The hills have ears

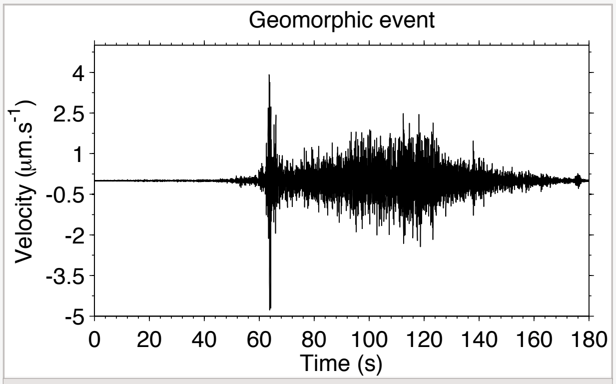
How seismic monitoring is reshaping geomorphology

If a tree falls in the forest, does anybody hear it? Well, the jury is still out on trees, but if it's a rockfall or a landslide occurring inside one of the rugged catchments studied by Niels Hovius, the answer is probably yes. Hovius is a geomorphologist at the GFZ German Research Centre for Geosciences in Potsdam, who has teamed up with seismologist Arnaud Burtin, also at GFZ, on an unconventional project. Together with colleagues from the Swiss Federal Institute for Forest, Snow and Landscape Research and the National Taiwan University, they have wired a handful of watersheds with sprawling networks of seismometers that listen for any signs of erosional activity. By zooming in on the details of individual study sites, Hovius and Burtin are pioneering a novel approach to monitoring geomorphic change.

The problem they are after is this: it is widely accepted that climate ultimately drives landscape evolution. It acts through the stealthy persistence of water reshaping the Earth's surface and through violent events of mass wasting in which, for lack of a better term, geology happens. But the details of these processes – when and why they happen and how they relate to weather conditions – remain poorly understood. Hovius and Burtin hope to elucidate the link between individual climate events and their erosional aftermath using 2D seismic arrays. As Hovius explains, the goal is "to study the driver and the geomorphic response at a similar resolution." Since automated weather stations already provide detailed meteorological data almost to the minute, their challenge rests in bringing the geomorphic side up to speed.

Luckily, pilot studies show them catching up fast. When I stumbled upon Hovius, speaking Friday afternoon at the EGU General Assembly in Vienna, he sparked a wave of tangible excitement in the crowded lecture room. He showed how a highly sensitive array of seismometers nestled in a rocky basin of the Swiss Alps could detect the increased foot traffic of the weekday lunch hour in the village below. In Taiwan, the team could tell when local farmers stayed inside, hiding from torrential rains. But this 'anthropogenic noise' is merely a fascinating accidental discovery unearthed by their study. The real treasures of their work lie in the streaks of high-frequency tremors associated with geomorphic events that punctuate their seismograms.

Their new method capitalises on what was previously viewed as a persistent nuisance in earthquake monitoring: that geomorphic events like large landslides pollute the seismic signal of tectonic activities. Hovius and Burtin, however, seize opportunities like this to study the characteristics of a geomorphic episode, decoding its origin using its unique seismic fingerprint. With their dense arrays of seismometers distributed over catchment-scale study areas, they can dissect the anatomy of an event with astonishing precision.



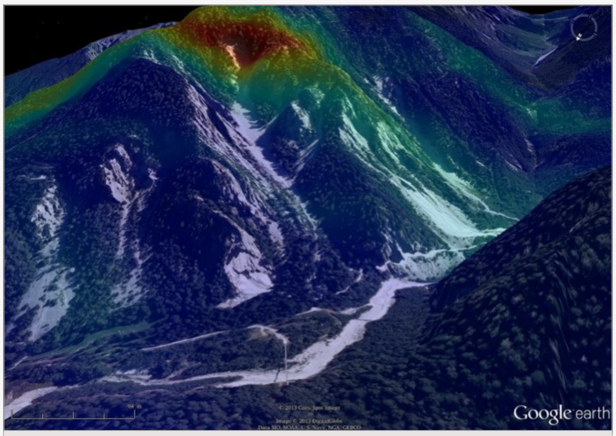
A seismogram of a rockfall in the Illgraben catchment, Switzerland. (Credit: Hovius et al., 2013)

