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Lightning in a Forest (Wild) Fire: Mechanism at the Molecular Level

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Abstract

The mechanism of lightning that ignites a forest fire and the lightning that occurs above a forest fire are explained at the molecular level. It is based on two phenomena, namely, internal charge separation inside the atmospheric cloud particles and the existence of a layer of positively charged hydrogen atoms sticking out of the surface of the liquid layer of water on the surface of rimers. Strong turbulence-driven collisions of the ice particles and water droplets with the rimers give rise to breakups of the ice particles and water droplets into positively and negatively charged fragments leading to charge separation. Hot weather in a forest contributes to the updraft of hot and humid air, which follows the same physical/chemical processes of normal lightning proposed and explained recently [1]. Lightning would have a high probability of lighting up and burning the dry biological materials in the ground of the forest, leading to a forest (wild) fire. The burning of trees and other plants would release a lot of heat and moisture together with a lot of smoke particles (aerosols) becoming a strong updraft. The condition for creating lightning is again satisfied which would result in further lightning high above the forest wild fire.

Keywords

Forest Wild Fire, Lightning, Molecular Level

1. Introduction

"Wild fires are generally caused by humans or lightning. But when conditions are right, some wild fires can create their own weather, including lightning strikes that can spark even more fires." This is a statement of Christy Climenhaga in her reportage [2]. That is to say, lightning ignites most natural forest fires (wild fires). When conditions are right, naturally occurring lightning could ignite a forest fire while during the burning of a forest, more lightning could occur igniting more forest fires. This year (2023) in many places around the globe such as British Columbia in Canada, in Europe, etc., forest fires were particularly strong and widespread. Yet, the mechanism of such lightning formation is still a myth [2]. In this work, the authors would like to give an explanation of the mechanism at the molecular level of the above-mentioned lightning in forest fires based upon the most recent work of the authors and co-workers [1] [3] that explains the general mechanism of lightning and rain gush.

2. Brief Review of Lightning Mechanism as Proposed in References [1] [3]

We shall first give a brief review of the general mechanism of lightning and rain gush as proposed in references [1] [3]. There are many steps.

1) Strong and moist updraft into the cold freezing region of the atmosphere (between 0 and −20˚C, roughly). Strong turbulence is stirred up in this region. The atmosphere in this region becomes supersaturated [4].

2) Sufficient amount of impurities/aerosols with a concentration of the order of or higher than 10^2 to 10^3 cm^{-3} occurs inside the updraft [5] [6]. This would allow the occurrence of sufficient amount of precipitation of water molecules on these impurities/aerosols (cloud condensation nuclei or CCN) becoming cloud particles.

3) Charge separation of impurity ions occurs inside all the cloud particles (water clusters/droplets/ice particles).

4) Supersaturated and super-cooled environments result in the formation of super-cooled water droplets, ice particles and rimers, etc. through collisions in the strong turbulence. (The word rimer is used to represent large particles such as graupels and hailstones.)

5) Violent collisions (due to the strong turbulence) of the ice particles and water droplets with the rimers give rise to breakups of the ice particles and water droplets into positively and negatively charged fragments; hence, charge separation. Surface chemistry of water molecules at the temporarily existing liquid water layer on rimers gives rise to a layer of positively charged hydrogen atoms sticking out of the surface of the liquid layer [7] [8]. These positively charged hydrogen atoms would attract the negatively charged fragments into the liquid layers which freeze up quickly, thus trapping the negatively charged fragments inside the rimers. The light-weight positively charged snowflakes would fly higher up into the atmosphere becoming a positively charged cloud while the much heavier rimers stay below the negatively charged cloud [9] [10] [11] [12] [13].

