ARISE

A European research infrastructure combining three measurement techniques

Technology first used to listen for secret H-bomb tests could help forecasters tell us what the weather is going to be like up to a month in advance. That is one of the aims of an exciting new international research project, Atmosphere dynamics Research InfraStructure in Europe (ARISE), which kicked-off in January 2012. Following studies that showed that the upper layers of the Earth's atmosphere could provide crucial information for more accurate longer-term weather forecasts, on timescales up to four weeks ahead, twelve partners from eight European member states and one associated country have joined forces to combine measurements of the stratosphere and mesosphere taken by three different kinds of instruments.

The ARISE project aims to revive existing collaborations among European scientists while developing and integrating, for the first time, a large set of complementary topics such as infrasound, gravity and planetary waves, stratosphere and mesosphere disturbances, satellite atmospheric studies and modelling of the atmosphere, and atmospheric dynamics. It is expected to bring much progress in atmospheric modelling, weather forecasting and the monitoring of extreme events relevant to civil security applications. It will provide new 3D images of the atmospheric state and its spatial and temporal variability.

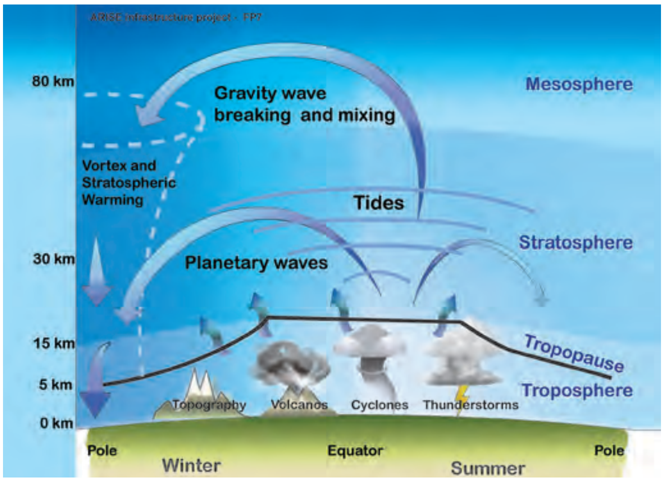
Atmospheric dynamics

For a long time the atmosphere was considered a stratified medium with negligible interactions between the upper layers and the troposphere in which we live. However, recent studies have revealed the key role that dynamics in the middle and upper atmosphere can play in both tropospheric weather and climate. Atmospheric oscillations, particularly gravity and planetary waves, drive this interaction and much of the large-scale atmospheric global circulation systems in the middle and upper atmosphere, including the Brewer-Dobson Circulation and Quasi-Biennial and Semi-Annual Oscillations.

Atmospheric waves carry energy and momentum from one region to another. The origin and dynamics of planetary and gravity waves are very different. Planetary waves owe their existence to the equator to pole gradient of potential vorticity and are produced by flows over orography and between land and ocean due to contrasts in temperature. They are most important in middle and high latitudes and can lead to dramatic deviations of flows from their climatological means. Understanding the location and structure of shear-zones in the mean-flow where planetary waves break is critical to the understanding and prediction of sudden stratospheric warming events. High-resolution observations of the stratosphere could greatly improve our understanding of these so-called "critical" layers.

Gravity waves are more ubiquitous and exist in a range of spatial scales from planetary to a few kilometres. They are produced both by flow over orography and by strong convection, for example, due to thunderstorms. Gravity waves play an important role in setting the mean climate of the stratosphere and mesosphere and in generating the predictable tropical oscillations of mean wind speeds, which can enhance the predictability of the climate system. Most small-scale gravity waves are not resolved by typical climate models and only partially resolved by weather forecasting models. Climate models, therefore, must parameterize gravity waves to ensure an accurate simulation of middle and upper atmosphere mean climate and variability. Many parameters of the gravity wave parameterizations are uncertain due to a lack of long-term high-resolution observations.

The amplitudes of the atmospheric tides are large in the middle atmosphere. Tides generated by stratospheric ozone and by the water vapour in the upper troposphere, can induce some systematic difference between non-simultaneous measurements and represent a key issue for satellite validation and long-term variability when times of measurements change. Though tidal theory is well-established, exact amplitude and phase characteristics have not yet been characterized as few measurements can observe them. ARISE measurements will allow the validation of tidal simulations with numerical models that will be used for systematic corrections of satellite comparisons and trend estimates.



Dynamics of the troposphere-stratosphere-mesosphere exchanges including contribution of gravity waves and planetary waves

Project concept

The ARISE Design Study will conceptualize a new infrastructure that integrates different atmospheric observation networks to provide a new 3D image of the atmosphere in each atmospheric layer from the ground to the mesosphere with unprecedented spatio-temporal resolution. The project will cover Europe and outlying areas, including polar and equatorial regions.

