Research Infrastructure Concept for Evaluation by the German Council for Science and Humanities

# In-service Aircraft for a Global Observing System

# IAGOS


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**CONTENT**

# I. BASIC INFORMATION ON THE RESEARCH INFRASTRUCTURE PROJECT

1 – Please describe the planned new research infrastructure or the planned extension of the research infrastructure and its relevance for the affected scientific or technical field on a national, European and global level (max. 2 pages).

IAGOS shall establish a cost efficient world class Research Infrastructure (RI) for high-quality observations of atmospheric composition on a global scale by merging scientific technology with the global infrastructure of commercial aviation. Partners are leading atmospheric research institutes and universities in Germany, France, and the U.K., as well as weather services, specialized companies and airlines. The proposed RI builds on 15 years experience in two European research projects, MOZAIC (www.mozaic.aero.obs-mip.fr) and CARIBIC (www.caribic.de). Both projects have proven the technical feasibility of deploying scientific instruments in passenger aircraft and the scientific value of the observations. In IAGOS, the two complementary approaches are combined:

1. IAGOS-CORE: Implementation and operation of autonomous instruments installed in up to 20 long-range aircraft for continuous measurements of important reactive gases and greenhouse gases (ozone, carbon monoxide, nitrogen oxides, carbon dioxide, methane, water vapour), as well as dust (aerosol) and cloud particles. The installation consists of fully automated instruments that can operate aboard the aircraft in unattended mode for several weeks. The data are transmitted automatically via the global mobile phone network into the database and via SATCOM for real-time data users (see Annex 14A for Details of the installation).

2. IAGOS-CARIBIC: Monthly deployment of a cargo container equipped with instrumentation for a much larger suite of components, including those above but also instruments that cannot yet be implemented in full routine operation. These include organic compounds, halocarbons, mercury, aerosol elemental composition, isotopes. The installation combines instrumentation for in-situ measurements and remote sensing, and the collection of samples for analysis in the laboratory (see Annex 14E for Details of the installation).

The two approaches are fully complementary with IAGOS-CORE providing global coverage on a day-to-day basis of key observables and IAGOS-CARIBIC providing a more complex set of observations with lesser coverage. Due to extensive preparatory work conducted since 2005 in two European projects, IAGOS is ready for implementation. It is projected to operate IAGOS over a period of at least 2 decades.

Progress in our understanding and prediction of atmospheric composition change and its impact on climate is only possible by increasing the quantity and quality of observations in the proper atmospheric domain. IAGOS, if realized, will eliminate a major deficiency in current atmospheric observation capabilities by filling the gap between satellite observations and ground based data. IAGOS will provide long term, frequent, regular, accurate and spatially resolved in-situ observations in the upper troposphere and lower stratosphere (UTLS), where information is very sparse compared to the surface, although this region is paramount for understanding the causes of climate change. IAGOS will also provide vertical profile information at many locations over the globe from thousands of take-offs and landings. As in numerical weather forecasting, these profiles are essential for the validation of numerical models and satellite data products. Real-time transmission of IAGOS multi-component datasets will enable weather services and airlines to exploit the data for improved (chemical) weather forecast, and potentially for enhanced crisis management during volcanic eruptions.

The MOZAIC and CARIBIC data are increasingly used by research groups worldwide (> 200 ISI-listed publications). The mandate by the international scientific user community was a major driver in proposing the transformation into a sustainable infrastructure and played an important role in the successful application of IAGOS to ESFRI. Large interest to join the new RI has already been expressed in North America and Taiwan. The strong interest of the aviation sector is demonstrated by commitments from Lufthansa, Air France, Iberia/British Airways, China Airlines and Cathay Pacific, who agreed to provide free transportation of the equipment. Reasons are their intention to contribute to a better understanding of climate change with particular emphasis on the impact of aviation and the scientific basis for emission trading.

2 – If applicable, please name further cooperating institutions and add each of the on-site responsible scientists and contact persons.

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## II. DIMENSIONS OF EVALUATION

If possible and useful, please reinforce your information on the four dimensions of evaluation (scientific potential, utilization, relevance for Germany as a location of science and research, feasibility) also with quantitative data.

### 1 – Scientific potential

1.1 What is the significance of the research infrastructure? Which issues of the relevant field(s) of research can be addressed via the research infrastructure? Which new fields of research could be made accessible through the planned research infrastructure? Which alternative ways have been explored to scientifically work on these research questions or fields of research? Please answer these questions with a short report against the background of the present state of research.

What is the significance of the research infrastructure?

The new infrastructure addresses important questions related to climate change and air quality by closing the gap between the existing worldwide satellite and ground-based networks for atmospheric composition monitoring.

State of the art

The report of the Intergovernmental Panel on Climate Change (*IPCC 2007, Summary for Policymakers, Annex 1*) concludes that climate change is driven by changes of greenhouse gases and of aerosol particles that enter the atmosphere due to natural processes and as a consequence of anthropogenic activities. According to IPCC, only approximately 50% of the temperature increase observed since the beginning of industrialization is caused by the increase of carbon dioxide (CO2), the rest is due to changes in the so-called “other greenhouse gases” (e.g., methane $CH_4$, nitrous oxide $N_2O$, ozone $O_3$, halocarbons CFC) and aerosol.

The assessment of climate change and the development of abatement/mitigation strategies are made with numerical models operating on various scales (from urban to global). Model products include validation of emissions of trace gases and particles, their impact on air quality and climate, as well as air quality forecasts, climate predictions or cost-benefit analyses of mitigation options.

The quality of the model products and the accuracy of the predictions depend on the ability of the models to simulate the relevant atmospheric processes. Modern climate models are capable of treating aerosol and cloud processes, albeit in a simplified and highly parameterized manner. Large uncertainties exist, e.g., in the description of deep convection, responsible for transport of trace gases from the surface into the upper troposphere. This process is strongly simplified in models, which results in particularly large uncertainties in the distribution of short-lived gases such as $NO_x$ and oxygenated volatile organic compounds (VOCs) and their impact on ozone.

In order to reduce the uncertainty of climate predictions, the models require input from measurements, both as boundary conditions and for the evaluation and improvement of parameterizations. Indeed, observational capacity is essential for all aspects of atmospheric research, including the assessment of causes for past changes as well as the prediction of further future changes and the economic and social consequences (c.f., *IPCC 2007, Summary for Policymakers, Annex 1; IGACO report, Annex 2, and IGCO report, Executive Summary, Annex 3*).

The largest uncertainties in our current knowledge on climate change are associated with the complex feedback mechanisms in the climate system, for example the amplification of the $CO_2$-induced greenhouse effect by water vapor (*Lacis et al., Science, 2010*), the effect of aerosol on cloud formation and cloud microphysics (*Clarke and Kapustin, Science, 2010*), or the modification of biological cycles by climate change (*Mahowald, Science, 2011*). These uncertainties, in turn, imply large unknowns in predicting the future climate, especially at regional scales (*Schiermeier, Nature, 2010; Lenton, Nature Climate Change, 2011*).

The atmospheric greenhouse effect is not confined to the lower atmosphere, but is largely driven by changes in the upper troposphere and the lower stratosphere (UT/LS) (see Fig. 1). For instance, the small increase of water vapor in the stratosphere (by only ~0.8 ppm between 1980 and 2010) is likely responsible for 25% of the total anthropogenic greenhouse effect of ~0.5°C during this time (*Solomon et al., Science, 2010*).

The UT/LS is characterized by high and variable wind speeds (jet stream systems) and strong vertical gradients across the tropopause, the boundary between the well mixed troposphere and the stratified stratosphere. Because of this complexity, the UT/LS is one of the least understood atmospheric layer and is very difficult to monitor by remote sensing from space, because of the spatial and temporal resolution required to resolve the fine structures in the UT/LS.

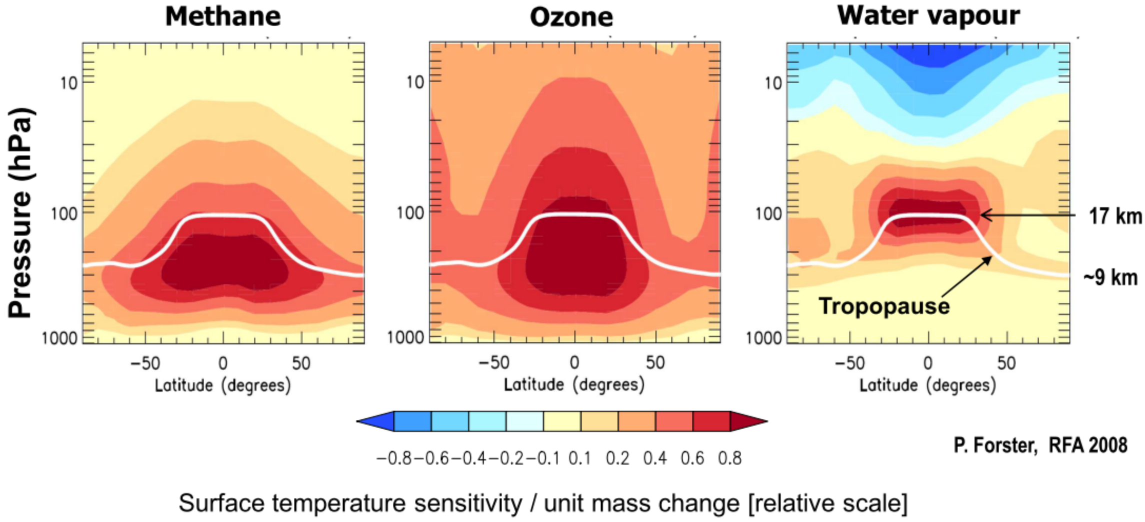


**Figure 1.** Changes in surface temperature due to changes in the concentrations of methane, ozone, and water vapour at altitudes between the surface (1000 hPa) and ~35 km (5 hPa). The upper troposphere / lower stratosphere (UT/LS) is the layer between ~6km and ~18 km; the white line indicates the tropopause, the transition between troposphere and stratosphere *(source: PREMIER, Report for Assessment, 2008).*

Climate change also influences air quality by modifying atmospheric transport and weather patterns (Zahn *and Storch, Nature, 2010; Min et al., Nature, 2011*) with impacts on air quality in Europe and other regions of the world due to long range transport of pollutants, ozone, and aerosol from growing economies (HTAP 2010 report, Executive Summary , Annex 4).

