Modelling tropical forest responses to elevated CO_2 in a nutrient-limited environment: JULES simulations at the AmazonFACE site

Peter Cook, Richard Betts, Mahdi André Nakhavali, Jefferson Goncalves De Souza, Lina M. Mercado, Maria Carolina Duran Rojas, AmazonFACE team

JULES Annual Science Meeting 2026

University of Reading, 9th September

The AmazonFACE Experiment

- Increased levels of atmospheric CO_2 are expected to have a fertilising effect on vegetation, increasing productivity from photosynthesis, and reducing transpiration so plants are less limited by water availability
- However, the size of this fertilising effect needs to be measured since vegetation productivity is also limited by nutrient availability so that the effect may not be as great as expected
- The Amazon Free-Air CO_2 Enrichment (AmazonFACE) large-scale field experiment is situated in old-growth forest 60km to the north of Manaus, Amazonas, Brazil, and will study the responses of a tropical forest ecosystem to elevated CO_2 (200 ppmv above ambient levels)
- In areas such as Manaus the soil is known to be poor in Phosphorus
- This experiment joins BIFoRFACE in the UK and EucFACE in Australia, all examining the responses of vegetation to enriched CO_2

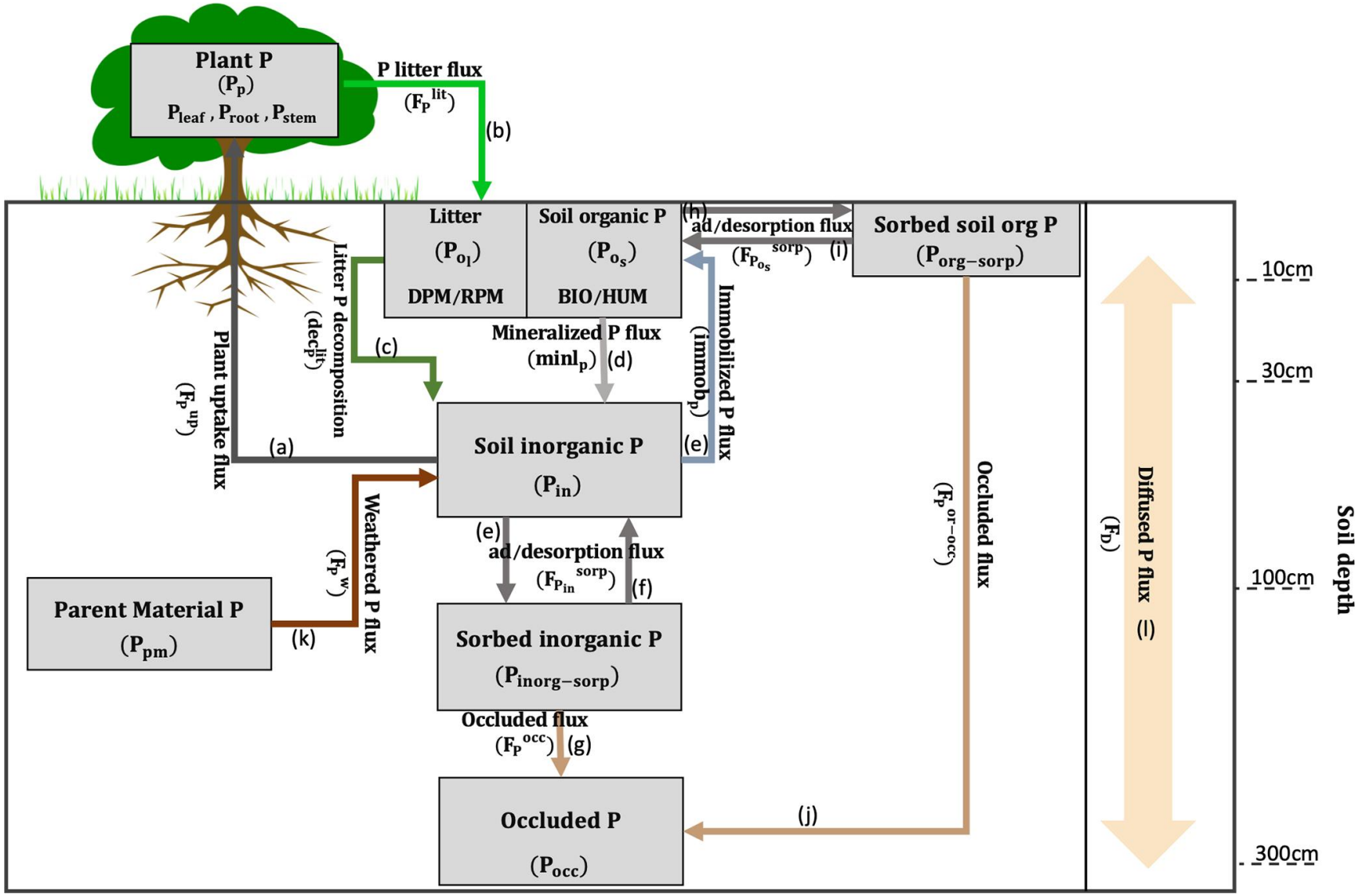
The AmazonFACE site near to Manaus

Photo: João M. Rosa

The JULES-CNP Land Surface Model

- A new version of JULES, the Joint UK Land Environment Simulator terrestrial ecosystem model of soils and vegetation, the land surface scheme of the UK Earth System Model, has been developed to include Phosphorus chemistry (Nakhavali et al. 2022, and the code is now in JULES suite dk173)
- Vegetation growth is limited by Phosphorus availability, taking inorganic Phosphorus from the soil and losing organic Phosphorus to plant litter
- JULES-CNP was set up to examine the vegetation near Manaus, and uses measurements of the soil properties and quantities of Phosphorus and Nitrogen that were obtained from a nearby project in the Amazon
- Fleischer et al. 2019 has already employed a number of land surface models with CNP chemistry to examine Phosphorus limitations on CO_2 fertilization for AmazonFACE, but JULES-CNP was not available then

