*Vitousek et al (1997)*
*"Human Domination of Earth's Ecosystems",*

40-50% of land surface
50% of accessible fresh surface water
50% of Nitrogen fixation
60% of marine fisheries (over exploited)

*Wackernagel and Rees 1992 1998*
*Ecological footprints*

*The problem is not just ecological and technical but social*
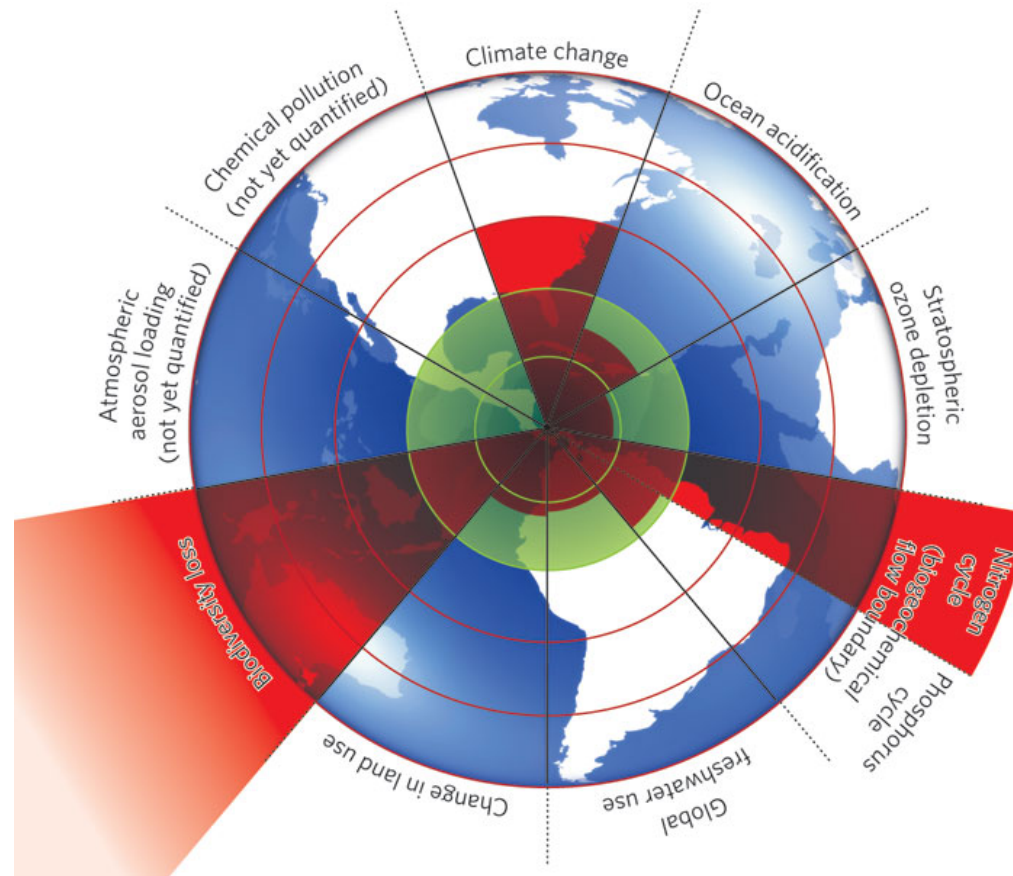
Modelling the Anthropocene?

Considering these and other major and still growing impacts of human activities on earth and atmosphere, and at all, including global, scales, it seems to us more than appropriate to emphasize the central role of mankind in geology and ecology by proposing to use the term "anthropocene" for the current geological epoch.

