

LETTERS

Many Uses for Diffusion Waves

I was excited to see “Diffusion Waves and Their Uses” on the cover of the August 2000 issue of PHYSICS TODAY and read Andreas Mandelis’s report (page 29) with great anticipation. It is a timely follow-on to an excellent article by Arjun Yodh and Britton Chance (“Spectroscopy and Imaging in Diffusing Light,” PHYSICS TODAY, March 1995, page 34) emphasizing optical tomography. A rapidly developing application in atmospheric science where the objects of study are dense clouds provides a further demonstration of the power of diffusing light.

From 1994 through 1996, I was part of a team at NASA’s Goddard Space Flight Center working on an observational curiosity in cloud remote sensing using reflected sunlight. The definitive explanation of this curiosity required radiative Green function theory.¹ Ignoring practical considerations, we theoreticians realized that one should go from passive to active remote sensing: A cloud’s Green function for photon diffusion could, in principle, be observed directly using laser radar (lidar) techniques. From this diffuse laser photon field, we can reliably (and some day cost-effectively) infer cloud thickness and density, possibly with some information about internal variability, at scales of about 0.5 km.²

The conceptual leap was to drop the routine single-scattering model for lidar signals and to work instead with the diffusion equation to model the time-dependent multiple scattering processes inside the opaque cloud mass. The corresponding instrumental leap was to detect the weak “off-beam” signal emerging from the cloud at large distances from the laser beam. This was successfully done under heavily overcast

skies at Goddard by September 1996 with a conventional zenith-pointing detector and a near-IR beam gradually deflected away from zenith.² The continuous-wave signal, within its natural variability, followed the theoretical prediction out to 12 degrees, corresponding to 0.3 km at cloud base; at that point, it was lost in the solar noise. Now, at NASA there is no progress without an acronym; thus “cloud THickness from Off-beam Returns (THOR) lidar” was born!

In September 1994, the first-ever atmospheric lidar experiment from space, the Lidar-In-space Technological Experiment (LITE), was successfully conducted by NASA’s Langley Research Center. LITE pulses returned from dense clouds proved to be temporal counterparts of the spatial Green functions we were to detect at Goddard. In spite of LITE’s conventionally narrow field of view (FOV), this is truly an off-beam signal since the unprecedented distance puts essentially all orders of in-cloud scattering into the FOV.

The remaining challenge in THOR lidar is to measure the diffuse laser-generated light field at once in both space and time.

During the same period in the early 1990s, but for entirely different reasons, researchers at Los Alamos National Laboratory had developed a highly sensitive imaging/timing detector for the Remote Ultra-Low Light Imaging (RULLI) project.³ A colleague of these individuals, Steven Love, quickly recognized that RULLI could be adapted to cloud studies. He and I discussed this at a meeting in 1995. In 1997, I joined the space and remote sensing sciences group at Los Alamos. With help from the RULLI team, we soon fielded a prototype Wide-Angle Imaging Lidar (WAIL). Interested readers can actually see cloud Green functions—literally, for bright green light at 532 nm—in “movies” downloadable from the Web at <http://nis-www.lanl.gov/~love/clouds.html>.

At Los Alamos we are currently redesigning the source-filter-detector suite to give WAIL daytime capability, hence the ability to monitor the important diurnal cycle of clouds. A

parallel effort is under way at Goddard’s THOR lab to build an airborne instrument. It will have a massive fiberoptic bundle feed at its focal plane to deliver light to an array of photomultiplier tubes, each assigned to an annular sector around the beam.

It is now easy to see why Yodh and Chance’s 1995 article made a deep impression on me. In medical imaging, it is vastly preferable to probe soft tissue with harmless near-IR photons rather than with high levels of x rays, especially to discover that the tissue is healthy. After heavy x-ray exposure, who can be sure? In meteorology, we have good reasons to probe clouds with visible light rather than the currently fashionable microwave approach. Earth’s climate is largely controlled by how clouds interact with sunlight; by using green light, we avoid the uncertain translation from the cloud’s radar reflectivity to the desired optical properties in the solar spectrum. So, we had invested our limited start-up funds to study “photon migration” and perform “optical tomography” of sorts with clouds, even before learning these expressions.

References

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The article on diffusion waves by Andreas Mandelis was a refreshing and interesting look at some applications of these waves, which are governed by a linear, parabolic partial differential equation. Readers may be interested in some other applications that arise from extensions of this governing equation in classical continuum mechanics. In porous media transport, for example,
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