Representation of the Asian summer monsoon circulation in Chemistry climate models

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Models:

Model	Horiz. Res.	Vert. Res. / U.Bound.	Underlying GCM	Group
E39C	T30	39 / 10 hPa	ECHAM4	DLR, Oberpfaffenhofen
MAECHAM4 CHEM	T30	39 / 0.01 hPa	MAECHAM4	MPI Chem, MPI-Met
UMSLIMCAT	2.5 x 3.75	64/ 0.01 hPa	UM	University of Leeds
WACCM (v3)	4 x 5	66 / 0.0000045 hPa	CAM	NCAR, Boulder, USA
LMDZrepro	2.5 x 3.75	50 / 0.07 hPa	LMDz4	IPSL, Paris, France

Introduction:

The Asian summer monsoon is a major source of interannual variability on the northern hemisphere (Annamalai et al., 1999). It is a significant moisture source for the upper troposphere outside the deep tropics with a potential to moisten the lower stratosphere (Dethof et al., 1999). The current generation of IPCC ocean-atmosphere climate models show variable skill in capturing aspects of the monsoon variability (e.g. Kripalani et al., 2007 and references therein).

Here, we will assess the ability of chemistry-climate models (CCMs), which are driven with natural variability and anthropogenic forcings according to Table 2, to capture the large scale monsoon circulation and its impact on trace gas distributions (water and ozone).

Two reanalysis datasets ERA-40 and NCEP/NCAR (hereafter denoted NCEP) are used to validate the temperature, zonal wind, and vertical velocity fields in transient REF1 CCM simulations of the past.

REF1 Simulations:

For more details see Eyring et al. (2006)

Model	QBO	Vol-canoes	Solar Cycle	SSTs	GHG	Halogens
E39C	Assim.	YES	YES	Hadley Centre	IPCC A2	WMO(2003)
MAECHAM4 CHEM	Assim.	YES	YES	Hadley Centre	IPCC A2	WMO(2003)
UMSLIMCAT	Internal	YES	NO	AMIP II	IPCC A2	WMO(2003)
WACCM (v3)	NO	YES	YES	Hurrell et al.	WMO(2003)	WMO(2003)
LMDZrepro	NO	YES	NO	AMIP II	WMO(2003)	WMO(2003)

Asian Summer Monsoon anticyclone

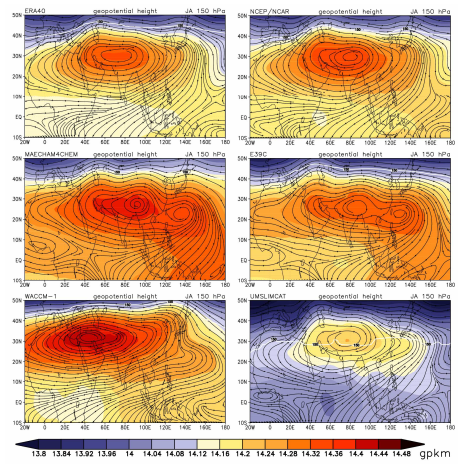


Figure 1: Mercator projection from 10°S – 50°N at 150 hPa for July/August of the long term monthly mean (20 years) geopotential height, shaded in gpkm. Shading intervall is 40 gpm. Overlaid as stream lines are the horizontal wind components. The white line indicates the lapse rate tropopause.

Figure 2: Latitude-height sections between 1000 and 50 hPa, from the Equator to 65°N for the July/August long term mean (20 years) meridional velocity averaged between 16° - 46°E (left) and 95° - 125°E (right), shading interval is 1 m/s. Displayed as contours in black are the temperature anomalies of the respective latitude sections against the zonal average. The height of the lapse rate tropopause is displayed in red (solid: sectional mean; dashed: zonal averaged). The blue arrows denote the meridional (in m/s) and vertical velocity (in mm/s).

