GFD II: Balance Dynamics ATM S 542

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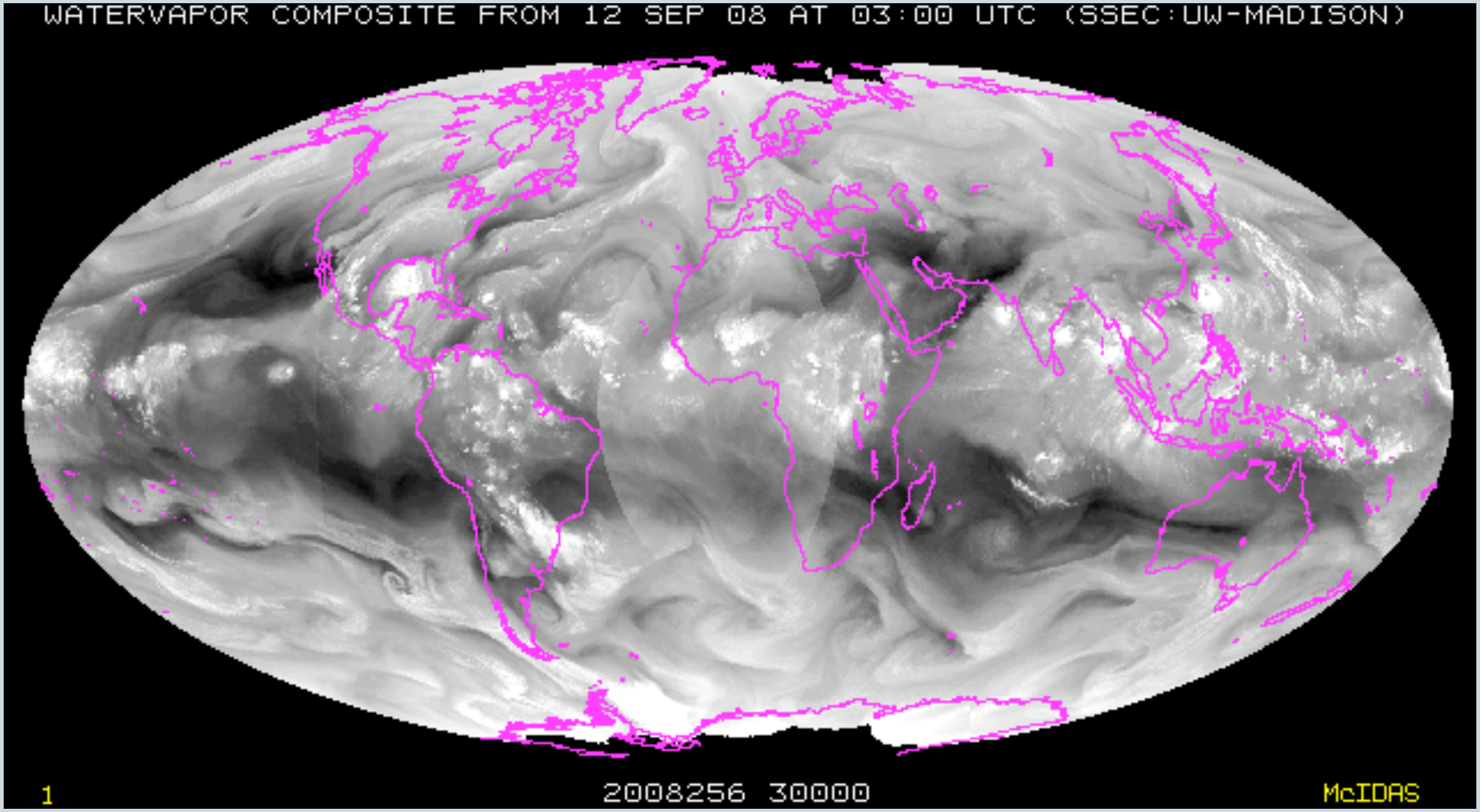
LECTURE 1: 3/28/11

Atmospheric Motions

- Fluid motion on the sphere!



Water vapor global composite (U Wisc)

Class Summary

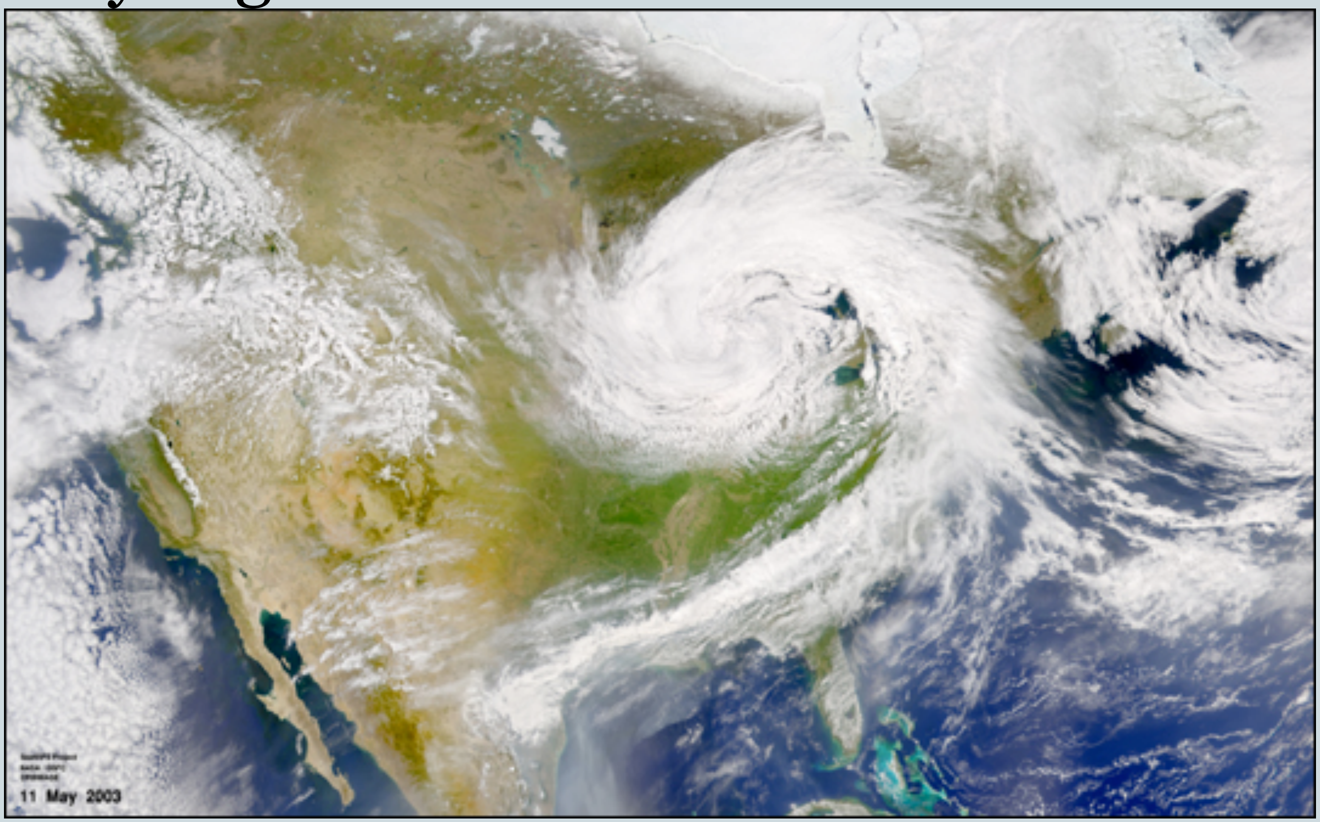
- Connecting GFD to the real atmosphere
- Looking for ways to interpret atmospheric circulations
  - Understanding of *why* different classes of motions occur

