Publishable Summary for 21GRD02 BIOSPHERE
Metrology for Earth Biosphere: Cosmic rays, ultraviolet radiation and fragility of ozone shield

Overview

One of the most significant – yet unexplored – ecological challenges facing EU member states and beyond is the impact on human and environmental health of the increasing atmospheric ionisation caused by extra-terrestrial radiation (cosmic rays and solar UV radiation) boosted by anthropogenic emissions. This project aims to develop the necessary tools, methodologies and measurement infrastructure needed to evaluate the mutual impact of cosmic rays and biologically active UV radiation on the Earth's biosphere, and to support EU policy makers with scientific assessments and information that have the potential to substantially improve policies on climate, health and anthropogenic emission activities.

Need

Cosmic rays, along with UV radiation and the Earth's natural radioactivity, are one of the main sources of atmospheric ionisation, contributing to the electrification of the lower atmosphere and, thus, to the climate system in general. Attempts to quantify the changes this radiation causes in climate processes (e.g., cloud formation and thunderstorms), however, are debated and remain poorly understood. Over millennia, living organisms have been continuously exposed to cosmic rays and solar UV radiation. Biological actions of many kinds have evolved to deal with such exposures and a balance between beneficial and harmful effects of these radiation fields has been established. In recent years, however, this balance has been disturbed due to anthropogenic (man-made) emissions and environmental pollution creating an urgent need to study how these combined radiation fields are shaping our natural habitat, affecting the evolution of the biosphere, and impacting on our health. To achieve this, a combination of observations is needed using modern satellite technologies and ground-based *in situ* and remote sensing in environmental biology, chemistry and also radiation protection, to start the evaluation of cosmic and solar radiation effects on the biosphere.

Ionisation of the biosphere by cosmic radiation is known to correlate significantly with disease prevalence in humans, infectious disease mortality, and overall mortality. This is in addition to the harmful effects caused by UV radiation alone, which increases the incidence of skin cancer by about 2 % for every one percent reduction in ozone. Genomic, epigenetic, transcriptomic, and metabolomic changes potentially responsible for cellular radio-sensitivity and possible long-term dysfunction remain, however, largely unknown. The lack of understanding of these effects is exacerbated further by ozone depletion-induced overexposure to UV radiation and its implications for cellular defence mechanisms. Therefore, monitoring, modelling, and correlating cosmic rays, terrestrial solar radiation, and ozone thickness is critical not only to understand the radiological sensitivity of cells, but also to make informed decisions regarding the global challenges facing our society.

Traceable metrological data on cosmic ray fluxes, solar UV spectra, and the total ozone column are key to assessing the role of cosmic rays as climate drivers but quantification of correlations between them is required to inform new approaches to chemistry-climate models that will help clarify current ambiguities in the scientific community related to climate variability. Cosmic rays entering the top of the Earth's atmosphere, or primary cosmic rays (PCR), interact with atmospheric constituents to produce secondary cosmic rays (SCR), which are measured by ground-based instruments. The generation of an improved understanding of the role of PCR and SCR in ozone depletion, would provide a better assessment of biological implications due to natural UV overexposure. Quantification of ionisation and the production rates of charged molecular fragments and other reactive species is needed to extend present-day models that are currently limited to ionisation and the nonspecific energy loss values required to produce an ion pair. The interaction cross sections for these

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processes need to be examined and measured experimentally to improve the reliability of the ionisation data of natural atmospheric and anthropogenic gases relevant to ozone layer chemistry. Implementation of these cross sections into simulation codes for space radiation propagating through the atmosphere leads to refined radical, ion and slow electron production rates, which are needed to enable a more accurate estimation of the effectiveness of the cosmic ray model compared to the photochemical model in depleting the ozone layer. This is important for predicting future trends in ozone hole dynamics and for assessing the role of new chemicals in the ozone depletion.

