Adaptive Observation Strategies for Advanced Weather Prediction

David P. Bacon, Zafer Boybeyi
Center for Atmospheric Physics
Science Applications International Corporation

Michael Kaplan
Dept. of Marine, Earth, & Atmos. Sci.
North Carolina State University

October 30, 2001
Weather forecasting relies on a system of systems:
- *In-situ* observations (surface, balloon, & aircraft)
- Remotely-sensed observations (satellite-based)
- Data assimilation (creating a physically consistent 3-D dataset)
- Prognostic models (extrapolation into 4-D)
In-situ Observations

- Irregular spatial distribution
  - Where the people (and planes) are
- Quasi-regular temporal distribution
  - Surface observations
    » Hourly with special reports for significant weather
  - Balloon observations
    » Twice-daily at 0000Z & 1200Z
  - Aircraft observations
    » Regular intervals
Remote Sensing Observation Strategies

• The beginning:
  – TIROS-1 (April 1, 1960)
    » Television and InfraRed Operational Satellite
  – ATS-1 (December 6, 1966)
    » Applications Technology Satellite – Geostationary
    » Communications system test bed

• Raster based systems
  – Vidicon tubes to CCDs
Data Assimilation

- **Goal:** A physically consistent 3-D representation of the atmosphere at an instant of time

- **Requirements:** Rationalize a disparate set of data that is a mix of irregular and grid point information at synoptic (0000Z & 1200Z) and asynoptic times

- **Modify large-scale effects to reflect small-scale features**
  - Capture steep gradients critical to severe weather
Prognostic Models

- Most models are based on a rectangular grid structure
  - Intuitively obvious
  - Simplest tiling
  - Simple operator decomposition
- Higher resolution is obtained by nesting
  - Conceptually easy
  - Numerically tricky
    » Reflective internal boundaries
    » Differing surface conditions
    » Scale interactive information exchange
- Initial conditions obtained from data assimilation system
  - Generally at synoptic times
A Vicious Circle

- Increased horizontal ($\alpha$) and vertical ($\beta$) resolution in models leads to:
  - Higher resolution initial conditions: $\alpha^2 \beta$
  - Increased run-time: $\alpha^2 \beta$
  - Increased output volume: $\alpha^2 \beta \max(\alpha, \beta)$
- Higher resolution ICs requires higher resolution observations
Dynamic Adaptation of Data Assimilation and Model Resolution

- Initial grid for an OMEGA simulation of Hurricane Floyd and the grid (inset) at 72 hours
OMEGA Forecast of Hurricane Floyd
Control Simulation

- Initialization:
  - 1200Z September 13
  - NOGAPS Analysis
- Boundary Conditions:
  - NOGAPS Forecast
- Grid Resolution:
  - 5 - 15 km
Verification of Control Simulation

- Storm Tracks
  - White: Observations
  - Red: Control
Coarse Resolution Simulation

- **Initialization:**
  - 0000Z September 14
  - NOGAPS Analysis
- **Boundary Conditions:**
  - NOGAPS Forecast
- **Grid Resolution:**
  - 75 - 120 km
Verification of Coarse Resolution Simulation

- Storm Tracks
  - White: Observations
  - Red: Control
  - Yellow: Coarse Res

- Significant westward track deviation
Adaptive Observations

• Control Run provides a source of pseudo-observations for OSSEs
• Control cell centroid closest to the Coarse cell centroid used to provide pseudo-sounding
Case #1: 654 Targeted Observations

- Coarse Resolution Configuration
- Added 654 observations
  - All cell centroids in box around storm
Verification of Case #1 (654 Targeted Observations)

- Storm Tracks
  - White: Observations
  - Red: Control
  - Yellow: Coarse Res
  - Orange: Case #1 (654)

- Noticeable improvement in forecasted track
Case #2: 100 Targeted Observations

- Coarse Resolution Configuration
- Added 100 observations
  - Regular 10 x 10 array around storm
- Storm Tracks
  - White: Observations
  - Red: Control
  - Yellow: Coarse Res
  - Orange: Case #1 (654)
  - Green: Case #2 (100)
- Virtually identical track to Case #1 with only 20% of the targeted observations
Case #3: 11 Targeted Observations

- Coarse Resolution Configuration
- Added 11 observations
  - Around initial storm location
- Storm Tracks
  - White: Observations
  - Red: Control
  - Yellow: Coarse Res
  - Cyan: Case #3 (11)
- Very minor difference from Coarse resolution simulation
Case #4: 50 Targeted Observations

- Coarse Resolution Configuration
- Added 50 observations
  - Along forecasted track
- Storm Tracks
  - White: Observations
  - Red: Control
  - Yellow: Coarse Res
  - Pink: Case #4 (50)

- While this case improved the forecast early on, it did not improve the track at later times as much as Case #1 or Case #2
Case #5: 25 Targeted Observations

- Coarse Resolution Configuration
- Added 50 observations
  - Along forecasted track
- Storm Tracks
  - White: Observations
  - Red: Control
  - Yellow: Coarse Res
  - Cyan: Case #5 (25)
- Track nearly identical to Case #4.
Conclusions and Ramifications

- Targeted observations can have a dramatic impact on storm forecasts
  - Improvement in initial storm conditions has the largest payoff
  - Other scenarios may have different requirements
- Greatest improvement will come in identifying and obtaining key observations for developing convective storms
  - The critical scales are so small and hence the volume of regular arrays of observations is so large that either the communications become a dominant problem or the extraction of a “signal” from the “noise” of data bits prevents utilization
- The routine utilization of targeted as opposed to general satellite observations has significant impact on satellite operations
  - Timeliness is key ⇒ Communication & data mining issues
- A tightly linked forecast and observational system can address these issues as well