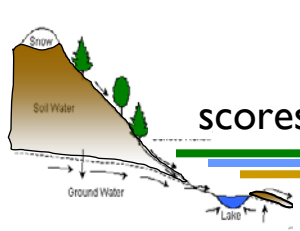




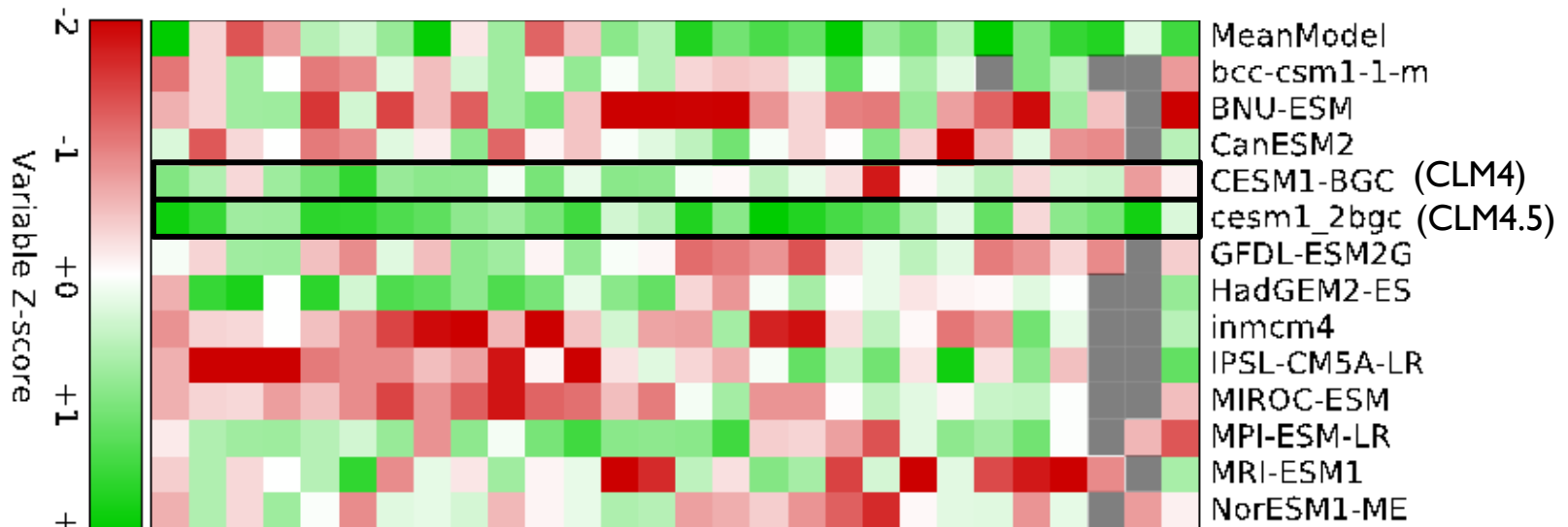
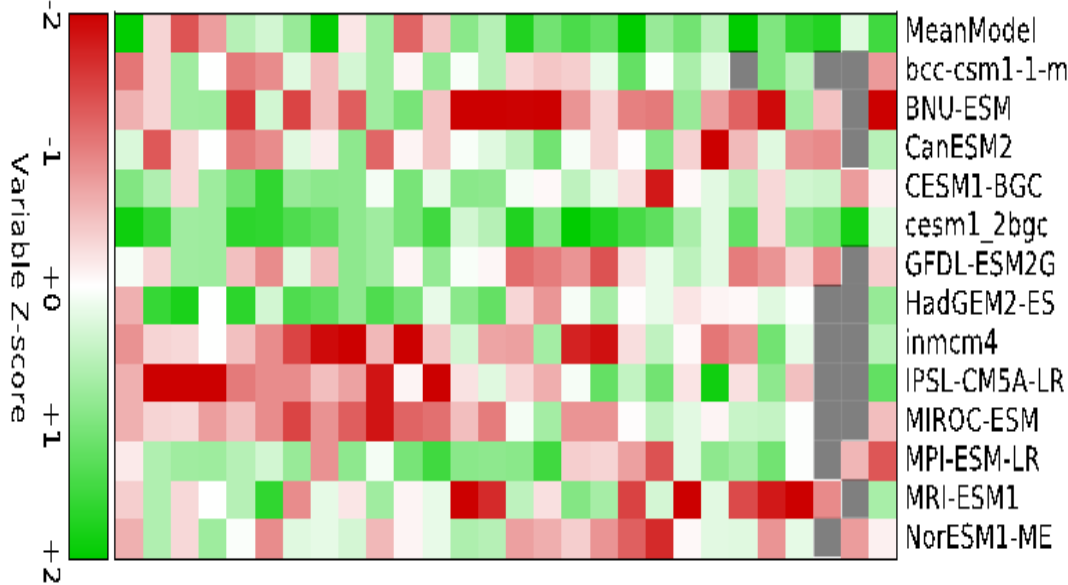
# Update on CLM5 progress

David Lawrence and the Land Model Working Group



# International LAnd Model Benchmarking (ILAMB) package

scores for RMSE, interannual variability, pattern correlation, variable-to-variable comparisons, +



Green: model performs better than average model

Red: model performs worse than average model



# Development targets for CLM5

- Land cover and land use change

- Global / transient crop capability with irrigation, fertilization, and cultivation of crops (land management) as default for historical and projection runs

- More realistic land cover change impact on water and energy fluxes

- Carbon and nutrient cycles

- Improved 20<sup>th</sup>C land carbon stocks and carbon stock trends

- Address ecological stones thrown at CLM4 (plants don't get N for free, leaf N isn't static, photosynthetic capacity should respond to environment, stomatal conductance not linked to N-limitation)

- Hydrology

- Hydrology representation closer to state-of-art hydrology understanding

- Increase utility for use in water resource and water-carbon interaction research

- Land-atmosphere chemistry coupling

- Enhanced interactions, fire emissions, ozone damage to plants, CH<sub>4</sub> emissions

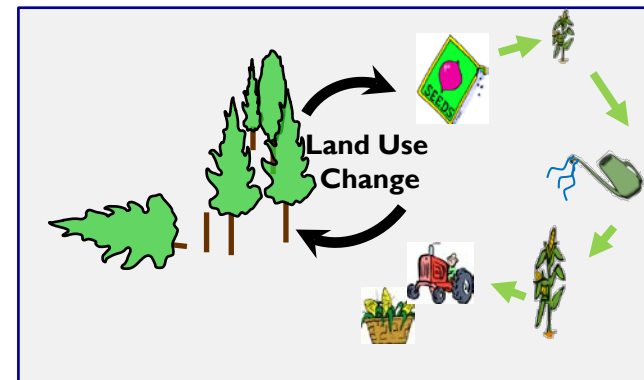
- Ecosystem Demography model – future biogeochemical core of CLM

- Functional CLM5(ED) for use in studies of biome boundaries, trait filtering, etc

- CESM2 coupled runs with CLM(ED) within CMIP6 timeframe; will not be CESM2 default configuration

