Solar-Terrestrial Centre of Excellence

Annual Report 2024

STCE

Solar-**T**errestrial **C**entre of **E**xcellence

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Front page - *The geomagnetic storm of 10-11 May 2024 was the strongest in more than 2 decades. Auroras were seen as far south as Mexico, Gran Canaria and North-India. This picture was taken from a location near Tubize (Belgium) by Gaël Cessateur (BIRA-IASB) on 10 May at 23:24 local time.*

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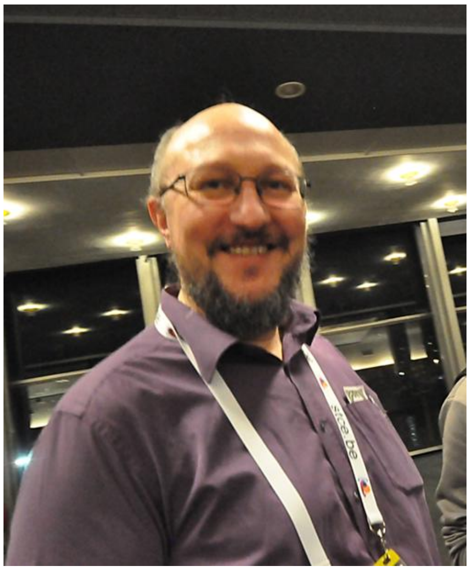
A word from the STCE coordinator



Dear reader,

You see before you the annual report of the Solar-Terrestrial Centre of Excellence. It highlights some of the finest results that were achieved in 2024 through collaborations across teams, institutes and borders.

The STCE, the Belgian space weather centre, reached out to organizations and institutes that have a connection with space weather. The first step is raising awareness, the second step is providing information and education, the third step is offering services, tools and a helpdesk. The STCE has put considerable effort into showing the relevance of space weather for society. The Space Weather Education Center of the STCE is the place where users can get what they need.

We expanded our services which form the ultimate bridge between the science community and the users. We safeguard the quality of these services by investing strongly in research in the different domains of solar-terrestrial sciences. Solar and heliospheric science, research of the Earth environment and collecting and analysing observational data are the keys to continuously improve and rethink our services. Especially in these geopolitical unstable times, our consolidated expertise and knowledge on the space environment of Earth can be of great help.

We look to the future as well, and work hard on preparing new missions and initiate new projects that will guarantee the future of the collaborations fostered by the STCE.

Besides what is highlighted in this report, much other progress was achieved in 2024 in the form of fresh ideas, new results, new collaborations, and new methods. For many of these projects, the details can be found through our elaborate list of presentations and publications that are listed at the very end of this report. Please contact us if you would like more information on any of those.

For now, happy reading!

Ronald Van der Linden
General Coordinator of the Solar-Terrestrial Centre of Excellence
Director General of the Royal Observatory of Belgium

Structure of the STCE

The Solar-Terrestrial Centre of Excellence is a project of scientific collaboration that focuses on the Sun, through interplanetary space, up to the Earth and its atmosphere.

The solid base of the STCE is the expertise that exists in the 3 Federal Scientific Institutes of the Brussels Space Pole: the Royal Observatory of Belgium, the Royal Meteorological Institute and the Royal Belgian Institute for Space Aeronomy. The STCE supports fundamental solar, terrestrial and atmospheric physics research, is involved in earth-based observations and space missions, offers a broad variety of services (mainly linked to space weather and space climate) and operates a fully established space weather application centre. The scientists act at different levels within the frame of local, national and international collaborations of scientific and industrial partners.

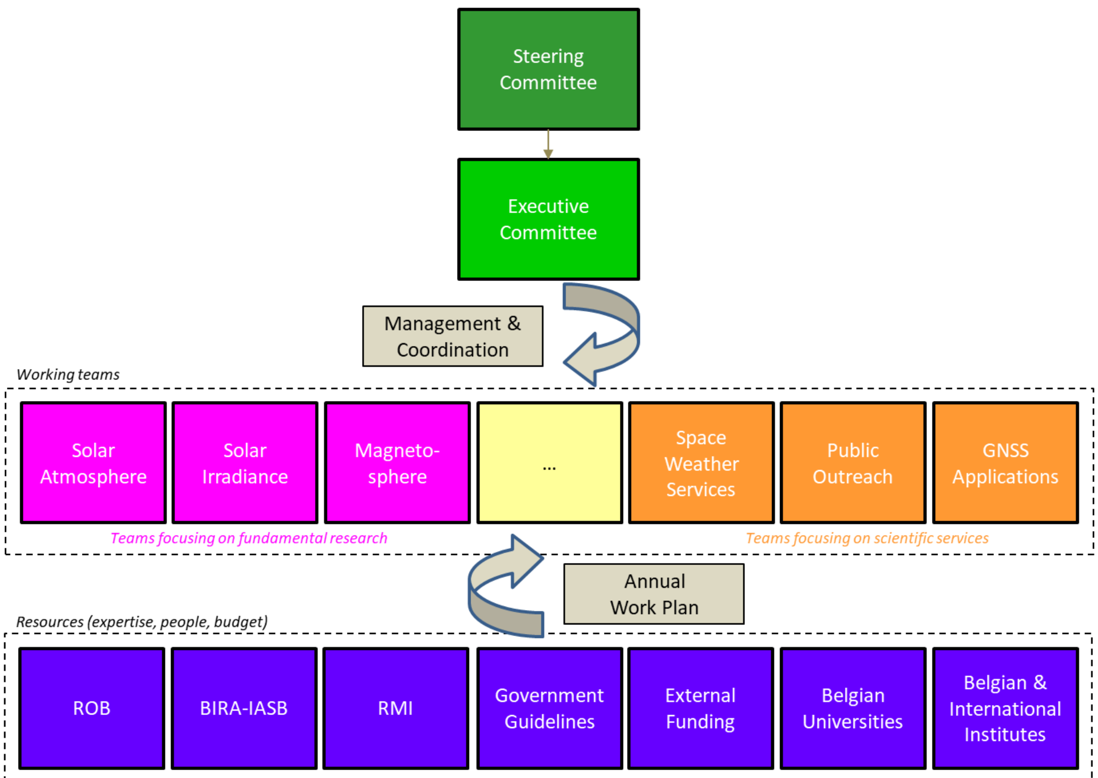


Figure 1: The STCE management structure

The STCE's strengths are based on sharing know-how, manpower, and infrastructure.

In order to optimise the coordination between the various working groups and institutions, as well as the available resources such as ICT, personnel and budget, a management structure for the STCE was put into place, consisting of a steering committee and an executive committee.

The ***steering committee*** takes all the final decisions on critical matters with regard to the STCE. It assures the integration of the STCE into the 3 institutions and the execution of the strategic plans. It is composed of:

- BELSPO General Director "Research and Space"

  Dr. Frank Monteny (BELSPO)

- Director General of each of the 3 institutions at the Space Pole

  Dr. Ronald Van der Linden (ROB)
  Dr. Daniel Gellens (RMI)
  Dr. Ann Carine Vandaele (BIRA-IASB)

The ***executive committee*** assures the global coordination between the working groups and the correct use of the budgetary means for the various projects. It also identifies new opportunities and is the advisory body to the Steering Committee. It is composed of:

- STCE Coordinator

  Dr. Ronald Van der Linden

- Representatives of the research teams in the 3 institutes

  Dr. David Berghmans (ROB)
  Dr. Judith de Patoul (ROB)
  Dr. Eric Pottiaux (ROB)
  Dr. Ann Carine Vandaele (BIRA-IASB)
  Dr. Martine De Mazière (BIRA-IASB)
  Dr. Johan De Keyser (BIRA-IASB)
  Dr. Norma Crosby (BIRA-IASB)
  Dr. Michel Kruglanski (BIRA-IASB)
  Dr. Daniel Gellens (RMI)
  Dr. Tobias Verhulst (RMI)
  Dr. Stijn Nevens (RMI)
  Dr. Roeland Van Malderen (RMI)

A promotional movie giving a flavor of the STCE's tasks, interactions and various research programmes can be found via the STCE website (in English, and subtitled in French and Dutch). A concise and more recent introduction to the STCE can be found on the STCE's YouTube channel (English).

Olivier Boulvin is getting ready to photograph a good portion of the Solar Influences Data analysis Center (SIDC) team of the Royal Observatory of Belgium following their Monthly Management Meeting (MMM) on 13 December 2024 (Credits: Sergey Shestov). During these near-monthly gatherings, held both on-site and online, topics such as well-being, science projects, people stuff, outreach events, and upcoming conferences are discussed. They are standing in front of a house-sized poster of the Sun made by Solar Orbiter's Extreme Ultraviolet Imager (EUI) containing no less than 83 million pixels in a 9148 x 9112 pixel grid, making it the highest resolution mosaic image of the Sun's full disk and outer atmosphere, the corona, ever taken. It's also the most photographed wall on the Space Pole.

Monitoring space weather: solar-terrestrial highlights in 2024

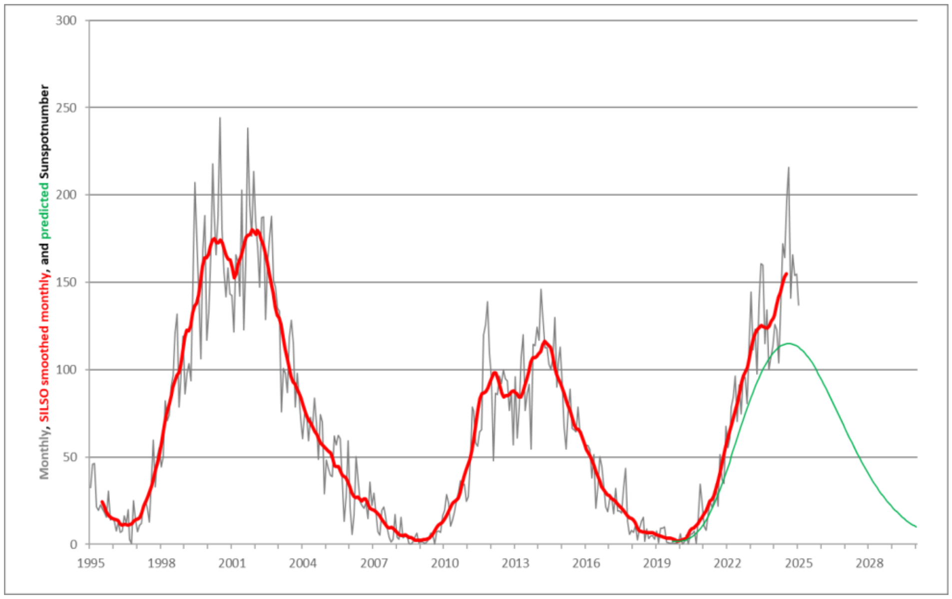


*Figure 2: The evolution of the monthly and SILSO smoothed monthly S_N (respectively gray & red) for the period 1995-2024 (**SILSO smoothing formula**). The monthly sunspot numbers in 2024 remained higher than the expected values (depicted in green), with the highest values observed during July and August. Solar maximum took place during the second half of 2024.*

The official annual sunspot number (S_N) for 2024, as determined by the WDC-SILSO (World Data Center - Sunspot Index and Long-term Solar Observations), was 154.7. This is a further increase compared to 2023 (125.5). The highest monthly sunspot numbers were recorded during July and August (resp. 196.8 and 216.0), and the smoothed monthly sunspot number seems to have reached a maximum around 160 during the autumn months of 2024. Consequently, SC25 maximum would be higher than the maximum of the previous solar cycle SC24 (116.4), but lower than that of SC23 (180.3). The evolution of SC25 for various space weather (SWx) parameters can be followed on the STCE's SC25 Tracking page.

The highest daily sunspot number was observed on 18 July (290), but also April, August and December had days when the sunspot number was above 250. Daily highs of 290 had not been observed since July 2002. The July 2024 period was mainly driven by a multitude of small sunspot groups , whereas in August the sunspot groups were a bit less numerous but much larger. Solar activity was dominated by the southern solar hemisphere in 2024. The observed (and flare-corrected) 10.7cm radio flux (Penticton) reached its highest daily value for the entire year on 9 August (305.5 sfu, with 1 sfu = 10^{-22} W m^{-2} Hz^{-1}), up from 231.8 sfu recorded on 15 January the previous year. The adjusted monthly radio flux reached 253.9 sfu in August, well above the 183 sfu in July 2023.

In 2024, no less than 7 active regions reached a sunspot area of 1000 MH (about 5 times the total area of the Earth), including the 3 largest sunspot groups of SC25 so far: NOAA 13590 in February (1450 MH), NOAA 13664 in May (2400 MH), and NOAA 13780 in August (1280 MH). These and several other sunspot groups were reported visible with the protected naked eye (eclipse glasses) throughout the year. On a few days in August and October, there were even -at the same time- 3 sunspot groups visible with the protected naked eye.

The Sun produced 54 X-class ("eXtreme") flares in 2024. You've read that right: fifty-four! Since GOES observations started in 1976, only four other years have produced more X-class events than 2024, the most recent one being 1991. Also, 2024 is only the third year with more than 900 M- and X-class flares in a single year, after 1989 and 1991 (resp. 922, 968 and 979). For comparison, SC24 produced only 1200 M- and X-class flares *during its entire duration*.

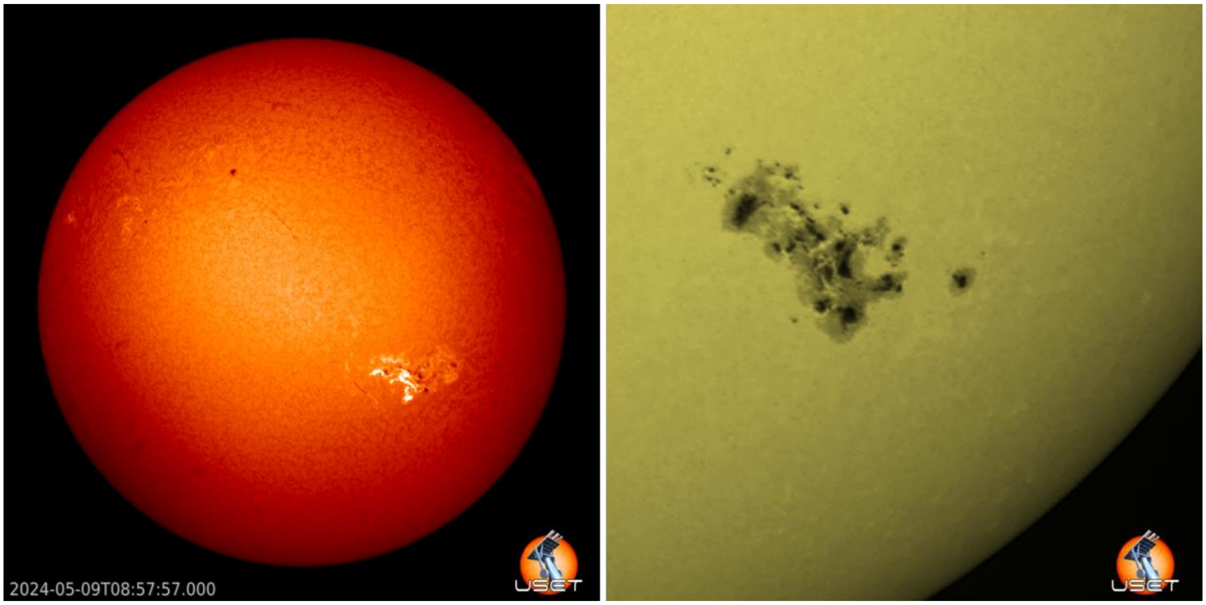


Figure 3: USET, the Uccle Solar Equatorial Table of the Royal Observatory of Belgium (ROB), has several solar telescopes at its disposal to observe and image the Sun in different wavelengths. On the left is a view on the X2.2 flare above active region NOAA 13664 on 9 May in H-alpha, a line in the red portion of the solar spectrum. On the right the same source region in white light, a day later. NOAA 13664 would produce its strongest flares on 11 May (X5.8) and 14 May (X8.7).

The main contributors to all the X-class flare activity were NOAA 13664 (12 - Figure 3), 13663 (5), 13697 (6), 13842 (4) and 13590 (3) combining for more than half of all X-class flares. They were also responsible for the strongest flares of 2024 and as such also of SC25 (so far): NOAA 13842 was the source of an X9.0 and an X7.1 event, NOAA 13664 produced an X8.7 and an X5.8 flare, and NOAA 13590 (X6.3) completes the current Top 5. It is very likely that the strongest flares of SC25 so far actually took place on the Sun's farside (as observed by Solar Orbiter/STIX), with a proxied X16 on 20 May 2024 as the current primus inter pares (Stiefel et al. 2025). Farside flaring activity was also discussed in several STCE newsitems.

Many of these strong flares were accompanied by intense solar radio bursts (SRB ; NOAA/SWPC and USAF). The strongest radio event took place on 9 May and accompanied the X2.2 flare produced by NOAA 13664 (Figure 4). The radio emission reached high levels, in particular at frequencies below 1 GHz and lasted more than an hour. Intensities around 600.000 sfu were reached at 245 and 410 MHz, and 240.000 sfu was recorded at 610 MHz. The solar radio burst was also noticeable at GNSS frequencies (Global Navigation Satellite Systems, such as GPS or Galileo), with an intensity of 31.000 sfu. The strongest SRB at GNSS frequencies took place on 9 October following an X1.8 flare in NOAA 13848, reaching an intensity of 70.000 sfu. For reference: typical solar radio emission values in these frequencies during solar cycle maximum range from around 20 sfu at 245 MHz to about 200 sfu at 2695 MHz.

During the year, several proton events were recorded. A proton event occurs when the greater than 10 MeV proton flux exceeds the threshold of 10 pfu (proton flux unit). The particle detector on board GOES recorded 5 minor, 9 moderate and 2 strong proton events in 2024. The first strong proton event (1030 pfu) was associated with an M9.7 flare on 8 June produced by NOAA 13697, the return of NOAA 13664. The strongest proton event of the year (1810 pfu) took place on 9-10 October and was associated with an X1.8 flare by NOAA 13848.

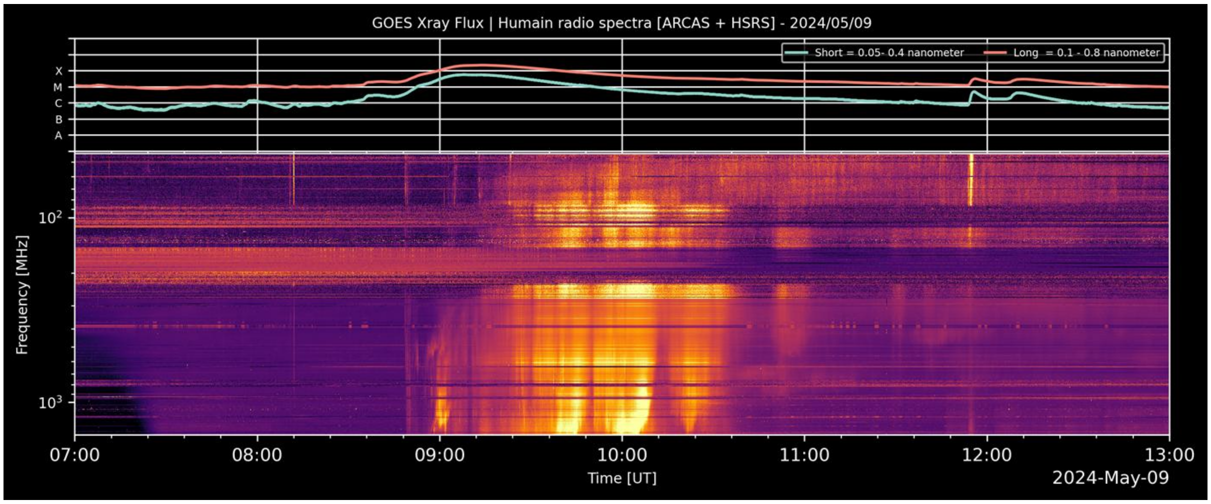


Figure 4: The strongest solar radio burst of 2024 took place during the morning hours of 9 May and was recorded by the radio telescopes of the Humain Radioastronomy Station at frequencies between 45 and 1495 MHz. Scanning continuously the intensity at these frequencies, a weak Type II disturbance from a CME-driven shock can be discerned around 09:00 UTC, but much more prominent is the intense broadband Type IV disturbance that lasted for 1.5 hours (from around 09:10 to 10:40 UTC). See the STCE's SWx classification page for more info on Type II, Type IV and other types of radio bursts. The top portion of the graph shows the evolution of the x-ray flux as measured by GOES.

Some of the proton events were associated with high-energetic protons, having energies of several hundreds of MeV. Following collisions with particles in the upper atmosphere of the Earth, they create a shower of secondary particles such as neutrons that may be recorded by ground-based neutron monitors such as at the Geophysical Centre in Dourbes, Belgium. Such an increase in the number of neutrons is called a Ground Level Enhancement (GLE), and it increases the natural background radiation at the Earth's surface. In 2024, three GLEs were recorded on 11 May, 8 June and 21 November . The latter was caused by what was most likely an X-class eruption in a sunspot region that was already 28° behind the Sun's west limb, i.e. well on the Sun's farside as seen from Earth!

The 11 May GLE was hard to miss. The top image of Figure 5 is a white-light coronagraphic image made by SOHO/LASCO C3 on that day. The coronal mass ejection (CME) that can be seen to the east ("left") is from farside solar activity. The two bright blobs on the left and right are respectively the planets Jupiter and Venus. The white "points" are from energetic protons impacting the pixels of the instrument's camera. The protons were associated with an X5 flare earlier that day and are not related to the ongoing extremely severe geomagnetic storm that started late on 10 May. This particular proton event consisted also of particles with energies of several hundred MeV, and was as such the source of a GLE. The graph at the bottom of Figure 5 shows the neutron flux evolution (percentage relative to the pre-increase) of this neutron flux from 10 to 12 May, for a suite of cherry-picked neutron monitors. The GLE can be seen as a brief hump in the neutron flux early on 11 May. The GLE (database maintained by the University of Oulu) happened right after a strong decrease in the neutron count (a so-called "Forbush decrease"), following the passage of the CME that triggered the geomagnetic storm and subsequently acted as a magnetic shield against the even more energetic cosmic ray particles.

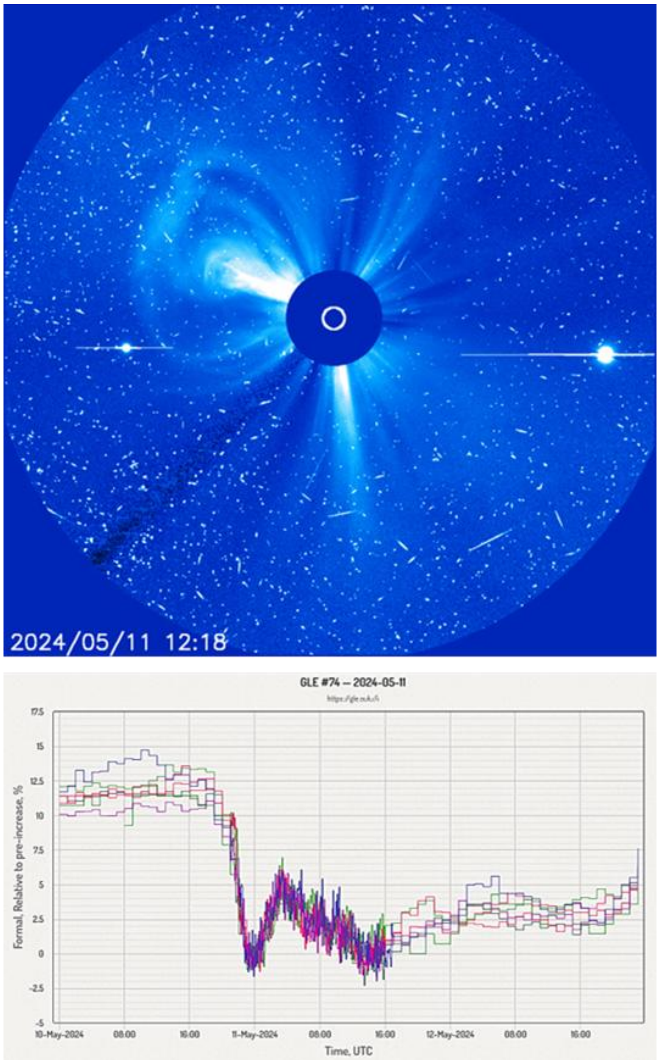


Figure 5: Impact of the 11 May proton event on SOHO/LASCO C3's white light coronagraphic imagery (top) and the recording of the associated GLE by the neutron monitors (bottom). More details are in the text.