Therefore, it is necessary to identify and quantify the relationship between cosmic radiation, ozone depletion and anthropogenic emission with the help of simultaneous modelling and traceable measurements of (i) ground-level muon and neutron fluxes, (ii) terrestrial solar UV-irradiance, and (iii) total ozone column (Objective 2). To achieve this, this project will characterise and calibrate novel SCR instrumentation – including an upgraded LIDAR system. Since generation and decay of SCR depend on air density, knowledge of atmospheric profile parameters such as temperature, density, and aerosols are needed to establish an accurate relationship between SCR and PCR fluxes (Objective 1). For the first time, this project will determine fundamental data on the interaction of low-energy cosmic-ray induced electrons with atmospheric gases of both natural and anthropogenic origin (Objective 3). This includes collision cross sections for the molecular processes such as dissociative electron attachment, molecular fragmentation and ionisation needed for the evaluation of mitigation strategies for the effects of anthropogenic emissions for the greater protection of human, animal and ecological health, and the development of policies that support these strategies. The impact of combined cosmic and UV irradiation on human health will be assessed by investigating structural and functional damages inflicted by such mixed radiation fields in human primary cells such as primary skin fibroblasts, blood monocytes and brain endothelial cells (Objective 4). Genomic, epigenetic, and transcriptomic changes that might be responsible for cell radiosensitivity and possible long-term dysfunction will be assessed, in this project, in connection with the fate of irradiated cells in terms of viability, morphology and functions.

Objectives

The overall aim of this project is to develop metrological methodologies to establish the correlations between primary and secondary cosmic rays (PCR and SCR), solar UV radiation and ozone layer thickness, and to assess their mutual impact on the Earth's biosphere.

The specific objectives of this project are:

1. To determine the dependence of SCR on PCR and atmospheric parameters (e.g., temperature, density, aerosol concentration), based on field measurements made using well characterised and traceable modified mobile SCR muon and neutron detectors, a novel semiconductor detector and adapted and/or existing LIDAR systems for vertical atmospheric profiling.
2. To identify and quantify the correlation between PCR and solar UV radiation on the ground including their dependence on anthropogenic gas emissions using simulations and traceable measurements of (i) ground-level muon and neutron fluxes, (ii) terrestrial solar UV-irradiance, and (iii) total ozone column.
3. To determine the molecular processes affecting ozone depletion and atmospheric dynamics, and to provide a complete database of collision cross-sections for natural atmospheric and anthropogenic gases. This is to be based on simulations and experimental validations that quantify molecular ionisation (absolute ionisation, excitation, dissociation cross section energies and projectile energy loss) and production rates of charged molecular fragments of both natural and anthropogenic atmospheric gases including CFCs and CH_2Cl_2 from interactions with low and medium energy (<10 eV - 2000 eV) electrons.
4. To assess the potential effect on human health from exposure at environmental levels to combined SCR and UV radiation fields using healthy human cell lines. This is to be based on simulating environmental level exposures under experimental conditions to establish correlations between radiation type and flux, and changes to cellular parameters (cell death, DNA damage and genomic instability, adhesion, and proliferation). In addition, to determine the expression profile of stress genes using established radiation effect models and systems biology approaches.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs and DIs, atmospheric monitoring networks), standards

developing organisations (e.g. IEC, ISO, CENELEC, CCRI (I) and EURAMET Technical Committee for Ionising Radiation (TC-IR)) and end users (e.g., health and environment regulatory bodies, research institutions focused on environment, climate, medicine and biology, and radiological protection, and instrument manufacturers).

Progress beyond the state of the art and results

Cosmic ray-induced low energy electrons and solar UV radiation are major drivers for atmospheric chemistry. For quantitative description of atmospheric ionisation, interactions with anthropogenic gases, collision and chemical processes involving ozone, climate-chemistry models require reliable cross-sections for the interactions of gases in the stratosphere with low energy electrons as well as for the production of reactive species by those interactions. This project will determine for the first time the medium to low-energy electrons cross sections for ionisation and fragmentation-ion production of atmospheric constituents such as N_2, O_2, NO, NO_2, selected chlorofluorocarbons (CFCs), halogenated molecules (such as HCl, HF, HBr, SF6), as well as aromatic and nitrogenated molecules (such as pyridines whose cations facilitate aerosol formation).

