Byeong-Gwon Song
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Gravity Wave Activities in the Upper Mesosphere Observed by Meteor Radar at King Sejong Station, Antarctica and Their Potential Sources

Byeong-Gwon Song[1], In-Sun Song[1], Hye-Yeong Chun[2], and Changsup Lee[1]

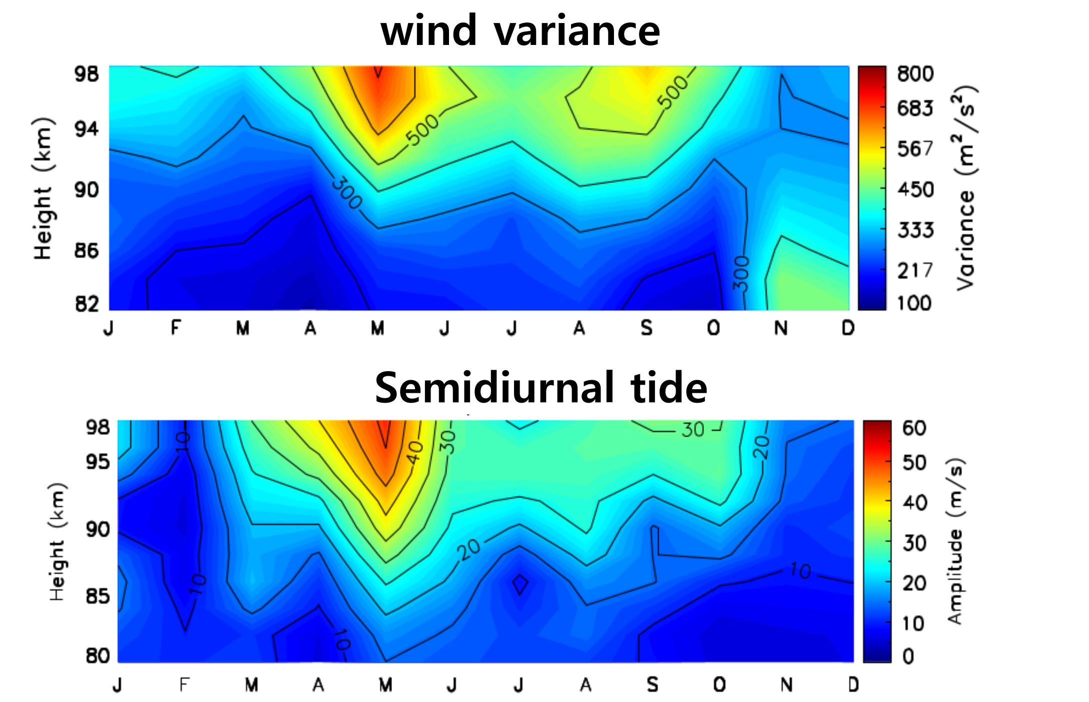
[1] Division of Polar Climate Research, Korea Polar Research Institute, Korea
[2] Department of Atmospheric Sciences, Yonsei University, Korea

Introduction

- Atmospheric gravity waves (GWs), which were generated from various sources in the lower atmosphere, play a major role in determining the spatiotemporal characteristics of the middle and upper atmosphere by transferring momentum and energy from the lower to the upper layers.
- GWs in the mesosphere have been observed using
  - radar (e.g., Vincent and Reid 1983; Vincent and Fritts 1987; Fritts and Vincent 1987)
  - lidar (e.g., Chanin and Hauchecorne 1981, Wilson et al. 1991, Beatty et al. 1992)
  - all-sky airglow imager (e.g., Fritts et al. 2002; Brown et al. 2004)
  - satellite (e.g., Ern et al. 2011; Kalish et al. 2016)
  - meteor radar (e.g., Mitchell and Beldon 2009; Beldon and Mitchell 2009; Lee et al. 2013; Song et al. 2017)
- Observational studies of GWs in the upper mesosphere using meteor radar have been primarily conducted in the Arctic and the Antarctic region.
- High latitude region in the southern hemisphere including the Antarctica is one of the areas where highest GW activities in the middle atmosphere exist. King Sejong Station (KSS) is in a hot spot of strong GW activity along the Antarctic Peninsula.

Introduction

- Upper mesospheric winds at KSS have been observed using very high frequency (VHF) meteor radar since March 2007, and researchers have examined GW activity at this level using wind variance method (Lee et al. 2013).
- However, the wind variances and the semidiurnal tidal amplitudes have very similar seasonal variability across the entire height range (Lee et al. 2013). Therefore, it is required to remove the large-scale wind components including tides properly to investigate the GW activity in the mesosphere.
- Understandin … lar regions, where climat … s a deeper knowledge of
- Because the … rtant to analyze the i … ospheric GWs variability.



(Lee et al., 2013, JASTP)

