Diabatic-Dynamical Interaction in the General Circulation (lecture 3)

Temperature and zonal wind as a function latitude and time

Radiative determined state lacks cold tropical tropopause

Today we couple the simple grey radiation scheme to a hydrostatic primitive equation model

We study the dynamics of an atmosphere which is devoid of water

Aarnout van Delden, 2014
http://www.staff.science.uu.nl/~delde102/C&HC.htm

Radiative determined temperature

Radiatively determined temperature [°C] as a function of latitude and pressure for day 75 (left) and for day 165 (right) in an atmosphere, which is transparent to Solar radiation and contains one well-mixed greenhouse gas. The **cyan** contour represents the 0°C isotherm. Temperatures below 0°C are indicated by **blue** contours. Temperatures above freezing (0°C) are indicated by **red** contours. The **heat capacity of the Earth's surface** is 10^7 J K^{-1} m^{-2}.

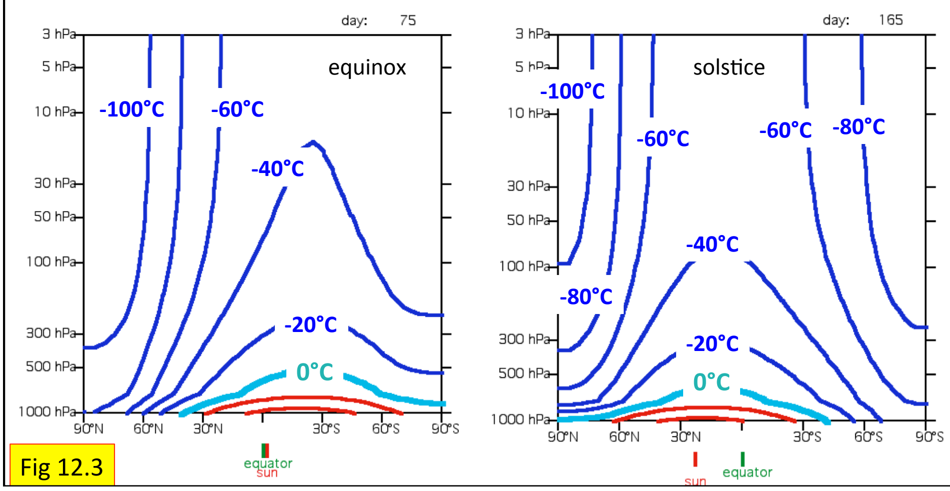


Fig 12.3

Observed temperature distribution

Observed (COSPAR International Reference Atmosphere) monthly average zonal average temperature [°C] as a function of latitude and pressure for March (left panel) and for June (right panel). Contour interval is 20°C. The **cyan** contour represents the 0°C isotherm. Temperatures below 0°C are indicated by **blue** contours. Temperatures above freezing (0°C) are indicated by **red** contours. The **heat capacity of the Earth's surface** is 10^7 J K^{-1} m^{-2}.

