Measuring the Land-Atmosphere Exchange of Ozone

Mhairi Coyle *et al*

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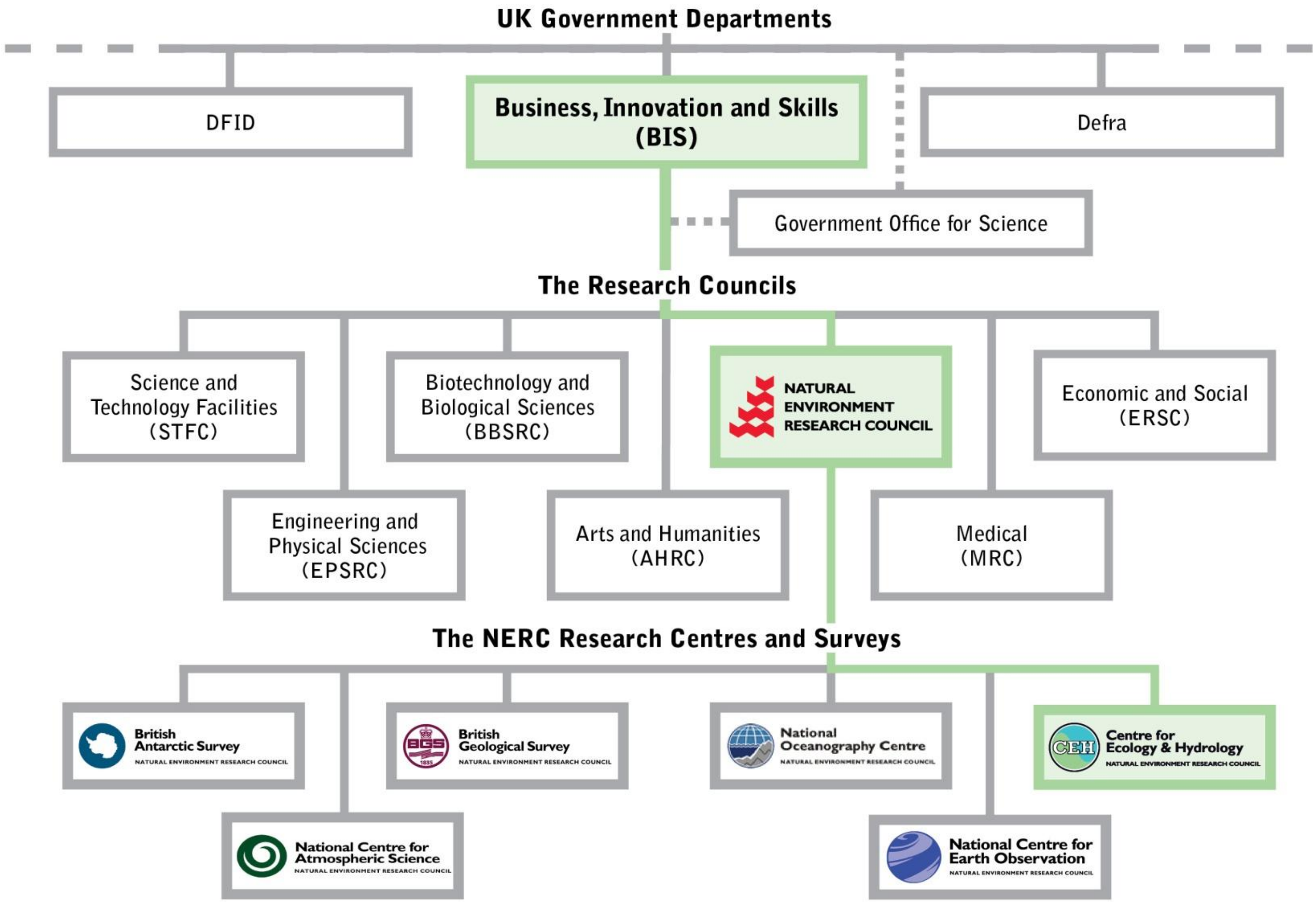
The Natural Environment Research Council in a UK Government setting



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CEH is the UK's Centre of Excellence for research in the land and freshwater environmental sciences

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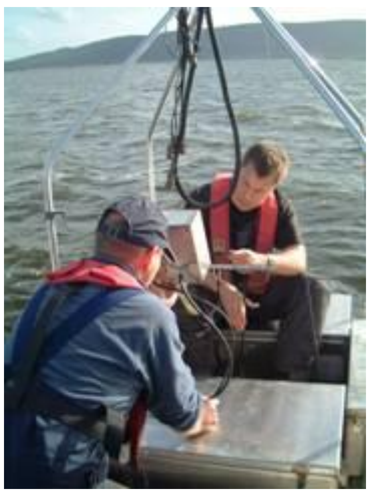

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Resources

325 scientists & 125 support staff spread across the UK

Photos - CEH

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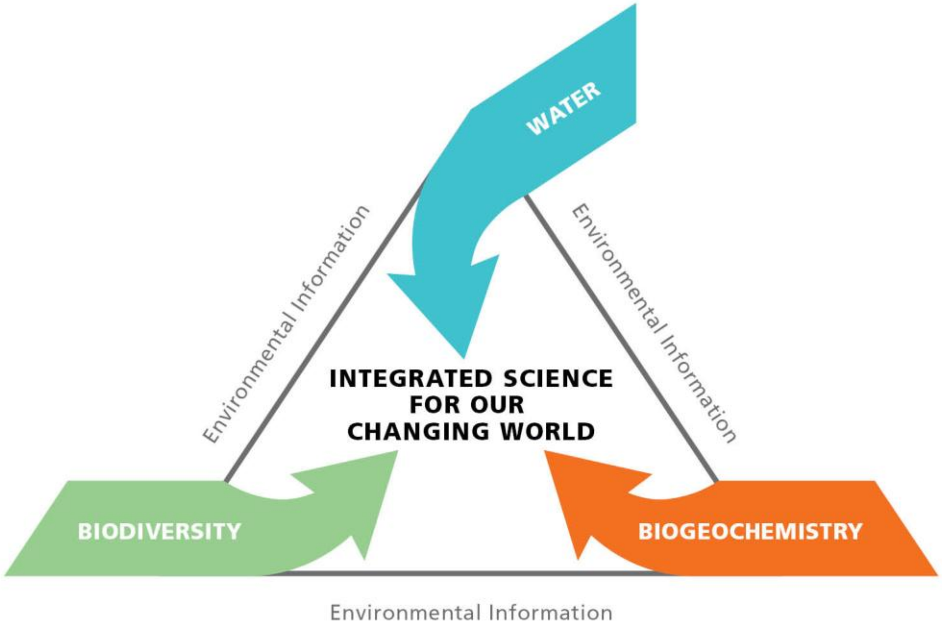
CEH integration of scientific disciplines

Science Programmes:

- **Water**
- **Biogeochemistry**
- **Biodiversity**

All linked through an **Environmental Information Data Centre**



Scientific disciplines are integrated to develop practicable solutions for environmental sustainability

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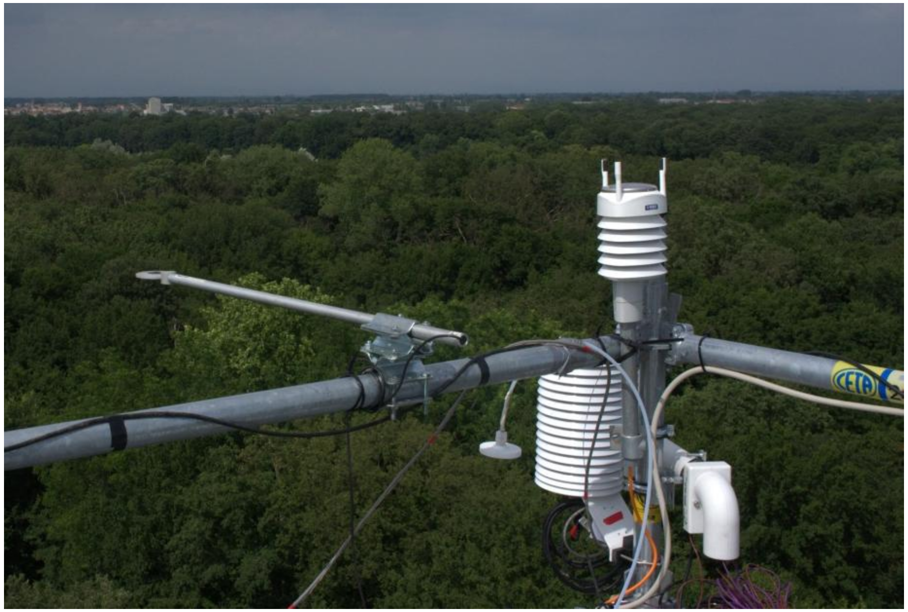
Biogeochemistry Science Programme

- Atmospheric chemistry cycles – Measuring & modelling trace gases, aerosol, nitrogen and carbon
- Climate change modelling of surface - atmosphere exchanges. e. g. soil carbon
- Quantifying the growing threat to plant & human health from changes in environmental chemistry

TOPICS

- Monitoring and interpretation of biogeochemical and climate change
- Biogeochemistry and climate system processes
- Managing threats to environment and health



