A study on earth climate change based on fine observations of the Antarctic atmosphere

Expedition Research Project for **the IXth** Japanese Antarctic Research Expedition (**JARE**)

(December 2016-January 2022)

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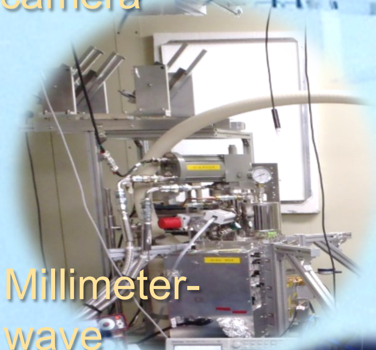
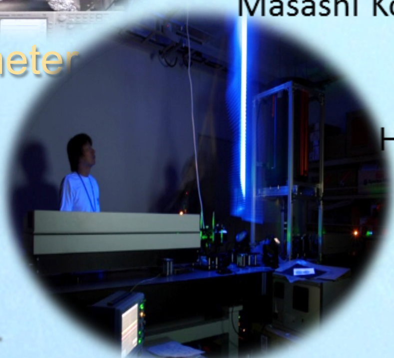




Atmospheric Dynamics in the High-Resolution Era

Real atmosphere

Ground-based obs

Satellite obs

Long-term monitoring

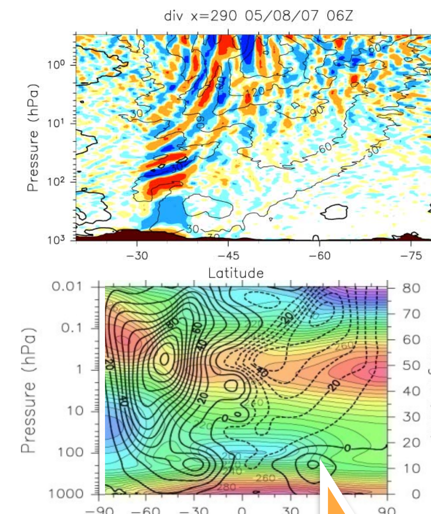
High-resolution obs

Huge data

High-resolution model

Virtual atmosphere

Idealized and realistic model simulation



Data centric science

Feedback

Feedback

New theory

Understanding of a wide spectral range of atmospheric phenomena

Better weather and climate prediction

The PANSY radar

Mesosphere-Stratosphere-Troposphere/Incoherent Scatter radar at Syowa Station (69S, 40E) in the Antarctic

System	Pulse Doppler radar. Active phased array system
Center freq.	47MHz
Antenna	Array consisting of 1045 crossed Yagi antennas <u>equivalent</u> to the circular area with a diameter of 160m ($18000m^2$), light and tough (12.6kg/antenna)
Transmitter	1045 solid-state TR modules Peak Power : 520kW
Receiver	55 channel digital receiving systems Ability of imaging and interferometry obs
Power consumption	75kW (E-class amplifier)
Peripheral	24 antennas for E-layer FAI observation

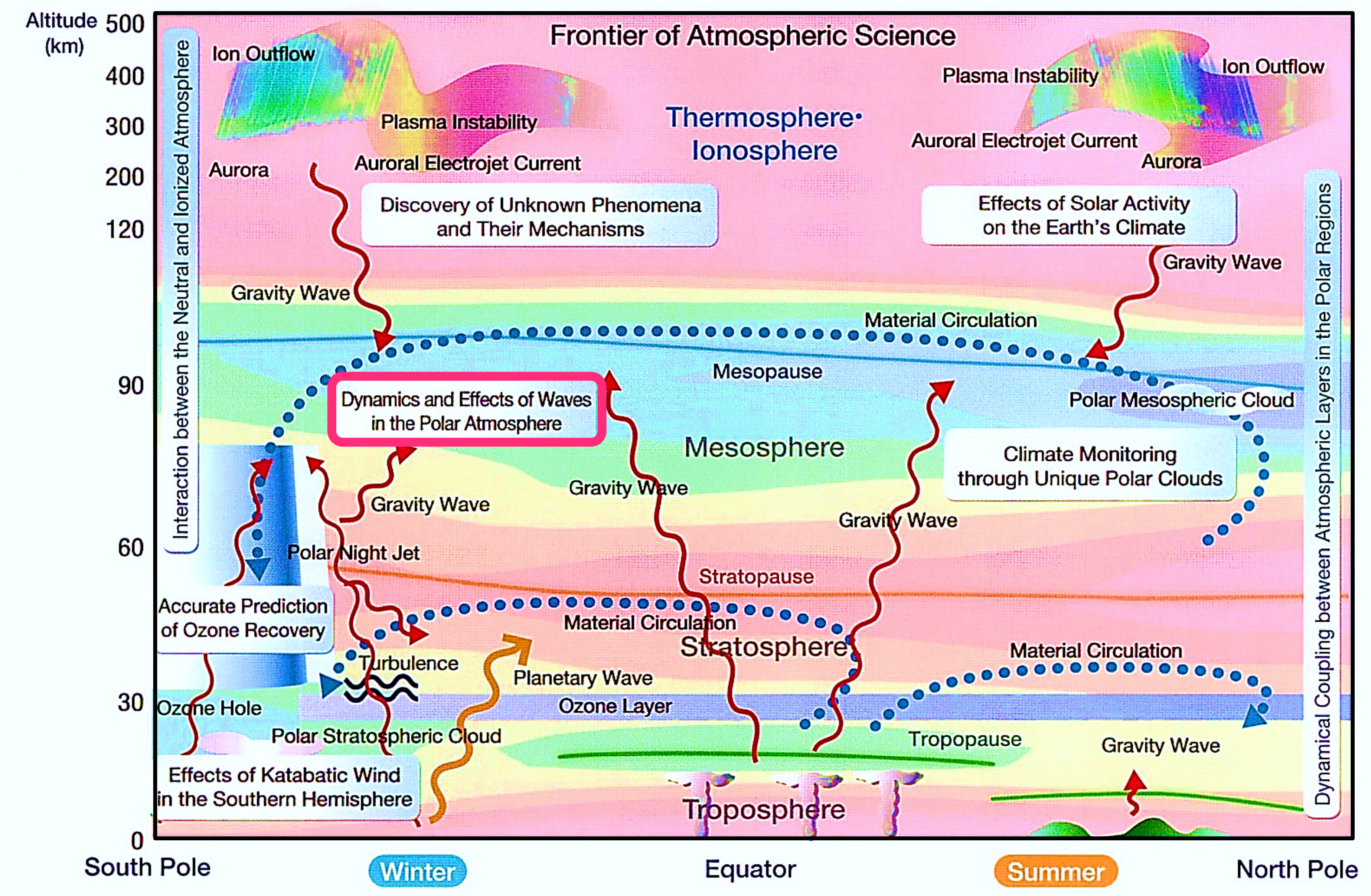
Observation of 3-d wind vectors in height regions of 1.5-20km and 60-90 km, and plasma parameters in 100-500 km with fine resolution and high accuracy

Direct estimation of vertical flux of horizontal momentum associated with gravity waves

PANSY project members

Research Topics of PANSY

Clarification of Roles of Antarctic Atmosphere in Earth Climate



The VIIIth JARE
PANSY radar construction and system tuning

JARE52 (S6, W2) 2010.12- (Dr. Tsutsumi)

Installation of 1045 antennas

1st obs with 3 grps (57antennas) on 30 Mar. 2011

JARE53 (S7, W2) 2011.12- (Drs. T. Sato, Tomikawa, Nishimura)

Relocation of antennas against heavy snow and assemblage of 12 grps. **Start of continuous obs.** on 30 April 2012

JARE54 (S5, W3) 2012.12- (Dr. Tomikawa & Mr. Hashimoto)

Assemble of additional 14 grps and continuous obs. with 11-12 grps

JARE55 (S4, W1) 2013.12-

Assemble of additional 21 grps and continuous obs. with 11-12 grps.
Test obs with a 80% system (47grps) using an exclusive power generator.

JARE56 (S3, W1) 2014.12-

Assemble of full system (55 grps) and start of **full system obs. in March 2015**.

JARE57 (S1, W2) 2015.12- (Dr. Kohma)

Successful **1st ICSOM campaign by a global MST radar network and complementary observations in Jan.-Feb. 2016**.

Continuous **MST** observation with a full system for Oct. 2015-Sep. 2016.

The radar construction started in 2010/2011

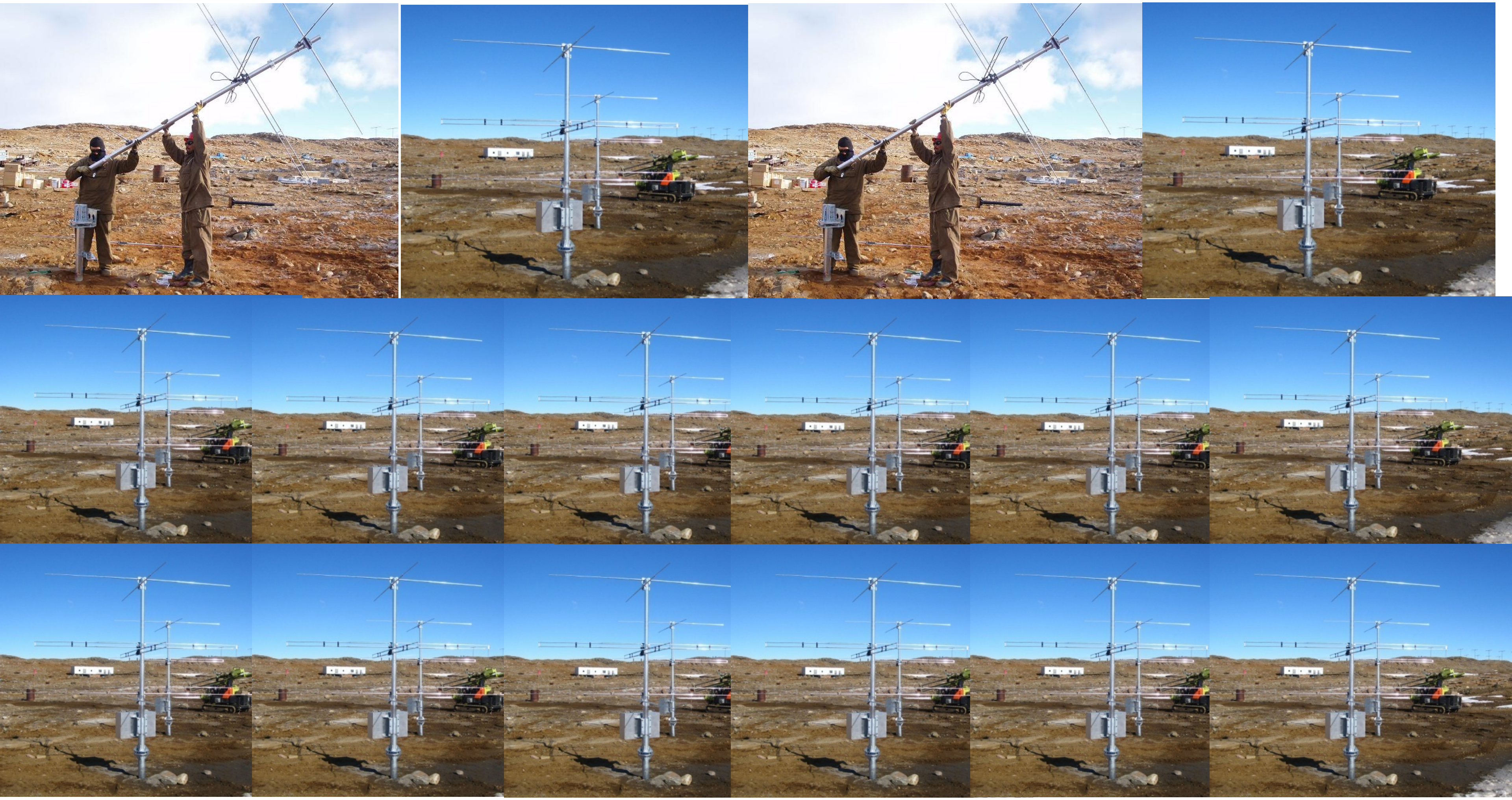
First came the antenna base installation using 4 boring machines

