Weather and Climate

Dennis Baldocchi
ESPM 2
UC Berkeley
Fall, 2017

Today's lecture is on Weather and Climate. Weather and climate are important to the biosphere as they provide the moisture and heat so necessary for life. As we will see later the types of climates across the world play an overwhelming impact on the type and distributions of plants and ecosystems.

Who Has Seen the Wind

Christina Rosetti

Who has seen the wind? Neither I nor you.

But when the leaves hang trembling, The wind is passing through.

Who has seen the wind? Neither you nor I.

But when the trees bow down their heads, The wind is passing by. -

English Romantic poet, 1830-1894

Outline

- Climate
  - California Climate
  - Global Climates
- Weather
  - Meteors
  - Fronts
  - General Circulation
  - Clouds and Precipitation
  - Big Weather Makers

Weather vs Climate

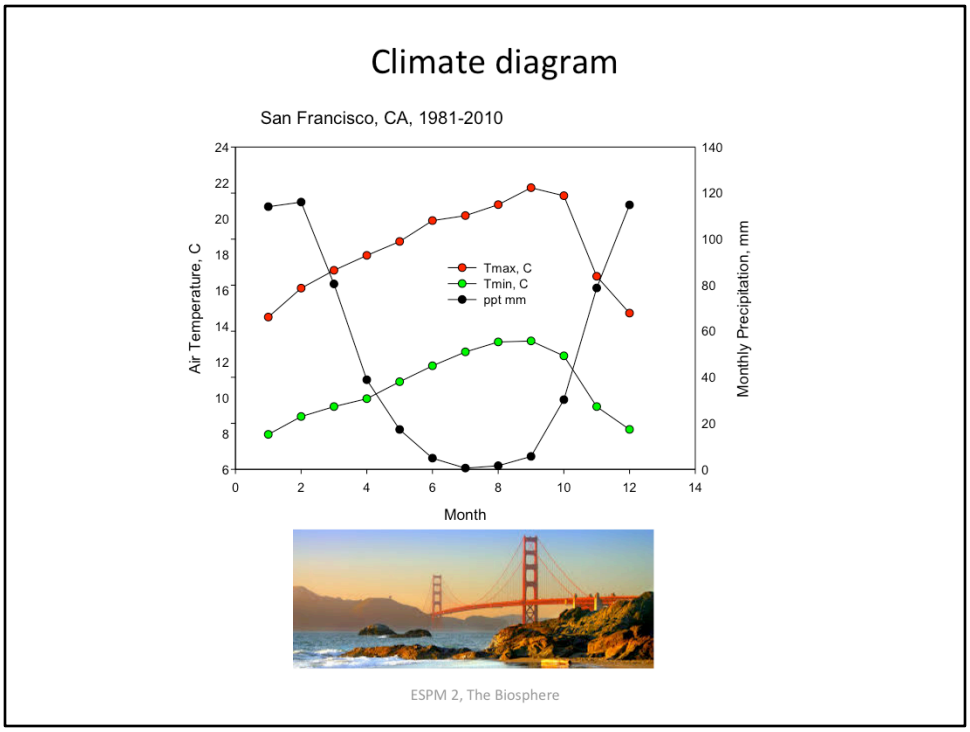
- *Climate is what we expect, Weather is what we get*.
  - Attributed to Mark Twain or Robert Heinlein
- Weather is the day to day conditions of the atmosphere that we experience
- Climate is the long term (> 30 years) average weather conditions, for a given day, season or year.

It is interesting in today's political environment that the term climate change is being purged from government, scientific web sites, yet climate deniers seem happy to talk about long term weather, instead, this term seems more innocuous.

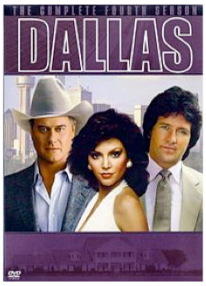
Types of Weather

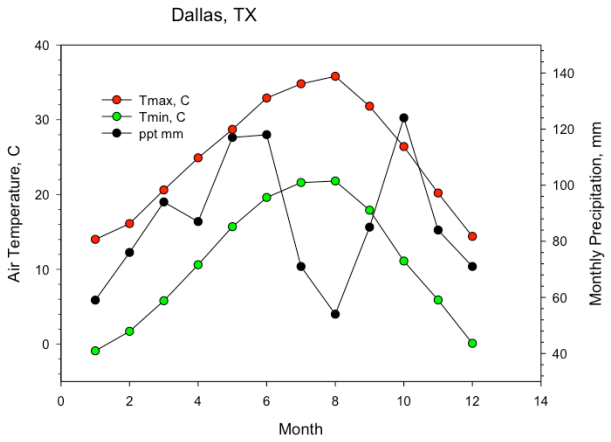
ESPM 2, The Biosphere

There is a panoply of weather types we experience each and every day, from hot to cold, sunny to cloud, dry to wet. Of course here in Berkeley we experience a mild, Mediterranean-type climate with coastal influences. Mild dry summers, with some marine layer fog or clouds, fall-winter rains interspersed with mild clear days. Temperatures are rarely below 10 C or greater than 30 C.



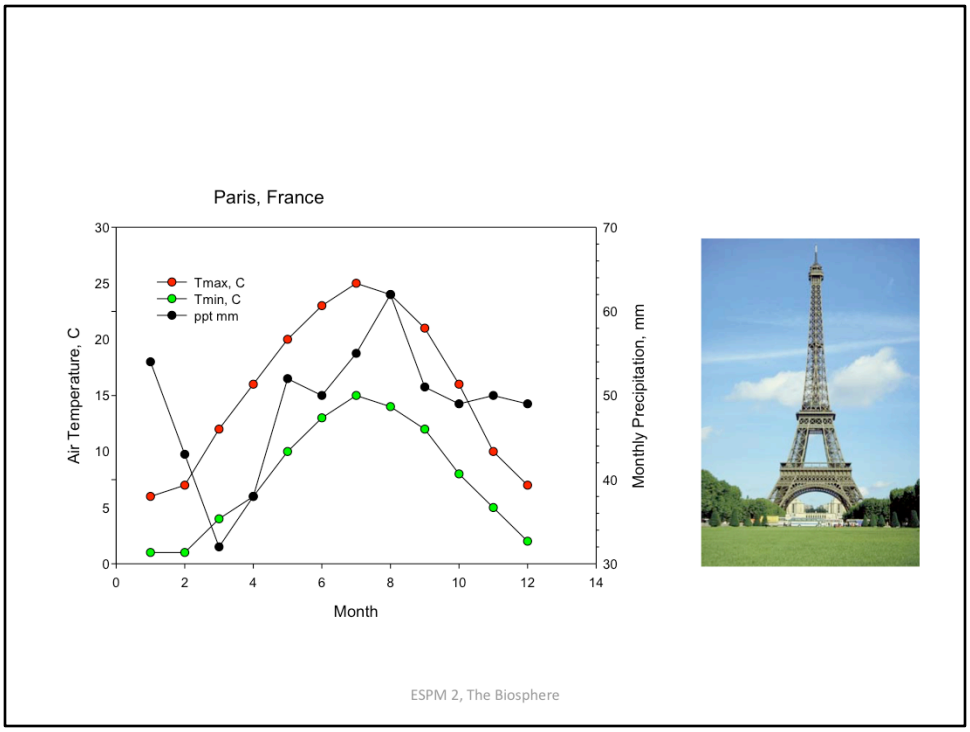
San Francisco has a moderate climate with a narrow range of highs and lows and on average it never freezes. Winters are wet and summers are rainless, characteristic of a Mediterranean type climate. Think about the type of plants that can grow with months of no rainfall.





ESPM 2, The Biosphere

In Dallas maximum summer temperatures average in the mid to high 30s..near 96 F and minimums are on average freezing. Note the summer minimum temperatures are on par with the Maximum temperatures in San Francisco, 20 C



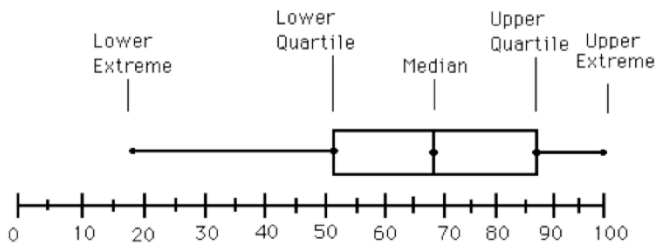
Paris is more temperate and continental. It experiences cold winters and warm summers. Rainfall is evenly spread throughout the year. And while central and northern Europe is considered to be wet the actual amount of annual rainfall (637 mm) is rather low, compared to the eastern US

Means, Average Maximums and Minimums are only Part of the Story

What is the Range in Extreme Highs and Lows?

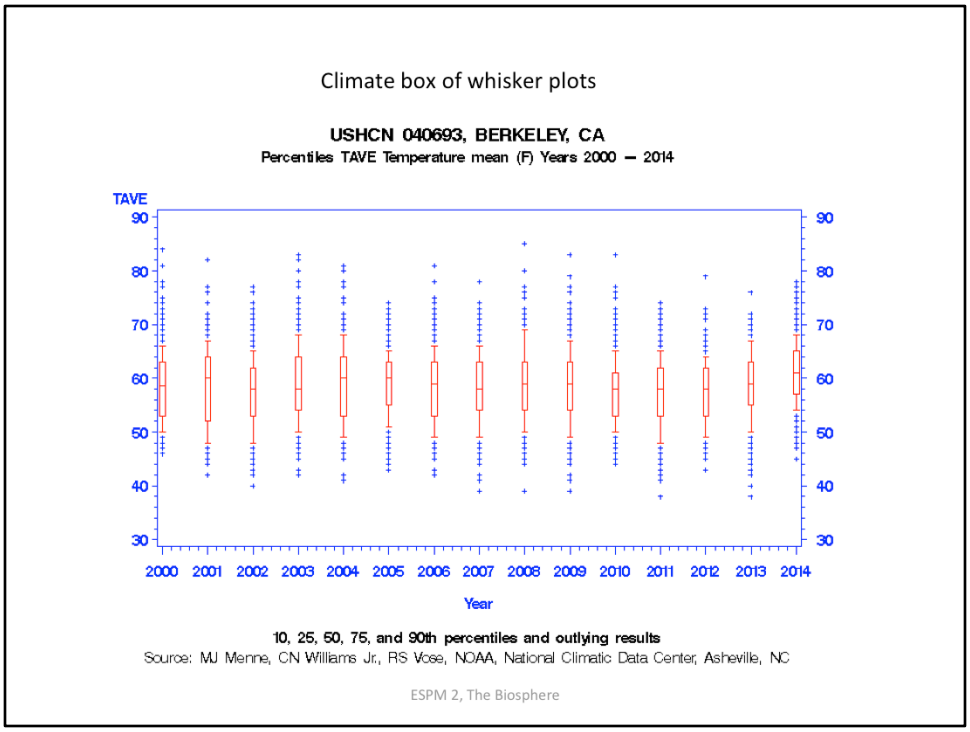
What is the Statistical Distribution?

Whisker or Box Plots Help



ESPM 2, The Biosphere

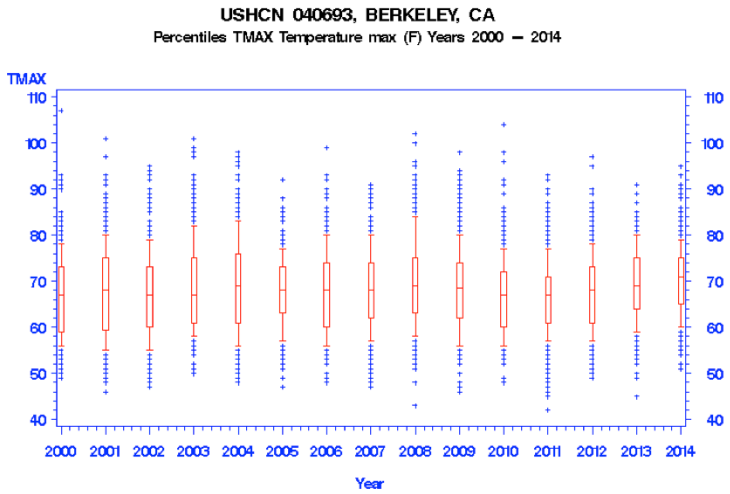
To better understand climate and weather we should understand its statistical distributions.



http://cdiac.ornl.gov/cgi-bin/broker?_PROGRAM=prog.climsite_monthly.sas&_SERVICE=default&id=040693#gplot_meanclim_mon_yr

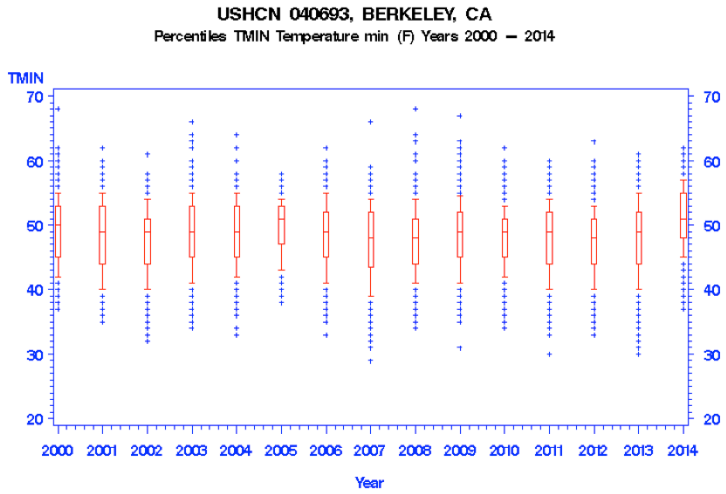
https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn

