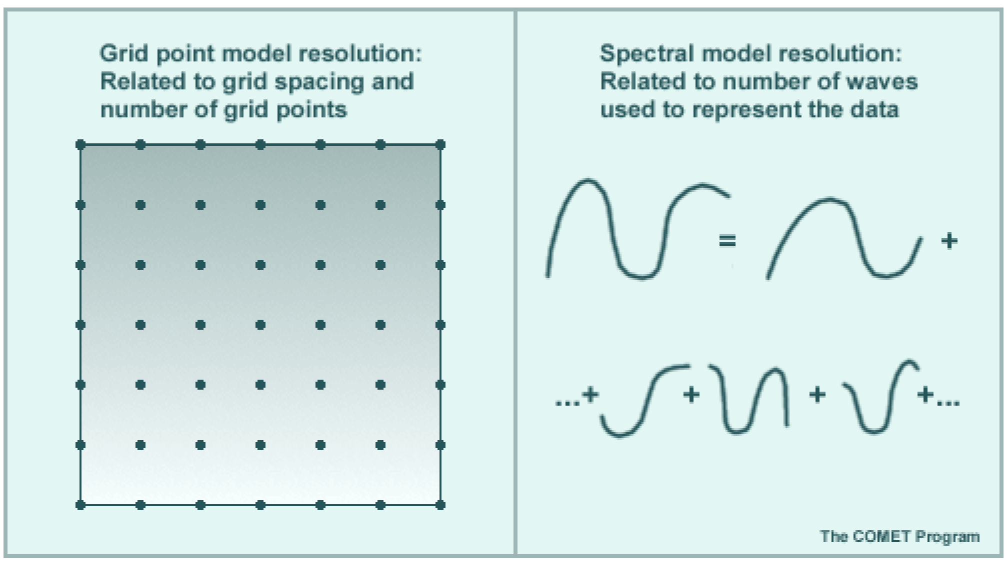
Horizontal Resolution (Part 1)

(Adapted from COMET online NWP modules)

1. Introduction

The horizontal resolution of an NWP model is related to the spacing between grid points for grid point models or the number of waves that can be resolved for spectral models. 'Resolution' is defined here in terms of the grid spacing or wave number and represents the average area depicted by each grid point in a grid point model or the number of waves used in a spectral model. Note that the smallest features that can be accurately represented by a model are many times larger than the grid 'resolution.' In fact, phenomena with dimensions on the same scale as the grid spacing are unlikely to be depicted or predicted within a model.



Although horizontal resolution plays a key role in determining a model's ability to resolve features, other factors, such as the vertical resolution, vertical coordinate, and physics package also have a significant impact. These factors are addressed in other sections.

When reviewing model guidance, one should be aware of

- The size and types of features that the model can be expected to resolve, based in large part on its horizontal resolution (grid point spacing or number of waves)
- The scale of features that need to be resolved. Is the model's horizontal resolution sufficient to resolve the size and types of features of interest? For example, can a 5-km grid point model resolve thunderstorms or sea breeze circulations?

This section expands on these and other issues related to horizontal resolution and should provide you with a better understanding of

- How horizontal resolution is defined for grid point and spectral models
- The relationship between horizontal resolution and
  - Terrain representation
  - Truncation error
  - Computer resources
- The role of horizontal resolution in the resolution of meteorological features

2. Grid Spacing

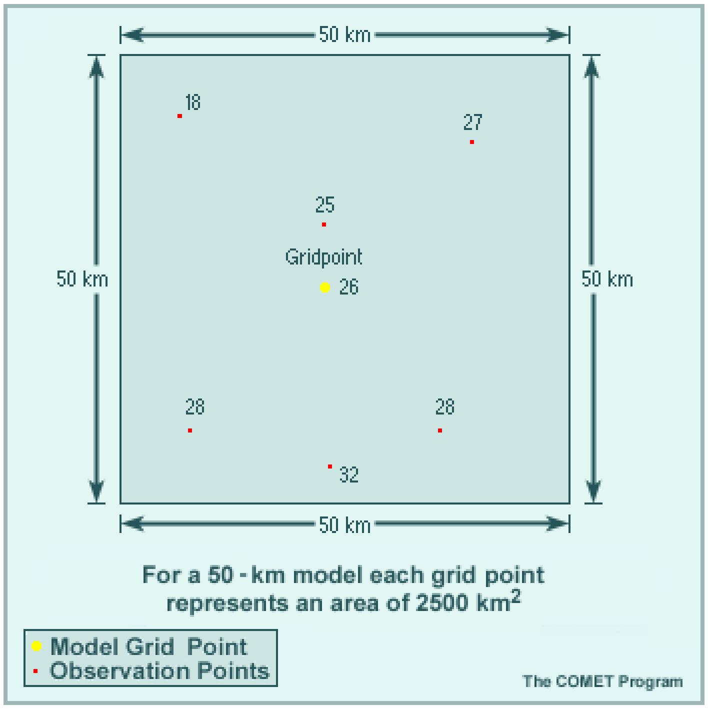
A grid point model's horizontal resolution is defined as the average distance between adjacent grid points with the same variables. For example, if all of a model's forecast variables (u-wind, v-wind, temperature, and moisture, etc.) are predicted at each of its grid points (as shown in the graphic), the model is considered to have a resolution equal to the minimum spacing between adjacent grid points at a specific latitude and longitude. In the example, all of the variables are computed at each grid point so the resolution is 50 km. A similar model with 10 km between adjacent grid points is considered to have 10-km horizontal resolution.

