Atm 401–501: Solution Synopsis for Homework #1: 28 January 2019

1. Discuss forecast error evolution as a function of time.

- Forecast error generally improved as forecast lead-time decreased.
- Forecast error did not improve linearly. Errors improved in a discontinuous or non-linear fashion as the GFS likely assimilated the location, magnitude, and structures of different features over the domain.
- Amplitude errors decreased most noticeably between the 5- and 3-day forecasts. Phase errors decreased most noticeably between the 7- and 5-day forecasts.

2. Discuss how the large-scale spatial distribution of forecast errors evolves.

- The GFS advertised a ridge over western North America and a trough over eastern North America in nearly every forecast. However, the phase, amplitude, and tilt of these features and the large-scale pattern over North America continually evolved between the 7- and1-day forecasts.
- The longer-range guidance failed to diagnose cold-air damming in the lee of the Rocky Mountains, dual jet streak development over North America, and the development of the "Groundhog Day Blizzard" (the GFS was unable to "hog" the limelight).
- The failure of the longer-range guidance appears related to the evolution of features over the North Pacific, the subsequent evolution of the western North America upper-level ridge, the location and magnitude of the upper-level trough over Northeast Canada, and the poleward transport of subtropical moisture out of the Gulf of Mexico.

3. Discuss smaller-scale spatial distributions of forecast error (e.g., quantify forecast error for specific cities…e.g., Albany, NY, Chicago, IL, Denver, CO).

- At Albany, the initial 7-day forecast features a 300-hPa jet to the south of the station. The verifying analysis shows a dual-jet structure over New England. As a result, 300-hPa geopotential height errors were >36 dam. The dual-jet structure over New England is a favorable pattern for enhanced quasi-geostrophic forcing for ascent, and supports the verifying cyclone over Lake Erie in the analysis.
- At Denver, the 7-day forecast guidance suggested 1000–500-hPa thickness values of ~540 dam. The verifying analysis featured 1000–500-hPa thickness values of <504 dam. The 36+ dam observed error in 1000–500-hPa thickness can be related to the evolution of the upstream upper-level trough (e.g., likely producing a favorable region of quasi-geostrophic forcing for descent and anticyclogenesis) and a subsequent terrain-influenced equatorward pressure surge in the lee of the Rocky Mountains. As a result, a rather benign forecast for the Southern Plains failed to verify as the region was dominated by much colder and windier weather.
- At Chicago, a very weak disturbance that was confined to the Gulf coast in the day 7 forecast became a stronger storm situated over southwestern Kentucky in the day 5 forecast as the flow pattern began to amplify. By day 3 the GFS had caught on that Chicago was going to experience a major snowstorm as the forecast flow pattern continued to amplify.

4. Discuss possible dynamical reasons for the evolution of observed forecast error over North America.

- Small errors in the magnitudes of the thermal wind (e.g., the 1000–500-hPa thickness gradient) and the magnitude of mid-tropospheric absolute vorticity can result in large errors in quasi-geostrophic forcing for ascent associated with the advection of absolute vorticity by the thermal wind.
- Similarly, large errors in the phase, amplitude, and tilt of troughs over the southwest US and northeast Canada and the ridge over western North America can result in large variability in quasi-geostrophic forcing for ascent and descent, respectively. These errors are observed in the 7-, 5-, 3-, and 1-day forecasts, notably in association with anticyclogenesis in the lee of the Rocky Mountains, the intensification and evolution of a dual-jet structure over eastern North America, and the subsequent development of the "Groundhog Day Blizzard" when the atmosphere went "hog" wild. "Hogwash" anyone?
- The evolution of the forecasted large-scale flow pattern, and attendant changes in the kinematic structure of the atmosphere, favored the poleward advection of subtropical moisture from the Gulf of Mexico. As a result, the verifying analysis contained an atmospheric river of precipitable water values >30 mm along the East Coast. Moisture availability plays a large and non-linear contribution to the quasi-geostrophic framework, notably in association with lowering the effective atmospheric static stability and producing more robust quasi-geostrophic forcing for ascent.
- The development of a coupled jet structure over the central US and eastern Canada by the day 3 forecast occurs as a deep arctic cold pool shifts more eastward and southward than forecast. This development likely acts to ensure greater cyclonic vorticity advection by the thermal wind in the downstream equatorward jet-entrance region over eastern Canada. More vigorous ascent occurs in this favorable region that contributes to the observed poleward shift of the lower Great Lakes cyclone as it moves eastward.