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

Diabatic-Dynamical Interaction in the General Circulation (lecture 4)

Temperature distribution as a function latitude and time

Energetics of the water cycle

Precipitation/Evaporation climatology

A simplified representation of the water cycle in a dynamical model

Dynamical response to the water cycle

Last week (lecture 2):

Temperature distribution as a function latitude and time

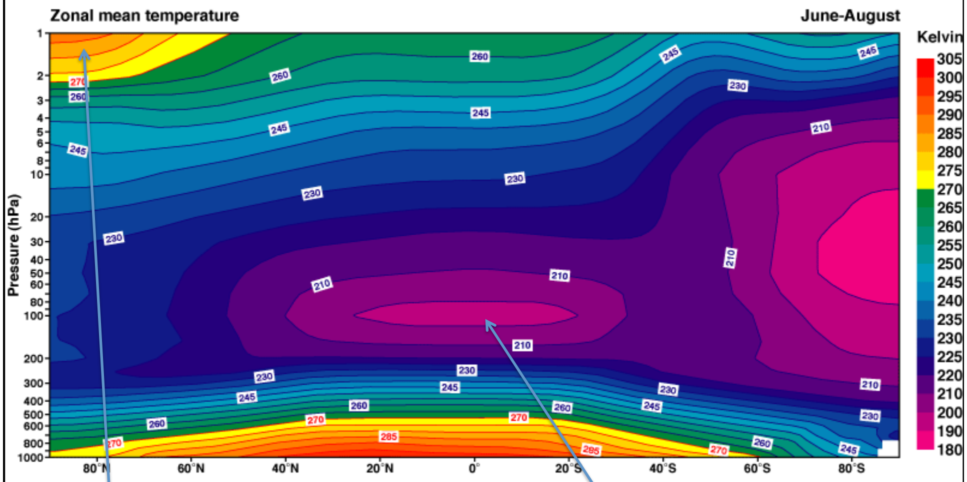
Radiative equilibrium state and radiative determined state

Importance of *thermal inertia*

Dynamics of an atmosphere which is devoid of water

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

Zonal mean temperature ERA-40

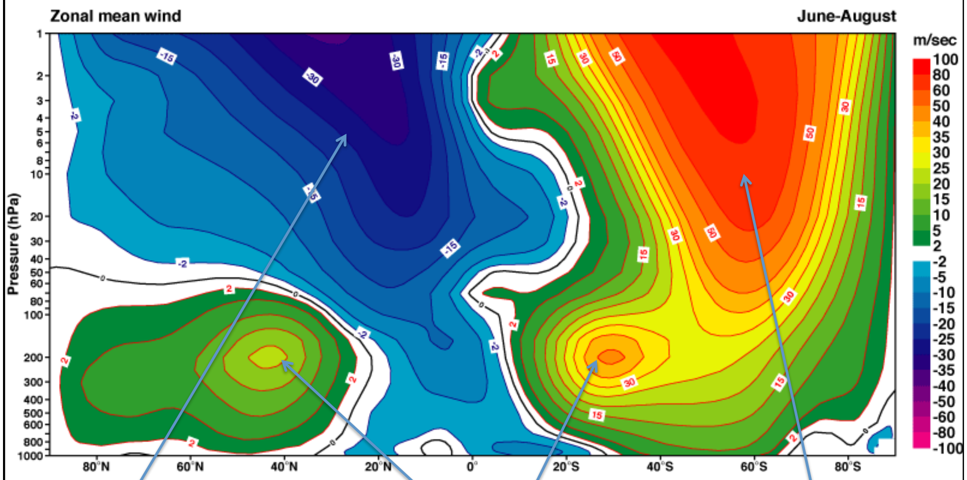


Warm summer stratosphere

Tropical “cold trap”

http://www.ecmwf.int/research/era/ERA-40_Atlas/

Zonal mean zonal wind ERA-40



Summer hemisphere

Winter hemisphere

Westward winds in the summer stratosphere

Subtropical jets

Stratospheric winter jet

http://www.ecmwf.int/research/era/ERA-40_Atlas/

What is the cause of these features of the general circulation?

Radiation (greenhouse effect, ozone)
Water cycle (evaporation, condensation)
Wave drag

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}.

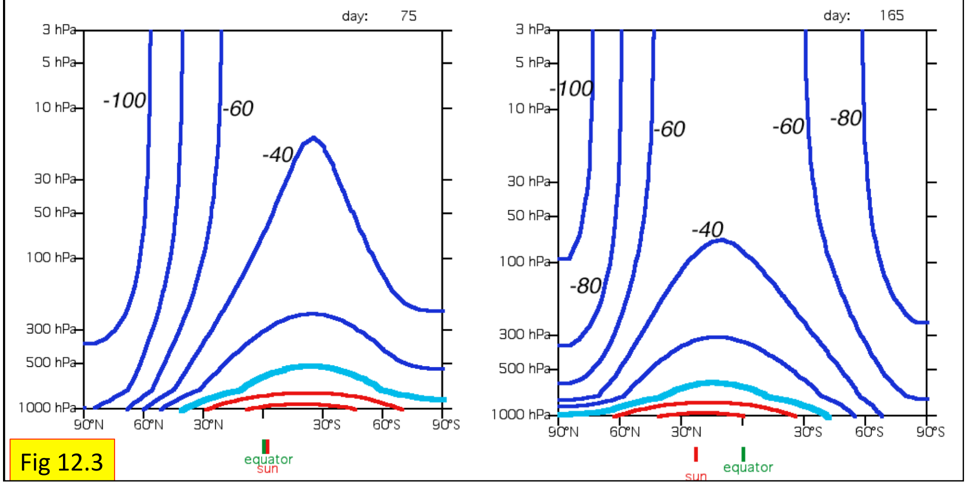


Fig 12.3

Coupling dynamics to "physics"

