

Lecture 0 (INTRODUCTORY LECTURE)

Dynamical Meteorology (NS-MO402M)

November 2022 - January 2023

Lectures:

Michiel Baatsen (m.j.l.baatsen@uu.nl) and Aarnout van Delden (a.j.vandelden@uu.nl)

Assistants:

Amber Boot (d.boot@uu.nl), Julia Weiffenbach (j.e.weiffenbach@uu.nl) & Sanne Veldhuijsen (s.b.m.veldhuijsen@uu.nl)

Lectures on Wednesday, 13:15-15:00 and on Friday, 09:00-10:45

Tutorials on Wednesday, 15:15-17:00 and on Friday, 11:00-12:45, sometimes also 13:15-15:00

Lectures 0&1 on Wednesday, 16 November 2022, 13:15-15:45 (BBG 001)

Lecture 2 on Friday 18 November 2022, 09:00-10:45 (KBG 208)

Introduction to Project 1 on Wednesday, 23 November 2022, 13:15-15:00

* **Lecture notes:** <https://webpace.science.uu.nl/~delde102/AtmosphericDynamics%5b2021%5dCh1.pdf>

Website: <http://www.staff.science.uu.nl/~delde102/dynmeteorology.htm>

Information: <https://uu.blackboard.com> (USERNAME & PASSWORD needed)

Schedule 2022-2023

Lectures

Wednesday 13:15-15:00 in weeks **46-51** of 2022 and weeks **2-3** of 2023

Friday 9:00-10:45 in weeks **46-50** of 2022 and weeks **2-3** of 2023

Tutorials (working on the projects and exercises and making a weather forecast)

Wednesday 15:15-17:00 in weeks **46-51** of 2022 and weeks **2-4** of 2023

Friday 11:00-12:45 in weeks **46-50** of 2022 and weeks **2-4** of 2022

Friday 13:15-15:00 in weeks **47-50** of 2022 and weeks **2-4** of 2023

Exam

Week **5** 2023 (Wed. 1 Feb. 2023) (retake: April 2023)

No lectures or practical sessions

On Friday 23/12/2022

Lecture Notes

ATMOSPHERIC DYNAMICS

AARNOUT VAN DELDEN

INSTITUTE FOR MARINE AND ATMOSPHERIC RESEARCH
UTRECHT UNIVERSITY
PRINCETONPLEIN 5
3584 CC UTRECHT, THE NETHERLANDS



Lago di Bolsena (Italy): view of growing Cumulus clouds over the mountains to the west of the lake on 25 July 2010, 17:23 LT.

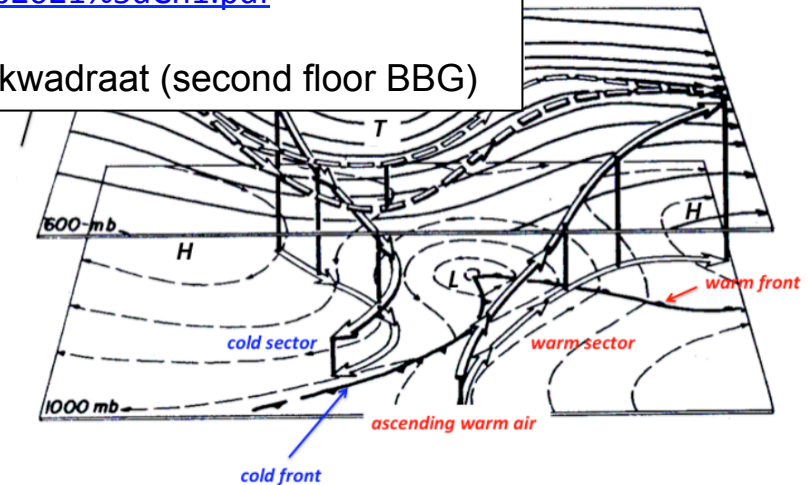


Lago di Bolsena (Italy): view of a thunderstorm over the mountains to the west of the lake on 25 July 2010, 18:24 LT. The rain shaft is visible below the darkest clouds and a shield of *high* Cirrus clouds (the anvil of the thunderstorm) is visible aloft.