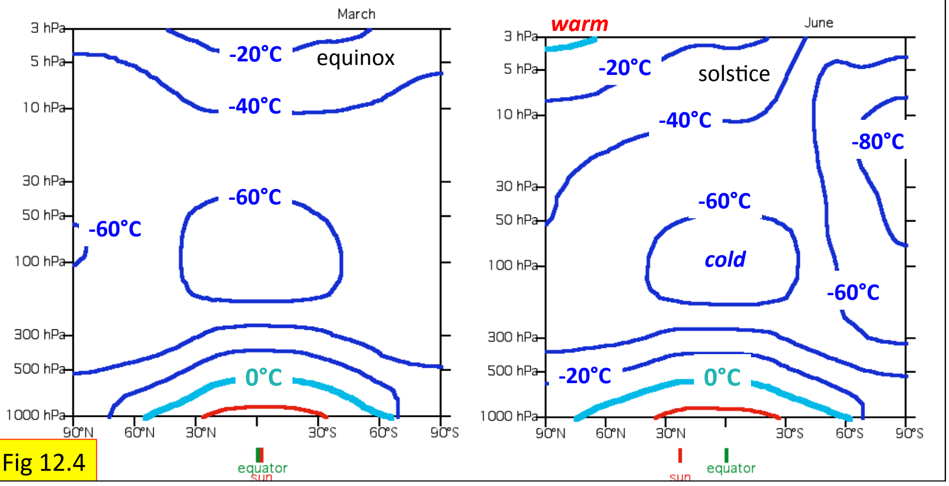


Fig 12.4

Radiative determined diabatic heating

Radiatively determined tendency of the *potential* temperature [K day^{-1}] (also called **cross-isentropic flow**) as a function of latitude and pressure for day 75 (second year) (just before Equinox) (left panel) and for day 165 (second year) (just before Solstice) (right panel) in an atmosphere, which is transparent to Solar radiation and contains one well-mixed greenhouse gas. Contour interval is 0.25 K day^{-1} (zero contour not drawn).

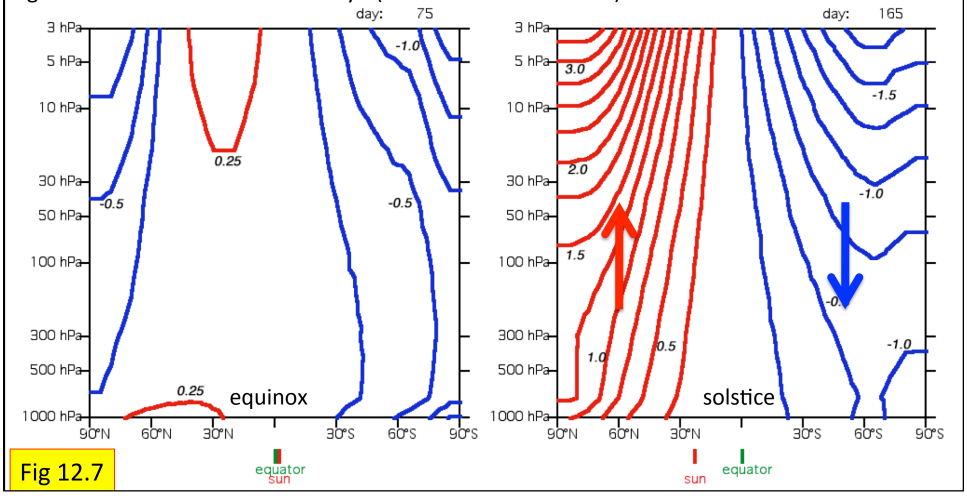
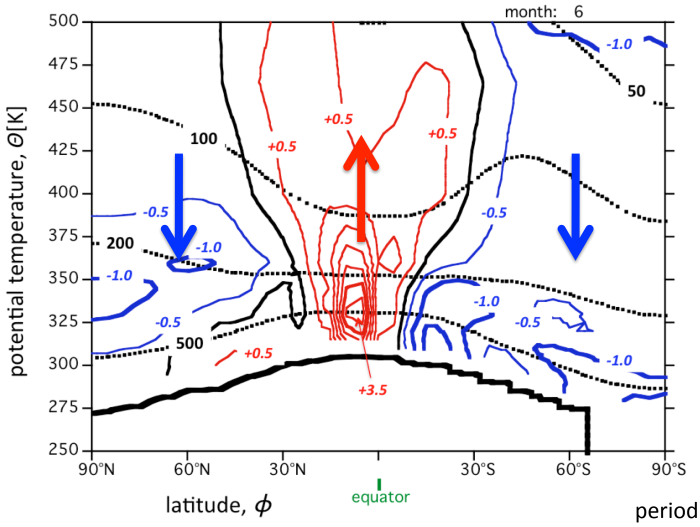


Fig 12.7

“Observed” (reanalysis) diabatic heating

June average isobars (dashed black lines[hPa]) and June average tendency of the *potential* temperature [K day^{-1}] (contour interval: 0.5 K day^{-1}), according to the ERA-40 reanalysis. The thick black line indicates the zonal mean position of the Earth’ surface.



