CORRESPONDENCE:

Radar backscatter is not a 'direct measure' of forest biomass

To the Editor — Accurately mapping forest carbon now has important financial and livelihood implications for many smallholder farmers, businesses, investors, land-use projects and governments. The urgent need to reduce uncertainties in the carbon cycle, the increasing focus on global sustainable forestry, and the international agenda on Reducing Emissions from Deforestation and Forest Degradation (REDD+) has led to the creation of new communities clamouring for robust methods to map forest aboveground biomass (AGB).

Satellite radar is often proposed as the best tool to overcome the substantial spatial, frequency and cost limitations of allometric-based field surveys. There is ample evidence that demonstrates the general sensitivity of long wavelength (L-band and larger) radar backscatter to AGB, up to a signal-saturation point[1–4], and we believe that radar is typically the best satellite-based remote-sensing tool for mapping forest extent[5], estimating forest structural variability[1,6], and detecting deforestation and degradation[2].

However, we are concerned that in some instances data have been over- or misinterpreted, often to match expectations, and this is leading to the case for imaging radar being overstated. To be specific, we contest the use of the term 'direct measurement'[5,7,8] to describe the application of radar backscatter intensity to map forest AGB. Although radar may employ a direct approach, whereby the signal is directly converted to AGB, it is not a direct measurement, which implies an unambiguous and well-defined relationship, an assertion that is neither expected from theory nor supported by measurements. We believe the use of this term in high-impact journals is creating confusion among policymakers as to the realistic potential of radar as a low-cost operational alternative to field inventories; it must be seen as a useful complement, not an alternative.

Radar backscatter intensity does not provide a direct measurement of forest AGB, even at very long wavelengths. Backscatter is determined by a variety of vegetation structural properties that may, or may not, correlate with AGB (in addition to the possible perturbations of the signal from soil moisture, slope and surface roughness characteristics). Variability in vegetation structure has such a large impact on long-wavelength radar backscatter intensity that when the structure (for example, number density or basal area) is well-correlated with AGB, the radar intensity will be also. However, not all forest ecosystems exhibit the same structural trends with biomass. Managed coniferous forests tend to have constant basal area and a (stem) number density that reduces with increasing AGB. Resource-limited systems (semi-arid, savannah, boreal) and areas of regrowth are the opposite: increasing AGB results from increasing basal area and/or increasing number density. Dense, full-cover tropical forest is different again, with variability in AGB governed partly by variability in basal area, but mostly due to the random distribution of the largest individual trees. Unfortunately, some studies[4,8,9] present results that cut across forest types. In these cases visual examination of graphs of radar intensity against AGB clearly differentiate clusters of points corresponding to different forest types, yet there is often no relationship within each cluster. With the application of only simple statistics to the whole dataset a high R-squared can be reported, painting an incomplete picture of the data.

We argue that it is this kind of variability that contributes to the inconsistency of the reported 'saturation' points: L-band saturation ranges from 30 to >150 Mg ha^{-1} (refs 3,4); and P-band from 100 to >300 Mg ha^{-1} (refs 6, 9).

Englhart *et al.*[8] provide an extreme example of an analytical error that is common in the literature. A log function is fitted even though a sigmoidal function is predicted by theory, and as a log curve is not asymptotic this visually suggests sensitivity beyond saturation. Subsequently the fitted log function, not the data, is used to project sensitivity to AGB values higher than 600 Mg ha^{-1}, even though sensitivity is clearly lost before 200 Mg ha^{-1}.

It is often the case that studies using the very long wavelength (VHF) CARABAS system[10] are cited as evidence of the inherently strong correlation between radar backscatter and AGB. However, this is misleading because CARABAS is a high-resolution airborne system that resolves individual trees, and so is not subject to the disruptive effect of number-density variability[11].

