Monsoon Onset in Bangladesh: Reconciling scientific and societal perspectives

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Dissertation for the degree philosophiae doctor (PhD)
at the University of Bergen

2015

Dissertation date: 13th February 2015

Year: 2014

Title: Monsoon Onset in Bangladesh

Reconciling scientific and societal perspectives

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Print: AIT OSLO AS / University of Bergen

Scientific environment

The work in this PhD study has been carried at Uni Research Climate, Bergen, Norway as a part of the Bjerknes Centre for Climate Research. The research was part of project "Institutional Support and Capacity Building for studies of, and adapting to, climate change in Bangladesh" funded by the Norwegian Ministry of Foreign Affairs, and in primary collaboration with the Bangladesh Centre for Advanced Studies (BCAS), Dhaka, Bangladesh.

The project funding ended in September 2012, and since then Uni Research has funded the remaining work. The Norwegian Research School for Climate Dynamics provided further travel funds.

The project included a full questionnaire survey that was designed in collaboration with BCAS. The survey was carried out by BCAS in summer 2011. Further collaboration was established with the Geophysical Institute, University of Bergen, Norway; University of Hawai'i, USA; University of Exeter, UK; University of Ontario, Canada.

uni Research

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Bjerknes Centre
for Climate Research

Acknowledgements

Due to a number of unforeseen circumstances, I was left without a supervisor for much of the first year of my PhD. This obviously led to challenges. Luckily, during my research stay at the University if Hawai'i, Manoa in 2011, Pao-Shin Chu stepped in and guided me through the initial stages. Our discussions throughout my PhD have helped me find direction and focus, and I sincerely thank him for that.

Once someone at University of Bergen agreed to be my supervisor, I was particularly lucky with whom it was. Thomas Spengler has truly inspired me during my PhD research. He has challenged me, advised me and always pushed me in the right direction. I am very happy that we will continue collaborating on new projects.

Despite not being my official supervisor, I don't think I would have been able to complete this PhD thesis without the input from David Stephenson. His positive feedback and superb methodological suggestions really brought the work together and helped me culminate the thesis. Thanks to Uni Research for supporting me after the original project funding dried up. My colleagues and superiors at Uni Research have always been and continue to be encouraging and supportive. Thanks also go to Tore Furevik and Ragna Breines and in their capacities at the Norwegian School for Climate Dynamics (Resclim). Resclims support during my PhD has helped me make crucial research trips to the University of Hawai'i, and international conferences. I also want to thank some of my university friends both in Bergen and abroad for their support and friendship throughout my PhD. There are many of you, but particular thanks goes to Iselin Medhaug, Johannes Röhrs, William Ball, Malte Stuecker, Scott Bremer and Anne Blanchard.

Some of the biggest thanks go to my family who have encouraged me every step of the way. I'm sure my parents are very happy that they no longer need to ask how my PhD is going. The very biggest thanks go to my wife, the most important person in my life. In a way, our marriage is a product of this PhD since I never would have lived in Hawaii in 2011 otherwise. Kiana gives me praise on the good days and encourages me on the bad days. I couldn't have done it without your support!

I would like to dedicate this PhD to five special people. Four of them are my grandparents. Even though you are no longer with us, you are still and will continue to be perfect role models for me. I miss you all very much. The final person I dedicate this to is my son who, as I deliver this PhD, should seriously be planning his entrance into this world!

Abstract

People of Bangladesh depend on the monsoon, and many of them depend on the timing of the monsoon onset for their livelihoods. In this study, we are motivated by the idea of providing information to these people about the monsoon onset that they can use. In order to provide information about the monsoon onset, we firstly have to define it. Once we have a definition, we can apply it to our data. However, a problem arises.

There are many different methods to define the monsoon and in Bangladesh these different methods can give very different results. To judge which scientific definition might be appropriate, we carried out a large-scale questionnaire and asked around 1200 people in rural Bangladesh about how they define the monsoon. The people defined the monsoon and its start date differently from region to region and also within regions. Thus, we need a robust way to compare them people's perceptions with the scientific information. Hence, this method needs to take into account local meteorological conditions, as we want to compare them with local perceptions. This entails using high-resolution data to identify the monsoon onset. When we use high-resolution data, we often come across the problem of false onsets, which give large variations in the scientific time series. In order to extract local information from high-resolution data, we develop a method that yields scientific time series of the monsoon onset with reduced false onsets at the level of individual grid points. In theory, this gives us local estimates of the monsoon onset that we can compare with the peoples perceptions.

To compare the local perceptions with the scientific times series, we start by constructing probability mass functions around the answers given by the people in the questionnaire survey. We refer to the functions as modified triangular distributions since they are based on triangular distributions, which are often used in risk analysis and cost projections in project management. With these distributions we simulate artificial time series from the people's perceptions. We use these simulations to compare with the scientific time series from the different monsoon definitions. This comparison is mostly qualitative. In order to measure this comparison, we use log-likelihoods to construct a score. We use this score to investigate which scientific time series best compares with the people's perceptions about the monsoon onset. The results give us an idea of which scientific monsoon definitions might be appropriate to use in a dialogue with the people of Bangladesh.

We clearly found that involving the people in this process gives us a better understanding of how they perceive the monsoon. This understanding can help to guide research in a direction that will more likely result in useful information for these people. This process is particularly important in regions where people are particularly vulnerable to present climate variability and future change.

List of Publications

Stiller-Reeve, M. A., Syed, A., Spengler, T., Spinney, J. A., & R. Hossain (2014). **Complementing scientific monsoon definitions with social perception in Bangladesh**. Accepted to *Bulletin of the American Meteorological Society*. doi: http://dx.doi.org/10.1175/BAMS-D-13-00144.1

Stiller-Reeve, M. A., Spengler, T., & P. S. Chu (2014). **Testing a Flexible Method to Reduce False Monsoon Onsets.** *PloS one*, *9*(8), e104386.

Stiller-Reeve, M. A., Stephenson, D., & T. Spengler. **On how to reconcile multiple climate definitions with multiple perceptions.** *To be submitted to Climatic Change*.

*[**Note**: The PhD candidate's author name for publications is Mathew Alexander Stiller-Reeve. He has yet to change his name officially after marriage, hence the author name on this thesis is Mathew Alexander Reeve to comply with University documentation]*

Contents

1. Introduction

If your livelihood depended on a certain weather phenomenon happening every year, you would probably want to know as much about it as possible. To get this information, you might look to science. After all, scientists know a lot about what happens in the atmosphere, when different weather phenomena occur and why. They may even be able to forecast these phenomena. However, what happens if you cannot relate to this scientific information? Maybe the scientists define the phenomenon differently to you. In this case, the information may confuse you and you will be unable to use it [1]. A situation like this leads to uncertainty where, in worst-case scenarios, inappropriate information prompts detrimental action. In this thesis, we are motivated to provide the people of Bangladesh with information about the monsoon onset. We want to be able to translate scientific knowledge into useable information. In Bangladesh, this task is complicated by some large uncertainties that surround the monsoon onset.

The monsoon onset is very important to the people of Bangladesh and the general South Asian monsoon region, as they depend on the rain that the onset brings. Late monsoon onsets can seriously affect peoples livelihoods, especially if they work within the agricultural sector [2,3]. This situation is complex, because people in Bangladesh rely on the monsoon onset in different ways. Some need rain for transplanting rice [4], which marks the beginning of the Aman rice season. Other communities must harvest the Boro season rice before the monsoon starts, otherwise they risk losing their entire crop [5]. Hence, information about the monsoon onset is very useful to both these communities, yet in rather different ways. So, if we aim to provide information, we need to understand the societal *and* scientific situation. We have to find a way to bring together science and society so that scientific information does not confuse or mislead. With this in mind, the objectives for this thesis are as follows:

BOX 1: OBJECTIVES

1 a). Understand how the people of Bangladesh define the monsoon and when they believe it starts.
b). Compare these perceptions qualitatively and quantitatively to previous scientific knowledge.

2 a). Identify aspects of present monsoon identification procedures that make it difficult to apply these procedures to a local level.
b). Develop and test a procedure to deal with one of the challenges in present identification procedures. In this case the challenge is the occurrence of false onsets.

3. Develop and test a procedure to compare perception with scientific based time series of monsoon onsets, in order to indicate which data sets and monsoon definitions might be most appropriate.