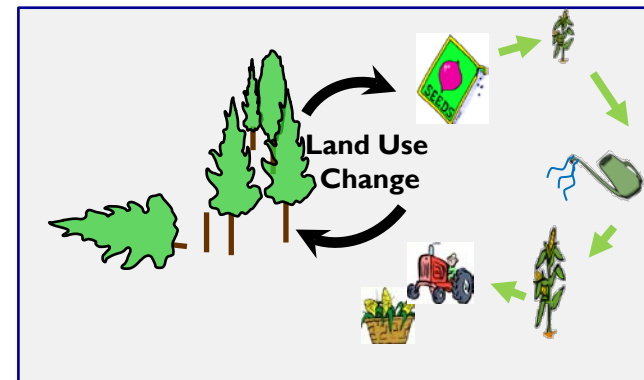
# What's new for CLM5

- Crops:** global crop model with transient irrig. and fertilization (8 crop types), grain prod. pool
- Hydrology:** dry surf. layer, var. soil depth w/ deeper (8.5m) max soil, revised GW, canopy interc
- Snow:** canopy snow updates, wind effects, 'firn' model (12 layers, max 10m SWE)
- Rivers:** Model for Scale-Adaptive River Transport (hillslope → tributary → main channel)
- Nitrogen:** flexible leaf C:N ratio, leaf N optimization, C cost for N (FUN)
- Carbon:** carbon allocation revised, deep soil decomposability increased
- Fire:** updates, trace gas and aerosol emissions
- Vegetation:** Ecosystem Demography, plant hydraulics, prognostic roots, ozone damage, stress decid phenology trigger
- Land cover/use:** dynamic landunits, revised PFT-distribution, wood harvest by mass
- Isotopes:** carbon and water isotope enabled

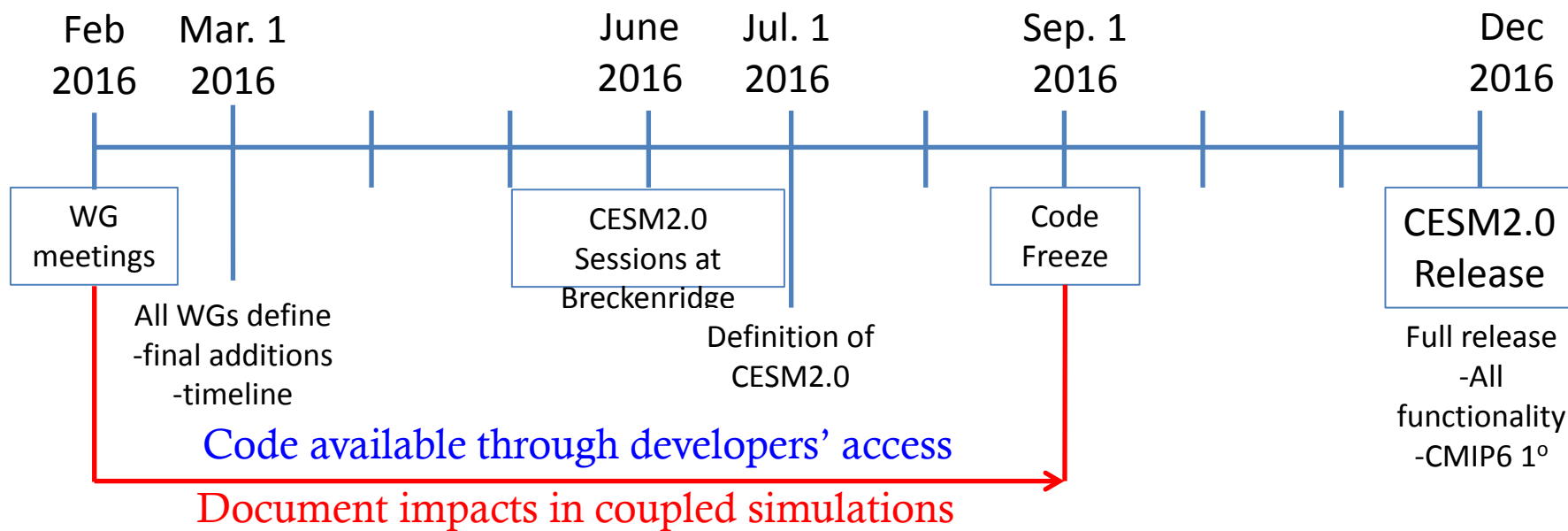


# What's new for CLM5

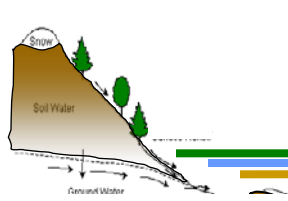
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- Isotopes: carbon and water isotope enabled



# Proposed revised timeline



Pending approval by the SSC



# To do list: Scientific development

- Continue to 'tamp down' new N-cycle
- Adjust params / parameterizations to try to resolve problems with simulations

Teamwork.com

<input type="checkbox"/>	You + 3 others	Low productivity bias in Arctic tundra <a href="#">more...</a>	2	👁
<input type="checkbox"/>	rosie f. + 4 ot...	Low LAI in central Asia boreal forest <a href="#">more...</a>	1	👁
<input type="checkbox"/>	rosie f.	Excessive fire in sub tropics <a href="#">more...</a>	1	👁
<input type="checkbox"/>	rosie f. + 2 ot...	LAI and GPP growth in offline and coupled runs is much larger than in CLM4.5 or CLM4 <a href="#">more...</a>	5	👁
<input type="checkbox"/>	rosie f. + 5 ot...	Occasional max LAI values near 100 in coupled run in dry (?) regions <a href="#">more...</a>		
<input type="checkbox"/>	rosie f. + 2 ot...	Small negative vegetation N <a href="#">more...</a>		
<input type="checkbox"/>	You + 2 others	Check dust emissions with new grass/bare soil distribution		
<input type="checkbox"/>	Bardan G.	Check if C:N ratio calculations for flexible_CN in CNGRsp are correct -- they don't change answers <a href="#">more...</a>	1	👁
<input type="checkbox"/>	Anyone	Negative CH4 emissions?		
<input type="checkbox"/>	Anyone	Rivers: Annual low flow values too high?		

+ Add a task

# To do list: Scientific development

## Update surface dataset tool to ingest CMIP6 land use dataset

### New History

- Hyde 3.2 based
- Landsat F/NF
- Multiple crop types (5)
- Multiple pasture types (2)
- Updated Forest Cover/B
- Updated Wood harvest
- Updated Shifting Cultivation
- Extended time domain (850-2015)

### New Mgt. Layers

#### Agriculture

- Fraction of cropland irrigated
- Fraction of cropland flooded
- Fraction of cropland fertilized
- Fertilizer application rates
- Fraction of cropland tilled
- Fraction of cropland for biofuels

#### Crop rotations

#### Wood Harvest

- Fraction used for industrial products
- Fraction used for commercial biofuels
- Fraction used for fuelwood

### New Future Scenarios

Six futures, SSP-based

### New Resolution

0.25°

### New Transition Matrix

	Pri F	Pri NF	Sec F	Sec NF	C3 Ann	C4 Ann	C3 per	C4 per	C3 N-Fix	Pasture	Rangeland	Urban
Pri F	■											
Pri NF		■										
Sec F			■									
Sec NF				■								
C3 Ann					■							
C4 Ann						■						
C3 Per							■					
C4 Per								■				
C3 N-Fix									■			
Pasture										■	■	
Rangeland											■	■
Urban												■

~ 50x information content of CMIP5!



