Applicant Summary Sheet

NOAA Climate & Global Change

Shubhi Agrawal

Indian Institute of Science

References:

Name	Institution	Role	Date Reference Letter Received
Arindam Chakraborty	**Indian Institute of Science**	**Advisor**	**04/06/2018**
J. Srinivasan	**Indian Istitute of Science**	**Reference**	**04/06/2018**
Ravi S Nanjundiah	**Indian Institute of Science**	**Reference**	**04/06/2018**
S.K. Satheesh	**Indian Institute of Science**	**Reference**	**04/06/2018**

Education: **PhD, (2018), Atmospheric and Oceanic Sciences, Indian Institute of Science, Bangalore**

PhD Thesis: **Impact Of Local And Remote Land-Atmosphere Coupling On The Indian Summer Monsoon**

Proposal: **Investigating the interplay between the North Atlantic Oscillation and the Indian monsoon**

Host Application: **Simona Bordoni, California Institute of Technology** **4/6/2018**

Applied Before:

To,
The Selection Committee,
Cooperative Program for the Advancement
of Earth System Science
NOAA Climate & Global Change
Postdoctoral Fellowship Program

Date- 6 April 2018

Dear Members of the Selection Committee,

My name is Shubhi Agrawal and I am a PhD student at the Centre For Atmospheric and Oceanic Sciences (CAOS), Indian Institute of Science, Bangalore, working under the guidance of Prof. Arindam Chakraborty. I have recently submitted my thesis (14 December 2017) and currently awaiting examiners' reviews. My PhD thesis is titled "Impact Of Local And Remote Land-Atmosphere Coupling On The Indian Summer Monsoon". I expect to receive my PhD degree by June of this year.

I have been looking for an exciting post-doctoral opportunity and I came across the advertisement of your prestigious NOAA Climate and Global Change Postdoctoral Fellowship Program, in the listing of jobs@rmets.org. I am interested in exploring the land-atmosphere interactions in the context of changing climate and analysing its effects on large scale teleconnection patterns and climate variability.

Fortunately, I was able to communicate with a potential host with similar research interests and expertise in this field. **Professor Simona Bordoni, at the California Institute of Technology, Pasadena**, has kindly agreed to support my application for this fellowship. My research proposal is titled "**Investigating the interplay between the North Atlantic Oscillation and the Indian monsoon**".

I strongly feel that I will get the best opportunity to explore my research interests under the expert guidance of Prof. Simona Bordoni and the highly invigorating environment of the California Institute of Technology. Hence, I wish to apply for the 2018 NOAA Climate & Global Change Postdoctoral Fellowship Program. I humbly request you all to consider me for the position. If given a chance, I assure my sincerity and diligence towards work.

Thank you very much for your time and consideration! I look forward to hearing from you.

Regards,
Shubhi Agrawal,
PhD Student,
Centre for Atmospheric and Oceanic Science,
Indian Institute of Science, Bangalore, India.

SHUBHI AGRAWAL

CONTACT INFORMATION

Centre for Atmospheric and Oceanic Sciences
Indian Institute of Science, Bangalore, India

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RESEARCH INTERESTS

Land-Atmosphere coupling
Atmospheric Dynamics, Climate modeling
Indian Monsoon: onset and intra-seasonal variability
Teleconnections and Mid-latitude circulations

EDUCATION

Indian Institute of Science, Bangalore *Aug 2012 - till date*
PhD Atmospheric and Oceanic Sciences

- Thesis topic: **Impact Of Local And Remote Land-Atmosphere Coupling On The Indian Summer Monsoon**
- Advisor: Dr Arindam Chakraborty
- Cumulative Performance Index (CGPA) of 7.0/8.0
- Thesis submitted for review on 14 December 2017

Maulana Azad National Institute of Technology, Bhopal *Aug 2005 - May 2009*
B.Tech Electronics and Communication Engineering

- Cumulative Performance Index (CGPA) of 8.2/10

Columbia Convent, Indore (CBSE) *2005*

- Class XII - 88%

Columbia Convent, Indore (CBSE) *2003*

- Class X – 91.2%

PROFESSIONAL EXPERIENCE

Provisional Research Associate *Jan 2018 - till date*
Divecha Centre For Climate Change,
Indian Institute of Science, Bangalore, India

Project Engineer in **Wipro Technologies** *April 2010 - June 2012*

- Testing of web services for Banking domain
- Training in Java, SQL, Data structures

JOURNAL PUBLICATIONS

Role of west Asian surface pressure in summer monsoon onset over central India: Chakraborty, A and **Agrawal, S.: Environ. Res. Lett.** 12 074002, https://doi.org/10.1088/1748-9326/aa76ca, 2017.

