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The Swabian Meteorite 2002/07/16 – acoustic point or line source?

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PHÄNOMEN

Mysteriöser Knall bei Nacht

Ein Knall weckte am Dienstag gegen 23.40 Uhr viele Menschen im Zollernalbkreis auf. Die Ursache des Phänomens ist bisher nicht bekannt.

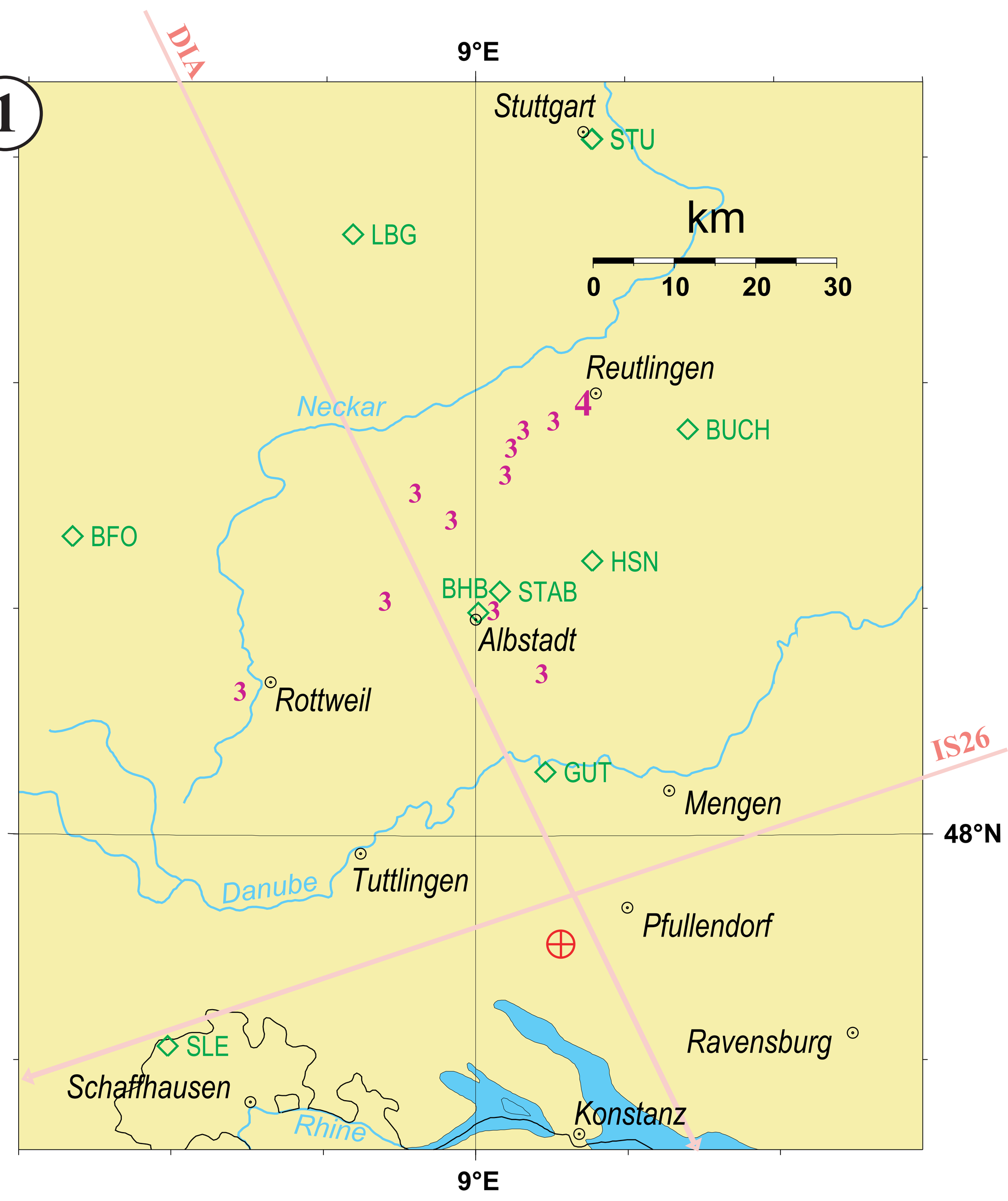
DANIEL SEEBURGER

ZOLLERNALBKREIS ■ „Es war unwahrscheinlich laut", berichtet ein 'Ohrenzeuge' aus Winterlingen, „das Haus hat vibriert". Gegen 23.40 Uhr wurde der Mann unsanft aus dem Schlaf gerissen. Er habe zuerst an ein Gewitter oder an ein Flugzeug gedacht, das die Schallmauer durchbrochen hat, so der Winterlinger. Doch beide Erklärungen zielen ins Leere. Der Steinlach-Bote in Mössingen ging dem Phänomen nach – bis gestern Abend wurde noch keine rationale Ursache für den nächtlichen Lärm gefunden. Man kann bisher lediglich sagen, was den Knall definitiv nicht verursacht hat. Laut Deutschem Wetterdienst hat es zu dieser Zeit kein Gewitter gegeben. Die Flugsicherheit wies darauf hin, dass keine Überschallflugzeuge unterwegs waren. Ausgeschlossen werden zudem ein Erdbeben und eine Explosion. Der Tübinger