A rockfall event, for instance, would produce a seismogram with specific characteristics, Hovius explains. "It may start with a sudden, short pulse of seismic energy at low frequency – around 1Hz – generated by the break-away. This could be followed by a few seconds of very limited activity, during free fall of the mass." Next, the frequency of the signal could increase if the rock shatters as it careens down a talus slope, or the amplitude could increase if several large boulders begin to pick up speed. Instruments installed at a pilot study in the Swiss valley of Illgraben recorded these very patterns when a series of ten rockfalls let loose above the village of Susten on New Year's Day 2013.

And while the mechanics of a rockfall are not particularly mysterious, real-time seismic monitoring can provide insights into more elusive aspects of landscape dynamics. With obvious excitement, Hovius explains, "we have opened the black box." In the Illgraben, for instance, "it has been difficult to determine how debris flows build in this catchment. With our seismometers we can now 'see' the build-up phase. It takes about 20 minutes for such flows to constitute and travel through the upper Illgraben channel." Understanding the timing here is more than academic as many residents live on a large debris fan below the catchment. This information could provide early warning for those in harm's way precious minutes before the existing alarm would sound.

But as Hovius and Burtin forge ahead into unexplored applications of seismic data, they have inevitably encountered challenges. These obstacles chiefly relate to calibration: most flavours of geomorphic noise have never been rigorously described. "Much work remains to be done on source characterisation and some of it is not very glamorous," admits Hovius. "For example, there are few, if any, publications on the seismic signal of rainfall or thunder, so we'll have to go and collect the relevant data ourselves." At the moment, they

BACK TO CONTENTS



The rockfall location was determined by studying common features of eight seismograms recorded at different stations in the catchment. The most likely location of the rockfall source is at the top of the steep avalanche gully as shown by the colour map draped over the terrain image. Here, warmer colours indicate a greater likelihood. (Credit: Hovius et al., 2013)

rely heavily on their geomorphological expertise to match seismic patterns to specific erosional processes.

Despite their substantial credentials in this department, some people remain sceptical of their approach. As with all new methods, Hovius' colleagues want validation. He says their initial work has been met with a common response: "Nice, but do you have independent evidence?" While vetting new methods is a fundamental part of science, Hovius notes that seismic data often stand alone as the only proof of geologic processes that are otherwise undetectable by humans. Only time and more data will reveal whether erosional applications should be viewed any differently.

Nonetheless, it seems clear that seismic monitoring will have significant impacts on the field of geomorphology. This work helps fill in long-standing gaps in the current understanding of erosional processes. "This method makes it possible to see how eroded mass travels through landscapes, from hillslopes into channels and onward into depositional settings," says Hovius. "The connectivity between different process domains is a crucial, but underconstrained aspect of landscape dynamics." An improved understanding of the mechanics of erosion will also strengthen models that aim to predict landscape dynamics under a changing climate.

From a societal perspective, such real-time monitoring can provide advance warning of natural disasters, like the debris flows of Illgraben. Seismic networks will also exponentially increase the number of observations of weather-driven erosion events, improving probabilistic estimates and statistical models used in hazard assessment. Looking at the astonishingly rich data they have produced, the possibilities seem endless and Hovius and Burtin sound understandably optimistic. Above all else, they see in this new approach "the promise that seismic monitoring will give the geomorphological community a new set of eyes with which to watch the landscape." Eyes which may eventually 'hear' that lone tree fall, answering an age-old question once and for all.

