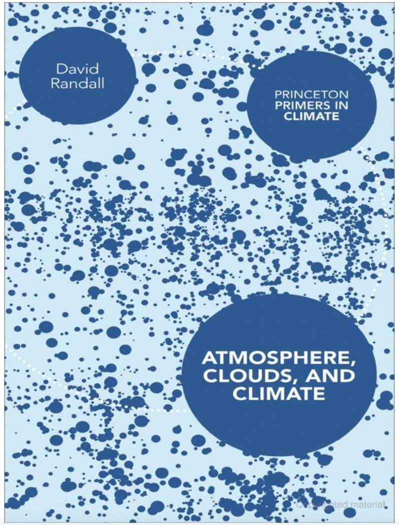
The Water Planet

Chapter - 6
Atmosphere Clouds and Climate



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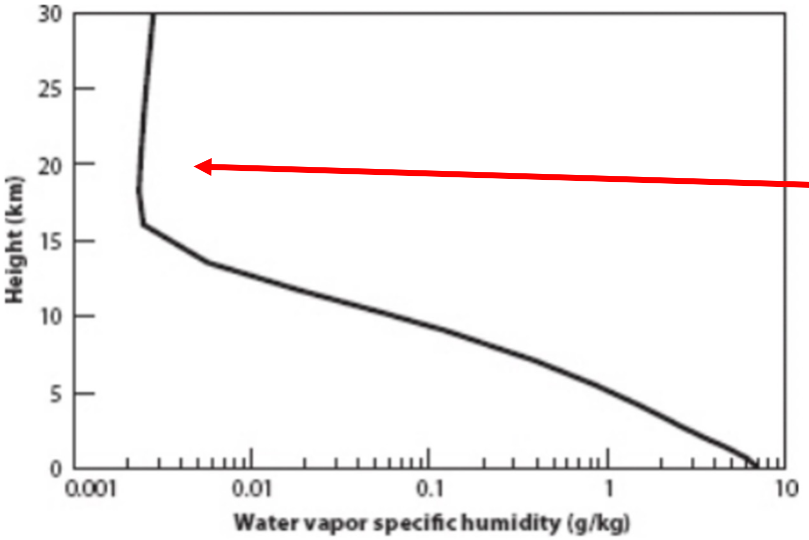
Bullets to dodge in the next ½ hour

- Understand the spatial distribution and dynamics of different components of water cycle in the earth system.

- Understand the coupling of water cycle with other cycles like Mass and Energy, using the concepts we have learnt in previous chapters (Cumulus convection, feedbacks, Hadley circulation, albedo, ocean transport etc).

- Understand the effects of global warming on the water cycle and circulations.

How Specific Humidity Changes Vertically?



Specific humidity ………… (increases/ decreases) in the troposphere by …..……. order of magnitudes.

What happens in the stratosphere?