1045 for antennas ＋ 55 for divider/combiner modules

= 1100

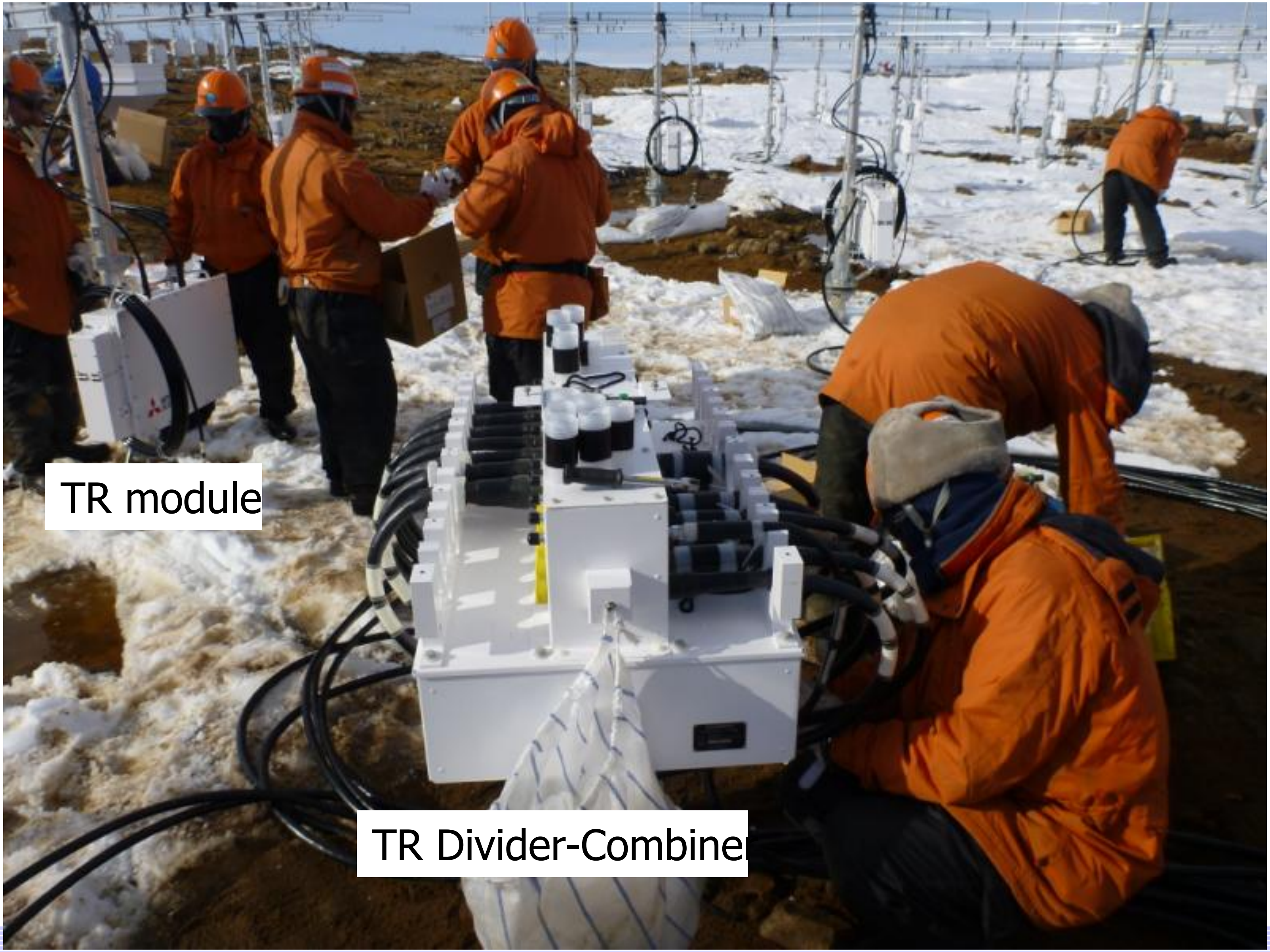
Antennas

Set up antennas on the bases

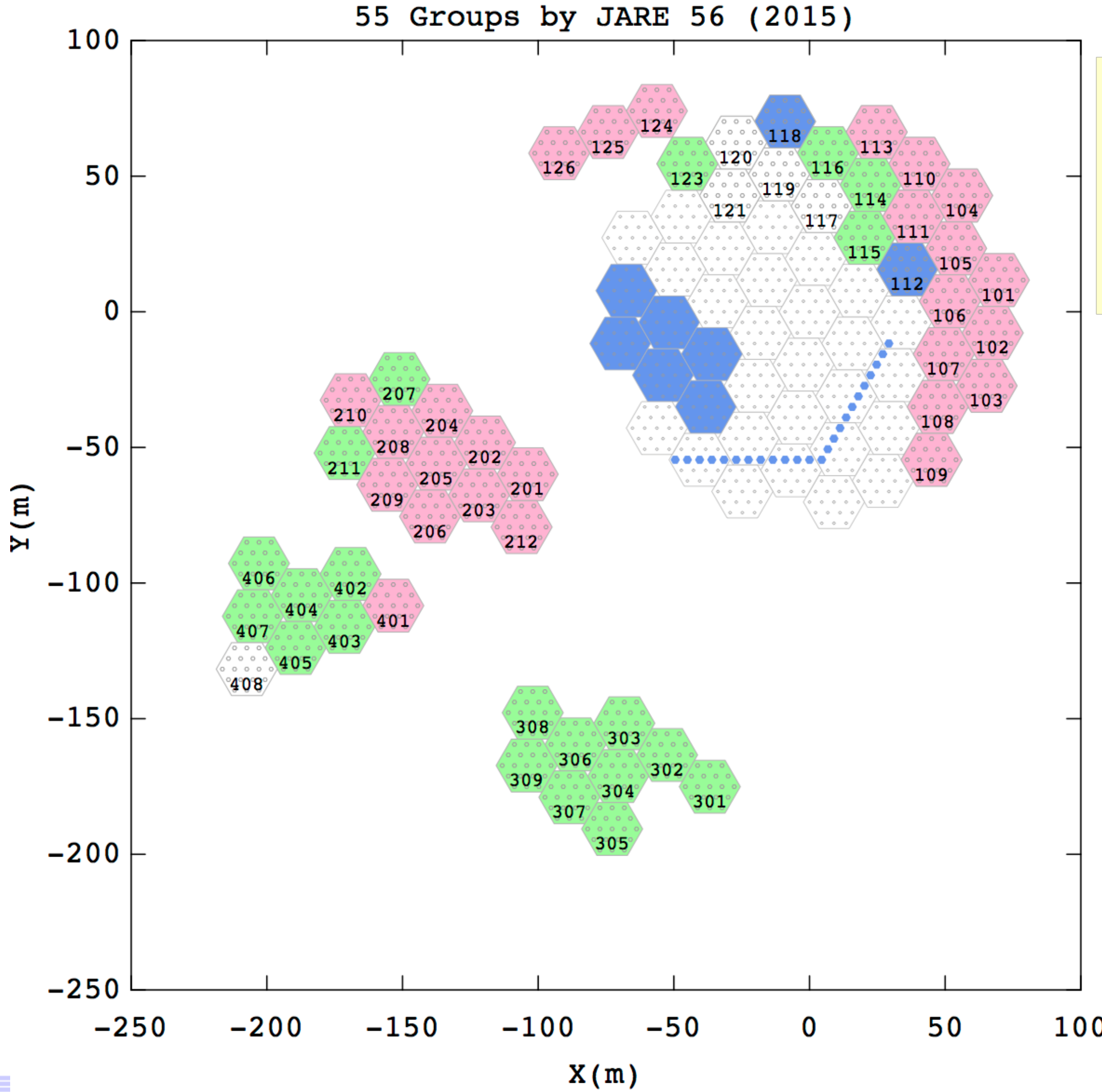


1045 antennas

Installation of TR modules



PANSY radar system



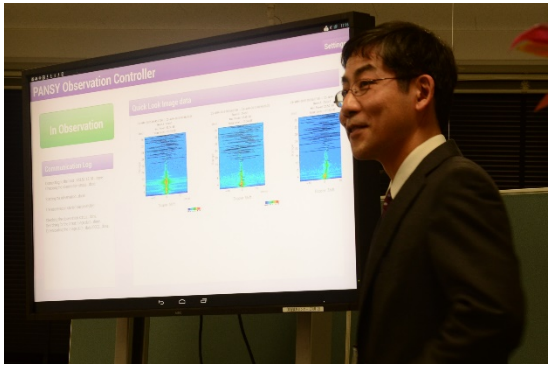
1045 antenna modules are individually controlled.
So, one beam can be formed by using all modules.

Different colors indicate modules installed in different years

The start of the PANSY complete system observation
23 March 2015

Prof. Susumu Kato
Prof. Isamu Hirota
Directors of NIPR
JARE conductors
Engineers in related-companies
PANSY group members

A ceremonial sake barrel

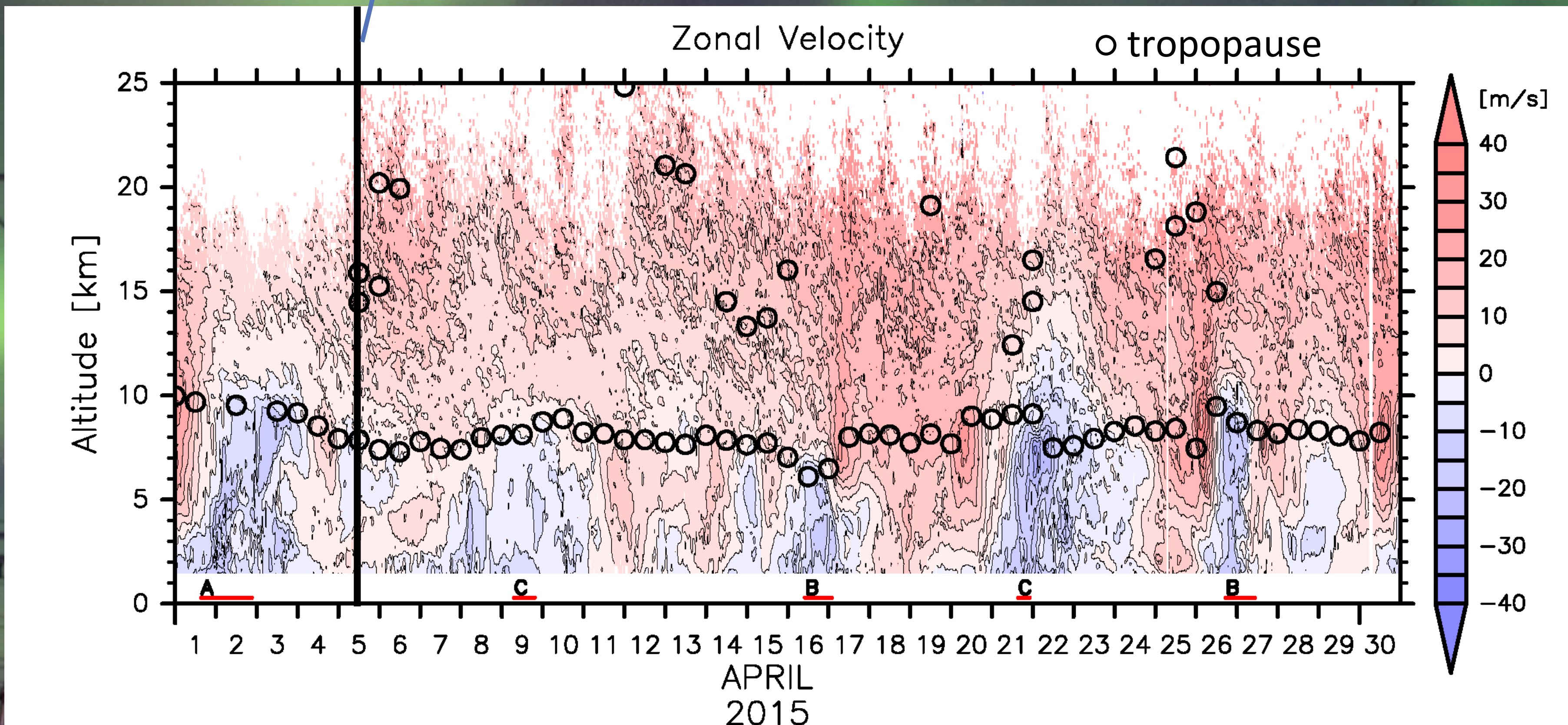


The QL plot of the first full-system observation

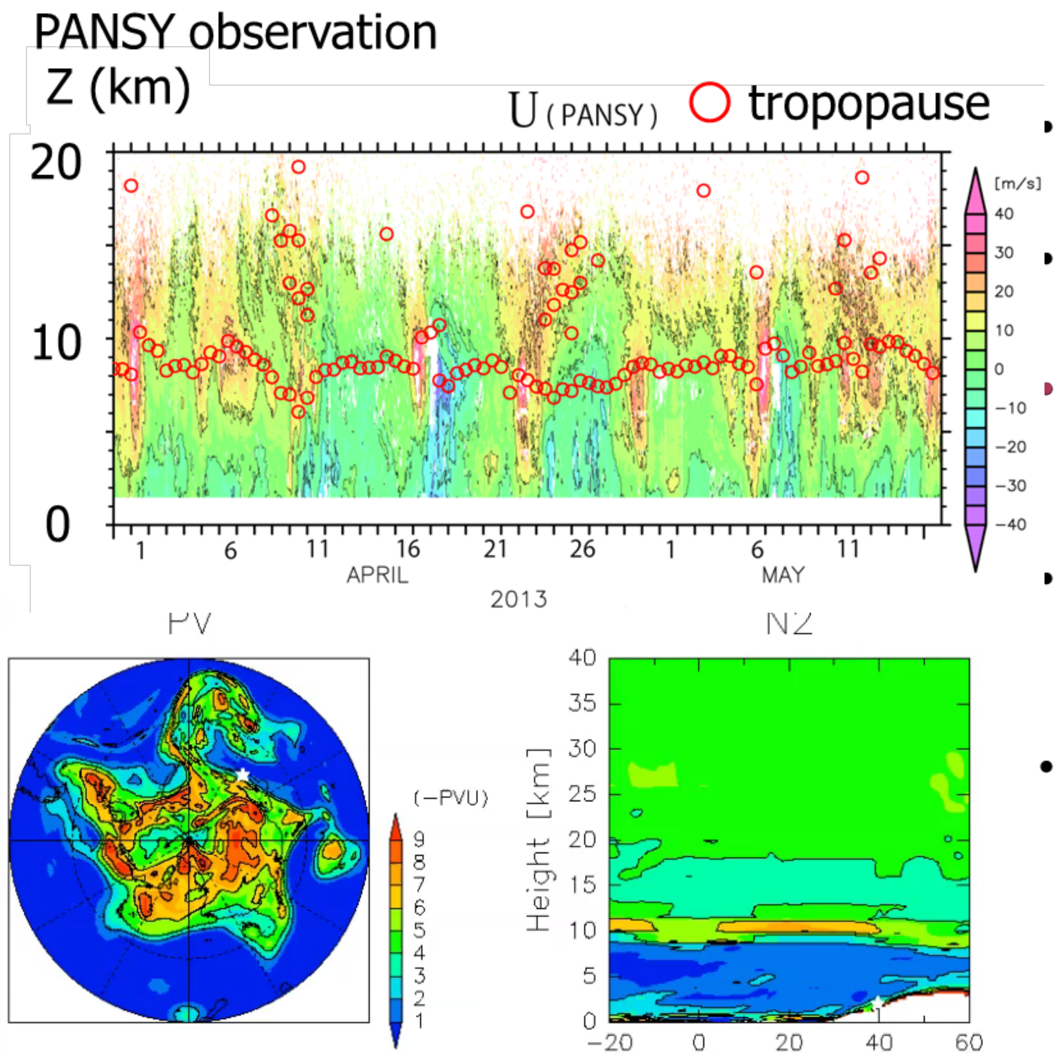
Prof. Kato sent a command to start the first full system observation to Syowa Station.

