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THE VENFOR PROJECT: WIND AND FOREST INTERACTIONS FROM THE TREE SCALE TO THE LANDSCAPE SCALE

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Abstract

The Venfor project was set up in the aftermath of the December 1999 stroms that strongly affected European forests. Its ultimate goal is to provide tools for predicting tree motion in various turbulent fields representing the natural environment of a tree, relative to its position in a forested landscape (distance to the edge, edge shape, forest fragmentation…). The project is structured along four main directions: (1) development of a biomechanical model able to simulate instantaneous tree motion in a given turbulent environment; (2) simultaneous acquisition of mechanical and dynamical data in a homogeneous forest in order to analyse tree motion and provide a data basis for the validation of the biomechanical model; (3) experimental characterization and numerical modelling of turbulent flow in edge regions; (4) analysis of the influence of forest fragmentation on the atmospheric flow in three-dimensional landscapes, using information from wind-tunnel experiments, numerical modelling and analysis of observed damages. This international and multidisciplinary project combines in-situ measurements, wind-tunnel experiments and the development of numerical models.

Introduction

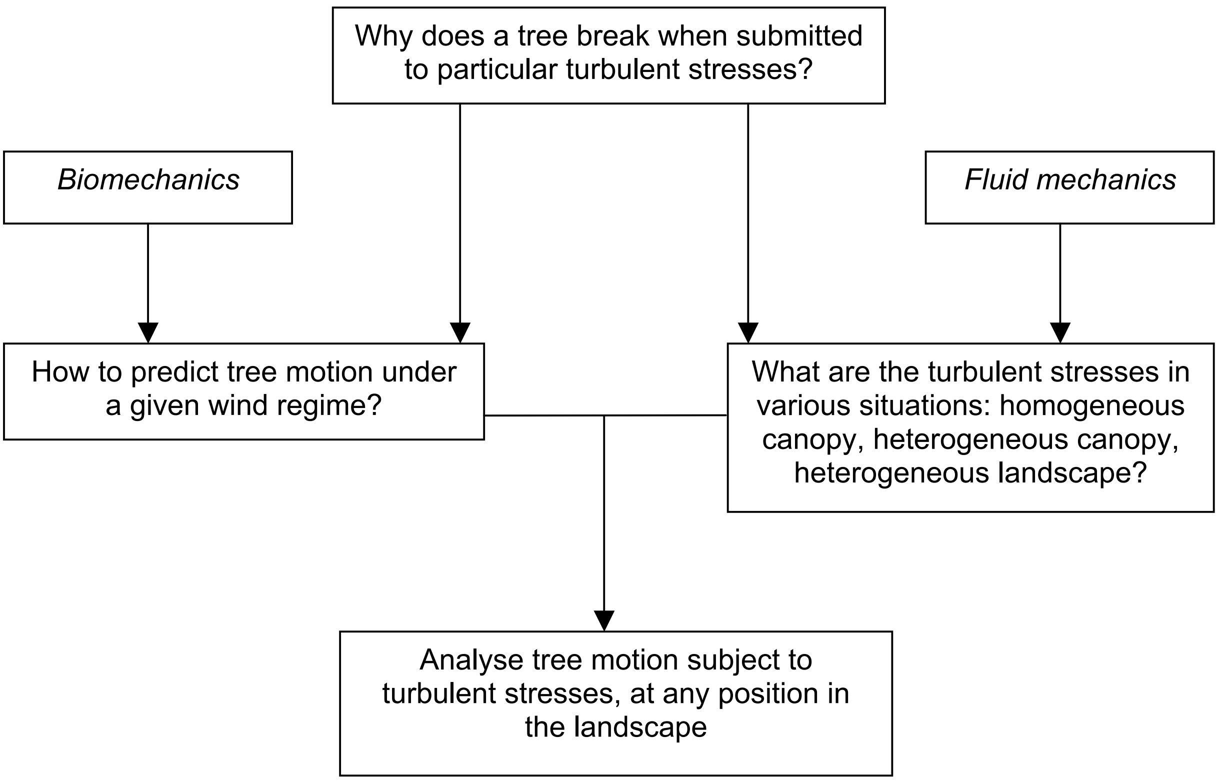
Wind damage in plantation forests is a major economic loss and appears to be increasing in intensity and frequency. The storms that affected France in December 1999 caused extensive damages to French forests and caused losses to all sectors of about € 8.5 billions. Annual average British losses are estimated to be a million cubic metres of timber per year. Although there is currently no clear signal from climate models of an increase in mid-latitude storminess, the next generation of models with better resolution may find differently. Therefore, there is a need to understand the detailed physics of wind-related tree stability across a range of spatial scales to help with the future management and planting of our forests.