Instabilities

- Exponential growth of perturbations

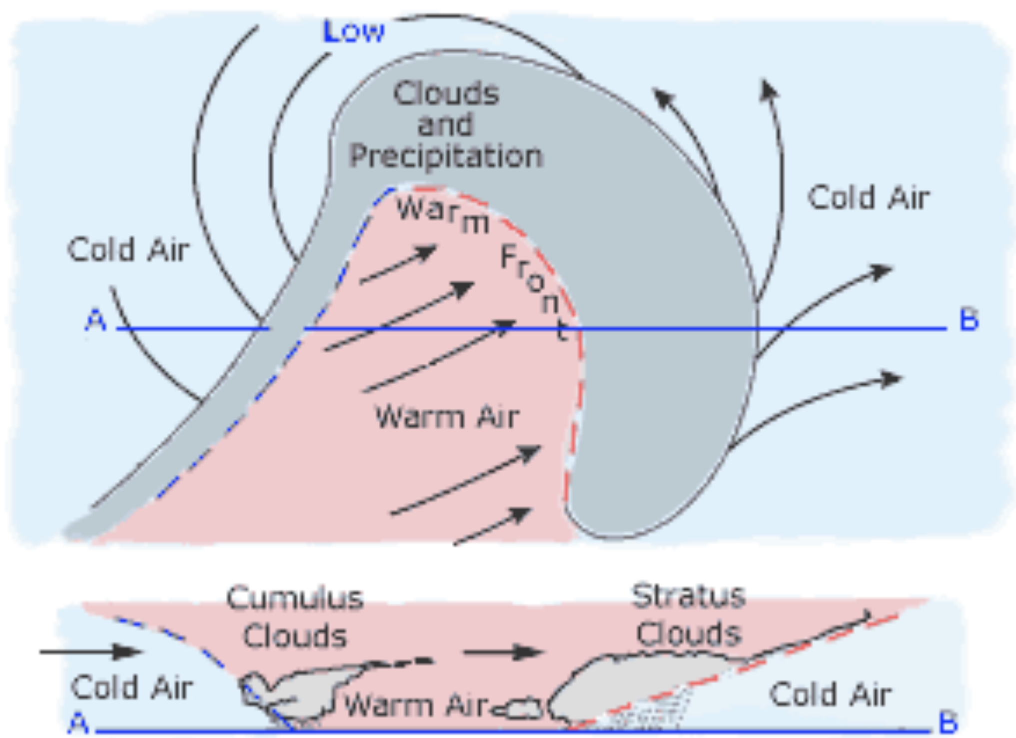
Baroclinic Instability

- Responsible for midlatitude weather patterns
- "Cyclogenesis"



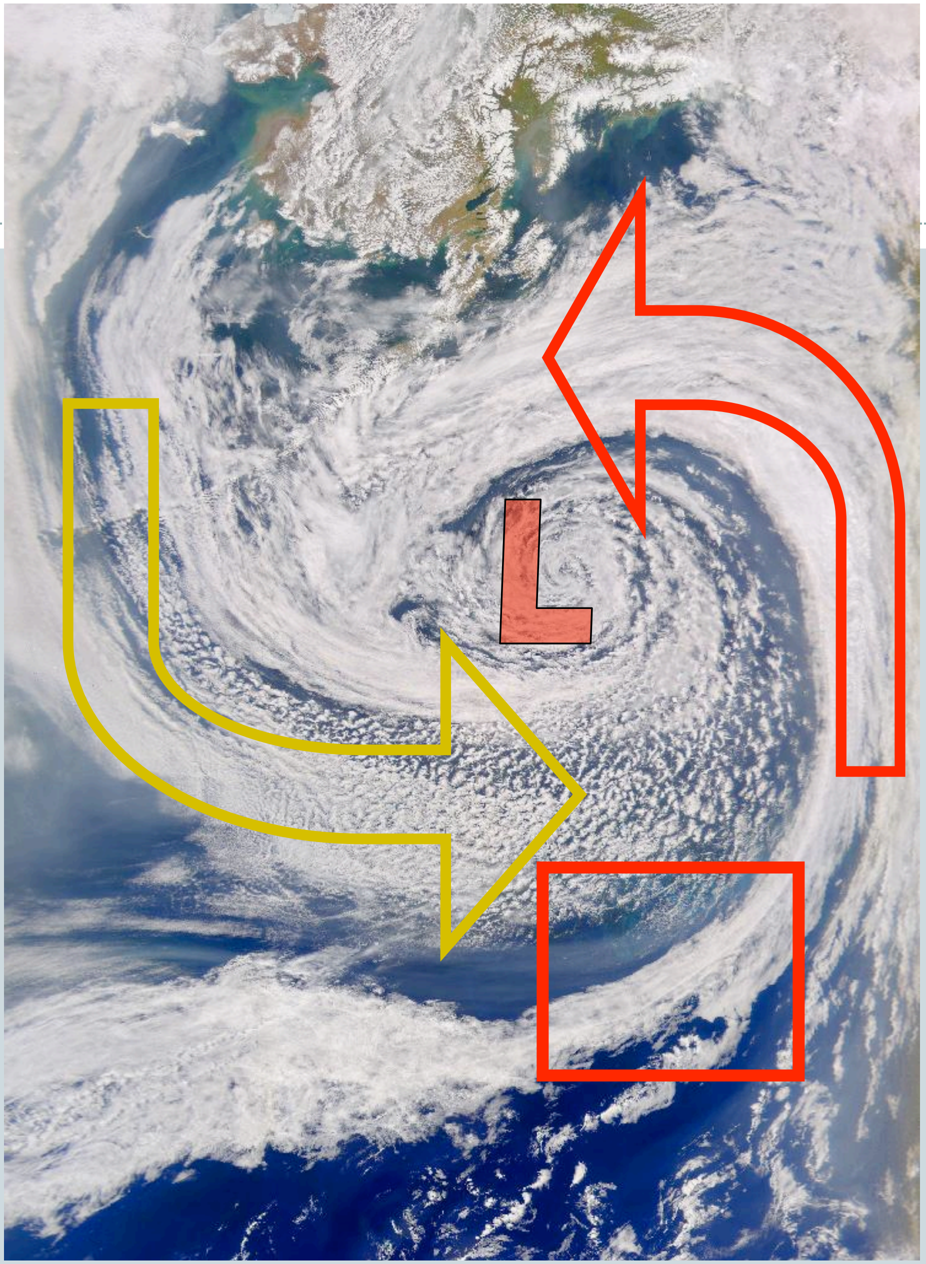
Slide courtesy of Greg Hakim

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.