Stefan et al., 2018

Zonally Averaged RH

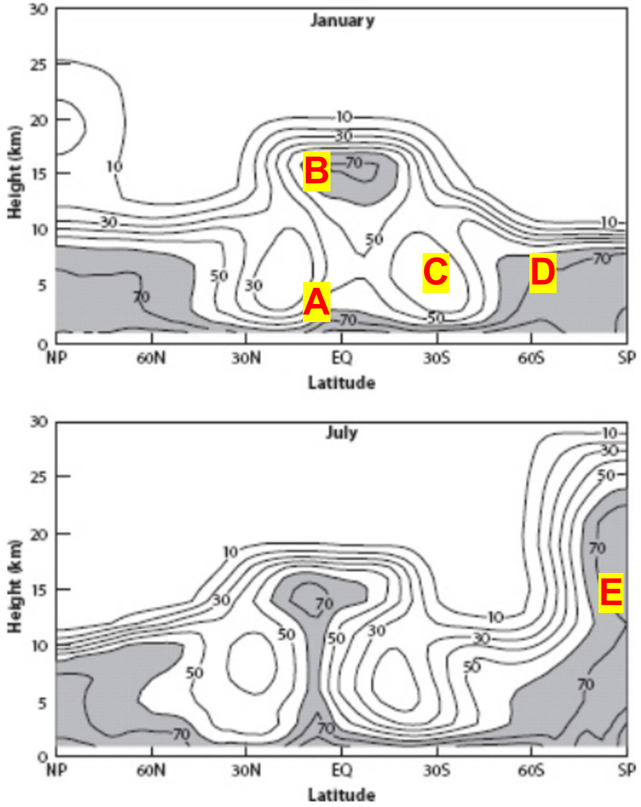
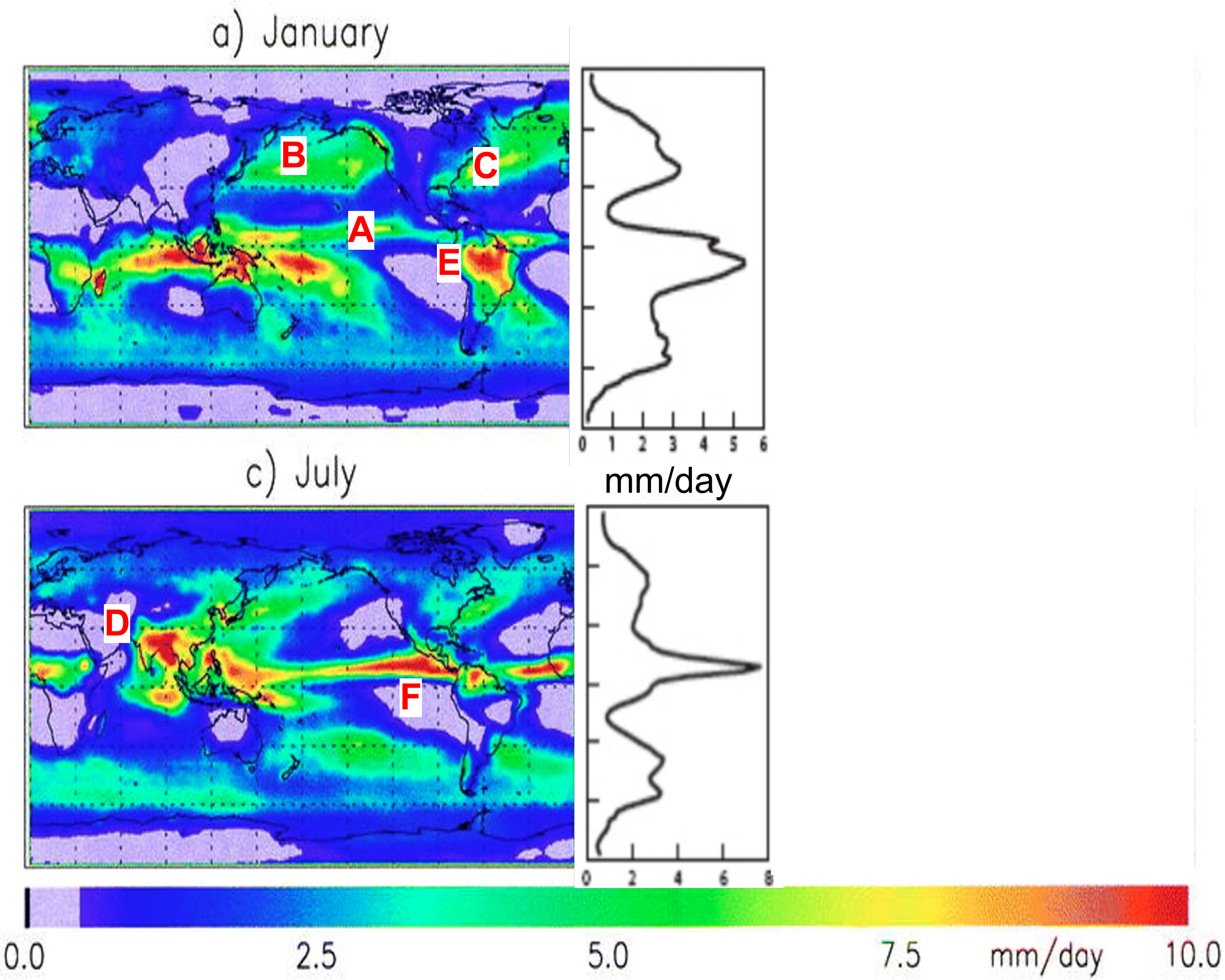


Figure 6.2. The observed latitude-height distribution of the zonally averaged relative humidity (in %)
Values larger than 60% are shaded.

