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Hector – A simple open source global carbon-climate model

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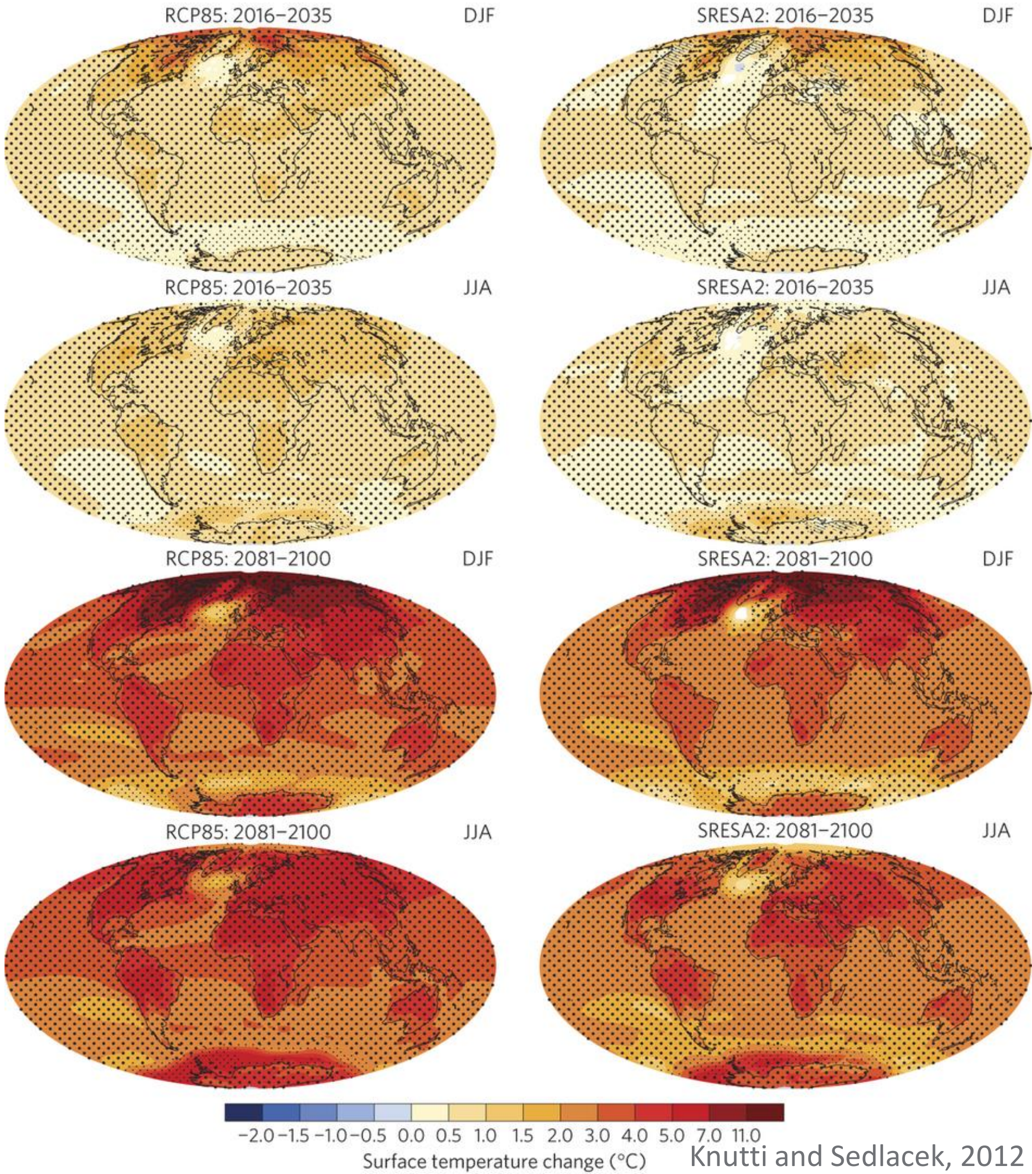
Motivation for Hector

- GCMs and ESMs are detailed and powerful.
- What if we to test 50 variations or run 10,000 times?
- What if we wanted to know average global temperatures under another scenario?
- GCMs are complex and therefore slow to run (~weeks-months) -- therefore, simple climate models are needed for some studies.



Knutti and Sedlacek, 2012

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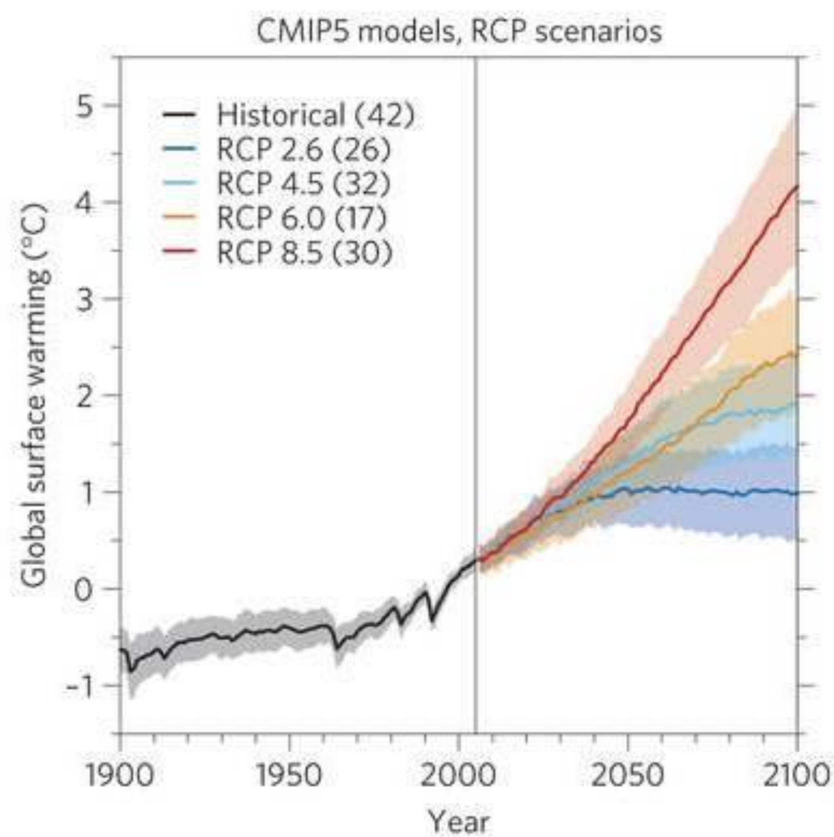
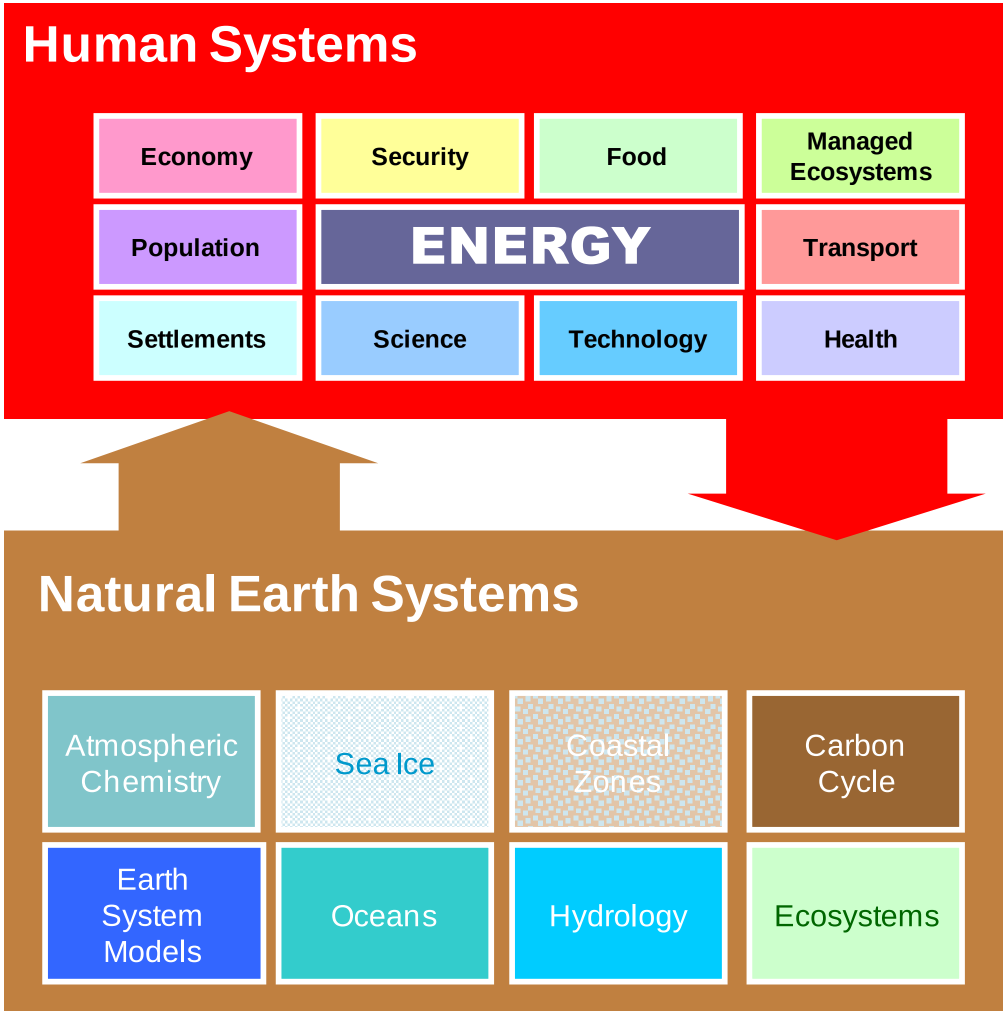


