Effects of winter temperature and summer drought on net ecosystem exchange of CO_2 in a temperate peatland

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Site description

- Auchencorth Moss (55° 47’ N, 03° 14’W) is a relatively flat, low-lying, ombrotrophic peatland in SE Scotland.
- The site was drained more than 100 years ago (drainage ditches now disused and overgrown).
- Land-use is primarily low intensity sheep grazing
- Peat depth ranges from <0.5 m to >5 m
- Vegetation consists of a patchy mix of grasses and sedges covering a primarily *Sphagnum* base layer on a typical peatland hummock/hollow microtopography.
- Mean water table depth is -12.5 cm, ranging from below -55 cm to +4.5 cm above the peat surface
- Auchencorth Moss is a CEH aquatic carbon catchment site (4 in the UK)

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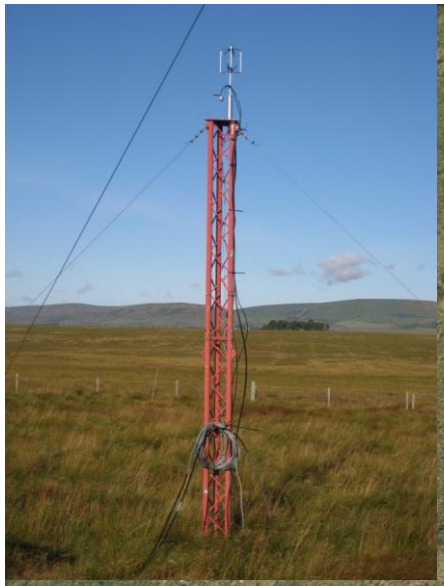
Site description: instrumentation



Eddy-covariance system (continuously since 2002):

- Gill Windmaster Pro ultrasonic anemometer
- Licor 7000 closed-path CO_2/H_2O analyser
- Measurement height 3.4 m
- Uniform fetch to North, West and South (several km)

Auchencorth Moss

Prevailing wind direction:
S-W (ca. 70% of the time)