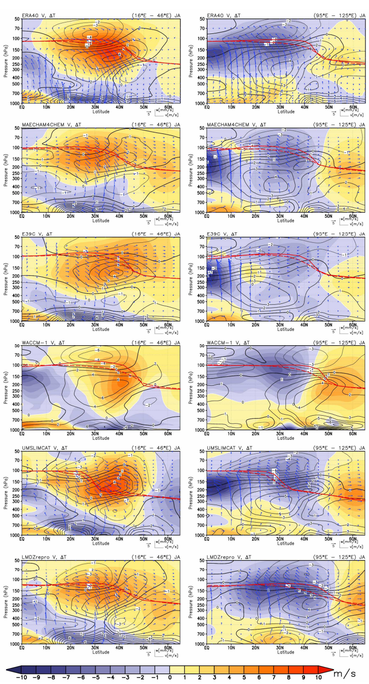
During northern hemisphere summer a large cyclone with its centre over Pakistan is a dominant feature in the lower troposphere. With increasing height this monsoon cyclone in the lower troposphere becomes an anticyclone in the upper troposphere and lower stratosphere (UT/LS). During the active phase of the Asian monsoon isentropic exchange on levels at and above 340 K has been diagnosed between the troposphere and the stratosphere (Chen, 1995).

As shown with Figure 1, the CCMs show differences in strength and position of the monsoon anticyclone in the upper troposphere. In UMSLIMCAT the position of the anticyclone is well reproduced but due to a cold bias the 150 hPa level is lower, compared to the reanalyses. WACCM has a stronger monsoon anticyclone, but the centre is shifted to the west. In MAECHAM4CHEM and E39C the centres are slightly shifted to the east. Compared with the reanalyses the anticyclone is more pronounced in MAECHAM4CHEM whereas in E39C it is slightly weaker.

The anticyclonic circulation leads to a pronounced northward flow west of the monsoon region and a southward flow to the east. The largest northward flow coincides with an acceleration of the zonal wind component (Dunkerton, 1995).

In Figure 2 the strongest northward directed meridional velocities in the sector from 16 – 46°E occur at 150 hPa between 30°N and 45°N with values up to 9 m/s. In the sector on the eastern side of the anticyclone the meridional wind is directed southward and the wind speed is more than 7 m/s.

Dynamical Asian summer monsoon structure:



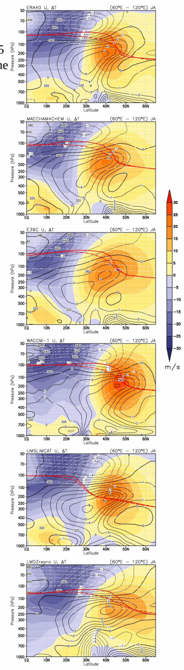


Figure 3: As Figure 2 for the zonal velocity averaged between 60° - 120°E , shading interval is 5 m/s. Displayed dashed white is the potential temperature (contour interval 20 K). Adapted from Randel and Park (2006), Fig.2.

Characteristic monsoon temperature pattern:

- positive anomaly in the troposphere,
- negative deviations in the UTLS region,
- elevated lapse rate tropopause.

The cold anomaly is most pronounced in the sector averaged over the center of the anticyclone with more than -5 K.

Western side of the monsoon anticyclone:

- northward directed convergent meridional motion,
- downward directed vertical velocity.

Eastern side of the monsoon anticyclone::

- divergent southward flow,
- upward vertical velocity.

Water vapour and ozone

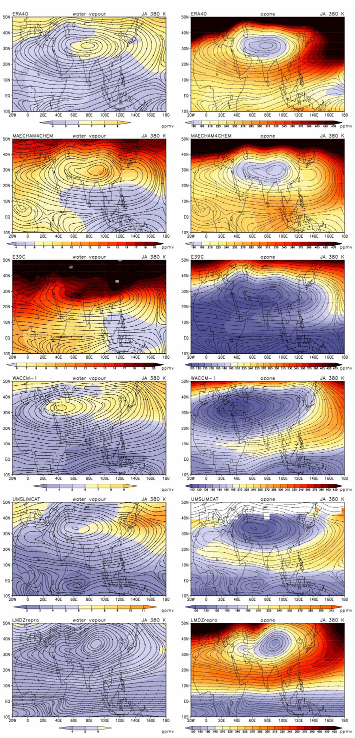


Figure 4: Mercator projection from 10°S -50°N at 380 K for July/August of the long term monthly mean (20 years), left: water vapour in ppmv, shaded with an interval of 2 ppmv; right: ozone in ppmv, shaded with an interval of 15 ppmv. Overlaid are stream lines of the horizontal wind.

The water vapour and ozone concentrations at the 380 K isentropic level are displayed with Figure 4, together with the stream lines of the horizontal wind fields.

