

Title: The impact of the Atmosphere on space-bound Vehicles

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Abstract: When rockets and space-bound vehicles are fired into space, they have to deal with turbulence, winds and waves in the Earth's atmosphere. Different height regimes cause different problems. In the lower regions (0 to 20 km altitude), winds and turbulence are major issues, whereas above 50 km altitude, large atmospheric waves have serious importance on safe passage. Similar issues arise on re-entry. In this talk, I will discuss the ways in which these atmospheric phenomena manifest themselves, and how they are best mitigated. One example of particular significance will be the Space Shuttle Columbia disaster, for which I consulted with NASA in respect to possible atmospheric influences. I will also describe some of the instrumentation used to measure these phenomena.

The impact of the Atmosphere on space-bound Vehicles

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Atmospheric Physics – how does it fit?

Nobel Prize Winners in Physics and Chemistry:

Physics:

Rayleigh (1904), Appleton (1947), Braun and Marconi (1909), Van der Waals (1910), Compton and Wilson (1927), Raman (optics – 1930),

Chemistry: Arrhenius (1903- Greenhouse), Langmuir (1932), Debye and Huckel (1936), Herzberg (1971), Crutzen, Molina and Rowland (1995).

Peace Prize: IPCC and Gore, 2007.

Other notables: Lorenz (Chaos theory), Richardson (Turbulence), Fourier (Greenhouse), Rossby, Bjerknes, Prandtl, von Karman ...

Studies in Atmospheric Physics requires background in..







Electromagnetism, Thermodynamics, Optics, Fluids, Non-linear processes, gas kinetics, radar, signal-processing, Quantum Mechanics, scattering theory, computer modeling, chemistry...

A typical weather forecast nowadays...



14°C
°C | °F

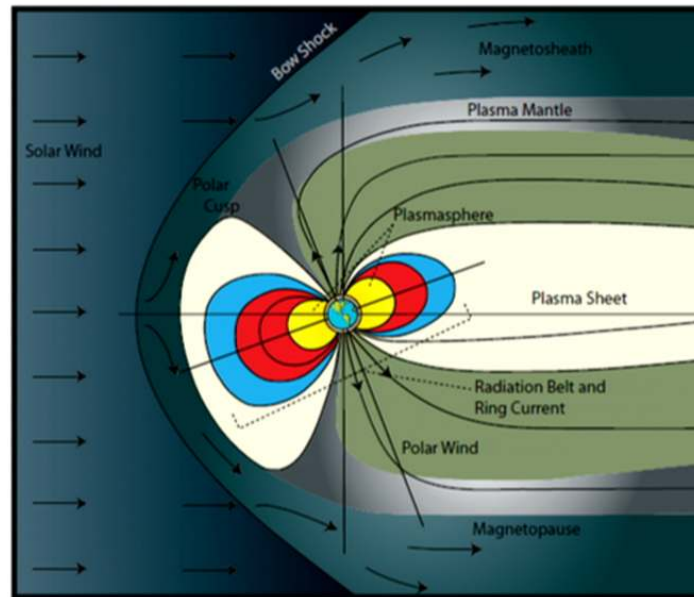
Observed at:	London Int'l Airport		
Date:	8:00 PM EDT Monday 3 June 2013		
Condition:	Mainly Sunny	Temperature:	14.4°C
Pressure:	101.7 kPa	Dewpoint:	5.6°C
Tendency:	falling	Humidity:	55%
Visibility:	24 km	Wind:	W 12 km/h

Forecast							AQHI
Mon	Tue	Wed	Thu	Fri	Sat	Sun	
3 Jun	4 Jun	5 Jun	6 Jun	7 Jun	8 Jun	9 Jun	
							
	20°C	19°C	19°C	18°C	20°C 30%	22°C	
6°C	8°C	10°C	13°C	12°C	12°C		

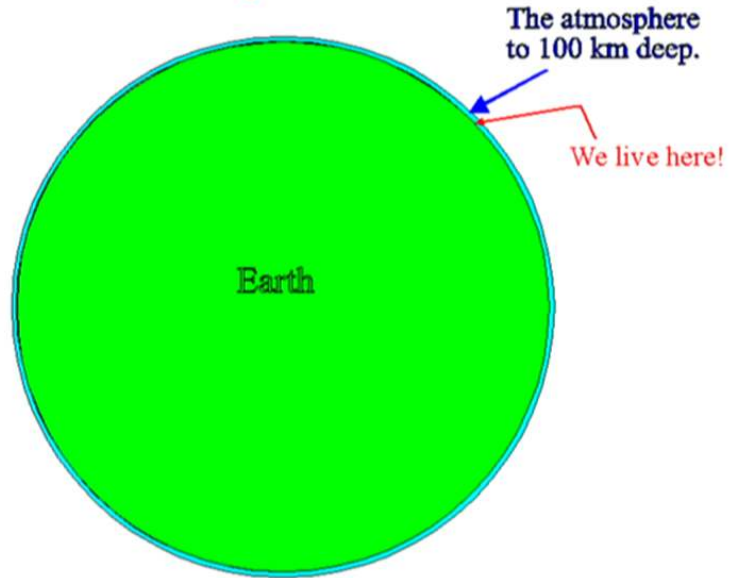
An aviation weather forecast is not too much different,
but might include wind maps, turbulence map.