Knutti and Sedlacek, 2012

Motivation for Hector

- Integrate multiple systems of interactions between human/policy systems and Earth systems
- IAMs need to know the climate impacts of the simulated policies, and need to run many times.
- Ideally the climate system is integrated directly into the IAM, so feedbacks are seen instantaneously



Motivation for Hector

- Fast executing simple global climate models
  - Quick 'what-if' (e.g. policy) analyses
  - Model analyses requiring *many* runs (e.g. MCMC)
  - Coupling to other models -- GCAM
- E.g. MAGICC
  - Used across many scientific and policy communities – instrumental in the IPCC
  - Many strengths
  - Old code to work with
  - Not open source, legal issues unclear

Dual developmental tracks for Hector

- A simple object-oriented and open source model for scientific and policy analyses of the global carbon cycle– Hector v0.1
  - **Hartin et al., in discussion** to Geoscientific Model Development
    - http://www.geosci-model-dev-discuss.net/7/7075/2014/gmdd-7-7075-2014.html
- Fully operational in GCAM
  - Technical aspects of the integration of Hector into GCAM is completed.
  - Starting to work through feedbacks, any issues, consistency…

Goals for Hector

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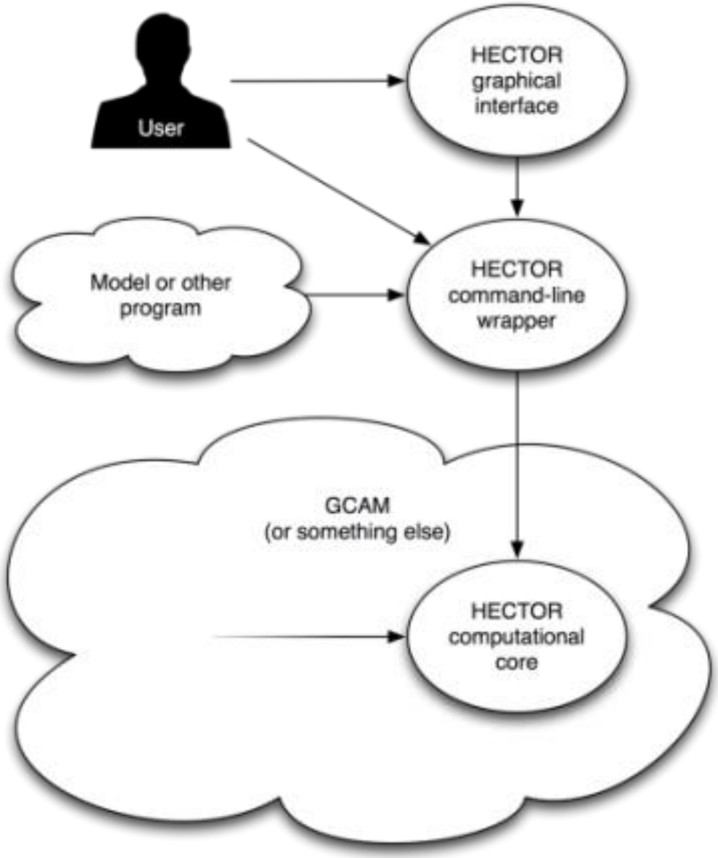
- Very fast executing
  - Adaptive-timestep solver
    - High emissions scenarios
    - Subannual time step
- Free and open source
  - Community model available to all
- Easy to use & well documented
- Modular
  - Easy coupling to other models – GCAM
- Reproduce first-order GCM responses (e.g., atmospheric CO_2, global temperature)

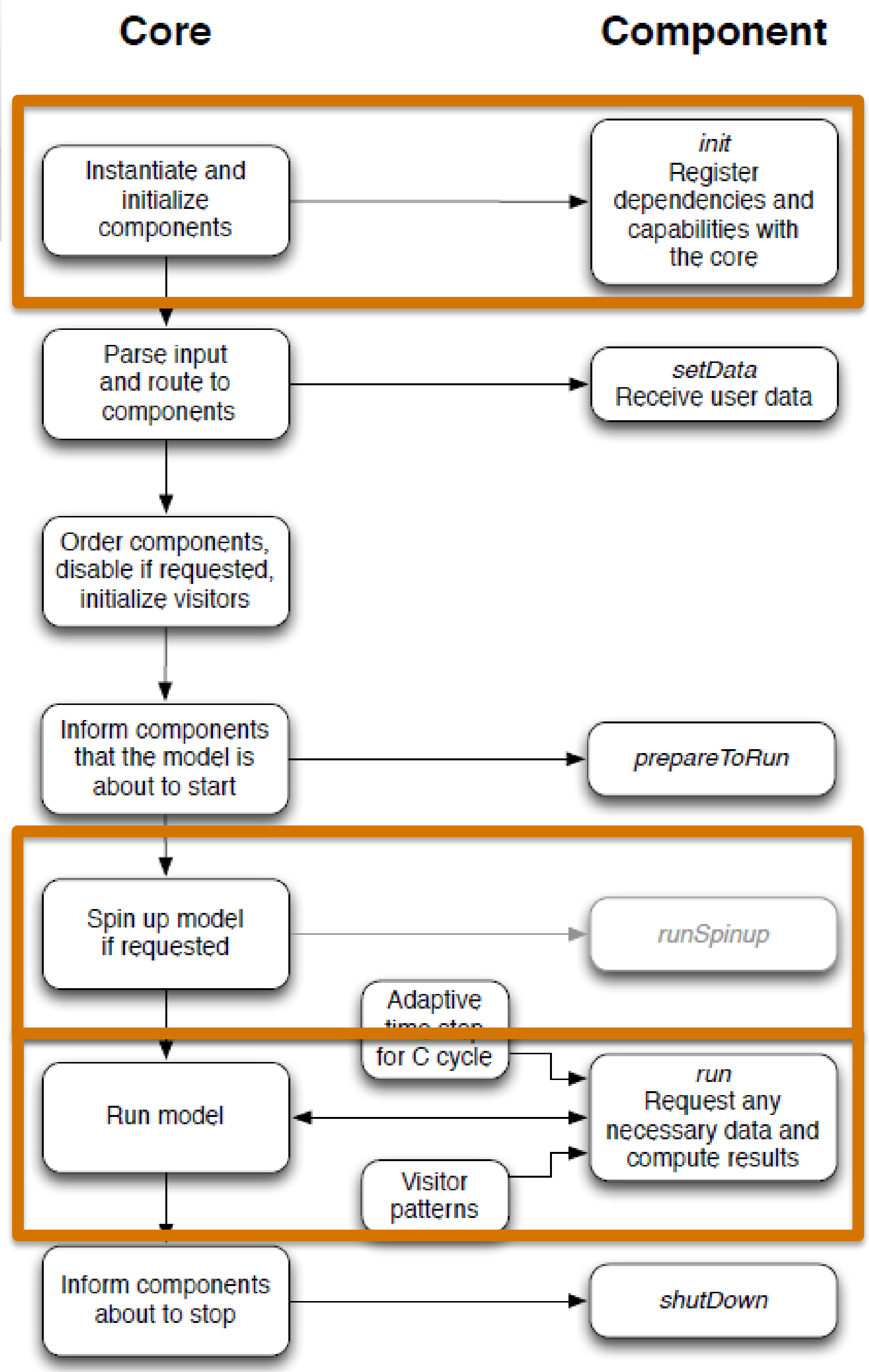


Hector philosophy and structure

- Complexity only where warranted
- Components can be enabled/disabled via inputs
  - E.g. you can test two different ocean submodels against each other
- Modern, clean structure
  - E.g. coupler enforces unit checking between submodels
- R backend for summarizing and analyzing results
  - Ships with MAGICC, CMIP5, and observational data for comparison

Model: open and object –oriented architecture

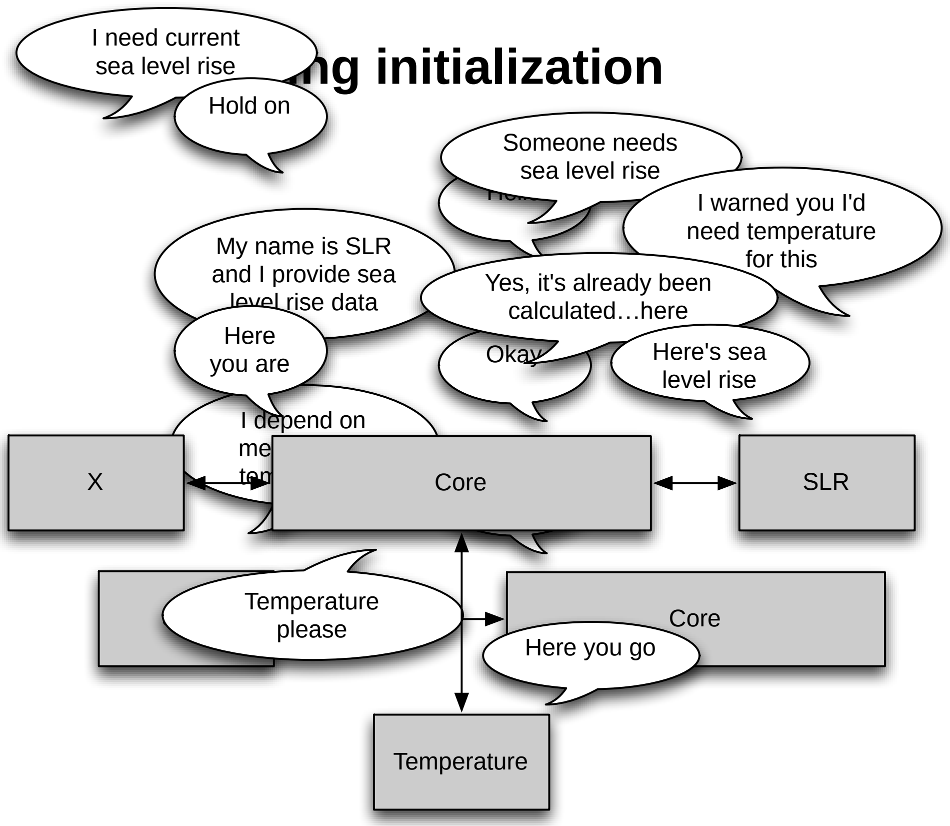
- Initialization
  - Input data are routed to model *components* via the model *core*
- Spin up
  - the carbon cycle is to equilibrium before the main run starts
- Main run



