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Overestimation in the sensitivity of soil respiration to climate change throughout the mid-latitudes

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GREENCYCLESII

Initial Training Network on global biosphere-climate interactions

Mid-latitude carbon-water coupling

Overestimation in the sensitivity of soil respiration to climate change throughout the mid-latitudes

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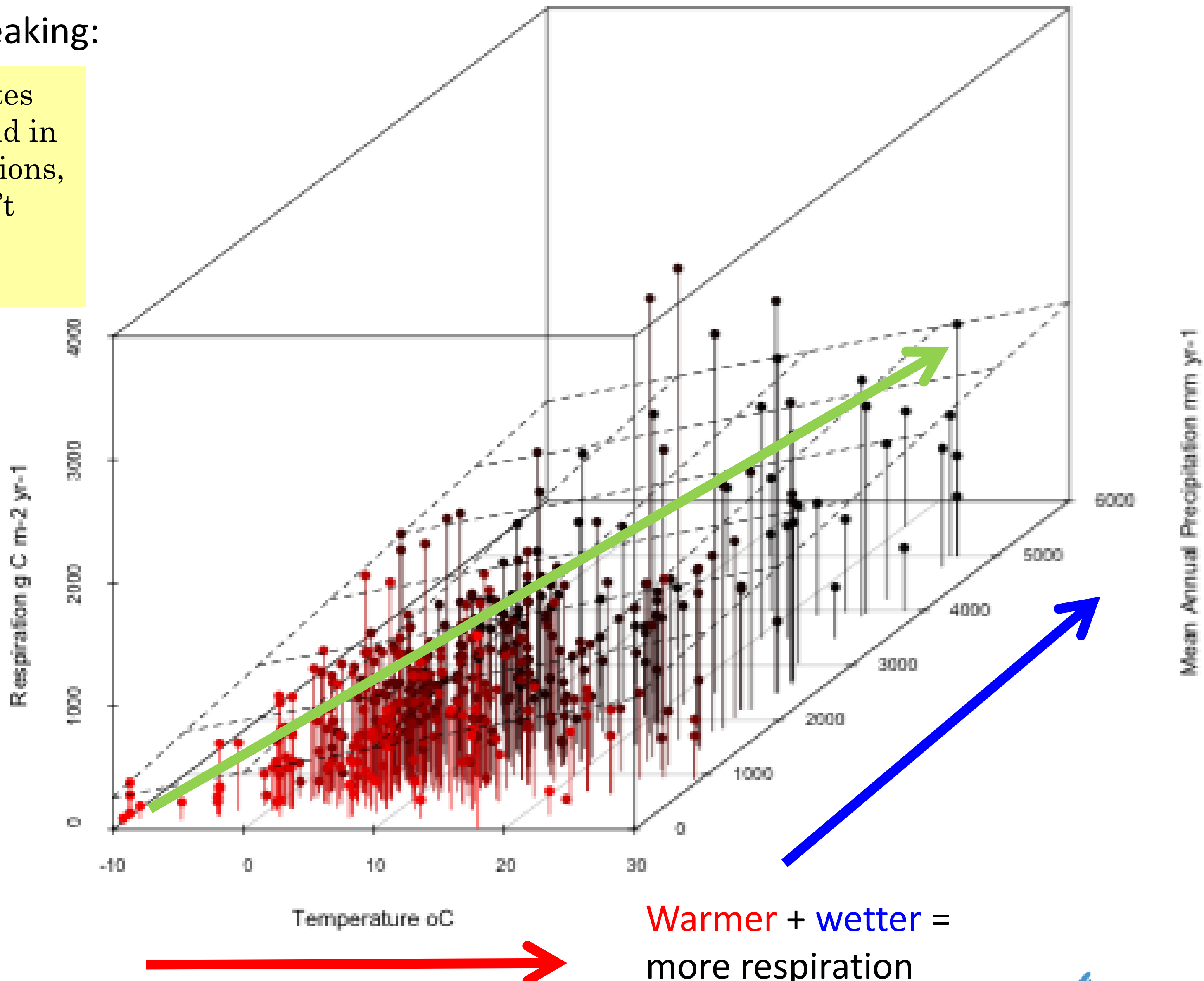
Why just the mid-latitudes?

Scientifically speaking:

Extreme climates can force a trend in global observations, that simply isn't relevant to the middle-ground.



Warmer + wetter = more respiration

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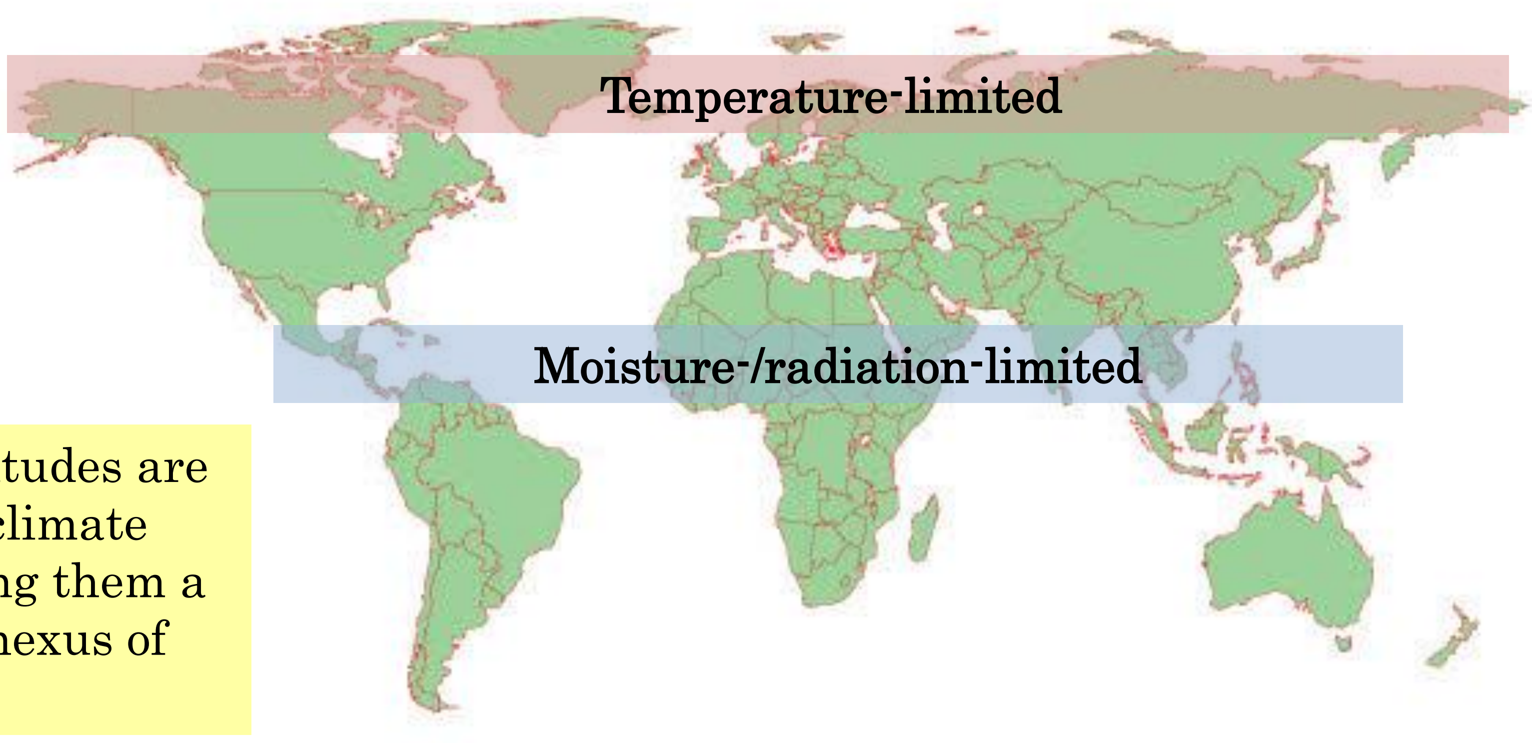
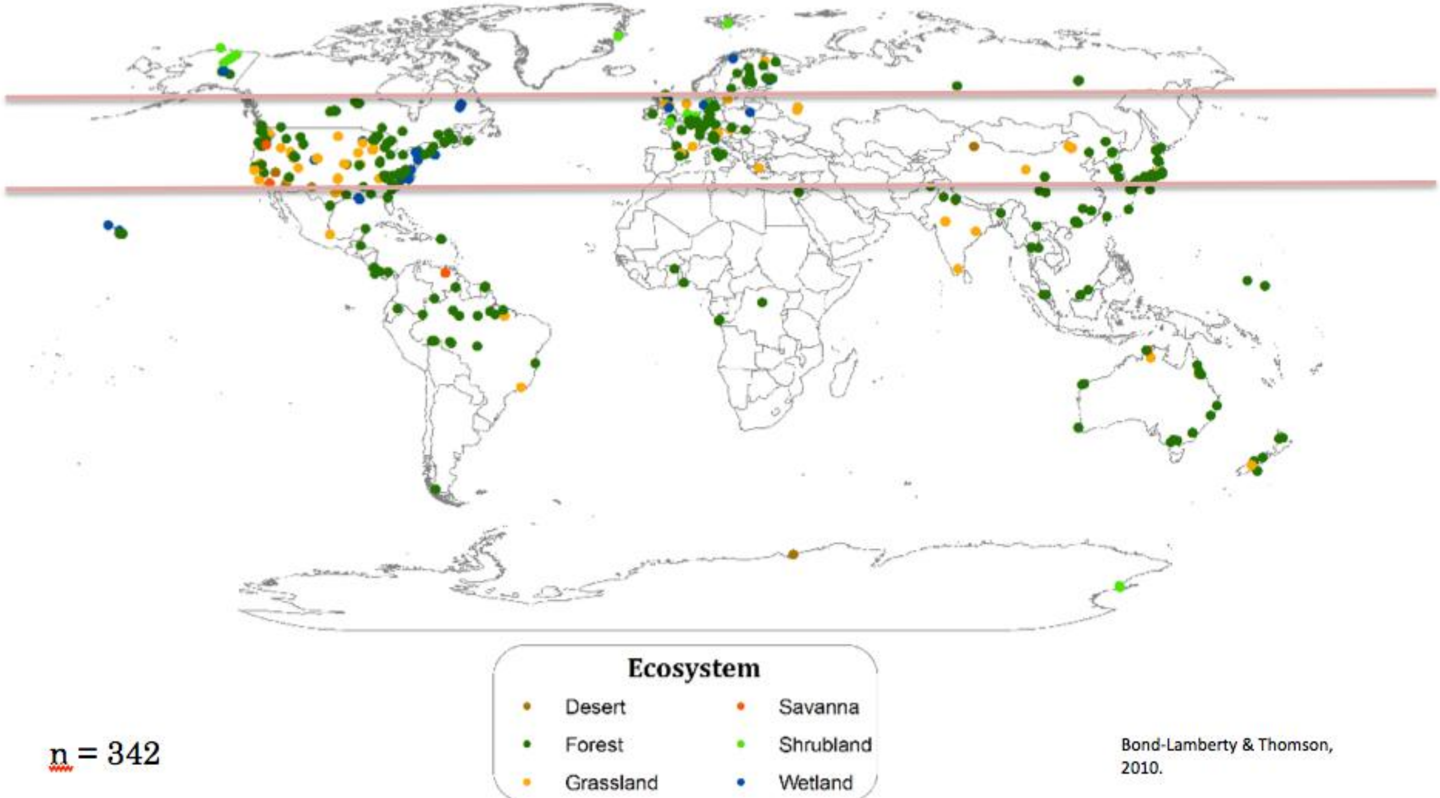