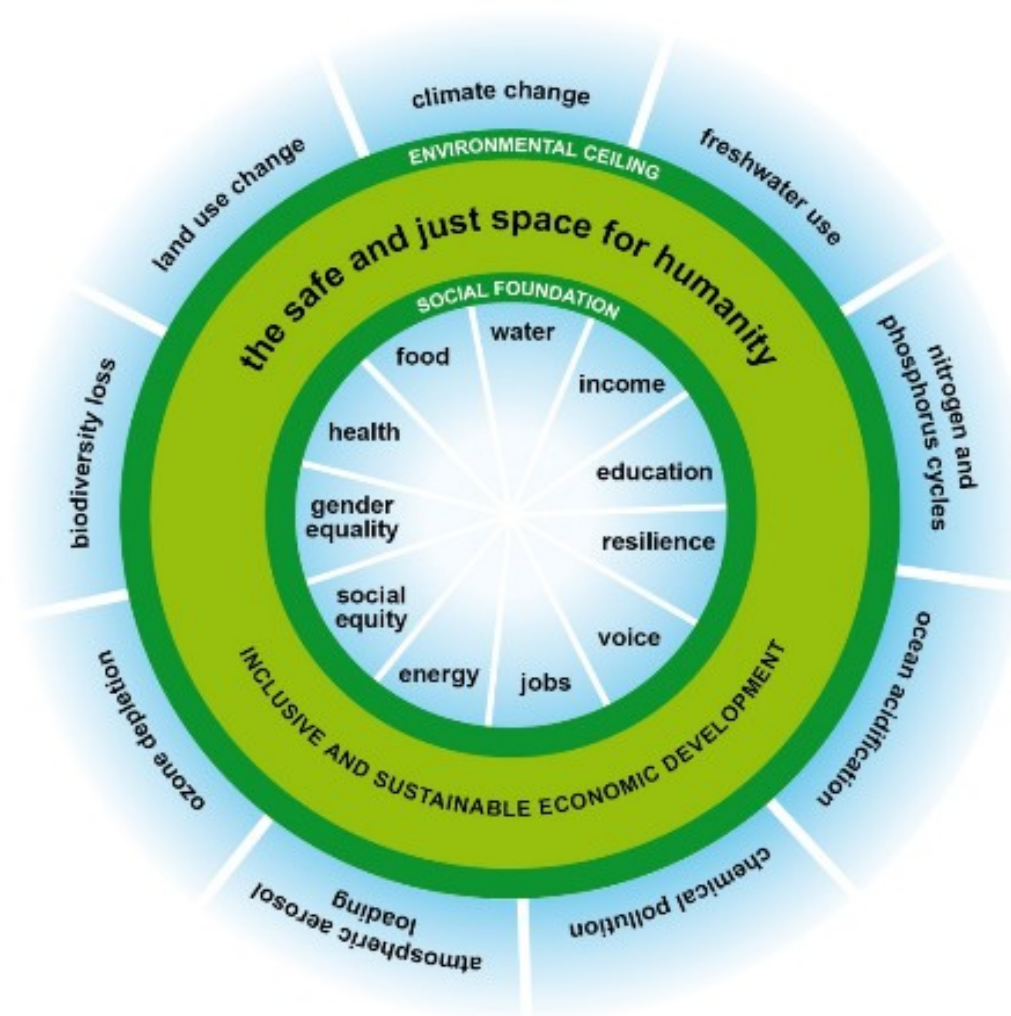Crutzen, P.J. and Stoermer  E.F. IGBP newsletter 41 (2000)
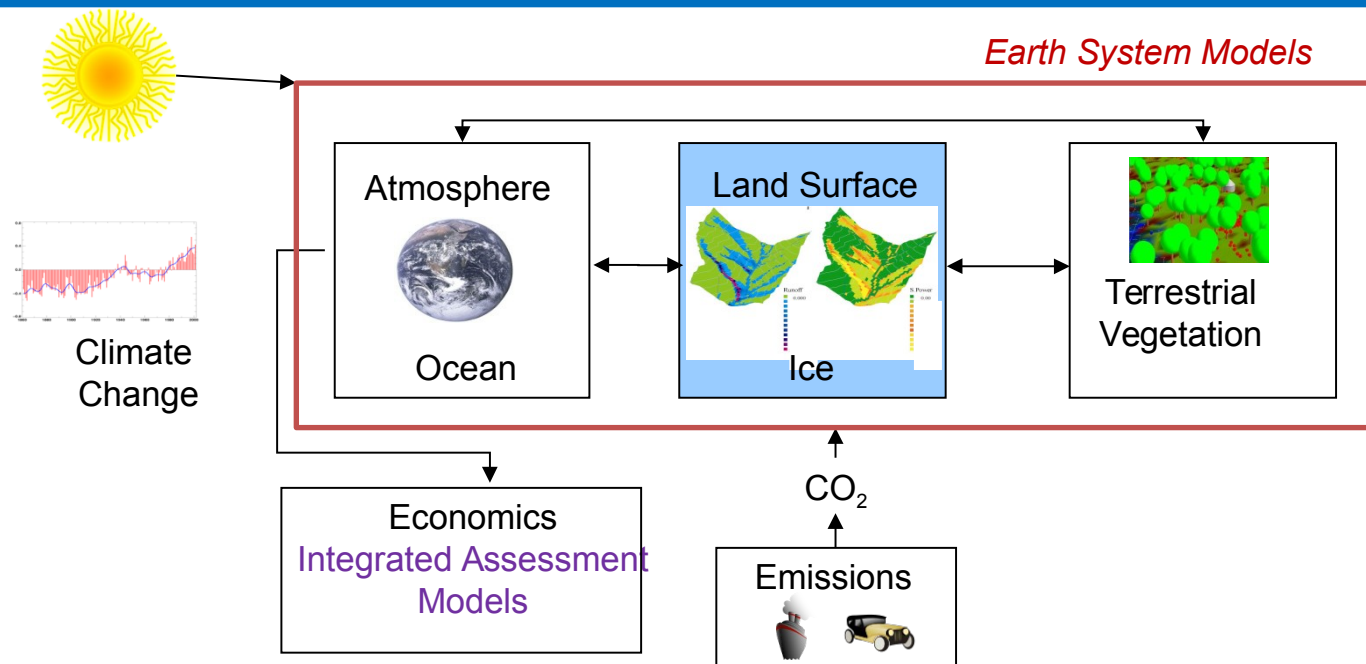
A safe operating space for humanity



