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Legal and Regulatory Issues Concerning the Concept of Cloud Seeding in Climate Change Mitigation

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Abstract

Cloud Seeding is a recent scientific discovery on weather modification and alteration that aims to enhance rainfall in addressing drought and climate change issues. However, despite this potent discovery there are several legal issues yet to be addressed in the usage of cloud seeding. Hence, the study examines the legal issue arising from cloud seeding. The study adopts a doctrinal method of study, relying on primary and secondary research material, such as laws, journal articles, internet articles, and other relevant research material. The data obtained were analyzed using a descriptive and analytical method. The study found that cloud seeding is a potential means of curtailing the incidence of drought and desertification caused by climate change arising from harmful industrial and human activities. However, the study also found that several legal issues may arise in utilizing cloud seeding, which includes a lack of comprehensive international law regulating cloud Seeding, the inability of the existing laws to address transboundary issues, liability, impose due compliance and sanction of wrong utilizing cloud seeding that adversely alter the natural state of the environment. Concerning this the study concludes and recommends that there is a need for a unified global legal framework to ensure the responsible use of cloud seeding and effective regulation.

KEYWORDS: Cloud, Seeding, International, Legal, Regulation

Introduction

Over time, protecting and safeguarding the global environment has been the global community's central concern[1]. This is concerning the fact that over the years the global community has witnessed severe climate change that has had a significant impact on climate Earth[2], thereby leading to extreme weather conditions such as prolonged droughts, water shortage, freshwater reduction, desertification, and loss of biodiversity[3]. Furthermore, several countries within the global environment have been witnessing erratic scarcity of water, and prolonged drying seasons resulting in severe wide fire outbreaks just like the recent case of the United States of America that occurred from 2025 and lasted for several days[4]. The Wide fire led to the destruction of life, property, and residence[5]. This incidence of climate change is a result of harmful human and industrial activities that involve the use of fossil fuel and other harmful chemicals that are unfriendly to the environment and health of man[6].

In this regard, it suffices to state that the global environment is very much aware that allowing this unfriendly act of humans and industries to continue could result in inimical disaster, hence for several years international environmental laws (such as the Stockholm Convention, United Nations Convention for Combating Desertification, the Biodiversity Convention[7], the Kyoto Protocol, the Paris Agreement and several others) and principles (Such as the sustainable development principles, the polluters pay principles, the precautionary principle and the common but different responsibility

[1] Paul Atagamen Aidonojie, Adebayo, K. Adesoji, Eregbuonye Obishie., Wakili S. Abacha, (2024), "Breaking Legal and Socio-economic Challenges to Plastic Waste Regulation in Nigeria: Lessons learned from Singapore", Yustisia, 13(1), 64-88

[2] Osikemekha A Anani, Abel Inobeme, Osayomwanbo Osarenotor, Frances Ngozi Olisaka, Paul Atagamen Aidonojie, Emmanuel Olusegun Olatunji, Aishatu Idris Habib, (2023), 'Application of Microorganisms as Biofactories to Produce Biogenic Nanoparticles for Environmental Cleanup: Currents Advances and Challenges', Current Nanoscience, 19(6), 770-782

[3] Adrii Samuel, Muriel Boleri., Eddy Peter and Claude Gloria., (2019), Depollution of mining effluents: innovative mobilization of plant resources', Environmental Science and Pollution Research, Vol. 26, 19327–19334, https://doi.org/10.1007/s11356-019-05027-y

[4] Kingsley Eghonghon Ukhurebor, Uyiosa Osagie Aigbe, Robert Birundu Onyancha, Hussain Athar, Benedict Okundaye, Paul Atagamen Aidonojie, Benita Ebindu Siloko, Ismail Hossain, Heri Septya Kusuma, Handoko Darmokoesoemo, "Environmental Influence of Gas Flaring: Perspective from the Niger Delta Region of Nigeria", Geofluids, vol. 2024, 17 pages, 2024. https://doi.org/10.1155/2024/1321022

[5] Blaž Gasparini, and Ulrike Lohmann "Why cirrus cloud seeding cannot substantially cool the planet", Journal of Geophysical Research, Atmospheres, Vol. 121 (9), (2016): 4877-4893, https://doi.org/10.1002/2015JD024666

[6] Katja Friedrich katja.friedrich@colorado.edu, Kyoko Ikeda, Sarah A. Tessendorf, Jeffrey R. French, Robert M. Rauber, Bart Geerts, Lulin Xue, Roy M. Rasmussen, Derek R. Blestrud, Melvin L. Kunkel, Nicholas Dawson, and Shaun Parkinson, "Quantifying snowfall from orographic cloud seeding", Proc. Natl. Acad. Sci. U.S.A. 117 (10), (2020): 5190-5195, https://doi.org/10.1073/pnas.1917204117

[7] Folasade Folake Aare, Olusola Raphael Olorunfemi, and Gogo George Ntor. "Legal Frameworks for Single-Use Plastic Management: Environmental Challenges and Solutions." KIULJ 6, no. 1 (2024): 63–85.

principles) has been established to curtail this incidence of climate change[8]. However, despite these laws climate change resulting in prolonged drought, desertification, scarcity of water and freshwater continue to persist[9]. Hence, to resolve this severe environmental impact scientists have been indulging in several environmental discoveries to remedy the harm caused to the environment. One of such ground-breaking scientific discoveries is known as cloud seeding.

The scientific concept of cloud seeding is said to have been first experimented on by two scientists Irving Langmuir and Vincent Schaefer in 1946[10]. Cloud seeding involves an artificial method of weather modification to induce rainfall, and improve air quality and fog in affected areas suffering from climate change[11]. Cloud seeding is achieved through the injection and dispersing of substances such as potassium chloride, silver iodide, or dry ice into the atmosphere to arouse the precipitation of rainfall, fog, or hail. It must be noted that several countries such as China, the United Arab Emirates, and the United States have suffered severed from prolonged drought, water scarcity, and poor water quality has embarked on investing in this project of cloud seeding to induce rainfall to curtail the incidence of prolong drought and improve on agriculture productivity[12]. It must be noted that despite the potential of cloud seeding several consequences may arise and these include; climate intervention, altering weather patterns that may be adverse, the release of chemicals that may be adverse to biodiversity and health of man, transboundary pollution, and several other unidentified environmental challenges. However, despite its growing application of cloud seeding and its potential threat to the global environment and the health of man[13]. It suffices to state that, there is the absence of a unified global legal and regulatory framework governing cloud seeding. Hence, this raises critical concerns over environmental safety, ethical considerations of the use of cloud seeding,

[8] Esther Christine Kisubi, Gabriel Adenyuma Godswill Owoche Antai, and Valentine Tebi Mbeli. "Utilitarianism in Uganda's Oil and Gas Sector: Balancing Utility and Responsibility for Environmental Justice." KIULJ 6, no. 1 (2024): 190–207.

[9] Uchechukwu Esther Oloworaran. "An Evaluation of the Legal Framework for Resolving Disputes in the Digital Ecosystem in Nigeria." KIULJ 5, no. 2 (2023): 50–64.

[10] Oluwatoyin Oyeronke Ajayi. "Mining in Nigeria and Environmental Protection: Examining the Legal and Institutional Frameworks." KIULJ 5, no. 2 (2023): 238–257.

[11] Imoisi E. Simon and Paul Atagamen Aidonojie, (2023). Legal and Socio-economic Issues Concerning Black Marketer's Activities of Petroleum Products in Nigeria. Yuridika, 38(2), 61-84, https://doi.org/10.20473/ydk.v38i2.44999

[12] Roelof T. Bruintjes, A Review of Cloud Seeding Experiments to Enhance Precipitation and Some New Prospects, Bulletin of the American Meteorological Society, Vol. 80(5), (1999): 805-820, https://doi.org/10.1175/1520-0477(1999)080<0805:AROCSE>2.0.CO;2

[13] Taha Al Hosari, Abdulla Al Mandous, Youssef Wehbe, Abdeltawab Shalaby, Noor Al Shamsi, Hajer Al Naqbi, Omar Al Yazeedi, Alya Al Mazroui and Sufian Farrah, "The UAE Cloud Seeding Program: A Statistical and Physical Evaluation". Atmosphere. 2021; 12(8):1013. https://doi.org/10.3390/atmos12081013

transboundary impacts, and disputes that may arise on the reliance on cloud seeding.

It is concerning the above that this study tends to focus on examining the dangers of climate change, and reliance on the concept of cloud seeding to mitigate drought, desertification, and wildfire caused by climate change. Furthermore, the study also examines the environmental challenges and impact caused by cloud seeding, and the lapses inherent in global environmental laws to address these challenges and proposes probable solutions.

Concerning the fact that the study examines environmental drought arising from climate change, which has resulted in the scientific discovery of cloud seeding, which is a major scientific breakthrough in weather modification in the creation of artificial rain. The study adopts a doctrinal method of study that places reliance on primary sources of research material, which include: Convention, Treaties, Protocol, Agreement, bilateral and multilateral agreements. Primary sources undergo a systematic analysis, through themes grounded in content analysis, interpretation of laws or legal rules for binding legal texts such as the 1977 Environmental Modification Convention (ENMOD), and other relevant environmental laws as it concern cloud seeding, and applicable case law. These legal texts, and others, such as reporting or permits, will be documented for their legal applicability, assessing basis of authority, legal enforceability, applicable governance of atmospheric intervention, principally regulations, statutes, protocols or procedural laws, including obligations related to sovereignty, liability, transboundary harm, and, ethical obligations including prior informed consent.

Furthermore, the study also relied on secondary sources of research material such as Journal articles, articles online, textbooks, monographs, and other relevant research material. The analysis on the secondary sources will reveal gaps in the legal regime, sometimes the theoretical underpinning (e.g., environmental justice and precautionary principle), and ascertain how researchers and even policymakers have reacted (with some regulations, invariably cloud seeding) to regulatory challenges faced by cloud seeding activity. The secondary sources will also be useful as secondary triangulation of findings from primary legal texts, enhancing the internal validity of the findings/conclusions established.