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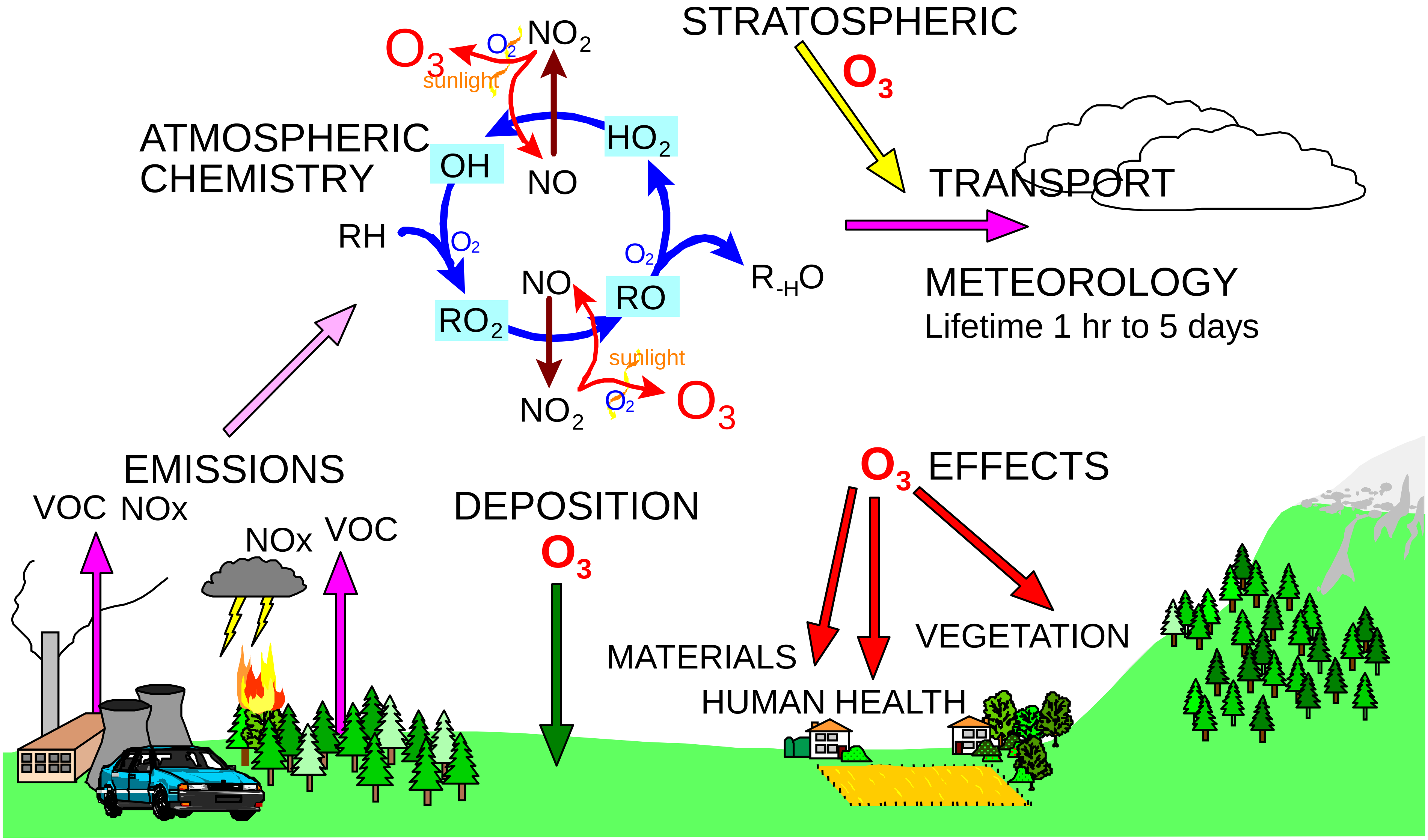
TROPOSPHERIC (GROUND-LEVEL) OZONE



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Pre-industrial concentrations ~10 ppb

Post -industrial have increased to ~30-40 ppb or more

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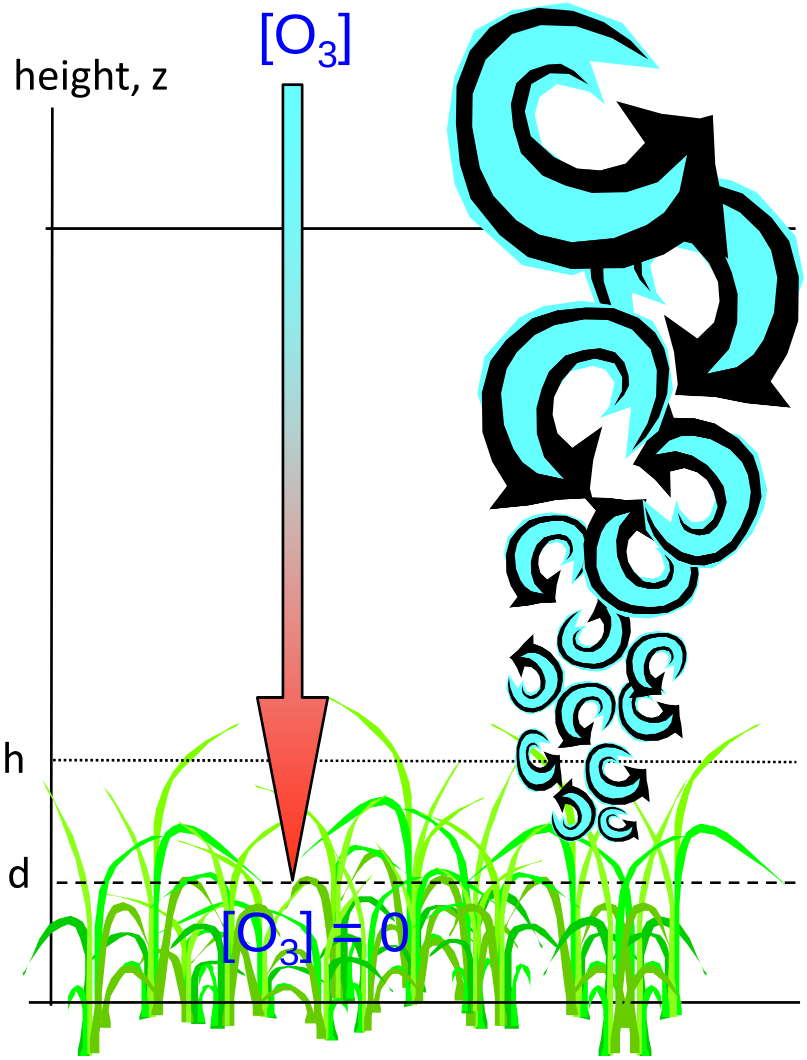
MICROMETEOROLOGY: EDDY-CORRELATION METHOD



$$F(O_3) = \overline{w'\chi'}$$

w' instantaneous variation in the vertical component of wind velocity

χ' instantaneous variation in O_3 concentration

- ✓ Simplest theoretically
- ✓ Least empirical
- x Requires fast instrumentation
- x Expensive

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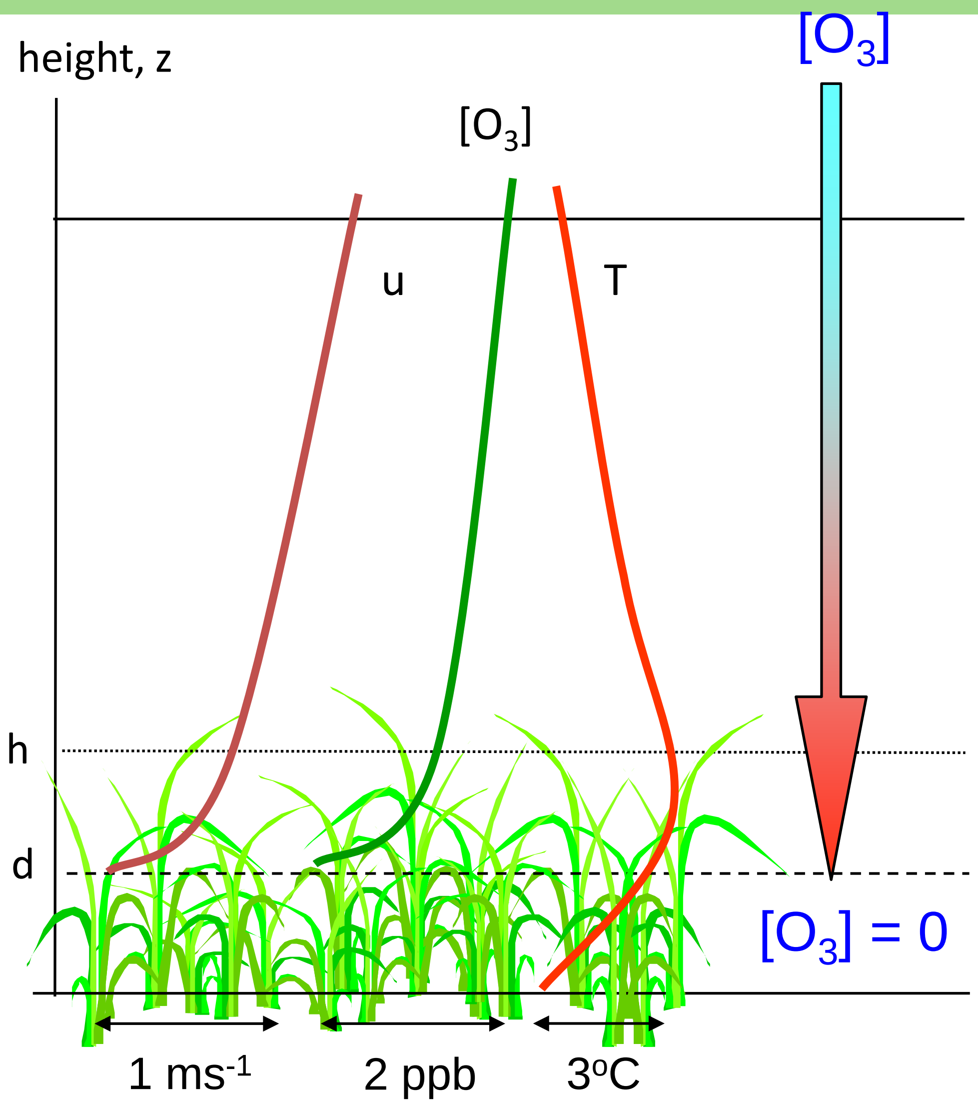
MICROMETEOROLOGY: GRADIENT METHOD



$$F(O_3) = K_{O3} \frac{\partial \chi_{O3}}{\partial z}$$

K_{O3} = diffusion coefficient
χ_{O3} = concentration

$$\tau = K_m \frac{\partial u}{\partial z}$$

τ = momentum flux
u = horizontal windspeed
K_m = diffusion coefficient

$$K_m \cong K_{O3}$$

- ✓ Simple instrumentation
- ✓ "low-cost"
- x Indirect method
- x Empirical relationships are used

