

論文の内容の要旨
Abstract of Dissertation

Title of Dissertation: A Study on Extremely Dry and Wet Summer Monsoon in Pakistan by Focusing on the Anomalous States of the Upper Troposphere

(対流圏上層の偏差に着目したパキスタンにおける夏季モンスーンの異常乾湿に関する研究)

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The summer monsoon, sometimes brings severe droughts and intense flooding in many parts of the world including South Asian countries like Pakistan. Human life and economy in Pakistan considerably depends on the summer monsoon activities. So, an essential question arises “how can we better manage the water resources (i.e. drought and flood management) of the region for the societal needs and benefits”. Therefore, to address the concern as a hydrologist, we need to develop a basis of the scientific understanding of the different contrast of the climatology during extremely dry and heavy rainfall events over Pakistan region. However, compared to other regional studies i.e. Indian Summer Monsoon (ISM) and South-East Asian Monsoon (SEAM), the basis of the thermodynamical structure and the processes associated with upper tropospheric conditions during the climatological mean Pakistan Summer Monsoon (PSM) and its extreme events have not been addressed deeply yet and need to be investigated. Thus, comprehensive understanding of the thermodynamical structure and the associated processes during climatological mean PSM and its extreme events is immensely vital for the hydrologist as a first step to develop the basis of scientific understanding. By data analysis, an attempt has been made to accomplish this objective in this study.

Firstly, the climatological tropospheric conditions and the associated processes from pre-monsoon phase to the PSM mature phase are investigated, with a special

focus on the vorticity and heat budgets on 10-day mean time scale. During pre-monsoon phase (last dekad of June), the stronger upper level convergence around Pakistan accompanies with the upper level vortex stretching, mid-upper level subsidence, radiative cooling and adiabatic warming, which suppresses the convective activities. During the PSM onset and mature phases (early and mid-late July), the basic structure of atmosphere significantly differs from the pre-monsoon phase. However, the PSM mature phase (second and last dekads of July) have following salient features compared to the pre-monsoon phase: (1) the mid-upper tropospheric warming, which causes the reversal of meridional temperature gradient (MTG), gets strengthened and expands; (2) the Asian Jet (AJ) together with the AJ ridge located around Caspian Sea (CS), slightly shifts northwestward; (3) the upper level convergence around Pakistan observed in pre-monsoon, shifts and reallocates to the northwest of Pakistan during mature phase; (4) the low level trough around Pakistan deepens and becomes stronger enough for the maturity of PSM during second dekad of July; and (5) the moisture flux associated with the low level deflected southeasterly and southwesterly monsoon winds respectively from the Bay of Bengal (BoB) and Arabian Sea (AS) increases and intrudes over Pakistan. Therefore during the PSM mature phase, the atmospheric structure (i.e. the upper level vortex stretching and the associated upper level convergence, mid-upper level subsidence and adiabatic warming) slightly moves northwestward of Pakistan which represents the weakening of the upper level convergence around Pakistan observed in pre-monsoon phase. In addition, there is associated rapid decrease (increase) of upper (mid) level adiabatic warming (diabatic heating) around Pakistan. Further in the lower troposphere, the monsoon trough around Pakistan deepens together with the deflected southeasterly and southwesterly moisture flux respectively from BoB and AS increases and intrudes over Pakistan.

Secondly, comparing the PSM mature phase climatological mean characteristics, the characteristics of the extremely dry (wet) PSM events are investigated by focusing their common anomalous tropospheric conditions observed during the period 1979-2008. The extremely dry (wet) PSM events are found to be closely related with the persistence of: (1) the anomalous mid-upper tropospheric cooling (warming) around Pakistan and to its north/northwest, which represents weakening

