Influence of Merapi Volcanic Eruption on the Stratospheric Water Vapour

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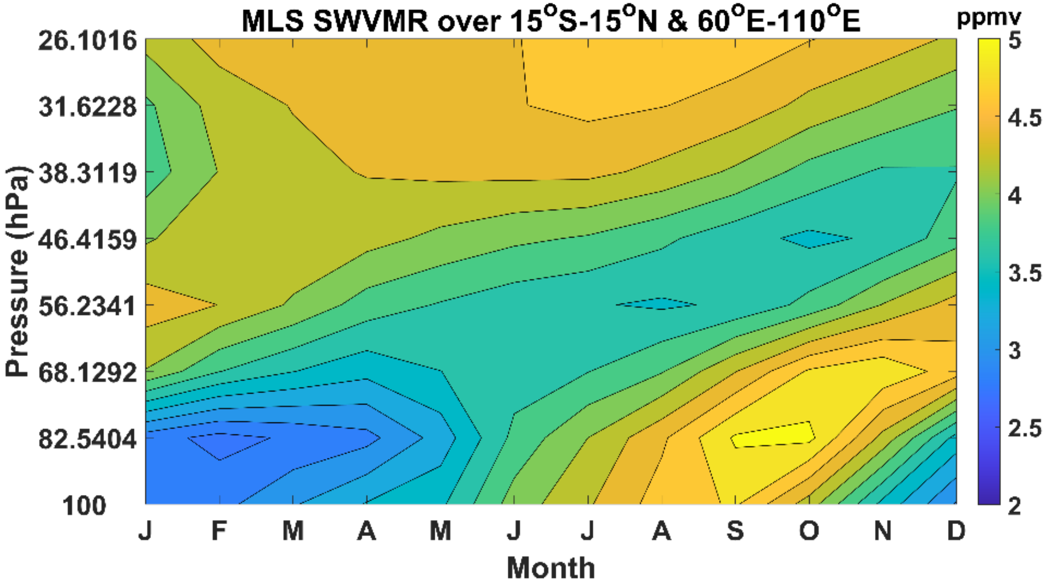
Stratospheric water vapour (SWV)

- It is an important greenhouse gas (Solomon et al., 2010) and it plays a key role in the delay of ozone recovery (Shindell, 2001).
- In spite of its low abundance, its radiative effects are significant (Houghton et al., 2001). RF: 0.19 W/m^2 with the increase of SWV from 6 to 6.7 ppm (Forster and Shine, 1999)
- Different pathways for the stratospheric entry
  - (i) Convection and mean transport circulation in tropics
  - (ii) Rapid transport across the isentropic level (~ 380K) and it occurs mainly in the northern hemisphere winter associated with breaking of` Rossby waves at mid latitudes.
- Oxidation of methane (Prominent only in the upper stratosphere)
- Water vapour can directly enter into the lower stratosphere through the tropical tropopause where the tropopause temperature determines the amount of water vapour entering into the stratosphere (Urban et al., 2014).
- QBO can modulate the SWV transport across the tropopause layer by its secondary meridional circulation (Giorgetta and Bengtsson, 1999)
- Warm ENSO and easterly QBO, there was an increase in tropopause temperature anomalies, which could increase the SWV.
- BDC can also influence (transport to higher latitudes)
- Volcanic eruptions



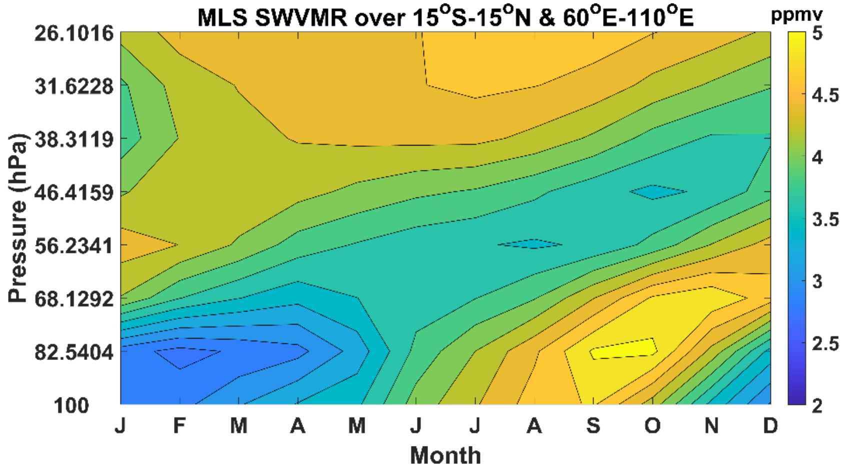
Seasonal variation of Stratospheric water vapour (SWVMR)

