Appendix A

Validation data

Data on the observed forest properties and top-of-the-canopy albedo for two pine stands and two beech stands were taken from the Infrastructure for Measurements of the European Carbon Cycle (IMECC) database (accessed online at 30 April 2013: http://fluxnet.ornl.gov/site_list/Network/32). Similar data for the oak stand were provided by the Tartu Observatory (Kuusk et al., 2009, 2013).

One pine stand was located at Järvselja in Estonia (coded EE-Jär; 58.31° N, 27.30° E). The stand of Scots pine (*Pinus sylvestris* L.) had a height of about 15 m, an age of 125 years (in 2013) and a stand density of 1122 trees per hectare. The other pine stand (also *Pinus sylvestris* L.) was at Loobos in the Netherlands (coded NL-Loo; 52.17° N, 5.74° E). It had a height of 15.6 m, an age (in 2013) of 106 years and a density of about 404 trees per hectare.

One beech forest (*Fagus sylvatica* L.) was located at Hainich in Germany (coded DE-Hai; 51.08° N, 10.45° E). This site has been totally unmanaged since 1997. Before being classified as a reserve the forest was occasionally logged for timber over a period of about 30 years. As a consequence the forest has moved towards a late successional forest with trees aged between 1 and 250 years with the tallest trees reaching 33 m in height. The tree density was about 334 trees per hectare; *Fraxinus excelsior* and *Acer pseudplatanus* are co-dominant. The other beech stand was located at Hesse in France (coded FR-Hes; 48.67° N, 7.07° E). It was a rather young forest (48 years in 2013) and, with 2616 trees per hectare, densely populated. The dominant tree cover was 21 m tall with a high canopy closure.

The oak stand was situated at Fontainebleau in France (coded FR-Fon; 48.48° N, 2.78° E). It consists mainly of *Quercus petraea* L. In 2006 the stand density was 1134 trees per hectare, of which 234 were *Quercus petraea* and 900 were *Carpinus betulus*. The average canopy height of *Quercus petraea* was about 27 m, whereas the *Carpinus betulus* were about 10 to 20 m tall; stand age (in 2013) was about 150 years.

For all validation sites, stand-level albedo was observed from in situ incoming and outgoing shortwave radiometric measurements and recorded in the IMECC database, with the exception of EE-Jär. From this database years was only selected when outgoing and incoming shortwave radiation were recorded. Albedo was calculated as the ratio of downward and upward radiation as observed with two-way pyranometers (Kipp and Zonen, Delft, The Netherlands). The overall expected instrumental accuracy is in the range 4–7 % with clear sky and 1–4 % in overcast conditions (Cescatti et al., 2012). The radiation measurements cover the wavelengths from 0.21 to 2.80 µm.

The albedo at EE-Jär was measured as top-of-the-canopy bidirectional reflectance factor (BRF) with a UAV spectrometer (Kuusk, 2011). The measured BRF was carried out at different dates in July and August in 2012 and transformed with the help of the 6S atmosphere radiation transfer model (Vermote et al., 1997) and the FRT forest reflectance model (Kuusk and Nilson, 2000) into visible and near-infrared albedo for the solar zenith angle 39.8° which corresponds to the maximum solar zenith angle at midday at the Järvselja site at summer solstice.

Only EE-Jär and DE-Hai provided measured crown sizes (Table 3). For the remaining sites, species-specific allometric relationships were used to estimate the height of the crown base, the crown radius and length derived from three different data sets (Condés and Sterba, 2005; Pretzsch et al., 2002; Zeidel, 1991). For sites where the coordinates of the individual trees were absent, we assumed a uniform tree distribution. Only the simulation for EE-Jär was run exclusively with observed parameters (see Table 3) and compared with simulated albedo. For all other sites, the observed albedo was, finally, compared to the calculated albedo. However, variation in the amount and timing of cloudiness causes considerable day-to-day variation which can be smoothed out when integrated over several weeks (Hollinger et al., 2010). Therefore, integrated daily values for the whole month of June were calculated to compare to the simulated values.

Every simulation was performed for 1 ha of forest. This 1 ha was divided in 25 squares (20 m $\times$ 20 m) and the albedo was simulated for each square separately. The variation between the squares was considered to be a measure of the sensitivity of albedo to the footprint for a given canopy structure. The scan line of the UAV spectrometer is about 2.5–3.0 m (Kuusk, 2011). The footprint of surface albedo measured by a pyranometer depends on its height above the canopy (ranging from 5 to 10 m). However, for the experimental sites under study, typically 80 % of the signal originates from within 300–1200 m^2 (i.e. 10–20 m) around the tower (Cescatti et al., 2012). To capture all possible spatial scales of observed albedo values, each site is presented as the mean albedo of June (2001–2010) by MODIS (Pinty et al., 2011a; Schaaf et al., 2002) at $\sim$1 km resolution. The range of MODIS observations are derived from nine pixels surrounding the tower.