Incorporating ForestGALES in the large-scale land surface model ORCHIDEE-CAN to quantify the storm damage

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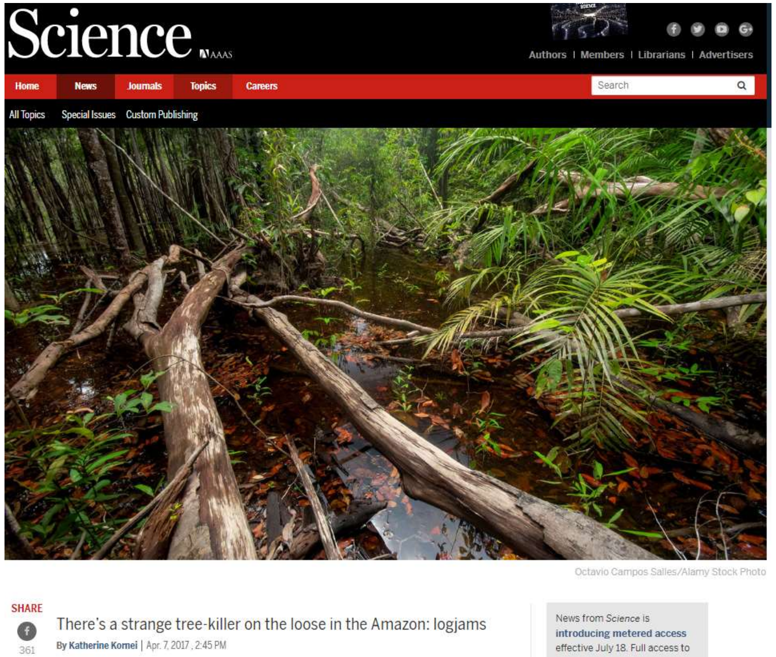
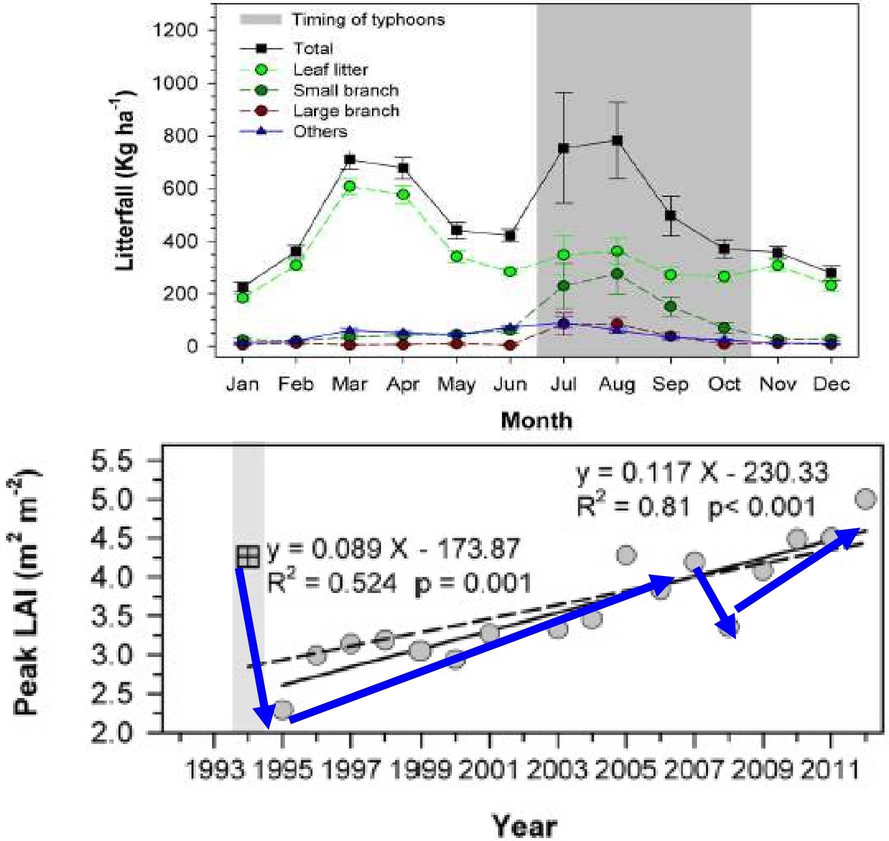
Impacts of increasing typhoons on the structure and function of a subtropical forest: reflections of a changing climate

There's a strange tree-killer on the loose in the Amazon: logjams



SCIENTIFIC REPORTS

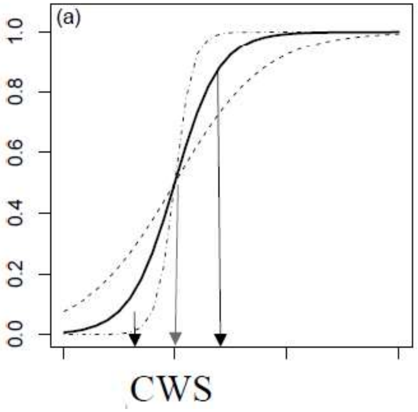


Kornei, 2017; Lin *et al.*, 2017

Storm disturbance (damage types)

- Uprooting (overturning)
- Stem breakage
- Branch/foliage damage

- Root/xylem damage



Relationships between critical wind speed and damage rate

Structural effects

- Gross productivity
- Regeneration
- Stand Composition

This is very important and can affect climate !