Continuous observations over 40 days from the PANSY full system in April-May 2015

Start of full system observation



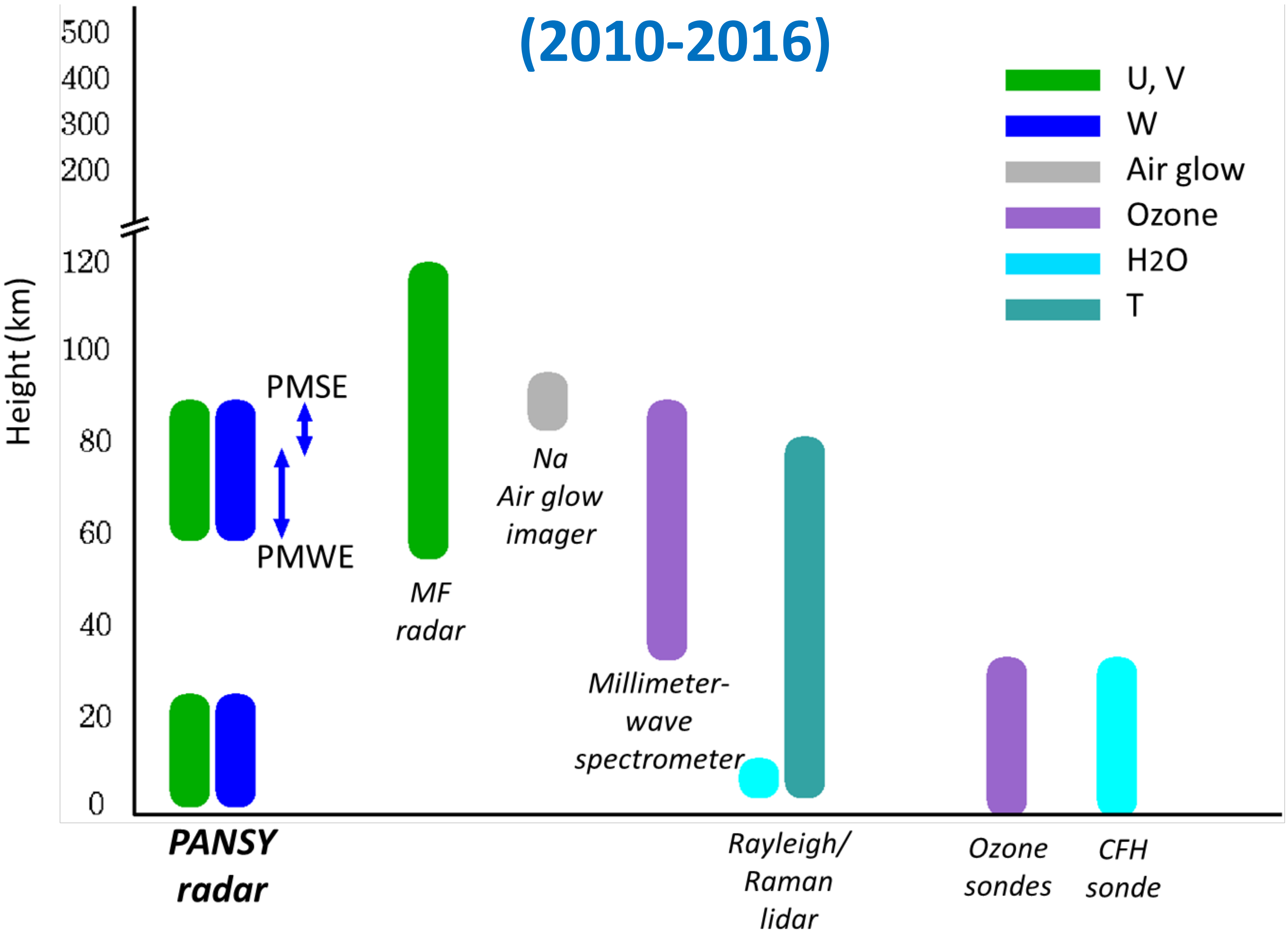
Published papers using observation data from a limited system of the PANSY radar



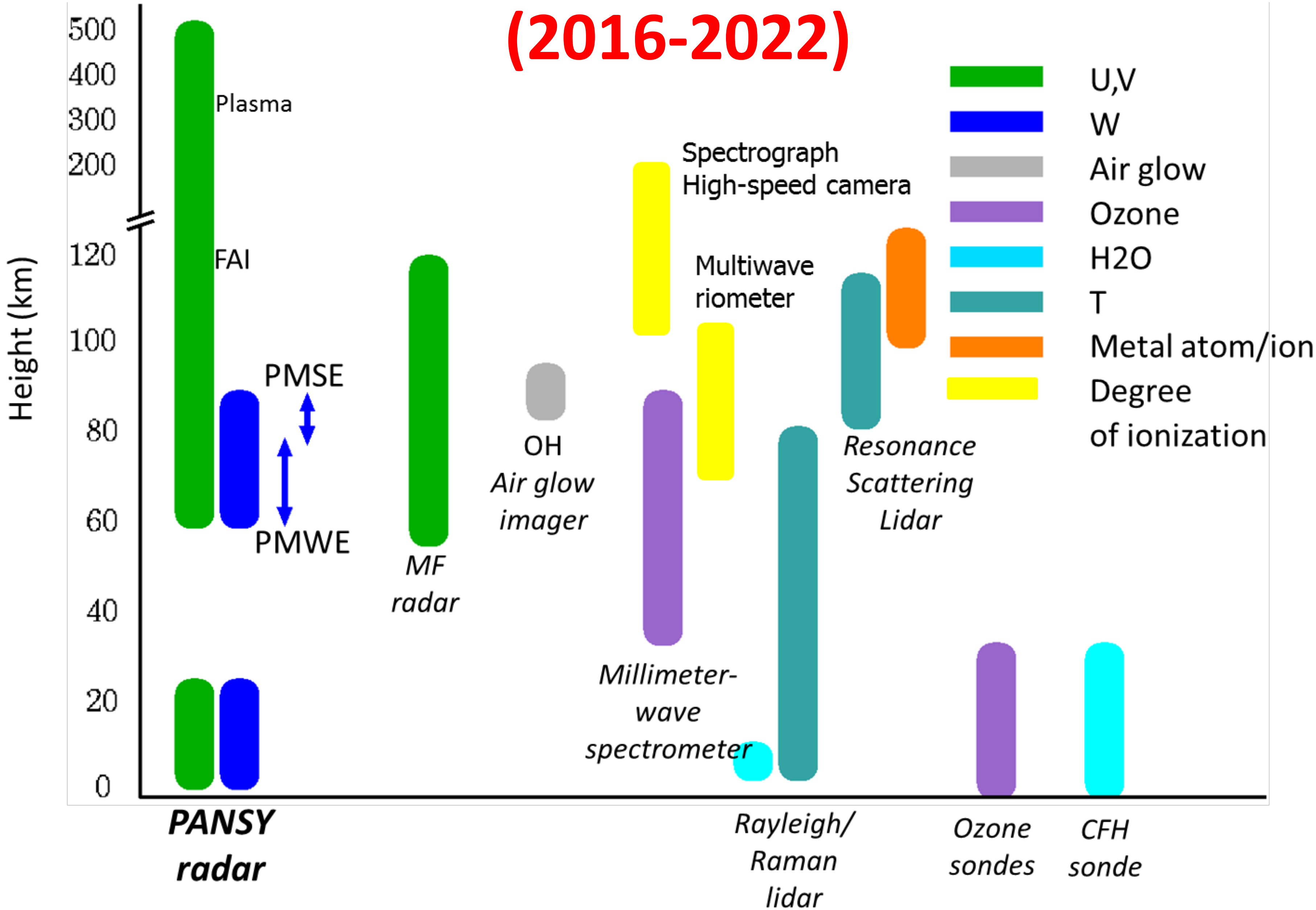
- **The PANSY program**
  Sato et al. (JASTP, 2014)
- **Strong wind events**
  Tomikawa et al. (MWR, 2015)
- **Inertia-gravity waves causing multiple tropopauses**
  Shibuya et al. (JAS, 2015)
- **Diurnal variation of Polar Mesosphere Winter Echo (PMWE)**
  Nishiyama et al. (GRL, 2015)
- **Climatology of vertical wind fluctuations and momentum fluxes in the lower troposphere**
  Minamihara et al. (SOLA, 2016)

Shibuya et al (JAS, 2015)

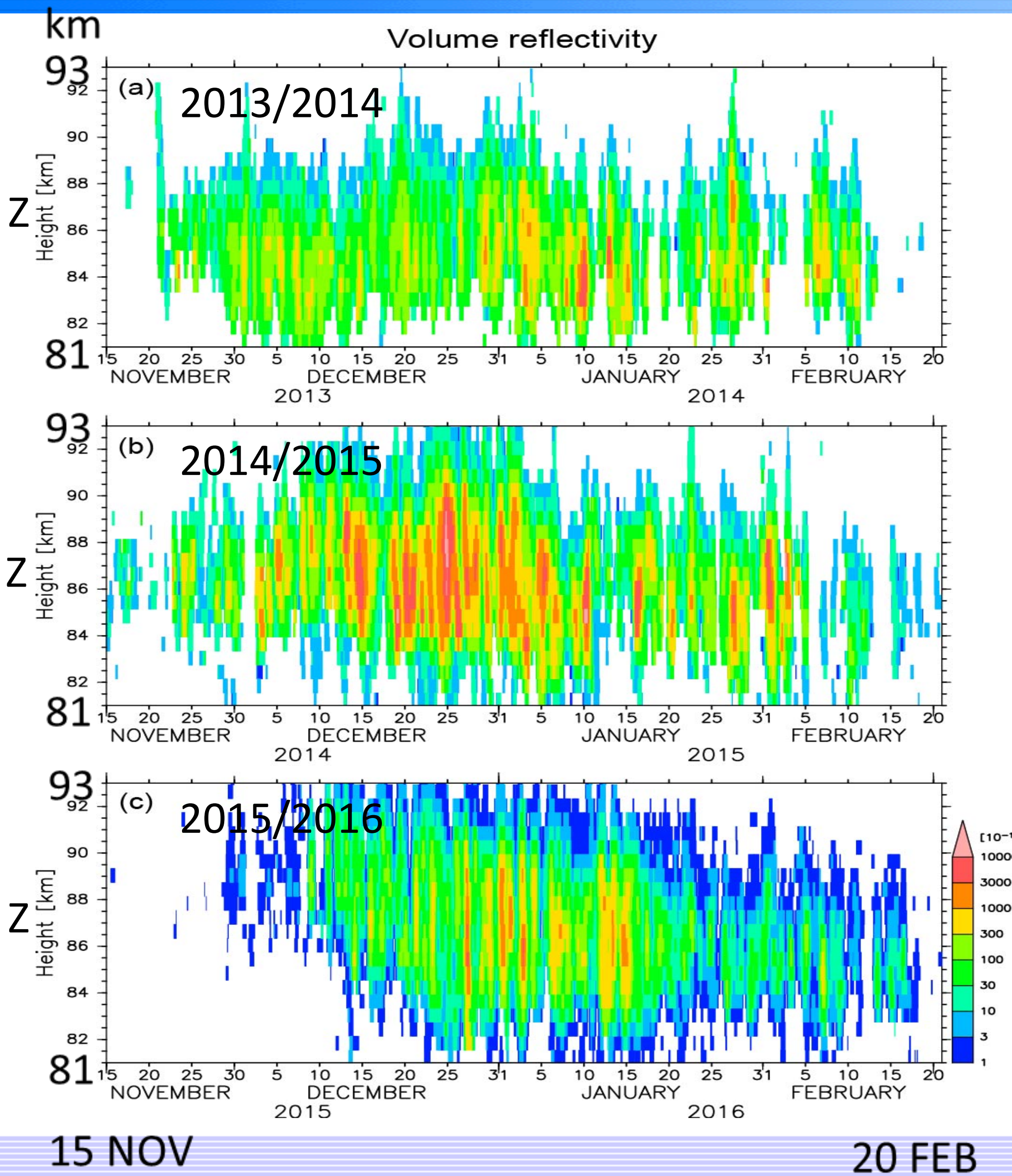
The VIIIth JARE period (2010-2016)



The IXth JARE period (2016-2022)



Polar Mesosphere Summer Echoes (PMSE) observed by the PANSY radar (69°S, 40°E)



- **PMSE are echoes likely related to polar mesospheric clouds** and mainly observed in polar regions.
- **PMSE in SH** was observed by Woodman *et al.* (1999) at Machu Picchu st., Morris *et al.* (2004) at Davis st. . and Kirkwood *et al.* (2007) at Wasa st.
- As **the PANSY radar currently has the largest power-aperture product** (a measure of the MST/IS radar performance) in SH, **PMSE is observed almost continuously**.
- In particular, **in 2015/2016 season, the PANSY radar operated with a full system** could detect echoes even from low volume reflectivity areas (dark blue regions).

