Lecture 20: Atmospheric Modeling

Working with Real Atmospheric Models

NWP Basics
Agenda

☐ Review Exam 2

☐ A little on NWP

☐ Taring files for our activities on Monday
Exam Problem 3

☐ CFL Criteria
Exam Problem 4

LEGEND:

ctrl
pert01
pert02
pert03
pert04
pert05
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enamean
operGFS

is run for 00Z 01Apr2007 valid 00Z05APR2007 24-hr precip. contour 0.5 in 1x1 degree resolution
Exam Problem 2
Contributions

- http://meted.comet.ucar.edu

- Numerical Weather Prediction
  - Model Fundamentals
  - 10 Common NWP Misconceptions
What we want

- Operational Meteorology
  - “Save Lives. Protect Property”
  - Numerical Weather Prediction
    - Global/Synoptic/Mesoscale

- Climate Research
  - Long Term Climate Impacts
  - General Circulation Models (GCM)
  - Regional Climate Models
You might remember these

- ATM Models are a collection of deterministic equations placed in a numerical solution framework

\[ \frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = -\delta_{i3} g + f_\varepsilon_{ij3} \bar{u}_j - \frac{1}{\bar{\rho}} \frac{\partial \bar{p}}{\partial x_i} + \nu \frac{\partial^2 \bar{u}_i}{\partial x_j^2} - \frac{\partial (u'_i u'_j)}{\partial x_j} \]

\[ \frac{\partial \bar{\theta}}{\partial t} + \bar{u}_j \frac{\partial \bar{\theta}}{\partial x_j} = - \frac{L_v E}{\bar{\rho} c_p} - \frac{1}{\bar{\rho} c_p} \frac{\partial \bar{Q}_j}{\partial x_j} + \nu_\theta \frac{\partial^2 \bar{\theta}}{\partial x_j^2} - \frac{\partial (u'_j \bar{\theta}')}{\partial x_j} \]

\[ \frac{\partial \bar{q}}{\partial t} + \bar{u}_j \frac{\partial \bar{q}}{\partial x_j} = + \frac{E + S}{\bar{\rho}} - \nu_\theta \frac{\partial^2 \bar{q}}{\partial x_j^2} - \frac{\partial (u'_j q')}{\partial x_j} \]

\[ \frac{\partial \bar{u}_j}{\partial x_j} = 0 \]
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Meteorological Models

Forecast

Verification

Forecast Process

Observations

Centralized Guidance

Understanding Met. Principles

Model Output

Direct Model Output

Statistical Guidance

Numerical Guidance

Postprocessing

Assimilation

Dynamics

Physics

Forecast Model

Numerics

Quality Control & Analysis

Computer Resources

Data

The COMET Program
Model Components

- The Atmospheric Modeling Process, though clearly discipline-specific, has many components important in other disciplines
  
  (If only as an example of key common modeling issues)
Data

- Data are collected to define the initial state of the atmosphere & boundaries. Sources include surface stations, satellite data, profilers, aircraft, soundings, radar and even GPS information.
- A major endeavor in ATM NWP
- GIGO!

11 April 2007
Data and Initialization

- We have a discretized grid of one resolution

- ... And Processes and Observational Data covering a spectrum of resolutions!
QC & Objective Analysis

Through a series of checks and test data are quality controlled to ensure the viability of info input into the model. This helps ensure that inaccurate data are adjusted or removed before proceeding to the analysis.

Data must be ingested into the model so that the fields represent the best mean value for that grid cell for the resolution and dynamics of the model.
Computer Resources

- The capacity and speed of computing resources available to run a Fx model govern the amount and complexity of the data and model components used. Thus, the computer resources can be a significant limitation in NWP
  - Data storage and access (networking/archiving)
  - Forward-in-Time Speed (Speed)
  - Memory (capacity and domain size & detail)
  - Multi-processing (speed & tasking)

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And we finally get to the actual model!

The Fx model contains all of the components needed to compute the current state and 3-D evolution of basic Wx variables. The components include the numerics, assimilation system, explicit dynamics and implicit physical processes.
Numerics

- Model numerics refers to the characteristics such as the mathematical formulations used to solve the Fx equations (shown earlier).
  - How data is represented
  - Model resolutions
  - Computational domain
  - Coordinate system
- These all affect the handling of dynamics and how consistently the initial conditions and physical processes are represented.
Some Key Numerics Issues

- Stability
- Finite Grids vs Elements vs Spectral
- Aliasing and Resolution Issues
- Predictability
  - Enter Chaos
Does a 20km grid represent 20km features?

☐ No. A grid can only resolve a wave that is twice its resolution

☐ And depending on the numerics that feature cannot be *predicted* to any reasonable degree unless its at least 4x bigger.
Does a 20km grid represent 20km features?

- No. A grid can only resolve a wave that is twice its resolution.
- And depending on the numerics that feature cannot be predicted to any reasonable degree unless its at least 4x bigger. (And the bigger the better!)
Here we see how an average slope (dashed slope) used to calculate the gradient at point “T3” may not be the same as that actually experienced at point “T3” (the solid slope).

\[
\frac{d\theta}{dt} = -U \frac{d\theta}{dx}
\]

\[
\frac{\Delta \theta_i}{\Delta t} = -U \frac{(\theta_{i+1} - \theta_{i-1})}{2\Delta x}
\]
Does a 20km grid represent 20km features?
Assimilation

- An assimilation system is a complex system by which observed meteo parameters are converted to forecast variables and blended with previous short-range Fx from earlier runs to create the initial conditions to start a new Fx.

