National Center for Atmospheric Research

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NCAR Fellows News

AUGUST NEWS

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Greece: Blue Skies, White Clouds and Cloudy Ouzo

by Matthew Hayman

This June I had the pleasure of attending the biennial International Laser Radar Conference (ILRC) hosted in Porto Heli, Greece. The conference was a raging success. I watched personalities, egos and cultures cooperate and clash. I saw an American fall from an inflatable jungle-gym into the Aegean Sea. A British scientist repeatedly reminded us that the weather in the UK has been "absolute rubbish" this spring. I saw French scientists dance to Greek music and watched the Italians beat the Germans in the European Cup (in the company of both nationalities). International conferences are nothing less than an adventure into personalities, culture, and new perspectives - and the ILRC didn't disappoint.

Figure 1: Matt Hayman stands next to a very blue and cloudy Aegean Sea

Porto Heli is a small town situated on a harbor on the Peloponnesian peninsula, roughly a two-hour bus ride outside of Athens. On that ride, one sees that the terrain is dry and rocky and covered in olive trees. The Aegean Sea is incredibly blue, cloudy in some places (see Figure 1) and in others, the clearest I have ever seen. The sea, along with the hotel's aforementioned inflatable jungle gym, proved to be the best way to beat the heat.

Wherever engineers and scientists gather, organizers turn to performance-enhancing libations to bring out the social side of the often introverted attendees. At AGU they have beer hour during the poster sessions and in Greece, we had ouzo.

Ouzo is a Greek liqueur with a "black liquorish" flavor. If you are a cultural ignoramus like me, your experience with this drink didn't bring scattering theory to mind, but our Greek hosts were kind enough to teach us that we must drink ouzo with ice. Keeping the bottle cold is no substitute.

Ouzo is clear, but when you pour the liqueur

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Cloudy Ouzo (continued)

Figure 2: Progression from clear to cloudy Ouzo. The melting ice results in the formation of a colloidal suspension of small oil droplets.

over ice, the drink begins to get cloudy. After a few minutes, the whole drink is white milky color (see Figure 2). This phenomenon is the result of some fancy chemistry and scattering theory. Ouzo (and several other liqueurs) contains an oil called *anise* that is not water soluble. However, an aqueous solution with ethanol can dissolve some anise. The higher the ethanol concentration, the more anise can remain in solution. The anise is fully dissolved in the bottled ouzo, but melting ice in the glass decreases the ethanol concentration, and small oil drops begin to form.

So why does the suspension appear white?

We generally break up scattering problems into two regimes. Particles which are much smaller than a wavelength are in the Rayleigh regime, and particles near or larger than a wavelength are in the Mie regime. The separation of these regimes is not artificial; there is a distinct physical difference between them.

Rayleigh scattering strongly depends on wavelength of incident light (see Figure 3) where the scattering cross-section is proportional to $1/\lambda^4$ (where λ is the wavelength of incident light). Since nitrogen and oxygen molecules are much smaller (less than 1 nm) than visible wavelengths (400-750 nm), shorter (blue) wavelengths are scattered much more than their longer (red) counterparts. Thus, the sky is blue.

By contrast, Mie scatterers exhibit no wavelength dependence, so all incident wavelengths are scattered more or less equally (see Figure 3). Typical cloud droplets have radii on the order of 10 µm, so they are Mie scatterers in visible light and clouds appear white (the sum of all colors). Likewise, the near white color of the ouzo suspension allows us to confidently assert that the oil drops must have radii near or larger than visible wavelengths.

Some lidar systems use a multi-wavelength approach to characterize particle size, without need for calibrated backscatter, be-

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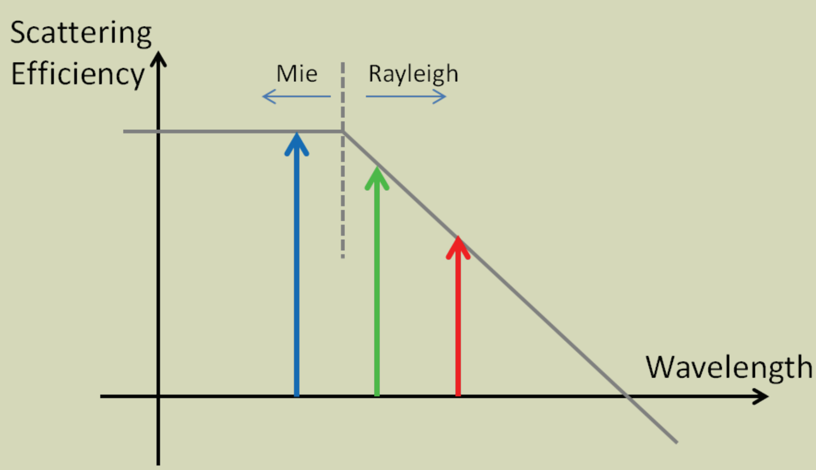

Figure 3: Rayleigh and Mie Scattering Regimes separated where the wavelength is approximately equal to the particle size.

