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Meridional Transport of Energy during Atmospheric Collapse on Ancient Mars

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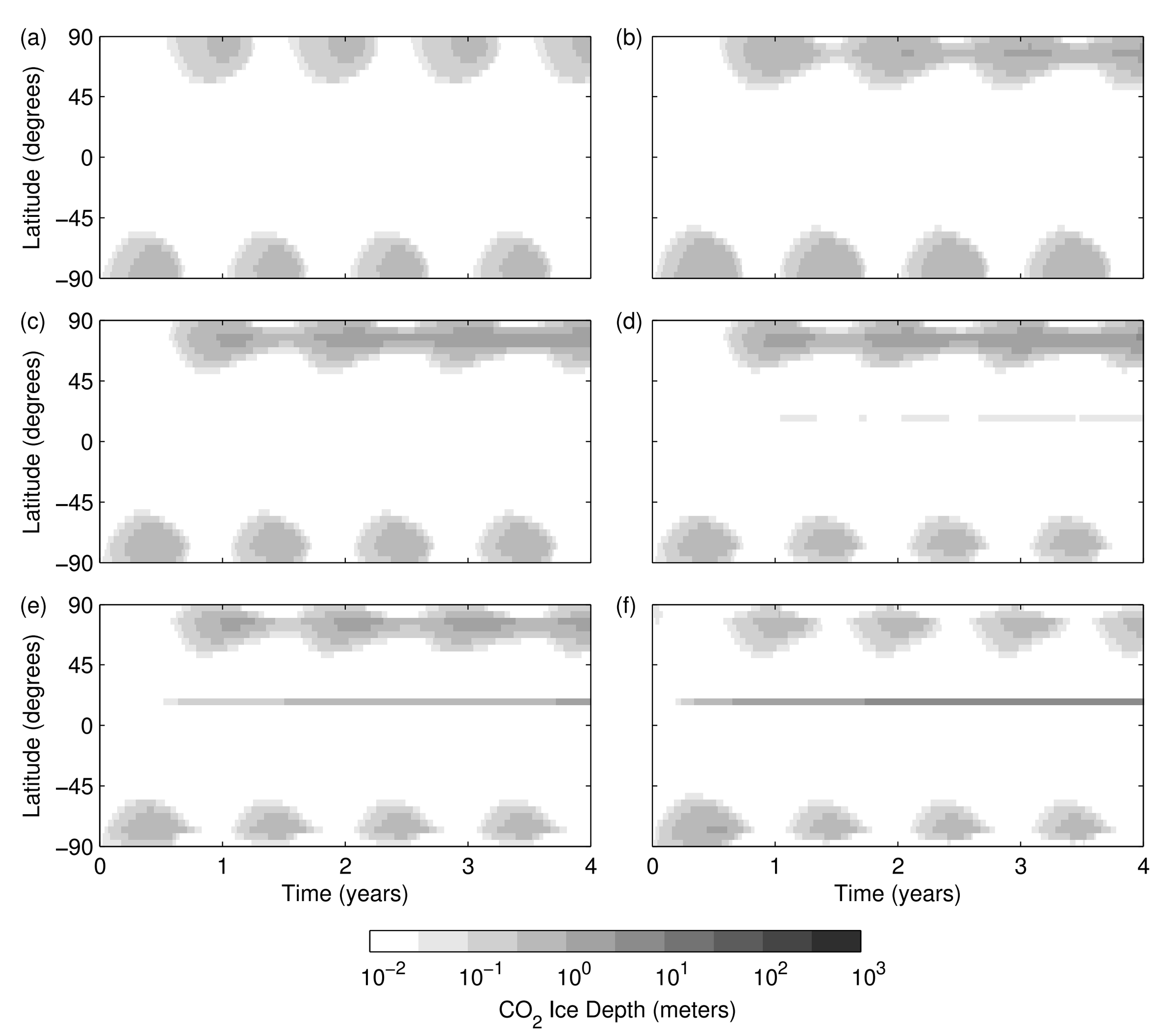
Thirty Second Summary, *i.e.*, the Abstract.