Julia Rosen
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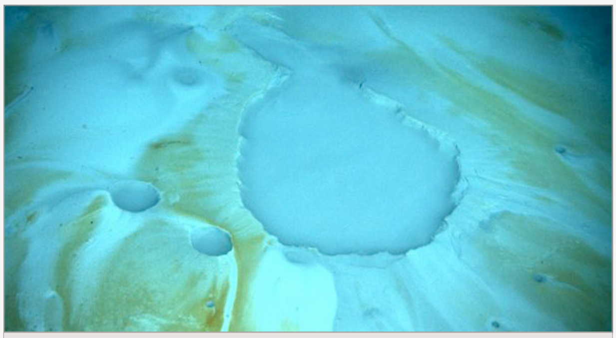
Reference

Hovius, N. et al.: Seismicity, seismology, and erosion, Geophys. Res. Abstr., 15, EGU2013-8967, 2013 (conference abstract)

Sampling the methane buffet

Ocean sediments are capable of storing large amounts of methane (both as methane hydrates and in sediment pore waters), a greenhouse gas that may be destabilised as the oceans warm. If this happens, this methane could be released into the atmosphere where it would accelerate the rate of climate change. Even without this warming, though, methane is still being released from the sea floor, particularly in cold seep environments. Here, pore waters enriched in methane are forced upward through the sediments, where they release the gas into the water column.

Much of this methane is consumed by methane-oxidising bacteria (methanotrophs), which rely on it for their energy needs. With the possibility of large-scale release of this greenhouse gas in the future, scientists want to know whether methanotrophs are capable of combatting it, but the environmental controls on the process are not fully understood. Thankfully, there are several teams working to better understand methane release, many of whom presented their research in a session on methane in the oceans and continents at the EGU 2013 General Assembly.

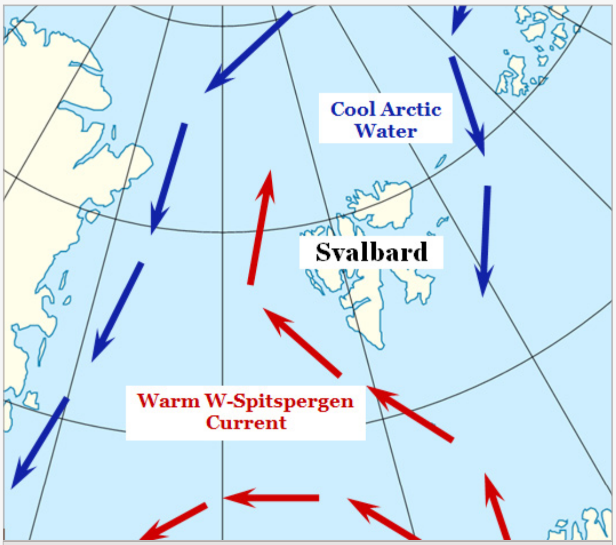


Cold seeps are also associated with brine pools (shown here), gas hydrates, mud volcanoes and a variety of biogenic structures including microbial mats and carbonate mounds. (Credit: NOAA-OER/BOEMRE)

The first part of this session gave an excellent review of current knowledge and recent progress in the research on methane release off the coast of the Arctic archipelago of Svalbard. Here, methane is stable below 400 m, but as the seafloor shoals, the gas is unleashead as plumes of methane bubbles. These methane beds have been active for hundreds of years, but research by Graham Westbrook (at the University of Southampton) and his collaborators suggests that the methane may have been stable at more shallow depths in the past and that methane hydrates were stable in the sediment 360 m below sea level only 30 years ago.

The concentration of methane in the Svalbard beds is greatest in the bottom waters (approximately 30 m above the sea floor) and decreases towards the surface as it is broken down through aerobic methane oxidation (MOx). Researchers can determine the fate of methane in the water column by measuring the methane oxidation rate. While there is a constant supply of methane in cold seep environments, MOx rates are highly variable, both temporally and spatially. They are particularly high in cool Arctic waters and much lower in the warmer current that runs to the West of Svalbard (the West-Spitsbergen Current). The reason for this lies in the distribution of methane oxidising bacteria.