Concerning the above, the data generated through the primary and secondary sources of research material were analyzed through the use of analytical and descriptive methods. The essence of incorporating doctrinal research method is aim at theorizing and conceptualizing climate issues as they pertain to environmental drought, the current scientific discovery known as cloud seeding and its legal implications given the intended legal issues that may sprout

Conceptual Issues on Adverse Weather Conditions Arising from Climate Change

Climate change is considered a global issue that has been rocking the global environment for years[14]. Several discoveries have reviewed the fact that climate change is majorly caused by bush burning, deforestation, and the use of fossil fuel products[15]. Bushing burning tend to affect biodiversity, reduce the number of trees in the global environment, and further result in desertification[16]. Also, deforestation tends to negatively place the global environment vulnerable to global warming[17]. This is concerning the fact that the use of fossil fuel products (such as gasoline, kerosene, diesel fuel, propane, ammonia, coal tar, coal gas, hydrogen, paraffin wax, and several others) often results in carbon gas emissions[18]. Hence, the use of fossil fuel products often results in depletion of the ozone layer thereby resulting in adverse global warming and climate change[19]. Furthermore, bush burning and deforestation reduce the number of plants and trees that could have been reliable in mitigating the climate change effect necessitated by global warming[20]. Trees and plants are said to be good conductors and remediation that could aid in trapping carbon gas and through photosynthesis convert the same to oxygen that is further released into the environment which the environment, humans, and animals need for survival[21]. Furthermore, the use of other industrial and harmful chemicals also contributes to the degradation of the global environment and causes severe health hazards for humans and man.

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[14] Olanrewaju Aladeitan and Chidinma Therese Odaghara. "Environmentalism and an International Court for the Environment." KIULJ 2, no. 1 (2018): 143–64.

[15] Paul Atagamen Aidonojie, Anani O. Anthony, Agbale O. Patient, Olomukoro O. John, Adetunji O. Charles. (2020). Environmental Law in Nigeria: A Review on its Antecedence, Application, Judicial Unfairness and Prospects. Archive of Science & Technology 1(2) (2020) 211-221

[16] Anani O. Anthony, Paul Atagamen Aidonojie and Olomukoro O. John, (2022), Environmental Principles and Ethics: Current Challenges in the Field of Bioscience and Law, Ethics, Media, Theology and Development in Africa: A Festchrift in Honour of Msgr. Prof. Dr. Obiora Francis Ike, Global.net Co-Publication & Others, Geneva, Switzerland, 142-158

[17] Valentine T. Mbeli. "An Analysis of the Legal Framework for Sustainable Fisheries' Financing in Uganda." KIULJ 3, no. 2 (2019): 1–22.

[18] Paul Atagamen Aidonojie, Ukhurebor . E. Kingsley, Oaihimire E. Idemudia, Ngonso F Blessed, Egielewa Peter, and Darmokoesoemo Hussein, (2023), Bioenergy revamping and complimenting the global environmental legal framework on the reduction of waste materials: A facile review, 9(1), https://doi.org/10.1016/j.heliyon.2023.e12860

[19] Ariyoosu D. Adeyemi and Abdulkadir O. Abdulrazaq. "Maritime Surveillance and Enforcement Privitisation Galore in Nigeria: A Compromise of State Sovereignty." KIULJ 1, no. 1 (2017): 134–49.

[20] Oladiran Akinsola Ayodele and Maruf Adeniyi Nasir. "Implementation of SDGs in Nigeria: Issues and Challenges." KIULJ 3, no. 2 (2019): 83–104.

[21] Paul Atagamen Aidonojie, Ukhurebor, E. Kingsley, Masajuwa, Florence, Imoisi, E. Simon, Edetalehn, O. Idemudia, Nwazi, Joseph, (2022). Legal Implications of Nanobiosensors Concerning Environmental Monitoring. In: Singh, R.P., Ukhurebor, E. Kingsley, Singh, J., Adetunji, O. Charles, Singh, K.R. (eds) Nanobiosensors for Environmental Monitoring. Springer, Cham. https://doi.org/10.1007/978-3-031-16106-3_21

The causes and execution of these harmful effects resulting in climate change are products of human and industrial activities. This is caused by utilizing fossil fuels and harmful chemicals in their daily activities and businesses, given the quest for globalization and economic development by countries[22]. The result and impact of global warming often place severe stress on the environment, thereby leading to climate change, such as prolonged drought resulting in water scarcity, poor soil moisture resulting in poor agricultural production, and possibly causing bush burning[23]. When soil lacks water, the quality of the moisture tends to drastically reduce, resulting in serious consequences for the agricultural sector. Prolonged drought leading to poor soil moisture could result in poor agricultural harvest, food shortage, loss of biodiversity, and adverse health effects on humans[24]. This is a concerning fact as plants, animals, and humans rely on water for their sustenance and survival.

Furthermore, prolonged drought could also result in a wildfire, just like the incident that occurs in the United States in 2025[25]. The incidence of wildfire has become a common issue and phenomenon in global terrain due prolonged absence of rain. The absence of rain for long periods often results in dry vegetation thereby causing the forest and bush to be highly combustible[26]. The adverse effect of wildfire often results in the loss of biodiversity, and destruction of the forest, homes, and agricultural products. A good example is the United States wildfire that rendered cities into relics and made them look like war zones, where lives and property were lost[27]. Furthermore, prolonged and extended drought could also lead to desertification, a process that results in unfertile and barren land due to soil

[22] Paul Atagamen Aidonojie (2023). Environmental Hazard: The Legal Issues Concerning Environmental Justice in Nigeria, Journal of Human Rights, Culture and Legal System, 3(1), pp. 17-32, https://doi.org/10.53955/jhcls.v3i1.60

[23] Paul Atagamen Aidonojie, Idahosa M. Ekata, Agbale O. Patient, and Oyedeji A, Ifeoluwa, (2022), The Environmental Conservation, and Ethical Issues concerning Herbal Products in Nigeria, Journal of Environmental Science and Economics, Vol. 1(3), 26-32 DOI: https://doi.org/10.56556/jescae.v1i3.124

[24] Paul Atagamen Aidonojie, Ikubanni O. Oluwaseye, Oyedeji A. Ifeoluwa and Oyebade A. Akinsola (2022) The Legal Challenges and Effect concerning the Environmental Security in Nigeria: A Lesson from International Perspective, Journal of Commercial and Property Law, Vol. 9(1), 110-120

[25] Shaista Malik, Haleema Bano, Rauoof Ahmad Rather, and Shakeel Ahmad, Cloud Seeding; Its Prospects and Concerns in the Modern World –A review, Int. J. Pure App. Biosci. 6(5): 791-796 (2018). doi: http://dx.doi.org/10.18782/2320-7051.6824

[26] Jeffrey R. French, Katja Friedrich, Sarah A. Tessendorf, Robert M. Rauber, Bart Geerts, Roy M. Rasmussen, Lulin Xue, Melvin L. Kunkel, and Derek R. Blestrud, "Precipitation formation from orographic cloud seeding", Proc. Natl. Acad. Sci. U.S.A. 115 (6), (2018): 1168-1173, https://doi.org/10.1073/pnas.1716995115

[27] Paul Atagamen Aidonojie, Majekodunmi T. Akintola, Eregbuonye Obishie and Adeyemi-Balogun O. Janet, (2024), Potential and Legal Challenges of Metaverse for Environmental Awareness and Sustainable Practice in Nigeria: A Comparative Study with Singapore, Administrative and Environmental Law Review 5 (1):37-64. https://doi.org/10.25041/aelr.v5i1.3230.

degradation and loss of vegetation[28]. The process of wildfire caused by prolonged drought often results in the release of large amounts of carbon dioxide, which is a major cause of global warming, thereby intensifying more severe impacts and depletion of the ozone layer[29]. Also, it has been proven scientifically that inhaling smoke emanating from wildfires could result in severe health hazards.

Concerning the above, it suffices to state that the continuous and prolonged drought and desertification due to climate change is considered a threat to the Earth's and man's climate. This is concerning the fact that man cannot survive under such harsh and severe weather conditions. Water, a healthy and conducive environment, are requirements for human survival. Hence, to curtail the incidence, several academic scholars and scientists have ventured into research to discover several scientific measures to address adverse climate change. One such scientific discovery and measure is cloud seeding.

The Scientific Concept of Cloud Seeding in Mitigating Adverse Climate Change and It Adverse Effect

Cloud seeding is a weather modification technique that involves spraying and introducing chemicals on clouds to arouse precipitation[30]. Cloud seeding incorporates and adopts the scientific principle of nucleation by introducing artificially formulated substances such as sodium chloride, silver iodide, or dry ice (solid carbon dioxide), which could turn into condensation or ice nuclei for accelerated precipitation[31]. These agents furnish a surface for the supercooled water droplets in clouds or the atmosphere to freeze into ice crystals that have to fall back to the region where it is introduced as precipitation[32]. As a result, the idea of cloud seeding has been proven as a

[28] Imoisi E. Simon, Paul Atagamen Aidonojie, and Edetalehn O. Idemudia., (2023), Legal Issues and Innovations Introduced by the Petroleum Industry Act 2021 in the Nigerian Oil Industry, Journal of Commercial and Property Law, 10(2), 229-243

[29] Paul Atagamen Aidonojie, Okuonghae Nosa, Moses-oke O. Rose, Majekodunmi T. Akintola, (2023), 'A Facile Review on the Legal Issues and Challenges Concerning the Conservation and Preservation of Biodiversity', Global Sustainability Research, 2(2), 34-46

[30] Ali M. Abshaev, Andrea Flossmann, Steven T. Siems, Thara Prabhakaran, Zhanyu Yao & Sarah Tessendorf, Rain Enhancement Through Cloud Seeding . In: Qadir, M., Smakhtin, V., Koo-Oshima, S., Guenther, E. (eds) Unconventional Water Resources . (2022), Springer, Cham. https://doi.org/10.1007/978-3-030-90146-2_2

[31] Vladimir P. Korneev, Ilya E. Potapov, & Georgy G. Shchukin, Environmental aspects of cloud seeding. Russ. Meteorol. Hydrol. 42, 477–483 (2017). https://doi.org/10.3103/S106837391707007X

[32] Xiaobo Dong, Chuanfeng Zhao, Zhaochu Huang, Rong Mai, Feng Lv, Xuewu Xue, Xiaorui Zhang, Shaoyu Hou, Yang Yang, Yikun Yang, Yue Sun, "Increase of precipitation by cloud seeding observed

remedy that should be applied for drought control, alleviation of weather-related severe conditions influenced by climate change, and water resource management[33]. Cloud seeding is one of the most important measures in mitigating and curtailing climate change by addressing sustained periods of drought[34]. Climate change has been known to aggravate and increase the frequency of droughts in many regions, leading to the creation of water scarcity for uses that include the destruction of agriculture[35]. Cloud seeding can help induce rainfall in drought areas to replenish water bodies, keep agriculture alive, and maintain ecological balance[36]. Countries including China, the United Arab Emirates, and the United States have successfully implemented cloud-seeding measures to augment the availability of water in arid and semi-arid regions[37].