The smoothed daily CME rate decreased very gradually from just below 6 in January to 5.3 by the end of 2024. Often, these CMEs had an earth-directed component disturbing the Earth's magnetic field. No less than 25 days reached moderate geomagnetic conditions (K_p = 6- or higher) and they almost exclusively had an interplanetary CME as their source. Significant events were the 10-11 May 2024 storm (K_p = 9o ; provisional Dst = -406 nT) and the 10-11 October 2024 storm (K_p = 9- ; provisional Dst = -333 nT).

The 10-11 May 2024 storm, also known as the "Gannon storm", the "Mother's Day storm" or the "Han Anniversary Storm" (Elvidge et al. 2025), was the strongest geomagnetic event in more than 20 years, in fact -in terms of Dst- the strongest since the storm of 20 November 2003. The source of this storm was a series of powerful, earth-directed CMEs associated with strong eruptions by NOAA 13664 during the 8 to 10 May period. As a result, the great geomagnetic storm of 10-11 May 2024 was not associated with a single fast CME but with a complex accumulation of multiple CMEs and southward interplanetary magnetic fields (IMFs). The first and main shock arrived at DSCOVR at 16:38 UTC on 10 May, with solar wind speed jumping from around 460 km/s to values near 700 km/s. Half an hour later, at 17:05 UTC on 10 May, it slammed into the geomagnetic field and significantly compressed the magnetosphere down to about 5 earth radii, thus exposing the satellites in a geostationary orbit (GEO) such as GOES and SDO to the turbulent solar wind for a continuous 6 hours. Solar wind speed would eventually reach values in excess of 900 km/s, and Bz would reach an unusual low -50 nT at several instances over the next 48 hours.

Auroras were observed at low latitudes around 20° to 30° such as from Mexico, Gran Canaria, Namibia, northern India and northeast Australia. Geomagnetic activity stayed significantly active with K_p > 8 for over 24 hours. This meant that the majority of the Earth's population experienced nighttime at some point during the activity period, giving them the best chance to observe the aurora.

Due to the increased atmospheric drag, automated station-keeping especially from the Starlink and Low-Earth-Orbit (LEO) constellation caused nearly half of all the active satellites in LEO to maneuver at once in response to the storm. While the storm represented a risk to the LEO environment in the short term, it also helped to hasten the removal of debris populations from orbit. Following the onset of the storm, power grid operators in New-Zealand set into action a mitigation plan to deal with the geomagnetically induced electrical currents (GICs) and keep the power grid stable (Clilverd et al. [2025](#)). In the United Kingdom, the observed GICs (and rate-of-change of the magnetic field) ranked the storm as a 1-in-30 years event. The magnetic field rate of change was not sufficiently large or rapid to cause any reported issues or damage to technical infrastructure.

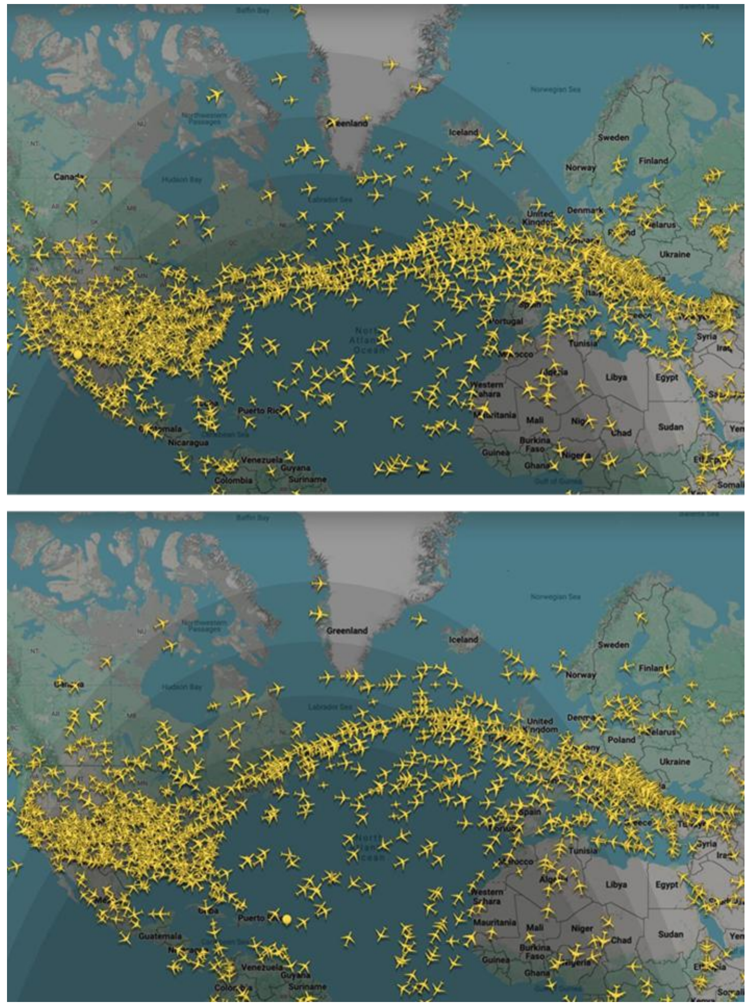


Figure 6: During the geomagnetic storm of 10-11 May 2024, many trans-Atlantic flights took more southerly routes across the ocean to avoid the risk of higher radiation for passengers and crew, as well as to avoid potential communication and navigation losses closer to the North Pole. The upper image shows a snapshot of flight patterns early on 11 May during the geomagnetic storm, when flights were redirected to more southern routes. The lower image shows the flight patterns one week later, on 18 May around the same time, as flights followed their typical route. Credits: ***Flightradar24***

The geomagnetic storm obviously had an important impact on the Earth's ionosphere, degrading the GNSS positioning accuracy considerably due to the many ionospheric irregularities that affected the satellites' signals during the storm event ("scintillation"). Some navigational systems in tractors and other farming equipment in the United States broke down at the height of planting season. The delays in planting and the inability to use precision farming technologies resulted in significant economic losses for farmers, up to $17.000 per farm.

Aviation suffered from radio communication problems, as well as reduced availability of certain GNSS based applications. Pilots flying between the U.S. and Europe noted communications anomalies near southwestern Greenland, and one transoceanic flight was rerouted due to loss of high-frequency (HF) communications (Figure 6). Some GNSS-based applications were disturbed or entirely unavailable. For example, LPV200, the vertically-guided landing approach aid for airplanes to as low as 200 feet (61 meters) above ground level, was not available for about a half day during the most powerful phase of the geomagnetic storm. This was only the very first time such outage occurred since the inception of WAAS (Wide Area Augmentation System, i.e. a GNSS application for aviation over North-America) back in 2007.

Some advisories were sent to the civil aviation for disturbances of HF Com and GNSS by space weather consortia such as PECASUS (Kauristie et al. 2021; Pierrard et al. 2025).

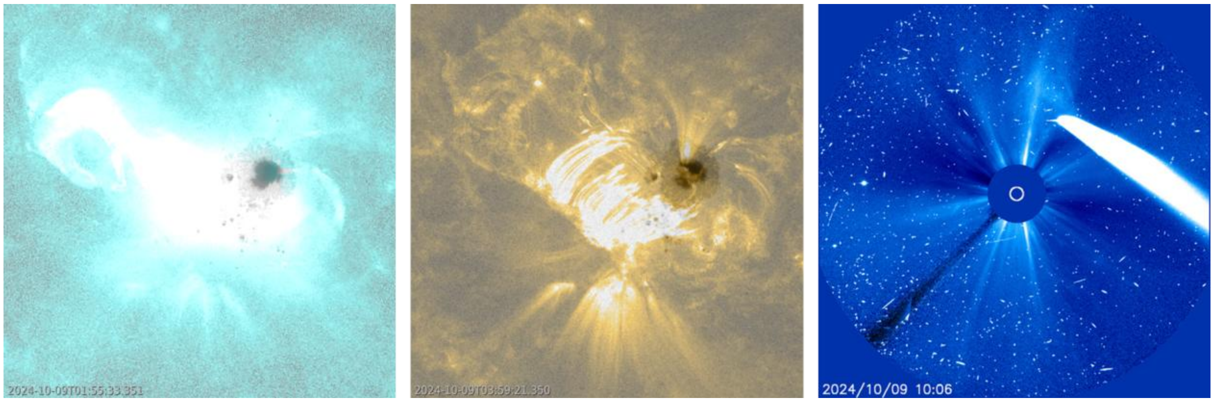


Figure 7: NOAA 13848 was the source of the CME that would cause the second strongest geomagnetic storm of 2024. In the two images on the left, extreme ultraviolet images from SDO/AIA are overlaid on white light images of NOAA 13848 (SDO/HMI). They show respectively the X-class flare during its peak early on 9 October, and a series of post-flare coronal loops ("arcade") two hours later. The right image shows the impact of the associated proton event on SOHO/LASCO C3 coronagraphic camera, i.e. most of the white dots are not stars but impacts from the energetic protons on the camera's pixels. The bright feature to the right is comet Tsuchinshan-ATLAS which was flying through LASCO's field of view.

The second strongest storm of SC25 took place on 10-11 October 2024 reaching severe storming levels (K_p = 9-, A_p = 300 nT ; see this STCE newsitem). The source interplanetary CME was related to a long-duration X1.8 flare released early on 9 October by active region NOAA 13848 (Figure 7). This storm was less severe than the one from May 2024, but still had some important impacts (STCE newsitem).

Auroras were observed and/or photographed as far south as California and Texas in the United States, and from Italy and Greece in Europe, as well as South-Africa and Australia. From Belgium, auroras were not as well observed as during the May storm due to cloud coverage.

Some GNSS applications for aviation were again not available over North-America (WAAS), this time for no less than 16 hours! HF Com, already affected during the preceding X-class flares, was again impacted, in particular during the days after the storm when the upper portion of the high frequencies (HF; 3-30 MHz) was depressed at some locations and for certain intervals, a so-called post-storm depression (PSD; Figure 8). Numerous advisories (i.e. alert messages) for disturbed HF Com and GNSS were again issued by space weather consortia such as PECASUS for the benefit of civil aviation. Belgian radio meteor observers from the

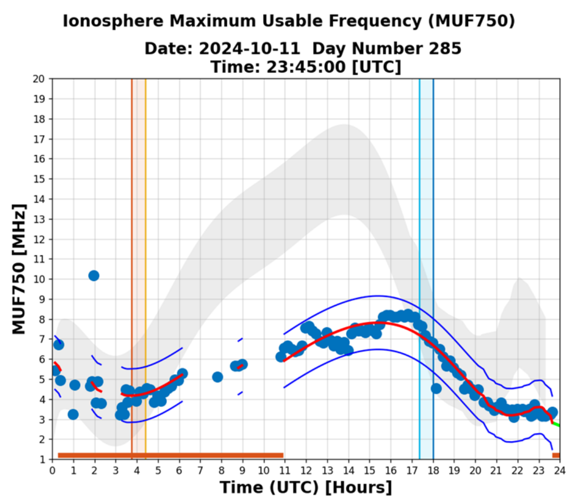


Figure 8: Following the strong negative phase of the ionospheric storm on 11 October, the lack of electrons to reflect the radio signal prevented the use of the higher portion of the HF Com frequencies, as shown in the graph above. MUF750 means the maximum usable frequency to bridge a distance of 750 km. The grey area indicates typical frequencies that can be used during a quiet day, and the blue dots are the true measurements of the MUF based on observations from the digital ionosonde in Juliusruh (Germany) during the geomagnetic storm on 11 October. They clearly are much lower than the expected values. Credits: DLR/IMPC and ESA's SWx portal

BRAMS (Belgian RAdio Meteor Stations; see this STCE newsitem for more info on BRAMS) recorded considerable noise in their radio displays hampering a good detection of any radio signature from a passing meteor. Geostationary satellites such as GOES were exposed to the turbulent solar wind for about 10 hours, complicating spacecraft operations and research. The increased atmospheric drag seems to have advanced the re-entry from a Starlink satellite at very low earth orbit by 10 days. ESA moved some satellites up in their orbits, to avoid premature re-entry (SWARM ; ESA-communication).

High-speed streams (HSS) from coronal holes (CHs) regularly disturbed the earth environment, but they were less prominent and had a smaller SWx impact than in 2023. In most cases, only minor geomagnetic storming resulted from the passing HSS. Maximum solar wind speeds associated with these HSS were around 600 km/s. The Sun's polar fields reversed their magnetic polarity in resp. January 2024 (North) and September 2023 (South; smoothed data from Wilcox Solar Observatory), though some brief spikes back to the old polarity were observed in the latter hemisphere. Polar CHs are expected to gradually reform, and indeed, 2024 saw the gradual development of small to moderately sized CHs with the new magnetic polarity at moderate to high latitudes (50-70°). As a result, the 365-day smoothed electron fluence (electrons with energies $\geq$ 2 MeV) reached a minimum in June 2024 (SC25 Tracking page). This heralds the return of large CHs in the coming years. The passage of the associated HSS may generate again elevated levels of energetic electrons in the Earth's outer radiation belt (GOES), renewing the deep-dielectric charging threat to satellites.

Aurora over the Brussels metropolitan area during the geomagnetic storm of 10-11 May, as photographed by Brenda Dorsch (SIDC).

Public outreach meets Science

Launch of Proba-3

One of the events for which the year 2024 will be remembered is the launch of Proba-3. This mission consists of a pair of satellites designed to create long-lasting solar eclipses that perfectly capture the lower portion of the corona, the Sun's hot atmosphere. With Proba-3, the European Space Agency (ESA) wants to demonstrate that extremely precise formation flying is possible in space. By virtue of this technology, we can also use the mission for scientific research.

Figure 9: The launch of Proba-3 was well covered by the national media. The image on the left shows David Berghmans from the Royal Observatory of Belgium and the image on the right Pierre Rochus (21 December 1950° - 20 February 2025[+]) from the Centre Spatial de Liège (CSL) as they are being interviewed. CSL had the lead of the consortium that built the eclipse maker ASPIICS.

Many people had worked for many years on this exceptional mission to imitate a natural solar eclipse, i.e. when the Moon passes in front of the Sun. Early December 2024, that moment had finally come. Proba-3 was placed on a rocket waiting to be launched from the Satish Dhawan Space Center on the Eastern coast of India.

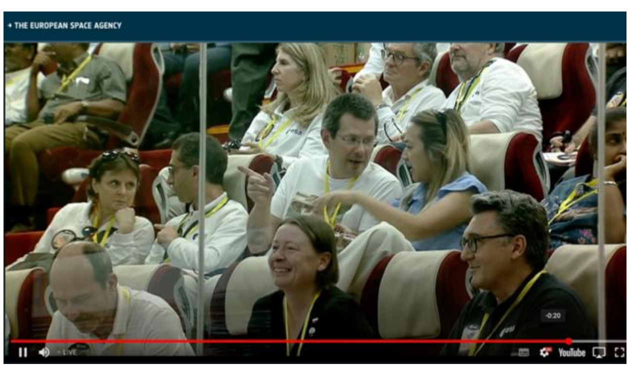


Figure 10: Andrei Zhukov, the principal investigator of ASPIICS, can be seen in the centre of the image. Andrei was one of the guests invited to watch the launch of Proba-3 on a big screen at the launch base in India. This is a screenshot taken during the live streaming of the launch on ESA Web TV.

The media coverage of the launch was enormous. Not only the press, but many other people were curious about Proba-3's space adventures: two satellites, separated by a distance of only about 150 meters, flying with millimeter precision in a hazardous environment where only few have been. A solar eclipse captures the imagination anyway. Anyone who gets the chance to experience a solar eclipse live, seizes it. It is a magical dance of the Sun and the Moon high above our heads in an immeasurably large ballroom: space.

The press and invited guests could follow the launch live from the venerable Meridian Room of the Royal Observatory of Belgium. The STCE had spared no effort to make the launch a festive occasion, with a demo, explanations by prominent scientists, visual material, and champagne. This was on 4 December.

During the event, a message was received that the launch had been postponed. Because we had a direct line of communication with the launch site, the reason for the delay became immediately clear: it turned out to be a technical malfunction. As a result, the launch was deferred until 5 December. On that day, the green light was finally given and Proba-3 began its long-awaited journey into space under the watchful eye of principal investigator Andrei Zhukov, one of the founders of this technologically challenging space mission.

Auroras under the lens: citizen scientists change the game!

Introduction *- With solar activity at its peak, intense auroras are reaching lower latitudes, as seen on e.g. 10 May 2024. Amateur photographers, equipped with highly sensitive cameras, have been capturing these displays. Their widespread presence enables large-scale auroral monitoring, providing crucial data to scientists. Citizen contributions have led to discoveries like STEVE, SARs, and recent* N_2^+ *upflows. By helping classify new auroral types, they prove that public participation is key to advancing auroral research.*

Figure 11: Aurora on 10 May 2024, observed on the shores of the Loire River, France. (Credits: E. Beaudoin)

When a solar storm becomes geoeffective, auroral phenomena can be visible even at lower latitudes. With advanced alarm systems in place, more and more people are ready to capture these stunning displays with their own cameras. Over the past two decades, camera technology has improved significantly, allowing an increasing number of amateurs to easily photograph auroras. Their contribution to auroral research has been critical for the past 10 years. Indeed, the increasing availability of images has led to the discovery of various types of auroras into polar regions, but also some new types of atmospheric emissions, such as STEVE (Strong Thermal Emission Velocity Enhancement) and SAR (Stable Auroral Red arc) phenomena, which are part of a broader class of sub-auroral events.

Aurora observations at mid and low latitudes are rare, typically appearing as diffuse red illuminations of the sky above the northern or southern hemispheres. This is because red auroras usually occur at much higher altitudes, and their lower parts, including the green, purple, and blue emissions, fall below the horizon.

However, the 10 May event, often referred to as the Mother’s Day Storm, was an extraordinary exception. It was one of the 10 most significant geomagnetic storms ever recorded, with the auroral oval extending as far south as the south of France. This rare event has been confirmed through numerous observations, ranging from all-sky cameras to images captured by astrophotographers, highlighting its uniqueness.

Another event, happening during the night of 24-25 September 2023, was also rather exceptional: a single blue aurora was captured by an astrophotographer in France, leading to a scientific study trying to explain such phenomena. Reviewing different physical processes, only one remained plausible to explain the blue emission visible at such low latitudes. The ionized N_2^+ from an auroral event is uplifted into the upper atmosphere, possibly up to 500 km, and will diffuse the sunlight, leading to a blue emission. This single event shows the possible synergy between amateurs and professionals, helping in the understanding of auroral physics.

Figure 12: Aurora observed during the night of 24-25 September 2023 close to Chartres, France. (Credits: E. Beaudoin)

MOMSTER: real science in the classroom

Most students learn about science from textbooks, but rarely get to do science. MOMSTER (Mobile Meteor Station for Education & Outreach) changes that by bringing real meteor detection into classrooms using simple radio technology.

How it works - When meteors enter Earth's atmosphere, they briefly reflect radio signals. MOMSTER's portable kit captures these "echoes", letting students:

- Detect real meteors in real-time;
- Analyse actual scientific data ;
- Contribute to citizen science through the Radio Meteor Zoo platform.

Why it matters - MOMSTER transforms science education by:

- Making abstract concepts tangible: Students see physics, geography and math in action;
- Requiring no special expertise: Easy-to-use kits work in any classroom;
- Connecting to real research: Student data contributes to actual scientific studies;
- Engaging diverse learners: Hands-on approach excites students who might not thrive in traditional science classes.

A model for STEM education - MOMSTER proves that authentic scientific research belongs in classrooms. By combining hands-on learning with citizen science, it offers a replicable blueprint for making STEM education more dynamic and relevant.

Figure 13: Left: a student setting up the MOMSTER antenna. Right: teacher training session organised during the VeLeWe (association of science teachers) congress in Ghent (2022). Teachers received hands-on experience with the MOMSTER meteor detection kits.

Explore further

- MOMSTER educational material (in Dutch and French);
- Contact: stijn.calders@aeronomie.be;
- Reference: Calders S., Lamy H., Sterken M., Kolenberg K. (2025). *MOMSTER: A mobile radio meteor detection kit for STEAM learning linked to citizen science*. Astronomy Education Journal (forthcoming) ;
- Related: STCE Annual Report 2021 (pages 12-13).

Quadrennial Ozone Symposium in Boulder (USA)

Every 4 years, the scientific ozone community gathers to present and discuss the state-of-the-art research on ozone and ozone depleting substances. The 2024 Quadrennial Ozone Symposium (QOS) was held from 15-19 July in Boulder, and is the 36th meeting of Ozone Scientists that began with the "Conference on Ozone and Atmospheric Absorption" in Paris in May 1929. The previous meetings have been highlighted with our growing understanding of processes affecting atmospheric ozone, its observations, photochemistry, impacts on air quality and human health, as well as the existential threat of ozone layer depletion by chlorofluorocarbons and halons. The focus of the 36th symposium was on the wildfire aerosol impacts on ozone, new findings of the Hunga volcanic eruption impact on the stratosphere, the anniversaries of the Aura satellite and commercial aircraft observations, increased awareness of ozone and stratospheric impacts on surface climate, and new satellite data from the Korean and American geostationary air quality monitoring instruments.

The QOS was organised in hybrid form and attracted about 250 participants from all over the world. As the previous QOS was completely virtual due to the COVID-19 pandemic, the large majority of the attendees preferred to be on site now. Members of the STCE or its contributing institutes (RMI & BIRA-IASB) presented their ozone research in talks and posters and were elected as a member (Roeland Van Malderen) and secretary (Corinne Vigouroux) of the International Ozone Commission (http://www.io3c.org).

Figure 14: Picture of the participants attending the Quadrennial Ozone Symposium in Boulder in July 2024.

Of particular interest to mention here is that the **Joseph C. Farman Award**, granted to one or more outstanding scientists who have created and used high-quality, long-term time series of atmospheric measurements related to the study of atmospheric ozone and/or surface ultraviolet radiation, has been awarded to Herman Smit from the Research Centre Jülich "*in recognition of his unique contribution to the calibration and quality of the global ozonesonde record*". For over 25 years, his institute hosts the World Calibration Center for Ozonesondes (WCCOS) which, together with the RMI/STCE as the Quality Assurance - Science Activity Centre (QA-SAC) for Ozonesondes (since 2022) are the two components of the global quality control and quality assessment for ozonesondes for the World Meteorological Organization. An example of the successful collaboration of these two partners is provided on pages 31-33 in this Annual Report.

On 31 January, his Majesty the King honored the Federal Scientific Institutes on the Uccle Plateau with a visit focusing on their space activities. For reasons of practical organisation, the entire visit took place on the premises of the BIRA-IASB. Upper left: David Berghmans (ROB) preparing his presentation on Solar Orbiter/Proba-3 and space weather. Upper right: Emmanuel Dekemper (BIRA-IASB) providing details on the ALTIUS mission. Lower left: A quick stop near the ExoMars Trace Gas Orbiter satellite model. Lower right: Upon his departure, his Majesty took a few minutes to converse with researchers and supporting staff from the Space Pole. A full account of the visit can be found on the website of the BIRA-IASB. Image credits: Judith de Patoul (ROB; upper left) and Pierre Gerard (BIRA-IASB).

Fundamental research

Solar Cycle 25 has reached its maximum

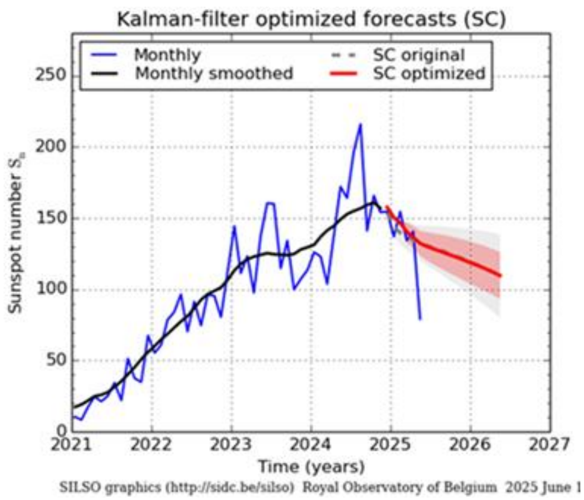


Figure 15: Solar Cycle 25 and its maximum seen in October 2024, as well as the 12-months ahead predictions that show a decreasing trend.