Staining a filtered water sample with the chemical DAPI allows us to pin down the number of methanotrophs in a particular sample. DAPI is a fluorescent stain that binds to cell DNA and, because bacteria are single-celled organisms, the number of fluorescing bodies corresponds to the number of bacteria. Different strains can then be identified using stable isotope analysis. Lea Steinle and her colleagues from the University of Basel found that the warmer West-Spitsbergen Current contained fewer bacteria than the cooler Arctic waters. This explains the differences in MOx rates: the Arctic waters are associated with high MOx rates because they contain a high standing stock of methanotrophs and the converse is true for the West-Spitsbergen Current, which contains much fewer.



Ocean currents off Svalbard (modified from source).

The reason why the standing stock of methanotrophs differs between the cooler Arctic bottom waters and warm West-Spitsbergen Current is unclear. It may be a function of temperature, salinity, competition with other microbes, or any number of other reasons. One thing is for sure, though: whatever the conditions are within each water body, ocean circulation is the dominant control on the abundance of methanotrophic bacteria in this region.

The West-Spitsbergen Current periodically displaces cold Arctic water with ocean flows that are warmer and less microbe rich. As the position of these water bodies shifts over the cold seep, so does the rate of methane oxidation. MOx in the Arctic Ocean off Svalbard is controlled oceanographically, but whether temperature is the dominant factor here remains to be seen.

If temperature is the dominant control on bacterial abundance, scientists anticipate ocean warming to negatively impact methanotroph populations in the Svalbard methane beds, which may lead to more methane reaching the atmosphere before it is oxidised. Even if temperature is not the main control on bacterial abundance, shifts in ocean circulation, expected as the climate changes, may alter the course of currents in this area. If the Arctic waters were to be diverted elsewhere, or the strength of this current was reduced, fewer methanotrophs would be available to break down the methane, which could also result in more of the gas reaching the atmosphere.

To better understand the risk of methane release to the atmosphere we need to comprehend the processes contributing to its breakdown, as well as those that liberate it from the sediment. Thanks to Steinle and her team, we now know there are strong oceanographic controls on methane's breakdown, but the case is not closed. What are the optimum conditions for methane oxidation? What makes methanotrophs thrive in these water bodies? And how will climate change influence the breakdown of methane in the oceans? Let the investigation continue!

Sara Mynott
EGU Communications Officer

References

Levin, L. A.: Ecology of cold seep sediments: interactions of fauna with the flow, chemistry and microbes, in Oceanography and Marine Biology: An Annual Review, 43, 1-46, CRC Press, 2005
Steinle, L. I. et al.: Microbial methane oxidation in the Arctic Ocean offshore Svalbard, Geophys. Res. Abstr., 15, EGU2013-4910-2, 2013 (conference abstract)
Westbrook, G. K., et al.: Escape of methane gas from the seabed along the West Spitsbergen continental margin, Geophys. Res. Lett., 36, L15608, 2009

BACK TO CONTENTS

Scattered to the wind

How dust grains are integral to our future climate

Dust particles that make it into the atmosphere have much more potential than the ones in your home. Depending on their size, these dust grains cool our atmosphere by reflecting sunlight, or they can blanket the globe trapping heat and causing the Earth to warm. If there's lots of dust in the atmosphere, the small grains can seed water droplets, resulting in rainstorms. Or the particles can fall out into the oceans where their iron rich nature can cause blooms of algae that absorb carbon dioxide. In short, dust has the potential to transform our global climate and some of its effects could mitigate those of global warming.

But computer models trying to predict how our climate may change in the future are struggling to understand just how much dust could affect their calculations. Most models are tuned to dust measurements taken many miles from dust sources such as in Miami or the Bahamas. Unsurprisingly, though, this isn't where most of the dust in the global system originates.

