Root anchorage and tree stability under wind load

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AMAP CIRAD Montpellier Thierry Fourcaud

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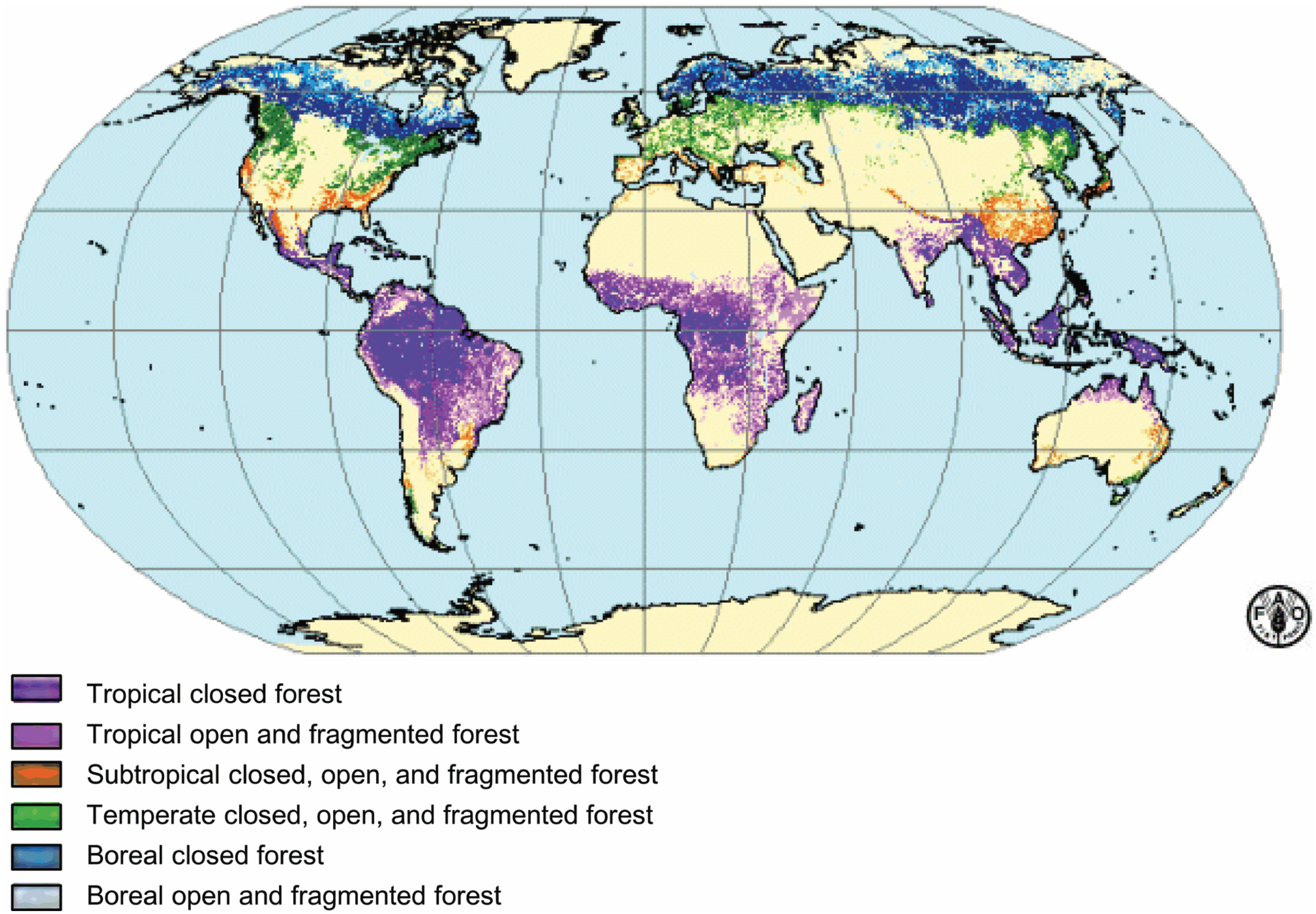
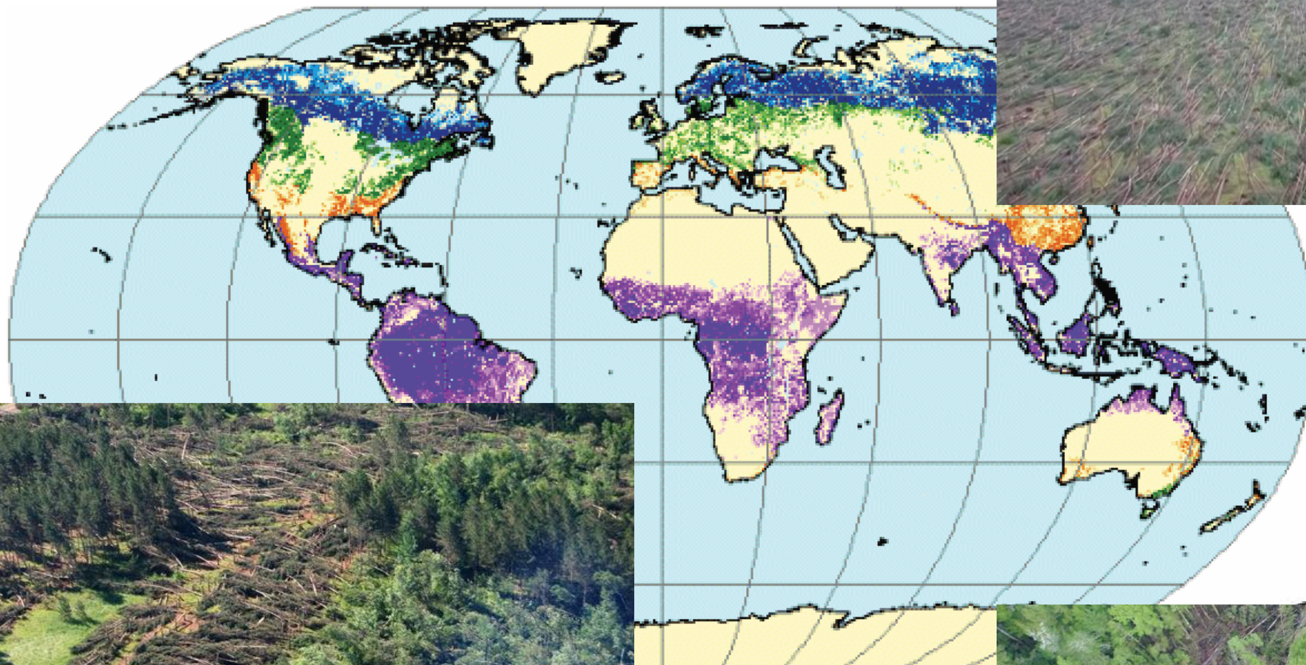
Context

Wind causes damage in forests


Tropical closed forest
Tropical open and fragmented forest
Subtropical closed, open, and fragmented forest
Temperate closed, open, and fragmented forest
Boreal closed forest
Boreal open and fragmented forest

Poland August 2017 (Image: Reuters)



Wisconsin July 2011
Credit: Stacy Hopke / Burnett County Sheriff's Office

NZ Cyclone Gita /Beech Forest April 2018

https://ourtrees.nz


Toppling
Photo : F. Danjon

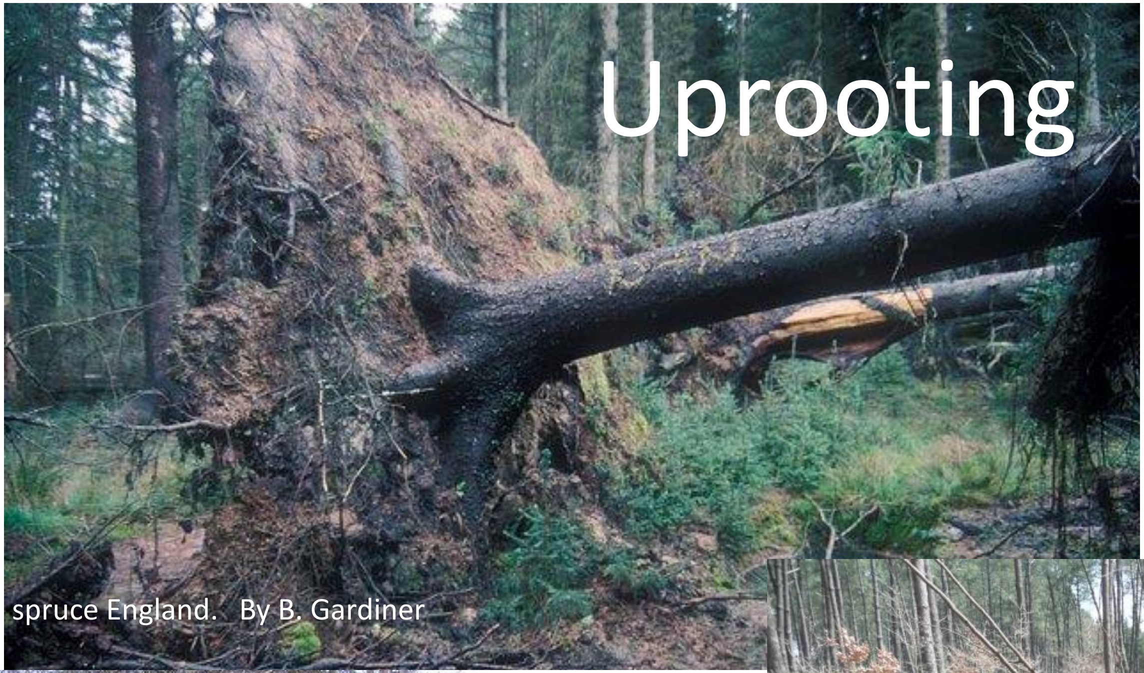
Toppling

3 years old

Photo : F. Danjon


Tree Breakage
Photo : D.Bert

Uprooting

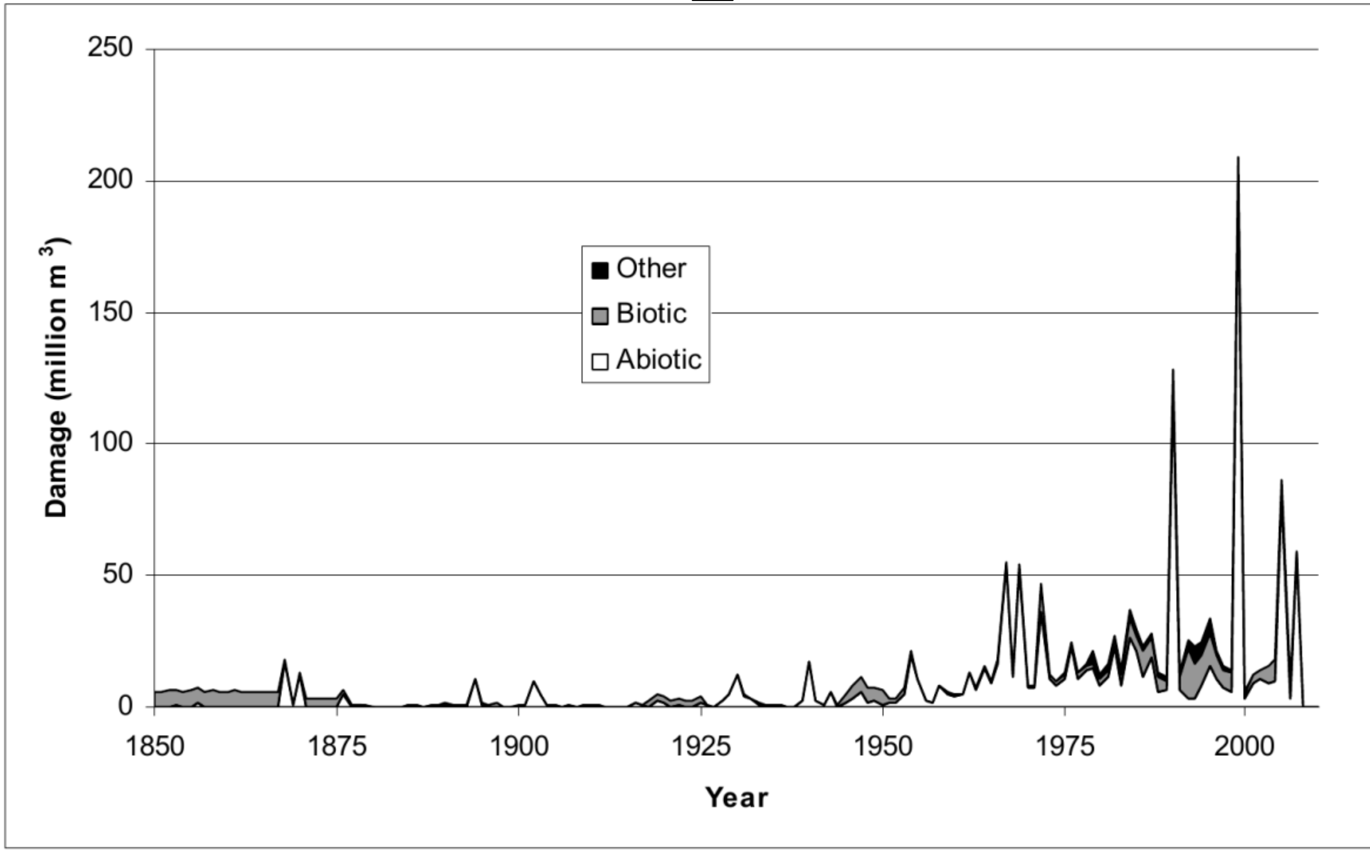


spruce England. By B. Gardiner

Larches Scotland (UK) © Richard Webb

Maritime Pine, France (photo: P. Défossez)