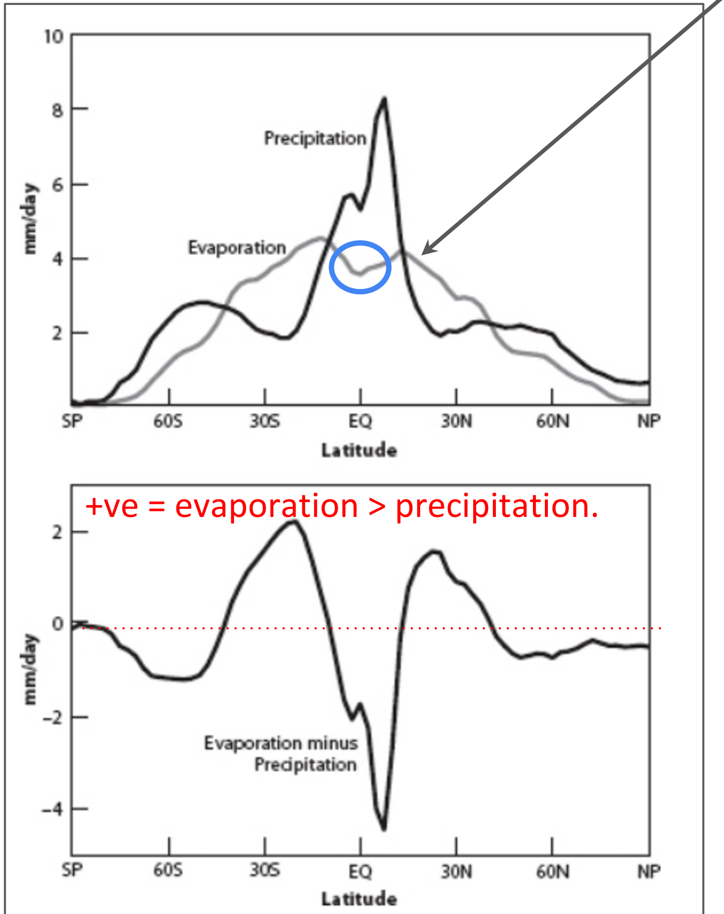
https://sites.ecmwf.int/era/40-atlas/docs/section_D25/parameter_zmtsp.html

Justify and Explain the observations in the following regions.



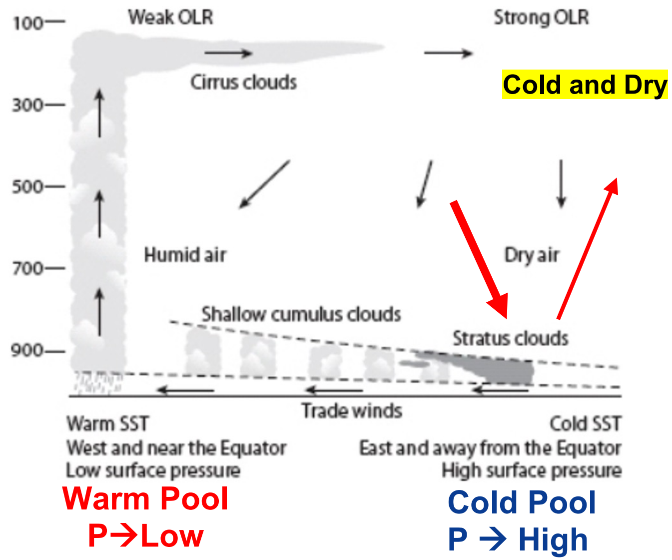
Adler et al., 2003

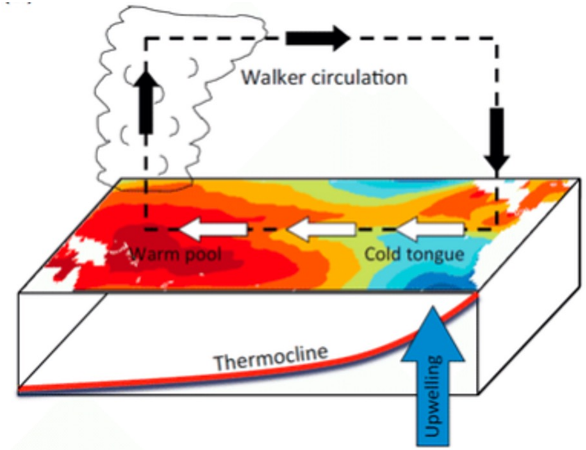
Zonal means of the annually averaged evaporation, precipitation, and their difference



Why the evaporation rate has maximums in the subtropics?

What processes move moisture away from the subtropics?





The Hadley - Walker Circulation

The east-west overturning circulations with the rising branch over the warm waters of the western Pacific Ocean and sinking branch over the cold water west of South America.

What is the reason for Weak OLR over warm pool and Strong OLR over the cold pool ?

