Impact of Orography on Climate

- Stationary waves in the NH winter
  - Charney and Eliassen (1954)]: the linear channel model of the response to topography along 45N
  - Response of an atmosphere model, with and without mountains.
- Stationary waves in the SH winter

East-West Asymmetries in the Midlatitudes

The classic solution in a QG channel by Charney and Eliassen (1954)

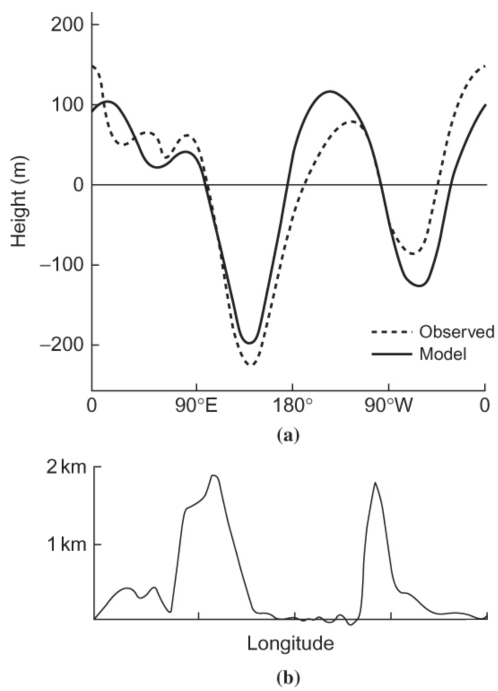
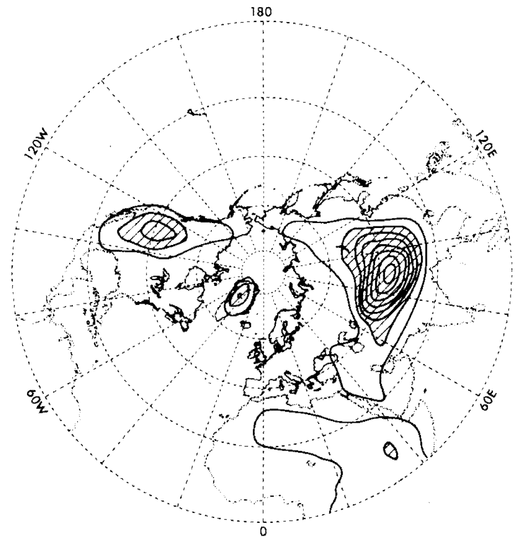


FIGURE 5.15 (a) Longitudinal variation of the disturbance in geopotential height ($\equiv f_0\psi/g$) in the Charney–Eliassen model for the parameters given in the text (*solid line*) compared with the observed 500-hPa height perturbations at 45°N in January (*dashed line*). (b) Smoothed profile of topography at 45°N used in the computation. (*After Held, 1983.*)

Lows at ~140E and 70W: downstream of Tibet/Mongolia (90E) and North American Cordillera (110W)

Response of a old atmosphere model to realistic boundary conditions



- Exp 1: A GCM forced by observed SST and orography
- Exp 2: A GCM forced by observed SST and no orography
  - The ”no-mountain” or “thermally forced model
- “Orographic forcing”: the solution with full forcing minus the “no mountain” solution (Exp 1 minus Exp 2)

Suki Manabe’s model (1982)

The relative role of land-sea temperature contrast and orography

Thermal Forcing
No Mountain (Exp 2)

Orographic Forcing
Full minus No Mountain (Exp 1 - Exp 2)

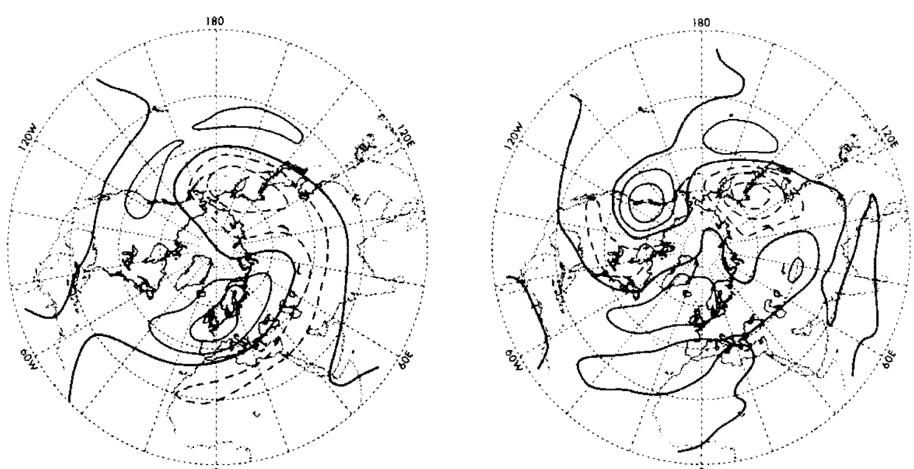


Fig. 6.22. The stationary eddy geopotential field of Fig. 6.21 split into its ‘thermal’ and ‘orographic’ components.

