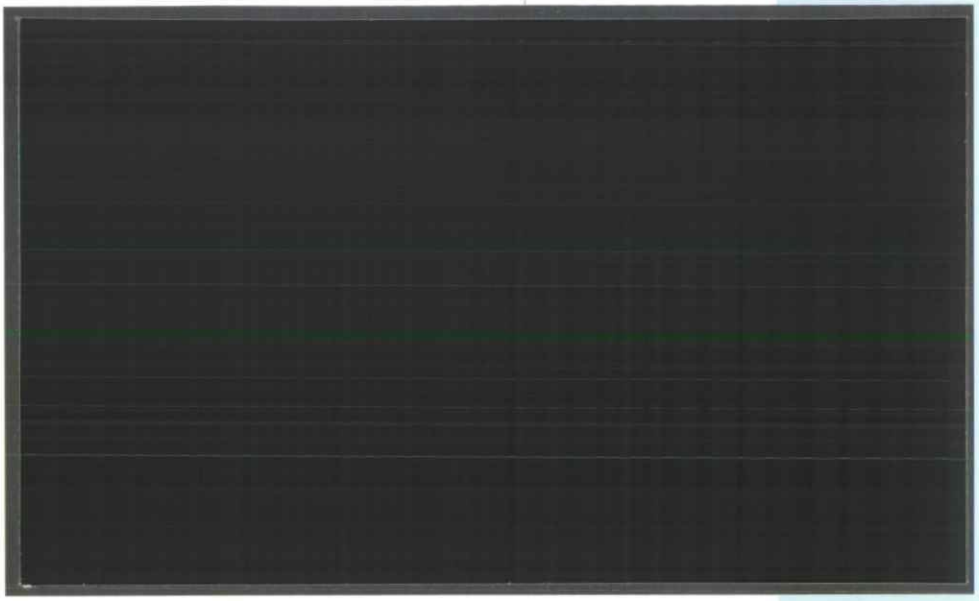
The

Centre for Ecology & Hydrology



Centre for
Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Formerly the Institutes of Hydrology,
Terrestrial Ecology, Freshwater Ecology,
and Virology and Environmental Microbiology

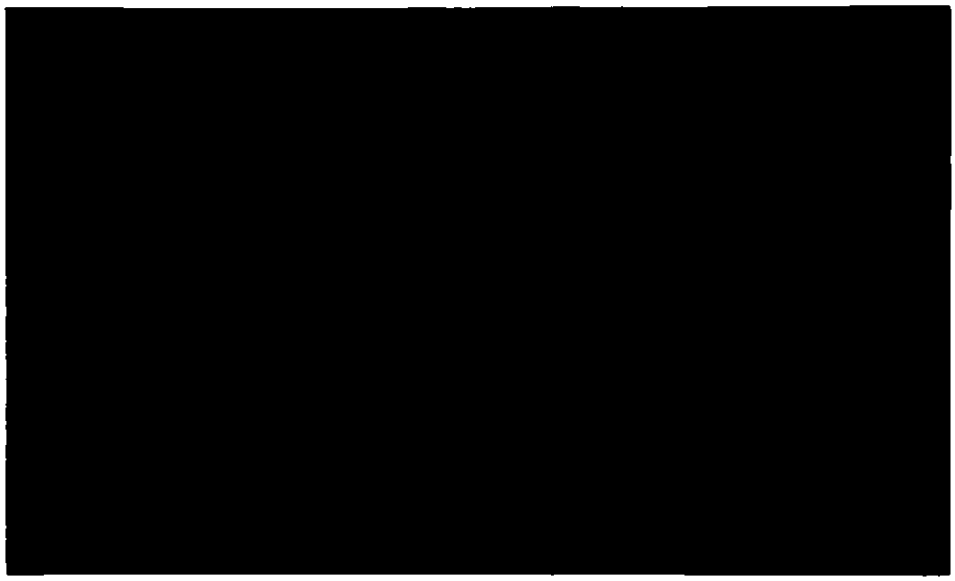
The **Centre for Ecology and Hydrology** is one of the Centres and Surveys of the Natural Environment Research Council (NERC). It was established in 1994 by the grouping together of four NERC Institutes, the Institute of Hydrology (IH), the Institute of Terrestrial Ecology (ITE), the Institute of Freshwater Ecology (IFE) and the Institute of Virology and Environmental Microbiology (IVEM). In 2000, the four component institutes were merged into a single research organisation.

Institute of Hydrology

Institute of Terrestrial Ecology

Institute of Freshwater Ecology

Institute of Virology and Environmental Microbiology



The CEH mission

- To advance the sciences of ecology, environmental microbiology (including virology) and hydrology through high-quality and internationally recognised research leading to a better understanding and quantification of the physical, chemical and biological processes relating to land and freshwater and living organisms within these environments.

- To investigate, through monitoring and modelling, natural changes in the ecological, microbiological and hydrological environments, to assess both past and future changes and to predict man's impact on these environments.

- To secure, expand and provide ecologically and hydrologically relevant data to further scientific research and provide the basis for advice on environmental conservation and sustainable development to governments and industry.

- To promote the use of the Centre's research facilities and data, to provide research training of the highest quality and to enhance the United Kingdom's research base, industrial competitiveness and quality of life.

An Integrated Hydro-Ecological Model

CEH Integrating Fund

Final Report

Autumn 2002

Chris Huntingford[+], Peter Levy*, Andy White* and Andrew Friend*

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Final report – CEH Integrating Fund Round 4

Development of an Integrated Hydro-Ecological Model (IHEM) for global change research.

By Chris Huntingford, Peter Levy, Andy White, Andrew Friend.
October 2002.

This report summarises the work undertaken between CEH Wallingford and CEH Edinburgh on the integrating fund titled "IHEM: development of an Integrated Hydro-Ecological Model".

There are two key components to this project report. The first is the scientific output to date, mainly in the form of research papers. The second concerns how the project has enabled many new links to be built between the CEH sites, and the fertilisation of a major new initiative, GHEM (Global Hydro-Ecological Model).

Project Background

The original objectives of the IHEM project were defined as:

- Develop efficient integrated models of surface-atmosphere gas exchange (including atmospheric and soil feedbacks) at a range of timescales.
- For longer timescales, include anthropogenic forcings.
- Increase the confidence with which land-surface responses to atmospheric changes may be predicted.
- Explicitly characterise such feedbacks.
- Try to be succinct and parameter-scare within resultant models.
- Ensure models are traceable to data.

IHEM Results

Land-atmosphere feedbacks are now recognised as having a very important role in the climate system. No longer is the terrestrial ecosystem regarded as static, simply responding to imposed climatological conditions, but is now known to be an integral part of the global hydrological and many other geochemical cycles.

This project has addressed land-atmosphere responses on three timescales. These are the daily timescale, seasonal and century timescale. The latter has implications regarding the greenhouse gas debate. A missing scale, not addressed by this project, is what occurs at the seasonal timescale.

All of these objectives have been addressed in some capacity through a set of individual but tightly connected subcomponents of the IHEM initiative. During the life time of this initiative, understanding global change has increased further in its importance, and is now very much an international scientific priority. Land surface

responses are seen as exceedingly important for making impacts assessments, and terrestrial response is now understood to play an important role on the climate itself. Until recently, the land surface was regarded by many as "passive", merely responding to climatic influences. Through simulations (crossing the full range of models from simple "box" climate models to conceptual Planetary Boundary-Layer feedback characterisations through to full Global Climate Models), the full extend of the land –surface to be both controlled by and influence atmospheric circulations and gas concentrations is emerging. Much effort has been placed upon relating model simulations to data, thereby providing confidence in simulations of existing climates and ability to project forward to potential behaviour within a "greenhouse gas" enriched situation. Output from the IHEM initiative is outlined below in the form of research papers or papers in progress.

Linkages with CEH

Some of the IHEM time has been used to build stronger linkages across the whole of CEH. Evolving from IHEM is a similarly named initiative called GHEM, which stands for Global Hydro-Ecological Model. This initiative includes ALL CEH sites, and collaborative visits have also been made to every site. The concept of the GHEM initiative is simple – there is a desperate requirement to extract CEH science for integration within the global climate modelling debate. This statement is made from first-hand experience of tight collaboration with the Hadley Centre (including extended visits by Chris Huntingford to the Met. Office). All parties agree that the CEH knowledge base requires mapping onto the global change arena. The GHEM project has just received a grant of 41K pounds for rapid initiation between now and March 2003, and may be regarded in many ways as a continuation of IHEM.

Other issues.

Personnel issues should be mentioned very briefly. The original proposal consisted of Chris Huntingford (CEH_Wallingford) and Andrew Friend and Andy White (CEH_Edinburgh). Within the lifetime of this project, both Andrew and Andy resigned from CEH, and Peter Levy (CEH_Edinburgh) continued with this project. Funding for year 3 of this project was held back and used instead in year 4. This was to allow Chris Huntingford to be transferred for a year to the emergency DEFRA study into climate change and the Autumn 2000 floods.

There now follows a list of particular activities undertaken within the IHEM framework.

Project Details (each piece of research follows in full within the report and after this summary document):

The behaviour of a mixed-layer model of the convective boundary-layer coupled to a big leaf model of surface energy partitioning.
Huntingford, C. and Monteith, J.L. (1998)
Paper status: Published: Boundary-Layer Meteorology **88**: 87-101
Timescale of interest: Diurnal

Daily mean values of the Priestley-Taylor (PT) coefficient are derived from a simple model of the daily growth of a convective boundary layer. For a particular control set of driving environmental variables, the mean PT is related to the inverse of the prescribed bulk surface resistance by a simple linear relationship. The dependence of the parameters of linearity on weather is explored and a potential use of this linear relation to provide information about regional values of stomatal resistance is indicated.

Contrasting responses of a simple terrestrial ecosystem model to global change.
Huntingford, C., Cox, P.M. and Lenton, T.M. (2000)
Paper status: Published: Ecological Modelling **134**: 41-58
Timescale of interest: Century

A simple parameter-scarce model of vegetation dynamics is introduced which described a single dominant vegetation type using three equations for vegetation carbon, fractional coverage by the vegetation and soil carbon. The model is driven by net primary productivity, as calculated by a submodel of photosynthesis and plant respiration. Three categories of response to prescribed increases in atmospheric CO2 concentration and temperature are identified: (1) The emergence of a new dominant vegetation type in a cold environment, (2) the robust behaviour of an established vegetation in a warm environment and (3) "Die-back", which can occur at high temperatures.

An analogue model to derive additional climate change scenarios from existing GCM simulations.
Huntingford, C., and Cox, P.M. (2000)
Paper status: Published: Climate Dynamics **16**: 575-586
Timescale of interest: Century
Funding source: Most of this occurred under subcontract to the Hadley Centre. However, a little of the writing occurred during GHEM time. Please note that a second phase of this work is currently underway, and includes the global carbon cycle including land-atmosphere feedbacks. This work will hopefully be published during the middle of 2003.

