Seasonal characteristics of mesospheric short period gravity waves observed on all-sky camera at King Sejong Station (62°S, 59°E)

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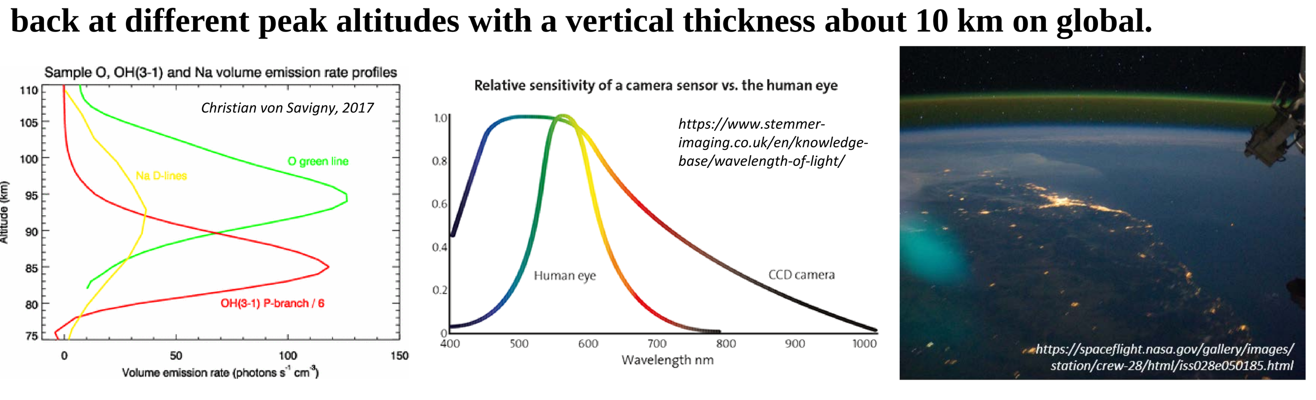
Abstract

We analyzed mesospheric gravity waves in OH airglow images observed during 2012- 2016 by an all-sky camera at King Sejong Station (KSS; 62°S, 58°W), Antarctica. Using a new method of 2D image analysis recently developed by Matsuda et al. (2014), we obtained power spectra of horizontal phase velocity from the image sequence of total 107 image windows. We found from total power spectrum density that wave activity is maximized during winter, as is previously known. We also derived wind blocking fields from MERRA2 reanalysis data for the altitudes 10 - 64 km and from KSS meteor radar data for 80 - 90 km. By comparing the dominant propagating direction of short period gravity waves with the wind blocking field, we found a significant anti-correlation between wind blocking fields and dominant propagating direction of gravity waves except fall season, indicating wind filtering effects. The finding is the direct evidence of wind filtering effects observed in the mesosphere for the first time. During fall, the wind blocking fields below ~40 km are not matched with the dominant propagating directions. Thus, we suggest that mesospheric gravity waves observed by the all-sky camera during fall were generated above ~40 km (upper stratosphere and lower mesosphere), probably due to secondary waves. This exception will open up theoretical questions in middle atmosphere dynamic research area.

What are the Gravity waves & Airglow?

Gravity Waves (GWs) are generated in a fluid medium or at the interface between two media when the force of gravity or buoyancy (by orography, convection..) tries to restore equilibrium.
→ GWs penetrating into mesosphere and lower thermosphere (MLT) region.
The short period (<1h) GWs
→ Energy & momentum transported to MLT region from lower atmosphere.
→ Important role in the global meridional circulation [*Fritts and Vincent, 1987*].

Airglows are emitted by in various wavelengths from infrared, visible light, to ultra violet when an atom or molecule in the atmosphere is excite to a high energy state and then sinks back at different peak altitudes with a vertical thickness about 10 km on global.

