Ozone and nitrogen interactions in birch trees

Felicity Hayes[1], Gina Mills[1], Harry Harmens[1], Richard Falk[2,3], Vicent Calatayud[4]

CEH-Bangor UK, CEH-Wallingford UK, University of Exeter UK, Fundación CEAM Spain

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Éclaire project and talk overview

- How will climate change alter the threat of air pollution on ecosystems?
- Measurements, models, innovative risk assessment and the economic implications
- Focus on N and O_3 and their interaction with other pollutants
- ‘new’ experiments, and existing datasets from current/recent experiments at complementary sites and ecosystems across Europe

- Physiological measurements on birch trees with combined ozone and nitrogen treatments

- How these will be used to model impacts

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éclaire
Effects of climate change on air pollution impacts and response strategies for European ecosystems
SEVENTH FRAMEWORK PROGRAMME

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Experiment set-up and aims

Birch in 7 ozone treatments and 4 nitrogen regimes

Stomatal conductance, Photosynthesis, A/Ci curves

Whole tree carbon and ozone fluxes

- ❑ Does nitrogen modify the response of birch to ozone?
- ❑ Does nitrogen and/or ozone affect the DO_3SE parameterisations for birch?
- ❑ Do fluxes of ozone and carbon become uncoupled?
- ❑ Are canopy (whole tree) alterations in fluxes a consequence of individual leaf physiological responses, or via reduced biomass?

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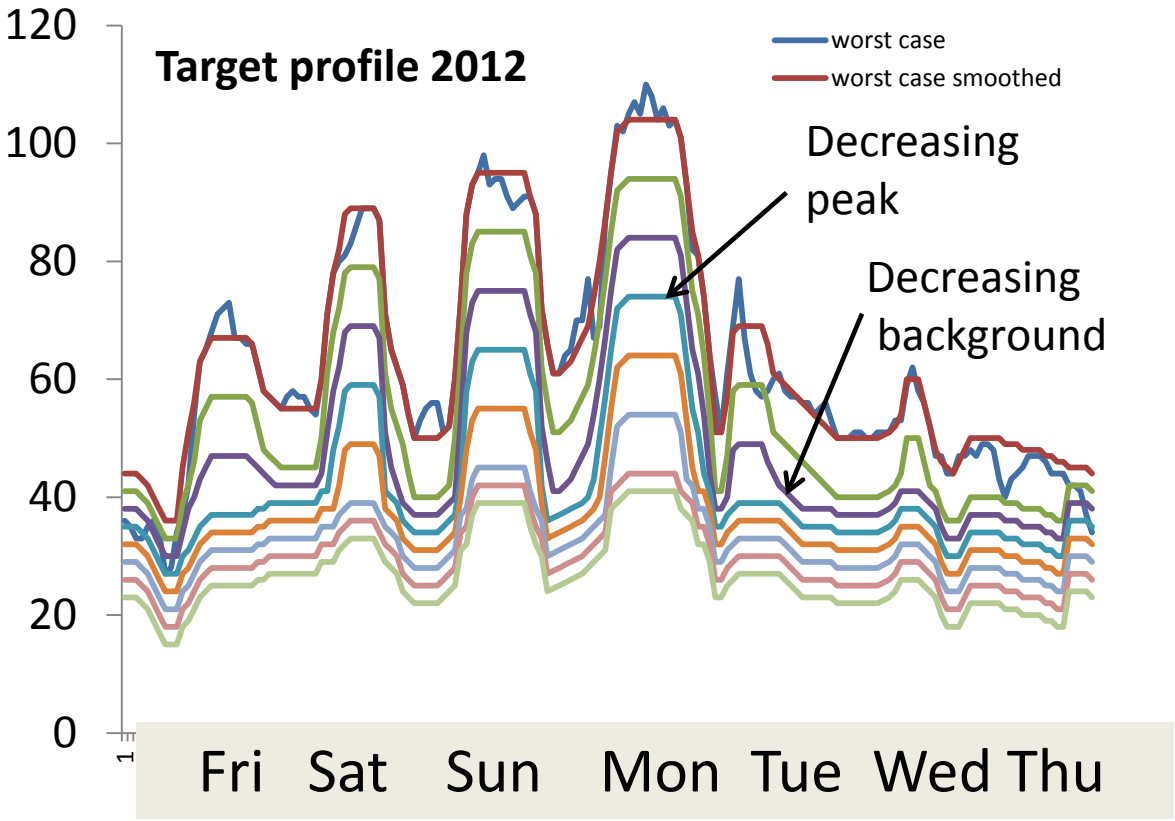
Ozone Regime – Peaks affected more than background



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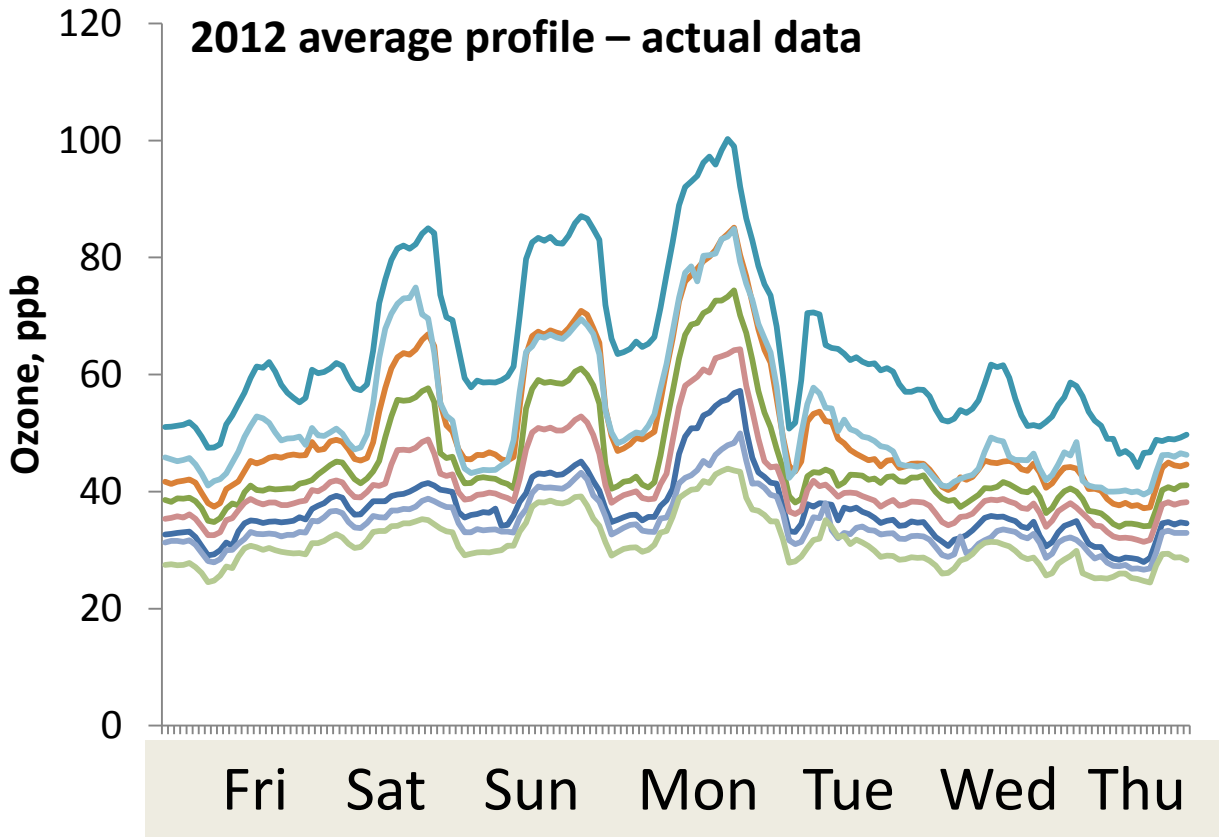