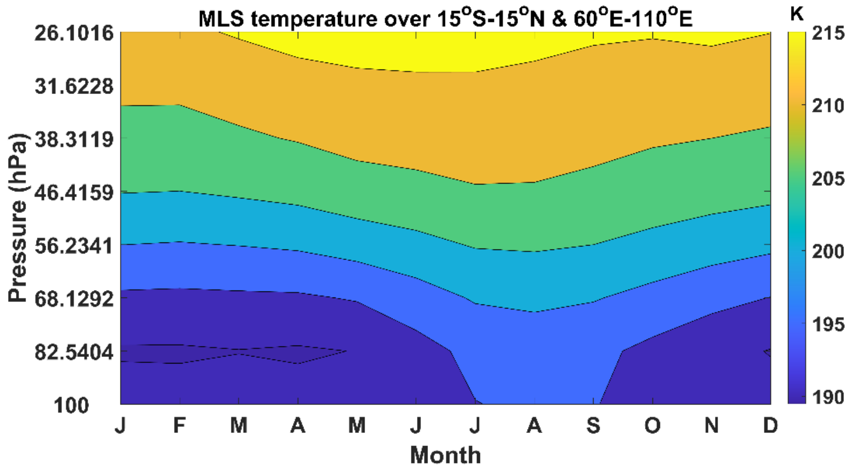
During Jan-May

- SWMR < 3ppmv (100-68 hPa)
- SWMR ~ 3-3.5 ppmv (68-56 hPa)
- SWMR > 3.5 ppmv (56-21 hPa)

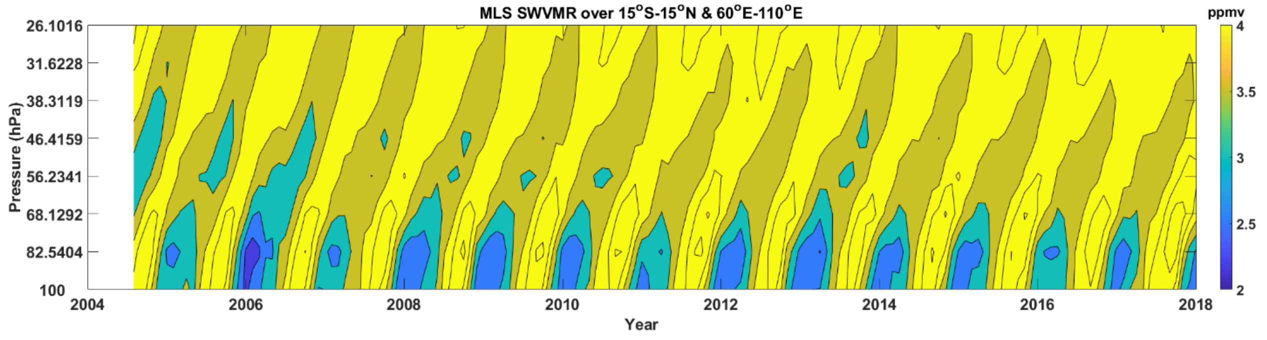
In the lower stratosphere, May onwards, it begins to increase (>3.5 ppmv) reaches a maximum of > 5 ppmv in August-September and it starts to decrease from November-December

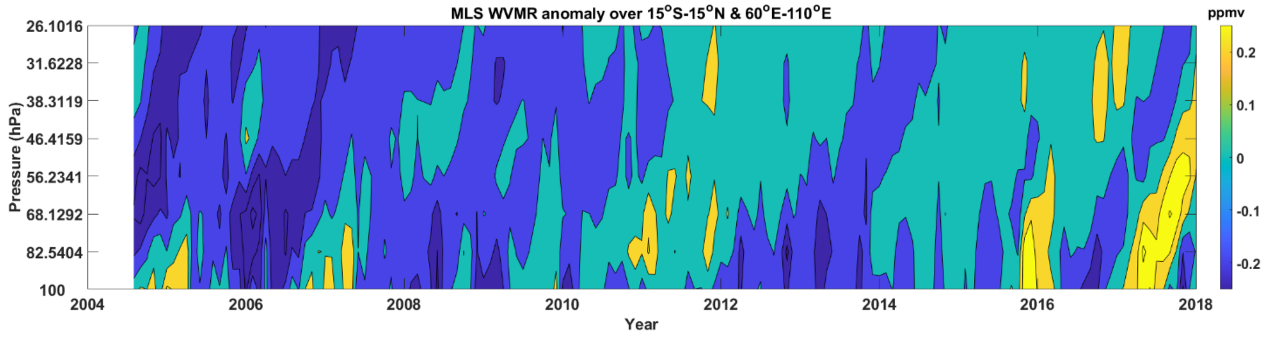
Seasonal variation of WVMR in the lower stratosphere follow the seasonal variation of tropical tropopause (Mote et al., 1996)



