12.810 Dynamics of the Atmosphere

General circulation of the atmosphere

Spinup of the general circulation in an idealized model

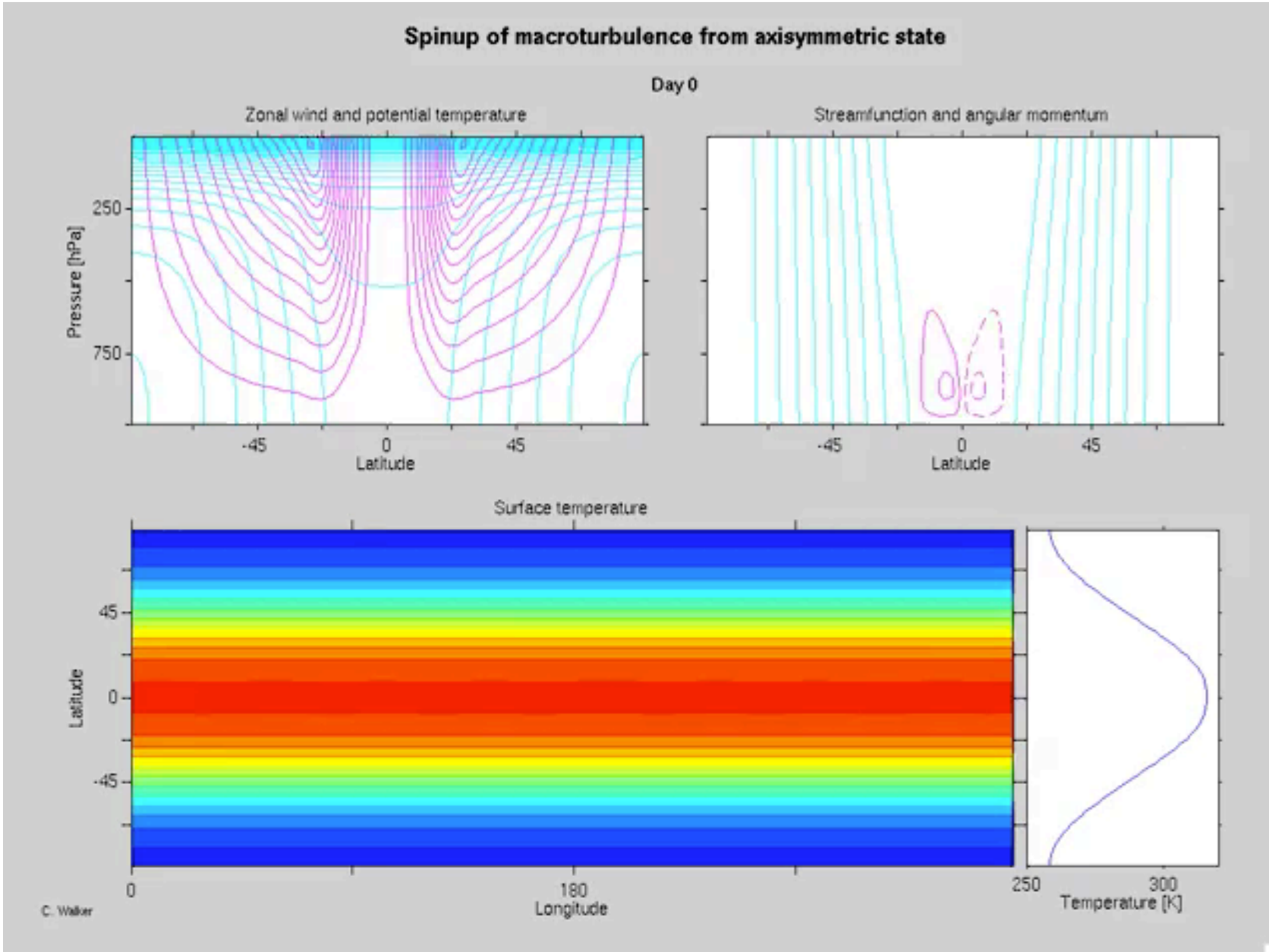
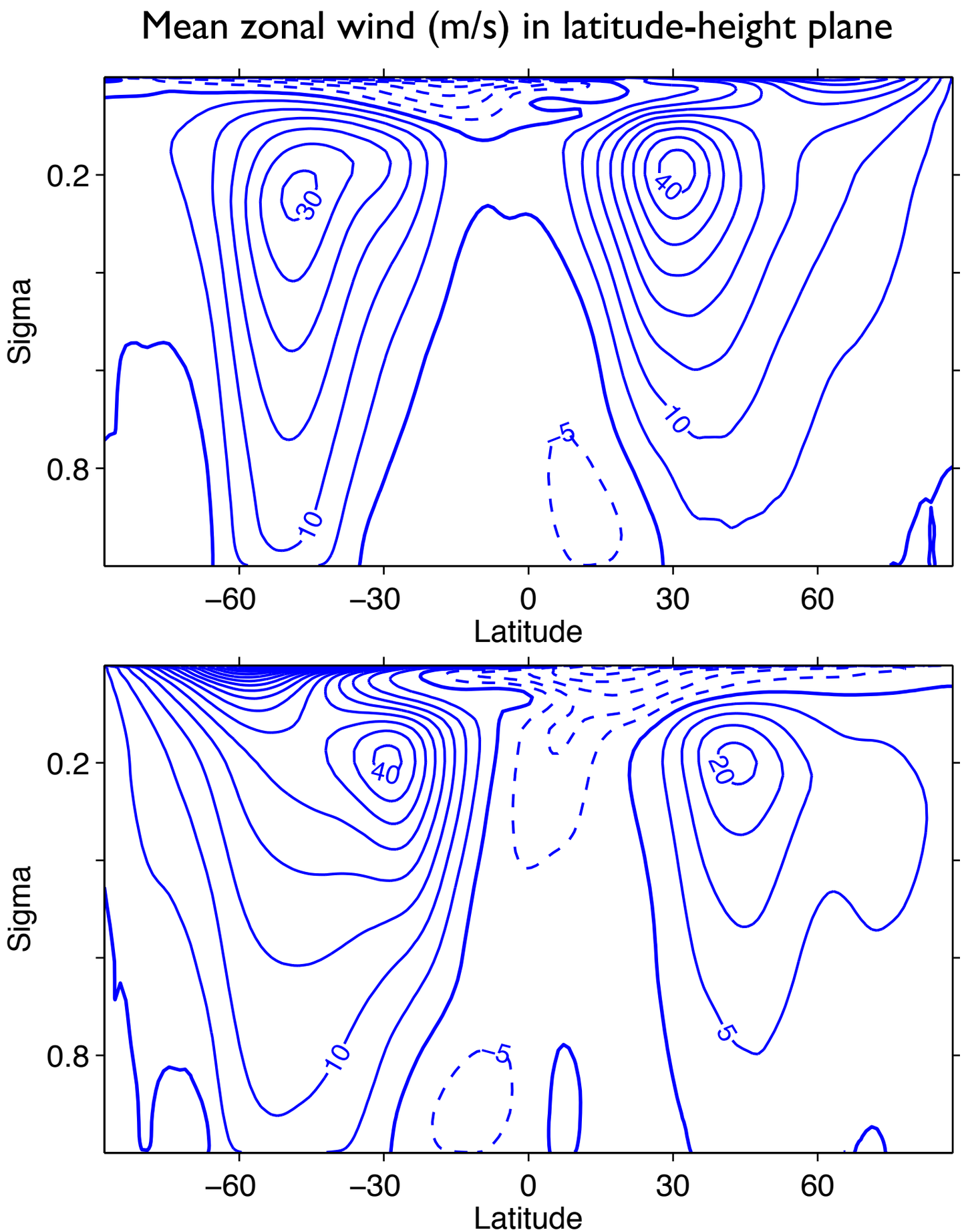


Fig. 1

Schneider, General circulation of the atmosphere, 2006



Midlatitude jets with surface westerlies in addition to subtropical jets

DJF

JJA

Fig. 2

(ERA40 reanalysis 1980-2001)

Both Hadley and Ferrel cells

Eulerian mean meridional streamfunction (10^{10} kg s^{-1})