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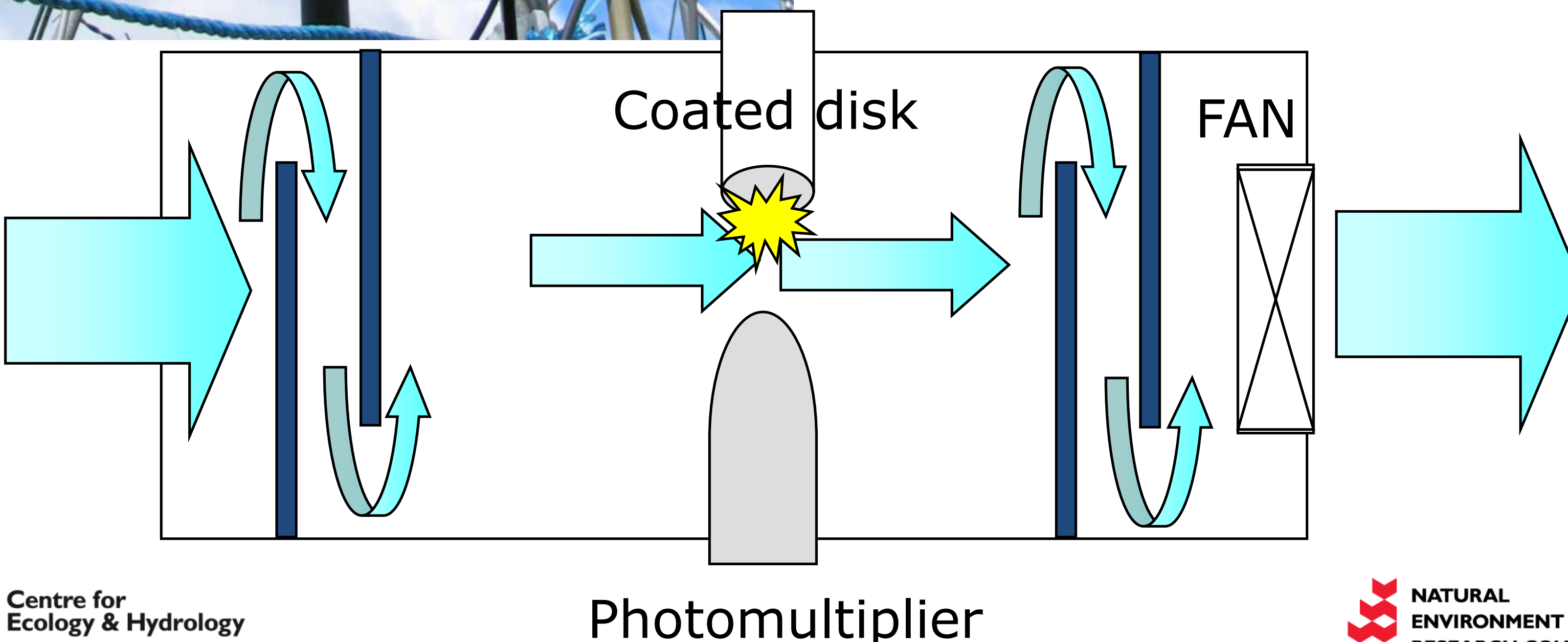
Eddy-correlation Ozone Fluxes

CEH ROFI
(Rapid Ozone Flux Instrument)

Chemiluminescent Method

- **Relatively simple to implement**
- **O_3 sensitive disks require regular replacement**
- **Commercially available**
- **Relative method so slow analyser required to measure O_3 concentrations**



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Ozone Fluxes – San Pietro di Capofiume

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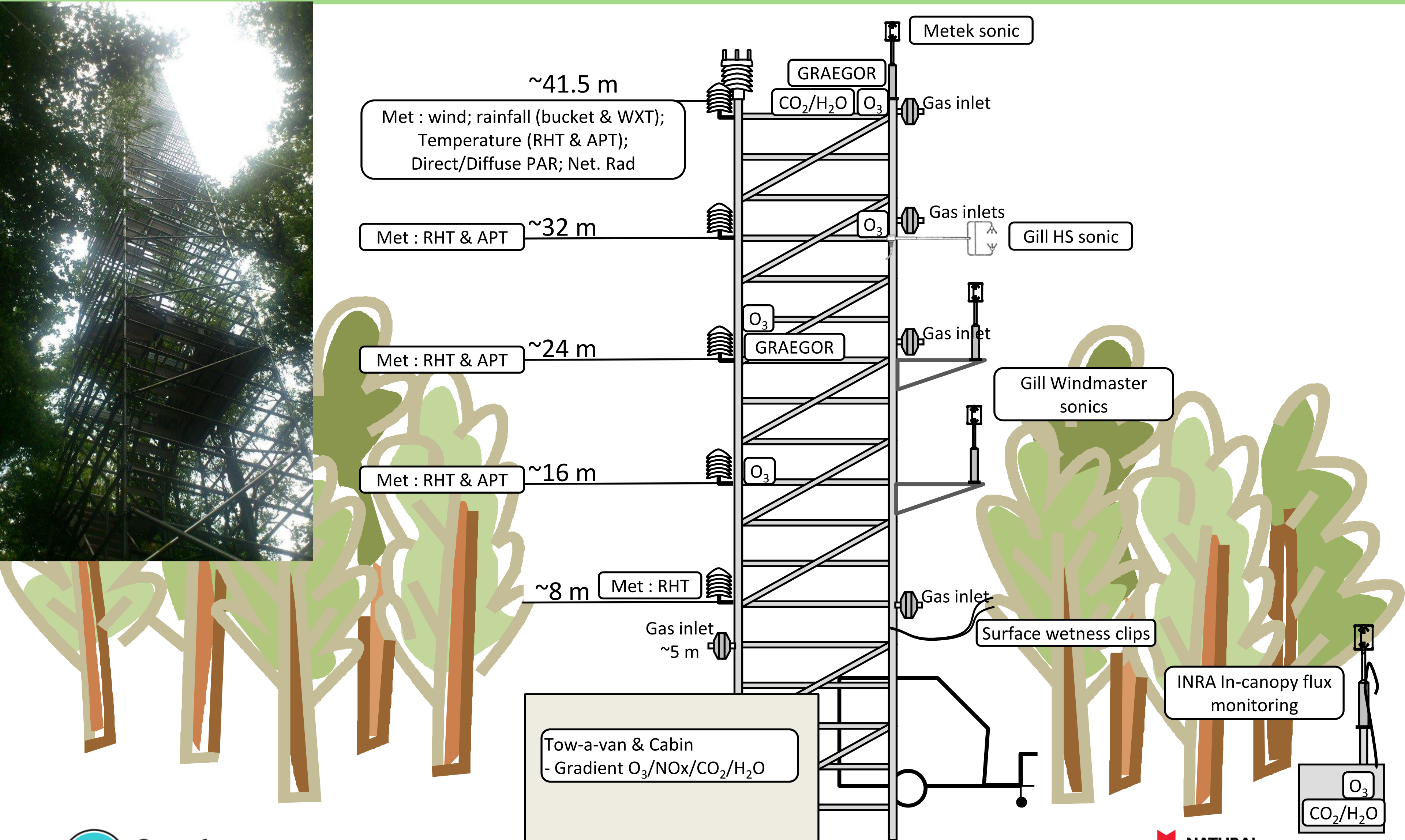
Bosco della Fontana, Mantova, Italy



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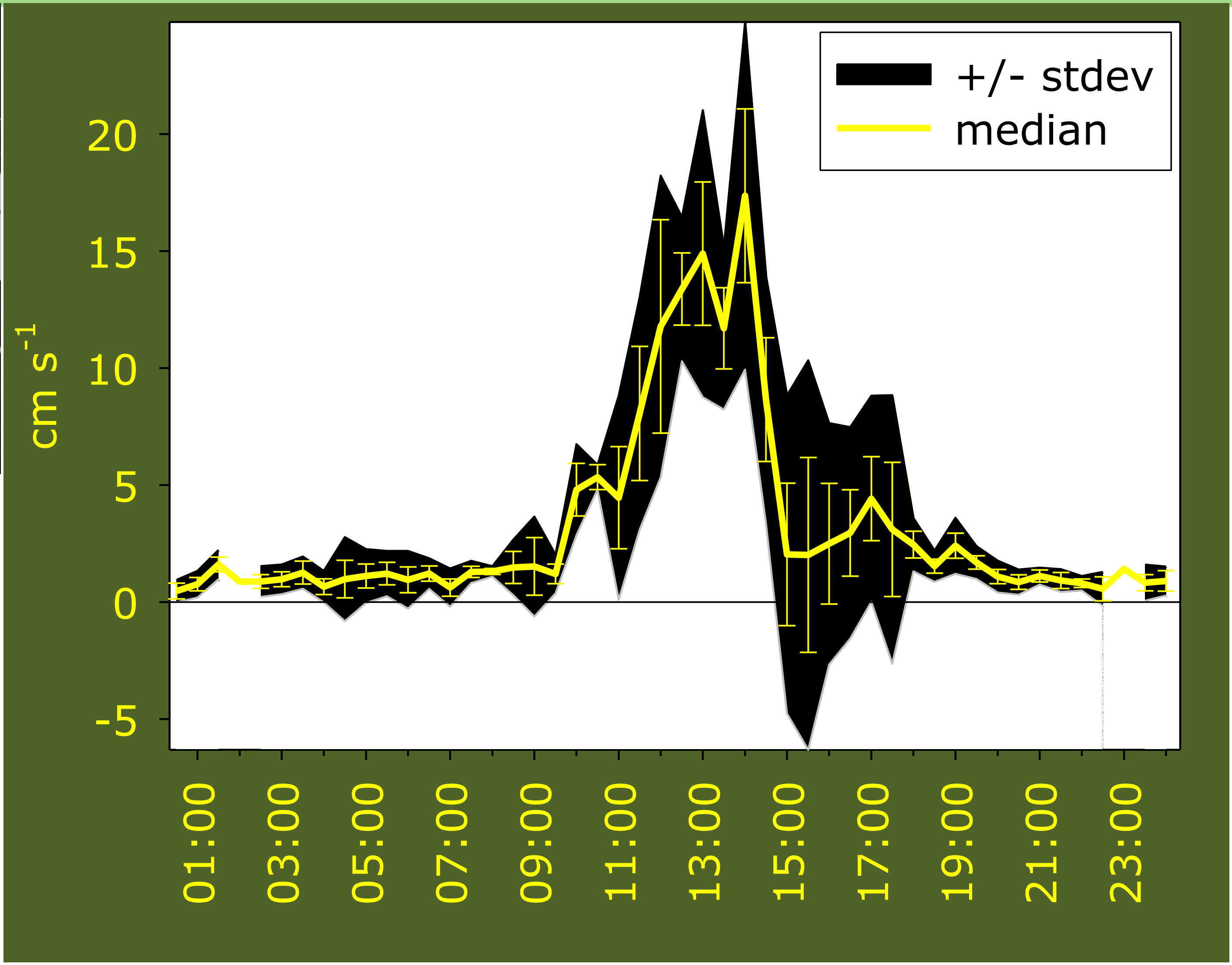
OZONE DEPOSITION VELOCITY – OIL PALM, BORNEO MAY-JUNE 2008