Changes in land surface driving variables predicted by GCM transient climate change experiments are confirmed to exhibit linearity in the global mean land temperature anomaly, DT_land. The associated constants of proportionality retain spatial and seasonal characteristics of the GCM output, whilst DT_land is related to radiative forcing anomalies. The resultant analogue model is shown to be robust between GCM runs and as such provides a computationally efficient technique of extending existing GCM experiments to a large range of climate change scenarios. As an example impacts study, the analogue model is used to drive a terrestrial ecosystem model, and predicted changes in terrestrial carbon are found to be similar to those when using GCM anomalies directly.

An equilibrium zonal energy balance climate model that incorporates a global carbon cycle.
Huntingford, C., Hargreaves, J.C., Lenton, T.M. and Annan, J.

Paper status: Submitted to Global Planetary Change (this work is co-funded with Earth System Model integrating fund)
Timescale of interest: Millennia

A global carbon cycle is introduced into a zonally averaged energy balance climate model. Overall, this is found to extend the range of insolation over which partial ice cover solutions may be found to occur. However, the introduction of the global cycle reduces the range of insolation values over which stable "small ice cap" solution exist.

Regional Climate Model predictions of extreme rainfall for a changing climate.
Huntingford, C., Jones, R.G., Prudhomme, C., Lamb, R., Gash, J.H.C. and Jones, D.A. (2003)
Paper status: In the press: Quarterly Journal of the Royal Meteorological Society
Timescale of interest: Hours
Funding source: Chris Huntingford was released from the IHEM initiative to work on the "emergency floods and climate" DEFRA report following the UK flooding events that many were attributing to climate change. This has since spawned a further study using a "nested" RCM simulation within the ECMWF re-analysis data. This allows assessment of the RCM disaggregation method without large scale propagating errors from the GCM. Such information is of vital importance when modelling how the land surface may change for different rainfall patterns in a greenhouse enriched climate. It is hoped that this second study will become a major "demonstrator" project within the GHEM initiative. For this reason, it is included in this report, although no IHEM funding was used.

Major floods occurred in Great Britain during Autumn 2000. These were caused by a rapid sequence of heavy rainfall events that occurred over a period of many weeks leading to record-breaking monthly to seasonal rainfall totals. The question was raised as to whether such rainfall events may be related to human induced climate change.

Climate model predictions of future changes in mean precipitation behaviour are well established. However, to understand flooding requires an examination of predictions of extreme rainfall behaviour and at a relatively small spatial scale. For three areas within Britain, output from a Hadley Centre Regional Climate model (RCM), "nested" within one of it General Circulation Models (GCMs), is compared to rainguage data averaged over these areas for the periods 1961-1990. This shows that the modelling system is good at predicting the statistical likelihoods of extreme rainfall events seen in historical data. This result holds for extreme rainfall totals over daily to monthly timescales.

When the modelling system is used to predict changes in these extreme events resulting from atmospheric CO2 concentrations that may be representative of the period 2080-2100, significant reductions in the return periods of such events are seen. For example, 30 day rainfall totals which happened in the recent past on average once in 20 years are predicted to happen once in 3-5 years. An interpolation method based upon climate model output and incorporating rainguage data is used to estimate how rainfall extremes may have changed between the middle of the 19th Century and fir a period centred on the year 2000. This also predicts that increased

greenhouse gases have led to reduced return periods of extreme rainfall events for three sites of interest thought in this case the changes are not statistically significant.

Seasonal Time-scale feedbacks between the atmospheric boundary-layer and terrestrial ecosystems.
Levy, P. and Huntingford, C. (2004?)
Paper status: Early start to write up for Agric. Forest Meteorology
Timescale of interest: Seasonal

A copy of a powerpoint presentation is attached of a lecture given by Peter Levy to American Geophysical Union. It outlines work looking at Planetary Boundary-Layer feedbacks at the seasonal timescale, including influences upon interactive vegetation. It is hoped that this work will eventually be mapped onto a manuscript for submission to a referred journal.

A theoretical analysis of flux dependency in existing models of stomatal conductance.
Huntingford, C. and Smith, D.M. (2003?)
Paper status: Accepted subject to changes, Plant Cell and Environment.
Timescale of interest: Diurnal

Stomatal conductance is variously depicted in current models as a function of environmental conditions (Jarvis, 1976, Phil. Trans. R. Soc. Lond. B 273, 593-610), transpiration (Monteith, 1995, Plant Cell Environ. 18, 357-364), net photosynthesis (Leuning, 1995, Plant Cell Environ. 18, 339-355) or chemical signalling from roots (Tardieu and Davies, 1993, Plant Cell Environ. 16, 341-349). A theoretical analysis of these models is undertaken to enable development of a potentially unified approach to modelling stomatal conductance. A single model is derived by combining the Tardieu and Davies model of stomatal regulation by abscisic acid and leaf water potential with Leuning's model of stomatal conductance as a function of net photosynthesis. The resultant model describes stomatal conductance using just four variables: these are the evaporative flux, net photosynthesis, soil water content and ambient CO2 concentration. Stomatal response is thus dependent on fluxes of carbon and vapour over diurnal timescales, as well as slower variation in soil moisture and CO2 concentration. Dependencies on the environmental variables of humidity deficit, surface temperature and light are implicit in the flux dependencies. The new model has similarities to the model of Jarvis and is consistent with the proposal by Monteith that the apparent response of stomatal conductance to humidity deficit is a proxy for a dependence on transpiration.

The response of a terrestrial carbon cycle model to imposed climate change.
Huntingford, C and Cox, P.M.
Paper status: About to be submitted to CEH internal review
Timescale of interest: Century

A dynamic terrestrial carbon cycle model (Cox, 1997) is analysed for its predictions of vegetation and soil carbon content under imposed initial and time dependent

climatic changes in temperature and gross primary productivity. The model is operated in both equilibrium and dynamic mode. The equilibrium solution, which provides a general overview of model behaviour, is studied in depth. The dynamic solution lag, when compared to the equilibrium solution, is analyzed and the largest difference between the two solutions occurs when a change in vegetation type is predicted. Such lags may be significant in size and therefore directly affect the global carbon cycle, verifying the necessity to introduce dynamic terrestrial carbon cycle models into GCMs.

Building a CEH Global Hydro-Ecological Model (GHEM)

The appendix contains three items related to this initiative:

1) The GHEM proposal
2) Extracts from the GHEM website this list around 40 new initiatives related land surface behaviour to climate variability
3) A powerpoint presentation made at CEH Merlewood to the CEH management team.

Remaining tasks

This project, through the various papers listed above (attached as appendices) has addressed a set of issues associated with land-surface feedbacks. The IHEM project also asked that a common, transparent and easy to use modelling framework be derived. The format for this is the GHEM (Global Hydro-Ecological Model) structure. Besides drawing together CEH knowledge of land surface responses in a changing climate, this initiative will link tightly with the UK climate modelling work as undertaken at the Hadley Centre. The GHEM "scoping study" phase has now been finished, and following on from this, NERC have offered a small grant between October 2002 and April 2003 to activate around three key "demonstrator" projects. If this works successfully, then it is hoped that GHEM will move forward as a new "super-integrating" fund across all CEH sites. This will allow many aspects of this IHEM project to find a more formal and publicly available setting. Hence this final report should be regarded as the completion of a first phase by CEH at combining climate and "weather" information with land surface response. It should not be regarded as the definitive CEH view on land-atmosphere feedbacks.

Funding and Acknowledgements

This study has allowed for both research into land-atmosphere feedbacks within its own right (including a set of publications), initiated further long term projects (especially GHEM) and provided important parallel analysis for more operational climate prediction analysis (through links with the UK Hadley Centre and floods/rainfall variation in a changing climate). The CEH Integrating Fund is gratefully acknowledged for allowing all of this to have occurred.

Seasonal Time-Scale Feedbacks Between the Atmospheric Boundary Layer and Terrestrial Ecosystems

Peter Levy
Christopher Huntingford
Centre for Ecology and Hydrology
U.K.

Why model feedbacks?

- Vegetation models are used for predicting future terrestrial carbon sink
- If vegetation-atmosphere feedbacks are large, these need to be run interactively with atmospheric models

Feedbacks between vegetation and atmosphere

Time scale	Vegetation	Atmosphere
Hourly - Daily	Transpiration Photosynthesis Respiration	H:LE energy partitioning ABL growth
Weekly - Seasonal	Soil moisture Plant growth	Albedo
>Annual	Nat. selection Migration	CO_2 conc.

Feedbacks between vegetation and atmosphere

Time scale	Vegetation	Atmosphere
Hourly - Daily	Transpiration Photosynthesis Respiration	H:LE energy partitioning ABL growth
Weekly - Seasonal	Soil moisture Plant growth	Albedo
>Annual	Nat. selection Migration	CO_2 conc.

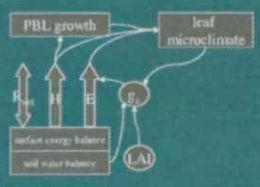
Daily time-scale feedback models

– Jacobs & De Bruin (1997)
- Predicting regional transpiration at elevated atmospheric CO_2: Influence of the PBL-vegetation interaction. *J. Appl. Meteorol.* 36:1663-1675.

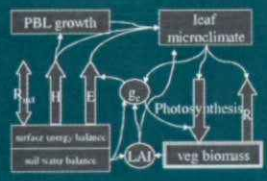
– Huntingford & Monteith (1998)
- The behaviour of a mixed-layer model of the convective boundary layer coupled to a big leaf model of surface energy partitioning. *Boundary-layer Meteorol.* 88:87-101.

Daily time-scale feedback models

eg. Huntingford & Monteith (1998)



Seasonal time-scale feedback model



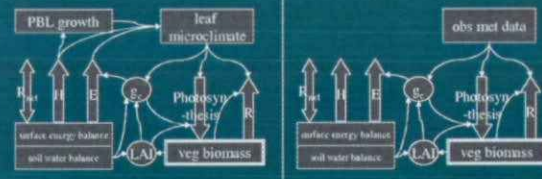
Seasonal time-scale effects are important

- LAI will alter with global change
  - 2 x CO_2 experiments
  - elevated T and N deposition experiments
  - existing gradients between biomes
- Effect on climate is significant
  - GCM simulations of Buermann *et al.* 2000 using satellite LAI instead of standard prescriptions

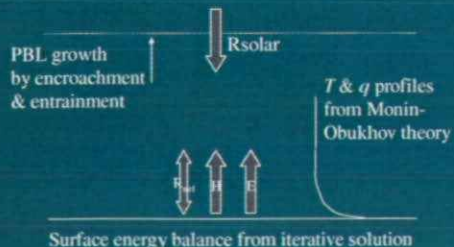
Aims

- develop a simple 1-D coupled model of the atmosphere & vegetation including seasonal dynamics of plant growth
- quantify the magnitude of feedback effects on LAI and evaporation (E)
  - perturb system with
    - CO_2 x 2
    - $T + 3^o$
- compare dynamic coupled vs. uncoupled simulations

Coupled vs Uncoupled model (prescribed climate)



Atmospheric Model



Limitations

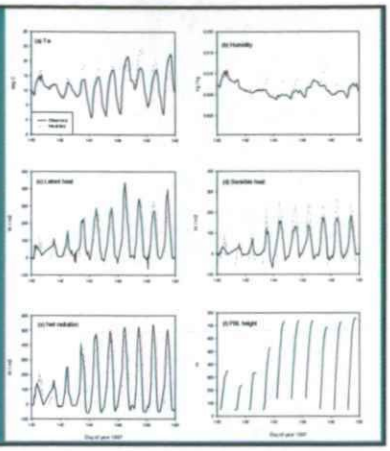
- Rainfall is not simulated
  - prescribed only
- Re-initialised each day
  - no "memory" of previous day

Behaviour of atmospheric model

Simulations at S. England grassland site.

