Water vapor variability in the Asian summer monsoon lower stratosphere from satellite observations and transport model simulations

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Summary

Stratospheric water vapor has important radiative and chemical impacts on climate. A localized water vapor maximum in the upper troposphere and lower stratosphere above the Asia summer monsoon is evident in both observational and reanalysis data; however, the processes that control the interannual and intra-seasonal variability in this water vapor maximum are less well understood. Here, we use pentad-resolution data from the Aura Microwave Limb Sounder (MLS) to examine climatological variations of water vapor anomalies in the Asia summer monsoon lower stratosphere (100-68 hPa) in the warm season (May–September) during 2005 to 2017. For example, we find that the lower stratosphere above the Asian summer monsoon was extremely wet during 2017. We then link the variability of water vapor at different time scales to variations in other factors such as cold point temperature, the upper tropospheric anticyclone, and deep convective activity, aiming to clarify the relative roles of these factors in the formation and maintenance of the water vapor maximum in this region. We use model simulations from the Chemical Lagrangian Model of the Stratosphere (CLaMS) driven by multiple reanalyses both to evaluate how well this model represents lower stratospheric water vapor variability above the Asian summer monsoon and to provide additional context on the factors controlling this variability, with particular focus on the anomalously wet and dry conditions in our focus domain.

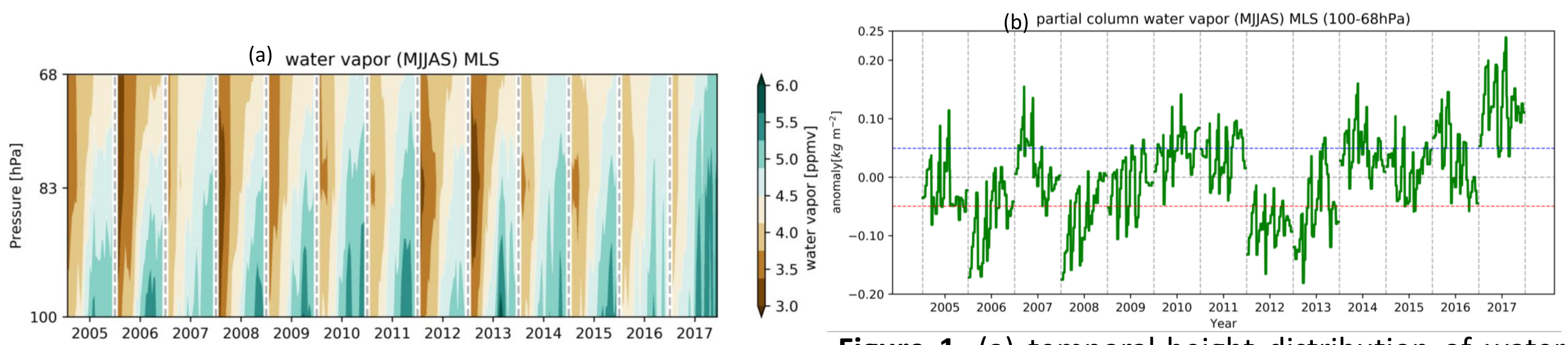
Key points

- CLaMS simulates the high-value center of partial column water vapor in the Aian summer monsoon lower stratosphere well when compared with MLS observations. Besides, CLaMS shows high consistency in the vertical pressure levels in the lower stratosphere.
- Even though CLaMS captures the intraseasonal and interannual variabilities of partial column water vapor, the anomalies are much noisy than the MLS Observatons.

Next step

- We make the hypothesis that the depth of deep convection also matters to the lower stratospheric water vapor. The cloud top height might be a proper proxy about the depth of the convection. Considering that CLaMS doesn't include the convection part, we will use CLaMS to analysis the analyze the impact of deep convection over water vapor.
- Do the similar analysis by using Stratosphere (CLaMS) driven by multiple reanalyses to answer the question that how well this model represent the lower stratospheric water vapor variability?
- Link the deep convection part with the monsoon depression in the north India and eddy shedding in the east Asia, to figure out how they interact with each other ?