Changing Sept 30, 2017 to LBL, ESS-DIVE



10, 25, 50, 75, and 90th percentiles and outlying results

Source: MJ Menne, CN Williams Jr., RS Vose, NOAA, National Climatic Data Center, Asheville, NC



10, 25, 50, 75, and 90th percentiles and outlying results

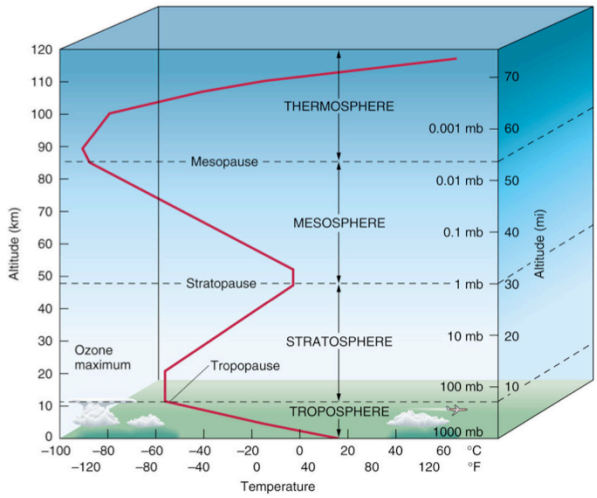
Source: MJ Menne, CN Williams Jr., RS Vose, NOAA, National Climatic Data Center, Asheville, NC

ESPM 2, The Biosphere

Part 1 take home points

- Climate and weather are distinct
- Be aware of the statistics of climate with means and distributions for the average, maximum and minimum temperatures
  - For the Biosphere, exceedance statistics are important for the absence and presence of life forms
- Different cities will have distinctly different patterns in temperature and precipitation
  - While this sounds obvious, many people tend to think the weather elsewhere is the same as that at 'home'

Vertical Profile of Temperature and Pressure



http://www.geog.ucsb.edu/~joel/g110_w08/lecture_notes/atmosphere/agburt01_09.jpg

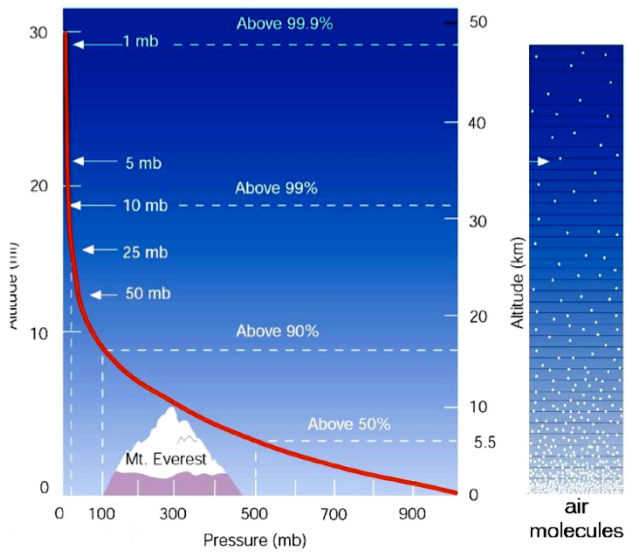
ESPM 2, The Biosphere

There are 4 major zones: 1) the Troposphere, where we live and where there is Weather; 2) the Stratosphere, where there is the ozone layer, where jets fly and is stable, hence the narrow contrails we see. The uppermost layers are the 3) Mesosphere and the 4) Thermosphere where there is less than 0.1% of the atmosphere, based on pressure.

Most important: is that 99.9% of the atmosphere is below 50 km. Temperature decreases with height in the Troposphere and it Increases with height in the Stratosphere.

Zones where temperature decreases with height allows convection and mixing to occur. Zones where temperature increases with height suppress convection and mixing and are more stable. The stratosphere is stably stratified and explains why jet contrails don't dissipate fast.

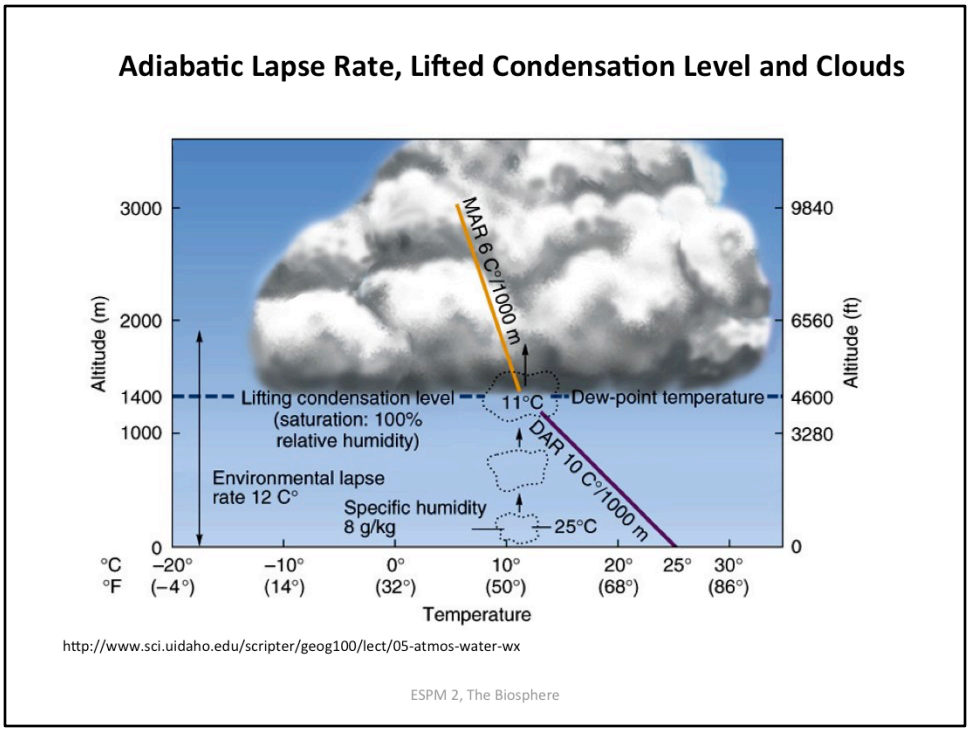
Why is the Temperate 'warm' in the stratosphere? This is where the stratospheric ozone layer resides. The absorption of shortwave, high energy ultraviolet light causes the temperature of this region to be elevated.



ESPM 2, The Biosphere

The pressure decreases exponentially with height. One is at about one-half of the atmosphere at about 5.5 km, about 18,000 feet, like many mountains in the Andes. If you climbed Denali (> 20,000 ft) in Alaska you would be above one-half of the atmosphere

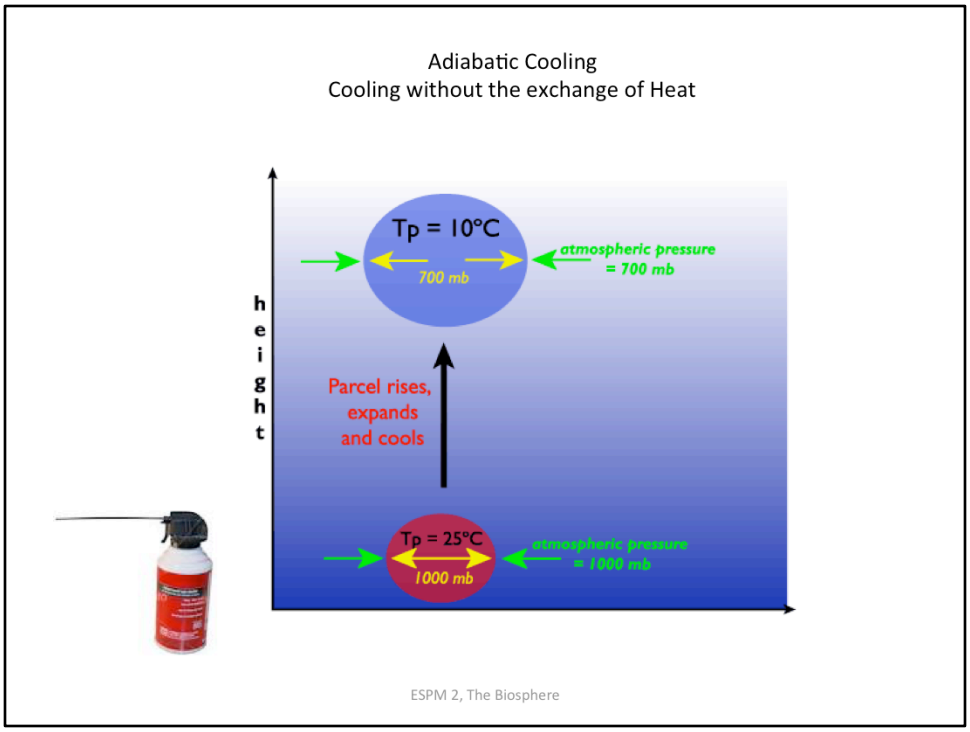
http://funnel.sfsu.edu/courses/metr201/images/PressureProfile.jpg



Why does air temperature decrease with height?

Why do clouds form with lifted air? As a parcel of air is lifted up into the atmosphere it is surrounded by less pressure, so the volume expands and the temperature decreases, without heat being added or lost. When the air temperature drops below the dew point condensation can occur and clouds formed; though it must be in the presence of cloud condensation nucleii.

The condensation of water vapor in an air parcel releases latent energy, the opposition of the energy needed to evaporate water. Hence, the wet adiabatic lapse rate is NOT as steep as the Dry adiabatic lapse rate



Before we can understand the change in phase of water from gas to liquid and vice versa, which are the processes that lead to clouds and rain we must first think about adiabatic processes.

From physics a 'diabatic' process is a physical process involving the transfer of heat. The prefix 'a' denotes without. So an A-diabatic process is one that occurs without the transfer of heat. Now this does not mean Temperature does not change

An adiabatic process represents a balance between internal energy of the parcel and work. NO heat is added or subtracted. Yet as the parcel expands its Temperature decreases. Important process in the atmosphere.

For an example if you press the nozzle of a compress can of air the can will feel cool to the touch. This is an adiabatic process. Pressure is changing in the can, so the Temperature decrease. You only allowed work. There was NO heat exchange

http://apollo.lsc.vsc.edu/classes/met130/notes/chapter6/graphics/adiab_cool.gif

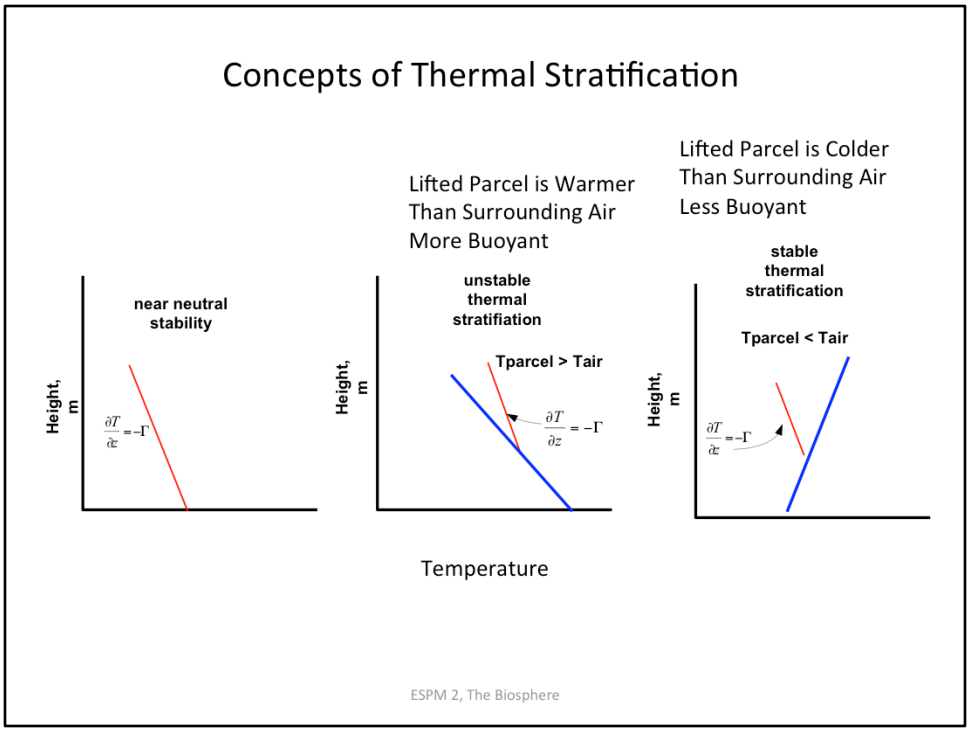
Lapse Rates, Temperature Decreases with Height

- Dry Adiabatic Lapse Rate
  - 9.8 C km^{-1}
- Moist Adiabatic Lapse Rate
  - 6 C km^{-1}

Change in Internal Energy Equals Change in Work Done on the Air Parcel

ESPM 2, The Biosphere

If you climb mountains or go skiing you experience adiabatic cooling. It is lots cooler at the top of the mountain. If the air is dry the temperature drops by 9.8 C per kilometer. If the air is moist condensation releases latent energy so the drop in temperature with elevation is less, 6 C/km



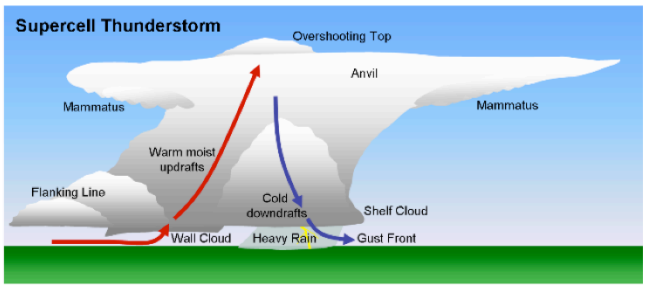
The adiabatic lapse rate also determines if the atmosphere is neutrally stratified, unstable or stable. Thermal stratification has a big impact on turbulent mixing, the formation of clouds, or fog, dispersion of pollution. In short of temperature decrease with elevation is steep the atmosphere will be unstably stratified. Parcels lifted according to the adiabatic lapse rate will be warmer, less dense and buoyant. Vice versa of the air temperature profile is inverted, it will be stably stratified.