Z300

A ~1982 model analyzed by Held (1983)

The response along 45N

Full solution

Role of Orography
Full minus No Mountain
(Exp 1 - Exp 2)

Thermal Forcing
No Mountain (Exp 2)

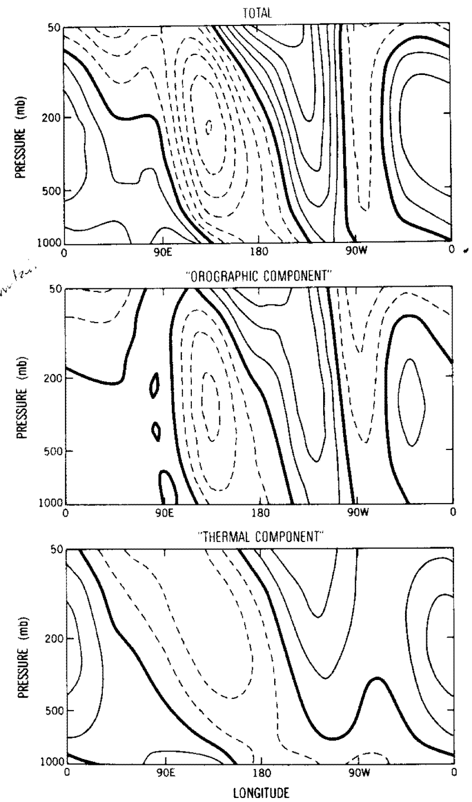


Fig. 6.20. The eddy geopotential height as a function of longitude and pressure at 45' for the mountain model ('total'), the mountain minus no-mountain flow ('orograpl component') and the no-mountain model ('thermal component'). The contour inter is 50 m with negative contours dashed. Model fields in Figs. 6.19–6.23 are averag over the three winter months in each of the 15 model years.

A ~1982 model analyzed by Held (1983)

The relative role of land-sea temperature contrast and orography

Thermal Forcing
No Mountain (Exp 2)

Full Forcing
(Exp 1)

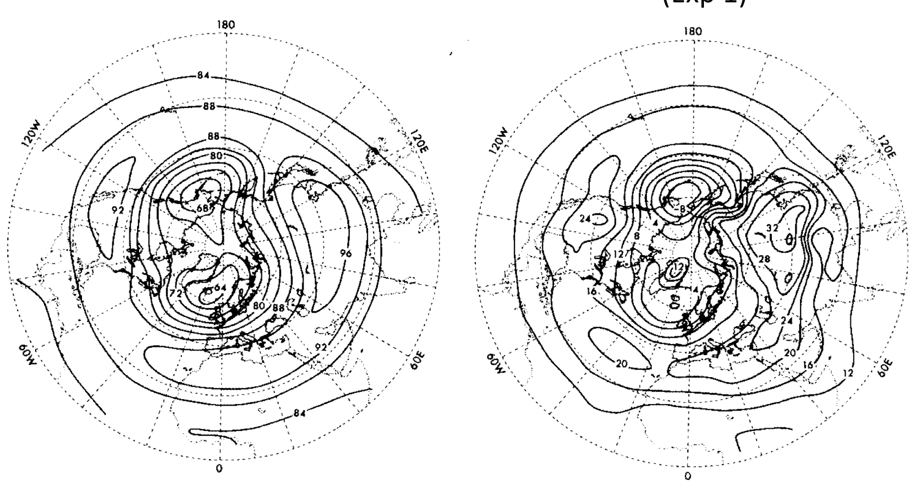


Fig. 6.24. The sea-level pressure for the mountain and no-mountain calculations. xx mb should be read 10xx mb for the mountain model and 9xx mb for the no-mountain model.