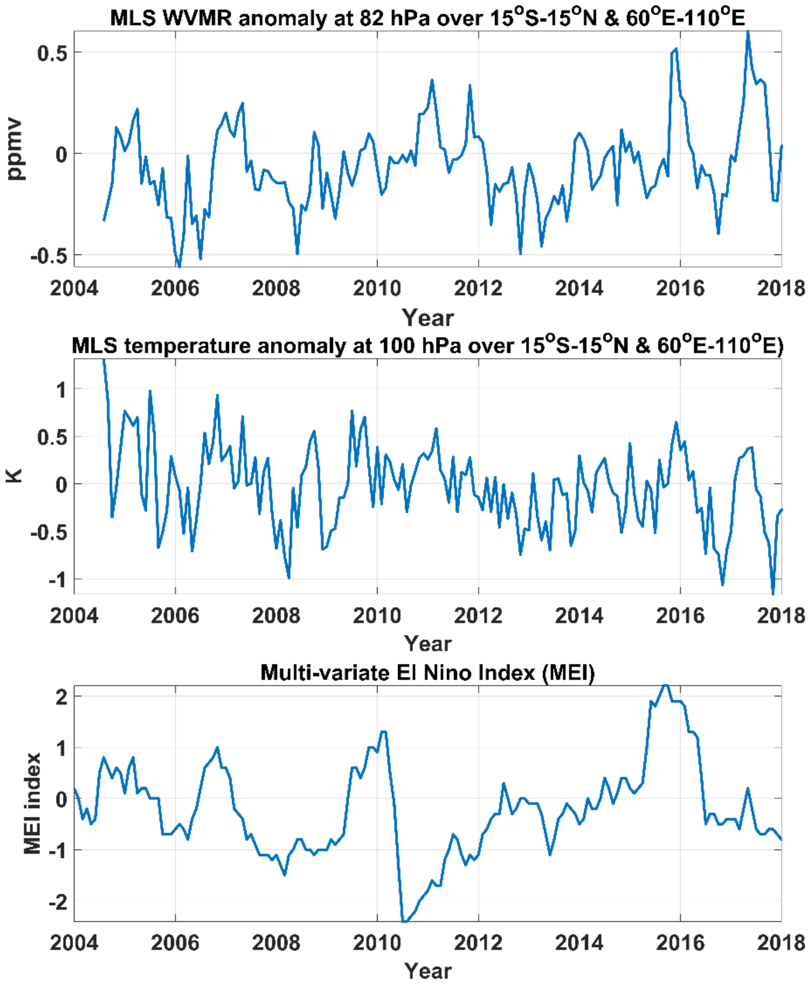


Interannual variability of SWVMR





- SWVMR shows an anomalous behaviour in the lower stratosphere (100-56 hPa) during the winter 2010-11 (November 2010-February 2011).
- Though seasonal variation is seen in 2011 also, WVMR at lower stratosphere shows relatively high value during the winter 2010-11 when compared to other years.

