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Input parameters for CFD flow modeling of forested terrains

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Summary

The purpose of this study is to present different methods for obtaining the forest characteristics required as inputs parameters in common CFD-RANS (Computational Fluid Dynamics, Reynolds-Averaged Navier-Stokes) modeling for wind energy assessment. We compare in situ measurements of forest height h and LAI (Leaf Area Index) together with terrestrial satellite measurements products acquired at different spatial resolutions, for which both spatial and time series were made available. It is shown that:

- For the forest height estimations, the SRTM and ASTER satellites include information from the forest, but far from the precision needed for the CFD modeling. The DSM based on aerial laser scans underestimate the forest height by several meters, whereas the maximum height deduced from the cloud points (raw data) were in good accordance with the forest inventory measurements (Fig. 6). Reprocessing the cloud points therefore is the most promising method for determining the forest height.

- For the LAI, the satellite-based estimates should be used with care as calibration to site specific measurements is necessary. The derived LAI values could be sensitive to a number of environmental factors (i.e. presence of clouds or biased winter reflectance) as well as to the different scaling relations involved in its derivation. A significant difference between the MODIS (LAI=3.1) and Landsat 7 (LAI=5.43, Fig. 7) satellites were obtained. The Landsat 7 showed unphysical variability in the derived LAI. However, the extraction of LAD and LAI from wind data taken within the canopy (Eq. 2, LAI=5.22) showed a good comparison with the mean value of an optical in-situ technique (LAI=5.67) and with the mean value of Landsat 7 (LAI=5.43) in the summer (Fig. 8).

Context

- In CFD-RANS modeling, the drag effect of the forest in the momentum equations is usually accounted trough a sink term as follows,

$$\frac{\partial U_i}{\partial t} = \cdots - C_d LAD(z) U_i |U|, \qquad (1)$$

where $C_d = 0.2$ is a drag coefficient and LAD(z) is the vertical plant area per unit volume.

- The height of the forest and its vertical distribution LAD(z) are thus required in order to evaluate this term.

- By applying a variety of simplification assumptions [1] to Eq. (1), the forest architecture can be related to atmospheric measurements by,

$$C_d LAD(z) = \left| \frac{\partial \overline{u'w'}}{\partial z} \right| \frac{1}{U(z)^2}. \qquad (2)$$

Example site:

- The Tromnæs beech forest edge experiment was located on the Falster island at 54⁰45' N, 12⁰2' E. From March-September 2008, a measurement campaign was conducted where both the foliated and the bare canopy period were covered. Complex flow phenomenons were observed making it a relevant test case for CFD validation.
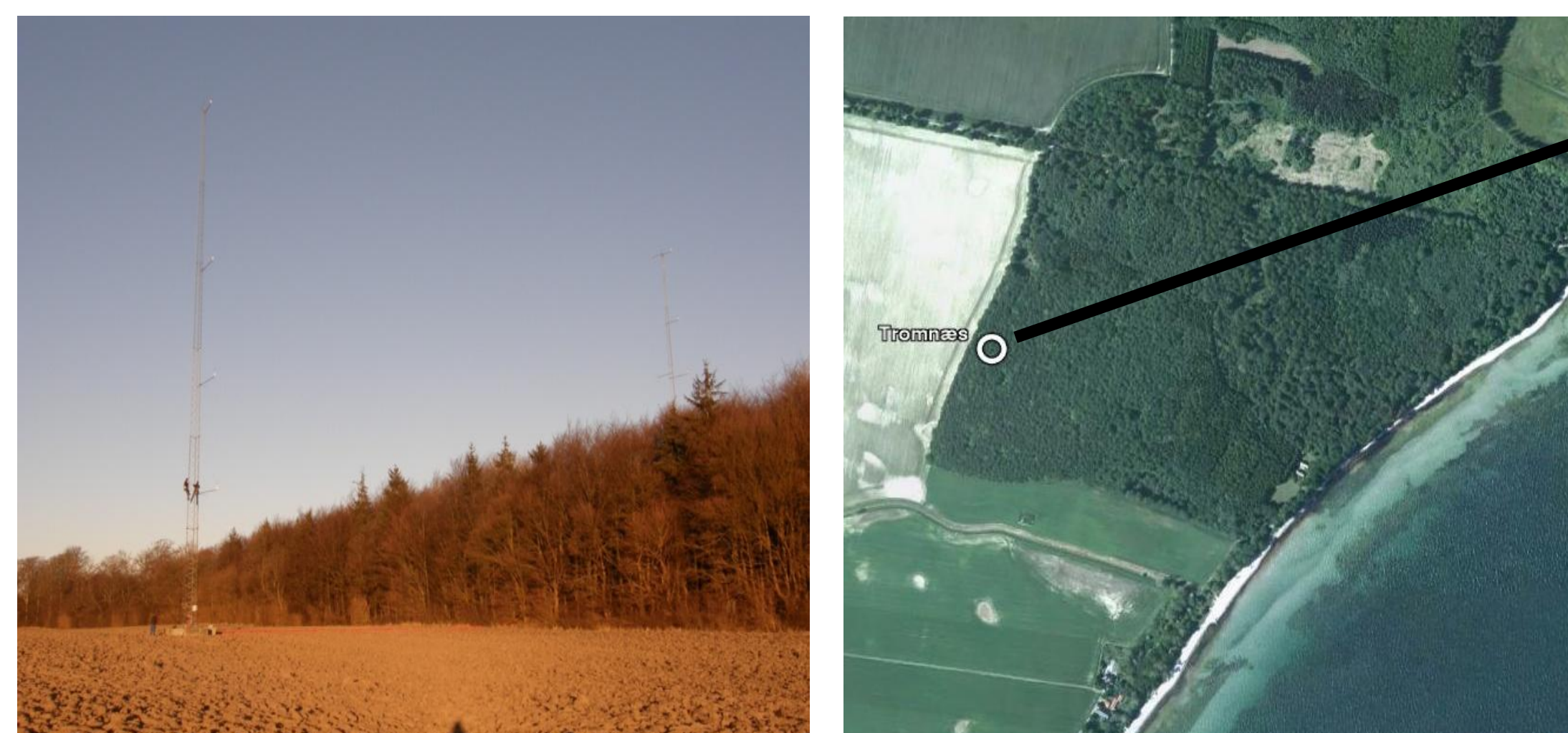
Fig. 1: Tromnæs forest edge experiment site. White circle: approx. mast location