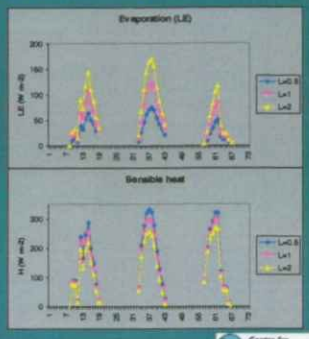
Model can reproduce diurnal cycles in *T* and energy fluxes

Further tests against measurements of humidity and PBL ht. from radiosondes

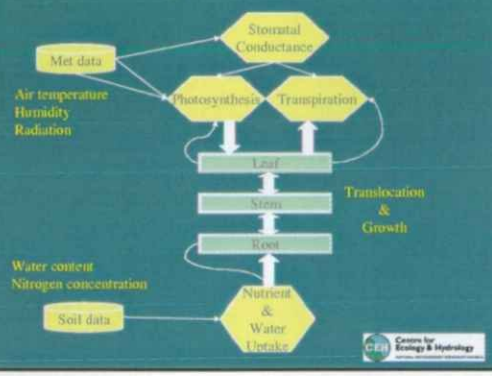


Behaviour of atmospheric model

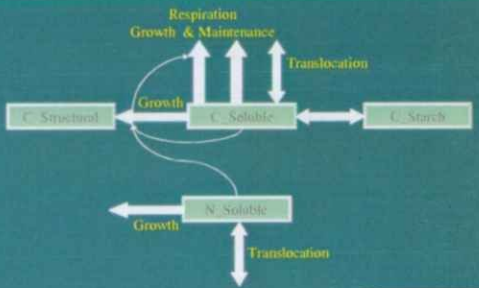
Energy partitioning at surface is sensitive to LAI



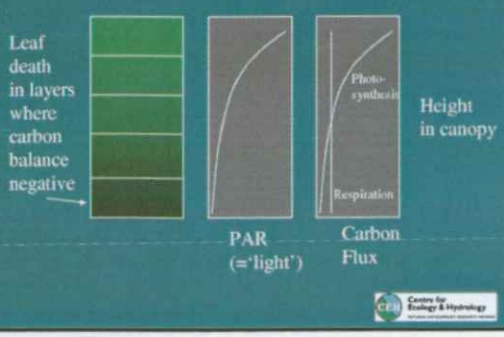
Vegetation Model



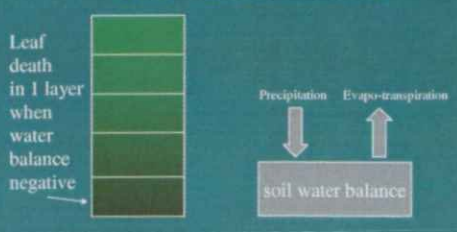
Organ-scale model structure



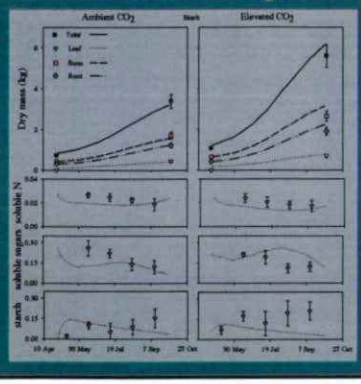
Self-regulation of LAI: Light Limitation



Self-regulation of LAI: Soil Water Limitation



Behaviour of vegetation model

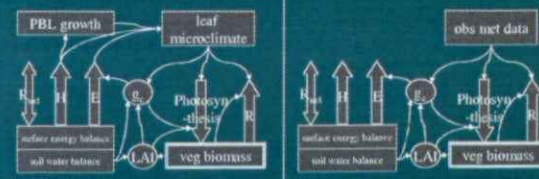


Parameters measured or fitted to control treatment data.

Elevated CO_2 treatment data used as independent test.

(Levy *et al.* 2000, *Tree Physiology*)

Coupled vs Uncoupled model (prescribed climate)

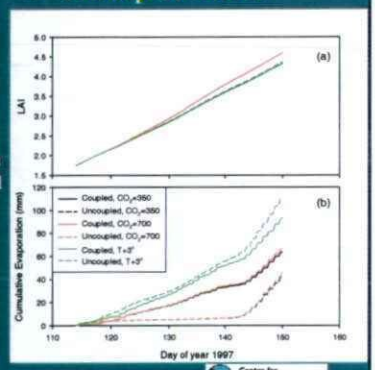


Coupled vs Uncoupled model

Simulations at S. England grassland site.

Compare output from coupled vs uncoupled simulations when perturbed by

- CO_2 x 2
- $T + 3^o$



Effect of CO_2 x 2

	E	LAI
$\Delta_{coupled}$	+4.25	+6.24
$\Delta_{uncoupled}$	+5.10	+6.16
Coupling sensitivity	+0.83	+1.01

$$\Delta = \frac{X_{CO2\,x\,2} - X_{ref}}{X_{ref}} \ (\%) \qquad \text{Coupling sensitivity} = \frac{\Delta_{coupled}}{\Delta_{uncoupled}}$$

Effect of $T + 3^o$

	E	LAI
$\Delta_{coupled}$	+45.72	-0.24
$\Delta_{uncoupled}$	+155.25	+0.77
Coupling sensitivity	+0.29	-0.31

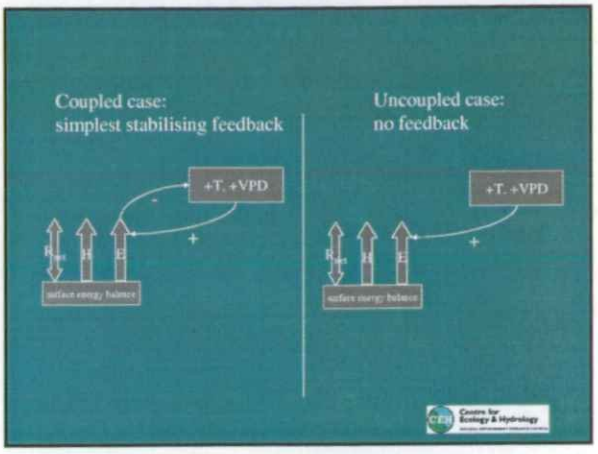
$$\Delta = \frac{X_{T+3} - X_{ref}}{X_{ref}} \ (\%) \qquad \text{Coupling sensitivity} = \frac{\Delta_{coupled}}{\Delta_{uncoupled}}$$

Effect of CO_2 x 2

- Effect of CO_2 x 2 on *E* and LAI is similar: increased by ~5%.
- LAI growth not very sensitive to coupling
  - existing light & water constraints act as negative feedbacks
- *E* is more sensitive to coupling
  - introduces negative feedback

Effect of $T + 3^o$

- Effect of $T + 3^o$ on LAI is small, ~ ±1%
  - coupling reverses sign of response
- E is v. sensitive to $T + 3^o$
  - v. sensitive to coupling - negative feedbacks reduce response to 29% of uncouple response



Limitations of approach

- Atmospheric model re-initialised each day with dawn T & q profiles
- Effectively simulating a strong advective influence
- Feedbacks will be stronger where advective influence is less

Major uncertainties

- Mainly in long-term plant responses
  - Downregulation of photosynthesis with CO_2 & effect on growth
  - Acclimation of respiration to temperature
  - Magnitude of g_s-CO_2 response

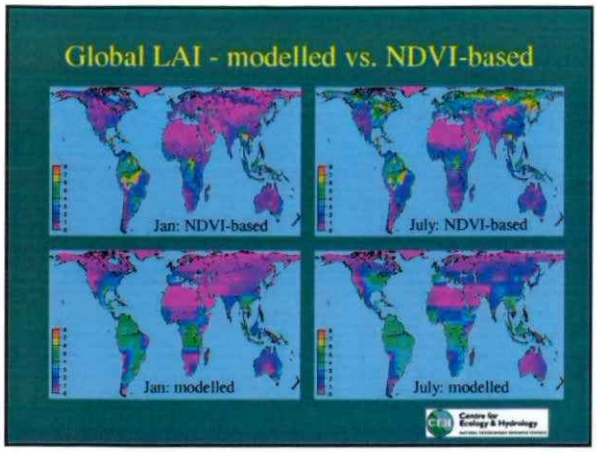
Extension to global scale

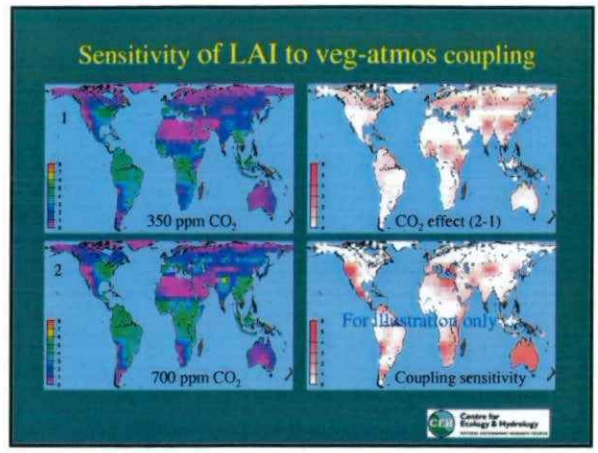
- How well can we predict global LAI with simple vegetation model?
- Which ecosystems are most sensitive to vegetation-atmosphere coupling?

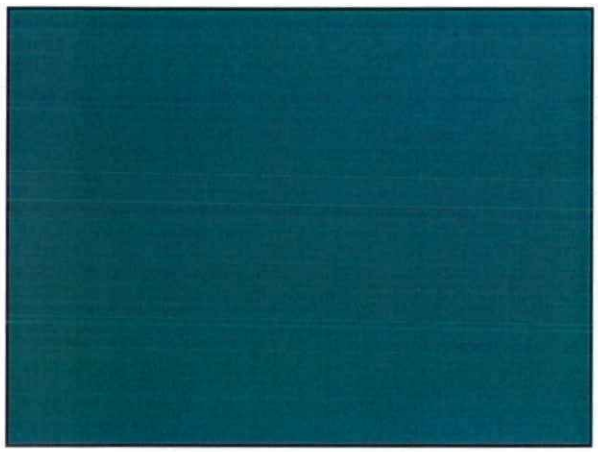
Global LAI simulations

10 x 10 ° resolution

simple interpolation between points


Global LAI - modelled vs. NDVI-based
Jan: NDVI-based
July: NDVI-based
Jan: modelled
July: modelled
Centre for Ecology & Hydrology


Sensitivity of LAI to veg-atmos coupling
1
350 ppm CO_2
CO_2 effect (2-1)
2
700 ppm CO_2
For illustration only
Coupling sensitivity
Centre for Ecology & Hydrology



Version 5: 16 August 2002

Report on a scoping study to investigate the feasibility of

Building a CEH Global Hydro-Ecological Model (GHEM)

Chris Huntingford and John Gash

(CEH-Wallingford)

16 August 2002

1 Summary

Climate modelling is now at a stage where improvements in prediction will rely on better linkages between climate predictions, and hydro-ecological feedbacks and impacts. CEH is uniquely placed to create the required linkages through the creation of a managed research programme based around a **Global Hydro-Ecological Model,** or **GHEM**. GHEM will be structured as a Central Node with two way links to hydrological and ecological process models using common software protocols. The Central Node will in turn link to the Hadley Centre GCM. At the heart of GHEM, and the main mechanism for impact research, will be the computationally efficient GCM Analogue Model. A Science Budget funded CEH programme is proposed, with a core team to manage the Central Node and set of research projects to develop and use the models.

