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On the intra-seasonal to decadal climate variability over South-Asia

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by

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Cover image: Topography of South-Asia (contour interval 500 m)

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This thesis is dedicated to

my mother

for her endless support and sacrifice !

Contents

Abstract 7

List of papers 9

1 Introduction 11

2 Mean Climate over South Asia 13

2.1 Winter Climate ………………………………………………….. 13

2.2 Summer Climate ………………………………………………… 14

3 Climate variability over South Asia 16

3.1 Tropical influences

3.1.1 Intra-seasonal oscillations (ISO) ………………………….. 16

3.1.2 El-Niño Southern Oscillation (ENSO) ……………………. 18

3.2 Extra-tropical influences

3.2.1 North Atlantic Oscillation (NAO) …………………………. 20

3.2.2 Extra-tropical teleconnections during the northern-hemisphere winter……………………………………………….……… 21

3.2.3 Extra-tropical teleconnection during the northern-hemisphere summer.…………………………………………...…….. 21

4 Outlook 24

5 Acknowledgements 25

6 References 26

ABSTRACT

South Asia, a land of contrasting landscapes, seasons and climates, is highly vulnerable to climate variability over intra-seasonal to decadal time scales. In winter, precipitation over the western parts of south Asia and fog over the Indo-Gangetic (IG) plains are the two major climatic features. During summer most of the region comes under the grip of monsoon.

Winter precipitation over the north-western parts of South Asia is associated with eastwards propagating ‘western disturbances’ originating mostly from Mediterranean. Both observations and regional climate-model simulations show that the winter precipitation increases/decreases during the positive/negative phases of the North Atlantic Oscillation (NAO) and the warm (cold) phase of the El Niño-Southern Oscillation (ENSO). During these phases, the intensification of western disturbances results from the effect of an enhanced trough visible at sea-level as well as at higher altitudes over central Asia. The inter-annual variability of fog is coupled over IG plains with a significant trend in the fog frequencies, both in observations and ERA-Interim reanalysis data. This increase shows two distinct regime shifts in 1990 and 1998 with respect to mean and variance, this in contrast to a gradual increase of the humidity over the region.

The thermodynamic analysis of the intra-seasonal summer monsoon active phases (APs) over Pakistan revealed that a few days before AP, an upper-level warm anomaly appears over the northern Hindu Kush-Himalaya region and is reinforced by surface heating. The baroclinic height anomalies, with a low-level anticyclone located east of the warming, causes a moisture convergence, strong enough to overcome the preexisting stable atmospheric conditions. The extratropical dynamics also play an important role for the inter-annual variation of the South-Asian monsoon. It is found that the two leading modes between the upper-level circulation in the Atlantic/European region and monsoon rainfall are the Circumglobal Teleconnection (CGT) and the summer NAO. The positive phase of the CGT is related to a widespread increase of monsoon rainfall, and a positive summer NAO is related to a precipitation dipole with its positive anomaly over Pakistan.

Keywords: *South Asia, monsoon, western disturbances, fog, climate variability, climate dynamics, teleconnections, ENSO, NAO, CGT*

List of Papers

The thesis consists of an introduction and the following four papers:

I: **Syed, F. S.**, F. Giorgi, J. S. Pal, and K. Keay (2009): Regional climate model simulation of winter climate over Central–Southwest Asia, with emphasis on NAO and ENSO effects. International Journal of Climatology, 30: 220–235. DOI: 10.1002/joc.1887

II: **Syed, F. S.**, J. H. Yoo, H. Körnich, and F. Kucharski (2010): Are intraseasonal summer rainfall events micro monsoon-onsets over the western edge of the South-Asian monsoon?, Atmospheric Research, 98:341–346. DOI:10.1016/j.atmosres.2010.07.006

III: **Syed, F. S.**, J. H. Yoo, H. Körnich, and F. Kucharski (2011): Extratropical influences on the inter-annual variability of South-Asian monsoon, Climate Dynamics. DOI 10.1007/s00382-011-1059-4

IV: **Syed, F. S.**, H. Körnich and M. Tjernström (2011): On the fog variability over South Asia. *Submitted to Climate Dynamics*

Reprints are made with permission from the publishers. Paper I was initiated by me. The analysis and text was also written by me with the help of Filippo Giorgi, the cyclone tracking algorithms were implemented with the help of Kevin Keay. The original idea of Paper-II was developed by Jin Ho and Fred Kucharski, Jin Ho Yoo is also responsible for some of the final figures and the text. I originated the idea behind Paper III, the manuscript evolved through discussions with my coauthors and the text was written by me. In Paper-IV the original idea and the analysis are due to me with the help of Heiner Körnich. The text was written by me and improved by Michael Tjernström and Heiner Körnich