In 2019, the Solar Cycle Prediction Panel convened to gather and combine predictions for the still infant Solar Cycle 25. The results of this gathering were published shortly thereafter: the Solar Cycle Prediction Panel expected the cycle's maximum value of the smoothed monthly sunspot number (S_N) to be in a very narrow range between 105-125 with the peak occurring between November 2024 and March 2026.

Six years later, we seem to have finally reached the maximum and the predictions from 2019 appear to have been significantly lower than reality. Of course, in terms of prediction accuracy, the closer we are to the actual maximum, the more the various prediction methods will converge. Indeed, last September, SILSO predicted a maximum S_N between 138 and 161 that would take place sometime between May and October 2024, while NOAA predicted a similar range between 137 and 164 but within a broader time window, i.e. between February 2024 and January 2025.

The results are now confirmed by SILSO: the maximum value of the monthly smoothed sunspot number for Solar Cycle 25 was reached in October 2024 and is 161 (see Figure 15), versus 159 for September and 157 for November 2024.

What this entails for the SIDC team, is that, at this stage of the Solar Cycle, the Sun is very active, and will remain at a similar level of activity well into 2026. Since the beginning of 2024, many large and complex active regions have crossed the solar disk regularly driving the daily sunspot number to well above 250 as can be attested by the SIDC/USET image for 7 August 2024 (Figure 16).

These active regions often were the source of strong solar flares, and the associated solar eruptions, when they are earth-directed, strongly affect the Earth's magnetic field. The important aurorae thus created are sometimes visible from countries further away from the polar regions, such as in May 2024 when the colourful display was also visible from Belgium (see this newsitem).

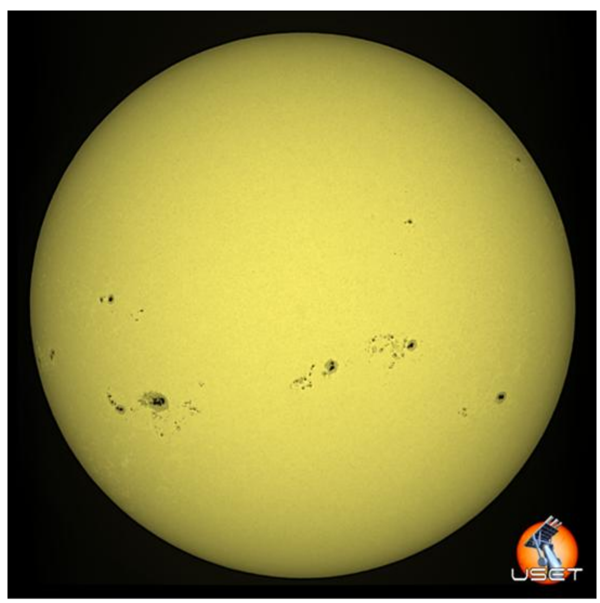


Figure 16: White light image of the photosphere of the Sun taken on 7 August 2024.

While storms of this magnitude occur approximately once every 12.5 years, the length of this specific storm was unusual, expected only once every 41 years (Elvidge & Themens [2025](#)). There were also important storms in October 2024, with in total for 2024 no less than 7 days for which geomagnetic conditions reached severe or extremely severe levels. These major solar storms and their impact on Earth help improve the accuracy of Space Weather forecasting as they enable us to sample solar events with the full range of instruments at our disposal today.

The years 2025 and 2026 thus promise a lot of sunspots to count and a lot of activity for the Space Weather team of the SIDC.

Effects of the Mother's Day superstorm event of 11 May 2024

Introduction *- The strongest geomagnetic storm for the last 20 years appeared during the night of 10 to 11 May 2024, caused by a big solar eruption that generated nice auroras visible in many European countries at unusual lower latitudes. It has been called the Mother's Day event due to its date. This geomagnetic storm had important consequences on the radiation belts, with the first observation of four electron belts and the exceptional injection of protons in the South Atlantic Anomaly.*

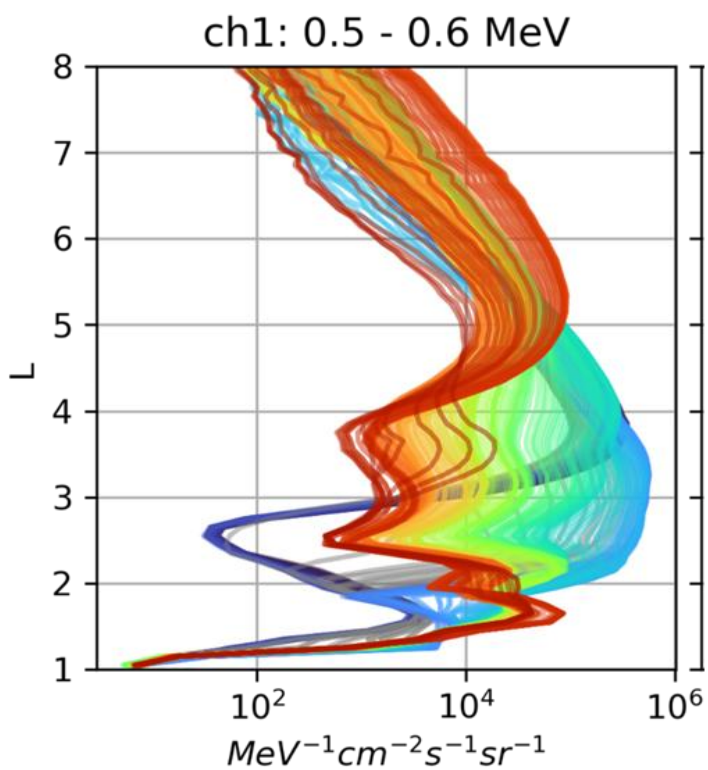


Figure 17: PROBA-V/EPT smoothed electron differential fluxes from 500 to 600 keV from 5 May 2024 (in dark blue, two belts) to 27 June 2024 (in red, 4 belts/peaks), revealing the formation of four electron belts one month after the 11 May storm, due to the loss of the injected electrons at very specific radial distances. This had never been observed before.

Unprecedented observations of 4 electron belts - For the first time ever, four electron belts were observed in the magnetosphere until one month after the storm, contrasting with the usual two (inner and outer) radiation belts (Pierrard et al. 2024). We showed that this was due to an important loss of electrons at very specific positions. The observation was made by the Energetic Particle Telescope (EPT) and confirmed by the MetOp satellite. EPT is a detector that BIRA-IASB developed together with Université Catholique de Louvain and Redwire Space. It was launched in 2013 on board the PROBA-V satellite at 820 km of altitude.

Exceptional injection of protons in the South Atlantic Anomaly - For the first time since the launch in 2013 of the PROBA-V satellite with the EPT, an injection of energetic protons in the southern portion of the South Atlantic Anomaly (SAA) was observed.

These injected protons are well visible by the red region in Figure 18 illustrating the proton fluxes at 820 km altitude observed in the first EPT proton channel, averaged in longitude and latitude bins from 13 to 19 May 2024 after the storm. The variations of the EPT proton fluxes in the SAA during the previous maximum solar activity in 2014 and at minimum activity in 2019 showed already a very different behaviour in the northern and southern portion of this region, compared to quiet solar conditions (Pierrard et al., 2023).

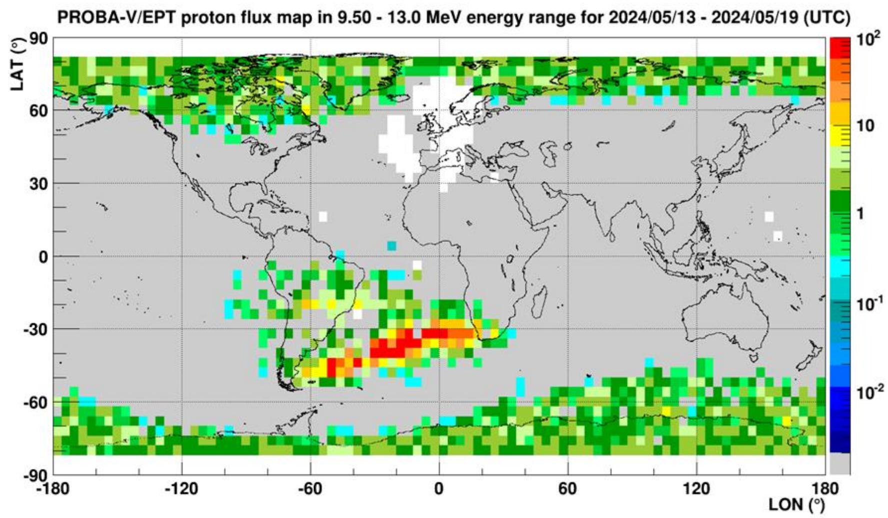


Figure 18: Map of EPT proton fluxes in the energy range 9.5-13 MeV at 820 km averaged in longitude and latitude bins from 13 to 19 May 2024.

GNSS highlights of the Mother's Day Storm 2024

Ionospheric response in Europe - The impact of the strongest geomagnetic storm of the 25th solar cycle -the so-called Mother's Day storm- occurred on 10-11 May 2024 and was investigated using the GNSS (Global Navigation Satellite Systems) observations of about 400 stations from the EUREF Permanent Network (EPN). An analysis of the ionospheric response to this storm was conducted over Europe and showed ionization variations with increases and decreases of the ionospheric Total Electron Content (TEC) up to 20 TECu (TEC units) in comparison to quiet ionospheric conditions. Figure 19 shows the TEC time series at three locations: Northern Europe, above Brussels, and in Northern Africa.

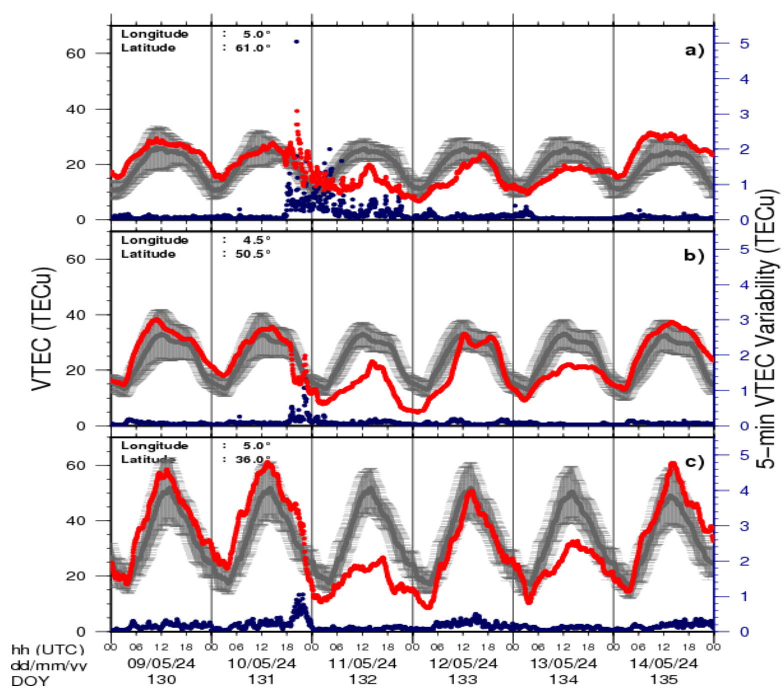


Figure 19: Vertical Total Electron Content (VTEC) time series at 3 locations in Europe from 9 May to 14 May 2024. The panel shows the time evolution of the VTEC (in red) at three locations: a) in the northern part of Europe (61°N, 5°E), b) above Brussels (50.5°N, 4.5°E), and c) in North Africa (36°N, 5°E).

There were positive variations of TEC in the North and South of Europe while they were negative at mid-latitudes, as shown in Figure 20. The top of this figure is a VTEC ("Vertical TEC") map with dots representing the VTEC derived from GNSS data and used for the interpolation. The bottom left map shows the VTEC differences with respect to the quiet ionosphere (15-day median). The bottom right map shows the VTEC variability reflecting the TEC variations during the 5-minute time span of the interpolation. Moreover, we showed that these positive and negative trends were associated with rapid and sudden variations of ionization in the northern part of Europe as the VTEC variability reached up to 5 TECu/5min around 20:20 UTC. This specific event analysis contributed to the paper accepted in 2025 with STCE colleagues from BIRA-IASB and RMI (Pierrard et al. [2025](#)).

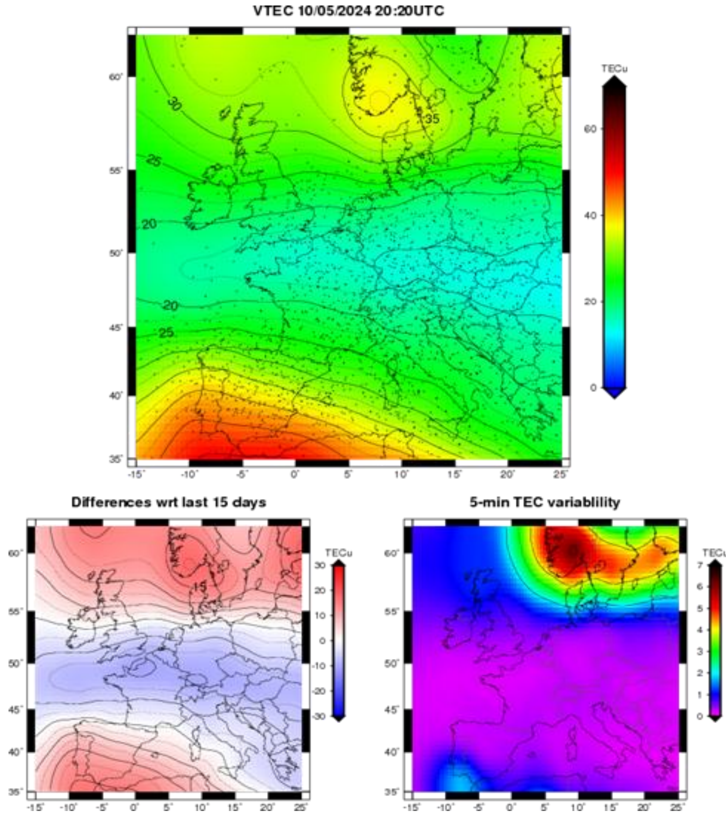


Figure 20: Ionospheric maps produced with ROB-IONO software on 11 May 2024, at 20:20 UTC. Explanations are provided in the text.

Global ionospheric response - During the year 2024, we started to extend our European ionospheric modeling on a global scale, using additional GNSS stations observations from the International GNSS Service (IGS), and by developing a new method ("median polish kriging interpolation") for the ROB-IONO software. This new methodology was applied for the May event and the first results show large enhancements up to 128 TECu with respect to the quiet state. These TEC maps are being developed also in the frame of the H2020 PITHIA-NRF project. This H2020 project aims at building a European distributed network that integrates observing facilities, data processing tools, and prediction models dedicated to ionosphere, thermosphere, and plasmasphere research.

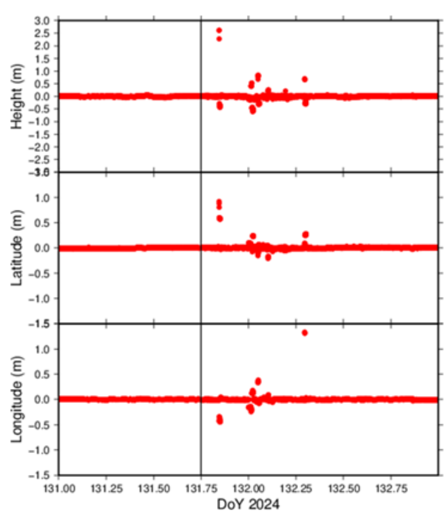


Figure 21: GNSS error positioning in Norway estimated during the 10-11 May 2024 storm (days 131-132) using the PPP-NRCAN online software.

Impact on GNSS positioning - At the user level, the storm impacted GNSS positioning. Figure 21 shows a time series of the position error of a station located in Norway, where the highest TEC variability was observed. GNSS error positioning was estimated using the PPP-NRCAN online software for the 10-11 May 2024 storm (days 131-132). After the arrival of the storm, the map clearly shows errors up to 2.5m in the vertical and 1.4m in the horizontal direction.

Impact on the GNSS data quality - The GNSS team also observed the impact of this storm on the daily ROB GNSS data quality monitoring of the stations of the EPOS network (European Plate Observing System; 2700+ stations). Significant GNSS signal degradations coincided with the geomagnetic storm that occurred on 10-11 May 2024 (Figure 22).

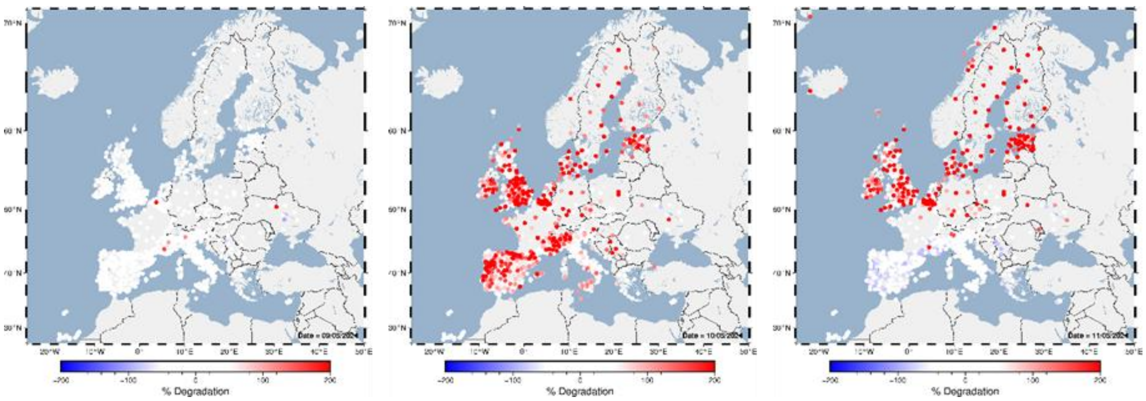


Figure 22: Daily GNSS signal interruptions of the EPOS-GNSS stations during the Mother's day storm, from 9 to 11 May 2024 (from left to right).

Impact of the solar radio burst on GNSS signal reception - Finally, prior to this geomagnetic storm, we also observed solar radio bursts (SRBs) associated with solar flares that occurred on 8 and 9 May. These SRBs were emitted in the range of the GNSS frequency signal bands and naturally jammed the signal reception of the GNSS stations for a few quarterly hours.

Figure 23 shows the evolution of the medians of the abnormal signal reception at the GPS frequencies L1C, L2P (=L1P), L2C and L5C based on observations from about 250 EPN stations during the SRBs of 8 and 9 May 2024. On 8 May, GNSS signal reception fades were observed from 12:00 to 12:15 UTC with a peak at 12:07:30 UTC; the maximum median fade of signal reception was -2.8 dB on the L2P signal, while the maximum fade for a station was of -5.9 dB.

On 9 May, signal reception fades were observed from 08:59 to 10:23 UTC with two peaks at 09:00:30 and 09:40:00 UTC; the maximum median fade of signal reception was -3.8 dB on L2P, while the maximum fade for three stations reached -7.5 dB.

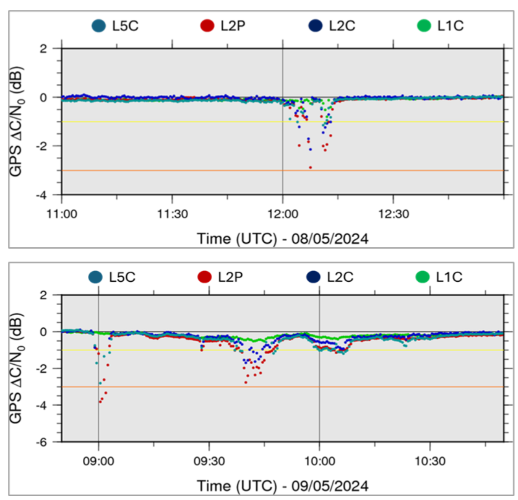


Figure 23: GPS abnormal variations of the signal receptions from the EUREF Permanent Network due to the solar radio burst on 8 May 2024 (top plot) and on 9 May 2024 (bottom plot).

As the head of the ROB/SIDC Space Weather Forecaster team, Judith de Patoul, seated in the middle of the front row, participated in COSPAR ISES 2024 conference that took place in Busan, South-Korea from 13 till 21 July 2024. It combined the 45th Scientific Assembly of the Committee on Space Research (COSPAR) with other associated meetings, such as that of the International Space Environment Service (ISES) that took place on 20-21 July. COSPAR is currently with 13 international scientific unions, 46 national committees as well as over 10,000 associates. The COSPAR assembly is a biennial event that attracts over 3000 participants from all over the world.

Instrumentation and experiments

Launch of the Proba-3 mission

Proba-3 is the most recent mission of the European Space Agency (ESA) in the PROBA (PRoject for OnBoard Autonomy) line of small technology demonstration satellites. Proba-3 is a mission dedicated to the in-flight demonstration of precise formation flying techniques and technologies. The concept of Proba-3 is to place two small satellites in a highly elliptical orbit around the Earth. The bigger spacecraft (coronagraph spacecraft) hosts the optical telescope, and the smaller spacecraft (occulter spacecraft) carries the circular occulting disk. The two satellites fly in a precise formation, producing a very long baseline solar coronagraph called ASPIICS (Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun). During extended periods of time (up to 6 hours), the occulter spacecraft covers the bright solar disk, thus allowing the dimmer corona to be seen by the coronagraph spacecraft, similarly to observations of a total solar eclipse. Such artificial eclipses could be produced regularly (twice per week on average).

In order to observe the corona, the two spacecraft must keep the precise position and orientation (i.e. "fly in formation") with respect to each other and to the Sun. During coronal observations, the distance between the two spacecraft is around 144 meters, and the precision of their alignment is around one millimeter (!). This allows blocking the bright light of the solar disk to observe the corona in eclipse-like conditions, i.e. close to the solar limb and with very low straylight.

Figure 24: The two Proba-3 spacecraft are seen mounted on top of the upper stage of the PSLV-XL launcher, in one of the last photos taken before the rocket fairing was closed. Satish Dhawan Space Centre, Sriharikota, India, 29 November 2024.

Proba-3 is also a Mission of Opportunity in the ESA Science Programme. The ASPIICS observations provide data that are crucial for solving several outstanding problems in solar physics, namely the origin of the solar wind and the mechanism behind coronal mass ejections. ROB hosts the Principal Investigator of ASPIICS who leads the international science team and prepares the data exploitation. The ESA Science Programme funds the ASPIICS Science Operations Centre (SOC) located at the ROB. The SOC is responsible for daily operations of ASPIICS, i.e. preparing observational commands, processing the downlinked data in the science pipeline, and making the data accessible to the science community.

Proba-3 was successfully launched on 5 December 2024 from the Satish Dhawan Space Centre in Sriharikota, India, aboard the Polar Satellite Launch Vehicle (PSLV-XL) of the Indian Space Research Organization. The launch was attended by the members of the Proba-3 Science Working Team, who also held their 10th meeting at the SRM Institute of Science and Technology in Chennai, India, on 5-6 December 2024.

Proba-3 is currently in the commissioning phase, when different systems of the two spacecraft and payload are being verified and fine-tuned.

Figure 25: The PSLV-XL rocket launched the Proba-3 mission on 5 December 2024 from the Satish Dhawan Space Centre, Sriharikota, India.

SIMBA returns to Earth

SIMBA was one of four ESA Technology CubeSats that burned up in the Earth's atmosphere during the summer of 2024. SIMBA and the other CubeSats were deployed at low altitudes, so their orbits naturally decayed over time.

The SIMBA (Sun-earth IMBAlance) CubeSat, was developed for ESA by a consortium led by the RMI with support from the STCE. It was launched in September 2020 and returned from space on 14 August 2024. SIMBA used a high-precision attitude determination and attitude control system based on an experimental star tracker camera and reaction wheels.