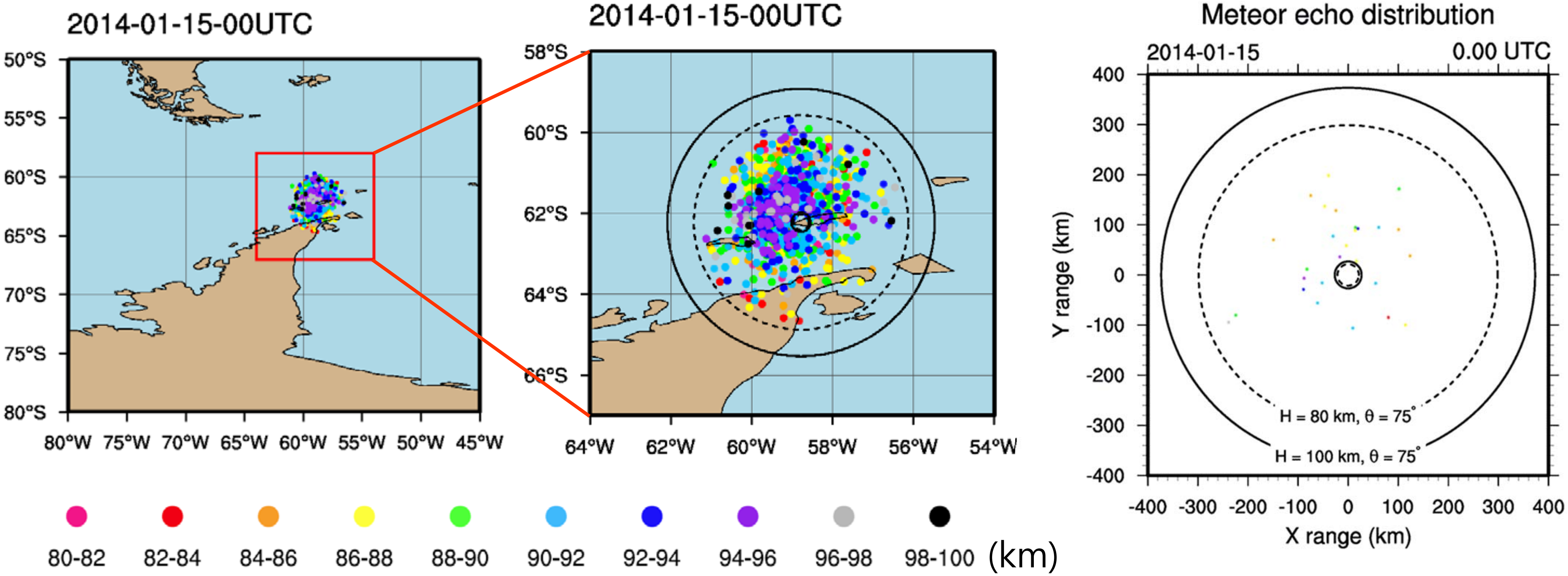
In this stu

- the vari … e using wind va … properly
- their **po**

Data and Methodology

❖ **Meteor radar data at KSS**

Meteor radar at KSS		
Variables		U, V, U variance, V variance
Period		Mar. 2007—Dec. 2014
Resolution	Temporal	1 hour (sampling: every 2 min)
	Vertical	2 km (80—100km, 11 levels)



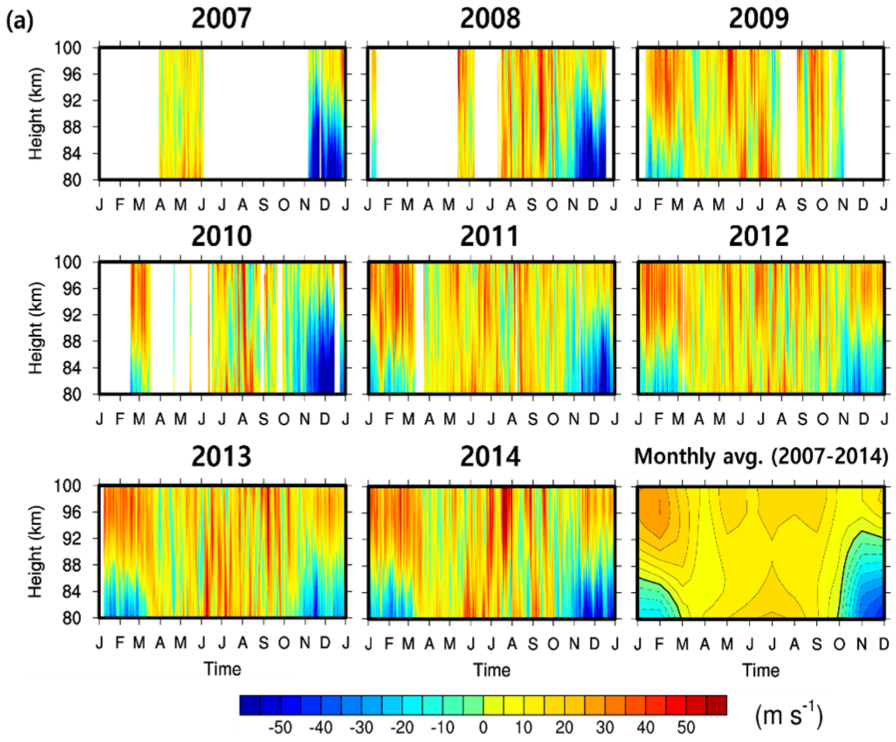
- The meteor radar at KSS can automatically monitor approximately 15,000 to 35,000 meteors per day, regardless of weather conditions
- Using the radial velocity and spatial information (azimuth angle, zenith angle, and distance to echo) of the meteor echo, we calculated the zonal and meridional winds averaged over an altitude-time space of 2 km and 1 hour

Data and Methodology

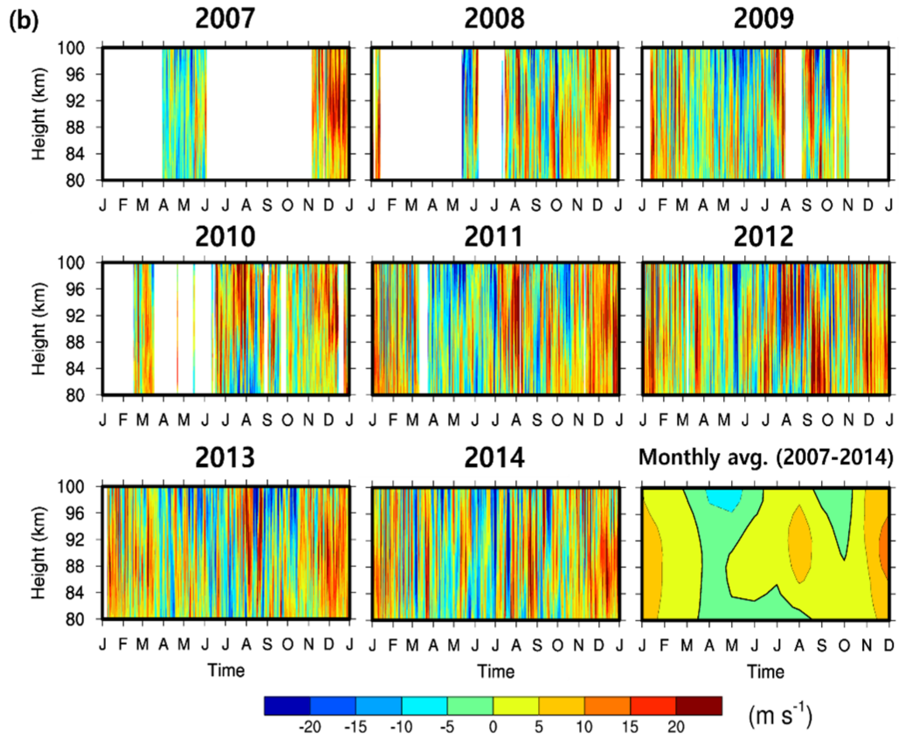
❖ Zonal and meridional wind

- Zonal and meridional components of horizontal winds are computed from the meteor radar echoes and radial velocities using the method by Hocking and Thayaparan (1997), in a time-height bin of 1 hour and 2 km.