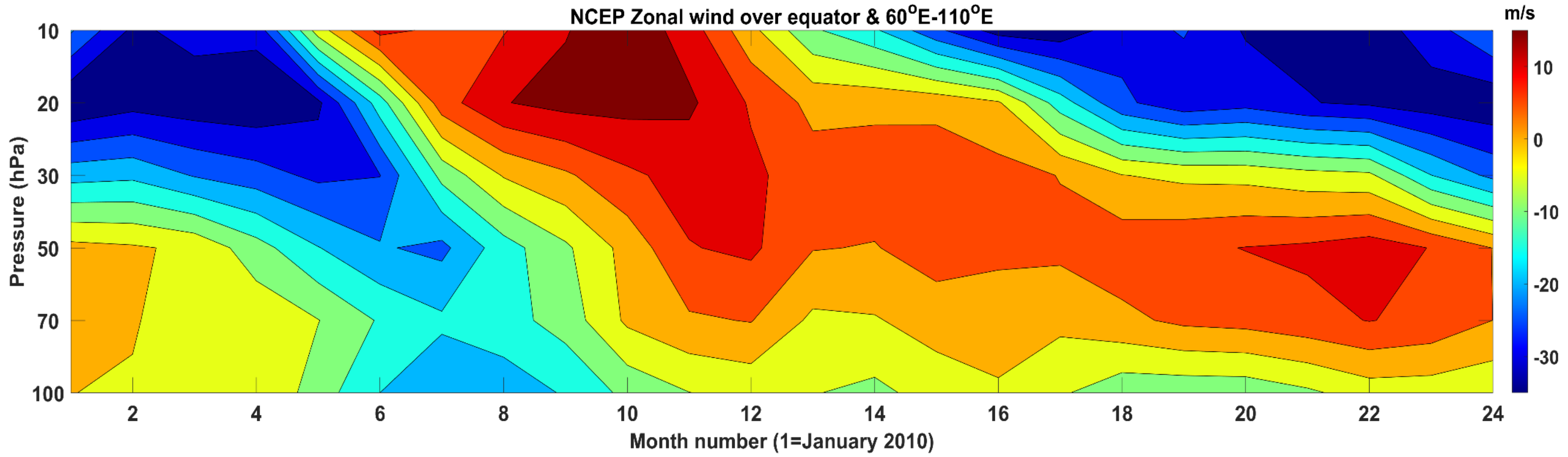


Link with ENSO

- The SWMR variability can be influenced by tropopause temperature, QBO, ENSO, BDC and (Dessler et al. 2013)
- Tropopause temperature is positive during when the large positive WVMR anomaly is observed
- GCM results show that SWMR increases 10% during El Nino events (Scaife et al. 2003).
- MEI is positive (El Nino) during January –April 2010 and negative (La Nina) during May 2010 to May 2012.

YEAR	DJ	JF	FM	MA	AM	MJ	JJ	JA	AS	SO	ON	ND
2010	0.9	1.3	1.3	0.5	-0.1	-1.3	-2.4	-2.4	-2.3	-2.2	-2	-1.9
2011	-1.8	-1.6	-1.7	-1.7	-1.2	-1	-0.7	-0.8	-1.1	-1.3	-1.1	-1.2
2012	-1.1	-0.7	-0.6	-0.4	-0.3	-0.3	0.3	0	-0.3	-0.2	0	0
2013	-0.1	-0.1	-0.1	-0.3	-0.7	-1.1	-0.8	-0.4	-0.3	-0.1	-0.2	-0.3
2014	-0.5	-0.4	0	-0.2	-0.2	0	0.4	0.2	-0.1	0.1	0.4	0.4
2015	0.2	0.1	0.2	0.3	1	1.9	1.8	2	2.2	2.2	1.9	1.9
2016	1.9	1.8	1.3	1.3	1.2	0.4	-0.5	-0.3	-0.3	-0.5	-0.5	-0.4
2017	-0.4	-0.4	-0.6	-0.2	0.2	-0.2	-0.6	-0.7	-0.7	-0.6	-0.6	-0.7
2018	-0.8	-0.7	-0.8	-1.3	-0.9	-0.5	0	0.5	0.6	0.5	0.3	0.2
2019	0.1	0.5	0.8	0.3	0.2	0.4	0.3	0.3	0.2	0.3	0.5	0.4
YEAR	DJ	JF	FM	MA	AM	MJ	JJ	JA	AS	SO	ON	ND
2020	0.3	0.3	0.1	-0.1	-0.2	-0.7	-0.9	-1	-1.1	-1.2	-1.1	-1.1
2021	-1.2	-1	-0.8	-0.9	-1.1	-1	-1.4	-1.3	-1.4	-1.5	-1.4	-1.2
2022	-1	-1	-1.3	-1.6	-1.6	-1.9	-2.2	-1.7	-1.7	-1.7	-1.5	-1.3
2023	-1.1	-0.9	-0.8	-0.4	0	0.4	0.5	0.5	0.7	0.5	0.9	1.1

Link with QBO



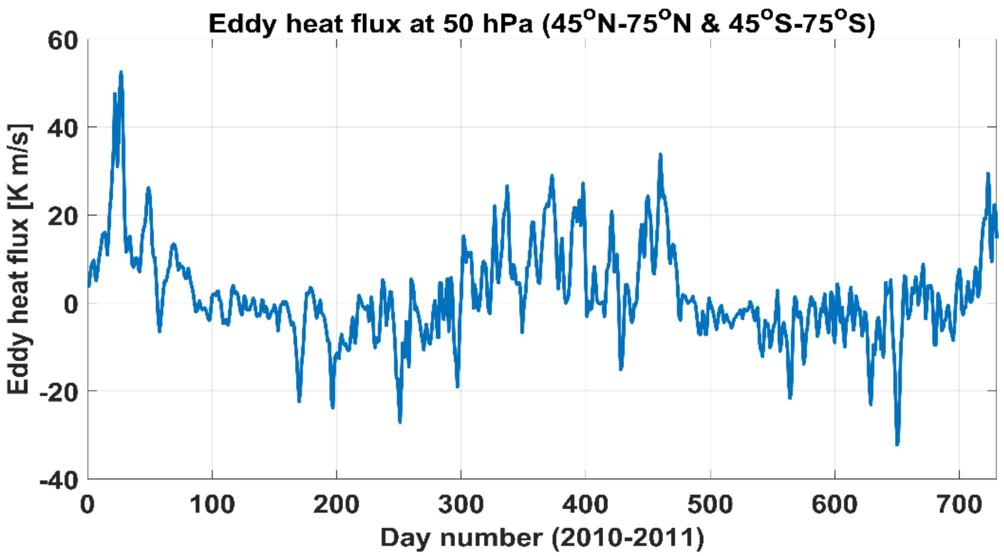
QBO can modulate the SWV transport across the tropopause layer by its secondary meridional circulation (Giorgetta and Bengtsson, 1999).