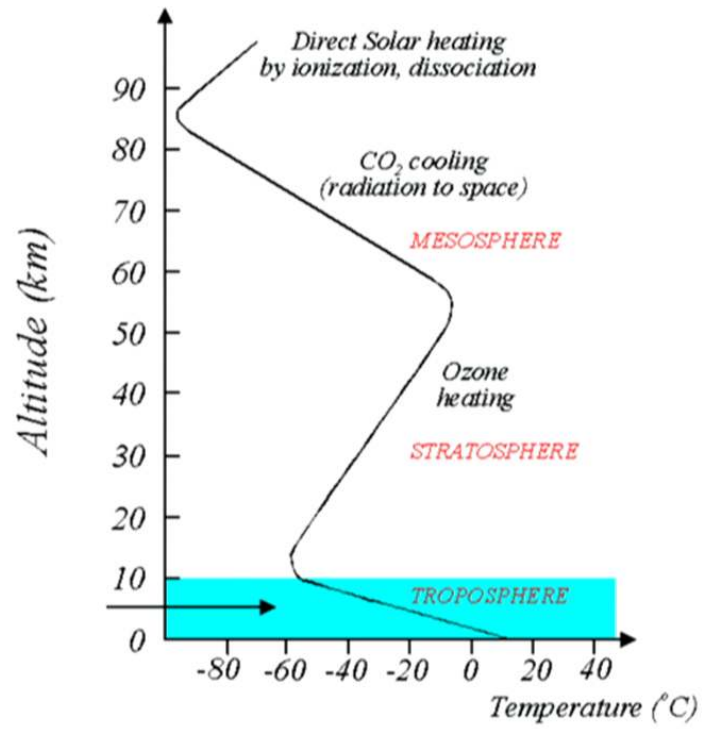
But what about in the future – what will a “weather
forecast” look like in the days of space travel?

So where is the future of flight? Certainly into
the upper atmosphere and beyond – so let us
prepare for that eventuality...



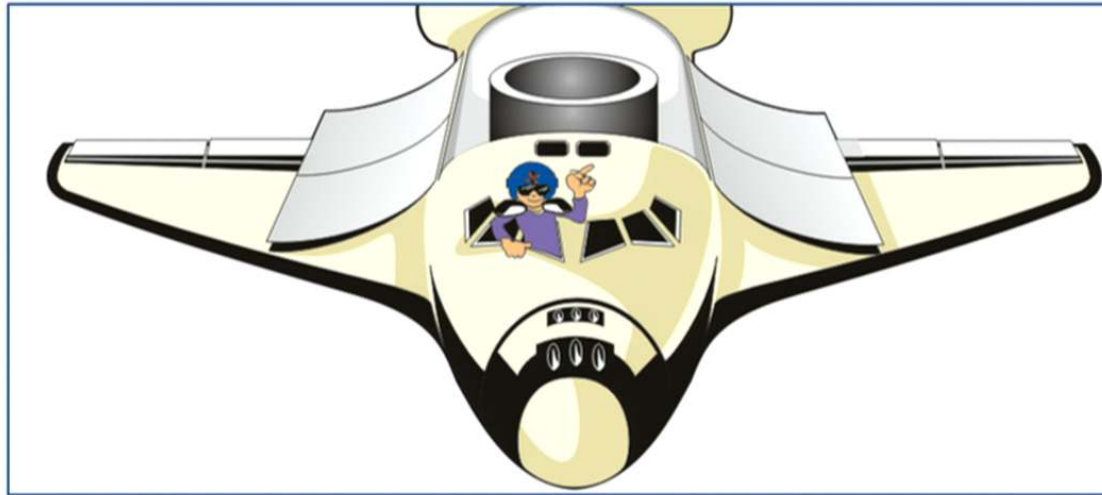
The atmosphere drawn to scale





V2



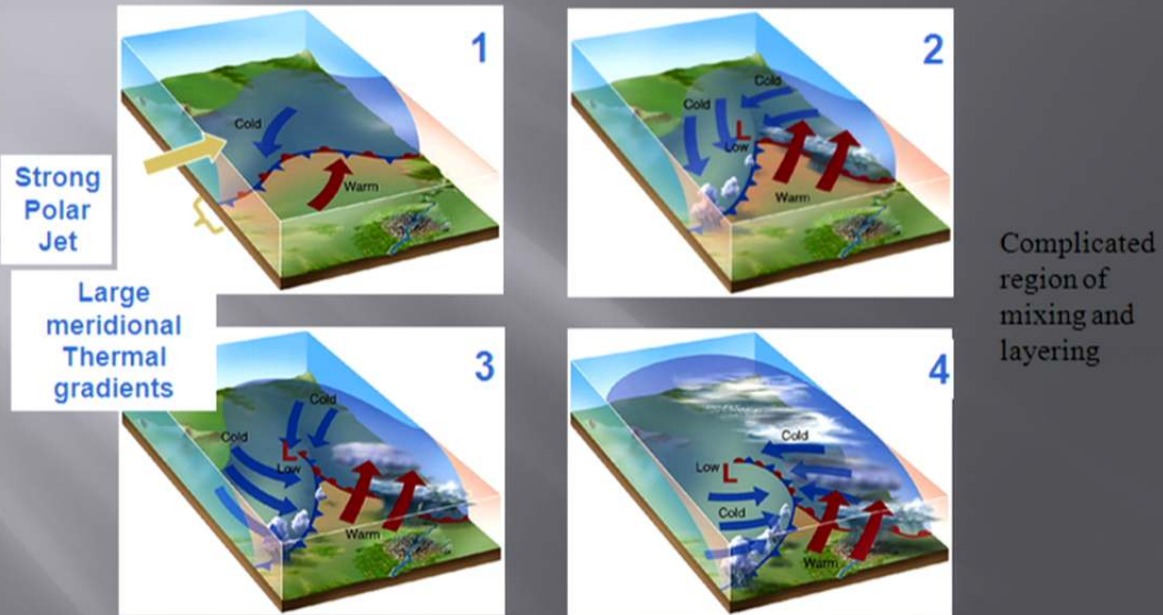


To infinity ... and beyond!