If we plan to provide stakeholders (like rice farmers) with scientific information about weather and climate to support decision-making, we are in the realm of climate services. With respect to our objectives, climate services aim to help people "*manage their climate-related risks and capitalize on favourable conditions [6]*". There's a growing movement within climate services that has recognized the challenge of translating climate research into practical application [6]. We need to both change the way we communicate and better understand our audience. This is where we can gain a lot of knowledge from social scientists. For example, Communications Professor Matthew Nisbet [7] said in an online interview:

> *"If you can understand more about mental models and frameworks you can communicate more effectively and explain why it matters…. and you can help facilitate and empower public participation, […] and that's how change will happen"*

In other words, a scientist should understand a stakeholder's knowledge and perceptions before communicating successfully. Only then can the science possibly empower stakeholders to act [8,9].

In this thesis, we had two large pieces in our puzzle. With our first piece, we found out how the people of Bangladesh define the monsoon season and when it starts and ends (objective 1). With our second piece, we developed a method, which allows us to extract local information about the monsoon onset from gridded data (objective 2). Finally, we fitted these two pieces together by developing a method to compare the science with the people's perceptions. In this way, our completed puzzle might provide a picture of the monsoon onset that the people are more likely to understand (objective 3). Even though we achieved the objectives outlined above, we realise that our approach lacked an important element.

Our approach thus far only consisted of one interaction with the people. Ideally, we would have had an iterative dialogue with them as we developed the research. This approach is exactly what many scholars advise with particular respect to climate services [10-12]. In this study, we only had one iteration of the recommended dialogue. Because of this limitation, we are careful about the conclusions we draw from the study.

The purpose of the following sections is to introduce the different perspectives with respect to the monsoon onset in Bangladesh. We have labelled these perspectives as narratives as they all provide different 'stories' about how the monsoon behaves. We then split these into scientific and societal narratives.

In section 2, we delve into the scientific narratives of the monsoon onset in Bangladesh. We will see that local meteorology can seriously influence our estimates of when the monsoon starts. Different scientific monsoon definitions can give startlingly different results, which leads to uncertainty, both in how we view present and future conditions. We investigate why these differences arise and how these theories evoke even more uncertainty.

Thereafter, we focus on the people's narratives of the monsoon onset (section 3). However, before we look at how the people describe the monsoon onset, it is important to understand why we ask them. Therefore, in section 3 we review relevant literature about why we should consider peoples perceptions in climate science, and in particular with regards to the monsoon onset in Bangladesh.

In section 4, we introduce the three papers that comprise the core of this thesis and explain how

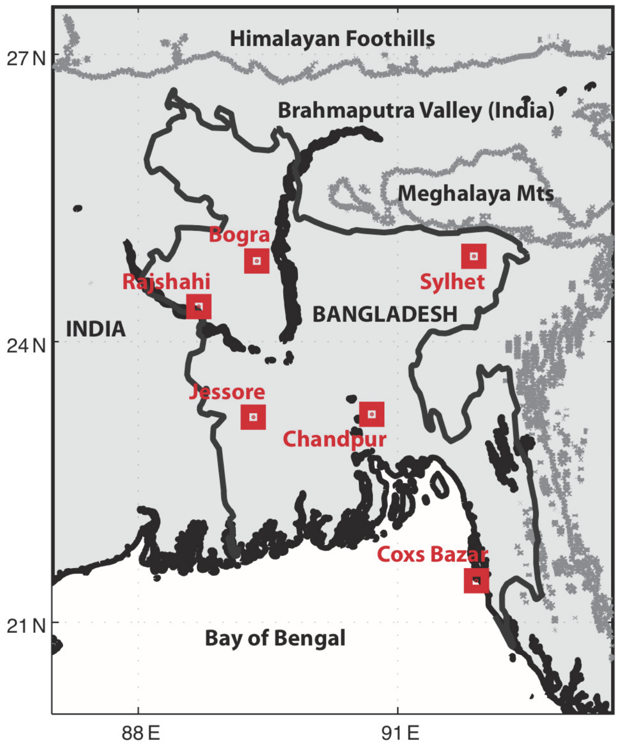

Figure 1: Map showing Bangladesh and some of the surrounding geography that is mentioned in this thesis. The locations where we carried out the questionnaire study in this project are marked in red.

they are motivated by the issues arising from the different narratives about the monsoon onset. Figure 1 shows Bangladesh, the six districts we carried out the questionnaire study and other important geographical aspects that we discuss in this thesis.

2. Scientific narratives

2.1 The South Asian Monsoon and its different definitions

One might think that defining a monsoon is straightforward for scientists, but it has actually been shrouded in controversy for many decades. Not only the monsoon has suffered this fate. Drought definitions arguably spark even more controversy [13-15]. The different definitions stem from different actors and sectors for which drought is important. The same applies to the monsoon.

Before we have a look at the different definitions of the monsoon and why they differ, we briefly describe the monsoon over southern Asia, where Bangladesh is situated:

In short, the South Asian monsoon is the reversal of the northward temperature gradient caused by the heating of the Indian subcontinent during the boreal spring/summer [16]. The reversal of the temperature gradient causes a reversal of the pressure gradient. This initiates southerly winds in the lower atmosphere across the Indian Ocean. Due to the Coriolis force and East African topography, the winds curve around the Indian Ocean and across the Arabian Sea from the west [17], picking up moisture on their way. This moisture is advected towards and over the Indian subcontinent. Because of the hot land surface, the moist air rises, cools, and the water vapour condenses and falls out as rain. This condensation leads to the release of large amounts of latent heat, which in turn, intensifies the flow towards India [16]. Bangladesh is part of the same system and is mainly influenced by the branch of the monsoon flow from the south over the Bay of Bengal.

The situation is far from straightforward, though. In reality, the Himalayas play a significant role although it is debateable what their main affect is [18-20]. There are also possible (and still uncertain) feedbacks including Eurasian snow cover [21,22], El Niño southern oscillation [23-26] and anthropogenic aerosols [26-28]. Despite the complexity of the whole system, we can understand the monsoon over Bangladesh as a reversal in the wind direction and an associated increase in rainfall. Rainfall is obviously an important parameter for people's livelihoods and many researchers use either rainfall amounts, indices, or proxies to define the monsoon [29-31]. Previously, however, wind was the main monsoon-defining parameter [32,33].

A wind-based definition of the monsoon may have previously dominated for very good reasons. It was the Romans and Greeks who first discovered the Monsoon's potential for oceanic trade as early as 45-50 AD [34,35]. The power of this trade was further fuelled by colonialism, slavery, and the rise of consumerism during the second half of the last millennium. The rich and wealthy aristocrats in Europe pined for the newly discovered luxuries: Coffee and tea from Asia, Ivory from Africa, and spices from Arabia. For better or worse, the Monsoon influenced the trade of all these consumer products and played a pivotal part in the making of the modern world. The fiction author Wilbur Smith describes how dependent this trade was on the monsoon winds [36]:

> "[Zanzibar] lay full in the track of the monsoon winds, which reversed themselves with the change of the seasons. The south-easterly monsoon carried shipping from India to Africa, and when the season changed, the north-westerly monsoon facilitated the return trip".

It's a different picture today, because the monsoon winds have relatively little influence on global trading success. Nowadays, it is difficult to think of a more important parameter for rain-dependent agricultural economies like India and Bangladesh than rainfall itself.

Hence, scientific definitions of the monsoon often emphasize rain, even if it is technically a by-product of the changing wind direction. If changes in wind direction and increases in rainfall always coincide, it would not matter which variable we use to define the monsoon. In reality, wind and rain are not perfectly in phase. Sometimes the winds can change long before the rainfall increases or vice versa [20]. A good example of this complicated situation occurs in Vietnam, where the monsoon has been defined according to rainfall in the northern and southern regions [37]. In central parts of Vietnam, a strong mountain shadow effect causes particularly dry conditions. Here, the same researchers defined the monsoon according to wind direction.

With these issues in mind, we have a closer look at how the different definitions manifest themselves over Bangladesh. The next sub-sections contain information about several monsoon definitions that have been used by different researchers. Other indices exist that look at the large-scale circulation [38,39], but we only include results that cover Bangladesh specifically.

BOX 2: PENTADS

Throughout the rest of the thesis, most of the data and results are discussed in pentad units. A pentad is a 5-day period. A Julian pentad is one of the 73 pentads that a normal year is separated in to.

2.1.1 Lau and Yang

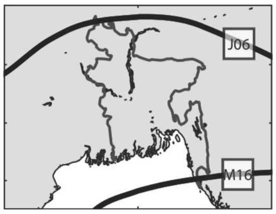

Figure 2: Average monsoon onset progression across Bangladesh from Lau and Yang [40]. Apr-April, M-May, J-June, so M16 indicates May 16th.