Primitive equation model equations

Heating flux due to dry convective adjustment

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

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

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

Wave drag

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

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

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

Friction in boundary layer

Response in absence of water cycle

Radiative dynamical interaction

Winter Hadley cell:

Upward motion in summer hemisphere;
Downward motion in winter hemisphere

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

No tropical "cold trap"

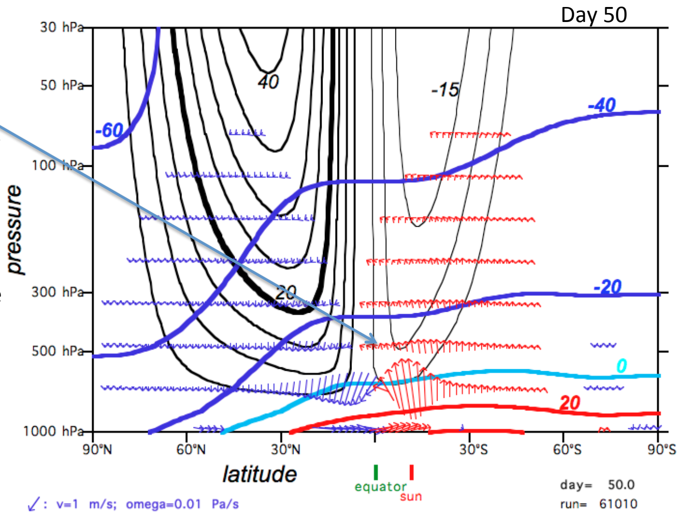


Fig 12.10

The water cycle

Consists of:

Evaporation of water at the earth's surface ← Latent heat consumption

Driven by net radiation at the surface:
About 100 W m^{-2} is available *

Transport of water vapour to ITCZ and mid-latitudes

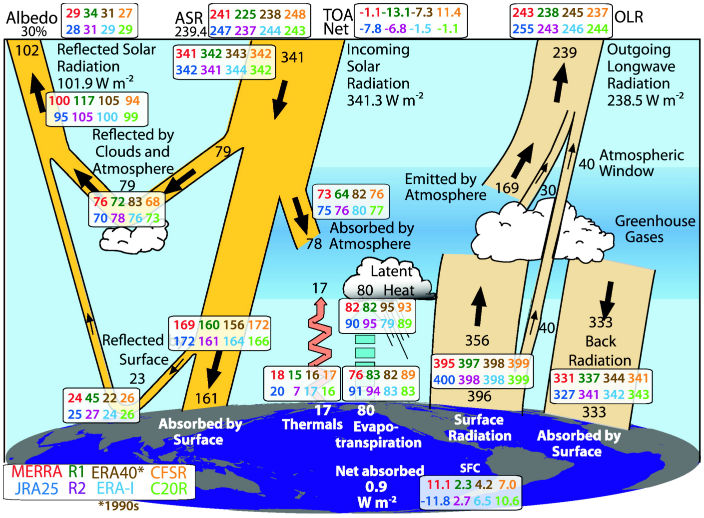
Condensation of water vapour in clouds ← Latent heat release

Precipitation

Run-off

* With L=2.5x10^{6} J kg^{-1}, this is equivalent 3.45 kg m^{-2}day^{-1} of water

Net radiation and evaporation

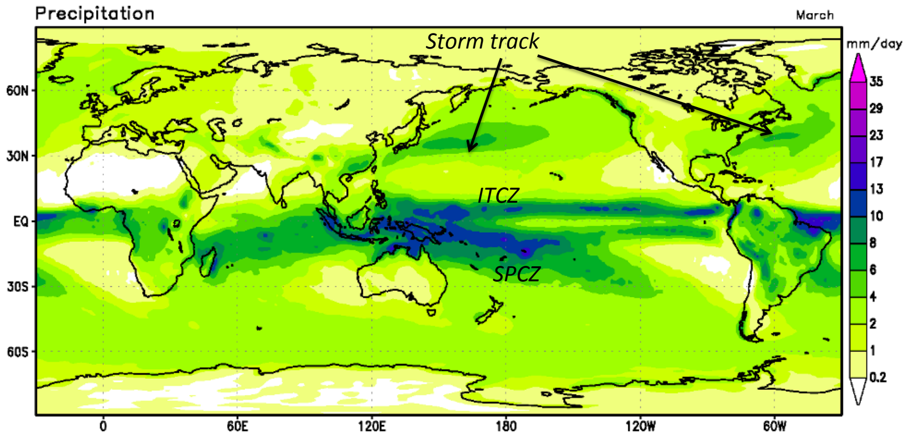


Values shown in black are based on observations for 2000–05. Superposed are values from the various reanalyses for the 2002–08 period except for ERA-40, which is for the 1990's (color coded; W m^{-2}). Above the graphic, values are given for albedo (%), Absorbed Solar Radiation (ASR), net Top of the Atmosphere (TOA) radiation, and Outgoing Long-wave Radiation (OLR); the box labeled SFC near the bottom gives the net flux absorbed at the surface. For the 1990's the latter value is 0.6 W m^{-2}.

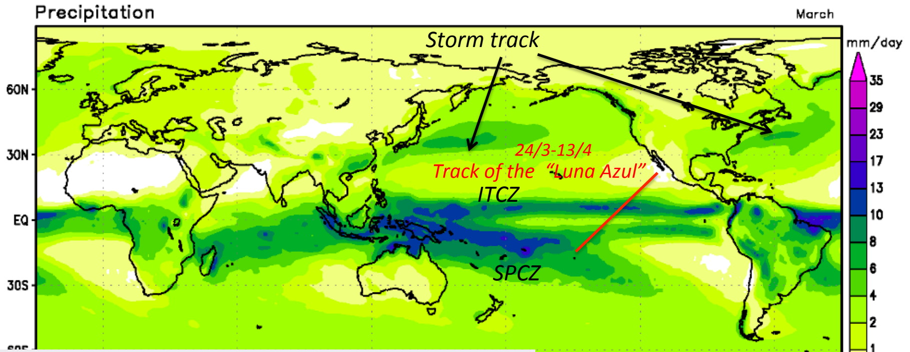
Trenberth et al., 2011. J.Clim.