- The system tries to find initial fields that will optimize the accuracy of the fx based on the available data and first guess fields.
Assimilation

- Assimilation is part of the initialization process
- Rather than starting with a “cold” start with the previous output + current conditions we can...
  - Use the previous fx as an initial WAG™
  - Add obs to these 1rst guess field
  - Start the model “before” our Fx period (e.g., 12 hr before)
  - Inject observations during the forecast period (Nudging)
Variational Assimilation

- J: Cost Function $\rightarrow \ln[P(x)]$
- $x = \text{the gridded forecast/analysis}$
  - Current analysis against forecasted analysis
- $y = \text{observations and grid-interpolated observation points}$
  - Real ob vs analysis point

\[
J(\tilde{x}) = \frac{1}{2} \left( \tilde{x} - \tilde{x}^b \right)^T B^{-1} \left( \tilde{x} - \tilde{x}^b \right) + \frac{1}{2} \left( y - y^o \right)^T \left( O + F \right)^{-1} \left( y - y^o \right)
\]
Nudging

- (or Newtonian Relaxation)
- Observed values of $a$ are delivered into the model as it runs

$$\frac{d\alpha}{dt} = \text{Forcings} + N(\alpha, t) \varepsilon [\alpha_0 - \alpha]$$
Dynamics

- In NWP, dynamic processes often refer to the ATM process best derived from “first principles” and are explicitly represented. These include grid scale advection, pressure gradient forces, adiabatic heating and cooling. These processes are described by a set of basic equations (shown earlier).

- These are also often called “explicit” processes.
Dynamics

- ATM Models are a collection of deterministic equations placed in a numerical solution framework.

\[ F = ma \]
\[
\frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = -\delta_{i3} g + f \varepsilon_{ij3} \bar{u}_j - \frac{1}{\bar{\rho}} \frac{\partial \bar{p}}{\partial x_i} + \nu \frac{\partial^2 \bar{u}_i}{\partial x_j^2} - \frac{\partial \left( \bar{u}_i \bar{u}'_i \right)}{\partial x_j}
\]

\[ dq = du + dw \]
\[
\frac{\partial \bar{\theta}}{\partial t} + \bar{u}_j \frac{\partial \bar{\theta}}{\partial x_j} = - \frac{L_v \bar{E}}{\bar{\rho} c_p} - \frac{1}{\bar{\rho} c_p} \frac{\partial \bar{Q}_j}{\partial x_j} + \nu_\theta \frac{\partial^2 \bar{\theta}}{\partial x_j^2} - \frac{\partial \left( \bar{u}_j \bar{\theta}' \right)}{\partial x_j}
\]

- Cons. of mass

\[
\frac{\partial \bar{q}}{\partial t} + \bar{u}_j \frac{\partial \bar{q}}{\partial x_j} = + \frac{\bar{E} + S}{\bar{\rho}} - \nu_\theta \frac{\partial^2 \bar{q}}{\partial x_j^2} - \frac{\partial \left( \bar{u}_j \bar{q}' \right)}{\partial x_j}
\]

\[ \frac{\partial \bar{u}_j}{\partial x_j} = 0 \]
Physics

In NWP, physical processes often refer to 3 types of processes:

- Those operating at scales below that of the model resolution
- Those involving exchanges of energy, water and momentum between the atmosphere and external sources (e.g., radiation and land/sea surface processes)
- Cloud and precip microphysics
Physics

- In other words, these are what we cannot model explicitly and must approximate based on those values and processes that we can predict explicitly.

- “Parameterizations!”
Physics

- In other words, these are what we cannot model explicitly and must approximate based on those values and processes that we can predict explicitly.

- “Parameterizations!”
Parameterizations

- The slide here “cartoons-out” (appropriately enough!) examples of many implicit processes in NWP
Post Processing

☐ OK.. The model’s done

☐ Here we begin the *most important* part of the forecast process.

☐ We begin to use the results of the model.
Numerical Guidance

- Products taken from the model output and placed in a form used by forecasters.
Numerical Guidance Sites

- http://www.wxmaps.org

- http://weather.unisys.com
Statistical Guidance

- Model Gridded Fields can be interpreted statistically by regressing key model output variables to past events of temperature, precip etc.

- “Model Output Statistics”
- (Can be said to works during the normal spectrum of weather)
Enter the Human

- No Model and its derivative products have no value other than what the user gives it.

- For that, you need the users. Here, we refer to users who understand the system they are charged with predicting.
The Interpretation and Use

- Here the Human interprets the model results and generates the lower level forecast products.

- Using their experience, the forecasters accept, spin, counter-bias and discard output from the models and subsequent processes.
Verification*

Forecasters use model verification data to identify specific limitations and statistical biases of model guidance and to compensate for them. Modelers use verification data to help identify deficiencies so they can improve forecast model components. Model verification is an integral part of the NWP development process.
Verification*

*Meteorologist use the term “verification” to represent the evaluation of not only the models but of the full forecast process.

(recall that there are some semantic bar fights in this area)
Now the Lab Activity

Ensemble NWP runs based on Physics Options
Today

Access the WRF-ARW Model

Learn about Tarballs
Run WRF for various physics options
We’ll distributed the tasks Monday
Wednesday

Look at the Output Together in IDV
De Tarball

- Tar files
  - Like Zip files without the Zip
  - To make a tar file
    - `tar -cvf tarfilename.tar [files or directory]`
  - To extract “untar” a file
    - `tar -xvf tarfilename.tar`
Shrink that file (or files)

- gzip and gunzip
  - “gzipped” files are marked with a .gz
  - Make me tiny
    - gzip –r [files or directory]
  - Make me really tiny
    - gzip –9r [files or directory]
- Unzip me
  - gunzip –r [files.gz or directory w/ zips]
- Unzip and untar at once – LINUX
  - tar –zxvf tarball.tar.gz