6) Continued charge separation would give rise to a high voltage difference between the two charged clouds, resulting initially in a corona discharge [3]. The corona discharge would induce a strong airflow between the charged clouds. This would enhance the strength of the turbulence which in turn would induce many more collisions and charge separations. Eventually, a strong discharge between the two charged clouds would occur. This is lightning between two charged clouds. There could also be a discharge between the bottom negatively charged cloud and the ground. This is lightning between the cloud and the ground.

7) Once lightning occurs, the turbulence becomes weaker because there is no more corona discharge, hence, no more corona-induced strong airflow. The updraft alone might not be able to support the heavier rimers. The latter would fall down to the earth's surface giving rise to a rain gush and/or a hail storm or both.

8) There could be cases when charge separation would occur between two cloud bodies to the extent that corona discharge would start to occur while the moisture in the turbulence would not be sufficient to continue supplying water molecules to create super-cooled water droplets as well as rimers. That is to say, the water content in this situation is low. In this case, cloud-to-cloud or cloud-to-ground discharge (lightning) would still occur with little or almost no precipitation reaching the ground.

3. Lightning Which Ignites a Forest Wild Fire

The mechanism of lightning that ignites a naturally occurring forest wild fire is essentially the same as that of normal lightning. That is to say, in a forest, when the weather is hot, a strong updraft of hot and humid air would blow upward into the cold atmosphere high up in the sky. Presumably, there would be a sufficiently large amount of aerosols inside the updraft. Consequently, the first and second conditions (steps (1) and (2) in Section 2) listed above would be satisfied. Once this happens, the subsequent steps would "naturally" follow until lightning occurs between two oppositely charged cloud bodies (negatively charged at the bottom and positively charged at the top) or between the negatively charged cloud body at the bottom and the ground. In the latter case, if the moisture were not sufficiently high in the updraft, very little or almost no rain would reach the ground following the lightning. This would have a high probability of lighting up and burning the dry biological materials in the ground of the forest. It could also discharge through, light up and ignite a tree. A fire would now be started. This fire would quickly spread out under hot and dry conditions. Eventually, it would become a forest (wild) fire.

4. Lightning during a Forest Fire

During a forest fire, there is more lightning above the burning forest. This is because the burning of trees and other plants would release a lot of heat and moisture together with a lot of smoke particles (aerosols). They would be carried (blown) upwards by the hot air into the cold region high up in the atmosphere. A strong turbulence would also be created. This is the first step towards the creation of lightning as stated above in steps (1) and (2) in Section 2. That is to say, water molecules would aggregate around the smoke particles becoming cloud droplets. The primitive picture is shown in **Figure 1**. Once the liquid form of a cloud droplet is materialized, the smoke particle would be solvated and broken up into two or more charged pieces, equally charged positively and negatively. Each of these charged pieces would be "immediately" solvated; *i.e.* surrounded by water molecules (**Figure 2**) and migrated to different places inside the droplet so as to be in chemical/physical equilibrium. This is internal charge separation. Shattering of these cloud particles later on would produce negatively and positively charged fragments responsible for charging the cloud. Once this happens and the supply of hot and moist updraft continues, sooner or later, a pyrocumulus cloud would occur in the high cold atmosphere. Following the subsequent steps

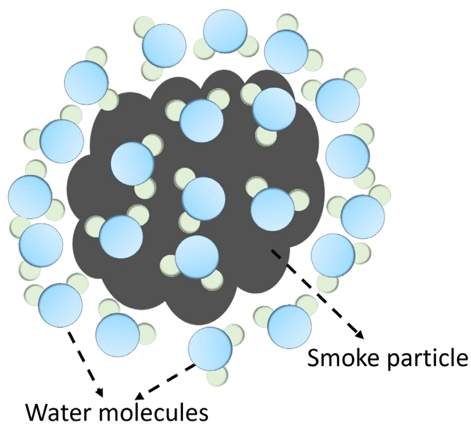

Figure 1. The primitive picture of water molecules aggregating around smoke particles becomes a cloud droplet.