The Tropopause

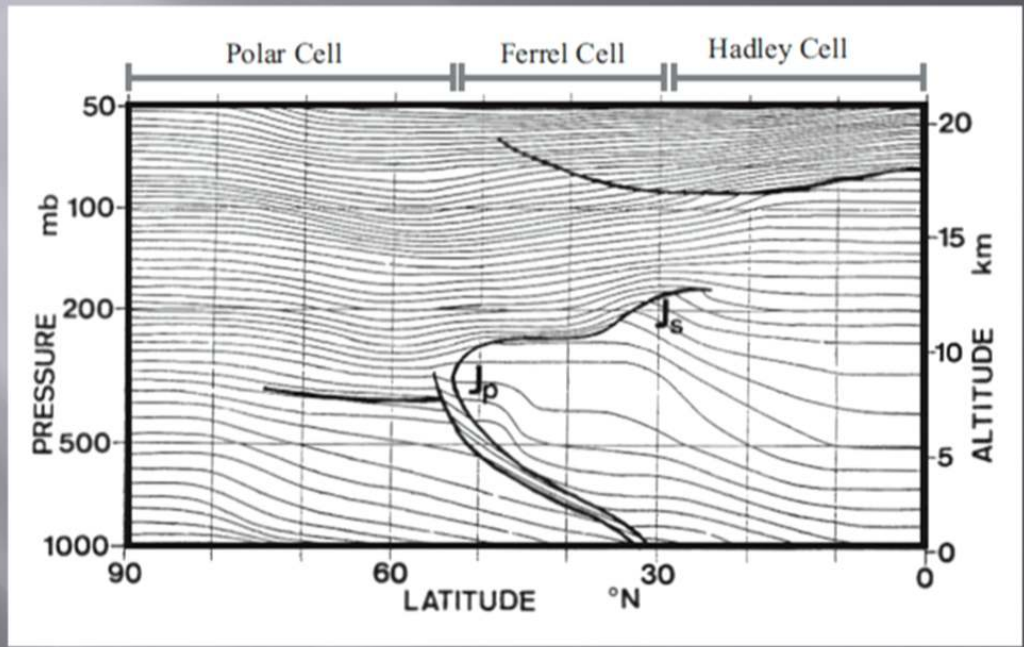
NOT a simple transition region – a complex region of physical and chemical processes involving multiple dynamical processes..

Classic Cyclogenesis

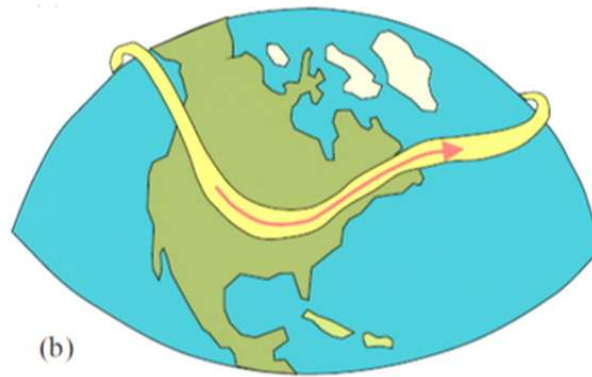


Kuhl... http://rst.gsfc.nasa.gov/Sect14/Sect14_1d.html

Tropopause Folding
Stratosphere-Troposphere Exchange



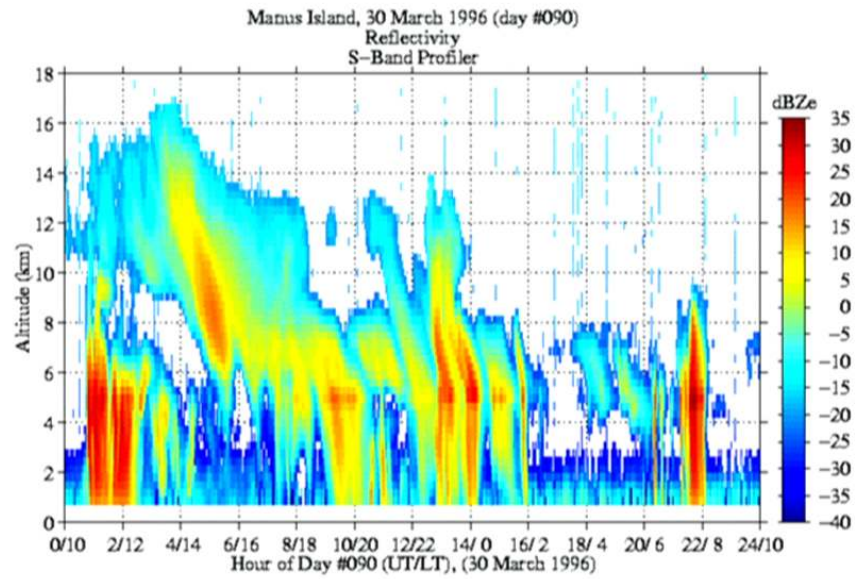
Complicated latitudinal structure



(b)

Jet-stream

Jet-stream flow over the Rockies is a major generator of low-pressure systems and ultimately severe weather.



Giant plumes of hot air rising into the stratosphere..

What does this picture tell us about the upper atmosphere?



Credit: Mel Wright



So... cold temperatures ... Triple point, sublimation curve..

