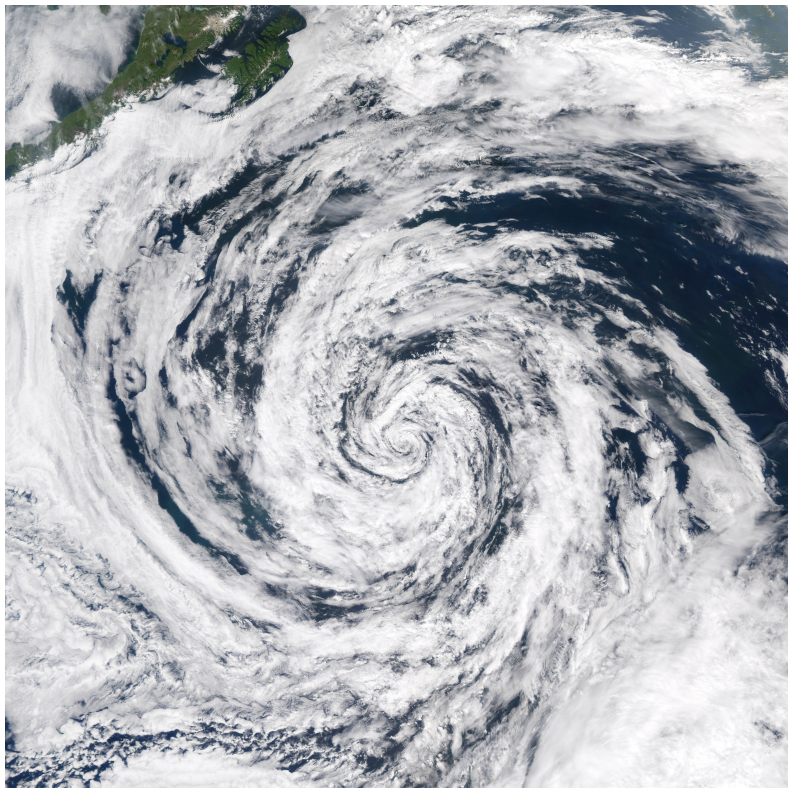
Can we predict cyclones by rolling dices?

F. BOUCHET (ENS-Lyon, France)

Stratford upon Avon, February 2013

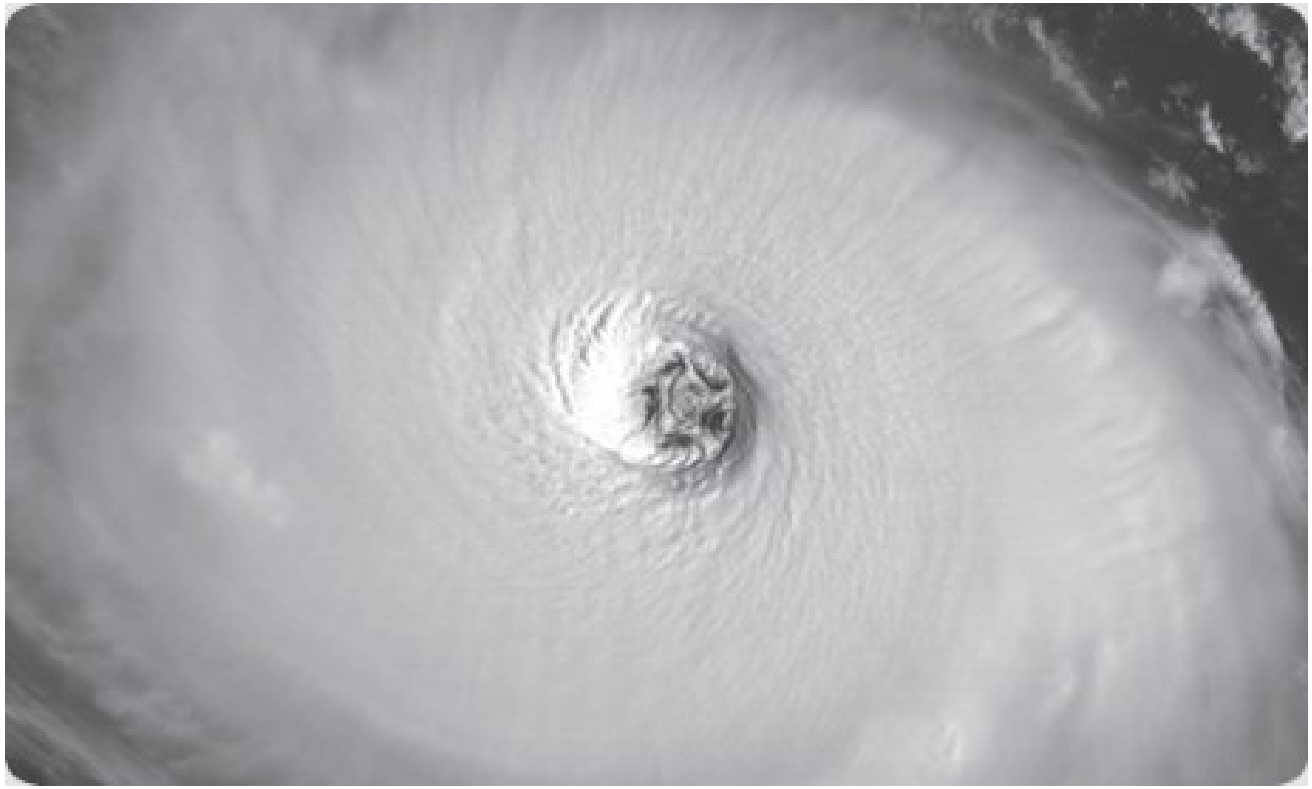
Cyclones and Anticyclones



A cyclone (low pressure disturbance)

- Geophysical fluid mechanics.

Cyclones and Anticyclones



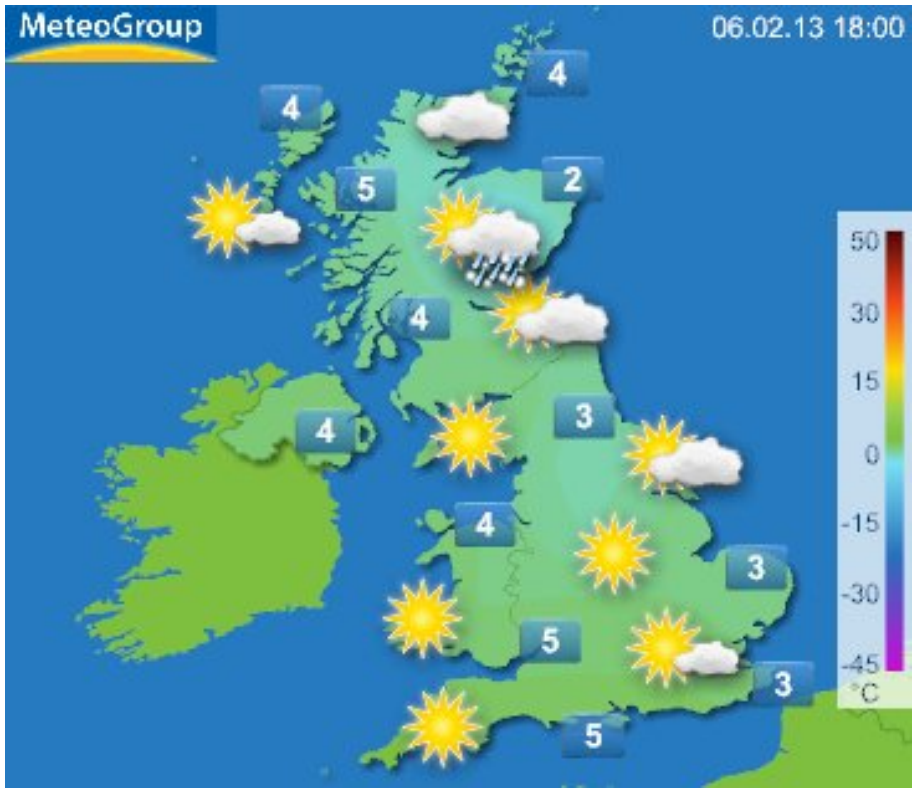
A tropical cyclone (hurricane Isabell)

- How does flows know about hexagons?

Can we predict cyclones by rolling dices?