Lau and Yang [40] used the Global Precipitation Index (GPI) from 1986 to 1994 to identify the monsoon onset. The GPI is based on satellite data from an instrument known as an Advanced Very High Resolution Radiometer [41]. The data is available in pentad values with 2.5 x 2.5 degree resolution. Lau and Yang [40] used this data because, at that time, it was the only rainfall proxy data that covered the entire Asian monsoon region both over land and ocean. Over the entire region, they took the multi-year mean for each Julian pentad in each grid point. They declared the monsoon onset as the first Julian pentad with a rainfall rate exceeding 6 mm/day. This gave an onset over Bangladesh between May 16th and June 6th (Figure 2). In other words, the monsoon starts firstly in southeast Bangladesh and propagates towards the northwest.

2.1.2 Wang and LinHo

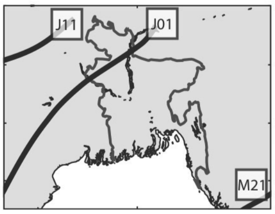

Figure 3: As for Figure 2, but for Wang and LinHo [29].

Wang and LinHo [29] also based their monsoon definition around rainfall. They used the Climate Prediction Center Merged Analysis of Precipitation (CMAP) [42]. CMAP was developed by merging rainfall observations and rainfall estimates from five satellites and numerical models. The CMAP data that Wang and LinHo [29] used CMAP data spanning 20 years from 1979 to 1998 with a resolution of 2.5 x 2.5 degrees. They calculated the multiyear mean for each Julian pentad (R_i) in each grid point and then subtracted the mean January pentad rainfall (R_{jan}) to obtain what they refer to as the *relative pentad mean rainfall rate* (RR_i):

$$RR_i = R_i - R_{jan}\,,\ i = 1,2,\ldots,73. \qquad (1)$$

They declared the monsoon onset in the Julian pentad when RR_i exceeds 5mm/day. They did this so that the threshold for identifying the monsoon onset was relative to the amount of rainfall each grid point experienced during a year, rather than applying a single static value.

Wang and LinHo [29] analysed each grid point separately and presented the results. However, on the final figure they added isochrones showing how the monsoon progressed across the region, to give an impression of the large-scale progression. These isochrones are included in Figure 3. The isochrones compare nicely with the results of Lau and Yang [40], in section 2.1.1 above. The main difference is that the monsoon seems to start slightly later over southeast Bangladesh (just after 21 May).

Despite the isochrones showing a southeast to northwest progression of the monsoon over Bangladesh, the actual grid point values (see Figure 6 in original publication [29]) showed an onset over much of Bangladesh in Julian pentad 24, which corresponds to the last few days of April. During a discussion with Bin Wang [43], he agreed that this mismatch between the grid point values and isochrones deserved further study.

2.1.3 Ahmed and Karmakar

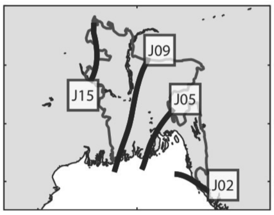

Figure 4: As for Figure 2, but for Ahmed and Karmakar [44].

Ahmed and Karmakar [44] considered both rainfall and wind direction for their definition of the monsoon onset. They stated that the monsoon started on the *"first day of a period of three or more consecutive days [...] with rainfall of 5mm or more, accompanied with southerly or south-easterly winds."* With these criteria, they investigated observations from 19 stations around Bangladesh between 1958-1987, limiting their study on dates after May 1st and onward. Some years the two main criteria failed to clearly identify the monsoon onset. In such years, Ahmed and Karmakar [44] used mean daily temperature and humidity to backup their analysis. The figure in the original article had isochrones at 1-day intervals. In Figure 4, we include isochrones with longer intervals to show the general progression across Bangladesh.

Again, we see a general progression of the monsoon from the southeast to the northwest around the beginning of June, which seems to fit well with the results shown in the subsections above.

2.1.4 Zeng and Lu

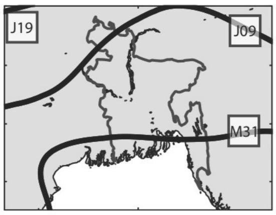

Figure 5: As for Figure 2, but for Zeng and Lu [31].

Zeng and Lu [31] explain the monsoon onset in relation to an abrupt increase in rainfall. They used a dataset developed by Randel and colleagues [45] which contained daily precipitable water (PW) values at a 1 x 1 degree resolution between January 1988 and December 1997. With this data, Zeng and Lu [31] started their analysis by converting all the values to a normalized precipitable water index (NPWI) as follows:

$$NPWI = \frac{PW - PW_{min}}{PW_{max} - PW_{min}} \quad (2)$$

where PW is the daily precipitable water, and PW_{max} and PW_{min} are the 10-year averages of the annual maximum and minimum daily PW at each grid point. From these values of $NPWI$, the authors defined the monsoon onset as the first day that $NPWI$ was greater than the Golden Ratio (0.618) for three consecutive days. In order to remove the effect of 'spurious' early onsets, they also stipulated that the onset could only happen if it simultaneously occurred at seven of the nine grid points surrounding (and including) the grid point in question. Zeng and Lu [31] considered their method to be 'objective' even though *"the selection of [the] parameters is somewhat subjective"*. Their 'objective' results describe a monsoon onset that passes across Bangladesh in a more south-to-north direction (Figure 5). The timings are about the same as the previous results, but the monsoon seems to start considerably earlier in the southwestern parts of Bangladesh in comparison.

2.1.5 Webster and colleagues

The monsoon paper by Webster and colleagues [46] is one of the widest cited papers in monsoon meteorology. Within the publication, the authors include a very clear figure showing how the monsoon onset progresses across South Asia. The map does not seem to be based on a specific definition applied to a specific dataset. The authors base the results on data from Ramage [47], Das [48], and Hastenrath [49]. Even though the monsoon onsets do not seem to be calculated by the authors themselves, we feel that it is important to include the results in this overview since it is such a widely cited work. We have reproduced the results in Figure 6, where we see a quicker monsoon progression over southeast Bangladesh compared with the rest of the country. The monsoon also starts particularly early over southeast Bangladesh, at around May 15. Overall, the monsoon propagates in a northwestward direction.

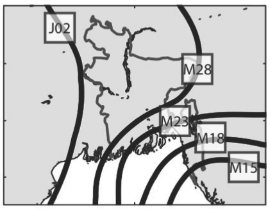

Figure 6: As for Figure 2, but for Webster and colleagues [46].

2.1.6 Rao

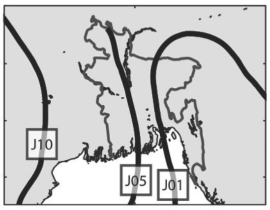

Figure 7: As for Figure 2, but for Rao [50].

In 1976, Rao [50] wrote the Indian Meteorological Departments (IMD) monograph on the southwest monsoon, so he is an important character in the recent history of monsoon research. His monograph included a figure showing how the IMD described the progression of the monsoon onset over India and Bangladesh. This image was faithfully reproduced by Mooley and Shukla [51] in 1987. Rao does not explicitly describe how the monsoon onset is determined. Rather, he lists changes that occur on account of the monsoon. These changes include southwesterly winds, decreased temperatures, and increased rainfall. He explains that the IMD *"has fixed the dates of onset [...] with reference to the rather sharp increase [in] the five–day means of rainfall and the changes in the circulation."*

These criteria are included in the IMD's forecasting procedure, which is where Figure 7 originates. Figure 7 shows the onset over Bangladesh according to Rao's monograph. It clearly shows a progression far more zonal than the previous definitions, with an earlier onset over northeastern parts of the country.

Rao does not describe the forecasting criteria in much detail. However, the modern procedures are best described in the most recent monsoon monograph [52]. Interestingly, this monograph still includes a map showing the monsoon onset progressing across Bangladesh in the same way.

2.1.7 Zhang

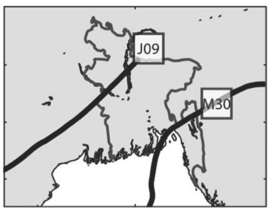

Figure 8: As for Figure 2, but for Zhang [53].

Zhang [53] emphasized that both wind and rainfall are important to consider when defining the monsoon. This is because both the wind direction and moisture are essential inputs for producing the large amounts of rain observed during the monsoon season. He used the same 'precipitable water' criterion as Zeng and Lu [31] (see equation 2), but added a wind criterion, which varied geographically. Zhang [53] used 2.5 x 2.5 degree ERA-40 reanalysis [54] data for the period of 1958–2001. When the 'precipitable water' criterion was met, then the monsoon was only declared between 20°S – 20°N if the 850 hPa westerly winds had also established themselves. In other words, the zonal wind averaged over the 9 grid points around a location had to remain positive (i.e., have a westerly component) for 3 consecutive days in their analysis. Northeast of 20°N and 90°E, the same criteria were applied but for a southerly wind component.