Wind damage in forests



1950 - 2000 : annual volume of damaged wood = 35 million m^3

storm: 53%, fire: 16%, scolytes : 8%, other biotic : 8%

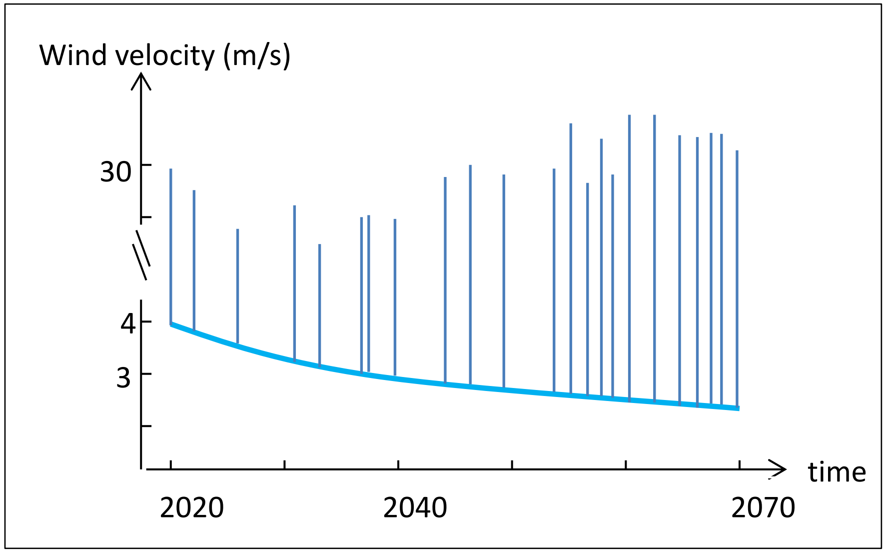
Schelhaas, 2008

What happens with climate change ?

Changes in soil properties

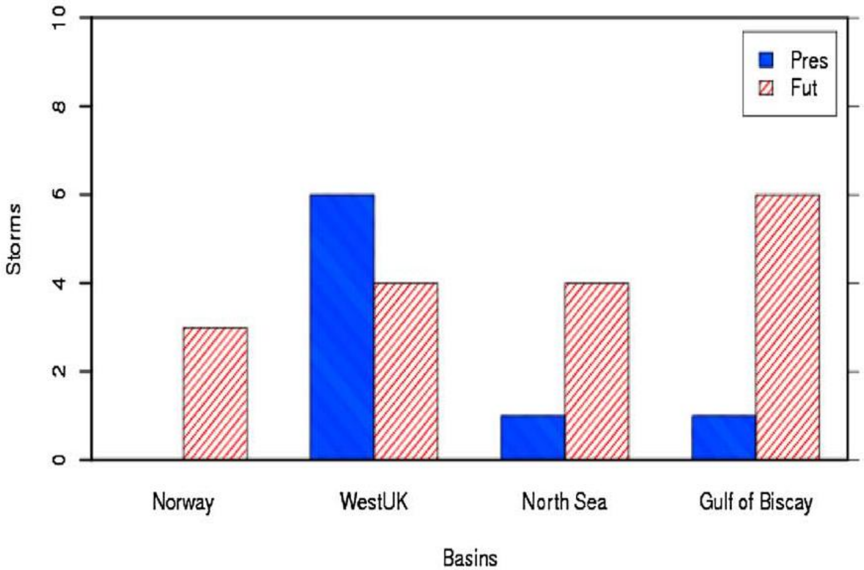
Agren et al 2015

Potential change in near-surface wind

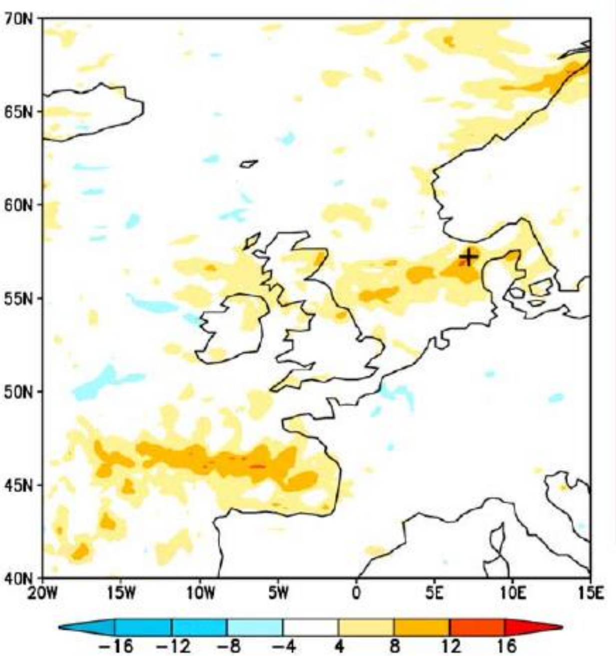


- Decrease in wind speed
- Increase in wind storm

McVicar et al., 2012 IPCC 2013



Haarsma et al 2013



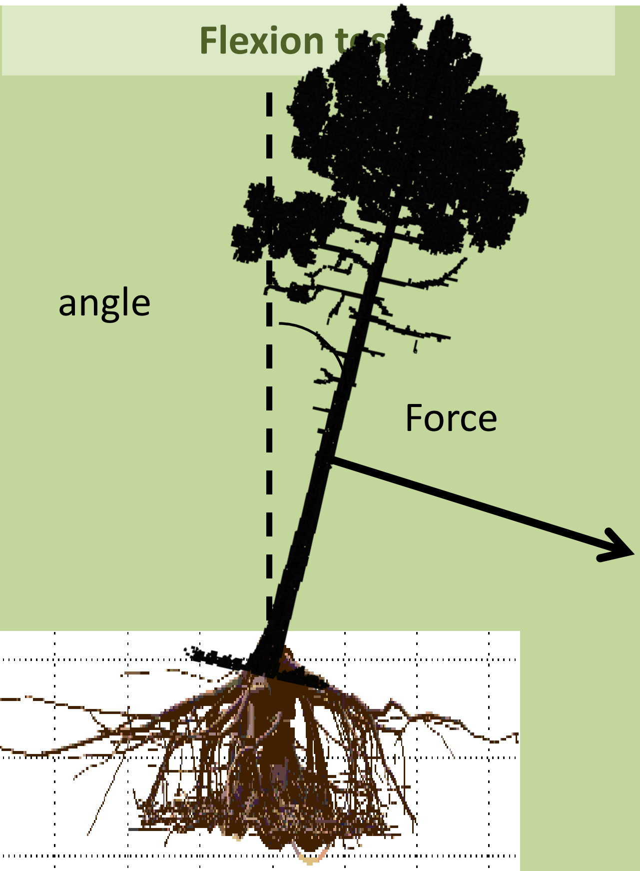
Haarsma et al 2013

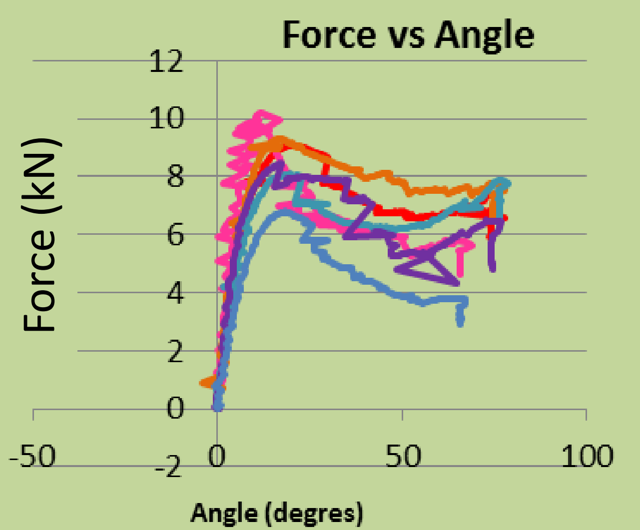
Climate change and wind risk in forests

Increase in wind risks

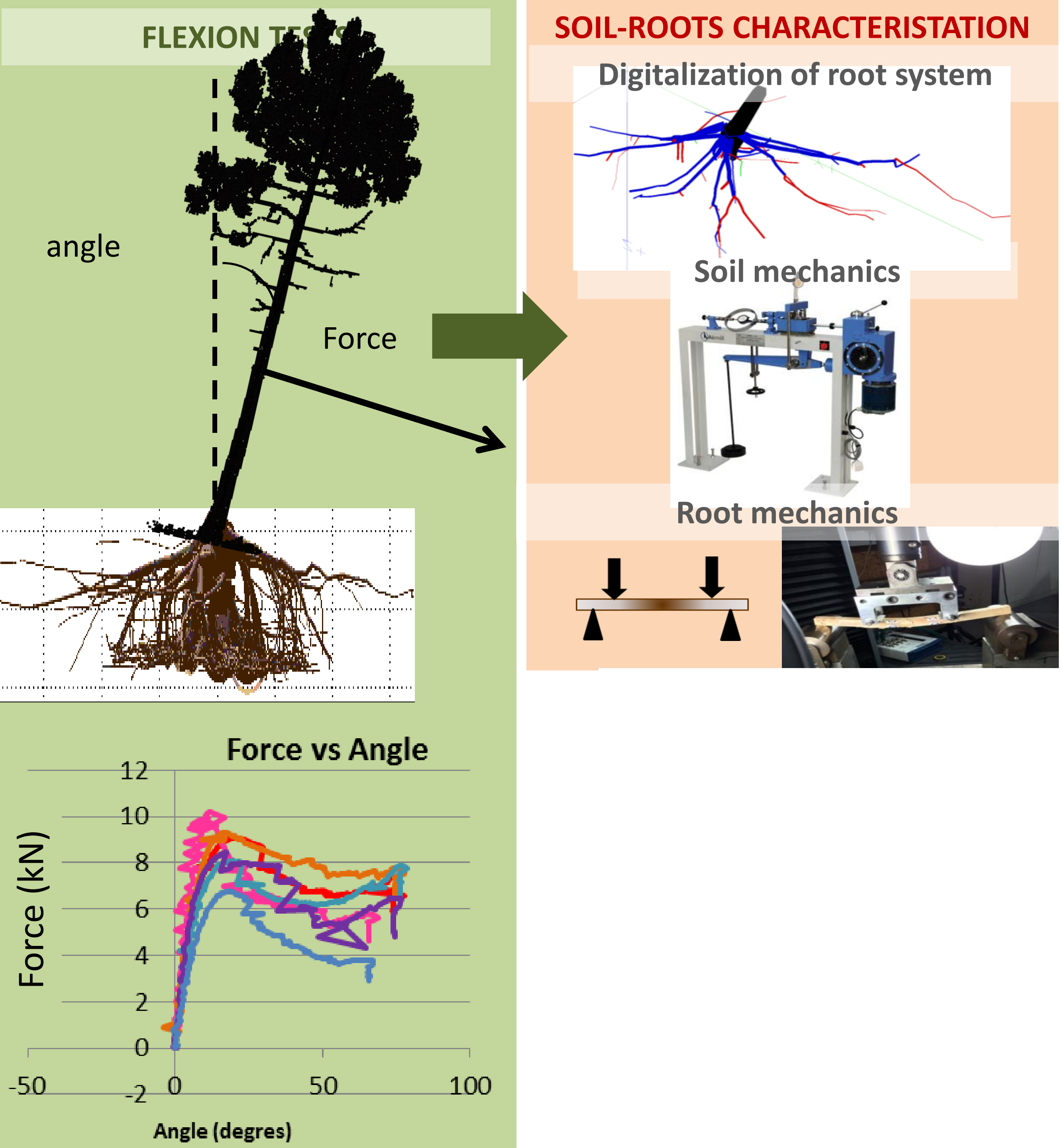
- Changes in soil properties
    - ➢ decrease in soil mechanical strength
- Potential change in near-surface wind
    - ➢ Decrease in chronics wind but increase in hurricane

