Forest Research
The Research Agency of the Forestry Commission

Development of an energy balance model to estimate stomatal conductance as an indicator of plant stress

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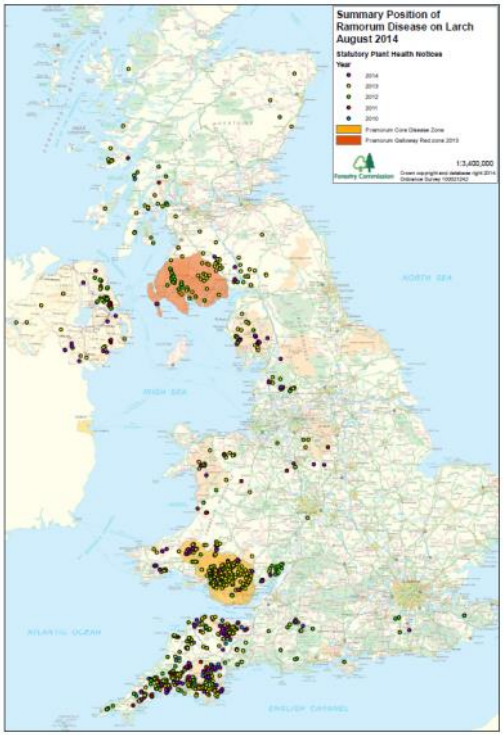
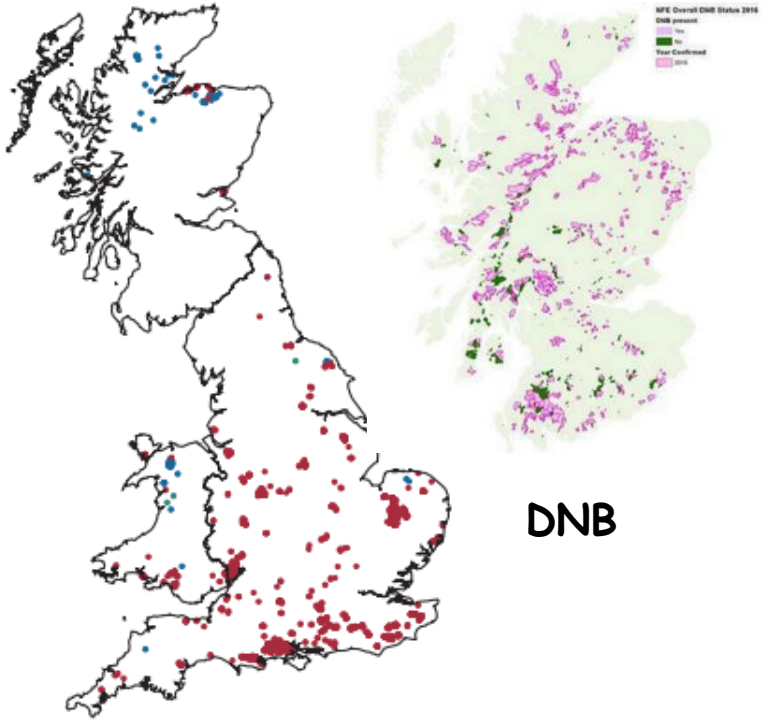
SEVENTH FRAMEWORK PROGRAMME
EUROPEAN COMMISSION
Thermo Lidar

New diseases are challenging British

1. Phytophthora ramorum in larch plantations
2. Dothistroma needle blight (Dothistroma septosporum) of Lodgepole pine (Pinus contorta), Corsican pine (Pinus nigra) or Scots pine (Pinus silvestris)
3. Chalara fraxinea of Ash