Download:

<https://webpace.science.uu.nl/~delde102/AtmosphericDynamics%5b2021%5dCh1.pdf>

Printed: for sale at A-Eskwadraat (second floor BBG)



Typical flow pattern between two isobaric surfaces (1000 hPa is near the Earth's surface; 500 hPa is at about 5 km above sea level) in a wave-like disturbance of the jet-stream in the northern hemisphere. The warm air rises along very slanted trajectories, giving rise to layered clouds, as shown in the figure below. See [FIGURE 1.43](#).



Layered clouds as background of "The Scream" (1893) by Edvard Munch (1863-1944).

Lecture Notes

Chapter 1 contains all the subject matter of the course

4

Chapter titles of these lecture notes

Introductory (this document)

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In depth (online)

2) Energy Balance
3) Hydrostatic Balance
4) Convection
5) Geostrophic Balance
6) Orographic Effects
7) Zonal Mean State and Potential Vorticity Inversion
8) Zonal mean thermal wind balance in the surf zone
9) Baroclinic Waves and Cyclogenesis
10) Numerical Simulation of the Life-Cycle of Unstable Baroclinic Waves
11) Planetary Waves, Wave Drag and Meridional Transport
12) Diabatic-Dynamical Interaction in the General Circulation
13) Zonal asymmetries in the General Circulation

Lecture notes for the course on *Dynamical Meteorology* (NS-MO402M), *Climate Dynamics* (NS-363B) *Boundary Layers, Transport and Mixing* (NS-MO412M) and *Simulation of Ocean, Atmosphere and Climate* (NS-MO501M) at Utrecht University in the academic year 2019-2020.

By Aarnout van Delden

Office: Room 615, Buys Ballot Gebouw (BBG), Princetonplein 5, 3584CC Utrecht, Netherlands

E-mail: a.j.vandelden@uu.nl

Website: <http://www.staff.science.uu.nl/~delde102/AtmosphericDynamics.htm>

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0 Preface

On understanding a complicated problem

Anyone who wants to analyze the properties of matter in a real problem might want to start by writing down the fundamental equations and then try to solve them mathematically. Although there are people who try to use such an approach, these people are the failures in this field; the real successes come to those who start from a *physical* point of view, people who have a rough idea where they are going and then begin by making the right kind of approximations, knowing what is big and what is small in a given complicated situation. These problems are so complicated that even an elementary understanding, although inaccurate and incomplete, is worth while having, and so the subject will be one that we shall go over again and again, each time with more accuracy...

Richard Feynman (1963) in *The Feynman Lectures on Physics*, chapter 39. vol. 1.

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i Introduction to atmospheric dynamics

These lecture notes have grown out of many years of giving the one-semester courses on *Geophysical Fluid Dynamics*, *Dynamical Meteorology* and *Climate Dynamics* at Utrecht University. I have given the lecture notes the more natural title *Atmospheric Dynamics*, which covers two subjects that are traditionally called *Dynamical Meteorology* and *Synoptic Meteorology*, as well as part of the subject of *Climate Dynamics*.

Climate Dynamics deals with the theory of the annual average or seasonal average and/or zonal average¹ state of the atmosphere, and usually also involves the ocean, the cryosphere (the glaciers and ice caps) and the biosphere.

Dynamical Meteorology deals with the theory of circulations associated with atmospheric weather phenomena such as cyclones, anticyclones, fronts, sea breezes, tornadoes, thunderstorms, lee-waves and severe downslope windstorms.

Synoptic Meteorology deals with the analysis of observations of these weather phenomena. This analysis is practically impossible without "**conceptual models**" of weather phenomena, or "synoptic models" as they are called on page 231 of Godske et al. (1957)². The two subjects (dynamical meteorology and synoptic meteorology) are of course intimately related and here we make no further attempt to separate them.