Eastern Pacific → Colder Ocean and strong subsidence

Stratus clouds → Albedo (50%) → Low SST

Central Pacific → Warmer oceans and weak subsidence

Cumulus clouds → 2-3 Km Moist air column → Fuels Warm Pool

“The Warm Pool emits weakly to space, while the Cold Pool emits strongly.”

Some Checks and Balances

- Why do we have **high/ low** temperature and pressure gradients in the tropics?

- What decides the width of warm and cold pools of the walker circulation?

Dry Static energy

$$s \equiv c_p T + gz.$$

$$\frac{Ds}{Dt} \cong \frac{\partial s}{\partial z}\frac{Dz}{Dt}$$

$$= \frac{\partial s}{\partial z} w$$

$$\left(\frac{\partial s}{\partial z}\right)\rho w = Q,$$

Upward mass flux → Heating

Downward mass flux → Cooling

Warm Pool

Warm Pool → Rising motion → Q > 0 (cumulus convection and radiation)

Thunderstorms → Moist adiabatic lapse rate → ds/dz > 0

convectively imposed dry static energy profile.

W > 0

Cold Pool

Cold pool → Sinking Motion → Q < 0 (radiative cooling)

Tropic is horizontally uniform → same ds/dz > 0 as of warm pool

The only other variable is the vertical velocity, w.

W < 0

"The rate at which the air sinks in the Cold Pool is determined by the radiative cooling rate and the convectively imposed dry static energy sounding."

Mass Balance

$$Mass\ Flux\ =\ \rho.\ width\ .\ w$$

Downward Mass flow (cold Pool) ⇒ Outflow by trade winds ⇒ Upward flow (Warm Pool)

Energy Balance

$$Energy\ Flux\ =\ \dot{Q}\ .\ width$$

radiative energy loss (Cold Pool)= latent heat release + possible radiative warming (Warm Pool)

Water Balance

precipitation (Warm Pool) = evaporation (Cold Pool)

which depends on the strength of the trade winds, and the SST and width of the Cold Pool.

The widths of the Warm and Cold Pools must adjust to achieve these balances.

Speed of the water cycle and negative feedback loop

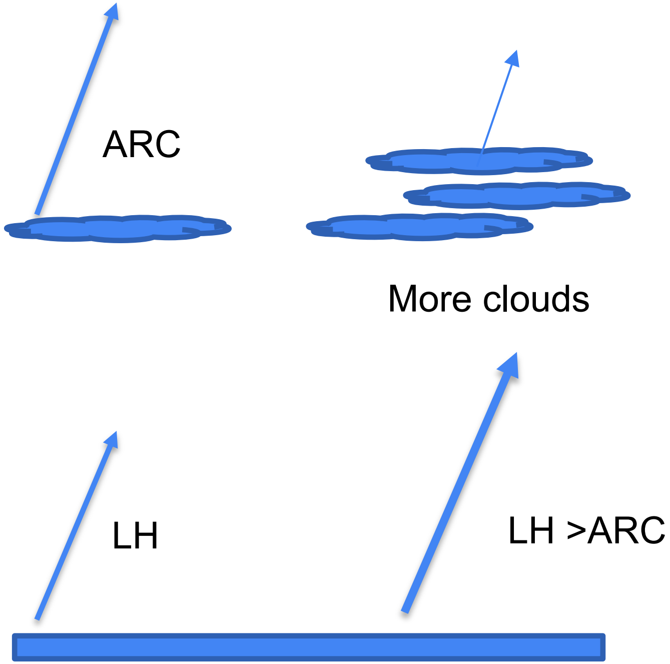
Speed → rate of evaporation and precipitation

Earth surface : radiative heating = evaporative cooling

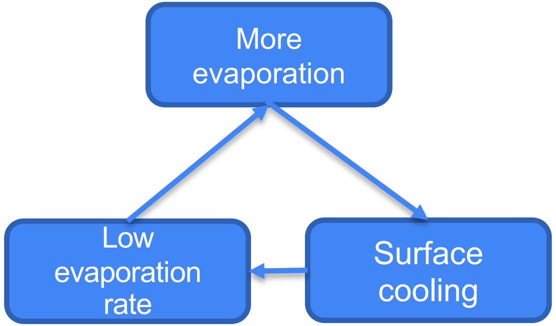
Atmosphere : radiative cooling (ARC) = Latent heat release