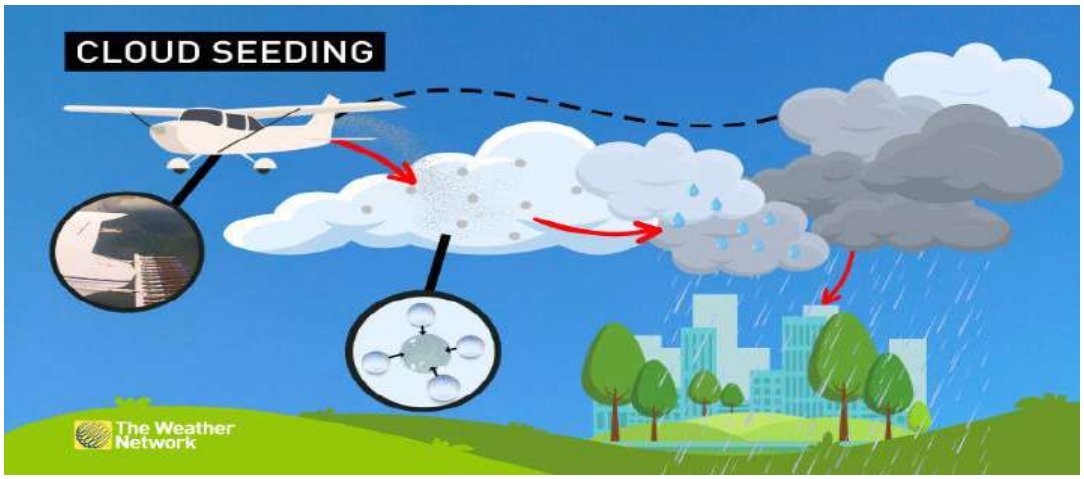

Figure 1: Diagrammatic view of Cloud Seeding
Source: Dennis Mersereau[38]

At the same time, cloud seeding is also relieving extreme heat conditions. Rising global temperatures and the consequent climate change

from a case study in November 2020 over Shijiazhuang, China", Atmospheric Research, Vol. 262, 2021, 105766, https://doi.org/10.1016/j.atmosres.2021.105766.

[33] Mohammad Sadeghi, Saeed Yaghoubi, "Optimization models for cloud seeding network design and operations", European Journal of Operational Research, Vol. 312 (3), (2024), 1146-1167, https://doi.org/10.1016/j.ejor.2023.07.041.

[34] Ibid

[35] Ibid

[36] Fei Wang, Baojun Chen, Zhiguo Yue, Jin Wang, Dejun Li, Dawei Lin, Yahui Tang and Tian Luan, "A Composite Approach for Evaluating Operational Cloud Seeding Effect in Stratus Clouds". Hydrology. 2024; 11(10):167. https://doi.org/10.3390/hydrology11100167

[37] Ibid

[38] Dennis Mersereau "What is Cloud Seeding? How Scientist Hope to Generate Rain" https://www.theweathernetwork.com/en/news/science/explainers/what-is-cloud-seeding-weather-modification-to-create-rain-snow

have engendered heatwaves endangering human and ecological health[39]. By causing rainfall, cloud seeding can cool the surrounding air through evaporative cooling[40]. Increased cloud cover from seeding can also reflect solar radiation back into space, helping to reduce ground temperatures and alleviate the urban heat island effect in crowded cities. Another pertinent aspect of cloud seeding in climate change mitigation is the potential for lessening the impacts of wildfires[41]. Due to extreme heat and prolonged dry conditions, the incidence of wildfires has risen, thereby releasing significant quantities of carbon dioxide and other greenhouse gases into the atmosphere[42]. Increasing humidity and precipitation in areas prone to wildfires through cloud seeding could prevent the ignition and spread of these fires. Countries such as Australia and the United States have contemplated cloud seeding as a wildfire prevention strategy in the face of extreme drought[43].

Cloud seeding is not only used to mitigate climate-related disasters but also stabilize ecosystems that suffer from anomalous precipitation[44]. Monsoons have become erratic, bringing floods and droughts in different areas due to climate change, and artificial enhancement of rainfall during dry seasons or little rainfall during the wet season would balance the hydrological cycle[45]. Improvement in this cycle would help agriculture, forests, wetlands, and dependent biodiversity[46]. Suffice it to say, then, that cloud seeding offers a scientifically sound, technologically viable alternative to some of the ailments inflicted by climate change[47]. Proven effective in augmenting precipitation, temperature cooling, risk reduction from wildfires, and ecosystem stabilization, this approach should therefore be carefully scrutinized regarding the environmental, ethical, and economic feasibility[48]. Continuous research

[39] Ulrike Proske, Verena Bessenbacher, Zane Dedekind, Ulrike Lohmann, and David Neubauer, "How frequent is natural cloud seeding from ice cloud layers (< −35 °C) over Switzerland?", Atmos. Chem. Phys., 21, (2021): 5195–5216, https://doi.org/10.5194/acp-21-5195-2021

[40] Xianghua Wu, Ni Yan, Huaying Yu, Shengjie Niu, Fangxiu Meng, Weiqi Liu, Haiyan Sun, "Advances in the Evaluation of Cloud Seeding: Statistical Evidence for the Enhancement of Precipitation", Earth and Space Science, Vol 5 (9), (2018): 425-439, https://doi.org/10.1029/2018EA000424

[41] Jinlong Yuan, Kenan Wu, Tianwen Wei, Lu Wang, Zhifeng Shu, Yuanjian Yang, and Haiyun Xia, "Cloud Seeding Evidenced by Coherent Doppler Wind Lidar" Remote Sensing 13, no. 19 (2021): 3815. https://doi.org/10.3390/rs13193815

[42] Blaž Gasparini, Zachary McGraw, Trude Storelvmo and Ulrike Lohmann, "To what extent can cirrus cloud seeding counteract global warming?", Environ. Res. Lett. 15 (2020): 1-12, https://doi.org/10.1088/1748-9326/ab71a3

[43] Ibid

[44] Ibid

[45] Ibid

[46] Ibid

[47] Joyce E. Penner, Cheng Zhou, and Xiaohong Liu, "Can cirrus cloud seeding be used for geoengineering?", Geophysical Research Letters, Vol. 42 (20) (2015): 8775-8782, https://doi.org/10.1002/2015GL065992

[48] Binod Pokharel, S.-Y. Simon Wang, Hongping Gu, Matthew D. LaPlante, Jake Serago, Robert Gillies, Jonathan Meyer, Stephanie Beall, Kyoko Ikeda, "A modeling examination of cloud seeding

and technological advancements are vital to improve efficiency and reduce any possible adverse impacts[49]. As climate change continues to wreak global havoc, the strategic use of cloud seeding remains an integral tool in the all-encompassing endeavor to manage and adapt to shifting climatic conditions[50].

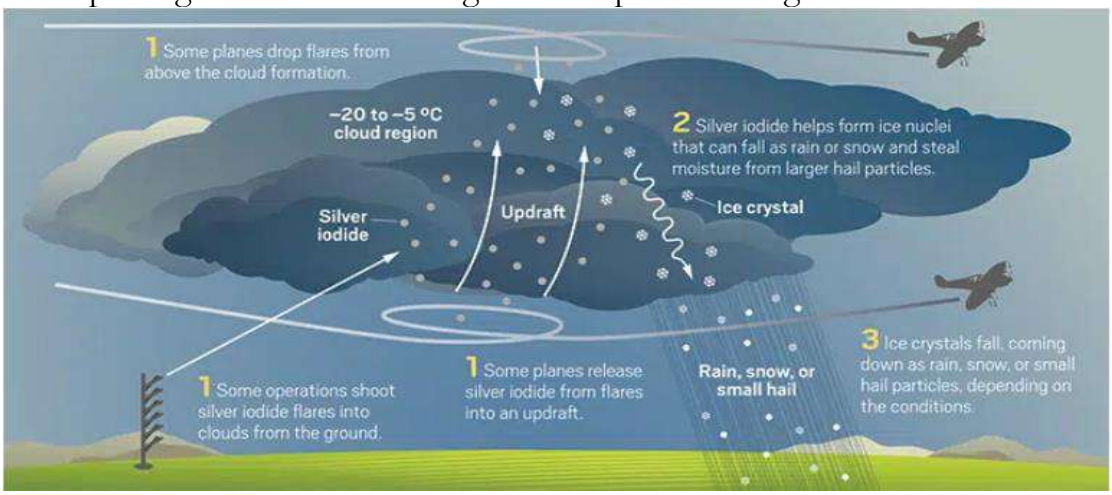

Figure 2: Process involve in Cloud Seeding
Source: Orkhan Huseynli[51]

However, notwithstanding the relevance of cloud seeding, it suffices to state that cloud seeding has its share of challenges and adverse effects[52]. Very heated scientific debates are ongoing regarding its long-term efficiency and environmental effects[53]. There are arguments in some of the research that silver iodide and other chemicals that are artificially introduced into the atmosphere may present risks to the ecosystem[54]. This is concerning the fact that cloud seeding entails several environmental and health hazards because of the chemicals utilize and unexpected changes that may occur in weather modification[55]. According to studies conducted by Xiaofeng et al , the prolonged deposition of silver iodide into the soil and aquatic systems, particularly in regions where cloud seeding is prevalent, may alter chemical compositions in such a way as to damage plants and microorganisms.

conditions under the warmer climate in Utah, USA,", Atmospheric Research, Vol. 248, (2021), 105239, https://doi.org/10.1016/j.atmosres.2020.105239.
[49] Ibid
[50] Ibid
[51] Orkhan Huseynli, "Unleashing the Power of Cloud Seeding: Navigating Potentials and Pitfalls", https://earth.org/unleashing-the-power-of-cloud-seeding-navigating-potential-and-pitfalls/
[52] Aleksandar Valjarević, Cristina Popovici, Anđelka Štilić & Milan Radojković "Cloudiness and water from cloud seeding in connection with plants distribution in the Republic of Moldova". Appl Water Sci 12, 262 (2022). https://doi.org/10.1007/s13201-022-01784-3
[53] Ibid
[54] Ibid
[55] Ibid

According to studies conducted by Xiaofeng et al[56], the prolonged deposition of silver iodide into the soil and aquatic systems, particularly in regions where cloud seeding is prevalent, may alter chemical compositions in such a way as to damage plants and microorganisms.