Determining the dependence of SCR on PCR and atmospheric parameters

The SCR flux measured at ground level is affected by the survival probability of the incoming parent PCR particles, the various atmospheric conditions such as air density and temperature, and the particle absorption rate down this path. Corrections which exploit the exponential dependence of pressure or temperature on altitude are currently used for these effects, but these do not consider the inhomogeneities of air density that affect the accuracy of the recorded SCR fluxes. This project will develop, for the first time, metrological methods to quantify the correlation between PCR and SCR using atmospheric profile parameters measured by LIDAR(s). These will include a novel mobile scintillator-based muon detector capable of measuring muon flux reaching the ground level with an energy distribution from a few hundred MeV to a few hundred GeV, a novel boron scintillator-based mobile neutron detector which can measure neutrons in a wide range of energies (from thermal up to several tens of MeV), and a spectral-tracking particle telescope assembled as stack array from 2 semiconductor pixel detectors (Timepix3) in miniaturised and portable architecture for high-angular resolution wide field-of-view mapping of SCR with resolving power of mixed-field components (muon, electron, proton, ion, gamma, X ray, neutron).

Identifying and quantifying the relationship between cosmic radiation, UV radiation and anthropogenic emission

Side-by-side measurement of the terrestrial solar UV spectrum, total atmospheric ozone, and SCR flux rate has never been attempted so far due to the lack of the proper measurement framework. This project will provide such measurements for the first time and will go beyond the state of the art not only by measuring these parameters simultaneously, but also by supporting the ground-based measurements with satellite measurements such as satellite observations of energetic electron, proton and Helium-ion fluxes. Simultaneous measurement of SCR fluxes, UV radiation spectrum and ozone column, enabling a quantification of the relationship between them, will be carried out at four European sites (Greece, Belgium, Czechia, and Germany). This will provide the necessary infrastructure for an accurate measurement of atmospheric profiling parameters and have different anthropogenic emission inventories to integrate the influence of anthropogenic emissions on ozone dynamics.

Molecular processes affecting ozone depletion and atmospheric dynamics

This project will produce for the first time a complete database of collision cross sections for natural atmospheric and anthropogenic gases relevant for ozone layer chemistry. The database will be in an open format and will also include the quantification of molecular ionisation and production rates of charged molecular fragments and other reactive species going beyond present-day models which restrict to ionisation and a nonspecific energy loss value per produced ion pair.

Effects of combined SCR and UV radiation fields on biological systems

Understanding the mutual impact of cosmic and ultraviolet radiation on human health is important not only for humans, but for all mammalian and plant species and the entire living ecosystem. This project will go beyond the state of the art by creating, for the first time, a database of results from irradiated and non-irradiated biological samples such as lung and primary skin fibroblasts, cerebral microvascular endothelial cells from the brain, and healthy blood monocytes. Through advanced bioinformatics and systems biology methodologies, a complex network of molecular changes related to cell death, DNA damage and genomic instability, adhesion and proliferation, and expression profile of stress genes will be established.

Outcomes and impact

Outcomes for industrial and other user communities

The project's data on the combined SCR and UV irradiation of human primary cell lines (such as primary skin fibroblasts, blood monocytes, brain cerebral microvascular endothelial cells) will be provided to enable key information on a plethora of biological effects such as DNA damage, genome instability, cell death, oxidative stress, subtle structural changes and transcriptomic changes. This information is crucial for assessing the impact of such radiation fields on human health. Therefore, European health groups and organisations such as ECCO (European Cancer Organisation), EORTC (European Organisation for Research and Treatment of Cancer), ESMO (European Society for Medical Oncology), and more globally World Health Organisation (WHO) will benefit from this project.

The cross-section data produced in this project will support worldwide monitoring programmes such as the Global Atmosphere Watch (GAW) of the World Meteorological Organisation (WMO) and the International Ozone commission (IO3C) of the International Association of Meteorology and Atmospheric Sciences (IAMAS). These data will also be a valuable input for the chemistry-climate models (CCM) such as, for example, SOCOL (SOlar Climate Ozone Links), MEZON (Model for the Evaluation of Ozone Trends), and CRAC:CRII designed to study the impact of different external factors such as galactic cosmic rays (GCR) and solar proton events (SPE) on the Earth climate system and the ozone layer.