Sail Planes and Raptors Use Lift from Thermals under Fair Weather Convective Clouds to Stay aloft

ESPM 2, The Biosphere

Types of clouds, like convective cumulus, reflect zones of uplift, used by sail planes and raptors

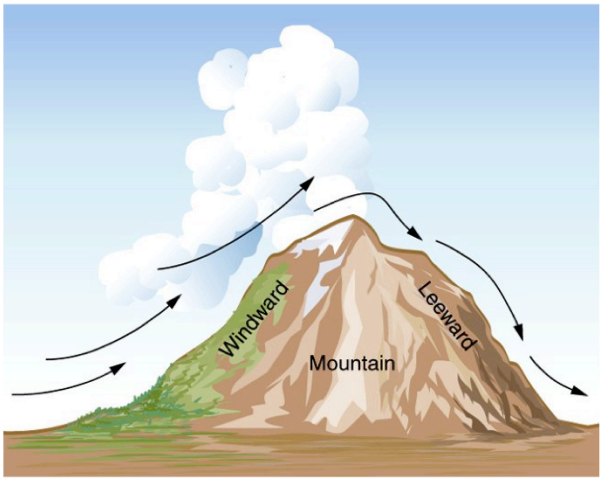
Thunderstorms and Anvil Clouds



ESPM 2, The Biosphere

Superstorms can form, yielding supercells, Thunderstorms, tornados, and intense wind and rain. Anvils are a noticeable attribute of these storms

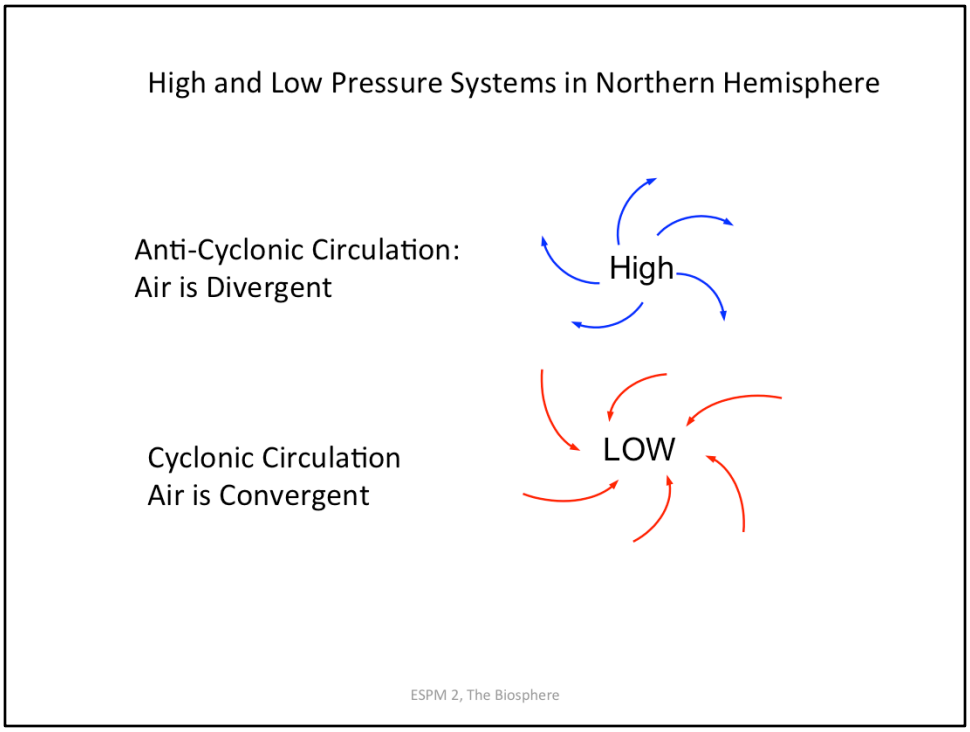
Orographic Precipitation
Air Lifted by a Mountain, Cools, Can Condense, Form Clouds and Rain/Snow



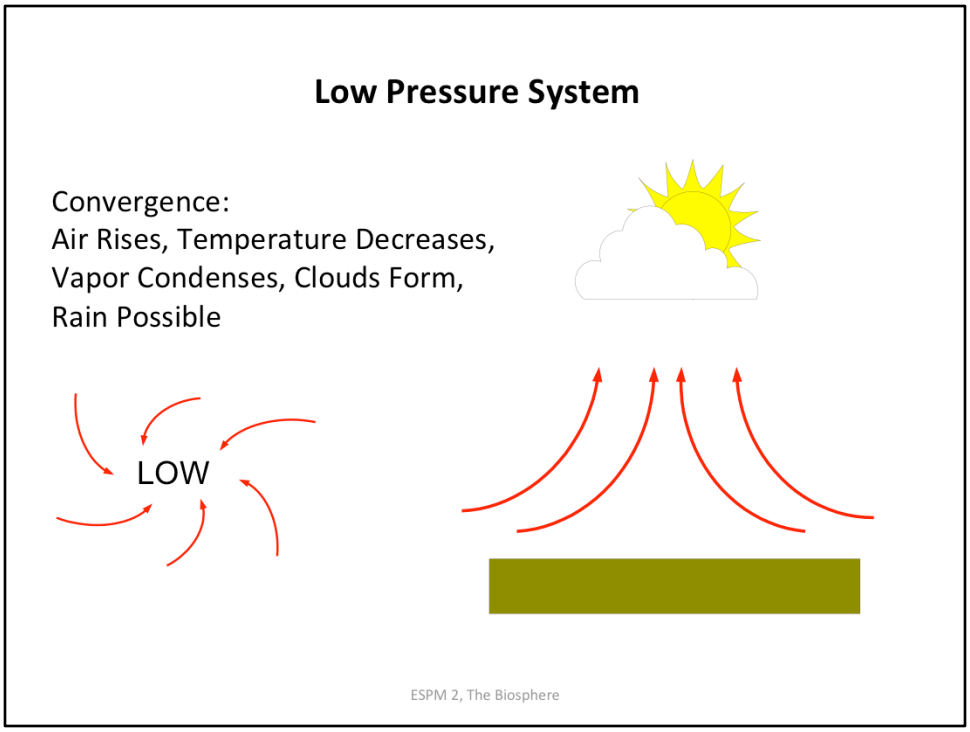
http://www.sci.uidaho.edu/scripter/geog100/lect/05-atmos-water-wx

ESPM 2, The Biosphere

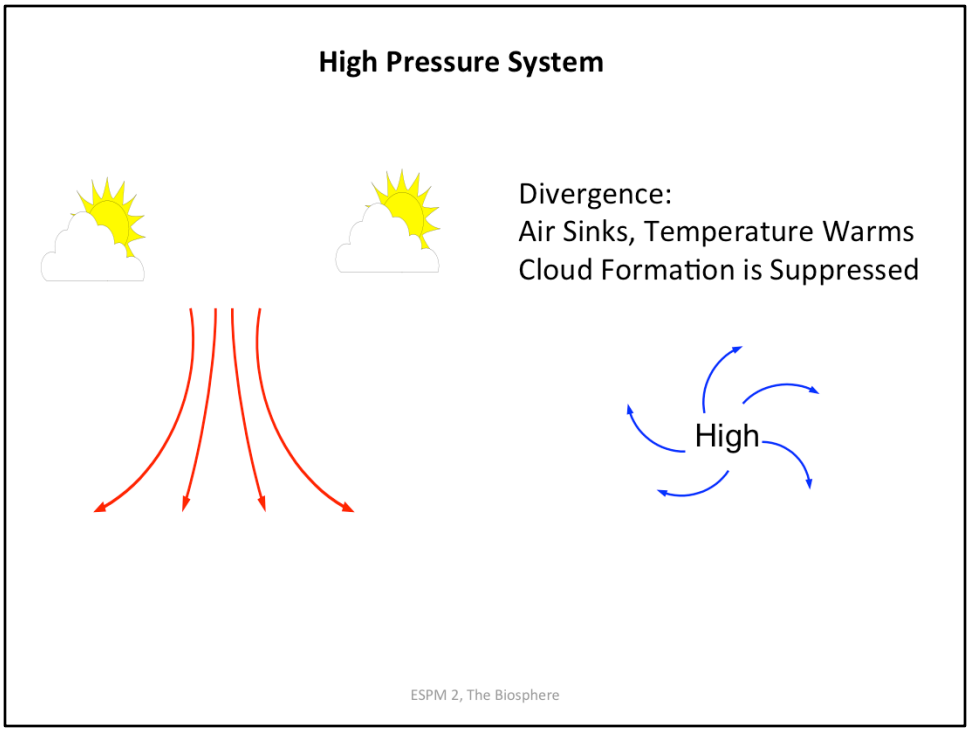
Mountains can provide orographic lifting, cooling parcels of air adiabatically, forming clouds and rain. On the back side of mountains a rain shadow can occur, like the east slope of the Sierra Nevada Mountains. This also explains why portions of Hawaii are so wet. Technically, its latitude is associated with the Doldrums or Horse-latitudes, where major deserts occur. Yet, the big mountains, surrounded by moist air yields to orographic lifting, condensation and precipitation



Weather types are associated with High and Low pressure systems, that are associated with divergent and convergent air. High pressure systems are divergent, as air moves from high to low pressure. The air moves clockwise away from the center of the pressure system. Low pressure systems are convergent as air moves to the low from the high. Here the air moves counterclockwise.
What happens in the Southern Hemisphere?



Why are low pressure systems associated with foul weather? In Lows, are converges and revolves around the pressure system in a counter clock wise manner. Due to mass continuity, convergence leads to rising air. Rising air cools abiabatically, cooling air may reach the dew point and condense. Condensation forms clouds, clouds can form rain.



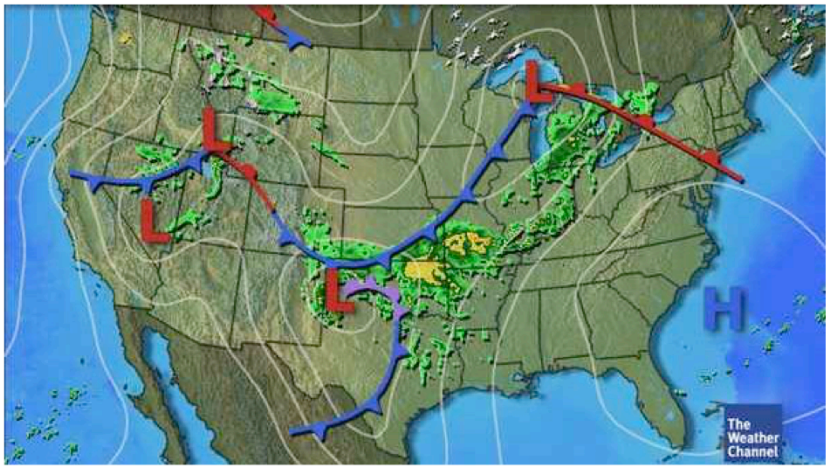
High pressure is associate with divergence and sinking air. Sinking air warms. Hence, hot dry conditions form under high pressure systems

Incoming Weather

ESPM 2, The Biosphere

Recent satellite image of Pacific coast with air masses with high cold clouds. Satellites give us great eyes of oncoming weather. Weather is generated by the clash between cold and warm fronts of air, associated with low and high pressure systems

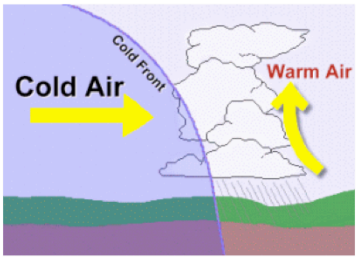
Weather Map
Fronts, Storms and Pressure Systems

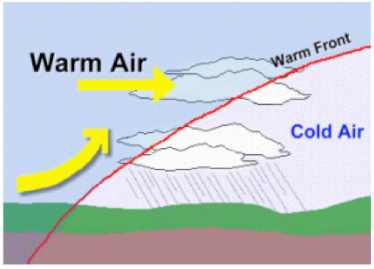


ESPM 2, The Biosphere

On this weather map you see cold and warm fronts, low and high pressure systems and radar with clouds and rain. Note how the rain is associated with the low pressure systems. We will see why next.

