Zonal and Meridional Winds

This is modified from UCLA Lecture notes, see here.
Zonal flow (or zonal wind) is air circulation parallel to the equator and latitudes, i.e., east-to-west or west-to-east. This type of circulation promotes stable temperatures along latitudes. Conversely, north-to-south or south-to-north air flow is termed meridional flow. The terms are used to mean regular winds (prevailing winds) in such direction, such as the Earth's trade winds and westerlies and are also used to mean the east-west component of any given wind.

Winds blowing from the west are called westerlies, Winds blowing from the east are called easterlies.
At the Earth’s surface, winds are primarily from the west in mid-latitudes and from the east in low and high latitudes.

In the diagram westerlies are positive speeds and easterlies are negative.
Zonal Mean wind velocity by altitude and latitude, see also here for another view.
Schematic showing outstanding features of the zonally averaged zonal wind distribution by altitude.

- **SUMMER JET** (~50 m/s)
- **POLAR-NIGHT JET** (~80 - 100 m/s)
- **SUBTROPICAL JET** (~35 m/s)
Annual-average atmospheric mass circulation in the latitude pressure plane (meridional plane). The arrows depict the direction of air movement in the meridional plane. The contour interval is $2 \times 10^{10}$ Kg/sec this is the amount of mass that is circulating between every two contours. The total amount of mass circulating around each "cell" is given by the largest value in that cell. Data based on the NCEP-NCAR reanalysis project 1958-1998.
The Hadley Cells

DJF and JJA meridional overturning circulation. Units are $10^{10}$ kg s$^{-1}$
Ocean heat transport

Dynamical cooling by advection

Dynamical warming by subsidence

Radiation solar down infrared up

Latent heating in convective rain

Evaporation

Heat transport by transients

Moisture transport

Moisture transport

Hadley circulation and heat budget in subtropics

Warm

Ocean heat transport
Three-Cell Circulation Model
The cells tops are around the tropopause

NORTH-SOUTH VERTICAL SECTION THROUGH TROPOSPHERE
We wish to examine in detail climatological transport in the meridional direction in a zonal-mean sense. Transport is the product of two quantities, the meridional wind and the variable being transported.

We might naively think that we could calculate it by simply multiplying zonal-mean, time-mean wind by zonal-mean, time-mean of the variable being transported. However, to calculate it accurately, it turns out we must consider the fact that wind and the transported variable may be correlated along a latitude circle in the time-mean and may also be correlated in time. In other words, we must consider the role of transient and stationary eddies.
Stationary and Transient Eddies

**Stationary eddies** are characterized by persistent zonal asymmetries in atmospheric variables. These zonal asymmetries average to zero along a latitude band (by definition), and so are completely absent from zonal mean climatologies. They generally arise from zonal asymmetries in the land/sea configuration, and therefore play a larger role in the climate of the Northern Hemisphere.

**Transient eddies** are characterized by departures from the time mean flow at a particular location. They are also absent from climatologies (by definition), and so are absent from zonal-mean characterizations of the atmosphere. Transient eddies play a larger role in the climate of the Southern Hemisphere.
An example of the impact of an eddy on mean transport

Fig. 6.6  Schematic of the streamlines (solid) and isotherms (dashed) associated with a large-scale atmospheric disturbance in midlatitudes of the Northern Hemisphere. Arrows along the streamline contour indicate the direction of wind velocity. The streamlines correspond approximately to lines of constant pressure, since the winds are nearly geostrophic. The signs of the deviations of the wind components from their zonal-average values are shown to illustrate that the NE–SW tilt of the streamlines indicates a northward zonal momentum transport, and the westward phase shift of the temperature wave relative to the pressure wave gives a northward heat transport.
Fig. 6.8  Meridional cross section of the zonally averaged northward flux of temperature by eddies. Note that in the Southern Hemisphere the poleward fluxes are negative as a result of our arbitrarily defining north as the positive direction. Contour interval is 5 K m s$^{-1}$. [Data from Oort (1983).]
mean meridional circulation transient and stationary eddies

Fig. 6.9 Northward fluxes of potential energy ($F_{PE}$), sensible heat ($F_{SH}$), latent heat ($F_{LH}$), and total energy by the atmosphere as functions of latitude and season. Panels on the left show fluxes by the mean meridional circulation and those on the right by eddy circulations. Units are $10^{19}$ calories per day and southward fluxes are shaded. [From Oort (1971). Reprinted with permission from the American Meteorological Society.]
Fig. 6.11  Annual average northward energy flux plotted versus latitude in the Northern Hemisphere. Units are $10^{15}$ W. Mean meridional circulation (MMC). [Data from Oort (1971). Reprinted with permission from the American Meteorological Society.]
The atmospheric circulation averaged over all longitudes and presented as a latitude-height cross-section. Zonal flows are shown with the colors.

If we calculate the speed of the zonal flow in the subtropical jet stream based on conservation of angular momentum of a parcel at rest at the equator which rises and makes its way poleward in the Hadley Cell, we find it is about 4 times larger than observed.

The excess angular momentum changes Earth’s rotational speed and its length of day (LOD).
Flow of Angular Momentum to the Atmosphere and back to solid Earth

**Fig. 6.16** Schematic illustration of the flow of angular momentum from Earth through the atmosphere and back to Earth.