

Lecture (15)

Grid Staggering

تداخل (تعاقب) الشبكات

15.1 Introduction

The next step after the choice of distribution of grid points (i.e., rectangular, triangular, hexagonal, etc.), is to arrange the prognostic variables on the grid.

- When all the prognostic variables are defined at the same point in a grid, it is called an unstaggered grid.
- On the other hand, when prognostic variables are defined at more than one point in a grid, it is called a staggered grid.
- The staggered grid has the values of the wind components at separate points than the thermodynamic variables (such as pressure, volume, temperature, energy and entropy) within the grid cell.
- The main benefit of the staggered grid over collocated grid, is that, unlike the collocated grid, the staggered grid does not result in the decoupling of the pressure and velocity, leading to the checkerboard problem.

Staggering is not only performed in the horizontal direction, but also in the vertical direction, as well as in time, and any combinations thereof.

15.2 Horizontal Staggering

Five different types of grids were introduced by Arakawa and Lamb and are shown in Figure 1. Of these grids, A is an unstaggered grid where the variables are defined at the same points, e.g., at the center or at the corners of the grid. Grids B through E are all staggered grids where the variables are defined at different points.

- Since all variables are defined at all the grid points in the A grid, it is easy to construct a higher-order accurate scheme. The main disadvantage is that the differences are computed over a distance of $2\Delta x$, and the adjacent points are not coupled for the pressure and convergence terms.
- In grid B, evaluation of the two sets of variables are at different points, e.g., one might evaluate the velocities at the center of a grid and masses at the grid corners. Since the B and E grids have wind components at the same point, they are often called semi-staggered. The B grid was chosen in the UK Met Office (UKMO) unified model for numerical weather prediction and climate simulation.
- In grid C, velocities are calculated at the mid-point between grid cells and h (geopotential height) is calculated at the corners. The main advantage of the C grid is that the pressure and convergence terms are computed over a distance Δx ,

which is half of that in the A grid indicating a doubling of the resolution compared to the A grid. Most non-hydrostatic mesoscale models like MM5) and WRF use the C grid.

- From the grids presented in Figure 1 it can be seen that the resolution of models does not depend solely on the size or shape of the grid but also the location in which the model calculates various atmospheric variables. As the number of grid cells increases, the differences in effective resolution between different grid types eventually goes to zero as the number of grid cells goes to infinity.
- In grid D, there is a slight variation of grid C, with the u and v variables being oriented with a rotation of 90°. This variation allows for a simple evaluation of the geostrophic wind. The D grid was used NMC's) nested grid model; however, this grid is no longer used in any popular atmospheric model because of no added benefit.
- The staggered E grid is rotated 45° relative to the B grid, but has an increased grid-spacing compared to the B grid. Centers for Environmental Prediction (NCEP) eta model uses grid E.

Although staggered grids have higher equivalent resolution than unstaggered grids, they are also more complex. Overall, the C grid is becoming more popular in recent times with the E grid its closest competitor.

