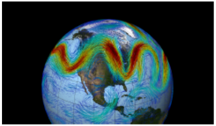
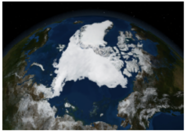
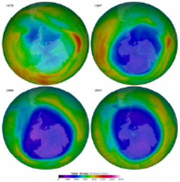
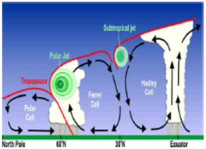




Fundamentals of Atmospheric Science (METR 5004)





Dr. Steven Cavallo
Fall 2013

Welcome to Atmospheric Science!

- *Atmospheric Science*: Study of the structure and evolution of the *planetary atmospheres* and with the wide range of phenomena that occur within them.
- *Atmospheric Science* is used synonymously with *meteorology*.
  - ➔ Meteorologist = weather forecaster
  - ➔ However, weather forecasting has evolved from an art based on experience and intuition into a science based on conservation laws.

Fig. 1.5 The limb of the Earth, as viewed from space in visible satellite imagery. The white layer is mainly light scattered from atmospheric aerosols and the overlying blue layer is mainly light scattered by air molecules. [NASA Gemini-4 photo. Photograph courtesy of NASA.]

Welcome to Atmospheric Science!

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  - ➔ Weather analysis and forecasting techniques (e.g. numerical weather prediction, data assimilation)

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  - ➔ Radiative transfer: The physical phenomenon of energy transfer in the form of electromagnetic radiation
  - ➔ The atmospheric boundary layer
  - ➔ Climate dynamics (e.g. ENSO, climate change)
  - ➔ Paleoclimate: Use of proxy methods to obtain data previously preserved within (e.g. rocks, sediments, ice sheets, tree rings, corals, shells and microfossils) to determine the past states of the Earth's various climate regions and its atmospheric system

Atmospheric science

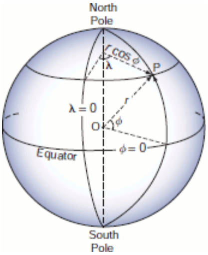
Even the term “atmospheric science” does not truly describe the complexities that we must consider in order to understand the atmosphere. For this reason, the term “Earth science” or “Planetary science” may be more appropriate.

The Development of Climate Models: Past, Present and Future

In this course...

I. Brief introduction to the atmosphere
II. Overview of the Earth System
III. Survey of the atmosphere:
    1. Dynamics
    2. Thermodynamics
    3. Weather systems: Extratropical
    4. Chemistry
    5. Cloud processes
    6. Boundary layer
    7. Radiative transfer
    8. Remote sensing with radar
    9. Weather Systems: High latitude and tropical
    10. Numerical weather prediction
    11. Climate dynamics
IV. Useful research tools in atmospheric science

Some definitions that we will use throughout



λ, ϕ, z:	Longitude, latitude, height above sea level
x, y, r:	Distances east of the Greenwich meridian, north of the equator, and from center of Earth
u, v, w:	Zonal, meridional, vertical velocity components
$r \simeq R_E$:	Radius and mean radius of Earth

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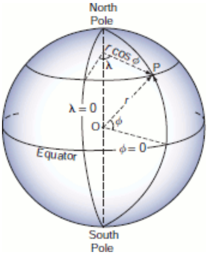

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$$\begin{aligned} dx &= r\, d\lambda\, cos\phi \\ dy &= r\, d\phi \\ (u, v, w) &= \left(\frac{dx}{dt}, \frac{dy}{dt}, \frac{dz}{dt}\right) \\ &= \left(R_E\, cos\phi \frac{d\lambda}{dt}, R_E \frac{d\phi}{dt}, \frac{dr}{dt}\right) \end{aligned}$$

Some definitions that we will use throughout

Notation	Term	Description
$\frac{\partial}{\partial t}$:	Local derivative	Rate of change at a fixed point in rotating (x,y,z) space
$\frac{d}{dt}$:	Total derivative	Rate of change following an air parcel as it moves long its 3-D trajectory through the atmosphere