Mechanisms of tree anchorage





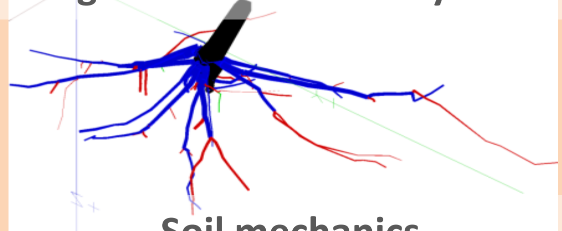
Photos: D. Garrigou


FLEXION TESTS
angle
Force
Force vs Angle
Force (kN)
Angle (degres)
12
10
8
6
4
2
0
-2
-50
0
50
100
SOIL-ROOTS CHARACTERISTATION
Digitalization of root system
Soil mechanics
Root mechanics

FLEXION TESTS

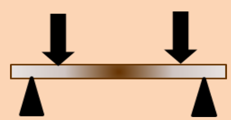
SOIL-ROOTS CHARACTERISTATION

Digitalization of root system

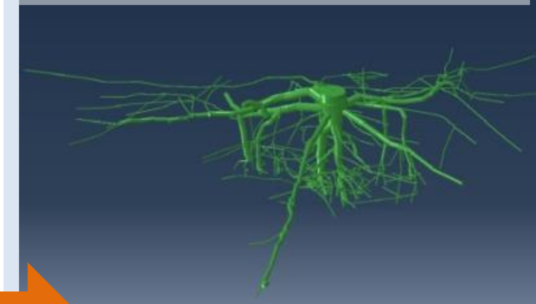


Soil mechanics

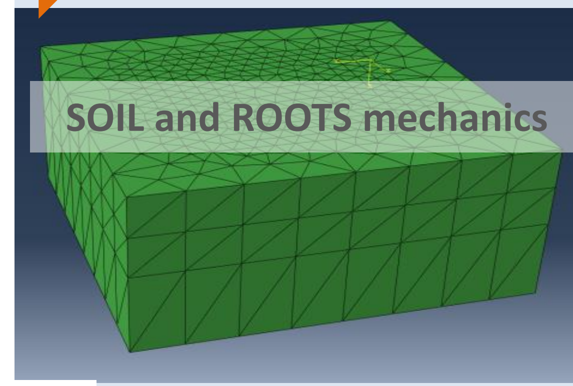
Root mechanics



Architecture modelization



MODEL INPUTS

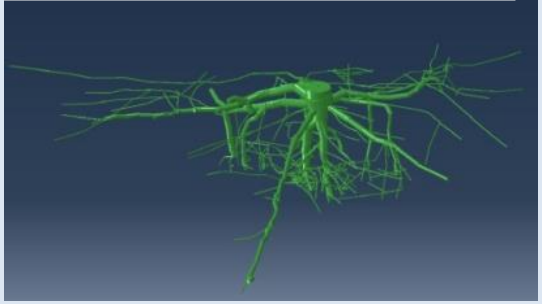


SOIL and ROOTS mechanics

FLEXION TESTS

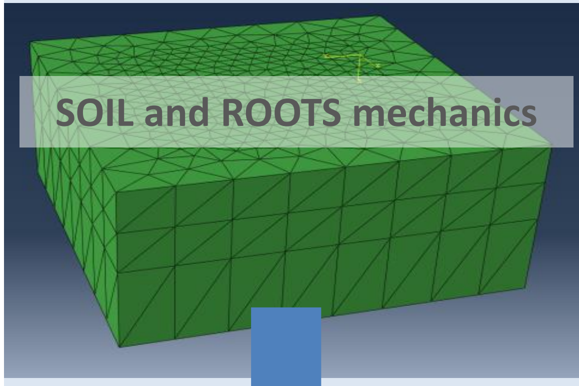
SOIL-ROOTS CHARACTERISTATION

Architecture modelization

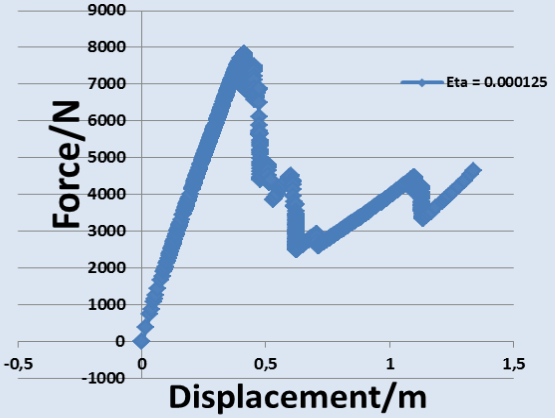


MODEL INPUTS

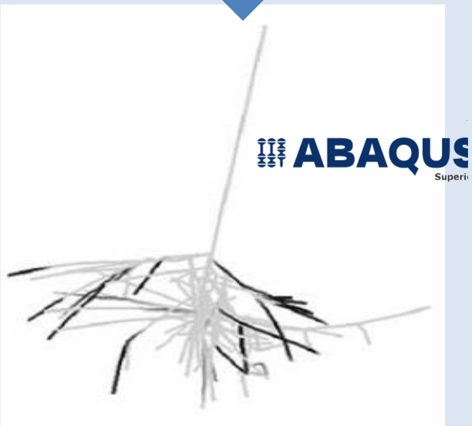
SOIL and ROOTS mechanics



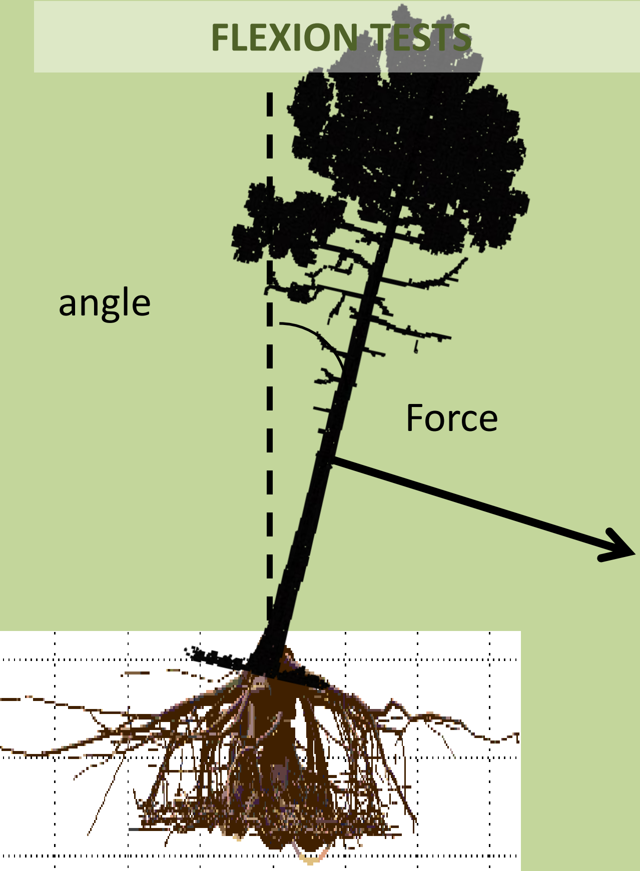
Simulation curve:

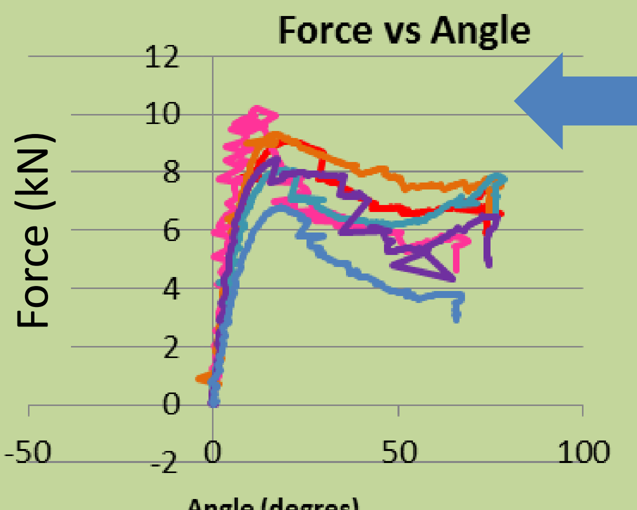


Anchorage model



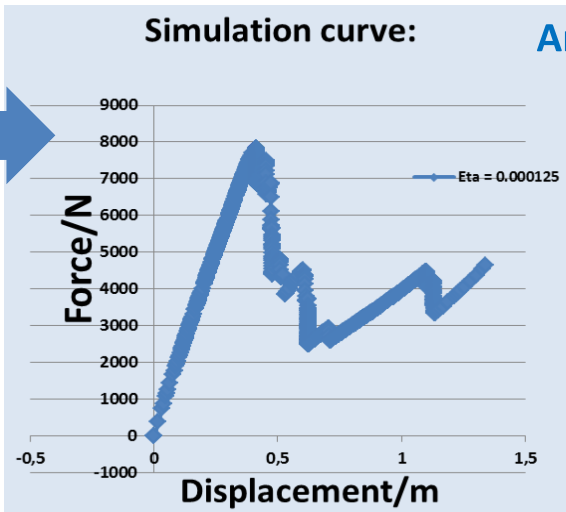
FLEXION TESTS





SOIL-ROOTS CHARACTERISTATION

MODEL INPUTS



Anchorage model

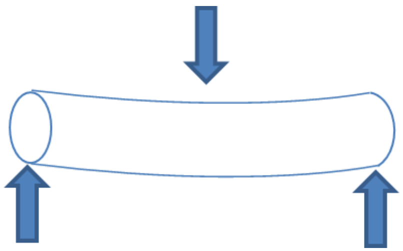
Dupuy et al 2005, Yang et al., 2014

The importance of root geometry

At root scale

At root scale

Flexion



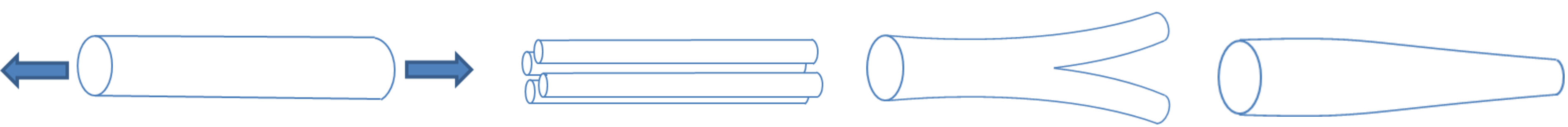
Diameter D

Tension

Maximum stress $\propto$ I $\propto$ D^4

Maximum stress $\propto$ I $\propto$ D^2

I moment of inertia



Number of roots

Branching

Tapering

At root scale

Flexion ∝ I

Tension ∝ I

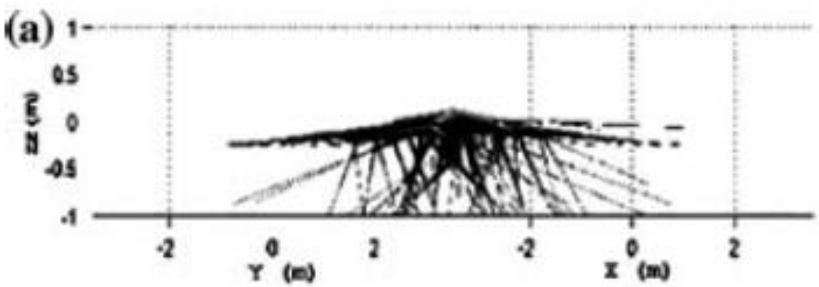
A=100 I=0.5 I=208 I=840

a,b,c: Maritime pine (from Danjon), d: black spruce (from Krause et al., 2014)