The mid-latitudes are a jumble of climate types, making them a interesting nexus of study

Why just the mid-latitudes?

Practically speaking:



n = 342

Bond-Lamberty & Thomson, 2010.

Data bias: most of our knowledge about respiration comes from northern mid-latitudes

Policy relevance: A lot of the governments capable/considering C sequestration in soils are in the (northern) mid-latitudes (Bangsund & Leistritz, 2008)

The good people at the Pacific Northwest Laboratory and:

ORNL DAAC Distributed Active Archive Center for Biogeochemical Dynamics

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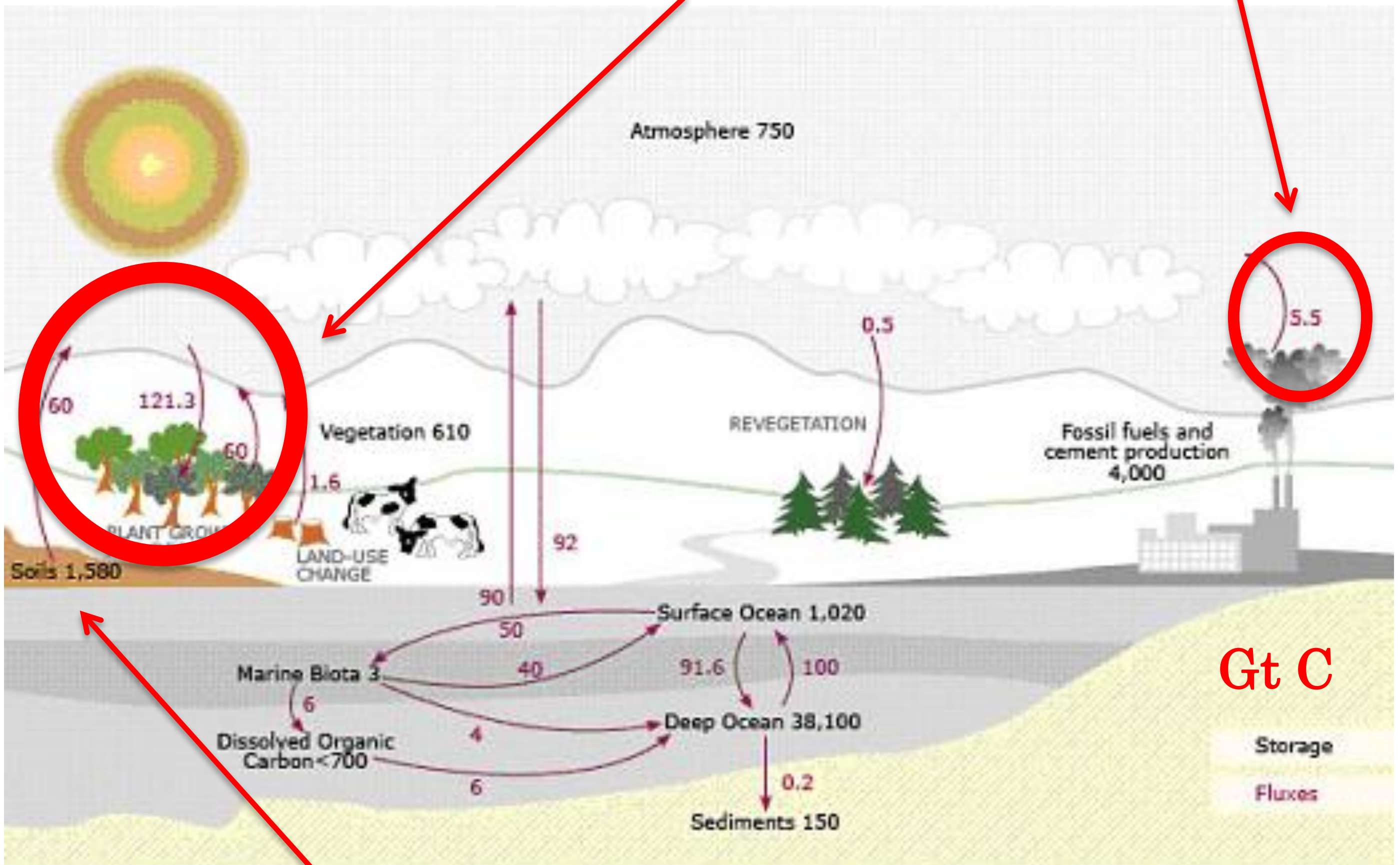
The Carbon Cycle

Enormous flux of CO_2 in biosphere 'breathing'; annually, an order of magnitude larger than all anthropogenic emissions (Field & Raupach, 2004; Boden et al., 2010)



Stores of carbon in the soils are HUGE
So we really need to know how changes in climate may affect future storage, emissions and sequestration

~1,672 in Northern Permafrost region ALONE
(Tarnocai et al., 2009)

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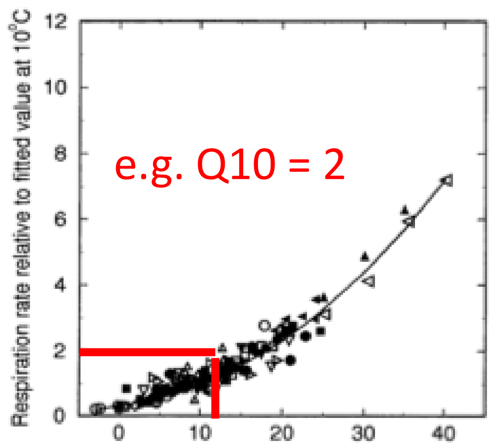
Modelling respiration

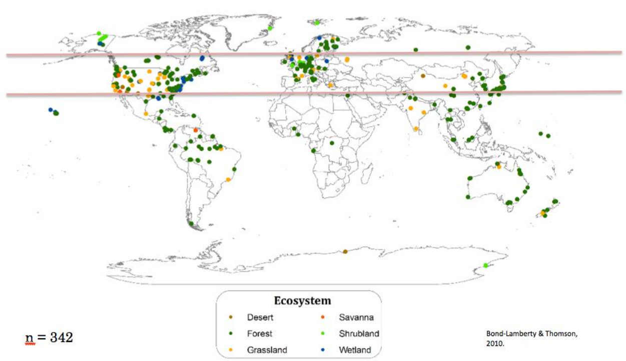


Respiration is modelled very, very simply in climate models

Interestingly, many of the independent field studies into respiration show a near-exponential relationship when plotted against temperature

Table 1 Land models and soil carbon representations used in coupled climate models (Friedlingstein et al. 2006)

Land carbon model	Coupled model	Soil carbon model structure	References
TRIFFID	HadCM3LC, UVic-2.7	Single C pool with moisture and Q_{10} temperature responses	Cox (2001)
SLAVE	IPSL-CM2C	Two litter pools, fast and slow soil C pools based on CENTURY model with moisture and Q_{10} temperature responses	Friedlingstein et al. (1995)
ORCHIDEE-STOMATE	IPSL-CM4-LOOP	Four litter pools; fast, slow, passive soil C pools with moisture and Q_{10} temperature responses	Krinner et al. (2005)
LSM-CASA	CSM-1	Nine soil C pools with soil moisture and transpiration control and Q_{10}/climate temperature responses	Potter et al. (1993)
JSBACH-BETHY	MPI	Two soil C pools with moisture and Q_{10} temperature responses	Knorr (2000)
IBIS	LNLL	Litter and soil C pools with soil water-filled pore space controls and Arrhenius temperature responses	Foley et al. (1996)
Sim-CYCLE	FRCGC	Two soil C pools with soil moisture and Arrhenius temperature responses	Ito and Oikawa (2002)
VEGAS	UMD	Three soil C pools with different Q_{10} temperature responses	Zeng et al. (2005)
LPJ	CLIMBER2-LPJ, BERN-CC	Above and belowground litter pools; 2 soil C pools with moisture and modified Q_{10} temperature responses	Sitch et al. (2003)
CLM-CN-Biome-BGC	CESM	Coarse woody debris, 3 litter, and 3 soil C pools that cascade with moisture and Q_{10} temperature responses	Thornton and Rosenbloom (2005)



in line with Arrhenius kinetics of decomposition and experimental observations (*Davidson et al*, 1998; *Tuomi et al*., 2008)