2 Introduction and Rationale

2.1 During the past 10 years both the realism and credibility of climate change predictions made with Global Circulation Models (GCMs) have improved dramatically. The fundamental basis of the models (ie the Newtonian equations of motion and the laws of conservation) has not changed - the improvements have been the result of the increased computer power, which has allowed the grid size and model time step to be progressively reduced, and improvements to the sub-models describing the individual (mainly physical) processes.

2.2 The reduced grid size of the global models has been complemented by the ability to nest limited area, fine scale models (currently 40 km grid length in the Hadley Centre model) in the global grid. This Regional Climate model allows predictions of local climate change to be made. It has also been demonstrated (Huntingford et al., 2003) that this combination of nested models can be used to make good predictions of extreme events. Because it is often the extremes, rather than the averages, of rainfall, temperature etc which determine systems, this development is of critical importance in predicting the ecological and hydrological impacts of climate change.

2.3 The GCM sub-models describing surface exchange now include CO_2 as well as energy and water, and the latest version of the Hadley Centre model also now includes interactive vegetation. Model vegetation type in the model can change in response to the predicted climate and thus feedback to amplify or dampen climate change.

2.4 Further reductions in grid size or refinement of the models describing the basic transfer processes are unlikely to result in dramatic improvements to the model predictions in the near future. But the time is now appropriate for a major initiative to forge linkages between the climate model, and ecological and hydrological process models. Some processes, such as forest fire (through changed albedo and surface energy balance), may introduce new feedbacks; others may be one directional but second or third order effects, eg changes in fish populations (through changes in river flow affecting water temperature). In most respects, the representation of such processes in, or outside, current climate models is still in its infancy.

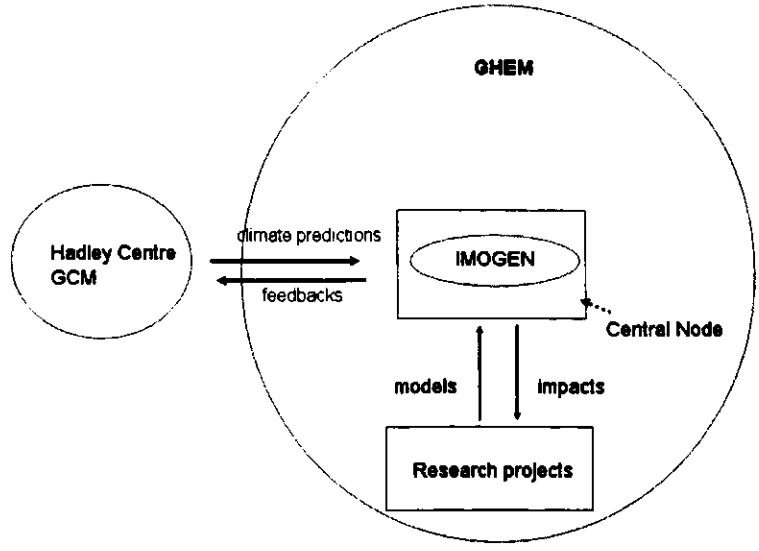
2.5 As an organisation, CEH is probably unique in having the necessary width of experience and expertise needed to create these new links with climate models. CEH also benefits from already strong links with the Hadley Centre, a world-leading climate modelling centre. This report investigates the feasibility of exploiting existing models, of creating new models and what formal methodology and infrastructure is needed to link this knowledge to numerical code that is compatible with GCMs.

3 Proposed new CEH modelling framework/methodology - GHEM

3.1 GCMs are formidable, complex computer programs requiring massive supercomputers. However the jointly-developed Hadley Centre / CEH-Wallingford model (called the "GCM Analogue Model", Huntingford and Cox, 2000) is relatively straightforward to use and requires minimal computing resources. The Analogue Model generates estimates of surface climatology at the individual grid-box scale, and now includes a global carbon cycle – all of which have been calibrated against the full Hadley Centre GCM. Hadley Centre land surface models (MOSES and TRIFFID) have been added to create a new impacts tool, called IMOGEN. This climate model retains the complexity of the land surface description of the full GCM, and yet is computationally fast when making future predictions of climate change impacts (IMOGEN operated globally for a simulation representing years 1860-2100 can be run in typically two days on a new computer).

3.2 IMOGEN is a powerful tool for eco-hydrological impact studies because it provides an intermediate link between developing land surface schemes and their eventual implementation within a GCM. This tool is ideal for generating and testing a new Global Hydro-Ecological Model (GHEM).

3.3 GHEM will be a direct expansion of IMOGEN. As indicated in the Figure, there will be a two way traffic of information into and out of IMOGEN. GHEM research projects will develop models which will feed into IMOGEN; model runs by IMOGEN will disseminate the



impact predictions outwards. Where climate feedbacks are identified IMOGEN may need to link into the full GCM to explore the effects of these feedbacks. IMOGEN will be extended to work with data from the Hadley Centre Regional Climate Model. The GHEM concept is thus not for a large single piece of model code to be run as one operation on a large computer, rather it is a set of compatible sub-models which can be plugged into a central node to be used for specific climate change feedback and impact studies.

3.4 GHEM will be made up of core or "frozen" code, to which individuals may add their own modifications. Modification will be in three phases, (i) experimental code to rapidly test previously missing processes within GHEM, (ii) testing of refined modifications, including assessment of implications for climate change and comparison against CEH databases where available, and (iii) acceptance as a full component of the GHEM and thereby a formal part of the next release of the model. This method of model development emulates current climate modelling practice as operated by the Hadley Centre. Involvement of Hadley Centre staff will be critical in ensuring eco-hydrological models dovetail into their GCM. Hadley Centre membership of a GHEM steering group (see below) will be particularly important in this respect.

3.5 The GHEM will be freely available to all CEH researchers, using standard computing practices for model dissemination. It will be a "community" model, owned by all who work in CEH.

3.6 The GHEM Central Node team will be responsible for establishing protocols that balance ease of use, development and flexibility of operation, against model management aspects. For example, they will need to define rules to be applied to the adoption of modifications within the core "frozen" code: coding standards, requirements for comment statements and unit definitions and the release of documentation that includes traceability and appropriate references from the scientific literature. The Central Node team will have responsibility for numerical code maintenance and help with GCM "modification adoption", where CEH successfully make the case for new processes to be included within the GCM. For historical reasons, the GCM analogue model (and the work involved in increasing its capability to link with the Regional Climate Model) and links to the Hadley Centre will continue to be managed at Wallingford, but the Central Node team may (or may not) be dispersed . It must be stressed again that the GHEM model will be flexible, fully documented and available (across the CEH Intranet). All the GHEM research projects will be expected to make and test their own local modifications or ideas.

4 Demonstrator projects

4.1 As part of the scoping study a set of demonstrator projects have been identified from a set of visits to CEH sites (all sites will have been visited by September 2002). Each demonstrator project represents an identified aspect of CEH science that would gain from interaction with climate change predictions. Each project could be developed as a module within GHEM, to produce a set of FORTRAN code. Most of the demonstrator projects will rely upon small extensions of work that is already being undertaken and is currently funded. It is hoped that taking GHEM forward in this fashion will: a) yield a very quick initiation of the GHEM concept and b) the varied projects will quickly highlight "what works and what doesn't", guiding GHEM development. The GHEM philosophy will be very much "evolution, not revolution". The demonstrator projects identified to date are as follows:

- Use of CO_2 flux data to calibrate land surface models for use in a GCM.
- Correlations between climate and toxic blue-green algae in lakes.
- Ecological states of rivers.
- Combining climate, water resource and socio-economic information.
- Linking North Atlantic Oscillations and CEH biogeochemical models.
- Life history strategies in salmon.
- Understanding regional climate model predictions of rainfall in a changing climate.
- Using data to calibrate models of land surface methane emissions.
- Relating different CEH approaches to vegetation modelling.
- Predicting the climate/glacier extent/downstream water resource linkages.
- Modelling shrubland ecosystem response in a changing climate.
- Trace gas exchange in tundra ecosystems.
- Using RCM data to investigate impacts of climate change on flood flows.
- Climate, pollutants in soil and rate of litter decomposition.
- Soil carbon pools, enzyme processes and temperature effects on CO_2 release.

5 Putting GHEM into practice

Phase 1 of GHEM will be implementing a selection of demonstrator projects based on on-going work. Phase 1 will allow rapid proof of concept. Phase 2 of GHEM requires a large, coordinated CEH programme. The programme must be focused on modelling those processes which are likely to produce climate feedback, or ecological and hydrological impact. This is likely to mean opening up some new lines of research.

6 Compatibility with the NERC Science Plan

GHEM will make a central contribution to the objectives of NERC's Priority Area: "Predicting and Mitigating the Impacts of Climate Change" as specified in the NERC Science Plan, "Science for a Sustainable Future, 2002-2007". A GHEM programme would therefore be an appropriate use of CEH core funds.

7 Conclusions and Recommendations

7.1 This scoping study has demonstrated the feasibility of, GHEM as a coordinated, core CEH programme which has the purpose of developing a modelling system which will interface CEH eco-hydrological models to the Hadley Centre GCM. GHEM will complement the SOC ocean model, the BAS ice sheet model and the (ex-CCMS) surge model. The Hadley Centre is supportive and has agreed to contribute through both the JCHMR, and by regarding certain aspects of the GCM as "community code".

7.2 The ultimate goals of GHEM are: (a) climate change predictions which include eco-hydrological feedbacks, and (b) predictions of the impacts of climate change on ecology and hydrology.

7.3 A set of demonstrator projects has been identified. These provide a starting point, but a programme of new projects is needed to develop areas where the eco-hydrological feedbacks are likely to be significant, or where the impacts important. These new research projects will

develop the models which will feed into the GHEM Central Node and will carry out the feedback sensitivity and impact studies.

7.4 A core team with experience of GCM modelling and links to the Hadley Centre through the JCHMR, should be created and funded to develop and operate the GHEM Central Node.

