Global Forest Structure and Biomass Monitoring from Space

**1. Challenges**

* Uncertainties in the level of carbon stored in forests and the changes in that level have a large impact on the uncertainty in future climate projection
* Uncertainties in tropical-forest carbon dynamics are particularly important for their potential role in the missing carbon sink, and associated future climate scenarios
* Spaceborne remote sensing of aboveground biomass is the only practical approach to measuring global carbon-cycle dynamics
* In order to assess what investments are needed, it is proposed that the Decadal Survey take a broad look at all spaceborne interferometric microwave possibilities from P-band to Ka-band, and their combination with lidar and various spectral options.

A principal challenge for Earth System Science is the global monitoring of forest structure to enable aboveground biomass (AGB) monitoring. Uncertainties in the level of carbon stored in forests and the changes in that level have a large impact on the uncertainty in future climate projection (e.g. Schimel et al. 2015). Methods of monitoring AGB must address changes in stored carbon on scales germane to land use and logging (50-100 m). They must cover the vegetated globe, especially the tropics, which accounts for about 50% of the world’s remaining terrestrial AGB.

The remote sensing of tropical-forest AGB will be a high priority in AGB-monitoring strategies. The amount of CO2 removed when a tropical stand is converted to agricultural use must be accurately measured, necessitating the measurement of *a priori* stock. Monitoring AGB must include accurate “change” measurements over many passes, which will be sensitive to slow rates of regrowth. These slow rates bear on the question of the missing terrestrial carbon sink. The origin of this substantial component of missing carbon is largely unknown, and constitutes a major hole in our understanding of global carbon cycle dynamics. This sink is approximately 67% of the net atmospheric uptake (LeQuere et al 2013). Recent studies hypothesize that this land sink could be due to increased forest uptake in the mature tropics due to the well-known increases in atmospheric CO2 over the last century (Pan et al. 2011, Schimel et al. 2015). The next-generation of structure-AGB sensors must rise to the challenge of detecting AGB change on 50-100 m scales in the tropics, with heavy cloud cover, in order to quantify the spatio-temporal origin of the missing sink. Climate change mitigation efforts designed to reduce emissions from deforestation and forest degradation (REDD+) will also require global, high spatial- and temporal-density AGB monitoring.

Direct gravity sensors in space, such as GRACE, are inadequate by orders of magnitude to measure the gravity signature of changing or accumulated AGB. Brightness, either optical or radar, is a good indicator of AGB only up to about 150 Mg/ha (e.g. Le Toan et al. 2004). Tropical forests have AGB well in excess of 150 Mg/ha, extending up to about 600 Mg/ha. The remote sensing of AGB has therefore been done most accurately by measuring some structural attribute of forests and correlating it with AGB. One challenge in AGB remote sensing via structure is to ascertain the best structural attributes from which to estimate AGB. There are a variety of attributes that have been used. For example, height (Drake et al. 2002, Dubayah et al. 2010) has been used to estimate AGB or AGB change with lidar. More complex structural attributes, such as the Fourier transform of the vertical profile of vegetation have been used with lidar and interferometric SAR (InSAR). One of the challenges for the Decadal Survey is therefore to ascertain, from published results and consultations, which set of structural attributes produce the most accurate AGB estimates. A subsequent challenge is to determine the optimal set of sensors, including lidar and InSAR, and their possible fusion with hyperspectral remote sensing.

**2. Timeliness and Readiness**

Pinning down the degree to which tropical forests are causing the missing sink might help to discriminate between the above and a competing hypothesis that northern hemisphere, temperate regrowth is causing the sink. Discriminating between these two hypotheses—tropical or northern origin—discriminates between future ecological trajectories. The “CO2-increase-tropical hypothesis” suggests a continuing sink, while the “northern regrowth hypothesis” could saturate and the sink could diminish. If this were to happen, greater atmospheric levels of CO2 might result in the future. A timely characterization of the sink is needed to understand future climate and to shape consequent REDD+ mitigation strategies.

Existing, primarily international missions define current technological readiness to monitor global AGB. The only dedicated two-spacecraft interferometer in space is TanDEM-X (X-band, InSAR, Germany), which has produced 10s of papers on forest structure and AGB (e.g. Askne et al. 2015, Treuhaft et al. 2015). The technology of TanDEM-X makes it promising, though not confirmed, for making progress on the challenge of global monitoring. TanDEM-X has demonstrated that the technology to fly a 2-spacecraft interferometer, capable of measuring AGB on ~50-meter scales, exists. Other, possible future missions, which are similarly candidates to address the challenge above, are BIOMASS (P-band, polarimetry, repeat-track InSAR, Europe), NISAR (L-band, S-band, polarimetry, repeat-track InSAR, United States), TanDEM-L (L-band, InSAR, Germany), PALSAR-3 (L-band, InSAR, Japan) and SAOCOM (L-band, InSAR, Argentina). The repeat-track InSAR missions are single-spacecraft. All the others are dual-spacecraft programs. A lidar mission, GEDI (infrared, United States) will be mounted on the space station to sample structure and AGB at fine (25 m) resolution scales. These missions will all contribute to substantial progress on the challenge above of AGB monitoring. Each has limitations that could signal the need for additional investments. These limitations include the inaccuracy of repeat-track InSAR due to scene change between passes, low bandwidths and consequent poor resolution, and restricted regions of operation and sparse coverage.

Frequencies from P-band to X-band have shown reasonable performance for InSAR-based structure and AGB estimation. Along with “bandwidth”, the carrier frequency, polarization and various other parameters will have to be reviewed by the Decadal Survey to determine what additional investments in sensor (or multiple-sensor) capability are necessary. Combining the above technologies with hyperspectral observations or multi-spectral lidar should also be investigated by Decadal Survey committees. In this RFI, it is simply proposed to take a broad look at all radar interferometric possibilities from P-band to Ka-band, and their combination with lidar and various spectral options. For the most part, the technology is ready, but the technical assessment as to the optimal suite of sensors, and their specifications, must be a part of the Decadal Survey process.

**3. The Need for Space-Based Observations to Address the Challenge**

In a recent study in Brazil, a 60 x 20 km area was covered by TanDEM-X. A number of 1000-hectare samples of that area were covered by airborne lidar. Based on the 1000-hectare samples, it was determined that coverage of the entire area would take about 10-20 days of airborne survey. The area was covered in 9 seconds by TanDEM-X. Disturbances occur on scales of 50 – 100 m, and occur in as little as a few weeks. In order to cover the entire vegetated globe at such fine spatial and temporal resolution, space-based instruments must be deployed. The broad scientific question of balancing global and regional carbon budgets can only be addressed from space with observations over many years. Beyond addressing regional and global concerns, the fine resolution and coverage enabled by space-based observations will benefit formulation of local mitigation strategies. They will also benefit local economies in their assessment of forest resources such as wood or chemical products that come from wood.

The science communities that would be engaged by space-based observations include carbon-cycle, remote sensing, and ecosystem scientists. Atmospheric and climate scientists similarly will be involved in using the end-products of space-based observations.

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