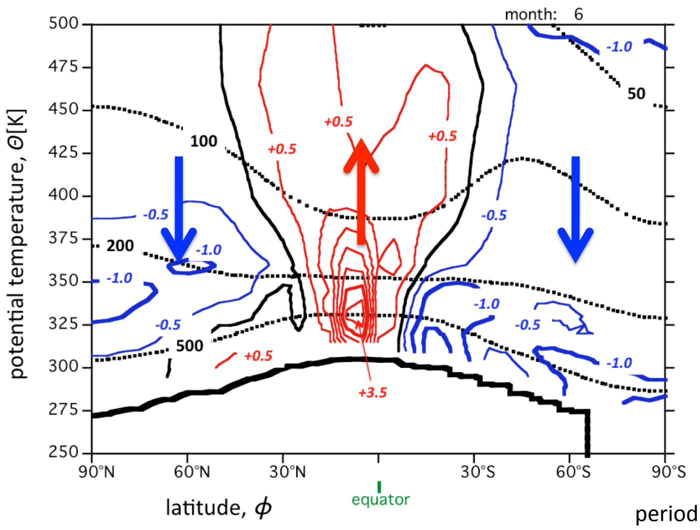
June

Fig 12.8

period 1979-2002.

“Observed” (reanalysis) diabatic heating

This quantity, which is also called “cross-isentropic flow”, is part of the so-called “diabatic circulation”. The diabatic circulation in reality is very different from the “diabatic circulation” in the radiatively determined state!



June

Fig 12.8

period 1979-2002.

A model of zonally symmetric radiative-dynamical adjustment

Couple radiation to dynamics

Assumptions radiation identical to previous assumptions

Dynamics: take primitive equation dynamical core model (see chapter 10 lecture notes of dynamical meteorology)

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

Model: adiabatic "dynamical core"

Model is 2 dimensional (*y*, σ) ($\sigma = p/p_s$) (chapter 10 lecture notes)

Note: Symbol σ is used many different quatities: vertical coordinate, isentropic density, static stability in QG-theory

Governing equations (adiabatic part) in flux form:

$$\frac{\partial p_s}{\partial t} + \frac{\partial p_s v}{\partial y} + p_s \frac{\partial}{\partial \sigma}\left(\frac{d\sigma}{dt}\right) = 0 \qquad \text{continuity}$$

$$\frac{\partial p_s \theta}{\partial t} = -\frac{\partial p_s v \theta}{\partial y} - \frac{\partial}{\partial \sigma}\left(p_s \theta \frac{d\sigma}{dt}\right) \qquad \text{energy/potential temperature}$$

$$\frac{\partial p_s u}{\partial t} = -\frac{\partial p_s uv}{\partial y} - \frac{\partial}{\partial \sigma}\left(p_s u \frac{d\sigma}{dt}\right) + \left(f + \frac{u \tan\phi}{a}\right) p_s v \qquad \leftarrow \text{momentum}$$

$$\frac{\partial p_s v}{\partial t} = -\frac{\partial p_s v^2}{\partial y} - \frac{\partial}{\partial \sigma}\left(p_s u \frac{d\sigma}{dt}\right) - \left(f + \frac{u \tan\phi}{a}\right) p_s u - p_s \frac{\partial \Phi}{\partial y} + RT \frac{\partial p_s}{\partial y}$$

$$\frac{\partial p_s}{\partial t} = -\int_0^1 \frac{\partial p_s v}{\partial y} d\sigma \qquad \text{continuity}$$

Inclusion of diabatic effects

Heating flux due to dry convective adjustment

diabatic heating due to absorption/emission radiation
& latent heat release

Wave drag

$$\frac{\partial p_s}{\partial t} + \frac{\partial p_s v}{\partial y} + p_s \frac{\partial}{\partial \sigma}\left(\frac{d\sigma}{dt}\right) = 0$$

$$\frac{\partial p_s \theta}{\partial t} = -\frac{\partial p_s v\theta}{\partial y} - \frac{\partial}{\partial \sigma}\left(p_s \theta \frac{d\sigma}{dt}\right) + p_s H + \frac{p_s J}{\Pi}$$