# To do list: Scientific development Parameter adjustment (tuning)

## Systematic (?) parameter adjustment

- Starting from TRY database estimates for leaf longevity, SLA, leaf C:N target
  - Tuning for what variables

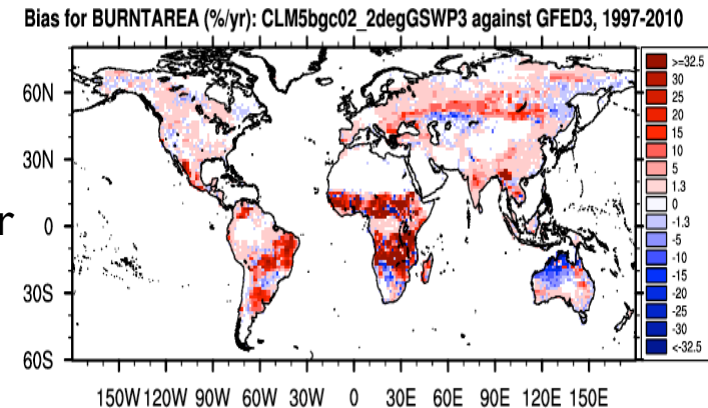
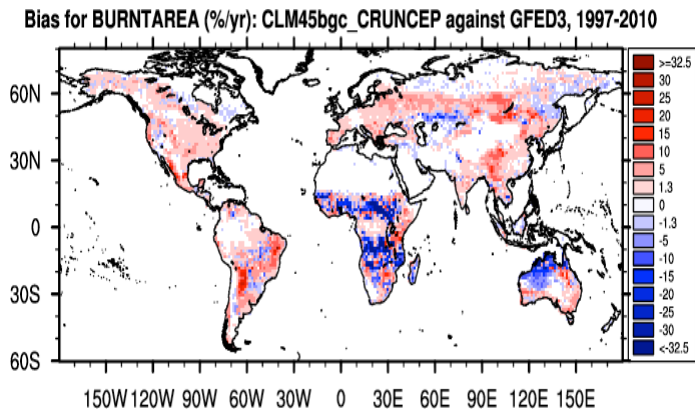
simulation characteristics

370 Mha/yr

- Separate coupled and land-only tuning
  - Fire
  - Methane (wetland distribution)
  - Dust

