Addressing Arctic-Boreal Plant Functional Type Biases in Carbon Cycling in the Community Land Model

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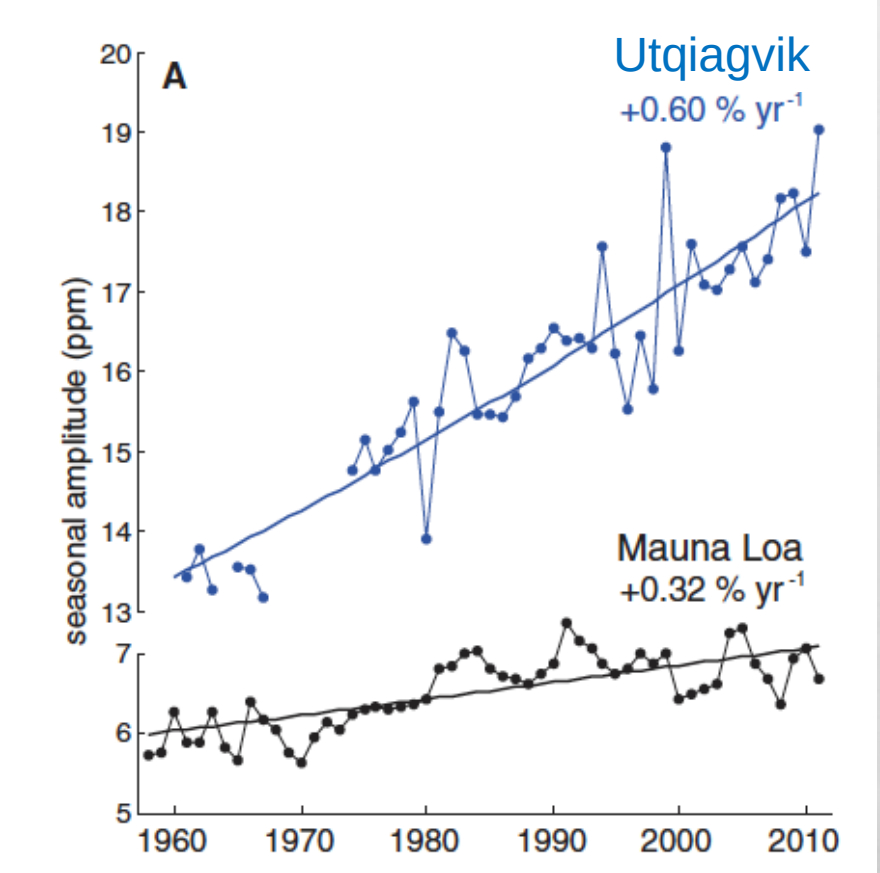
WOODS HOLE RESEARCH CENTER

ABoVE

ARCTIC - BOREAL VULNERABILITY EXPERIMENT

Seasonal Amplitude of CO_2 Fluxes in the Arctic-Boreal is Increasing

- This trend is particularly strong at high latitudes
- More carbon is released/respired to the atmosphere in fall/winter
- More carbon is taken up from the atmosphere in summer
- The mechanisms controlling this increase are not completely understood.
- We plan to assimilate observations in a modelling framework to investigate this.



Graven et. al 2013

ABoVE
ARCTIC - BOREAL VULNERABILITY EXPERIMENT

Community Land Model (CLM5.0)

The land model component of the Community Earth System Model (CESM2.0)

Improvements in the Arctic

Multiple soil layers for permafrost
Biogeochemistry and nutrient cycling have new parameterizations
Plant hydraulics have also been updated

Model Set-up with Biogeochemistry

- 0.5º grid resolution
- Arctic focus above 40ºN
- GSWP meteorological forcing data from 1850-2014
- Landuse is transient
- Atmospheric CO_2 is transient

Comparison of CLM to FluxCom

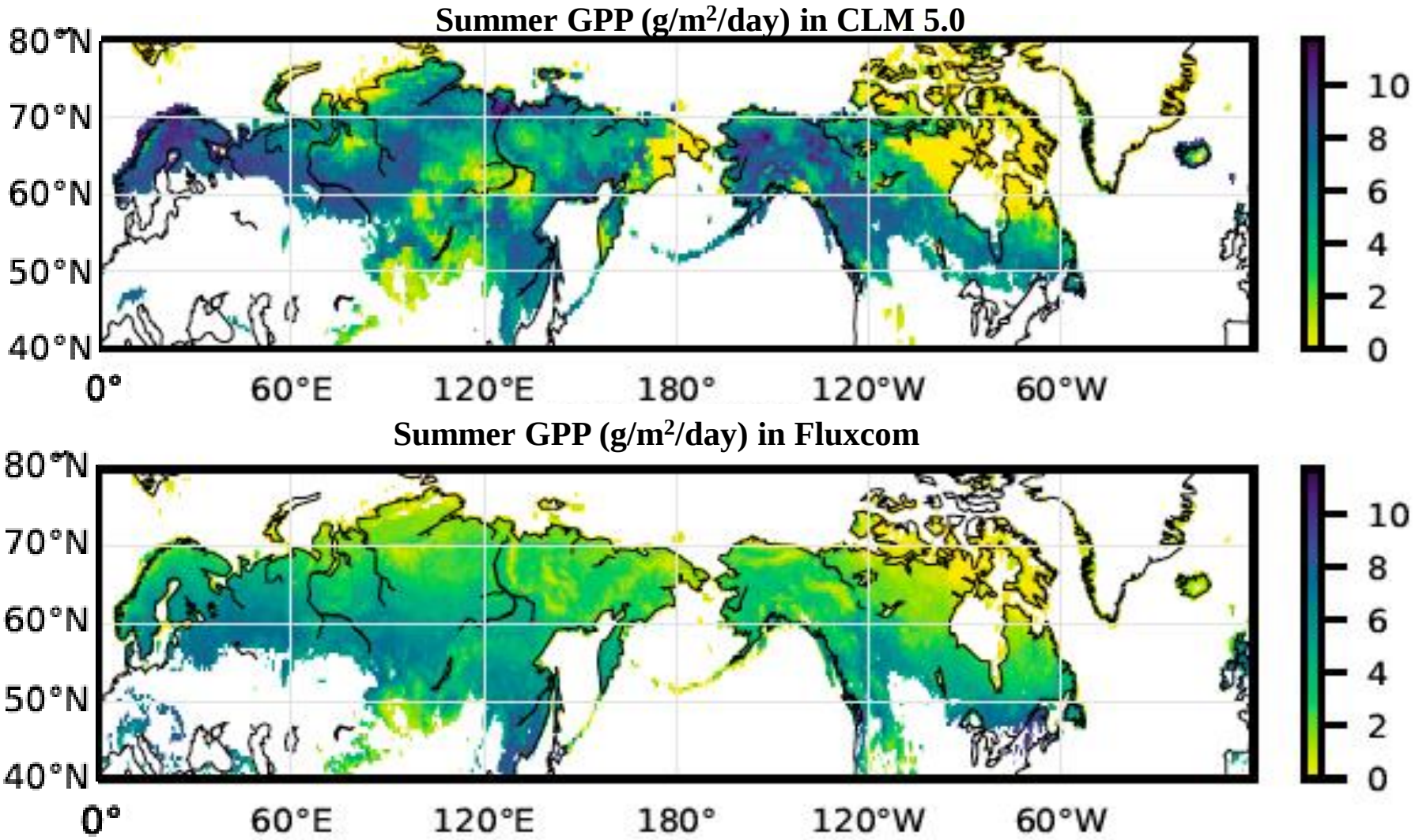
FluxCom uses upscaling approaches based on machine learning methods that integrate FLUXNET site level observations, satellite remote sensing, and meteorological data.

Jung, Martin, et al. "Compensatory water effects link yearly global land CO 2 sink changes to temperature." *Nature*541.7638 (2017): 516.

NCAR http://www.cesm.ucar.edu/models/clm/

FluxCom http://www.fluxcom.org/

Productivity in CLM vs. Fluxcom



- Note the lack of a latitudinal gradient in the Gross Primary Productivity (GPP) in CLM

PFT Specific Comparisons of CLM to FluxCom

- PFT= Plant Functional Type:

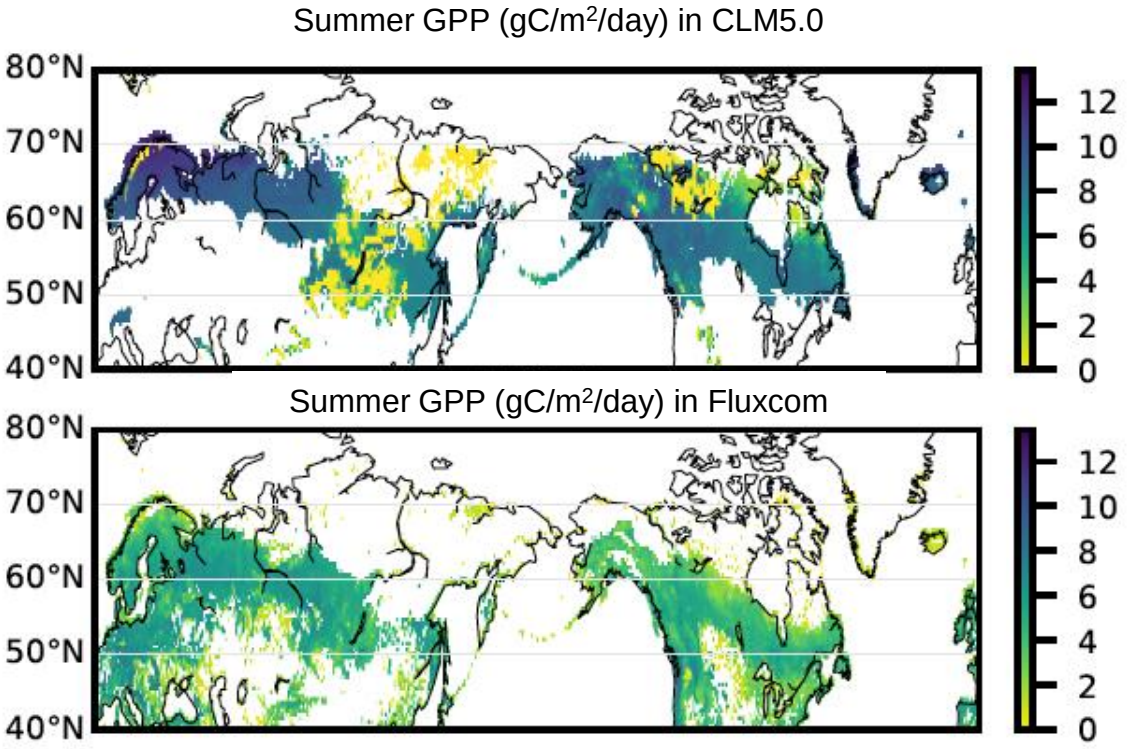
  Needleleaf Evergreen Trees, Needleleaf Deciduous Trees, Broadleaf Deciduous Trees, Shrubs, C3 Grasses

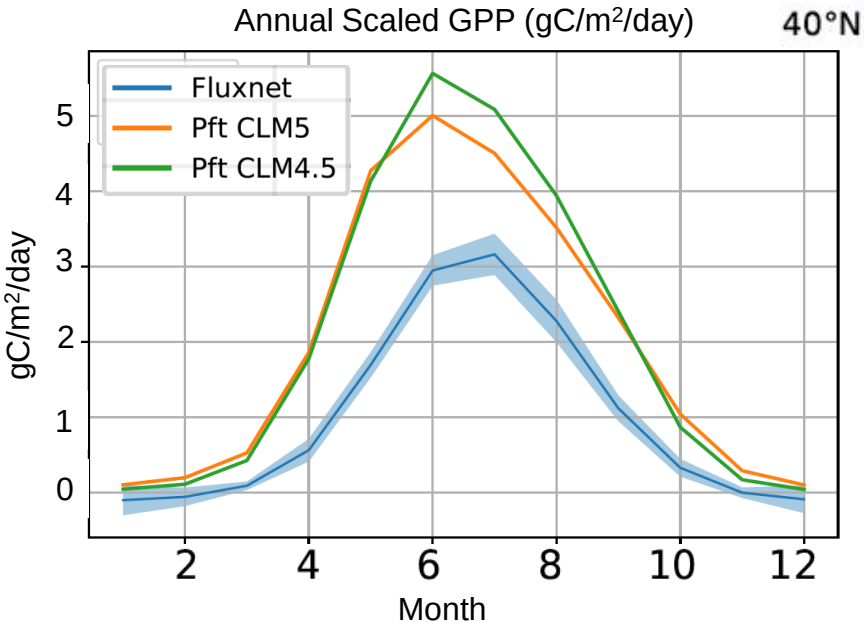
- CLM aggregates the PFTs into grid cells, but to better understand the biases in productivity, we examine how each PFT behaves before they are combined.

- Differences in vegetation are part of the story why the seasonal amplitude of CO_2 fluxes are increasing.

Needleleaf Evergreen Trees

- Across the Arctic-Boreal, the needleleaf evergreen trees are highly productive in CLM compared to Fluxcom.
- GPP=0 indicated areas with no productivity indicating dead plants in contrast to the mask

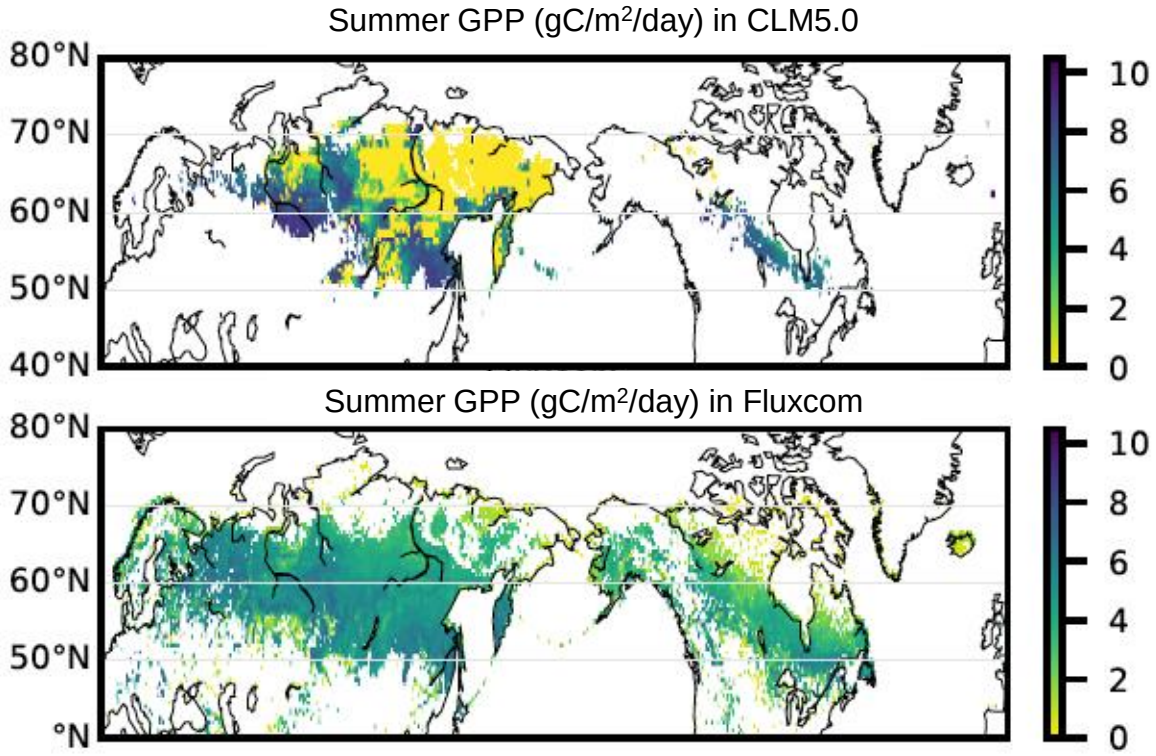


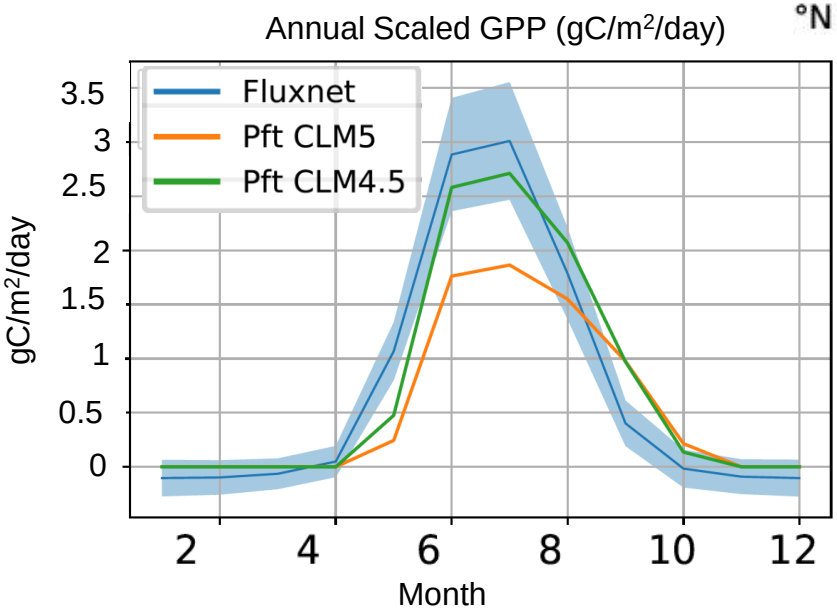


- Averaging over the grid points CLM and Fluxcom have in common, CLM is shown to be too productive
- CLM also has peak productivity in June, which is too early.

Needleleaf Deciduous Trees

- GPP=0 indicates areas with no activity in the middle of larch forests
- In areas with GPP>0, the productivity may be too high.

