Future Development of the iESM

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Acknowledgements: DOE

Outline of Status of the iESM System

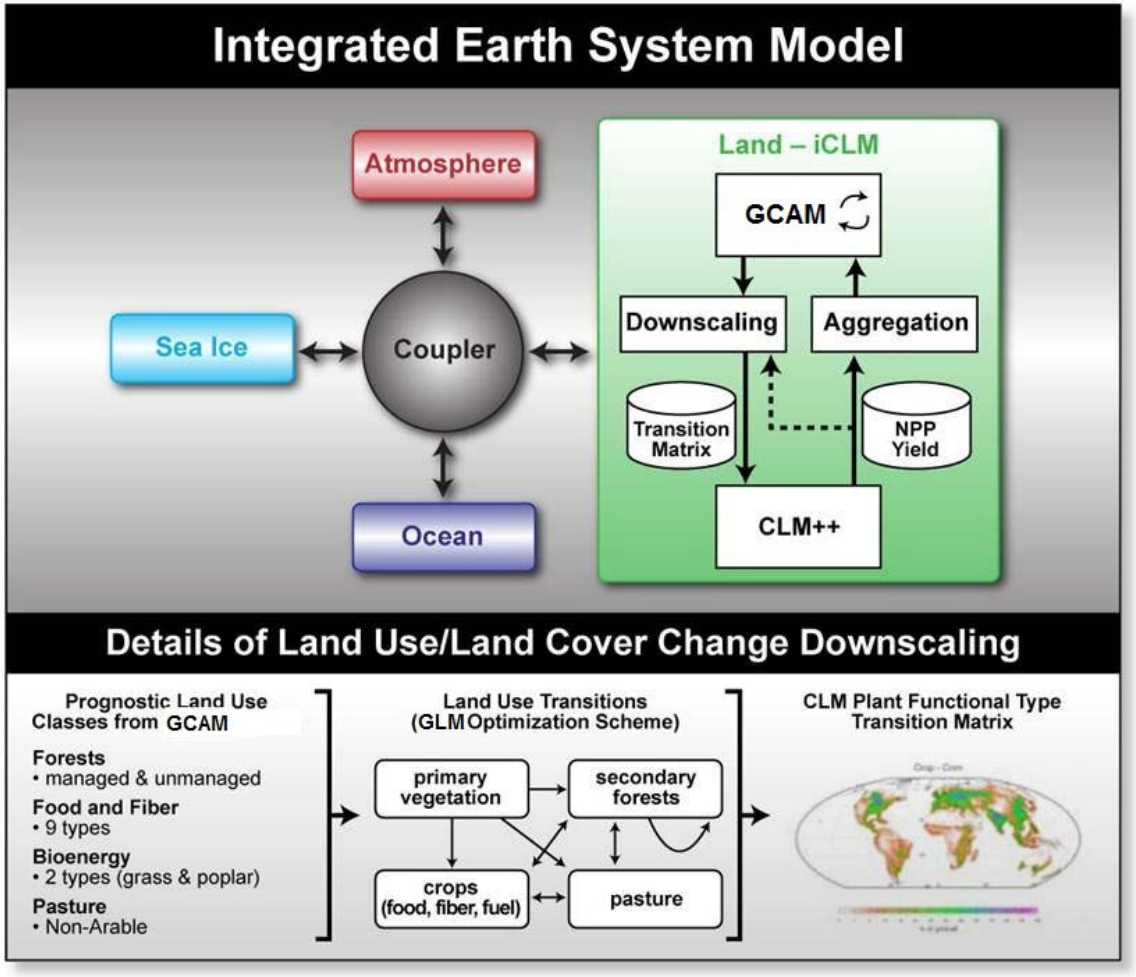
- **Status of code for the integrated Earth System Model (iESM)**
- **Experiments and proposed extensions to the iESM system**
- **Interactions among the iESM team, SDWG, and CESM**

Human Dimensions

Clean Energy

Water Supplies

iESM schematic



Foundations for iESM are:

- Global Change Assessment Model (GCAM):
- Global Land Model (GLM):
- Community Earth System Model (CESM):

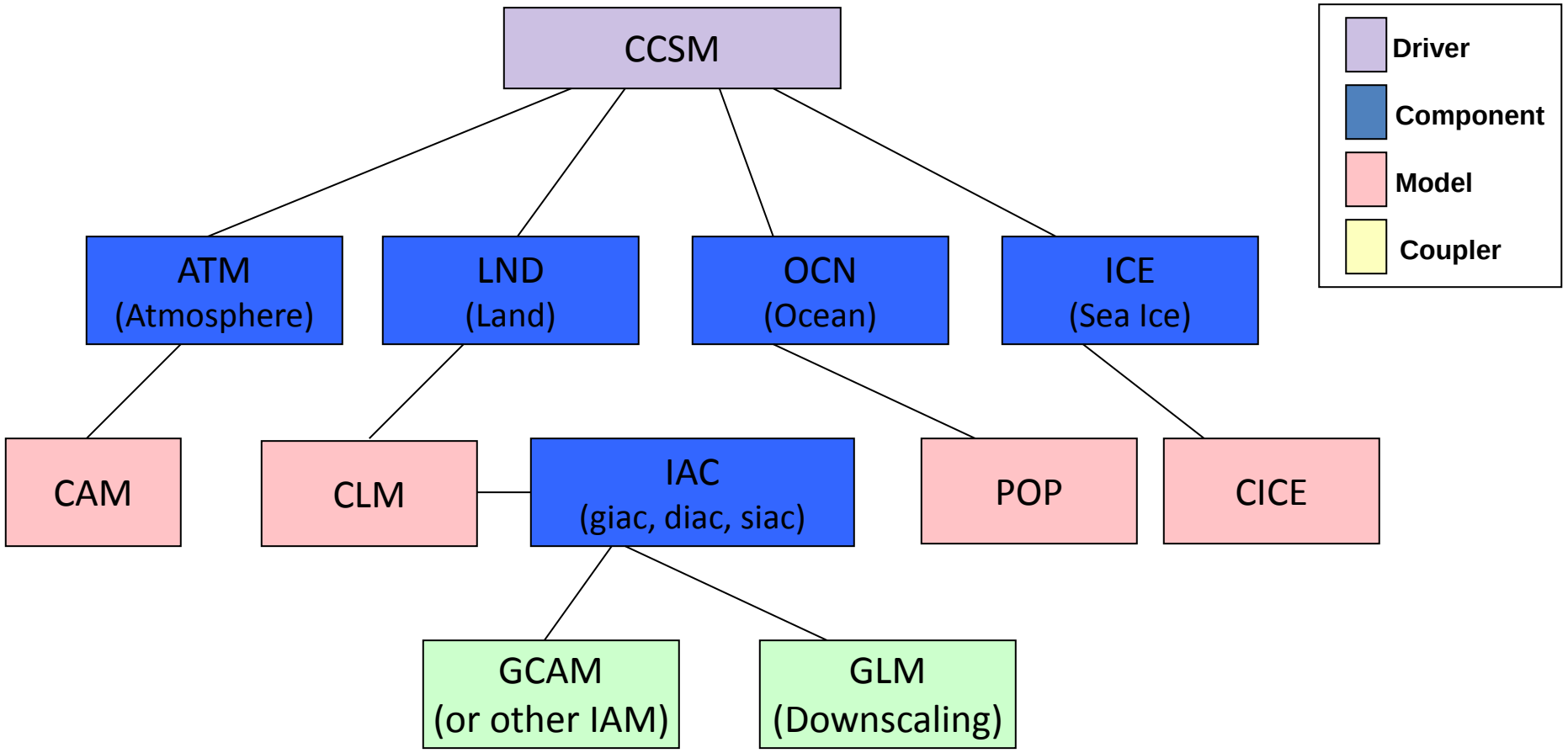
Applications:

RCP 4.5

Land-use in AR5

IPCC simulations

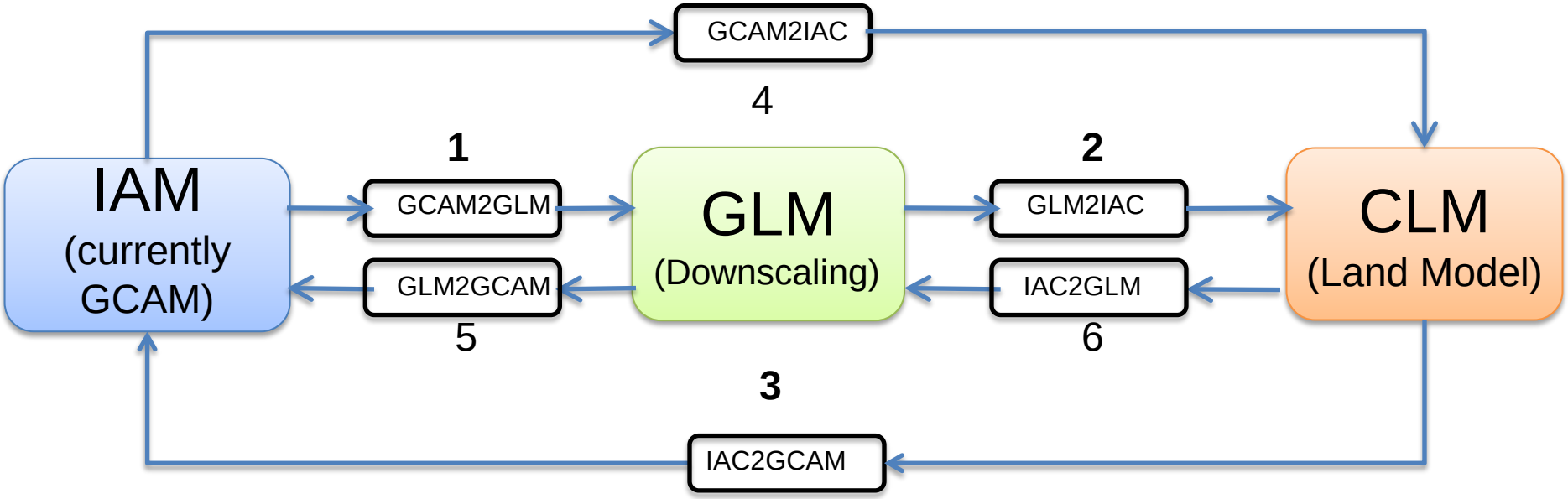
Current iESM Coupling Implementation



Status:

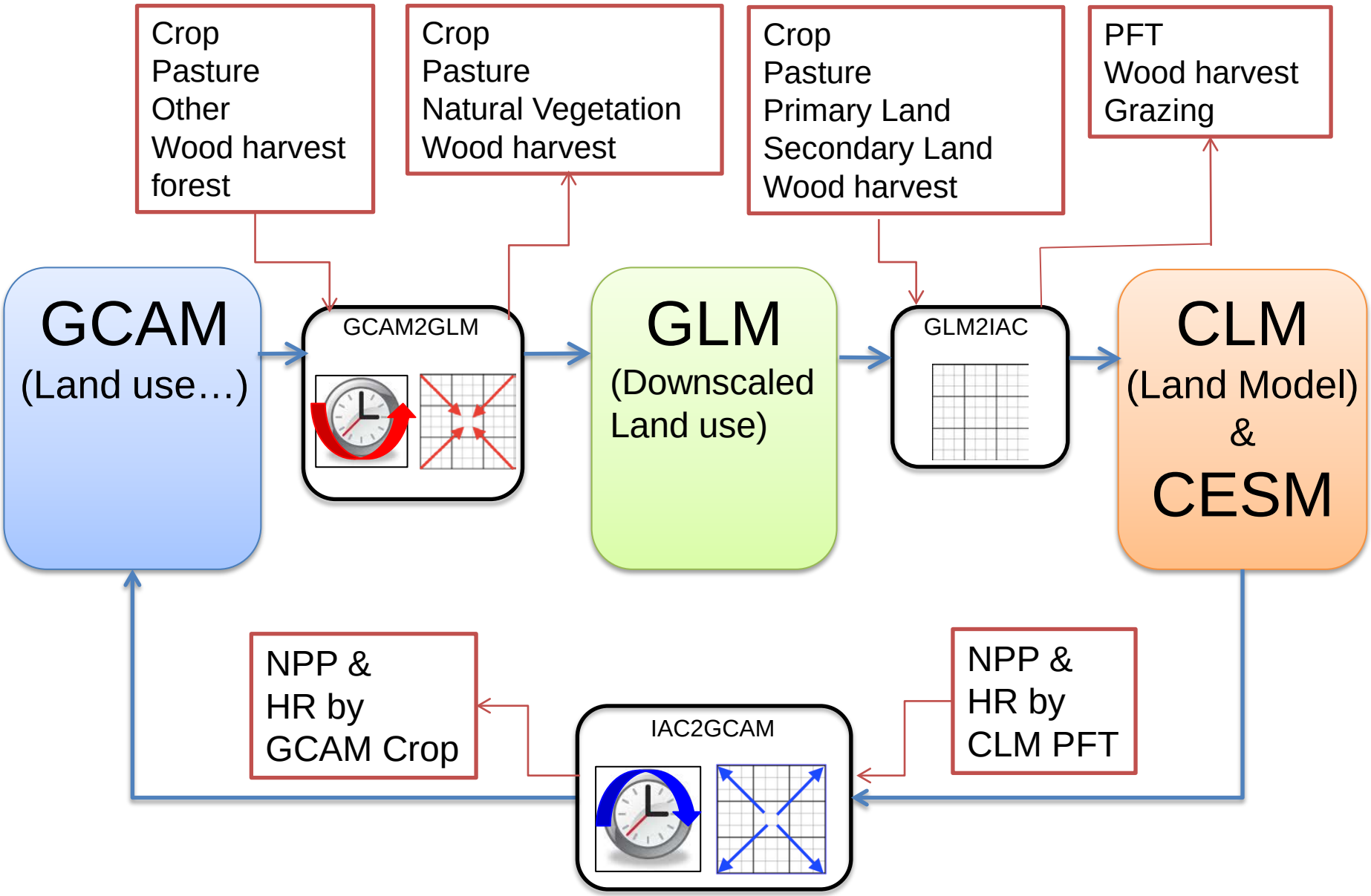
- iESM code is written.
- iESM code is running at multiple DOE computing centers and at JGCRI.
- Validation against conventional uncoupled RCP integrations is mostly complete.