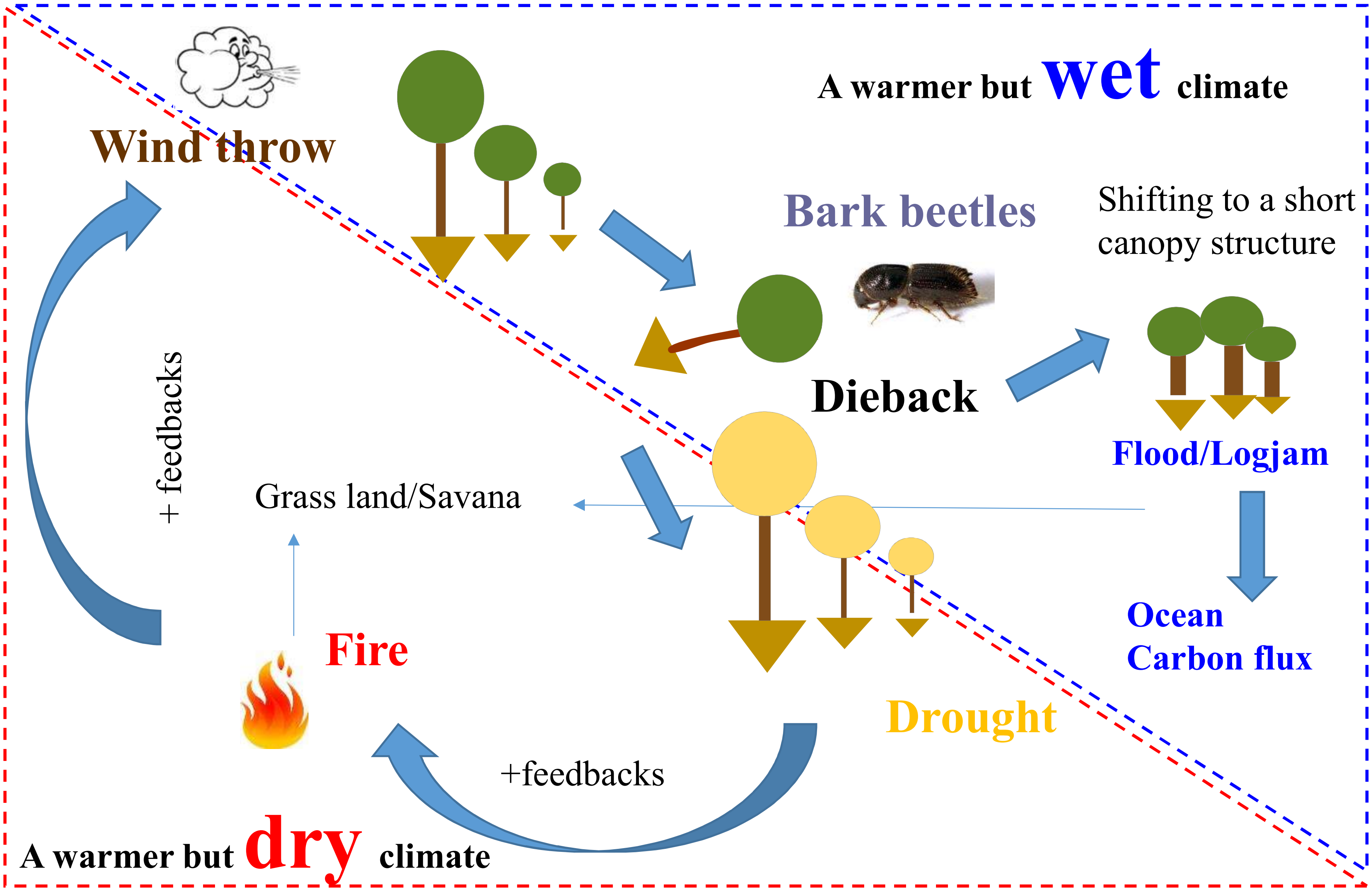


Functional effects

- Less productivity
- Allocation
- Heterotrophic respiration
- Weathering/runoff

Also important but its temporal scale is less than structural effects.

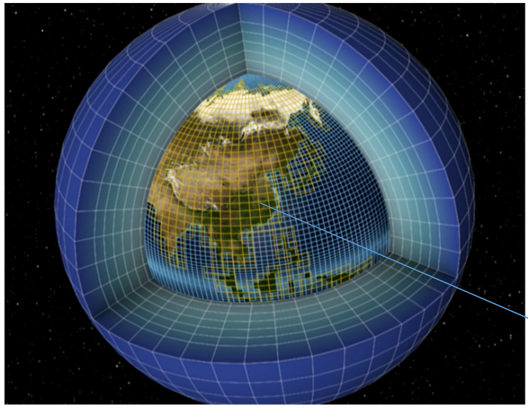
Natural disturbances to tree mortality and canopy structure



Seidl *et al.*, 2014; Seidl *et al.*, 2017; Lin *et al.*, 2017

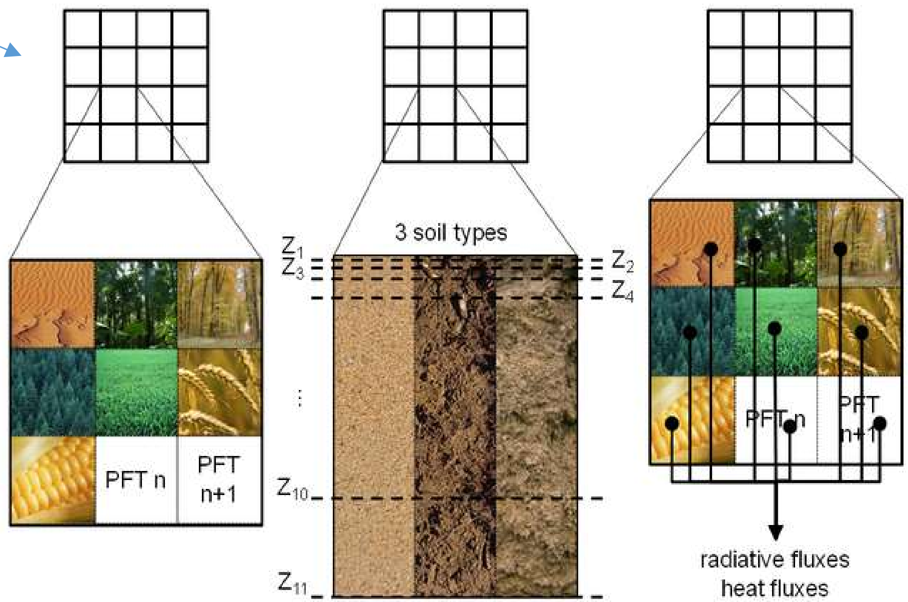
Introduction- Earth System Models, IPSL-CM structure

Atmospheric physics
LMDZ



Ocean physics
NEMO

Land and vegetation
ORCHIDEE



Meteorological variables updated every 30-min / Carbon &Nitrogen 1day
Spatial resolution is 50 x 50 km

ForestGALES: Physical description of critical wind speed calculation

Canopy structure, stand scale

Empirical term for root resistance, canopy properties, aero-dynamic

Streamlining, aero-dynamic

Canopy structure, landscape scale

$$CWS_{ov} = \left(\frac{1}{\kappa\, D}\right)\left(\frac{C_{reg}\ SW}{\rho G d}\right)^{\frac{1}{2}} \ln\left(\frac{h-d}{z_0}\right)\left(\frac{1}{f_{edge}}\right)^{\frac{1}{2}}$$

Canopy structure, stand scale

Canopy properties, aero-dynamic

Streamlining, aero-dynamic

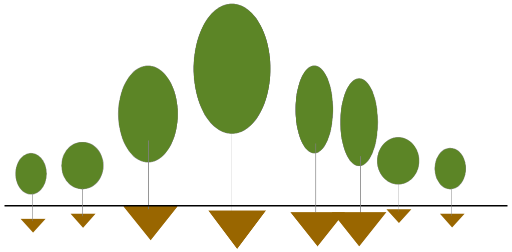
Canopy structure, landscape scale

$$CWS_{bk} = \left(\frac{1}{\kappa\, D}\right)\left(\frac{\frac{\pi}{32} f_{knot} MOR\ diam^{3}}{\rho G(d-1.3)}\right)^{\frac{1}{2}} \ln\left(\frac{h-d}{z_0}\right)\left(\frac{1}{f_{edge}}\right)^{\frac{1}{2}}$$

Nicoll *et al.*,2006; Gardiner *et al.*, 2010; Hale *et al.*, 2015

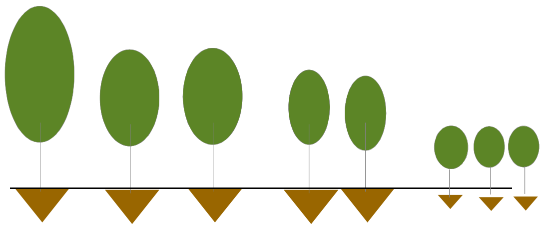
Model development –Vegetation structure (Stand scale)

Natural FOREST



FOR EXAMPLE TROPICS & OLD FOREST

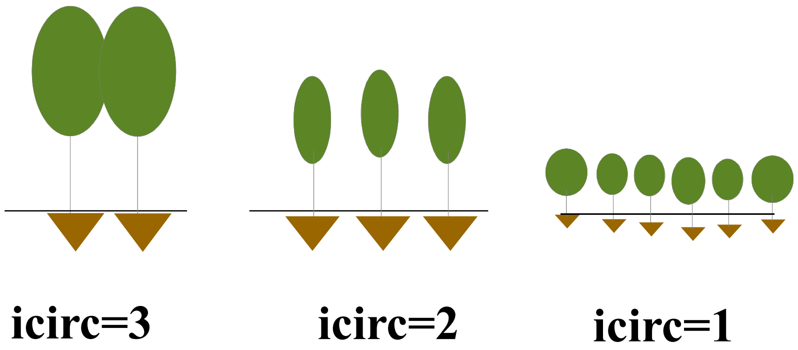
NCIRC=3 ➔ LARGE DIFF BETWEEN DIAMETER CLASSES



FOR EXAMPLE MANAGED TEMPERATE & BOREAL

NCIRC=3 ➔ SMALL DIFF BETWEEN DIAMETER CLASSES

LOOP over diameter classes to make a VIRTUAL STAND STRUCTURE (abv. ground biomass)