1. Introduction

In the last decades there has been considerable focus on climate-change issues. The Intergovernmental Panel on Climate Change (IPCC) in its different assessment reports has developed scenarios of climate change for the 21st century. With the development in the science of climate change, the uncertainties in future climate projections are now very well understood. Similarly the prediction of weather for the next few days has reached the status of an art, and national weather centers around the world give quite accurate predictions of weather for the next few days. In short, we have good knowledge about what is going to happen after a few days and what could be the global climate in 100 years, but we know very little about what is going to happen in between, especially on the regional scale. Presently there is high degree of interest in the scientific community on the issue of predictability on timescales from seasons to decades, since climate information over these time scales is highly useful for policy makers. The variability at these timescales is generally governed by the natural climate processes. Climate variability has been the principal source of fluctuations in global food production in the arid and semi-arid tropical countries of the developing world (Sivakumar et al. 2005). South Asian countries include Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, the Maldives and Sri Lanka, and the climate of this region is as diverse as its landscape. It spans a variety of climate zones, including arid deserts, parched rangelands, freezing alpine mountains, and humid tropical islands. The year-to-year variations of the long-term monsoon precipitation over the Indian region are strongly correlated with food production over the region (Parthasarathy et al. 1988; Webster et al., 1998). The extremes in these long-term precipitation variations manifest themselves in the form of large-scale floods and droughts (Shukla, 1987; Mooly and Shukla, 1987) and cause devastating human and economic losses in conjunction with other physical, social and political-economic effects. Hence it is imperative that these aspects are well understood, this in order to formulate more sustainable policies and strategies to promote water and food security in the region.

The geographic patterns of South Asia are very complex, with extensive mountain ranges; the Himalayan mountain system (extending over Bhutan, Nepal, India, Pakistan and Afghanistan) includes Karakoram, a large mountain range north of the Himalayan Range spanning the borders between Pakistan, India and China (including K-2 the second highest peak in the world 8,611 m), the Hindu-Kush mountain range that stretches about 800 km between central Afghanistan and northern Pakistan and other, lesser, ranges that extend out from the Pamir Knot. This great wall of high mountains system effectively closes the region from the mid-latitude influences of Central Asia and plays an important role in shaping the unique climatic characteristics of the region. There are large river basins, plateaus, deserts and a long coastline flanked by the Arabian Sea, the Bay of Bengal and the north Indian Ocean. These complex geographical features pose a great challenge to climate models aiming at reproducing the observed climate and its variability.

The rainfall over the region is subject to a high degree of spatial and temporal variability, which leads to a variety of climatic zones, ranging from arid to moist tropical rain-forests. The regional contrasts in rainfall are very striking, the worlds highest annual average rainfall of 1080 cm is found in Cherrapunji in the north-east of India and can be contrasted with almost rainless years in the Sind province in south Pakistan (Pant and Rupa Kumar 1997). The surface temperatures in the region range from -50°C in the Himalayas during winter to +50°C in the western desert regions during summer. There are fascinating contrasts in the climate in different seasons: snow storms and blizzards are frequent in winter over the western and central Himalayas associated with the eastward-propagating midlatitude cyclones (known as western disturbances) from the Mediterranean region and, on the other hand dust and sand storms over desert regions and the southwest monsoon over most parts of South Asia in summer.

The thesis mainly focuses on the precipitation variability associated with the large scale circulation on intra-seasonal and inter-annual time scales. More specifically Paper I and Paper IV examines the inter-annual variability of winter climate. The effects of El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) on the variability of winter precipitation and western disturbances are examined in Paper-I and inter-annual variability and trends in the winter fog over the Indo-Gingatic plains are discussed in Paper-IV. The variability in the South Asian monsoon (SAM) is examined in Paper II and III. The dynamics of intra-seasonal monsoon active phases over western South Asia are discussed in Paper II and extra-tropical interactions, particularly the influence of the Circumglobal Teleconnection (CGT) and summer NAO on the inter-annual variability of SAM are examined in Paper-III.

This thesis summary provides a general overview of the climate and climate variability over South Asia and the associated large-scale phenomena in order to give a proper context to the reader for understanding the four papers constituting the basis of the thesis. An introduction to the mean climate is given in section 2, where after Section 3 describes the major tropical and extra-tropical phenomena that affect the climate of South Asia.

2. Mean Climate over South Asia

South Asia has two principal seasons, winter (December-March) and summer (June-September), and in between there are transitional seasons: the hot weather (pre-monsoon months) April and May and the retreating monsoon (post-monsoon) months of October and November. However, these periods are defined in a general large-scale sense, the actual rainy periods differ widely over various parts of the subcontinent. Over Pakistan and north-western India the monsoon onsets in the beginning of July and the with-drawal of the monsoon begins in early September, and thus the effective duration of the southwest monsoon or SAM is only about 2 months (July and August). Therefore Papers II and III only consider the core monsoon months of July and August.

The orography plays an important role for determining the spatial distribution of precipitation and the surface temperature distribution also generally follows the topographical features over the land areas of South Asia. Monthly precipitation and temperature data from Climate Research Unit, CRU TS 3.1 data set (Mitchell and Jones, 2005) is used to get seasonal mean precipitation and temperature and distributions shown in figure 1 and 2.