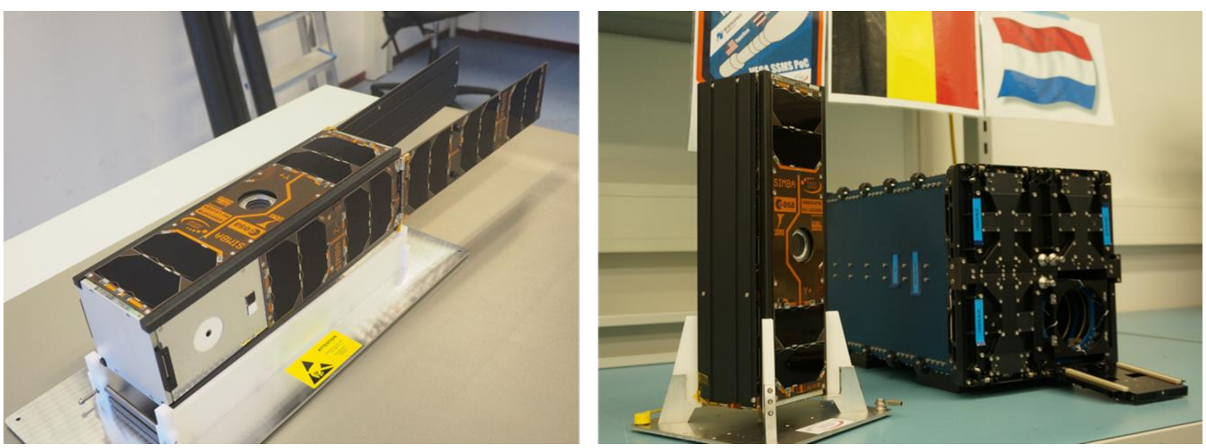


Figure 26: (left) The finished satellite with open solar panels as it looked in space. Only the antennas are still stowed away. (right) SIMBA just after final preparation for flight.

Based on radiation measurements through radiometers, SIMBA's goal was to estimate the radiation balance of our planet. The radiation balance gives the amount of energy our planet retains rather than reflecting or radiating away and is one of the fundamental drivers of climate change. Fitting a radiometer aboard such a small satellite proved challenging, and some features of conventional radiometers were omitted, requiring additional work in data processing,

On two occasions, the SIMBA consortium received positive evaluations of its mission goals by the European Space Agency, as well as the accompanying recommendation to extend the mission. This quadrupled the mission duration from its initial six months to more than two years. During this extra time, the satellite received a number of upgrades to its software to significantly improve targeting precision and download more scientific data, among other things.

"The build and mission were quite a challenge for the small team at the RMI, but we learned a lot and that will translate into better instruments on the ground in the near future," says Dr. Stijn Nevens, principal investigator for the mission. "It feels weird not having SIMBA in the sky anymore!"

ASIS, the Auroral Spectrograph In Skibotn: 1.5 years of observations

Auroras are the most spectacular display of the complex interactions between the solar wind and the Earth's magnetosphere and ionosphere. They are usually studied using radar and/or optical observations. Most of the optical instruments use cameras and narrow or RGB (red, green and blue) filters providing an accurate view of the phenomenon but at specific wavelengths (or for specific emission lines). There are very few auroral spectrographs worldwide, able to simultaneously cover many auroral emission once in a large wavelength range. There are the MISS2 (The Meridian Imaging Svalbard Spectrograph) and ASG (Auroral SpectroGraph) instruments in Svalbard (located inside the polar cap), two TREx (TRansition Region Explorer) spectrographs in Canada (one in the auroral oval and one equatorward), and an additional spectrograph at the ZhongChen Chinese station in Antarctica. Therefore, there was a need for such an auroral spectrograph inside the auroral oval in Scandinavia. Moreover, such an instrument can also help shed light on the recently discovered mysterious continuum auroral emissions associated with strong dynamical aurora.

Figure 27: Aurora captured above the astronomical dome of the Skibotn observatory, in Norway. Credits: Gaël Cessateur

For all these reasons, we have set up in October 2023 the ASIS (Auroral Spectrograph In Skibotn) instrument at the Skibotn observatory, as a collaboration between BIRA-IASB (Belgium) and IPAG (France), which funded the instrument, and UiT (Norway) who is hosting it.

ASIS is using a small astronomical lens pointing along the local magnetic field line to capture auroral light within a circular field-of-view of 4 degrees (see Figure 28 left). The light is directed inside an optical fibre and focused on the adjustable slit of a spectrograph equipped with a turret containing 3 gratings. The selected grating splits the incoming light and produces an auroral spectra onto a CCD camera cooled with a Peltier.

Since October 2023, ASIS has continuously acquired data without any failure despite the harsh Arctic conditions. It is fully automated, starting and ending observations respectively after sunset and before sunrise. It is also controllable remotely which allows to modify e.g. the choice of grating, the exposure time or even the slit width. So far, data have been obtained with a 300 lines/mm grating and a slit width of 100 μm providing a spectral range from roughly 400 to 700 nm with a spectral resolution of about 0.3 nm. ASIS has been calibrated on-site in February and October 2024 using lamps calibrated at the B.RCLab (https://brclab.aeronomie.be). Data are automatically transferred every day and archived at BIRA-IASB. After calibration, they become available on a dedicated website (https://asis.aeronomie.be).

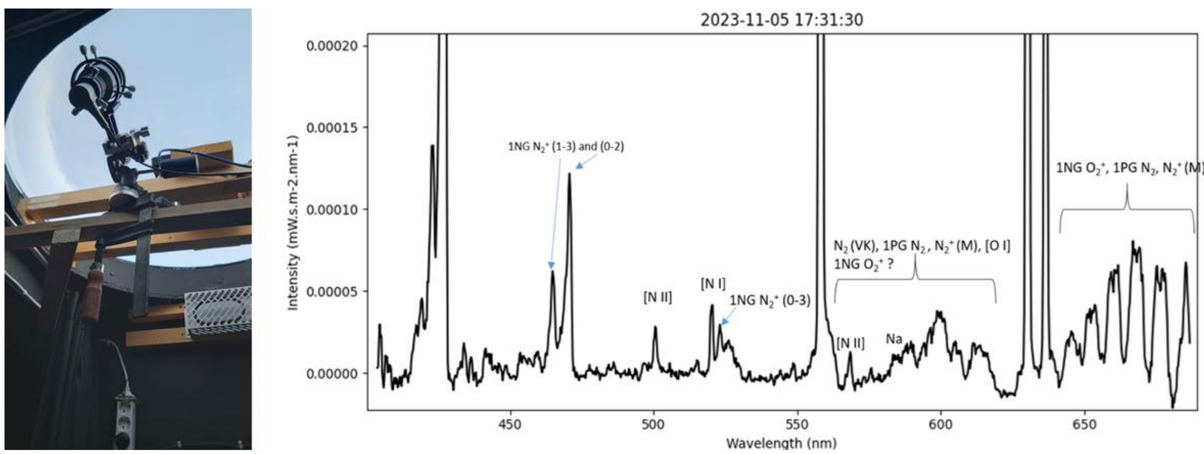


Figure 28: (left) The small astronomical lens used to capture auroral light and inject it into our spectrograph and CCD camera is located at the Skibotn observatory, Norway. Here, the view is from inside the dome. (right) An example of a spectrum obtained with ASIS on 5 November 2023 during a geomagnetic substorm. The intensity scale has been adapted such that all the smaller emission lines and bands are clearly visible and some of them have been annotated.

An example of a spectrum obtained with ASIS during a geomagnetic substorm is shown in Figure 28 (right). It demonstrates the richness of the spectrum in addition to the strongest usual auroral emission lines at 427.8 nm (blue), 557.7 nm (green), and 630.0 / 636.4 nm (red). A zoom on the intensity (vertical) scale was made to make the additional emission lines and bands clearly visible.

ASIS is currently the only spectrograph located in the auroral oval in Scandinavia. Moreover, the Skibotn observatory is located only 2 km from the main site of the future EISCAT_3D radar facility. ASIS will therefore provide extremely valuable and complementary data to the future radar observations and to other optical instruments located nearby, opening the possibility for many collaborations.

A new window for auroral observations

The observatory in Skibotn, Norway, is a prime location for monitoring the auroral activity. Installed in October 2024, the Polar Light Imager (PLI) can be remotely controlled from Belgium to capture high-resolution images of the aurora. Equipped with multiple narrow-band filters targeting key auroral spectral lines, PLI plays a crucial role in studying the dynamics of the aurora. Analysing these images provides valuable insights about the properties of the precipitating electrons, responsible for these captivating northern lights.

The northern lights are one of the most striking manifestations of the Sun-Earth connection. Electrons from the solar wind can become trapped and accelerated within Earth's magnetosphere before precipitating into the atmosphere. When this happens, atomic oxygen emits light at 557.7 nm and 630 nm, producing green and red auroras, respectively. Additionally, ionized nitrogen (N_2^+) emits at 427.8 nm, generating blue auroras at lower altitudes.

To monitor auroral activity, BIRA-IASB has developed various instruments. In collaboration with the University of Tromsø, the Polar Light Imager (PLI) was installed in October 2024. This system uses commercial cameras equipped with wide-field lenses and narrow-band filters specifically designed for this experiment. PLI captures auroral images in the three main spectral lines associated with the northern lights. Furthermore, a fourth camera, fitted with an H-alpha filter, is used to detect proton auroras. When protons from the solar wind precipitate into Earth's atmosphere, they can recombine with electrons, forming excited hydrogen. This process leads to emissions in the H-alpha and H-beta spectral lines.

Figure 29: PLI instrument installed under a dome at the Skibotn Observatory, Norway.

Beyond capturing mesmerizing images, PLI plays a crucial role in determining key parameters of precipitating electrons, such as their mean energy and flux. To achieve this, electron transport models like Trassolo and Aeroplanets are used to generate look-up tables based on the ratios of spectral line emissions—for example, the red emission at 630 nm relative to the blue emission at 427.8 nm.

Using artificial intelligence, the images will soon be classified into different auroral categories, such as steady arcs, discrete auroras, and diffuse auroras. Each category corresponds to a different phase of geomagnetic storms and substorms. These images will also be integrated into a large database to support the reconstruction of auroral volume emissions using tomography techniques.

New insights in the ozonesonde instrument from simulation chamber experiments

Although developed half a century ago to measure the vertical distribution of ozone in the atmosphere, the ozonesonde instrument has not revealed all its secrets yet. This lightweight instrument is carried by a weather balloon, and consists of a pump that brings the air into electrochemical concentration cells (ECC), filled with sensing solutions that react with the ozone molecules in the atmosphere. The ECC ozonesonde, in principle an absolute measuring device, encounters in the course of its flight several imperfections, e.g. changing pump and chemical conversion efficiency, that need to be corrected for. One of the major challenges of ozonesonde observations is that each ozonesonde instrument is unique, is typically launched only once and must be carefully prepared prior to launch in order to obtain accurate data.

Processing of the final measurements is carried out using certain parameters determined during pre-launch. In addition, there are two manufacturers of ozonesondes that show systematic offsets relative to each other. Further biases in ozonesonde datasets can occur because three variants of the sensing solution that produce the ECC current signal from the ozone are currently in use.

One key element in the global standardisation and quality control/quality assessment of the ozonesonde measurements was the establishment of the World Calibration Center for Ozone Sondes (WCCOS) with a custom-designed Environmental Simulation Facility (ESF) at the Forschungszentrum in Jülich, Germany, in 1995. The ESF consists of an absolute ozone measuring reference, i.e. a fast response (2 seconds), very accurate (2 %-3 %) dual-beam UV-absorption ozone photometer (OPM), that is attached to the chamber that enables control of pressure, temperature and ozone concentration simulating flight conditions of an ozone sounding at up to 35 km over about 2 hours. Up to four ozonesonde instruments at once can be intercompared through this process. Since 1995, nine Jülich Ozone Sonde Intercomparison Experiment (JOSIE) campaigns have been conducted in the simulation chamber at Jülich.

In a recent study (Smit et al. 2024), data from all these campaigns were for the first time analysed all together, and complemented with some dedicated laboratory measurements in Uccle. The paper provides experimental evidence that the ozonesonde response (i.e. chemical reaction pathways) is driven by a dominant fast component (with a time constant of 20 to 25 seconds) and a slow component (around 25 minutes) that is dependent on the post ozone exposure. On top of that, the ozone sensor signal seems to have a constant ozone-independent background current. In the paper, a new methodology of data processing has been developed that resolves both the time responses of the slow and fast components, uses the real measured pump efficiency correction factors, and refers via calibration functions the measurements to one common standard, i.e. the photometer in the simulation chamber in Jülich.

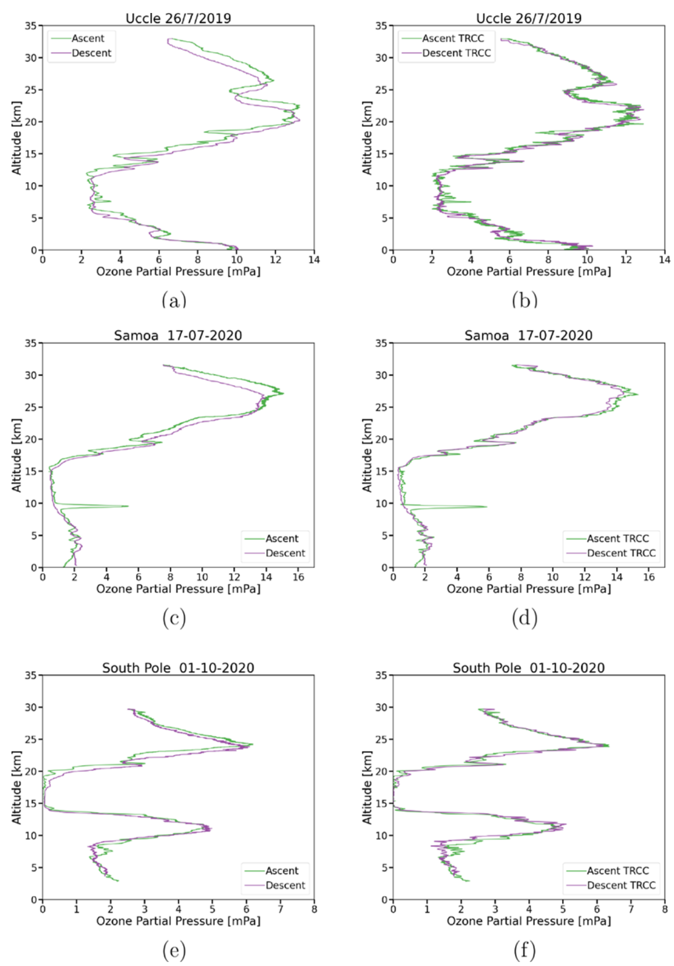


Figure 30: Comparison of vertical ozone profiles obtained during ascent (solid green line) and descent (solid purple line) at three different ozone sounding stations (Uccle, Samoa, and South Pole) by applying the conventional method (a, c, e), and the new TRCC method (b, d, f).

An illustration of the new methodology, TRCC (Time Responses Correction & Calibration), in comparison with the conventional method is shown in Figure 30. It should be clear that the agreement between the ascent and descent profiles is much improved after applying the new method, and this is the case for the three different sites. The TRCC figures are remarkable in amplifying the features after correcting for the fast time constant.

The new methodology should now be implemented and tested in a wider range of ozonesonde measurements and compared with other, independent, ozone profile measuring techniques before replacing the conventional data processing.

Radiometric and thermal-vacuum characterisations at B.RCLab

The D42 section of BIRA-IASB has a long-standing involvement in solar irradiance measurements and radiometry through international collaborations, for example during the SOLSPEC (for SOLar SPECtrum) project in collaboration with the LATMOS (France). This space-qualified spectroradiometer contributed to the dissemination of reference solar spectra. More recently at B.RCLab (the so-called "Belgian Radiometric Characterization Laboratory" located at BIRA-IASB - https://brclab.aeronomie.be/), UV-VIS sensors and a NIR detectors were characterised, respectively for the LATMOS CubeSat INSPIRE-SAT 7 and the important MAJIS/JUICE project.

In 2024, a new campaign took place for a significant space mission. We characterised the flight model of a miniaturized near-infrared (NIR) spectrograph for UVSQ-SAT NG, a 6U CubeSat developed by LATMOS and the Université de Saint-Quentin-en-Yvelines (UVSQ) dedicated to studying Earth's radiation budget. The spectrograph equipped with InGaAs (Indium gallium arsenide) is designed to measure greenhouse gas concentrations in the 1.2 µm - 2 µm wavelength range.

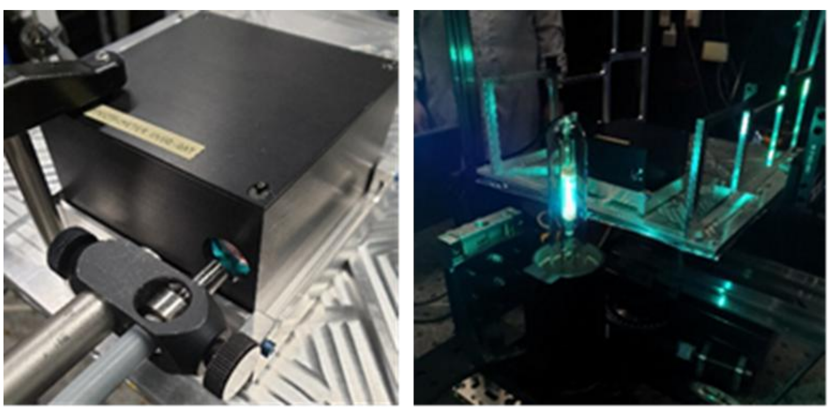


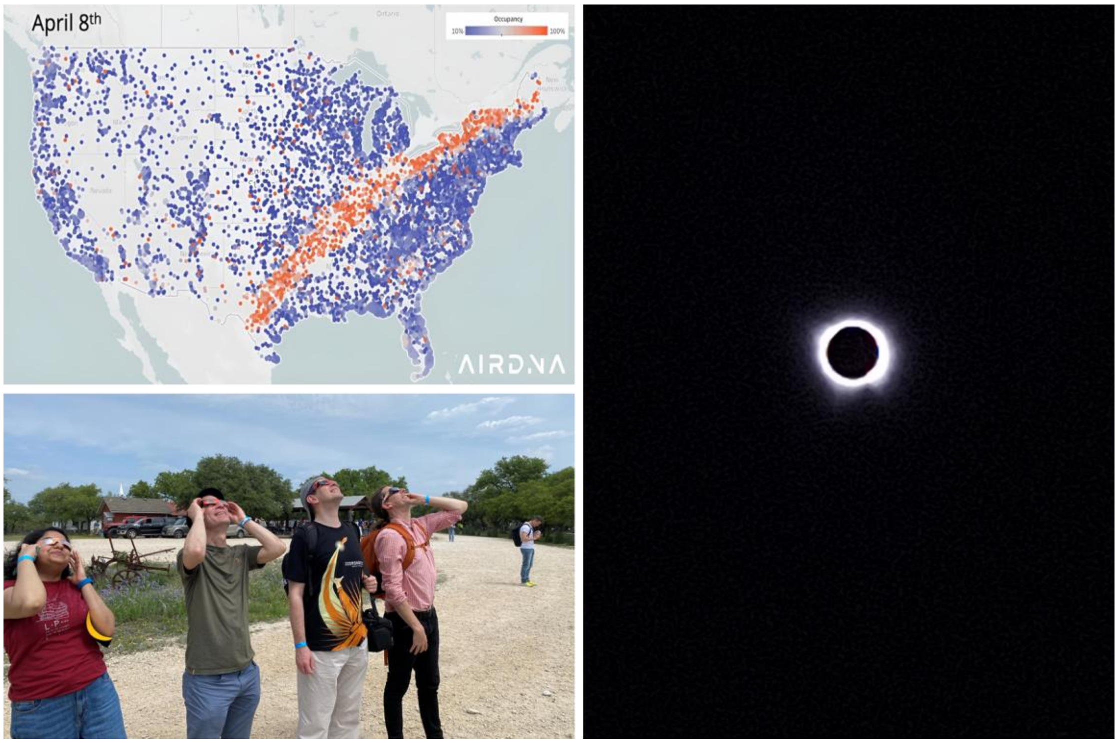
Figure 31: The NIR spectrograph of UVSQ-SAT NG and its wavelength calibration using spectral lamps.

The B.RCLab played a major role in its radiometric characterisation, focusing on key parameters such as the wavelength scale calibration, the measurement of instrumental function, the absolute calibration and mapping the operability of the spectrograph NIR detector. A full radiometric characterisation of a spectrograph must indeed include the analysis of the instrument spectral resolution and the accurate identification of the wavelength band covered by each detector pixel. The absolute radiometric calibration was performed using standards lamps of spectral irradiance to determine the conversion between the detector raw electronic signal in physical radiometric units.

In parallel, we worked in 2024 on the upgrade of the thermal-vacuum (TVAC) facility that was developed for the MAJIS/JUICE project. The new objective was to make it operational for radiative cooling of payloads. Up to now, a cooling cycle was only possible by conduction using copper thermal links between the cold head of the cryocooler and the DUT (Device Under Test). A cold box is now integrated in the chamber. The base plate and all panels of this box are thermally connected to the cryocooler head. These panels are used as shrouds for radiative cooling down to at least -100 °C. This new configuration is under validation. This upgrade is required for a thermal-vacuum characterisation campaign scheduled for 2025 for COMPLIMENT. This instrument is a spherical Langmuir probe, part of the Comet Interceptor mission, the F-class mission of ESA Science Programme designed to visit a comet (target launch date by 2029). The COMPLIMENT probes will be subject to strong temperature variations when changing from an illuminated to a shadowed state. The reason is a very little conductive coupling between the probe and the spacecraft platform. The goal of the thermal cycling test will be to identify whether the probes can tolerate such temperature fluctuations. For that purpose, the probe will be tested in simulated space conditions (vacuum, cryogenic temperatures) and illuminated through viewports using a solar simulator light source.

Figure 32: View of the cold box panels representing the new internal configuration of the TVAC.

In parallel to COMPLIMENT, the B.RCLab team prepares the next involvements in space projects: VenSpec-H/ENVISION and SoSpIM. In both cases, the thermal vacuum chamber will be also used in a dedicated configuration. The current laboratory equipment is compatible with the requirements for flight model characterisation, concerning the safety and cleanliness (ISO-5 environment) for example.



The solar eclipse of 8 April 2024 - Upper left: AirDNA, a company that analyses short-term rental data, produced a map of Airbnb occupancy data along the path of the total solar eclipse in the United States. The visualization shows the higher occupancy rates in red along the path of totality and lower occupancy rates in blue. American cities in the 2024 solar eclipse path saw rental occupancy rates increase to 88%, showing the growth in demand for housing during the rare event. Credits: @airdna.co Lower left: As it happened, several conferences took place in cities along the eclipse path exactly during that week. Several scientists from the ROB/SIDC were able to observe the eclipse from San Antonio, Texas. Credits: David Berghmans. Right: Grégory Vanden Broeck (SIDC/SILSO) was able to capture this image during totality from a location near Dallas, Texas.

Applications, modeling and services

Providing access to data, tools and models with PITHIA

Summary *- The PITHIA-NRF project stands for Plasmasphere Ionosphere Thermosphere Integrated Research Environment and Access services: a Network of Research Facilities (https://pithia-nrf.eu/). After 4 years of work, its e-Science Centre (https://esc.pithia.eu) provides formalised open access to experimental facilities, data and models, standardised data products and training services to support scientific research on the plasmasphere - ionosphere - thermosphere system.*

Figure 33: Logo of the PITHIA-NRF H2020 project

The project - PITHIA-NRF is a Research Infrastructure project funded by the Horizon 2020 Programme of the European Commission. Launched in March 2021 with a duration of four years, the project brings together 22 partners. Among them, 12 participating organisations across 11 European countries operate experimental facilities, known as nodes. These nodes focus on optimising their observing facilities and offer transnational access (TNA) to scientists and engineers, through eight calls issued over the course of the project.

Figure 34: The PLIP instrument installed in the main dome of the Skibotn observatory in Norway during the November 2022 PITHIA-NRF TNA campaign. (Credits: Gaël Cessateur)

PITHIA-NRF integrates key national and regional research infrastructures at the European level, including EISCAT (European Incoherent Scatter Scientific Association), LOFAR (Low-Frequency Array), ionosondes and digisondes, GNSS receivers, Doppler sounding systems, riometers, and VLF receivers. These tools help scientists better understand space weather and its effects on our planet.

