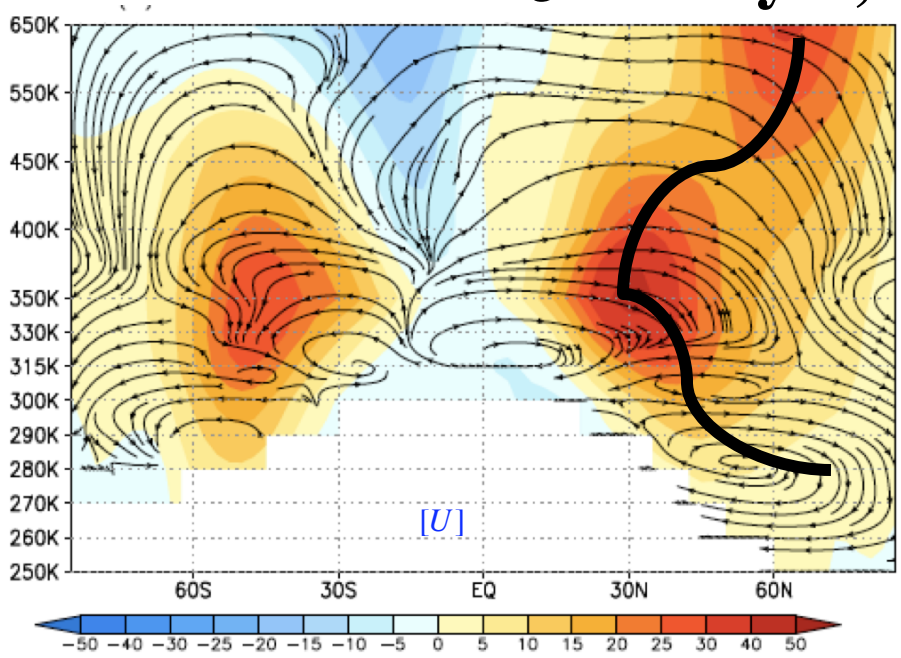
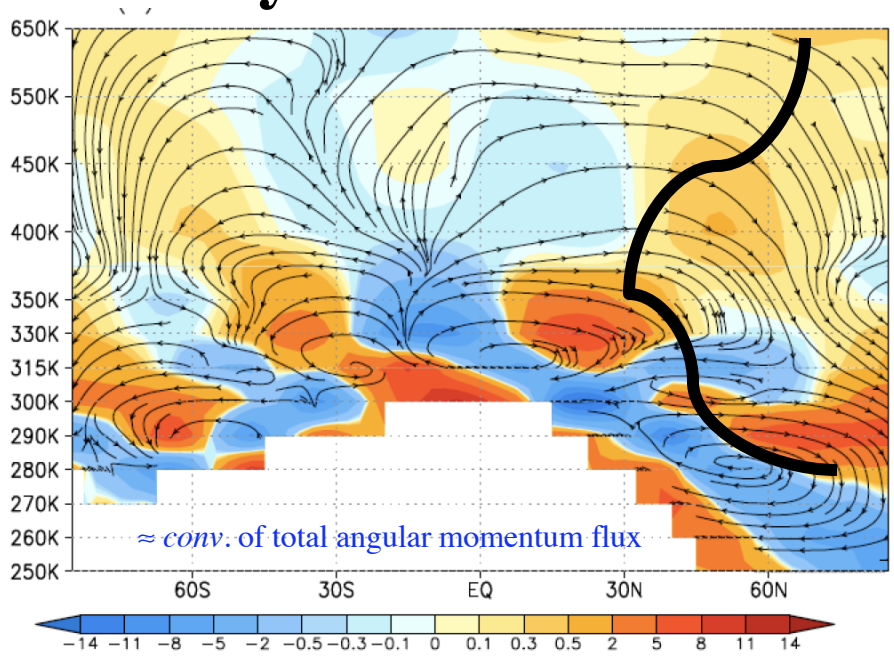
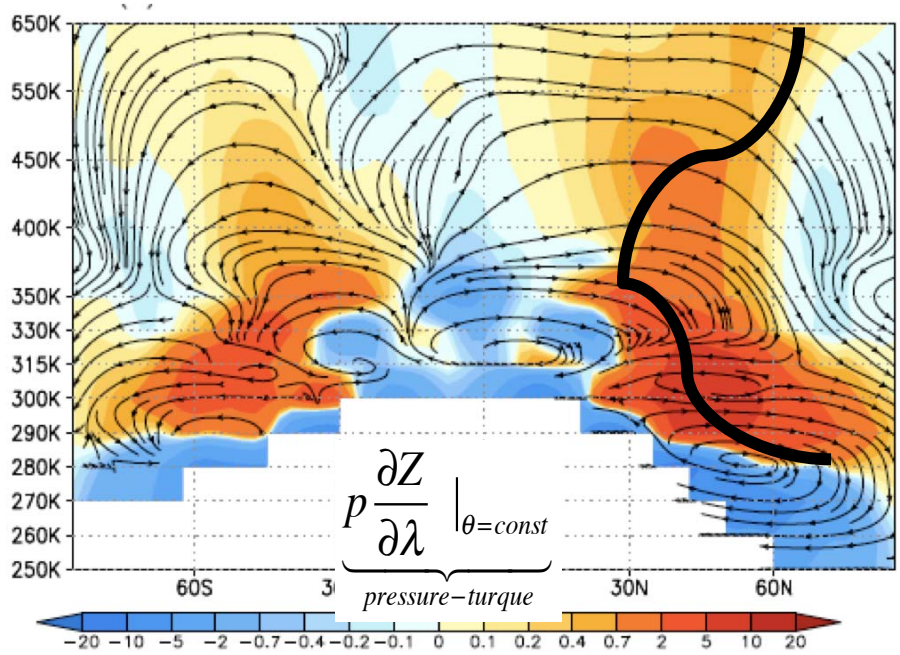
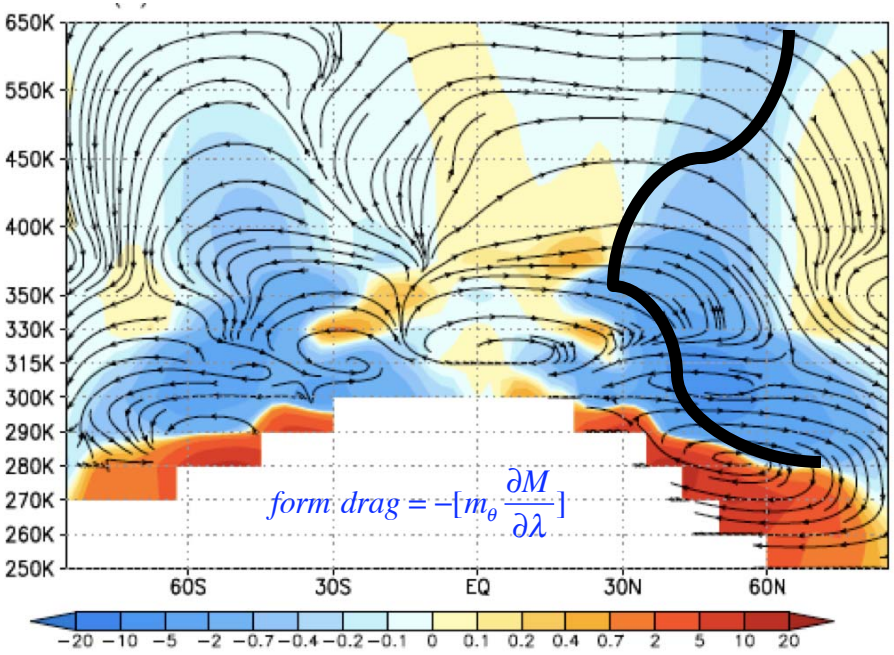
January 7, Annual Cycle