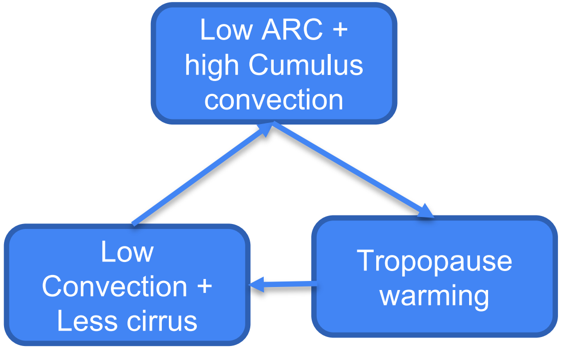
Let's speed up the hydrological cycle:

More LH (evaporation) + Less ARC (Cirrus clouds)



Negative Feedback





Water cycle and global warming

How will increase in temperature affect the water vapor?

- Intensity of extreme events will increase
- ↑ water vapor → ↑ rainfall rate ……. But at a much smaller rate, why?

Let's see why ☺

↑ rainfall rate → ↑ radiative cooling (warmer air temperatures + high H2O greenhouse) → Hydrological cycle will speed up → negative feedback ☺

So overall rainfall rate will only increase by 2% per Kelvin

If **dq is large** and **dp is small** what will happen to **Mc** in warmer climates ?

$$P = qM_c$$

$$\frac{dM_c}{M_c} = \frac{dP}{P} - \frac{dq}{q}$$

P → Precipitation rate
Mc → Convective mass flux
q → lower tropospheric water vapour

$$\frac{d(\rho w)}{\rho w} = \frac{dQ}{Q} - \frac{d(\partial s/\partial z)}{\partial s/\partial z}.$$

We know, in the descending branch of Hadley cell
Warming due to sinking (adiabatic) = radiative cooling

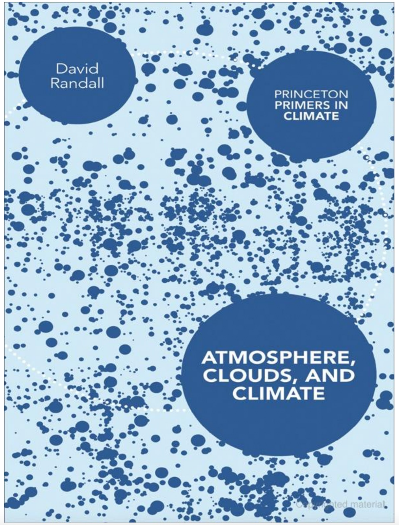
surface warming → needs more radiative cooling → **dQ/Q >0**

↑ radiative cooling → ↑ adiabatic warming → Decrease in moist adiabatic lapse rate → **d(ds/dz)/(ds/dz) >0**

