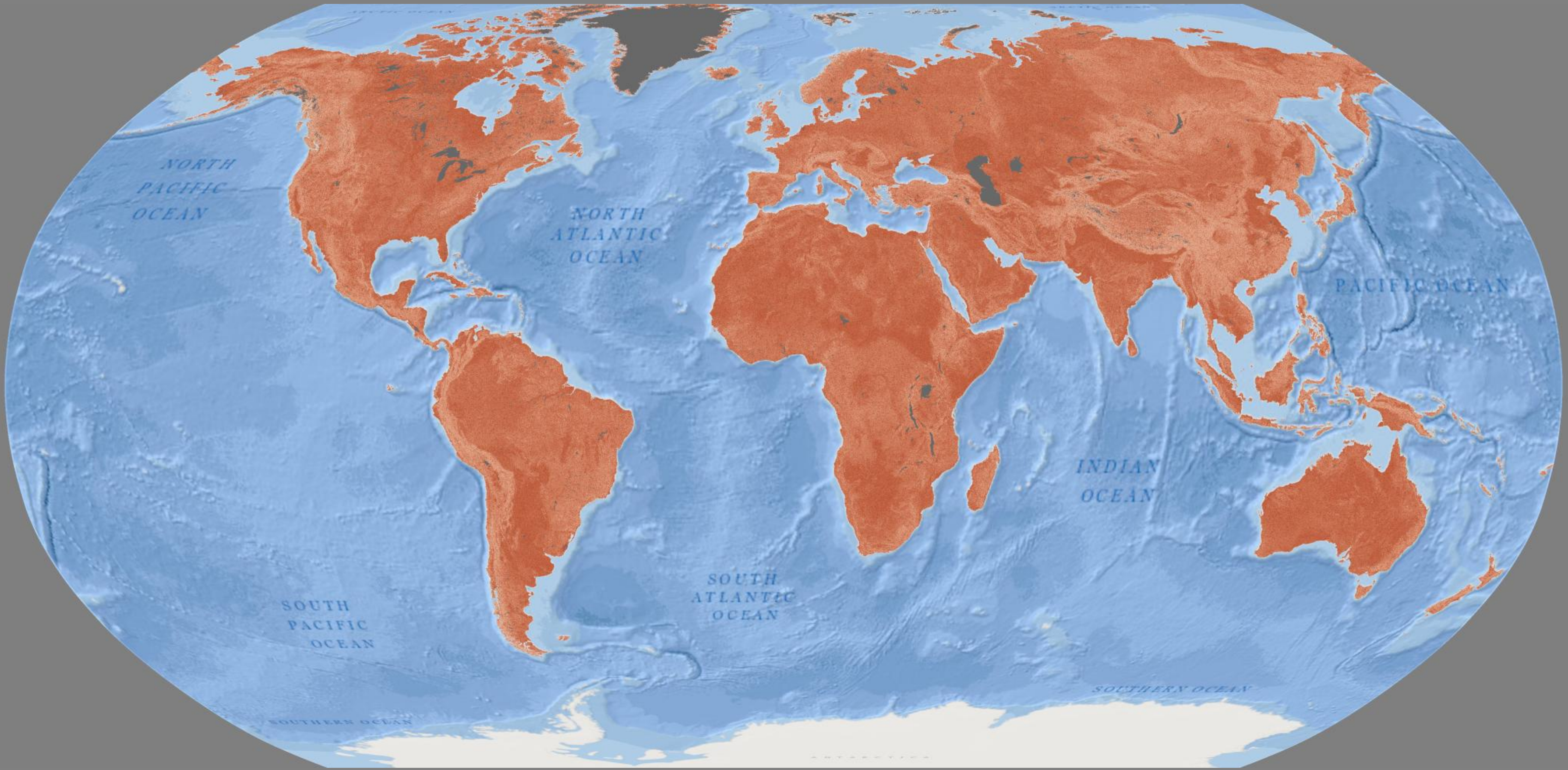

Land Surface Models (LSMs)

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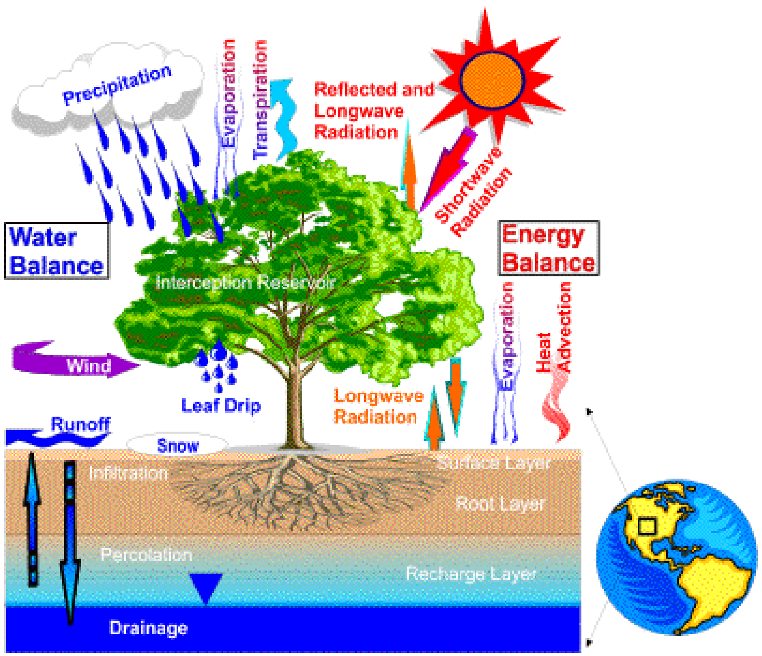
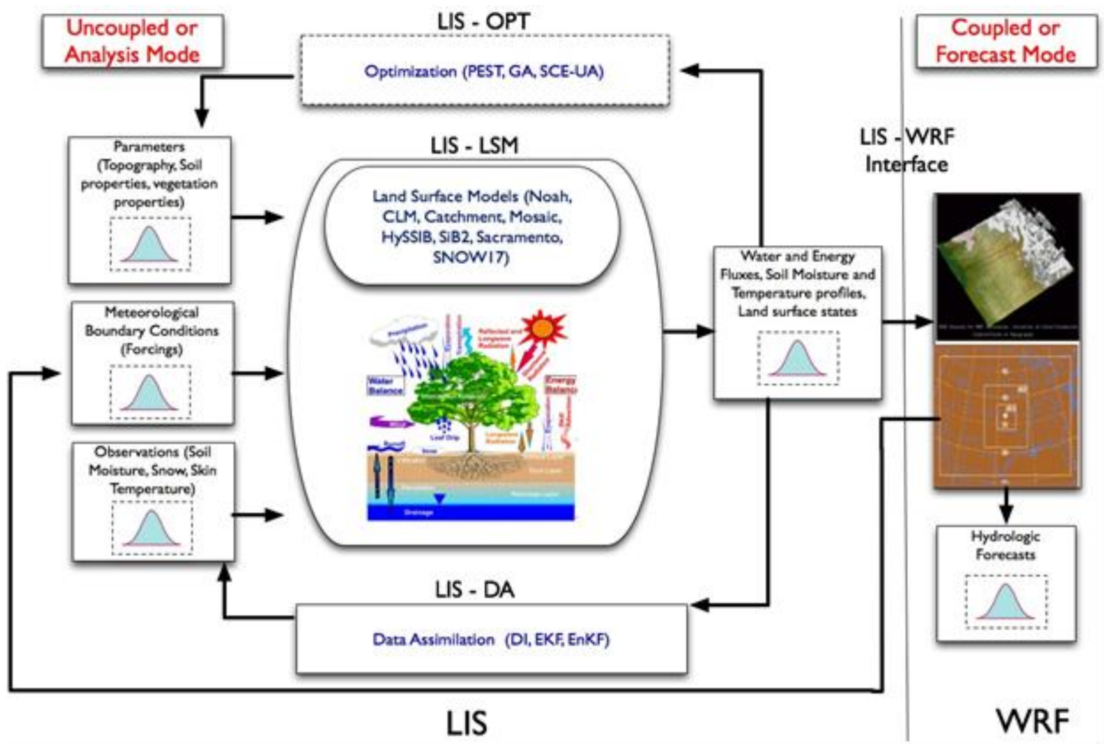
Land Surface Models (LSMs)

In mechanistic models, you simulate the processes of current vegetation dynamics explicitly (calibrating the model on currently-observable dynamics) and then run the simulation forward to predict future distributions. Here's how NASA explains the concept:





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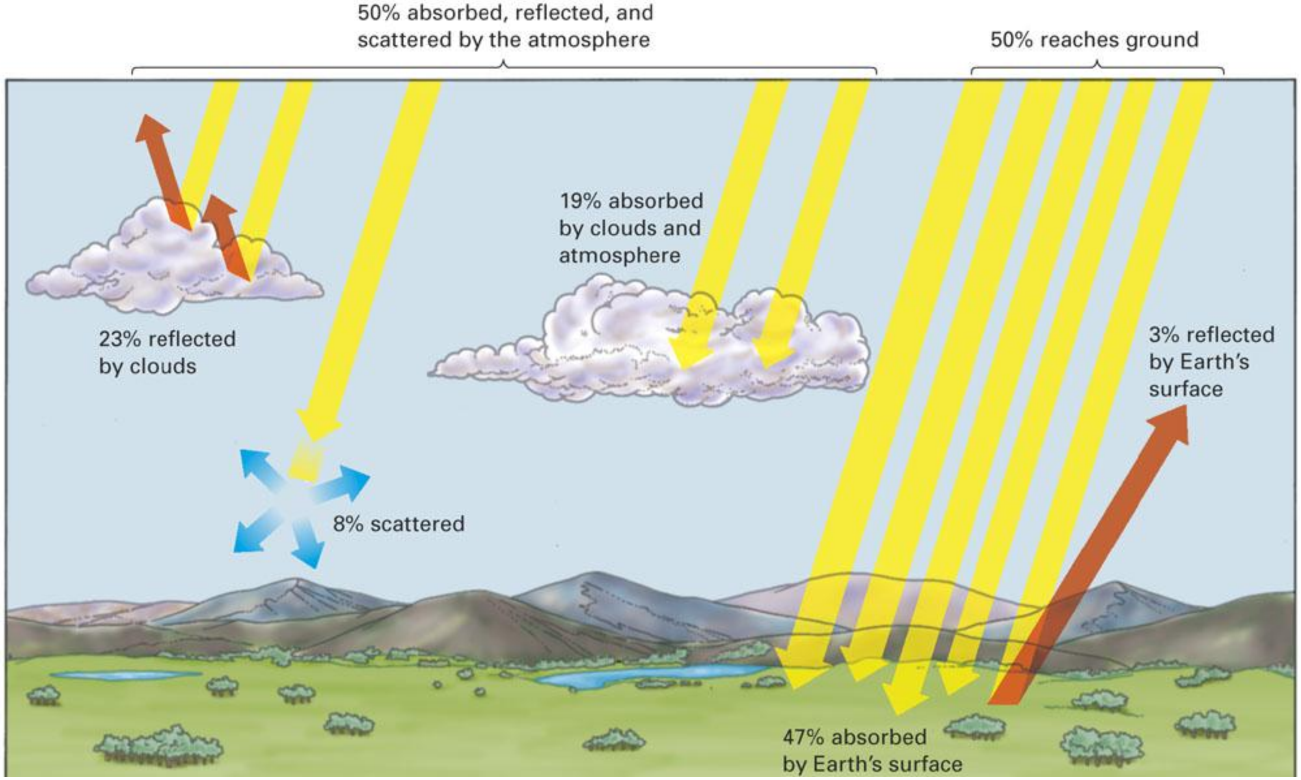
Land Surface Models (LSMs)

Climate models handle all the stuff ‘up there’ above the turbulence layer above the forest canopy top, and the products of these models is used to run vegetation simulations.

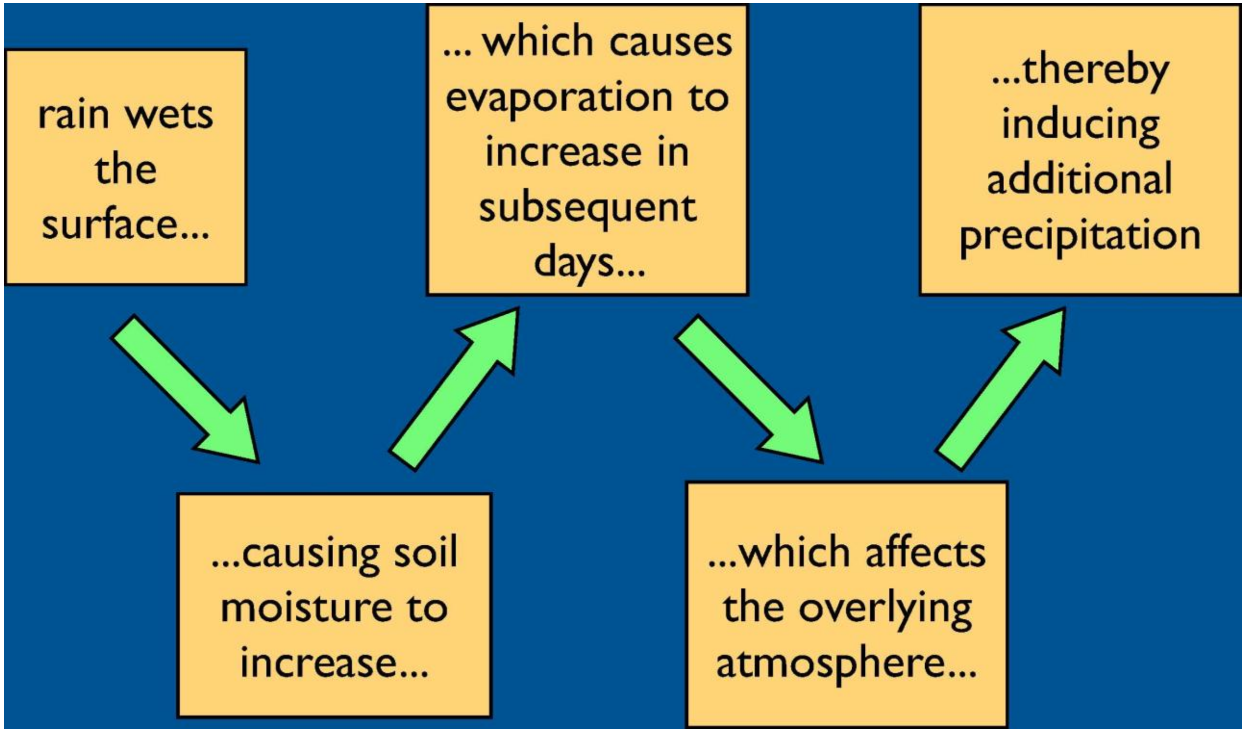


• Worldwide climate models are called **Global Circulation Models (GCMs)**, e.g. HadCM3 (Hadley Centre, UK), ARPEGE (France). These work at a large scale (usually 300 x 300 km grid cells).

• Predictions of future climate are based on scenarios (SRES, RCP) of future social development, carbon emissions, industrial production, etc..

Land Surface Models (LSMs)

It's not always the climate controlling the land surface, however: here's the 'soil precipitation effect', which is an example of a *land-atmosphere feedback*.



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Land Surface Models (LSMs)

This is the general structure of a Land Surface Model (from Prentice *et al.* 2007):

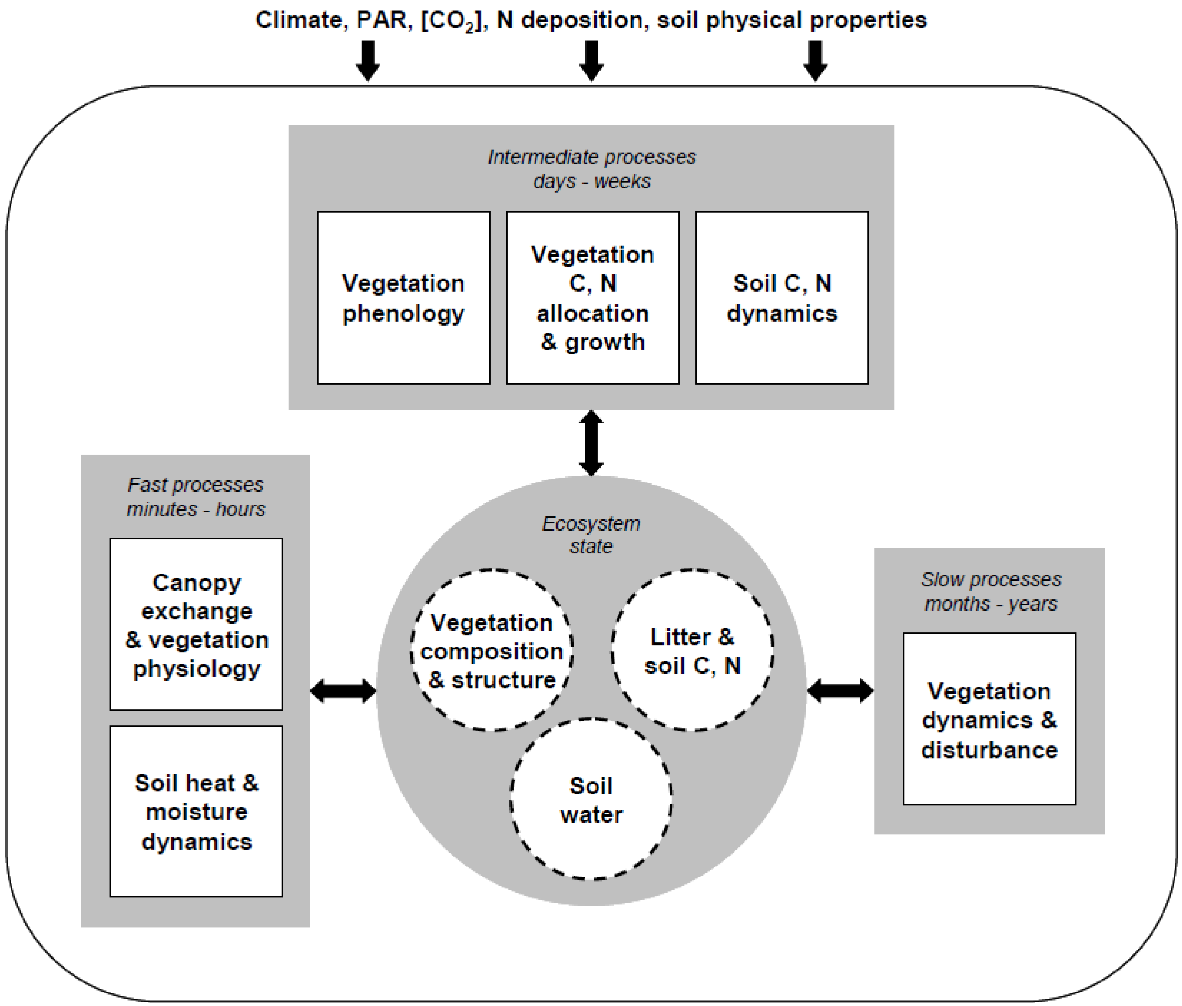
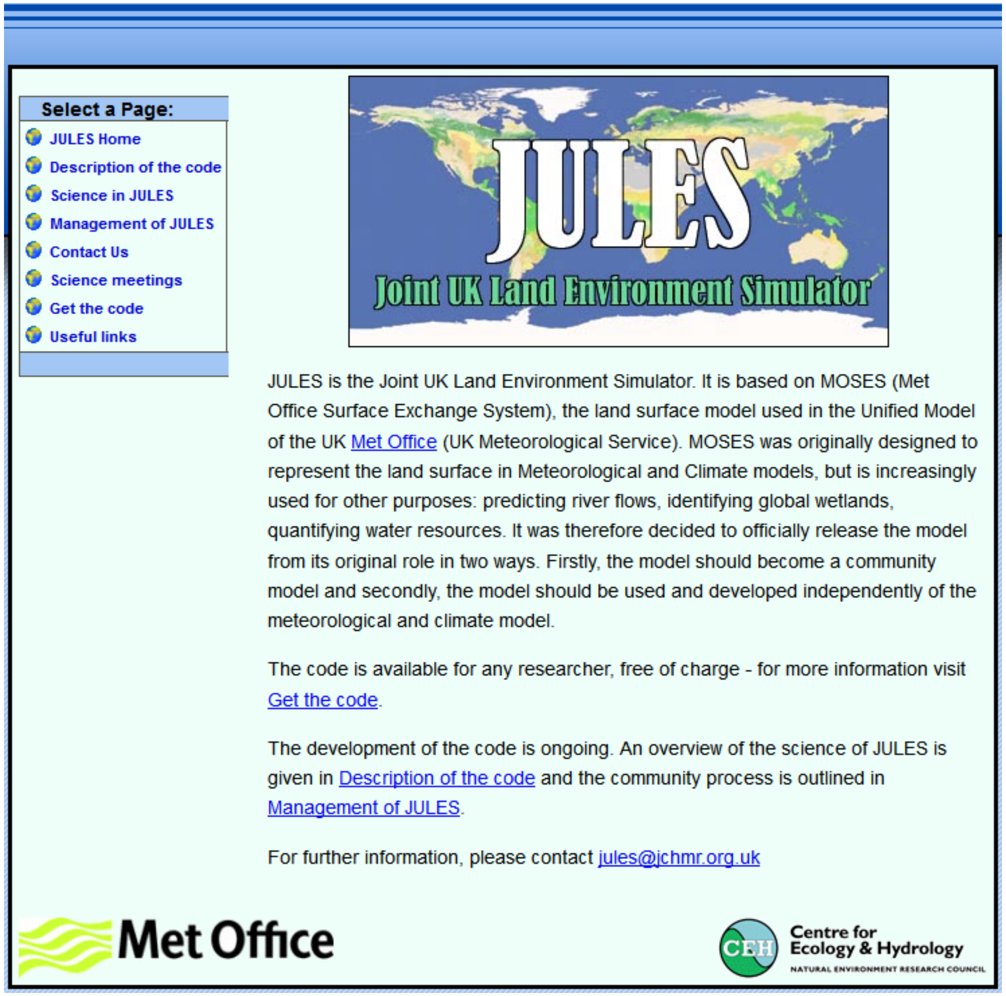


Fig. 15.2.
DGVMs are structurally rather similar. This figure illustrates a typical structure, showing driving variables, main process modules (organized by operational timestep) and state variables

Land Surface Models (LSMs)

JULES (Joint UK Land Environment Simulator http://www.jchmr.org/jules/) is the Land Surface Model that I use (it's one of ~22 such models around the world and is the UK's contribution to this field).