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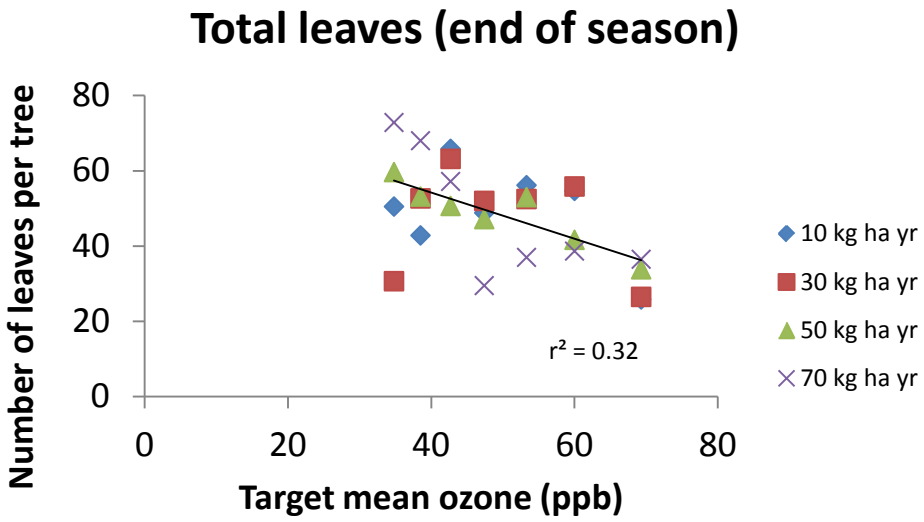
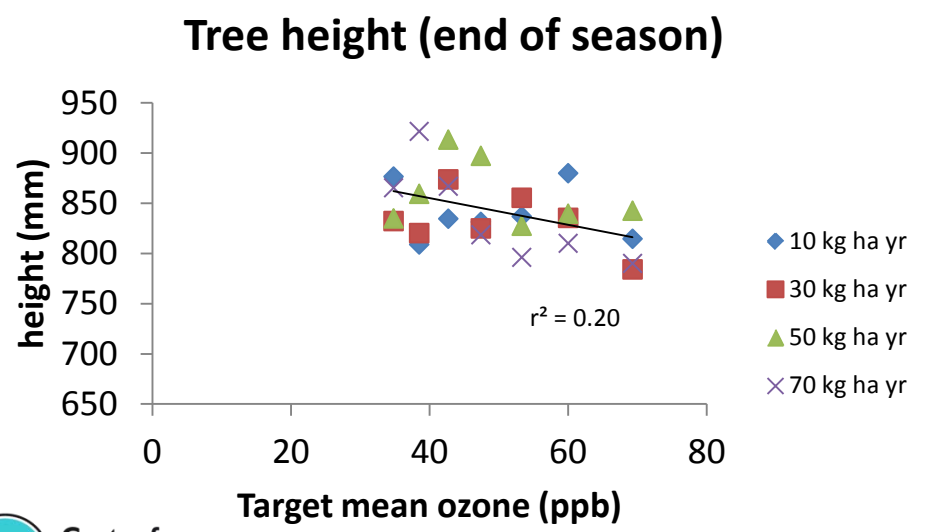
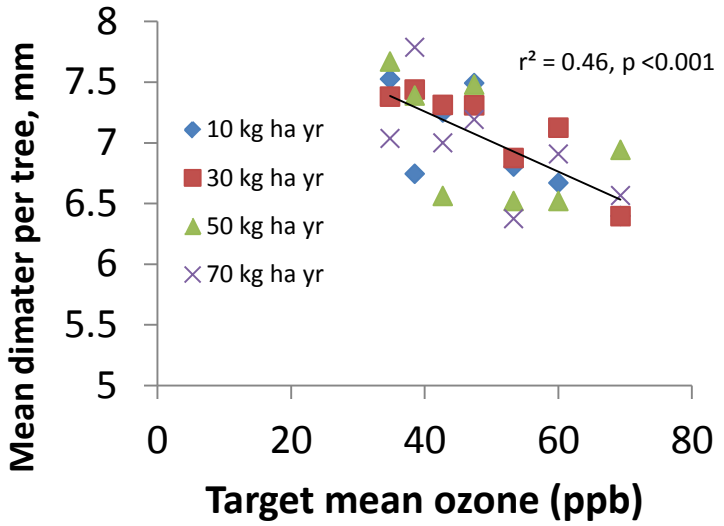
Tree size



Decrease in tree height, stem diameter and leaf number with increase in ozone exposure

There was no effect of nitrogen (although only the first year of study)