Outline

Weather Maps Dynamics

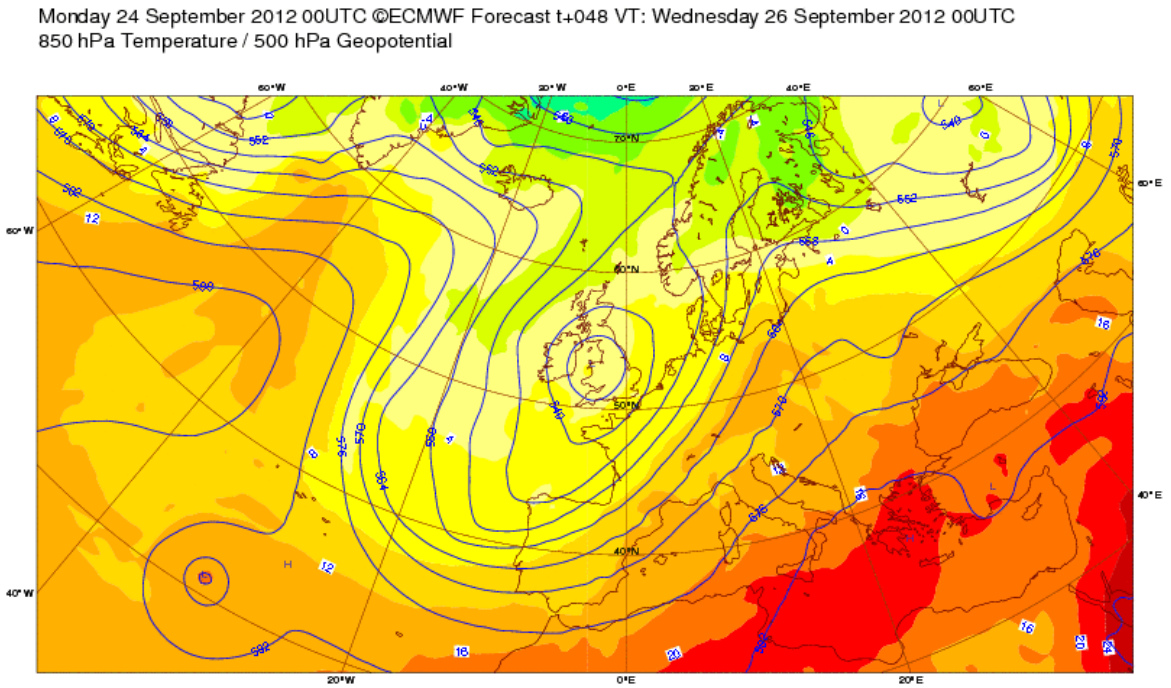


- What are the causes for weather changes?

Pressure Maps Explains Weather

- Weather is correlated to pressure maps. Lows (low pressure) are cyclones. High (high pressure) are anticyclones.
- Can we understand the dynamics of pressure maps?

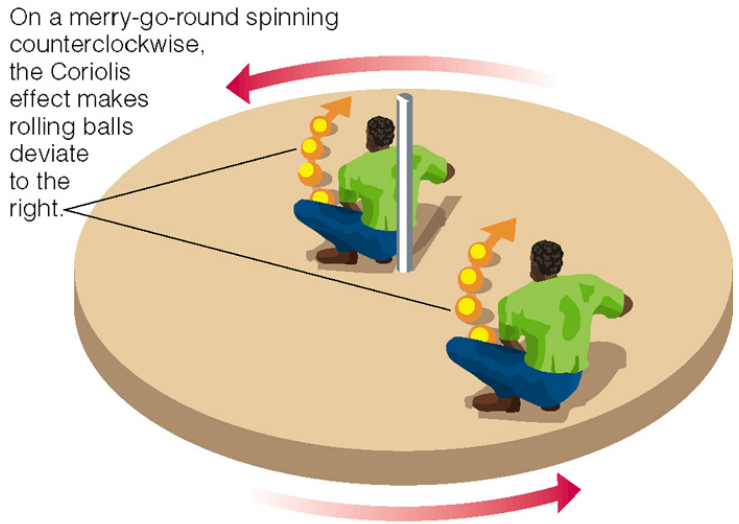
England has not the Right Scale



Temperature and pressure maps over Europe (26/09/2012)

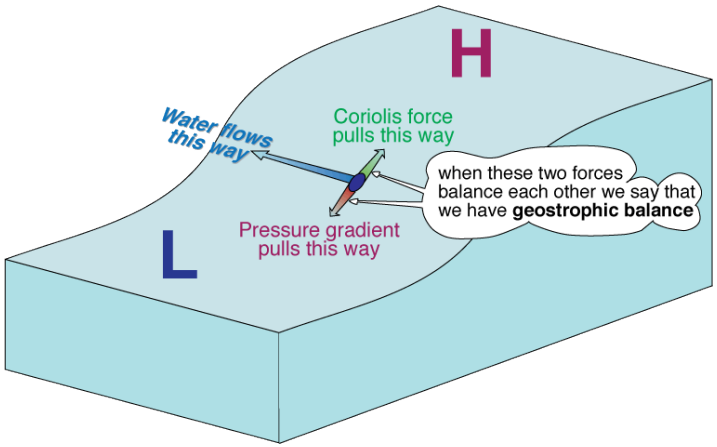
- The good scale to understand atmosphere dynamics is synoptic scale (thousands of kilometers).

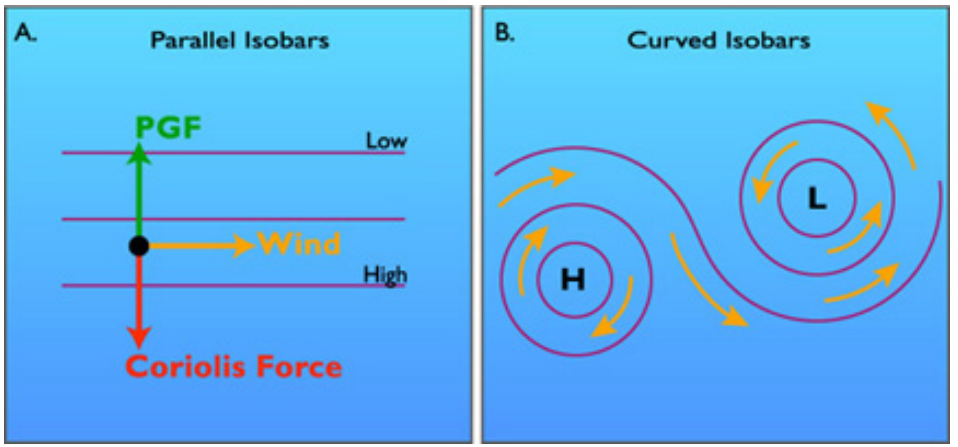
Coriolis Force



- Coriolis force is a force felt by a body moving with respect to a rotating reference frame.
- Coriolis force (depends on the velocity) is different from centrifugal force (does not depend on the velocity).

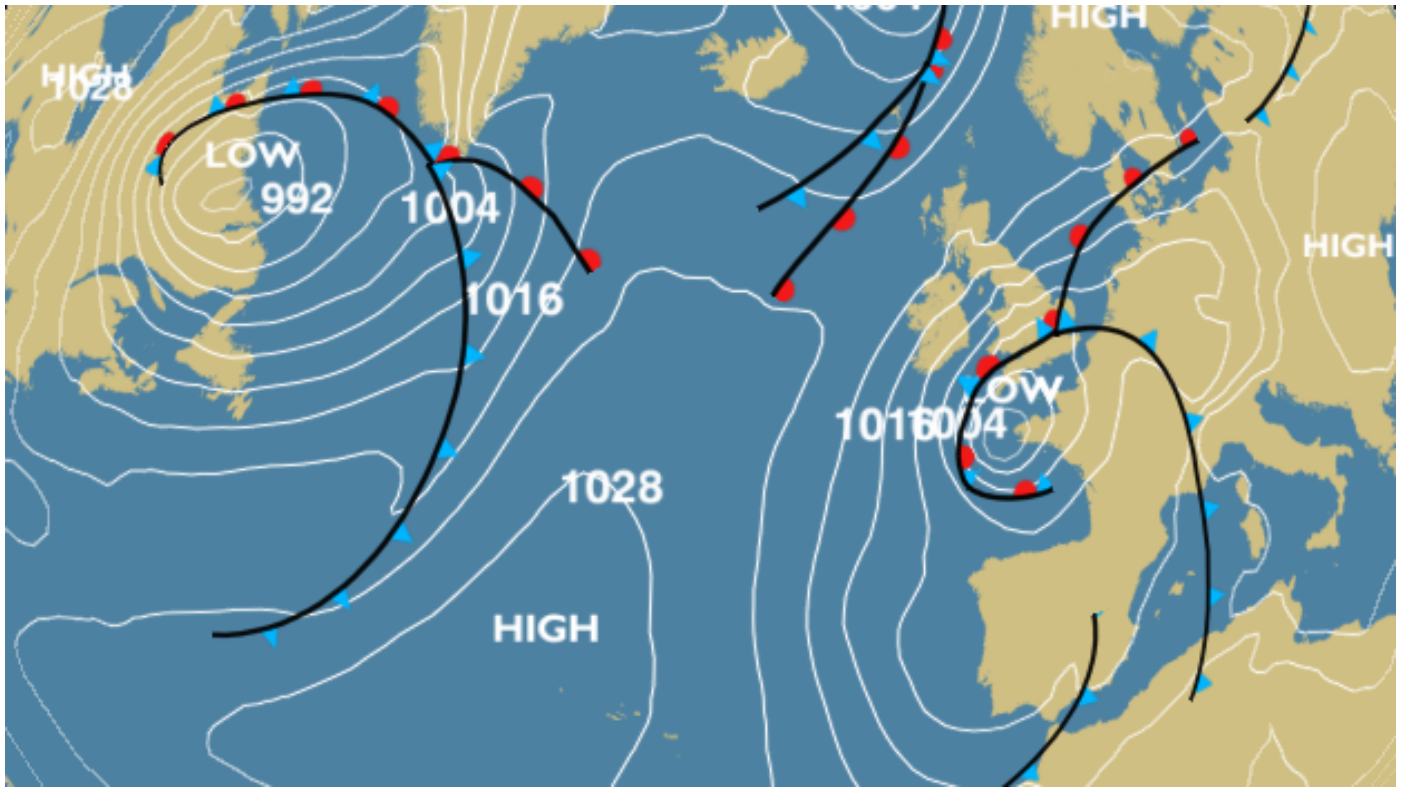
Winds Flow along Constant Pressure Lines





- Winds flow clockwise around anticyclone (high pressure) and flow anti-clockwise around cyclones (high pressure).
- This is reversed in the southern hemisphere. Why?