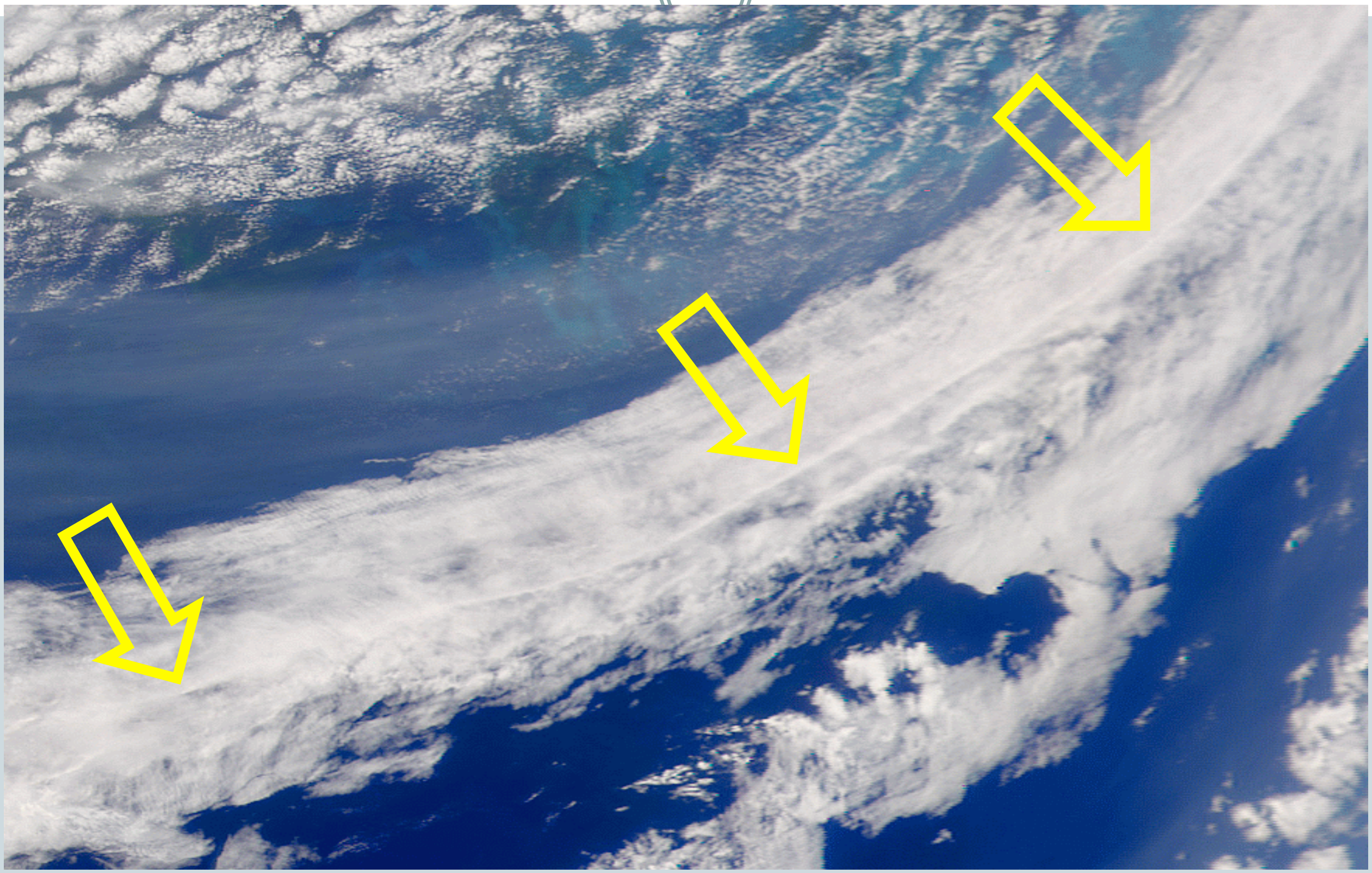
Pacific Extratropical Cyclone



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

Zoom in on cold front…

Frontogenesis



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

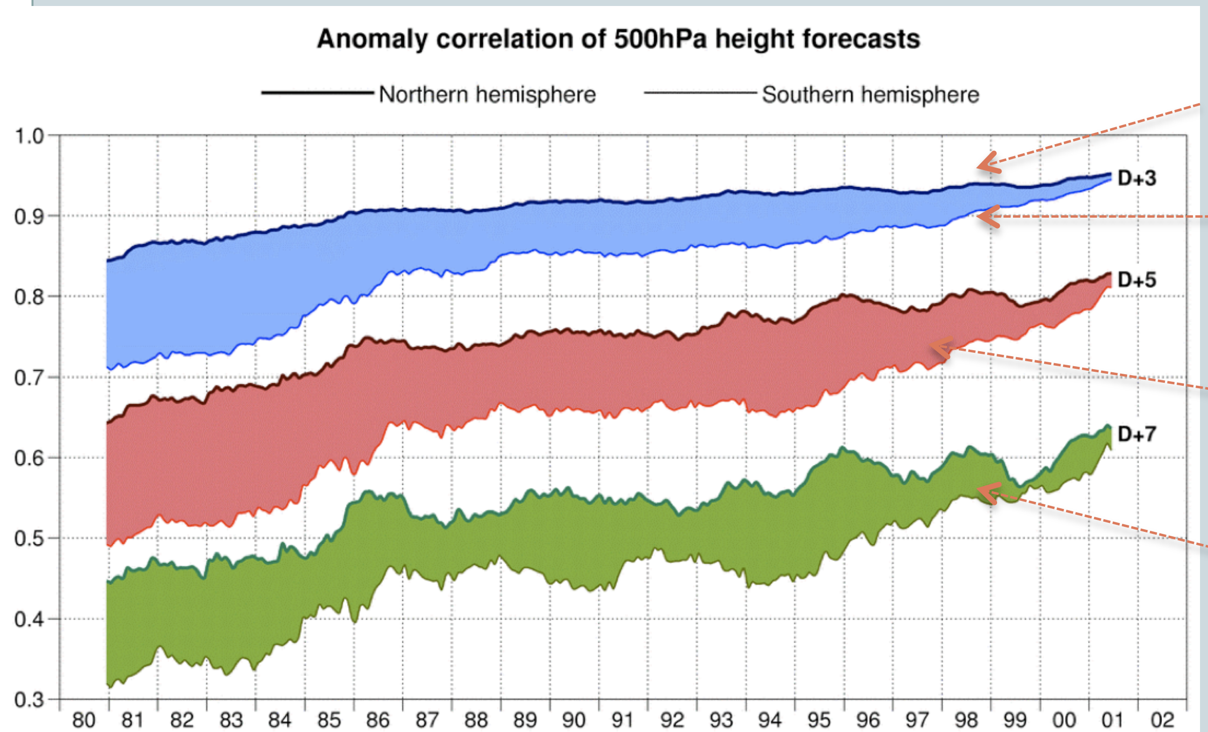
What is “balance dynamics” anyway?