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What is the total derivative?
Multivariate chain rule: Let $x = x(t)$ and $y = y(t)$ be differentiable at t and suppose that $z = f(x, y)$ is differentiable at the point $(x(t), y(t))$. Then $z = f(x(t), y(t))$ is differentiable at t and

$$\frac{dz}{dt} = \frac{\partial z}{\partial x}\frac{dx}{dt} + \frac{\partial z}{\partial y}\frac{dy}{dt}.$$

Some definitions that we will use throughout

For our applications, suppose a scalar ϕ varies in space and time such that $\phi = \phi(x, t)$. Then applying the multivariate chain rule gives:

$$\frac{d\phi}{dt} = \frac{\partial\phi}{\partial x}\underbrace{\frac{dx}{dt}}_{u} + \frac{\partial\phi}{\partial t}\frac{dt}{dt}$$

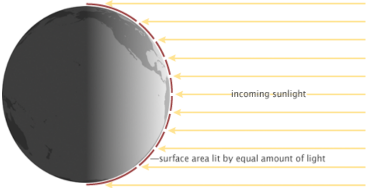
$$\frac{d\phi}{dt} = u\frac{\partial\phi}{\partial x} + \frac{\partial\phi}{\partial t}.$$

More generally if $\phi = \phi(x, y, z, t)$, then

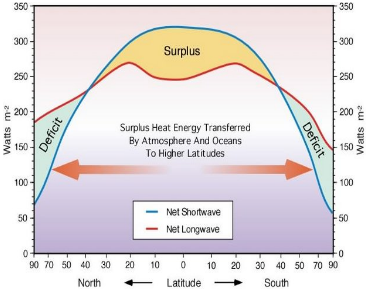
$$\begin{aligned}\frac{d\phi}{dt} &= \frac{\partial\phi}{\partial t} + u\frac{\partial\phi}{\partial x} + v\frac{\partial\phi}{\partial y} + w\frac{\partial\phi}{\partial y} \\ &= \frac{\partial\phi}{\partial t} + \vec{U}\cdot\nabla\phi\end{aligned}$$

where $\vec{U} = (u, v, w)$.

Brief survey of the atmosphere

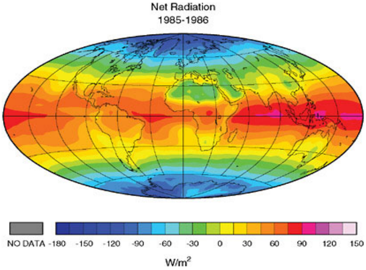


Solar radiation is not absorbed equally at all latitudes.

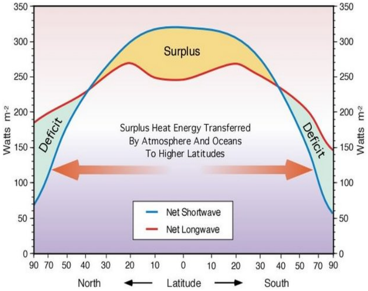


This results in an energy imbalance between lower and higher latitudes.

Brief survey of the atmosphere



Net radiation balance at the top of atmosphere



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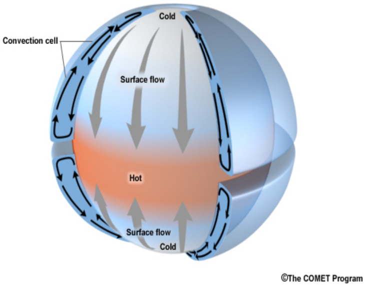
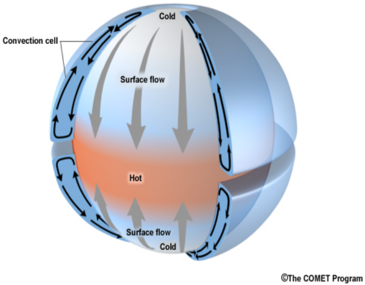
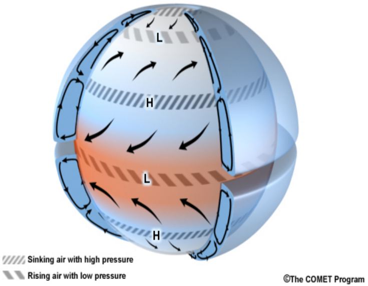
Brief survey of the atmosphere



If there were only a pressure gradient force, then the energy would balance out by meridional transport.

