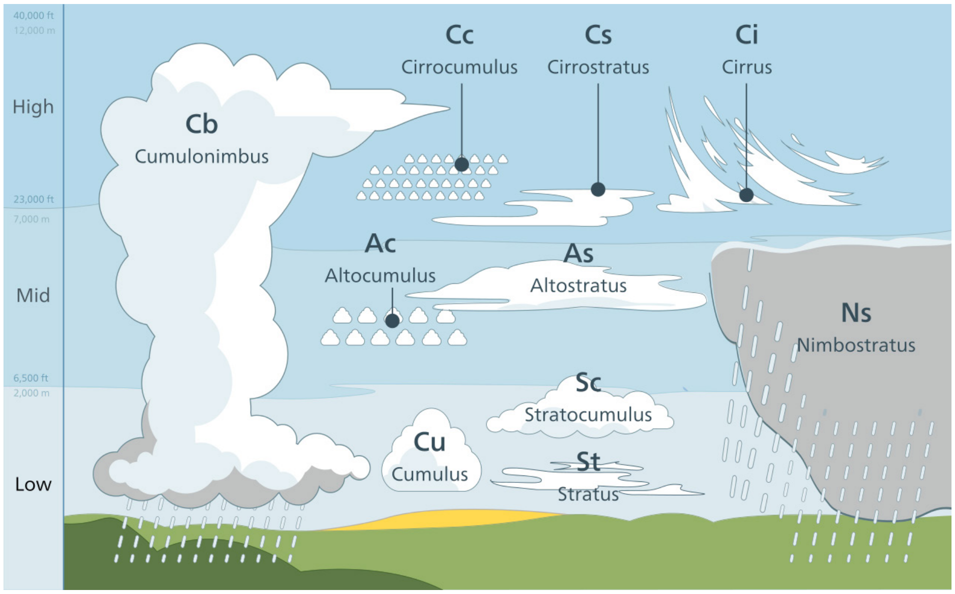
CLUBB: A UNIFYING PARAMETERIZATION OF LOW CLOUDS

Clouds continue to be one of the largest sources of uncertainty in earth system models (ESMs). Global temperatures are greatly influenced by clouds, which can have a cooling or warming effect. Low, thick clouds reflect much of the solar radiation and hence have a cooling effect on Earth's surface, whereas high, thin clouds trap heat and tend to warm the atmosphere.

ESMs solve fluid-flow equations using a mesh of grid points covering the globe and arranged in contiguous grid columns and vertical levels. Even with today's supercomputers, the spacing between grid points is coarse. For instance, a typical ESM might have a horizontal grid spacing of ~100 km and 100 vertical grid levels. Some clouds are much smaller than these grid cells with a horizontal width of 1 km, for example. These small clouds are important because they reflect sunlight and transport heat, moisture, and momentum in the vertical direction.



Graphic of the most common cloud types. Shallow cumulus clouds, also known as fair-weather cumulus clouds, are small in size, somewhat sparsely distributed, and often do not produce precipitation compared to larger cumulus clouds formed by deep convection such as cumulus congestus clouds. *Image from Wikipedia. Image file licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license. No changes have been made to the image.*

To approximate their effects, most large-scale models employ multiple "cloud parameterizations," which estimate the effects of small-scale cloud elements and turbulence on the larger resolved scales in a fluid-flow model.

ESTIMATING THE COOLING EFFECT OF CLOUDS

Estimates of potential future warming must account for the cooling produced by the reflectivity of clouds. The reflectivity of clouds depends partly on the concentration of aerosols (fine particles suspended in the atmosphere). When the aerosol concentration is high, such as over polluted regions, clouds tend to have smaller droplets and be more reflective. Most current-generation ESMs include aerosol effects in the stratocumulus cloud parameterization, but not in the shallow cumulus cloud parameterization.

The Cloud Layers Unified By Binormals (CLUBB) unifies the parameterization of all low cloud types —including stratocumulus, shallow cumulus, and intermediate cloud types. In this way, CLUBB allows the treatment of aerosols, already included in the stratocumulus cloud parameterization, to be extended to shallow cumulus clouds. Because of this, the U.S. Department of Energy's Energy Exascale Earth System Model (E3SM, e3sm.org) is one of the few earth system models today that includes aerosol effects in all low clouds, including shallow cumulus clouds.

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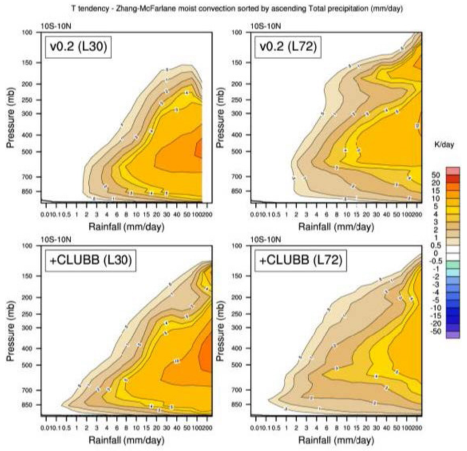

Groups of conditionally sampled probability density functions (PDF) of temperature tendency from the Zhang-McFarlane deep convection in E3SM version v0.2 simulation with 30 vertical levels (L30) and 72 levels (L72) without and with CLUBB cloud parametrization. Each figure is conditionally binned based on precipitation rate. The figures show PDF sensitivity to vertical resolutions and inclusion of CLUBB. Deep convection tendencies are often sensitive to changes in horizontal and vertical resolution and it is apparent this is the case with the E3SM v0.2 model. (Large, W. 2018. “2014-2018 Summary of NCAR activities in the Earth Energy Exascale System Model (E3SM) project,” 10.2172/1483278.)

As seen from space, cloud cover limits solar radiation from penetrating the atmosphere and being absorbed by the ocean or land surface and instead reflects it into space. *Photo courtesy of NASA*.

CLUBB is a parameterization of clouds, turbulence, and other small-scale variability. Its purpose is to estimate the effects of small-scale clouds and turbulence on the whole of an earth system simulation. CLUBB predicts the multivariate probability density function (PDF) of thermodynamic, turbulent, and microphysical quantities, not just an average value. The use of a PDF provides a detailed description of small-scale fluctuations.

The software’s design offers two key benefits for ESMs: It describes all low cloud types with a single equation set, and its mathematical framework adheres closely to the governing equations of fluid flow.

UNIFIED PARAMETERIZATION

In typical climate models, the stratocumuli are modeled using one parameterization, while shallow cumuli are modeled using a second parameterization. Because the formulations of the cloud parameterizations are so different, two microphysics parameterizations are needed. However, this is unnecessarily complex. CLUBB, instead, unifies the estimation of shallow cumulus and stratocumulus clouds with a single equation set. This also enables a unification of the microphysics and aerosols.

To achieve the generality required to parameterize both shallow cumulus and stratocumulus, CLUBB uses a detailed equation set. Specifically, it uses a higher-order closure approach that is borrowed from turbulence researchers—a set of equations is derived from the governing equations of fluid flow. These equations contain higher-order terms, such as co-variance between variables, that must be “closed” or approximated. The resulting equation set is rich in physical processes.

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