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Modelling respiration

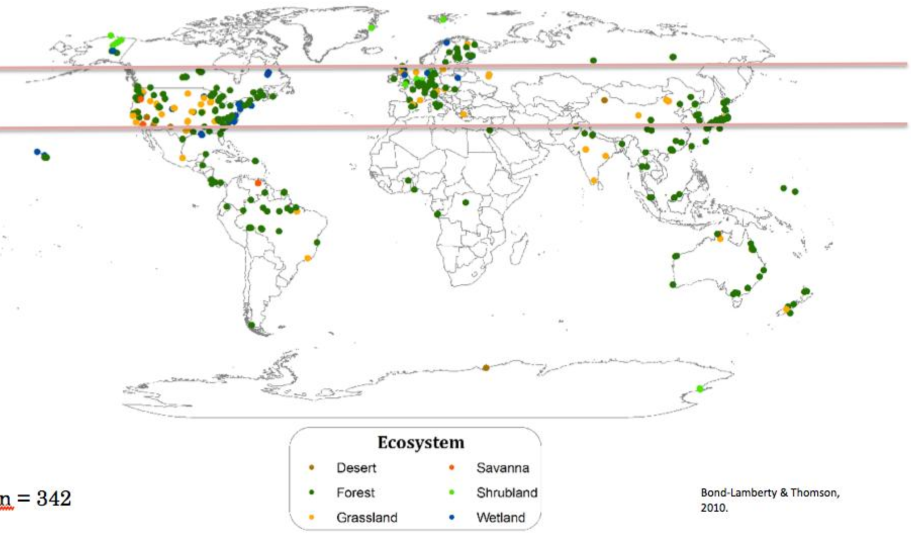
Hypothesis → SOC decomposition is temperature sensitive

Why? Simply, decomposition is an enzyme-mediated reaction, and thus the rate-limiting step is temperature (to a point…). Enzyme kinetics works the same everywhere- so there is a global Q10 (Mahecha et al. 2010)

Assumption → All SOC is **equally** sensitive to temperature in all soil types in all regions under all climate zones on Earth

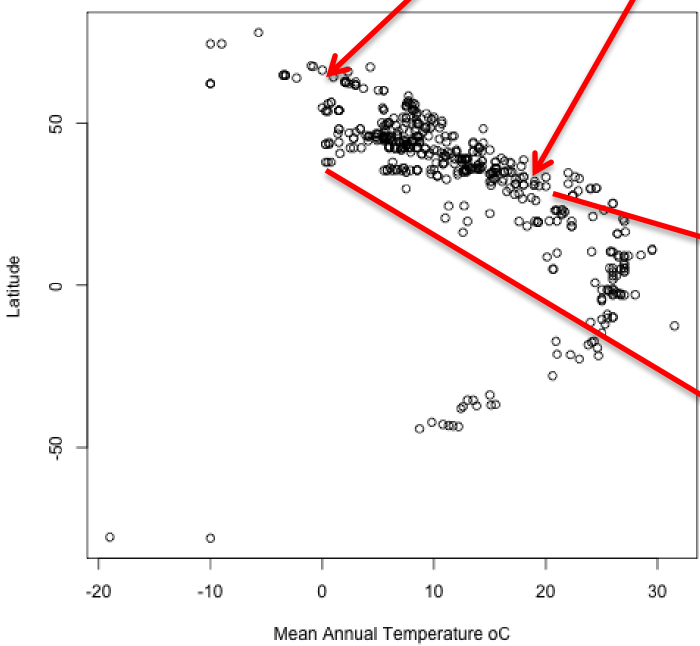
Can we see this at the extra-site scale?

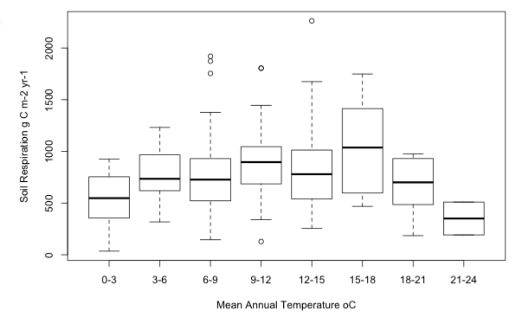
Models run at the extra site scale e.g. 50 x 50 km



n = 342

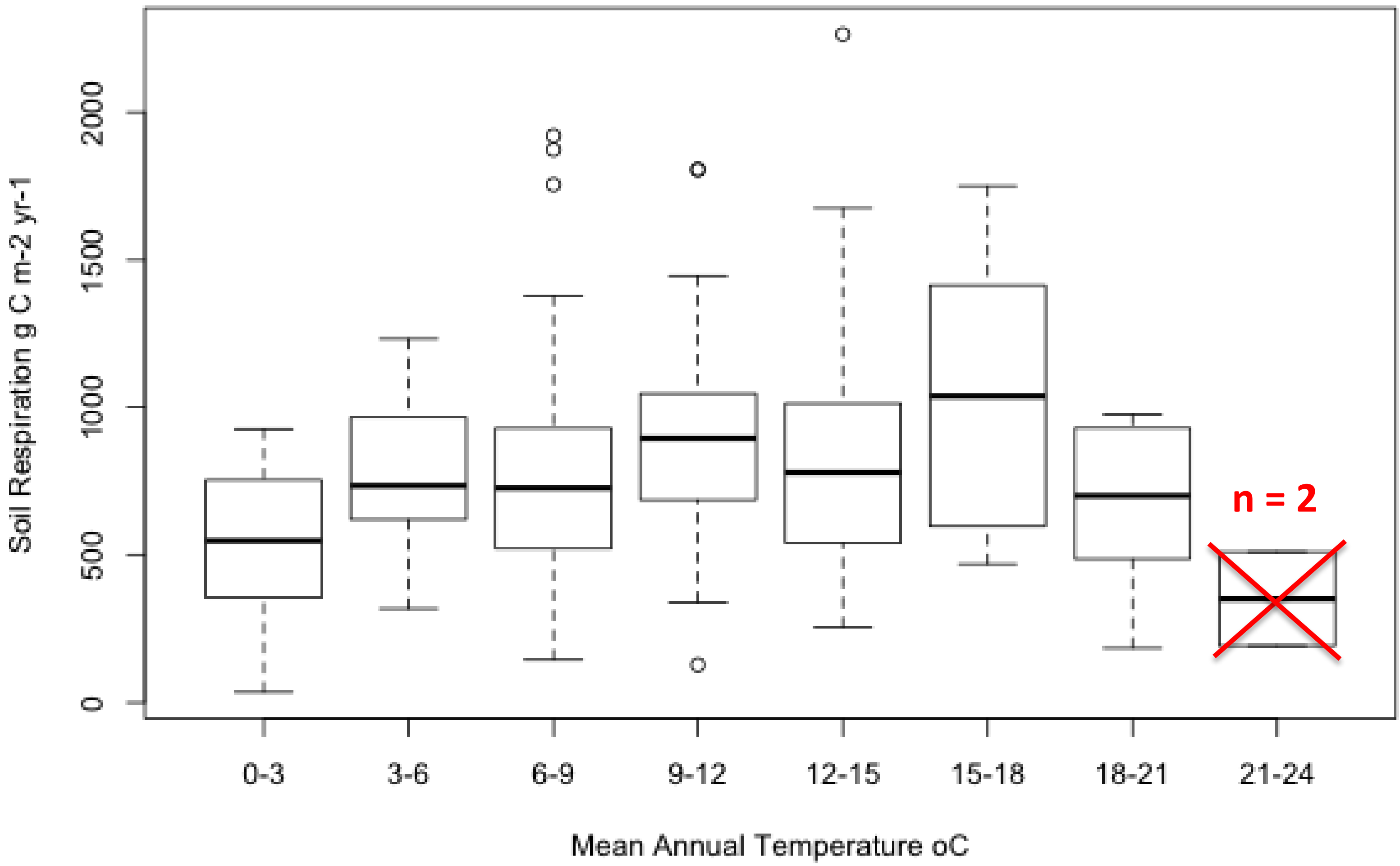
Bond-Lamberty & Thomson, 2010.





Can we see the respiration-temperature relationship at the extra-site scale?

No.



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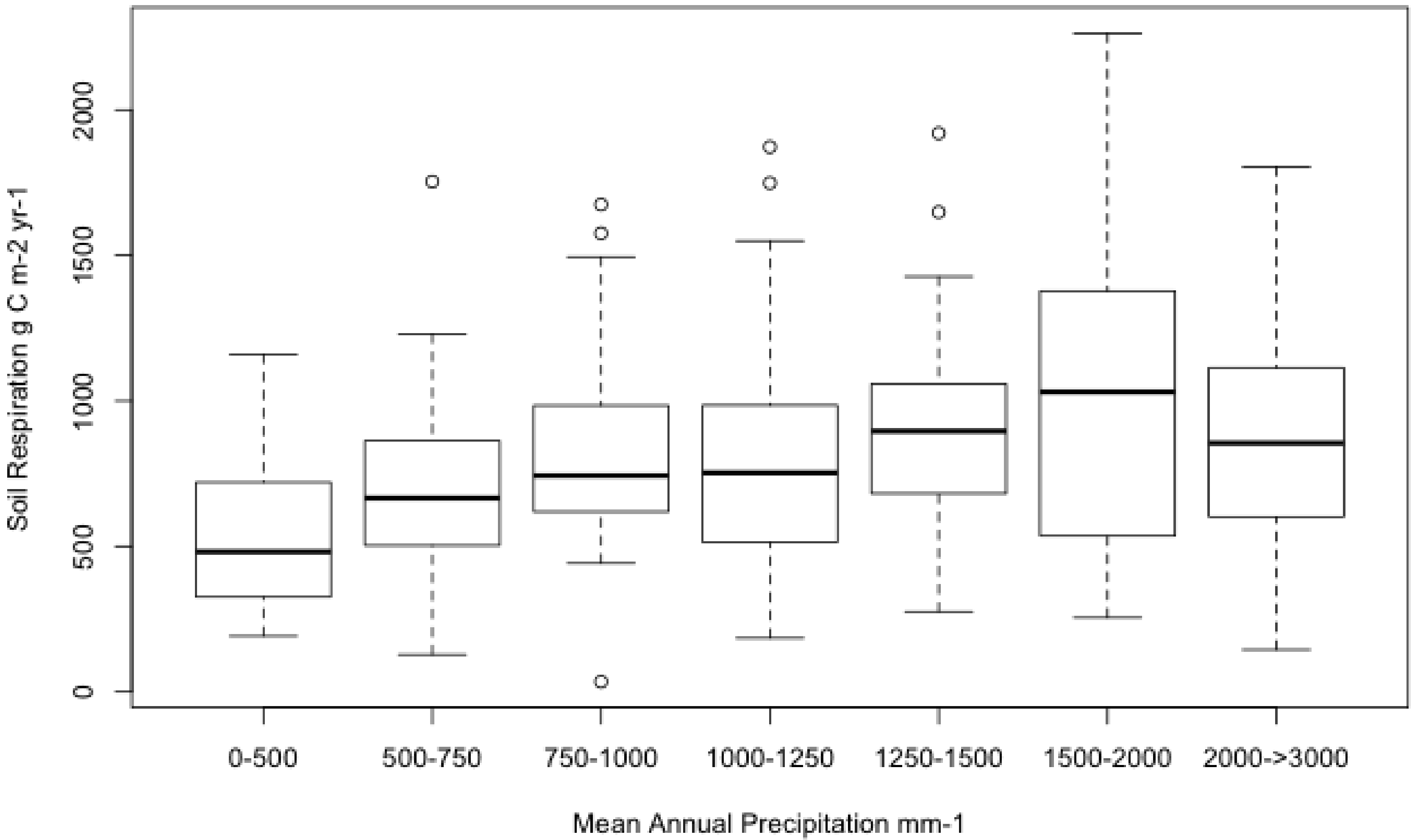