The iESM Coupling Diagram



Coupler	Input	Output	Status
1	**IAM**	**Downscaling**	**Running**
2	**Downscaling**	**Land Model**	**Running**
3	**Land Model**	**IAM**	**Running**
4	*IAM*	*Land Model*	*Coded*
5	*Downscaling*	*IAM*	*Coded*
6	*Land Model*	*Downscaling*	*Coded*

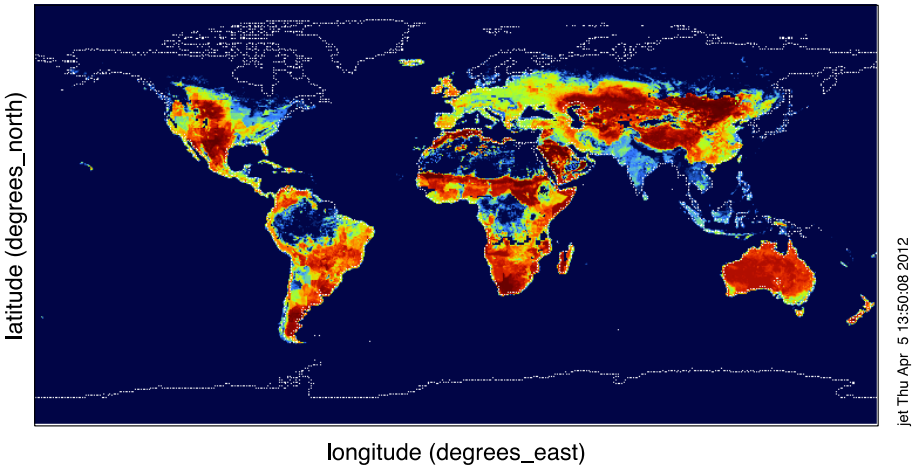
The iESM information exchange and feedbacks



Emulation of pasture distributions using iESM

Coupled iESM

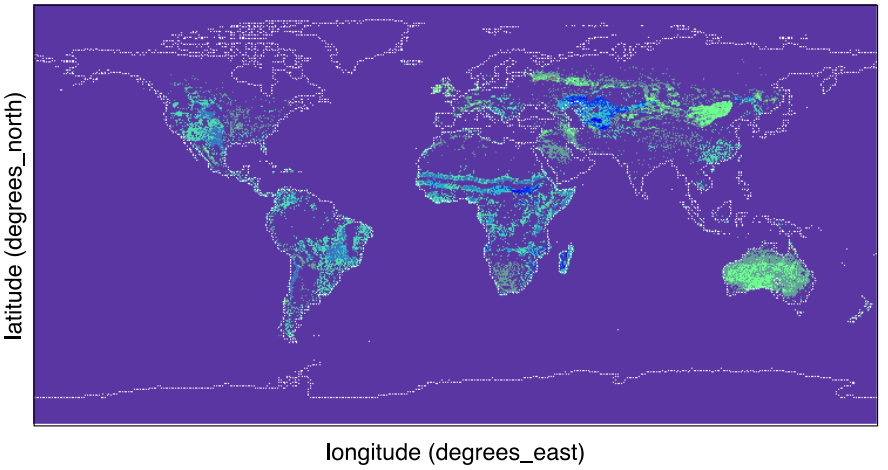
gpast



Range of gpast: 0 to 1 (null)
Range of longitude: -179.75 to 179.75 degrees_east
Range of latitude: -89.75 to 89.75 degrees_north
Current time: 0 day as %Y%m%d.%f
File glm_state_2020.orig.nc

Coupled – "Sneaker Net" iESM

gpast



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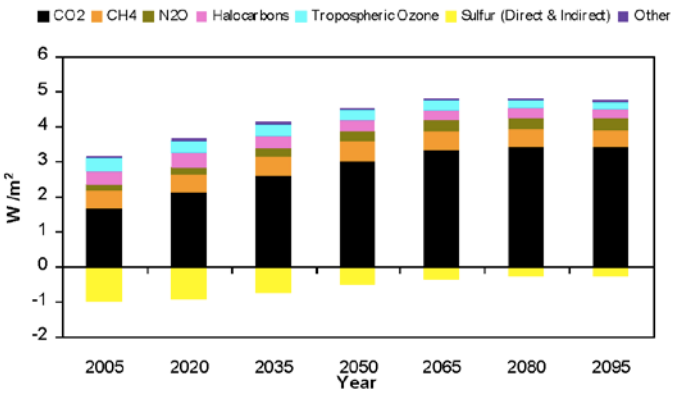
Range of latitude: -89.75 to 89.75 degrees_north
Current time: 0 day as %Y%m%d.%f
File glm_state_diff_2020.nc

Status:

- We can reproduce the distributions of pasture to 1 part in 100,000.