Rockstrom *et al.* (2008) Nature

A safe *and just* operating space for humanity



Raworth (2012) Oxfam

*Earth System Models*

Climate Change

Atmosphere

Ocean

Land Surface

Ice

Terrestrial Vegetation

Economics
Integrated Assessment Models

$CO_2$

Emissions

Scenarios are used for future emissions

No method to test whether these are dynamically achievable

Purves *et al.* (2013) Nature



Evans *et al.*(2013)Proc Roy Soc. B

Modelling Global Social-Environmental-Technical Systems

UNIVERSITY OF CAMBRIDGE
Department of Geography

Earth System Models

General ecosystem models

Climate Change

Atmosphere
Ocean

Land Surface
Ice

Terrestrial Vegetation

Animals

Hazards

Landscape Change, Flood, Fire…

Economics
Integrated Assessment Models

Finance
£

$CO_2$

Emissions

Governance

Social Systems
Behavioural Change

Land use change
Agriculture

Socio-economic +political systems

Social-ecological systems

Decision support tools

Infrastructure
Roads
Power
Water
Mines…

Networks

Cities

Socio-technical systems

= "Nexus" models

# Reasons for Global Models

- **De facto dynamics is already global**
- **Integration is needed with other existing global models**
- **More is Different**
- **Boundary conditions are problematic (esp. for validation)**
- **Space and timescales are not independent**
- **Social justice is both local and global**
- **Material flows should be closed (no magic!)**
- **Global datasets provide many constraints**
- **Rumsfeldian reasons (we don;t know what to leave out)**
- **Attempting to construct such models will lead to learning**
- **The computing power exists**

# Previous attempts (not exhaustive...)

- **One big global box – e.g. "Limits To Growth" (LTG) –**
  - **approx 100 integro-differential equations**
  - **Disaggregate it gradually into regions/ smaller units?**
    - **Mesarovic, M.D. and Pestel E. (1974) "Mankind at the Turning Point"**
    - **Quirin ,Sethi and Todd (1977)"Market Feedbacks and Limits to Growth"**
- **Cellular automata**
  - **Cells as agents**
    - **Turchin et al 2013 "War space and the evolution of old world societies"**
- **Agent-based models**
  - **An agent for every person? Household? Business? City...Country...**
    - **Simplified general models – Sugarscape... Gooding 2014 "Modeliing societies ecvolutionary forces"**
    - **Parker& Epstein 2011 "A distributed platform for global-scale agent-based models of disease transmission" - + other disease models**
  - **Aggregates to save computation (e.g. agent cohorts)**
    - **Harfoot et al 2014 "Emergent Global patterns of ecosystem structure and function from a mechanistic general ecosystem model"**
    - **(Parry and Bithell 2012 "Large scale agent-based modelling")**
  - **Functional types to reduce variety**
    - **Harfoot et al 2014**
    - **(Rounsevell et al 2011 "From actors to agents in socio-ecological systems models")**

