Dimitar Ouzounov

Atmospheric signals could act as precursory warnings of an earthquake

- Earthquakes are notoriously difficult to predict, yet their impacts can be catastrophic.
- The international scientific community is working together to identify key signals both on Earth and in space that might act as precursors to future earthquakes.
- Dr Dimitar Ouzounov at Chapman University, USA, studied the lithosphere-atmosphere-ionosphere coupling (LAIC) associated with earthquake preparation processes.
- It revealed the synergy of six physical parameters of the atmosphere and ionosphere, including radon emissions and air temperature.
- By studying these precursory signals, scientists are gaining a better picture of pre-earthquake processes, providing hope for predicting some of the most challenging and devastating natural hazards on our planet.

A 7.8-magnitude quake hit southern Turkey and northern Syria on 6th February 2023, killing more than 40,000 people and decimating entire cities.

Predicting earthquakes is notoriously challenging, but their effects can be devastating. We only need to look back to recent history, when the magnitude 7.8 earthquake shook Turkey on 6th February 2023 to see the thousands of lives lost and extensive economic damage caused. It is imperative that we gain as much advance warning of impending earthquakes as possible to minimise human and economic loss. So how can the international scientific community detect pre-earthquake phenomena that might reduce the tragedy?

Precursors to a tragedy

In 2015, the magnitude 7.3 and 7.8 Gorkha-Nepal earthquakes were caused by a sudden slip along the fault line between the Indian and Eurasian Plates. The power of the shift in the Earth's surface instigated avalanches on Mount Everest and left more than 17,800 people injured, while over 8,600 people sadly died. Dr Dimitar Ouzounov at Chapman University, USA, and collaborators have discovered new evidence which may provide precursory clues of an earthquake, and indeed provided early warnings before these devastating events.

In 2014, the team began testing the Sensor web approach, which uses a network of satellites and ground observations to detect changes in the atmosphere which have been linked to pre-earthquake phenomena. Satellite data can provide evidence of thermal anomalies in earthquake-prone areas. Ouzounov originally tested the parameter on data from Japan, which revealed satellite radiation anomalies several days before M5.5 earthquakes occurred in 2015. The subsurface was on the move.

On 25th April 2015, a M7.8 earthquake shook Nepal, only 200km south of where the thermal anomalies had been detected. Just weeks later, data suggested that the area was not safe yet, and a rapid increase in radiation occurred from Earth's atmosphere near the future epicentre of an aftershock. Additionally, Ouzounov identified a strong anomaly in the outgoing longwave radiation in early May, before the M7.3 earthquake on 12th May. Perhaps these parameters should be considered pre-earthquake phenomena that need to be monitored across the world where earthquakes pose a significant risk.

Geospace weather and earthquakes

Beyond our planet, Ouzounov suggests that earthquake precursors may be impacted by the geospace, too. Among scientists, there is an understanding that solar activities and geomagnetic storms (when solar wind interacts with the magnetic field around Earth) could potentially affect seismicity. But how?