Zonal wind



Meridional wind



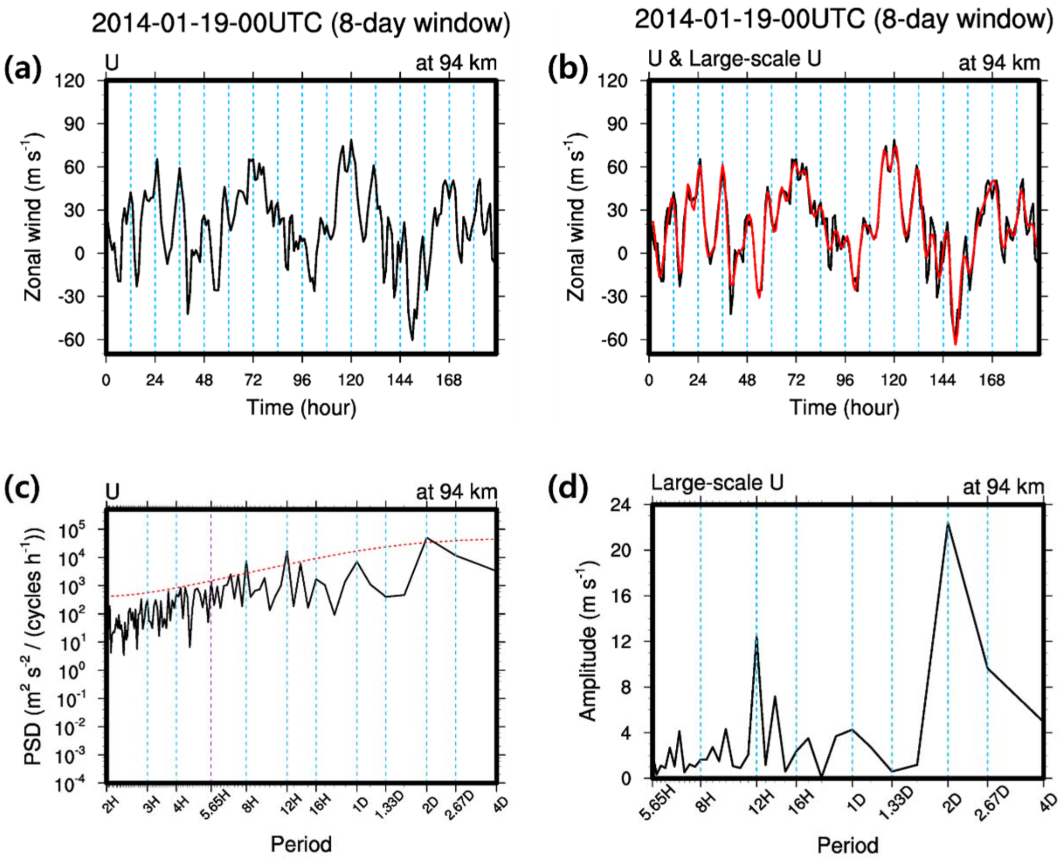
- Late spring–early autumn:
  easterlies (~–40 m s^{-1}) at 80–90 km,
  westerlies (~30 m s^{-1}) at 90–100 km
- Late autumn- early spring: westerlies

- Smaller than the zonal wind
- more various from the daily to annual timescales than the zonal wind
- mostly southerly, except in autumn and spring

Data and Methodology

❖ Large-scale wind components

- The wave components with periods longer than 5.5 hour within a 8-day (192 hrs) window that moves 1-hour increment is defined as the large-scale wind at KSS (Song et al., 2017).
- This includes diurnal (24 h), semidiurnal (12 h), terdiurnal (8 h), and quardiurnal (6 h) tides, and 2-day and 4-day waves

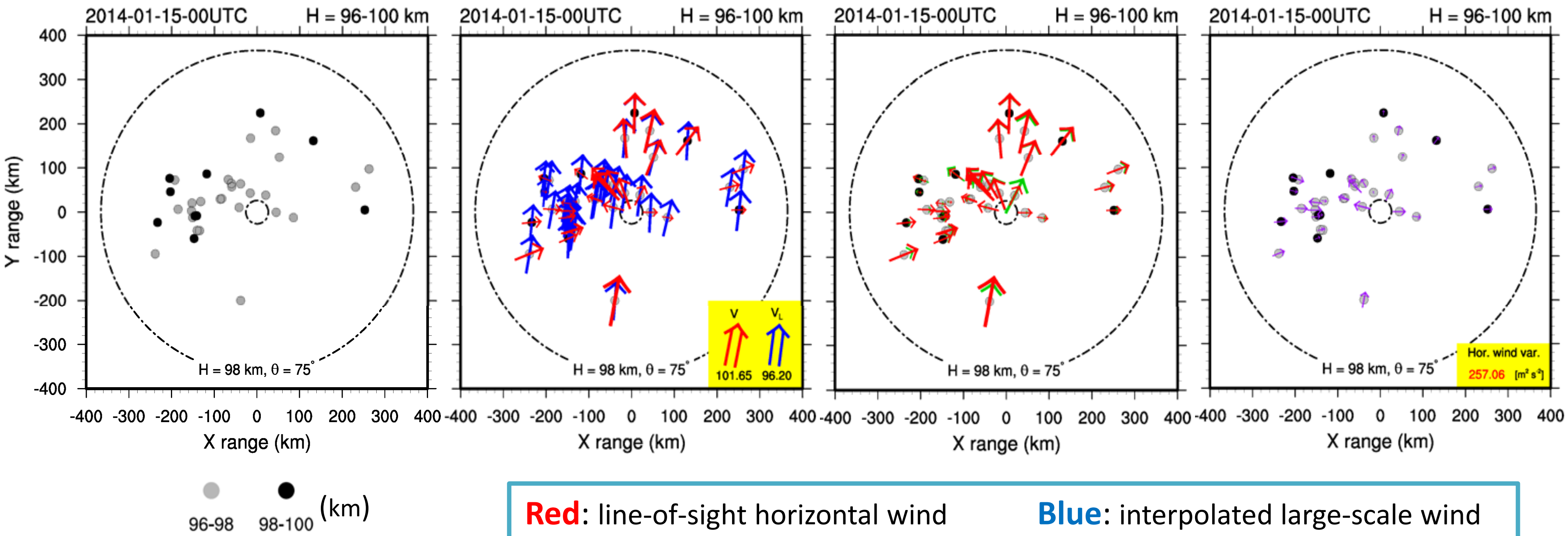


- The 2-day wave has the largest amplitude (> 20 m s^{-1}), and the amplitude of 4-day is also significant (larger than 5 m s^{-1})
- The amplitude of the semidiurnal tide is about of 12 m s^{-1}, which is the largest among the four tidal components.
- Activities of the 2-day waves observed in the polar regions are known to be strong in both summer and winter (Baumgaertner et al. 2008)