Inter tree spacing, D_1, D_2, and D_3

Tree diameter, DBH_1, DBH_2, and DBH_3

Critical wind speed, CWS_1, CWS_2, and CWS_3

$$A_{inner} = \frac{1}{4}\cdot\left(\left(A_{gap}^{\frac{1}{2}} + 2\cdot 9h\right)^2 - A_{gap}\right)\cdot\left(\frac{A_5}{A_{gap}}\right)$$

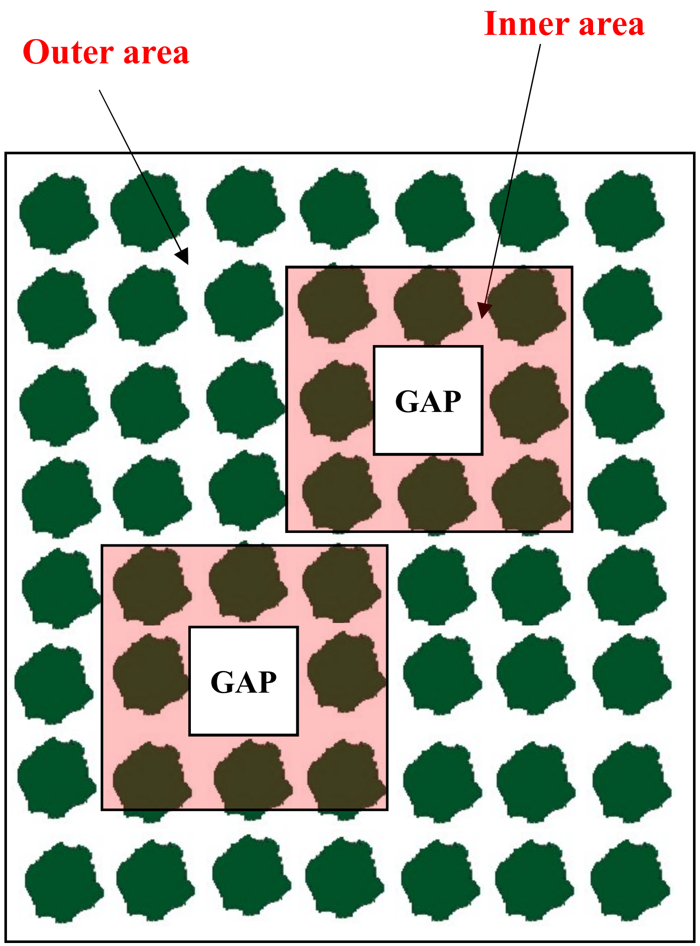
A_{inner}: Inner area,
A_{gap}: Gap area,
A5: Accumulative harvest area in previous five years

$$f_{edge} = \frac{(2.7193(\frac{D}{h}) - 0.061) + (-1.273(\frac{D}{h}) + 0.9701)\cdot(1.1127(\frac{D}{h}) + 0.0311^{\frac{x}{h}})}{(0.68(\frac{D}{h}) - 0.0385) + (-0.68(\frac{D}{h}) + 0.4785)\cdot(1.7239(\frac{D}{h}) + 0.0316^{\frac{x}{h}})}$$

$$A_{outer} = \begin{cases} A_{grid} - (A_5 + A_{inner}), \text{ when } A_5 + A_{inner} < A_{grid} \\ 0 \text{ and } A_{inner} = A_{grid}, \text{ when } A_5 + A_{inner} \geq A_{grid} \end{cases}$$