Select a Page:

- JULES Home
- Description of the code
- Science in JULES
- Management of JULES
- Contact Us
- Science meetings
- Get the code
- Useful links

JULES

Joint UK Land Environment Simulator

JULES is the Joint UK Land Environment Simulator. It is based on MOSES (Met Office Surface Exchange System), the land surface model used in the Unified Model of the UK Met Office (UK Meteorological Service). MOSES was originally designed to represent the land surface in Meteorological and Climate models, but is increasingly used for other purposes: predicting river flows, identifying global wetlands, quantifying water resources. It was therefore decided to officially release the model from its original role in two ways. Firstly, the model should become a community model and secondly, the model should be used and developed independently of the meteorological and climate model.

The code is available for any researcher, free of charge - for more information visit Get the code.

The development of the code is ongoing. An overview of the science of JULES is given in Description of the code and the community process is outlined in Management of JULES.

For further information, please contact jules@jchmr.org.uk

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Land Surface Models (LSMs)

Fieldwork is key: we still need better data for these modelling efforts: meaning really good, quantitative carbon cycle data. This has been a strong motivating argument behind the network of RAINFOR Intensive sites set up by the Ecosystems Lab here and now called GEM (http://gem.tropicalforests.ox.ac.uk/).

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Land Surface Models (LSMs)

Land Surface Models (LSMs)

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Land Surface Models (LSMs)

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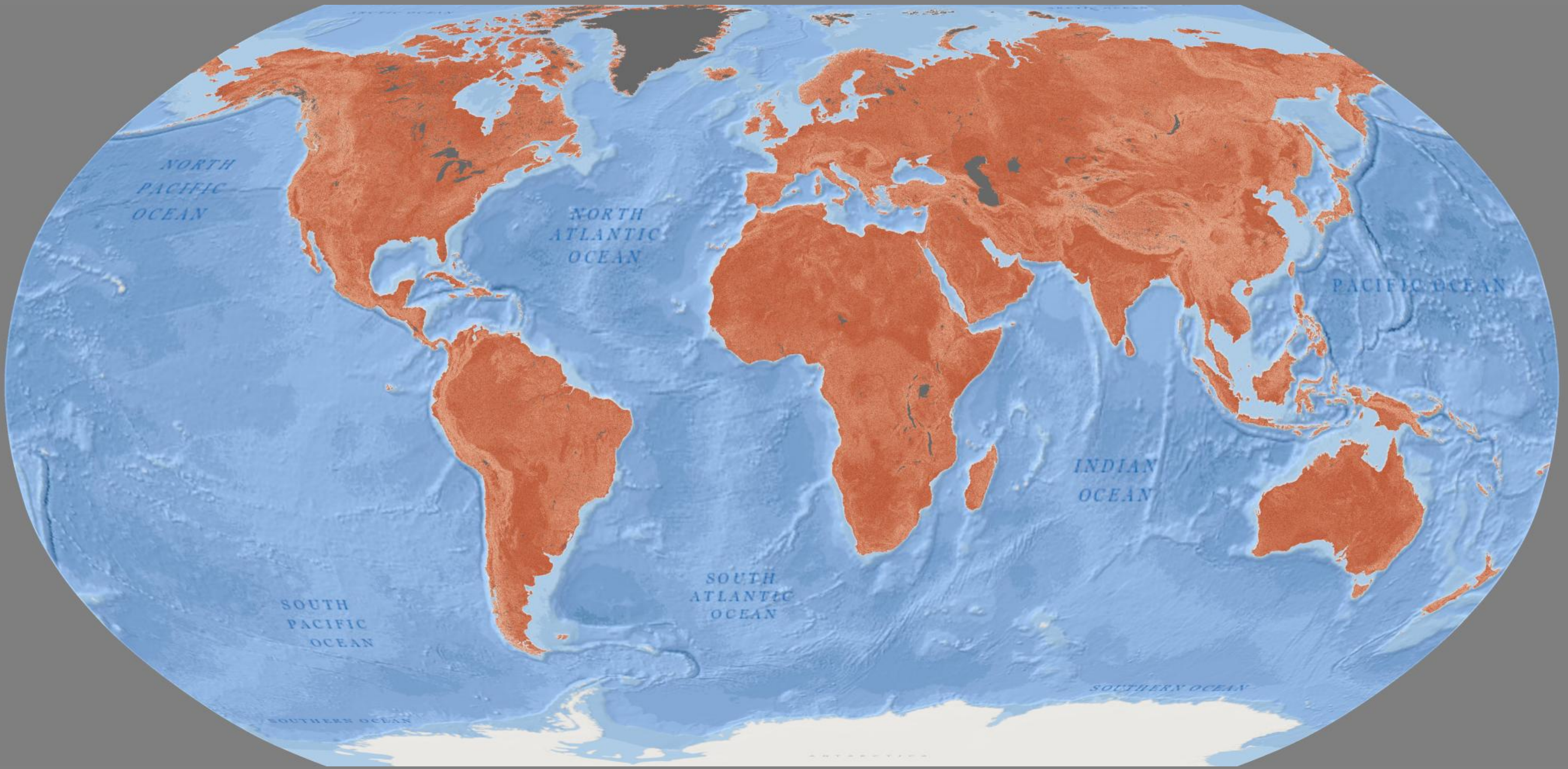
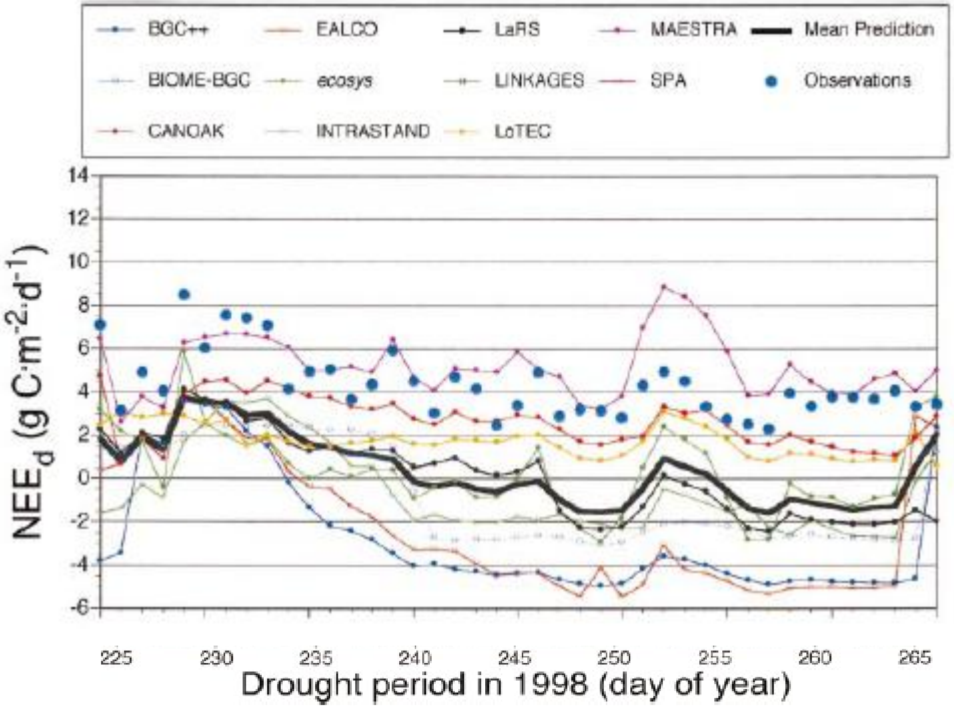
Land Surface Models (LSMs)



Applications of LSMs

Applications of LSMs

Hanson *et al.* (2005) showing a comparison of LSM simulation results to data from flux tower sites.



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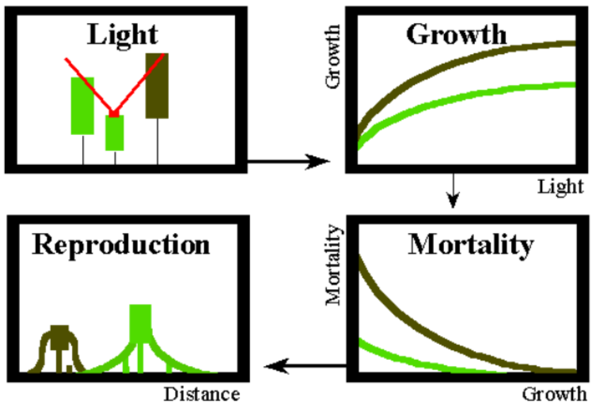
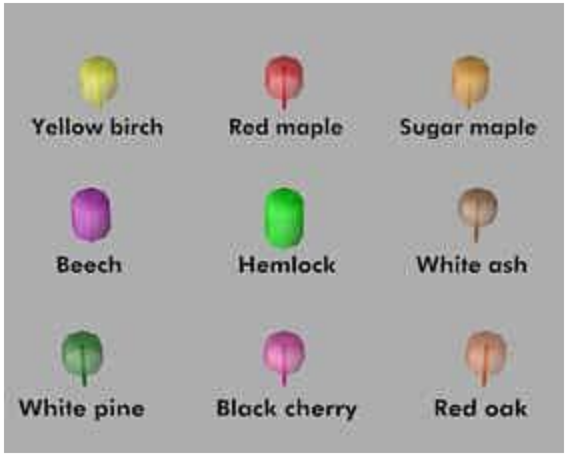
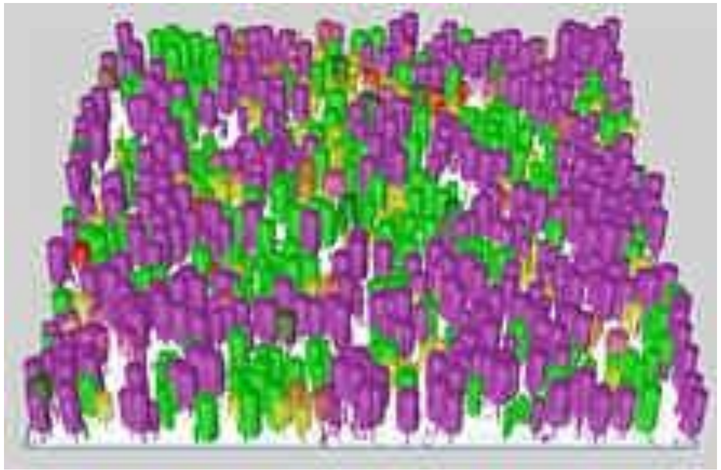
Applications of LSMs

The SORTIE model: an example of an individual-based gap dynamics model.







A 500-year SORTIE forest simulation

Applications of LSMs

A forest carbon budget is composed of **fluxes into** (deposits) and **fluxes out of** (withdrawals) the **forest carbon stock** (in a forest context, these are usually in the form of CO_2):

Photosynthetic CO_2 fixation
= Gross Primary Productivity *GPP*
(flux in)

See the *RAINFOR-GEM* protocols
http://gem.tropicalforests.ox.ac.uk/

Other important quantities:

Net Primary Productivity *NPP* **(total NPP, i.e. both above- and below-ground) = *GPP* - R_a**

Net Ecosystem Productivity *NEP* = *GPP* - R_a- R_h

Carbon Use Efficiency *CUE* = *NPP* ÷ *GPP*

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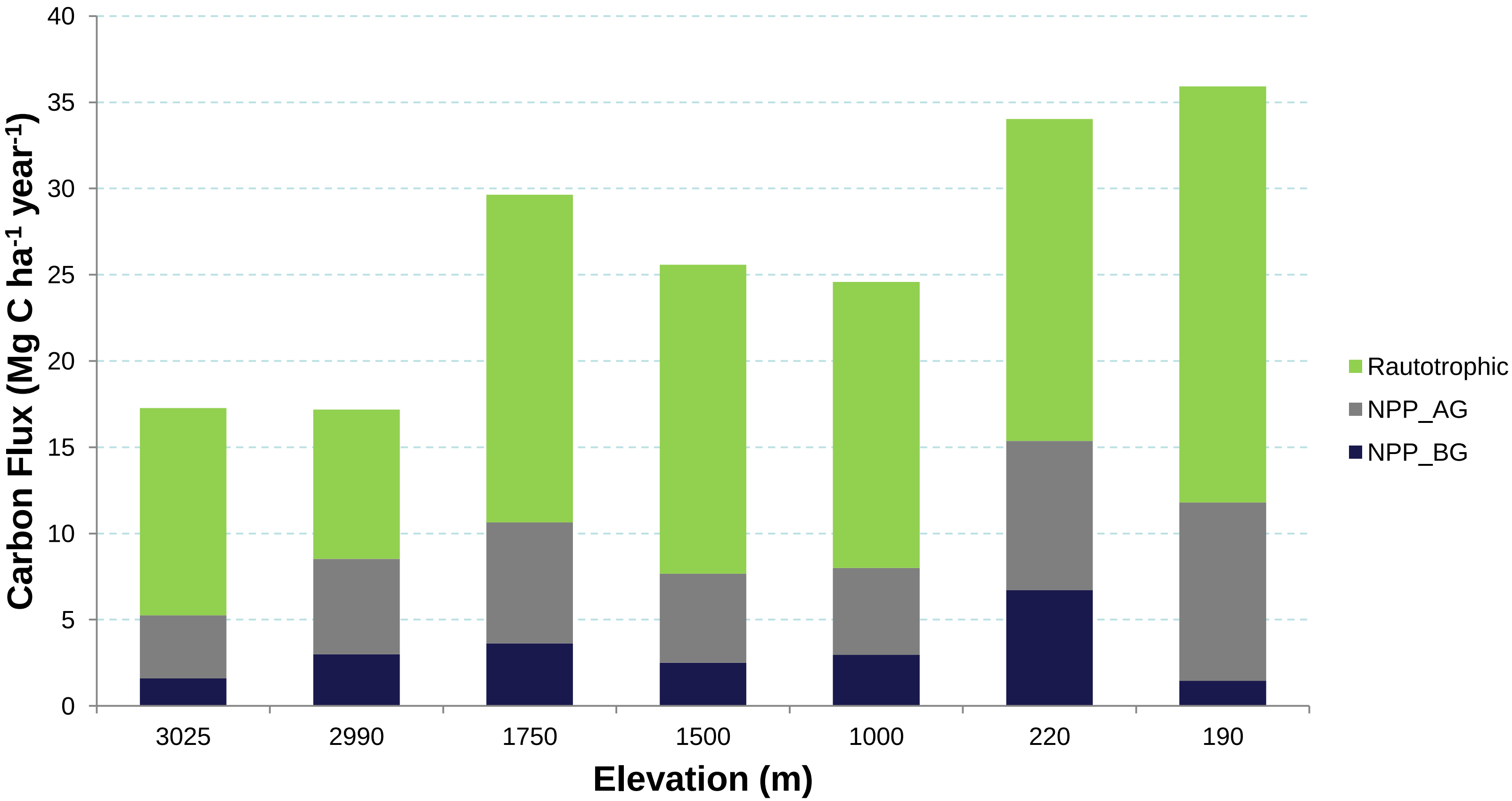
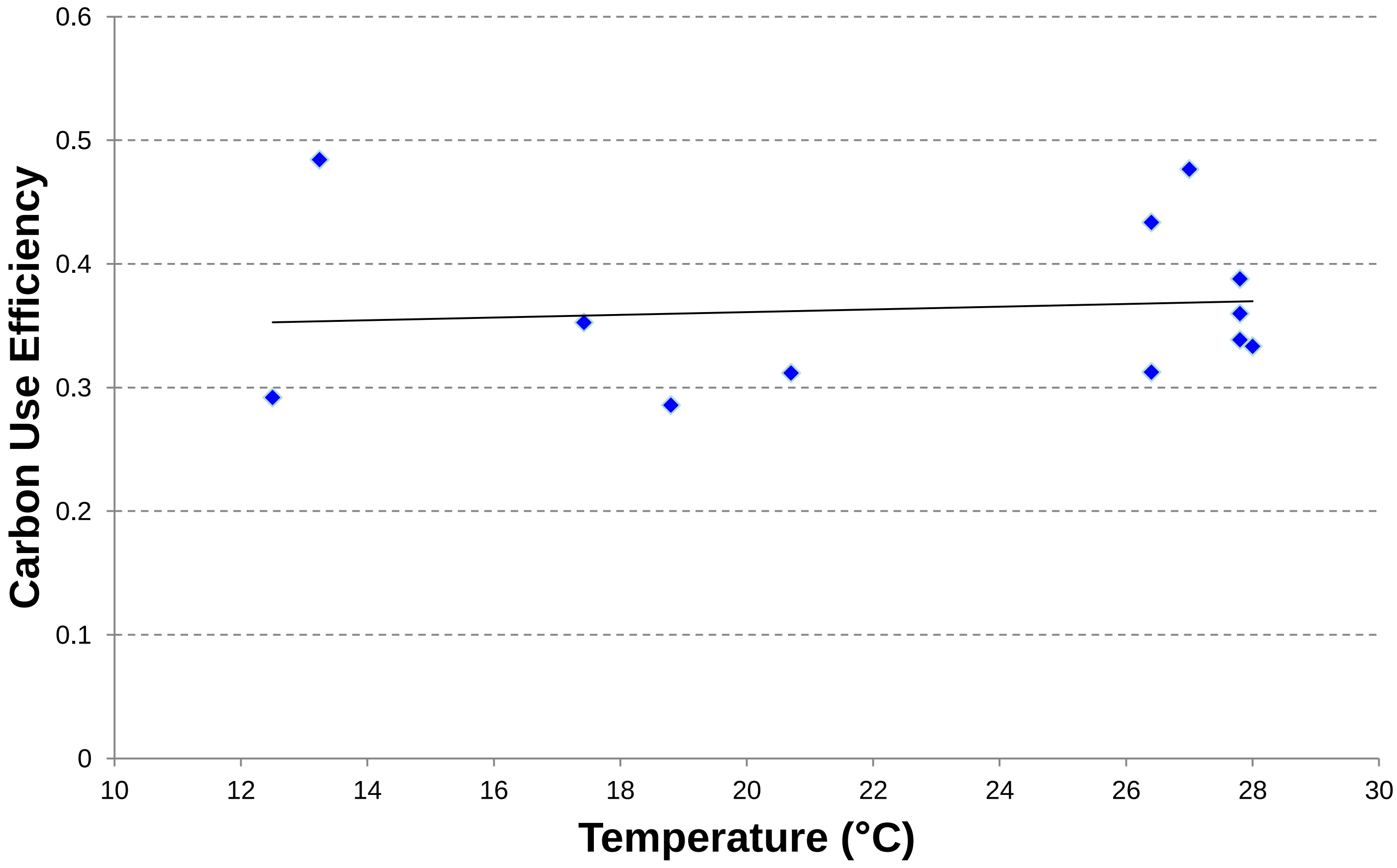
Applications of LSMs

GPP tends to decline with elevation in the Kosñipata Valley, SE Peru, ...



Applications of LSMs

...but carbon use efficiency (NPP/GPP) shows no trend with elevation.



Applications of LSMs

Over the last few years, fieldwork from our group in Oxford has pointed towards values for *CUE* (=(*NPP*/*GPP*) =1-(R_a/*GPP*)) being generally around 0.30-0.40 in tropical forests as opposed to 0.50-0.60 in temperate forests (Marthews *et al.* 2012, *GCB*).

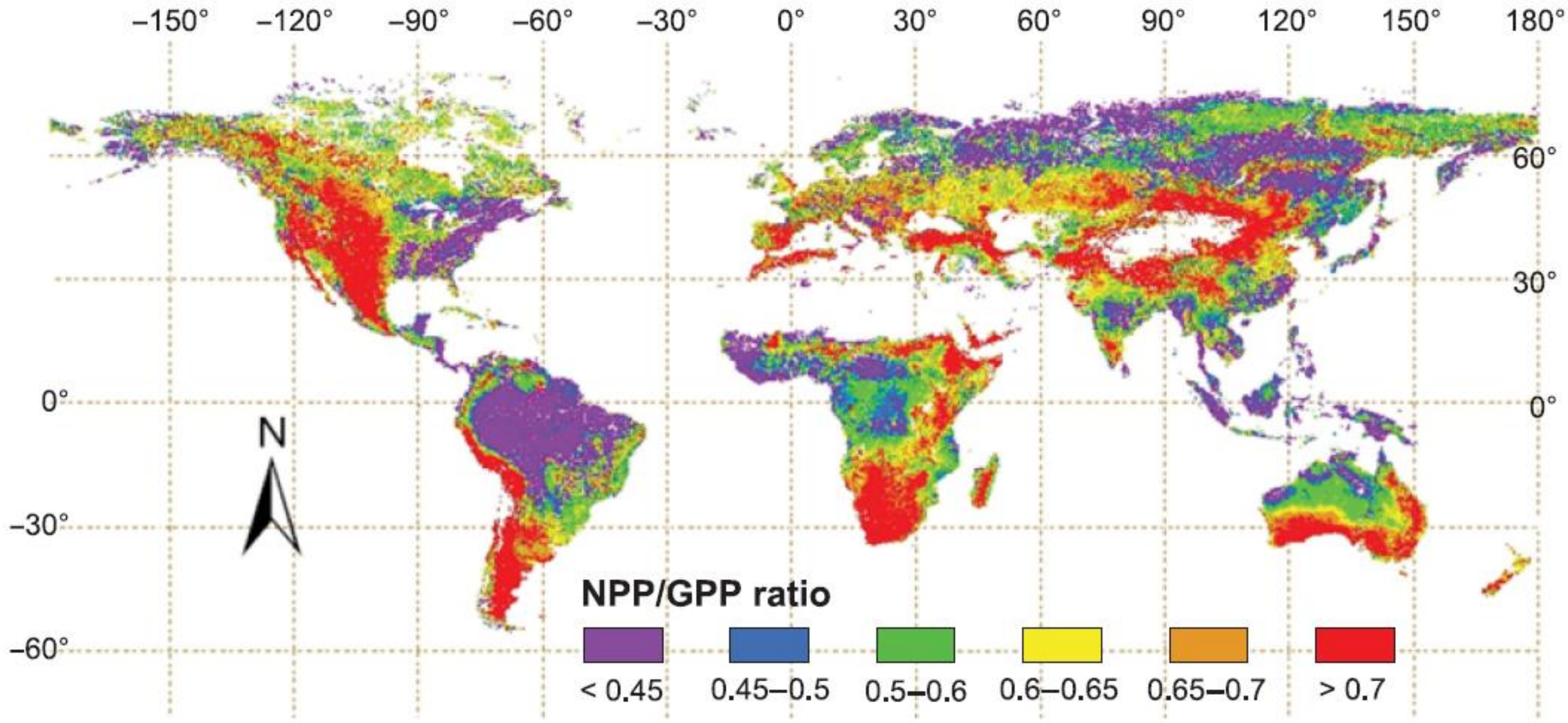


Figure 1 Global spatial pattern of the average NPP/GPP ratio.