Astrophysiker Stefan Jordan bezeichnete laut Steinlach-Bote einen möglichen Meteoriten-Niedergang als unwahrscheinlich. Außerdem hat der Wissenschaftler zur besagten Zeit nichts beobachtet oder gemessen. Gehört wurde der Knall unter anderem in Reutlingen, Rottweil, Balingen, Hechingen, Mössingen und in Hohentengen bei Saulgau. Besonders gut zu hören war er in Winterlingen und Grosselfingen. Dort haben nach Zeugenaussagen die Scheiben vibriert. Auch die Balinger Polizei hat keine Erklärung für das nächtliche Phänomen. „Es gibt keine Erklärung, keine Ursache und keine Schäden", sagte Polizeisprecher Mehler gestern Nachmittag.

Shortly before midnight on 2002/07/16 people in Reutlingen (S of Stuttgart, Germany) were startled by a loud detonation or boom and heavily rattling windows. According to the European Macroseismic Scale this could be assigned an intensity of 4 (see Fig. 1). The next day Sabine Lohr of the Schwäbisches Tagblatt compiled all available reports (see press clipping) ranging over 50km to the South of **Reutlingen** (assigned intensities of 3 and less). Ground shaking was not percepted while there were a few eyewitness reports of sky illumination in spite of bad weather.