2.1 Winter DJFM (December-March) Climate

During winter, the general flow of surface air is from north to south; northwesterly in the Indo-Gangetic plains, northerly over central India and northeasterly in southern peninsular India and Sri Lanka. The western disturbances (WDs) that originate from the mid-latitude cyclones over West Asia, the Mediterranean and sometimes from as far as the Atlantic Ocean, travel eastwards across Iran, Afghanistan, Pakistan and India and affect the region north of 30°N by giving rise to cloudiness and precipitation (Fig. 1a). Generally when WDs reach South Asia they do not have well developed cold or warm fronts either at the surface or at the upper levels, most of them being at occluded stage (Pant and Rupa Kumar 1997). The different characteristics of WDs, including cyclogenesis, cyclolysis, climatology and the variability associated with NAO and ENSO, are discussed in detail in Paper I.

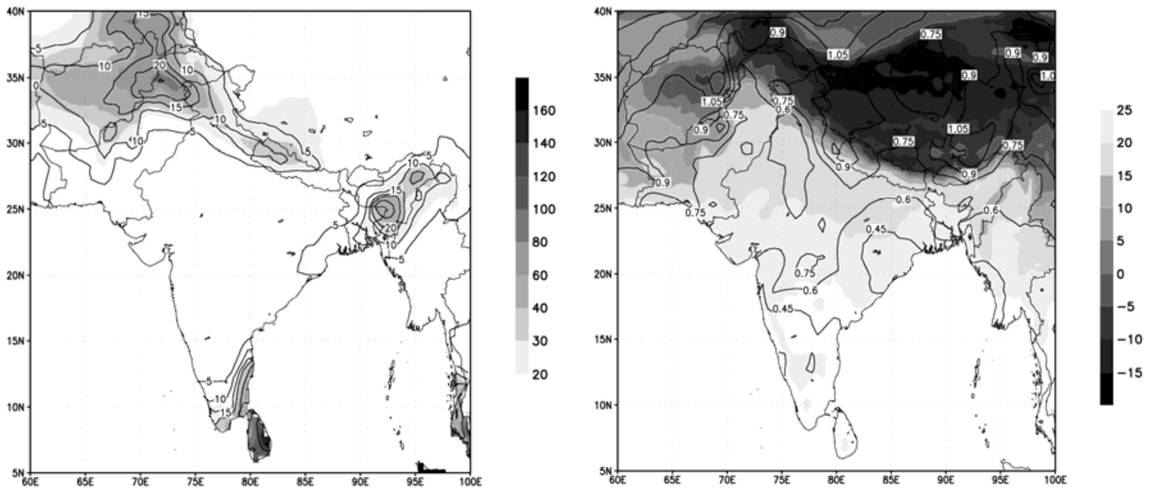

Figure 1: (a) DJFM mean precipitation (1980-2009) in mm/month (shaded) and the standard deviation of precipitation (contours), (b) as in (a) but for the 2 m temperature (°C)

The mean winter precipitation is about 100 mm/month over northern Pakistan, with a high standard deviation (SD) of 20 mm/month (Fig. 1a). The highest SD of the temperature is observed over the high mountains, where the mean seasonal temperature is below 0°C (Fig. 1b). The winter season is also known as the north-east or winter monsoon and is the main rainy season over the southern tip of India and Sri Lanka. Another conspicuous feature of the winter climate is the occurrence of heavy fog over the Indo-Gangetic plains encompassing most of northern and eastern India, from Pakistan to Bangladesh. The inter-annual variability and trends of the fog phenomenon over South Asia are discussed in Paper IV.

2.2 Summer JJAS (June-September) Climate

During the summer-monsoon months the surface winds take the opposite direction, viz. from sea to land, bringing with them large amounts of moisture and precipitation. The wind direction in the major parts of the Arabian Sea and the Bay of Bengal is northeasterly. The seasonal changes of winds and rainfall can be interpreted as a result of the northward seasonal migration of the east-west oriented precipitation belt (the Inter-Tropical Convergence Zone, ITCZ) from the southern hemisphere winter to the northern hemisphere in summer (Gadgil, 2003). The largest northward excursion of the rain belt takes place over the South Asia region where it moves from a mean position of about 5°S in winter to about 20°N in the northern summer (Waliser and Gautier, 1993). During the summer monsoon season, the most prominent feature of the monsoon circulation at the surface is a monsoon trough extending from the heat low over southern Pakistan up to Gangetic west Bengal. It is a semi-permanent major feature of the summer monsoon circulation in the lower troposphere. As the monsoon sets in over South Asia, the ITCZ gradually merges with the monsoon trough. The monsoon depressions, which originate over the Bay of Bengal, move along the trough line, across the Gangetic plains in the north-westerly direction. The variation in the position of the trough axis defines the spatial distribution of rainfall, and during monsoon-break periods the trough line shifts to the foot-hills of the Himalayas, which decreases the rainfall over central India and increases it over north India along the Himalayan foot-hills.