A_{outer}: Outer area
A_{grid}: Simulation grid area

f_{edge}=1.0

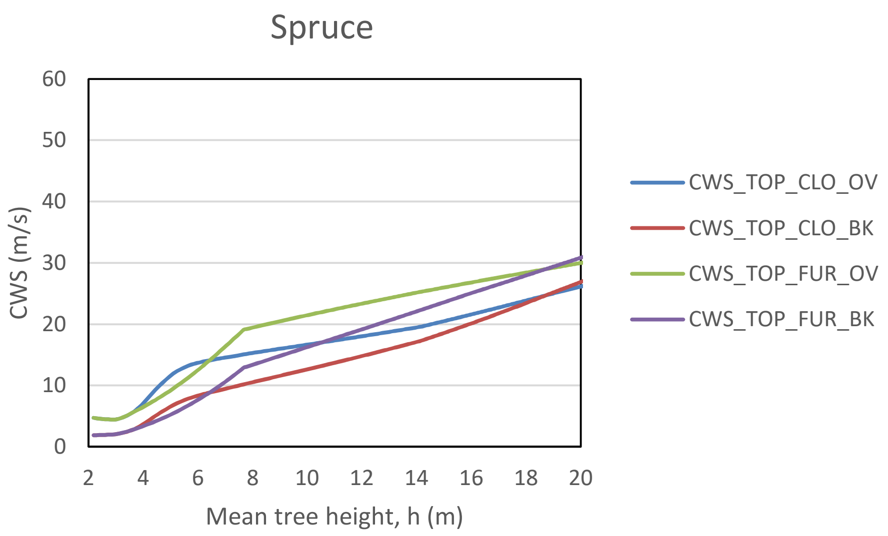


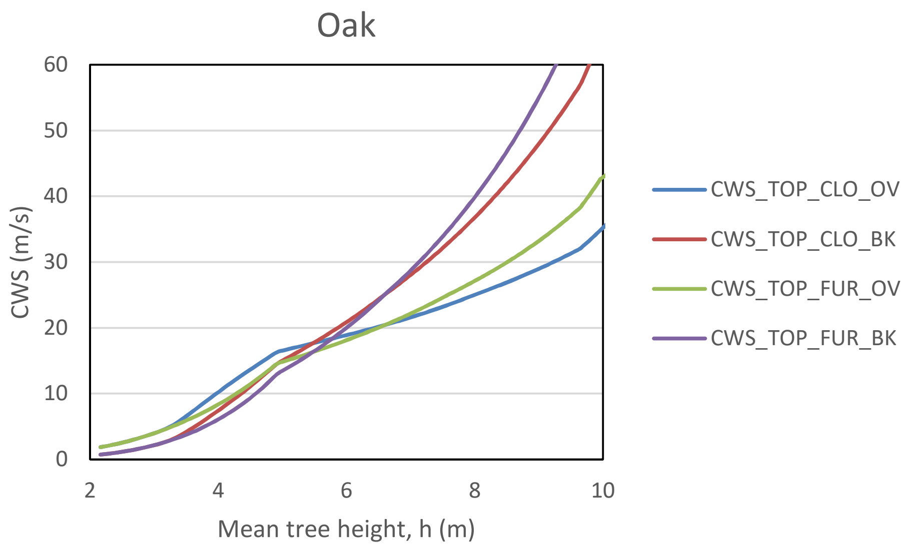
Gardiner *et al.*, 2000

Model testing – CWS calculation with dynamic canopy structure in the ORCHIDEE

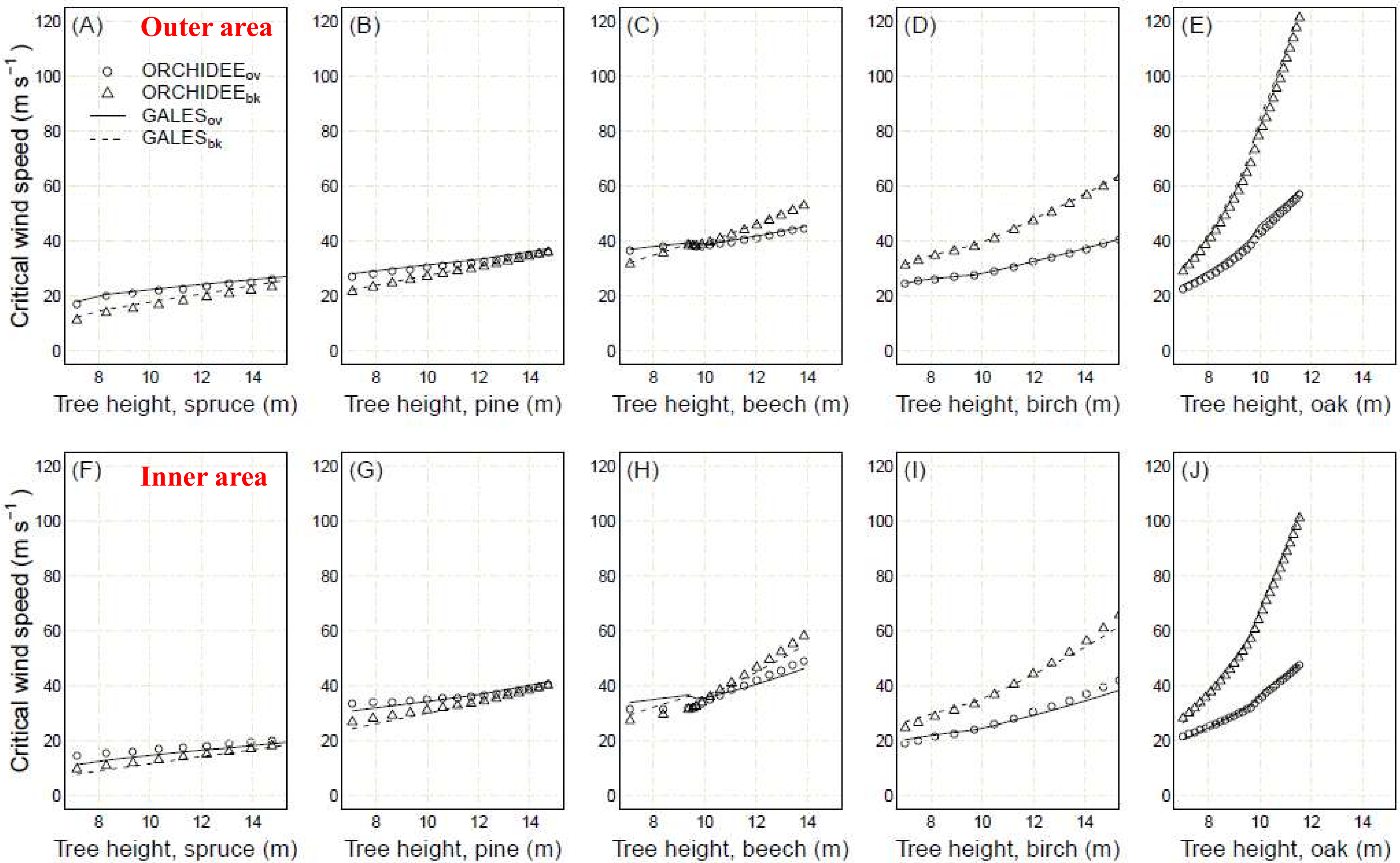
By planting trees grow up at the Fontainebleau Forest (200 years from 1901 to 2100)

(ForestGALES Physics + ORCHIDEE Canopy Structure + Paris Climate)

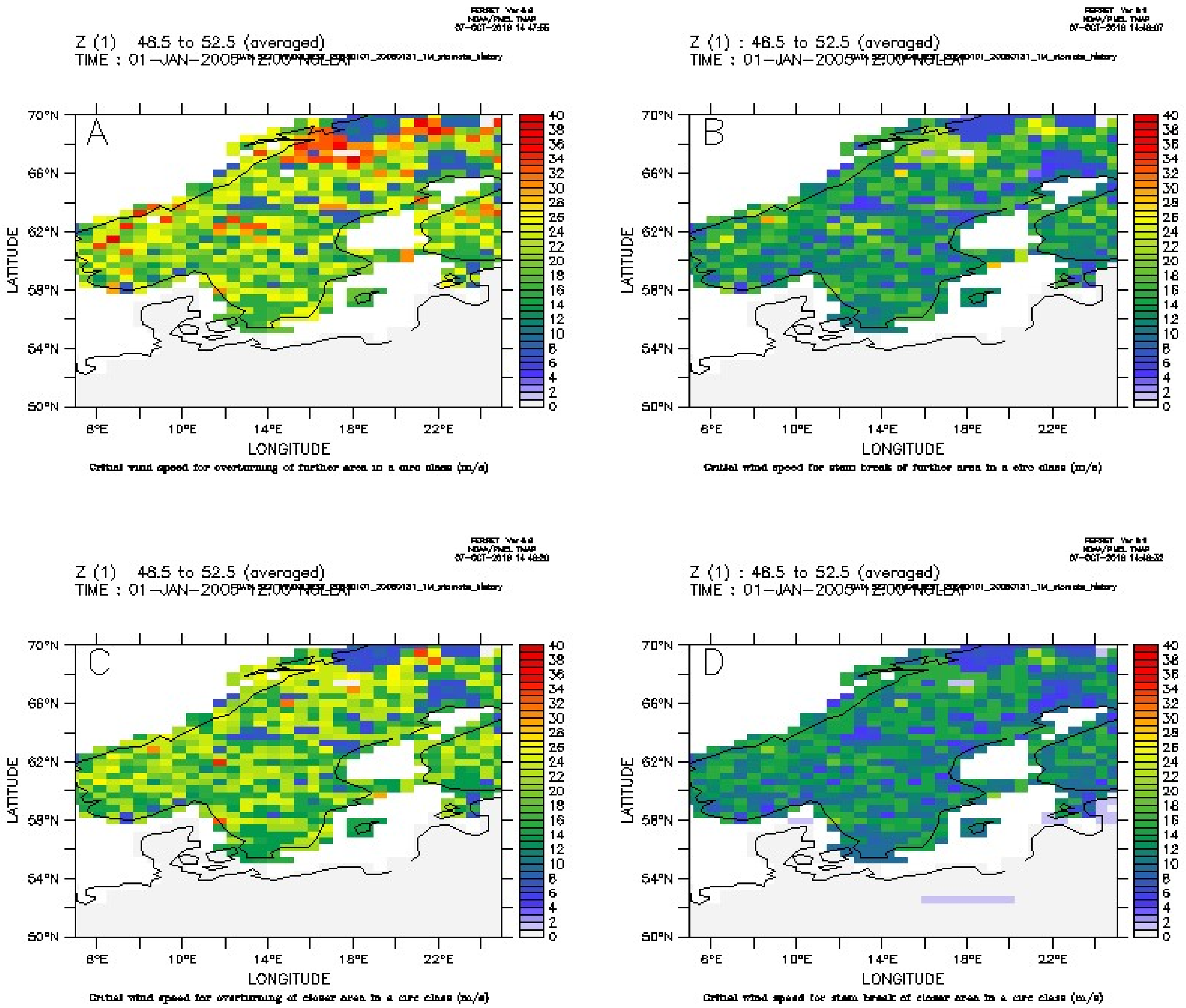




Model intercomparison – ForestGALES and ORCHIDEE-windthrow (rev.3964)



