Numerical Weather Prediction

Meteorology 311
Fall 2012
Closed Set of Equations

• Same number of equations as unknown variables.

• Equations
  – Momentum equations (3)
  – Thermodynamic energy equation
  – Continuity equation
  – Equation of state

• Variables: \( u, v, w, T, p, \rho \)
Nomenclature

• Dynamics: Atmospheric motions and their time evolution
  – Application of Newton’s second law.

• Kinematics: Properties that can be deduced without reference to Newton’s second law.
Solve Equations

• Approximate mathematical equations
  – Not enough data to compute continuous derivatives.
• Discretization needed.
  – Approximation needed in both time and space.
  – Centered difference and one-sided upstream scheme are both used.
• What about edges of domain or boundaries?
  – Model approximates conditions at the boundary, or
  – Model gets data from another model.
    • Regional models get boundary data from global models.
Method

• Collect observations of weather (data).
• Quality control data to remove spurious reports.
• Perform Objective Analysis to model grid points.
  – Observations don’t match the model grid.
  – They need to be “gridded” before they are useful to the model.
• Initialize the model insuring that balance occurs.
• Integrate the model forward in time to produce model forecast.
• Post-process results to produce nice looking graphs.
• Interpret the results.
  – Adjustment based on forecaster understanding and model biases.
Model Types

• Finite difference models
  – Gridded data
  – Use methods that you learned in class.
    • Centered-difference and One-sided upwind difference.
    • Taylor-series expansions about a point.
    • Accuracy and computational error depends on how many terms you keep.
  – Typically regional models.

• Spectral models
  – Fourier series to represent waves in the atmosphere.
  – Global models.
  – Resolution given by R (Rhomboidal truncation) or T numbers (Triangular truncation).
  – T159 ~ 126km, T511 ~ 39km, T1279 ~ 16km
Taylor Series

Taylor series: 
\[ f(a) + f'(a)(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \frac{f'''(a)}{3!}(x-a)^3 + \cdots + \frac{f^{(n)}(a)}{n!}(x-a)^n + \cdots \]

Taylor polynomial: 
\[ f(a) + f'(a)(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \frac{f'''(a)}{3!}(x-a)^3 + \cdots + \frac{f^{(n)}(a)}{n!}(x-a)^n \]

Remainder: 
\[ R_n(x) = \frac{f^{(n+1)}(\xi)}{(n+1)!}(x-a)^{n+1} + \frac{f^{(n+2)}(\xi)}{(n+2)!}(x-a)^{n+2} + \frac{f^{(n+3)}(\xi)}{(n+3)!}(x-a)^{n+3} + \cdots \]

Derivative form of remainder: 
\[ R_n(x) = \frac{f^{(n+1)}(\xi)}{(n+1)!}(x-a)^{n+1} \text{ where } \xi \text{ is a number between } a \text{ and } x. \]

Integral form of remainder: 
\[ R_n(x) = \frac{1}{n!} \int_a^x f^{(n+1)}(t)(x-t)^n \, dt \]
Important Features

• Horizontal resolution
  – “Effective” resolution is 4-5 times model grid spacing.

• Vertical coordinate
  – Sigma coordinate – terrain following coordinate.

• Vertical resolution
  – Spacing of vertical grid.

• Domain
  – Regional or Global.
Boundary conditions periodically fed in at boundaries from global model.
Sigma Vertical Coordinate

Vertical Grid
Sigma Hydrostatic Pressure Coordinate

Pressure (mb)

Horizontal Distance
NCEP Operational Models

• New NAM (NMM)
  – North American Mesoscale
  – Currently NMM-B
  – WRF-ARW

• Really old NAM
  – ETA

• GFS
  – Global Forecast System

• RAP
  – Rapid Refresh – Replaced the RUC (Rapid Update Cycle in May 2012.)
Non-NCEP models

- ECMWF
  - European Centre for Medium-Range Weather Forecast

- UKMET
  - British atmospheric model

- GEM
  - Global Environmental Multiscale
  - Canadian forecast model
MOS/FOUS

• MOS
  – Model Output Statistics.
  – Statistical equations used to calculate meteorological variables.
  – Accounts for persistent model biases.

• FOUS
  – Forecast Output United States
  – Raw model data.
  – Data will contain model biases
MOS features

- Equations developed over time.
  - Types of events that occurred over the development time are well handled.
  - Rare events will not be well handled by MOS equations.
  - New models require time to develop robust MOS equations.
- Different equations for different regions.
- Two sets of equations based on time of year.
  - Summer/Winter set of equations.
- Three slides: Advantages/Disadvantages/Poor MOS forecasts.
MOS Advantages

• Account for persistent model bias.

• Take advantage of model derived variables that are not observed.
  – Vorticity.
  – Upward vertical velocity.

• Emphasize reliability of forecast.
MOS Disadvantages

• Change in model requires the development of new MOS equations.

• Long development time for MOS equations (2 seasons of data).
  – 2 years, thousands of equations to develop.

• MOS forecasts tend to lack sharpness.
When will MOS produce a poor forecast?

- After a model change.

- If the current weather was not experienced during the development period of the MOS equations.

- If the circumstances from today’s weather differ from the norm.

- If the forecast depends on mesoscale effects not accounted for in the MOS equations.