In March 2015, a geomagnetic storm occurred, just 39 days before a Nepalese

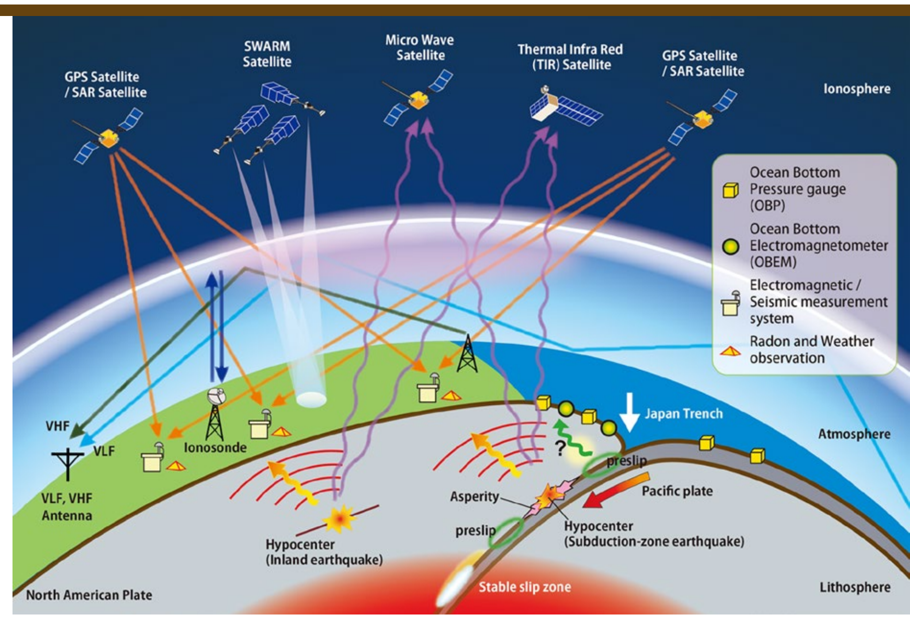

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Fig 1 The 2018 Sensor Web integration concept of multi-satellite, GNSS, and ground observations (case study for Japan), proposed for detecting atmospheric boundary layer modification linked to pre-earthquake phenomena.

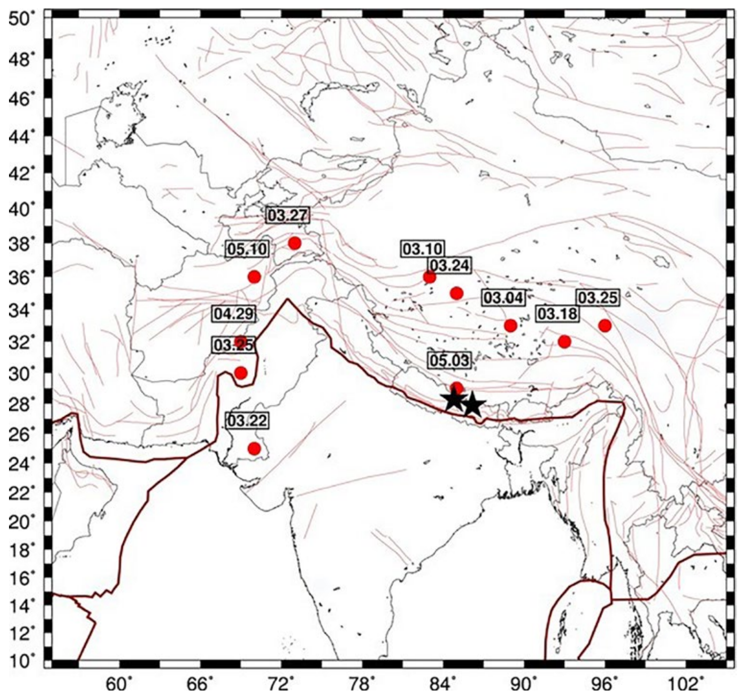

Fig 2 'Dance of Anomalies': Spatial distribution of Thermal Radiation Anomalies (TRA), March-May 2015. Black stars depict the epicentres of M7.8 (25th April 2015) and M7.3 (12th May 2015).

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M7.4 earthquake. Ouzounov needed to test whether similar patterns could be seen for other earthquakes. On St Patrick's Day (17th March) in 2013 and 2015, geomagnetic storms were detected. Shortly after each storm, major earthquakes were observed: M7.7 in Iran on 16th April 2013 and M8.3 beneath the Sea of Oshotsk on 24th May 2013. Similarly, there was a M7.8 earthquake in Nepal on 25th April 2015 and M7.8 in the Pacific Ocean on 30th May 2015. Are these coincidences, or does the science suggest a connection?

The timing of the geomagnetic storms is important. In 2013, the storm began at 06:04 UT and at 04:48 UT in 2015. At these times, the locations of the future earthquakes were positioned close to the polar cusp, which is the area on Earth's surface where the solar wind plasma has direct access to the environment. Similarly, the Turkish M7.5 and M7.8 earthquakes experienced in 2023 were proceeded by a geomagnetic storm in November 2022, with the future epicentres located beneath the magnetic polar cusp.