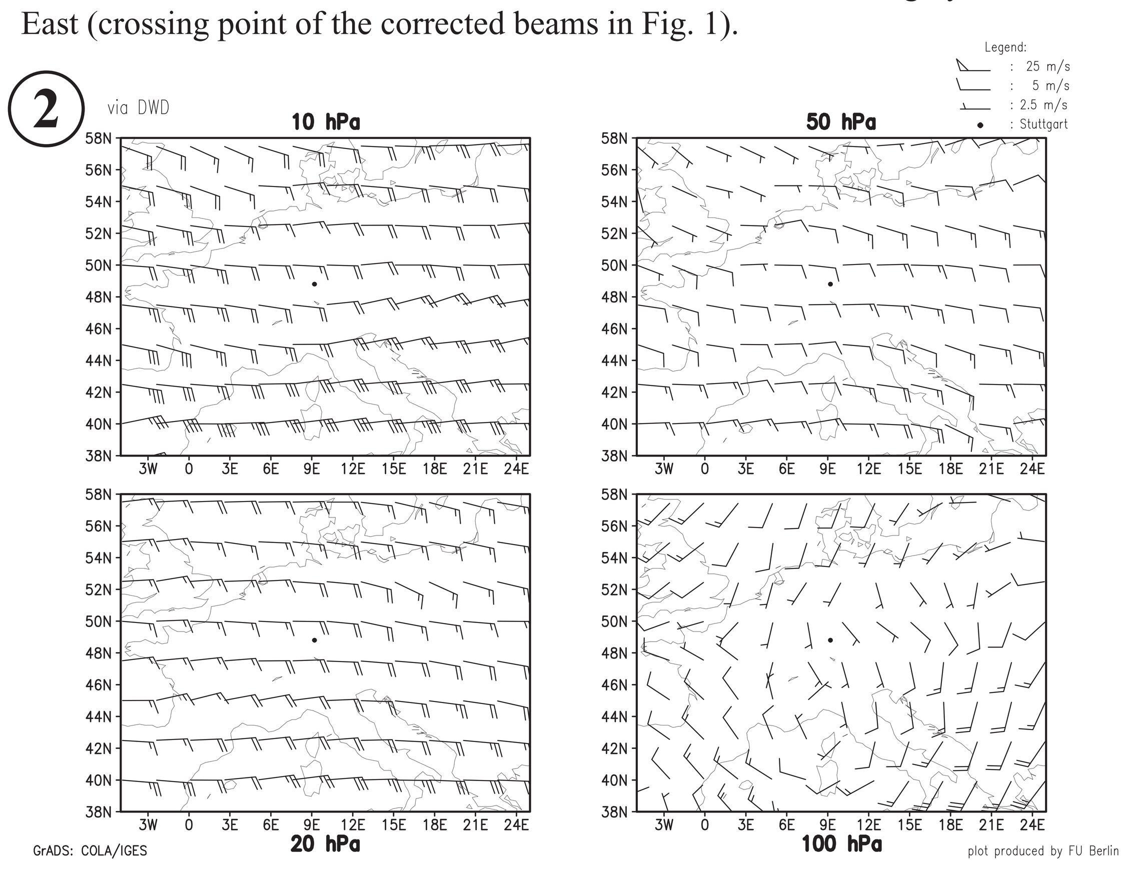
Inquiries at the weather survey and the air traffic control could exclude a thunderbolt or a supersonic plane as the source of the phenomenon. Läslo Evers with the Dutch Infrasound Array (DIA) performed a sound source localisation by analysing **infrasound** data from DIA and IS26 (Bavarian Forest) and taking a cross bearing. At this time the event was assumed to have been a **meteorite** exploding in the atmosphere.

1



The result of the infrasound cross bearing was corrected to first order **wind drift**: the four panels in Fig. 2 display wind direction and velocity in the atmosphere 3 hours after the meteorite fall (satellite and other data compiled by ECMWF and provided by Barbara Naujokat, FU Berlin). While around the tropopause (100hPa correspond to a height of about 16km) the thunderstorm prone area in Middle Europe can be well spotted, the stratosphere (10hPa ≅ 32km) shows rather uniform wind conditions which led to a shift of the sound source of roughly 10km to the East (crossing point of the corrected beams in Fig. 1).

2



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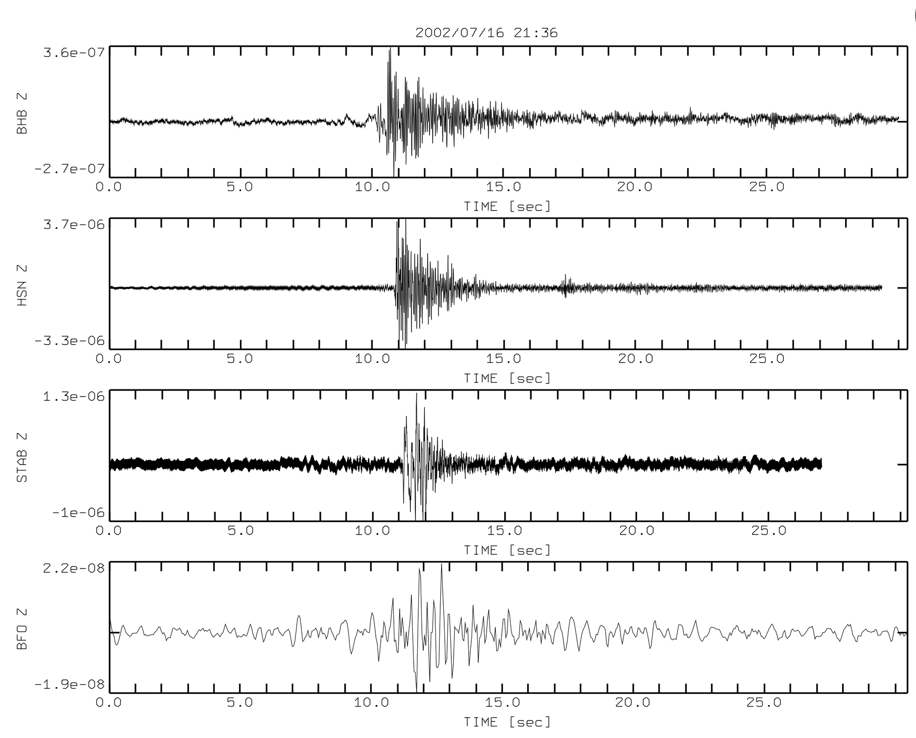