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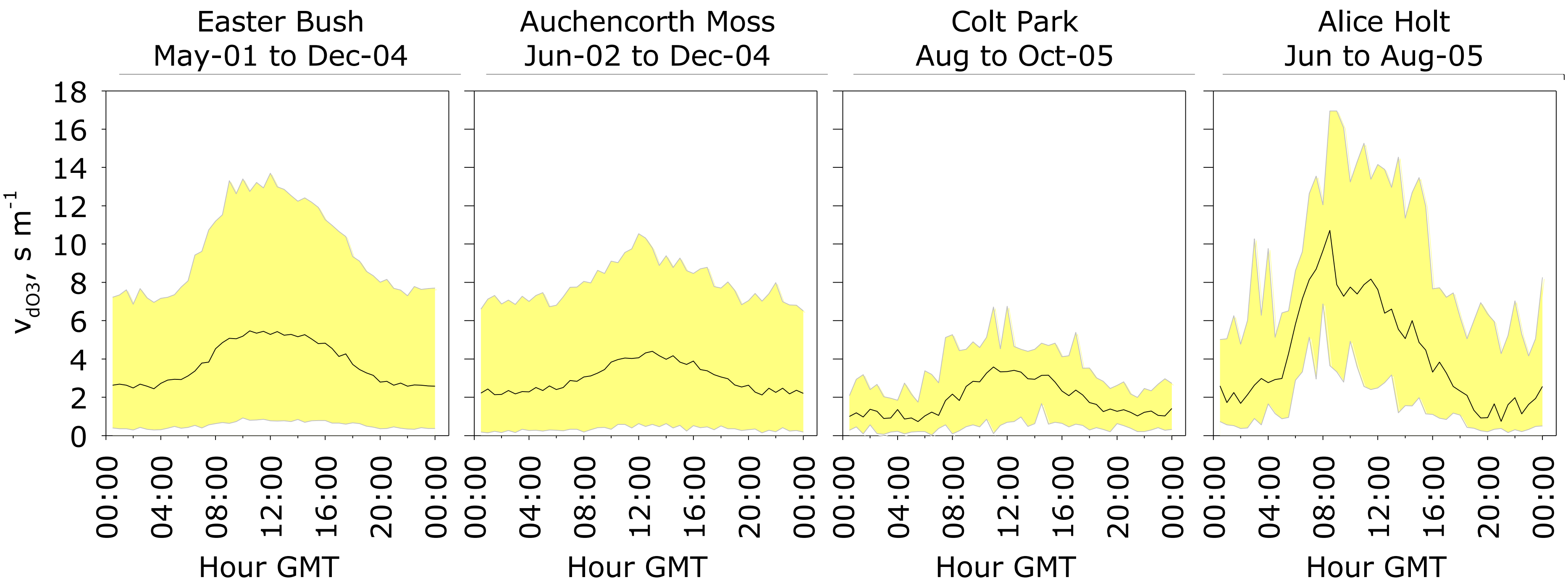
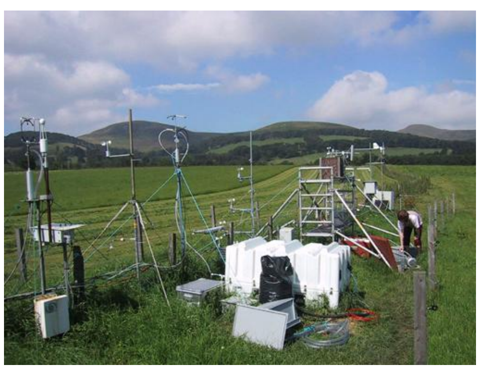
OZONE DEPOSITION VELOCITY – 4 UK SITES





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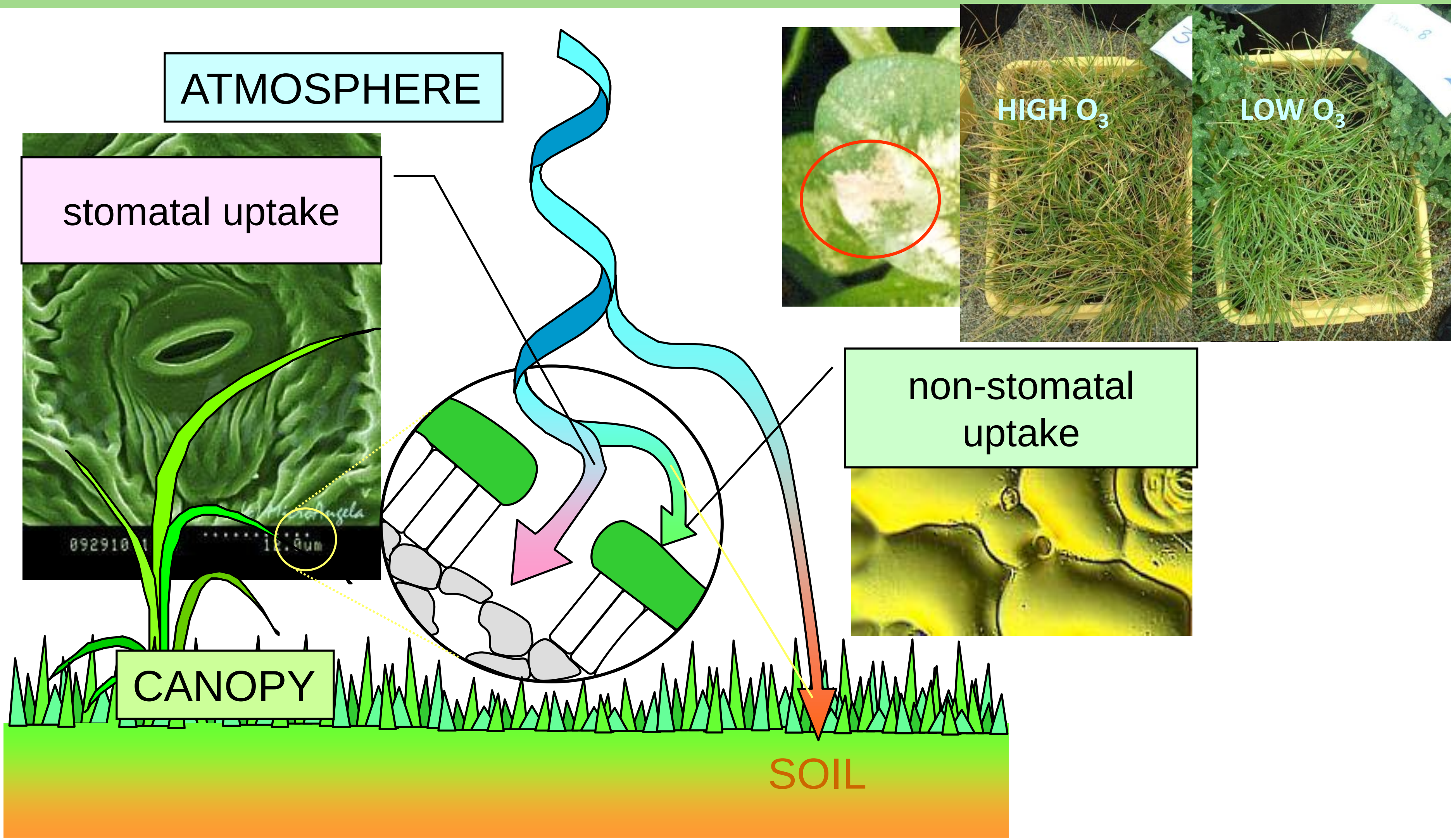
OZONE DEPOSITION



