Use of CLM Carbon Dynamics in the Land Component of the NASA GMAO Earth System Model

Fan-Wei Zeng[1,2]

Randal D. Koster[2], Eunjee Lee[2,3], Melanie B. Follette-Cook[4,5], Brad Weir[2,3], Peter R. Colarco[5], Lesley Ott[2], Benjamin Poulter[6]

[1] Science Systems and Applications, Inc.

[2] Global Modeling and Assimilation Office, NASA's Goddard Space Flight Center

[3] Goddard Earth Sciences Technology and Research, Universities Space Research Association

[4] Morgan State University

[5] Atmospheric Chemistry and Dynamics Laboratory, NASA's Goddard Space Flight Center

[6] Biospheric Sciences Laboratory, NASA's Goddard Space Flight Center

fanwei.zeng@nasa.gov

Overview

1. Introduction of Catchment-CN (Catchment LSM & CLM CN)

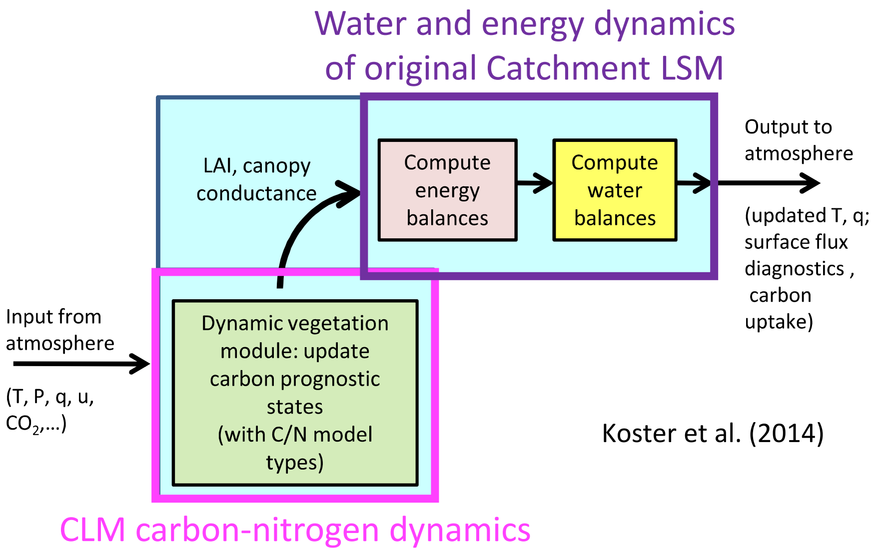
2. Performance of Catchment-CN4.0 (CN from CLM4)
   - GPP spatial and seasonal variability
   - NBP seasonal variability

3. Performance of Catchment-CN4.5 (CN from CLM4.5)
   - Site-level GPP seasonal variability
   - Fire burned area and carbon emissions

All the results are for two-leaf canopy

Catchment-CN model

- Land component in NASA Goddard Earth Observing System, Version 5 (GEOS)
- Merger of Catchment LSM & CLM CN dynamics
- The Catchment LSM:
  - Calculates all the water and energy balances
  - Provides the CN model:
    - Soil moisture and temperature
    - Canopy temperature
    - Snow depth and coverage
- The CN model:
  - Calculates all the carbon and nitrogen fluxes and reservoirs, and
  - Provides the Catchment LSM LAI and canopy conductance.

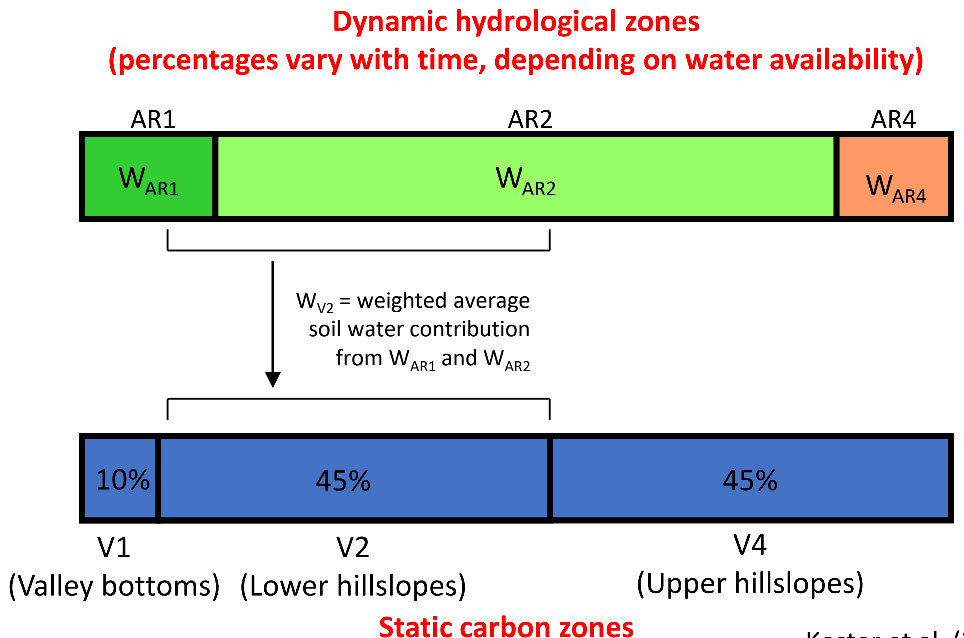


⇨ **We do <u>not</u> use CLM soil layer structure, hydrology, energy balance calculations, etc..**
⇨ **We use <u>only</u> CLM photosynthesis, stomatal conductance, and C and N flux and reservoir calculations.**

Unique feature of our implementation

Each basic Catchment land surface element is separated into

- Three dynamic hydrological sub-areas that vary with time depending on water availability
- Three non-dynamic sub-areas (10%, 45%, 45%); independent carbon states are saved in each.

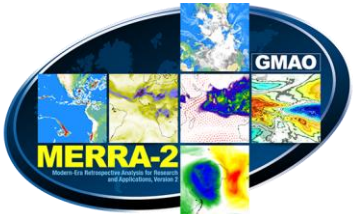


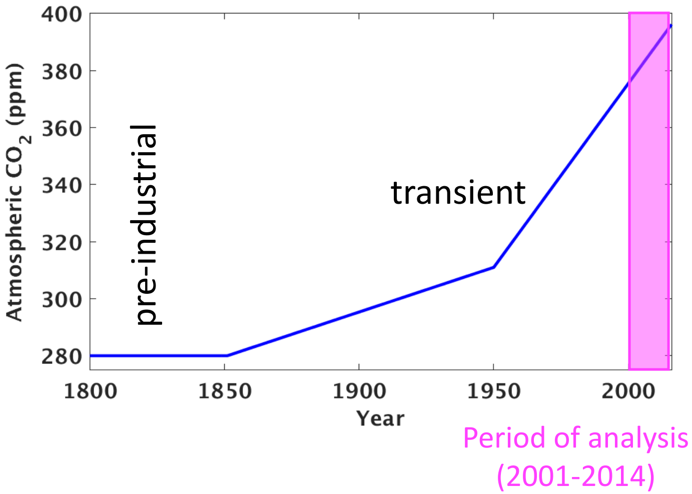
Koster et al. (2014)

Our treatment of subgrid-scale hydrology can thus capture topographical effects on vegetation distributions.