More about Pressure Maps



Pressure maps over North Atlantic (29/04/2012)

Where are We?

- Atmosphere dynamics is about pressure, temperature and wind.
- The right scales to understand these phenomena are thousands of miles or more.
- Winds flow along constant pressure line, clockwise around anticyclone and anti-clockwise around cyclones.
- What's next?

Few Interesting Issues

- Why does atmosphere moves at all?
- What is the energy source for this motion?
- How does it moves?

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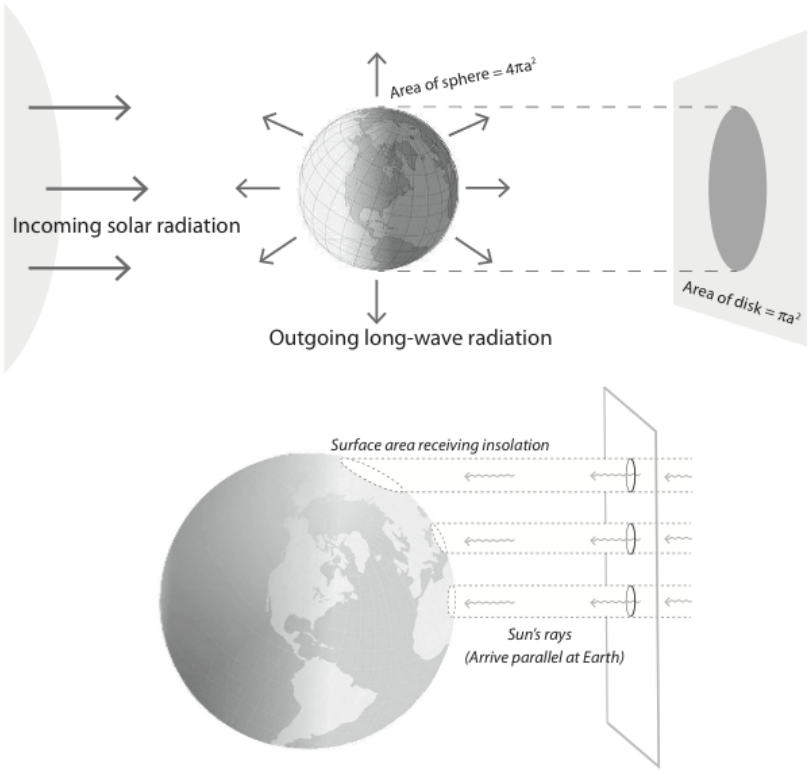
Outline

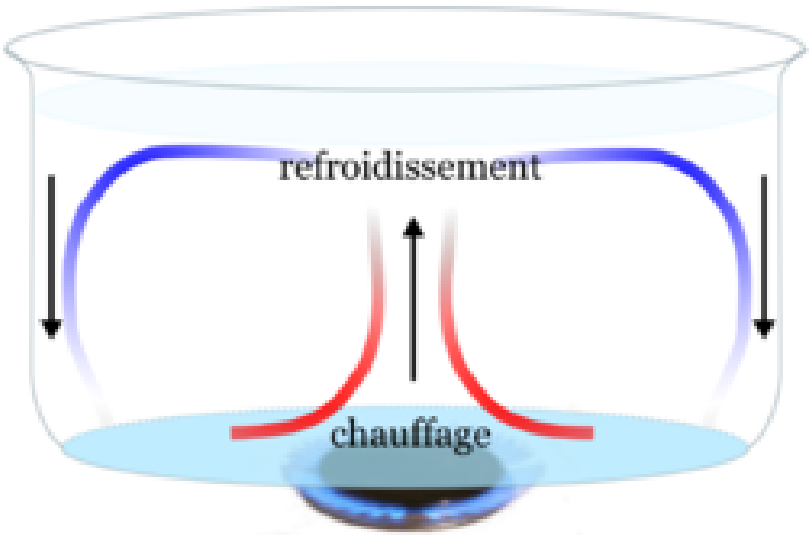
The Sun is the Source of most of Earth Energy



Why and how insolation varies with latitude.

- The source of the motion is the temperature difference between equator and poles, due to differences in insolation.