The e-Science Centre - The e-Science Centre is a core element of the project. Its architecture and ongoing development are controlled by a systematic ontology that governs the collection of scientific observations and research models, collectively referred to as data collections. Dozens of data collections have already been registered, in accordance with the FAIR principles (Findable, Accessible, Interoperable, and Reusable). The e-Science Centre facilitates the execution of research projects initiated by researchers from within and outside the PITHIA-NRF consortium. These projects often require access to, and understanding of, data collections - comprising observations and models - residing at one or several PITHIA-NRF nodes (see Belehaki et al. 2025).

BIRA-IASB participation - BIRA-IASB is an active consortium partner in this project. In February 2024, the team co-organised the second training school in Leuven, in collaboration with KU Leuven (web page). BIRA-IASB scientists contribute by providing access to Cluster/WHISPER electron density data in the plasmasphere as well as very low frequency (VLF) whistler data. They also offer the possibility to run a plasmaspheric model directly on the e-Science Centre (model access).

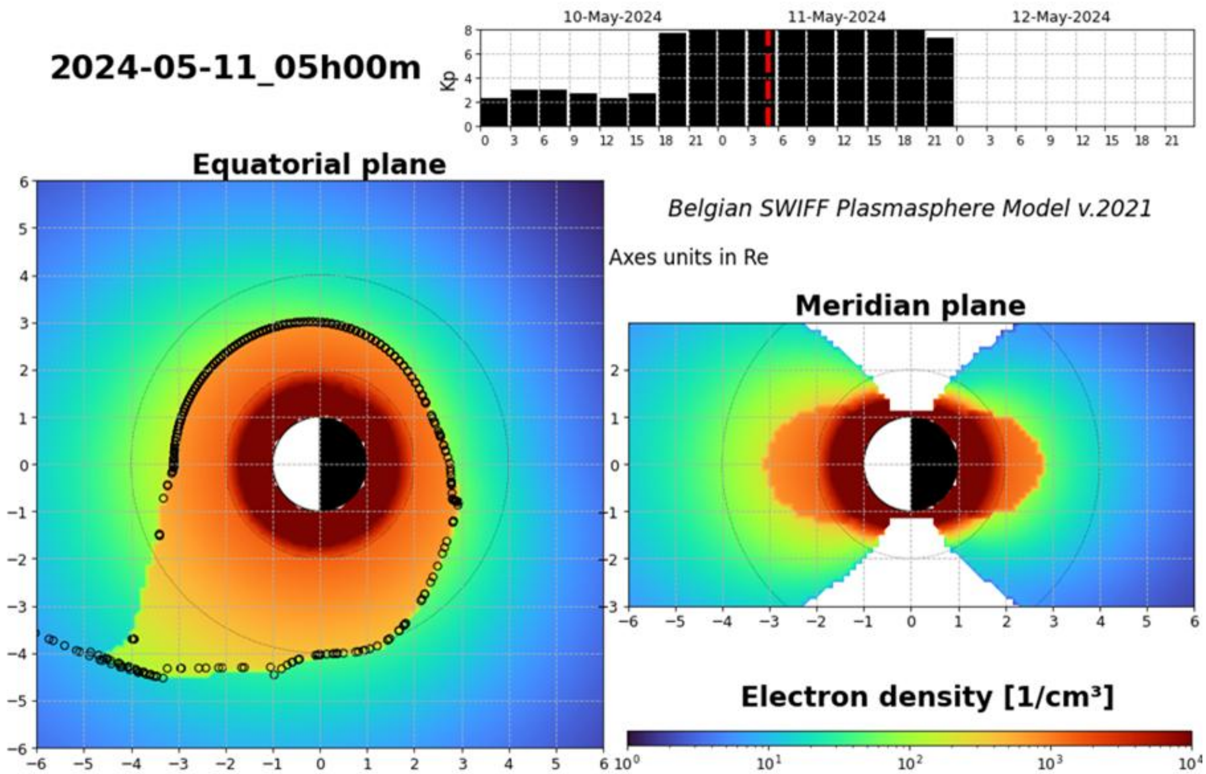


Figure 35: Electron density obtained with the BSPM plasmasphere model (Pierrard et al. 2021) coupled to the ionosphere on 11 May 2024 at 5:00 UTC after the very big Mother's Day geomagnetic storm. The plasmasphere (orange region) is illustrated in the equatorial plane (left) and in the meridian plane (right). The Bartels geomagnetic index K_p from 1 day before to 1 day after the simulated day is shown in the top panel, with a red dashed line to indicate the exact illustrated time. BSPM is the Belgian Space Weather Integrated Forecasting Framework (SWIFF) Plasmasphere Model (Credits: Viviane Pierrard)

Additionally, a group of researchers at BIRA-IASB requested and successfully obtained observation time from the EISCAT node through a TNA call. The goal was to combine measurements from their instrument, the Polar Lights Imaging Polarimeter (PLIP), with data from EISCAT. During a 10-day observation campaign in November 2022 with PLIP at the Skibotn Observatory in Norway, the team obtained 8 hours of EISCAT observations. While PLIP measured the degree and the angle of linear polarisation of the three main auroral emissions (green, red and blue) across a wide field of view, EISCAT provided complementary data from its ultrahigh frequency (UHF) antenna in Tromsϕ, located approximately 50 km from Skibotn. Unfortunately, poor weather conditions in Sweden prevented additional optical observations from the ALIS_4D camera network.

REENOM: Radiation Environment & Effects NOwcasts for the Moon

Summary *- The Space weather group at BIRA-IASB coordinates one of the four International Science Teams that have been granted early access to data from the European Radiation Sensor Array and the Internal Dosimetry Array instruments on the Lunar Gateway, in the framework of the international Gateway Heliophysics and Space Radiation Working Group. The REENOM team focuses on improving the understanding of the lunar radiation environment and its impacts on both hardware and humans. A service will be developed to provide timely and accurate space weather information.*

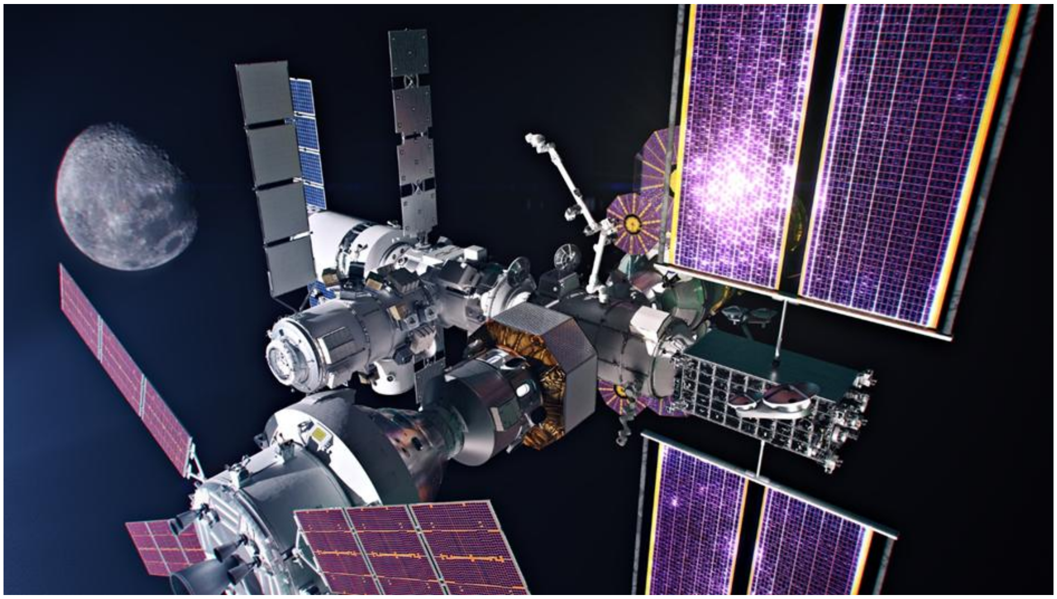


Figure 36: An artist's concept of the Gateway space station orbiting the Moon. Credits: NASA

A unique vantage point in deep space - The Gateway space station will offer an opportunity to study extensively the dynamical space environments inside and outside the Earth's magnetosphere, as well as in the vicinity of the Moon. In particular, the European Radiation Sensor Array (ERSA) will provide continuous measurements of the radiation environments due to the Solar Energetic Particles (SEP) and the Galactic Cosmic Rays (GCR). At the same time, the Internal Dosimetry Array (IDA) will provide radiation levels inside the Gateway.

Understanding the changing radiation environment around the Moon and at the Gateway - The Radiation Environment & Effects NOwcasts for the Moon (REENOM) team, led by the BIRA-IASB Space weather group, is one of the four International Science Teams that have been selected in the framework of the international Gateway Heliophysics and Space Radiation Working Group and will be given early access to the ERSA and IDA data.

Our scientific objective is to improve the current knowledge of the relevant radiation environments and their effects. The first task will be to derive high-quality intercalibrated particle fluxes from the provided measurements. In turn, we will use those data to investigate the influence of the dynamic magnetosphere on the SEP propagation.

Moreover, we will use the data from ERSA and IDA to study the radiation impact on biological and technological systems in deep space. Having a better view on the radiation exposure could help us to develop new radiation-resistant materials for shielding and spacecraft structures.

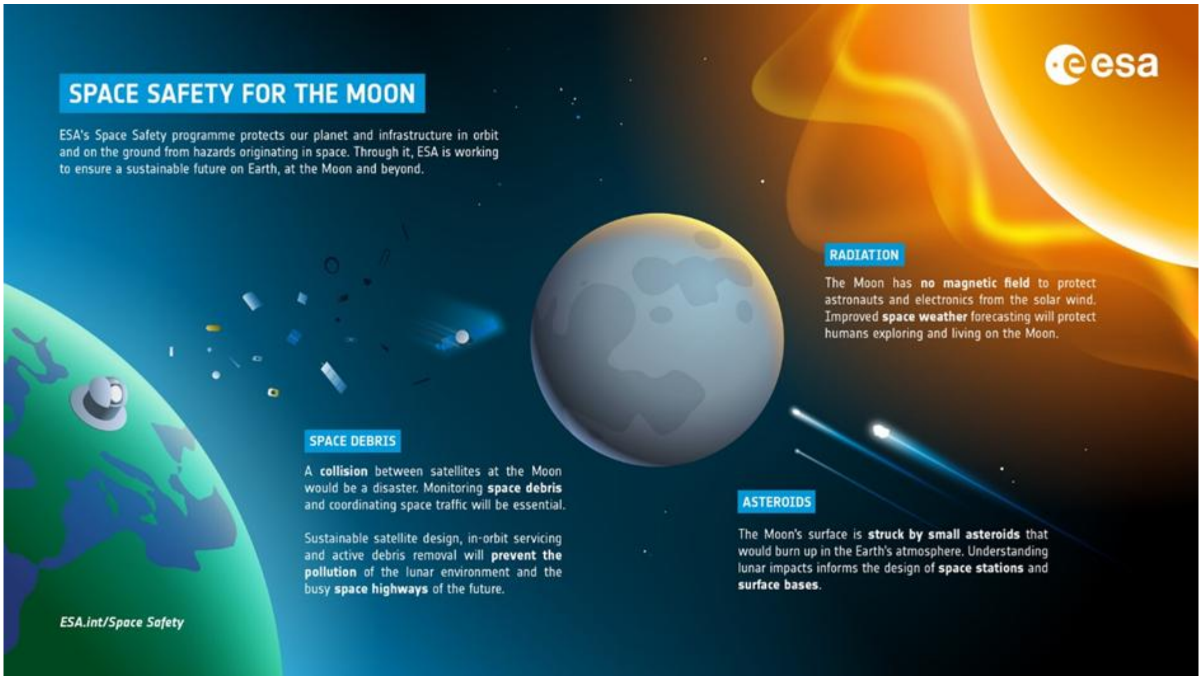


Figure 37: Infographic showing the environmental hazards in the lunar environment including space radiation, space debris and asteroids. Credits: ESA

Developing a timely space weather service - The ultimate goal of this activity is to provide timely and accurate space weather information and warnings for the Gateway and the lunar surface. By analysing radiation patterns, ERSA data can contribute to early space weather forecasts. Such information will be crucial for operational decision making to ensure astronaut safety during future lunar missions and beyond.

Iterated-Tikhonov regularisation of ASIMUT retrieved profiles

Remote sensing is an excellent way to gather geological and atmospheric parameters over large coverage areas. Atmospheric parameters derived from remotely sensed measurements often need complex radiative transfer computations, further complicated by the fact that the parameters are usually smoothed within the measurement. In practice, a small error in the measurements can produce a relatively much larger error in the derived parameter. Regularisation or smoothing of the parameter is often required to avoid unrealistic solutions. A compelling regularisation method was proposed in Quémerais et al. (2006), used in several dozen papers since then, and is now available within the ASIMUT package. ASIMUT is short for "Atmospheric Spectra Inversion Modular Utility Tools". It is a radiative transfer and inversion software developed by the Belgian Institute for Space Aeronomy (BIRA-IASB).

The method used within the ASIMUT package is the "iterated-Tikhonov" method. It is a technique for solving ill-posed problems that iteratively refines the solution obtained from standard Tikhonov regularization. It applies Tikhonov regularization multiple times, using the result of one iteration as the starting point for the next, which can lead to a more accurate solution, especially in the presence of noisy data. This technique is often used in inverse problems, such as image deblurring. Thus, the iterated-Tikhonov method has the advantage of improving the accuracy of the regularisation in the presence of noise, and fine-tunes the regularisation without needing any a priori knowledge of the uncertainties on the parameter to be retrieved. This algorithm is currently used for the retrieval of Mars atmospheric parameters from measurements from the NOMAD instrument on board the ExoMars Trace Gas Orbiter (TGO), a collaborative project between the European Space Agency (ESA) and the Russian Roscosmos agency (Trompet et al. 2023). However, it can be used for any profile retrieved with ASIMUT.

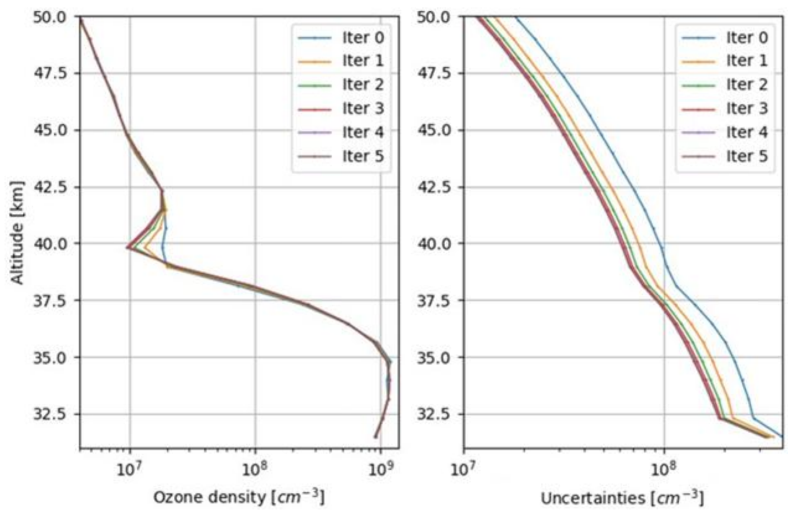


Figure 38: Left panel: an example of regularised profiles with the iterated-Tikhonov method for an ozone density profile derived from NOMAD/TGO. Each profile corresponds to one step of the algorithm. Further iteration improves the smoothing of the profile and the separation between the two layers of ozone. Right panel: Variation of the uncertainties associated with the derived profiles in the left panel.

CONIOPOL: identifying aerosols in real time with a pioneering algorithm

In recent years, there has been an increase in the intensity and frequency of smoke plume events over North America (sometimes reaching Europe) and dust plume events reaching Europe from Africa. As these can potentially affect surface air quality, environmental agencies are increasingly interested in being able to identify the nature of aerosol plumes, monitor it in real time and determine whether its interaction with the atmospheric boundary layer will impact surface air quality. The automatic LIDAR-ceilometer (ALC) primarily designed for cloud base height detection has greatly improved over the last years and now provides vertical profiles of backscatter from aerosols and clouds. Recently, a new type of ALC with a depolarization function (VAISALA CL61) is commercially available for distinguishing cloud phase (which is useful for weather forecasting) and also makes it possible to support the type identification of aerosols.

The CONIOPOL algorithm is a pioneering algorithm developed at the Royal Meteorological Institute of Belgium (RMI) that uses polarization LIDAR (VAISALA CL61) data to automatically and in real time identify the phase of clouds, types of precipitation, and types of aerosols. It combines the concepts of "CONIOlogy" (cloud, precipitation, and aerosol) with "POLarisation" to analyse backscatter and depolarization profiles from the CL61 instrument, providing an operational tool for atmospheric monitoring and forecasting by detecting and monitoring aerosol plumes and identifying other atmospheric phenomena. CONIOPOL cannot provide an independent and unambiguous identification of the aerosol type based only on CL61 operates on a single wavelength. Nonetheless, CONIOPOL is a very useful operational support allowing a quick identification in real time of the type of aerosols in combination with forecasts and backward trajectories models.

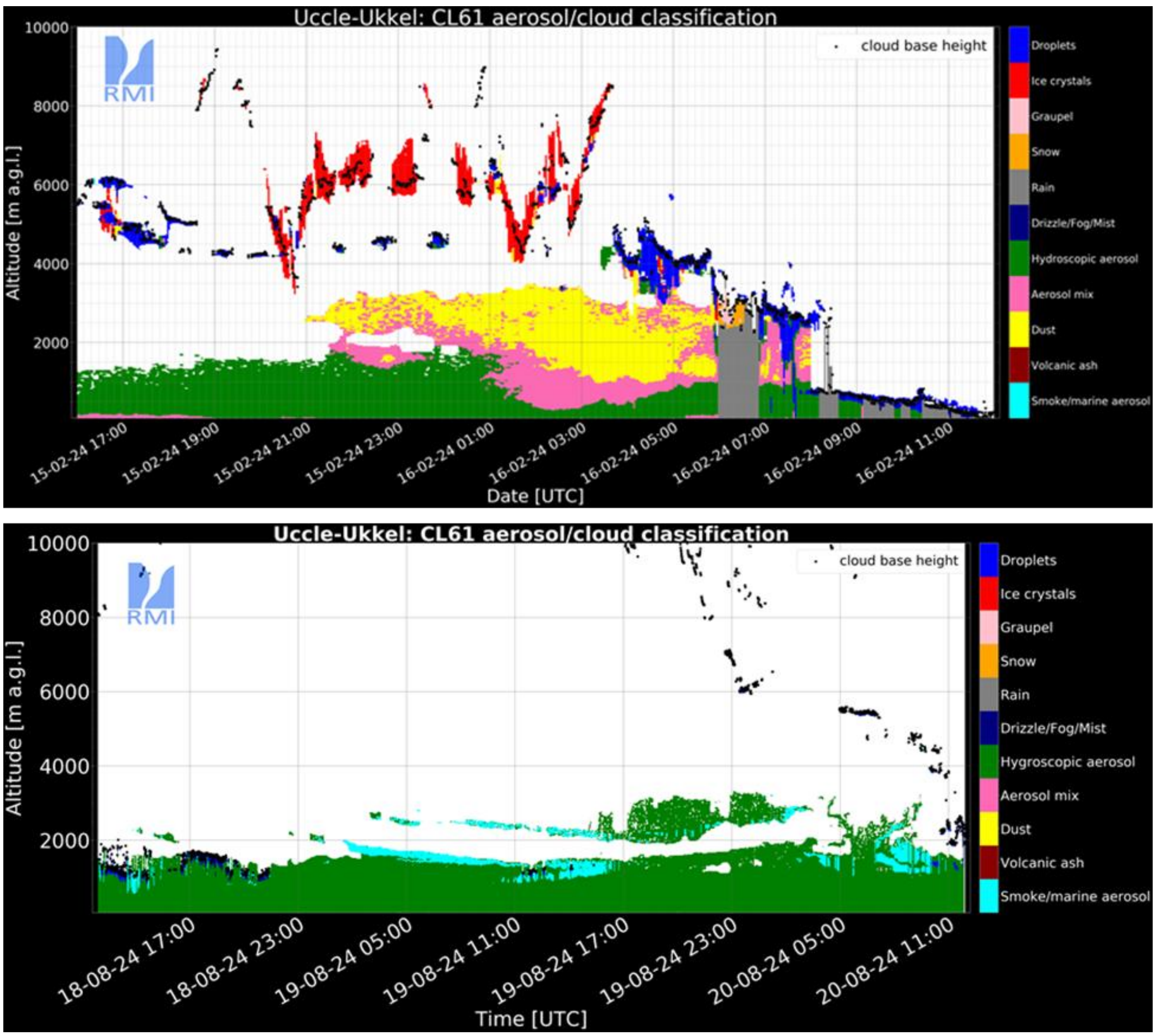


Figure 39: Example of output of CONIOPOL with the classification of aerosol type, cloud phase and precipitation type in function of the altitude and in function of the time. (upper panel) In yellow, detection of dust plume coming from Sahara. (lower panel) In cyan, detection of smoke plume coming from wildfires in Canada.

Participants and lecturers in this very international April 2024 edition of the Space Weather Introductory Course ([SWIC]). Selfie by Junghee Cho from the Korean Space Weather Center.

Publications

This overview of publications consists of three lists: the peer-reviewed articles, the presentations and posters at conferences, and the public outreach talks and publications for the general public. It does not include non-refereed articles, press releases, the daily, weekly and monthly bulletins that are part of our public services,… These data are available at the [STCE website] or upon request.

Authors belonging to the STCE have been highlighted in the list of peer-reviewed articles.