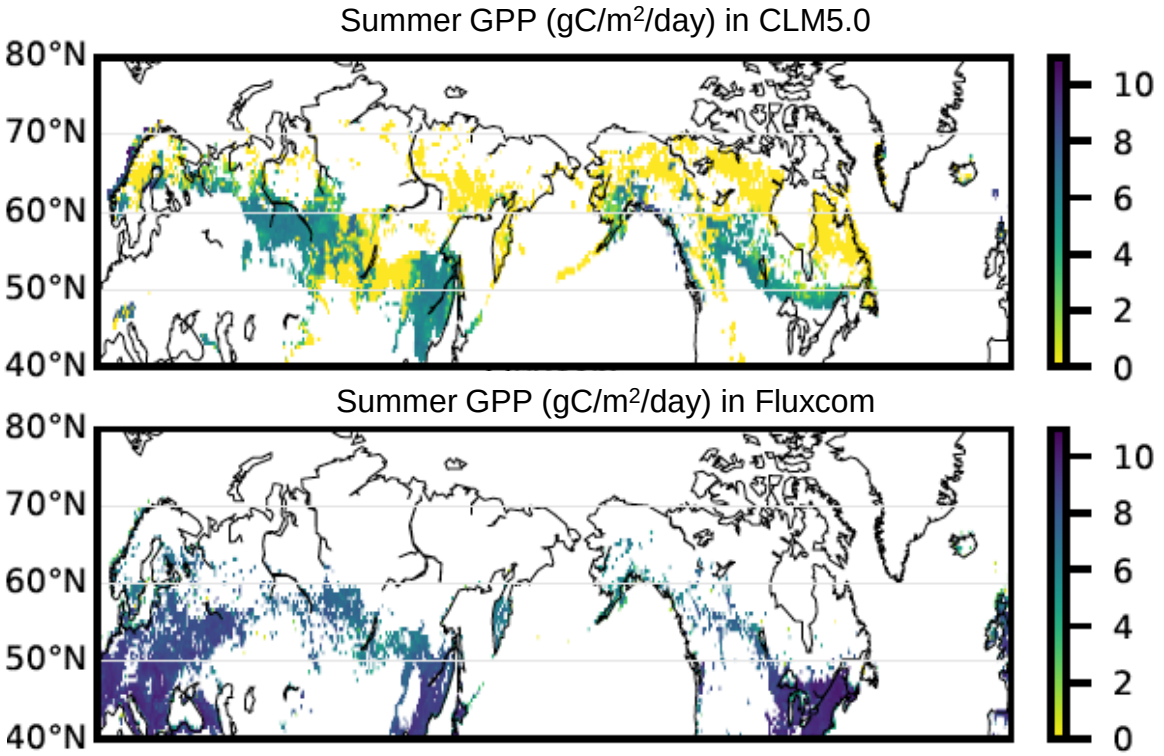


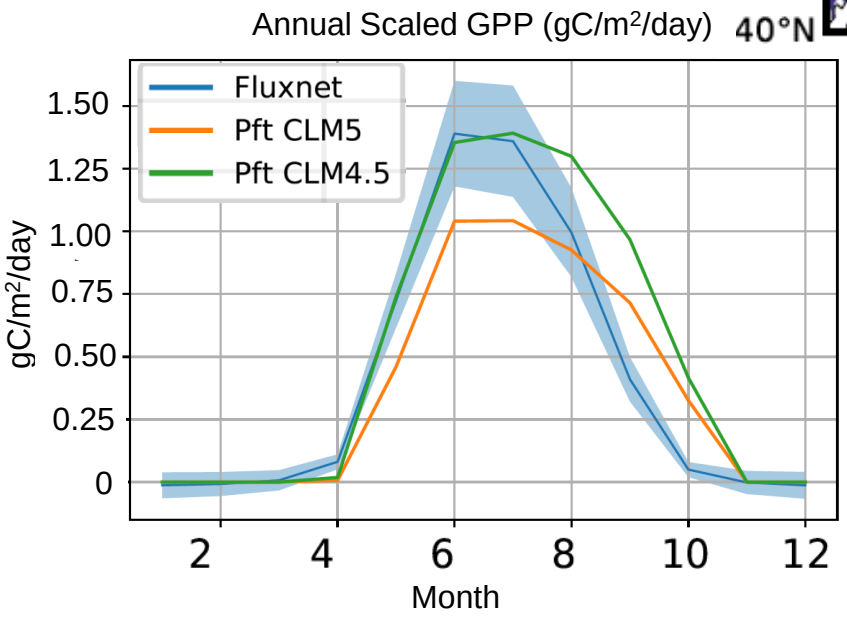


- Averaging Over the points, CLM and FluxCom have in common, CLM is not productive enough.
- CLM is also late for onset and offset of productivity.

Broadleaf Deciduous Trees

- GPP=0 indicates areas with no productivity in summer
- In areas with GPP>0, the productivity is possibly too low.

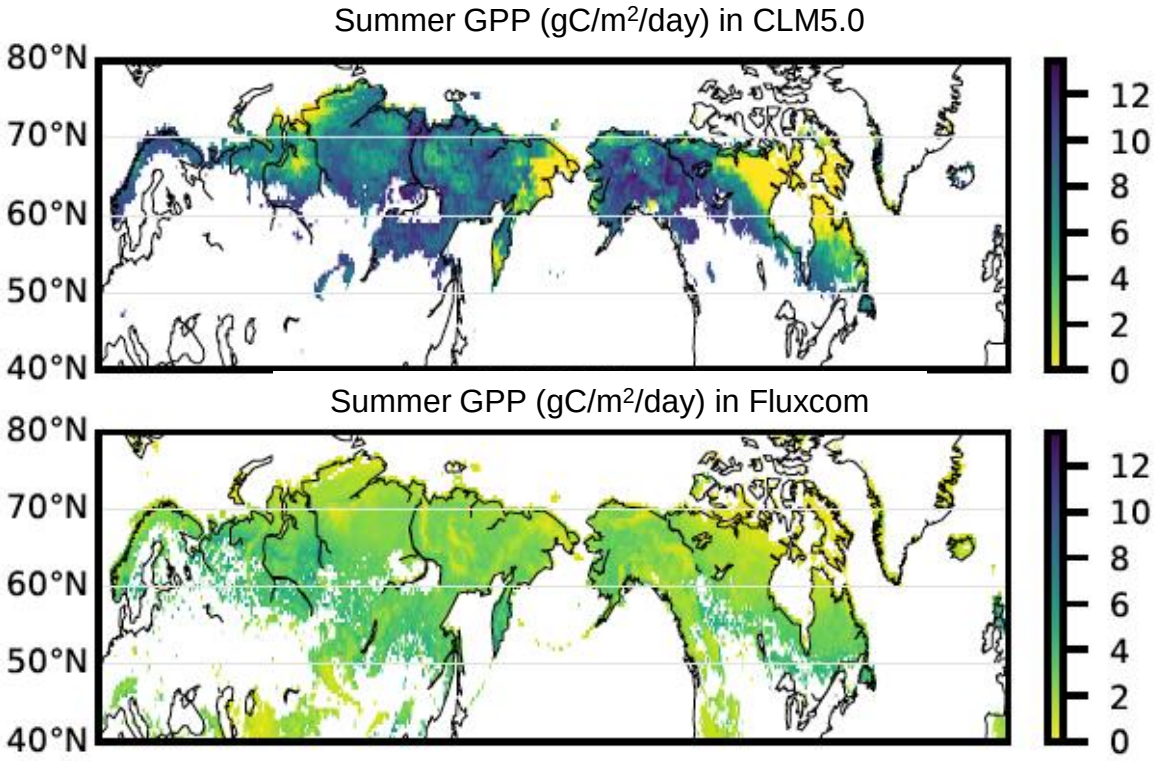


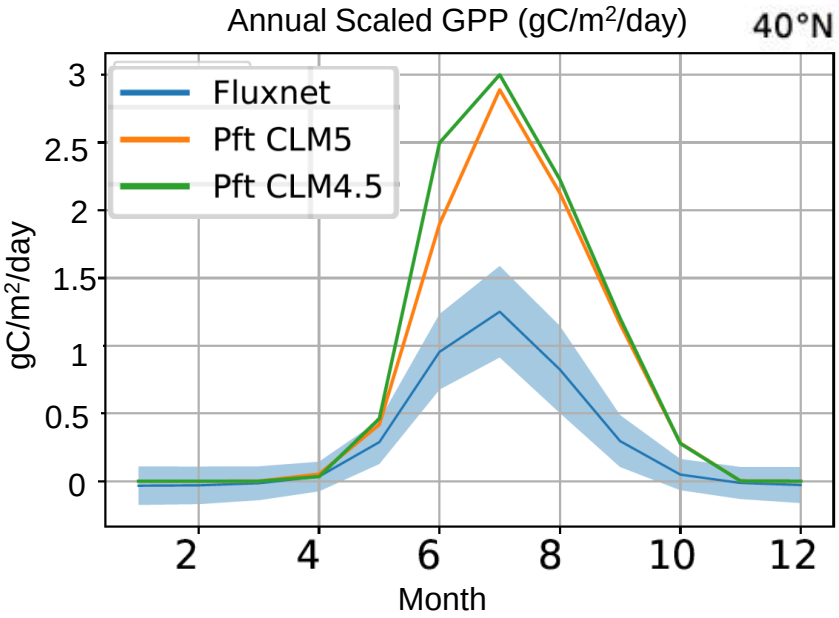


- Averaging Over the points, CLM and Fluxcom have in common, CLM is not productive enough.
- CLM is also late for onset and offset of productivity.