In the aftermath of the December 1999 storms several French governmental bodies opened calls for research projects. The Venfor project was set up as a response to the "Forest, Wind and Risks" 2001 call of the GIP Ecofor. Its ultimate goal is to provide tools for predicting tree motion in various turbulent fields representing the natural environment of a tree, relative to its position in a forested landscape (distance to the edge, edge shape, forest fragmentation…). This international and multidisciplinary project combines in-situ measurements, wind-tunnel experiments and the development of numerical models.

The objectives of the Venfor project

The Venfor project is centered on the mechanical interactions between wind and tree. It is structured around two main complementary lines: (1) the mechanical behaviour of a tree subject to turbulent stresses (the idea being to evaluate the risks of damage for any incoming flow) and (2) the influence of the structure (of the tree, of the canopy, of the landscape) on the atmospheric flow (the idea being to predict the flow around the tree in any given configuration). Coupling these two lines should allow us to predict the risk of tree damage for any position in the landscape. Two key features of the project are therefore (1) to couple biomechanics and fluid mechanics, with strong emphasis given to numerical modelling, and (2) to analyse the wind and tree interactions at several spatial scales: the individual tree, the homogeneous forest canopy, the two-dimensional heterogeneous canopy (edge regions) and the fully three-dimensional forested landscape.

The general outline of the project can be illustrated as follows:



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Part 1: Modelling tree biomechanics

The objective of Part 1 is to develop a dynamical model of tree mechanics, able to simulate instantaneous tree motions in response to turbulent fluctuations. This is the object of a PhD thesis (D. Sellier). The finite element Abaqus code is used for this, with boundary conditions representing the distribution of instantaneous drag forces all along the structure.

Extensive measurements are being performed to determine all necessary parameters (tree architecture, elasticity modules, damping coefficients, etc) and provide reference data to validate the model. Examples of such measurements are given in a companion paper (Sellier et al 2003).

The expected results are: (1) the determination of the swaying frequency for a given architecture, (2) the localization and intensity of the maximum longitudinal strains in tension and compression in the trunk, (3) the analysis of tree motions (displacements and velocities over a given period of time, under fluctuating turbulent stresses) and (4) the estimation of anchorage forces.

Part 2: Tree motion and turbulent flow in a homogeneous forest canopy

Over the past few years many data sets have been collected in a maritime pine forest site near Bordeaux in South-West France, in order to characterize and analyse turbulent flow within and above the canopy. These measurements include (1) continuous two-point measurements with sonic anemometers located above the canopy and in the trunk space, respectiveley; (2) turbulence profiles on a tower during intensive periods, using 7 to 8 sonic anemometers; (3) large-scale three dimensional arrays of sonic anemometers.

In summer 1999 two accelerometers were set up on a trunk in the vicinity of the tower and provided data on instantaneous tree motion, recorded simultaneously with the turbulence measurements. A companion paper presents a first analysis of this data set (Lohou et al 2003).

A new experiment is planned in autumn 2003, with more intensive measurements of tree motion along with a vertical profile of turbulence measurements. The results will be used to further analyse the coupling between tree motion and turbulent flow and will provide a reference data set to validate the tree model.

A numerical flow model based on a k-ε closure scheme has also been developed and shown to provide good simulation of the various variables of interest (vertical profiles of mean wind velocity, shear stress, turbulent kinetic energy, dissipation, etc). It allows the vertical distribution of drag forces to be computed in a homogeneous canopy with a given architecture. The model is presented in a companion paper (Foudhil et al 2003).

Part 3: Wind flow across forest edges

Special emphasis is given to forest edge regions that are known to exert an important role on the development of turbulence, and where damages to the trees have often been observed during storms. This sub-project combines wind-tunnel simulation, in-situ measurements and numerical modelling.

