Measuring the Planet 2013
The First ASTROTROP Conference
Royal Observatory, Edinburgh, 30-31 October 2013

Conference Report

1. Introduction

ASTROTROP is a unique collaboration between a network of UK and European astronomers (AstroGrid/Euro-VO), and a network of UK scientists that is studying the role of tropical forests in global environmental change and has links to numerous international networks (TROPGLOBE).

The project, which is funded by the Science and Technology Facilities Council (STFC), aims to: (a) advance measurement of Planet Earth by enabling global change scientists to better understand the methods of astronomers; (b) build bridges across disciplinary boundaries within tropical forest research by exchanging and combining multiple datasets on multiple forest attributes; (c) adapt AstroGrid/Euro-VO virtual observatory software for use in a Pan-Tropical Forest Observatory and test its feasibility; (d) demonstrate the functionality of such an observatory by enabling tropical forest researchers, who would be its main users and sources of data, to exchange and combine multiple datasets, both manually and virtually using the adapted AstroGrid/Euro-VO software; (e) by further adapting AstroGrid/Euro-VO software, and other innovations, develop new global environmental observatory technologies with commercial applications; and (f) use these activities as proof of concept of hosting a Pan-Tropical Forest Observatory on an STFC server to benefit UK tropical forest researchers.

This document summarizes presentations and discussions at the First ASTROTROP Conference, "Measuring the Planet 2013", which was held at the Royal Observatory, Edinburgh, on October 30th and 31st 2013. The goals of the conference were to (a) discuss and refine the project plan; (b) scope AstroGrid/Euro-VO software adaptation; (c) launch dialogues between different disciplines and between global change scientists and astronomers; (d) hear stakeholder information/technology needs; (e) agree on project organization; and (f) begin planning Web-based dataset exchange methods. Participants are listed in Appendix 1.

2. Sessions on 30 October

2.1 Welcome

Participants were welcomed by Lesley Yellowlees, Vice-Principal of the University of Edinburgh, and Catherine Ewart, Head of the STFC Futures Programme.

2.2 *Overview: Alan Grainger*

Since remote sensing satellites have been collecting global data since 1972, ideally these data would have been converted into global digital information on the distribution of forests, other ecosystems and land use which scientists could analyse. Instead, although satellite data have been used for many localized studies and occasional studies at higher spatial scales, we lack regular measurements of changes in world forest area. Consequently, many national, regional and global estimates of related changes in biodiversity and carbon fluxes have had to depend on compilations of unreliable national statistics. This has limited the accuracy of scientific research into global environmental change, and of information available to policy makers.

A World Forest Observatory would produce annual maps of world forest area, biodiversity and carbon density, which scientists worldwide could analyse. The availability for the first time of global empirical information would lead to the rapid growth of a new global change science. Scientists working on changes in forest biodiversity and carbon would no longer have to depend on national statistics for area information, or to hire their own remote sensing scientists to provide area maps, since they could now download these from the observatory. A World Forest Observatory would be the pilot for other global environmental observatories, covering such key phenomena as biodiversity loss, desertification, and land use change.

The initial plan for a World Forest Observatory, produced in 2010, relied on a *hub* design, in which 10-20 teams across the world would produce digital maps of these three forest attributes. These maps would then be combined on a central geographical information system at a global hub, from which users would download global digital maps. However, an alternative *virtual* design would retain the decentralized approach to monitoring multiple forest attributes, but use a central server to access the standardized databases of the monitoring teams, so that multiple attribute maps would still appear to be overlaid in the computers of users. This design involves similar challenges to the first one, e.g. ensuring collaboration between different disciplines and setting common standards, and it is important to assess its practical feasibility and cost relative to the £2 million annual budget of the hub design.

The ASTROTROP project is funded by STFC's Challenge-Led Applied Systems Programme, which aims to: apply STFC-Funded Research to have impacts in STFC Global Challenge Areas, which include the environment; fill technology gaps, which include the automated monitoring of ecosystems and carbon emissions; produce "demonstrable deliverables for a potential market", in this case scientists, companies, policy makers and other stakeholders; and have environmental, social and commercial benefits.

Activities in Year 1 of the project will involve an evaluation of the potential to adapt AstroGrid/Euro-VO; informal manual exchanges of multiple tropical forest attribute datasets over the Web and their combination by groups of partners; work to design new technologies; and meetings between astronomers, tropical forest researchers in individual universities. The next meeting, Measuring the Planet 2014, will report on progress in Year 1, report on the changes needed in AstroGrid/Euro-VO before it can be used for virtual overlays of tropical forest datasets; and refine the project plan for Year 2, which otherwise will continue the activities of Year 1. The final conference, Measuring the Planet 2015, will report on the feasibility of using AstroGrid/Euro-VO in a Pan-Tropical Forest Observatory; agree on the budget for hosting this on an STFC server; and present plans for new technologies.

Establishing a Pan-Tropical Forest Observatory in the UK as a pilot for a World Forest Observatory would be highly appropriate given the leading role of UK scientists in tropical forest research, and the rapid changes in tropical forests. It would also act as a focus for a vibrant industry devoted to developing the innovative technologies needed for a growing family of global environmental observatories and ensuring a seamless chain from satellite data to information on policymakers' desks. This is consistent with the goals of the new UK Satellite Applications Catapult, and of the European Commission's Copernicus Programme, formerly known as the Global Monitoring for Environment and Security Programme.

2.3 Astro-Grid/Euro-VO Software: Keith Noddle and Andy Lawrence

Astro-Grid and later virtual observatory (VO) software have been devised to allow astronomers to solve large and complex problems that require access to multiple datasets distributed all over the world. Astronomers can store data in their own datasets in their preferred formats, but a set of standards agreed under the auspices of the International Virtual Observatory Alliance, together with intermediate data services software, ensure compatibility between datasets from different databases.

Data services are just one component of the "middleware" that glues things together. Other components include a registry (the equivalent of Yellow Pages), access control, and VO space for storage, but these all remain invisible to individual users. Users have access to various analytical tools, such as Aladin and TOPCAT.

A virtual observatory allows production and comparison of alternative measurements, but does not remove the need for quality control operations by scientific users. AstroGrid/Euro-VO has no built-in feature to measure polygon areas, but equal and unequal area polygon methods are available in the HEALpix application.