Brief survey of the atmosphere

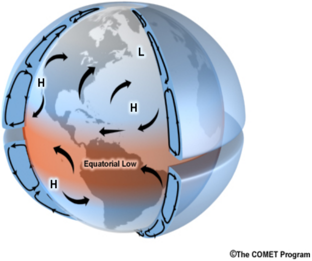




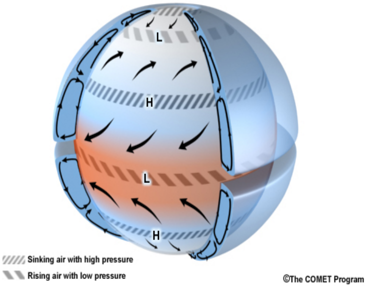
If there were only a pressure gradient force, then the energy would balance out by meridional transport.

However, adding in the Earth's rotation makes zonal transport as well.

Brief survey of the atmosphere



Land and water surfaces have different heat capacities, further altering pressure differences.



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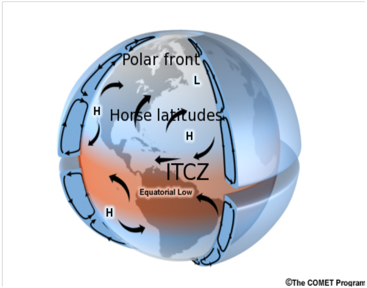

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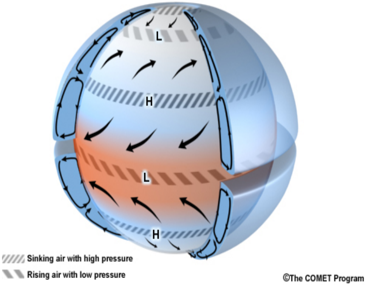

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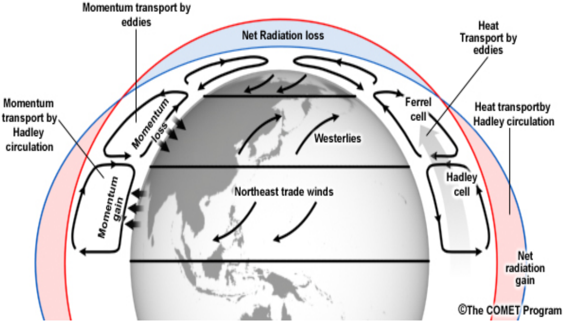
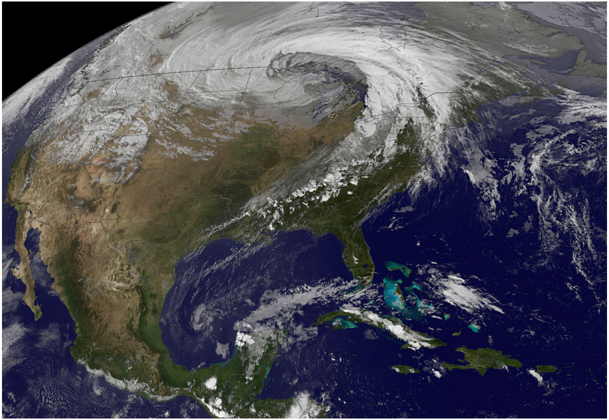


The end result is that energy is tranported poleward via eddy transport. This is accomplished in extratropical cyclones.