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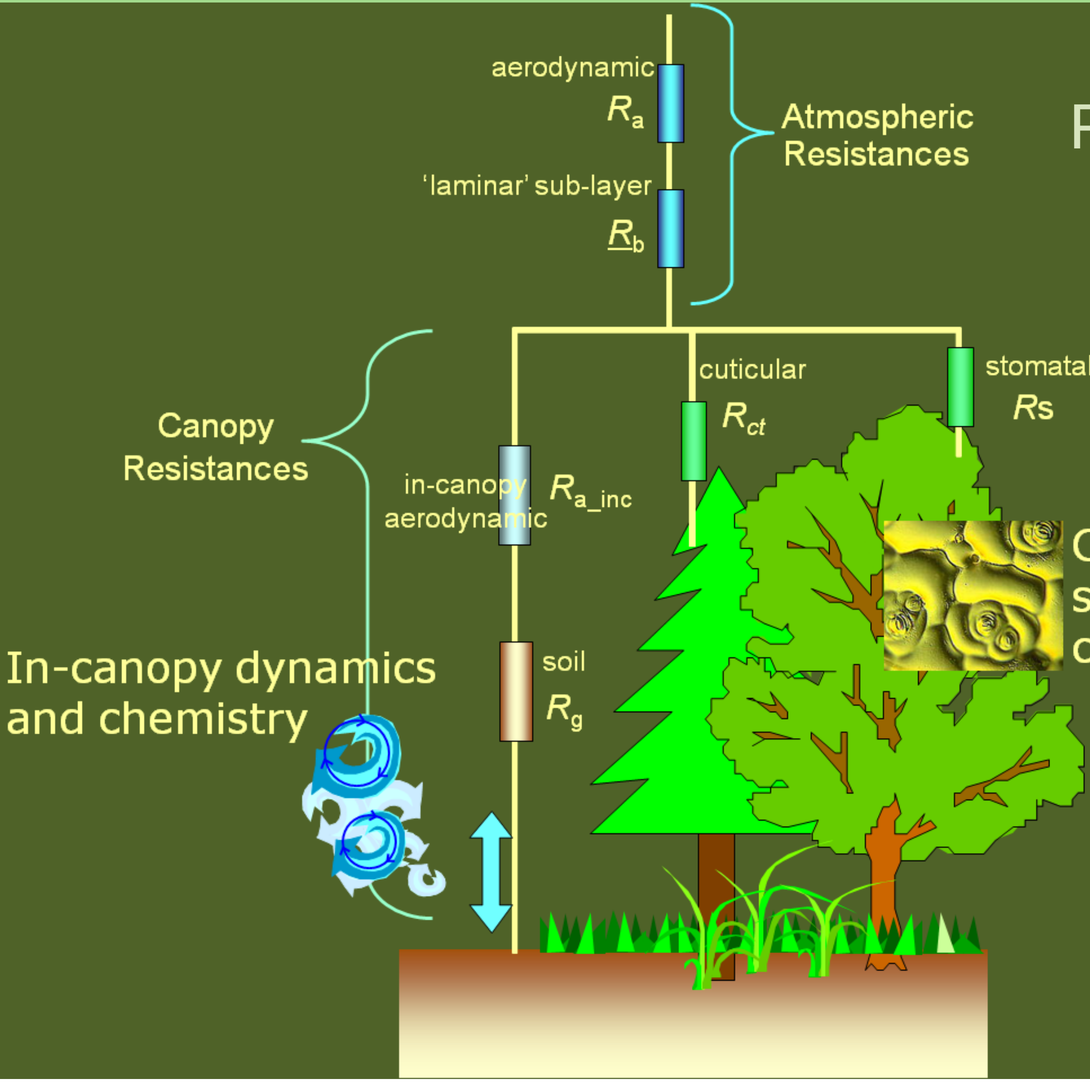
Deposition Resistance Analogy



$$\text{FluxO}_3\ (\mu g\ m^{-2}\ s^{-1}) = -[O_3]/R_t$$

$$R_t = R_a + R_b + R_c$$

Stomatal flux

Cuticular interactions – surface water, chemistry, temperature

$$R_c = [R_s^{-1} + R_{ns}^{-1} + (R_{a\_inc} + R_g)^{-1}]^{-1}$$

$$v_d = F/[O_3] = 1/R_{total}$$

$$= \text{deposition velocity, m s}^{-1}$$

$[O_3]$ = ozone concentration, $\mu g\ m^{-3}$

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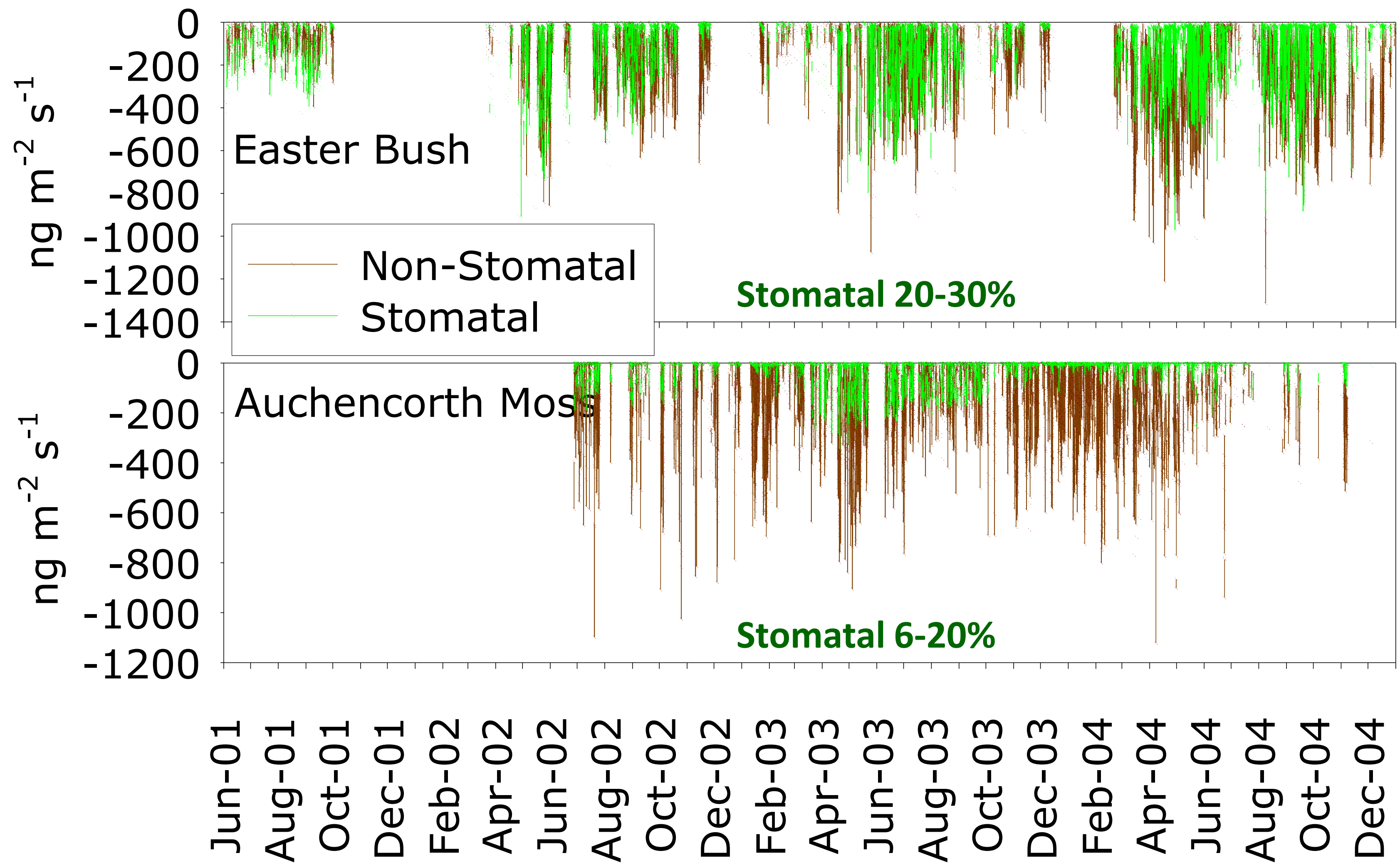
0.5 Hourly Stomatal and Non-stomatal Flux



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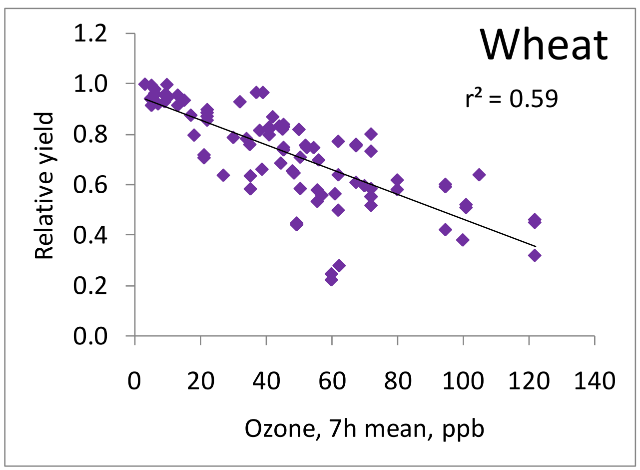
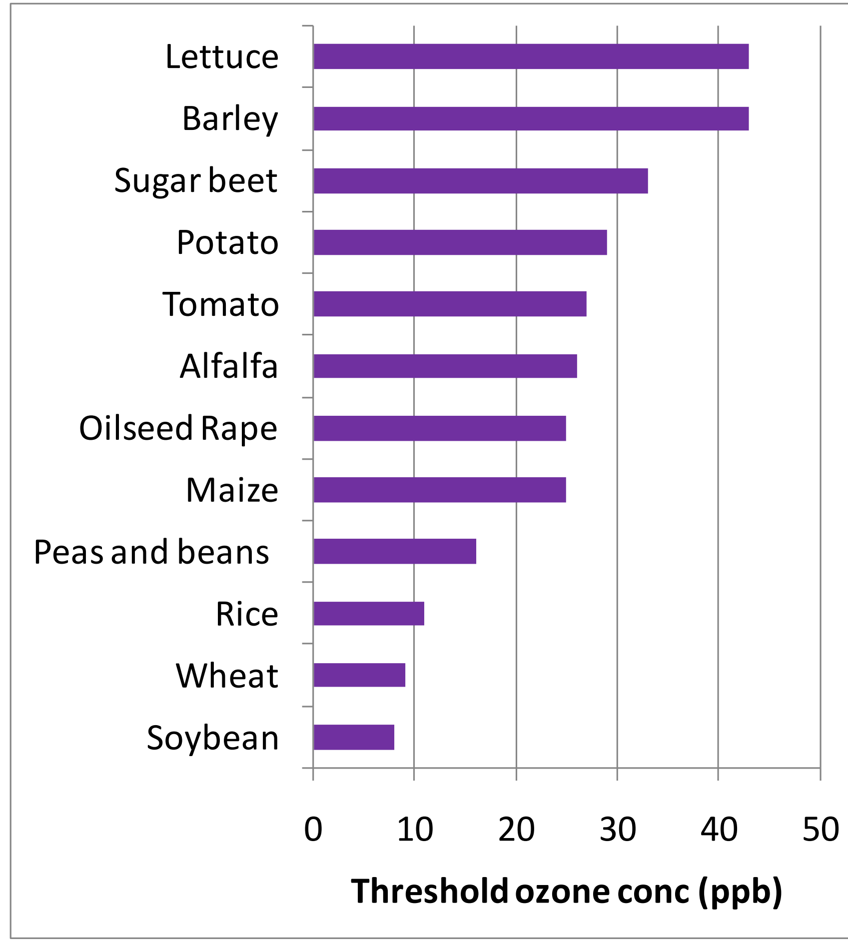
Crop-specific O_3 response functions