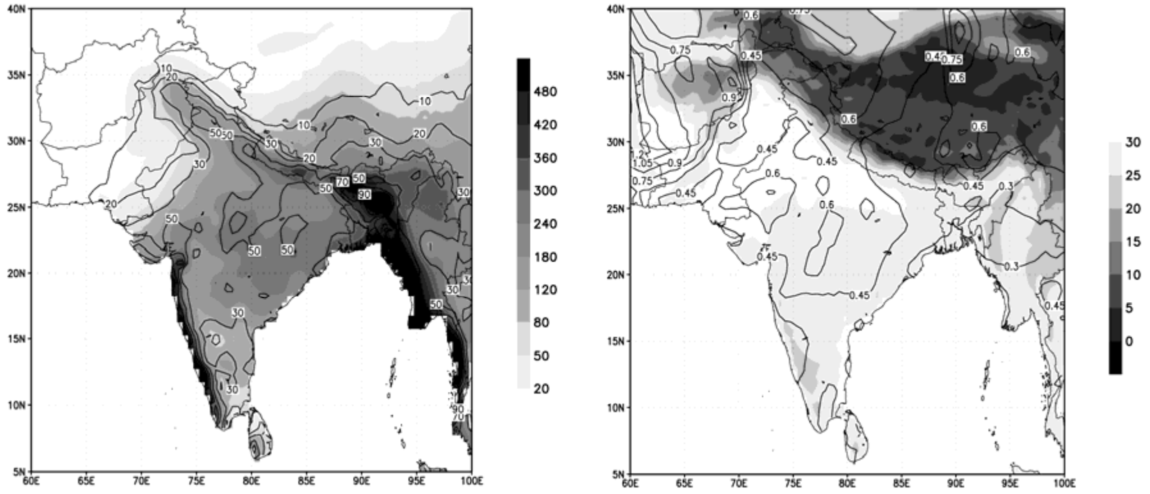

Figure 2: (a) JJAS mean precipitation (1980-2009) in mm/month (shaded) and the standard deviation of precipitation (contours), (b) as in (a) but for the 2 m temperature (°C)

Prominent spatial maxima in the summer monsoon rainfall can be seen along the west coast of the Indian peninsula, the Himalayan foot-hills, north-east India, Bangladesh and adjoining areas (Fig. 2a), where the highest values of the inter-annual summer rainfall SD are also observed. There is also a region of maximum mean precipitation and SD observed over northern Pakistan and north-western India. The dynamics of the active monsoon phases over this region differ from those in rest of the region and are discussed in detail in Paper II. The northern Bay of Bengal, which is the formation area of monsoon depressions, receives the highest mean summer rainfall of more than 500mm. From the west coast, the monsoon rainfall decreases sharply on the leeside of the Western Ghats, and the reaches a minimum over the Deccan Plateau and then increases gradually towards the east coast. In contrast, the Thar Desert in the western India and southern Pakistan receives very little rain during this season. The highest temperatures are observed during the months of May and June, whereafter the temperature decreases with the arrival of monsoon rains over the region. Again the spatial pattern of the temperature follows the orography (Fig. 2b).

3. Climate variability over south Asia

3.1 Tropical influences

3.1.1 Intra-seasonal oscillations (ISO)

The Madden–Julian oscillation (MJO) is one of the dominant modes of tropical variability on intra-seasonal time scales (Madden and Julian 1972) and has significant effects on the atmospheric circulation throughout the global Tropics, its variations projecting on to seasonal and lower frequency scales. As we improve our understanding of the MJO and its predictability, the skill of seasonal prediction should also improve. The MJO, typically in the time scales of 30-60 days, can be characterized by the large-scale convective anomalies that develop over the tropical Indian Ocean and propagate eastwards to the western Pacific (Knutson and Weickmann 1987; Hendon and Salby 1994). During boreal summer the northward-propagating monsoon intra-seasonal oscillations (ISOs), related to or independent of the eastward-propagating MJO, are vigorous over the Indian Ocean. Pai et al. (2011) found that during MJO, Phases 1 and 2 (enhanced convection in the western and central equatorial Indian Ocean), break monsoon type rainfall distributions are observed over India. Subsequently, as the MJO propagates eastwards, a gradual northward shift of the above-normal rainfall band from southern to northern India is observed. The propagation of this rainfall/cloud band is intimately associated with the active and break cycles of the monsoon intra-seasonal variability (Krishnamurti and Subrahmanyam, 1982; Murakami et at., 1984; Webster et al., 1998). However, a spectral analysis of 10-60 day filtered daily precipitation station data over monsoon region of Pakistan does not show any significant peak of northward-propagating 30-60 days ISOs. Goswami and Mohan (2000) showed that the part of the inter-annual variations of the seasonal mean that is independent of external forcing arises from the changes in the statistics of the ISOs of the SAM. They also showed that intra-seasonal and inter-annual variations of SAM are governed by a common mode of spatial variability and the probability of occurrence of active conditions during strong monsoon years is higher. Krishnamurthy and Shukla (2007) showed that the intra-seasonal modes on two different time scales (20 and 45 days) oscillate around seasonally persisting components, which are the main contributors to the seasonal mean rainfall.