7.5 A Programme Manager should be appointed. He/she should report to the Director CEH and be responsible for delivering the science. The mechanism for selecting research projects will need to be decided by the Director CEH and implemented by the Programme Manager.

7.6 A GHEM steering committee should be set up to advise on areas where new projects should be initiated and monitor progress towards objectives. To ensure relevance and excellence this committee should include external experts from academia, and government departments and agencies, as well as representatives from the Hadley Centre.

7.7 The success and international impact of GHEM will obviously depend on the resources which are allocated to it. We recommend that GHEM consists of a Programme Manager, the core Central Node team and at least 10 research projects - this would require funding at approximately £1.1M pa of CEH Core Funds.

7.8 A proposal for GHEM is attached as an annex to this report.

8 References

Huntingford, C. and Cox, P.M., 2000. An analogue model to derive additional climate change scenarios from existing GCM simulations. *Climate Dynamics*, **16** (2000): 575-586.

Huntingford, C., Jones, R.G., Prudhomme, C., Lamb, R., Gash, J.H.C. and Jones, D.A., 2003. Regional climate model predictions of extreme rainfall for a changing climate. *Q. J. R. Met. Soc.*, (in press).

GHEM home page

Home | The Science | Project Diary and Info | The Models | People

This project is designed to:

- Combine aspects of CEH science into a more co-ordinated modelling framework called "GHEM" (**G**lobal **H**ydrological **E**cological **M**odel).
- Create a set of **demonstrator projects** (which may be based on on-going work already) across CEH sites, that gain from the GHEM concept. Where climate drivers are required, link to the "GCM analogue model" framework.
- Advise and identify aspects of the CEH knowledge base that may be important in a changing climate and should therefore be included in global climate modelling experiments.

There are four main components to this GHEM website:

- The Science
- Project Diary (and other general information)
- Documentation, code and summary of the "GCM analogue model"
- People involved in GHEM project

Fast ANALOGUE MODEL on the WEB for POLICYMAKERS:

This link (click on this sentence) takes the user to a particular version of the GCM analogue model for policy makers, as available on the internet. Individuals submit their **own predictions** of **emissions** and a computer at CEH Wallingford undertakes the calculations. This is under development - the amount of GHEM science held within this version of the analogue model is still to be determined. However, click here for initial "mock-up" of advanced questions open to users who wish to configure the "model on the web" concept. Also available here is more detailed technical information on the Hadley Centre Global and Regional Climate Model, and different emission scenarios.

Overview documents and Media Issues:

- Please click here for a word document that is a report on the GHEM concept and aims Also available is a "powerpoint" presentation and finally a version of the proposal sent out for external review (word document).
- Click here for 5 minute video clip of impacts issues discussed live on Sky News (warning - large file!).

The Science

Scientific issues are listed in the table below. Each is characterised by i) general issues, ii) work already undertaken, iii) **GHEM Demonstration Projects** and iv) possible future work.

Science Issues - click below for "start-up" meeting notes	**Project Type**	**MORE details available? If YES then click**
Use of CO_2 flux data to calibrate land surface models for use in a GCM	GHEM Demonstrator	YES
Correlations between climate and toxic blue-green algae in lakes	GHEM Demonstrator	YES
A view of missing hydrological issues within land surface schemes (word document)	General / Future	No
Combining climate, water resource and socio-economic information	GHEM Demonstrator	YES
Carbon fluxes in polar regions (powerpoint poster)	Future	No
Ecological states of rivers	GHEM Demonstrator	No
Linking NAO oscillations and CEH Bangor biogeochemical models	GHEM Demonstrator	No
Life history strategies in Salmon	GHEM Demonstrator	No
Understanding regional climate model predictions of rainfall in a changing climate	GHEM Demonstrator	YES
Seasonal Vegetation Growth and Senescence (Phenology)	Existing work / Future	No
Using data to calibrate models of land surface methane emissions	GHEM Demonstrator	No
A view on some missing processes from SVATs	General	No
Relating the CEH Bangor and CEH Edinburgh approaches to vegetation modelling	GHEM Demonstrator	No
An overview of the GCM analogue model (pdf document)	Existing work	No
Predicting the climate-glacier extent-downstream water resource linkages	GHEM Demonstrator	No
Insect abundance and interaction with vegetation - link with climate.	Future	No
Vegetation "die-back" predicted in the GCM.	Existing work	No
Modelling shrubland ecosystem response in a changing climate.	GHEM Demonstrator	No
Trace gas exchange in tundra ecosystems.	GHEM Demonstrator	No
Using RCM data to investigate impacts of climate change on flood flows	GHEM Demonstrator	No
Predicting nitrogen limitation in soils and associated effect on	GHEM	

pollutants	Demonstrator	No
Modelling soil carbon pools and their variability at the global scale	GHEM Demonstrator	No
Soil carbon pools, enzyme processes and temperature effects on CO_2 release.	GHEM Demonstrator	YES
Climate, pollutants in soil and rate of litter decomposition	GHEM Demonstrator	No
The characterisation of fire and influence upon land surface behaviour.	Future	No
Is there the possibility of Amazonian "die-back" in a changing climate?	GHEM Demonstrator	YES
Modelling large scale ecosystem response on the global carbon cycle	GHEM Demonstrator	No
Climate change and Salmon populations in Scotland	GHEM Demonstrator	No
Changes in hydrological behaviour and snow melt in the Cairngorms	GHEM Demonstrator	No
GIS as a further disaggregation tool of climate change - application to Dee catchment	GHEM Demonstrator	No
Herbivore manipulation of the climate system through overgrazing of arctic mosses	GHEM Demonstrator	No
Climate change influence on distribution of non-native plant species	GHEM Demonstrator	No
The threat of invasion of alien species introducing new diseases	GHEM Demonstrator	No
Use of ECN data to predict changes in grassland productivity in future climate	GHEM Demonstrator	No
Use of ECN data to predict changes in butterfly populations in a future climate	GHEM Demonstrator	No
A CEH overview on the links between climate change and biodiversity	GHEM Demonstrator	YES
Flux measurements in Amazonia (powerpoint poster)	Existing work / Future	No

Project Diary and Info

- The original proposal
- 12th March 2002 - Click for letter sent to CEH site directors.
- 1st May 2002 - This web site initialised.
- 21st May 2002 "Young scientists meeting with Pat Nuttall at the MRC in London". Advised to investigate potential for a GHEM style initiative.
- Scientific notes from visit to CEH Oxford (11th June 2002 and 2nd August 2002)
- Scientific notes from visit to CEH Windermere (13th/14th June 2002)
- Scientific notes from visit to CEH Bangor (17th June 2002)
- Purchase communal laptop computer for GHEM study (12th July 2002)
- Decision to set up GHEM steering group.
- Copy of this site sent to Mike Wilson (Merlewood).
- Scientific notes from visit to CEH Dorset (22nd July 2002)
- Scientific notes from CEH Wallingford (29th July-)
- Software exploitation Day at CEH Dorset (8th August)
- Scientific notes from visit to CEH Edinburgh (21st/22nd August)
- Scientific notes from visit to CEH Banchory (2nd September)
- Powerpoint presentation as given to the CEH Conference (5th September)
- Scientific notes from visit to CEH Merlewood (23rd/24th September)
- Powerpoint presentation as given the the CEH management board (24th September)
- October 2002 - large push to check all aspects of the GCM analogue model are functioning correctly.
- Monday 14th October - two Hadley Centre land surface modellers start work in Wallingford JCHMR
- Week spent by Chris Huntingford at CEH Edinburgh
- Scientific notes from visit to CEH Bangor (17th June 2002)

The Models

The page is the "portal" to all the models (with links to datasets) associated with the GHEM initiative. Anything within this project that involves operation of numerical models, visualisation methods, comparison with datasets (along with any documentation) should be found here.

Background to Models

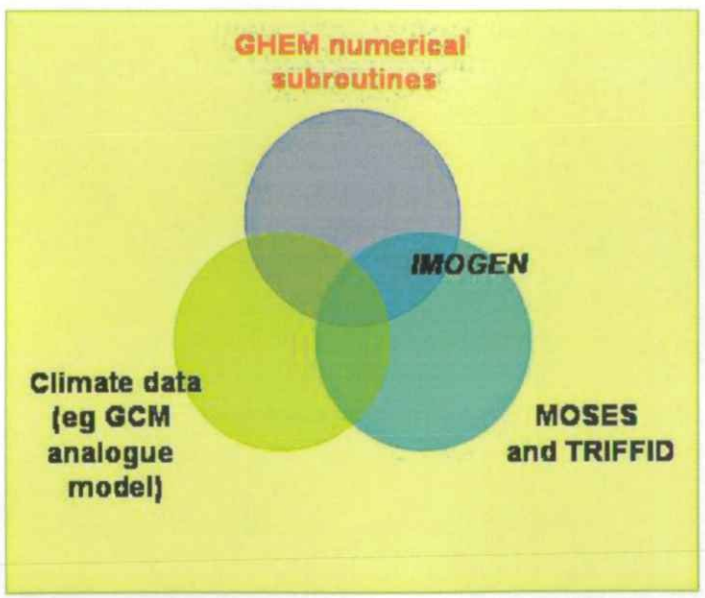
There are three distinct but tightly related model components. These are as follows:

- GHEM modules - these are sections of numerical code that come about through the GHEM initiative, and are based around the science demonstrator projects described elsewhere.
- Climate driving data - this comes from either a range of GCMs, RCMs, UKCIP or interactively from the GCM analogue model.
- MOSES and TRIFFID - these are the existing land surface numerical schemes developed at the Hadley Centre. The Hadley Centre have generously agreed that a version of this code may be regarded as Hadley-NERC community code. Numerical output from many of the GHEM demonstrator projects outlined above are explicitly aligned to interact with this code.

A "GCM analogue model" came about through a four month visit by Chris Huntingford to work with Peter Cox at the Hadley Centre. The combining of TRIFFID and MOSES with the GCM analogue model is referred to as a an entity in its own right, called IMOGEN. The acronyms are as follows:

MOSES: Met Office Surface Exchange Scheme, **TRIFFID:** Top-down Representation of Interactive Foliage and Flora Including Dynamics and **IMOGEN:** Integrated MOdel of the Global Effects of climatic aNomalies

The models link together as follows:



Links to different model components

- GCM analogue model
- Some information on MOSES (external link to the Met Office).
- Some information on TRIFFID (external link to the Met Office)

People

People who have been involved so far are as follows. Click on name for more information within this web site:

- Phil Bacon (Banchory)
- Mark Bailey (Oxford)
- Nicholas Bertrand (Oxford)
- Eleanor Blyth (Wallingford)
- Dick Bradford (Wallingford)
- James Bullock (Dorset)
- Melvin Cannell (Edinburgh)
- Peter Carey (Dorset)
- Peter Cox (Hadley)
- Alex Elliott (Windermere)
- Bridget Emmett (Bangor)
- Chris Evans (Bangor)
- Dawn Field (Oxford)
- Jon Finch (Wallingford)
- John Gash (Wallingford)
- Anna-Marie Giacomello (Wallingford)
- Robert Griffiths (Oxford)
- Richard Harding (Wallingford)
- Harry Harmens (Bangor)
- Phil Harris (Wallingford)
- Kim Heyworth (WHEB c/o NERC HQ)
- Phil Hulme (Banchory)
- Chris Huntingford (Wallingford)
- Anton Ibbotson (Dorset)
- Richard Jones (Hadley Centre)
- Alison Kay (Wallingford)
- Robert Kenward (Dorset)
- Peter Levy (Edinburgh)
- Colin Lloyd (Wallingford)
- Stephen Lofts (Windermere)
- Stephen Maberley (Windermere)
- Jeremy Meigh (Wallingford)
- Michael Morecroft (Merlewood)
- Nick Ostle (Merlewood)
- Gwyn Rees (Wallingford)
- Nick Reynard (Wallingford)
- Brian Reynolds (Bangor)
- John Roberts (Wallingford)
- Ian Simpson (Merlewood)
- Caroline Sullivan (Wallingford)
- Jeremy Thomas (Dorset)
- Ian Thompson (Oxford)
- Mike Tricker (NERC HQ)

- Rene Van Der Wal (Banchory)
- Marcel Van Oijen (Edinburgh)
- Andy Whiteley (Oxford)

The GHEM Initiative

(short presentation at CEH Merlewood)

Chris Huntingford

(CEH Wallingford)

... and with help from across all of CEH.....