From Zhang *et al.* (2009, *Global E&B*)

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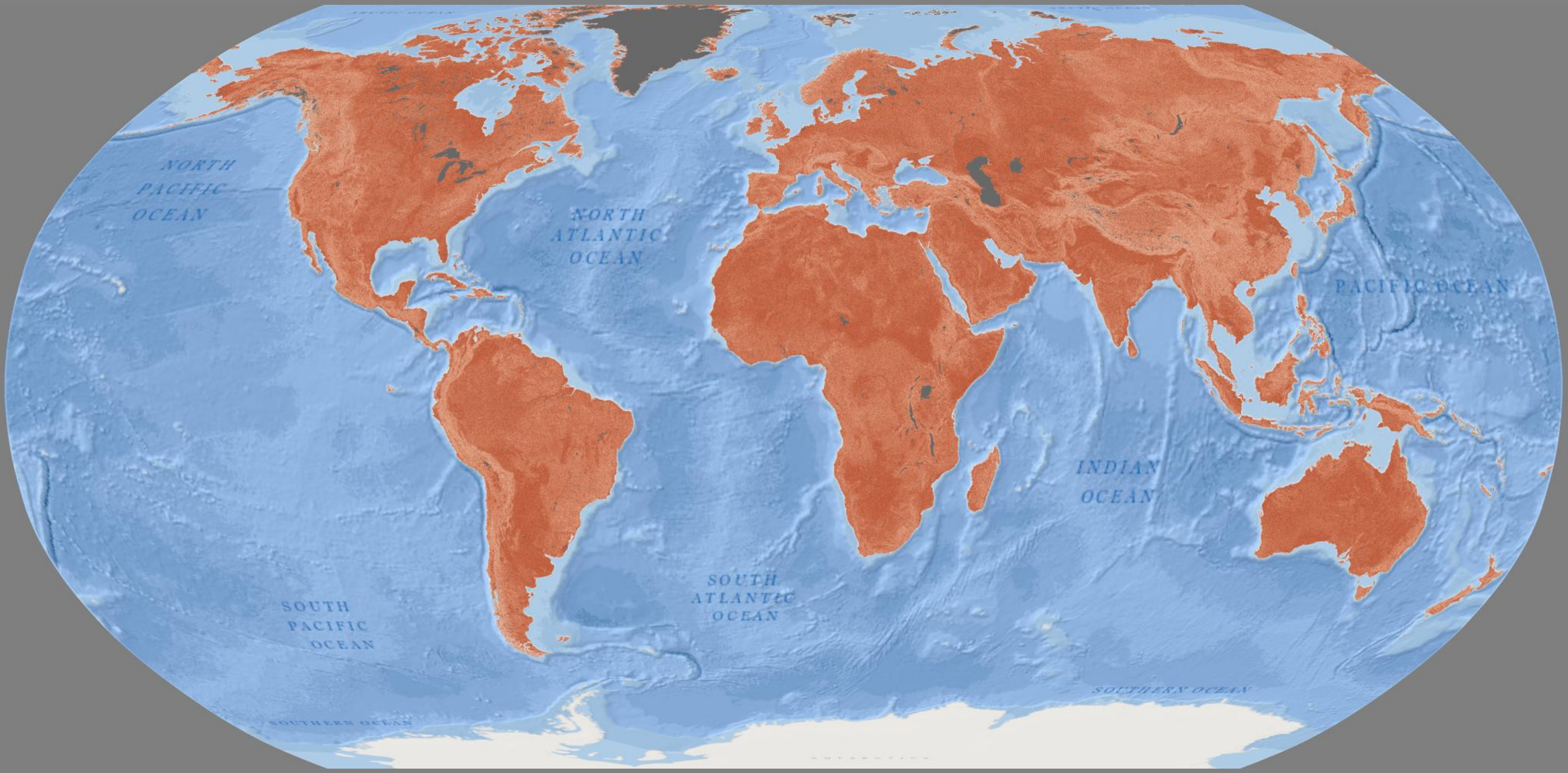

NBMs vs. Mechanistic Models

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NBMs vs. Mechanistic Models

Disadvantages of NBMs:

- Low validity for runs in new areas

- Low validity for far-future predictions

- Acclimation of species cannot be modelled

- Novel species mixes cannot be modelled

- Time-related effects such as transients or lag effects cannot be modelled.

- High dependence on quality of the climate data driving the model

- High dependence on choice of habitat variables

- Predictions are ‘explanation-less’

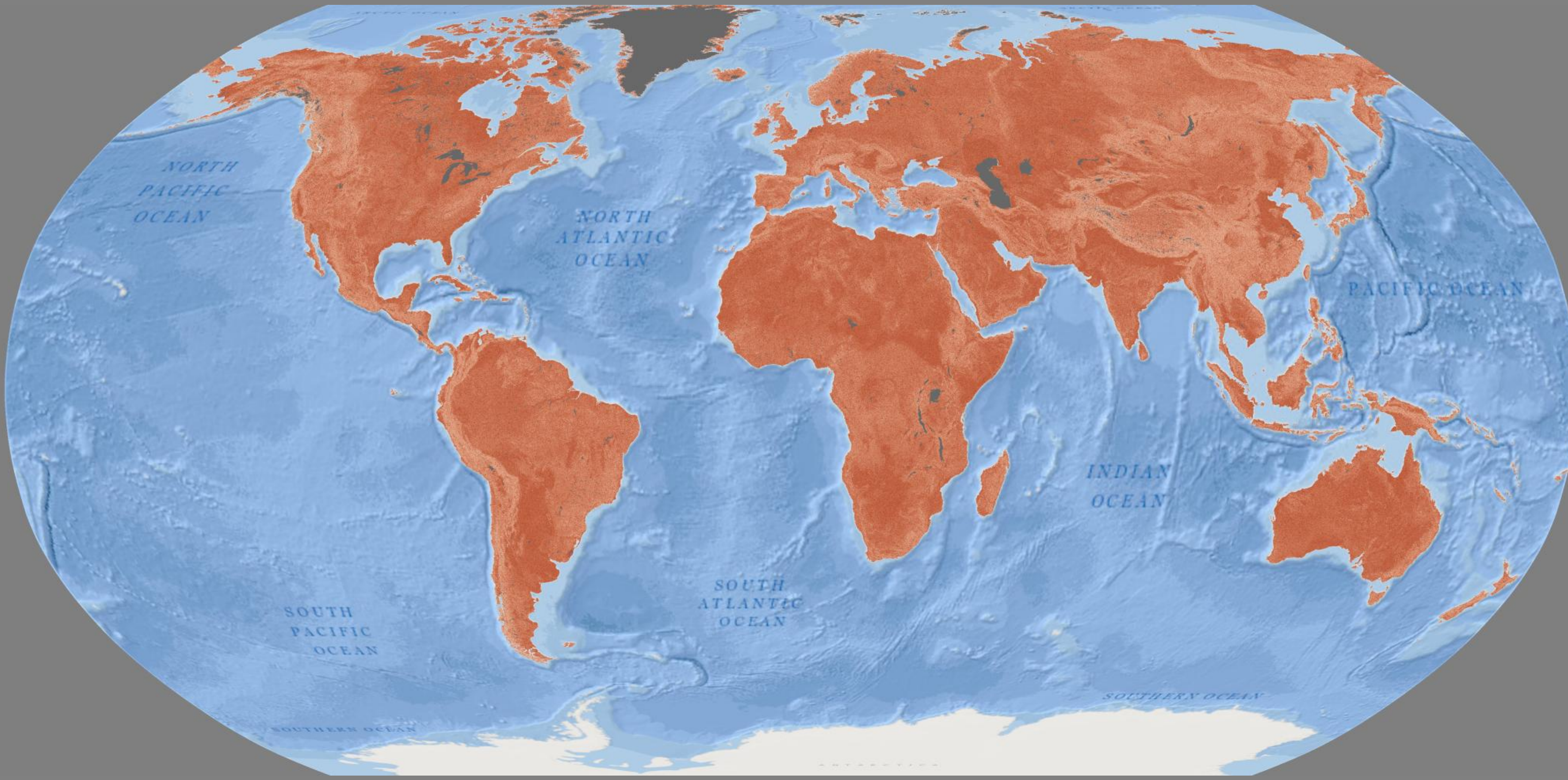
Disadvantages of Mechanistic Models:

- Require lots of biometric data

- Complex and therefore difficult to explain and justify to others (e.g. protected area managers)

- Time-consuming to set up

However, it’s not really an either-or choice: we need NBMs for quick-response solutions and for robust predictions we need the greater detail of Mechanistic Models.



PART 2: Systems Analysis (System Dynamics)

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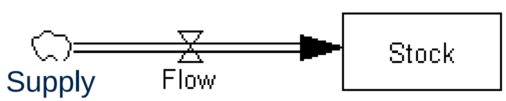
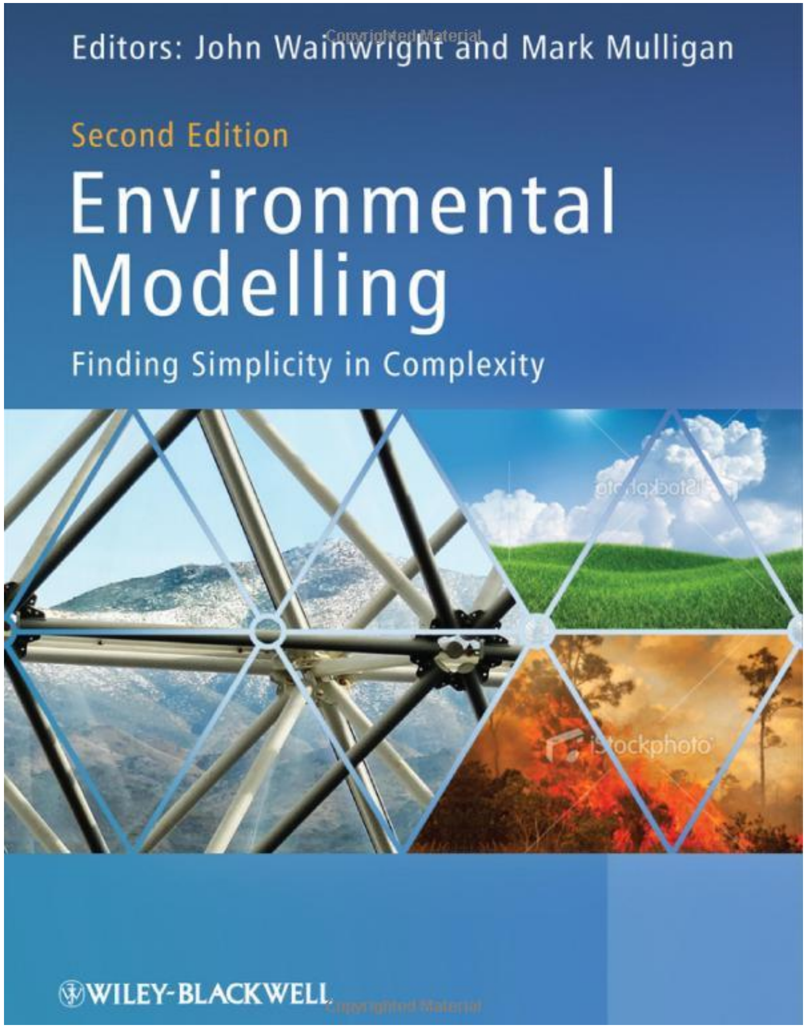
Systems Analysis (System Dynamics)

The System Dynamics approach to modelling (Jay Forrester, MIT in the 1950s).

Systems analysis is the 'study of the composition and functioning of systems'.

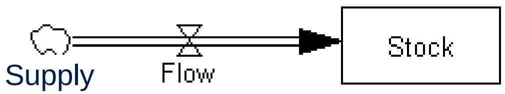
Systems are comprised of ***compartments*** or ***stores*** that represent quantities (e.g. height, mass) and which are added to or subtracted from by ***flows*** or ***fluxes*** (e.g. height increment, evaporation).

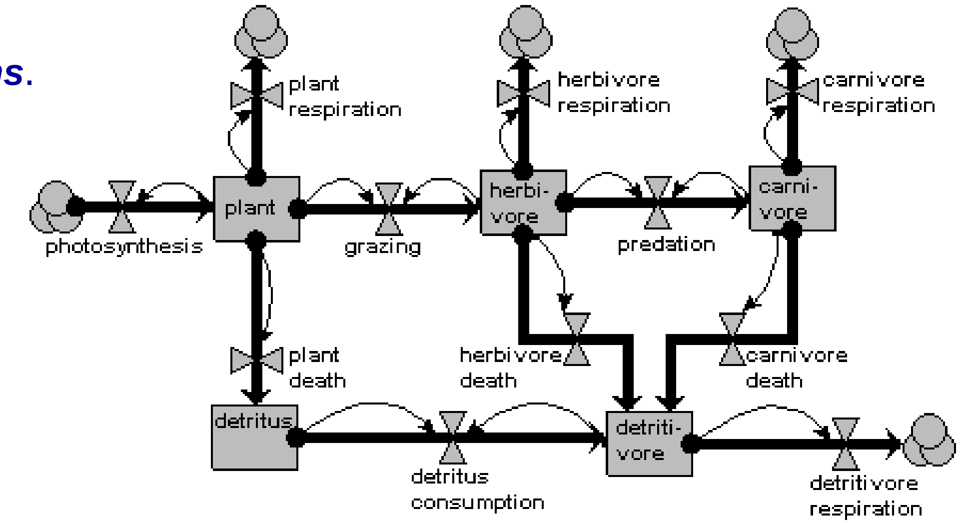




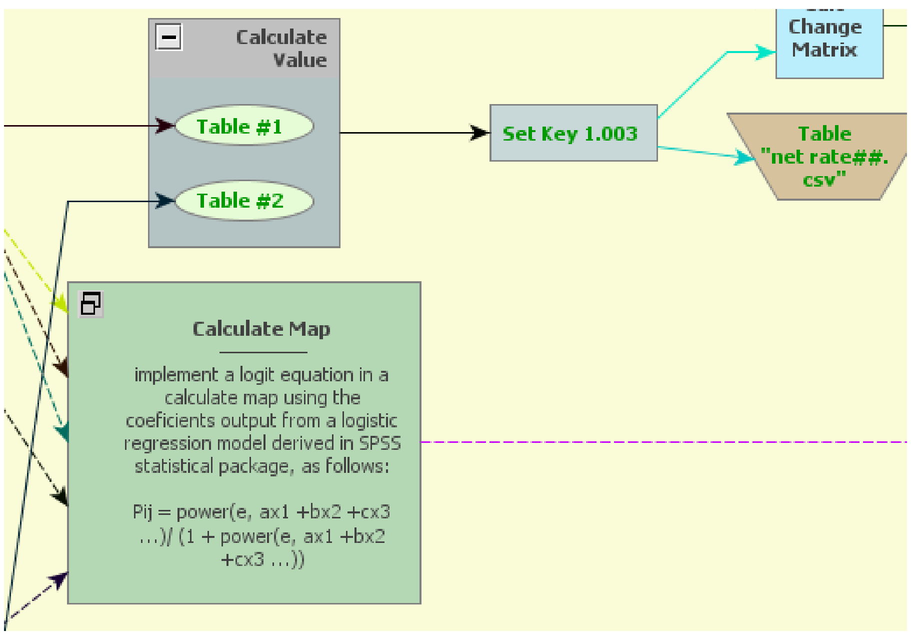
Systems Analysis (System Dynamics)

These sorts of diagrams are called ***Forrester diagrams***.

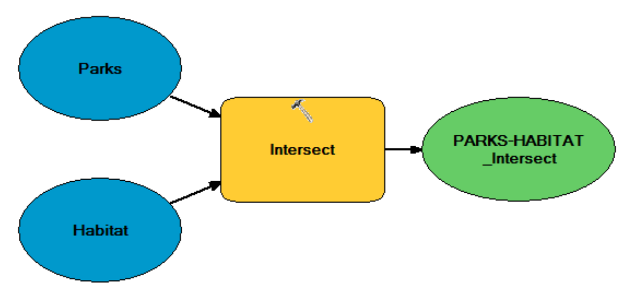




Data flow diagrams and GIS workflows are similar.



Dinamica EGO



ArcGIS Model Builder

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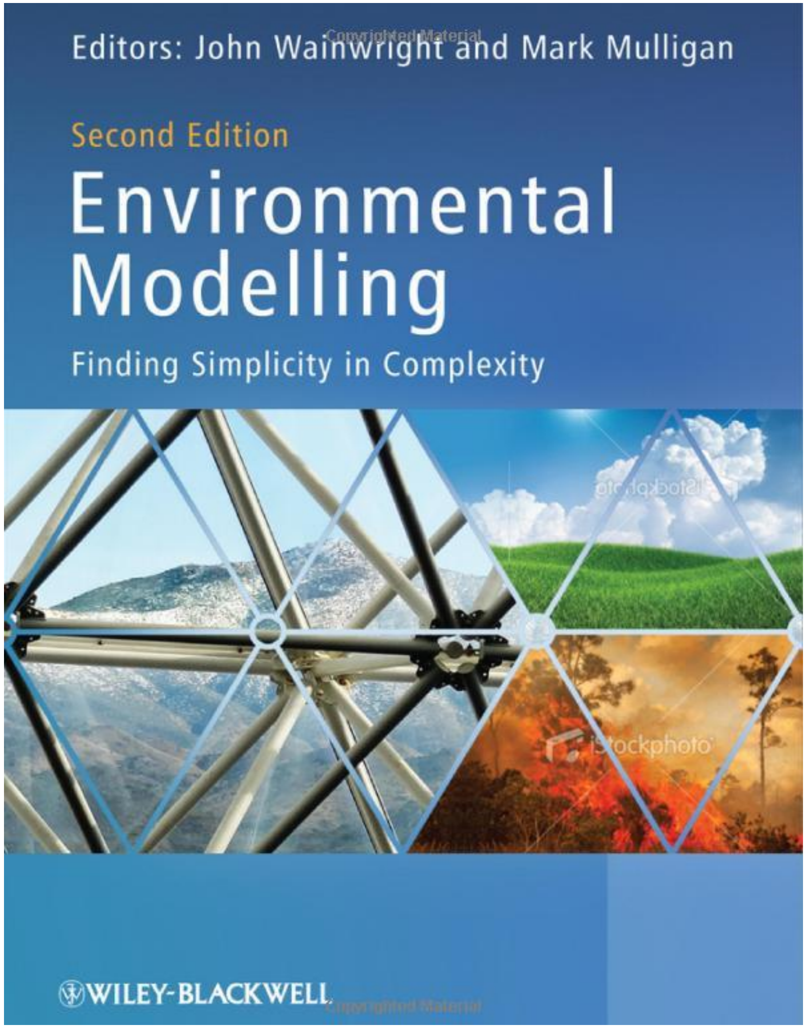
Systems Analysis (System Dynamics)

Constructing models through a 'flowchart'-style interface is called ***Model Building***.

Here is a selection of Graphical Model Building Environments (Dinamica Ego is freeware, the others please check):

•STELLA (http://www.iseesystems.com/softwares/Education/StellaSoftware.aspx)
•Dinamica EGO (http://csr.ufmg.br/dinamica/)
•SIMILE (http://www.simulistics.com)
•VENSIM (http://www.vensim.com)
•Powersim (http://www.powersim.com)
•ModelMaker (http://www.cherwell.com)
•SIMULINK (linked to MATLAB) (http://www.mathworks.co.uk/products/simulink/)



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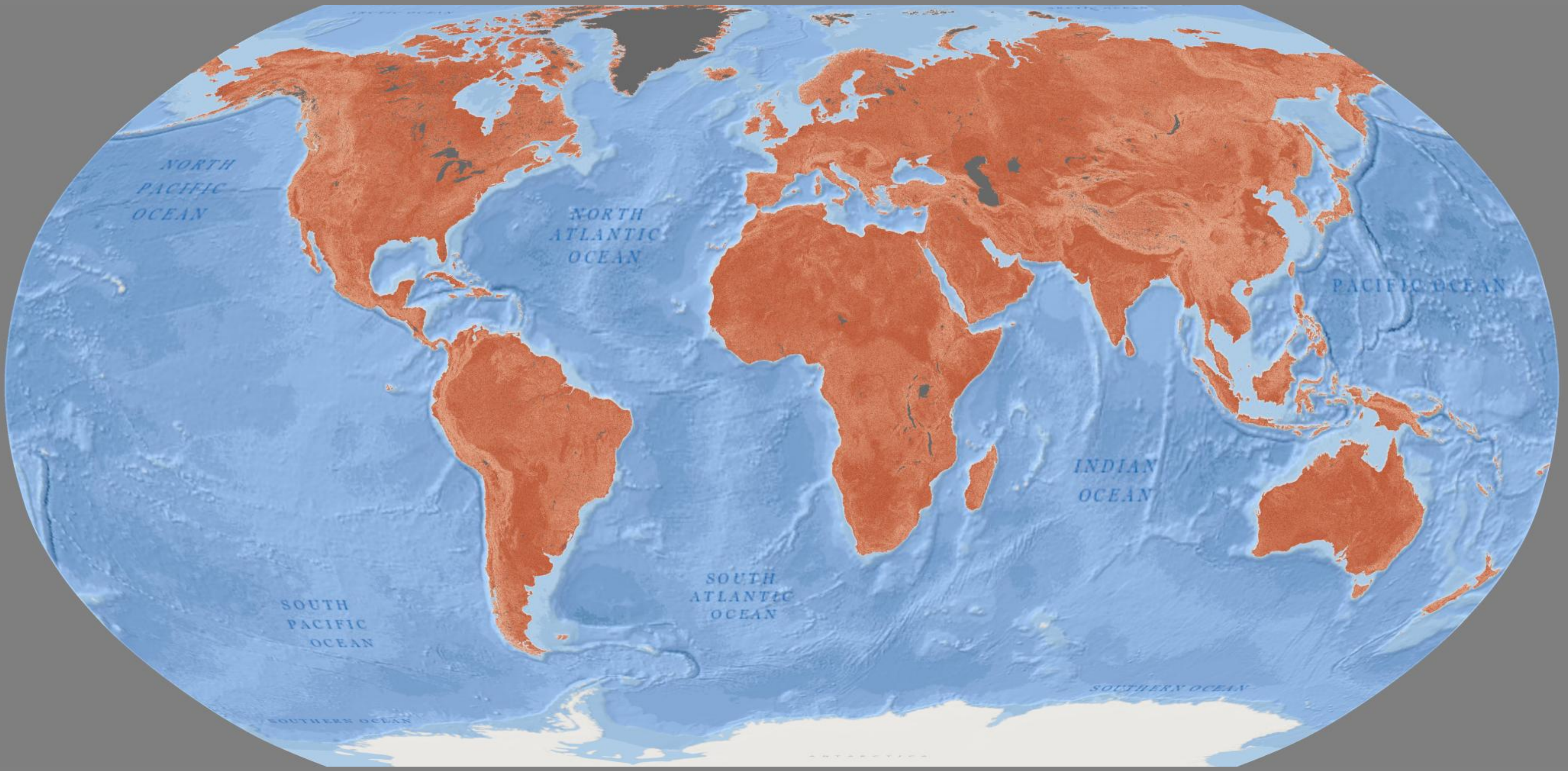

Coding

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Coding

Programming languages are either *script languages* or *compiled languages*. Scripts are relatively slow but are much easier to write. Using compiled code means you have to use a compiler (which is often surprisingly problematic) but your code runs 100x faster.

