Nat. Hazards Earth Syst. Sci. Discuss., 1, 7271–7283, 2013
www.nat-hazards-earth-syst-sci-discuss.net/1/7271/2013/
doi:10.5194/nhessd-1-7271-2013
© Author(s) 2013. CC Attribution 3.0 License.

Natural Hazards and Earth System Sciences
Discussions
Open Access

This discussion paper is/has been under review for the journal Natural Hazards and Earth System Sciences (NHESS). Please refer to the corresponding final paper in NHESS if available.

Brief communication
"Earthquake–cloud coupling through the global atmospheric electric circuit"

R. G. Harrison[1], **K. L. Aplin**[2], **and M. J. Rycroft**[3,4]

[1]Department of Meteorology, University of Reading, Earley Gate, Reading RG6 6BB, UK
[2]Clarendon Laboratory, Denys Wilkinson Building, Keble Road, Oxford OX1 3RH, UK
[3]CAESAR Consultancy, 35 Millington Road, Cambridge, CB3 9HW, UK
[4]Centre for Space, Atmospheric and Oceanic Sciences, University of Bath, Bath BA2 7AY, UK

Received: 11 November 2013 – Accepted: 27 November 2013 – Published: 6 December 2013

Correspondence to: K. L. Aplin (karen.aplin@physics.ox.ac.uk)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

We illustrate how coupling could occur between surface air and clouds via the global electric circuit – through Atmospheric Lithosphere–Ionosphere Charge Exchange (ALICE) processes – in an attempt to develop physical understanding of possible relationships between earthquakes and clouds.

1 Introduction

The possibility that there are visible changes in the atmosphere that are associated with earthquakes, or even provide a precursor of earthquakes, appears from time to time in the specialist literature. Because of the widespread availability of high quality satellite imagery, such optical possibilities are clearly compelling. Recently, for example, Guangmeng and Jie (2013) considered the potential for using observations of cloud changes as an earthquake precursor, by examining sequences of satellite images around the times of earthquakes. A full statistical climatology of the cloud behaviour in any earthquake region concerned is clearly essential before any cloud feature can be truly regarded as anomalous, but, more importantly, a plausible physical mechanism able to link earthquakes with clouds has also been lacking.

Generating a physical mechanism connecting earthquakes with clouds is troublesome because there is no clear agreement on what constitutes an “earthquake cloud”, and a wide range of disparate cloud-related phenomena have been attributed to the indirect effects of earthquakes. For example, there are several reports of anomalous cloud formations over fault zones near earthquakes (e.g. Guangmeng and Jie, 2013; Guo and Wang, 2008), although the height of the clouds affected is not consistent. In some other cases the clouds described have been iridescent, implying that detailed droplet properties, such as size, might be affected by an underlying physical process. There are also observations of enhanced clear-sky emission in the thermal infrared radiation detected by satellites. Typically these are equivalent to a temperature change of a few Kelvin, beyond the natural variability (Tramutoli et al., 2005), appearing some days before the earthquake (e.g. Saraf et al., 2008; Guo and Wang, 2008).

At the simplest level, clouds require water vapour, which could be released from the earth's crust by seismic changes. Whilst such plumes of water vapour might be initially buoyant from geothermal heating, mixing processes in the naturally variable lower atmosphere seem likely to remove the identity of the seismically-generated water vapour (or water vapour fluctuations) during ascent to cloud levels. (There seems little prospect of high-level clouds being affected in this way, such as those formed from ice.) The thermal anomalies identified could also be generated by surface outgassing, such as the infra-red absorbing gases of carbon dioxide and methane (Saraf et al., 2008).