Model: open and object – oriented architecture

As the model runs

- Components have a defined interface (API)
- They register their *dependencies* and *capabilities* with the core
  - e.g., sea level rise depends on temperature
- Core orders components by their dependencies
- Components query the core for data
  - Core routes request to appropriate component



Sample Input File

```
; Config file for hector model: RCP4.5
[core]
run_name=rcp45
startDate=1745
endDate=2300
do_spinup=1                 ; if 1, spin up model before running (default=1)
max_spinup=5000             ; maximum steps allowed for spinup (default=2000)

[onelineocean]
enabled=0                   ; putting 'enabled=0' will disable any component
ocean_c=38000, Pg C

[ocean]
enabled=1                   ; putting 'enabled=0' will disable any component
spinup_chem=0               ; run surface chemistry during spinup phase?
tt  = 72000000               ; 7.2e7 thermohaline circulation, m3/s
tu  = 49000000              ; 4.9e7 high latitude overturning, m3/s
twi = 12500000               ; 1.25e7 warm-intermediate exchange, m3/s
tid = 200000000             ; 2.0e8 intermediate-deep exchange, m3/s

k = 0.2                     ; ocean heat uptake efficiency  (W/m2/K)

[simpleNbox]
; Initial (preindustrial) carbon pools
atmos_c=588.071                        ; Pg C in CO2, from Murakami (2010)
veg_c=550                              ; Pg C
detritus_c=55                          ; Pg C
soil_c=1782                            ; Pg C
```

Initial values for the ocean and land components

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Science: Introduction

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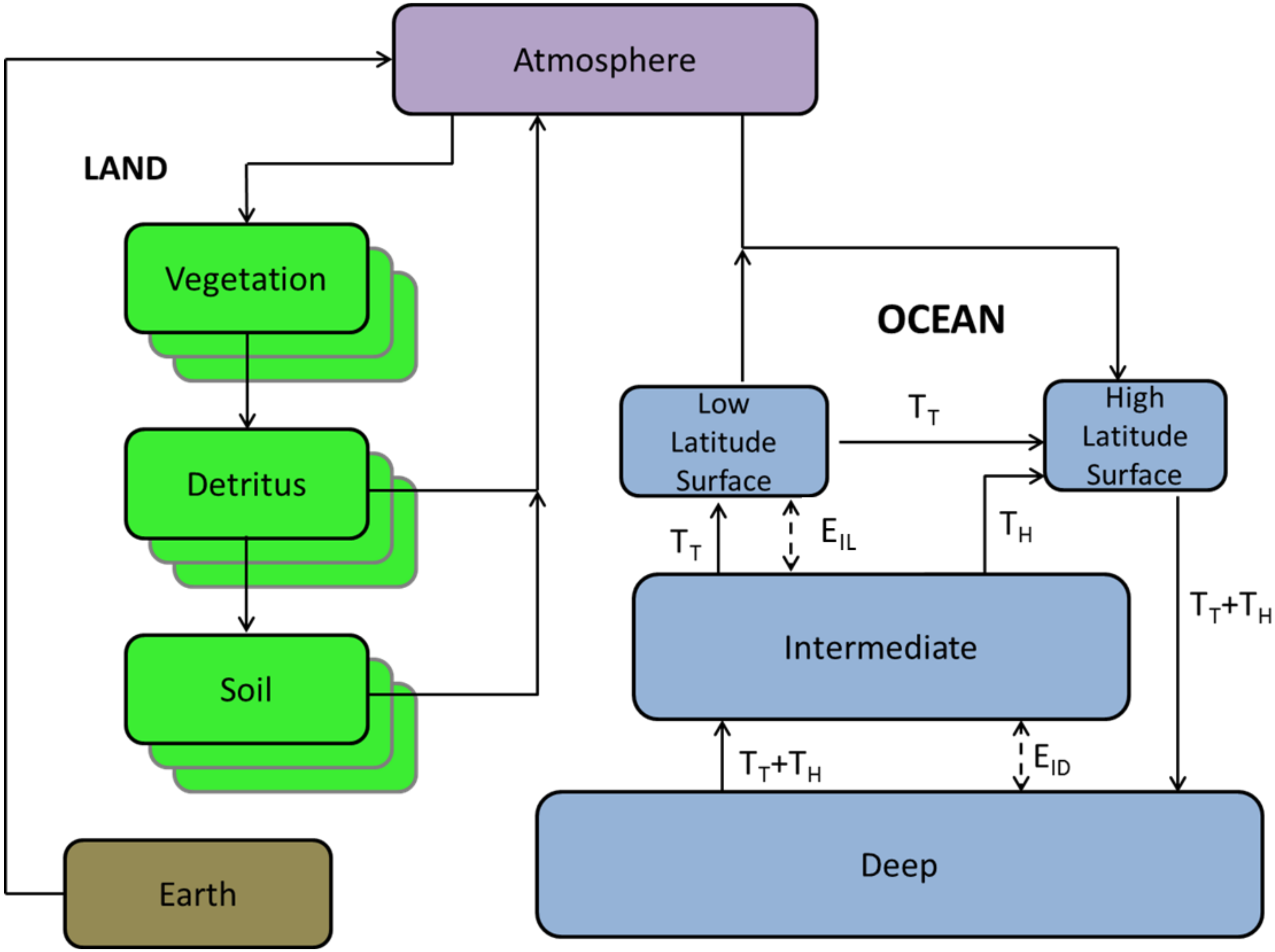
- Science code in Hector represents long standing techniques used in simple earth system modeling
  - Developed independently of MAGICC
- Modular architecture and open source makes future improvements easy
  - Built a platform for interested researchers to develop

Science: Introduction



Science: Atmosphere

- Well mixed globally averaged atmosphere
- Forced with emissions from RCP scenarios
  - CO_2 – anthropogenic & LUC
  - BC/OC
  - CH_4/N_2O → in concentrations for now
  - 26 halocarbons
  - Sulphate aerosols
  - Volcanic emissions
- Calculate:
  - Stratospheric H_2O
  - Tropospheric O_3
- Radiative forcing
  - include both indirect and direct effects on radiative forcing

