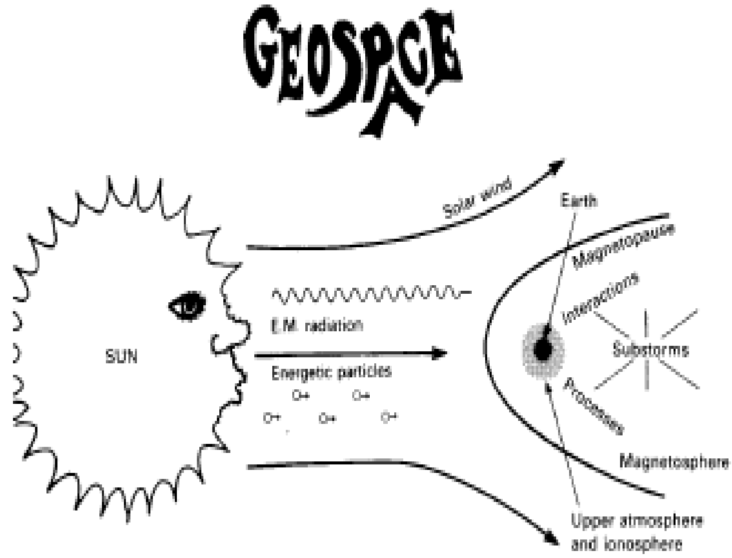
General Introduction

The Earth in space



Introduction

1. The solar-terrestrial environment, nowadays sometimes called *geospace*, includes the upper part of the terrestrial atmosphere, the outer part of the geomagnetic field, and the solar emissions which affect them. It could be defined as that region of space closest to the planet Earth, a region close enough to affect human activities and to be studied from the Earth, but remote enough to be beyond everyday experience.
2. Clearly, it is not the familiar atmosphere of meteorology; nor is it the inter-planetary space of astronomy, though it interacts with both.
3. The material found there is mainly terrestrial in origin and strictly a part of the atmosphere of the Earth, though it is greatly affected by energy arriving from the Sun. Starting some 50-70 km above the Earth's surface and extending to distances measured in tens of Earth radii, geospace is a region of interactions and of boundaries: interactions between terrestrial matter and solar radiation, between solar and terrestrial magnetic fields, between magnetic fields and charged particles; and boundaries between solar and terrestrial matter, and between regions dominated by different patterns of flow.
4. We shall be concerned with three broad regions:
   - The space between Sun and Earth, across which solar-terrestrial influences propagate.
   - The terrestrial atmosphere, neutral and ionized, with which the solar emissions react.
   - The geomagnetic field external to the solid Earth, which influences the ionized atmosphere and controls the Earth's outermost regions.

The Sun and the solar wind

1. The rather ordinary star at the center of the solar system establishes for each planet a radiation environment which controls its temperature and determines the rate of evolution of that planet, the composition of its atmosphere, and its suitability for life.
2. The planet Earth is intermediate between the extreme heat of the planets closer to the Sun and the extreme cold of the outer planets.
3. The Earth's surface temperature permits water to exist in all three phases. Life emerged in the liquid phase and proceeded to alter the composition of the atmosphere, adding oxygen to the nitrogen and carbon dioxide already present.
4. The presence of water as vapour also provided a source of hydrogen, which, as we shall see, is important at the atmosphere's higher levels.
5. Thus the general level of solar radiation, combined with the distance between Sun and Earth, has largely determined the nature of the Earth's atmosphere.
6. At the higher levels of the atmosphere, though, the changes that accompany variations of solar activity may be large and rapid.
7. The upper atmosphere, (where most of the more energetic solar radiations are stopped, and which is heated by them), is very responsive (سريع الاجابة) to solar activity variations in general, as well as to the short-lived, intense and localized outbursts known as *solar flares.*

8. In addition to radiation the Sun also emits a stream of matter. The Sun, is not in equilibrium and continuously loses matter as well as radiation into space.
9. This stream of matter is the *solar wind*, which forms the second vital connection between Sun and Earth.

The atmosphere and the ionosphere

1. Near the ground the atmosphere is a relatively dense gas, mainly composed of molecular nitrogen and oxygen with smaller amounts of carbon dioxide, water and various trace gases.
2. With increasing altitude the pressure and density decline. At 50 km 99.9% of the mass of the atmosphere is below, and at 100 km all but 1 part per million.
3. Into these rarified upper levels penetrate the ultra-violet and X-ray emissions emanating from the Sun, photons which are sufficiently energetic to dissociate and to ionize the atmospheric species, thereby altering the atmosphere's composition and heating it.
4. The heating creates a hot upper region called the *thermosphere* which is less turbulent than the lower regions, and in which gases of different density may separate. Thus the composition of the atmosphere changes with altitude, the lighter gases, particularly hydrogen, becoming progressively more dominant.
5. Because of the low pressure above about 100 km, ionized species do not necessarily recombine quickly, and there is a permanent population of ions and free electrons.
6. The net concentration of ions and free electrons (generally in equal numbers) is greatest at heights of a few hundred kilometers, and although the electron concentration may amount to only 1 % of the neutral concentration the presence of these electrons has a profound effect on the properties and behavior of the medium.
7. This *ionosphere* is electrically conducting and can support strong electric currents. The ionized medium also affects radio waves, and as a plasma it can support and generate a variety of waves, interactions and instabilities that are not found in a neutral gas.

