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Executive summary

The leading objectives of EUFAR have been to promote efficiencies in the use of existing airborne research facilities through collaboration, networking and joint research activities and to provide access to facilities to scientific users without such access in the own country of employment. EUFAR overall strategy was guided by the Strategic Advisory Committee, which provided particular advice on the prioritisation of Transnational Access (TA) flight projects and the selection of future Joint research Activities (JRAs). The SAC was re-constituted towards the end of the project period to ensure the representation of key stakeholders and partner organisations going forward.

Members of the EUFAR2 consortium successfully negotiated the establishment of EUFAR AISBL, an international not-for-profit association under Belgian law, in order to ensure a continuing level of collaboration in airborne research in the future. 11 organisations from 8 different countries are full members of the association in the first year with agreed mechanisms to encourage wider participation. The work-plan of the AISBL will be supported mainly by in-kind contributions of personnel and other resources by its members, with small cash membership fees to cover other items.

Wider international collaboration with the airborne research community in the USA as represented in the ICCAGRA committee has taken place, leading in particular to the organisation of the 2nd International Conference on Airborne Research for the Environment (ICARE). This was hosted by DLR in Germany during July 2017 with the objective to discuss issues around the development of airborne research infrastructure to meet future scientific demands and had 175 registered participants.

Transnational Access (TA) to EUFAR facilities was provided to user groups without normal access through their national research funding systems. 6 sets of Calls for Proposals were published via the EUFAR website, with proposals then being sent for peer-review. Those meeting minimum standards during the review were then presented to an independent User Group Selection Panel (UGSP) for final allocation in response to priorities established by the SAC. 32 projects were approved for funding across the two main areas of EUFAR activity – atmospheric in-situ measurements and imaging of the terrestrial surface. Of these, 29 were eventually flown, supporting 224 scientific users and 80 summer school students. These figures are below the original targets due principally to larger than anticipated demand for selected high-cost facilities and short-notice operational issues that prevented facility operators from supporting projects that had been allocated to them.

Two Joint Research Activities (JRA) were supported, both being developed in response to previous EUFAR activities and focussed on the improvement of airborne data quality and the development of innovative new data products. JRA1 (HYLIGHT) concerned the development of software tools for the integration of airborne imaging data with airborne lidar scanning (ALS) whilst JRA2 (TGOE) concerned the development and implementation of new procedures and hardware for the calibration of airborne trace-gas measurements.

Open-source software tools and other reports from these activities are published on the EUFAR website (www.eufar.net).

A number of additional Networking Activities were organized to consider the future development of the EUFAR fleet, to support Expert Working Groups on a range of airborne research topics, to encourage technology and innovation transfer, to review and support the uptake of appropriate standards for data and metadata and broader access to EUFAR airborne data via a database and newly-developed search tools and to provide a range of education and training opportunities for early-career scientists to broaden the existing scientific user base. An additional activity was devoted principally to the re-development of the EUFAR website as a central portal to European facilities, services and data in airborne research. This became fully-available to the community during the second half of the EUFAR2 project period.

Summary description of the project context and main objectives

EUFAR2 is an Integrating Activity of the 7th Framework Programme (FP7) of the European Commission, following three previous contracts under FP5, FP6 and FP7. EUFAR2 brings together 24 European institutions and organisations involved in airborne research, operating 19 instrumented aircraft, ranging from low and slow flying aircraft (ENDURO) to 4-engine turbo-jet aircraft carrying several tons of instrumentation pay-load (BAe146), and providing access to 5 remote-sensing instruments.

EUFAR's overall goal is to provide researchers with easy and open access to the airborne research facilities that are most suited to their needs and that are not available/financially accessible in their home countries. To this end, EUFAR aims to:

- develop transnational access to national infrastructures;
- reduce redundancy, fill the gaps, and optimise the use and development of airborne infrastructure;
- improve the quality of the service by strengthening expertise through knowledge exchange, maintaining a central database of airborne data and developing standards and protocols for this database to be fully interoperable with Earth observation databases;
- support joint instrumental research activities dedicated to (i) the development of methodologies and tools for the integrated use of airborne hyperspectral imaging data and airborne laser scanning data and (ii) the development of robust calibration systems for the core gas-phase chemical measurements currently made on-board research aircraft;
- promote the use of research infrastructure, especially for young scientists from countries where such facilities are lacking, by providing education and training courses on airborne research;
- optimise the use and development of airborne research infrastructure, through (i) the constitution of a Strategic Advisory Committee in which representatives of research institutions define scientific priorities, jointly support Open Access with in kind contributions to the operation and the harmonised development of the European fleet and (ii) the constitute of the EUFAR sustainable legal structure;
- support both market pull and technology push driven innovation in airborne research, and develop a culture of cooperation between the airborne research community and industry in order to transform airborne research instruments, methodologies and software into new products.

The project's networking and research activities and their corresponding objectives are summarised as follows:

The Strategy and European Integration (N1SEI) is dedicated to (i) scientific coordination of all EUFAR2 activities to ensure they pursue the same high level objectives in terms of EU integration; (ii) constitution of and guidance for the Strategic Advisory Committee (SAC), made up of representatives from research institutions and industry, which provides recommendations and priorities for academic and applied research, innovative instrumental developments, and future developments of the EUFAR fleet;(iii) international coordination in particular with the US counterparts to ensure EUFAR2 activities are in line with international efforts in structuring airborne research; (iv) constitution of a sustainable legal structure; and (v) support to dissemination by the EUFAR Office.

The Transnational Access Coordination (N2TAC) networking activity is the unified management structure facilitating transnational access to research aircraft and instruments by providing fully-funded flight hours. It uses peer-review and an independent selection panel guided by the SAC to achieve a high scientific impact for the supported flight activities.

The Future of the Fleet (N3FF) networking activity objectives are to (i) evaluate the capability of the existing fleet in response to the scientific needs; (ii) provide directions for enhancing the capability of the fleet; and (iii) outline strategies for the long-term development and harmonisation of the fleet.

The Expert Working Groups (N4EWG) networking activity aims to (i) improve the scientific expertise in the field of airborne research; (ii) facilitate the transfer of expert knowledge, innovative airborne instrumentation, and software to users, operators, funding agencies, and industry and small business; (iii) support the activities of the Technology Transfer Office (TTO) with a review of existing expertise and technologies in EUFAR; and (iv) compile supplementary material to the EUFAR handbook on "Airborne Measurements for Environmental Research – Methods and Instruments".

The Technology Transfer Office (N5TTO) networking activity supports both market pull and technology push driven innovation, and aims to foster a culture whereby EUFAR experts and SMEs closely interact and develop partnerships to transfer airborne research instruments, methodologies and software into new products.

The Education and Training (N6ET) networking activity provides training opportunities in airborne atmospheric research, field campaigns and remote sensing of the Earth surface, with the aim to develop a community of young researchers, though four main objectives: (i) attract early-stage researchers to airborne research; (ii) educate and train (theoretically and practically) early-stage researchers and trainers (e.g. university lecturers) in airborne atmospheric research and airborne remote sensing of the Earth surface; (iii) define an optimised (fixed) EUFAR training course concept; and (iv) develop/consolidate EUFAR training course educational material.

The Standards and Protocols (N7SP) networking activity aims to (i) develop, expand and implement common protocols for airborne surveys and airborne data handling in consensus with international initiatives towards standardization and harmonization; (ii) support users and operators with recommendations on best practice and state-of-the-art software for airborne data pre-processing and further analysis; (iii) develop, maintain and publish open source software toolboxes for higher level data products, and data analysis; (iv) define and help implement standards for data transfer in real-time; and (v) implement the ENVRI reference model to clearly define roles and processes in EUFAR in order to help in the preparation of EUFAR in the process of moving towards a sustainable legal structure.

The Data Base (N8DB) networking activity aims to (i) develop and expand the centralised gateway to data (both in situ and remote sensed) and metadata collected by the EUFAR fleet during the EUFAR projects and training schools, including linking to existing online data archives and provision of an archive for otherwise offline data); ii) help data providers achieve the community-agreed data formats and metadata standards identified during the previous phase of EUFAR; (iii) maximise the discoverability of EUFAR archive at the dataset level by publishing INSPIRE compliant metadata to appropriate metadata "discovery" portals, with the production of a clear intuitive tool where users and interested parties can search for specific data within the EUFAR archive, including auxiliary information (e.g. temporal and geospatial coordinates, project location, responsible parties, etc.).