The event was also recorded at several seismograph stations of the State Earthquake Survey of Baden-Württemberg (LED), of the Swiss Seismological Service, and of the German Regional Seismic Network. In the **seismograms** (short period, vertical component) plotted in Fig. 3 one can distinguish ground coupled energy (BFO, BHB 1st phase) and an "air slap" (HSN, BHB 2nd phase). Besides the waveform data there were "monitor"-recordings available from stations BUCH, LBG, and GUT from which a time pick and a maximum amplitude could be extracted. Stations south of Lake Constance (e.g. WIL and KAMOR) showed no signals above noise level.

Time differences between stations from the beginning excluded an earthquake or an impact. A proper localisation with a constant-velocity model (v=0.33km/s) resulted in the epicentre marked with ⊕ in Fig. 1 which corresponds nicely with the infrasound solution.

The trade off between height and time of the source could be limited by the time tag of a **light-curve** (Fig. 4) recorded in the Czech Republic by Pavel Spurny (Astronomical Observatory Ondřejov). This is noteworthy since in seismology the source time of an event is nearly never known. A light-curve denotes sky illumination with a dominant sensitivity in the near infrared. In this case the intensity increase – lasting for about 2 seconds – was peaked by 4 distinct spikes. This is unequivocally the signature of a **fireball** or **bolide** rushing through the atmosphere and blowing up.