Data and Methodology

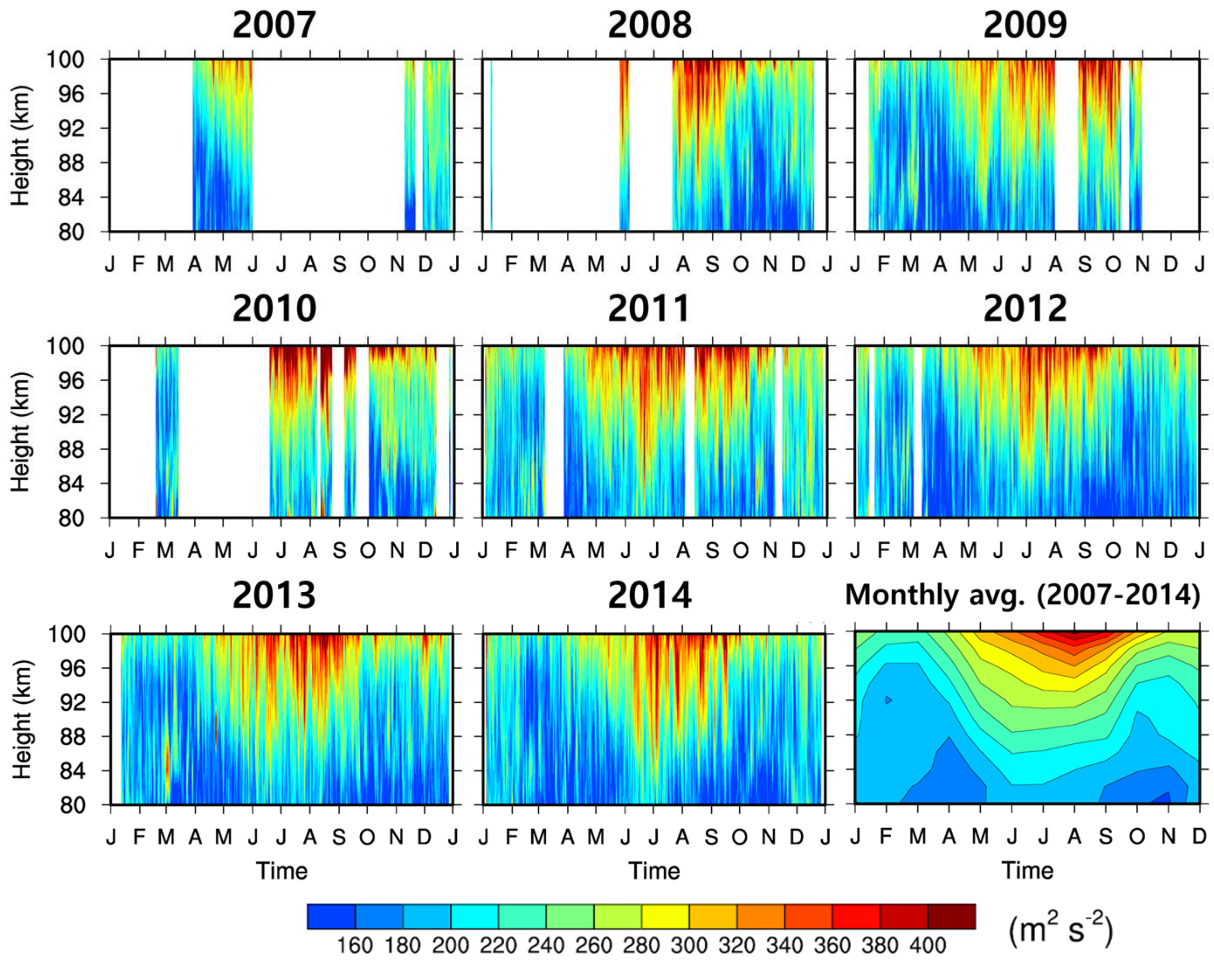
❖ Extracting GW components

- We propose a new methodology to explicitly remove the large-scale wind from each meteor echo by interpolating the large-scale winds into each meteor echo location and time.
  - interpolate 2-dimensional (time and height) wind data
  - project the interpolated winds in the line-of-sight horizontal direction
  - subtract the projected large-scale winds from the observed winds
  - calculate GW variances



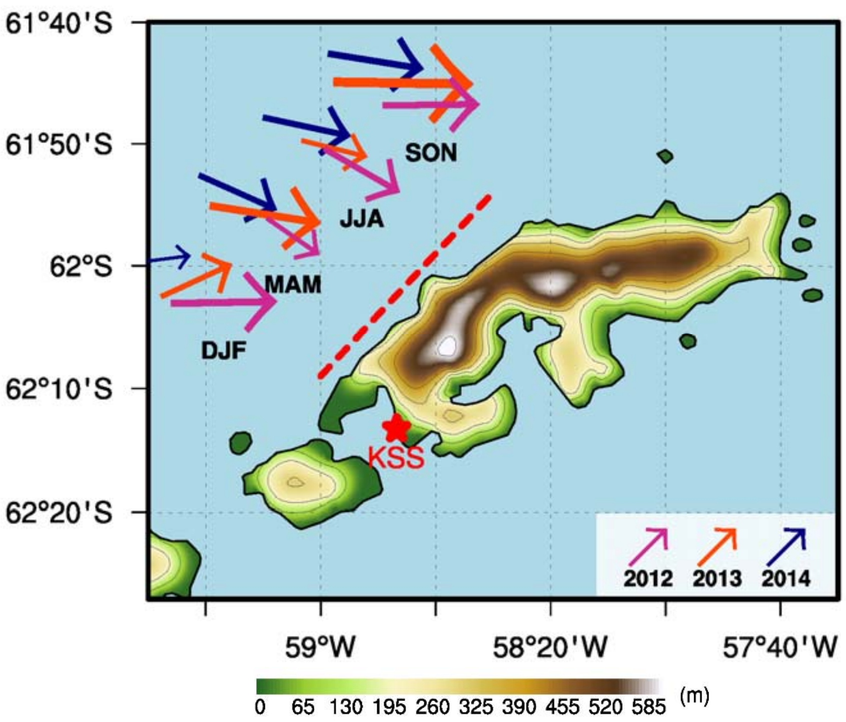
Red: line-of-sight horizontal wind **Blue**: interpolated large-scale wind
Green: large-scale wind projected on the line-of-sight direction
Purple: difference between the red and green (**small-scale GWs**)