Furthermore, the introduction of substances such as silver iodide, calcium chloride, and potassium chloride, into the atmosphere can contaminate water and soil, which in turn affects the environment, aquatic life, and plant growth[57]. Other effects are associated with many rains that may lead to floods, hailstorms, and other climatic disasters disrupting the local ecosystem[58]. Also, overcloud seeding may interfere with the natural weather cycles, which may lead to rainfall shortages in regions where it is not expected, subsequently leading to degradation in other regions of the country[59]. Apart from this, heavy unnatural rains brought in by cloud seeding may interfere with the ecological balance. Sudden precipitation increases bring along soil erosion, nutrient runoff, and flooding, all of which pose threats to agricultural systems and native vegetation. In arid or semi-arid centers, ecosystems have adapted to the low availability of water. Smoothly changing moisture regimes of these ecosystems may lower the resistance capacity of native species, triggering invasive species. A document of the World Meteorological Organization (WMO) issued in 2008[60] cautioned against the potential of cloud seeding to destabilize ecological systems if undertaken without adequate environmental impact consideration, as opposed to enhancing environmental outcomes.

Healthwise, human beings are known to experience severe respiratory problems and skin irritations after prolonged exposure to silver iodide, which is a common cloud-seeding agent to modifies weather conditions[61]. The airborne chemicals that are used in cloud seeding may also add up to air contamination, especially for individuals with respiratory problems, most

[56] Lou Xiaofeng, Fu Yu, Su Zhengjun. Advances of silver iodide seeding agents for weather modification. J Appl Meteor Sci, 2021, 32(2): 146-159. DOI: 10.11898/1001-7313.20210202

[57] Jung Mo Ku, Ki-Ho Chang, Sanghee Chae, A.-Reum Ko, Yonghun Ro, Woonseon Jung & Chulkyu Lee "Preliminary Results of Cloud Seeding Experiments for Air Pollution Reduction in 2020". Asia-Pac J Atmos Sci 59, 347–358 (2023). https://doi.org/10.1007/s13143-023-00315-7

[58] Zahar Koretsky, and Harro van Lente, "Technology phase-out as unravelling of socio-technical configurations: Cloud seeding case", Environmental Innovation and Societal Transitions, Vol. 37, (2020): 302-317, https://doi.org/10.1016/j.eist.2020.10.002.

[59] Ibid

[60] World Meteorological Organization (WMO). (2008). Guidelines for the Planning of Weather Modification Activities (WMO-No. 998). Geneva: WMO. Retrieved from https://library.wmo.int/doc_num.php?explnum_id=9442 Accessed 20th July, 2025

[61] Katherine Gayatri, Thara Prabhakaran, Neelam Malap, Mahen Konwar, Dinesh Gurnule, Shivdas Bankar, P. Murugavel, "Physical evaluation of hygroscopic cloud seeding in convective clouds using in situ observations and numerical simulations during CAIPEEX", Atmospheric Research, Vol. 284, (2023): https://doi.org/10.1016/j.atmosres.2022.106558.

especially asthmatic patients[62]. Furthermore, it must be noted toxic accumulation in soil and water could result in poison in agricultural food and water safety[63]. A study conducted by Carlos et al.,[64] in the study area place several decades of weather modification operations. The researchers documented that chemical use in cloud seeding could cause moderate adverse effects on freshwater phytoplankton and soil bacteria, particularly posing adverse effects on microbial viability and photosynthesis. From this point, it suffices to state that if cloud seeding could impact freshwater phytoplankton and soil bacteria, there should be a call for further health monitoring for the residents, as well as long-term epidemiology studies on the potential harm of cloud seeding on the health of humans.

Concerning the above, it suffices to state that the environmental hazards outweigh the possible benefits of cloud seeding with respect to water resource management, and climate adaptation cannot be ignored. In addition to this, not limited to, are some risks to biodiversity, ecosystem change, and odor health outcomes, none of which were identified following public health guidelines for human health risk assessment from uncertain exposures, by the precautionary principle should be carefully followed. This requires a clear approach for cloud seeding environmental hazards and effects to include environmental impact studies as standard, ongoing ecological monitoring, and international regulatory programs. Furthermore, these interventions must be based on credible science and the legal framework to ensure ecological sustainability because countries are considering cloud seeding within their climate change adaptation strategy.

Stakeholders' Perspective of Cloud Seeding

Cloud seeding encompasses a collaborative constellation of individuals and organizations, including government businesses, water managers, downstream users, farmers, environmental NGOs, private businesses and contractors, and the general public[65]. Each of them possesses relative interests beyond providing additional water supplies, maintaining ecological integrity,

[62] Yanlong Tai, Haoran Liang, Abdelali Zaki, Nabil El Hadri, Ali M. Abshaev, Buzgigit M. Huchunaev, Steve Griffiths, Mustapha Jouiad, and OrcidLinda Zou, "Core/Shell Microstructure Induced Synergistic Effect for Efficient Water-Droplet Formation and Cloud-Seeding Application", ACS Nano, Vol 11 (12), (2017): 12318–12325, https://doi.org/10.1021/acsnano.7b06114

[63] Ibid

[64] Carlos Fajardo, Gloria Costa, Luis T. Ortiz, Mendis Nande, Martins L. Rodríguez-Membibre, Marenda Martín, and Savie Sánchez-Fortún "Potential risk of acute toxicity induced by AgI cloud seeding on soil and freshwater biota", Ecotoxicol Environ Saf, 2016, 133:433-41. https://doi.org/10.1016/j.ecoenv.2016.06.028

[65] Abdulbasit Kolapo Imam, Ethical Implications and Legal Void in Cloud Seeding As A War Strategy, LexScriptio 1, no. 1, (2024): 155-177

or respecting open and transparent processes. Bixby[66] (2024) highlights that cross-boundary cloud seeding operations can escalate water conflicts, as downstream users feel that they are wrongly impacted by upstream activities, especially when water quantity is limited. Public perception is a major determinant of the acceptance and successful implementation of any cloud seeding activity. Farhar[67] (1977) conducted survey-based research that illustrates the importance of community participation and informed public engagement to garner long-term local commitment to weather-modification programs in the United States. Moreover, extra attention is needed in rural areas, where precipitation from the project area can benefit adjacent regions. Currently, a 2021 Pew Research Center poll[68] stated that while roughly half of American adults undoubtedly think cloud seeding could reduce climate change impacts, a strong majority are opposed due to its potential downstream impacts. This demonstrates the public desire for an open process and stakeholder engagement.

Cloud seeding governance must reconcile the scientific uncertainties and liability risks inherent to cloud seeding from a regulatory viewpoint. However, operational permits, licensing, and public notice encourage stakeholders to recognize their safety and liability challenges in a project, despite uncertain scientific causation. The function of legal arrangements is to ensure stakeholders consider the project as responsibly governed. As a result, agencies are focusing on establishing procedural transparency rather than contingent liability routes. However, with an invested interest in environmental justice, stakeholders like NGOs and communities raise questions around distributive fairness and informed consent. The sustainability governance literature recognizes that just cloud seeding governance means adaptable processes, allows for inclusive consultation, and recognizes how a range of interests in cloud seeding will fall outside of consultation processes; importantly, that representation exists in decision-making for marginalized or downstream communities. Stakeholder equity frameworks reinforce that those directly affected by seeding (and those downwind) have opportunities to engage meaningfully in decision making. Meteorological researchers and operational agencies, for example, water resource authorities, advocate for an emphasis upon technical uncertainty and planning horizons of more than 10 years, and the BAMS review report

[66] Adam Bixby, The Silver Lining Solution: Alleviating Water Insecurity in the Colorado River Basin through Cloud Seeding, J.L. & Pub. Pol'y 34, (2024): 189-215

[67] Barbara C. Farhar, The Public Decides about Weather Modification. *Environment and Behavior*, 9 no. 3, (1977): 279-310. https://doi.org/10.1177/001391657700900301

[68] Courtney Johnson and Brian Kennedy, "U.S. adults have mixed views on whether geoengineering would help reduce effects of climate change" https://www.pewresearch.org/short-reads/2021/06/11/u-s-adults-have-mixed-views-on-whether-geoengineering-would-help-reduce-effects-of-climate-change/?utm_source=chatgpt.com accessed 21st July, 2025

prepared by Flossmann et al.,[69] details of long term (catchment) scale trials, in Australia, Israel and the U.S., show very modest gains (usually<20%), and due to the modest gain, cost benefit assessment in cloud seeding is uncertain. Scientists must adopt a dual stakeholder role: designing good experiments and limiting great expectations.

Suffices to also state that, there are private companies, insurers, and politicians, all viewing cloud seeding through the lenses of dollars and reputations. The uncertainty of the outcomes affects both ROI and political risk, while service providers also consider public perception and liability. A wider understanding of governance frameworks indicates that we should not see cloud seeding as a silver bullet, or as a single solution in our water management toolbox but instead as that particular tool with transparent communications to stakeholders, and transparency on their accountability to stakeholders. As a result, stakeholder views on cloud seeding represent a complex matrix of competing priorities and perspectives. Communities want no less than transparency and inclusion; scientists remind us to temper our expectations regarding efficacy; regulators remind us of the necessity of legal safeguards; and environmental representatives remind us of issues of equity and justice. Understanding this stakeholder matrix will be paramount to designing legitimate, adaptive, and ethically based cloud seeding governance systems.

Global Legal Regulation Concerning Cloud Seeding

Concerning this study, it suffices to state that the scientific discovery of cloud seeding is a novel and trending issue and it has attracted several scholarly discourses[70]. However, it must be noted that there are no specific treaties, conventions, declarations, or protocols that contemplate or expressly provide for cloud seeding[71]. However, several international conventions, treaties, and protocols could also apply in regulating the scientific discovery of cloud seeding. Hence it will be relevant to consider some of these laws to ascertain the extent the concept of cloud seeding could be regulated in terms of it use and its dangers.