Convection: Temperature Differences Creates Motion in a Fluid

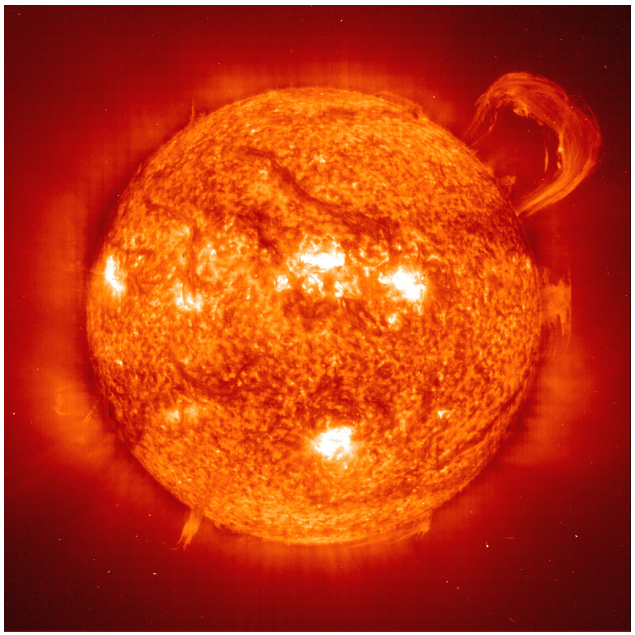


Convection in a pan heated from below

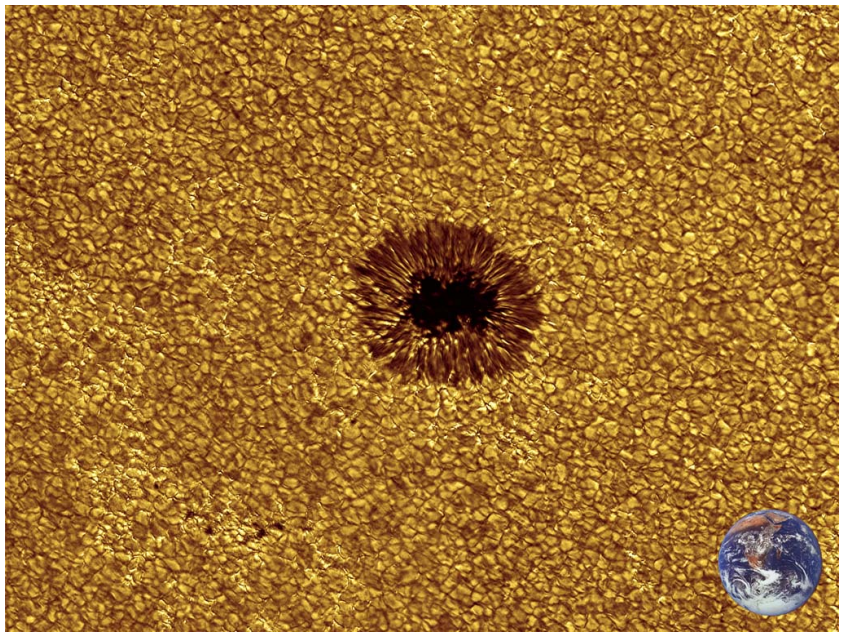
Rayleigh–Bénard convection

Sun Convection Cells

Sun is a plasma with an internal energy source

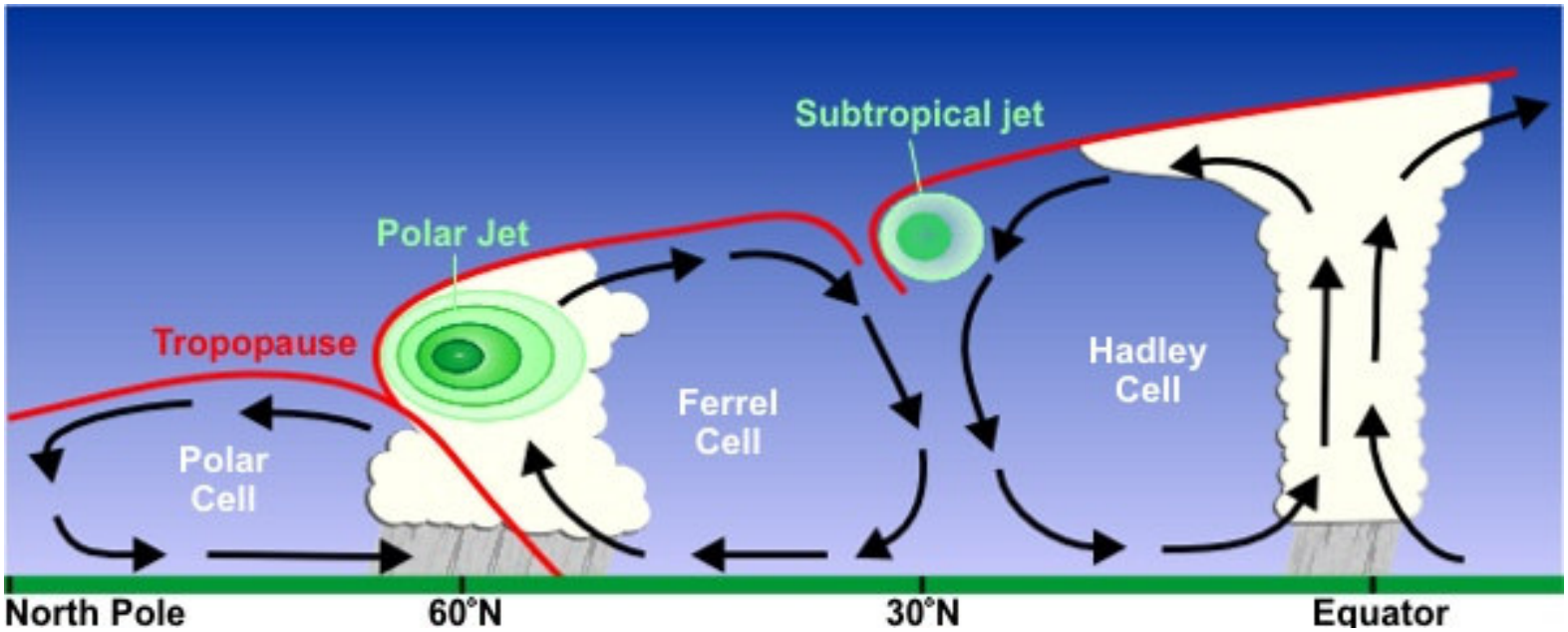


Sun observed by Soho satellite



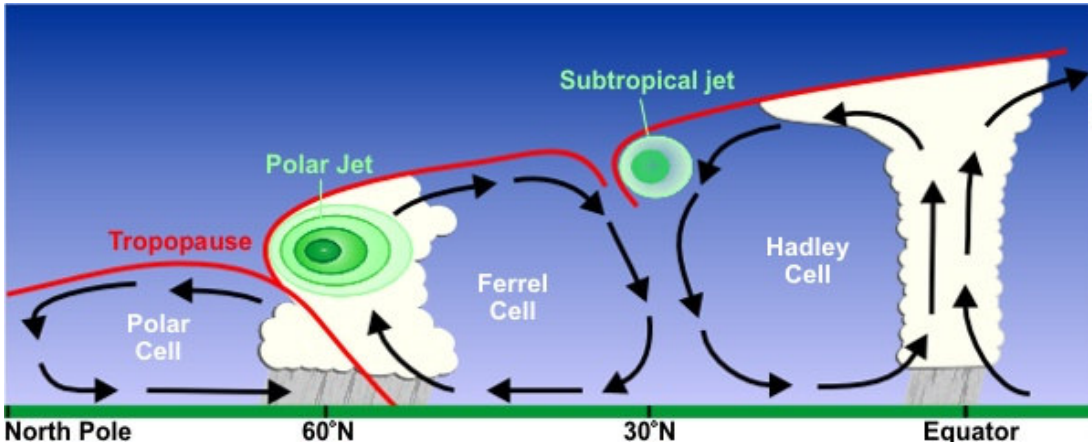
Sun convection cells

Atmosphere Convection

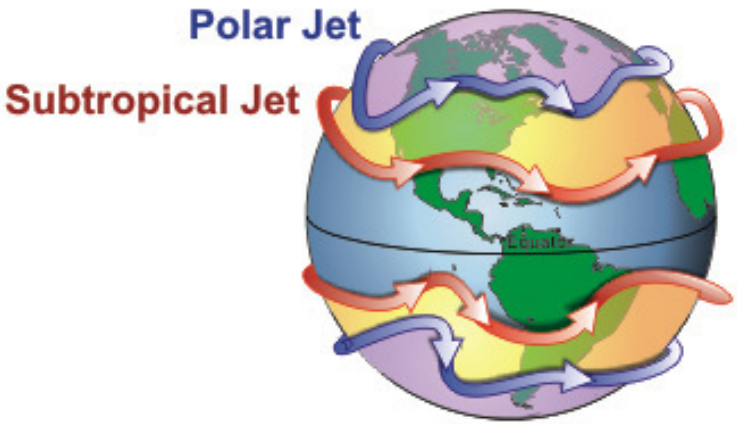


Atmosphere convection cells

Atmosphere Convection and Jet Streams

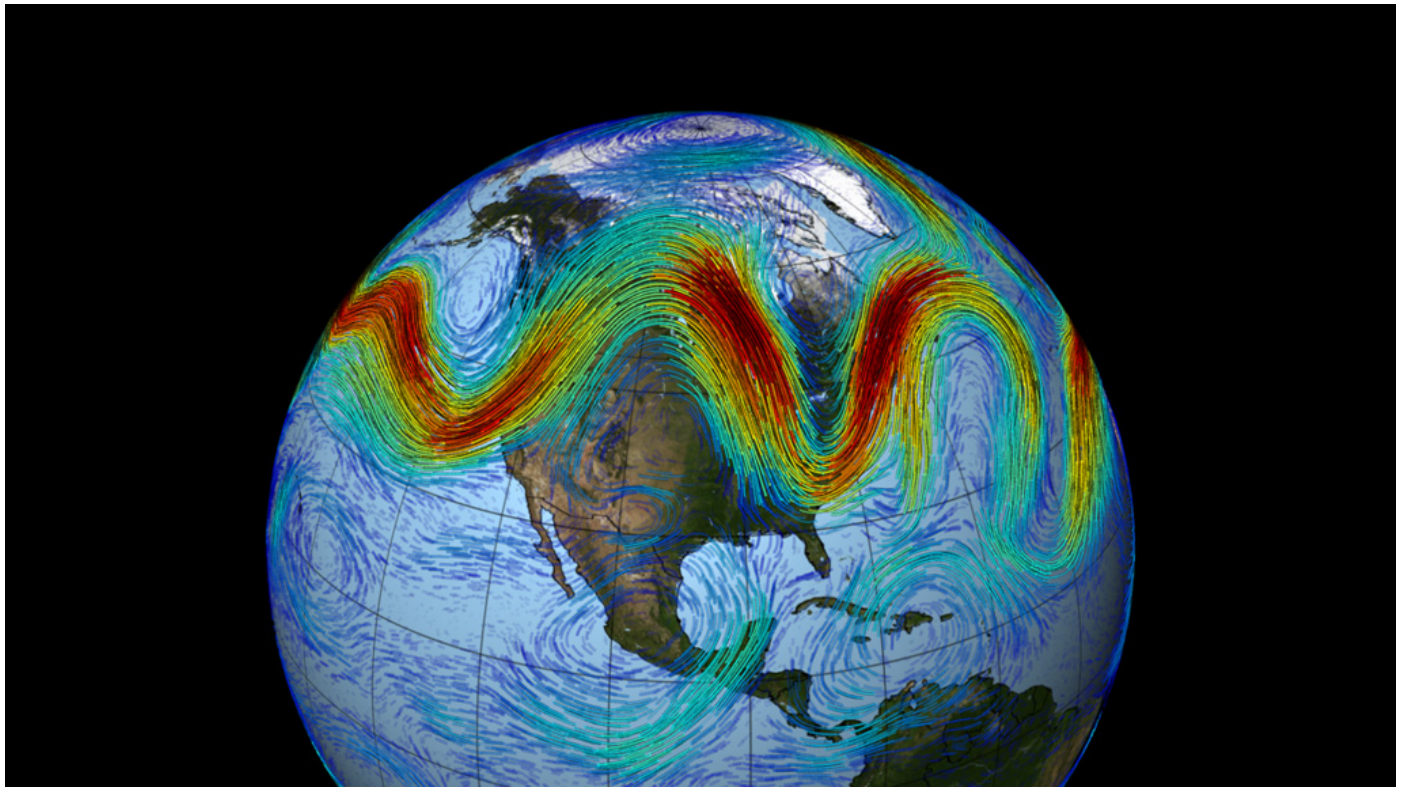


Atmosphere convection cells



Schematic jet stream configuration

Atmosphere Jet Dynamics

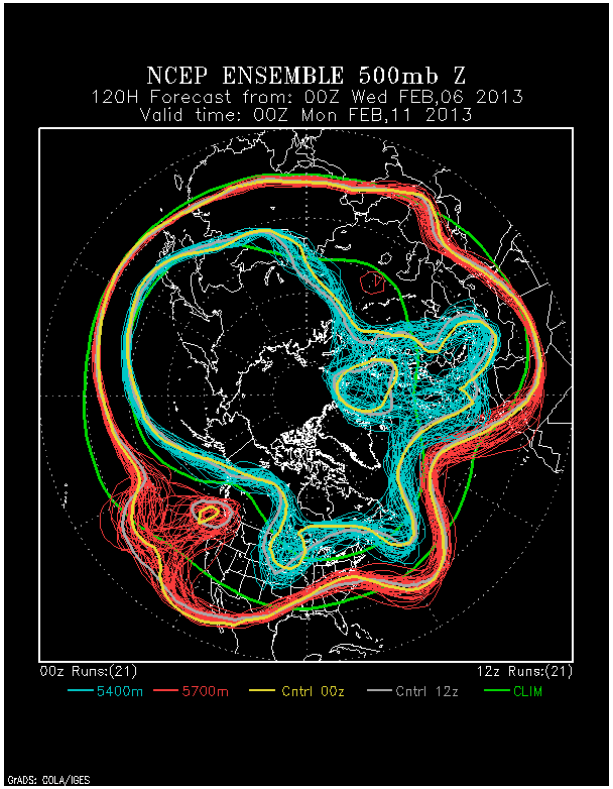


Upper atmosphere velocity

Outline

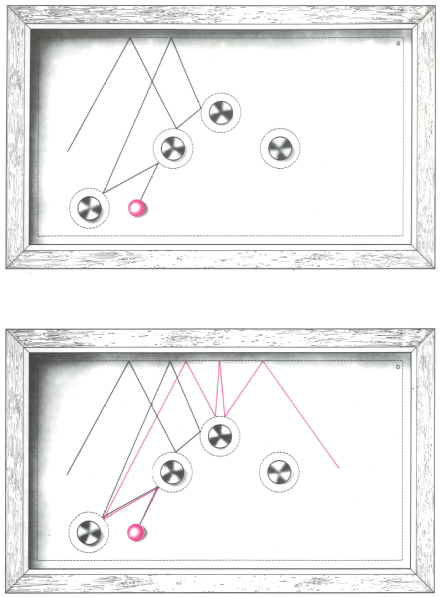
The Dynamics of Atmosphere Jets is Chaotic

Sensitivity to initial conditions (butterfly effect)



- The weather can not be predicted up to more than two weeks.