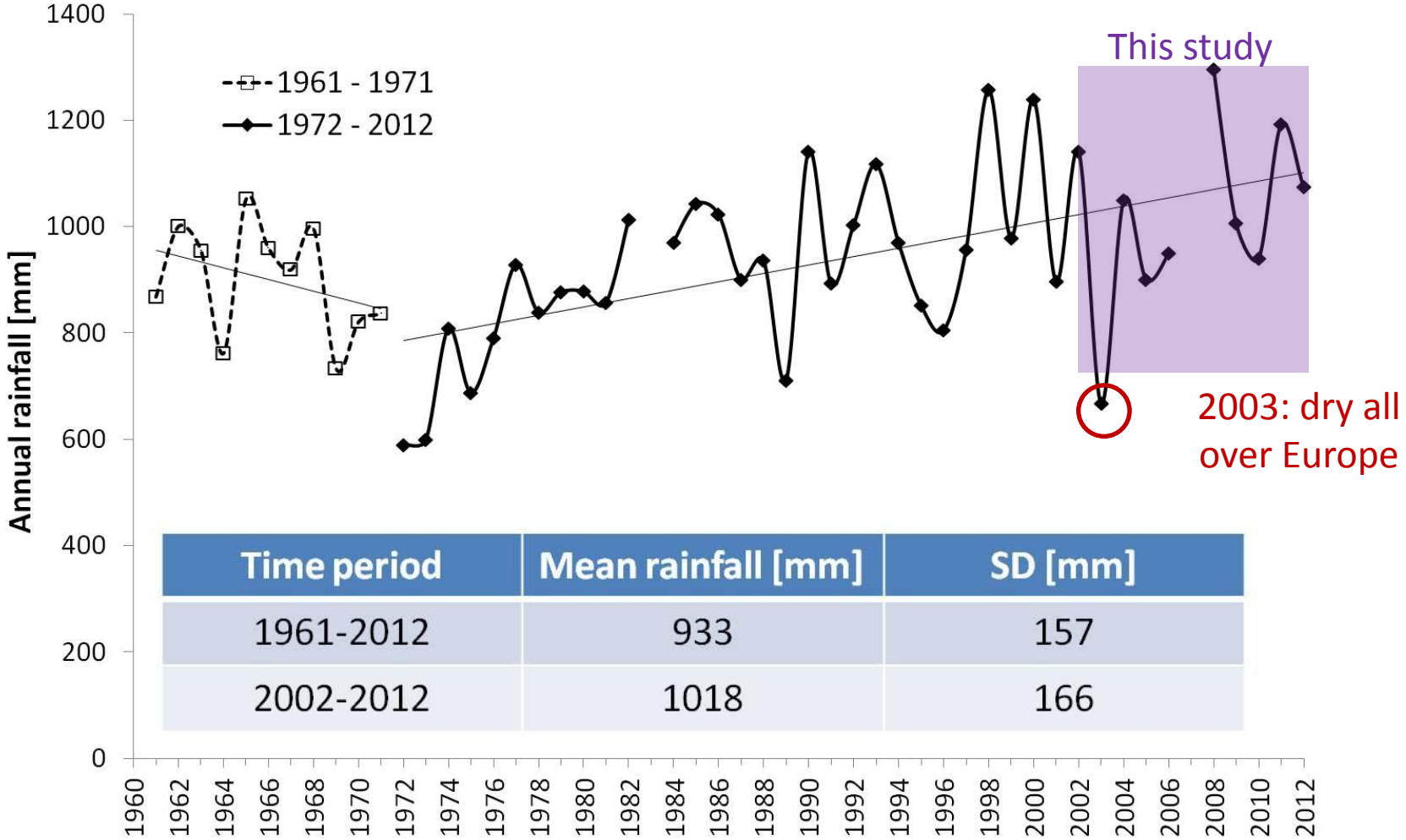
100 m

Meteorological measurements include:

- Air and soil temperature
- Rainfall
- Radiation (total solar, PAR, net radiation)
- Water table depth

Local climate - precipitation

Overall upward trend despite large inter-annual variability