DNB

Effect of pathogens in British forestry

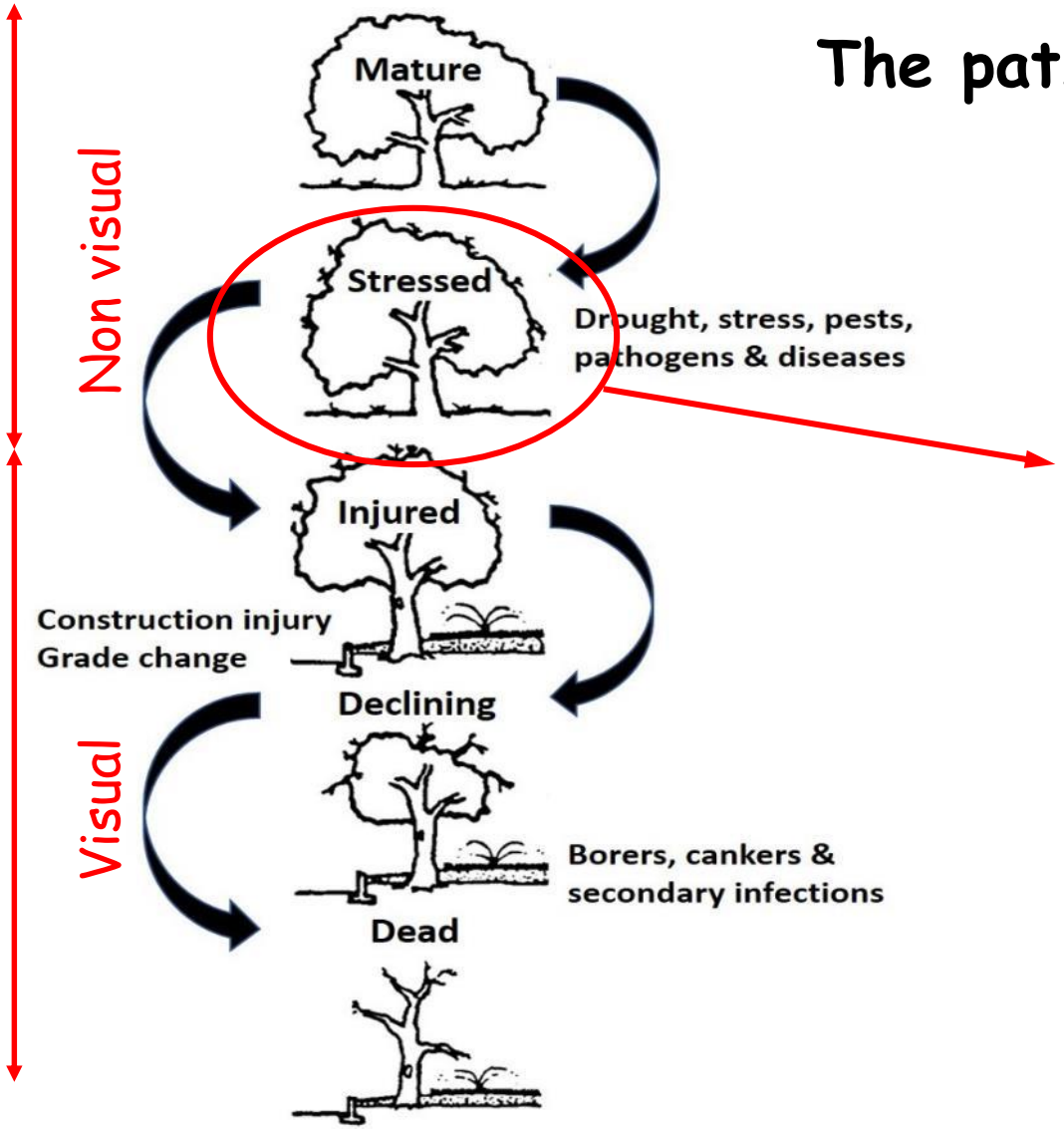
- Crop destruction (Phytophthora ramorum in Glen Toool 2012-2013

- Reduction in timber production (DNB in Scots pine)

Why a monitoring system is needed?

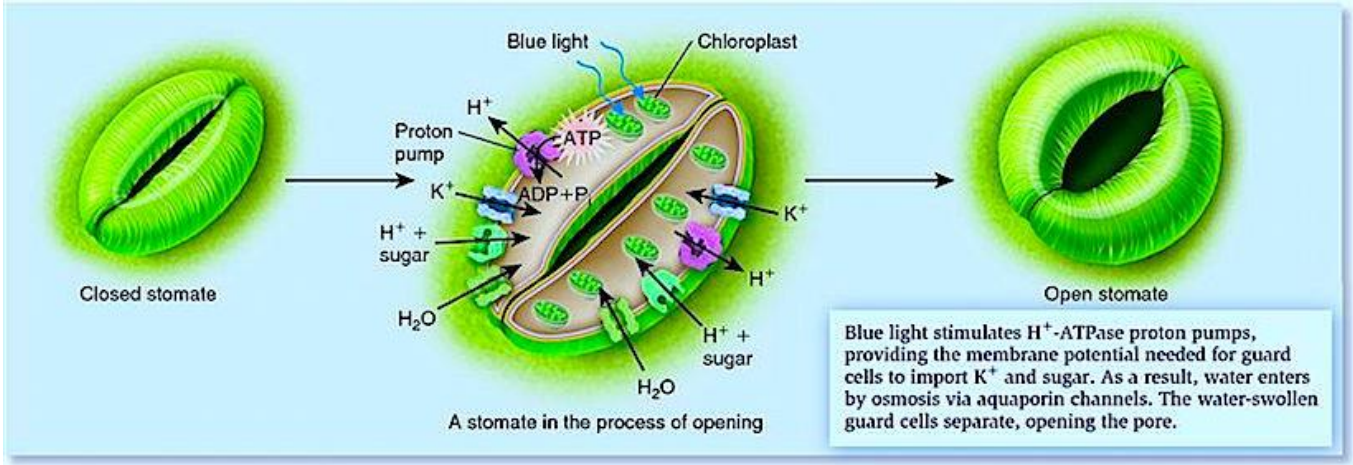
- Target field inspections
- Need to implement strategies of containment
- Evaluate the feasibility of some species for future plantations
- Organise salvage operations
- Quantify the impact of pests and diseases
- Detect pockets of resistance