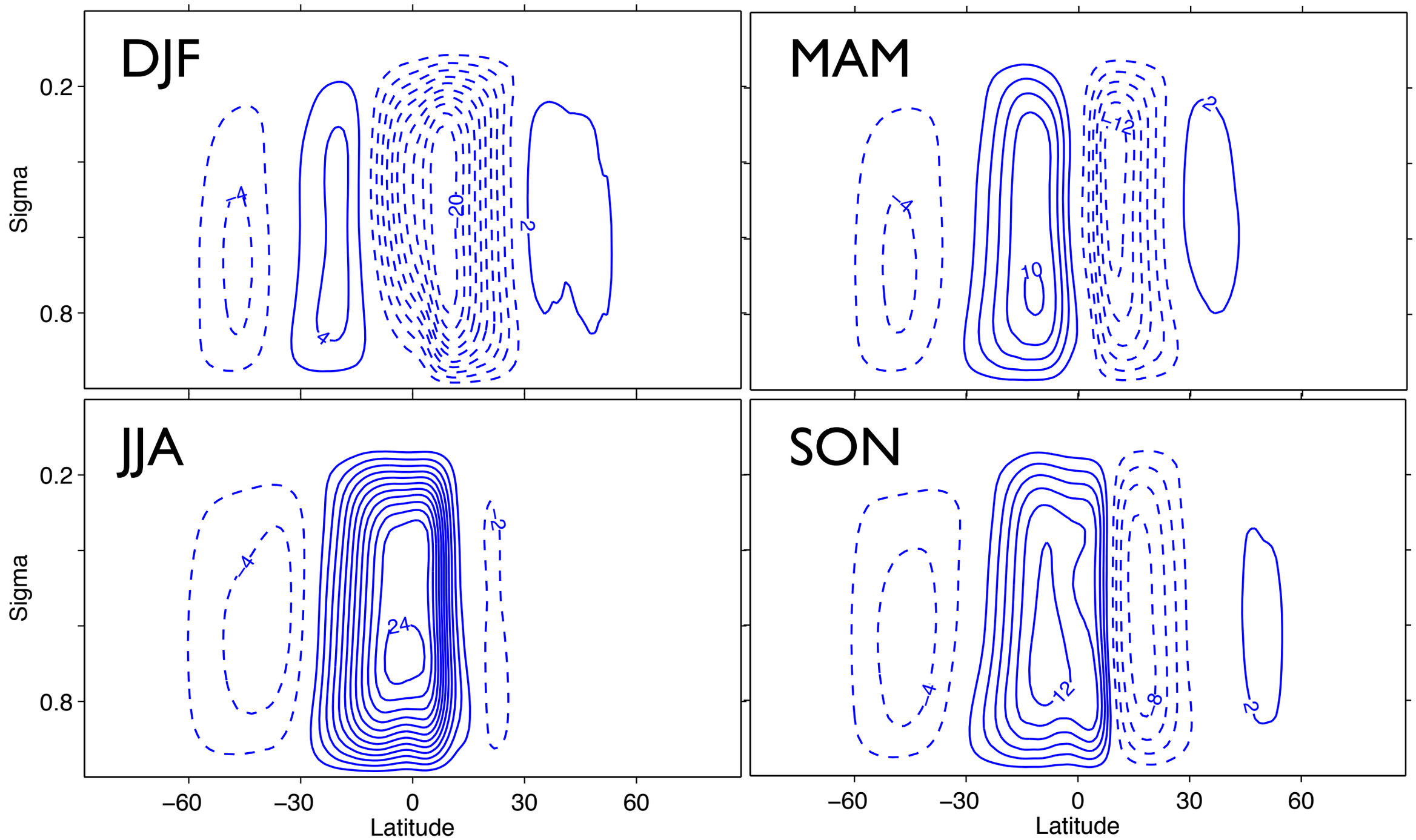


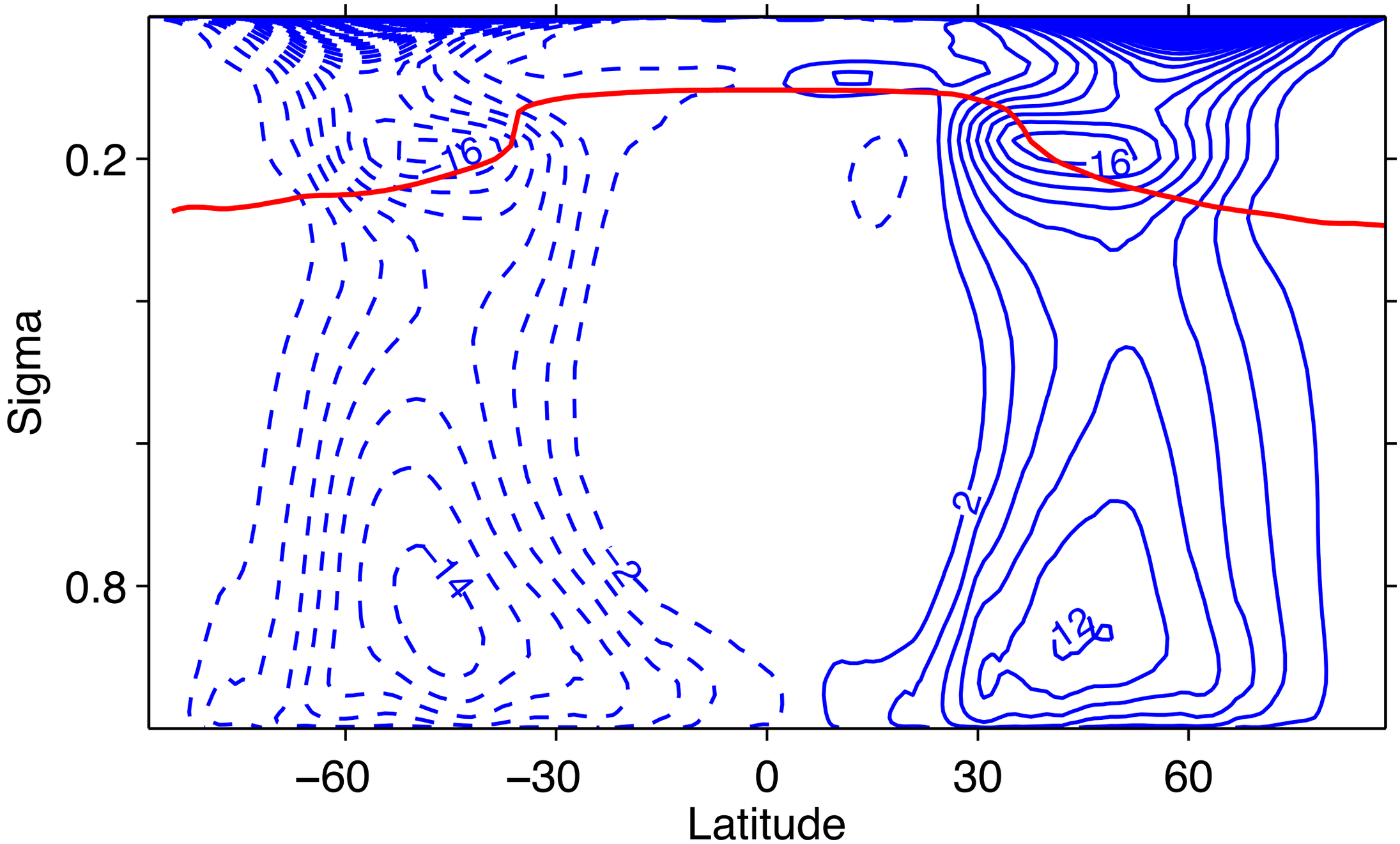
Fig. 3

(ERA40 reanalysis 1980-2001)

General circulation of the atmosphere: subtopics

1. The generation of midlatitude westerlies
2. Effect of eddies on the Hadley Cell
3. Circulation in isentropic coordinates and transport of tracers

Eddy meridional heat flux: poleward in both hemispheres



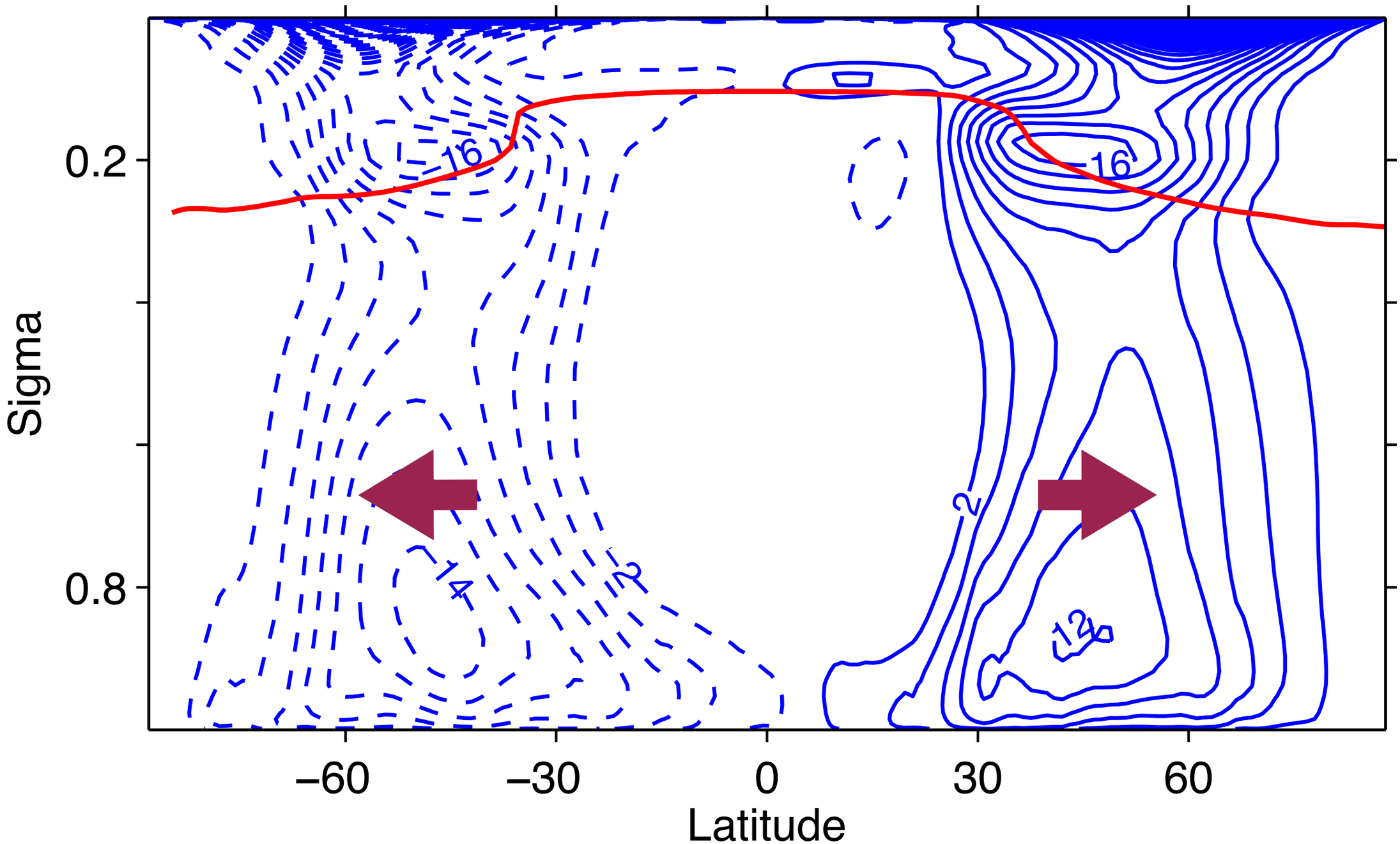
Zonal and time mean of $v'\theta'\cos(lat)$ in $ms^{-1}K$

