T's CMIP6 Biological Nitrogen Fixation QUIZ

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Q1: How does BNF fit into the modelled terrestrial C and N cycle?

a) N is an essential nutrient for plant growth and carbon uptake, and BNF is the main natural source of N. The amount of N available will potentially limit how much atmospheric carbon dioxide could be taken up by the terrestrial biosphere in future.
b) BNF comes from nodules on legumes and other plants in symbiotic relationships with N fixing bacteria and is highest in tropics.
c) N is the next thing on the endless list of model developments and CLM had it in CMIP5, so now all models have to include it.

CRESCENDO

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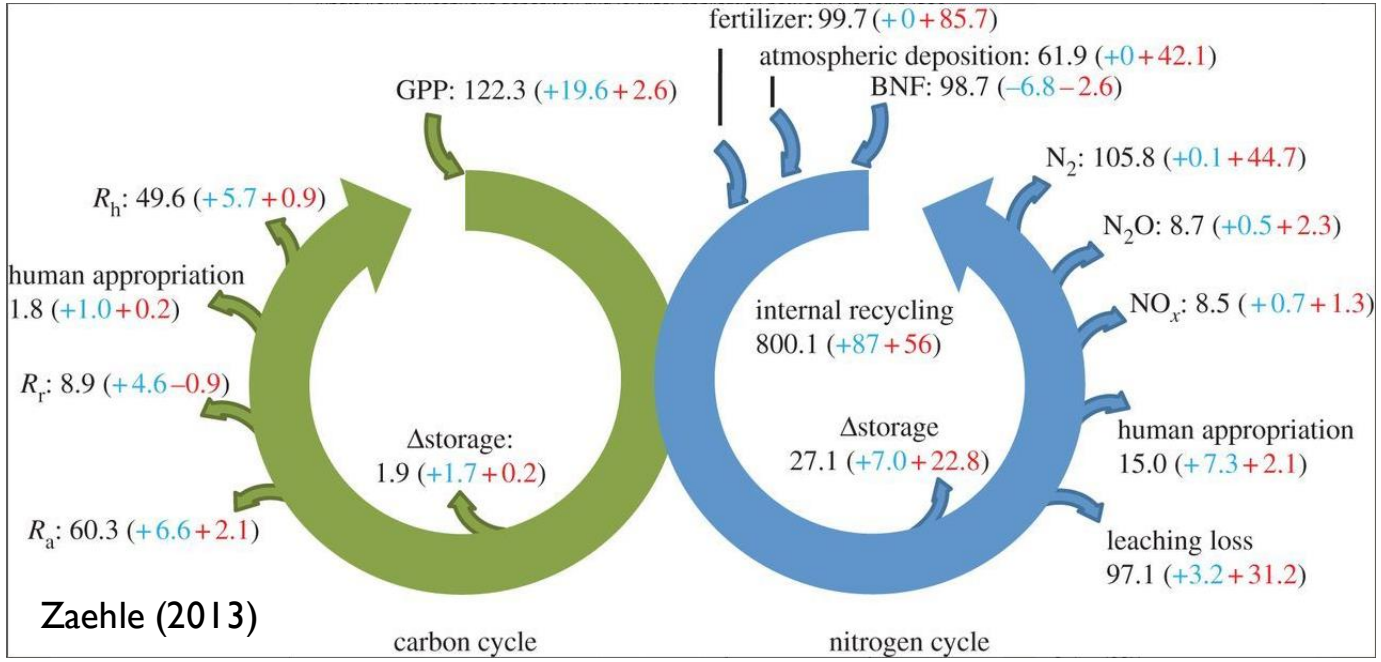
Yes, the answer is **a**.
Although BNF is best known as being the nodules on plants like clover, BNF occurs in significant quantities in both symbiotic and free-living situations, and in an array of places, from soil, canopy, plant stems, moss, lichens, and leaf litter.
BNF is heterogeneously distributed, with no natural strong spatial pattern (see right).
Because of its importance and connection to the C cycle, (see below) an N cycle has been added to 9 CMIP6 ESMs.