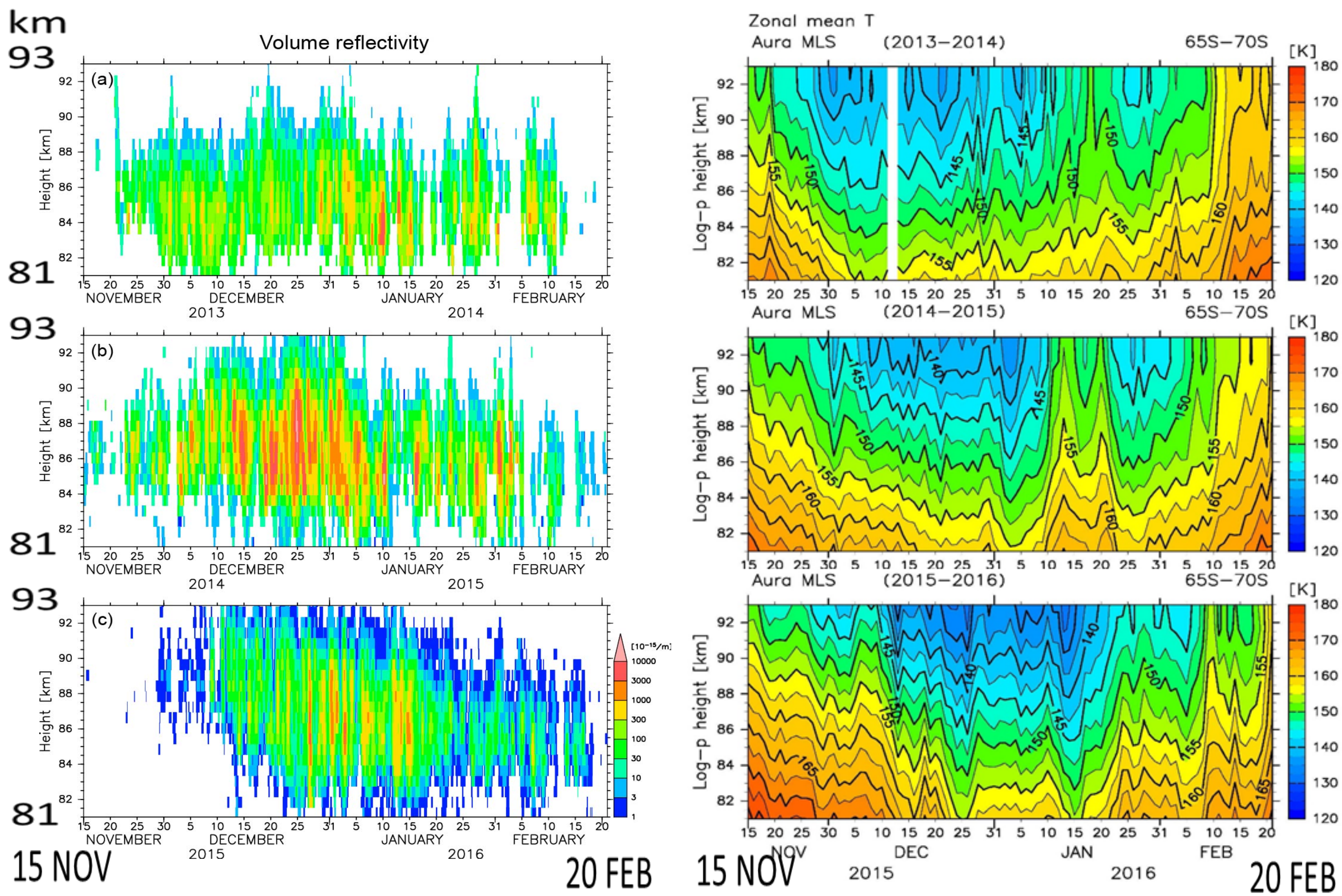
Sato et al. (in preparation)

Comparison between PMSE from the PANSY radar and temperature from Aura MLS

2013/2014

2014/2015

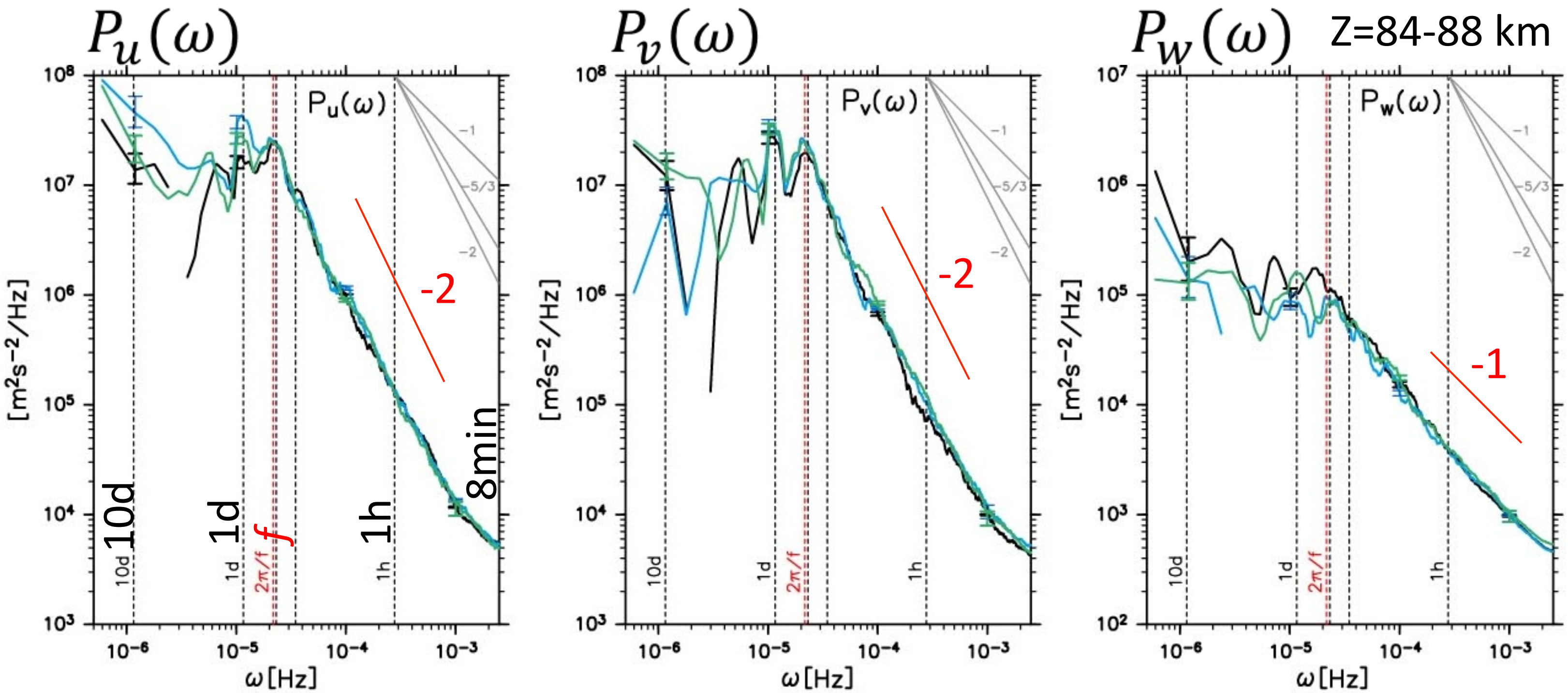
2015/2016



- Year-to-year variation of the seasonal evolution of PMSE is large.
- It seems related to temperature evolution in the mesosphere which depends on the year.

Sato et al. (in preparation)

Power spectra of u', v', and w' in the mesosphere

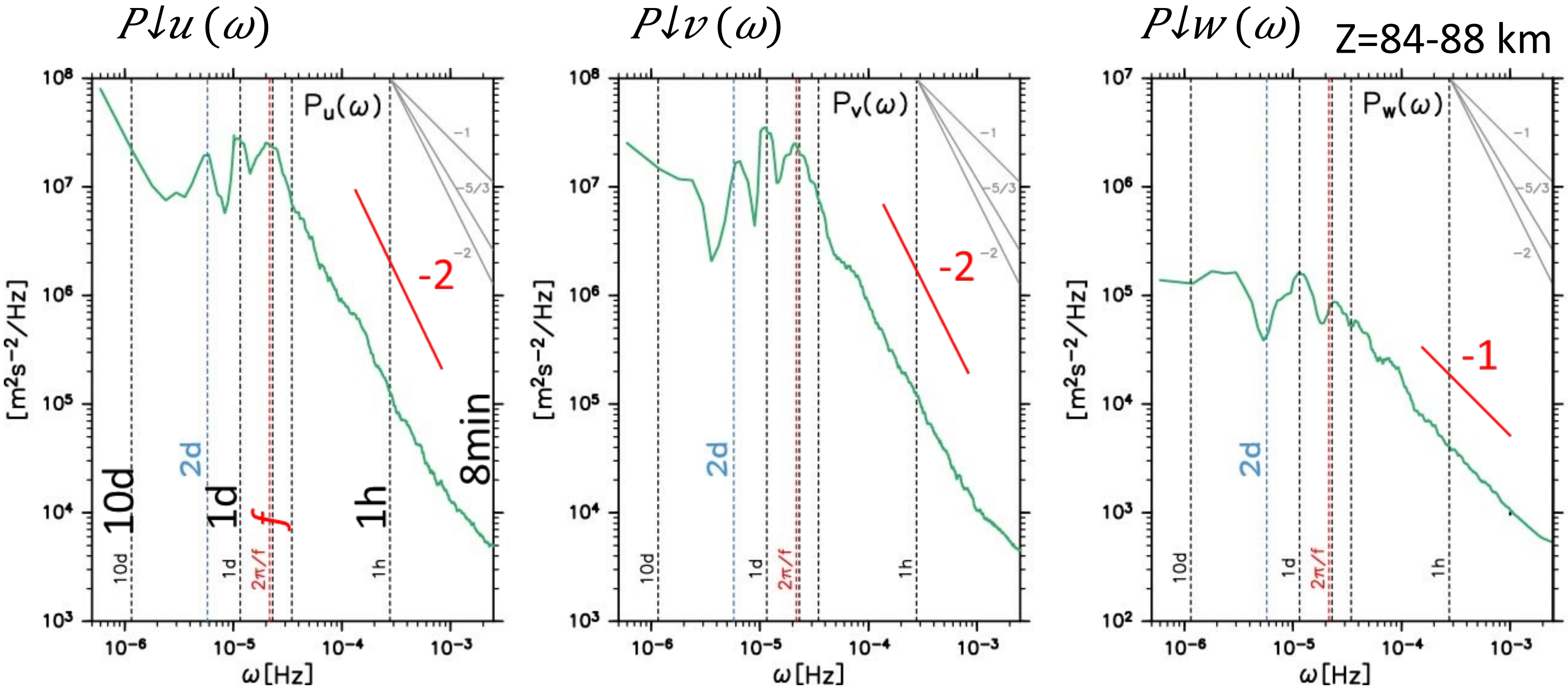


Dec. 1-Jan. 31 for **2013/2014, 2014/2015;** Dec. 16-Feb.15 for **2015/2016**

- Spectral shapes for respective quantities are similar for all years.
- u and v spectra $\propto \omega^{-2}$ for $\omega > f$ and $\propto \omega^0$ for $\omega < f$.
- w spectra $\propto \omega^{-1}$ for $\omega > f$ and $\propto \omega^0$ for $\omega < f$.