More than 2000 years ago meteorology was an integral part of physics. Some would have claimed, "meteorology is physics". Unfortunately, less than a century ago the position of meteorology was less privileged. This is illustrated very well by the following words from the *Feynman Lectures on Physics* (1963)³.

¹ Zonal average is the average with respect longitude.

² Godske, C.L., T. Bergeron, J. Bjerknes and R.C. Bundgaard, 1957: **Dynamic Meteorology and Weather Forecasting**. American Meteorological Society, Boston and Carnegie Institution, Washington D.C., 800 pp.

³ R.P. Feynman, R.B. Leighton and M. Sands, 1963: **The Feynman Lectures on Physics**. Addison-Wesley Publishing Company. Online edition: <http://www.feynmanlectures.caltech.edu>. Richard Feynman received the Nobel Prize in Physics in 1965.

1

Introduction to the atmosphere

On mathematics in physics

A little more mathematics isn't going to bail you out of your troubles. Newton knew less mathematics than many a present day undergraduate, but I haven't noticed any *Principias* coming out of our colleges lately. What mathematics can do is to help you formulate and express your problems in such a way that you can easily locate the critical points at which your *creative* physical thinking must begin. And this is no mean service to you. ... But don't expect that mathematics will give you an easy answer to any physical problem. If you find that it does, that is evidence that you picked a poor problem to begin with. Blair Kinsman (1965) in *Wind Waves*, Dover Publications, New York, p. xi.

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Dynamical Meteorology: grading and dates

“Learning by doing” in 2022-23

Projects and grading (weights)

Project 1: Simulating the vertical motion of an air parcel (problem 1.6): 15%

Project 3: Simulating the sea breeze at the coast (problem 1.15) : 15%

Project 5: Analysing teleconnections with Principal Component Analysis (problem 1.24): 20%

Exam: 50% - (minimum grade: 4/10)

Subject matter for the exam on 1 Feb. 2023: see page 9 of the lecture notes

All projects can be done in groups of maximum 3 students

Dates

Project 1: introduced on Wed. 23 November 2022 (lecture 3) (deadline hand-in: Wed. 30/11)

Project 3: introduced on Fri. 2 December 2022 (lecture 6) (deadline hand-in: Fri. 9/12)

Project 5: introduced on Wednesday 14 December 2022 (only an oral presentation in January 2023)

Book (optional)

Holton, J.R., 2004: **An Introduction to Dynamic Meteorology**, *fourth edition*. Academic Press, 535pp.

The first (1972), second (1979) and third (1992) edition are also very useful.

Jim Holton died suddenly in 2004 at the age 65 (while running).

A fifth edition of Holton's book has appeared in 2012 with Gregory Hakim as co-author. I prefer the fourth edition

Electronic version of the 4th edition is available as pdf
http://www.staff.science.uu.nl/~delde102/Holton_2004.pdf

Prior knowledge

If you have passed the bachelors course **Geophysical Fluid Dynamics**, you will be familiar with much of the subject matter of **Part A** of the lecture notes, except maybe with the complications associated with the fact that the atmosphere is a *compressible fluid*.

Central Question

John Dutton has phrased it in the following way.

“The basic problems of atmospheric dynamics revolve around the question of why the observed responses are those that are chosen”

One of these **responses** consists of an **adjustment to some kind of balance of forces**.

What balance of forces?

Response to what?

Central Question

John Dutton has phrased it in the following way.

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One of these **responses** consists of an **adjustment to some kind of balance of forces**.

What balance of forces?