Time period	Mean rainfall [mm]	SD [mm]
1961-2012	933	157
2002-2012	1018	166

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[1]MIDAS station; 3.5 km North of measurement site

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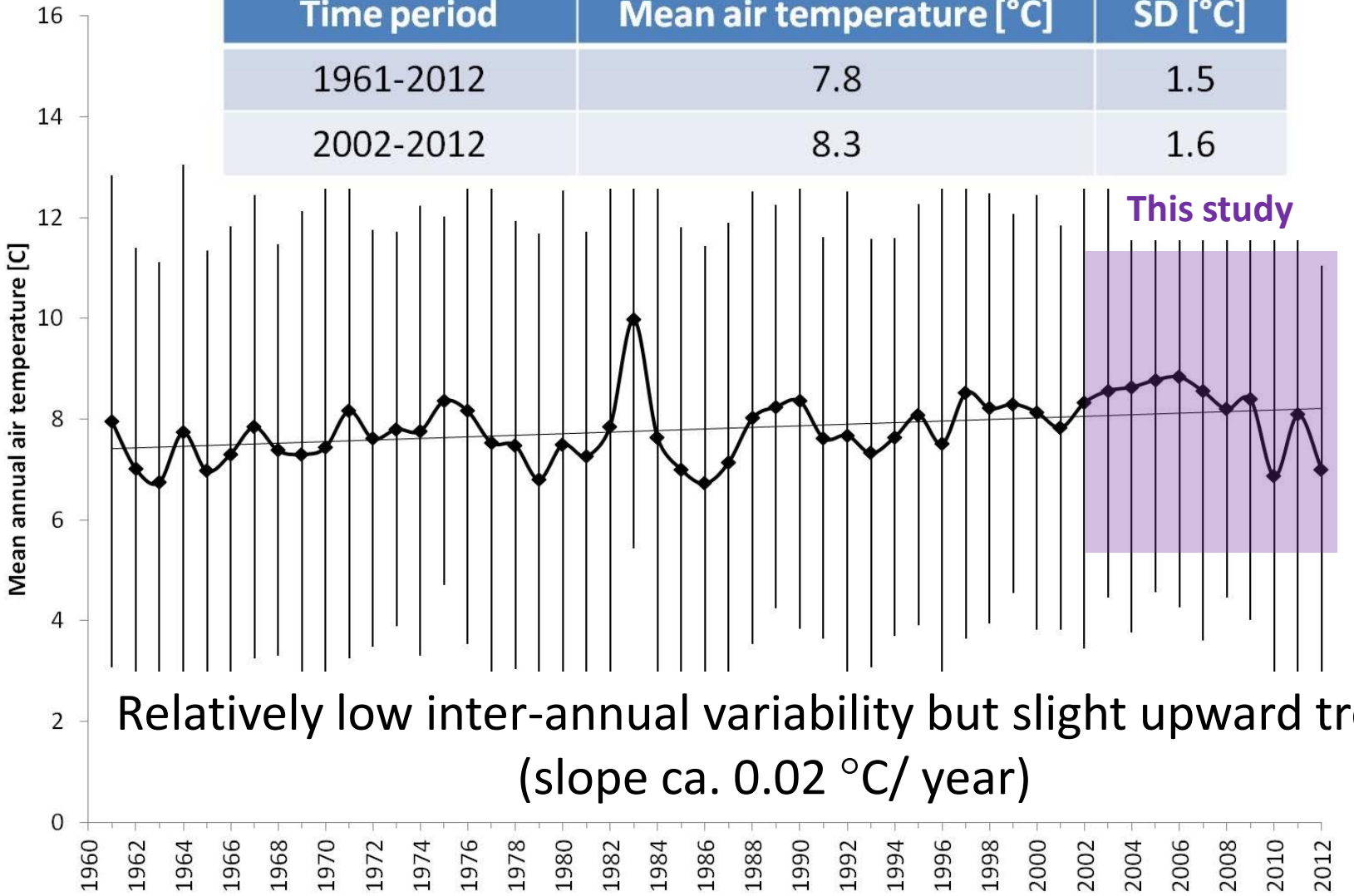
Local climate - temperature