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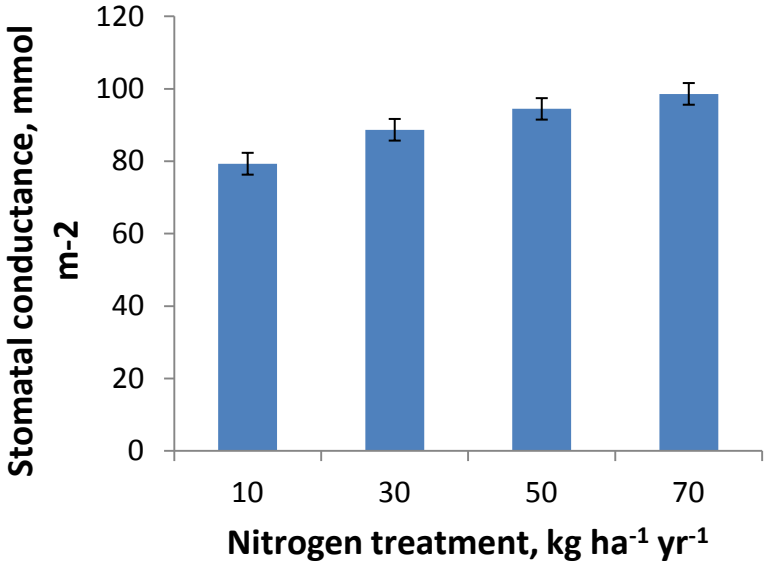
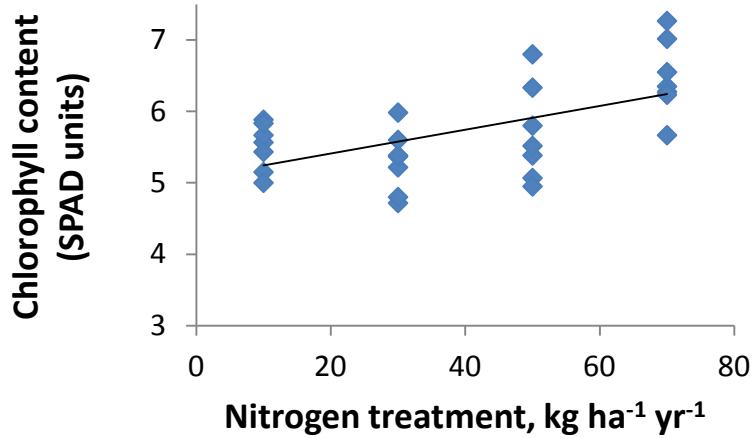
Nitrogen

- Towards the end of the ozone exposure, leaves from the highest nitrogen treatment had elevated stomatal conductance and elevated chlorophyll content
- The DO_3SE model (models fluxes of ozone into a leaf based on climatic and other variables) can be tweaked to account for the effect of N on g_{max}
- Initially this has been run by running the model for each nitrogen treatment separately



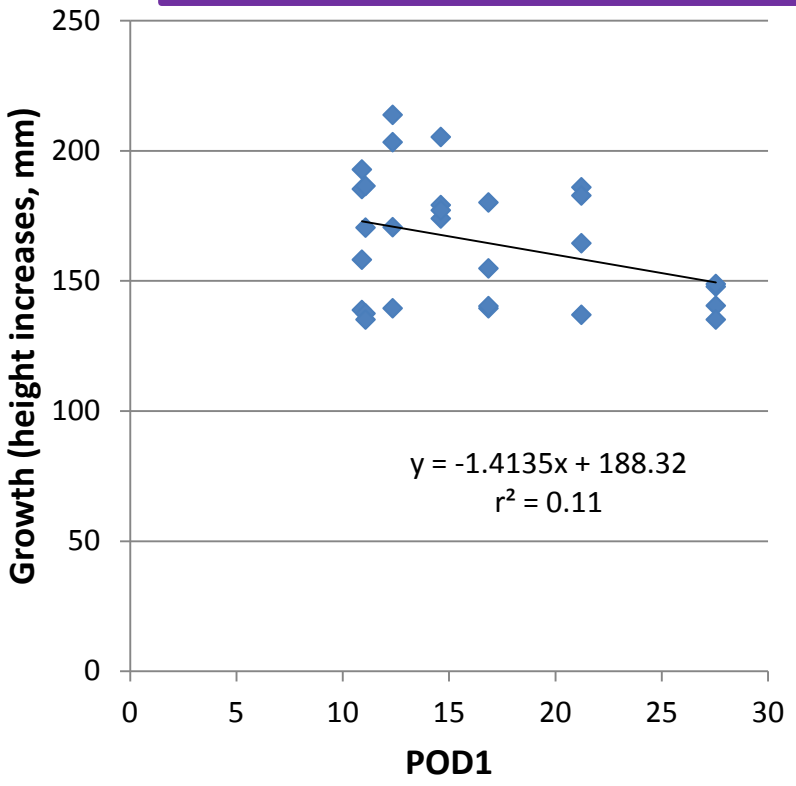


CEH Bangor unpublished data

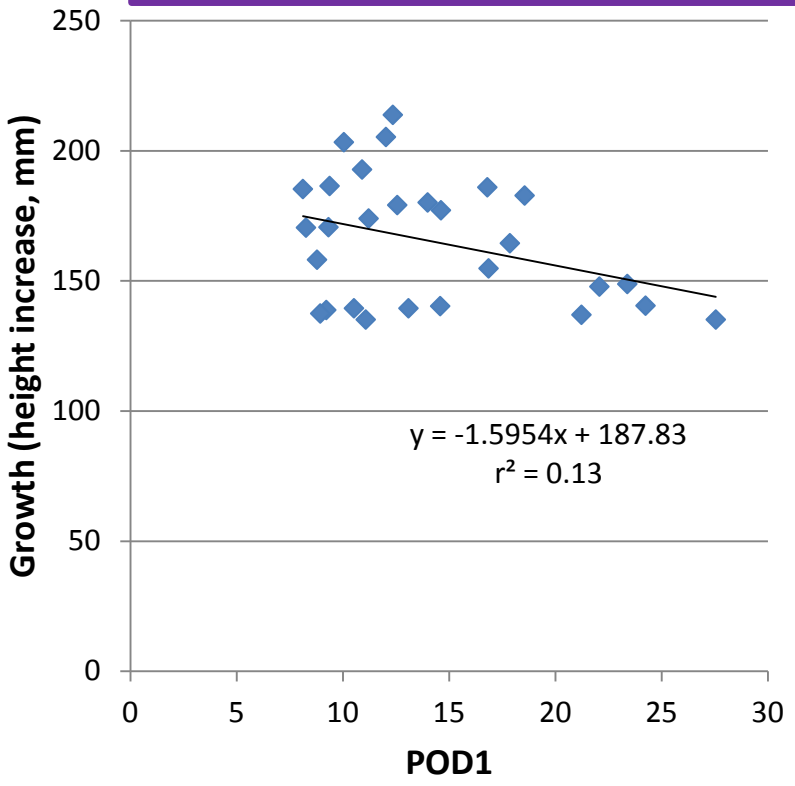
Ross-Albert, Calatayud, Falk, Harmens, Hayes and Mills

