Update on plans for global CESM CH_4 simulations

William D. Collins

Lawrence Berkeley Lab and UC Berkeley

Philip Cameron-Smith

Lawrence Livermore National Laboratory

And the IMPACTS Team

(Investigation of the Magnitudes and Probabilities of Abrupt Climate TransitionS)

LLNL-PRES-535519

Core requirements for Coupled CH_4 Simulations

The IMPACTS project has introduced:

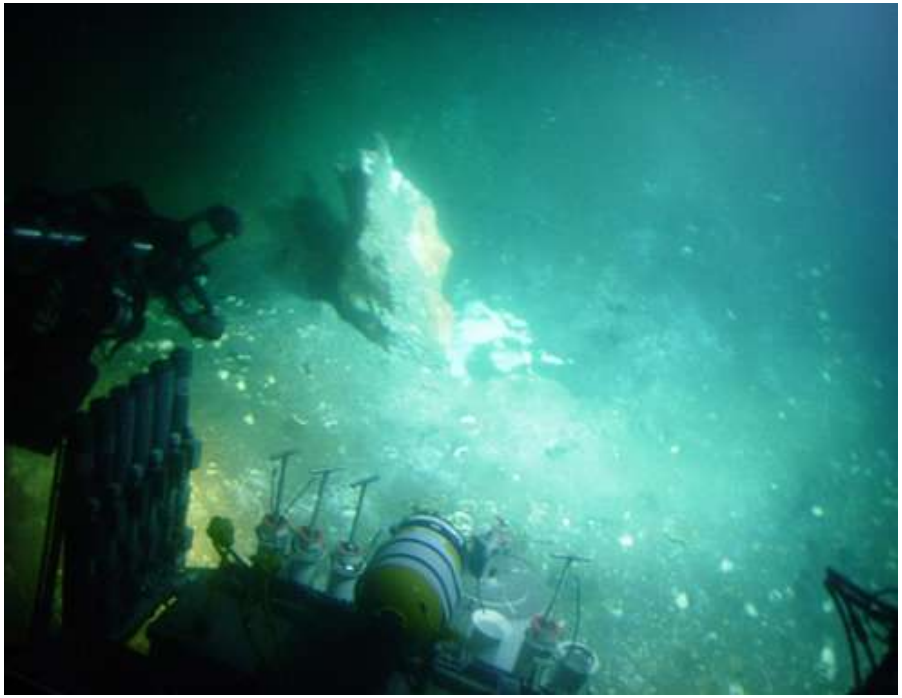
- ✓ Development of oceanic CH_4 cycle
- ✓ Development of a terrestrial CH_4 cycle
- ✓ Capability for CH_4 radiative forcing of climate

Also adapted existing capabilities:

- Fast chemistry designed for CH_4 emissions
- TOUGH+HYDRATE ocean sediment model

These capabilities = foundation for coupled runs.

The fate of oceanic clathrates and atmospheric CH_4



Dissociation of Methane Clathrates: Basin Scales

Objectives:

- Establish the sensitivity of subsea methane clathrates to climate change
- Estimate the total quantity of CH_4 that could be released into the water column

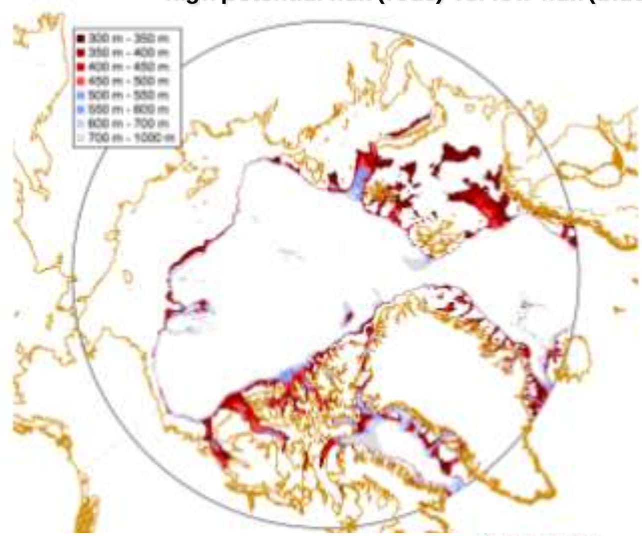
Implementation:

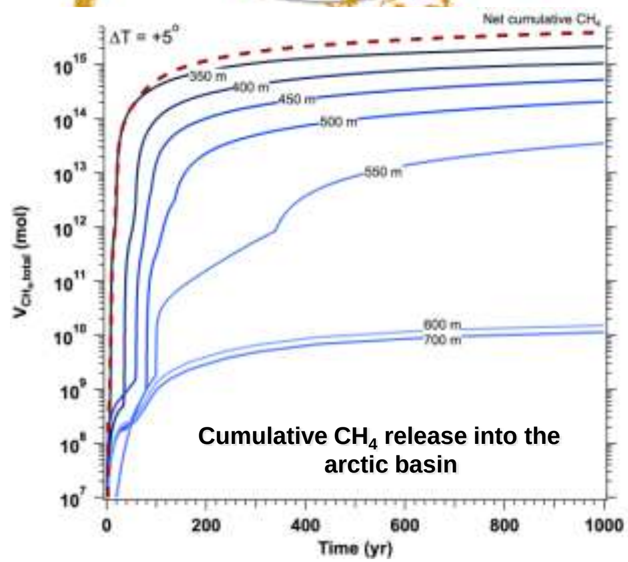
- Use TOUGH+HYDRATE to model coupled flow, transport, phase changes, and heat flow in sediments
- Apply temperature changes at the seafloor
- Model dissociation and the aqueous and gaseous CH_4 flux for each depth, location, and ΔT
- Integrate across ocean basins to estimate maximum potential release

Results:

- CH_4 release a strong function of depth/T/location
- Fluxes significant on century timescales
- Coupling CH_4 flux to the water column

Depth contours; coloring represents areas of high potential flux (reds) vs. low-flux (blues)





Cumulative CH_4 release into the arctic basin

Chemistry of clathrate CH_4 *in* the Arctic Ocean

Objectives:

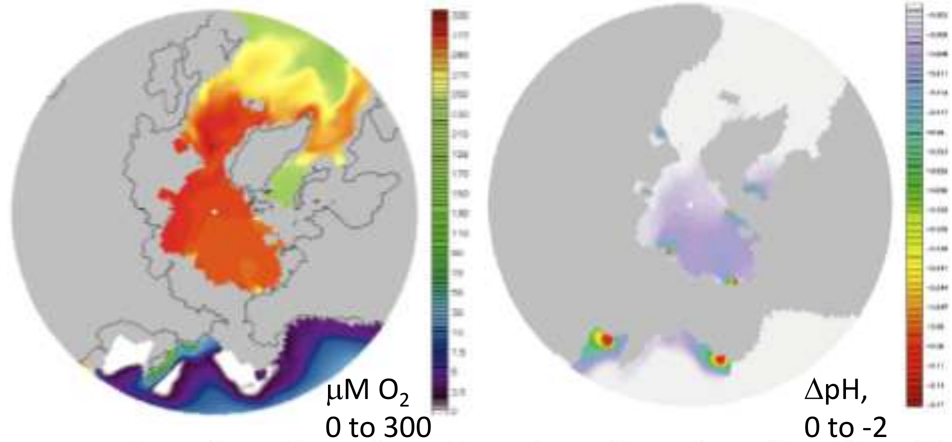
- Assess potential for sea floor hydrate to alter water column geochemistry
- Also compute gas reaching surface