•I use R for all my scripting, which is freeware. See my Friendly Beginners' Online R Course at http://www.tobymarthews.com/course-notes.html. The huge advantage of R is that every statistical test you can imagine is implemented in it so you don't need to use SPSS or SAS or MiniTAB (etc.) ever again.

•Python is a free script language more or less equivalent to R. Python is widely-used in large organisations such as Google, Yahoo!, CERN and NASA. It is partially integrated with ArcGIS as ArcPy.

•MATLAB is another script language more or less equivalent to R but perhaps with some better graphics routines. It is widely used in engineering and academia (inc. this department) but it's not free and licences are expensive.

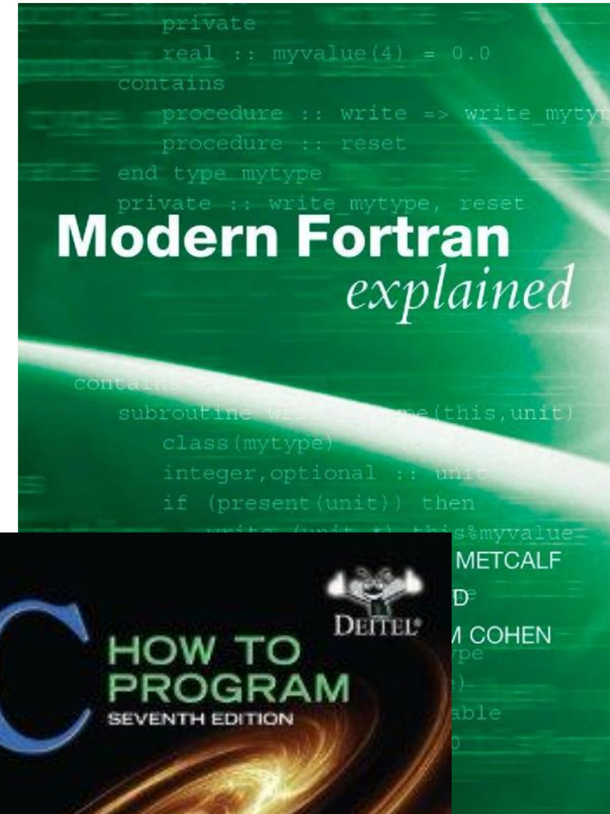
Coding

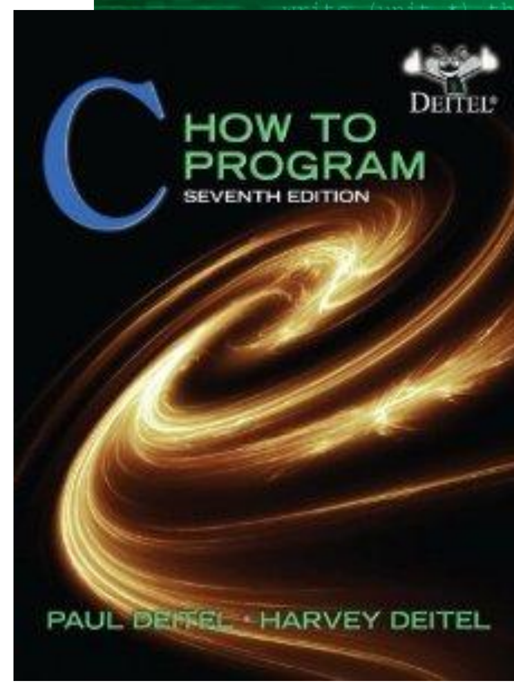
- Options for compiled languages are more restricted, but basically you will almost certainly use either FORTRAN or C:

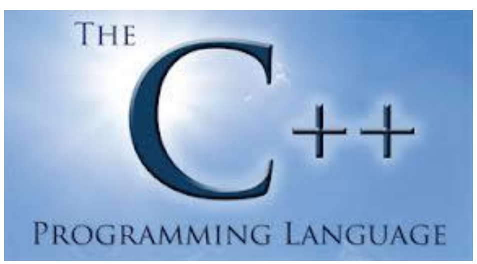
- C and FORTRAN are more or less equivalent.

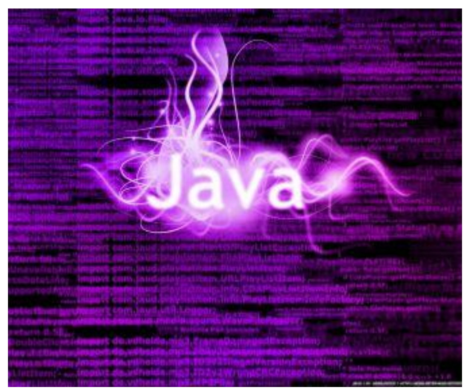
- C++ and Java are object-oriented so that it's easier to write apps and server code, but I have not yet found any application in ecology where this was necessary and it's usually easier to write in C or FORTRAN.

- To use any compiled language you almost certainly need familiarity with UNIX too.



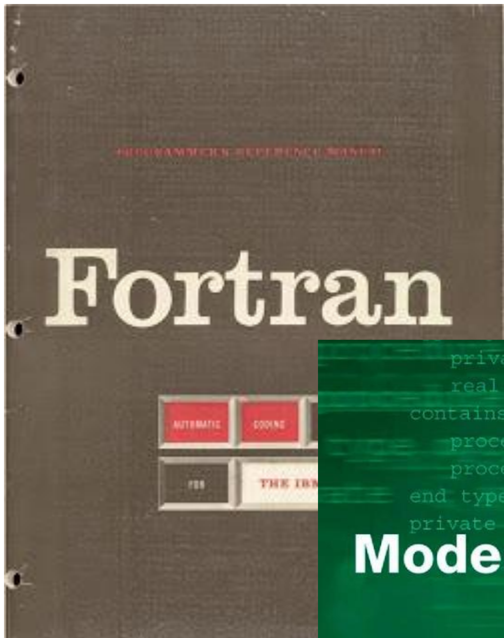




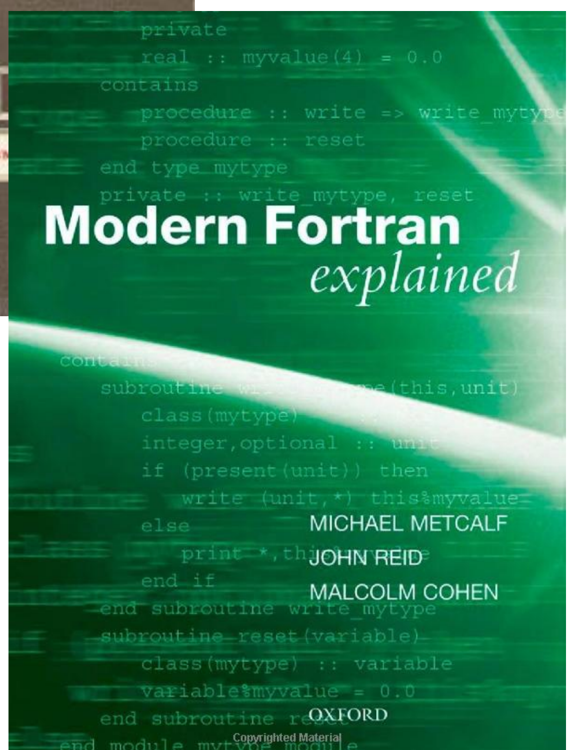


Coding

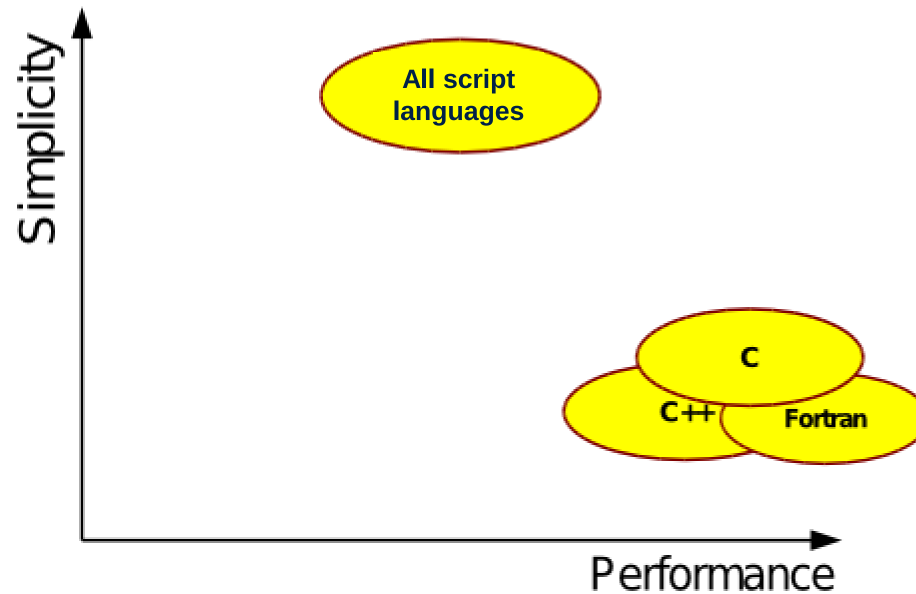
Quite amazingly considering how fast things change in the world of computers, the earliest of all the programming languages is still the most powerful one to use and the one used universally for compiled applications at the MET Office and in most climate labs.



Fortran in 1956



... and in 2011



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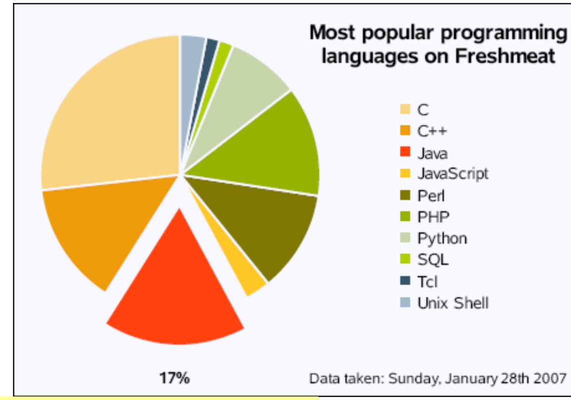
Coding

So which is the best? Well, it depends who you ask (of course). The TIOBE Programming Community Index puts C and Java at the top (Nov 2013), but I found these other measures too.

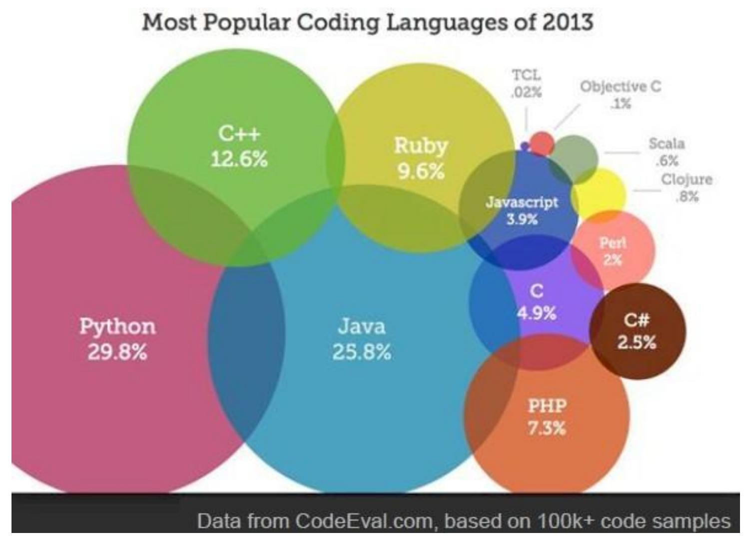


Note that FORTRAN does poorly on all these popularity scales, but of course that’s like saying Aldabra is not an amazing place to go to because hardly anyone has been there ....

If you want to learn coding I suggest to choose one of the script language
“programming”

DEMONSTRATE SOME R WORK

What programming languages you used for data mining / data analysis in the past 12 months? [570 voters]	
R (257)	45%
SQL (184)	32%
Python (140)	25%
Java (139)	24%
SAS (121)	21%
MATLAB (83)	15%
C/C++ (73)	13%
Unix shell/awk/gawk/sed (59)	10%
Perl (45)	7.9%
Hadoop/Pig/Hive (35)	6.1%
Lisp (4)	0.7%
Other (70)	12.0%
None (7)	1.2%



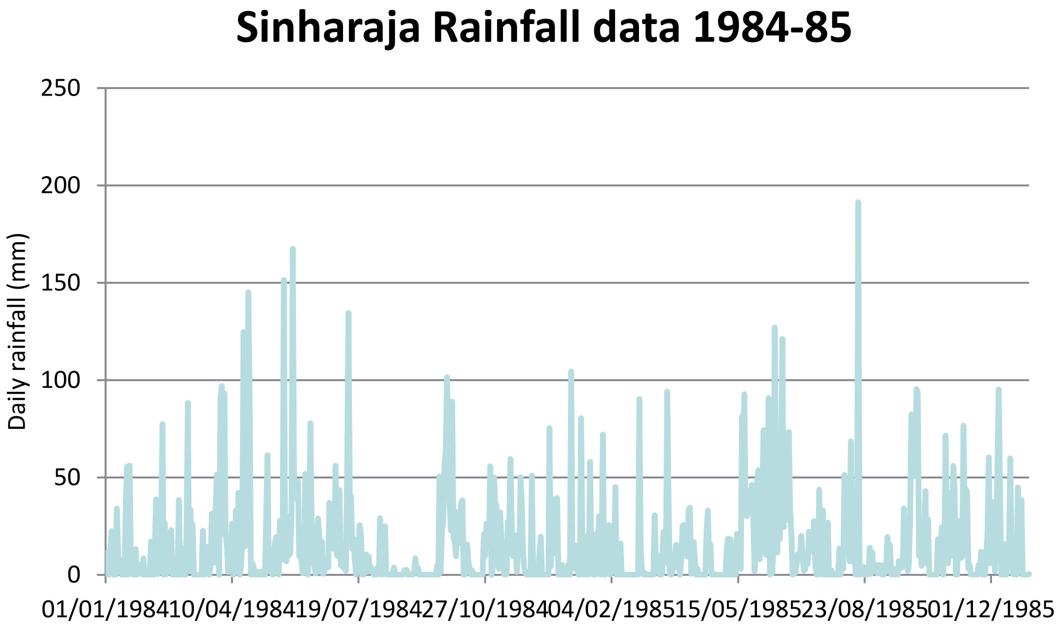
Coding

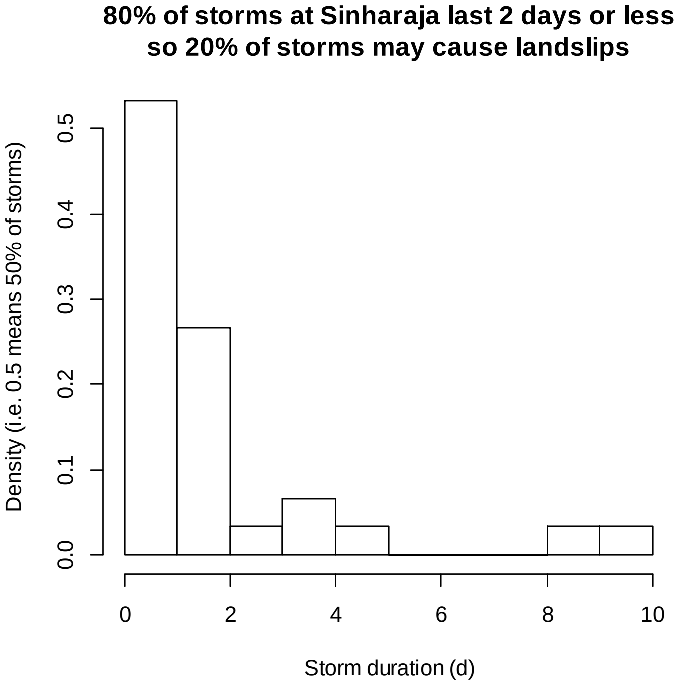
Left shows rainfall data for Sinharaja, Sri Lanka.

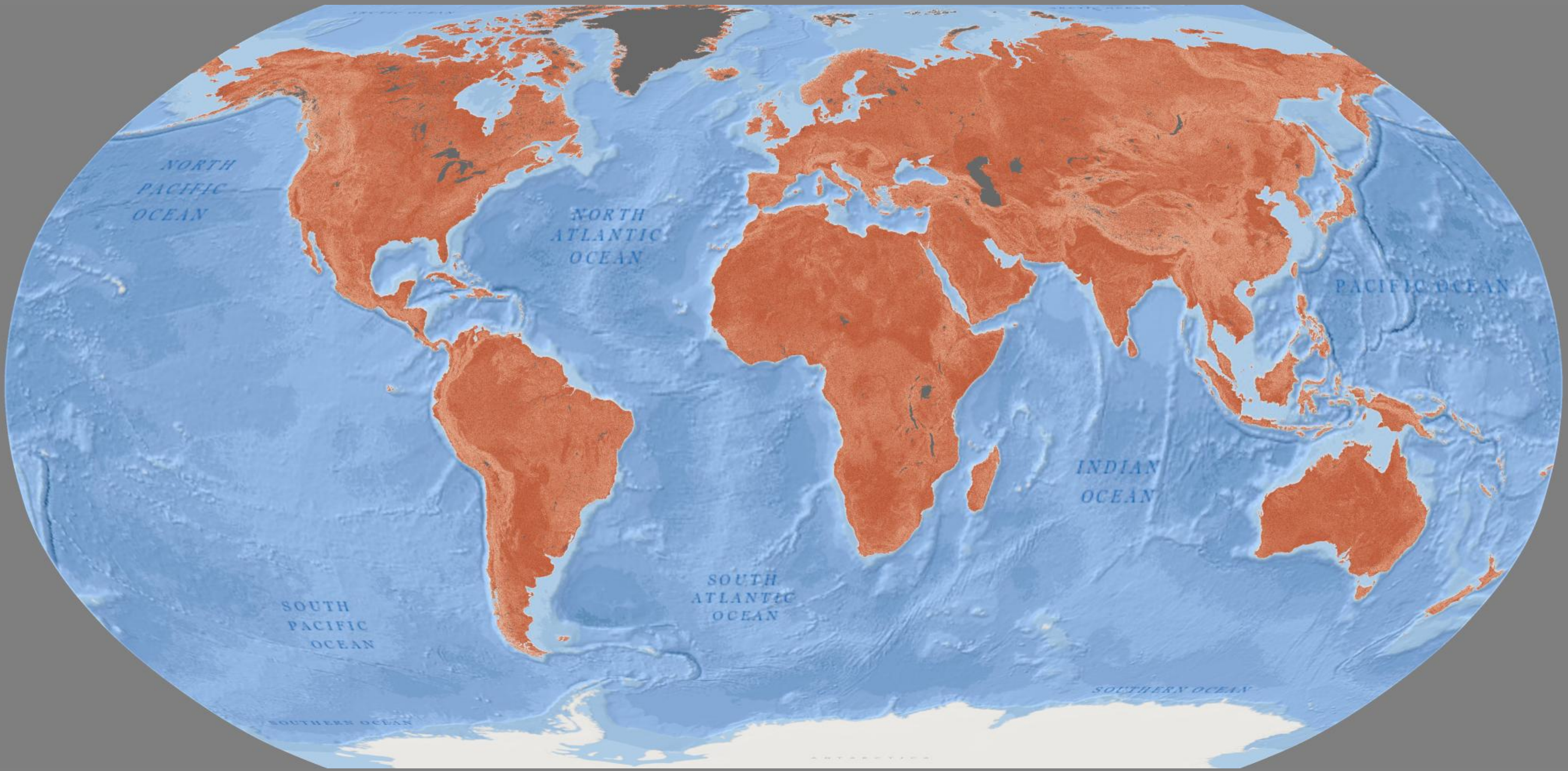
Right shows a possible analysis based on those data that took me only minutes in R but would be very tricky to do in MS Excel. The commands are on the right → (very tiny but you can expand it on the downloaded lecture notes)

```
datain=read.csv("exampledata.csv",header=TRUE,na.strings="MISSING")
head(datain)
dd=as.Date(datain$Date,"%d/%m/%Y")
yy=as.numeric(as.character(datain$Rainfall.mm))
plot(x=dd,y=yy,bty="l",type="l",xlab="",ylab="Rainfall (mm)",main="Sinharaja rainfall")
hist(yy)
hist(yy,breaks=0:192)

#Let's say in Sinharaja it's known that heavy rainfall >50 mm/day (a 'storm', say) and not dropping below 20 mm/day for at least 3 days are the main cause of
landslips
yy[!is.finite(yy)]=0                                        #For now, replace the MISSING values with zeros
thresh1=50;thresh2=20
n=nrow(datain);durations=rep(NA,times=n)
for (ii in 2:n) {
 if (yy[ii]>thresh1 && yy[ii-1]<=thresh2) {durations[ii]=min(which(c(yy[ii:n],0)<=thresh2))-1}
                                                            #For each day of rain newly >thresh1 mm (day ii), store in durations[ii] the
no. of days the rain is >thresh2 mm afterwards
}
res=hist(durations,breaks=0:10,freq=FALSE,xlab="Storm duration (d)",ylab="Density (i.e. 0.5 means 50% of storms)",main="80% of storms at Sinharaja last 2
days or less\nso 20% of storms may cause landslips")        #80% comes from sum(res$density[1:2])*100
```







Geographic Information Systems (GIS)

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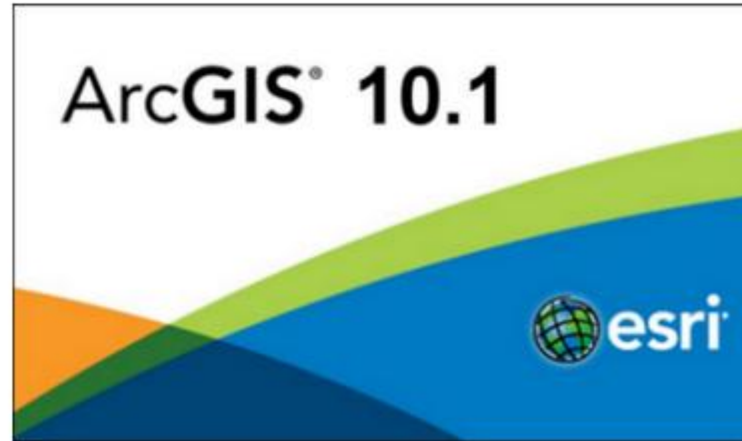
Geographic Information Systems (GIS)

•Personally, I use ArcGIS from ESRI because many large firms use it.

