Sentinel-5P in the Copernicus Ecosystem

Welcome. In this video, we explore Sentinel-5P, the atmospheric monitoring mission of the Copernicus Earth Observation Programme. The Copernicus programme includes a family of satellite missions, each focused on a different aspect of Earth observation. Sentinel-1 focuses on radar observations of the surface. Sentinel-2 provides high-resolution multispectral optical imagery of land cover. Sentinel-3 observes large-scale environmental dynamics, including surface temperature and ocean conditions. Sentinel-5P addresses a fundamentally different domain: the composition of the atmosphere itself.

Operational since 2017, Sentinel-5P is dedicated to delivering high-precision, global measurements of key atmospheric constituents, including both pollutants and greenhouse gases. Its data supports applications in air quality management, climate research, urban planning, and agriculture. While the other Sentinel missions primarily observe what is on or near the surface, Sentinel-5P observes what is above it, providing the atmospheric dimension of environmental intelligence within the Copernicus programme.

The TROPOMI Instrument

At the core of Sentinel-5P is the TROPOMI instrument, which stands for Tropospheric Monitoring Instrument. TROPOMI is an advanced spectrometer capable of measuring the concentration of a wide range of atmospheric components across the entire globe. Its spatial resolution of approximately seven by seven kilometers makes it one of the most detailed atmospheric sensors currently in orbit. Unlike earlier instruments that focused on specific gases or geographic regions, TROPOMI provides continuous global coverage and delivers a comprehensive view of atmospheric composition on a daily basis.

The components measured by TROPOMI include ozone, nitrogen dioxide, methane, carbon monoxide, sulphur dioxide, formaldehyde, aerosols, particulate matter, and water vapor. Each of these plays a specific role in atmospheric chemistry, air quality, and climate dynamics. Together, they form a complete picture of atmospheric state that no single previous instrument could provide with this level of spatial detail and global consistency. This breadth of measurement is what makes Sentinel-5P uniquely valuable within the Copernicus architecture.

Atmospheric Components Monitored by Sentinel-5P

Nitrogen Dioxide, Sulphur Dioxide, and Formaldehyde

Nitrogen dioxide, or NO2, is one of the primary pollutants tracked by Sentinel-5P. It is produced mainly by combustion processes, including vehicle emissions, industrial activity, and fossil fuel combustion. Elevated NO2 concentrations are most commonly found in urban environments, where transportation and energy consumption are concentrated. Beyond its direct health effects, which include respiratory and cardiovascular problems, NO2 plays a key role in the formation of ground-level ozone through chemical reactions with other atmospheric compounds in the presence of sunlight.

Sulphur dioxide, or SO_2, is emitted by volcanoes, power plants, and various industrial processes. It is harmful to respiratory health and also reacts in the atmosphere to form acid rain, which can damage ecosystems and infrastructure. Monitoring SO_2 concentrations is therefore particularly valuable in regions with active volcanic activity or significant industrial emissions. Formaldehyde, or HCHO, is another pollutant measured by TROPOMI. It is a significant precursor of ground-level ozone and a contributor to atmospheric pollution in industrial areas. Monitoring formaldehyde is essential for understanding the chemical dynamics of atmospheric pollution and the processes that drive ozone formation.

Methane and Carbon Monoxide

Methane, or CH_4, is one of the most important greenhouse gases tracked by Sentinel-5P. Despite being present in the atmosphere in smaller quantities than carbon dioxide, methane has a significantly higher warming potential. Emissions originate from a variety of sources, including livestock farming, rice paddies, landfills, and oil and gas production. By detecting methane hotspots at global scale, Sentinel-5P provides critical data for climate modeling and emissions monitoring, enabling policymakers to identify emission sources and target mitigation efforts more effectively.

Carbon monoxide, or CO, is a colorless, odorless gas produced mainly by combustion processes, including wildfires, biomass burning, and fossil fuel use. Measuring CO concentrations across large areas provides insights into both urban pollution levels and large-scale combustion events. Historical CO data, for instance, allows researchers to track changes in the intensity of wildfires and the impact of biomass burning events over time, making it a valuable variable for both air quality assessment and climate research.

Ozone: Stratospheric and Tropospheric

Ozone, or O_3, plays a dual role in the atmosphere and must therefore be interpreted carefully depending on where it is found. In the stratosphere, the ozone layer absorbs harmful ultraviolet radiation, protecting life on Earth. This protective function makes stratospheric ozone monitoring important for assessing the long-term health of the ozone layer. At ground level, however, ozone is a harmful secondary pollutant. It is formed when nitrogen dioxide and volatile organic compounds react in the presence of sunlight, contributing to smog and causing adverse effects on both human health and vegetation. Sentinel-5P monitors both stratospheric and tropospheric ozone, providing data to track ozone layer conditions while also identifying areas where surface ozone poses a risk to health and ecosystems.