2.4 Forest Area Mapping: Kevin Tansey

Satellite remote sensing techniques have been used to map forest area change based on canopy reflectance in the optical spectrum since the early 1970s, but only since 1990 have studies at continental and higher scales been attempted. More recently, radar and Light Detection and Ranging (LiDAR) sensors have been used to estimate canopy height and in turn forest biomass. There is great potential, initially by ASTROTROP Demonstrator Groups and later within a Pan-Tropical Forest Observatory, to share, combine and analyse multiple geo-referenced maps of forest area, biomass and other attributes at pan-tropical and lower scales, and to compare alternative maps of the same attribute. For this purpose they can use generic geographical information system (GIS) software or specialist software (such as OE).

Planetary measurement has been facilitated by two recent developments. First, the free availability of data collected by Landsat and MODIS satellites. Second, the production by NASA of composite image datasets, initially in their Global Land Survey (GLS) composites of the highest quality images for 2000, 2005 and 2010 for the whole world (http://landsat.usgs.gov/science_GLS.php), and most recently in the pre-processed Web Enabled Land Data (WELD) series, produced initially for the continental USA only (http://landsat.usgs.gov/WELD.php). Both datasets do, however, still require classification for mapping purposes.

As part of the ASTROTROP project, TROPGLOBE members can download the University of Maryland's Global Land Cover Global Forest Area Map for 2000, based on GLS composites of Landsat images (http://glcfapp.glcf.umd.edu:8080/esdi); Terra-i maps of Latin American Forest Area produced at Kings College, London (www.terra-i.org); and a new Forest Area map of the Congo Basin which is being produced at the University of Leicester using data from various sensors (www2.le.ac.uk/departments/geography/people/kjt7).

A suggestion that emerged in the subsequent discussion was that satellite data and the spatial information generated from these should be given quality flags.

2.5 Science and Technology Programmes: Alan Grainger

ASTROTROP will be implemented in three work packages, each associated with one of three main groups of partners: Interface Groups (Work Package 1), Demonstrator Groups (Work Package 2), and Incubator Groups (Work Package 3).

The activities of the Demonstrator Groups and Incubator Groups will be aggregated within a Science Programme and Technology Programme, respectively. Both are underpinned by work at Royal Observatory Edinburgh to adapt Astro-Grid/Euro-VO software in Work Package 1. The conference enabled partners to discuss the Science and Technology Programmes in detail and scope software adaptation.

The key goal of the Demonstrator Groups is to demonstrate the functionality of a future Pan-Tropical Forest Observatory within the constraints imposed by available funding and existing datasets. To do this, TROPGLOBE members will engage in manual and virtual informal exchanges and combinations of spatial data and information in six main Demonstrator Groups: biodiversity; carbon; ecosystem processes; gaseous processes; hydrological services; and forest management. Some exchanges could lead to publishable scientific outputs, but the main focus will be to record exchanges as typical demonstrations in the Science Programme component of the final project report, and on the project website.

The Science Programme therefore comprises both demonstrations that partners wish to attempt now, and a list of priorities which the partners would like to tackle when a future Pan-Tropical Forest Observatory becomes operational.

Another element of the Science Programme will be informal discussions between teams of astronomers and global change scientists in Interface Groups at those universities which have members of both the AstroGrid/Euro-VO and TROPGLOBE networks. These discussions will allow astronomers and global change scientists to exchange information about their activities so they can learn from each other and identify new methods which can benefit their own research.

The Technology Programme will consist of plans discussed within Incubator Groups to devise new software and hardware technologies. Some of these technologies will be derivatives of Astrogrid/Euro-VO; others will be stand-alone, but will nevertheless contribute to comprehensive global environmental observatory technologies.

A suggestion that emerged in the subsequent discussion was that Demonstrator Groups and Incubator Groups should be linked more closely.

2.6 Demonstrator Groups Breakout Sessions

Participants divided into three Demonstrator Groups to begin discussions about informal exchanges of data in Demonstrator Groups in Year 1 of the project. Meeting in just three groups was considered optimal because the number of partners attending the conference who did not study biodiversity or carbon was relatively small. The reports of each group indicate the partner who convened it on the day in question.

All groups recognized that top priority should be given in the project to undertaking selected demonstrator projects that will support a larger bid for a future Pan-Tropical Forest Observatory. To identify the most appropriate projects, they sought to identify: (a) key scientific questions that could form the focus for collaboration; (b) the practical aspects which would constrain their choices; and (c) the scope and geographical location of existing forest datasets held by individual partners, and which could be exchanged and combined for demonstration purposes. For convenience, and following recommendations by these groups, a draft inventory of partners' datasets is listed here in a single location in Appendix 2.

2.6.1 Biodiversity: Adrian Newton

2.6.1.1 Potential Elements of the Science Programme

For the biodiversity component of the Science Programme to be feasible it should not be overambitious, but build on existing research to demonstrate the potential for:

a. Producing a pan-tropical map of the distribution of tropical timber tree species in remaining forests, to support conservation assessments initiated by Bournemouth University, Botanic Gardens Conservation International and IUCN.

b. Producing more rigorous biome maps that are linked across scales to species distribution maps.

c. Using these maps to (i) improve ground truthing for satellite image classification; (ii) track the spread of pathogens or invasive species; (iii) evaluate, challenge or refine earlier studies; (iv) assess forest degradation; and (v) evaluate potential impacts on biodiversity of policy interventions, such as the Reducing Emissions from Deforestation and Degradation (REDD+) scheme of the UN Framework Convention on Climate Change.

d. Undertaking more sophisticated studies, which could include: (i) linking species and biome maps with maps of plant functional types and the functional diversity of forests, in order to explore links with ecosystem service provision; and

(ii) monitoring functional changes over time that could lead to forest collapse via critical tipping points.

2.6.1.2 Practical Issues

To facilitate integration of forest area maps derived from remote sensing data with biodiversity data collected by ground measurements, it will be necessary to experiment with combining polygon data and point data, respectively, building on experience in other initiatives, such as the Map of Life Project, and the Terra-i mapping project whose forest area maps will be available to partners.

Progressing from manual integration of these two types of information/data, in Year 1, to virtual integration using the adapted Astrogrid/Euro-VO software, in Year 2, will require careful planning, and identification of priority activities that will provide good demonstrator case studies and tackle scientific priorities too.