Simulation using Catchment-CN4.0

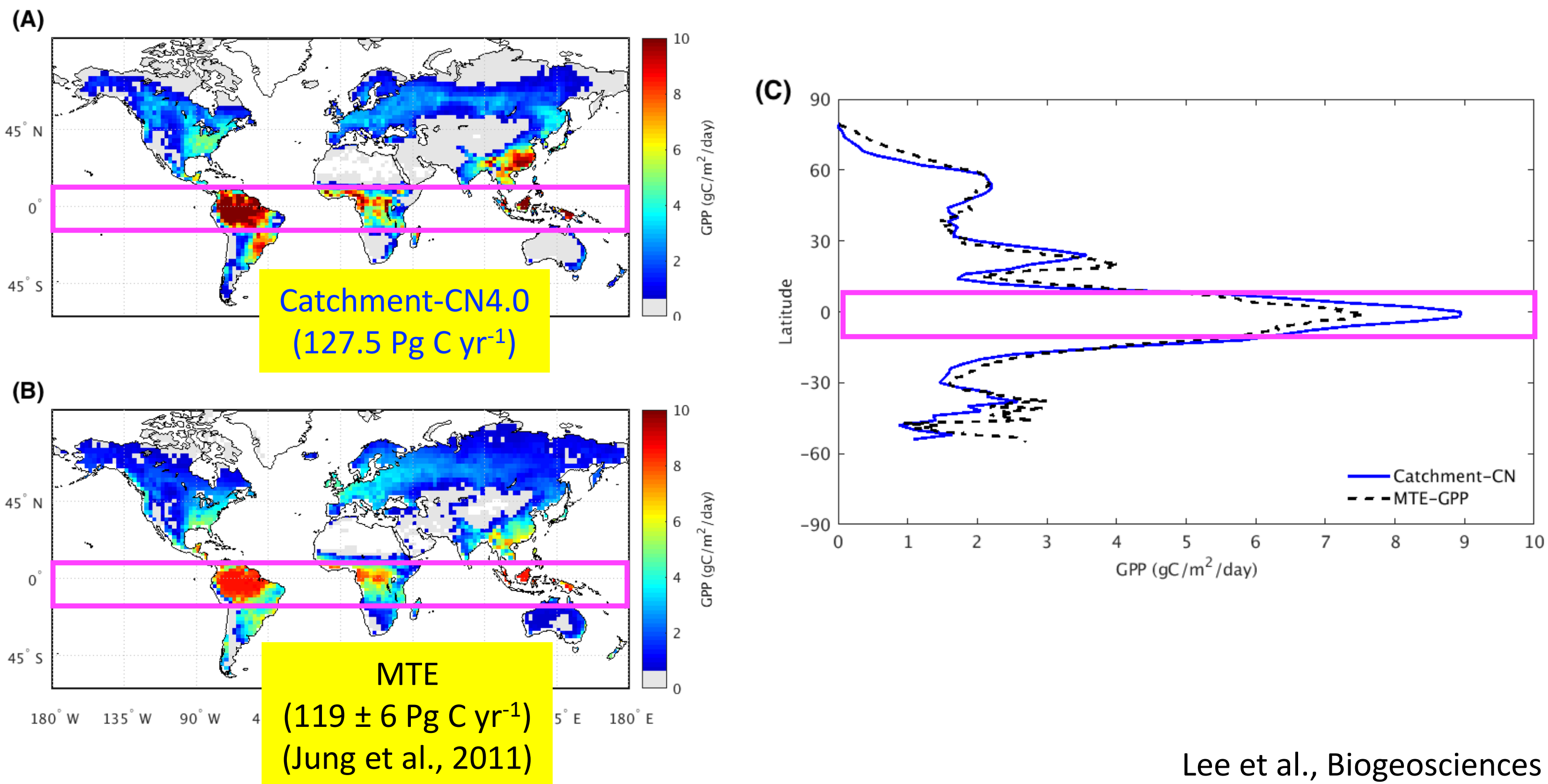
1. Meteorology forcing: 0.5° ×0.625°, hourly
   - NASA's MERRA-2 reanalysis
     - Modern-Era Retrospective analysis for Research and Applications, version 2 (Gelaro et al., 2017).
     - https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/
   - Precipitation
     - Estimates from GEOS-5 corrected with gauge observations (Reichle et al., 2017)
2. Atmospheric CO_2: 2° ×3°
   - Before 2001: Global annual mean approximates historical record (see plot). Spatial, seasonal, and sub-diurnal CO_2 variations extracted from CarbonTracker (CT).
   - 2001-2014: 3-hourly, spatially varying CT CO_2
3. Land cover (static):
   - From European Space Agency, mapped into the CLM4 vegetation classes (Mahanama et al., 2015).
4. Resolution of simulation:
   - Spatial: irregular catchments on average of order 20 km
   - Temporal:
     - Catchment: 7.5 min
     - CN: 90 min





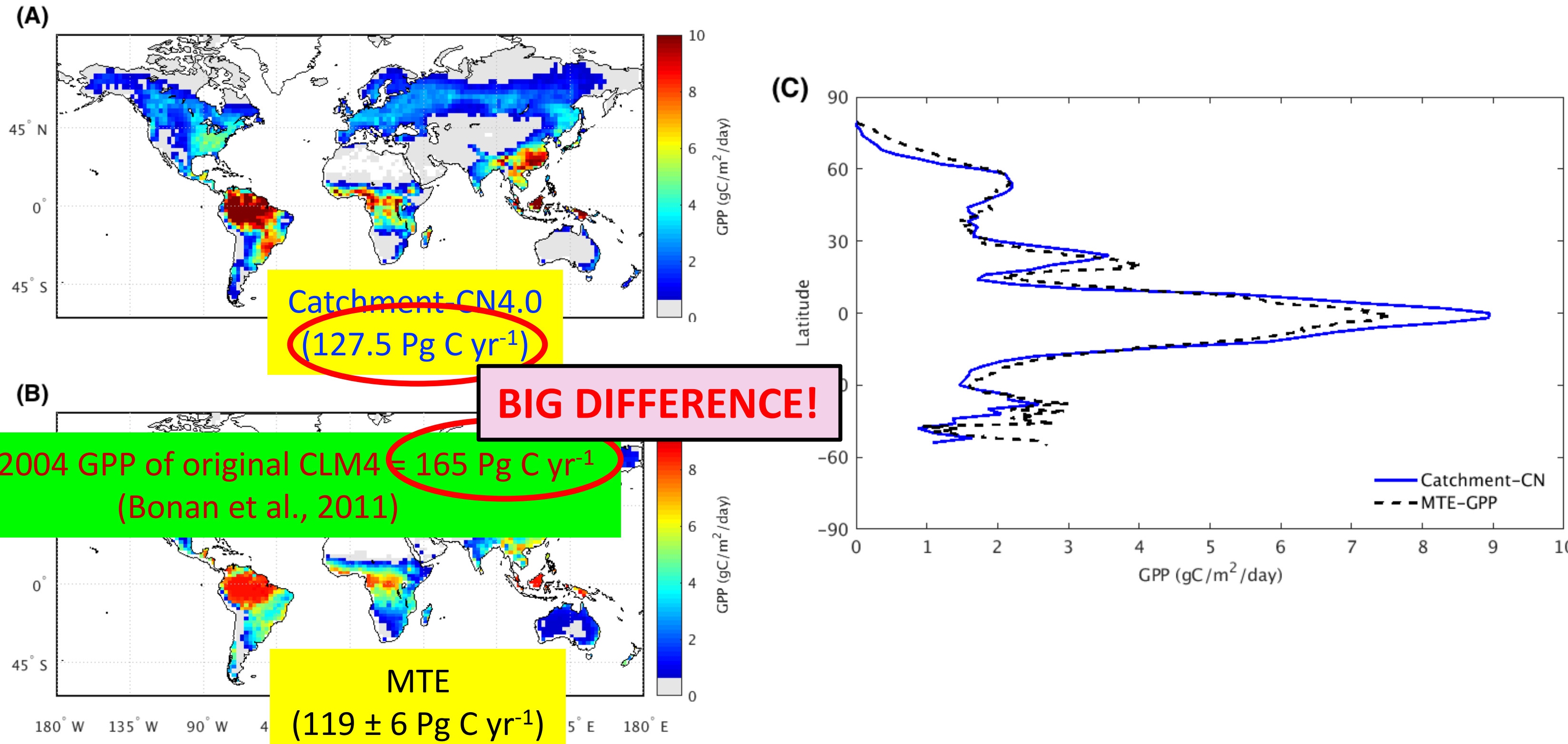
Following https://www.eea.europa.eu/data-and-maps

Catchment-CN4.0 model performance GPP spatial patterns (2002-2011)



Lee et al., Biogeosciences 2018

Catchment-CN4.0 model performance GPP spatial patterns (2002-2011)



Catchment-CN4.0 (127.5 Pg C yr^{-1})

BIG DIFFERENCE!