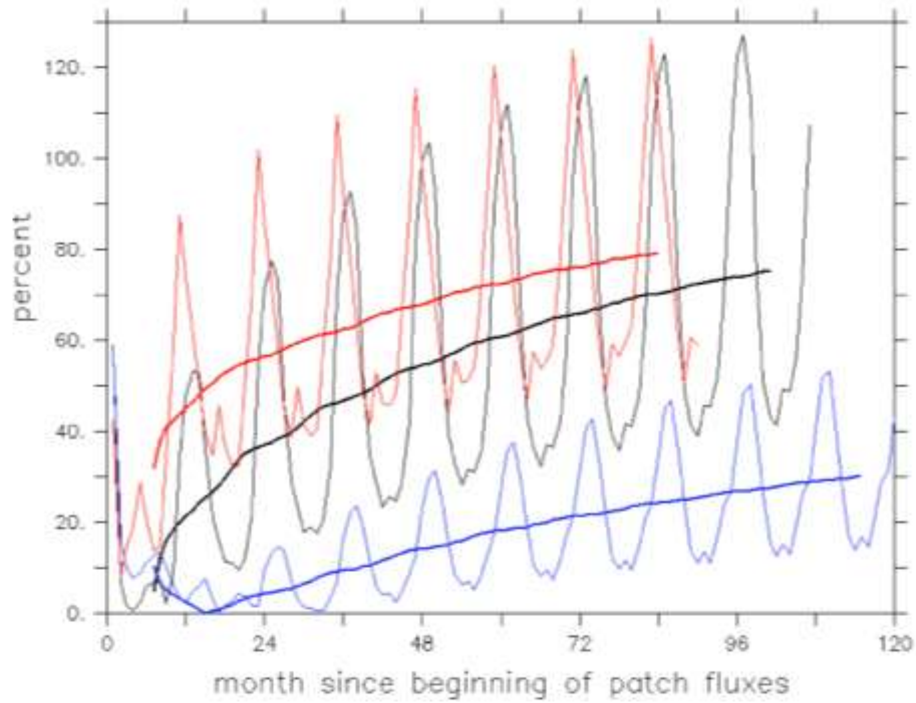
Implementation:

- Background sources are sinking particles, global upward sea bed flow
- Add reactions with O_2, N, Fe, Cu as mediated by marine methanotrophs
- Run natural ocean cycle as background
- LBL patches at 300 meters, bubble rise

Experiments:

- Arctic fate/effects over 30 year runs
- Results: hypoxia, acidification, nutrient depletion and strong rise to interface
- Some cases tens of percent to surface
- See *Elliott et al. GRL 2010, JGR 2011*





Oxygen loss and acidification in POP, fraction to surface for bubble heights 50, 100, 150 meters

Clathrate CH_4 *in* the Arctic Ocean: Uncertainties

Objectives:

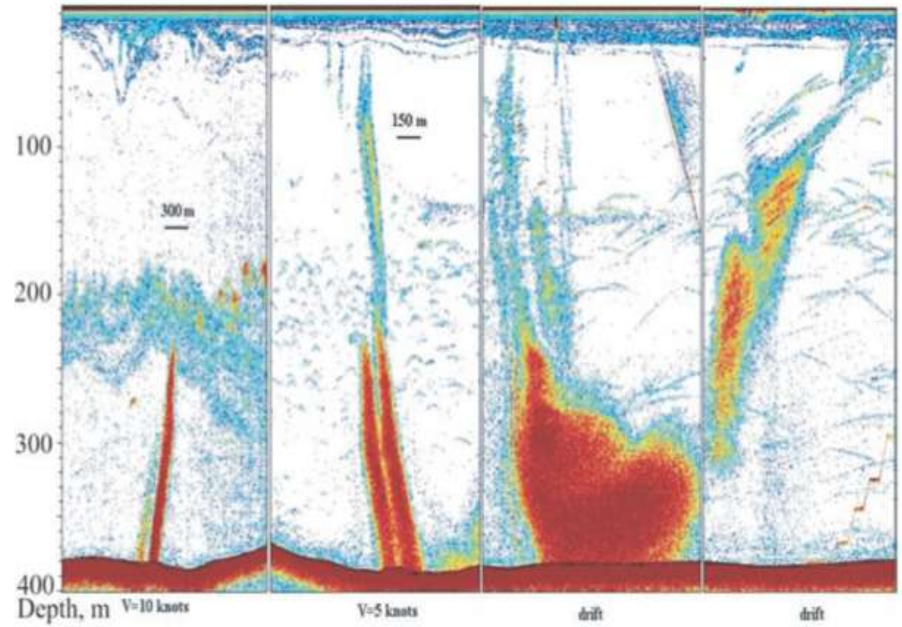
- Preliminary simulations of sea floor release, hypoxia, acidification and nutrient depletion now complete
- See *Elliott et al. GRL 2010, JGR 2011*
- Add physical chemistry of bubble rise, full microbial ecology with trace metals