Cold and Warm Fronts and Rain
Two Ways to Lift Parcels of Air, Form Clouds and Rain





http://www.worsleyschool.net/science/files/aboutweather/coldfront.gif

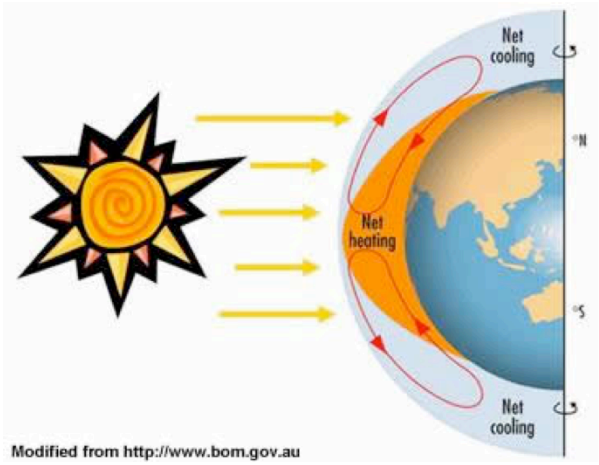
ESPM 2, The Biosphere

The clash of cold and warm fronts lead to ascending air, condensation and precipitation. A cold front pushes up against warmer and more buoyant air. A warm front overrides colder and denser air of a cold air mass.

Key points

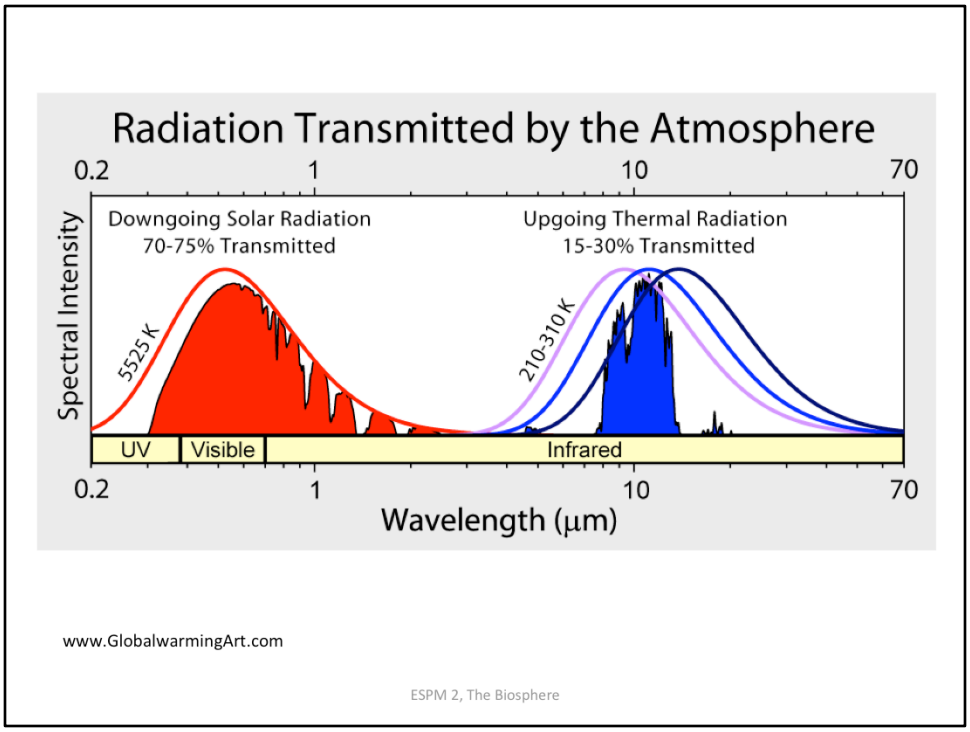
- Adiabatic processes are responsible for why lifted parcels of air may cool, condense, form clouds and rain
- Lifting is cause by fronts, convergence around low pressure, mountains (orography) and unstable thermal stratification (convection)
- Which way does air circle around High and Low pressure systems, in the Northern Hemisphere?; in the Southern Hemisphere?

Solar Heating and Global Circulation



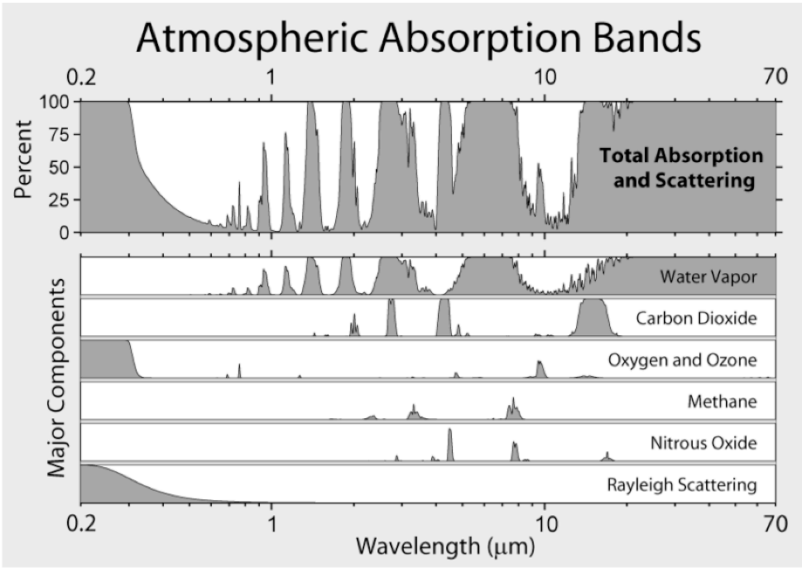
ESPM 2, The Biosphere

The uneven solar heating across the planet leads to circulations due to the movement of air from warmer to cooler regions



The sun emits shortwave energy, much visible, other in the near infrared range. The cooler earth emits longwave or infrared radation

You can see most of the longwave, or infrared radiation, is emitted to space through the atmospheric windows, the blue region in the 8 to 15 micron range. The blue range here is the white gap in the previous figure. Look at them back and forth to get a feel of wavebands that absorb energy and wavebands that let it transmit, acting as a window.



www.GlobalwarmingArt.com

ESPM 2, The Biosphere

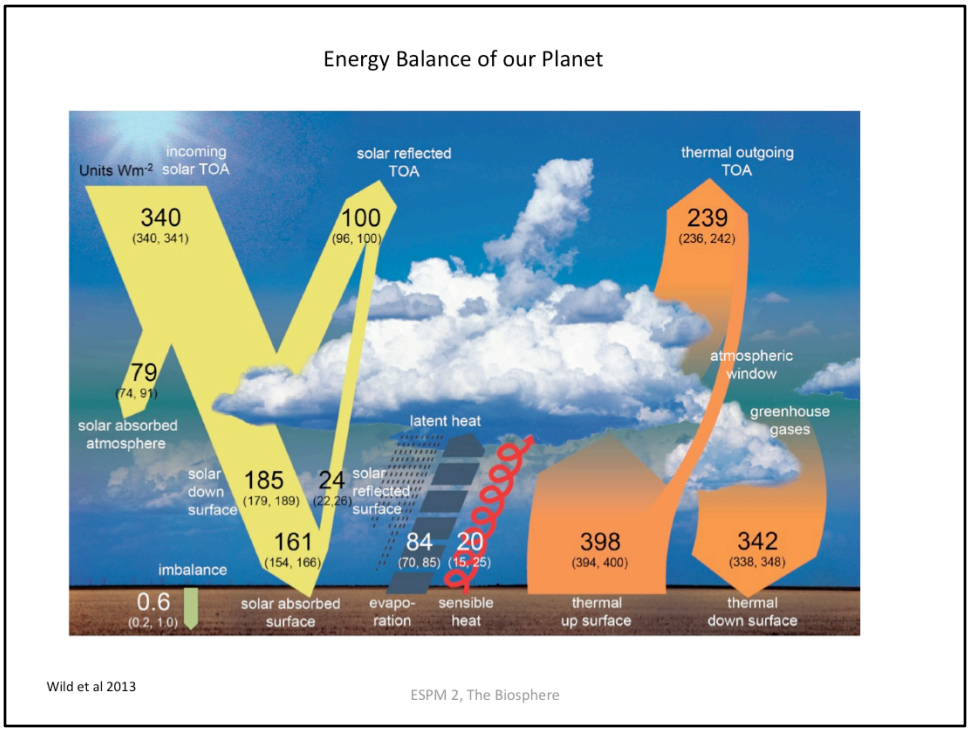
This figure is an enhanced version of the prior one, but with more gases absorbing infrared radiation and with a spectrum of the net absorption and emission spectrum

Enrichment

- You-Tube Video on how CO_2 absorbs Infrared radiation
- http://www.youtube.com/watch?v=Ot5n9m4whaw

ESPM 2, The Biosphere

The video is really cool and it is narrated by a guy with a British accent, so it must be true..☺…(is this statement fallacious or not?; the quality of the content is independent of the accent of the narrator; on the other hand he is a compelling speaker, Iain Stewart, and gives a great presentation)

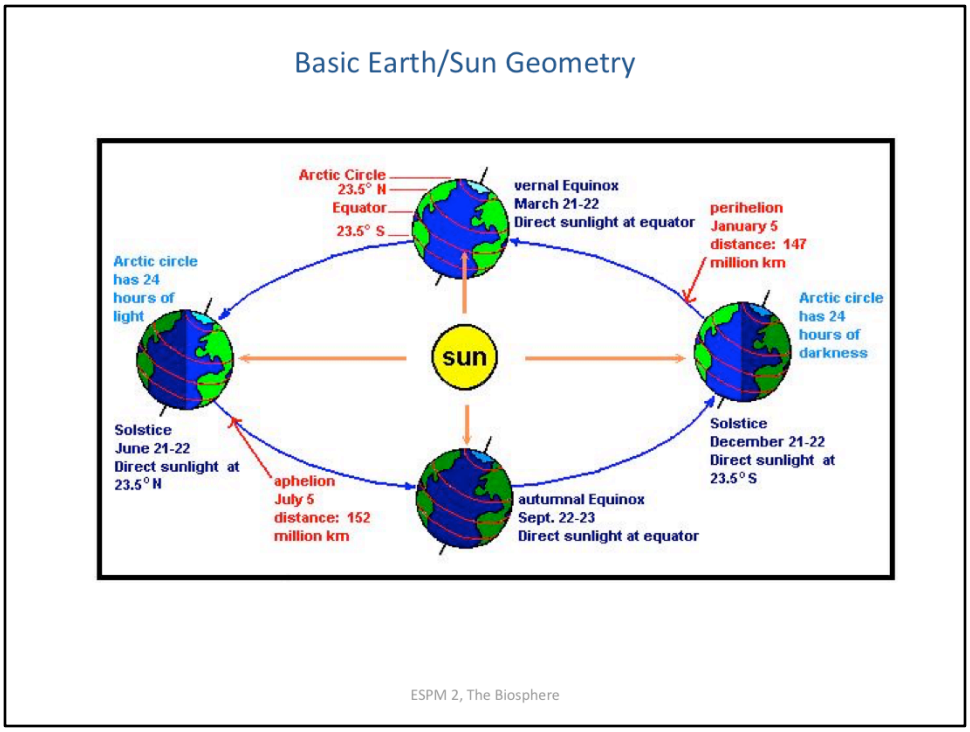


This is the textbook version of the partitioning of energy across the earth system. Know the Flows and Streams of Energy, incoming and outgoing

It starts with the amount of solar energy distributed across the hemisphere of the planet; 341 W m^{-2} ~ the solar constant, divided by 4: 1364/4 W m^{-2}. Some of this energy is reflected by clouds or is absorbed by molecules of gas in the atmosphere. Some is transmitted through the atmosphere and reaches the surface, where it is either absorbed or reflected. Energy absorbed by the air and clouds warms and emits longwave energy, upward and downward at its equivalent temperature. Ultimately, the amount of longwave energy emitted to space equals the difference between solar incoming minus that reflected according to the planetary albedo.

Top of the atmosphere the incoming minus reflected (341 -102) equals the outgoing longwave energy emitted by the planet (239 W m-2). Global warming will not change this Top of the atmosphere exchange. It will remain the same. It affects how longwave energy is distributed throughout the atmosphere and how much reaches the surface.

The surface is relatively warm, compared to the effective sky temperature because it receives longwave energy from the sky. This keeps the surface above freezing and water liquid for life! Finally the net radiation budget at the surface drives sensible



We experience seasons because the axis of the revolving Earth is tilted relative to the plane on which it revolves around the sun. What season is approaching? How long will day and night be?

At the equinox it is daylight 12 hours per day everywhere. And at noon the sun is directly overhead at the equator; solar elevation decreases with latitude, so at 10 degrees the sun is at 90 degrees at noon.

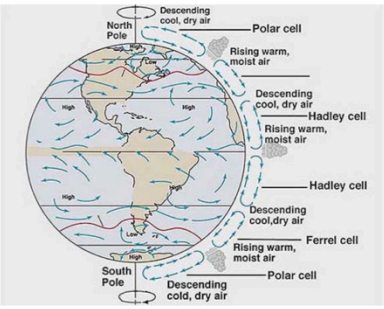
At the summer solstice it is sunlight 24 hrs above the Arctic circle and dark 24 hours a day below the Antarctic circle; and vice versa during the winter solstice.