Activities should also be planned by taking into account how the different disciplines within tropical forest research operate on a daily basis, and identifying any limitations that these operations could impose on the success of the project.

It would be desirable if, within the limited funds available for this project, activities by partners could generate new scientific methods and new discoveries. Partners recognized that the potential for linking data at local, regional, national, continental and global scales during the project would represent an important advance.

Links have already been made with key national government policy stakeholders, such as DEFRA and the Forestry Commission, but partners saw the potential to extend this to international policy processes, such as the Convention on Biological Diversity, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem services, and the UN Forum on Forests.

2.6.2 Carbon: Yadvinder Malhi

The Carbon Group also discussed what scientific priorities to address in the project and practical aspects of collaborations between partners.

2.6.2.1 Potential Elements of the Science Programme

Since the two-year timeline of the project imposes limitations on what can be accomplished, the focus should be on deliverables that are easily achieved using available remote sensing data and datasets, e.g. data on carbon fluxes held at Oxford, Leeds and other universities. This suggested four key scientific priorities:

a. Combining carbon data from local plots with forest area maps at larger scales. This would provide proof of concept of a larger bid for a future Pan-Tropical Forest Observatory. It would also add value to projects based on local data collection by providing easy access to forest area maps, and improving calibration of pan-tropical carbon maps.

b. Comparing the resulting maps of carbon density distribution with earlier forest carbon maps.

c. Comparing a time series of carbon density maps to investigate the dynamics of tropical carbon pools and fluxes.

d. Collaborating across Demonstrator Group boundaries by combining maps of biodiversity, carbon and hydrological services.

2.6.2.2 Practical Issues

Actions necessary to achieve these priorities include: (a) assembling a list of datasets that partners have constructed; (b) identifying the formats in which data are stored, e.g. SQL; (c) agreeing common data standards; (d) developing a common query language; (e) experimenting with combining different polygon and point datasets to facilitate future manual and virtual overlays; and (f) ensuring efficient data interfaces with space agencies, such as the use of metadata to identify the quality of satellite images, e.g. by using Group on Earth Observations (GEO) standards.

2.6.3 Ecosystem Services: Alan Grainger

The 'Ecosystem Services' Group which met at the conference comprised partners who study hydrological services and gaseous processes.

2.6.3.1 Potential Elements of the Science Programme

Key scientific questions which the group wished to tackle were:

a. Combining hydrological data with spatial data on forest area to map the supply of hydrological services from selected catchments by extrapolating from case study sites to larger areas.

b Linking changes in hydrological services to forest cover change and its societal drivers, by overlaying environmental and socio-economic spatial datasets.

c. Tackling broader ecological questions by linking the datasets in (a) to other spatial datasets on soil, e.g. from UNESCO, and climate, e.g. satellite-derived precipitation data collected by the Tropical Rainfall Monitoring Mission (TRMM).

d. Improving the hydrological content of global climate models (GCMs), whose resolution is currently too low to take proper account of terrestrial hydrological fluxes. This work could be facilitated by establishing data exchange and other links with the Global Energy and Water Exchanges Project (GEWEX) and Global Run-Off Data Centre (GRDC).

e. Using enhanced maps of the distribution of gaseous emissions to improve validation of the outputs of regional and global climate models.

2.6.3.2 Practical Issues

The potential for large-scale mapping of hydrological services is limited, since hydrologists work at local scale and there are only about 20 good case study sites in the entire tropics. Partners working in the Western Ghats have experienced difficulties in extrapolating from case study sites to large areas, though an initial solution may involve a nested basin approach. Many other relevant hydrological data are reported in journal review articles, but using these data will be difficult since the articles often do not list precise grid references for measurement sites.

Users of information from a Pan-Tropical Forest Observatory could be asked to feed back into the Observatory the more complex information they have generated from observatory information. This would be facilitated if the findings of this research were reported in new types of digital journals modelled on the *Biodiversity Data Journal,* which includes conventional papers plus data in transferable digital form.

Trace gases are also measured as point sources. Gaseous data are also collected by a small number of long-term measurement stations but, unlike hydrological services, these are supplemented by hundreds of sustained field campaigns, especially in Borneo and West Africa. However, extrapolating from point sources to large areas is less robust than for hydrological services. Members of TROPGLOBE who study gaseous processes would benefit from using data from the British Atmospheric Centre Database, and the Environmental Information Data Centre at the Centre for Ecology and Hydrology (which has a lot of metadata).

2.7 Using Astronomical Methods in Global Change Research: Andy Lawrence

The top priority for all ASTROTROP partners at the start of the project is to identify concrete outputs that will be feasible to achieve.

2.7.1 Using Virtual Observatory Software

Astronomers now use virtual observatory (VO) software to: (a) easily locate the datasets they need for their research; (b) take a uniform approach to obtaining and analysing data; (c) mix and match data; and (d) remove barriers to practising science. Just as in the Web all documents are inside your PC, in a virtual observatory it feels as if all databases in the world are inside your PC. The Web is very powerful but very simple: Web standards, for example, say nothing about quality, content or meaning.

The functionality of AstroGrid/Euro-VO relies on three factors:

a. Infrastructure, which includes registries of datasets; VO space; cloud storage; the data services interface; and parsing.

b. Standardization, which involves either using actual standards or copying processes for image/table formats, data source portals, time/space definitions, semantics of column headings, and data models. Astrogrid uses a standard interface format but not a standard database format.

c. Tools, which include displaying images, e.g. by using Aladin; table manipulation and plotting, e.g. by using Taper; spectral analysis, e.g. by using Split; and various Web query approaches.

Lessons that astronomers have learned and which may be valuable for global change scientists include:

a. Loose coordination through the International Virtual Observatory Alliance (IVOA) helped astronomers to reach agreement on standards and other matters. There is no central "VO Command", since a VO is not an entity but a way of life.

b. AstroGrid was developed in practice by holding meetings of partners twice a year; organizing working groups; and sharing process models in the Web.

c. AstroGrid partners also engaged with the international and multidisciplinary Research Data Alliance.

d. The more successful AstroGrid became the more invisible it was to users. So when global change scientists use adapted AstroGrid/Euro-VO software in a Pan-Tropical Forest Observatory they could also soon take it for granted as an everyday tool.

e. AstroGrid greatly benefited from changes in government priorities. A key reason for its development was that in 2002 "e-science" became fashionable in UK government. This enabled astronomers to gain funds to find solutions to problems that had increasingly concerned them over the past 10 to 15 years. Current developments in the policies of the UK government, and also in the UN Framework Convention on Climate Change (through the Reducing Emissions from Deforestation and Degradation (REDD+) scheme) and the Convention on Biological Diversity (the Aichi Targets), could benefit a Pan-Tropical Forest Observatory in a similar way.