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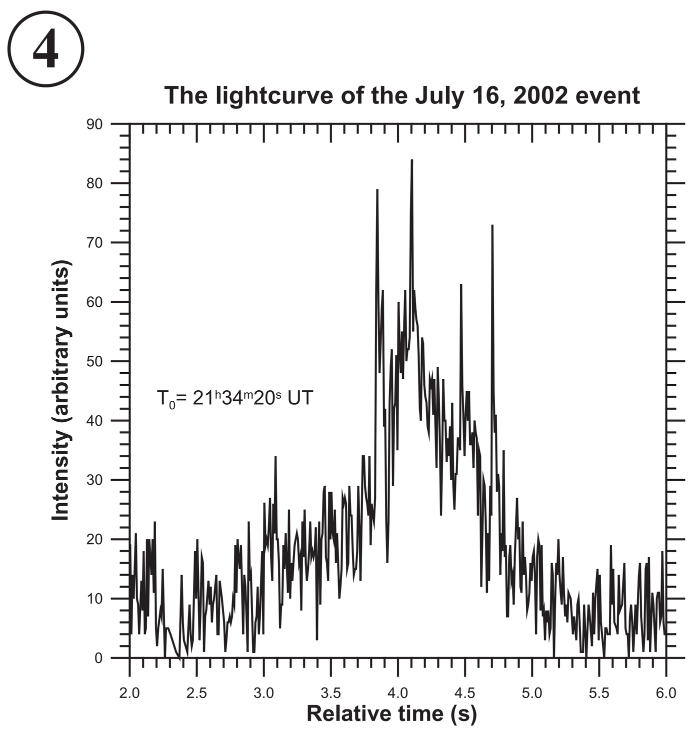
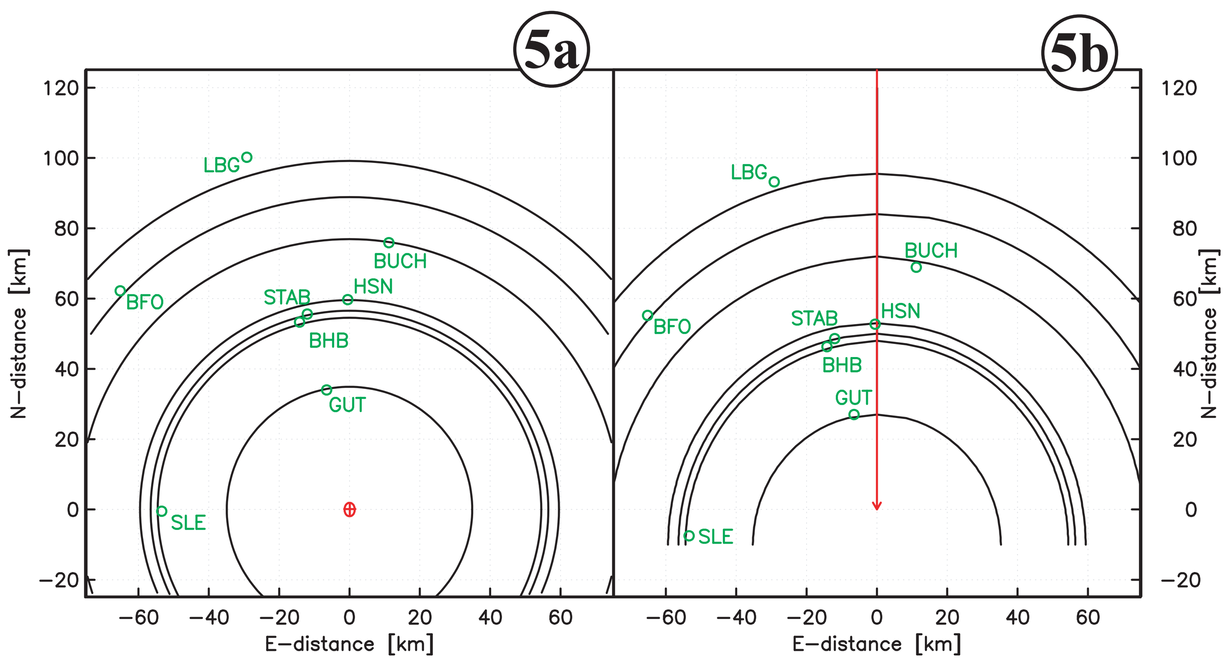