$$\frac{\partial p_s u}{\partial t} = -\frac{\partial p_s uv}{\partial y} - \frac{\partial}{\partial \sigma}\left(p_s u \frac{d\sigma}{dt}\right) + \left(f + \frac{u \tan\phi}{a}\right) p_s v + p_s D + p_s F_x$$

$$\frac{\partial p_s v}{\partial t} = -\frac{\partial p_s v^2}{\partial y} - \frac{\partial}{\partial \sigma}\left(p_s u \frac{d\sigma}{dt}\right) - \left(f + \frac{u \tan\phi}{a}\right) p_s u - p_s \frac{\partial \Phi}{\partial y} + RT \frac{\partial p_s}{\partial y} + p_s F_y$$

$$\frac{\partial p_s}{\partial t} = -\int_0^1 \frac{\partial p_s v}{\partial y} d\sigma$$

Friction in boundary layer

This lecture: only radiation and convective adjusment

Heating flux due to dry convective adjustment

diabatic heating due to absorption/emission radiation
& latent heat release

Wave drag

$$\frac{\partial p_s}{\partial t} + \frac{\partial p_s v}{\partial y} + p_s \frac{\partial}{\partial \sigma}\left(\frac{d\sigma}{dt}\right) = 0$$

$$\frac{\partial p_s \theta}{\partial t} = -\frac{\partial p_s v\theta}{\partial y} - \frac{\partial}{\partial \sigma}\left(p_s \theta \frac{d\sigma}{dt}\right) + p_s H + \frac{p_s J}{\Pi}$$

$$\frac{\partial p_s u}{\partial t} = -\frac{\partial p_s uv}{\partial y} - \frac{\partial}{\partial \sigma}\left(p_s u \frac{d\sigma}{dt}\right) + \left(f + \frac{u \tan\phi}{a}\right) p_s v$$

$$\frac{\partial p_s v}{\partial t} = -\frac{\partial p_s v^2}{\partial y} - \frac{\partial}{\partial \sigma}\left(p_s u \frac{d\sigma}{dt}\right) - \left(f + \frac{u \tan\phi}{a}\right) p_s u - p_s \frac{\partial \Phi}{\partial y} + RT \frac{\partial p_s}{\partial y}$$

$$\frac{\partial p_s}{\partial t} = -\int_0^1 \frac{\partial p_s v}{\partial y} d\sigma$$

Friction in boundary layer

Model run with seasonal cycle

The model is initialized on January 1: atmosphere is **isothermal** and **in rest**.

The atmosphere containes **one well-mixed greenhouse** gas as a proxy for CO_2.

There is **no water** and $\boldsymbol{C=10^7}$ **J** $\boldsymbol{K^{-1}}$ $\boldsymbol{m^{-2}}$.

A tropical meridional cross-equatorial Hadley circulation forms within a few days

Temperature is modified such that the cross-equatorial temperature gradient is eliminated

However, the structure of the zonal wind is not realistic, as we see in the follwing slide

http://www.staff.science.uu.nl/~delde102/PeN-Model.htm

Influence of dynamics on temperature

Temperature [°C] determined by radiation only (left panel) and **temperature determined by dynamics *and* radiation (right panel)** for day 50 after initialization on January 1 of a two-dimensional model of a **dry isothermal (290 K) atmosphere in rest** containing one well-mixed greenhouse gas and no ozone. Contour interval is 20°C. The cyan contour represents the 0°C isotherm. The heat capacitv of the Earth's surface is 10^7 J kg^{-1} m^{-2}.