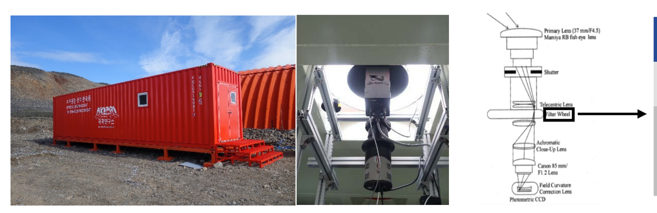


Volume Emission Rate profile of OH, OI, Na — *Airglow detection from CCD* — *Airglow above the horizon, captured from ISS*

Observation

KSS ASC (All Sky Camera)

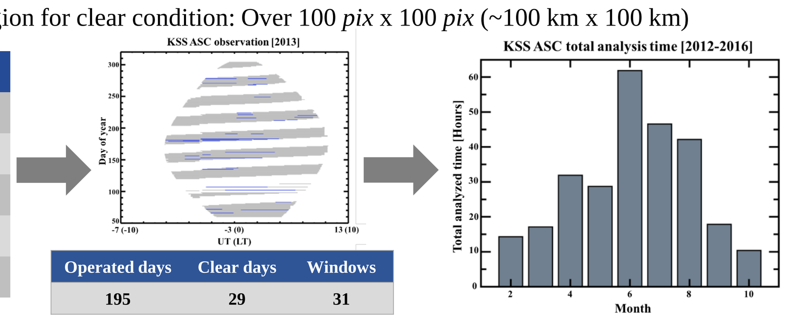
- has been operating since May 2008.
- consists of a 180° FOV lens with telecentric optics for a multi-wavelength filter system.



Airglow Type	Central Wavelength	Altitude
OH Meinel bands	720.0 – 820.0 nm	87 km
OI 557.7 nm	557.7 nm	96 km
OI 630.0 nm	630.0 nm	250 km

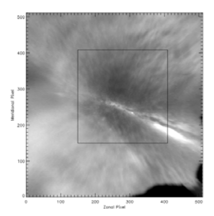
❖ We analyzed ASC data of March ~ October, 2012-2016.

- Criteria of clear condition image sequence for analysis window (image sequence)
  ① Duration time for clear condition: Over 1 hour
  ② Valid region for clear condition: Over 100 *pix* x 100 *pix* (~100 km x 100 km)



Year	Operated day
2012	216
2013	195
2014	210
2015	197
2016	187

Operated days	Clear days	Windows
195	29	31



Total analyzed windows
107

KSS MR (Meteor Radar)

- has been operating since March 2007.
- daily detects meteor echoes of 15,000 – 40,000.
- obtains horizontal wind information from radial velocities of echoes backscattered by meteor trail in the MLT region → Wind profiles from 80 to 100 km with bin of 2km.

MERRA2 (Modern-Era Retrospective analysis for Research and Applications)

- is global atmospheric reanalysis data.
- produced by NASA Global Modeling and Assimilation Office.
- obtains horizontal wind profiles in 0 – 64 km were derived.

ASC Data Analysis

- We applied a new spectral analysis method (M-transform) developed *by Matsuda et al. (2014)* to ASC image sequences to derive phase velocity spectra.

