Communicating Research to the General Public

At the March 5, 2010 UW-Madison Chemistry Department Colloquium, Prof. Bassam Z. Shakhashiri, the director of the Wisconsin Initiative for Science Literacy (WISL), encouraged all UW-Madison chemistry Ph.D. candidates to include a chapter in their Ph.D. thesis communicating their research to non-specialists. The goal is to explain the candidate's scholarly research and its significance to a wider audience that includes family members, friends, civic groups, newspaper reporters, program officers at appropriate funding agencies, state legislators, and members of the U.S. Congress.

Over 50 Ph.D. degree recipients have successfully completed their theses and included such a chapter.

WISL encourages the inclusion of such chapters in all Ph.D. theses everywhere through the cooperation of Ph.D. candidates and their mentors. WISL is now offering additional awards of $250 for UW-Madison chemistry Ph.D. candidates.

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The dual mission of the Wisconsin Initiative for Science Literacy is to promote literacy in science, mathematics and technology among the general public and to attract future generations to careers in research, teaching and public service.

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New Light on Earth's Energy Budget and Its Implication for Solar Energy Potential

by

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Communicating Research to Non-Scientists

This chapter is supported by the Wisconsin Initiative for Science Literacy (WISL) to “promote literacy in science, mathematics and technology among the general public.” I would like to sincerely thank WISL for this valuable opportunity. During my graduate school, I have been fortunate to communicate my research with middle school students, college students, and scholars studying politics and economics through meetings and public forums. I deeply believe that communicating research to non-scientists is significant for students, policy makers, practitioners, and interdisciplinary research institutions.

1.1 Overview of Earth's Energy Budget (EEB)

The Earth's climate is a solar powered system that maintains a balance between solar energy reaching the Earth and energy emitted from the Earth back to space. The Earth distributes the energy received from the sun into five components of our planet including water, ice, atmosphere, rocky crust, and all living things. Therefore, understanding the energy change in each component is critical to helping us quantify the changing climate (Stephens et al., 2012). However, the Earth's energy balance depends on many factors, such as the spatial and time-related variations of clouds and aerosols that regulate incoming and outgoing radiations. Aerosols are fine solid particles or liquid droplets that become suspended in the air. Aerosols can be natural or human-caused, and include both dust and pollutants, among many other things; these tiny particles can have an enormous impact on our climate.

As shown in Figure 1.1, some clouds and aerosols substantially prevent sunlight (shortwave radiation) from arriving at the Earth's surface, resulting in a cooling effect. At the same time, clouds can also block the energy emitted from the Earth (we call this longwave radiation), warming the Earth's surface. Since aerosols' effect on longwave radiation is weak, in most scenarios only shortwave radiation is considered for the influence of aerosols.