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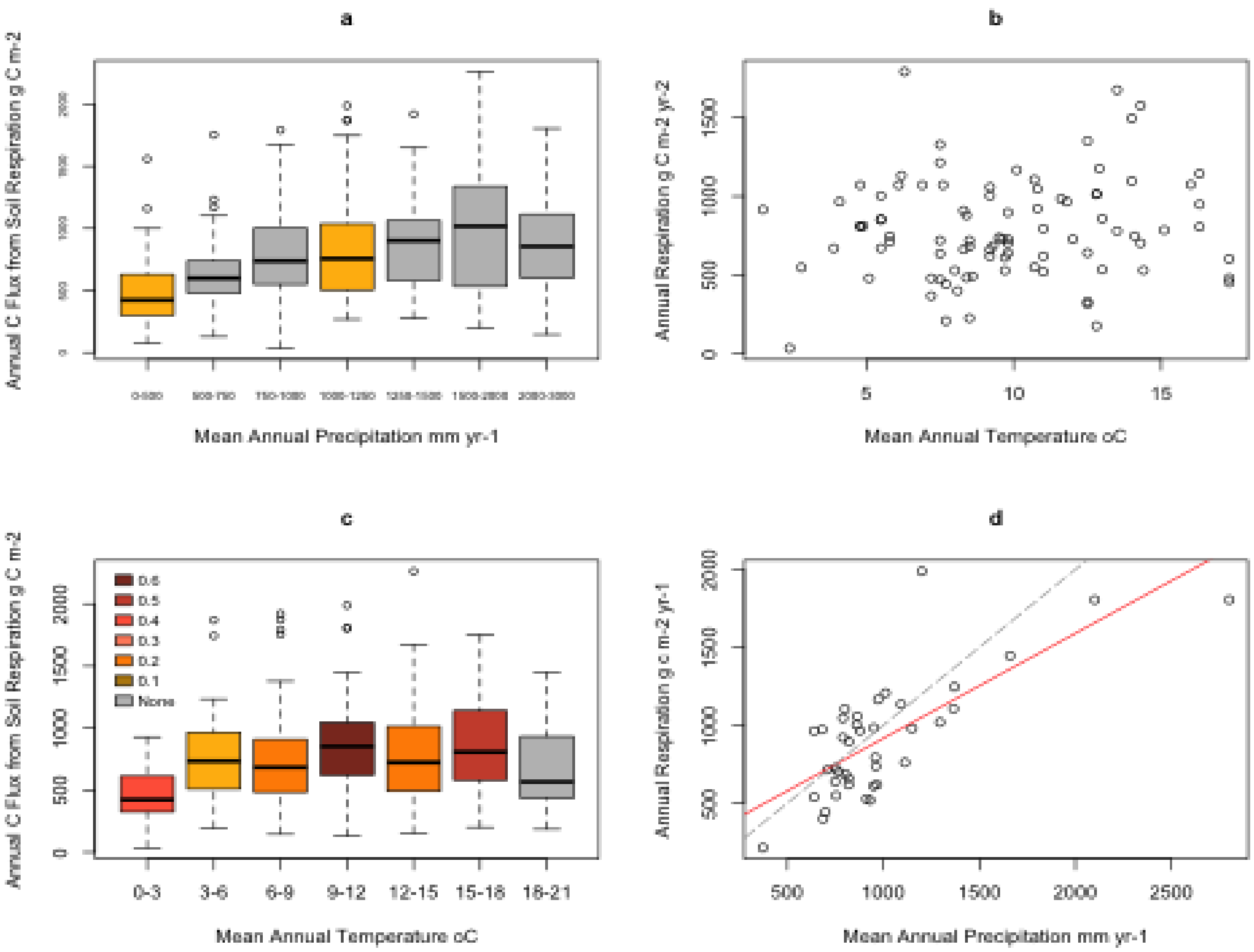
Can we see the respiration-temperature relationship at the extra-site scale?



Discretisation has the coarse effect of removing the influence of temperature on respiration in order to better assess the influence that precipitation/temperature alone can have

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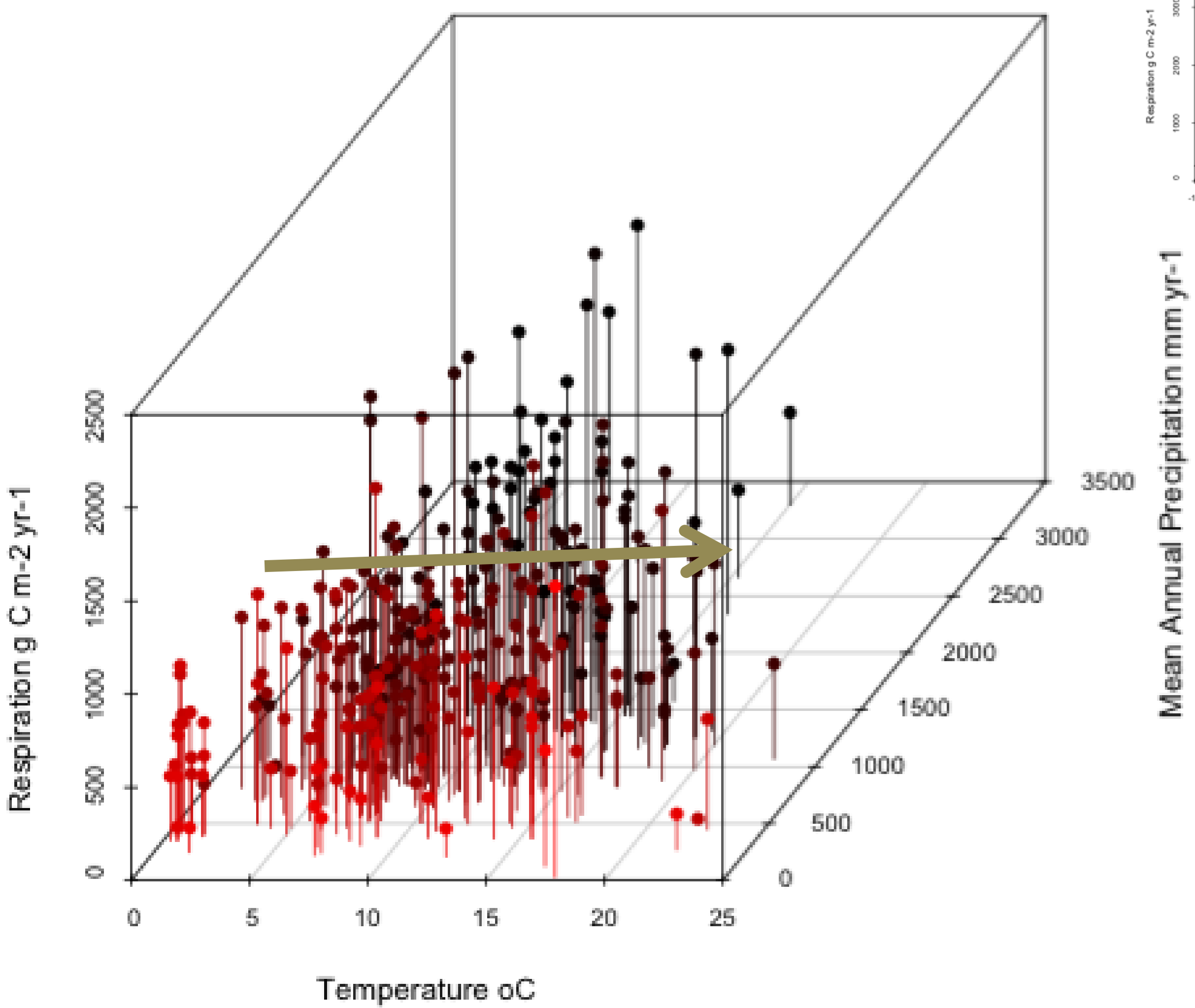
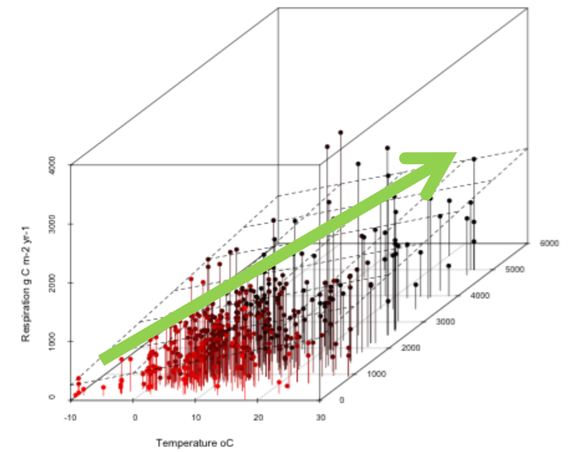
So the temperature sensitivity can only be seen when there is sufficient moisture?