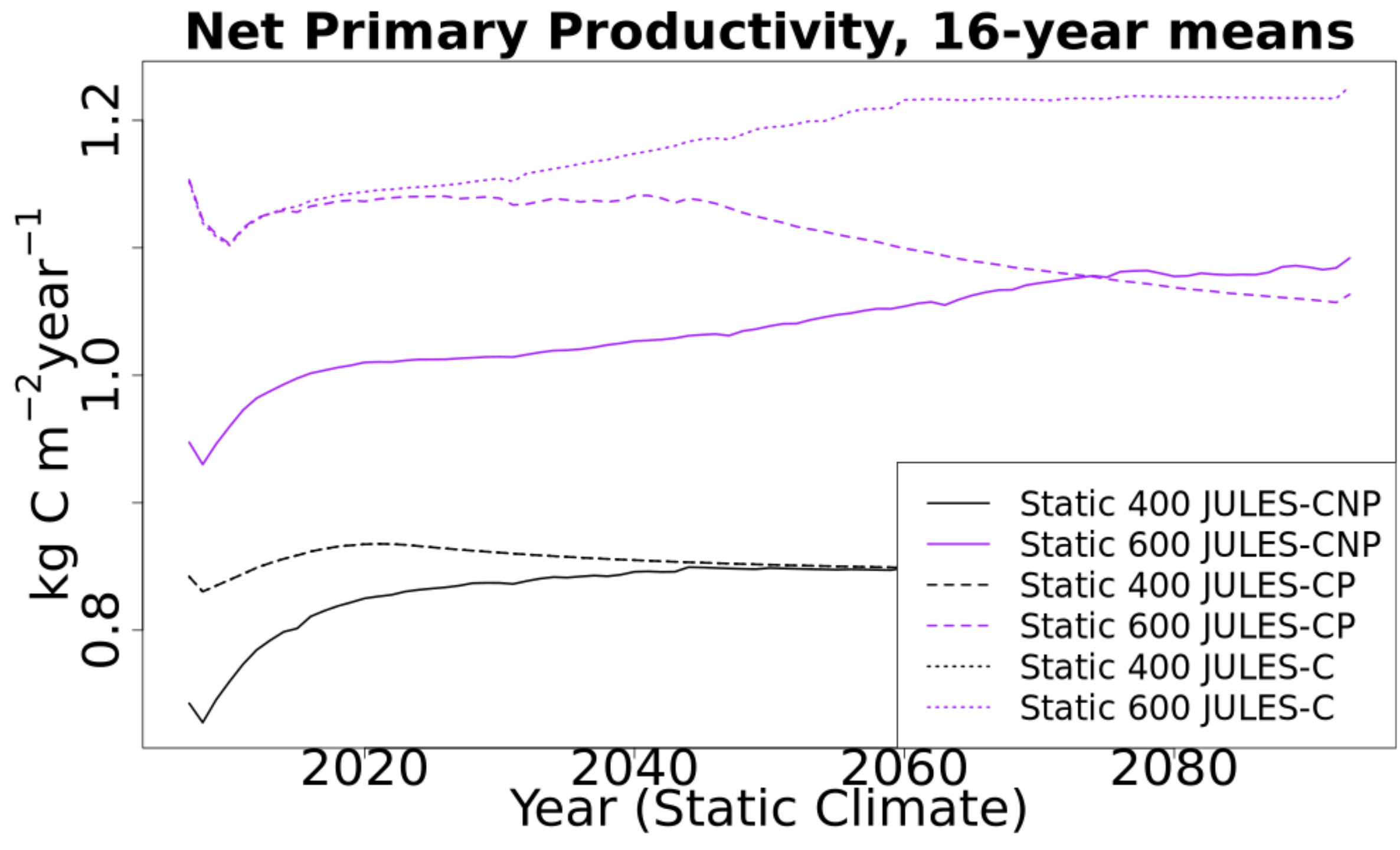
The eight Phosphorus pools in the JULES code

