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What Have We Learned About Clouds and Radiation After 30 Years?

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What Have We Learned About Clouds and Radiation After 30 Years?

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Although a lot of information about the detailed properties of clouds and cloud processes was compiled from extensive collections of surface and aircraft measurements before 1982, these measurements tended to be concentrated at lower-levels (liquid clouds) over midlatitude land areas. Nevertheless, global cloud cover maps based on surface observations were published as early as 1917. Likewise, many measurements of surface radiative fluxes were compiled, limited mostly to land areas. Top-of-atmosphere fluxes were not directly sampled, and then only sparsely, until the first satellite missions (notably Explorer 7 and Nimbus 3), but outgoing longwave (not albedo) maps had been produced before satellite measurements. Radiative flux profiles could only be inferred from limited upper air and cloud vertical distribution information collected from aircraft and weather balloons. Hence, when concerns about possible human-induced climate change arose in the mid-1970s, the lack of comprehensive, i.e. global and quantitative, information about cloud properties, their variations and their effects on radiative fluxes ("cloud feedbacks") was identified as a crucial lack that had to be addressed. Thus, the International Satellite Cloud Climatology Project (ISCCP) was established in 1982, as the first project of the World Climate Research Program, to exploit the growing constellation of weather satellites to obtain some of the needed information. This project continues today and has now transitioned from research to operational data processing for the future.

At the time that ISCCP began, and still true today, the only two wavelengths consistently measured in common by all the weather satellites were visible (VIS) and "window" infrared (IR), but fortunately, these two wavelengths could be used to measure the leading cloud properties that affect radiative fluxes, namely cloud areal coverage, cloud top temperature and cloud optical thickness. These two wavelengths had been selected for weather imaging because the atmospheric effects were smallest, which maximizes the contrast between clear and cloudy scenes and provides the best estimate of (radiatively important) cloud cover. Cloud top temperature indicates the radiating top of the cloud, although its interpretation becomes ambiguous for optically thinner clouds overlying thicker clouds (but the frequency of occurrence of this condition was not known), and provides a good basis for estimating upward top-of-atmosphere longwave fluxes. At the time, the usefulness of this information for estimating downward longwave fluxes at the surface was not well-known either, although comparison with surface cloud observations helped. It turns out that most clouds are relatively thin (1-3 km) layers so cloud top location provides useful information about cloud base location. Cloud optical thickness, being a column quantity, allows for a good estimate of both reflected and transmitted shortwave radiation, however, information is still lacking about the complete diurnal cycle of this quantity. That these three cloud properties can provide pretty accurate estimates of top-of-atmosphere and surface radiative fluxes was subsequently demonstrated by comparison of calculated fluxes to more direct satellite measurements at the top-of-atmosphere and more careful surface measurements.

Newer satellite instruments have added to the information obtained by ISCCP. The most important for the radiation budget are measures of cloud vertical structure by combined satellite radar and lidar. With these data the cloud effects on top-of-atmosphere fluxes can be determined better by resolving the ambiguity of the location of cloud tops for thin cloud layers overlying thicker clouds, surface fluxes can be improved by better estimates of cloud base location, and most importantly cloud effects on the shape of the vertical profiles of radiative heating can obtained from explicit cloud vertical structures and associated with different meteorological conditions.

The other key aspect of clouds (mention of which will be brief in a radiation meeting) is precipitation formation, where the microphysical properties of clouds (particle size distribution, phase and shape distribution) are more important than they are for radiation (these quantities are still needed to improve the accuracy of shortwave flux

calculations, however they are not first order). Earlier observations provided a good characterization of liquid water clouds (more accessible from the surface) and the warm rain process. Satellites have extended liquid cloud droplet size information to global extent but we lack complete information about diurnal variations. It was also thought that the aircraft-based information about ice clouds was complete, but early satellite-driven results were the discovery of much more frequent occurrence of very small ice particles and very thin ice clouds (early estimates of total cloud cover were low because the thinnest clouds were missed). Nevertheless, quantitative descriptions of the complexity of microphysical properties in ice clouds are still mostly based on aircraft experiments as comprehensive observation of the properties of ice clouds from space has not occurred, although additional information is being derived from polarization and lidar measurements. Moreover, the difficult question of the role played by mixed phase layers, especially in precipitation production, still has significant uncertainties. Hence, along with the next issue, precipitation as a cloud process is still highly uncertain and warrants deploying new kinds of measurements.

To complete the loop that is cloud feedback on climate requires linking cloud property variations and associated radiative and latent heating to atmospheric dynamics, which was always the hardest part of the problem anyway. Here progress seems stalled. This judgement is based on the fact that atmospheric models, from high resolution, so-called cloud resolving models up to GCMs still do not "satisfactorily" represent clouds. There are several problems. One is defining just what "satisfactory" means. But the primary one is the scale jump from deterministic cloud micro-processes to atmospheric dynamics that has both stochastic and deterministic aspects. Despite significant advances in satellite remote sensing of cloud properties, what has not been done is to exploit the ability of the satellite constellation to characterize the cloud variations (dynamics) across essentially the complete range of dynamical scales, especially analysis at high time resolution. The capability exists to investigate "cloud dynamics" directly; there is no real reason why this type of study has not been done.

In summary, we now have detailed, global, quantitative information on the main radiative properties of clouds and their variations from diurnal to decadal scale, sufficiently accurate to determine their effects on top-of-atmosphere and surface radiative fluxes. We can determine the radiative heating of the bulk atmosphere, but detailed vertical profiles in all meteorological situations are still in work. We can now provide quantitative statements about the effects of clouds on radiation. The story of clouds and precipitation still requires more work and new observations to get at details that we do not have currently. However, to complete the job of cloud feedbacks, we have to finish investigating cloud dynamics.