Science: Land

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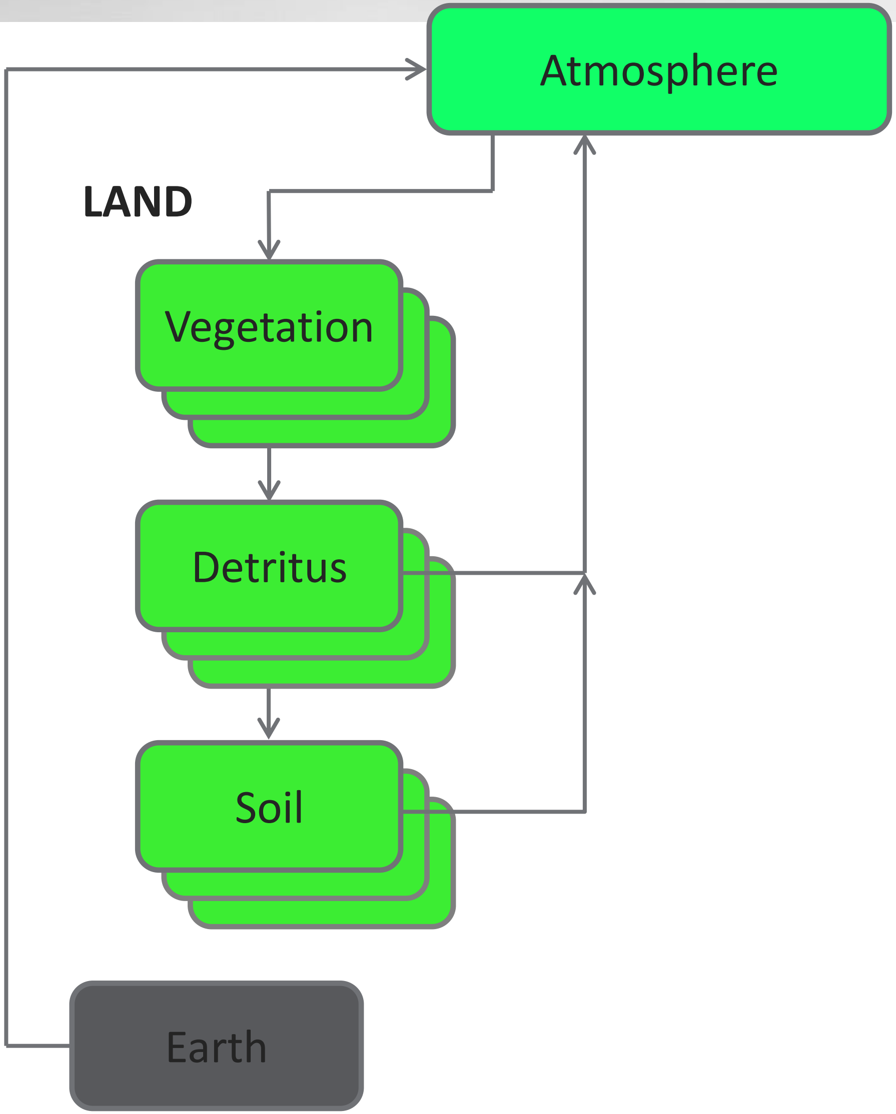
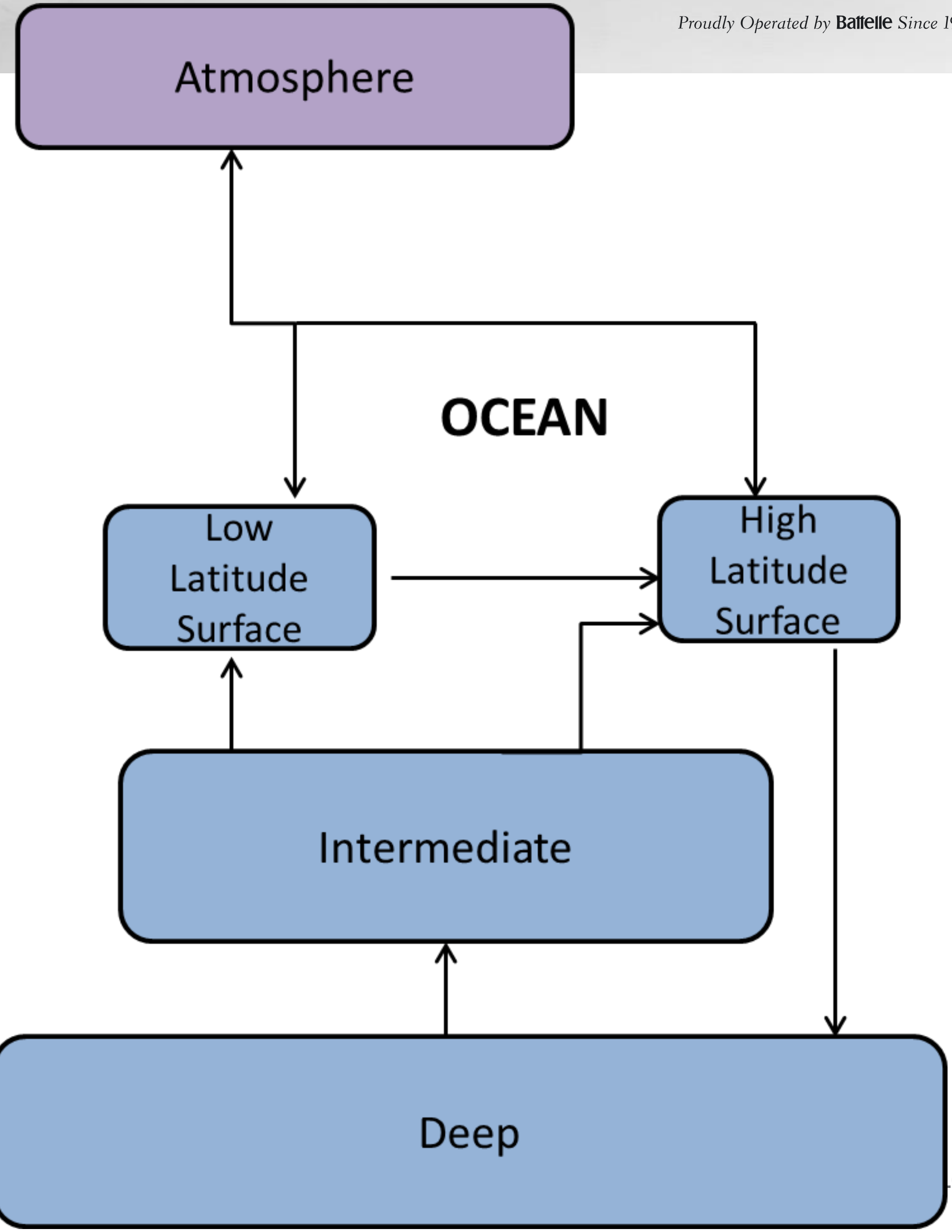
- A classic simple design: five boxes
- NPP, R_H, litter fluxes scaled by global temperature and CO_2
- Optional biomes – ex. Boreal and tropical
- Continual mass balance to check for 'leaks'



Science: Ocean

- 4 boxes
  - 2 surface boxes (100m)
  - Intermediate box
  - Deep box (~3777m)
- Advection and water mass exchange
- Heat uptake in surface boxes
- Carbon chemistry in surface boxes (e.g., atmosphere-ocean flux, pH, $CaCO_3$ saturations)



Science: Ocean Carbon Chemistry

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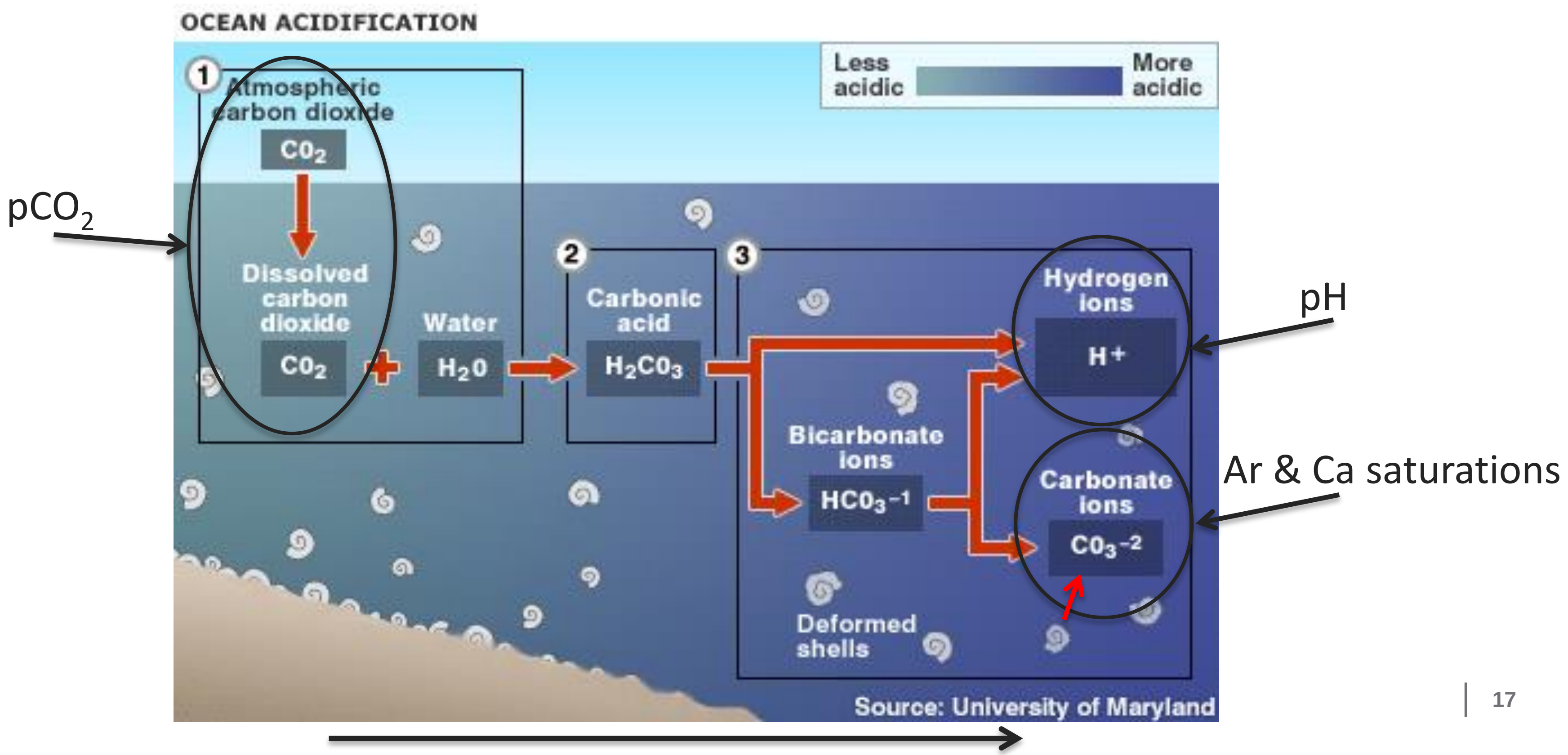
- Active carbon chemistry calculated in surface (Zeebe and Wolf-Gladrow, 2001)
- Non-linear system
  - pCO_2, Alkalinity, pH
  - DIC – HCO_3^-, CO_3^{2-}, CO_2
  - Aragonite and calcite saturations