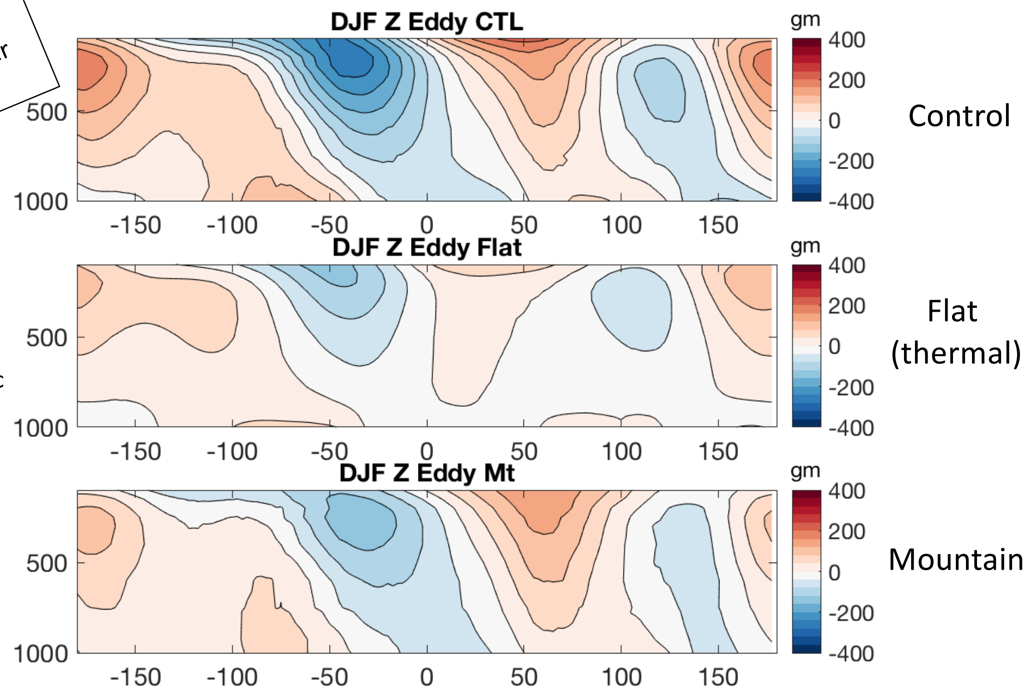
SLP

A ~1982 model analyzed by Held (1983)

A zonal cross section of geopotential height along 50-60N

Another look with a better model

Winter: most of the tropospheric stationary wave comes from orographic forcing

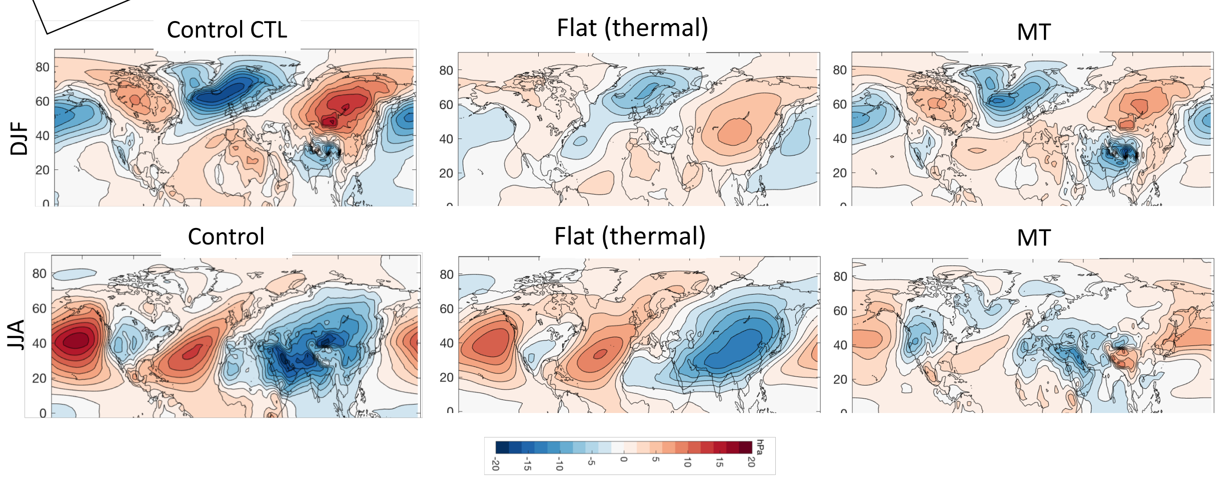


Two experiments with the NCAR WACCM Model
Control = modern day orography; Flat – globally topography flattened