- Non-dimensional tree-specific profiles of LAD can be constructed from the mast measurements of the wind using Eq. (2) and the observed h:
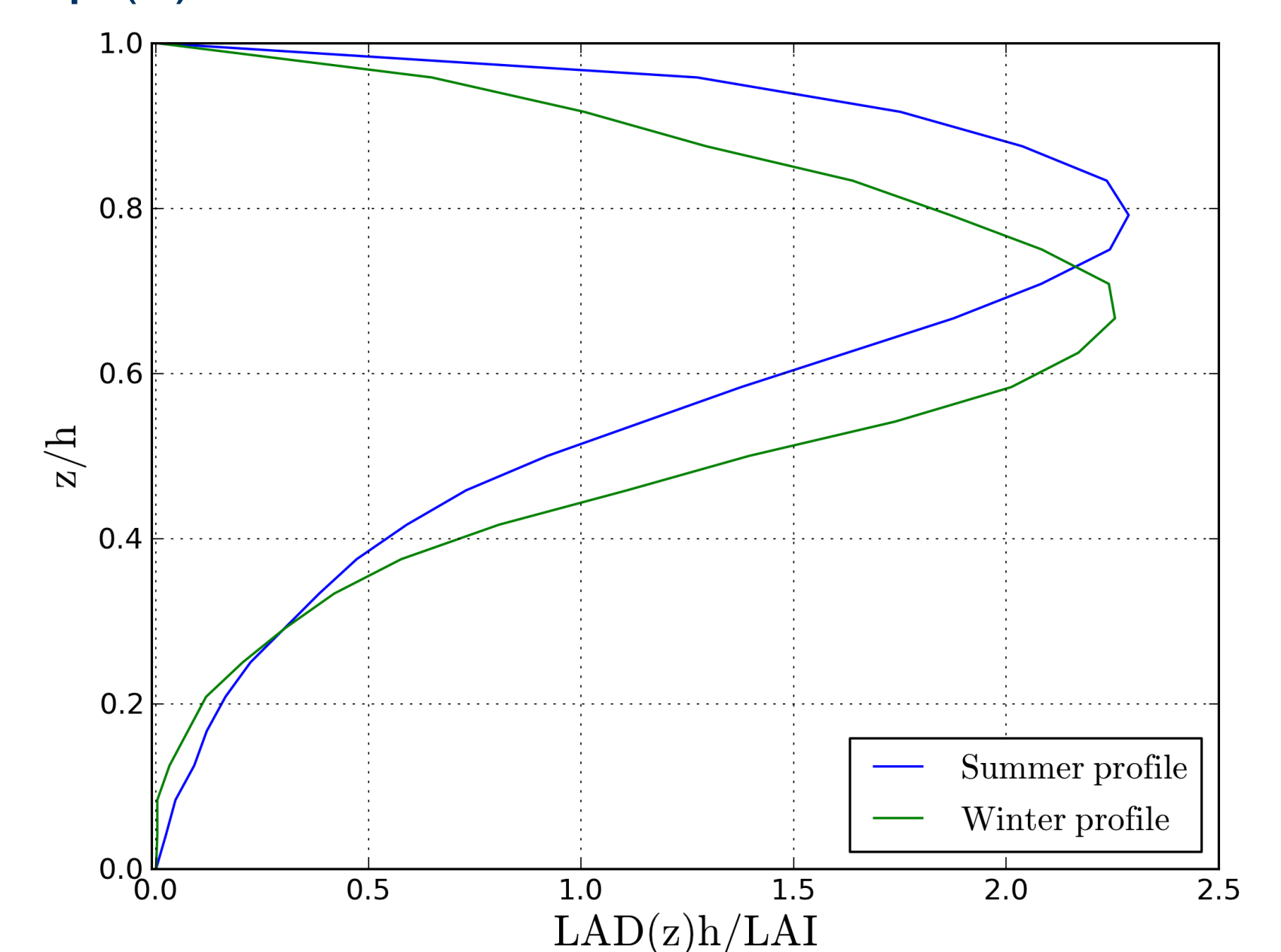

