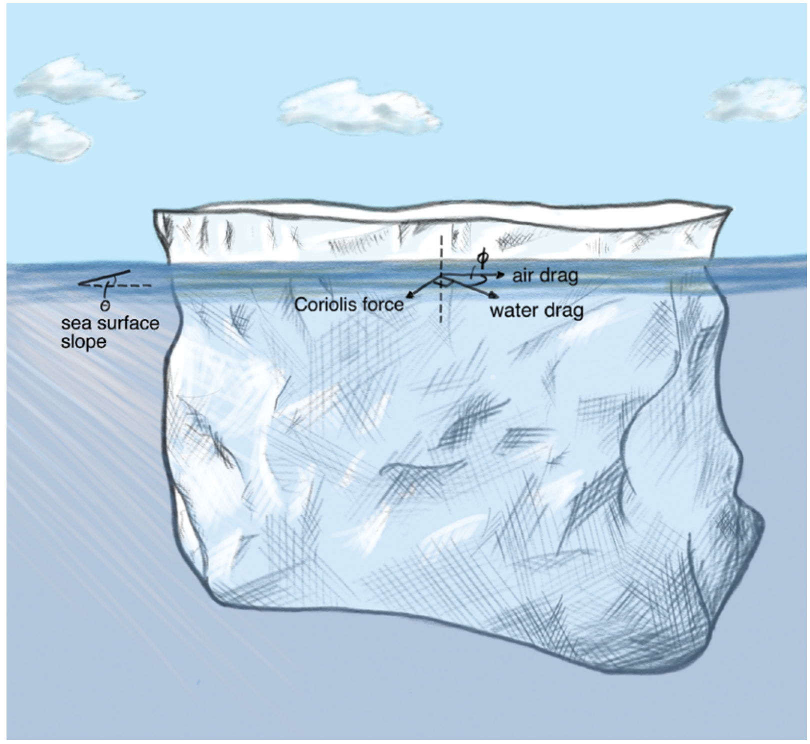
storm size on prediction of storm track and intensity using the 2016 Operational GFDL Hurricane Model," in the August issue of *Weather and Forecasting.*

The Influence of Winds Versus Ocean Currents on Iceberg Drift

Fluxes of icebergs from the Greenland and Antarctic Ice Sheets into the polar oceans have increased during recent decades, and some projections suggest dramatic further increases during the coming century. When an iceberg loses mass, it releases freshwater into the upper ocean, which influences ocean circulation through its effect on seawater density. Since the ocean transports heat, this can also have important influences on the global climate system. This suggests the importance of understanding what determines the drift of icebergs and how this drift would be influenced by changes in the winds or ocean currents. Our research investigated how winds and ocean currents drive icebergs, and we showed analytically how their roles vary with iceberg size.



Force balance on an iceberg. The drift of icebergs in the open ocean is typically largely determined by the balance of the forces illustrated here: drags exerted by surface winds and ocean currents (acting at a horizontal angle ϕ to each other), the Coriolis force associated with the iceberg's velocity, and the pressure gradient force associated with the sea surface slope, θ.

Icebergs have been modeled previously using Newton's second law (i.e., momentum balance), which relates the iceberg's acceleration to a number of forces, most of which involve the iceberg's velocity. Unraveling individual influences on iceberg motion can be difficult: although computing a momentum budget will reveal the strength of each force, identifying how the iceberg's trajectory would change in response to a change in the winds or currents is hampered by nonlinearities in the terms of the momentum balance. Such questions can be approximately addressed with the simpler empirical rule-of-thumb that icebergs drift at the ocean current velocity plus 2% of the wind velocity. This relationship has been observed in empirical studies for decades, but it has never previously been derived from first principles.