Whether a model is considered high or low resolution depends upon the size of the domain and the scale of weather phenomenon that the model is trying to predict. A resolution on the order of 20 to 50 km is considered high for a global model, while for a storm-scale model, a resolution of 100 to 500 m is considered high and necessary to resolve the internal processes of convection.

Categorizing models as to their resolution (high or low) is a poor method for describing models since the term is relative and changes as new models come on-line. Today's high-resolution model may be tomorrow's low-resolution model, independent of its domain.

2.1 Grid Box Area

It is important to know the amount of area between grid points, since atmospheric processes and events occurring over areas near to or smaller than this size will not be included in the model. For a 50-km model, each grid box covers 2500 square kilometers, with the grid points located at the center of the boxes. Hence, the central "grid point" represents the mean value of the data within the 2500 square kilometer area of the grid box surrounding the "grid point."



In the example, the grid point is assigned a value of 26, which approximates the average of the observed values within the grid box. This representation may be adequate when the area is under a rather homogeneous, large-scale feature, such as a large high-pressure system. However, if the scale of the phenomena being forecast is less than the area represented by the grid box, the phenomena will not be correctly represented and can, if not treated properly, actually degrade the quality of forecasts of large-scale features.

Grid spacing also has direct and indirect effects on

- Model terrain representation
- Truncation errors in equation computations
- Computer resources
- A model's ability to resolve different scales of features

These effects are discussed more throughout the rest of the Horizontal Resolution section.

2.3 Spectral Resolution

In spectral models, the horizontal resolution is designated by a "T" number (for example, T80), which indicates the number of waves used to represent the data. The "T" stands for triangular truncation, which indicates the particular set of waves used by a spectral model.

Spectral models represent data precisely out to a maximum number of waves, but omit all, more detailed information contained in smaller waves. The wavelength of the smallest wave in a spectral model is represented as

$$\text{minimum wavelength} = \frac{360\ \text{degrees}}{N}$$

where N is the total number of waves (the "T" number).

Complications arise because non-linear dynamics and physics are calculated on a grid and then converted to spectral form to incorporate their effects in a spectral model. This introduces errors, which make the final result less exact than one might expect from calculations done strictly in spectral space.

2.4 Grid Point Equivalency

Grid point models can incorporate data at all resolutions, but can introduce errors by doing so. It takes about five to seven grid points to get reasonable approximations of most weather features. Still more points per wave feature are often necessary to get a good forecast.

Because spectral and grid point models preserve information in different ways, no precise equivalent grid spacing can be given for a spectral model resolution. However, we can approximate the grid spacing to obtain equivalent accuracy to a spectral model with a fixed number of waves using a very simple approach. First, we assume that three grid points are sufficient to capture the information contained in each of a series of continuous waves. The approximate grid spacing with the same accuracy as a spectral model can then be represented as

$$\Delta X \approx \frac{360^\circ}{3N}$$

For a T80 model, this results in a maximum grid spacing for equivalent accuracy of about

$$\Delta X \approx \frac{360^\circ}{3 \times 80} \approx 1.5^\circ \sim 160\ \text{km}$$

In fact, the dynamics of spectral models retain far better wave representation than grid point models with this grid spacing. However, the spectral model physics is calculated on a grid, with about three times as many grid lengths as number of waves used to represent the data. Since it takes five to seven grid points to represent 'wavy' data well and even more for features that include discontinuities, the resolution of the physics is poorer than the above formulation indicates and degrades the quality of the spectral model forecast.

In summary, spectral models do a fine job with 'dry' waves in the free atmosphere, but have coarser representation of the physics, including surface properties. The resulting overall forecast quality is somewhere between these two extremes and varies on a case-by-case basis. The more physics that is involved in the evolution of the forecast, the less the advantage in spectral model forecasts compared to comparable resolution grid point forecasts.

3. Terrain Representation Effects

The following list contains more detailed information on the effects of inadequately depicted model terrain on the prediction of weather features and processes. Note that the list is not all-inclusive.

- Vertical motion fields are shifted away from the mountains due to insufficient terrain slope
- Upward motion is often shifted upwind of the highest mountain peaks and is often too weak
- Downward motion is shifted too far downwind of mountain ranges and is often too weak
- Precipitation maxima and minima are misplaced or missing in regions of complex terrain. Coincident with vertical motion fields, precipitation maxima are often too far upwind of mountain peaks, smoothed out, and too far downwind of mountain ranges, and can be insufficient in quantity and intensity
- Downslope winds, valley winds, drainage winds, and other small-scale processes typically cannot be depicted
- The propagation speeds of near-surface frontal zones are impacted
- Mountain wave development often cannot be accurately depicted
- Valley inversions and cold air damming are often difficult to resolve and are not well represented
- Many of these deficiencies are found in the current global and synoptic-scale models, although some are being mitigated in mesoscale and local models, as well as some higher-resolution regional models.
- Note that the vertical coordinate and vertical resolution also strongly impact the nature of terrain effects.