White et al, in prep

Another look with a better model

"Eddy" SLP

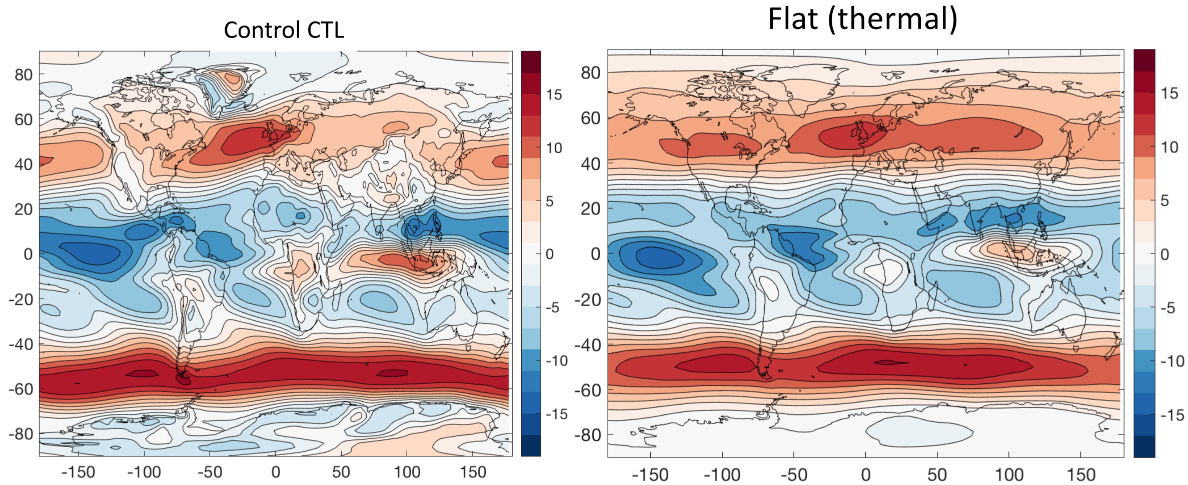


Winter: much of the eddy SLP comes from orographic forcing (orographically forced stationay waves)
Summer: most of the eddy SLP comes from diabatic forcing (land-sea temperature differences)

White et al, in prep

Another look with a better model

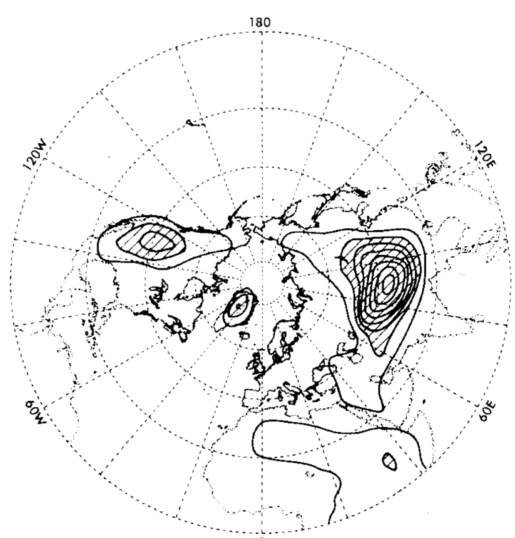
DJF Mean Zonal Wind (850 hPa)



The presence of mountains in greatly slows the NH westerlies

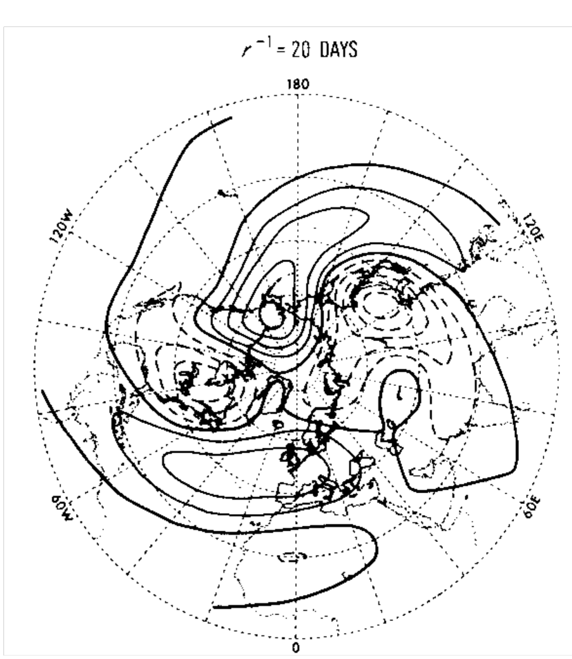
White et al, in prep

Response of a linear ***barotropic*** model on a sphere to NH orography

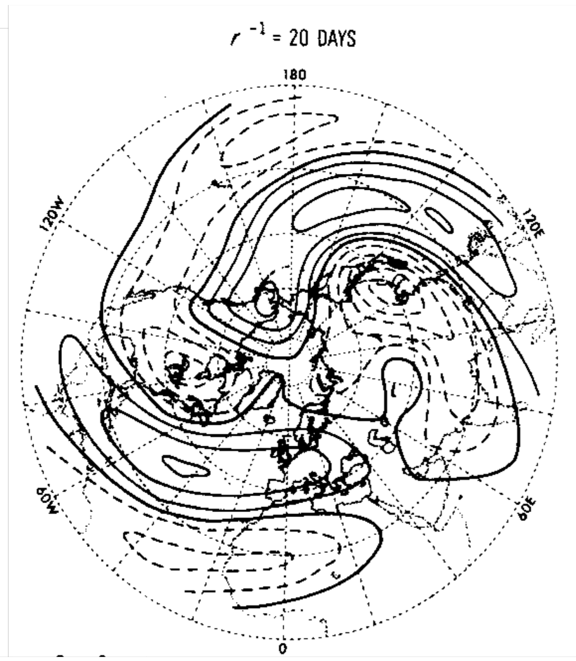


Held (1983) prescribed the climatological 300 hPa zonal average flow (U(y) from the AGCM run with no mountains and calculated the stationary barotropic wave response on the sphere

