NEMO - A GLOBAL NEAR REAL-TIME FIREBALL MONITORING SYSTEM

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Proc. 1st NEO and Debris Detection Conference, Darmstadt, Germany, 22-24 January 2019, published by the ESA Space Safety Programme Office
Ed. T. Flohrer, R. Jehn, F. Schmitz (http://neo-sst-conference.sdo.esoc.esa.int, January 2019)

ABSTRACT

NEMO is a global NEar real-time MOnitoring system for bright fireballs. It is under development and consists of an alert system based on social media. Its aim is to combine as much information as possible from all available data sources. This way, the maximal amount of knowledge can be achieved for a fireball event. The utilized sources range from witness reports to infrasound data.

The knowledge about the fluxes and characteristics of extra-terrestrial objects in the intermediate size range is still not complete. The gap between large meteoroids and small asteroids has to be closed. This is one of NEMO's goals. These objects are the ones that cause bright fireballs. This intermediate-sized range has to be considered for space safety. In addition to the natural meteoroids and asteroids, space debris has to be taken into account for these considerations. Re-entering debris can also cause bright fireballs. To study these re-entries, NEMO's monitoring system can also be used. For every fireball it is planned to analyse if the entering object was of natural origin or man-made.

This paper will give an overview on proposed synergies between NEMO and debris re-entry detection.

1 INTRODUCTION

A large amount of extra-terrestrial material reaches the Earth every day: interplanetary dust, meteoroids, or asteroids with a total of about 54 tons on average [8]. Meteors are usually results of these objects entering our atmosphere with high velocities from about 11 km/s to up to above 72 km/s. If these objects are large enough they can produce very bright meteors, which are called fireballs. If space debris re-enters the atmosphere it can also cause bright and long-lasting fireballs which look quite spectacular, especially due to the characteristically strong fragmentation and the joint onward flight of the fragments.

Enhancing the knowledge of the fluxes and characteristics of this extra-terrestrial material is one aim of the introduced system called NEMO. The NEar real-time MOnitoring system has been developed since August 2017 and its goal is to be a global near real-time fireball monitoring system. Several ground-based networks exist for meteor and fireball observations, but so far, there is no world-wide database of events. Furthermore, different data sources have to be combined to reach the aspired coverage since most of them only cover a part of the Earth's surface. Additionally, the aim is to maximize the amount of scientific knowledge by combining all available data.

NEMO's goal is to collect information on intermediate-sized objects. These objects regularly impact the Earth's Atmosphere. They are too small to be detected by the NEO surveys, but big enough to cause bright fireballs. The idea is to close the gap between large meteoroids and small asteroids, taking space debris into account. The fluxes and characteristics of objects in this intermediate size range are still not well known but are an important factor that has to be taken into account for space safety considerations.

Social media is a source for very fast information. NEMO contains an alert system, which is still being tested and improved, based mainly on these media. It yields world-wide information but is biased towards highly populated areas and daytime events. A relatively unbiased source is the infrasound detection system from the International Data Centre (IDC) using data from the International Monitoring System (IMS) that are part of the CTBTO (Comprehensive Nuclear-Test-Ban Treaty Organisation). It is designed to be a global continuous covering system. The infrasound stations can detect the energy released by entering extra-terrestrial or re-entering terrestrial objects as shown by e.g. [17], [5], [13], etc. In addition to these two sources - social media and infrasound - there are various others including meteor networks and witness reports. For every captured fireball it is essential to analyse if the object that caused the phenomenon was of natural origin or if it was a re-entering man-made object.

This paper will give an overview on synergies within the NEMO project and its cooperation partners. As a demonstration, the 21 June 2018 bright daytime fireball event over Russia is analysed. This fireball caused a lot of public attention and was picked up by the NEMO alert system. Furthermore, it was recorded with at least ten infrasound stations of the IMS ranging up to about 8660 km distance from the event, allowing us to compute a source energy of about 2.4 kt TNT and a size estimation of the entering asteroid of about 4 m in diameter. Additionally, the object turned out to be of natural origin.

Section 2 gives an overview on NEMO and introduces its data sources briefly. For further information the reader is referred to [9]. Section 3 presents the NEMO events so far, during its first 15 months of operation NEMO has collected 180 events in its database. At least seven of them turned out to be re-entering space debris. A summary and conclusions are given in Section 4 and 5.