Sato et al. (in preparation)

Power spectra of u', v', and w' in the mesosphere



Dec. 16-Feb.15 for 2015/2016

- There are peaks around 1 day and a half (or $2\pi/f$) day for all spectra.
- However, a peak around 2 days is observed only for u and v spectra, which is consistent with the previous studies' implication that it is due to a normal-mode Rossby wave.

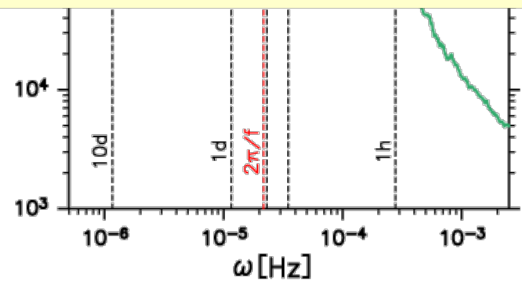
Sato et al. (in preparation)

Comparison of u spectra between the mesosphere and troposphere

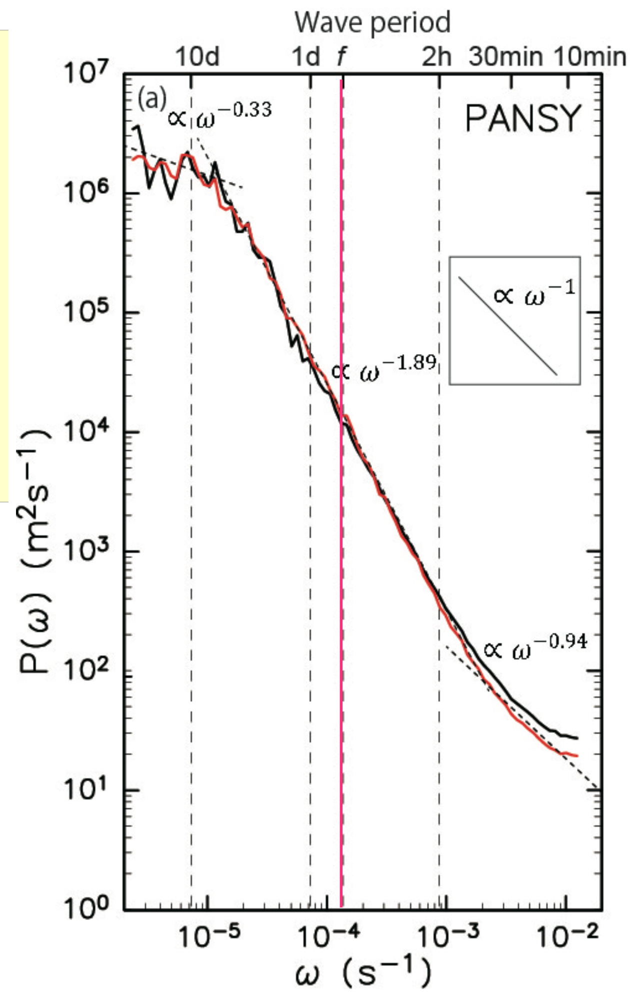
Mesosphere

Troposphere

- The transition frequency is $\sim f$ in the mesosphere, while it is about $2\pi/(5d)$ in the troposphere.
  This is consistent with the Charney & Drasin theorm (1961).
- The spectral shapes (i.e., slope) are similar for higher frequencies.

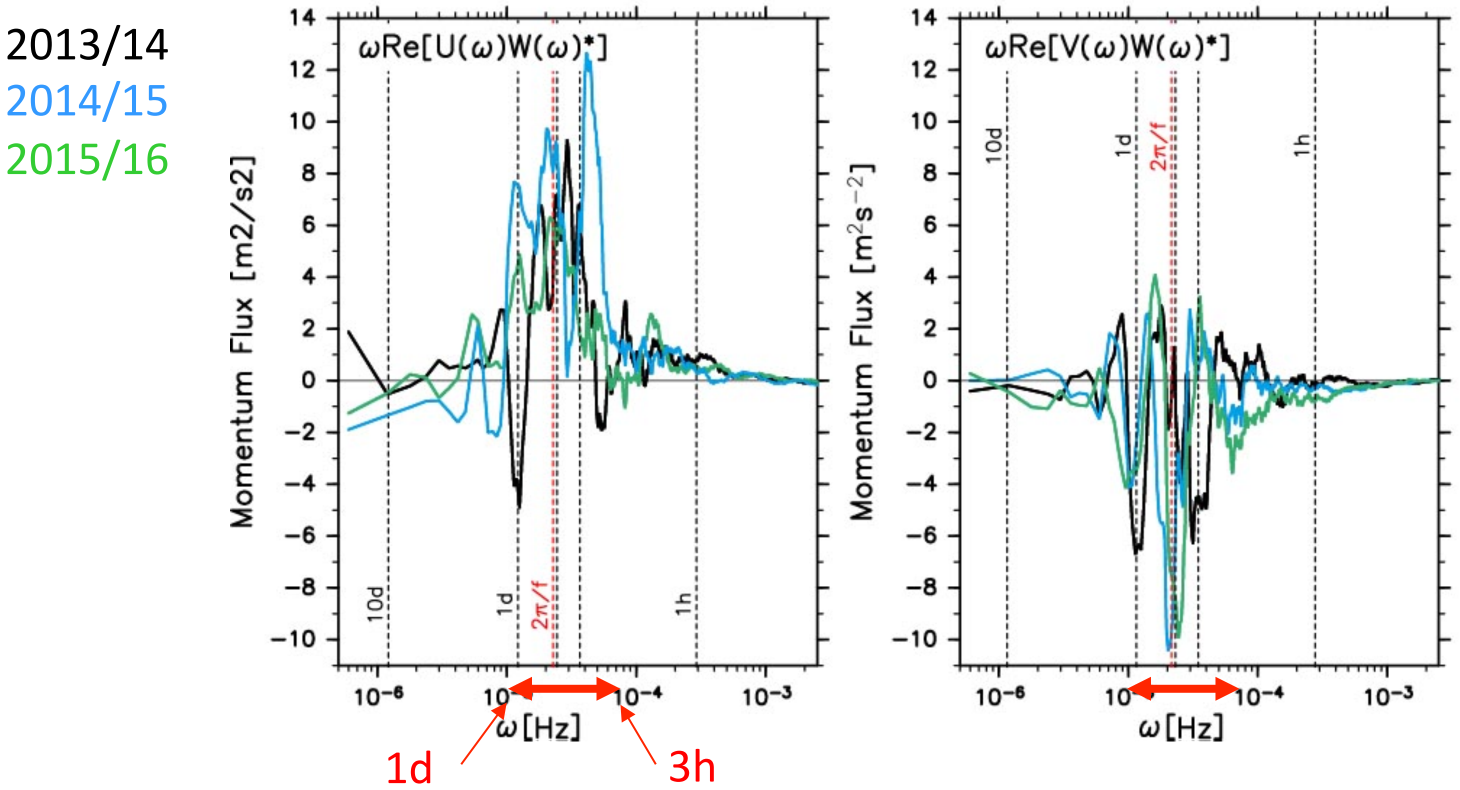


Sato et al. (in preparation)



Minamihara et al. (SOLA, 2016)

Momentum flux spectra in the polar summer mesosphere



- $\overline{u'w'}$ **are mainly positive (eastward propagation relative to the mean wind)**
- $\overline{v'w'}$ **are mainly negative (poleward propagation relative to the mean wind).**
- **Both momentum fluxes are contributed to largely by components with long periods of $\mathbf{1d \geq \tau \geq 3h}$**, and contribution from shorter-period components is small.

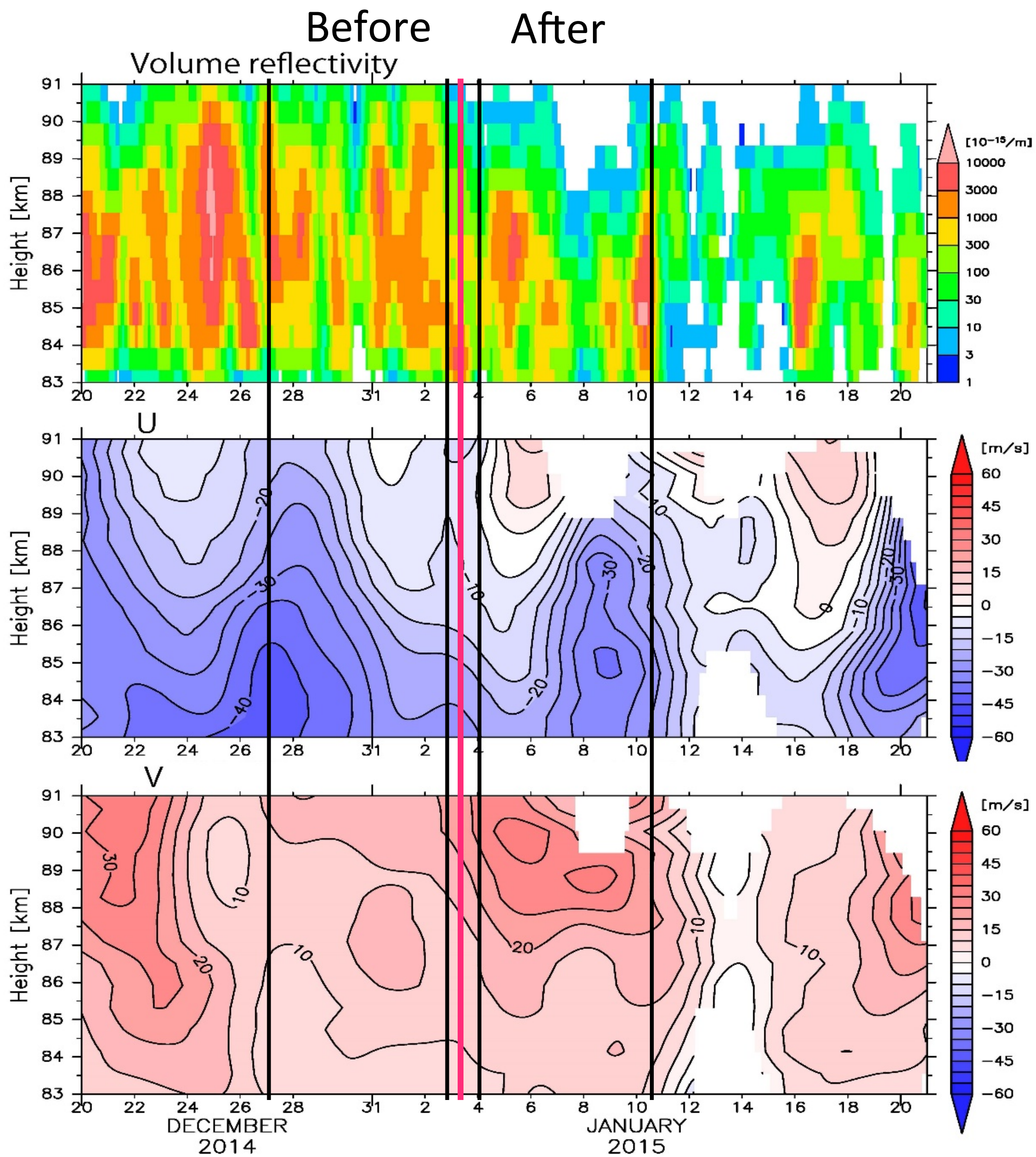
Sato et al. (in preparation)

PANSY radar observation of PMSE in 2014/15

PMSE
(Volume reflectivity)

U

V



January 3
(NH SSW onset, e.g., Manney et al., 2015)

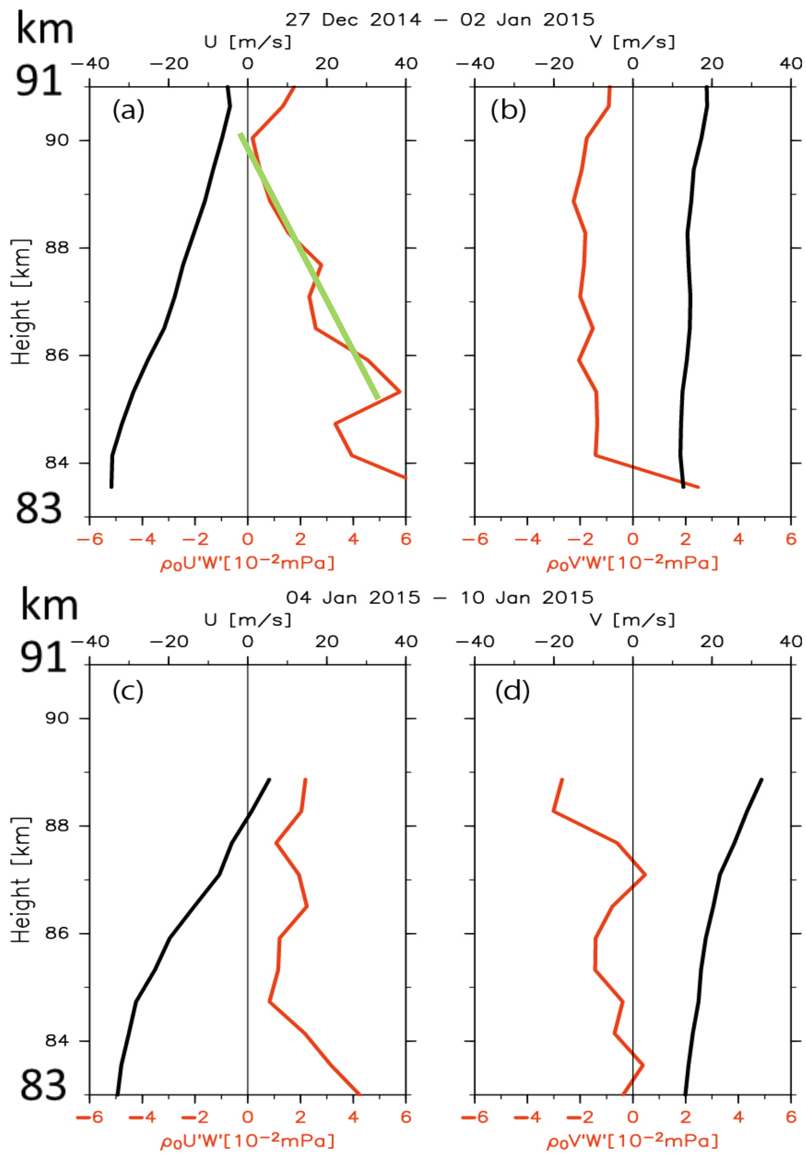
Sato et al. (in preparation)

Change in time mean wind and momentum fluxes

$\overline{u}(z)$ and $\rho_0\overline{u'w'}(z)$ | $\overline{v}(z)$ and $\rho_0\overline{v'w'}(z)$

Before NH SSW
(27 Dec 2014
-2 Jan 2015)

After NH SSW
(4-10 Jan 2015)



Before NH SSW onset

- Positive $-\mathrm{d}\rho_0\overline{u'w'}/\mathrm{d}z$ is significant ($\sim$ 16m/s/day).