Results – Model Calculated CWS for overturning and stem breakage



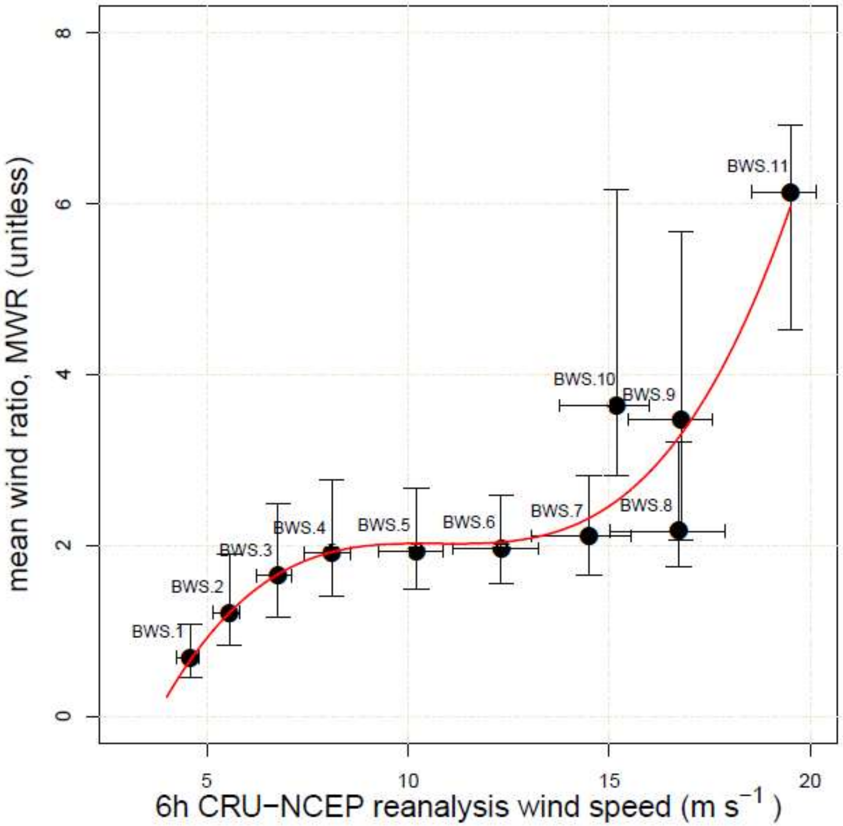
CWS for overturning **CWS for stem-break**

Fig. 1 Simulated CWS for the smallest diameter class for overturning and stem-breakage in forest that were further or closer to a forest edge on January 8th 2005.

The presented CWS are the average CWS for the four age classes of *Picea abies* simulated in ORCHIDEE. **CWS for overturning** in further area (A), **CWS for stem breakage** in further area (B), **CWS for overturning** in closer area (C), **CWS for stem breakage** in closer area (D).

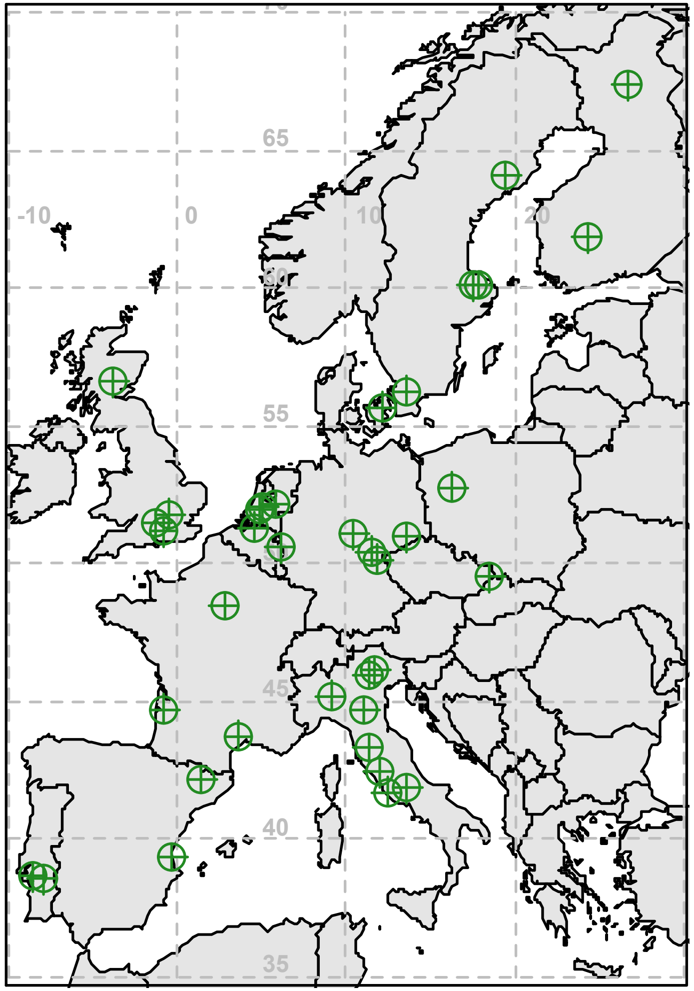
Results – Wind speed downscaling

$$MWR = \frac{U_{Fluxnet}}{U_{CRU-NCEP}}$$



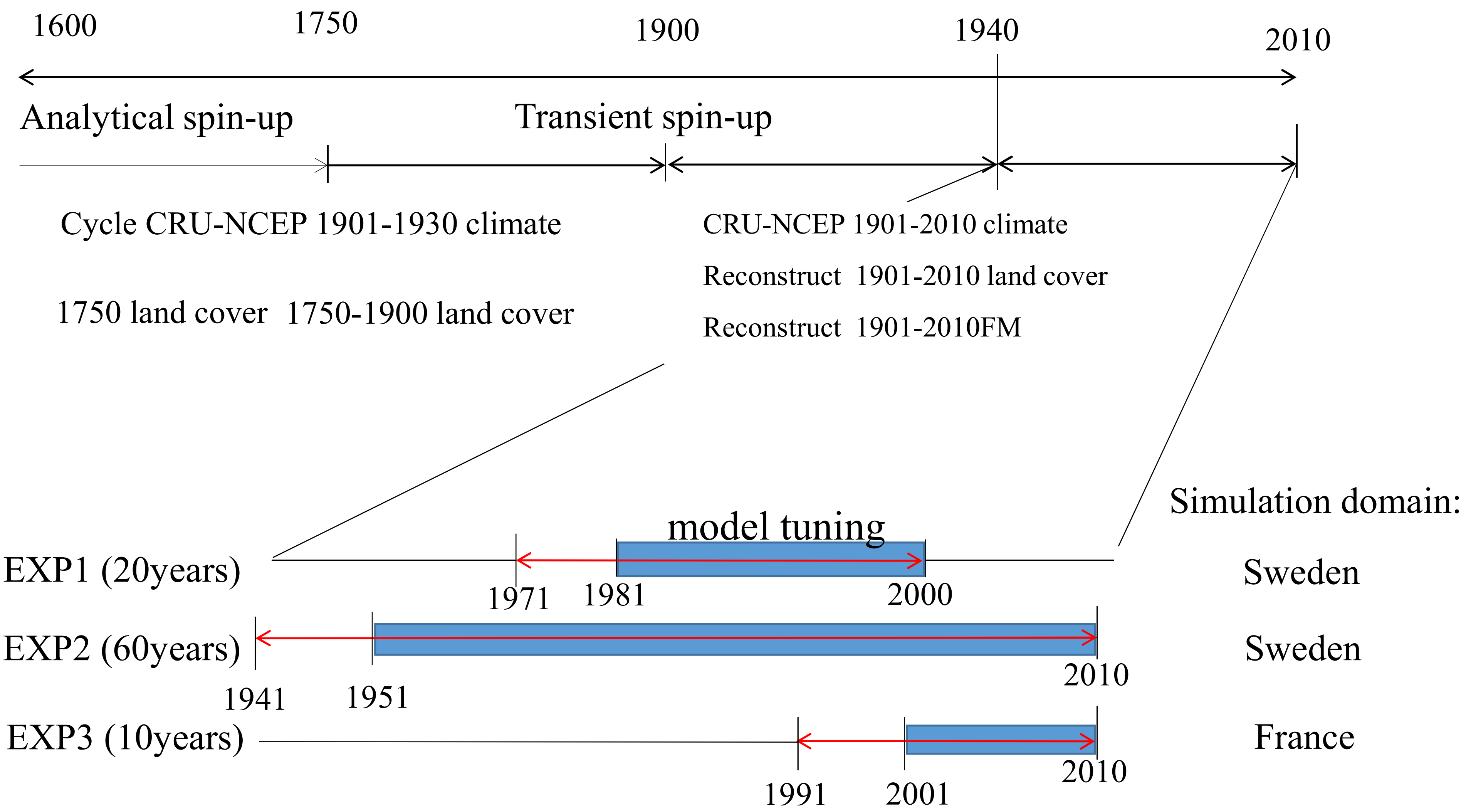
$$U_{max} = a_0 U_{CRU-NCEP} + a_1 U^2_{CRU-NCEP} + a_2 U^3_{CRU-NCEP} + a_3 U^4_{CRU-NCEP}$$

