Annual report

Royal Belgian Institute for Space Aeronomy (BIRA-IASB)

2021-2022

Colophon

Royal Belgian Institute for Space Aeronomy (BIRA-IASB)

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Martine De Mazière

«BIRA-IASB can present excellent scientific results in 2021-2022 as this report – which highlights only the most important achievements – clearly shows. In particular, we are proud that two new experiments with significant contributions from BIRA-IASB on board future ESA missions have been selected for further development.»

Dear readers,

If 2021 followed on from 2020 with the continuation of the corona pandemic and with hopeful expectations for the future of Federal Science Policy, 2022 has been a year of change.

We were fortunately able to quietly climb out of the corona crisis during 2022, not without it leaving its mark. Digital acceleration has definitely set in. The return to the workplace has been accompanied by arrangements for more extensive teleworking, and the countless journeys to participate in meetings and scientific symposia have been replaced by an alternation between physical meetings, teleconferences, or hybrid meetings. BIRA-IASB adapted smoothly to this new style of working. Clearly, the (partial) return to work was indispensable for many, either for their mental health and social engagement, or in order to not lose motivation for work, or both.

The war that broke out in Ukraine in February 2022 also affected BIRA-IASB as an institution: for some staff members, in their collaborations with Russian and/or Ukrainian colleagues; for others, in their private lives. The biggest impacts on BIRA-IASB have been the delays of planned space missions - as cooperation with Russia for satellite launches has been suspended - resulting in delays and cost increases on the supply of equipment (instruments or their components, IT equipment, etc.), and of course the increase in energy prices and the effects of inflation on staff salaries. Despite helpful grants from the federal government to partially absorb these increased costs, we are struggling with a marked reduction in available resources. If this reduction continues, the current level of scientific activities will necessarily have to decline in the short to medium term.

Nevertheless, BIRA-IASB can present excellent scientific results in 2021-2022 as this report – which highlights only the most important achievements – clearly shows. In particular, we are proud that two new experiments with significant contributions

from BIRA-IASB on board future ESA missions have been selected for further development, namely the Venspec-H instrument on board EnVision, and the Sweeping-Langmuir probes proposed by BIRA-IASB for the Comet Interceptor mission. BIRA-IASB's contributions to the development, validation and operation of the Sentinel-5P mission provide a variety of important and internationally recognised results concerning global air quality, ozone and climate, making BIRA-IASB even stronger for its participation in the future Sentinel-4 and –5 atmosphere missions. Meanwhile, BIRA-IASB has also demonstrated itself in the first geostationary Korean satellite mission dedicated to air quality research and in the future EUMETSAT-led CO2M mission, the first European mission entirely focused on the detection and quantification of carbon dioxide and methane emissions, with a launch scheduled for 2026. BIRA-IASB also plays an important role in the ESA Climate Change Initiative programme, the Copernicus Atmosphere Monitoring Service (CAMS) and Climate Change Service (C3S); the integration of BIRA-IASB's model for stratospheric chemistry into the CAMS models will lead to a significant improvement of the CAMS products.

BIRA-IASB naturally also continues to play its leading role in the international atmospheric composition monitoring networks, partly integrated into the European research infrastructures ICOS (Integrated Carbon Observation System) and ACTRIS (Aerosol, Clouds and Trace gases Research InfraStructure). In the Space Weather area, BIRA-IASB has taken on the coordination of the European Space Weather Network (SWESNET).

Policymakers, citizens and students have not been forgotten: not only do we offer them information and training, but we also involve them directly in a number of research projects.

An important milestone from 2022 is the anchoring of the Belgian User Support and Operations Centre (B.USOC)

– previously managed by BELSPO - within BIRA-IASB, thus ensuring the future of B.USOC after the winding down of its missions to support experiments aboard the International Space Station. A second important initiative is the creation of the Federal Climate Centre in November 2022: BIRA-IASB has made a significant effort in the working groups and committees that have developed the vision, mission, and management structure of this Centre. Third, we have put the Belgian Radiometric Characterization Laboratory (B.RCLab) on the map in Belgium.

So it is with a certain pride that I dare say that we, as an institute, have so far miraculously survived the two recent major crises, even if it was a tough period for many staff members.

Despite these excellent scientific results, even in crisis times, and despite the fact that BIRA-IASB is strong thanks to a close-knit group of dynamic and motivated staff members, I look to the future with some suspicion, even fear. In 2021, there was hope for a revival of Federal Science Policy and more efficiency and autonomy in the management of Federal Scientific Institutions. In late 2022 - early 2023, I am sad to note the opposite. The bureaucratic (digital) paper mill is ever-increasing, just as the procedures are getting heavier and the controls are increasing. There is little sign of administrative simplication; just because some processes have been digitised does not make them simpler and/or more efficient! Our autonomy is being cut back more and more. The functioning of the Federal Science Policy has not yet noticeably improved. Even the urgent renovation of our buildings is still pending.

It seems that scientific activities must be sacrificed in favour of a greater administrative and procedural burden. In my view, and in line with our mission, the first priority in BIRA-IASB should be the advancement of scientific work, and that is also the ambition of the staff we recruit for this purpose. Good management of

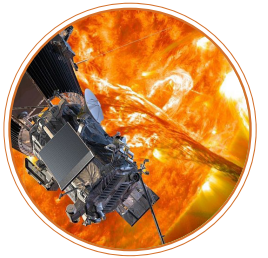
the institute is important, but it must first and foremost aim to efficiently support that scientific work. If management comes first and scientific work has to shift to second place or be hampered in return, we are doing the wrong thing.

I hope that my fears regarding a shift in priorities and the resources allocated to them are unfounded and that, in two years time, we will be able to present scientific results that are just as excellentand numerous, thanks to a motivated and dynamic team, and not at any cost!

Finally, I wish to thank and congratulate all BIRA-IASB staff for the wonderful results we are able to present today as an Institution, which we would like to share with you, dear readers, in this report and in the accompanying more comprehensive online version.

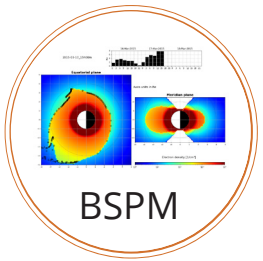
Martine De Mazière
Director General a.i.

Space physics



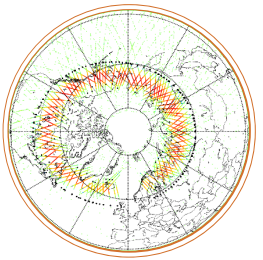
Solar wind observed close to the Sun by Parker Solar Probe

The mission Parker Solar Probe (PSP), launched by NASA on 12 August 2018, completed its 14th solar orbit in December 2022. It has perihelion under 15 solar radii where no spacecraft could fly before, which provides invaluable new insight into the fundamental mechanisms of the acceleration of the solar wind using the kinetic models developed by BIRA-IASB's solar wind team. It allowed our scientists to confirm the presence of suprathermal electrons at very low radial distances, as predicted, and to detect for the first time broadband electrostatic waves in the near-Sun solar wind.



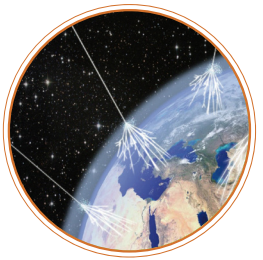
Plasmasphere model improvement

The Belgian Space Weather Integrated Forecasting Framework (SWIFF) Plasmasphere Model (BSPM) has been developed at BIRA-IASB to simulate the Earth's inner magnetosphere cold plasma environment. It has been recently improved, mainly by using Van Allen Probes data to complete the plasmatrough and by analyzing the refilling process after storms. It has been made available on different platforms.



Radiation belts observed by PROBA-V/EPT

Using the Energetic Particle Telescope, a detector developed at BIRA-IASB with UCLouvain and QinetiQ Space and launched on the satellite PROBA-V in 2013, we have been able to measure energetic electron and proton fluxes at 820 km for over 9 years already. This instrument, which is presently still active, delivers exceptional observations simultaneous to the NASA Van Allen Probes that have allowed us to determine the dynamics of the radiation belts during geomagnetic storms, and compare their boundaries to the plasmapause and the auroral oval.



