Numerical Modeling

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Motivation

• Offer great opportunity for improved forecasting

• Research tool:
  – for weather research at all time-scales (including diurnal processes),
  – develop a model with parameterizations that properly reflect African conditions

• Decision-making tool (what if scenarios)

• A tool for cooperation among local universities, government agencies and the private sector regarding weather and climate information.
What is a Model?

• Take the equations that describe atmospheric processes.
• Convert them to a form where they can be programmed into a large computer.
• Solve them so that this software representation of the atmosphere evolves within the computer.
• This is called a “model” of the atmosphere.
What do we mean by “solve the equations”

- The equations describe how the atmosphere changes with time.
- For example, one equation would be
\[
\frac{T_{\text{change}}}{\text{time}} = \text{solar} + \text{IR}(\text{gain}) + \text{IR}(\text{loss}) + \text{conduction} + \text{convection} + \text{evaporation} + \text{condensation} + \text{advection}
\]
So – “solving” the equation would be to estimate the terms on the right side, add them up, and obtain the rate of change of temperature
Similar Equations Would be Solved for

- East-west wind component
- North-south wind component
- Specific humidity (or RH)
- Pressure
- Cloud water
- Rain/snow water
Two Types of Models

• **Global** – grid covers the entire atmosphere of Earth (global models)
  – Weather (GFS)
  – Climate (e.g. CCSM)

• **Limited-area** – grid covers a region of the atmosphere such as continent or a state or a city (limited area models)
  – Weather (WRF, eta)
  – Climate (WRF, PRECIS, RegCM3)
Uses of Atmospheric Models

- Daily weather prediction (let models run into the future for 1-10 days)
- Climate prediction (let models run for years)
  - “what-if” experiments, e.g., what will happen if we double the CO$_2$?
  - simply let the model run forward
- Research – Study the model solution when you don’t have good observations of real atmosphere
Why WRF

- It is free
- It is a community-based model
- Technical support by NCAR (wrfhelp@ucar.edu)
- Rapid community growth
- Two dynamical cores, numerous physics, chemistry
- Has both operational and research capabilities
What can WRF be used for?

- Operational NWP
- Data Assimilation
- Parameterized physics research
- Downscaling climate simulations
- Driving air-quality, agricultural, etc models
WRF Supported Platforms

• MacOS
• Linux
• Unix (UNICOS, AIX, IRIX, Solaris)
Computing Resources

- Single processor desktop
- Dual core or quad desktop system
- Linux cluster
- Supercomputer - many processors
Why Important

• Can be coupled to application models for
  – Agriculture
  – Water resources
  – Health
  – Energy
  – Transportation (aviation, turbulence, etc)
Research Questions

What are the effects of these on the weather and climate?

- Change in SSTs
- Change in vegetation
- Presence or absence of a lake
- Irrigation system
- Urbanization
- Deforestation
What will you like to do with the model

- Key points
- Action items
CASE STUDY

August 28, 2005 Mesoscale Convective System over West Africa
Some features of WRF-ARW

- Nonhydrostatic with hydrostatic option
- Two-way nesting with multiple nests and nest levels
- One-way nesting
- Vertical grid-spacing can vary with height
- See Users Guide for more
Model

- WRF version 2.1.2
- Grid resolution is 12 km, 4km
- Grid size: 251x201, 216x196, 31 levels
- BC and IC: NCEP and ECMWF
- Period of simulation Aug. 27:00UTC to August 30:00UTC
Simulation domain

Simulation Domain

Sirba
Kori Dantiandou
Upper Oueme

14.5 N
8.5 N
1.5 W
3 E
Satellite Evidence
Animation 2

Dataset: exp1K InnB out  REF: rain d2  InOr: 0000 UTC Sat 27 Aug 20
Post: 00 h  Valid: 0000 UTC Sat 27 Aug 65 (1800 MDT Fri 36 Aug 65)
Total precip. in past 1 h
Total precip. in past 1 h

KF
Lin et al.
ECMWF
Animation 3

Dataset: convK thornb.out  RF: rain d8
Inlt: 0000 UTC Sat 27 Aug 05
Post: 00 h
Valid: 0000 UTC Sat 27 Aug 05 (1900 MDT Fri 8 Aug 05)
Total precip. in past 1 h
Total precip. in past 1 h

KF
Thompson
ECMWF
Still picture of Animation 1
Still picture of Animation 1(d1)
<table>
<thead>
<tr>
<th>Animation</th>
<th>BMJ</th>
<th>Reasonable timing, wrong orientation</th>
</tr>
</thead>
<tbody>
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<td>WSM6</td>
<td></td>
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<tr>
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<tr>
<td>Animation 2</td>
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</tbody>
</table>
24-hour rain 6h-6h Aug 27

NOAA CPC Precipitation Estimate (mm):
   based on GPI, SSM/I, AMSU & GTS

AUG 27 2005

CPC

WRF

KF

WSM6

ECMWF
24-hour rain 6h-6h Aug 28

NOAA CPC Precipitation Estimate (mm):
based on GPI, SSM/I, AMSU & GTS

CPC

WRF

KF

WSM6

ECMWF
Comparison of IWV (Model and GPS)

WSM6, BMJ (d1 only) (4 km resolution)

Djou (9.69N, 1.66E) Aug. 28, 2005

Integrated water vapor (kg/m²)

42.0 45.0 46.0 46.5 47.0 51.0 54.0 57.0

time (hr)

Niam (13.47N, 2.18E) Aug. 28, 2005

Integrated water vapor (kg/m²)

42.0 45.0 46.0 46.5 47.0 51.0 54.0 57.0

time (hr)
Comparison of IWV (Model and GPS)
Thanks
Governing Equations

- Conservation of momentum or Newton’s 2nd law (3 equations for u,v,w)
- Conservation of mass or continuity equation
- First law of thermodynamics or conservation of energy
- Equation of state for ideal gases
- Moisture equation or a conservation equation for water mass
History of NWP

• 1904 - Bjerknes (suggested use of hydrodynamic and thermodynamic equations), Richardson (hand-calculations)
• After World War II - mathematical forecast possible (using Bjerknes suggestion). Simple forecasts in 1950s
• 1962 - US launched first operational quasi-geostrophic baroclinic model, followed by Britain in 1965
• 1966 - First global PE model (NMC, Washington DC): 300km resolution, 6 vertical layers
• http://www.ecmwf.int/products/forecasts/guide/The_history_of_NWP.html
• Idealized simulations (PBL eddies, convection, baroclinic waves)
Model Web sites

- Real-Time Demonstration home page
  http://www.ral.ucar.edu/projects/wafrika

4DWX home page
http://www.rap.ucar.edu/projects/4DWX

References page
http://www.rap.ucar.edu/projects/armyrange/references.html