The E-Communication (N9 EC) networking activity contributes to the improved access to and use of the infrastructures via the website, by (i) elaborating new solutions for the EUFAR web portal providing easy access to up-to-date information on the European fleet of research aircraft, opportunities for users within the EUFAR fleet, and education and train opportunities offered by EUFAR; (ii) improving the proposal-submission system and (iii) developing new tools to support collaborative and networking activities.

Joint Research Activity 1 (HYLIGHT) aims to (i) develop, test and validate methodologies and tools for the integrated use of airborne hyperspectral imaging (HSI) data and airborne laser scanning (ALS) data in order to produce improved combined HSI and ALS data products, and (ii) develop HYLIGHT tools and make them available for further use.

Joint Research Activity 2 (TGOE) aims to develop robust calibration systems for the core gas-phase chemical measurements currently made on-board research aircraft. This activity aims to reduce the uncertainty in these key parameters, facilitate improved cross-platform research by ensuring that the measurement technologies are all tied to a common baseline, and hence enable critical comparisons between the airborne measurements, numerical models and different satellite observations.

The Management of the Consortium (MNGT) includes the overall management of the project, linking together all the project components and maintaining communication with the Commission. The EUFAR Office (EO) supports the beneficiaries for the overall legal, ethical, financial and administrative management including, for each of the beneficiaries, obtaining of certificates on financial statements, and on the methodology and costs relating to financial audits and technical reviews. The EO also manages the collective T&S budget, and provide logistical and communication support to the activities of networking activities.

Description of the main S&T results/foregrounds

The Strategy and European Integration (N1SEI) activity is dedicated to the scientific coordination of all EUFAR2 activities to ensure they pursue the same high level objectives in terms of EU integration; constitution of a sustainable legal structure for EUFAR; international coordination and collaboration. This activity provides both internal and external oversight of the broad range of EUFAR activities. The Scientific Coordinator of EUFAR acts to ensure that all activities proceed in line with objectives and standards described in the work plan. He also acts as a point of contact between EUFAR and other international airborne research infrastructures, especially in the USA. The Strategic Advisory Committee provides independent external advice on the priorities within the Transnational Access flight program as these are promulgated to users via the published Calls for Proposals.

Within the lifetime of EUFAR2, a major objective was to establish EUFAR as a legal entity, in the preferred form of an AISBL – an international not-for-profit association under Belgian law. Significant progress has been made in gaining the commitment of a core group of partners to form such an association and on drafting its statutes, internal rules and financial plans. After a lengthy period of negotiation from May 2015 to August 2017 with 11 meetings of the ad hoc working group dedicated to the constitution of the AIBSL, 8 European institutions representing 6 different countries (VITO (BE), CzechGlobe (CZ), CNRS, Météo-France & ONERA (FR), DLR (DE), UWAR (Poland), and the Met Office (UK)) signed the necessary Statutes to constitute EUFAR as an AISBL. The Statutes were deposited with the Belgian on 30 August 2017, and the EUFAR AISBL was formally constituted in January 2018, with the royal acknowledgement of the AISBL as published in the Moniteur Belge on 23 January 2018.

The EUFAR AISBL has already held two General Assemblies and Executive Board meetings in Oct 2017 (Brussels, Belgium) and Jan 2018 (Lugo, Spain) respectively. During the first set of meetings, the GA representatives and AISBL members were elected, the internal regulations were signed and the 4-year activity plan was discussed. The 2018 GA marked the admission of three new members (FUB (DE), UNICH (IT), and INCAS (RO)). To secure funding for future transnational access and joint research activities, a lot of discussion in the GA2018 was dedicated to the EUFAR AISBL proposal for the Horizon2020 call INFRAIA-01-2018-2019: Integrating Activities for Advanced Communities, single-stage RIA Research and Innovation action.

As part of the proposal will include joint research activities (JRAs), a Call for Expressions of Interest (EoIs) was launched in May 2017. The call was successful and 15 interesting submissions were received, which were thereafter reviewed for possible inclusion as JRAs in the H2020. In early December 2017, 8 EoIs were shortlisted for further review. The leaders of the selected EoIs were requested to prepare their JRA proposal in an adapted template for inclusion in the final submission providing details on identification of potential members, a draft budget of about €750k, list of deliverables, etc. The 8 shortlisted EoIs were presented during the final EUFAR GA in Jan 2018, and 4 propositions were selected by the AISBL with the help of the SAC for inclusion in the proposal (2 dedicated to in-situ observation and 2 to Earth observation).

During RP2, EUFAR has been represented at a meeting of IAGOS (which operates atmospheric observing systems on in-service aircraft) and an annual meeting of the ACTRIS ground-based atmospheric RI. Closer engagement has taken place between EUFAR and the ENVRIplus cluster (of which ACTRIS is a member). EUFAR is now represented on BEERi, the oversight body of ENVRIplus and is working (within the N7SP activity) on implementation of the ENVRIplus Reference Model applied to airborne research observational data and further collaborations. Indeed EUFAR also participates actively in the ENVRI community dedicated to environmental research infrastructures, projects and networks. For example, EUFAR took part in the 5th ENVRI week, ENVRI Industry Forum and ENVRIplus Reference Model meeting in RP3. The Scientific

Coordinator represents EUFAR at meetings of ICCAGRA, the committee that oversees airborne geophysical research in the USA and which includes representatives of NASA, the National Centre for Atmospheric Research and National Science Foundation.

Another significant achievement in RP3 was the organisation of the ICARE 2017 conference (2nd International Conference on Airborne Research for the Environment), hosted by DLR - the German Aerospace Research Centre, in Oberpfaffenhofen (Germany), from 10 to 13 July 2017. This is the second edition of the conference following ICARE 2010.The conference was organised in collaboration with the airborne research community in the USA, including both NASA and the National Centre for Atmospheric Research (NCAR). Mainly funded by EUFAR and the conference registration fees, the conference also received significant in-kind contributions from DLR. The European Space Agency (ESA) offered to provide funding to support the attendance of a number of early-career scientists, but thanks to the registration fees EUFAR budget was sufficient to cover those expenses. "Developing the infrastructure to meet future scientific challenges" was the theme of this 4-day event. More than 175 leading participants across Europe, the United States and beyond, including expert scientists, aircraft operators and instrument developers participated in the conference and contributed to making the event a great opportunity to exchange expertise and experience, and review the scientific issues for future airborne measurements. There were plenary and parallel sessions covering four principal subject areas: i) science drivers for future airborne science missions, ii) organisation of future field campaigns, iii) developing future airborne science capabilities and platforms, and iv) new developments in instrumentation and data. The conference programme included a total of 20 invited and 41 contributed presentations with a further 25 posters presented during a dedicated session. In addition, an aircraft exhibition was organised, allowing participants to view both the interior and exterior of 11 research aircraft. In essence, the ICARE 2017 conference was a great success and the EUFAR AISBL will incorporate a third edition of ICARE in its 4-year plan with potential EU funding within the H2020 EUFAR proposal.

A number of significant dissemination activities were carried out during the 4-year period, such as the regular publication of the EUFAR newsletter (on average 3 issues a year, 12 in total), publication of EUFAR articles in the Open Government Access Journal (two articles and one e-book) and EU Researcher magazine (one article) and in the EUFAR website (62 events, 52 news, 20 airborne research stories), animating a EUFAR stand at the annual EGU General Assemblies (2014, 2015, 2016 and 2017), and participating in the GEO Week in October 2017 in Washington DC, to mention a few.

The principal objective of the Transnational and Open Access Coordination (N2TAC) activity is to continue to support scientific flight activities through the Transnational Access (TA) process. Transnational Access provides fully-funded flight time to Principal Investigators and User Groups who do not have access to the required airborne observing facilities via national funding within their country of employment. Applications are encouraged from new users who have not participated previously in airborne research. A small amount of travel/subsistence funding is available to assist the PI and other users to participate in the field campaign and/or any necessary pre- or post-project meetings.

The amount of flight time available to each project is approximately 10 hours. In order to maximise the scientific impact of the TA-supported flying, applications are encouraged that can be clustered with larger nationally- or internationally-supported flight observing campaigns. This allows the TA to spend longer in the field with a greater chance of obtaining optimum observing conditions and interacting with a larger group of experienced scientists. Project proposals are peer-reviewed and flight awards approved by an independent User group Selection Panel (UGSP) comprised of relevant expert scientists.