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What are the GHEM hypotheses?

- CEH science base has direct relevance to the global geochemical cycles (especially **carbon**) – hence an opportunity to improve significantly climate predictions.

- CEH science base is important to providing accurate impacts assessments for a changed climate, based upon **sound physical understanding**.

- GHEM will formally characterise the relative importance on livelihoods between **global change and local change** (eg adjusted rainfall patterns vs urbanisation, land use). Possibly includes economic considerations.

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How will GHEM work?

- Combine "demonstrator" projects (based upon data and/or local modelling capability) into a more cohesive framework.

- All CEH sites are involved.

- Emphasis throughout is totally on **science**, and especially through new insights at the climate/eco-hydrological interface.

- Computing methods will be simple, transparent and "bog standard".

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Progress to date with GHEM: the "scoping study" phase.

- 8 sites visited *(Monk's Wood very shortly).*
- 26 "Demonstrator" projects identified.
- Over 40 staff already signed up.
- Everyone involved to date regards the initiative as timely and are keen to see project go forward. Many far reaching questions have been asked about the scientific format, but a consensus is emerging.

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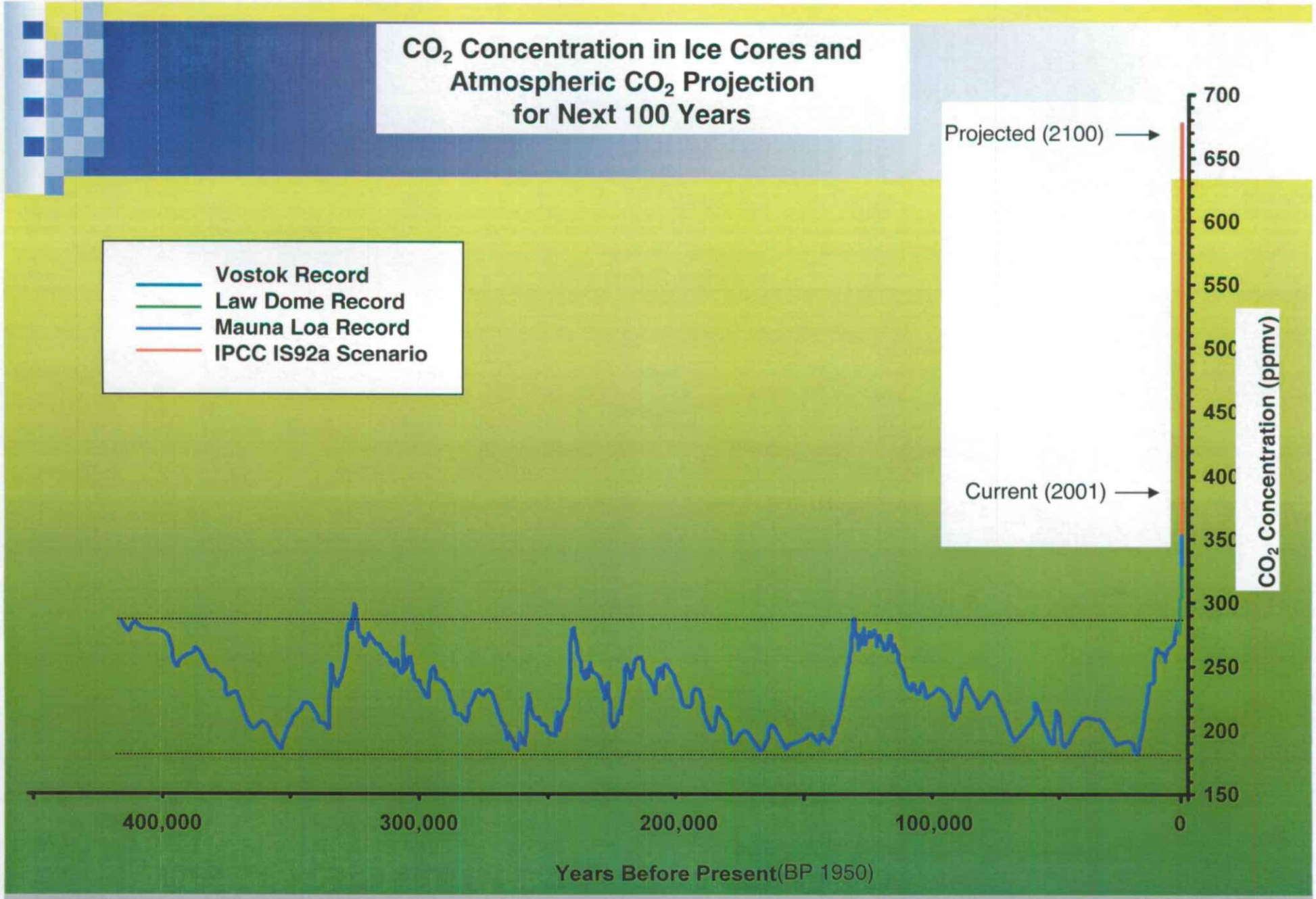
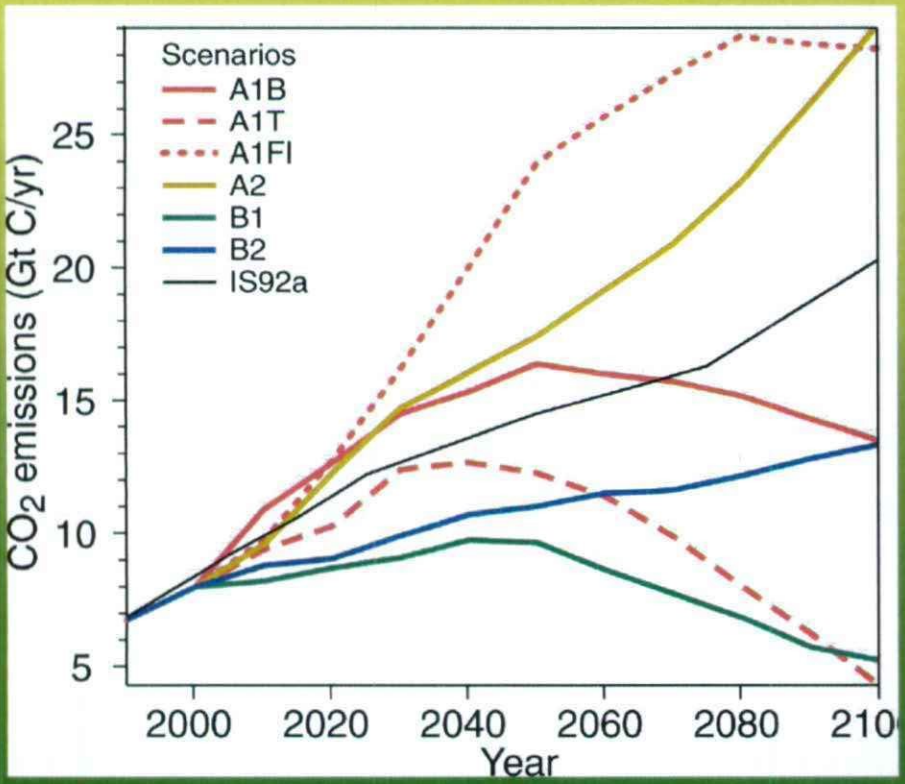
CO_2 Concentration in Ice Cores and Atmospheric CO_2 Projection for Next 100 Years



Source: C. D. Keeling and T. P. Whorf; Etheridge *et.al.;* Barnola *et.al.;* *(PAGES* / IGBP); IPCC

Emission scenarios



- We know roughly how these emission scenarios relate to climate.
- But what does it *really* mean in terms of catchment scale hydrology and ecology?
- Are *local* pollution and land practises of more concern.
- What are the *economic* environmental consequences of the various emission scenarios.
- What is the *real* impact on human well-being?

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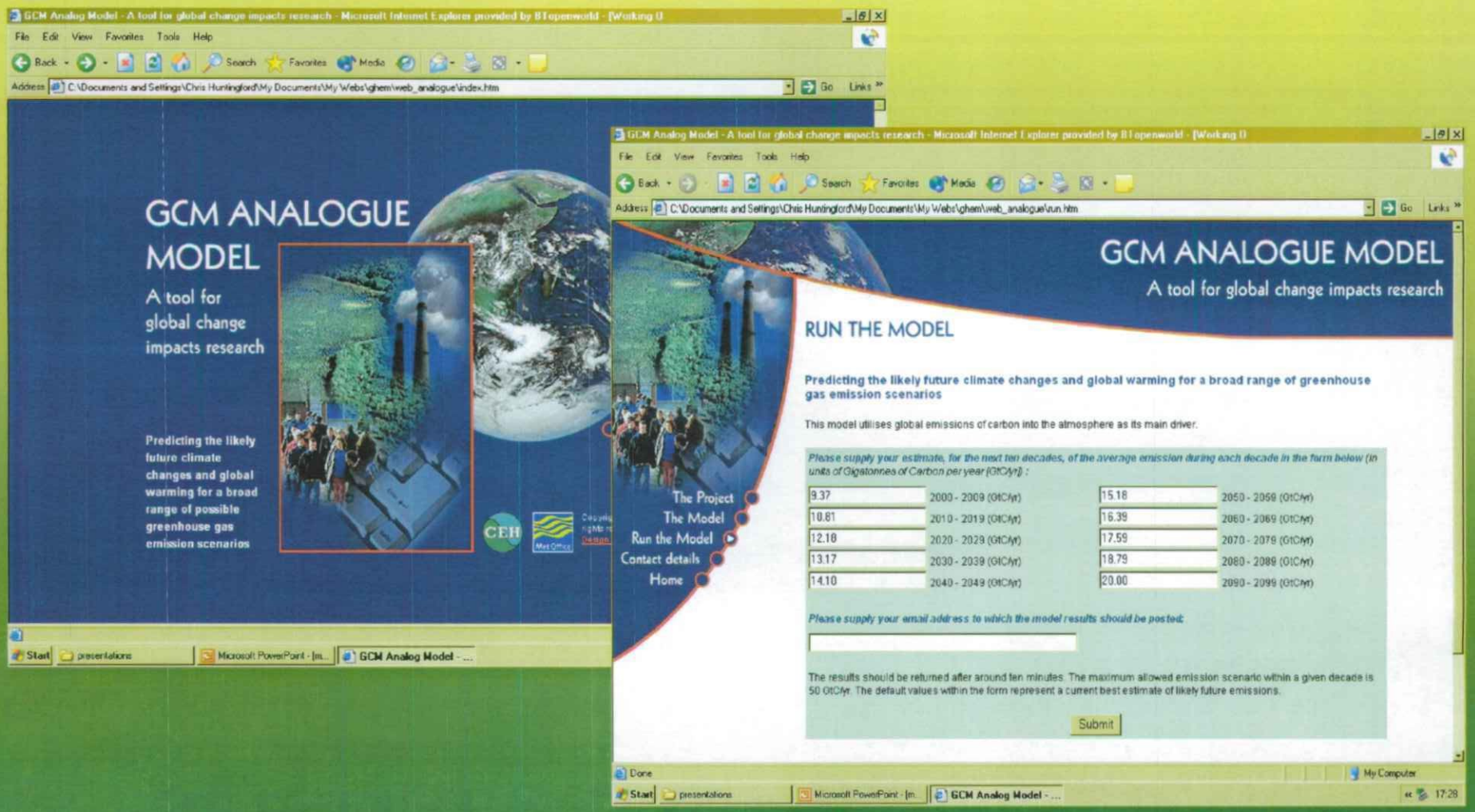
GHEM interface