Shrubs

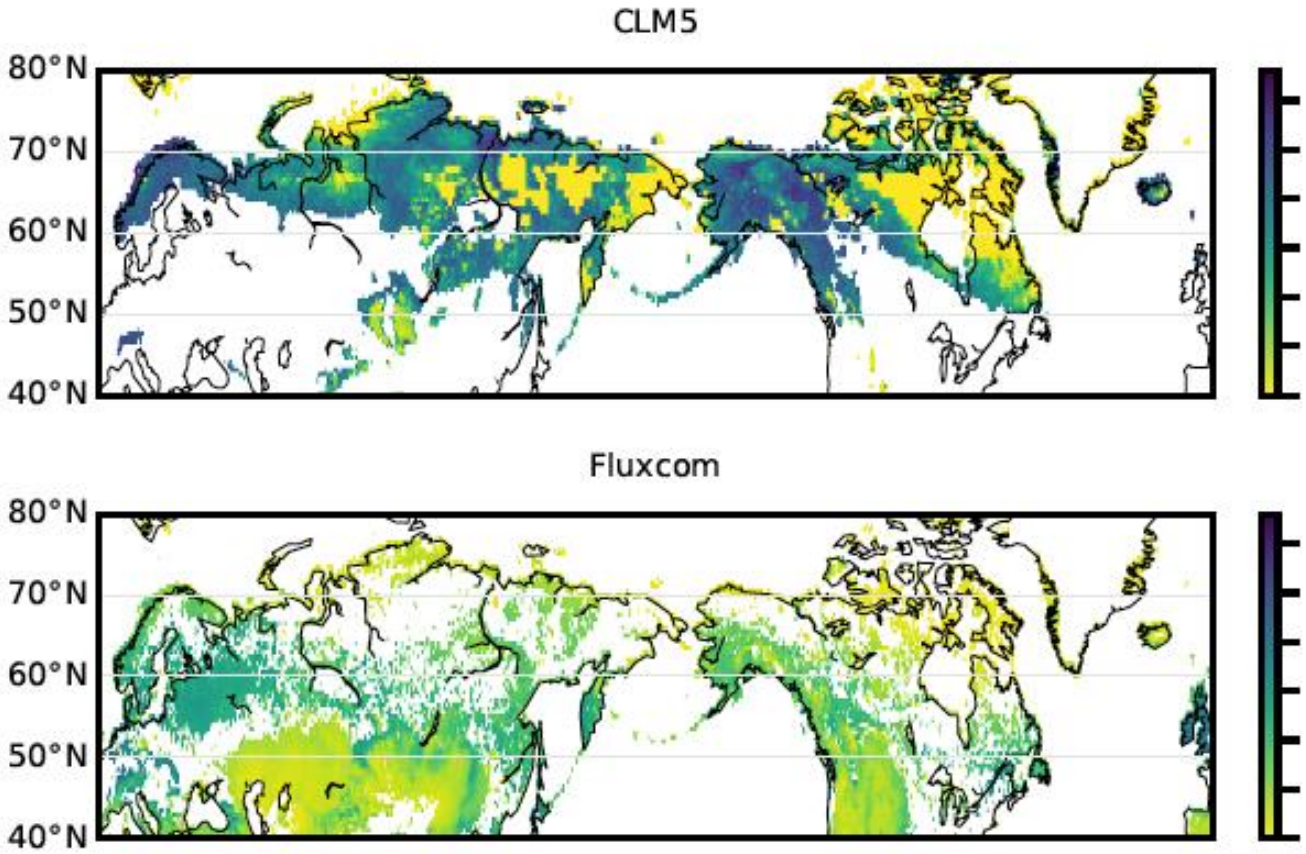
- There is no latitudinal gradient.
- GPP=0 indicates areas with no productivity in summer
- In areas with GPP>0, the productivity is much higher than Fluxcom





- Averaging Over the points, CLM and Fluxcom have in common, CLM much more productive than CLM
- The offset of CLM may be too late.

Artic C3 Grasses



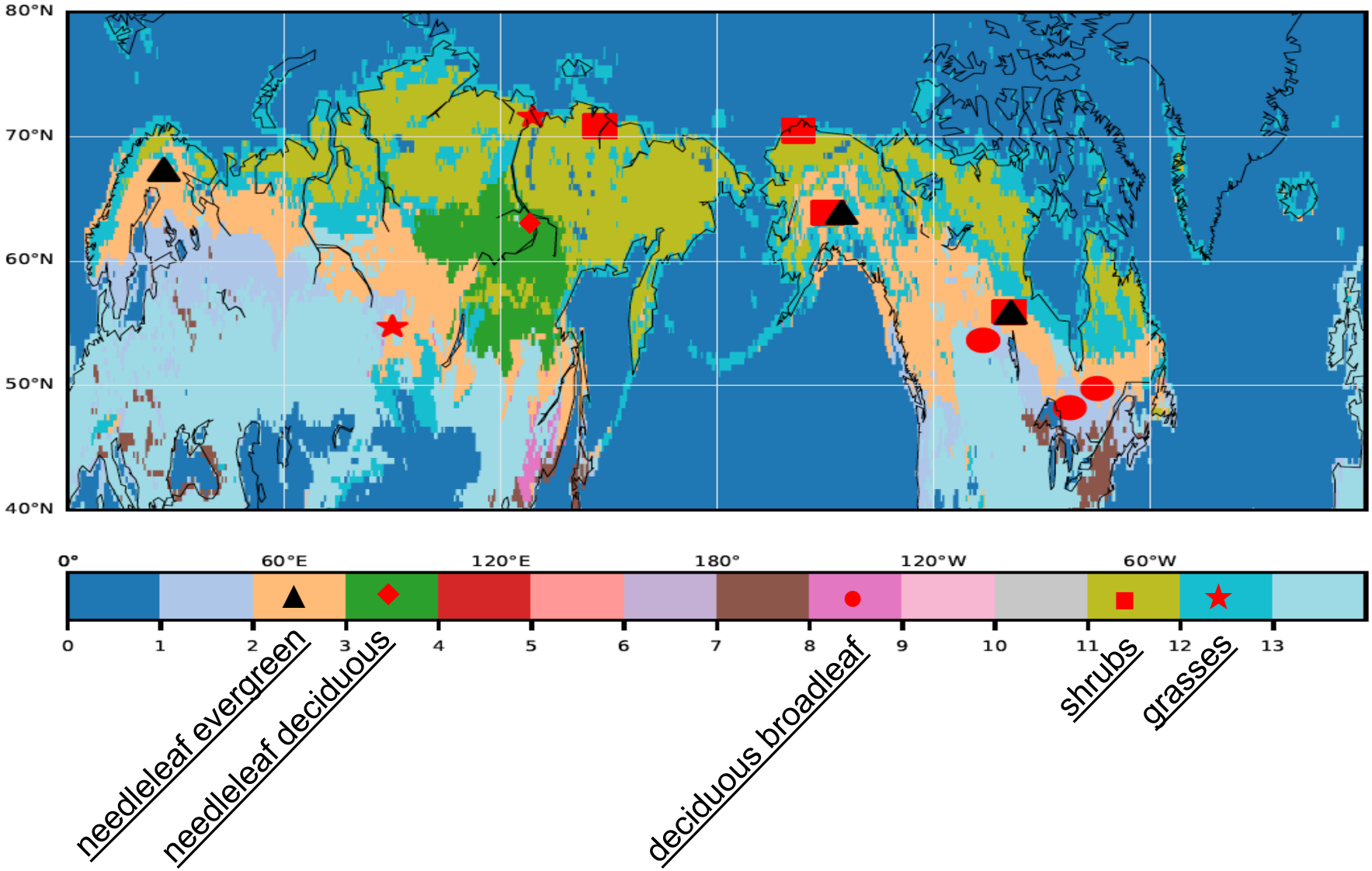
- The maps in Fluxcom and CLM are not the same at all, making the comparison difficult.
- CLM appears to be much too productive, but CLM5 appears to be improved compared to CLM4.5
- CLM5 consistently has areas with no productivity

Site Comparison for Model Development

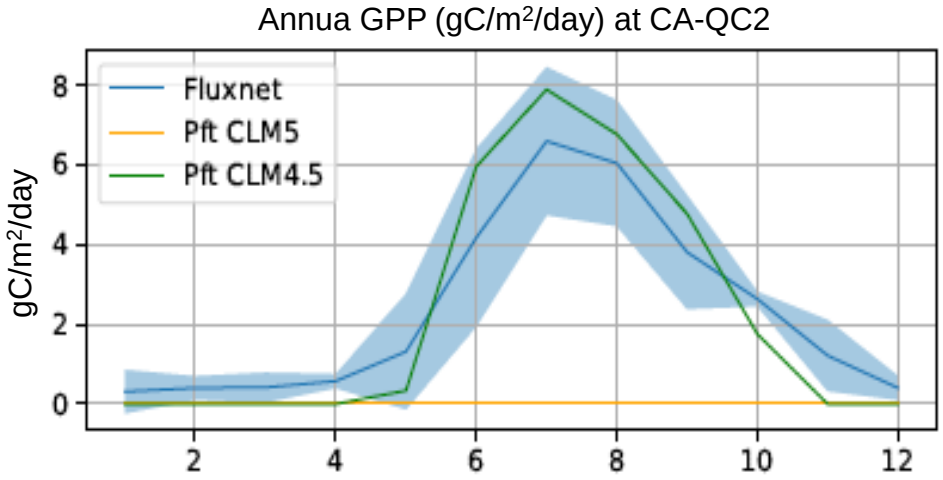
- We want to more closely compare CLM with observations using flux tower data.
- Observational data come from Fluxnet, Ameriflux, AsiaFlux, and from researchers directly.
- We compare the CLM PFT specific output to sites with the matching well documented vegetation.