Fig. 2: Normalized beech Leaf Area Density (LAD) profiles

- The use of these profiles could be extrapolated to regions where h and LAI can be obtained from any of the techniques shown below.

Forest height (h) estimation

- Different canopy height estimates based on DSMs (Digital Surface Models), DTM (Digital Terrain Model) and forest inventory were obtained:
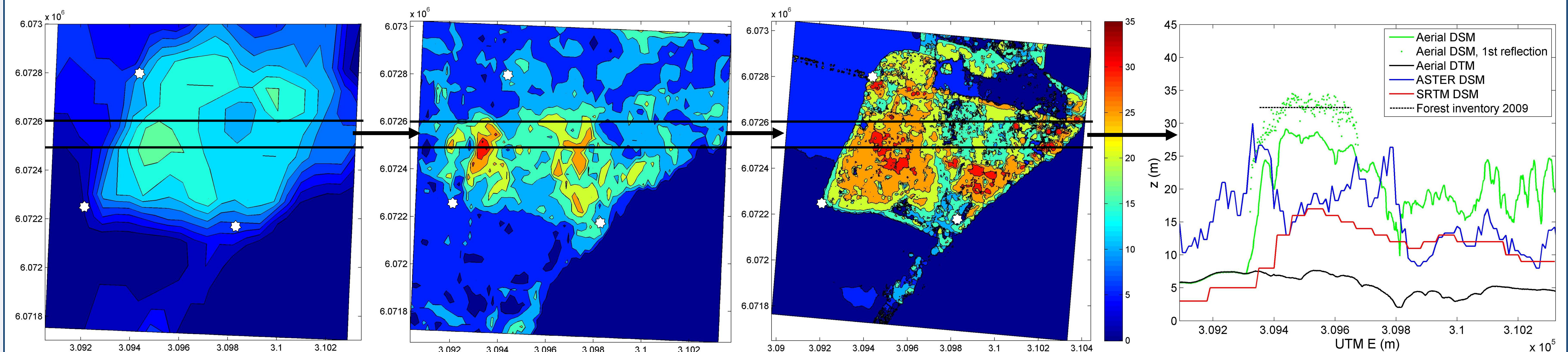

Fig. 3: Space shuttle SRTM (100 m resolution, 2000/02)

Fig. 4: Satellite ASTER [2] (15-90 m resolution)

Fig.5: Aerial laser-scan (1.6m resolution, 2007/05/01)

Fig.6: Forest height intercomparison (forest transect)

Leaf Area Index (LAI) estimation

- The total drag of the canopy is reflected in the LAI parameter,

$$LAI = \int_0^h LAD(z) dz. \qquad (3)$$

- The LAI can be obtained from satellite images [3, 4] using the reflectance ratio from different wavelength intervals [5] or from in-situ instruments (Fig. 8).