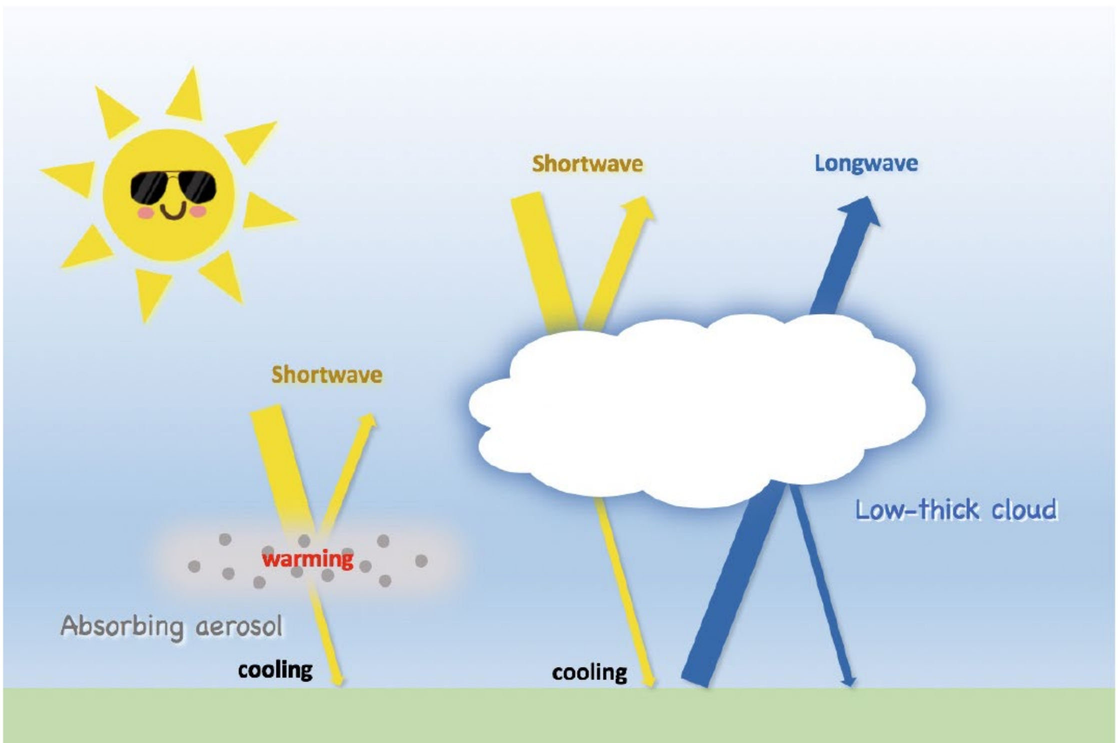

Figure 1.1 The role of low-thick cloud and absorbing aerosol in regulating Earth's energy budget.

The Earth system is constantly trying to maintain an energy balance between the incoming solar energy and an equal outgoing energy flow from Earth to space. Globally, the Earth system absorbs solar power from the sun and radiates the same energy amount back to space annually. If an energy imbalance situation occurs, the Earth's temperature will change correspondingly to restore a new energy balance. Thus, keeping an eye on the Earth's energy budget is important to understanding the link between climate change and global warming.

To closely monitor how the Earth's climate system balances the energy budget, processes occurring at three levels need to be considered, including the top of the atmosphere, where solar radiation enters the Earth's system; the surface of the Earth, where most solar heating takes place; and the atmosphere between the surface and the top of the atmosphere. However, previous estimates of the Earth's energy budget from passive sensor approaches that only measure reflected sunlight were limited in providing information on the impact of clouds and aerosols at the Earth's surface and in the atmosphere.

1.2 The Role of Clouds and Aerosols in EEB

Clouds are masses of liquid water, ice, or mixtures of both phases suspended in the atmosphere. Figures 1.2 a-h show photos of eight single-layered cloud types. Cumulus, stratus, and stratocumulus clouds are low-level clouds with cloud bases lower than 3 km (Figure 1.2 a-c). Cumulus clouds appear relatively big and fluffy, like giant cotton balls in the sky. Stratus clouds appear uniformly gray in color and look like fog but do not reach the surface. Stratocumulus clouds are relatively lumpy with a large horizontal scale around 5-50 km. Altostratus, altocumulus, and nimbostratus clouds are mid-level clouds with cloud bases lower than 7 km but higher than 2-3 km (Figures 1.2 d-f). Altostratus clouds float like parallel strips of clouds that are sometimes thin enough to reveal the sun. Altocumulus clouds are white or gray and generally layered with one part darker than the other. Nimbostratus clouds are thick and continuous clouds that appear dark gray. Cirrus clouds are thin and light clouds with cloud bases higher than 7 km

(Figure 1.2g). Deep convective clouds are many kilometers thick with cloud tops that are always higher than 10 km. In the real world, in addition to single-layered clouds, we also have multilayered cloud systems such as the one shown in Figure 1.2I, a multilayered cloud system that consists of a layer of low-thick liquid cloud beneath a layer of high-thin cirrus cloud.