38 FLUXNET Sites, 208 site years



Experiment design– Case study of storm Gudrun in 2005

Forced climate (offline simulation)

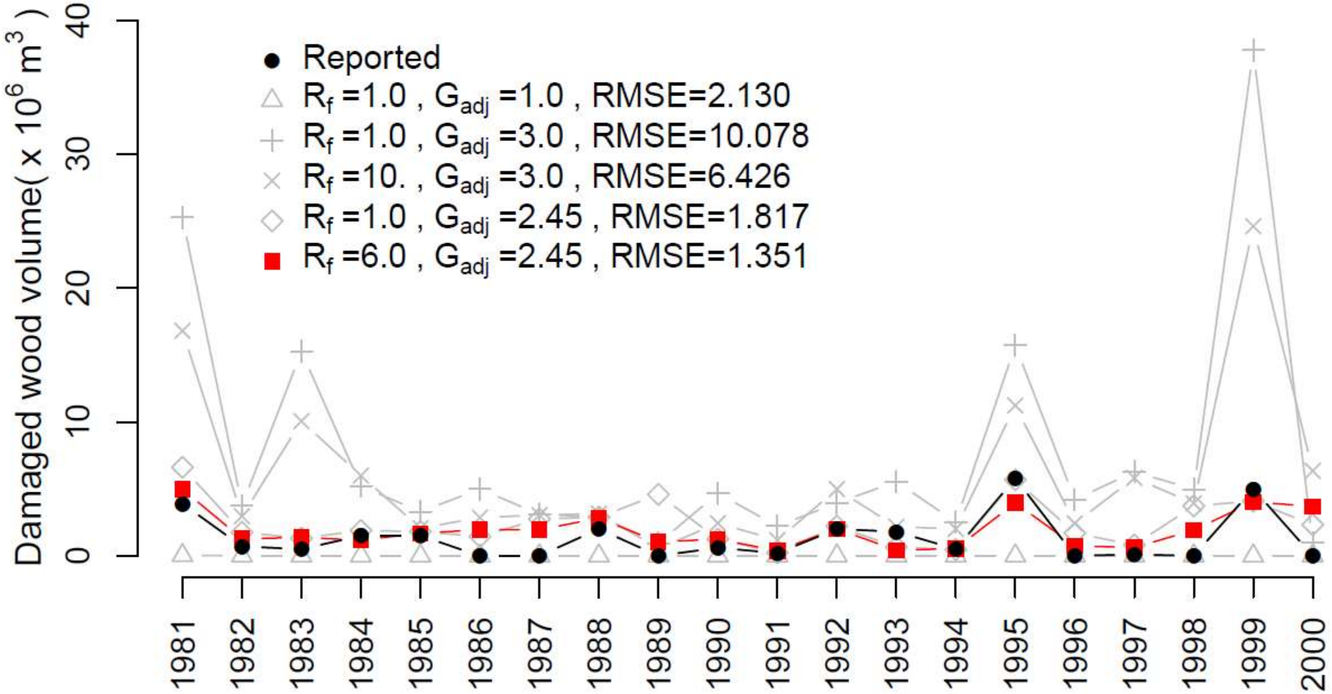


McGrath *et al.* 2015, Naudts *et al.* 2016, Chen *et al.*, in preparation

EXP1 – Modeling tuning

$$G = \left((-2.1 \cdot \frac{D}{h} + 0.91) \cdot \frac{x}{h} + (1.0611 \cdot ln(\frac{D}{h}) + 4.2) \right) \cdot G_{adj}$$

$$D_\beta = D_{max} \left(\frac{1}{1 + e^{-(\frac{U_{max} - CWS_{bk,ov}}{R_f})}} - \frac{1}{1 + e^{(\frac{CWS_{bk,ov}}{R_f})}} \right)$$