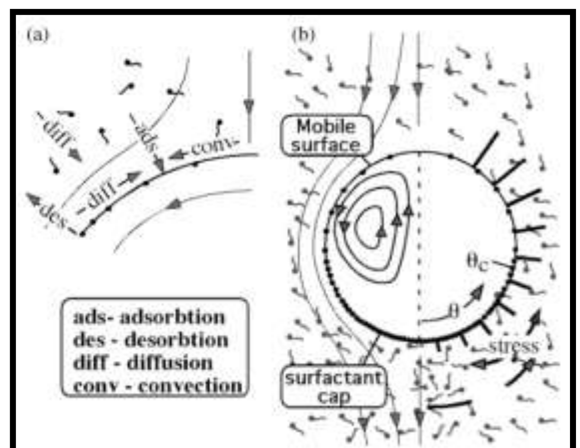
Implementation:

- Parameterize bubble dynamics with organic/surfactant chemistry
- Then nitrate, iron, copper consumption
- Emphasize resource restrictions on methanotrophs at true injection level

Experiments:

- Offline CH_4 vertical rise and dissolution
- Offline nutrient interplay (O_2, N, Fe, Cu)
- Tests in POP, production runs CESM





Methane plumes off Sakhalin (Obzhirov), bubble coating scheme (Leifer), marine methanotrophs

Atmospheric Impact of Methane Clathrate Emissions

Objective:

- Study the impact of methane clathrate emissions on the atmosphere.

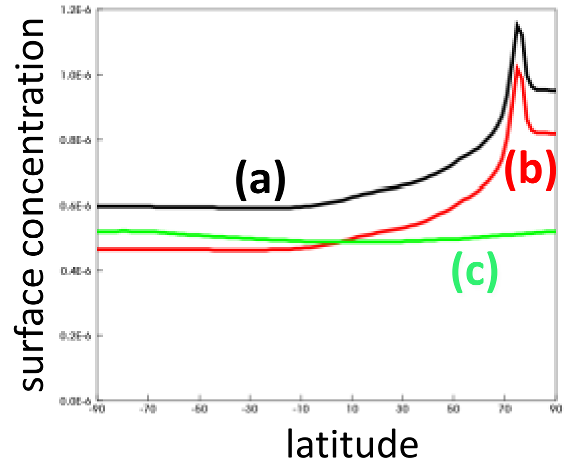
Implementation:

- Implemented Fast Methane Chemistry in CESM1_0_beta14, using CAM4 physics and RRTMG radiation.

Simulation Experiments :

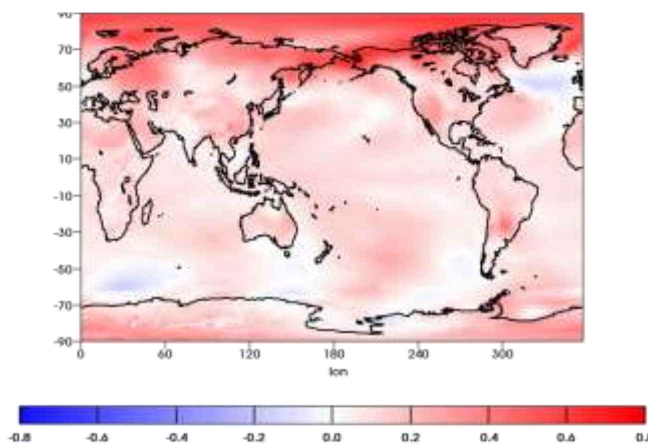
- **Control Case:** CESM, full ocean, fast methane chemistry, 2 degree resolution.
- **Arctic Methane Emission Case:** Simulating Arctic Methane Emission (22% increase),
  - Impacts CH_4, T, rainfall, air-quality.

Methane Increase from Arctic Clathrates



(a) 100 year zonal mean
(b) 20 year zonal mean
(c) 20 year Uniform Emission Case

Change in Surface Air Temperature



100-year difference between Arctic methane emission & control cases

Interaction of high-latitude regions and climate change

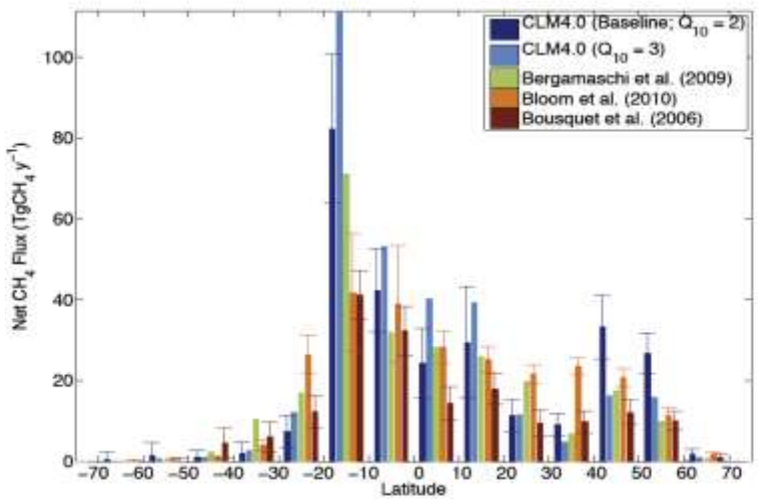
Inclusion of a Terrestrial CH_4 Model into CESM1 (CLM4Me)