- This is not a practical problem, this a fundamental property of atmosphere dynamics. It is chaotic.

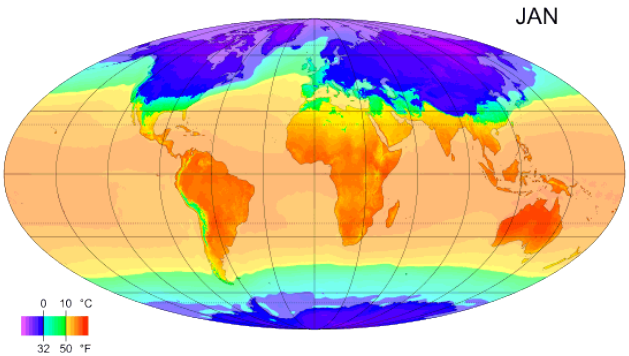
Billiard Dynamics and Sensitivity to Initial Conditions

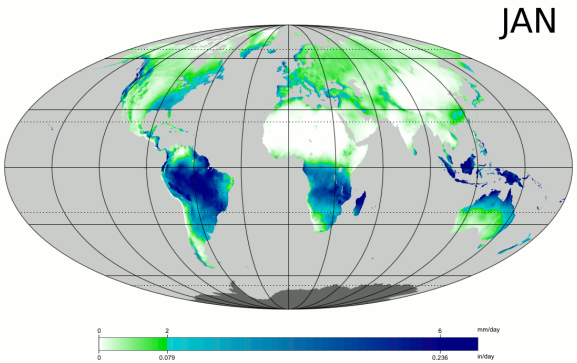


- Most billiards are chaotic: essence of chaos.
- Most dynamics in nature are chaotic.

What is Climate? Is it Different from Meteorology?

Climate is about the statistics (averages, standard deviations, and so on) of atmosphere properties

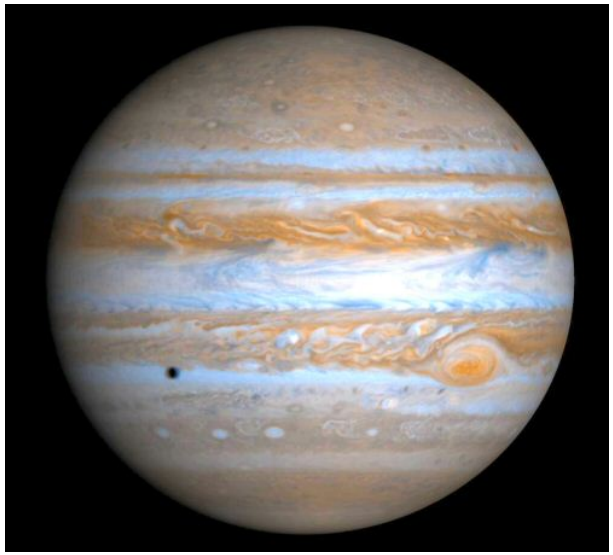




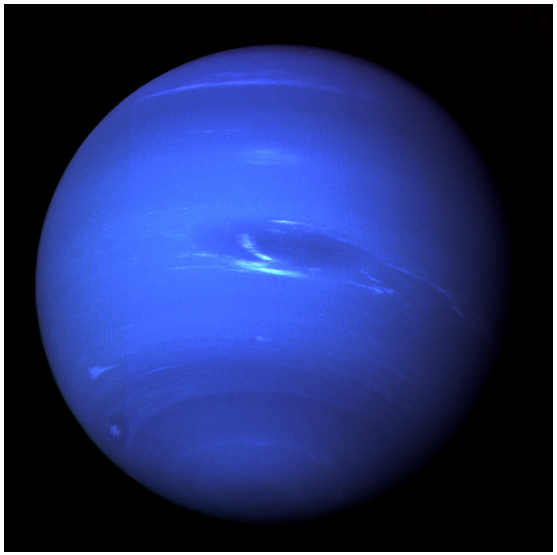
Monthly averaged temperature and precipitation (animation Temp.,animation Prec) (NCEP-NCAR)

- Meteorology is about weather today and tomorrow, climate is the average weather over long periods.

Changing Scale Again: Jupiter



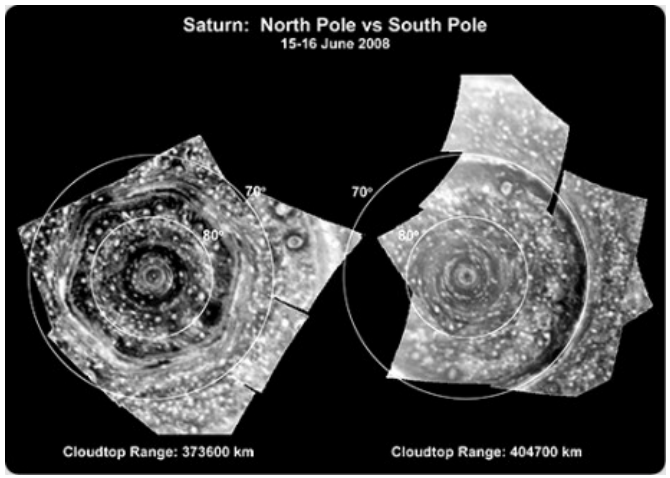
Jupiter atmosphere

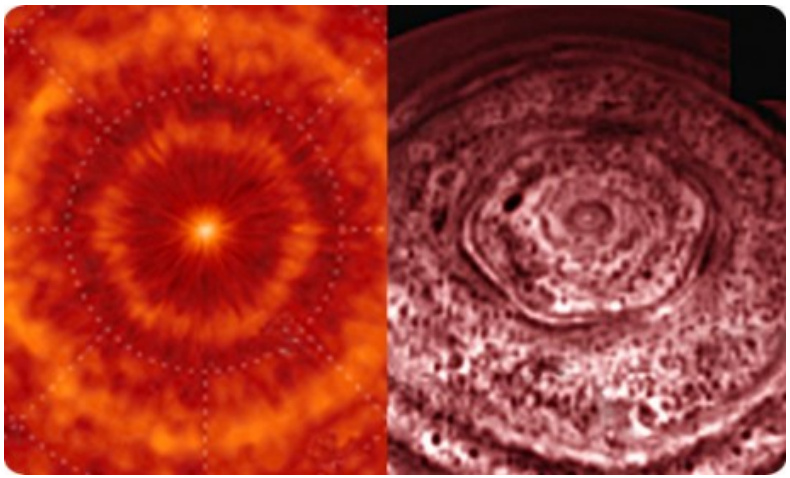


Neptune atmosphere

- Organization into jets, cyclones and anticyclones is universal for rotating fluids.