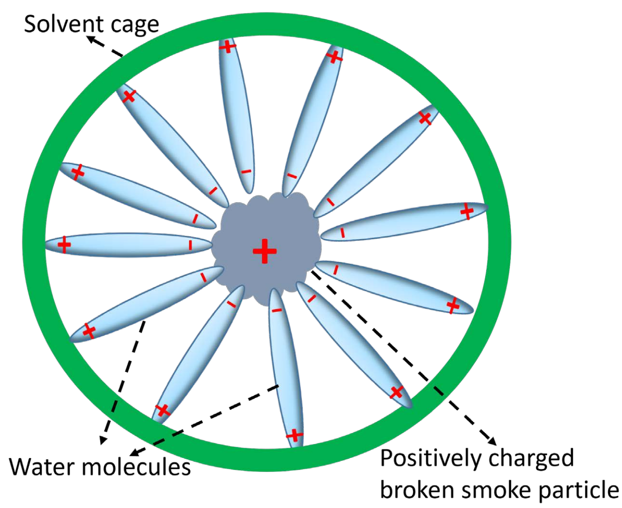

Figure 2. A primitive picture of a solvated positively charged broken smoke particle in a solvent cage. The cigar-shaped dipoles are water molecules. Hydrogen bonds are not indicated. After solvation, the ensemble becomes a positively charged "ball".

described in Section 2, lightning from the pyrocumulus cloud would follow. However, under such a condition, the supply of moisture through burning might not be enough. That is to say, lightning would occur but it would not result in any significant rain reaching the ground. Hence, one would call this dry lightning.

5. Discussion

5.1. Forest Wild Fire, A Natural Phenomenon

The creation of forest wild fires comes naturally once some atmospheric conditions are satisfied. In the case of the first lightning that ignites a local forest fire, the fundamental conditions are steps (1) and (2) as described in Section 2; *i.e.* a warm weather would induce the release of a large quantity of humid air together with a lot of aerosols from the forest. They would become a strong updraft that blows into the cold high atmosphere. Subsequent steps in Section 2 would follow "automatically" resulting in a lightning discharge. In the case of lightning during a forest fire, again, a large quantity of warm and humid air due to burning together with a large quantity of ashes (aerosols) would be released into the cold high altitude forming the pyrocumulus cloud. Subsequent reactions as stated in Section 2 would result in lightning.

Moreover, a strong forest fire would contribute to the induction of lightning over neighboring forests. That is, over a strong forest wild fire, warm and humid updrafts carrying a large amount of ashes (aerosols) would be blown upward forming the pyrocumulus clouds which would move and spread out over neighboring regions under predominant upper-level wind conditions. If there were a local updraft of warm and humid air in a neighboring zone, the incoming wind containing a lot of ashes (aerosols) would accelerate the induction of a new local lightning which would ignite a fire again locally. Such spreading would continue rather fast over a vast region in a warm and dry (no rain) season.

At the same time, such lightning would spread across a long distance following the dominant wind direction. For example, in the case of a forest fire (as of August 2023) burning in British Columbia in Canada, a colder region near the Arctic in the North West Territory (NWT) could have been affected. The air in a forest in this northern region is relatively clean containing a very small amount of aerosols. Normally, even in a "warm" summer, the local temperature might still not be very high. An updraft from the forest might be generated but it would not be strong enough and would contain a small amount of aerosols. There would thus be an insufficient amount of precipitation of water molecules around these local impurities/aerosols (charge condensation nuclei or CCN) becoming cloud particles in the high and cold atmosphere. The charges separated inside these limited number of cloud particles would be insufficient to induce lightning; hence, lightning is not probable under normal conditions. But when the pyrocumulus cloud and water vapor from above an existing forest fire plus the ashes and heat from the fire in the south is blown over into the cold region in the north, they would contribute to the creation of much more precipitation of water molecules in the high cold atmosphere. The consequence would be that there would be a sufficient amount of precipitation into cloud particles and hence a sufficient amount of charge separation inside the water droplets and ice particles in the high cold atmosphere. This would eventually lead to the first lightning towards the ground (see Section 3) but with little rain accompanying it. A new forest fire would thus be ignited. The recent "delayed" forest fire in Yellowknife in the North West Territory (NWT) of Canada might have been due to this "propagation" effect.