### Which alternative ways have been explored to scientifically work on these research questions or fields of research?

The optimum strategy for Integrated Global Atmospheric Chemistry Observations (IGACO) was established by an international panel of scientists under the lead of the World Meteorological Organization (WMO) and the European Space Agency (ESA). As is outlined in the IGACO report *(Annex 2)*, today's and future atmospheric composition monitoring capacity relies on three cornerstones: space-borne remote-sensing, ground-based monitoring networks, and passenger aircraft.

The IGACO report has also formed the basis for the recommendations of a Working Group established under the lead of the European Environment Agency (EEA) and

WMO for the development of the in-situ component for the European strategy on Global Monitoring for Environment and Security (GMES).

According to these reports, routine aircraft observations represent the only way to collect detailed and representative information in the altitude range where the natural and anthropogenic greenhouse effect is largely generated (see Fig. 1) and where the dynamical complexity and physical limitations (e.g. for satellite instruments, remote-sensing instruments) hamper representative monitoring by any other platform existing today. Passenger aircraft also represent the only means for collecting in-situ measurements of vertical profiles of many traces gases and aerosol at the same time throughout the troposphere in a representative manner.

Because of the much higher operational costs (cf. *Annex 9*), the use of research aircraft is limited to short campaigns with specific objectives. Furthermore, only ca. 10 of the today's worldwide fleet of research aircraft are capable to reach the UT/LS. Thus, data from research aircraft, while being paramount for detailed process studies, are not appropriate to retrieve seasonal and inter-annual variations or long-term trends (*Kunz et al., 2008*).

Which issues of the relevant field(s) of research can be addressed via the research infrastructure?

The data sets provided by IAGOS are unique and extremely powerful for answering the more general questions listed above. Specifically, the data are essential for the

- Validation of fundamental physical, radiative and chemical processes in climate models, chemical transport models, and air quality models and to assess their long-term performance. MOZAIC data have already been used in model comparisons, including those for IPCC and HTAP;
- Validation of the existing ground-bases and satellite-borne network for atmospheric composition monitoring;
- Quantification of the distribution, budget and trend of water vapour, (ice) clouds, ozone, GHGs, CFCs, and many chemically important trace gases in the UTLS;
- Attribution to anthropogenic and natural causes, e.g. long-range transport of emissions from developing economies and biomass burning (wild fires);

- Distribution and budget of aerosol in the free troposphere and its influence on regional air quality and aviation (influence of long-range transport, sand storms, and volcanoes);
- Improved understanding of the Formation and persistence of aircraft contrail and their currently largely unexplained impact on climate, as well as improved understanding of the distribution of ice clouds and their long-term change;
- Reduction of the currently existing uncertainties regarding the environmental and climate impact of aviation.

Which new fields of research could be made accessible through the planned research infrastructure?

IAGOS is a specific infrastructure for atmospheric research. The special technological know-how and concept can be shared with other research fields such as Geophysics or Astronomy.

1.2 For which field(s) of research is the research infrastructure of relevance? What significance does this project have for the development – at the moment and on the long run – of the field(s) of research? What would the consequences for the field(s) of research be if the research infrastructure was not supported?

IAGOS is important for the research fields Atmosphere, Meteorology, Environment, and Climate Change.

IAGOS data help to answer questions related to atmospheric dynamics (stratosphere-troposphere-exchange), greenhouse gases/global warming, aerosol particles and clouds, atmospheric oxidation capacity, long-range pollution transport and air quality. IAGOS will also provide detailed information on long-term trends of atmospheric composition for future generations.

As detailed in IGACO, IAGOS will as one of the three pillars of atmospheric composition monitoring (besides ground based observations and remote sensing) deliver quality controlled in-situ data to data assimilation systems such as currently under development for GMES. These systems combine the different data streams to generate a realistic view of the atmosphere. Vertical profile information from IAGOS represents the key link between the ground-based network and the indirect remote sensing observations from space. On the long run, IAGOS is expected to result in fundamental improvements in models for air quality and climate research. This included the development of higher resolved and more quantitative approaches for representing in-situ data, the consistent description of chemical processes as well as of aerosol and carbon cycles. The enormous value of representative datasets is clearly shown in the example of numerical weather prediction.

Without IAGOS, the gap between ground-based and space-borne observations cannot be closed, and the resulting uncertainties in atmospheric and climate research would remain. The further development of the research field would be hampered due to the lack of knowledge of the state and long-term change of a crucial part of the atmosphere. Early detection of atmospheric changes, even nowadays unforeseen, would be reduced and therefore limit the societal responsibilities of the research fields.

Sustainable operation of autonomous equipment aboard passenger aircraft at large scale requires long-term funding commitments because of the relatively long lead times (ca. 1-2 years) for implementation of equipment aboard the commercial aircraft and the need for closing long duration (5 – 15 years) contracts with many airlines world wide. Without sustainable funding, there is the danger that the technical competence and specific know-how needed for successfully cooperating with industry, airlines and aviation authorities is lost.

1.3 Which scientific and technological innovations are expected of the research infrastructure? Will new cooperations be supported within and beyond the discipline due to the planned research infrastructure?

IAGOS PIs have been working at the forefront of instrument development and have successfully deployed the new instruments on board of several research aircraft during national and international field studies. Like for space-borne instrumentation, the technical requirements for deploying instrumentation aboard aircraft are demanding in terms of weight, sensitivity, accuracy, reliability, self-calibration, and fully automatic function. These extreme demands have already triggered substantial technical innovations in the IAGOS pre-studies, i.e. (cf. *Annex 14*):

- A new instrument for measurements of ozone and carbon monoxide (collaboration between CNRS Laboratoire d’Aérologie, Toulouse, and Lacroix and LGM, France).

- A new concept for integration of the new instruments into the avionics compartments of Airbus A340 and A330 aircraft (collaboration of several IAGOS Partners with Sabena Technics SAS, France).
- A new instrument for measurements of nitrogen oxides (collaboration between FZJ and enviscope GmbH)
- The most precise multi-species measurement system for GHGs, capable of long-term unattended operation (collaboration between MPI and Picarro Inc., USA).
- The most sensitive ozone detector worldwide (developed by IMK for CARIBIC and now commercially available via enviscope GmbH, Germany).
- A novel miniature, non-intrusive Backscatter Probe for cloud particles (collaboration between Univ. Manchester and Droplet Measurement Technologies Inc., USA)
- A new Optical Particle Counter for airborne research (collaboration between DLR and GRIMM GmbH)

The technical developments and certification for the use aboard aircraft were conducted in close collaboration with industry. Further innovations of this kind are expected for the future as new scientific questions arise and as novel methodologies become available (see chapter III for specifically planned innovation). Because of its special expertise, IAGOS can also provide improved measurement techniques for implementation into operational meteorological networks, i.e., AMDAR, where cooperation already exists. Airlines and weather services are particularly interested in small and reliable aircraft-certified instruments for operational monitoring of water vapour, clouds and volcanic ash particles. As a consequence of discussions between IAGOS and aviation (c.f. *Annex 5A*), an expansion of the aerosol measurement systems towards monitoring volcanic ash is already ongoing (See *Annex 5B*).

The close collaboration with the aviation industry will also help to reduce the uncertainties in the assessment of the environmental and climate impact of aviation.

The global nature of IAGOS and its novel observations covering a broad range of observables will foster international collaboration between experimental and theoretical fields of atmospheric research and with the remote sensing community.

### 1.4 Which possible modes of operations will be opened up by the planned research infrastructure? Can these change within the course of the lifetime of the infrastructure (*multipurpose platform*), or is it a specific infrastructure?

Although IAGOS is a specific infrastructure, the IAGOS concept is not restricted to the specific scientific questions and technical solutions planned today. Besides providing long-term observational data IAGOS will allow

- validation of regional and global climate and air quality models in regions and resolution not accessible today,
- validation of satellite retrievals
- harmonization and additional quality assurance for ground based networks.

Future applications include the adaptation to new questions in atmospheric research, for example the monitoring of potential effects caused by future geo-engineering approaches aimed at mitigation of climate change, but also the deployment of sensors for other research fields such as geophysics or astronomy.