- 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

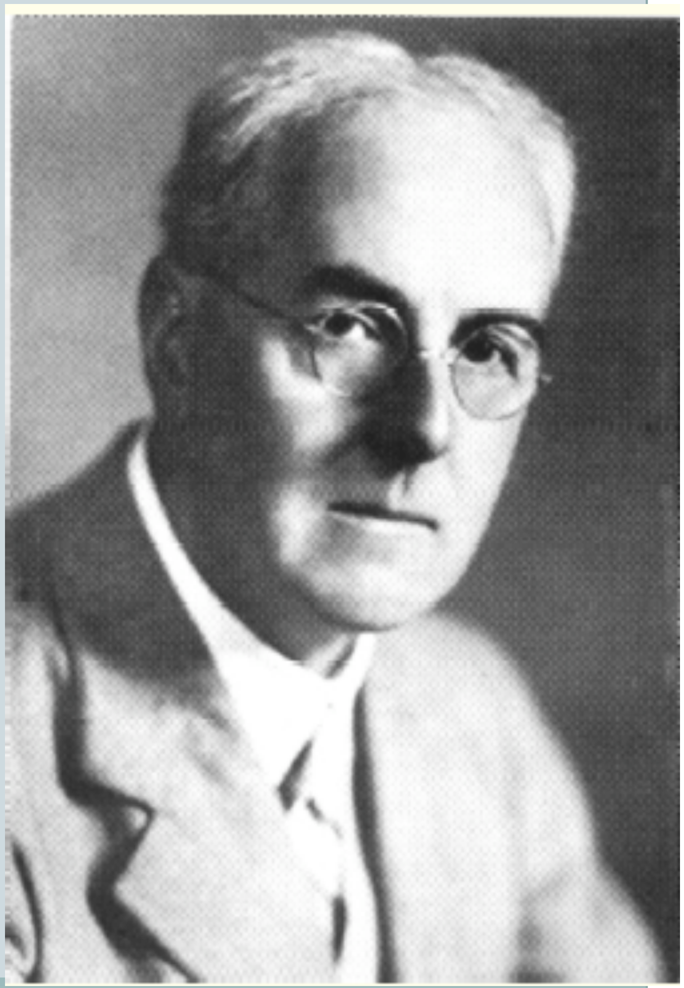


Simmons & Hollingsworth '02

Lewis Fry Richardson

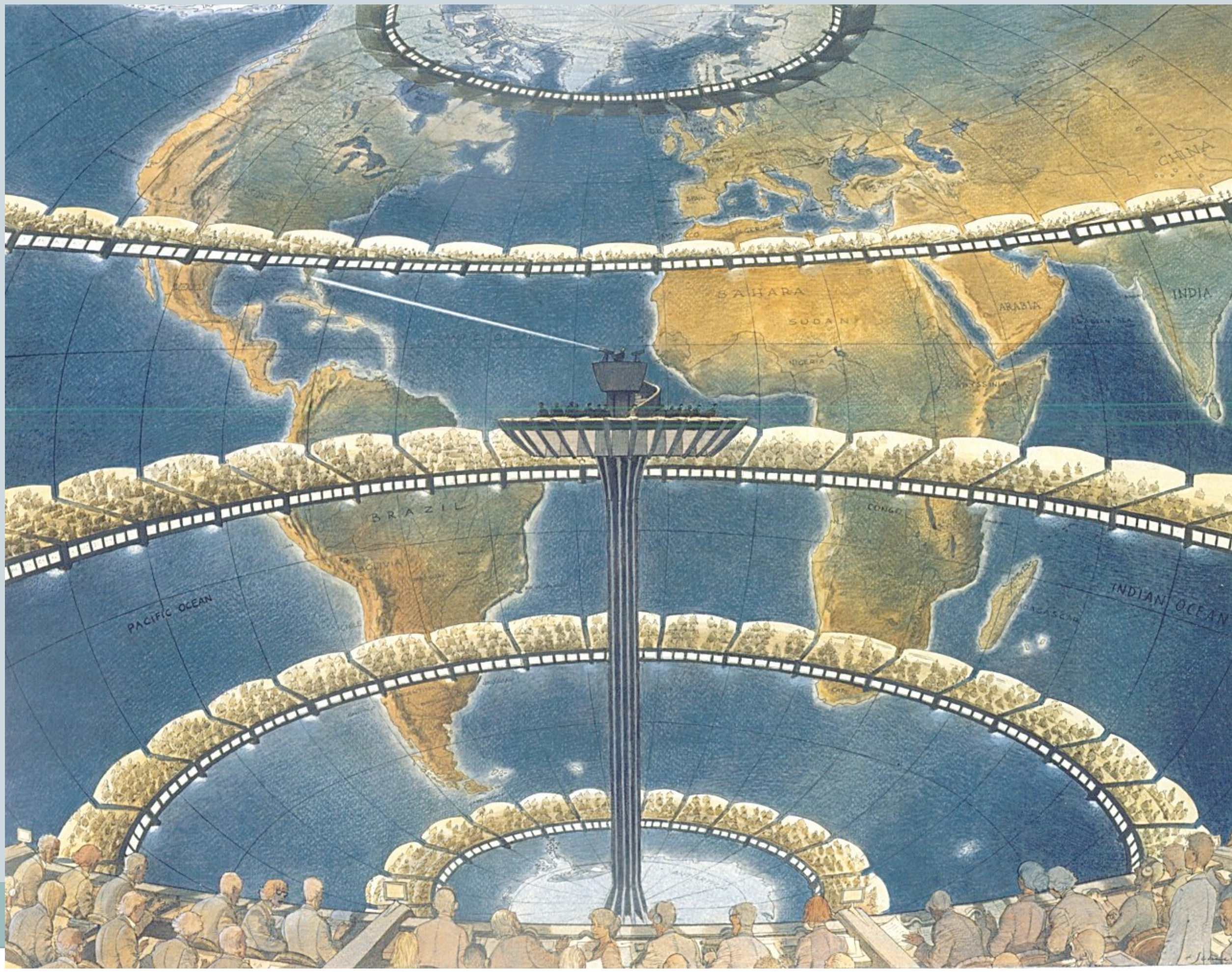
- British mathematician, physicist, atmospheric scientist
- Scientific career very influenced by his Quaker beliefs (pacifism)
- Made the first numerical weather prediction in ***1922***