Interaction of space particles with Earth's atmosphere

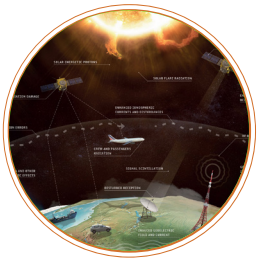
10 High-energy particles interact with the atmosphere and contribute to the radiation present at lower altitudes, which may represent a threat for aircraft crew. Moreover, space radiations cause the ionisation of the atmosphere, which has a major impact on atmospheric chemistry. Using satellite observations, we study the dynamics of high-energy particles near the Earth. The radiation dose and the ionisation rate at different locations and various altitudes are addressed with the Atmospheric Radiation Interaction Simulator (AtRIS) and a model of the geomagnetic field.

An imager for the polarisation of the northern lights

BIRA-IASB has been involved in the study of polar lights for a long time, both with observations and modelling, shedding some light on the physical processes at play for the formation of the aurora and for the complex coupling between the magnetosphere and the ionosphere. Recently, we investigated the polarisation of polar lights with the PLIP instrument, an imager dedicated to measure the polarisation of the three main auroral spectral lines over a large field of view.

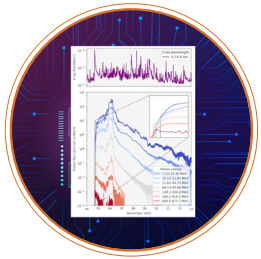
A prototype space weather service for the Van Allen radiation belts

Space assets can be easily damaged by high energy particles during strong geomagnetic storms driven by events at the Sun heading towards the Earth, like CMEs (Coronal Mass Ejections) or CIRs (Corotating Interaction Regions). The EU H2020 SafeSpace project built a prototype service contributing to the safety of space assets against the natural hazards of space weather. This was achieved through the combination of 10 numerical models from the Sun to the Van Allen radiation belts of the Earth. BIRA-IASB was involved in the plasmasphere part of this modelling chain.



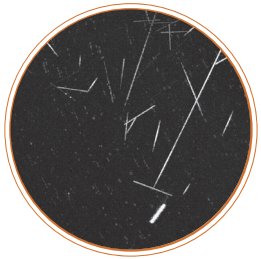
Tailored space weather information for end-users

In the context of ESA's Space Weather Service Network, BIRA-IASB's Space weather group (in collaboration with ROB) has developed a programme of tailored space weather bulletins together with high-priority users in the domains of power systems operation, aviation, spacecraft operation and GNSS services, including land transport and maritime downstream users. End-users receive warning and alert messages, and have access to up-to-date detailed graphical and textual information regarding expected and ongoing space weather activity.



How can space weather forecasts benefit from machine learning?

12 Machine learning is occupying an increasingly important place in society due to its potential to improve predictive capabilities compared to more traditional methods. To explore how space weather forecasts can benefit from machine learning techniques, an extensive literature study of existing approaches was conducted leading to the development of two forecast models. These models covered two different physics domains to be able to draw up guidelines for future developments of space weather forecast models.



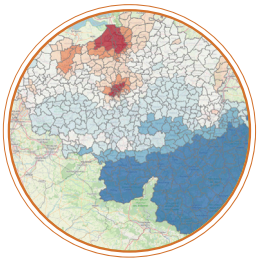
Meteoroid trajectory and speed determination using BRAMS data

BRAMS is a Belgian network using reflection of radio waves on ionised meteor trails to detect meteoroids passing through the upper atmosphere. In order to accurately reconstruct the trajectory and speed of meteoroids using BRAMS data, we developed a method using time delays between meteor echoes recorded at various receiving stations. The obtained results were compared with optical observations from the CAMS-BeNeLux network. A second method using complementary data from the radio interferometer in Humain clearly improved the accuracy of the reconstruction.

Impact of short-lived pollutants on air quality and climate

High-resolution atmospheric composition over Belgium

Large industrial centers near Antwerp lead to high nitrogen dioxide (NO_2) pollution in the region, observed by ground-based instruments. A high-resolution model (WRF-Chem) is used to evaluate the consistency in NO_2 retrievals between different observations, and assess the accuracy of local emission inventories. The results suggest a slight underestimation of NO_2 columns obtained by the Tropospheric Monitoring Instrument TROPOMI, consistent with previous work, as well as an underestimation of NO_x emissions over the cities of Brussels and Antwerp.

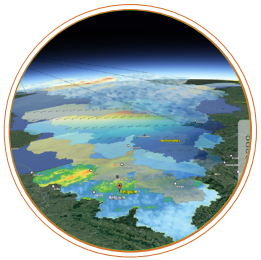


Sentinel-5p monitoring of NO_2 over Belgian municipalities

14 Environmental policy-making that aims for improved air quality (AQ) requires objective assessment of the real effects of historical, current and future legislation. To this end, the LEGO-BEL-AQ system provides an AQ monitoring service tailored for the different legislative entities in Belgium, from federal and regional to municipal levels. This service makes synergistic use of AQ observations from the international AQ satellite constellation, and of in-situ measurements collected by the Belgian Interregional Environment Agency.

Measuring NO_2 in Brussels by bike

In large cities like Brussels, exceedances of European regulations on nitrogen dioxide (NO_2) concentrations, a main air pollutant affecting air quality, are regularly reported. We have equipped BIRA-IASB's SpeedPedelec bike of with a NO_2-measuring system composed of two complementary instruments allowing us to simultaneously measure the integrated NO_2 column and its concentration at the surface. This system was deployed in summer 2022 to characterise the spatial variability of NO_2 in different parts of Brussels. Results were also used to interpret observations from the TROPOMI satellite instrument.

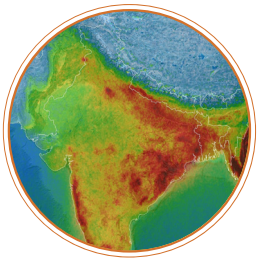


Machine learning to derive surface concentrations of NO_2

Near-surface nitrogen dioxide (NO_2) is of great concern due to its impact on air quality and human health. Machine learning (ML) is an innovative approach to establish a non-linear mapping between surface NO_2 distributions and geophysical predictors at high resolution and accuracy. However, it remains challenging for ML to produce surface NO_2 operational products with realistic spatial patterns and uncertainty quantification. We are exploring a systematical scheme for a stable ML-based surface NO_2 product provision.

Paving the way for space-based observations of reactive nitrogen

The ESA-funded NITROCAM campaigns, coordinated at BIRA-IASB, focus on the simultaneous measurement of the most important reactive nitrogen compounds in the atmosphere, nitrogen dioxide (NO_2) and ammonia (NH_3), which are at the root of a wide range of environmental problems. These campaigns are organised in preparation of NITROSAT, a satellite dedicated to making high-resolution observations (500 m) of nitrogen pollution sources. It is in the running to become ESA's 11th Earth Explorer mission.



Monitoring hydrocarbon emissions from space with TROPOMI

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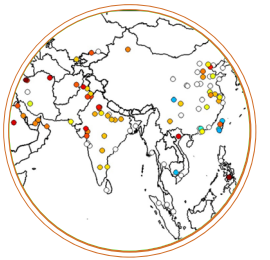
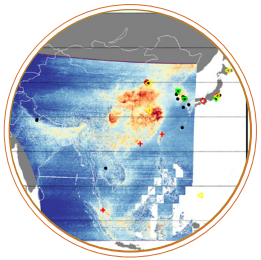
Hydrocarbons in the atmosphere play a critical role in air quality and tropospheric ozone formation. BIRA-IASB significantly contributes to their global monitoring through the development of formaldehyde and glyoxal space observations. Both species provide important information on hydrocarbon emissions from natural or human origin. The outstanding performances of the TROPOMI instrument led to a drastic improvement of the observation precision, allowing for a better-than-ever identification of localised emission sources and a rapid detection of exceptional events.