Red line indicates the tropopause

(ERA40 reanalysis 1980-2001)

Fig. 4

Eddy meridional heat flux: poleward in both hemispheres



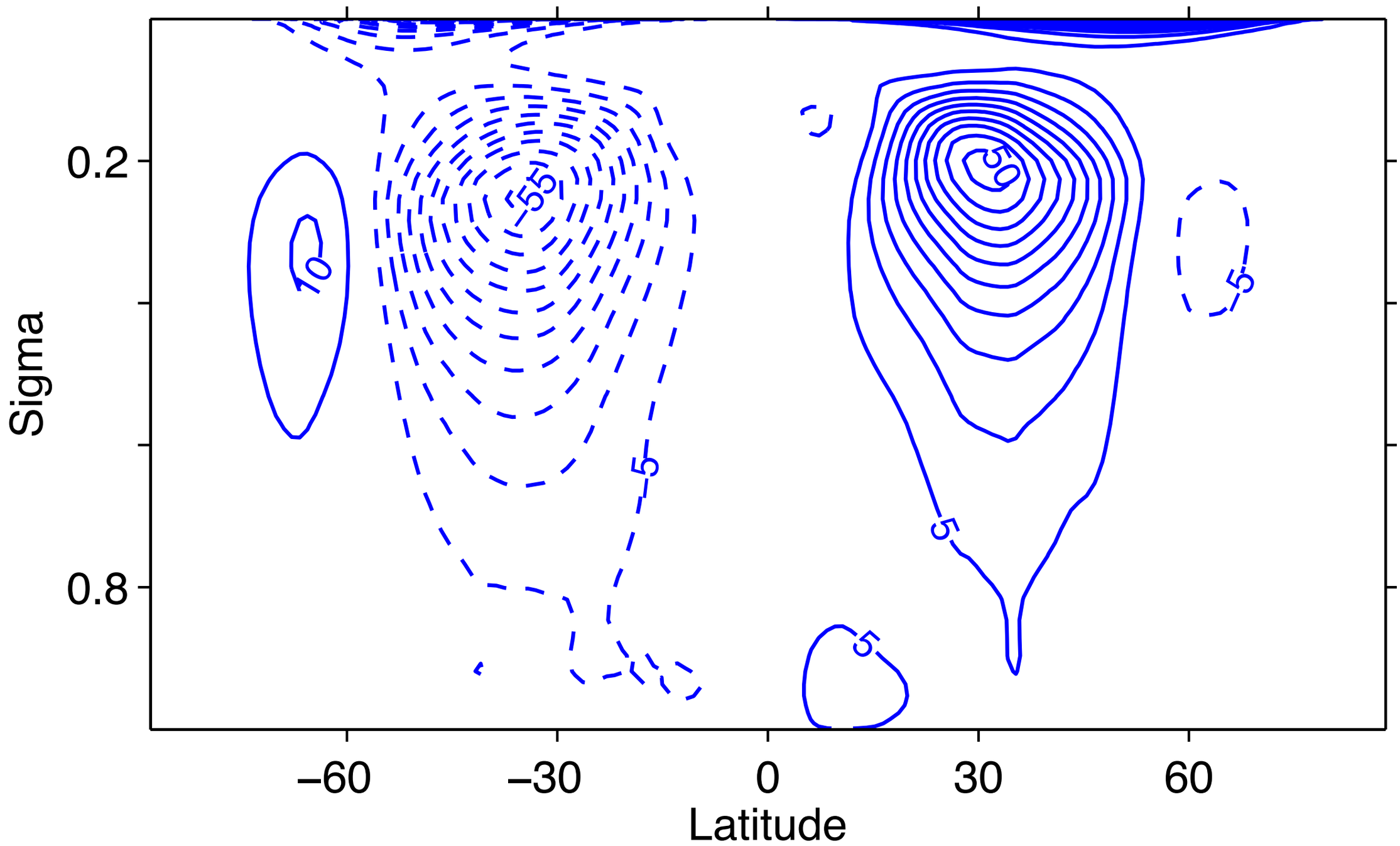
Zonal and time mean of $v'\theta'\cos(lat)$ in $ms^{-1}K$

Red line indicates the tropopause

(ERA40 reanalysis 1980-2001)

Fig. 4

Eddy momentum flux: converges at midlatitudes (mostly poleward)

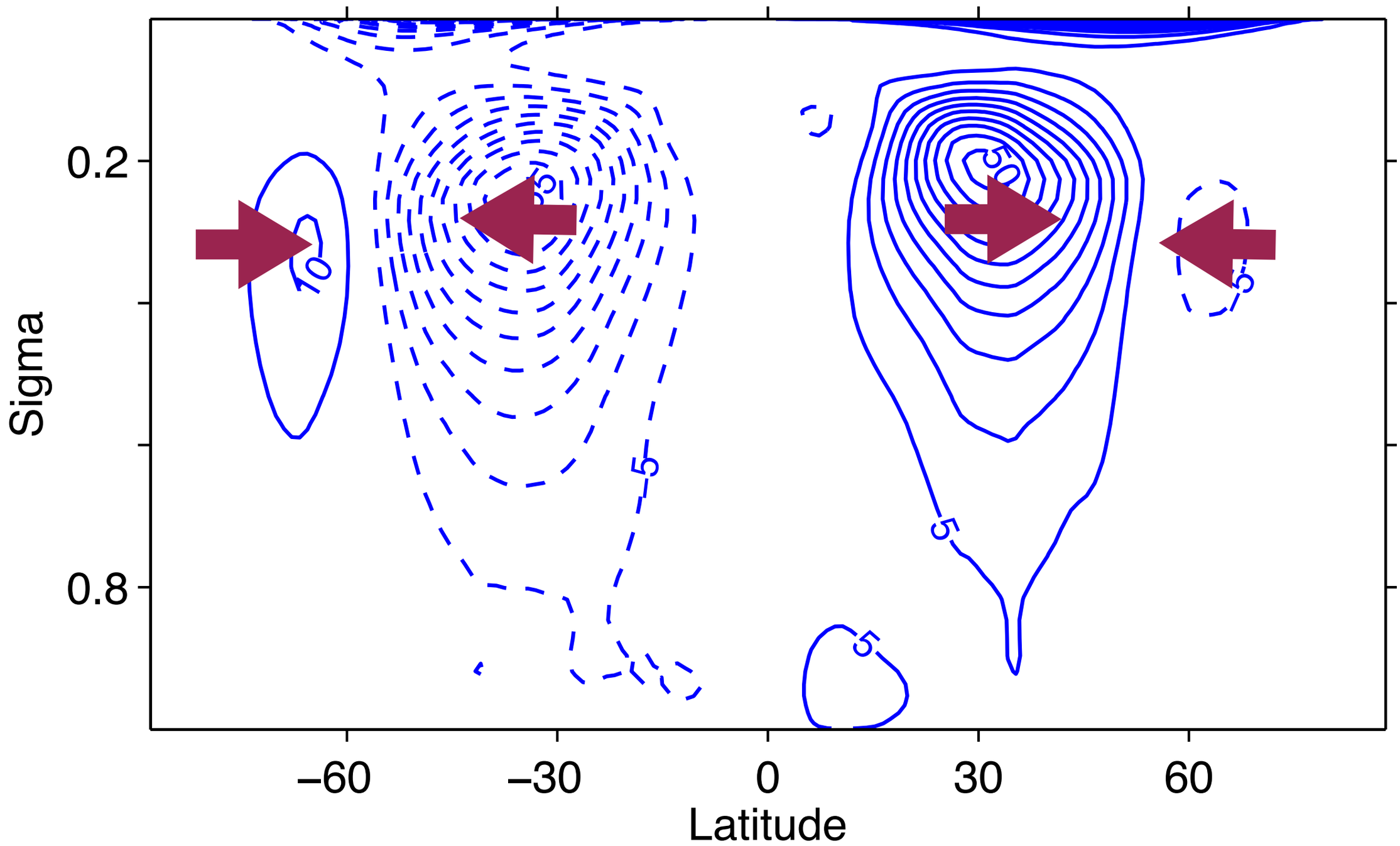


Zonal and time mean of $u'v'\cos(lat)$ in m^2/s^2

Fig. 5

(ERA40 reanalysis 1980-2001)

Eddy momentum flux: converges at midlatitudes (mostly poleward)