At the summer solstice the sun is directly above the tropic of Cancer (23.5 N) at noon. And it is above the tropic of Capricorn (23.5 S) at noon during the winter solstice.

http://www.sercc.com/education_files/geometry.jpg

Major Circulation Features

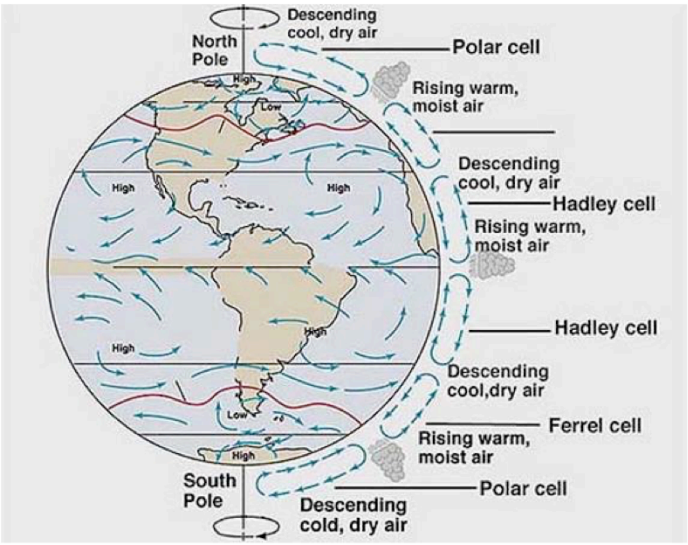
- InterTropical Convergence Zone (ITZ)
  - Doldrums, Easterly Trade Winds
- Hadley Cell
  - Horse-Latitudes
- Ferrel Cell
  - Polar Front, Jet Stream
  - Westerlies
- Polar Cell
  - Easterlies



ESPM 2, The Biosphere

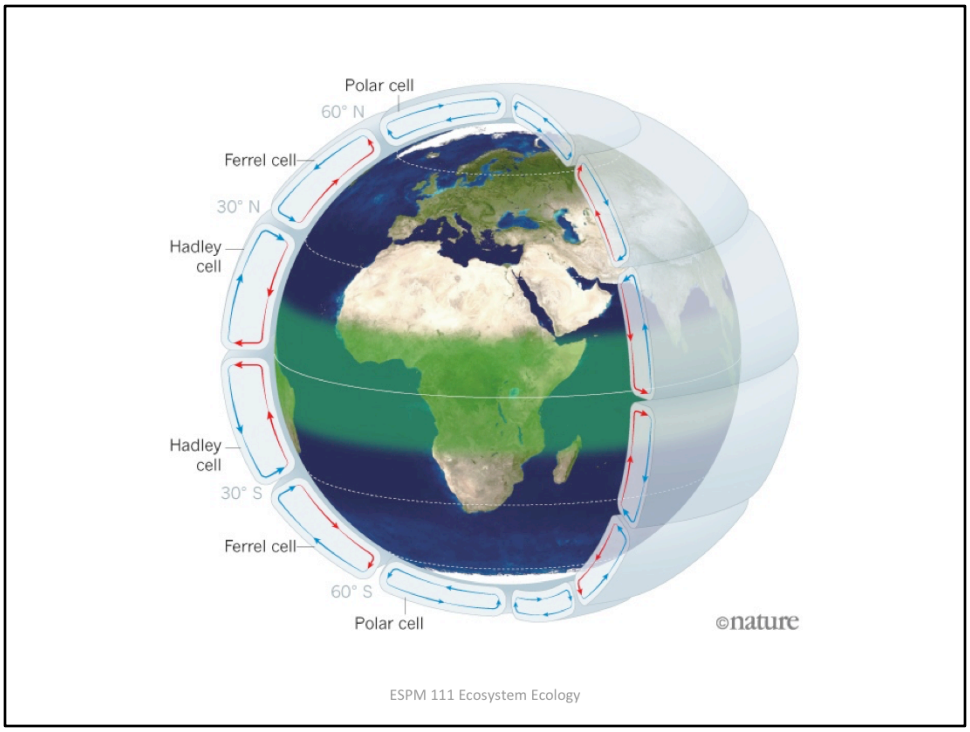
These major circulations features affect the weather and climate across the globe. Here are the main circulation features. They played major roles in the discovery of the new world as it allowed boats to sail from east to west.

Global Circulation



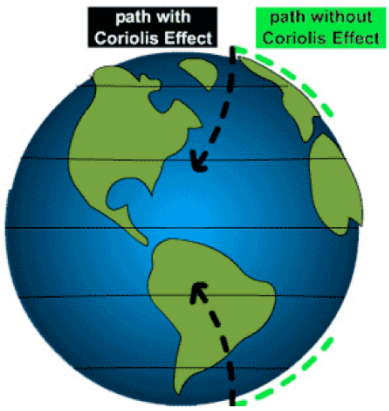
ESPM 2, The Biosphere

Differential heating of the planet and its rotation sets up cells of ascending and descending air, that become associated with the great forests and deserts of the world. Warm air rises at the equator with the Hadley cell. What goes up must come down and it does along the horse latitudes of the tropics, where many of the great deserts occur. At mid-latitudes the Ferrel cell forms and near the poles are the polar cells. Rising air at the interface between the Ferrel and Polar cells is associated with the stormy regions of the temperate world of North America, Europe and Asia. And as discussed in early lectures the poles are essentially deserts with low precipitation because of the descending air.



http://www.nature.com/polopoly_fs/7.33624.1454417360!/image/hadley-cell-feature-graphic-04.02.16.jpg_gen/derivatives/landscape_630/hadley-cell-feature-graphic-04.02.16.jpg

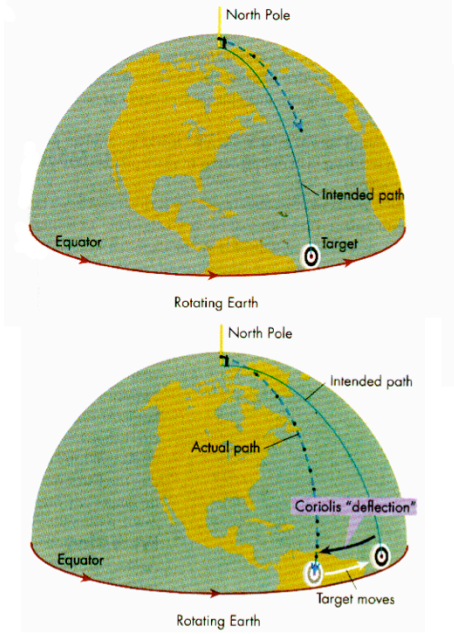
Coriolis Force on a Rotating Sphere



The Earth Rotates counter-clockwise, so deflects are to the right

ESPM 2, The Biosphere

Coriolis force is a term added to the equations of motion due to the rotating frame of reference of the Earth, a sphere. In a reference frame with clockwise rotation, the deflection is to the left of the motion of the object; in one with counter-clockwise rotation, the deflection is to the right.



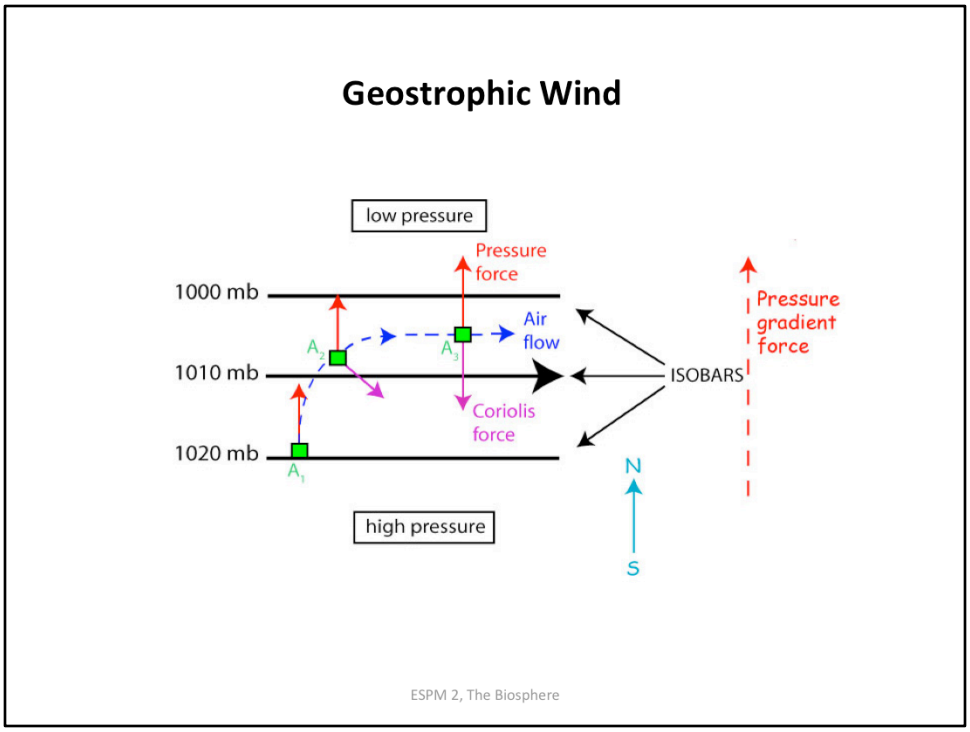
ESPM 2, The Biosphere

http://abyss.uoregon.edu/~js/images/coriolis_effect.gif

Do Toilets flush backwards in the Southern Hemisphere due to the Coriolis Force?

ESPM 2, The Biosphere

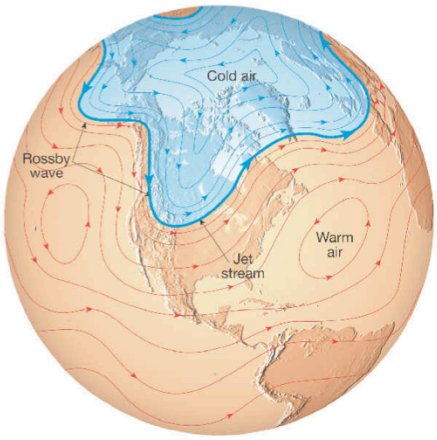
It is urban myth that toilets flush backwards in Australia. The Coriolis force is too small at the scale of a toilet. Whether the water leave in clockwise or counter-clock wise rotation depends which direction the water jets are pointing.



In the northern hemisphere air does not move directly across isobars from regions of high to low pressure. The axis of Earth is spinning yielding a Coriolis Force that tends to revolve around the pressure system and follow the isobars. In this case air moves clockwise around the high.

Rossby Waves

4- 6 Long Meandering Planetary Waves
They Slowly Drift West to East and Affect the Location of the Jet Stream

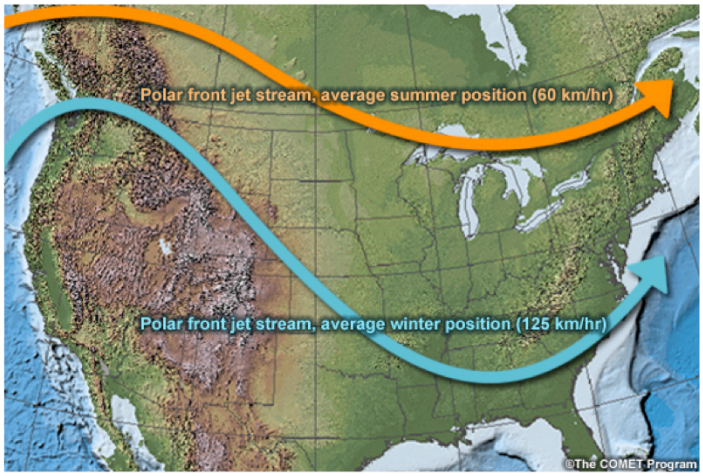


ESPM 2, The Biosphere

Quasi-stationary waves circumnavigate that planet. These are called Rossby waves and they consist of 4 to 6 waves. They have big impacts on the transport of cold air from the Arctic to the temperate latitudes.

Francis, J. A. and S. J. Vavrus. 2015. Evidence for a wavier jet stream in response to rapid Arctic warming. Environmental Research Letters **10**:014005.
Weakening of North South gradient with Arctic warming will: slow upper zonal winds, causing jet stream to meander more and slower west to east transitions of troughs and ridges

Jet Stream
Westerly Flow Aloft
Steers the Polar Front



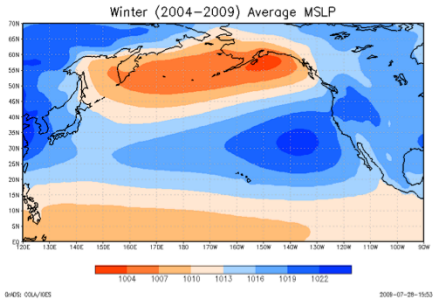
ESPM 2, The Biosphere

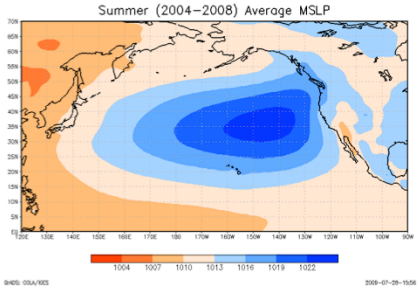
The jet stream steers our weather across the US from west to east. Shift of the jet stream from east to west, or vice versa, can cause big weather anomalies, like heat spells, droughts, cold spells and persistent wet periods that are independent of climate warming or cooling.

