

Investigating the Connection Between Cloud Cover and Cosmic Rays

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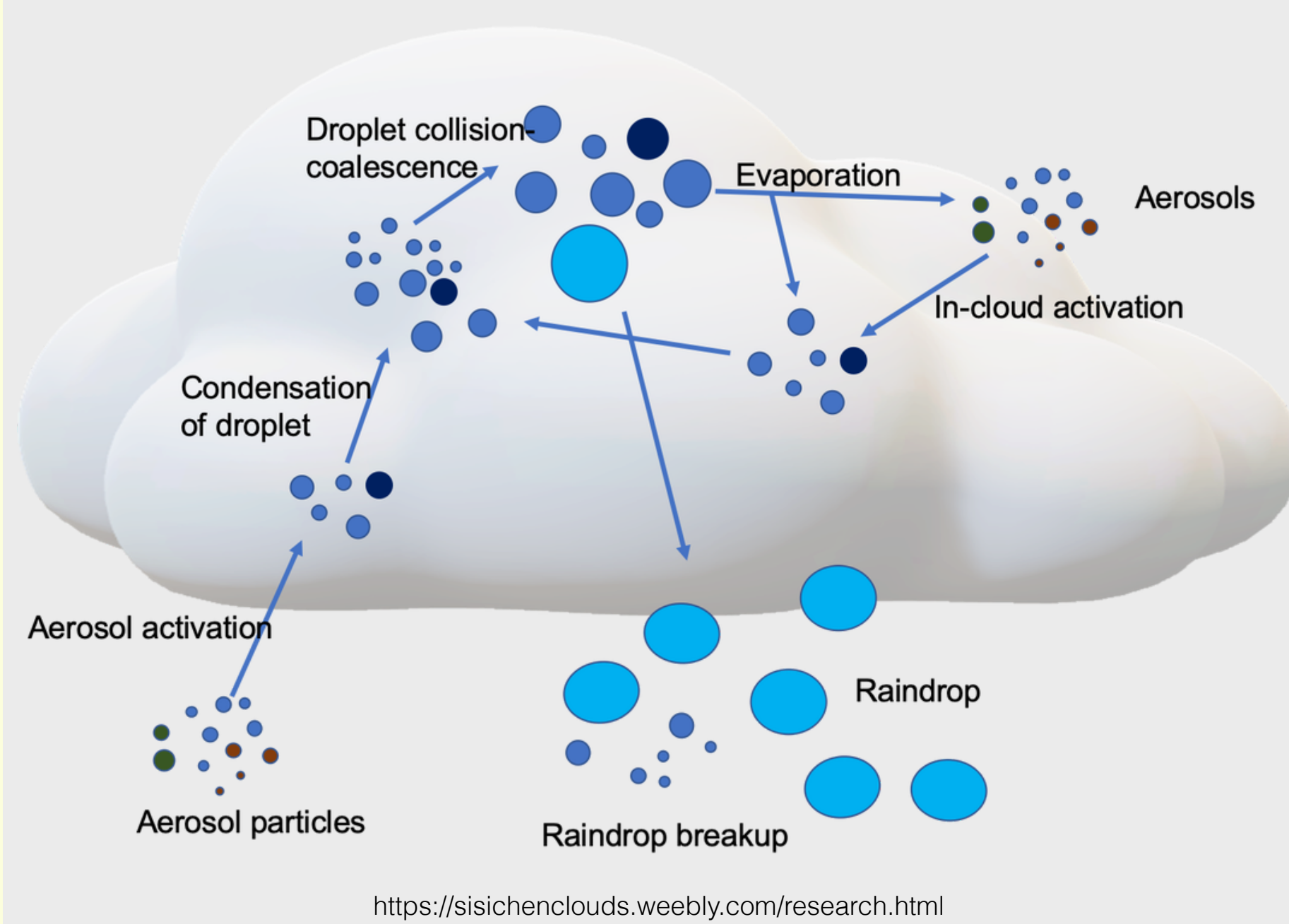
Atmospheric Physics

History of Atmospheric Physics

The formal study of electricity in the atmosphere began in the 18th century, through the experiments of Franklin and D'Alibard (Harrison 2004). As the field progressed, people learned that electricity was still present in the atmosphere even in the absence of thunderstorms because of Lemonnier studying clear air and Canton observing non-thunderstorm clouds (Harrison 2004). It was not until 1997 that Svensmark and Friis-Christensen began to formally investigate how cosmic rays could affect atmospheric electricity.