Japanese reanalysis (JRA) of precipitation between 1979 and 2004

http://ds.data.jma.go.jp/gmd/jra/atlas/eng/atlas-tope.htm



Intermezzo: Between 24 March and 13 April 2014 I involved in guiding the Luna Azul on a trip from Mexico to French Polinesia, through (double) ITCZ




zondag, 20 april 2014 07:25

http://www.wearesailing.nl/

Oversteek In Vogelvlucht

Geschreven door Marion

Anaho, Nuku-Hiva, Marqueses, Frans Polynesie

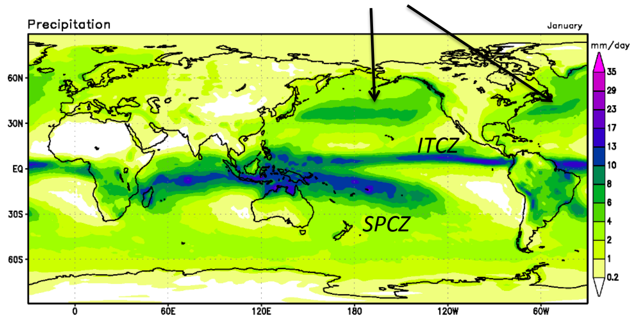
Tientallen glanzend zwarte walvissen leiden ons 'dansend' de baai van Socorro uit. Een mooi afscheidscadeautje van Mexico.

We beginnen aan de non-stop trip naar Frans Polynesië. Vanuit NL worden we bijgestaan door vriend en meteoroloog Aarnout. Hij adviseert ons bij het passeren van de ITCZ. Dat is het gebied voor en na de evenaar waar de winden van het noordelijk en zuidelijk halfrond bij elkaar komen. Dat leidt tot heftige regenbuien en windstoten.

Luna Azul: 47 feet

Japanese reanalysis (JRA) of precipitation between 1979 and 2004

http://ds.data.jma.go.jp/gmd/jra/atlas/eng/atlas-tope.htm



Storm track

ITCZ

SPCZ

Japanese reanalysis (JRA) of precipitation between 1979 and 2004

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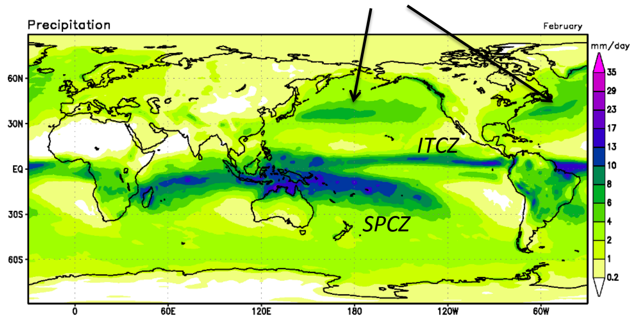

Storm track

ITCZ

SPCZ

Japanese reanalysis (JRA) of precipitation between 1979 and 2004

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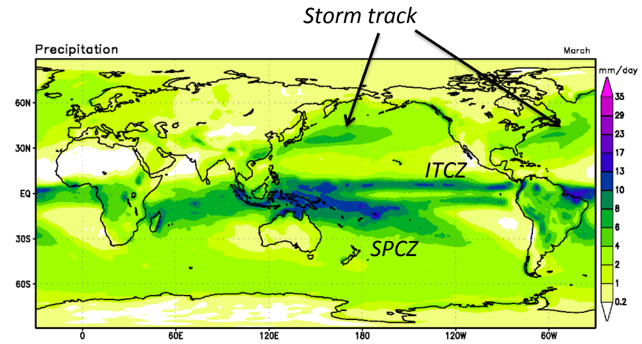

Japanese reanalysis (JRA) of precipitation between 1979 and 2004

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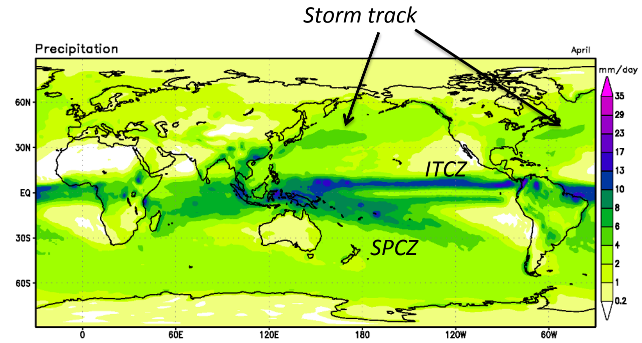

Japanese reanalysis (JRA) of precipitation between 1979 and 2004

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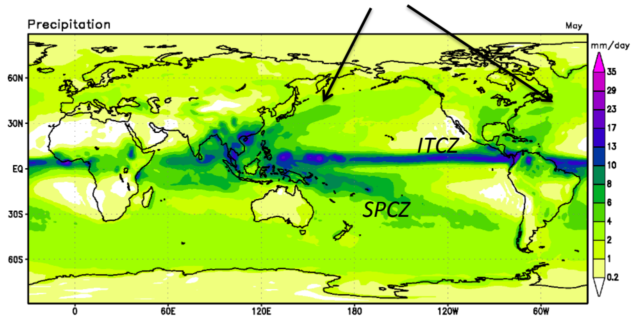