Zhang [53] went further to minimize the affect of *"middle latitude interference",* in other words, synoptic storm systems. He stated that *"any monsoon onset at latitudes higher than 20°S and 20°N can only occur when monsoon onset has already been declared at one or more location within* *the tropics (20°S–20°N)".* He also reduced the chance of false onsets by removing incidents where the algorithm identified a monsoon retreat 2 days or less after the onset was first identified.

With all these criteria and the 9-grid smoothing technique, Zhangs [53] results showed a particularly smooth progression of the monsoon onset over Bangladesh (Figure 8). Thus, with Zhangs [53] results we return to a northwestward propagation of the monsoon that starts first in southeast Bangladesh at the end of May and crosses the country in roughly 10-14 days.

2.1.8 Ashfaq and colleagues

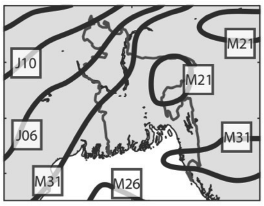

Figure 9: As for Figure 2, but for Ashfaq and colleagues [55].

In 2009, Ashfaq and colleagues [55] showed how the monsoon onset may change in the future with climate change. They presented the baseline climatology of monsoon onsets by applying the same definition to the same dataset (CMAP) as Wang and LinHo [29]. The difference is that they presented the results with an isochrones plot alone. The isochrones are based on the grid point results, unlike Wang and LinHo [29]. The results (Figure 9) show an earlier onset over a region in northeastern Bangladesh. During the analysis they applied a cut off date at Julian pentad 28, which meant that no onset dates appeared prior to this date, which is around 16-21 May.

2.1.9 Matsumoto

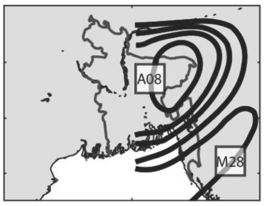

Figure 10: As for Figure 2, but for Matsumoto [30].

We round off with the results from Matsumoto [30]. In his paper, he alludes to the effect of orography on the monsoonal circulation. He explained that if orographic effects vary geographically then so should the threshold for determining the rainy season onset. He therefore used the mean pentad rainfall amount for the whole year as the threshold to identify the start of the rainy season (same as R_i in equation (1) above). He used rainfall amounts from observation stations and stated that the rainy season begins on the first of three Julian pentads when the rainfall exceeded this threshold. Matsumoto [30] was very clear that he identified the rainy season onset and not necessarily the monsoon.

This is a pertinent issue. As we have already discussed, the onset of increased rains may not coincide with the reversal of the monsoonal winds or the large-scale monsoon season. Even though Matsumoto distinguished between monsoon and rainy season, we include his results here. This is because his results have been referred to as the *monsoon* onset specifically in subsequent publications [56]. We should therefore include the results in our discussion, as there is a clear potential for confusion.

Matsumoto's [30] results (Figure 10) over Bangladesh show a particularly early onset (8th April) over the northeastern part of the country. This is because a huge amount of rain falls over this region before the large-scale monsoon circulation makes its mark. But why does this rainfall affect the results of Matsumoto and not others to the same extent? We will discuss one reason in the next section.

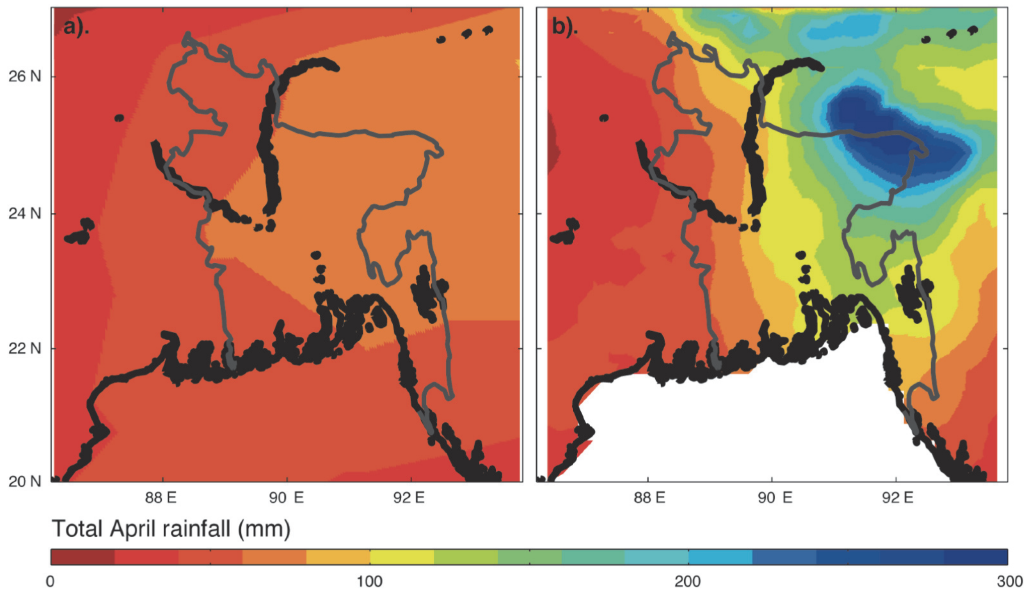

Figure 11. Total rainfall in April for Bangladesh and surrounding region calculated from a). NCAR-NCEP Reanalysis with a 9-gridpoint smoothing and b). APHRODITE.

2.2 Large scale versus local scale

The studies that use low-resolution data and strict smoothing (e.g., Zhang [53]) have different results compared with the studies that consider data from weather stations separately (e.g., Matsumoto [30]). Let us consider how data resolution and smoothing can change the way we see rainfall around Bangladesh.

In Figure 11 a) and b) both show average April rainfall for Bangladesh between 1978-2007. The difference is in the data set and the smoothing applied to it. In Figure 11 a), we used 2-degree resolution NCEP Reanalysis data [57] and applied a 9-grid point smoothing technique (akin to Zhangs smoothing explained in 2.1.7). In Figure 11 b), we used 0.25-degree resolution APHRODITE data [58] and calculated average April rainfall for each grid point separately. Moron and colleagues [59] show a similar, but more detailed analysis over Indonesia, where the influence of diurnal convective cycles emerges in the higher resolution data.

The reasons for the differences in Figure 11 may seem obvious. Smoothing shrouds the smaller scale variations so that we can more easily analyse the larger scales. After all, the monsoon system is a particularly large-scale system covering most of Indian Ocean and influencing all the surrounding landmasses. It is important to keep in mind that the smaller scale features can seriously influence local climate. And it is the local climate that impacts people's lives. If we smooth the data, we instantly lack details that might be of interest to local people and communities. It is clear in Figure 11 that smaller scale processes in Bangladesh are quite striking. The heavy rainfall in April in some regions is obviously a dominant process. This rainfall is part of the heavy rain that falls before the large-scale monsoon starts. In Bangladesh, this coincides with the season Bangladeshis call summer. We therefore refer to this rainfall as *early-summer rainfall* hereafter. This rainfall is particularly important because it causes the differences we see in some of the monsoon definitions we discussed above.

2.3 Theories for the early summer rainfall

A considerable amount of rain falls in northeast Bangladesh during the months of March-May. Interestingly, this early summer rainfall is not completely understood by the research community. There are several theories about how the convection is triggered, most of which relate to the orography around the northeast regions (see Figure 1). One particularly intriguing aspect is the convections

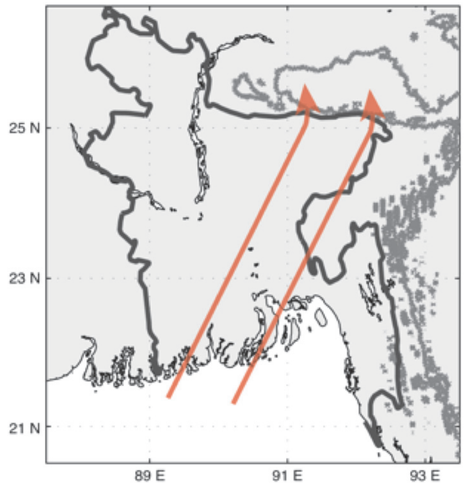

Figure 12: Illustration of winds across Bangladesh (black border) during summer months. The southerly flow brings moist air from the Bay of Bengal towards the Meghalayas where it rises. 500m altitude marked with grey contour.

diurnal cycle. Early summer rainfall in northeast Bangladesh shows maximum activity at late night/early morning [60]. Only relatively few weather stations show this nighttime convective maximum. However, total rainfall at these stations almost equals the total recorded at all the other stations in Bangladesh [60]. If we want to explain this early summer rainfall, we also need to clarify the diurnal convective cycle. Until now, researchers have not agreed on what triggers this convection or what influences the diurnal cycle.