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Electrostatic Bursts Generated by the Ion-Ion Acoustic Instability with Solar Wind Plasma Parameters
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Presentations and posters at conference

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2. Alonso Tagle, M.L.
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Belgian Physical Society general scientific meeting, VUB, Brussels (Belgium), 29 May 2024

3. Al Qaaod, A.; Papayannis, A.; Krasniqi, F.; Tsaknakis, G.; Finta, V.; Pierrard, V.; Mylonaki, M.
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4. Auchère, F.; Rebellato, J.; Zhang, X.-Y.; and 12 others, and the EUI team
Pre-flight calibration of the Full Sun Imager on board Solar Orbiter
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5. Bamahry, F.; Legrand, J.; Bruyninx, C.; Pottiaux, E.
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6. Barczynski, K.; Harra, L.; Janitzek, N.; Berghmans, D.; Verbeeck, C.; Zhukov, A.N.
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7. Barczynski, K.; Rodriguez, L.; Shukhobodskaia, D.; Harra, L.; Berghmans, D.; Warmuth, A.; Schuller, F.
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8. Bechet, S.; Vanden Broeck, G.; Clette, F.; Rauw, G.
The plage time series from various viewing angles: impact on temporal modulation detection
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9. Bechet, S.
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10. Berghmans, D.; Lim, D.; Petrova, E.; Zhong, S.; Shrivastav, A.K.; Mandal, S.; Kraaikamp, E.; Verbeeck, C.; Stegen, K.; Zhukov, A.N.; Gissot, S.; Van Doorsselaere, T.
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11. Berghmans, D.; and the EUI team
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12. Berghmans, D.; Zhukov, A.N.; Verbeeck, C.; Lim, D.; Kraaikamp, E.; Auchère, F.; Andretta, V.
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17. Berghmans, D.
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18. Berghmans, D.
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19. Berghmans, D.; Kraaikamp, E.
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20. Bhattacharya, S.; Lefèvre, L.; and the USET team, HUMAIN team and SWOP team
Space Weather Cooperation in the context of ground based Observational Data at the SIDC
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21. Bolsée, D.; Winant, A.
BIOSPHERE an EURAMET project to assess the effect of atmospheric ionization induced by extraterrestrial radiation on the Earth's biosphereT
World Metrology Day 2024: Metrology for Sustainability, SCK CEN, Mol (Belgium), 24 May 2024

22. Bolsée, D.
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24. Botek, E.; Pierrard, V.
Progress in the Belgian BSPM plasmaspheric model on the CCMC platform
11th CCMC Community Workshop, University of Maryland, College Park, Maryland(USA), 3-7 June 2024 (invited talk)

25. Botek, E.; Pierrard, V.
The Belgian SWIFF plasmaspheric model (BSPM) at the PITHIA e-Science Centre
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29. Calders, S.; and others
Empowering citizen scientists: studying meteors through Radio Meteor Zoo and MOMSTER
CAP conference, Toulouse (France) and online, 24-28 June 2024

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Promoting inclusive participation at the European Space Weather Week: Strategies for enhanced accessibility
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31. Carcaboso, F.; Warmuth, A.; Schuller, F.; … ; Rodriguez, L.; and 41 others
Insights of Solar Energetic Electron Transport and Acceleration Provided by a Large Solar Orbiter Collaborative Effort
AGU Fall Meeting, Washington, D.C. (USA), 9-13 December 2024 (poster)

32. Collier, H.; Hayes, L.; Purkhart, S.; Ryan, D.; Krucker, S.; Polito, V.; Berghmans, D.; Kraaikamp, E.; Dominique, M.; Dolla, L.; Verbeeck, C.
Short-exposure EUV observations of solar flares from EUI/FSI combined with STIX
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33. Delcloo, A.; Van Malderen, R.; Poyraz, D.; Tuinder, O.N.E.
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34. Delouille, V.; Verstringe, F.; Maneva, Y.; Vinoelst, L.; Millas, D.; Shukhobodskaia, D.; Senthamizh Pavai, V.; Magdalenic, J.; Rodriguez, L.; de Patoul, J.; Cecconi, B.; Erard, S.; Mays, M.L.; Wiegand, C.; Verbeke, C.
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Vigil Data Utilization from Solar Weather ESC perspective

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36. Deshpande, K.; Magdalenic, J.; Jebaraj, I.C.; Senthamizh Pavai, V.; Krupar, V.
Validating Coronal Plasma Density Estimates from EUHFORIA using Parker Solar Probe and Radio Observations
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37. Deshpande, K.; Valentino, A.; Magdalenic, J.
Complex interactions of the shock wave and ambient coronal structure
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38. Dierckxsens, M.; Zychová, L.; Kindarkhedia, D.; Crosby, N.
COMESEP SEPForecast: Performance during 10 Years of Operations
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39. Dominique, M.; Gissot, S.; Talpeanu, D.-C.; and the SOSPIM team
How can we use SoSpIM to help calibrate EUVST?
Solar-C Science Working Group meeting, Nagoya (Japan), 5 March 2024 (invited talk)

40. Dominique, M.; Gissot, S.; Talpeanu, D.-C.
How can we use SoSpIM to help calibrate EUVST?
SOSPIM Science meeting, Davos (Switzerland), 24-26 June 2024

41. Dominique, M.
Science cases combining SOSPIM and EUVST
Solar-C Science Working Group meeting, Online, 27 September 2024 (invited talk)

42. Dominique, M.; Thiemann, E.; and the E-SWAN and OAIDM WG
The Importance of Collecting Multi-Source Sporadic Observations for Space Weather Monitoring and Model Verification: The Potential Role of E-SWAN
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024

43. Dominique, M.; Collier, H.; Hayes, L.; Bechet, S.; Wauters, L.; Dolla, L.; Marqué, C.; Berghmans, D.; Verbeeck, C. ; Krucker, S.
QPPs in the flare sequences of May 2024
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44. Dominique, M.; Collier, H.; Hayes, L.; Bechet, S.; Wauters, L. ; Dolla, L.; Marqué, C.; Berghmans, D.; Verbeeck, C.; Krucker, S.
The May 2024 flare sequence: a rich opportunity for QPP analysis
ESPM-17, Turin (Italy), 9-13 September 2024

45. Dominique, M.
The flare sequence of May 2024: What perspectives for QPP analysis?
STIX Meeting, Paris (France), 3-6 June 2024

46. Doppler, L.; Bolsée, D.; Van Laeken, L.; Zuber, R.
UV spectra measured with ultraviolet solar radiation instruments in EURAMET BIOSPHERE campaigns
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47. Doppler, L.; Bolsée, D.; Van Laeken, L.; Rapp, B.; Zuber, R.; Al-Qaaod, A.; Krasniqi, F.
The project EURAMET BIOSPHERE instrumentation development and atmospheric measurements
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48. Dorsch, B.D.; Talpeanu, D.-C.; Rodriguez, L.; D'Huys, E.; Mierla, M.; Shukhobodskaia, D.; West, M.; Berghmans, D.; Zhukov, A.N.; Verbeeck, C.
Statistical study of prominence eruptions in the wide field of view of Solar Orbiter/EUI/FSI
CoCo-Con: rain, prominences and eruptions, Leuven (Belgium), 21-24 May 2024

49. Dorsch, B.D.; Rodriguez, L.; Magdalenic, J.; Shukhobodskaia, D.; Mierla, M.; Maharana, A..
Analysis of Coronal Mass Ejections through novel Extreme Ultraviolet Imager observations and modeling
XIV COLAGE, Monterrey, Nuevo León (Mexico), 8-12 April 2024

50. Dorsch, B.D.; Rodriguez, L.; Magdalenic, J.
Modelling of coronal mass ejections through the novel FRi3D model and the effect of the twist parameter
ESPM-17, Turin (Italy), 9-13 September 2024 (poster)

51. Echim, M.; Shukhobodskaia, D.; Rodriguez, L.; Zhukov, A.N.; Bacchini, F.; Aravindakshan, H.; Voitcu, G.; Teodorescu, E.; Munteanu, C.
ICME impact on plasma turbulence and complexity at Venus, Earth and Mars
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024

52. Echim, M.; Rodriguez, L.; Lapenta, G.; Shukhobodskaia, D.; Aravindakshan, H.; Teodorescu, E.; Munteanu, C.
Magnetosheath turbulence and intermittency at Venus, Earth and Mars observed during space weather events
EGU General Assembly 2024, Vienna (Austria), 14-19 April 2024 (poster)

53. Gorman, J.; Chitta, L.P.; Peter, H.; Berghmans, D.; Auchère, F.; Aznar Cuadrado, R.; Teriaca, L.; Solanki, S.K.; Verbeeck, C.; Kraaikamp, E.; Stegen, K.; Gissot, S.
Diffuse Quiet Solar Corona
DKIST/Parker Solar Probe/Solar Orbiter Joint Meeting, San Antonio, Texas (USA), 9-12 April 2024 (poster)

54. Guinta, A.; Fludra, A.; Spadaro, D.; Berghmans, D.; Kraaikamp, E.; Auchère, F.; Romoli, M.; Susino, R.; Leeks, S.; Guest, S.; Sidher, S.; Grundy, T.
Spectroscopic measurements from Solar Orbiter Full Disk Mosaic
ESPM-17, Turin (Italy), 9-13 September 2024

55. Hayes, L.; Verbeeck, C.; Ryan, D.; Berghmans, D.; Kraaikamp, E.; Kerr, G.; Collier, H.; Dominique, M.; Krucker, S.; Parenti, S.
High-Resolution Observations from the Solar Orbiter Major Flare SOOP Campaign: Insights from X-ray and Fast Cadence EUV Observations of Solar Flares
ESPM-17, Turin (Italy), 9-13 September 2024

56. Janitzek, N.P.; Roco, M.; Barczynski, K.; and many others
Linking solar flare observations to a series of impulsive solar energetic particle events measured by Solar Orbiter at 0.5 au
DKIST/Parker Solar Probe/Solar Orbiter Joint Meeting, San Antonio, Texas (USA), 9-12 April 2024 (poster)

57. Kanaya, Y.; Sommariva, R.; Saiz-Lopez, A.; and 32 others, the TOAR-II database team members, and the TOAR-II Oceans WG members
Collection of observational ozone data over the global oceans & polar regions to assess chemistry and temporal evolution: Efforts of the TOAR-II Oceans Working Group
iCACGP-IGAC 2024 Joint Conference, Kuala Lumpur (Malaysia), 9-13 September 2024 (poster)

58. Keppens, A.; Di Pede, S.; Hubert, D.; and 25 others
Six years of Sentinel-5p TROPOMI operational ozone profiling and geophysical validation using ozonesonde and lidar ground-based networks
Quadrennial Ozone Symposium, Boulder, Colorado (USA), 15-19 July 2024 (poster)

59. Kollonige, D.E.; Stauffer, R.M.; Thompson, A.M.; Johnson, B.J.; Cullis, P.; Chang, K.-L.; Van Malderen, R.
Southern Hemisphere Additional Ozonesondes (SHADOZ) 2024 Project Updates: Archive News and Ozone Trends
GML 52nd Global Monitoring Annual Conference, Boulder, Colorado (USA), 21-22 May 2024 (poster)

60. Kollonige, D.E.; Stauffer, R.M.; Thompson, A.M.; da Silva, F.R.; Wolff, K.R.; Northam, T.E.; Smit, H.G.J.; Van Malderen, R.; Wright, C.J.; Fedkin, N.M.; Schmidlin, F.J.
Maintaining High Quality Ozonesonde Datasets for O3 Trends Studies: Using NASA Wallops Flight Facility and SHADOZ Dual Soundings and Long-term Records for Demonstration
AGU Fall Meeting, Washington, D.C. (USA), 9-13 December 2024 (poster)

61. Kraaikamp, E.; Gissot, S.; Shestov, S.; Berghmans, D.; Verbeeck, C.; Stegen, K.
EUI HRI-EUV in-flight calibration challenges
DKIST/Parker Solar Probe/Solar Orbiter Joint Meeting, San Antonio, Texas (USA), 9-12 April 2024 (poster)

62. Krasniqi, F.S.; Rapp, B.; Bolsée, D.; Dorn, A.; Georgakilas, A.G.; Pierrard, V.
Metrology for Earth Biosphere: Cosmic rays, ultraviolet radiation and fragility of ozone shield
1st CIPM STG-CENV Stakeholder meeting, BIPM Sèvres (France), 16 -18 September 2024 (poster)

63. Lamy, H.; Cessateur, G.; Bosse, L.; Bolsée, D.; Barthélemy, M.; Sequies, T.; Johnsen, M.G.
Optical auroral spectra obtained at the Skibotn Observatory
EGU General Assembly 2024, Vienna (Austria), 14-19 April 2024 (poster)

64. Lefèvre, L.; Bhattacharya, S.; Mampaey, B.; Delouille, V.; Ritter, C.
The sunspot number recalibration, an ongoing effort
Joint Symposium of Space Climate Symposium 9 and ISEE Symposium, Nagoya (Japan), 1-4 October 2024 (invited talk)

65. Lim, D.; Van Doorsselaere, T.; Berghmans, D.; Verbeeck, C.; Narang, N.
Quasi-periodic pulsations in campfires
EUI/STIX Workshop 2024, Windisch (Switzerland), 22-24 October 2024

66. Lim, D.; Van Doorsselaere, T.; Berghmans, D.
Characteristics and energy flux distributions of decayless transverse oscillations depending on coronal regions
11th Coronal Loops Workshop, La Laguna, Canary Islands (Spain), 25-28 June 2024

67. Lim, D.; Van Doorsselaere, T.; Berghmans, D.; Petrova, E.
Characteristics and Energy Flux Distributions of Decayless Transverse Oscillations in Different Coronal Regions
ESPM-17, Turin (Italy), 9-13 September 2024 (poster)

68. Lim, D.; Van Doorsselaere, T.; Berghmans, D.; Petrova, E.
Characteristics and Energy Flux Distributions of Decayless Transverse Oscillations in Different Coronal Regions
CoCo-Con: rain, prominences and eruptions, Leuven (Belgium), 21-24 May 2024 (poster)

69. Lim, D.

The role of high-frequency transverse oscillations in coronal heating
AAPPS-DPP2024, Malacca (Malaysia), 3-8 November 2024 (invited talk)

70. Lim, D.
Waves in the solar corona and their heating
COSPAR 2024 - 45th Scientific Assembly, Busan (Korea), 13-21 July 2024 (invited talk)

71. Magdalenic, J.; Senthamizh Pavai, V.
Solar wind modelling with EUHFORIA and the PSP observations
ESPM-17, Turin (Italy), 9-13 September 2024 (poster)

72. Maharana, A.
Advanced CME models for improved geo-effectiveness predictions
Thesis, Public PhD Defense, KUL, Leuven (Belgium), 28 August 2024

73. Maharana, A.; Dasso, S.; Pal, S.; Asvestari, E.; Rodriguez, L.; Magdalenic, J.; Scolini, C.; Poedts, S.
On quantifying the impact of CME magnetic flux and mass erosion on geo-effectiveness
EGU General Assembly 2024, Vienna (Austria), 14-19 April 2024

74. Mandal, S.; Peter, H.; Klimchuk, J. A.; Solanki, S. K.; Chitta, L. P.; Cuadrado, R.A.; Schuhle, U.; Terrace, L.; Berghmans, D.
Stereoscopic analysis of coronal loop morphology and dynamics
11th Coronal Loops Workshop, La Laguna, Canary Islands (Spain), 25-28 June 2024

75. Maneva, Y.; de Patoul, J.; O'Hara, J.; the SWOP team and STCE
Space Weather Alerting for ICAO during severe geomagnetic storms on April 23-24 2023
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024

76. Maneva, Y.; de Patoul, J.; O'Hara, J.
5 years of STCE's space weather service to aviation
UKSWSE Meeting II, Exeter (UK), 9-12 September 2024

77. Mangold, A.; Van Malderen, R.; De Bock, V.; Pezzetti, N.; Laffineur, Q.; Delcloo, A.
Time series analysis of UV measurements at Uccle (Belgium) and Utsteinen (Antarctica)
Quadrennial Ozone Symposium, Boulder, Colorado (USA), 15-19 July 2024 (poster)

78. Manuel Mascarenhas, A.; Maurice, L.; Martínez Picar, A.; Marqué, C.
First Meteor Observations with SPADE
International Meteor Conference 2024, Kutná Hora (Czech Republic), 19-22 September 2024

79. Martínez Picar, A.; Marqué, C.
First Radio Solar Observations with SPADE
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024 (poster)

80. Maurice, L.; Manuel Mascarenhas, A.; Martínez Picar, A.; Marqué, C.
Pulse radar transmitter for the Humain BRAMS array?
International Meteor Conference 2024, Kutná Hora (Czech Republic), 19-22 September 2024 (poster)

81. Messios, N.; De Donder, E.
Simulating missions to the Moon with SPENVIS
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024 (poster)

82. Mierla, M.
Exploring Coronal Mass Ejections: An Overview
ESPM-17, Turin (Italy), 9-13 September 2024 (invited talk)

83. Miglio, A.; Bruyninx, C.; Fabian, A.; Legrand, J.
Application of FAIR data principles on the EPN Historical Data Center
EUREF 2024 Symposium, Barcelona (Spain), 5-7 June 2024

84. Narang, N.; Verbeeck, C.; Berghmans, D.; Mierla, M.
EUV transient brightenings in quiet-Sun corona
EUI/STIX Workshop 2024, Windisch (Switzerland), 22-24 October 2024

85. Narang, N.; Verbeeck, C.; Mierla, M.; Berghmans, D.; Auchère, F.
Extreme-ultraviolet transient brightenings in the quiet-Sun corona observed with Solar Orbiter/EUI
ESPM-17, Turin (Italy), 9-13 September 2024 (poster)

86. Narang, N.; Verbeeck, C.; Mierla, M.; Berghmans, D.; Auchère, F.; Stegen, K.; Delouille, V.; Kraaikamp, E.; Gissot, S.; Lim, D.
Statistical study of fine scale Extreme-UV quiet Sun brightenings: Closest Perihelion observations of the quiet solar corona with SolO/EUI
DKIST/Parker Solar Probe/Solar Orbiter Joint Meeting, San Antonio, Texas (USA), 9-12 April 2024 (poster)

87. Niemela, A.E.
EUHFORIA and PARADISE: A story about CMEs shocks and particles
Thesis, Public PhD Defense, KUL, Leuven (Belgium), 10 October 2024

88. O'Hara, J.
STCE: How to connect SWSC end-users with existing SWSC services?

ESWW20, Coimbra (Portugal) and online, 4-8 November 2024 (invited talk)

89. Pacione, R.; Pottiaux, E.
Climate Applications of Geodetic Tropospheric Parameters
GGOS Topical Meeting on the Atmosphere, Potsdam (Germany), 7-9 October 2024 (invited talk)

90. Panesar, N.K.; Hansteen, V.H.; Tiwari, S.K.; Berghmans, D.; Cheung, M.; Muller, D.; Auchère, F.
The Magnetic Origin of Solar Campfires: Solar Orbiter and SDO Observations
11th Coronal Loops Workshop, La Laguna, Canary Islands (Spain), 25-28 June 2024

91. Pereira, N.; and many others
Upcoming Venus missions and synergies between Venus and Exoplanetary analogues
Vienna ELT Science + Simulations Workshop #1, Vienna (Austria), 27-29 November 2024

92. Pereira, N.; and many others
Retrievals of Eco-Venuses with Planetary and Exoplanetary Radiative Transfer Models
Exoplanets 5, Leiden (The Netherlands), 17-21 June 2024 (poster)

93. Péters de Bonhome, M.; Pierrard, V.; Winant, A.; Botek, E.
Advancing understanding of solar wind acceleration: A systematic approach with new Parker Solar Probe observations and kinetic modeling
Belgian Physical Society general scientific meeting, VUB, Brussels (Belgium), 29 May 2024 (poster)

94. Péters de Bonhome, M.; Pierrard, V.; Goosse, H.
Advancing understanding of solar wind acceleration
Chaire Lemaitre, UCLouvain, Louvain-la-Neuve (Belgium), 6 March 2024 (poster)

95. Péters de Bonhome, M.; Bacchini, F.; Pierrard, V.
Advancing understanding of solar wind acceleration: A systematic approach with new Parker Solar Probe observations and kinetic modeling
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024 (poster)

96. Petrova, E.; Van Doorsselaere, T.; Berghmans, D.; Magyar, N.; Parenti, S.; Valori, G.; Plowman, J.
How high resolution observations improve our understanding of the high frequency dynamics in corona
11th Coronal Loops Workshop, La Laguna, Canary Islands (Spain), 25-28 June 2024 (invited talk)

97. Pevtsov, A.; Bechet, S.
International cooperation on ground-based and multi-vantage point observations of the sun
COSPAR 2024 - 45th Scientific Assembly, Busan (Korea), 13-21 July 2024

98. Pierrard, V. ; Péters de Bonhome, M.
Origin of the Solar Wind: Acceleration by Ambipolar Electric Field
21st AIAC, Turin (Italy), 25-29 March 2024 (invited talk)

99. Pierrard, V.
Links between the cold plasmaspheric plasma and the energetic particles of the radiation belts
National Astronomy Meeting, Hull (UK), 14-19 July 2024 (invited talk)

100. Pierrard, V.
Interactions between space particles and the terrestrial upper atmosphere
Switch to Space: Space for a Safer World, Brussels (Belgium), 2 October 2024 (invited talk)

101. Pierrard, V.
Proton flux variations during Solar Particle Events
BIOSPHERE Training course and 1st stakeholder workshop, Prague and Milešovka (Czech Republic), 1-2 October 2024 (invited talk)

102. Pierrard, V.; Winant, A.; Botek, E.; Péters de Bonhome, M.; Krasniqi, F.
Effects of the geomagnetic storm of 11 May 2024 on the radiation belts, ionosphere and ozone in the atmosphere
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024 (poster)

103. Pierrard, V.; Péters de Bonhome, M.
Evolution of the solar wind from the corona to the heliosphere
DKIST/Parker Solar Probe/Solar Orbiter Joint Meeting, San Antonio, Texas (USA), 9-12 April 2024 (poster)

104. Pierrard, V.; Winant, A.; Botek, E.; Ripoll, J.F.
Multi-point Observations of the Plasmasphere, Radiation Belts and Other Regions of the Magnetosphere
URSI AT-RASC 2024, Gran Canaria (Spain), 19-24 May 2024 (invited)

105. Pierrard, V.; Winant, A.; Péters de Bonhome, M.; Botek, E.
Project Biosphere: Study the Effects of the Solar and Cosmic Radiation on the Terrestrial Atmosphere
Belgian Physical Society general scientific meeting, VUB, Brussels (Belgium), 29 May 2024

106. Poniatowski, L.
Radiation hydrodynamics under extreme conditions
Fundamentals of Stellar Outflows: Celebrating and Amplifying the Scientific Life of Stan Owocki, Leuven (Belgium), 8-12 July 2024 (invited talk)

107. Pottiaux, E.; Bamahry, F.; Bruyninx, C.; Fabian, A.; Mesmaker, D.; Miglio, A.; Moyaert, A.; Legrand, J.
European Plate Observing System (EPOS): GNSS Data and Products Thematic Core Service (TCS)
E-GVAP Joint Expert Team Meeting 2024, Grange, Dunsany (Ireland), 26-27 November 2024

108. Pottiaux, E.; Bruyninx, C.
ROB's Contribution to E-GVAP: Achievements, Challenges, and Future Plans
E-GVAP Joint Expert Team Meeting 2024, Grange, Dunsany (Ireland), 26-27 November 2024

109. Ripoll, J.F.; Hartley, D.P.; Thaller, S.S.; and 13 others
Cold Electrons and Electromagnetic Waves in the Near-Earth Space
DASP meeting, Edmonton, Canada, February 19-23, 2024. (talk)

110. Roco, M.; Janitzek, N.P.; Berger, L.; and 18 others
Linking Solar Flare Observations to a Series of Impulsive Solar Energetic Particle Events Measured with Solar Orbiter at 0.5 AU
EGU General Assembly 2024, Vienna (Austria), 14-19 April 2024 (poster)

111. Rodriguez, L.; Dorsch, B.D.; Shukhobodskaia, D.; Mierla, M.; Talpeanu, D.-C.; D'Huys, E.; West, M.; Berghmans, D.; Zhukov, A.N.; Verbeeck, C.; Patel, R.
Statistical study of prominence eruptions in the wide field of view of Solar Orbiter/EUI/FSI
EUI/STIX Workshop 2024, Windisch (Switzerland), 22-24 October 2024

112. Sasso, C.; Vourlidas, A.; Berghmans, D.; Suarez Orozco, D.; Landini, F.; Auchère, F.; Valori, G.; Russano, G.; Strecker, H.; Hirzberger, J.; Rodriguez, L.; Hess, P.
Analysis of solar eruptive events captured by Solar Orbiter during the "Eruption Watch" coordination campaigns
ESPM-17, Turin (Italy), 9-13 September 2024 (poster)

113. Sasso, C.; Landini, F.; Russano, G.; and 14 others
Preliminary results from Solar Orbiter "Eruption Watch" campaigns
IAUGA 2024, Capetown (South Africa), 6-15 August 2024 (poster)

114. Sasso, C.; Landini, F.; Russano, G.; and 14 others
Results from "Eruption Watch" Solar Orbiter coordination campaigns
DKIST/Parker Solar Probe/Solar Orbiter Joint Meeting, San Antonio, Texas (USA), 9-12 April 2024 (poster)

115. Sasso, C.; Landini, F.; Russano, G.; Auchère, F.; Berghmans, D.; Hirzberger, J.; Hess, P.; Orozco Suárez, D.; Rodriguez, L.; Strecker, H.; Valori, G.; Vourlidas, A.
Results from the Solar Orbiter "Eruption Watch" coordination campaigns
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024

116. Senthamizh Pavai, V.; Magdalenic, J.
How changing of source surface height parameter in EUHFORIA affect solar wind simulations
ESPM-17, Turin (Italy), 9-13 September 2024

117. Senthamizh Pavai, V.; Magdalenic, J.
Effects of changing source surface height parameter in solar wind simulations using EUHFORIA
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024 (poster)

118. Shen, C.; Li, X.; Ko, Y.K.; Raymond, J.C.; Guo, F.; Polito, V.; Pierrard, V.
Modeling of Ionization and Recombination Process in Plasma with Arbitrary Non-Maxwellian Electron Distribution
AGU Fall Meeting, Washington, D.C. (USA), 9-13 December 2024 (poster)