Eastward phase at top and westward (easterly) phase at bottom can form warm tropopause

Warm ENSO and QBO are in phase : El Nino and eastward (westerly) phase of QBO,
there was an increase in tropopause temperature anomalies, which could increase the SWV (Liang et al. 2011)

Or, La Nina and descending westward phase

Link with BDC



Eddy heat flux averaged for 45°S-75°S and 45°N-75°N shows large values during November 2010-May 2011 indicating Large planetary waves and hence BDC is stronger during this time.

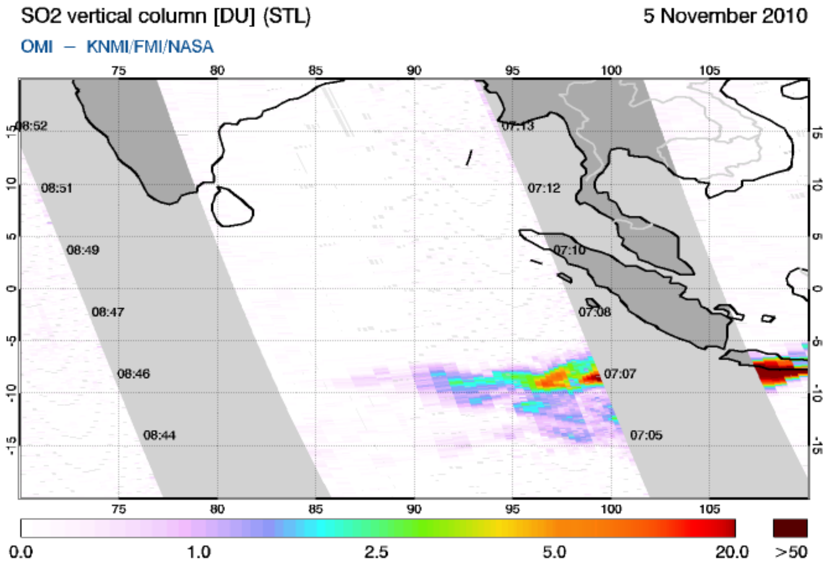
As BDC transports minor constituents from tropics to higher latitudes, there can be anti-correlation between mid-lat PW activity and tropical SWVMR (Dhomse et al., 2008)

So, BDC plays a minor role in the water vapour increase during the 2010-11 winter.

Link merapi volcanic eruption

- Huge volcanic eruptions can inject large amounts of WV into the stratosphere (Joshi and Jones, 2009) For example, the eruption of the Hunga Tonga-Hunga Ha'apai volcano on January 15, 2022,
- Or it can increase tropopause temperature and hence increase the WV entry to the stratosphere (Joshi and Shin, 2003)
- A major volcanic eruption occurred during 26 October-12 November, 2010
- Largest eruption day: 5 November 2010
- WV is one of the principal compounds ejected during volcanic eruptions followed by sulfar-dioxide (SO2)
- However, in the present case direct injection of water vapour by volcanic eruption did not happen, as the SWVMR increases only during the first week of December 2010

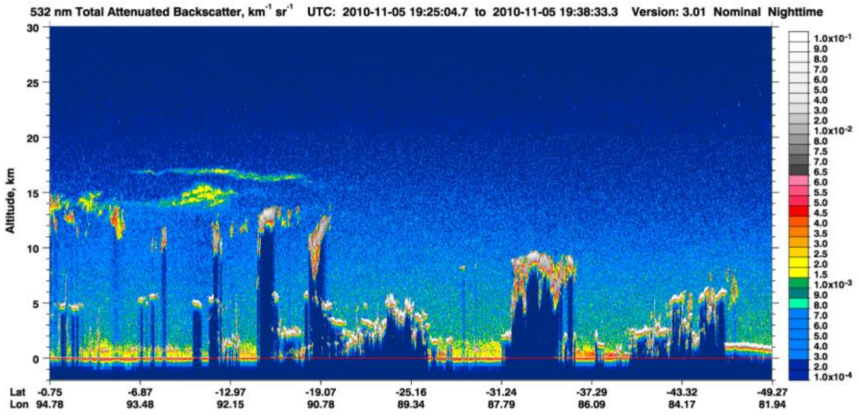
SO2 vertical column (5 November 2010)



