

# Climate Dynamics (PCC 587): Atmospheric General Circulation



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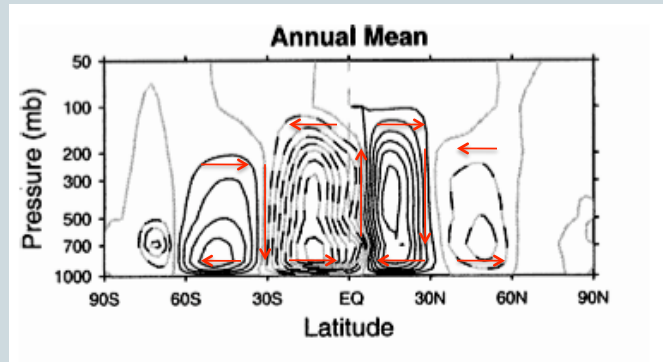
## Definitions...



- *Zonal* winds: winds around latitude circles
  - Easterlies, westerlies...
- *Meridional* winds: North/South winds

## Mean Meridional Circulation

- Streamlines of overturning circulation:

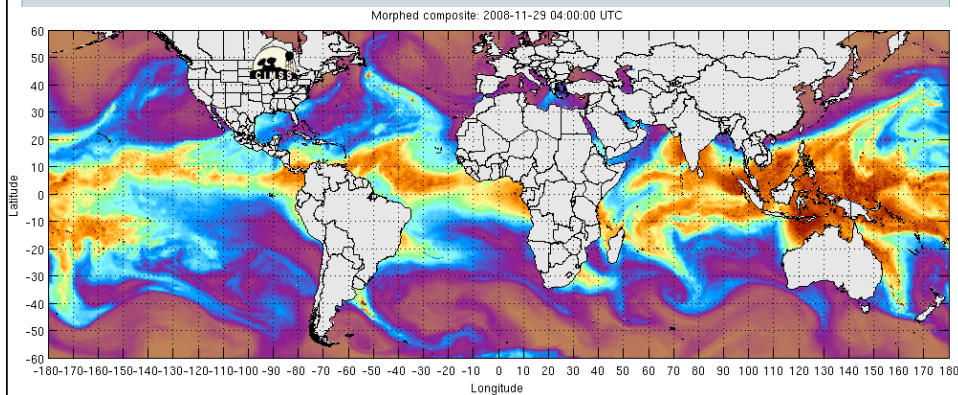


Tropical *Hadley* cells  
 Midlatitude *Ferrel* cells

Dima and Wallace (2003)

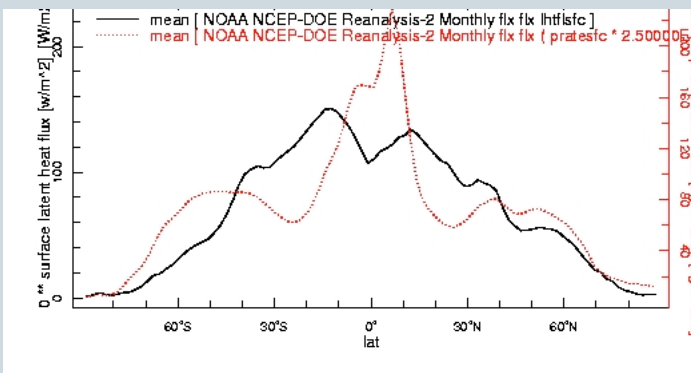
## Eddies Dominate in Extratropics...

- Indirect Ferrel cell is somewhat artificial
  - Not indicative of parcel trajectories



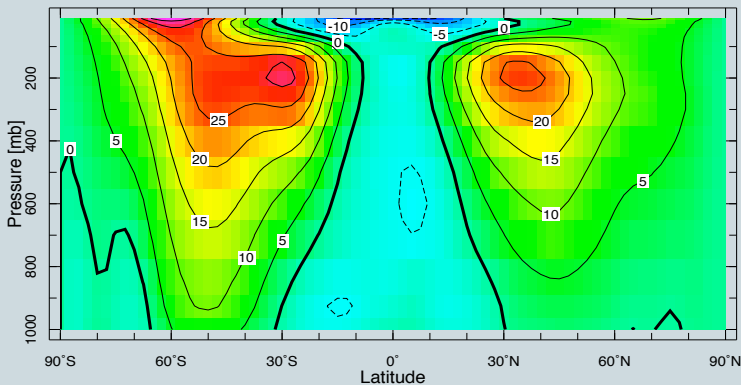
### Precipitation and Evaporation

- Precipitation (red) and evaporation (black):



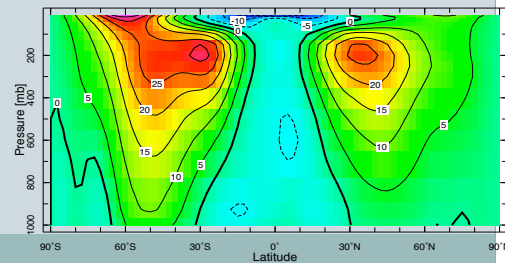
### Zonal Winds

- Average zonal winds:



## Zonal Winds

- Zonal winds are usefully separated into two parts:
  - Surface winds
    - ✦ Easterly in tropics
    - ✦ Westerly in midlatitudes
  - Variation of winds with height (shear)
    - ✦ Winds get more westerly with height everywhere in troposphere

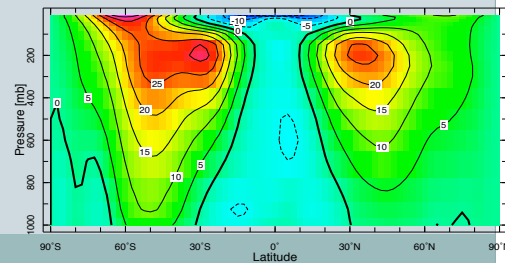


## “Thermal Wind” Explains Variation with Height

- “Thermal wind”:
  - Geostrophic balance + hydrostatic balance
- Westerly shear when temperatures decrease poleward
  - Schematic on board...

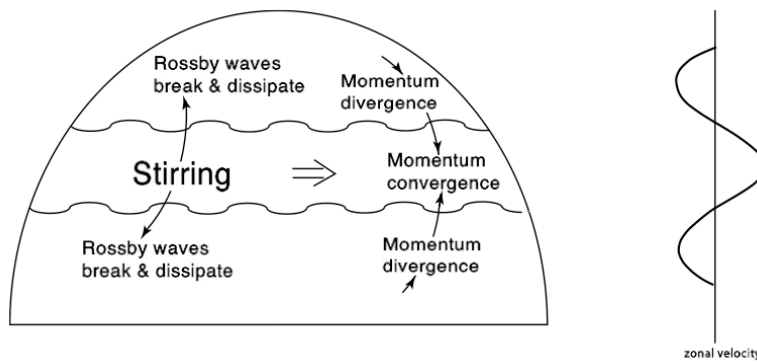
## Surface Winds

- Friction at the surface constantly decelerates surface winds
  - Westerly momentum is constantly pumped into midlatitudes
  - And is taken out of tropics



## Momentum Fluxes Explain Surface Winds

- Eddies in midlatitude converge momentum into their source region
  - Rossby waves are key to this

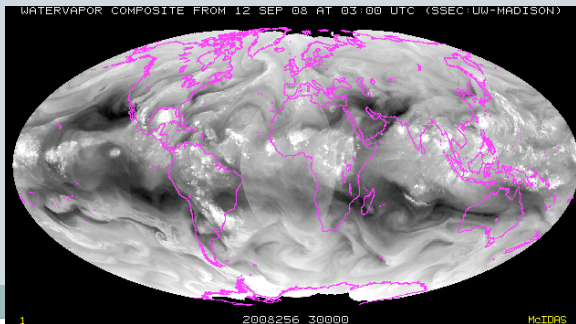


## Ferrel Cell Derivation

- Eddy momentum flux convergence → indirect circulation
  - On board...

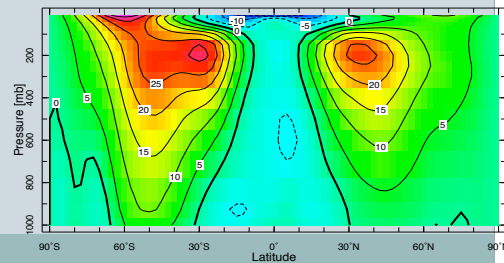
## Baroclinic Instability

- Baroclinic instability causes weather patterns in midlatitudes
  - Driven by temperature gradients
  - Scale ~ 1000 km
  - Growth rate ~ couple days



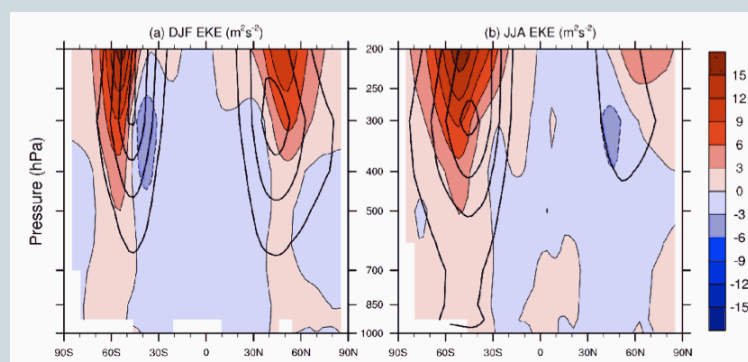
## Changes with Global Warming

- **Poleward shift** of jet streams and Hadley cell boundaries is predicted in model simulations
  - Dry zones in subtropics expand
  - Surface winds, midlatitude storm tracks shift poleward
- **Already happening, esp. in Southern Hemisphere**
  - May be mostly caused by ozone depletion in S. Hem. though



## Poleward Shift of Eddies

- From Yin 2005 (black contours are current mean, colors are predicted change):



- **Poleward (and upward) shift**