1982-2004 GPP of original CLM4 = 165 Pg C yr^{-1} (Bonan et al., 2011)

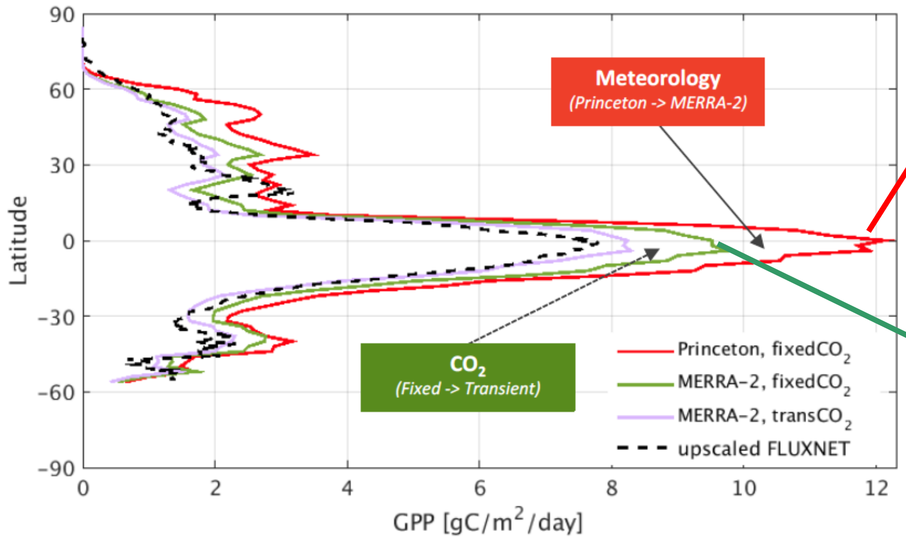
MTE (119 ± 6 Pg C yr^{-1}) (Jung et al., 2011)

Lee et al., Biogeosciences 2018

Possible reasons for different global GPP between Catchment-CN4.0 and CLM4

1. Different energy balance calculations, hydrology, etc.…

2. (More likely) Different meteorological forcing data (as we've determined from multiple offline analyses).



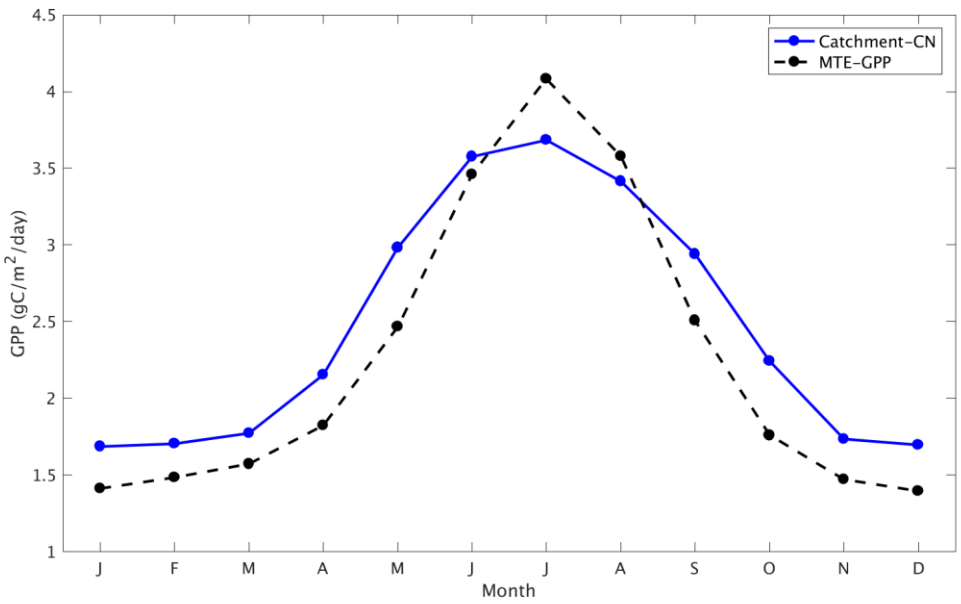
GPP simulated using Princeton forcing which is similar to Qian et al. (2006) used in Bonan et al. (2011)

GPP simulated using MERRA-2 forcing and precipitation in Reichle et al. (2017)

https://gmao.gsfc.nasa.gov/research/science_snapshots/est_GPP.php

Catchment-CN4.0 model performance GPP seasonal variability (2002-2011)

- Agrees well with MTE
- Smaller amplitude:
  - Lower in July and August
  - Higher in other months of the year

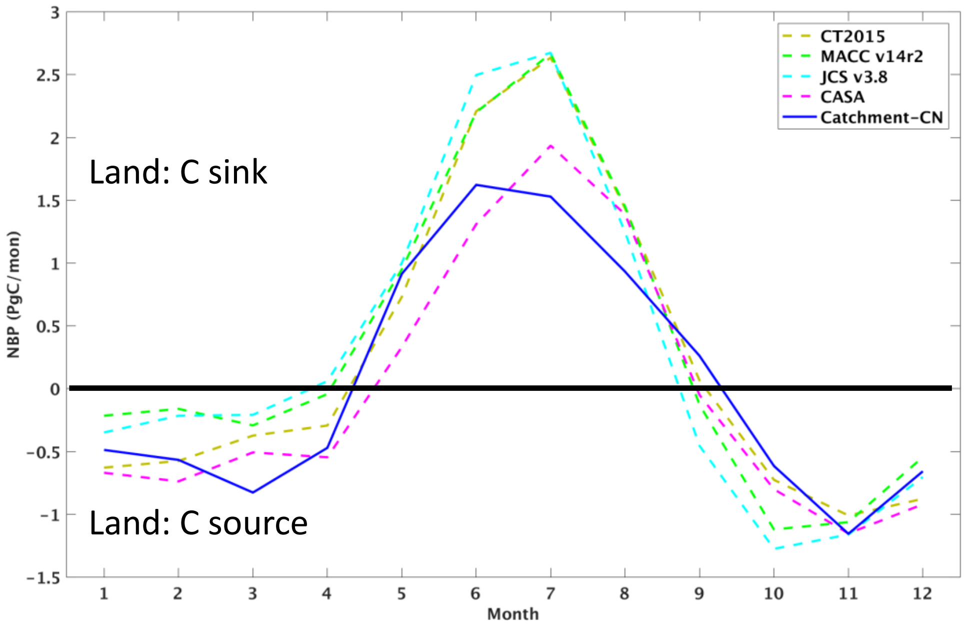


Lee et al., Biogeosciences 2018

Catchment-CN4.0 model performance NBP seasonal variability (2004-2014)

NBP = GPP - Ra - Rh - Fire
Ra: autotrophic respiration
Rh: heterotrophic respiration

- Phasing agrees well with inversions, e.g. spring green-up
- Sink size smaller than inversions



Lee et al., Biogeosciences 2018

Science analyses performed to date with Catchment-CN4.0

1. Impacts of hydroclimate on the means and variability of GPP (Koster et al., 2014)
2. Impacts of vegetation initialization on subseasonal forecast (Koster and Walker, 2015)
3. Impacts of atmospheric CO_2 variability on simulated GPP and NBP (Lee et al., 2018)
4. Studies with coupled land-atmosphere system: Impacts of drought on terrestrial carbon fluxes and atmospheric CO_2 variability (2018 AGU talk)

⇨ This whole effort fits in with growing research direction in GMAO: carbon cycle science

References:

- Koster et al. (2014) J of Climate, Hydroclimatic controls on the means and variability of vegetation phenology and carbon uptake
- Koster and Walker (2015) Journal of Hydrometeorology, Interactive vegetation phenology, soil moisture, and monthly temperature forecasts
- Lee et al. (2018) Biogeosciences, The impact of spatiotemporal variability in atmospheric CO_2 concentration on global terrestrial carbon fluxes