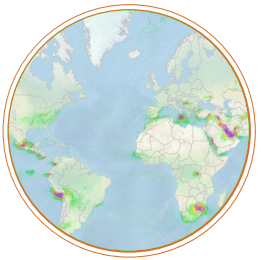
Satellite evidence for significant anthropogenic emission trends in Asian cities

Long-term (2005-2019) satellite records of formaldehyde measured with the OMI sensor aboard the Aura payload reveal strong positive trends over the Middle East (3.6%/year) and the Indian subcontinent (2.4%/year), where regulations of volatile organic compound (VOC) emissions from human activities are currently limited. Weaker trends are observed over Chinese cities, where such regulations were only recently introduced. Mostly negative trends are observed above cities located in Taiwan and Japan, where legislation has been in place since the early 2000s.



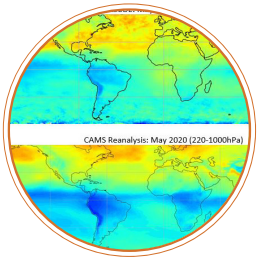
Pioneering geostationary air quality monitoring with GEMS

Since its launch in 2020, GEMS contributes to the monitoring of several trace gases and aerosols over East Asia, including their diurnal variation at the city scale. BIRA-IASB is involved in the validation of operational L2 products and supports the Korean teams in the development of the retrieval of trace gases such as NO_2, HCHO, CHOCHO, SO_2 and O_3. The work is a pioneering preparation for the upcoming American TEMPO and European Sentinel-4 missions (to be launched in 2023 and 2024, respectively) that will form a geostationary constellation.



Sulphur dioxide plumes detection from Sentinel-5P TROPOMI

Emission of SO_2 can have an important impact on air quality and climate, as well as pose a threat to aircraft in case of injection into the upper atmosphere after volcanic eruptions. The "UV-visible observations" group is developing new algorithms for the high-resolution Sentinel-5P TROPOMI instrument, which enables us to determine the SO_2 column and height with an unprecedented level of detail and sensitivity.

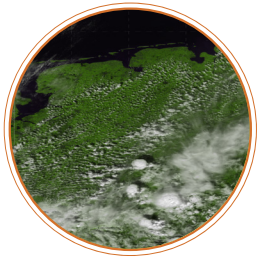


The challenge of measuring tropospheric ozone columns from satellites

Absorbing a large part of the aggressive UV-radiation, the remote stratospheric ozone layer protects life on the surface. Tropospheric ozone, on the other hand, is a toxic molecule affecting human health, crops and ecosystems. It is thus necessary to monitor both layers separately on a global scale, but measuring tropospheric ozone from space remains a real challenge. BIRA-IASB keeps investing its expertise in validation and data assimilation techniques to help solve this challenge.

International Tropospheric Ozone Assessment

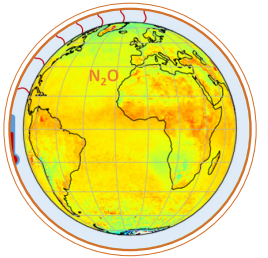
Several BIRA-IASB research teams contribute to the Tropospheric Ozone Assessment Report (TOAR-II), initiated in February 2020. These contributions include tropospheric ozone and precursors (NOx, VOCS, CO and CH_4) data collection and harmonisation for both satellites and ground-based networks, and assessments of the distribution and trends of these species. Where possible, tropospheric ozone trends are attributed to precursor changes, stratosphere-troposphere exchanges, inter-hemispheric exchanges, etc.



Impact of clouds on atmospheric trace gas retrievals

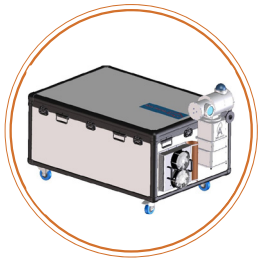
Clouds have a strong influence on the analysis of tropospheric trace gases from space-borne instruments. Effects of 3D features like spatial heterogeneities and structured cloud boundaries increase when the spatial resolution of the observing instrument approaches the dimensions of cloud features. This happens for instruments like TROPOMI and the future Sentinel-4 and Sentinel-5 sensors, which are designed to resolve horizontal features equal to or better than 7×7 km². Therefore, we investigated the influence of important 3D cloud effects on trace gas retrieval using a 3D radiative transfer model.

Impact of long-lived pollutants on air quality and climate



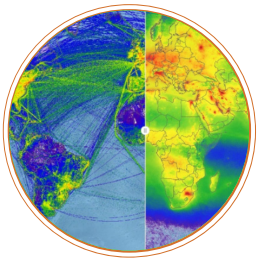
N_2O: a less known greenhouse gas now monitored from space

Nitrous oxide (N_2O) is the third most important anthropogenic greenhouse gas (after carbon dioxide, CO_2, and methane, CH_4) in terms of contribution to radiative forcing, with its long atmospheric lifetime of about 120 years and a continuous concentration increase since the 1970s. During the last several years, we developed a method to retrieve the N_2O concentration from satellite observations in the thermal infrared. The IASI instrument allowed us to obtain global data twice a day since 2006, enabling us to derive and analyse long-term trends of N_2O in the future.



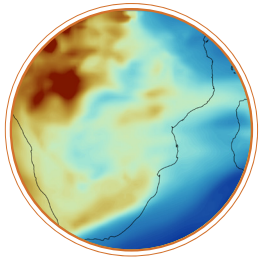
Assessing new remote sensing platforms for GHG reference measurements

High-resolution Fourier transform infrared spectrometers form the basis for high-quality remotely sensed greenhouse gas measurements contributing to the TCCON and the NDACC-IRWG networks. BIRA-IASB is co-leading the ESA-funded FRM4GHG project to assess new compact remote sensing platforms for greenhouse gas measurements. These instruments are crucial to filling gaps in the existing networks and in covering critical emission source regions where the standard high-resolution instruments cannot be deployed.



A look at the emissions behind the satellite data

Mitigation of climate change and health issues caused by poor air quality by reducing the emissions of greenhouse gases and pollutants is high on the agenda in Belgium, at the European level, and worldwide. Tracking the progress on emission reduction, identification of unknown sources, regular monitoring, reporting and verification of emissions are mandatory. In the framework of a EUMETSAT contract, BIRA-IASB has developed a service that provides the users with tools to visualise various satellite data alongside emission inventory data.



Sources and sinks of long-lived greenhouse gases at Réunion Island

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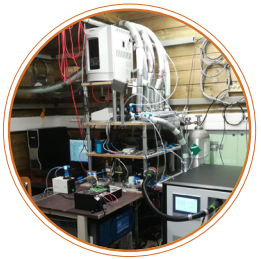
In the context of international atmospheric monitoring networks, BIRA-IASB is measuring time series of atmospheric concentrations of CO_2, CH_4 and CO at Réunion Island. In order to understand the underlying causes of the observed concentrations and their variability, we compare them to the concentrations simulated with the regional atmospheric transport model WRF-GHG. It shows that surface observations are dominated by local emissions and dynamical processes such as wind speed and direction, while column observations are influenced by larger-scale mechanisms such as biomass burning plumes from Africa or South America.

Biosphere-troposphere exchanges

Source apportionment of VOCs at Maïdo observatory

During the 2-year OCTAVE project, a high-resolution Proton-Transfer-Reaction Mass-Spectrometry instrument was deployed to monitor a selection of Volatile Organic Compounds (VOCs) at the remote high-altitude Maïdo observatory, located on Réunion Island in the Southern Hemisphere. Source identification showed that human activities on the island affect the locally observed concentrations of VOCs more than the combination of atmospheric background and remote pyrogenic sources, or the native ecosystems located in the vicinity of the observation site.

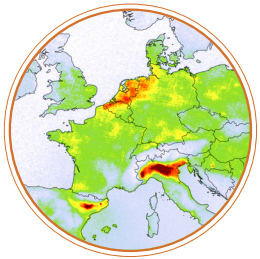


VOC measurements at the Vielsalm mixed forest site in Belgium

Volatile Organic Compounds (VOCs) are key precursors for air quality and climate-related components. To reduce uncertainties on their (bidirectional) exchange between forest ecosystems and the atmosphere, BIRA-IASB and ULiège jointly developed a new infrastructure at the Vielsalm ICOS site, allowing for reactive trace gas flux and vertical profile measurements using state-of-the-art instruments and methodologies.

