Atmospheric Dynamics I

ATS 601
Instructor: Prof. Elizabeth (Libby) Barnes
TA: Andrea Jenney

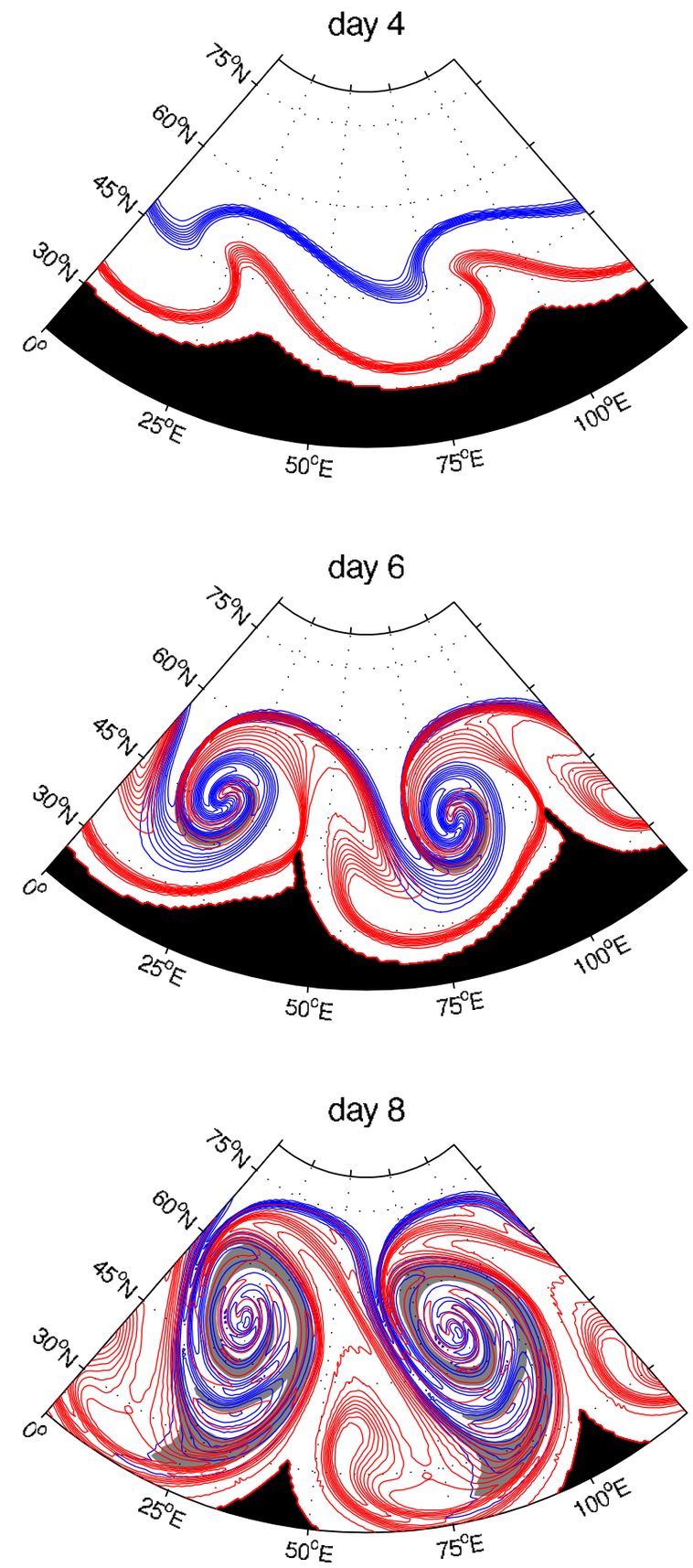


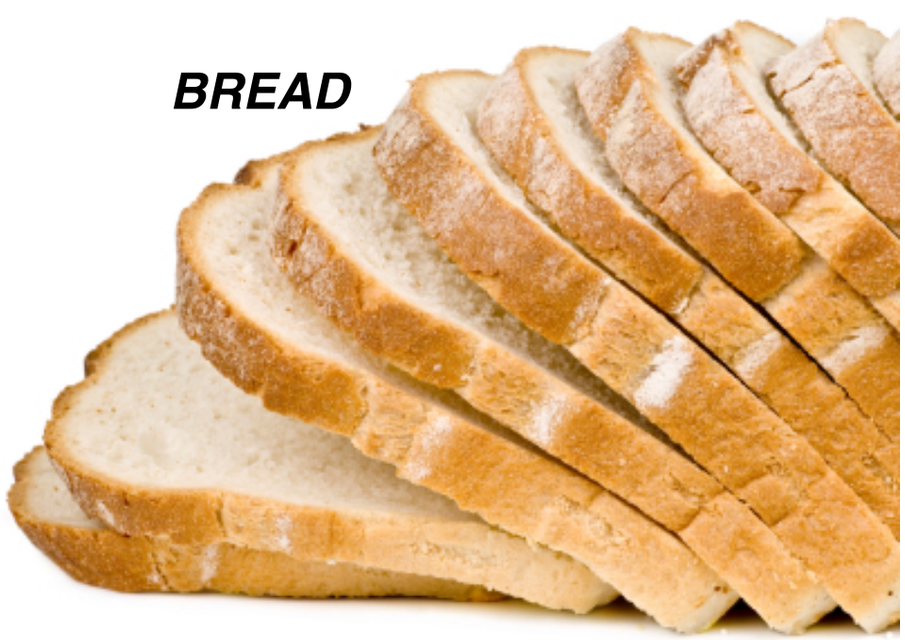
Figure 12, Polvani & Esler (2007)

About your instructor

- Assistant Professor, joined CSU in 2013
- Bachelors in Mathematics & in Physics, U. of Minnesota
- Ph.D. in Atmospheric Science, U. of Washington
- Postdoc at Columbia University's Lamont-Doherty Earth Observatory
- Research Topics: large-scale tropospheric dynamics, jet-stream variability, transport and mixing, subseasonal-to-seasonal prediction

What are we going to do here?