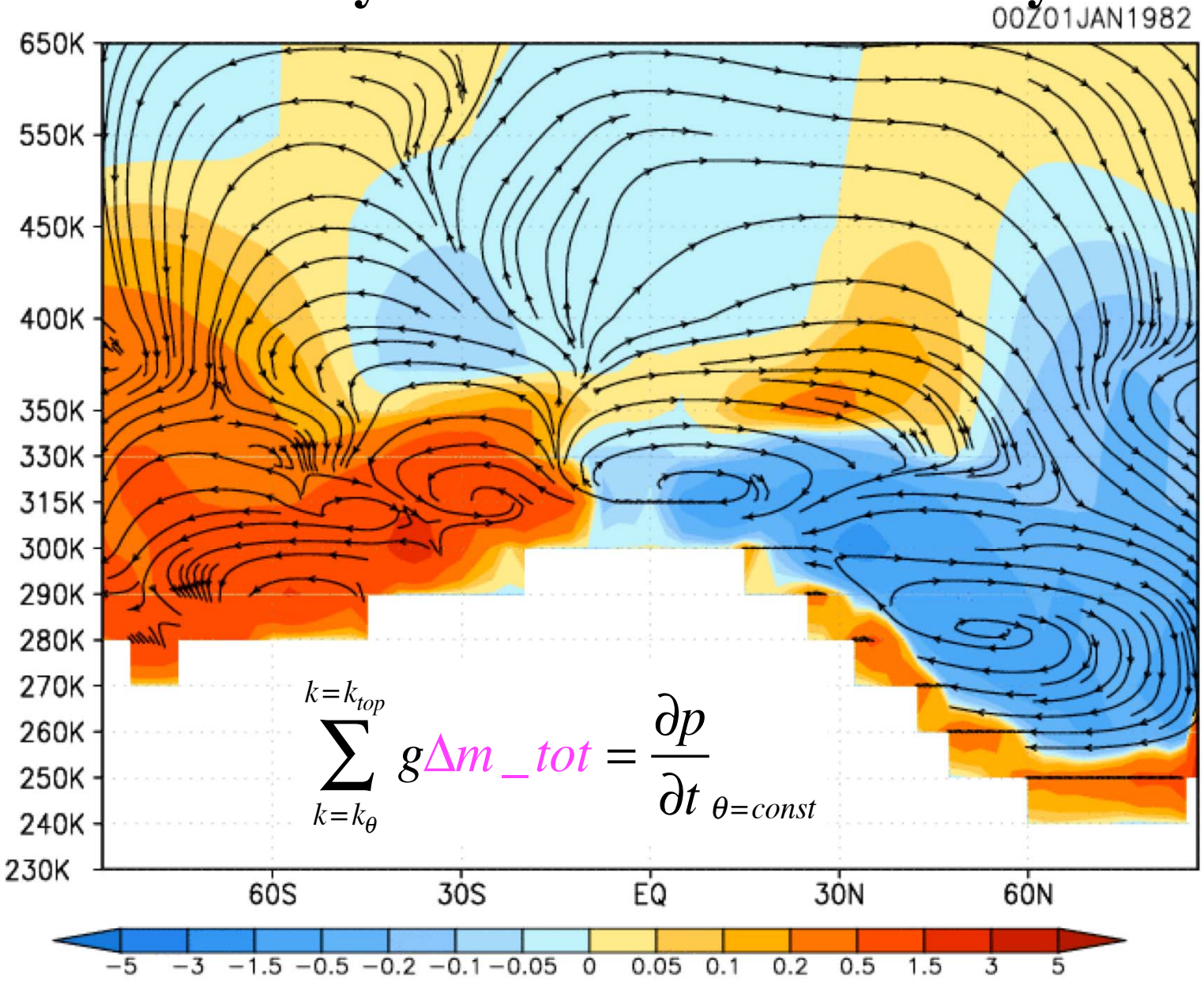




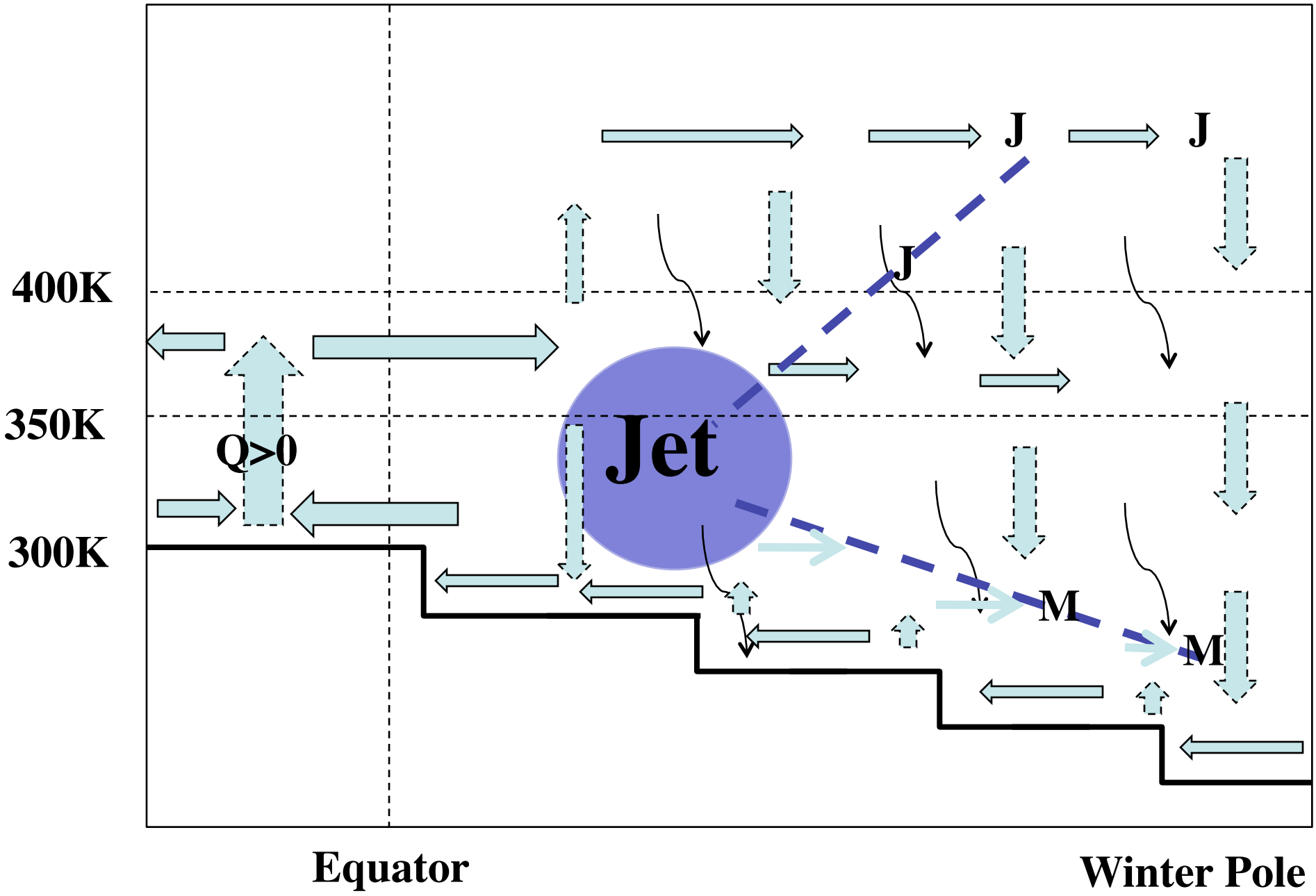




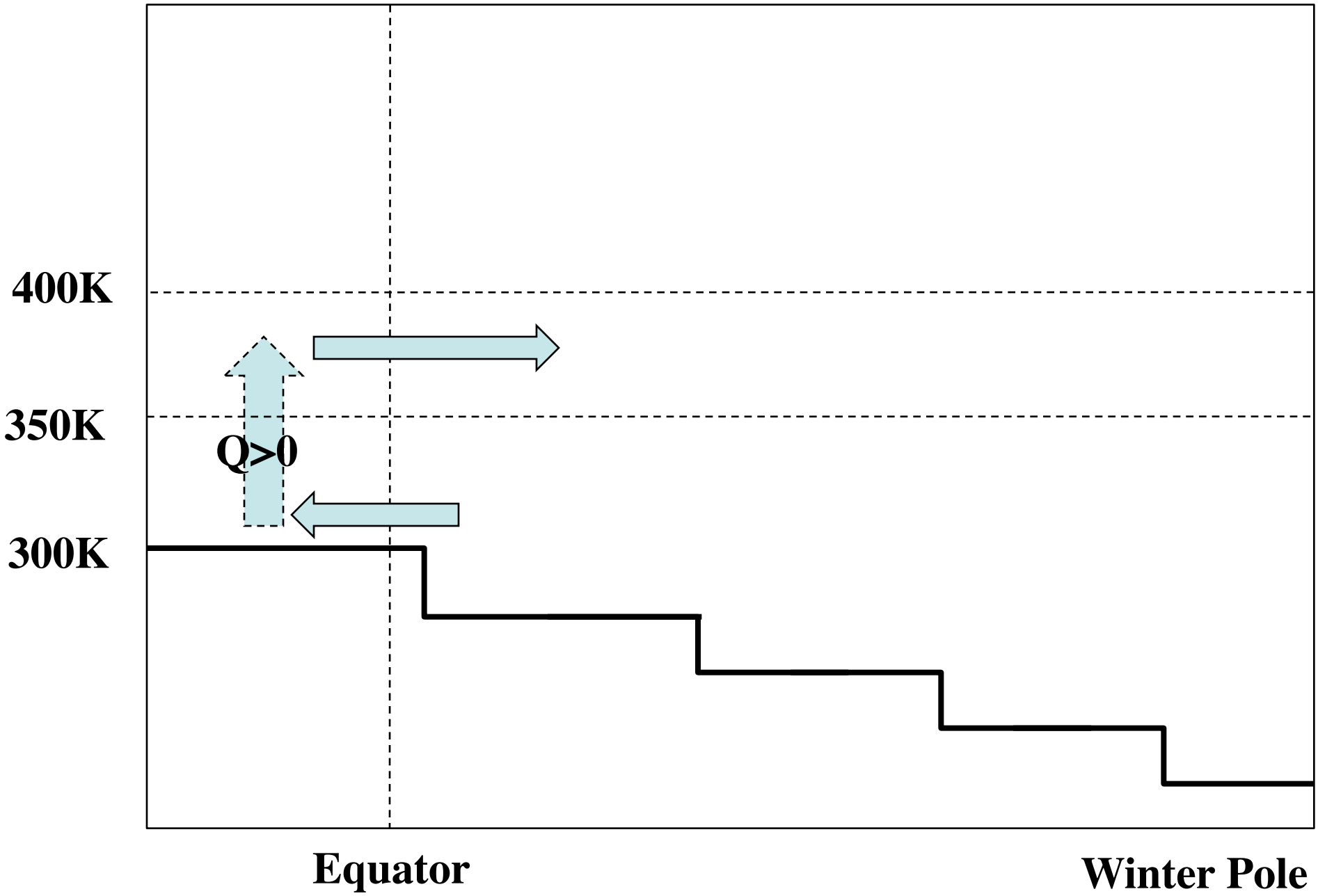
Vertically cumulative mass tendency

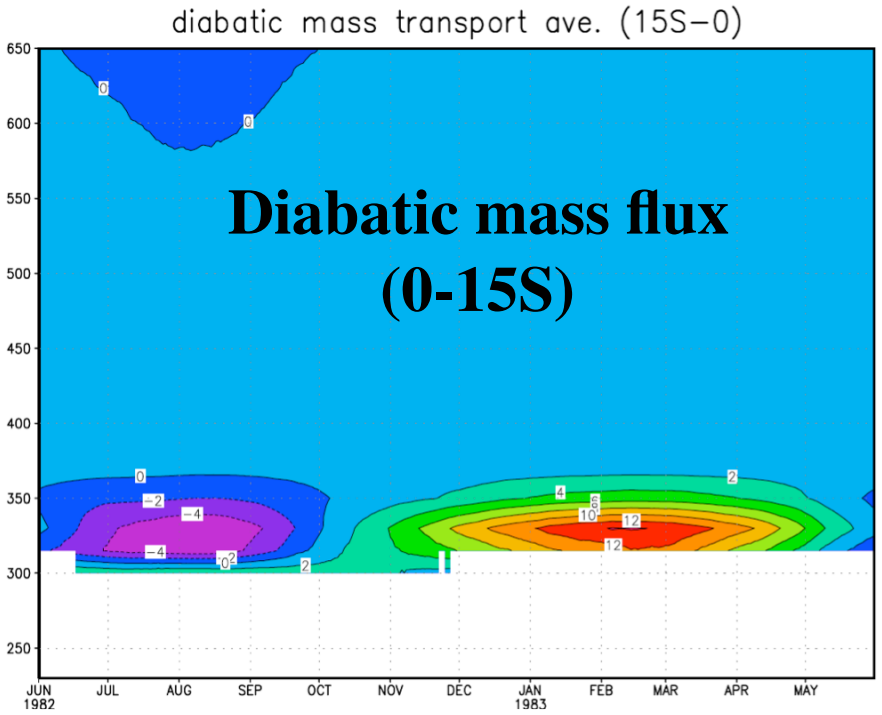