(strengthening) of the reversal of MTG; (2) the climatological mean AJ ridge located around CS contracts (expands) out longitudinally and also shifts southward (northward) together with the AJ, which is associated with the anomalous upper tropospheric cyclonic (anticyclonic) circulation around northwest of Pakistan; (3) the anomalous upper level convergence (divergence) located around Pakistan is associated with the deceleration (acceleration) of air mass over the AJ north of Pakistan; (4) the PSM low level trough anomalously weakens (strengthens) the climatological mean PSM trough to suppress (enhance) the PSM activities; and (5) the anomalous northwesterly (southeasterly) low level monsoon winds moving along the southern slope of the Tibetan Plateau (TP) towards BoB (Pakistan), which anomalously decreases (increases) the climatological mean deflected southeasterly and southwesterly moisture flux respectively from the BoB and AS to intrude over Pakistan. The associated processes of the PSM dry (wet) events are investigated and the author found that associated with the anomalous cyclonic (anticyclonic) circulation is the shifting of AJ southward (northward) together with the CS ridge contraction (expansion) longitudinally. And associated with the anomalous cyclonic (anticyclonic) circulation, is the anomalous upper level negative (positive) advection of absolute vorticity i.e. NAVA (PAVA) around Pakistan. In addition to NAVA (PAVA), negative (positive) vertical advection of relative vorticity i.e. NVVA (PVVA) is balanced by vortex stretching (shrinking). Further, the upper level anomalous vortex stretching (shrinking) has to accompany with the upper level anomalous convergence (divergence) and the associated anomalous subsidence (updraft) below to suppress (enhance) PSM activities. The anomalous upper level convergence (divergence) is associated with the anomalous extratropical (subtropical) northerly (southerly) ageostrophic wind related with the deceleration (acceleration) of air mass over the AJ north of Pakistan. In addition, the mid tropospheric anomalous diabatic cooling (heating) and the cold (warm) horizontal advection balanced with the anomalous warm (cold) vertical advection. The wind glides (does not glide) down the sloping isentropes to partly enhance subsidence (updraft), which is associated with the anomalous diabatic cooling (heating) over Pakistan. Further, the mid-upper tropospheric cold (warm) temperature anomaly around Pakistan and to its north represents anomalous weakening (strengthening) of the positive reversal of the MTG,

which is consistent with the anomalous lower-upper level westerly (easterly) around Pakistan. Associated with the anomalous mid-upper level downdraft (updraft) is the suppressed (enhanced) PSM convective activity through anomalous weakening (deepening) of the low level trough and the anomalous decrease (increase) of the deflected southeasterly and southwesterly moisture flux from the BoB and AS to intrude over Pakistan. So, all these processes occur simultaneously.

However, hydrologists need to improve their scientific understanding of the triggering mechanism for this kind of the knowledge for the improvement of Integrated Water Resources Management (IWRM). If hydrologists get a signal in advance, IWRM will be much more effective. However, for the anomalous states following precursors are found:

1. Circulation anomaly northwest of Pakistan triggers the PSM convection anomaly.
2. Circulation anomaly northwest of Pakistan might be associated with some upstream event around midlatitude or the anomalous state of Atlantic Ocean Oscillation (NAO) through the midlatitude wave train (i.e. pressure pattern anomaly).
3. Anomalous state of El-Niño (La-Niña) might bring PSM suppressed (enhanced) convection anomaly.
4. Northward propagating convective perturbation triggers the PSM convection anomaly. However further research is needed to clarify, what triggers the convective perturbation around equator and how this convective perturbation propagate northward around Pakistan region?

Therefore, the above mentioned Sr.1-4 researches on predictability, especially, should be strengthened. Further, the persistence of the cyclonic (anticyclonic) circulation northwest of Pakistan are presented for further study i.e. (1) the persistence of extratropical upper tropospheric alternate pressure pattern anomaly (negative-positive and positive-negative) contrast; and (2) the suppressed (enhanced) monsoon activities around the tropical monsoon region i.e. AS and western India. Therefore, it is speculated that the extremely dry (wet) events over the PSM region might be triggered by the disturbances from the tropics and/or extratropics which act at the same time or act individually, which needs further investigations to reach a definite conclusion.