Saturn also Knows about Hexagons





Hexagons on Saturn north pole

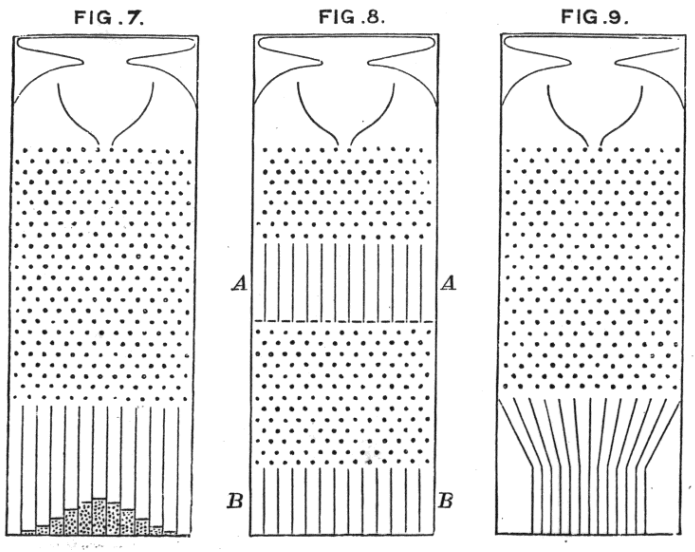
Fundamental Questions

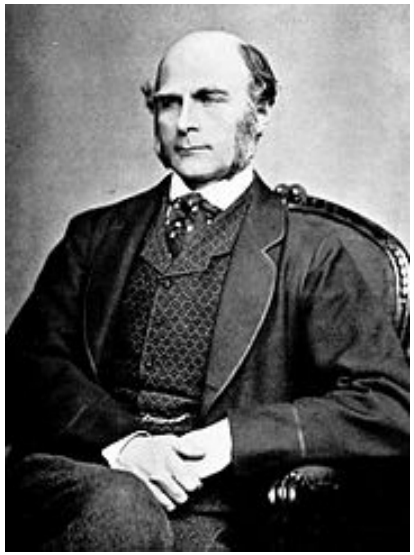
- How can we predict climate if we can not predict weather?
- Can we explain why the emergence of jets, cyclones and anticyclone is so universal?

Outline

Galton's Quincunx

A probability machine





Galton's probability machine

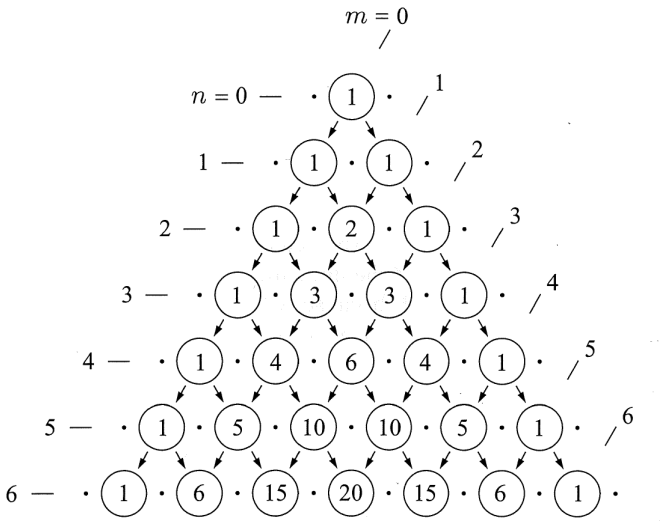
Galton (1822-1911)

- Simple mechanical systems have probabilistic behaviors.

Pascal Triangle

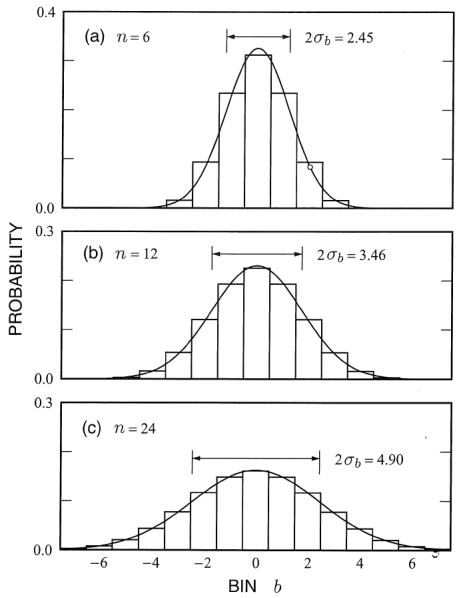
Binomial probability for two equiprobable events (p=1/2)

We pick at random the right or left direction, with probability 1/2. Pascal triangle counts the number of outcomes that finish at a given position after n steps.



Pascal triangle gives a binomial law with parameter $p = 1/2$

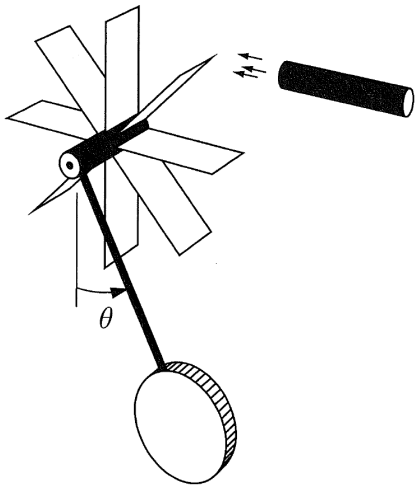
Evolution of Pascal Triangle and Gaussian Probability



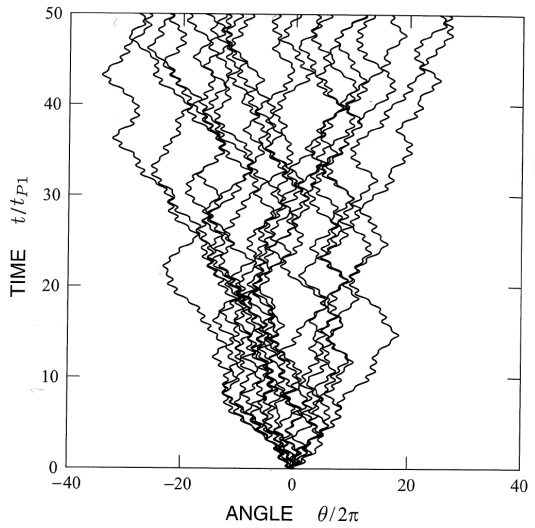
Evolution of a binomial law as a function of n : convergence towards a Gaussian probability

A Pendulum with Periodic Forces

An other probability machine



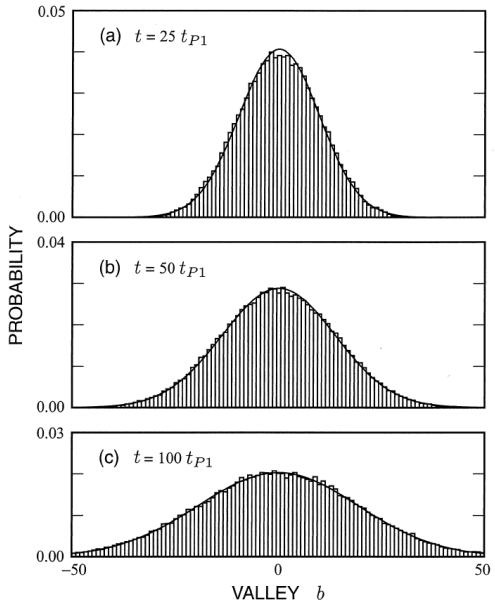
A pendulum with periodic forces



Evolution of pendulum positions

- Simple mechanical systems have probabilistic behaviors.