Current research suggest that d(ds/dz)/(ds/dz) increases more than dQ/Q

Predictability of Weather and Climate

Chapter - 7
Atmosphere Clouds and Climate



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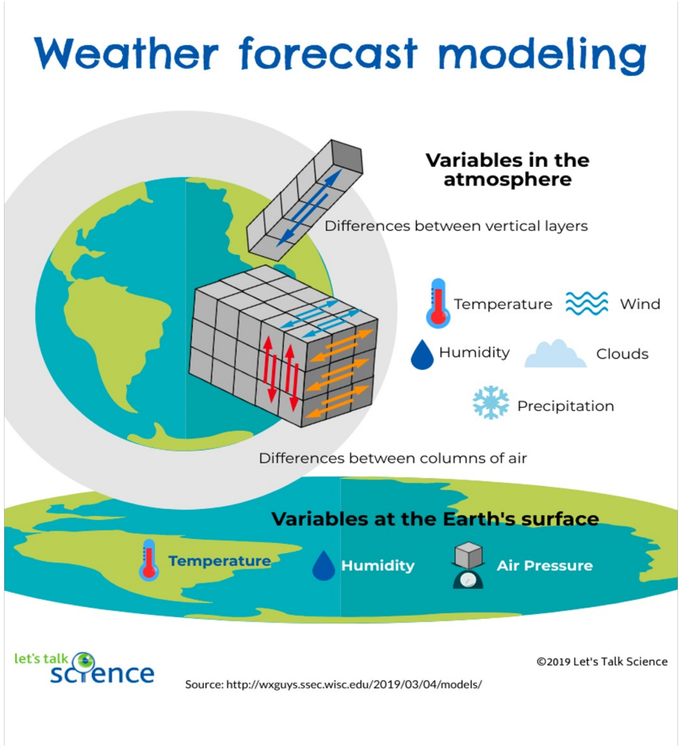
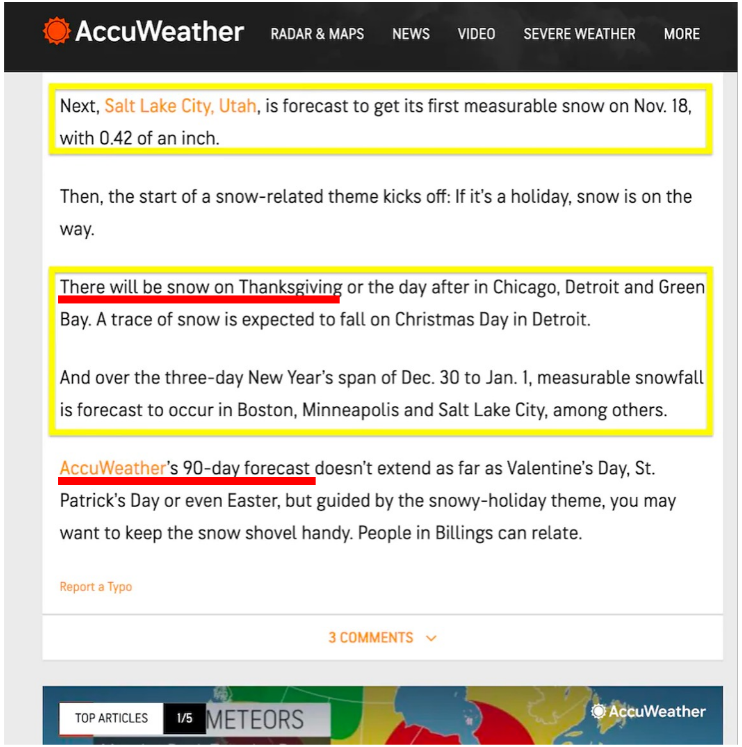
How Forecast is made?



https://letstalkscience.ca/educational-resources/stem-in-context/why-weather-so-hard-predict

How predictable is the weather?


AccuWeather RADAR & MAPS NEWS VIDEO SEVERE WEATHER MORE

Next, Salt Lake City, Utah, is forecast to get its first measurable snow on Nov. 18, with 0.42 of an inch.

Then, the start of a snow-related theme kicks off: If it's a holiday, snow is on the way.

There will be snow on Thanksgiving or the day after in Chicago, Detroit and Green Bay. A trace of snow is expected to fall on Christmas Day in Detroit.

And over the three-day New Year's span of Dec. 30 to Jan. 1, measurable snowfall is forecast to occur in Boston, Minneapolis and Salt Lake City, among others.

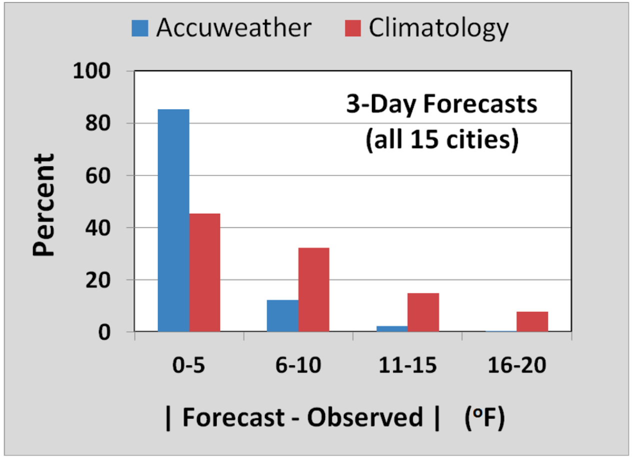
AccuWeather's 90-day forecast doesn't extend as far as Valentine's Day, St. Patrick's Day or even Easter, but guided by the snowy-holiday theme, you may want to keep the snow shovel handy. People in Billings can relate.