One of these International environmental laws is the Convention on the Prohibition of Military or Any Other Hostile Use of Environmental

[69] Andrea I. Flossmann, Michael Manton, Ali Abshaev, Roelof Bruintjes, Masataka Murakami, Thara Prabhakaran, and Zhanyu Yao, "Review of Advances in Precipitation Enhancement Research"
[70] Osikemekha Anthony Anani, Maulin P Shah, Paul Atagamen Aidonojie, Alex Ajeh Enuneku, (2023), "Bio-Nano Filtration as an Abatement Technique Used in the Management and Treatment of Impurities in Industrial Wastewater" Bio-Nano Filtration in Industrial Effluent Treatment, 171-182
[71] Ukhurebor, E. Kingsley, and Paul Atagamen Aidonojie (2021). The influence of climate change on food innovation technology: review on topical developments and legal framework. Agric & Food Security 10, 50.

Modification Techniques[72] (herein also called ENMOD). This Convention was enacted in 1977 with the main purpose of curtailing and preventing the act of scientific modification and alteration of the global environment as a weapon of warfare[73]. Concerning this, the preamble of the convention defines the modification of weather to mean the alteration of the natural state of climate or ecosystem to remodify its patterns through scientific techniques. Concerning this, article I and II of the ENMOD[74] specifically prohibits and curtails the incidence of weather, ocean, atmospheric conditions, or geological alteration as a means of military engagement or engaging in hostile and deleterious environmental alterations that could have long and severe effects on the climate thereby resulting in climate change. However, it must be noted that the ban on weather alteration is specifically on the aspect of weaponizing it as a means of military attack or warfare. In this regard, the act of using it for the benefit of humans, concerning article III of the convention[75] provides that state parties could engage in medication such as cloud seeding to enhance and mitigate climate change such as drought, and desertification and improve agricultural practice. Concerning this, the concept of cloud seeding is legally recognized as a scientific means that could curtail climate change but is restricted as a means of a military weapon. Hence, the ENMOD tends to promote and encourage environmental science toward climate sustainability. It must be noted that though the ENMOD tends to provide for and recognize cloud seeding, one major challenge is the inability to provide for assessment, impact, and sanction of the use of cloud seeding or any other weather modification techniques or scientific discovery that could severe environmental challenges to the ecosystem, plant, animal, and man. This is concerning the fact that by article V of ENMOD[76], it stipulates that state parties are required to engage in consultations and collaborate in ensuring compliance, allowing for diplomatic resolutions in case of suspected violations. Hence, the provision of Article V of ENMOD[77] seems to suggest that there is no effective enforcement mechanism to detect and sanction violations of the convention. In this regard, it is therefore obvious that the ENMOD treaty lacks the necessary provision to ensure the act of weather modification is or is not channeled toward warfare.

Also, another notable international environmental law is the Convention on Long-Range Transboundary Air Pollution enacted in 1979[78].

[72] Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques adopted in 1977
[73] Ibid
[74] Ibid
[75] Ibid
[76] Ibid
[77] Ibid
[78] Convention on Long-Range Transboundary Air Pollution enacted in 1979

This convention is mainly meant to address the issue of transboundary air pollution beyond the national boundaries of states within Europe. Although, this convention does not seem to expressly and directly provide for the regulation of cloud seeding, however, there is a relevant provision that appears to relate to cloud seeding given the fact that the notable international environmental law is the Convention on Long-Range Transboundary Air Pollution seems to regulate the incidence of air pollution and its control which cloud seeding could cause. In this regard, article 2 of the convention[79] prohibits transboundary air pollution and requires member states to take necessary measures to prevent air pollution that is capable of long-range. Furthermore, the article of the convention specifically requires members of the state to engage in scientific research and sharing of scientific findings that could aid in monitoring and detecting airborne substances that could or are capable of transboundary spread. In this regard, by implication, this provision applies to cloud seeding that requires the use or reliance of sodium chloride, silver iodide, potassium chloride, solid carbon dioxide, liquid propane, calcium chloride, and Urea, for weather modification. This is concerning the fact that the substance use in cloud seeding could pose substantial and severe weather implications and are capable of transboundary movement of air pollution. Furthermore, article 6 of the convention[80] further requires the need for member states to indulge in acts towards pollution control and mitigation. Hence, in circumstances where cloud seeding will result in severe weather conditions, it requires that member states should take precautionary measures to curtail and avoid cloud seeding. Furthermore, the Gothenburg Protocol of 1999 and Helsinki Protocol 1985 which is an offshoot of the Convention on Long-Range Transboundary Air Pollution[81], tend to set a baseline for pollutants emission. This in essence also applies to cloud seeding that utilizes substance towards weather alteration.

Also, it must be noted that the United Nations Framework Convention on Climate Change also referred to as the UNFCCC [82]is another relevant and major law as it concerns combating climate change to curtail the greenhouse gas effect within the atmosphere. Hence, the UNFCCC aims to promote the sustainable use of the environment through sustainable practices that are environmentally friendly and conservative. Though a perusal of the UNFCCC review there is no express mention of the scientific concept of cloud seeding, however, there are several provisions that tend to impliedly apply in the assessment of the potential positive and negative effects of cloud seeding given its potential environmental impact. Concerning this it will be relevant to

[79] Ibid
[80] Ibid
[81] Ibid
[82] United Nations Framework Convention on Climate Change also referred to as the UNFCCC

consider and examine some of the provisions of UNFCC as they relate to the assessment of cloud seeding. Article 1. of the UNFCCC[83] requires state parties to always take cognizance of early warning signs that could result in environmental catastrophe and result in severe global warming. Furthermore, article 4[84] also stipulates that state parties should endeavor to cooperate and engage in any discovery that could aid in climate change mitigation. In essence, it suffices to state by implication the provision of article 4 seems to have impliedly referred to cloud seeding which is a trending scientific discovery towards weather modification and alteration in curtailing severe climate change such as drought and desertification. Hence, there is a need to also have a close assessment and careful investigation of the potential harm and damage the use of cloud seeding could cause to the environment, biodiversity, and man. Furthermore, Article 3(3) of the UNFCCC[85] requires members who are parties to treaties to take adequate measures and precautionary measures to curtail the incidence of environmental degradation arising from any form of pollution. In this regard, states using cloud seeding should utilize the same carefully and ensure precautionary measures are put in place to mitigate the adverse effect of weather that could arise from the weather alteration. Concerning this, it suffices to state that the ideal principles of sustainable development contemplated by the UNFCC also apply to the use of cloud seeding.

Also, the international community has further realized that there has been a spike and sporadic growth of industrial, digital, and scientific discoveries within the global fare. In this regard, though some of these developments could be a great advantage to the global community. However, they could also pose a severe threat and damage to man and the environment. Concerning this, global governance further adopted the Espoo Convention on Environmental Impact Assessment in a Transboundary Context in 1991[86]. Hence the Espoo Convention is meant to assess the impact and dangers of transboundary pollution emanating from any activities. Concerning this several provisions seem to relate and require the assessment of the harmful impact of cloud seeding. Article 2 of the Espoo Convention[87] requires member states to adopt relevant legal, administrative, and other relevant mechanisms towards the implementation of environmental impact assessment of projects or activities that could pose potential damage to the environment. Furthermore, articles 3 and 5 of the convention[88] stipulate that where a project is likely to cause transboundary pollution or affect a neighboring state,

[83] Ibid
[84] Ibid
[85] Ibid
[86] Espoo Convention on Environmental Impact Assessment in a Transboundary Context in 1991
[87] Ibid
[88] Ibid

the executing state of the project must notify the affected state. Furthermore, it also requires member states involved in the project and the affected state should indulge in consultation and decision-making as it concerns the mitigating measures to curtail the adverse impact emanating from the project. Concerning this, it suffices to state that cloud seeding which is considered a scientific project that could aid in climate change mitigation is subject to the provision of the Espoo Convention[89]. Hence, a member state of the convention utilizing cloud seeding must comply with the provision of the convention that requires cloud seeding environmental impact assessment and precautionary measures to curtail its harmful effect.

Furthermore, several other international environmental laws could also apply to the scientific discovery of cloud seeding. Some of these laws include the Aarhus Convention which was adopted in 1998. The Convention requires access to relevant information from the general public and participation in the decision-making process by the general public as it concerns issues or environmental concerns that may have a severe impact on the public. Furthermore, the Convention on Biological Diversity is also considered a notable law that tends to apply to cloud seeding in its fair use to not contaminate or cause severe damage to the ecosystem. However, it suffices to state that despite these international environmental laws there are several legal issues, health challenges, and environmental and socio-economic challenges that could arise in the use of cloud seeding.

Legal Challenges and shortcoming of the Global Regulation of Cloud Seeding

One of the critical challenges about cloud seeding in international environmental law regulation is that there is no clearly defined international legal framework that prescribes the rules specifically regulating such scientific discovery of cloud seeding. The Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, which concerns weather alteration and modification, is primarily viewed as an instrument prohibiting the use of cloud seeding in warfare. In this regard, it is not a law specifically dedicated to regulating civilian cloud seeding. It does not contain any provisions for the evaluation of environmental, socio-economic, and health effects of cloud seeding and creates gaps in enforcement and compliance mechanisms. However, Article V of ENMOD seems to promote diplomatic consultations rather than provide for strict sanction and accountability for possible adverse consequences emanating from cloud seeding, thus rendering weak enforcement mechanisms and procedures. Another challenge is the Convention on Long-Range Transboundary Air

[89] Ibid

Pollution, which regulates air pollution across the borders of countries. Although this convention could be applied indirectly to matters related to cloud seeding, most especially airborne substances used during this particular process. However, it does not deal with the practice of air pollution explicitly. Furthermore, states now have no clear directives regarding levels of dispersal permitted for chemicals, possible liability for effects across national borders, and state co-reporting requirements for cloud seeding activities. Thus, this has created ambiguity which can lead to disputes between state parties affected by unintended changes brought by the weather modification.

