Predicting the risk of wind damage to multiple forest types in a changing climate

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Plan of Talk

Tools for supporting decisions on forest storm risk management

- Short background to forest wind damage in Europe
- Development of ForestGALES wind damage risk model
  - Development of risk model for uniform coniferous plantation
  - Addition of broad-leaved species
  - Application in different countries
  - Development of a single tree version for complex forest structures
- Integration of ForestGALES with other computer-based tools:
  - Integration within Excel spreadsheet
  - Integration in QGIS
  - Integration with airflow model
- Current/Future developments of ForestGALES
  - Library in R for integration in other DSS
  - Link with growth models and climate prediction
  - Link between single tree version and LiDAR survey data
Storm Klaus 24th January 2009: Aquitaine
Damage Trends in European Forests

Thanks to Mart-Jan Schelhaas, ALterra
RISK PERCEPTION  RISK ANALYSIS  RISK MANAGEMENT
Risk Models in Risk Management

- Risk mitigation analysis
- Modify forest management plans
- Provide stakeholders tools & information
- Stakeholder meetings
- Develop crisis plan
- Access funding
- Insure forests
- Training for managers & emergency workers

Immediate assistance
- Restore access and power
- Assess damage
- Assess markets & economic impact
- Stakeholder meetings
- Prepare roads & landing areas
- Harvest timber
- Transport timber
- Control diseases and pests

- Access regional/national/European funding
- Stakeholder meetings
- Restore infrastructure
- Regional development
- Risk mitigation analysis
- Forest management planning
- Forest restoration
- On-going social & economic recovery

PREPARE
COMMUNICATE
RESPONSE
RECOVER

Risk Management Cycle
Windthrow Hazard Classification: Early Wind Damage DSS

Windiness Scores
- Region
- Elevation
- Topographic Shelter (Topex)

Soil Score
- Rooting Depth
Integrating knowledge: Decision Support Systems

Thanks to Juan Suarez
ForestGALES: Modèle de Risque de Vent

ForestGALES 2: A Wind Risk DSS
Versions of ForestGALES: Basaize 1.2 and ForêtTempête 1.1
ForestGALES Inputs and Outputs

- Tree-pulling Experiments
- Forest Inventory
- Wind Climate
- Terrain Conditions

Parameters

- Growth/yield model

ForestGALES

- Airflow Model

GIS

- Decision-tree Analysis

Kamimura et al. 2008 (Forestry)
ForestGALES was only designed for uniform coniferous stands.

1. Needed to add broadleaved species

2. Needed to be usable in complex forest stands (multi-species, multi-age)
New Method: Turning Moment Coefficient

\[ TMC = \frac{M_{\text{max}}}{u^2} \]  

\[ TMC = f(D, H) \]

TMC related to competition index

\[ T_c (\text{kg}) \] vs. 

- \( C_{10} \)
- \( C_{11} \)
- \( C_{12} \)
ForestGALES for Broadleaf Species

Birch
Silver birch
Betula pendula

Beech
European beech
Fagus sylvatica

Oak
Pedunculate oak
Quercus robur
### ForestGALES in Excel

#### Insert Function

**Search for a function:**

- Type a brief description of what you want to do and then click Go
- Or select a category: Exported R Functions

**Select a function:**

- `R.cols.Break(species, mean ht, mean dbh, spacing)`

**Exported Function:**

- `R.cols.Break`
ForestGALES in QGIS
ForestGALES coupled with WAsP Airflow Model
Current/Future developments of ForestGALES

• FOSPREF-Wind:
  • Integration of ForestGALES R library with other models/DSS: Link with growth models and climate predictions

• Link between single tree version and LiDAR survey data
FOSPREF-Wind - Link with growth models and climate predictions

Data
- Stand
- Soil
- Climate

Models
- 3PG
- ForestGALES

Outputs
- Stand growth
- Vulnerability
- Risk

Stand growth models and climate predictions connect with growth models and climate predictions through the following data and models:

- Stand
- Soil
- Climate

The outputs include:
- Stand growth
- Vulnerability
- Risk
FOSPREF-Wind - Link with growth models and climate predictions

Models

3PG


We know their parameter/input sensitivities

ForestGALES

FOSPREF-Wind - Link with growth models and climate predictions

Models

3PG: Physiological Principles Predicting Growth (Landsberg and Waring, 1997)

- Climate: Monthly values of Temperature (max, min, mean), rainfall, solar radiation, evaporation, VPD, rainy days, frost days
- Soil: Available soil water (max and min), Soil Class, Soil Fertility Rating
- Stand: tree species, sph, initial biomass compartments
- Outputs: biomass compartments, mortality, mean tree allometry, at monthly intervals
FOSPREF-Wind - Link with growth models and climate predictions

Models

3PG: Physiological Principles Predicting Growth (Landsberg and Waring, 1997)

• Climate: Monthly values of Temperature (max, min, mean), rainfall, solar radiation, evaporation, VPD, rainy days, frost days
• Soil: Available soil water (max and min), Soil Class, Soil Fertility Rating
• Stand: tree species, sph, initial biomass compartments
• Outputs: biomass compartments, **stocking density, mean tree allometry**, at monthly intervals
FOSPREF-Wind - Link with growth models and climate predictions