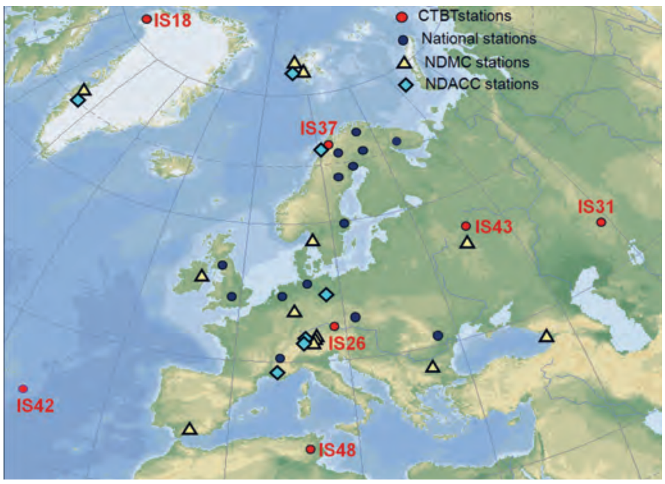
The infrastructure will include the infrasound networks developed for verification of the Comprehensive Nuclear Test Ban Treaty, the Network for the Detection of Atmospheric Composition Change – using LIDAR (LIght Detection And Ranging) – and the Network for the Detection of Mesopause Change, dedicated to airglow layer measurements in the mesosphere. It will also include the complementary infrasound stations of various countries, specific infrasound stations located near volcanoes for volcanic source studies and ionospheric arrays to determine coupling with near Earth space.

Data collected by these multiple networks will be analyzed to extract an optimized estimation of the evolving state of different atmospheric layers, which would help to constrain the parameterization of gravity waves and to better initialize forecasts of the middle and upper atmosphere.

Airglow spectrometer installed at the Schneefernerhaus near the summit of Zugspitze

The expected benefits would be a better description of the atmosphere and an improved accuracy in short- and medium-range weather forecasts. ARISE measurements will also be used to improve the representation of gravity waves in stratosphere-resolving climate models, crucial to estimating the impact of a range of stratospheric climate forcing on the troposphere. The data will be used for monitoring middle atmosphere climate, its long-term mean trends and changes in extreme events. The benefits also include civil applications related to monitoring of natural hazards.

The ARISE Design Study aims to integrate and coordinate scientific communities that have never previously worked



Map of stations that participate in the ARISE project together and to design a large infrastructure that adds significant value for understanding the atmosphere. A large part of the project is dedicated to defining the specifications of new high added value observational parameters that can be derived from different measurement techniques. It also integrates studies and simulations based on data used for modelling the atmosphere and weather and climate forecasting.

Societal impacts and benefits

The monitoring of the Earth's atmosphere with data from vanguard technologies using infrasound, LIDAR and airglow measurements offers a wide range of civil security applications that may contribute to human welfare and safety. The ARISE project's collection of advanced data relative to the following phenomena will be used for monitoring extreme events and for civil security applications.

Volcano monitoring and aviation safety

Measurements of infrasonic atmospheric waves is of importance for monitoring volcanoes and extreme events. Monitoring infrasound from volcanoes provides relevant information about ash injection in the atmosphere when satellite information is not available because of cloud coverage. The International Airways Volcano Watch Operation Group, supported by the International Civil Aviation Organization, encourages the improvement of tools for detecting and forecasting of volcanic ash. The Group recognizes the interest of the infrasound technology for such a purpose.

The global density of infrasound stations is steadily increasing and signals from volcanic activity are routinely recorded. The characteristics of the detected signals, and the maximum range for observing these signals, depend on the type of eruption, which are either effusive or explosive in their behaviour. Large eruptions sometimes release significant amounts of ash into the upper atmosphere. The geographical region covered by the ARISE project encompasses volcanoes located in Europe (Italy, Iceland) and Africa (Tanzania, Democratic Republic of Congo, Comoros and La Réunion). In addition, temporary portable infrasound arrays installed near the crater of active volcanoes will provide important observations and measurements. These data should help the scientific community to better understand the specificity of individual volcanoes, and should improve the participation of Europe in volcano warning systems.

With the future completion of the International Monitoring System (IMS) Infrasound Network complemented by

Infrasound experiment at Yasur volcano, Tanna island, Vanuatu national facilities, the objective of providing low-latency volcanic explosion detection notifications to Volcanic Ash Advisory Centres will be more attainable. Such early warning systems may help to prevent eruption disasters and mitigate the impact of ash clouds on aviation.