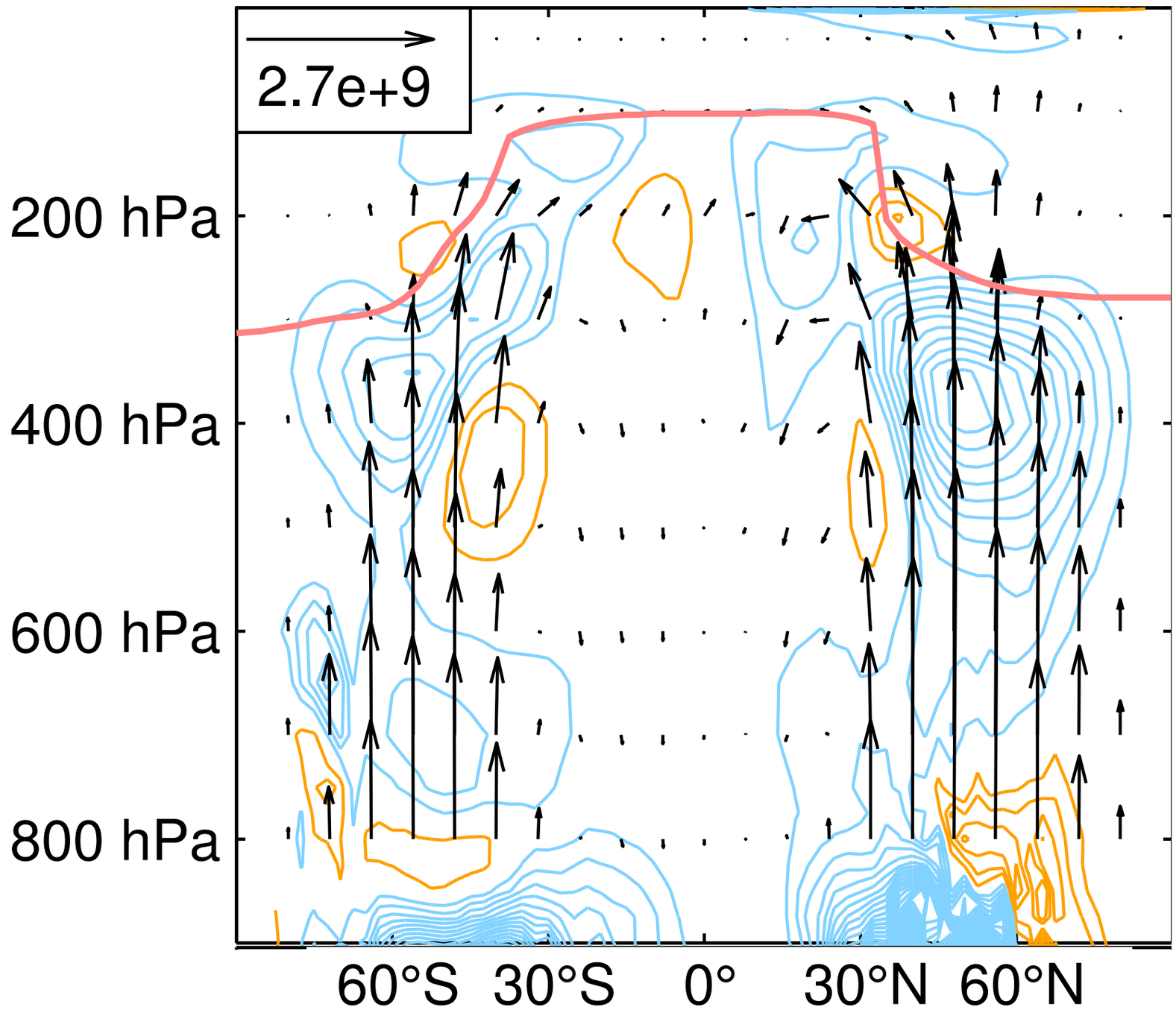


Zonal and time mean of $u'v'\cos(lat)$ in m^2/s^2

Fig. 5

(ERA40 reanalysis 1980-2001)

Eliassen-Palm fluxes: upwards and then equatorward



EP fluxes (arrows); orange is divergence, blue is convergence

The reference arrow has units m^3s^{-2}. The contour interval is 75 m^2s^{-2}.

Red line is the tropopause. Based on ERA-interim DJF 1980-2013. (*Dwyer & O'Gorman, 2017*)

Fig. 6

E-P fluxes and their divergence in baroclinic lifecycle

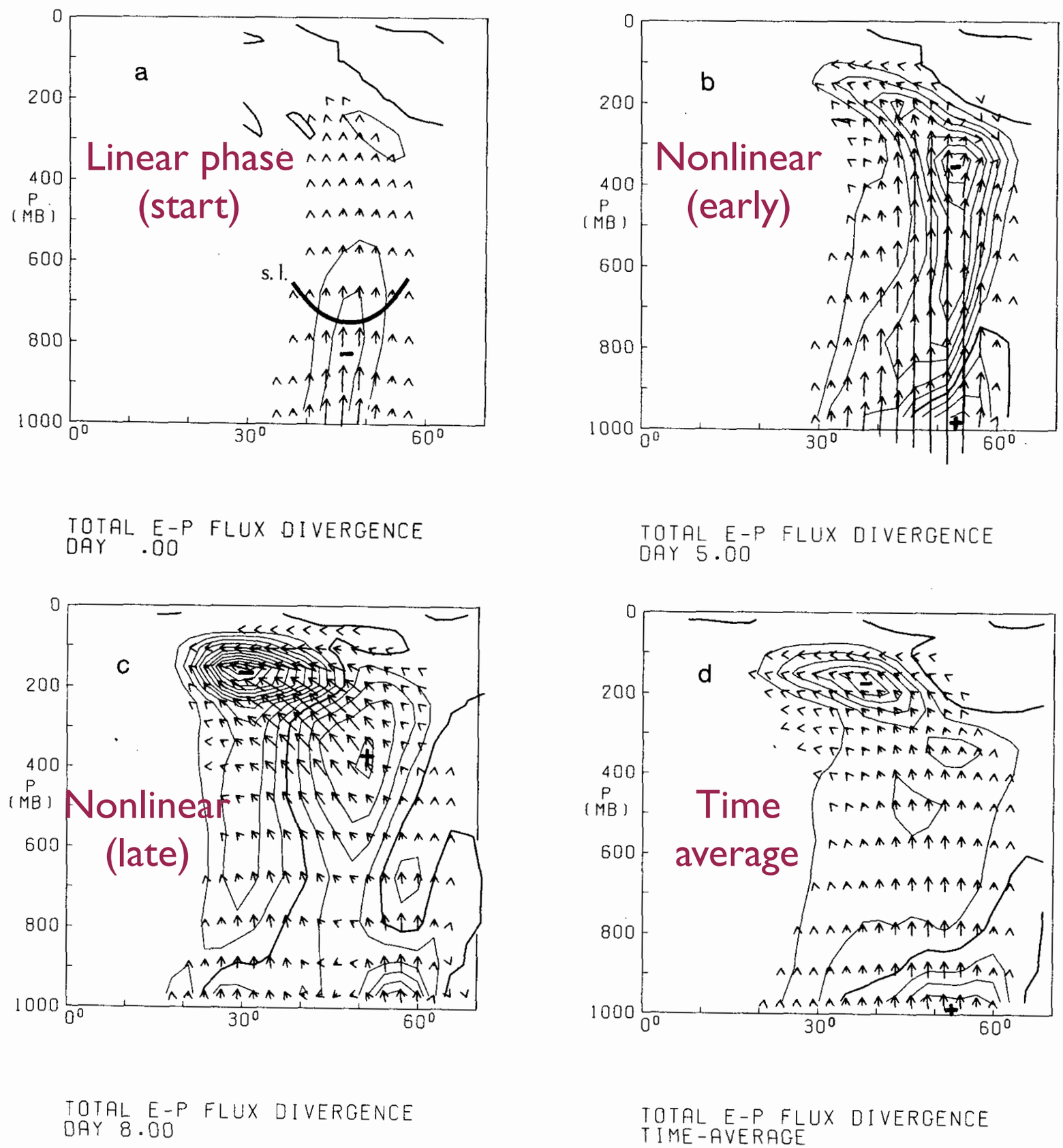


FIG. 3. (a) Eliassen-Palm cross section for a linear, growing baroclinic instability on a realistic mean state [the first case studied in Simmons and Hoskins (1980); (b), (c) cross sections for two stages in the life cycle of the same disturbance after it goes nonlinear; (d) time-averaged cross section for the life cycle. The contour interval is 4×10^{15} m^3 for (b) and (c), and 1.5×10^{15} m^3 for (d). The arrow scales are the same in all three, and such that the distance occupied by 10° of latitude represents a value 12.5×10^{15} m^3 of $\hat{F}_{(\varphi)}$, and that occupied by 100 mb represents a value 7150×10^{15} m^3 mb, or 715×10^{15} m^3 kPa, of $\hat{F}_{(p)}$.