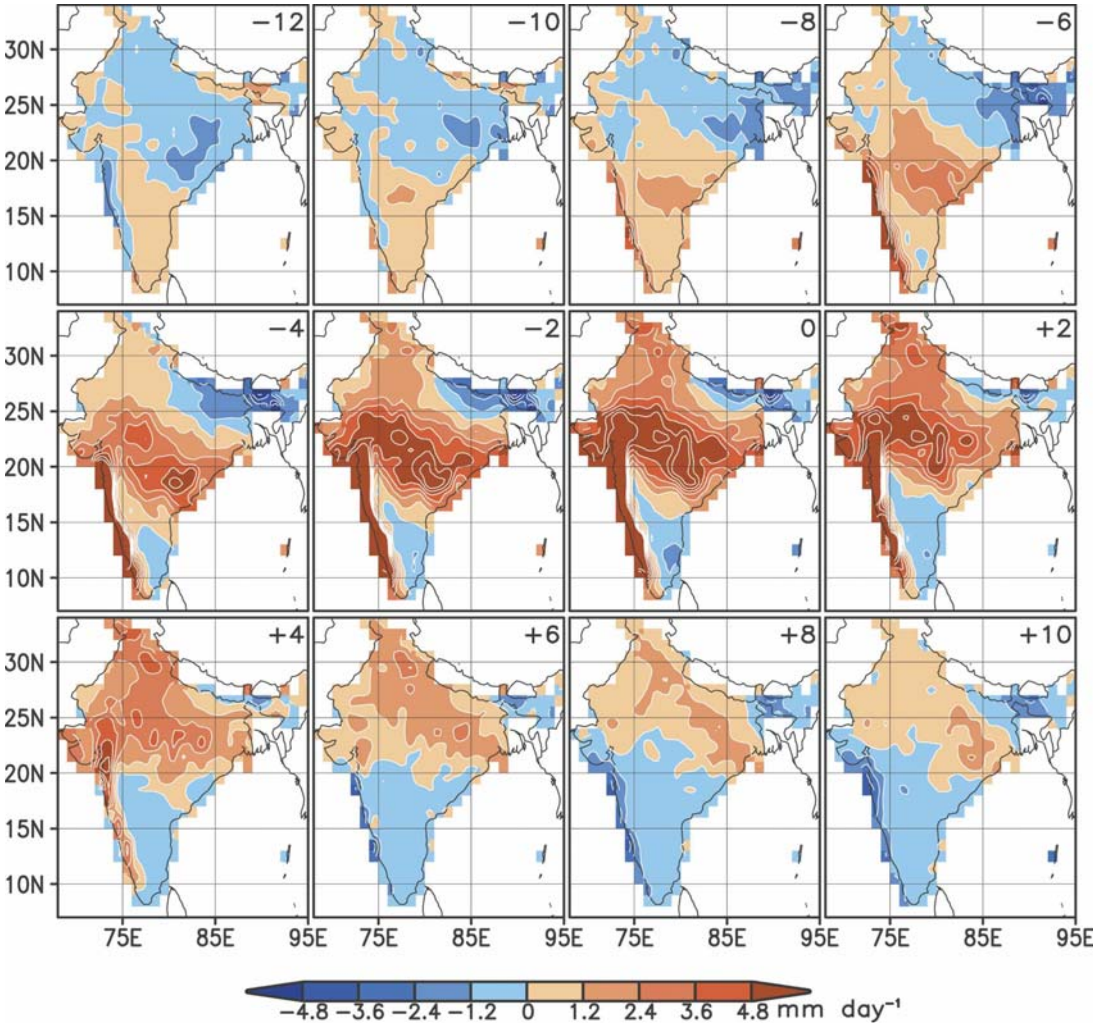

Figure 3: Lagged active phase composites of daily rainfall anomalies (mm day-1) for JJAS 1901–70. Lag (-) or lead (+) day is indicated at the top right corner of each panel. Lag 0 corresponds to the midpoint of each active phase. The figure is taken from Krishnamurthy and Shukla (2007)

By analyzing a 70-yr-long observed daily rainfall data set over India, Krishnamurthy and Shukla (2007) also found that the life cycle of the active/break period of the monsoon lasts about 16 days on average. The positive (negative) rainfall anomalies start over the Western Ghats and the eastern part of central India and then the anomalies intensify and cover all of central India and parts of north India while negative anomalies are established over the sub-Himalayan region and over southeast India during the subsequent evolution of the active period (Fig. 3). The analysis of the active phases of the monsoon over Pakistan, which lies on the north-western edge of SAM showed different dynamics, a feature which is discussed in Paper II.

