



Atmospheric Suppression of Rainbow Visibility a Systematic Review of Agents, Optical Mechanisms, and Unresolved Questions

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Received: September 02, 2026

Published: October 05, 2026

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Abstract

Rainbows are directional optical phenomena generated by refraction, dispersion, internal reflection, and subsequent refraction of sunlight within water droplets. Their visibility, however, is not determined solely by the presence of rainbow-producing droplets. The observed signal also depends on atmospheric transmission, extinction, scattering, spectral redistribution, and the radiance of the surrounding background. This review examines rainbow visibility as an optical-contrast problem and synthesizes established rainbow optics, aerosol-radiation interactions, atmospheric radiative transfer, cloud-seeding literature, and published observations of aerosols affecting rainbow appearance.

Published atmospheric modeling demonstrates that rainbows can become washed out or disappear as background brightness increases. Satellite observations have also documented aerosol-associated darkening and spectral alteration of primary rainbows. These findings establish the general physical proposition that atmospheric optical modification can alter rainbow visibility without eliminating the underlying droplet-scattering process.

The review uses a five-state evidence framework: Directly Demonstrated (D), Mechanistically Supported (M), Indirectly Supported (I), Unresolved/Insufficiently Investigated (U), and Specifically Negative (N). Candidate atmospheric classes are evaluated conservatively. The review does not infer atmospheric deployment, intentionality, or motive from optical observations. Its principal contribution is a conceptual synthesis linking rainbow-producing radiance with wavelength-dependent optical depth and aerosol-generated background radiance. Agent-specific suppression thresholds remain an empirical research question requiring measured optical properties, atmospheric geometry, radiative-transfer modeling, and defined detection criteria.

Keywords: Rainbow Optics; Atmospheric Aerosols; Radiative Transfer; Optical Depth; Scattering; Extinction; Atmospheric Visibility; Aerosol-Radiation Interaction; Weather Modification

Introduction and Research Question

A primary rainbow is an optical phenomenon produced when sunlight interacts with water droplets. The familiar bow results from wavelength-dependent refraction and dispersion, internal reflection, and a second refraction as light leaves the droplet. The

resulting radiation is concentrated into characteristic angular regions relative to the antisolar point.

The existence of rainbow-producing radiation does not, however, guarantee visual detection. The rainbow is observed against a radiative background whose intensity and spectrum are affected by molecular scattering, aerosols, clouds, terrain, solar geometry, and

other sources of illumination. The present review therefore treats rainbow visibility as a problem of signal transmission and contrast rather than simply rainbow formation.

The principal research question is: Can atmospheric modification of scattering, absorption, extinction, spectral transmission, or diffuse background radiance reduce rainbow contrast sufficiently for the bow to become substantially weakened or visually undetectable?

This paper does not claim that any particular material has been deployed to suppress rainbows. It does not infer deployment from atmospheric observations and does not assign an intentional objective to any atmospheric release. The scientific objective is to identify established mechanisms, distinguish evidence from inference, and identify research gaps.

Review Methodology

The literature framework addresses six areas: (1) rainbow formation and atmospheric radiative transfer; (2) aerosol effects on rainbow radiance and polarization; (3) aerosol scattering, absorption, extinction, and optical depth; (4) cloud seeding and atmospheric particulate release; (5) particle-size and optical-property relationships; and (6) agricultural spray drift and atmospheric persistence.

Priority is given to peer-reviewed literature, primary research, major scientific organizations, government technical material, and authoritative reviews. Evidence is classified conservatively. Absence of a publication is not treated as evidence that an effect does not occur.

Evidence classification

- **D — Directly Demonstrated:** Experiment, observation, or validated model directly addressing the relevant effect.
- **M — Mechanistically Supported:** Established optical properties support the mechanism, but the exact rainbow-suppression proposition has not been directly tested.
- **I — Indirectly Supported:** Evidence comes from a closely related atmospheric or optical phenomenon.
- **U — Unresolved/Insufficiently Investigated:** No adequate direct test was identified.

- **N — Specifically Negative:** A relevant effect was specifically investigated and found ineffective or negligible under the studied conditions.

Physical formation of the primary rainbow

Sunlight entering a water droplet is refracted at the air-water interface. Because the refractive index of water varies with wavelength, the components of white sunlight undergo wavelength-dependent refraction and dispersion. A portion of the radiation undergoes internal reflection before leaving the droplet through a second refraction. The resulting angular concentration produces the primary rainbow.

In simplified form:

Sunlight → refraction → dispersion → internal reflection → refraction → observer

The rainbow is therefore a radiative signal rather than a colored material occupying a fixed location in the atmosphere.

Rainbow visibility as an optical-contrast problem

A useful conceptual contrast measure is:

$$C_R(\lambda) = I_R(\lambda)/I_B(\lambda)$$

Where I_R is rainbow-producing radiance and I_B is background radiance. As background radiance increases, rainbow contrast can decrease even if the rain droplets continue to generate the rainbow-producing radiation.