2 NEMO'S DATA SOURCES

NEMO started in August 2017. The system combines information from different data sources, from Social Media via re-entry predictions to infrasound data. The main sources will be explained briefly in the following.

2.1 Social Media

In order to be informed about fireball events in near-real time, an alert system is set up within the framework of the NEMO project. This is based on Social Media.

Especially over densely populated areas in Europe and the USA, these usually provide very fast information when a fireball has been spotted and caused public attention. Twitter turned out to be a particularly fast source of information. The Google Alert system is also used. This finds online newspaper articles, which in many cases already provide further information, for example additional reports of local experts with e.g. first velocity estimations provided by preliminary analysis of optical data. Thus, Social Media are in many cases the first source of information for a NEMO event. Furthermore, Social Media can also often be used to identify the data sources that have or may have data on the event.

The AMS/IMO (American Meteor Society / International Meteor Organisation) [2] collects witness reports for fireballs. A collaboration with NEMO is steadily growing. The AMS/IMO provides fast information regarding the time and location of a fireball. NEMO supports the IMO by writing summaries for some events which are published on the IMO homepage. These summaries include all available information of the different data sources NEMO could collect as well as the results derived from the combination of these. Further information on the AMS/IMO can be found e.g. in [11].

2.2 Local Networks

All over the world there are different meteor and fireball detection networks. Fireballs detected with these networks are usually, or can be, analysed in great detail by these networks themselves and a lot of scientific results are already available. Since these networks only observe parts of the atmosphere, it is part of the NEMO project to find out which network could have information about a fireball event and to collaborate with various networks to bundle the available information for world-wide events.

The French FRIPON (Fireball Recovery and InterPlanetary Observation Network) covers the sky over France and is extending into the rest of Europe. The network consist of all-sky cameras and is designed for fireball detection and meteorite recovery. With this network a cooperation is already well established. NEMO receives information about their detections every day. For further information about FRIPON, see [7].

In addition, local "non-meteor-specific" camera networks can be used to gather information, such as weather all-sky cameras.

2.3 Infrasound

A source of information that provides world-wide information for the major events is infrasound. NEMO's collaborations allow analysis of the data of the infrasound network of the IMS, which is operated by the CTBTO. The IMS monitors continuously and in real-time the entire Earth’s Atmosphere with the aim of detecting nuclear explosions. The system detects all kind of explosions world-wide and is therefore also able to detect fireballs as shown in various publications. The energy released by meteoroids or asteroids respectively, when they enter the atmosphere, is partially converted into a shock wave. The infrasound waves generated by the fireball impacting the atmosphere can travel over great distances. These waves can be recorded with the infrasound sensors of the IMS.

The analysis of the infrasound data allows for example the determination of the energy, and hence the size, of the impacting object which generated the fireball. For further information on meteor generated infrasound the reader is referred to the recently published review paper [18].

2.4 Further Data Sources

There are many other data sources in which information about fireballs can be found. These range from meteorological satellites (see e.g. [4], or [14]), lightning sensors (see e.g. [12]) to meteorite findings.

As a world-wide data source, the NEMO project also uses data based on events recorded by US government satellites published by NASA’s CNEOS (Center for near-Earth object studies) at JPL (Jet Propulsion Laboratory) of the California Institute of Technology. For some of the larger events, this database publishes publicly accessible information about the location, speed, and energy of the impacting object [6].

2.5 Space Debris

For each event, NEMO attempts to determine if the object, that entered the Earth’s Atmosphere, is of natural origin or man-made. If videos of the fireball were found by the NEMO alert system a first estimation can be given on a visual basis - whether it is a meteoroid or an asteroid or space debris. Space debris usually produces very long lasting fireballs which can be visible for some minutes. These fireballs are also relatively slow (with a velocity of about 8 km/s) and have various clear visible fragmentations in most cases. These fragments do not disintegrate very fast but travel close to the main body, which can cause the fireball to look like a formation of meteors following the fireball. An example is shown in Fig. 1, presenting a ATV-1 re-entry as an example.