Previous work has also considered the electrical changes in atmospheric properties more unique to earthquakes. Changes in cloud features and associated thermal anomalies have been attributed to water condensation onto seismically-released ions (Pulinets and Ouzounov, 2011; Freund, 2011), which may exceed the existing natural background production of ions. However, a major difficulty with the ion-induced nucleation proposal is that condensation onto ions – a process exploited in the Wilson cloud chamber to visualise cosmic ray tracks – requires extreme levels of water supersaturation which are many orders of magnitude greater than those naturally occurring in the terrestrial atmosphere (e.g., Harrison and Carslaw, 2003). Changes in the surface structure of rocks under stress have also been suggested to lead to infra-red emission and subsequent thermal anomalies (Freund, 2011). Further, seismically-released atmospheric ions may themselves directly absorb infra-red radiation (e.g. Rycroft et al., 2012). Finally, a link between enhanced ionisation from radioactivity and clouds was suggested from the long-range cloud dissipation apparent in a satellite image of the Chernobyl reactor plume (Brandli and Leuck, 1987)[1].

[1]Ionospheric changes during two major nuclear reactor accidents are inconsistent. Fuks et al. (1997) observed an ionospheric response following the Chernobyl incident, but Kakinami et al. (2011) did not consider the ionospheric changes around the Fukushima event to be unambiguously linked with the nuclear accident.

NHESSD
1, 7271–7283, 2013

2 Global circuit coupling

An alternative route for earthquake coupling to clouds seems possible through atmospheric electricity. Previously, Harrison et al. (2010) argued that enhanced ionisation in the lower atmosphere (and, specifically, in the planetary boundary layer), will increase the vertical current flow always present in fair weather[2] from the global atmospheric electric circuit (e.g. Rycroft et al., 2012). The importance of the vertical current density – denoted J_c – is that it links surface air ionisation changes directly to the ionosphere, unlike surface electric field changes which are insufficient to cause ionospheric electrical changes (Denisenko et al., 2013). This mechanism of Atmospheric Lithosphere–Ionosphere Charge Exchange (subsequently referred to here by the acronym ALICE), provides an explanation for satellite observations of pre-earthquake changes in natural radio waves (Nìmec et al., 2009) in non-disturbed weather. Encouraged by the agreement between the postulated changes and those now observed across a range of earthquakes (Piša et al., 2013), the ALICE mechanism is extended here to consider effects on layer clouds (such as low level stratus clouds) in semi-fair weather circumstances, through which the vertical current must pass in overcast conditions.

The consequence of vertical current flow through the horizontal edge of a layer cloud is the local generation of charge at the horizontal cloud–air boundary – see Fig. 1. This has, for example, been directly observed within clouds using balloon-carried instrumentation (e.g. Rycroft et al., 2012). Charging of the water drops at the upper and lower cloud boundaries is anticipated to influence, in some cases, the evaporation-condensation of drops, and also the collisional interactions between small droplets (Rycroft et al., 2012). These effects result from the charge obtained by the droplets after they have formed. The droplet charging is proportional to the vertical current flow-

[2]Fair weather conditions are those in which there is no local charge generation, without fog or convective cloud. Semi-fair weather conditions as considered here refer to situations in which there is also no local charge generation, but extensive layer clouds (stratus or stratocumulus) are present.

CC BY

ing and the vertical gradient of the cloud to clear air transition, with the charge per unit volume ρ at the cloud boundary given by

$$\rho = -\varepsilon_0 J_\mathrm{c} \frac{\mathrm{d}}{\mathrm{d}z}\left(\frac{1}{\sigma}\right) \tag{1}$$

in which the conductivity σ varies vertically with height z across the horizontal cloud–air boundary, and ε_0 is the permittivity of free space.

Equation (1) shows that properties of the cloud – namely, the charge per unit volume at the cloud edge – are linked to the vertical current flow. Should the current flow be modified by ionisation changes near the surface, such as through the release of radon or the fracture of rocks, the cloud droplet charge would also vary in response. The global circuit current therefore provides a link between surface changes and the cloud directly above.