Objectives:
- Identify uncertainties
- Predict 21st century CH_4 emissions
- Quantify potential for abrupt feedbacks.

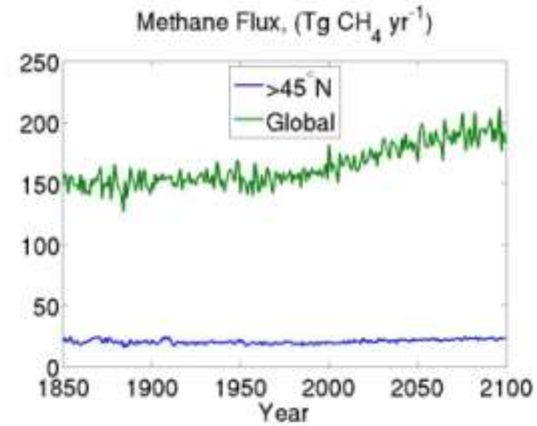
Implementation:
- Vertically resolved biochemical model
- 2 reactions and 3 transport processes
- Implementation designed to integrate with future land model improvements.

Experiments:
- Compared present CH_4 emissions to 15 sites and 3 atmospheric inversions.
- Identified critical uncertain parameters
- Showed declines in high-latitude inundation may limit 21st century increases in emissions
- Developing subgrid peatland ecosystem model

Comparison of CH_4 emissions from CLM4Me and several atmospheric inversions.



RCP 4.5 emissions from vegetated ecosystems without old soil carbon source.



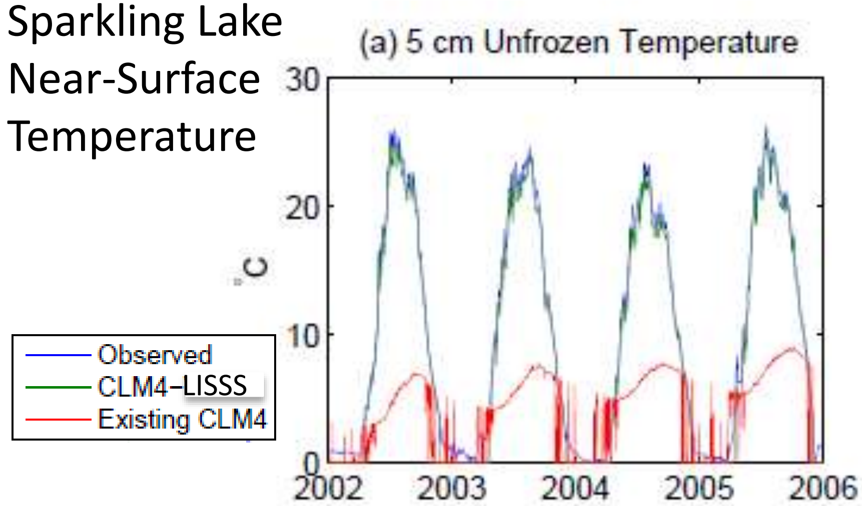
Improved Lake Model in CESM1 (CLM4-LISSS)

Objectives:
- Correct deficiencies in CLM4 lake model
- Integrate processes required for modeling high-latitude shallow lakes.
- Determine atmospheric response to altered Boreal lake distribution