On the success side, 32 TA projects were decided to be supported, evenly split between the use of in-situ atmospheric measurements and the use of imaging systems for Earth Observation, including 4 summer

schools (see section on N6ET), two TA projects via cross-RI links with ACTRIS (CIIMA and DOGMA projects), and TA projects in remote or distant location via clustering with existing campaigns (for example, the SAVEX-D TA campaign was clustered with ICE-D in Cape Verde, and the APSOWA, MICWA and OLACTA TA campaigns were clustered with DACCIWA in West Africa in 2016, and ALLDUST-SA and EriSMA TA campaigns were clustered with AEROCLO-sA in Namibia in 2017). Due to operational issues, only 29 of the approved TA projects have conducted a flight campaign. This activity will finish slightly under budget with project/users supported below target (38 projects) due to a number of reasons, principally, the inability to fly and consequent cancellation of three approved TA projects, lack of uptake of low-cost facilities and no requests for use of polar aircraft despite the dedicated Calls for Proposals for use of these aircraft. There was also more support than planned to use of expensive facilities. Overall there were fewer applications for TA submitted which could have resulted from the fixed deadline for Calls for Proposals and/or insufficient flight hours allocated per project. Delays in review of TA projects need to be addressed in the future, and visibility of the available facilities and up-to-date planning of the fleet needs to be improved on the EUFAR website.
The activity also sought to implement an Open Access agreement between EUFAR partners in which flight time is exchanged for a contribution of other resources in-kind – the latter consisting of personnel, instrumentation development, field campaign overheads etc. Since this requires the donor partner to commit resources beyond its previous needs, it was recognised that a scientific collaboration first needs to be established between the partners. Whilst there has been discussion of the scientific collaboration to underpin such an arrangement, it has not been possible to reach a final agreement on its implementation during the EUFAR2 project period due to several limitations such as the lack of incentive to provide personnel resources in exchange for very small amounts of flight time and lack of pre-existing scientific collaborations. In essence, there is a need to create a more realistic vision for Open Access to be developed and implemented by the EUFAR AISBL. In addition, there is a need for comparison of the access cost models applied for national facilities and national users.

The objectives of the Future of the Fleet (N3FF) activity are to evaluate the capability of the existing fleet in response to the scientific needs, to provide directions for enhancing the capability of the fleet, and to outline strategies for the long-term development of the fleet. A questionnaire was formulated and submitted to the scrutiny of the European scientific community, to evaluate the user needs of the airborne community and provide directions for enhancing the capability of the fleet and to outline strategies for its long-term development. The questionnaire was shared via various communication channels with the European airborne research community towards the end of 2014. The survey results were collected in January 2015 illustrated that participants in the survey showed an overall appreciation for the EUFAR activities, interest toward new platforms, especially Remotely Piloted Aircraft Systems, and demand for a common European strategy for research aircraft platforms. Summary results from the questionnaire have been made available on the EUFAR website.

The availability of existing stratospheric and Heavy Payload Long Endurance (HPLE) platforms has been assessed, and possibility to use innovative platforms in the future, as stratospheric airships, has been studied. Contacts with NASA have been undertaken in order to study the possibility for European scientists to access their stratospheric platforms. Cooperation with the aircraft industry for a common exploitation of their HLPE test facilities has also been explored. Regarding the status of stratospheric platforms, the Geophysica had problems with aircraft control clearances and bureaucratic issues which prevented two planned campaigns from taking place. However, there have been two successful EU funded campaigns, in Greece in September 2016 and in Nepal in July 2017. The EGRETT (operated by GROB Aerospace) has been used as a demonstrator for several tours in S.E Asia and is accessible for scientific purposes. WB 57 (operated by NASA) had its last campaign in 2015 (HDSS/HIRAD). The three aircraft are available for European research: advertisements on the three aircraft were prepared and made available in RP3 on the EUFAR website and

newsletter. Airbus' test aircraft A350 will be available for scientific purposes, and its rental cost will include fuel, crew, taxes and aircraft maintenance and modification.

One interesting future opportunity may come from the INTA Spanish programme FENYX, which to some extent resumes the objective of COPAL to develop a heavy-payload, long-endurance aircraft capable of reaching any area of the planet. The FENYX project includes the acquisition, modification and instrumentation of a brand new aircraft, with payload capability around 10 tons, ferry range around 6000km and service ceiling around 10km. A call for tenders is currently being prepared and the aircraft selection planned around summer 2018, and a partnership research is in sight. This is an interesting opportunity that can be exploited in the future to overcome the lack of an HPLE aircraft available for the European scientific community. INTA seems to be open to collaboration with other countries, regarded either as partners, or users.

Although the stratospheric research aircraft M55 Geophysica has successfully conducted a field campaign in Nepal on July 2017, its availability for the medium term is still not secured and, despite a strong interest in airborne stratospheric research, at the present time there is neither an already established consortium of research Institutes and agencies, nor a formal proposal for accessing a stratospheric platform. Hosted by CNR in Rome, a EUFAR scoping workshop on future strategies for stratospheric airborne research in May 2017, and the participants, from different European institutions and agencies, reaffirmed the need to secure the availability of stratospheric platform in the long-term in order to tackle important open research problems. There is an interest in creating a consortium to guarantee the availability of a stratospheric aircraft for the coming decade; moreover, there is some consensus that the established EUFAR AISBL may provide a good, already established, legal structure to host the activities of such a possible consortium. There is also awareness and motivation among some scientific institutions to further explore the opportunity of joining the AISBL to make use of its structures for specifically such an aim. These possible developments will be monitored in the future, within the activities of the AISBL.

In conclusion, although currently there is neither an already established consortium of research institutes and agencies, nor a formal proposal for accessing a stratospheric platform, there is progression toward that via the up-scaling of the EUFAR N3FF activities and the constitution of the EUFAR AISBL which, it is likely, will be a "think tank" responsible for elaborating future strategies, and possibly playing a role to implement them. With regard to UAVs, collaboration continues with the ISARRA community; EUFAR participated in the ISARRA conference in May 2016. Common activities have also been pursued, as including a component on the use of RPAV in the EUFAR SWAMP training course (Obrzycko-Rzecin, Poland, 6-16 July 2015). Contacts with the RPAV community have not been fully satisfactory but there is the need to further pursue the integration of the two communities to explore more meaningful synergies of the respective platforms.

The activities of the Expert Working Groups (N4EWG) focused on three tasks: (i) organising nine Expert Working Groups (EWGs) workshops and several technical meetings, (ii) restructuring the EWGs, and (iii) preparing and updating a booklet on innovative EUFAR technologies (jointly with the N5TTO activity) (iv) contribution to the ICARE 2017 conference. Regarding the first task, it was decided to focus the limited funding available for the EWG workshops on workshops centred on the planned ICARE 2017 conference. Consequently, only one thematic workshop took place within RP1 on Airborne Laser Scanning (ALS) software (Nov 2014, Vienna, Austria). Further workshops were held during RP2,

a) EUFAR Survey of Innovative Technologies,
b) Data Processing, Analysis and Presentation Software of Cloud Probes (July 2016, Manchester, UK),
c) Hyperspectral Remote Sensing for Soil Applications (Sept 2016, Potsdam, Germany),
d) Atmospheric Correction of Remote Sensing Data (Oct 2016, Berlin, Germany),
e) Hyperspectral Imaging from UAVs - Applications in Precision Farming (Dec 2016, Milano, Italy),

f) Certification and Operations (Sept 2015, Schiphol, The Netherlands, and Feb 2016, Athens, Greece).

An expert workshop on calibration/validation (Oct 2015, Edinburgh) also took place along the course of RP2 but this was not headed by EUFAR. In RP3, as part of ICARE2017, one EWG workshop was organised on "Processing of Cloud Particle Measurements" from 7-9 July 2017, as a follow-up to the EWG workshop on cloud probes in 2016. It took place in combination with the ICARE2 conference of EUFAR at DLR in Oberpfaffenhofen (July 2017). Furthermore, the N4EWG activity leader actively partook in discussions on the organisation of sessions and speakers during ICARE 2017.

Regarding the second task, after discussions during web meetings and during the first General Assembly (2014) a new structure of the EWGs was defined, which principally corresponds to the chapters in the EUFAR handbook on airborne measurements developed by the EWGs in the previous EUFAR contract (2008-2013) (Wendisch & Brenguier, 2013). Part of the N4EWG was dedicated to providing complementary material to and revising the EUFAR handbook. However, as the publisher (Wiley) is not in support of a second edition of the entire book, revisions and additional material are to be restricted to the Appendix A of Supplementary Online Material, which can be downloaded from: https://media.wiley.com/product_data/excerpt/63/35274099/3527409963.pdf. During RP3, two new contributions were finalised – i) a revised version of the processing toolbox and ii) airborne hyperspectral imagery and laser scanning data for improved processing and interpretation, which will be hopefully added to the supplementary online material.