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# The limits disaggregated

- **Limits To Growth has been shown recently to be disturbingly accurate**
- **The model has never been fully dis-aggregated spatially**
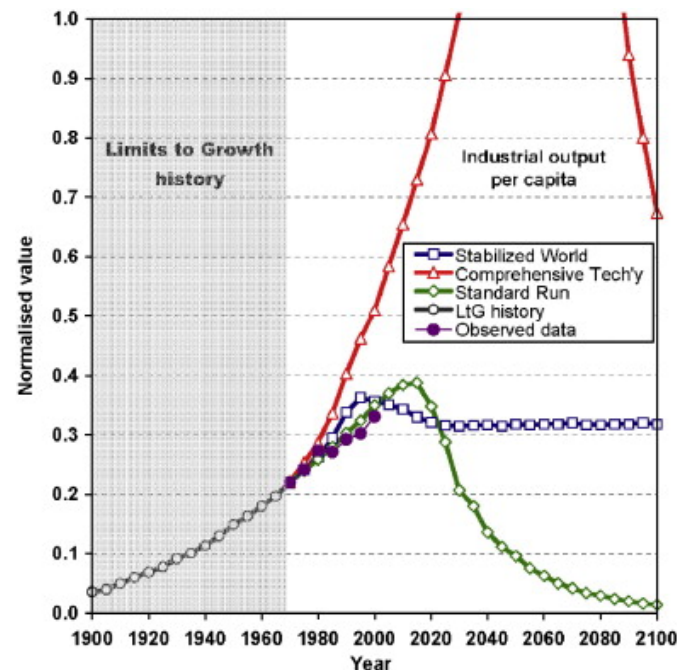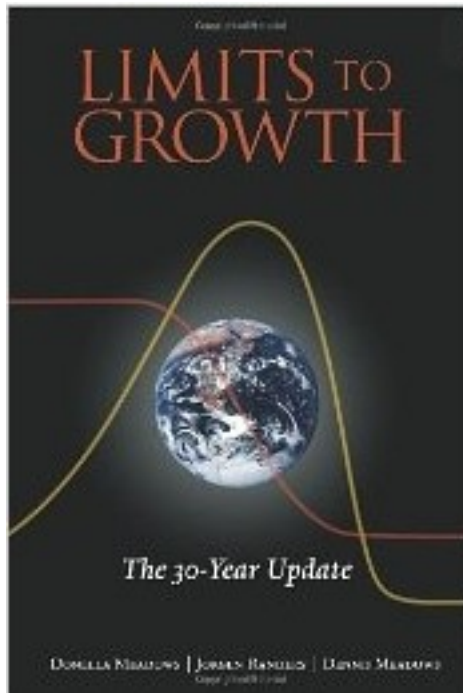


