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Discussions

Interactive comment on "Pre-seismic Thermal Anomalies from Satellite Observations: A Review" *by* Zhong-Hu Jiao et al.

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Dear Dr. Freund,

Thank you very much for your careful checking of the manuscript and the insightful comments and suggestions. After detailed revisions, we think the paper has been improved a lot. Our responses to the comments and suggestions are also enclosed in the pdf file.

Q1.

In the Introduction, on L 27-33, the text reads:

"Tectonic earthquakes are caused by the sudden dislocation of active faults due to

surging tectonic stress (Freund, 2011). In addition to the considerable amount of strain energy released during the earthquake itself, the stress energy continuously accumulates during the preparation process of the earthquake. To some extent, these changes lead to pre-seismic thermal anomalies in seismogenic areas, such as regional warming and increased greenhouse gas concentration, which can be observed through satellite sensors." In my cited 2011 publication I had presented at great length that the most important processes during the earthquake preparation process are (1) the build-up of tectonic stresses and (2) the activation of omnipresent defects in all crustal rocks, which releases electronic charge carriers, called "positive holes". (1) is obvious and accepted by everybody. (2) is based on a large body of work that I have published since the 1980s, ïňĄrst in a basic material sciences context, unrelated to earthquakes, but subsequently applied to earthquakes and, speciïňĄcally, pre-earthquake processes.

Though the authors of this Review cite my 2011 paper, they seem to have missed or misunderstood its contents. This is obvious from their list of follow-on processes to which the authors draw attention, namely ". . .the growth of surface microïňĄssures and gas ionization effects, following with changes in water content, underground gas, and earth electromagnetism around active faults. . . regional warming and increased greenhouse gas concentration," This list indicates that the authors are intent on reviewing the relevant literature without taking into account my work. Why, then, do they cite my 2011 paper at such a prominent place?

Throwing in the words "gas ionization effects" reinforces the impression that the authors have not made an effort to inform themselves about HOW air ionization at the Earth surface takes place. Likewise, what do they mean by writing "with changes in water content, underground gas (and) earth electromagnetism around active faults"? These are meaningless words unless substantiated by some physical insight into the underlying processes. I have gone to some length describing the underlying physical processes in my 2011 paper, including electromagnetic processes and air ionization at the Earth surface. I have the impression that the authors of this review have not made an effort to familiarize themselves with these processes. '

Answer:

In this paper, we attentively review the advances in possible earthquake precursors and thermal anomaly detection approaches over the last decade. Thus, we did not give insight into various literatures about the mechanisms of pre-seismic anomalies. We just simply described the possible physical processes that we had known from the papers we read routinely, resulting in some misunderstanding about different theories or mechanisms. According to your suggestions and criticism, we referred many relevant papers and rewrote the mentioned paragraph as follows:

Tectonic earthquakes are caused by the sudden dislocation of active faults due to surging tectonic stress. In addition to the considerable amount of the strain energy released during the earthquake itself, the stress energy continuously accumulates during the preparation process of the earthquake. Different theories to explain the physical mechanism of the pre-seismic anomalies derived from optical satellite data have been proposed. The p-hole model (Freund, 2011; Freund et al., 2009) indicates that electronic charge carriers, also known as positive holes, in crustal rocks activated by tectonic stress and flow out of the stressed rock volume and propagate fleetly. They cause the air ionization at the land surface-atmosphere interface when accumulated in a thin surface/subsurface layer, and generate non-thermal infrared emission as a result of the recombination of positive holes. The rock stress adjustment from active faults probably causes anomalies of land surface or air temperatures prior to the earthquake, which could be observed through satellite TIR sensors (Chen et al., 2015; Ren et al., 2017; Wu et al., 2006). The spatiotemporal evolution of rock temperature field is closely related with its deformation. The rock shear strain or compression causes the obvious increase of temperature, and rock tension gives rise to temperature reduction. The solid Earth is about 1650 times of thermal capacity of the atmosphere. The change of elastic stress of 1 MPa is likely to bring in the variation of air temperature with the order of 1 K based on the energy balance. The local greenhouse effect due to the emana-