Fig. 7

Edmon et al 1980

Tilts in Rossby waves leads to poleward flux of eastward momentum

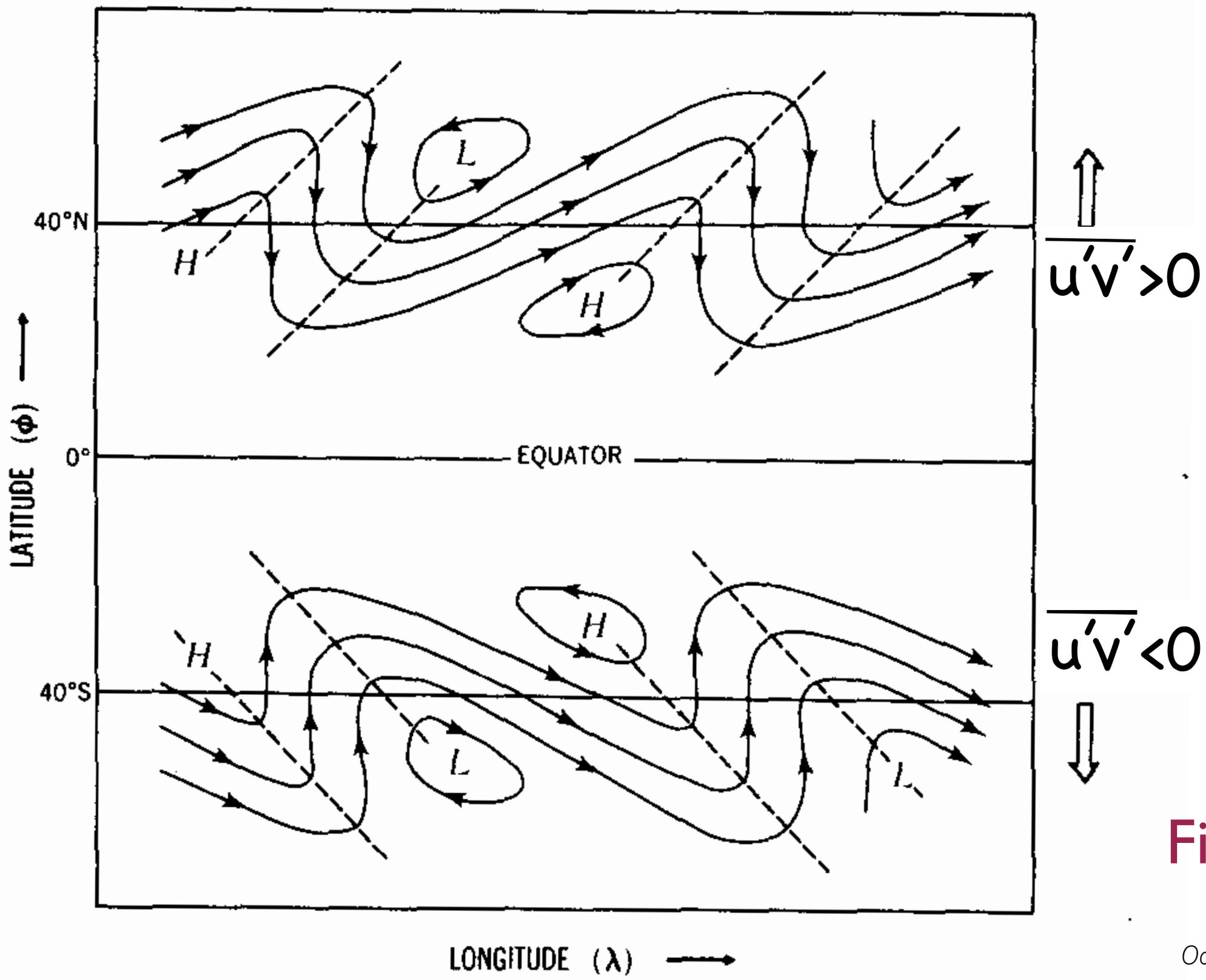


Fig. 8

Oort, 1989

Eddy momentum fluxes and and the strength of the Hadley cells

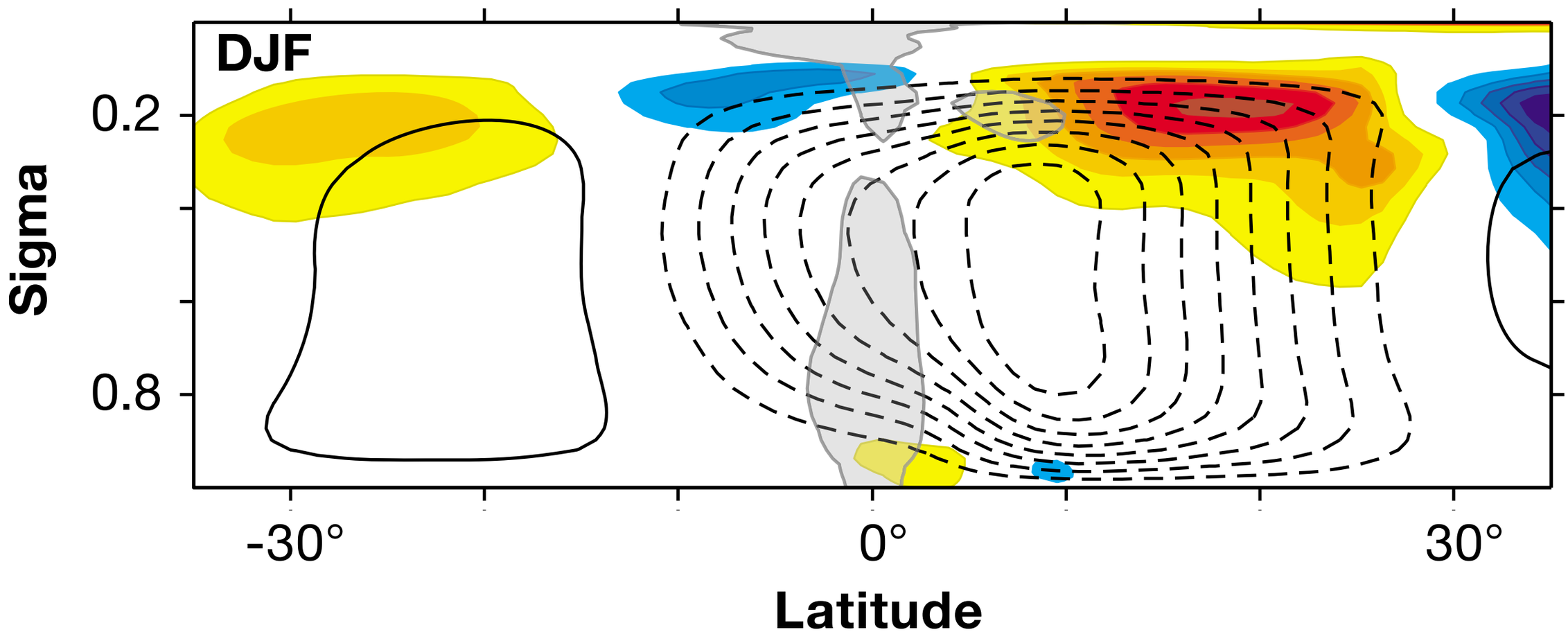
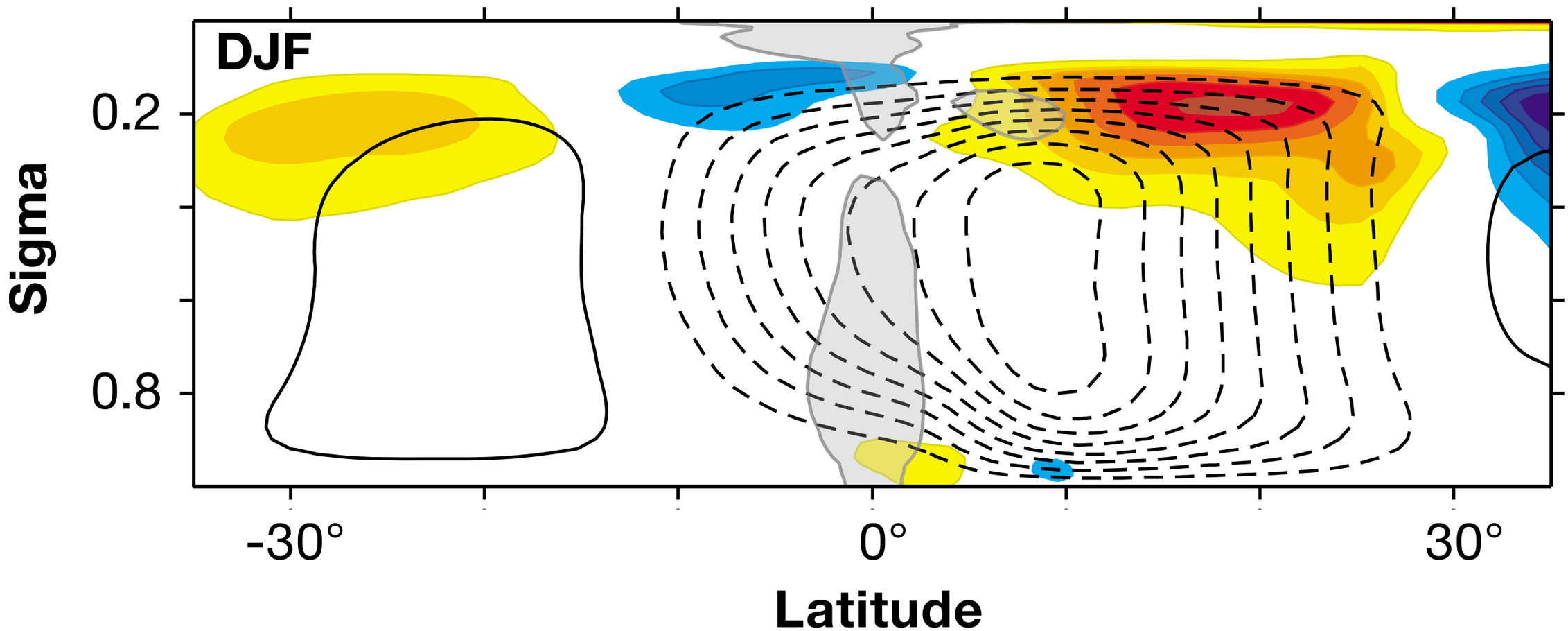


Figure 5. Earth's Hadley circulation over the course of the seasonal cycle. Black contours show the mass flux stream function, with dashed (negative) contours indicating clockwise motion and solid (positive) contours indicating counterclockwise motion (contour interval is 25×10^9 kg s^{-1}). Colors indicate horizontal eddy momentum flux divergence div($\overline{u'v'}\cos\phi$), with the overbar denoting the seasonal and zonal mean and primes denoting deviations therefrom (contour interval 8×10^{-6} m s^{-2}, with red tones for positive and blue tones for negative values). Gray shading indicates regions in which $|Ro| > 0.5$. The vertical coordinate $\sigma = p/p_s$ is pressure p normalized by surface pressure p_s. Computed from reanalysis data for the years 1980–2001 provided by the European Centre for Medium-Range Weather Forecasts [*Kållberg et al.*, 2004; *Uppala et al.*, 2005].