Report a Typo

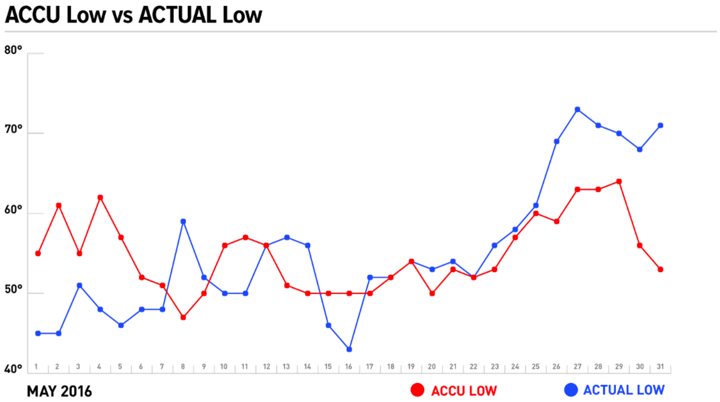
3 COMMENTS

TOP ARTICLES 1/5 METEORS AccuWeather

https://www.accuweather.com/en/us/college-park/20740/october-weather/333562
https://www.washingtonpost.com/weather/2019/11/07/science-says-specific-weather-forecasts-cant-be-made-more-than-ten-days-advance/



https://www.washingtonpost.com/news/capital-weather-gang/wp/2013/12/26/students-put-accuweather-long-range-forecasts-to-the-test/



https://www.josh-rosenberg.com/2013/06/accuweather-long-range-forecast-accuracy/

"It turns out that, for fundamental physical reasons that are unrelated to any specific forecast method, it is impossible to make a skillful weather forecast more than about two weeks ahead."

What Is the Predictability Limit of Midlatitude Weather?

Fuqing Zhang[1], Y. Qiang Sun[1], Linus Magnusson[2], Roberto Buizza[2], Shian-Jiann Lin... View More +

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Page(s): 1077–1091

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Abstract/Excerpt | Full Text | PDF

Abstract

Understanding the predictability limit of day-to-day weather phenomena such as midlatitude winter storms and summer monsoonal rainstorms is crucial to numerical weather prediction (NWP). This predictability limit is studied using unprecedented high-resolution global models with ensemble experiments of the European Centre for Medium-Range Weather Forecasts (ECMWF; 9-km operational model) and identical-twin experiments of the U.S. Next-Generation Global Prediction System (NGGPS; 3 km). Results suggest that the predictability limit for midlatitude weather may indeed exist and is intrinsic to the underlying dynamical system and instabilities even if the forecast model and the initial conditions are nearly perfect. Currently, a skillful forecast lead time of midlatitude instantaneous weather is around 10 days, which serves as the practical predictability limit. Reducing the current-day initial-condition uncertainty by an order of magnitude extends the deterministic forecast lead times of day-to-day weather by up to 5 days, with much less scope for improving prediction of small-scale phenomena like thunderstorms. Achieving this additional predictability limit can have enormous socioeconomic benefits but requires coordinated efforts by the entire community to design better numerical weather models, to improve observations, and to make better use of observations with advanced data assimilation and computing techniques.

Reason 1 → Errors in Initial Conditions

Instrumental Errors

Gaps in the data

Small scales are not well observed

Reason 2 → Imperfections on the Models

Limited computational resources

Parameterization

Numerical approximations to mathematical laws

Reason 3 → Sensitive dependence on initial conditions

Instabilities

- Shear instability → meters or less
- Buoyancy Driven instabilities (cumulus instability) → 100 ms – 10s Kms
- Baroclinic Instability → 1000s Km

Scale Interactions

Small-scale weather systems, such as cumulus clouds, can modify the larger scales, such as baroclinic waves, and the latter in turn can strongly influence where and when the cumulus clouds grow.

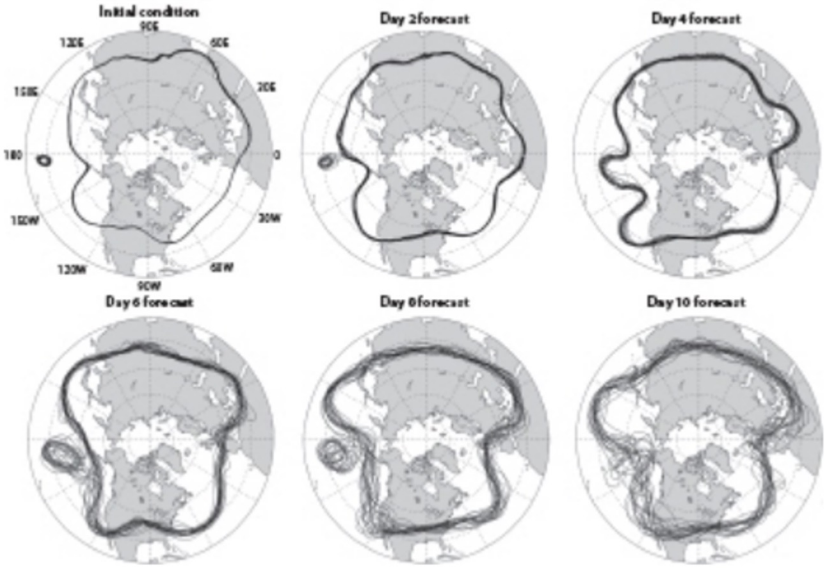


Figure 7.1. Actual forecasts of the shapes of the 5,640 m height contour for a pressure surface in the middle troposphere.