M-transform

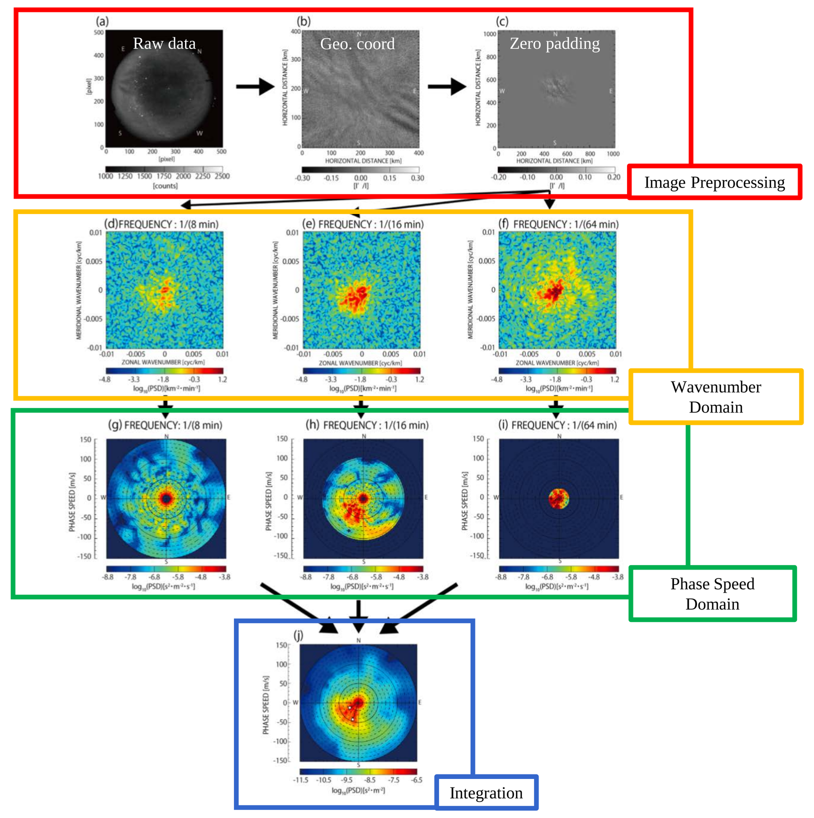


Image preprocessing
$F_0(\theta,\varphi,t) \rightarrow F_1(x,y,t)$

Coble et al., 1998

3D-FFT
$F_1(x,y,t) \rightarrow F_2(k,l,w)$

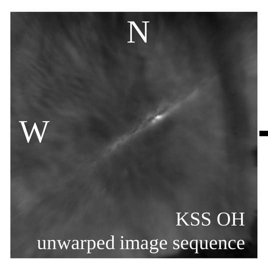
Matsuda et al., 2014

[Horizontal]
Wavenumber to phase speed domain
$F_2(k,l,w) \rightarrow F_3(v_x,v_y,w)$
$v_x = \frac{wk}{k^2+l^2} \quad v_y = \frac{lk}{k^2+l^2}$

Integration over frequency
$F_3(v_x,v_y,w) \rightarrow F_4(v_x,v_y)$

1. Requires time series of 2D images (x,y,t) preprocessed by a sequence of ①Star removal ②Dark count removal ③Projection onto geographical coordinates ④Calculating relative airglow intensity perturbation ⑤Prewhitening ⑥2-D Hanning window ⑦Zero padding.
2. Uses 3 Dimensional-Fast Fourier Transform (3d-FFT) and calculates 3-D spectrum as a function of frequency(w), zonal wave number(k), meridional wave number(l) by performing the 3-D discrete Fourier transformation [*Coble et al., 1998*]. Then, the 3-D spectrum is converted to the phase velocity domain.
3. Calculates 2-D phase velocity spectrum from the integrated 3-D phase velocity spectrum in the frequency domain.

- Can display the distribution of GW phase velocity and direction, providing information on GW amplitudes and spatial extent of wave packet in the ASC image sequence.
- Provides objective results with a shorter analysis time and uses ASC data spatially broader, longer in time and wider in frequency than conventional manual ASC data analysis ASC data.
- Is simple and user-friendly IDL software package for ASC data spectral analysis developed from National Institute of Polar Research (NIPR) [*Perwitasari et al., 2018*].

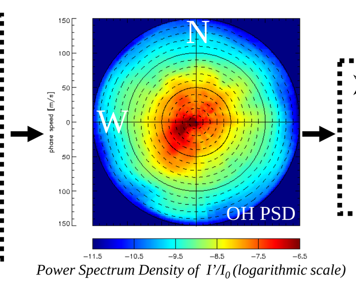


M-transform

$I'/I_0(=\rho'/\rho_0)$

Input data: $\frac{I'}{I_0} = \frac{I-\bar{I}}{\bar{I}}$

$\bar{I}$: Temporal mean of image sequence
Horizontal wavelength range: 10-100 km