Time period	Mean air temperature [°C]	SD [°C]
1961-2012	7.8	1.5
2002-2012	8.3	1.6



Relatively low inter-annual variability but slight upward trend (slope ca. 0.02 °C/ year)

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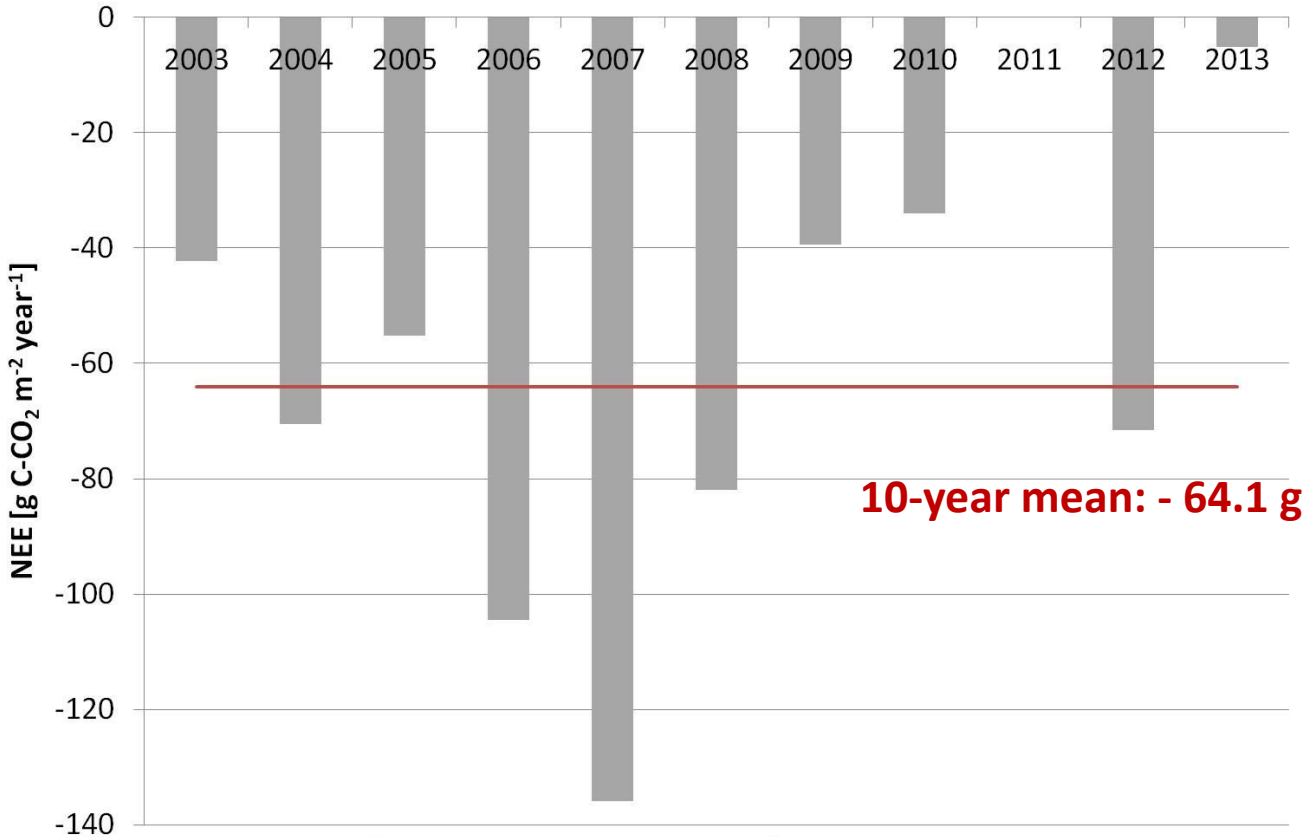
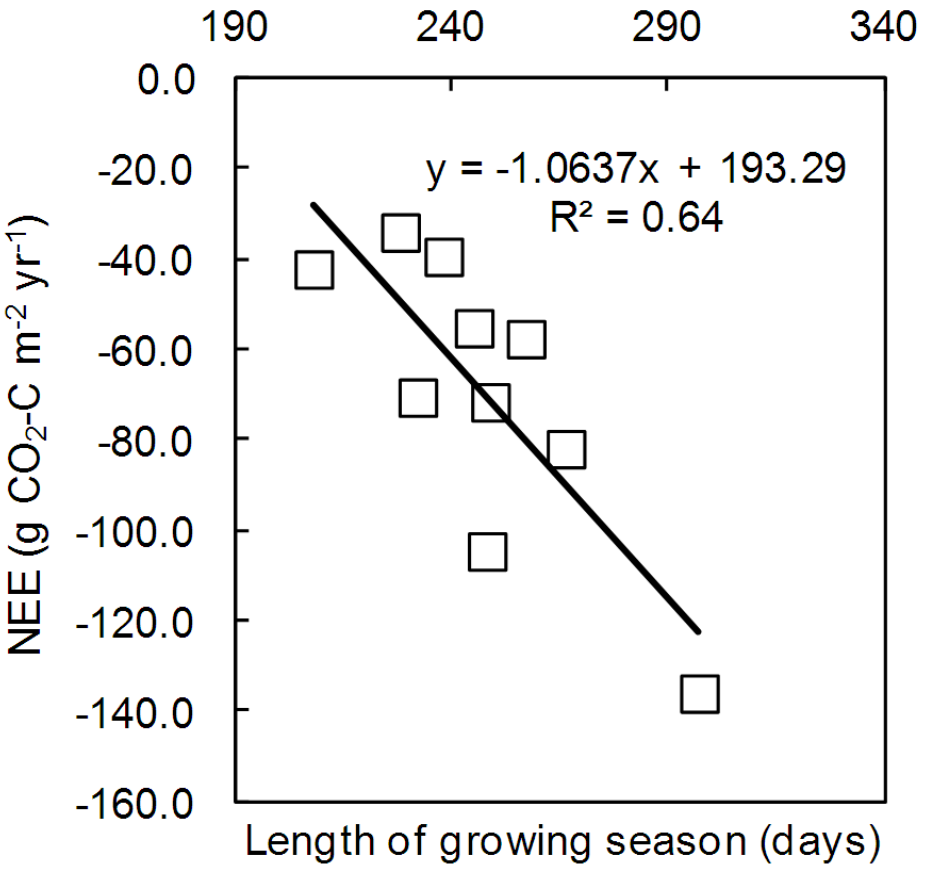
[1]MIDAS station; 3.5 km North of measurement site

Annual CO_2 budget



Site	Duration [years]	Min NEE [g C-CO_2 m^{-2}]	Max NEE [g C-CO_2 m^{-2}]	Mean NEE [g C-CO_2 m^{-2}]
Auchencorth Moss (this study)[2]	9	-5.2	-135.9	-64.1 ± 33.6
Mer Bleue[3]	6	-2	-112	-40.2 ± 40.5
Glencar[4]	6	-12.5	-84	-47.8 ± 30.0
Degerö[5]	2	-42	-55	-51.5 ± 4.9

