PHYSICS OF THE ENVIRONMENT I

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The main part of this course examines how various components of the climate system (atmosphere, ocean, land, and cryosphere) interact in determining its observed state. The goal of this course is for a conceptual basis for understanding of how earth's present climate comes about and how the various components of the climate system interact to do so. This knowledge is necessary to understand how change to the climate system can come about.

A monographic treatment of the dispersion of gaseous pollutants in the atmosphere will also be given.

Primary textbook: Hartmann, D.L., *Global Physical Climatology,* Academic Press, 1994.

Helpful references:

Peixoto J.P. and A.H. Oort, “Physics of Climate”, *American Institute of Physics*, 1992.

Wallace, J.M. and P.V. Hobbs, “Atmospheric Science: An Introductory Survey”, *Academic Press*, 1977.

Holton, J.R., “An Introduction to Dynamic Meteorology”, 3rd edition, *Academic Press*, San Diego, 1992.

Outline of the course

1. **Observations of the climate system**: atmospheric temperature. Atmospheric composition. Hydrostatic balance. Atmospheric humidity. Ocean, land, cryosphere.

2. **The earth's energy balance**: orbital characteristics of the earth and distribution of insolation. Concept of energy balance as applied to the earth: emission temperature, greenhouse effect, distribution of insolation, top of atmosphere energy balance, poleward heat transport.

3. **Atmospheric radiative transfer**: physics of electromagnetic radiation; Planck's law. Absorption and emission of radiation by gases. Radiative transfer. Radiative and radiative-convective equilibrium temperature profiles. Role of clouds and cloud feedback.

4. **Surface energy balance**: radiative, latent and sensible fluxes.
Heat storage at the surface.
The atmospheric boundary layer.
Fluxes and their dependence on surface characteristics.
Diurnal and seasonal variations.

5. **Atmospheric circulation and its relationship to climate**:
how the circulation is set up and how it is related to the global energy balance. Equations of motion. Hydrostatic and geostrophic balance.
The zonal mean circulation and meridional heat transport.
Large scale circulation patterns.

6. **Ocean circulation and its relationship to climate**:
properties of seawater. Processes in the ocean mixed layer that determine its temperature and circulation.
Deeper waters and the thermohaline circulation.
Meridional heat transport in the ocean.

7. **The cryosphere**: observed characteristics and relationship to the energy balance.
Ice sheets and glaciers, sea ice, snow.
Ice-albedo feedback.

8. **Examples of interannual and decadal variability of climate**
(e.g. El Nino-Southern Oscillation and the North Atlantic Oscillation).

9. **Global warming:** a synthetic review of the debate concerning the Earth's global warming and a brief discussion about the natural and anthropogenic mechanisms that are deemed to share a responsibility for it and for Climate Change.

10. **Atmospheric dispersion of gaseous pollutants**: a monographic treatment of the basic concepts.
Guest lecturer: **Dr. D. Anfossi.**

CLIMATE

The traditional knowledge of weather and climate focuses on those variables that affect daily life most directly: average, maximum and minimum temperature, wind near the surface of the Earth, precipitation in its various forms, humidity, cloud type and amount, and solar radiation.
These are the variables observed hourly by a large number of weather stations around the globe.

However this is only part of the reality that determines weather and climate.

The growth, movement and decay of weather systems depend also on the vertical structure of the atmosphere, the influence of the underlying land and sea and many other factors not directly experienced by human beings. Climate is determined by the atmospheric circulation and by its interactions with the large scale ocean currents and the land with its features such as albedo, vegetation and soil moisture.

The climate of the Earth as a whole depends on factors that influence the radiative balance, such as for example, the atmospheric composition, solar radiation or volcanic eruptions.

To understand the climate of our planet Earth and its variations and to understand and possibly predict the changes of the climate brought about by human activities, one cannot ignore any of these many factors and components that determine the climate.
We must understand the *climate system*, the complicated system consisting of various components, including the dynamics and composition of the atmosphere, the ocean, the ice and snow cover, the land surface and its features, the many mutual interactions between them, and the large variety of physical, chemical and biological processes taking place in and among these components.
"Climate" in a wider sense refers to the state of the climate system as a whole, including a statistical description of its variations.

The climate system

The climate system is an interactive system consisting of five major components: the *atmosphere,* the *hydrosphere,* the *cryosphere,* the *land surface* and the *biosphere*, forced or influenced by various external forcing mechanisms, the most important of which is the Sun (see last slide).
Also the direct effect of human activities on the climate system is considered an external forcing.

The *atmosphere* is the most unstable and rapidly changing part of the system. Its composition is of central importance to the climate. The Earth's dry atmosphere is composed mainly of N_2, O_2 and Ar. These gases have only limited interaction with the incoming solar radiation and they do not interact with the infrared radiation emitted by the Earth.