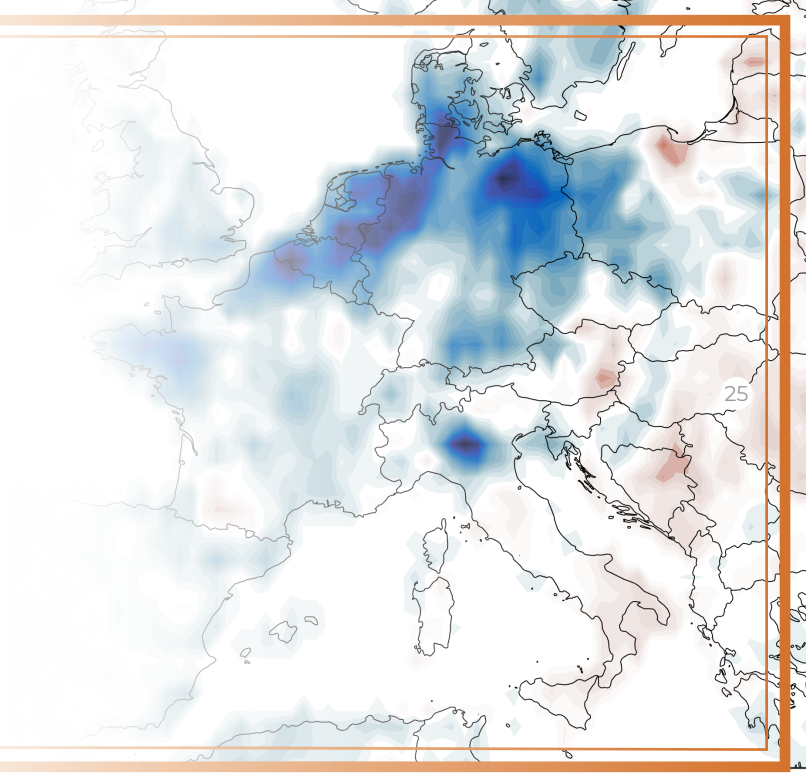
Effects of human pressures and drought on hydrocarbon emissions by vegetation

The STEREO III project ALBERI, jointly carried out by BIRA-IASB, Ghent University and the University of California aimed to better understand and quantify the response of isoprene emissions to land cover changes and drought stress. Long-term satellite land cover and soil moisture datasets, complemented by biogenic emission models and atmospheric chemistry simulations, reveal negative emission trends over tropical forests due to deforestation, and a gradual reduction of biogenic emission capacity under severe or prolonged drought due to reduced photosynthesis.

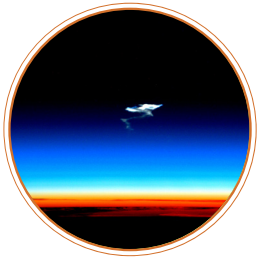


Weekly cycle of ammonia over Europe detected by satellite

While the weekly cycle in nitrogen dioxide emissions has been largely documented, it has never been shown at a large scale for ammonia. Here we expose for the first time the presence of a weekend effect in the ammonia total columns measured by the IASI satellite sounder over the main agricultural source regions in Europe. Ground-based measurements from the Dutch national monitoring network corroborate our results. The weekend effect identified presents a strong seasonality due to agricultural activities and associated regulations.



Stratospheric composition and climate



Better understanding the changing Brewer-Dobson circulation

The Brewer-Dobson circulation (BDC) in the stratosphere consists in upward motion in the tropics, followed by poleward and downward motion at the high latitudes. The BDC determines the distribution of chemical tracers in the stratosphere, e.g., ozone and water vapor. Changes in the pattern of the BDC significantly affect the tracer distributions and are a challenging topic of research. We assess changes in the BDC in the past decade using satellite and ground-based observations and model simulations of the long-lived tracer nitrous oxide.

Translate the complex role of aerosols in climate datasets

Aerosols are a key player of climate due to their ability to scatter or absorb light, affecting atmospheric temperatures. While volcanism has so far been the main aerosol source in the stratosphere, wildfires increasing in the warming climate are making them a game-changer. Satellite observations help us to identify aerosols and understand their role, but their signature needs to be carefully retrieved from these measurements. BIRA-IASB this challenge for many years and provides aerosol climate data records to the scientific community.

Model and observations joined to study stratospheric species

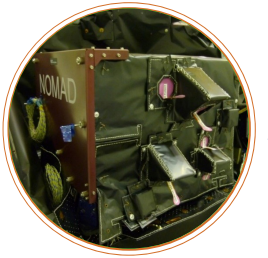
The CAMS European atmospheric model, IFS, provides operational analyses and forecasts of the atmospheric composition. BIRA-IASB contributes to this effort through the integration of its stratospheric chemistry module BASCOE into the IFS, as well as through the extension of the aerosol module in the IFS from the troposphere to the stratosphere. A major objective is to forecast the evolution of large aerosol events like volcanic eruptions and large wildfires.

Operational validation framework for the constellation of atmospheric composition satellites

28

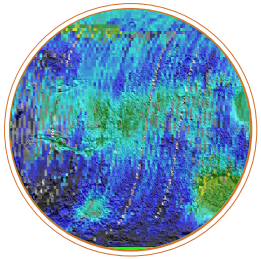
The European programme Copernicus is implementing a coordinated constellation of new-generation satellite sounders for the monitoring of air quality, climate change, emissions of pollutants and greenhouse gases, stratospheric ozone evolution, and environmental hazards. As part of this, BIRA-IASB builds on a three-decade expertise in satellite validation to develop operational services ensuring the necessary quality assessment of the atmospheric data, interoperability of the different sounders, and early warning of anomalies.

Planetary aeronomy



ExoMars NOMAD reveals new insights into the atmosphere of Mars

NOMAD, an instrument onboard the ExoMars Trace Gas Orbiter, was launched in 2016 and has been measuring the atmosphere of Mars since 2018. Recently, scientists in the NOMAD team have published 16 papers, presenting new results on a wide range of topics: atmospheric temperature and density; measurements of dust and aerosols; measurements of CO_2 ice clouds; water vapour concentration and isotope ratios; ozone concentrations; carbon monoxide concentrations; measurements of airglow; and observations of surface frost and ice.



Understanding the role of dust in the Martian atmosphere

30 Dust plays a major role in determining the weather of Mars. Combining observations of atmospheric composition from orbit and laboratory measurements here on Earth using analogues of Martian soil, we are learning more about this important climate driver. Some of the questions we are working on include how dust becomes airborne and transported, its role in cloud formation and how it scatters and absorbs sunlight.

The birth of a scientific space mission

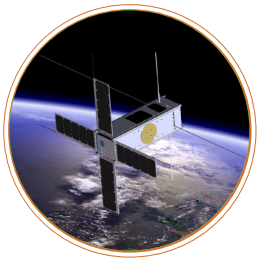
In 2021 ESA launched a call for new scientific space missions – crucially important, because the scientific harvest of these missions will feed a new generation of researchers. BIRA-IASB is involved in 2 missions out of the 5 remaining candidates:

- Plasma Observatory proposes a multi-spacecraft constellation for magnetospheric research.
- M-MATISSE is a two-spacecraft monitor of the solar wind effects on the Martian magnetosphere and ionosphere.

ESA will further scrutinise these candidates during a preliminary mission design study.

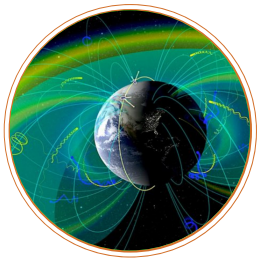
ALTIUS: getting ready for Belgium's O_3 mission operations

ALTIUS is an upcoming satellite mission for monitoring the ozone layer (O_3), our planet's shield against harmful solar UV radiation. This shield is still far from recovering from ongoing damage caused by the infamous CFC emissions. ALTIUS will measure O_3 abundance from space by observing the light from the Sun and other stars being absorbed in the atmosphere. The mission is currently in its implementation phase within ESA's Earth Watch programme. BIRA-IASB is responsible for developing the level 2 processors, i.e. the algorithms which retrieve the O_3 information from raw observation data.