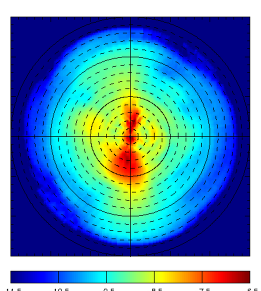


Power Spectrum Density of I'/I_0 (logarithmic scale)

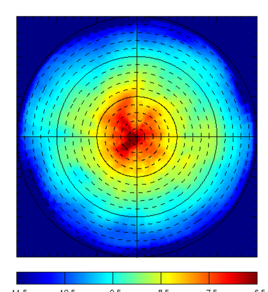
➢Providing Wave Properties
✓ Propagating direction
✓ Phase velocity
✓ Spectral power

Motivation: Different seasonal behavior of GWs on KSS ASC

Please scan to see using QR codes!



Fall & Spring
→ Monochromatic structures

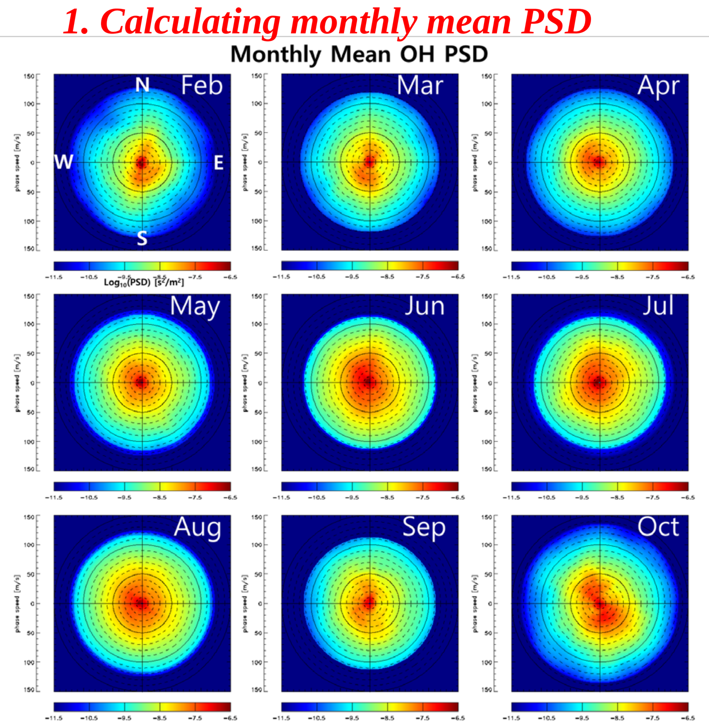


Winter
→ Complex structures

Results & Discussion

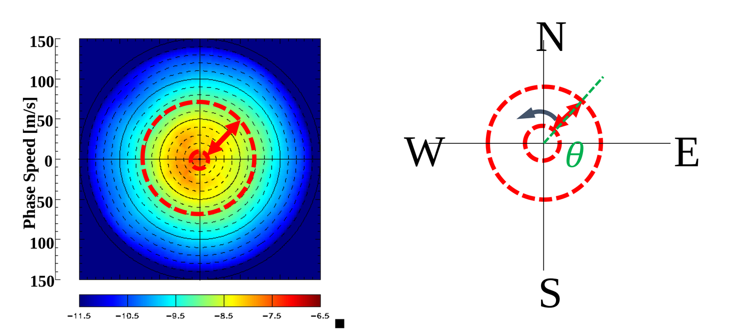
◆ Climatologic pattern of mesospheric short period GWs over KSS