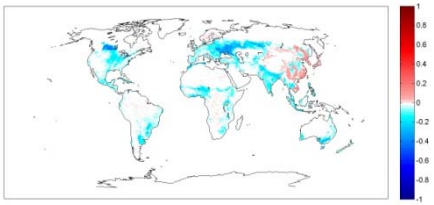
iESM experiment 0:
Bioenergy scenarios with one-way coupling

- *Information flow:* IA to downscaling to Earth System Model
- *Sanity check:* Does the one-way pass of information replicate the original RCP4.5 simulation done in CMIP5?
- *Policy sensitivity:* For different policy but same concentration pathway, does the evolution of the climate system differ?
- *Experiment 0:* Contrast two pathways:
  - RCP4.5 – carbon price on all carbon (UCT)
  - RCP4.5 – carbon price ONLY on fossil carbon (FFICT)



Janetos, Jones, et al, 2012
Jones et al, 2012

Experiment 0 work flow



Historical LULCC information

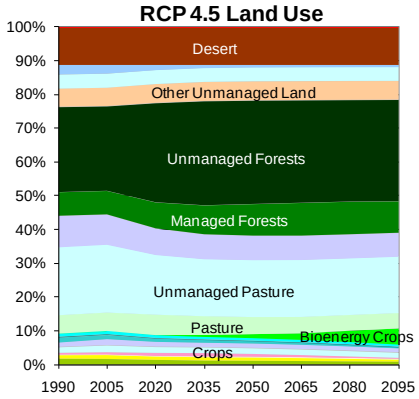
GLM

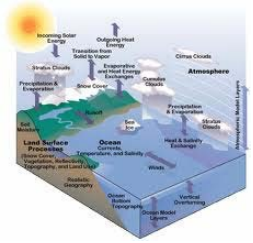
Transition matrix

CLM translator

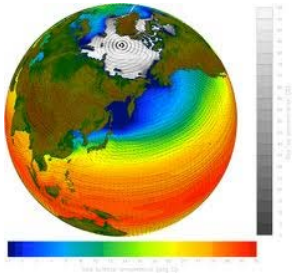
dynpft file

GCAM scenario LULCC information





CLM / CCSM



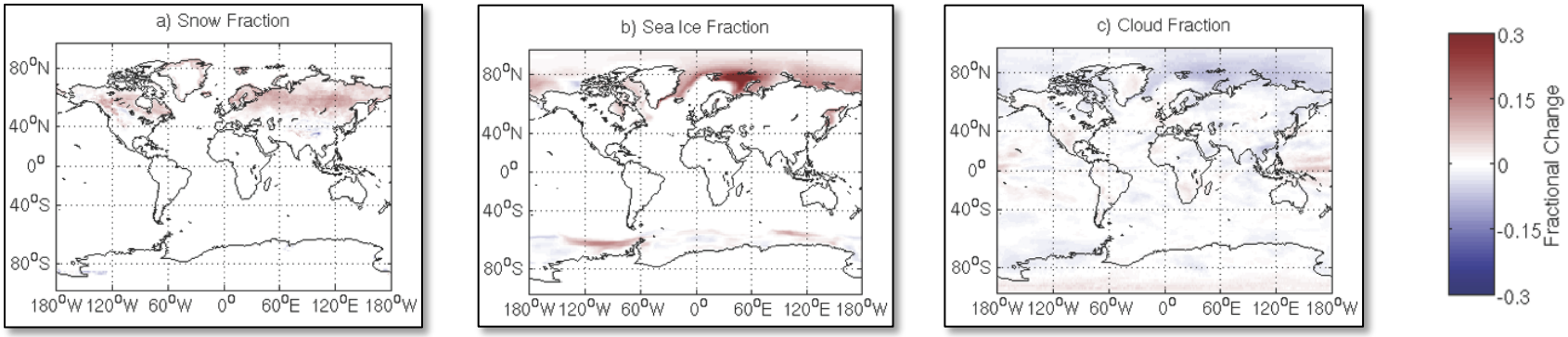
Climate change

Carbon stocks

Carbon fluxes and [CO_2]