tion of CO2, CH4, etc. has been invoked to explain the anomalous variations of TOA brightness temperature or OLR (Ouzounov et al., 2006; Ouzounov et al., 2007; Tronin et al., 2002). Besides, the increased emission of radon from active faults and cracks in seismogenic regions is also considered to bring about the air ionization, which can concentrate water molecules on air ions, further lead to the anomalies of the atmospheric water vapor and temperature, and accelerate the latent heat flux before earthquakes (Pulinets et al., 2006).

Q2.

Frankly, despite the near-universally cited 1968 BSSA paper by Chris Scholz “Microfractures, aftershocks, and seismicity“, nobody has ever presented evidence that microfracturing is taking place in the Earth crust, either at the surface, in shallow depth or at great depth. Nobody seems to have ever raised the question, whether it is possible for rocks at seismogenic depth (7-45 km and deeper) to undergo microfracturing. I mind you, every fracture event, micro or macro, is possible only, if the volume can expand. The reason is that, by deïňĄnition, fracturing creates new surfaces. Creating new surfaces is possible only if and when empty space is created between the two sides of the crack. However, at the depth of kilometers to tens of kilometer, the overload of the rock column is such that the amount of work to be done (thermodynamically) to increase the volume of the stressed rocks is very large. Hence, the chance of creating any fracturing, micro or macro, is very small. Nonetheless the geoscience community, including the authors of this review, blankly accept the microfracturing maxim.

If one digs deeper into why microfracturing is so popular, an interesting story emerges. Geophysicists have for decades noted increases in the electrical conductivity of the rock volumes deep in the crust that are being stressed prior to major seismic events. Nobody could explain such increases except by assuming that brines were penetrating into the stressed rock volumes. Hence, the assumption that fractures must be opening deep below allowing water to rush in. This facile explanation was so tempting that nobody seems to notice that this assumption contradicts the fact that, below 5-7 km depth, the open porosity of rocks disappears. The reason: the difference between hydrostatic and lithostatic pressure becomes so large that open porosity cannot be maintained – even not over geologically short time scales.

Answer :

Thanks for the detailed comments about the microfracturing. Frankly speaking ,we did take the microfracturing at the seismogenic depth (7-45km and deeper) for granted, which might resulting from our major, i.e. remote sensing, as well as the relative lack of the fundamental knowledge of seismology and geology. Your explanation enlightened us and made us think about the theory in a new way. To remind the readers who might have similar misunderstanding or ignorance, we learned from your explanation and modified the item 7) in the Section 5 as follows.

7) The study of geophysical mechanisms and development of theoretical models about pre-seismic thermal anomalies should be strengthened or even updated. The numerical simulation based on knowledge of seismo-tectonics can be used to establish the relationship between anomalous signals and seismic events. The diagnostic index with practical value could be created based on this relationship, and the problem of anomaly index construction may be theoretically solved. Meanwhile, the former theories should also be examined with new minds and technologies. For example, the microfracturing theory is somehow fragile (Freund, 2011). By the basic definition, fracturing can create new surfaces and is possible only if empty space is created between the two sides of the crack. For the rocks at seismogenic depth (7-45 km and deeper), the overload is so large that the chance of creating any micro- or macro-fracturing, is very small. In other word, the difference between hydrostatic and lithostatic pressure becomes so large that open porosity of rocks cannot be maintained. Besides, the synergistic observations of relevant parameters from underground to ionosphere in seismically active regions are necessary to validate these theoretical models.

Q3.