Obs: 360 Mha/yr

810 Mha/yr



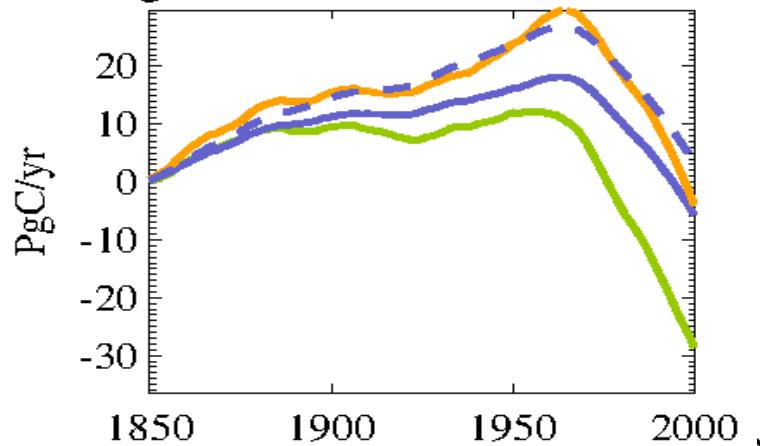
CLM5

CLM5 without new N

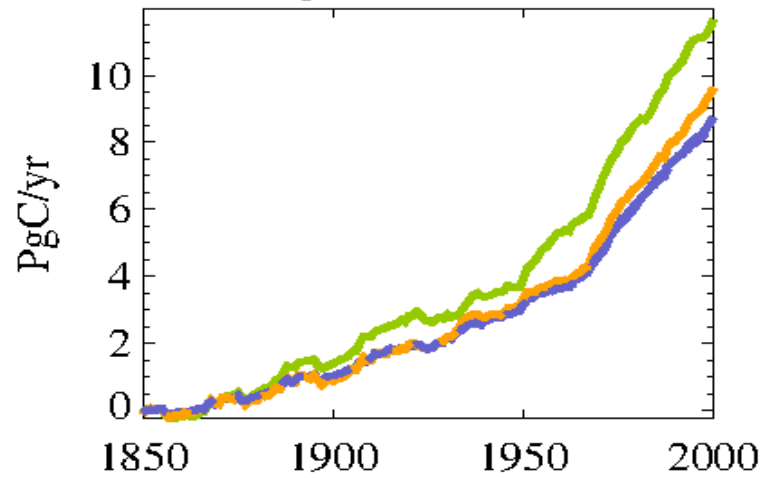
CLM4.5

CLM5 with new wood harvest

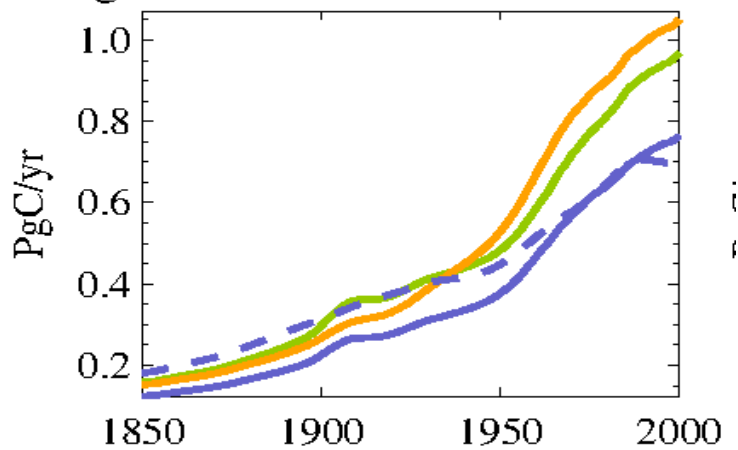
global Accumulated NBP



global NPP



global WOOD\_HARVESTC

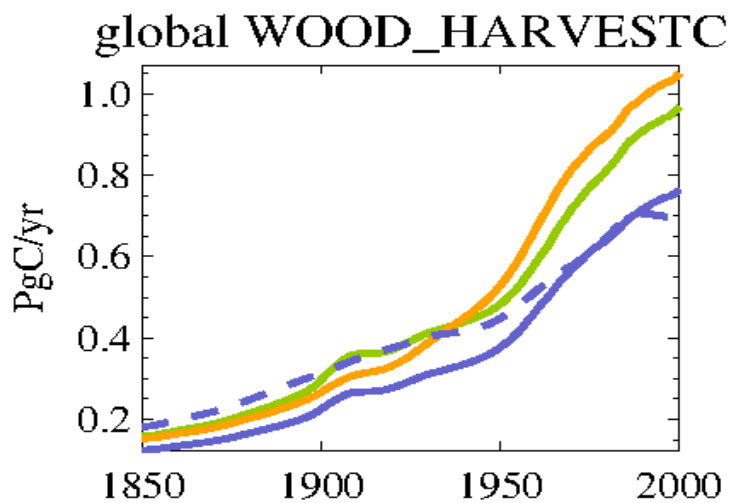
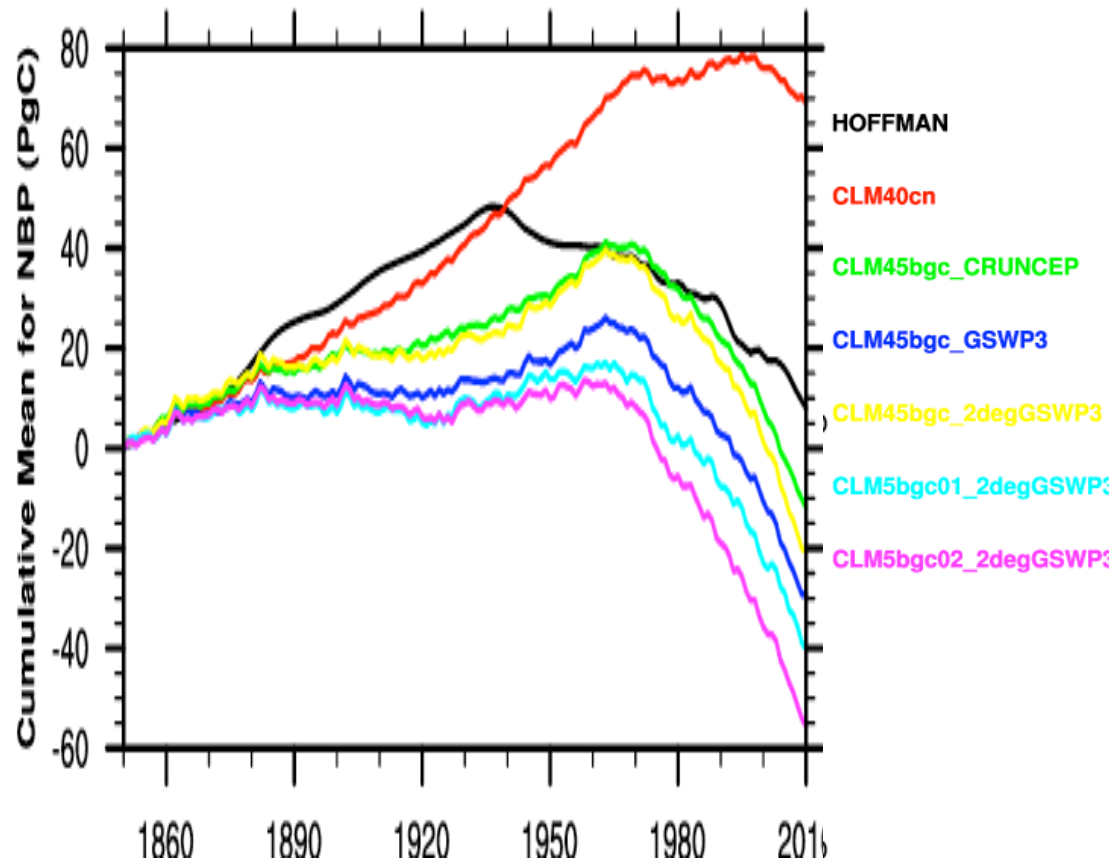
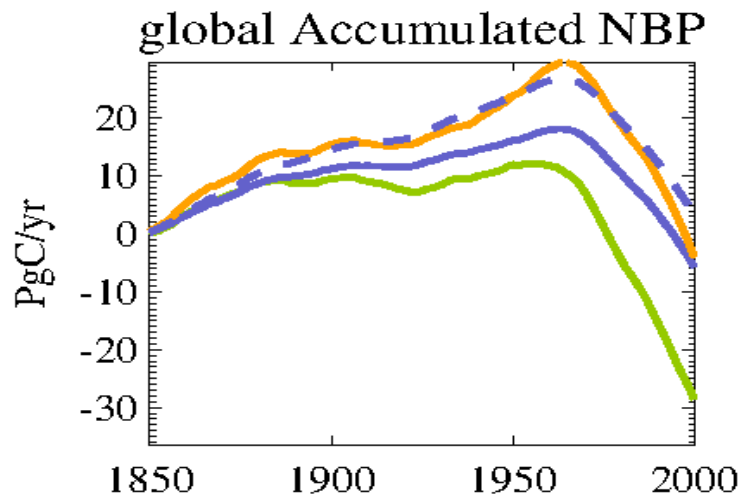