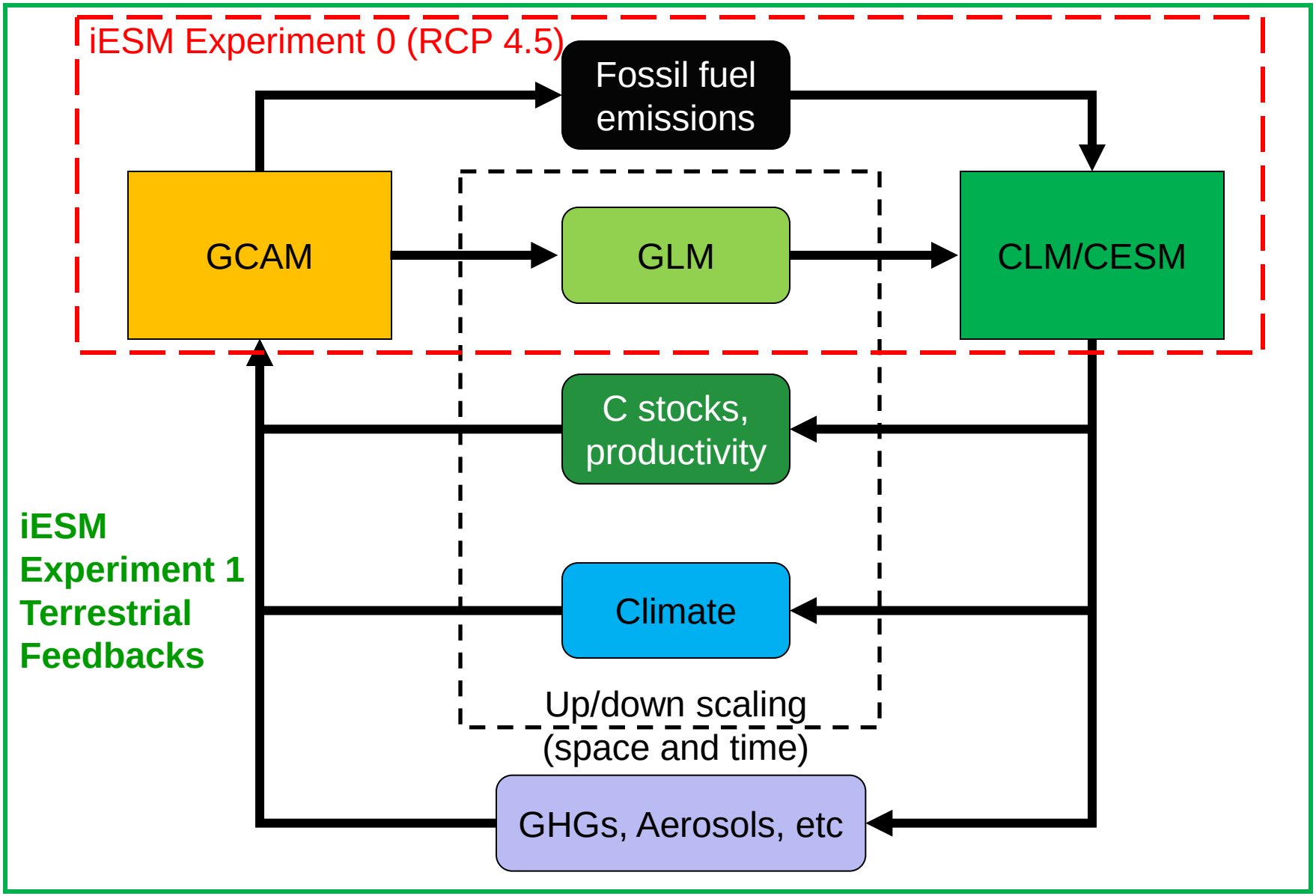
Major findings of experiment 0

- The two scenarios have the **same radiative forcing from GHGs.**
- Yet they are **substantially different** in the evolution of the climate: the equivalent of 1.5 W/m^2, or about 0.5°C global annual average.
- But it is also true that **the actual policy chosen matters** – in this case the very large land-use change associated with FFICT.
- **Radiative forcing by GHGs is not a complete metric** for evaluating the evolution of the climate system
- Next steps: Extend iESM to rest of forcings in RCP protocol.



Jones et al, 2012

iESM multi-phase coupling strategy



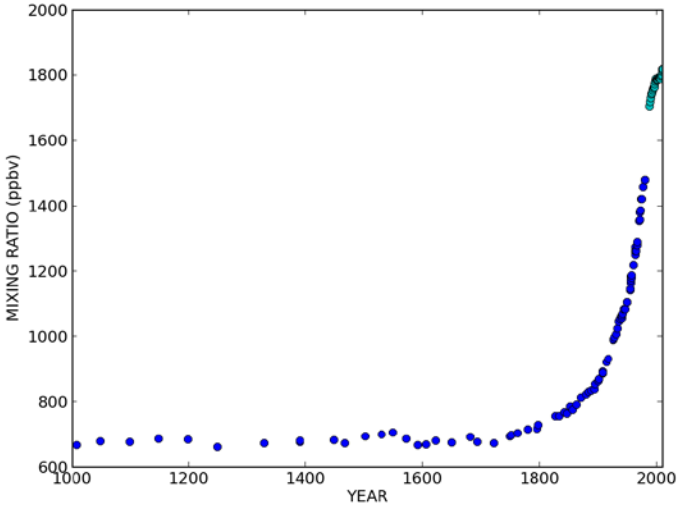
Experiment 1.2 underway

- Experiment includes feedbacks on land productivity from CLM to GCAM.
- These feedbacks alter agriculturally-driven land allocation in GCAM.
- This experiment has illuminated many issues with the RCP conceptual framework and implementation in AR5.
- However, the team is still working to reconcile:
  - Three different representations of plants and crops in GCAM, GLM, and CLM.
  - Three different treatments of the carbon cycle in the same models.
- The team is confident these issues can be resolved.

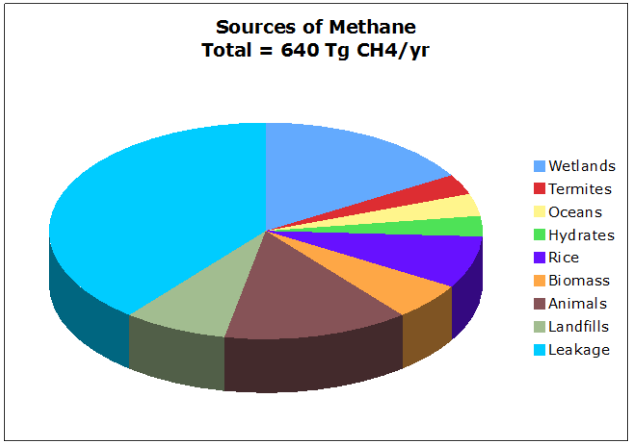
Atmospheric Methane

- Atmospheric concentrations up by 2.5X.
  - Preindustrial concentration = 700 ppb.
  - Current concentration = 1794 ppb.

- Since 1750, CH_4 contributed 0.5 W/m^2 to direct radiative forcing of climate.
- CH_4 is most abundant GHG after H_2O & CO_2.
- Methane is 30X effective as a GHG than CO_2.
- Methane is the most abundant reactive trace gas in the troposphere.

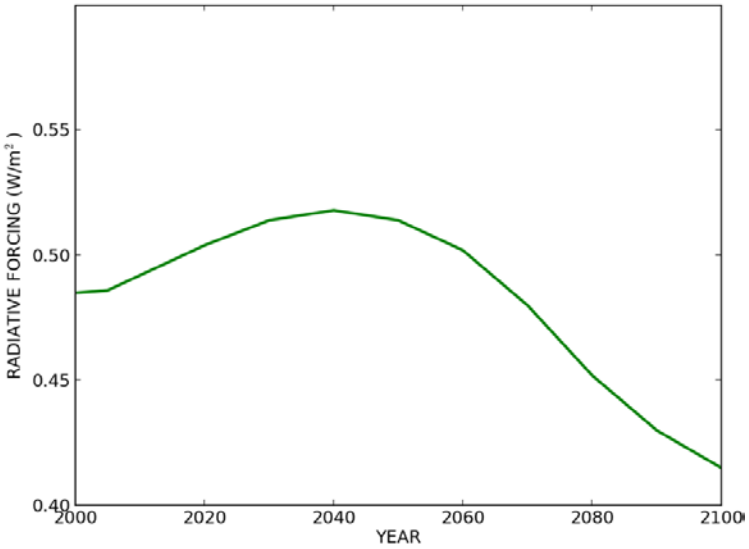


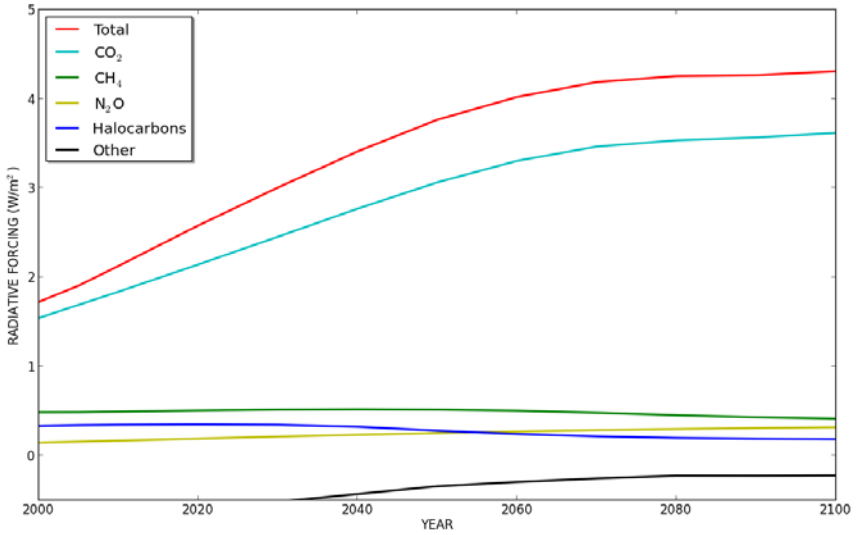
Methane budgets for the current climate.