2.7.2 Collaborating in Interface Groups

Discussions in Interface Groups could identify how the experiences of astronomers can benefit global change scientists, and vice versa. In particular, they could identify the similarities and differences between what astronomers have already done and what global change scientists would like to do.

Similarities between astronomy and global change research which have already been identified in embyronic Interface Groups at Edinburgh, Leeds and Leicester include: (a) a desire to mix and analyse data sources; (b) the use of pixel data; (c) the presence of universally agreed coordinate systems; (d) the existence of catalogues of object/point properties; (e) the large scale of data, covering 400 billion trees in tropical forests, and 200 billion stars in our galaxy; and (f) the fact that nearly everything can be described using images, tables and polygons. In tables, unlike images, columns can be swapped but the table still remains.

Differences between the two communities include: (a) global change scientists experience greater political and commercial constraints; (b) data sources are more heterogeneous in global change than in astronomy; (c) polygons are used instead of objects to represent entities; and (d) end users are far more diverse, each having different needs for information, visualization, and for summaries instead of raw data.

2.8 Enhancing Project Organization: Andy Lawrence and Alan Grainger

Overall coordination will be provided by the three Co-PIs: Andy Lawrence, Keith Noddle (who coordinate Work Package 1) and Alan Grainger (who coordinates Work Packages 2 and 3). They will report to an Ad Hoc Steering Committee, which includes partners contributing to all major activities in the project: (a) software (Andy Lawrence and Keith Noddle); (b) website (Keith Noddle); (c) TROPGLOBE (Alan Grainger); (d) Biodiversity Demonstrator Group (Adrian Newton and William Milliken); Carbon Demonstrator Group (Yadvinder Malhi and Shaun Quegan); Ecosystem Processes Demonstrator Group (Jill Thompson); Gaseous Processes Demonstrator Group (Neil Harris); Hydrological Services Demonstrator Group (Mark Mulligan); Forest Management Demonstrator Group (Jim Lynch); forest area and other remotely sensed map provision (Mark Mulligan, Kevin Tansey and Iain Woodhouse); Incubator Groups (Jim Lynch); and stakeholders (Peter Allan and Juan Suarez). Self-nominations from other partners wishing to serve on the Committee are welcomed, since owing to busy schedules not all members can attend every meeting.

Partners made several proposals for improving how the project will be implemented:

1. Exploit synergies within the project partnership better. In the original project plan, each Demonstrator Group would work on its own in Year 1, with members exchanging and combining datasets and gaining experience in overlaying these with forest area maps. However, there was enthusiasm for closer collaboration between these Demonstrator Groups in Year 1, and for interchanges between the Demonstrator Groups, Incubator Groups and Interface Groups.

2. Exploit synergies with other networks and groups better. The datasets of many partners are linked to international networks, some of which are listed in the project proposal, and other members of these networks can collaborate with the project if they wish. Other data centres which could be involved include the Global Runoff Data Centre, the World Meteorological Organization (which is the focal point of the Global Energy and Water exchanges Project (GEWEX)), and the UN Food and Agriculture Organization (FAO). Collaborative projects could be established in return for accessing their data. The International Hydrological Programme of the UN Educational, Scientific Educational and Cultural Organization (UNESCO) has also been successful in circumventing restrictions on data sharing by convening regional meetings at which scientists with data to share can make contact.

3. Broadening international collaboration even further would facilitate project implementation and encourage national operational and funding agencies to give even more support to it, and to the long-term objective of a Pan-Tropical Forest Observatory. AstroGrid greatly benefited from joining the Research Data Alliance (RDA) and it was suggested that ASTROTROP should do so too, as this would align it with other related activities in the minds of donors. ASTROTROP could first establish an RDA Interest Group and then a RDA Working Group. Another important international scientific grouping is the International Council for Science, which is

currently converting its family of World Data Centres into "a common, globally interoperable, distributed World Data System".

3. Sessions on 31 October

3.1 Using the Project Website: Keith Noddle

The project website is currently being constructed using DokuWiki, an easy-to-use software. The Meetings tab was already fully functional in time for the Conference, leaving pages in other tabs to be added or amended later. The website will serve as the public face of the project and communicate activities and findings to stakeholders. It will also enable partners in the project to communicate with each other and exchange data and information. Some parts of the website will be static and others dynamic. Some parts will be publicly visible but others will be restricted to partners to allow freedom of communication and the editing of key documents. Each Demonstrator, Incubator and Interface Group will have its own set of editable pages. Partners will be able to access their pages by logging in with their user names.

3.2 Area Mapping: Mark Mulligan

The Terra-i Project at King's College, London maps forest area in Latin America every 16 days using MODIS satellite imagery. The maps begin in 2004, and are calibrated by links between vegetation greenness and rainfall between 2001 and 2004, as well as by Landsat data. The aim is to expand the scope of monitoring to the whole tropics in 2014. ASTROTROP partners can download maps from www.terra-i.org.

Because the MODIS sensor only has 250 m resolution Terra-i does not show small-scale deforestation, e.g. of the order of 1 hectare, which is typical of widespread clearances by shifting cultivators. On the other hand, it offers near real-time monitoring (with a 3 month delay due to processing) and time-series information on trends in forest area that is easy to access and visualize. ASTROTROP partners can download maps with regional, national and sub-national coverage to combine with their own non-area data. The King’s College team itself also conducts research on ecosystems services and already demonstrates multiple attribute mapping in its Co$ting Nature application (www.policysupport.org/costingnature).

3.3 Demonstrator Groups Breakout Sessions

Demonstrator Groups continued the discussions they had begun on Day 1, with two main objectives. First, to refine the list of priority scientific questions to include in the ASTROTROP Science Programme. Second, to continue examining practical aspects of data exchange, and in particular to scope the adaptation of Astrogrid software by looking at the formats of datasets currently used by members of TROPGLOBE, and typical queries they will make when using the "New Astrogrid".