Results: Data

- 11 CMIP5 models
  - RCMIP5 R package
  - http://cran.r-project.org/web/packages/RCMIP5/
- MAGICC6 and MAGICC5.3
- Observations
  - Atmospheric CO_2
    - Mauna Loa
    - Law Dome
  - Global temperature
    - HadCRUT4
  - Ocean chemistry
    - HOTS
    - BATS

Model	Institute
bcc-csm1-1	Beijing Climate Center, China Meteorological Administration, China
CanESM2	Canadian Center for Climate Modeling and Analysis, BC, Canada
CESM1-BGC	National Center for Atmospheric Research, United States
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory, United States
HadGEM2-ES	Met Office Hadley Centre, United Kingdom
inmcm4	Institute of Numerical Mathematics, Russia
IPSL-CM5A-LR	Institut Pierre Simon Laplace, France
MIROC-ESM	Atmosphere and Ocean Research Institute; National Institute for Environmental Studies, Japan Agency for Marine-Earth Science and Technology, Japan
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany
MRI-ESM1	Meteorological Research Institute Earth, Japan
NorESM1-ME	Norwegian Climate Center, Norway

Results: Radiative Forcing

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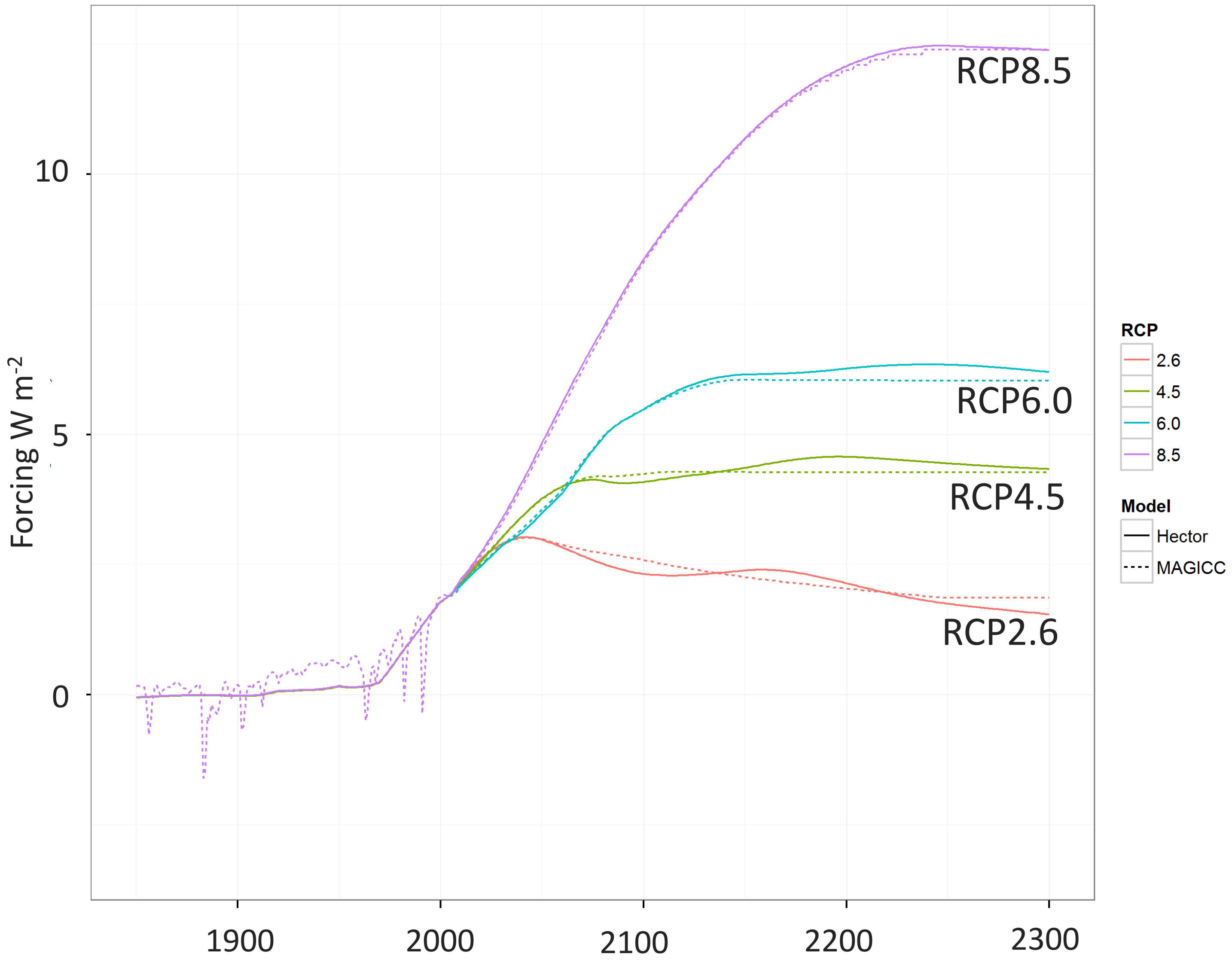
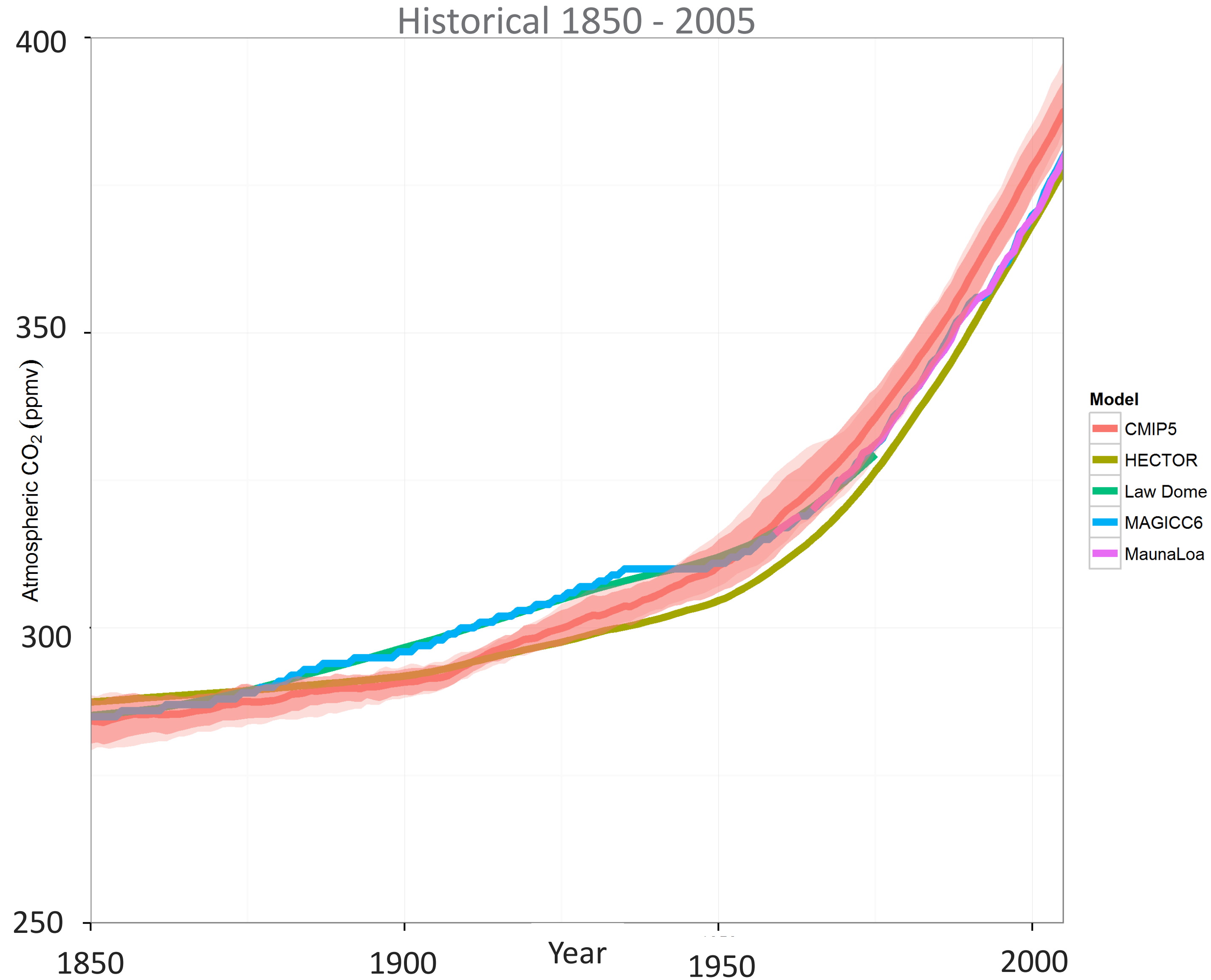