Source: JGCRI

Methane emissions and forcing scenarios



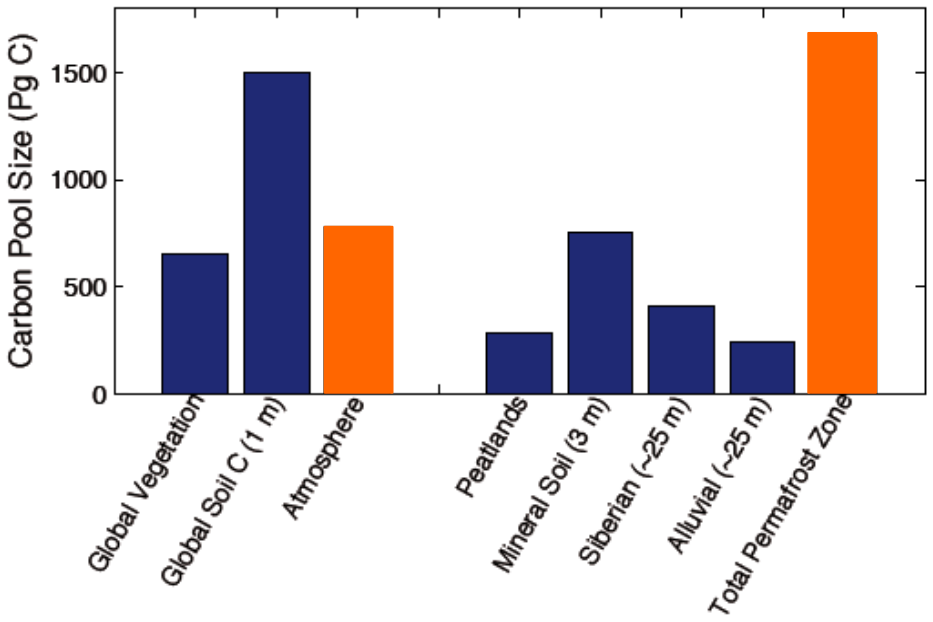


- GCAM is basis of Representative Concentration Pathway (RCP) 4.5, with 4.5 W/m^2 forcing by 2100.
- Anthropogenic emissions and forcing peak mid-century, then decline.
- **Will higher natural fluxes counteract lower anthropogenic emissions?**

Source: JGCRI

Methane Biogeochemical Models for Land

- CH_4 emissions are hardest to predict of “big 3” LLGHGs:
  - Net emissions = small differences between large gross fluxes
  - Net emissions, have non-linear dependence on system properties and state variables (e.g., moisture, temperature)

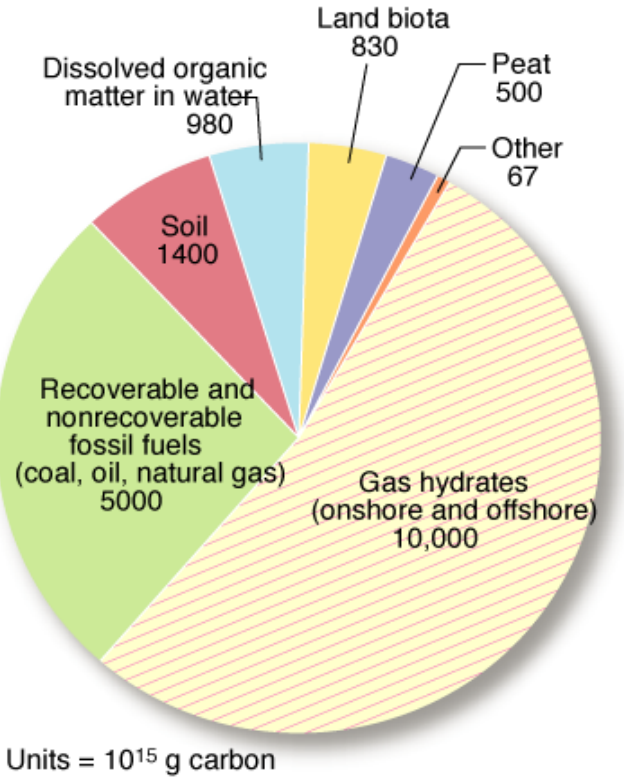


Global

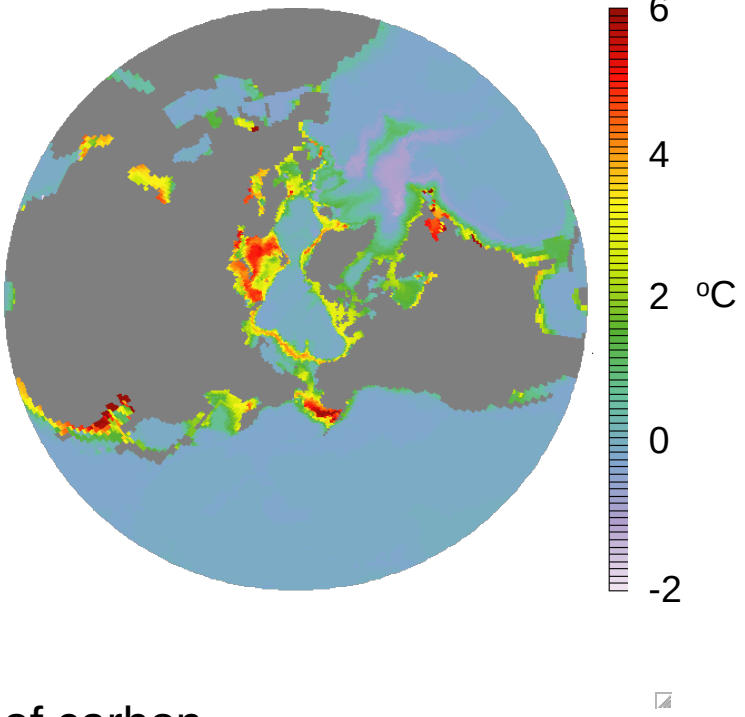
Permafrost Zone

[Jobaggy 2000, Field et al. 2007, Zimov et al. 2006, Tarnocai et al. 2009, Schuur et al. 2008]

Ocean hydrates: A positive feedback?