I can go on with my critic (which I offer in a constructive spirit) when I read in L49 “due to the unclear physical mechanism of pre-seismic thermal anomalies”. I for one posit that the physical mechanisms are no longer “unclear”. The authors’ misconception comes from the fact that they don’t realize the difference between “thermal anomalies” and “thermal infrared anomalies”. The difference is huge– from a physics perspective. Saying “thermal anomalies” automatically implies a temperature difference, e.g. a “tangible” Joule temperature difference. Saying “thermal infrared anomalies” refers to the ONLY observables that infrared-sensing satellites can deliver: intensity and, to some extent, spectral distribution of the infrared emitted from the ground, from the lower atmosphere and from the top of the atmosphere. All of remote sensing depends upon the interpretation of these infrared emission processes.

Much of the remaining paper endorses, either implicitly or directly, the conventional interpretation of the different kinds of remotely sensed pre-earthquake IR anomalies. I’m convinced that the remote sensing community has been on the wrong track for most of the time, I but hesitate to express my concerns. The reason is that my concerns are so fundamental that, if rigorously applied, not much is left of this review paper to recommend. However, I want to help the authors.

For instance, on L428, late in their Review, under 3.6 Other methods, they introduce the night thermal gradient (NTG) method, ïňĄrst used by Nevin Bryant at JPL and then applied extensively by Luca Piroddi and Gaetano Ranieri in Italy as quoted in L430. Regrettably, the authors continue to use the blanket terminology “surface, soil and air temperature” without mentioning that they are actually talking about the “radiative temperature” derived from infrared emission off the surface, the soil and the air.

Answer :

Thanks for your kindness. We did have some misunderstanding about “thermal anomalies”. We misused “thermal anomalies” as a general concept that indicate all the anomalies of thermal radiation related parameters, such as outgoing longwave radiation, water vapor and land surface temperature (LST). Meanwhile "thermal infrared anomalies" are considered as the anomalies of TOA radiances or brightness temperature, which include the thermal infrared (TIR) emissions from the ground surface and the entire atmosphere.

The parameters derived from satellite data are different from the data itself. Various parameters can be retrieved from the multispectral optical satellite data as mentioned in our paper. For example, the LST can be retrieved from two thermal infrared atmospheric window channels. Although LST is derived from TIR data, but it is no longer remotely sensed TIR radiance. The LST represents a remarkably thin surface layer of medium temperature state, which is a physical quantity that can also be measured at the ground. However, the retrieved LST is not exactly same as the ground measurements, and the accuracy is used to express this bias.

In order to clearly and simply express the concept of the "pre-earthquake anomalies", we update the expression as "LST anomaly", "water vapor anomaly" or "OLR anomaly" instead of calling them "thermal anomalies" generally and ambiguously. Besides, the title of this paper is also modified as "Pre-seismic Anomalies from Optical Satellite Observations: A Review".

After reading more papers about the physical mechanism of pre-seismic anomalies, I agree with you that the physical mechanism is already relatively clear and partially proven. However, we have to admit that because of the complexity of seismogeology and geophysics, various theories and mechanisms have not been widely verified and accepted. As for more detailed application logic of remote sensing technology in the field of the pre-earthquake anomalies, as well as the thoughts on the present study track, we would like to make more effort in the next paper that focuses on our method.

Q4.

Why is the NTG method introduced so late in this review and under the title Other methods? The authors do not realize that, by using data from the European geostationary

satellite (providing thermal images every 15 min) Piroddi's work has provided much more profound information. For instance, by analyzing a full year of night-time data for the entire Italian peninsula, Piroddi has shown (1) that regional TIR anomalies come and go over the course of time, in a matter of days, expanding over relatively wide areas, but only occasionally linkable to large seismic events, (2) that the TIR intensities wax and wane on time scales of hours, (3) that the TIR anomalies move across the landscape on time scales even shorter than hours, and – most importantly – (4) that the TIR anomalies have a clear tendency to be associated with hill tops and mountain tops. In fact, the intensity of the TIR emissions from valleys is much less than from the tops of adjacent mountains. If the authors of this review paper would have paid more attention to the work by Piroddi and his thesis advisor, Professor Ranieri, they would have noted that the populist interpretation of the TIR anomalies off the Earth's surface, namely that they are due to warm gases or greenhouse gases seeping out of the ground, must be fundamentally wrong. The NTG analysis clearly points to an alternative mechanism, for which I have laid the groundwork: IR emission due to the radiative de-excitation of peroxy entities at the Earth surface. I attach an extended abstract from the 2015 EMSEV Workshop, in which the preference of the TIR emission from mountain tops is unambiguously documented (at least for one well studied case, the M=6.3 2009 L'Aquila event).