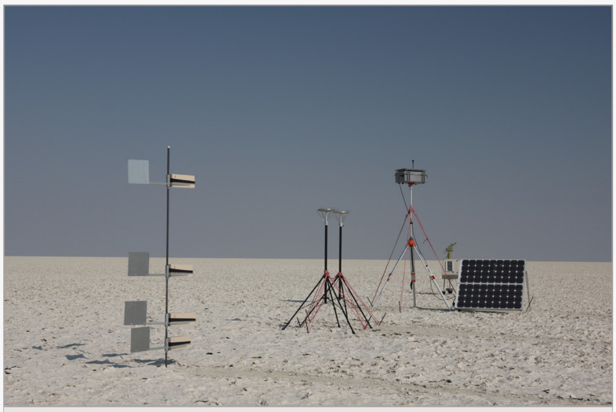
That honour falls to the Bodélé depression, a huge dry seabed in Chad. This depression is covered by a thick layer of dead diatoms – a type of algae – left behind when the water evaporated. The lack of vegetation means there is nothing to secure sand grains on the surface of the dry seabed which, when blown by the wind, bombard into the diatom remains and whip them up into the atmosphere as a dust storm where they can travel for miles around the globe.

For a climate model, this flat pan should be the easiest type of landscape to make dust calculations for, as there's no vegetation or other factors to complicate matters. But even at this simple level the models struggle. On top of this, the political instability of the area makes it near impossible for scientists to gain access, so very few actual measurements exist. This makes it difficult to test how well the climate models are really predicting dust emissions, but researchers from Oxford University are trying to rectify this.

The DO4 Models: Dust Observation project is looking at dust emission sites around the globe to see what conditions cause dust to be emitted, and to try and produce dust models which will, in turn, help us to fine tune our climate models.

"We wanted to go to areas in deserts where dust is being emitted and find out why and how it is emitted in the first place. Is it moisture? Vegetation? Grain size? What?" asks Giles Wiggs, one of the co-investigators on the project.

One of these areas is the Makgadikgadi Pan in Botswana. The team visited it twice, once in 2011 and again in 2012, trekking through blistering heat and being blinded by dust storms to measure how and where the dust is being emitted. The Makgadikgadi Pan is almost 6,200 square miles (over 16,000 square kilometres) of perfectly flat, bright-white salty clay. Like the Bodélé depression, this would be interpreted by climate models as somewhere with no vegetation and not much moisture, meaning most models expect the whole pan to have a huge emission of dust from its surface.



Taking measurements in the Makgadikgadi Pan. (Credit: Giles Wiggs)

But the research shows that the pan only emits dust from small areas and at specific times. In particular, areas that were getting rained on late in the season emitted more dust, because the rains caused the soft, broken-up crust to be disrupted. The researchers now believe soil moisture could be the most useful measurement for dust emissions. Unfortunately, few people use soil moisture as a measurement of these dust sources. Instead, most people measure crust thickness or the strength of the crust (using a penetrometer to see how much strength is required before it cuts through the crust).

"We were trying to come up with a simple model to say: 'when the crust is like this, you can expect this much dust from it.' But, as it turns out, things are much more complicated – we found almost no relationship at all between either of these attributes and how much dust comes off of it. Nothing defines dust well," says Wiggs.

The data, presented at the EGU 2013 General Assembly, were collected in a 12 x 12 km square grid – a size chosen because it is the smallest resolution most climate models can make calculations for.

Some researchers don't think this resolution is high enough to provide accurate climate measurements. But for Wiggs' post-doctoral researcher, James King, who was required to trek almost two hundred kilometers to make observations over the four-month fieldwork period, it must have seemed huge, particularly in the harsh field conditions.