Vertical column SO2 obtained from OMI in the height region 15-20 km on the largest eruption day (5 November 2010) indicates large amount of SO2 injection to the UTLS region

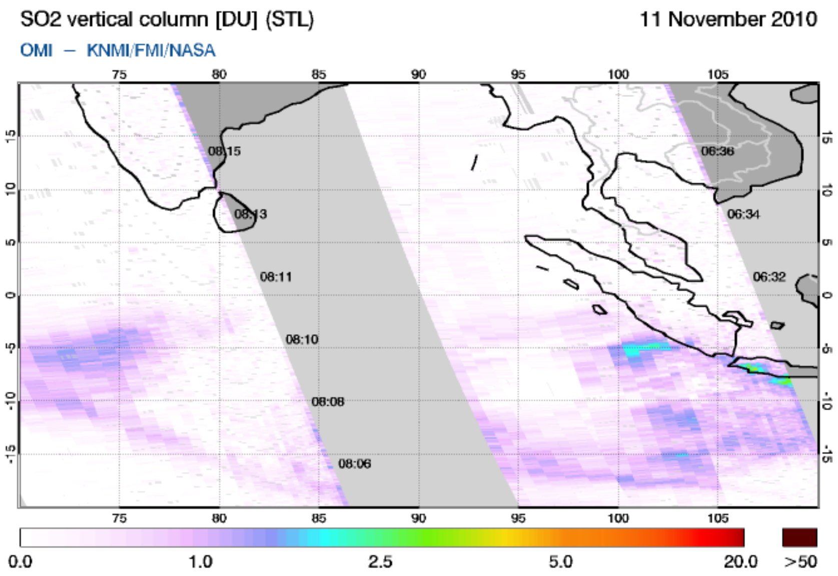
Westward spread of ash clouds from 110E where the Merapi volcano is situated to even 90E can be observed.

532 nm total attenuated backscatter (5 November 2010)



Total attenuated backscatter obtained from CALIOP observations on 5 November 2010 shows a presence of an aerosol layer in the height region of 17-18 km on the day of the largest eruption. Along with this, an aerosol cluster can also be seen in the height range 12-15 km.

SO2 vertical column (11 November 2010)

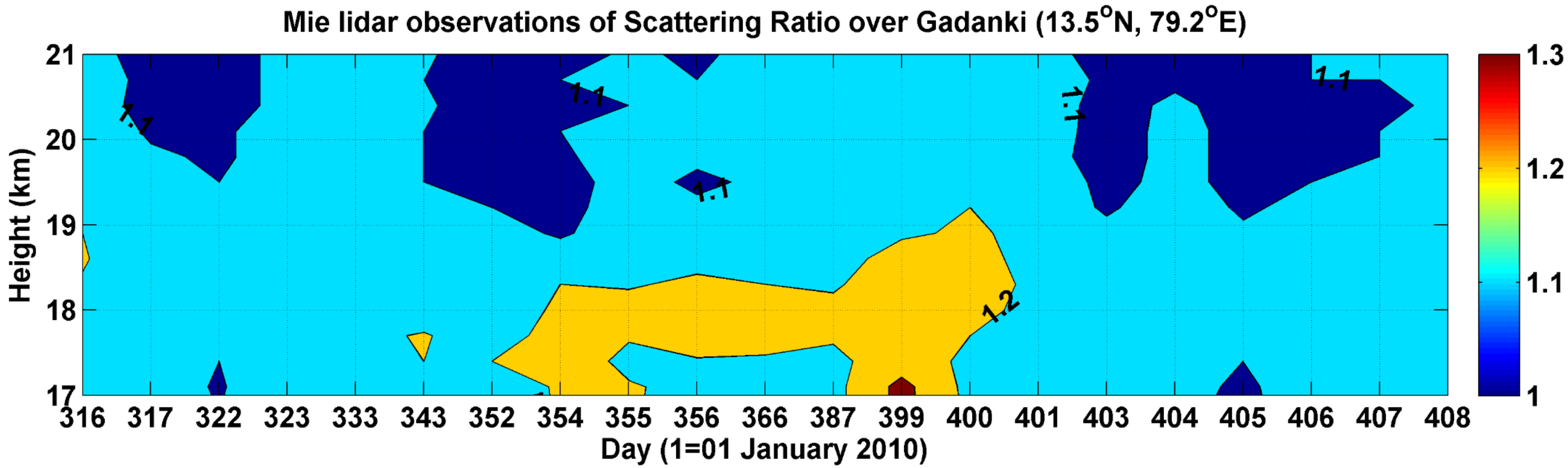


Vertical column SO2 obtained from OMI in the height region 15-20 km on a later day revels that though large concentration of SO2 is present near 5°S, 100 ° E, the spread of UTLS SO2 towards western side (reaching up to 60 ° E) of volcano site

It is well known that the aerosols with volcanic origin in stratosphere can spread all over the globe within some weeks to months.