Storm track

ITCZ

SPCZ

Japanese reanalysis (JRA) of precipitation between 1979 and 2004

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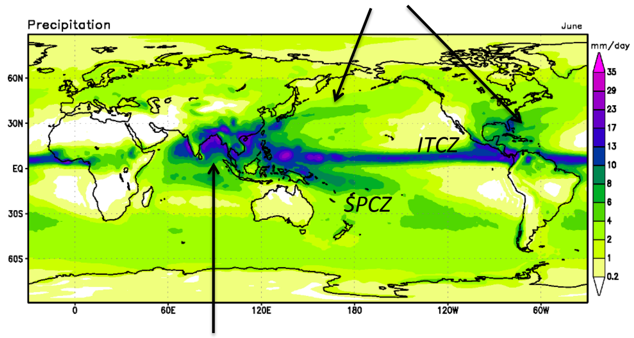

Storm track

ITCZ

SPCZ

Asian Monsoon

Japanese reanalysis (JRA) of precipitation between 1979 and 2004

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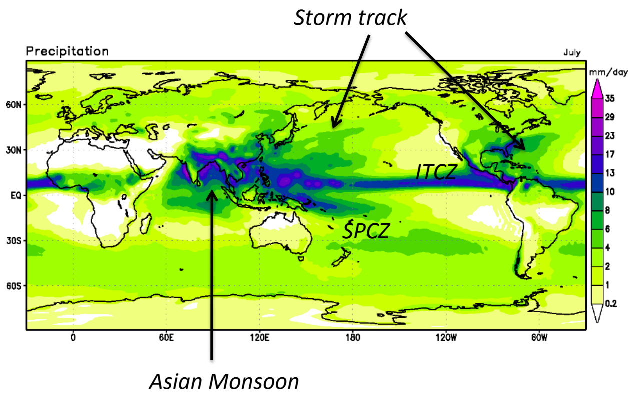


Storm track

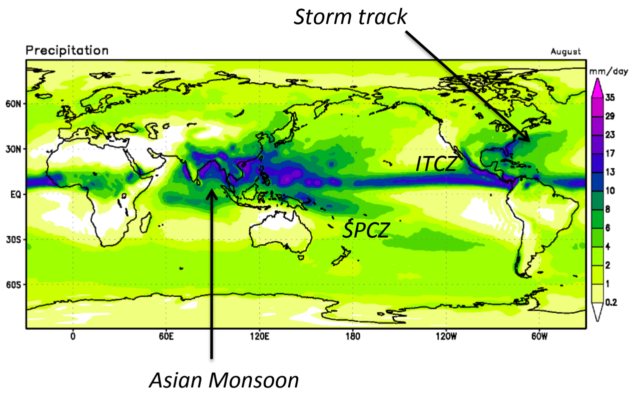
ITCZ

SPCZ

Asian Monsoon

Japanese reanalysis (JRA) of precipitation between 1979 and 2004

http://ds.data.jma.go.jp/gmd/jra/atlas/eng/atlas-tope.htm



Storm track

ITCZ

SPCZ

Asian Monsoon

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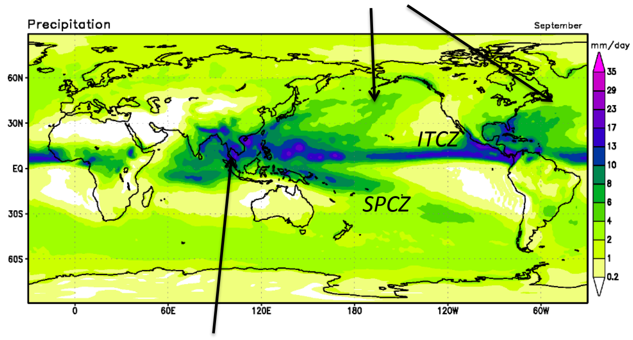

Storm track

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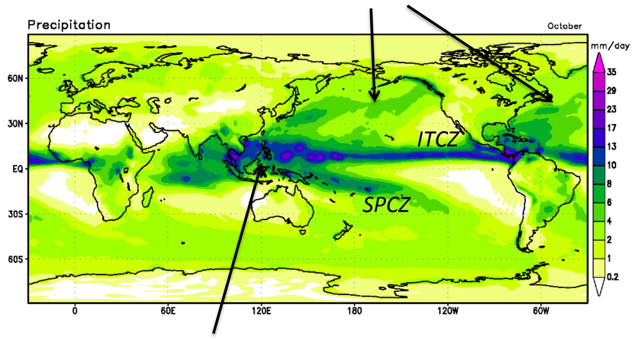

Storm track

ITCZ

SPCZ

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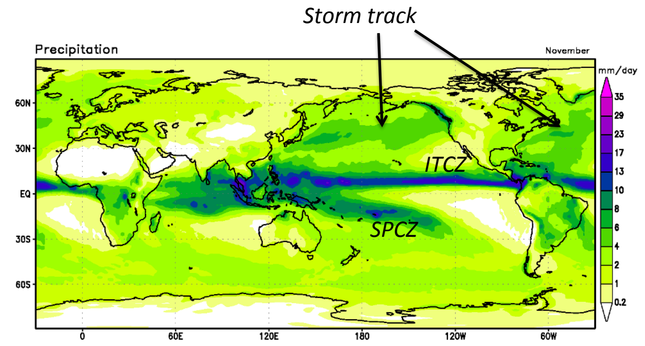

Japanese reanalysis (JRA) of precipitation between 1979 and 2004

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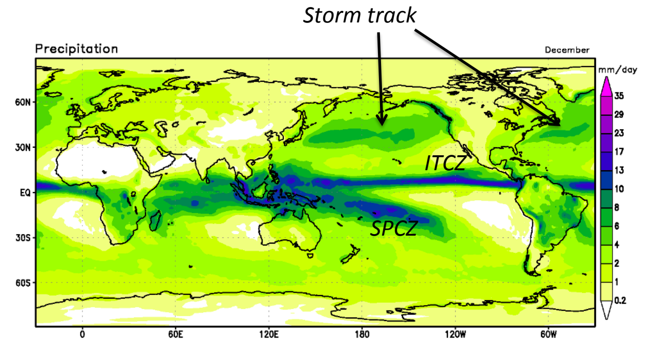