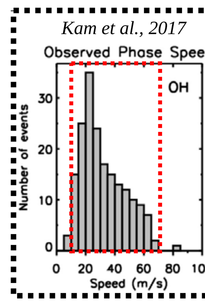
1. Calculating monthly mean PSD



2. Calculating mean PSD on

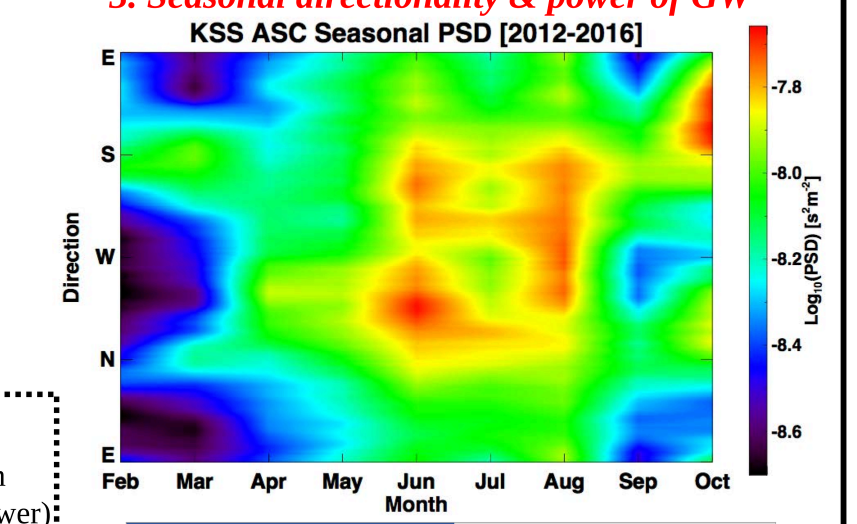
1° resolution of azimuth angle (θ) & phase speed between 10-70m/s





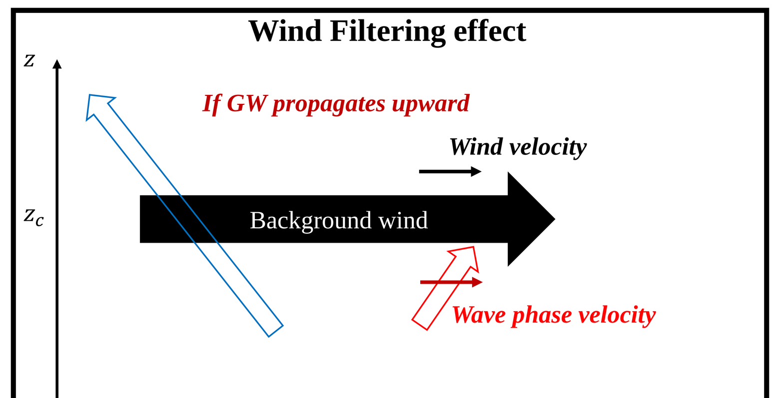
Select a dominant range of phase speed from results of striking events analysis (strong power)
→ 10m/s ~ 70 m/s : 99.5% of distribution
(Maximum counts in 20-25 m/s)

3. Seasonal directionality & power of GW

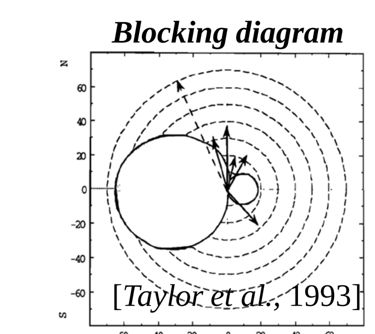


Dominant propagating direction	Fall: Southward Winter: Westward Spring: Southern-eastward
Wave activities (power & spread)	Fall < Spring < Winter

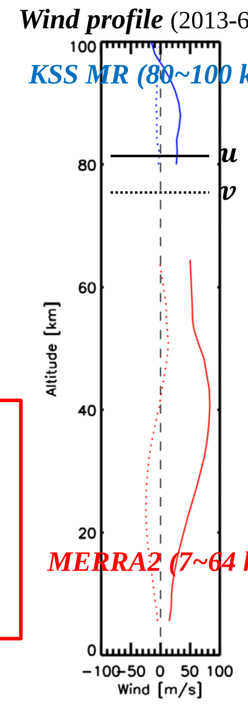
◆ Wind filtering effect: Inference from Blocking Diagram using horizontal winds



z_c: Horizontal wave vector ≈ Wind vector
→ Intrinsic phase speed ≈ 0
Before wave reaches z_c
→ Production of turbulence.
→ Wave field breaks down into turbulence.
→ Wave cannot propagate above z_c.