- All of you have eaten bread - some of you have even made bread … but have you actually started from “scratch”?
  - Planting the wheat, growing the wheat, grinding the wheat into flour…
- Dynamics is the same way - while many of you have probably studied aspects of atmospheric dynamics, most (if not all) of you probably have not made it from “scratch”



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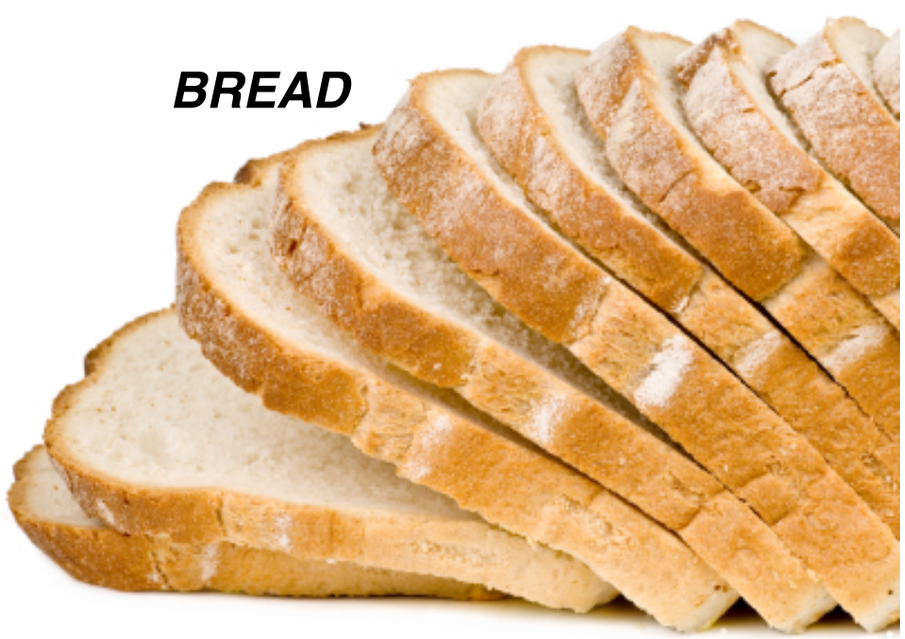
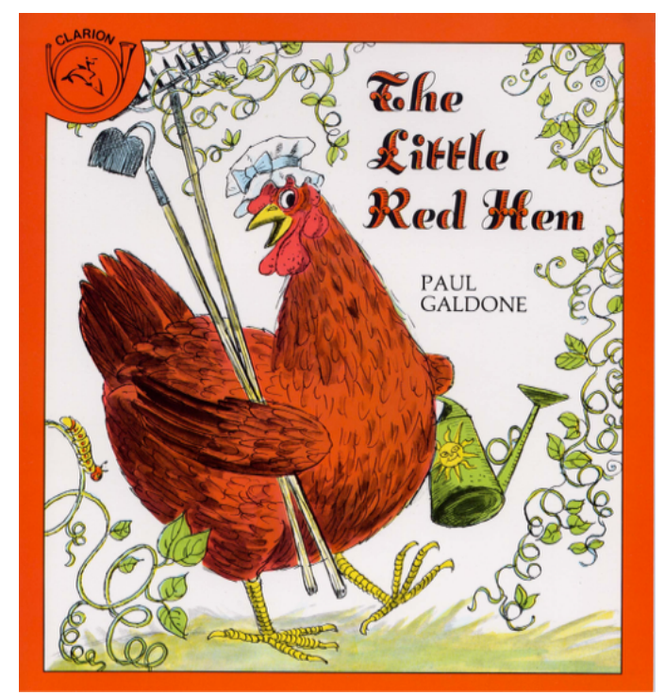


in this class, you will be the Little Red Hen



What are we going to do here?

- In this class, you are going to learn how to “make” the equations that describe atmospheric motions
  - e.g. momentum equations, equation of state, mass continuity, the thermodynamic equation
- We will not be discussing all of the things you can “do” with these equations - that is for more advanced dynamics courses (e.g. 602)

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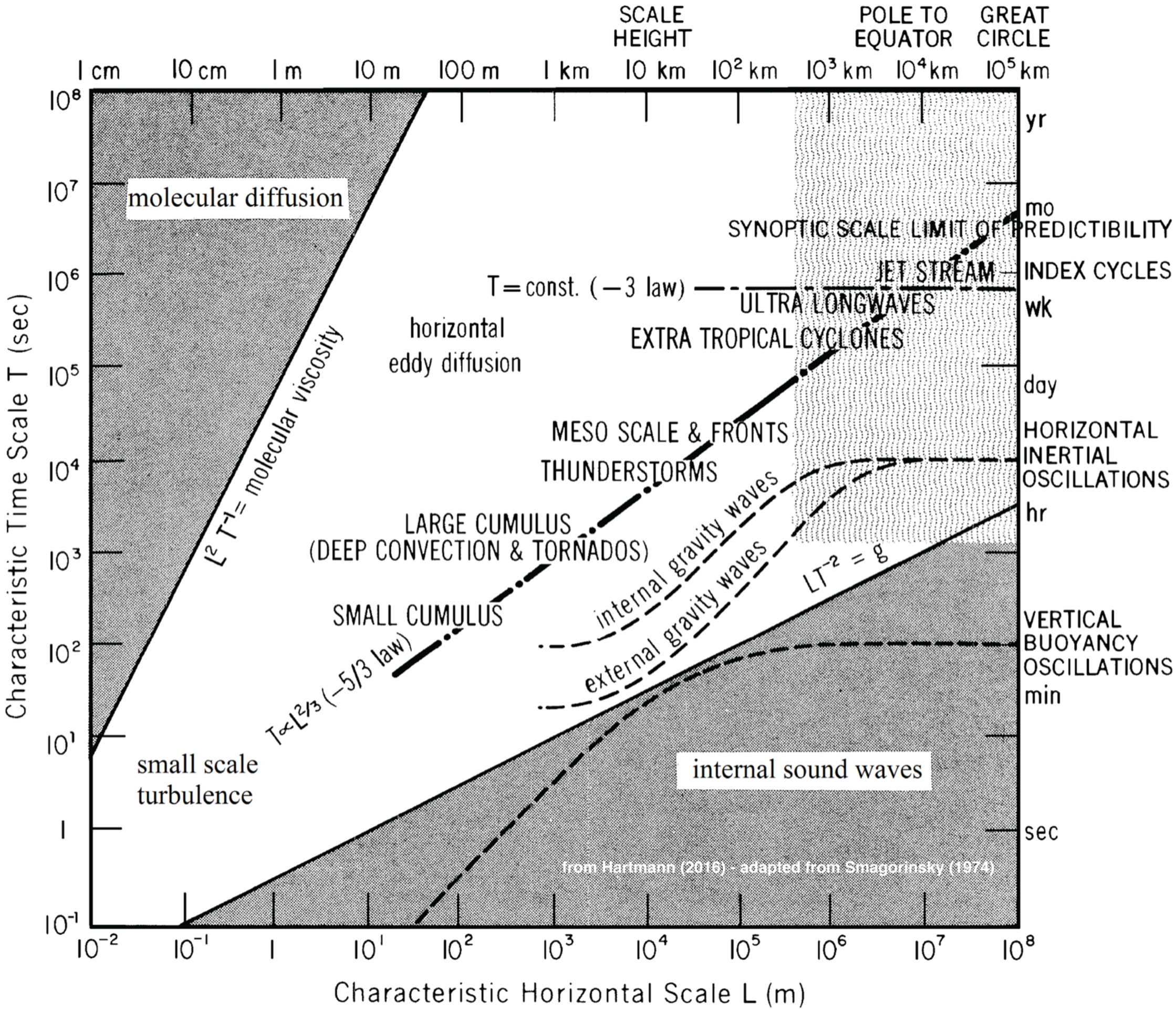
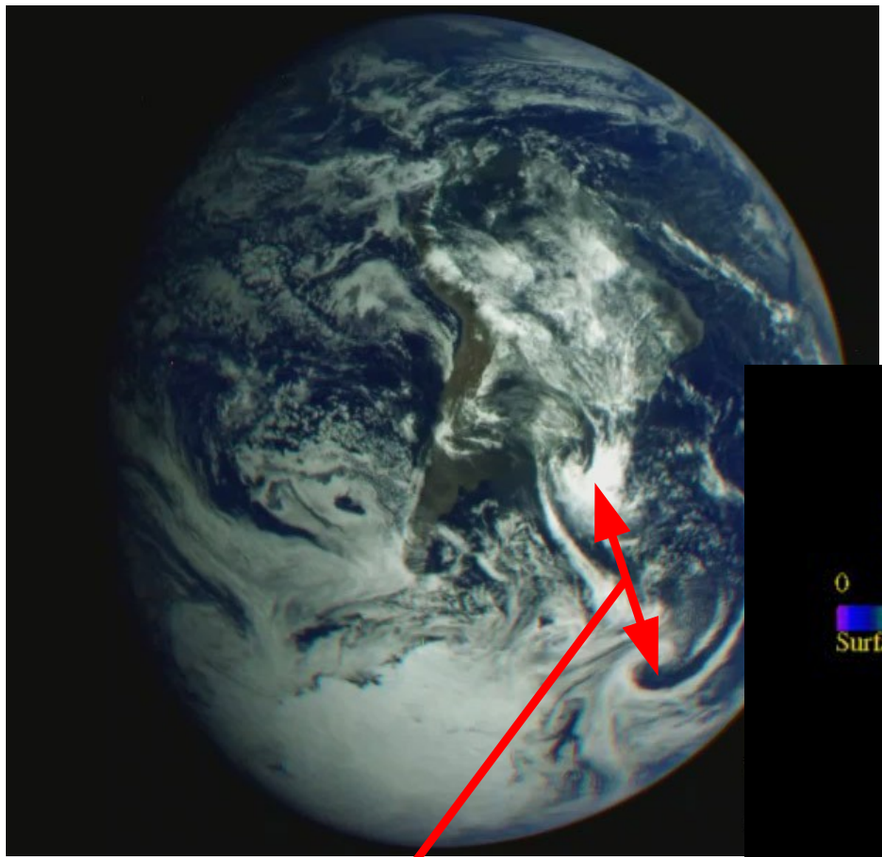
THINGS BREAD CAN “DO”