Simulation using Catchment-CN4.5 two-leaf canopy

1. Meteorology forcing, land cover, and temporal resolutions:
   - Same as the previous Catchment-CN4.0 simulation

2. Atmospheric CO_2: 390ppm

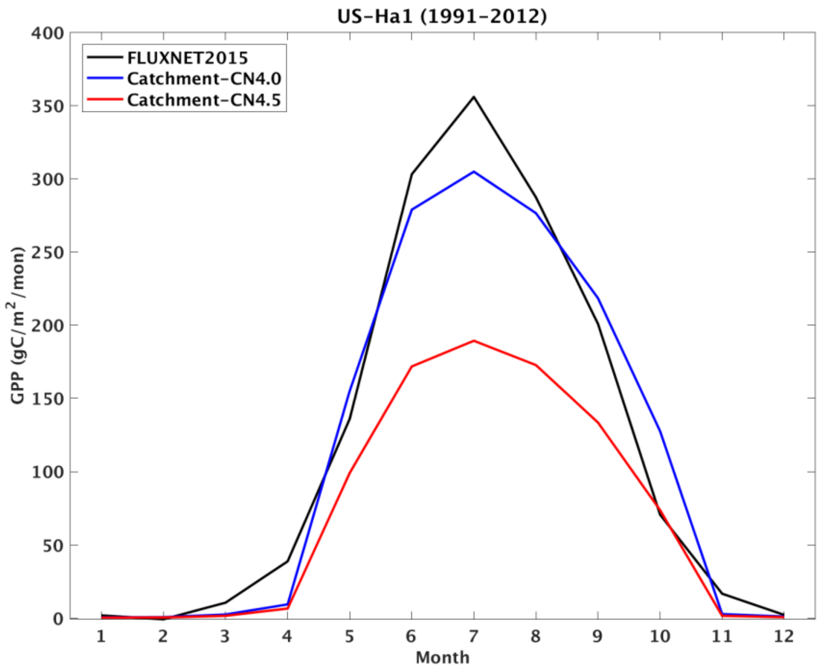
3. Spatial resolution: 0.5° ×0.5°

4. Spun up using 1980 initial conditions from a Catchment-CN4.0 simulation that used 390ppm CO_2

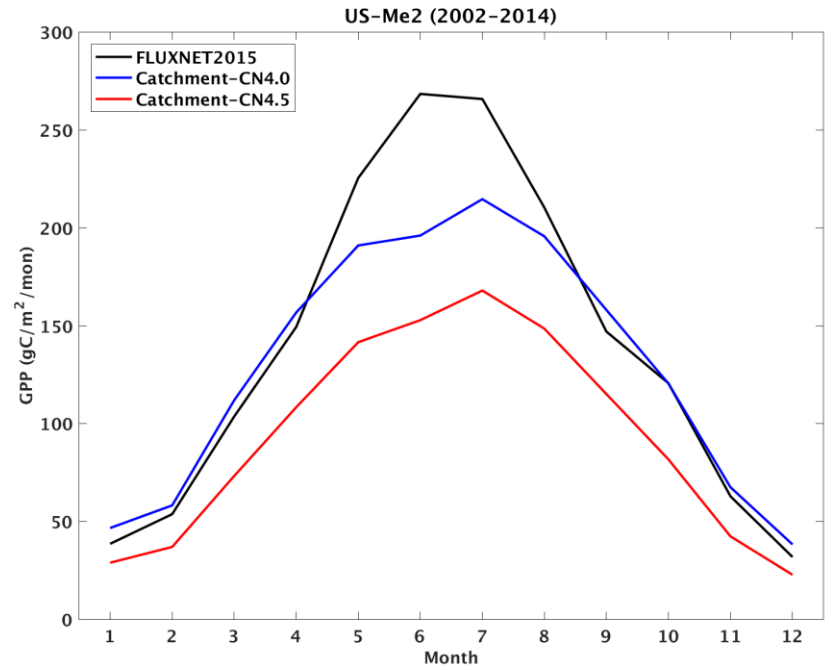
5. Compare with the same set-up using Catchment-CN4.0 – different from set-up described above to isolate sensitivity

Catchment-CN4.5 model performance GPP seasonal variability (site-level)

(42.54N, 72.17W)
Deciduous Broadleaf Forest



(44.45N, 121.56W)
Evergreen Needleleaf Forest



Our main issue with CLM4.5 and global GPP

NCAR

CLM4 C,N | CLM4 Energy, Water | Qian et al. (2006) Forcing data

⇨ GPP=165 Pg C yr^{-1}

(Bonan et al. 2011)

TOO HIGH!

Update to CLM4.5

CLM4.5 C,N | CLM4 Energy, Water | Qian et al. (2006) Forcing data

⇨ GPP=130 Pg C yr^{-1}

(Bonan et al. 2011, 2012)

About right

GMAO

CLM4 C,N | Catchment Energy, Water | MERRA-2 Forcing data

⇨ GPP=127 Pg C yr^{-1}

(Lee et al. 2018)

About right

Update to CLM4.5

CLM4.5 C,N | Catchment Energy, Water | MERRA-2 Forcing data

⇨ GPP= …

TOO LOW!

Our main issue with CLM4.5 and global GPP

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CLM4 C,N | CLM4 Energy, Water | Qian et al. (2006) Forcing data

⇨ GPP=165 Pg C yr^{-1} **TOO HIGH!**

(Bonan et al. 2011)

Update

CLM4.5 C,N | CLM4 Energy, Water | Qian et al. (2006) Forcing data

⇨ GPP=130 Pg C yr^{-1} **About right**

(Bonan et al. 2011, 2012)

GMAO

CLM4 C,N | Catchment Energy, Water | MERRA-2 Forcing data

⇨ GPP=127 Pg C yr^{-1} **About right**

(Lee et al. 2018)

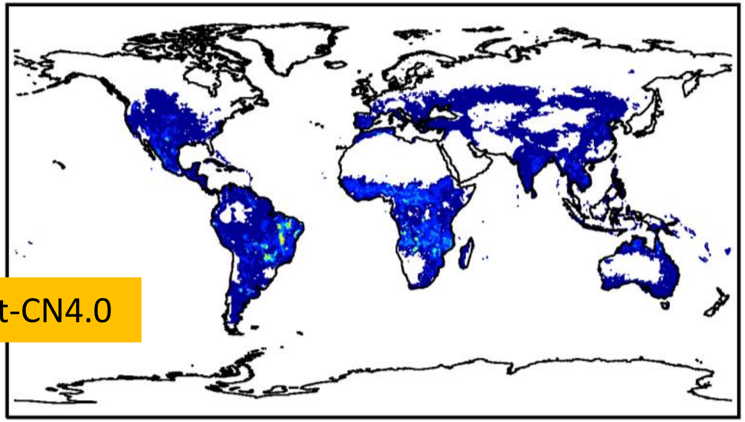
CLM4.5 C,N | Catchment Energy, Water | MERRA-2 Forcing data

⇨ GPP= … **TOO LOW!**

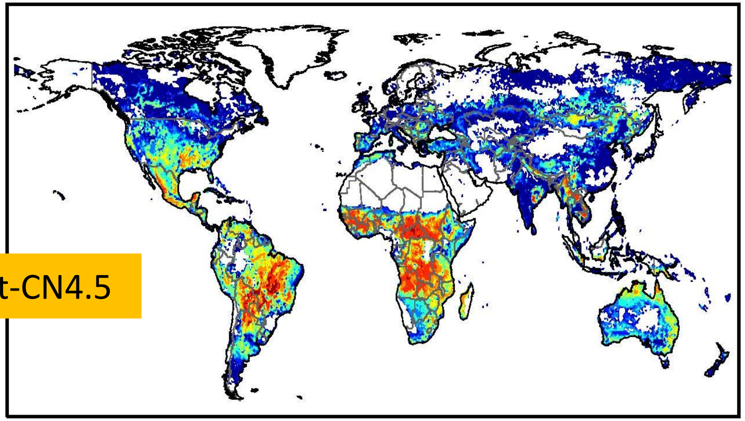
We need your advice on how to modify the carbon and nitrogen physics in Catchment-CN4.5 to return GPP to a reasonable value!

Catchment-CN4.5 model performance
Fire burned area (1997-2016)