Periodically, the polar regions of ancient Mars received low levels of insolation due to Mars' frequent obliquity oscillations. Thus, Mars likely experienced large scale condensation of its carbon dioxide atmosphere, a process which is often called "atmospheric collapse". The partitioning of meridional transport of energy changes during atmospheric collapse. Here we show the partitioning of the meridional transport of energy into the classical mean and eddy terms as well as into a condensation flow term. The condensation flow is the vertical integration of the movement of the bulk atmosphere in response to condensation. On non-collapsing atmospheres, like current Mars and Earth, this condensation flow is small and contributes insignificantly to the meridional energy transport. For a collapsing atmosphere, this condensation flow of meridional energy controls the onset and strength of atmospheric collapse. For Mars, the condensation flow determines the threshold of atmospheric collapse as a function of obliquity.

Zonal CO_2 Ice as a Function of Time

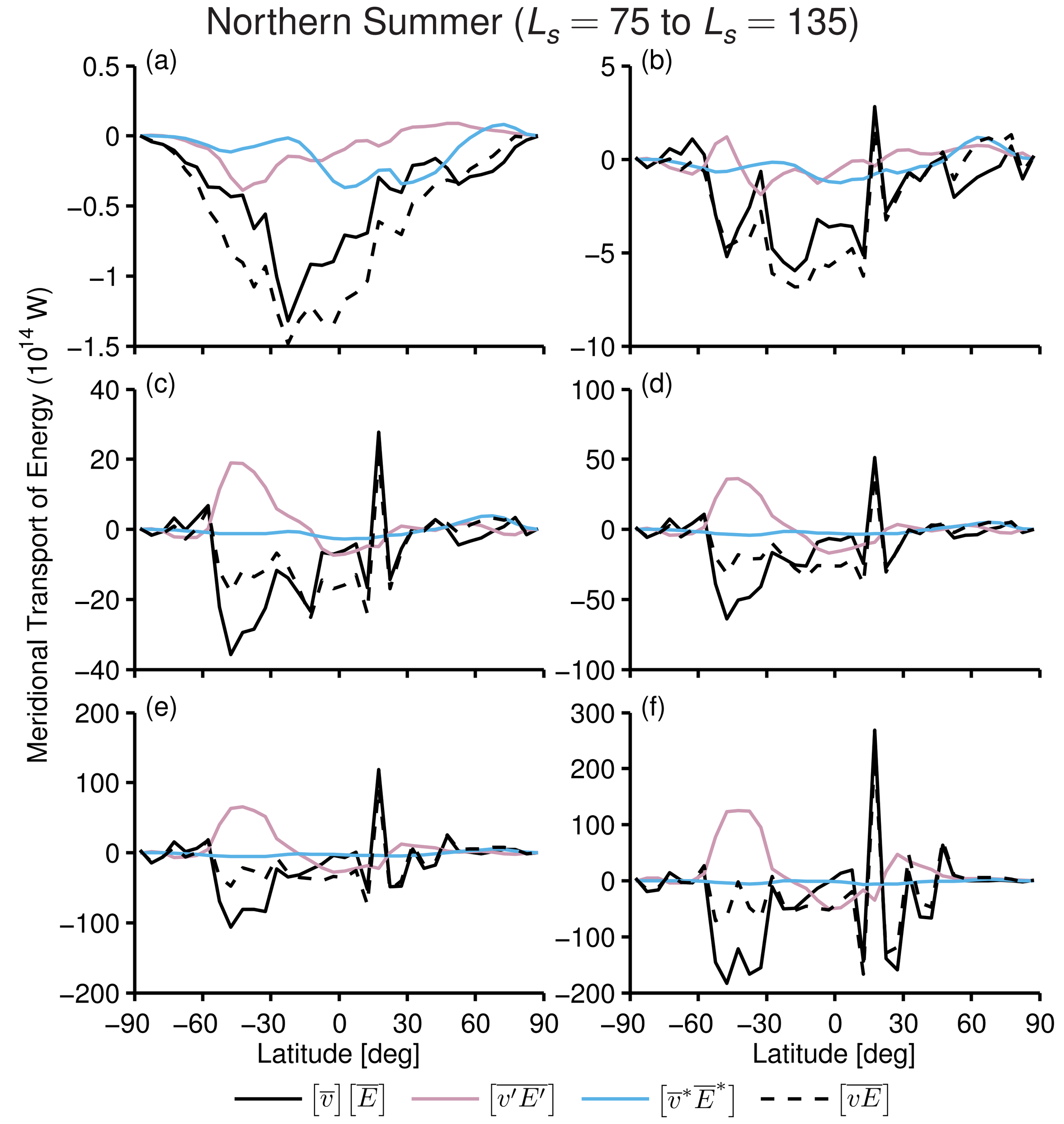


Above: For the initial surface pressures: (a) 6 mb, (b) 60 mb, (c) 300 mb, (d) 600 mb, and (f) 1200 mb.