As the volcano was located near the equator and it injected a sufficient quantality of SO2 into the stratosphere, the resulting chemical reactions could create reflective aerosols that could persist for a long period

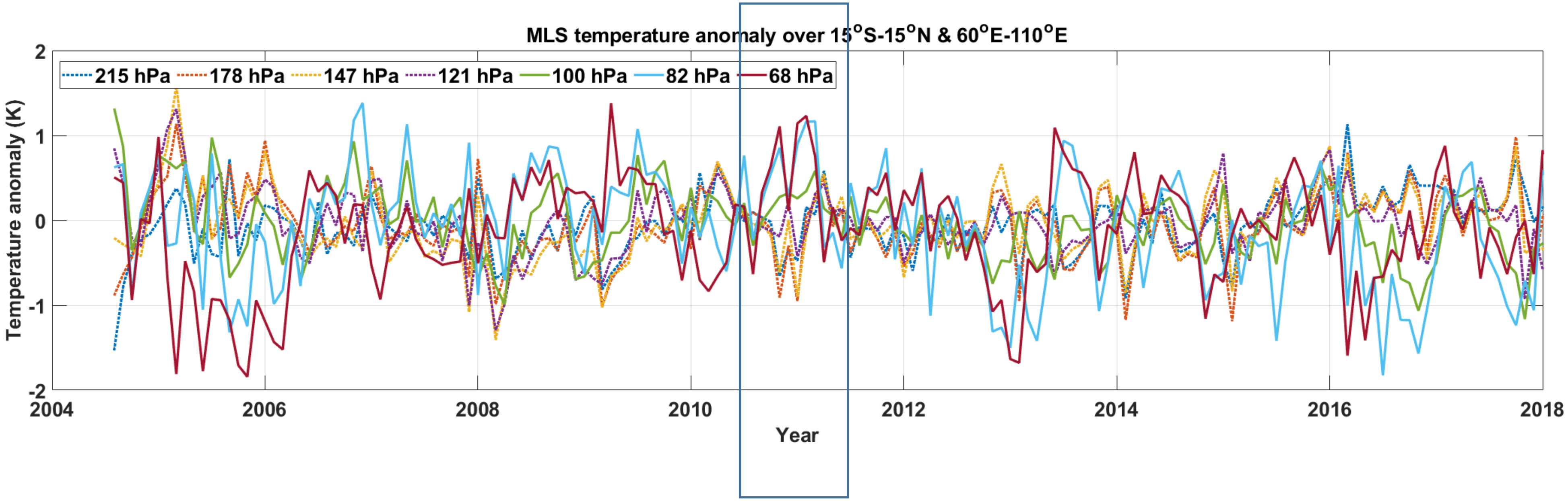
Mie-lidar observations over NARL Gadanki



Mie lidar observations over NARL Gadanki shows the presence of an aerosol layer in the height region 17-19 km persisting for more than one month.

These aerosol layer formed during volcanic eruption can lead to stratospheric warming by absorption of solar radiation and tropospheric cooling by reflection of solar radiation back to space (Free and Angell, 2002)