In the mid-latitudes, there is no obvious increase in annual respiration with concomitant increases in temperature and precipitation

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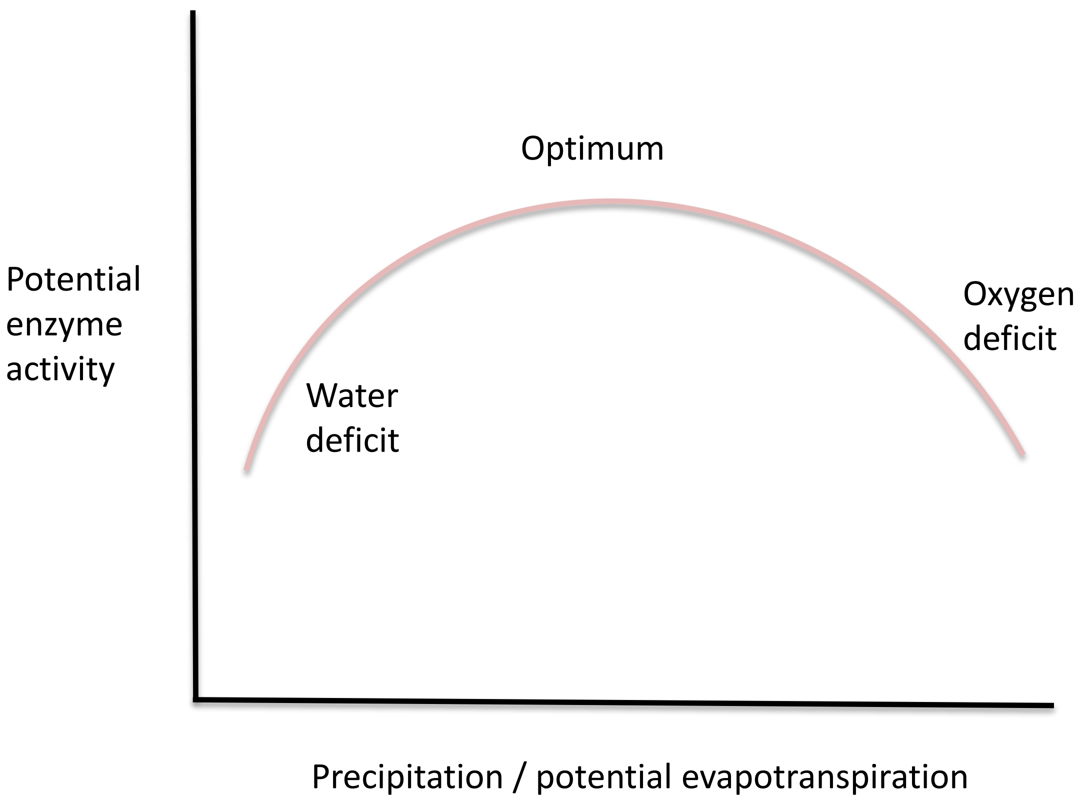
Maybe mean annual precipitation is a useless proxy for bio-available soil moisture.

Unfortunately, this sort of data is very sparse in the Bond-Lamberty dataset



MAT	MAP	PET	MAP/PET
6.9	220	1817	0.1210787
6.9	220	1817	0.1210787
15.5	370	800	0.4625
15.5	370	800	0.4625
15.5	370	800	0.4625
0.81	435	21051	0.0206641
0.5	435	21051	0.0206641
0.3	435	21051	0.0206641
4.9	470	1600	0.29375
4.9	470	1600	0.29375
15	500	725	0.68965517
15	500	700	0.71428571
15	500	700	0.71428571
9.8	750	670	1.11940299
5.5	842	480	1.75416667
12.5	973	790	1.23164557
12.5	973	790	1.23164557
16.8	1577	990	1.59292929
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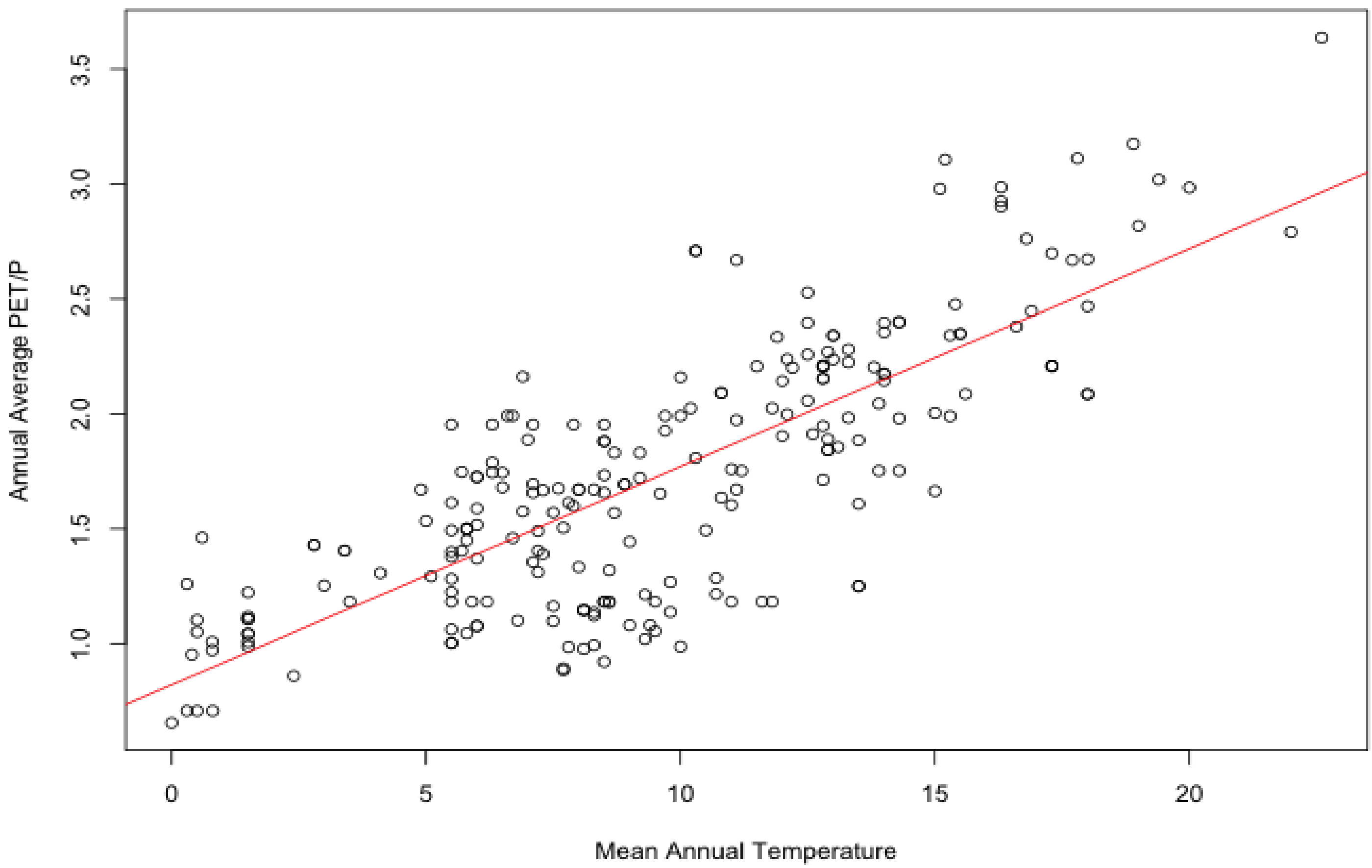
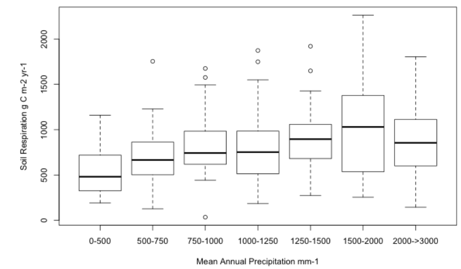
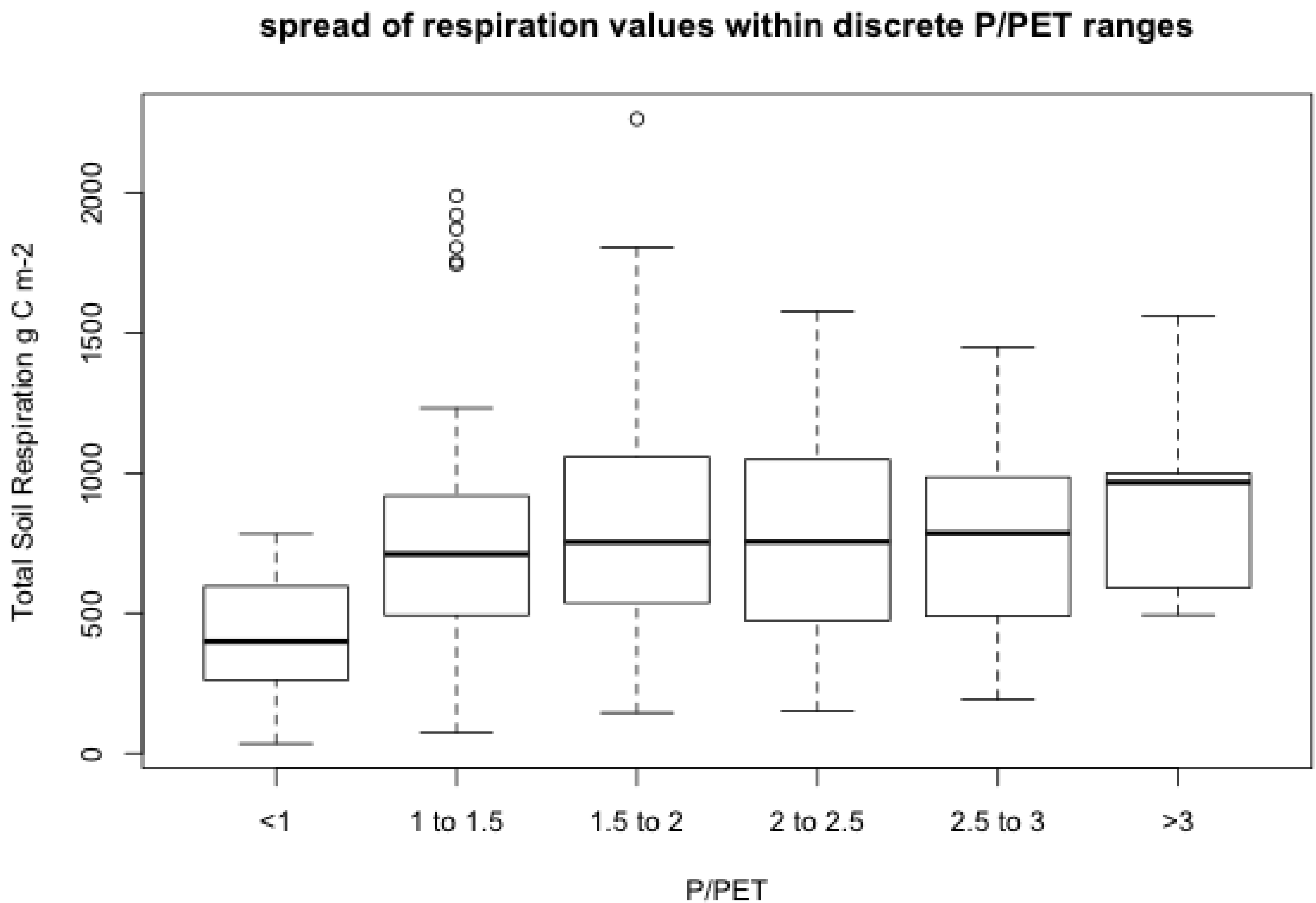
Maybe mean annual precipitation is a useless proxy for bio-available soil moisture.