Methods: We used the MarsWRF general circulation model to simulate the Martian climate. Simulations were run with 0° eccentricity and 25° obliquity at the current solar luminosity.

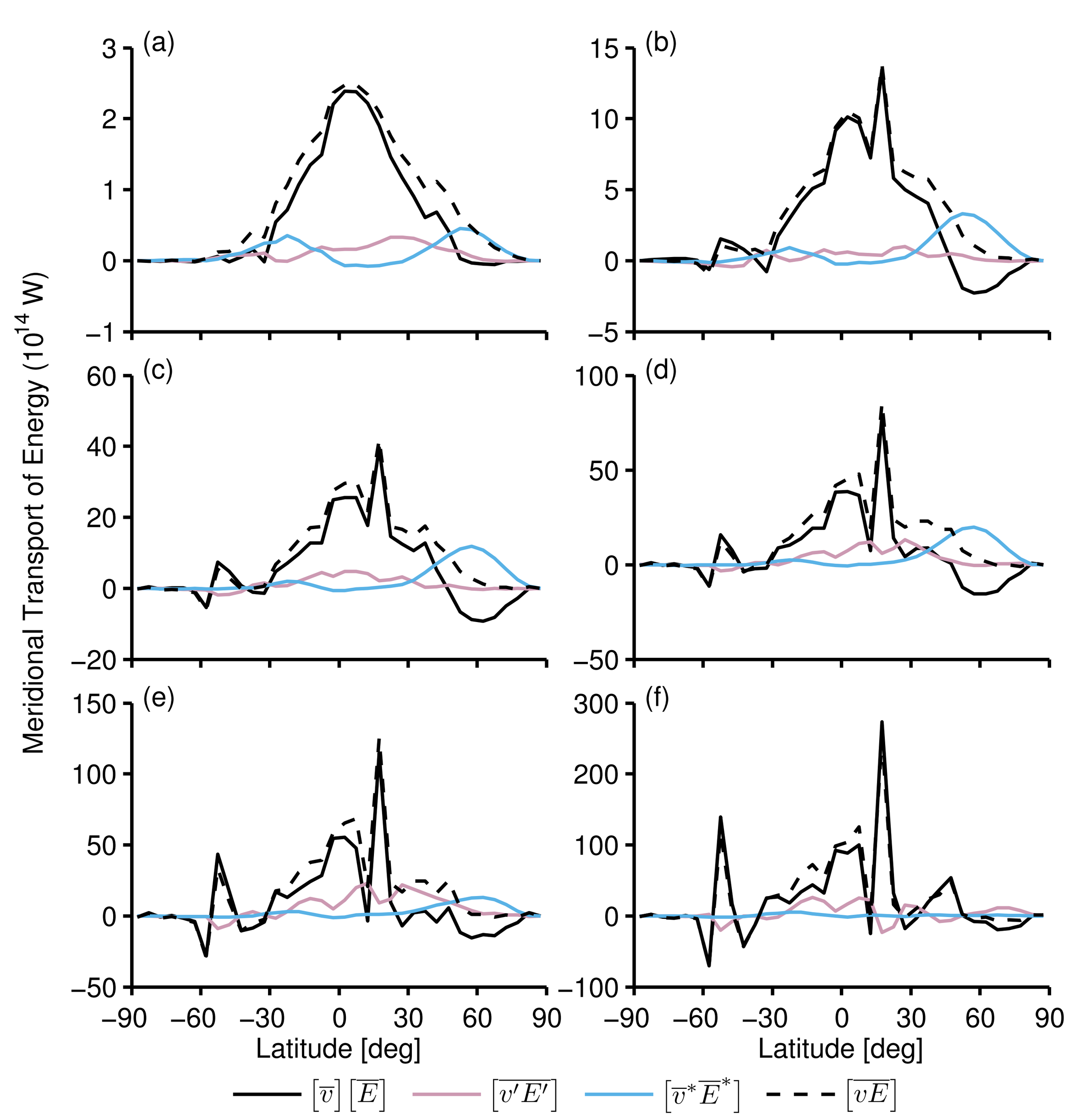
Meridional Transport of Dry Static Energy

Northern Summer ($L_s = 75$ to $L_s = 135$)



Above: Initial mean surface pressures of (a) 6 mb, (b) 60 mb, (c) 300 mb, (d) 600 mb, and (f) 1200 mb.