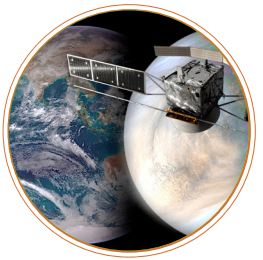
PICASSO: farewell to the golden CubeSat

PICASSO, the first CubeSat mission of the Royal Belgian Institute for Space Aeronomy, ended its mission in 2022. It demonstrated the feasibility of atmospheric remote sensing and in-situ ionospheric plasma measurement with a CubeSat and taught us valuable lessons about this new technology.



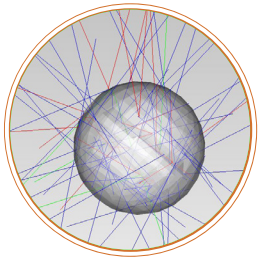
Up down front back left right ... charged particles everywhere

PROBA-3 is an ESA-mission (to be launched 2024) that consists of two satellites that will perform a formation flight. 3DEES is an electron spectrometer on board one of these satellites. The design, manufacturing and surface treatment of the instrument structure, and the structural qualification of this very compact instrument, were in the hands of BIRA-IASB's engineering division.



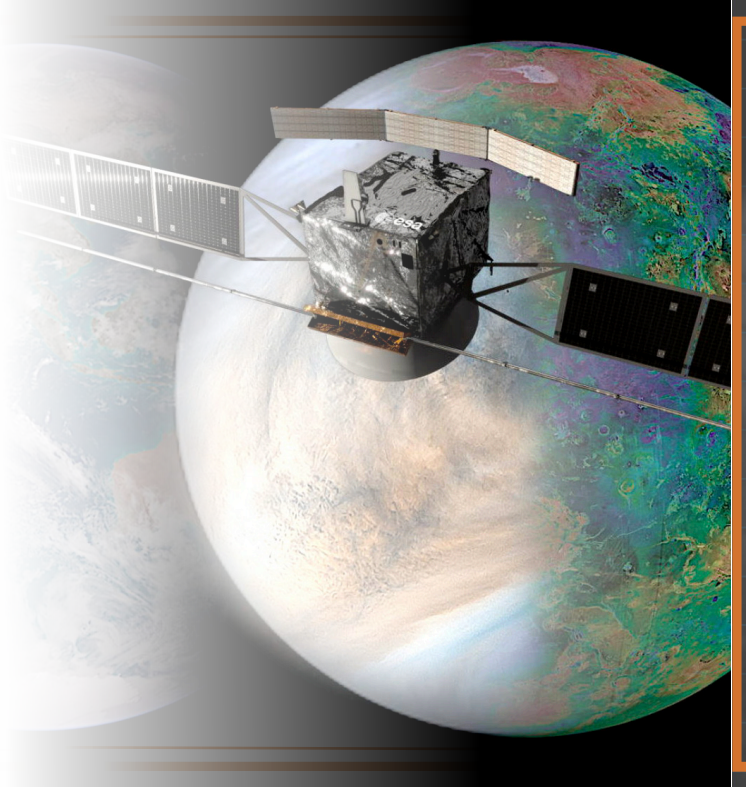
Engineering helps to open night windows at Venus

EnVision is an ESA satellite that will leave for Venus in 2031 to study the planet from below the surface to the high atmosphere. BIRA-IASB is leading the development of the VenSpec-H spectrometer on board. VenSpec-H will probe through the clouds into Venus' lower atmosphere via well-chosen sspectral windows which only open at night. The lower atmosphere of Venus is controlled by exhibits a very pronounced greenhouse effect, but otherwise not much is known about the atmospheric processes there.



Radiation analysis for EnVision's VenSpec-H instrument

34 BIRA-IASB is developing a Venus Spectrometer with High resolution (VenSpec-H) as part of the ESA EnVision mission to Venus. We have used the in-house developed Space Environment Information System (SPENVIS, https://www.spenvis.oma.be) to assess the impact of the space radiation environment on the VenSpec-H instrument.



Ground-based and airborne instrument development: science & technology

Follow the Sun … but do it small scale

"Follow the Sun" is a much-heard motto in atmospheric research. Sunlight is crucial to study the composition of the atmosphere with optical spectrometers. Over the past two decades, BIRA engineers have designed, built, and used different types of solar trackers. It is time now to retire the first-generation trackers. A second-generation mini solar tracker is ready to take over. It is much more compact and better equipped to withstand the harsh weather conditions it will have to operate in.

The NO_2 camera

Sometimes we invent new ground instruments inspired by space technologies. The NO_2 camera is one such example: it is made for observing NO_2 in industrial plumes or above urban areas, though the technology has been derived from the ALTIUS satellite mission.What makes our NO_2 camera so special is the combination of remote sensing and imaging. After a demonstration phase, interest is now rising in the air quality community, and we recently obtained funding from an ESA-led programme to emphasise the added capabilities of this innovative instrument.

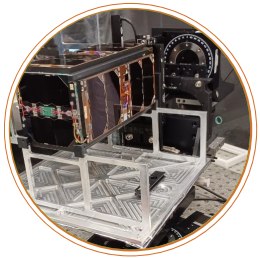
Regular airborne mapping of NO_2 above Berlin and Bucharest

BIRA-IASB equipped research aircraft in Germany and Romania with several versions of the in-house developed imaging instrument SWING. We used these airborne devices to produce regular mappings of the NO_2 fields above Berlin and Bucharest in 2021 and 2022. These measurements reveal the urban emissions of NO_x at a high spatial resolution, enabling us to distinguish hotspots such as power plants from the more diffuse traffic and heating sources, in order to study the yearly variations of the NO_x fluxes, and to validate the TROPOMI air quality satellite.

Belgian Radiometric Characterization Laboratory

MAJIS/JUICE for the observation of Jupiter and its icy moons

The Moons And Jupiter Imaging Spectrometer (MAJIS) is a Franco-Italian instrument on board the JUICE ESA mission (launch in April 2023). It is designed for a detailed study of Jupiter's atmosphere and icy moons. MAJIS has two channels, measuring in the VIS-NIR (visible and near-infrared) and IR (infrared). The Belgian Radiometric Characterization Laboratory (B.RCLab) integrated in BIRA-IASB has been involved in 2021 to successfully characterise with success the spare model (SM) detector using a high-performing radiometric and thermal vacuum facility.



Radiometric characterisation of the French INSPIRE-SAT 7 CubeSat

38

INSPIRE-SAT 7 is a French 2-unit nanosatellite, part of the INSPIRE (International Satellite Program In Research and Education) programme. It is dedicated, among other things, to the in-orbit observation of essential climatic variables such as solar irradiance and radiation reflected by the Earth. It will measure the Earth's radiation balance. A radiometric calibration bench has been designed by the Belgian Radiometric Characterization Laboratory (B.RCLab) integrated in BIRA-IASB. It has been used in 2022 to characterise the sensors of INSPIRE-SAT 7.

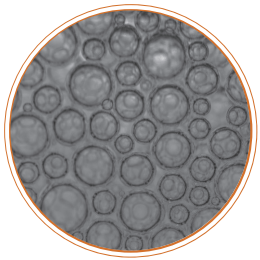
Belgian User Support and Operations Centre

Relocation of ASIM external payload on the International Space Station

In December 2021, the mission of the Atmosphere-Space Interactions Monitor was planned to end and to give up its location to another payload outside the Columbus module on board the International Space Station (ISS). Thanks to the outstanding science in catching upper-atmosphere electrical discharges such as red sprites or blue jets, ESA agreed to relocate the payload instead of rremoving and disposing of it. In a very short time, the ground teams overcame all of the technical hurdles and transformed the nadir-viewing payload into a limb-viewing one, now producing new science.

Managing ESA's Space Weather Service Network

40 Conditions on the Sun can directly or indirectly lead to potentially hazardous and sudden effects on some human activities in space or on Earth. To support the evaluation and mitigation of those effects, ESA started in 2008 the set-up of a Space Weather Service Network to provide timely and reliable space weather information to the different user communities. Since February 2021, B.USOC is leading a consortium of 52 teams all over Europe in charge of operating, developing and improving this network of services.