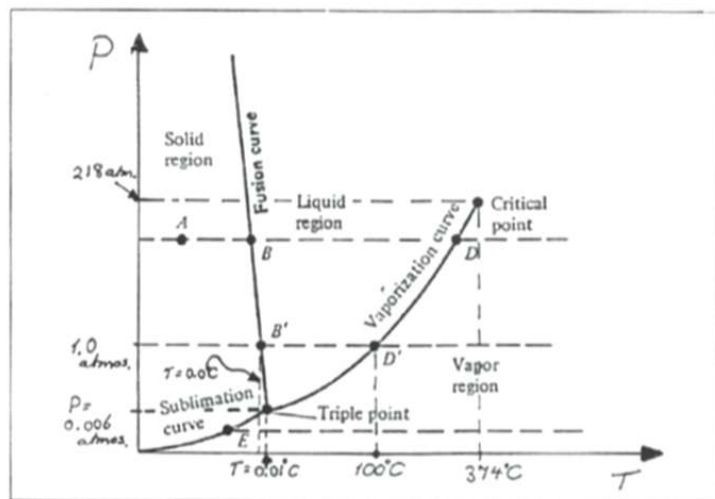


Figure 3.6: More realistic phase diagram for water. Remember that for most substances the fusion curve points up and to the right - it only points to the left as water expands on freezing.

So... cold temperatures, no water..just ice and vapour

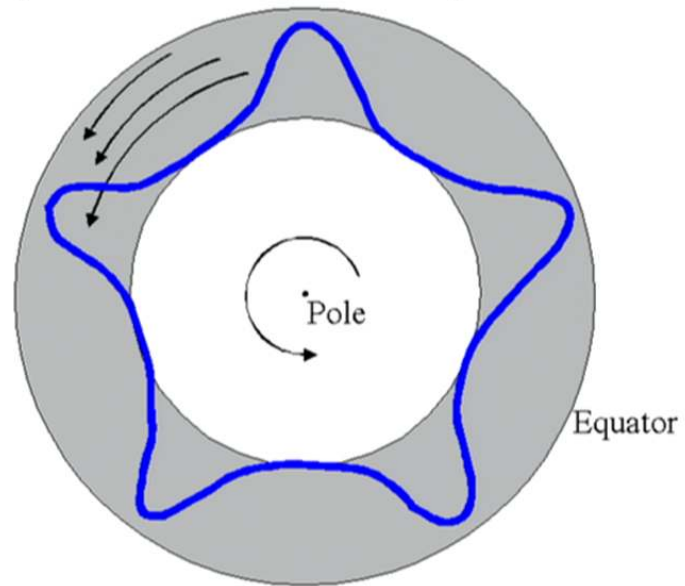
Stable temperature profile, (heating due to Ozone chemistry) – pretty boring, right?

But something else enters the picture...

... WAVES....

PLANETARY WAVES

Development of large-scale waves
by differential heating and velocity shear.



Buoyancy (Gravity) Waves



Waves – generated either in-situ or in the troposphere, and propagate upward.

Navier-Stokes

$$\frac{D\vec{u}}{Dt} = -\frac{1}{\rho}\nabla P - 2\vec{\Omega} \times \vec{u} + \vec{g} + \nu\nabla^2\vec{u}, \quad (2.1)$$

$$\frac{D\rho}{Dt} = \frac{1}{c_s^2} \frac{DP}{Dt} \quad (2.2)$$

$$\frac{D\rho}{Dt} + \rho\nabla \cdot \vec{u} = 0 \quad (2.3)$$

$$\frac{D\Theta}{Dt} = \frac{\kappa}{\rho}\nabla^2\Theta \quad (2.4)$$

Impact:

Waves carry energy, momentum long distances

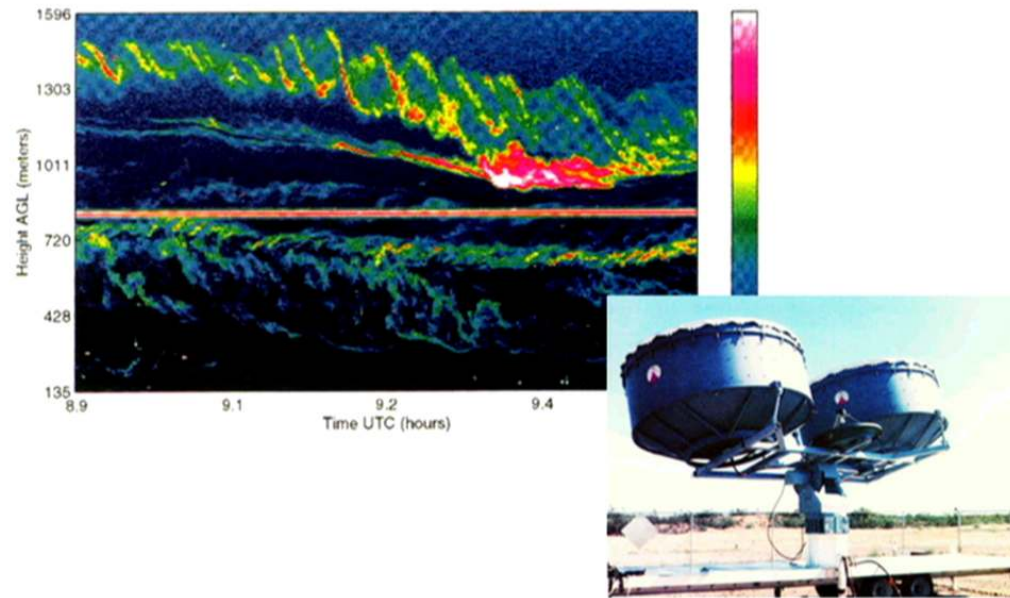
They also break, and are THE major source of turbulence above the atmospheric boundary layer..