3.3.1 Biodiversity 1: William Milliken

ASTROTROP partners will benefit from exchanging data as this will give them access to multiple data sets with higher levels of spatial resolution and accuracy than are currently available to them as individuals. They may even be unaware of the existence of some of these datasets. Although the ASTROTROP project is only providing proof of concept for a future Pan-Tropical Forest Observatory, similar methods would be used in a more comprehensive World Forest Observatory, or in a Global Biodiversity Observatory covering all terrestrial ecosystems and not just forests.

3.3.1.1 Potential Elements of the Science Programme

Key scientific questions which could be tackled include:

a. Modelling links between forest carbon density and biodiversity by a number of integrated case studies which integrate small-scale point data on species distributions and carbon density with higher scale raster map data on forest area and ecosystem type.

b. Combining biodiversity datasets with land use change maps, linked to socio-economic data on human population growth and economic development. This would improve simulations of the impact of deforestation on biodiversity degradation, and increase the accuracy of inputs to the IUCN Red List process.

c. Developing new integrated taxonomies for classifying biodiversity that are consistent with the different classification systems used on different sides of national borders. Assembling distribution maps of ecosystem, species and genetic diversity in a Pan-Tropical Forest Observatory could assist efforts under the Pro-iBiosphere Project and other projects to realize this goal.

3.3.1.2 Practical Issues

a. It would be good to collaborate with the Global Biodiversity Information Facility (GBIF), which is building a global database on data held in different centres.

b. Datasets containing plot data are more dispersed than the herbaria and other data centres listed by the GBIF. Including plot data would potentially make a vast amount of information available to a Pan-Tropical Forest Observatory, though many existing forest plot networks have strict data access conditions and these may present challenges.

c. There is scope to incorporate community-based monitoring data (including crowd sourcing), and other small datasets, which are collections-based or inventory-based. Many small datasets currently remain isolated, but incorporating them would be facilitated if scientists in future publish data in digital form in the *Biodiversity Data Journal* and similar journals.

d. Using both high-level databases and small datasets will require careful consideration of the structure and format of the datasets if these are to be compatible with observatory software.

e. Establishing protocols for geo-referencing data should not be a problem for most biodiversity datasets. The Pro-iBiosphere Project is exploring how to develop common international protocols for all biodiversity data.

f. As historical data are often not georeferenced, any attempt to use them will involve imprecision. It will be necessary to quantify uncertainty levels, and incorporate polygon data. However, historical data are a potential goldmine, allowing backwards-looking as well as forwards-looking analysis. Polygons may include species or vegetation/ecosystem type locations based on surveys or maps, as well as more general references to the localities where specimens were collected.

g. Species identification also involves uncertainty. Challenges to address include the shifting, and to some degree, subjective nature of taxonomy; variation in names between datasets; and the recognition of taxa by different names in different countries and regions.

h. Vegetation/ecosystem type classification is potentially an important bridge between point and spatial data. However, global vegetation is still only classified at relatively low resolution, and different scientists employ different global vegetation classification systems. As individual countries and regions often have their own systems this makes it difficult to engage in cross-border analysis at higher resolution.

3.3.2 Biodiversity 2: Adrian Newton

ASTROTROP can identify research that is impossible now but might be possible in the future when pan-tropical datasets on multiple forest attributes become available, and demonstrate the potential for this by undertaking selected case studies based on datasets currently held by partners.

3.3.2.1 Potential Elements of the Science Programme

Key scientific questions which could be tackled include:

a. Starting to map the distribution of tropical timber tree species in existing forests, by combining point data on species location with forest area maps based on remote sensing data. This would fill a critical gap in the conservation biology literature, as few attempts have been made to do this until now. It would also support a tropical tree conservation assessment that is currently under way.

b. Overcoming the limitations of existing global biome/ecosystem type classifications by reanalysing them using new data on species distributions.

c. Combining maps of forest biodiversity and carbon density, to assess potential impacts of REDD+ projects targeted on carbon conservation, and improve understanding of links between carbon density and species distributions.

d. Analysing dynamic forest landscapes to study successional mosaics; map forest regrowth in ways that distinguish between forest plantations and natural regeneration; map the areas and types of forest degradation, for REDD+ applications; and detect forest dieback and collapse.

e. Studying relationships between forest biodiversity and other ecosystem services.

f. Interrogating multiple spatial datasets for the same area or location to generate and test new hypotheses that can advance biological theory.

3.3.2.2 Practical Issues

ASTROTROP can make a major advance by helping scientists to bring together in an easy way large numbers of different datasets, such as those on species distributions listed by GBIF and in the IUCN Red List database, or contained in databases that integrate data from networks of forest plots, and combine these with forest area maps based on remote sensing data.

To identify feasible case studies that can demonstrate proof of concept, and plan future activities for when a Pan-Tropical Forest Observatory has been established, it would help if partners were to list on the internal project website information about the existing datasets which they have collected in the course of current or previous projects, using a common template provided for this purpose.

Prerequisites for using data not held by ASTROTROP partners include establishing formal links with GBIF, IUCN and other bodies, and devising a protocol for creating an inventory of forest plot data. Data ownership and access barriers may arise for some data, particularly for those derived from networks of forest plots.

A review of the state of the art in integrating remote sensing data and data on species distributions etc. would provide valuable support to the demonstration of the proof of concept provided by the case studies. Partners could assist this review by contributing summaries of their current research activities on the internal project website, again using a common template.

3.3.3 Carbon: Alan Grainger

3.3.3.1 Potential Elements of the Science Programme

Key scientific questions which could be tackled include:

a. Combining forest area maps with carbon density data from the hundreds of forest plots in the RAINFOR and other networks to produce forest carbon maps. An example of a map that has already been produced using RAINFOR data was shared with participants.

b. Combining maps of forest carbon density in forest plots with maps of species distributions. This would improve understanding of the link between tree growth and tree species.

c. Charting trends in forest areas and deforestation rates, by taking advantage of the high frequency of forest area mapping by Terra-i.

d. Charting trends in tropical forest carbon content over the last 30 years. This would greatly improve estimates of the global carbon budget. Datasets for below-ground biomass could be added to those for above-ground biomass.

e. Identifying links between changes in forest area and carbon content and socio-economic driving forces, by interfacing forest area and carbon information layers with socio-economic information layers, and allowing for political influences.

f. Comparing maps of trends in forest area with information on the occurrence of fires from other international datasets.

g. An ASTROTROP toolkit for combining spatial information layers on the distribution of multiple ecosystem services would provide a "one-stop shop" for evaluating the impact of maximizing conservation for one service, such as carbon cycling, on other services, such as biodiversity.