Trials and tribulations of FSL and its experiment containers

Over the last several years, the Fluid Science Laboratory onboard the ISS saw a lot of sample exchanges and complete Experiment Containers coming and going. In early 2021, the RUBI Experiment Container was replaced by the SMD Experiment Container. This container investigated CompGran and Foam-C samples, both for their second installment. Later that year, laser issues (that even some well-placed hammer blows could not solve) resulted in a 5-month science hiatus. Operations were able to resume in March 2022 with the installation of a new container and PASTA samples.

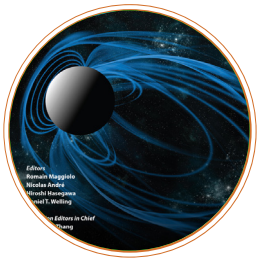
Knowledge dissemination, communication and education

A Touch of Space Weather - Outreach project for visually impaired students

A Touch of Space Weather brings the science of space weather into the hands and ears of blind and visually impaired students. Through workshops and a website, students can explore the Sun, Earth's atmosphere and magnetic field, aurora, and other space weather-related topics through touch and sounds. The project developed tactile images for children's workshops so the children can visualise space weather through touch. It also provides online tutorials on the website and will soon offer audio booklets.

MOMSTER, a Mobile Meteor Detection Station for Education and Outreach

42 BIRA-IASB studies the rubble or dust from space entering the Earth's atmosphere. In collaboration with the KU Leuven, the Planetarium of the Royal Observatory of Belgium, and the International Polar Foundation, we have set up an educational project called MOMSTER. In this project, students between 16 and 18 years old get to work as scientists by analyzing images with radio signals from meteors on the computer. Together with their teacher, they investigate the solar system in this way, and more specifically the dust it contains.



A new book on the magnetospheres in our Solar System published by Wiley

A book on the magnetospheres in our solar system has been published by Wiley for the American Geophysical Union. The 47 chapters of this book, edited by our BIRA-IASB colleague Romain Maggiolo, present the current state of knowledge about the magnetospheres in the solar system. The book gives a comprehensive overview of the current knowledge and future research directions in magnetospheric physics, from the mini-magnetospheres of Mercury to the giant magnetospheres of Jupiter and Saturn.

Open doors at Aeronomy Institute: Space for Climate

During the last weekend of September 2022, the Space Pole (the Royal Observatory of Belgium, the Royal Meteorological Institute and the Royal Belgian Institute for Space Aeronomy) opened its doors to the public. This year's theme, «Space for Climate», was an opportunity to highlight climate-related research, without forgetting the other research conducted at our institute. BIRA-IASB staff welcomed visitors of all ages, sharing their knowledge and motivation for Earth and Space sciences. During the open doors, one of our scientists, Noel C. Baker, created a live painting, featured on the cover of this report.

Reaching out to all of our audiences

Diversity in science is reflected in the diversity of our target audiences and the diversity in the topics we bring. Throughout the past two years, we organised a network event for the Belgian space industry, an Academic Session during the Belgian Space Week and the opening event of the Federal Climate Centre. Citizens and students have not been forgotten, either: we offer them information and training, but we also involve them directly in a number of research projects. At all times, we keep in mind that not everyone has easy access to science.

Open Science objectives and dissemination of Open Data

44 In line with the EU's open science policy and Belgian open data protocols, BIRA-IASB's IT department has developed a visualisation toolbox improving accessibility of the data products of our institute. The toolbox is used in prototype data portals of Belgian contributions to EU research infrastructures. In addition, BIRA-IASB has developed an Application Programming Interface based on the OpenAPI Specification, which is the basis of data distribution programmes funded by the EU. The API enables unambiguous distribution of data, emphasizing machine-to-machine distribution.

BIRA-IASB in numbers (*)

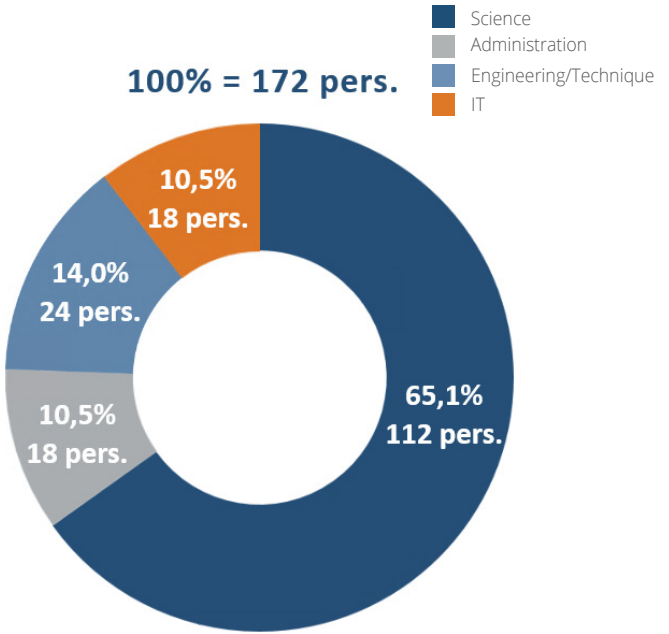
Between 2020 and 2022 (i.e. since our previous annual report), the institute has continued to grow. On 31 December 2022, a total of 172 employees (or 160.95 FTE) were working at the Royal Belgian Institute for Space Aeronomy. We can repartition them in 4 main categories: science (65%), administration (10,5%), engineering & technique (14%), and IT (10,5%). In particular, the number of PhD candidates increased significantly, from 8 at the end of 2020 to 15 at the end of 2022.

Apart from the aforementioned 172 employees, many other people have contributed to the work performed at the institute during the period 2021-2022; this includes people with an external contract, such as 3 IT persons with an Egov contract, 2 persons with an FNRS contract and visiting scientists, or people that have left the institute in the course of this 2-year period. They were not included in our graphs, but you will find their names inthe list on pp. 56-58.

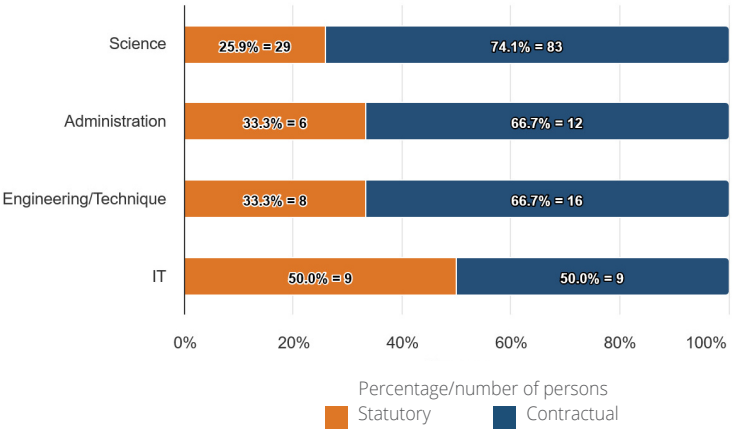
More info can be found in the online version of this annual report.