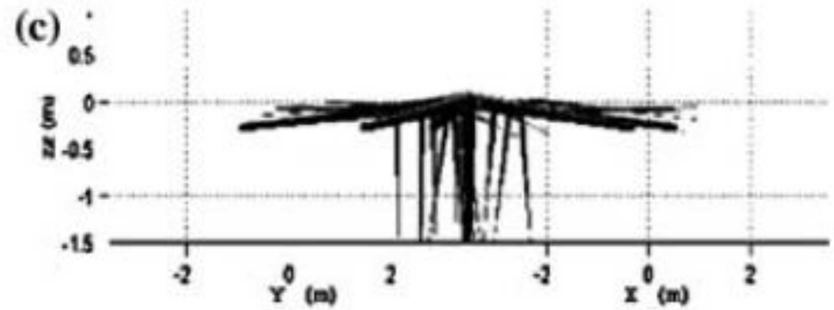
Root architecture

Root architecture

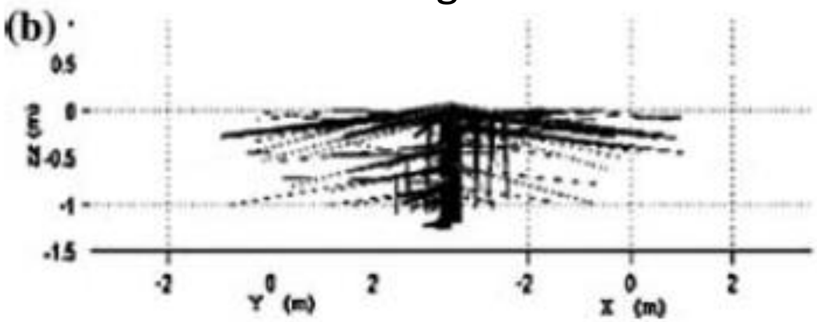
Heart



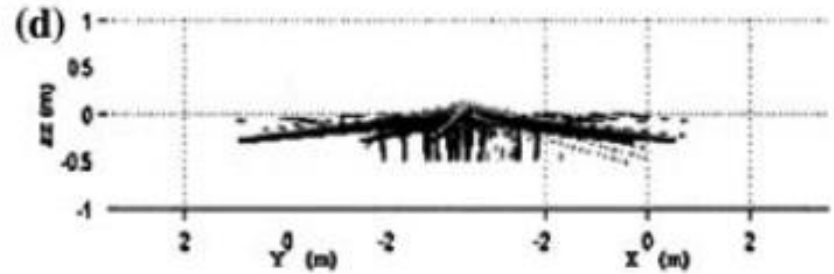
Tap-root



Herringbone



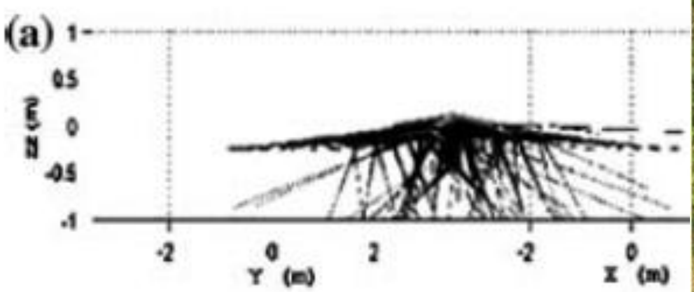
Plate



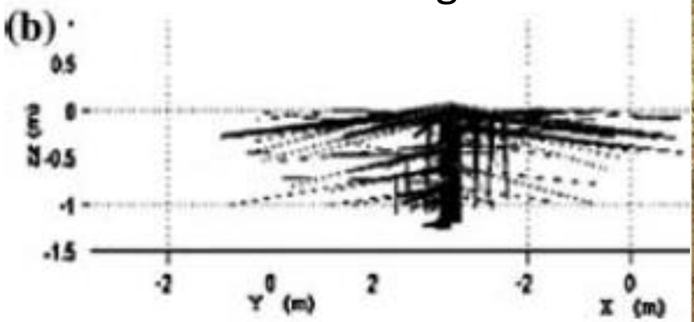
Dupuy et al 2005

Root architecture

Heart



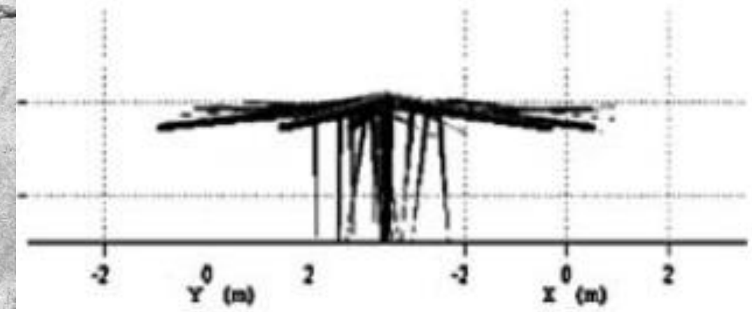
Herringbone



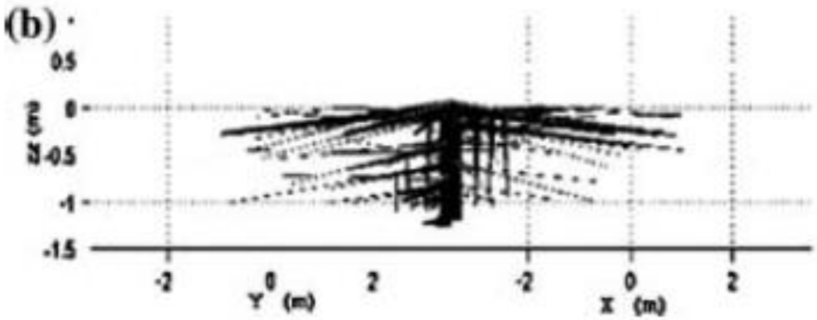
Oak, from Zanetti et al, 2015

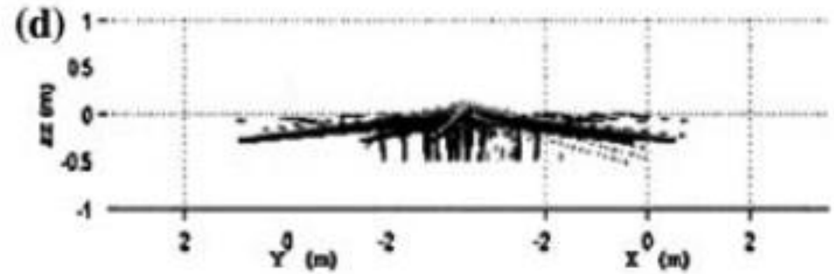
Root architecture