Large Scale Patterns Dominate Weather in California

Aleutian Low Steer Storm Tracks during Winter

North Pacific High Block Storms during Summer





http://www.pacificstormsclimatology.org/index.php?page=regional-overview

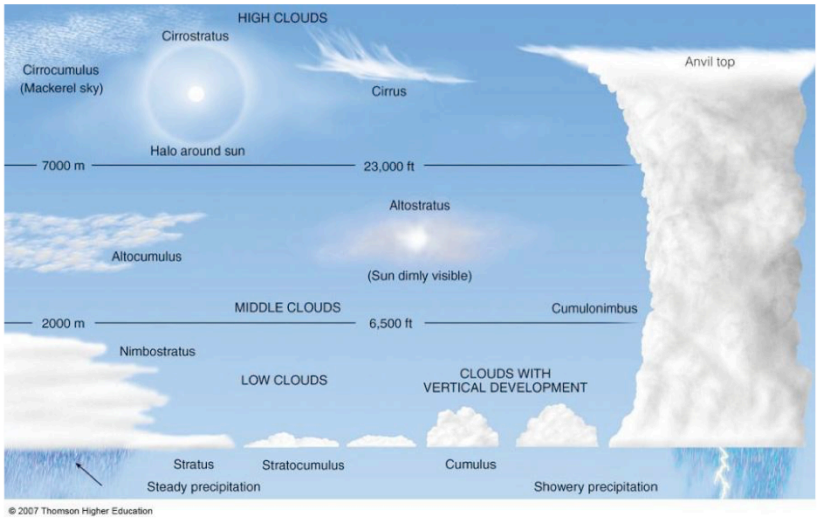
ESPM 2, The Biosphere

Position of high and low pressure systems dominate the weather in California. During the summer there is a high pressure system that leads to our sunny, clear weather and Mediterranean climate. During the winter storms are generated by the Aleutian Low and then can proceed towards Washington, Oregon and California, bringing storms.

Take home points, part two

- The differential heating of earth causes distinct circulation patterns
  - Changes by season and latitude
  - large scale circulation patterns form wet tropical zones, dry sub tropical zones, temperate zones dominated by fronts, and cold, dry polar areas
- Rotation of the sphere causes convergence around Low pressure systems and Divergence around High pressure systems
  - regions are associated with convergence and upward motion
  - These will sustain cooling, condensation, clouds and rain
  - Divergence will sustain adiabatic warming, inhibit rain formation and are associated with desert regions.
- The Position and Amplitude of Large Scale Circulation patterns, such as Jet Stream and El Nino, can cause much year to year variation in weather

Clouds in the Sky



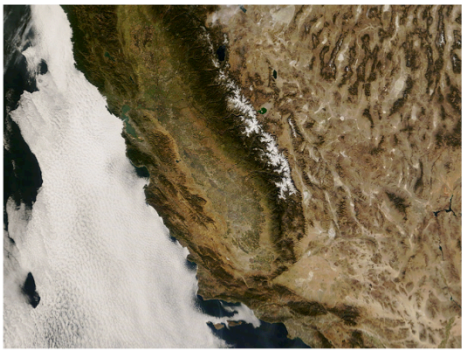
ESPM 2, The Biosphere

Clouds are indicators of weather. They consist of condense droplets of water and ice. Low clouds tend to be stratus clouds, like the clouds that hug the coast during the summer. Cumulus clouds represent more convection and uplifting. They can range from fair weather clouds to the giant cumulonimbus of great thunderstorms. High clouds are cirrus and tend to be precursors of oncoming storms.

Common Clouds in California

Fair Weather Cumulus Clouds

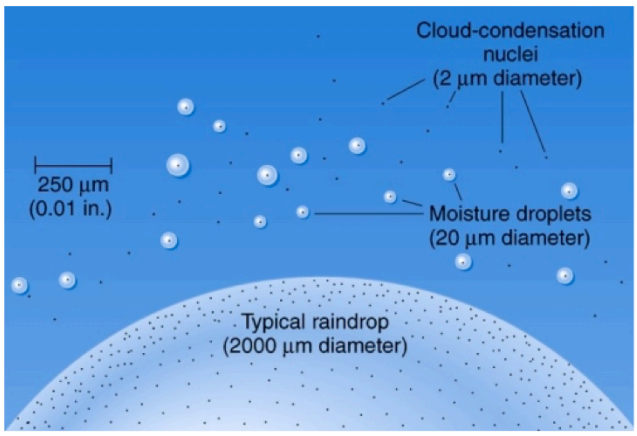
Marine Stratus off the Coast



ESPM 2, The Biosphere

In California we don't get lots of interesting weather and clouds, per se. Most of the summer is clear..or if you live on the coast you are immersed in dense coastal fog. As a grad student in Nebraska I was amazed by the mountains in the sky, the huge anvils of impending thunderstorms

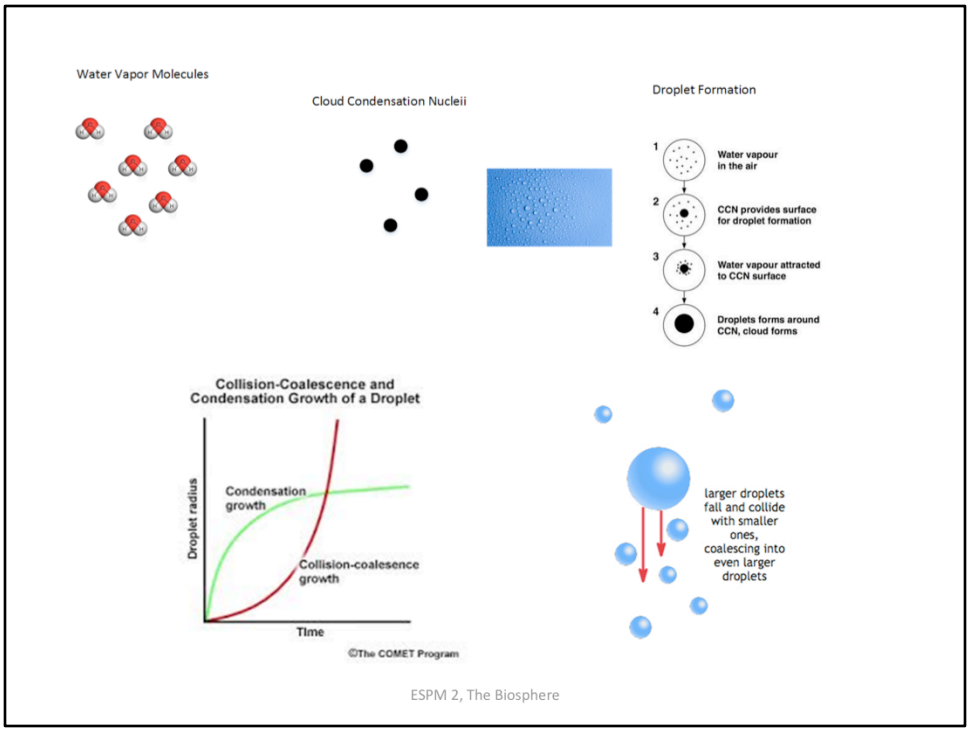
Structure and Function of Clouds



ESPM 2, The Biosphere

http://ffden-2.phys.uaf.edu/211_fall2010.web.dir/Levi_Cowan/images/water_droplets.jpg

Water vapor molecules, cloud condensation nucleii are the ingredients that lead to the formation of cloud droplets and rain drops.



Droplets form when water vapor condenses. This occurs when adiabatic lifting, and cooling, causes the temperature of the air parcel to drop below the dewpoint. Yet, condensation nucleii are needed to catalyze this process, as in clean air super cooled clouds can form. Once droplets form they grow by collision and coalescence. Once they become big enough to overcome drag forces rain drops fall to the ground.

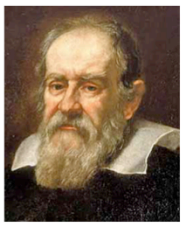
Clouds and Precipitation

Why Drop Cloud Droplets fall out of the sky?

They have mass and physical size.
Galileo proved two objects of different masses fall at the same rate

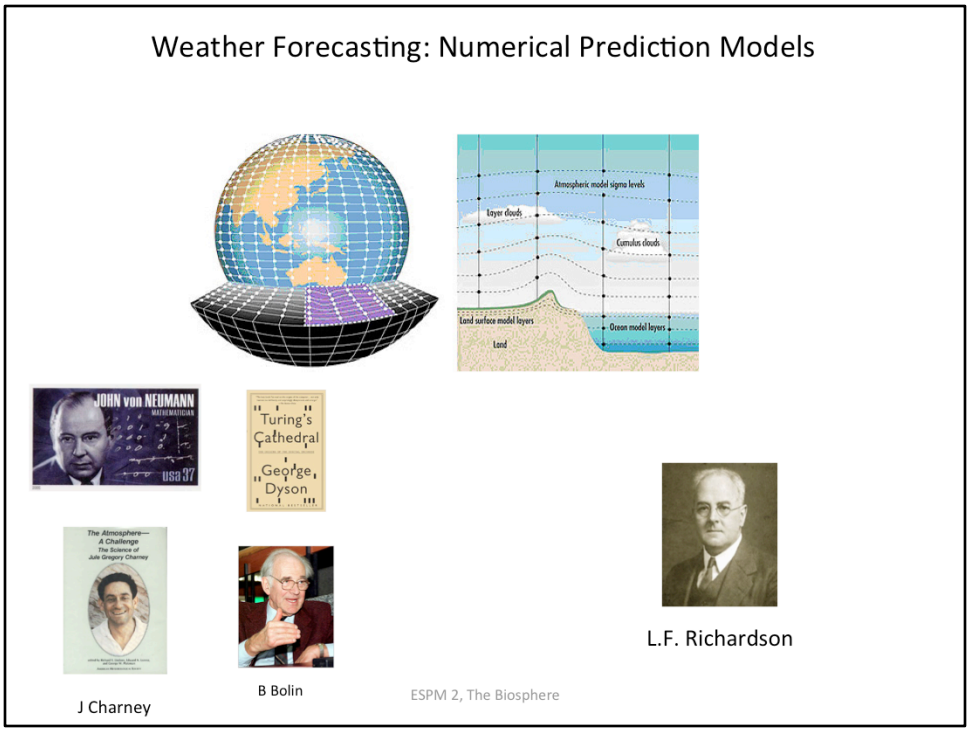
Gravitational Forces = Drag Forces

Thinking dropping a stone vs feather



ESPM 2, The Biosphere

http://www.crystalinks.com/galileo.jpg



Bauer, P., A. Thorpe, and G. Brunet. 2015. The quiet revolution of numerical weather prediction. Nature **525**:47-55.

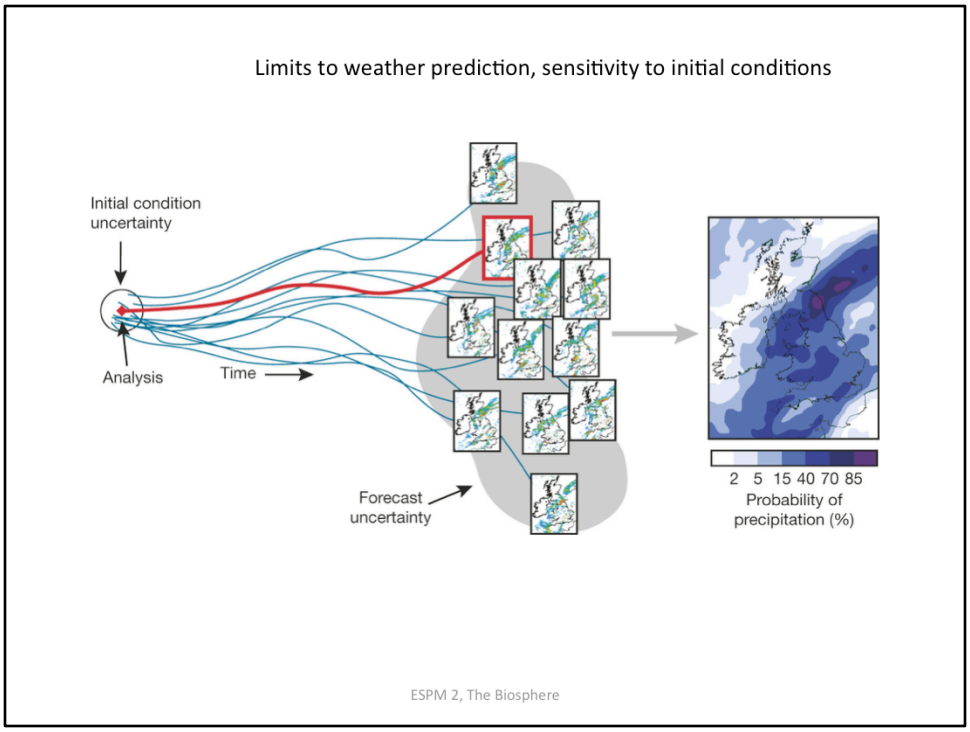
The Navier–Stokes and mass continuity equations (including the effect of the Earth's rotation), together with the first law of thermodynamics and the ideal gas law, represent the full set of prognostic equations upon which the change in space and time of wind, pressure, density and temperature is described in the atmosphere4 http://www.dpi.nsw.gov.au/__data/assets/image/0004/194899/cchangev2-figure5-page15-510px.j

Richardson envisioned the 1st numerical simulation in the 1920s, involving thousands of human 'computers', doing calculations by hand or with adding machines and passing the information to one another.

Von Neumann was critical thinker in developing early computers and numerical methods. He worked with Charney (prof at MIT and mentor of Inez Fung) to perform one of the first computer based weather predictions (in this case a hindcast). Bert Bolin (who was installed in Rossby's former chair in Stockholm, Sweden at the early age of 32) produced one of the first true forecasts with a numerical model.