Results: Atmospheric CO_2



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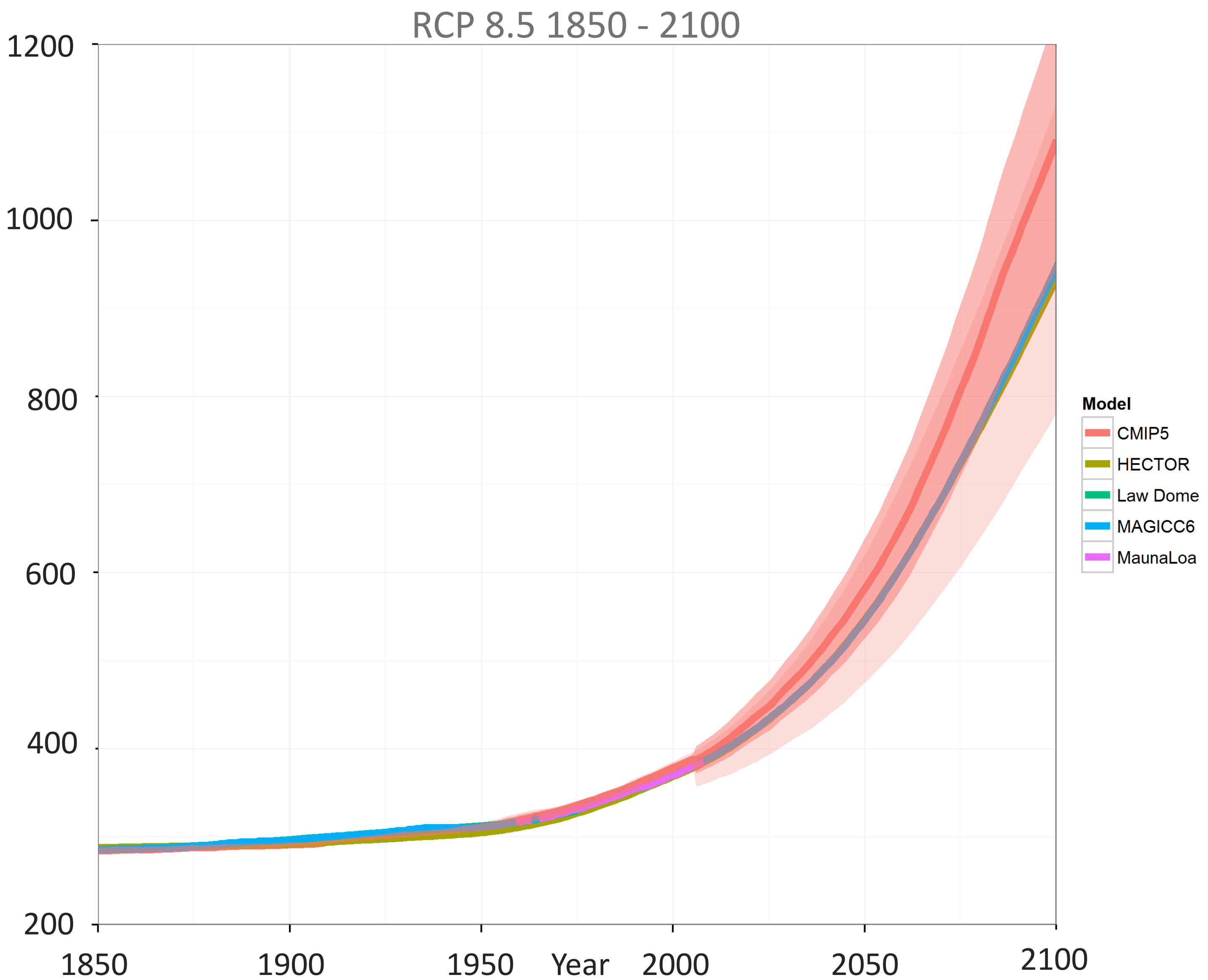

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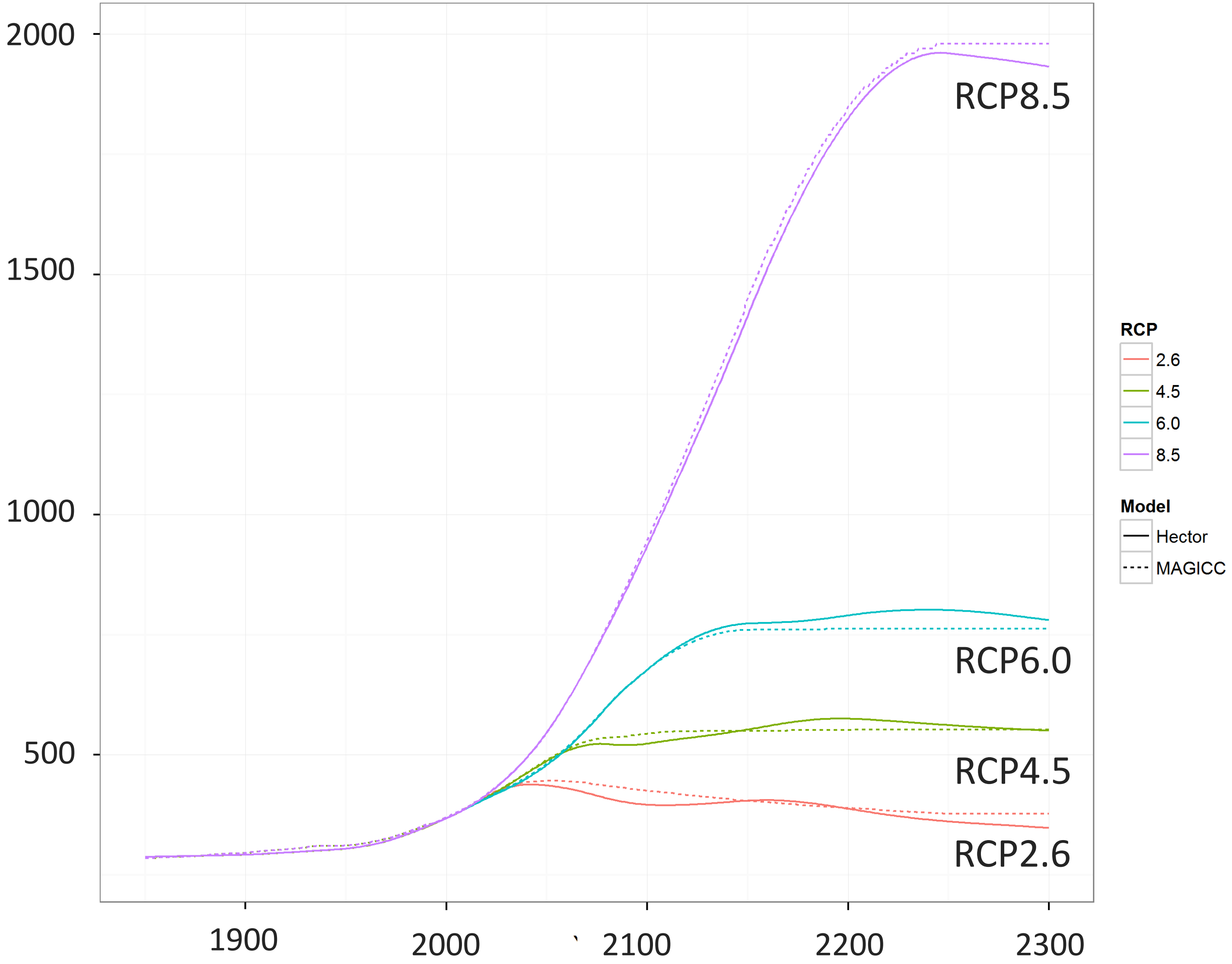

Results: Global Temperature

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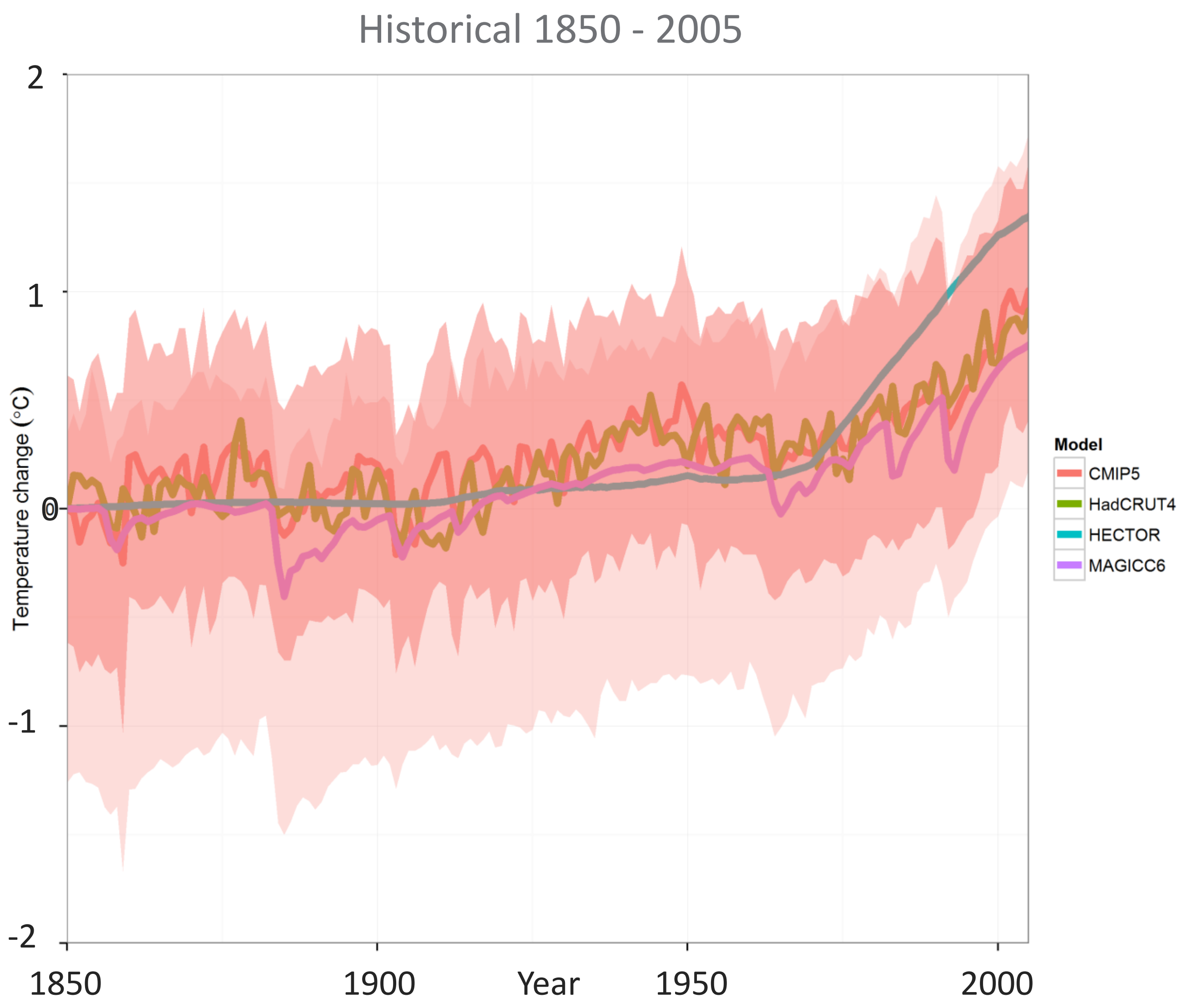