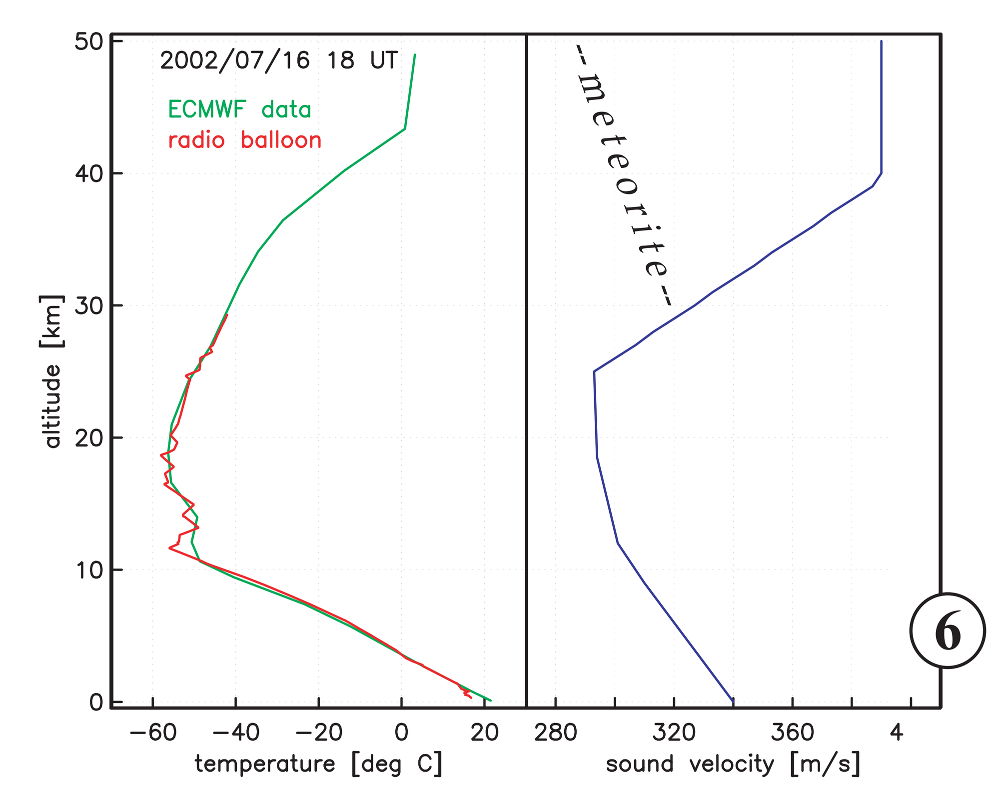
Fig. 5a sketches the isochrones of the absolute **travel times** for an explosion at a height of 28km in a constant-velocity model. Travel-time residuals do not exceed 10 seconds at any seismic station resulting in a localisation error of only a few kilometres.

Alternatively, Fig. 5b shows isochrones of the **sonic boom** emitted by a bolide entering the atmosphere steeply (20° from vertical) and from N at 10km/s (Mach number 30). For constant parameters travel times are computed following Qamar (1995). But, the nearest station (GUT) gets its energy from below the supposed height of final disintegration (end of the supersonic flight) at a height of about 30km. Travel-time residuals are even smaller than for the explosion probably due to the now 6 degrees of freedom instead of 3. Unfortunately, the azimuth of the flight path is purely resolved: it may vary by nearly 90° from N through W.

5a 5b



For a dynamic evaluation of the acoustic wave propagation a detailed velocity model of the atmosphere is needed. In the lower part of the atmosphere **sound velocity** is mainly controlled by the **temperature** which is measured up to an altitude of about 30km by means of a radio balloon launched by the German Weather Survey (DWD) every 6 hours from Stuttgart and other locations. A sound-velocity model (Fig. 6) was calculated from the data (provided by Bernhard Muehr, Lacunosa Wetterberatung) of the launch 3 hours before the occurrence of the meteorite. Temperatures up to 50km were taken from ECMWF-data for the grid point 47N/10.5E. More on atmospheric velocity models can be found on the website of L. Evers (http://www.knmi.nl/~evers).