** All statistics in this activity report are calculated on 31 December of the year concerned and are based on staff numbers, not on FTE's (full time equivalents).*

Breakdown of staff by category (2022)

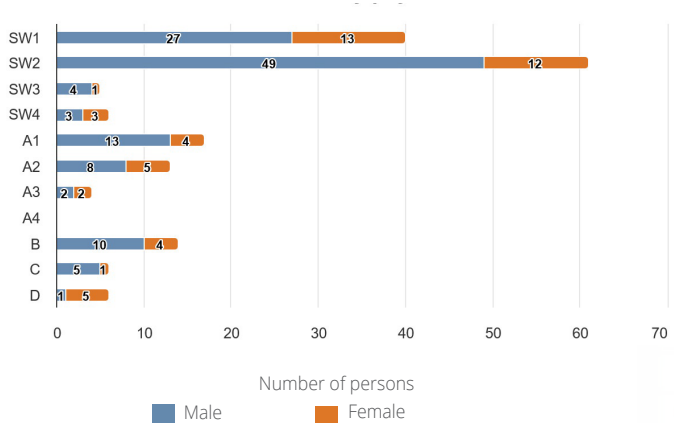


Share of contractual staff per category (2022)

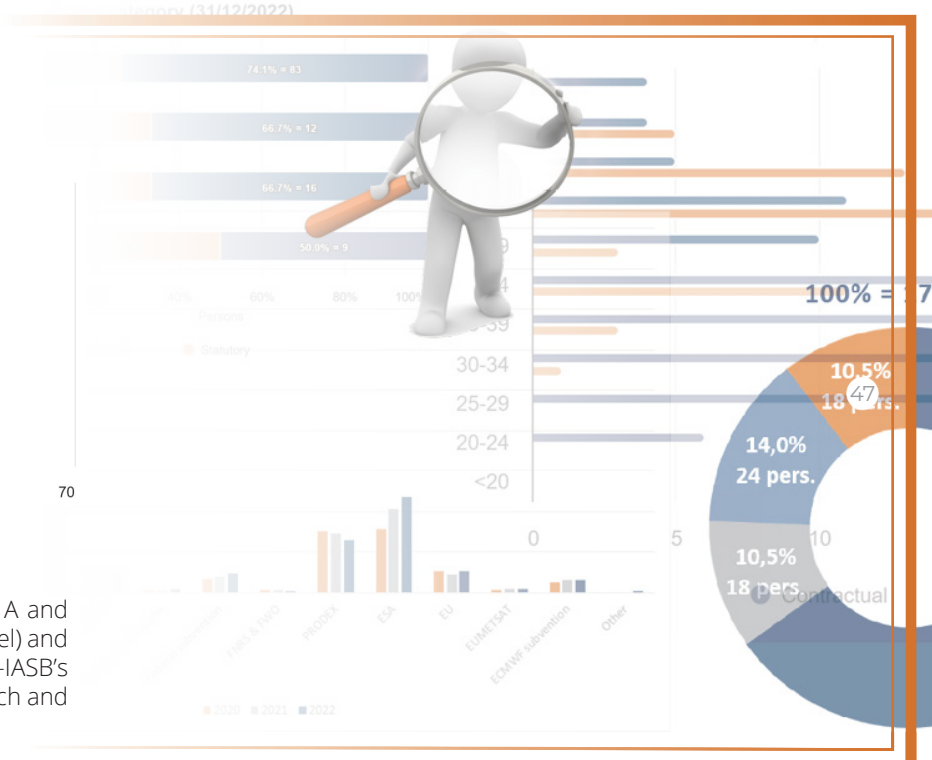


The percentage of contractual personnel workforce at BIRA-IASB is slightly rising. The share of contractual employees is especially large among scientists and reached almost 75%: a rise of 2%, from ~72% at the end of 2020 to ~74% at the end of 2022.

Breakdown of staff by level (2022)



The workforce within BIRA-IASB consists of 85% levels A and SW (master level or higher), only 8% level B (bachelor level) and 7% lower levels (C and D). This is directly related to BIRA-IASB's basic missions, which are essentially focused on Research and Development.



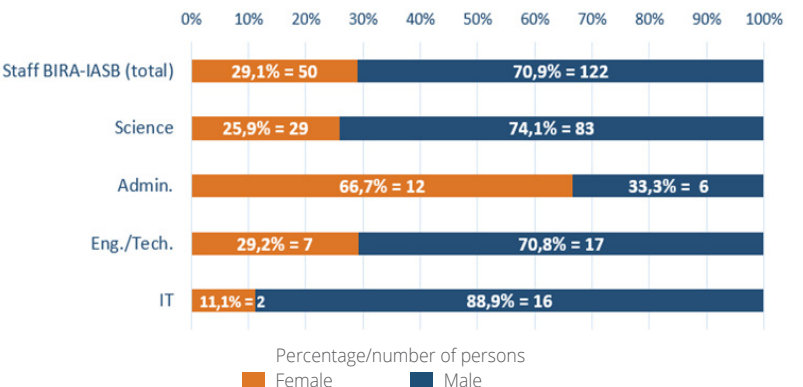
Diversity

At BIRA-IASB, we want to promote awareness of diversity and encourage measures to make all of us feel comfortable with and respectful of diversity of all kinds.

Gender

In response to recent European and Federal rules, BIRA-IASB published a Gender Equality Plan (GEP) with an action plan addressing aspects of work-life balance, leadership, career progression, research and teaching, and possible gender-based violence internally. A Gender & Diversity Team was created at BIRA-IASB to implement this GEP, but also to address other aspects of diversity.

Breakdown of staff by gender (2022)

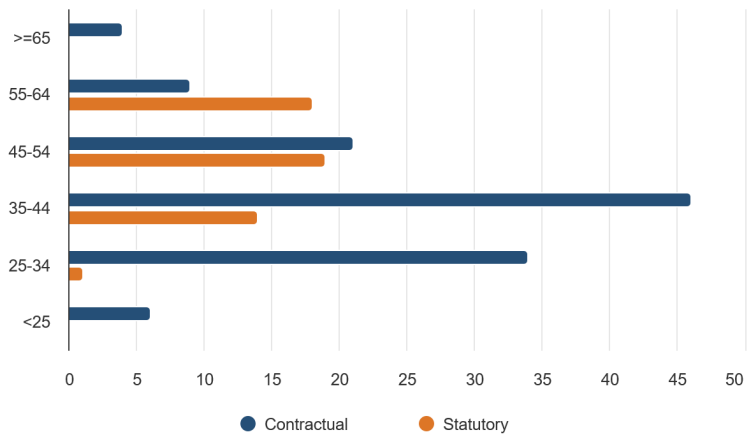


Nationalities

BIRA-IASB is proud of its international recognition and working environment. The countries of birth of the institute's staff give a good indication of the diversity of people we find among our collaborators: 49 out of 172 staff members are from foreign origin. They were born in 31 different countries. Some have lived for a long time in Belgium and even obtained the Belgian nationality. By the end of 2022, 21% of our workforce (36 persons) still have a foreign nationality, while in 2013, this was only 18% (28 persons). As of 2022, the institute hosts 18 different nationalities (including Belgian).

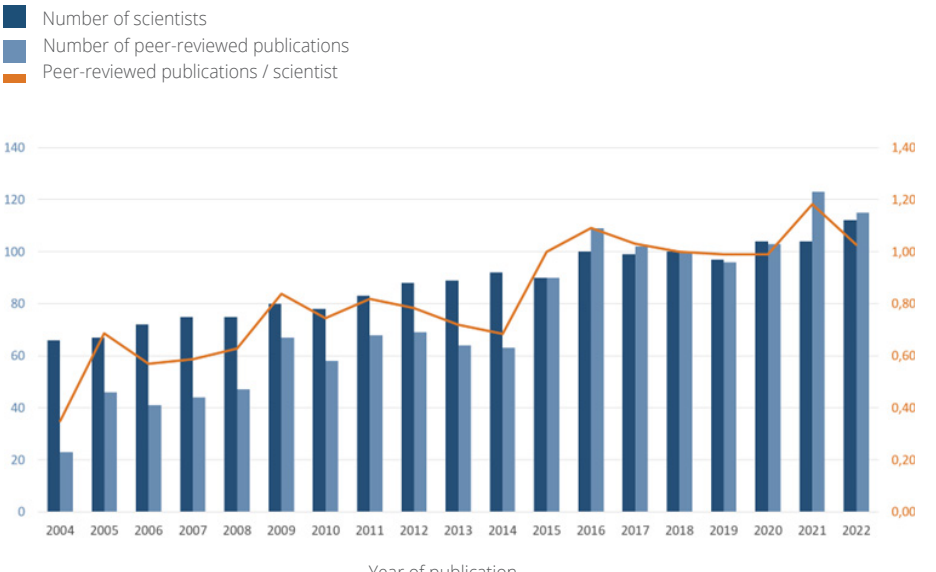
Age

The increasing number of PhD students within BIRA-IASB brings with it a rejuvenation of the population; however, this rejuvenation is limited to contractual staff. The lack of resources to recruit statutory staff causes a predominance in the statutory staff of people above the age of 45. The bulk of staff (statutory and contractual together) are in the 35-44 age group, which includes mainly contractual personnel. Only the 55-64 age group is dominated by statutory staff.