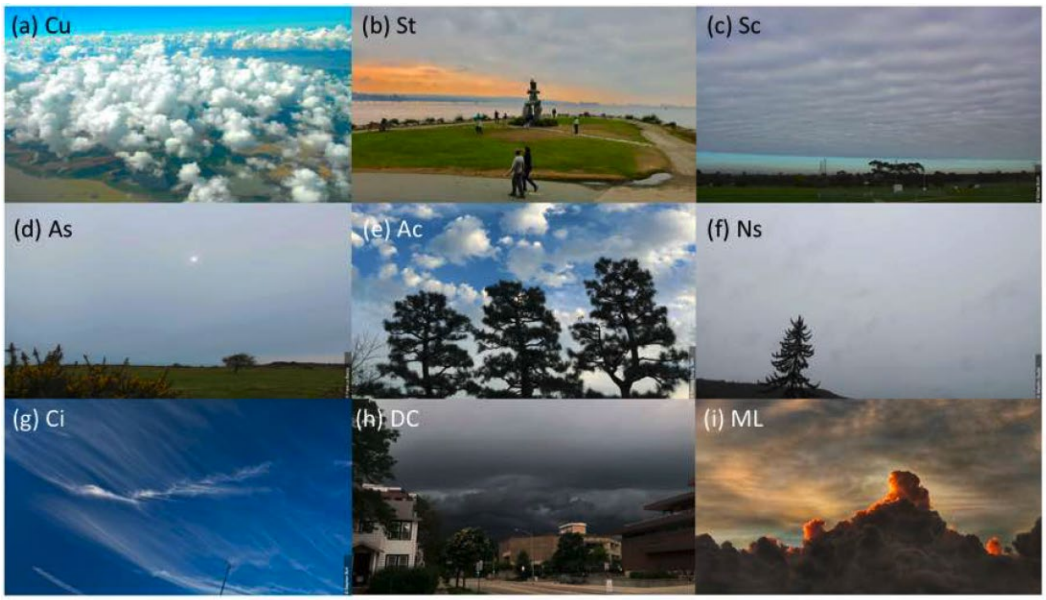

Figure 1.2 Photos of nine cloud types: (a) cumulus (©Yun Hang), (b) stratus (©Yun Hang), (c) stratocumulus (©Michael Bruhn), (d) altostratus (©Frank Le Blancq), (e) altocumulus (©Kwong Hung Tam), (f) nimbostratus (©Martin Gudd), (g) cirrus (©Stephen Burt), (h) deep convective clouds (©Yun Hang), (i) multilayered cloud systems (©Zhu Chen).

Different types of clouds with various heights, thickness, and structure regulate global energy balance in different ways. Figure 1.3 compares radiative impacts of three common single-layered cloud types. Low-thick liquid clouds (Figure 1.3a) near the surface substantially reflect sunlight back to space, imposing a net cooling effect. In contrast, high-thin clouds (Figure 1.3b) let most shortwave solar radiation pass through them but trap the upwelling longwave radiation emitted by the Earth's surface, warming the planet like greenhouse gases. Between these two extremes, high-thick clouds (Figure 1.3c) largely block sunlight but also trap heat emanating from the surface, exerting neutral or slight cooling radiative effects. In addition to single-layered clouds, multilayered cloud systems also cover the Earth and influence the energy balance. The most common type of multilayered cloud system consists of low-thick cloud and high-thin cloud (Figure 1.3d). As shown in Figure 1.3, adding a low-thick cloud below a high-thin mutes the warming effect of the upper-level high-thin cloud. As a result, both accurate specification of cloud characteristics and separation of single- and multilayered cloud scenes are critical for quantifying cloud radiative effects (Oreopoulos et al., 2017, Hang et al., 2019). Therefore, a precise accounting of the radiative feedbacks owing to cloud type changes is essential to accurately modeling the global energy budget.

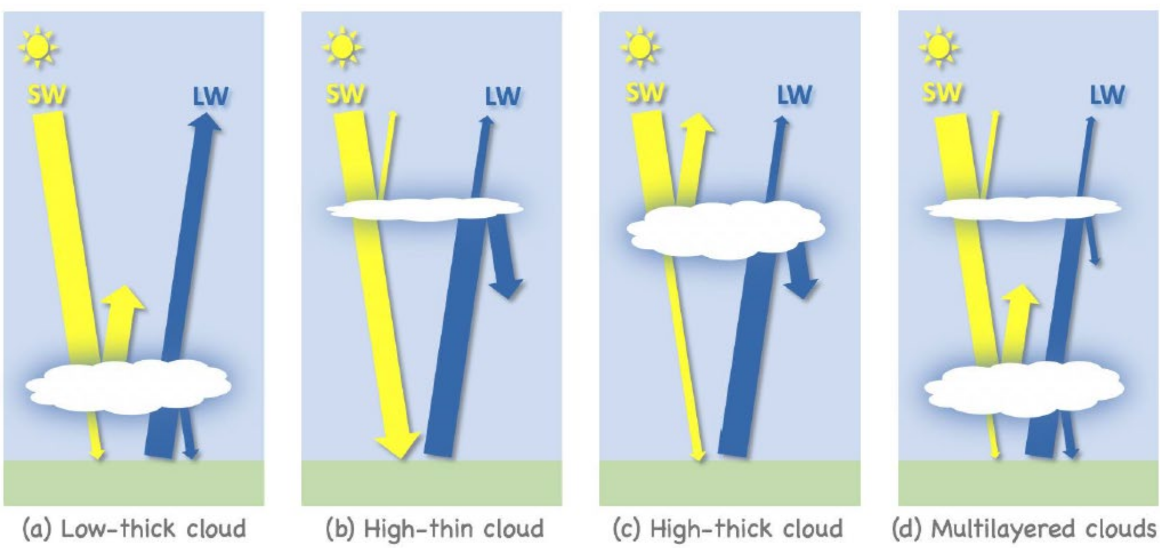

Figure 1.3 Cloud radiative impact of four common cloud types.