Furthermore, it must be noted that the UNFCCC advocates for environmental sustainability and practices but does not mention or provide for any issues as it concerns weather modification techniques. Article 4, for example, advocates scientific cooperation between state parties to curtail the negative effects of climate change but fails to set a clear baseline on which to measure possible risks that could emanate from cloud seeding. Furthermore, the non-definition of precautionary measures under UNFCCC could enable state parties to indulge in cloud seeding activities without conducting a proper environmental assessment, thereby subjecting the environment to severe climate change, such as excess rains or floods, and ecological disparity. Hence, the absence of binding enforcement mechanisms of UNFCCC makes it more difficult for the international community to monitor and regulate cloud seeding activities effectively. Also, it must be noted that the Espoo Convention on Environmental Impact Assessment in a Transboundary Context is another relevant global law that also applies to cloud seeding. However, the convention also has lacuna and shortcomings, as according to its provisions, activities having a transboundary environmental risk should be subjected to environmental impact assessment (EIA). However, this does not expressly cover cloud seeding as one of the regulated scientific discoveries. Therefore, it suffices to state that uncertainty arises on whether cloud seeding projects need to be subjected to the EIA procedures before implementation. Furthermore, provisions under Articles 3 and 5 remain subject to consideration by the state on whether to notify and consult affected states, which means that some states may proceed with their cloud-seeding activities without proper notification or consultation with neighboring countries. This situation could result in international disputes over weather manipulation and its possible unintended effects.

Also, there are other international environmental laws, such as the Aarhus Convention and the Convention on Biological Diversity. These laws seem to provide for the principles for public participation and protection of ecology as such. However, they do not provide specific guidelines for cloud seeding. In effect, the use of the Aarhus Convention to be publicly accessible to environmental information is insufficient, this is concerning the fact that

most cloud seeding projects are sponsored by governments or private institutions without adequately involving the general public. Furthermore, the Convention on Biological Diversity, though based on conservation of the global environment, does not contemplate the introduction of chemicals into the atmosphere using cloud seeding, which could alter the natural state of biodiversity.

In this regard, it suffices to state that though the applicability of these legal instruments is clear, there are still critical gaps in their direct regulation of cloud seeding, especially concerning liability, enforcement, and oversight mechanisms. The ongoing discussion on the potential of cloud seeding as an instrument of climate change mitigation leaves the domain prone to possible environmental, socioeconomic, and legal conflicts with no comprehensive international regulatory framework to manage them. Hence, more refined and legally binding instruments would be necessary.

Furthermore, it suffices to state that sovereignty is also one of the serious legal issues relating to cloud seeding and weather modification. Article 1 of the UN Charter reaffirms the sovereign right of states to self-govern in their airspace. If, however, cloud seeding done by one state significantly changes any atmospheric or precipitation phenomena in neighboring states (s), sovereignty is potentially breached. For example, when Texas engages in cloud seeding to combat drought in its state, the two neighboring states can be impacted and their sovereignty violated if changes happen as a result of Texas's activities[90]. In response to imposing on neighboring dronée state attributes, the contiguous southwestern U.S could allay fears and develop certain rules and interstate regulations, such as the Texas Weather Modification Act that deals with weather modification by requiring licenses, reporting, and working with other states[91]. As for China, it has been engaged in governmental weather modification programs since the early 2000s, largely to mitigate droughts or to affect atmospheric events shortly time prior to the 2008 Beijing Olympics and lately in its western provinces[92]. Among the legal issues that China needs to resolve includes competing for atmospheric moisture among its provinces which has led to disputes related to jurisdictions[93]; in repose, China decided to create a national legal and regulatory space under the Meteorological Law (revised 2016) creating a

[90] Ray Jay Davis, Legal Response to Environmental Concerns about Weather Modification. J. Appl. Meteor. Climatol., 1975, 14:681–685, https://doi.org/10.1175/1520-0450(1975)014<0681:LRTECA>2.0.CO;2.

[91] Manon Simon, Jan McDonald and Kerryn Brent, Transboundary Implications of China's Weather Modification Programme. Transnational Environmental Law. 2023;12(3):594-622. https://doi.org/10.1017/S2047102523000146

[92] Ibid

[93] Bettina Bluemling, Rakhyun E Kim and Frank Biermann, "Seeding the clouds to reach the sky: Will China's weather modification practices support the legitimization of climate engineering? Ambio. 2020, 49(1):365-373. https://doi.org/10.1007/s13280-019-01180-3

determination for the cloud seeding process and program with China Meteorological Administration (CMA) providing a regulatory regime and attempting create a standardized practice to lessen the inter-national jurisdictional disputes.

Potential liabilities issue is also a major legal challenge to cloud seeding. One of the challenges is that the effects of cloud seeding can be difficult to predict, and attributing damages, like unintentional flood, drought displacement, or loss of crops, to cloud seeding events can prove extremely difficult[94]. For example, in Thailand, in 2015[95]The Farmers Union reportedly contributed to a lawsuit against the state by farmers where cloud seeding was performed, and farmers alleged that they had been deprived of rainfall due to rainfall being "diverted" away[96], and the lawsuit was dismissed after it was determined that no conclusive relationship could be identified due to the scientific uncertainty regarding degrees of causality. This is a strong example of the limitations of tort liability systems as an instrument of accountability when diffuse environmental interventions like cloud seeding are admitted. The study also investigated the ethics of weather modification, which generally involves distributive justice and equity for future generations. For example, if the reason one region is receiving rain due to cloud seeding, then other regions could be deprived of rain, and cloud seeding can cause disruption in normal weather and precipitate weather changes[97]. To add to the conundrum, the United Arab Emirates (UAE) has one of the most active cloud seeding programs in the world, but has faced declining criticism from environmental organizations for not consulting with neighboring Gulf countries (in advance) on the potential transboundary effects[98]. The UAE report indicated that no formal lawsuits have been laid against the UAE over cloud seeding[99]; however, the other Gulf countries had little recourse, and the ethical injustice of not having a regional consent agreement for cloud seeding practices raises serious concerns, and may fall under informed consent for a principle referred to as prior informed consent from international environmental law.

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[94] Conrad G. Keyes, George W. Bomar, Thomas P. Defelice, Don A. Griffith and Darin W. Langerud, *Guidelines for Cloud Seeding to Augment Precipitation*, third edition, America Society of Civil Engineering, 2018

[95] William L. Woodley, Daniel Rosenfeld, and Bernard A. Silverman, Results of On-Top Glaciogenic Cloud Seeding in Thailand. Part I: The Demonstration Experiment. J. Appl. Meteor. Climatol., 42, (2003):920–938, https://doi.org/10.1175/1520-0450(2003)042<0920:ROOGCS>2.0.CO;2.

[96] Ibid

[97] Almheiri, Khalid B., Rabee Rustum, Grant Wright, and Adebayo J. Adeloye. 2023. "A Review of Hydrological Studies in the United Arab Emirates" Water 15, no. 10 (2023): 1850. https://doi.org/10.3390/w15101850

[98] Ibid

[99] Marine Krauzman, "Emirati Rain Enhancement Projects: A Legal Analysis" https://thesecuritydistillery.org/all-articles/emirati-rain-enhancement-projects-a-legal-analysis?utm_source=chatgpt.com accessed 21st July, 2025

Some regions have sought to implement proactive regulatory measures to address these gaps in governance. The United States specifically pioneered a transparent method of regulation with the Weather Modification Reporting Act (1972), which requires operators to report any weather modification activity to the National Oceanic and Atmospheric Administration (NOAA)[100]. The purpose of this law is to create transparency about weather modifications that occur in the vicinity of local jurisdictions or neighboring jurisdictions. While enforcement is still localized, and there are still no federal laws on cloud seeding requiring environmental impact assessments (EIAs), the Weather Modification Reporting Act is an example of a regulatory gap[101]. On the international front, there is no legally binding multilateral treaty that addresses weather modification for peaceful purposes. The one treaty that does cover weather modification, the Environmental Modification Convention (ENMOD, 1977)[102], restricts hostile uses of weather modification, but does not cover uses undertaken during peacetime. This gap in treaty law indicates that new treaties are required, or at a minimum, protocols to existing treaties such as the United Nations Framework Convention on Climate Change, or the United Nations Environment Program on the governance of atmospheric interventions, as a response to climate change[103].

Conclusion

Although cloud seeding is probably one of the mechanisms to counter the impacts of climate change such as drought and desertification, its legal and regulatory framework remains inadequate both at the national and international level. As observed, most of the existing environmental treaties and conventions, not necessarily limited to the ENMOD Convention, the Convention on Long-Range Transboundary Air Pollution, and UNFCCC, which only indirectly refer to the regulation on cloud seeding, do not cover many issues such as liability, transboundary environmental harms, or possible health risks related to chemicals from cloud seeding. Moreover, current international law does not have strict enforcement mechanisms, which makes it inadequate since one cannot easily monitor compliance and impose sanctions for wrongful or harmful applications of cloud-seeding technology. It

[100] Manon Simon, Jan McDonald and Kerryn Brent, Transboundary Implications of China's Weather Modification Programme. Transnational Environmental Law. 12 no. 3, (2023):594-622. https://doi.org/10.1017/S2047102523000146

[101] Ibid

[102] Ibid

[103] Aarti Gupta, Frank Biermann, Ellinore van Driel, Nadia Bernaz, Dhanasree Jayaram, Rakhyun E. Kim, Rakhyun E. Kim, Louis J. Kotzé, Dana Ruddigkeit, Stacy D. VanDeveer and Margaretha Wewerinke-Singh, Towards a Non-Use Regime on Solar Geoengineering: Lessons from International Law and Governance. Transnational Environmental Law. 2024;13(2):368-399. https://doi.org/10.1017/S2047102524000050

does not fall into a clearly and strongly defined legal framework, which would leave the door open to misuse of cloud seeding and its unintended adverse environmental and socio-economic consequences.

In this regard, to fill in these gaps, a unified international legal framework, particularly applicable to cloud seeding, should be developed preferably under global environmental governance organizations like UNEP and IPCC. Such a framework would have to provide clear guidelines on the admissible use of cloud seeding, environmental impact assessment, and liability provisions regarding damages arising from transboundary weather modification. It should also prescribe precautionary measures including scientific risk assessments and public disclosure of cloud seeding activities to ensure transparency and accountability. Integration of cloud seeding in climate change policies already in place would ensure responsible and sustainable use of the technology by governments. Furthermore, countries that then engage in cloud seeding must set up national regulatory bodies to supervise and enforce compliance with environmental and public health standards. Moreover, such national regulatory authorities should cooperate with relevant international institutions in harmonizing standards and facilitating cross-border cooperation in managing weather modification technologies risks. Relevant public participation and stakeholder engagement at the regulatory stage may also strengthen cloud seeding efforts in mindful consideration of affected community interests. These would finally make for a balanced approach in utilizing cloud seeding to mitigate climate change while reducing its possible adverse effects on the environment and human health.