Water vapor Variability(MLS)



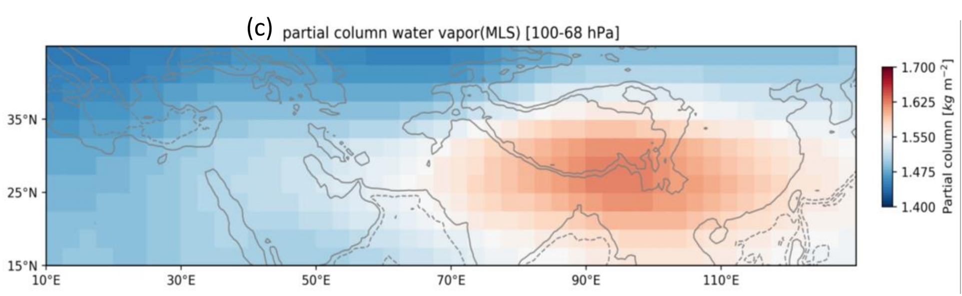
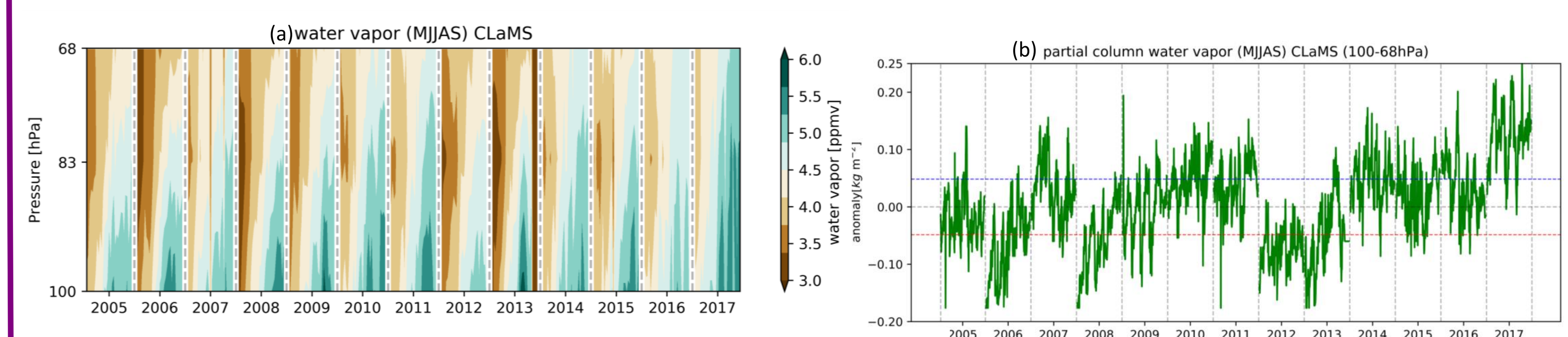


Figure 1. (a) temporal-height distribution of water vapor from 100 hPa to 68 hPa, derived from May to September.(b) time series of deseasonalized partial water vapor anomalies in the ASM. Blue and red dashed lines indicate the threshold of identify extreme wet/dry phase.(c) climatological partial column water vapor in LS over ASM.

Water vapor Variability(CLaMS)



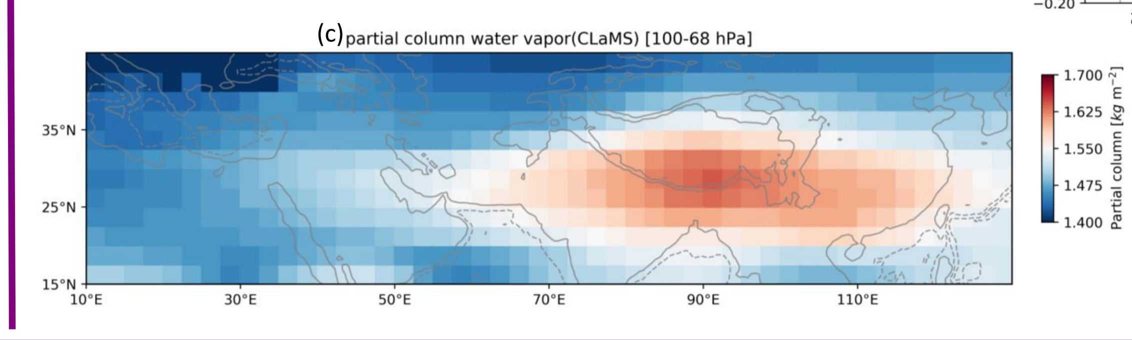


Figure 2. Same as **Figure.1,** but derived from CLaMS , which is driven by the ERA-Interim reanalysis data.

Cold Point Temperature

Based on composited extreme wet and dry phase of partial column water vapor anomalies from **Figure 1b**, we choose the correspond time series of tropopause temperature ,Anticyclone and deep convection to study the mechanisms control water vapor variability.