Felicity Hayes and Gina Mills



Functions in Mills et al., 2007 were updated where possible

Threshold for significant yield effects



7h mean ozone conc. required for a significant effect on yield

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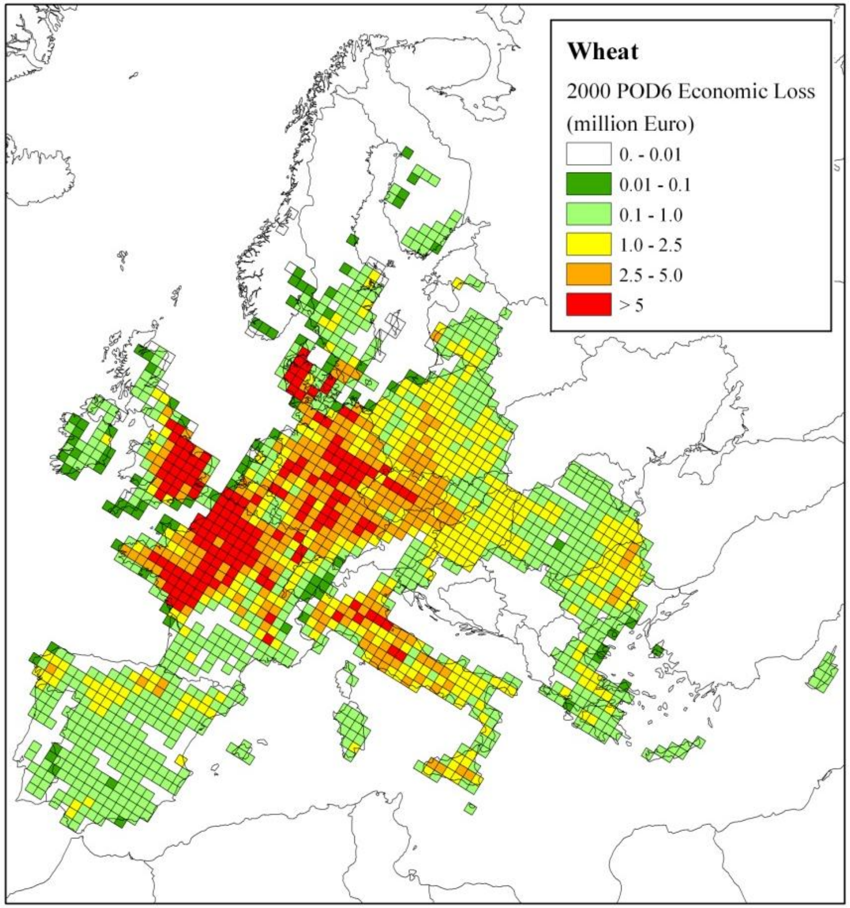
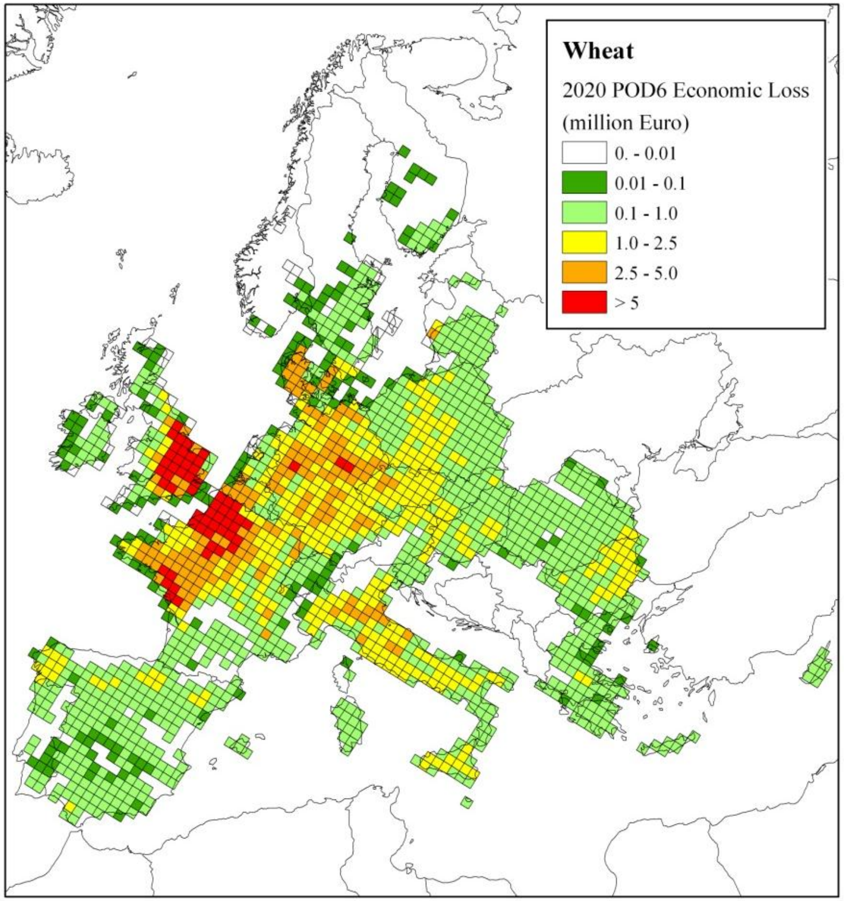
From: Mills et al., 2011, download from http://icpvegetation.ceh.ac.uk/

Economic losses for wheat in Europe

2000



2020



Losses are in million Euro per 50 x 50 km grid square:

0 – 0.01 | 0.01 – 0.1 | 0.1 – 1.0 | 1.0 – 2.5 | 2.5 – 5.0 | > 5

* Assumes adequate soil moisture available

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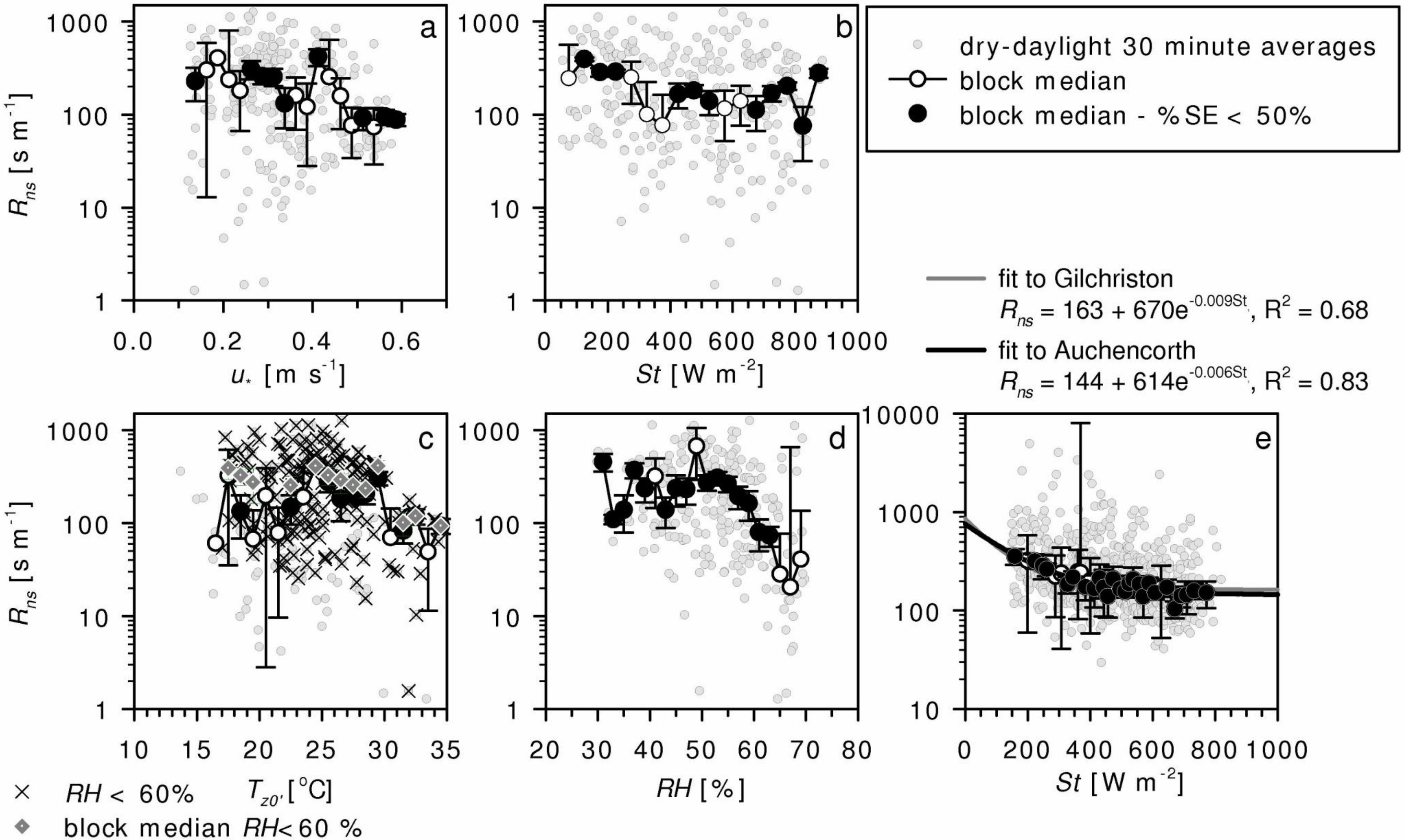
From: Mills et al., 2011, download from http://icpvegetation.ceh.ac.uk/