Impact of Mountains: linear stationary waves on a sphere, forced observed NH topography



Z300



300 hPa Streamfunction

Held 1983

Same solution, only shown as streamfunction w/ forcing confined to western or eastern hemisphere

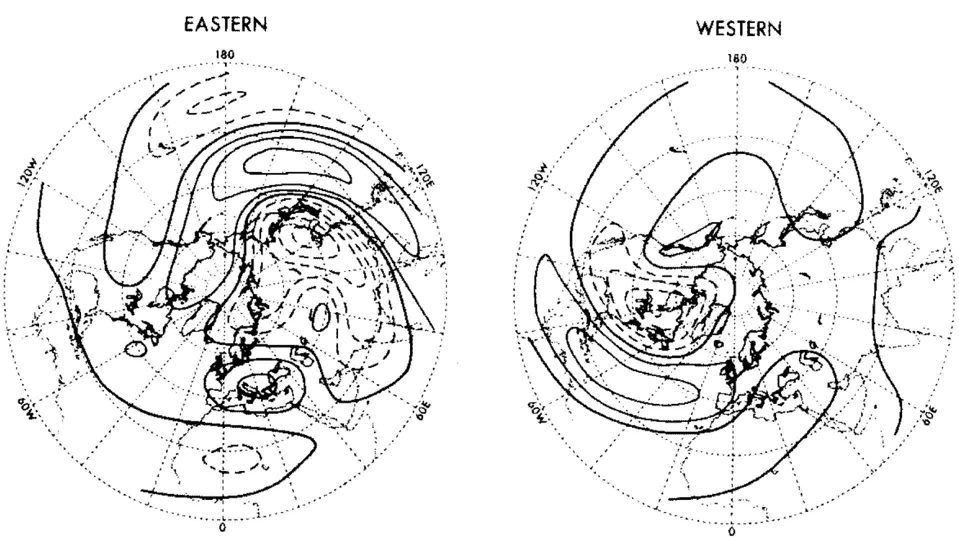
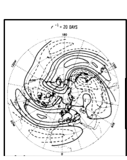


Fig. 6.9. The streamfunction response of Fig. 6.7 with $r^{-1} = 20$ days, split into the responses to the topography of the Eastern and Western Hemispheres.