IAGOS will serve to maintain and expand the German and European expertise in the development of high-tech instrumentation and their technically challenging implementation on board passenger aircraft. Hence IAGOS will proof the value of passenger aircraft as a platform for other research communities or for commercial applications. (*See also section 1.3 for industrial applications*)

### 1.5 What are the differences between the planned and other existing or planned research infrastructures? Please specify competing and complementary research infrastructures from all over the world in the appendix. In case of an overlap, what is the additional benefit? Are synergies made use of?

IAGOS is unique in several aspects: In Europe, no similar atmospheric research infrastructure exists. World-wide, there is only the smaller CONTRAIL project in Japan, where 3 – 5 aircraft measure a much smaller suit of species (only $CO_2$ is measured continuously, in addition to collection of samples for subsequent analysis of $CH_4$, CO, $N_2O$, $H_2$, and $SF_6$). The CONTRAIL flights mostly cover the pacific and south-east Asian region.

IAGOS provides a substantially broader picture than CONTRAIL, both in spatial coverage by cooperating with multiple airlines and in terms of species measured and research fields addressed. Furthermore, IAGOS foresees real-time transmission of atmospheric composition data to operational and scientific users (e.g. the GMES Atmospheric Service) via the communication channel used for meteorological variables.

Collaboration between IAGOS and CONTRAIL already exists via, e.g., joint publications, exchange of scientists, and participation of the PIs in advisory panels. Although the two approaches will likely remain their own image, it is foreseen to closely coordinate IAGOS and CONTRAIL in order to avoid duplication of efforts.

A complementary infrastructure in Europe is the Integrated Carbon Observation System (ICOS) which is also in its preparatory phase. ICOS seeks to implement an atmospheric, oceanic and ecosystem network across Europe to study the carbon cycle on multi-decadal time scales. There is significant synergy between IAGOS and the atmospheric component of ICOS, where GHGs are measured from tall tower observatories. IAGOS will extend these measurements by providing the vertical profiles needed for the calibration of the models used in ICOS. Collaboration between ICOS and IAGOS is ensured through formal cooperation in France, and through the strong participation of MPI-BGC in both projects. This collaboration ensures that the existing synergies are fully exploited. A compilation of worldwide existing and planned observation systems is given in the IGACO report (*Annex 2*).

## 2 – Utilization

2.1 Who will use the planned research infrastructure? Please define the size of the user groups, their disciplinary and institutional origin, preferably differentiated by their intensity of utilization. Does the capacity of the planned infrastructure fit to the size of the expected user group? Are new user groups supposed to be attracted by the new research infrastructure? Do concrete expressions of interest of institutions exist? How big is the percentage of international users? Why is the international community of users interested in the research infrastructure? Are companies interested in the research infrastructure?

The IAGOS infrastructure will be used by scientists engaged in atmospheric and climate research from Germany (HGF, MPG, IfT, Universities), from Europe (e.g. CNRS, Meteo France, KNMI, Universities of Toulouse, Paris, Norwich, Manchester, Cambridge, Stockholm and Szeged) and world-wide (USA, Taiwan, Hong Kong, India, Australia, WMO, etc.). The strong interest of many international researchers in the data of MOZAIC and CARIBIC and the extension to the global scale and to include novel measurement systems was a key driver to transfer the projects into a sustainable infrastructure (see *references in Annex 6*).

Past experience from MOZAIC and CARIBIC shows that the size of the different user groups ranges from individuals to a few tens. World-wide there are more than 100 research groups involved in the analysis and scientific exploitation of data from MOZAIC and CARIBIC. This group of direct users comprises about 500 persons world-wide. A list of publications resulting from these projects is given in *Annex 7*.

Furthermore, interest in participation in the new RI also exists in terms of proposals for new technical developments (e.g. Videoton/HILASE ltd., Hungary), and by researchers in the USA and Taiwan to fully join in the operation of the RI (*Letters of Intent in Annex 6*).

Global Monitoring for Environment and Security (GMES):

In-situ data from IAGOS have been identified as important for the GMES Atmospheric Service (GAS), which is currently under preparation in the FP7 project MACC (Monitoring Atmospheric Composition and Climate) (see *letter of support from ECMWF and EEA in Annex 6A and 6B resp.*). This also concerns the future GMES Climate Service.

The GMES Atmospheric Service will also generate downstream products for policy and the general public such as already planned in IGACO. GMES is a European contribution to GEO/GEOSS.

The data products delivered by IAGOS are also of interest to weather prediction centres. Meteo France is already involved in the preparation of IAGOS, and the German Weather Service has expressed interest in IAGOS data (*letter by DWD in Annex 6C*).

Aeronautic Industry:

Key information for the aviation industry delivered in IAGOS is to improve the scientific basis for estimating the impact of aviation on air quality and climate change, with direct relevance to emission trading (ETS). Within the European aeronautical industry, IAGOS is considered as potential provider for measurements of ash particles which may cause severe threats to aviation (cf. *Annex 5*). The experience gained in IAGOS is expected to influence significantly the development of robust and small-sized on-board sensors for aviation industry by direct transfer of knowledge. This group comprises the airlines currently engaged in IAGOS (DLH, AF, BA/IB, CAL, CPA) as well as engine and airframe manufacturers (RR, P&W, Airbus, Boeing) and the modelling community engaged in ash forecasting (VAACs). It is expected that more airlines will be participating in IAGOS once the system has been established (interest expressed by, e.g., Quantas, South African, Phillipine Airlines, Finair).

### 2.2 What impact will the planned research infrastructure have on the use of other already existing research infrastructures?

In the field of Earth observation, there is no comparable infrastructure capable to address and answer the above questions. The existing, large-scale atmospheric ground networks or satellite projects have different, complementary strengths. In fact, significant improvements in the quality of data delivered from space observations are expected by the use of IAGOS data for evaluation and improvement of the retrieval algorithms.

By using the same instruments and quality assurance procedures for measurements everywhere, IAGOS will provide internally consistent datasets that will serve as a reference system for harmonization of the global network of ground based observation organized in the Global Atmosphere Watch (GAW) program of the WMO.

### 2.3 How will the access to the planned research infrastructure be organised? The choice of research projects respectively the authorised people is based on which criteria? Will access procedures vary for users from different countries or institutions? Will the operating of the research infrastructure be co-financed via user fees?

IAGOS is planned to be an open infrastructure in the following aspects:

1. Access to data:

The data measured onboard the IAGOS aircraft will be transferred to a central data base and interested users can access the data base free of charge after having signed a data protocol. Access to real-time data will also be free of charge and is foreseen to be achieved in the framework of GMES via the European meteorological network, i.e. EUMETNET (MoU under signature at Meteo France). The access will be regulated in contracts with the EEA, who is designated to handle the provision of in-situ data for GMES. Contacts have already been established. It is foreseen that GMES will provide a significant contribution to the operational budget of IAGOS (see *EEA-letter, Annex 6B*).

2. Experimental participation/partnership:

The IAGOS general assembly will decide on the approval of proposals for new instrumentt developments and on the admission of new partners within the consortium. Assessments made by the scientific advisory board in advance will be used as a basis for decisions. New partners are expected to appropriately contribute to the funding.

### 2.4 Which expertise is required for the utilization of the planned research infrastructure? How will it be ensured that users actually have this expertise?

The use of the IAGOS data does not require special knowledge and all information for its use will be implemented, partially in form of metadata. Potential new instrument providers must have detailed knowledge on instrument development and on the deployment of instruments aboard research aircraft. Following successful instrument development, an initial integration into the CARIBIC container is likely, before the more complex and costly certification process for the IAGOS-CORE system is started. Many years of experience shows that it takes about 2-3 years for the development of new instrumentation. In addition, the infrastructure will maintain cooperation with aeronautic companies that can be recommended to new users in order to facilitate their tasks.

The provision of the special knowledge in instrument certification will be provided by the IAGOS institutes via the organization of workshops and summer schools and via the exchange of students and researchers.

## 3 – Relevance for Germany as a location of science and research

3.1 Does the planned research infrastructure follow up on the strengths of Germany's research or does it compensate a weakness? In what respect does it strengthen Germany's research? How does the planned research infrastructure support the medium- and long-term visibility and attractiveness of Germany as a location of science and research within the European and international context, especially with the new generation of academics in mind?

The new research infrastructure will join the activities of major German research institutions, namely from the Helmholtz Society (HGF), Max Planck Society (MPG), Leibniz Association (LA) and Universities engaged in the field of atmospheric research. The founding of IAGOS is essential to secure the German (and European) capacities for high quality in-situ observations of atmospheric composition.

IAGOS provides systematic observations of key parameters, which the BMBF *High-Tech Strategy for Climate Protection* regards as indispensable prerequisite in acquiring the basic knowledge of processes involved in climate change. The strategy identifies the important role of Germany in assuming leadership.

Germany has assumed the leading role within IAGOS already during the IAGOS preparatory phase project. Founding of the IAGOS infrastructure will ensure the leading role of Germany in this scientifically important area and will increase both the visibility in the global atmospheric community and will increase the attractiveness of Germany for young researchers and students from other countries.

3.2 For which German scientific institutions (universities/non-university research institutes) is the planned research infrastructure of importance? Which role does the research infrastructure play especially for the training of the new generation of academics?