Regarding the third task, as a result of two meetings and a broad discussion within the community, a questionnaire to prepare the booklet on innovative EUFAR technologies (jointly with N5TTO) was distributed and analysed. After discussions during several meetings including General Assembly meetings the first version of the booklet was compiled and submitted in August 2016 with 11 innovative technologies. In RP3, the booklet was updated to include 11 innovative technologies with some potential to be further developed as industrial applications. The last part of task of the activity was dedicated to disseminating and providing complementary material to the EUFAR handbook.

The Technology Transfer Office (N5TTO) supports the transfer of technology between experts in airborne measurements and industrial players and SMEs that drive innovation, by organising workshops on specific technologies and further supporting their partnership with expertise on issues related to exchange of knowledge. Work performed since the beginning of the project includes: (i) two joint N4EWG/N5TTO workshops (July 2014, February 2016)), presentation and "educational sessions"; (ii) writing of the Guide on technology transfer issues for R&D partnership including specific remarks following the workshop with EUFAR scientific community during the joint EWG/TTO meeting in March 2015; (iii) first evaluation of the industrial community around EUFAR. Thanks to all actions led, first educational results are observed and a second version of the "Guide on technology transfer issues for R&D partnership" was submitted in August 2016.

The guide was published on the EUFAR website and shared with the scientific community of EUFAR. Once industrial players consider EUFAR as a technology and know-how provider, this may lead to partnerships with possible funding. Moreover, the first set of Technology Transfer projects initiated within EUFAR will create further partnerships, a higher recognition of EUFAR as a technology provider for companies, and jobs and/or company creation following the implementation of new technologies by EUFAR industrial partners. With the success story "ALIDS", an airborne laser interferometric drop sizer developed as a joint research activity of the contract EUFAR (2008-2013)) and successfully transferred to the industry by launching a dedicated start-up, and with the participation of the N5TTO leader in EWG workshops in 2016, the scientific community is now aware of the importance of technology transfer issues; since the beginning of the project,

11 innovative technologies have been collected and published in a booklet (jointly with the N4EWG activity) and scouting of additional technologies of interest for selected partners has been performed.

These technologies developed within the EUFAR community were selected according to their potential to be applied to industry. The leadership of the activity changed along the course of RP3, setting this activity further back, however, at the end of RP3, the new activity leader managed to take an active part in the Remotely Piloted Aircraft Systems (RPAS) Civil Operators & Operations Forum (CIV Ops) in Paris (16-17 January 2018), where she presented EUFAR and the booklet of 11 technology transfer sheets, which were considered as highly relevant by the participants visiting the booth.

During the TGOE activities new Quantum Cascade Laser (QCL) based technologies emerged (http://www.aerodyne.com/products/ethane-monitors) on the market through Aerodyne Research Inc. The team from Univ of York have worked closely with the manufacturers providing user feedback which the Aerodyne scientists are incorporating into updated designs and operational protocols. Maintaining such lines of communication with instrument developers/manufacturers as they deploy new technologies is essential not only to improve data quality, but also to highlight problems which could be addressed in newer models of instruments. All too often, there is a tendency for individual research groups to make modifications to their individual instrument in order to produce high quality data from a bespoke instrument. While this can lead to some high quality observations for a few selected studies, it must be acknowledged that the more impactful approach is to share such modifications and engineering solutions with the manufacturers. In that way, any improvements are more readily applied on multiple platforms and will lead to improved data quality throughout the entire measurement community. Such knowledge exchange between users across the research community as well as commercial manufacturers is a prime motivation for the TGOE JRA. Lastly, over the project period, EUFAR has been promoting SMEs involved in airborne research via its website and newsletter (e.g. Metair and ATMOSPHERE), and will continue to invite other relevant SMEs to advertise their services and products via the EUFAR portal.

EUFAR "internal customers' voice" has been collected in order to highlight the positive and negative points of the activity and identify room for improvement on several aspects (namely software). In the scope of the EUFAR AISBL, TTO will seek to provide recommendations, guidance, support (for example, how to manage patents), and feedback to partners and AISBL members on what has been successful. For example the open source software sharing could benefit the SMEs, EOSC (European Open Science Cloud) and EARSC (European Association of Remote Sensing Company) that the EUFAR AISBL could eventually join as a partner. CodeOcean – a cloud-based executable research platform that allows authors to share their algorithms in an effort to make the world's scientific code more open and reproducible – could also be investigated to share open source for algorithm publication.

The objectives of the Education and Training (N6ET) activity are (i) to attract early-stage researchers to airborne research; (ii) to educate and train (theoretically and practically) early-stage researchers and trainers (e.g. university lecturers) in airborne atmospheric research and airborne remote sensing of the Earth surface; (iii) to define an optimised (fixed) EUFAR training course concept; (iv) to develop/consolidate EUFAR training course educational material. Based on the evaluation of previous EUFAR FP6 and FP7 training courses and other training courses in airborne research, and existing educational material for airborne research used at previous EUFAR training courses and other training courses in airborne research, a concept of a fixed EUFAR training course including a list of existing EUFAR educational material was prepared and submitted to the EC.

The ET activity offers four types of training opportunities for early-stage researchers, university lecturers and also for aircraft/instrument operators: (i) training courses on airborne research (ET-TC), (ii) invited access to Existing Campaigns (ET-EC), (iii) participation in the design of a new flight campaign, in the frame of

Transnational Access (ET-TA), and (iv) visit to aircraft/instrument Operators for exchange of knowledge and know-how (ET-VO). In RP1, only one training course took place due to the lack of proposals submitted to host a training course. The 6th EUFAR Training Course on 'Spectrometry of a Wetland And Modelling of Photosynthesis with Hyperspectral Airborne Reflectance and Fluorescence (SWAMP)', jointly organised with the COST Action OPTIMISE and hosted by the Poznan University of Life Sciences was held from 6 to 16 July 2015 in Obrzycko and the instrumented POLWET site (Rzecin) in Poland. The SWAMP training course was co-funded and co-organised by EUFAR2 (for Transnational Access to the DLR Dornier 228 aircraft and the APEX sensor operated by VITO), COST ACTION ES1309 OPTIMISE (for access to ground equipment and small UAVs) and the European Space Agency. 20 early-stage researchers (PhD students and post-docs) and university lecturers from 12 European member states and associated states (selected from 47 applications), funded by EUFAR and OPTIMISE, participated in the SWAMP training course. SWAMP training course presentations have been made available on the EUFAR website and a report on SWAMP training course was prepared and submitted. Hands-on lessons with pktools (http://pktools.nongnu.org) including tools and data for vegetation classification were prepared and used at the SWAMP training course.

In 2017 three (two with a focus on atmosphere research and one with a focus on remote sensing of the Earth Surface) EUFAR Training Courses were organised (i) Training course on "Exploring Air-Sea Interaction via Airborne Measurements" (EASI), held in Shannon Ireland from 25 June to 4 July 2017. Organised by CNR-ISAC (Italy), the summer school trained 20 students (of 12 nationalities working in 11 EU member states and associated states), on the use of a research aircraft, and the experimental possibilities this opens for atmospheric physics and chemistry research. During the course, a full flight experiment was carried out using SAFIRE's ATR42 aircraft with support from the N2TAC activity, and participants also had the opportunity to visit the Mace Head Atmospheric Research Station. (ii) "School and training on Aircraft News techniques for Atmospheric Composition Observation" (STANCO) took place in Cambridge and Cranfield (UK) from 26 June to 6 July 2017. Organised by the University "G. d'Annunzio" of Chieti-Pescara (Italy) and the University of Leeds (UK), STANCO offered the 19 PhD students and Post-Docs, from 10 nationalities working in 9 EU member states, the background on atmospheric chemistry, aerosols, climate change and the technical skills required for measuring the main atmospheric trace gases, for instrument fitting on aircraft platforms as well as processing of airborne chemical and aerosol data. FAAM's Bae-146 aircraft was used for the flight experiment. (iii) Training course on "Airborne remote sensing for monitoring essential biodiversity variables in forest ecosystems" (RS4ForestEBV), organised by the University of Twente (Netherlands) and hosted jointly at DLR in Oberpfaffenhofen and the Bavarian Forest National Park from 3 to 14 July 2017. The training course dealt with the use of airborne hyperspectral, LiDAR and thermal remote sensing data for monitoring essential biodiversity variables in forest ecosystems. 19 early-stage researchers and university lectures from 10 different European member states participated in the RS4ForestEBV training course, which was structured as 4 stand-alone but interlinked working groups: hyperspectral, thermal hyperspectral, atmospheric correction and LIDAR and lasted 11 days. In addition, an airborne campaign with a NERC Twin Otter for the concurrent acquisitions of hyperspectral imaging data in visible, near-infrared, shortwave-infrared and longwave-infrared (thermal) wavelengths as well as LiDAR data (with full wave form component) was conducted. During the second week, participants were able to attend certain sessions of ICARE 2017, in particular the aircraft exhibition.