Solar storm facilitates major earthquakes

It has been known for many years that the solar wind plays a crucial role in the Solar System

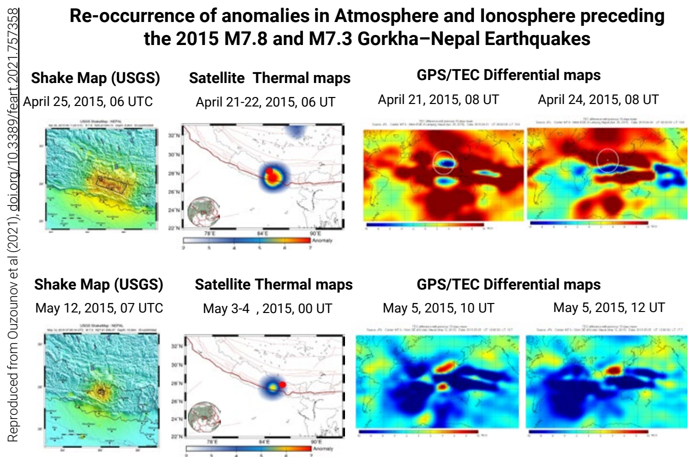

Fig 3 Thermal radiation anomalies and GPS /TEC anomalies observed before the M7.8 and M7.3 earthquakes in Nepal (top and bottom left) as well as shake maps (USG) from the day of the earthquake.

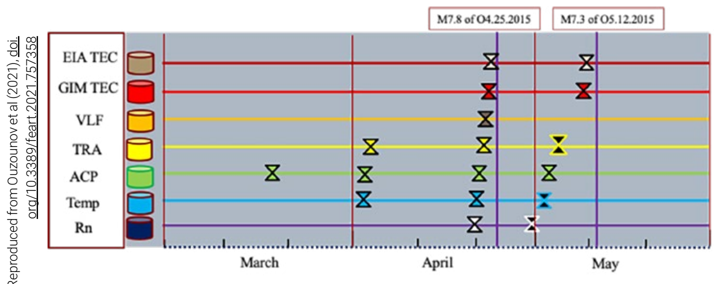

Fig 4 Time diagram of multiparameter precursors analysis. Analysed parameters include (bottom-up): Rn (Radon gas); Temp (Meteorological Atmospheric temperature); ACP (Atmospheric chemical potential); TRA (Thermal Radiation Anomaly); VLF (Vert low Frequency); GIM TEC (Global Ionospheric Model, Total Electronic Contents); EIA TEC (Equatorial Ionospheric Anomaly, Total Electronic Contents).

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and in controlling the effects of space weather on Earth. Previous studies have suggested that solar wind increases the atmosphere's mass, which may in turn impact Earth's rotation – subtle changes that could have big implications for the movement of Earth's crust. Other studies have suggested solar radiation may impact the earthquake preparation processes, where solar flare radiation is absorbed by the ionosphere, strengthening the electric current which then runs through Earth's continents and oceans (known as the telluric current) by two to three orders above average. In fact, experiments have even shown that electromagnetic currents can trigger weak earthquakes after researchers injected artificial electric pulses into Earth's crust in the earthquake-prone areas of Pamir and Northern Tien Shan.

Ouzounov further tested the possibility of space weather influencing earthquake process by analysing global seismic activity between 2013 and 2015. Ten other earthquakes with magnitudes greater than 7.5 were found to have followed a geomagnetic storm some days to months prior, with the epicentres located beneath the polar cusp. The reason for the delay between the solar storms and the earthquakes is still being investigated, but the current hypothesis is that solar wind influences the movement of fluids in the outer core, which strongly influences tectonic earthquakes.