119. Shukhobodskaia, D.; Talpeanu, D.-C. ; Rodriguez, L.; D'Huys, E.; Mierla, M.; Dorsch, B.D.; West, M.; Berghmans, D.; Zhukov, A.N.; Verbeeck, C.
Statistical study of prominence eruptions in the wide field of view of Solar Orbiter/EUI/FSI
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024 (poster)

120. Smit, H.G.J.; Thompson, A.M.; Van Malderen, R.; Tarasick, D.W.; Stauffer, R.M.; Johnson, B.J.; Voemel, H.; Davies, J.; von der Gathen, P.; Kollonige, D.E.; Morris, G.
More than 25 Years Of Ozonesonde QA/QC And Data Quality Improvements: In-sights from JOSIE and ASOPOS
Quadrennial Ozone Symposium, Boulder, Colorado (USA), 15-19 July 2024

121. Smit, H.G.J.; Thompson, A.M.; Tarasick, D.W.; Van Malderen, R.; Stauffer, R.M.; Johnson, B.J.; Vömel, H.; Davies, J.; Morris, G.A.; Kollonige, D.E.
Quality Assurance of the Global Ozonesonde Network: A Continuous Process of Reporting and Assessing the Sondes Measurement Quality on their Consistency and Uncertainty Budget
AGU Fall Meeting, Washington, D.C. (USA), 9-13 December 2024 (poster)

122. Stauffer, R.M; Thompson, A.M.; Smit, H.G.J.; and 10 others
Development of Trend Quality Ozonesonde Profile Data through 30 Years of Laboratory and Field Experiments (invited)
iCACGP-IGAC 2024 Joint Conference, Kuala Lumpur (Malaysia), 9-13 September 2024

123. Steinbrecht, W.; Velazco, V.A.; Dirksen, R.; Doppler, L.; Oelsner, P.; Van Malderen, R.; De Backer, H.; Maillard Barras, E.; Stübi R.; Godin-Beekmann, S.; Hauchecorne, A.
Ground-based monitoring of stratospheric ozone since the 1960s in Germany
Quadrennial Ozone Symposium, Boulder, Colorado (USA), 15-19 July 2024

124. Talpeanu, D.-C.; D'Huys, E.; Rodriguez, L.; Mierla, M.; Shukhobodskaia, D.; Dorsch, B.D.; West, M.; Berghmans, D.; Zhukov, A.N.; Verbeeck, C.
Statistical study of prominence eruptions in the wide field of view of Solar Orbiter/EUI/FSI
DKIST/Parker Solar Probe/Solar Orbiter Joint Meeting, San Antonio, Texas (USA), 9-12 April 2024 (poster)

125. Talpeanu, D.-C.; Rodriguez, L.; D'Huys, E.; Mierla, M.; Shukhobodskaia, D.; Dorsch, B.D.; West, M.; Berghmans, D.; Zhukov, A.N.; Verbeeck, C.
Statistical study of prominence eruptions in the wide field of view of Solar Orbiter/EUI/FSI
IAU Symposium 388: Solar and Stellar Coronal Mass Ejections, Krakow (Poland), 5-10 May 2024

126. Thompson, A.M.; Van Malderen, R.; Kollonige, D.E.; and 10 others
Trends (2000-2022) from TOAR II/HEGIFTOM Global Ground-based Tropospheric Ozone Measurements: A Reference Dataset for Satellite Products & Models
iCACGP-IGAC 2024 Joint Conference, Kuala Lumpur (Malaysia), 9-13 September 2024 (poster)

127. Thompson, A.M.; Kollonige, D.E.; Stauffer, R.M.; Van Malderen, R.; Smit, H.G.J.; Johnson, B.J.; Chang, K.-L.
Trends (2000 to 2022) from TOAR II/HEGIFTOM Global Ground-based Tropospheric Measurements: A Reference Dataset for Satellite Products & Models
CEOS Atmospheric Composition Virtual Constellation (AC-VC) meeting, College Park, Maryland (USA), 15-18 October 2024

128. Thompson, A.M.; Van Malderen, R.; Smit, H.G.J.; and 11 others
Trends in Free Tropospheric Ozone from Homogenized Ground-based and Profile Datasets (1995-2020): The TOAR II/HEGIFTOM Project
AMS 104th Annual Meeting, Baltimore (USA), 28 January - 1 February 2024

129. Thompson, A.M.; Van Malderen, R.; Kollonige, D.E.; and 13 others
Global Ground-based Tropospheric Ozone Measurements: Reference Trends (2000-2022) from the TOAR-II/HEGIFTOM Project
GML 52nd Global Monitoring Annual Conference, Boulder, Colorado (USA), 21-22 May 2024

130. Vanden Broeck, G.; Bechet, S.; Rauw, G.; Clette, F.
Effect of the inclination angle of solar rotation axis on Ca II K structures using direct solar observations
TESS 2024, Dallas, Texas (USA), 7-12 April 2024

131. Vanden Broeck, G.; Bechet, S.; Rauw, G.
Effect of the inclination angle of the solar rotation axis on disk-resolved indices from full-disk solar images in the Ca II K line
IAUGA 2024, Capetown (South Africa), 6-15 August 2024 (poster)

132. Vanlommel, P.
Trainings by the STCE
NATO MIL SWx, Mons (Belgium), 26 March 2024 (invited talk)

133. Vanlommel, Petra; D'Huys, Elke; Van der Linden, Ronald
Space Weather Courses & Trainings by the STCE
UKSWSE Meeting II, Exeter (UK), 9-12 September 2024 (invited talk)

134. Vanlommel, P.; D'Huys, E.
Space Weather Institute of Belgium Solar-Terrestrial Centre of Excellence
ESWW20, Coimbra (Portugal) and online, 4-8 November 2024 (poster)

135. Van Malderen, R.
International Ozonesonde Activities
ORM12, Geneva (Switzerland), 24-26 April 2024

136. Van Malderen, R.
Harmonization of tropospheric ozone data for TOAR-II
Ozone CCI 2nd User Workshop, Online, 28-29 May 2024

137. Van Malderen, R.; Thompson, A.M.; Smit, H.G.J.; and 18 others
Tropospheric ozone column trends from homogenized ground based profile ozone datasets from the TOAR II HEGIFTOM Focus Working Group
Quadrennial Ozone Symposium, Boulder, Colorado (USA), 15-19 July 2024

138. Van Malderen, R.; Smit, H.G.J.; Petropavlovskikh, I.; and 17 others
TOAR-II Activities
NDACC Steering Committee meeting, Santiago (Chile), 11-15 November 2024

139. Van Malderen, R.; Thompson, A.M.; Kollonige, D.E.; and 11 others
Trends (2000 to 2022) from TOAR II/HEGIFTOM Global Ground-based Tropospheric Measurements: A Reference Dataset for Satellite Products & Models
NDACC Steering Committee meeting, Santiago (Chile), 11-15 November 2024

140. Van Malderen, R.; Poyraz, D.; Smit, H.G.J.; and 25 others
Ozonesonde Data Quality Assessment (O3S DQA) homogenization of the European ECC ozonesonde time series: evaluation and long term trends
Quadrennial Ozone Symposium, Boulder, Colorado (USA), 15-19 July 2024 (poster)

141. Van Malderen, R.; Pottiaux, E.
Long-term Global Navigation Satellite System (GNSS) retrievals of total column water vapour
Climate Workshop on Observations for Climate Model Validation, RMI, Brussels (Belgium), 2 February 2024

142. Verbeeck, C.; Kraaikamp, E.; Loumou, K.; and 25 others and the EUI Team
EUI onboard Solar Orbiter: unique data for high resolution, far corona and connection science
EUI/STIX Workshop 2024, Windisch (Switzerland), 22-24 October 2024 (poster)

143. Verbeeck, C.; Zhukov, A.N.; Talpeanu, D.-C.; and 24 others
EUI onboard Solar Orbiter: unique data for high resolution, far corona and connection science
ESPM-17, Turin (Italy), 9-13 September 2024 (poster)

144. Verbeeck, C.; Berghmans, D.; Kraaikamp, E.; and many others
How can EUI data help your research?
DKIST/Parker Solar Probe/Solar Orbiter Joint Meeting, San Antonio, Texas (USA), 9-12 April 2024 (poster)

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151. Wild, J.; Petropavlovskikh, I.; Abromitis, K.; and 14 others
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3. Berghmans, D.; Zhukov, A.N.
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4. Berghmans, D.
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5. Bolsée, D.
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6. Bolsée, D.
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7. Calders, S.
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8. Calders, S.
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10. Dolla, L.
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28. Pierrard, V.
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30. Pierrard V.
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SWIC for SWx forecasters, ROB and online, 15 October 2024

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D'Huys, E.; Janssens, J.; Vanlommel, P.; STCE collaborators (Martinez, A.; Lefèvre, L.; Bechet, S.; Lemaitre, O.; Verhulst, T.G.W.; Zychova, L.; Chevalier, J.-M.; Bergeot, N.; SIDC/RWC) and international partners (Brchnelova, M. (KUL); van der Laan, W.-P. (MTO/SME Space Weather))
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- SWIC 2024/1 on 22-25 January 2024
- SWIC 2024/2 on 22-25 April 2024
- SWIC 2024/3 on 30 September - 03 October 2024

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46. Van Malderen, R.
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47. Verbeeck, C.
Planetoïden, kometen en meteoren
Pubic Observatory Urania, Hove (Belgium), 19 December 2024

48. Verbeeck, C.
Bestaat er buitenaards leven?
Probus Voorkempen, Brasschaat (Belgium), 14 May 2024

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Solar Orbiter
Public Observatory Beisbroek, Brugge (Belgium), 28 February 2024

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51. Zhukov, A.N.
Interview (Proba-3) to the INDUS podcast
INDUS podcast, 13 November 2024

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The PROBA-3 Mission - Artificial Total Solar Eclipse in Space
FotonFest, Urania Public Observatory, Hove (Belgium), 18 May 2024

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ASGARD, Brussels (Belgium), 25 April 2024

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"I am a human" Exposition - scientific curation & moderation
Observatory & Planetarium, Brno (Czech Republic), 10 October 2024

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Volkssterrenwacht AstroLAB IRIS, Ypres (Belgium), 29 November 2024

A portion of the Space Pole in January and February 2024 as seen through the eyes of Brenda Dorsch (top), Sergei Shestov (middle), and Thomas Lecocq.

List of abbreviations

~	About, proportional to
Δ	Delta (difference)
‖	Parallel
⊥	Perpendicular
%	Percentage
1D, 2D, 3D,…	One, two, three,… dimensional
^{3}He	Stable isotope of Helium
Å	Ångstrom (0.1 nm)
A	Article
AAPPS-DPP	Association of Asia Pacific Physical Societies - Division of Plasma Physics
AAS	American Astronomical Society
ACE	Advanced Composition Explorer
ACM	Asteroids, Comets, Meteoroids (conference)
AC-VC	Atmospheric Composition Virtual Constellation
AGU	American Geophysical Union
AI	Artificial Intelligence
AIA	Atmospheric Imaging Assembly (SDO)
AIAC	Annual International Astrophysics Conference
Airbnb	Air Bed & Breakfast
AirDNA	Airbnb Data & Analysis
ALC	Automatic LIDAR-Ceilometer
ALIS	Auroral Large Imaging System
ALTIUS	Atmospheric Limb Tracker for Investigation of the Upcoming Stratosphere (BIRA-IASB)
AM	Amplitude Modulation
AMS	American Meteorological Society
ANeMoS	Athens Neutron Monitor Station
AOGS	Asia Oceania Geosciences Society
A_p	Planetary A-index
APL	Applied Physics Laboratory (JHU)
APS	(1) American Physical Society ; (2) Active Pixel System (PROBA2)
AR	(1) Active Region ; (2) Annual Report
ARCAS	Augmented Resolution Callisto Spectrometer
ASG	Auroral SpectroGraph
ASGARD	An educational space programme for schools (no acronym)
ASIMUT	Atmospheric Spectra Inversion Modular Utility Tools (code; BIRA-IASB)
ASIS	Auroral Spectrograph In Skibotn (Sweden)
ASL	Above Sea Level
ASPIICS	Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun (Proba-3)
AT-AP-RASC	ATlantic / Asia-Pacific Radio SCience meeting
ATLAS	Asteroid Terrestrial-impact Last Alert System
AU, au	Astronomical Unit; about 150 million km
B	Magnetic field (strength)
B_0	Heliographic latitude of the central point of the solar disk (The range of B_0 is $\pm$7.23°)
BE	Belgium
BELSPO	Belgian Science Policy Office
Benelux	Belgium, The Netherlands, and Luxembourg
Bifrost	MHD code (no acronym); the name of the rainbow bridge from Midgard (the realm of man) to Asgard (the realm of the gods)
BINA	Belgo-Indian Network for Astronomy and Astrophysics
BIOSPHERE	Not an acronym, but stands for "Metrology for Earth Biosphere: Cosmic rays, ultraviolet radiation and fragility of ozone shield" (EURAMET)
BIPM	Bureau international des poids et mesures
BIRA	Koninklijk Belgisch Instituut voor Ruimte-Aëronomie
BIRA-IASB	Royal Belgian Institute for Space Aeronomy
BKG	German Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie)

BNCGG	Belgian National Committee for Geodesy and Geophysics
BRAIN-be	Belgian Research Action through Interdisciplinary Networks (BELSPO)
BRAMS	Belgian RAdio Meteor Stations
B.RCLab	Belgian Radiometric Characterization Laboratory
BSPM	Belgian SWIFF plasmaspheric model
BUKS	Belgium, UK, and Spain
B.USOC	Belgian User Support and Operation Centre
Bz	Component of the IMF perpendicular to the ecliptic ("north-south" component)
°C	Degrees Celsius
C1, C2, C3	Coronagraphs of LASCO (SoHO)
C-class flare	Common x-ray flare
C/N_0	Carrier-to-Noise
CA	COST Action (COST)
Ca II H	A blue line in the solar spectrum at 396.85 nm
Ca II K	A blue line in the solar spectrum at 393.37 nm
CACTus	Computer Aided CME Tracking software
CALLISTO	Compound Astronomical Low frequency Low-cost Instrument for Spectroscopy and Transportable Observatory
CAMS	Cameras for Allsky Meteor Surveillance (Benelux)
CAP	Communicating Astronomy with the Public
CCD	charge-coupled device
CCI	Climate Change Initiative
CCMC	Community Coordinated Modeling Center
CEOS AC-VC	Committee on Earth Observation Satellites Atmospheric Composition Virtual Constellation
CESRA	Community of European Solar Radio Astronomers
CH	Coronal Hole
CH_4	Methane
CH_4TIR	CH4 Thermal InfraRed
CIPM STG-CENV	International Committee for Weights and Measures Sectorial Task Group on Climate and Environment
CIR	Co-rotating Interaction Region
Cluster	ESA/NASA mission to study the Earth's magnetosphere (no acronym)
cm, cm^2, cm^3	centimeter, square centimeter, cubic centimeter
CME	Coronal Mass Ejection
CMOS	Complementary Metal-Oxide-Semiconductor
CmPA	Centre for mathematical Plasma-Astrophysics (KUL)
CNES	Centre national d'études spatiales (France)
CNRS	Centre national de la recherche scientifique (France)
Co.	Cooperation
CO_2	Carbon Dioxide
CoCo-Con	Coronal Cooling Conference
COH	Cohesive (Ozone; NOAA)
COLAGE	Conferencia Latinoamericana de Geofísica Espacial
COMESEP	COronal Mass Ejections and Solar Energetic Particles
COMPLIMENT	COMetary Plasma Light InstruMENT (Comet Interceptor; ESA)
CONIOPOL	CONIOlogy and POLarisation (RMI)
COPUOS	COmmittee on the Peaceful Uses of Outer Space (UN)
COR (1/2)	Coronagraph (Inner/Outer) onboard STEREO
CORS	Continuously Operating Reference Stations (GNSS)
COSPAR	COmmittee on SPAce Research
COST	(European) COoperation in Science & Technology
COTS	Commercial off-the-shelf
CPU	Central Processing Unit
CR	Carrington Rotation
CRAF	Committee on Radio Astronomy Frequencies
CROM	A type of pyrheliometer developed by D. Crommelynck (RMI)
CSL	Centre Spatial de Liège
CubeSat	A small satellite measuring 10cm x 10cm x 10cm

dB	Decibel
dB FS	Decibels relative to Full Scale
dB-Hz	decibel-Hertz (bandwidth relative to 1 Hz)
D.C.	District of Columbia
DECOS	Detector for Cosmic Showers
DEM	Differential Emission Measure
DeMeLab	Detector Measurements Laboratory (aka STCL)
Digisonde	Digitally Integrating Goniometric IonoSONDE
DIGISUN	A software application for digitization of scanned sunspot drawings (ROB)
DKIST	Daniel K. Inouye Solar Telescope
DLR	German Aerospace Center
dm, dm^2, dm^3	decimeter, square decimeter, cubic decimeter
DOI	Digital Object Identifier
DOU	Dourbes (Intermagnet)
DoY	Day of Year
DPS	(1) Division for Planetary Sciences (EPSC) ; (2) Digital Portable Sounder
Dr.	Doctor
DRBS	Dourbes (Belgium, NMDB)
DSCOVR	Deep Space Climate Observatory
Dst	Disturbance Storm Time index (geomagnetic)
DUT	Device Under Test
E	East
E, E_- , E_+	Energy, Ingoing energy, Outgoing energy
e.g.	exempli gratia (example given)
e-Callisto	extended Compact Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory
EC	European Commission
ECC	Electrochemical Concentration Cell
ECMWF	European Centre for Medium-range Weather Forecasts
ed.	Edition
EDPS	EDP Sciences (Édition Diffusion Presse Sciences)
Eds.	Editors
EFW	Electric Field and Waves instrument (Van Allen probes)
EGNOS	European Geostationary Navigation Overlay Service (Galileo/Europe)
EGNSS	European GNSS
EGU	European Geosciences Union
E-GVAP	EUMETNET GNSS water Vapour Programme
EIS	EUV imaging spectrometer (Hinode)
EISCAT	European Incoherent SCATter scientific association
EIT	Extreme ultraviolet Imaging Telescope (SOHO)
ELF	Extreme Low frequency (3-30 Hz)
ELT	Extremely Large Telescope
EM	(1) Electromagnetic (2) Engineering Model
EMFISIS	Electric and Magnetic Field Instrument Suite and Integrated Science (Van Allen Probes)
EMS	European Meteorological Society
ENVISAT	Environmental Satellite (ESA)
EnVision	ESA's Venus orbiter (no acronym)
EPD	Energetic Particle Detector (SolO)
EPN	(1) EUREF Permanent Network (2) Europlanet
EPOS	European Plate Observing System
EPS	European Physical Society
EPSC	European Planetary Science Congress
EPT	Energetic Particle Telescope (PROBA-V)
ERA	ECMWF re-analysis
ERAI , ERA5	ERA-Interim, 5th ERA
ERB	Earth Radiation Budget
erg	10^{-7} Joule
ERSA	European Radiation Sensor Array
Es	Sporadic E-layer (ionosphere)
ES	Earth System (Science and Environmental Management (COST)
ESA	European Space Agency

ESAC	European Space Astronomy Centre (ESA)
ESC	Expert Service Centre (SSCC)
ESD	ElectroStatic Discharge
ESCAPE	(1) European SpaceCraft for the study of Atmospheric Particle Escape (2) European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures
ESERO	European Space Education Resource Office
ESF	Environmental Simulation Facility
ESFRI	European Strategy Forum on Research Infrastructures
ESLAB	Environmental Simulation Laboratory
ESOC	European Space Operations Centre
ESPD	European Solar Physics Division (EPS)
ESPM	European Solar Physics Meeting
ESTEC	European Space Research and Technology Centre
ESURIN	European Space Research Institute (ESA)
E-SWAN	European Space Weather and Space Climate Association
ESWW	European Space Weather Week
et al.	et alii (and other)
etc.	et cetera (and so forth)
ETH	Eidgenössische Technische Hochschule Zürich
EU	European Union
EUHFORIA	European Heliospheric Forecasting Information Asset
EUI	Extreme-Ultraviolet Imager (Solar Orbiter)
EUMETNET	Network of European Meteorological Services
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EURAMET	European Association of National Metrology Institutes
EUREF	EUropean Reference Frame
EUV	Extreme Ultraviolet
EUVST	EUV High-throughput Spectroscopic Telescope (Solar-C ; Jaxa)
EUVI	Extreme Ultraviolet Imager (STEREO/SECCHI; LGRRS)
eV	electron volt (1 eV = 1.602 × 10^{-19} joules)
EVE	Extreme ultraviolet Variability Experiment (SDO)
ExoMars	Exobiology on Mars (ESA, Roscosmos)
f	frequency
$F_{10.7}$, $F_{10.7\ cm}$	Solar radio flux at 10.7 cm wavelength
F_2	Main ionospheric layer
FAIR	Findable, Accessible, Interoperable, and Re-usable
F-class	Fast class (ESA)
Fe IX-X	8 respectively 9 times ionized iron
FFCP	free form corrector plate (VenSpec-H)
FITS	Flexible Image Transport System
FM	(1) Flight Model (2) Frequency Modulation
FMI	Finnish Meteorological Institute
FNRS	Fonds National de la Recherche Scientifique
foE	Critical frequency E-layer
foEs	Sporadic E critical frequency
foF2	Critical frequency F2-layer
FORS	FORecasting System (TID, PITHIA)
FOV	Field-Of-View
FP7	Framework Programme 7 (EU)
FRi3D	(1) Flux Rope in 3D (2) "Fried" (electronics and frites)
FRS	Fonds de la Recherche Scientifique
FSI	Full Sun Imager (Solar Orbiter / EUI)
ft	foot or feet (1 ft = 30.48 cm)
FTE	Full-Time Equivalent
ftp	file transfer protocol
FUV	Far Ultraviolet
G	(1) Gauss (10^{-4} Tesla or 10^5 nT); (2) Gigabyte (10^9 bytes)
Gaia	ESA satellite (no acronym)
Galileo	European GNSS