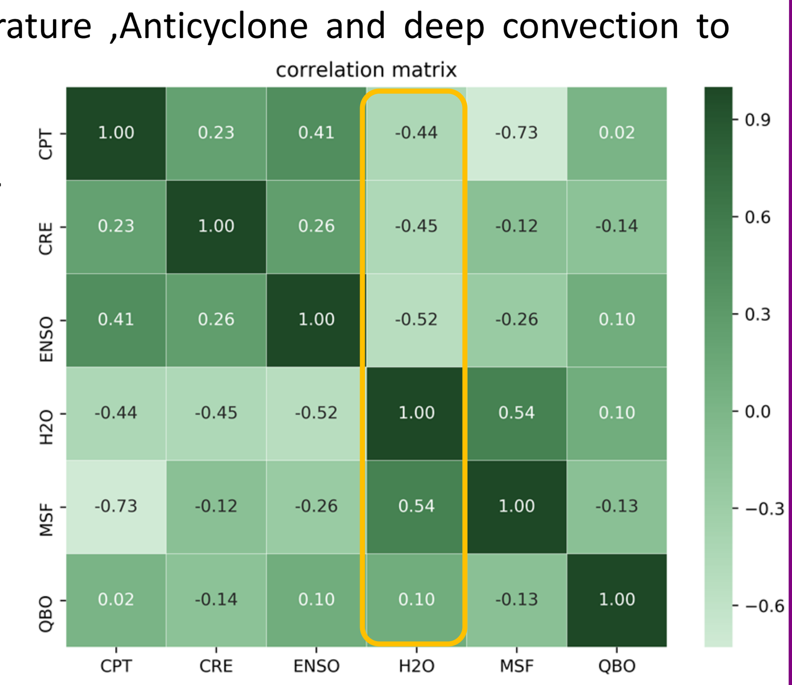


Figure 3. Correlation matrix among the partial column water vapor in the lower stratosphere and factors possibly impact it. QBO has a smallest correlation coefficient with partial column water vapor. we ignore the impact of QBO in this article.

Dipole structure of the correlation maps show the important baroclinic isentropic surface transport of water vapor from the tropopause, which prove again that the dehydration in cold part especially in the Himalaya south slope plays an important role in the lower stratospheric water vapor, (*Wright et al., [2011]*).

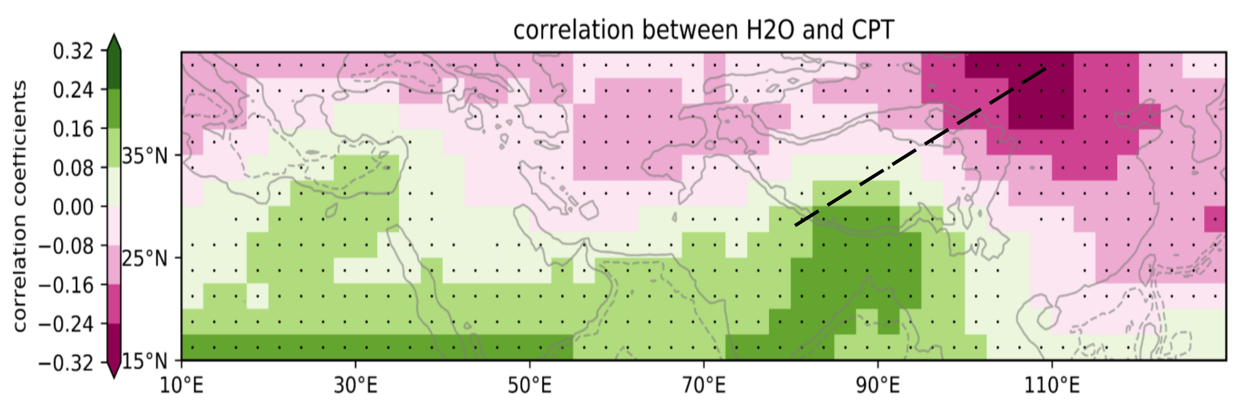


Figure 4. Spatial correlation maps between partial column water vapor and Cold point temperature. Shading indicate the correlation coefficients and black spots denotes pass 95% significance test.