After NH SSW onset

- $\overline{u}$ is decelerated above 86 km by about 15m/s and slightly positive above 88 km.
- Simultaneously positive $\overline{v}$ gets stronger.
- The change in the mean wind is consistent with the case of SH SSW in 2002 reported by Becker and Fritts (2006)
- These features suggest that positive gravity wave forcing removes angular momentum from the mean wind, resulting in an excess of equatorward pressure gradient force.

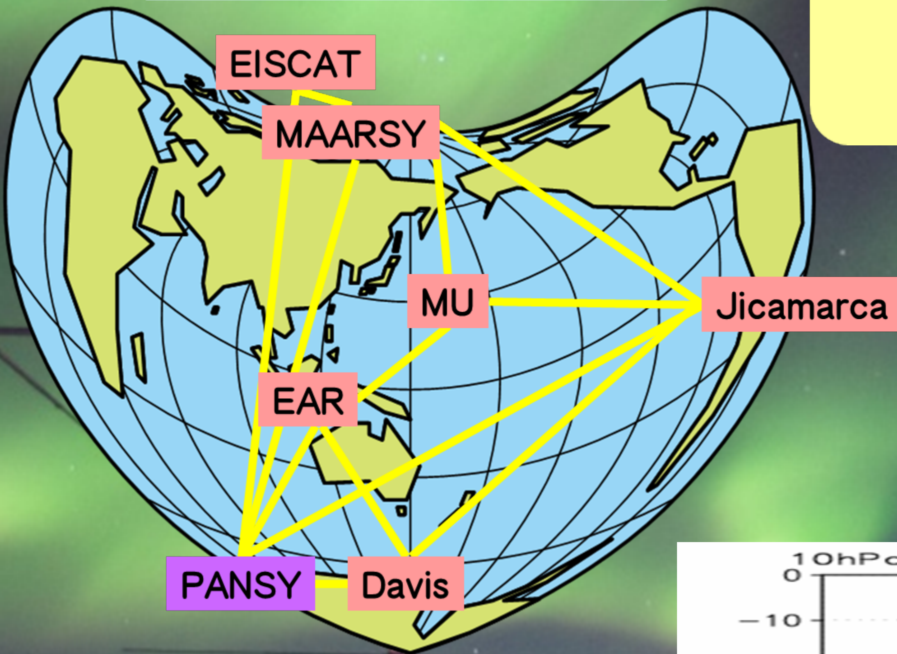
Sato et al. (in preparation)

SCOSTEP/VarSITI/ROSMIC

Interhemispheric Coupling Study by Observations and Modelling (ICSOM)

PI: K. Sato

ICSOM MST radar network



Two minor SSWs were successfully captured

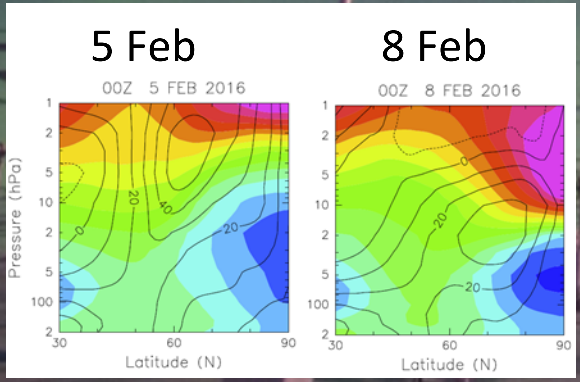
ICSOM campaign : 22 Jan-5 Feb 2016

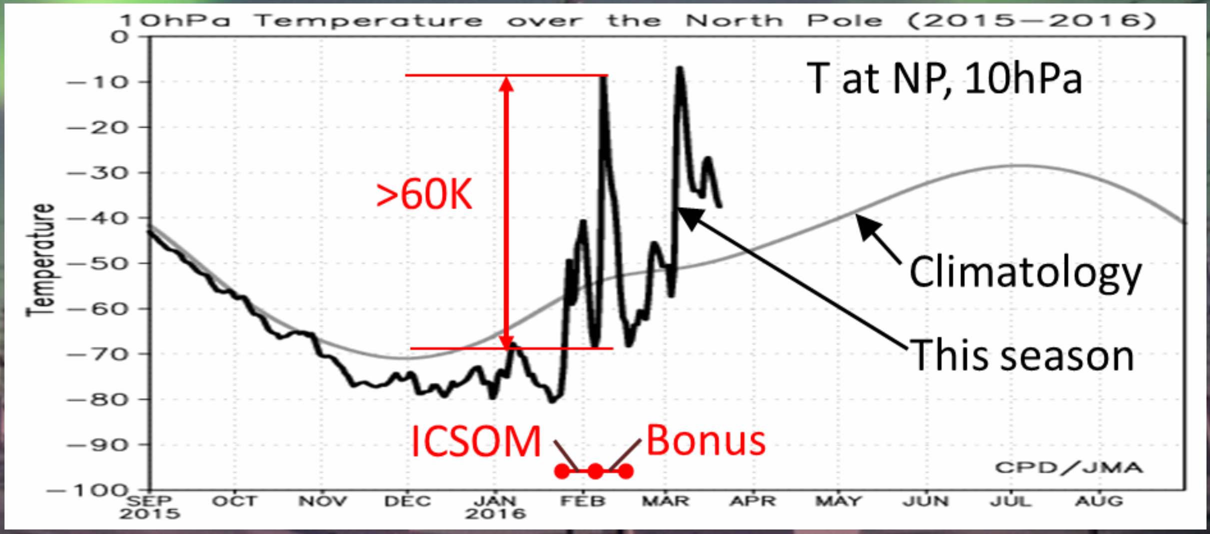
Bonus campaign :6-16 Feb 2016

MF radars
Meteor radars
Lidars
Imagers
High-resolution
Satellite obs.

Real atmosphere simulations by GCMs (JAGUAR, NICAM)

More than 30 participants in eight countries





A possible interhemispheric coupling mechanism

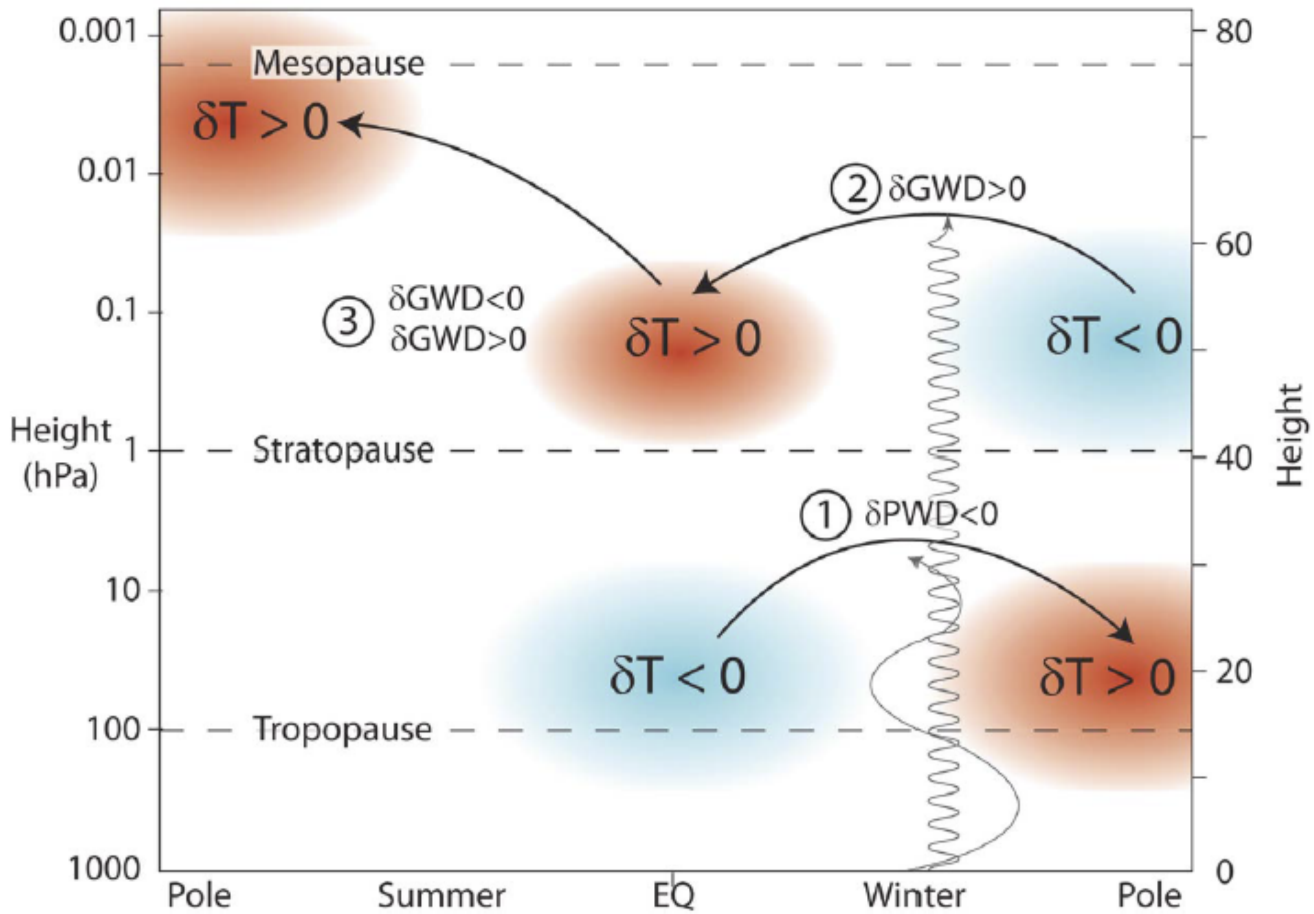
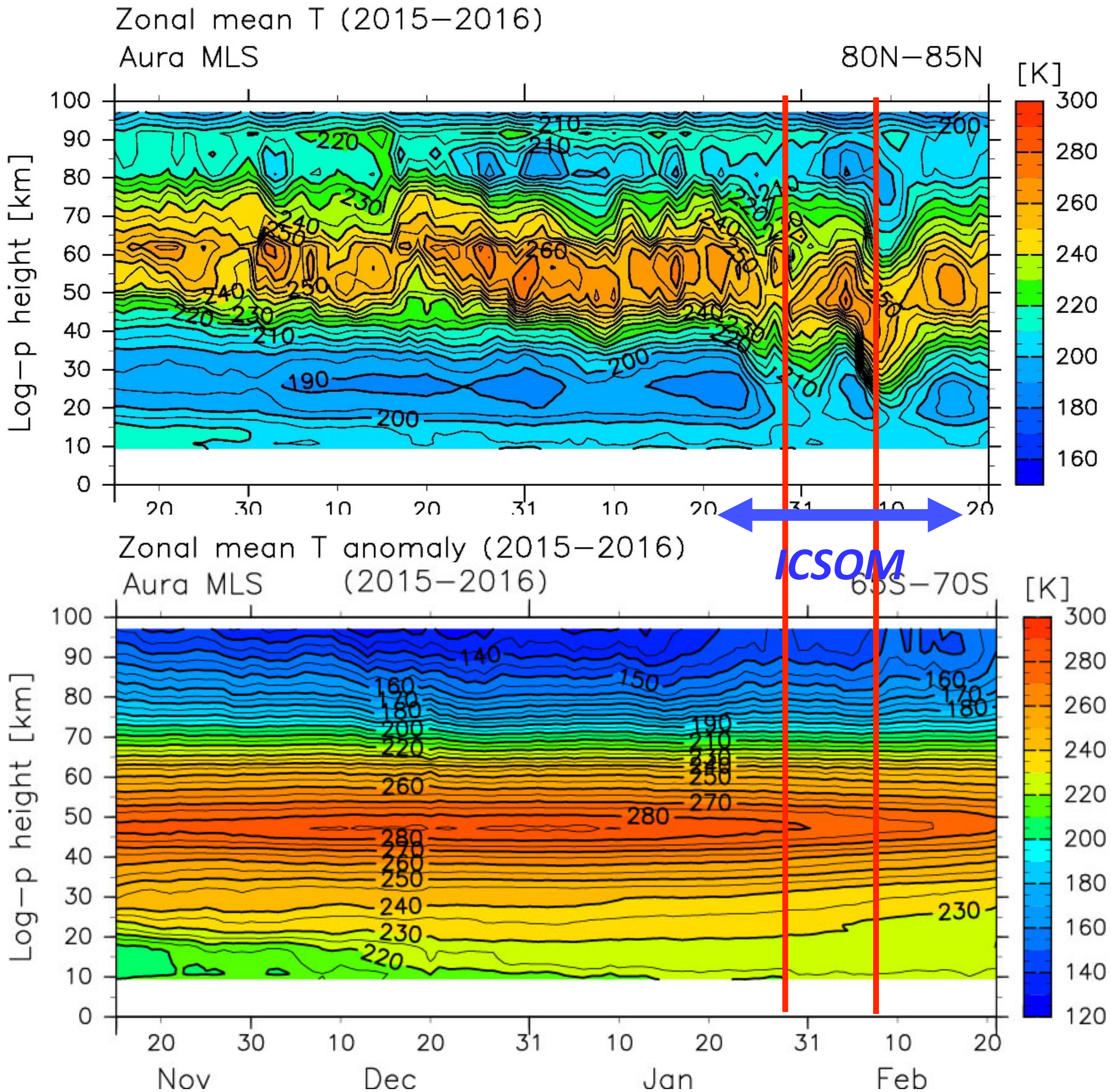