Statistics of Forced Pendulum



Evolution of probabilities for the pendulum position

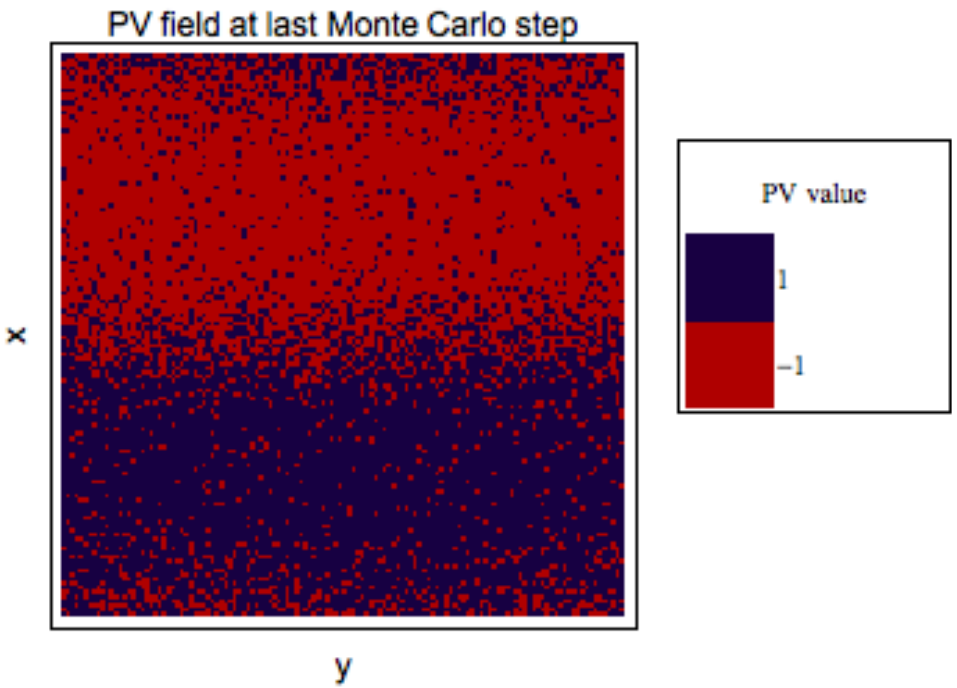
- Even if dynamics is chaotic and unpredictible, the probability evolution is regular and can be predicted.
- Here too, for large time, the probability is a Gaussian curve.

Probability and Chaotic Systems

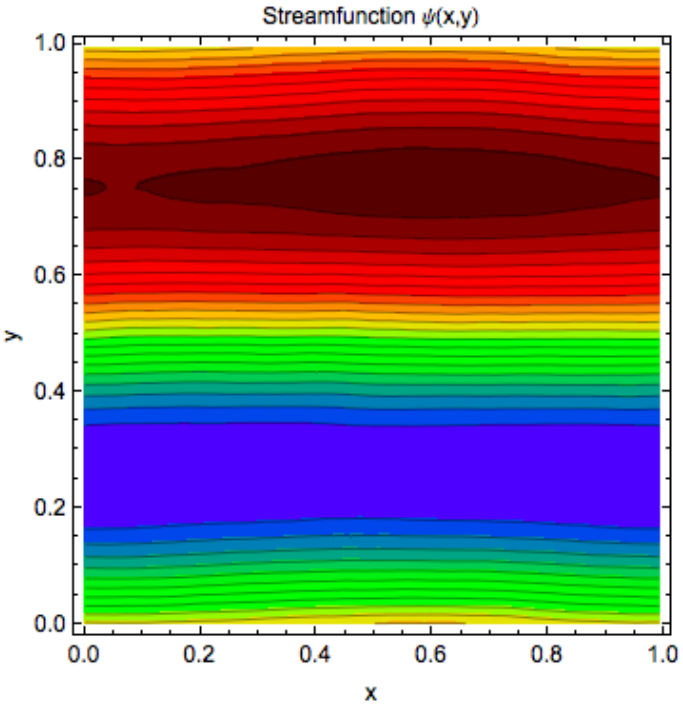
- In nature most dynamics have an unpredictable behavior after some times.
- Those dynamics are called chaotic.
- Their probability can then be predicted.
- Climate can be predicted even if weather cannot after about several days.

Outline

Throwing Vortices at Random Positions

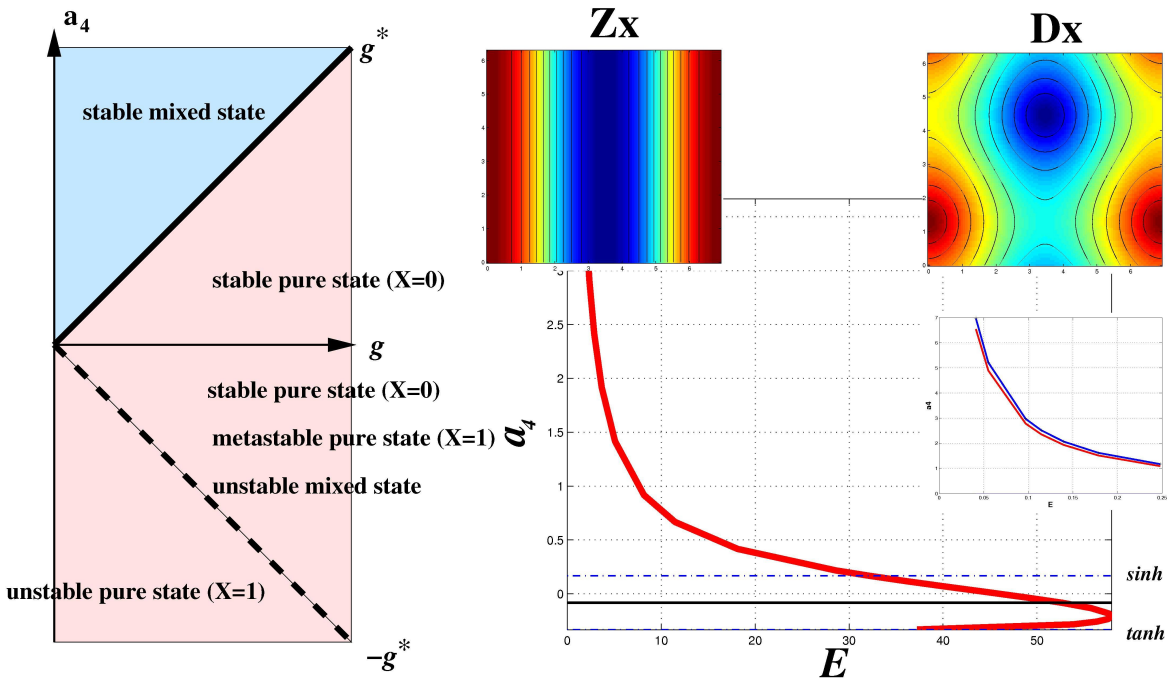


Random vortices



Pressure Lines

Jets, Cyclones and Anticyclones from Random Vortices

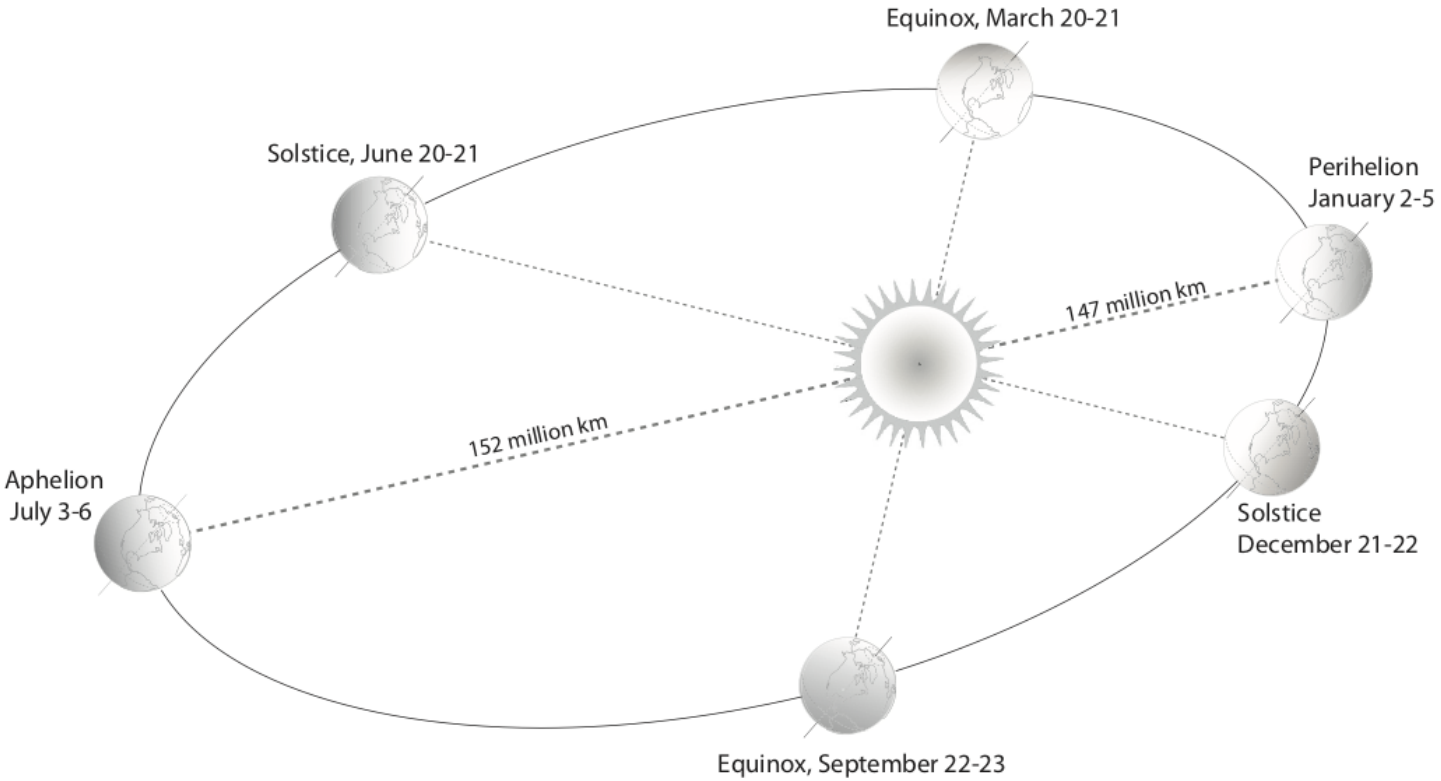


Statistical Mechanics of Jupiter's Great Red Spot

- Random vortices with energy conservation explains the emergence, **stability**, and predictability of Jupiter vortices.