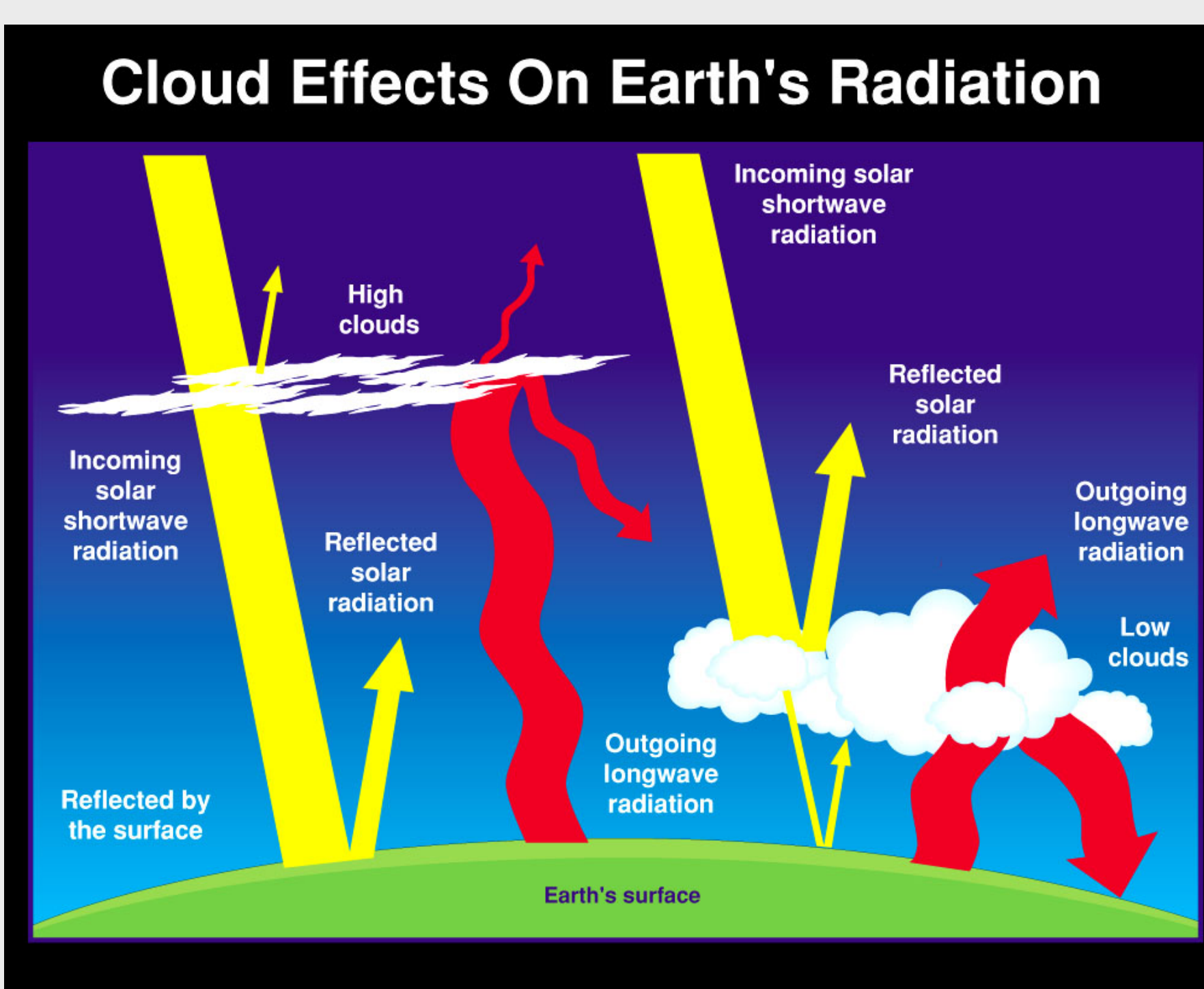
Introduction to Cloud Physics

The atmosphere includes aerosols, which are a variety of suspended particles. When enough of these gather, through a process called coagulation, their total diameter exceeds 100 nm and can begin serving as a center for water vapor to collect (Pierce and Adams 2007). Once this happens, they are called Cloud Condensing Nuclei. With enough aerosols and humidity in an area, cloud droplets are formed. Therefore, clouds themselves are just assemblies of these droplets (Rogers 1976).



Cloud Properties

What effect clouds have on the weather and climate depends not only on the cloud properties but its altitude. An important feature is the cloud albedo. This is a measure of its broadband (including infrared) reflectivity. Multiple factors determine a cloud's albedo, such as thickness, the properties of the individual aerosols and the abundance of ice particles and water content (Han *et al.* 1997). Clouds both reflect radiation from both directions, i.e., space (cooling) and infrared (heating the planet) (Svensmark and Friis-Christensen 1997). The cooling dominates, which leads to a net lower temperature for Earth, implying that cloud cover should be correlated with temperature.



<https://visibleearth.nasa.gov/images/54219/cloud-effects-on-earths-radiation>

Cosmic Rays

The Earth resides in what we call the Heliosphere, which is defined as the region of space dominated by energetic particles from the sun. These particles shield us from cosmic radiation from outside, to what extent depends on the phase of the solar cycle. Galactic cosmic rays undergo collisions with nuclei in our atmosphere. These result in free protons, neutrons, pions and secondary nuclei. The secondary particles lose energy with every interaction until, eventually, they no longer generate particle cascades. The greatest ionization happens in the lower atmosphere (Marsh and Svensmark 2000). This phenomenon was seen by V.F. Hess with his balloon and airship experiments (Hess 1928).

Of the variety of secondary particles produced, we detect >10 MeV neutrons at the ground level with neutron monitors. Through a combination of fission in Pb and moderation by hydrogenous material, the neutron number is multiplied and thermalized to be captured by boron (BF₃ gas) in the monitor. See poster by Kuhlman *et al.* this session.