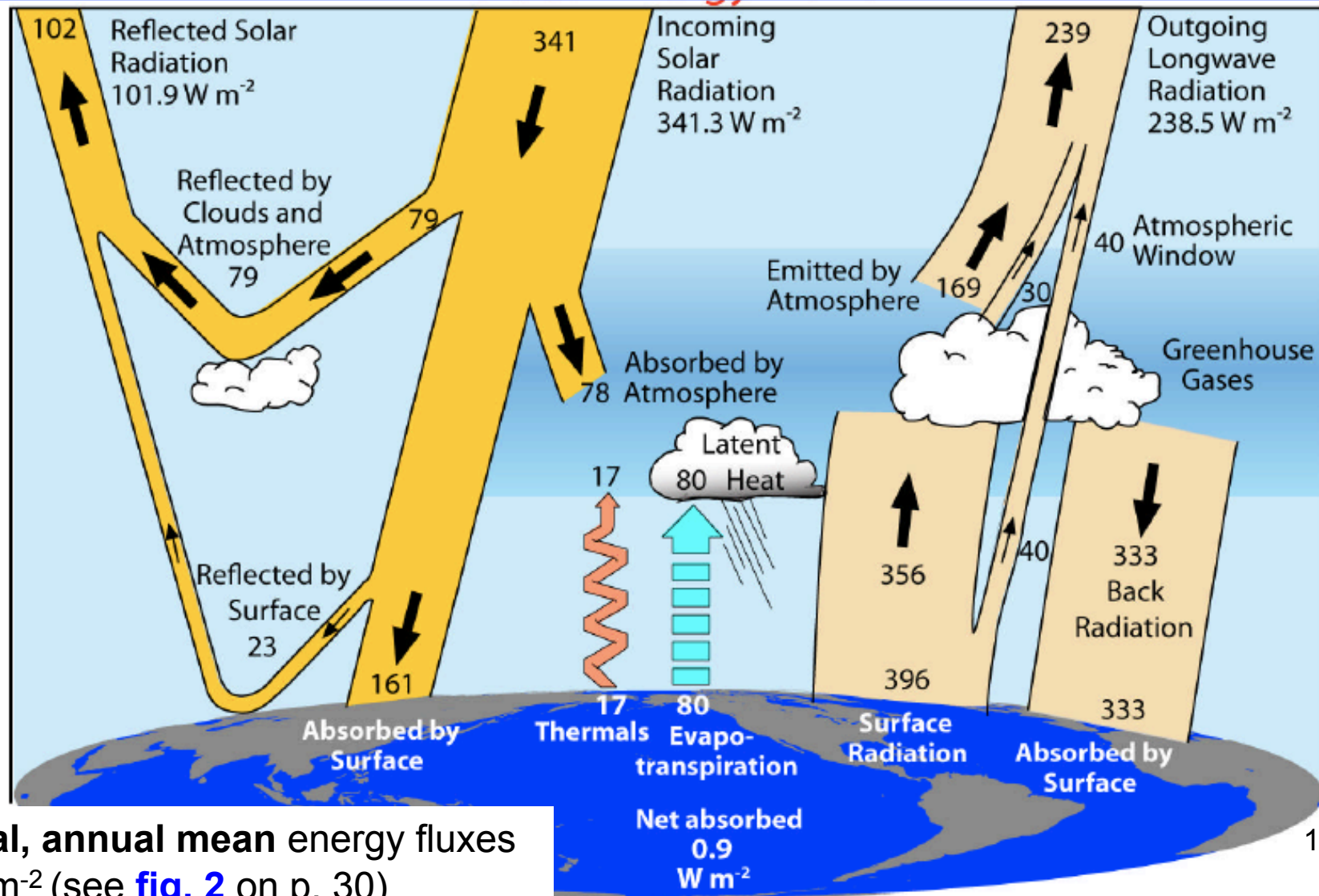
**Hydrostatic balance &
geostrophic balance**

Response to what?