3 Quantitative considerations

Changes in the vertical conduction current from surface ionisation changes can be calculated by considering the balance between ion generation and loss to atmospheric particles, for a unit area column of atmosphere. The full methodology was discussed in the description of the ALICE mechanism given in Harrison et al. (2010). For an ionospheric potential V_I, the conduction current density J_c is given by

$$J_\mathrm{c} = \frac{V_\mathrm{I}}{R_\mathrm{c}} \approx V_\mathrm{I} \bigg/ \left[\frac{k}{\sigma_\mathrm{s}} + R_\mathrm{FT}\right] \tag{2}$$

where R_c is the resistance of an unit area column between the surface and the ionosphere. This can be approximated using the total surface layer conductivity σ_s, which is considered to represent the resistance in a layer of scale height k ($\sim$ 100 m to 500 m) together with the resistance of the upper (“free troposphere”) part of the columnar resistance R_FT). The surface air’s total conductivity σ_s depends on the mean concentration

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

NHESSD

1, 7271–7283, 2013

Earthquake–cloud coupling

R. G. Harrison et al.

cc BY

of small bipolar ions present n and their mean mobility μ, from

$$\sigma_s = 2n\mu e \tag{3}$$

where e is the magnitude of the elementary charge (Harrison and Carslaw, 2003). This can be determined in terms of the ion production rate q and loss rate by ion-ion recombination and ion-aerosol attachment as

$$\sigma_s = \mu e \frac{\left[\sqrt{(\beta^2 Z^2 + 4\alpha q)} - \beta Z\right]}{\alpha} \tag{4}$$

where α is the ion–ion recombination coefficient ($1.6 \times 10^{-12}\,\mathrm{m^3\,s^{-1}}$), Z the monodisperse aerosol number concentration and β the ion-aerosol attachment coefficient, which is $\sim 4 \times 10^{-11}\,\mathrm{m^3\,s^{-1}}$ for 0.2 µm radius aerosol. Harrison et al. (2010) also pointed out that the response depends on the background aerosol concentration. This is because the sensitivity of the vertical conduction current to surface ionisation changes is greater in polluted air, as ion loss to aerosol particles is less effective at removing ions than, in clean air, the annihilation of ions by recombination of a positive ion with a negative ion.

It can be seen from Eq. (4) that the air conductivity varies with the ion production rate q, and that, through Eq. (2), the conduction current will respond, leading, through Eq. (1), to a change in the cloud edge charge. Hence a long-range relationship exists between the surface ion production and the cloud properties.

Calculation of the sensitivity of the vertical conduction current requires some estimate of the likely changes in ionisation rate associated with earthquakes, both from radon release, and from fractoemission (Table 1). Measurements of ionisation rate anomalies before earthquakes are sparse and it is difficult to trace some of the quoted figures to reliable sources. Nevertheless, there is good data available from the time of the Kobe earthquake in Japan in 1995 (e.g., Yasuoka et al., 2010). In Yasuoka et al. (2010), Ishikawa et al. describe radon concentrations increasing for about 2

NHESSD
1, 7271–7283, 2013

cc BY

months before the earthquake, reaching a peak (at well over three standard deviations above the previous background) 17 days before the earthquake, which was sustained until the earthquake. When electricity supplies to the instruments resumed after the earthquake, radon levels had returned to the previous background level. Based on the radon increase of 10 Bq m^{-3}, and concurrent ion measurements, Omori et al. (2007) estimated a 40 % change in ion concentration. In aerosol-free air, the ion concentration is proportional to the square root of the ion production rate and, in polluted urban air, the ion concentration scales linearly with the ionisation rate (e.g. Harrison and Carslaw, 2003). The enhanced radon concentrations observed therefore correspond to a change in the ion production rate of 40–100 %, i.e. q = 14–20 cm^{-3} s^{-1}, assuming a background ionisation rate of q = 10 cm^{-3} s^{-1}.

The ion measurements cited by Omori et al. (2007) imply the ionisation rate was at the larger end of the estimates deduced from radon concentrations, but Liperovsky et al. (2005) report a much greater ionisation rate enhancement of 100–10 000 cm^{-3} s^{-1}. The fractoemission mechanisms proposed by Freund (2011) do not yet provide an adequate estimate of the volumetric ionisation rate, so a combination of the radon-enhanced ionisation rates presented in Table 1 has been used to estimate a change in ionisation rate of up to 100 cm^{-3} s^{-1}.