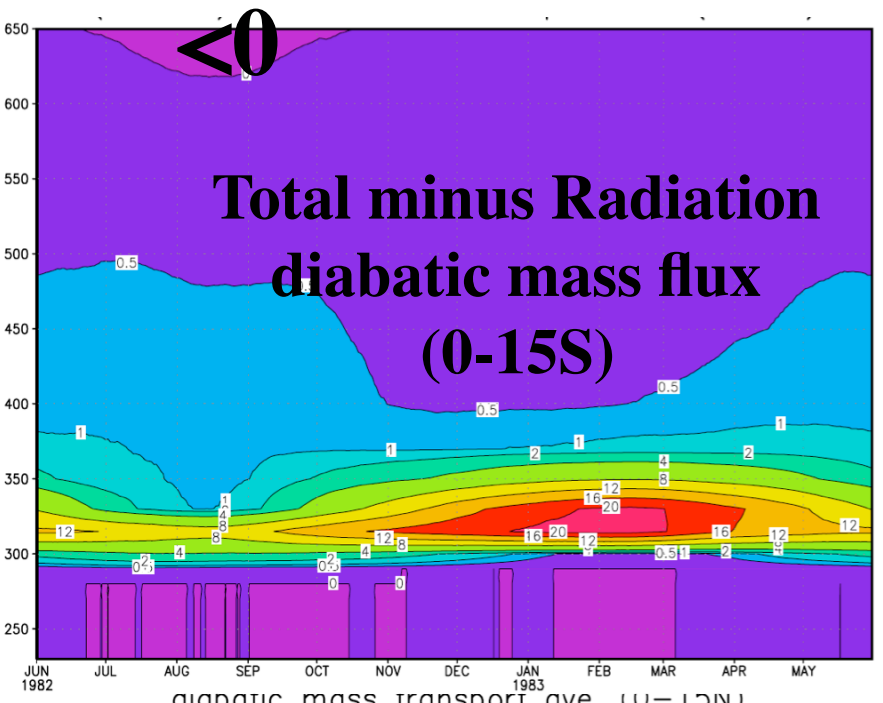
Atmospheric (Meridional) Conveyor Belt

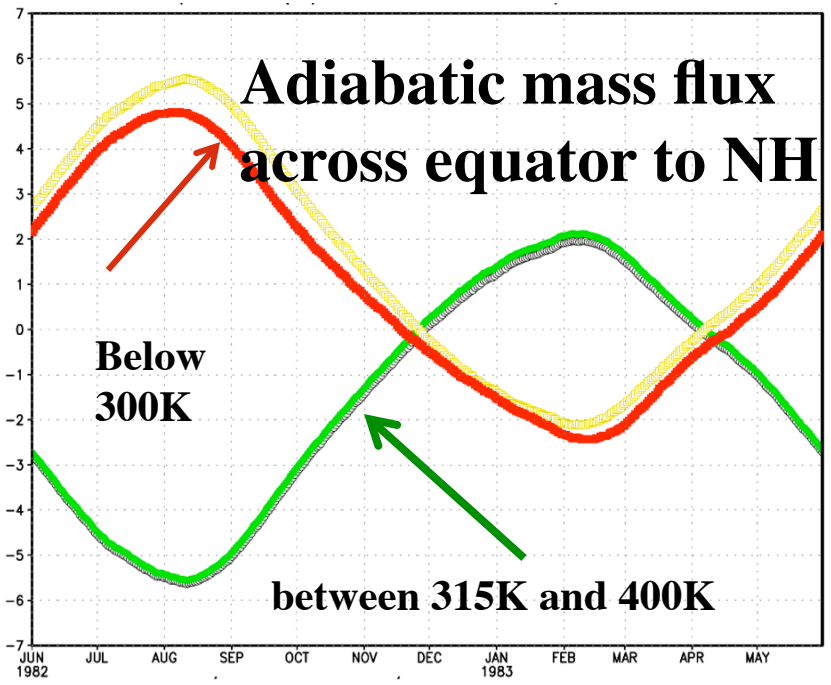


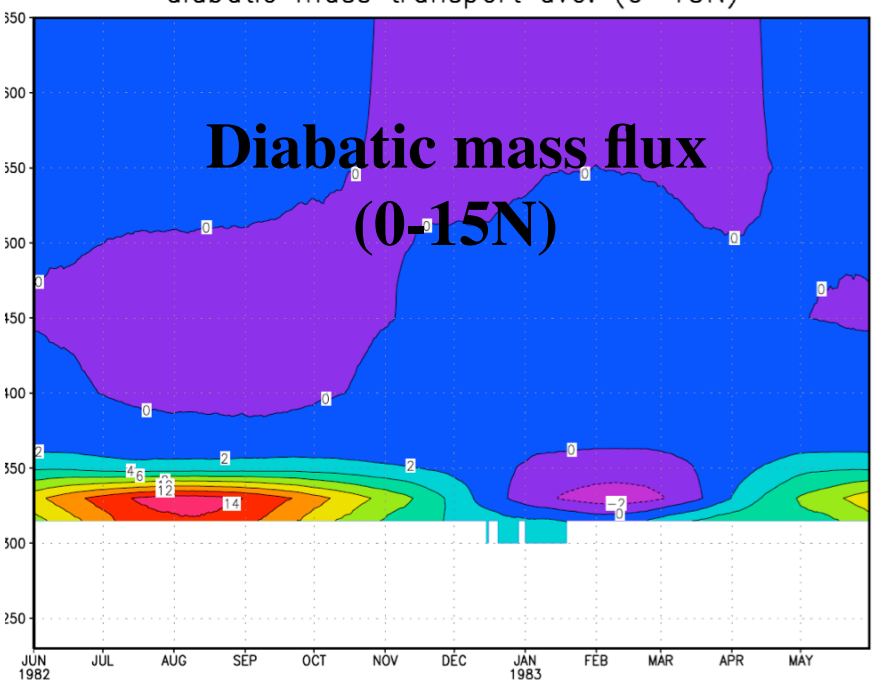
Atmospheric (Meridional) Conveyor Belt