On average the 380 K isentropic level coincides well with the thermal tropopause at latitudes near the equator, and lies in the lower stratosphere in high latitudes. Figure 3 shows that the tropopause above the monsoon anticyclone is higher than the zonal mean tropopause.

The surface of the 380 K isentropic level therefore intersects the tropopause and lies in the upper troposphere between 30 – 40°N.

Some of the CCMs simulate too high water vapour concentrations (E39C, MAECHAM4CHEM). This is partly caused by a positive temperature bias.

LMDZrepro has a low tropopause (~120 hPa near the Equator), and therefore has a very weak monsoonal water vapour signal.

Generally **strong convection during the Asian Summer monsoon leads to**:

- **higher water vapour** concentrations,
- **lower ozone** concentrations,

inside the monsoon anticyclone.

With Figure 5 we analyse the percentage changes in water vapour concentration (shaded) together with the circulation anomalies (zonal velocity component as contour, meridional and vertical velocity as arrows) due to the Asian summer monsoon. Averages of three sections, on the eastern (16 – 46°E) and western edge (120 – 160°E), and in the center (60 – 120°E) of the anticyclone are compared. All anomalies are calculated with respect to the zonal mean.

References:

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Water vapour anomalies

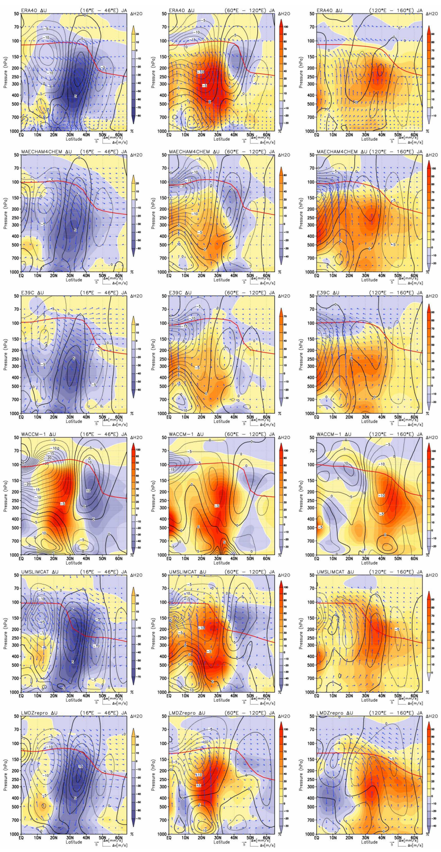

Figure 5: Latitude–height sections between 1000 and 50 hPa, from the Eq. to 65°N of three sections averaged between: 16 – 46°E (left), 60 – 120°E (center), and 120 – 160°E (right), for the Jul/Aug anomalies of water vapour (percentage change, shading interval is 10%), the zonal wind component (black contour with 2.5 m/s interval), the meridional (in m/s) and vertical velocity (in mm/s), displayed as arrows. The anomalies are calculated with respect to the zonal averages. The tropopause height is displayed in red.

Western edge of the anticyclone:

- negative water vapour anomaly in the troposphere peaking with values up to -80% between 500 and 250 hPa.

Center of the monsoon anticyclone, eastern edge:

- strong positive water vapour anomalies of up to 100% in the troposphere.

The dry anomalies at the western edge may be caused by the strong northward meridional flow that transports the dry air from the convective outflow in the subtropics, together with the subsidence prevailing in this sector. Inside the warm tropospheric center of the monsoon higher water vapour values are found compared to the zonal mean, as shown by the averages from 60 – 120°E Fig. 5 (center), and 120 – 160°E Fig. 5 (right).

Summary:

Specific differences between the CCMs are discussed, but generally the CCMs are able to capture most of the climatological features of the Asian Summer monsoon circulation:

- **Western side of the monsoon anticyclone:**
  - northward directed convergent meridional motion,
  - downward directed vertical velocity
  - leads to negative water vapour anomaly in the troposphere.
- **Center of the monsoon anticyclone, Eastern edge:**
  - divergent southward flow,
  - upward vertical velocity,
  - strong positive water vapour anomalies in the troposphere.
- Latent heat release from deep convection produces **positive tropospheric temperature anomaly**, and **negative lower stratospheric temperature anomaly.**
- **Elevated tropopause**, connected with monsoon activity.

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