Water vapor and the hydrological cycle
Time and zonal mean *saturation* specific humidity

![Graph showing time and zonal mean saturation specific humidity](image)

**Fig. 1**

*ERA40, 1980-2001*
Time and zonal mean specific humidity

Fig. 2
Time and zonal mean *relative* humidity: seasons

Fig. 3
Time mean relative humidity at 500hPa

NCEP/NCAR Reanalysis
500mb Relative Humidity (%) Composite Mean

Fig. 4

CDC interactive plotting
Vertical-mean zonal flux of water vapor (m/s g/kg)

Fig. 5

Peixoto and Oort, Fig 12.7
Vertical-mean *transient* zonal flux of water vapor (m/s g/kg)

**Fig. 6**

Peixoto and Oort, Fig 12.7
Vertical-mean meridional flux of water vapor (m/s g/kg)

Fig. 7

Peixoto and Oort, Fig 12.10
Meridional flux of water vapor (m/s g/kg)

Peixoto and Oort, Fig 12.11
Vertical eddy flux of water vapor ($10^{-10}/s$)

* sigma coordinate vertical velocity, both transient and stationary eddies

Fig. 9

ERA40, 1980-2001
FIGURE 12.18. Streamlines of the zonal-mean transport of water vapor for annual, DJF, and JJA mean conditions in $10^8 \text{ kg s}^{-1}$ (from Peixoto and Oort, 1983).
Fig. 11

E-P (mm/day)
FIGURE 12.16. Meridional profiles of the zonal-mean divergence of the total water vapor transport $[\text{div } \mathbf{Q}] \approx [E - P]$ in $0.01 \text{ m yr}^{-1}$ for annual, DJF, and JJA mean conditions. Some annual-mean estimates of $E - P$ by Baumgartner and Reichel (1975) are added for comparison (see also Table 7.1).
Schematic of water vapor transports

Hadley Cell Transport

net precipitation

tropics

Transient Eddy Transport

net evaporation

sub-tropics

net precipitation

mid and high latitudes

Fig. 13
DJF Water vapor flux (each barb 2 m s\(^{-1}\) g kg\(^{-1}\)) and some streamlines
Estimates of evaporation and precipitation rates
Estimation of precipitation

GSMaP_MVK refers to the Kalman filter-based system; a near-real-time system named GSMaP_MVK_RT contains the propagation process forward in time. Rain gauges provide relatively accurate and trusted measurements of precipitation at single points but are unavailable over many sparsely populated and oceanic areas and can be affected by sampling errors. Satellite observations provide precipitation information with homogeneous spatial coverage but contain nonnegligible random errors and biases owing to the indirect nature of the relationship between the observations and precipitation, inadequate sampling, and deficiencies in the algorithms. Many attempts have been made to merge different sources of information to overcome these problems while tapping into the individual advantages of the different methods, to obtain optimal precipitation analyses with regular gridded fields (Figure 4). The CPC Merged Analysis of Precipitation (CMAP) (Xie & Arkin, 1997) and GPCP (Adler et al., 2003) are the most widely recognized and used merged data sets. The GPCP precipitation product was first released in 1997 and version 2 was released in 2002. It is based on the sequential combination of MW, IR, and gauge data. For the SSM/I period 1987 to the present, MW measurements from the SSM/I and the Special Sensor Microwave Imager Sounder (SSMIS) calibrate the GPI between 40°S and 40°N and are combined with estimates based on data from the TIROS Operational Vertical Sounder (TOVS) and the Atmospheric IR Sounder to offer globally complete satellite-only precipitation estimates. For the pre-SSM/I periods, the calibrated Outgoing long-wave radiation (OLR) Precipitation Index (OPI) (trained against GPCP for the period of 1988–1997) is used globally between 1979 and 1985; for other time periods, the Adjusted Global Precipitation Index is used between 40°S and 40°N and the calibrated OPI is used elsewhere. Then, the multisatellite field is merged with rain gauge analyses (over land) by adjusting the satellite estimates to the gauge

Figure 4. Flowchart for the precipitation products. The images for satellite adapted from Hou et al. (2014).
GPCP: long-term mean precipitation

Fig. 4. The 23-yr (1979–2001) annual mean precipitation (mm day⁻¹).
Fig. 1. Block diagram of the Version-2 satellite–gauge (SG) precipitation combination technique. Shaded boxes with thin borders are input datasets, shaded boxes with thick borders are output datasets produced in the SG, and unshaded boxes are intermediate datasets produced in the SG. Arrows show data flow. Hatched background and dotted arrows indicate the years for which various parts of the computation are done, as described in the text.

Adler, J. Hydrometeor., 2003
Fig. 14. Scatterplot of precipitation (mm day$^{-1}$) for collocated GPCP grid blocks and Pacific atoll rain gauge stations for 1979–2001.

Adler, J. Hydrometeor., 2003; fig 14
Atafu atoll; South Pacific near New Zealand
GPCP: comparison with independent rain gauges in Oklahoma

Bias = 1.1 mm/month (+1%)
RMS Diff = 18 mm/month
Corr Coeff = 0.94

Adler, J. Hydrometeor., 2003; fig 15c
Comparison of annual precipitation (mm) from different global precipitation datasets

Sun, Reviews of Geophysics, 2018

Fig. 20
Surface latent heat flux (negative upwards, W/m²)

Fig. 21
Zonal-mean evaporation rate over oceans (cm/year)

**FIGURE 7.27.** Meridional profiles of the zonal-mean evaporation rate (in cm yr$^{-1}$) over the oceans computed using Eq. (10.38) and our 1963–73 surface data. Baumgartner and Reichel’s (1975) ocean values from Fig. 7.26 have been added for comparison.
Sensitivity of outgoing longwave radiation to a change in local specific humidity (W/m²/K).

Change in specific humidity is the change that would occur at constant relative humidity for a 1K increase in temperature.

Radiative importance of upper-tropospheric water vapor

Held and Soden, 2001 (July; ECMWF, ISCCP data)

Fig. 23

Sensitivity of outgoing longwave radiation to a change in local specific humidity (W/m²/K). Change in specific humidity is the change that would occur at constant relative humidity for a 1K increase in temperature.
Transport and mixing of water vapor in the troposphere

**Figure 8** A height-latitude schematic of the large-scale atmospheric trajectories involved in the transport and mixing of moisture within the troposphere.

Held and Soden, 2001
Potential temperature (K)

(ERA40 reanalysis data 1980-2001)
Last saturation analysis of mean relative humidity: NCEP winds and MATCH tracers
RH from NCEP/MATCH

Reconstructed RH using tracers of last saturation

Fig. 9. DJF 2001/02 zonal-mean RH: (a) MATCH hydrologic cycle applied to NCEP–NCAR reanalysis data; (b) reconstructed from tracer calculation.

Fig. 25

Galewsky et al, JAS, 2005; fig 9
Fig. 12. Zonal-mean probability of location of last saturation for two reference points: (a) upper region of dry zone (location of point shown by white square in Fig. 9a); (b) central region of dry zone (location of point shown by white circle in Fig. 9a). Contours are potential temperature in degrees kelvin.