The pathways of forest decline

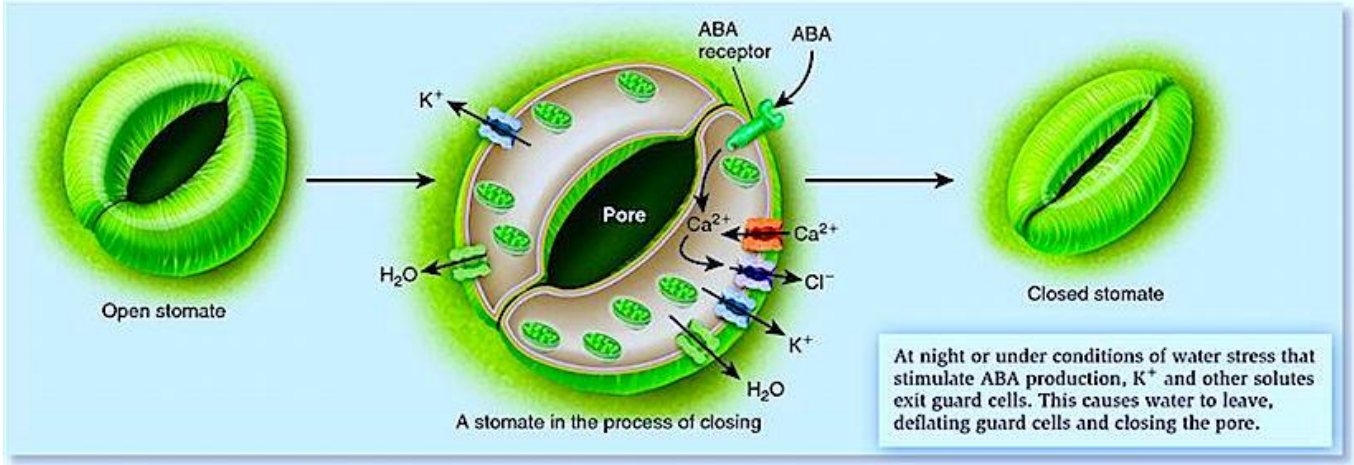


- Pre-visual detection of plant stress because it is probably when the problem has a solution
- BUT… we need to understand plant language

How can we detect stress? Stomata activity



(a) The process of stomate opening

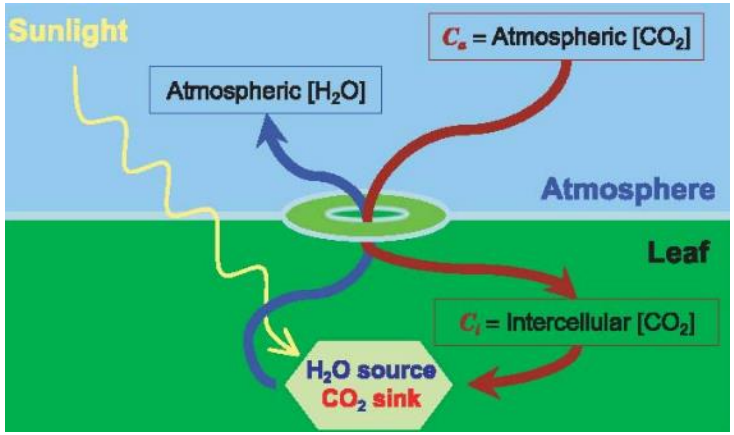


(b) The process of stomate closing

Source: Comstock and Mencuccini (1998)

How can we detect stress?

- **Plants under water stress show alterations in transpiration (drought and pathogens)**.
- As stomata close, photosynthesis becomes constrained and less water is being pumped to the atmosphere.. Therefore, **temperatures increase in upper layer of the foliage**
- Tanner (1963) or Monteith and Szeicz (1962) proposed that plant **temperature could be used as a proxy to quantify stress**.
- Blonquist at al. (2009) proposed to monitor **stomatal conductance to create stress indices**, calculated from environmental measurements and energy balance principles



What is canopy stomatal conductance?

- **Stomatal conductance**: *Rate of exchange* between atmosphere and needles/leaves through stomata
  - For H_2O and CO_2

- Canopy stomatal conductance is defined as the sum of all individual leaves in each canopy layer i

$$g_c = \sum_{i}^{n} \overline{g_{L_i}} L^*$$

Where:

g_c = canopy stomatal conductance (mol m^{-2} ground area s^{-1}),

$\overline{g_{L_i}}$ = <u>mean stomatal conductance</u> over the canopy layer (measured from a number of sample needles/leaves)

L^* = leaf area index (an index of the available needles/leave area of a stand per unit of ground area).

Calculating g_C using the energy balance approach (Blonquist et al. 2009)

- The energy balance at a canopy level:
  - $R_{nC} = H_C + \lambda E_C + A_n$
    - R_{nC} Net radiation = Incoming radiation – Outward radiation
    - H_C **Sensible heat** = Energy due to temperature difference between canopy and atmosphere
    - λE_C **Latent heat** = Energy due to canopy evapotranspiration
    - A_n **Net assimilation** = Photosynthesis – Respiration
- As g_C **is influencing latent heat,** to solve the equation for g_C we get a looooooooooooooong equation… that basically **combines incoming and outward radiation with weather variables to convert energy into a physiological process**

Calculating g_C using the energy balance approach (Blonquist et al. 2009)