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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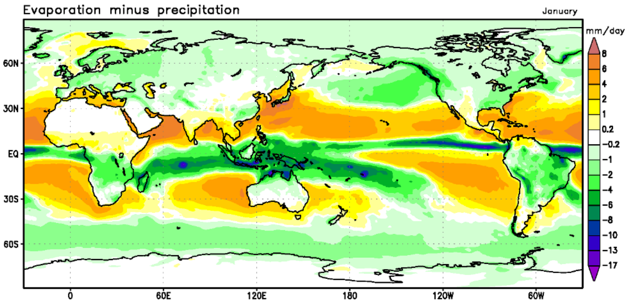

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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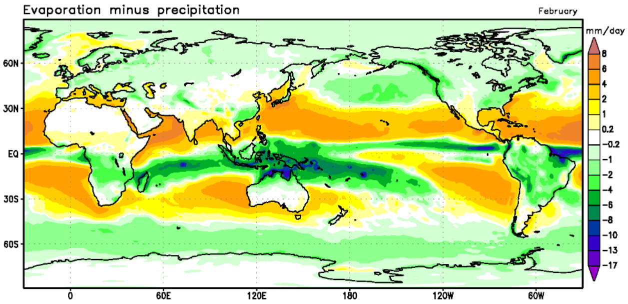

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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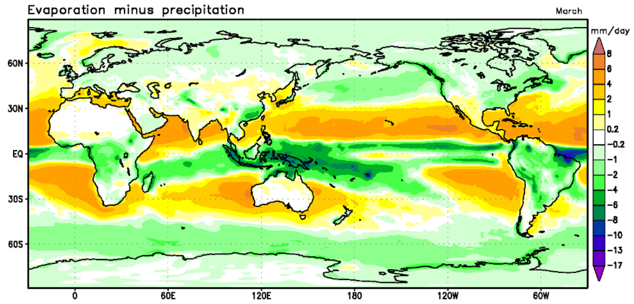

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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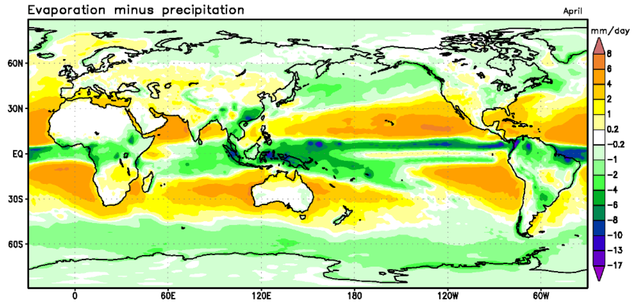

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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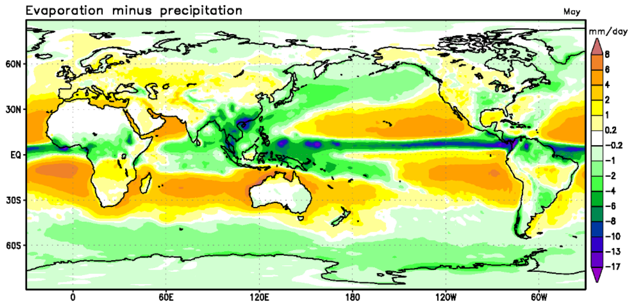

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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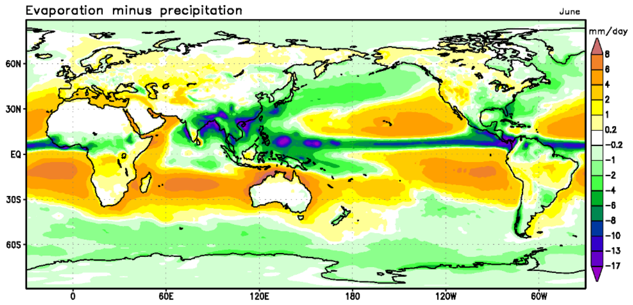

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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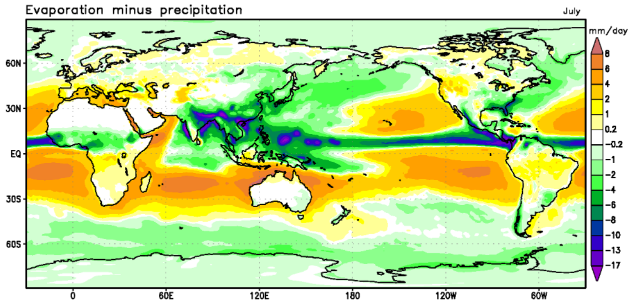

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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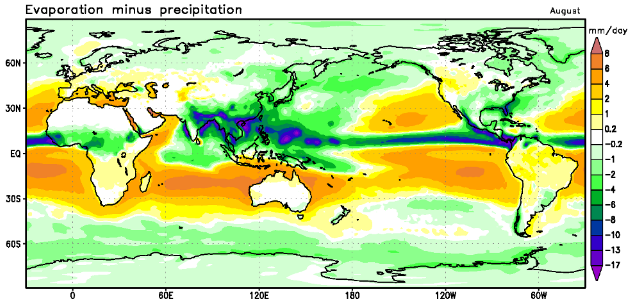