The three training courses received funding from EUFAR and significant logistical support from the EUFAR Office. Presentations, scientific reports and photos from all three summer schools have been made available on the EUFAR website. Following the training courses in RP3, the list of EUFAR education material has been revised (first version released in RP2), and made available on the EUFAR website under the tools and previous training course sections with the objective of providing online free access to airborne research education material to EUFAR members. The activity leader has also been collaborating with other relevant programmes and structures such as the COST action OPTIMISE, ENVRI and MSCA TRUSTEE network. Up to

date, 9 EUFAR training courses have been organised since EUFAR's creation, 4 of which took place during the EUFAR2 FP7 contract. New avenues for progress in this activity include holding post-training course meetings, supporting the participation of early-stage researchers in conferences, and supporting e-learning opportunities.

The Standards and Protocols (N7SP) activity aims to harmonise different processes and documentation concerning the data acquisition and campaign management as well as data handling within EUFAR. The overall suite of EUFAR's airborne data is addressed, ranging from atmospheric research to Earth observation including in-situ and remote sensing airborne data. Baselines for the developments of N7SP are the common protocols, the best practices and guidelines, and the toolboxes, which were developed during the previous funding period (2008-2013). Since the beginning of the project, the focus has been on the update and extension of the common protocols and assuring their compatibility with international standards. Therefore, an assessment of the existing guidelines of international initiatives working on standards and protocols (e.g. ASPRS, CEOS, GEO, Copernicus, etc.) and the current N7SP products has been conducted. The implementation of the common protocols and the data and metadata standards is mainly realised by the modification of the different tools (e.g. Airborne Science Mission Metadata Creator (ASMM)) and databases (e.g. list of aircraft). RP2 focused on the further development of the toolboxes for common metadata (ASMM and EUFAR Metadata Creator (EMC)) and data analysis (EUFAR General Airborne Data-processing Software (EGADS)), and the improvement of the EUFAR webpages on tools, the glossary and best practices. The publications database on the EUFAR website has also been cleaned up and a system of keywords has been integrated into the database to facilitate searches by users.

There has been significant cooperation with the European standardisation initiative for research infrastructures ENVRIplus. RP3 was dedicated to the finalisation of training material, implementation of the ENVRI Reference Model (RM) to the EUFAR case and further development of the toolbox of data analysis (EGADS). Regarding collaboration with ENVRI, the RM, which offers a simple, structured explanation of the main features to be expected in the information systems of typical environmental Research Infrastructures, has been implemented and tested by EUFAR to serve as a real case example. Moreover, the EUFAR RM case study will be completely modelled to be part of the ENVRIplus Knowledge Base, providing reusable solutions to common challenges to analyse and compare the characteristics of Research Infrastructures. Regarding the use of the RM, the experiences of EUFAR are mentioned in the "ENVRI Reference Model News" and will be reported in a film that aims to present success stories of the ENVRI RM. The EUFAR RM case was presented at the 5th ENVRI week in Malaga, Spain in November 2017. Lastly, the N7SP team took part in two EUFAR training courses (STANCO and EASI) in 2017, during which the N7SP engineer gave a presentation on the activity and N7SP toolboxes.

The Database (N8DB) activity ensures that the valuable data and supporting metadata collected during EUFAR transnational access projects are widely available through a central portal to facilitate data exchange, collaboration and re-use. Providing a well-formed, well-documented, long-lasting archive and linking to existing repositories facilitates discovery and re-use of the data, and therefore, maximises its potential. The dedicated EUFAR archive set at the Centre for Environmental Data Analysis (CEDA), has been reviewed and made ready to receive further data – this includes updates of the archive structure, metadata catalogue records, and existing supporting software. The CEDA archive contains >20 TB of data for 169 flights from 15 aircraft, out of which about 3TB is solely EUFAR data. These data are made up of: (i) 19216 files 3TB in the dedicated EUFAR Archive; (ii) 66896 files 16TB linked via ARSF archive; and (iii) 850 files 39GB linked via FAAM. (data from a few remaining projects are still awaited- expected spring 2018). All data can be accessed through the main EUFAR website http://www.eufar.net/ under Resources, Data Archive. Progress in RP3 includes the addition of PIs to and cleaning of all project records, and inclusion of geographical information

(using the EFF). So far 169 dataset records have been published from 69 projects (with corresponding DOIs for the majority of datasets (113)). These data are publicly available via the EUFAR website www.eufar.net following the EUFAR data archive link (under resources). Further data will be added as it is collected and processed for a few outstanding projects. The dedicated EUFAR archive has been reviewed and updated, additional metadata records to facilitate data discovery have been created. This activity also provides technical support to the many aircraft data providers to achieve community agreed standard data formats, and contacts with all data providers have been renewed. At the end of EUFAR2, 968 users were recorded, 1622 days of activity and >1TB data downloaded.

By realising these standard formats it is possible to develop tools to use on this data. One such tool is an innovative new geospatial-temporal-keyword search tool – named the EUFAR Flight Finder (EFF) – which has been developed to assist with the identification and discovery of EUFAR flight data to maximise usage. This search tool scans the primary aircraft data files, extracting flight paths, temporal information, keywords, parameter names, etc. into an Elastic Search repository which can then be queried through a graphical web interface. The EFF and all data are available since February 2016 via the EUFAR website www.eufar.net following EUFAR data archive link. The EFF has since then been revised to include the new EUFAR data archived, and extended to include additional EUFAR aircraft and non-EUFAR flights from some aircraft. The EFF software has been updated in RP3 to allow for the inclusion of JSON files to its database, to locate satellite data (including 2 million Sentinel 1, 2, 3 and Landsat 5, 7, 8 scenes in the CEDA archives in the CEDA Satellite Finder (http://geo-search.ceda.ac.uk). 95% of all EUFAR flights are now included in the search tool.

Software was also developed to extract and collate metadata records for all flights in the archive to produce landing pages for Digital Object Identifiers. Digital Object Identifiers (DOIs) were then published for 113 finalised flight datasets (remaining flights will get DOIs when all details are complete) using the flight level catalogue records as the landing pages. The N8DB activity leader has also worked alongside the N7SP team on the implementation case of the ENVRIplus Reference Model for EUFAR. Some efforts have also been made to collaborate with IAGOS (In-service Aircraft for a Global Observing System) to discuss the viability of exporting EUFAR metadata to the IAGOS data portal and vice versa, in order to increase visibility and strengthen the collaboration between the two infrastructures. Similar to EUFAR, IAGOS is a research infrastructure that conducts long-term observations of atmospheric composition, aerosol and cloud particles on a global scale. However unlike EUFAR, IAGOS uses commercial aircraft of internationally operating airlines to carry out such measurements. Following the successful launch of the EFF in May 2015, the capability of the flight-finding tool was widened to include the full catalogue of flights from the FAAM BAe-146 aircraft and the NERC-Airborne Research Facility (formerly ARSF), also stored in the CEDA archive, and now covers 120TB of data and nearly 2000 flights. Further aircraft catalogues will also be added in future, and discussions on metadata exchanges with the IAGOS project have been held. The number of users of the EUFAR data archive showed a marked increase following the launch of the EUFAR Flight Finder (EFF) tool. The activity leader also participated in the STANCO summer school in June/July 2017 where she gave a presentation on the EUFAR archive.