Accounting for nitrogen in DO_3SE

Unadjusted model



DO_3SE model adjusted to account for N response



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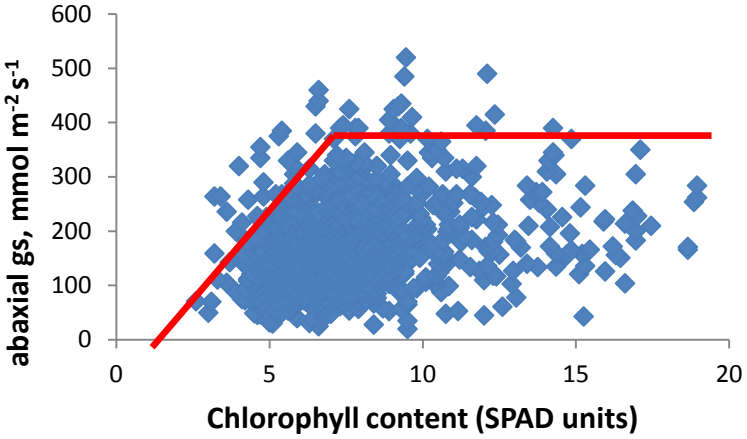
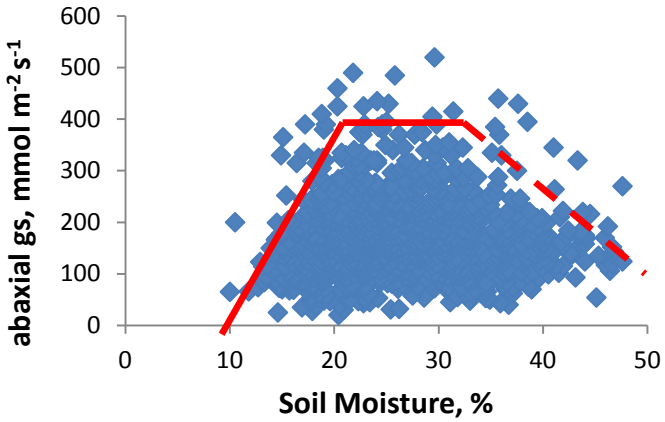
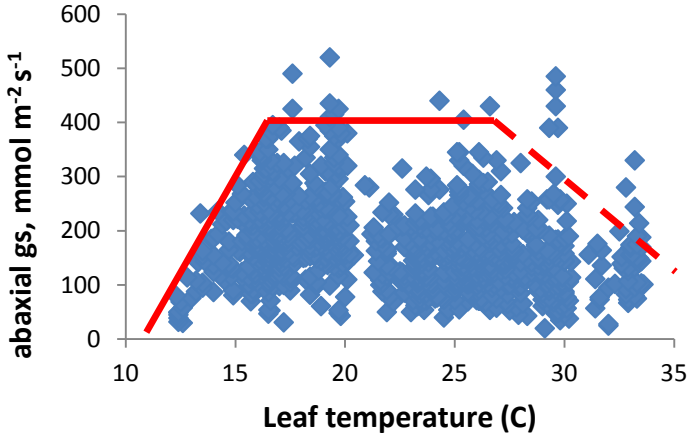
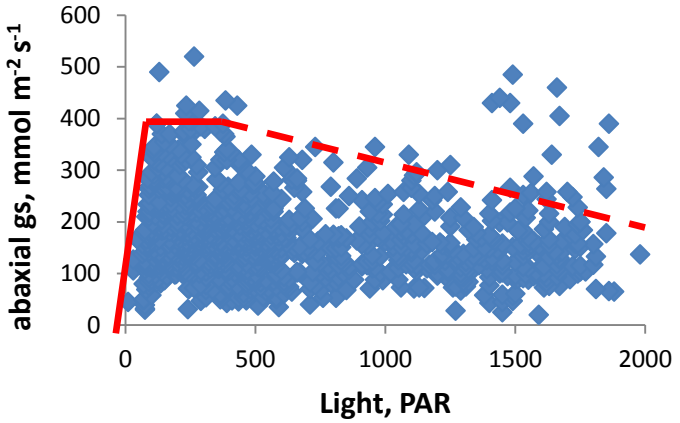
Other factors influencing stomatal conductance