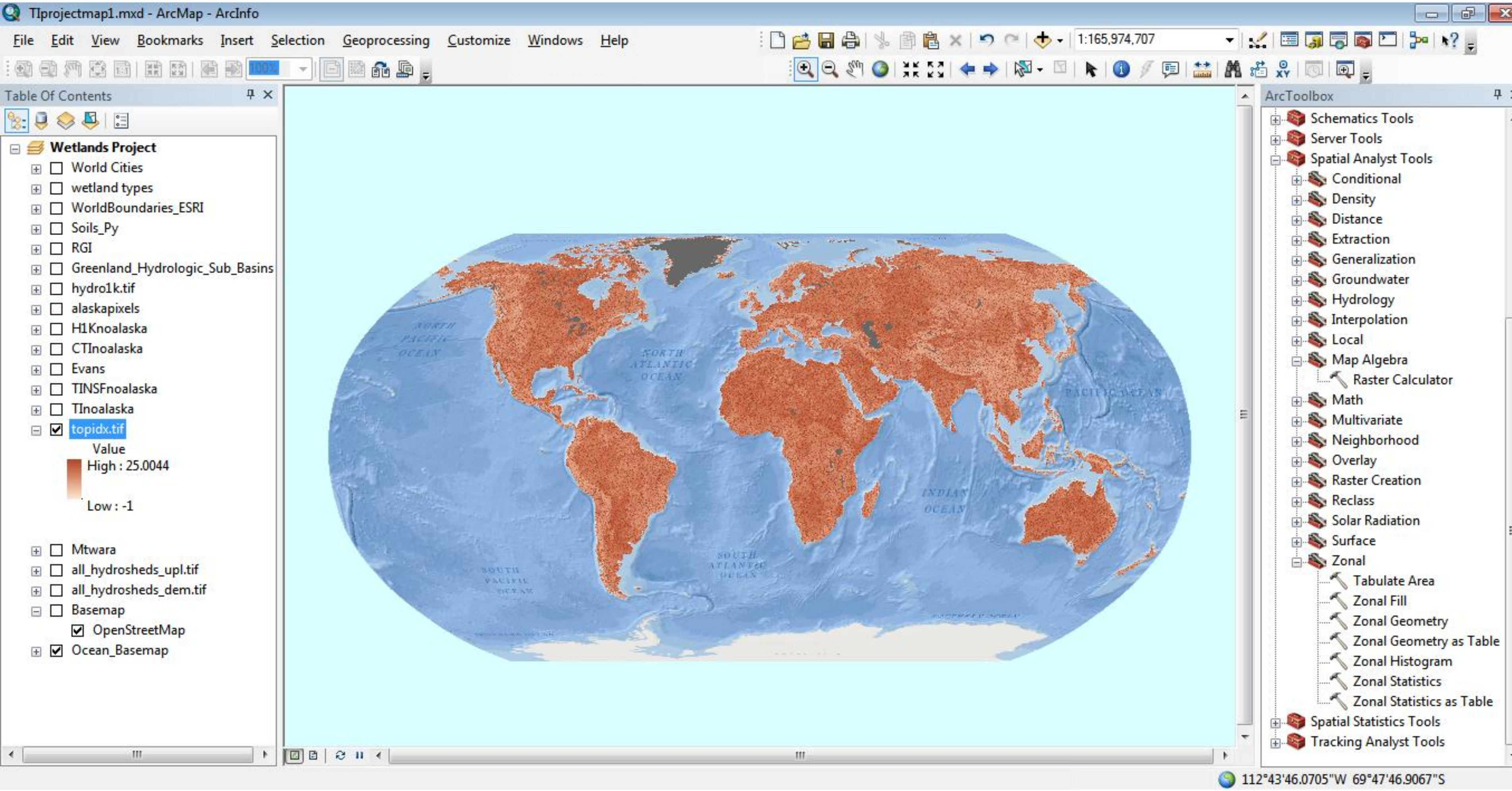
•ENVI is probably ArcGIS's closest competitor.

•The leading freeware package is QGIS (which incorporates the tools of Grass GIS as well)

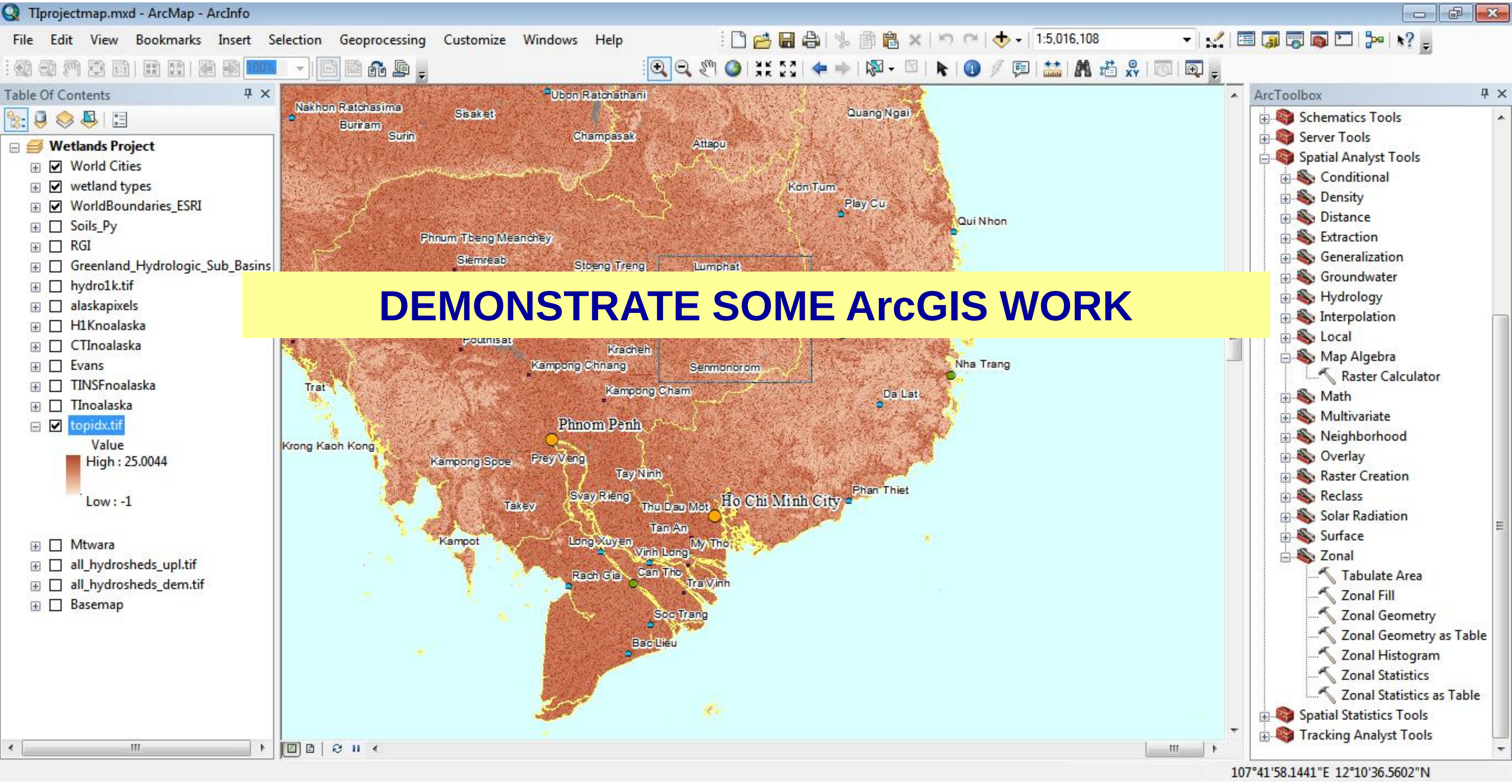


ENVI

Geographic Information Systems (GIS)



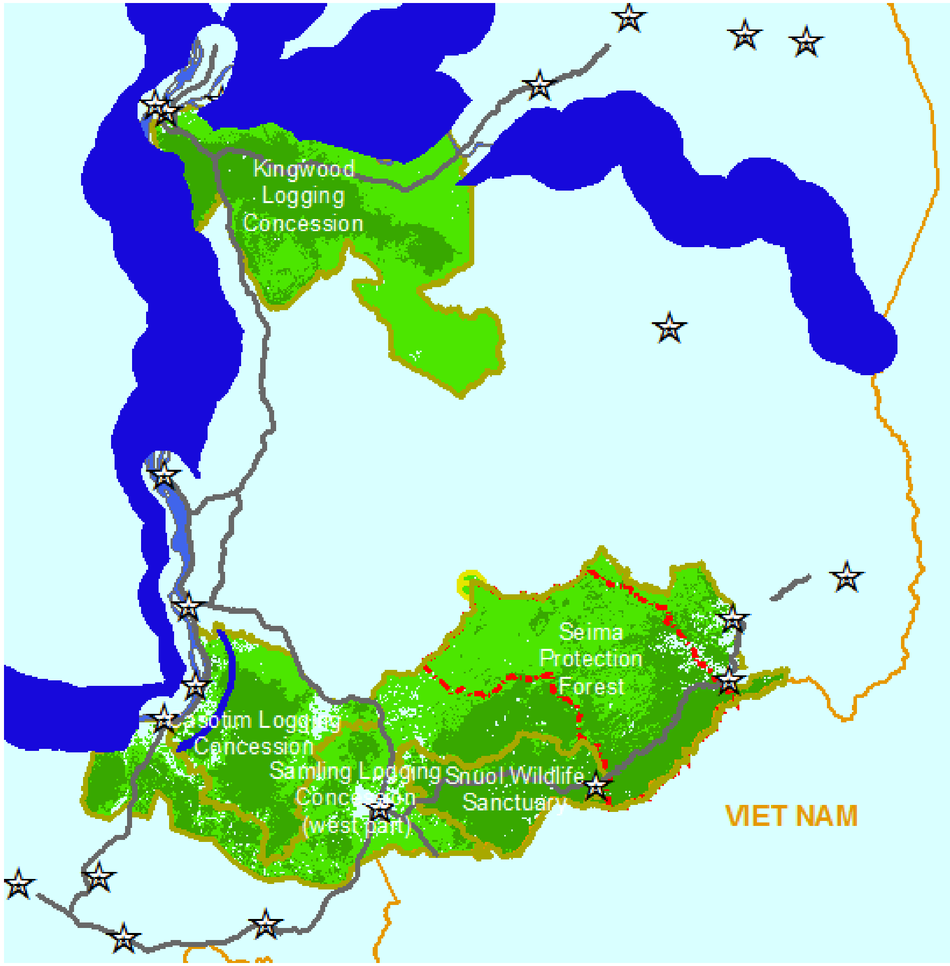
Geographic Information Systems (GIS)



DEMONSTRATE SOME ArcGIS WORK

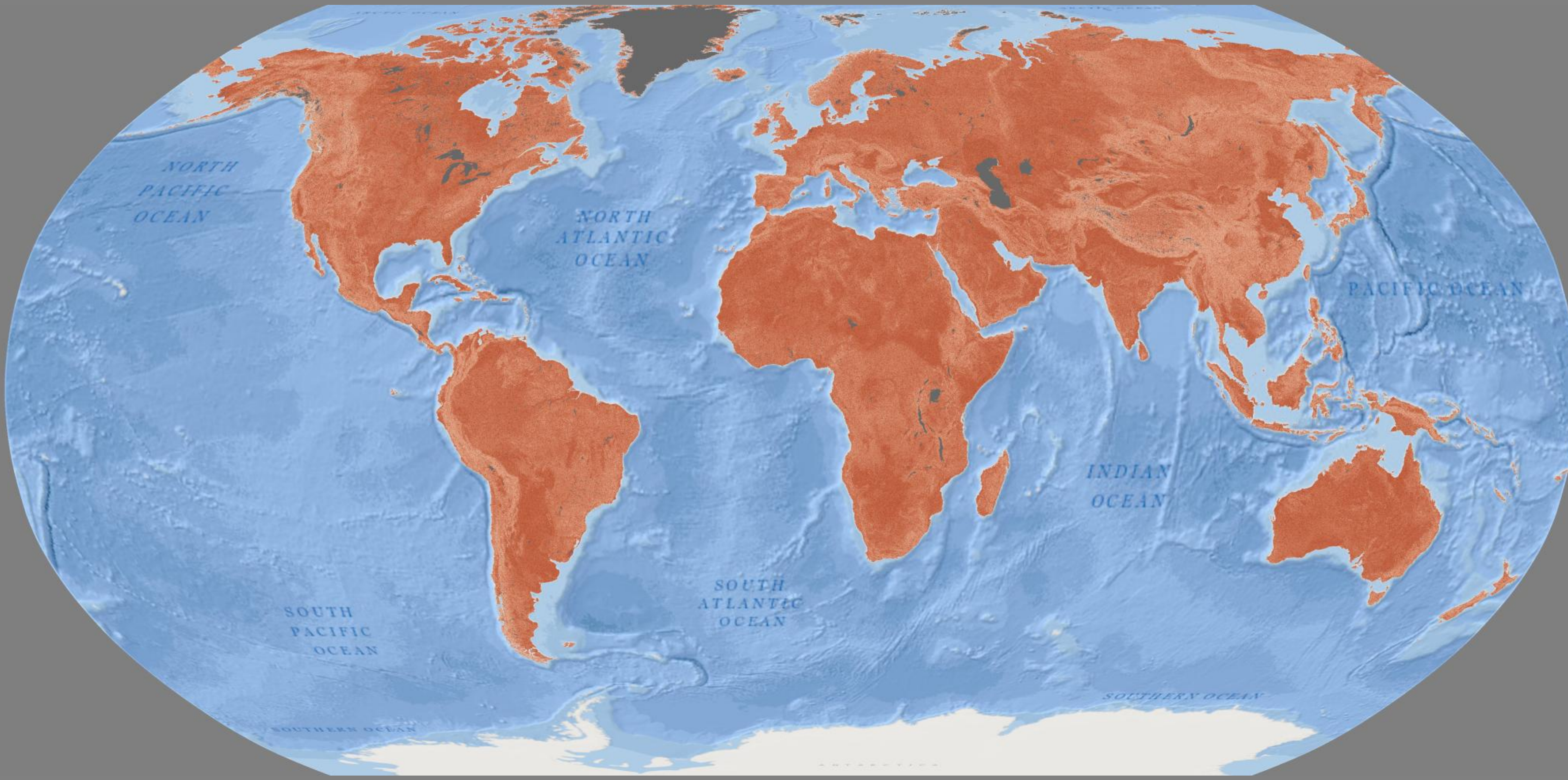
Geographic Information Systems (GIS)

Blue shows the suitable habitat for this example Cambodian amphibian that can only survive within 7 km of a river and >5 km away from major roads. All details in the lecture.



ArcGIS commands →

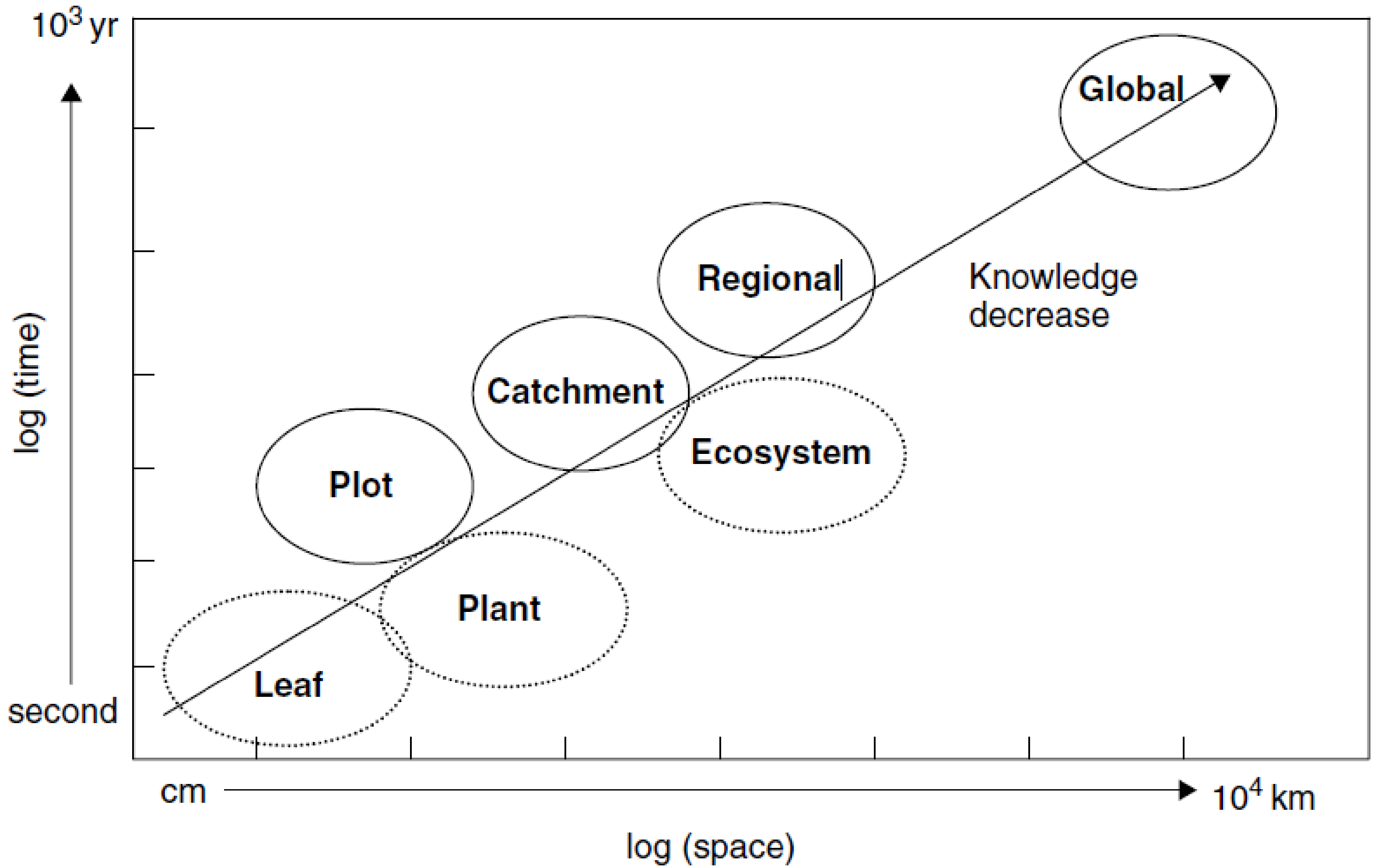
```
#Say there's a certain species of Cambodian amphibian that can only live within 7 km of a river and that this amphibian can't survive
within 5 km of a road. This amphibian's potential habitat can be found from a niche-based analysis:
Euclidean Distance with input = RoadsRiversEtc\Major Roads 2012 and output Rdist1
Euclidean Distance on RoadsRiversEtc\Water Courses\LakeLow (all major rivers) with output Ldist1
Con("Rdist1">5000,1,0) to make Rgood
Con("Ldist1"<7000,1,0) to make Lgood
Con("Rgood" & "Lgood",1,0) to make Suitable
```



Sundry points

Spatial Scale

I won't say much about spatial scale here, but I mention it because it's something you need think about when considering which model to use.