The plots look down on the North Pole, and North America is at the bottom center of each panel. The forecast times shown are the initial conditions (top left), and then, proceeding to the right across the upper row and then left to right across the bottom row, every two days after that, out to 10 days. The plotted curves show the positions of the contours as predicted in an ensemble of forecasts that are started from initial conditions that differ very slightly from each other. These are called "spaghetti diagrams."

https://mag.ncep.noaa.gov/model-guidance-model-parameter.php?group=Model%20Guidance&model=gefs-spag&area=namer&cycle=20221023%2012%20UTC&param=500_510_552_ht&fourpan=no&imageSize=M&fhr_mode=image&loop_start=-1&loop_end=-1&skip_num=1

Deterministic Non-Periodic Flow

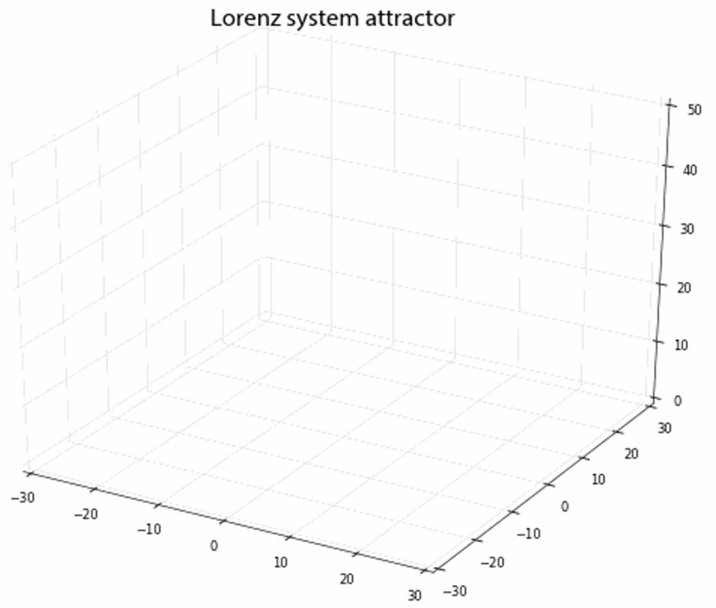
Future evolution of the system is completely determined by a set of rules.

Is Atmosphere Deterministic ?

A periodic system (or flow) is one whose behavior repeats exactly on some regular time interval.

Is Atmosphere Periodic ?

Deterministic and Non-Periodic



- Wings are called attractors (probabilities)
- Random transition between attractors

Lorenz Model

Coupled 1st order ODEs

$$\dot{X} = -\sigma X + \sigma Y$$
$$\dot{Y} = -ZX + rX - Y$$
$$\dot{Z} = YX - bZ$$

Nonlinear terms →XY, ZX interactions of time scales

- For some values of parameters, all the steady and periodic solutions are unstable
- The instability arises on different scales and then scales interaction makes system nonperiodic

Instabilities + scale interactions are properties of the atmosphere itself, which limits our predictability; we cannot make them “go away” by improving our models or our observing systems.

No matter what method is used to make a forecast, the predictability limit comes into play. It is not the limitation of NWP Models!

If you can't predict a month forget about a decade!

What makes Climate Predictable ?

Two Major Reasons

1. Climate system have components with long memories. Example Oceans, stratosphere, plate tectonics

2. The climate system response is systematic and predictable to external forcings

Example → Seasonal cycle

Lets assume a model is starting on 1st January over College park.

We can say → average July temperature will be higher than January
Every single day in July will be warmer than January 1

But the same model cannot predict the weather of CP on January 15th

Climate prediction is possible when there is a strong, predictable change in the external forcing of the system.

Eg. Earth's motion around sun is predictable, it's a strong change in RF and therefore we can predict climate! Same with Ice ages and global warming

Weather change is not due to changes in external forcing, but changes in climate are.

Weather prediction is limited by sensitivity dependence of past history, climate prediction is not.