Chosen Flux Tower Sites

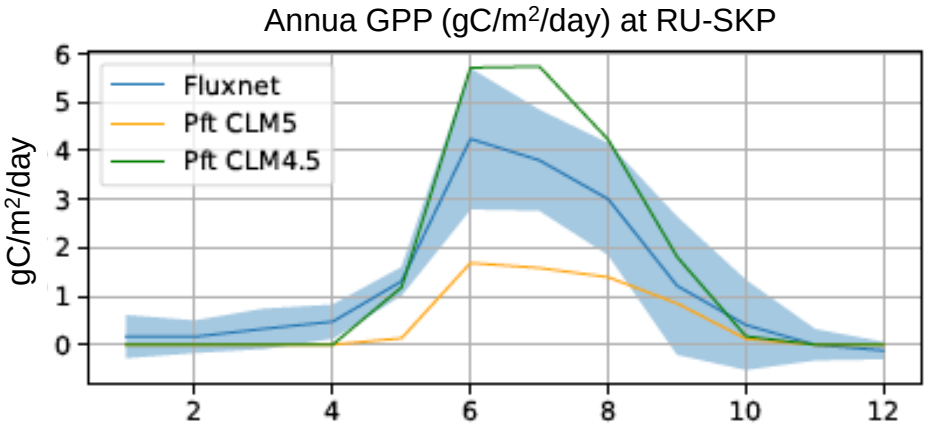
▲-needleleaf evergreen, ◆-needleleaf deciduous,
●-deciduous broadleaf, ■=shrubs, ★=grasses



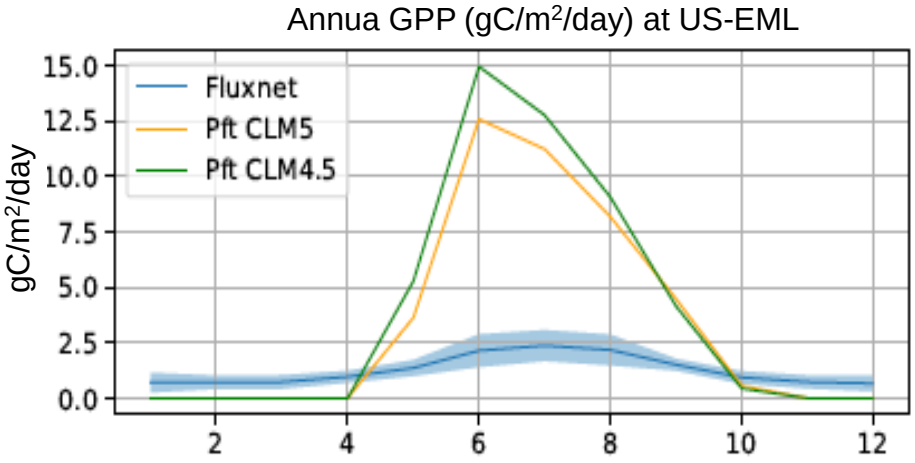
Flux Tower Comparisons to CLM



- CA-QC2: Mixed forest of evergreen and deciduous trees
- Deciduous Trees are not productive here in CLM5.0



- RU-SKP: Larch Forest in Siberia
- The Deciduous Trees are not productive enough in CLM.



- US-EML: Eight Mile Lake
- Grasses, shrubs, and sedge vegetation
- CLM is too productive here

Issues in Arctic PFTs

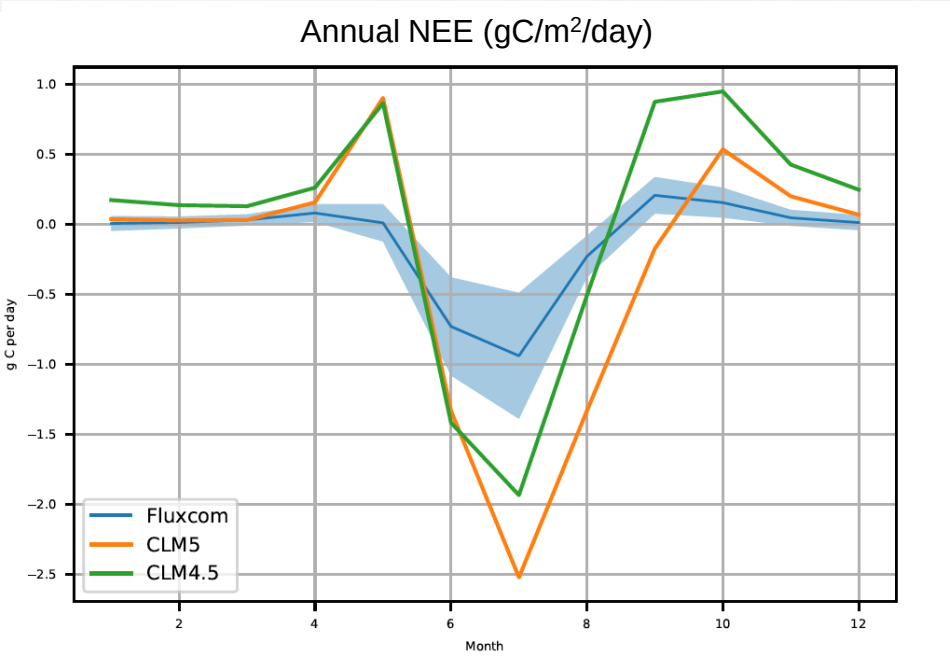
1. There is no latitudinal gradient in CLM
2. The grasses and shrubs are way too productive at high latitudes
3. There are large areas of “dead” PFTs in CLM
4. Needleleaf evergreen trees productivity peaks in June and onset too early
5. Shrubs and deciduous trees have a late GPP onset
6. Generally, all the PFTs appear to stay productive for too long in the Fall.

Current Development Investigation

1. Shrubs and deciduous trees have a late GPP onset
2. Generally, all the PFTs appear to stay productive for too long in the Fall.
3. Large areas of “dead” PFTs.
4. Grasses and shrubs are too productive.

Current Development Investigation

1. Shrubs and deciduous trees have a late GPP onset
2. Generally … or too long in the Fall.
3. Grasses a…
4. Large are…



- NEE spring spike could be from late onset or excessive respiration?

Onset is based on:

20.3.1 14.3.1 Seasonal-Deciduous Onset Trigger

The onset trigger for the seasonal-deciduous phenology algorithm is based on an accumulated growing-degree-day approach (White et al., 1997). The growing-degree-day summation (GDD_{sum}) is initiated ($GDD_{sum} = 0$) when the phenological state is dormant and the model timestep crosses the winter solstice. Once these conditions are met, GDD_{sum} is updated on each timestep as

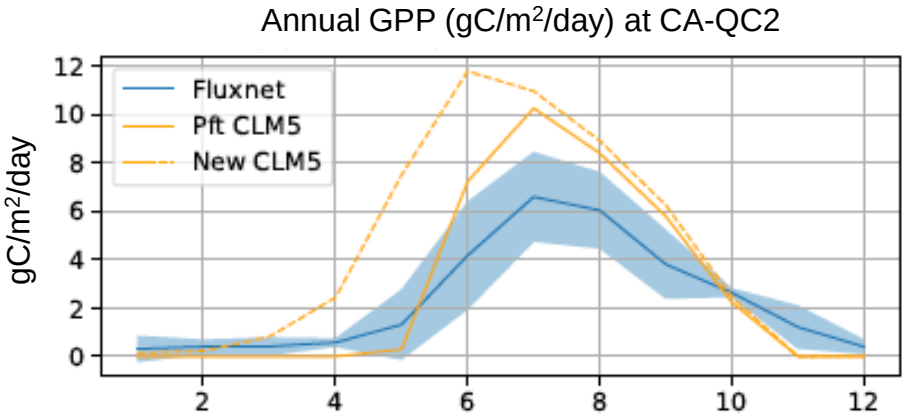
$$GDD_{sum}^{n} = \begin{cases} GDD_{sum}^{n-1} + (T_{s,3} - TKFRZ)\, f_{day} & \text{for } T_{s,3} > TKFRZ \\ GDD_{sum}^{n-1} & \text{for } T_{s,3} \leq TKFRZ \end{cases} \quad (20.46)$$

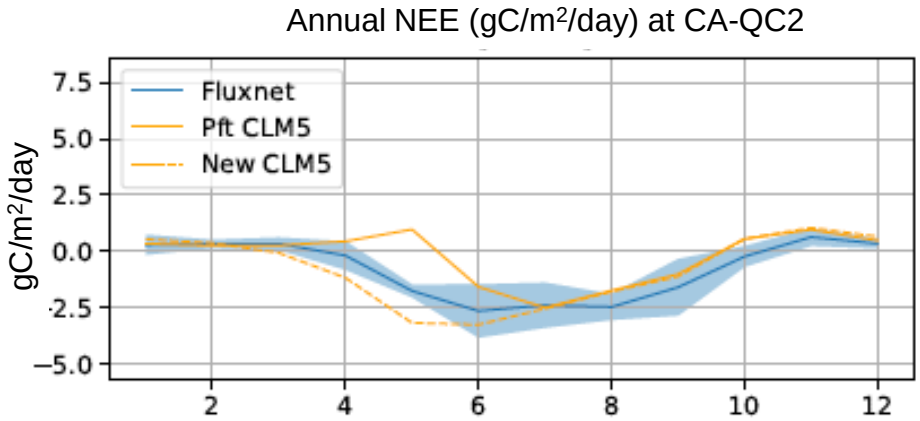
where $T_{s,3}$ (K) is the temperature of the third soil layer, and $f_{day} = \Delta t / 86400$. The onset period is initiated if $GDD_{sum} > GDD_{sum\_crit}$, where

$$GDD_{sum\_crit} = \exp\left(4.8 + 0.13\, (T_{2m,ann\_avg} - TKFRZ)\right) \quad (20.47)$$