Abitibi breaking wave



Kelvin Helmholtz (credit: Mel Wright)



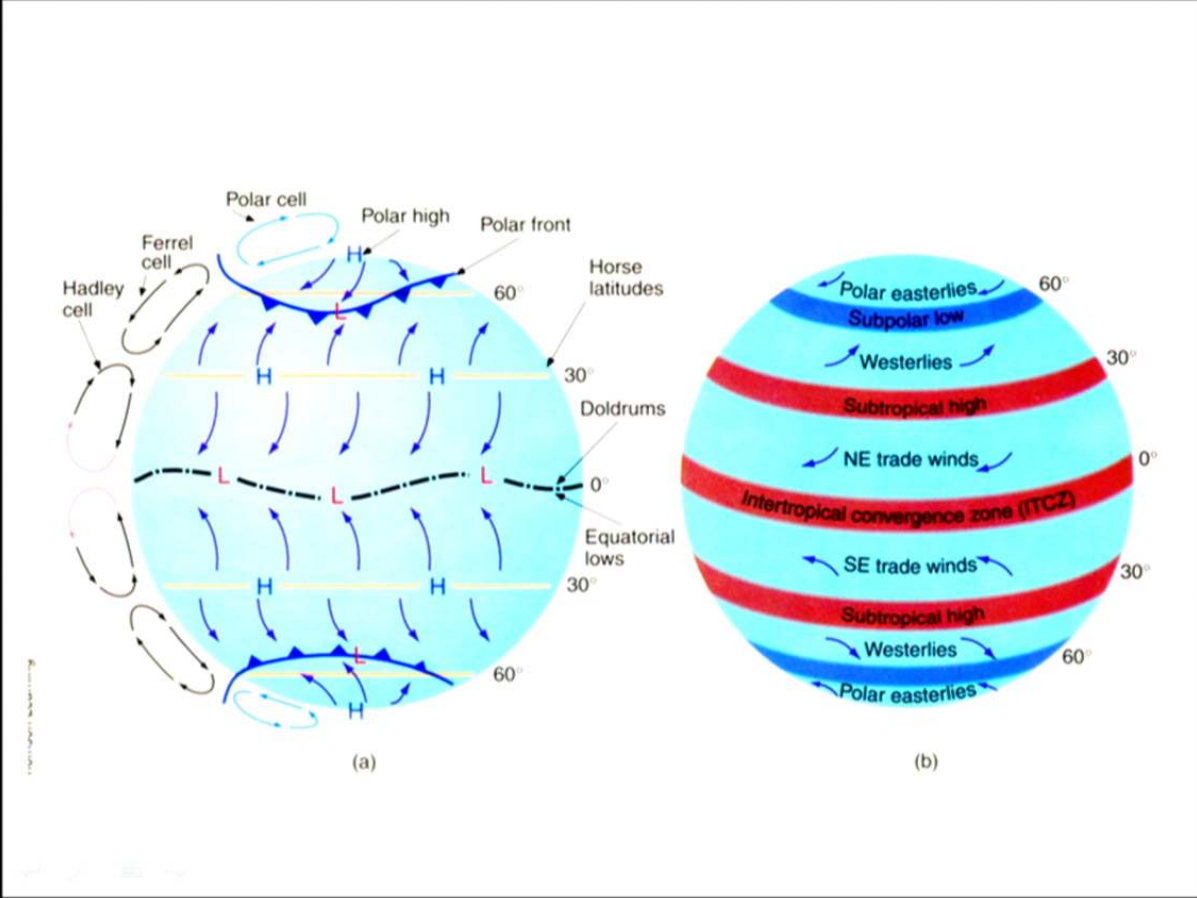
In the stratosphere, two main impacts for aircraft:

1. Highly developed non-linearities in planetary-waves lead to development of subsequent radiated waves and turbulence

Breakdown of gravity waves leads to development of clear-air-turbulence, which can be quite severe.

Dynamically, even more important, since they impact the general circulation of the atmosphere.

First, remind ourselves of the causes of the tropospheric circulation



- These effects, combined with other factors like ocean currents, land-sea differences, local orography, and water-related effects (latent heat transport, precipitation) are responsible for much of our “weather”.
- Largely radiatively driven
- But what about the “upper” atmosphere?

Stratosphere:

Driven by pole-to-pole pressure gradient above 40 km altitude (no clouds mean heating is dominant at the summer pole)

Surf-zone... breaking planetary waves – ozone bubbles...

Planetary waves DRIVE the stratospheric circulation (Brewer-Dobson)

Breaking gravity waves produce additional; dynamical driving of the atmosphere.. a very different circulation to that of the troposphere.

Breaking planetary waves and gravity waves produce hazards for transport.