Anticyclone

Montgomery stream function at 395K represents the anticyclone in our focus domain. The anticyclone can confine and isolate the water vapor in it's range. A stronger anticyclone confines and isolates more water vapor. The Spatial correlations indicate in the eastern side of the anticyclone in East Asia, anticyclone influence water vapor mainly through eddy shedding and in the southwest side of the anticyclone, the monsoon decompression probably control the transport of water vapor from troposphere to lower stratosphere. The movement of anticyclonic center could also influence the maintainance of lower stratospheric water vapor. Eastward anticyclonic center contribute more water vapor to the stratosphere and westward anticyclonic center cause the stratosphere to be drier.

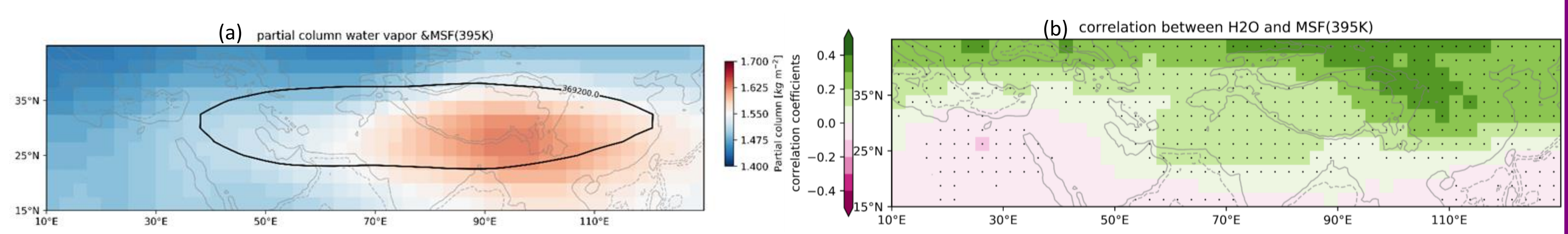


Figure 7. (a) Extent of anticyclone is shown in the black circle and the shading indicate the climatological partial column water vapor as **Figure 1c** shows. (b) Spatial correlation maps between partial column water vapor and MSF(395K) Shading indicate the correlation coefficients and black spots denotes pass 95% significance test.

