COSMOCLIMATOLOGY

HOT TAKES

1. High-energy cosmic rays striking the atmosphere could lead to more clouds.
2. Bright clouds reflect solar radiation back to space, cooling the atmosphere.
3. If increased solar activity shields the Earth from cloud-forming cosmic rays then its warming impacts could be amplified.

Can the highly energetic sub-atomic particles constantly raining down from distant reaches of the Milky Way lead to more clouds? This is a question worth considering because clouds are very important for the radiative energy balance of the Earth. Any systematic changes in cloud cover, no matter how slight, will noticeably affect the temperature of the atmosphere and, ultimately, the climate. The British science writer Nigel Calder coined the name *cosmoclimatology* to describe the study of cosmic effects on climate.

The story began in 1996[1] with the unexpected discovery that variations in global cloud cover may correlate with the intensity of galactic cosmic rays[2]. These highly energetic particles are known to penetrate deep into the atmosphere to the levels where clouds form. The scientific challenge is to understand how high energy particles from outside the solar system are able to affect clouds. The Intergovernmental Panel on Climate Change (IPCC) has concluded that[3]:

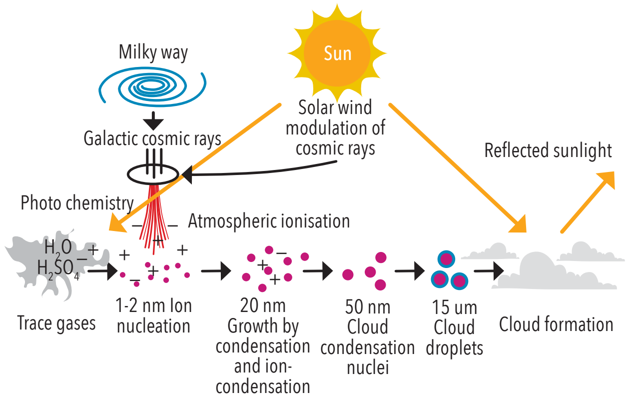
"Cosmic rays enhance new particle formation in the free troposphere, but the effect on the concentration of cloud condensation nuclei is too weak to have any detectable climatic influence…"

However not all researchers agree with this assessment. A consistent theory is described below that explains the link between cosmic rays and clouds. The link has also been tested in laboratory experiments.

The Cosmic Ray – Cloud Hypothesis

The cosmic ray – cloud hypothesis is summarised in Figure 1. Solar variability manifests itself as changes in the intensity of the solar wind[4] streaming from the Sun. Galactic cosmic rays are electrically charged particles so they can be deflected by magnetic fields such as those associated with the solar wind and the Earth. Changes in the solar wind due to changes in solar activity can also impact the shape of the Earth's magnetic field. The cosmic ray particles that make it through the Earth's magnetic field into the atmosphere collide with and ionise gas molecules, leading to ion-nucleation and stabilisation of cloud-seeding aerosols[5] formed from trace aerosol-forming compounds in the atmosphere.

Figure 1: The cosmic ray – cloud hypothesis[6]



The physical mechanism linking solar activity variations to climate change is as follows: a) a more active Sun, b) stronger solar wind, c) fewer galactic cosmic rays able to impact the atmosphere, d) less atmospheric ionisation, e) less ion-nucleation of aerosols and slower growth, f) fewer cloud condensation nuclei, g) clouds with fewer droplets and shorter lifespans, h) less reflectivity, i) less reflection of sunlight and a warmer Earth.
nm = nanometre. A nanometre is one millionth of a millimetre.

Aerosols are minute particles of liquid or solid suspended in the atmosphere. Their sizes can range from 1 to 1,000 nanometres. If these aerosols clump together into large enough particles they can reach the sizes required to act as cloud condensation nuclei, and thus assist the formation of clouds. This can happen when the aerosol particles grow larger than about 50 nanometres.

A change in the density of cloud condensation nuclei will change both the radiative properties and the lifespan of clouds. Any systematic changes in the clouds, no matter how slight, can affect the energy budget of the Earth – hence the temperature of the atmosphere and, ultimately, the climate.

If such a relationship exists between cloud cover and cosmic rays then a correlation might be expected between observed variations in solar activity (hence the intensity of the solar wind), and changes in the climate.

One example of such a real-life link is the multi-millennial agreement between the temperature of the Indian Ocean as mirrored in the ratio between oxygen isotopes[7] in stalagmites in a cave in Oman, and solar activity, estimated from the concentration of the cosmogenic carbon-14 isotope produced by cosmic ray variations[8].

Experimental Evidence for a Cosmic Ray – Cloud Link

The cosmic ray – cloud hypothesis has been experimentally tested[9]. An eight cubic metre reaction chamber was filled with air resembling the atmosphere over the tropics, with fixed trace gas concentrations of water vapour, ozone and aerosol-forming sulphur dioxide. In nature, one specific type of aerosol is typically composed of sulphuric acid droplets formed by photochemistry in the atmosphere. Natural photochemical processes were replicated using ultra-violet radiation. The reaction chamber could also be irradiated with gamma rays of varying intensity. Gamma rays are ionising radiation. They ionise some of the gas in the chamber, replicating the same ionising effect charged cosmic ray particles have when they enter the atmosphere.