4 Estimate of cloud response

Changes in cloud properties associated with conduction current changes can be estimated from studies of polar night clouds, which show an averaged response in the cloud base consistent with conduction current changes (Harrison and Ambaum, 2013). Polar night clouds were chosen for this analysis to remove the usual dominating influence of diurnal variations from solar heating, and a response observed was in the cloud base height. The determination of cloud base height is essentially a measurement of vertical visual range, which can be regarded as indicating a change in the cloud base droplet properties, such as droplet size or concentration. In this study, which averaged

NHESSD
1, 7271–7283, 2013

CC BY

the polar night cloud base measurements made, a similar response was found for both the Arctic and Antarctic of about 4 m change in visual range to cloud base for a unit percentage change in the conduction current density.

If this sensitivity is appropriate to semi-fair weather layer clouds in general (and a similar sensitivity was found through an entirely different approach at a mid-latitude continental site by Harrison et al., 2013), then the possible cloud response to earthquake-induced changes can be estimated in similar terms. Figure 2b applies this response to the calculations of current density change from ionisation, obtained from Fig. 2a. The sensitivity of the change in cloud properties is, as expected, greater in the polluted case, although it must be emphasised this is a highly-idealised calculation which neglects any additional interactions between the cloud and pollution and indeed any other sources of variability. However, it still serves to illustrate the magnitude of the potential link between surface ionisation changes and cloud properties aloft.

5 Conclusions

In reality, there is always considerable variability present in the atmosphere and in clouds. Consequently there are many competing sources of cloud variability which may obscure effects solely resulting from the surface ionisation changes. However, there may also be conditions in which a cloud response is observable, or indeed has possibly already been observed. Our purpose here is merely to suggest that there is a possible physical mechanism which can provide earthquake–cloud coupling based on the ALICE ideas presented previously, which should be explored further. An appealing feature of this mechanism is that, rather than requiring transport of the surface ionisation up to the cloud despite appreciable ion loss processes (with uncertain or indeed unlikely responses in the cloud properties), the global circuit conduction current directly, and rapidly, connects surface air ionisation changes to the properties of the cloud above in semi-fair weather. Many details clearly remain to be worked out, which

NHESSD
1, 7271–7283, 2013

we hope can be achieved despite the traditional discipline boundaries existing between atmospheric and Earth sciences.

References

Brandli, H. W. and Leuck, D.: Nuclear summer, Satellite, 12, 23–24, 1987,

Denisenko, V. V., Ampferer, M., Pomozov, E. V., Kitaev, A. V., Hausleitner, W., Stangl, G., and Biernat, H. K.: On electric field penetration from ground into the ionosphere, J. Atmos. Sol.-Terr. Phys., 102, 341–353, 2013.

Freund, F.: Pre-earthquake signals: underlying physical processes, J. Asian Earth Sci., 41, 383–400, 2011.

Fuks, I. M., Shubova, R. S., and Martynenko, S. I.: Lower ionosphere response to conductivity variations of the near-earth atmosphere, J. Atmos. Sol.-Terr. Phys., 59, 961–965, 1997.

Guangmeng, G. and Jie, Y.: Three attempts of earthquake prediction with satellite cloud images, Nat. Hazards Earth Syst. Sci., 13, 91–95, doi:10.5194/nhess-13-91-2013, 2013.

Guo, G. and Wang, B.: Cloud anomaly before Iran earthquake, Int. J. Remote Sens., 29, 1921–1928, 2008

Harrison, R. G. and Ambaum, M. H. P.: Electrical signature in polar night cloud base variations, Environ. Res. Lett., 8, 015027, doi:10.1088/1748-9326/8/1/015027, 2013.

Harrison, R. G. and Carslaw, K. S.: Ion-aerosol-cloud processes in the lower atmosphere, Rev. Geophys., 41, 1012, doi:10.1029/2002RG000114, 2003.

Harrison, R. G., Aplin, K. L., and Rycroft, M. J.: Atmospheric electricity coupling between earthquake regions and the ionosphere, J. Atmos. Sol.-Terr. Phys., 72, 376–381, 2010.

Harrison, R. G., Nicoll, K. A., and McWilliams, K. A.: Space weather driven changes in lower atmosphere phenomena, J. Atmos. Sol.-Terr. Phys., 98, 22–30, 2013.