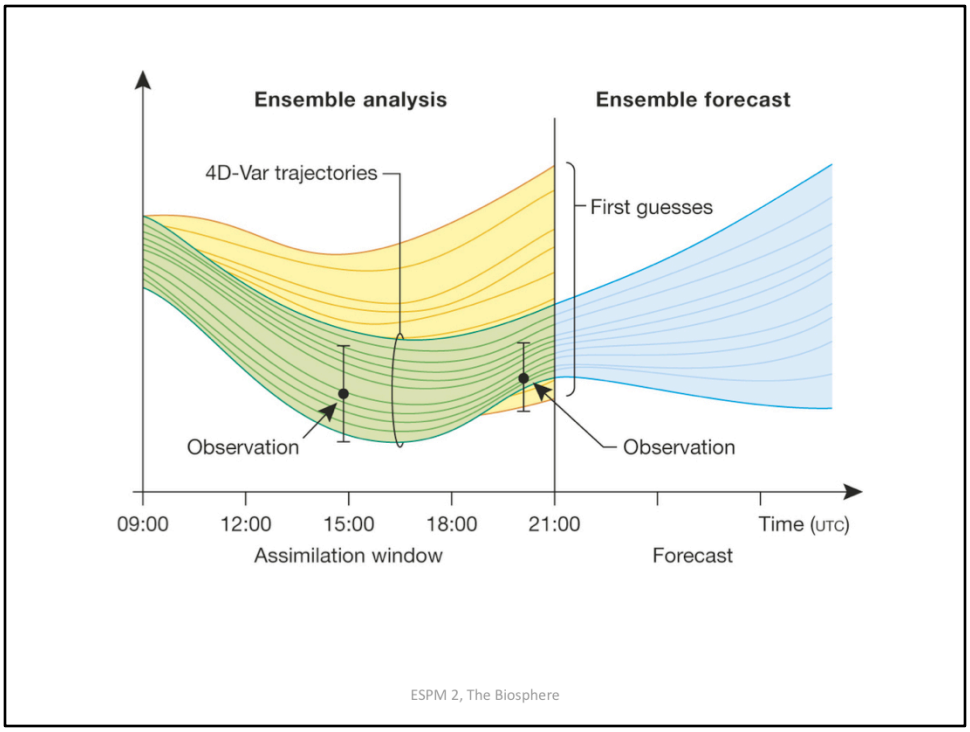
Basics of Numerical Weather Prediction Models

- The Navier–Stokes and mass continuity equations (including the effect of the Earth's rotation)
- first law of thermodynamics
- the ideal gas law
- full set of prognostic equations upon which the change in space and time of wind, pressure, density and temperature is described in the atmosphere



Now weather models run ensemble simulations and compute probabilities of occurrence

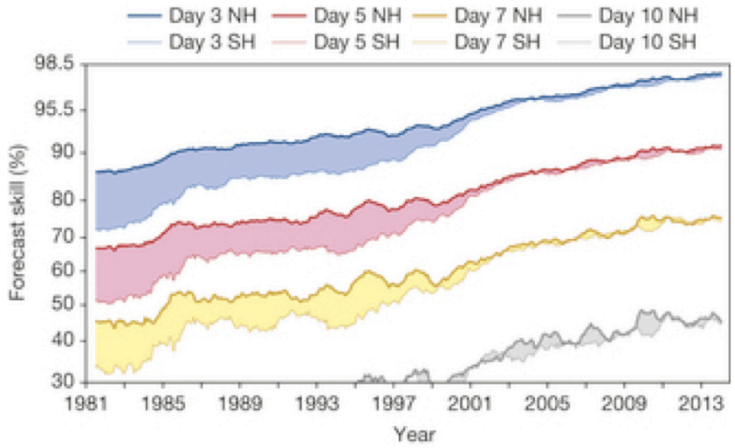
Bauer, P., A. Thorpe, and G. Brunet. 2015. The quiet revolution of numerical weather prediction. Nature **525**:47-55.



They also apply data assimilatin to update forecasts in time, nudging so the best information is used.

Bauer, P., A. Thorpe, and G. Brunet. 2015. The quiet revolution of numerical weather prediction. Nature **525**:47-55.

A measure of forecast skill at three-, five-, seven- and ten-day ranges, computed over the extra-tropical northern and southern hemispheres.



Bauer et al 2015 Nature

ESPM 2, The Biosphere

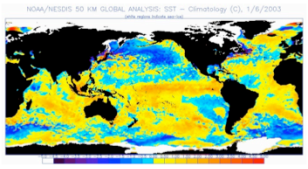
Despites complaints about the weather the degree of forecasting accuracy continues to increase and is pretty darn good on the 3 day range, better than 95%.
Week to 10 day outlooks are closer to a coin toss, but also improving

http://www.nature.com/nature/journal/v525/n7567/carousel/nature14956-f1.jpg

Big Weather Generators

Monsoon

Hurricanes/Typhoons

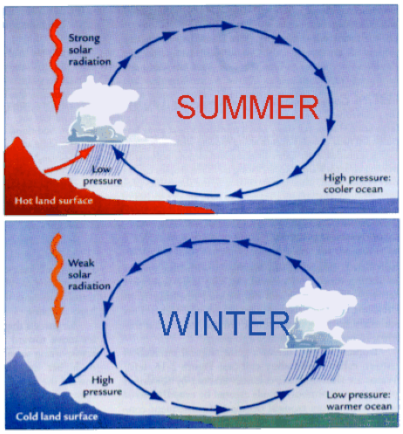


El Nino/La Nino

ESPM 2, The Biosphere

Monsoons, Hurricanes, and ENSO are self-organized features with the complex system of the Earth's atmosphere
Friends and colleagues of mine teach big weather, so I thought a brief intro to these may be of interest

Monsoons



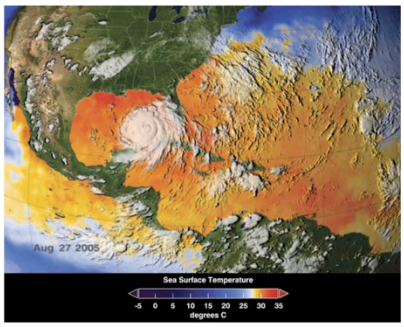
ESPM 2, The Biosphere

A cyclic, seasonal weather pattern of alternative wet and dry periods as air cycles between land and sea, like in the Indian Ocean and Southeast Asia. A billion Indians rely on the occurrence of the monsoon from a break in weather (temperatures exceeding 40 C) and for rain.

Hurricanes

Hurricanes are Heat Engines fueled by latent heat from the condensation of water vapor

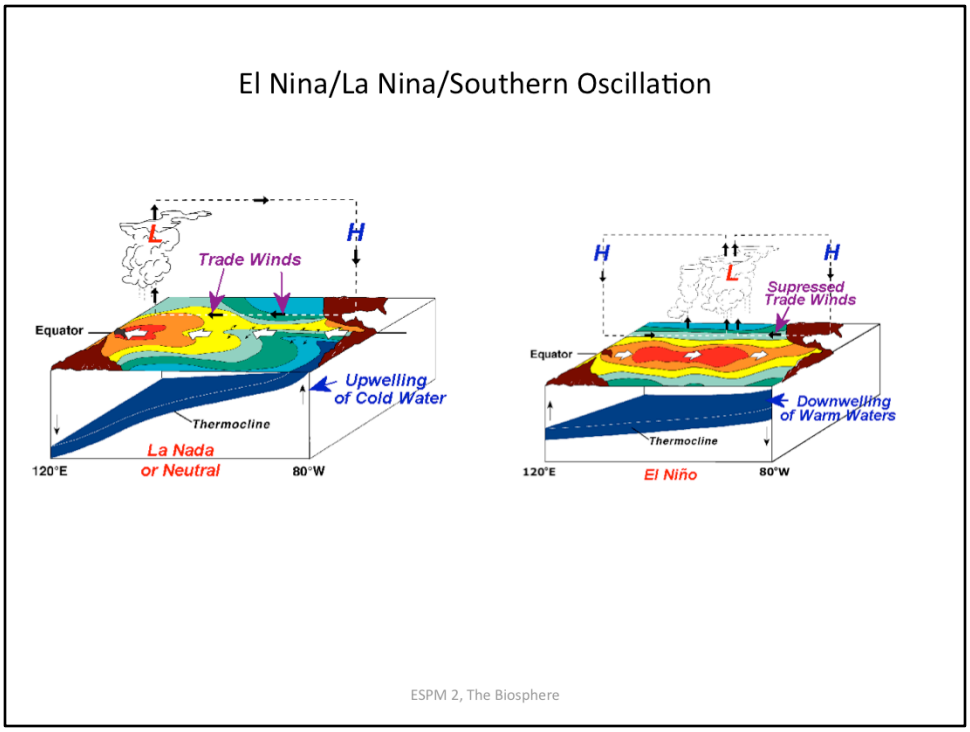
Form over seas warmer than 27 C and in the latitude belt between 5 and 20 degrees, where the Coriolis Force is neither strong or weak



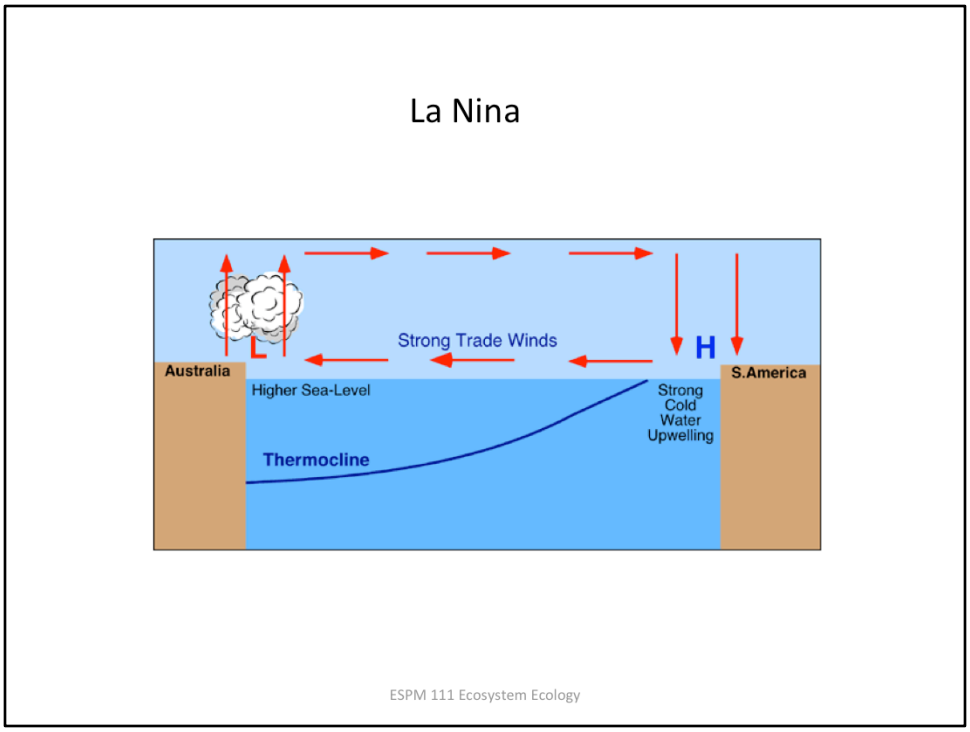
Hurricane Katrina

ESPM 2, The Biosphere

Hurricanes are heat engines formed by latent heat released water vapor condenses. They tend to form when sea temperature is about 27 C and in the latitude belt between 2 and 20 degrees, where the Coriolis force is neither too weak or too strong.

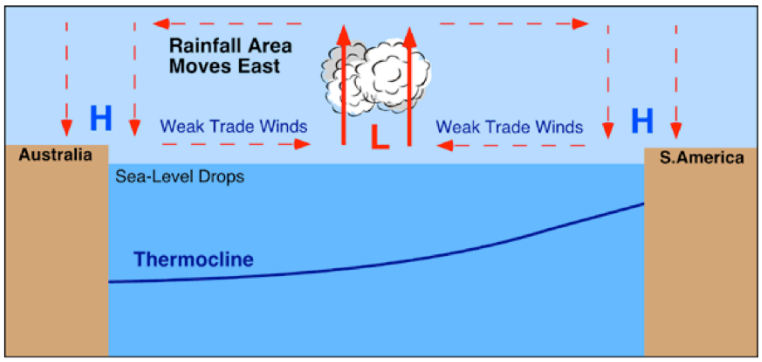


Trade wind system near the Equatorial Pacific associated with the position of warm and cool waters and the upwelling of deep ocean water. Has impact on weather world-wide, as well as on fisheries. The circulation was discovered by fishermen off Peru and Ecuador who found poor fishing on certain years near Christmas, time of the Christ child, El Nino. Warmer waters off the coast stymied upwelling that normally brought cold and nutrient rich waters to the surface that supported the rich fisheries. In California El Nino years bring lots of rain to the state during the winter, especially to SoCal.



La Nina and El Ninos can cause much year to year variation in climate. The role of distant oceans on local climate is profound. When I was a grad student we used to laugh about papers on correlations on corn yield in Iowa with some weather far away. Yet, they were detecting effects of El Nino before it become a popular idea.

El Nino



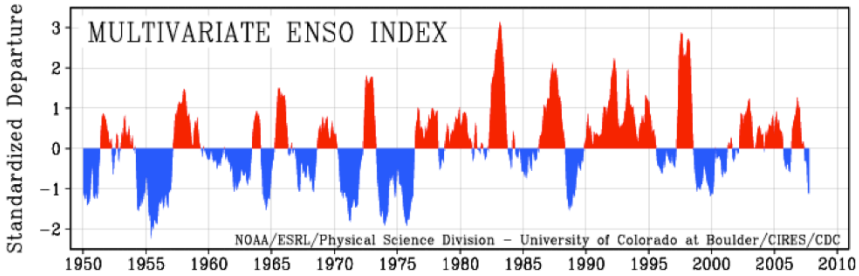
http://weatherevents.co.uk/widespread-flooding-in-australia-and-the-affect-of-la-nina/

ESPM 111 Ecosystem Ecology

Shift in the convection zone towards the eastern Pacific and it weakens the trade winds. This also stymies the upwelling of cold and nutrient waters off the coast of Latin America, causing a crash in the fisheries, which lead to the detection and naming of this phenomenon. Fishermen noted poor catches during Christmas, the time of the child, El Nino.