Mass movements of the Earth's surface

The utilization of ARISE infrasound data to study natural hazards related to massive earth displacements – earthquakes, landslides and avalanches – is also relevant for civil security applications.

Infrasound technology detects and localizes surface Earth motion. Infrasound intensity maps that characterize large earthquakes may help to identify populated regions that are at high disaster risk. For specific events, a detailed signal analysis could be performed to identify the location of the ground-to-air coupling sources and these could be compared with seismic intensity maps.

Risk assessment of snow avalanches is mostly related to weather conditions and snow cover. Avalanche risk forecasting based on snow modelling is still at an early stage and requires objective avalanche observation for validation. This observation is mostly visual but for several years now it has been complemented by experimental seismic detection. Avalanche observation would, therefore, greatly benefit from infrasound as it is the only technology able to detect the pressure transients produced by avalanches. ARISE will analyse hundreds of signals detected by infrasonic arrays deployed in the Alps to assess whether it is possible to unambiguously identify avalanches. This could have a large impact on the forecast modelling and risk management community worldwide.

During the course of the ARISE project, portable equipment may also be deployed in the Alps for measuring the characteristics of infrasound signals produced by natural and artificial snow avalanches. Avalanche experiments are conducted in several test sites located in Switzerland and Austria every year. The ARISE project may be used to reinforce the work of civil engineering teams specialized in avalanche danger management. The detection and location of avalanches may complement human observations, confirming the occurrence of events when visibility conditions are poor such as in remote mountainous areas, in bad weather conditions or at night time. A better understanding of avalanche infrasound signatures may also help to identify and provide advance notice of non-observable sequences related to instability in the snow cover that could be precursors of major episodes – similar in manner to the seismic foreshocks observed before major earthquakes.

Severe weather

The data collected from infrasound, LIDAR and airglow networks should help to improve understanding of upper atmosphere properties and their variability in time. Centralized in a database, this information would provide a unique dataset for continuous and long-term monitoring of the intensity and evolution of extreme events from severe storms to tornadoes and cyclones.

The Eurosprite campaigns, started in several countries in 2005, use optical cameras and complementary instruments to detect transient luminous events (sprites) that occur in the middle atmosphere above large thunderstorms. In line with the campaigns, ARISE ground-based observing facilities are introducing additional techniques for measuring the signature of sprites and using infrasound to investigate the mechanisms that generate lightning and sprites.

ARISE proposes to determine the parameters that would best characterize these severe weather phenomena. In the long-term applications, ARISE network observations could be included in existing meteorological models in order to improve the accuracy of short- and medium-range weather forecasts.

The monitoring of extreme events such as thunderstorms and cyclones is also important to determine the evolution of such events with climate change.

Oscar Van der Velde

South Dakota, US, thunderstorm, 28 May 2006

Meteorites

The explosion of large meteorites in the atmosphere – though rarely impacting the Earth's surface – are often reported by eye-witnesses or recorded by all-sky cameras. The ARISE infrasound network can perform continuous monitoring of the entry of such large space objects into the atmosphere.

Infrasound is increasingly contributing to the observational data for meteor events. On a global scale, the recurrence of exploding meteorites is about 1–2 events per month for bodies 1 meter in diameter and 1 per decade for bodies 10 meters in diameter. The largest events may be detected at distances of up to thousands of kilometres, as shown by the Sulawesi event detected by the IMS infrasound network in October 2009.

The dense coverage of the ARISE infrasound network should be able to detect and characterize any significant meteor explosion occurring in the European region. Single infrasound detections bring statistical information about large fireballs, and contribute to the databases on extraterrestrial objects that collide with the Earth. The results may become even more interesting when observations from other regional networks become available and allow constraining or reconstruction of the trajectory of the source meteors.

Success apparent

The success of ARISE is already apparent from the increasing number of associated members and links with international groups involved in climatological and environmental studies. Some recent phenomena have been observed by ARISE partners which demonstrate the relevance of its measurements. The fist relates to a major sudden stratospheric warming event that took place in the period from December 2012 to January 2013: three ARISE instruments installed at the Haute Provence Observatory revealed that there can be a temperature difference of 20°C between models and observations.

The other relates to the increased activity of the Etna volcano in January 2013, observations of which are now being thoroughly analyzed in order to improve infrasound monitoring of remote volcanic regions. Results emanating from the analysis of ARISE observations will help to describe the global dynamics of such complex large scale events, and this will increase the use of ARISE data and results for modelling the mechanisms of such events and their impact on weather.

The expansion of ARISE into Africa also provides exceptional coverage from equatorial to Polar Regions.

More information about the project can be found at http://arise-project.eu

Howard Edin

A meteorite falling through the atmosphere