C & N cycles, relative size of contributions

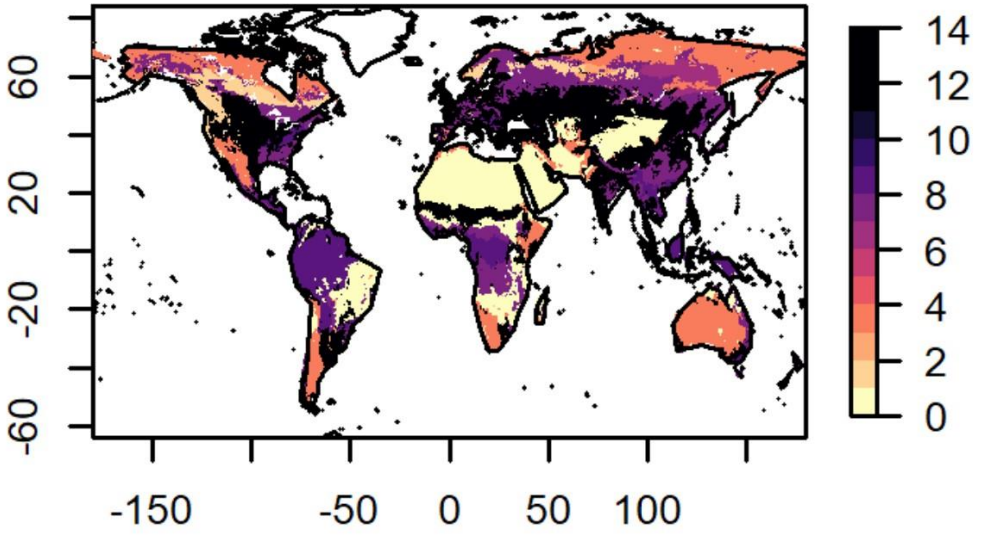


Zaehle (2013)

Q2: What is the most common empirical relationship for BNF in ESM/LSMs?

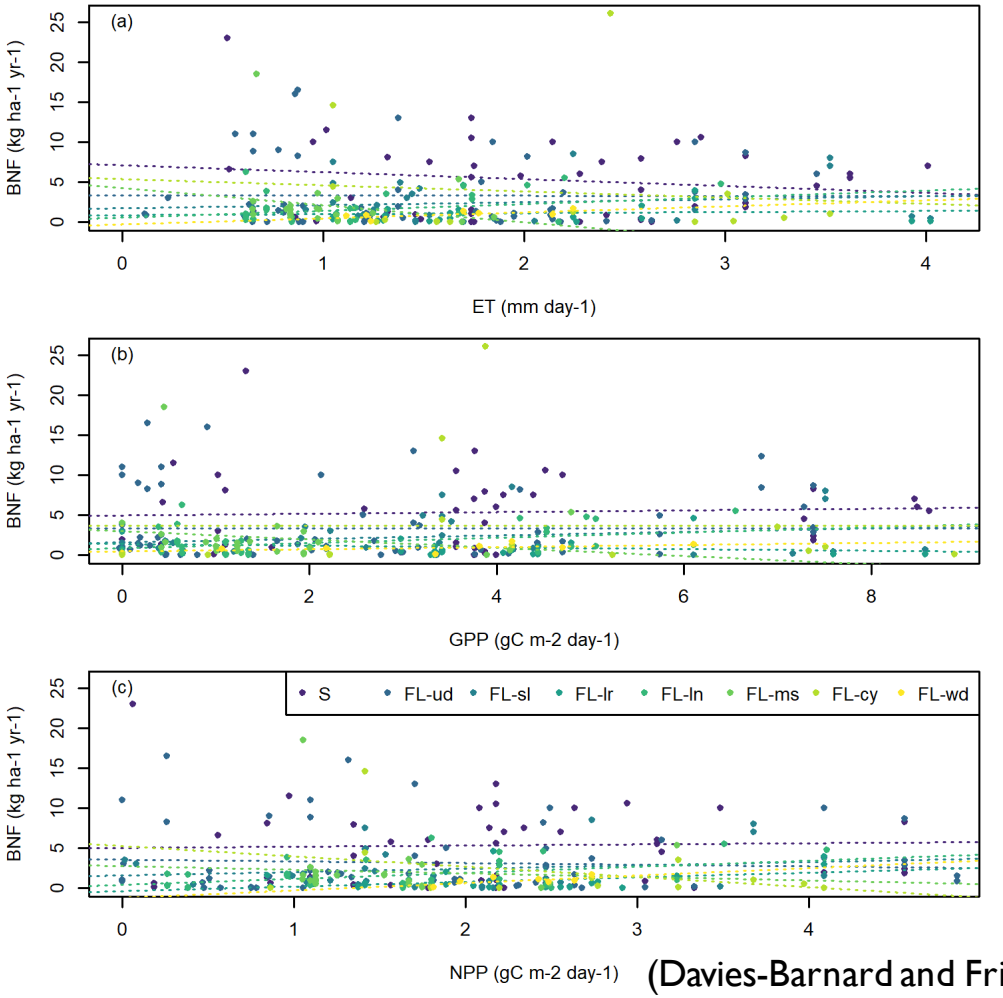
a) ET (evapotranspiration)
b) NPP (net primary productivity)
c) Cheeseburgers