Also had a dream of the future of weather prediction…



The Forecast Factory

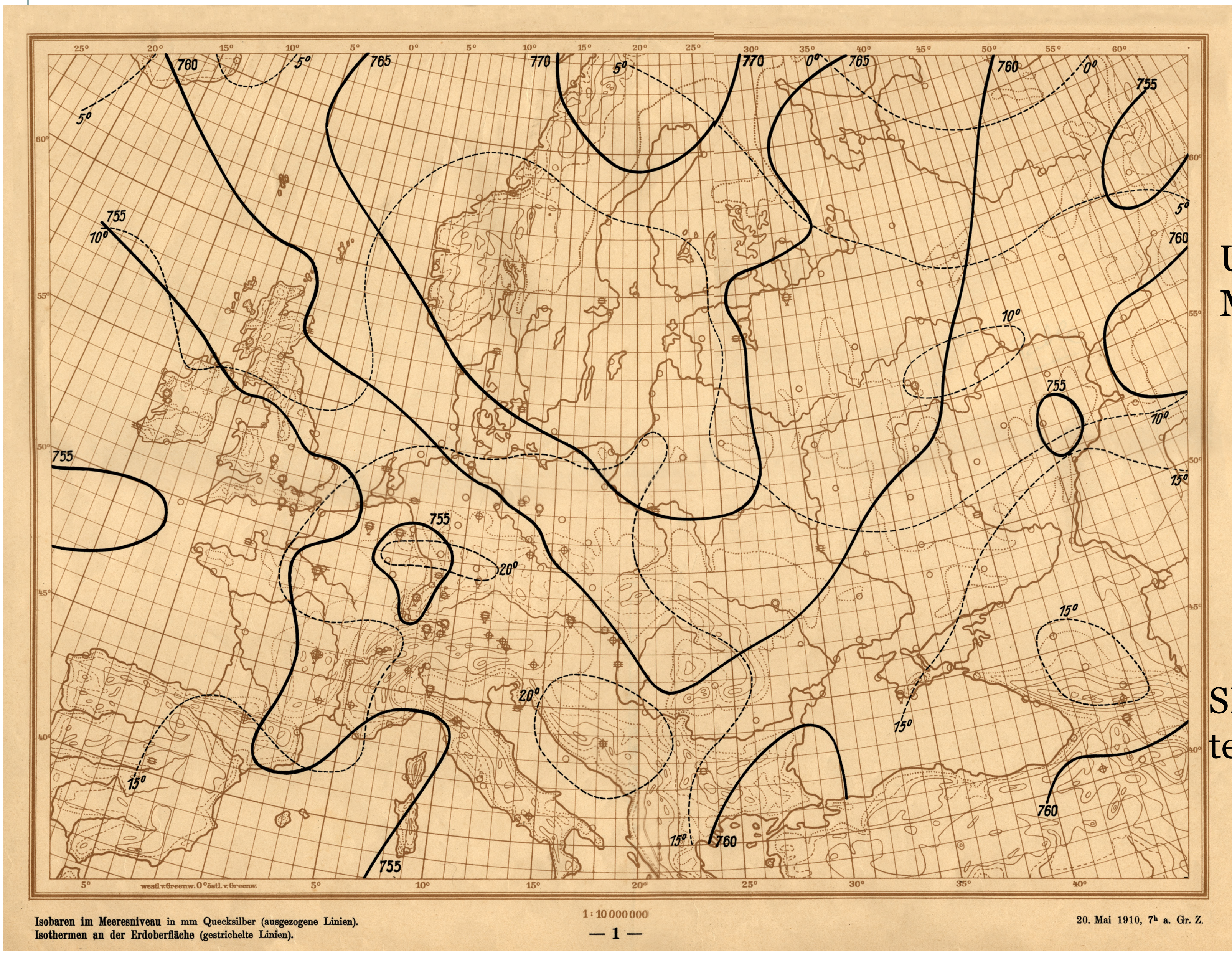
- Filled with employees ("computers") doing calculations



Richardson's dream in 1922 of a global forecasting system

He estimated 64,000 "computers" (people) would be necessary to forecast over the globe