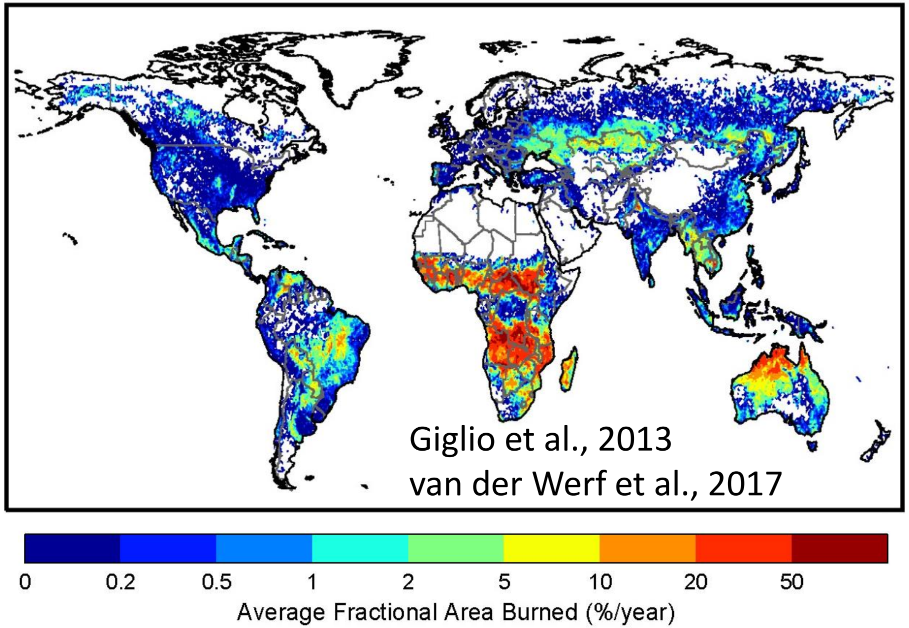
Catchment-CN4.0



Catchment-CN4.5

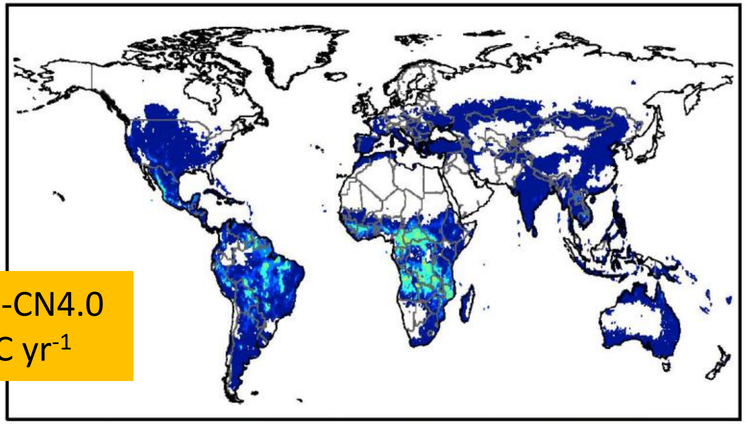


GFED v4.1s

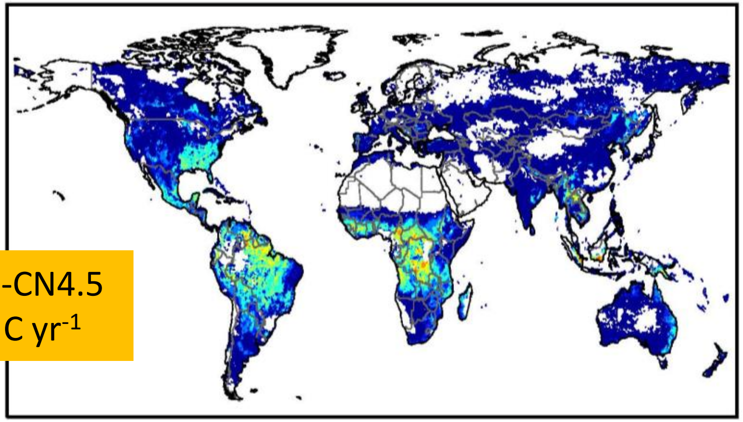


(Credit: Melanie)

Catchment-CN4.5 model performance
Fire carbon emissions (1997-2016)

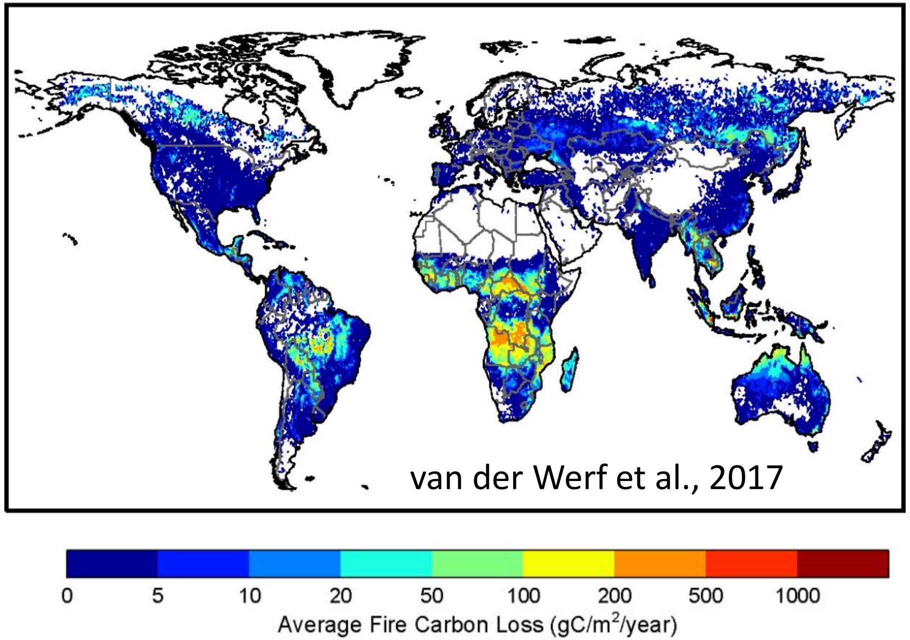


Catchment-CN4.0
~500 Tg C yr^{-1}



Catchment-CN4.5
~1700 Tg C yr^{-1}

GFED v4.1s
~2100 Tg C yr^{-1}



(Credit: Melanie)

Summary

1. Catchment-CN4.0 using MERRA-2 forcing and realistic initial conditions:
   - GPP agrees well with the observation-based MTE GPP in global values, spatial variability and seasonal variability.
   - NBP agrees well with atmospheric inversions in the timing of spring green-up, though the sink size is likely too small.

2. Catchment-CN4.5 using the same meteorology:
   - GPP is too low.
   - Fire burned area and carbon emissions are greatly improved.

3. **Your advice is needed on how to modify the carbon and nitrogen physics in Catchment-CN4.5 to return GPP to a reasonable value.**

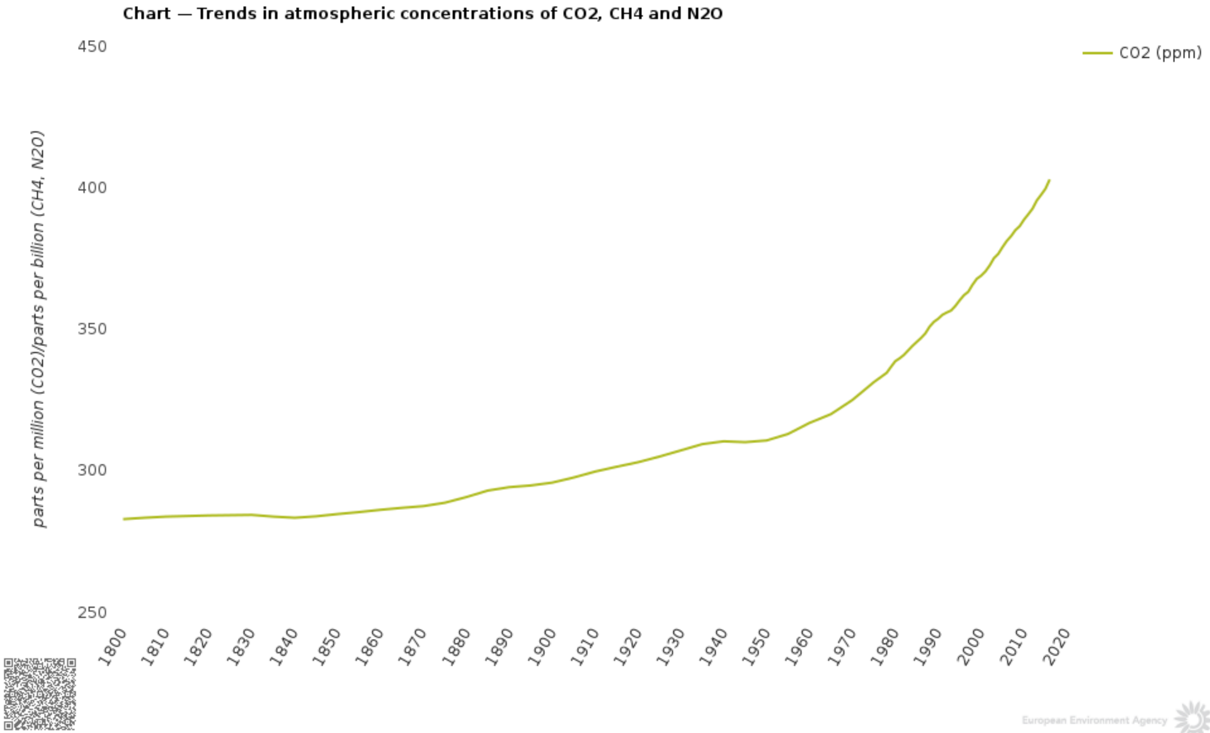
Questions and suggestions?