Northern Winter ($L_s = 255$ to $L_s = 315$)



Above: Initial mean surface pressures of (a) 6 mb, (b) 60 mb, (c) 300 mb, (d) 600 mb, and (f) 1200 mb.

Dry Static Energy

We used Reynolds decomposition to calculate the mean circulation, stationary eddy, and transient eddy terms of the meridional transport of the dry static energy. The dry static energy is defined as

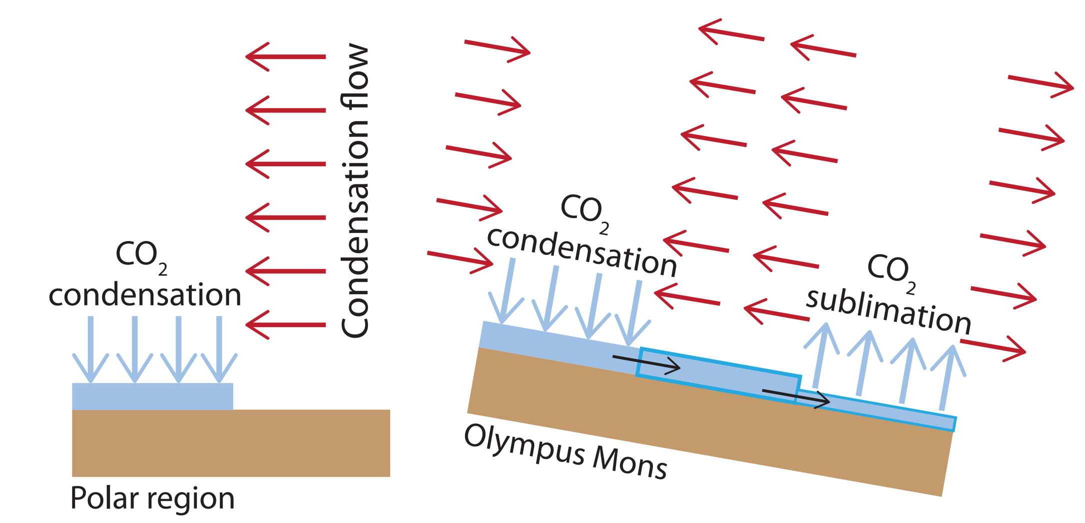
$$E = gz + c_pT$$

where g is gravity, z is height, c_p is the specific heat capacity, and T is the air temperature.

The decomposition of the zonal and temporal mean of the total transport, $[\overline{vE}]$,

$$[\overline{vE}] = [\bar v][\bar E] + [\bar v^*\bar E^*] + [\overline{v'E'}]$$

where $[\bar v][\bar E]$ is the mean circulation term, $[\bar v^*\bar E^*]$ is the stationary term, and $[\overline{v'E'}]$ is the transient term. All of these terms are vertical averages.



Condensation Flow

The condensation flow is calculated by taking the mass-weighted vertical average

$$[\bar v_c] = \int_1^0 \left[\overline{(P_s - P_t)v}\right] \mathrm{d}\sigma \Big/ \left[\overline{P_s - P_t}\right]$$

where v_c is the condensation flow meridional velocity, v is the total meridional velocity at each vertical level, σ is the vertical coordinate, and $(P_s - P_t)/g$ is the column mass. The condensation flow velocity, while a function of latitude, is a constant value at every vertical level.