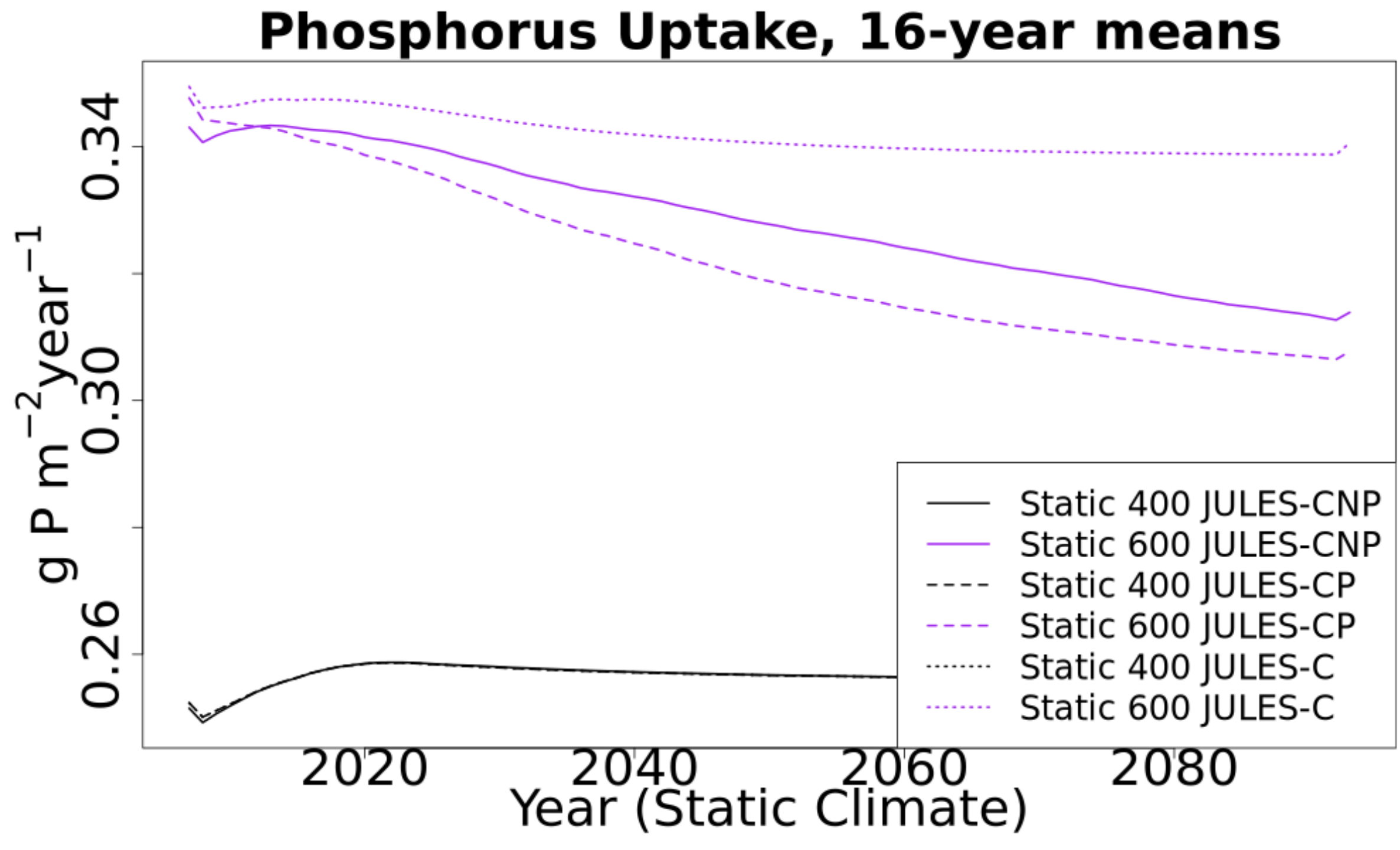


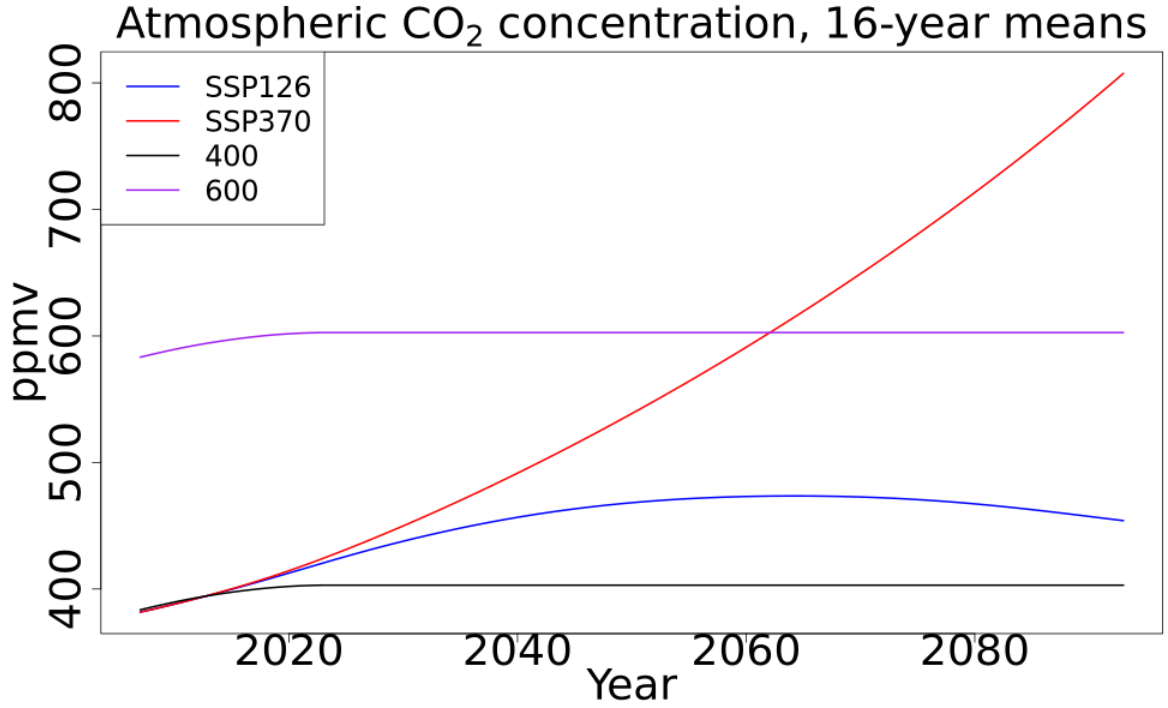
Nakhavali et al. 2022, Figure 1

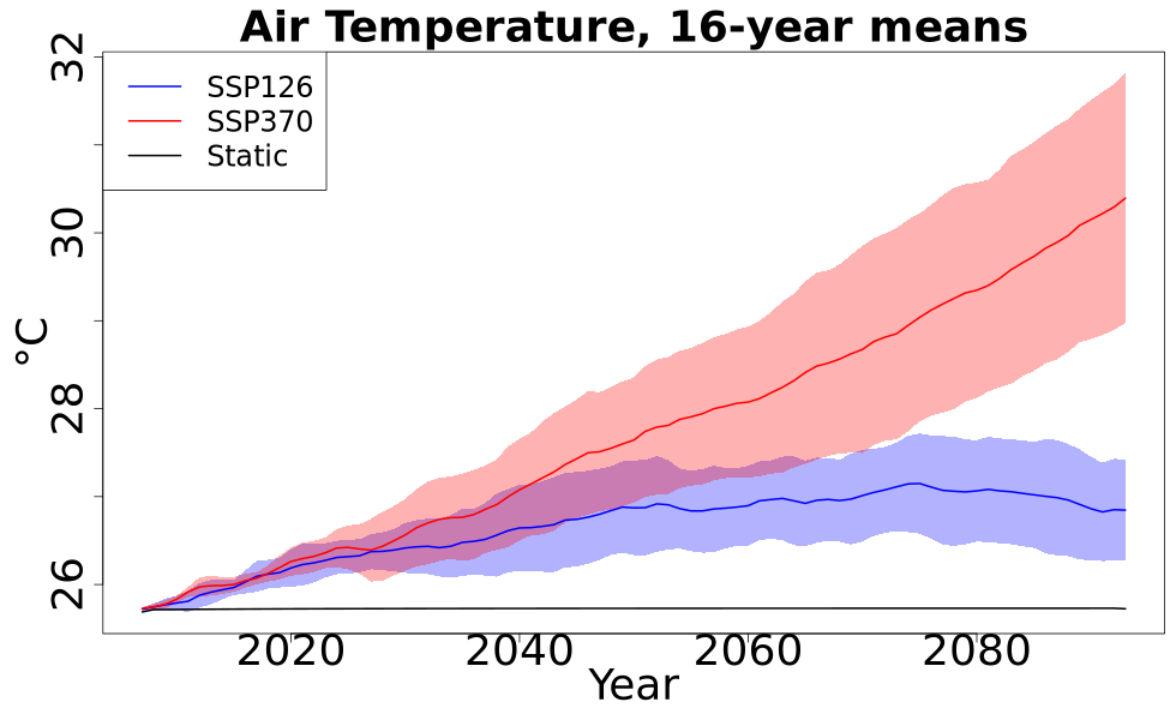
Simulations using JULES-CNP in this study

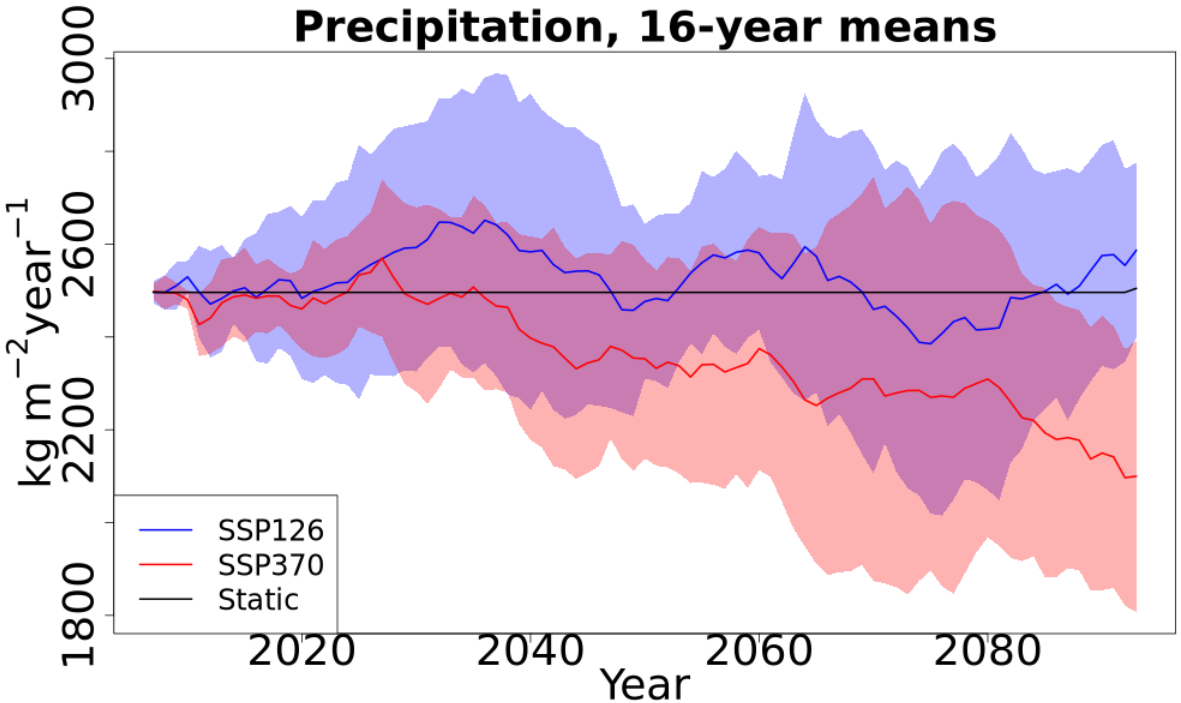
- Simulations of 100-years at Manaus were carried out with either Nitrogen and Phosphorus limitations (JULES-CNP), only Phosphorus limitations (JULES-CP) or no nutrient limitations (JULES-C)
- Firstly, with “static climate” and either present day CO_2 (400 ppmv) or enriched CO_2 (600 ppmv)
- Then using projected climate change at the AmazonFACE site in low (SSP126) and high (SSP370) scenarios from 5 Global Climate Models during 2000-2100, as used in the Inter-Sectoral Impacts Model Intercomparison Project (ISIMIP)
- The “static climate” used mean values from across the 5 Global Climate Models Simulations in ISIMIP during 2000-2015, then looped over these 16-years for the 100-year simulations