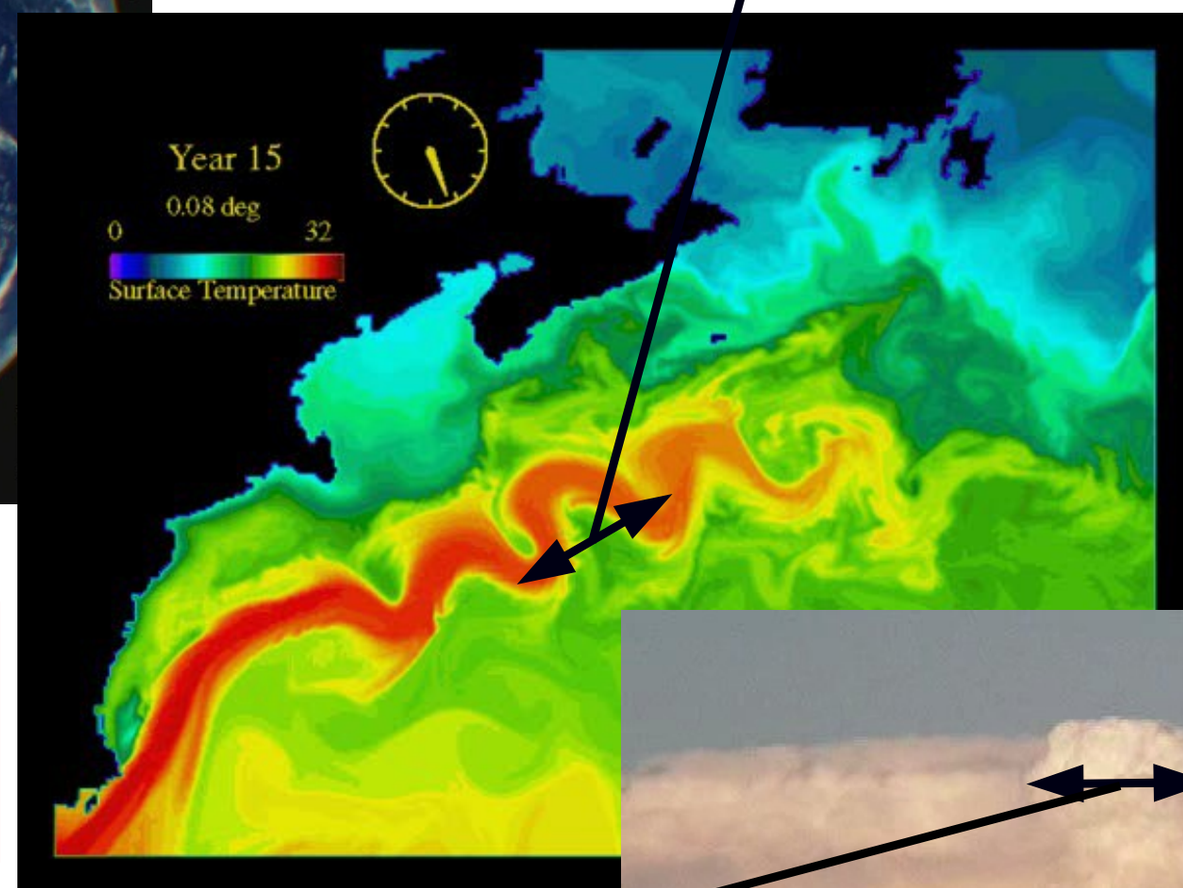
Specifics…

- Fundamentals of geophysical fluid dynamics (GFD) with an emphasis on the atmosphere
- GFD aims at understanding the underlying mechanisms of atmospheric and oceanic motion over a vast range of scales (both spatial and temporal)
  - centimeters (molecular diffusion)
  - 10,000 kilometers (planetary waves)
  - seconds (sound waves)
  - years (global circulations)
- Need to simplify the equations, guided by empirical knowledge of the system…but many of the conclusions carry-over to the real world!