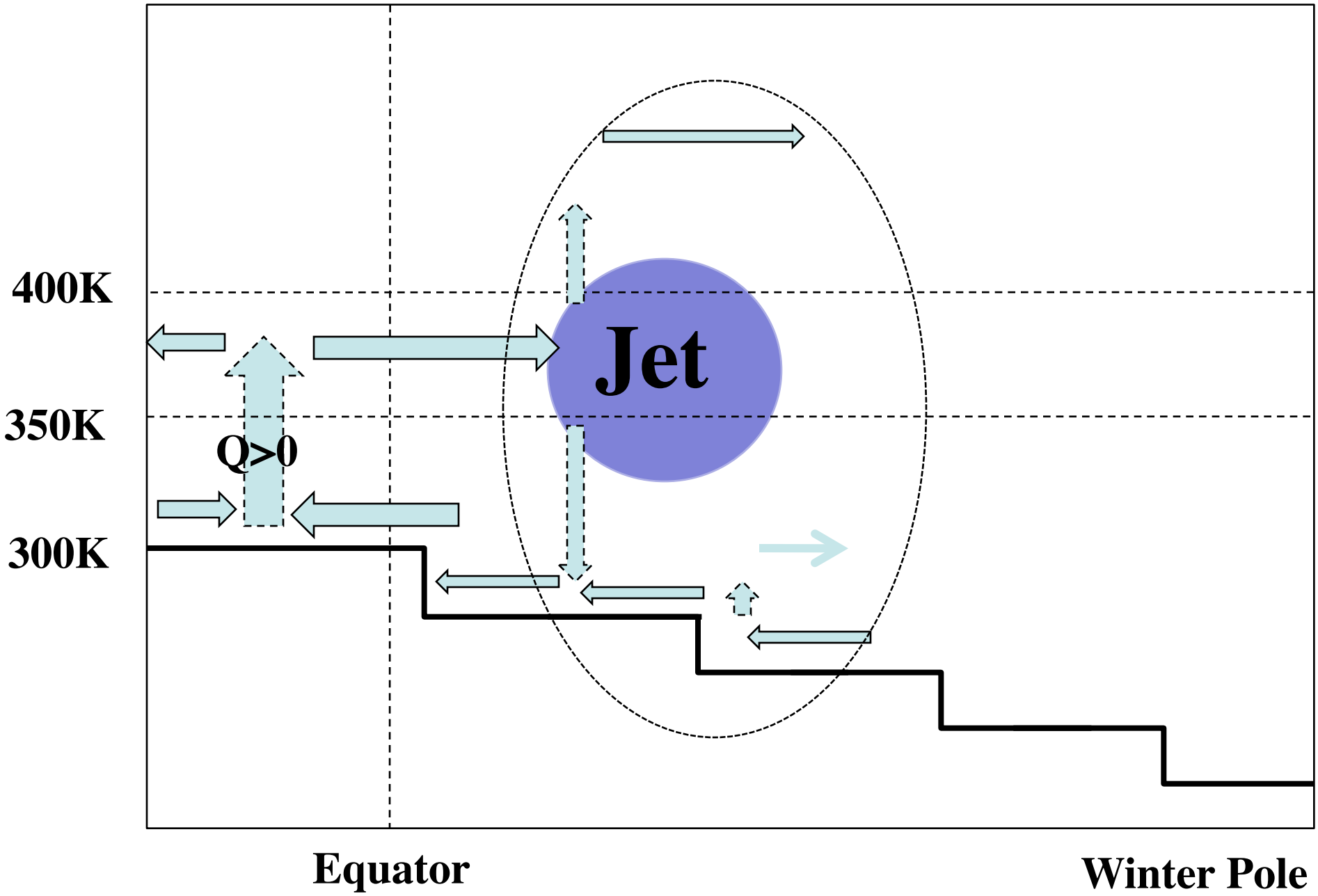

diabatic mass transport ave. (15S–0)
Diabatic mass flux
(0-15S)

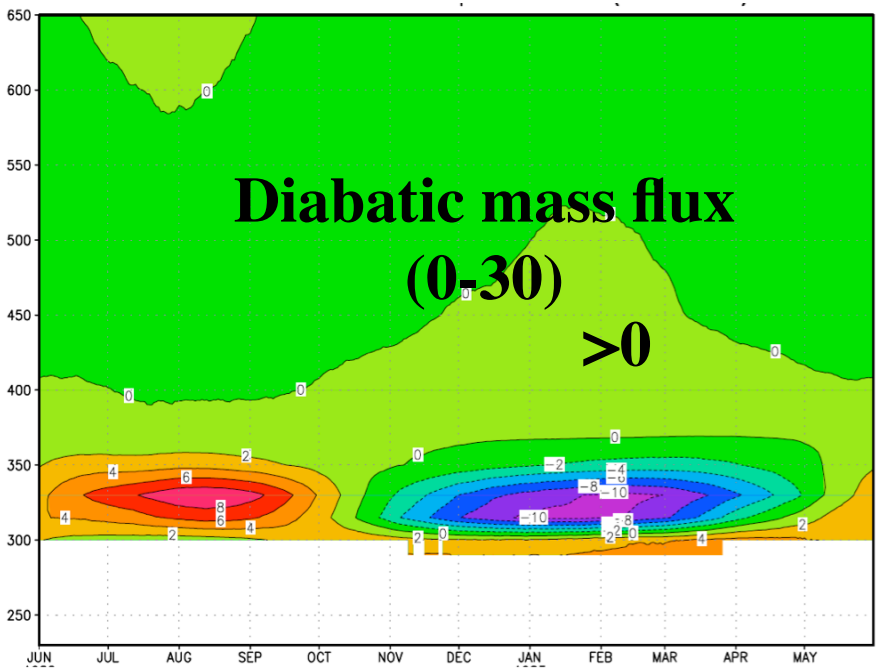

<0
Total minus Radiation
diabatic mass flux
(0-15S)