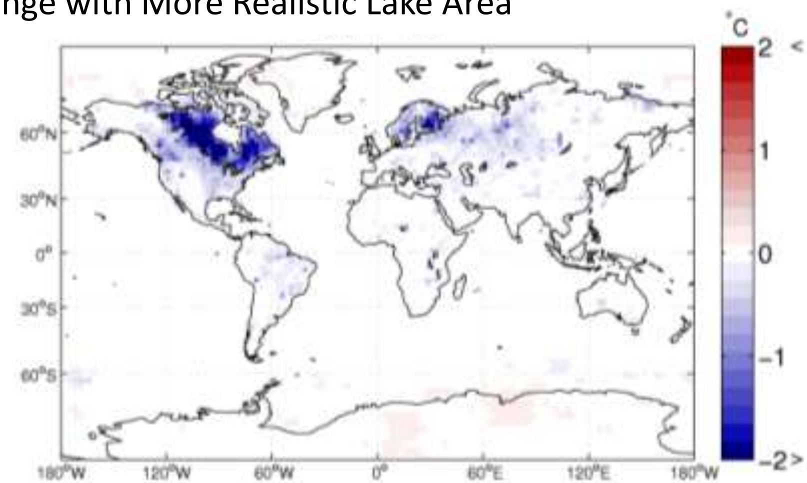
Implementation:
- Extended the Hostetler parameterization
- Included ice, snow, and sediment

Experiments:
- Evaluated predictions at 13 lakes
- Tested regional surface flux sensitivity to 14 processes and parameters
- Three CLM4 offline and CCSM4 slab-ocean experiments with altered lake area
- Idealized aqua-planet experiments explored extra-tropical terrestrial surface forcing
- Will predict 21st century thaw under thermokarst lakes

Sparkling Lake Near-Surface Temperature



Change in JJA Diurnal Surface Air Temperature Range with More Realistic Lake Area



Belowground Carbon Processes

Objectives:

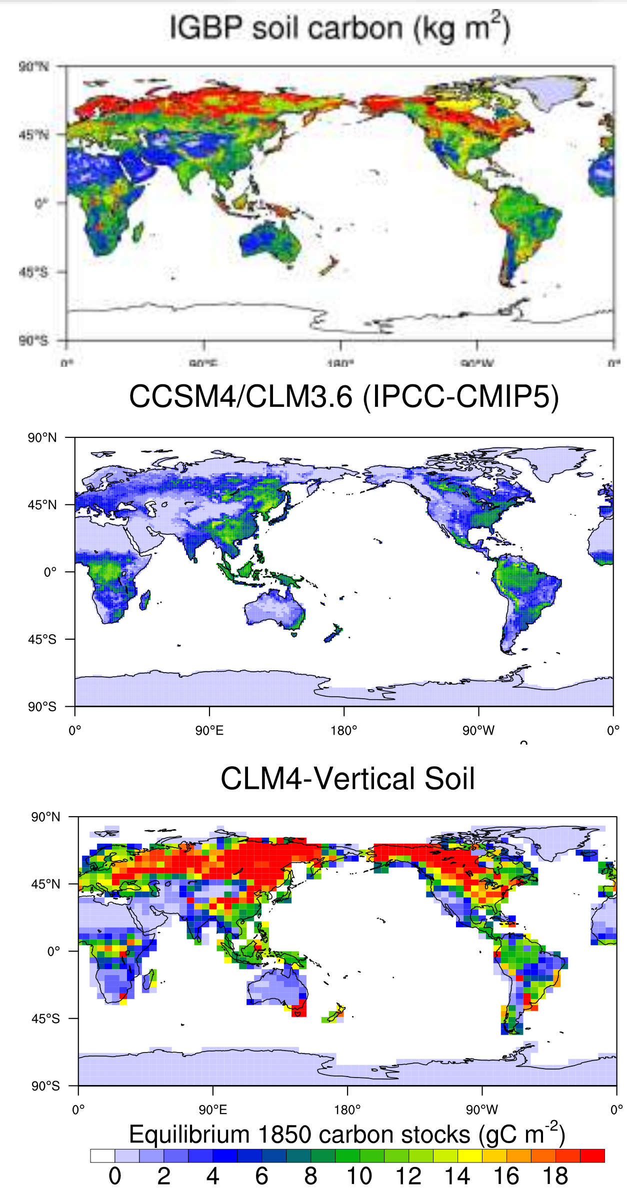
- Represent processes responsible for growth and loss of permafrost C, which is a large (>1000 Pg) and vulnerable fraction of the terrestrial C pool.