However there are a number of trace gases, such as CO_2, CH_4,N_2O and O_3, which do absorb and emit infrared radiation.

These so called greenhouse gases, with a total volume mixing ratio in dry air of less than 0.1% by volume, play an essential role in the Earth's energy budget.

Moreover the atmosphere contains water vapour (H_2O), which is also a natural greenhouse gas. Its volume mixing ratio is highly variable, but it is typically in the order of 1%.

Because these greenhouse gases absorb the infrared radiation emitted by the Earth and emit infrared radiation up- and downward, they tend to raise the temperature near the Earth's surface.

Water vapour, CO_2 and O_3 also absorb solar short-wave radiation.

The atmospheric distribution of ozone and its role in the Earth's energy budget is unique. Ozone in the lower part of the atmosphere, the troposphere and lower stratosphere, acts as a greenhouse gas. Higher up in the stratosphere there is a natural layer of high ozone concentration, which absorbs solar ultra-violet radiation. In this way this so-called ozone layer plays an essential role in the stratosphere's radiative balance, at the same time filtering out this potentially damaging form of radiation. Beside these gases, the atmosphere also contains solid and liquid particles (aerosols) and clouds, which interact with the incoming and outgoing radiation in a complex and spatially very variable manner.

The most variable component of the atmosphere is water in its various phases such as vapour, cloud droplets, and ice crystals.

Water vapour is the strongest greenhouse gas.

For these reasons and because the transition between the various phases absorb and release much energy, water vapour is central to the climate and its variability and change.

The *hydrosphere* is the component comprising all liquid surface and subterranean water, both fresh water, including rivers, lakes and aquifers, and saline water of the oceans and seas. Fresh water runoff from the land returning to the oceans in rivers influences the ocean's composition and circulation.

The oceans cover approximately 70% of the Earth's surface. They store and transport a large amount of energy and dissolve and store great quantities of CO_2. Their circulation, driven by the wind and by density contrasts caused by salinity and thermal gradients (the so-called thermohaline circulation), is much slower than the atmospheric circulation. Mainly due to the large thermal inertia of the oceans, they damp vast and strong temperature changes and function as a regulator of the Earth's climate and as a source of natural climate variability, in particular on the longer time-scales.

Vegetation and soils at the *land surface* control how energy received from the Sun is returned to the atmosphere. Some is returned as long-wave (infrared) radiation, heating the atmosphere as the land surface warms. Some serves to evaporate water, either in the soil or in the leaves of plants, bringing water back into the atmosphere. Because the evaporation of soil moisture requires energy, soil moisture has a strong influence on the surface temperature.

The texture of the land surface (its roughness) influences the atmosphere dynamically as winds blow over the land's surface. Roughness is determined by both topography and vegetation.

Wind also blows dust from the surface into the atmosphere, which interacts with the atmospheric radiation.

The *cryosphere*, including the ice sheets of Greenland and Antarctica, continental glaciers and snow fields, sea ice and permafrost, derives its importance to the climate system from its high reflectivity (albedo) for solar radiation, its low thermal conductivity, its large thermal inertia and, especially, its critical role in driving deep ocean water circulation.

Because the ice sheets store a large amount of water, variations in their volume are a potential source of sea level variations.

The marine and terrestrial *biospheres* have a major impact on the atmosphere's composition. The biota influence the uptake and release of greenhouse gases. Through the photosynthetic process, both marine and terrestrial plants store significant amounts of carbon from carbon dioxide. Thus, the biosphere plays a central role in the carbon cycle, as well as in the budgets of many other gases, such as methane and nitrous oxide. Other biospheric emissions are the so-called volatile organic compounds (VOC) which may have important effects on atmospheric chemistry, on aerosol formation and therefore on climate.

Because the storage of carbon and the exchange of trace gases are influenced by climate, feedbacks between climate change and atmospheric concentrations of trace gases can occur.

Interactions among the components

Many physical, chemical and biological interaction processes occur among the various components of the climate system on a wide range of space and time scales, making the system extremely complex. Although the components of the climate system are very different in their composition, physical and chemical properties, structure and behaviour, they are all linked by fluxes of mass, heat and momentum: all subsystems are open and interrelated.

As an example, the atmosphere and the oceans are strongly coupled and exchange, among others, water vapour and heat through evaporation. This is part of the hydrological cycle and leads to condensation, cloud formation, precipitation and runoff, and supplies energy to weather systems.