CHELSA - Climate projections @1km (RCP8.5) – Some downscaled to 25m

ESDAC Soil maps: Soil hydraulic properties

ESDAC Soil maps: Soil type/depth

Landscape data: gaps and edges

Copernicus DEM

Orographic speed-ups for 8 directions ($D_0$)

Critical Wind Speeds

$fgr$

3PG-R

Stand/Tree growth forecasts

Roughness changes speed-ups for 8 directions ($D_0$)

EURO-CORDEX: MPI-ESM-LR+ RCM RCP8.5 ua850 & va850 @6hr

Max $u(D_0)$/yr for 10 years

Fisher-Tippett T1 w/Gumbel ($D_0$)

CWS$_S_o(D_0) = \text{CWS} - \text{orography effects} (D_0)$

CWS$_S_oS_R(D_0) = \text{CWS}_S_o(D_0) - \text{roughness changes effects}$

CWS$_S_oS_R(D_0) @ 850hPa$

Tennekes’ derivation of geostrophic drag law

RISK ($D_0$)
FOSPREF-Wind - Link with growth models and climate predictions

Scottish case study area: coastal Scots Pine (Pinus sylvestris) forests in north Aberdeenshire

- Increased resolution of temperature CHELSA Climate 3PG input raster files with lapse rates

- 3PG functions extracted from existing FORTRAN code (Xenakis, 2007) and R shiny web app (Arias-Rodil et al.), rebuilt as R package: [https://github.com/drGeorgeXenakis/threePG](https://github.com/drGeorgeXenakis/threePG)

- Calibrated 3PG-R for SP using FC permanent sample plots data

- ForestGALES complete R package (`fgr`) released (both stand-level and individual tree methods): [https://github.com/tom-locatelli/fgr](https://github.com/tom-locatelli/fgr)

- Created QGIS Toolbox algorithm to run `fgr` within QGIS – tested for Maritime Pine (Pinus pinaster) forests in Aquitaine, France

- Calculated orographic speed-ups maps for cardinal & intercardinal directions with WASP ([https://www.wasp.dk/](https://www.wasp.dk/))

- Coded and tested R functions for landscape-level aerodynamic roughness speed-ups and depth of boundary layer as a function of roughness changes
FOSPREF-Wind - Link with growth models and climate predictions

NEXT:

• Test aerodynamic roughness speed-ups scripts on raster files of land use change

• Package these scripts in a corollary R package to \textit{fgr (foRest.aiRflow?)}

• Run the coupled models in R using EURO-CORDEX data

• Create QGIS Toolbox scripts to facilitate forest managers’ planning operations
Link between single tree version and LiDAR survey data
Link between single tree version and LiDAR survey data
Link between single tree version and LiDAR survey data

- Dem of surrounding area
- Fairly gentle
- Quite uniform predominant direction of valleys

- Management coupes only partially match topography
- Other characteristics might be important: soils, previous management history
Link between single tree version and LiDAR survey data

Previous thinning

Forest in 2002

No data in 2002
Link between single tree version and LiDAR survey data

Forest in 2006

- First instances of wind damage
- New thinnings
- Harvested areas
Link between single tree version and LiDAR survey data

Forest in 2008

Additional wind damage

New wind damage
Link between single tree version and LiDAR survey data

Forest in 2012

- Stands opened/destabilised by previous damage/harvests/thinnings
- Catastrophic wind damage propagation
Link between single tree version and LiDAR survey data

- Tree-level investigation allows discriminating tree vulnerability not only between but also within forest compartments
- Can help with planning management operations
- Can inform re-designing of management coupes

Darker blues: high CWS = less vulnerable
Lighter colours: low CWS = more vulnerable
Link between single tree version and LiDAR survey data
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Link between single tree version and LiDAR survey data
To Date
1. ForestGALES wind risk model developed in UK for homogeneous conifer plantation
2. Model has been modified to work in France, Northern Spain, Canada (Quebec and BC), Japan, Denmark, New Zealand, USA, Brazil, etc.
3. New tree pulling experiments have added additional species including *Pinus pinaster*, *Fagus sylvatica*, *Pinus radiata*, *Eucalyptus globulus*. Other species parameterisations are based on data from other tree pulling experiments in other countries. Total of 20 species.
4. Model is available as “stand alone” version, integrated in Excel or as an R library.
5. Maps of wind risk in individual forests can be produced at stand level for current conditions and into the future using stand data, soil data, wind climate data and growth models.
6. With LiDAR data model can calculate wind damage risk to individual trees in a stand.
7. Model can be adapted for any country in the world with knowledge of species choice, soils and wind climate.

Current/Future
1. Standardisation of tree resistance to overturning using database of tree-pulling from around the world.
2. Integration of the R version of ForestGALES with growth models and climate models to make predictions of the impact of a changing climate on wind risk
3. Validation of single tree ForestGALES through development of linkage with LiDAR data