Brief survey of the atmosphere



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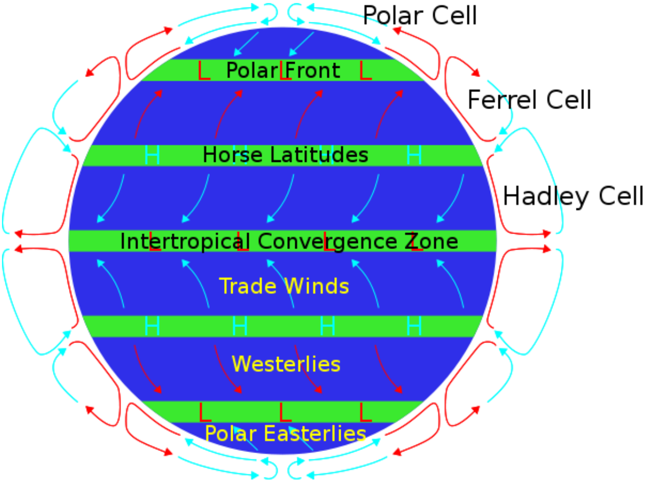
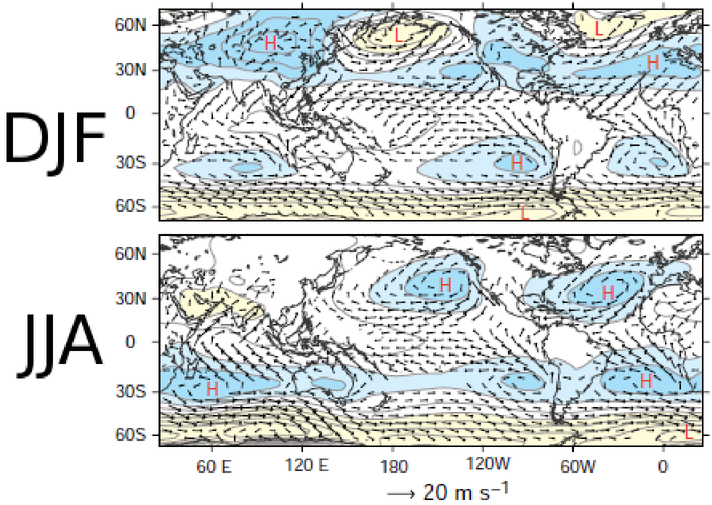


Brief survey of the atmosphere

Mean sea level pressure and winds



Brief survey of the atmosphere

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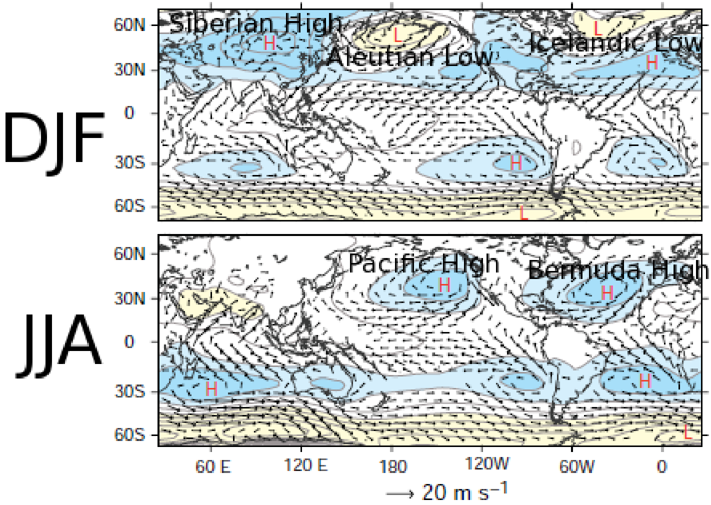
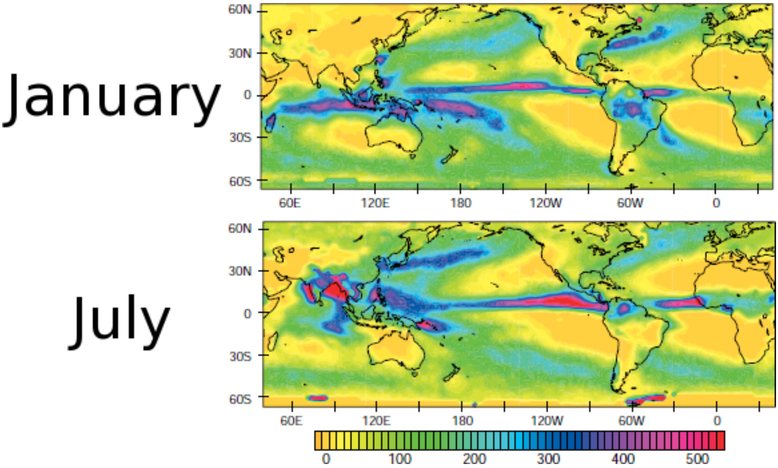


