It has been said that

"weather is an initial value problem, whereas climate is a boundary-value problem."

- What is meant by this statement?
- Is this statement true?

Climate vs. Weather

"Climate is what you expect … weather is what you get!"

- Climate is an "envelope of possibilities" within which the weather bounces around
- Climate is determined by the properties of the Earth system itself (the boundary conditions), whereas weather depends very sensitively on the evolution of the system from one moment to the next

Predictability

"If they can't predict the weather, how can they possibly hope to predict the climate?"

- Weather forecasts are only useful for a few days, maybe a week at best
- Forecasting is limited by modeling skill and inadequate observations, but even if these were perfect, the limit of predictability would be about 2 weeks
- This limit is a property of the atmosphere itself, not a failure of our science!

Limits to Predictability

- The dynamical equations governing the motions of the atmosphere and oceans are strongly nonlinear
- This makes them very sensitively dependent on their initial conditions
- Errors in the initial conditions, no matter how trivial or on how small a spatial scale, quickly grow in magnitude and propagate to larger spatial scales
- Butterfly analogy of Lorenz (1963) 

Airplane analogy

- The flow around an airplane wing is governed by the same strongly nonlinear Navier-Stokes equations that govern the atmosphere
- For the same reasons we will never forecast the weather a month in advance, we can never predict the details of the flow around the wing
- But given boundary values and parameters, we can predict with confidence the statistics of this flow, or flight would be impossible!

Predictability Times

- Boundary-layer eddy: 10 minutes
- Cumulonimbus clouds: 1 hour
- Mid-latitude cyclone: 3 days
- Big standing waves: 10 days
- El Niño: 100 days
- Deep ocean circulation: 50 years(?)

Long-term Forecasting

- Can't forecast the weather in Fort Collins on the last day of fall semester in December (Snow? Sunshine? -30 C? +20 C?)
- Can "forecast" with complete confidence that -100 C < T_{max} < +100 C, or even that it will be colder than it is today
- Why?
- Boundary conditions!
  - Solar constant
  - Atmospheric composition
  - Tilt of Earth's axis, Fort Collins latitude, etc

Slow vs. Fast Climate Components

- Some parts of the Earth system are slower to respond to changes than the atmosphere (e.g., ocean temperatures, soil moisture)
- Such slow processes give the climate "memory"
- If processes that control these "slow" processes are known, they may be predicted
- The statistics of the weather respond in systematic an'd predictable ways to changes in boundary forcing

Seasonal Forecasting

- In the past 10 years, we've learned a lot about the processes that control tropical Pacific sea-surface temperatures (El Niño and La Niña)
- Once these processes get started, we can predict their evolution with some skill
- Weather anomalies associated with these events are then forecast several months in advance
- Works much better in some places than others (not too reliable in Colorado)

Other slow components

- Soil moisture anomalies have been shown to amplify drought and flood conditions
- These anomalies develop slowly, and are difficult to reverse … think "inertia"
- Some increased skill in seasonal prediction if soil moisture is well known
- Seasonal snow accumulation may also have potential in this regard