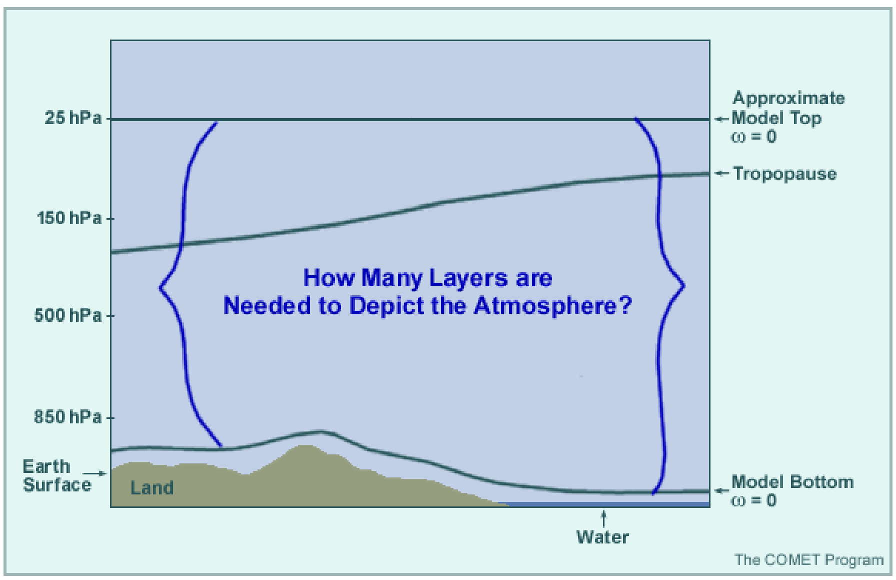
Vertical Resolution

(Adapted from COMET online NWP modules)

1. Vertical and Horizontal Resolution

Just as sufficient horizontal resolution is necessary to depict different atmospheric phenomena, NWP models and analysis systems must be designed with adequate vertical resolution to forecast the vertical structure and effects of a variety of meteorological events. However, unlike horizontal model structure, where either discrete or continuous configurations can be used, virtually all operational models use discrete vertical structures. As such, they produce forecasts for each layer of the atmosphere contained between the vertical coordinate surfaces.



It is interesting to note that the ratio of the horizontal and vertical resolutions must be consistent with the slope of the weather phenomena of interest. If consistency is not maintained, model forecasts with fine resolution in one dimension can actually be worse than forecasts with lower resolution.

2. Improving Vertical Resolution

Early primitive equation forecast models only employed 2 to 6 vertical layers. In the late 1980s, the three operational NWS models had increased vertical resolution to 7 to 18 vertical layers. By 2000, the Eta Model will have 50 vertical levels and the AVN/MRF will have 42. By reducing domain size and time scales and increasing computing power, some mesoscale and storm-scale models can now run with even higher vertical resolution.

To improve the deficiencies in past and current NWP systems, increases in vertical resolution now seek to

- Incorporate the effects of diurnal heating and cooling throughout the forecast period
- Incorporate the local effects of surface characteristics in the weather forecasting guidance
- Depict flow in the boundary layer related to the development and propagation of surface fronts, low-level jets and moisture transports, and convective instabilities, etc.
- Capture details of ageostrophic flow regimes associated with upper-tropospheric jet streaks
- Detect interactions between the polar and sub-tropical jet streams and between the stratosphere and troposphere
- Monitor stratospheric flow regimes that can affect medium-range forecasts and trace gas concentrations. These can impact human health as well as satellite observations (for example, ozone)

3. Impact of Vertical Resolution

The impact of vertical resolution on model forecasts can vary greatly by location and season. For example, in the midlatitude winter, high resolution in the 500- to 300-hPa range can improve the depiction and forecast of baroclinic systems and associated features, including jet streaks, fronts, ageostrophic circulations, and upper-level turbulence. Similarly, increased lower tropospheric resolution improves the depiction of vertical frontal structure near the surface, the development, movement, and modification of low-level cold air masses, and aircraft icing potential.