NEE: Inter-annual variability



Mean length of growing season:
247 days ± 24 days

Start: 15/03 ± 20 days
End: 19/11 ± 19 days

Large inter-annual variability but NEE is closely linked to the length of the growing seasons

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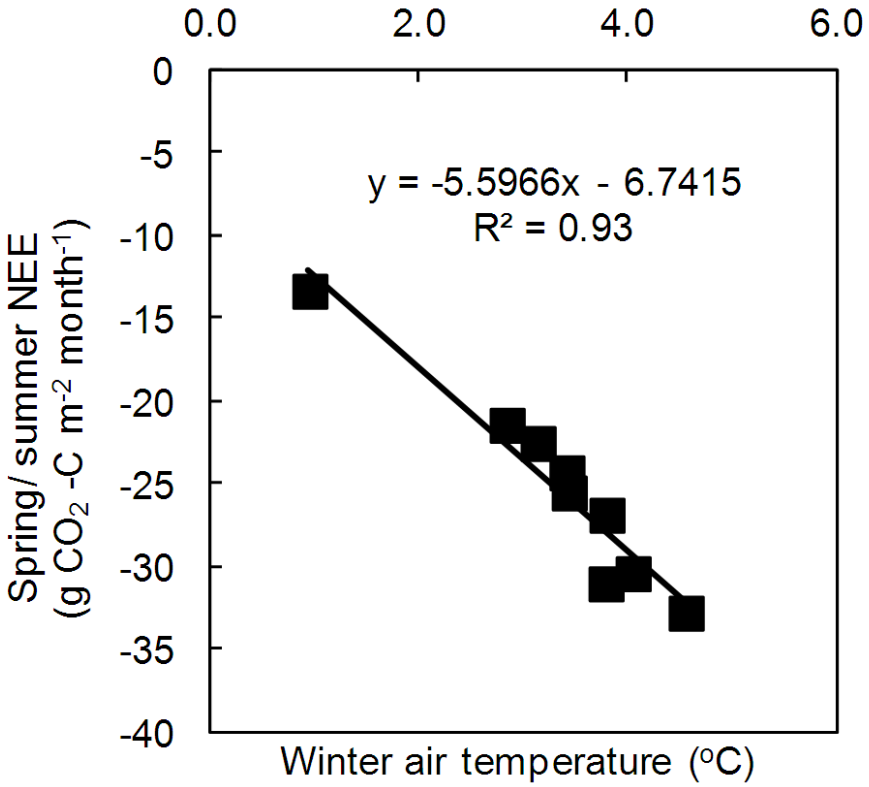
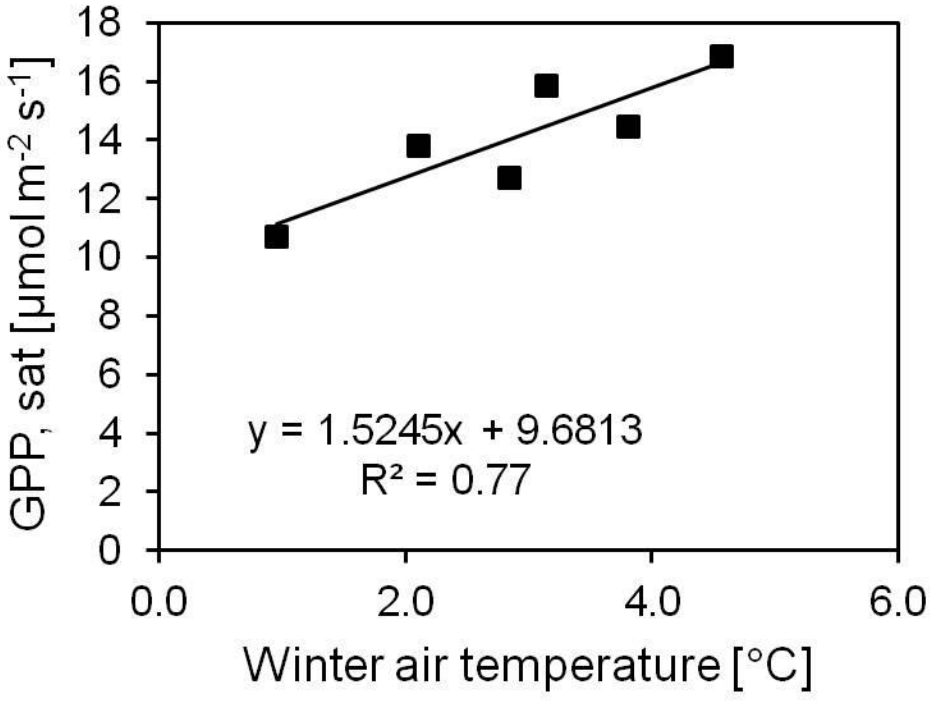
Effect of winter temperatures





- Winter air temperature is the strongest predictor for NEE and GPP_{sat} during the growing season
- Short-term effect on phenology?