Role of surface hydrology in determining the seasonal cycle of Indian summer monsoon in a general circulation model: **Agrawal, S**. and Chakraborty, A.: **Hydrol. Earth Syst. Sci. Discuss.**, https://doi.org/10.5194/hess-2016-591, 2016.

Effects of winter and summer-time irrigation over Gangetic Plain on the mean and intra-seasonal variability of Indian summer monsoon. **Shubhi Agrawal,** Arindam Chakraborty, Nirupam Karmakar, Simon Moulds, Ana Mijic, Wouter Buytaert. (Submitted to Climate Dynamics)

Evaluation of satellite derived soil moisture product using in-situ observations over India. **Shubhi Agrawal,** Arindam Chakraborty. (Manuscript in preparation)

CONFERENCE PUBLICATIONS

Irrigation as an important anthropogenic forcing on the mean and intra-seasonal variability of Indian summer monsoon. **Shubhi Agrawal,** Arindam Chakraborty, Nirupam Karmakar, Simon Moulds, Ana Mijic, Wouter Buytaert. **European General Assembly,** Vienna, Austria, April 2017. **Poster presentation.**

Land-atmosphere coupling characteristics over Indian region obtained from satellite observations and model simulations. **Shubhi Agrawal**, Arindam Chakraborty. **SPIE Asia Pacific Remote Sensing Conference**, New Delhi, India, April 2016. **Oral presentation**.

Soil-Moisture and Precipitation coupling in GCM over intra-seasonal timescales. **Shubhi Agrawal**, Arindam Chakraborty. **National Climate Science Conference**, 2-3 July, 2015, Divecha Centre for Climate Change, Indian Institute of Science, Bangalore, India. **Poster presentation.**

Soil Moisture and Precipitation coupling in observations and GCM over intraseasonal timescales. **Shubhi Agrawal**, Arindam Chakraborty. **American Geophysical Union Fall Meeting**, 2014 December, San Francisco, USA. **Poster presentation.**

AREAS OF EXPERTISE

- Land-atmosphere over Gangetic Plain and its influence on the seasonal cycle of Indian summer monsoon.
- The role of pre-monsoon surface pressure over western Asia in controlling the monsoon onset over core monsoon zone of India.
- Relation between Pacific Decadal Oscillation and the monsoon onset over Indian region.
- Anthropogenic effects of irrigational activities over Gangetic Plain in modulating the mean and intra-seasonal variability of Indian summer monsoon.
- Relation between winter time North Atlantic Oscillation index and subsequent Indian monsoon strength.

TECHNICAL SKILLS

- Expert in global climate modeling, NCAR's CESM: setting-up and configuring the model, modifying model codes for experiment designs, nudging surface variables in climate land model (CLM 4.0) and detailed knowledge of Biogeophysics algorithm, modification and addition of code snippets in land modules.
- Expert in NCL, Fortran, Matlab and can handle and analyse large NetCDF data with all of them.
- Proficient in LATEX, Ferret, C.
- Experience of working on Linux operating system and parallel computing environment for modeling.
- Adept at handling and manipulating large climate datasets (including output from global climate model simulations; CMIP5) and NetCDF Operators.
- Mathematical techniques: Multichannel Singular Spectrum Analysis (MSSA), spectral analysis using Fourier transform, Wavelet transform.

TEACHING EXPERIENCE

Teaching Assistantship *Fall 2014*
Atmospheric Thermodynamics
Instructor: Arindam Chakraborty, Ph.D
Centre for Atmospheric and Oceanic Sciences,
Indian Institute of Science, Bangalore

RELEVANT COURSES

During Ph.D. – Atmospheric Thermodynamics, Introduction to Atmospheric Dynamics, Atmospheric Radiation and Climate, Geophysical Fluid Dynamics, Climate Modeling, Mathematics for Geophysics, Satellite Meteorology, Ocean Dynamics, Biogeochemistry, Introduction to climate system, Observational Techniques.