CLM5

CLM5 without new N

CLM4.5

CLM5 with new wood harvest



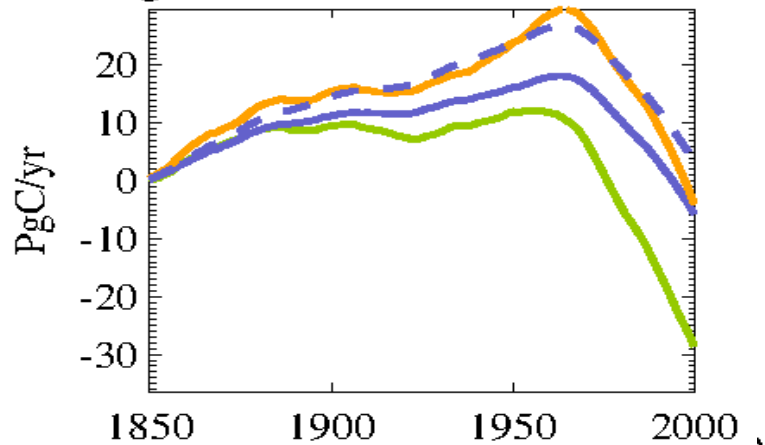
CLM5

CLM5 without new N

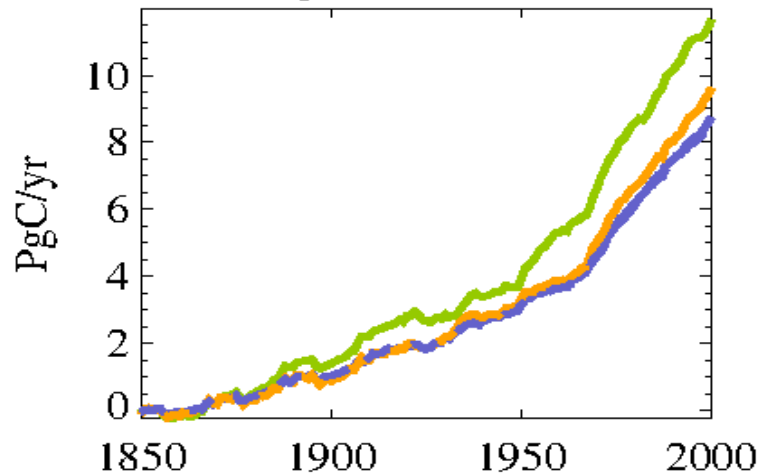
CLM4.5

CLM5 with new wood harvest

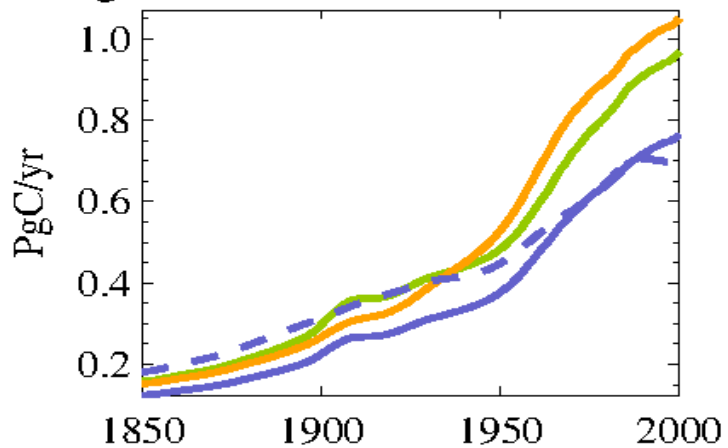
global Accumulated NBP



global NPP



global WOOD\_HARVESTC



# Soil Temperature bias at Boreholes

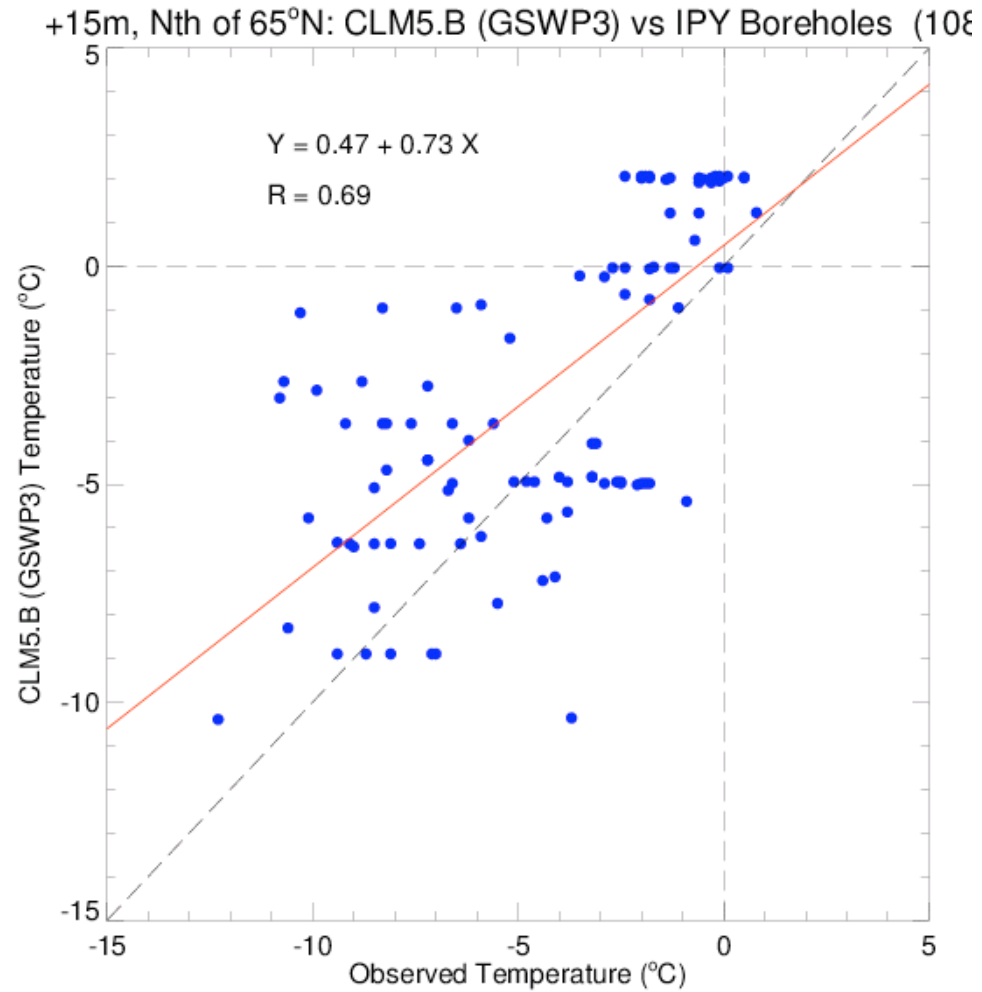
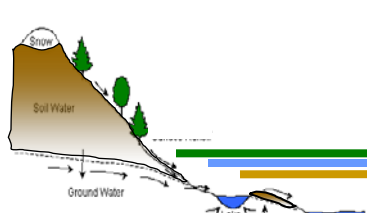


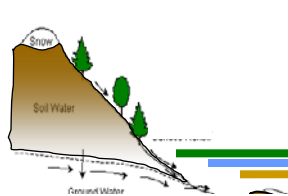
Figure courtesy A. Slater



# To do list: Software development

- Integrate “loose-end” projects
  - Carbon / nitrogen conservation for dynamic landunits
  - Plant hydraulics
  - Dynamic roots
  - Water isotopes (BeTR)
  - Winter wheat
  - Crop tilling
  - Dynamic local river flood stage
  - Permafrost excess ice
  - Switch for PFTs on own column
  - Prescribed soil moisture code
  - ....
- Code cleanup
  - Rapid code integration for science has lead to accumulation of lots of “Technical Debt”
- Performance
  - CLM5BGC-crop costs ~5-10x over CLM4CN
- Model output rationalization
  - Over 550 fields archived by default

# CLM5 development report card

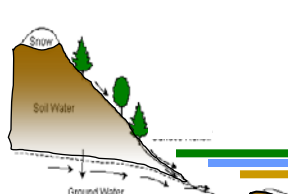


## The good

- Strong participation from the LMWG/BGCWGs (>50 people, 15 inst.)
- Scientific basis of model is significantly improved
- Functionality is expanded
- CLM5 should permit greater breadth and quality of scientific inquiry
- >165 CLM tags since CLM4.5 (June 2013)

REPORT CARD	
MATH	A
PE	B+
HISTORY	A-
ART	B
ENGLISH	C

# CLM5 development report card



## The good

- Scientific basis is significantly improved
- Functionality is expanded
- CLM5 should permit greater breadth and quality of scientific inquiry

## The bad

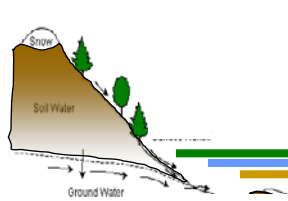
- Model improvement not readily apparent in diagnostics (yet)

A hand-drawn report card with a yellow header that says 'REPORT CARD'. The card lists five subjects and their corresponding grades: MATH (A), PE (B+), HISTORY (A-), ART (B), and ENGLISH (C). The drawing is simple and appears to be done with a marker or thick pen.

REPORT CARD	
MATH	A
PE	B+
HISTORY	A-
ART	B
ENGLISH	C



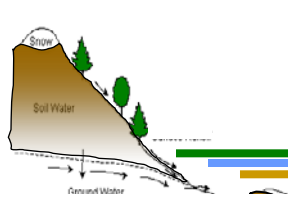
# CLM5 versus CLM4.5 ILAMB scores



	CLM45bgc_2degGSWP3	CLM5bgc01_2degGSWP3
<b><u>Global Variables</u></b>	<b>0.70</b>	<b>0.68</b>
<b><u>Variable to Variable</u></b>	<b>0.73</b>	<b>0.68</b>
<b><u>Overall</u></b>	<b>0.71</b>	<b>0.68</b>

	CLM45bgc_2degGSWP3	CLM5bgc01_2degGSWP3
<b><u>Aboveground Live Biomass</u></b>	<b>0.71</b>	<b>0.64</b>
<b><u>Burned Area</u></b>	<b>0.51</b>	<b>0.42</b>
<b><u>Gross Primary Productivity</u></b>	<b>0.75</b>	<b>0.72</b>
<b><u>Leaf Area Index</u></b>	<b>0.57</b>	<b>0.58</b>
<b><u>Global Net Ecosystem Carbon Balance</u></b>	<b>0.47</b>	<b>0.45</b>
<b><u>Net Ecosystem Exchange</u></b>	<b>0.49</b>	<b>0.51</b>
<b><u>Ecosystem Respiration</u></b>	<b>0.73</b>	<b>0.70</b>
<b><u>Soil Carbon</u></b>	<b>0.56</b>	<b>0.58</b>
<b><u>Summary</u></b>	<b>0.60</b>	<b>0.58</b>