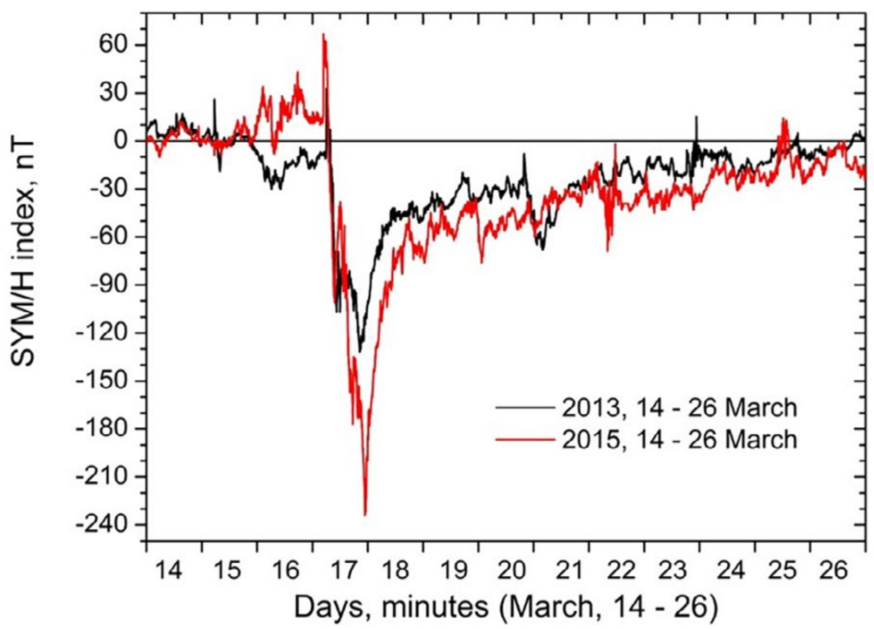
Linking Earth's systems

After earthquakes, there is a plethora of data available for analysis to better understand the processes leading up to the event. Of these, six physical parameters associated with the atmosphere and ionosphere (part of Earth's upper atmosphere where ultraviolet rays and x-rays ionise atoms to form electrons) were assessed by the team for their ability to act as precursors for earthquakes. The parameters included outgoing longwave radiation at the top of the atmosphere, very low-frequency signals at seismic wave receivers, GPS/TEC (total electron content between a satellite and receiver), radon gas emissions, atmospheric chemical composition, and air temperature.

How are these changes linked to an earthquake? Well, the Earth is one interconnected system. Near an active fault, radon gas emissions escaping from the fractured rocks cause ionisation of the air. This process heats the air, creating a temperature anomaly. Warmer air rises by convection, which then also creates a detectable pressure anomaly. This is known as the lithosphere-atmosphere-ionosphere coupling (LAIC) mechanism.

Hope for the future

The Earth is a dynamic system, and understanding more about how small imbalances could warn us of an impending earthquake is crucial to minimise economic damage and human loss. By studying precursory signals, scientists are gaining a better picture of pre-earthquake processes and the interactions between the lithosphere and space, providing hope for predicting the most challenging and devastating of all natural hazards on our planet.



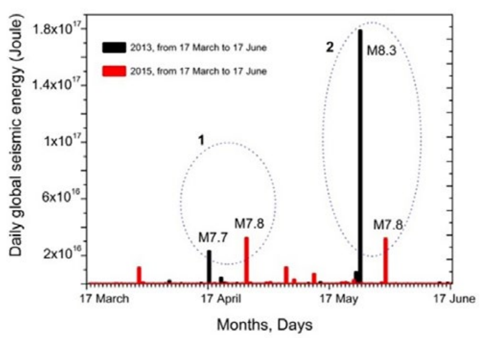


Fig 5 Left: 1-min geomagnetic SYM/H index for 14–26th March in 2013 (black) and 2015 (red) from the database OMNI. Right: The histogram of released seismic energy at the globe per day from 17th March to 17th June 2013 and 2015 (black and red columns, respectively) were estimated using data on M ≥ 4.5 from the USGS seismological catalogue.

Personal response

What inspired you to conduct this study?

In 1999, I started supporting the new NASA satellite MODIS (Moderate Resolution Imaging Spectroradiometer) mission to study global atmospheric interaction and climate. Shortly after that, on 26th January 2001, a major earthquake, M7.6, occurred in Gujarat, India. More than 20,000 people died. Having a background in earthquake studies, I checked the new satellite data for any unusual signals related to the earthquake. Indeed, I did find an anomaly in the thermal bands of MODIS, which occurred days before the earthquake in India. The new results were reported at the 2002 conference. The same year, another devastating earthquake hit, this time in Italy. On my way to work, I listened to live public radio reporting from San Giuliano di Puglia, Southern Italy. A nursery school had collapsed entirely on itself after an M6 earthquake, trapping 56 children, their teachers, and two janitors inside as they celebrated Halloween. At that moment, I realised that my new research could help the future development of early warnings for mitigating earthquake hazards. That is why and how I started doing these studies.