EXP2 – Modeling validation

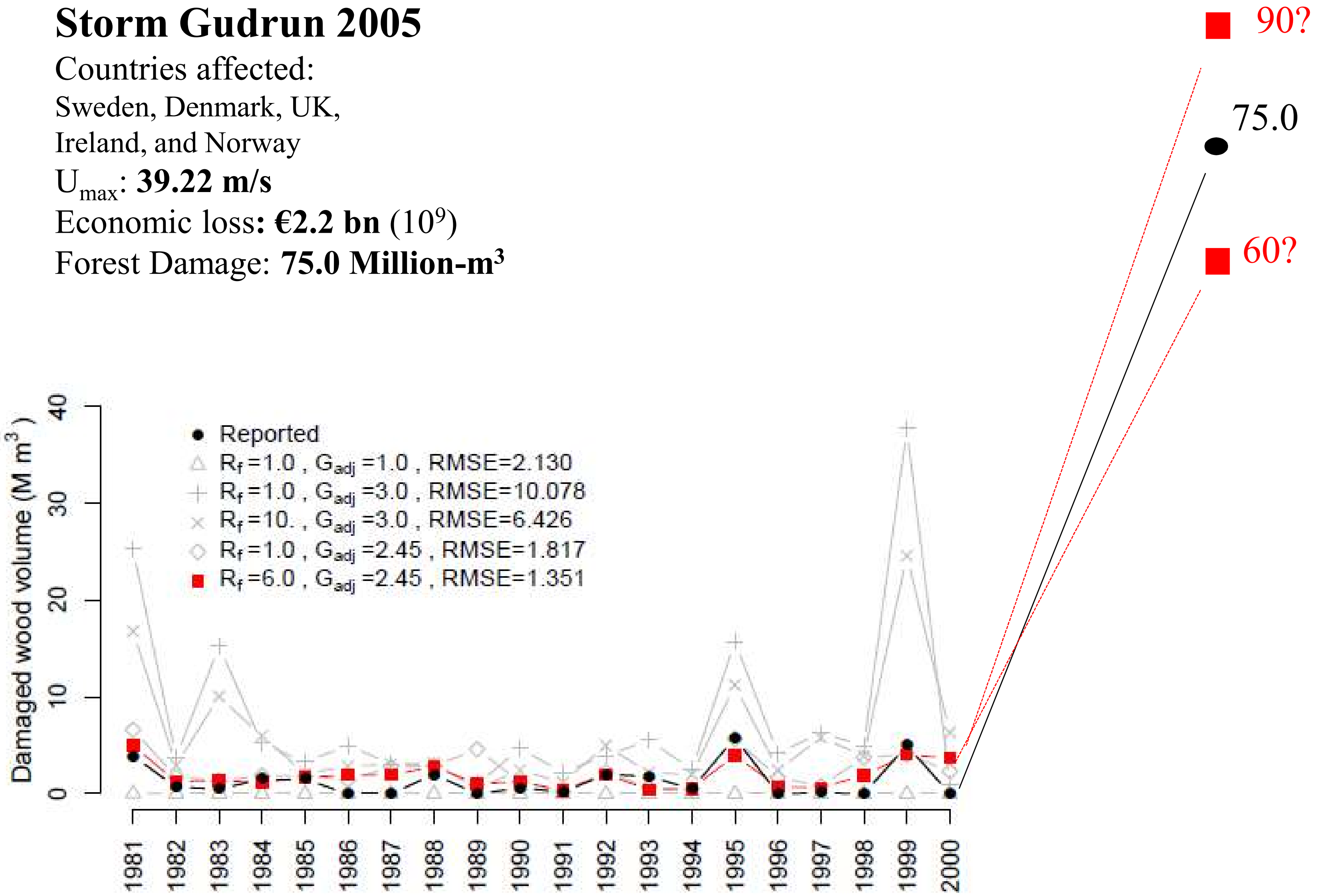
Storm Gudrun 2005

Countries affected:
Sweden, Denmark, UK,
Ireland, and Norway

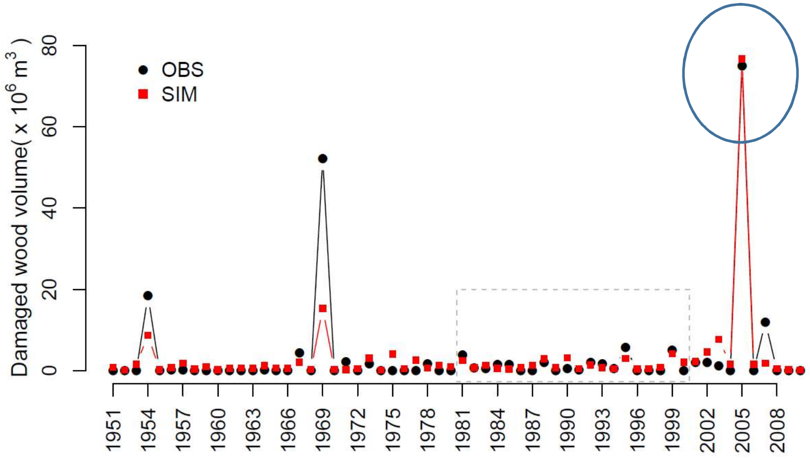
U_{max}: **39.22 m/s**

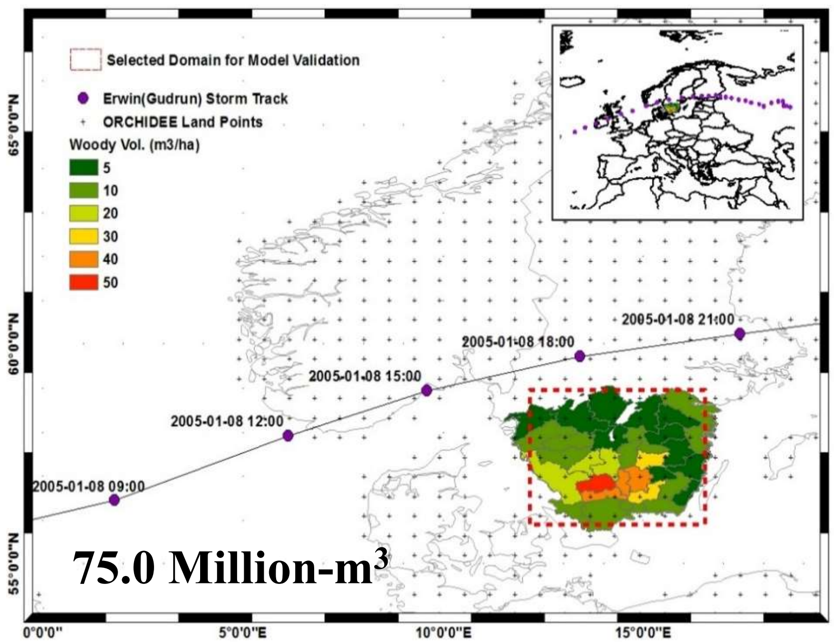
Economic loss**: €2.2 bn** (10^9)