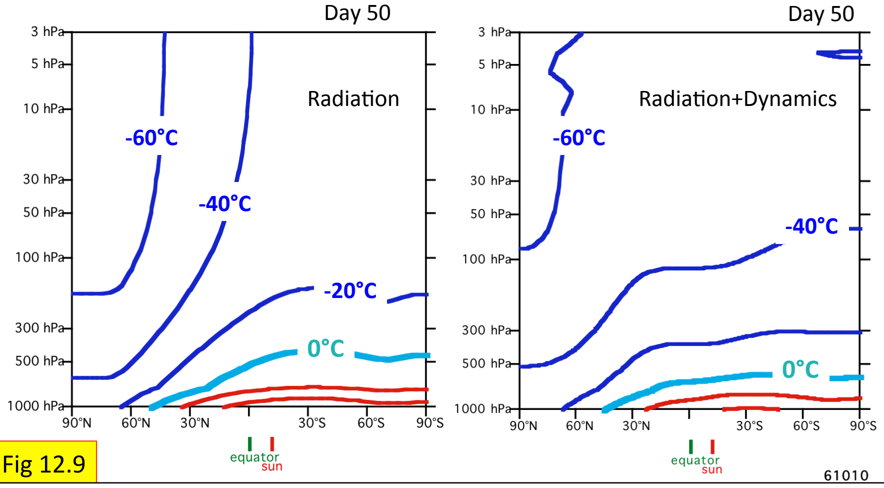


Fig 12.9

Influence of dynamics on temperature

Radiatively determined cross-equatorial temperature gradient, which represents a dynamical imbalance, is reduced to zero by the dynamics, i.e. by a cross-equatorial meridional "Hadley circulation".

Summer hemisphere is cooled, while tropics and winter hemisphere are warmed by dynamics

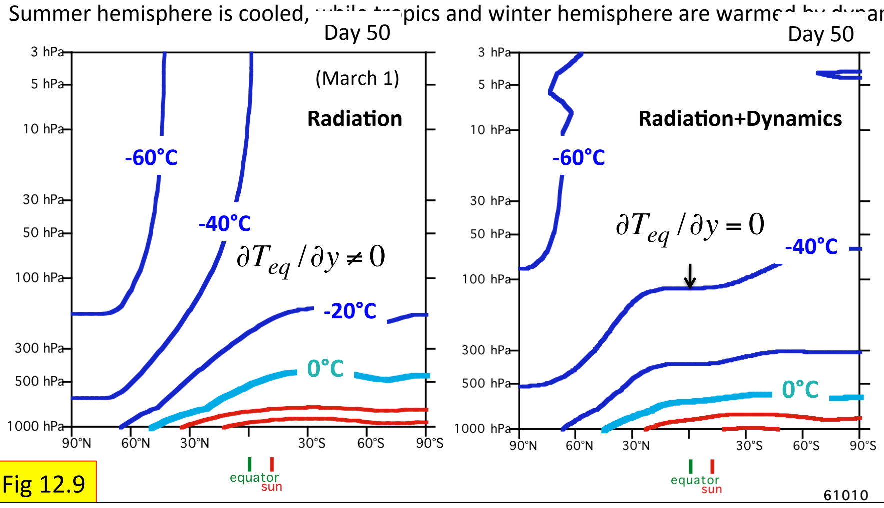


Fig 12.9

Meridional Circulation in the model

Meridional circulation (arrows), temperature [°C] and zonal wind velocity (black contours) after 50 days of integration. Red arrows indicate upward motion; blue arrows indicate downward motion. Arrows are drawn only if $|w|$>0.001 Pa s-1. Isotachs [m s^{-1}] (contour interval: 5 m s^{-1}). Thin black contours correspond to negative values of the zonal wind velocity (i.e. westward wind).

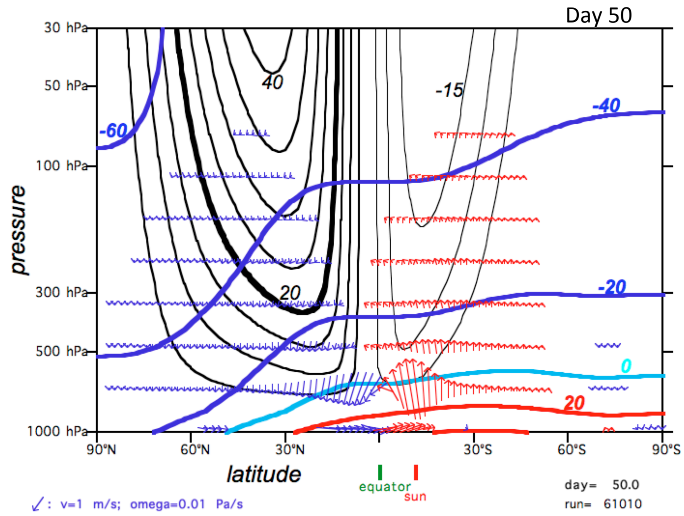


Fig 12.10

Meridional Circulation in the model

Radiatively determined cross-equatorial temperature gradient is reduced to zero by dynamics.