Biome BNF in kgN ha^{-1} yr^{-1}



(Davies-Barnard and Friedlingstein 2020)

Though all are good answers, **b** is correct.
Most models use a simple empirical function of NPP for BNF (see table, right). NPP and ET are popular options, but research has shown the relationship between BNF and NPP or ET to be weak (see below).



(Davies-Barnard and Friedlingstein 2020)

Q3: What is the (rounded) present day range of BNF in ESMs?

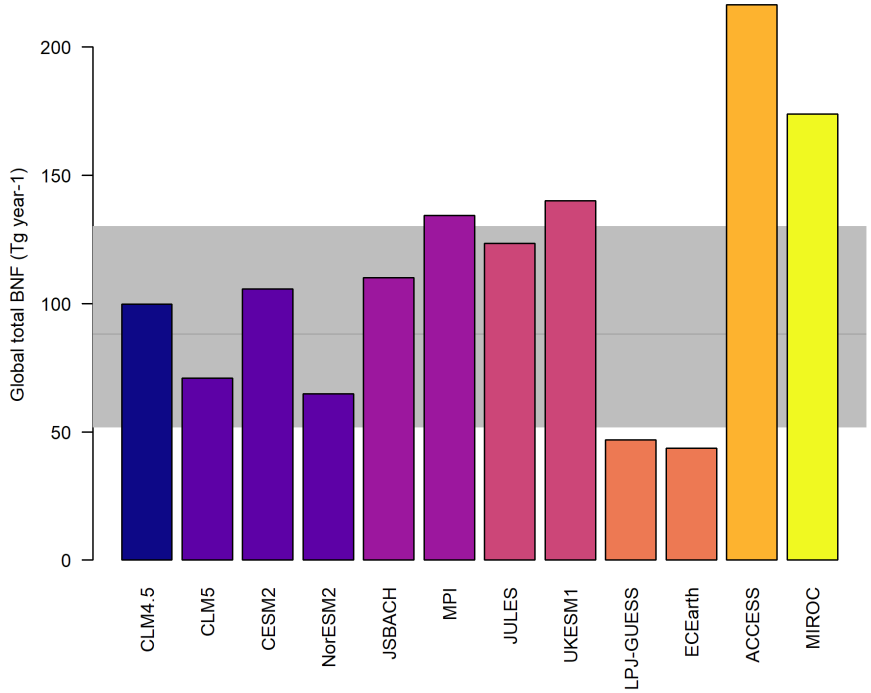
a) 40 - 220 Tg N yr-1
b) 70 - 160 Tg N yr-1
c) 100 - 300 Tg N yr-1

Model BNF functions

NPP - direct	NPP - indirect	ET
JULES-ES & UKESM1	CLM5 & CESM2 & NorESM2	LPJ-GUESS & EC-Earth
CLM4.5 & CMCC-CM2	ACCESS	MIROC
JSBACH & MPI-ESM		

The answer is **a**, as the range of total global BNF is 43 – 216 Tg N yr^{-1} in ESMs (figure below).
The latest estimate of BNF is 52 – 130 Tg N yr^{-1}, so while most models are in the correct range, there are models which are overestimating BNF by a substantial amount. This is an issue because other sources of N input are either relatively well constrained (e.g. N deposition) or small (e.g. lightning). If a model is starting from a baseline that mis-estimates the supply of N then the amount of extra N required in future could also be wrong.