Geomagnetic field and magnetosphere

1. As William Gilbert, physician to Queen Elizabeth I, realized 400 years ago, the Earth is itself a magnet.
2. The geomagnetic field is generated by electric currents flowing deep within the solid Earth and to a first approximation may be represented as though due to a short bar magnet at the center of the Earth.
3. As a dipole field it extends beyond the planetary surface, through the troposphere on which it has no effect, and into the ionized atmosphere where its effects are considerable.
4. The geomagnetic field affects the motions of ionized particles, and thus modifies ionospheric electric currents and the bulk movement of the plasma. The importance of the magnetic field increases with altitude as the atmosphere becomes sparser and its degree of ionization increases.

5. At the highest levels, more than a few thousand kilometers above the surface, all behavior is so dominated by the geomagnetic field that this region is called the magnetosphere.
6. There is no sharp boundary between the ionosphere and the magnetosphere, but between the magnetosphere and the solar wind is a boundary, the *magnetopause,* which is very significant.
7. At this boundary energy is coupled into the magnetosphere from the solar wind, and here is determined much of the behavior of the magnetosphere and of the ionosphere at high latitudes.
8. In the sunward direction the magnetopause is encountered at about 10 Earth-radii, but in the anti-solar direction the magnetosphere is extended downwind in a long tail, the magnetotail, within which occur plasma processes of great significance for the geospace regions.

Table A.1

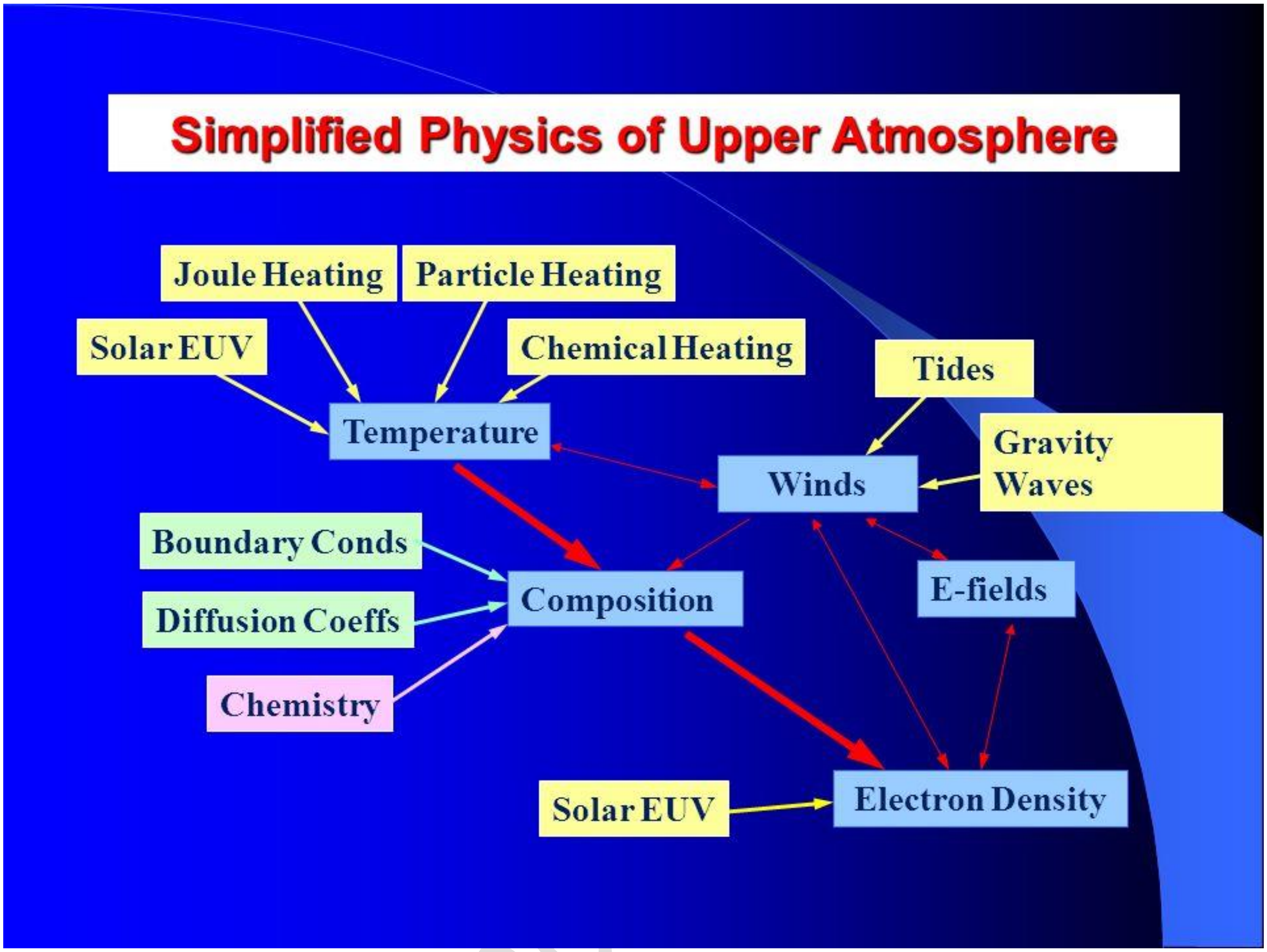
Constant	Symbol	Numerical value
Universal constants		
Universal gas constant	R	$8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
or (SI value)		$8.31 \times 10^3\ \mathrm{J\,K^{-1}\,kmol^{-1}}$
Avogadro's number	N_A	$6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
or (SI value)		$6.02 \times 10^{26}\ \mathrm{kmol^{-1}}$
Planck constant	h	$6.63 \times 10^{-34}\ \mathrm{J\,s}$
Boltzmann constant	k_B	$1.38 \times 10^{-23}\ \mathrm{J\,K^{-1}}$
Speed of light	c	$3.00 \times 10^8\ \mathrm{m\,s^{-1}}$
Stefan–Boltzmann constant	σ	$5.67 \times 10^{-8}\ \mathrm{W\,m^{-2}\,K^{-4}}$
(Note that $\sigma = 2\pi^5 k^4/(15h^3c^2)$)		
The Earth		
Mean acceleration due to gravity at the Earth's surface	g	$9.81\ \mathrm{m\,s^{-2}}$
The Earth's mean radius	a	6371 km
The Earth's mean rate of rotation	Ω	$7.29 \times 10^{-5}\ \mathrm{s^{-1}}$
Standard surface pressure	p_0	1013.25 hPa
The Sun		
Solar constant	F_s	$1370\ \mathrm{W\,m^{-2}}$
Mean distance between the Earth and the Sun		$1.50 \times 10^{11}\ \mathrm{m}$
Mean radius of the Sun		$6.96 \times 10^8\ \mathrm{m}$