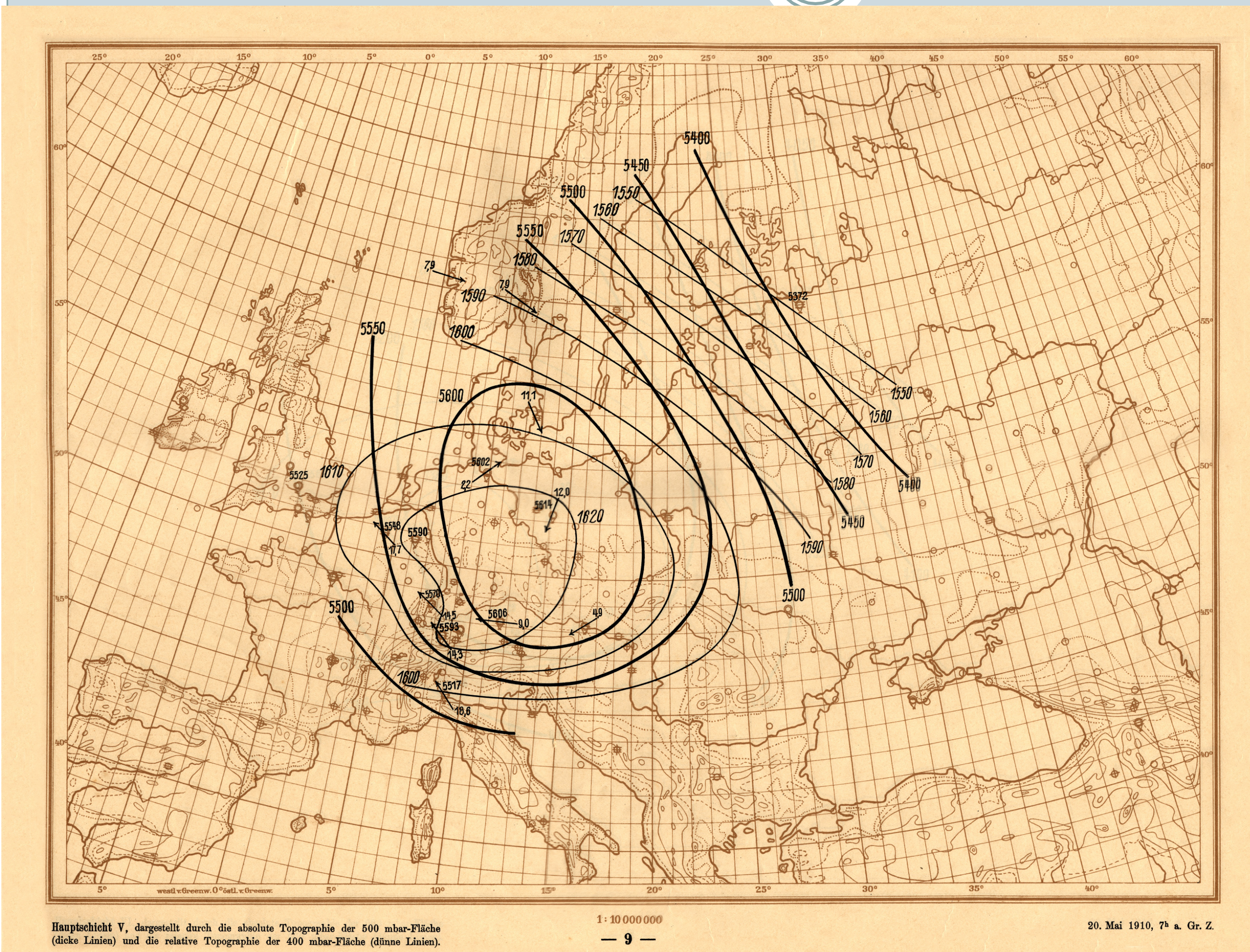
Richardson's Experiment



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*

COMPUTING FORM P XIII. Divergence of horizontal momentum-per-area. Increase of pressure

The equation is typified by: $-\frac{\partial R_{96}}{\partial t} = \frac{\partial M_{E96}}{\partial e} + \frac{\partial M_{N96}}{\partial n} - M_{N96}\frac{\tan\phi}{a} + m_{H8} - m_{H6}^{*} + \frac{2}{a}M_{H96}$. (See Ch. 4/2 #5.)

* In the equation for the lowest stratum the corresponding term $-m_{G8}$ does not appear

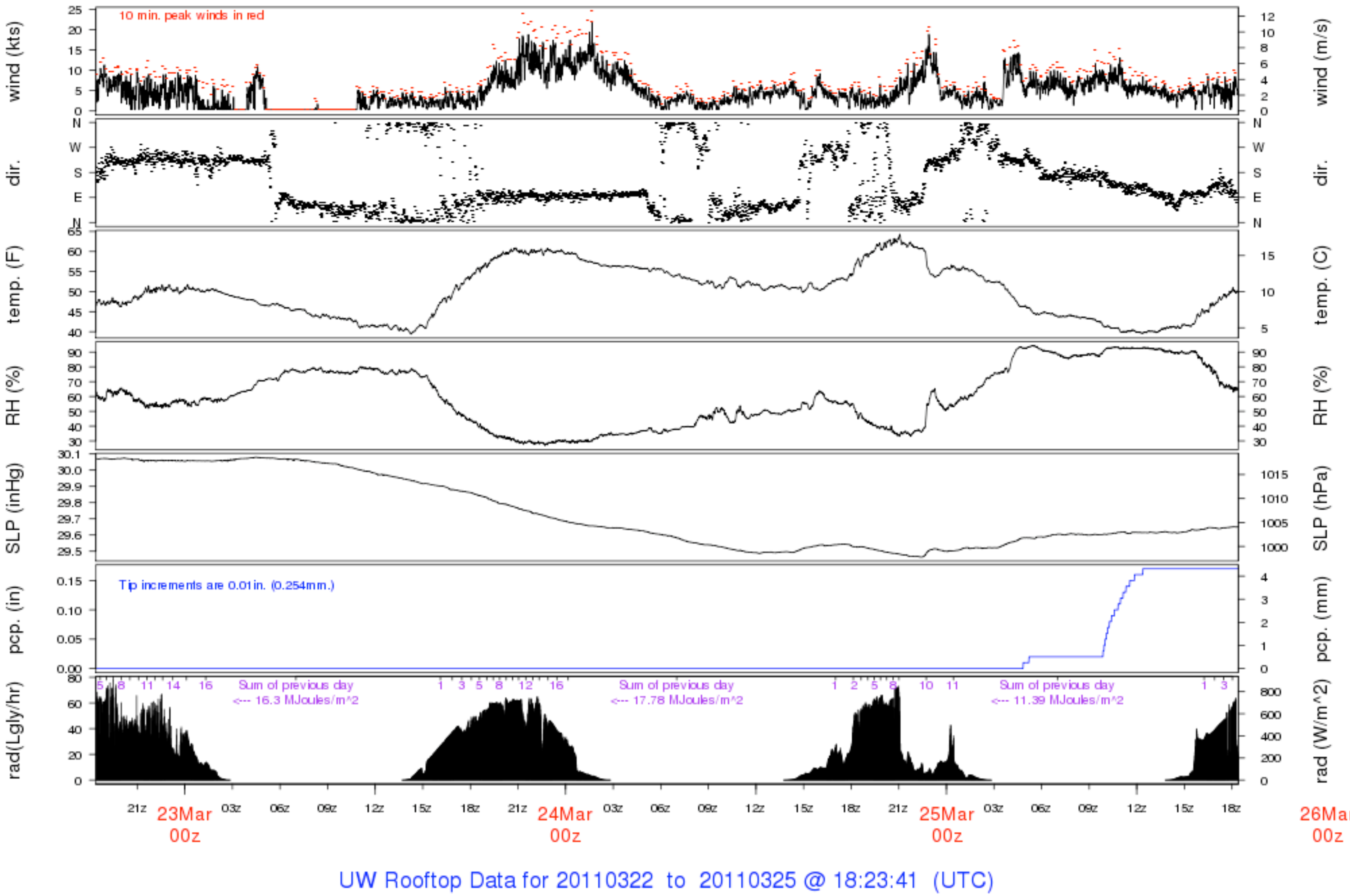
Longitude *11° East*, $\delta e = 441 \times 10^5$ — Latitude *5400 km North*, $\delta n = 400 \times 10^5$ — Instant *1910 May 20ᵈ 7ʰ G.M.T.*, $a^{-1}.\tan\phi = 1{\cdot}78 \times 10^{-9}$ — Interval, δt *6 hours*, $a = 6{\cdot}36 \times 10^8$