Even though we do not specifically study the convective mechanisms in this thesis, we feel that these unsolved questions add to the uncertainty surrounding the monsoon onset in Bangladesh. This is because this rainfall can directly influence our estimates of monsoon onset timing. We can clearly see this by comparing the results from Zhang [53] with Matsumoto [30] in sections 2.1.7 and 2.1.9 respectively. The differences arise because Matsumoto's method resolves the early summer rainfall in northeast Bangladesh. This rainfall can clearly influence scientific narratives about how and when the monsoon begins. Because of this, we feel it is important to have a basic understanding of the theories explaining this early summer rainfall. Below, we present some of the theories of convective triggering over northeast Bangladesh. Some of the more robust theories also explain the diurnal convective maximum. Locations mentioned in the following sections are shown in Figure 1 for reference.

2.3.1 Orographic lifting

During the pre-monsoon months of March-May, the north Indian landmass warms up and causes a heat low [26,33]. This heat low influences the wind pattern over the Bay of Bengal and Bangladesh. The winds change to southerly direction and force moist air over Bangladesh. This moist air crosses Bangladesh and is forced to rise over the Meghalaya Mountains (Figure 12). This rising air triggers convection over the mountains and the northeastern part of Bangladesh.

Several authors have suggested orographic lifting as one of the main causes of early summer rainfall [61-63]. However, this explanation alone fails to explain the diurnal convective cycle. Thus, while orographic lifting must be important, there is most-likely something else influencing convection.

2.3.2 Nocturnal jet

Orographic lifting may intensify if the speed of the incoming air increases. Terao and colleagues [64] analysed rawinsonde and pilot balloon observations in 2000 and 2001 and found that the winds below 900hPa accelerated between evening and midnight. This 'nocturnal jet' arises when the daytime convection (albeit dry convection at this time of year) ceases. The daytime convection causes turbulent

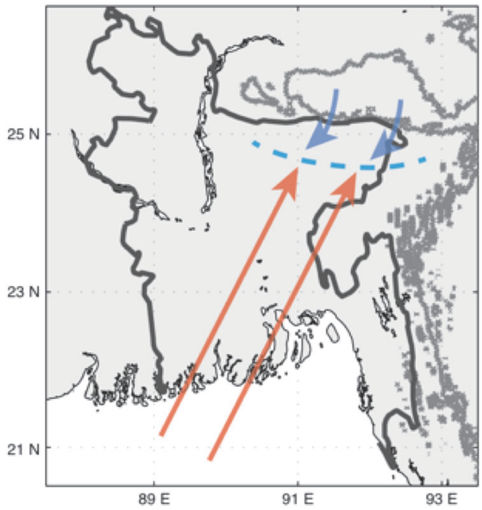

Figure 13: Moist low-level flow from the south (red arrows) can converge (dotted line) with the cooler downslope katabatic flow from the Meglahayas (blue arrows) at night.

momentum flux upward in the atmospheric column, which slows the low-level flow. This reduces the transport of moisture inland from the Bay of Bengal.

Terao and colleagues [64] made it very clear, however, that other mechanisms could also play a role. One possibility is that the nocturnal jet is converging with other air masses, thereby triggering the night-time convection.

2.3.3 Katabatic convergence

During the evening and night, the slopes of the Meghalaya Mountains cool. The cool surface cools the overlying air. The denser cool air flows downslope as a gravity current. This flow is a katabatic wind or mountain breeze. Some researchers have suggested that this katabatic flow is the main cause of the night-time convective maximum [60]. Back in 1974, Prasad [65] explained that the convergence of the mountain breezes from the Himalayas (north) and the Meghalayas (south) caused the night-time convective maximum in the Brahmaputra Valley. In northeast Bangladesh, to the south of the Meghalayas, the night-time convective maximum could be triggered as the katabatic winds flowing south (blue arrows in Figure 13) converge with the moist prevailing wind off the Bay of Bengal (red arrows in Figure 13).

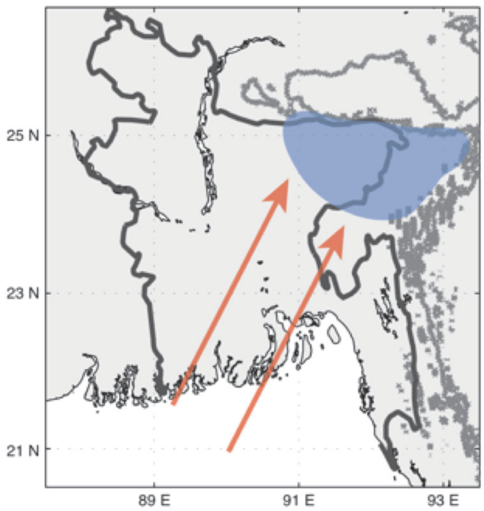

Figure 14: A cold pool (blue shading) forms over northeast Bangladesh causing an increase in pressure. Warm moist low-level flow from south converges with this region of cooler, denser air and triggers convection.

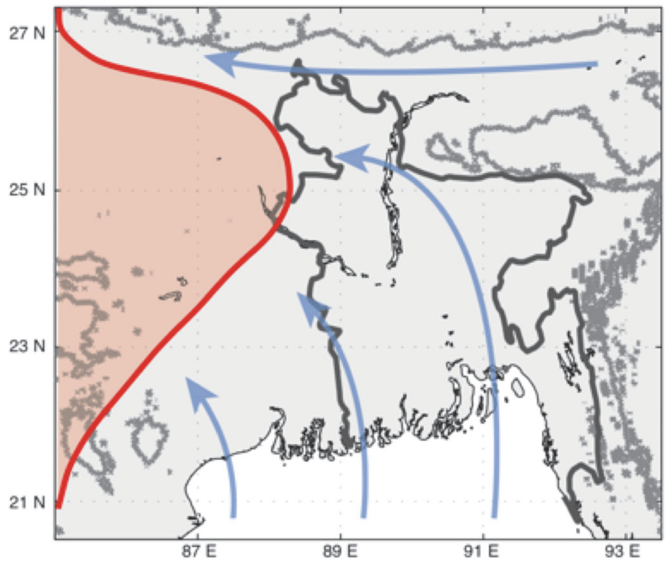

Figure 15: A dry-line forms at the discontinuity between hot dry air (red shading) over continental India and the moist low-level inflow (blue arrows) from the Bay of Bengal.

The katabatic wind theory combined with the nocturnal jet is an attractive option since it explains the location and timing of the convective maximum in the diurnal cycle. However, Kataoka and Satomura [66] simulated an active precipitation period in northeast Bangladesh and found that the katabatic mountain wind 'was not a major player'. Instead, a cold pool develops.

2.3.4 Cold pool convergence

Kataoka and Satomura's [66] simulations from June 17 1995 featured the development of a low level cold pool due to the evaporative cooling of falling precipitation. This cool air can be trapped over northeastern Bangladesh giving a low-level high-pressure region with an outflow boundary to the south and east. Along this outflow boundary, moist air from the south can be forced to rise resulting in convection (see Figure 14).

So far, the mechanisms we have presented seem reasonable when we explain convection that develops directly over northeast Bangladesh and the Meghalaya Mountains. However, Rafiudden and colleagues [67,68] described convective systems in the early summer period (March-May) that also develop further westward. So what causes this convection further west and how could it influence rainfall in northeast Bangladesh?

2.3.5 Dry-line

During the pre-monsoon months of March-May, we find a discontinuity between the warm moist air over Bangladesh and the hot dry air over India. This discontinuity is called a dry-line.

Dry-lines are prevalent in the USA, where they have been the focus of a lot of research from the early work of Schaeffer and thereafter [69-72]. We find much less research on the dryline in northeast India and Bangladesh, despite being first identified in the 1970's. Weston [73] showed where the dryline is located (Figure 15) and designed a model, which explained how the transverse circulation within the moist air layer produces favourable conditions for convection near the dryline itself. Sanderson and Ahmed [61] located the dryline directly across Bangladesh, and more recently Lefort [74] viewed the dryline with an operational forecasting perspective. He showed how the dryline propagates, which is similar to drylines observed in the USA. The dryline (red line in Figure 15) propagates westward during the night as the low level flow (blue arrows in Figure 15) increases owing to decreased convective mixing. During the daytime the dryline retrogrades eastward. Dryline convection presumably triggers closer to the west of Bangladesh, in the late afternoon [75].