Sitka spruce, from B. Gardiner



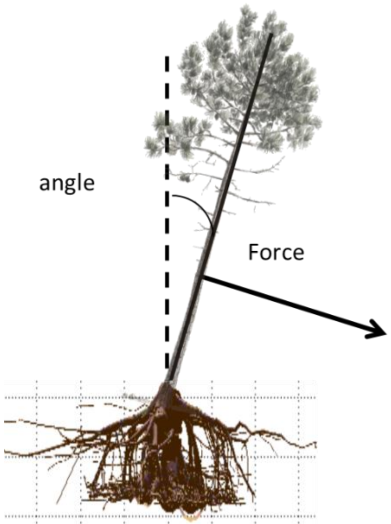
Plate

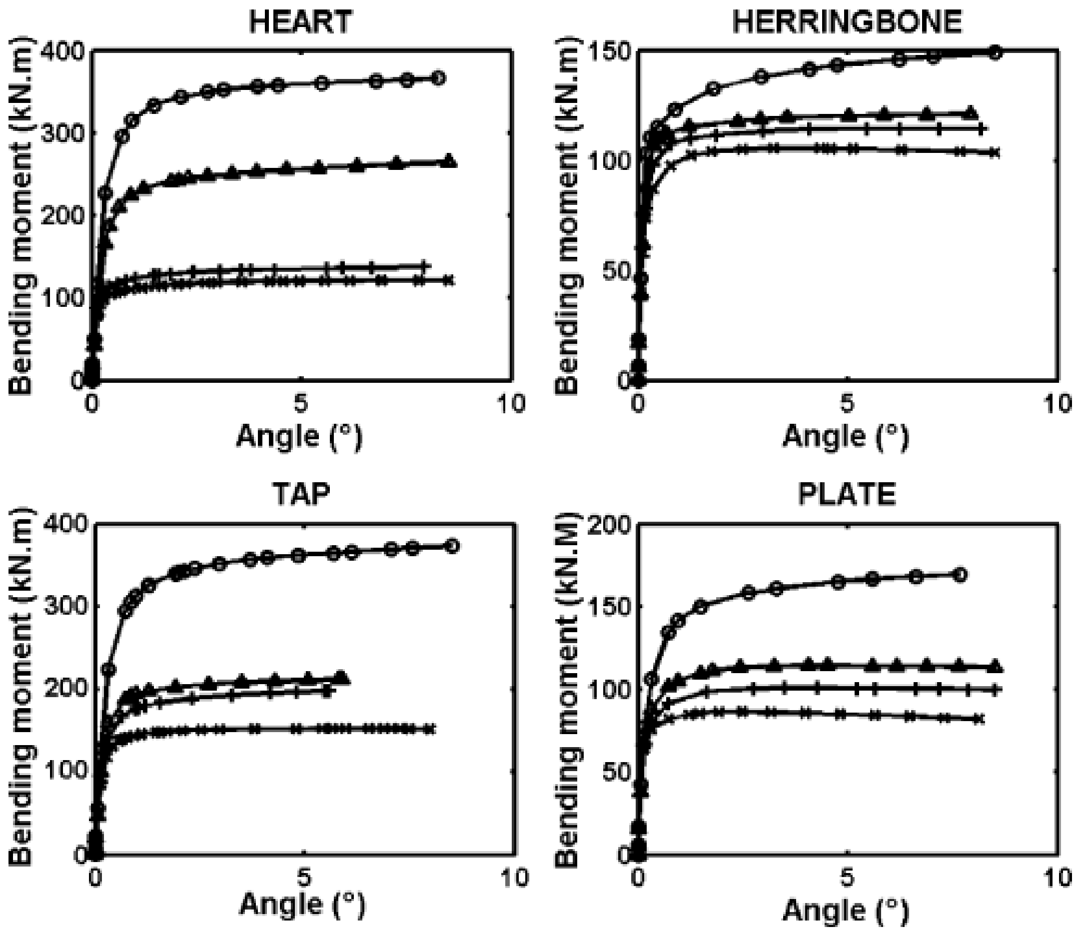




Root architecture

$M_{critique}$

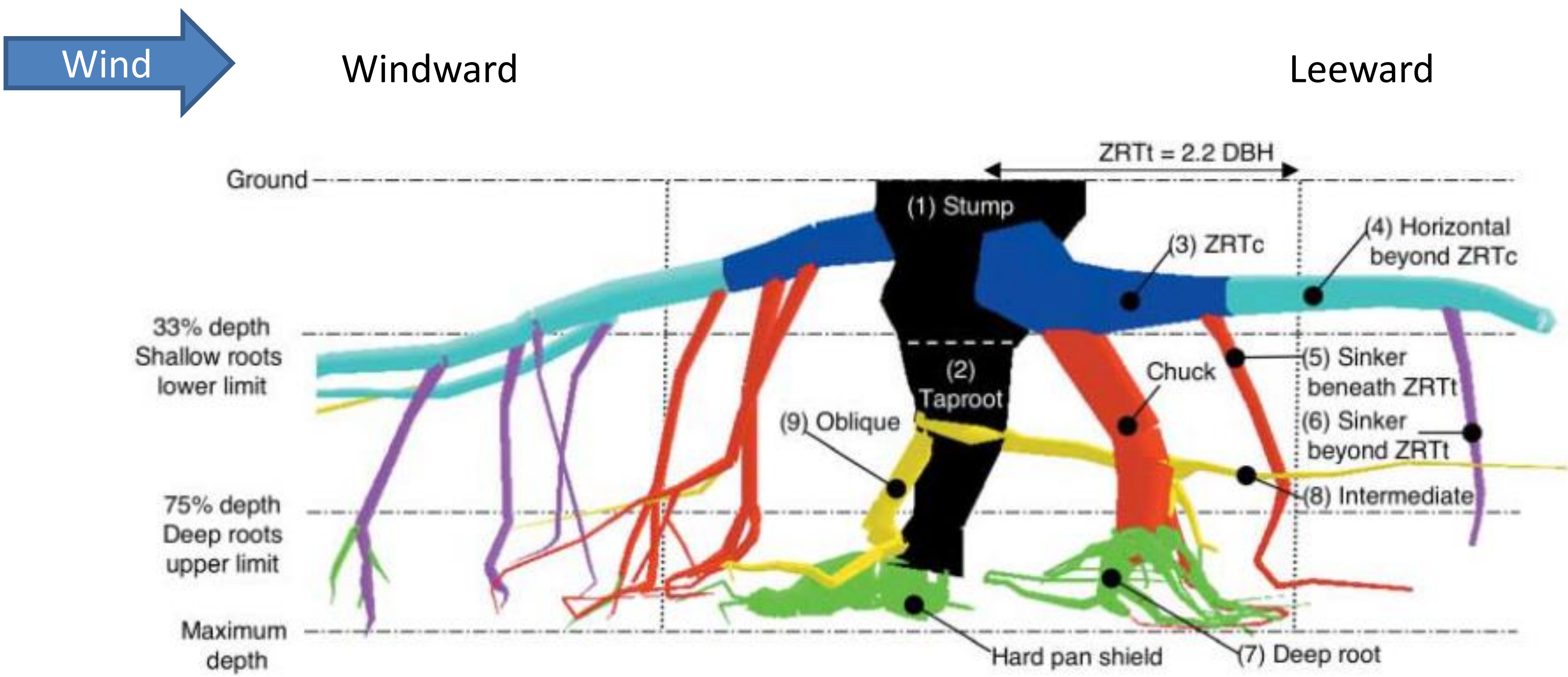




Dupuy et al 2005

Root architecture

- Typology of roots
- Variability and plasticity of morphology

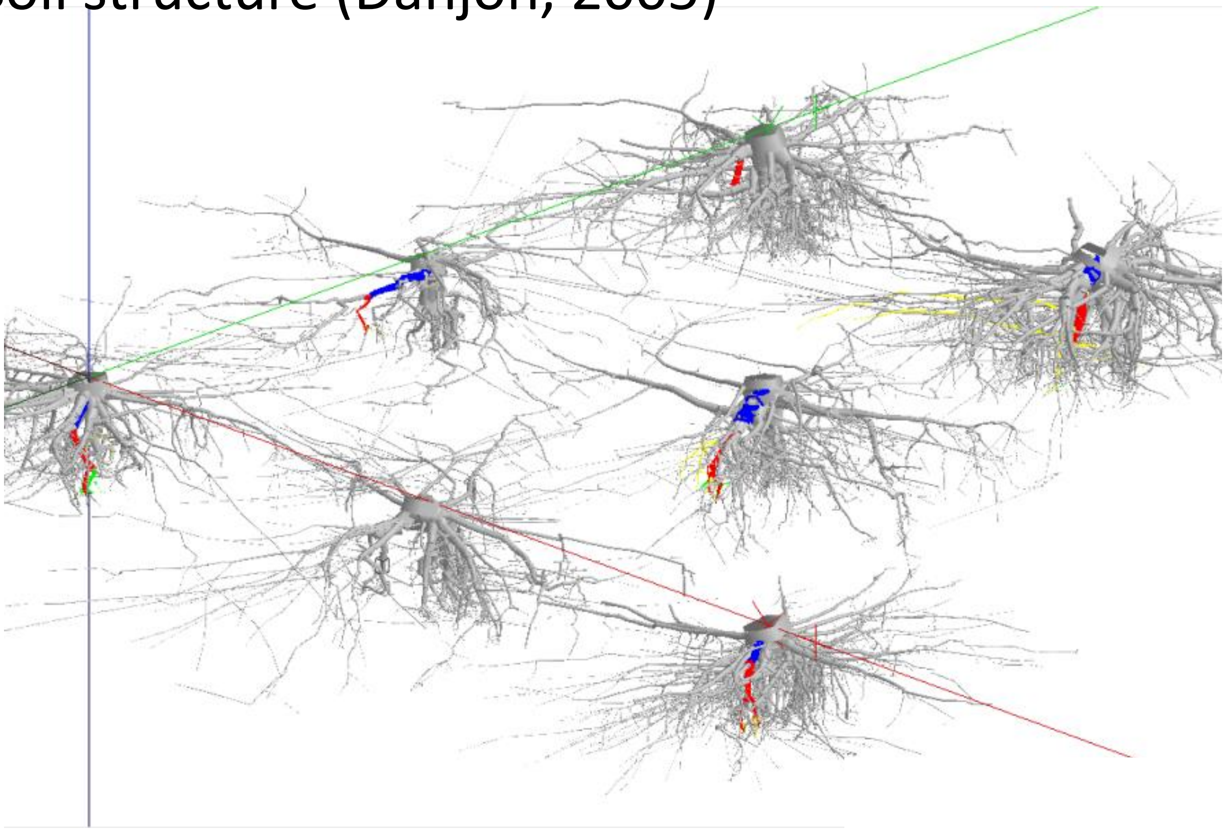


Danjon et al., 2005

Variability and plasticity of root sytems

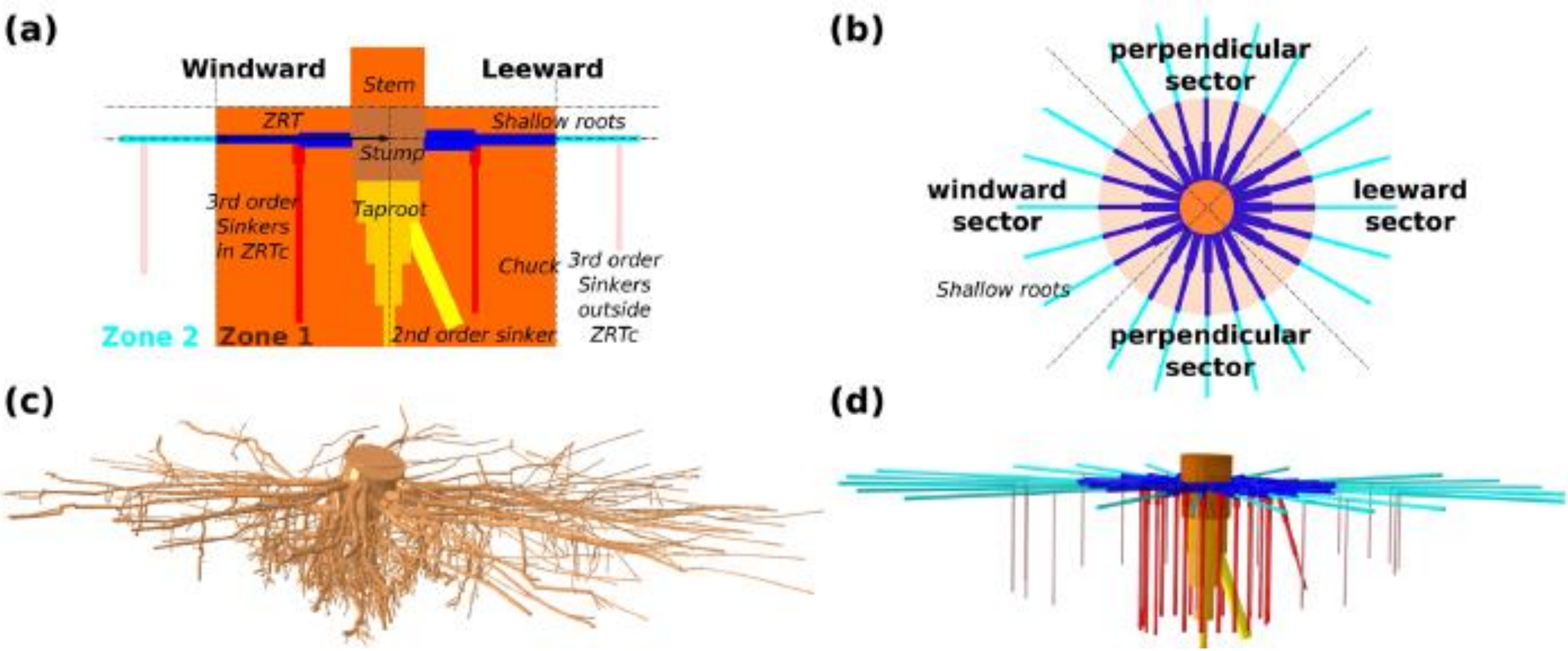
- Environmental stress
  - Prevailing wind
  - Soil structure (Danjon, 2005)

  ...

