AT622
CLASS NOTES
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AT622
Introduction to the Course

Aims of the course

The meteorological and climatological literature is concerned with the many different ways that motion in the atmosphere and oceans relate to the state of the thermal reservoir. Fig 1 is a schematic representation of the reservoirs of thermal and mechanical energies and the interactions between these reservoirs. The quantities shown are supposed to be integrated over the entire atmosphere and averaged over an annual cycle. Important in this view are the arrows associated with radiation processes. This simple diagram raises a number of questions and it is the aim of this course to address the answer to these questions at different levels: These include: What exactly are the arrows? What do the arrows mean? What defines their magnitude and how do we estimate or measure the magnitude? What are the space/time characteristics of them?

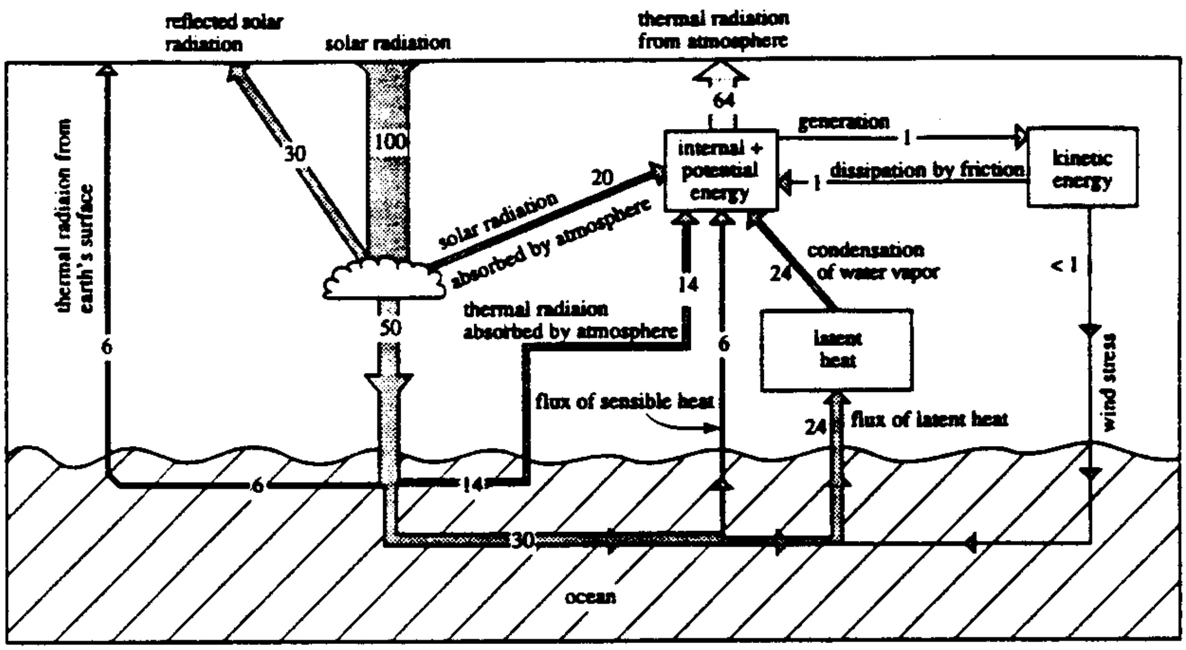

Fig. 1 Energy fluxes between the surface, atmosphere and space and internally between major energy reservoirs. Fluxes are expressed in terms of percentages of incident solar radiation.

Road-map of this course

In seeking answers to the above questions, a number of important concepts emerge. Understanding these concepts is the basic goal of this course and the concepts might be summarized as follows:

1. **The nature of radiation** - how is energy carried and how do we describe this energy? How is radiation created? Here the notion of radiometry is introduced. The concepts of intensity and fluxes and the relation between the two are important to grasp as these concepts are used throughout the course. What emerges is a set of basic laws and relations that quantify how radiation is emitted, which requires the notion of blackbody radiation.

2. **Radiative transfer in a molecular absorbing atmosphere** - radiative transfer is the mathematical construct by which we describe the flow of radiation in the atmosphere and hence calculate the direction and magnitude of the arrows of Fig.1. This construct is expressed in terms of the radiative transfer equation (RTE), and there are two basic forms of RTE that you will be exposed to in this class. The first applies to a nonscattering atmosphere with and without emission. This is treated first. It may be thought of as characterizing IR radiative transfer in clear skies. The scattering is dealt with later in the course. You should be able to derive the equations of relevance from first principles and formulate solutions to these equations, including the emissivity form of the equation. (2 weeks)