SCALE HEIGHT
POLE TO EQUATOR
GREAT CIRCLE
1 cm
10 cm
1 m
10 m
100 m
1 km
10 km
10² km
10³ km
10⁴ km
10⁵ km
yr
mo
wk
day
hr
min
sec
molecular diffusion
SYNOPTIC SCALE LIMIT OF PREDICTIBILITY
JET STREAM
INDEX CYCLES
T = const. (−3 law)
ULTRA LONGWAVES
EXTRA TROPICAL CYCLONES
horizontal eddy diffusion
L² T⁻¹ = molecular viscosity
MESO SCALE & FRONTS
THUNDERSTORMS
HORIZONTAL INERTIAL OSCILLATIONS
LARGE CUMULUS (DEEP CONVECTION & TORNADOS)
internal gravity waves
external gravity waves
LT⁻² = g
SMALL CUMULUS
T∝L^{2/3} (−5/3 law)
VERTICAL BUOYANCY OSCILLATIONS
small scale turbulence
internal sound waves
from Hartmann (2016) - adapted from Smagorinsky (1974)
Characteristic Time Scale T (sec)
Characteristic Horizontal Scale L (m)



Oceanic Baroclinic Eddies: ~100 km, several weeks



Atmospheric Baroclinic Eddies: ~1,000 km, ~1 week

Convective Plumes: ~1–10 km, min–hours

Convective Organization: ~10–100 km, several hours

Simplification…

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- “…we need a model hierarchy on which to base our understanding, describing how the dynamics change as key sources of complexity are added or subtracted.” - Held (2005; BAMS)
- “The general success of the forecasts in data-rich areas bears witness to the fact that the cyclogenetical process is indeed now well understood - at least by the computer!” - Reed (1990)