3.3.3.2 Practical Issues

Adapting the AstroGrid/Euro-VO software for use in ASTROTROP requires knowledge of the formats in which existing datasets are structured. Only one member of the Carbon Group uses SQL for their datasets; others use Excel spreadsheets.

Comments on the diversity in database formats included: SQL servers use the table access protocol; universal control descriptors describe columns; AQL is a subset of SQL which also includes metadata; SQL is not as fast as Simple Image Access; Excel spreadsheets might be sufficient for early databases, though a tabular standard would be needed to make all data available to ASTROTROP partners.

Only limited progress was made in discussing the structuring of searches. TermSearch is used in AstroGrid to search within a circle of given radius about a point with a specific latitude and longitude, so this could be used for tropical forest applications. GEO wanted to devise a generic search protocol for satellite data but it is not clear if it has succeeded yet. ESA has introduced the Gaia Programme for the same end.

It would help if NASA and ESA agreed to new standards for the ASTROTROP registry. The fact that NASA has standards for astronomical data and supports the IVOA suggests that it will be amenable to doing the same for terrestrial databases.

Developing a virtual observatory approach for a Pan-Tropical Forest Observatory would benefit from a similar body to the IVOA for global environmental monitoring in general. Becoming part of the Research Data Alliance could facilitate this, for even though the RDA does not fund initiatives it does help them to align with potential donors.

Possible names for the adapted AstroGrid/Euro-VO software include “TropaGrid” and “AstroTROP”, though other names could be equally attractive.

3.3.4 Ecosystem Services: Mark Mulligan

Activities in Demonstrator Groups should identify scientific questions which have policy relevance and which members of each Demonstrator Group have the data and skills to tackle with the help of virtual observatory software.

3.3.4.1 Potential Elements of the Science Programme

Key scientific questions to examine include:

a. Overlaying different forest area datasets, and comparing the areas in which they agree and disagree on the presence of forest, taking into account the resolution of satellite sensor, image classification method and other data used to produce each map.

b. Combining a digital map of long-term forest area change, based on Terra-i, with a global runoff dataset such as GRDC, to understand the relationship between land cover change on specific catchments and changes in the runoff ratio from those catchments.

c. Evaluating the impact of forest area change on multiple ecosystem services, including biodiversity, carbon cycling and hydrological services.

d. Assessing the impact on society of the changes in forest ecosystem services quantified in (c), by combining digital maps of multiple forest ecosystem services with maps of socio-economic variables and how services are delivered to populations.

3.3.4.2 Practical Issues

ASTROTROP should establish direct links with data providers and users, rather than establishing remote links with datasets, since only those who construct and subsequently use datasets will know their limitations. This will also ensure that ASTROTROP always has access to the most up-to-date dataset.

It is important to evaluate the uncertainty associated with datasets, with the use of models to integrate and extrapolate point data to larger scales, and with the time taken to audit the quality of derived spatial information before it is publicly released.

ASTROTROP need not reinvent the wheel when devising standards for datasets, but instead could take advantage of osgeo.org open standards. The same would apply to data abstraction libraries, and web mapping, web processing and web feature services.

Using social sciences datasets in addition to biophysical datasets is crucial since, by definition, ecosystem services should meet the needs of human populations.

3.4 Stakeholder Panel: Genevieve Patenaude

A panel including Peter Allan (Satellite Applications Catapult), Helen Bellfield (Global Canopy Programme), Ed Mitchard and Iain Woodhouse (University of Edinburgh), and Richard Tipper (Ecometrica), examined how establishing a virtual Pan-Tropical Forest Observatory could meet the needs of stakeholders.

To identify the needs of stakeholders it is important to: recognize that they are incredibly diverse in their needs; engage early with them by sharing with them ‘cool’ case studies that show how the Observatory could help them; and seek the help of intermediary stakeholders, such as INPE in Brazil, who use academic methods, but engage closely with governmental stakeholders.

Stakeholder needs include user friendly web tools that can ensure a seamless progression from data to information to knowledge to policy by: grabbing data or information easily; interfacing with wider tools, such as iPhone apps; and integrating with data sources for community-based projects.

To realize the long-term goal of a virtual Pan-Tropical Forest Observatory (PTFO) the panel suggested that partners should take an ambitious approach that specifies what is to be achieved, preferably by identifying realistic 5, 10 and 20 year goals. New software will be needed, preferably with generic algorithms, but full use should be made of existing software. The PTFO should generate information products that address the problems faced by stakeholders, who generally want answers to questions now and not in 10 years time. The PTFO's website could provide a portal to ASTROTROP case studies, and allow stakeholders to feed in information, perhaps using a wiki link like that developed by the International Institute for Applied Systems Analysis (IIASA).

The ASTROTROP project should therefore choose attractive case studies that have a big impact; integrate easily with existing databases; and focus on particular countries. Most successful endeavours first use marketing to create demand and then supply this demand, ASTROTROP could do the same by formulating a marketing plan to create demand among scientists and stakeholders for a Pan-Tropical Forest Observatory, and ensuring that the project website engages with stakeholders as well as scientists.

3.5 Incubator Groups Breakout Sessions: Jim Lynch and Alan Grainger

Participants divided into two groups to brainstorm on potential commercial technologies which could be developed in Incubator Groups. The first group focused on REDD+ systems and new remote forest sensors, while the second group discussed generic virtual observatory applications and enhanced decision-support systems for end users. Because key gaseous processes partners could not attend the conference a special workshop on low-cost ground gaseous sensors will be held at a later date.

Participants agreed that ASTROTROP can inspire innovative technologies if partners focus on practical technologies. These should complement those of other groups in the same field. We could showcase our technologies at venues where they will attract the attention of innovative companies, e.g. the Royal Society Summer Exhibition.