GASS	General Assembly and Scientific Symposium
GAW	Global Atmospheric Watch (WMO)
GB	Gigabyte (10^9 bytes)
GBO	Ground-Based Observatory
GCR	Galactic Cosmic Rays
GEANT-4	GEometry ANd Tracking (simulation platform)
GEO	A geostationary orbit , i.e. a circular geosynchronous orbit 35.786 km in altitude
GERB	Geostationary Earth Radiation Budget
GeV	Giga electronvolt (10^9 . 1.6 . 10^{-19} Joule)
GFZ	Deutsches GeoForschungsZentrum (German Research Centre for Geosciences)
GGOS	Global Geodetic Observing System
GHz	Gigahertz (10^9 Hz)
GIC	Geomagnetically induced current
GLE	Ground Level Enhancement
GLONASS	GLObal NAvigation Satellite System (Russia)
GMAC	Global Monitoring Annual Conference
GML	Global Monitoring Laboratory
GNSS	Global Navigation Satellite System
GNSS(GRE)	GNSS corrections based on GPS-GLONASS-GALILEO constellations (GPS/Russia/Europe)
GOES	Geostationary Operational Environmental Satellite
GOME	Global Ozone Monitoring experiment (SCIAMACHY)
GOMESCIA	GOME/SCIAMACHY/GOME-2
GONG	Global Oscillation Network Group
GPS	Global Positioning System (USA)
GRAPE	GNSS Research and Application for Polar Environment
GSE	Geocentric Solar Ecliptic system
GSFC	Goddard Space Flight Center
GTO	Geostationary Transfer Orbit
h	(1) hour ; (2) Planck's constant (6.62607004 × 10^{-34} m^2 kg / s)
H	(1) Hydrogen ; (2) Heat flux
H-alpha (Hα)	A red visible spectral line at 656.28 nm created by Hydrogen
H-beta (Hβ)	A line in the solar spectrum at 486.14 nm created by Hydrogen
H2020	Horizon 2020 (EU)
H_2O	Water
He, He II	Helium, ionized Helium
HEGIFTOM	Harmonization and Evaluation of Ground-based Instruments for Free Tropospheric Ozone Measurements
HEK	Heliophysics Events Knowledgebase
Helios 1, 2	Two joint German-American space missions in the 1970s (no acronym)
HESPERIA	High Energy Solar Particle Events foRecastIng and Analysis
HF	High Frequency (3-30 MHz)
HF Com	HF Communication
HI	(1) Neutral atomic Hydrogen ; (2) Heliospheric Imager (STEREO)
Hinode	A JAXA/NASA solar mission: Solar-B satellite ("sunrise")
h_mF_2	peak density height of F_2-layer
HMI	Heliospheric and Magnetic Imager (SDO)
hPa	hectopascal (atmospheric pressure)
HRI	High Resolution Imager (Solar Orbiter / EUI)
HRIEUV	High Resolution Imager in the EUV (Solar Orbiter / EUI)
HRILYA	High Resolution Imager in Ly-α (Solar Orbiter / EUI)
HSRS	Humain Solar Radio Spectrograph
HSS	High Speed Stream
HuRAS	Humain Radio Astronomy Station
HXR	Hard x-rays
Hz	Hertz (per second)

i	The index in a counter or series
I	Current
I-V	Current-Voltage
IABG	Industrieanlagen-Betriebsgesellschaft mbH (German company; Proba-3)
IAC	International Astronautical Congress
IAG	International Association of Geodesy
IAGA	International Association of Geomagnetism and Aeronomy
IAGOS	In-service Aircraft for a Global Observing System
IAS	Institut d'Astrophysique Spatiale (France)
IASB	Institut royal d'Aéronomie Spatiale de Belgique
IASC	International Arctic Science Committee
IAU	International Astronomical Union
IAUGA	International Astronomical Union General Assembly
iCACGP	international Commission on Atmospheric Chemistry and Global Pollution
ICAO	International Civil Aviation Organization
ICCC	Inter-Commission Committee on "Geodesy for Climate Research" (IAG)
ICMA	International Commission on the Middle Atmosphere
ICME	Interplanetary CME
ICSO	International Conference on Space Optics
ICT	Information and Communication Technologies
IDA	Internal Dosimetry Array (Gateway)
IDL	Interactive Data Language
i.e.	"id est" (that is)
IEEE	Institute of Electrical and Electronics Engineers
IGAC	International Global Atmospheric Chemistry project
IGS	International GNSS Service
IKFS	Infrared Fourier Spectrometer (the K is from the Russian word "Krasny", meaning "Red")
IMC	International Meteor Conference
IMF	Interplanetary Magnetic Field
IMO	International Meteor Organization
IMPC	Ionosphere Monitoring and Prediction Center (DLR)
InGaAs	Indium gallium arsenide
INGV	Istituto nazionale di geofisica e vulcanologia (Italy)
INSPIRE	(1) International Satellite Program in Research and Education (2) Infrastructure for Spatial Information in the European Community (EU)
IO3C	International Ozone Commission
IOP	Institute of Physics
IPAG	Institut de Planétologie et d'Astrophysique de Grenoble (France)
IPC	International Pyrheliometer Comparison
IQR	InterQuartile Range
IR	Infrared
IRAP	Institut de Recherche en Astrophysique et Planétologie (France)
IRI	International Reference Ionosphere
IRIS	Interface Region Imaging Spectrograph (NASA)
IRM(B)	Institut Royal Météorologique (de Belgique)
ISAS	Institute of Space and Astronautical Science
ISBN	International Standard Book Number
ISC	(1) International Science Council; (2) International Steering Committee
ISEE	Institute for Space-Earth Environmental research
ISES	International Space Environment Service
ISN	International Sunspot Number
ISO	International Organization for Standardization
iso-B lines	Lines of equal magnetic field strength

iso-L lines	Lines of equal L (see L*)
ISS	International Space Station
ISSI	International Space Science Institute
ISSS	(1) International School of Space Science; (2) International School/Symposium for Space Simulations
ISTP	International Solar Terrestrial Physics program
ISWAT	International Space Weather Action Teams (COSPAR)
ISWI	International Space Weather Initiative
IT	Information Technology
IUGG	International Union of Geodesy and Geophysics
IVOA	International Virtual Observatory Alliance
IWV	Integrated Water Vapour
J	Joule
JAXA	Japan Aerospace Exploration Agency
JEDI	Joint coronal EUV Diagnostic Investigation (Vigil)
JGR	Journal of Geophysical Research
JHU	Johns Hopkins University
jHV	jHelioViewer
JOSIE	Jülich Ozone Sonde Intercomparison Experiment
JPEG	Joint Photographic Experts Group
JSON	JavaScript Object Notation
JSWSC	Journal of Space Weather and Space Climate
JUICE	JUpiter ICy moons Explorer
JVS	Jongerenvereniging Voor Sterrenkunde (Belgium)
k	wave number
K	(1) Local K index: A 3-hour geomagnetic index, ranging from 0 (quiet) to 9 (extremely severe storm); (2) degrees Kelvin
K*	Local 1-minute resolution K index
Ka-band	"Kürz above": Radio frequency band from 27-40 GHz
KAW	Kinetic Alfvén Waves
KBEL	Local K index for Belgium
keV	kilo-electronvolt ($10^3 . 1.6 . 10^{-19}$ Joule)
kHz	kilohertz (10^3 /second)
KI	Potassium iodide
km, km^2	kilometer, square kilometer
km/s	kilometers per second
KMI	Koninklijk Meteorologisch Instituut
KNMI	Koninklijk Nederlands Meteorologisch Instituut
K_p	"planetarische Kennziffer", a geomagnetic index, ranging from 0 (quiet) to 9 (extremely severe storm)
KSO	Kanzelhöhe Solar Observatory
KSB	Koninklijke Sterrenwacht van België
KUL, KULeuven	Katholieke Universiteit Leuven
kV	kilovolt (10^3 Volt)
λ	wavelength
λ_e	electron inertial length
l/m^2	Liter per square meter
L-class	Large class satellite (ESA)
L	(1) Letter (manuscript); (2) L-shell (see L*)
L*	Set of Earth's magnetic field lines which cross the Earth's magnetic equator at * earth radii from the centre of the Earth (e.g. L = 2); also known as McIlwain parameter
L_0	Heliographic longitude of the central point of the solar disk
L1, … , L5	First, … , fifth Lagrangian point
L1, L2, L5	GPS frequencies: L1 = 1575.42 MHz, L2 = 1227.60 MHz, L5: 1176.45 MHz
LASCO	Large Angle Spectrometric Coronagraph (SOHO); small (C2) and wide (C3) field of view
LASP	Laboratory for Atmospheric and Space Physics
Lat	Latitude
LATMOS	Laboratoire ATmosphères, Milieux, Observations Spatiales (France)
LBL	line-by-line
LDE	Long-Duration Event
LEO	Low Earth Orbit (below 2000 km ASL)

LIDAR	LIght Detection And Radar
LIEDR	Local Ionospheric Electron Density profile Reconstruction
LMSAL	Lockheed Martin Solar and Astrophysics Laboratory
LOC	Local Organising Committee
LOFAR	Low-Frequency Array
Lon	Longitude
LOTUS	Long-term Ozone Trends and Uncertainties in the Stratosphere
LPV-200	Localizer Performance with Vertical guidance until the aircraft is 200 ft above the runway
Ls	Solar longitude
LT	Local Time
LTP	Long-term planning (Solar Orbiter)
LUT	Look-Up Tables
Ly-α	Lyman-alpha, a spectral line in the VUV at 121.6 nm
LYA	Ly-α
LYRA	Large Yield Radiometer, formerly called Lyman Alpha Radiometer (PROBA2)
LWS	Living With a Star
μm	micrometer (10^{-6} meter)
M-class	Medium class satellite (ESA)
M-class flare	Medium x-ray flare
m, m^2, m^3	Meter, square meter, cubic meter
MAB	Manhay (Intermagnet)
MagEIS	MAGnetic Electron Ion Spectrometer (Van Allen probes)
MAJIS	Moons And Jupiter Imaging Spectrometer (JUICE)
MB	megabyte (10^6 bytes)
mbar	millibar
MEO	Medium Earth Orbit (between 2000 and 35.786 km ASL)
Meteosat	Series of geostationary meteorological satellites operated by EUMETSAT
METIS	Multi Element Telescope for Imaging and Spectroscopy (SolO)
MetOp	Meteorological Operational satellite (ESA)
MeV	mega-electronvolt ($10^6 . 1.6 . 10^{-19}$ Joule)
MH	Millionths of a solar hemisphere (1 MH = ~ 3 million km^2). Area Earth = ~167 MH
MHD	Magnetohydrodynamics
MHz	megahertz (10^6/s)
MIDIM	Mars Imager for Dust and Ice clouds Monitoring
MISS	Meridian Imaging Svalbard Spectrograph
MIT	Massachusetts Institute of Technology
MJD	Modified Julian Day
MLH	mixing layer height
MLT	Magnetic Local Time
mm, mm^2	millimeter (10^{-3} meter), square mm
Mm	megameter (10^6 meter)
MMM	Monthly Management Meeting (SIDC)
mm/s	millimeter per second
MOC	(1) Mission Operations Center; (2) Maintenance and Observations Center (PECASUS)
MOMA	Multi-wavelength Observations and Modelling of Aurora
MoMo	Model of Mars Ionosphere
MOMSTER	MObile Meteor STation for Education & outreach
MOST	Multiview Observatory for Solar-Terrestrial science
MPPC	Max Planck-Princeton Center
MPS	Max Planck Institute for Solar System Research
ms	millisecond (10^{-3} second)
MUF, MUF3000	Maximum Usable Frequency, the maximum radio frequency which can be reflected by the ionosphere for a given distance of transmission e.g. 3000 km
MUV	Mid Ultraviolet
ν	Frequency
N	North
N-S	North-South
N_2	Nitrogen
N_2^+	Ionized molecular nitrogen
N_2O	Nitrous oxide ("laughing gas")
nA	nanoampère (10^{-9} meter)

NAOJ	National Astronomical Observatory of Japan
NASA	National Aeronautics and Space Administration
NASU	National Academy of Sciences of Ukraine
NATO	North Atlantic Treaty Organization
Nc, Ns, Ng	the number of spots Ns, the number of groups Ng, and the composite Nc = Ns + 10Ng
NDACC	Network for the Detection of Atmospheric Composition Change
NeQuick	Electron density Quick calculation model (ionospheric model)
Net-TIDE	Pilot Network for Identification of Travelling Ionospheric Disturbances in Europe
NG	Next Generation
NIR	Near IR
NL	The Netherlands
NM	Neutron Monitor
nm	nanometer (10^{-9} meter)
NMDB	Neutron Monitor DataBase
N_mF_2	peak density of F_2-layer
No.	Number of
NO_2	Nitrogen dioxide
NOAA	National Oceanic and Atmospheric Administration
NOMAD	Nadir and Occultation for MArs Discovery (ExoMars)
NRCan	Natural Resources Canada
NRT	Near Real Time
ns	nanosecond (10^{-9} second)
NSF	National Science Foundation
NSO	National Solar Observatory
nT	nano-Tesla (10^{-9} Tesla)
NUV	Near Ultraviolet
NV/SA	Naamloze Vennootschap / Société Anonyme
NWC	Northwest Cape of Australia
NWP	Numerical Weather Prediction
O	Oxygen
O_3	Ozone
O3S	Ozone (O_3) Sonde
O3S-DQA	O3S Data Quality Assessment
ODC	On Duty Center (PECASUS)
OpenGGCM	Open Geospace General Circulation Model
OPM	Ozone PhotoMeter
ORB	Observatoire Royal de Belgique
ORFEES	Observation Radio Fréquences pour l'Etude des Eruptions Solaires
ORM	Ozone Reference Managers meeting
P	The position angle between the geocentric north pole and the solar rotational north pole measured eastward from geocentric north. The range in P is $\pm 26.3°$
P2SC	PROBA2 Science Center
PARADISE	PArticle Radiation Asset Directed at Interplanetary Space Exploration
PB	Petabyte (10^{15} bytes)
PBC	Primary Backup-Center (PECASUS)
PC	Personal Computer
PCF	Polar Crown Filament
PDF	Probability Density Functions
PECASUS	Pan-European Consortium for Aviation Space weather User Services (ICAO)
PFSS	Potential Field Source Surface
pfu	particle (proton) flux unit: the number of particles registered per second, per square cm, and per steradian
PhD	Doctor of Philosophy
PHI	Polarimetric and Helioseismic Imager (Solar Orbiter)
PI	Principal Investigator
PIC	Particle -in-Cell
PICASSO	PICo-satellite for Atmospheric and Space Science Observations
PITHIA-NRF	Plasmasphere Ionosphere Thermosphere Integrated Research Environment and Access services: a Network of Research Facilities (EU)
PLI	Polar Light Imager
PLIP	Polar Lights Imaging Polarimeter
PPP	Precise Point Positioning
PRESTO	(1) Fast warning message for important SWx events (2) PREdictability of the Solar-

	Terrestrial Coupling (SCOSTEP)
PROBA, Proba	PRoject for OnBoard Autonomy
PROBA-V	PROBA-Vegetation
PRODEX	PROgramme de Développement d'Expériences scientifiques (ESA ; Programme for the development of scientific experiments)
PROSPER	PRObabilistic Solar Particle Event foRecasting model
ps	picosecond (10^{-12} second)
PSD	Post-storm depression
PSLV	Polar Satellite Launch Vehicle
PSP	Parker Solar Probe
PTB	Physikalish-Technische Bundesanstalt (Germany)
px	pixel
Python	Programming language (no acronym)
Q&A	Questions and Answers
QA	Quality Assurance
QA-SAC	Quality Assurance - Science Activity Centre
QC	Quality Control
QE	Quantum Efficiency
QOS	Quadrennial Ozone Symposium
QPP	Quasi-periodic pulsation
ρ_T	gyroradius
R	Resistor
$R_{\odot}$	Solar radius (696.000 km)
r^2	the square of the correlation coefficient
R&D	Research and Development
R-ESC	Space Radiation ESC (SSCC)
RAD	International Conference on Radiation, Natural Sciences, Medicine, Engineering, Technology and Ecology
RAL	Rutherford Appleton Laboratory
RAS	Royal Astronomical Society
RBSP	Radiation Belt Storm Probes (now called the “Van Allen probes”)
R_e	Earh radius (radii)
REENOM	Radiation Environment and Effects NOwcasts for the Moon
RF	Radio Frequency
RGB	Red, green and blue
RHESSI	Reuven Ramaty High Energy Solar Spectroscopic Imager
RICAP	Roma International Conference on AstroParticle Physics
RMI(B)	Royal Meteorological Institute (of Belgium)
RMS	Root Mean Square
RMSE	Root Mean Square Error
ROB	Royal Observatory of Belgium
Roscosmos	Russian Space Agency
RPW	Radio and Plasma Waves (Solar Orbiter)
RS-IIC	Remote Sensing-Inter-Instrument Communication (EUI; SolO)
RSSB	Royal Statistical Society of Belgium
R_s	Solar radius (radii)
R_{sun}	Solar radius (~ 696.000 km)
RWC	Regional Warning Center
Rx	Receiver
σ	sigma (confidence level)
s	second
S	South
S-band	Radio frequency band from 2-4 GHz
S/C	Spacecraft
S-class	Small class satellite (ESA)
SAA	South Atlantic Anomaly
SACS	Support to Aviation Control System
SANSA	South African National Space Agency
SAR	(1) Superactive region; (2) Synthetic Aperture Radar (3) Stable Auroral Red arc
SAT, Sat	Satellite
SATCOM	Satellite Communication
SAWS	SEP Advanced Warning System
SBC	Secondary Backup-Center (PECASUS)
SC24, SC25	Solar Cycle 24, Solar Cycle 25
SCAR	Scientific Committee on Antarctic Research
SCIAMACHY	SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (ENVISAT)

SCK-CEN	Studiecentrum voor Kernenergie - Centre d'Etude de l'Energie Nucléaire
SCOPE	Solar Coronagraph for OPErations
SCOSTEP	Scientific Committee on Solar Terrestrial Physics
SDO	Solar Dynamics Observatory
SECCHI	Sun Earth Connection Coronal and Heliospheric Investigation (STEREO)
SEE	Single Event Effects
SEP	Solar Energetic Particle
SEPEM	Solar Energetic Particle Environment Modelling
SEPVAL	SEP model VALidation working meeting
SEU	Single Event Upset
SFU, sfu	Solar Flux Unit (10^{-22} W m^{-2} Hz^{-1})
SGEPSS	Society of Geomagnetism and Earth, Planetary and Space Science
SHADOZ	Southern Hemisphere Additional Ozonesondes
SHINE	Solar Heliospheric & Interplanetary Environment
SIDC	Solar Influences Data analysis Center
SILSO	Sunspot Index and Long-term Solar Observations (ROB)
SIMBA	Sun-earth IMBAlance
SLP	Sweeping / Segmented / Single/ Split / Spherical Langmuir Probe
SLT	Solar Local Time
SM	Spare Model
SMD	Safety and Metrology Division (Federal Services for Metrology)
SMILE	Solar wind-Magnetosphere-Ionosphere Link Explorer (ESA)
SMILE MWG	SMILE - Modeling Working Group
sms	short message service
S_N , SN	(1) Sunspot Number ; (2) Space weather and Near-earth objects ; (3) Standard normal homogenization tests
SO	Solar Orbiter
SOC	Science Operations Centre
SOHO, SoHO	SOlar & Heliospheric Observatory
Solar-C	Next Generation Solar physics Mission (JAXA)
SOLARNET	European network of solar physics researchers and facilities (H2020)
SOLCON	SOLar CONstant radiometer
SolEx	Solar Explorer (telescope)
SOLIS	Synoptic Optical Long-term Investigations of the Sun (NSO)
SolO	Solar Orbiter
SOLSPEC	SOLar SPECtrum (spectroradiometer)
SOOP	Solar Orbiter Observing Plan (SolO)
SOP	Standard Operating Procedures
SoSpIM	Spectral Solar Irradiance Monitor (Solar-C)
SOVA	SOlar constant and VAriability
SPADE	Small Phased Array Demonstrator (Humain)
SPD	Solar Physics Division (AAS)
SPENVIS (-NG)	SPace ENVironment Information System (- Next Generation)
SPHINX	Solar Particles in the Heliosphere validation INfrastructure for SWx
SPICE	Spectral Imaging of the Coronal Environment (SolO)
SPIE	Society of Photo-optical Instrumentation Engineers
SPRING	Solar Physics Research Integrated Network Group (SOLARNET)
SPS	Science for Peace and Security (NATO)
sr	steradian
SRB	Solar Radio Burst
SREM	Standard Radiation Environment Monitor (Integral, Rosetta)
SRM	Sri Ramaswamy Memorial
SSA	(1) Space Situational Awareness ; (2) singular spectrum analysis
SSCC	SSA Space Weather Coordination Centre (ESA)
SSI	Solar Spectral Irradiance

SSN	SunSpot Number
SSWRF II	2nd international workshop on Small Satellites for Space Weather Research and Forecasting
STCE	Solar-Terrestrial Centre of Excellence
STCL	Space Technology & Calibration Laboratories
STEM	Science, Technology, Engineering, Mathematics
STEAM	Science, Technology, Engineering, Arts, Mathematics
STEREO	Solar-TErrestrial RElations Observatory
STEVE	Strong Thermal Emission Velocity Enhancement
STIX	Spectrometer Telescope for Imaging X-rays (Solar Orbiter)
SunPy	software library for solar physics based on Python
SunSCC	Automated tool for sunspot segmentation, clustering, and classification (ROB)
SUVI	Solar Ultraviolet Imager (GOES)
SVO	Solar Virtual Observatory
SW	Space Weather (journal)
SWAP	Sun Watcher using APS detector and image Processing (PROBA2)
SWARM	A constellation of three satellites (Alpha, Bravo, Charlie) studying the Earth's magnetic field (ESA)
SWAVES	STEREO WAVES
SWE	Space Weather
SWEC	Space Weather Education Center
SWEK	Space Weather Event Knowledgebase
SWIC	Space Weather Introductory Course
SWIFF	Space Weather Integrated Forecasting Framework
SWOP	Space Weather OPerations
SWPC	Space Weather Prediction Center (USA)
SWSC	Space Weather Space Climate
SWT	Science Working Team
SWx	Space weather
SXR	Soft x-rays
SYM-H	Index to describe the symmetric (SYM) disturbances of the horizontal (H) component of the geomagnetic field
SZA	Solar Zenith Angle
τ, t	Time
T	(1) Tesla ; (2) Terabyte (10^{12} bytes)
TB	Terabyte (10^{12} bytes)
TAP	Table Access Protocol
TCS	Thematic Core Service
TEC	Total Electron Content
Tech-TIDE	Warning and Mitigation Technologies for TIDs Effects
TECu	TEC unit ($10^{16} e^{-} m^{-2}$)
TESS	Triennial Earth-Sun Summit
T-FORS	Travelling ionospheric disturbances FORecasting System
TGO	Trace Gas Orbiter (ExoMars)
TID	Travelling Ionospheric Disturbance
TIGRE	Telescopio Internacional de Guanajuato Robotico Espectroscopico
TIR	Thermal InfraRed
TNA	TransNational Access
TOAR	Tropospheric Ozone Assessment Report
TOAR-II	Tropospheric Ozone Assessment Report, Phase II
TOST	Trajectory-mapped Ozonesonde dataset for the Stratosphere and Troposphere
TRCC	Time Responses Correction & Calibration
TREx	Transition Region Explorer (Canada)
TROPOMI	TROPOspheric Monitoring Instrument (Sentinel-5 Precursor)
TSI	Total Solar Irradiance
Tx	Transmitter
TVAC	Thermal-VACuum
U	Unit (e.g. CubeSat)
UCL, UCLouvain	Université Catholique de Louvain
UFO	University FOrum (Ghent, Belgium)

UHF	Ultra-high frequency (0.3 - 3 GHz)
UiT	The Arctic University of Norway
UK	United Kingdom
UKSWSE	UK Space Weather and Space Environment
ULB	Université libre de Bruxelles
ULF	Ultra Low Frequency (0.3 - 3 kHz)
Ulysses	A joint ESA/NASA/Canada NRL mission to study the Sun (1990-2009; no acronym)
UNCOPUOS	United Nations Committee on the Peaceful Use of Outer Space
URAN	Ukrainian Radio Interferometer of NASU
URL	Uniform Resource Locator
URSI	International Union of Radio Science - Union Radio-Scientifique Internationale
US(A)	United States (of America)
USAF	United States Air Force
usb, USB	Universal Serial Bus
USET	Uccle Solar Equatorial Table
UT(C)	(Coordinated) Universal Time
UV	Ultraviolet
UVSQ	Université de Saint-Quentin-en-Yvelines
v	Velocity (speed)
V	Volt, voltage
V1, V2, …	Version 1, 2, …
VeLeWe	Vereniging Leraars Wetenschappen
VenSpec-H	Venus Spectrometer with High resolution (EnVision)
VHF	Very High Frequency (30-300 MHz)
VIP	Very Important Person
VIRGO	Variability of solar IRradiance and Gravity Oscillations (SoHO)
VIS	Visible
VKI	Von Karman Institute
VLF	Very Low Frequency (3-30 kHz)
VO	Virtual Observatory
VSWMC	Virtual Space Weather Modelling Centre
VTEC	Vertical TEC
VUB	Vrije Universiteit Brussel
VUV	Vacuum Ultraviolet
VVS	Vereniging Voor Sterrenkunde (Belgian Astronomical Association)
W	(1) Watt; (2) West
WAAS	Wide Area Augmentation System (GPS/North-America)
W/m^2	Watt per square meter
WAVES	Radio and plasma wave investigation (WIND, STEREO)
WCCOS	World Calibration Center for Ozonesondes
WDC	World Data Center
WFOV	Wide Field Of View
WG	Working Group
WGCV	Working Group on Calibration and Validation
WGN	Werkgroepnieuws (Working Group News, bimonthly journal of the IMO)
WHISPER	Waves of High Frequency and Sounder for Probing the Earth's Radiosphere
WL	White Light
WMO	World Meteorological Organization
WP	Work Package
WPI	Wave-Particle Interactions
WRC	World Radiation Center
WS	Workshop
WSA	Wang-Sheeley-Arge (model for solar wind)
X-band	Radio frequency band from 8-12 GHz
X-class flare	Extreme x-ray flare
XRT	X-Ray Telescope (Hinode)
Zpc	McIntosh sunspot classification, where ‘Z’ is the modified Zurich class, ‘p’ describes the penumbra of the principal spot, and ‘c’ describes the distribution of spots in the group’s interior
ZTD	Zenith Total Delay