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Effect of winter temperatures

1-way ANOVA of summertime GPP, R_{eco} & NEE with respect to mean winter air temperature: 4 temperature classes (< 1 ° C, 2-3 ° C, 3-4 ° C, > 4°C).

P-value	Wet (WTD < 5 cm)	Dry (WTD > 5 cm)	Ensemble
GPP	0.30	**0.016**	0.08
R_{eco}	0.52	**0.002**	0.05
NEE	0.38	**0.019**	**0.03**

- Mean winter air temperatures have a statistically significant effect on summertime NEE.

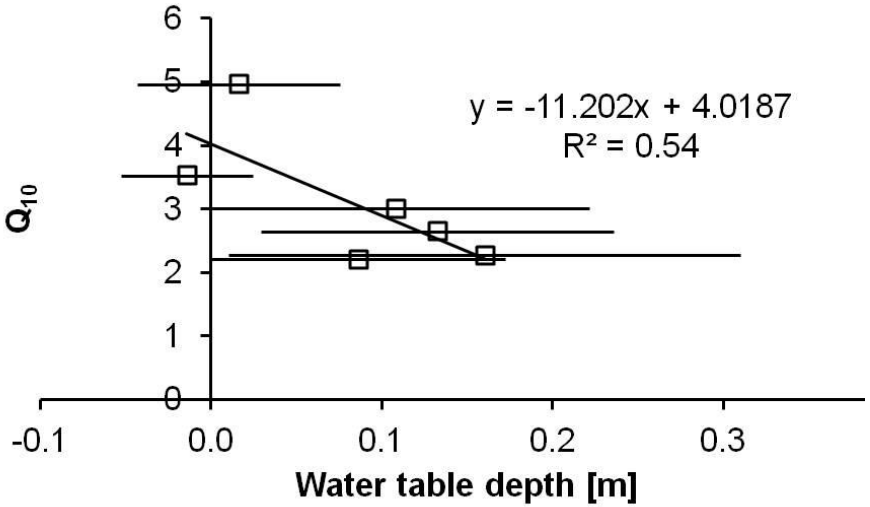
- Impact on phenology: stunted/ delayed growth? No direct/independent observation.

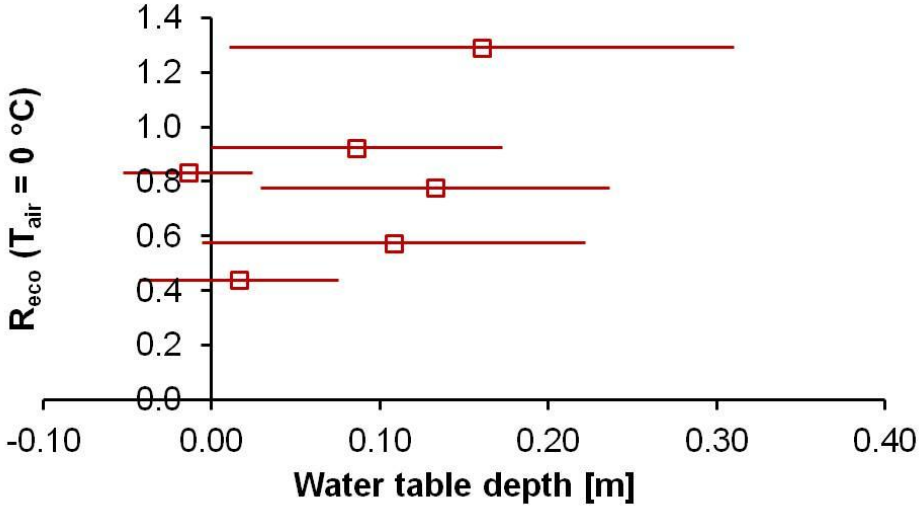
- Overlapping effect of water table position: statistical significance extends to GPP and R_{eco} under low water table conditions (> 5 cm below peat surface).