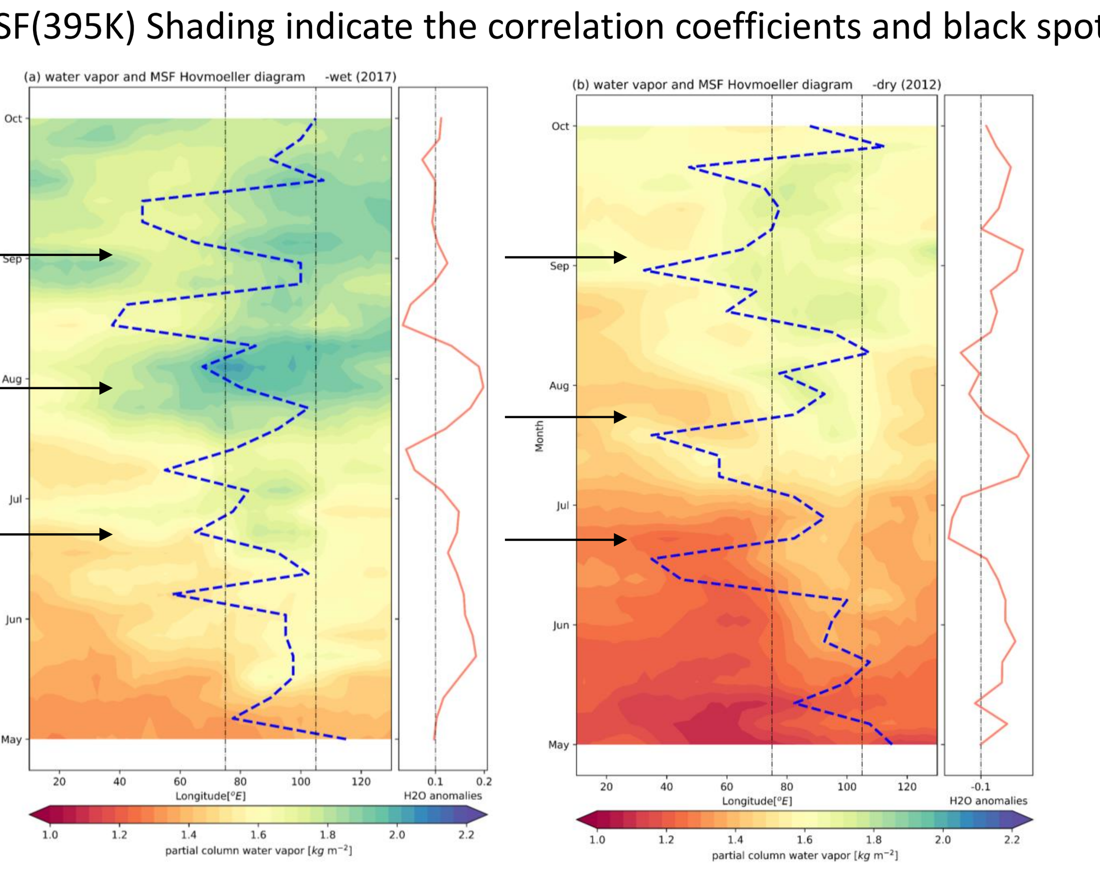


Figure 8. Hovmöeller plots (longitude vs. time) of partial column water vapor averaged over 15°N-45°N during summer time(from May to September) for (a) wet year 2017 and (b) dry year 2012.Blue dashed lines are the center of the anticyclone based on pentads data. the red solid lines are seasonal variations of partial column water vapor. Black dashed lines indicate the range of Tibetan Plateau. Small black arrows indicate the most obvious eastly and westerly position of the anticyclonic center.

Deep Convection

Longwave cloud radiative effect (CRE_LW) can reflect the deep convection especially the frequency of deep convection even though lots of scientists choose Outgoing Longwave Radiation (OLR) to represent the deep convection. Composite CRE_LW anomalies for wet and dry lower stratospheric water vapor extreme values over ASM indicate that , in southeast slope of Tibetan Plateau, a wetter stratosphere is associated with mote frequent deep convection and vice versa, a drier stratosphere is associated with less frequent deep convection. However in the north part of India, the situation is quite different, In around 20°N- 30°N, 60°E-75°E, a wetter stratosphere corresponds to stronger deep convection and a drier stratosphere corresponds to weaker deep convection. The mechanisms behind this phenomenon still remains unclear and needs more work on it.

