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Cloud Iridescence as Visual Analog of Droplet Size

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Abstract

In this research, we convert the visual gradient of an iridescent wave cloud into a data-rich gradient of temperature and relative humidity, by linking the Kelvin Curve of homogeneous nucleation to the Fraunhoffer Diffraction and Babinet's Principle-derived formula for angular coronal size. We analyze how compatible the parameters and assumptions of Fraunhoffer and Babinet are, and then isolating the parameters that can be observed without instrumentation. The final equation takes variables that can be visually approximated- order of interference, wavelength, and angular distance from the sun- into temperature and relative humidity.

1. Introduction

What is understood to be the Earth's largest interferometer? We argue that it has been clinging to mountaintops, and coyly emblazoning the sky with iridescent colors, for longer than anyone can remember. Solar coronae and iridescent clouds are a direct interferometer which reveal a wealth of data about the weather. Meteorology consists of analyzing many variable gradients, most of which are generated by linking data from discrete observation points.
Ironically, we largely ignore the colorful visual gradients within the atmosphere itself. Clouds of similar droplet sizes provide a background of approximate optical isotropy, against which anisotropic aberrations can be seen. We borrow the language of crystallographers in order to understand the cloud iridescence for what it truly is- the analogous crystalline birefringence in the sky. The optical properties of these packets are uniform enough over a significant enough area to create visible interference patterns [1]. Just as instances of crystalline birefringence are a result of anisotropy in the optical transmission axis, instances of cloud iridescence are a result of subtle changes in atmospheric variables.

2. Parameters and Assumptions

2.1 Assumptions

The process of this research involved understanding the compatibility of all assumptions that apply to our starting equations (1) and (3). The first, and perhaps most crucial, assumption to this derivation is that all droplets form through homogeneous nucleation, and therefore, the radius of each droplet must be greater than or equal to the critical radius. The critical radius is the radius that a water droplet must reach in order to remain a droplet rather than evaporate. The Kelvin Curve represents the tendency of very small droplets to evaporate unless they reach the critical radius. The next assumption is the compilation of all parameter assumptions listed in Table 1: that all droplets are perfectly spherical and suitable for Fraunhoffer diffraction, regardless of the state of water that comprises the droplet. That is to say, all diffracting droplets, regardless of whether they are ice, liquid, or super-cooled liquid, diffract light in the same manner. With this assumption, we can treat all diffraction as a function of diffracting radius only. A third assumption buried within the previous assumption is that super-cooled liquid, actual liquid, and solid ice all diffract light in the same way, given that they are all spherical and have the same diameter. All three assumptions are reasonable in wave clouds due to rapid changes in relative humidity, temperature, and pressure that yield the supersaturation necessary to produce a significant number of droplets through homogeneous nucleation. The plausibility of these assumptions are covered at length in Shaw and Neiman [1-3].

2.2 Parameters

The parameter assumption note in the last row of table 1 is more relevant to the discussion section than the results. We assume that the wavelength can be approximated on sight because of the unique chromatic signatures of each level of interference.

Table 1. Parameter list

Parameter	Description	Value	Parameter Assumptions
r	droplet radius	$[m]$	All droplets are spheres
$e_s(r)$	sat. vap. over droplet	$[Pa]$	n/a
$e_s(\infty)$	sat. vap. over plane	$[Pa]$	n/a
S	Saturation Ratio	$\frac{e_s(r)}{e_s(\infty)}$	n/a
σ	Surface inter-facial energy of H_20	$[m]$	cell 8
k	Boltzmann constant	$1.38 * 10^{-23}[\frac{J}{K}]$	ideal gas behavior
T	Absolute Temperature	$[K]$	n/a
θ	Corona angular distance	$[degrees]$	none
$2m$	Order of Interference	see Table 2	order can be inferred on sight
λ	wavelength of light	$[m]$	See parameters

3 Results

We begin with the equation for droplet radius resulting from homogeneous nucleation [5]:

$$r = \frac{2\sigma}{nkTln(\frac{e_s(r)}{e_s(\infty)})} \tag{1}$$

We solve the corona angular distance equation for the same value- droplet radius.

$$2m = \frac{2r\pi}{\lambda} * sin(\theta) \tag{2}$$

$$r = \frac{2m\lambda}{(2\pi)sin(\theta)} \tag{3}$$

Equations (1) and (3) give:

$$\frac{2m\lambda}{(2\pi)sin(\theta)} = r = \frac{2\sigma}{nkTln(\frac{e}{e_s})} \tag{4}$$

Then, we isolate the variables which can be visually approximated to the left-hand side, and put all other variables and isolated constants on the right-hand side, eliminating r.

$$\frac{2m\lambda}{\sin(\theta)} = \frac{4\sigma\pi}{k}\frac{1}{nT\ln(\frac{e}{e_s})} \tag{5}$$

4 Discussion

Equation (5) show the relationship between variables that can be visually approximated, and microscopic cloud characteristic distributions. Gedzelman made simulations of the effect that particle size has on which chromatic patterns appear (cited in Shaw and Neiman). As you can see Figure 1, the chromatic orders of interference follow the radial outward bessel function-based distribution expected of intensity from diffraction. This is because they are directly linked- both are functions of droplet radius. this is the link between corona as a diffraction phenomenon, and as a chromatic interference pattern. Those connections allow us to get 3 key parameters on sight: wavelength, gamma, angular distance from sun theta, and bessel function order value 2m. By consolidating the assumptions, parameters, and scales of the two original functions, we are left with a constant multiplied by the inverse of temperature times the natural log of relative humidity. This highlights the direct relationship between what we see, and the microscale features of a cloud. Take the following 3 example of iridescence in wave clouds in Colorado- the same location and cloud type that inspired Shaw and Neiman. The best takeaway from this research is that, by glancing at a cloud to see which chromatic orders are represented and how far away they are from the sun, you can approximate the pressure and relative humidity.

Figure 1. Wave clouds displaying the iridescence phenomenon explored in this research. Note that the different chromatic range between the clouds closest to the sun (top and center) and those furthest from the sun (below and beside) are the spectra associated with a pure interference phenomenon. [4]

5 Conclusion

Our research is just the first of many steps in the journey towards a visual approximation of microscale atmospheric characteristics. Further research could include testing the validity of the homogeneous nucleation assumption by comparing the rawinsonde data gathered by Shaw and Neiman to their estimated droplet radii, or rederriving the relationship explored here for a Kohler-curve based heterogeneous nucleation process. Regardless of future work, this research stands alone as the first attempt at approximating microscale cloud characteristics by the naked eye.

6 Citations

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