PROJECT EXPERIENCE

Worked in HYDROFLUX - a Joint India-UK Project, *2012-16*
Focus- Understanding the hydrological cycle over Gangetic Basin that includes land-atmosphere coupling, effect of land use/land change and irrigational activities, impact on regional climate.
Participants- Indian Institute of Science Bangalore, Imperial College London, University of Reading, Indian Institute of Technology Kanpur.

AWARDS & HONORS

- Jeremy Grantham Fellowship from Divecha Centre for Climate Change, Indian Institute of Science, Bangalore, for outstanding performance in PhD coursework. (January 2013–Dec 2017).
- Indian Institute of Science, Bangalore Fellowship for PhD students. (August 2012–July 2017).
- Awarded Feather In My Cap Award in SOA QA Team, Wipro Technologies as recognition for outstanding performance and dedication. (Dec 2011)
- Secured position in Top 10% in Part A of National Standard Examination in Physics 2004-2005 held at Sica Senior Sec. School, Indore
- Achieved Special Merit Position (Top 0.1%) in AISSE 2003 (10^{th} board), CBSE, New Delhi.
- Severed as the Head Girl of Columbia Convent, Indore for session 2004-2005.
- Secured first position in 12^{th} board and 10^{th} board, CBSE, in Columbia Convent, Indore.

EXTRA-CURRICULAR ACTIVITIES AND HOBBIES

- Participated in "ROBOKRITI"- A workshop on Robotics, organised at NIT Bhopal in collaboration with Technophilia Solutions, Jan 2008.
- Secured First position in Chess Competition for Girls at NIT Bhopal, for session 2007-2008.
- Secured Second position in "Tycoons" in IIT Kharagpur Techfest, February 2007.
- In spare time, like to read novels and paint. Love travelling and exploring places with a history. Write travel blogs occasionally.
- Hiking and high altitude trekking to reconnect with Nature. Completed Kashmir Great Lakes trek, Kedarkanth trek, Kudremukh trek and several small treks.

REFERENCES

Prof. Arindam Chakraborty (Thesis Advisor)
Associate Professor, Centre for Atmospheric and Oceanic Sciences
Indian Institute of Science, Bangalore, India.
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Prof. J. Srinivasan
Distinguished Scientist, Divecha Centre for Climate Change
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Prof. Ravi S. Nanjundiah
Director, Indian Institute of Tropical Meteorology, Pune, India.
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Prof. S. K. Satheesh
Chairman, Divecha Centre for Climate Change
Professor, Centre for Atmospheric and Oceanic Sciences
Indian Institute of Science, Bangalore, India.
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PhD Dissertation Abstract

Title - "**Impact Of Local And Remote Land-Atmosphere Coupling On The Indian Summer Monsoon**"

India lies on the edge of the Asian summer monsoon domain and receives almost 80% of its annual rainfall during June to September (referred as Indian summer monsoon rainfall: ISMR). The dominant forcing behind inter-annual variations of ISMR, the sea surface temperature (SST), explains only 50% of the total variance of Indian summer monsoon. In this thesis, we analyse the effect of land-atmosphere coupling on the Indian monsoon and its characteristics, like the seasonal cycle, the onset of monsoon, mean seasonal precipitation, and intra-seasonal variability. Using decade-long simulations of a general circulation model (GCM), we show that land-atmosphere interaction over India as well as over its surroundings plays the central role during the onset phase of monsoon and thus modulates the seasonal cycle of monsoon. The GCM, in its default configuration, simulates early onset and excess precipitation (about double of that observed) over the Gangetic plain (GP) in June. We find that excessive moisture advection and its convergence over Gangetic Plain are the main reasons for this June precipitation bias, whereas local evaporation contributes minimally. Moreover, the model has large positive surface soil moisture bias over India throughout the year and negative bias over the arid-semiarid regions to the north-west of India during the pre-monsoon months. From multiple sensitivity experiments, it is discerned that the remote dry soil moisture bias in the model over the western Asia region intensifies the tropospheric low-level wind circulation causing excessive moisture advection towards Indian region, followed by moisture convergence over the GP, which results in heavy June precipitation. The remote influence is particularly strong during the onset phase of monsoon but weakens once the monsoon is established over Indian region Local soil moisture over GP makes a diminutive contribution to precipitation bias in June but is crucial in determining the trade-off between local evaporation and moisture advection into GP in the later phase of monsoon. Through a consolidated experiment, in which surface soil moisture bias is corrected in the model by nudging towards observed values over Gangetic Plain and western Asia simultaneously, we showed an improvement in the model simulation of the Indian monsoon and its seasonal cycle.