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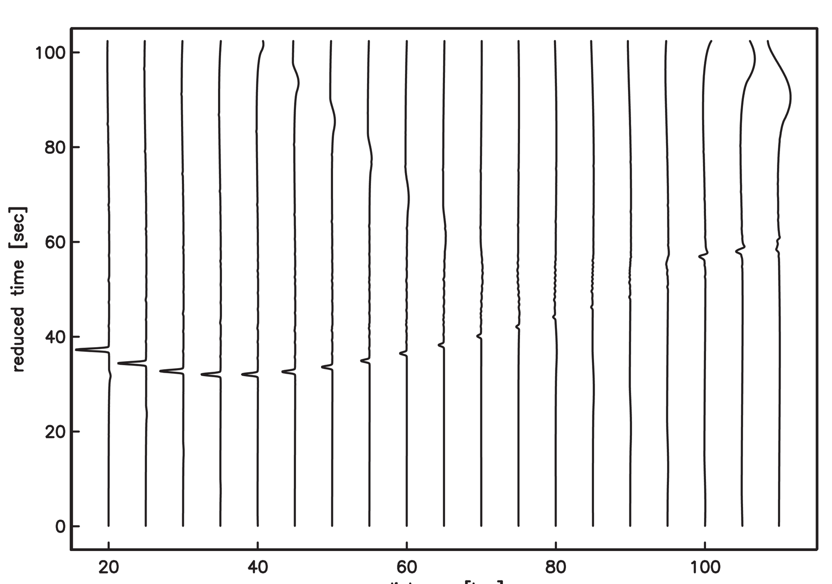
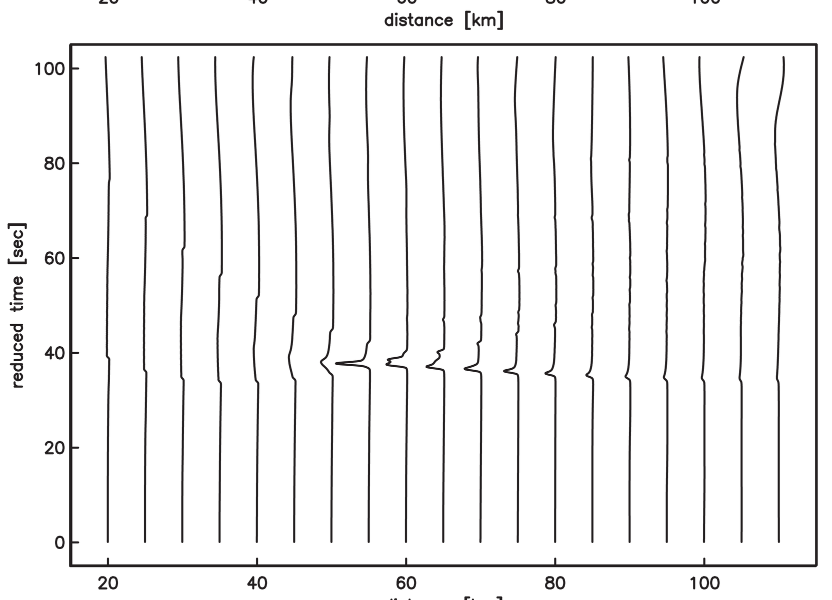
The reflectivity method (Kennett, 1980; Müller, 1985) was used to compute **theoretical seismograms** for the atmospheric model. The code – based on a program by Gerhard Müller – was not exactly suited for this kind of model but gave a very good idea about relative amplitudes. Fig. 7a displays vertical P-wave seismograms at epicentral distances from 20km through 110km for an explosion at a height of 30km. The traces have a length of 102s and times are reduced with v_{red}=500m/s. As expected, amplitudes decrease with increasing distance, except around 100km where another branch of the travel-time curve shows up. This does not fit the observations (small signal at station GUT, lack of signal to the South).

For Fig. 7b the supersonic meteorite was modelled with 80 small explosions ripple-fired from 50km through 30km height. A flight path of 20° from vertical and a speed of 10km/s was simulated. The profile of seismograms is situated right beneath the flight path, "epicentral" distances measured from the end point of the flight. The effect of the Mach cone becomes instantly visible. Amplitudes at short distances are as small as for the largest distances while the biggest amplitude (the loudest bang) is found around 55km. This is the actual sonic boom.