Kakinami, Y., Masashi, K., Liu, J. Y., Watanabe, S., and Mogi, T.: Ionospheric disturbance associated with radiation accidents of Fukushima I nuclear power plant damaged by the M9.0 2011 Tohoku Earthquake, Adv. Space Res., 48, 1613–1616, 2011.

Liperovsky, V. A., Meister, C.-V., Liperovskaya, E. V., Davidov, V. F., and Bogdanov, V. V.: On the possible influence of radon and aerosol injection on the atmosphere and ionosphere before earthquakes, Nat. Hazards Earth Syst. Sci., 5, 783–789, doi:10.5194/nhess-5-783-2005, 2005.

CC BY

Nìmec, F., Santolik, O., and Parrot, M.: Decrease of intensity of ELF/VLF waves observed in the upper ionosphere close to earthquakes: a statistical study, J. Geophys. Res., 114, A04303, doi:10.1029/2008JA013972, 2009.

Omori, Y., Nagahama, H., Kawada, Y., Yasuoka, Y., Ishikawa, T., Tokonami, S., and Shinogi, M.: Preseismic alteration of atmospheric electrical conditions due to anomalous radon emanation, Phys. Chem. Earth, 34, 435–440, 2009.

Piša, D., Nìmec, F., Santolik, O., Parrot, M., and Rycroft, M.: Additional attenuation of natural VLF electromagnetic waves observed by the DEMETER spacecraft resulting from preseismic activity, J. Geophys. Res.-Space Phys., 118, 5286–5295, doi:10.1002/jgra.50469, 2009.

Pulinets, S. and Ouzounov, D.: Lithosphere–atmosphere–ionosphere coupling (LAIC) model – an unified concept for earthquake precursors validation, J. Asian Earth Sci., 41, 371–382, 2011.

Rycroft, M. J., Nicoll, K. A., Aplin, K. L., and Harrison, R. G.: Recent advances in global electric circuit coupling between the space environment and the troposphere, J. Atmos. Sol.-Terr. Phys., 90–91, 198–211, 2012.

Saraf, A. K., Rawat, V., Banerjee, P., Choudhury, S., Panda, S. K., Dasgupta, S., and Das, J. D.: Satellite detection of earthquake thermal infrared precursors in Iran. Nat. Hazards, 47, 119–135, 2008

Tramutoli, V., Cuomo, V., Filizzola, C., Pergola, N., and Pietrapertosa, C.: Assessing the potential of thermal infrared satellite surveys for monitoring seismically active areas: the case of Kocaeli (Izmit) earthquake, August 17, 1999, Remote Sens. Environ., 96, 409–426, 2005.

Yasuoka, Y., Nagahama, H., and Ishikawa, T. (Eds.): Anomalous Radon Concentration prior to an earthquake: a case study on the 1995 Kobe Earthquake, Japan (Collected Papers), Lambert Academic Publishing, Saarbrücken, 2010.

NHESSD

1, 7271–7283, 2013

Earthquake–cloud coupling

R. G. Harrison et al.

CC BY

Table 1. Summary and quantitative estimates of mechanisms by which rock stresses can produce excess ionisation in surface air before earthquakes.

Mechanism, example	Ionisation changes	Reference
Radon emission before 1995 Kobe earthquake	Radon increase measured, conservatively estimated at $10\,\mathrm{Bq\,m^{-3}}$. Ion balance equation used to infer a 40 % change in ion concentration. Measured increases in ion concentration before the earthquake of $1000–1400\,\mathrm{cm^{-3}}$ were consistent with changes inferred from the radon data. This implies a change in volumetric ionisation rate of 40–100 %, i.e. a rate of $14–20\,\mathrm{cm^{-3}\,s^{-1}}$	Omori et al. (2007) and references therein Yasuoka et al. (2010) and references therein
Radon emission in general before earthquakes	volumetric ionisation rate = $100–10\,000\,\mathrm{cm^{-3}\,s^{-1}}$	Liperovsky et al. (2005)
Fractoemission	Ions per unit area at rock surface given as $10^9\,\mathrm{cm^{-2}\,s^{-1}}$; vertical dimension of region into which the ions were released not available	Freund (2011)