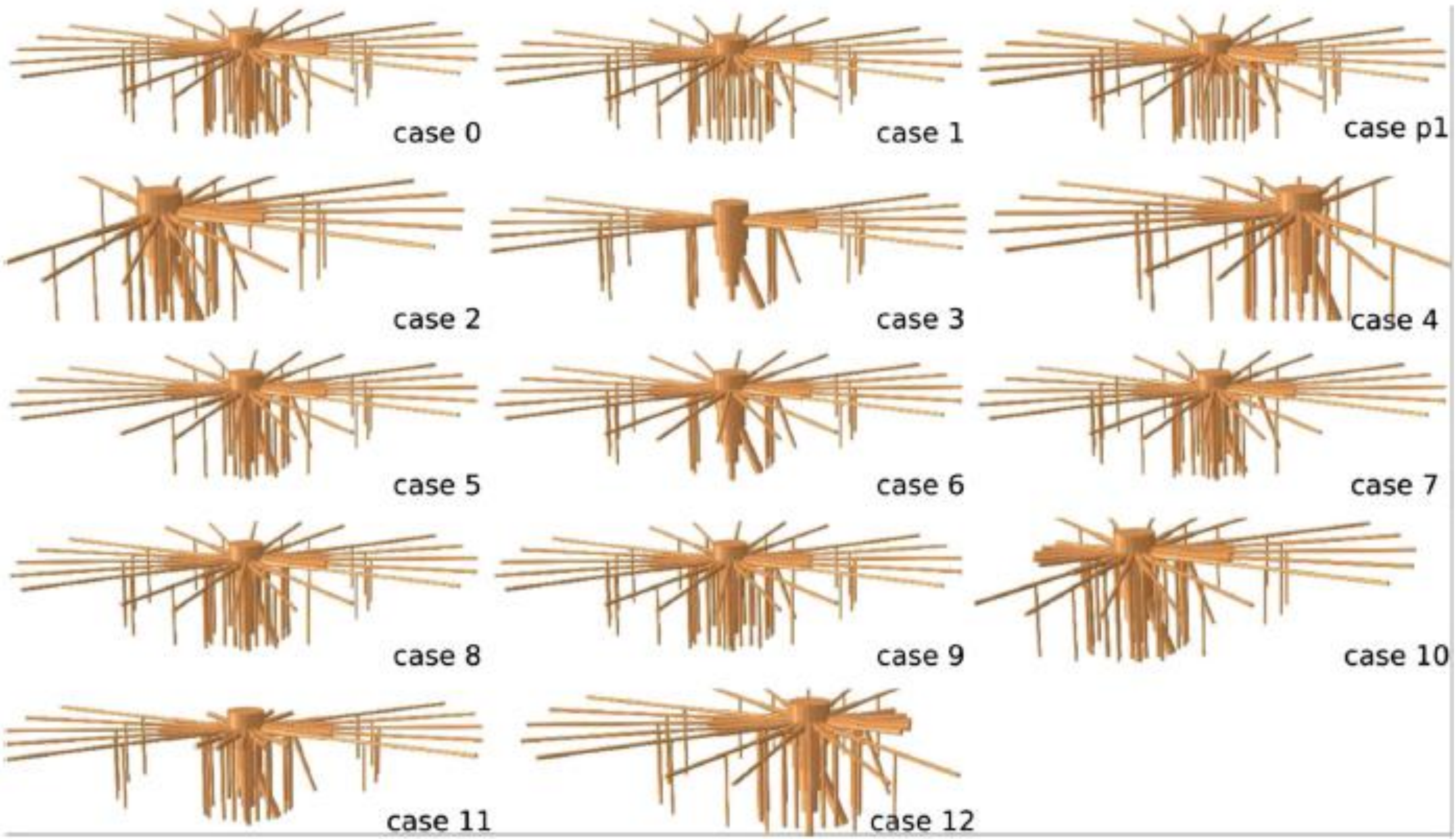


Danjon et al., 2013

Virtual root patterns



The importance of root geometry

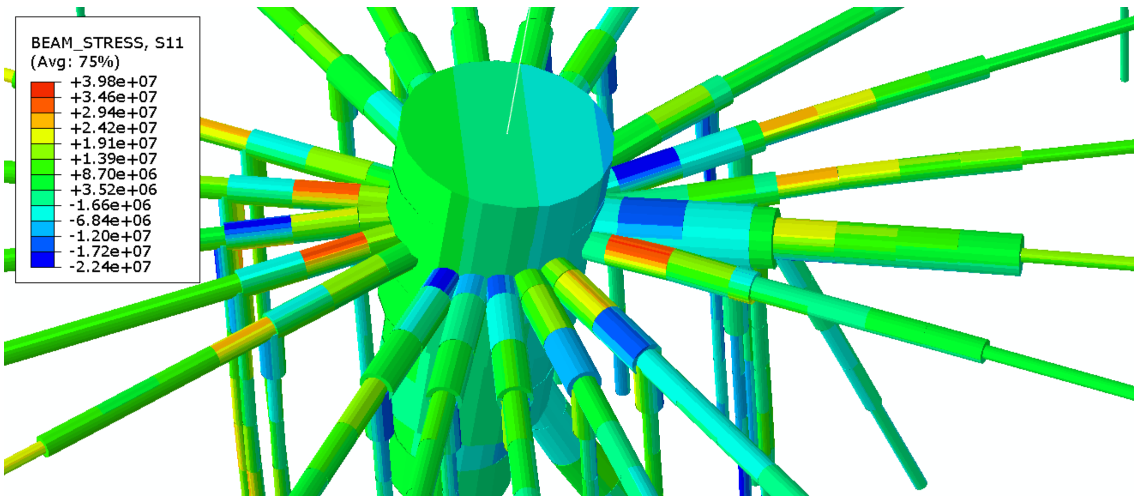


The importance of root geometry

FORCE

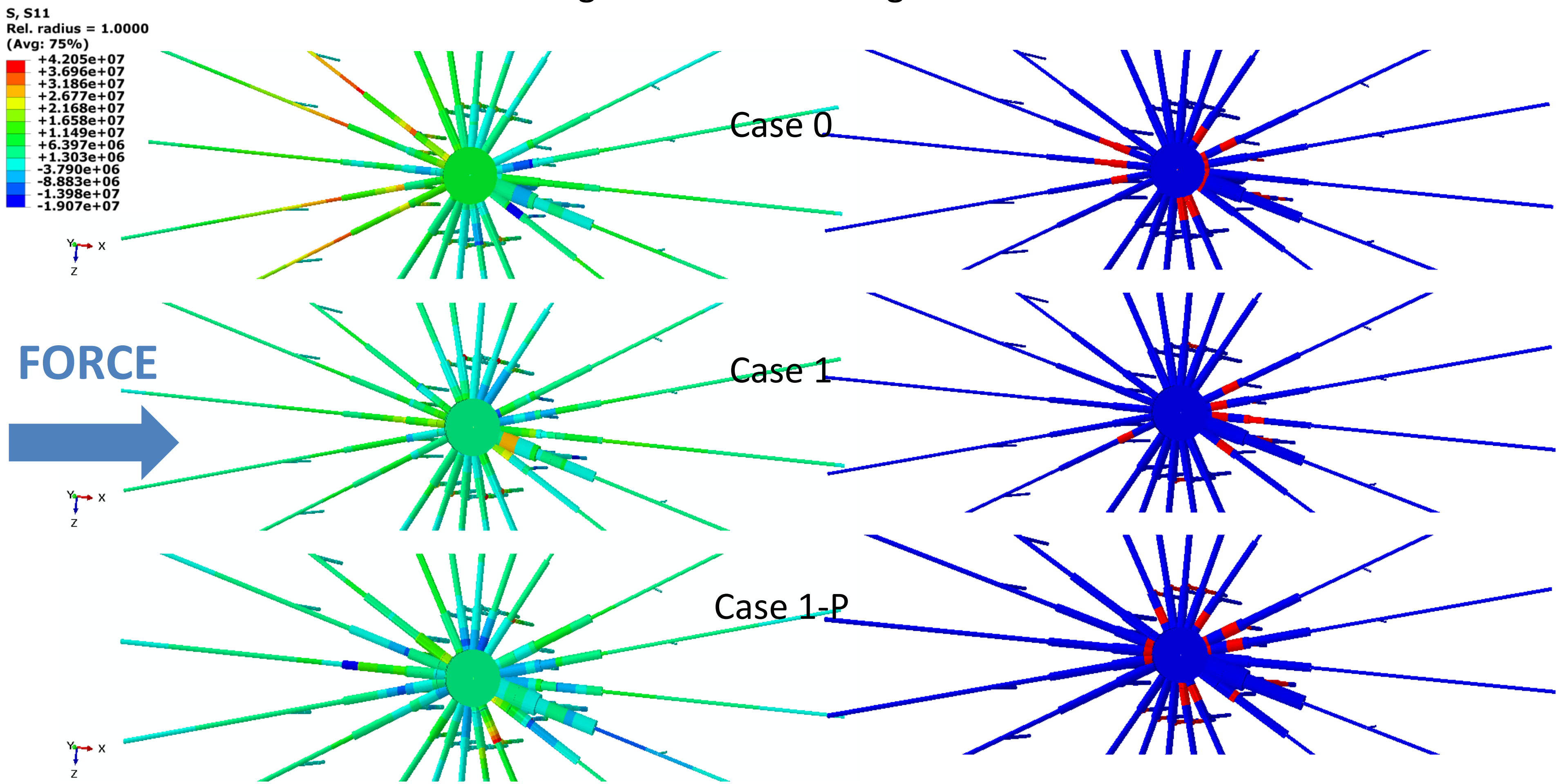
Tension

Flexion



The importance of root geometry

Deflection angle at critical turning moment for each case



- Result: Root strength = 60 % taproot, 25 % windward

Yang et al. 2016

How does the tree anchorage change with time ?

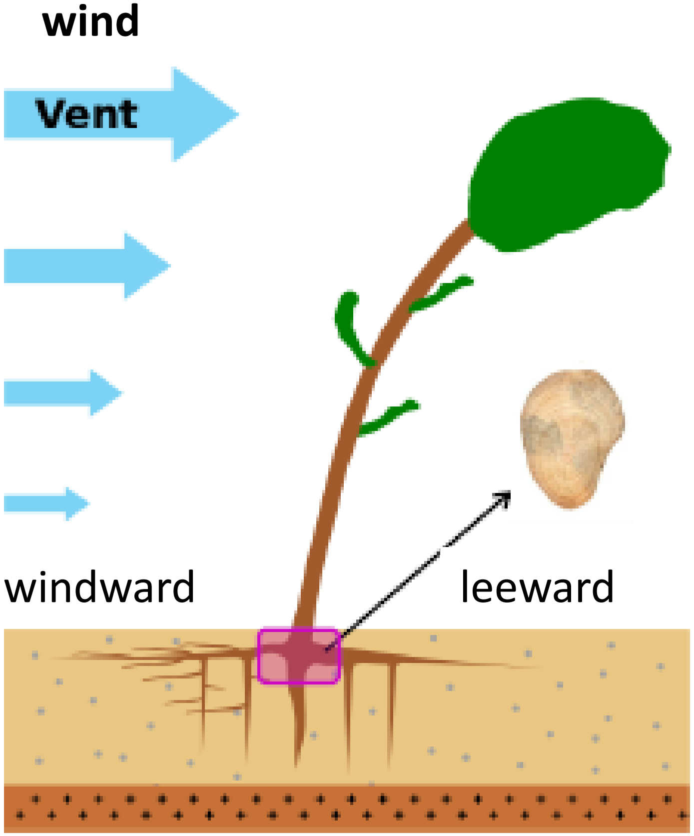
The role of soil properties

Soil properties change with climate conditions

How does the tree anchorage change with time ?

Acclimation of roots under wind

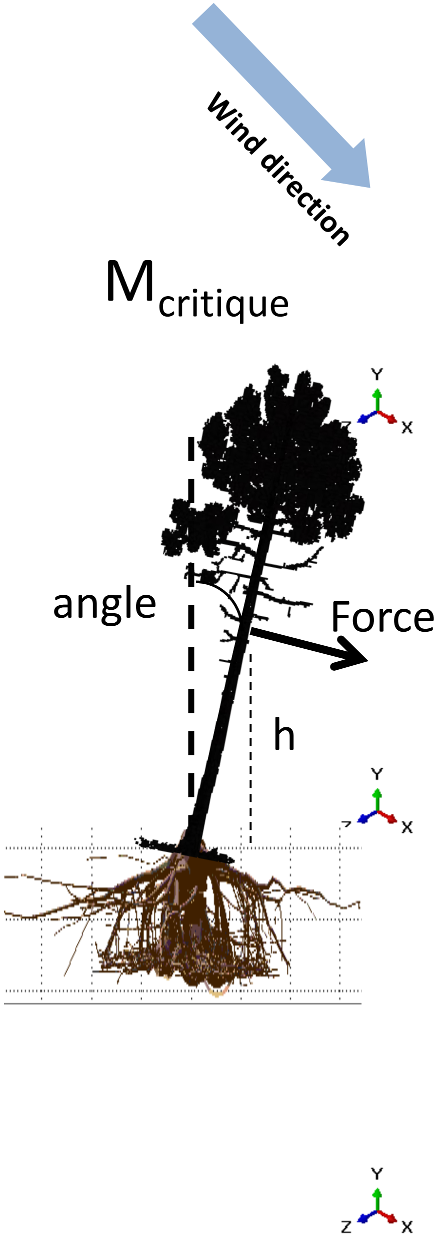
Wind acclimation in roots

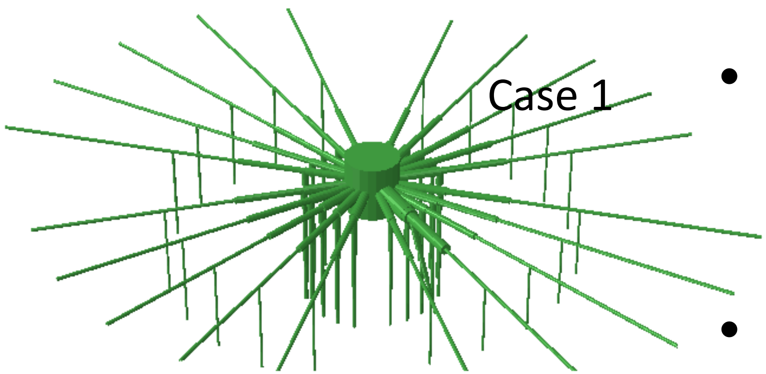


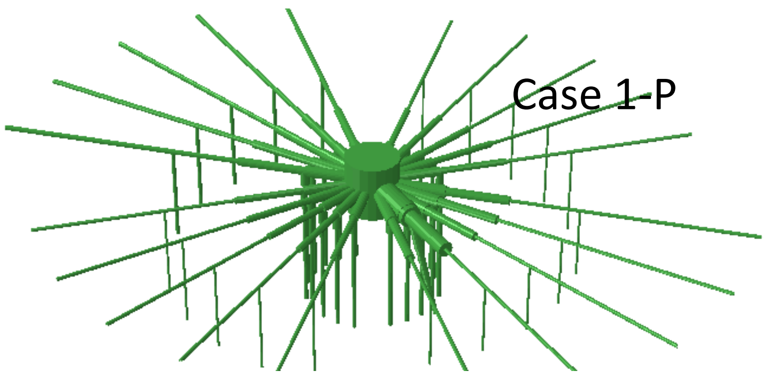
- Higher root diameter in leeward sector
- oval cross-section of root
- Increase of root ramification in windward sector