PUBLICATIONS

Over the period 2021-2022, BIRA-IASB personnel (co-)authored 238 peer-review articles (123 in 2021 and 115 in 2022), which comes down to an average of more than 1 publication per scientist per year. This graph shows the significant growth of the number of peer-reviewed publications per staff member since 2004. All publications are stored in the federal institutional Open Access repository, Orfeo: https://orfeo.belnet.be/



RESEARCH PROJECTS AND BUDGETS

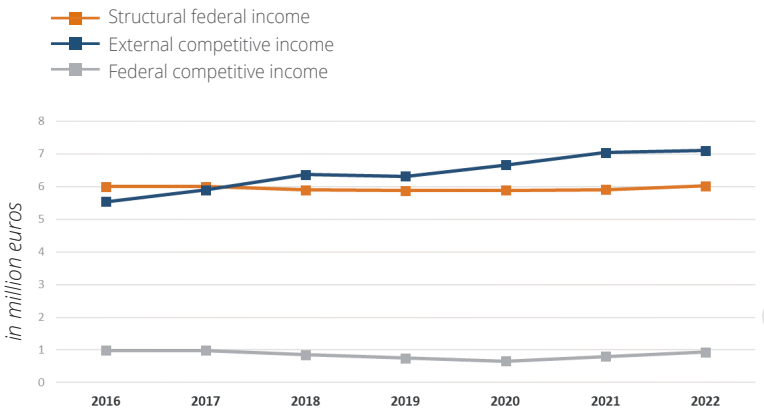
BIRA-IASB reaches a record number of ongoing research projects

That high-quality research is paramount at BIRA-IASB as proven by the most recent list of accomplished projects. No fewer than 45 new projects were launched in the past two years (23 in 2021 and 22 in 2022). While some funding sources have disappeared (FNRS, FWO), a few new funders have appeared on the scene: FPS VVVL, LOTTO, EURAMET; a nice recognition of the efforts made.

Source of funding	2020	2021	2022
Dotation	-	-	-
STCE	-	-	-
Commercial income	-	-	-
ESA	33	31	32
FNRS	3	2	0
PRODEX	12	14	15
Federal subvention	16	17	15
EU	10	11	10
EUMETSAT	2	2	3
ECMWF	5	8	4
FED-tWIN	1	3	5
FPS VVVL	0	1	1
LOTTO	0	1	1
EURAMET	0	0	1
TOTAL	82	90	87

Smoothed evolution of income (liquidation credits; 4-year running means)

Researchers at BIRA-IASB are pushing very hard to acquire external funding. Research resources are scarce and competition in calls for R&D projects is fierce. Nevertheless, BIRA-IASB researchers managed to secure a record research budget in 2021-2022. The position of our researchers is thus further strengthened and recognised nationally and internationally.

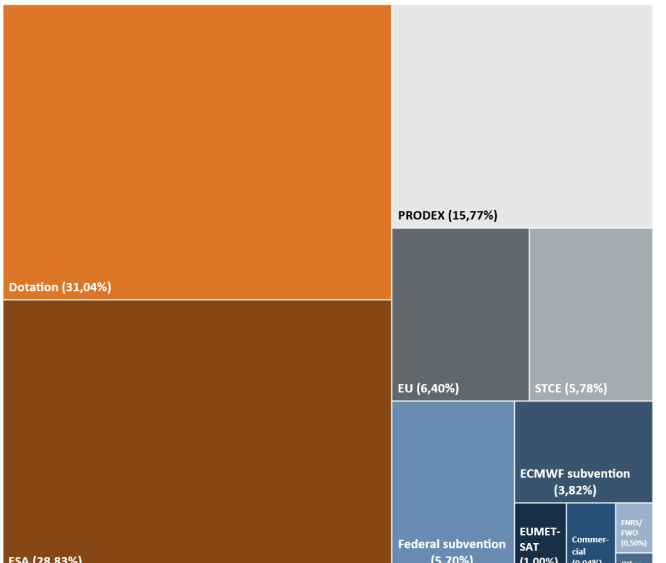


Since we work with multi-annual projects and related expenses and incomes, it is dangerous to compare the evolution of budgets on an annual basis. Hence, we have chosen to show 4-year running averages, with 4 years being the typical duration of a research project; i.e., 2022 represents here the average income over the period 2019-2022, 2021 the average over period 2018-2021, etc. The same accounts for the figures on pp. 54 and 55

Sources of income (liquidation credits; 4-year running means)

We can state that the structural government funding consisting of dotation and Solar-Terrestrial Centre of Excellence (STCE) represents about 1/3rd of our budget, with ESA funding another third. The remaining third of the budget consists of about half from PRODEX funding, and half from various national and European R&D projects funding. Apart from some annual variations, this partitioning remains rather stable throughout the years.

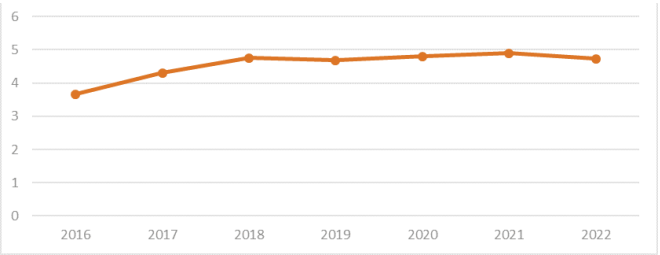
Share of funding sources (average for 2019-2022)

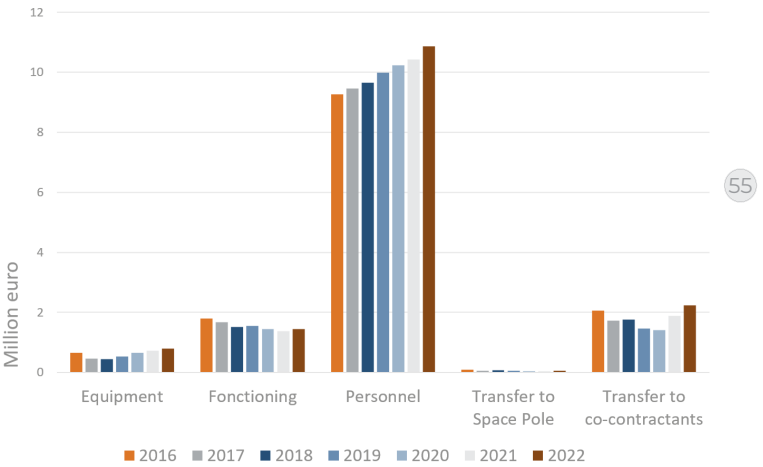


Expenses

The vast majority of our expenditure (> 70%) is on personnel. This cost rises every year and draws increasingly from our structural federal funding source that, as shown earlier, has not increased accordingly. This leaves less room for hiring statutory personnel and harms the basic functioning of the institute.

Ratio of payroll to operating & equipment costs (4-year running means)





Thank you!

Alonso Tagle Maria Luisa
Amelynck Crist
Anciaux Michel
Aoki Shohei
Arijs Yenn Michel
Aubry Aurélien
Bacchini Fabio
Baker Noel Catherine
Balis Joachim
Bauwens Maite
Beeckman Bram
Berkenbosch Sophie
Berthelot Antonin
Bevernaegie Jessica
Billot Pierre
Bingen Christine
Bjorklund Robin
Bogaert Pieter
Bogaerts Brigitte
Bolsée David
Bonnewijn Sabrina
Bosse Léo
Botek Edith
Brassine Ansje
Brenot Hugues
Brouckmans Kristien
Brun Nicolas
Bulcke Johan
Calders Stijn
Calegaro Antoine
Callewaert Sieglinde
Cardoen Pepijn
Cessateur Gael
Chabanski Sophie
Chabrillat Simon
Chakraborty Debdutta
Cierkens Jana
Cisneros Miriam
Clairquin Roland
Compernolle Steven
Counerotte Frédéric
Crosby Norma Bock
Cüneyt Nerovali
Da Pieve Fabiana
Daerden Frank
Darrouzet Fabien

De Brouwer Benedicte
De Cock Roderick
De Donder Erwin
De Grave Charlotte
de Harenne Christina
De Keyser Johan
De Mazière Martine
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De Rudder Anne
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