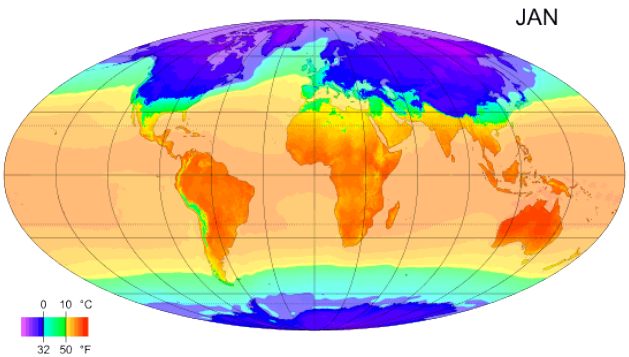
Outline

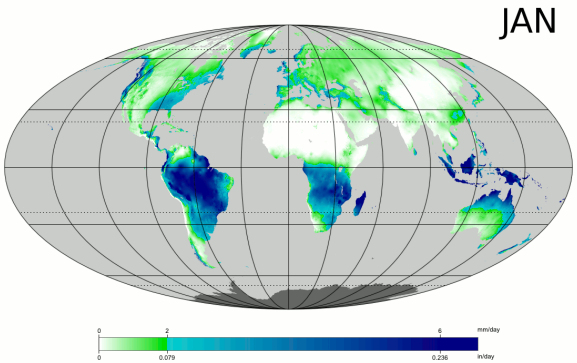
Seasonal and Yearly Variations of Insolation



Obliquity of Earth rotation axis and seasonal variations

Seasonal Temperatures and Precipitations

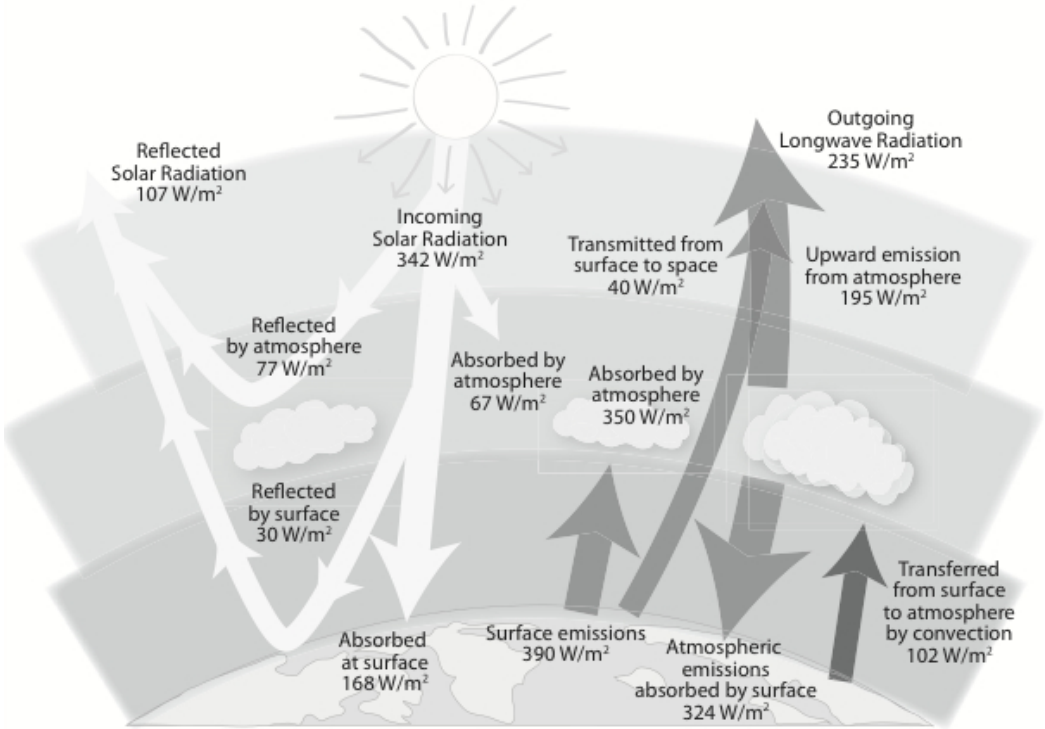




Monthly averaged temperature and precipitation (animation Temp.,animation Prec) (NCEP-NCAR)

The Greenhouse Effect

A natural phenomena, giving a Earth a nice climate

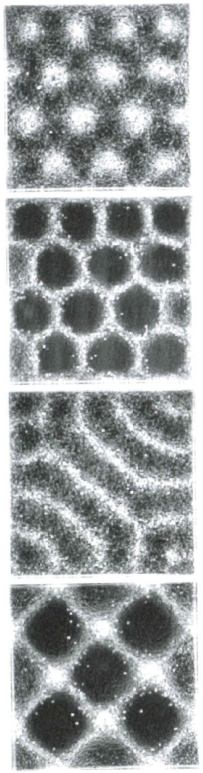


- The Greenhouse effect is deeply perturbed by CO_2 and methane emissions (fossil fuel burning).

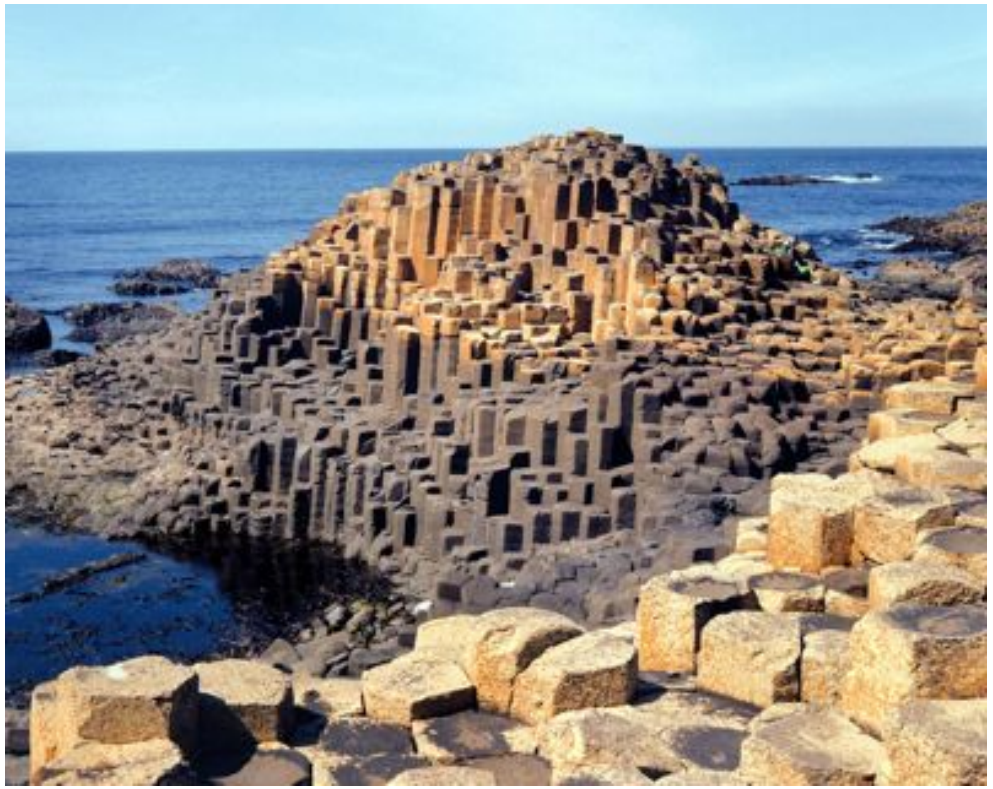
Conclusions

- The sun is the source of energy for atmosphere dynamics.
- It is dominated by Coriolis force. Anticyclones (Highs) flow clockwise, cyclones (Lows) flow anti-clockwise.
- Weather is unpredictable after several days (chaotic), but climate is predictable.
- Many features are universal. This is really appealing and push us for finding explanations.

Playing with Sand in Giant's Causeway



Sand on vibrated plates



Basalt rocks on Giant's Causeway (North Ireland)