REF.:—				previous 3 columns	previous column		Form P XVI	Form P XVI	equation above	previous column	previous column	previous column
h	$\frac{\delta M_E}{\delta e}$	$\frac{\delta M_N}{\delta n}$	$-\frac{M_N \tan\phi}{a}$	$\mathrm{div}'_{EN}M$	$-g\delta t\,\mathrm{div}'_{EN}M$		m_H	$\frac{2M_H}{a}$	$-\frac{\partial R}{\partial t}$	$+\frac{\partial R}{\partial t}\delta t$	$g\frac{\partial R}{\partial t}\delta t$	$\frac{\partial p}{\partial t}\delta t$
	$10^{-5}\times$	$10^{-6}\times$	$10^{-5}\times$	$10^{-5}\times$	$100\times$	Leave the subsequent columns to be filled up after the vertical velocity has been computed on Form P XVI	$10^{-5}\times$	$10^{-5}\times$	$10^{-5}\times$		$100\times$	$100\times$
h_0							0					0
	−61	−245	−6	−312	656				−229	49·5	483	
h_2							−83					483
	367	−257	2	112	−236			0·06	−136	29·4	287	
h_4							165					770
	93	−303	−16	−226	478			0·11	−124	26·8	262	
h_6							63					1032
	32	−55	−12	−35	74			0·07	−110	23·8	233	
h_8							138					1265
	−256	38	−8	−226	479			0·03	−88	19·0	186	
h_G												1451
	NOTE: $\mathrm{div}'_{EN}M$ is a contraction for $\frac{\delta M_E}{\delta e} + \frac{\delta M_N}{\delta n} - M_N\frac{\tan\phi}{a}$				SUM = 1451 $= \frac{\partial p_G}{\partial t}\delta t$							check by $\Sigma - g\delta t\,\mathrm{div}'_{EN}M$