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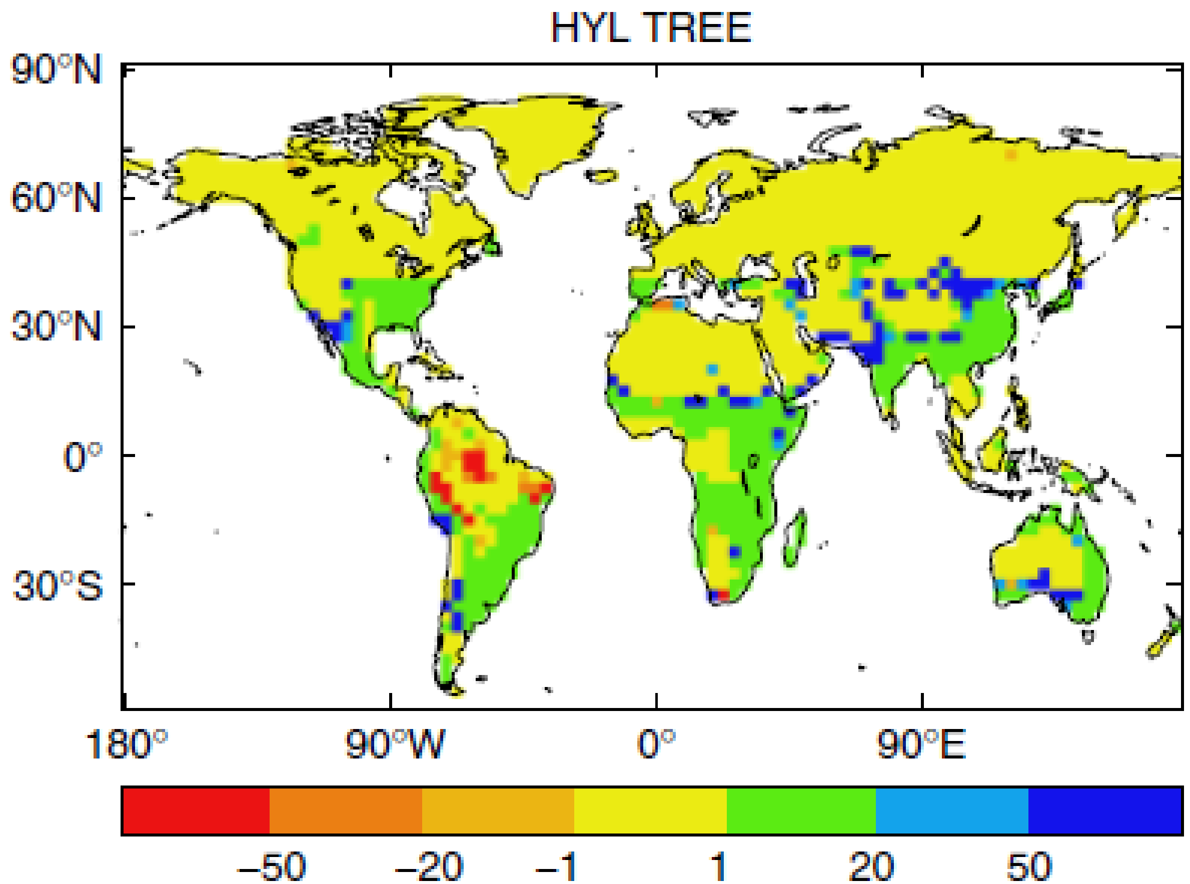
Spatial Scale

Sitch *et al.* (2008): GCM resolution 3.75° x 2.5° (1631 global gridboxes). Simulation resolution depended on resolution of available climate data, computing power. Input data: Climate data (temperature, precipitation, SW Radiation, windspeed, surface pressure), atmospheric composition (CO_2, other GHGs), soil texture - not all available at the same resolution.



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Do you need mathematics?

THE WALL STREET JOURNAL.

EUROPE EDITION Friday, April 5, 2013 As of 10:07 PM EDT

Home | World | Europe | U.K. | U.S. | Business | Markets | Market Data | Tech | Life

ESSAY | April 5, 2013, 10:07 p.m. ET

Great Scientist ≠ Good at Math

E.O. Wilson *shares a secret: Discoveries emerge from ideas, not number-crunching*

Article | Comments (244)

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By E.O. WILSON

For many young people who aspire to be scientists, the great bugbear is mathematics. Without advanced math, how can you do serious work in the sciences? Well, I have a professional secret to share: Many of the most successful scientists in the world today are mathematically no more than semiliterate.

Vahram Muradyan

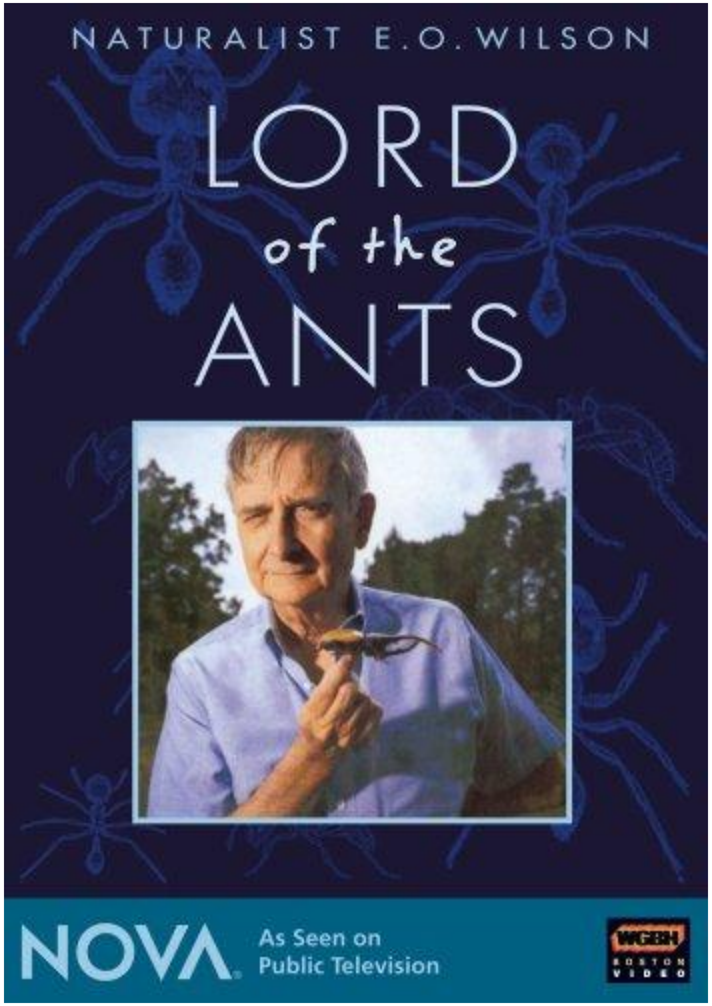
During my decades of teaching biology at Harvard, I watched sadly as bright undergraduates turned away from the possibility of a scientific career, fearing that, without strong math skills, they would fail. This mistaken assumption has deprived science of an immeasurable amount of sorely needed talent. It has created a hemorrhage of brain power we need to stanch.

I speak as an authority on this subject because I myself am an extreme case.

.....

Newton invented calculus in order to give substance to his imagination. Darwin had little or no mathematical ability, but with the masses of information he had accumulated, he was able to conceive a process to which mathematics was later applied.

For aspiring scientists, a key first step is to find a subject that interests them deeply and focus on it. In doing so, they should keep in mind Wilson's Principle No. 2: For every scientist, there exists a discipline for which his or her level of mathematical competence is enough to achieve excellence.



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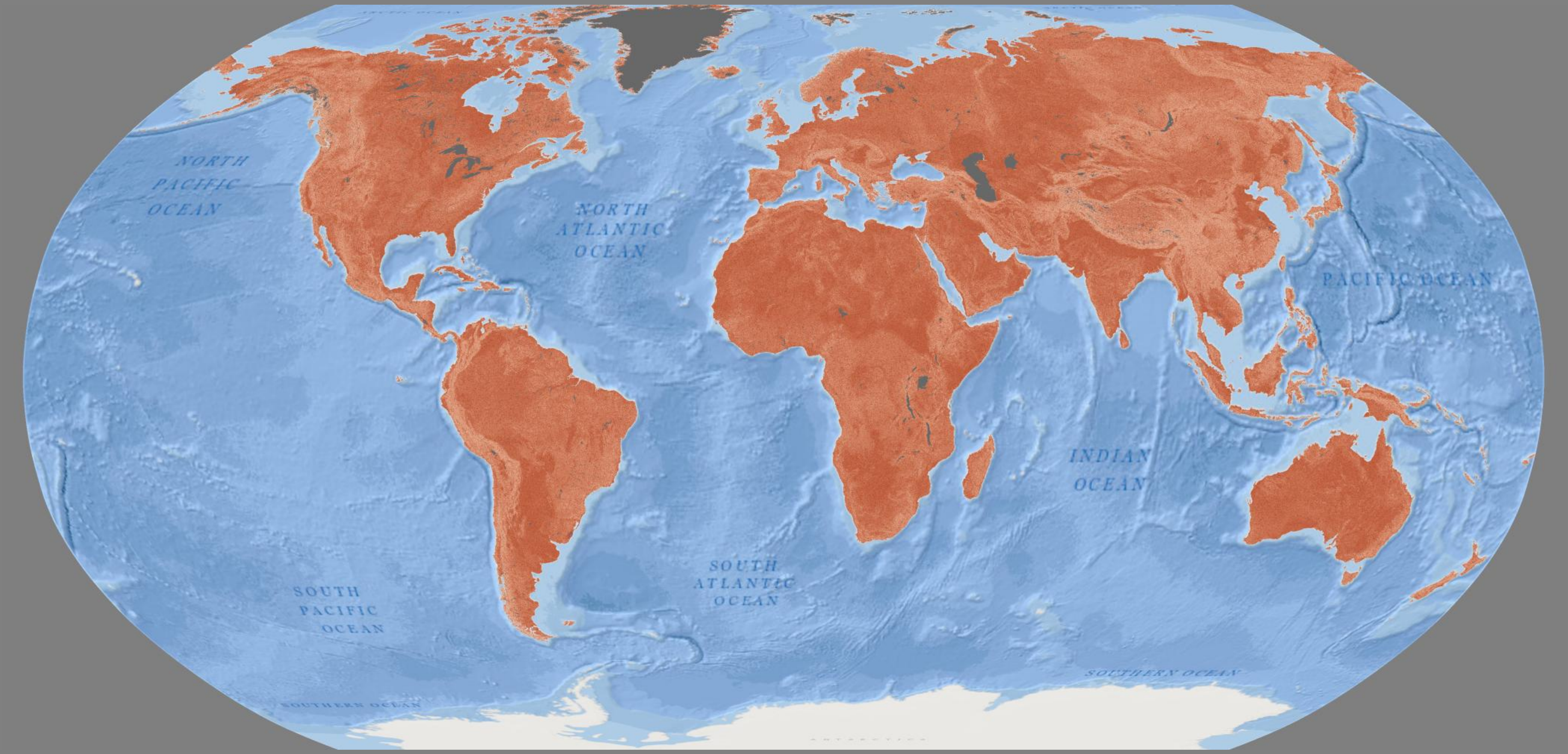

PART 3: Case Study of the Amazon Dieback

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Case Study of the Amazon Dieback

In the late 1990s, it was noticed by several researchers that running future simulations for the Amazon forest to 2050 under some global warming scenarios produced a huge ‘dieback’ of the forest as its eastern portions dried out and converted to savanna (White et al. 1999, GEC; Cox et al. 2000, Nature; Cox et al. 2004, T&AC; Malhi et al. 2009, PNAS)

Wissenschaft

KLIMA

Wälder auf der Kippe

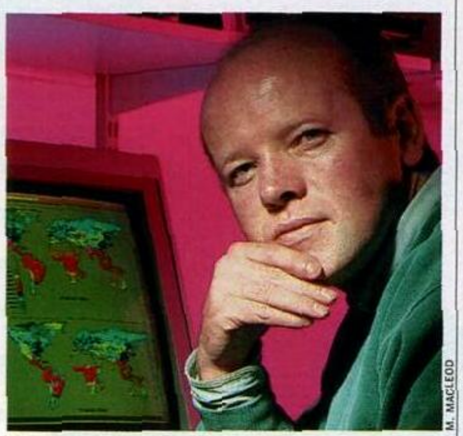
Wüsten am Amazonas, Steppen in Europa, Mißernten in den USA: Kann der Treibhauseffekt dazu führen, daß das Ökosystem Erde plötzlich entgleist?

Während Nicaragua, Honduras und El Salvador in Schlammfluten ertrinken, befaßt sich ein Forscher im schottischen Edinburgh mit einer Katastrophe ganz anderer Art: „In den südamerikanischen Tropen“, warnt er, „wird das Wasser knapp.“

Andrew Friend heißt der Vater des befremdlichen Szenarios. Zusammen mit seinen Mitarbeitern hat er ein Computerprogramm geschrieben, das simuliert, wie Wälder, Wüsten und Steppen auf den Treibhauseffekt reagieren werden. Als er es startete, spielte sich auf seinem Monitor ein furchteinflößendes Drama ab. Hauptdarsteller: der blaue Planet.

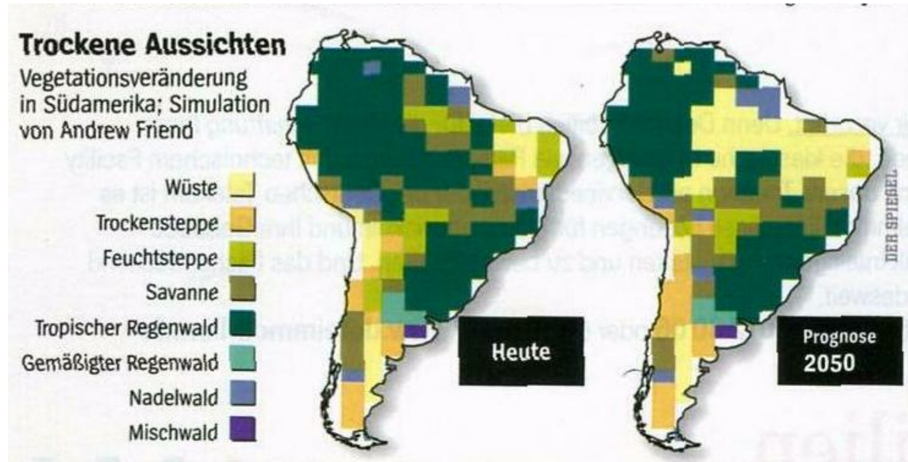
Auf dem Bildschirm sah es aus, als habe eine Krankheit das ganze Ökosystem Erde befallen. Die Infektion begann im tropischen Brasilien und breitete sich von dort über den ganzen Globus aus.

Erst, so Friends Computer-Prognose, verdorrt der Dschungel am Unterlauf des



Klimaforscher Friend
Kakteen treten das Erbe der Lianen an

Computer den Kassandraruf entlockt. In der argentinischen Hauptstadt verhandeln gegenwärtig Umweltpolitiker aus aller Welt über den Klimaschutz. Vor einem Jahr ha-



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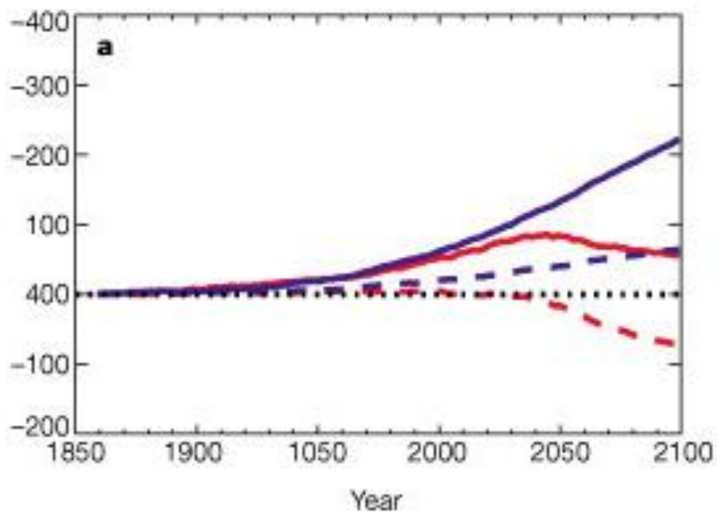
Case Study of the Amazon Dieback

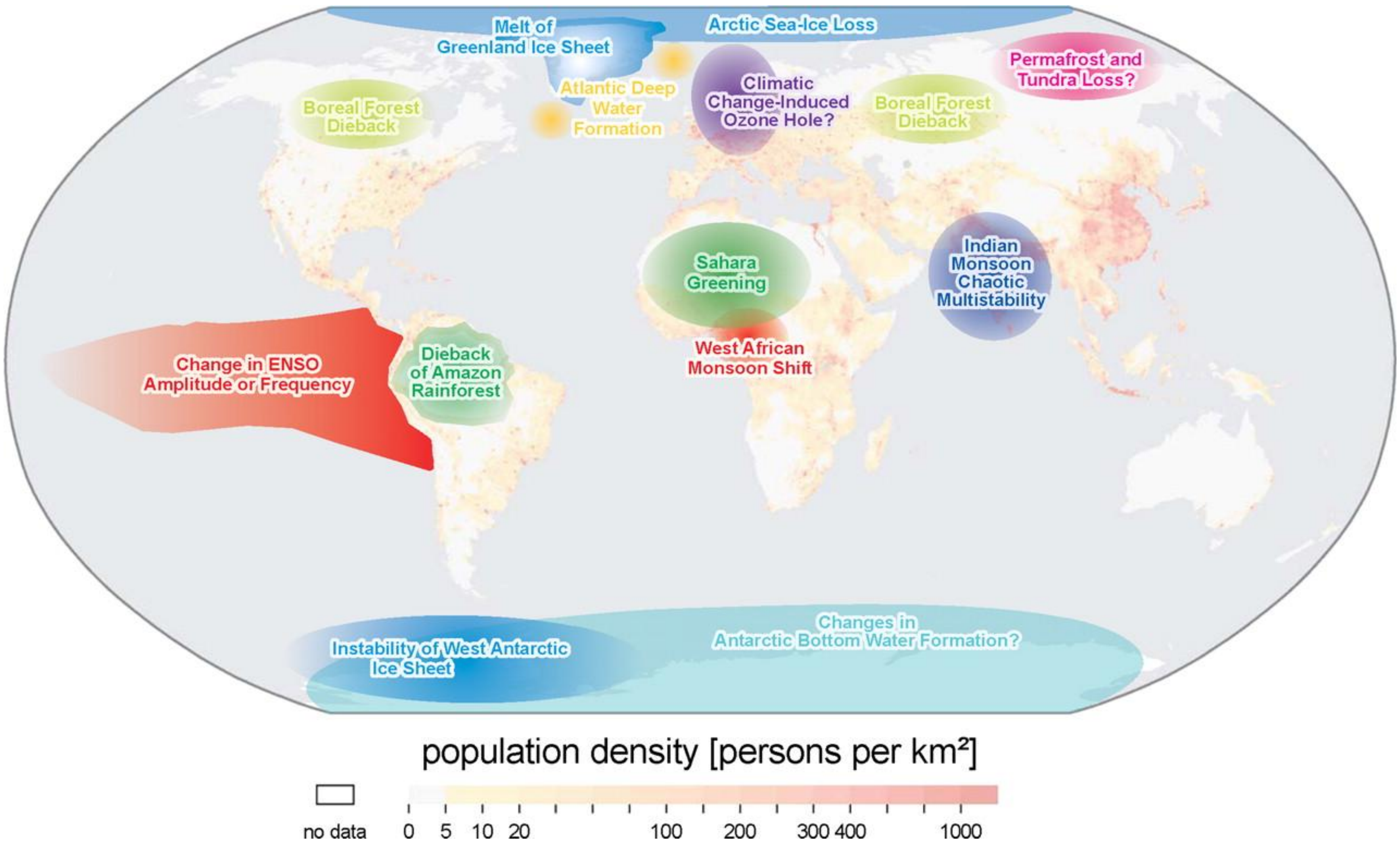
Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model

Peter M. Cox*, Richard A. Betts*, Chris D. Jones*, Steven A. Spall* & Ian J. Totterdell†



Case Study of the Amazon Dieback

Potential tipping elements in the climate system, overlain on global population density:



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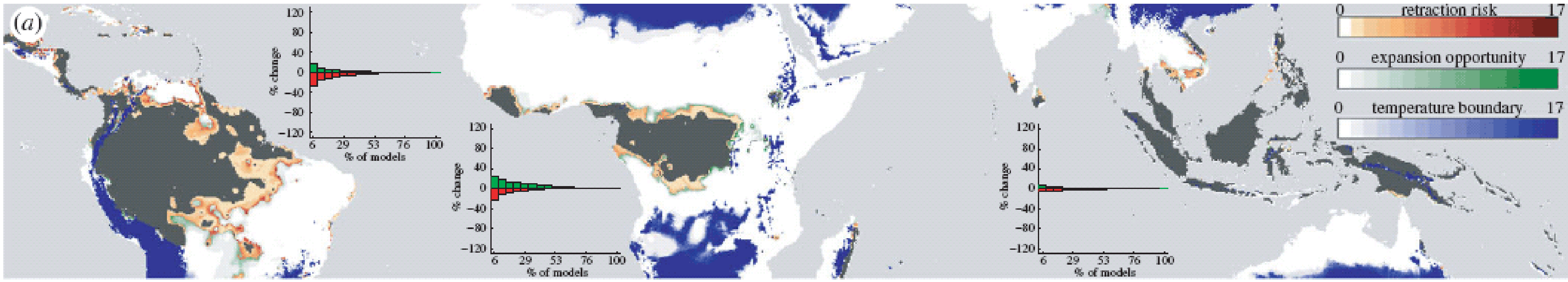
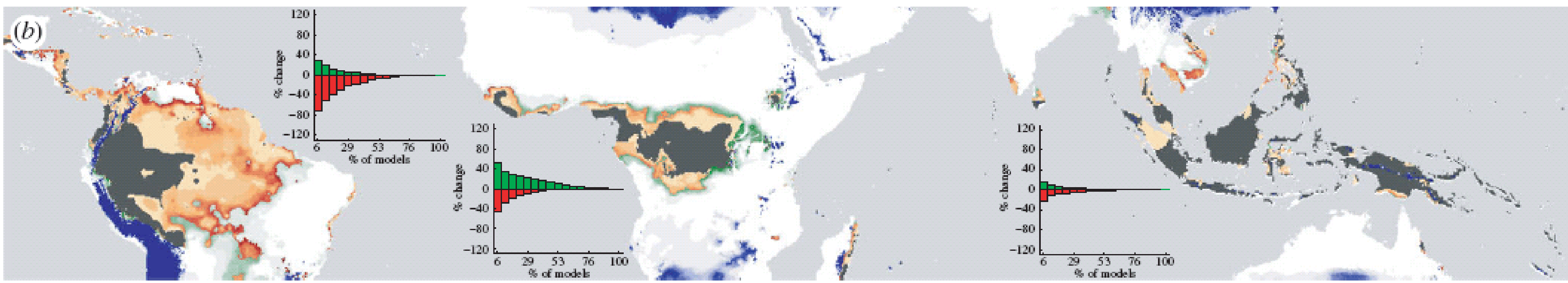
Lenton TM *et al*. (2008). *PNAS* 105:1786-1793.