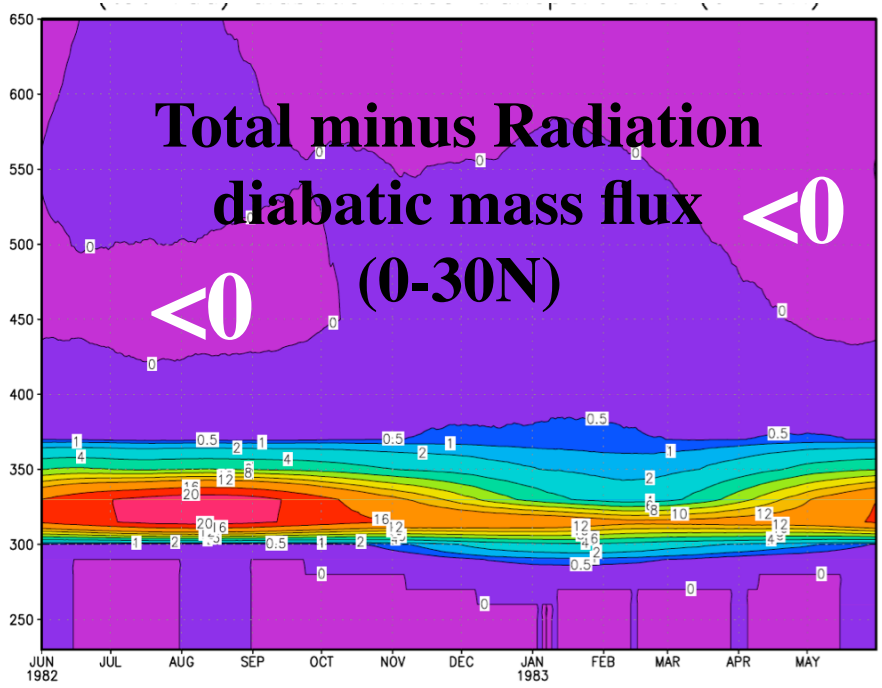

Adiabatic mass flux
across equator to NH
Below
300K
between 315K and 400K

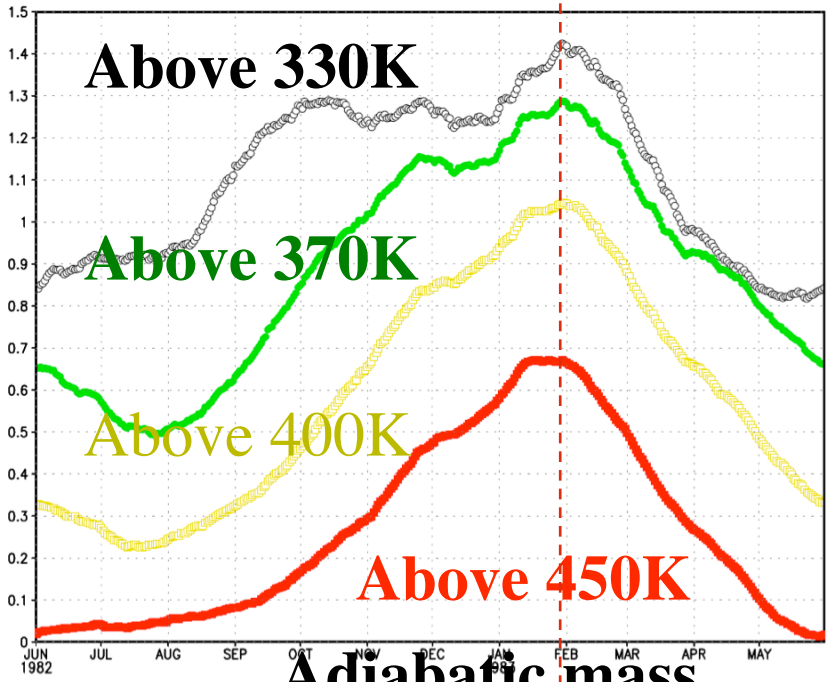

Diabatic mass flux
(0-15N)

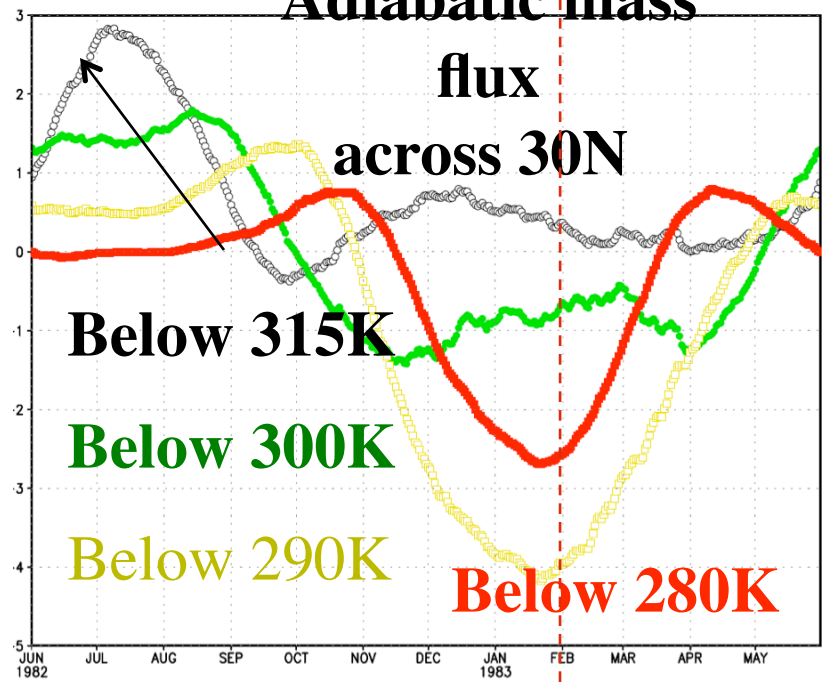
Atmospheric (Meridional) Conveyor Belt



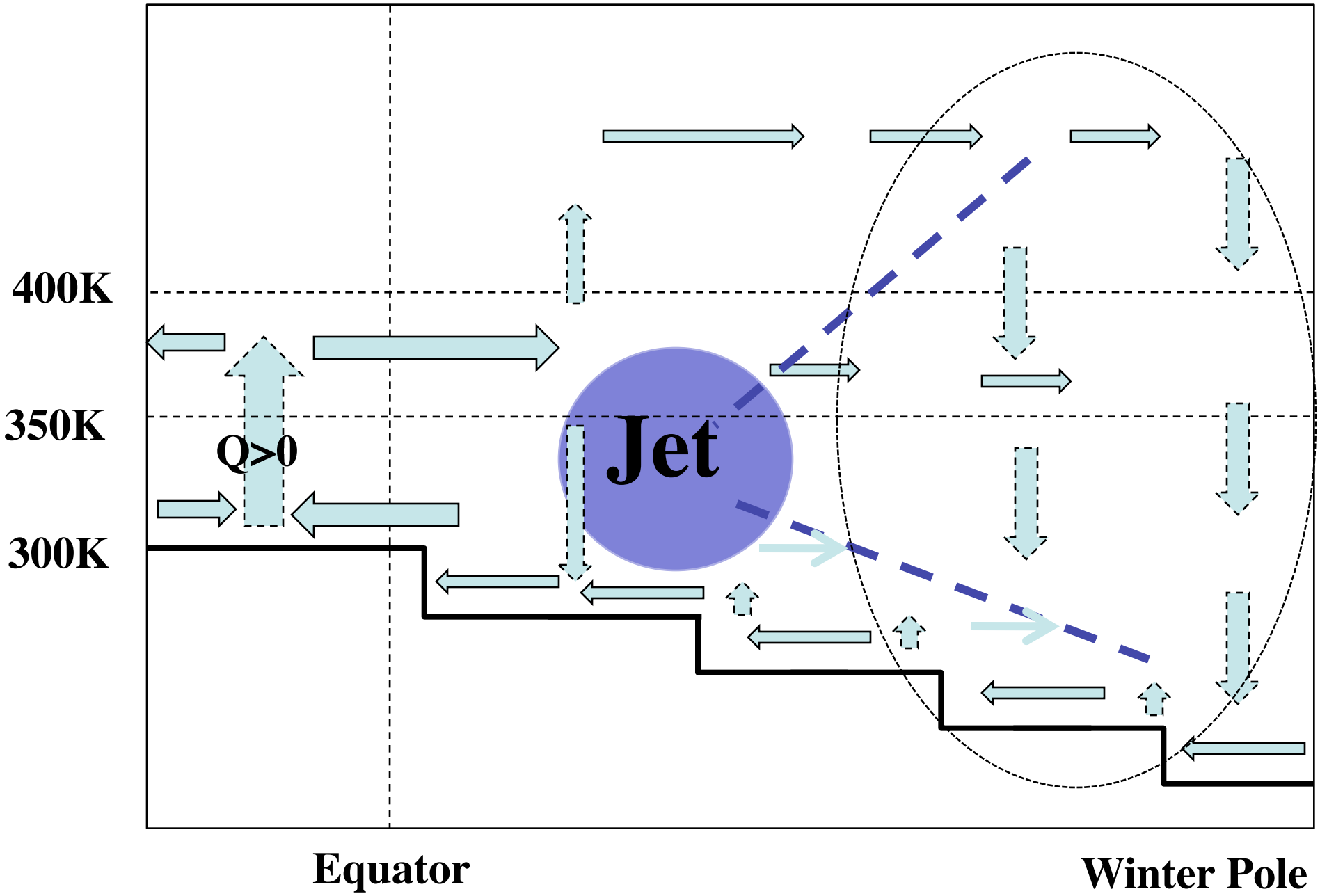

Diabatic mass flux
(0-30)
>0
650
600
550
500
450
400
350
300
250
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY

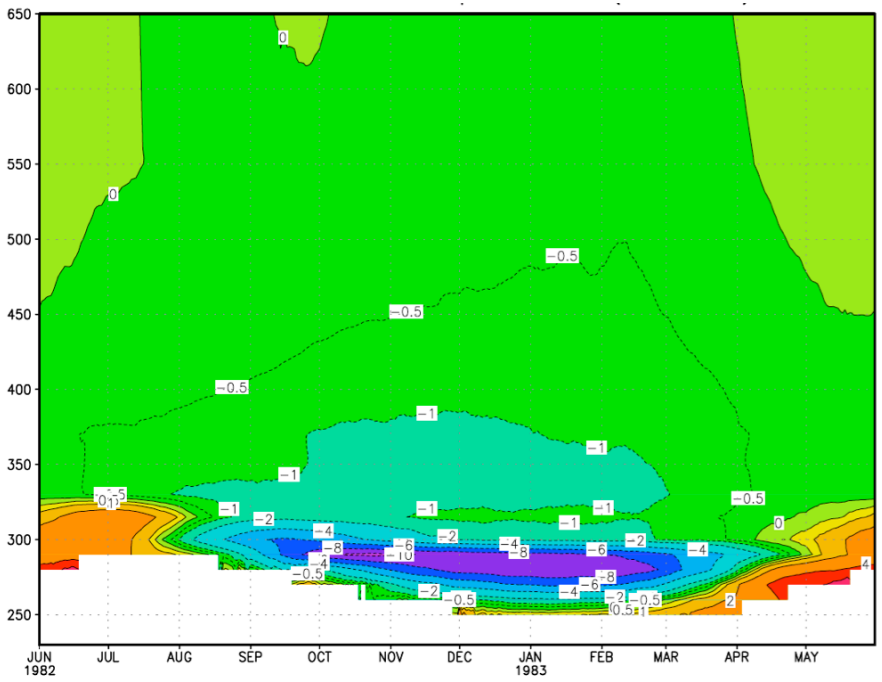

Total minus Radiation
diabatic mass flux
(0-30N)
<0
<0
650
600
550
500
450
400
350
300
250
JUN
1982
JUL
AUG
SEP
OCT
NOV
DEC
JAN
1983
FEB
MAR
APR
MAY

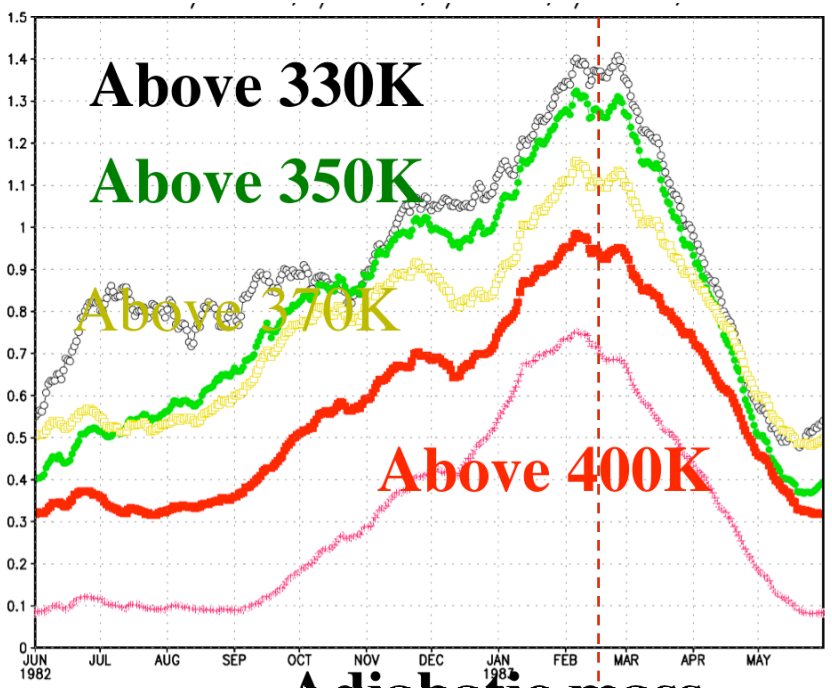

Above 330K
Above 370K
Above 400K
Above 450K
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
JUN
1982
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY

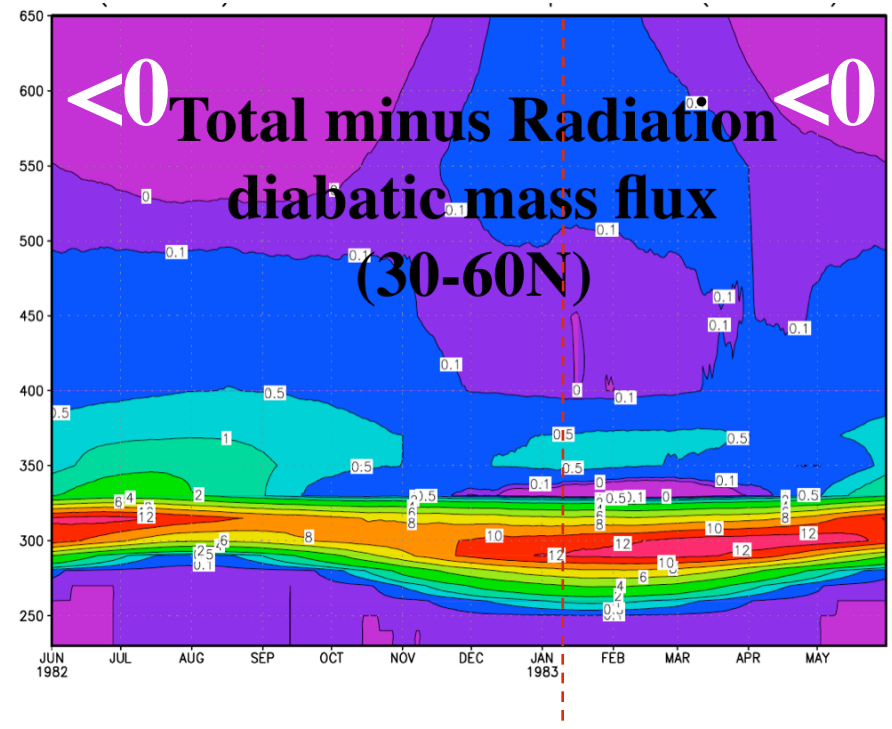

Adiabatic mass
flux
across 30N
Below 315K
Below 300K
Below 290K
Below 280K
3
2
1
0
-1
-2
-3
-4
-5
JUN
1982
JUL
AUG
SEP
OCT
NOV
DEC
JAN
1983
FEB
MAR
APR
MAY