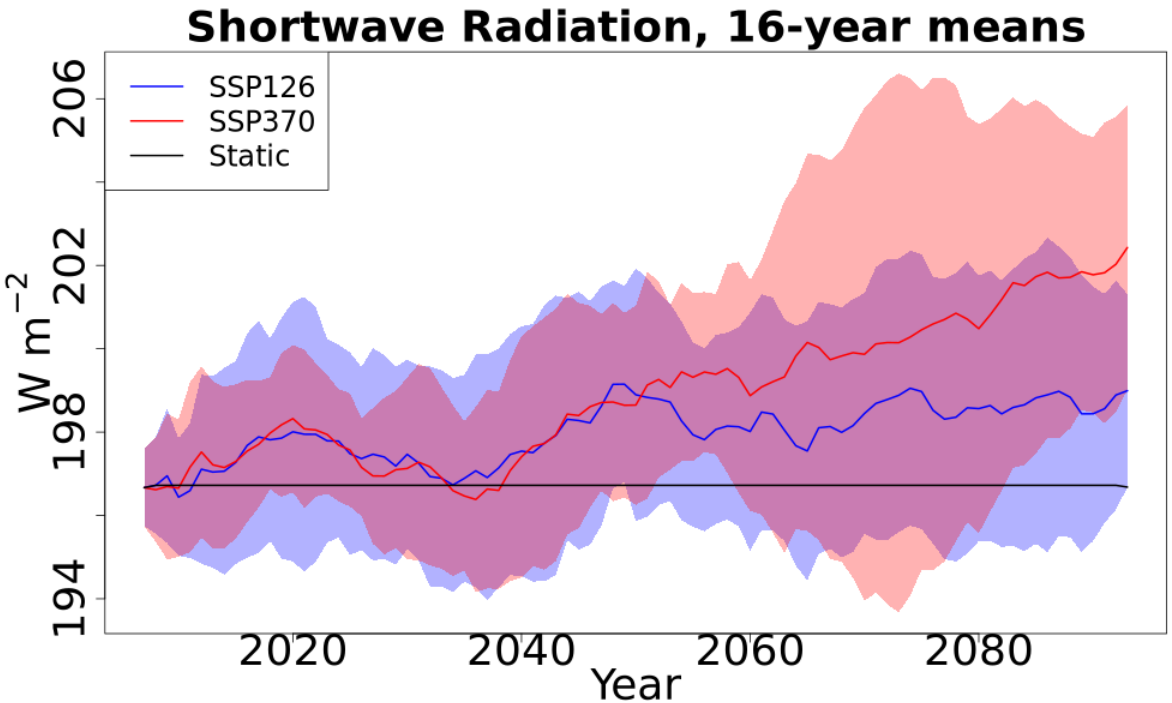

Net Primary Productivity, 16-year means
kg C m^{-2}year^{-1}
0.8
1.0
1.2
2020
2040
2060
2080
Year (Static Climate)
Static 400 JULES-CNP
Static 600 JULES-CNP
Static 400 JULES-CP
Static 600 JULES-CP
Static 400 JULES-C
Static 600 JULES-C