Case Study of the Amazon Dieback

Changes in the potential distribution of tropical forests on a warmer planet:

2°C global warming





4°C global warming

Depending on future scenario, the current (AR4) IPCC predictions show a likely range up to 6.4°C to 2099.

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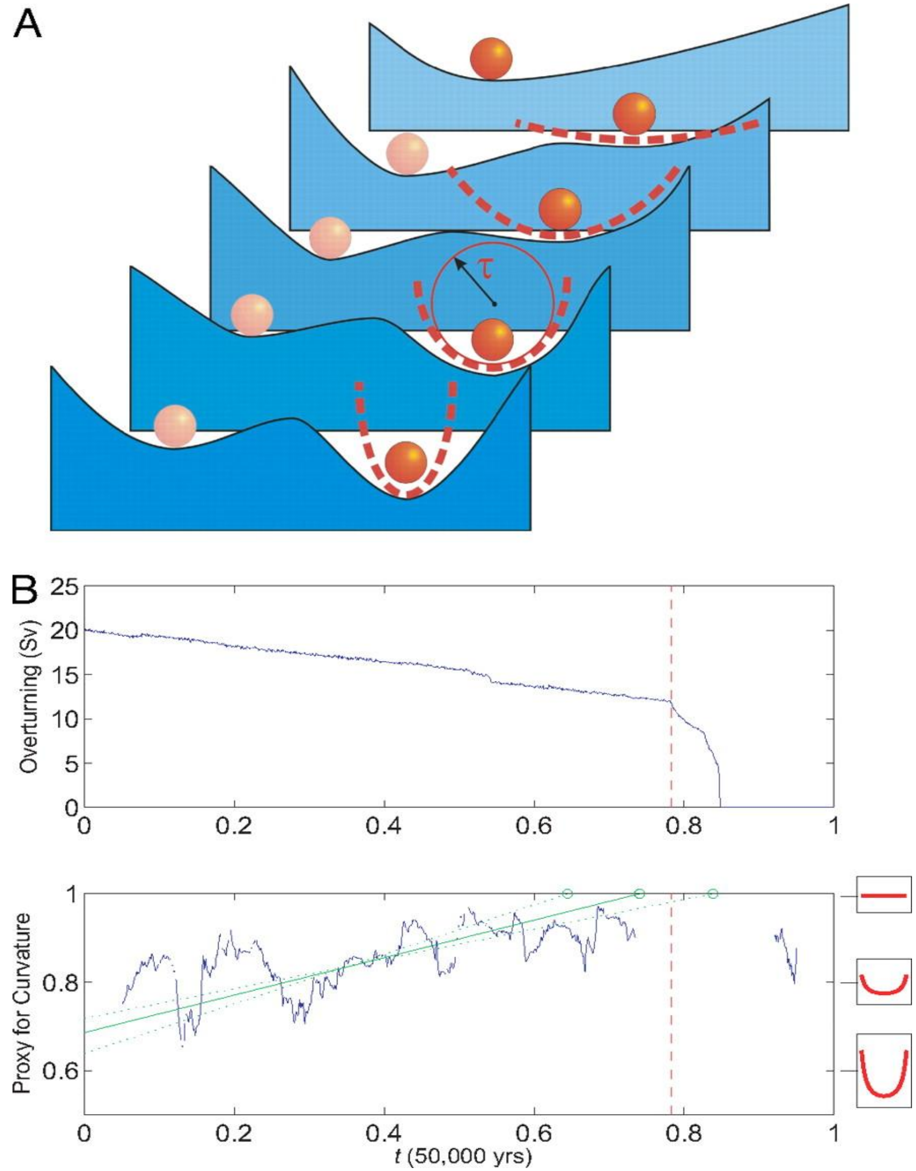
Zelazowski *et al.* (2011). *PTRS* A 369:137-160.

Case Study of the Amazon Dieback



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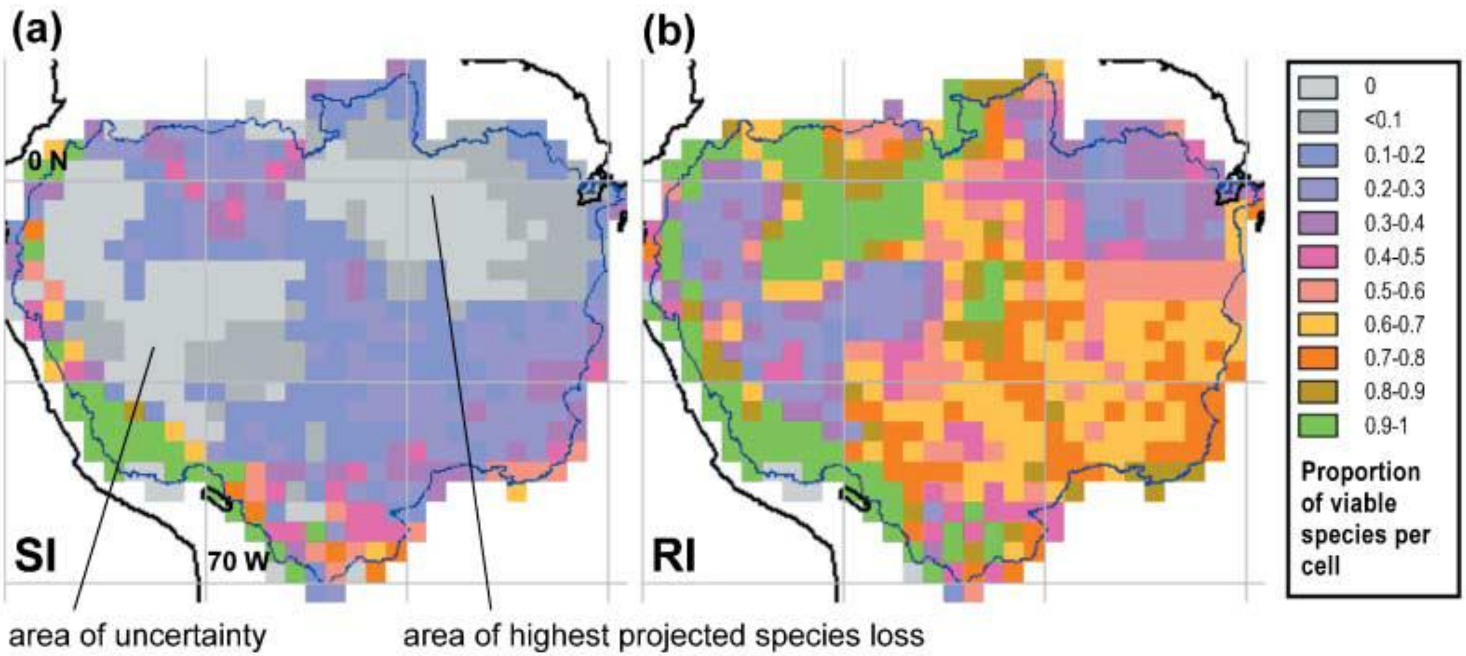
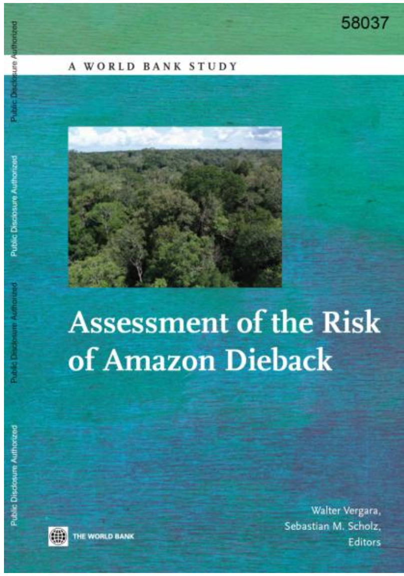
Lenton TM *et al*. (2008). *PNAS* 105:1786-1793.

Case Study of the Amazon Dieback

Naturally, this issue worries a large number of people (not just in the Amazon Basin). The potentially huge species loss (Miles *et al.* 2004) would be catastrophic, for example.





Amazon rainforest at risk of ecological catastrophe.
Climate change could kill the Amazon rainforest even if deforestation and emissions are curbed, scientists at the Met Office fear.
The Daily Telegraph, 12 Mar 2009

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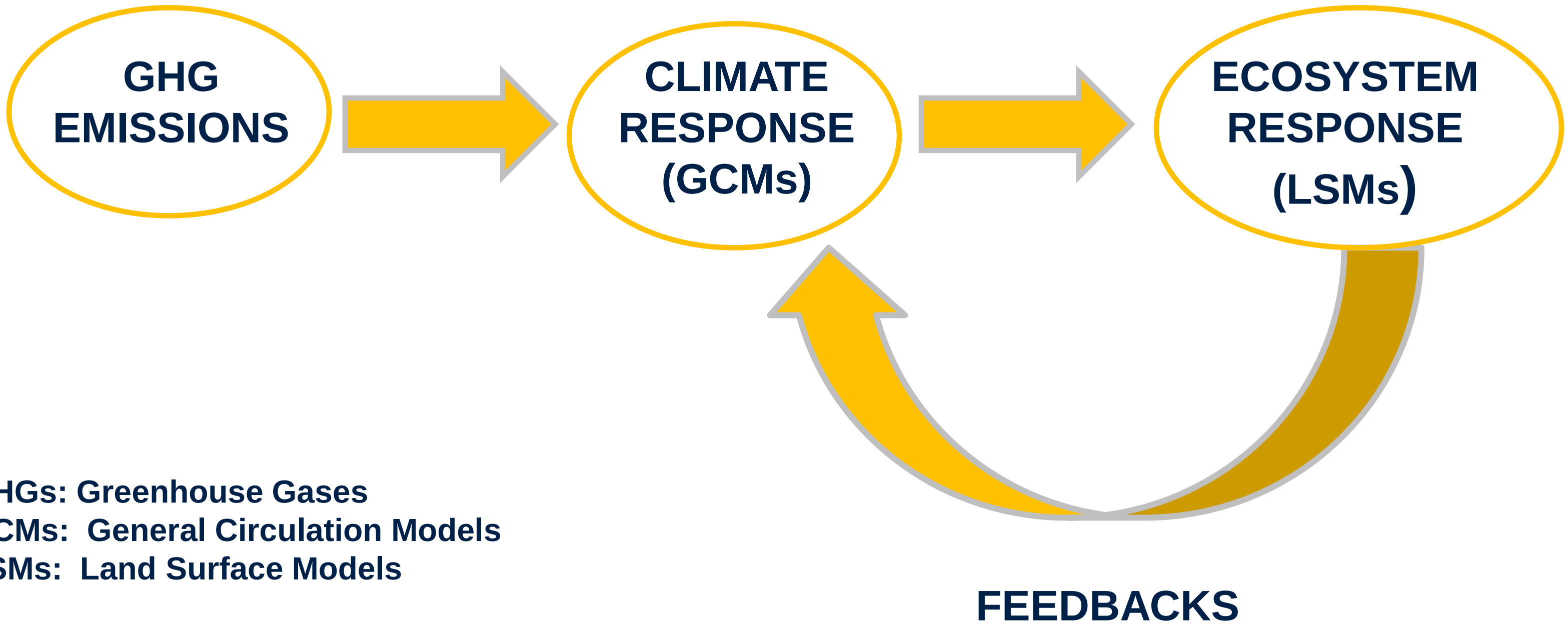
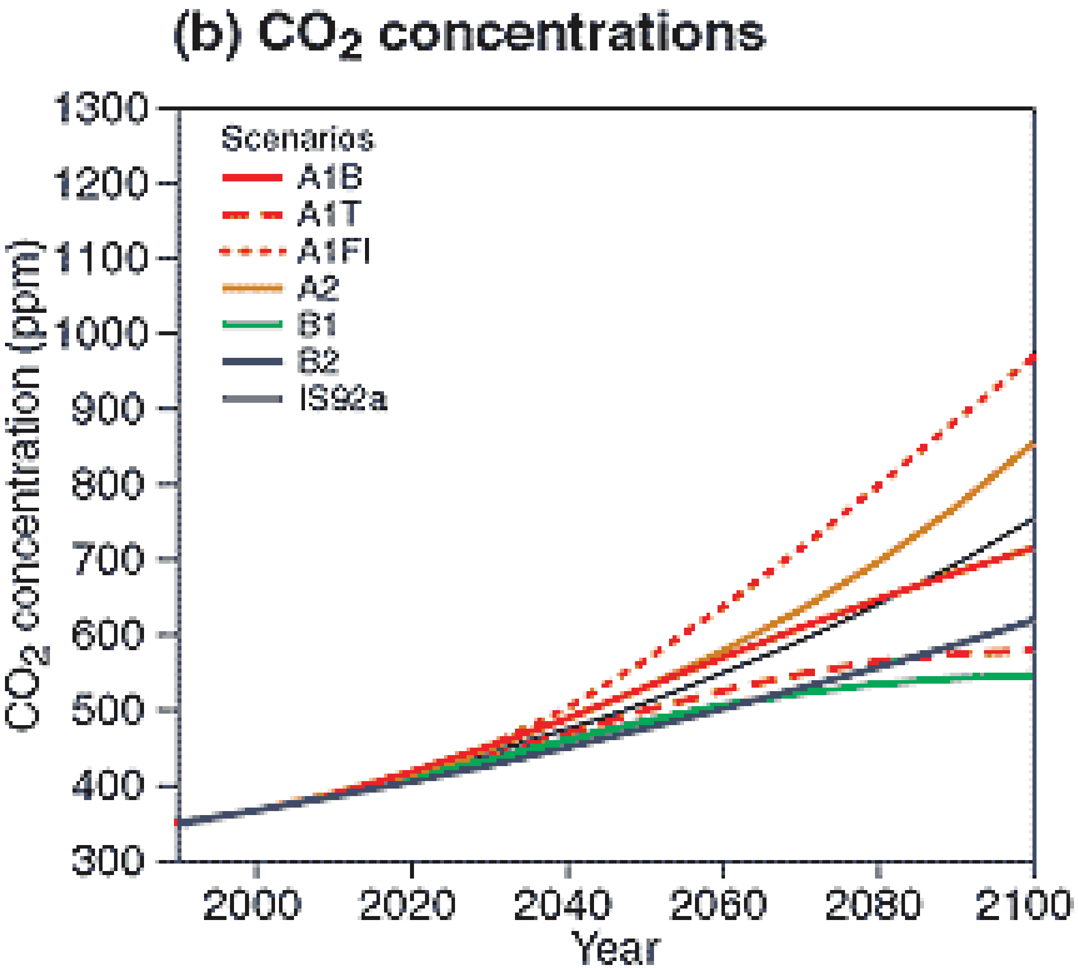
However, uncertainty in the LSMs used to make these predictions is very high.



GHGs: Greenhouse Gases
GCMs: General Circulation Models
LSMs: Land Surface Models

Case Study of the Amazon Dieback

There is uncertainty in the predictions of future CO_2 concentrations:



IPCC, 4th Assessment Report

Case Study of the Amazon Dieback

There is uncertainty in the Climate Response to Future GHG Emissions. For example, temperature: GCMs simulate an increase in mean annual temperature of 3-8°C over Amazonia this century.

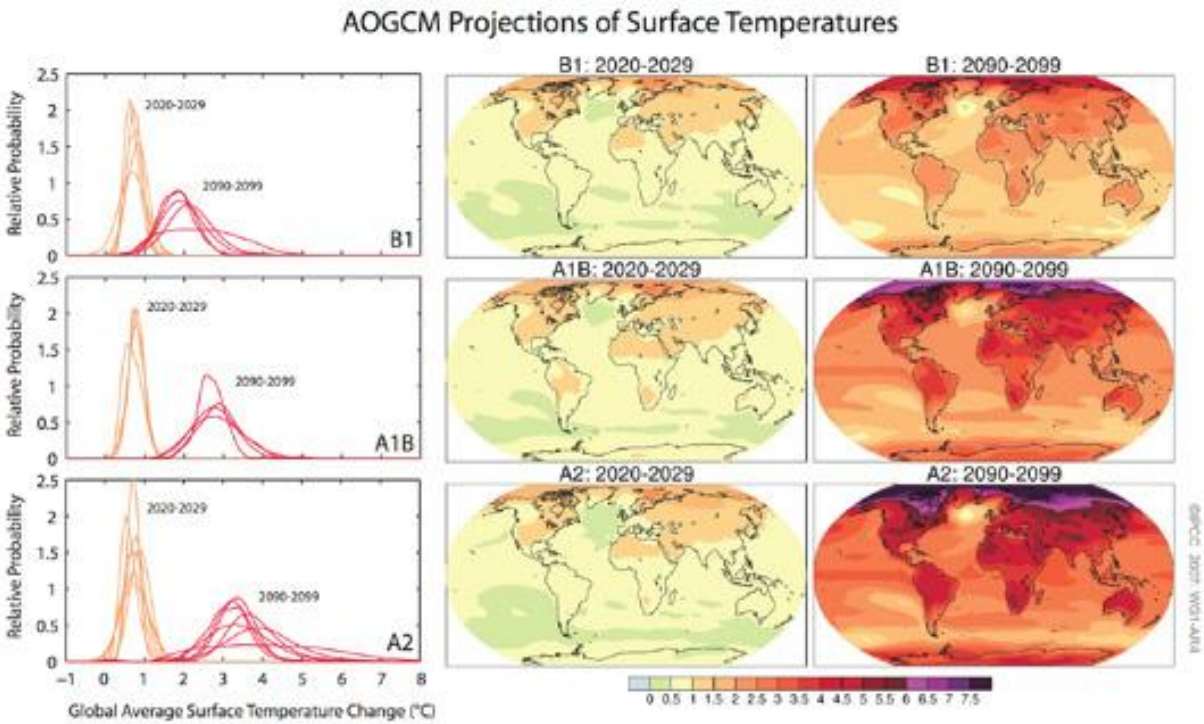
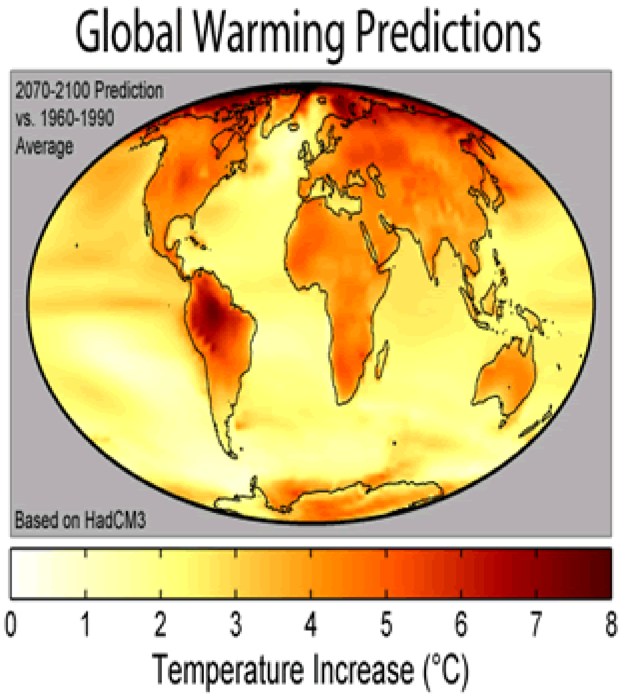


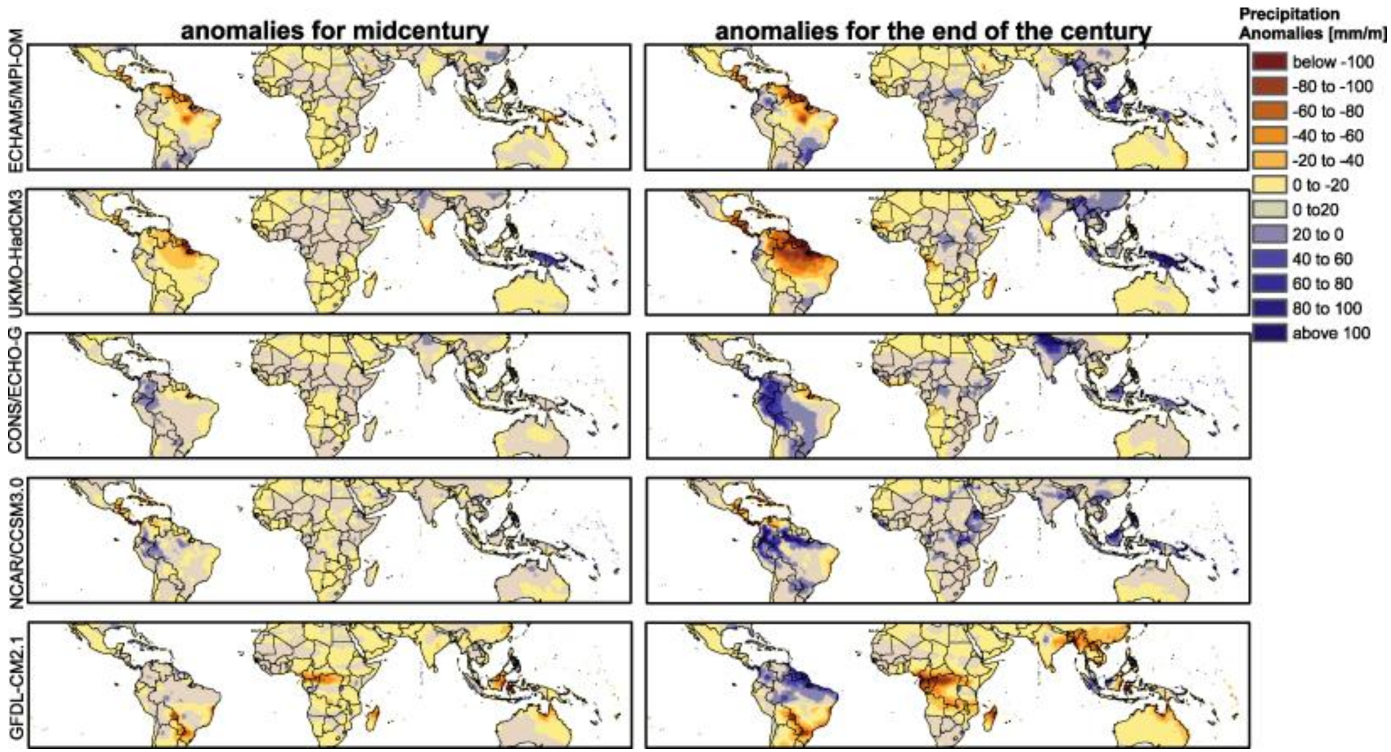
Figure 5. Projected increase in average temperatures from 1960-1990 to 2070-2100.