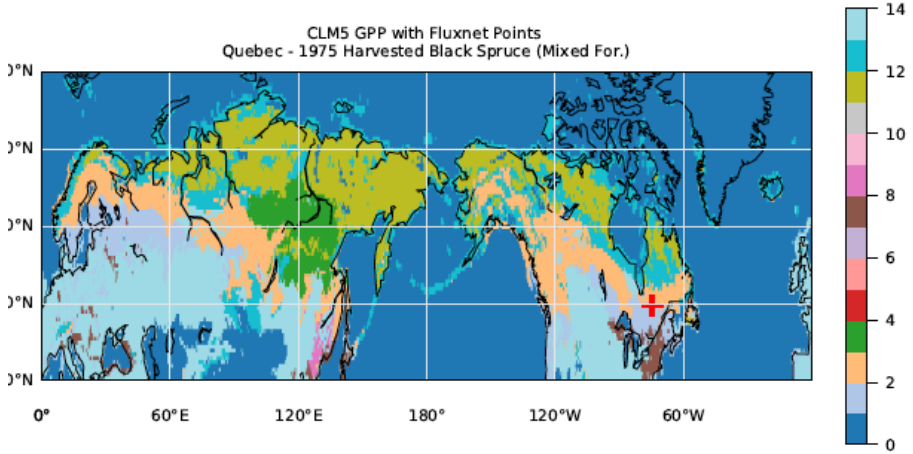
- Based on White et al. 1997, which used climatology from 1990-1992 over the continental United States
- This equation relies on a relationship between annual temperature and soil temperature

Simulation with no GDD threshold:





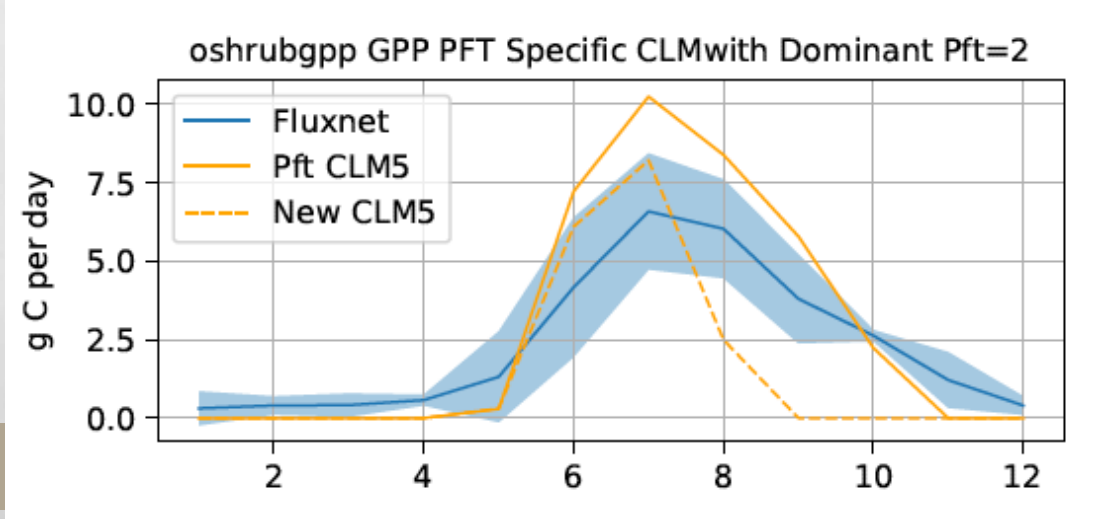
- CLM is very sensitive to the onset threshold
- Choosing one more appropriate for the Arctic can also fix the spike in NEE in spring



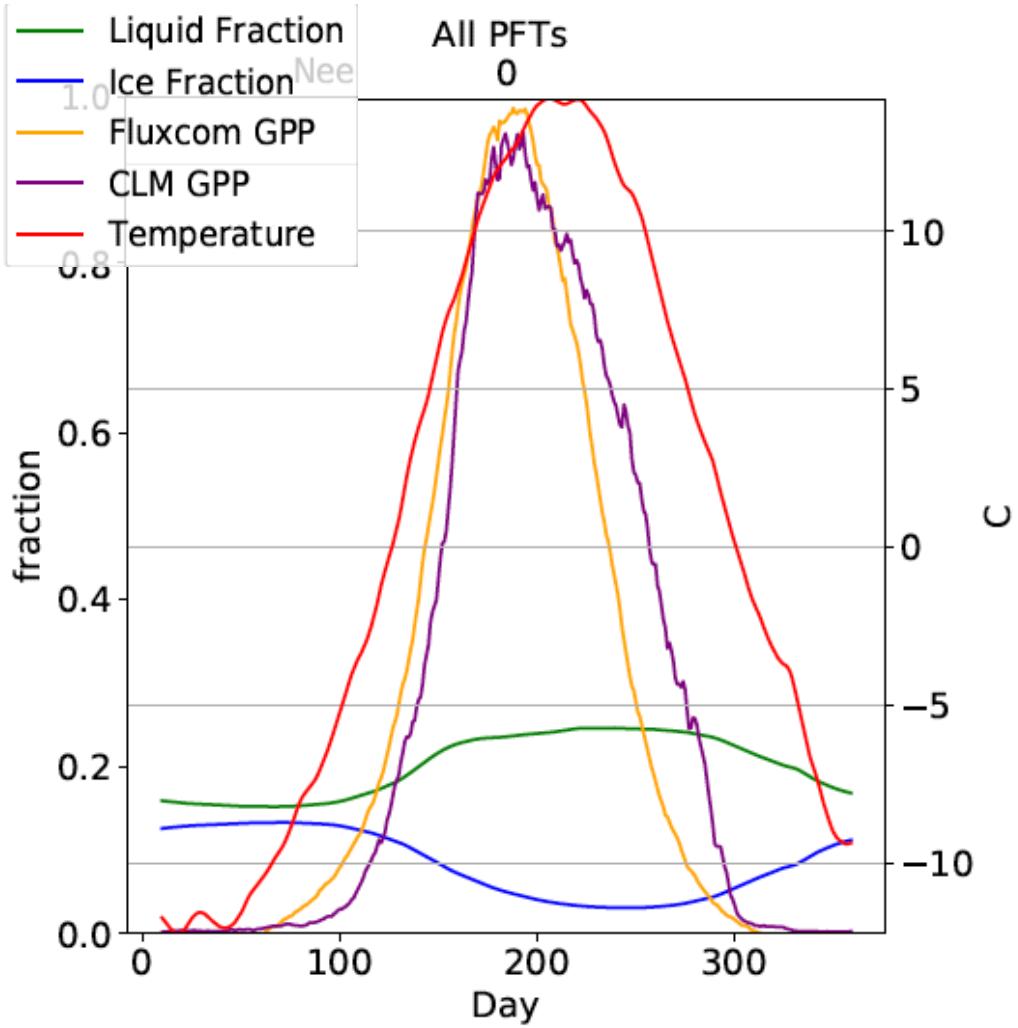
Offset begins when daylight is less than 655 min or <11hrs

- This applied over the whole globe as based on White et al. (1997), but maybe it should be different for the Arctic, through a latitudinal gradient
- Jan Eitel et. al (2019): Proximal remote sensing of tree physiology at northern treeline: Do late season changes in the photochemical reflectance index (PRI) respond to climate or photoperiod?

What if we allow offset to occur at 15hrs?

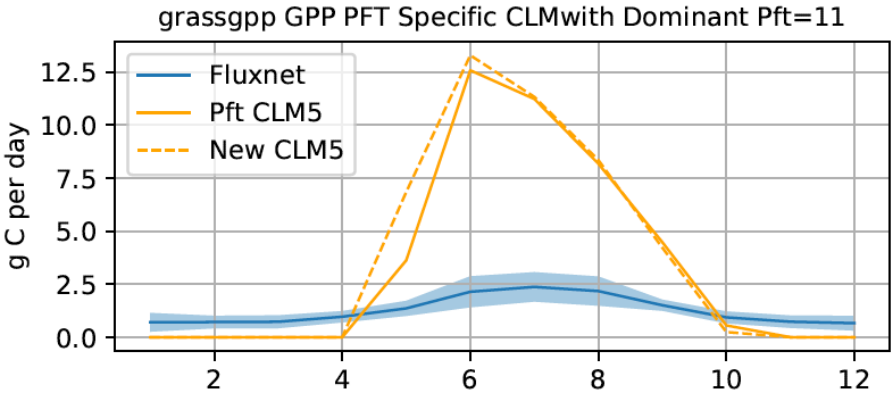


Can we define a more mechanistic relationship between phenology and climate variables?