Thanks!

fanwei.zeng@nasa.gov

Extra slides

European Environment Agency atmospheric CO_2 concentrations



https://www.eea.europa.eu/data-and-maps/daviz/atmospheric-concentration-of-carbon-dioxide-3#tab-chart_5_filters=%7B%22rowFilters%22%3A%7B%7D%3B%22columnFilters%22%3A%7B%22pre_config_polutant%22%3A%5B%22CO2%20(ppm)%20%22%5D%7D%7D

Our modifications to Catchment-CN4.0

1. Respiration:
   - Heterotrophic respiration is prohibited (i.e. set to 0) when the soil water is frozen.

2. Vegetation types:
   - To resolve the issue of occasional odd behavior in stress deciduous types (particularly grass and crop):

Each of the four temperature and moisture stress deciduous types:
Broadleaf deciduous shrub
Cool C3 grass
Warm C4 grass
Crop

→

Moisture stress only
Moisture stress plus a seasonal deciduous trigger

Plant functional types in Catchment-CN

0	bare
1	needleleaf evergreen temperate tree
2	needleleaf evergreen boreal tree
3	needleleaf deciduous boreal tree
4	broadleaf evergreen tropical tree
5	broadleaf evergreen temperate tree
6	broadleaf deciduous tropical tree
7	broadleaf deciduous temperate tree
8	broadleaf deciduous boreal tree
9	broadleaf evergreen temperate shrub
10	broadleaf deciduous temperate shrub [moisture + deciduous]
11	broadleaf deciduous temperate shrub [moisture stress only]
12	broadleaf deciduous boreal shrub
13	arctic c3 grass
14	cool c3 grass [moisture + deciduous]
15	cool c3 grass [moisture stress only]
16	warm c4 grass [moisture + deciduous]
17	warm c4 grass [moisture stress only]
18	crop [moisture + deciduous]
19	crop [moisture stress only]

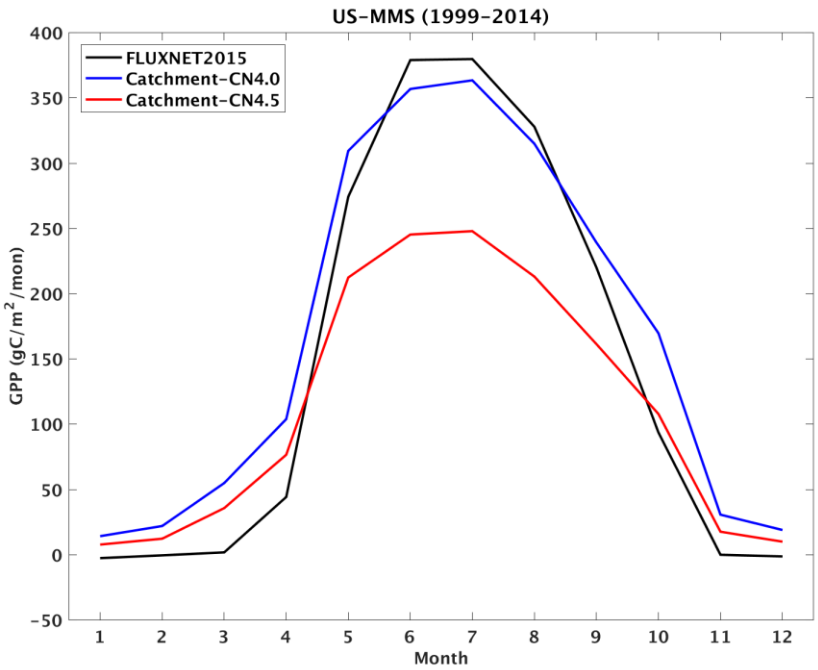
Modification to Catchment-CN4.5 Suggested by Jinyun Tang

We changed the method used in subroutine HYBRID to iterate until intracellular leaf CO_2 converges and thereby produces final values of intracellular leaf CO_2, leaf stomatal conductance and photosynthesis.

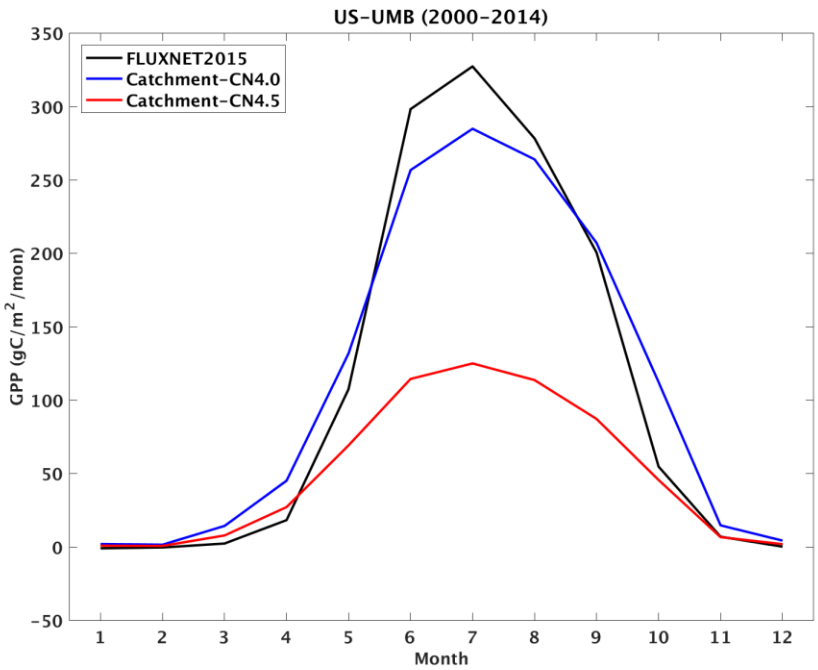
- This modification prevents negative intracellular leaf CO_2 during the iterations.

Catchment-CN4.5 model performance GPP seasonal variability (site-level)