Simplification…be wary of the spherical cow

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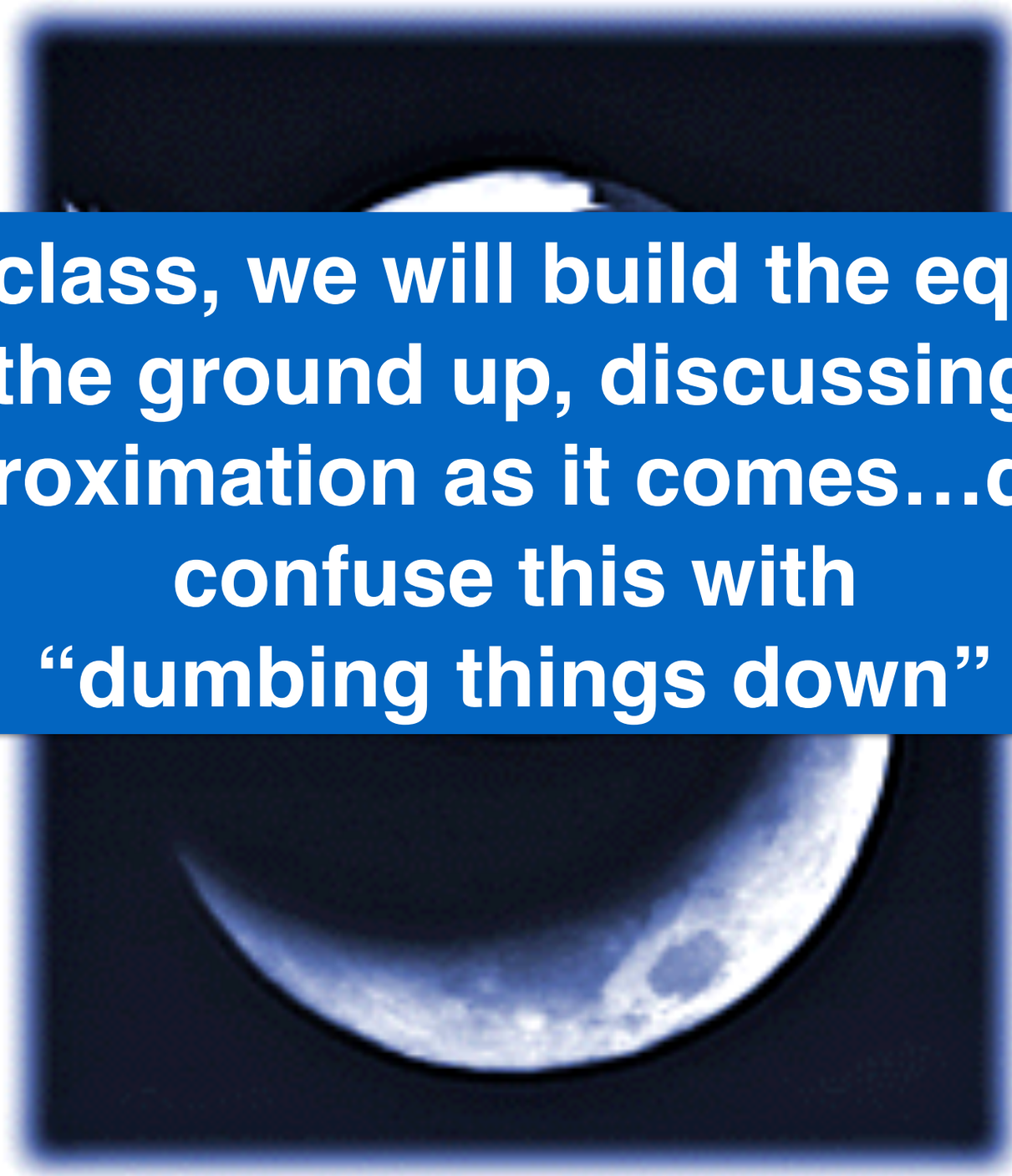
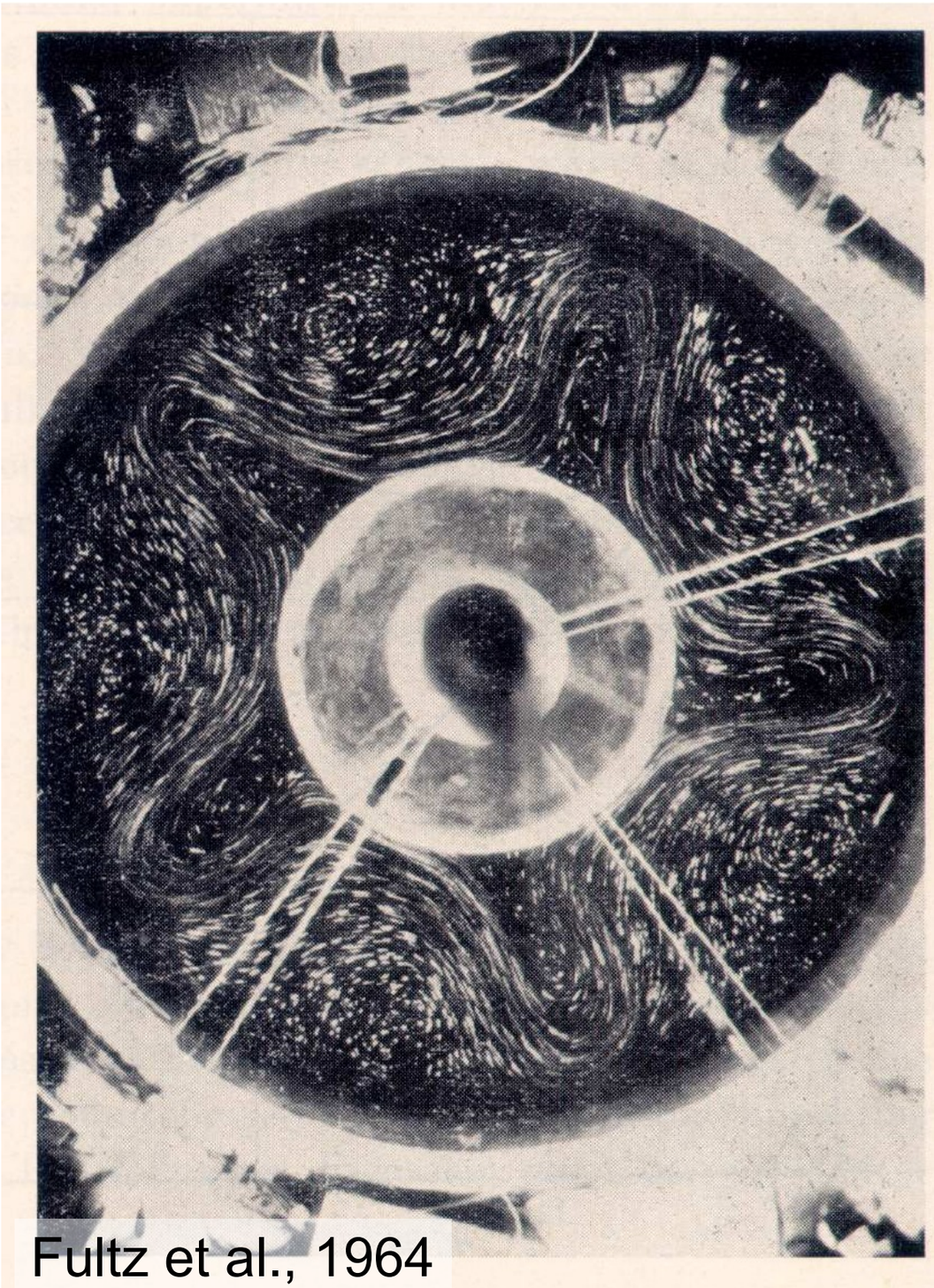
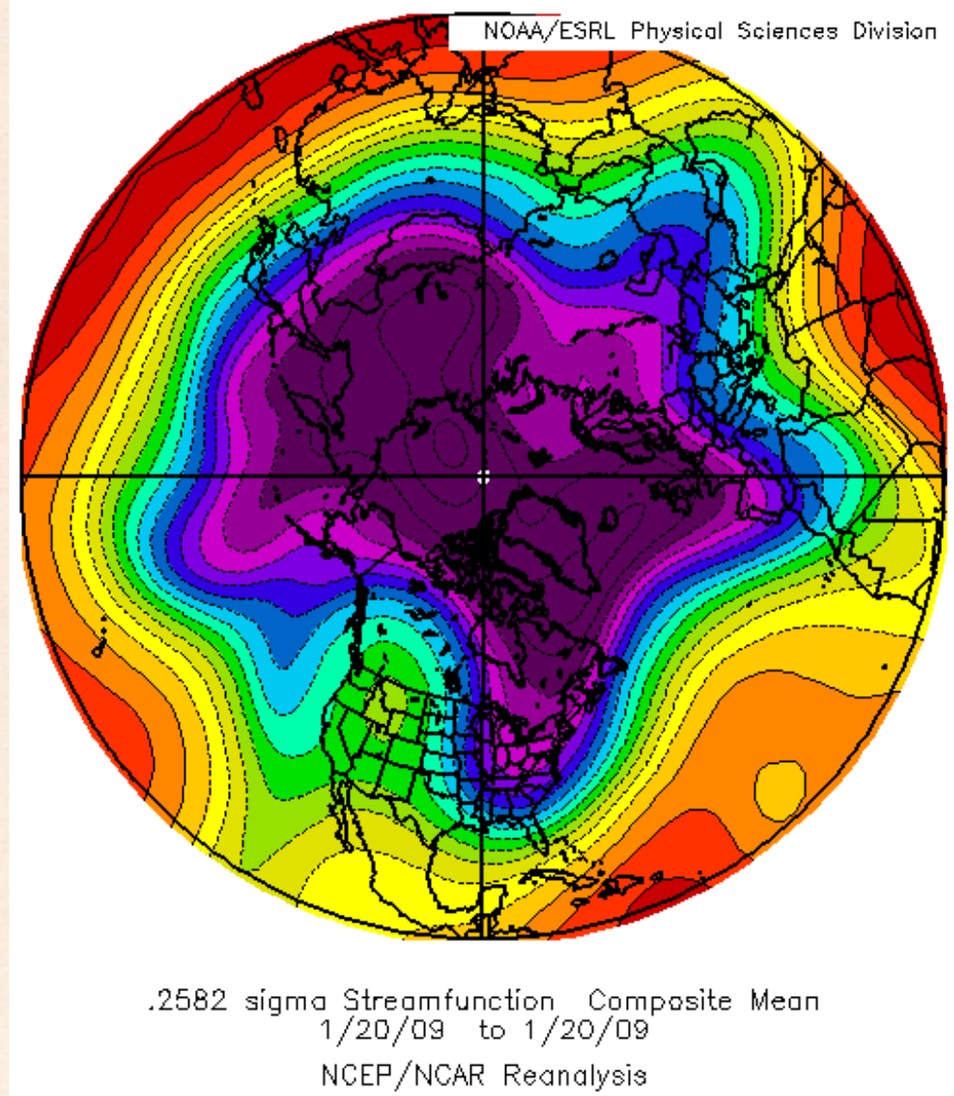