In the tropics and during midlatitude summer, however, the impact of improved resolution between 500 and 300 hPa can be significantly less because baroclinic processes generally are not as important and the tropopause is higher. In these cases, improved depiction of boundary-layer processes and surface fluxes of heat and moisture can have a much larger impact on improving forecasts of convection, the diurnal cycle, and surface moisture fluxes, etc.

In trying to meet these diverse needs, modelers have had to balance the benefits of adding layers to improve NWP forecasts against the costs involved in doing so.

4. Influence of Model Type on Vertical Resolution

Because NWP models use discrete vertical layers, the placement of those layers can be influenced significantly by the numerical methods used in the models.

In **grid point** models, the models' computational stability is determined almost entirely by the relative distance between grid points that a parcel of air can move within one computational time step. As such, the comparatively small time steps dictated by the maximum expected **horizontal** wind speed assure that air parcels will always remain near their initial vertical level during one time step.

The situation is nearly reversed in **spectral** models, where the continuous nature of the computational approach allows models to use a very long time step. In this case, the vertical levels must be spaced widely enough apart to assure that parcels will not pass from one level to the next within one time step. As a result, global spectral models must usually have their coarsest vertical resolution in the region of the atmosphere where the vertical motions are expected to be largest globally. This is usually found between 500 and 300 hPa over the tropical oceans, where deep convection plays a critical role in determining the strength and configuration of the general circulation. Because vertical layer spacing must be the same throughout the model domain, vertical resolution is relatively poor for phenomena associated with cold season upper-tropospheric features in the middle and high latitudes, such as jet streaks and ageostrophic circulations.

5. Varying Vertical Coordinate Resolution

When determining a model's optimal horizontal resolution, sufficient detail is needed to ensure that similar weather events can be forecast equally well at almost any location over the entire forecast domain. However, when determining optimal vertical resolution, the fact that certain atmospheric processes are usually confined to specific vertical regions of the atmosphere allows the vertical resolution to be structured such that the highest resolution is placed where it is needed most.

For example, vertical resolution must be quite fine (on the order of a few hPa) near the earth's surface to portray the transfer of heat and moisture into the boundary produced by daytime radiative heating. This same degree of resolution is not necessary in the middle troposphere, although an increase in resolution is necessary near and below the troposphere to predict the jet stream accurately. Again, annual variations in the elevation of the tropopause must be taken into consideration when determining the specific vertical configuration of the model in question.

6. Vertical Resolution Requirements

The vertical resolution of operational models must be sufficient enough to

- Incorporate the effects of diurnal heating and cooling
- Incorporate local effects of spatially variable surface characteristics
- Depict flow and shear in the boundary layer
- Capture ageostrophic regimes associated with upper-tropospheric jet streaks
- Detect interactions between the stratosphere and troposphere, including multiple high-level jets
- Monitor stratospheric regimes that affect medium-range forecasts and trace gas concentrations

To accomplish this, modelers have had to balance the benefits of adding layers to improve NWP forecasts against the costs involved in doing so.

7. Vertical Coordinate Systems

The strengths of the different vertical coordinate systems in depicting various aspects of atmospheric processes are summarized below.

Coordinate System *	Adaptability of Layers	Well-depicted Portions of the Atmosphere
Sigma	• Predefined by modeler	• Boundary layer • Other targeted levels (jet stream)
Eta	• Predefined by modeler, constrained by the need to resolve both topography and atmosphere	• Boundary layer at low elevations • Regions of steep surface slopes • Other targeted levels (jet

		stream)
Hybrid isentropic-sigma	• Isentropic regime: Adaptive • Sigma regime: Predefined by modeler	• Boundary layer • Baroclinic features in free atmosphere • Tropopause

***** Note that spectral models, regardless of their vertical coordinate system, are more constrained because they use a longer time step. As such, large vertical motions in the tropical mid- to upper-troposphere prohibit the use of fine vertical resolution at those levels anywhere around the globe.