Response to input of energy

Global/annual mean input & output of energy

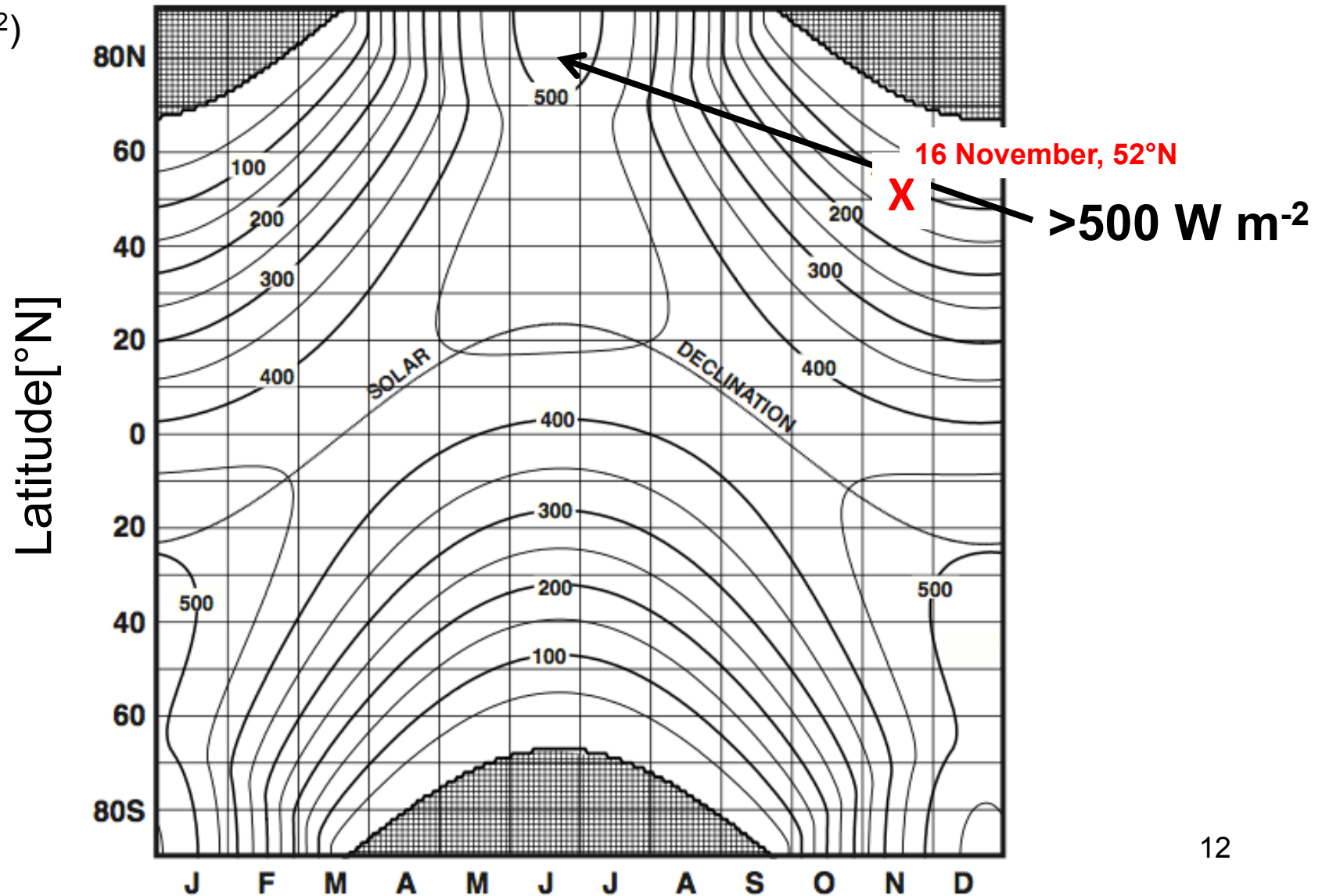
Radiative energy fluxes and water cycle (2000-2004)