In IAGOS, institutes from all major German research branches engaged in atmospheric research are represented (see 3.1). Thus IAGOS is important for the German atmospheric research community as a whole. Due to established collaboration with universities and the particular challenges by working across the fields of high-tech instrument development, atmospheric modelling, validation of remote sensing, and aviation, IAGOS is attractive for students from many disciplines, including atmospheric research, physics chemistry, meteorology and engineering. This has already been the case in the preceding projects (~20 diploma/master and ~30 doctoral theses).

The educational aspect will be addressed by IAGOS in special workshops and summer school for students.

3.3 How does the planned research infrastructure fit into the whole field of research infrastructures in Germany, in Europe and world-wide? How is it related to existing German research infrastructures that are competing or complementary? Please add a list of competing and complementary research infrastructures of the field from around the world which already exist or are planned in the appendix. How have the preparation, construction and operation of these research infrastructures been coordinated with the institutions?

IAGOS is one oft he smallest infrastructures within the ESFRI roadmap. It combines existing activities in Germany and Europe and is an essential complement to the existing monitoring networks and infrastructures. IAGOS is unique within Europe. Worldwide there are already MoUs and letters of intent to participate in IAGOS by Taiwan, Hong Kong and USA. With the exception of the Japanese Projects CONTRAIL there is no competition. Planning is coordinated with CONTRAIL (CONTRAIL is represented on the advisory board of IAGOS-ERI).

The coordination of the infrastructure necessary for Atmospheric Research has taken place within the framework of IGACO. The IGACO report (*Annex 2*) also lists the complementary infrastructures, particularly in the area of satellite remote sensing and ground-based monitoring networks. The institutions participating in IAGOS are heavily involved in the preparation, operation and scientific utilization of these complementary infrastructures (*Annex 8*). In particular, IAGOS partners also act as operators and users of most of the German research aircraft (DLR, HGF, MPG, IFT, enviscope). This ensures the clear separation of research activities as well as the realization of synergies.

A complementary infrastructure on the ESFRI Roadmap is ICOS, to which close ties exist in Germany and France. Thus strong synergies are expected to be realized (see II.1.5).

### 3.4 How can the research infrastructure help Germany address the grand challenges? Have measures been arranged for the support or activation of the realization of concrete solutions?

Climate change represents arguably the most serious environmental issue facing mankind today, with severe implications on economy, social stability, and policy. Reliable predictions of the future climate using climate models are a central and fundamental requirement for determining future mitigation strategies. These models require global datasets in order to accurately model the radiative forcing by GHGs, aerosol and clouds. Only IAGOS can provide such high-resolution, long-term, in-situ data (cf. chapter II. 1)

Increasing globalisation and the industrial development in Asia lead to new challenges in global air quality. For example, long-range transport of emissions in remote countries has a large influence on air quality in Germany and Europe. The development of mitigation options for air quality and protection of the environment therefore require first hand knowledge of the changing atmospheric composition and its causes.

The development of solution strategies related to climate change and environmental policy is mainly located in the fields of economy, sociology and international law and hence beyond the scope of IAGOS. However, by providing essential information to the GMES Atmospheric Service (c.f., 2.1), IAGOS will contribute to the development and evaluation of socioeconomic strategies including geo-engineering approaches.

### 3.5 In case of an international project: What position does Germany have (leading position/taking over important work packages)? Have the interests of Germany been adequately taken into account within the concept?

As agreed between the major stakeholders, Germany assumes the leading role in IAGOS. German institutes represent the majority of institutes involved in IAGOS and have developed the majority of the novel measurement systems for IAGOS (see IAGOS-DS, IAGOS-ERI contracts and CARIBIC web page). The interests of Germany are adequately addressed by:

- Leadership and operation of the IAGOS secretariat
- German institutions adequately participating in the measurements and research activities

- Involvement of German companies in the operation (Lufthansa, enviscope, GFM)

### 3.6 Where does the exceptional political significance of the planned research infrastructure for the German science and research landscape additionally lie?

IAGOS provides continuous and systematic observations of key parameters requested by the BMBF *High-Tech Strategy for Climate Protection:*

*"Monitoring, the regular and systematic observation of important climatic parameters, is an essential requirement for observing change in its totality as it occurs and to expanding our knowledge of the processes of change."*

The strategy also highlights the important role of GMES and GEOSS in global monitoring, and indeed, IAGOS will form one of the cornerstones of GMES for atmospheric in-situ observations, and thus will provide data to the entire international scientific community and will be integrated in international programmes under the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP).

IAGOS is also closely linked to the Helmholtz programme "Atmosphere and Climate", and to international research policies such as the European GMES initiative, and the WMO-GAW programme. IAGOS will provide information directly related to the following issues:

- Climate change, carbon cycle and climate-chemistry interactions (IPCC, Kyoto protocol)
- Stratospheric ozone depletion (UNEP/WMO assessments, Montreal protocol)
- Global and regional air quality (CLRTAP/HTAP, GMES)
- Emission trading, especially for aviation

## 4 – Feasibility

*Technical requirements*

4.1 Are there technical innovations necessary for the realization of the research infrastructure? Which steps are planned for these?

An important innovative aspect was the technological challenge to establish a complex monitoring system with high measurement accuracy in unattended operation under the strict safety regulations applicable for passenger aircraft. As outlined in section III 1.2, the majority of the innovation steps have already been accomplished with the help of European funding under FP6 (IAGOS-DS) and FP7 (IAGOS-ERI) and with national funding from Germany, France and the UK. As a result, the first IAGOS aircraft has been modified successfully. The last few steps awaiting completion as final deliverables in IAGOS-ERI concern the implementation of the real-time data transmission (under responsibility of Meteo France), and finalisation of the EASA certification of the novel instruments for greenhouse gases and aerosol (Packages 2c and d). Extension of the IAGOS STC to Airbus A330 aircraft is also a deliverable of IAGOS-ERI (under responsibility of CNRS). The CARIBIC container was also modified and re-certified in IAGOS-ERI. Therefore, implementation of the RI can start immediately.

4.2 Have technical alternatives – also in respect of cost-benefit-aspects – been checked? (Justification required not only in terms of the general financing but also from a technological point of view)

Using instrumented passenger aircraft as in-situ platform for the global observation of the UT/LS is without alternative, both in terms of achievable representativeness and cost-benefit. As outlined in section II.1, satellite instruments and ground based remote sensing do not provide the required resolution for the UT/LS and in the free troposphere.

The institutions behind IAGOS also operate instruments on board of research aircraft a few of which are capable of reaching the lower stratosphere (DLR-Falcon, DLR-HALO, Learjet, MF-Falcon, see *Annex 9*). However, research aircraft are by far too expensive for being used for representative scientific monitoring on the global scale. On average, one flight hour of the IAGOS core equipment (120 kg) costs ~15 €, whereas the operational costs per hour for research aircraft range from ca. 5000 to 25000 Euro (see *Annex 9*), without accounting for the initial investment. Even the costs of transportation for the CARIBIC measurement container (400 € per hour for 1.5 tons of equipment) are more than a factor of 10 cheaper than the cost of research aircraft.

Moreover, the airlines (Lufthansa, British Airways/Iberia, CPA, CAL) agreed to waive the costs for transportation of the IAGOS-CORE system, which contributes significantly to covering the operating costs of IAGOS (see chapter III).

4.3 Are preliminary studies necessary? If this is the case, are these already scheduled or planned? (For completed preliminary studies cf. III.1.2).

Pre-studies have already been conducted successfully during the past decade: MOZAIC, CARIBIC, IAGOS-DS, IAGOS-ERI (see III.1.2). No need for additional pre-studies has been identified.

4.4 Are there special requirements for e-infrastructures? If so, which plans exist for the provision of it and how is it embedded into the national and European landscape of e-infrastructures?

IAGOS has considered the requirements for e-infrastructure from the beginning. Two data portals are in preparation under the lead of French partners. This includes the implementation of a specific data portal at CNRS (in cooperation with CNES under ETHER) for scientific users and the use of existing e-infrastructure of the Meteorological Services for real-time data, i.e., the E-ADAS system operated by EUMETNET and the WMO Information System (WIS). The adaptation to existing structures of the meteorological services has a large advantage for the users, as they can utilize their usual data pathways. The data formats and encoding/decoding software has been developed by Météo France in close cooperation with the users.

IAGOS principal investigators are members of Global Atmospheric Watch Scientific Advisory Groups which ensures the linkage of IAGAS data into the WMO-GAW structures. Further enhancement of the accessibility of the IAGOS data base for non scientific users including interoperability with other geo-datasets is foreseen as part of a proposal (IGAS: IAGOS for the GMES Atmospheric Service) submitted to the FP7 Space Call 2012.

*Institutional requirements*

4.5 Why is the hosting institution interested in becoming the headquarters of the planned research infrastructure project? How is the new research infrastructure integrated into the long-term strategy of the hosting institution (and the cooperating institutions)? How will the hosting institution get involved (including the financial support)?

FZJ and the associated IAGOS partners have the leading role in the operation of MOZAIC and CARIBIC. IAGOS is a key element of the HGF Programme ATMO, in which FZJ, KIT and DLR are participating. Continuation and expansion of the work started in CARIBIC and MOZAIC by foundation of IAGOS received a strong recommendation by the HGF-Programme review panel. At the FZJ, Global Observation is established as an own research group with IAGOS forming the key building block for the observational part.