When the thermal neutron is captured by a ¹⁰B nucleus, there are two possibilities, depending on which excited state the B finds itself in. The Q-Values of 2.792 MeV or 2.310 MeV correspond to the ground and first excited states of ⁷Li, respectively. The reaction favors (94%) the excited state. Because some reactions take place in proximity to the detector wall, either the lithium or alpha particle can leave the detector, not depositing its full energy in the gas. This is called the Wall Effect and produces a continuum of energy deposits.

Current Understanding of the Connection

Cosmic rays have various correlations with Earth's climate but significant causal relationships have yet to be proven. There have, however, been multiple proposed observations and theories that could lead to a more definitive link. For example, by changing the number of ions in the atmosphere, cosmic rays modify the current flow in the global electric circuit, which can result in an increased number of thunderstorms (Singh and Bhargawa 2020). An even stronger study came out (Harrison *et al.* 2011), which measured how exactly the global atmospheric electrical circuit affected cloud edges and compared this information to neutron monitor data. They found that cloud base heights decreased and low clouds were more numerous when neutron counts were high. Another possibility is that cosmic rays affect the rate of formation of ice particles within clouds (Harrison 2004). So, if we can establish a connection between cosmic rays and clouds, then we can show cosmic rays to have significant, albeit indirect, ramifications on the weather.

A possible process that relates the two is the ion-aerosol clear-air mechanism. This theory states that the charged secondary particles created by cosmic rays not only add to the population of potential condensation nuclei, but also these particles have an easier time attracting aerosols due to their polarity. This could increase the number of particles growing from 1 nm to 5 nm by a factor of 2 (Carslaw *et al.* 2002). This mechanism could help explain why observed nucleation rates are so much higher than theoretical calculations.