Implementation:

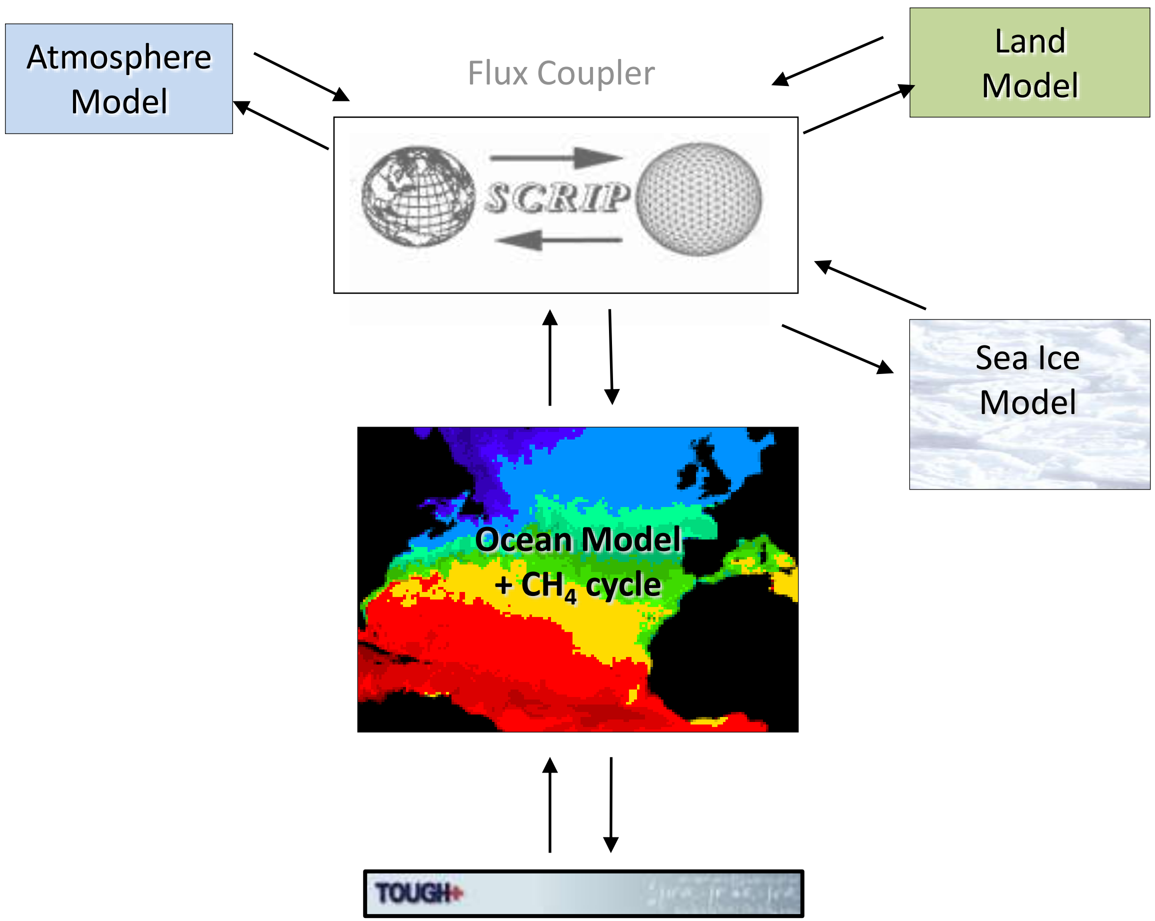
- Developed vertically-resolved belowground biogeochemistry, mixing.
- Improved SOM dynamics, growth of Permafrost C pools
- Improved N cycle at high latitudes leads to better productivity

Experiments and Next Steps:

- Equilibrium experiments, sensitivity to parameters and model structure
- Next Steps: Future scenarios; Coupling between soil and wetland biogeochemistry; coupled soil BGC and soil physics



Next: Simulate effects of hydrates on climate



Progress toward CH_4 Coupled Runs

- **Introduction of a terrestrial methane cycle into CESM1, for release in 2012.**
- **Simulation of methane clathrate dissociation in ocean sediment (TOUGH+).**
- **Creation of a process-based and field-tested oceanic methane cycle for CESM1.**
- **Simulation of atmospheric methane chemistry in CESM1.**
- **Creation of a chemistry-capable version of CAM5, by JF Lamarque.**
- **Introduction of new coupler with flexible chemical exchanges, by NCAR.**
- **Plan for initiation of coupled experiments during 2012.**