Institution: University of Sheffield

Unit of Assessment: 10 – Mathematical Sciences

Title of case study: BIOMASS: measuring global forest biomass from space

1. Summary of the impact

A €470 million earth observation mission (BIOMASS) based on research carried out in the University of Sheffield's Centre for Terrestrial Carbon Dynamics was approved by the European Space Agency Programme Board on 7 May 2013, for launch in 2020, to measure the biomass and height of the Earth's forests, globally, at a scale of ~200 m. The twenty European member states have committed contributions to fund the mission, representing a significant reallocation of public budgets. The mission was selected as the most scientifically convincing of the six initially shortlisted in 2005 (further down-selected to three in 2009), and is the only one that will be funded. The project has already led to two European industrial consortia receiving some €5.6 million for studies to demonstrate feasibility. A further €277 million of the €470 million approved funding has been specifically earmarked for industrial spending to prepare for the mission.

2. Underpinning research

Professor Quegan's and the University of Sheffield's leading role in the BIOMASS mission arises from the breadth of Quegan's research, including carbon-cycle studies using satellite and ground data with models; estimation of forest properties from satellite data; ionospheric modelling and assessment and correction of its effects on spaceborne systems; measurement properties, information extraction and signal processing for radar remote sensing systems; and the theory of radar scattering from land surfaces and vegetation. Knowledge in all of these is necessary to develop the science underlying the BIOMASS mission. The gestation period for BIOMASS has been long: the basic concept goes back to the early 1990s, but interest waned once it became clear that international regulations would not allow spaceborne use of the key wavelength. Only in 2004 did this change, as a result of evidence from earlier airborne studies. Correction of ionospheric effects exploits research carried out in the 1980s, reincarnated for BIOMASS.

The BIOMASS concept as it was understood in 2008 is given in [**R4**], but further science development led to considerable changes, as described in the key ESA reports [**S1-S3**] giving the science case for the mission, referenced in Section 5. Quegan wrote large parts of these reports, and edited them all, in his capacity as chairman of the BIOMASS Mission Advisory Group.

The use of BIOMASS-type data to test and improve carbon flux estimates from ecosystem models is demonstrated in [**R2**], based on early crude measurements of the biomass of Siberian forests from space in the EU SIBERIA-1 project, in which Quegan was the Technical Coordinator.

The value of long-wavelength radar for monitoring tropical deforestation is demonstrated in Whittle, Quegan *et al*. (*Remote Sensing of Environment*, 2012), which also illustrates the limitations of sensors with shorter wavelengths than BIOMASS.

Optimal methods to combine data at different polarisations and from different times to make precise measurements at the spatial scales needed by BIOMASS are derived in [**R1**]. This is unique in deriving an analytical expression for the measurement precision, which is a critical parameter in designing the biomass inversion procedure.

Ionospheric Faraday rotation will badly corrupt the multiple polarisations used by BIOMASS, and ionospheric scintillations can degrade image contrast and distort intensity measurements, so both effects must be removed from BIOMASS data. Characterisation of Faraday rotation and methods to correct it are given in [**R3**] (also in Wright, Quegan *et al*. *IEEE Transactions on Geoscience and Remote Sensing*, 2003). Analysis of scintillation [**R6**] led to the selection of a dawn–dusk orbit for

BIOMASS; this removes any significant scintillation impact on biomass measurements (but not on secondary ice measurements).

A related key problem, solved in [**R5**], is to derive estimates of system errors in the presence of Faraday rotation, and to use them to calibrate the measurements. This process also allows ionospheric structure and dynamics to be measured, leading to the adoption of space weather as a secondary mission objective.

3. References to the research [* **=** References that best indicate the quality of the research]

R1* Quegan, S., Yu, J.J. (2001). Filtering of multichannel SAR images, *IEEE Transactions on Geoscience and Remote Sensing,* **39**, 11, 2373-9.

R2* Le Toan, T., Quegan, S., Woodward, F.I., Lomas, M.R., Delbart, N. (2005) Relating radar remote sensing of biomass to modelling of forest carbon budgets. *Climatic Change*, **67**, 379-402.

R3 Chen, J., Quegan, S. (2010) Improved estimators of Faraday rotation in spaceborne polarimetric SAR data. *IEEE Transactions on Geoscience and Remote Sensing Letters*, **7**, 4, 846-50.

R4* Le Toan, T., Quegan, S., Davidson, M., Balzter, H., Paillou, P., Papathanassiou, K., Plummer, S., Rocca, F., Saatchi, S., Shugart, H., Ulander, L. (2011). The BIOMASS Mission: Mapping global forest biomass to better understand the terrestrial carbon cycle. *Remote Sensing of Environment*, **115**, 2850–60.

R5 Chen, J., Quegan, S, Yin, X.J. (2011) Calibration of spaceborne linearly polarized low frequency SAR using polarimetric selective radar calibrators. *Progress in Electromagnetic Research*, **114**, 89-111.

R5 Rogers, N.C., Quegan, S., Kim, J.S., Papathanassiou, K.P. (2013) Impacts of ionospheric scintillation on the BIOMASS P-band satellite SAR. *IEEE Transactions on Geoscience and Remote Sensing* doi: 10.1109/TGRS.2013.2255880.