Aerosols are suspended solid particles or liquid droplets in Earth's atmosphere. They can be generated from both natural sources and anthropogenic ones (meaning they result from human activity). For example, dust and sea salt are natural aerosols, while black carbon and sulfate generated from fossil fuel combustion and urban emission are anthropogenic aerosols.

Similar to clouds, aerosols can directly interact with radiation. Since aerosols' effect on longwave radiation is weak, in most scenarios only shortwave radiation is considered (that is, incoming radiation from the sun).

As illustrated in Figure 1.4, "scattering" aerosols like sulfate generally act to cool the atmosphere, whereas strongly absorbing aerosol particles like black carbon warm the atmosphere. Quantifying these aerosol radiative effects has attracted more and more researchers in recent years because it is closely related to urbanization and industrialization and their influences on global warming. Also, some aerosols generated from human activities have been found to affect regional atmosphere visibility degradation, especially over anthropogenically polluted regions such as eastern China (Norris et al., 2009). The influence of aerosol on solar radiation could reduce substantial solar energy production (Li et al., 2017). Thus, monitoring the impacts of aerosols on regional energy budgets is necessary to make solar energy reliable.

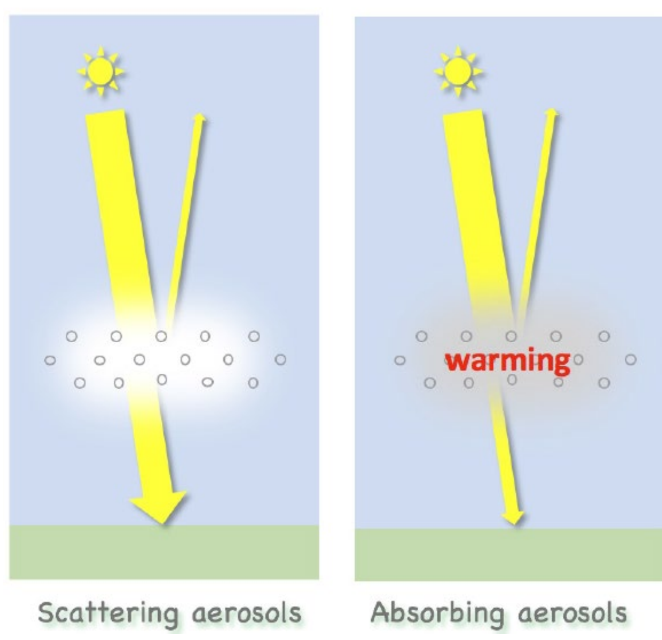

Figure 1.4 Aerosol direct radiative mechanisms of scattering and absorbing aerosols.

1.3 My Research: Accessing Influences of Clouds and Aerosols from Satellite Data

A new satellite algorithm 2B-FLXHR-LIDAR (2BFLX) provided us an opportunity to access and measure the role of clouds and aerosols on the Earth's energy budget. 2BFLX uses data from two complementary satellites that can estimate the amount of radiation at the top of the atmosphere, through the atmosphere, and at the Earth's surface. So, in this dissertation we used four years of 2BFLX data, from 2007-2010, to quantify global cloud radiative impacts and regional aerosol radiative impacts.

We further used another satellite algorithm 2B-CLDCLASS-LIDAR (2BCLD) to estimate the impacts of different cloud types. In 2BCLD, there are eight single-layered cloud types as introduced in Figure 1.2. One unique strength of 2BCLD is it can also separate multilayered cloud systems. In this dissertation, we found that multilayered cloud systems and stratocumulus clouds make the most cloud-related contributions to the global energy budget, not only at the top of the atmosphere but also at the surface. The results of this study help advance current understanding of cloud radiative influences to reduce uncertainties in representing these effects in climate models. This study also estimates the influence of different types of aerosols on regional energy budgets. We used the 2BFLX algorithm to calculate radiative influences from aerosols. At the same time, we used observations from satellite CALIPSO (https://www-calipso.larc.nasa.gov/) to identify different aerosol types. In this dissertation, we found that anthropogenic aerosols substantially reduce regional solar radiation in Asia during winter. This information is important for evaluating local solar energy potential over regions where face severe air pollution problems. The influence of aerosols on regional Earth's energy budget need to be considered in solar energy planning.

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