MODIS derived estimates of precipitation / potential evapotranspiration



A more accurate proxy?





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Why can't we see common site observations at the extra-site scale?*

1.

Other drivers cloud climate signal

"Site"

> Immense site heterogeneity

> Lack of inter-site consistency

That respiration is temperature dependent may be de jure at the site scale, but de facto up-scaling to represent global phenomena may not not defensible

*We should, as this is the scale that climate models aim to replicate

Why can't we see common site observations at the extra-site scale?*

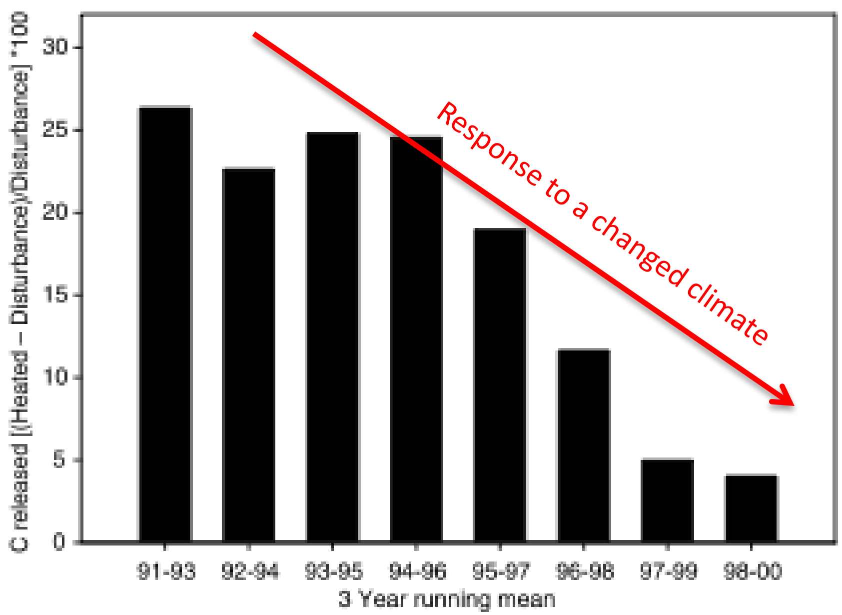
2.

Attenuation of response

Even short-term experimental studies see attenuation of response

Acclimation of ecosystem CO_2 exchange in the Alaskan Arctic in response to decadal climate warming

Walter C. Oechel*, George L. Vourlitis†*, Steven J. Hastings*, Rommel C. Zulueta*, Larry Hinzman‡ & Douglas Kane‡



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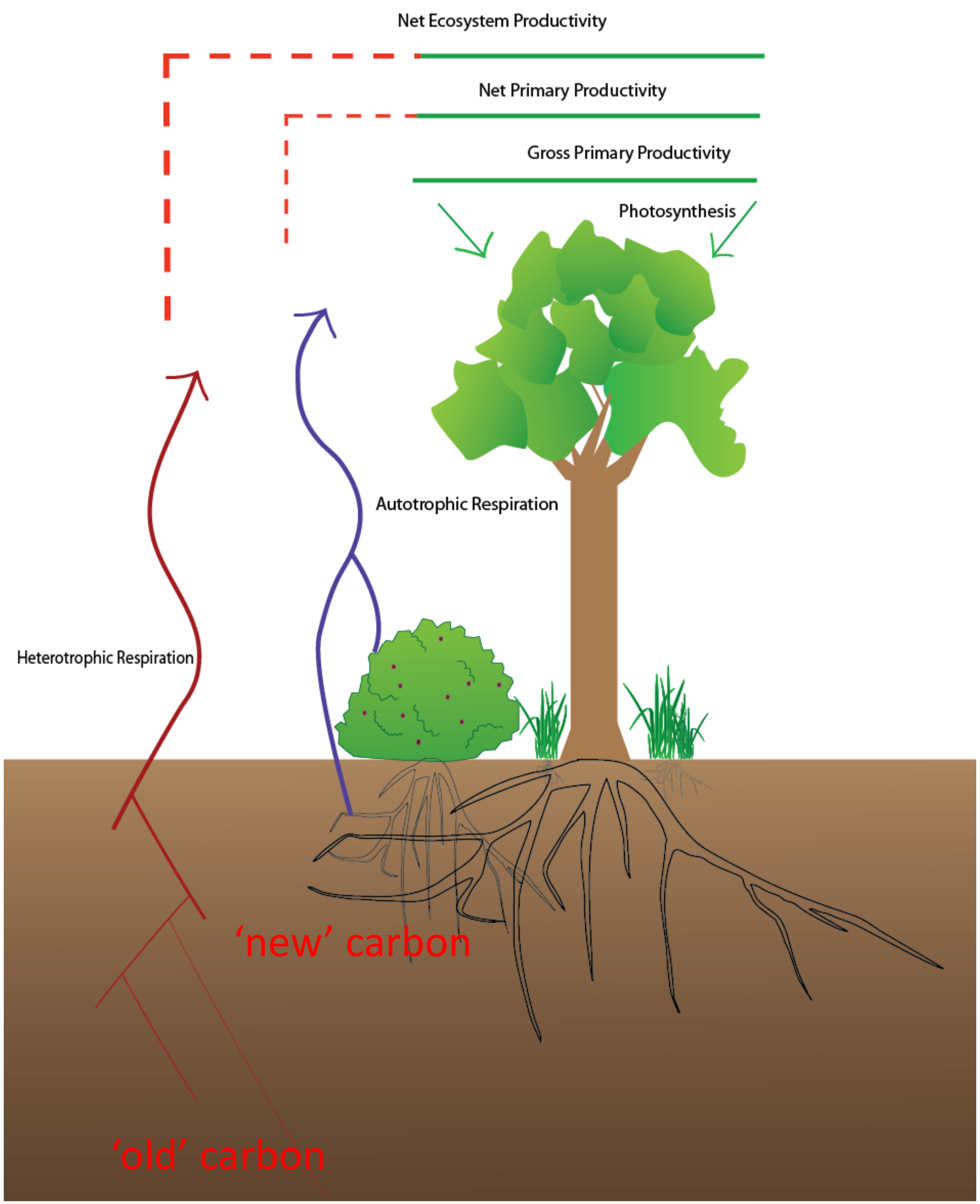

Why would mean annual precipitation show more relation to respiration than actual precipitation observations?

A product of how respiration is measured in the field

$$NPP = GPP - Ra$$

$$NEP = NPP - Rh$$

Net Ecosystem Productivity = the summation of all fluxes

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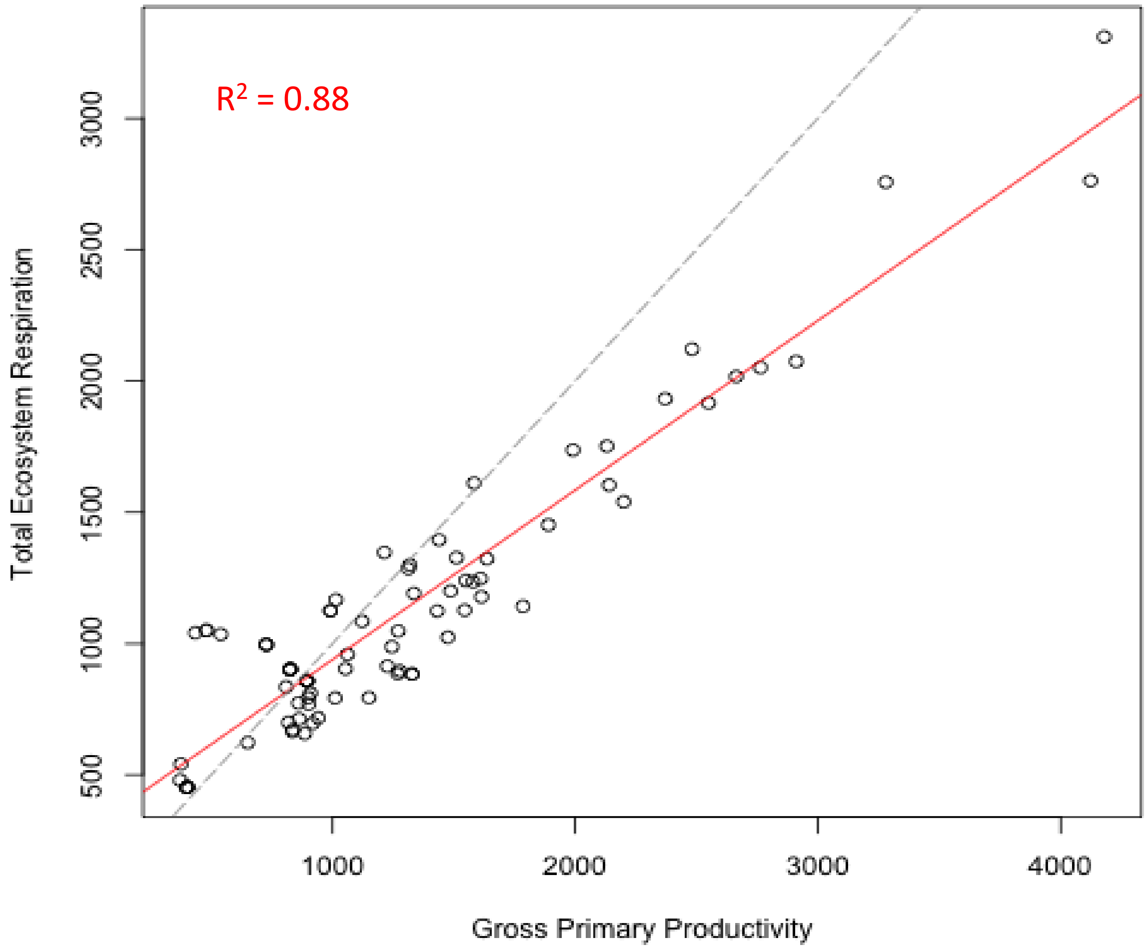
We can see this in the data