"When you're trekking up and down in temperatures of 42 °C and the wind starts to blow, it feels like you're standing in a fan oven, you can feel the moisture being sucked out of your skin. Then the dust erupts and you can only see a few metres in front of you," says Wiggs. King was required to battle these conditions to place a portable wind tunnel at the centre of each kilometer square in the grid, to test how different wind speeds and directions affected erosion of the crust.

The team are now conducting experiments in other dust source areas, such as dried up river beds in Namibia, and trying to make more precise measurements of soil moisture in relation to dust.

BACK TO CONTENTS

New research suggests it may get more dusty in the future, meaning this team, and the DO4 project, will only become more important. But while the project can help us understand dust emissions today, it's still unclear how these will change in the future.

Harriet Jarlett
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Reference

King, J. et al.: The role of moisture on controlling dust emissions from crusted supply-limited surfaces, Geophys. Res. Abstr., 15, EGU2013-12332, 2013 (conference abstract)

Interview with climate scientist Andrew MacDougall

At the EGU 2013 General Assembly, press-assistant Becky Summers had the opportunity to interview Andrew MacDougall, a PhD candidate from the University of Victoria, Canada. He talked to her about his preliminary work, presented at the conference, on undoing climate change and restoring a Holocene-like climate.

Hi Andrew – could you tell us why you started this work?

Well it's about reversibility and a little bit of hope. Many of the climate scenarios are dismal and demoralising and this was a side project asking: can we ever fix this? And if so, what would be the realistic time scales involved. The idea is to look at future scenarios and map out how long it would take to get the Earth's climate back to a pre-industrial CO_2 levels (around 280 parts per million).

So how long will it take to restore?

Using the middle of the road scenario, a Holocene-like climate can be re-established by the late 24th or 25th century. However, surface temperatures remain above the pre-industrial temperature until at least the 30th century. In addition, due to carbon-cycle feedbacks the amount of carbon that has to be removed is larger by 15-90% than the original quantity the humanity emitted.

How did you look so far into the future?

We forced the University of Victoria Earth-System Climate Model with future atmospheric gas concentration pathways based on those used in the upcoming IPCC [Intergovernmental Panel on Climate Change] fifth assessment report. The carbon emissions reach zero in different years: the low scenario at 2050, medium at 2175 and high at 2250. So in that year, human emissions are eliminated and not only do we stop emitting carbon but we actively start to synthetically remove CO_2 from the atmosphere and store it in some geologically stable form.

The model was spun up over a time period of 1000 years with the equilibrium being at an 1850 climate. Carbon dioxide reduction is mirrored at the same rate it increased and we were looking at the gradual return back to pre-industrial atmosphere.

So we not only decarbonise but actually remove carbon too?

Yes, using technology such as carbon capture and storage. Scientists like David Keith from Harvard University are designing machines that could work at a commercial level to suck tens of thousands of tons – or more – of carbon out of the air, that can be moved into geological storage deep underground. More exotically, the carbon dioxide could be turned into limestone but this uses phenomenal amounts of energy.


Andrew MacDougall (Credit: N. Roux)

But who decides the Earth's temperature? Do we really want the pre-industrial climate?

This was used as a baseline because this 20th century figure implies you will have restored the climate that we have known in the previous few decades. If it were decided that people in the mid millennium wanted the temperature at a degree and half warmer, CO_2 would be stabilised at a higher level.

However, even though global temperature would be similar to today, by the 24th century you would still expect a different climate. This is because the oceans warm up and cool down slower than the continents. Imagine when you take a pot of water and put on stove, it warms up. When you take it off, it takes a long time for the water to cool down.

Is there any policy relevance here?

Not really – I mean politicians often have trouble thinking four years into the future let alone 400 years! But there's scientific value here. We've shown that, at civilisation timescales and with some monumental effort, the climate can be restored to a 20th-century-like climate. However, we have also shown that humanity will be living with the consequences of fossil fuel emissions for a very long time.

Interview conducted by Becky Summers
Freelance science writer

BACK TO CONTENTS