Results: Global Temperature

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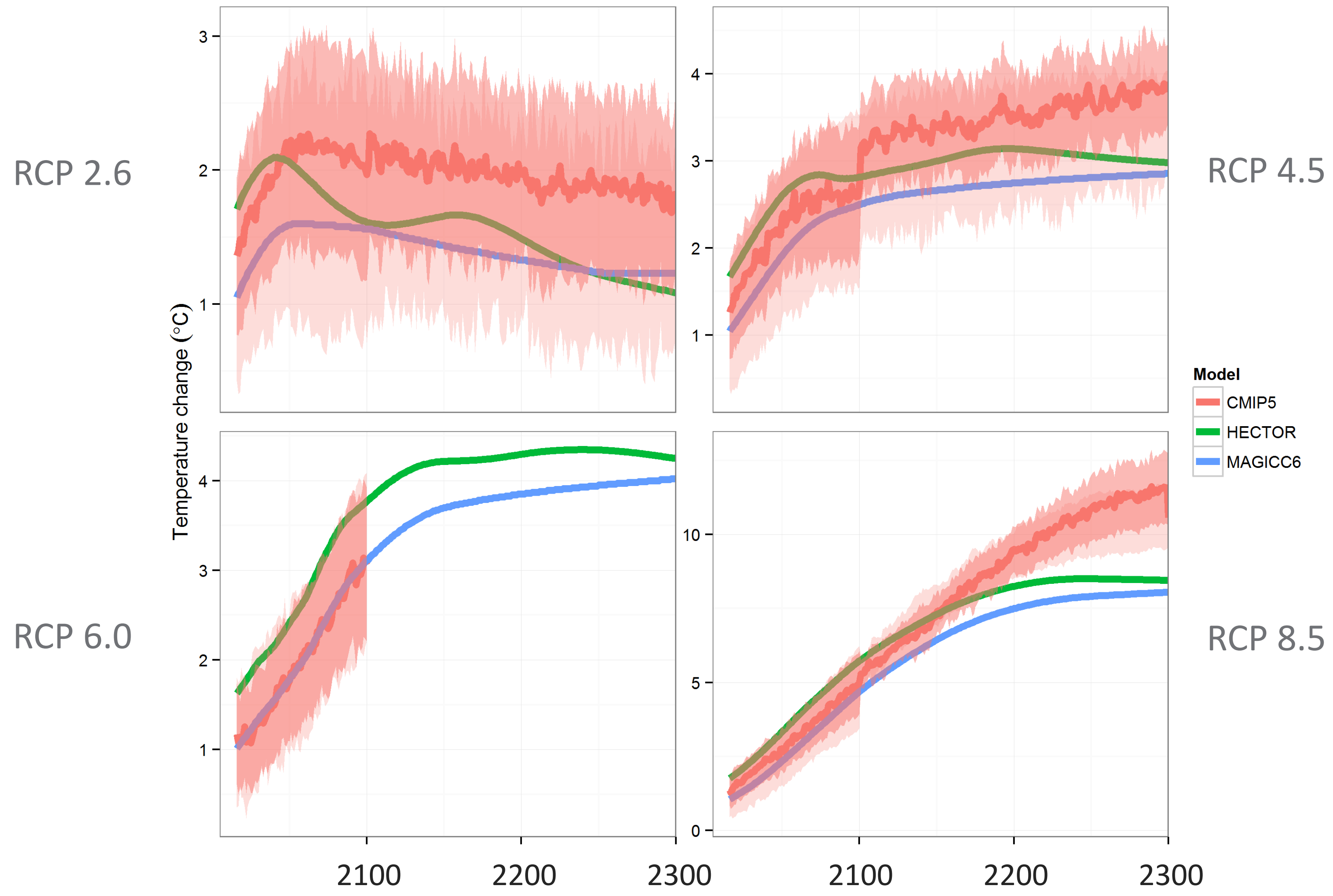
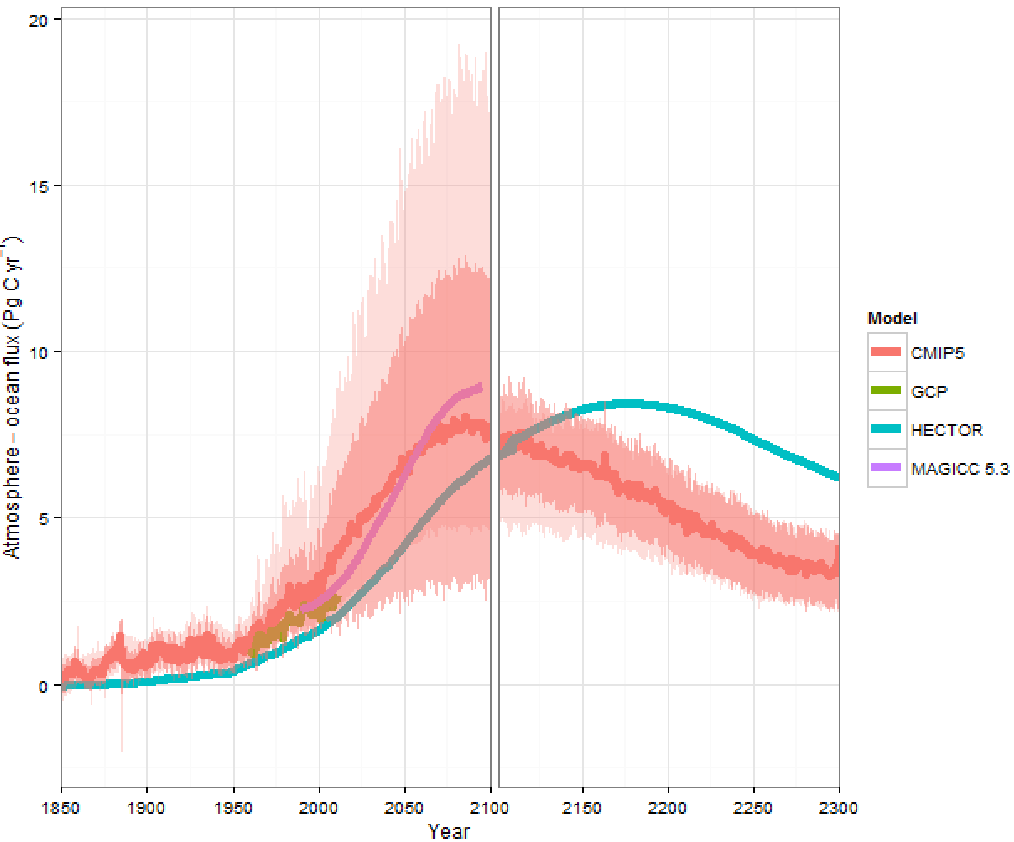
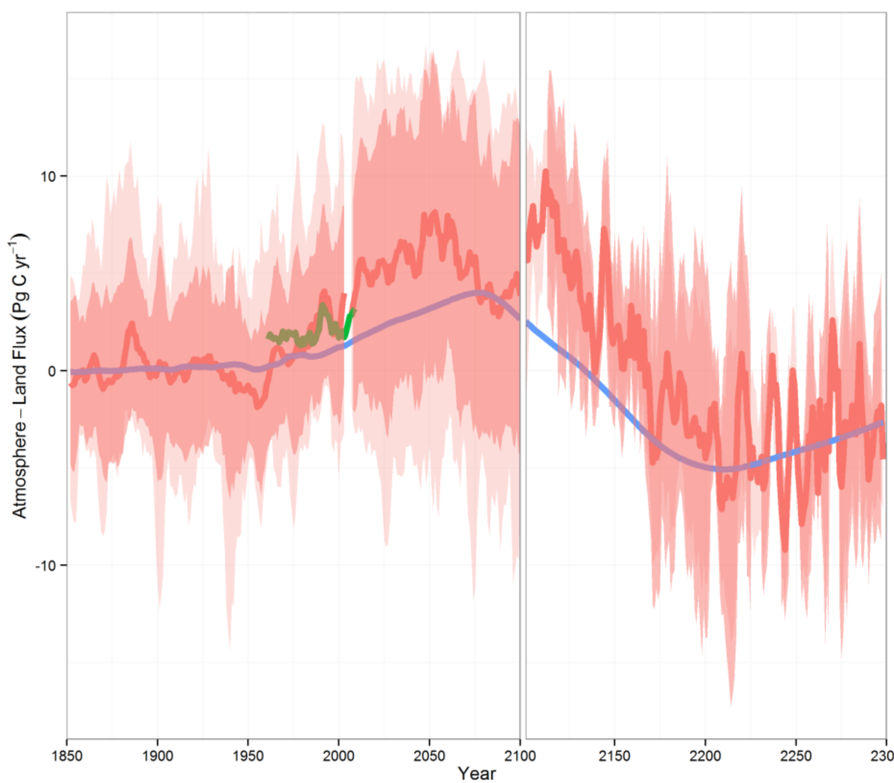