Winter Hadley cell:

Upward motion in summer hemisphere;
Downward motion in winter hemisphere

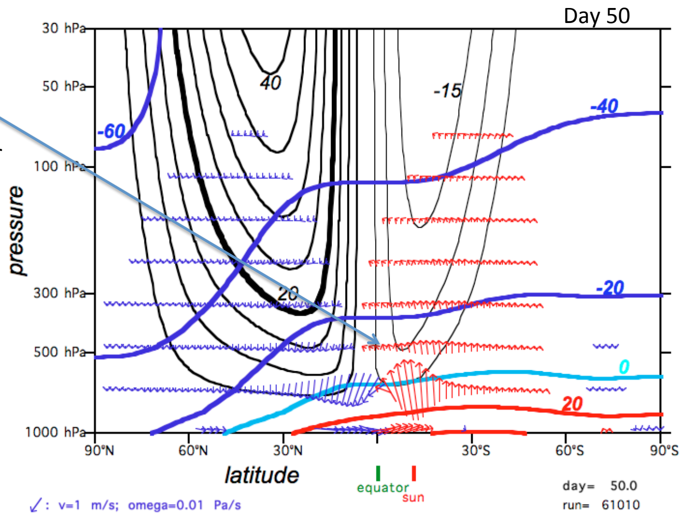


Fig 12.10

Meridional Circulation in the model

Some aspects of the solution are not realistic:

The subtropical jet and the stratospheric winter jet do not develop into separate entities.

No tropical “cold trap”

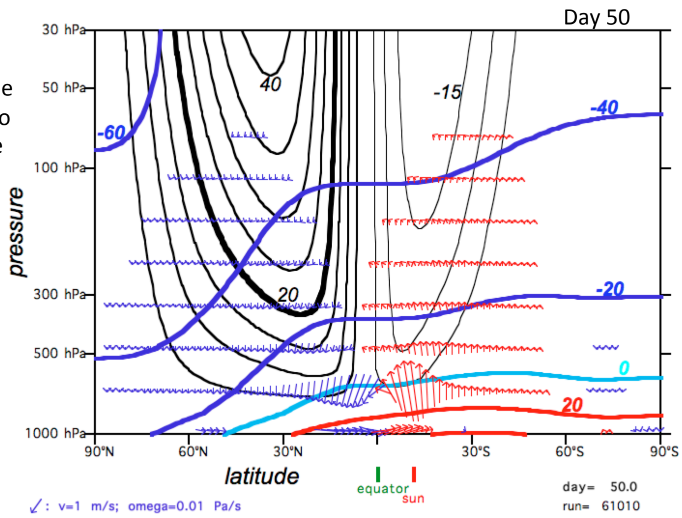


Fig 12.10

Assignments (3)

Individual assignment:
*Make a review of the paper entitled, "**PV-ϑ** **View of Diabatic-Dynamical Interaction in the General Circulation"***
(500-1000 words).
Hand in on or before 11 June 2014.

Assignment for two students:
Presentation (20 minutes on 25 June 2014) on the following topic.
The water cycle in a climate model (history, method and performance)

http://www.staff.science.uu.nl/~delde102/C&HC.htm

Examples of climate models

GFDL, CCSM, ECHAM, HadCM, MIROC

http://en.wikipedia.org/wiki/General_Circulation_Model

http://en.wikipedia.org/wiki/Climate_model

https://www.wmo.int/pages/themes/climate/climate_models.php

Next lecture

Wednesday 14/5, 2014, 13:15-15:00

Introducing the water cycle and investigating role of water in the general circulation.

http://www.staff.science.uu.nl/~delde102/C&HC.htm