However, in a tropical zone where the humidity is very high, lightning would be accompanied by a rain gush most of the time [3]. Also, the vegetation and debris at the base of any tropical forest/jungle are always wet and humid. Lightning might char up the vegetation along its path but would most probably not ignite a large fire. That is why wild fire due to lightning in a tropical zone is almost unheard of.

5.2. Control of Lightning in a Forest Fire

Based upon the above understanding of the mechanism of lightning in a forest, we might want to ask if such lightning activities could be stopped or reduced. To achieve this goal, the first two conditions given in Section 2 should NOT be valid; *i.e.* the updraft should be weaker, the water vapor content in the updraft should be lower and the aerosol content inside the updraft should also be lower. This would mean that the temperature in the forest should be lower so that there is less evaporation of water vapor and hence, weaker updraft and fewer aerosols. This condition is contrary to the forest wild fire condition when the weather is hot resulting in a lot of evaporation. It is thus not possible to reduce lightning activities in a hot and humid environment in the high latitude (non-tropical) regions.

5.3. Laser and Satellite Technology

Observation of lightning from a satellite should be possible, in principle. It might help indicating the first ignition of a forest fire. If a local fire were detected, it might be possible to quickly send in fire fighters to control the fire or to stop the fire from spreading. Recently, satellite-based detection of aerosols from desert storms and from wild fires in Canada as of June 5, 2023, was carried out successfully [14]. This satellite technology could be applied to lightning detection eventually. Moreover, laser-guided lightning was shown to be feasible in a recent experiment [15]. Thus, it would be feasible to make use of laser beams either from the ground or from a satellite to create a partial discharge (lightning) between two oppositely charged clouds. This would reduce the total amount of charges in the lower charged cloud so that a discharge (lightning) between the lower charged cloud and the ground would not take place or would become much less probable. A forest fire would thus be less probable or avoided.

6. Conclusion

The mechanism of lightning induced forest fires in countries/regions of high latitude can be explained qualitatively based upon the mechanism of lightning at the molecular level recently proposed by the authors and co-workers [1]. The mechanism is based on two phenomena of internal charge separation inside the atmospheric cloud particles and the existence of a layer of positively charged hydrogen atoms sticking out of the surface of the liquid layer of water on the surface of rimers. Strong turbulence-driven collisions of the ice particles and water droplets with the rimers break up the ice particles and water droplets into positively and negatively charged fragments leading to charge separation. Hot weather in a forest contributes to the updraft of hot and less humid air. Therefore, lightning would have a high probability of lighting up and burning the dry biological materials in the ground of the forest, leading to a forest (wild) fire. Once the burning of trees and other plants occurs, it releases a lot of heat and moisture together with a lot of smoke particles (aerosols) becoming a strong updraft. The condition for creating a lightning is again satisfied which would result in further lightning high above the forest wild fire. Such events could result in the induction of lightning over neighboring forests as well as distant forests in the northern colder part of a large region. An example is western Canada during the month of August, 2023. Forest wild fire spread and "jumped" locally and new but delayed forest fires spread over large regions. Delayed forest fire took place even in Yellowknife in the NWT. The latter might have been induced by the forest fire in the south. To reduce the probability of lightning in a forest, the weather should be cold so as to reduce the rate of moisture evaporation and the strength of the updraft. Unfortunately, climate change seems to push the weather towards a warmer one. Lightning and forest fires are thus unavoidable and will intensify in the future because the weather is getting warmer. Satellite and laser technologies might help in reducing the spread of forest fire. More work in this direction might have to be carried out in the future.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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