NHESSD
1, 7271–7283, 2013

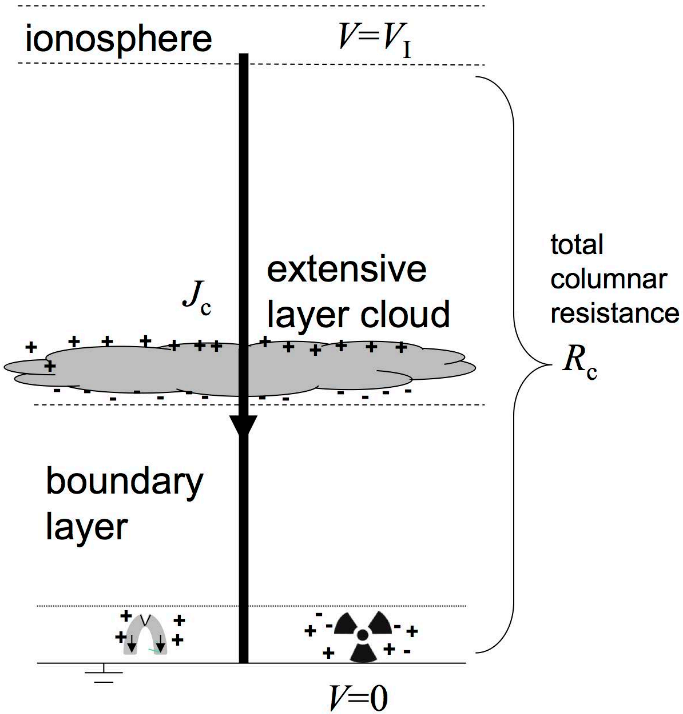

Fig. 1. Coupling of surface ionisation changes to layer clouds through the global circuit. The conduction current flowing (density J_c), is related to the vertical columnar resistance R_c and the globally-established ionospheric potential V_I. The boundary layer in the base of the lower atmosphere contributes the majority of the columnar resistance. Hence, ionisation released into this region by rock fracturing (shown on the left) or radioactivity (shown on the right) will reduce R_c and increase J_c for fixed V_I, from Ohm's Law. The charge accumulating on cloud droplets at the upper and lower cloud boundary is proportional to J_c and, therefore, in turn, to the surface ionisation. This charge may influence the cloud microphysical processes, e.g., via droplet interactions.

NHESSD
1, 7271–7283, 2013

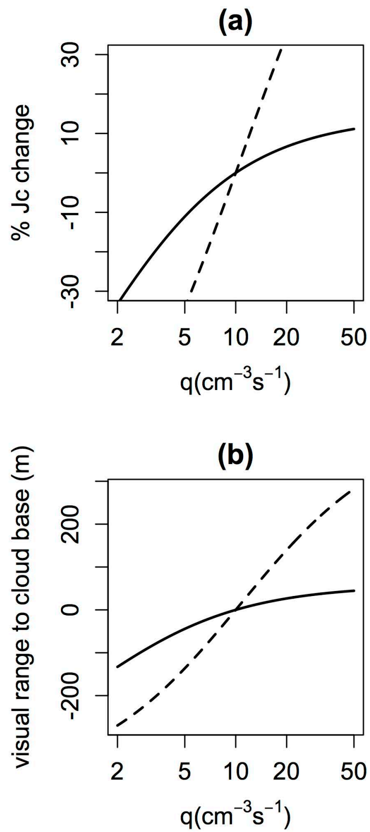

Fig. 2. Calculated response in atmospheric electric and cloud parameters to changes in the surface air volumetric ion production rate q for low pollution air (solid lines) assuming 2000 particles cm^{-3} of radius 0.2 µm, and polluted air (dashed lines), assuming 15 000 particles cm^{-3}. Variations are shown for **(a)** the vertical conduction current J_c and **(b)** changes in the vertical visual range to the cloud base.

NHESSD
1, 7271–7283, 2013