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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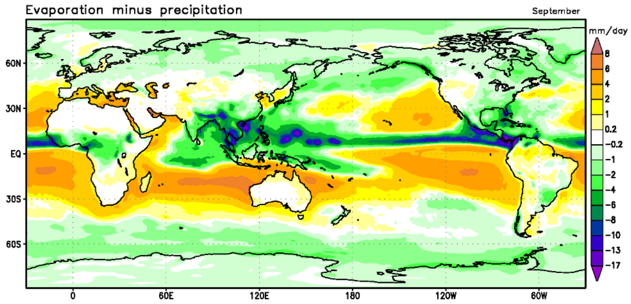

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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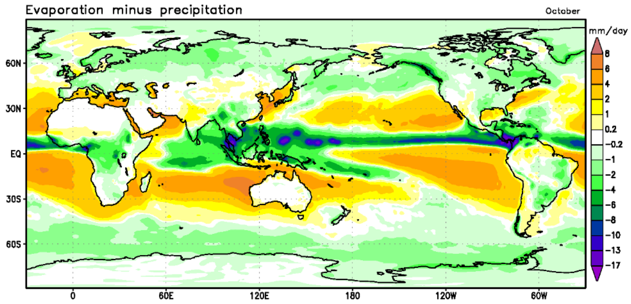

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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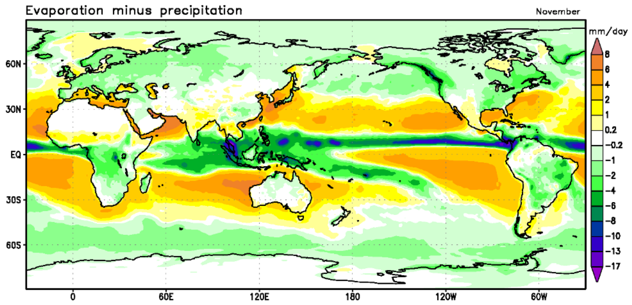

Japanese reanalysis (JRA) of Evap-Precip between 1979 and 2004

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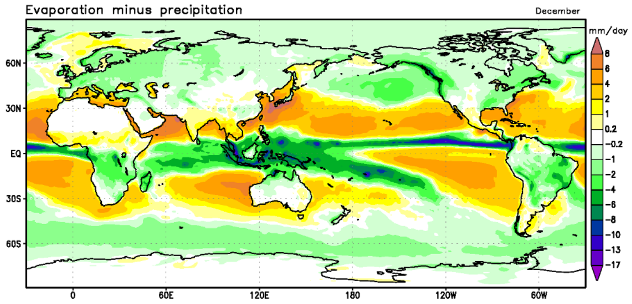
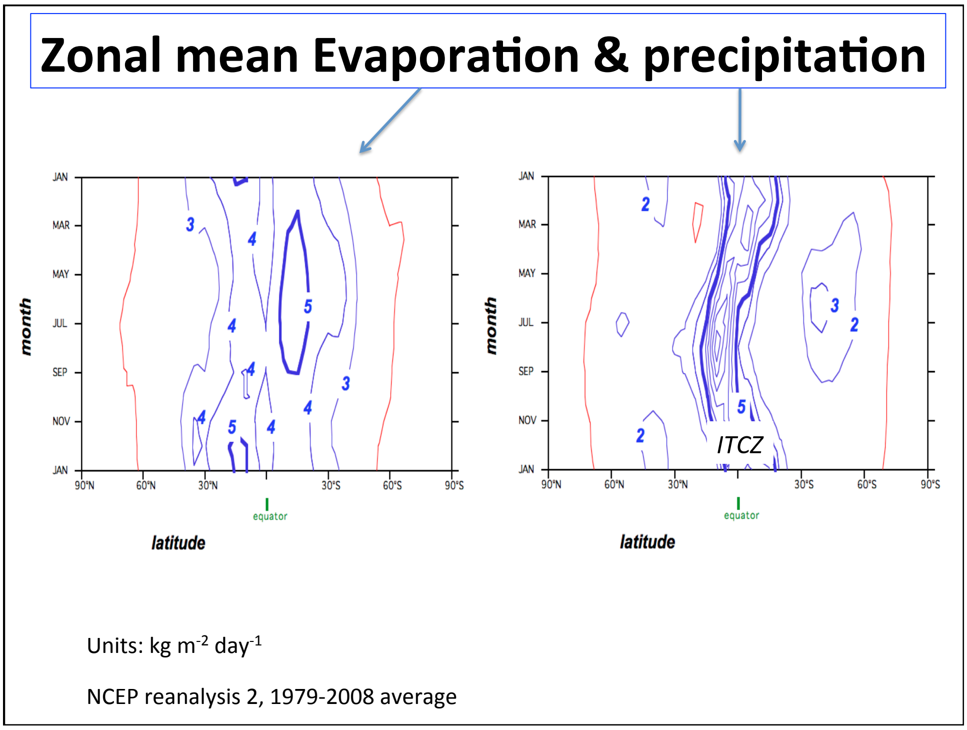


Some conclusions on important features of the water cycle

Precipitation and associated latent heating of the atmosphere is dominated by the ITCZ

Evaporation is by far most intense over the subtropical ocean areas



Zonal mean Evaporation & precipitation

Units: kg m^{-2} day^{-1}

NCEP reanalysis 2, 1979-2008 average

The water-cycle in the model

Evaporation, E_s , is computed from the surface sensible heat transport, H_s. from the *Bowen ratio*, H_s/E_s=0.25 (at all latitudes)

Vertical sensible heat transport is computed from a dry convective adjustment scheme (eq. 12.9)

80 % of the locally evaporated water is precipitated locally

The remainder is added to the local precipitation in the ITCZ.