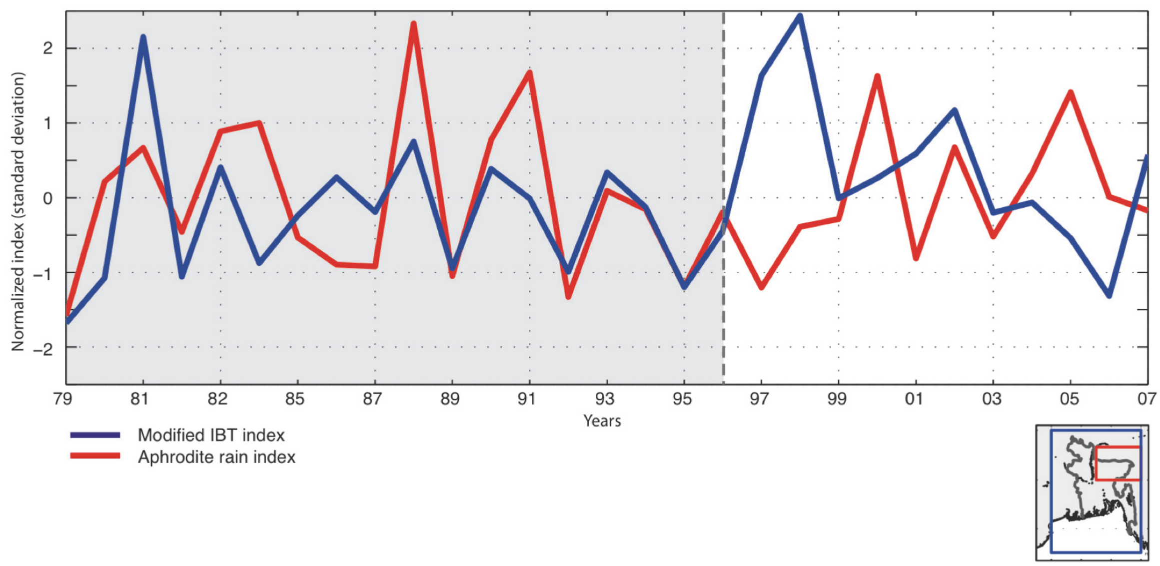

Figure 16: Time series of the modified India-Burma trough index and normalized rainfall over NE Bangladesh for the period 1979-2007

Late afternoon convection does not help to explain the late-night convective maximum in northeast Bangladesh. However, the systems that trigger along the dryline usually propagate in a south-eastward direction. Hence, they arrive from the northwest and are called nor'westers by locals. They do not therefore reach northeast Bangladesh until late-night or early morning.

Rafiudden and colleagues [76] allude to a dry-line structure in their simulation of an arc-shaped convective system from 26 April 2002. These instabilities occur in northwest Bangladesh, in the vicinity of the dryline, and the resulting convective systems move eastward. The authors state that convective instability is caused by the inflow of moist air from the south and intensified by moderate to strong westerlies in the mid-upper troposphere.

2.3.6 India-Burma trough

To our knowledge, researchers have not considered the impact of vorticity in the mid-upper tropospheric westerly jet on the precipitation in the pre-monsoon period (March-May). Wang and colleagues [77] develop an index for the India-Burma trough, which was first described by Yin [78] back in 1949. According to Wang and colleagues [77], the trough is found at 700 hPa around the region of Bangladesh, which is between India and what used to be Burma, now Myanmar. The trough is an artefact of flow splitting around the Himalayas [78]. Wang and colleagues [77] also showed how the trough index in December-January-February is correlated to the amount of rainfall in Bangladesh at the same time. However, no one had looked at the trough index during early summer periods.

We calculated the Indian-Burma Trough (IBT) index and compared it with a rainfall index over northeast Bangladesh during the same period. Originally the IBT index is calculated as the normalized vorticity at 700 hPa during a certain period over a number of years. In this short calculation we focused on March-May and calculated the IBT index between 1979-2007, using ERA Interim vorticity data [79] at 600 hPa. We used 600 hPa since Yamane and colleagues [80] showed that the westerlies at this level increases during periods of high convective activity. We also restricted the size of the box where the IBT index is calculated (see Figure 16) compared with the definition of Wang and colleagues [77]. For the rainfall, we averaged and normalized the March-May APHRODITE rainfall data set (1979-2007) [58] over a region covering north east Bangladesh. With time series of the IBT and rainfall indices, we carried out a simple boot-strapping technique with 10000 permutations of the time series in order to calculate statistical significance of the correlation. The results in Figure 16 show a high correlation between IBT and rainfall 1979-1996. During this period the correlation is 0.57, which is significant at 99% confidence. Between 1996-2007, the correlation breaks down. The correlation for the whole period is only 0.24.

We cannot conclude anything about causality, but we think these simple findings illustrate a potential mechanism, which warrants further study. The IBT will not trigger convection directly, but it may intensify it. If the strength of these IBT westerlies shows a diurnal cycle, then it may also influence the intensification of night-time convection in north-east Bangladesh during early summer months. On a wider scale, if the IBT westerlies are influenced by flow splitting around the Himalayas, then much larger scale processes also influence this rainfall. In fact, the early summer rainfall is likely caused by an interaction at multiple scales as discussed by Sabin and colleagues [81]. There is also a debate about whether the rainfall over Bangladesh and northeast India is influenced by El Niño, or more specifically the speed of the El Niño transitions in boreal spring [82,83].

2.4 Discussion

We have shown that different monsoon definitions can give different results over Bangladesh. Many definitions show the monsoon propagating across the country in a west- or northwest direction around the beginning of June. However, some of the definitions show a much earlier onset, in particular over northeast Bangladesh.

These differences might be caused by data resolution and whether the analysis focuses on large scale or small-scale processes. If we focus on the smaller scales, we see that early summer rainfall over parts of Bangladesh heavily influence our estimates of when the monsoon starts.

We still do not fully understand what triggers the early summer rainfall. Several different theories explain the convective triggering mechanisms for this rainfall, but the situation is still uncertain. In a recent conversation with Sayeed Ahmed Choudhury (Director of the Bangladesh Meteorological Department in Sylhet) [84], we discussed further theories about how surface moisture and land-use probably also play a role. The issues of surface moisture and land-use are valid considerations, but have not arisen in the theories described here. The processes surrounding the pre-monsoon rainfall are clearly linked to orography but are also highly complex. This complexity is illustrated by Houze [85], who writes:

> "there are too many degrees of freedom with wind temperature, humidity, latitude, proximity to ocean, shape of terrain and atmospheric non-linearity to identify absolute analogies for precipitation influenced by orography."

This is certainly the case for Bangladesh. It's true that most of the theories we have presented above can be considered as 'absolute analogies', as Houze puts it. We therefore suspect that several of the theories play a role in the precipitation that the people of north-east Bangladesh witness each year before the large scale monsoon commences. Indeed, we see several different types of convective system during the early summer period [75]. Some originate from above the Meghalayas, some along the Himalayan foothills, and others towards the west, where one may expect the dryline to be located.

The dryline and the Indian Burma trough theories above illustrate possible interactions with larger scales. We suspect these interactions are extremely important for the early summer rainfall in northeast Bangladesh and deserve further study. I believe that we have responsibility to understand this rainfall if we want to analyse the monsoon onset in this region, and especially if we want to communicate with the people, either local farmers, policy makers, business owners, or NGO's, and the government.

But how can we communicate scientific knowledge with different groups if the scientific knowledge is so uncertain? How do we choose the information to communicate, when we have many different monsoon definitions that give different results? The issue of the early summer rainfall complicates the matter further, especially as we do not know entirely how this convection is triggered. We also do not know if the people of northeast Bangladesh even value the early season rainfall. We do not know if this rainfall impacts the peoples' perceptions about the monsoon onset. The societal situation is therefore uncertain, as well as the scientific situation as we have illustrated above. To deal with these problems of uncertainty we have to engage with the people, those we would like to communicate our science with. In the next section we will explain why we should engage with the people of Bangladesh when it comes to an issue such as the monsoon onset.