In the second part of the study, the remote influence from western Asia on the onset phase of Indian monsoon is examined by using 68-years of observational data of precipitation and meteorological variables. It is found that a negative surface pressure anomaly over western Asia acts as a precursor to an early onset over central India, a region which is a fair representation of core monsoon zone. A lower than normal surface pressure over western Asia strengthens the equator-to-pole surface pressure (and geopotential) gradient, resulting in stronger zonal winds over the Arabian Sea, bringing in more moisture toward Indian monsoon region. This increases the moist

static energy in the lower layer, which consequently decreases atmospheric stability, causing early monsoon onset. The phenomenon is not restricted to the surface only, signatures of early onset can be seen in mid-troposphere and upper-level circulations as well, which show correlation with surface pressure anomalies over western Asia. May surface pressure over western Asia is strongly influenced by surface heating over arid regions of western-central Asia, and sea surface temperature anomalies over the central-north Pacific Ocean and Nino 3.4 region. Thus, may surface pressure over western Asia acts as an integrated indicator and shows the highest correlation to onset date over central India (0.53). In addition, we found that the relationship between western Asia surface pressure and onset date shows variability at decadal time scale, specifically related to change in sign of the Pacific Decadal Oscillations (PDO). After the late 1970s, when a change in the PDO phase from negative to positive has been reported, the relationship between surface pressure and onset date has weakened, whereas an increased correlation between surface temperature over western Asia and the onset over central India is noticed.

In the third part of the study, anthropogenic effects of intensification of irrigation over Gangetic Plains are analysed, as irrigational activities add a huge amount of moisture to top layer of soil and thus can alter land-surface properties. The effects of irrigation on the mean and intra-seasonal variability of Indian monsoon are analysed using the general circulation model and a high-resolution soil moisture dataset. We find that winter-time irrigation increases monsoonal precipitation over Indian region through large-scale circulation changes, which are analogous to a positive phase in North Atlantic Oscillation (NAO) during winters. The effects of positive phase of NAO persist from winters to pre-monsoon months through the changes in surface characteristics over Eurasia and western Asia, which makes the pre-monsoon conditions suitable for a subsequent good monsoon over India. Reduction in the intensity of low-frequency oscillations is also noted with winter-time irrigation. However, when irrigation is done throughout the year, that is during both winter and summer seasons, a localised decrease, significant at 95%, in June-September precipitation over Gangetic Plain is noted, in addition to a decreased variability in the low-frequency oscillations. In specific, these changes show a remarkable similarity to the long-term trends in observed rainfall spatial patterns and low-frequency variability over India. Summertime irrigation alone does not cause significant changes in mean rainfall or low-frequency variability during monsoon. Decreasing trend in rainfall in the last few decades over Indo-Gangetic Plains of northern India as seen from ground-based observations, along with swiftly perishing groundwater resources, pose a serious threat to water sufficiency and agricultural productivity of the region. Our results suggest that the water crisis could exacerbate, with irrigation having a negative feedback on the monsoonal climate over Gangetic Plains.

Investigating the interplay between the North Atlantic Oscillation and the Indian monsoon

1. Introduction

The North Atlantic Oscillation (NAO) is a large-scale pattern of natural climate variability with important impacts on weather and climate in the North Atlantic and surrounding continents. Its positive phase is characterized by an increase in surface pressure over southern Europe, extending up to the eastern coast of America, and a decrease in surface pressure over Greenland (Barnston and Livezey, 1987; Hurrell, 1995). Numerous studies on the NAO provide a wide view on the relationship between the winter NAO index and the atmospheric circulation, Eurasian snow cover, and also the strength of the subsequent Indian summer monsoon (Hahn and Shukla, 1976).

A stronger pressure gradient between the Aleutian low and the Azores high (van Loon and Rogers, 1978) results in stronger advection of warmer air from the Atlantic ocean into the southern Europe, which increases the near surface air temperature and reduces snowfall over Eurasia and central Asia. Snow depth anomalies over Eurasia can persist from winter to spring, and thus can cause changes in spring-time soil moisture, surface temperature, and surface albedo. These snow depth anomalies have been shown to influence the Indian monsoon (Hahn and Shukla, 1976; Bamzai and Shukla,1999), but exact mechanisms of the connection between the winter-time NAO index and the subsequent Indian monsoon remain unclear.