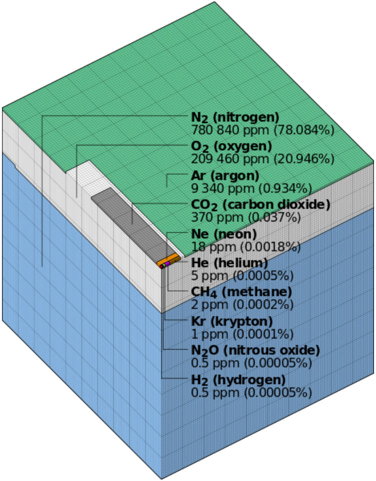
Brief survey of the atmosphere

Mean precipitation



Brief survey of the atmosphere

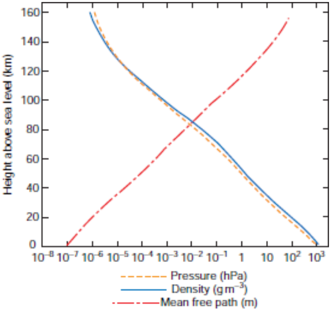
Molecular composition of atmosphere



- Most gases are not good absorbers of radiation and thus do not have much effect on temperature and climate (e.g. N_2, O_2, Ar)
- Water vapor (H_2O) has fractional concentration by volume of 0-5%, so it is ranked just after Ar
- Gases that are good absorbers of longwave radiation are called **Greenhouse gases**.
  - ➔ Best absorbers: H_2O, CO_2, and O_3
  - ➔ Trace constituents: CH_4, N_2O, CO, chlorofluorocarbons (CFCs)

Brief survey of the atmosphere

Vertical structure of pressure and density



Mean free path is the distance a molecule can be expected to move before colliding with another molecule.

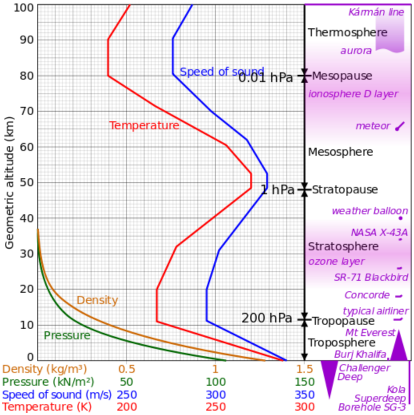
$$p \simeq p_0 e^{-z/H}$$

where p_0 is the pressure at some reference level, $H = \frac{R_d \overline{T}}{g}$ is the **e-folding depth** or **scale height**, $R_d = 287 \text{ J K}^{-1} \text{ kg}^{-1}$ is the dry air gas constant, $\overline{T}$ is the mean temperature in the layer between p and p_0, and g is the acceleration due to gravity.

- Density and pressure decrease exponentially with height.
- H ranges roughly from 7-8 km in the lowest 100 km.

Brief survey of the atmosphere

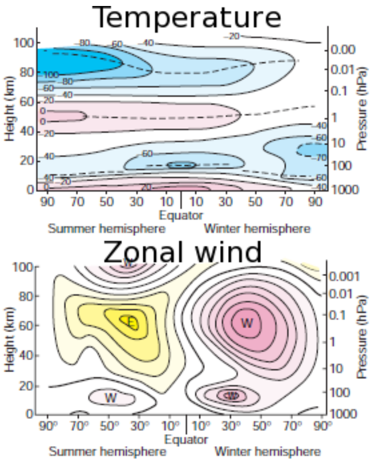
Vertical structure of pressure, density, and temperature



- ~80% of the mass of the atmosphere lies within the troposphere.
- Ground absorbs solar radiation and warms, but atmosphere is generally transparent to solar radiative heating, *except* in stratosphere where photons are absorbed by ozone (O_3).
- The average **lapse rate** in the troposphere is $\Gamma \equiv \frac{\partial T}{\partial z}$ ~6.5 K km^{-1}.

Brief survey of the atmosphere

Meridional structure of atmosphere (December)



- Tropopause $\sim$17 km in tropics, $\sim$10 km elsewhere
- Westerly midlatitude tropospheric jet streams centered on tropopause
- Lower mesospheric/upper stratospheric jet streams are westerly (easterly) during winter (summer)