Capacities for the scientific exploration of IAGOS data are established at all partner institutions. IAGOS is one of the major infrastructure projects in the domain of atmospheric research at FZJ, MPG, KIT, DLR and IfT. All participating institutions are committed to provide substantial contributions to the operation of the new RI (ca. 50% on average, see chapter III) and contributed in the past during the installation and operation phase of the precedent projects MOZAIC and CARIBIC. DLH has supported MOZAIC and CARIBIC from the beginning and has embedded the support of environmental and climate research in its company profile.

4.6 If the project is part of a research network or some other project-like research association: How is it guaranteed that the project outlasts the existence of the association?

The German and French institutions participating in the preparatory phase of IAGOS have successfully managed to sustain the projects MOZAIC and CARIBIC during almost two decades, including periods without project funding. One major task of the EU project IAGOS-ERI is the establishment of a sustainable structure for the long-term operation of IAGOS. For achieving this goal, an International Association under Belgian law will be founded. All IAGOS partners are foreseen to become members of the Association and FZJ will host the project office.

The associated institutions have expressed long-term commitments for the support of IAGOS (see *letters in Annex 10*). In France, IAGOS is on the national roadmap for large RIs (see *letter by CNRS-INSU in Annex 10C*). The universities of Manchester, Utrecht, and Lund have also committed to contribute to IAGOS-CORE and –CARIBIC (*Annex 10D-F*).

4.7 What kinds of scientific expertise already exist within the hosting institution regarding the field(s) of research that is/are related to the research infrastructure? Please quote five relevant publications of scientists of your institution of the last five years.

FZJ: The Institute for Energy and Climate research: Troposphere (IEK-8) has over 30 years of experience in the field of Atmospheric Chemistry with a particular strong focus on the measurements of trace gases and aerosol combined with global to regional modelling. About 70 scientists, engineers, technicians and doctoral students are currently working in the field of atmospheric chemistry. Experimental field studies, from ground, the airship Zeppelin NT, research aircraft and long term measurements from passenger aircraft together with simulation chamber experiments and model calculations are used to investigate the processes that control the chemical transformation, spatial distribution of trace compounds, and their ultimate removal from the atmosphere. FZJ has coordinated the pre-study IAGOS-DS and is coordinator of IAGOS-ERI.

MPI-C: The Max Planck Institute for Chemistry (MPI-C) is one of the leading institutes for atmospheric chemistry in the world. At the MPI-C almost the entire atmospheric spectrum ranging from laboratory kinetics, over all kinds of atmospheric field measurements, to advanced modeling (EMAC, MATCH-MPIC) is covered. CARIBIC coordinated by MPI-C is one of the two major experimental projects within the atmospheric chemistry division of MPI-C.

MPI-BGC: The Department of Biogeochemical Systems at MPI-BGC is strongly involved in carbon cycle research, with particular focus on Greenhouse gases $CO_2$ and $CH_4$. This involves long-term and intensive campaign based observational programs using ground based in-situ and remote sensing systems as well as aircraft based observations. Process understanding and GHG balances are gained from global to regional scale atmospheric inverse modeling.

KIT: The Institute of Meteorology and Climate Research (IMK) is part of the Karlsruhe Institute of Technology (KIT). With its four departments it is one of the worldwide leading institutes in atmospheric research and employs various in-situ and remote sensing instruments on ground, aircraft, balloons, and satellites as well as atmospheric models for trace gases and aerosol/cloud particles. Particular focus of the activities of IMK is to investigate the complex links and feedbacks between climate change, dynamics and transport, and atmospheric chemistry.

DLR: Deutsches Zentrum für Luft- und Raumfahrt (DLR) has long experience in airborne measurement of climate-relevant aerosol properties across the troposphere in various environments, e.g., boreal forest fires (Petzold et al., 2007), mineral dust (Petzold et al., 2009), and anthropogenically polluted air masses (Hamburger et al., 2011). DLR was founding member of IAGOS where it has led the development of the IAGOS instrument for aerosol measurements, based on the experience gained during diverse large-scale interhemispheric experiments on the characterisation of aerosol properties in the free troposphere.

IfT: The Leibniz Institute for Tropospheric Research (IfT) is one of the worldwide leading research institutes in the field of atmospheric aerosol particles and clouds. In this context IfT has more than 15 years of experience in airborne particle measurements using balloons, small (turboprop) aircraft, large (jet) aircraft, and helicopter platforms. As World Calibration Centre for Aerosol Physics (WCCAP) within the framework of the WMO-GAW program, IFT provides know-how, experience, and instrumentation for the development, calibration, and operation of aerosol devices and inlet systems.

IUP: The Institute of Environmental Physics (IUP) at the University of Heidelberg is well known for its environmental research activities covering a wide spectrum of processes in atmospheric sciences, soil sciences, hydrology, and oceanography. The IUP is one of the leading institutes in the world in remote sensing DOAS (Differential Optical Absorption Spectroscopy) systems. DOAS is the basis for many satellite observation based studies and for a host of other applications, for instance monitoring volcanic plumes or bromine explosions. This DOAS expertise is also used in IAGOS.

A list of publications (5 per institution) is given in *Annex 7B*.

### 4.8 Which technological expertise is necessary for the preparation, construction and operation of the research infrastructure? Which skills do the involved have? (For maintenance staff cf. 4.11).

Sustainable operation of research equipment onboard passenger aircraft requires, in addition to scientific competence, extensive experience in the development of specific measurements systems, including the provision of certification and legally approved servicing of the equipment. The IAGOS consortium combines all these expertises.

FZJ has gained long-term high-level experience in operating automated instrumentation on passenger aircraft during MOZAIC. The German CARIBIC consortium actually runs 11 largely home-made instruments on a Lufthansa A340-600. DLR has particular experience in operating research aircraft and MPI-BGC has long-standing expertise in the development and operation of instruments on research aircraft.

Enviscope GmbH and its partner Gomolzig as an EASA approved Production Organisation (EASA Part 21G) and Maintenance Organisation (EASA Part 145) holds all required approvals for manufacturing and maintenance inclusive the "Release to Service" of equipment for deployment on board of civil aircraft. This includes the capabilities for maintenance of oxygen cylinders.

Lufthansa plays a leading role in the international aviation business and can thus serve as a communicator for promoting the IAGOS idea and the value for aviation. Because of its longstanding involvement in MOZAIC and CARIBIC, Lufthansa can also provide an expert opinion on the feasibility of operating scientific instruments in commercial aviation operation to other airlines.

### 4.9 Which concepts of governance – if applicable also for different implementation phases – have been developed?

It was agreed between the IAGOS-ERI partners to initially manage IAGOS as an International Association under Belgian law (AISBL) and to investigate the option for founding a European Research Infrastructure Consortium (ERIC) after the initial construction phase. The seat of the AISBL will be established in Brussels at the HGF offices. The project office will be located at FZJ. The choice of an AISBL as initial governance structure follows from previous experience in PRACE (an ESFRI Infrastructure for Supercomputing led by FZJ) and ECATS (a former European Network of Excellence in the area of Aeronautics that was transformed into an AISBL under the lead of DLR).

Draft statutes (see *Annex 11*) are currently being circulated among the partners in Germany, France and the UK. Finalization of the Business Model and the Statutes is a deliverable of IAGOS-ERI. The transition from an AISBL to an ERIC will be discussed in the IAGOS Stakeholders Interim Council (ISIC) between the Stakeholders from Germany France and the UK.

4.10 In case of a totally new construction will existing facilities of the hosting institution be abandoned? To what extent could costs be reduced?

Not applicable since no new buildings are planned. In order to reduce costs, IAGOS will use existing laboratory space at the partner institutions. This will not lead to the closing down of facilities, as the activities are already part of the respective research programmes (see *letters of commitment in Annex 10*).

4.11 Do any ethical and/or legal issues need to be taken into account concerning the construction, operation and decommissioning of the project? Any environmental consequences? How high is the risk of modification or abortion due to ethical, legal or environmental reasons? What method has been planned as to clarify the issue at an early stage and to come to a decision?

Installation of the research infrastructure does not require the acquisition of additional aircraft or ground-based infrastructure. Decommissioning of the infrastructure only requires the removal of equipment and associated structures from the instrumented aircraft.

The only legal risk identified so far is that certain countries my not allow conduction of in-situ measurements in their airspace. This has never happened during the 18 years of operation of MOZAIC or CARIBIC. Furthermore, the conduction of measurements for atmospheric monitoring is covered by WMO Resolution 40 (see *Annex 12*). For the unexpected case, technical solutions have been established to interrupt data collection over restricted areas. The impact on the environment is negligible, i.e. limited to the $CO_2$ emissions from transportation of the equipment.

*Personnel requirements*

4.12 Which personnel capacities in the scientific and technological (maintenance staff) area do the involved have? If these are not sufficient for the preparation and respectively the operation, what concepts for the recruitment have been developed?

The personnel resources required for construction of the infrastructure are available at the participating institutions (See Table in *Annex 13*). Additional personnel required during the operational phase can be recruited from own education and in the framework of existing cooperation with universities. The estimation is based on experience from the precursor projects.

Industrial companies suitable for conducting certification and maintenance in the aeronautic framework have already been involved in the preparatory phase (e.g., enviscope GmbH, GFM GmbH and P3-Digital Services, Sabena Technics, Atmosphere, Tryagnosis, and LGM, CGP Associates ltd.).