Danjon et al, 2005; Nicoll and Ray, 1996; Stokes, 1995

Wind acclimation in roots







Adult trees

- Case 0

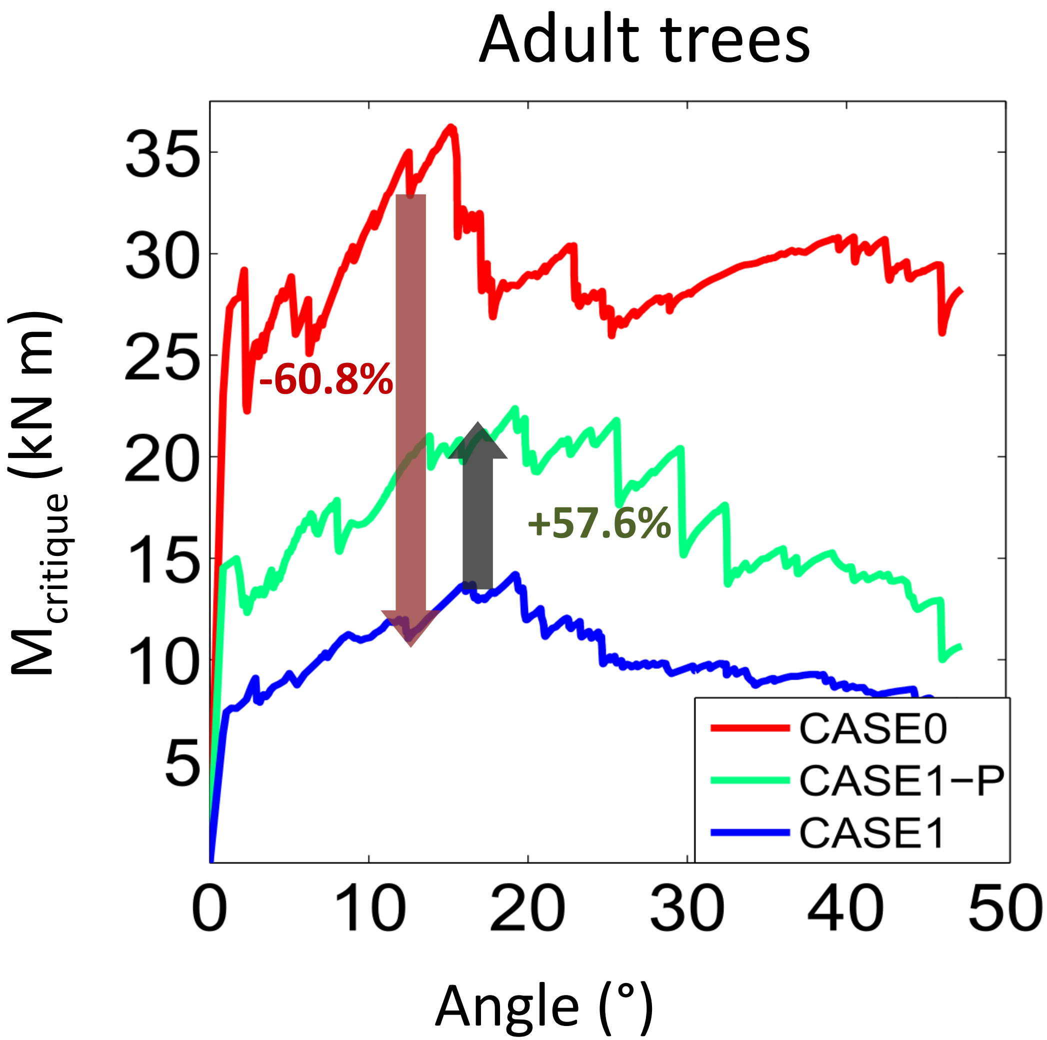
  maritime pines 19 Years (reference)

- Case 1

  case 0 without taproot

- Case 1-P

  Without taproot but with increase in root diameter of leeward sector



Results

- Taproot major component
- Acclimation may balance taproot loss

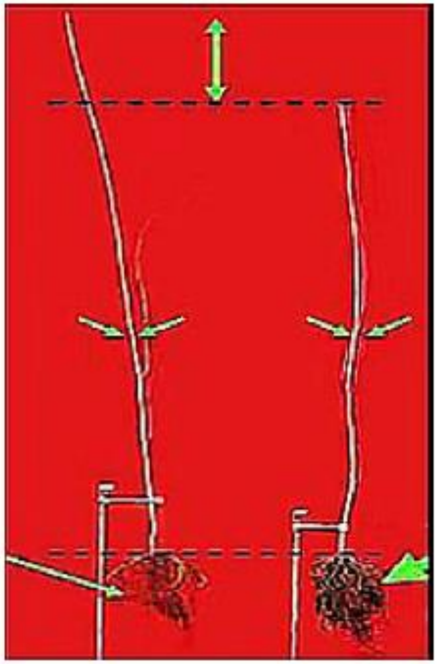
Yang et al. 2016
Yang et al. 2018

Mechanisms of wind acclimation in roots ?

Wind acclimation

Aerial part

Strain perception => growth response (h, D)

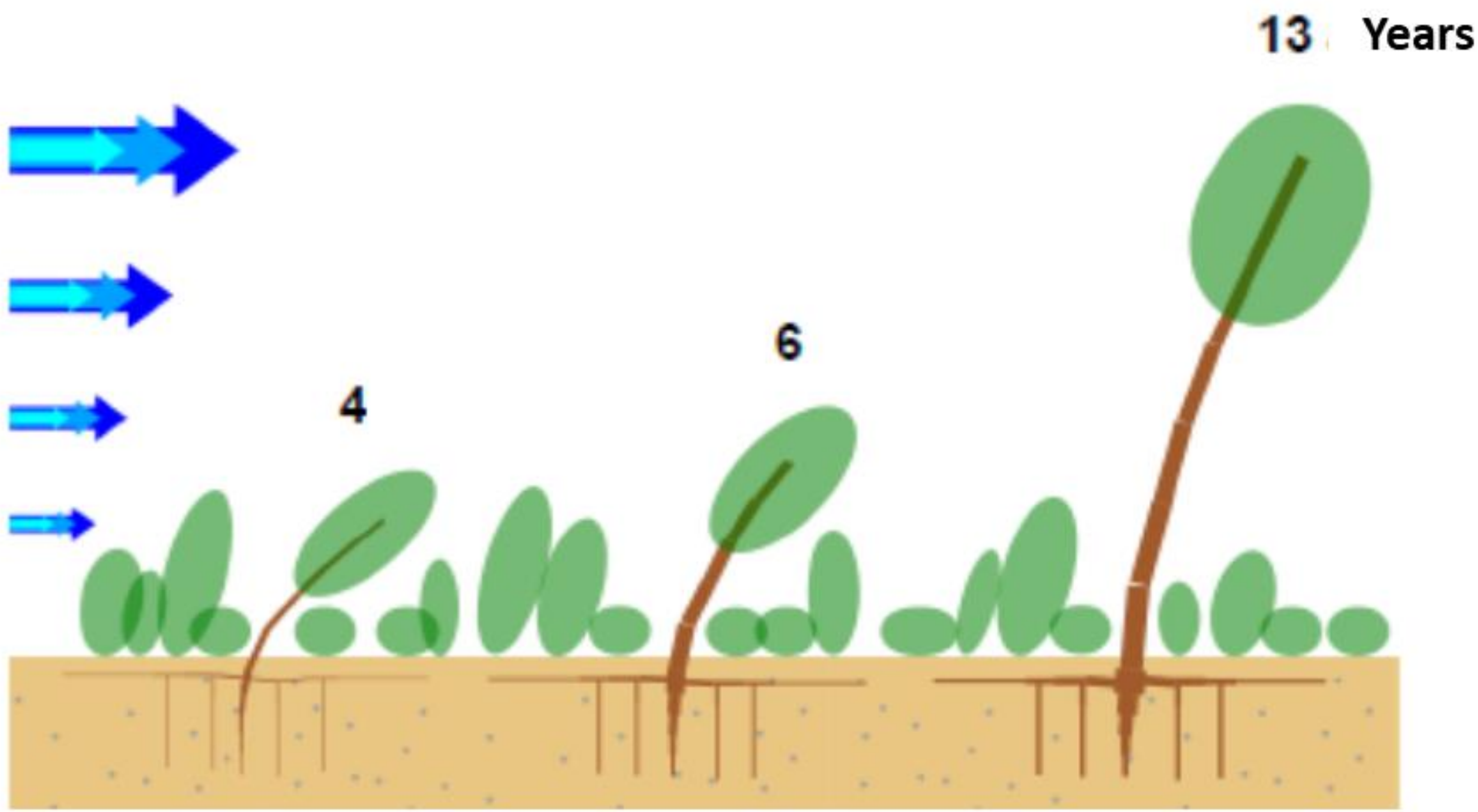


Prunus avium (Coutand, 2010)

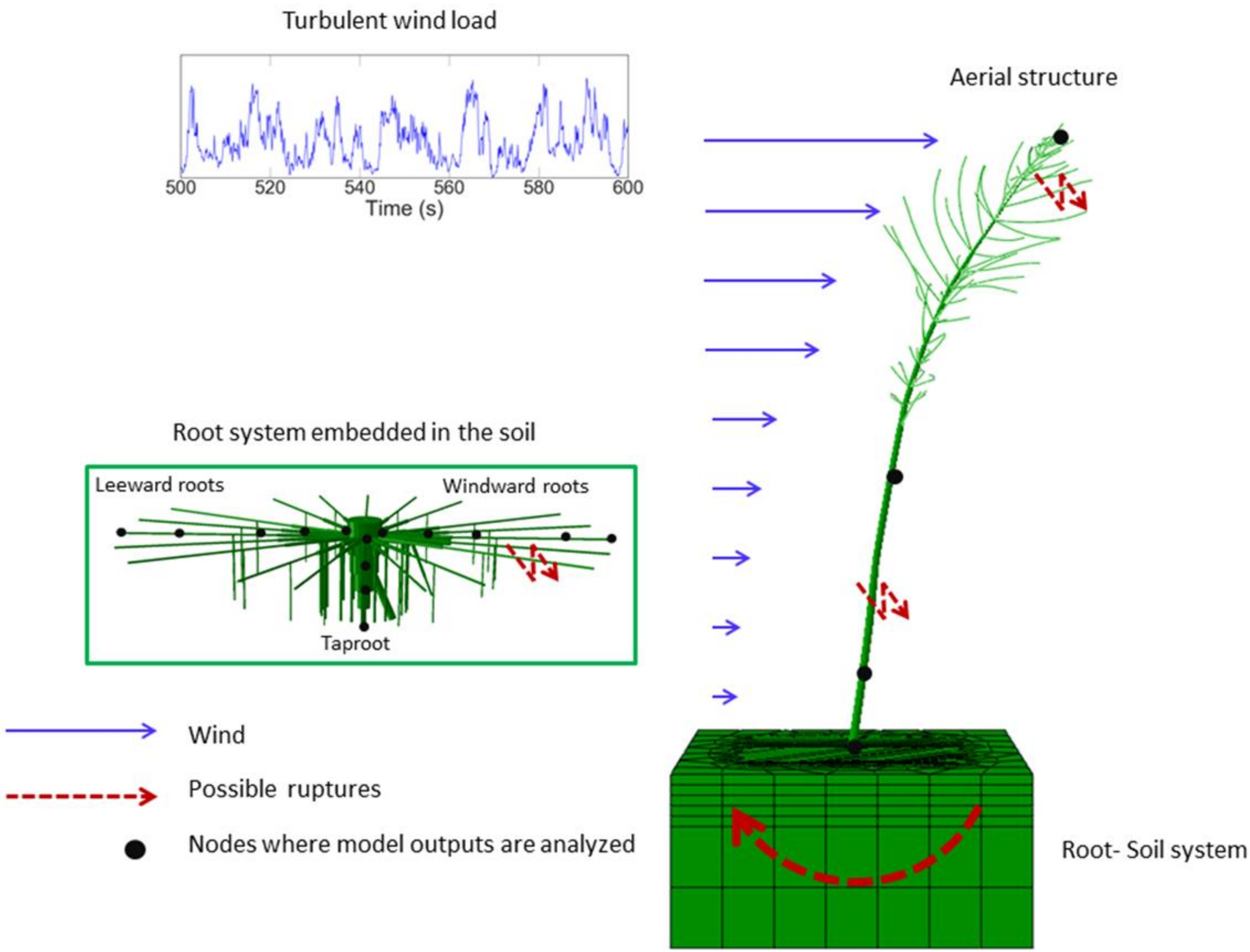
Root part ???