East Asian topography matters more than North American orography



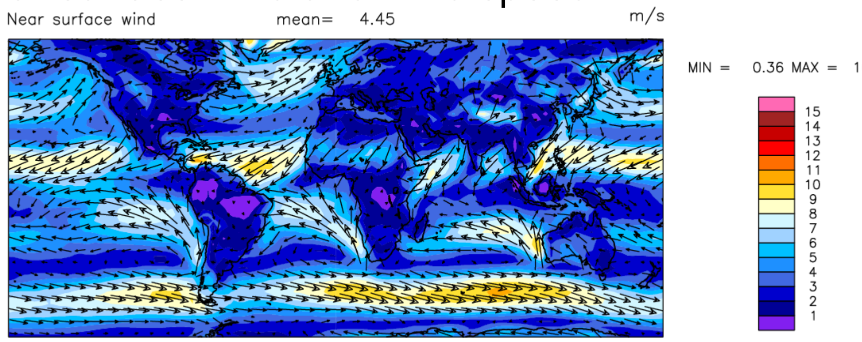
= sum of the two figures above

Held 1983

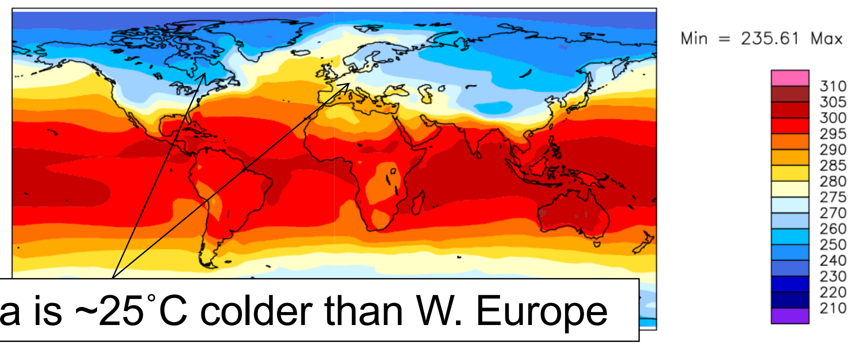
Role of the Major Mountain Ranges

Observed near surface wind and wind speed

Observed DJF near surface wind

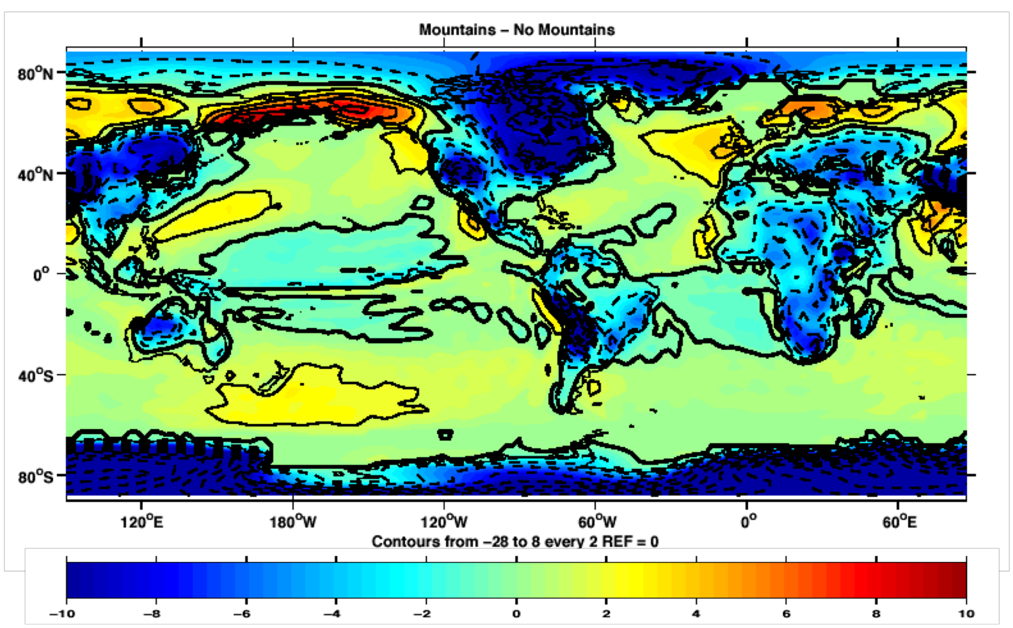


Observed DJF surface temperature



E. Canada is ~25˚C colder than W. Europe

The impact of mountains on DJF temperature



Without the Rockies, the Northeast US would be ~ 12˚C warmer and Alaska would be ~8˚C colder

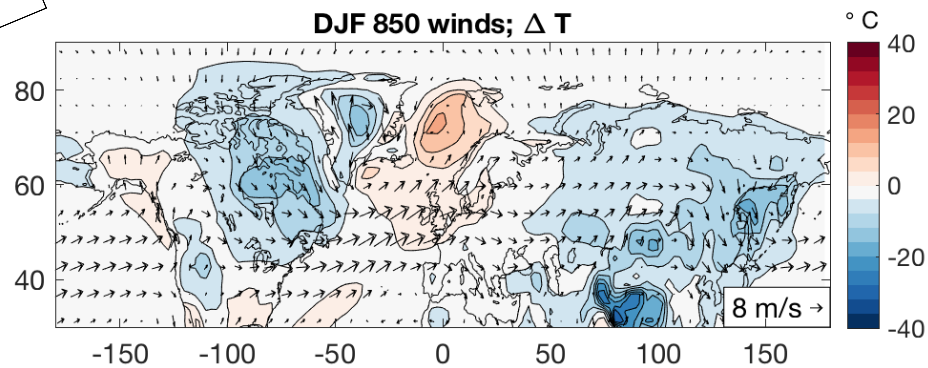
Europe is "warm" in winter because of the Rockies and *atmospheric* heat transport

Seager et al 2002

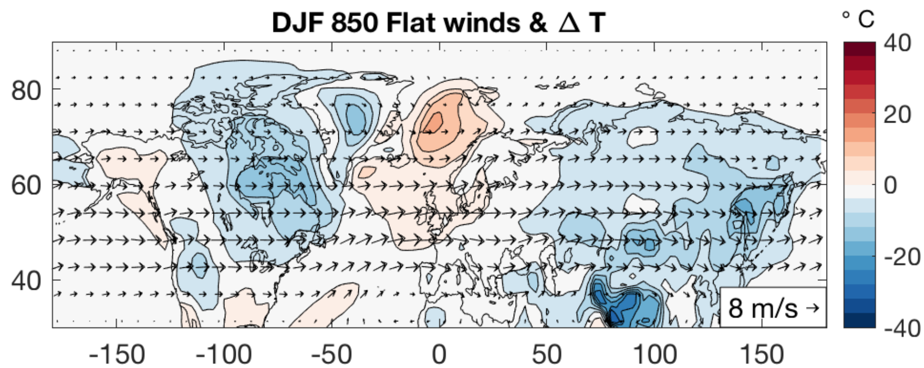
Another look with a better model

Changes in winter (DJF) winds

Control



FLAT (thermal)