Influenced by wind effect

Sensible heat

$$g_C = \frac{g_V P_B[(R_{nC} - A_n) - \boxed{g_H C_P (T_C - T_A)}]}{g_V \lambda (e_{SC} - e_A) - P_B[(R_{nC} - A_n) - g_H C_P (T_C - T_A)]}$$

where:

g_C = canopy stomatal conductance to water vapour (mol m^{-2} s^{-1})
R_{nC} = net radiation in the canopy (W m^{-2})
A_n = net assimilation (W m^{-2})
C_P = heat capacity of air (J mol^{-1} C^{-1})
T_C = aerodynamic canopy temperature (°C)
T_A = air temperature (°C)
λ = latent heat of evaporation (J mol^{-1})
e_{SC} = saturated vapour pressure at Tc (kPa)
e_A = vapour pressure of air (kPa)
P_B = barometric pressure (kPa)
g_H = boundary layer heat conductance (mol m^{-2} s^{-1})
g_V = boundary layer water vapour conductance (mol m^{-2} s^{-1})

Thermal imagery to monitor stomata activity

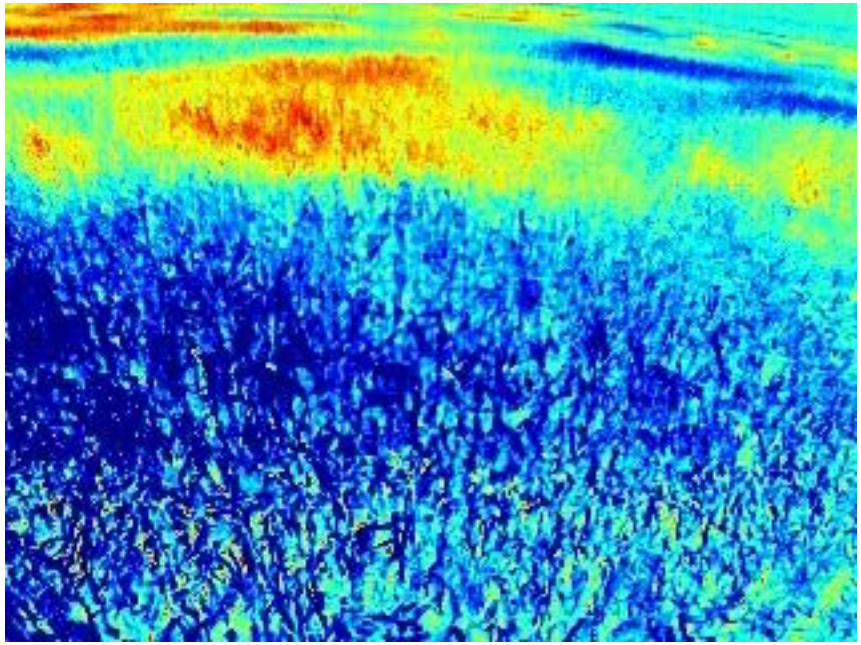
g_C provides a **link between meteorological conditions** (radiation, temperature, humidity and air speed) **and plant physiological response**. It treats the canopy as a big leaf

T_C and R_{nC} are difficult to measure because it is difficult to separate canopy temperature from soil and background vegetation