On the other hand, precipitation has an influence on salinity, its distribution and the thermohaline circulation. Atmosphere and oceans also exchange, among other gases, carbon dioxide, maintaining a balance by dissolving it in cold polar water which sinks into the deep ocean and by outgassing in relatively warm upwelling water near the equator.
Some other examples: sea ice hinders the exchanges between atmosphere and oceans; the biosphere influences the carbon dioxide concentration by photosynthesis and respiration, which in turn is influenced by climate change. The biosphere also affects the input of water in the atmosphere through evapotranspiration, and the atmosphere's radiative balance through the amount of sunlight reflected back to the sky (albedo).

These are just a few examples from a virtually inexhaustible list of complex interactions some of which are poorly known or perhaps even unknown.
Any change, whether natural or anthropogenic, in the components of the climate system and their interactions, or in the external forcing, may result in climate variations.

The next slide shows a schematic view of the components of the global climate system.

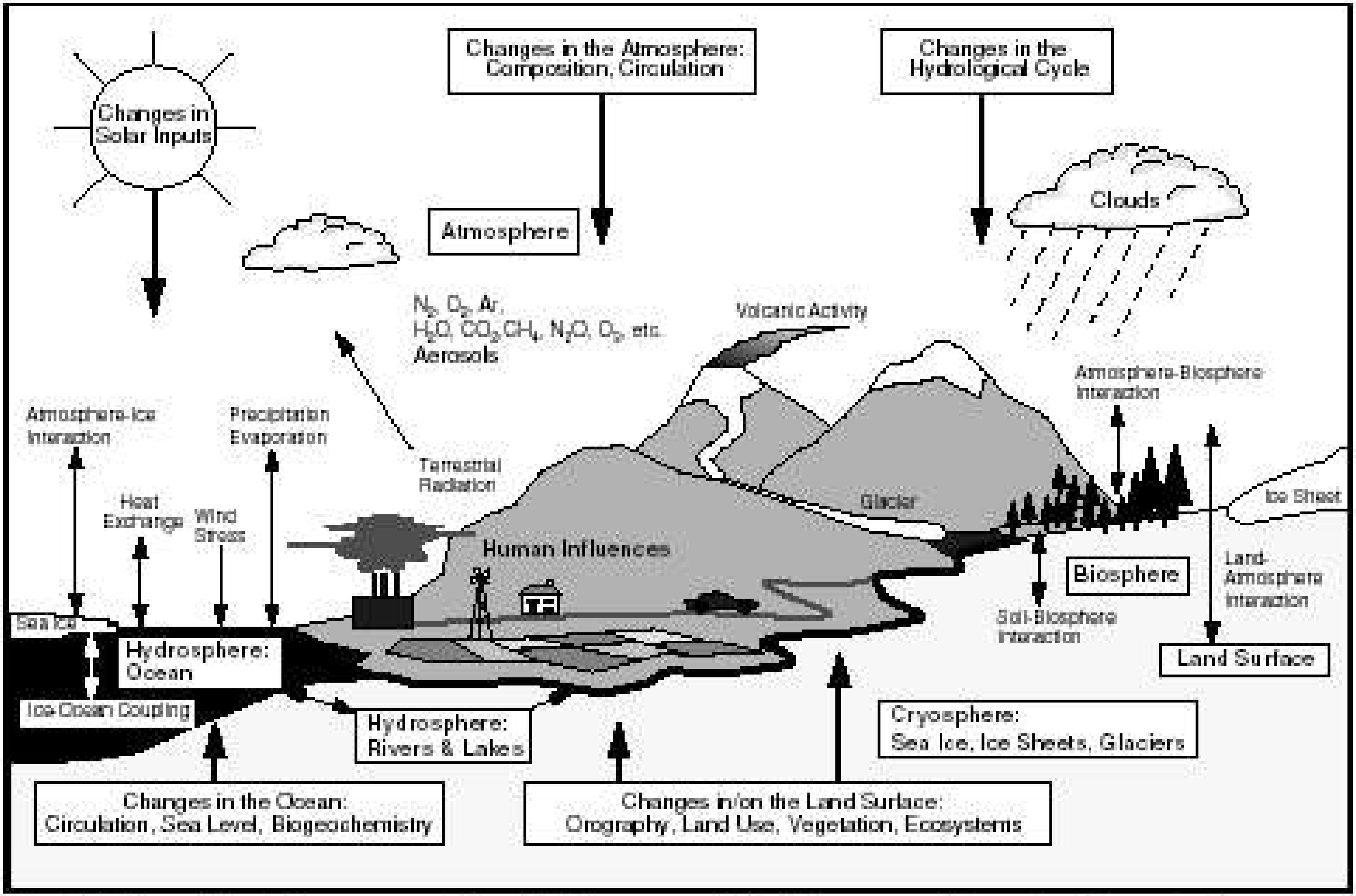

Figure 1.1: Schematic view of the components of the global climate system (bold), their processes and interactions (thin arrows) and some aspects that may change (bold arrows).

Source: IPCC Climate Change 2001- The Scientific Basis