Enviscope GmbH is partner in IAGOS-ERI responsible for the work package “certification and operation for the RI” and provides qualified staff. For further development of the RI a detailed process description of the technical service has been issued, comprising exact work orders for new personnel (See Table in *Annex 14F*). Lufthansa - as all large airlines - has highly qualified service personnel and longterm experience in supporting environmental projects.

4.13 How will you recruit and train the new generation of academics? Do any concepts exist? Do any cooperations with (further) universities exist?

FZJ: A. Wahner is full professor at the faculty of mathematics and natural science at the University of Cologne. Close cooperation exists with the universities of Aachen, Wuppertal and Bonn, and Engineering Schools, for supervision of Bachelor-, Master- and PhD thesis (ca. 10/yr). Jülich has a longstanding tradition in the education of technical staff (Physics, Chemistry, Mathematics). The present technical personnel has bee recruited from own education.

MPI-C: An important part of the research carried out at MPI-C in Mainz encompasses PhD dissertation projects. The International Max Planck Research School (IMPRS) for Atmospheric Chemistry and Physics was established in 2003. In recent years about 75 students were part of the IMPRS. MPI-CH is also partner in the Max Planck

Graduate Centre. MPIC-CH also is closely linked to the University of Mainz through a joint professorship with the Institute for Atmospheric Physics.

MPI-BGC: The International Max Planck Research School for Global Biogeochemical Cycles (IMPRS-gBGC) was established in 2010 in cooperation with the Friedrich-Schiller-University. In addition, a close collaboration has been established with the IMPRS on Earth System Modelling (IMPRS-ESM), which has been founded by the MPI for Meteorology, Hamburg in cooperation with the University of Hamburg.

KIT: J. Orphal is full professor at the faculty physics and meteorology of the KIT. The education includes courses and lectures for bachelors and masters in meteorology at KIT-IMK. The institute regularly hosts many master students and ~40 PhD students with university degrees in meteorology, physics, chemistry, and electronic engineering.

DLR: The director of the Institute for Atmospheric Physics, currently to be nominated, will be full professor at the faculty of physics at the Ludwig-Maximilians-University Munich. A. Petzold ist Privatdozent für das Fach Meteorologie in der Fakultät für Physik der LMU München. Enge Kooperationen bestehen mit der FH München bei der Durchführung von Praktika sowie der Betreuung von Bachelor- und Masterarbeiten. Das am DLR für IAGOS vorhandenen technische Personal wurde auf diese Weise rekrutiert.

IfT: IfT recruits the majority of its master and PhD students from the University of Leipzig. There is a close collaboration in teaching, including a theoretical and practical course on “Airborne Physical Measurements: Methods and Instruments”.

IUP: IUP is part of the University of Heidelberg and one of the two most renowned University Institutes for Environmental Physics in Germany. The IUP members offer a variety of lectures (e.g. Physics of the Atmosphere) and practical courses on environmental sciences, where for example master students can learn the basics of DOAS in a practical course. Several Master and PhD students work at the IUP or at other institutes (e.g. MPI-C or KIT) in close collaboration with the IUP

International cooperation within IAGOS includes several European and international universities (e.g., Toulouse, Paris, Manchester, Cambridge, East Anglia, Hong Kong, Taipei, Harvard, Stockholm, Szeged), and research laboratories (e.g., CNRS-LA, CNRS-SA, NCAR, NOAA, NASA, KNMI, NIES). They provide, as already exercised in CARIBIC and MOZAIC, excellent opportunities for scientific collaboration, including joint research proposals and exchange of staff.

## III. LEVEL OF REALIZATION

### 1 – Project status

1.1 Which level of realization has the project reached? Please add a detailed work breakdown structure in the appendix.

As outlined in the structural plan (*Annex 15A*) and in the following sections, IAGOS is ready for implementation as RI with completion of the ESFRI Preparatory Phase Project (IAGOS-ERI) in 2012.

1.2 What kind of preliminary studies already exist? If there are any, how should the results of the preliminary studies be assessed? Please add the results to the appendix.

The timeline of the different pre-studies performed in preparation of the RI are summarized in a Gantt chart in *Annex 15B*.

MOZAIC and CARIBIC both started as independent research projects, originally with limited capabilities. After 3 phases of EU funding, the MOZAIC consortium decided in 2004 to develop into a research infrastructure. Starting point was a FP6 Design Study for new RIs (IAGOS-DS). Main results were the redesign of the MOZAIC equipment into much smaller, flexible instrument packages that could be retrofitted on Airbus A340 aircraft (the original MOZAIC instrumentation had been installed in 1994 by Airbus during the production process of the 5 aircraft). A major task was to obtain the EASA approval for the installation of the new packages on passenger aircraft in form of a so-called STC. This was achieved in July 2011 (M1) with financial support from BMBF for the installation process aboard an A340 of Lufthansa (*Annex 14B*).

In IAGOS-DS, new partners were included (DLR, Univ. Manchester, MPI-BGC) and the development of new instruments for Cloud Particles, Aerosol, and Greenhouse Gases was started.

In 2005 the consortium was invited to submit a proposal to ESFRI. The application was successful and IAGOS was included on the Roadmap 2006. Thereby, IAGOS became eligible for application to the so-called Preparatory Phase for new RIs. The project (IAGOS-ERI) was started in 2008. At this point, it was decided to include CARIBIC in IAGOS.

CARIBIC started its operation in 1997 on a Boeing 747 operated by LTU. A major pre-study was conducted in the German programme AFO2000, where the installation of a new inlet system and provisions for mounting of the instrumentation on a Lufthansa aircraft was achieved. After a major revision of the instrumentation in IAGOS-ERI, CARIBIC is again operational since 2010 (see *Annex 14E*).

The main objectives of IAGOS-ERI were:

- to complete the certification of the scientific instrumentation
- to complete the scientific data base
- to prepare the legal and organizational preconditions for the new RI, including preparation of the governance structure and statutes,
- to investigate the needs for funding, and
- to establish the legal preconditions for installation, operation and maintenance of the new instrumentation aboard passenger aircraft in compliance with aeronautic regulations.

The tasks and results of IAGOS-ERI are included in the breakdown structure (Annex 15A). The major part of the work has been completed. Completion of the remaining tasks (EASA approval for the new instruments for aerosol, NOx and greenhouse gases and the extension of the STC from A340 to A330 aircraft) is expected by the end of IAGOS-ERI in 2012, M2 in Gantt chart).

Preparation for a legal entity (initially AISBL) is also in progress. Draft statutes (Annex 11) have been prepared by FZJ and have been circulated in 2011 among the partners for comments. The agreed business model and final statutes are deliverables of IAGOS-ERI, due in August 2012.

## 2 – Level of negotiation

### 2.1 Are there any expressions of interest or commitments of further hosting institutions?

Several Institutions have expressed their interest in participating in IAGOS (*see Letters of Intent in Annex 10*). Besides the participating German institutions, the most important commitment is that by France, where several institutions are involved in the preparatory phase and where IAGOS has already been implemented (together with ICOS) on the French Roadmap of Très Grande Infrastructure des Recherche (TGIR).

Negotiation of a draft Letter of Intent (*Annex 11*) between the main Member States involved in IAGOS has been initiated in 2011 by the IAGOS Stakeholders Interim Council (ISIC). Further expressions of interest to participate in the new RI have been obtained by Institutions from the U.K., Sweden and The Netherlands, involved in measurements in IAGOS-CORE or –CARIBIC (*Annex 10*).

A MoU has been signed with partners in Taiwan, including the Central National University and China Airlines. In the USA, a group has formed with the firm intention to rise funding for a US-participation in IAGOS (*LoI and White Paper in Annex 10*). In Hungary, three Universities and the company Videoton have also expressed strong interest in participation. On the international level, the WMO is partner in IAGOS-ERI and ECMWF is one of the key users for future data from IAGOS in the GMES Atmospheric Monitoring Service (GAMS), see *Annex 6*.

### 2.2 Are there any expressions of interest or commitments of financiers (organisations, companies, nations)? Please add the corresponding documents (e.g. Letters of Intent; Memorandum of Understanding etc.).

Financial commitments have been obtained by the German institutions participating in this proposal. Another major financial commitment is by France, where IAGOS has already been established as TGIR on the French Roadmap, together with ICOS. As is outlined in the attached Letter by CNRS-INSU (*Annex 10*), a budget line has also been established. Other financial commitments exist by the University of Manchester (*Annex 10*) for contributions to the data analysis and quality assurance of the data from the cloud droplet probe.

Financial contributions are also expected from partners in Taiwan (MoU in *Annex 10*), who will deploy IAGOS equipment on aircraft operated by China Airlines in cooperation with the Taiwanese “Pacific Greenhouse Gases Measurements Project” (PGGM). In the USA a group has formed to raise national funds for equipping and operating US-based IAGOS aircraft.

The airlines so far associated with IAGOS (see *Annex 10*) have agreed to free transportation of the equipment for IAGOS-CORE. The same business model will be negotiated with new airlines.

Funding for IAGOS is also expected to become available from the operational budget of the GMES atmospheric Service (letters by ECMWF and by EEA, who is in charge of the in-situ component for GMES, in *Annex 6A and 6B*).

## 3 – Time schedule

Please specify the precise schedule with all the possible starting points, the duration of the preparatory phase with the duration of preliminary studies as well as the duration of the construction, operation and decommissioning phases of the research infrastructure. Please enclose your schedule for the whole process of the realization and of the operation of the research infrastructure in the appendix.