# CLM5 development report card

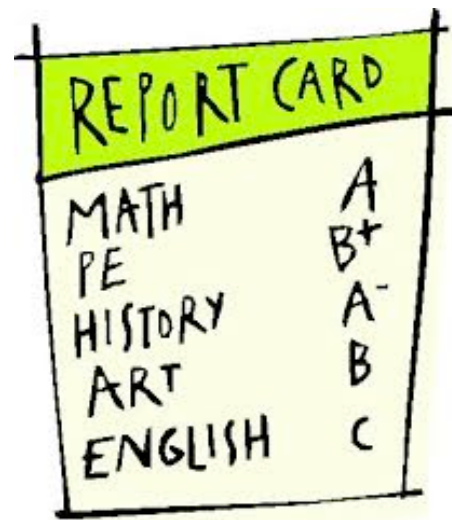


## The good

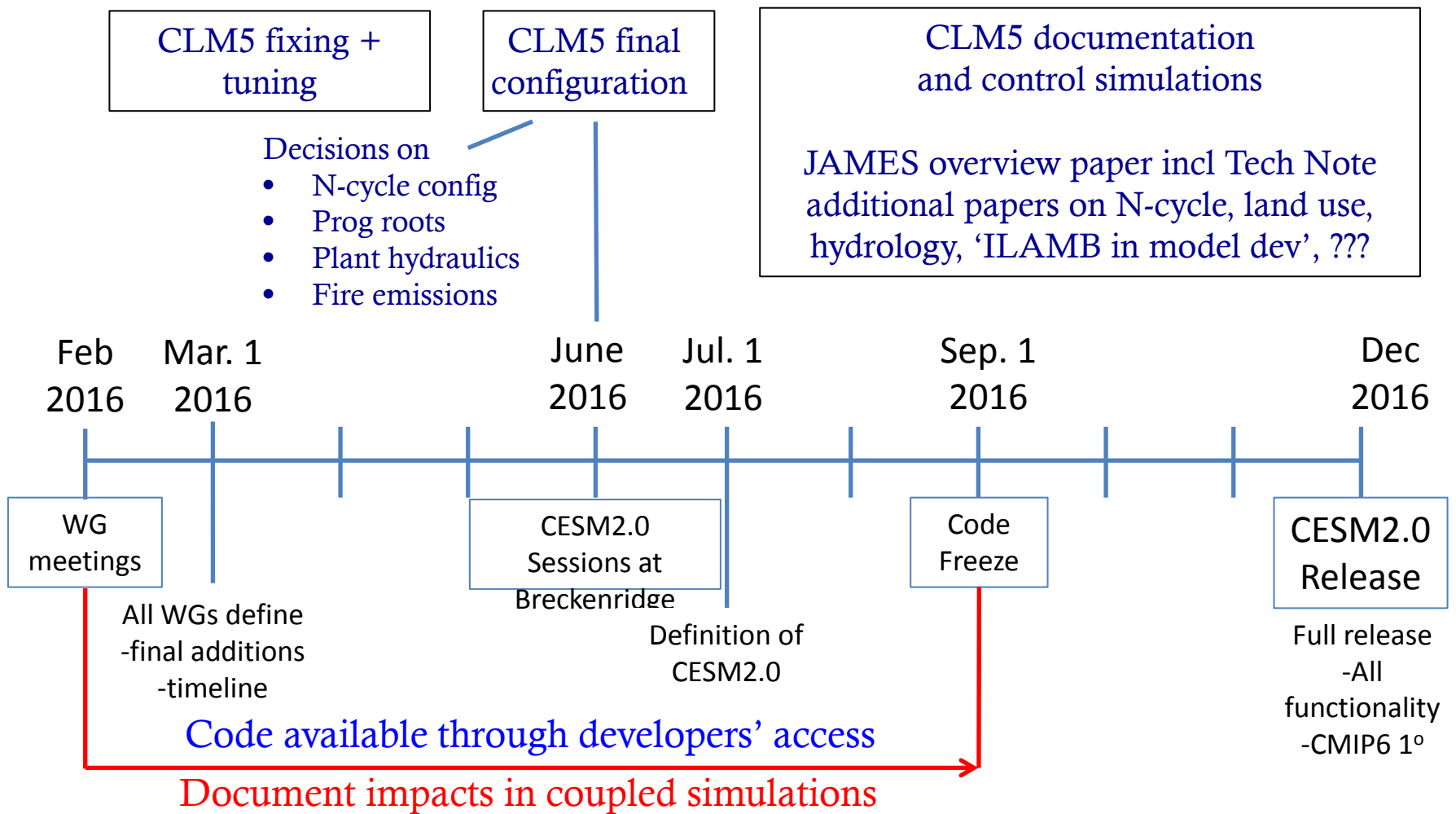
- Scientific basis is significantly improved
- Functionality is expanded
- CLM5 should permit greater breadth and quality of scientific inquiry

## The bad

- Model improvement not readily apparent in diagnostics (yet)
- CLM was limiting factor (some of the time) in CESM2 testing
- Process has been chaotic, stressful (but also fun at times), inefficient (at times), long, and exhausting for CLM group



# Proposed revised timeline



Pending approval by the SSC

2<sup>nd</sup> CLM Tutorial scheduled for **September 12-16, 2016**

- Lectures on underlying model physics, hydrology, biogeochemistry, ecology, etc
- Practical sessions about how to run, modify, and analyze CLM simulations
- CLM5 / CESM2

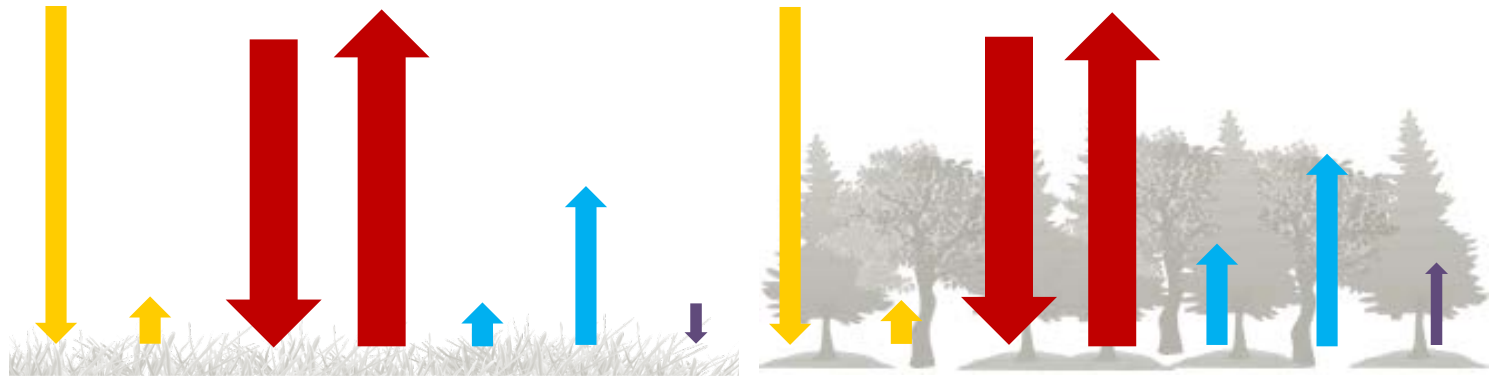
~ 40 students

- Graduate students, postdocs, early career faculty are eligible
- Acceptance criteria includes relevance to CLM/CESM project
- Students will have to secure own travel funding (no add'l registration fee)