Change in ocean bottom temperature during the 21st century



- Oceanic hydrates are a significant reservoir of carbon.
- Could warmer oceans melt the hydrates?
- Could this appreciably enhance the Earth's greenhouse effect?

Modeling Natural and Anthropogenic CH_4

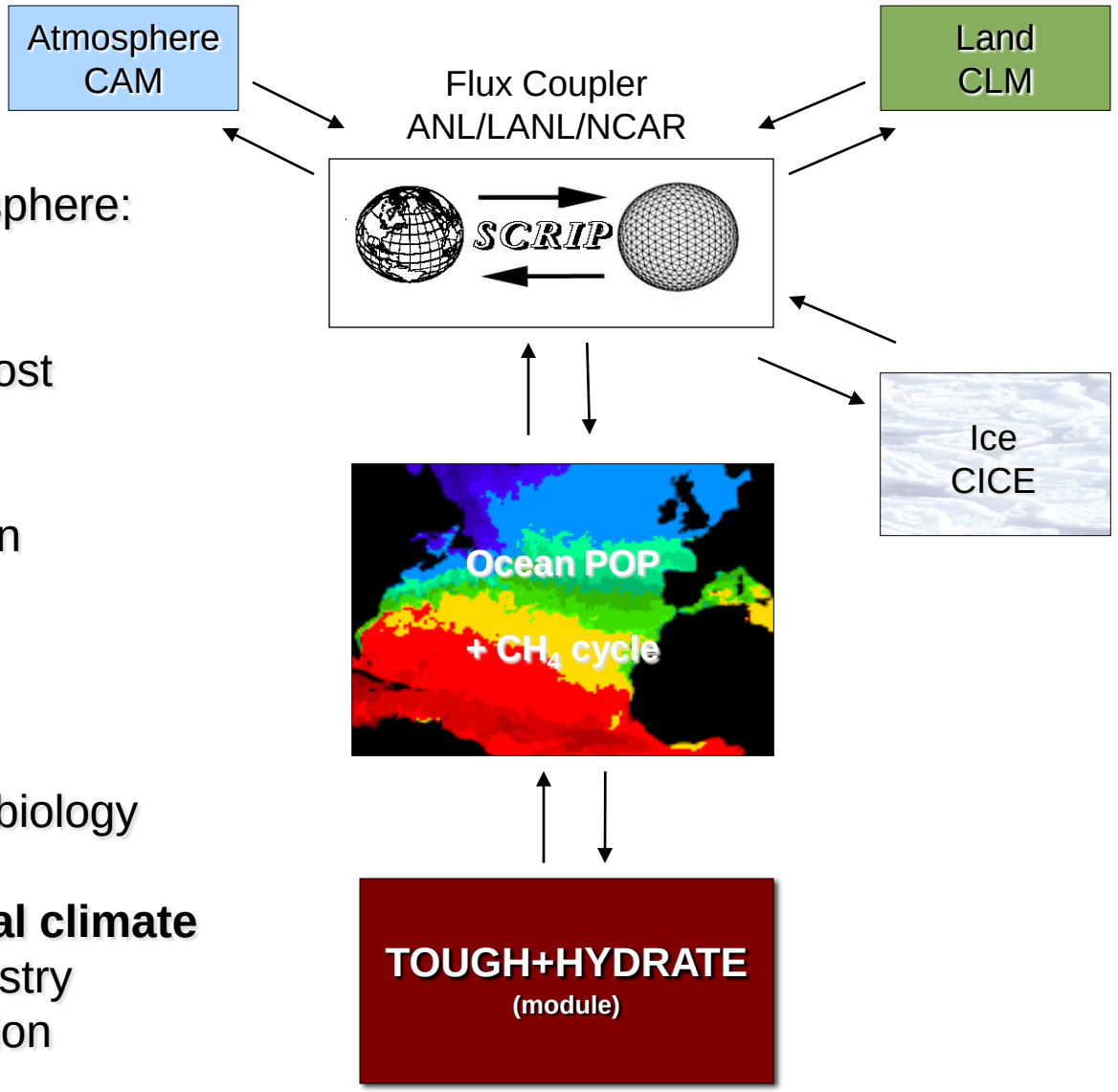
Couple emissions -> atmosphere:

1) **Land surface**
   - Peat and Permafrost

2) **Sub-seafloor**
   - Hydrate dissociation
   - Fluid transport

3) **Ocean water column**
   - Methane transport
   - Geochemistry and biology

4) **Atmosphere and global climate**
   - Atmospheric chemistry
   - Atmospheric radiation



Opportunities afforded by iESM

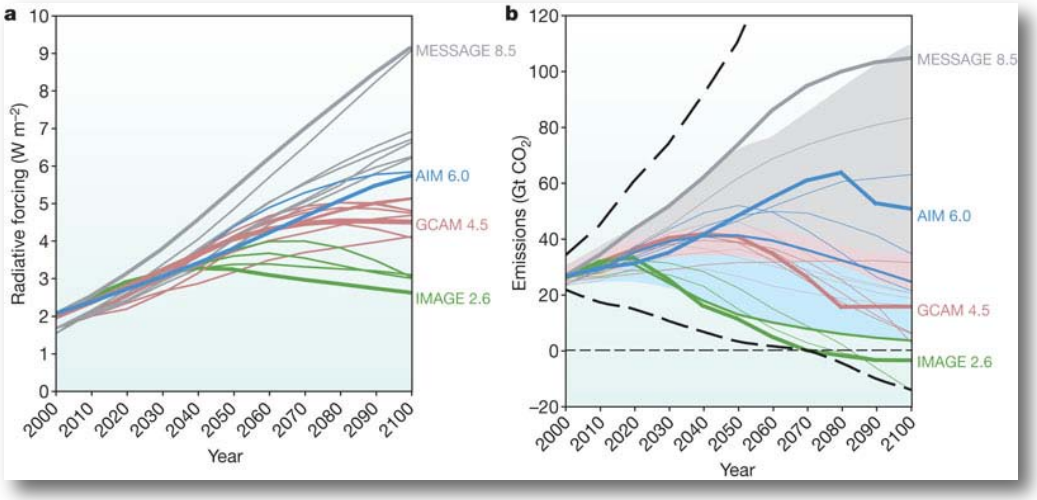
- **iESM provides the capability for immediate tests** of future scenarios as these scenarios are developed.
- It enables quantification of impacts of feedbacks ***that are yet to be treated under current protocols and yet could be significant on mitigation timescales.***
- **Effects of CH_4, aerosols, and short-lived agents on energy markets** can be readily explored in this framework.
- Modeling community has made major strides in developing prognostic representations of CH_4 (N_2O next).
- Net effects of higher natural methane emissions and lower anthropogenic emissions remains to be determined.