The timeline for planning, installation and operation of the new RI is outlined in the attached Gantt chart (*Annex 15C*). IAGOS is a special infrastructure in the sense that the phases for construction and operation overlap significantly. In fact, operation has already started with completion of the revision of the CARIBIC container and installation of the IAGOS-CORE equipment on the first aircraft (see III.1.2).

Implementation of the infrastructure can start immediately after completion of the Preparatory Phase (IAGOS-ERI project) in the second half of 2012. Planning for installation of equipment on the next 3 aircraft (CAL, AF, CPA) is already completed and has been negotiated with the airlines. Securing of funding for instrumentation is required before continuing negotiations with airlines for the next installations. It is planned to complete the installation of 20 aircraft within the first 6 years. Operation of the 3 remaining MOZAIC aircraft (2 Lufthansa, 1 Air Namibia) is foreseen to be continued during this phase as part of IAGOS, unless the aircraft (in service since 1994) are decommissioned earlier by the airlines.

Operation of the CARIBIC container is also ongoing. Within the next five years, some of the older instruments, e.g. the proton transfer reaction mass-spectrometer (PTR-MS) or the condensation particle counters (CPCs), are planned to be replaced by more powerful devices. In the same time, a new light-weight chemical mass-spectrometer for $SO_2$ will be integrated. A changeover of the installation to a newer aircraft is planned for 2016/2017.

It is foreseen to operate and further develop the new RI over at least 20 years with regular scientific reviews and with adaptation to new scientific issues and technological developments. IAGOS-CORE equipment will be operated continuously aboard all aircraft (ca. 500 flights per year and a/c); deployment of the CARIBIC container is foreseen with a typical frequency of four consecutive flights per month (ca. 50 flights per year).

Decommissioning of the infrastructure is fairly simple, as it requires only the removal of the installation from the aircraft. Further decommissioning procedures are not necessary.

## 4 – Financial concept

### 4.1 Please tabulate an estimation of the expenses (quantity structure) necessary for the realization of the planned research infrastructure. Please detail them as follows:

*Investments:*

A: Construction/ Building:

Not required. The necessary laboratory, storage and office space is provided by the participating institutions or will be rented by the company foreseen for logistics (see annual tabulation in Annex 16A).

B: Acquisition of real estate: not required

C: Special technical equipment:

This concerns special provisions in the laboratories for calibration and quality assurance of the instruments and special storage areas according to aeronautic rules. (see Annex 16A under logistics)

D: Supply / construction of devices and equipment:

<u>IAGOS-CORE:</u>

Special instruments (including spares) for equipping of 20 aircraft: 25 Package 1 ($O_3$ und CO), 25 $H_2O$ Sensors, 25 BCP, 20 Units for Realtime Data Transmission (RTTU), 9 each Package 2c (Aerosol) and 2d (Greenhouse gases), repectively;13 Package 2a/b ($NO_y/NO_x$); 20 kits for installation of the IAGOS instruments on board of the aircraft and modification of 20 aircraft. See "Investments" in Annex 16A.

IAGOS-CARIBIC:

The container has already been equipped and is operational. As listed in Annex 16A, several instruments are foreseen to be replaced by more powerful ones during the construction phase.

*Operating costs*

A: Personnel costs: see Table in Annex 16

Required at the beginning for construction of the infrastructure, preparation of the instruments, new developments, and maintenance and quality assurance of the data. Maintenance costs incur at the airlines and at the institutes. Major costs incur for the aeronautic quality management according to EASA rules in order to obtain the Release to Service certificate and for transportation of the

instruments between airlines, maintenance organisation and scientific institutions. Other cost items concern the data transmission and maintenance of the data base.
Other noteworthy investments (replacement purchases) required for keeping the infrastructure and equipment on an adequate level, reflecting the state-of-the-art, are also listed in Annex 16.

4.2 Please tabulate the expenses for the realization of the research infrastructure (investment costs) on the basis of the time schedule (annual tranches). In doing so please also present the operating costs for the first five years after the completion of the construction phase. Please also consider the additional noteworthy investments or replacement purchases during the planned/estimated life expectancy.

See Tables in Annex 16A. The construction phase has already started and is planned until 2016.

4.3 If costs have already been estimated, please also tabulate these estimations. Please specify the basis of the cost estimate (add the corresponding documents).

See Tables in Annex 16.

The cost estimate for investments is based on commercial offers for the CORE instruments (Annex 16E) and the experience gained with the first IAGOS-CORE installation in 2011. The costs for operation of the instruments, including the required personnel resources and consumables in the institutions for scientific quality assurance (calibrations etc.) are based on the longterm experience in MOZAIC and CARIBIC. Costs for special aircraft layovers have not been included because the modification can be achieved during scheduled layovers.

The costs for world-wide operation of the equipment were estimated in IAGOS-ERI by enviscope GmbH, together with FZJ and CNRS. These include the costs for shipping of the instruments between airlines, maintenance centre and institutions, customs, and maintenance personnel and logistics for recertification of the equipment (EASA Form 1) and for supply of gases and chemicals required for operation of the Packages 2. It also includes regular updates of the certification basis, such as trainings and audits by the authorities. Audit costs are estimated from experience by GFM GmbH, in charge of the initial certification of Package 2 and re-certification after maintenance in the institutions.

### 4.4 Please outline a table of required public funding for the research infrastructure (in annual tranches). How many own financial resources will the hosting institution supply? How many third party funds are expected (please add the corresponding documents, q. v. above III. 2.2)? What is the expected amount of user fees (science and economy)? Please also list potential financial risks.

According to the planned distribution of work between the main partners in IAGOS-ERI, the German contribution to the total estimated budget is ca. 50%. The contribution by France is ca. 25%. The remaining costs are foreseen to be covered by partners from, e.g., U.K., USA, Taiwan, The Netherlands, and Hungary as well as new partners.

The airlines contribute significantly to the total cost of operation, by waiving the additional fuel costs caused by the IAGOS-CORE equipment. This amounts to ca. 15% of the running costs.

The committed contributions by the German institutions amount to ca. 50% of the foreseen German contribution, as listed in Annex 16E. The institutions contribute substantially with personnel resources, by providing the required laboratory and office space and by contributions to the operational budget and to the investments.

The situation in France is similar with about 50% contribution by the institutions participating in IAGOS.

A significant contribution (ca. 20% of the operational costs) is expected to be realized after the construction phase from the operational budget of GMES (see chapter III.2). This is expected to reduce the amount of funding required in Germany and France. From past experience, it is also very likely the EU-funding can be acquired for upgrading and innovation.

The financial risks are considered relatively small as there is no need for construction. The instruments have already been developed in the pre studies and suitable commercial partners have been found. Furthermore, as construction is planned to be carried out over several years, it is possible to postpone aircraft installations in case of unforeseen difficulties, until new partners have been found. Particularly important is the very low risk associated with decommissioning of the RI, because the costs for deinstallation of the instruments are negligible.

## A.I GLOSSARY

| | |
|---|---|
| ACTRIS | Aerosols, Clouds, and Trace Gases Research Infrastructure Network |
| a/c | Aircraft |
| ADM-AEOLUS | Atmospheric Dynamics Mission (expected to launch in 2013) |
| AF | Air France |
| AFO2000 | Atmosphärenforschung 2000 |
| AIRBUS | Airbus Operations SAS |
| AISBL | Association Internationale Sans But Lucratif (International non-profit association under Belgian Law) |
| ALADIN | Atmospheric Laser Doppler Instrument (Payload of ADM-AEOLUS) |
| ALLAS | Ausrüstung eines Linienflugzeuges der Lufthansa für die Langzeitmessung von atmosphärischen Spurengasen |
| AMDAR | Aircraft Meteorological Data Relay |
| AQUA | Earth Observing Satellite (launched on May 4, 2002) |
| ATLID | Cloud-Aerosol High-Spectral Resolution Lidar (Payload of EARTHCARE) |
| ATMO | HGF Programme Atmosphere and Climate |
| ATMOSAT | Atmospheric Satellite in Planning |
| AURA | Earth Observing Satellite (launched on July 15, 2004) |
| BA | British Airways plc |
| BCP | Backscatter Cloud Probe |
| BMBF | Bundesministerium für Bildung und Forschung |
| CAL | China Airlines |
| CALIPSO | Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations Satellite (launched in April 28, 2006) |
| CAMAACC | Civil aircraft for regular investigation of the atmosphere based on an instrument container |
| CARIBIC | Civil Aircraft for the Regular Investigation of the Atmosphere Based on an Instrument Container |
| CFC | Chlorofluorocarbon |
| CGP | Company CGP Associates ltd., UK |
| $CH_4$ | Methane |
| CLOUDSAT | Satellite with first satellite-based millimeter-wavelength cloud radar (launched in April 28,2006) |
| CLRTAP | Convention on Long-range Transboundary Air Pollution |
| CNES | Centre National d'Etudes Spatiales |
| CNRS | Centre National de la Recherche Scientifique |
| CNRS-LA | CNRS-Laboratoire d'Aérologie |
| CNRS-SA | CNRS-Service d'Aeronomie |
| CO | Carbon Monoxide |
| CONTRAIL | Comprehensive Observation Network for Trace gases by Airliners |
| $CO_2$ | Carbon Dioxide |
| CPA | Cathay Pacific Airways |