The E-Communication (N9EC) activity aims (i) to elaborate new solutions for EUFAR web portal (www.eufar.net) providing easy access to up-to-date information on the European fleet of research aircraft, opportunities for users within the EUFAR fleet, education and training opportunities offered by EUFAR; (ii) to elaborate new solutions for proposal-submission system and new tools to support collaborative activities between experts and users; (iii) to implement new facilities required and suggested by partners and needed for networking activities. At the end of RP1, 2075 active members were registered on the EUFAR website database, versus 1780 at the end of the previous contract (EUFAR FP7 2008-2013), and at the end of RP3, 3118 users were registered.

With the addition of new functionalities and intuitive and clear interface, the EUFAR website was elevated to a new level. The user-friendly, as well as graphically appealing design encourages new users to browse the website. A modern design approach allows for the usage of the system on a personal computer as well as on different mobile devices. The developer team's aim for the EUFAR website in its present state is to encourage the EUFAR community to use it as a daily tool. In the first phase of the project, the existing EUFAR system was analysed and a detailed inventory was conducted to specify the functionalities and content. The concept for the website was designed taking into account the Responsive Web Design approach which allows the user to browse through the website on mobile devices. The emphasis was put on implementing a clear and modern interface for the Front End as well as Back End part of the website. A new graphic design was created for the website and applied in other components of the system. Such components include: mailing templates, printing templates and Newsletter layout. A visual identification system was therefore created for the EUFAR community.

A website code, tested and ready to use, was implemented on the Production Server. Data migration and data updating began in August 2015 and were completed in October 2015. The launch of the new EUFAR website system occurred in November 2015. The hosting server is a Virtual private Server (VPS) in the OVJH data centre. The entire year of 2016 was devoted to improve the system and meet all users' needs with the implementation of testing procedures and new facilities. RP3 was the second year for the functioning of the new EUFAR2 website. As previously reported this new website version has provided a new communication model, enriched with many functionalities designed according to the activity leaders' needs. Thus, communication between activity participants and dissemination of tasks was made simpler and more effective.

As the website is opening accessible to the public at large it was exposed to content indexing robots penetration but was simultaneously visible to the hacking groups. The website traffic intensified proportionally with attempts to break security. Hence, the current response to emerging threats, improving website security and preventative measures became the primary challenge. Tasks in this period can be divided into the following groups: design and development of new functionalities according to the needs of activity leaders, optimisation of existing applications, current management of resources, removal of threats and consequences of events in OVH Data Centre, fixing user faults, management of changes in University of Warsaw IT infrastructure and support for users. In conclusion, the entire RP3 period was devoted to improving the system aimed at perfect fit functionality to meet the needs of its users.

The EUFAR Office continued to regularly update the website content, collecting and posting information on news within the EUFAR community, events, publications, tools, flight campaigns and so on. Over RP2 and RP3, the N7SP team contributed significantly to the EUFAR webpages dedicated to tools and the glossary, and was responsible for updating and cleaning the database of publications accessible via the EUFAR website. The website continues to serve as an important portal for dissemination of information, keeping the public up to date on all the happenings within EUFAR and beyond. The website has also been used to advertise research platforms (e.g. stratospheric aircraft) and opportunities (TA or training) offered by other RIs and such as ENVRI and ACTRIS.

The JRA1-HYLIGHT activity results from discussions and priorities identified during the EUFAR joint EWG meeting, 14 April 2011, the Joint Research Activity HYQUAPRO (11 EUFAR beneficiaries), the user requirement survey conducted by FP6 HYRESSA and the fact that more full-waveform ALS systems become available at various EUFAR operators. The objectives of JRA1 are to develop, test and validate improved Hyperspectral Image (HSI) processing using airborne Laser Scanning (ALS) data and improved ALS data processing using HSI and to make developed HYLIGHT tools freely available worldwide. Seven common data sets of airborne hyperspectral images (HSI) and airborne laser scanning data (ALS) of mainly forests were made available as

an in kind contribution by CVGZ/CzechGlobe, UZH, VITO, TAU and PML for use in the EUFAR (2008-2013) JRA1-HYLIGHT project.

The HYLIGHT working group met on several occasions during the EUFAR General Assemblies to discuss the implementation plan and progress on the tool development. 14 topics were defined and categorised in (i) combined analyses of ALS and HSI, (ii) ALS to improve HSI and (iii) HSI to improve ALS. For each of these topics an ATBD (Algorithm Theoretical Baseline Document) and DPM (Detailed Processing Model) are described. Using these topics as a starting point, 14 HYLIGHT tools were developed.

One of the topics identified is the calculation of the shadow fraction per hyperspectral pixel based on the Digital Surface Model (DSM) derived from ALS data and the sun geometry. Open source pktools (http://pktools.nongnu.org/html/index.html) are used to create this shadow fraction percentage map and were used for the development of an open source HYLIGHT 'Shadow Fraction Tool' made available on the EUFAR website. Tools like this will help researchers to produce improved forestry maps (tree species maps, maps of biophysical variables) for forestry managers. HYLIGHT tools will contribute to a better management of forests, one of our precious ecosystems playing a crucial role in our society for their recreational but also economical purposes.

All HYLIGHT tools together with installation guides and user manuals including contact details can be downloaded by registered members from the EUFAR website http://eufar.net/cms/development-hylight-tools/, with the exception of the ICARE-HS tool. This tool can be accessed by contacting yannick.boucher@onera.fr. Links to publications related to the HYLIGHT activity have also made available on the EUFAR website. The HYLIGHT team also contributed to a new chapter to the EUFAR handbook, accessible as supplementary online material entitled 'Airborne hyperspectral imagery and laser scanning data for improved processing and interpretation'. In the framework of the activity and based on the ATBD and DPM, this chapter illustrates some improvements of the combined use of ALS and HIS, HSI for improved ALS processing and ALS for improved HSI processing with reference to the HYLIGHT tools. The chapter will be integrated to the existing supplementary online material available here: https://media.wiley.com/product_data/excerpt/63/35274099/3527409963.pdf.

The concept of JRA2-TGOE has long been a key discussion item in the EUFAR 2008-2013 gas-phase EWG, and TGOE is the culmination of these discussions. The objective of JRA2 is to develop robust calibration systems for the core gas-phase chemical measurements currently made on-board research aircraft. It will reduce the uncertainty in these key parameters and will facilitate improved cross platform research by ensuring that the measurement technologies are all tied to a common baseline. Comparisons between airborne data, numerical models and satellite observations will also be critical beneficiaries of the output from TGOE.

In order to understand many of the processes occurring in the atmosphere, it is critical that we have a good measure of the abundance of a range of chemical compounds. This is further challenged by the fact that many of these compounds are reactive and undergo transformations in the atmosphere. We need to be capable of making observations throughout the atmosphere as well as close to the initial emission source. To this end *in situ* observations are critical to unravelling these atmospheric processes and ultimately aircraft provide access to the third atmospheric dimension, the vertical. *In situ* observations also permit us to test the numerical models that we use to try to simulate the atmosphere; this then allows us to reduce the levels of uncertainty associated with these models. However these observations themselves have sampling and instrumental uncertainties also and it is vital that we understand these before we can then perform the model comparisons. In addition models themselves often rely upon emission inventories to provide input data and sadly many such inventories are outdated, becoming rapidly inaccurate as technology moves on and pollution control measures become more stringent. A final beneficiary of the improvement of in situ data

is that the satellite validation activities undertaken by research aircraft capable of these observations. Our ability to constrain emissions inventories closer to reality will provide local authorities and government agencies to better predict ambient levels of air pollutants.

The first reporting period for TGOE provided a review of current systems in use by the gas-phase community across Europe. During the EUFAR2 project period new technologies have emerged which the TGOE team have worked on with the developer/manufacturer. Aerodyne Research Inc now produce a fast response QCL system for ethane and methane. Instruments were installed into the UK BAe146 aircraft and operated during a series of test flights in early 2017 where rigorous instrument performance tests were performed including an entire flight where the instruments sampled only a cylinder of target gas. The aim of this was to observe the variation in the reported concentration of ethane due to changes in cabin conditions and other factors specific to aircraft platforms which would not be apparent from lab testing. The ethane mixing ratio observed was found to vary significantly during the flight. It appears from the test flight results that there are a number of factors contributing the reported ethane mixing ratio, though it is difficult to definitively determine what these are. The largest factor appears to be changes in-cabin pressure, but here also appears to be contributing factors of aircraft pitch angle and acceleration. Efforts to determine, limit and control these effects are underway and the research groups at NCAS and the Universities of York and Manchester are in close contact with each other and, crucially, with Aerodyne, the manufacturer of the instrument. With such ongoing advances in the technologies applied to these measurements and TGOE being comprised of leading researchers in their fields any such improvements are incorporated into the TGOE knowledge base as well as informing the developers/manufacturers. Such activities as these emphasise TGOE as drawing from state of the art technologies and providing a unique facility for manufacturers to understand the operational issues faced by the airborne observational community.