Aerosols, Particulate Matter, and Secondary Aerosols

Aerosols are fine particles suspended in the atmosphere, originating from dust storms, wildfires, volcanic eruptions, and industrial emissions. They have significant effects on both climate and air quality, influencing cloud formation, reflecting solar radiation, and altering the Earth's energy balance. Sentinel-5P measures aerosol optical thickness, or AOT, in both the near-infrared and shortwave infrared spectral bands. AOT is a dimensionless coefficient that quantifies the amount of aerosol present in the atmosphere: higher values indicate higher concentrations. These measurements are particularly valuable for climate modeling, as they help scientists understand how aerosols interact with incoming solar radiation and affect cloud formation processes, two factors that directly shape the energy exchange between the atmosphere and the surface below.

The size distribution of aerosol particles is also analyzed, since particles of different sizes behave differently in the atmosphere. Fine aerosols can remain suspended and travel longer distances, while larger particles tend to settle more quickly, a distinction that matters both for air quality assessment and for understanding the geographic reach of pollution events. Sentinel-5P also provides data on secondary inorganic aerosols, including sulfates, nitrates, and ammonium. These compounds are formed in the atmosphere through chemical reactions between gases such as sulphur dioxide and nitrogen oxides with water vapor. Monitoring them allows a more complete understanding of how pollution sources contribute to overall atmospheric composition.

Particulate matter, classified by size as PM10 and PM2.5, is another critical variable. Fine particles are of particular concern because they can penetrate deep into the lungs and enter the bloodstream, contributing to respiratory and cardiovascular diseases. Estimated concentrations, expressed in micrograms per cubic meter, help assess pollution levels across urban and rural environments, guide public health responses, and inform the design of air quality regulations aimed at protecting the most vulnerable populations.

Water Vapor

Water vapor is the most abundant greenhouse gas in the atmosphere and plays a fundamental role in weather and climate dynamics. Sentinel-5P measures total column water vapor, or TCWV, which describes the total amount of water vapor integrated vertically through the atmosphere above a given location. This measurement is essential for weather forecasting, as water vapor directly influences cloud formation, precipitation dynamics, and the exchange of energy between the surface and the atmosphere. Beyond its role in climate science, TCWV data also has practical value in agriculture, where understanding atmospheric moisture conditions supports irrigation planning, helps anticipate periods of crop stress caused by water deficit or excess humidity, and improves the management of water resources at the field scale.

Applications in Urban Environments

Urban environments are among the primary areas of application for Sentinel-5P data. Cities concentrate industrial activity, transportation, and energy consumption, making them major contributors to atmospheric pollution. Sentinel-5P provides urban managers and planners with the ability to monitor pollutant concentrations across large areas and identify the zones most affected by poor air quality.

Real-time monitoring of NO2 allows the identification of pollution hotspots, enabling targeted interventions such as traffic restrictions, clean energy transitions, or the expansion of green infrastructure. During high pollution events or wildfire outbreaks, the spatial data from Sentinel-5P allows authorities to rapidly identify affected areas and implement timely mitigation measures to protect public health. During periods of elevated ozone concentration, municipalities can issue health warnings or adjust industrial activity to protect vulnerable populations, particularly children and the elderly. Methane monitoring is also directly relevant in urban contexts, where leaks from natural gas pipelines or storage facilities can be detected and rapidly addressed, improving both safety and environmental performance.

In the longer term, tracking how pollutant levels evolve over months and years in response to regulatory changes or infrastructure investments allows decision-makers to evaluate the effectiveness of their interventions and refine urban environmental policies accordingly.

Applications in Agriculture

In agricultural contexts, Sentinel-5P data provides important insights into how atmospheric conditions affect crop health and farming sustainability. Ground-level ozone is one of the most direct threats: prolonged exposure to elevated ozone concentrations can damage sensitive crops and reduce yields. Monitoring ozone levels spatially and over time allows agricultural managers to identify areas at risk and adjust harvest schedules or farming practices to minimize damage before it becomes economically significant. More broadly, air quality data from Sentinel-5P can support decisions on irrigation scheduling, soil management, and crop stress assessment, helping farmers anticipate how atmospheric conditions might affect their land and plan accordingly.