# Tropical grid [6.13°N, 288.75°E]

## 20 year annual mean

**CTRL**

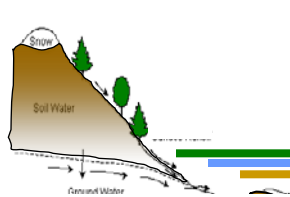


	SW↓	SW↑	LW↓	LW↑	H	λE	G	SW↓	SW↑	LW↓	LW↑	H	λE	G
[Wm <sup>-2</sup> ]	207.3	30.7	429.2	468.4	26.2	96.5	14.7	207.3	26.4	429.2	463.0	61.2	117.7	-31.8

**PFT-COL**



	SW↓	SW↑	LW↓	LW↑	H	λE	G	SW↓	SW↑	LW↓	LW↑	H	λE	G
[Wm <sup>-2</sup> ]	207.3	30.7	429.2	470.8	31.7	103.3	-0.04	207.3	26.4	429.2	459.3	45.2	105.6	-0.03
<b>DIFF</b>	--	<b>0</b>	--	<b>2.4</b>	<b>5.5</b>	<b>6.8</b>	<b>14.74</b>	--	<b>0</b>	--	<b>3.7</b>	<b>16</b>	<b>12.1</b>	<b>31.77</b>



## The bad

- CLM was limiting factor (some of the time) in CESM2 testing
- Process has been chaotic, stressful, inefficient (at times), long, and exhausting for CLM group, ... but new management tools/methods show promise for future

## Some observations

- Considerable fraction of new code came from external collaborators
  - External code was of highly variable quality
  - Somewhat successful getting external and internal scientists to utilize SVN revision control and software testing
  - Most new code broke a 'kitchen sink' run
- Complexity of process spurred experimentation with Project Management Tools

## CESM CLM and RTM Development cseg.cgd.ucar.edu Public

### CLM Software Meeting Agenda

Unit test walkthrough WJS

2016-01-04 1/1

2015-12-21 11/12

2015-12-14 3/3

2015-12-07 12/12

2015-11-30 5/6

2015-11-23 10/10

2015-11-16 11/11

2015-11-09 4/4

2015-11-02 10/10

2015-10-26 11/11

2015-10-19 3/3

2015-10-12

### Upcoming tags - next couple of weeks

clm4\_5\_7\_r164 Update cime again (and mosart) 1

FUN changes from Rosie 3 2/5

Change default settings 2

Rework / remove fglcmask WJS

new surface datasets and initial conditions  
Add a card...

### Software Engineering (new functionality, refactoring, etc)

Fire parameters for tuning... 1 0/8

Cleanup duplication between clm45FIRE and clm50FIRE 1 0/5

Remove extra field sent between: RUNOFF, CPL, and CLM

FUN Cleanup 0/10

FUN Cleanup 0/5

Cleanup dynroot 0/21

Refactored code and new features to support C & N conservation with dynamic landunits WJS

next testlist refactor 0/4

ED source clean-up and unit tests 2/9

Misc. bug-fixes that are bit-for-bit 1/25

Turn on glc by default, always WJS

### Science development (LMWG)

Default forcing dataset(s)? GSWP3, CRUNCEP? 2 SS O

Change wind-dependent snow density to use 10-m wind 1 WJS

N-fixation

Ozone: second stage 0/5

C13 bug fix (Charlie and collaborators) 1

Keith Lindsay Carbon isotope bugs 1

Add a card...

### Beyond CLM5 soft freeze

Caspian Sea Added to CLM 2/6

ciso fire fix and exit-spinup ciso fix add ciso SSP test

Plant hydraulics - Pierre Gentine and Daniel Kennedy 1

Jinyun hydrology reordering non-bfb

BeTR code and water isotopes 1

Shrub/tundra distribution in Arctic

Dynamic Landunits 1

Population density fields for projection periods

Multiple levels of history output and subgrid archiving by default

New Land Use Dataset

cultivation from Sam 2/4

Land management developments 4

## Tasks

+ Add task list

All Lists

- CLM5 N cycle development

Integration of the FlexCN (LBNL), LUNA (LANL) and FUN (JPL) codes into the CLM5 code in preparation for Oct 1 deadline.

- You + 3 others Launch a flexCN-LUNA-FUN simulation [more...](#) FlexCN x FUN x LUNA x 12
- rosie f. + 3 ot... Check performance of FlexCN and LUNA withOUT crops [more...](#) 5
- You + 7 others Recognize change in answers for CROP when FUN is on [more...](#) FUN x 1
- rosie f. + 3 ot... Determine how to calculate sminn\_to\_plant\_vr in context of FUN [more...](#) 2
- Anyone revisit allocation parameters 7
- rosie f. + 2 ot... Determine appropriate respiration form for CLM5. 11
- Anyone re-revise spinup 13
- rosie f. + 1 oth... change cpool and npool error to an end run 1
- You + 7 others Bugs in flexCN, LUNA, FUN [more...](#) 11
- You + 4 others Solve issue with crop productivity in crop x FUN x LUNA x FlexCN runs 26

+ Add a task 20 completed

- CLM5 land use development

- Danica L. Crop grain yield to 1-yr product pool [more...](#) 6
- Danica L. Introduce namelist option to turn fertilizer off 4
- Danica L. Add and revise crop output variables [more...](#) 1
- Peter L. Modify wood harvest to be by mass rather than by area 4
- Peter L. Evaluate impact in global transient simulation
- Dave L. Assess net impact of wood harvest with no harvest simulation [more...](#) (Start: 4 months ago, Wed Sep 9th) → (Due: 4 months ago, Fri Sep 11th)
- Peter L. Change land use interpolation so that interpolation for year Y occurs during year Y rather than year Y+1 [more...](#)

- Task lists**
- CLM5 N cycle development 11
  - CLM5 land use development 20
  - CLM5 assessment 0
  - CLM5 hydrology developmen... 3
  - CLM5 plant hydraulics dev... 11
  - CLM performance 11
  - CLM5 issues 3