CAUTION, preliminary results. Right: Total global BNF 2005 – 2014 per year in CMIP6 models and corresponding LSMs (using CRUNCEP forcing). Grey area is a meta-analysis of the observed range (Davies-Barnard and Friedlingstein 2020).

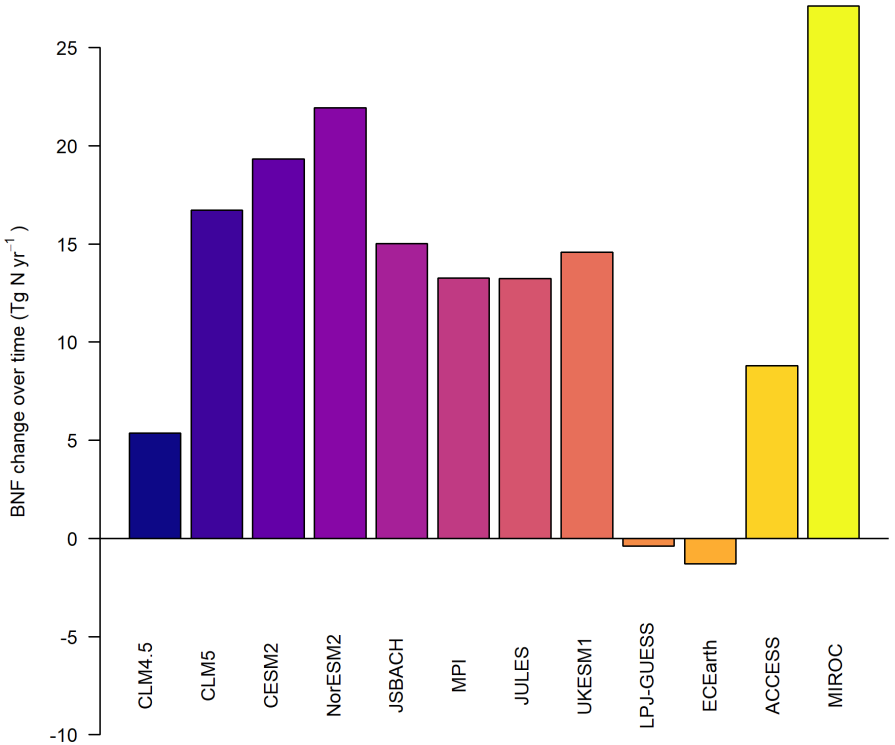


Q4: Why does it matter what BNF calculations are based on?

a) Because the overall integrity of our models is reliant on the accuracy of each individual component.
b) Because different assumptions lead to different amounts of BNF under high CO2 scenarios, and since the future allowable emissions rely (partially) on how much terrestrial carbon can be taken up, indirectly changes in BNF are policy relevant.
c) Because correlation is not causation.
d) All of the above.

The answer is **d**, all of the above.
But the biggest issue for BNF is that if we are getting the 'right' (or an acceptable) present day value for the wrong reason, we cannot have confidence in projections of future changes.
We can see the importance of this by comparing the change in BNF from 1950-59 to 2005-2014 (below), where models hindcast a large range of changes (-3% (ECEarth) to +50% (NorESM)).

CAUTION, preliminary results. Right: Total global BNF anomaly 2005 – 2014 compared to 1950-1960, per year in CMIP6 models and corresponding LSMs (using CRUNCEP forcing).



Conclusions

- The basis of modelled BNF (NPP, ET, etc) really matters for the change over time, but has little relationship with the absolute amount of BNF in the model
- Some ESMs vary substantially from their LSM, possibly because the function is reliant on a variable that is different between CRUNECP and GCM forcing.

The quiz is just a bit of fun. Why not share your score in the comments?

References:
Zaehle, S. Terrestrial nitrogen–carbon cycle interactions at the global scale. Philosophical Transactions of the Royal Society of London B: Biological Sciences 368, 20130125 (2013).
Davies-Barnard, T. and Friedlingstein, P.: The Global Distribution of Biological Nitrogen Fixation in Terrestrial Natural Ecosystems, Global Biogeochemical Cycles, 34(3), e2019GB006387, doi:10.1029/2019GB006387, 2020.