Gedzelman's atmospheric simulations explicitly incorporated an aerosol layer and scattered background light and found that modeled rainbows could be washed out or disappear as atmospheric background brightness increased. This provides direct support for the central optical proposition that visibility can be reduced without eliminating the droplet-level rainbow mechanism.

Aerosol extinction and atmospheric transmission

Aerosols alter radiation through scattering and absorption. The extinction coefficient can be represented as:

$$\beta_{\text{ext}}(\lambda) = \beta_{\text{sca}}(\lambda) + \beta_{\text{abs}}(\lambda)$$

The corresponding aerosol optical depth along an atmospheric path is:

$\tau_{\text{ext}}(\lambda) = \int \beta_{\text{ext}}(\lambda,z) \, dz$

And transmission can be represented approximately by:

$T(\lambda) = \exp[-\tau_{\text{ext}}(\lambda)]$

The effect on a rainbow depends on where the optical depth is located relative to the Sun, the rainbow-producing droplets, and the observer. Optical attenuation before rainbow production, after rainbow production, and additional diffuse scattering into the observer’s field of view can have different consequences.

Aerosol effects on rainbow radiance

Published observations provide evidence that aerosols can modify rainbow appearance. Satellite observations of primary rainbows associated with aerosol layers above clouds have documented darkening and spectral changes, including wavelength-dependent effects associated with aerosol optical thickness.

These observations are important because they demonstrate that aerosol-radiation interactions can modify the rainbow signal itself. They do not, however, establish that a particular aerosol was introduced for the purpose of suppressing a rainbow.

Atmospheric background radiance

Rainbow visibility depends on the ratio between the rainbow signal and its surrounding radiative environment. Aerosol

scattering can increase diffuse sky radiance while extinction can reduce the direct and rainbow-producing components of the radiation field. These processes may operate simultaneously and can have wavelength-dependent effects.

Consequently, an atmospheric layer need not eliminate rainbow-producing droplets in order to reduce the apparent bow. The relevant physical question is whether the combined radiative transfer produces a sufficiently reduced signal-to-background relationship.

Candidate atmospheric agent classes

Candidate classes discussed in the literature include hygroscopic salts, cloud-seeding materials, mineral aerosols, metallic and heavy-metal compounds, engineered nanoparticles, carbonaceous particles, agricultural spray droplets, and mixed aerosol populations. These categories must not be treated as equivalent: optical behavior depends on chemical form, particle size, morphology, concentration, refractive index, absorption properties, humidity, and vertical distribution.

The following classifications are deliberately conservative. A material’s established use in weather modification, agriculture, industry, or another context does not constitute evidence that it has been evaluated for rainbow suppression.

Agent class	Relevant optical property	Current evidence	Principal limitation
Hygroscopic salts	Scattering; humidity-dependent growth	M	Strong dependence on humidity and particle size
Dry ice	Cloud/ice microphysics	M/U	Transient and context dependent
Aluminum oxide	Scattering	M/U	Specific rainbow test not identified
Iron oxides	Scattering + absorption	M/I	Chemical form matters
Barium compounds	Form-dependent scattering/absorption	M/U	Element is not a unique optical class
Lead iodide/lead compounds	Form-dependent optical behavior	M/U	Compound and particle size are essential
TiO ₂ nanoparticles	Strong visible scattering	M	Specific rainbow threshold not established
SiO ₂ /Al ₂ O ₃ nanoparticles	Scattering	M/U	Concentration and aggregation matter
ZnO/CeO ₂ nanoparticles	Scattering + spectral effects	M/U	Visible response is material/size dependent
Ag/Au/Cu nanoparticles	Resonant scattering/absorption	M/U	Strong size/shape dependence
Carbonaceous particles	Absorption + scattering	M/U	Atmospheric persistence varies

Agricultural spray droplets	Liquid-droplet scattering	M/U	Droplet spectrum and evaporation dominate
Glyphosate formulation	Droplet/formulation optical effects	U/M	No direct rainbow-specific study identified
Mixed aerosol populations	Combined scattering/absorption	M/U	Interactions and vertical distribution matter

Table 1

Cloud Seeding: Relevant but distinct

Cloud seeding is an established form of deliberate weather modification in which particles are introduced into suitable clouds to influence cloud microphysics. The scientific endpoint of cloud seeding is precipitation or cloud-property modification, not rainbow suppression. Evidence that a material modifies cloud microphysics therefore cannot be treated as evidence that the same material suppresses a rainbow.

This distinction is essential to the present analysis. A material may have a demonstrated atmospheric function while its specific effect on rainbow visibility remains unresolved.

Agricultural spray aerosols and glyphosate

Agricultural sprays should be analyzed primarily as populations of liquid droplets and residual particulate material rather than as gases. Droplet size, formulation, evaporation, atmospheric stability, humidity, and release conditions influence drift and persistence. Such droplets can scatter visible radiation.

The present review does not identify a direct study establishing glyphosate-specific rainbow suppression. Accordingly, the appropriate classification for that proposition is unresolved rather than negative. The glyphosate molecule itself should not be conflated with the optical behavior of an applied spray formulation.