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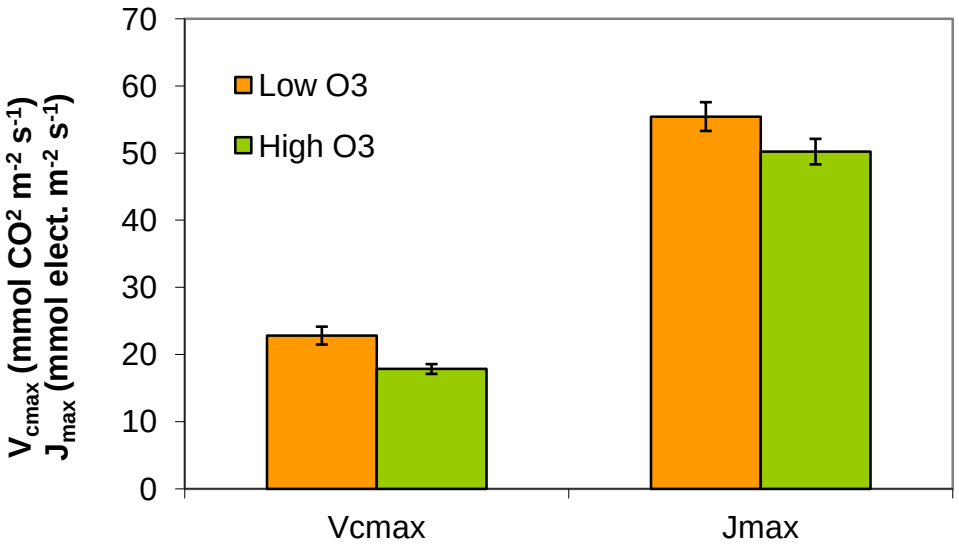
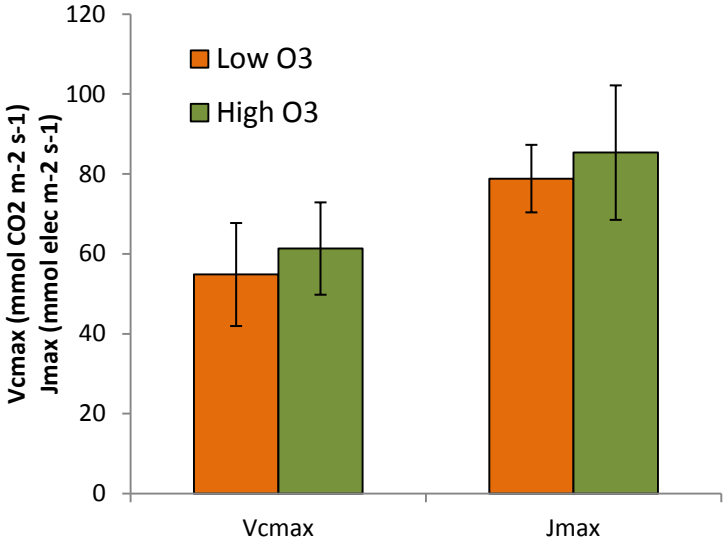
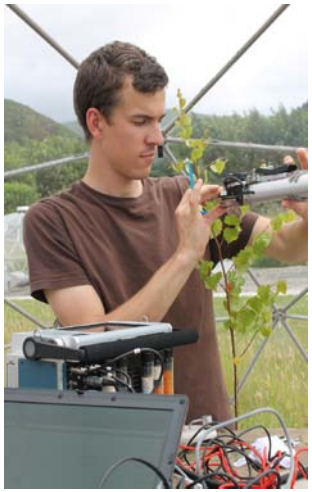
Leaf Level Effects – young leaves



V_{cmax} and J_{max} (photosynthetic efficiency and capacity) both decreased with elevated ozone in leaves representative of canopy in the summer



For young leaves in the autumn this did not occur.



Richard Falk – PhD student. University of Exeter and CEH

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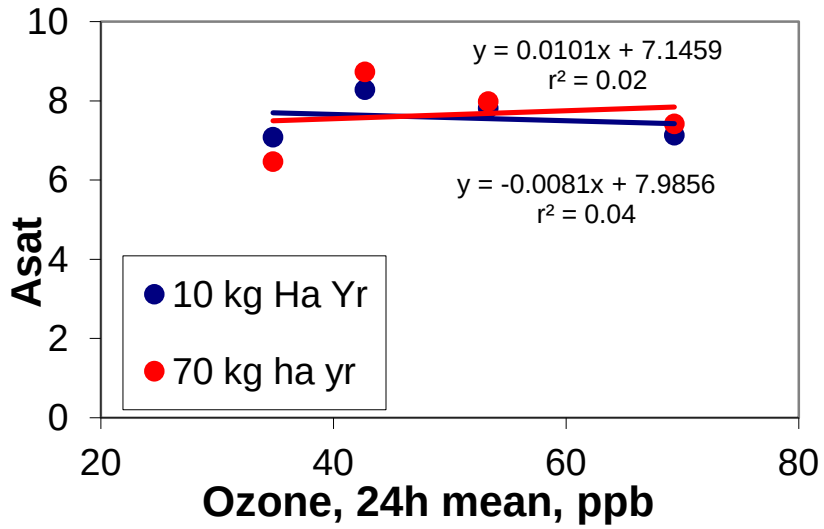
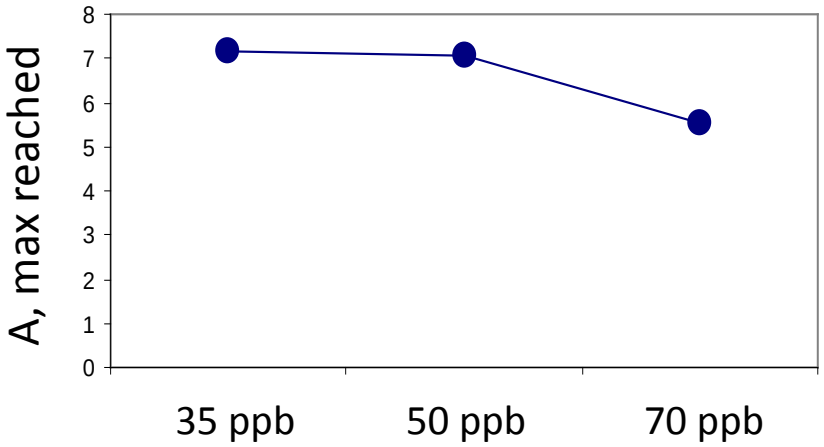
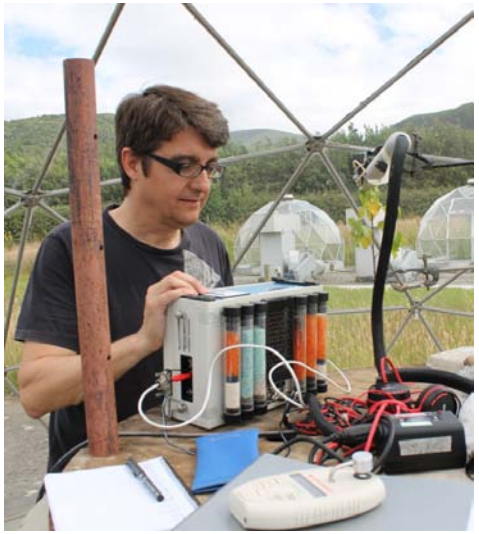
Leaf Level Effects – young vs old leaves



No evidence of an effect of either ozone or nitrogen on the A_{sat} of young leaves (leaf 3)

Slightly reduced photosynthesis (and stomatal conductance) with increasing ozone for older leaves





Vicent Calatayud, Fundación CEAM, Spain

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Is this:
Adaptation

Re-allocation of resources to new leaves at the expense of older leaves?

Or

Ozone damage is very slow and cumulative?