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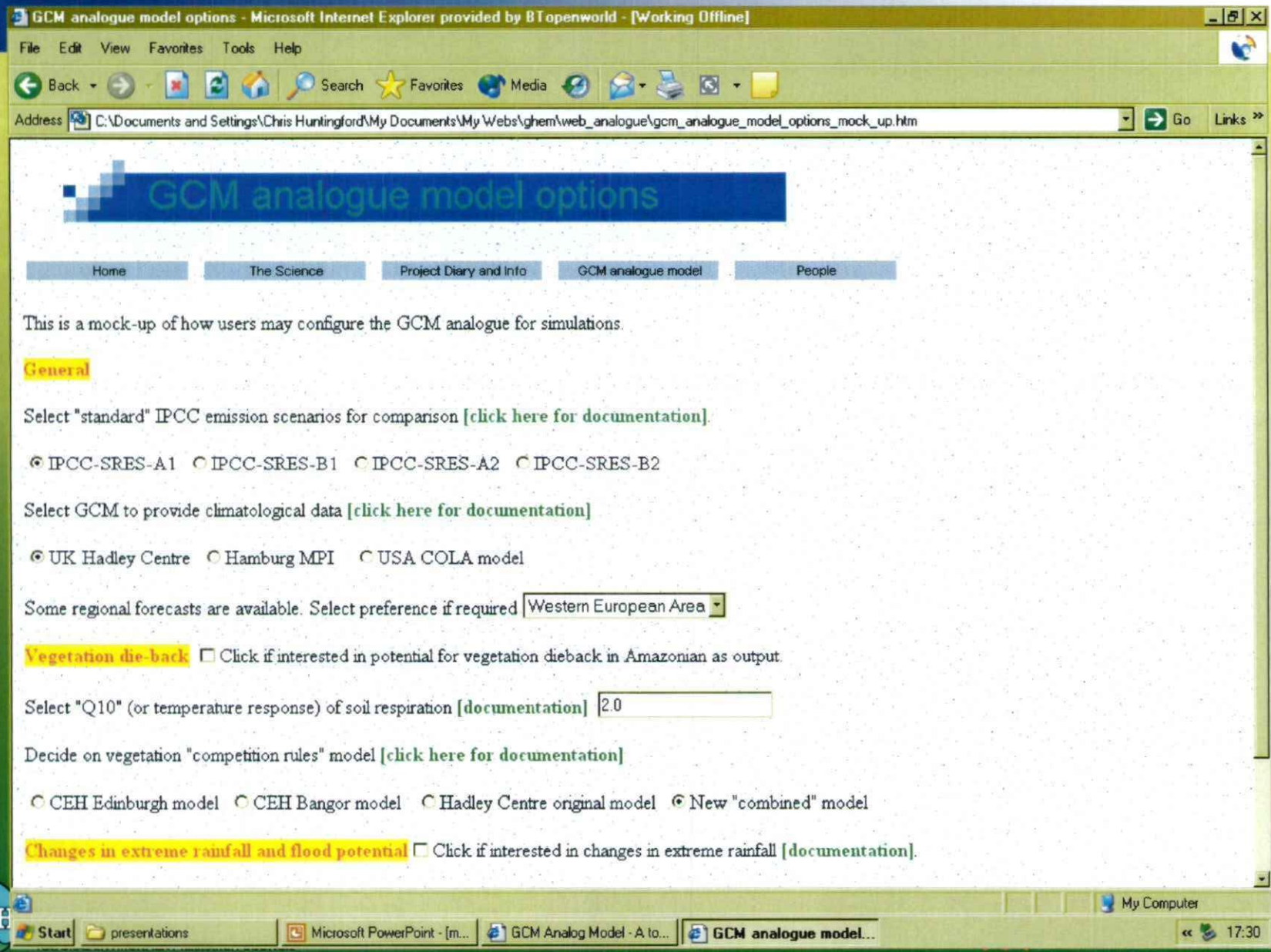
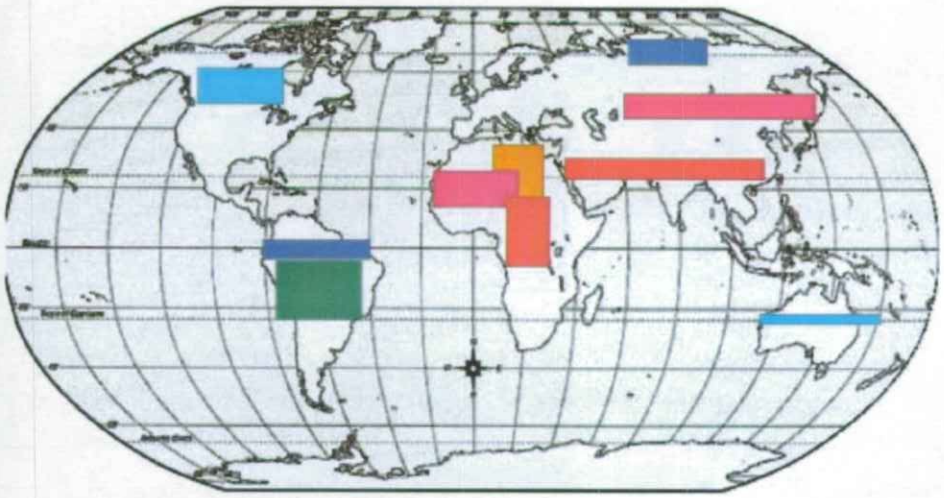
Interface with CEH science



Critical "thresholds"

Dangerous "threshold" in atmospheric CO2
for CEH PROCESS "A" - plot "mock-up"



500 ppm
600 ppm
700 ppm
800 ppm
900 ppm
1000 ppm

- GHEM could yield powerful graphical methods.
- GCM analogue model allows *inversion* of carbon cycle.
- We can ask the far more useful question **"what emission scenario is safe?"** - not "what happens for scenario X".

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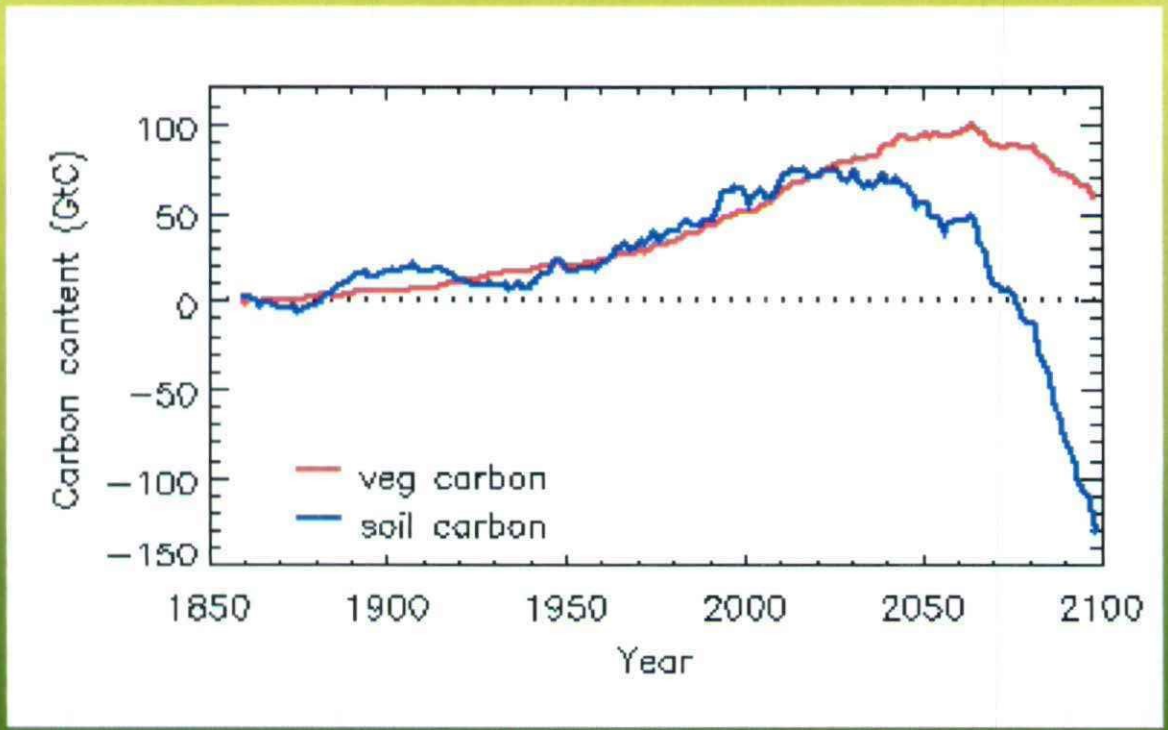
Amazon "die-back" in global context- 1



Inclusion of vegetation in "carbon trading" may come back to haunt us (ie carbon stored now may be released later).

- Beyond 2100, there is a possible risk of "climate runaway".
- Currently running forward the GCM to test this hypothesis.
- CEH/Hadley GCM analogue model also running at this moment.