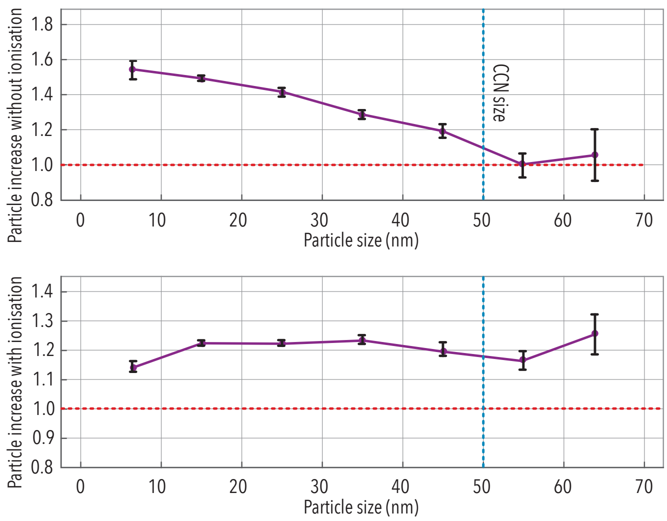
The idea was to measure the effect of changing ionisation in the chamber as small aerosols grow to the sizes required for cloud condensation nuclei. A number of experiments simulated what would happen in the atmosphere without the presence of cosmic rays. Small electrically neutral aerosols of 6–7 nanometres were injected continuously into the experimental volume and their growth towards cloud condensation nuclei sizes was observed. In Figure 2, the top panel shows how the small molecular clusters fail to grow sufficiently to increase the number of cloud condensation nuclei (larger than 50 nanometres). In a second series of experiments, when the air in the chamber is exposed to ionising radiation simulating the effect of galactic cosmic rays, all additional small aerosols formed (3 nanometres) grew to cloud condensation nuclei sizes (over 50 nanometres) – see bottom panel.

In summary, ions assist the formation of new small aerosols via ion-nucleation, as galactic cosmic rays interact with the atmosphere. Ions are also important in the growth process by helping small aerosols survive and grow to cloud condensation nuclei sizes, at which size they can influence clouds.

Conclusion

Progress has been made in understanding how the Sun influences Earth's climate. Galactic cosmic rays may play a part. By ionising the air, cosmic rays help to form aerosols that may grow into the cloud condensation nuclei that are required for water vapour to condense into the droplets that form reflective low-altitude clouds. As these types of clouds exert a strong cooling effect, increases or decreases in the cosmic-ray flux, which thereby increase or decrease cloudiness, can lower or raise the Earth's temperature.

Figure 2: Experimental tests of aerosol growth into cloud condensation nuclei[9]



Top panel: without ionisation. Small aerosol particles decline as the aerosol particles grow to cloud condensation nuclei sizes; Bottom panel: with ionisation. In this case all the small aerosols grow to cloud condensation nuclei sizes.

SEE ALSO

FACT SHEET #12: TROPICAL CONVECTION: COOLING THE ATMOSPHERE
FACT SHEET #13: REFLECTIONS ON THE IRIS EFFECT

Information in this fact sheet has been drawn from *Climate Change: The Facts* 2020 (IPA 2020), Chapter 10, by Dr Henrik Svensmark. Fact Sheet series general editor: Dr Arthur Day

1. Svensmark, H & Friis-Christensen, E 1997, 'Variation of cosmic ray flux and global cloud coverage-a missing link in solar-climate relationships', *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 59, p. 1225.
2. Galactic cosmic rays originate from outside the solar system. They are highly energetic sub-atomic particles that have been ejected at close to the speed of light from exploding stars. They mostly consist of high energy protons (the nuclei of hydrogen atoms), but there is a smaller fraction of much heavier atomic nuclei as well.
3. Boucher et al. 2013, Clouds and Aerosols: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter07_FINAL.pdf.
4. The solar wind is a stream of charged particles released from the upper atmosphere of the Sun. As a rapidly moving charged plasma it has magnetism, allowing it to modify the Earth's magnetic field and deflect galactic cosmic rays.
5. Aerosols are suspensions of fine particles or liquid droplets in the air, such as smoke or sea spray. There are many kinds of aerosols, both natural and man-made, and they have widely different origins. They can heavily influence the formation of clouds and therefore the climate.
6. Source: Adapted from Svensmark, H 2019, *Force Majeure: The Sun's Role in Climate Change*, The Global Warming Policy Foundation, report 33, ISBN 978-0-9931190-9-5.
7. Isotopes are variants of a particular chemical element which differ in neutron number, and therefore mass, making them chemically the same but still distinguishable from each other.
8. Neff, U, Burns, SJ, Mangini, M, Mudelsee, D, Fleitmann, D & Matter, A 2001, 'Strong coherence between solar variability and the monsoon in Oman between 9 and 6 kyr ago', Nature, vol. 411, p. 290.
9. Source: Adapted from Svensmark, H, Pedersen, OP, Marsh, ND, Enghoff MB & Uggerhøj, UI 2007, 'Experimental evidence for the role of ions in particle nucleation under atmospheric conditions', *Proceedings of the Royal Society A*, vol. 463, pp. 385–396.

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