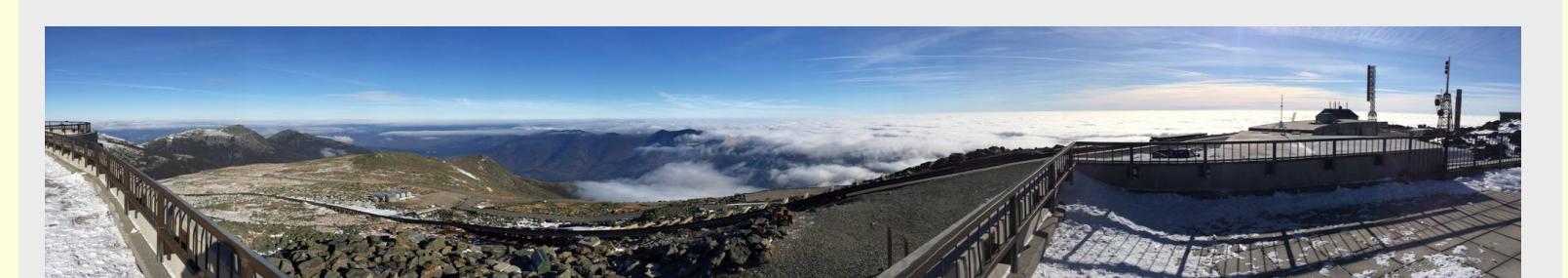
Although this possibility seems promising, the theory is not bulletproof. Many studies have conflicting results. For instance, in addition to the heliosphere shielding Earth from GCRs, the planet's own magnetic field does this. This effect is weakest at Earth's magnetic poles but evidence has shown the strongest correlation between cosmic rays and clouds at lower latitudes. Near the equator, cosmic rays with less than 10 GeV are almost completely blocked (Lanci *et al.* 2020). This would mean the Cloud Condensing Nuclei must somehow travel between these two regions to produce the correlation in the first place (Pierce and Adams 2009). Additionally, the Cosmic Leaving Outdoor Droplets (CLOUD) experiment was designed to test this very link through and only found a weak GCR-CCN response. (Pierce 2017).

However, this point can be countered by the fact the locations with high latitudes, such as Antarctica, do experience different weather conditions that can be attributed to cosmic rays. A 2017 study took measurements of atmospheric electric current density and observed how rates of snowfall changed with cosmic rays. The researchers found that both low and high clouds were correlated with cosmic ray flux, by 23% and 8% respectively (Kumar *et al.* 2017). It could be the case that there is some unknown mechanism that explains the correlation between clouds in low latitude areas and cosmic rays. Even if the ion-aerosol clear-air mechanism itself is insufficient to prove a strong causal link between cosmic rays and clouds, other possibilities exist and should be investigated.

Methods

One problem investigating this connection is that because they are two very different areas of science, the data to study them typically does not come from the same location. For example, despite the CLOUD experiment being done with sophisticated technology, it was done under laboratory conditions and with simulations. Similarly, the Harrison (2011) study had caveats in their data taking. The cloud and GCR data came from entirely different countries (the USA and the UK, respectively) and the data were not taken at the same cadence (The cloud data are described as "sporadic"). Both cloud coverage and cosmic rays are very dependent on longitude, latitude, and altitude so if the data come from different places, hidden parameters make establishing a causal relationship difficult.

We have the opportunity, because of our relationship with the Mount Washington Observatory, to conduct a controlled field experiment. The Observatory staff observes the heights and types of clouds on an hourly basis, along with their locations. We will use these data in combination with data from the UNH neutron monitor co-located with the Observatory. The high altitude of the monitor also means we will have greater precision in our measurements. To our knowledge, no study on this topic has been performed using co-located observations.