(continued)

Table A.1 (cont.)

Constant	Symbol	Numerical value
Dry air		
Molar mass of dry air	M	$28.97\ \mathrm{kg\ kmol^{-1}}$
Density of dry air at STP	ρ_0	$1.29\ \mathrm{kg\ m^{-3}}$
Specific heat capacity of dry air at STP:		
at constant pressure	c_p	$1005\ \mathrm{J\ K^{-1}\ kg^{-1}}$
at constant volume	c_v	$718\ \mathrm{J\ K^{-1}\ kg^{-1}}$
Specific gas constant for dry air	R_d	$287\ \mathrm{J\ K^{-1}\ kg^{-1}}$
Water		
Molar mass of water	M_w	$18.02\ \mathrm{kg\ kmol^{-1}}$
Density of liquid water at STP	ρ_w	$1000\ \mathrm{kg\ m^{-3}}$
Density of ice at STP	ρ_i	$917\ \mathrm{kg\ m^{-3}}$
Specific heat capacity of water vapour at 0 °C:		
at constant pressure		$1850\ \mathrm{J\ K^{-1}\ kg^{-1}}$
at constant volume		$1390\ \mathrm{J\ K^{-1}\ kg^{-1}}$
Specific heat capacity of liquid water at 0 °C		$4217\ \mathrm{J\ K^{-1}\ kg^{-1}}$
Specific heat capacity of ice at 0 °C		$2106\ \mathrm{J\ K^{-1}\ kg^{-1}}$
Specific gas constant for water vapour	R_v	$461\ \mathrm{J\ K^{-1}\ kg^{-1}}$
Specific latent heat of vaporization at 0 °C	L_v	$2.50 \times 10^6\ \mathrm{J\ kg^{-1}}$
Specific latent heat of vaporization at 100 °C	L	$2.26 \times 10^6\ \mathrm{J\ kg^{-1}}$
Specific latent heat of fusion at 0 °C	L_f	$0.33 \times 10^6\ \mathrm{J\ kg^{-1}}$
Specific latent heat of sublimation at 0 °C	L_s	$2.83 \times 10^6\ \mathrm{J\ kg^{-1}}$
(Note that $L_\mathrm{s} = L_\mathrm{v} + L_\mathrm{f}$)		

Sources include Kaye and Laby (1986) and Lide (1995).


Simplified Physics of Upper Atmosphere
Joule Heating
Particle Heating
Solar EUV
Chemical Heating
Tides
Temperature
Gravity Waves
Winds
Boundary Conds
Composition
E-fields
Diffusion Coeffs
Chemistry
Solar EUV
Electron Density