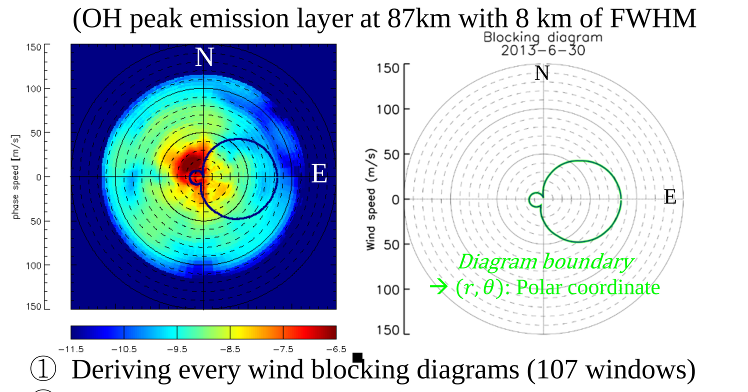
$\widehat{c_h} = c_h - (u\cos\theta + v\sin\theta)$
$\widehat{c_h}$: Intrinsic phase speed
c_h: Ground-based phase speed
u: **zonal wind**
v: **meridional wind**
θ: propagating direction (0°~360°)



4. Climatologic wind blocking diagram

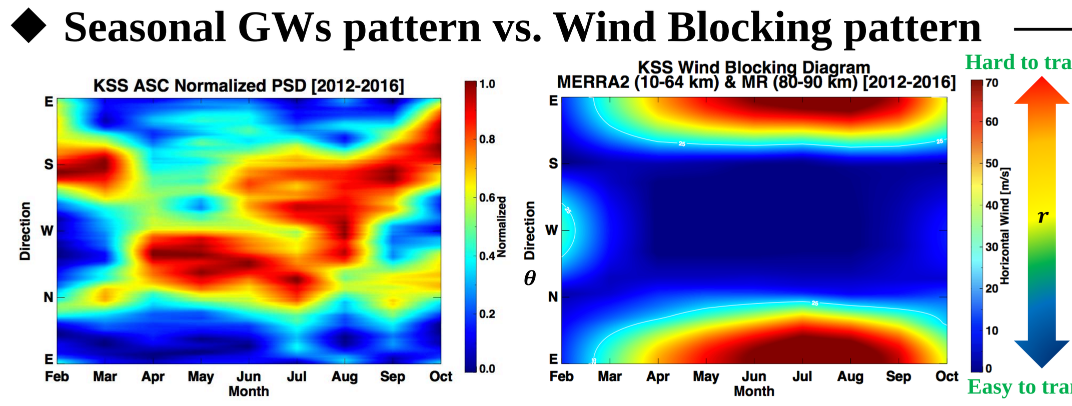
Wind selection range: 10-64 km & 80-90 km
- MERRA2: 10 ~ 64 km
- KSS MR: 80 ~ 90 km

(OH peak emission layer at 87km with 8 km of FWHM



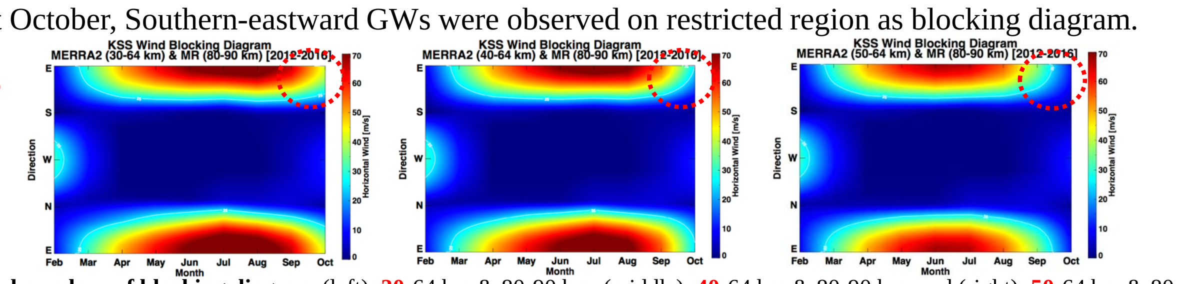
① Deriving every wind blocking diagrams (107 windows)
② Monthly averaged blocking diagram for 5 years
③ Converting polar coordinate (r,θ)
: r - magnitude of diagram boundary at θ (azimuth angle)
→ resolution of 1m/s & 1°