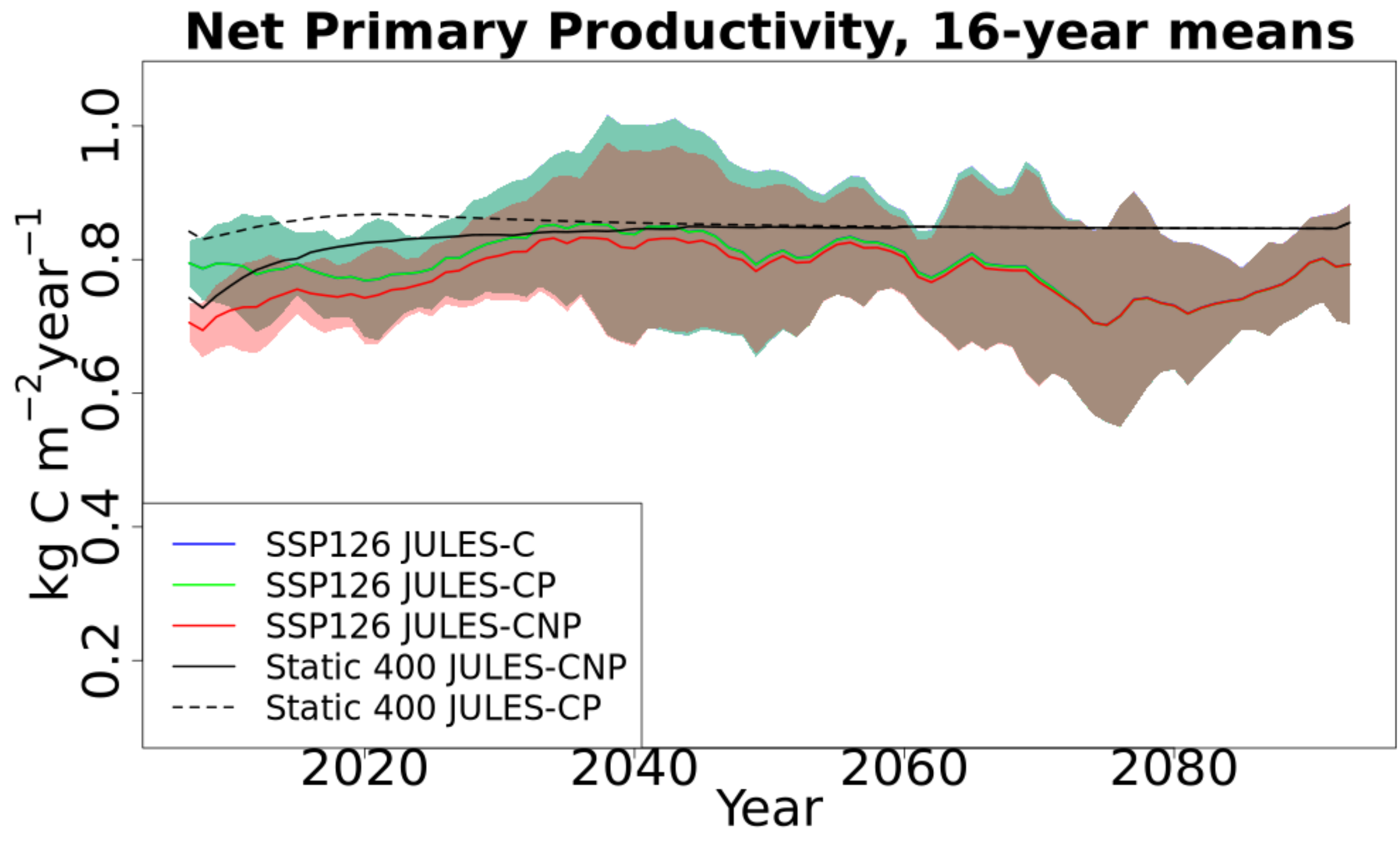

Phosphorus Uptake, 16-year means
g P m^{-2}year^{-1}
0.26
0.30
0.34
2020
2040
2060
2080
Year (Static Climate)
Static 400 JULES-CNP
Static 600 JULES-CNP
Static 400 JULES-CP
Static 600 JULES-CP
Static 400 JULES-C
Static 600 JULES-C

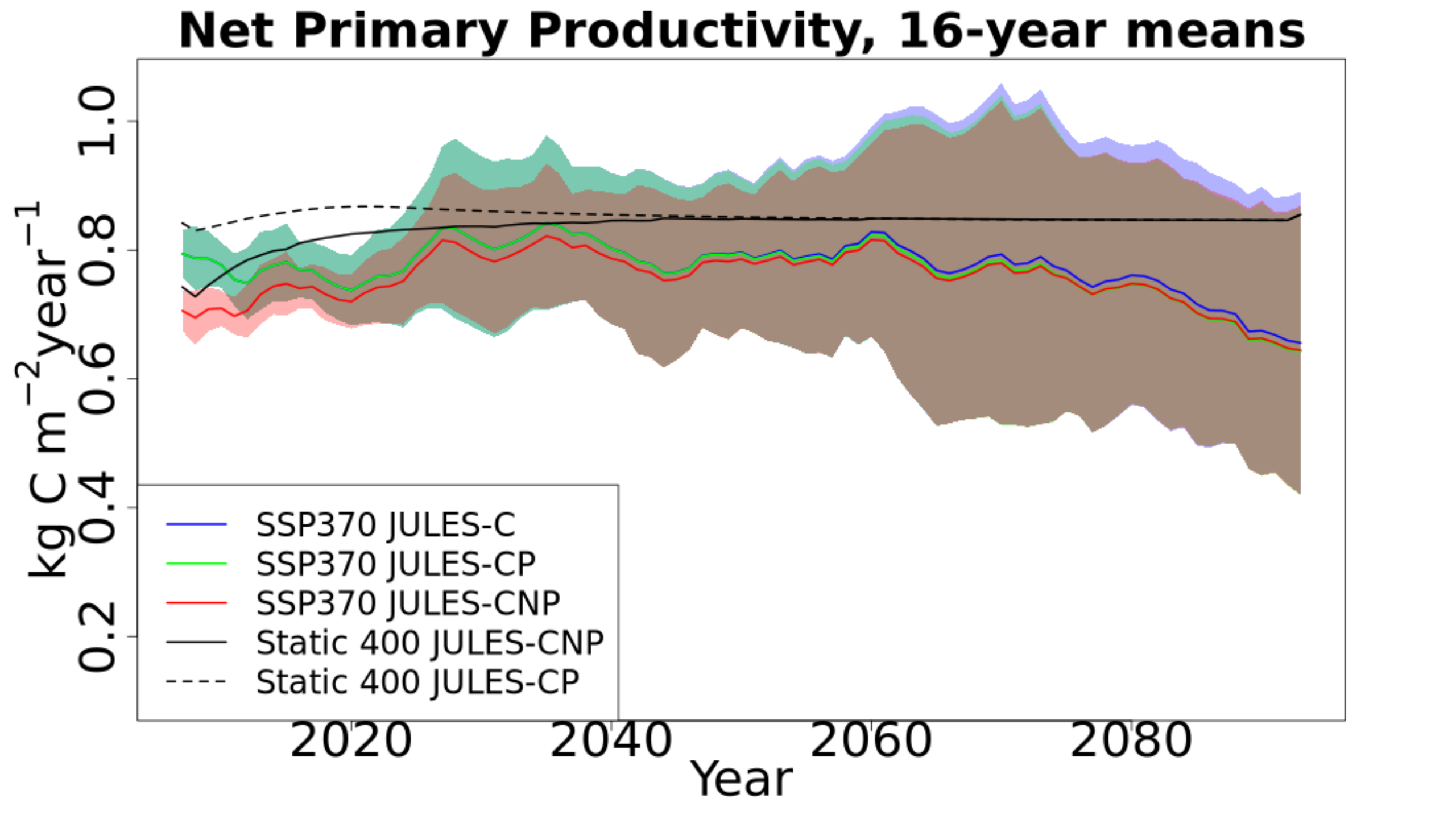

Atmospheric CO_2 concentration, 16-year means
SSP126
SSP370
400
600
ppmv
400
500
600
700
800
2020
2040
2060
2080
Year