Altitude and vertical distribution

Altitude is not itself an optical agent, but vertical placement changes the atmospheric environment in which particles and droplets exist. Temperature, pressure, humidity, evaporation, vertical mixing, and residence time can alter particle size and optical depth. The location of an aerosol layer relative to the Sun, rain shaft, and observer is also consequential because attenuation and additional scattering can occur before or after rainbow production.

Final synthesis formula

The analytical framework developed in this review can be summarized by a conceptual rainbow-visibility function:

$$V_R(\lambda) = [I_{R,0}(\lambda) \exp(-\tau_{in}(\lambda) - \tau_{out}(\lambda))]/[I_B(\lambda) + I_A(\lambda)]$$

Where V_R is a conceptual measure of observable rainbow contrast; $I_{R,0}$ is the unmodified rainbow-producing radiance; τ_{in} and τ_{out} are wavelength-dependent optical depths before and after the rainbow-producing interaction; I_B is natural background radiance; and I_A is additional aerosol-scattered radiance.

The optical depth can be expanded as:

$$\tau_{total}(\lambda) = \int \sum_i N_i(r,z) C_{ext,i}(r,\lambda,m_i) dr dz$$

Where N_i represents the number-density distribution of particle class i , $C_{ext,i}$ is its extinction cross-section, r is particle size, z is vertical position, λ is wavelength, and m_i represents the relevant complex refractive properties.

Together these expressions incorporate material identity, particle size, concentration, refractive and absorptive properties, wavelength, humidity-dependent growth, altitude, and vertical distribution.

A comparative suppression index may then be defined as:

$$S_R(\lambda) = 1 - V_{R,modified}(\lambda)/V_{R,baseline}(\lambda)$$

This index is not proposed as a validated universal threshold for human visual disappearance. Rather, it provides a quantitative framework for comparing baseline and modified atmospheric states in future radiative-transfer simulations or controlled experiments.

Demonstrated findings and unresolved questions

Discussion

The principal result of this review is the distinction between the general optical proposition and the agent-specific proposition. The general proposition—that atmospheric optical modification can reduce rainbow visibility—is supported by direct modeling and

Question	Current conclusion	Evidence
Can aerosols alter rainbow appearance?	Yes; published observation and modeling demonstrate alteration.	D
Can increased atmospheric background wash out a rainbow?	Yes; demonstrated in atmospheric rainbow modeling.	D
Can aerosols attenuate rainbow-producing radiation?	Yes; established by aerosol radiative transfer and observations over clouds.	D
Can aerosols alter rainbow color balance?	Yes; aerosol-associated darkening and spectral alteration have been observed.	D
Can a specific metal nanoparticle suppress a rainbow to a defined threshold?	Requires material-specific optical modeling and measurement.	U/M
Can a glyphosate formulation specifically suppress a rainbow?	No direct rainbow-specific study identified in this review.	U
Can mixed aerosols produce more complex suppression?	Physically plausible and radiatively modelable; material-specific testing required.	M/U
Does altitude affect the optical result?	Yes, through vertical optical depth, atmospheric state, particle evolution, and geometry.	D/M
Does cloud-seeding evidence establish rainbow suppression?	No; the scientific endpoints are distinct.	D
Has an intentional rainbow-elimination technology been established?	No such technology is established by the reviewed literature.	U

Table 2

observation. The agent-specific proposition is considerably less developed. Many materials possess optical properties that make an effect mechanistically plausible, but direct rainbow-specific testing is uncommon.

This distinction is methodologically important. Atmospheric optics can establish a mechanism without establishing a particular material, concentration, atmospheric distribution, or intentional application. Conversely, a lack of direct investigation should not be represented as a negative experimental result.

The principal research opportunity is therefore quantitative: controlled radiative-transfer modeling and laboratory or field measurements could determine how aerosol optical depth, spectral extinction, particle size, polarization, and vertical placement translate into measurable changes in rainbow contrast [1-7].

Limitations

This review is not an exhaustive systematic review registered in a prospective review database. Agent-specific classifications

are conservative and may change as additional primary literature is identified. The synthesis equations are conceptual radiative-transfer relationships rather than validated universal thresholds for human visual disappearance. The paper does not infer atmospheric composition from visual observations of a rainbow. No conclusion about intentional deployment, operational use, or motive follows from the optical analysis.

Conclusion

Rainbow visibility is an emergent optical property of the interaction among sunlight, water droplets, the atmosphere, and the observer. The literature establishes that aerosols and atmospheric radiative conditions can modify the appearance and visibility of rainbow signals. In particular, increased background radiance can wash out a rainbow, while aerosol optical depth can attenuate and spectrally modify the observed signal.

The unresolved scientific question is not whether atmospheric optical modification can affect rainbow visibility; that general

proposition is supported. The unresolved question is the quantitative effect of particular atmospheric materials and particle populations under specified conditions.

The conceptual framework presented here links rainbow-producing radiance, atmospheric optical depth, particle populations, and background radiance in a common formulation. It provides a basis for future experimental and computational work designed to determine material-specific suppression thresholds and observable consequences.

Author Note

This paper is intentionally limited to atmospheric science and optical analysis. The analysis does not use theological, biblical, historical, ethical, or philosophical claims as scientific evidence.

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