Furthermore, NEMO events which show circumstantial evidence that they could have been caused by re-entering space debris are compared with the re-entry prediction databases of ESA [10] and Aerospace [1]. A match is usually identified by its location and time. A more detailed investigation usually requires an exact trajectory and/or visible high-quality images.

Figure 1. Fireball produced by the re-entry of space debris. The image was taken during a ATV-1 re-entry observation campaign. Image credit: ESA/Seti.

2.6 Russian Fireball

On 21 June 2018 NEMO's alert system found a fireball over Russia. The asteroid entered the Earth's Atmosphere that day at 01:15 UT (04:15 LT) near the Russian city of Ozerski and attracted much public interest by creating a particularly bright fireball. In the Social Media was a lot of activity about this event. There were many tweets and videos of dashcams available already shortly after the event. Just a little later many newspapers reported about the event.

We could conclude from the videos that the entering object was most likely of natural origin. A picture of the fireball is presented in Fig. 2. A comparison with Fig. 1 clearly shows that the Russian fireball does not show the fragmentation the way that is typical for fireballs caused by re-entering space debris, with the characteristically strong fragmentation and the joint onward flight of the fragments. Furthermore, the event was too short-lived, indicating an impacting asteroid. For an object of natural origin, the density of an asteroid can be assumed, enabling us to determine a preliminary size of the object with more precision.

Based on the combination of three videos a collaboration of researchers (Nikolai Kruglikov, Michail Larionov (Ural Federal University), Esko Lyytinen (Finnish Fireball Network), and Maria Gritsevich (University of Helsinki)) were able to compute a trajectory of the asteroid as well as a strewn field. On the basis of which meteorites could be found only four days after the event [19].

In addition, the fireball was detected with the EUMETSAT weather radar satellites [3].

The airburst created by the asteroid when entering the Earth's Atmosphere could also be detected with the infrasound sensors of the IMS. Signals in the data of ten stations could be associated to the fireball and were used to calculate a size of the entering asteroid of 4 m in diameter, or a source energy of the entering object of about an equivalent of 2.4 kt TNT.

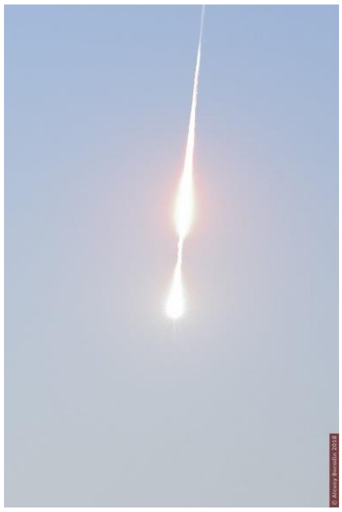

Figure 2. Photo of the Russian fireball. Image credit: Alexey Borodin.

In the course of the NEMO project an article on the AMS/IMO homepage was written about this fireball [15]. The analysis of the infrasound data of this fireball is explained in more detail in [16].

3 NEMO EVENTS

Until the middle of November 2018 NEMO's alert system has found 180 events. These are the first 1.25 years in which NEMO collected data. A world map is shown in Fig. 3 with the number of events color-coded. This map clearly shows the bias from the system towards highly populated areas and countries in which Twitter is a popular social medium. It is obvious that fireballs which occur over the sea stay undetected in most cases. Moreover, NEMO is more sensible for day-time events, since fireballs that happen during the night often do not receive public attention.

Of these 180 events, at least seven were found to be caused by space debris. They could already be classified as such after the first analysis. Either on the basis of conclusive videos of the event or through an online article, that was found by the NEMO alert system, in which the event was associated with a re-entry. In a next step, all NEMO events will be compared with re-entry prediction databases in a systematically way.

To check in more detail whether a reported event corresponds to a re-entering spacecraft we plan the following steps: We first check the ESA Discos database for objects having an estimated re-entry date corresponding to the event. Then we use the last Two-Line Elements of the object to compute the projected ground track of the object. If this ground track is close to the location of the observed event, we can estimate the time of when the object would be at this location. If this matches too, chances are high that the report corresponds to the re-entry of the object.

Figure 3. World map of NEMO events.