In this class, we will build the equations from the ground up, discussing each approximation as it comes…don't confuse this with "dumbing things down"

Large-scale dynamics



Fultz et al., 1964



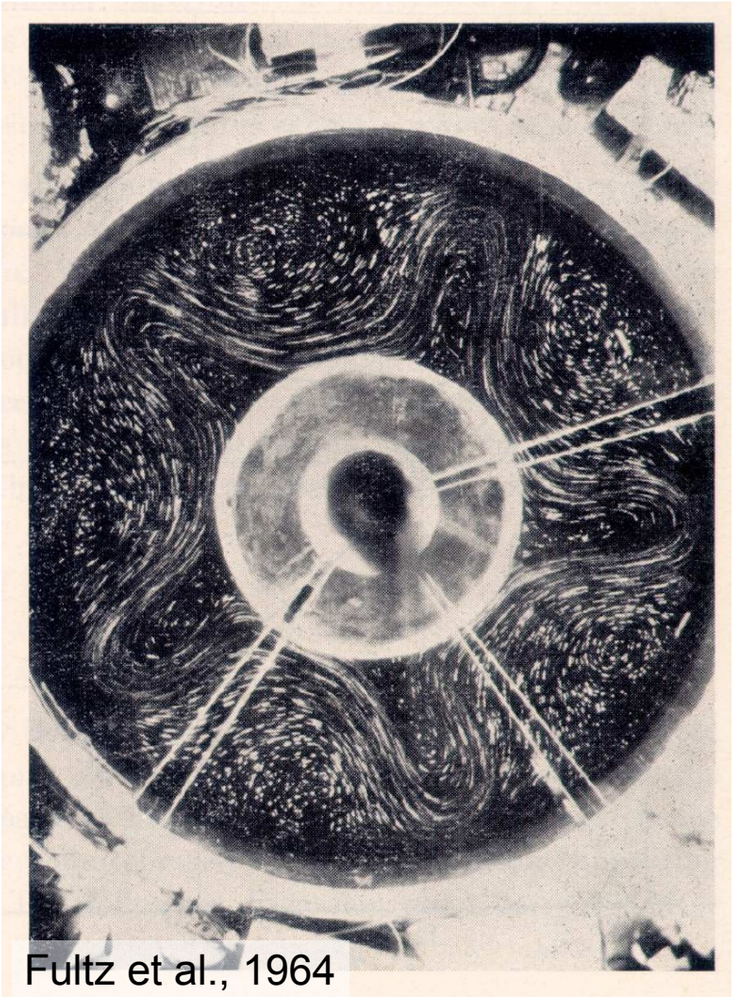
Differentially heated annulus experiment (rotating tank)

Rossby waves

$$\frac{\partial \zeta}{\partial t} + \mathbf{u} \cdot \nabla \zeta + \beta v = 0$$

Carl-Gustaf Rossby identified waves in 1939

In the real world: http://svs.gsfc.nasa.gov/vis/a010000/a010900/a010902/



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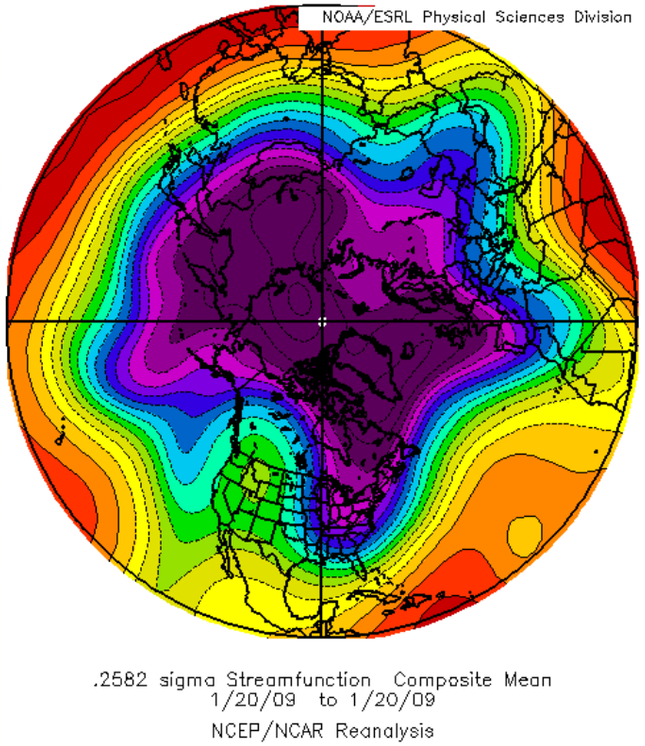
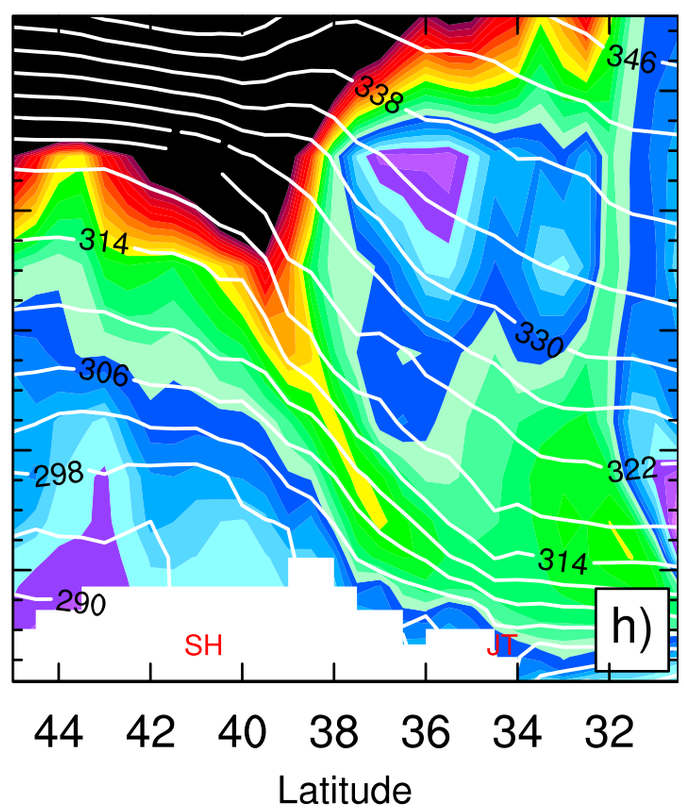


Differentially heated annulus experiment (rotating tank)