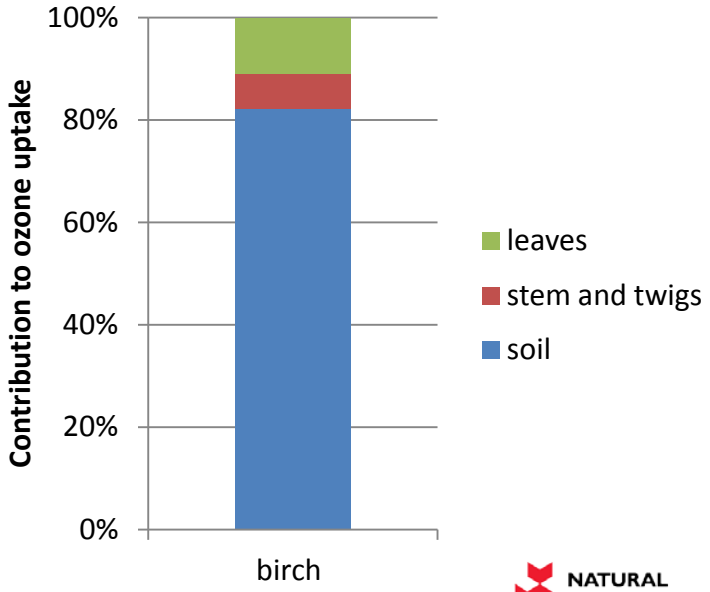
Ozone injury on birch – early season only

Whole–tree measurements

Within a solardome (with ozone on) and using a custom built tree-chamber in the light and in the dark:

Fluxes of carbon dioxide
Ozone fluxes
(humidity for some measurements)

Technological challenges, particularly for ozone



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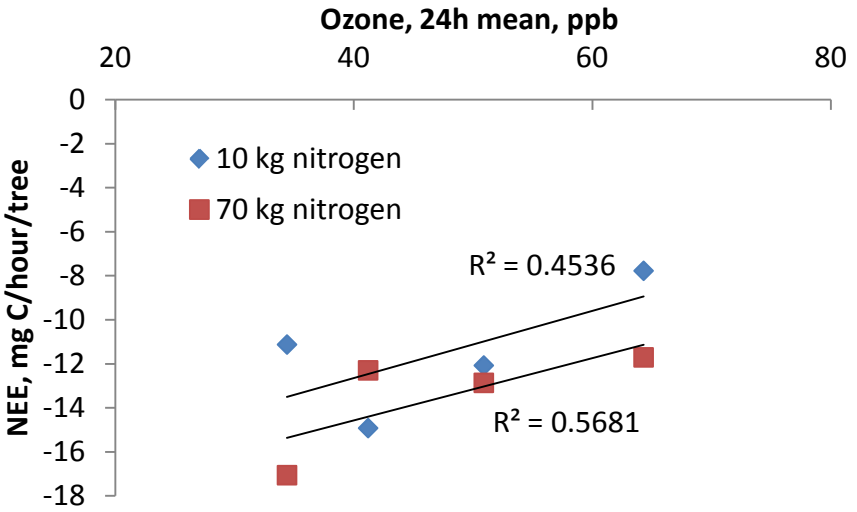
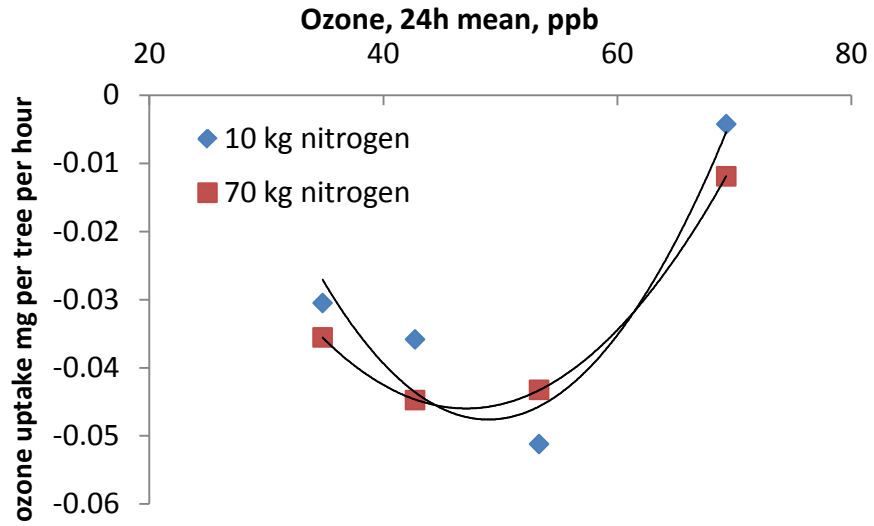
Whole–tree measurements





24th July 2012

Decreased uptake of ozone and CO_2 with increasing ozone exposure, possibly related to reduced leaf area

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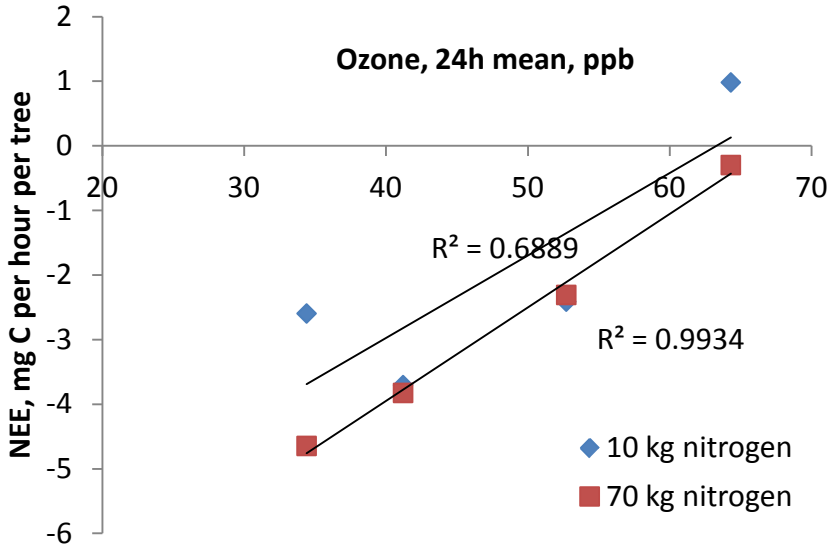
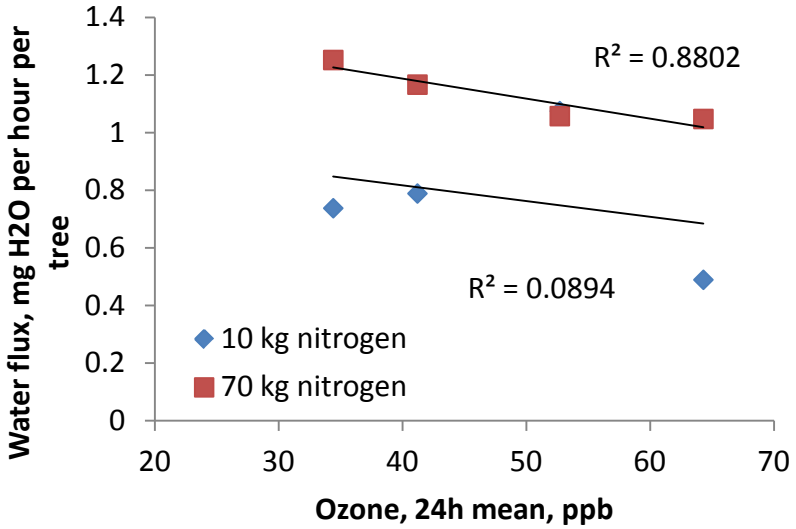
Whole–tree measurements