4 SUMMARY

Meteoroids or asteroids in the intermediate size range cause bright fireballs when they enter the Earth's Atmosphere. Re-entering space debris can also cause bright and long-lasting fireballs.

NEMO (NEar real-time MOnitoring system) is being developed at the moment and was started in August 2017 and will be a global near real-time monitoring system for bright fireballs. It will provide a world-wide database of events. To achieve this, data from different sources are combined. On the one hand, this enables to reach the aspired world-wide coverage since most of the systems for fireball monitoring only cover a part of the Earth's surface. On the other hand, the amount of scientific knowledge about an event is maximized by combining all available data.

In the course of the NEMO project an alert system, so far still under development, has been created to ensure near-real time information for events. It is based mainly on Social Media. This has the advantage that the collected information are from events all over the world. However, the data is subject to a strong bias towards densely populated areas and strongly dependent the times of day. A fireball that happens in the middle of the night often remains unobserved, as is an event over the ocean in most cases not seen. Nevertheless, NEMO has been able to detect over 180 events in less than 1.5 years of development.

At this point it should be mentioned that the popularity of Social Media services can be very country specific. Certain services are more popular in a certain country or region than in others. Integrating further Social Media services is one of the following steps in the framework of the NEMO project.

A further source of world-wide information for fireballs is infrasound data since it is possible to detect the energy released by entering extra-terrestrial or re-entering terrestrial objects. In the course of the NEMO project a collaboration is built and the data of the infrasound detection system from the International Data Centre (IDC) using data from the International Monitoring System (IMS) that are part of the CTBTO (Comprehensive Nuclear-Test-Ban Treaty Organisation) can be used. This monitoring system is designed to be a global continuous covering system. Furthermore, there are various other data sources that can have detected a fireball and provide scientific information e.g. meteor networks, weather satellites, and witness reports.

One very important question that has to be answered for every fireball event is whether the object that caused the phenomenon was of natural origin or if it was a re-entering man-made object. Often, this could be answered by an analysis of video data of the event, if such data is available. Moreover, re-entry prediction databases will be checked as a next step and dates and locations compared. So far, seven of NEMOs 180 events were found to be re-entering space debris. We would argue that it is highly possible that a number of further events were caused by re-entering debris which have to be analysed separately and disregarded for flux determinations of natural extra-terrestrial objects.

The NEMO system collects information on bright fireballs and hence on objects that impact the Earth's Atmosphere on a regularly basis but are not detected by the NEO surveys, since they are not large enough. Studying the fluxes and characteristics of extra-terrestrial material in the intermediate size range is one of NEMO's goals. This will enhance the lack of information for objects in the intermediate size range, large meteoroids and small asteroids that have to be taken into consideration for space safety considerations.

On 21 June 2018 a bright fireball occurred over Russia, later called the Ozerki daytime fireball. It caused a lot of public attention and was, due to this, detected by the NEMO alert system. The fireball was recorded with the infrasound network of the IMS. In at least ten infrasound stations we could identify a signature of the fireball. We were able to calculate a source energy of about 2.4 kt TNT and a size of the entering object of about 4 m in diameter from the infrasound wave data. Since there were video recordings of this fireball, it could already be assumed on that basis that it was not caused by re-entering space debris. The fireball was too fast, too short-lived, and the typical fragmentation was not visible either. Later meteorite findings confirmed that this fireball over Russia was a crashing asteroid.

5 CONCLUSIONS

NEMO already has 180 events in its database after its first 15 months of operation. A combination of different data sources enabled us to achieve more information on diverse fireball events including more precise size estimations for the entering objects. This already shows that the NEMO system has proven itself to be a very useful tool for fireball science. This will enhance the knowledge of the fluxes and characteristics of large meteoroids and small asteroids as well as of space debris that are important factors for space safety considerations

6 ACKNOWLEDGEMENTS

We thank the European Space Agency and the University of Oldenburg for funding this project. We are also grateful to all networks and projects that have already agreed to cooperate with this endeavour. A special gratitude goes to the CTBTO for the help with this work and for providing us with data and software. CTBTO is providing access to vDEC platform (https://www.ctbto.org/specials/vdec/) for research related to NEMO. We further thank the BGR (Bundesanstalt für Geowissenschaften und Rohstoffe).

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