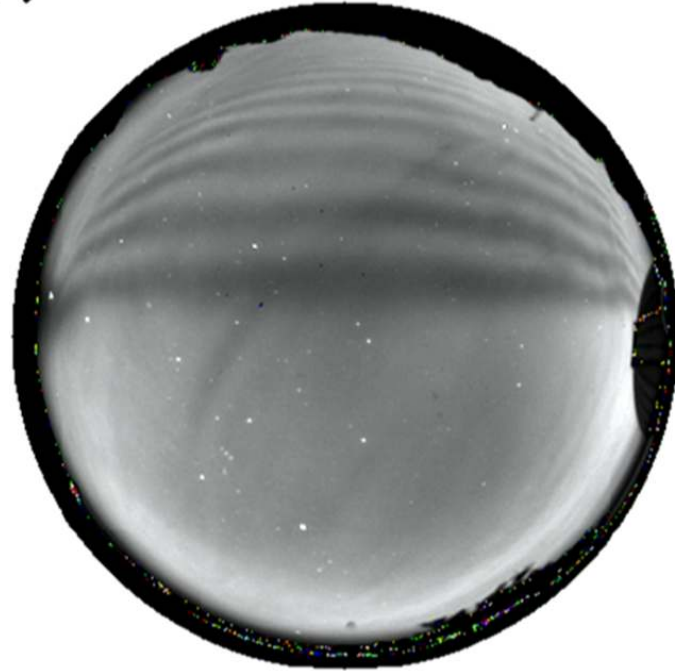
Ozone heating produces TIDES...

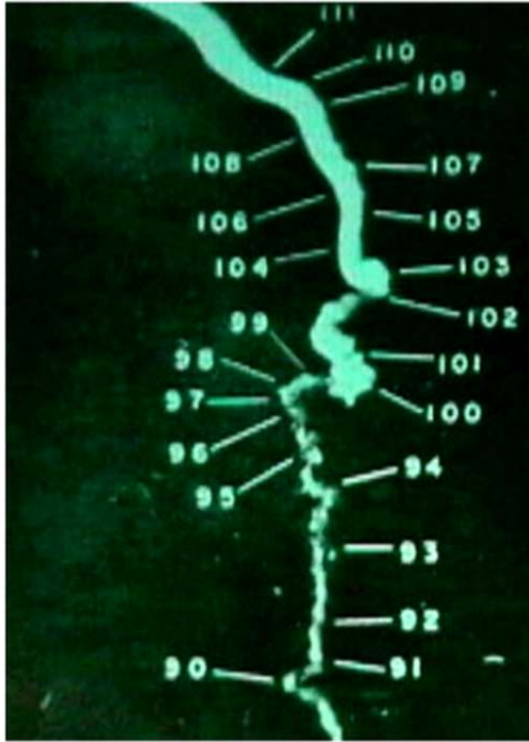
Mesospheric Circulation

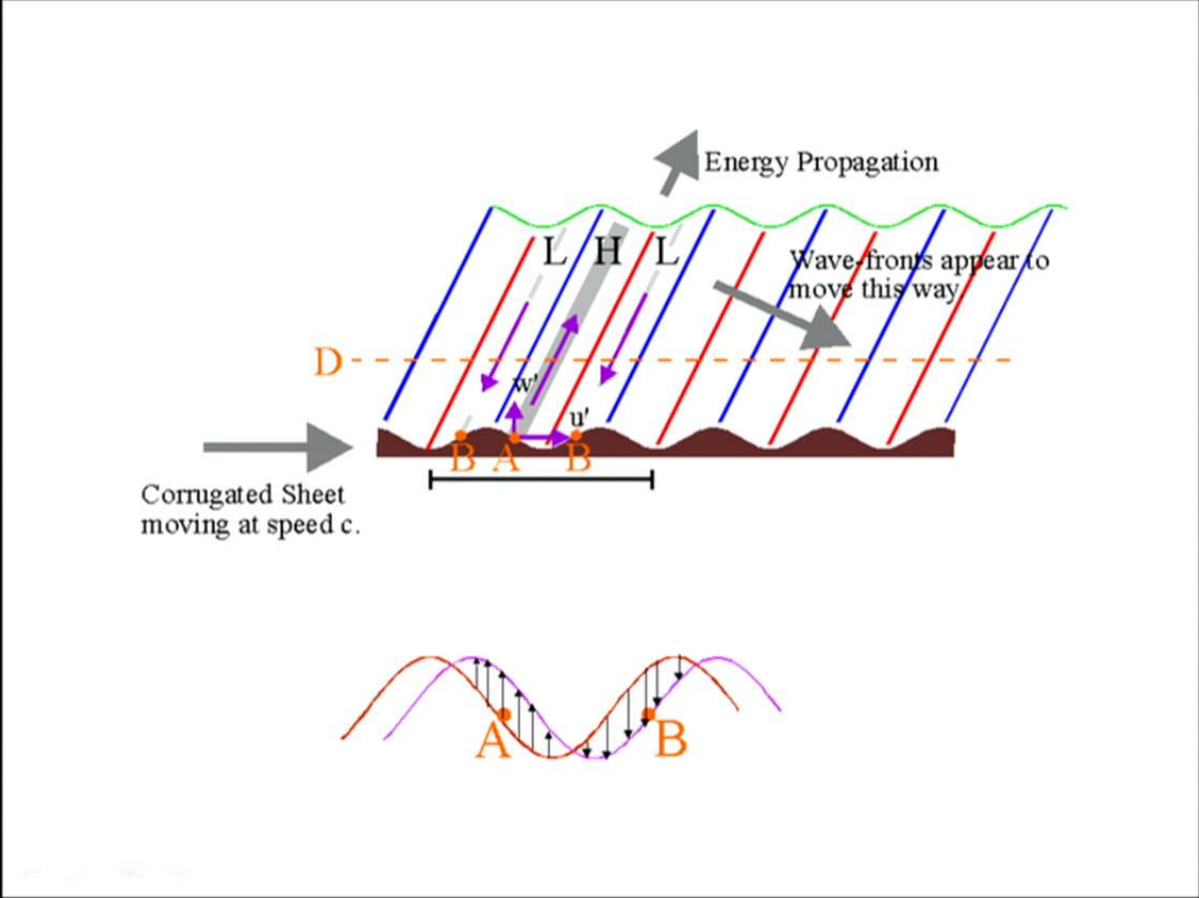
- Little to no water vapour
- Heating distribution differs
- Ozone heating, particle heating, IR radiation
- Dynamical and wave processes much more important
- **Waves** ***
- No direct frictional drag due to ground
- coupling with troposphere and ionosphere

In the mesosphere, Buoyancy waves (gravity waves) and TIDES become areas of major concern to our space-travellers, being even more important than planetary waves.