During the second reporting period, intercalibrations of TGOE measurements and standards within EUFAR and with IAGOS and ACTRIS were conducted. The work comprises of both laboratory based studies to establish best practice for the larger community. Beyond the laboratory work there have been some comparisons 'in the field' during a number of aircraft deployments, such as during the "Dynamics-aerosol-chemistry-cloud interactions in West Africa" (DACCIWA) multinational campaign (summer 2016), involving a number of TGOE scientists who were tasked with conducting cross calibration checks between the different platforms/instruments involved. There were a number of comparison activities undertaken during the lifetime of TGOE (DACCIWA, EMERGE, CLARIFY/ORACLES, ACRIDICON/GO AMAZON and the EUFAR ICARE-2017 conference). The TGOE working group were also heavily embedded (McQuaid was co-director and Bauguitte a tutor) in the very successful EUFAR STANCO training course (Cranfield, June/July 2017), which focused on measurement techniques, data analysis and specifics of airborne measurements of species relevant in the atmosphere. Emphasis was on new instruments and emerging techniques for aircraft observations for the benefit of 19 PhD students and early-stage career scientists from 9 countries across Europe.

Regarding MNGT – Management of the Consortium, five General Assembly meetings and the Mid-Term Review meeting were organised by the EUFAR Office. Two Steering Committee meetings were physically held and numerous exchanges by email between the scientific coordinator, project coordinator and activity leaders ensured a successful management of the project. Three periodic reports were submitted to the EC and one amendment to the contract was approved by the EC.

The EUFAR Office collectively managed the travel and subsistence (T&S) costs for attendees to the management meetings and to the networking meetings and workshops, for teachers and students attending the training courses, and for users of transnational access.

Description of the potential impacts

Impact on the structuration of the European Research Area

Over the past 17 years, EUFAR has built a new landscape in airborne science where scientific users, aircraft operators, and experts in airborne measurements closely and efficiently interact. As a result, EUFAR is now recognised as the portal to European airborne research in environmental and geo-sciences and it plays a leading role in the international community (e.g. publication of the handbook on airborne measurements, organisation of two International Conference on Airborne Research for the Environment (2010 and 2017), organisation of 9 training courses in total, to mention a few). Two indicators confirm these reinforced interactions: (i) the EUFAR network now incorporates all the operators of airborne research in environmental and geo-sciences (in situ, remote sensing and Earth surface observation); (ii) the number of proposals for transnational access has continuously increased from 40 in FP5 and 61 in FP6 to 78 in FP7 and 52 in this contract (EUFAR2 FP7). Today, the EUFAR transnational access is overbooked by a factor of more than 2 (out of the 52 proposals for TA received in this contract, 29 campaigns were supported and flown). In EUFAR2, the main effort was assigned to the involvement of end users of both academic research (e.g. national research programmes and EU-JPI) and applied research (EU environmental organisations and industries) for a better synergy between the bottom-up and top-down approaches in structuring the ERA. A key objective was to open the Member State operated research infrastructures to the whole European user community. With regard to airborne science, the main obstacle is the high additional cost of the flight operation. Through the Open Access scheme, EUFAR2 aimed to provide national infrastructure parent institutions and research organisations from countries lacking airborne infrastructures with the opportunity to share the additional cost, hence significantly increasing the flying potential of the aircraft for the benefit of new users. However limited progress was made and the Open Access scheme by resource-sharing could not be implemented during the EUFAR2 project period due to several limitations such as the lack of incentive to provide personnel resources in exchange for very small amounts of flight time and lack of pre-existing scientific collaborations. In essence, there is a need to create a more realistic vision for Open Access to be developed and implemented by the EUFAR AISBL. In addition, there is a need for comparison of the access cost models applied for national facilities and national users.

Improved access to researchers

An efficient procedure has been developed and consolidated for evaluation of the eligibility, feasibility and scientific merit of the transnational access proposals. Transnational access overbooking now calls for additional measures to increase its effectiveness: (i) a new criterion will be introduced in the evaluation process: end users participating in the SAC will provide EUFAR with a list of scientific priorities and their representatives in the UGSP will evaluate the pertinence of the selected proposals with respect to these priorities, hence increasing their potential scientific impact; (ii) the SAC members will also inform EUFAR about the most promising opportunities of clustering with already funded cutting edge airborne experiments, for sharing flight costs and the collected data, hence increasing the effectiveness of transnational access in terms of benefit to cost ratio; (iii) enhanced visibility of and up to date planning of the fleet on the website. Early-stage researchers also have the opportunity to take part in flight campaigns via the opportunities proposed in the N6 Education & Training activity (training courses, opportunity to join an existing flight campaign or visit an aircraft operator).

Coordinated approach between infrastructure operators, users and public authorities

This was the weakest point in the previous EUFAR projects. A gap analysis was performed in FP5 and a proposal was selected in the ESFRI roadmap in FP6 (COPAL) for filling this gap. In parallel, legal structure

models have been carefully examined to develop a sustainable structure for EUFAR. Both initiatives failed because public authorities were not involved in the process. Within the new SAC, public authorities will be in a position to drive and oversee the EUFAR initiatives for the development of the fleet and the sustainability of the network. The involvement of EU environmental organisations will also contribute by introducing a transnational perspective on these issues, and the industry players will suggest alternative approaches such as sharing high performance test aircraft between applied and academic research.

Improved use of the pool of research infrastructures

The networking activities N7SP and N8DB will address the current and newly-emerging initiatives towards common standards in environmental and geo-sciences. The current developments within these networking activities will be compliant with international standards and contribute to additional values of airborne related objectives to the different initiatives. With the incorporation of the developed standards in bigger initiatives, airborne measurements will be established in programmes such as GMES, ESA CCI, etc. Through these two activities EUFAR has also been taking an active part in the ENVRI community and has collaborated significantly with ENVRIplus on its Reference Model. Offering a simple, structured explanation of the main features to be expected in the information systems of typical environmental Research Infrastructures, the Reference Model has been implemented and tested by EUFAR to serve as a real case example. Moreover, the EUFAR RM case study will be completely modelled to be part of the ENVRIplus Knowledge Base, providing reusable solutions to common challenges to analyse and compare the characteristics of Research Infrastructures. The networking activity N9EC will contribute to improve the access to and use of the infrastructures via the new and improved EUFAR website, which offers a unique portal to all airborne research activities in environmental and geo-science in Europe. The portal provides detailed information on aircraft performance, instruments, opportunities of transnational access, publications, education and training, and clustering with already funded field experiments. Online templates are available to access proposals, which can then be submitted via the EUFAR Electronic Submission System. Once submitted, the proposals enter the evaluation workflow where their progress can be monitored and undue delays can be traced. The workflow also archives all documentation to monitor, support and justify EUFAR2 activities. Such capability will be further developed to ensure that the best science is supported by the most appropriate infrastructure with a suitable level of resources.

Cross disciplinary fertilisations and wider sharing of knowledge

The networking activity N4EWG supports a framework in which experts in airborne measurements from 12 research disciplines can interact and share knowledge. The enthusiasm of the participants is clearly obvious from the EWG workshops which delivered significant output in terms of useful reports, book chapters and special issues. To perpetuate the legacy of their contributions, the experts collectively published in 2013 a handbook on airborne measurements. The electronic version of the handbook is a living document that will progressively integrate new contributions. In the previous contract (EUFAR FP7 2008 – 2013) there were 20 expert working groups, however these groups were restructured to be more in line with the chapters of the EUFAR Handbook in order to develop supplementary material. During the last EUFAR2 FP7 contract (2014-2018), new revised and complementary material has been developed by the N7SP team (a revised version of the processing toolbox) and JRA1-HYLIGHT working group (a chapter on airborne hyperspectral imagery and laser scanning data for improved processing and interpretation), which will eventually be integrated in the Appendix A of the handbook: supplementary online material. Beyond the airborne measurements community, cross disciplinary fertilisation between environmental research infrastructures such as IAGOS and ENVRIplus, and exploratory ones such as EUROFLEETS and ACTRIS, is a promising initiative that will be promoted by organising joint expert meetings.