3.1.2 El-Niño Southern Oscillation (ENSO)

The inter-annual variability of winter precipitation is relatively large in the north-western parts of South Asia. During the period 1998-2002 the region suffered the most severe drought conditions experienced in the last 50 years (Barlow et al., 2002). This drought has been linked to sea surface temperature (SST) anomalies in the tropical Pacific and Indian Oceans (Barlow et al., 2002; Hoerling and Kumar, 2003). Yadav et al. (2006) found that during the years of excess winter precipitation over north-western India, the SST was above normal over the equatorial Indian Ocean, the surface air temperature was below normal over the eastern Mediterranean and the Himalayan region, and upper-tropospheric westerlies strengthened and shifted southwards. Syed et al. (2006) investigated the effects of the ENSO on winter precipitation in Central Southwest Asia (CSWA) on the basis of observed climate data. A positive precipitation anomaly was found to correspond to the warm ENSO phase over a sub-region encompassing northern Pakistan, Afghanistan, Tajikistan and southern Uzbekistan. We proposed a physical mechanism (Fig. 3) for understanding this effect whereby WDs are intensified over the region as they encounter the low pressure trough which is a dominant feature of warm ENSO conditions. This mechanism is explored in Paper I. ENSO is also indirectly linked to the fog variability in winter, which is discussed in Paper IV.

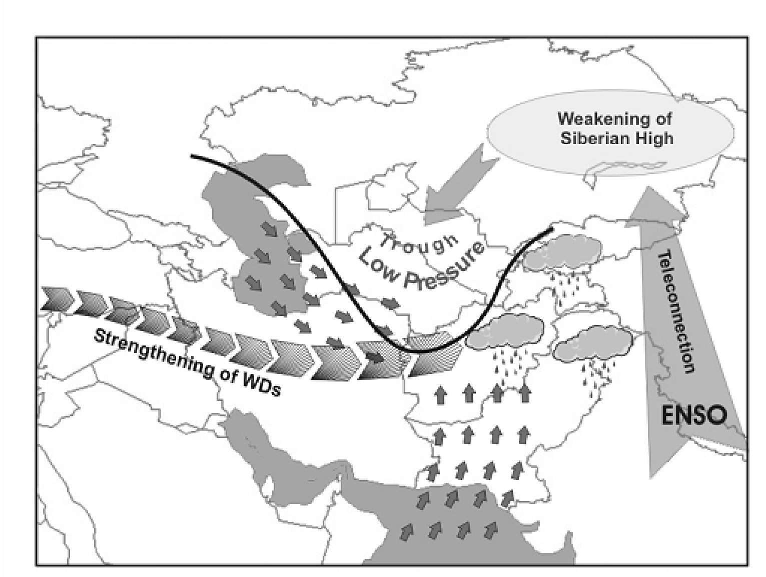

Figure 4: Proposed mechanism for the effect of the warm ENSO phase on the winter precipitation over CSWA. The figure is taken from Syed et al. (2006)

The main contributors to the inter-annual variability of SAM are the large-scale El Nino Southern Oscillation forcing (Webster and Yang, 1992; Ju and Slingo, 1995), the tropical Tropospheric Biennial Oscillation (Meehl, 1997; Chang and Li, 2000; Meehl et al., 2003; Wu and Kirtman, 2004; 2007) and the Indian Ocean Dipole (Saji et al., 1999; Webster et al., 1999; Ashok et al., 2004). During an El Niño event, the region of maximum sea surface temperature (SST) in the Pacific Ocean shifts eastward, bringing more precipitation over the central and eastern Pacific Ocean. During these periods the eastern

Indian Ocean, Indonesia, and south Asia are in the subsiding part of the Walker circulation that shifts eastward from its climatological position (Webster et al., 1998). Goswami and Xavier (2005) showed that ENSO induces decreased SAM rainfall by delaying the onset and advancing the withdrawal. There is a connection between the Asian monsoon and ENSO, but it is not possible to predict the strength of the monsoon solely from the phase of ENSO, as these monsoon–ENSO correlations have variable lag-lead times (Webster and Yang, 1992). During the 1997/98 El Niño events, the Indian rainfall remained essentially normal (Webster et al,. 1998; Torrence and Webster, 1999). Kumar et al. (1999) provided evidence of weakening of the ENSO-monsoon relationship in recent decades. Kucharski et al. (2008) linked these deviations in the ENSO-monsoon relationship with the SST over the southern equatorial tropical Atlantic. Using the observed dataset and an AGCM, Ashok et al. (2001) demonstrated that the weakening of the ENSO–monsoon relationship apparently is due to the frequent occurrence of strong positive Indian Ocean Dipole (IOD) events that neutralize the impact of the ENSO. IOD (Saji et al., 1999) is the coupled ocean-atmosphere interaction mode in Indian Ocean, which may induce unusual rainfall. Positive IOD is characterized by anomalously cool SSTs in the southeast equatorial Indian Ocean off Sumatra due to coastal upwelling and anomalous warming in the west equatorial Indian Ocean. Cool water in the eastern Indian Ocean gives rise to easterly anomalies along the equator. These conditions develop in the boreal summer season and peak during the boreal autumn season. The presence of a positive IOD has facilitated normal or excess rainfall over the Indian region during summers, (despite the simultaneous occurrence of the negative phase of the Southern Oscillation) by making IOD-induced convergence over the Indian Ocean replace the ENSO-induced divergence (Behera et al., 1999; Webster et al., 1999). On the other hand, during some years the El Niño and the prevailing negative IOD together caused an anomalous deficit of rainfall during the monsoon season.