Outcomes for the metrology and scientific communities

The new metrological method for determining the dependence of the SCR flux to the ground on PCR and atmospheric profile parameters will greatly improve the prediction accuracy of the SCR rate at ground stations as a function of pressure and temperature, which is particularly needed during intercomparisons of environmental monitors. This would also lead to better quantification of ground level enhancements (GLEs) and subsequent radiation dose assessments. The participants will also provide input to BIPM Consultative Committee for Photometry and Radiometry on matters related to photometry and ozone dynamics. The metrology infrastructure and methods developed in this project will help estimate the on-ground magnitude of cosmic events such as Solar Proton Events (SPE) and Gamma Ray Bursts (GRB) and will provide information for designing biomedical studies for assessing the impact of radiation exposure on human health, in relation to radiation dose and dose rates. In addition, quantifying the dependence of SCR on atmospheric profile parameters such as temperature would enable improvements to the tracking of short-term atmosphere dynamics such as Sudden Stratospheric Warmings and geoscience applications such as characterising the density structure of volcanoes. This would be of interest to organisations such as the European Geosciences Union (EGU) and the European Space Weather Community.

Traceable metrological data on cosmic ray fluxes, solar UV spectra, and the total ozone column generated by this project are key to assessing the role of cosmic rays as climate drivers. Quantifying the correlations between these three observables will contribute to new approaches to chemistry-climate models that will help clarify the ambiguities in the scientific community.

The new database of collision cross sections for natural atmospheric and anthropogenic gases will enable modellers, developers and end users to assess the role of low-energy cosmic electrons on the ozone depletion and atmospheric dynamics. The project’s new database with results of irradiated and non-irradiated biological samples will enable modellers, developers and end users to assess the effects of combined SCR and UV radiation fields on human health.

Outcomes for relevant standards

The project will provide guidance for stakeholders and input to international standardisation bodies (ISO, IEC, CENELEC), for both ionising and non-ionising radiation protection via input to the following committees: ISO TC 85/SC 2/WG 2 (Radiological Protection, Reference radiation fields), IEC/TC45 (Nuclear Instrumentation, SC45B Radiation protection instruments, WG9 Detectors and systems), CENELEC/TC 45B (Radiation Protection Instrumentation). Thus, the project will support the harmonisation of procedures and methods for the measurement of cosmic rays and solar UV radiation in the environment and hence their inclusion into European and international standardisation.

Longer-term economic, social and environmental impacts

This project will provide data that will help assess the contribution of cosmic rays and UV radiation exposure in the risk for developing chronic diseases and cancer. The data and methods ensuing from the current project will be useful for ecological correlative studies, providing a first glimpse of some of the possible unexplored interactions between the environment and human health. Such findings will have significant economic implications, particularly in terms of public health, agricultural production and food security on a global scale. Policymakers and regulatory bodies will be able to make better informed decisions on climate and environmental policies by using an improved understanding of ozone depletion and its effects on the Earth's Biosphere.

List of publications

n/a

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:	1 October 2022, 36 months	
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Internal Beneficiaries: 1. PTB, Germany 2. BFKH, Hungary 3. CEA, France 4. CMI, Czechia 5. GUM, Poland 6. IMBiH, Bosnia and Herzegovina 7. TUBITAK, Türkiye	External Beneficiaries: 8. ADVACAM, Czechia 9. BIRA-IASB, Belgium 10. DTU, Denmark 11. DWD, Germany 12. IFIN-HH, Romania 13. IVB, Romania 14. LZH, Germany 15. MPG, Germany 16. NOVA, Portugal 17. NTUA, Greece 18. Raymetrics, Greece 19. UJF CAS, Czechia	Unfunded Beneficiaries: 20. CSIC, Spain 21. GGO, Germany 22. IRM, Belgium