- For the summer, the LAI values obtained from the satellite-based MODIS instrument was 3.1 (not shown). The Landsat 7 showed unrealistic variability compared to the in-situ measurements (Fig 8), although the mean values agreed well (5.43 and 5.67 respectively) with the estimate of 5.22 (point in Fig. 8) based on Eq. (3) and the LAD summer profile presented in Fig. 2.
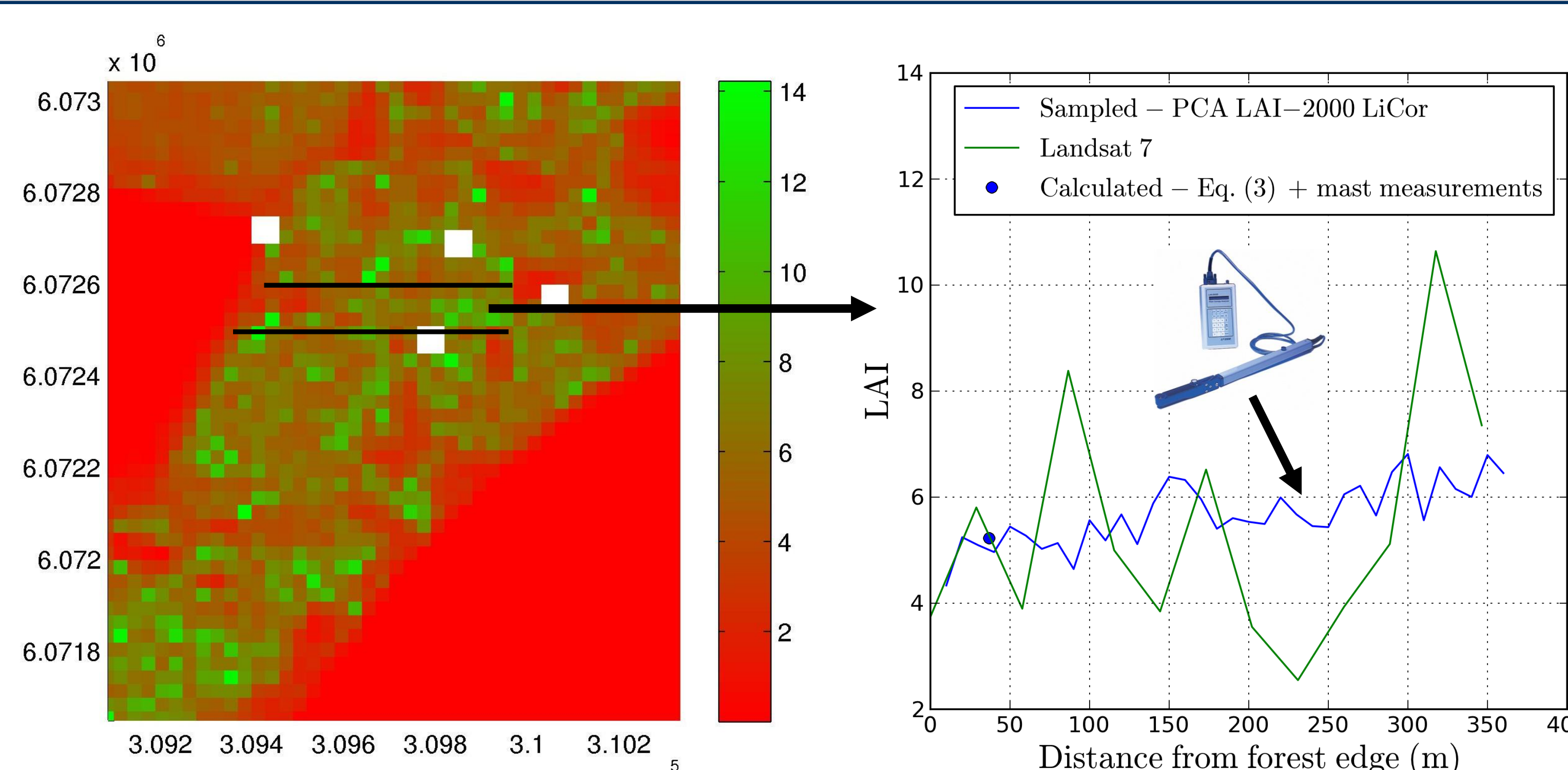
Fig.7: Satellite Landsat 7 ETM+ [6] (30m resolution, 2002/06/08)

Fig.8: LAI intercomparison (forest transect)

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EWEA 2012, Copenhagen, Denmark: Europe's Premier Wind Energy Event