Cloudy Ouzo (continued)

cause the "knee" between Rayleigh and Mie scattering provides a fixed reference point (see Figure 3). Instead of absolute backscatter, we use color ratios, which are ratios of signal intensity between different wavelengths. Such lidar systems typically transmit and receive wavelengths at 1.064 (near infrared), 0.532 (Green), and 0.355 µm (ultraviolet) which are the fundamental, second and third harmonics of Nd:YAG laser systems.

I took a color photo of the ouzo solution, so we can look at the relative scattering intensities of red, green and blue by the ouzo suspension. A simulation of the scattering efficiency as a function of particle size is shown in Figure 4 for the three different colors. Blue light scatters the most in the Rayleigh regime. Also the transition from Rayleigh to Mie scattering occurs at smaller particle radii in the blue than green and red.

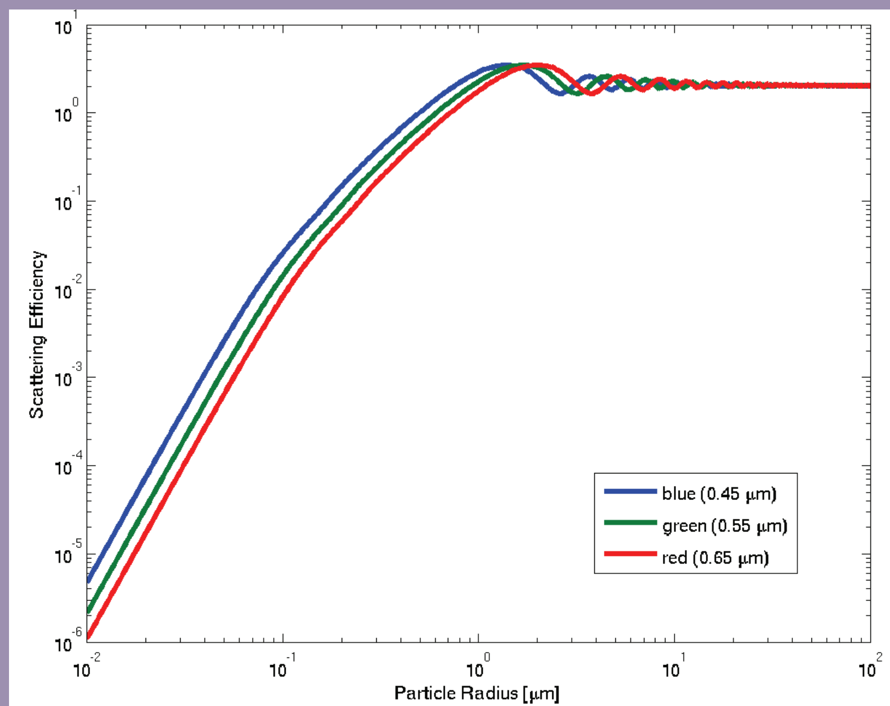

Figure 4: Scattering efficiency of blue, green and red wavelengths as a function of particle size. We can compare the relative scattering efficiencies between the three wavelengths to estimate the average particle size in the ouzo.

From this simulation, we then produce color ratios as a function of particle size, which are referenced to red:

CR1 = green intensity/ red intensity

CR2 = blue intensity/ red intensity

I have plotted these expected color ratios in Figure 5 for those colors recorded by the camera. The z-axis corresponds to particle radius. At the extremes of particle size, the color ratios approach constant values. For particles larger than 10 µm in radius, the color ratios both approach 1 because all three wavelengths are in the Mie regime. For smaller particles of radii less than 0.1 µm, the color ratios tend toward constants as well because all three wavelengths are in the Rayleigh regime. For the wavelengths the camera records, we can estimate particle radius over about two orders of magnitude. The color ratios the camera observed in ouzo are approximately 1.3 and 1.1, which match with the plot in Figure 5 when the particle radius is approximately 1.2 µm.