| | |
|---|---|
| CPC | Condensation Particle Counter |
| CPR | Cloud Profiling Radar (Payload of EARTHCARE) |
| DAS | Data Acquisition System |
| DLH | Deutsche Lufthansa AG |
| DLR | Deutsches Zentrum für Luft- und Raumfahrt |
| DMT | Droplet Measurement Technologies, USA |
| DOAS | Differential Optical Absorption Spectroscopy |
| DS | Design Study |
| DWD | Deutschen Wetterdienst |
| EARLINET | European Aerosol Research Lidar Network |
| EARTHCARE | Earth Cloud Aerosol and Radiation Explorer (will be launched in 2013) |
| EASA | European Aviation Safety Agency |
| ECATS | Environmental Compatible Air Transport System |
| ECHAM | Atmospheric General Circulation Model |
| ECMWF | European Centre for Medium Range Weather Forecast |
| EEA | European Environment Agency |
| EMAC | ECHAM/MESSy Atmospheric Chemistry Model |
| ENVISAT | Earth Observation Satellite (launched in 2002) |
| EOS | Earth Observing System |
| ERIC | European Research Infrastructure Consortium |
| ESA | European Space Agency |
| ESFRI | European Strategy Forum on Research Infrastructures |
| ETHER | Thematic Assembly Center of CNES |
| ETS | Emission Trading Scheme |
| EU | European Union |
| EUMETNET | The Network of European Meteorological Services |
| EUFAR | European Fleet for Airborne Research |
| EUSAAR | European Supersites for Atmospheric Aerosol Research |
| E-ADAS | E-AMDAR Data Acquisition System |
| E-AMDAR | EUMETNET-AMDAR |
| FP | Framework Programme |
| FZJ | Forschungszentrum Jülich |
| GCC | GMES Climate Service |
| GAMS | GMES Atmospheric Monitoring Service |
| GAS | GMES Atmospheric Service |
| GAW | Global Atmospheric Watch |
| GFM | Gomolzig Flugzeug- und Maschinenbau GmbH |
| GEO | Group on Earth Observations |
| GEOSS | Global Earth Observation System of Systems |
| GHG | Greenhouse Gases |
| GMES | Global Monitoring for Environment and Security |
| GOSAT | Greenhouse Gases Observing Satellite (launched January 23, 2009) |
| HGF | Helmholtz-Gemeinschaft Deutscher Forschungszentren |
| HTAP | Task Force on Hemispheric Transport of Air Pollution |
| $H_2$ | Hydrogen |
| IAGOS | In-service Aircraft for a Global Observing System |
| IAGOS-DS | Integration of Routine Aircraft Measurements into a Global Observing System – Design Study |

| | |
|---|---|
| IAGOS-ERI | In-service Aircraft for a Global Observing System – European Research Infrastructure |
| IASI | Infrared Atmospheric Sounding Interferometer (Payload on METOP-A/B/C) |
| IB | Iberia |
| ICOS | Integrated Carbon Observation System |
| IEK-8 | Institut für Energie und Klimaforschung: Troposphäre |
| IFT | Leibniz-Institut für Troposphärenforschung |
| IGACO | Integrated Global Atmospheric Chemistry Observations |
| IGAS | IAGOS for the GMES Atmospheric Service |
| IGBP | International Geosphere-Biosphere Programme |
| IGCO | Integrated Global Carbon Observation Theme |
| IMK | Institute of Meteorology and Climate Research |
| IMPRS | International Max Planck Research School |
| IMPRS-ESM | IMPRS on Earth System Modelling |
| IMPRS-gBGC | International Max Planck Research School for Global Biogeochemical Cycles |
| INSU | Institut National des Sciences de l'Univers |
| IPCC | Intergovernmental Panel on Climate Change |
| ISIC | IAGOS Stakeholders Interim Council |
| ISS | International Space Station |
| IUP | Institute of Environmental Physics, University of Heidelberg |
| KIT | Karlsruhe Institut für Technologie |
| KNMI | Koninklijk Nederlands Meteorologisch Instituut |
| LA | Leibniz Association |
| LGM | French Company responsible for IAGOS Instrument manufacturing |
| LHT | Lufthansa Technik AG |
| LIDAR | Light Detecting and Ranging |
| LMU | Ludwig-Maximilians-Universität München |
| LoI | Letter of Intent |
| LSCE | Laboratoire des Sciences du Climat et l'Environnement |
| LTU | Lufttransportunternehmen (German Airline) |
| MACC | Monitoring Atmospheric Composition and Climate |
| MACE | Middeck Active Control Experiment (Payload on ISS) |
| MATCH-MPIC | Model of Atmospheric Transport and Chemistry - Max Planck Institute for Chemistry version |
| MERLIN | Methane Remote Sensing Lidar Mission (expected to launch 2016) |
| MESSy | Modular Earth Submodel System |
| METEOSAT | Geostationary Weather Satellite |
| METOP-A/B/C | European Meteorological Polar-Orbit Satellites (A: launched 2006, B: May 2012, C: October-November 2016) |
| MF | Météo-France |
| MIPAS | Michelson Interferometer for Passive Atmospheric Sounding |
| MODIS | Moderate Resolution Imaging Spectroradiometer (Payload of TERRA and AQUA) |
| MoU | Memorandum of Understanding |
| MOZAIC | Measurements of Ozone, Water Vapour, Carbon Monoxide and Nitrogen Oxides with In-service Airbus Aircraft |

| | |
|---|---|
| MPI | Max-Planck-Institut |
| MPI-C | Max-Planck-Institut für Chemie, Mainz |
| MPG | Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. |
| MPG-BGC | Max-Planck-Institut für Biogeochemie, Jena |
| NASA | National Aeronautics and Space Administration |
| NCAR | National Center for Atmospheric Research, Boulder, USA |
| NDACC | Network for the Detection of Atmospheric Composition Change |
| NIES | National Institute for Environmental Studies |
| NO | Nitric Oxide |
| $NO_2$ | Nitrogen Dioxide |
| $NO_x$ | $NO + NO_2$ |
| $NO_y$ | The sum of NO and its atmospheric oxidation products |
| $N_2O$ | Nitrous Oxide |
| $O_3$ | Ozone |
| PGGM | Pacific Greenhouse Gases Measurement Project |
| PI | Principal Investigator |
| PRACE | Partnership for Advanced Computing in Europe |
| PREMIER | Process Exploration through Measurements of Infrared and Millimetre-wave Emitted Radiation (Payload on ATMOSAT) |
| PTR-MS | Proton Transfer Reaction Mass-Spectrometer |
| QA | Quality Assurance |
| QC | Quality Control |
| RI | Research Infrastructure |
| RR | Rolls Royce |
| RTTU | Real Time Transmission Unit |
| SABER | Sounding of the Atmosphere Using Broadband Emission Radiometry (Payload on TIMED) |
| SCIAMACHY | Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (Payload on ENVISAT) |
| $SF_6$ | Sulfur hexafluoride |
| SNT | Sabena Technics |
| $SO_2$ | Sulfur Dioxide |
| STC | Supplemental Type Certificate |
| TCCON | Total Carbon Column Observing Network |
| TERRA | Earth Observing Satellite (launched on December 18, 1999) |
| TGIR | Trés Grande Infrastructure de la Rechérche |
| TIMED | Thermosphere, Ionosphere, Mesophere, Energetics & Dynamics Satellite (launched December 7, 2001) |
| UCAM | The Chancellor, Masters and Scholars of the University of Cambridge |
| UEA | University of East Anglia |
| UMAN | University of Manchester |
| UN | United Nations |
| UNEP | United Nations Environment Programme |
| UT/LS | Upper Troposphere/Lower Stratosphere |
| VAAC | Volcanic Ash Advisory Centre |
| VOC | Volatile Organic Compound[s] |
| WCCAP | World Calibration Centre for Aerosol Physics |

| | |
|---|---|
| WCRP | World Climate Research Programme |
| WIS | WMO Information System |
| WMO | World Meteorological Organization |

## A.II LIST OF ANNEXES

**Annex 1: Intergovernmental Panel on Climate Change Report 2007 (Summary for Policymakers)**

**Annex 2: Integrated Global Atmospheric Chemistry Observations (IGACO) Report**

**Annex 3: Integrated Global Carbon Observation Theme (IGCO) Executive Summary**

**Annex 4: Task Force on Hemispheric Transport of Air Pollution (HTAP): Report 2010 Executive Summary**

**Annex 5:**

A: Report of WMO/IAGOS Technical Experts Workshop on Requirements of In-Service Aircraft Aerosol Measurement Systems, 2011

B: Proposal by Droplet Measurement Technologies Inc. for enhancing the capabilities of the Backscatter Cloud Probe

**Annex 6: Letters of Support received for IAGOS**

A: European Centre for Medium Range Weather Forecast (ECMWF) and MACC project

B: European Environment Agency EEA)

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D: Letters received in support of the pre-study IAGOS-DS

**Annex 7: References**

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L: Draft Letter of Intent by KNMI (The Netherlands)

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E: Report on IAGOS-ERI Deliverable D5.3 (CARIBIC Container)
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**Annex 16: Financial Planning**
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B: Annual Breakdown of Overall Costs for Implementation and Operation
C: Annual Breakdown of Expenditure Germany
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