T_C changes with height and wind effects

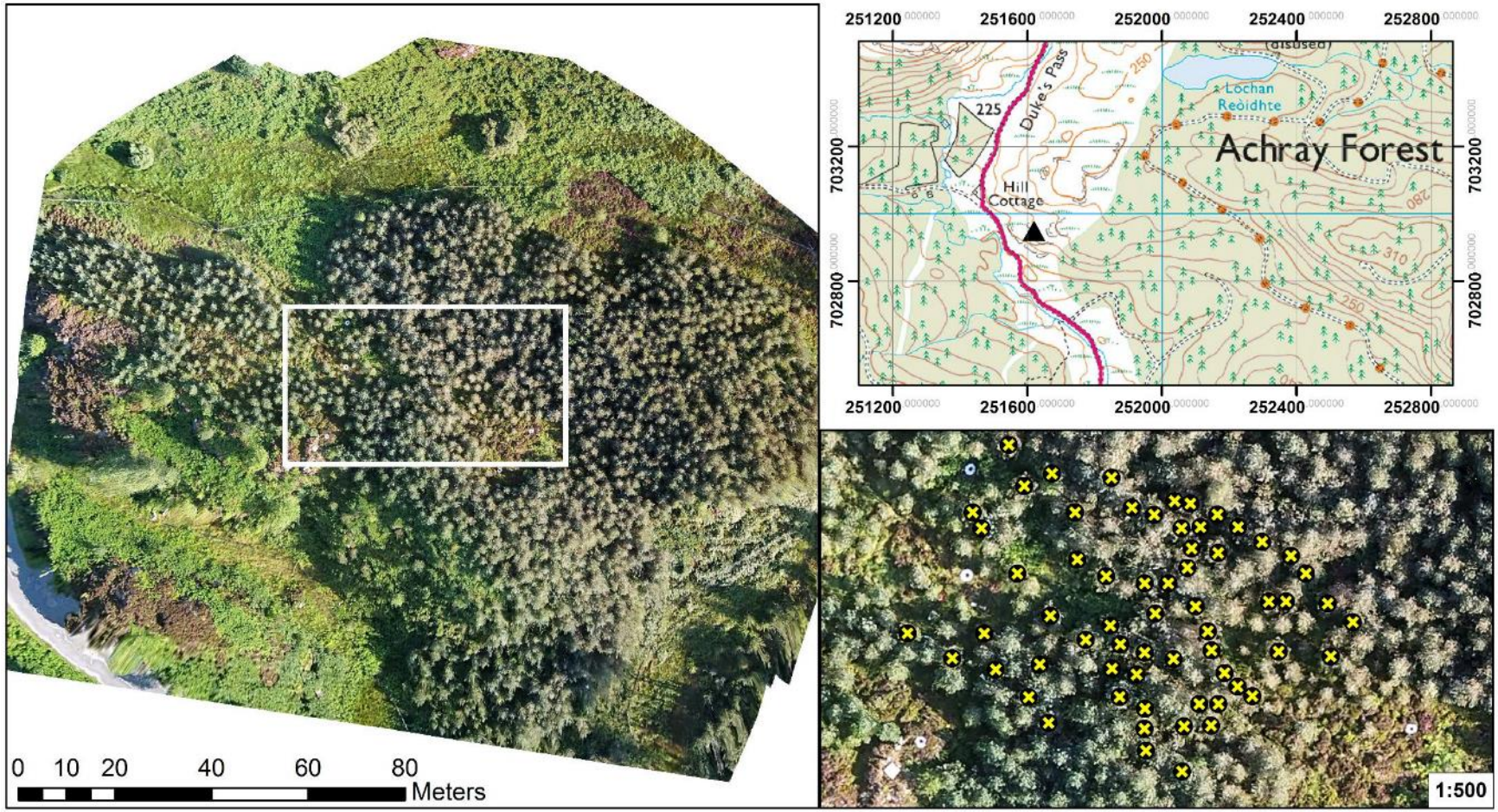
Therefore,

- **images should be captured at different compass directions off-nadir and readings averaged** to minimise the difference between *aerodynamic and radiometric temperatures*
- **Readings should be taken over a period of time and averaged**.