The positive phase of the NAO is associated with a northward shift of the north Atlantic jet stream and storm track (Chang et al, 2001). It is also characterized by high index circulation, that is, a stronger zonal component of mid-latitude circulations. These changes in mid-latitude circulations have the potential to strongly influence the early phase of the Indian monsoon and its northward propagation (Ramaswamy, 1962; Banerjee et al., 1978). Mid-latitude circulations also feature a characteristic low-frequency oscillation which can possibly modulate the Indian monsoon on intraseasonal timescales, through westerly dry air intrusions (Krishnamurti et al., 2010). While plausible, the possible influence of the NAO on the intraseasonal variability of the Indian monsoon has not been previously investigated and remains an outstanding scientific question.

Recently, many studies have reported a trend toward a more positive NAO phase in the past decades (Serreze et al, 2000; Hoerling et al, 2001; Visbeck et al, 2001; Delworth et al, 2016), with resulting trends in temperature and precipitation over the Northern Hemisphere. Similarly, Indian monsoon has also undergone significant changes in recent decades. Several studies have suggested a decrease in the low-frequency variability of the Indian monsoon (Karmakar et al, 2015) and in the number of monsoon disturbances (Patwardhan and Bhalme, 2001; Pattanaik, 2007; Vishnu et al, 2016), over the last few decades. Whereas, an increase in the frequency

of extreme rainfall events has also been reported over certain parts of India (Goswami et al, 2006; Rajeevan et al, 2008; Krishnamurthy et al, 2009). We speculate that NAO variability can cause large scale circulation changes, which in turn can affect the Indian monsoon variability. The large impact of the NAO-related variability across the Eurasian continent is a major motivation behind pursuing this analysis between the Indian monsoon and the NAO. The NAO-related variability also has the potential to influence regional weather across the globe through changes in large-scale atmospheric circulation patterns.

This discussion motivated the scientific questions that we want to address in this study:

1. What is the effect of a positive NAO phase on the pre-monsoon conditions and monsoon conditions over the Indian region?
2. How does the NAO affect the intraseasonal variability of the Indian monsoon?
3. Does the Indian monsoon, in turn, have any influence on the NAO in the subsequent months (October to December)?
4. Does the NAO - Indian Monsoon interplay have any impact on weather patterns over more remote regions of the world?

2. Methods

2 a. Observational Data: We will use in-situ precipitation data over the Indian region from the India Meteorological Department (Rajeevan et al., 2006). This daily data set of precipitation is at a spatial resolution of 1 x 1 degree and is available starting in 1901. The atmospheric variables will be taken from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/ NCAR) reanalysis product (Kalnay et al., 1996). This daily dataset covers the globe and is available since 1948. Additionally, more recent and improved reanalysis products, for example, MERRA-2 and ERA-Interim (Dee et al., 2011) will also be used as these datasets provide higher temporal resolution and are available starting 1979. We will also examine if large differences exist between these reanalysis products. The sea surface temperature dataset from Hadley Centre analysis (Rayner et al., 2003) will also be used.

2 b. Model and Experiments: We will use the general circulation model of NCAR, that is, Community Earth System Model (CESM) in our study. It is able to simulate the climatology of the Northern Hemisphere and Indian monsoon reasonably well and has been used by many studies to examine the impacts of climate change. This model can be used in various configurations, for example- coupled land-atmosphere model with climatological SSTs, fully coupled land-atmosphere-ocean model, and coupled land-atmosphere model with a simple slab ocean model. Thus, it offers the flexibility to design model experiments that, by isolating or suppressing certain processes, can be used to advance mechanistic understanding. The CESM model also offers high grid resolution (0.43 (lat) x 0.63 (lon)).

Few initial experiments that will be carried out for this study are listed below:

i. A control run with coupled land and atmosphere models, with SSTs fixed at observed climatology.
ii. An experiment in which a gradient of SSTs will be introduced over the North Atlantic Ocean, which resembles a positive NAO phase. This SST gradient will be calculated by taking the composite of years with positive NAO phase. Note that over all other ocean basins SSTs will be maintained at climatology.
iii. An experiment with the fully coupled land-atmosphere-ocean model, to study the teleconnection between NAO and the Indian monsoon and extended global impacts.