Fig. 9

Schneider et al, Rev. Geophysics, 2010

Eddy momentum fluxes and and the strength of the Hadley cells



Colors: eddy momentum flux divergence (red positive)

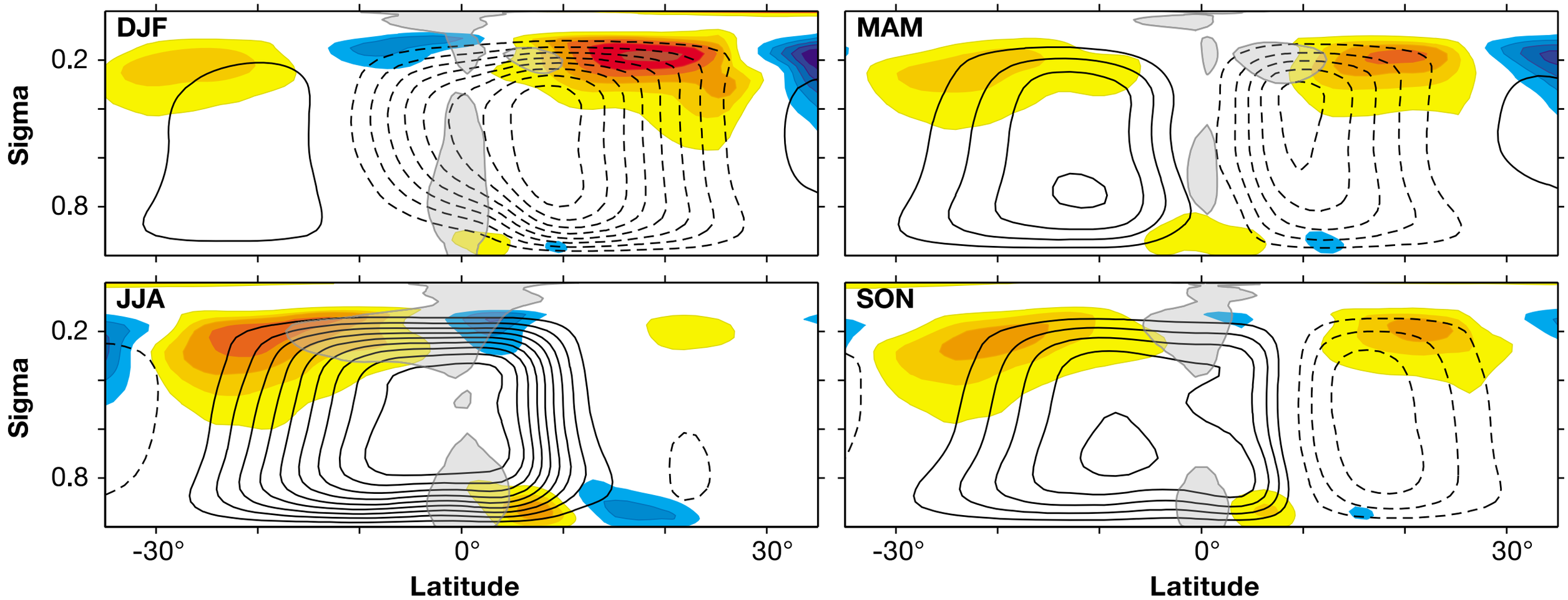
Lines: Eulerian meridional streamfunction

Gray shading: Magnitude of local Rossby number > 0.5

Fig. 9

Schneider et al, Rev. Geophysics, 2010

Eddy momentum fluxes and and the strength of the Hadley cells



Colors: eddy momentum flux divergence (red positive)

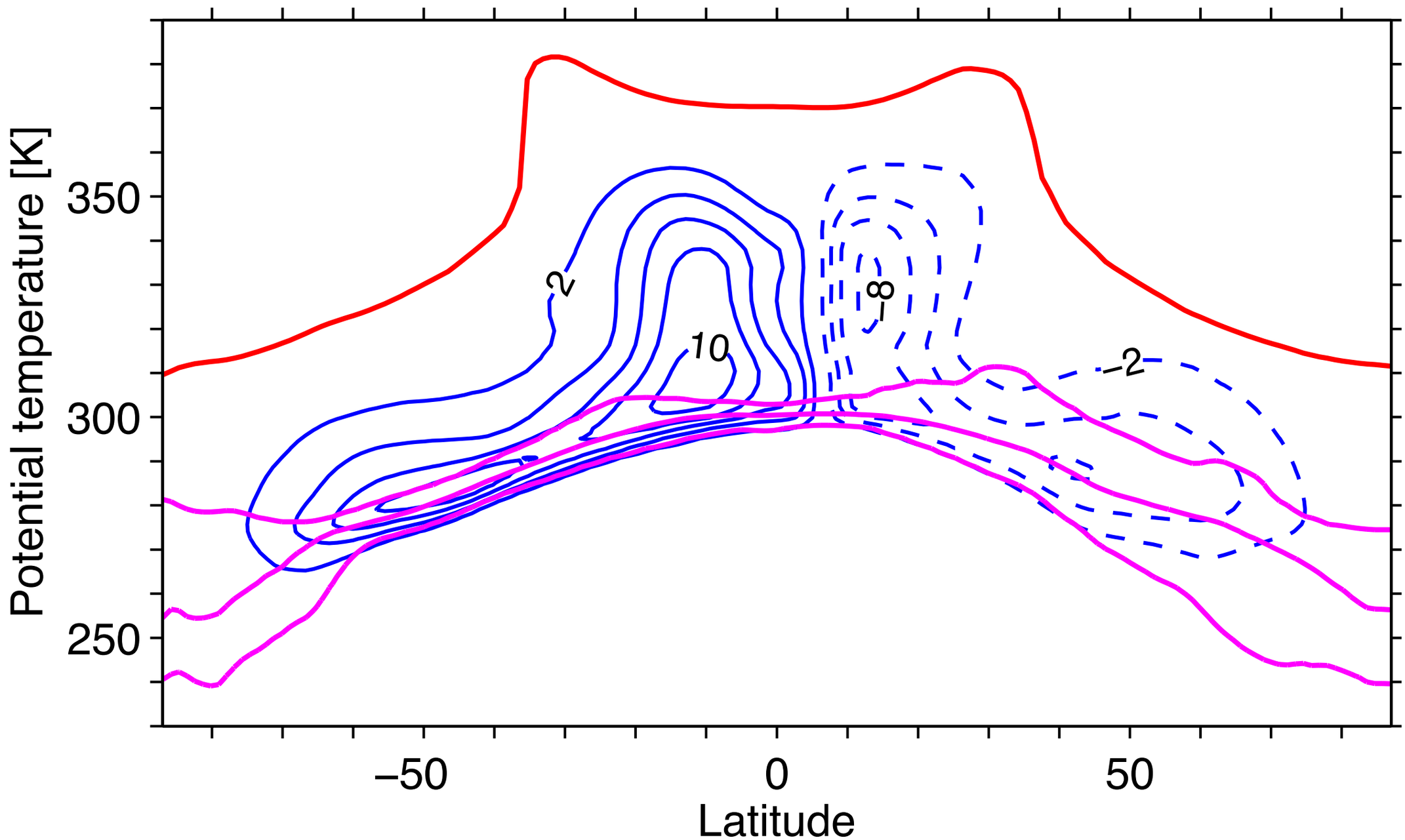
Lines: Eulerian meridional streamfunction

Gray shading: Magnitude of local Rossby number > 0.5

Fig. 9

Schneider et al, Rev. Geophysics, 2010

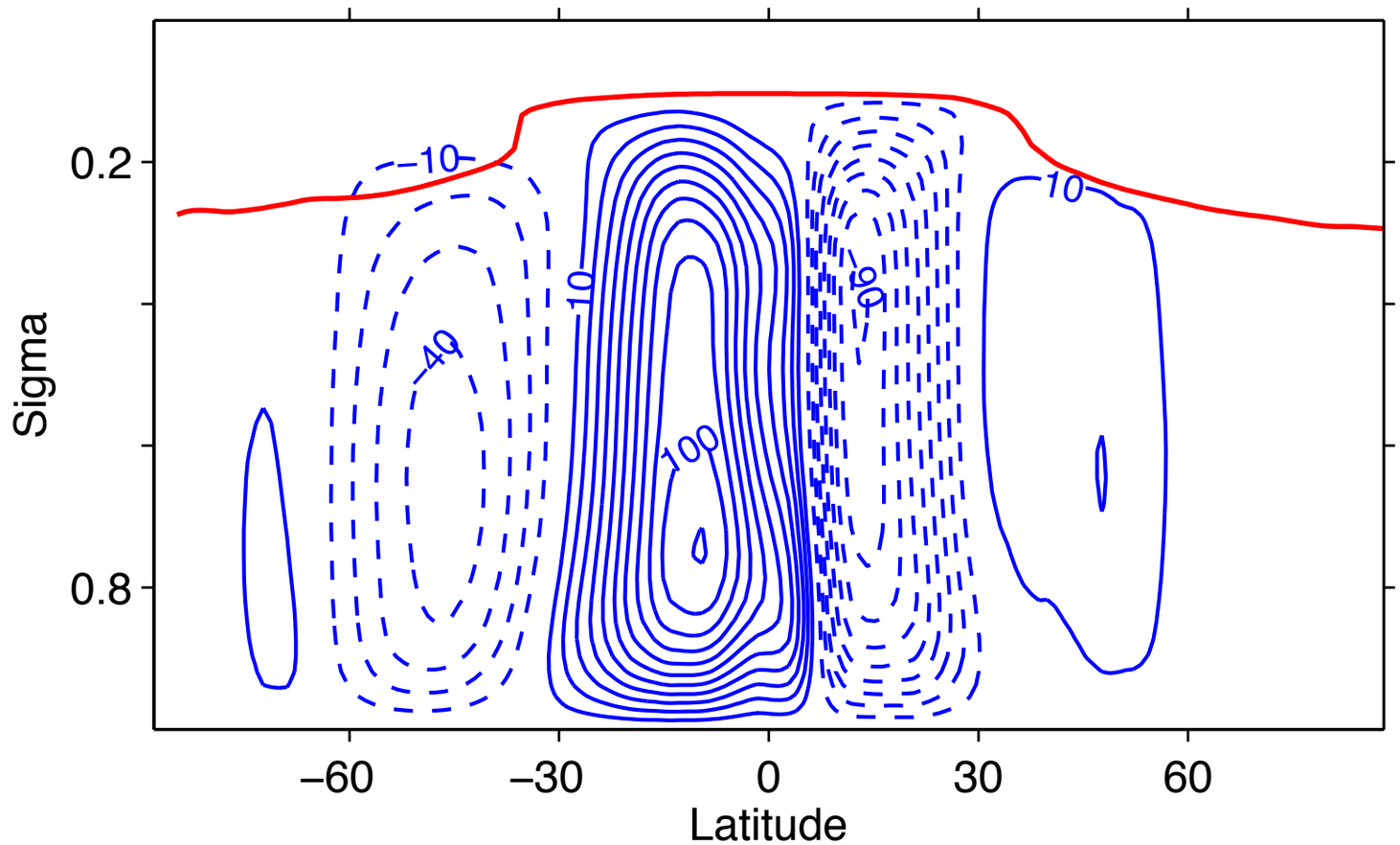
Dry-isentropic mean meridional streamfunction (10^{10} kg s^{-1})