3.2 Extra-tropical influences

3.2.1 North Atlantic Oscillation (NAO)

The effect of the North Atlantic Oscillation (NAO) on winter precipitation over the Hindu Kush-Himalayan (HKH) region has also been investigated by Syed et al. (2006). A positive precipitation anomaly is found, corresponding to the Positive NAO phase over a sub-region encompassing northern Pakistan, Afghanistan, Tajikistan and southern Uzbekistan. We proposed a physical mechanism (Fig. 5) for such effect which is similar to ENSO, by which western disturbances are intensified over the region as they encounter a low pressure trough. This mechanism, related to the NAO, is discussed in Paper I. Yadav et al. (2009) reported that during recent decades, the influence of ENSO over north-western India has increased while the influence of NAO has decreased. These authors proposed that WDs are intensified over north-west India by intensification of Asian westerly jet stream over the Middle East during positive NAO phases. The summer NAO influence on the SAM is discussed in Paper III. A positive summer NAO is related to a precipitation dipole with its positive phase over Pakistan and the negative phase over northern India

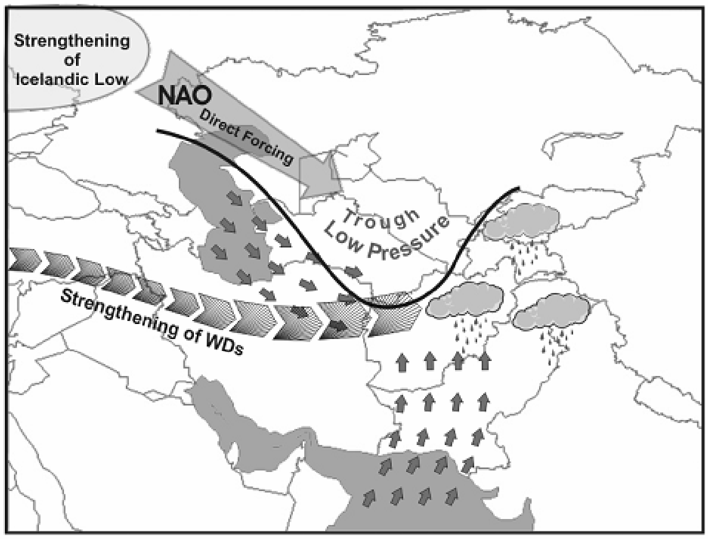

Figure 5: Proposed mechanism for the effect of positive NAO phase on winter precipitation over CSWA. The figure is taken from Syed et al. (2006)

3.2.2 Extra-tropical teleconnection patterns during the northern-hemisphere winter

The major northern hemisphere (NH) teleconnection patterns during NH winter were first recognized nearly three decades ago (e.g., Wallace and Gutzler 1981; Horel 1981; Barnston and Livezey 1987). Branstator (2002) found a wintertime circumglobal waveguide pattern in the NH extratropical circulation based on an analysis of the internal variability of observational data and model output. This pattern exhibits a strong zonal wavenumber-5 component with peak amplitude around the latitude of the Asian jet stream. The nodes and antinodes in the zonal direction are not well-defined. Watanabe 2004 showed by means of a simple linear regression analysis to observed monthly anomalies, that the North Atlantic Oscillation (NAO) does have a wider horizontal scale in a certain month, contributing to high correlation with the Arctic Oscillation (AO) index during that period. The nearly hemispheric scale of the NAO is due to a downstream extension toward East Asia and the North Pacific by a zonally oriented pattern in upper air circulation anomalies, which appears the same as the circumglobal teleconnection described by Branstator (2002). In addition Watanabe 2004 also used a linear barotropic model and detected vorticity sources that effectively excite the Rossby waves and hence link the NAO signal over the Atlantic with the downstream circulation anomalies. Paper IV discusses the role of this teleconnection for the fog variability over South Asia.

3.2.3 Extra-tropical teleconnection patterns during the northern-hemisphere summer

During the boreal summer, the NH westerly jet weakens and shifts poleward, resulting in weaker teleconnection patterns, and the tropical SST anomalies also tend to be weaker than during winter, this because ENSO episodes usually reach their mature stage toward the end of the calendar year (Rasmusson and Carpenter 1982). Hence, the summer time ENSO-related tropical–extratropical linkage is less clear than during winter. Barnston and Livezey (1987) recognized three significant NH summertime teleconnection patterns: the North Atlantic Oscillation, a subtropical zonal mode, and a single centered Asian monsoon mode. A Eurasian teleconnection pattern oriented along the westerly jet stream was also pointed out (Joseph and Srinivasan 1999; Lu et al. 2002; Enomoto et al. 2003). However, none of these patterns has explicitly been linked to ENSO.