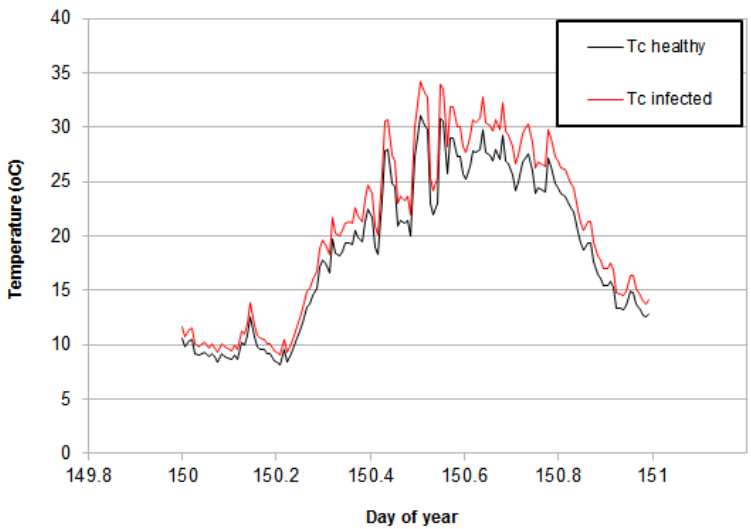


Corn field in South France

DNB monitoring – Study area in Aberfoyle



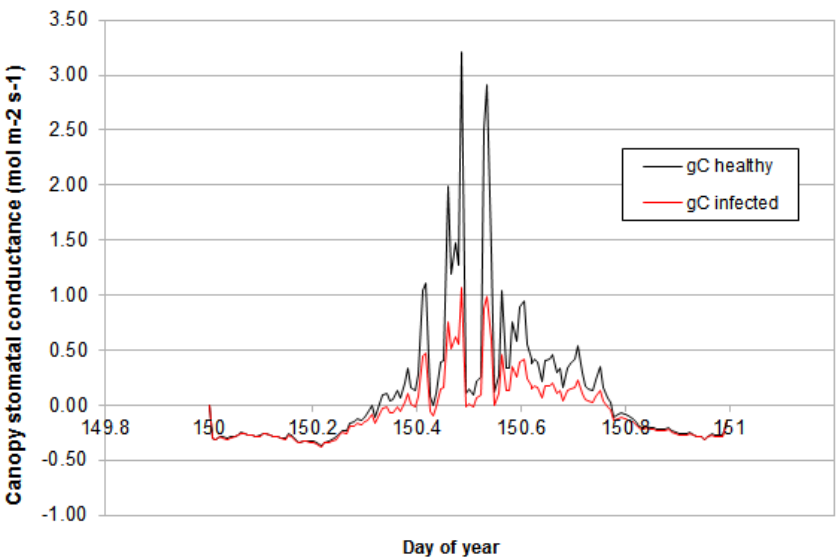
Source: Magdalena Smigaj, 2017

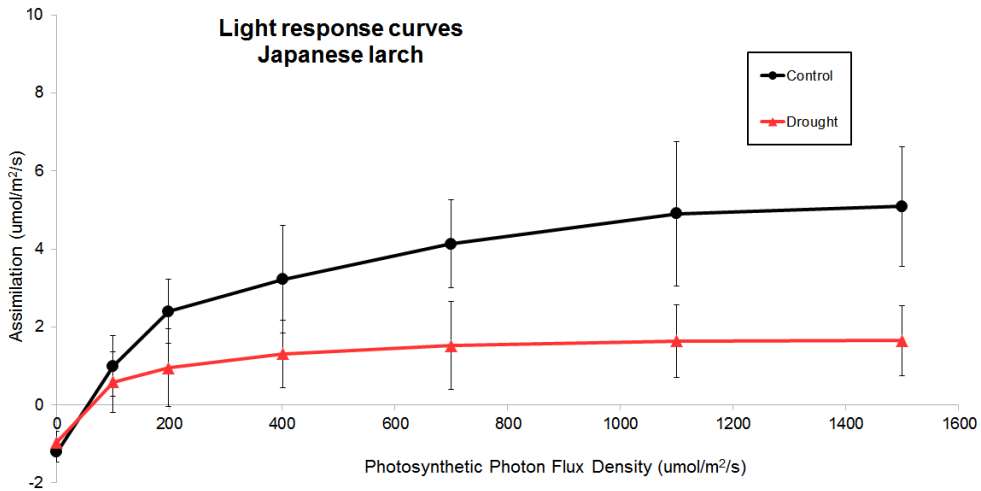


Outputs of the energy balance model in field measurements

Maximum stomata activity normally peaks at noon and reduces activity towards the afternoon.

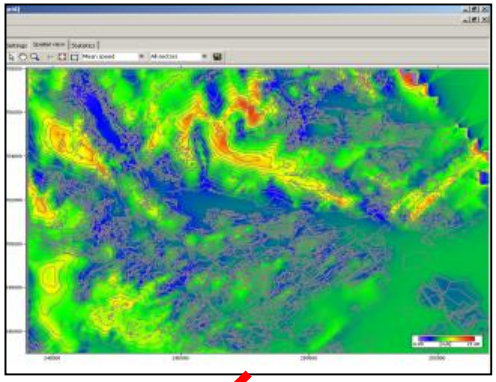
Stomata activity is also variable during a growing season





Estimated canopy conductance in a study area with Thermolidar software

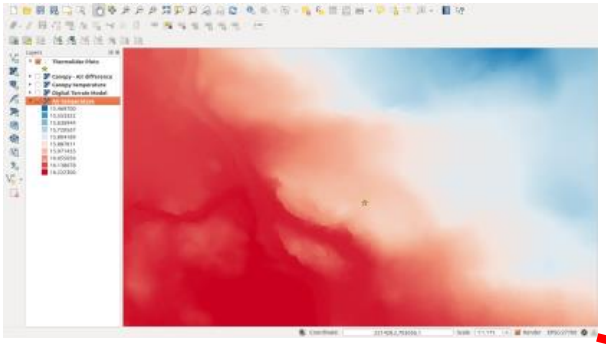
Wind speed and direction



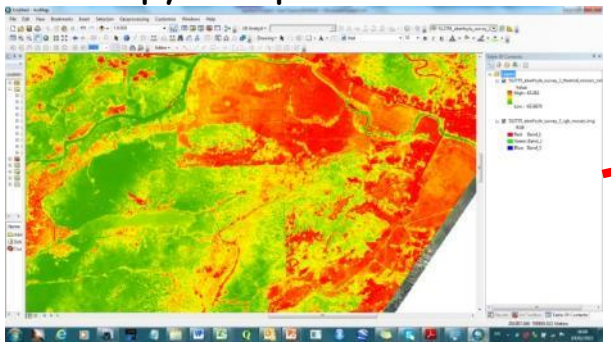
Net radiation (R_{nc})

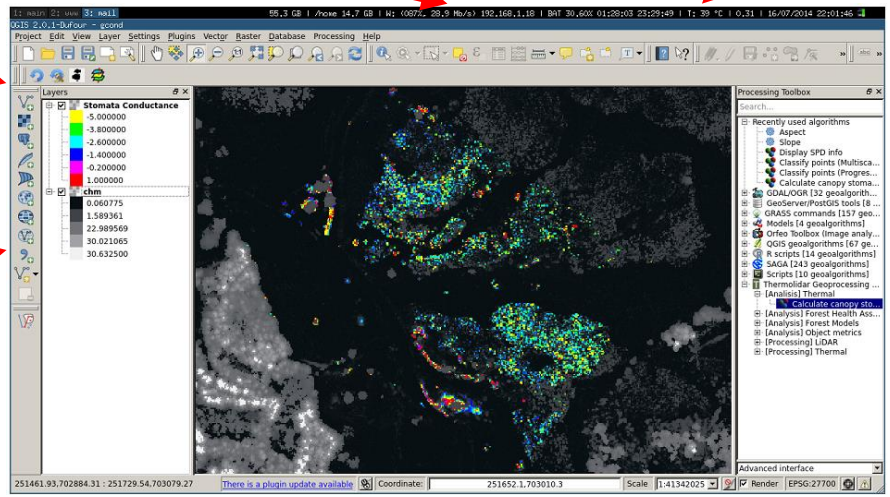
- Assumptions about tree species and local barometric pressure values
- Model estimation using sun position at a particular day and time (currently included in the ThermoLiDAR module)