Figure 6. Three stages of the effect of a perturbation to the background dynamical state of the middle atmosphere at solstice [after *Körnich and Becker*, 2010].

Zonal mean fields in high latitudes in NH and SH during the ICSOM campaign

NH

SH

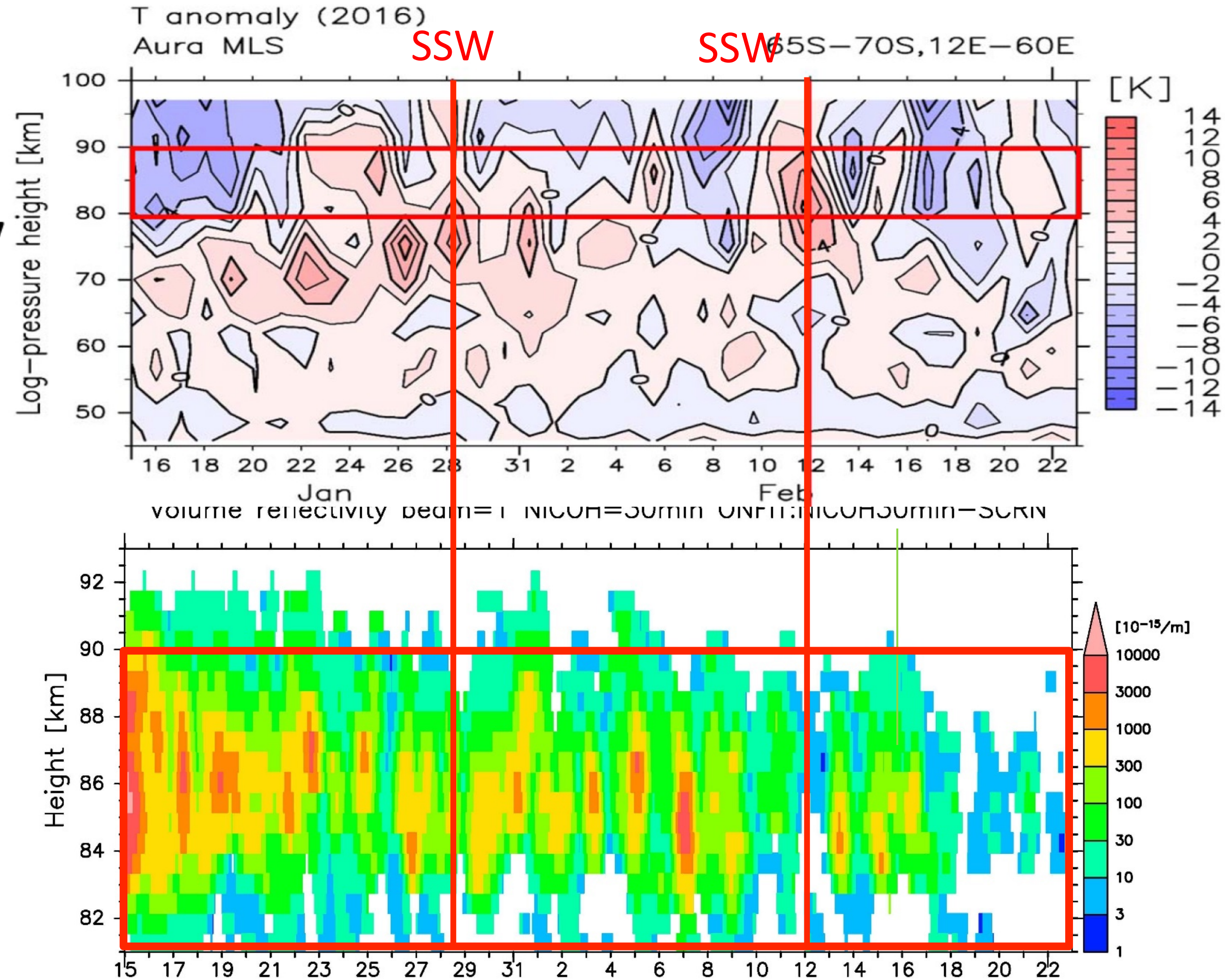


- Two minor warming occurred during the campaign.
- Anomalies in T from climatology is observed in the SH mesosphere

PANSY observations and comparison with Aura MLS Temperature

Temperature anomaly from Aura MLS

PMSE (in volume reflectivity) detected by the PANSY radar



- When warming anomalies are observed around NH SSW, PMSE detected by PANSY weakened.

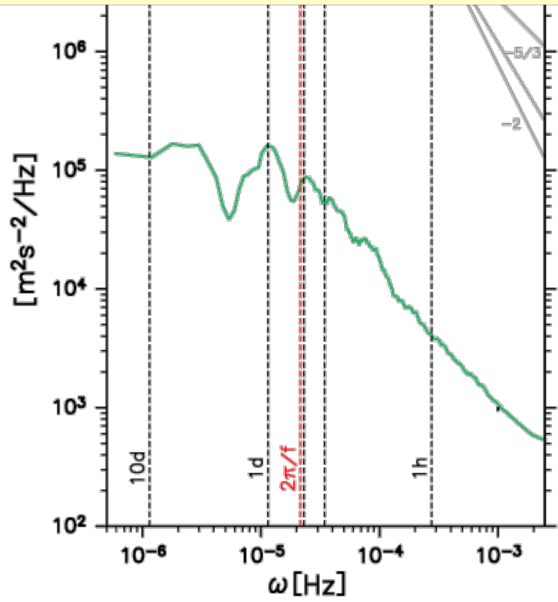
Summary

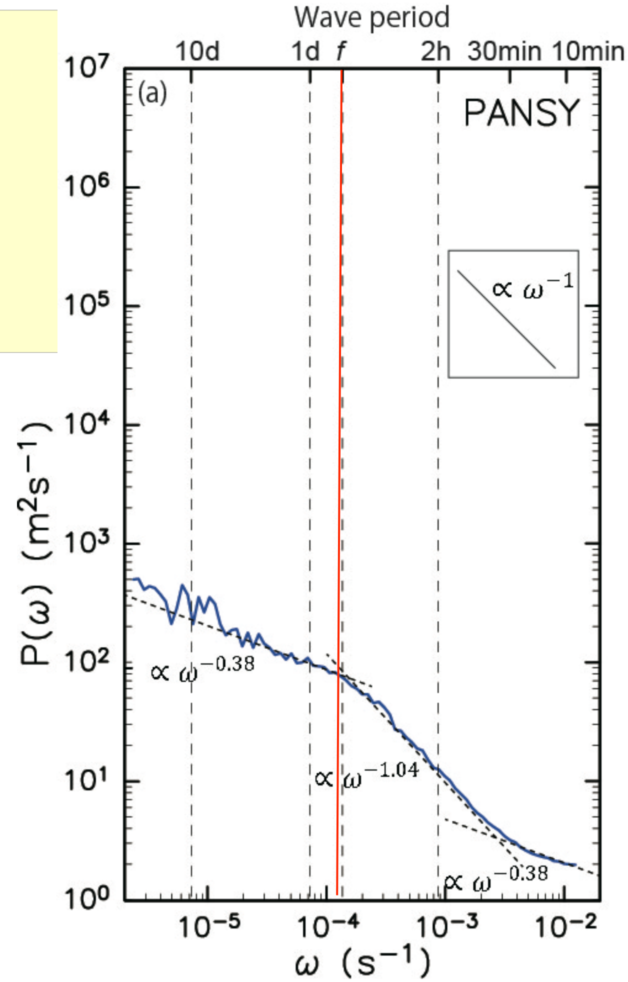
- The PANSY radar construction was completed during the VIIIth JARE period, and **the full-system operation of the PANSY radar was started in March 2015**.
- Results of the analysis **for PMSE data over 3 years including a full-system observation of 2015/16** were shown.
- **The IXth JARE (2016-2012) is the main observation period of the PANSY radar**. The combination of the PANSY radar with its complementary instruments was **adopted as one of three expedition research projects of JARE** by Japanese government (grant only for operation and not for research).
- **The 1st international collaboration** by networking MST radars on the globe with several complementary observations (**ICSOM**) **was performed in Jan. 22-Feb. 11, 2016 and successfully captured two minor SSWs in NH**.

Comparison of w spectra between the mesosphere and troposphere

Mesosphere | **Troposphere**

- The transition frequency is almost the same ($\sim f$).
- The spectral slope is similar at higher frequencies but shallower at lower frequencies and in the mesosphere.

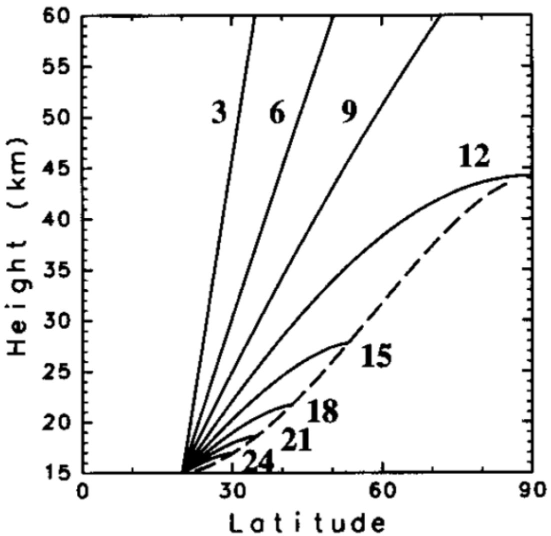




Sato et al. (in preparation)

GWs originating from tropical convection likely reach the polar mesosphere

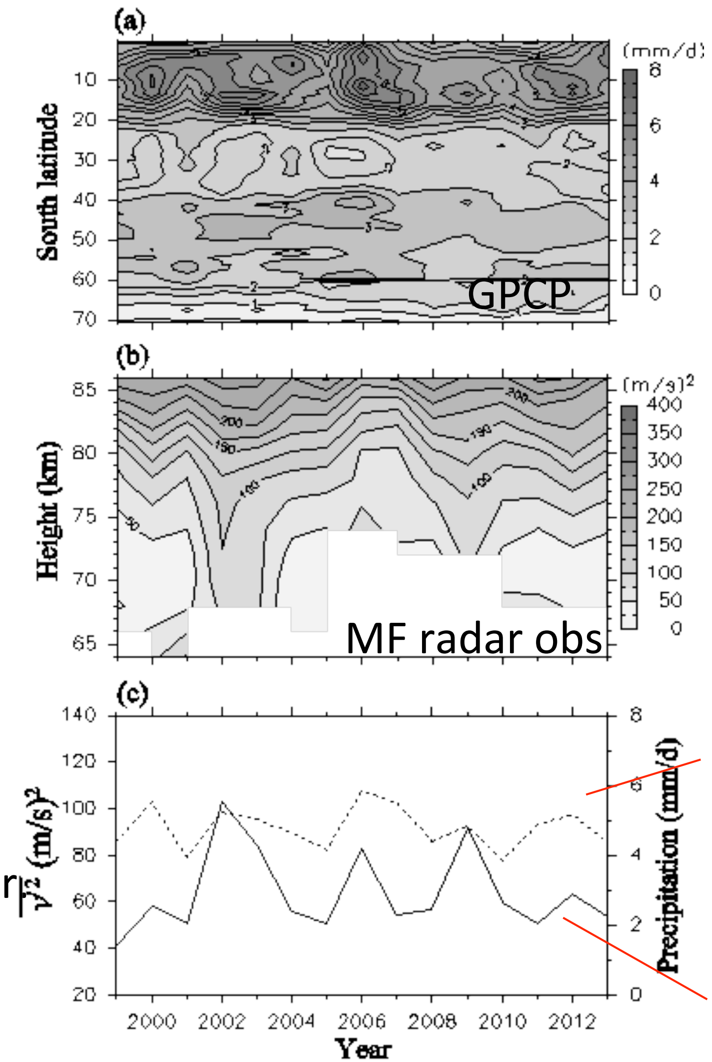
Southernmost ray path of IGWs originating tropical convection as a function of wave period.