Answer:

We agree that the NTG method has relative clearly physical definition and is effective for the anomaly detection. Nevertheless, we have to admit that it has not been widely used or frequently referred in present scientific papers. In this paper, we intend to list and discuss the possible seismic precursors and detection methods selectively based on their respective application and influence. Thus, we put the NTG method under the section "Other methods". As you said, "only occasionally linkable to large seismic events" is an important reason why we discuss the limits of this technique in Section 4 and 5. We also point out the drawback of the TOA brightness temperature, which is effected strongly by the entire atmosphere in Section 2.2. It is also one of the reasons that cause the variation of TIR intensities at a short time scale. The terrain effects that indicated by the NTG method might be related with the fact that this method does not remove the TIR background information from current observations, which is an essential step in the Z-score or RST methods. Of course, it can also be explained by the alternative mechanism of IR emission due to the radiative de-excitation of peroxy entities at the Earth surface.

We would love to learn some merits from the 2015 EMSEV Workshop abstract that you mentioned above. However, we did not find it in the attachment and failed to search it on the Internet. Could you please offer us more information about it?

Q5.

All this also links to the Section 4 Issues with thermal anomaly detection. It is correct, as the authors note in L460, that the issue is “highly controversial”, but they do not penetrate the superïňĄcial appearance of the widespread controversy. In L461 they use the word “warming”. The casual use of this word reveals that they= authors do not understand the physical principle of the radiative nature of the remote sensing signals analyzed by the community.

Answer:

Thanks for your reminding. We misused the inappropriate word “warming” in this sentence. Indeed, the warming phenomenon is just one of the anomalies prior to a main shock. We replaced “warming” with “anomalous” and rewrote the sentence as follows: The anomalous phenomena often occur prior to various earthquake cases, whereas the features of these phenomena are often different.

Q6.

In L512-514 the authors refer to the “uniïňĄed LAIC model, widely promoted by Sergey Pulinets and his numerous collaborators. However, a close examination of the LAIC

model reveals that it is based on ad hoc assumptions regarding radon. Radon has been proposed to the driver of the LAIC model even though, in the larger context, it is physically impossible that radon can play this role. If radon were responsible to the increase of air ionization prior to majort seismic events, it would have to increase the normal air ion concentration from the “fair weather average” of about 200 per cubic centimeter to 20,000 to 50,000 per ccm. In average crustal rocks, radon is rarer than gold by 6 orders of magnitude. There is about one mole Rn in Earth’s atmosphere. Measured close to the ground or in holes in the ground, the pre-earthquake Rn emanation increases by a factor of about 10. Just calculate the number of Rn atoms perccm of normal air and ask yourself, how the decay of these rare Rn atoms can cause a regional increase of the air conductivity by a factor 100-250.

Answer:

Thanks very much for the enlightening quantitative explanation of LAIC model and radon. We rechecked the theories, and modified the description in the paragraph 6 of Section 4 as follows.