Turner (2008)
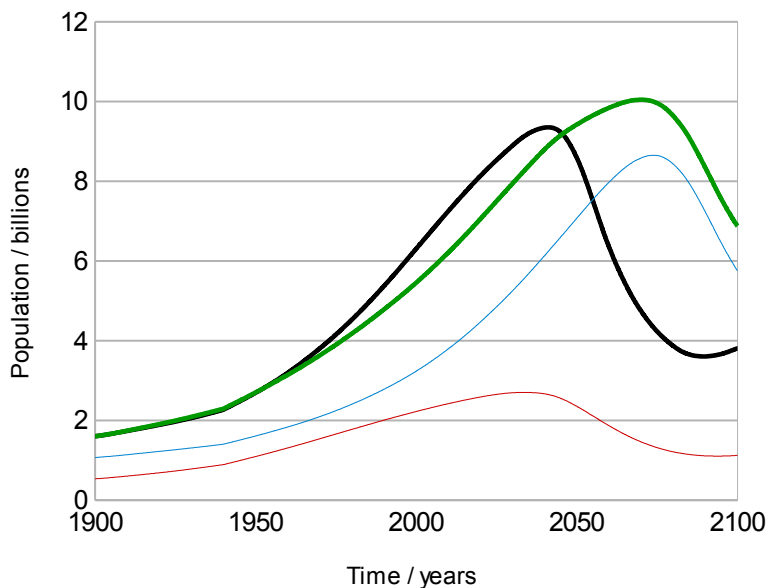A comparison of limits to growth with 30 years of reality
Global Environmental Change 18, 397-411
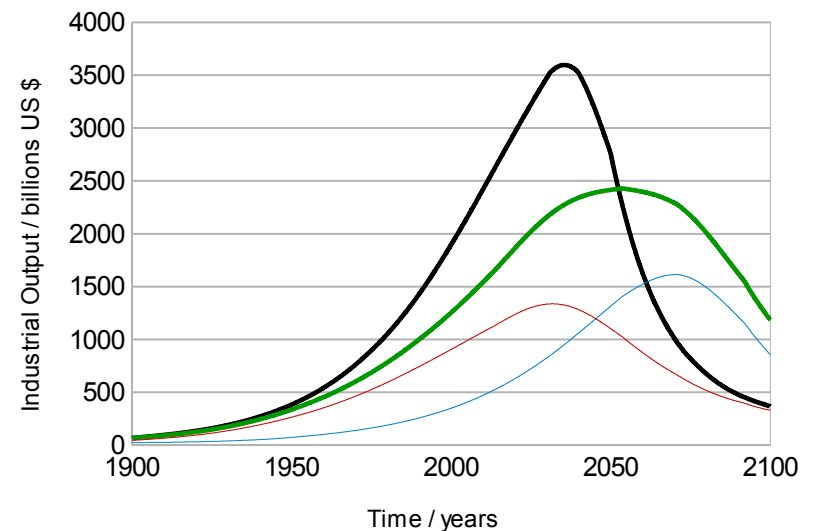
# The limits disaggregated

- **Work by Neil Grant**
- **Any number of regions can now be added**
- **Even with just 2 uncoupled regions we have different aggregate dynamics**