Case Study of the Amazon Dieback

There is uncertainty in the Climate Response to Future GHG Emissions. For example, rainfall (Gumpenberger *et al*. 2010):

Figure 1. Precipitation anomalies (bias-corrected, mm/months) for midcentury (2041–2050) and the end of the 21st century (2090–2099), in comparison to the reference period (1991–2000), for five different climate scenarios.



- Most GCMs underestimate present-day rainfall over Amazonia
- No consistent trend across GCMs in terms of the direction of change of mean annual rainfall
- Little relationship between a model's ability to simulate present-day rainfall and the direction of future rainfall change

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Case Study of the Amazon Dieback

There is large recognised uncertainty in the vegetation responses to future climate (Malhi *et al.* 2009, PNAS)

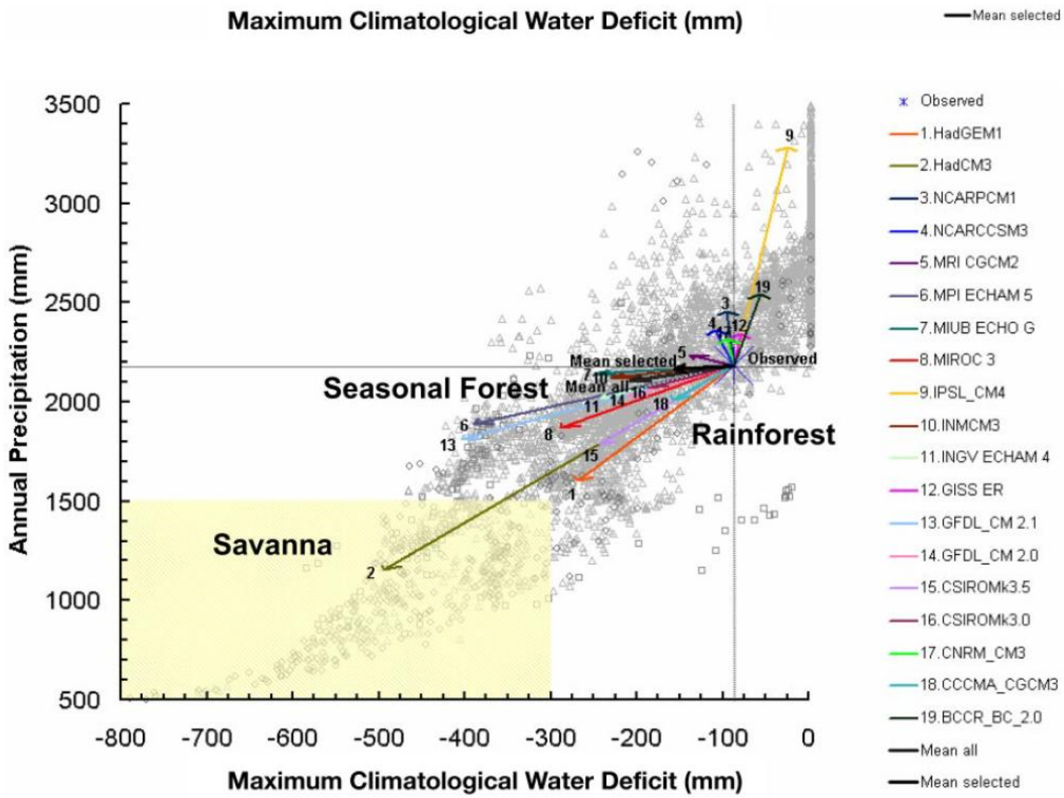

Fig. 2. An evaluation of GCM simulations in change of rainfall regime in E. Amazonia.
(*B*) The trajectories of changes in GCM rainfall regime when recalculated as relative changes forced to start from the CRU observed climatology. The tip of the arrow indicates the late 21st-century rainfall regime. Our suggested savanna zone is shaded (MCWD < −300 mm, AP < 1500 mm).

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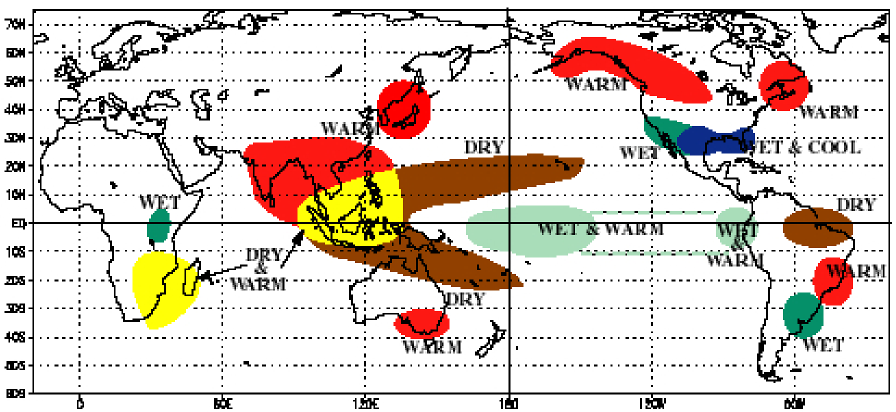
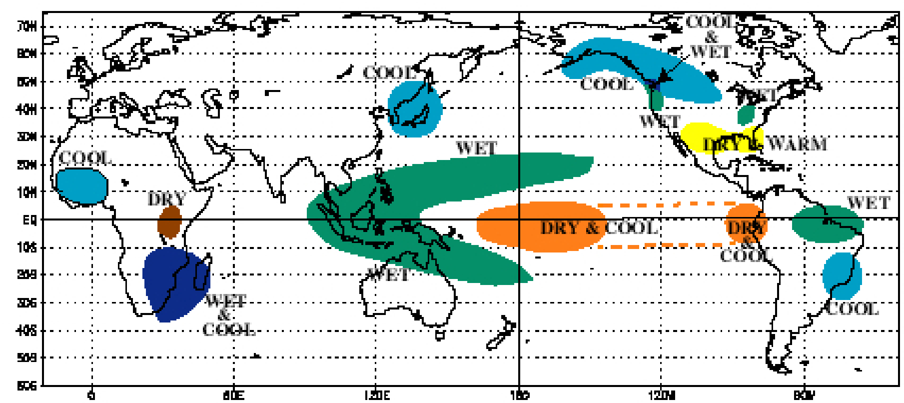
Case Study of the Amazon Dieback

El Niño and La Niña effects are not yet well-characterised in GCMs.

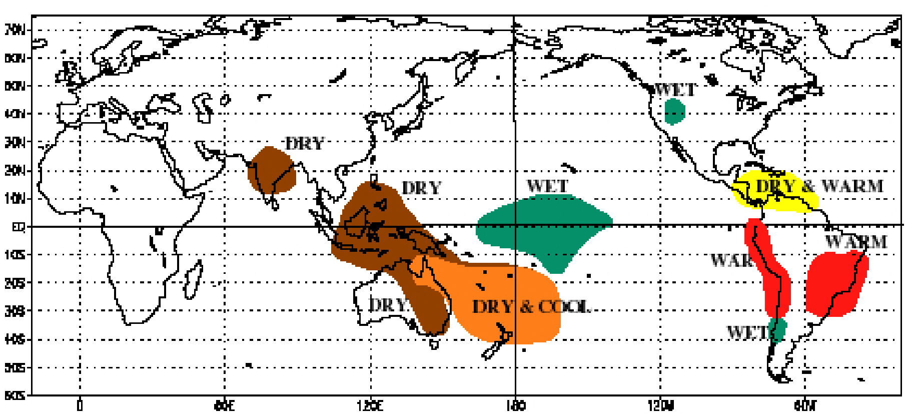
WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



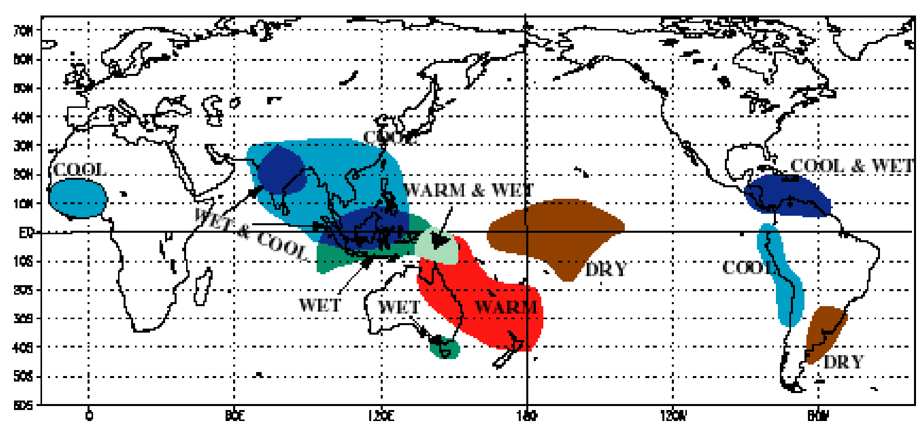
COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



WARM EPISODE RELATIONSHIPS JUNE - AUGUST

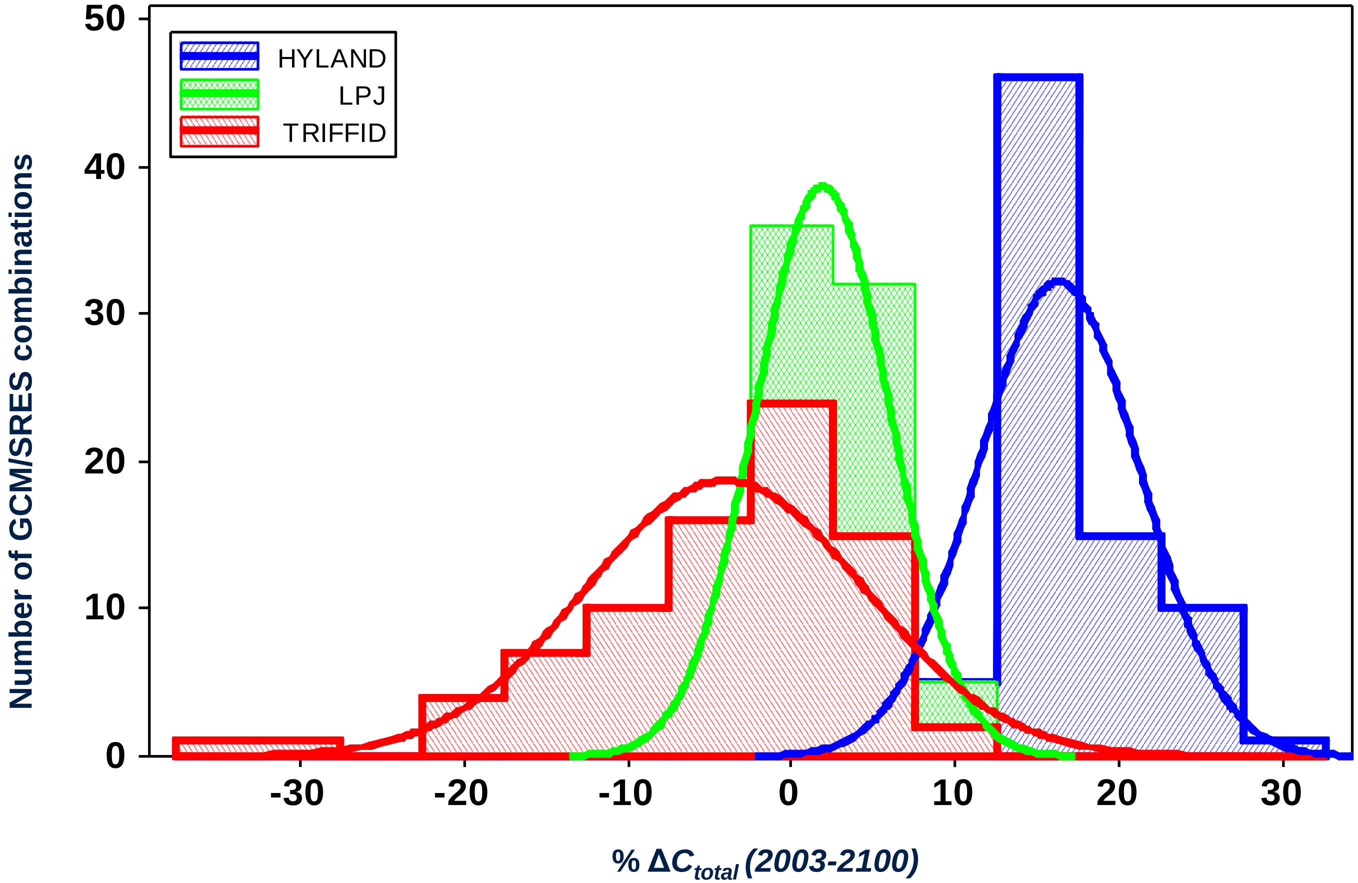


COLD EPISODE RELATIONSHIPS JUNE - AUGUST



Case Study of the Amazon Dieback

Which source of uncertainty is the most important? LSMs explain 2/3 of the variance in modelled changes in Amazonian C stocks (240-member ensemble (20 GCMs, 4 SRES Scenarios, 3 LSMs) in Galbraith *et al.* 2010).



Case Study of the Amazon Dieback

The network of RAINFOR Intensive sites now called GEM (http://gem.tropicalforests.ox.ac.uk/) can help: not only will the fieldwork reduce uncertainties in the LSMs but we are also measuring increasing amounts of long-term MET data.

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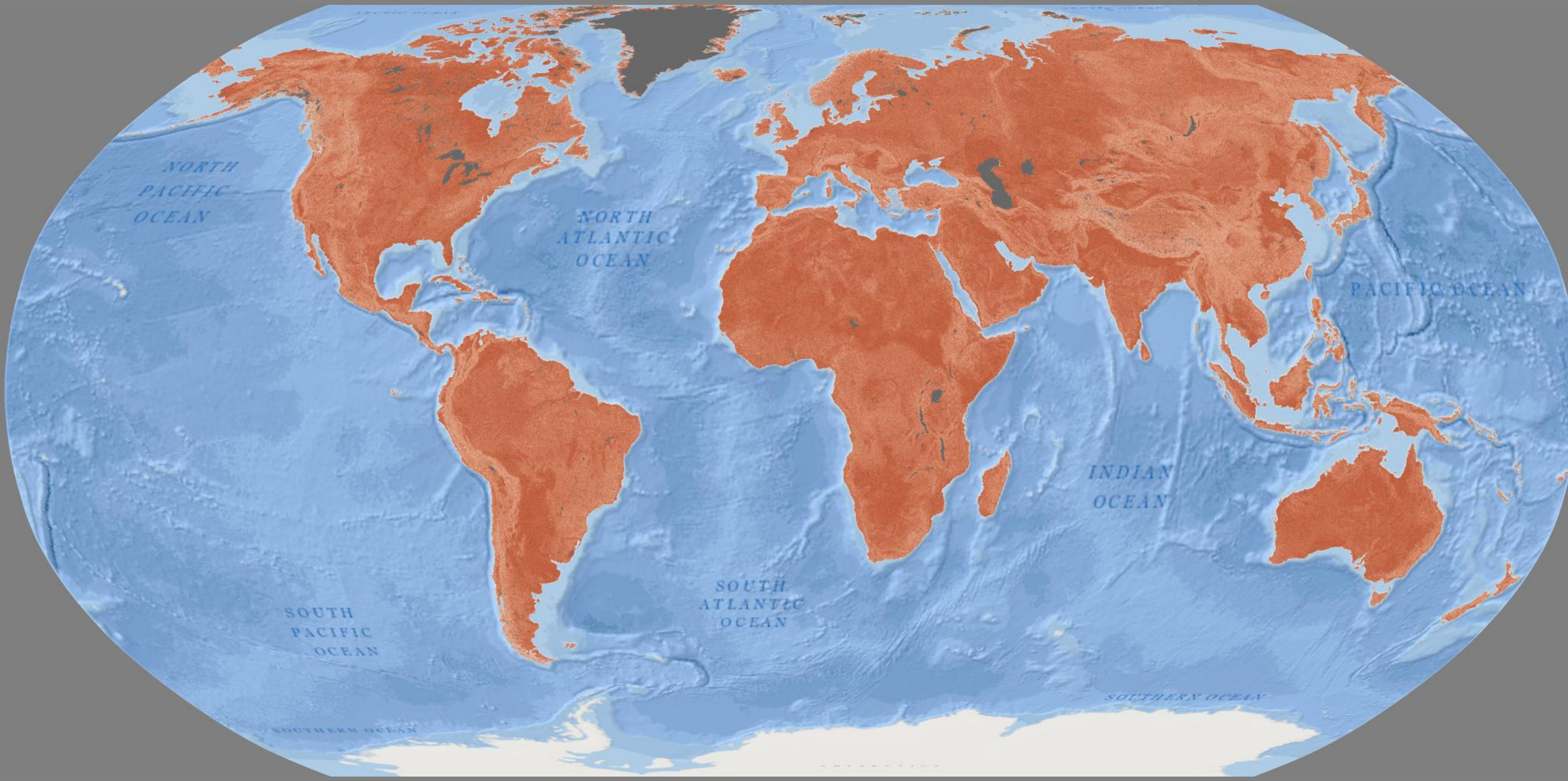

Summary

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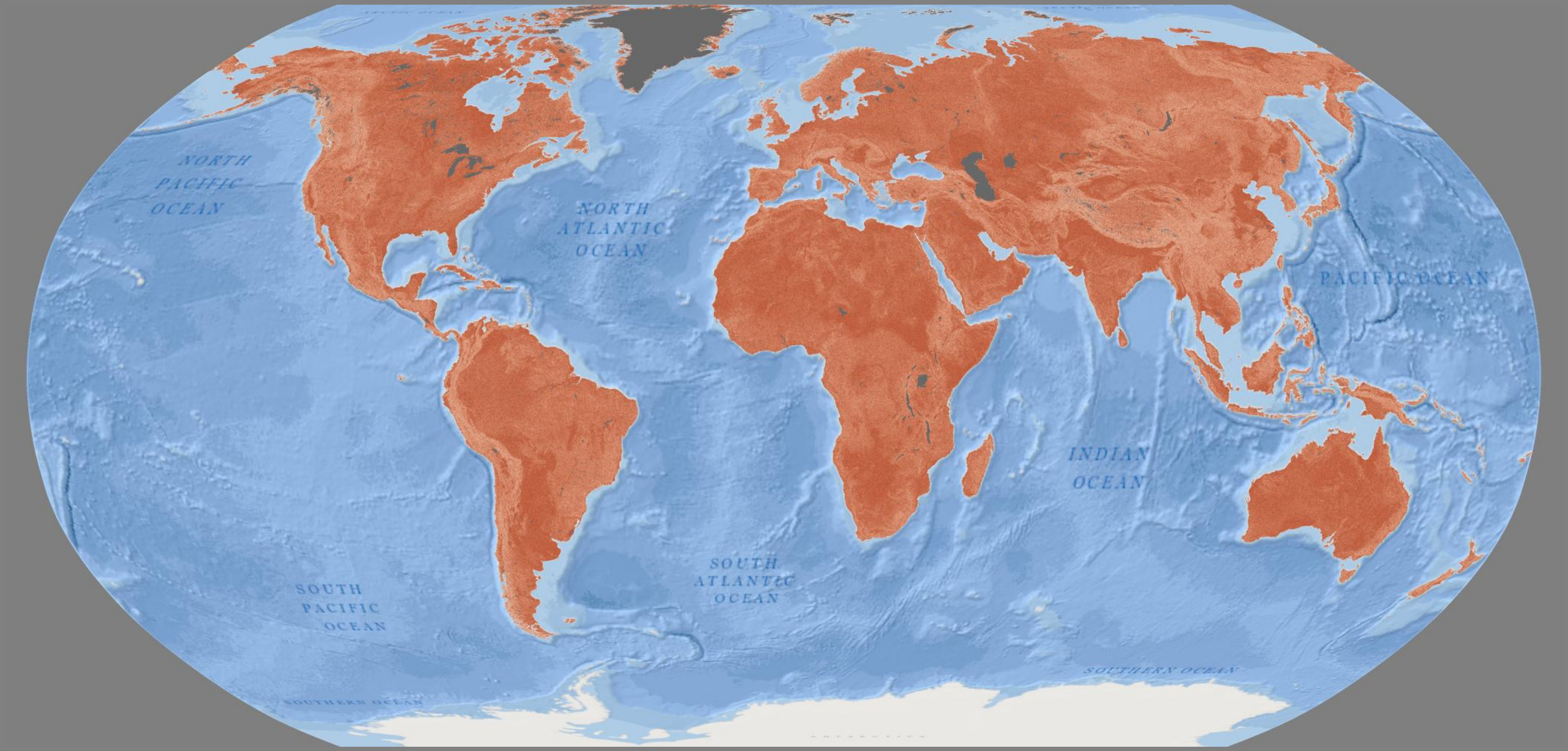
Summary

•Ecosystem simulation models are either niche-based models or mechanistic models, both of which have distinct advantages and disadvantages.

•You can implement models in various ways, the most usual being either using code (scripts or compiled code) or graphically through Model Building software. GIS software has interfaces for both approaches.

•Land Surface models are mechanistic models that allow for feedbacks between different components of the Earth System (land surface, atmosphere, ocean, etc.). Applying them to predict the future of the Amazon has produced very useful, but mixed results.

•Mathematical models are useful tools for understanding ecosystem processes and predicting the future, but you have to think carefully about the uncertainties there might be in the model outputs.



Thank you

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