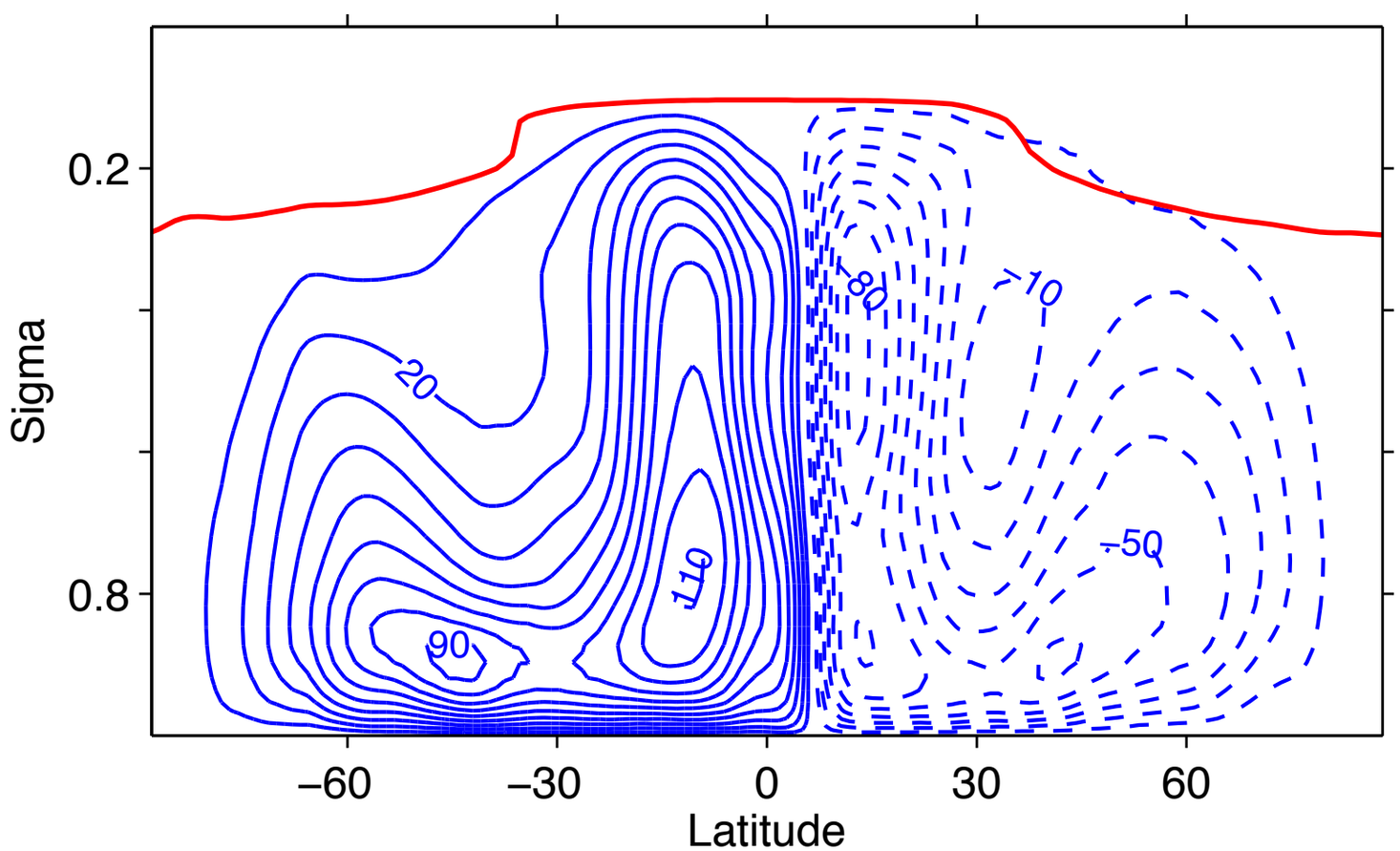
Red: Tropopause
Magenta: 10, 50, 90 percentiles of surface potential temperature distribution

(ERA40 reanalysis 1980-2001)

Fig. 10



Eulerian-mean (i.e. calculated in sigma coordinates) circulation (10^9 kg s^{-1})



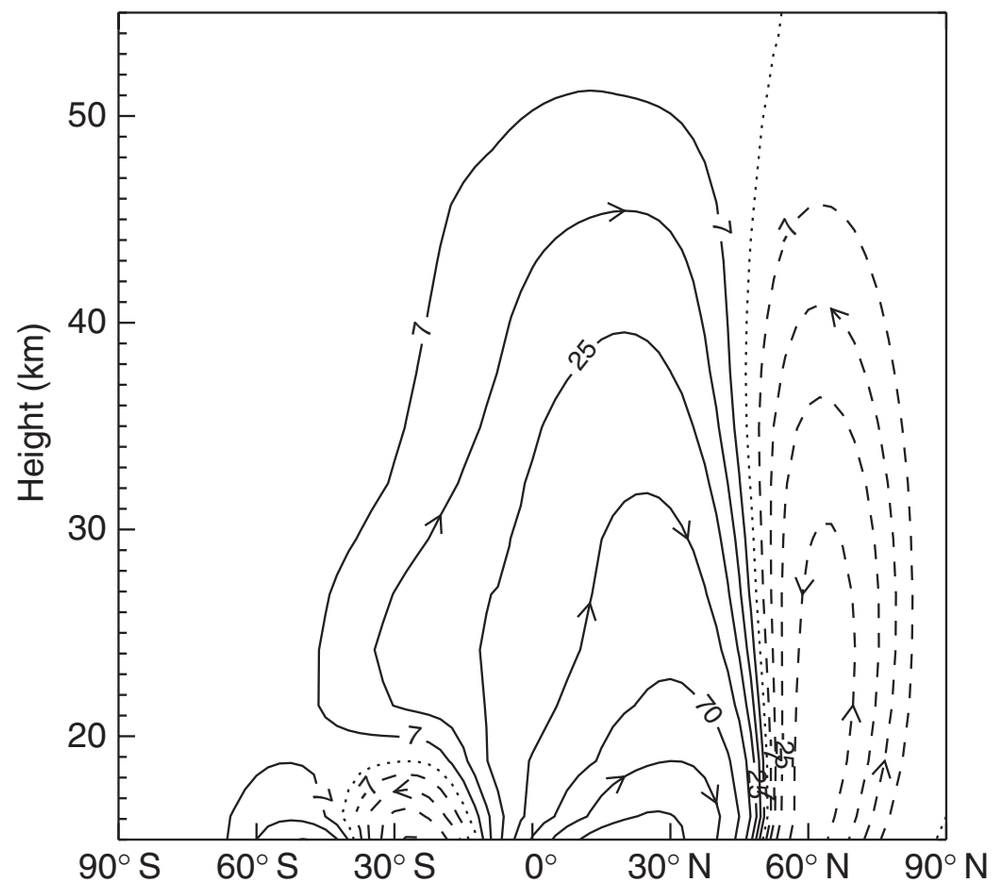
Dry isentropic circulation interpolated to sigma coordinates (10^9 kg s^{-1})

Fig. 11

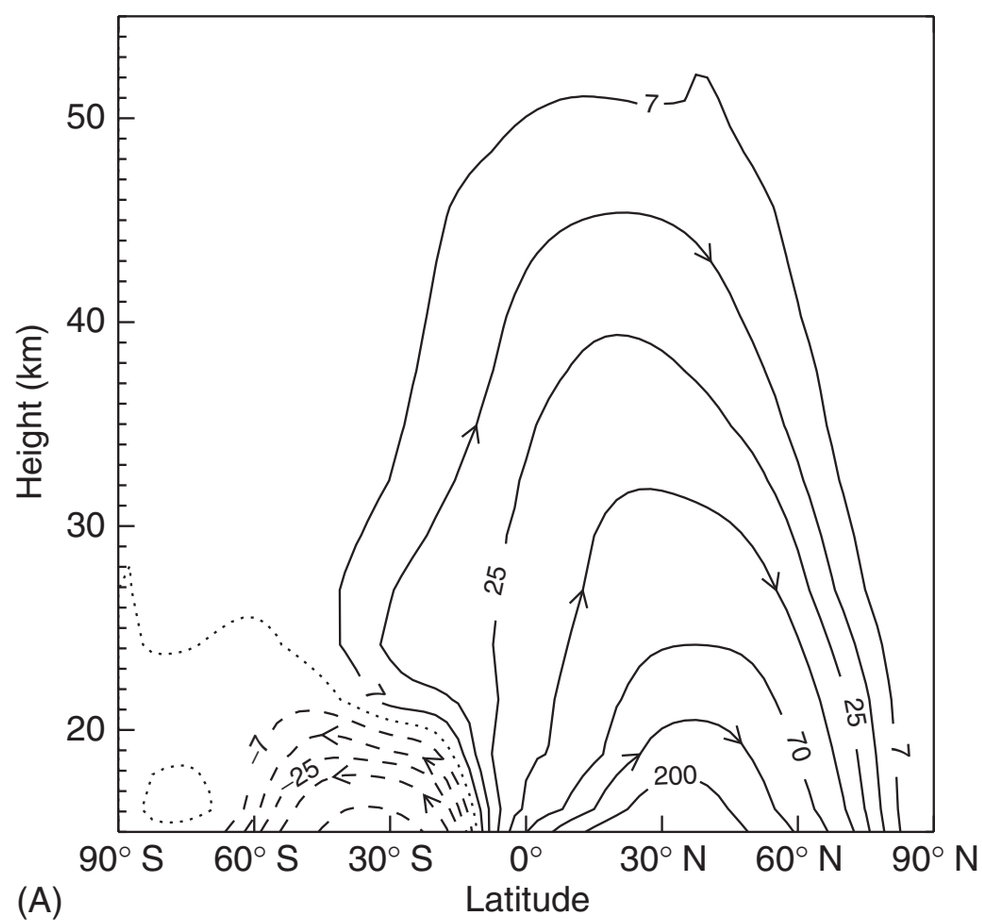
(ERA40 1980-2001)