Population Growth in World3-91
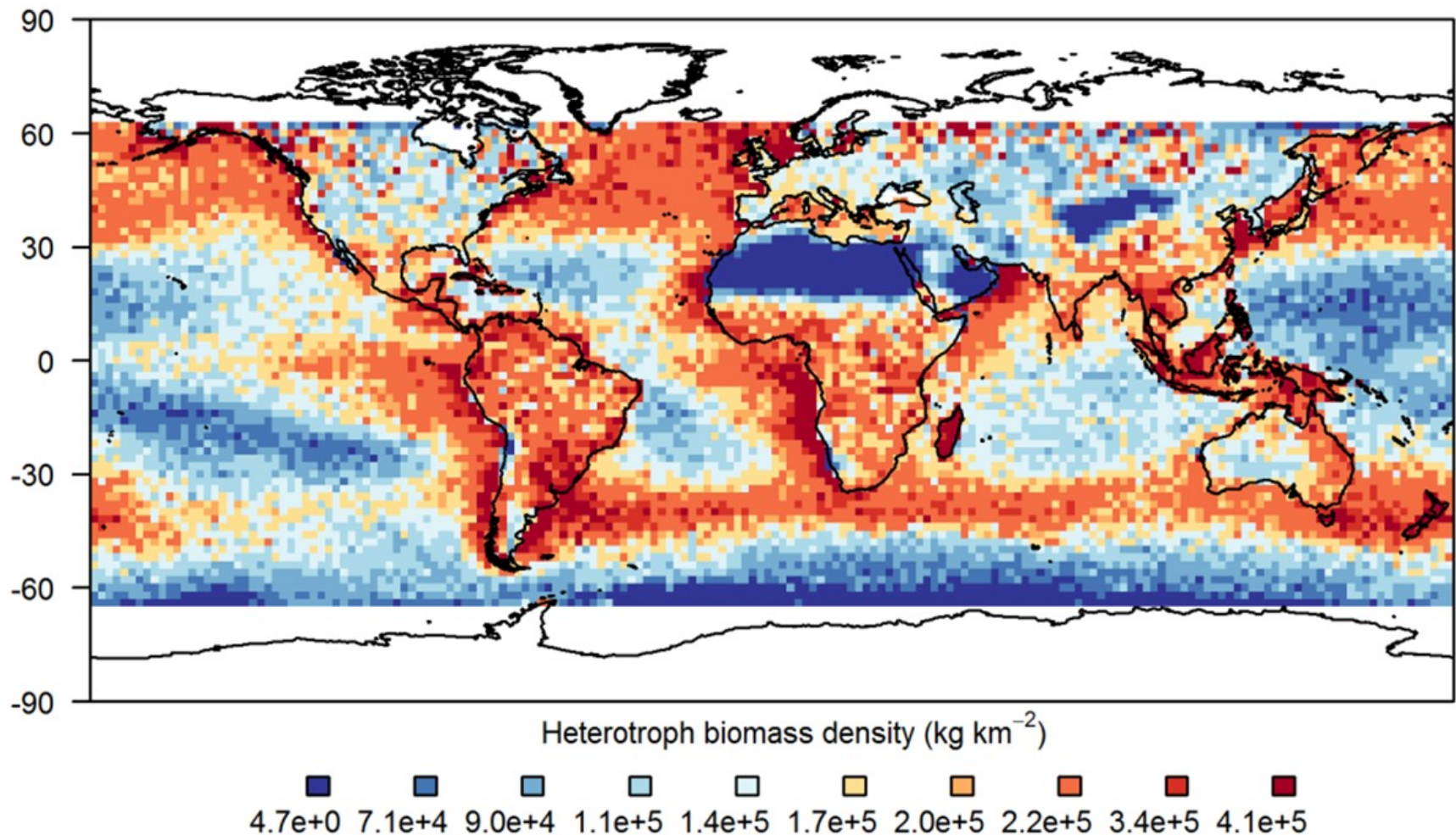
Industrial Output in World3-91