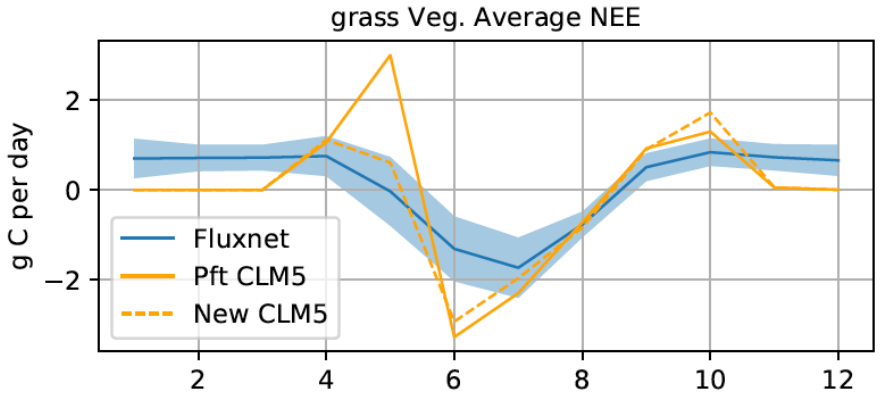


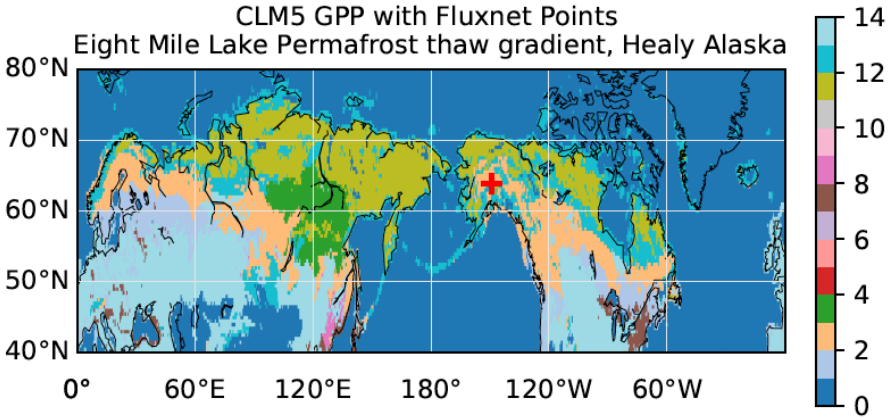
- We take onset from FluxCom and compare it against soil variables like temperature, liquid water fraction, and ice fraction.
- It appears onset occurs when the lagged soil temperature is above freezing.
- Offset appears more difficult to pin down here

Testing onset when ground is no longer frozen at high latitudes



- Changes in both onset and offset are implemented here.
- Offset was chose to be 13 hours, but is not quite right.

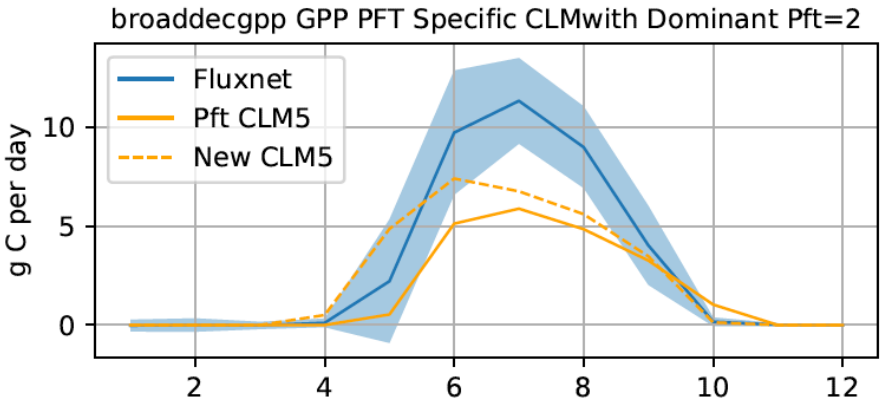


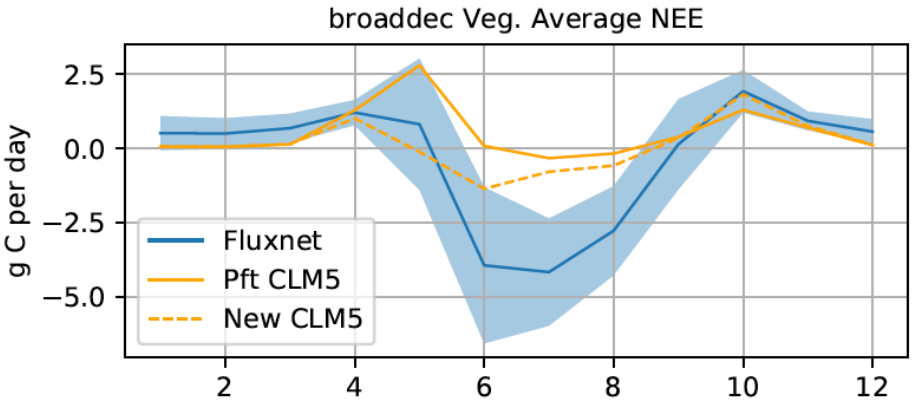


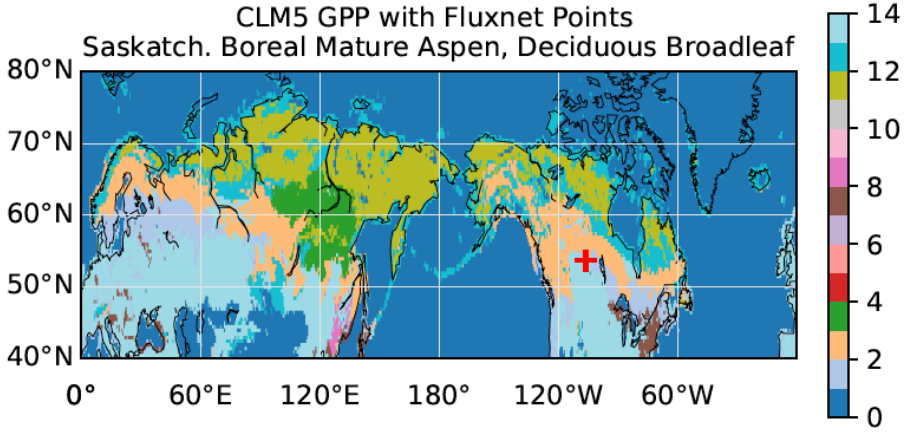
- Onset timing is better and greatly reduces the NEE spike in spring, but the grasses and shrubs are actually even more productive.

Putting onset and offset together in the Boreal

- The onset is not quite right here, but is likely due the simplistic threshold in place.
- Offset of 13 hours works very well here, but a combined light and temperature limit is probably better.