Potential for innovation and partnership with industries

In the previous FPs, there have been a few cases of technology transfer from EUFAR JRAs to the industries but the process was not structured. This is the most innovative contribution in EUFAR2. Within the framework of the EUFAR SAC, large industries driving innovation will express their most critical requirements, hence pulling innovation, while the EUFAR Office for Technology Transfer with the support of the Expert Working Groups will raise awareness of SMEs on innovative technologies developed by EUFAR researchers. SMEs as the key drivers of innovation will quickly and efficiently transform new ideas in successful businesses. The Technology Transfer Office will also bring innovation support services such as advice, guidance, promotion of expert technologies, partner search activities and networking events between experts and industry to facilitate the cross-border exploitation and commercialisation of research results. Within the last contract (2014-2018), some progress was made on technology transfer with the publication of the technology booklet with a detailed list of 11 innovative technologies with potential application to industry developed within the EUFAR community and the drafting of a preliminary list of potential industrial contacts. The next step, which was not achieved in this contact, would be to present the technologies to industry and foster meaningful partnerships.

Benefits of JRA1 for the EUFAR scientific user community

HYLIGHT developments (FW) ALS combined with HSI will lead to improved quality of the HSI Level 2 georeferenced reflectance products (e.g. by improved BRDF correction, visibility estimation for atmospheric correction) and Level 3 (e.g. better classification accuracy, more accurate derived biochemical parameters) products and (FW) ALS data having a direct impact on the application-oriented research performed by the EUFAR scientific community. Scientific users will benefit from the higher quality products with reduced uncertainty when developing higher level products. More accurate products will advance the development of existing applications like forestry, archaeology, and biodiversity mapping as more detailed maps with improved classification accuracy would be derived but will also enable the development of new applications, bringing in new application areas, which open up airborne research to other scientific disciplines. The latter will lead to broadening the EUFAR scientific user community. Through EUFAR FP7 a good link is established between users of HSI and EUFAR operators/processing facilities. Cooperation between HSI and (FW) ALS partners within HYLIGHT can be used to establish a link between (FW) ALS users and EUFAR operators/processing facilities leading to enlarging the EUFAR scientific user community.

Benefits of JRA1 for the broader European and international scientific user community

HYLIGHT tools are accessible for download via the EUFAR toolbox (N7SP). HYLIGHT developments have also been made available through the online supplementary material to the EUFAR handbook in Appendix A, including a chapter on “Integrating airborne hyperspectral imagery and (full-waveform) laser scanning data for improved image processing and interpretation” showing the value of the FW ALS data from instruments newly available in Europe and the added value of combining HSI and (FW) ALS. This HYLIGHT material can be used by university lecturers and at EUFAR or other training courses (N6ET) to educate and train early-stage researchers, preparing them, for example, for EUFAR TA flight applications.

Benefits of JRA1 for the EUFAR operators

All EUFAR operators/processing facilities acquiring/processing HSI and (FW) ALS data will benefit from the HYLIGHT developments as the 14 HYLIGHT tools are accessible for download via the EUFAR toolbox on the website. HYLIGHT developments also will be made available through Appendix A – supplementary online material to the EUFAR handbook including a chapter on “Integrating airborne hyperspectral imagery and (full-waveform) laser scanning data for improved image processing and interpretation”. This will enhance the

processing capabilities not only of the HYLIGHT partners but also of the other EUFAR operators/processing facilities for airborne hyperspectral and (FW) ALS data. A more integrated use of HSI and FW (ALS) and thus an increased level of automation of correction and classification will improve the data flow and efficiency of the processing facilities which will shorten the time between acquisition and delivery to the scientific users.

Benefits of JRA1 for the HSI and (FW) ALS industry

During EUFAR FP7 HYQUAPRO, links were established between the HYQUAPRO coordinator (VITO) and the hyperspectral sensor manufacturer SPECIM, Finland (http://www.specim.fi) and with ACTIMAR, France (http://www.actimar.fr/) which showed interest in the improvements of the EUFAR hyperspectral image processing capabilities and the development of quality layers for hyperspectral images in HYQUAPRO. HYQUAPRO/HYLIGHT cooperation with industry (e.g. SPECIM, ACTIMAR) will be exploited further in collaboration with EUFAR2 N5TTO. TU Vienna already established a close link with the (FW) ALS sensor manufacturer Riegl, Austria (http://www.riegl.com/). NERC-ARSF/PML has established contacts with Leica, Switzerland (http://www.leica-geosystems.com/). Industry will benefit from the HYLIGHT tools which will be made freely accessible through the EUFAR toolbox.

Benefits of JRA2 for the EUFAR scientific user community

Uncertainty is a hot topic in climate and atmospheric science and the increasing complexity of numerical models made available by leaps in processing power. Ultimately this means that the reliability of observations that are both being compared to and ingested into models needs to follow this trend. The impact of TGOE upon the uncertainties associated with the gas-phase observations made across the EUFAR fleet will be significant. Model sensitivity analysis has shown that photochemistry during intercontinental transport may be on the order of only a few ppb, thus such a difference between the measurements on two different aircraft platforms is far from ideal. This factors result in there being a data community who are poised to exploit the TGOE products. TGOE material will be available for use by those involved in teaching and training young scientists, in addition this material will be used to support EUFAR2 training courses. Several members of the TGOE have a history of managing and teaching EUFAR training courses to educate and train early-stage researchers in gas-phase measurements. In the past there has been something of a focus to measure the more challenging molecules which, on occasion, has inadvertently moved attention from the core measurements. TGOE is focussing on these core measurements. Whilst the measurement principle may be relatively straightforward, the application of robust sample handling as well as traceable calibration protocols. All instrument operators have some level of commitment to calibration of their instrumentation, however financial and time constraints can often prioritise collecting more data over collecting good data. TGOE highlights the importance of robust QA/QC procedures to the overall quality of the data product. Beyond the instruments themselves, the sampling handling train is critical for the transfer of external ambient air through the cabin wall into the measurement point within the instrument. TGOE will provide a forum for operators to understand issues associated with the different species in the TGOE suite. The key to producing a solid legacy from TGOE is the staff it will engage with, solid measurements are underpinned by excellence in making the observation and the understanding of the limitations of a specific methodology or approach. With such knowledge it will be possible to reduce the levels of uncertainty in the measurements through well developed and accredited procedures. TGOE will train the next generation of aircraft scientists, highlighting the importance of traceability in their measurements, this will be particularly important as more and more multi-platform experiments are flown.

Benefits of JRA2 for the broader European and international scientific user community

TGOE will establish a network of excellence in calibration techniques and this knowledge base will be an invaluable resource beyond the EUFAR community, this will be done through web-based forum/wiki and also TGOE will leave a legacy for the community, the protocols and standard operating procedures will be combined into a single chapter which will then be incorporated into future editions of the EUFAR handbook, the majority of the TGOE team were section leaders of this book. There are a number of networks which have very clear crossover, these include ground-based networks such as ACTRIS, INGOS, GAW as well those which are more aircraft observation facing such as MOZAIC and IAGOS. Protocols developed by TGOE will be made available to these networks and through the cross fertilisation of good practice all communities will benefit. A key objective for TGOE is the generation of an open network of expert instrument scientists who can train future users beyond the immediate EUFAR community.

Benefits of JRA2 for the EUFAR operators

TGOE will ensure more robust and reliable measurements for a wide range of key atmospheric chemical species as such this will in turn provide the science customers a better overall product. A further impact of TGOE will be improved maintenance procedures which in turn reduce downtime for instruments and this leads to enhanced instrument productivity for the EUFAR operators. Ultimately close collaborations between TGOE, GAW-WDCGG, GAW-VOCWCC and ACTRIS will ensure that best laboratory practices, materials and methods are observed by both ground-based instrumentation and airborne instruments within the EUFAR fleet.

Benefits of JRA2 for the instrument providers

Such TGOE activities provide multiple benefits across the user and instrument supplier community, improved instrument performance for the manufacturer coupled to better levels of quality assured data with more sustained quality control. It highlights the importance of programmes such as EUFAR-TGOE which support this type of activity which is often deprioritised due to the time restraints of busy research schedules with defined scientific objectives.

Benefits of MNGT for the future activities of EUFAR

The managerial experience gained through this project will benefit the EUFAR AISBL and EUFAR H2020 proposal for the Horizon2020 call INFRAIA-01-2018-2019: Integrating Activities for Advanced Communities, single-stage RIA Research and Innovation action, particularly in terms of efficient management & coordination practice and reporting guidance.