The ITCZ follows the position of the overhead sun and has a meridional scale of about 3000 km

Latent heat release is assumed to occur within clouds…
with cloud base at 900 hPa
and cloud top at 400 hPa in mid-latitudes and at 200 hPa in the ITCZ

Clouds do not interact with radiation

Water vapour distribution

Water vapour is distributed according to

$$\rho_v(z) = \rho_v(0)\exp\left(-\frac{z}{H_v}\right)$$

Density of water vapour

Scale height: 2 km

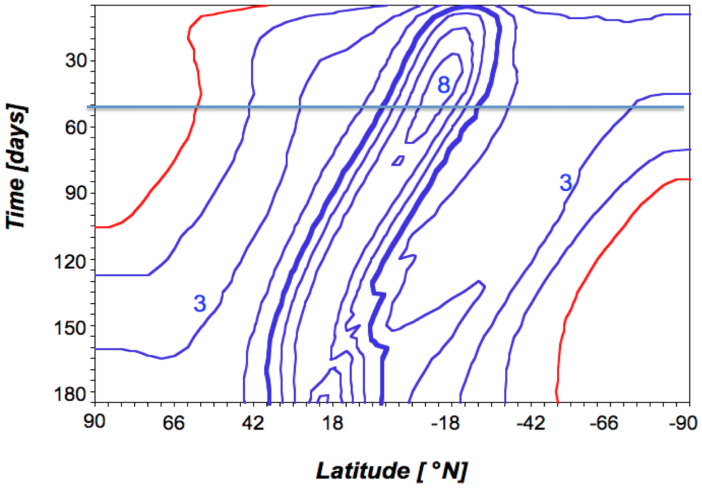
Relative humidity at the earth's surface is fixed at 75%.

Therefore, the density of water vapour depends on the temperature (Clausius Clapeyron):

$$PW = \rho_v(0)H_v = \frac{RH_g e_s(T_g)}{R_v T_g} H_v \left[\mathrm{kg\ m^{-2}}\right]$$

Water vapour interacts with thermal (long wave) radiation as a grey absorber.

Modelled precipitation



50 days after initialization on 1 January with an isothermal (290 K) atmosphere at rest: next slide….

Precipitation [kg m^{-2} day^{-1}] in the model

Temperature, circulation and zonal wind

50 days after initialization on 1 January with an isothermal (290 K) atmosphere at rest

With water cycle

Hadley circulation is much more intense than in the run without the water cycle…

Upward motion in summer hemisphere; Downward motion in winter hemisphere

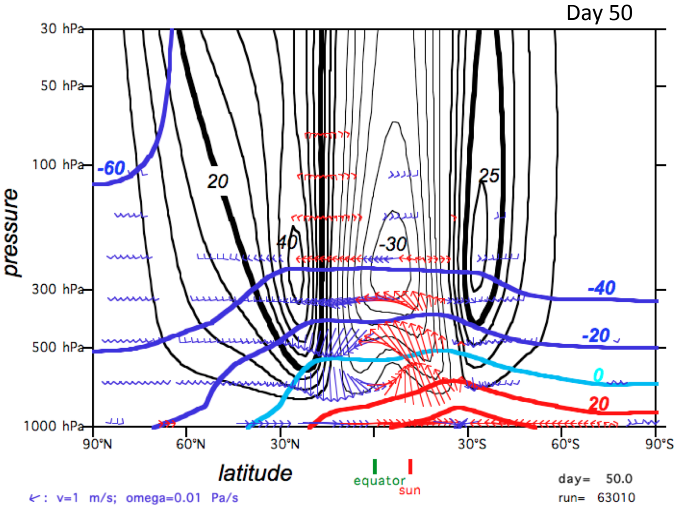


Fig 12.15

T [°C] and *u* [m s^{-1}]

Temperature, circulation and zonal wind

50 days after initialization on 1 January with an isothermal (290 K) atmosphere at rest

Without water cycle (discussed last week)

Upward motion in summer hemisphere; Downward motion in winter hemisphere

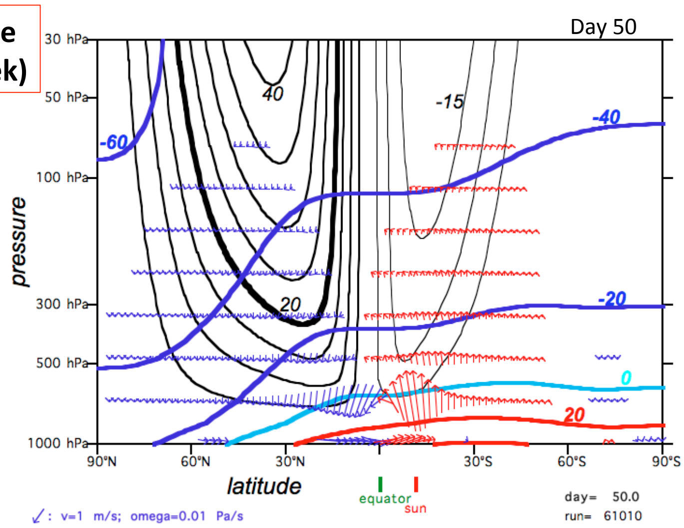


Fig 12.10

T [°C] and *u* [m s^{-1}]

Temperature, circulation and zonal wind

50 days after initialization on 1 January with an isothermal (290 K) atmosphere at rest

With water cycle

The influence of water:

1. upper atmosphere colder
2. Summer subtropics hotter
3. Winter subtropics colder