Elevated levels of NO2 can also signal atmospheric pollution that affects soil health and crop development, and when sustained over time, such air quality trends can become a direct risk factor for vegetation vitality. By combining Sentinel-5P air quality data with vegetation indices derived from Sentinel-2, agronomists can operationally assess whether areas showing reduced vegetation vigor are also experiencing elevated pollutant concentrations, enabling a more targeted and evidence-based approach to crop management decisions.

Methane monitoring is particularly relevant for understanding emissions from livestock farming and rice paddies. By identifying methane hotspots through Sentinel-5P data, farmers and environmental managers can target areas of excessive emissions and implement measures such as biogas capture systems or adjusted feeding practices to reduce their environmental footprint and contribute to climate mitigation goals.

Climate Research and Environmental Monitoring

Beyond urban and agricultural applications, Sentinel-5P plays an essential role in broader climate and environmental research. Long-term monitoring of greenhouse gases such as methane provides scientists with the data needed to assess emission trends, understand how human activities are altering atmospheric composition, and develop projections for future climate conditions. This long-term observational record is one of the most valuable outputs of the mission, as it transforms individual measurements into a continuous archive of atmospheric change.

Aerosol monitoring contributes directly to climate science, since aerosols influence cloud formation and the Earth's energy balance by reflecting and absorbing solar radiation. Understanding the distribution and concentration of aerosols at different atmospheric levels is essential for improving the accuracy of climate models. In regions affected by intense dust storms, wildfires, or volcanic activity, aerosol data from Sentinel-5P provides situational awareness that supports both scientific analysis and operational response.

Visualization in EagleArca: The Air Quality Layer

Within the EagleArca platform, Sentinel-5P data is made available through the Air Quality layer. This layer provides both real-time and historical atmospheric information, displayed as an interactive two-dimensional map that allow users to observe the distribution of pollutants and track changes in atmospheric conditions over time. Each day, the platform updates the layer with the most recent data available from Sentinel-5P, providing near-real-time access to variables such as NO2, methane, CO, ozone, and SO2 concentrations. This daily update capability is particularly valuable for operational monitoring and public health management. In cases of high pollution events or wildfire outbreaks, the data allows rapid identification of affected areas and supports timely mitigation responses.

Equally important is the access to historical data. As Sentinel-5P continuously acquires atmospheric observations, EagleArca archives this information and makes it available for time-series analysis. Users can examine how pollutant concentrations have evolved over periods ranging from days to years, observe the seasonal progression of ozone or methane on a month-by-month or year-over-year basis, monitor long-term trends in greenhouse gas concentrations across specific regions, and verify whether air quality measures or emissions regulations implemented over time have produced measurable, quantifiable improvements. This depth of temporal context transforms the Air Quality layer from a snapshot tool into a genuine decision-support environment, one capable of sustaining ongoing environmental assessments and informing the next cycle of policy and planning decisions.

Integration with Other Sentinel Missions

Sentinel-5P reaches its full analytical potential when its data is combined with the information provided by other Copernicus missions. Within EagleArca, the Air Quality layer can be overlaid with Sentinel-2 optical imagery and vegetation indices to relate atmospheric pollution patterns to land cover and crop or forest health. For instance, combining NO2 or ozone data from Sentinel-5P with NDVI from Sentinel-2 allows analysts to assess whether areas showing reduced vegetation vigour are also experiencing elevated pollutant concentrations.

Integrating Sentinel-5P data with thermal observations from Sentinel-3 supports the study of how urban heat and atmospheric pollution interact. In dense urban environments, high sensible heat flux and elevated pollutant concentrations often co-occur, compounding their effects on air quality and human comfort. Understanding this relationship is particularly relevant for climate resilience planning, where addressing heat accumulation and air quality together produces more effective outcomes than treating them as separate problems.

Sentinel-5P and the Future of Atmospheric Monitoring

Sentinel-5P represents a critical component of modern Earth observation. Its TROPOMI instrument provides a level of atmospheric detail and global consistency that was not previously available from operational satellite systems. By tracking pollutants, greenhouse gases, aerosols, and additional atmospheric variables at high spatial resolution on a daily basis, it enables continuous environmental monitoring across a wide range of scales, from local pollution events to global climate trends.

When combined with the surface, thermal, and structural information provided by the other Sentinel missions, Sentinel-5P contributes the atmospheric dimension to a comprehensive and multi-layered picture of the Earth system. Together, these missions demonstrate how modern satellite infrastructure is enabling a new generation of integrated environmental intelligence, capable of supporting informed decision-making across air quality management, agricultural sustainability, urban planning, and climate science.