January circulation in the stratosphere

Streamfunction units are kg/m/s



Eulerian mean circulation



Residual circulation (roughly the same as the circulation in isentropic coordinates)

Fig. 12

W. Norton

Relevance of isentropic circulation: Zonal-mean methane concentration

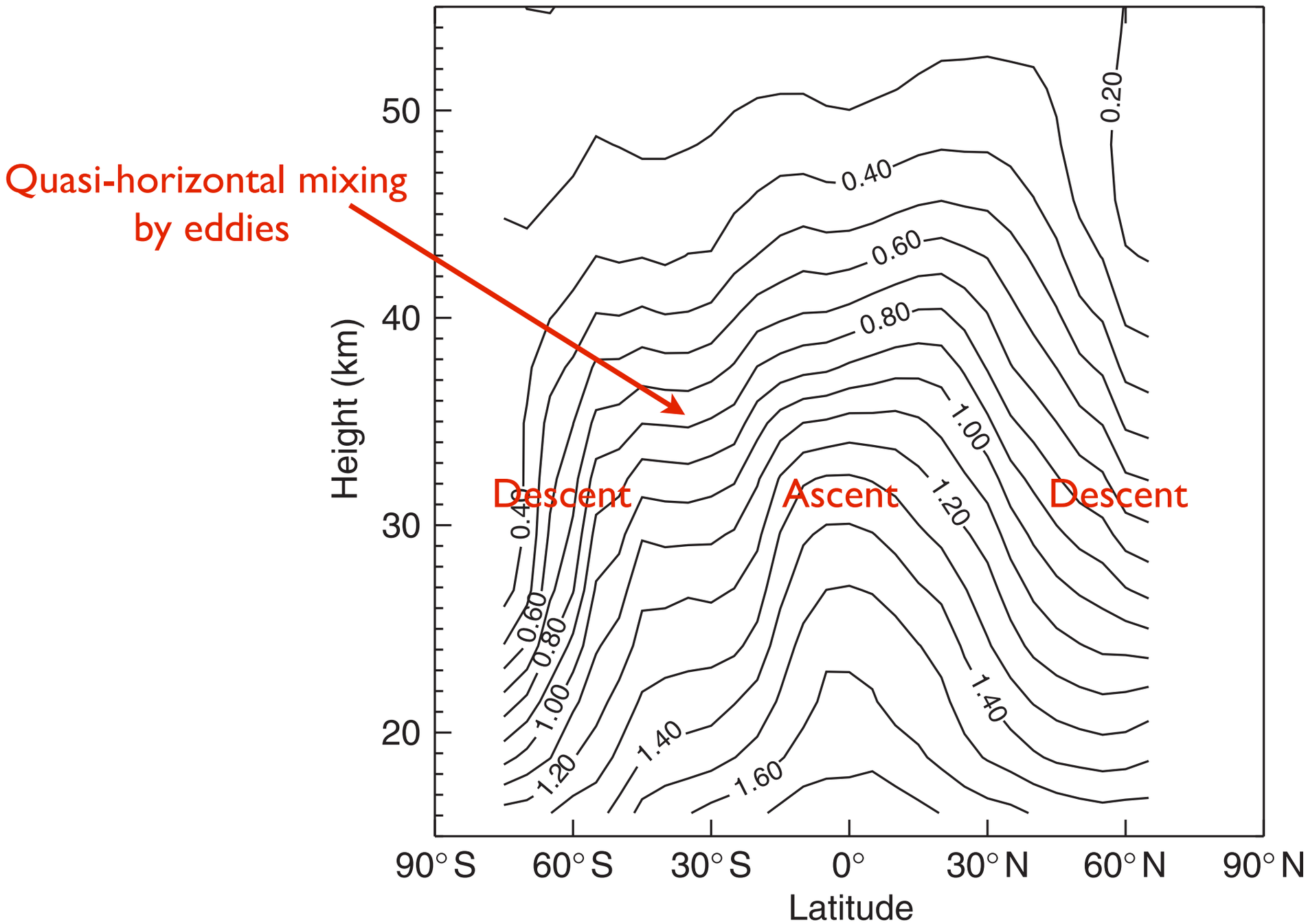


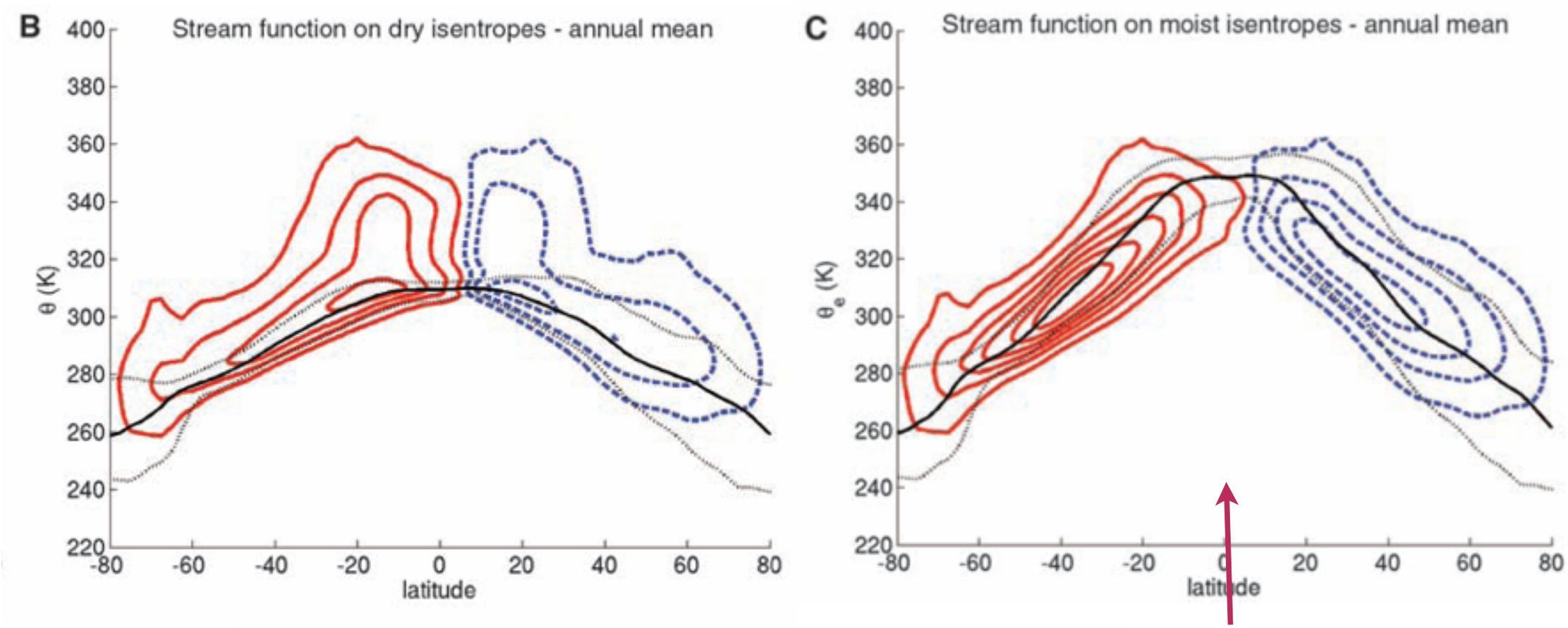
Figure 5 Zonally averaged mixing ratio of methane for October (1993–1999) as measured by Halogen Occultation Experiment (HALOE) on the UARS. Contour interval is 0.2 ppmv.

Fig. 13

W. Norton

Mean meridional circulation on dry and moist isentropes:

averaging on θ_e surfaces (moist isentropes) gives simplest circulation



Moist isentropes give very simple circulation

(Pauluis et al, Science, 2008)

Fig. 1. The global mean circulation from the NCEP-NCAR Reanalysis. (**A**) Stream function on pressure surfaces Ψ_p. (**B**) Same as (A) for the stream function on dry isentropes Ψ_θ. (**C**) Same as (A) for the stream function on moist isentropes Ψ_{θ_e}. Contour interval is 2.5×10^{10} kg s^{-1}. Solid contours are positive values of the stream function and correspond to northward flow at low levels, whereas dashed contours are negative values of the stream function and correspond to southward flow at low levels. In (B) and (C), the thin solid line and two dotted black lines show the 50, 10, and 90 percentiles, respectively, of the surface potential or surface equivalent potential temperature distributions.

Fig. 14