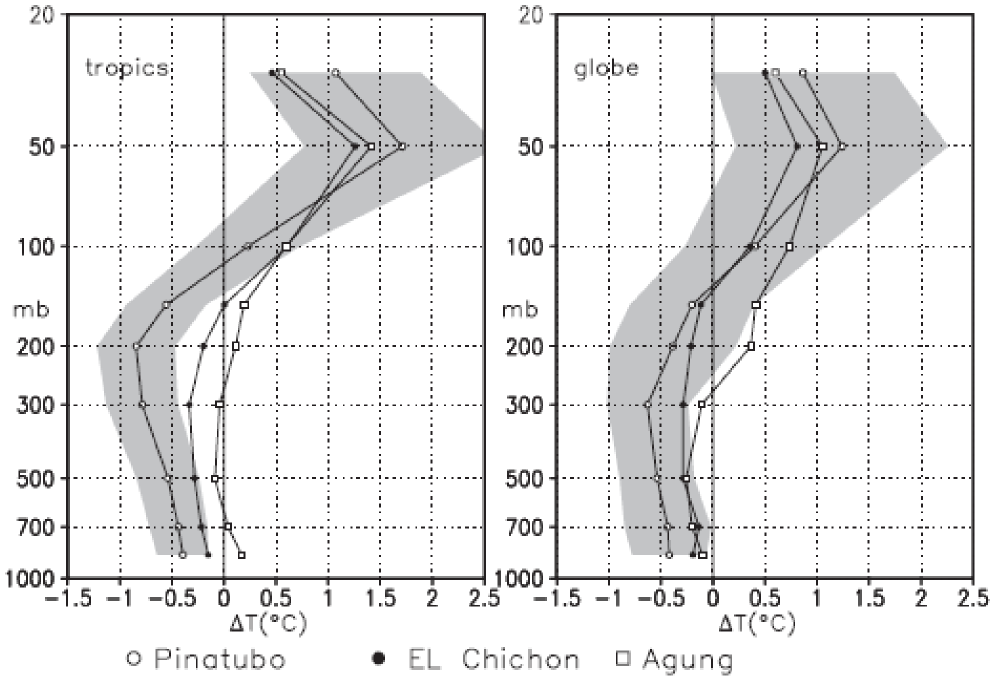
MLS temperature anomaly

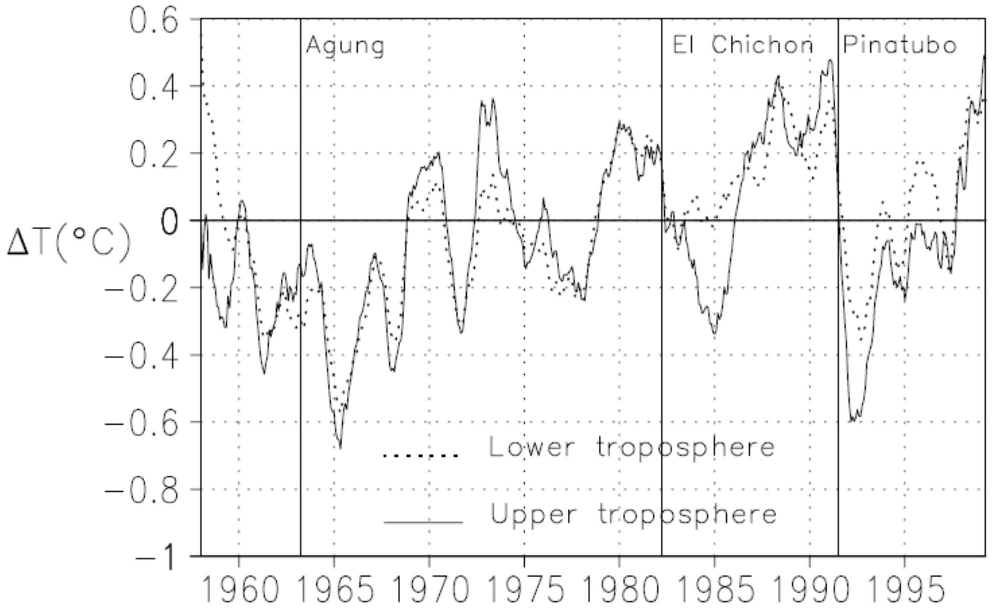


The temperature anomaly shows large positive values 1.2 K, 1.16 K and 0.76 K at 82 hPa, 68 hPa and 100 hPa However, temperature anomaly at upper troposphere (215-121 hPa) shows negative (~ -1 hPa).

Accordingly, the temperature anomaly exhibits the pattern of stratospheric warming and tropospheric cooling During the winter 2010-11.

Modification in the vertical thermal structure due to volcanic eruption





Free and Angell, 2002

Large cooling in the UT after the Pinatubo eruption.
Response of tropical thermal structure is different for different eruptions
Different eruptions have different patterns of cooling and heating in the ULTS region
The shift from tropospheric cooing to stratospheric warming occurs at 100 hPa, 200 hPa, and 300 hPa for Pinatubo, Chichon and Agung eruptions respectively

In the case of Merapi eruption of 2010-11, the shift occurs at 100 hPa
The positive anomaly of SWVMR is attributed to the Merapi volcanic eruption

Summary

- The WVMR shows positive anomaly at 2010end-2011begin
- Major volcanic eruption occurred during October-November 2010
- Mie-lidar observations over Gadanki reveals a presence of thick aerosol layer for an extended period of time
- The positive anomaly of SWVMR is attributed to the Merapi volcanic eruption, as the role of other possible sources (QBO, ENSO, BDC, CH4) appears to be minor

Thank you!