(39.32N, 86.41W)
Deciduous Broadleaf Forest

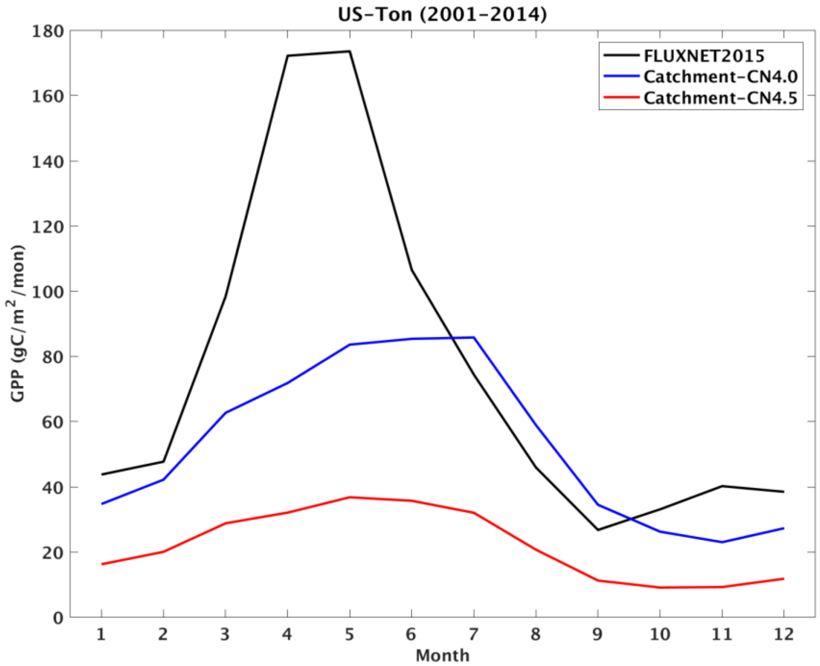


(45.56N, 84.71W)
Deciduous Broadleaf Forest

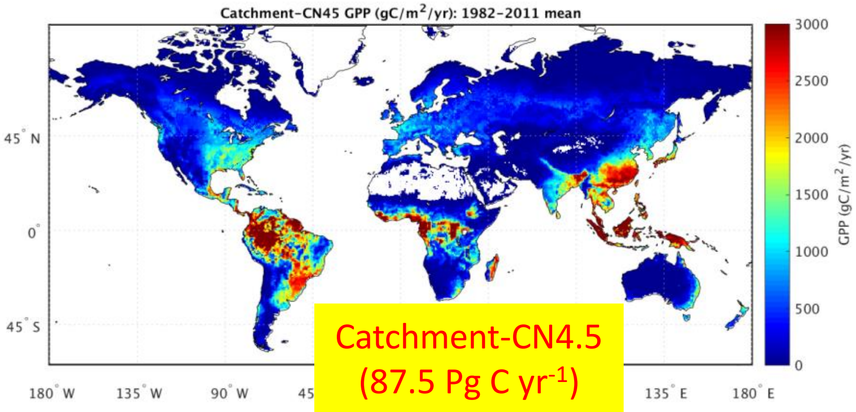


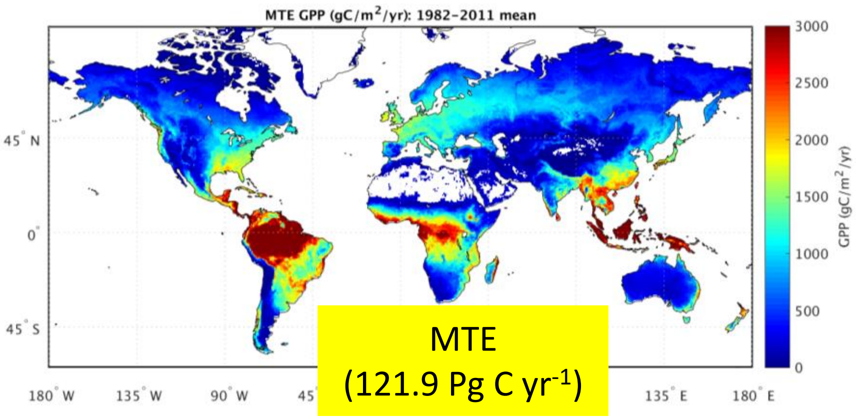
Catchment-CN4.5 model performance GPP seasonal variability (site-level)

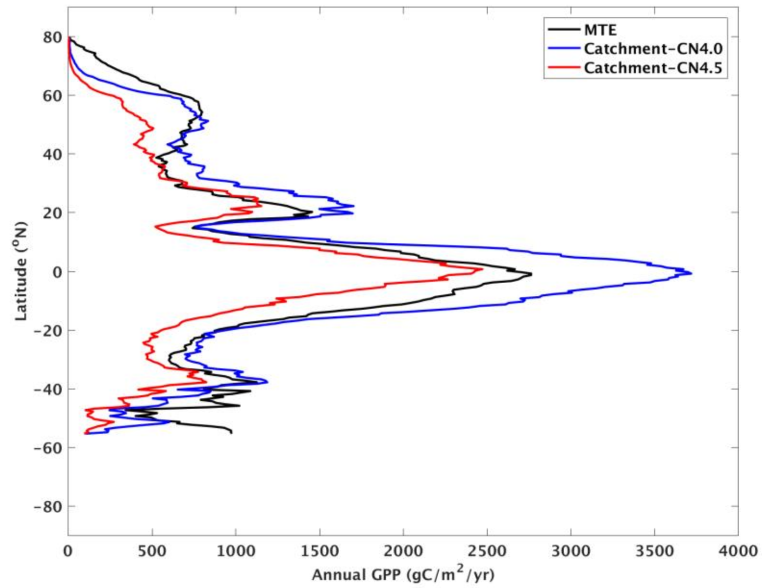
(38.43N, 120.97W)
Woody Savannas



Catchment-CN4.5 model performance
GPP spatial patterns (1982-2011)

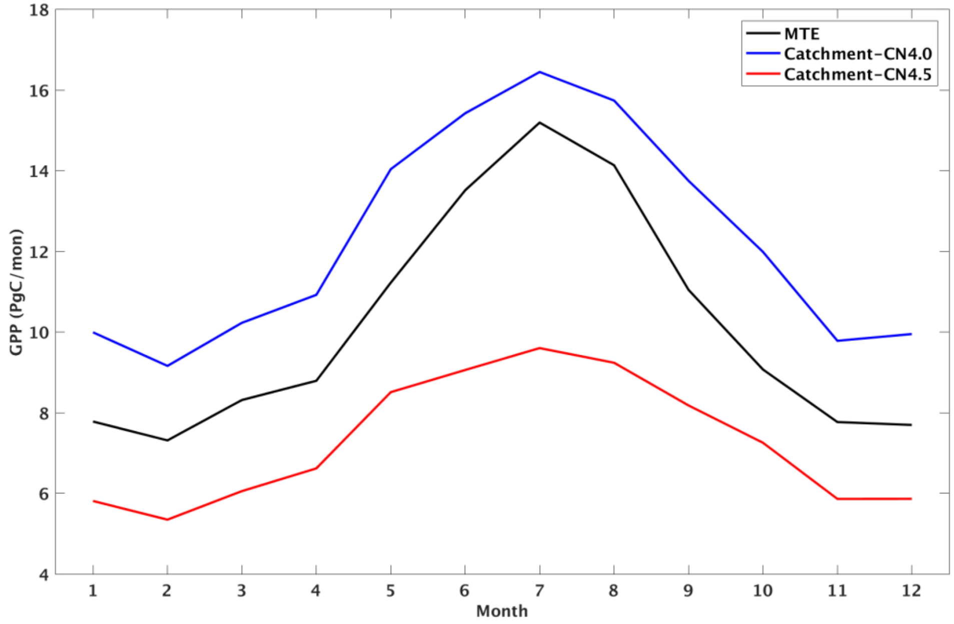




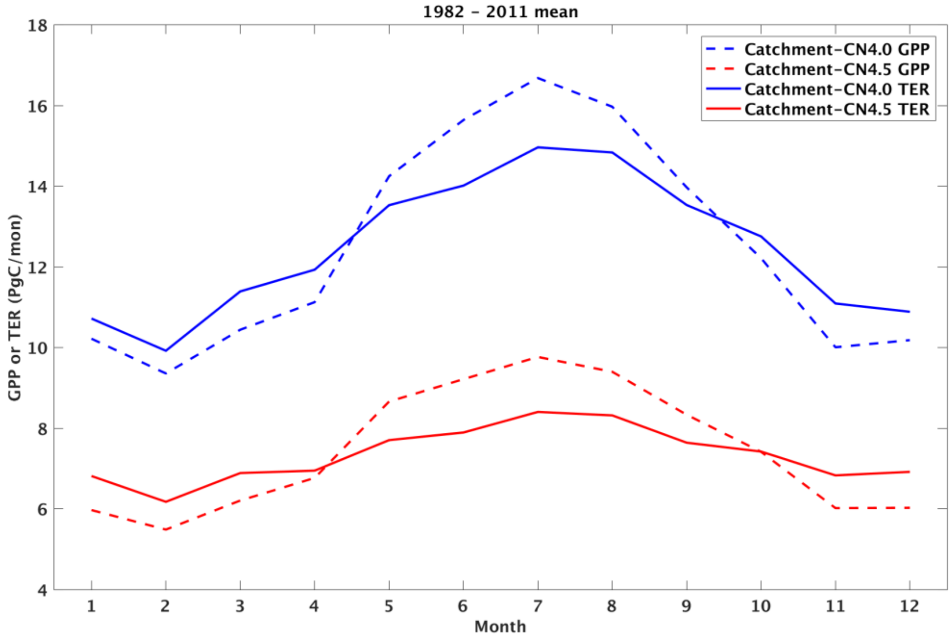


Catchment-CN4.0
(147.5 Pg C yr^{-1})