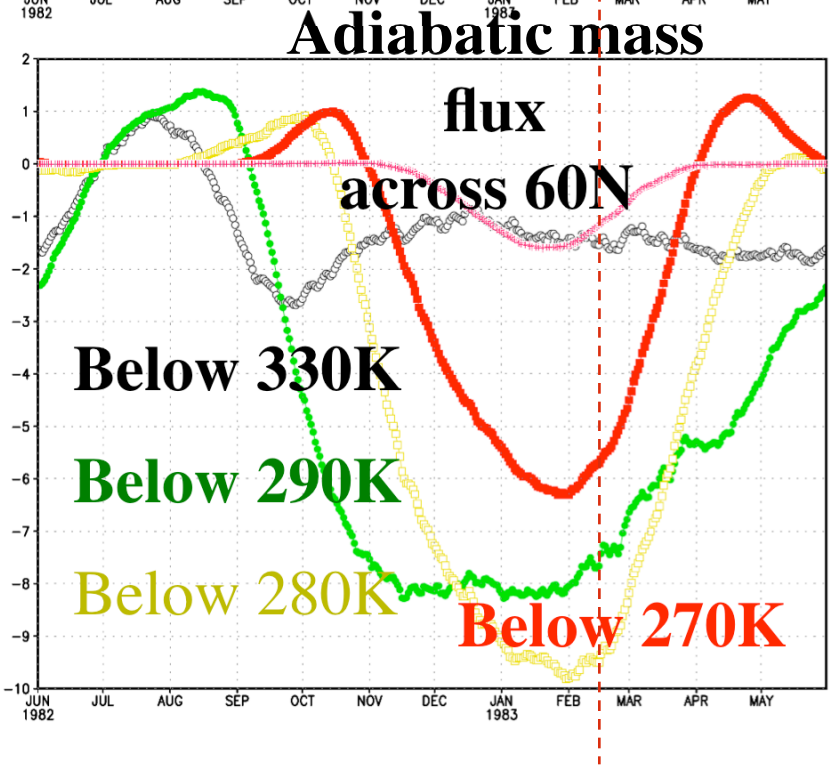
Atmospheric (Meridional) Conveyor Belt

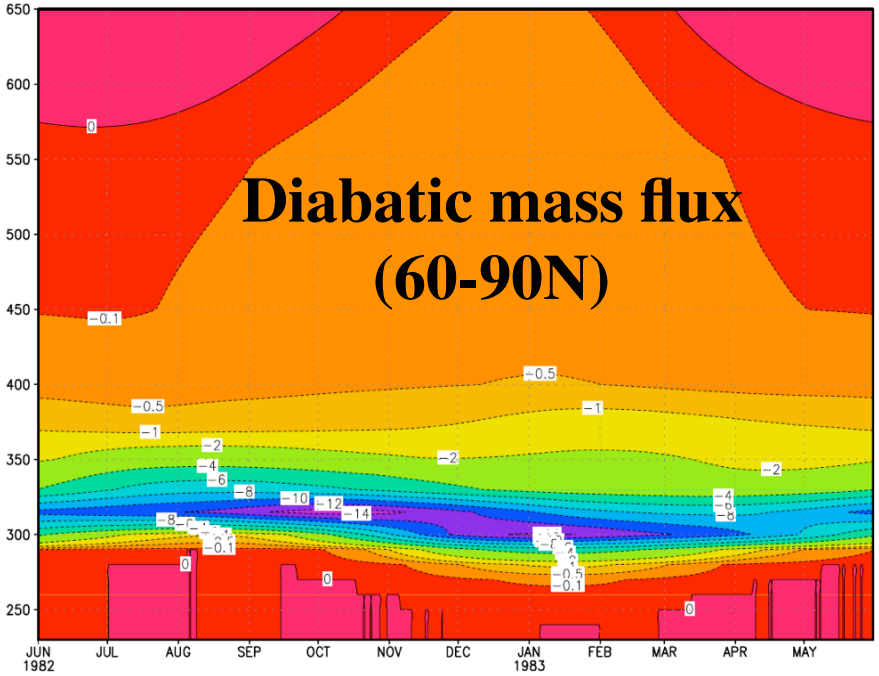


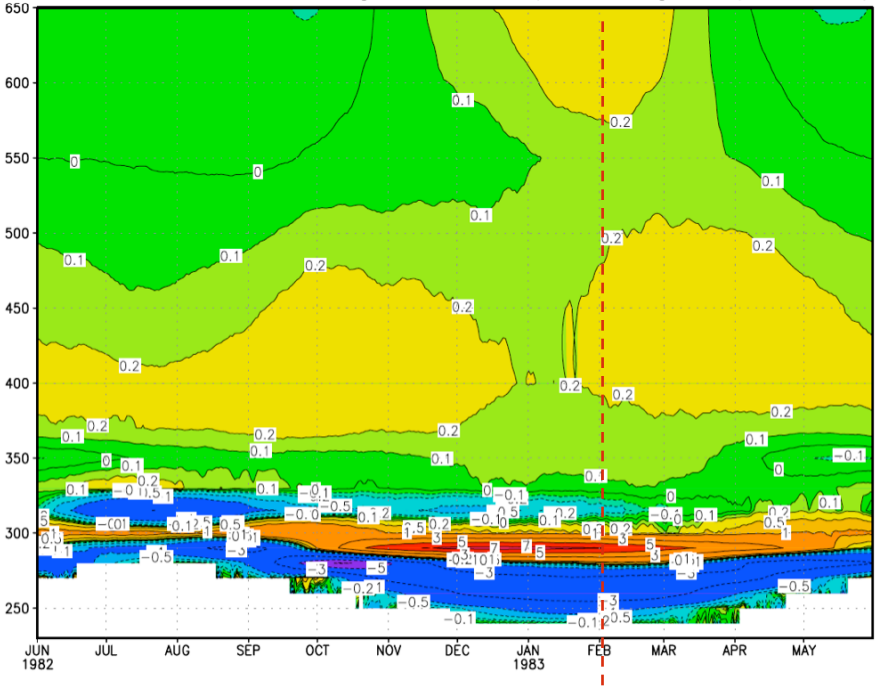

650
600
550
500
450
400
350
300
250
JUN 1982
JUL
AUG
SEP
OCT
NOV
DEC
JAN 1983
FEB
MAR
APR
MAY

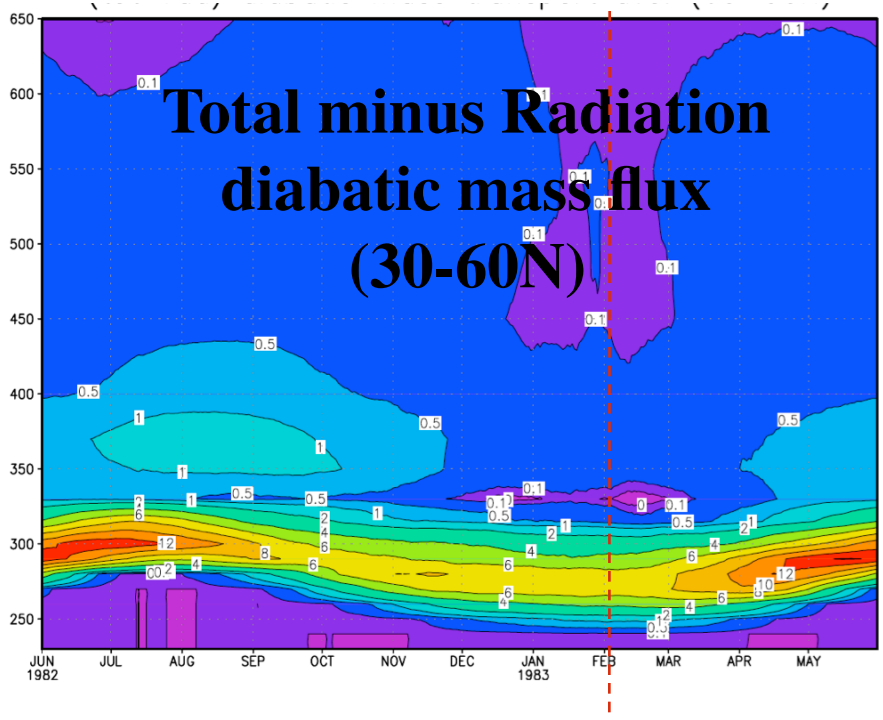

Above 330K
Above 350K
Above 370K
Above 400K
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
JUN 1982
JUL
AUG
SEP
OCT
NOV
DEC
JAN 1983
FEB
MAR
APR
MAY