Mechanism of pre-seismic thermal anomalies is still inconclusive in the scientific community. Several mechanisms for generation of pre-seismic thermal anomalies detected by satellite have been proposed and aroused a lot of discussion. For example, positive hole theory has been proposed to explain this phenomenon. The electronic charge carriers (positive holes) can be released when the peroxy links break in the stressed rocks, arrive at the Earth’s surface and lead to the ionization of air at the ground-air interface. And the recombination of charge carriers at the surface can lead to a spectroscopically distinct, non-thermal IR emission (Freund, 2011; Freund et al., 2009). Besides, a unified LAIC model is proposed, in which the Radon emission in fault zones plays an important role (Molchanov et al., 2004; Pulinets and Ouzounov, 2011). Later, Wu, et al. added the coversphere to the LAIC model after analyzing its importance in the understanding of mechanisms and geophysical processes in earthquake preparation areas (Wu et al., 2016). However, LAIC model is physically impossible based on the p-hole model. Radon is very rare in the average crustal rocks. Moreover, the measurements of radon emanation on the ground or in the underground shows that Radon emission increases only by a factor of about 10 prior to an earthquake. These insufficient radon atoms cannot bring in a significant increase of the air conductivity by a factor 100-250. Therefore, further validation of these distinctive models is required from physical simulation experiences and synergetic measurements of multiparameter.

References

Chen, S., Liu, P., Guo, Y., Liu, L., & Ma, J. (2015). An experiment on temperature variations in sandstone during biaxial loading. Physics and Chemistry of the Earth, Parts A/B/C, 85-86, 3-8

Freund, F. (2011). Pre-earthquake signals: Underlying physical processes. Journal of Asian Earth Sciences, 41, 383-400

Freund, F.T., Kulahci, I.G., Cyr, G., Ling, J., Winnick, M., Tregloan-Reed, J., & Freund, M.M. (2009). Air ionization at rock surfaces and pre-earthquake signals. Journal of Atmospheric and Solar-Terrestrial Physics, 71, 1824-1834

Molchanov, O., Fedorov, E., Schekotov, A., Gordeev, E., Chebrov, V., Surkov, V., Rozhnoi, A., Andreevsky, S., Iudin, D., Yunga, S., Lutikov, A., Hayakawa, M., & Biagi, P.F. (2004). Lithosphere-atmosphere-ionosphere coupling as governing mechanism for preseismic short-term events in atmosphere and ionosphere. Nat. Hazards Earth Syst. Sci., 4, 757-767

Ouzounov, D., Bryant, N., Logan, T., Pulinets, S., & Taylor, P. (2006). Satellite thermal IR phenomena associated with some of the major earthquakes in 1999–2003. Physics and Chemistry of the Earth, Parts A/B/C, 31, 154-163

Ouzounov, D., Liu, D., Chunli, K., Cervone, G., Kafatos, M., & Taylor, P. (2007). Outgoing long wave radiation variability from IR satellite data prior to major earthquakes. Tectonophysics, 431, 211-220

Pulinets, S., & Ouzounov, D. (2011). Lithosphere–Atmosphere–Ionosphere Coupling (LAIC) model – An unified concept for earthquake precursors validation. Journal of Asian Earth Sciences, 41, 371-382

Pulinets, S.A., Ouzounov, D., Karelin, A.V., Boyarchuk, K.A., & Pokhmelnykh, L.A. (2006). The physical nature of thermal anomalies observed before strong earthquakes. Physics and Chemistry of the Earth, Parts A/B/C, 31, 143-153

Ren, Y., Ma, J., Liu, P., & Chen, S. (2017). Experimental Study of Thermal Field Evolution in the Short-Impending Stage Before Earthquakes. Pure and Applied Geophysics

Tronin, A.A., Hayakawa, M., & Molchanov, O.A. (2002). Thermal IR satellite data application for earthquake research in Japan and China. Journal of Geodynamics, 33, 519-534

Wu, L., Liu, S., Wu, Y., & Wang, C. (2006). Precursors for rock fracturing and failure - Part I: IRR image abnormalities. International Journal of Rock Mechanics and Mining Sciences, 43, 473-482

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-211/nhess-2017-211-AC2-supplement.pdf

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