7a



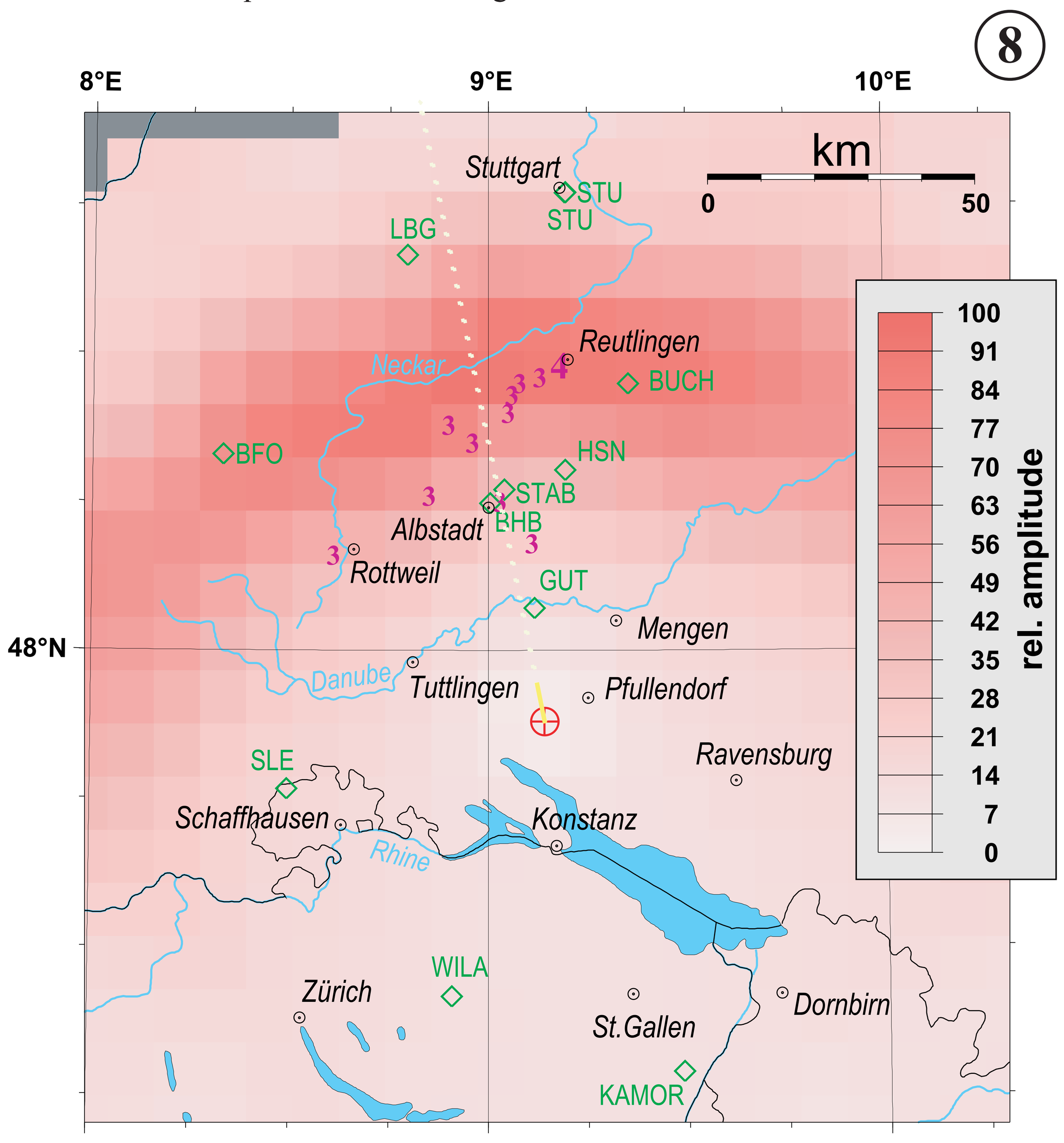
7b

Fig. 8 shows the geographical distribution of theoretical maximum amplitudes around the epicentre of the end of the supersonic flight (the azimuth is 169°). The distribution compares nicely with the observations: the loudest boom was heard around Reutlingen, station GUT recorded only a tiny signal, and S of Lake Constance as well as N of Stuttgart there was nothing to be detected.

Hence, it can be concluded that this simple model of a **finite supersonic line source** explains the observations quite well. Moreover, amplitude distribution requires that the meteorite came in from N or NNW.

An impact of remaining fragments of the fireball remains purely speculative. Nevertheless, inspection of the ground motion at station GUT exhibits that it could not have had an equivalent Richter magnitude of more than 0.5.

8



The conclusion of this study is that a steeply descending supersonic fireball may well be mistaken for an earthquake or surface explosion at first sight. However, combined utilization of data from seismological and infrasound recordings as well as optical and acoustic observations reveals the true origin of the phenomenon. Modelling of acoustic "seismograms" from a supersonic moving source (a "line"-source of 20km length) in the atmosphere complements the sparse arrival-time data and fits the entire set of observations much better than a point source (explosion) can do.

Acknowledgement

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