Additional targeted experiments will be conducted to investigate mechanisms that might be revealed from the observational component of this work.

3. Research Plan

Task 1: Our first goal will be to characterize the observed relationship between the NAO and the Indian monsoon, as revealed by reanalysis and other observational data. Reanalysis data is available for more than 6 decades, which will provide robust statistics on this observed relationship. Many studies (Chakraborty and Agrawal, 2017) have used compositing techniques on certain indices and further analyzing the climatology for the different composites. We will use similar approaches to investigate in detail possible associations between the phase of the NAO and the Indian monsoon strength. For instance, we will categorize years based on the following criteria: NAO index, total Indian summer monsoon rainfall, and difference between most recent 3 decades and previous 3 decades. Atmospheric fields such as upper level winds, low level winds, surface temperature, mid-level geopotential fields, surface snow depth, etc will be analyzed for various composites, to identify significant anomalies between years with positive and negative NAO phases and/or larger and smaller total Indian summer monsoon rainfall.

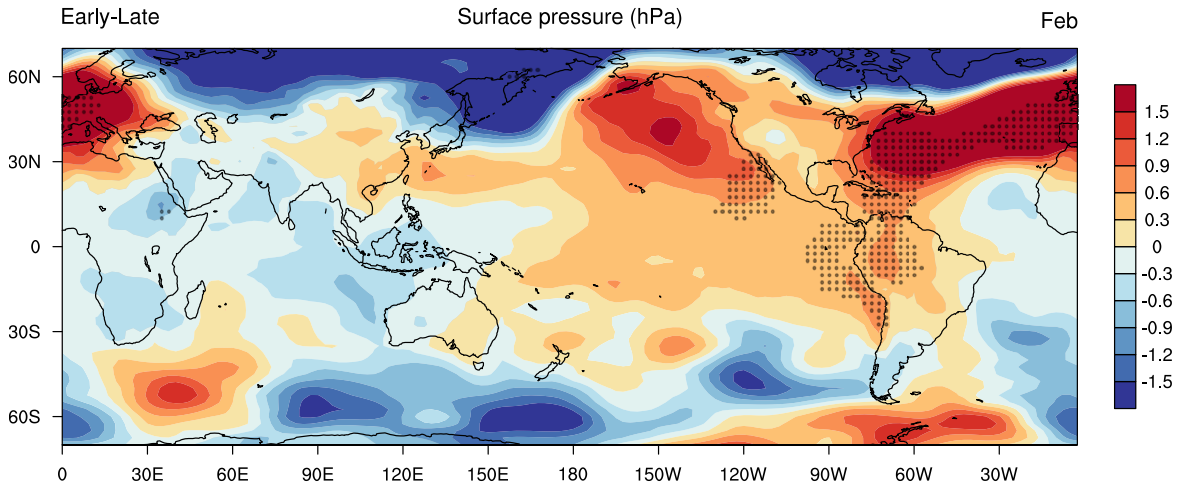


Figure 1. Difference in February mean surface pressure (hPa) between early and late monsoon onset year composites. Data is from the NCEP/NCAR reanalysis, over the 1948-2015 analysis period. Differences significant at 95% are highlighted.

For example, it has been suggested that winter-time positive NAO index is followed by a stronger than normal Indian monsoon season. Hence, composites of mean surface pressure during February over Eurasia based on monsoon onset dates (highly correlated to June rainfall) over central India should reveal an NAO-like signal. A preliminary analysis supports this hypothesis (Fig.1), with a statistically significant positive NAO signal emerging over western Europe. Similar patterns emerge in January and March. The monsoon onset date is calculated for central India (76°– 86° E, 16°– 26° N) following the work by Chakraborty and Agrawal, 2017.

The effect of the positive phase of the NAO can persist up to the pre-monsoon months of March-May, through changes in snow depth and surface temperature over Eurasia and central Asia. Conducive pre-monsoon conditions, that is, warmer western and central Asia (negative snow depth anomalies), can enhance the monsoon circulation and thus result in early onset and higher June rainfall (Chakraborty and Agrawal, 2017). Additionally, because of its strong modulation on mid-latitude circulations, the NAO might also affect the intra-seasonal variability of the Indian monsoon, as mid-latitude circulations strongly influence the active-break cycles of monsoon over India.