Upward motion in summer hemisphere; Downward motion in winter hemisphere

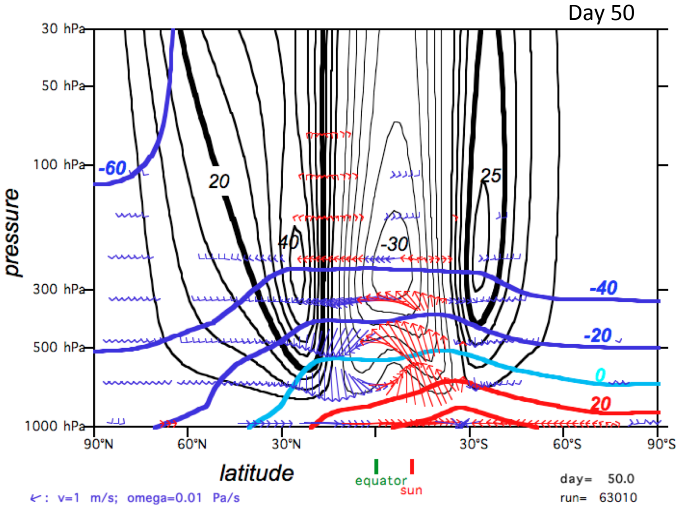


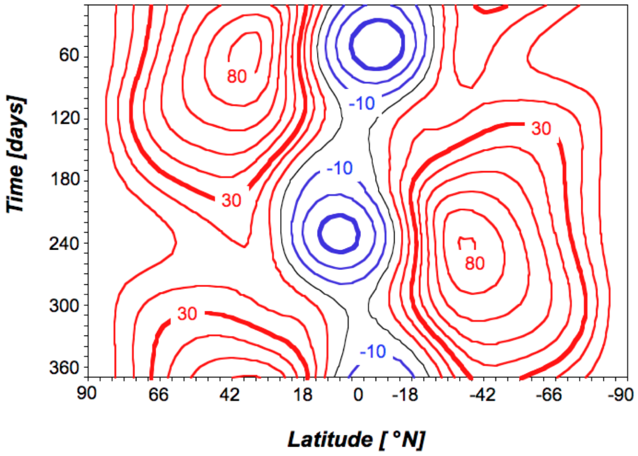
Fig 12.15

T [°C] and *u* [m s^{-1}]

Seasonal cycle of zonal wind at 50 hPa

Modelled (including water cycle)

No reversal of the zonal wind



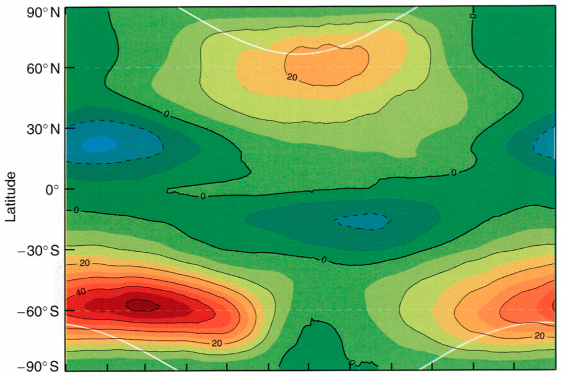
Second year of simulation

Fig 12.16

u [m s^{-1}]

Seasonal cycle of zonal wind at 50 hPa

observed



Zonal mean wind speed at 50 hPa (labels in units of m s^{-1}). The polar jet begins to intensify just after equinox and continues to grow in strength reaching a peak in mid- to late winter. White lines indicate the edge of the polar night. Source: **Encyclopedea of Atmospheric Science**. Edited by J.R. Holton et al., 2002. Elsevier.

Fig 12.17

Model with water cycle

Both Hadley cells now more clearly present

But no temperature minimum in the tropics at approximately 100 hPa

No wind reversal in the stratosphere

Next week: *introduction of wave drag will solve these problems*

Assignment 4

Hand in answer on or before 21 May 2014

Problem 12.3 (p. 686). Testing the model assumptions concerning the water cycle with reanalysis data

Investigate the realism of the model assumptions concerning the water cycle (section 12.4). Do this for a particular month or year. Restrict the analysis to the zonal mean.

The principal model assumptions are that (1) the relative humidity at the ground is 75%, (2) total precipitation is instantaneously in balance with total evaporation, (3) the Bowen ratio is 0.25 at all latitudes, (4) local precipitation is 80% of the locally evaporated water, except in the ITCZ, (5) total precipitable water vapour is equal to the density of water vapour near the surface times the scale height (eq. 12.19).

You need to retrieve the following fields from the ERA-Interim website: *net radiation* at the Earth's surface, *sensible heat flux* from the Earth's surface to the atmosphere, *evaporation* at the Earth's surface, *precipitation*, *precipitable water vapour* and the *temperature* and *dewpoint* at 2 m (from which you can retrieve the *relative humidity*) as a function of latitude.

Next lecture

Wednesday 21/5, 2014, 13:15-15:00

Discussion of second assignment

Remaining topics:
The missing element: "wave drag".

Parametrization of wave drag

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

Schedule of the C&HC-2

23 April: Introduction to radiative transfer; "grey gas"; radiative equilibrium
study sections 2.1-2.4 & boxes 2.1-2.4;
(1)** problem 12.1 (response time)* ***(0.5)
30 April: Radiatively determined state; Reanalyses
(2)** problem 12.2 (radiation at TOA; ERA-Interim)* ***(2.0)
7 May: Radiative-dynamical interaction in a dry atmosphere; GCM's
***(3)** article for review (**yes/no**); Topic of presentation (GCM)*
14 May: Role of water cycle in the general circulation (the ITCZ)
(4)** problem 12.3 (check of model assumptions)* ***(2.5)
21 May: Role of wave drag in the general circulation (the surf zone)
(5)** problem 12.5-12.9 (what-if? thought experiments)* ***(1.0)
4 June: The Hadley-circulation and the Brewer-Dobson Circulation
(6)** problem 12.12 (Hadley-circulation theory)* ***(1.5)
11 June: Isentropic coordinates and potential vorticity (inversion)
*(**7**) hand in review*
18 June: Zonal mean mass- and potential vorticity budget
***(8)** presentations on GCM's 1 (**2.5**)*
25 June: ***(8)** presentations on GCM's 2 (**2.5**)*
No exam