Results: Carbon Fluxes

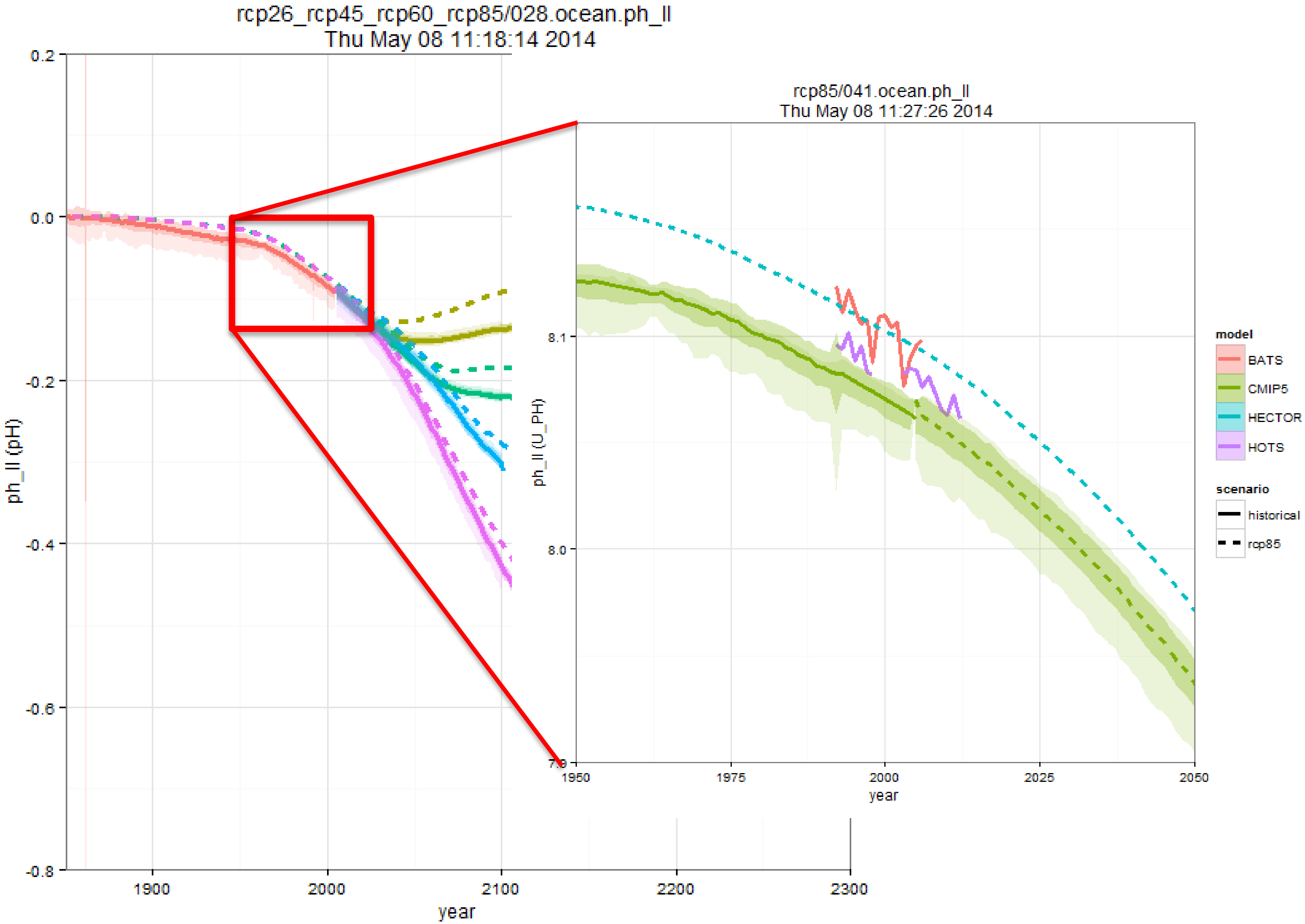


Air-Sea Fluxes 1850 - 2300

Air-Land Fluxes 1850 - 2300

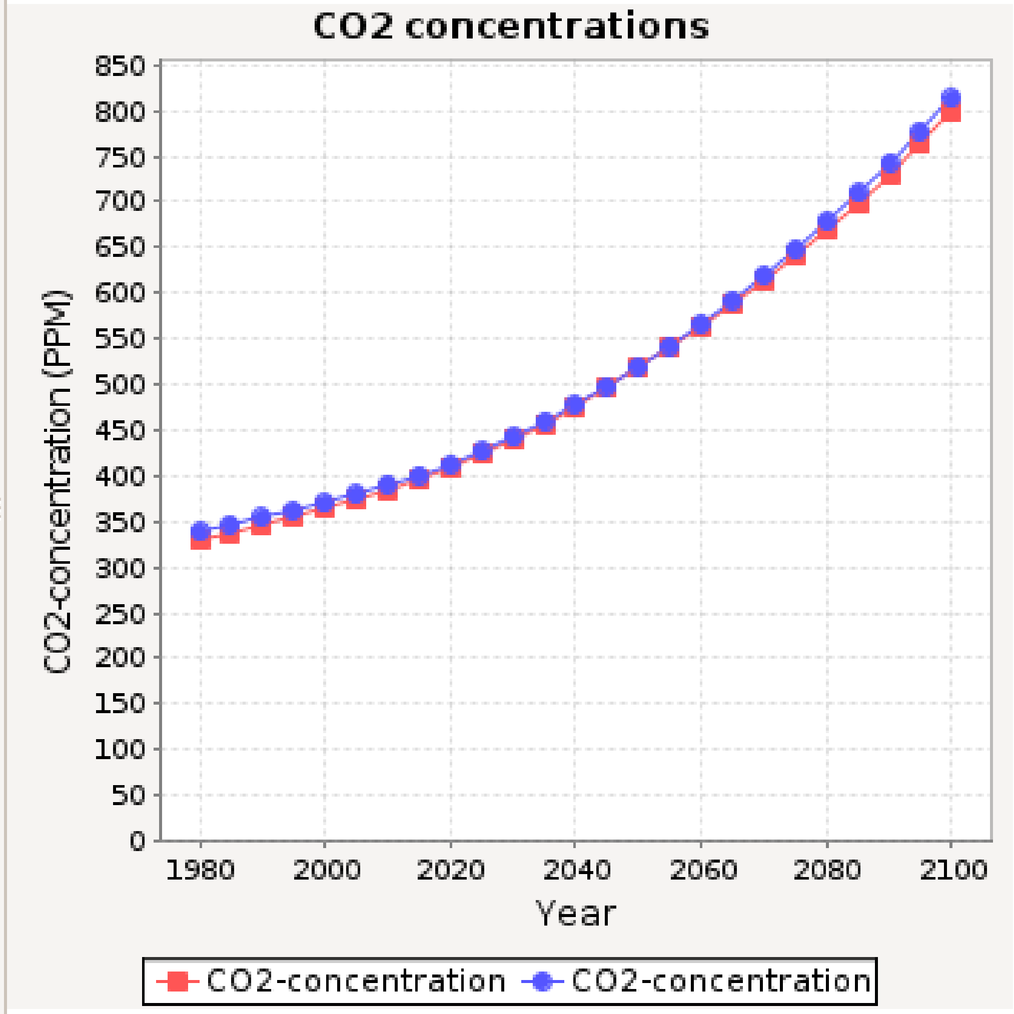


Results: Ocean Carbon Chemistry



GCAM integration of Hector

- Ongoing process
  - The technical work of integrating has been completed.
- Red - Hector
- Blue – MAGICC
- 2 way coupling:
  - Temperature effects on AC/Heating in GCAM.



Hector:

- Four primary innovations:
  - Innovative science – ocean chemistry
  - Adaptive time step
  - Object oriented architecture
  - Open source
    - Community development
    - Integration into other IAMs

Future directions

- Dual developmental tracks for Hector:
  - Open source community model → develop science and code
    - Collaborations with Pennsylvania State University
    - Sea-ice and sea-level rise
    - Land/ocean temperature contrasts
    - Uncertainty analyses
  - Integration into GCAM
    - *Endogenous impact studies*
      - Temperature effects on AC/Heating in GCAM.
      - Climate effects on hydropower linking with GCAM water supply model
      - Agricultural impacts – open question about emulation
    - Separate the land component into GCAM regions
    - Mitigation targets for ocean acidification
    - Fast-executing emulation and policy/model exploration
- We welcome feedback and future use!
- **https://github.com/JGCRI/hector**

Acknowledgements

- DOE, Office of Science, Integrated Assessment Research Program
- EPA Climate Change Division