3.5.1 REDD+ Systems

Now that agreement has just been reached by the UNFCCC to put the REDD+ scheme into action there will be an urgent need for new off-the-shelf technologies. These should allow countries without functioning forest inventory systems to establish not only these systems but also the Monitoring, Reporting and Verification (MRV) systems for forest carbon that they will need to participate effectively in REDD+. Since GOFC-GOLD and the GEO Global Forest Observations Initiative (GFOI) are focusing on the appropriate use by governments of satellite images for forest monitoring, there is a need for a complementary approach that focuses on the easy integration of non-satellite data from multiple sources. AstroGrid/Euro-VO software could be adapted to produce comprehensive national maps of forest carbon by linking together forest inventory datasets from large numbers of highly dispersed sites within a country. There is every reason to expect that such maps can be produced rapidly, and updated easily without the need for large numbers of skilled personnel.

3.5.2 Forest Sensors

New generic forest sensors that could build on the expertise of the UK Astronomy Technology Centre include:

1. Low cost nano-sat satellites, such as CubeSat, which have high (10 m) ground resolution.

2. Airborne sensors, to survey trace gas emissions areas where existing datasets are limited, non-existent, or out-of-date.

3. Fixed-installation remote sensing from towers, which has extremely high spatial and temporal resolutions but can cover multiple square kilometre areas and may be applicable to monitoring forest plots.

3.5.3 Generic Virtual Observatory Applications

AstroGrid/Euro-VO software could also be adapted for generic applications. The most obvious one is the NERC Environmental Virtual Observatory (EVO), which aims to link together large numbers of dispersed datasets collected during NERC-funded projects so that other scientists can use them. A representative of the NERC EVO attended the conference. Once AstroGrid/Euro-VO has been adapted for the Pan-Tropical Forest Observatory, by using middleware on top of AstroGrid/Euro-VO to ensure interchangeability between AstroGrid point calculations and environmental raster calculations, it should be easy to adapt it again to meet NERC EVO needs.

3.5.4 Enhanced Decision-Support Systems for End Users

Global environmental observatories, for which the Pan-Tropical Forest Observatory is intended to be a pilot, will represent a considerable advance in fulfilling the vision of the EC Copernicus Programme of a seamless chain from satellite data to information on the desktops of policymakers and other stakeholders. The remaining links in the chain, which link scientists to stakeholders are by no means trivial, and are often obstructed by political barriers which ASTROTROP cannot address. However, this project can provide technologies to improve stakeholder access on the assumption that these barriers do not exist or are removed by other means.

Possibilities for innovation include:

i. Creating smooth channels between the virtual observatory software used to power the Pan-Tropical Forest Observatory and existing commercial software, such as OE, which is already used by stakeholders.

ii. Creating new generic interfaces, which will allow non-scientific end users to access the Pan-Tropical Forest Observatory directly, or can be used by commercial partners to enhance their own existing software. The group suggested that new interfaces should allow users to perform calculations with data, and test their own hypotheses about different scenarios, with complex algorithms kept in the background. The interfaces should be slick; user-friendly; capable of being fine-tuned to meet the different needs of diverse stakeholders; contain different applications which different users can select and which are compatible with software on different servers. Based on past experience, some end-users will prefer a command interface, some a menu interface, and others a browser interface (as in OE).

3.5.5 Additional Funding Sources for Incubator Groups

Possibilities sources of additional funding to support the work of Incubator Groups in ASTROTOP include:

a. The European Space Agency (ESA), which has a current call for proposals to which partners could respond, including generic thematic areas.

b. The Technology Strategy Board (TSB) has a call for seed projects that favour the UK economy. A number of partners have already received TSB funding.

c. The Universities Innovation Fund.

Individual universities could also form Regional Hubs. The core software would be the same in each hub but the relationship between the university and the surrounding region would be unique. The University of Leicester has experience in acting as a hub for space ideas with funds from the TSB.

STFC's Climate and Environmental Monitoring System (CEMS) server is intended to facilitate the derivation of information from space data and dialogues between the academic and business communities, and could form a hardware nexus for ASTROTROP's interactions with commercial partners. Experience in the first 18 months of CEMS operation is currently being evaluated, so this is a good time to engage with the CEMS team.

3.6 Interface Groups Panel

A panel including Keith Noddle, Andy Lawrence and Iain Woodhouse (University of Edinburgh), Alan Grainger and Roy Ruddle (University of Leeds), and Jonathan Tedds (University of Leicester) reported on the results of initial local interactions between members of the AstroGrid/Euro-VO and TROPGLOBE networks, and ranged more widely on the achievements of the Conference.

Local discussions in embryonic Interface Groups have proved very fruitful. They have enabled astronomers and global change scientists to identify similarities between the problems they are tackling and prompted ideas for generic solutions. Looking at global problems through the eyes of astronomers, and vice versa, has enabled members of each network to see their own problems in a fresh light, and given confidence that collaborations in ASTROTROP will have major benefits over the next two years. Talks between astronomers and tropical forest researchers at Leicester have already progressed to consider joint masters modules.

Collaborating in ASTROTROP can add value to both the AstroGrid/Euro-VO and TROPGLOBE networks by enabling global change scientists to learn about astronomy software, and use it to integrate data in new ways. Manual exchanges and combinations in Year 1, followed by virtual exchanges and combinations in Year 2, will offer a simple and low cost demonstration of what can be achieved by establishing a Pan-Tropical Forest Observatory to serve the wider tropical forest research community.

The project has an exciting vision and further discussions in Demonstrator Groups, Interface Groups and Incubator Groups, and in the next two project meetings, will enable partners to realize its full potential. After seeing what can be accomplished within the limits imposed by funding for ASTROTROP over the next two years partners should seek more funding to achieve even more. It was agreed that joining the Research Data Alliance, as proposed earlier in the Conference, by forming first an Interest Group and then a Working Group, would facilitate the raising of more funds, since the global transparency of aligning ASTROTROP to international and national priority issues would make it attractive to funding agencies at home and overseas.

3.7 Refining the Project Plan in the Light of Conference Discussions

There was general agreement that this Conference had made major progress, and had been a great success in launching dialogues between astronomers and global change scientists, and between the different disciplines which study tropical forests, that will provide a solid foundation for implementing the ASTROTROP project.