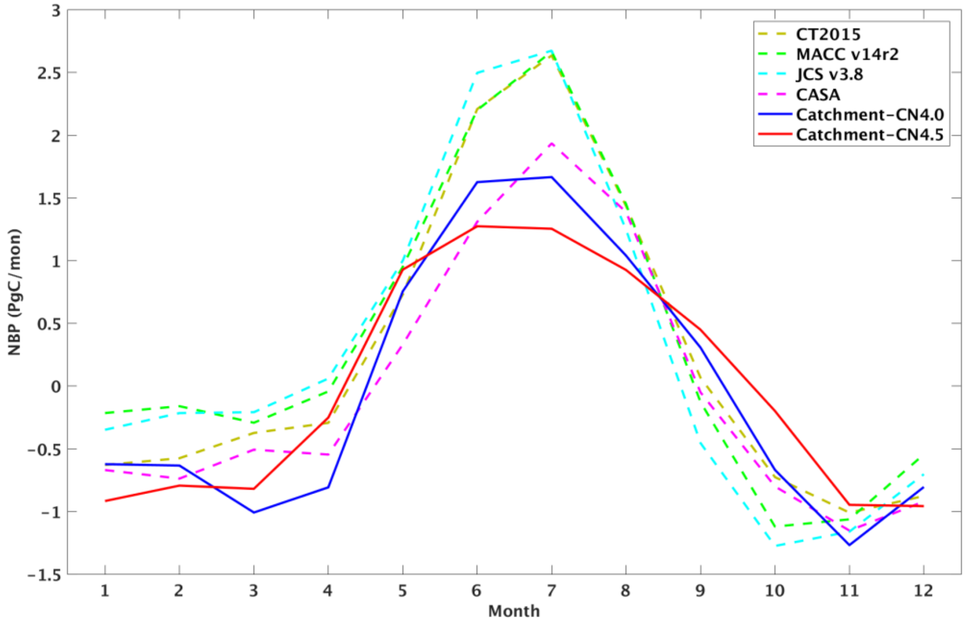
Catchment-CN4.5 model performance GPP seasonal variability (1982-2011)



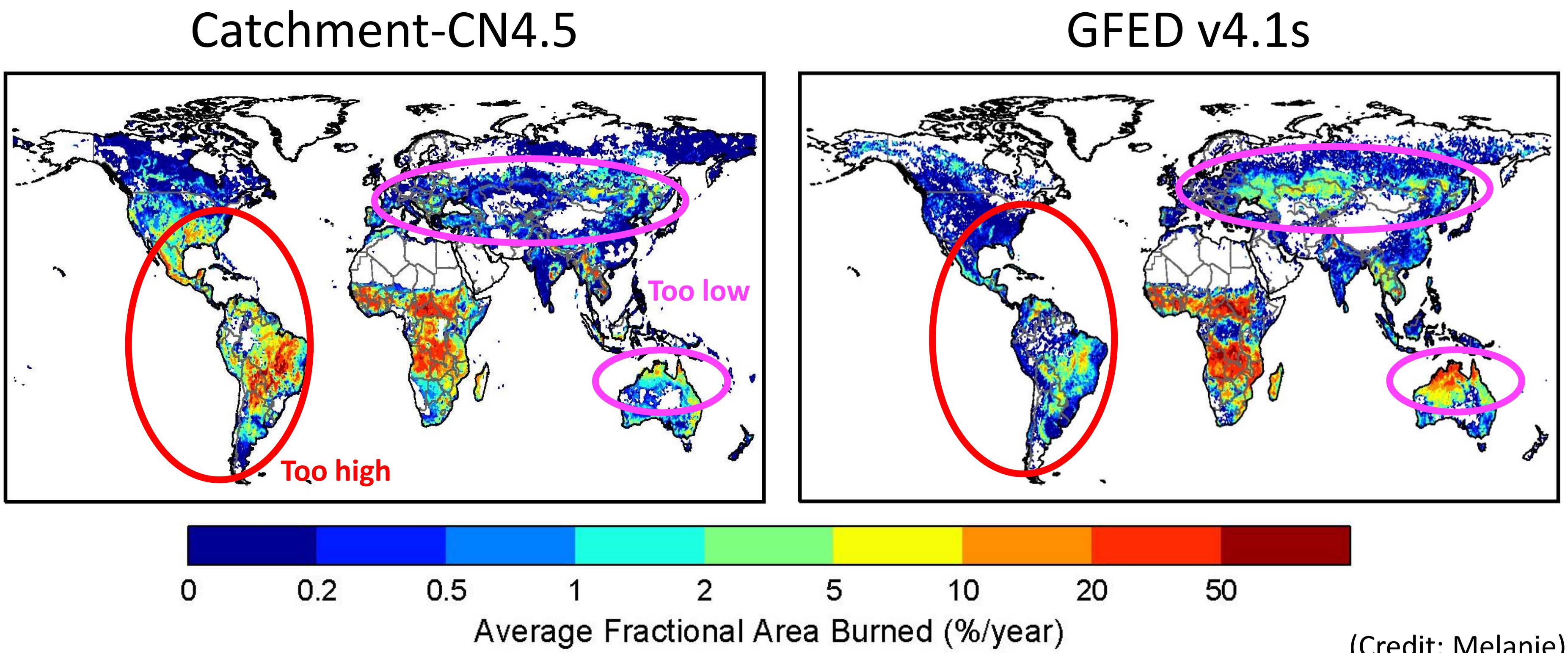
Catchment-CN4.5 model performance TER seasonal variability (1982-2011)



Catchment-CN4.5 model performance
NBP seasonal variability (2004-2014)

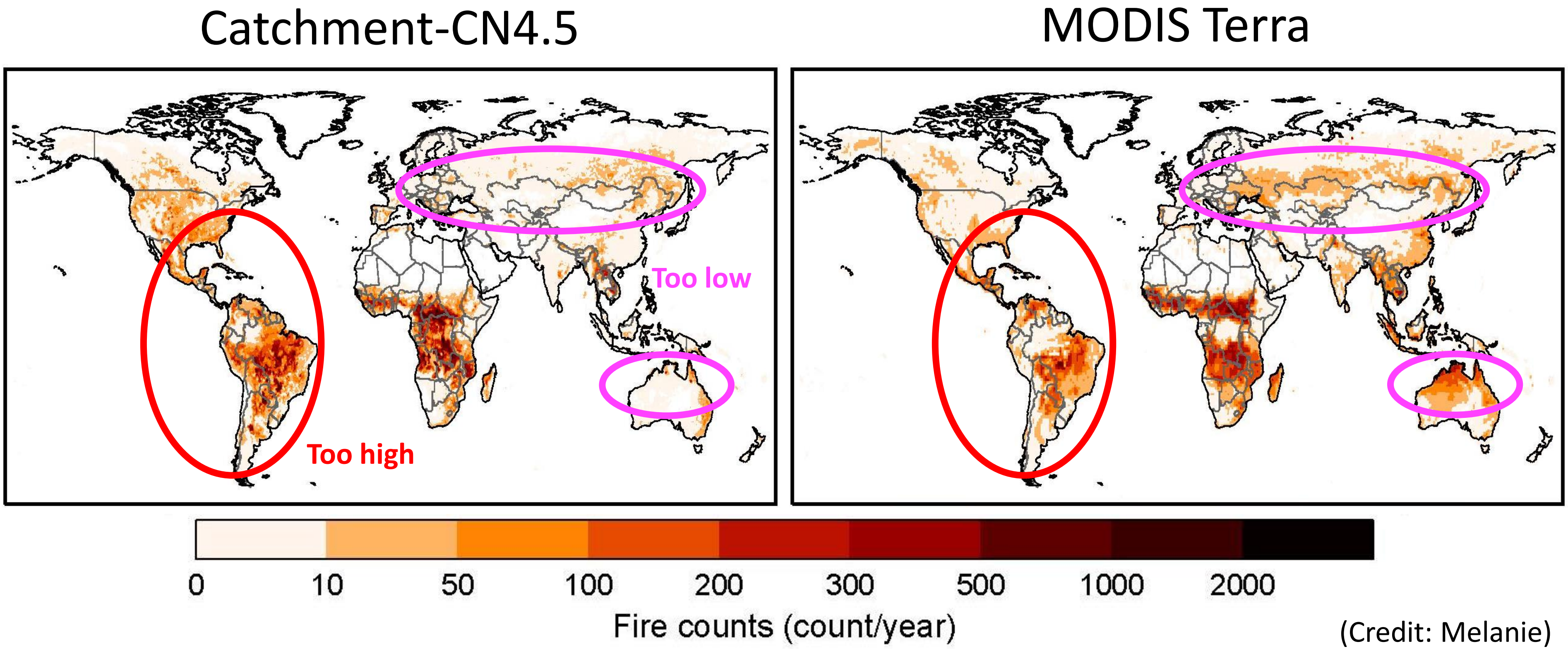


Catchment-CN4.5 model performance
Fire burned area (1997-2016)



(Credit: Melanie)

Catchment-CN4.5 model performance
Fire counts (2001-2015)



(Credit: Melanie)