Horizontal wind variance in the upper mesosphere at KSS



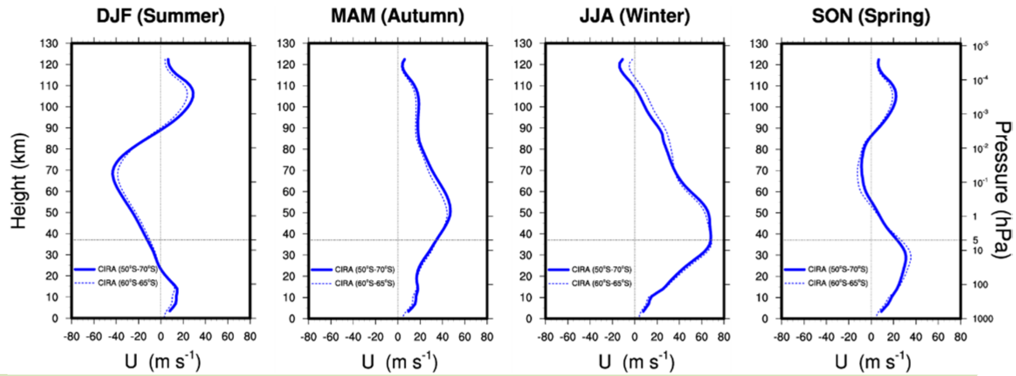
- GW activity in the upper mesosphere shows a semi-annual variability, with a dominant peak in winter (June-September), secondary peak in summer, and minimum in the equinoxes.
- This is related to the seasonal changes in the background wind, which is the strongest in the solstices and the weakest in the equinoxes.

Potential Sources of the Observed GWs- Orography



➢ Percentage of days when rotation of the horizontal wind vector at the northeast side of the King George Island is less than 90° in the altitude range 925–1 hPa.

	DJF	MAM	JJA	SON	(%)
2012	17.6	58.7	78.3	25.3	
2013	28.6	79.3	80.4	27.5	
2014	51.6	64.1	72.8	28.6	
Avg.	32.6	67.4	77.2	27.1	



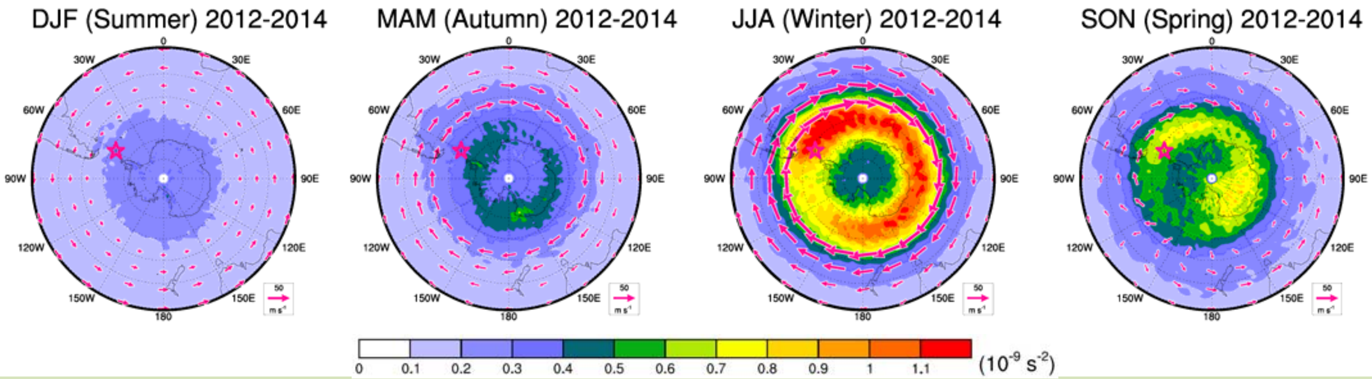
- KSS located at King George Island where steep mountains exist.
- Following Yamashita et al. (2009), we calculate percentages of days when rotation of the horizontal wind vector is less than 90° in the altitude range 925–1hPa under assumption that GWs are filtered by critical level if the rotation of wind vector exceeds 90°.
- Orography can be considered as a major wave source in winter.

Polar night jet

❖ **RNBE (residual of nonlinear balance equation** (Zhang 2004; Chun et al. 2013, 2019)

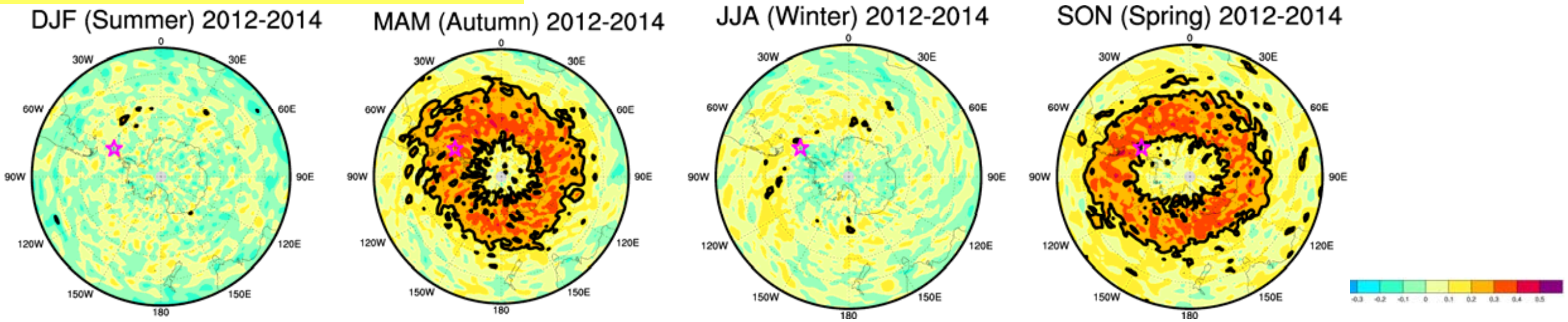
$$RNBE = f\zeta - \nabla^2\Phi + 2J(u,v) - \beta u + X - \left(\vec{\nabla}\cdot\vec{V}\right)^2 - \frac{\partial \vec{V}}{\partial p}\cdot\vec{\nabla}\omega$$

5 hPa



- Large |RNBE| along the **polar vortex** in the stratosphere, especially during **winter** season