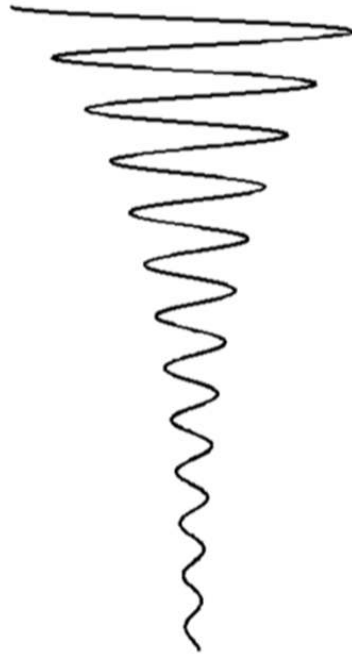
(a) OI 557.7 nm 10:45:32 UT







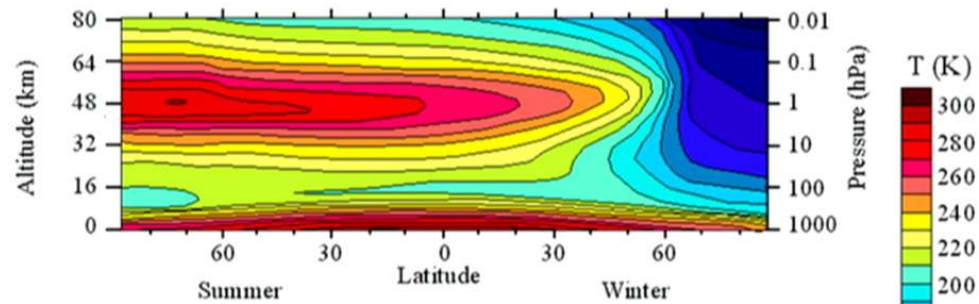
Gravity Waves....



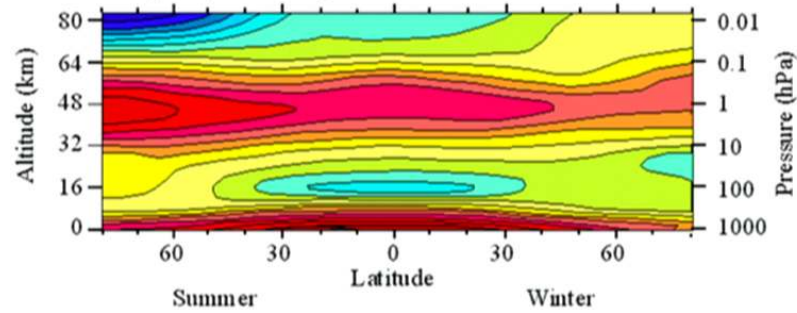
1. Grow exponentially with height in order to conserve kinetic energy per unit volume
2. Can achieve velocity amplitudes of the order of tens of metres per second.
3. Dissipate when they encounter a critical level (phase speed equals mean wind)
4. Convectively break down when their amplitude u' exceeds $|u-c|$.
5. Can also break down by other processes (slant-wise instability, K-H instability etc.)

Asymmetric filtering of gravity waves produces
net forcing on the upper atmosphere, completely
altering the large-scale dynamical flow.

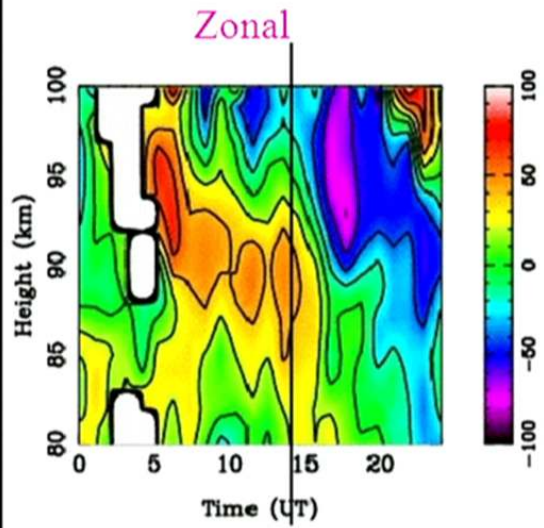
What a difference- and the summer pole is the coldest place on Earth!
With radiative balance



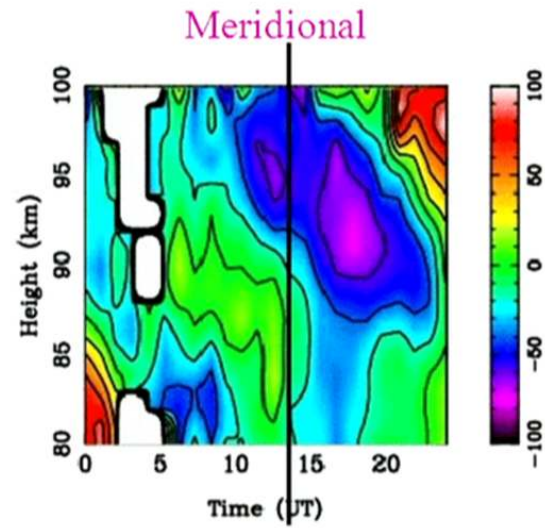
With gravity wave drag



Maui, 1 Feb 2003.