◆ Seasonal GWs pattern vs. Wind Blocking pattern

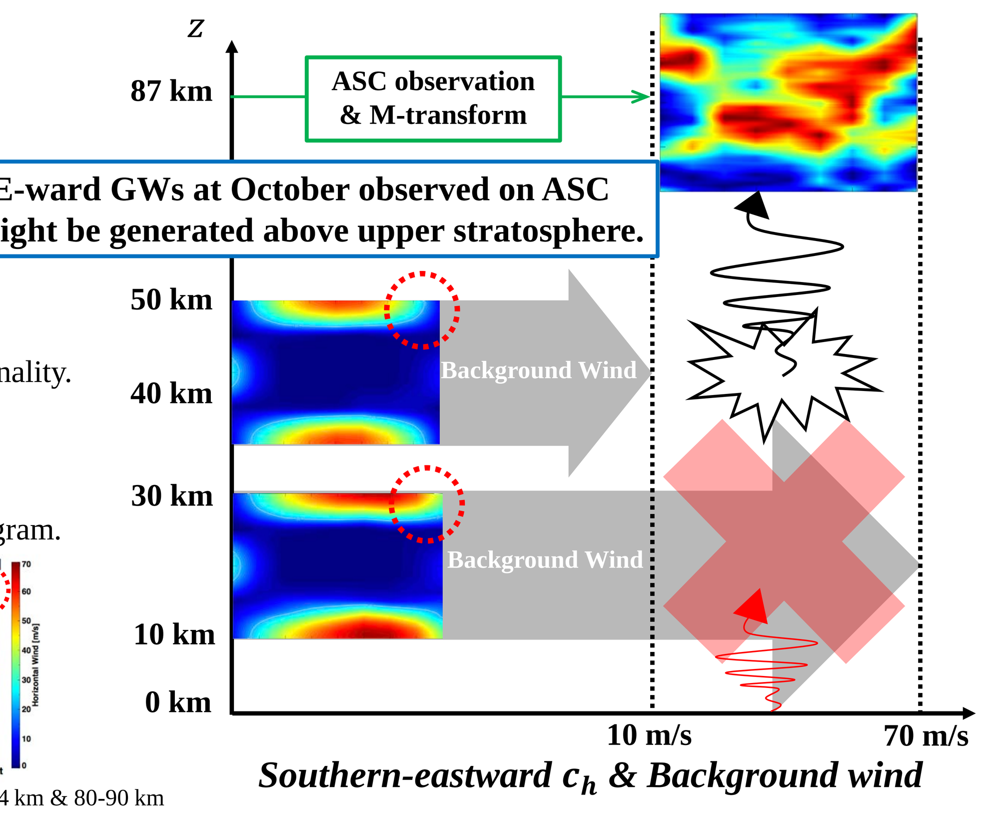


Calculating monthly normalized PSD (left) to concentrate on seasonal dominant propagating directionality.
1. Significant anti-correlation between GW PSD (left) and the wind blocking diagram (right).
→Obvious evidence of critical level filtering from KSS ASC observation.
2. By the blocking diagram, Southern-eastward GWs should not be observed at October.
→ However, at October, Southern-eastward GWs were observed on restricted region as blocking diagram.

Inference SE-GWs source at October



Changing the lower boundary of blocking diagram (left): **30**-64 km & 80-90 km, (middle): **40**-64 km & 80-90 km, and (right): **50**-64 km & 80-90 km



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