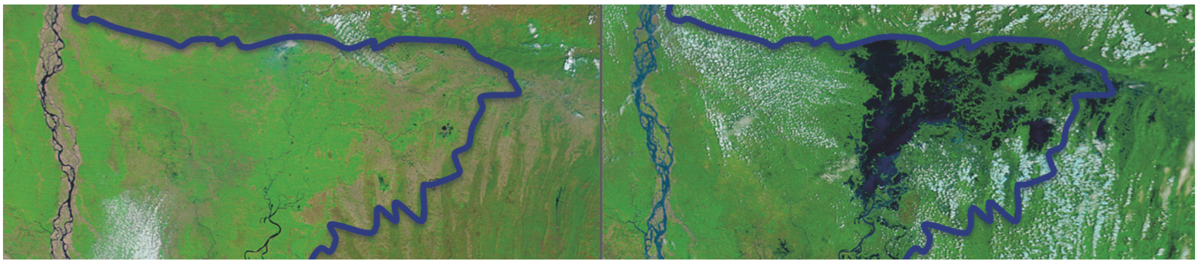

Figure 17: Images showing northeast Bangladesh from the MODIS Terra satellite (bands 7-2-1) a).22 March 2010 b). 3 May 2010. Haors are huge lakes that fill up during the summer rainy season. The Haors show up clearly as the darker areas in b).

3. Societal narratives

We turn our attention to how the people of Bangladesh perceive the monsoon onset. We refer to these perceptions as the *societal narratives* of the monsoon onset. Unfortunately we cannot review these societal narratives like we have done with the scientific narratives. This is because there is no literature to review. So instead of reviewing previous literature, we present some of the ideas that lay behind this thesis. We explain why we have taken the societal narratives of the monsoon onset so seriously and tried to integrate them as much as possible in our research agenda.

We know that the monsoon is important to the people of Bangladesh. However, the presently available science cannot necessarily provide the information that people can use. In its present form, the scientific information cannot help people "*manage their climate-related risks and capitalize on favourable conditions [6]"*. Even though, all the science we reviewed in previous sections is of high scientific quality, it may have its limits for the task of informing the people. To make sense of these limits, there are a variety of approaches from the humanities and social sciences that we can adopt including 'sustainability science' [86], 'Mode 2 science' [87], and 'transdisciplinarity' [88]. In this thesis, we view the situation through the theoretical lens of 'post-normal science', first put forward by Funtowicz and Ravetz [89,90]. They state that in situations of uncertainty and high decision stakes, scientific knowledge alone might be unable to address the issues. So what are the uncertainties and high decision stakes related to the science of the monsoon onset in Bangladesh?
We have uncertainty because there are many monsoon definitions. Such plurality of definitions also applies to the term 'drought'. Wilhite and Glantz *[91]* state that *"Meteorological droughts do not necessarily coincide with periods of agricultural drought"*. With regards to the monsoon, the different definitions give different monsoon onsets and progressions across Bangladesh. The timings of the onset sometimes depend on whether or not the underlying data resolves the early summer rainfall in parts of the country. Uncertainty also arises because we do not properly understand the mechanisms triggering this early summer rainfall.

This uncertainty would not be a problem if no one lived in Bangladesh and no one cared about the monsoon. In this imaginary world, we could continue tackling these uncertainties with the same rigorous scientific process we see in previous monsoon research. But in the real world, Bangladesh is home to millions of people who depend on the yearly monsoon rains. The monsoon onset influences people's decisions and actions [3]. The outcomes influence the people's food security and thereby their whole well-being. The monsoon onset is therefore related to very high decision stakes.

The high decision stakes are increased further because the timing of the monsoon onset in Bangladesh means different things to different people. An early onset is advantageous for some people, and catastrophic for others. For example, the outcome could depend on which rice crop a farmer cultivates. Bangladesh has three main rice crops. The monsoon or rainy season onset dictates when the Aman rice can be transplanted from the nursery to the paddy fields. However, in northeast Bangladesh large areas are under Boro crop [5]. This crop needs to be harvested before the summer rains begin and the land is flooded. A late onset could be beneficial to a Boro crop, but detrimental an Aman crops. In other sectors, fisherman need the rain so the Haors fill up (Figure 17), whereas schoolteachers see a dramatic decrease in class attendance because many children cannot get to school [5].

So how can the approach of post-normal science help in situations of uncertainty and high decision stakes? We start by judging the quality of information differently. Instead of accepted scientific metrics, we can assess knowledge by its '*fitness for function'*. To assess 'fitness for function', we need to have an interactive dialogue among stakeholders, otherwise known as an extended peer community. In other words, in the shadow of all this uncertainty we need to actively collaborate with the people if we are to be successful at translating scientific knowledge into action. This process must start with an "*inquiry into the cultural meaning that underlines [a stakeholder's] understanding of climate* [92]".

From this point of departure, post-normal science scholars join others from fields of philosophy of science, social studies of science, environmental management amongst others, Together they propose extending legitimacy to other knowledge systems outside natural science. These thoughts have infiltrated meteorology and climate studies, especially when related to climate services. For example, several researchers have looked at how people –particularly in climate vulnerable regions-perceive climatic trends and whether these perceptions correspond to meteorological observations [93-97]. Beyond these comparisons others have looked into the benefits of bringing together local knowledge and climate adaptation strategies [98,99] and indeed overall scientific research agendas [100,101]. For example, Hossain and colleagues [102] present how they actively involved stakeholders in the development of a satellite flood-forecasting system in Bangladesh. Eakin and colleagues [103] used an iterative process to involve stakeholders in focussing relevant climate adaptation measures in Hermosillo, Mexico.

Not all knowledge is of equal quality for the task in hand. We have to negotiate this quality with the people. For us, we might want to negotiate which of the many monsoon definitions are best suited to help decision-making processes. This process might firstly entail interacting with the people to find out how they define the monsoon.

To find out how Bangladeshis perceive the monsoon and its timing was one of the main objectives of this thesis (Box 1). Then we apply this information to assess the 'fitness of function' of some of the monsoon definitions that have previously been published. Maybe then, we can use this assessment to help translate the scientific knowledge into something the people can use. For this thesis, the uncertainty and high stakes surrounding the monsoon onset only became clear to us as the project progressed. We had not considered a post-normal perspective previously, but it turned out to be an excellent lens through which to view the situation. By the time these perspectives were familiar to us, we did not have the resources to carry out a truly iterative approach with the people of Bangladesh. Despite this, we hope that the steps we take in this thesis might encourage further and more iterative approaches in the future. In fact, in section 5, we present a research project that has just begun and applies the ideas of post-normal science and iterative dialogues to climate issues in northeast Bangladesh.

4. Summary of Papers

4.1 Paper I: Complementing scientific monsoon definitions with social perception in Bangladesh

In this paper, we dealt with the first of the thesis objectives (see Box 1), namely to understand how the Bangladeshis perceive the monsoon and to qualitatively compare these perceptions with previous scientific research. To do this we had two main tasks. Firstly, we asked the Bangladeshi people about their perceptions. Secondly, we compiled previous scientific results ready to compare with the people's responses. Each task demanded different approaches.

The first task demanded a collaborative approach, where we worked closely with our colleagues at the Bangladesh Centre for Advanced Studies (BCAS) to plan and carry out a questionnaire survey (Figure 18). We used a couple of months to design the questions and the survey procedure. We put a lot of emphasis on the locations where the questionnaires would be carried out because we needed answers from across Bangladesh to compare with the scientific results. Six regions were chosen and

Figure 18. Nabir Mamnun (middle) and Md. Abu Syed (right) from the Bangladesh Centre of Advanced Studies carrying out a questionnaire with a Bangladeshi farmer.

field teams from BCAS carried out the survey (see Figure 1). Just over 1200 respondents took part in the survey and answered questions about the monsoon onset, withdrawal, and climate trends. In this paper, we analysed the answers about how people defined the monsoon and when they thought it started.

This is where the second task of the project began. This task demanded an initial literature review about the monsoon in Bangladesh. During the review, we had come across many different monsoon definitions and quickly realized that the results varied greatly across Bangladesh. For the purpose of this study, we compiled as many results as possible in the same map format to facilitate the comparison with the people's perceptions. We saw that some of the previous scientific definitions compared better with the people's perceptions than others. It was clear that the people of northeast Bangladesh perceived a much earlier monsoon onset. This early monsoon onset is resolved by only a few of the scientific monsoon definitions.

In the paper, we emphasised the implications of the results. We argued that if societal and scientific narratives disagree we must be very careful when designing strategies such as climate services, especially at a local level. The results show that the monsoon onset is an inherently uncertain topic. It is uncertain in people's perceptions and within scientific research. In the context of this thesis, this uncertainty is not a negative aspect. In fact, this uncertainty lays the foundation that the whole thesis is built upon.