Numerals denote GW period in hours

Sato et al. (APUAR, 2000)

DEC-JAN



Precipitation

GW variance in the summer mesosphere at (69S, 40E)

Precipitation for subtropical region (10S-20S)

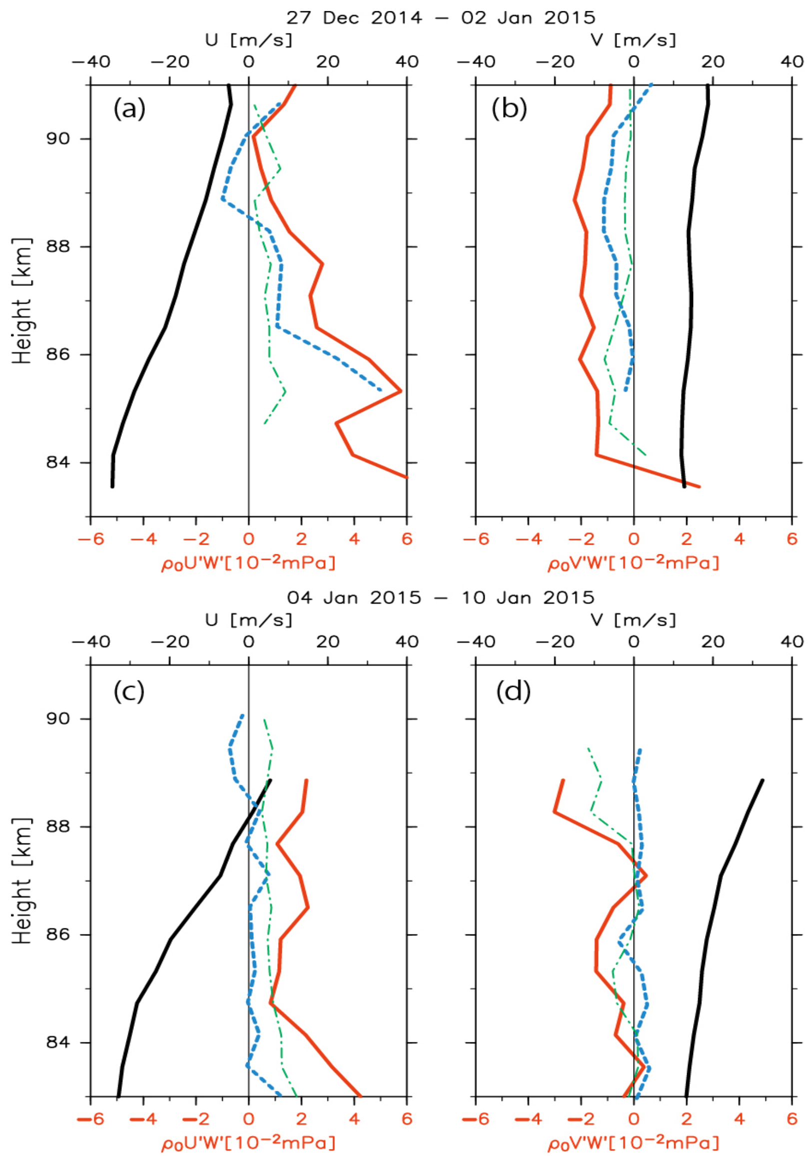
GW variance at (69S, 40E) averaged for z=72-76km

Yasui et al. (SOLA, 2000)

$\bar{u}(z)$ and $\rho_0 \overline{u'w'}$ $\bar{v}(z)$ and $\rho_0 \overline{v'w'}$ (z)

Before NH SSW
(27 De2014c
-2 Jan 2015)

After NH SSW
(4-10 Jan 2015)

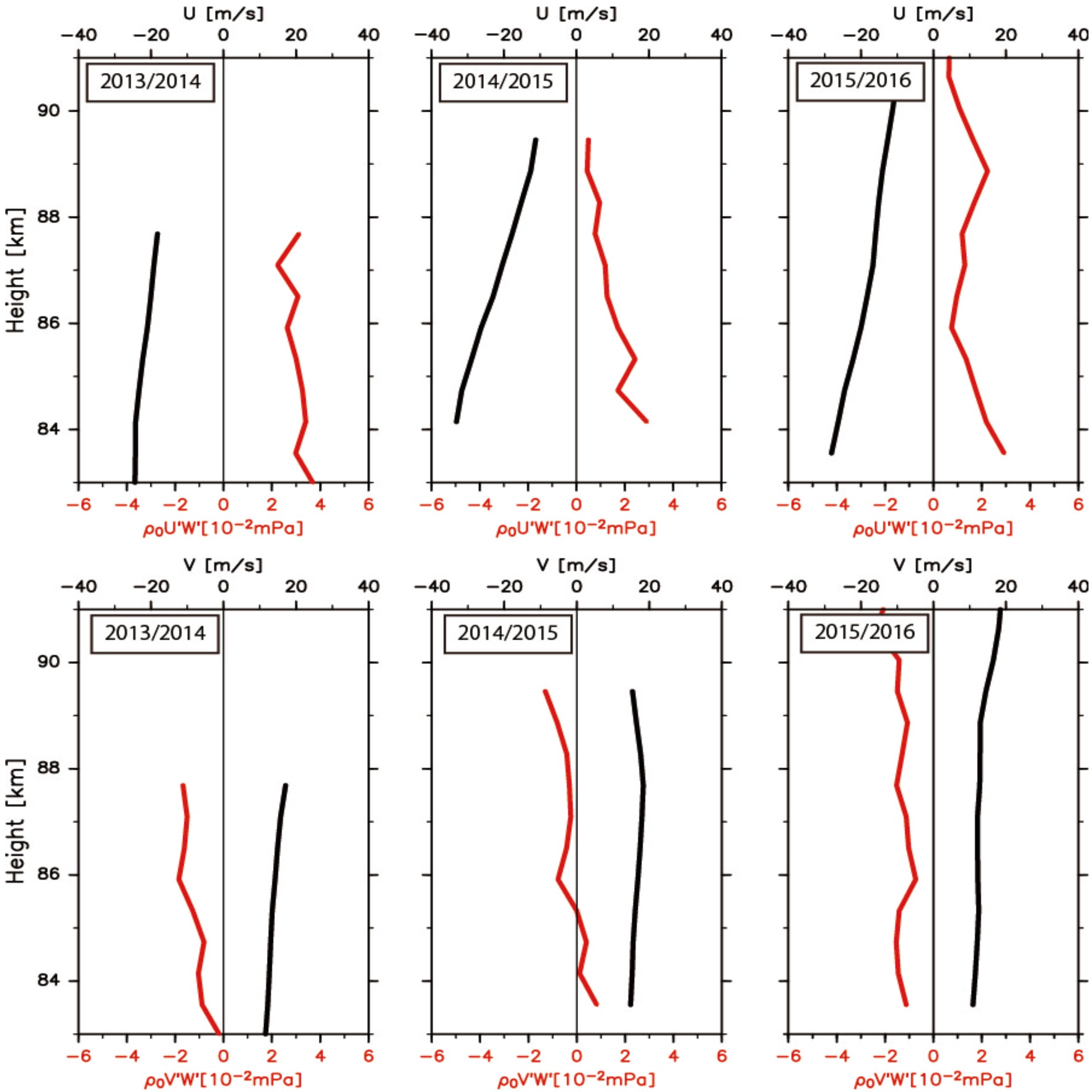


Blue: $3h<\tau<15h$
Green: $8min<\tau<3h$
Red: Total ($8min<\tau<24h$)

- Significantly positive zonal GW forcing ($-d\rho_0 \overline{u'w'}/dz$) before NH SSW is associated with long period ($15h>\tau>3h$) components.
- Contribution by shorter period components is small.

The relation between NH SSW onset and SH mesosphere changes needs to be examined for future studies.

Vertical profiles of momentum fluxes



$\bar{u}(z)$ and $\rho_0 \overline{u'w'}(z)$

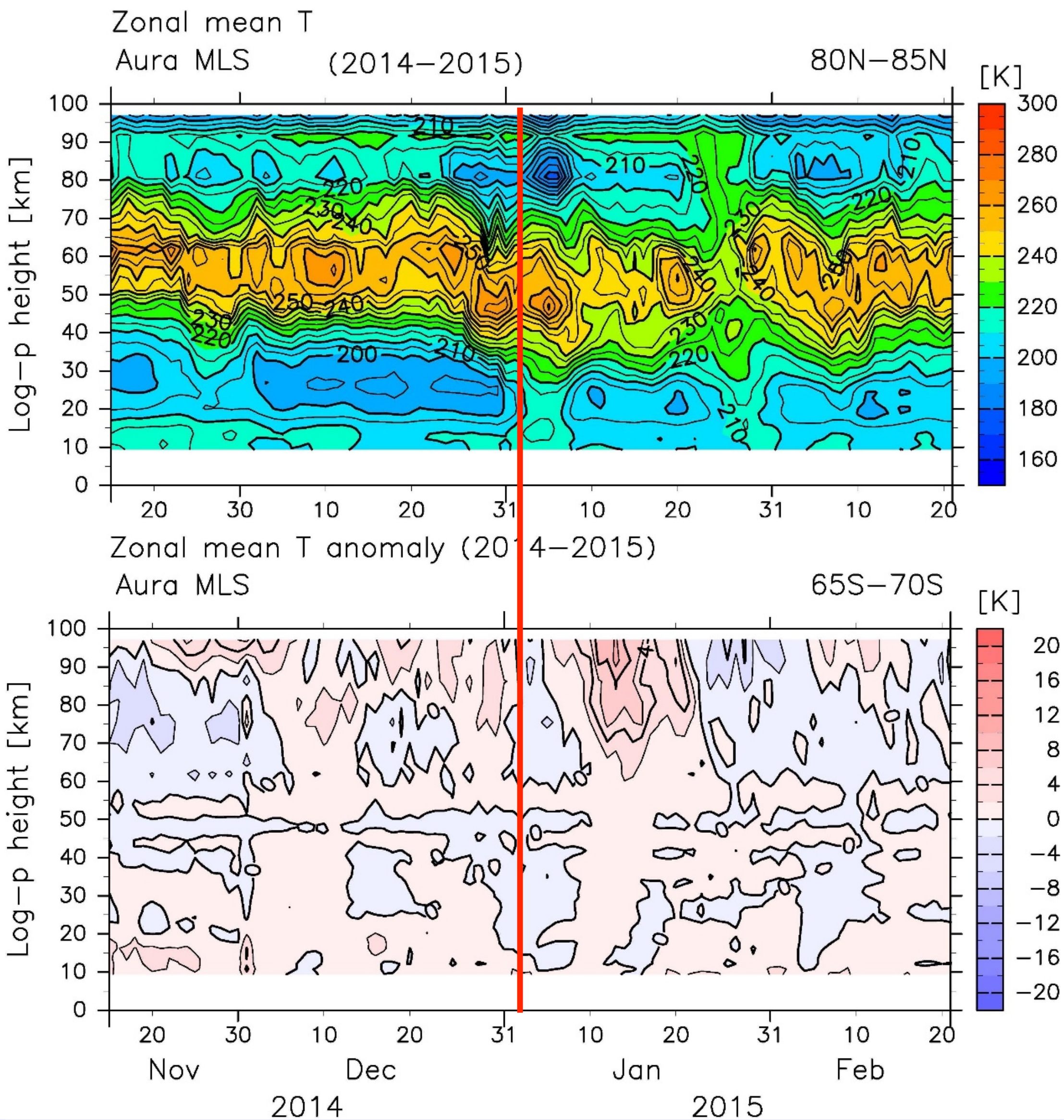
$\bar{u}<0$, and $\rho_0 \overline{u'w'}$ seems to decrease with height for years with strong eastward shear in $\bar{u}$.

$\bar{v}(z)$ and $\rho_0 \overline{v'w'}(z)$

$\bar{v}>0$, as is consistent with $-\mathrm{d}\rho_0 \overline{u'w'} / \mathrm{d}z>0$. $\rho_0 \overline{v'w'}<0$, indicating dominance of southward (poleward) propagation of GWs.

Sato et al. (in preparation)

Difference in SH GW characteristics between periods before and after a NH SSW around January 3, 2015



- Minor SSW occurred around 3 January in NH (e.g. Manney et al 2015).
- During the period around the NH SSW, the SH mesosphere seems to have changed.
- T in the SH mesosphere became lower after January 3.

Sato et al. (in preparation)