c.i. = 4°C

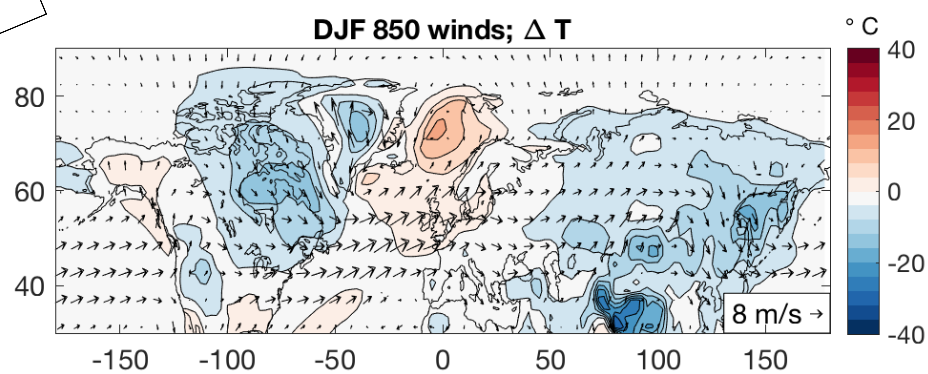
Eastern Canada is ~12˚C colder because of the Rockies

White et al, in prep

Another look with a better model

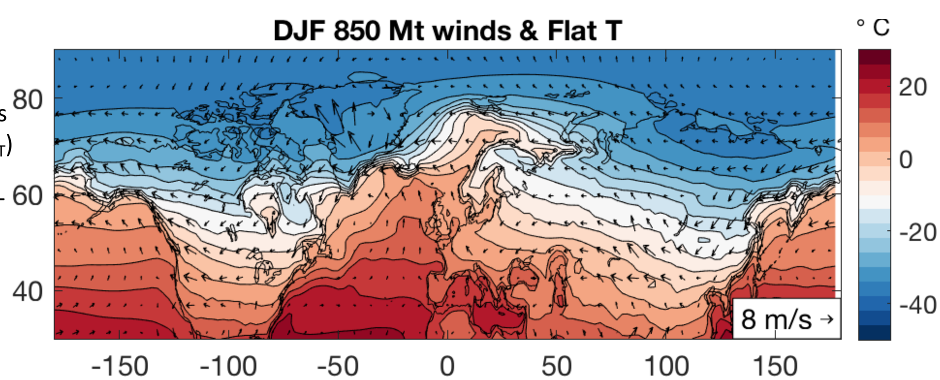
Changes in winter (DJF) winds

Impact of mountains on wind **V** and Ts



c.i. = 4°C

Change in winds due to MT ($\Delta \boldsymbol{V}_{MT}$) & Climatological T from FLAT



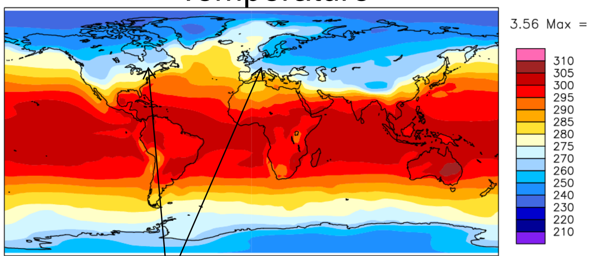
In most places, the temperature change is due to $\mathbf{V_{MT}} \cdot \nabla T_{flat}$

White et al, in prep

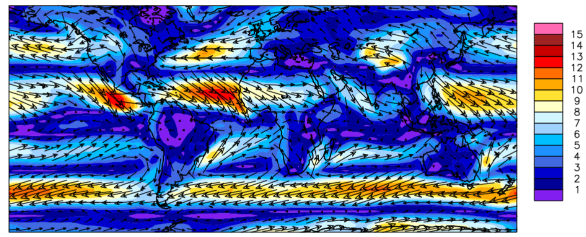
Mountains *and* Rotation of Earth Matter

DJF Climate on a Backward Rotating Earth

Temperature

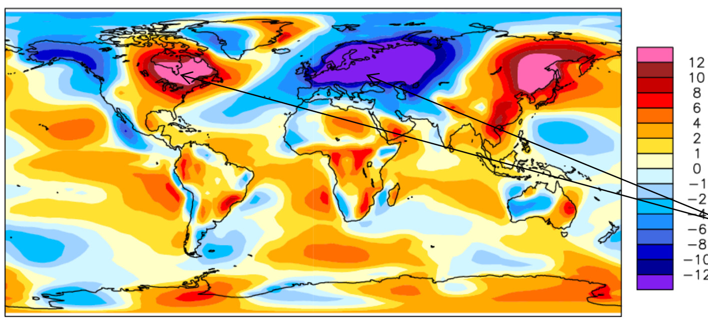


Near Suface Winds



Now NE Canada is ~10˚C *warmer* than W. Europe!