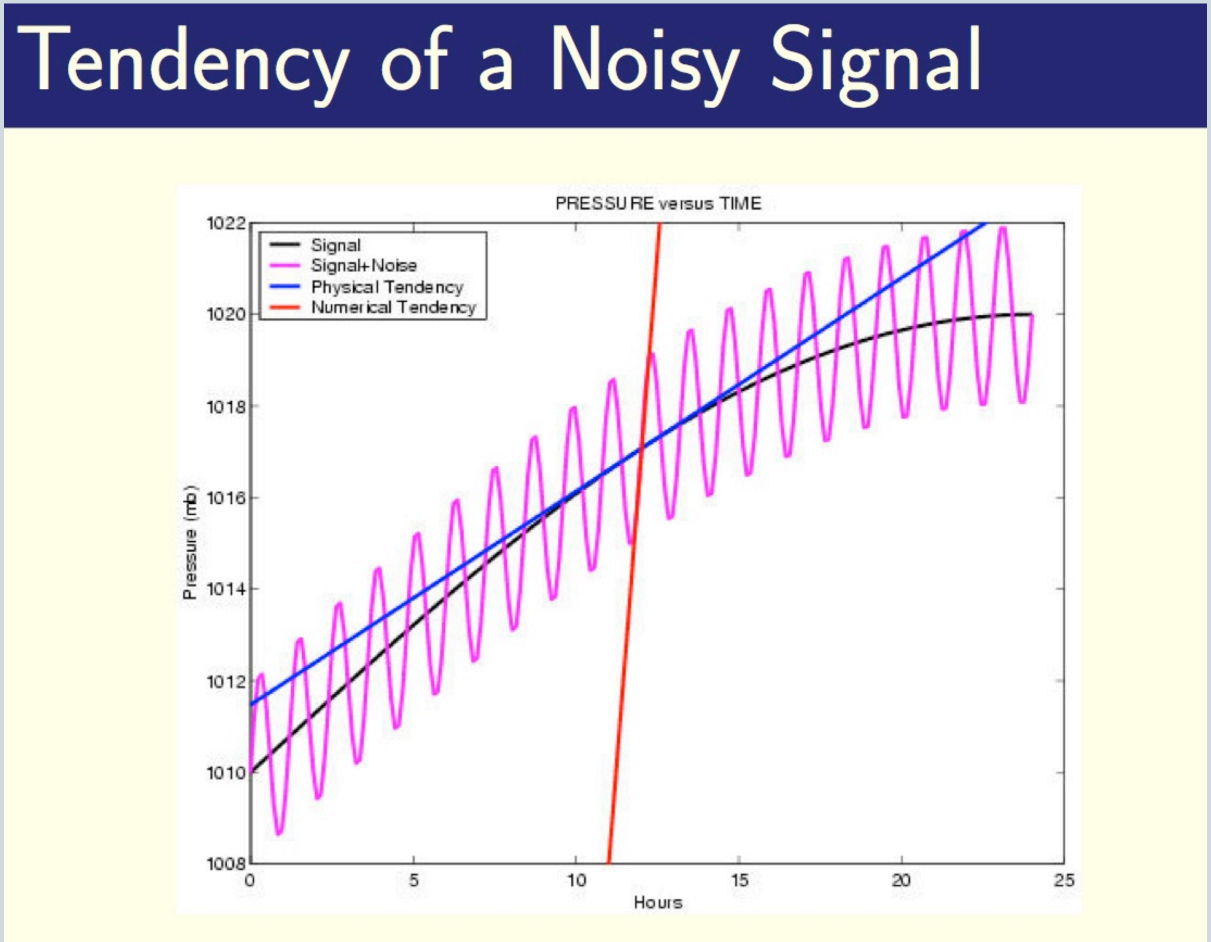
Richardson's Computing Form P_{XIII}

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

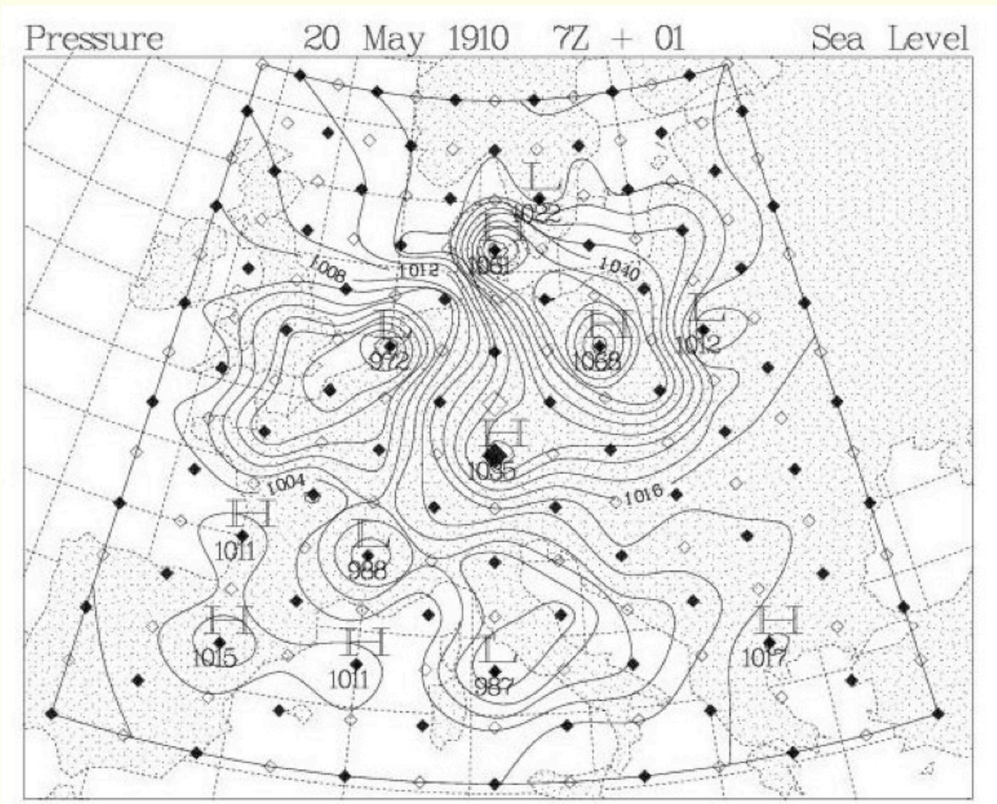


Unbalanced motions which average to zero on top of a smoothly changing signal can really mess up forecasts!

Balancing initial conditions is still a problem today!
(big problem in data assimilation)

Richardson's forecast

Forecast without Filtering



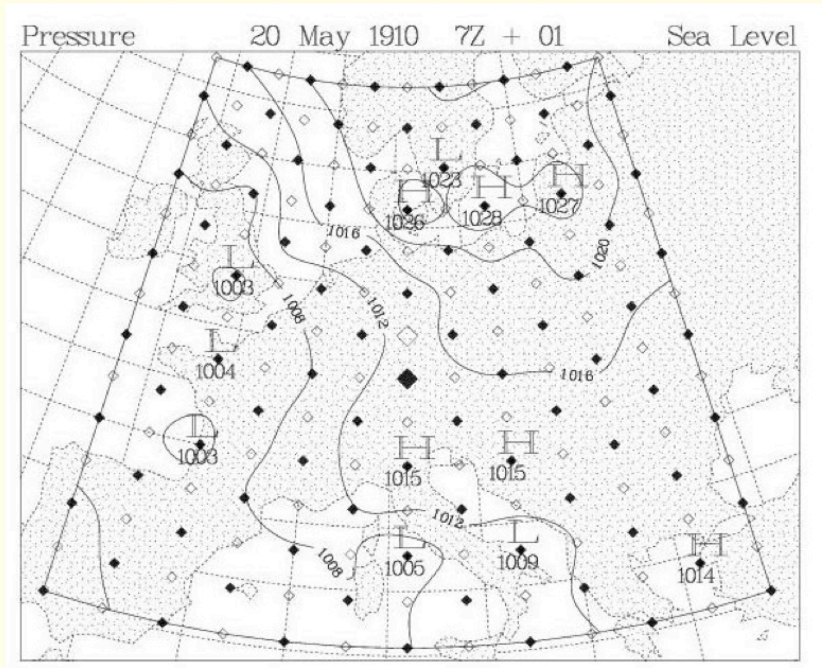
Short-range forecast of sea-level pressure, from *uninitialized data*. The contour interval is 4 hPa. Single forward time step of size $\Delta t = 3600\,\text{s}$.

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



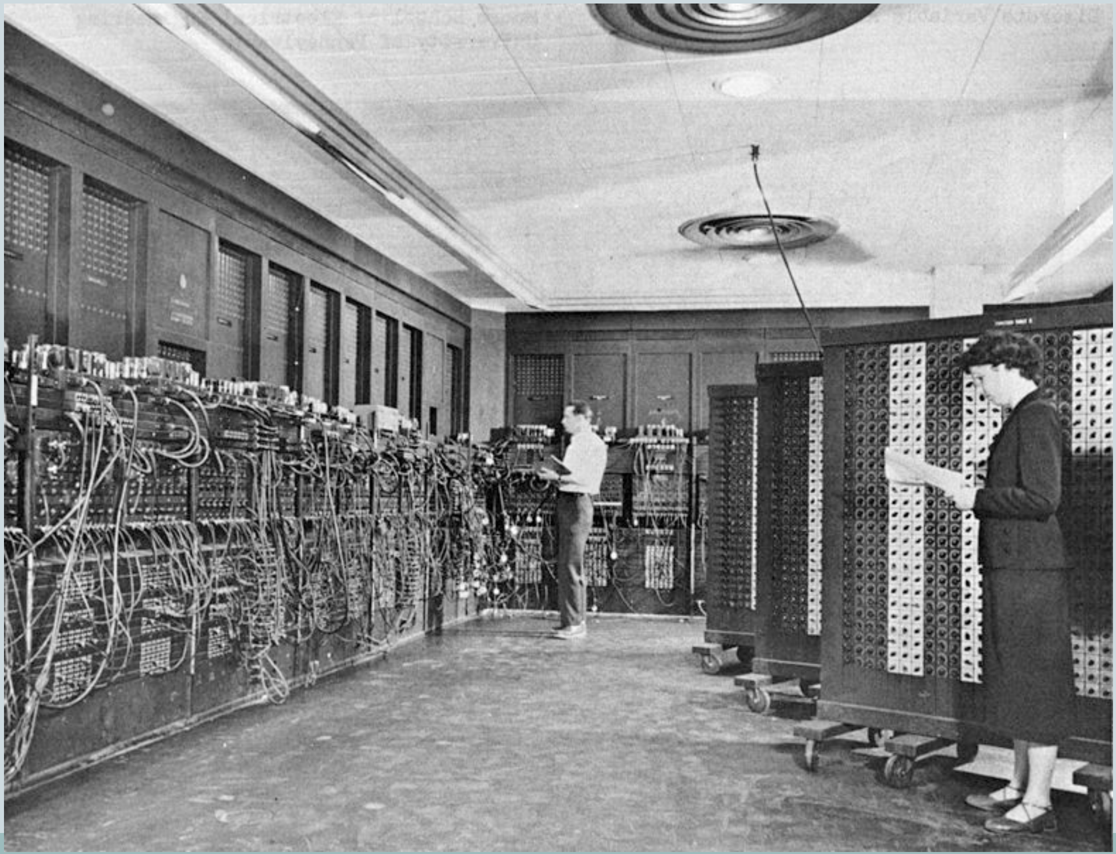
Short-range forecast of sea-level pressure, from *filtered data.* The contour interval is 4 hPa. Single forward time step of size $\Delta t = 3600\,\mathrm{s}$.

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



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