Dry spells/ drought

- Automated water table depth (WTD) measurements began in April 2007.
- The site is usually wet (WTD < 3 cm below peat surface for 42 out of 67 months) but dry spells have occurred in summer every year since 2007, except for 2012.
- Usually waterlogged in autumn and winter.
- Spring/ summer WTD range: - 3 cm to + 49 cm (July 2013).
- Drainage rate up to 3 cm day^{-1}, and rapid refilling.

Dry spells/ drought





- Sensitivity of ecosystem respiration to air temperature (Q_{10}) decreases with deepening water table.

- Theoretical value of ecosystem respiration for T_{air} = 0 °C increases with deepening water table.

Do heterotrophic processes become dominant as water table level decreases?

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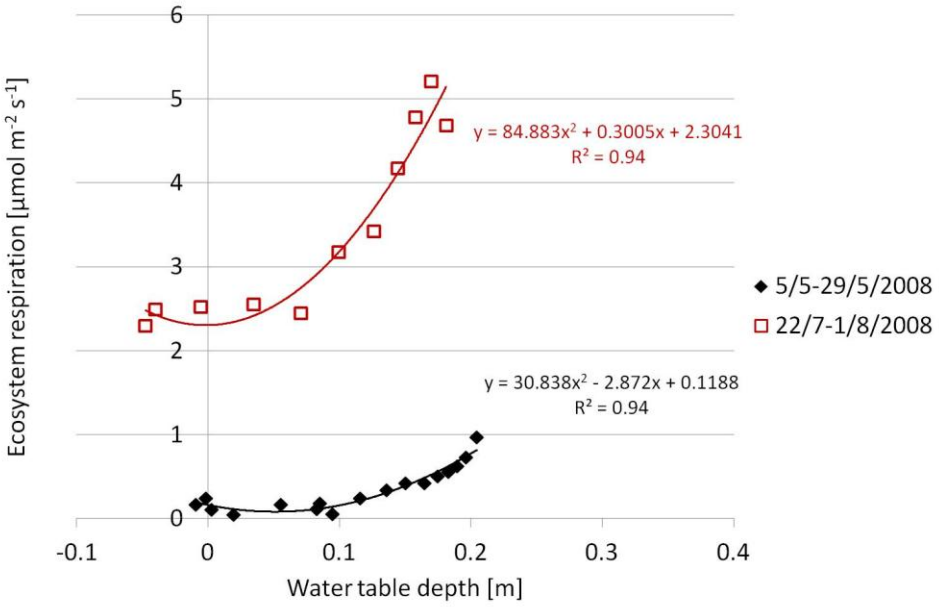
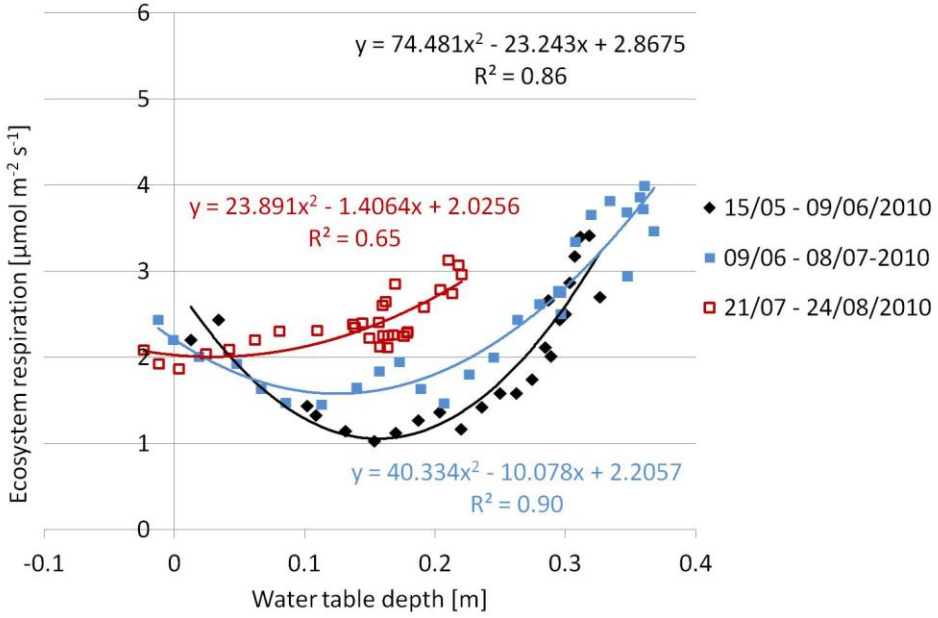
Dry spells/ drought