This has many teleconnections with other circulation patterns across the globe, affecting winter weather in CA, for instance.

ENSO Periodicity
It occurs on intervals between 2 and 7 years



ESPM 2, The Biosphere

The index is determined between pressure readings in Tahiti and Darwin, Australia. El Ninos occur when the index is negative

Tornados

Tornadoes

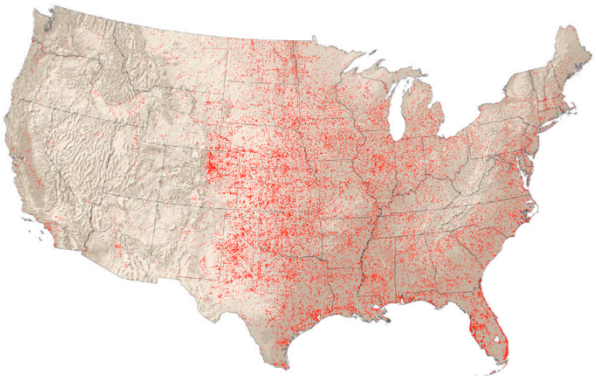


Figure 1. | Map of tornadoes in the United States. Tornado observations for 1954–2009 are indicated by the red points.

Long and Stoy, 2014 GRL

Final set of Take Home Points

- Clouds need seeding by condensation nucleii.
- Numerical Prediction models are based on the laws of motion and thermodynamics
- They can simulate future weather out to a week with good confidence
- Big Weather occurs in the form of Monsoons, ENSO, Hurricanes
  - Attributes of Self-Organization of Complex systems
  - Hard to predict perfectly, due to lack of perfect information on initial conditions
  - Confidence is growing for predictions out to 10 days
  - We can also predict the mean state of the climate well on longer time scales

Discussion

- For those form out of State describe and discuss your local climate and weather compared to California
- Plot and examine climate of Berkeley

State of the Climate, Supplementary Material

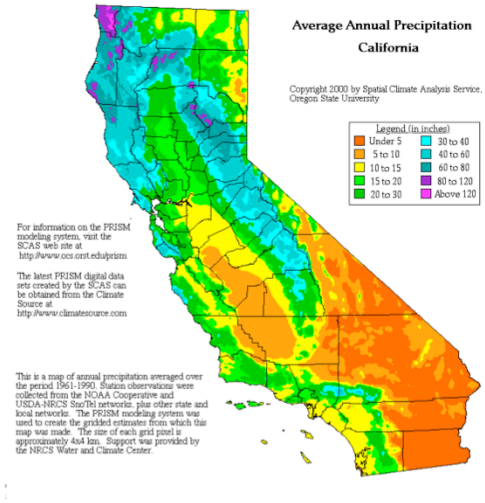
http://www.ipcc.ch/report/ar5/wg1/

ESPM 2, The Biosphere

Recently the new, 5th, report from the Intergovernmental Panel on Climate Change (IPCC), AR5, was released. Some of the findings will be relayed in the rest of this lecture.

There are links to the technical summary, report for policy makers and the full 2000+ page technical report. http://www.ipcc.ch/report/ar5/wg1/

Precipitation Across California
Roles of Microclimates, Valleys, Hills, Ocean and Mountains



ESPM 2, The Biosphere

Rainfall across Ca can range from less than a foot to more than 10 feet (120 in) as one traverses the State from South to North, West to East

http://tchester.org/srp/plants/communities/figures/ca_rainfall.gif

California Rainfall

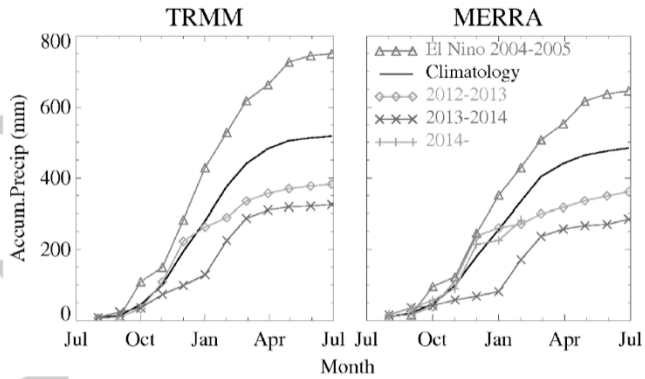
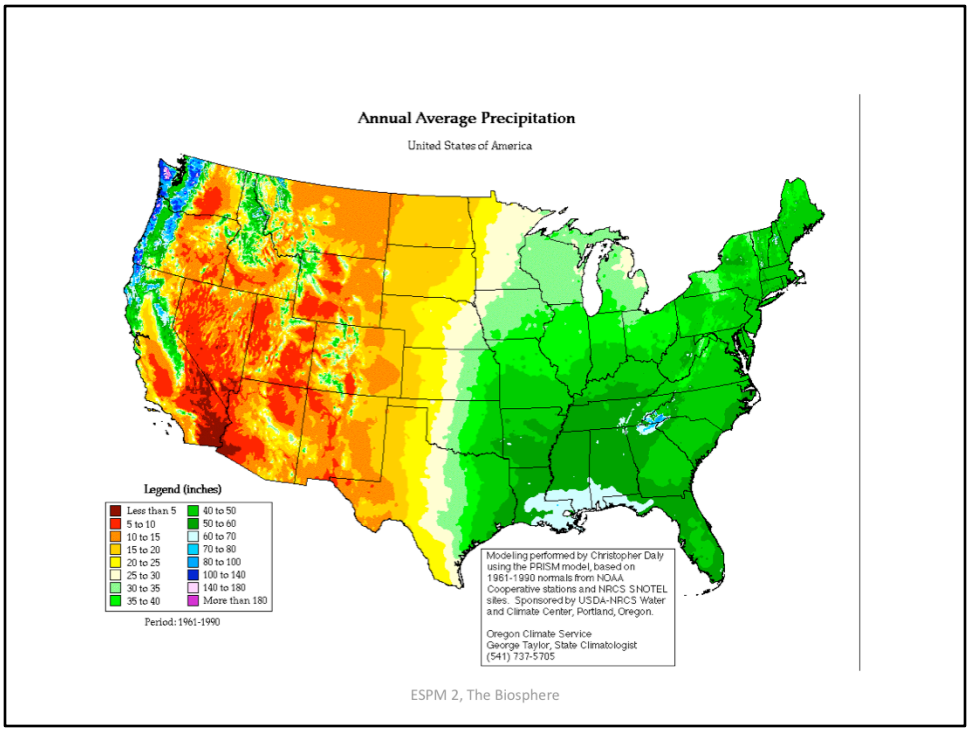
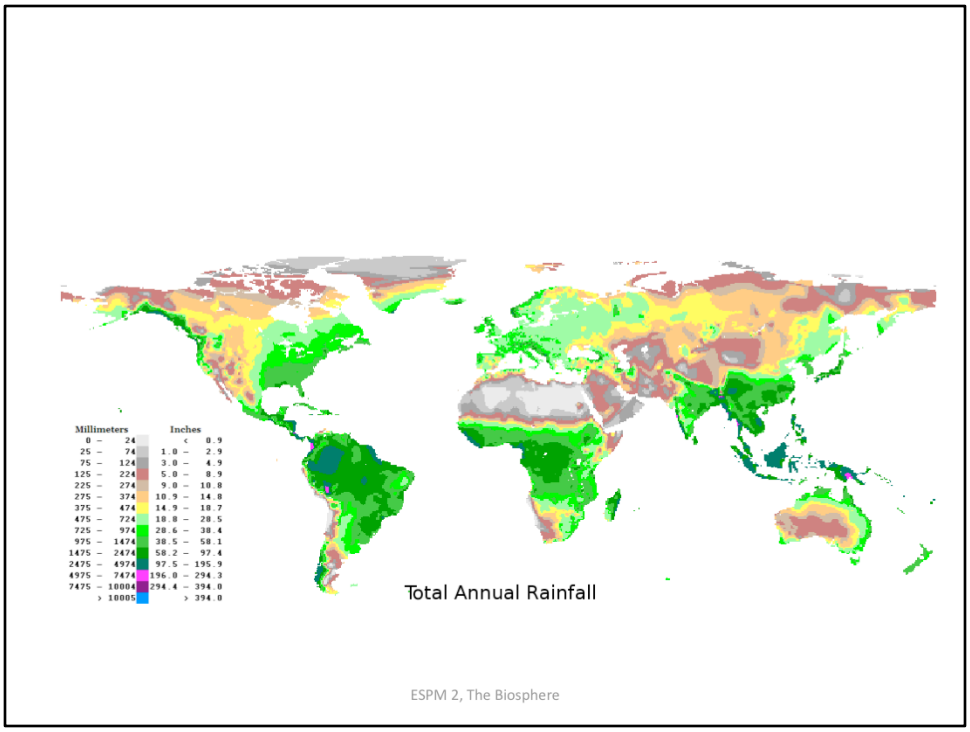


Figure 4. Accumulation of precipitation in California. Expected average accumulation (climatology) from MERRA and TRMM, as compared to El Nino 2004, and the recent dry seasons of 2012-2013, and 2013-2014.

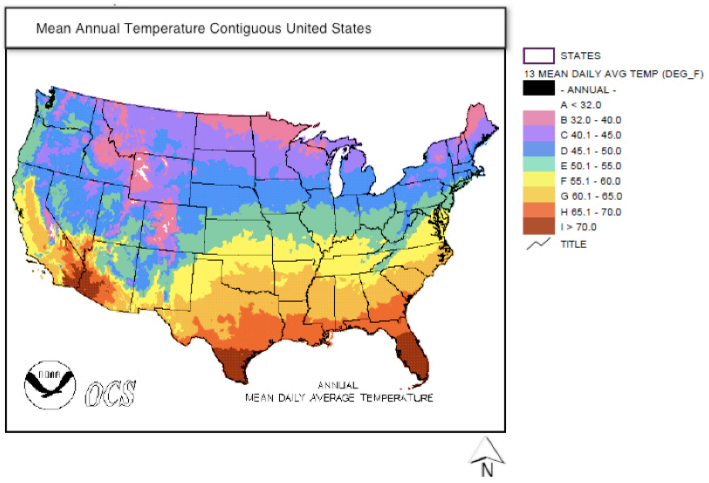
Savtchenko et al 2015 JGR Atmos



http://www.wrcc.dri.edu/pcpn/us_precip.gif

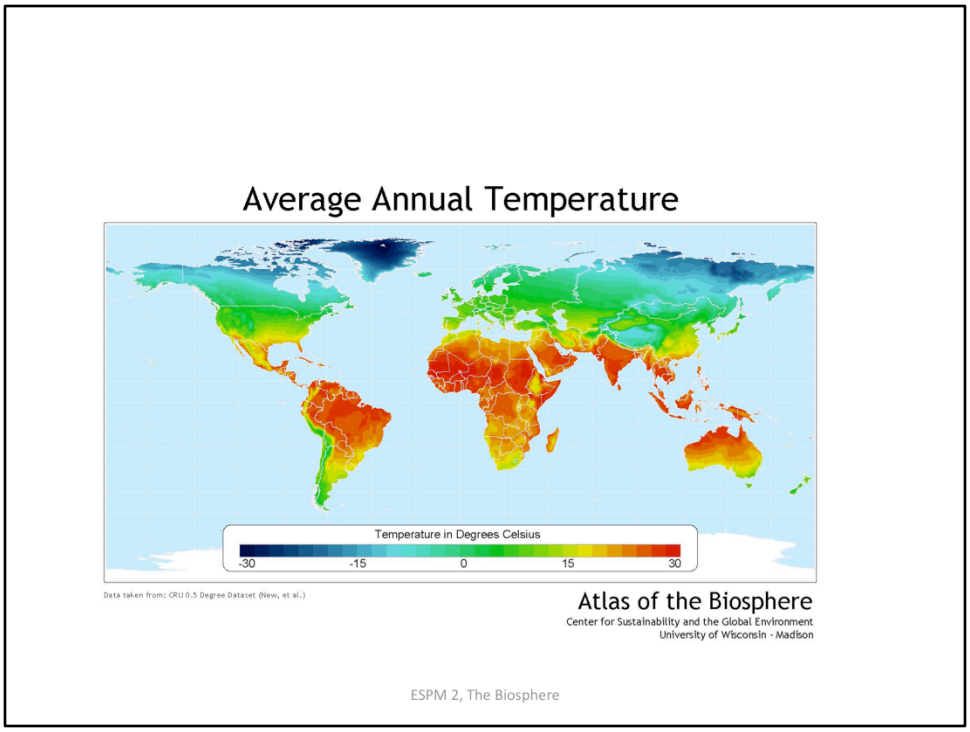


http://www.climate-charts.com/images/world-rainfall-map.png



ESPM 2, The Biosphere

http://d32ogoqmya1dw8.cloudfront.net/images/eslabs/drought/mean_annual_temp.jpg



http://nelson.wisc.edu/sage/data-and-models/atlas/maps/avganntemp/atl_avganntemp.jpg