Atmospheric Motions

- Fluid motion on the sphere!

Water vapor global composite (U Wisc)
Class Summary

- Connecting GFD to the real atmosphere
- Looking for ways to interpret atmospheric circulations
  - Understanding of *why* different classes of motions occur
Instabilities

- Exponential growth of perturbations

Kelvin-Helmholtz Instability
Baroclinic Instability

- Responsible for midlatitude weather patterns
- “Cyclogenesis”
Cyclone Structure

- Center has lowest pressure
- Winds are ~geostrophic
- Warm air moves poleward and upward
- Cold air moves equatorward and downward
- “Warm front” & “cold front”
- Clouds & precipitation
  - ~ “comma” shape.
Pacific Extratropical Cyclone

- Intense vortex
  - Cold air: shallow cellular convection
  - Warm air: stratiform cloud
  - Sharp frontal boundaries

Zoom in on cold front...

Slide courtesy of Greg Hakim
Frontogenesis

Scale collapse at cold front: “rope cloud”---narrow line convection.

Slide courtesy of Greg Hakim
What is “balance dynamics” anyway?

- And why is it important?
- We’ll illustrate this with some history:
  - The first NWP experiment (Richardson, 1922)
  - The first successful NWP model (Charney, Fjortoft, & von Neumann, 1950)

All info on this topic is from Peter Lynch: Check out his book “The Emergence of NWP”!
Numerical Weather Prediction (NWP)

- Improvements in weather prediction over the last 60 years are among the most impressive accomplishments of society

Simmons & Hollingsworth ‘02

Northern Hem. 3 day forecast
Southern Hem. 3 day forecast
5 day forecasts (NH & SH)
7 day forecasts (NH & SH)

Anomaly correlation of 500hPa height forecasts

Northern hemisphere
Southern hemisphere

1980 2002 Simmons & Hollingsworth ‘02
Lewis Fry Richardson

- British mathematician, physicist, atmospheric scientist
- Scientific career very influenced by his Quaker beliefs (pacifism)
- Made the first numerical weather prediction in 1922

Also had a dream of the future of weather prediction...
The Forecast Factory

- Filled with employees ("computers") doing calculations

Richardson’s dream in 1922 of a global forecasting system

He estimated 64,000 “computers” (people) would be necessary to forecast over the globe
Richardson’s Experiment

Used data from May 20, 1910

SLP and surface temperature
Richardson’s Experiment

Data taken when Halley’s Comet was passing through the atmosphere

Tabulated values from these charts by hand!

500 mbar heights and 500-400 mbar thickness
Richardson’s Calculations

- Served as ambulance driver with the Friends’ Ambulance Unit in France during WWI
  - Transported injured soldiers, often under heavy fire
- Took 1000 hours of work to perform the calculations
  - “My office was a heap of hay in a cold rest billet”
- Calculation book was lost during the battle of Champagne
  - But recovered months later under a heap of coal
- Eventually published in 1922
Richardson's **Spread-sheet**

**Richardson's Computing Form** P_{XIII}

The figure in the bottom right corner is the forecast change in surface pressure: **145 mb in six hours!**
UW Rooftop data variability
Extrapolating noisy rates of change

Unbalanced motions which average to zero on top of a smoothly changing signal can really mess up forecasts!

Balancing initial conditions is still a problem today! (big problem in data assimilation)
Richardson’s forecast

Forecast without Filtering

Short-range forecast of sea-level pressure, from uninitialized data. The contour interval is 4 hPa. Single forward time step of size $\Delta t = 3600$ s.
Richardson’s Forecast

- Richardson himself realized that gravity waves ("imbalanced initial conditions") were the problem.
- He suggested smoothing of initial conditions.
  - And proposed 5 different methods for this.
- Unfortunately he couldn’t implement them due to computational expense.
  - But we can reproduce the results using today’s computers...
“Balancing” the initial conditions

Forecast with Filtering

Short-range forecast of sea-level pressure, from *filtered data*. The contour interval is 4 hPa. Single forward time step of size $\Delta t = 3600$ s.
The First Successful NWP Experiment

- **Fast gravity waves were the problem:**
  - Why not try predicting with a model that has no gravity waves?
- **John von Neumann, Jule Charney, Ragnar Fjortoft**
- **Research proposal proposed three uses for NWP:**
  - Weather prediction (duh)
  - Planning where to take observations
  - Weather modification!
The First Computer!

- ENIAC: The Electronic Numerical Integrator and Computer
The First Computer!

- ENIAC: The Electronic Numerical Integrator and Computer