2nd October

- Reduced CO_2 uptake with increasing ozone – matches the reduction in leaf number
- Smaller effect on water vapour fluxes
- Larger water vapour fluxes at high nitrogen correspond to the higher gs measured on individual leaves





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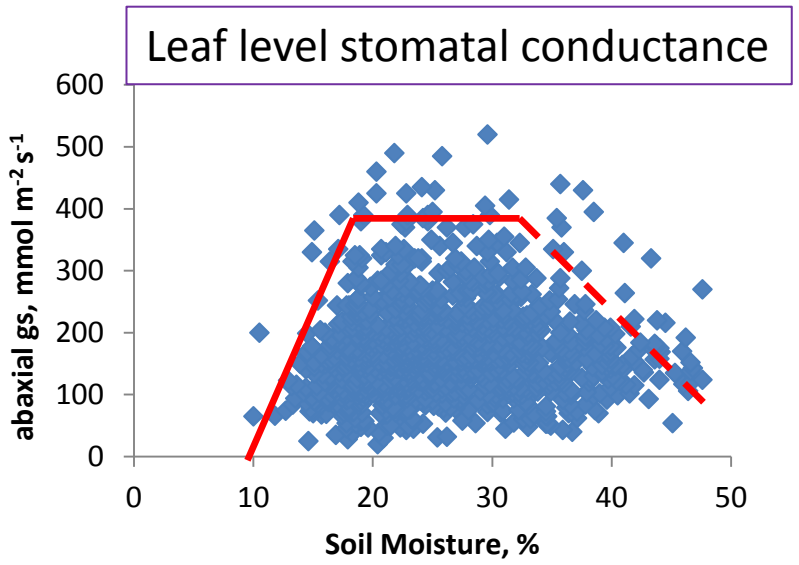
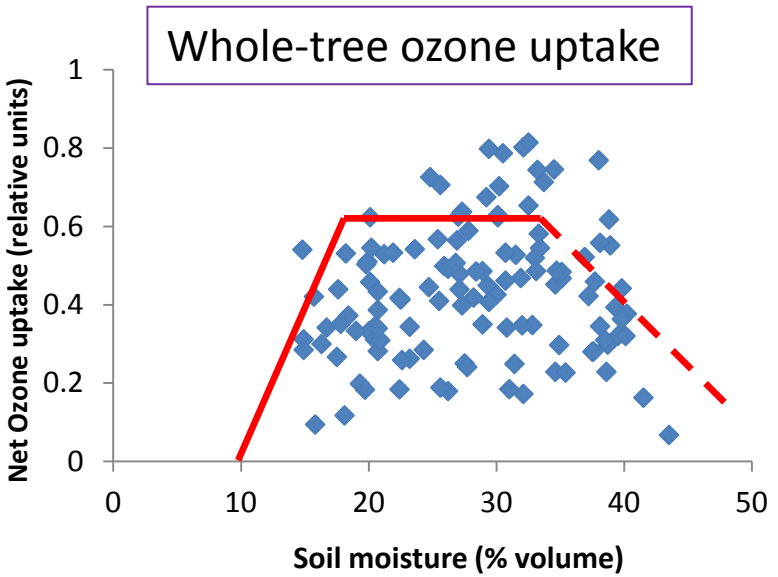
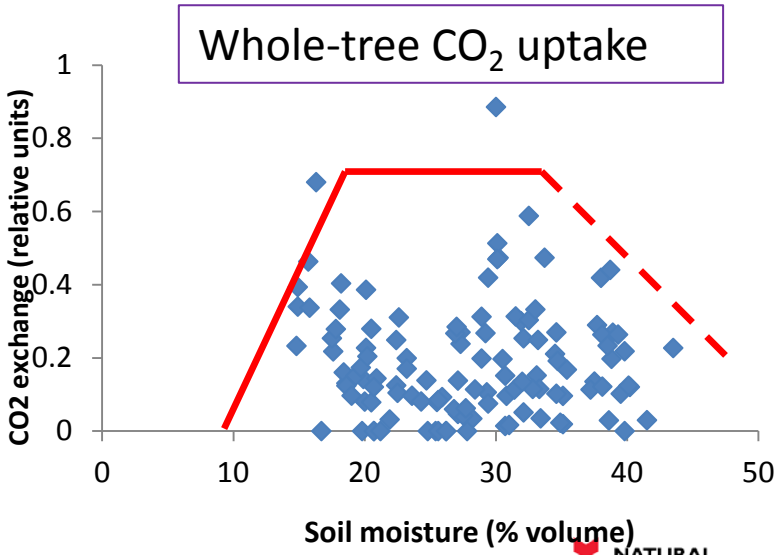
Comparing single leaves and whole trees





By eye – a reasonable match between leaf level gs and whole-tree ozone uptake in response to soil moisture

Not sure whether whole tree ozone and CO_2 uptake in response to soil moisture are matched or not (more data needed)