Over landscapes where the forest exhibits consistent structural changes with AGB, and when accompanied by forest-type specific ground data and/or vegetation structure data from airborne or spaceborne lidar, we are confident that radar may be used to create accurate AGB and AGB-change maps within a landscape[2]. Gaining a deep understanding of how forest structure mediates the biomass–backscatter relationship should continue to be a high priority alongside radar-system development. Nonetheless, we believe it is at best unhelpful, and at worst misleading (especially in a REDD+ implementation context), to suggest that radar intensity provides a direct measurement of forest aboveground biomass. ❒

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COMMENTARY:

Geothermal energy in China

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The potential for power generation from geothermal energy in China is vast but as yet largely untapped.

Over the past three decades, rapid economic growth and heavy reliance on fossil fuels have transformed China into the number one greenhouse-gas emitter. The country is anxious for low-carbon energy to help sustain economic development and social stability. Wind and solar power have been raised as bright stars of renewable energy, but more reliable geothermal energy is essentially untapped for electricity generation in China. At present China has a total geothermal power capacity of less than 20 MW (Supplementary Table S1), as compared with its wind power capacity of 62,400 MW (ref. 1). The great potential of geothermal energy as an indigenous resource has not been well recognized in China.

Geothermal basis

Geothermal energy comprises heat generated by the decay of radioactive elements contained within the Earth and the heat left over from the planet's original coalescence. This internal energy is transferred outwards slowly through heat conduction of crustal rocks at a rate of about 44 TW (ref. 2).

As a direct consequence of the steady energy flux from greater depths, the ground temperature on global average increases around 3 °C with every 100 m increase in depth. Some places have a greater geothermal gradient than others, depending on their specific geological settings. Most attractive geothermal areas are located along active tectonic plate boundaries.

Geothermal energy can be harvested by extracting water/steam from a naturally formed hydrothermal system. The first geothermal power station was built 100 years ago in Italy's Larderello volcanic region. High-temperature hydrothermal fluids are now used to generate electricity in hundreds of geothermal power plants around the world.

The internal heat can also be extracted from an enhanced or engineered geothermal system (EGS; Fig. 1), created artificially by injecting fluid into hot rock. In principle, there is no limit to EGS application because, if one could drill deep enough, the temperature would be high enough to meet various needs. In practice, volcanic areas remain most attractive for EGS development because hot rocks lie at shallower depths in those areas.

A report published in 2007 by the Massachusetts Institute of Technology[3] concluded that geothermal energy is the most promising low-carbon source capable of replacing fossil fuels for electric power generation. In the wake of this great potential, the worldwide geothermal power industry grew by about 20% over the 2005–2010 period[4], despite the widespread economic downturn.

Current Chinese status

Sandwiched by the continental collision zone to its west and the oceanic subduction zone to its east, China is rich in geothermal energy[5]. Thousands of hot springs have been reported across the country. Chinese people have a long tradition of using geothermal water for therapeutic, recreational, agricultural and aquacultural purposes. However, China lags behind most geothermal countries in the more contemporary application for power generation.

The first Chinese geothermal power station of 300 kW capacity was built in Fengshun County of Guangdong Province in 1970, as a result of a national campaign for geothermal energy inspired by the late Li Siguang (1889–1971), the first geology minister of the People's Republic of China, who proposed treating geothermal energy as a resource just as important as fossil fuels. Six additional geothermal power plants of 100–300 kW capacities were built in the 1970s in the eastern part of the country, using hot ground water of 67–98 °C (Fig. 2 and Supplementary Table S1), but the enthusiasm for geothermal energy in China faded quickly after the death of its powerful sponsor.

Furthermore, the focus on developing geothermal power in China shifted geographically from east to west after the mid 1970s, with three more geothermal power plants, all with megawatt capacities, being built in Tibet. For various reasons, including the lack of government support, China now has only three working geothermal power plants (Supplementary Table S1)[6]. Yangbajing geothermal plant is operating at 18.5 MW capacity, Langjiu plant at a reduced 0.4 MW and Fengshun plant at 0.25 MW. The other plants are decommissioned.

Tengchong in the southwest Yunnan Province, near the border of Burma was selected for a prospective 20 MW geothermal power plant. However, the plan has been obstructed by local government. Tengchong's hot springs and fumaroles attracted hundreds of thousands of tourists every year. The county administrators do not want to risk ruining their spectacular geothermal tourism resource for electricity that can be generated by small hydrological power stations.