How easy is it for scientists to monitor these parameters in real time to predict earthquakes across the world?

The reporting of physical phenomena before large earthquakes has a long history. Fogs, clouds, and animal behaviour have been recorded since the days of Aristotle in Ancient Greece, Pliny in Ancient Rome, and multiple scholars in ancient China. Unsurprisingly, a large accumulation of stress in the Earth's crust would produce precursory signals. By observing possible lithosphere-atmosphere coupling, we could improve our understanding of the lead-up to earthquakes at global scales. We also found that no single existing method for precursor monitoring can provide reliable short-term forecasting on a regional or global scale, probably because of the diversity of geologic regions where the seismic activity occurs and the complexity of earthquake processes. We found that the solution is multidisciplinary observation. Our international collaborative work found that reliable detection of pre-earthquake signals associated with major seismicity (magnitude greater than 6) could be done only by integrating space- and ground-based observations. However, a significant challenge for using precursor signals for earthquake prediction is gathering data from a regional or global network of monitoring stations to a central location and conducting an analysis to determine if, based on previous measurements, they indicate an impending event. In addition, detecting pre-earthquake phenomena requires cross-border cooperation and integrated observation, which is not always successful.

Do you have any hypotheses as to why there might be a delay between solar storms and earthquakes?

We hypothesise that such a time delay could appear if the sudden solar wind influences the upward lifting of fluids in the outer core, which are active contributory participants in tectonic earthquakes. We do not yet know what happens to fluids at the depth of the earthquake source, but we can anticipate that sometimes the fluid dynamics effects manifest themselves at the Earth's surface. If this hypothesis proves accurate, we must understand that fluid uplifting in the outer core happens predominantly only in the time sector of a cusp, transitional change. To address this, we looked at the CHAMP and DMSP satellite's discovery that the density of the neutral atmosphere in the solar penetrative cusp funnel continuously increases, on average, by one and a half times relative to the density in neighbouring areas. That suggests that the rise of thermosphere gases occurs most effectively in the solar storm polar cusp funnel, and the processes in different geospheres are electromagnetically interconnected. Then, the upward surge of intra-terrestrial fluids (gasses) can also occur along the bundle of these specific geomagnetic lines, evolved from the solar storm penetration, and earthquakes will occur 'targeted' at the footprint of these variable geomagnetic lines. The journey of intra-terrestrial fluids from the deep Earth, outer mantle, as they move upward creates fractures, mainly in the upward direction. These fractures then serve as conduits through the solid lithosphere for the liquid rise. When these fluids reach near-surface pressure, they transform into gases such as methane, carbon dioxide, hydrogen, and various trace gases like radon, which is well observable on the Earth's surface (Ouzounov and Khachikyan, 2024a).

Finally, we came to understand the processes behind the 'dance of anomalies' phenomena that we observed. According to the LAIC concept, during the last stage of earthquake genesis, we observe the activation of faults within the earthquake formulation zone, leading to increased emanation of gases such as carbon dioxide, methane, hydrogen, and helium as well as radon. Radon, due to its radioactivity, produces air ionization, which causes a relative drop in air humidity because of the water vapor condensation on ions. Then, the latent heat release rises, and air temperature grows. The additional heat flux due to the latent heat release could be registered in the 'long wave' part of the infrared emission within the transparency window of the atmosphere, with a range of 8–14 μf, observed from the satellites (Pulinets and Ouzounov, 2011). Multiple satellite-observed thermal anomalies, representing the 'dance of anomalies', have revealed the intensified deep fluid migration from the outer core up to the Earth's surface and the consequent release of gases.

Details

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Collaborators

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Bio

Dr Dimitar Ouzounov is a Research Professor in Geophysics at the Institute for Earth, Computing, Human and Observing (Chapman University, USA). He has researched Earth systems science and natural hazards. His work on Earth's lithosphere-atmosphere-ionosphere coupling has unlocked a new phenomenon, showing how geospheres interact with significant earthquakes and other natural disasters.

Further reading

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