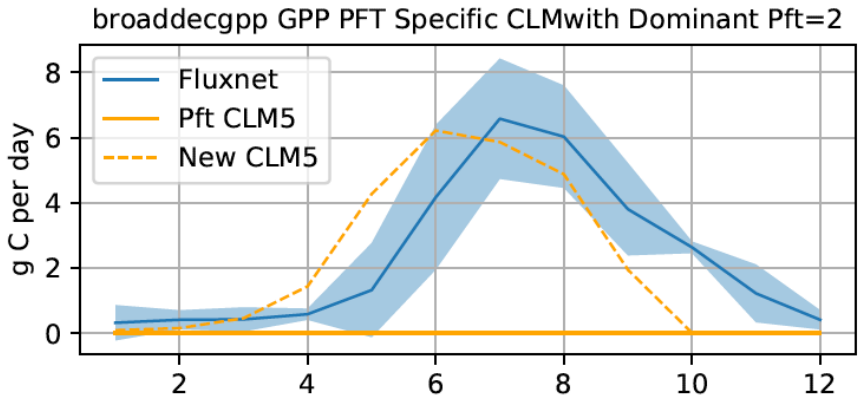


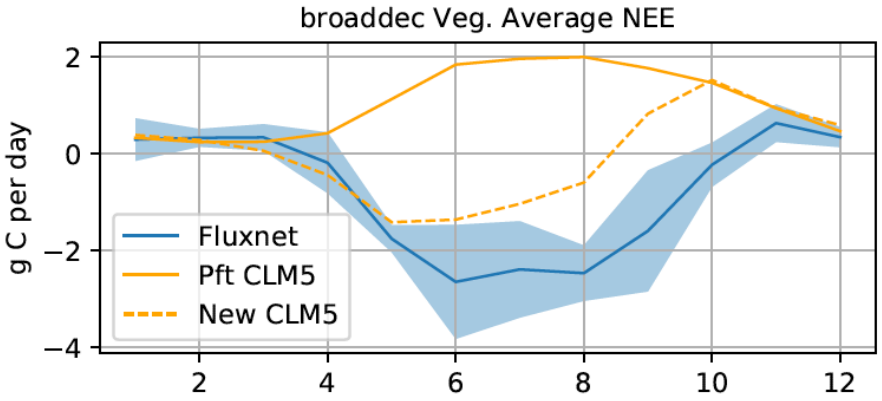




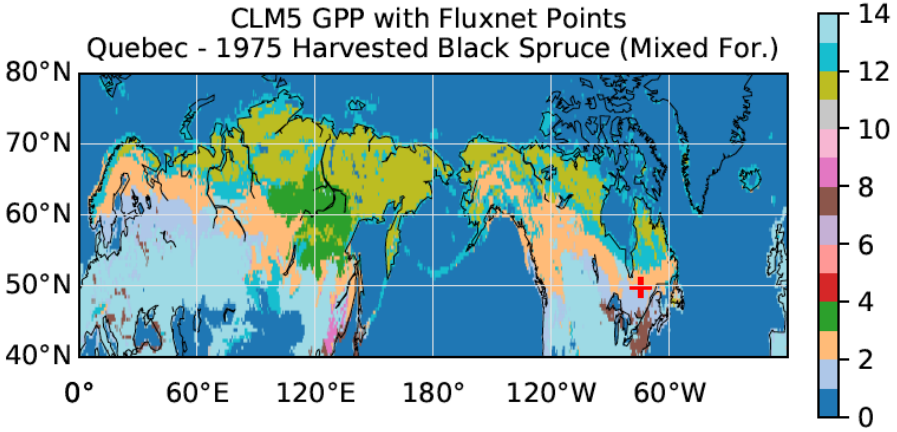
Response of “Dead” Zones

- Fixing the timing of onset/offset appears correct the dead zones

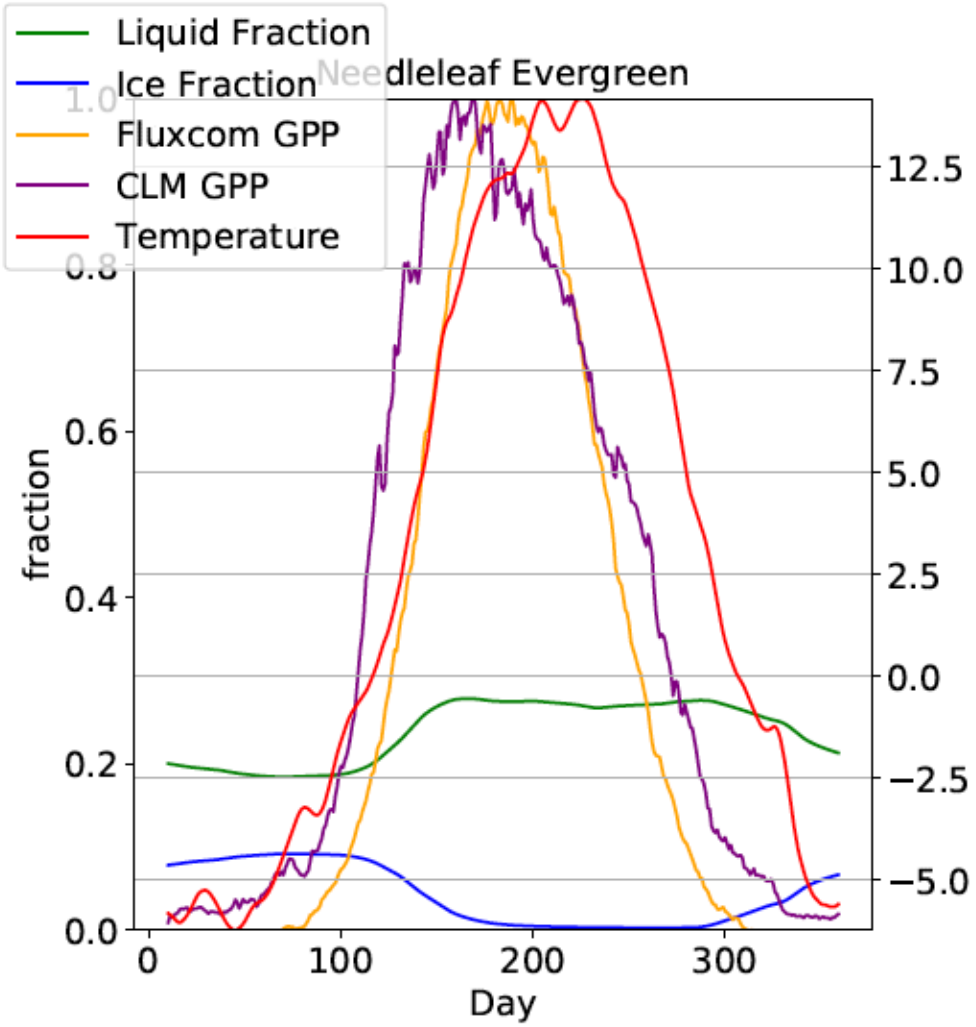




- Running CLM with this new onset/offset through the 20th Century allows for live PFTs.
- But onset is too early now.



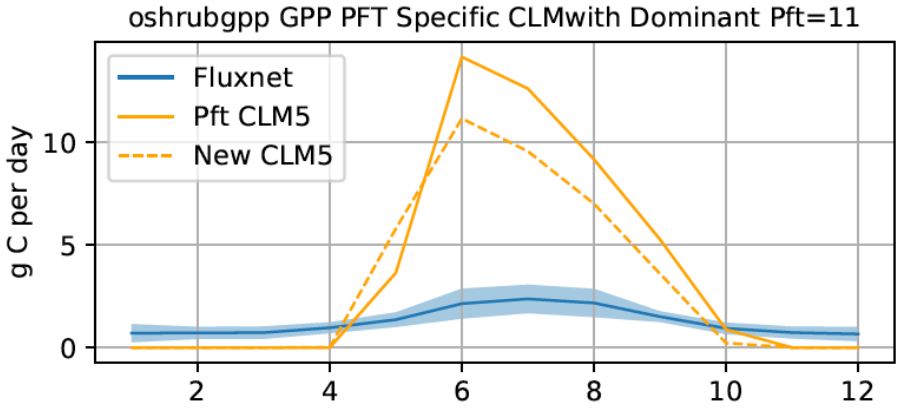
Can we add onset to the needleleaf evergreen scheme?

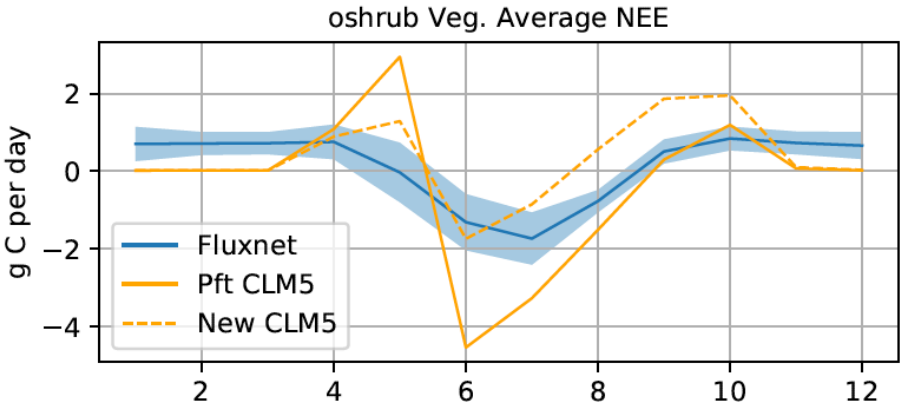


- The needleleaf evergreen scheme has no onset restriction and GPP increases early.
- Adding thresholds for onset and offset may help the evergreen timing.

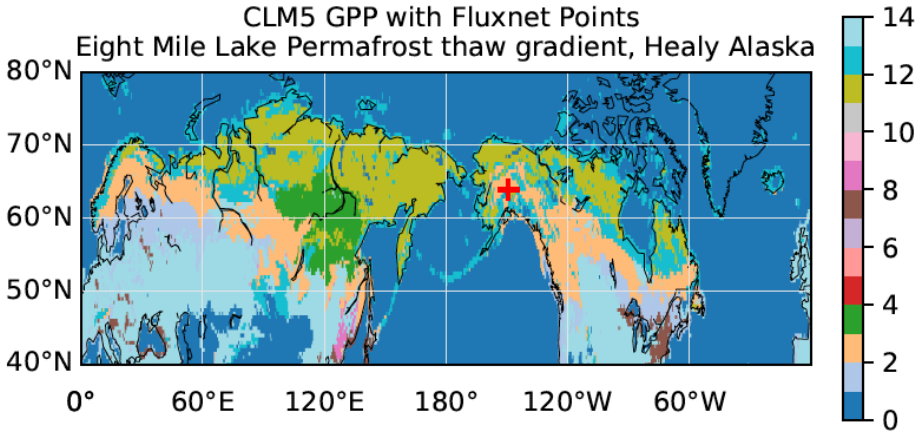
Grasses and Shrubs are too Productive

- Can we tune parameters to make the grasses and shrubs less productive?





- Modifying some of the tuned parameters in CLM5.0 can reduce productivity in the grasses, but further examination is needed.



Summary of Issues

1. Shrubs and deciduous trees have a late GPP onset
   - Onset with a soil temperature threshold makes timing and productivity better, but needs more work.
2. Generally, all the PFTs appear to stay productive for too long in the Fall.
   - Offset with a photoperiod threshold better suited for the Arctic performs better, but could more dynamic with a temperature threshold.
3. Large areas of “dead” PFTs
   - Fixing onset and offset appears to keep PFTs alive
4. Grasses and shrubs are too productive.
   - Their parameters likely need to be tuned.

Questions and Comments?: lbirch@whrc.org

Future Plans

Model Development

- Additional point simulations of the dead zones and then gridded simulations to examine onset/offset.
- Examination of algorithms and parameters of productivity and respiration at flux tower points spanning the whole pan Arctic

Addressing the Seasonal CO_2 Amplitude

- Comparison of CLM with fall/winter respiration from Natali et al. (in review)
- With less biases in CLM, we will begin diagnosing the mechanisms affecting the seasonal CO_2 amplitude over the Arctic-Boreal Zone

Thanks for listening!

Questions and Comments?: lbirch@whrc.org