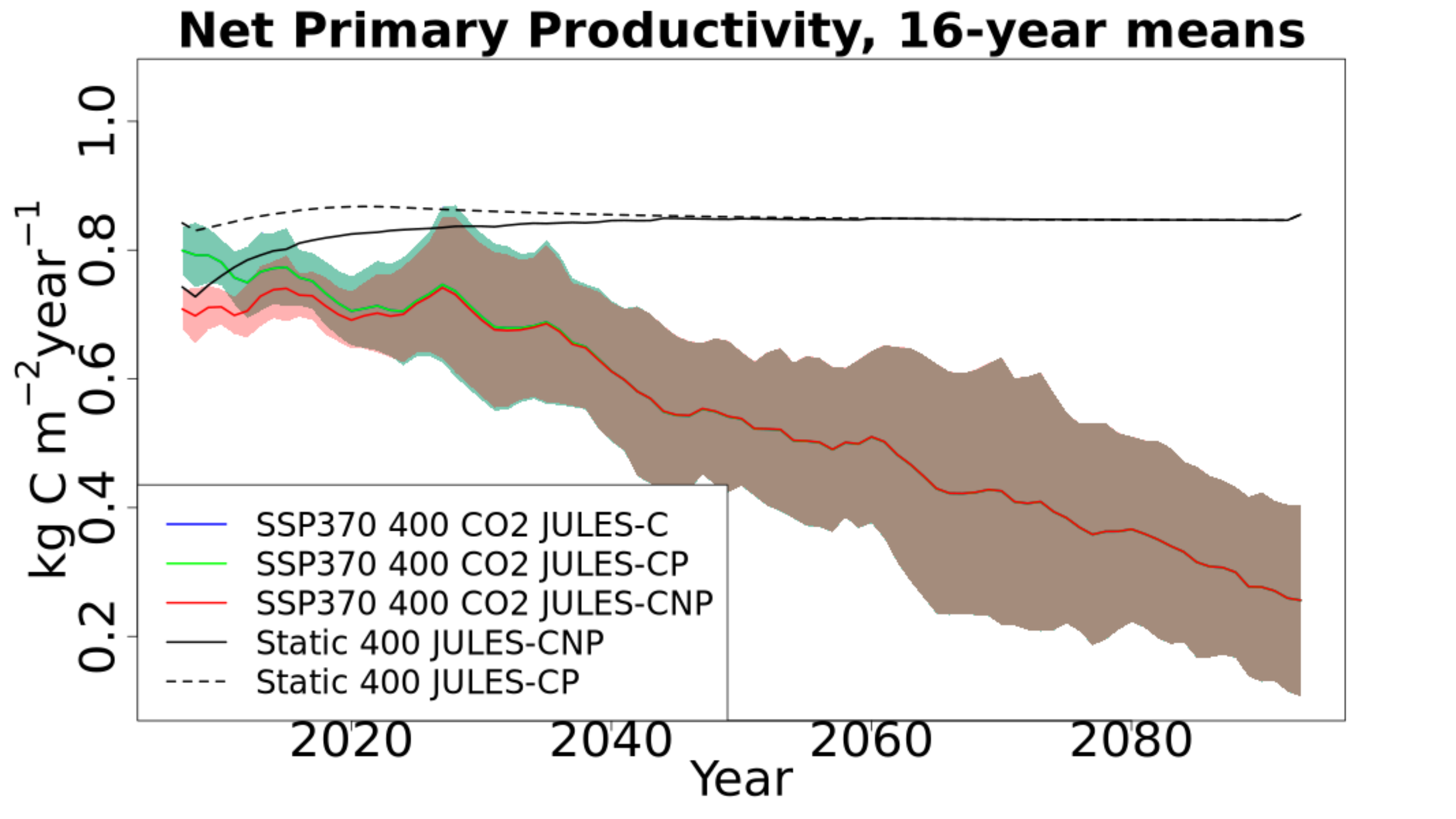

Air Temperature, 16-year means
SSP126
SSP370
Static
°C
26
28
30
32
2020
2040
2060
2080
Year


Precipitation, 16-year means
SSP126
SSP370
Static
kg m^{-2}year^{-1}
1800
2200
2600
3000
2020
2040
2060
2080
Year


Shortwave Radiation, 16-year means
SSP126
SSP370
Static
W m^{-2}
194
198
202
206
2020
2040
2060
2080
Year

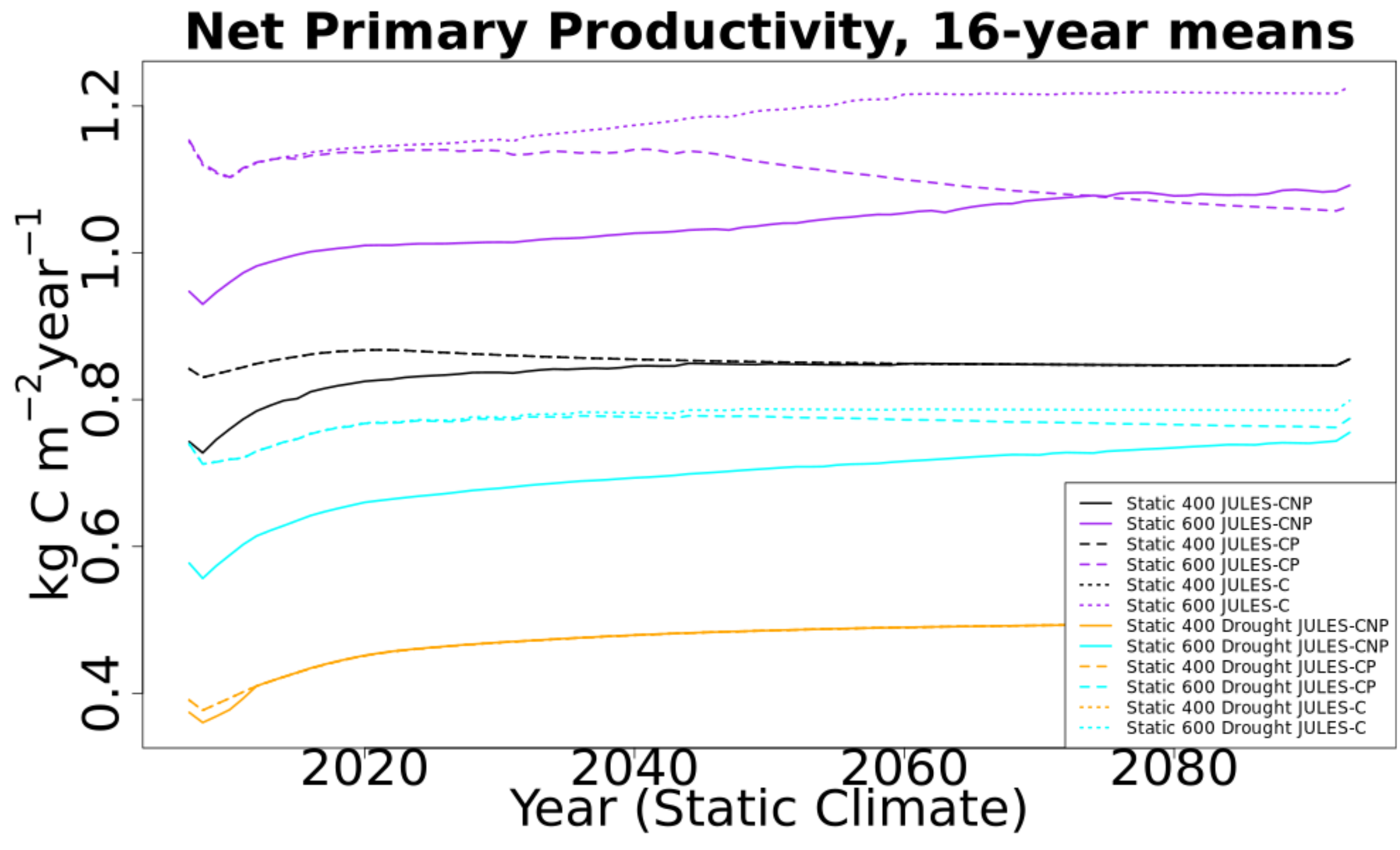

Net Primary Productivity, 16-year means
kg C m^{-2}year^{-1}
0.2
0.4
0.6
0.8
1.0
2020
2040
2060
2080
Year
SSP126 JULES-C
SSP126 JULES-CP
SSP126 JULES-CNP
Static 400 JULES-CNP
Static 400 JULES-CP