With this condensation flow velocity, $[\bar v_c]$, we decomposed the mean meridional velocity at each vertical level into

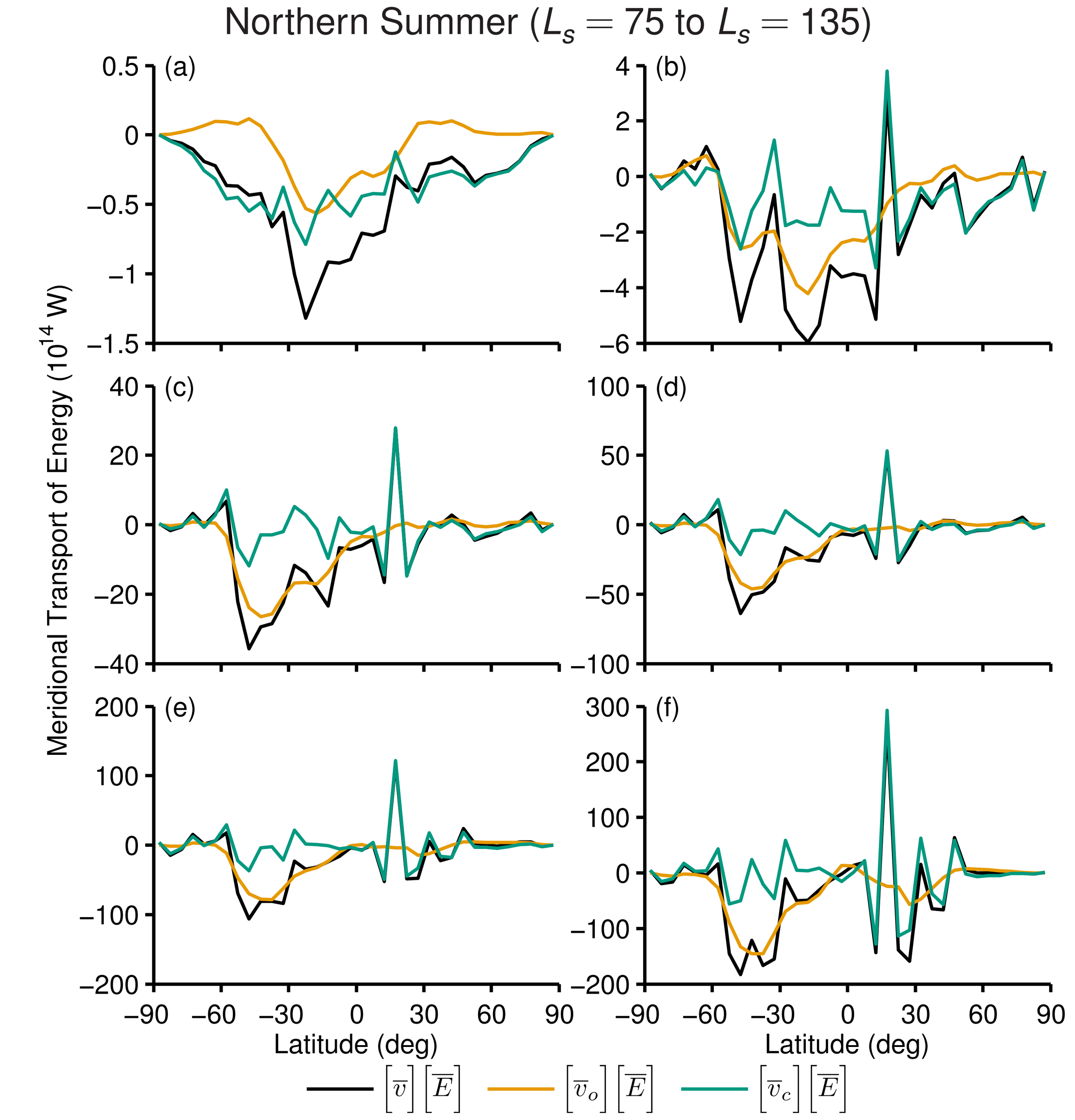
$$[\bar v] = [\bar v_o] + [\bar v_c]$$

where $[\bar v_c]$ is the condensation flow velocity and $[\bar v_o]$ is the velocity of the overturning cells, which is calculated by $[\bar v_o] = [\bar v] - [\bar v_c]$.

By decomposing the mean meridional wind into an overturning flow and a condensation flow we determined how the atmospheric collapse affects the mean meridional circulation.