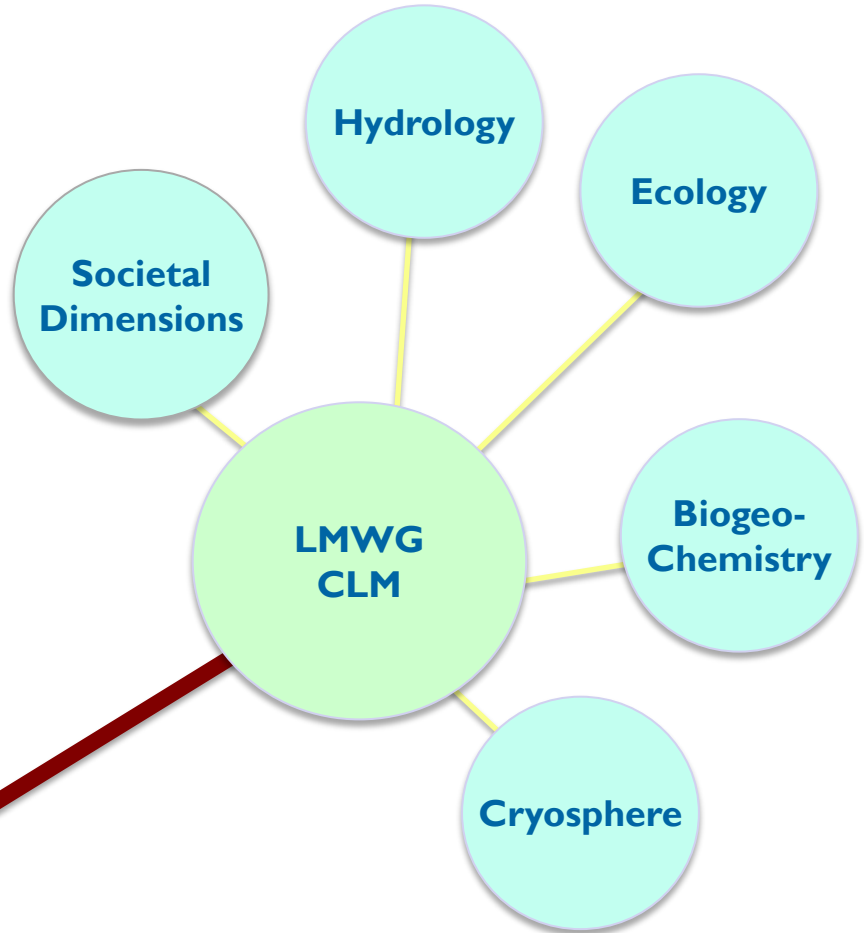
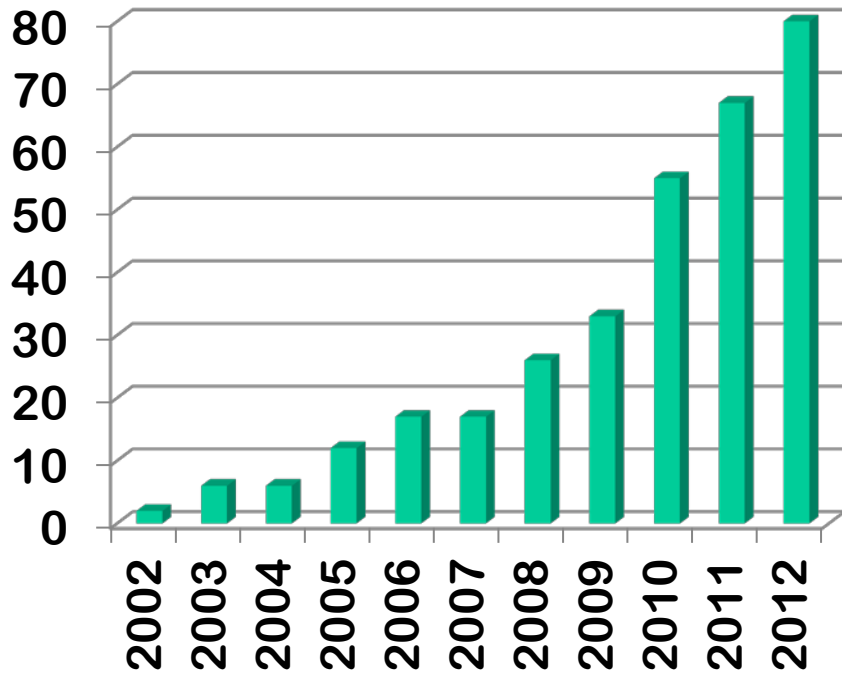
- Completed task lists**
- CLM5 stress deciduous phenol 5

- Reports**
- Task Lists Report
  - Gantt Chart Export...
  - Gantt Chart



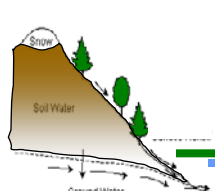
# CLM as a community modeling tool

Presentations with CLM in abstract or title at AGU



model

# Model Developers' Guide (thanks to CLM software team)

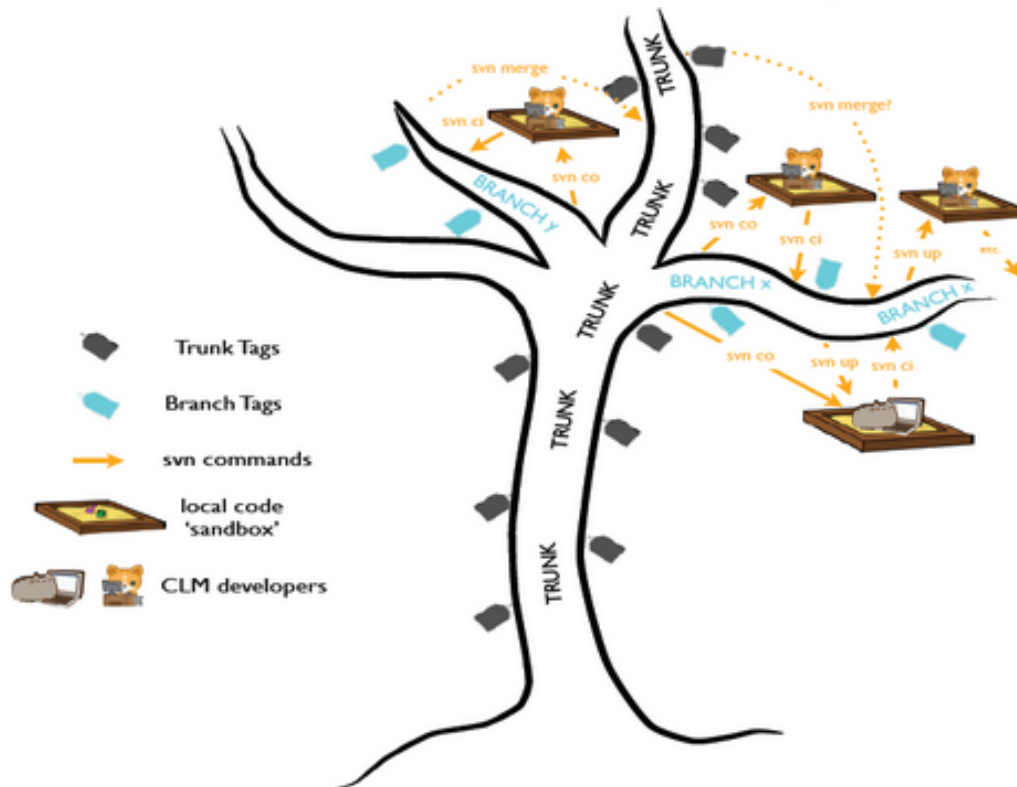


## Software development guidelines

- [Software developer's guide](#): read this for general information on the steps in the model development process including information on coding standards, maintaining a branch, testing, and working with the CLM Code Management Team
  - [Coding practices](#)
  - [Using SVN to work with development branches](#)
  - [CLM testing](#)
  - [Upcoming CLM branch and trunk tags](#)
  - [Recent CLM code refactoring](#)

- Code refactoring: more modular and object-oriented code has promise to ease development process

- Unit testing





# Collaborative Nitrogen Cycle Project