Shuttle re-entry



Shuttle re-entry

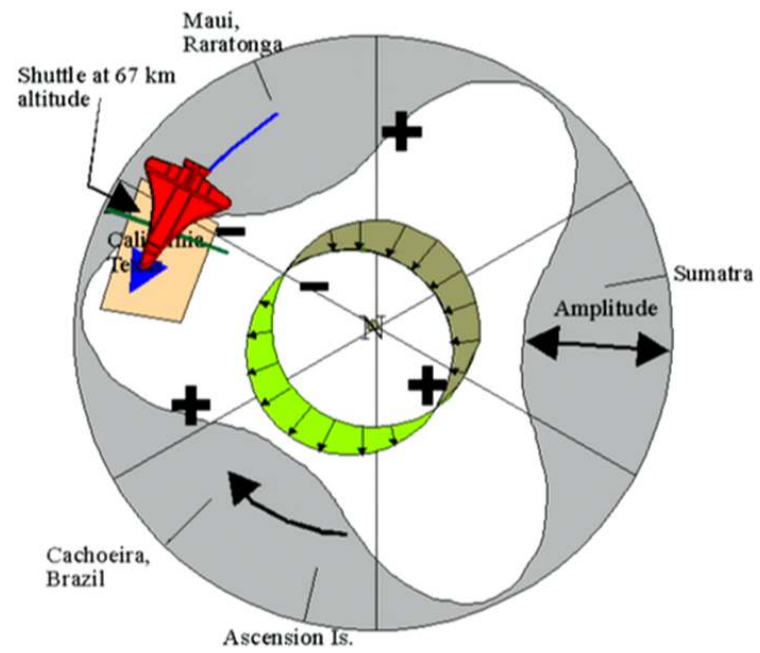
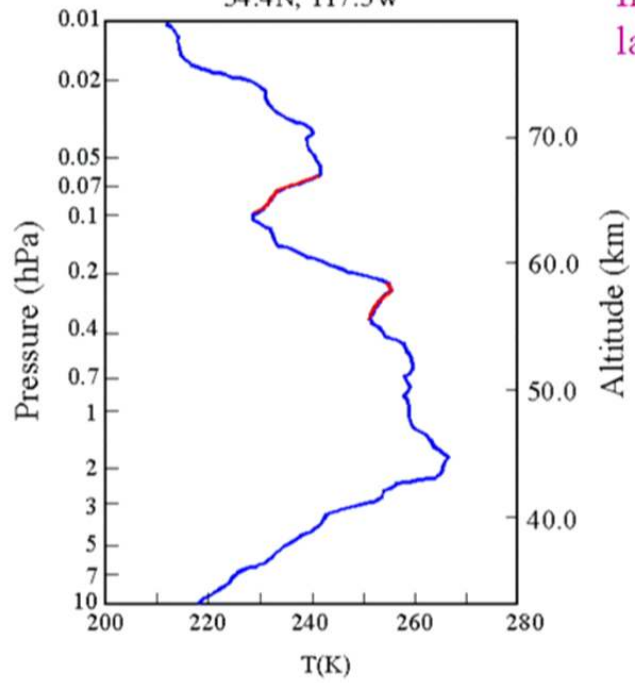


Table Mt. Lidar temperatures
Feb 1, 2003, 12Z.
34.4N, 117.5W



No turbulent layer –
In fact 2 very stable
layers!!

We need to recognize that

- Total density $\rho = \langle \rho \rangle + \rho'$
- Total velocity $v = \langle v \rangle + v'$

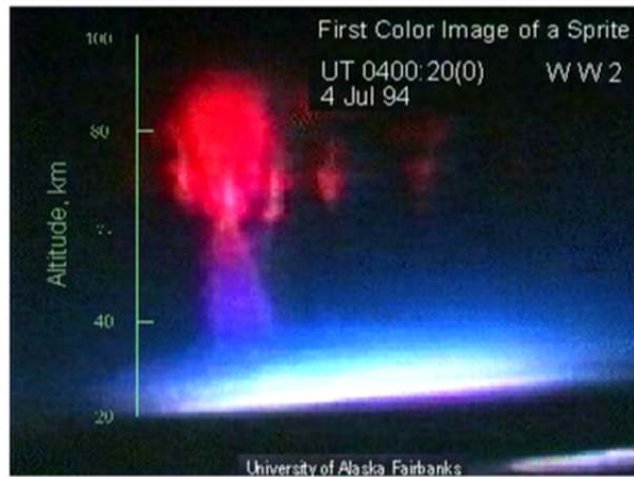
The degree of buffeting experienced by the space-craft is

$$\sigma_F = 0.5 C_D A \rho_0 u_0 v_{RMS} (2 + \beta u_0)$$

where v_{RMS} is the RMS along-track velocity, u_0 is the shuttle speed,

and $\beta \propto 1 / \sqrt{(gT)} \sqrt{(dT/dz + \Gamma_a)}$

The nett result is that at low speeds, (< Mach 1), buffeting is due to standard turbulence, BUT... at high speeds (~ Mach 18) the dominant source of buffeting is the spacecraft bouncing off gravity-wave density perturbations as it hurtles through the air!



Sprites and Elves – 30-95 km
“lightning” and electromagnetic
pulses (durations a few milliseconds)



Aurora Borealis

So... lots of reasons for “flight cancelled” announcements!

SPACE TRAVEL...???