Backward minus Forward



Rotation+Mts warm NE by ~20˚C and cool Europe ~15˚C

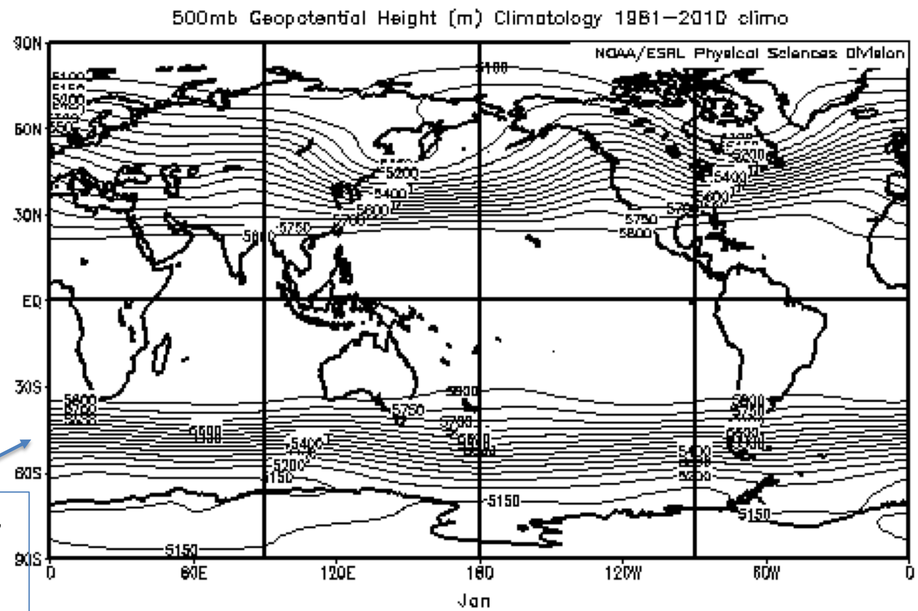
Why is Europe warm in winter (compared to New England)?

Europe minus New England Temperature (DJF)

Observed	**25˚C**
The Rockies	12˚C
Westerlies blowing over wet motionless ocean	12˚C
Ocean Circulation (MOC and Gulf Stream)	1˚C
Total	25˚C

Stationary Waves in the SH?

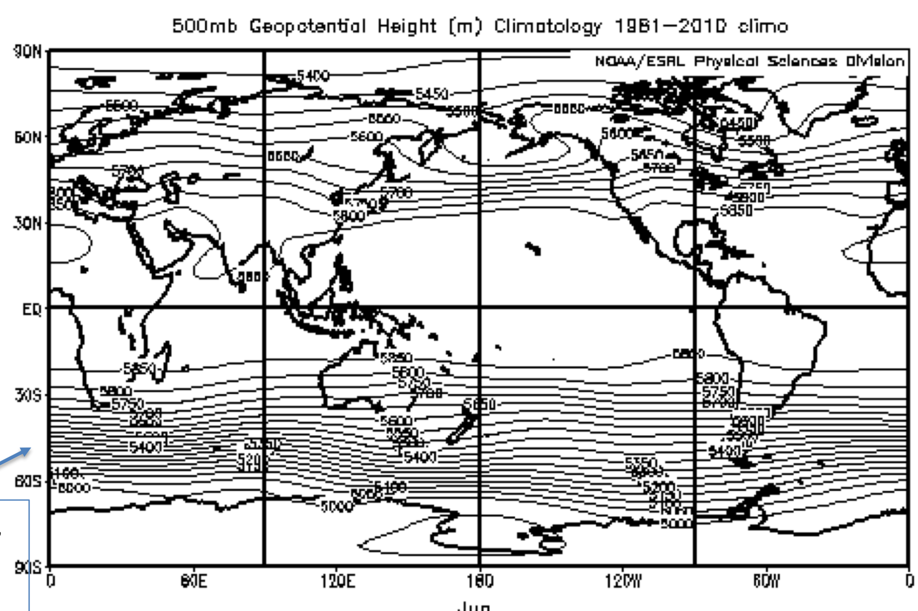
Summer (Jan)



Strong flow, but no stationary waves

Stationary Waves in the SH?

Winter (June)



Strong flow, but no stationary waves