In our study, we apply a number of approximations to the momentum balance for an iceberg in order to derive an analytical solution for the iceberg velocity as a function of time. The approximations include that the forces balance (that is, we neglect iceberg acceleration), that the iceberg speed is negligible compared with the wind speed, and that forcing by ocean waves and drag due to sea ice are negligible. We show that the analytical solution reduces to the empirical 2% relationship in the limit of small icebergs (or strong winds), which approximately applies for typical Arctic icebergs. We show that the 2% value comes from a term involving the drag coefficients of water and air and the densities of the iceberg, ocean, and air. The opposite limit of large icebergs (or weak winds) approximately applies for typical Antarctic icebergs with horizontal length scales greater than about 12 km. In this limit, we find that the 2% relationship is not applicable and that icebergs instead move with the ocean current, unaffected by the wind.

The results of this study shed light on why icebergs of different sizes follow different drift patterns under the same ocean currents and winds. This can be understood in terms of the relative importance of the wind and ocean current drag terms compared with the Coriolis and pressure gradient force terms. The former scale with the surface area of the iceberg sidewall, whereas the latter scale with the iceberg volume. Hence the ratio scales with the iceberg's horizontal dimension, and the drag terms dominate for small icebergs, whereas the Coriolis and pressure gradient force terms dominate for large icebergs. This causes the small iceberg limit to depend on the wind velocity, while large icebergs move independently of the wind velocity. —Till J. W. Wagner (Scripps Institution of Oceanography, University of California at San Diego), R. W. Dell, and I. Eisenman, "An analytical model of iceberg drift," in a forthcoming issue of the *Journal of Physical Oceanography*.

Influence of Atmospheric Cloud Radiative Effects on Large-Scale Stratospheric Circulation

Atmospheric cloud radiative effects (ACRE) are defined as the difference between cloud radiative effects at the top of the atmosphere and the surface. They are dominated by the longwave component, as shortwave cloud radiative effects are mainly manifested at the surface. ACRE have an important influence on both the vertical and horizontal distribution of atmospheric diabatic heating, and thus have a profound impact on the tropospheric circulation as demonstrated from previous studies. Our research explored the influence of ACRE on the stratospheric circulation, and we found that they are important in determining the structure, amplitude, and time scale of the stratospheric circulation.

We assessed the stratospheric circulation response to ACRE by comparing simulations run with and without ACRE conducted under the auspices of the Clouds On-Off Klimate Intercomparison Experiment (COOKIE). We determined that the stratospheric circulation response to ACRE is reproducible in a range of different GCMs and can be interpreted in the context of both a dynamically driven and a radiatively driven component. The dynamic component is linked to the enhanced flux of wave activity into the lower stratosphere and changes in the meridional propagation of wave activity within the stratosphere when ACRE are included in the simulation. The ACRE-induced increases in the vertical flux of wave activity are consistent with enhanced upper-tropospheric baroclinicity and baroclinic wave amplitudes. They account for the strengthening of the Brewer–Dobson circulation, the cooling of the tropical stratosphere juxtaposed against the relatively weak warming of the mid-/high-latitude stratosphere above 70 hPa, and the weakening of the zonal wind in the upper stratosphere at high latitudes. The ACRE-induced enhanced equatorward flux of wave activity in the lower subtropical stratosphere accounts for strengthening of the westerly zonal flow in the subtropical lower and midstratosphere. The ACRE-induced increases in the flux of wave activity also lead to a more disturbed stratospheric polar vortex and thus a shorter time scale of variability in the circulation.

The radiative component is linked to ACRE-induced changes in the flux of longwave radiation into the lower stratosphere. The changes in radiative fluxes lead to a cooling of the extratropical lower stratosphere, decreases in static stability, and increases in cloud fraction near the extratropical tropopause. The negative ACRE imposed on the upper extratropical troposphere act to enhance the amplitude of the (already negative) clear-sky radiative cooling rates in the upper troposphere. The increased amplitude of the (negative) radiative cooling rates leads to shorter radiative damping time scales in the extratropical upper troposphere and lower stratosphere, which, in turn, also lead to lessened persistence of the stratospheric flow.

Our results highlight a previously overlooked pathway through which stratospheric and tropospheric processes are coupled via the influence of tropospheric cloud radiative effects on stratospheric climate. —Ying Li (Colorado State University), D. W. J. Thompson, Y. Huang, "The influence of atmospheric cloud radiative effects on the large-scale stratospheric circulation," in the August *Journal of Climate*.