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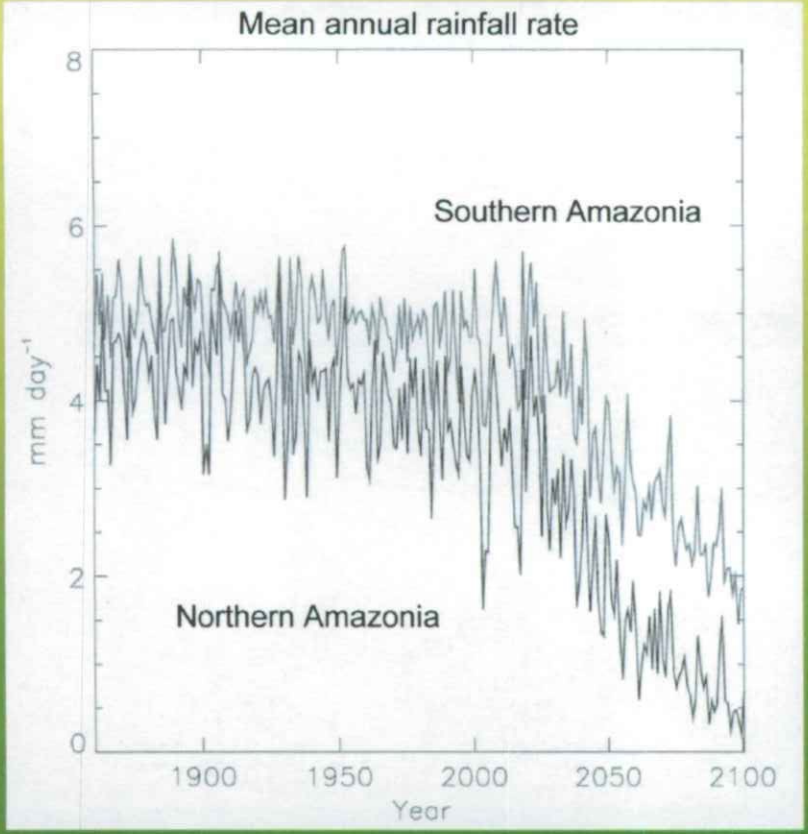
Amazon "die-back" - 2



- Significant decrease in rainfall driven by ocean surface temperature change.
- Land temperatures also increase.
- Photosynthesis drops but plant respiration increases.
- Trees "die-back", replaced with other biomes (eg shrubs)
- Soil respiration increases.
- Hadley Centre published work, but CEH Edinburgh first to alert possibility of "die-back"

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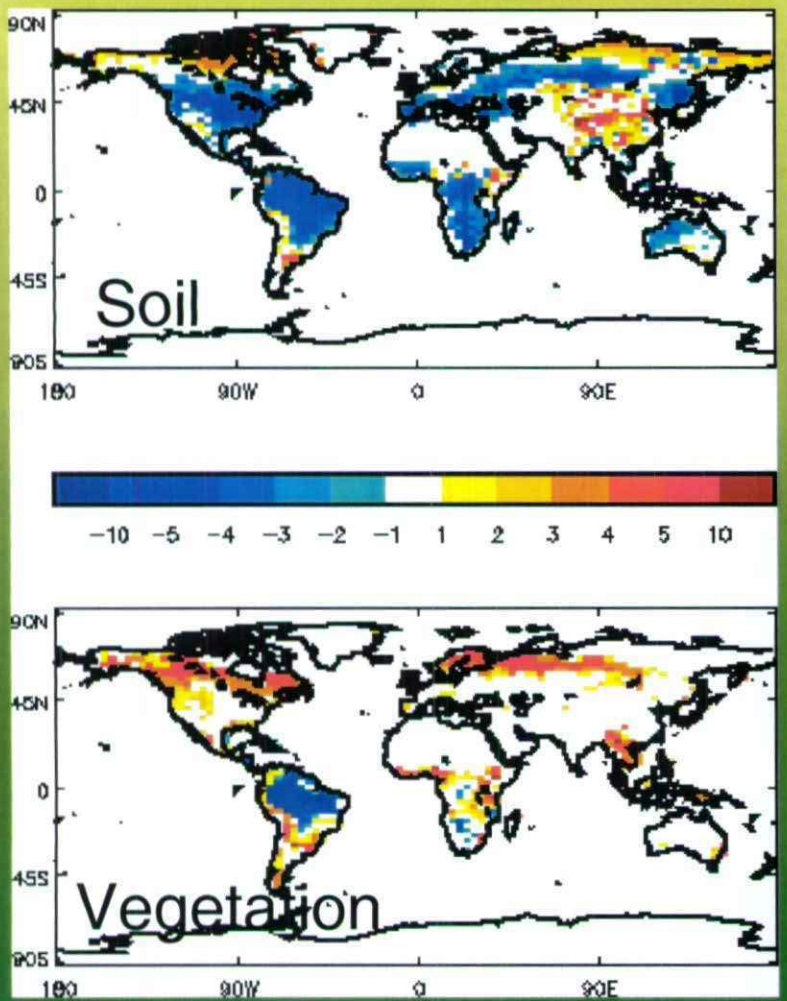
Amazon "die-back" - 3



- This is the Hadley Centre best estimate of terrestrial carbon change by 2100 (kg C /m2).
- What is the **CEH view** on this (ie rainforest die-back, tundra gain and massive soil carbon loss)?
- What would the CEH view translate to within the GCM?
- What happens with CEH science in other GCMs?

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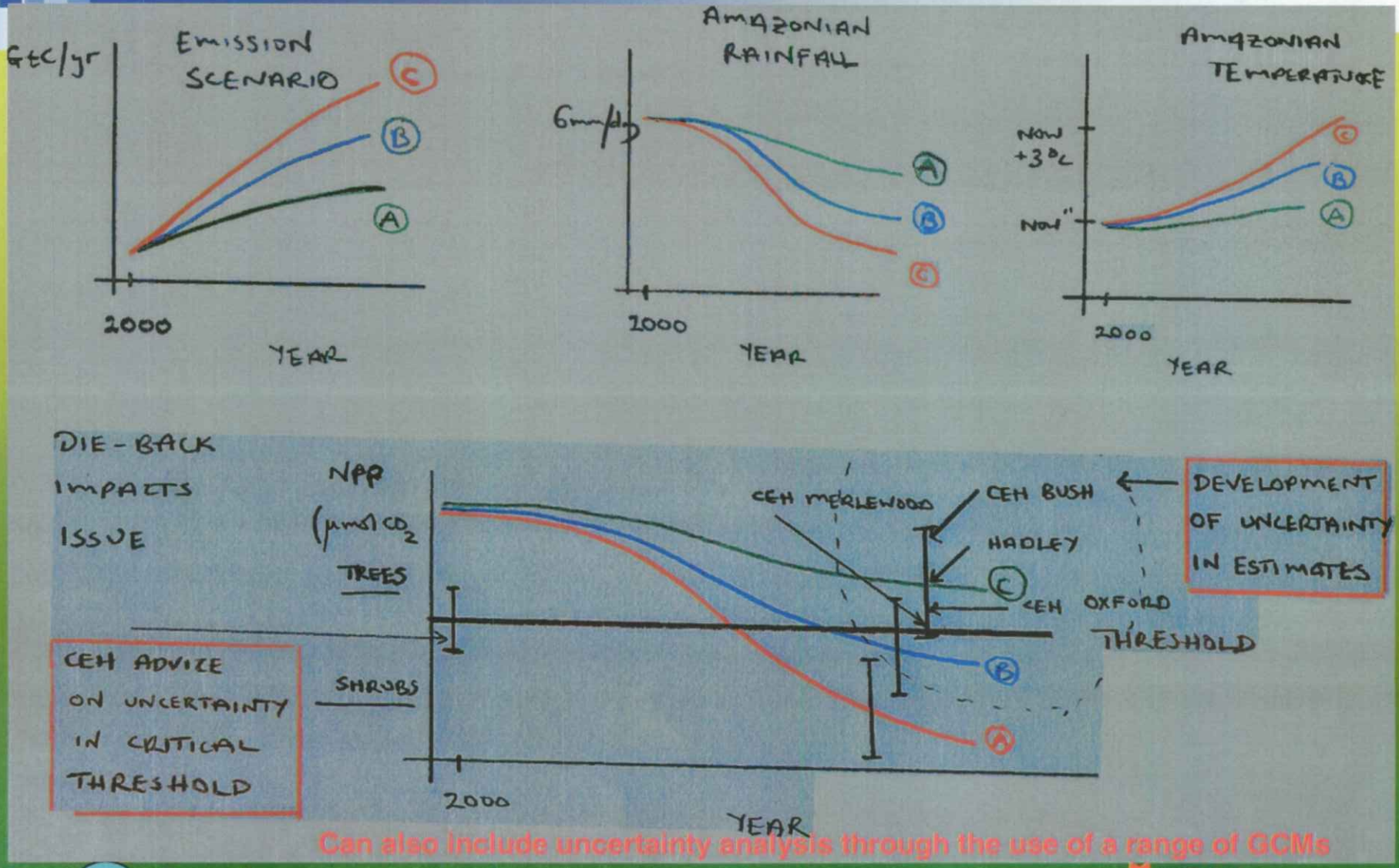
Amazon "dieback" - 4



Can also include uncertainty analysis through the use of a range of GCMs

Merlewood demonstrators-1

Processes controlling soil carbon source/sinks (semi-natural ecosystems):

- Turnover times and fate of carbon.
- Trace gas fluxes (CO_2, N_20, CH_4).
- Soil respiration.
- Litter decomposition (25 years of data).
- Soil biodiversity.
- Above and below ground interactions.
- Land use change and countryside survey datasets.
- ECN (Environmental Change Network).

NERC soil biodiversity programme datasets.

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Merlewood demonstrators-2

Soil Biodiversity Programme Model

(NERC contract – CEH Merlewood manage the database and the whole programme)

- To predict carbon fluxes and transformations.
- To include the functional roles of major groups of biota.
- Allow generalisation to other soil ecosystems.

So, "recapping" - three types of project:

- **Type 1:** Terrestrial feedbacks upon the climate system – the formal incorporation of CEH knowledge into GCM simulations. Special emphasis on the carbon cycle. *GHEM will act as a conduit between CEH and GCM groups.*

- **Type 2**: High quality, scientifically rigorous impacts studies at small spatial scales and probably with special emphasis upon extremes. *GHEM acts as conduit between CEH and DEFRA (for instance).*

- **Type 3**: Link to social economic information to aid governments make sensible and balanced decisions about the environment. *GHEM acts as conduit between CEH and policymakers, "stakeholders", governments and public.*

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With an immediate start to GHEM, by 2005:

- CEH science will drive high quality impacts studies *(what will really happen to the environment around us?)*
- CEH science will drive the simulations of land surface feedbacks within GCMs *(and contribute to IPCC reports)*.
- CEH science has potential to become more interdisciplinary through "demonstrator projects", and also their eventual linkages.
- All modelling exercises "backed-up" by CEH datasets.
- CEH will formally quantify local vs global environmental concerns.

(The last "bullet point" in particular is the "clear blue water" between us and other environmental research organisations – eg Hadley).

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The Centre for Ecology and Hydrology has 600 staff, and well-equipped laboratories and field facilities at nine sites throughout the United Kingdom. The Centre's administrative headquarters is at Monks Wood in Cambridgeshire.

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Further information about CEH is available on the World Wide Web at www.ceh.ac.uk

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