# VVCLOUD
## Scientific Description

**Background**

According to the National Transporation Safety Board (NTSB), from 1994-1998 low clouds directly or indirectly account for the largest number of weather-related aircraft accidents. These are mainly general aviation aircraft, and while it is impossible to determine for each case, these accidents likely occur when less experienced pilots become disoriented in cloudy conditions and lose track of their position in the airspace. While larger commercial aircraft accidents due to low clouds are rare, these conditions can impact them economically by closing or restricting major airports, causing ground delays.

Clouds form when air is saturated with moisture. Almost all clouds form when an air parcel rises and its temperature cools to its dew point temperature. Upward vertical motions range from a few cm $s^{-1}$, an almost imperceptible amount, to a violent 50 m $s^{-1}$ or more. It is the parcel's vertical speed that largely determines the cloud type.

VVCLOUD is an algorithm that converts the cloud liquid water (CLW) output from the VVICE algorithm (McCann 2006) to a cloud forecast. VVICE analyzes numerical forecast model data for many forms of vertical motion which allows for VVCLOUD to forecast many types of clouds.

**The VVCLOUD algorithm**

Vertical velocity is forced by many atmospheric processes, and a prominent one is convection. For convection to happen, three ingredients are necessary in the atmosphere. 1) The environmental lapse rate must be conditionally unstable, i.e., lower than the moist adiabatic lapse rate. 2) The parcel's initial temperature and moisture content must be high enough to have a level of free convection (LFC). If, by lifting, it becomes warmer than its environment, the parcel reaches its LFC. Then the parcel will accelerate upward by buoyant forces until it becomes cooler than its environment again. The amount of buoyant acceleration at any level is proportional to the temperature difference between the lifted parcel and the environment. Since one can compute the parcel acceleration, one knows the updraft velocity (*w*) at any level. 3) There also must be a mechanism that will lift the parcel to its LFC.

At every model grid point VVICE first determines the most unstable parcel by finding the level with the highest equivalent potential temperature. Then it examines the model information for potential lifting mechanisms at that level. These include two-dimensional frontogenesis, Eckman-layer lifting, and the model's own forecast vertical motion. The diagnosed upward motion is inflated by a function of the model resolution and its height above ground. VVICE follows the lifted parcel upward, layer-by-layer, to see if it reaches its lifting condensation level (LCL) and its LFC. See McCann (2006) for details. In layers above the parcel's LCL, it computes the condensed CLW from the thermodynamic equation (Rauber and Tokay 1991).

$$q_c = q_b + \rho\left(\frac{c_p\left[\Gamma_d - \Gamma_m\right]}{L_w} + \frac{gr_w}{R_d T}\right)dz$$

where $q_c$ is the CLW in the layer, $q_b$ is the CLW carried upward from the layer below, $dz$ is the layer thickness, $\rho$ is the layer air density, $c_p$ is the specific heat at constant pressure, $\Gamma_d$ and $\Gamma_m$ are the dry and moist adiabatic lapse rates, $L_w$ is the latent heat of condensation, $g$ is the acceleration of gravity, $r_w$ is the mixing ratio, $R_d$ is the gas constant for dry air, and $T$ is the layer temperature. The second and third terms compute the CLW generated in the layer from upward motion. Note that a parcel need only be above its LCL and moving upward for CLW to be generated. Often, a parcel may reach its LCL but not its LFC which is typical in cumulus and stratocumulus. Similarly, a saturated parcel may have a non-buoyant upward velocity which is typically forced in a large-scale storm. In these cases the model's own vertical motion is sufficient to produce the clouds, typically stratus and nimbostratus..

**U**sing the foregoing analysis assumes that the conditions at the model grid point are representative of all the surrounding area, which ignores the atmospheric variability between grid points. Many times only a fraction of the grid box is cloudy. Wood and Field (2000) found a useful relationship between aircraft cloud fraction (C) measurements and model forecast moisture:

$$C = 0.5\left(1 + \tanh\left[A\left(\frac{q_t}{q_s} - B\right)\right]\right)$$

where $q_t = (q + q_c)$ is the total water content defined as the sum of the specific humidity ($q$) and the cloud liquid water ($q_c$) and $q_s$ is the saturated water content. $A$ and $B$ are constants representing the best fit of the data and are 17.0 and 0.95, respectively. The ratio, $q_t/q_s$, defines a "total relative humidity."

This relationship can produce a significant cloud fraction even in a low relative humidity when there is a large CLW. Conversely, without CLW even a model relative humidity near 100% will yield a low or no cloud fraction. Numerous tests of the relationship showed an obvious underforecast bias, so $B = 0.9$ in the current version of VVCLOUD.

**Operational Interpretation**

VVCLOUD outputs grids of cloud fraction at all model levels. When mapped and displayed, forecasters can easily see the model's forecasted cloudy areas at the various flight levels. A composite of the maximum cloud fraction gives the forecasted total cloud cover. One can also analyze the grids for cloud bases and tops. Furthermore, subtracting the surface elevation from the cloud base yields the above ground level (AGL) clouds with which areas of where Instrument Flight Rules (IFR) apply or areas of mountain obscuration can be displayed.

**References**

McCann, D.W, 2006: Parameterizating Convective Vertical Motions for Aircraft Icing Forecasts. *Proc. 11th Conf. on Aviation, Range, and Aerospace Meteorology*, Atlanta GA, Amer. Meteor. Soc.

Wood, R. and P.R. Field, 2000: Relationships between total water, condensed water, and cloud fraction in stratoform clouds examined using aircraft data. *J. Atmos. Sci.*, **57**, 1888-1905.