This technique was somewhat crudely applied to determine the mean size of anise drops in ouzo, but it can also be used to produce accurate range-resolved profiles of aerosol particle size in the atmosphere. These aerosol particles have the potential to impact climate directly, by scattering solar radiation, and indirectly, by acting as condensation nuclei for clouds. Some are pollutants or pollens that may impact public health. Knowledge of these particle sizes helps us deter-

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Cloudy Ouzo (continued)

mine what and how much aerosol we are observing. The use of multi-wavelength scattering information aids aerosol studies and, perhaps just as important, helps satisfy our curiosity about the size of the anise drops in our beverages.

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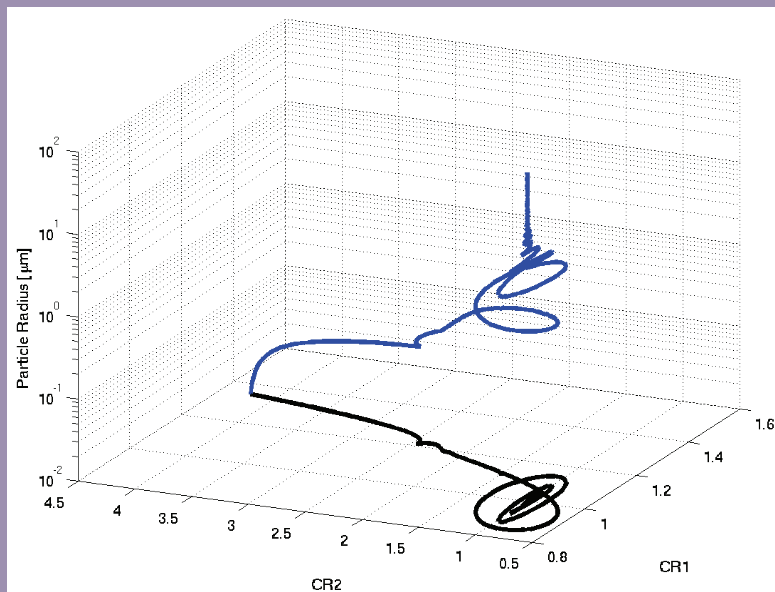

Figure 5: Color ratios 1 (green/red) and 2 (blue/red) as a function of particle size. The black shadow of the color ratio trajectory is shown for reference. The arrow shows the approximate location of the anise drop size on the trajectory.

Family Friendly Science

Did you know that last fall the National Science Foundation announced the "NSF Career-Life Balance Initiative," a 10-year plan to provide greater work-related flexibility to women and men in research careers? Among the best practices that NSF will expand Foundation-wide, are ones that will allow researchers to delay or suspend their grants for up to one year in order to care for a newborn or newly adopted child or fulfill other family obligations. — maximizing current policy to facilitate scientists' reentry into their professions with minimal loss of momentum. The new initiative will offer a coherent and consistent set of family-friendly policies and practices to help eliminate some of the barriers to women's advancement and retention in STEM careers. It will:

- **Allow postponement of grants for child birth/adoption** – Grant recipients can defer their awards for up to one year to care for their newborn or newly adopted children.
- **Allow grant suspension for parental leave** – Grant recipients who wish to suspend their grants to take parental leave can extend those grants by a comparable duration at no cost.
- **Provide supplements to cover research technicians** – Principal investigators can apply for stipends to pay research technicians or equivalent staff to maintain labs while PIs are on family leave.
- **Publicize the availability of family friendly opportunities** – NSF will issue announcements and revise current program solicitations to expressly promote these opportunities to eligible awardees.
- **Promote family friendliness for panel reviewers** – STEM researchers who review the grant proposals of their peers will have greater opportunities to conduct virtual reviews rather than travel to a central location, increasing flexibility and reducing dependent-care needs.
- **Support research and evaluation** – NSF will continue to encourage the submission of proposals for research that would asses the effectiveness of policies aimed at keeping women in the STEM pipeline.
- **Leverage and expand partnerships** -- NSF will leverage existing relationships with academic institutions to encourage the extension of the tenure clock and allow for dual hiring opportunities.

For more information, please see the announcement at
http://www.whitehouse.gov/the-press-office/2011/09/26/white-house-and-national-science-foundation-announce-new-workplace-flexi