- 2D General Global General Ecosystem Model
- Externally forced by climate files
- Agent based with functional group cohorts
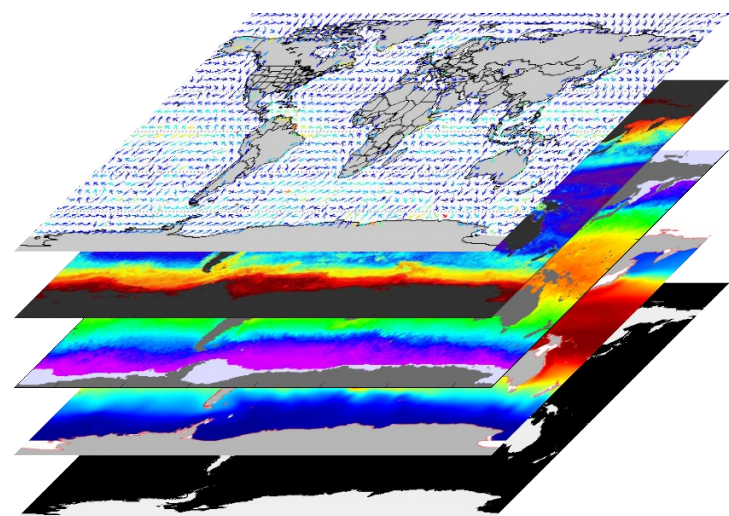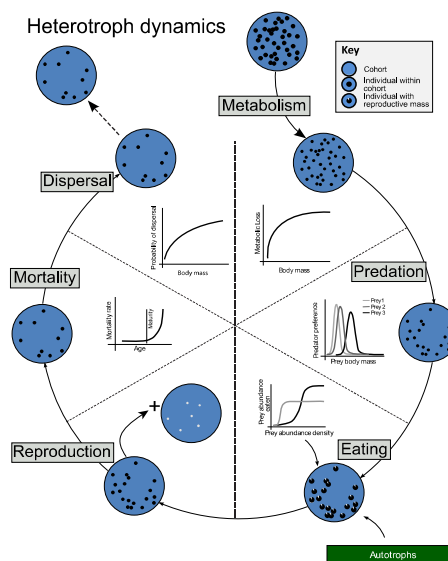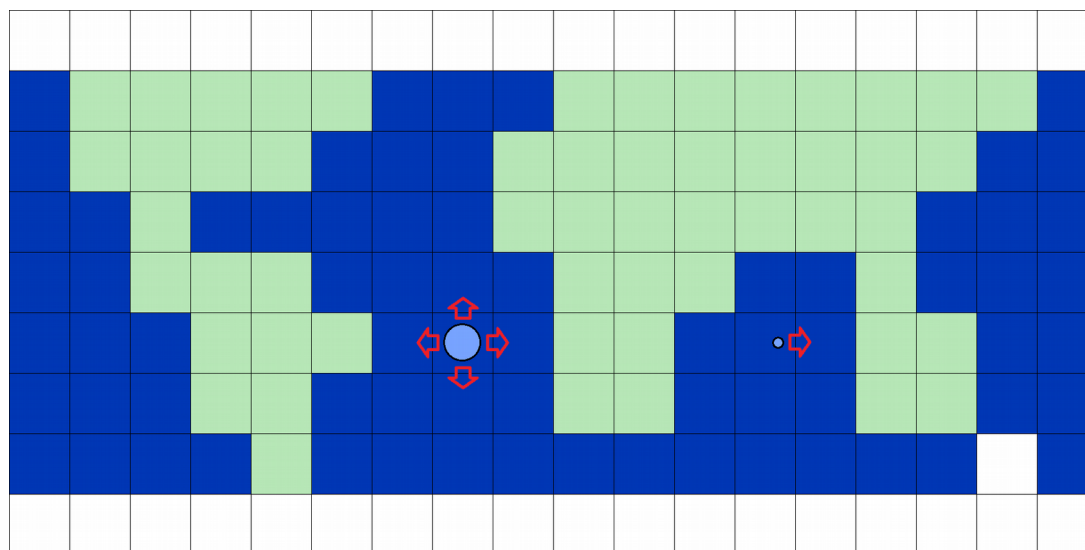
## Global Ecosystem Example Output



Heterotroph biomass density (kg km$^{-2}$)

4.7e+0  7.1e+4  9.0e+4  1.1e+5  1.4e+5  1.7e+5  2.0e+5  2.2e+5  3.4e+5  4.1e+5

Harfoot et al. (2014). PLoS Biology, 12(4).

# Current extensions

- *Downscale and extend LTG*

- *Parallelise Madingley and add human components*
OpenMP at first then MPI using



Repast for High Performance Computing

from Argonne -
Includes support for:-
- Networks
- Domain decomposition
  - Not clear how well this plays with global networks
- Agents
  - Scales out to 6 x$10^{10}$

# Saving the ~~World~~ Civilization?

- **Truly dynamic *persistent* global models that incorporate humans endogenously**
  - **Multiple global models made by separate teams (cf atmospheric GCMs)**
  - **Tools for unification of separate disciplines**
    - **Hazards, governance, economics, finance, social-ecological and socio-technical systems...**

- **Models are generators of "big data" - use big data tools e.g Apache spark, MS azure, AWS**
  - **"Embarrassingly parallel" tools for sensitivity analyses**
  - **Classification tools to reduce dimensionality of the output data**
  - **Machine learning for structure characterization**
  - **Data assimilation to push models toward observation (Malleson et al)**
  - **Continuous improvement of models by pattern oriented testing against multiple data streams of increasing length,detail and reliability**
    - **Global data as constraints on models**
    - **Make use of long satellite time series**

- **Increasing knowledge of what can be modelled successfully and meaningfully**
  - **Can we model the recent past – e.g. 20th century?**
  - **Are there predictions that are robust? About what kinds of things?**
    - **Where are the symmetries?**
  - **Is fore (now)casting ever possible, for what, and on what time and space scales?**