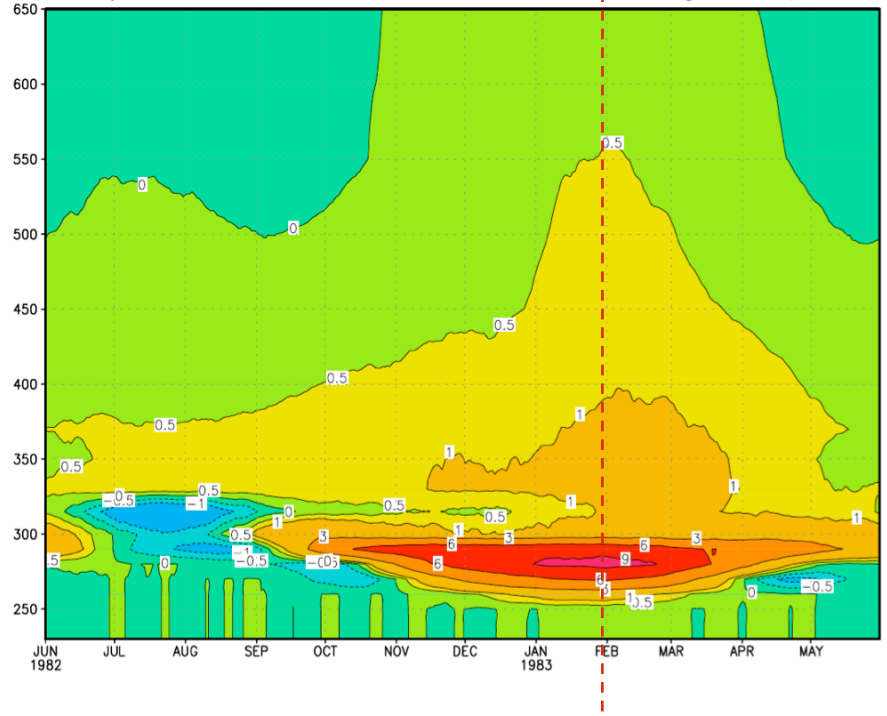

<0
Total minus Radiation diabatic mass flux (30-60N)
<0
650
600
550
500
450
400
350
300
250
JUN 1982
JUL
AUG
SEP
OCT
NOV
DEC
JAN 1983
FEB
MAR
APR
MAY

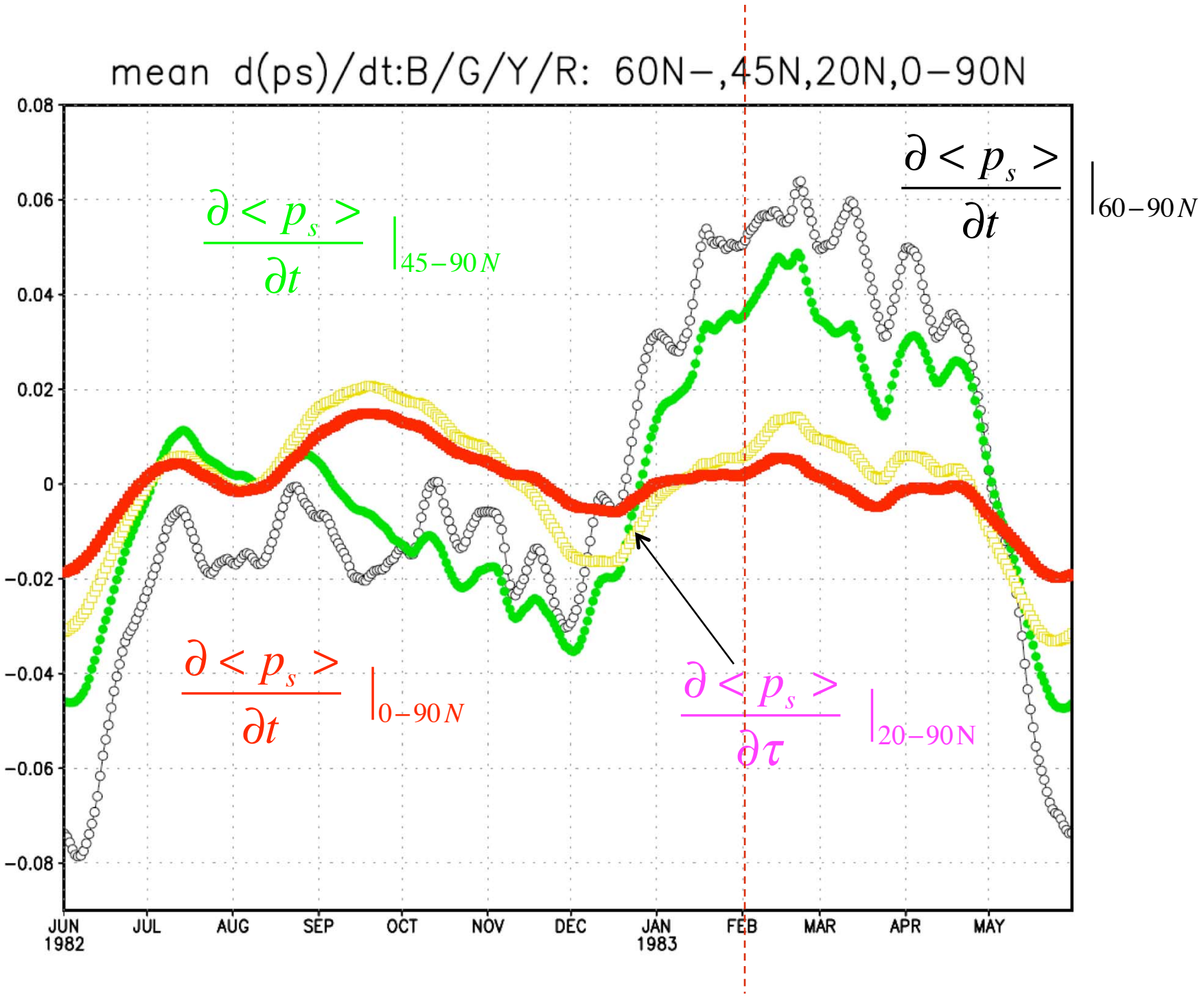

Adiabatic mass flux across 60N
Below 330K
Below 290K
Below 280K
Below 270K
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
JUN 1982
JUL
AUG
SEP
OCT
NOV
DEC
JAN 1983
FEB
MAR
APR
MAY


Diabatic mass flux
(60-90N)




Total minus Radiation
diabatic mass flux
(30-60N)




mean d(ps)/dt:B/G/Y/R: 60N−,45N,20N,0−90N
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
JUN 1982
JUL
AUG
SEP
OCT
NOV
DEC
JAN 1983
FEB
MAR
APR
MAY
$\frac{\partial < p_s >}{\partial t}\Big|_{45-90N}$
$\frac{\partial < p_s >}{\partial t}\Big|_{60-90N}$
$\frac{\partial < p_s >}{\partial t}\Big|_{0-90N}$
$\frac{\partial < p_s >}{\partial \tau}\Big|_{20-90N}$

Summary

- Atmospheric (meridional) conveyor belt: starting from convection (diabatic and adiabatic ascending) in summer tropics to winter subtropics, to stratosphere, to polar surface via diabatic and diabatic descending, and back to tropics near the surface (subject to diabatic heating from the surface)=> responsible for surface polar high (via mass convergence in stratosphere) and surface easterly wind over polar region in winter;)
- Stronger poleward advancement of warm air in the stratosphere turns the extratropics troposphere to be a "dumping ground" of westerly angular momentum => restricting direct mass circulation between subtropcis and high-latitudes in the upper troposphere => Maximum westerly wind tilts towards high latitudes with height.
- Shallow (mini Hadley) cells in the low troposphere (driven by diabatic heating on the returning equator cold air near surface) also transport westerly angular momentum poleward, responsible maximum westerly wind tilts high latitudes downward.

Potential Implication for climate changes

- "Tropical widening" or "tropopause rising" in tropics would be associated with a stronger meridional mass circulation and would imply:
  1. "tropopaus falling" in high latitudes (polar region) (or falling of isentropic surfaces in high latitudes)
  2. Poleward shifting of polar jet.
  3. Intensification of westerly wind in the extratropical troposphere and at surface.
  4. Intensification of easterly wind in the tropics (including surface).
  5. Intensification of subtropical high (due to intensification of accumulation of mass above)?
  6. Rising surface pressure and intensification of easterly wind over polar region (a trend towards negative phase of AO)?
- "3" and "4" above would imply a stronger subduction of water mass into equatorial thermocline and a stronger trade wind in tropics => shifting towards a more "La Nino" mean state and changes in "memory" and intensity of ENSO.

Implications for climate predictions: Monitoring and Dynamical/Statistical Forecast

- Use stratospheric parameters as predictors in addition to SST.
- Use isentropic mass anomalies as indices for monitoring and predicting intra-seasonal climate variability.
- Use Ozone data to monitor the annular mode variability, as SST for ENSO. Ozone data over subtropical region are particularly useful since they are available even in boreal winter.

Personal Reflection

- 人往高处走，水往低处流: **Humans want to climb up, and water flows downward.**
  (heating/cooling causes elevation change, and gravity does the rest)
- 滴水穿石: **Constant dripping wears away a stone**
  ("secondary circulation" changes primary circulation/time mean flow).
- Hadley was almost right (except not knowing the excessive westerly angular momentum would have to be dumped to the ground in the extratropics).