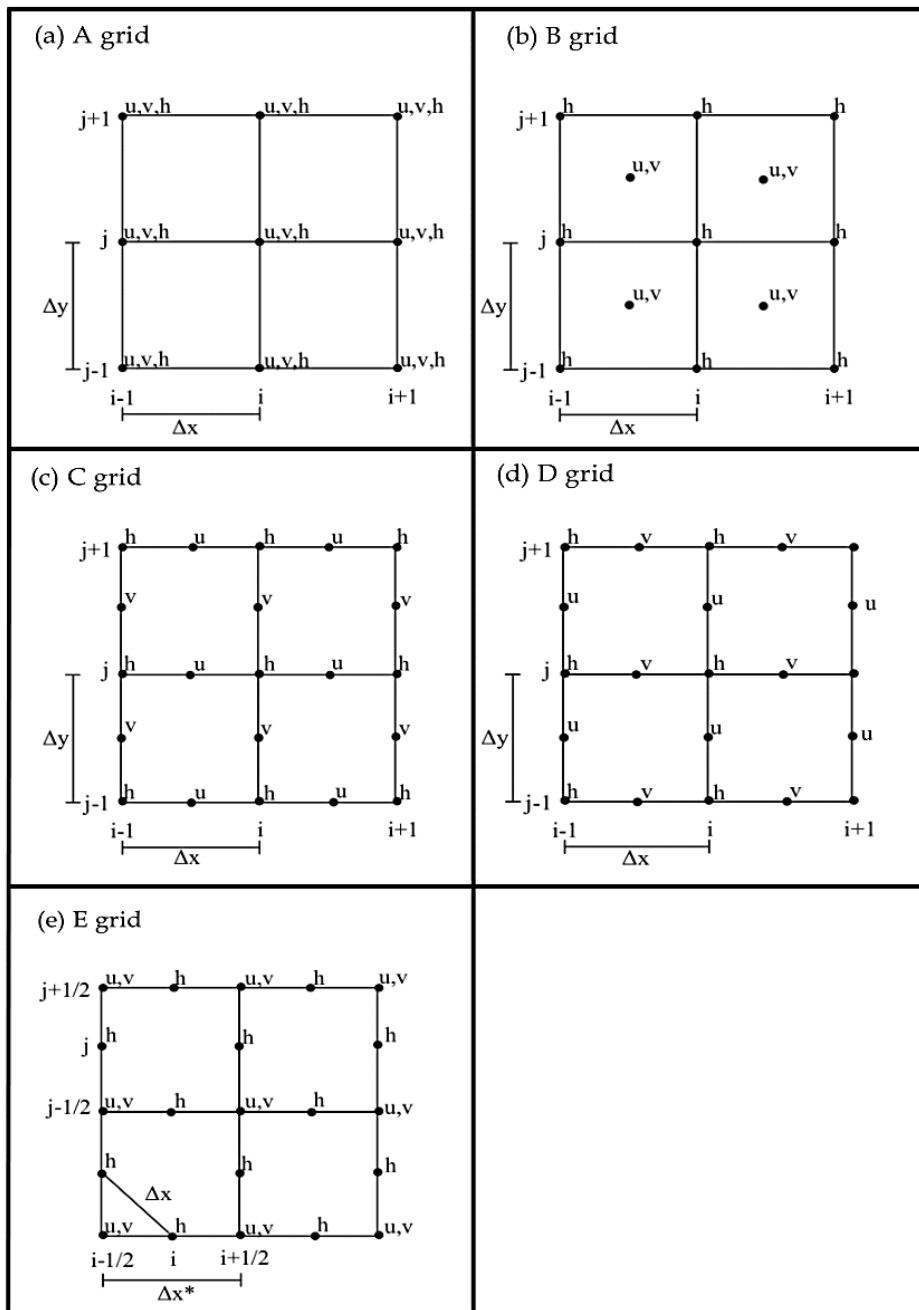


Figure 1. Grid types based on horizontal staggering, namely, (a) the A grid, (b) the B grid, (c) the C grid, (d) the D grid and (e) the E grid. Δx is the east-west resolution and Δy is the north-south resolution.

15.3 Vertical Staggering

Staggering of grids in the vertical direction also provides certain advantages (Figure 2). Most of the present state-of-the-art numerical models have staggered grids in the vertical direction with prognostic variables at the center of the layer and the vertical velocity at the boundary of the layers. Such an example is shown in Figure 3 from the WRF model.

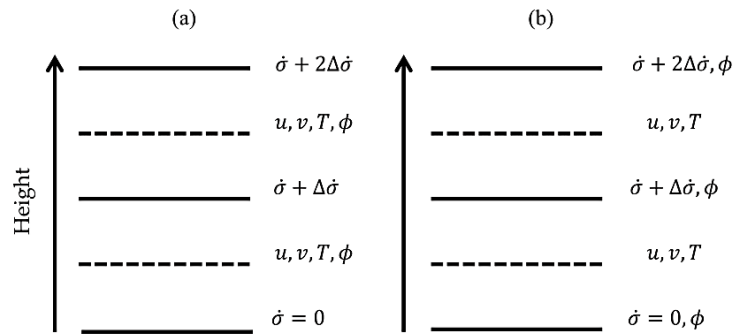


Figure 2. Staggered grids in the vertical following (a) Lorenz & (b) Charney-Phillips.

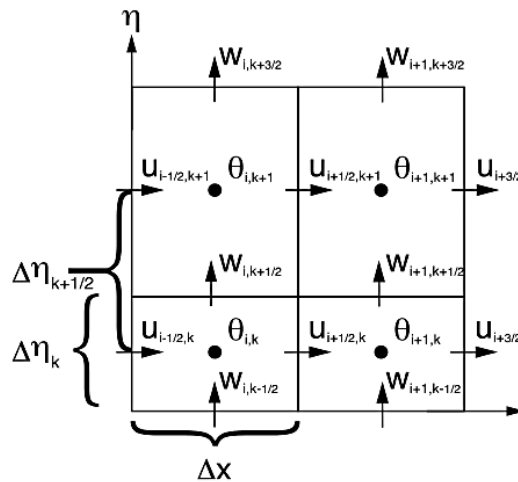


Figure 3. Vertically staggered grid from the WRF model.

15.4 Time staggering

Staggering of grids is not confined in space, staggering can also be in time. For example, for atmospheric flow using the leapfrog scheme grid D is ideal when staggered in time (Figure 4). Time staggering mostly involves defining variables at every second time step on an offset D grid. All the differences are calculated on a distance Δx . However, time staggering is not always used due to the complexities that arise from the additional staggering and need of special procedures for starting the leapfrog scheme.

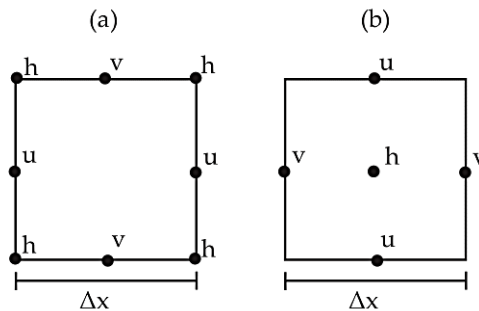


Figure 4. Staggered grids in space and time with (a) even time steps (b) odd time steps.