Investigation of the quality of reanalysis climate datasets via a vorticity equation model reforecast experiment

C. A. Ballesteros, M. Herrmann, H.P. Huang

School for Engineering of Matter, Transport and Energy, Arizona State University

Motivation

- Replicate the first numerical simulations of the atmosphere, as performed by Charney, Fjörtoft and von Neumann (*Tellus,* 1950), and repeat them with modern data
- Qualitatively determine the utility of a simple, limited-area quasi-geostrophic vorticity equation model when run with present-day observations as inputs
- Are there any notable improvements in the quality of the forecasts produced with modern data?

Numerical Method

- Quasi-geostrophic vorticity equation along divergence-free isohypse (~ 500 mb), as used by Charney, Fjörtoft and von Neumann:

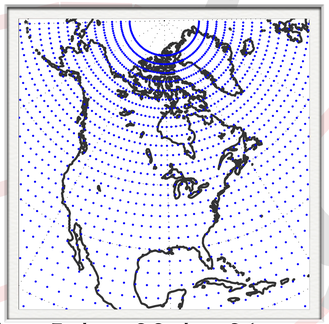
$$\frac{\partial}{\partial t}(\nabla^2 z) = \frac{\partial \eta}{\partial x}\frac{\partial z}{\partial y} - \frac{\partial \eta}{\partial y}\frac{\partial z}{\partial x}$$

- Set $\xi = \nabla^2 z$ as intermediate solution variable: model becomes the following coupled system of equations:

$$\frac{\partial \xi}{\partial t} = \frac{\partial \eta}{\partial x}\frac{\partial z}{\partial y} - \frac{\partial \eta}{\partial y}\frac{\partial z}{\partial x} \qquad \nabla^2 \frac{\partial z}{\partial t} = \frac{\partial \xi}{\partial t} \qquad \eta = \frac{g}{f}\xi + f$$

- Solve system over North America:

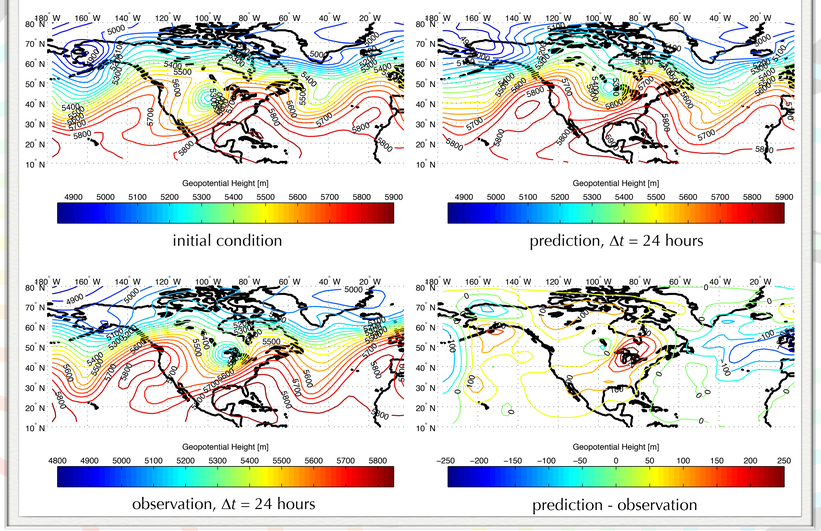
  latitude ϕ = [10 °N–80 °N]
  longitude λ = [2.5 °W–180°]
  $\delta\phi = \delta\lambda = 2.5°$