Next steps for the integrated Earth System Model

- Extensions underway to handle forcings besides LULCC:
  full RCP complement of LLGHGs, aerosols, etc.

- **Proof-of-concept experiments of extensibility to other IAMs**
  that conform to the RCP “handshake” protocol.

- Friendly-use release to CESM Societal Dimensions Working Group and **global climate community**.

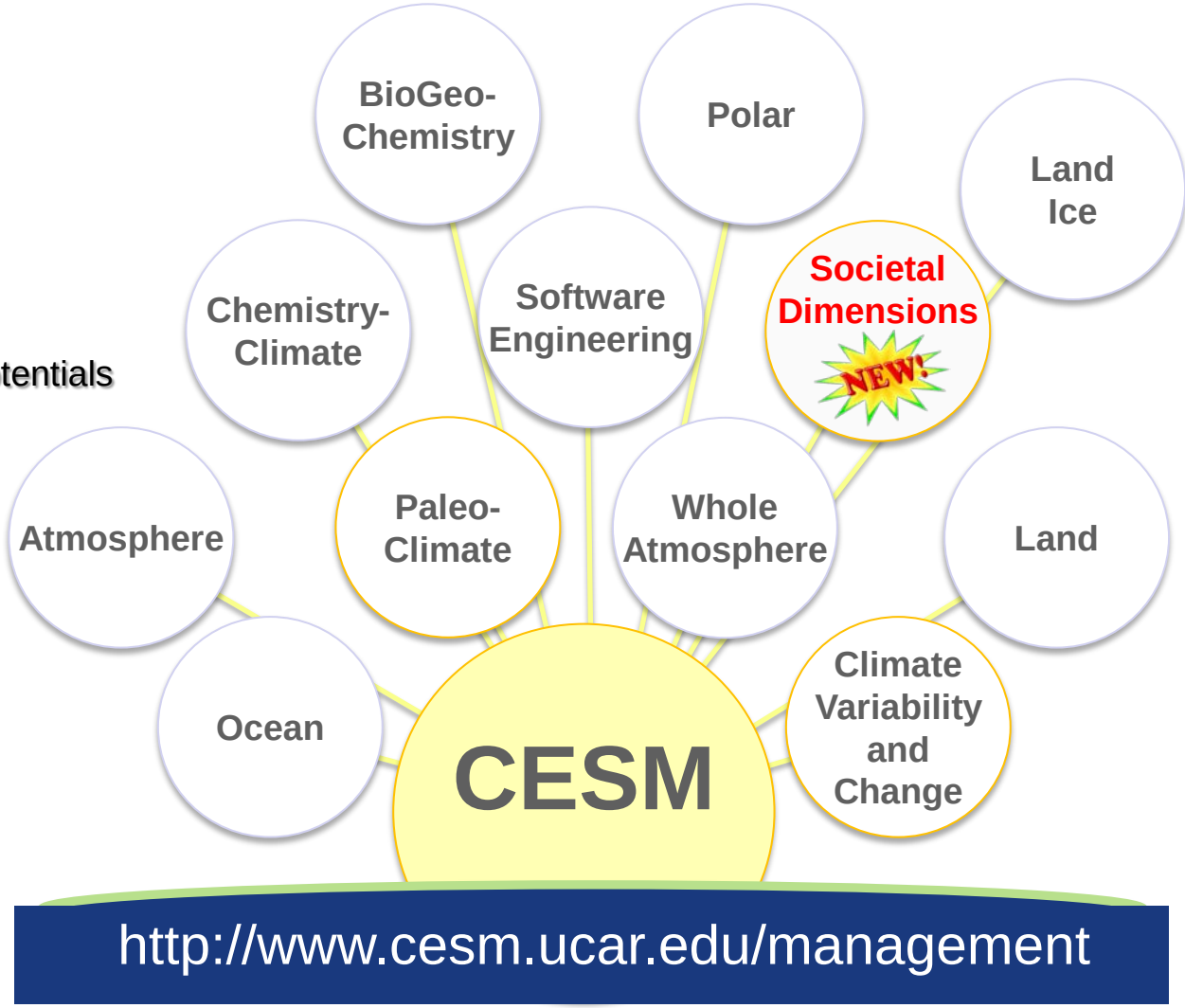


Moss et al, 2010

Relation of iESM to CESM's new Societal Dimensions Working Group (SDWG)

SDWG Areas of Interest:

- Land use
- Agriculture (AgMIP)
- Urban areas and energy use
- Water in IAMs
- Forestry management
- Assessing renewable energy potentials
- Air quality, climate, and impacts



CESM is primarily sponsored by the National Science Foundation and the Department of Energy

http://www.cesm.ucar.edu/management

Plans for public release of iESM

- **Next milestone: "Friendly" release to SDWG:**
  - Code (for inspection)
  - User documentation and technical manuals:
    - ✓ CESM and GCAM technical documentation
    - ✓ GLM draft technical description
    - ✓ iESM draft online user guide and manual
  - Peer-reviewed papers describing iESM
    - ✓ CESM, GCAM, and GLM literature well established.
    - ✓ Experiment 0 paper in press at the *Journal of Climate*
    - ✓ iESM conceptual overview submitted to *PNAS.*
  - **Input and output from the iESM**
- **Proposed timeline of public release:**
  - 1st step: "Friendly release to SDWG"
  - 2nd step: Review by the SDWG
  - 3rd step: If OK'ed by SDWG, review by CESM SSC
  - 4th step: If OK'ed by SSC, public release of iESM as part of CESM
- **iESM framework should admit other IAMs (tests underway)**

Topics for consideration by the SDWG

- **Exchange of experiences using ESMs for any societally relevant analysis**

- **Provision of climate model simulations for IAM community activities**
  - Simulations tailored for Latin America Modeling Project?
  - Simulations for SSP reference scenarios?

- **Coordinated research activities involving CESM**
  - Sensitivity of climate to regional land use change, and vice-versa

- **Provision of code for linking models (e.g., iESM)**

Discussion

- **Capability to run all RCPs with output from IAMs participating in RCP process substituted for GCAM?**
  - ✓ *Testing underway using IMAGE.*
- **Capacity to use other RCP models interactively in iESM?**
- **Extensibility of iESM framework to link other IAMS and ESMs?**
- **Potential for iESM to advance community interactions?**

Human Dimensions

Clean Energy

Water Supplies