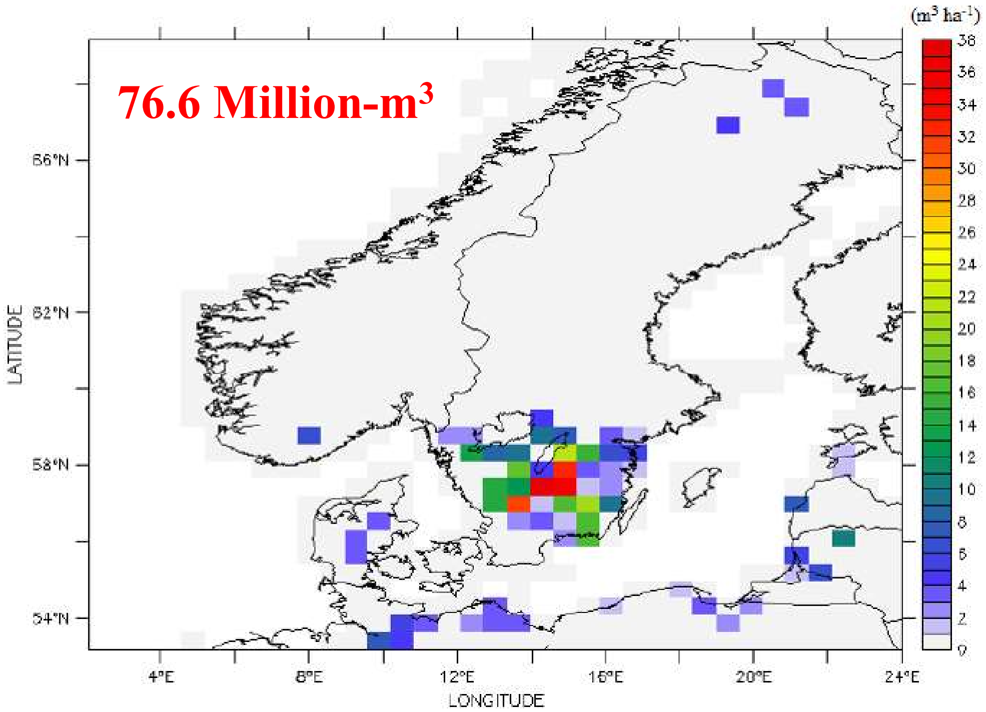
Forest Damage: **75.0 Million-m³**



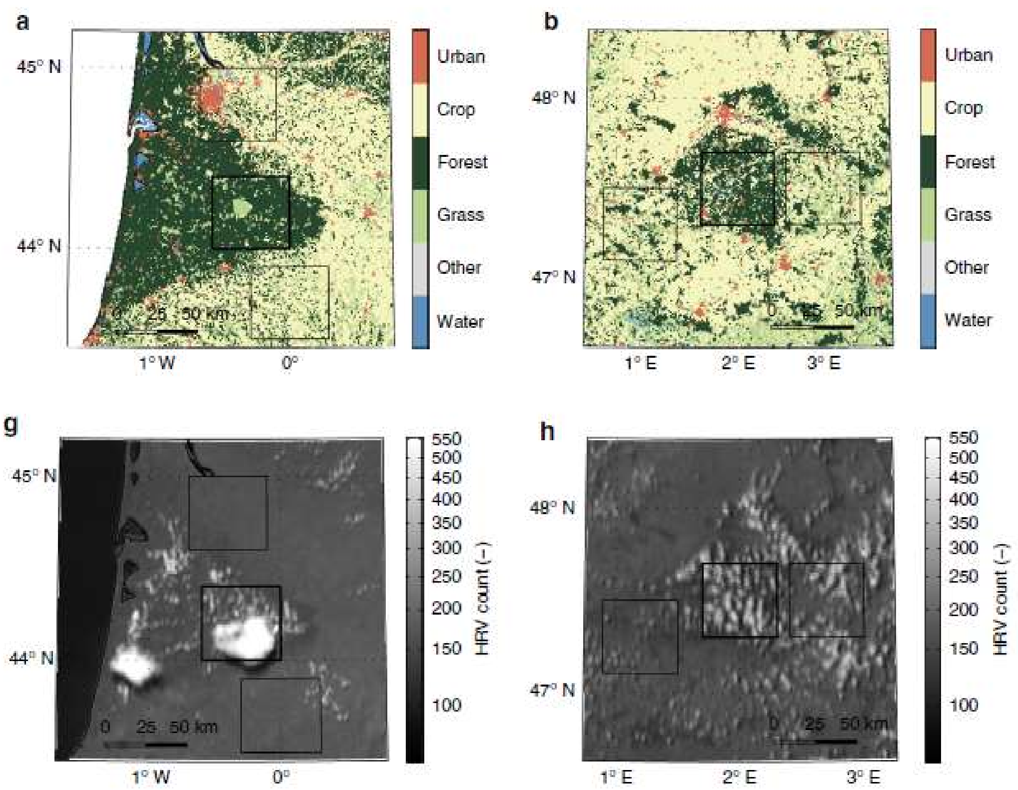
EXP2– Storm Gudrun 2005





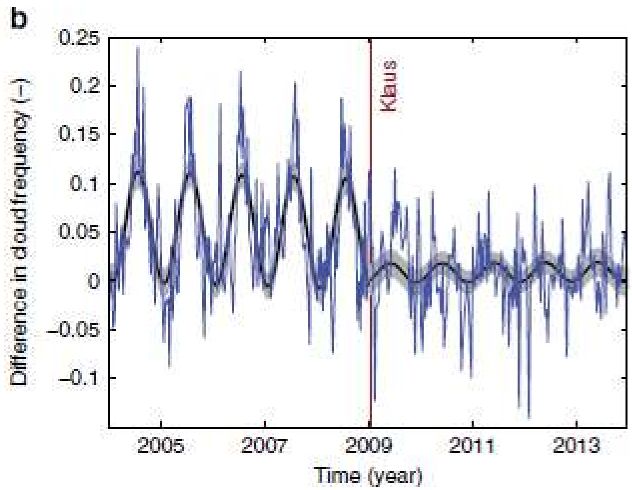


The observation evidence of "forest breeze" at "Les Landes" and "Sologne" forests



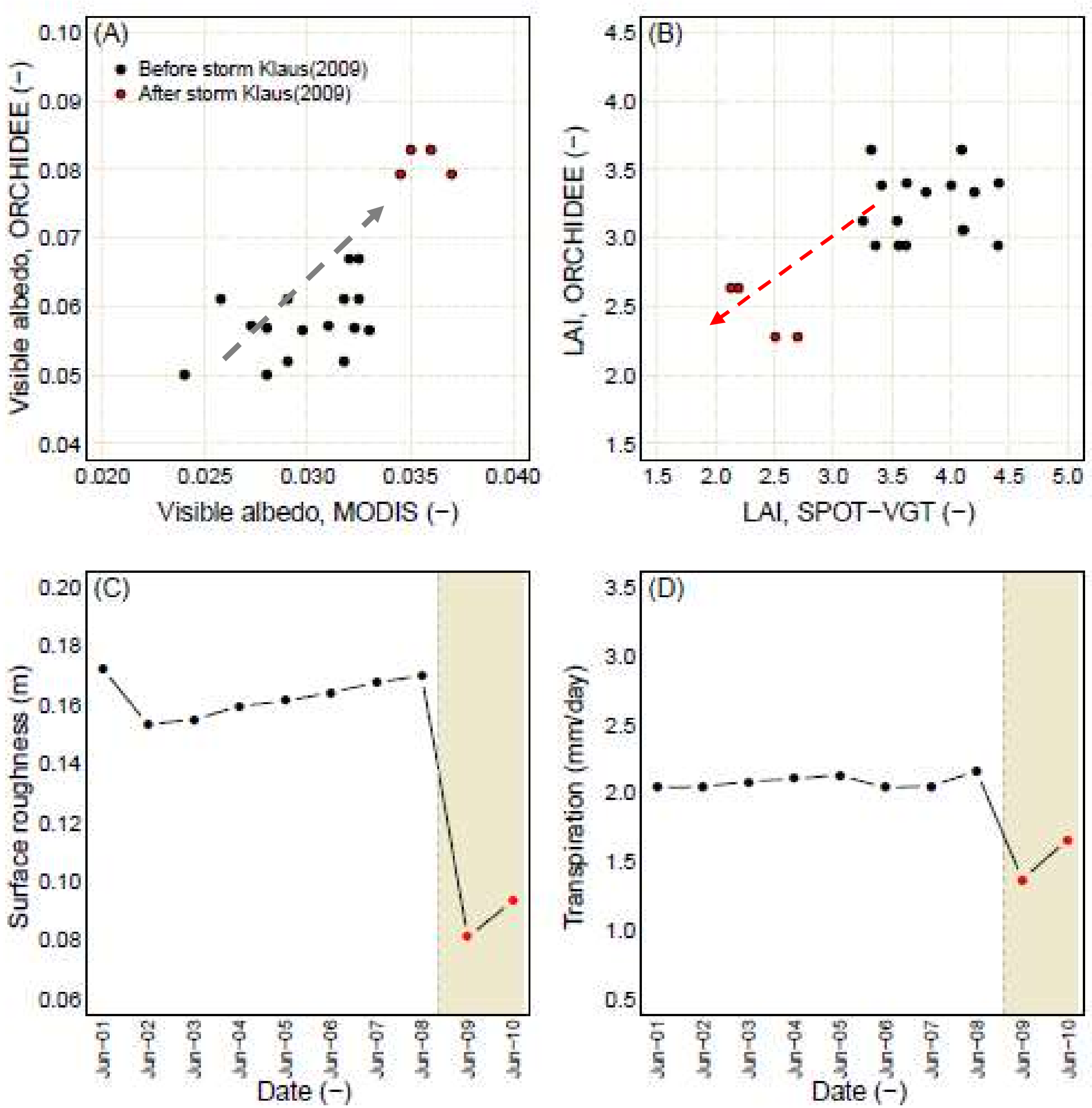
~300 Km

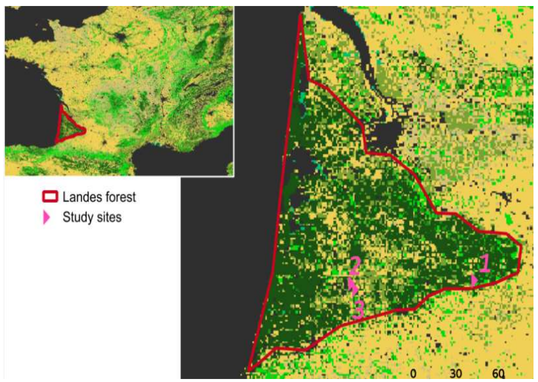
Storm damage does change the cloud frequency.



Can these bio-physical and bio-chemical changes (reduce the local cloud frequency) drive the local climate change?

EXP3– Storm Klaus (2009)





Summary

- We adapted the physical based stand model ForestGALES to calculate CWS at large scales.
- When all parameters are constrained within observed ranges we can simulate a very reasonable damage for a large storm over Sweden and canopy structure changes of les landes forest due to the storm Klaus.

Remaining Issues:

- **Downscaling wind field:** Dynamic downscaling of gridded wind field from large scale model is still required to improve the model performance on the storm damage estimation and model coupling task.
- **Subpixel heterogeneity:** 1. Description of the gap size is time invariant, and the relationship between gap size and gustiness was not accounted for. 2. Topographic induced trees exposure to the wind and trees acclimate were also not considered. 3.Within a modeled grid, all tree species shared with a signal soil water column, thus the representation of soil water content heterogeneity may need to be improved for some unique cases.
- **Species parameters:** Within the ORCHIDEE-CAN 21 tree species, we only test five species. Some tree species parameters are still missed, which is assigned an average value from other species. Expanding the species parameters to a wide range is also required for the work of large scale experiment to investigate the feedbacks between the natural disturbances, such as fire, drought, storms in the global scale.

Applications:

- **Wind risk map**: Over storm prone areas including TW, JP or KO… the wind throw risk can be estimated.
- **How the forest disturbances feedback to the climate?**

Acknowledgement

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My email: yiyingchen@gate.sinica.edu.tw

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