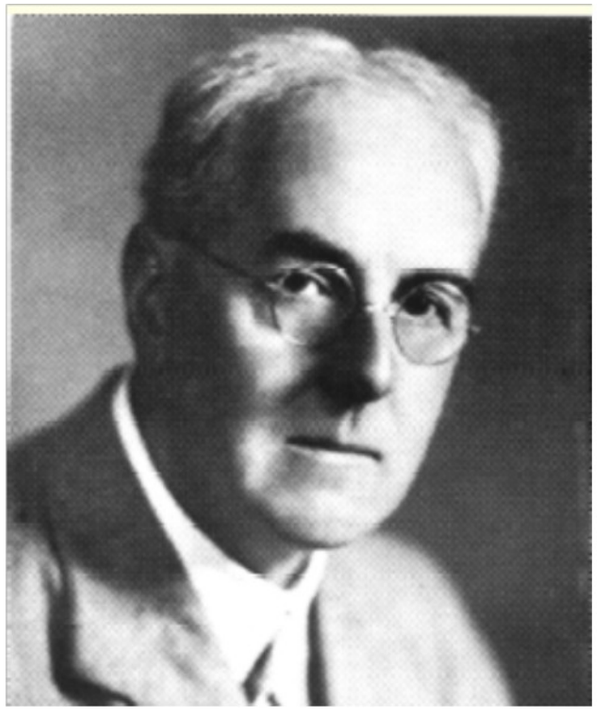
Regional atmospheric chemistry

Poor air quality
what atmospheric conditions lead to these events?

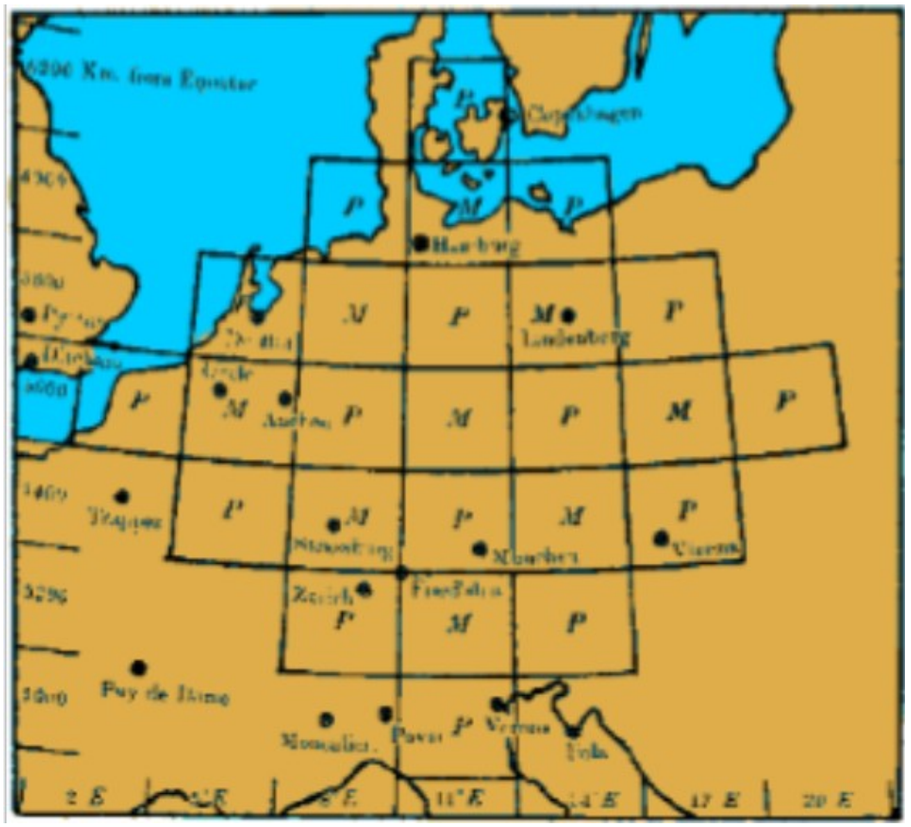


Ozone being transported from the stratosphere to western U.S.