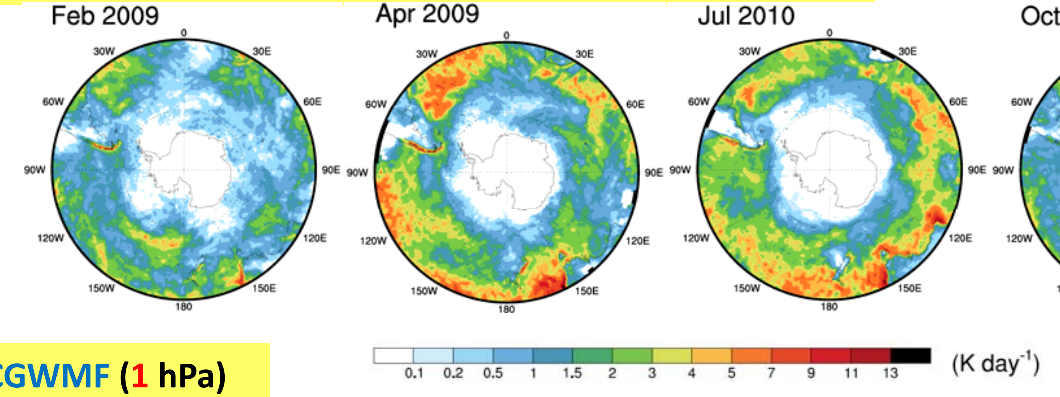
Corr. Wind variance (98km) vs |RNBE| (5 hPa)



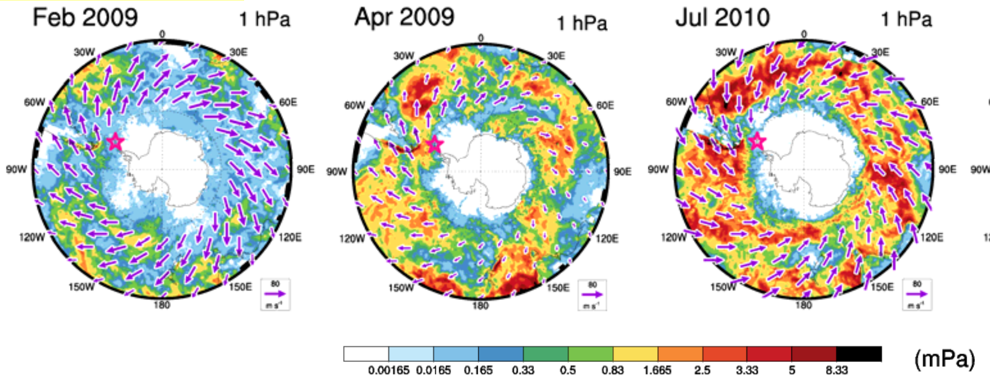
- GW activities observed in the upper mesosphere in **spring** and **autumn** are **associated with the jet stream** in the upper stratosphere
- In **winter**, there are **no** areas with **significant correlation**, due to the critical level **filtering** and the **Doppler shifting** by the strong wind speed and wind shear in wintertime.

Convection

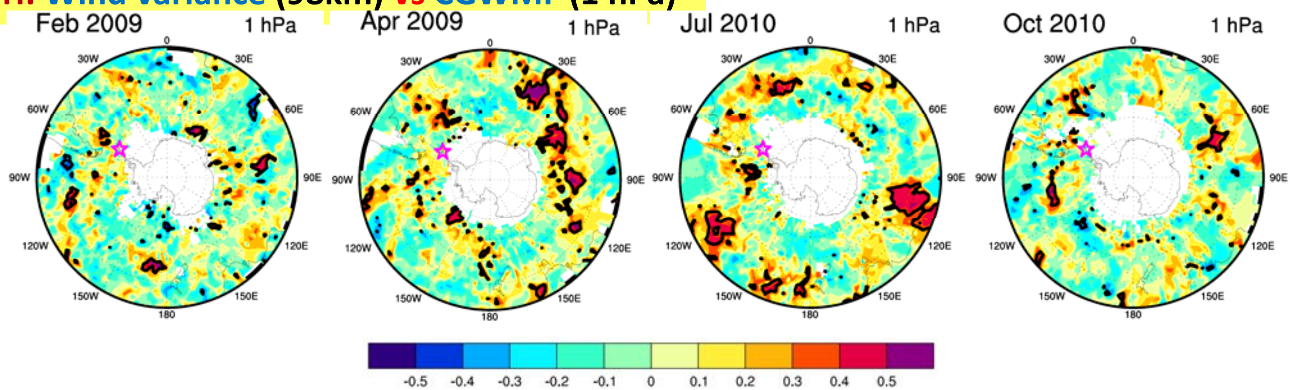
Column-maximum deep Convective Heating rate (DCH)



CGWMF (1 hPa)



Corr. Wind variance (98km) vs CGWMF (1 hPa)



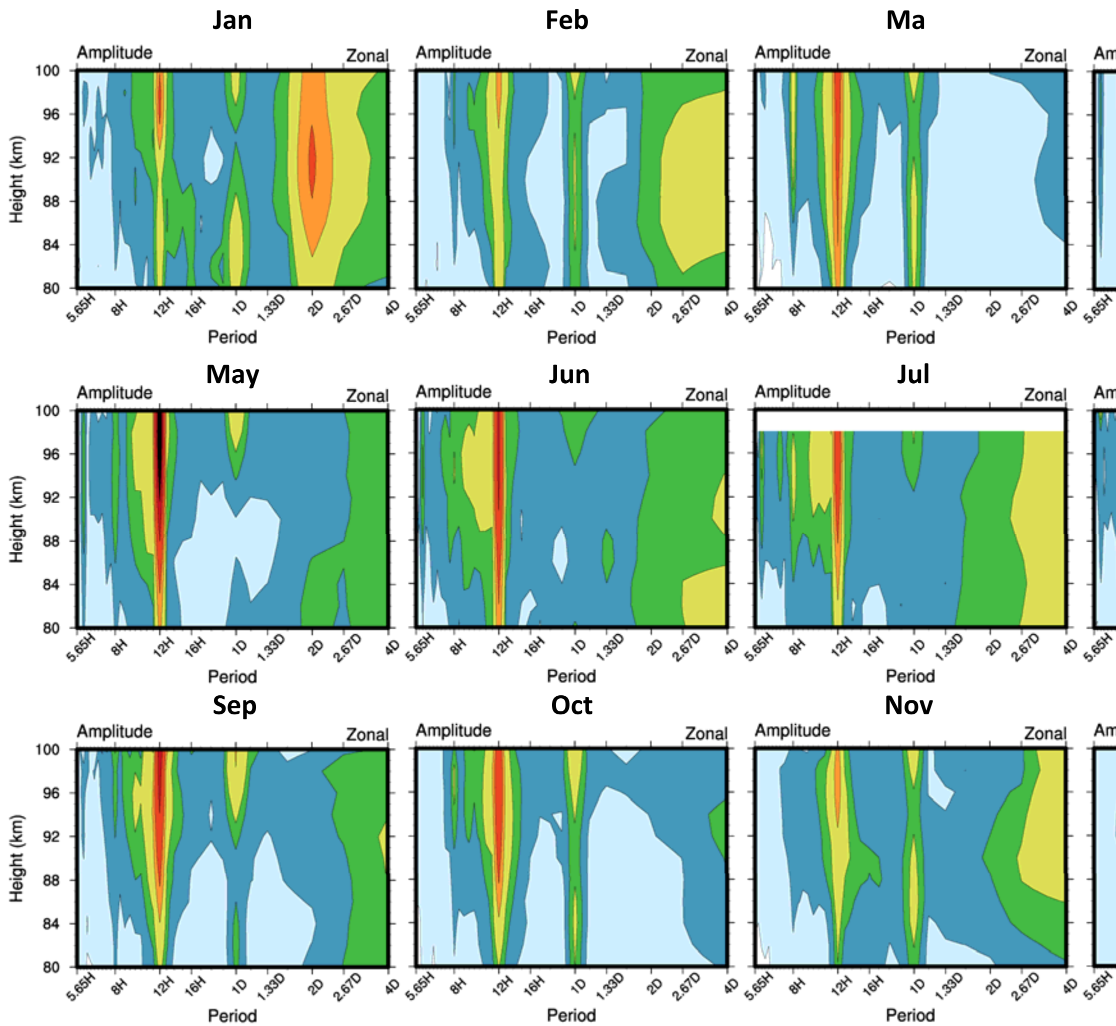
- DCH is provided from CFSR global reanalysis data (Saha et al. 2010) and momentum flux of convective GWs (CGWMF) is calculated using off-line convective GWD parameterization by Kang et al. (2018, JAS) using the CFSR data.
- The largest CGWMF exist in the storm-track regions in the wintertime.
- Significant correlations suggest that convection in storm tracks can be a possible source of GWs observed at KSS in wintertime, although strong correlation occurs locally in other seasons as well.