- R_{eco} well-parameterised by $T_{air.}$
- Usually little or no dependence on WTD.
- Non-linear correlation of R_{eco} to WTD during dry spells with ~ constant $T_{air.}$
- 2 dry spells exhibit marked initial decline in R_{eco} with lowering of WTD (minimum R_{eco} at WTD ~ 15 cm below peat surface) followed by increase.

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Dry spells/ drought

Period	Drainage rate [cm day^{-1}]	Maximum WTD [cm]	Time lag [days]	Minimum R_{eco} [µmol m^{-2} s^{-1}]	WTD for min R_{eco} [cm]	Mean Tair [° C]	Wind direction [°]
5-29/5/2008	1.2	20.4	2	0.03	1.5	10.1	70
22/7-1/8/2008	3.0	19.1	3	2.31	4.5	16.1	100
15-26/5/2010	1.6	30.7	2	1.05	15.6	12.9	181
9-24/6/2010	2.0	36.1	0	1.58	12.5	13.0	176
21/7-8/8/2010	2.0	22.1	5	2.01	2.9	11.4	191

- Initial decline in respiration caused by a reduction in plant metabolic activity as water availability decreases?
- Lowering of the WT enables aerobic processes and microbial decomposition of organic matter in the peat profile increases.
- Minimum R_{eco} could correspond to equilibrium between declining autotrophic and increasing heterotrophic respiration.
- Subsequent net increase in R_{eco} with deepening WTD could correspond to a gradual increase in the ratio of heterotrophic to autotrophic respiration.

Dry spells/ drought

1-way ANOVA on daily GPP, R_{eco} and NEE with respect to 10 WTD classes (< 0 cm to > 45 cm in increments of 5 cm).

Year\p-value	NEE	R_{eco}	GPP	Period for WTD > 0 cm
2007	0.0002*	**0.0242**	0.0002*	12/4-17/9
2008	0.1421	**0.0055**	**0.024**	5/5-1/8
2009	0.72068	**0.0363**	0.808	25/05-6/09
2010	0.93	**0.0012**	**0.0007**	11/04-13/09
2012	0.0314*	0.0582	0.484	23/3-16/8
2013	**0.035**	**0.003**	0.054	18/05-11/09

* *Equal variance test failed*

- R_{eco} always significantly correlated to water table position (except for 2012 – very wet year).
- GPP and NEE exhibit little sensitivity to water table depth.
- Significant correlation of GPP & R_{eco} to WTD in 2008, 2010 & 2013 (R_{eco} only).
- Summer droughts (2008 & 2010) affected both autotrophic and heterotrophic processes.

Conclusions

- Auchencorth Moss is a net sink of CO_2 (average - 64.1 ± 33.6 g C-CO_2 m^{-2} $year^{-1}$).
- The sink strength is highly variable year on year but strongly linked to the length of the growing seasons.
- Summertime NEE is significantly correlated to mean winter time air temperature suggesting short-term effects on the local phenology.
- Ecosystem response (GPP, R_{eco} & NEE) to winter conditions is more pronounced when the growing season is dry (WTD > 5 cm).
- R_{eco} is significantly correlated to the position of the water table and Q_{10} decreases with deepening WT suggesting a shift in the balance between heterotrophic and autotrophic terms.
- Very weak net sink of CO_2 in 2013 as a result of a long, cold winter and a dry summer.

References

[1] UK Met Office - MIDAS Land and Marine Surface Station Data

[2] *A decade of continuous NEE measurements at a Scottish peatland*. Helfter et al. (in prep.)

[3] *Contemporary carbon balance and late Holocene carbon accumulation in a northern peatland*. Roulet et al., GCB (2007).

[4] *How strong is the current carbon sequestration of an Atlantic blanket bog?* Koehler et al., GCB (2011).

[5] *Contemporary carbon accumulation in a boreal oligotrophic minerogenic mire – a significant sink after accounting for all C-fluxes*. Nilsson et al., GCB (2008).