Air temperature



Canopy temperature



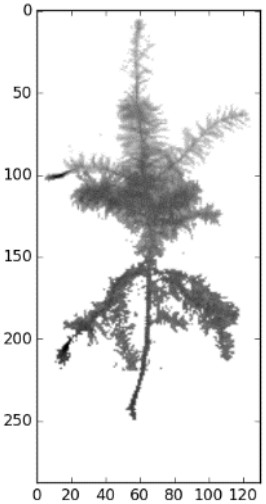


Thermal imagery taken on growth rooms Japanese larch on water stress

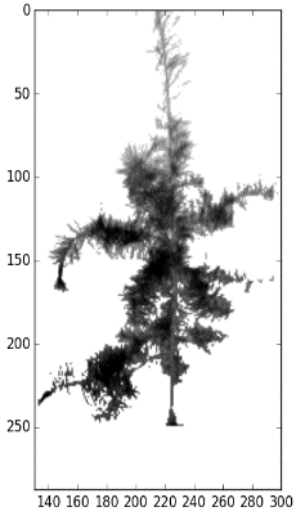
Thermocouples attached to different parts of canopy in stressed and health trees

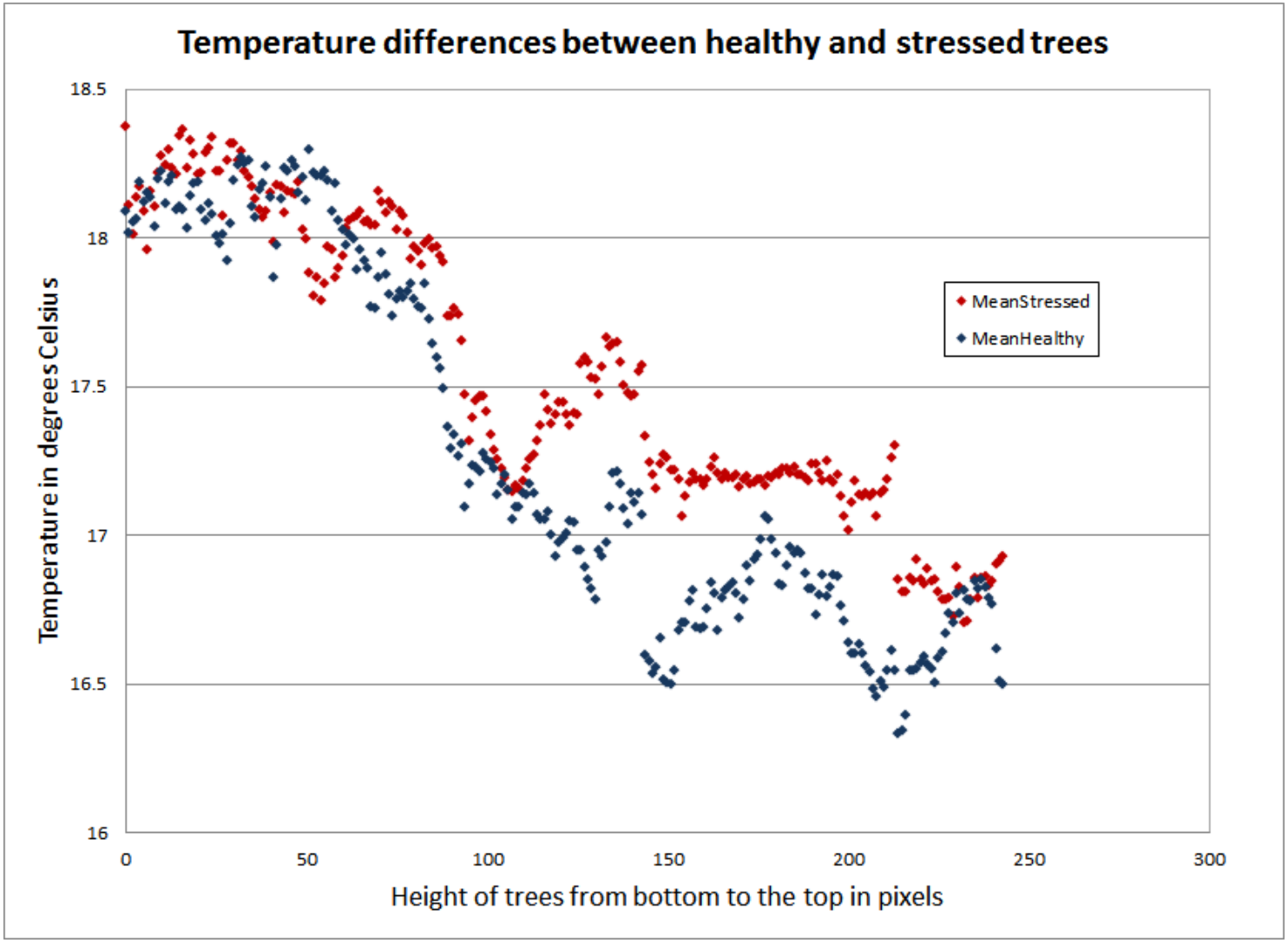
Data taken over an hour with variable illumination conditions