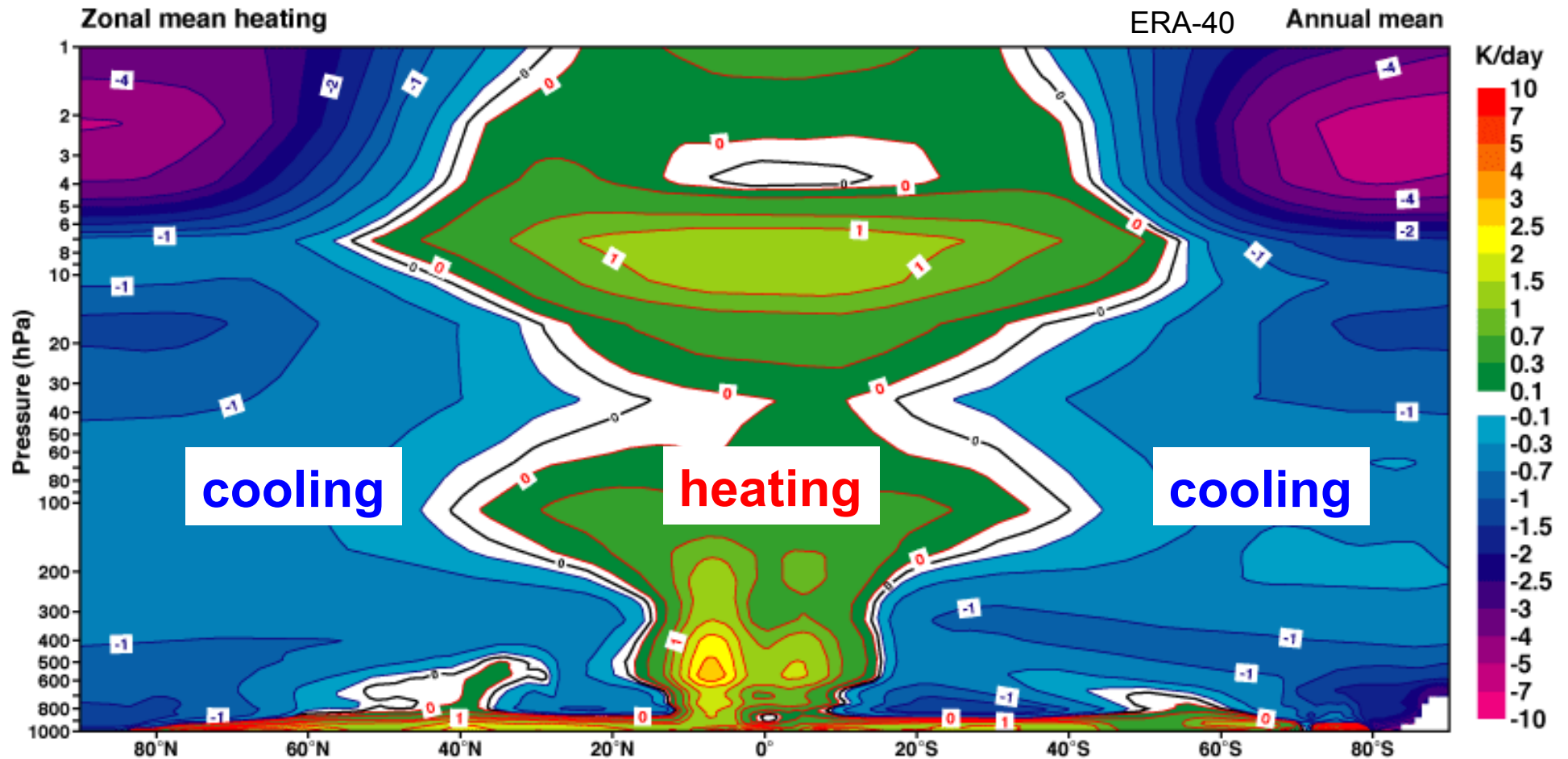
Global, annual mean energy fluxes
in W m^{-2} (see [fig. 2](#) on p. 30)

Seasonal cycle of insolation at the top of the atmosphere

(W m⁻²)