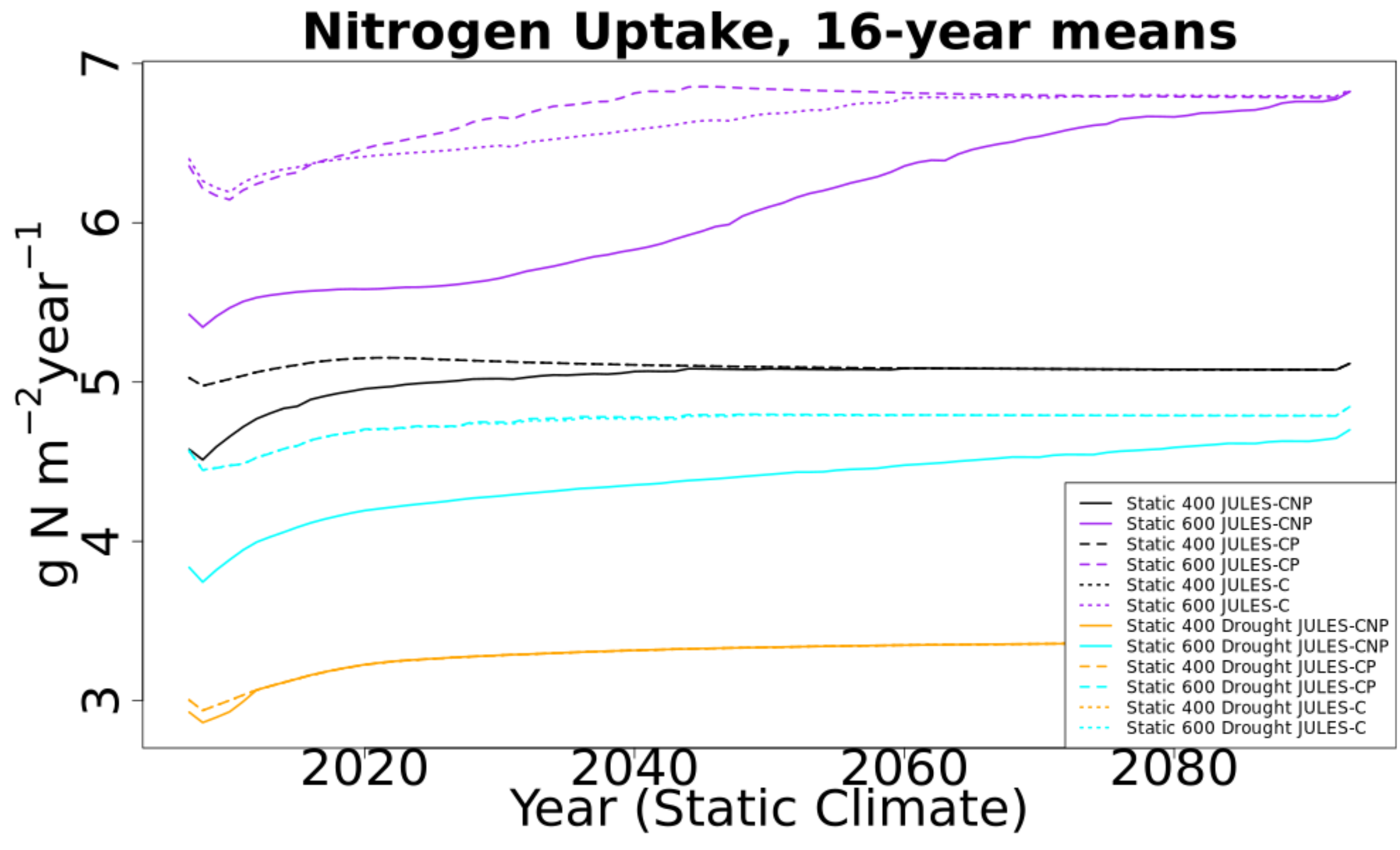

Net Primary Productivity, 16-year means
kg C m^{-2}year^{-1}
0.2
0.4
0.6
0.8
1.0
2020
2040
2060
2080
Year
SSP370 JULES-C
SSP370 JULES-CP
SSP370 JULES-CNP
Static 400 JULES-CNP
Static 400 JULES-CP

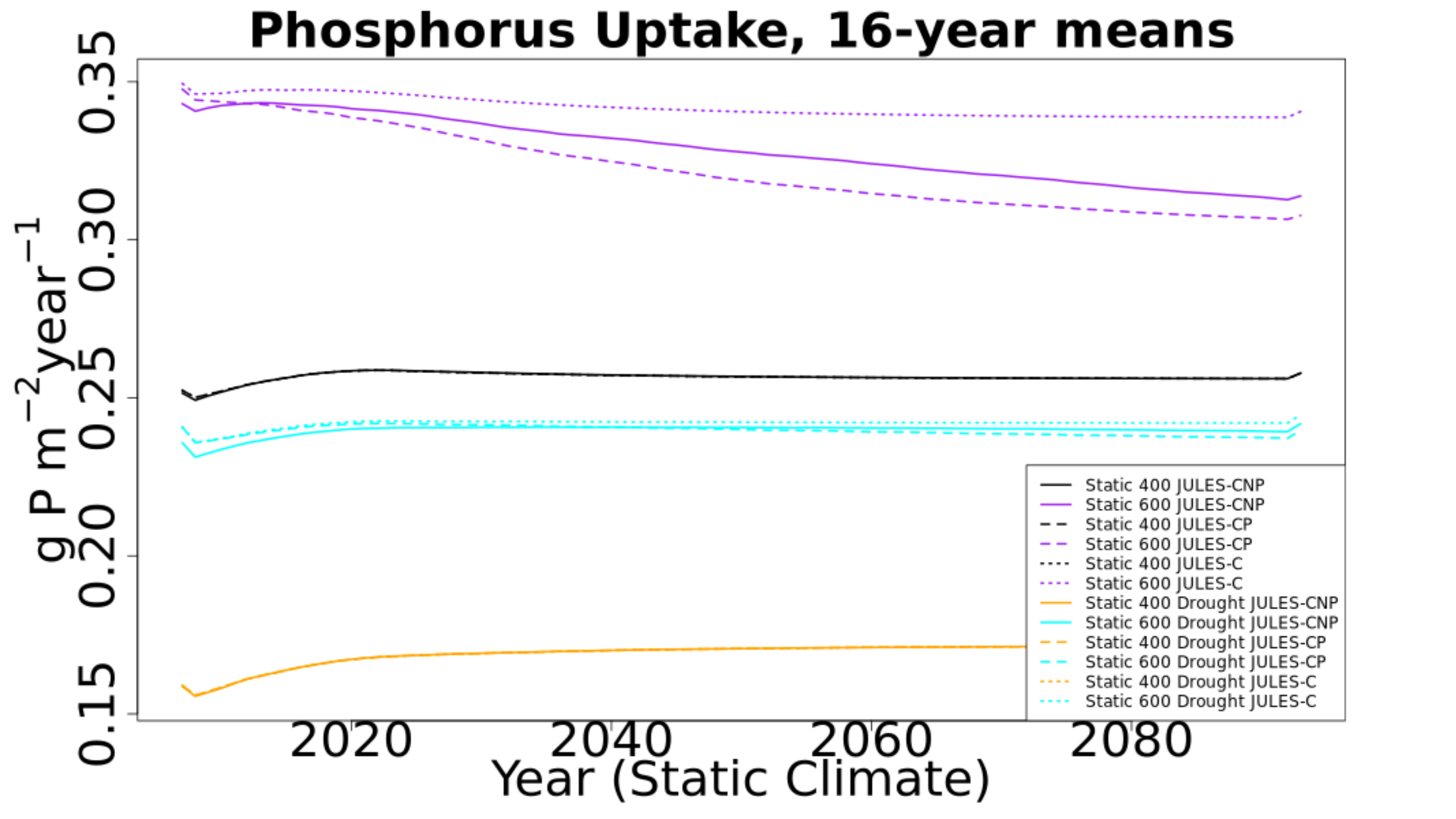

Net Primary Productivity, 16-year means
kg C m^{-2}year^{-1}
0.2
0.4
0.6
0.8
1.0
2020
2040
2060
2080
Year
SSP370 400 CO2 JULES-C
SSP370 400 CO2 JULES-CP
SSP370 400 CO2 JULES-CNP
Static 400 JULES-CNP
Static 400 JULES-CP