3. **The radiation budget of the Earth - a course primer -** The story behind Fig. 1 begins with the radiation at the top of the atmosphere. The flows into and out of the upper portion of the atmosphere is referred to as the Earth's radiation budget (ERB). It is important to grasp an understanding of what parameters define the magnitudes of these fluxes and their space-time variation. This gives a kind of integrated view of all the topics that will follow throughout the semester. The important factors that you will want to grasp include (i) what defines the disposition of solar energy at the top of the atmosphere (TOA) relative to the horizontal surface (we call this insolation and the factors include the radiation output from the sun itself and the elevation of the sun at any point in time), (ii) what defines the sunlight reflected from the planet (these factors include clouds, solar elevation, surface albedo), (iii) what governs the emission of IR radiation to space (gases, clouds, and surface), and (iv) what are the implications of the spatial variation of these fluxes? Finally you should be cognizant of the research programs that exist to measure and monitor the radiation budget (e.g., ERBE, CERES). (2 weeks)

4. **The properties of the molecular atmosphere: absorption** - One of the most important processes that defines the magnitudes of the arrows of Fig 1 as they relate to the atmosphere (i.e., as they relate to radiation leaving the atmosphere or absorbed by the atmosphere) is the process of molecular absorption. (We also learn from basic laws that once the absorption is known, then we also to a large extent know the emission.) The important concepts to learn from this part of the course is to be able to understand why only certain gases absorb radiation, how these gases absorb radiation, what defines the spectral character of this absorption, and how do we practically calculate this absorption. The importance of absorption coefficients and transmission functions arises in this discussion and you will want to be able to distinguish between several forms of transmission functions since different transmission functions appear in different forms of the radiative transfer equation. You will also learn that this transmission function is the way the physical properties of gases (such as density of gas) relate to the radiative properties of gases (i.e., transmission). (2-3 weeks)

5. **The radiative heating of the atmosphere -** Of all the topics, addressed in this course, this is perhaps the most critically important topic. It builds on 1-4 above. We will derive the heating rate equation from first principles. Solar heating by gaseous absorption is considered first (this is a relatively simple problem if we make certain assumptions). Next, infrared heating by gaseous absorption is addressed. You should know the spectral nature of the radiative heating and understand why it has the properties it has. It will be important to contrast these properties for clear skies against those for cloudy skies later in the course. (2 weeks)

6. **The properties of the scattering atmosphere** - Once we have an understanding of gaseous absorption and how we treat this absorption, we then consider scattering. This topic follows naturally from the molecular view of radiation with a conceptual understanding of Rayleigh scattering and how this in turn can be used to build up a conceptual view of scattering by large

chunks of matter (i.e., particles like aerosol and cloud droplets). From this portion of the course you will be expected to understand the nature of scattering, what properties define scattering, why and how it is different from molecular absorption, and how we express the degree of scattering. The definition of particle extinction and single scatter albedo are critical, and knowledge of the scattering phase function and what defines the structure of this phase function is also important. As in the case of molecular absorption,, you will be able to associate the properties of particles (composition, size, number density) to radiative properties. (2 weeks)

7. **Radiative transfer in a scattering atmosphere - radiative properties of clouds and aerosol** - Only a very cursory treatment of this topic is provided in this course. A simple form of radiative transfer equation that expresses the transfer in a scattering atmosphere will be introduced. What is important is not necessarily deriving the form of solution (although enough material will be provided for advanced and interested students to do so) but identifying those properties of clouds and aerosol that govern this transfer. The optical depth of clouds, single-scatter albedo, and some integrated moment of the scattering phase function emerge from this view. These properties are discussed and their association to other properties of clouds and aerosol (e.g., albedo, emissivity, and radiative heating) is described. (1 week)

8. **Radiative equilibrium and radiation balance** - The purpose of this section is to provide you with an understanding of how radiative heating influences the thermal properties of the atmosphere and the surface. The effects of gaseous absorption and clouds in shaping the atmospheric temperature profile will be discussed and you should be able to differentiate between radiative equilibrium and radiative and convective equilibrium. Next energy balance is discussed in the context of simple energy balance models. (2 weeks)

Course References

(1) AT 622 Notes
(2) Stephens, G. L., 1994: Remote Sensing of the Lower Atmosphere: An Introduction. (ATSL)
(3) Liou, 1980: Introduction to Atmospheric Radiation (ATSL)
(3) Liou, 1992: Radiation and Cloud Processes in the Atmosphere (ATSL)
(5) Goody and Yung. 1989: Atmospheric Radiation (ATSL)
(6)Taylor and Stamnes, 1999: (ATSL)
(6) Bohren and Huffman, 1983: Absorption and Scattering of Light by Small Particles. (ATSL)
(7) Assorted papers cited in notes.

Course Evaluation

1) 2 Homework Sets	10%
2) 2 Projects/Labs	30%
3) 2 Midterm Exam	30%
5) Final Exam	30%