Summary

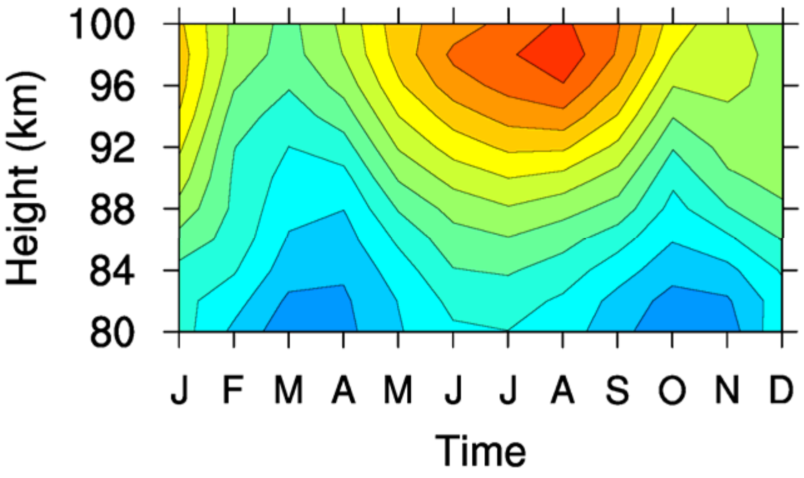
- Meteor radar at KSS in the Antarctic Peninsula are used to analyze winds and wind variances in the upper mesosphere over an 8-year period (2007–2014).
- A semi-annual variation of GW activities in the upper mesosphere with solsticial maxima and equinoctial minima exists, except above 94 km where maximum GW variance appears in August–September.
- GWs generated by orography can reach the upper mesosphere without encountering a critical level due to the strong westerly from the troposphere to the mesosphere in wintertime.
- The RNBE in the upper stratosphere correlated well with observed GWs in the upper mesosphere, particularly in spring and autumn.
- Deep convection in the midlatitude storm-track regions can be considered as a possible source of GWs in autumn and winter.
- In order to understand the source of GWs more accurately, 3-dimensional propagation of GWs should be considered. To this end, we are now using KSS meteor radar and airglow all-sky camera data to examine the backward integration of a 3-dimensional GW ray-tracing model.

THANK YOU.

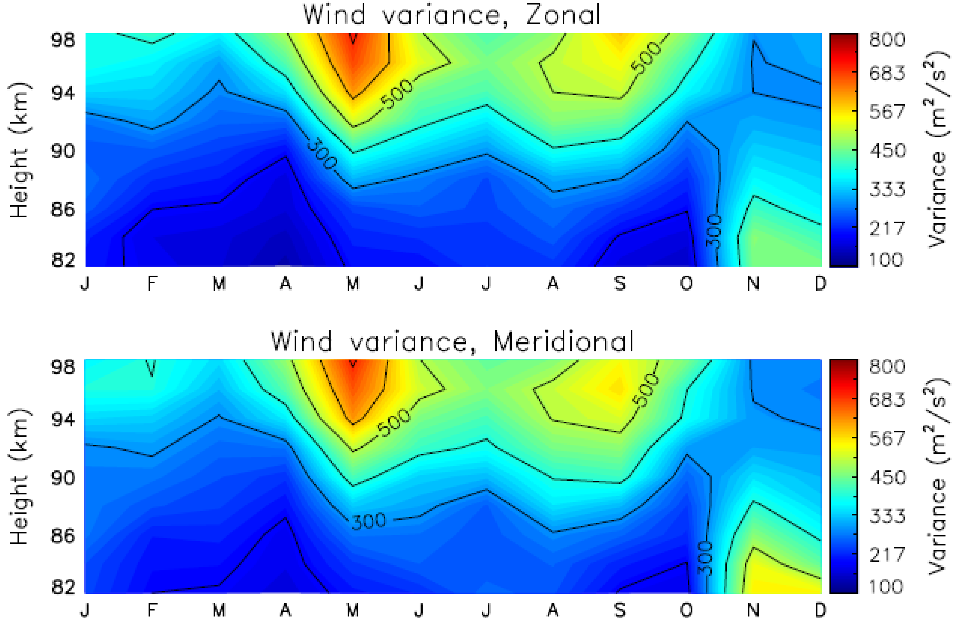
Large-scale wind components



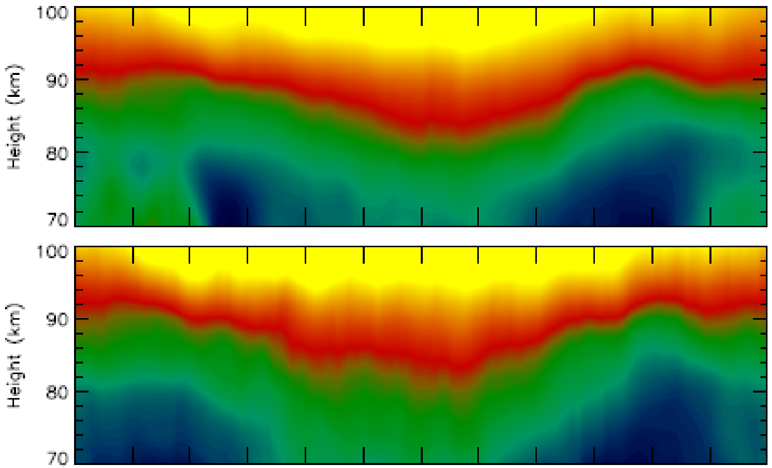
Motivation



Wind variance (GWs)