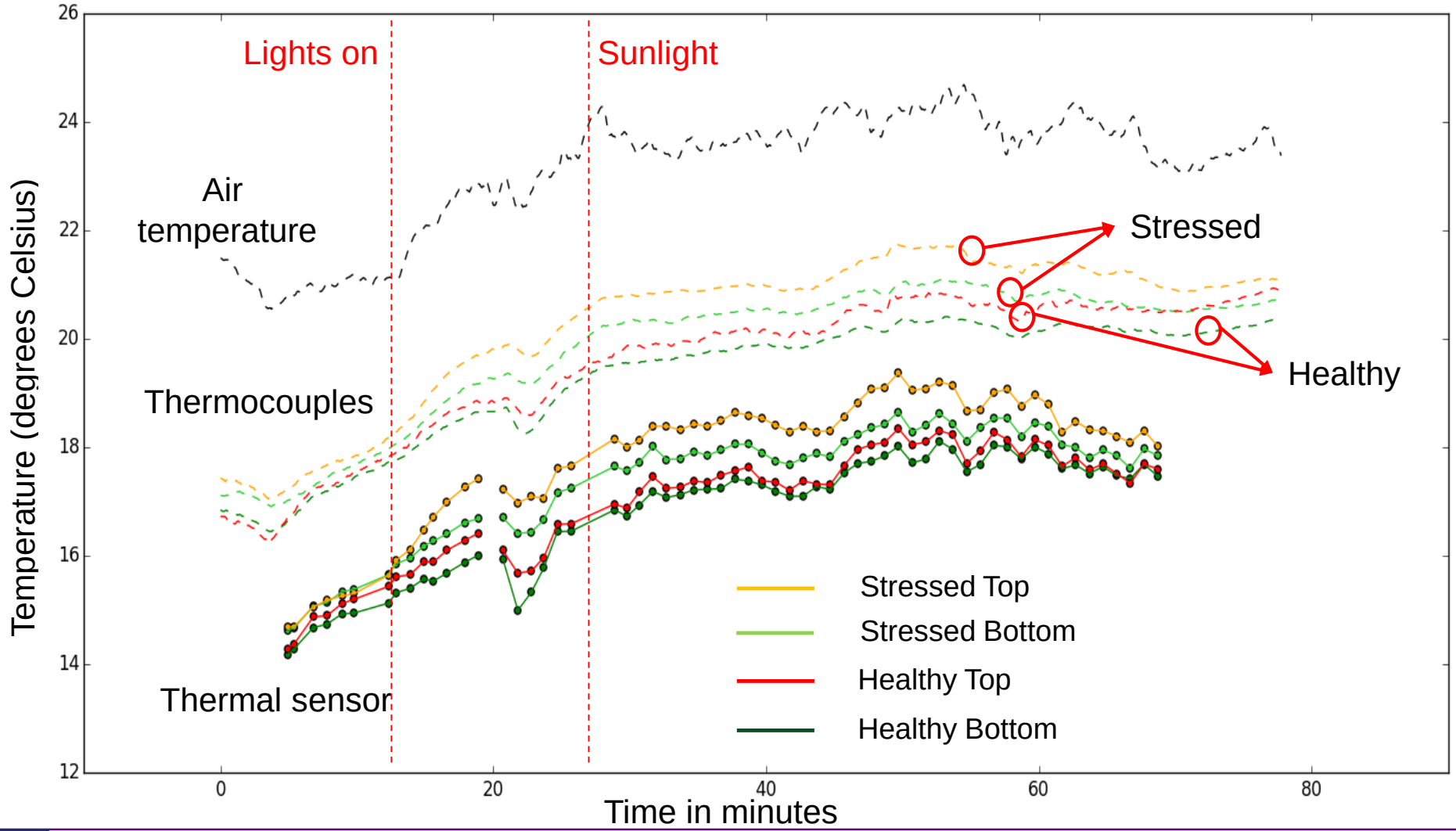
Stress by water deficiency



Healthy plant






Lights on
Sunlight
Air temperature
Thermocouples
Thermal sensor
Stressed
Healthy
Stressed Top
Stressed Bottom
Healthy Top
Healthy Bottom
Temperature (degrees Celsius)
Time in minutes
26
24
22
20
18
16
14
12
0
20
40
60
80

Conclusions

- **Stomata conductance as a method to classify levels of stress** in the vegetation based on fundamental principles of plant physiology combined with weather variables
- It may provide **a pre-visual method to monitor processes of decline** associated to pathogen activity and climate change
- More work is needed to **reduce uncertainty in some of the most sensitive variables** such as the air and canopy temperature. Still broad assumptions on rates of Photosynthesis and Respiration (Net Assimilation)
- **The most effective method of operating thermal cameras to monitor tree physiology is still a steep learning curve**