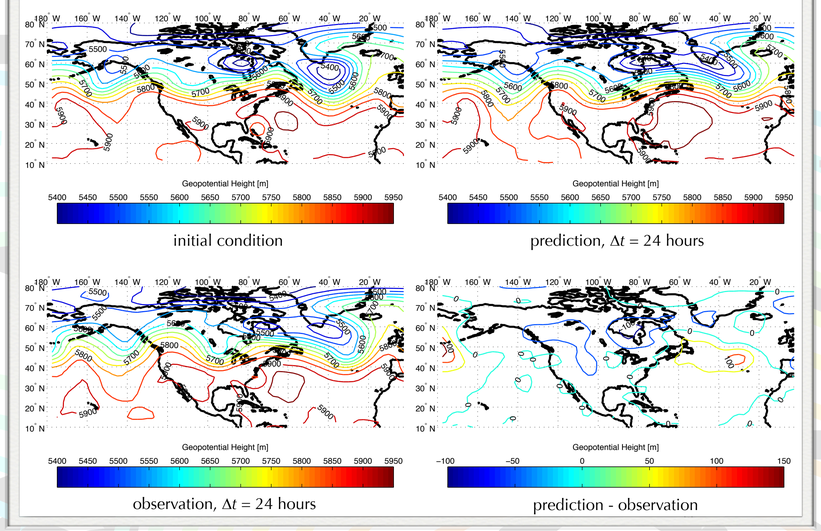
- Grid is not equidistant in longitude:
  $\Delta y = R_\oplus \delta\phi$
  $\Delta x_j(\phi) = R_\oplus \cos(\phi)\delta\lambda$
- Initial tests: perform simulations for Jan. 5, Jan. 30, Jan 31, and Feb. 13, 1949; as well as Sept. 2, and Dec. 3, 2010
  - Use NCEP/NCAR Reanalysis I database (Kalnay et al., *B. Am. Meteorol. Soc.*, 1996) for the initial conditions (geopotential height of 500 mb pressure surface at 00Z)
  - Through-flow boundary conditions for outflow regions; Neumann boundary conditions for inflow regions; second-order central (spatial) and first-order forward (temporal) finite difference discretizations
- **Modern-day simulations have smaller errors in the predicted geopotential height of the 500 mb pressure surface than simulations initialized with late-1940s data**
- **Is this improvement in the vorticity model's forecast skill a lucky coincidence, or is there an underlying trend in the accuracy of the initial conditions?**

Initial Tests

Evolution of geopotential height of 500 mb surface, January 5, 1949



Evolution of geopotential height of 500 mb surface, September 2, 2010



Extended Simulations

- Repeat simulations with the same model for all dates in the Reanalysis I database (**R1**) and in version 2 of the NOAA/ ESRL PSD 20th Century Reanalysis (**20CR**, Compo et al., *Quarterly J. Roy. Meteorol. Soc.*, 2011)
  - Reanalysis I: Jan. 1, 1948–December 31, 2010
  - 20th Century Reanalysis: Jan. 1, 1871–December 31, 2010
- Initialize simulations at 00Z and 12Z; run model to 36 hours, store results for +06, +12, +24, and +36 hours
- Quantify errors at each snapshot by using anomaly correlation coefficient (Saha and van den Dool, *Mon. Wea. Rev.*, 1988) weighted by latitude

$$AC = \frac{\sum_i \sum_j z'_m(\lambda_i,\phi_j)\, z'_o(\lambda_i,\phi_j)\cos(\phi_j)}{\sqrt{\sum_i \sum_j \left(z'_m(\lambda_i,\phi_j)\right)^2 \cos(\phi_j)}\sqrt{\sum_i \sum_j \left(z'_o(\lambda_i,\phi_j)\right)^2 \cos(\phi_j)}}$$

- Where $z'_m(\lambda_i,\phi_j) \equiv z_{\text{model}}(\lambda_i,\phi_j) - \bar{z}(\lambda_i,\phi_j)$ and $z'_o(\lambda_i,\phi_j) \equiv z_{\text{obs}}(\lambda_i,\phi_j) - \bar{z}(\lambda_i,\phi_j)$

  and $\bar{z}$ is calculated by the average of the reanalysis observation data at a given forecast time (00Z, 06Z, etc.) for the same calendar day for the entire forecast period
- **Future work: Perform more detailed analysis of spatial / seasonal dependence of anomaly correlation**

Results / Conclusions

- **Short-term forecasts using modern data are noticeably improved than those made with historical data**
- **Lower anomaly correlations in the first decade of R1, late 1920s and early 1930s in 20CR reflect lower quality of underlying observations**
- **Model runs using initial conditions from 20CR, on average, performed better than simulations that used R1 data**

Anomaly correlation time series for R1 (red) and 20CR (blue) datasets