Funding

G1 NERC: Ionospheric effects on P-band satellite radar, 2007–08, £75,000

G2 ESA: Simulation of Ionospheric Disturbances and Impact Assessment on BIOMASS Product Quality, 2007-08, £77,949

G3 ESA: Ionospheric mitigation schemes and their consequences for BIOMASS product quality, 2009–11, £150,760

G4 NERC: IonoSAR, 2010–12, £65,339

G5 ESA: End-to-End BIOMASS Simulator, 01/2011–06/2012, €30,000

Preparation for the BIOMASS mission has also led to ESA funding for science studies in several international research institutes and contracts to industry. The approximate total values of these contracts (exact values are not available) are:

€5.6M for industry (split between Astrium and Thales)
€1.3M for science studies and airborne campaigns

4. Details of the impact

Accurate knowledge of the spatial distribution of forest biomass and its changes over time are needed to improve present assessments and future projections of the terrestrial carbon cycle, as they integrate processes that release (e.g. through deforestation) and absorb (e.g. through reforestation) carbon dioxide. This knowledge is essential to understanding the role of forests in climate change and the carbon cycle.

However, it has hitherto been impossible to make accurate large-scale measurements of biomass *in situ* because of logistical issues. This is a major obstacle to carbon trading schemes that finance forest management in developing countries to reduce emissions. In particular, the proposed United Nations mechanism “Reductions of Emissions from Deforestation and Degradation” (REDD+) may never be ratified unless the difficulties of monitoring and verifying reported values of biomass change in tropical forest countries are resolved.

The lack of reliable biomass information also has severe consequences for climate calculations. Biomass loss from tropical deforestation gives rise to between 9 and 24% of total anthropogenic emissions (Intergovernmental Panel on Climate Change, 2007). This huge uncertainty yields even greater uncertainty in the uptake of carbon land surface, because this is estimated as a residual after accounting for total emissions, the growth of atmospheric carbon dioxide and carbon flux into the oceans. The size of land uptake, its location, and how much is stored as forest biomass therefore constitute major unknowns about the Earth’s carbon cycle.

Quegan contributed some of the key ecological and technological research underpinning the BIOMASS mission concept, and was crucial in creating the convincing scientific basis that led to the concept being selected for implementation [**S1-S5**].

The BIOMASS mission aims to take measurements of forest biomass to assess terrestrial carbon stocks and fluxes. The mission employs a novel P-band synthetic aperture polarimetric radar operating at 435 MHz with a 6 MHz bandwidth. In addition to unprecedented data on forest biomass, the deployment of this wavelength for the first time in space means that the mission will also provide new information on ice-sheet thickness and internal structures in cold regions, subsurface geology and water resources in arid regions, as well as data on soil moisture, permafrost, the ionosphere and sea-surface salinity.

This is the seventh in the ESA’s Earth Explorer series of missions, of which three are currently in orbit. The first was launched in 2009. Earth Explorer is one of ESA’s “optional” programmes, meaning that funding from member states is voluntary, but the individual member states have all approved the spending on BIOMASS from their public budgets.

The project has had significant economic impact both in terms of the money already been spent in the European economy through the initial phases, and in the quantifiable re-allocation of public spending committed for the future mission.

Re-allocation of spending

ESA has committed €470M to the mission up to its launch in 2020. To put this in context, the total ESA budget for 2013 is €4,282M, of which 22.9% is earmarked for Earth Observation missions such as BIOMASS. Individual member states are expected to commit additional funding to the project. Of the overall €470M approved by ESA, €277M has been specifically earmarked for spend with industry, as well as a share of a further €32M. The mission has already led to at least €5.6M of ESA money being spent with two European industrial consortia led by Astrium and Thales since 2009, with a further €1.3M spent on science and campaigns.

5. Sources to corroborate the impact

S1 European Space Agency (2008). *BIOMASS Report for Assessment*, European Space Agency, ESA SP 1313/2, page 3 corroborates Sheffield contribution to the underpinning science.

S2 European Space Agency (2012). *BIOMASS Report for Selection: an Earth Explorer to measure forest biomass*, European Space Agency, ESA SP 1324/1. Page ii confirms Sheffield membership of Biomass Mission Advisory Group; page 185 confirms Quegan's research outputs cited.

S3 European Space Agency (2013). *Earth Explorer 7 Candidate Mission Biomass: Addendum to the Report for Mission Selection*, EOP-SM/2458/MD-md.

S4 Further confirmation of the essential contribution of Quegan's research to the Biomass mission being selected can be obtained from the ESA BIOMASS Mission Scientist, Mission Science Division, ESA-ESTEC (the European Space Agency's space research and technology centre, where all ESA space missions are developed and managed).

S5 Further confirmation of the essential contribution of Quegan's research to the Biomass mission being selected can be obtained from the Business Development Manager, Earth Observation, EADS Astrium. Astrium is the European leader, and second in the world, in space transportation, satellite systems and services, with 18,000 employees.