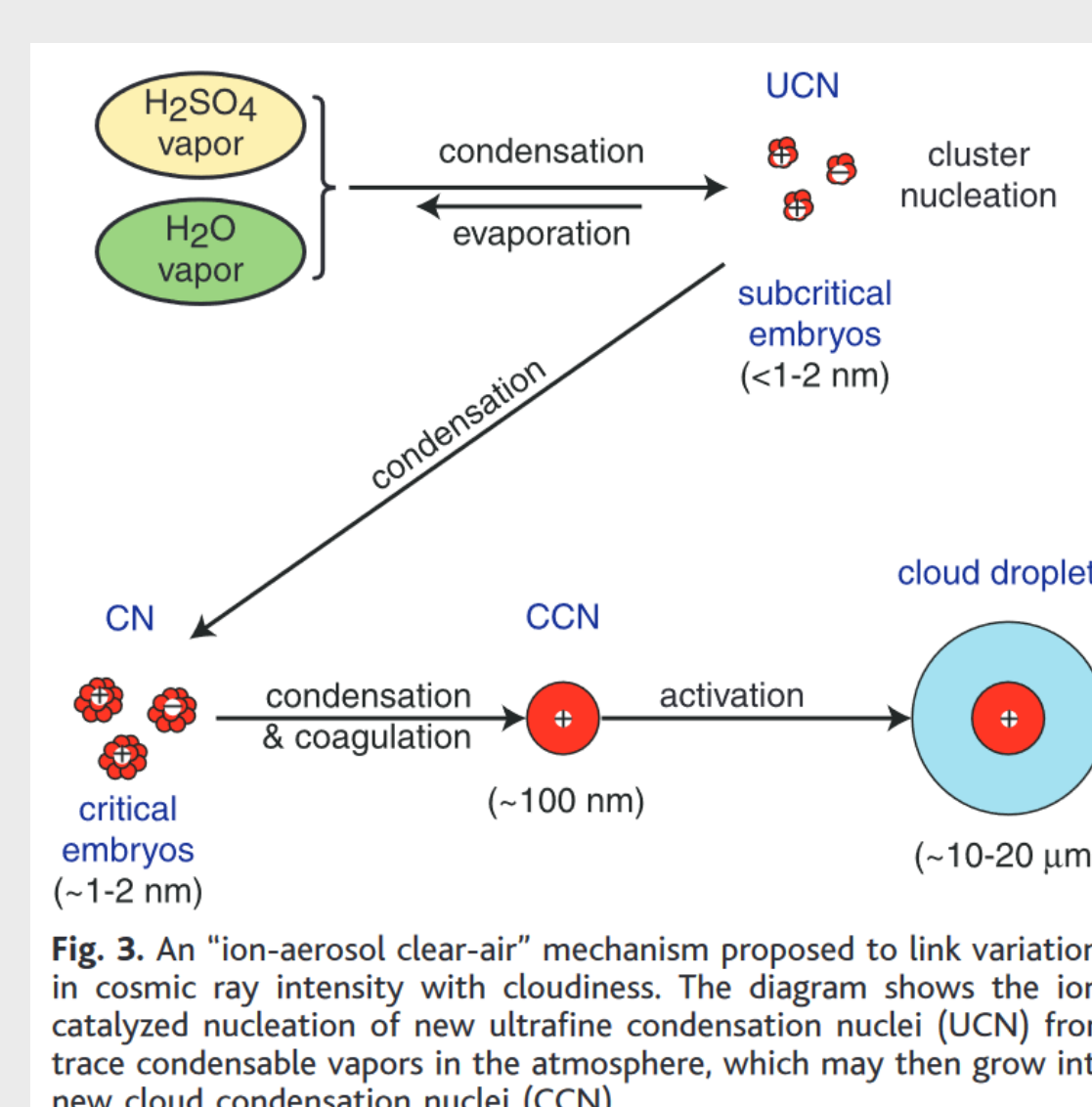
Mount Washington Summit

Acknowledgments

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Carslaw *et al.* 2002

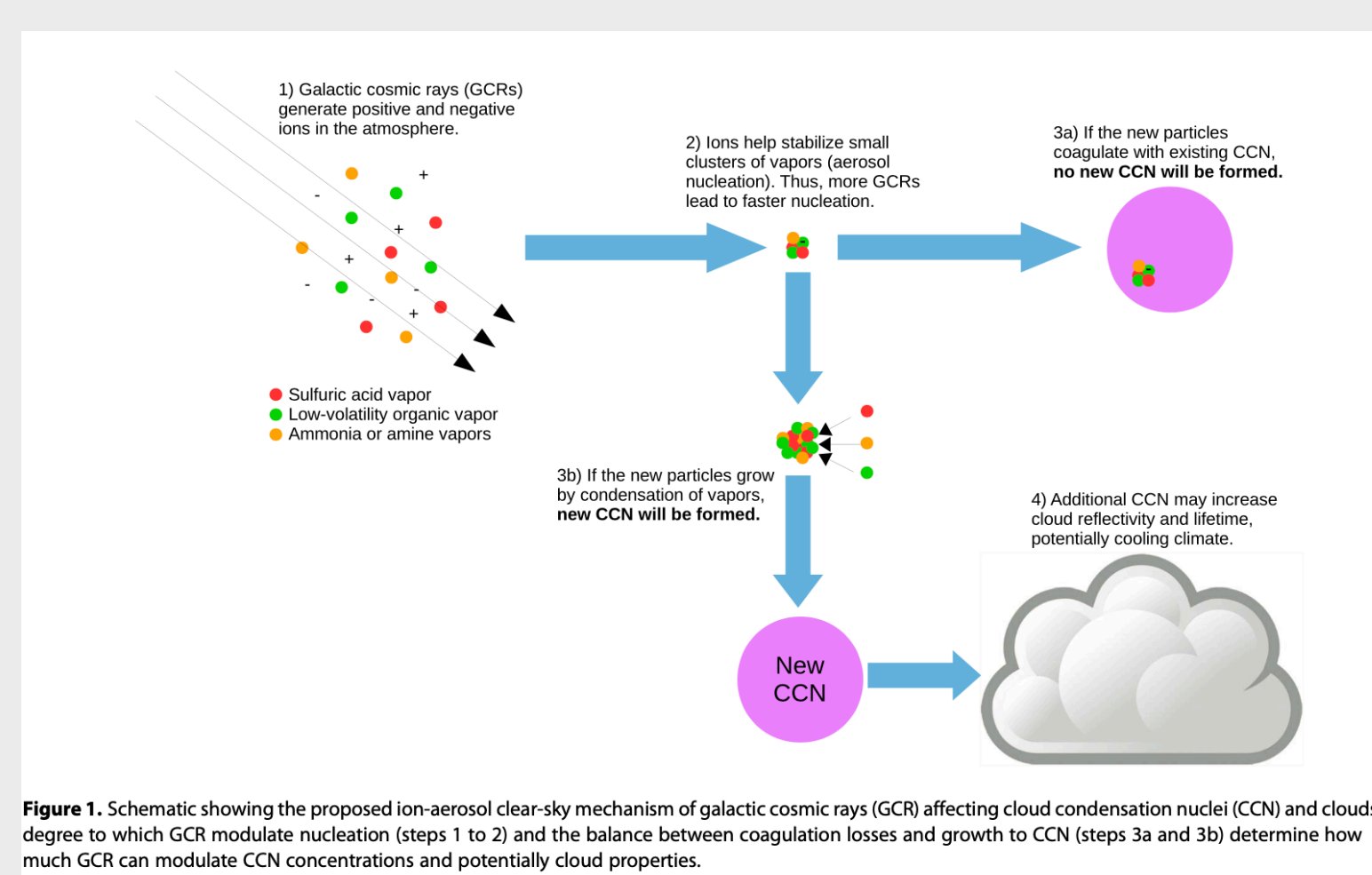


Figure 1. Schematic showing the proposed ion-aerosol clear-air mechanism of galactic cosmic rays (GCR) affecting cloud condensation nuclei (CCN) and clouds. The degree to which GCR modulate nucleation (steps 1 to 2) and the balance between coagulation losses and growth to CCN (steps 3a and 3b) determine how much GCR can modulate CCN concentrations and potentially cloud properties.

Pierce 2017