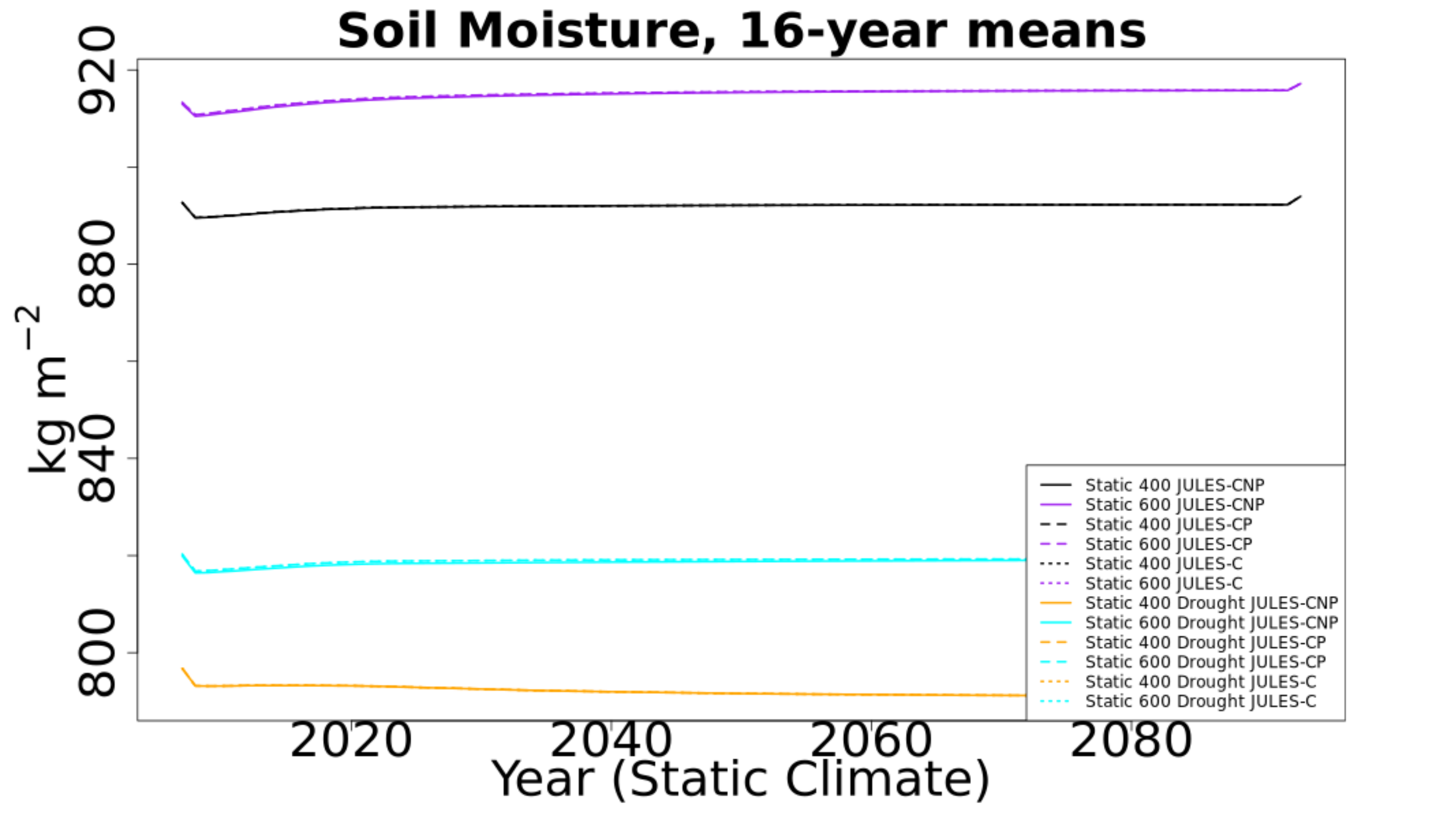
Summary

- Enriched CO_2 results in significantly greater productivity of vegetation
- In this version of JULES-CNP productivity is limited by the available Nitrogen early in the simulations, until Nitrogen in the soil is increased by deposition
- Also in this version, with enriched CO_2 and no limitations in available Nitrogen and water, productivity declines late in the simulations as Phosphorus in the soil is depleted, but without the Phosphorus limitation productivity remains high
- In low climate change projections (SSP126) productivity remains fairly constant as precipitation stays high, but in high climate change projections (SSP370) productivity declines as precipitation declines
- However, model development is still ongoing so these results should not be regarded as definitive


Net Primary Productivity, 16-year means
kg C m^{-2}year^{-1}
0.4
0.6
0.8
1.0
1.2
2020
2040
2060
2080
Year (Static Climate)
Static 400 JULES-CNP
Static 600 JULES-CNP
Static 400 JULES-CP
Static 600 JULES-CP
Static 400 JULES-C
Static 600 JULES-C
Static 400 Drought JULES-CNP
Static 600 Drought JULES-CNP
Static 400 Drought JULES-CP
Static 600 Drought JULES-CP
Static 400 Drought JULES-C
Static 600 Drought JULES-C


Nitrogen Uptake, 16-year means
g N m^{-2}year^{-1}
3
4
5
6
7
2020
2040
2060
2080
Year (Static Climate)
Static 400 JULES-CNP
Static 600 JULES-CNP
Static 400 JULES-CP
Static 600 JULES-CP
Static 400 JULES-C
Static 600 JULES-C
Static 400 Drought JULES-CNP
Static 600 Drought JULES-CNP
Static 400 Drought JULES-CP
Static 600 Drought JULES-CP
Static 400 Drought JULES-C
Static 600 Drought JULES-C


Phosphorus Uptake, 16-year means
g P m^{-2}year^{-1}
0.15
0.20
0.25
0.30
0.35
2020
2040
2060
2080
Year (Static Climate)
Static 400 JULES-CNP
Static 600 JULES-CNP
Static 400 JULES-CP
Static 600 JULES-CP
Static 400 JULES-C
Static 600 JULES-C
Static 400 Drought JULES-CNP
Static 600 Drought JULES-CNP
Static 400 Drought JULES-CP
Static 600 Drought JULES-CP
Static 400 Drought JULES-C
Static 600 Drought JULES-C


Soil Moisture, 16-year means
920
880
840
800
kg m−2
2020
2040
2060
2080
Year (Static Climate)
Static 400 JULES-CNP
Static 600 JULES-CNP
Static 400 JULES-CP
Static 600 JULES-CP
Static 400 JULES-C
Static 600 JULES-C
Static 400 Drought JULES-CNP
Static 600 Drought JULES-CNP
Static 400 Drought JULES-CP
Static 600 Drought JULES-CP
Static 400 Drought JULES-C
Static 600 Drought JULES-C