

AT622
Spring 2025

Christian D. Kummerow, Professor

AT622

Introduction to the Course

Aims of the Course

An understanding of the global climate system requires careful examination of the sources and sinks of energy. AT622 aims primarily to understand how solar radiation incident upon Earth is redistributed in the Earth/Atmosphere system. Figure 1 is a schematic representation of this redistribution. 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 defines the magnitude of these arrows and how do we estimate or measure the magnitude? What are the space/time characteristics of them? How might they change if the atmosphere is perturbed?

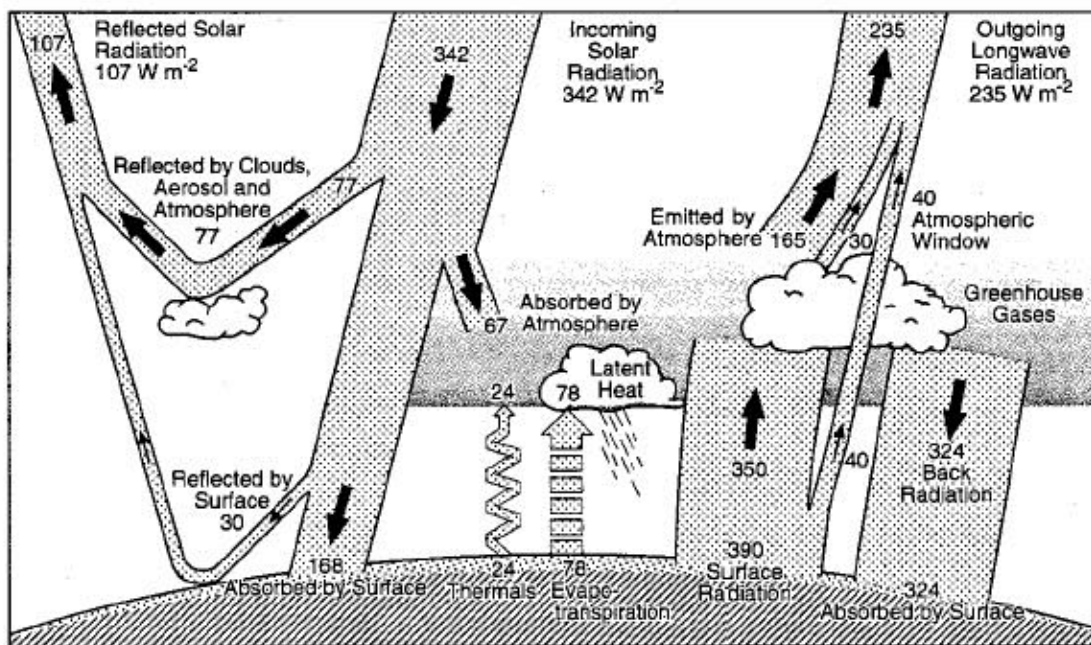


Fig. 1 The Earth's annual global mean energy budget. Units are in W/m^2 . [From Kiehl, J. T. and K. Trenberth, 1997: Earth's annual global mean energy budget. *Bull. Amer. Meteorol. Soc.*, **78**, 197-208.]

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 an 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 absorbing/emitting atmospheres with and without scattering. It may be thought of as characterizing most of IR radiative transfer. To do this, the course will cover the main atmospheric absorbers and where the absorption strengths come from before tackling the radiative transfer equation. At the end of this section, students should be able to derive the equations of relevance from first principles and understand the behavior of the solution.
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 understand 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).
4. **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.
5. **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.
6. **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 the 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.

Course References

- (1) AT 622 Notes
- (2) Petty, G. W., 2004: *A First Course in Atmospheric Radiation* (available at <http://www.sundogpublishing.com>)
- (3) Liou, K.N., 2002: *Introduction to Atmospheric Radiation*
- (4) Coakley, J. and P. Yang, 2014: *Atmospheric Radiation: A Primer with illustrative solutions*, Wiley, 256 pp.
- (5) Liou, K.N., 1992: *Radiation and Cloud Processes in the Atmosphere*
- (6) Goody, R.M. and Yung, Y.L., 1989: *Atmospheric Radiation: Theoretical Basis*
- (7) Thomas, G.E. and Stamnes, K., 1999: *Radiative Transfer in the Atmosphere and Ocean*
- (8) Bohren, C.F. and Huffman, D.R. 1983: *Absorption and Scattering of Light by Small Particles*.
- (9) Stephens, G.L., 1994: *Remote Sensing of the Lower Atmosphere: An Introduction*.

Course Evaluation

1) 2 Homework Sets	10%
2) 2 Projects/Labs	40%
3) 1 Midterm Exam	20%
4) Final Exam	30%

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Week 1:	1/22	Intro to course – logistics and importance of radiation
Week 2:	1/27	E&M waves, power and energy fluxes
	1/29	Ch.2 Solid angles, Radiances, and Fluxes
Week 3:	2/3	Ch.3 – The Plank Function – history, derivation and properties
	2/5	Ch.3 - Radiative balance / simple flux problems. Assign Hwk #1
Week 4:	2/10	Ch.4 – Radiative transfer – Beer’s law
	2/12	Ch.5 – The sun Hwk #1 due.
Week 5:	2/17	Ch.8 – Molecular spectroscopy – vibration & rotation lines
	2/19	Ch.8 – Line broadening & multi-line models
Week 6:	2/24	Radiative transfer with a source term. Assign Project # 1
	2/26	Radiative transfer with a source term. Assign Hwk #2
Week 7:	3/3	The weighting function & atmospheric Soundings.
	3/5	Review of gases in the atmosphere. Hwk #2 due
Week 8:	3/10	Odds and ends & review for exam
	3/12	Midterm Exam (through radiative transfer with a source term)
		Spring break
Week 9:	3/24	A look at the midterm.
	3/26	Ch.6 – The Grey body approximation & Rad/Conv Equilibrium.
Week10:	3/31	Ch.6 –Earth’s energy budget and fluxes + Ch11 – Heating. Proj. # 1 due
	4/2	Ch.7 – Clouds, Radiation and Climate
Week11:	4/7	Ch.7 – Earth’s radiation budget (ERB).
	4/9	Scattering concepts. Assign Project. #2

Week 12:

4/14 Ch.13 – Dielectric materials

4/16 Ch.14 – Rayleigh scattering

Week13:

4/21 Ch.14 –Mie and Ensemble particle scattering.

4/23 Single vs Multiple Scattering

Week14:

4/28 Two Stream Methods (Spencer Jones)

4/30 Two Stream Methods (Spencer Jones)

Week 15:

5/5 Radiation and Remote Sensing Project #2 due

5/7 Review

Final Exam is on Monday, May 12, 10:30 – 12:30