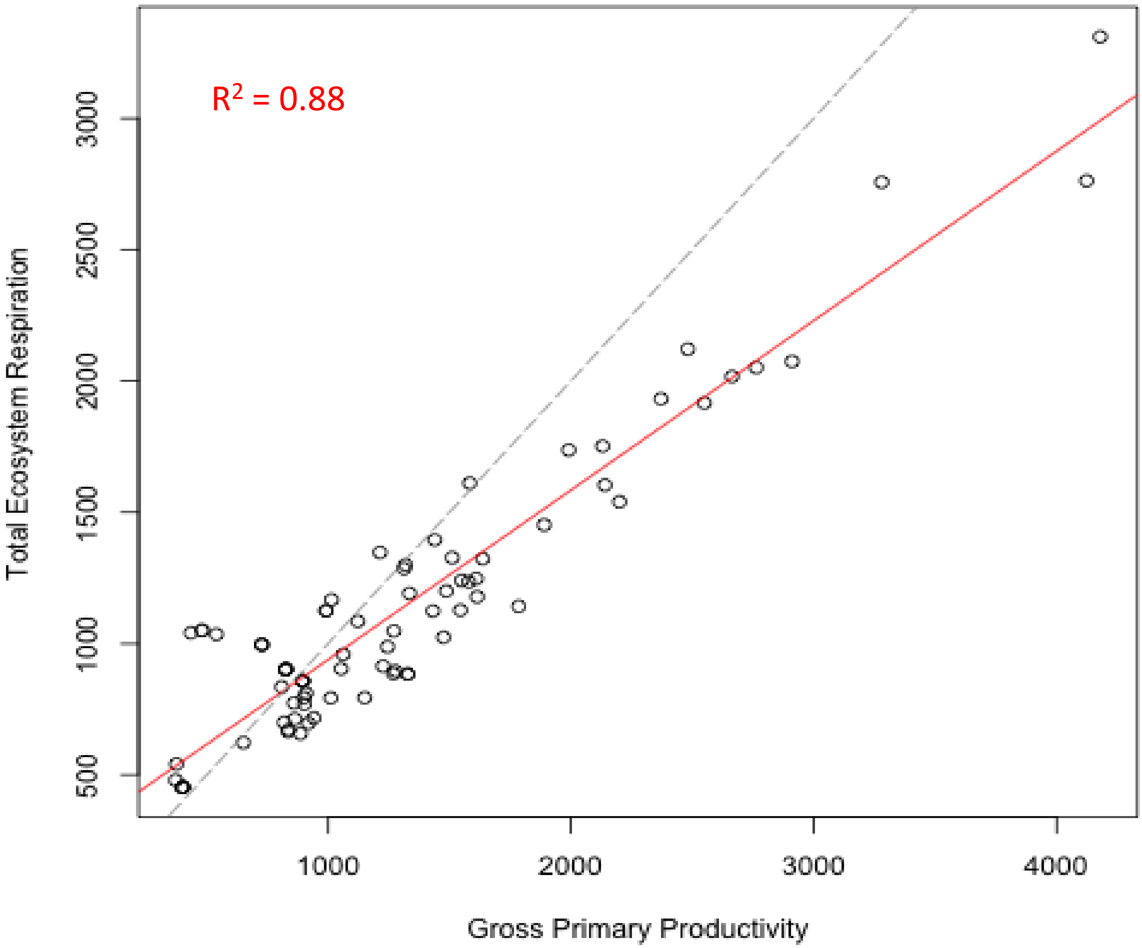


$$NPP = GPP - Ra$$

$$NEP = NPP - Rh$$

Excellent correlation between GPP and total ecosystem respiration: but this is hardly surprising as autotrophic respiration *is* primary productivity