As expected, the Conference identified important technical questions that needed further investigation as part of the software evaluation study scheduled for Year 1. First, the issue of global coordinates was not completely resolved and it is important to agree on how to use these. Second, it will be vital to select the most appropriate ways to define arbitrary areas as polygons: one possibility is a hierarchical triangular mesh. Third, sensitivities about sharing raw data are greater in the global change community than among astronomers, but there are various possible ways to accommodate these sensitivities, such as a "smart dropbox".

The key organizational refinement proposed in conference discussions was for more interchanges between Demonstrator Groups, Incubator Groups and Interface Groups. Participants also felt that the Conference had given all partners much to reflect on about who is going to do what and at what time in the two years of the project.

Alan Grainger, on behalf of all participants, thanked Andy Lawrence, Keith Noddle, Nathalie Dupin and Paula Wilkie, and all other members of the Royal Observatory, Edinburgh, for their outstanding hospitality and for organizing such a successful conference. The Conference was closed at 1625.

Appendix 1
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Appendix 2. Draft Inventory of Datasets Held by TROPGLOBE Partners

	Africa	Asia	Latin America	Notes
Area				
Heiko Balzter (Leicester)	Sudan			
Mark Cutler (Dundee)		Sabah		
Giles Foody (Nottingham)		Sabah		
Richard Lucas (Aberystwyth)	Africa, Congo Basin, Guinea-Bissau	Malaysia, Queensland	Amazonia	Mangroves
Mark Mulligan (Kings)	Kenya, Tanzania		Latin America, Andes	Pan-tropical 2014 Montane forests
Edward Mitchard (Edinburgh)	Africa, Cameroon, Gabon, Mozambique			
Shaun Quegan (Sheffield)		Sumatra		
Kevin Tansey (Leicester)	Congo Basin	C. Kalimantan		
Iain Woodhouse (Edinburgh)	Malawi, Mozambique		Belize, Guyana	Open woodlands
Biodiversity				
Antje Ahrends (RBG Edinburgh)	Kenya, Tanzania			
Jos Barlow (Lancaster)			Amazonia	
David Burslem (Aberdeen)	Tanzania	Brunei, Sabah	Ecuador	
Mark Cutler (Dundee)		Sabah		
Rob Ewers (Imperial)		Sabah	Brazil	
Giles Foody (Nottingham)	West Africa	Sabah	Brazil, Peru	
Toby Gardner (Cambridge)	Tanzania		Amazonia, Brazil	Pan-tropical
Alan Grainger (Leeds)				Pan-tropical
John Healey (Bangor)	Tanzania	Sumatra	Jamaica, Peru	
Ross Hill (Bournemouth)			Mexico, Peru	
Tom Meagher (St Andrews)	Madagascar			
William Milliken (RBG Kew)			Amazonia, Brazil, Peru	
Mark Mulligan (Kings)			Colombia	
Adrian Newton (Bournemouth)			Central America, Mexico	
Alan Paton (RBG Kew)	Equatorial Guinea	Thailand		
Kelvin Peh (Cambridge)	Cameroon	P. Malaysia, Singapore		Pan-tropical
Toby Pennington (RBG Edinburgh)			Amazonia, Andes, Bolivia, Brazil, Panama, Peru	
Oliver Phillips (Leeds)		Borneo	Amazonia	
Tiina Sarkinen (RBG Edinburgh)			Latin America, Andes, Peru	Dry tropical forest
Chris Thomas (York)		Sabah	Latin America	Pan-tropical
Yongyut Trisurat (Kasertsart)		Thailand		

Carbon				
Antje Ahrends (RBG Edinburgh)	Tanzania, Uganda	New Caledonia		
Tim Baker (Leeds)			Amazonia, Brazil, Peru	
Pru Foster (Bristol)	D.R. Congo		Costa Rica	Pan-tropical
Manuel Gloor (Leeds)			Amazonia	Pan-tropical
John Grace (Edinburgh)	Cameroon, Ghana		Brazil, Peru	Pan-tropical
Simon Lewis (UCL)	Africa, Cameroon, Tanzania			
Yadvinder Malhi (Oxford)	Congo Basin	Sabah, Sulawesi	Amazonia, Andes, Brazil, Peru	
Robin Matthews (James Hutton)		Sumatra		Peatland
Patrick Meir (Edinburgh)	Cameroon, Ghana, Mozambique		Andes, Bolivia, Brazil, Peru Amazonia	
Edward Mitchard (Edinburgh)	Cameroon, Gabon, Mozambique, Uganda			Pan-tropical
Sue Page (Leicester)		C. Kalimantan		Peatland
Oliver Phillips (Leeds)	Africa, Tanzania	Sabah	Amazonia, Peru	Pan-tropical
Shaun Quegan (Sheffield)		Sumatra		
Ecosystem Services				
Luiz Aragao (Exeter)			Amazonia, Brazil, Peru	
Lindsay Banin (CEH)		Sabah, Sri Lanka		
Mike Bonell (Dundee)		India, Nepal, Queensland		
Nick Chappell (Lancaster)		India, P. Malaysia, Sabah, Thailand		
Daisy Dent (Stirling)		Sabah	Panama	
David Galbraith (Leeds)			Amazonia	Pan-tropical
Mark Mulligan (Kings)		Queensland	Costa Rica	
Kelvin Peh (Southampton)				Pan-tropical
Simon Queenborough (Sheffield)			Brazil, Costa Rica, Ecuador Panama	
Ed Tanner (Cambridge)			Jamaica, Panama	
Jill Thompson (CEH)	Cameroon, Congo Basin	India, P. Malaysia, Philippines, Sarawak, Sri Lanka, Thailand	Amazonia, Colombia, Costa Rica Ecuador, Panama, Puerto Rico	
Naresh Vissa (Dundee)		India		
Sue White (Cranfield)	Congo Basin, Tanzania			
Guy Ziv (Leeds)		Mekong Basin		
Fires				
Thomas Smith (Kings)		Brunei, Indonesia, Malaysia		
Kevin Tansey (Leicester)	Africa			
Forest Management				
Jim Lynch (Surrey)				Pan-tropical
Stephen Morse (Surrey)	Nigeria, Tanzania			

Gaseous Emissions

Mat Evans (York)	W. Africa	Sabah		
Pru Foster (Bristol)				Pan-tropical
Neil Harris (Cambridge)	W. Africa	Sabah		
Alastair Lewis (York)	W. Africa		S. America	
Eric Sofen (York)		Sabah	S. America	