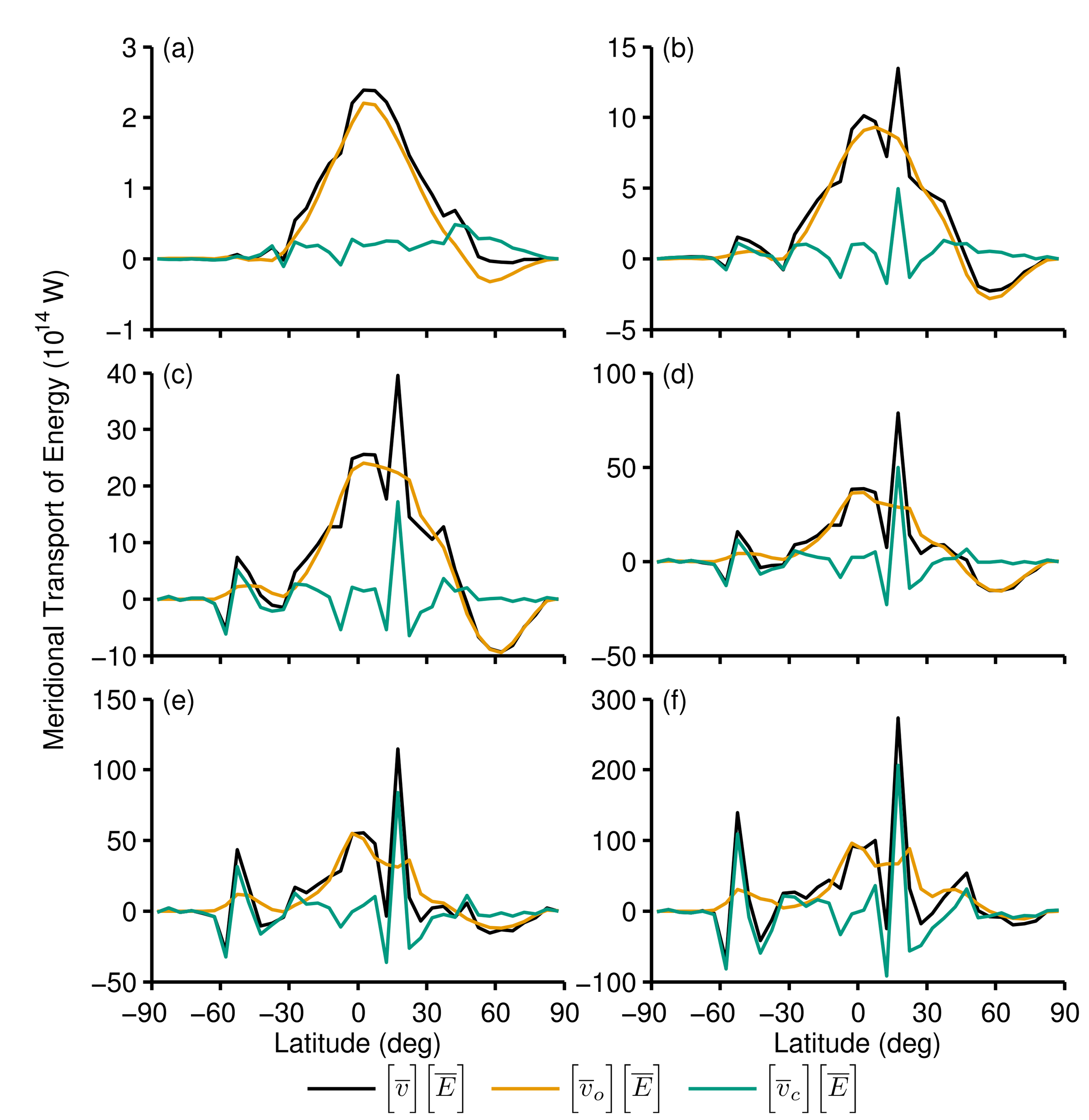
Meridional Transport of Condensation Flow

Northern Summer ($L_s = 75$ to $L_s = 135$)



Above: Initial mean surface pressures: (a) 6 mb, (b) 60 mb, (c) 300 mb, (d) 600 mb, (e) 1200 mb, and (f) 3000 mb.

Northern Winter ($L_s = 255$ to $L_s = 315$)



Above: Initial mean surface pressures: (a) 6 mb, (b) 60 mb, (c) 300 mb, (d) 600 mb, (e) 1200 mb, and (f) 3000 mb.

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