We can see this in the data



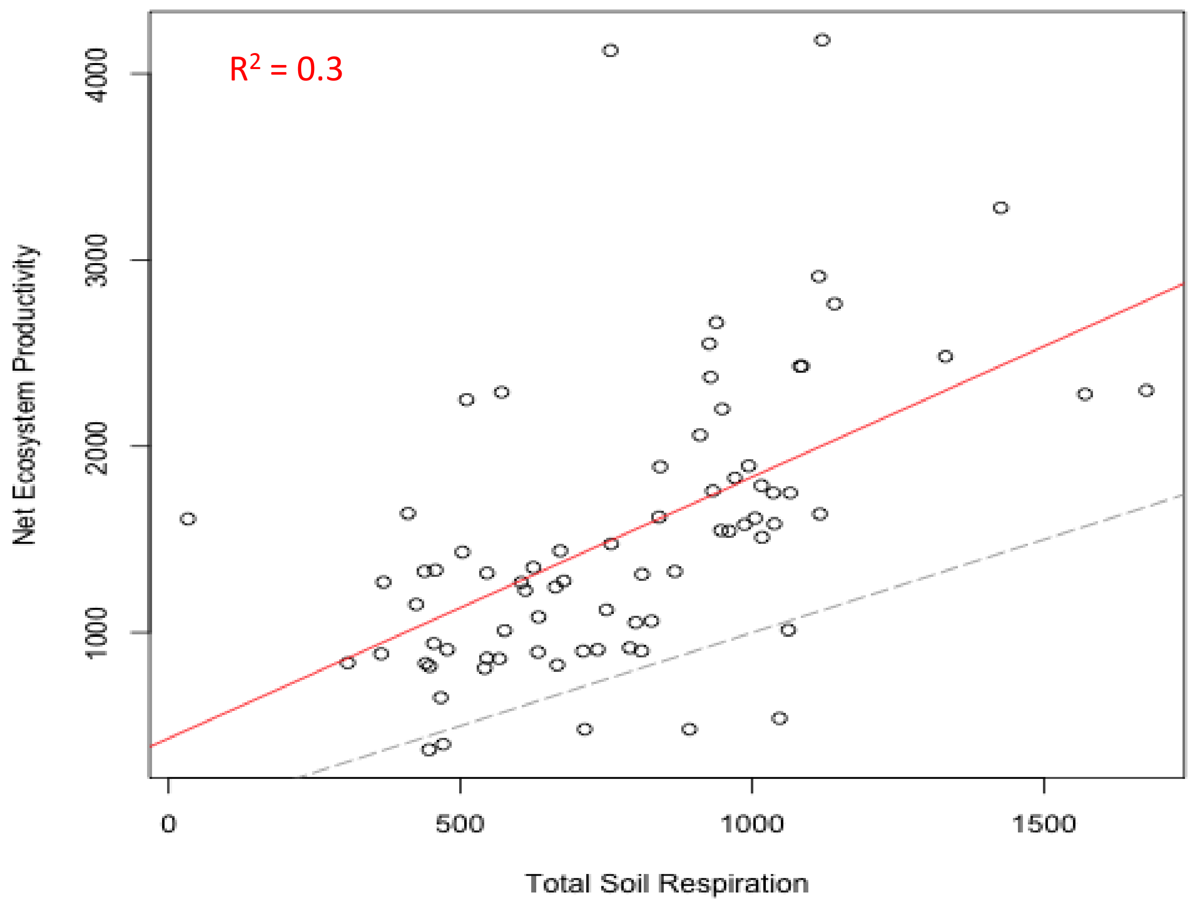
$$NPP = GPP - Ra$$

$$NEP = NPP - Rh$$

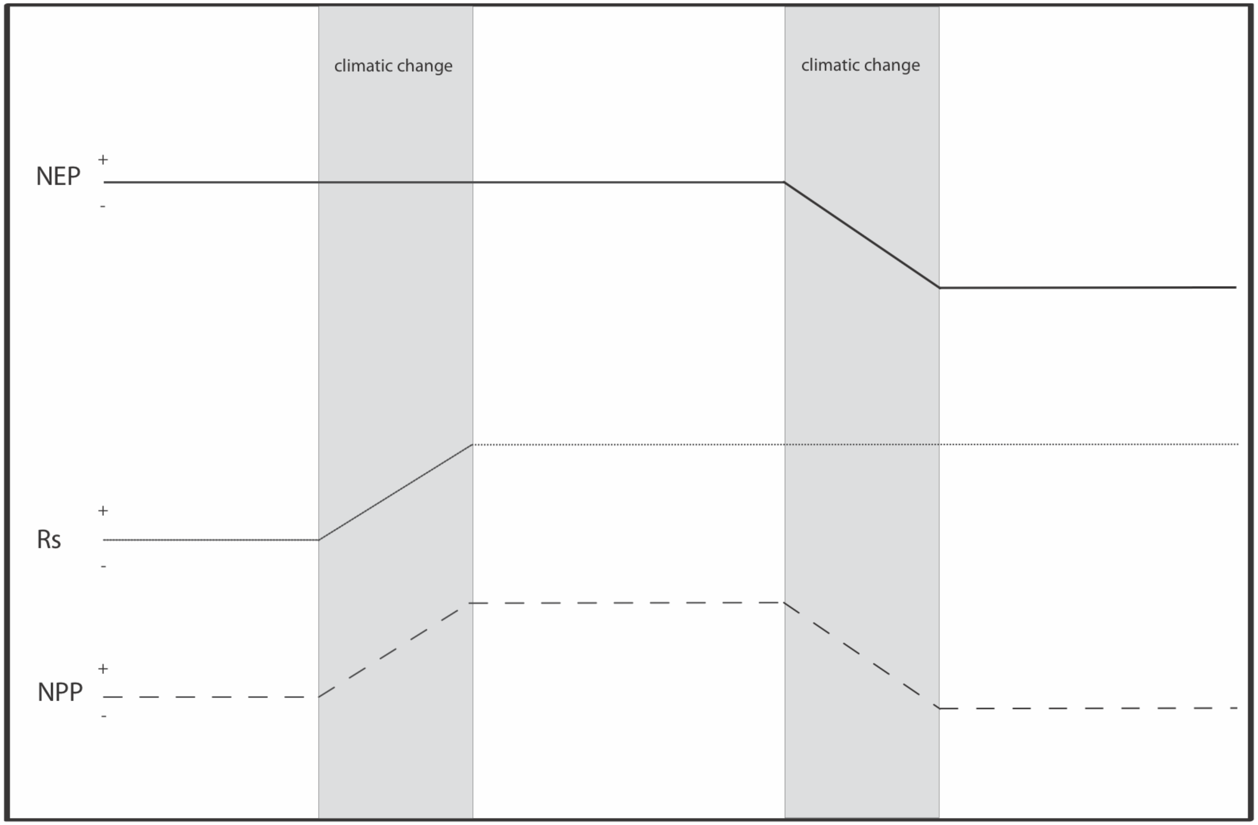
Ruehr & Buchmann [2009] presented a strong correlation between photosynthetic active radiation (and thus GPP) and Ra

We find the Ra component of Rs to be 42% ± 2.35 (where n = 255)

De-coupling of Rh and Ra respiration components?



Such an absence is conspicuous, and points to the relative importance of Rh in ultimately determining the carbon balance; if GPP and Rh were governed by the same drivers, as GPP and Ra are, then one would expect NEP to be in steady-state with soil respiration and GPP



In order to achieve an increase in NEP with increases in GPP the drivers of soil respiration must be different, or at least have a different sensitivity, to those that drive GPP. If the responses of GPP and Rs were equal, there would be no change in the net uptake/loss of carbon as GPP changes. Likewise, the decoupling of total soil respiration with NEP in the presence of a strong correlation between GPP and NEP points to a certain degree of independence in the response of these two processes to the same stimuli, otherwise Rs would also correlate with NEP; as autotrophic respiration is a direct corollary of production, it is deduced that the heterotrophic component of Rs dictates the scatter

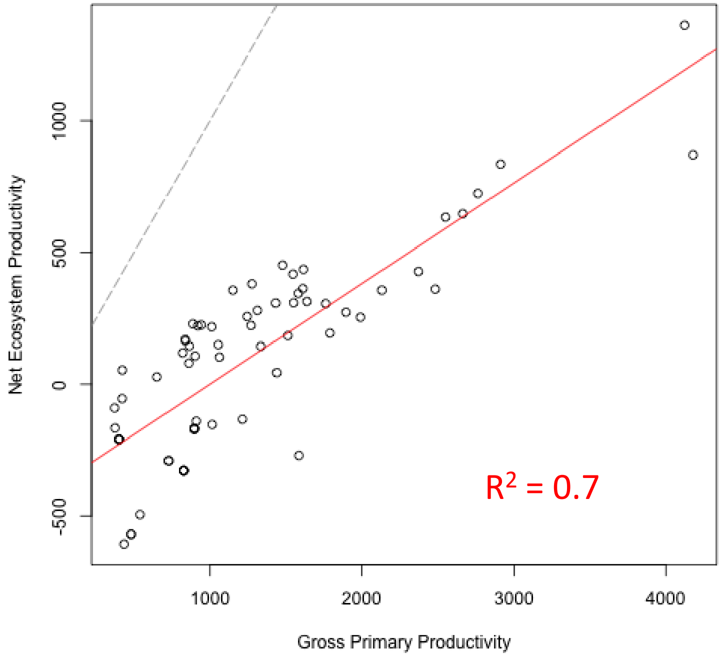
Is this OK?

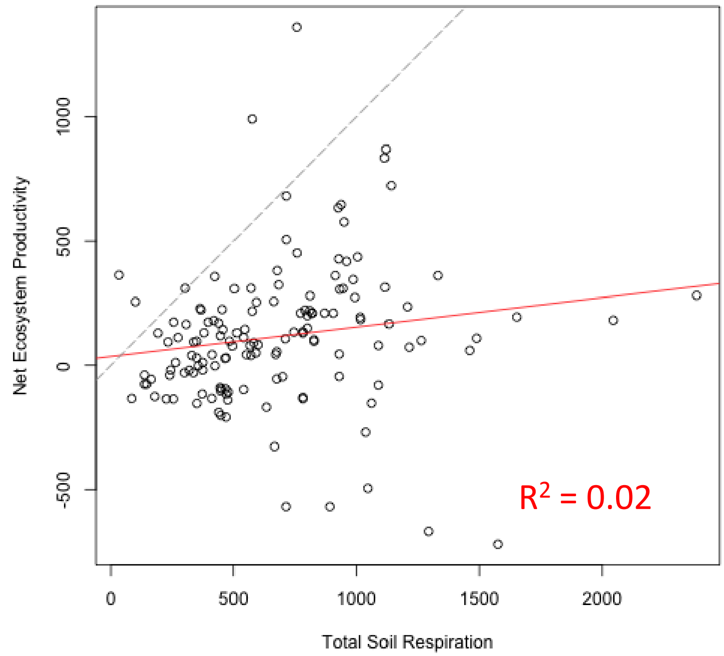
$$NPP = GPP - Ra$$

$$NEP = NPP - Rh$$

It is this component that determines how NEP varies with GPP

We model respiration as the temperature sensitive decomposition of recent and old litterfall- but if they respond to different drivers, or at least with a different sensitivity, then what can this tell us about resolving the balance of the terrestrial carbon cycle?





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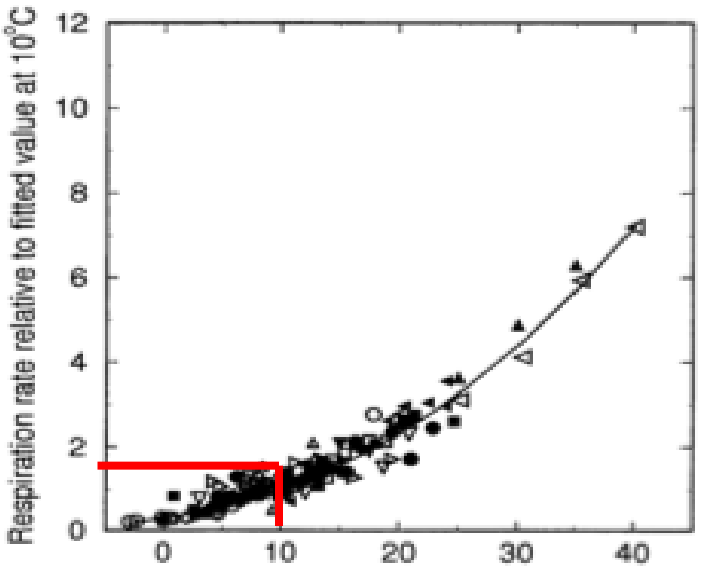
“...impossible to measure *actual* temperature response of R_S, and that a range of confounding effects creates the observed *apparent* temperature relations reported in the literature” Subke & Bahn, 2010.

Implications



e.g. Q10 = 2

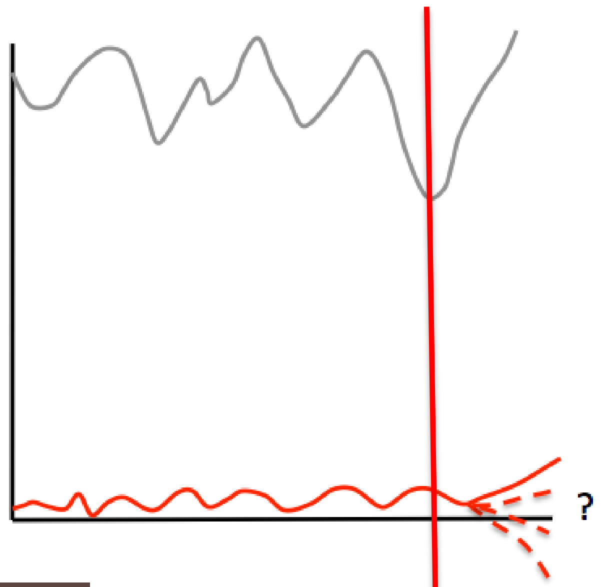
Modelling 101: "Statistical models contain no understanding of the processes involved, so it is unlikely to be accurate if used to predict results well outside the conditions for which it was developed" Smith & Smith, 2009.

Which is *exactly* the purpose of climate models

ignores the actual underlying mechanisms, such as substrate supply and quality or microbial competition and survivorship, and as such the true response of respiration to changes in climate cannot be mechanistically predicted [*Subke & Bahn*, 2010].

Modelling respiration

We are interested in the long-term balance between the total production and respiration, as this determines how much carbon soils will contain, and how much will be in the atmosphere



Analogous to the gradual exudation of carbon to the atmosphere from burning fossil fuels

We need to know the long-term response of the 'background' flux of 'old' carbon due to changes in climate

Parameterising models with 'soil respiration' from a few years of measurement can not tell us this temporally or spatially-boundary conditions

Modelling respiration

Despite the enormity of both fluxes, primary productivity draws the most research attention, allowing vegetation component of land C models to develop rapidly (Foley et al., 1996; Sitch et al., 2008)

Therefore: relatively poor understanding of soil heterotrophic processes relative to plant photosynthesis (Todd-Brown et al. 2011)

Very little change in representation of decomposition processes. Models have not kept pace with rapid advances in the ecology of microbial decomposition (Chapin et al., 2009).

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