Non-Stomatal - Potatoes



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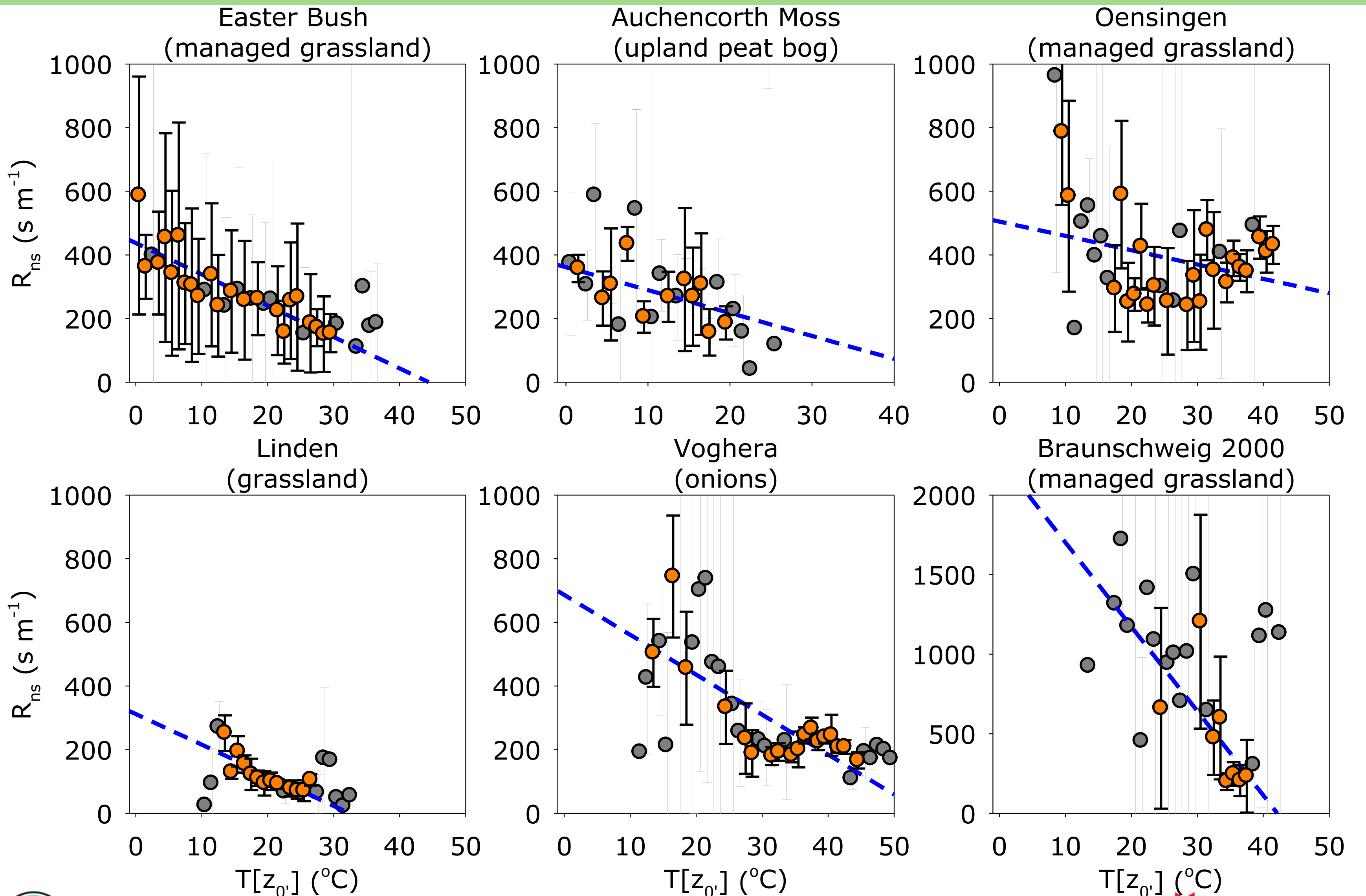
R_{ns} *vs* $T_{z0'}$ Dry Surfaces – short canopies



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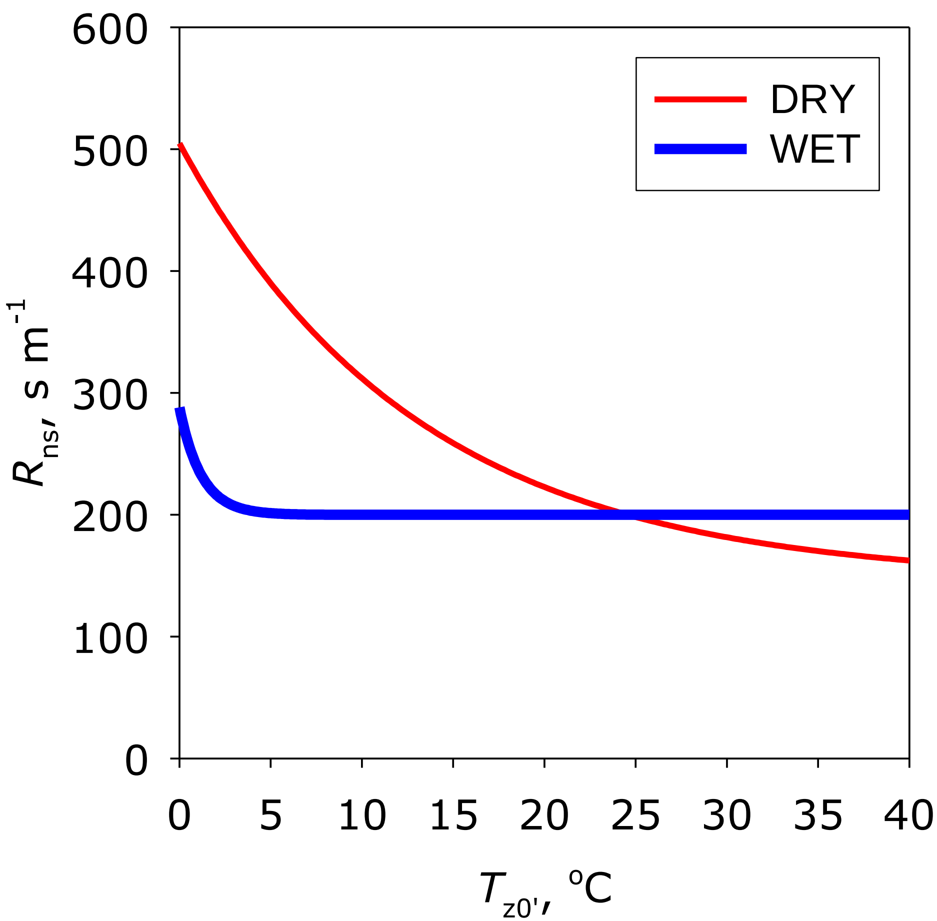
R_{ns} vs $T_{z0'}$, Dry & Wet Surfaces – short canopies



- Non-stomatal deposition depends on: surface area, surface moisture, leaf temperature and solar radiation
- Many studies find increased surface water can enhance deposition, by 10-30% on average (Zhang *et al* 2002)
- Increased leaf temperature and solar radiation both increase deposition rates (Fowler *et al* 2001).
- Wetter warmer surfaces could lead to greater ozone deposition and so reduce boundary layer concentrations.

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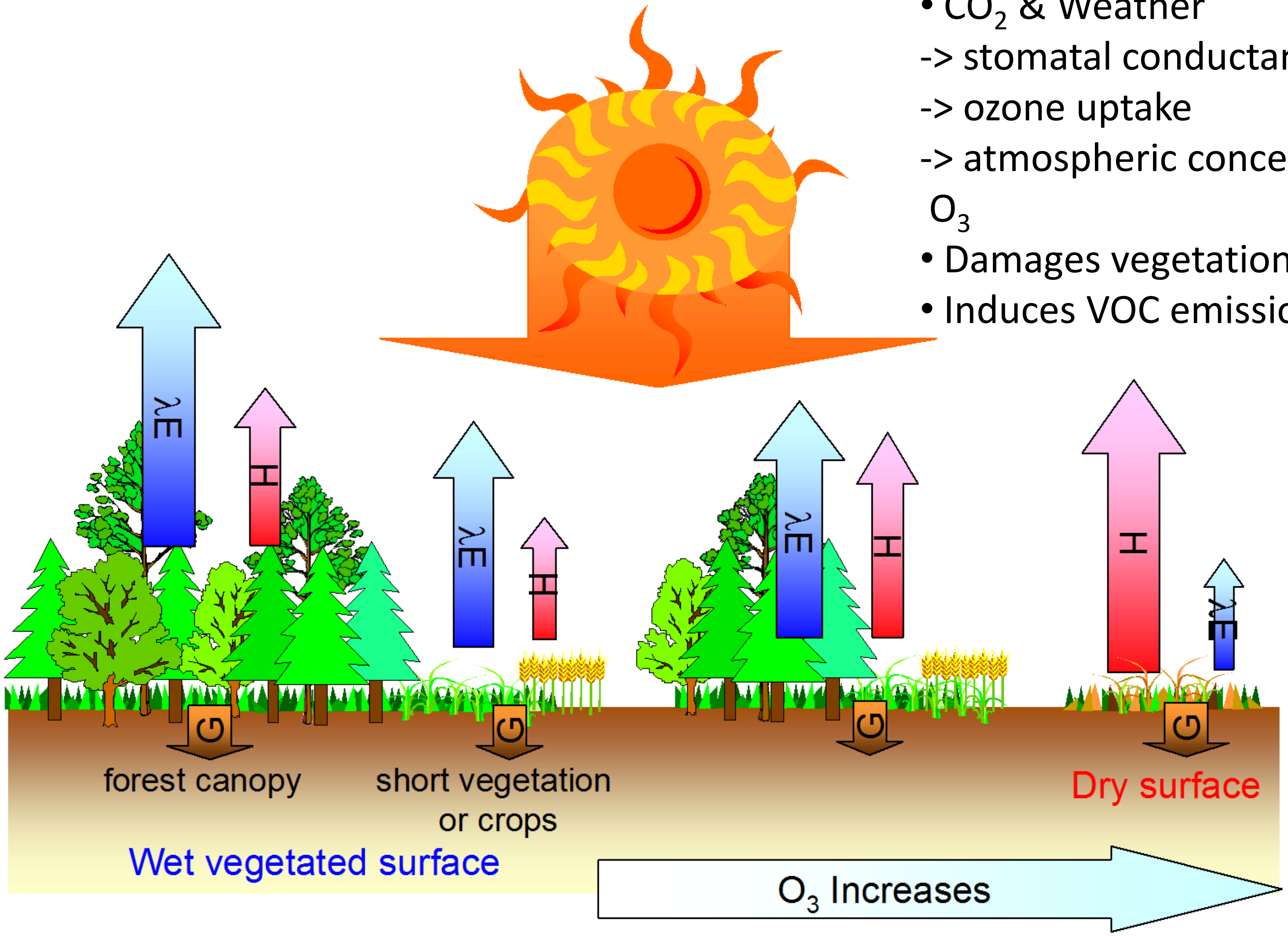
Climate Feedbacks