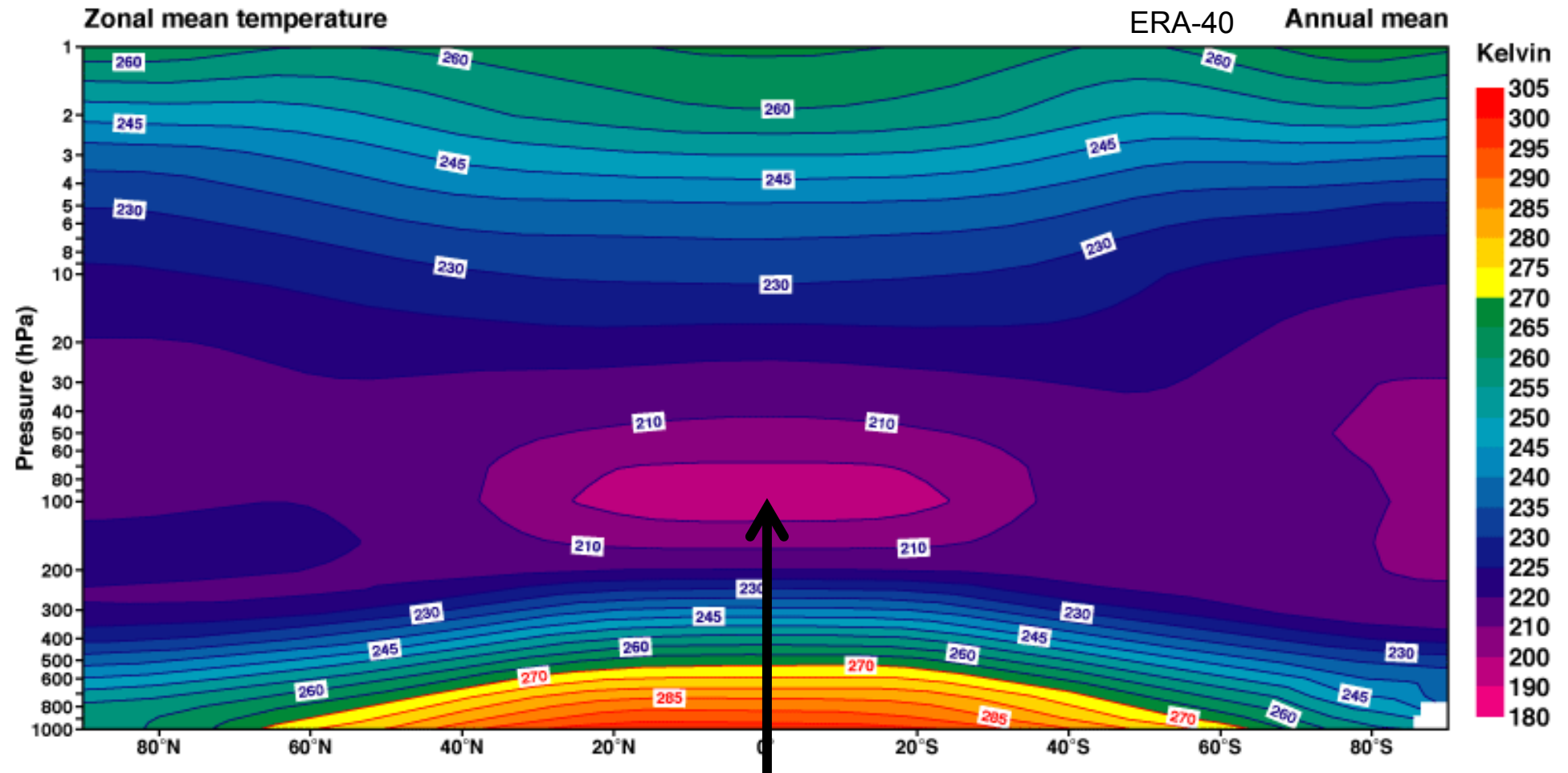


Zonal mean heating



Heating in the tropics; cooling at the poles. Is this as expected?

Zonal mean temperature



Very cold in the tropics despite heating ! Why?