4.2 Paper II: Testing a Flexible Method to Reduce False Monsoon Onsets

If we want to inform the Bangladeshi people about the monsoon onset, we need to firstly decide on a couple of things. We need to apply a definition that speaks to the people's understanding of the monsoon. We also need to make sure that the information is relevant at the local level. Hence, in the second paper of this thesis we aim to identify a shortcoming in present procedures for identifying monsoon onsets. This shortcoming is the occurrence of false monsoon onsets, which can make it challenging to apply results at a local level. In the paper, we develop and test a method to alleviate this problem.

The local aspect is extremely important in Bangladesh. Bangladesh may be a small country but the regional climate varies considerably. Early summer rainfall and monsoon Haors (see Figure 17) are dominant components in the local climate in northeast Bangladesh. In the northwest, there is much less rainfall, and communities have to deal with the threat of drought. In the south, local populations worry about cyclones, storm surges and salt intrusion. With such varying climates, communicating information from an observation station 50 km away may describe a very different climate. We have to ensure that the information we provide to a local community is relevant to that community.

When it comes to the monsoon onset, different definitions give different results and local or mesoscale processes influence the situation. The monsoon onset and how it varies are important issues for people in Bangladesh. For an agricultural community, the timing can mean the success or failure of rice crops. For communities like these, we should provide information about the monsoon onset at that locality or region. A problem arises when we look at the local scale (i.e., down to grid point level in datasets). We could refer to this problem as noise, which manifests itself as large fluctuations in our estimates of the monsoon onset. This noise is what several scholars call *false onsets* [104,105].

The false onsets are caused by individual periods of intense convection before the more continuous monsoon season begins. Sometimes these early periods of convection appear as the actual monsoon onset in scientific results. Hence, they are known as 'false onsets', and they can seriously influence our calculations of mean and interannual variability of the monsoon onset date.

Previously, researchers have resolved this by averaging and smoothing data and results [53]. However, if we smooth the data we cannot extract meaningful information about the monsoon onset and it's variability at the smallest scales. If we want to provide local information we need to resolve the problem of false onsets. This paper guides the reader through the development of a different method to identify monsoonal transitions that reduce the occurrence of false onsets in a high-resolution rainfall data set. We tested the method on the Matsumoto definition that we introduced in section 2.1.8. The method reduced the occurrence of false onsets and withdrawals over Bangladesh and much of northern India.

We designed the method so it could, in theory, be applied to any monsoon definition, in any part of the world. This is important because the method needs to be adaptable to the different definitions of the people we want to inform.

4.3 Paper III: On how to reconcile multiple climate definitions with multiple perceptions

From the previous two papers, we understand how the people in Bangladesh perceive the monsoon and, we have improved our time series of monsoon onsets. As a next step, we wanted to choose a monsoon definition that corresponds best with the people's perceptions. Therefore, the main objective of Paper III was to develop and test a procedure to compare perception with scientific based time series of monsoon onsets. This comparison indicates which data sets and monsoon definitions might be most appropriate to the local people. In other words, we tested the different monsoon definitions and their 'fitness of function' as we discussed in section 3.

We began with the answers from the local people (see Paper I) about when they believe the monsoon starts. We had asked them when a normal monsoon onset occurs, and when the earliest and latest onsets have occurred over the past 20 years. It is challenging to compare these three values with a time series of monsoon onsets from a data set. So we had to design a method to evaluate this comparison.

We apply a probability distribution function to the people's answers, which gives us the opportunity to quantitatively compare them with the scientific time series. From this comparison we develop two different scores, which indicate how well the different monsoon definitions correspond to the peoples perceptions.

In the full study, we had 8 time series for each of the 6 locations around Bangladesh (Figure 1). If we included every location in the paper, it would quickly become convoluted. Hence, we use a single location as a case study to demonstrate the methodology.

It's important to note that this methodology is not the final piece in the puzzle. As mentioned several times, climate services and communication should be carried out in an iterative framework, where the people can influence the generation of knowledge. In this case, our results should be presented back to the people, and we should have a dialogue about what works. Only then can we truly find a monsoon definition that we can apply to high-resolution data that speaks to the people and could be used in their decision-making processes.

5. General conclusions and future perspectives

The overarching aim of this thesis was to take steps towards translating science about the monsoon onset into useable information for the people of Bangladesh. We found that there was a lot of uncertainty in the science and high decision stakes surrounding the monsoon onset. We looked to perspectives like post-normal science to give us ideas about how to proceed, and found that we should include the people in the dialogue about which scientific knowledge might be appropriate.

We began this thesis by trying to understand the 'mental models' of the Bangladeshi people with regards to the monsoon onset. We asked them how they define the monsoon onset and when they thought it started. We then took these perceptions and found a method to compare them with the scientific definitions of the monsoon that have previously been used. We also developed an improved methodology to identify the monsoon onset in high-resolution data sets. We reduced the problem of false monsoon onsets, which means that we can more likely extract information relevant at local levels. It is these levels that people are interested in. The success of this workflow has depended on a good collaboration between disciplines. This has been an important aspect of the PhD work.

We have tried to demonstrate that we need to take a more interdisciplinary approach to climate science if we truly want to help the people in climate vulnerable regions like Bangladesh. If we take lessons from frameworks such as post-normal science, then our research will become truly participatory involving the stakeholders or local people in mobilising knowledge. In the process, we may also discover a wealth of local knowledge that science may also benefit from. Participatory research is more likely to be understood by the stakeholders or local people. Therefore participatory research is more likely to empower the people to act.

Natural scientists are not usually trained in methods to make their research participatory. To make the project a success, we had to actively collaborate with our colleagues in Bangladesh and other social scientists in Norway and Canada. This type of work clearly requires an interdisciplinary framework. This framework must be built upon strong mutual respect, where all disciplines respect each other's viewpoints and methodologies. Only then can we learn to communicate effectively between disciplines, and among the stakeholders involved. For this to work, we need to have a continuous and iterative dialogue. Unfortunately, we did not carry out a fully iterative approach in this project, and we concentrated on the initial integration of people's perceptions into the scientific

Figure 19: TRACKS workshop in Sylhet. Groups discussed important local weather events and how they impact the lives of the local people in different areas of northeast Bangladesh (photo: Anne Blanchard)

analysis. Ideally, this knowledge would then be input back into the dialogue with the people. We would have liked to integrate the people much more thoroughly in our process of knowledge generation. This is in fact what we are doing in a new research project, called Transforming Climate Knowledge with and for Society (TRACKS: see http://www.uib.no/en/rg/tracks).

TRACKS stems directly from the work of this thesis, where we have seen a disagreement between science and perception and we have gained an understanding into the uncertainty and high stakes at play in Bangladesh. In Bangladesh, some of the largest uncertainties seem to be centred over the northeast regions, where the early summer rainfall influences the local climate. Because of this uncertainty, TRACKS focuses on rural communities in northeast Bangladesh. We will take the work presented in this thesis to the next level, and integrate perspectives from the people and a range of academic disciplines in the process of generating climate knowledge.

TRACKS started in June 2014 and we had our first project visit to Bangladesh in October. We carried out 2 workshops: one in Dhaka, the capital city and one in Sylhet, the capital of the northeast region (see Figure 19). We also carried out 9 pilot interviews, and will carry out a further 200 later in 2014. From these workshops and pilot interviews we have heard many stories about what weather events are important for the people of northeast Bangladesh. We heard that different people valued different aspects of the climate. We asked them which of these aspects influenced their lives or the lives of others in northeast Bangladesh. Different aspects were important for different people. Some said that fog was a big problem, whilst others mentioned cold spells, extreme heat, tornadoes, and erratic rainfall amongst many other things. Many stories related to how the early summer rainfall impacts the lives of the people in the region. For some, this rainfall had a positive impact, and for others, it had a negative impact.

These early results motivate further climate research in this area and legitimize the work we have completed in this thesis. We hope that we can generate knowledge that is *with and for* society in northeast Bangladesh through the robust interdisciplinary approach we are taking in TRACKS.

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Errata for
Monsoon Onset in Bangladesh: Reconciling scientific and societal perspectives

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Thesis for the degree philosophiae doctor (PhD)

at the University of Bergen

(signature of candidate)

(signature of faculty)

2nd January 2015

Errata

Page 55: Inclusion of previously excluded Figure 6 in Paper 1 on page 56. Following page numbers change accordingly.