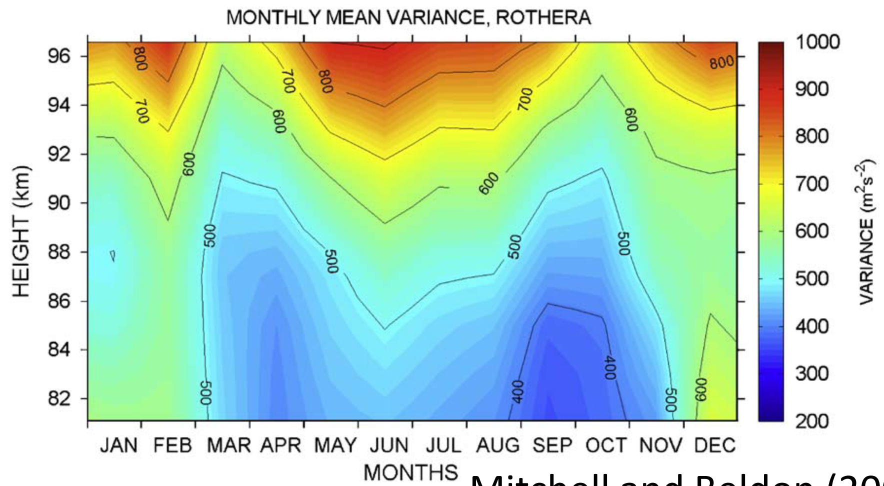
Lee et al. (2013)



Davis

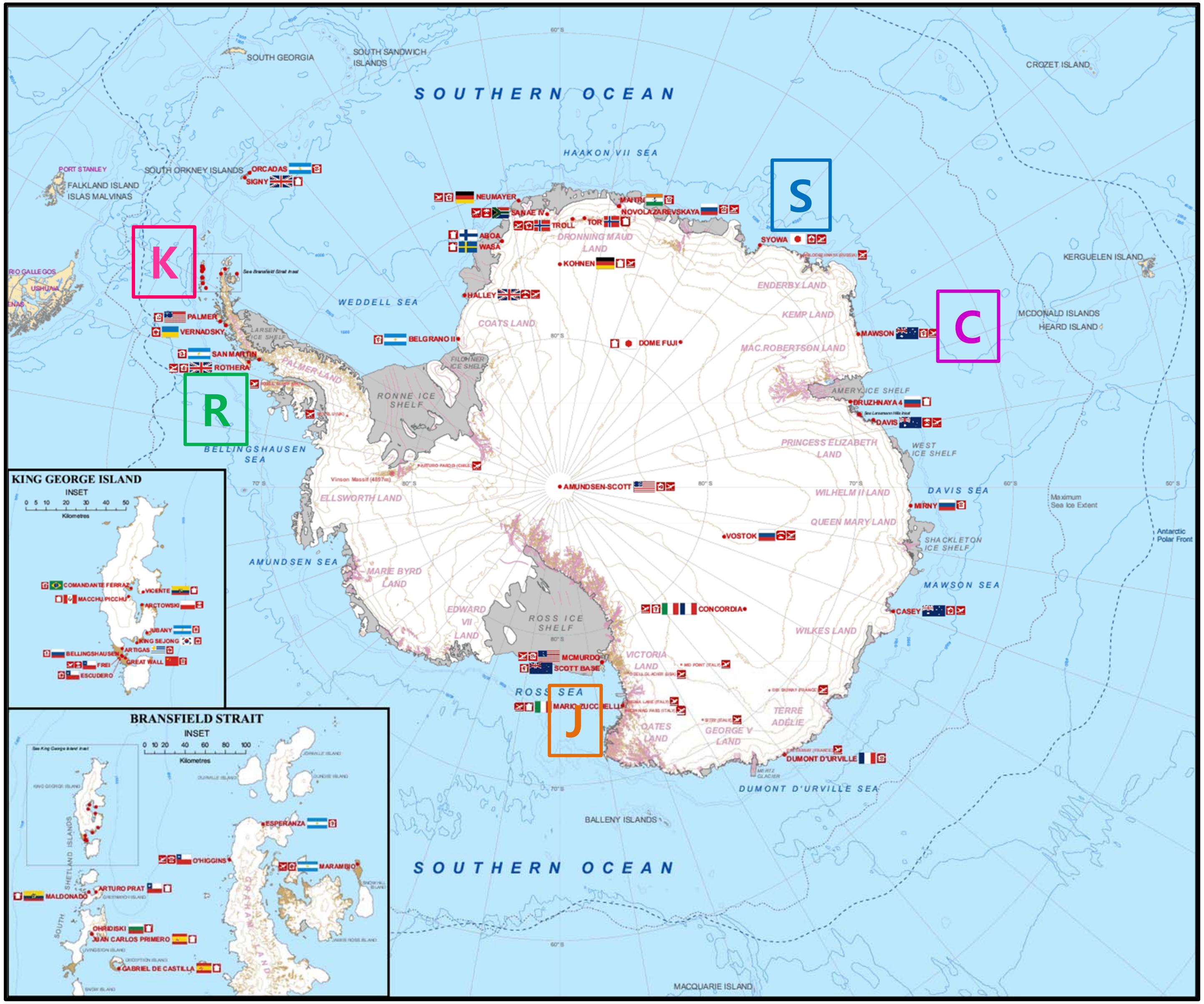
Syowa

Dowdy et al. (2007)



Mitchell and Beldon (2009)

Research stations in Antarctica



Rothera (67˚S, 68˚W)

Syowa (69˚S, 39˚E)

Casey (66˚S, 110˚E)

KSS (62˚S, 58˚W)

JBS (74˚S, 164˚E)