A wind-tunnel experiment was performed in winter 2003 in an atmospheric wind tunnel at the University of Oxford. A model canopy made of plastic trees was set up downwind of a smoother surface simulating a moorland. A PIV system was used to collect instantaneous vertical and streamwise velocity components over two-dimensional windows. One of the model trees was set up on a miniature two-component balance in order to measure instantaneous along-wind and cross-wind bending moment components. Several configurations have been set up, representing (1) mid-forest flows (the tree on the balance is placed far from the edge of the model plantation), (2) upstream-facing edge flows (the tree is placed at various distances from the upstream edge), (3) downstream-facing edge flows (the tree is placed at several distances into the plantation upstream of the edge and (4) forest gap flows (the tree is located at various distances on either side of a gap, created at right angles to the flow direction. All measurements have been performed and some preliminary results are presented in a companion paper (Morse et al 2003). The analysis will focus on the relation between the tree bending moment components and the characteristics of the incoming flow at the various positions considered (statistical properties, presence of gusts, etc).

The numerical model mentioned above (Part 2) has also been used to simulate wind flow across edges, and validated against wind-tunnel measurements collected earlier in the CSIRO wind tunnel at Canberra (see Foudhil et al 2003). It has been shown to give good prediction of the mean wind and the turbulent kinetic energy across forest-clearing-forest transitions, except at some locations where the flow is strongly distorted. An LES model developed over the past few years at the University of California is also used in Venfor (see Morse et al 2003) and provides complementary insight on edge flows.

Previous experimental data collected on four towers upwind and downwind the edge of a real forest is also used (Morse et al 2003). A new experiment in a rather short forest (about 10 m high) with a well-defined edge will be performed in summer 2003 in the South of France. It should provide another complementary data set for Venfor.

Part 4: Wind flow across a fragmented forest landscape

At a larger scale the structure of a fragmented forested landscape is thought to have impacts on the structure of the bottom part of the atmospheric boundary layer. In other words the characteristics of the wind flow should partly depend on the structure of the upstream surfaces, in a way that has never been properly studied.

Another wind-tunnel experiment has been planned within Venfor to investigate this at CSIRO, Canberra. Three-dimensional patchworks of forested and non-forested areas will be simulated in the wind tunnel, with LDV measurements. The experiment has two main aims:

(1) look at non-transverse edges, that have not been considered previously, and (2) look at the patchiness or clustering of roughness on total momentum absorption and the spatial distribution of the momentum flux, the mean wind speed and the drag coefficient. Several surfaces will be used with the same spatial average tree density, but with different clustering.

Numerical modelling of the atmospheric flow will be used too. At such scales the model mentioned previously is not suitable and we must turn towards submeso scale atmospheric models, able to consider a thick enough layer of the atmosphere. Such a model is currently under development at the Ecole Centrale de Nantes (France). With the use of a grid nesting technique it seems possible to get a few metre resolution in regions of interest within simulated domains extending over several kilometres. A drag-porosity model has to be implemented in the existing model and simulations will be performed over configurations similar to those used in the wind tunnel.

Finally a complementary, more empirical, study is being performed. The damages caused by the December 1999 storm to the forests in Aquitaine exhibit large spatial variability. The idea here is to "take advantage" of the storm to analyse the location and intensity of the damages across a given region, in relation with the landscape structure upstream from each plot considered. The study is conducted over the Nezer forest, a 4000 ha site 40 km South-West of Bordeaux, with around 300 plots of various age, height and density. All past sylvicultural operations are known and each plot is described in terms of morphological characteristics (plant area index, height, density…). Aerial photographs were taken two weeks after the storm and a method has been develop to estimate the damage intensity of each plot according to a three-class scale. All available information has been implemented into a Geopraphical Information System and an algorithm has been developed to describe the upwind landscape structure at each plot, along transects of several kilometres. Relationships between the damage intensity and various indices related with the landscape structure are being sought.

Conclusion

One originality of the Venfor project is to combine observation, in-situ measurements, wind-tunnel experimentations and numerical modelling. It assembles specialists of biomechanics, micrometeorologists and fluid dynamicists. It has been designed to improve our understanding of wind and tree interactions at various scales and should provide tools and methods for predicting the risks of tree damage in various configurations.

The Venfor project is in its second year now and several lines of action have been initiated or are now well advanced. In its initial form it should be completed within three years but, given the ambition of its objectives it will run for longer. Anyone interested in Venfor is invited to get in touch with the participants.

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