REFERENCES

Aare, Folasade Folake, Olusola Raphael Olorunfemi, and Gogo George Ntor. "Legal Frameworks for Single-Use Plastic Management: Environmental Challenges and Solutions." *KIULJ* 6, no. 1 (2024): 63–85.

Abshaev, Ali M., Andrea Flossmann, Steven T. Siems, Thara Prabhakaran, Zhanyu Yao, and Sarah Tessendorf. "Rain Enhancement Through Cloud Seeding." In *Unconventional Water Resources*, edited by M. Qadir, V. Smakhtin, S. Koo-Oshima, and E. Guenther, Springer, Cham, 2022. https://doi.org/10.1007/978-3-030-90146-2_2.

Adeyemi, Ariyoosu D., and Abdulkadir O. Abdulrazaq. "Maritime Surveillance and Enforcement Privitisation Galore in Nigeria: A Compromise of State Sovereignty." *KIULJ* 1, no. 1 (2017): 134–49.

Aidonojie, Paul Atagamen, Anani O. Anthony, Agbale O. Patient, Olomukoro O. John, and Adetunji O. Charles. "Environmental Law in Nigeria: A Review on Its Antecedence, Application, Judicial Unfairness, and Prospects." *Archive of Science & Technology* 1, no. 2 (2020): 211–21.

Aidonojie, Paul Atagamen, Idahosa M. Ekata, Agbale O. Patient, and Oyedeji A. Ifeoluwa. "The Environmental Conservation and Ethical Issues Concerning Herbal Products in Nigeria." *Journal of Environmental Science and Economics* 1, no. 3 (2022): 26–32. https://doi.org/10.56556/jescae.v1i3.124.

Aidonojie, Paul Atagamen, Ikubanni O. Oluwaseye, Oyedeji A. Ifeoluwa, and Oyebade A. Akinsola. "The Legal Challenges and Effect Concerning Environmental Security in Nigeria: A Lesson from an International Perspective." *Journal of Commercial and Property Law* 9, no. 1 (2022): 110–20.

Aidonojie, Paul Atagamen, K. Adebayo, Eregbuonye Obishie, and Wakili S. Abacha. "Breaking Legal and Socio-Economic Challenges to Plastic Waste Regulation in Nigeria: Lessons Learned from Singapore." *Yustisia* 13, no. 1 (2024): 64–88.

Aidonojie, Paul Atagamen, Majekodunmi T. Akintola, Eregbuonye Obishie, and Adeyemi-Balogun O. Janet. "Potential and Legal Challenges of Metaverse for Environmental Awareness and Sustainable Practice in Nigeria: A Comparative Study with Singapore." *Administrative and Environmental Law Review* 5, no. 1 (2024): 37–64. https://doi.org/10.25041/aelr.v5i1.3230.

Aidonojie, Paul Atagamen, Okuonghae Nosa, Moses-Oke O. Rose, and Majekodunmi T. Akintola. "A Facile Review on the Legal Issues and Challenges Concerning the Conservation and Preservation of Biodiversity." *Global Sustainability Research* 2, no. 2 (2023): 34–46.

Aidonojie, Paul Atagamen, Ukhurebor E. Kingsley, Masajuwa Florence, Imoisi E. Simon, Edetalehn O. Idemudia, and Nwazi Joseph. "Legal Implications of Nanobiosensors Concerning Environmental Monitoring." In *Nanobiosensors for Environmental Monitoring*, edited by R. P. Singh, E. Kingsley Ukhurebor, J. Singh, O. Charles Adetunji, and K. R. Singh. Cham: Springer, 2022. https://doi.org/10.1007/978-3-031-16106-3_21.

Aidonojie, Paul Atagamen, Ukhurebor E. Kingsley, Oaihimire E. Idemudia, Ngonso F. Blessed, Egielewa Peter, and Darmokoesoemo Hussein. "Bioenergy Revamping and Complimenting the Global Environmental Legal Framework on the Reduction of Waste Materials: A Facile Review." *Heliyon* 9, no. 1 (2023). https://doi.org/10.1016/j.heliyon.2023.e12860.

Aidonojie, Paul Atagamen. "Environmental Hazard: The Legal Issues Concerning Environmental Justice in Nigeria." *Journal of Human Rights, Culture and Legal System* 3, no. 1 (2023): 17–32. https://doi.org/10.53955/jhcls.v3i1.60.

Ajayi, Oluwatoyin Oyeronke. "Mining in Nigeria and Environmental

Protection: Examining the Legal and Institutional Frameworks." *KIULJ* 5, no. 2 (2023): 238–257.

Al Hosari, Taha, Abdulla Al Mandous, Youssef Wehbe, Abdeltawab Shalaby, Noor Al Shamsi, Hajer Al Naqbi, Omar Al Yazeedi, Alya Al Mazroui, and Sufian Farrah. "The UAE Cloud Seeding Program: A Statistical and Physical Evaluation." *Atmosphere* 12, no. 8 (2021): 1013. https://doi.org/10.3390/atmos12081013.

Aladeitan, Olanrewaju, and Chidinma Therese Odaghara. "Environmentalism and an International Court for the Environment." *KIULJ* 2, no. 1 (2018): 143–64.

Almheiri, Khalid B., Rabee Rustum, Grant Wright, and Adebayo J. Adeloye. "A Review of Hydrological Studies in the United Arab Emirates." *Water* 15, no. 10 (2023): 1850. https://doi.org/10.3390/w15101850.

Anani, Osikemekha A., Abel Inobeme, Osayomwanbo Osarenotor, Frances Ngozi Olisaka, Paul Atagamen Aidonojie, Emmanuel Olusegun Olatunji, and Aishatu Idris Habib. "Application of Microorganisms as Biofactories to Produce Biogenic Nanoparticles for Environmental Cleanup: Current Advances and Challenges." *Current Nanoscience* 19, no. 6 (2023): 770–82.

Anani, Osikemekha Anthony, Maulin P. Shah, Paul Atagamen Aidonojie, and Alex Ajeh Enuneku. "Bio-Nano Filtration as an Abatement Technique Used in the Management and Treatment of Impurities in Industrial Wastewater." In *Bio-Nano Filtration in Industrial Effluent Treatment*, 171–82, 2023.

Anthony, Anani O., Paul Atagamen Aidonojie, and Olomukoro O. John. "Environmental Principles and Ethics: Current Challenges in the Field of Bioscience and Law." In *Ethics, Media, Theology, and Development in Africa: A Festschrift in Honour of Msgr. Prof. Dr. Obiora Francis Ike*, 142–58. Geneva, Switzerland: Global.net Co-Publication & Others, 2022.

Ayodele, Oladiran Akinsola, and Maruf Adeniyi Nasir. "Implementation of SDGs in Nigeria: Issues and Challenges." *KIULJ* 3, no. 2 (2019): 83–104.

Bixby, Adam. "The Silver Lining Solution: Alleviating Water Insecurity in the Colorado River Basin through Cloud Seeding." *Journal of Law & Public Policy* 34 (2024): 189–215.

Bluemling, Bettina, Rakhyun E. Kim, and Frank Biermann. "Seeding the Clouds to Reach the Sky: Will China's Weather Modification Practices Support the Legitimization of Climate Engineering?" *Ambio* 49, no. 1 (2020): 365–373. https://doi.org/10.1007/s13280-019-01180-3.

Bruintjes, Roelof T. "A Review of Cloud Seeding Experiments to Enhance Precipitation and Some New Prospects." *Bulletin of the American Meteorological Society* 80, no. 5 (1999): 805-820.

https://doi.org/10.1175/15200477(1999)080<0805:AROCSE>2.0.CO;2.

Davis, Ray Jay. "Legal Response to Environmental Concerns about Weather Modification." *Journal of Applied Meteorology and Climatology* 14 (1975): 681–685. https://doi.org/10.1175/1520-0450(1975)014<0681:LRTECA>2.0.CO;2.

Dong, Xiaobo, Chuanfeng Zhao, Zhaochu Huang, Rong Mai, Feng Lv, Xuewu Xue, Xiaorui Zhang, Shaoyu Hou, Yang Yang, Yikun Yang, and Yue Sun. "Increase of Precipitation by Cloud Seeding Observed from a Case Study in November 2020 over Shijiazhuang, China." *Atmospheric Research* 262 (2021): 105766. https://doi.org/10.1016/j.atmosres.2021.105766.

Fajardo, Carlos, Gloria Costa, Luis T. Ortiz, Mendis Nande, Martins L. Rodríguez-Membibre, Marenda Martín, and Savie Sánchez-Fortún. "Potential Risk of Acute Toxicity Induced by AgI Cloud Seeding on Soil and Freshwater Biota." *Ecotoxicology and Environmental Safety* 133 (2016): 433–441. https://doi.org/10.1016/j.ecoenv.2016.06.028.

Farhar, Barbara C. "The Public Decides about Weather Modification." *Environment and Behavior* 9, no. 3 (1977): 279–310. https://doi.org/10.1177/001391657700900301.

Flossmann, Andrea I., Michael Manton, Ali Abshaev, Roelof Bruintjes, Masataka Murakami, Thara Prabhakaran, and Zhanyu Yao. "Review of Advances in Precipitation Enhancement Research." *Bulletin of the American Meteorological Society* 100 (2019): 1465–1480. https://doi.org/10.1175/BAMS-D-18-0160.1.

French, Jeffrey R., Katja Friedrich, Sarah A. Tessendorf, Robert M. Rauber, Bart Geerts, Roy M. Rasmussen, Lulin Xue, Melvin L. Kunkel, and Derek R. Blestrud. "Precipitation Formation from Orographic Cloud Seeding." *Proceedings of the National Academy of Sciences of the United States of America* 115, no. 6 (2018): 1168-1173. https://doi.org/10.1073/pnas.1716995115.