- CO_2 & Weather
-> stomatal conductance
-> ozone uptake
-> atmospheric concentrations
O_3
- Damages vegetation reduces CO_2 uptake
- Induces VOC emissions



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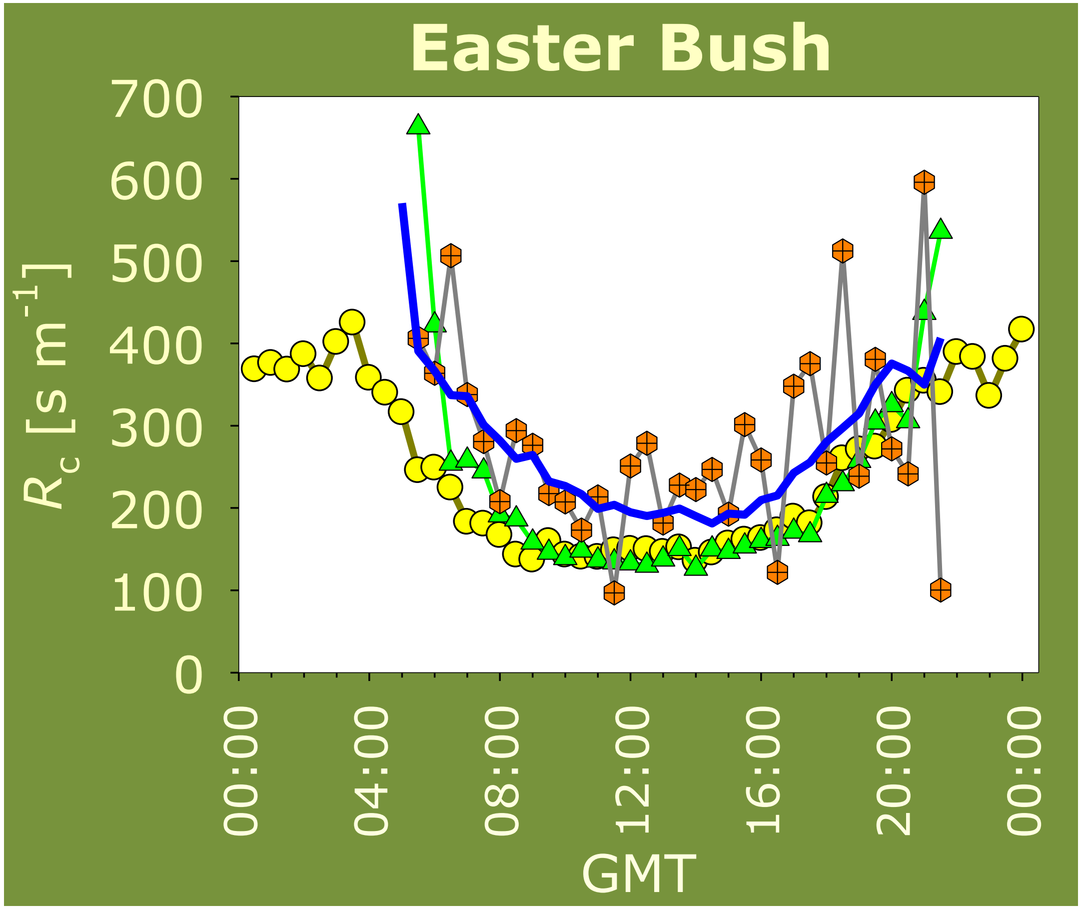
R_{ns} vs $T_{z0'}$ & Solar Radiation



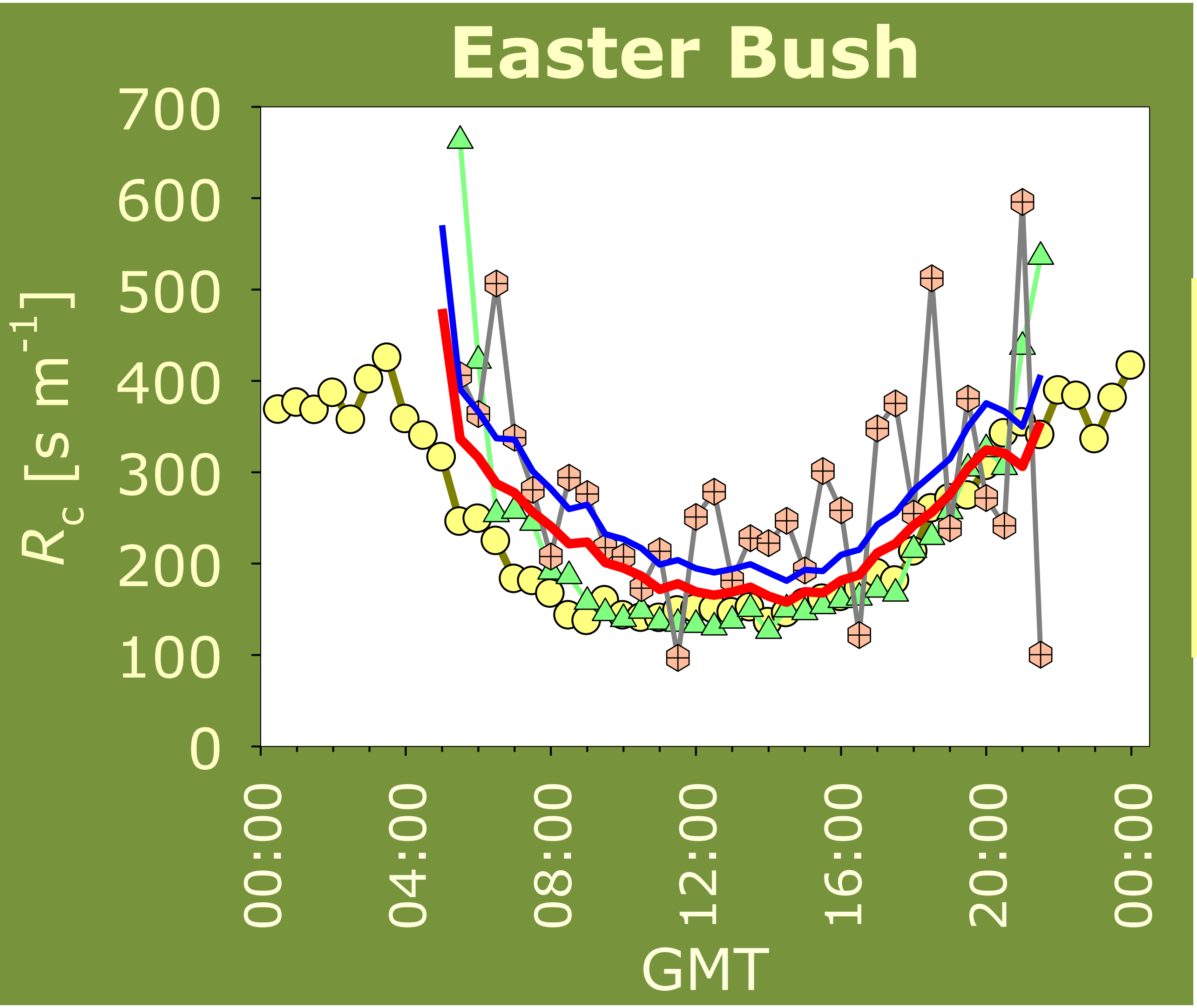
$$R_{ns} = R_{ns\_max}[f(T_{z0'})f(S_t)]$$

f 0 ..1

$$f(T_{z0'}) = R_{ns0} + a\ln(T_{z0'})$$

$$f(S_t) = R_{ns0} + a\ln(S_t)$$

Grassland Canopy Resistance: Modelled Rns + 4°C



- 13% Reduction in R_{ns}
- 6% Increase in Total Ozone Flux
- Stomatal Fraction Reduced by 3%

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Summary

- Ozone is a secondary air pollutant with a wide range of impacts and interactions with atmospheric chemistry and climate
- Deposition is one of the major removal processes and it can be readily measured using established techniques
- Estimates of total deposition are important in modelling atmospheric concentrations
- Uptake by vegetation causes yield losses, changes in biodiversity and sensitivity to other stressors
- Quantifying the different deposition pathways helps provide accurate estimates of ozone effects and better estimates of total deposition
- Non-stomatal uptake is still poorly understood and models use very simple empirical formula
- Limited work has been done in the Asian region (mainly short-term campaigns)