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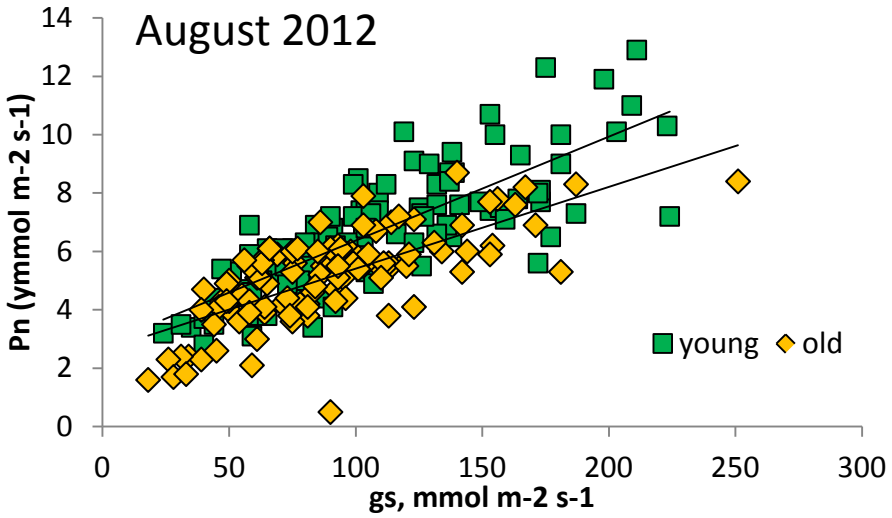
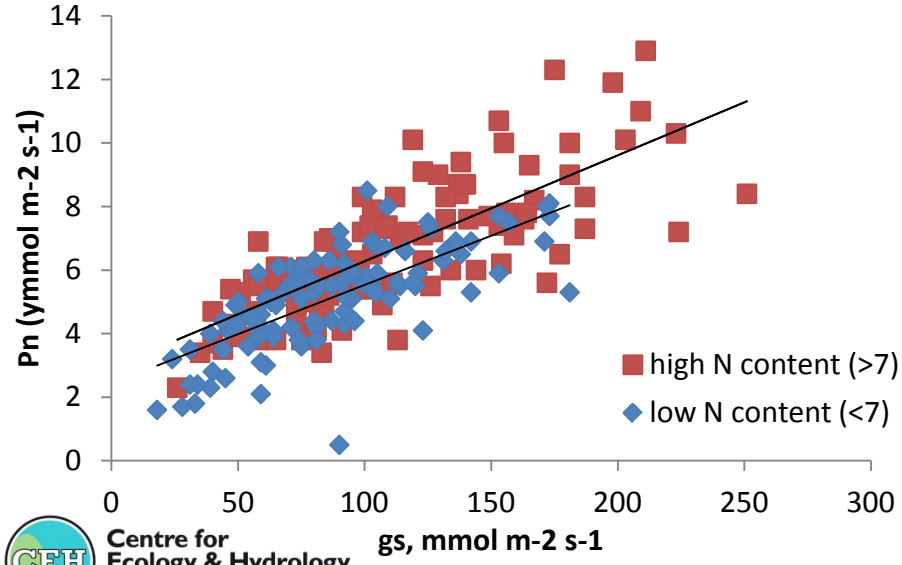
Further thoughts on uncoupling of gs and Pn



Coupling between photosynthesis and stomatal conductance may also be affected by other factors such as leaf age…..



….. but not as simple as 'just' nitrogen content of the leaves (used here as a possible surrogate for RUBISCO content)

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Ambient measurements using a CIRAS II

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What next - Plants?

All trees have overwintered outside, with nitrogen treatments maintained

Trees will be re-exposed to ozone in 2013 – will we see cumulative effects or adaptation?
- Will we see nitrogen effects at the whole-tree level?

More measurements at leaf- and whole-tree level over a range of ozone, nitrogen and environmental conditions

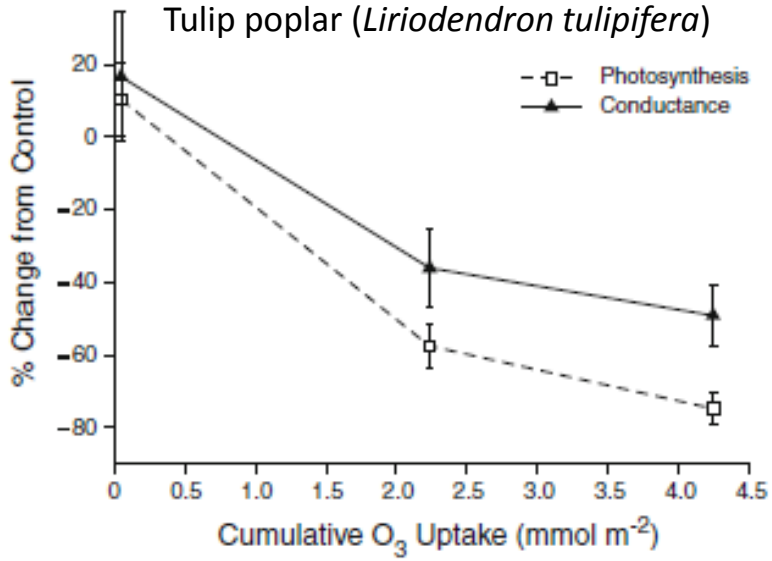
What next – using the data?

Modelling within éclaire

- Further investigation of whether O_3 alters stomatal conductance (thereby affecting CO_2 and O_3 fluxes)
- Direct effect of ozone on photosynthesis
- 'costs' associated with detoxification
- uncoupling of photosynthesis from stomatal conductance

Possible solution = modify Ball-Berry stomatal predictions independently of photosynthesis

Tulip poplar (*Liriodendron tulipifera*)



Coupled models over-predict decreases in transpiration compared to the uncoupled model. This affects atmospheric water vapour and surface hydrology (particularly in the tropics and mid-latitude)

Lombardozzi et al. 2012. Oecologia 169:651-659
Lombardozzi et al., 2012. Biogeosciences 9: 3113-3130

Summary and Conclusions

There are interactions between ozone and nitrogen at the leaf-level
Only ozone effects were apparent at the whole tree (growth) level after 1 season

'Patterns' of physiological responses at the leaf-level matched those at whole tree level, but no reliable functions exist to scale between these

Effects on individual leaves, coupled with reduced numbers of leaves, resulted in decreased fluxes of carbon dioxide, ozone and water at the whole-tree level

Fluxes of carbon dioxide, water and ozone may be uncoupled by elevated ozone, and possible with other environmental variables such as soil moisture, and plant factors e.g. leaf age

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