Wind acclimation in roots

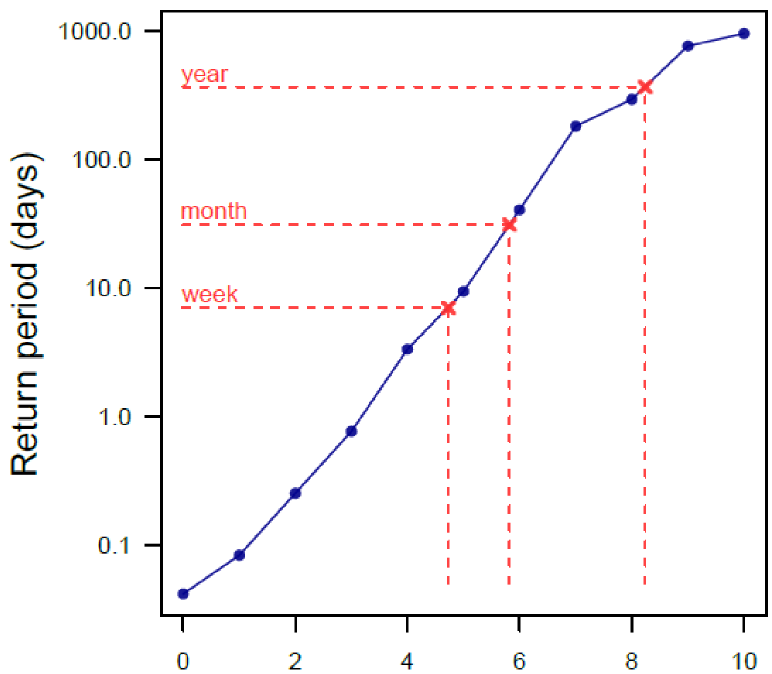
Numerical experiments to investigate stress/strain experimented by roots during the tree development



Wind acclimation in roots



Simulations

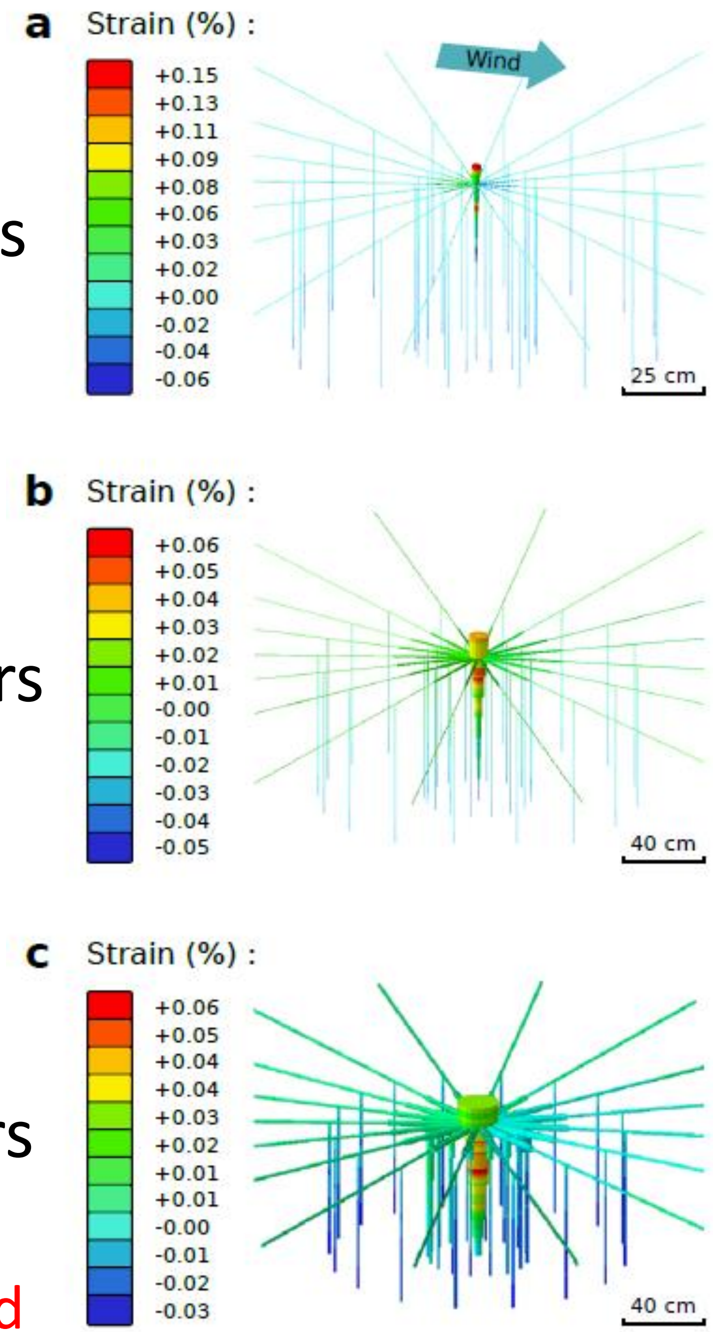


4 years

6 years

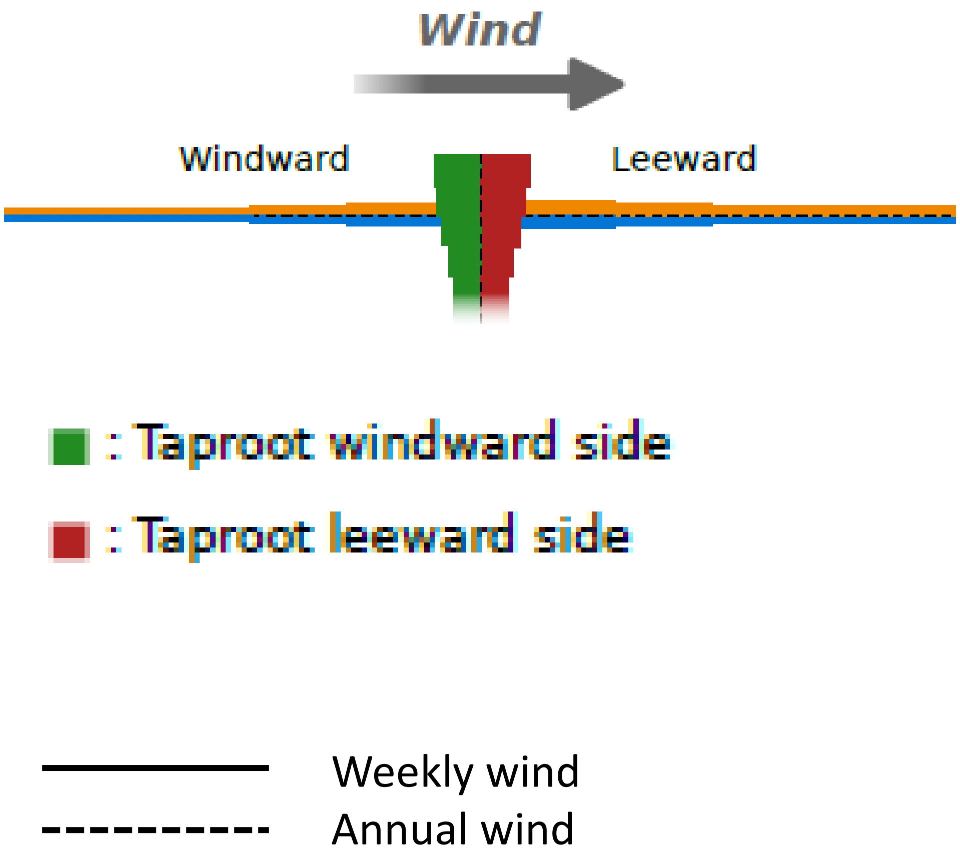
13 years

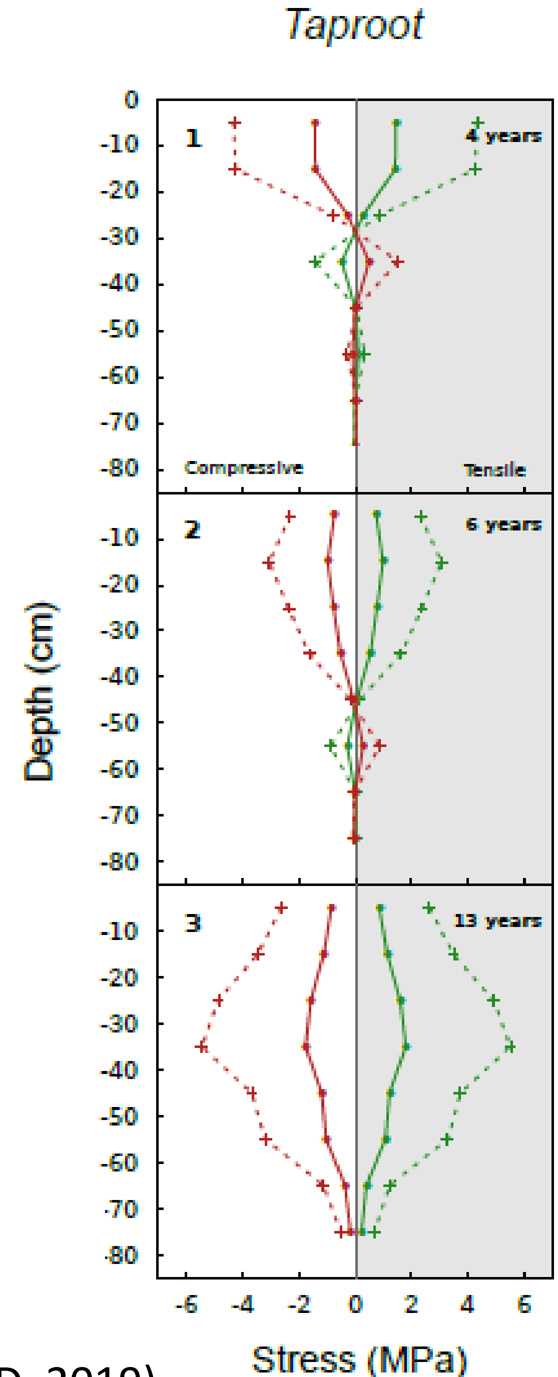
Monthly wind



Saint Cast (phD, 2019)

Wind acclimation in roots





➢ **Result: Change in stress distribution with tree development**

Saint Cast (phD, 2019)

Conclusions

- The importance to consider dynamic sollicitations inducing fatigue during the passage of wind storms
  - Implication for modeling wind risk in forests
- The ability of trees to acclimate their root architecture during their developpemnt as function of their environment
  - Implication for the tree survives in changing environnement

Perspectives

- To better understand the soil strength under cyclic loading
- To investigate the acclimation processes in root system

Acknowledgments

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- Computer staff : S. Griffon, M. Irvine

Grants

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