Forecasting: Richardson

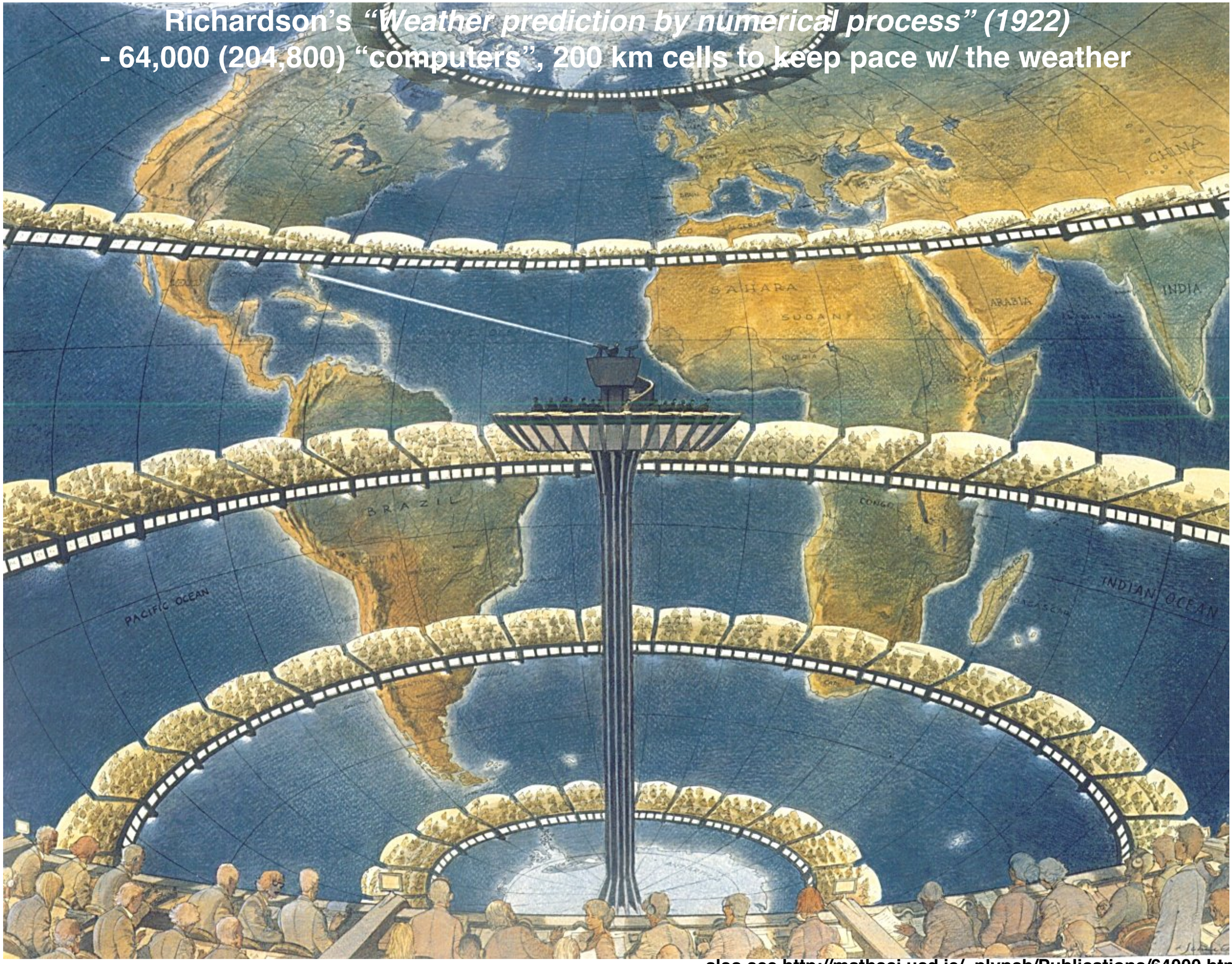


- Lewis F. Richardson made forecasts of wind and pressure at two points using data on May 20, 1910
- Finite difference solutions to the *simplified primitive equations*
- He says the 6-hour forecast took him 6 weeks (but others argue must have taken him 2 years at 40-hours per week)



results were a FAILURE:
predicted pressure change ~150 hPa
change was actually only ~3 hPa

Richardson's *"Weather prediction by numerical process" (1922)*
- 64,000 (204,800) "computers", 200 km cells to keep pace w/ the weather



also see http://mathsci.ucd.ie/~plynch/Publications/64000.html

Jule Charney

Forecasting: ENIAC

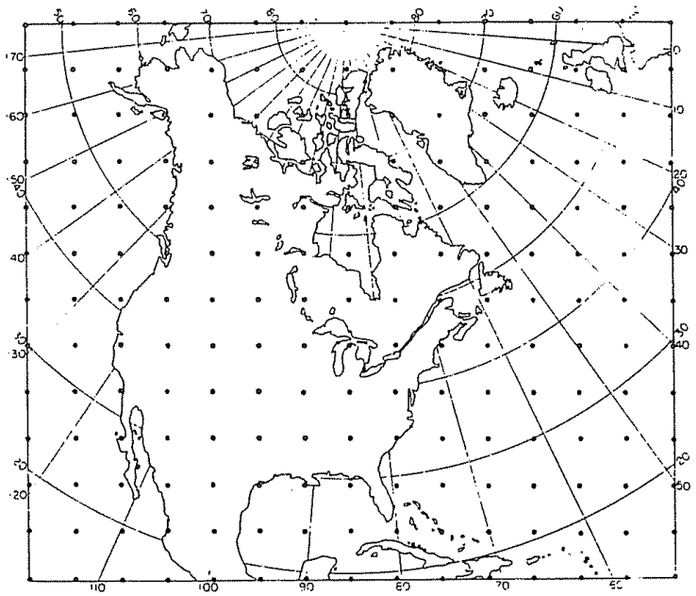
Numerical Integration of the Barotropic Vorticity Equation

By J. G. CHARNEY, R. FJÖRTOFT[1], J. von NEUMANN
The Institute for Advanced Study, Princeton, New Jersey[2]

John von Neumann

- Emergence of computer 1920-1950
- ENIAC at Institute for Advanced Studies
- Instead of primitive equations, much simpler barotropic vorticity equation was used

$$\frac{D}{Dt}(f+\zeta)=0$$



- First forecast 1950: resolution 750km, time-step 1 hour
- Required 25,000 punch cards
- 24 h forecast took 24 h
- Overall, did ok!

Goals

- practice speaking the language of dynamics (e.g. mathematics)
- become familiar with some dynamics jargon
- learn fundamental physics of GFD
- become comfortable running and analyzing a simple atmospheric model
- practice writing-up results in a professional manner

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I want all of you to be able to sit through a seminar and follow the dynamical equations - and if you don't, know the language so you can look it up!

ATS 601: FALL 2017

last updated Aug. 21, 2017

DATE	WEEK	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
Aug 21-25	1			**1. lecture (time changed) 10:00-10:50 ATS 101**		**2. lecture (time changed) 10:00-10:50 ATS 101**
Aug 28-Sept 1	2			3. lecture *(may change)* 9:00-9:50 ATS 101		4. lecture *(may change)* 9:00-9:50 ATS 101
Sept 4-8	3	**CSU Holiday**		5. lecture *(may change)* 9:00-9:50 ATS 101		6. EXAM 1 9:00-9:50 ATS 101
Sept 11-15	4			7. lecture 9:00-9:50 ATS 101		8. lecture 9:00-9:50 ATS 101
Sept 18-22	5			9. lecture 9:00-9:50 ATS 101		10. lecture 9:00-9:50 ATS 101
Sept. 25-29	6			11. lecture 9:00-9:50 ATS 101		12. lecture 9:00-9:50 ATS 101
Oct. 2-6	7			13. EXAM 2 9:00-9:50 ATS 101		14. lecture 9:00-9:50 ATS 101
Oct. 9-13	8			15. lecture 9:00-9:50 ATS 101		16. lecture 9:00-9:50 ATS 101
Oct. 16-20	9			17. lecture 9:00-9:50 ATS 101		18. lecture 9:00-9:50 ATS 101
Oct. 23-27	10			19. lecture 9:00-9:50 ATS 101		**NO CLASS**
Oct 30-Nov 3	11	**20. make-up lecture 10:00 - 10:50 ATS 101**		21. lecture 9:00-9:50 ATS 101		22. EXAM 3 9:00-9:50 ATS 101
Nov. 6-10	12			23. lecture 9:00-9:50 ATS 101		25. lecture 9:00-9:50 ATS 101
Nov. 13-17	13			25. lecture 9:00-9:50 ATS 101		26. lecture 9:00-9:50 ATS 101
Nov. 18-24	14	**CSU Holiday**	**CSU Holiday**	**CSU Holiday**	**CSU Holiday**	**CSU Holiday**
Nov. 27-Dec. 1	15			27. lecture 9:00-9:50 ATS 101		28. lecture 9:00-9:50 ATS 101
Dec. 4-8	16			29. lecture 9:00-9:50 ATS 101		30. lecture 9:00-9:50 ATS 101
Dec. 9-15	**FINALS**		EXAM 4???			

Course Webpage

http://barnes.atmos.colostate.edu/COURSES/AT601_F17/index.html

username: ats601
password: jellybeans

Discuss syllabus