Friedrich, Katja, Kyoko Ikeda, Sarah A. Tessendorf, Jeffrey R. French, Robert M. Rauber, Bart Geerts, Lulin Xue, Roy M. Rasmussen, Derek R. Blestrud, Melvin L. Kunkel, Nicholas Dawson, and Shaun Parkinson. "Quantifying Snowfall from Orographic Cloud Seeding." *Proceedings of the National Academy of Sciences of the United States of America* 117, no. 10 (2020): 5190-5195. https://doi.org/10.1073/pnas.1917204117.

Gasparini, Blaž, and Ulrike Lohmann. "Why Cirrus Cloud Seeding Cannot Substantially Cool the Planet." *Journal of Geophysical Research: Atmospheres* 121, no. 9 (2016): 4877-4893. https://doi.org/10.1002/2015JD024666.

Gasparini, Blaž, Zachary McGraw, Trude Storelvmo, and Ulrike Lohmann.

"To What Extent Can Cirrus Cloud Seeding Counteract Global Warming?" *Environmental Research Letters* 15 (2020): 1-12. https://doi.org/10.1088/1748-9326/ab71a3.

Gupta, Aarti, Frank Biermann, Ellinore van Driel, Nadia Bernaz, Dhanasree Jayaram, Rakhyun E. Kim, Louis J. Kotzé, Dana Ruddigkeit, Stacy D. VanDeveer, and Margaretha Wewerinke-Singh. "Towards a Non-Use Regime on Solar Geoengineering: Lessons from International Law and Governance." *Transnational Environmental Law* 13, no. 2 (2024): 368–399. https://doi.org/10.1017/S2047102524000050.

Imam, Abdulbasit Kolapo. "Ethical Implications and Legal Void in Cloud Seeding As A War Strategy." *LexScriptio* 1, no. 1 (2024): 155–177.

Imoisi, E. Simon, and Paul Atagamen Aidonojie. "Legal and Socio-Economic Issues Concerning Black Marketer's Activities of Petroleum Products in Nigeria." *Yuridika* 38, no. 2 (2023): 61–84. https://doi.org/10.20473/ydk.v38i2.44999.

Imoisi, E. Simon, Paul Atagamen Aidonojie, and Edetalehn O. Idemudia. "Legal Issues and Innovations Introduced by the Petroleum Industry Act 2021 in the Nigerian Oil Industry." *Journal of Commercial and Property Law* 10, no. 2 (2023): 229–43.

Johnson, Courtney, and Brian Kennedy. "U.S. Adults Have Mixed Views on Whether Geoengineering Would Help Reduce Effects of Climate Change." *Pew Research Center*, June 11, 2021. https://www.pewresearch.org/short-reads/2021/06/11/u-s-adults-have-mixed-views-on-whether-geoengineering-would-help-reduce-effects-of-climate-change/?utm_source=chatgpt.com. Accessed July 21, 2025.

Keyes, Conrad G., George W. Bomar, Thomas P. DeFelice, Don A. Griffith, and Darin W. Langerud. *Guidelines for Cloud Seeding to Augment Precipitation*, 3rd ed. American Society of Civil Engineers, 2018.

Kisubi, Esther Christine, Gabriel Adenyuma Godswill Owoche Antai, and Valentine Tebi Mbeli. "Utilitarianism in Uganda's Oil and Gas Sector: Balancing Utility and Responsibility for Environmental Justice." *KIULJ* 6, no. 1 (2024): 190–207.

Korneev, Vladimir P., Ilya E. Potapov, and Georgy G. Shchukin. "Environmental Aspects of Cloud Seeding." *Russian Meteorology and Hydrology* 42 (2017): 477–483. https://doi.org/10.3103/S106837391707007X.

Krauzman, Marine. "Emirati Rain Enhancement Projects: A Legal Analysis." https://thesecuritydistillery.org/all-articles/emirati-rain-enhancement-projects-a-legal-analysis?utm_source=chatgpt.com. Accessed July 21, 2025.

Ku, Jung Mo, Ki-Ho Chang, Sanghee Chae, A.-Reum Ko, Yonghun Ro,

Woonseon Jung, and Chulkyu Lee. "Preliminary Results of Cloud Seeding Experiments for Air Pollution Reduction in 2020." *Asia-Pacific Journal of Atmospheric Sciences* 59 (2023): 347–358. https://doi.org/10.1007/s13143-023-00315-7.

Lou, Xiaofeng, Yu Fu, and Zhengjun Su. "Advances of Silver Iodide Seeding Agents for Weather Modification." *Journal of Applied Meteorological Science* 32, no. 2 (2021): 146–159. https://doi.org/10.11898/1001-7313.20210202.

Malik, Shaista, Haleema Bano, Rauoof Ahmad Rather, and Shakeel Ahmad. "Cloud Seeding; Its Prospects and Concerns in the Modern World – A Review." *International Journal of Pure and Applied Bioscience* 6, no. 5 (2018): 791-796. https://dx.doi.org/10.18782/2320-7051.6824.

Mbeli, Valentine T. "An Analysis of the Legal Framework for Sustainable Fisheries' Financing in Uganda." *KIULJ* 3, no. 2 (2019): 1–22.

Oloworaran, Uchechukwu Esther. "An Evaluation of the Legal Framework for Resolving Disputes in the Digital Ecosystem in Nigeria." *KIULJ* 5, no. 2 (2023): 50–64.

Penner, Joyce E., Cheng Zhou, and Xiaohong Liu. "Can Cirrus Cloud Seeding Be Used for Geoengineering?" *Geophysical Research Letters* 42, no. 20 (2015): 8775-8782. https://doi.org/10.1002/2015GL065992.

Pokharel, Binod, S.-Y. Simon Wang, Hongping Gu, Matthew D. LaPlante, Jake Serago, Robert Gillies, Jonathan Meyer, Stephanie Beall, and Kyoko Ikeda. "A Modeling Examination of Cloud Seeding Conditions under the Warmer Climate in Utah, USA." *Atmospheric Research* 248 (2021): 105239. https://doi.org/10.1016/j.atmosres.2020.105239.

Proske, Ulrike, Verena Bessenbacher, Zane Dedekind, Ulrike Lohmann, and David Neubauer. "How Frequent Is Natural Cloud Seeding from Ice Cloud Layers (<−35 °C) over Switzerland?" *Atmospheric Chemistry and Physics* 21 (2021): 5195–5216. https://doi.org/10.5194/acp-21-5195-2021.

Sadeghi, Mohammad, and Saeed Yaghoubi. "Optimization Models for Cloud Seeding Network Design and Operations." *European Journal of Operational Research* 312, no. 3 (2024): 1146-1167. https://doi.org/10.1016/j.ejor.2023.07.041.

Samuel, Adrii, Muriel Boleri, Eddy Peter, and Claude Gloria. "Depollution of Mining Effluents: Innovative Mobilization of Plant Resources." *Environmental Science and Pollution Research* 26 (2019): 19327–34. https://doi.org/10.1007/s11356-019-05027-y.

Simon, Manon, Jan McDonald, and Kerryn Brent. "Transboundary

Implications of China's Weather Modification Programme." *Transnational Environmental Law* 12, no. 3 (2023): 594–622. https://doi.org/10.1017/S2047102523000146.

Tai, Yanlong, Haoran Liang, Abdelali Zaki, Nabil El Hadri, Ali M. Abshaev, Buzgigit M. Huchunaev, Steve Griffiths, Mustapha Jouiad, and OrcidLinda Zou. "Core/Shell Microstructure Induced Synergistic Effect for Efficient Water-Droplet Formation and Cloud-Seeding Application." *ACS Nano* 11, no. 12 (2017): 12318–12325. https://doi.org/10.1021/acsnano.7b06114.

Ukhurebor, E. Kingsley, and Paul Atagamen Aidonojie. "The Influence of Climate Change on Food Innovation Technology: Review on Topical Developments and Legal Framework." *Agric & Food Security* 10 (2021): 50.

Ukhurebor, Kingsley Eghonghon, Uyiosa Osagie Aigbe, Robert Birundu Onyancha, Hussain Athar, Benedict Okundaye, Paul Atagamen Aidonojie, Benita Ebindu Siloko, Ismail Hossain, Heri Septya Kusuma, and Handoko Darmokoesoemo. "Environmental Influence of Gas Flaring: Perspective from the Niger Delta Region of Nigeria." *Geofluids* 2024 (2024): 17 pages. https://doi.org/10.1155/2024/1321022.

Valjarević, Aleksandar, Cristina Popovici, Anđelka Štilić, and Milan Radojković. "Cloudiness and Water from Cloud Seeding in Connection with Plants Distribution in the Republic of Moldova." *Applied Water Science* 12 (2022): 262. https://doi.org/10.1007/s13201-022-01784-3.

Wang, Fei, Baojun Chen, Zhiguo Yue, Jin Wang, Dejun Li, Dawei Lin, Yahui Tang, and Tian Luan. "A Composite Approach for Evaluating Operational Cloud Seeding Effect in Stratus Clouds." *Hydrology* 11, no. 10 (2024): 167. https://doi.org/10.3390/hydrology11100167.

Woodley, William L., Daniel Rosenfeld, and Bernard A. Silverman. "Results of On-Top Glaciogenic Cloud Seeding in Thailand. Part I: The Demonstration Experiment." *Journal of Applied Meteorology and Climatology* 42 (2003): 920–938. https://doi.org/10.1175/1520-0450(2003)042<0920:ROOGCS>2.0.CO;2.

World Meteorological Organization (WMO). *Guidelines for the Planning of Weather Modification Activities (WMO-No. 998)*. Geneva: WMO, 2008. https://library.wmo.int/doc_num.php?explnum_id=9442. Accessed July 20, 2025.

Wu, Xianghua, Ni Yan, Huaying Yu, Shengjie Niu, Fangxiu Meng, Weiqi Liu, and Haiyan Sun. "Advances in the Evaluation of Cloud Seeding: Statistical Evidence for the Enhancement of Precipitation." *Earth and Space Science* 5, no. 9 (2018): 425-439. https://doi.org/10.1029/2018EA000424.

Yuan, Jinlong, Kenan Wu, Tianwen Wei, Lu Wang, Zhifeng Shu, Yuanjian

Yang, and Haiyun Xia. "Cloud Seeding Evidenced by Coherent Doppler Wind Lidar." *Remote Sensing* 13, no. 19 (2021): 3815. https://doi.org/10.3390/rs13193815.

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