Based on an analysis of monthly-mean anomaly data, Ding and Wang (2005) found a boreal summer stationary circumglobal teleconnection (CGT) pattern in the NH. In contrast to the boreal winter circumglobal waveguide pattern, the centers of action of the summer CGT pattern tend to be phase-locked with preferred longitudes. It was shown that the CGT pattern is closely associated with SAM variability. These authors also proposed a scenario (Fig. 6) to explain the global extent of the CGT. The European wavetrain excited in the jet exit region of the North Atlantic may enhance the anomalous Central Asian High and thus the northern Indian-Pakistan rainfall. The enhanced SAM rainfall in turn reinforces the Central Asian High and further stimulates downstream Asian-Pacific Rossby wavetrain that extends to north Pacific and north America. Ding and Wang (2005) suggested that the interaction between the extratropical wavetrain and the SAM heat source may be instrumental for maintaining the structure of the boreal summer wavetrain, and the barotropic instability in the exit region of the north Atlantic jetstream may be responsible for the recurrence of the CGT. However, the precise mechanism responsible for generation and maintenance of the CGT remains unclear. To understand the dynamics of the wavetrain and its effects on the SAM, a CGT classification has been undertaken in Paper III.

Recently Ding et al. (2010) suggested that there are three major factors in producing tropical–extratropical teleconnections during the NH summer: ENSO forces a zonally symmetric response in the tropics and extratropics, and it also modulates the rainfall in the SAM and other regional NH monsoons; the monsoons, in turn, act to excite the wave components of the CGT and western Pacific–North Americ (WPNA) patterns. ENSO also affects the wave structure of the CGT and WPNA indirectly, by modulating the strengths of the Indian and western North Pacific monsoons

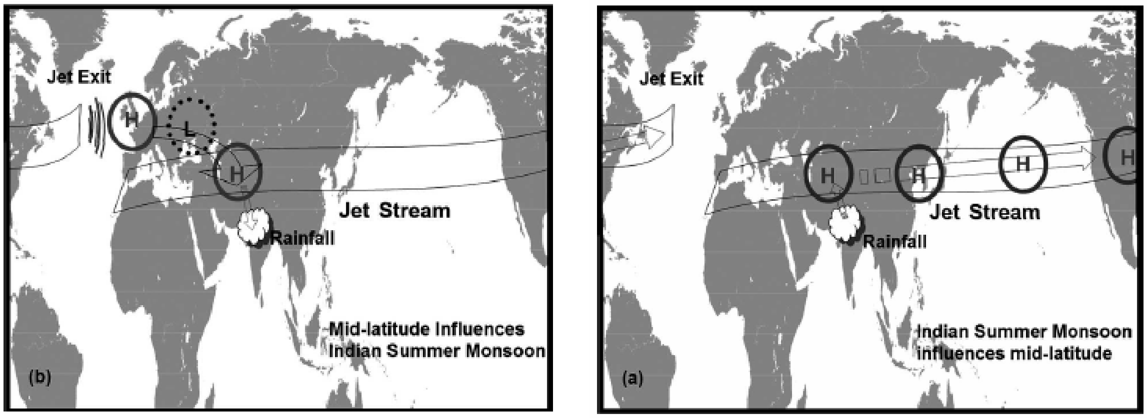

Figure 6: Schematic diagram illustrating the entire mechanism of the CGT consisting of two scenarios during the positive phase of CGTI. The cloud denotes the strong ISM and the circles represent the CGT in the upper level. The figure is taken from Ding and Wang (2005).

4. Outlook

The investigation of the relationship between precipitation variability over South Asia and large-scale forcing has revealed many important processes that could form a basis of climate prediction from intra-seasonal to decadal time scales. It is recognized that seasonal climate anomalies result both from chaotic low-frequency variability of the atmosphere and from coupled interactions with the underlying ocean and land surfaces. The coupled interactions with the slowly-evolving Ocean and land exert a sustained influence on climate anomalies extending over a season or longer, and thus they provide a potential basis for predictions with lead times of a season or longer. I would like to work on climate prediction by validating and assessing the current state and quality of seasonal forecasts by bringing merging retrospective forecast data issued from international research projects (e.g., SMIP2/HFP, DEMETER, ENSEMBLES, and APCC) as well as data available from operational centers.

I am interested in further examining the thermodynamic structure of the break phase of the monsoon over Pakistan. Its dynamics may not be the opposite of APs and therefore it is important to understand the physical mechanisms for future predictions of intra-seasonal variability over the region. Fog is a major hazard over the region during winter and fog forecasting by applying physically-based diagnostic approaches to the forecast outputs from numerical weather prediction models could be a very useful tool. And I am also interested in the investigation on the role of aerosols in the trends in the fog frequency.

5. Acknowledgements

My journey to Sweden started with the scholarship for PhD from Higher Education Commission of Pakistan (HEC) in collaboration with the Swedish Institute (SI). I still remember my first day and the orientation given by Michael Tjernström and Erland Källén, about the targets that I have to achieve to get a PhD degree from the Department of Meteorology, Stockholm University (MISU), that included 4 publications, 75 credits of course work, 8 seminars, public PhD defense and so on. At that time I was listening and thinking in the back of my head that I could have gone to some other university in Europe to get an easy degree :-) But now after working 4 years in the excellent environment that MISU has provided, I feel really happy and proud to be a part of MISU.

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