Latitudinal Double-Peak Structure of Stationary Planetary Wave 1 in the Austral Winter Middle Atmosphere & Possible Generation Mechanism

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Introduction

- (Quasi)-stationary PW: Wave perturbations barely change with time, while have zonal wave structure dominated by wavenumber 1, 2, 3.
- Stationary planetary waves (SPWs) are forced by airflow over large-scale topography, planetary-scale differential heating, and averaged effects of synoptic-scale eddies.
- Cause Perturbations: Geoh: ± 1 km U(V): ± 50 m/s T: ± 20 K

MERRA-2 Geopotential Height Pert @ 50 km

NH SPW structure is dominated by 1-peak, while SH shows 2-peak structure
**Motivation From MERRA2 (1981-2016)**

36 Yearly-Mean (Vector) Monthly-Mean SPW1 Amplitudes

- Show one single peak in the winter hemisphere during boreal winter (Dec, Jan, and Feb), which is the strongest in a year.
- Latitudinal double peak structure in austral winter (May, Jun, and Jul), which shows weakest magnitude. [Definition: primary high-latitude peak + secondary middle-latitude peak.]
- During equinoxes, wave activities can be found in both hemispheres, where westward winds are prevailing, allowing wave propagation.

**SPW1 Structure Individual Years (1981-2016)**

**June**

- Monthly Mean Amplitude
- Occurrence Rate: 97%
- 2002 is an exception dominated by single strong peak
- May: 61%
- July: 53%
- August: 25%

Lu et al., 2018
Significant Difference in Jan SPW1

Jan

Month

Mean

Amplitude

Occurrence

Rate: 0%

SPW1 structure has salient inter-hemispheric asymmetry in winter-hemisphere

SABER Validating Double-Peak Structure

- SABER and MERRA-Z results are very consistent with each other in terms of SPW1 amplitudes and phases.
- The double peak structure is captured by both datasets. Smoother structure shown in MERRA2 is likely due to the larger amount of data samples.
Comparison of NH and SH SPW1

MERRA-2 Geopotential Height Pert @ 50 km

NH SPW1 structure is relative more stable than SH SPW1 structure.

36 Yearly-Mean (Absolute) Monthly-Mean SPW1 Amplitudes

Due to the differences in the occurrence rate of the double-peak structure, the yearly-mean SPW1 structure shows most salient DP feature in June, but not in other months if we simply average the absolute amplitude of each year.
If wave phase does not change from one to the other, we should expect the same results from vector mean and absolute mean. Difference (or ratio) from these two averaging methods indicate the variation of phases, or stability of wave structure. Wave structure tends to be more stable around austral winter than boreal winter.

### Yearly-Mean Monthly-Mean SPW1 Amplitudes Absolute VS. Vector Averaging

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute Ave</td>
<td>1.12</td>
<td>0.89</td>
<td>0.55</td>
<td>0.36</td>
<td>0.37</td>
<td>0.41</td>
<td>0.38</td>
<td>0.60</td>
<td>0.93</td>
<td>0.87</td>
<td>0.93</td>
<td>1.06</td>
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<tr>
<td>Vector Ave</td>
<td>1.07</td>
<td>0.82</td>
<td>0.46</td>
<td>0.31</td>
<td>0.28</td>
<td>0.32</td>
<td>0.32</td>
<td>0.51</td>
<td>0.83</td>
<td>0.79</td>
<td>0.87</td>
<td>0.95</td>
</tr>
<tr>
<td>Abs/Vec</td>
<td>0.96</td>
<td>0.91</td>
<td>0.85</td>
<td>0.86</td>
<td>0.75</td>
<td>0.78</td>
<td>0.84</td>
<td>0.85</td>
<td>0.89</td>
<td>0.91</td>
<td>0.94</td>
<td>0.90</td>
</tr>
</tbody>
</table>

- 2002: No DP feature, dominated by upward and equatorward EP flux
- Other years: Significant downward EP fluxes are located around the secondary peak in middle latitude.
Where Do Downward Energy Flows Come From?

WACCM Monthly-Mean SPW1 (May)

Modified Run: GW drag averaged zonally in WACCM physics module for every time step.
- GW drag forcing is largely responsible for the SPW above 80 km.
- Downward EP fluxes are significantly suppressed after doing zonal mean of GW drag, and DP structure disappears.
- With GW drag being averaged, downward EP flux may originate from wave reflection.

What if the zonal mean wind has changed?

- Zonal mean wind does change from the default to modified WACCM run.
- Refractive index also changes. The question is: how does it impact wave propagation and structure?
Linear Mechanistic Model

2-D Geopotential (potential vorticity) equation (Matsuno [1970] and Smith and Avery [1987]): Study how background wind affects SPW propagation and along with dissipation (RF and NC), & how do they determine the overall SPW structure.

Lower Boundary Condition

![Graph of SPW amplitude vs. latitude](image)

Friction (Damping)

![Graph of damping coefficients vs. altitude](image)

- Ubar and lower boundary condition are both obtained from WACCM: Differences between WACCM and should be caused by nonlinear wave-mean flow and wave-wave interactions.

Rayleigh friction (RF) and Newtonian cooling (NC) are incorporated in vorticity and thermodynamic equations, respectively.

Credibility of the Linear Mechanistic Model:
1) Sensible vertical and latitudinal structure of SPW1
2) Reasonable phase progression indicating upward wave energy propagation

- Both mean wind fields do not give DP structure directly:
  - Wave propagation only dictated by mean wind and wave dissipation can not give double-peak structure in a linear manner.
Observations (MERRA2 + SABER):

1) Latitudinal double-peak structure with polar primary and subtropical secondary peak is a robust feature in austral winter.
2) Downward EP fluxes are often found around the secondary peaks.
3) SPW1 structure is more stable in NH winter than SH winter.

Modeling (WACCM + Linear Mechanistic Model)

A possible mechanism:

Filtered GW forcing provides in-situ wave source in the MLT
Downward waves interfere with upward primary waves wave interference secondary peak.

Primary wave needs to be weak to have more efficient wave interference, which may explain why this feature doesn’t show in NH winter, when SPW1 is strong.