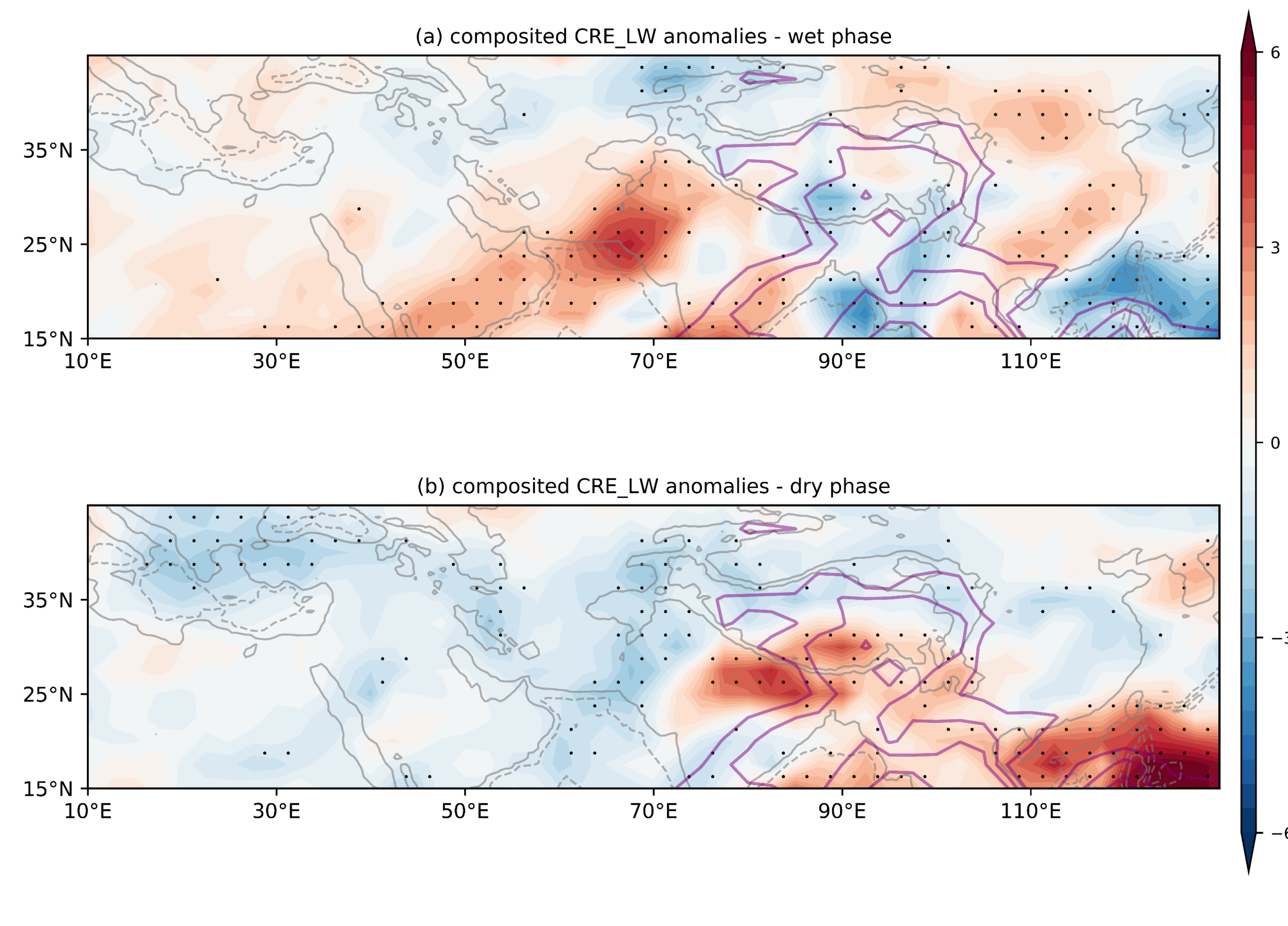


Figure 10. Composited CRE_LW anomalies for (a) wet and (b) dry lower stratospheric partial column water vapor over ASM. Colors indicate CRE_LW variations, red indicate a stronger (more frequent) deep convection and blue indicate weaker (less frequent) deep convection. Stippling denotes the regions of statistical significance. The purple solid lines indicate the background average Outgoing Longwave radiation (OLR) (smaller than 230 $w \cdot m^2$),highlighting the location of climatological deep convection.

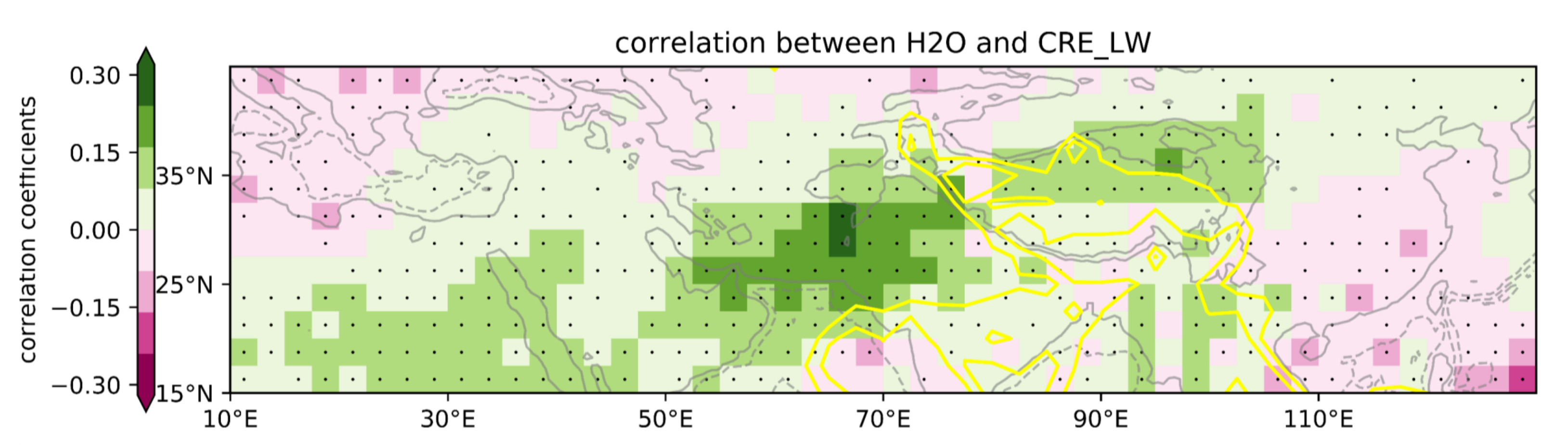


Figure 11. Spatial correlation maps between partial column water vapor and CRE_LW. Shading indicate the correlation coefficients and black spots denotes pass 95% significance test. Yellow lines indicate the background average OLR(smaller than 230 W/m2),highlighting the location of climatological deep convection.