Variations in the Indian monsoon can strongly modulate global circulations and consequently propagate the effect of the NAO to other parts of the world. Years with early and late monsoon onset show large and significant SST anomalies over the Pacific Ocean in the following fall (Fig. 2). These preliminary analyses suggest that some important and yet unexplored connections exist between NAO variability and the Indian monsoon.

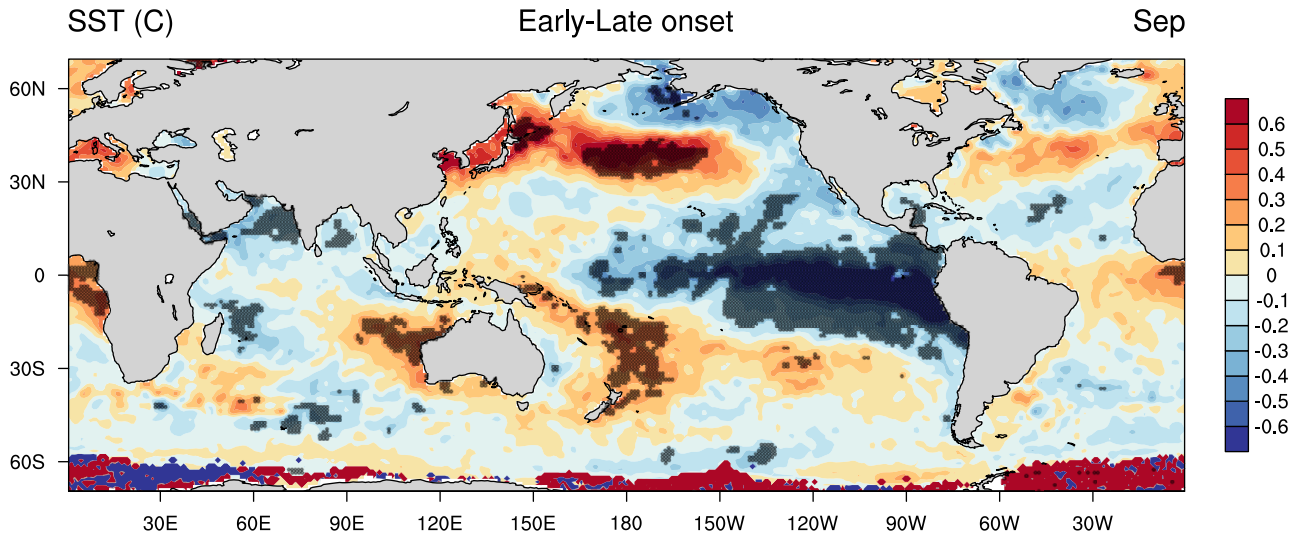
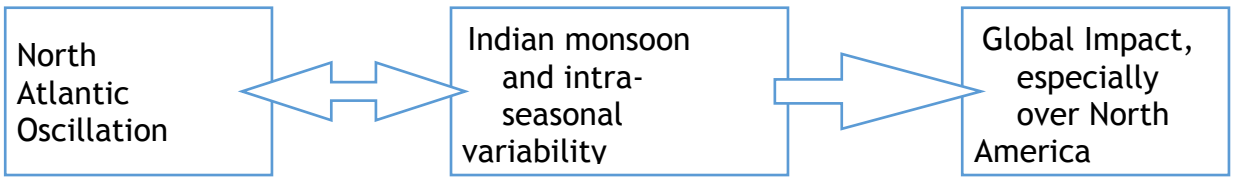


Figure 2: Sea surface temperature (C) differences between early and late monsoon onset year composites for the month of September. Data is from the Hadley Centre.

In this Task, we will characterize these connections in depth, both in terms of mean monsoon features (circulation, mean rainfall) and its variability. Additionally, we may deploy some robust data filtering techniques, for example- Multichannel Singular Spectrum Analysis (MSSA) and empirical orthogonal function (EOF) analysis, to identify primary modes of variability in the Northern Hemisphere and the Indian monsoon.

Task 2: In this task, we will use carefully designed numerical experiments to unravel potential mechanisms that mediate the interaction between the NAO and the Indian monsoon. Few initial experiments are already planned to address the problem statement. On examining the differences between the control and perturbed experiments, we will be able to identify the role that land-atmosphere coupling over Eurasia plays in how the NAO influences the following monsoon season. Further, through a fully coupled experiment, we will be able to study the global impact of this teleconnection.

We are specially interested in analyzing the effects of this NAO-Indian monsoon link on the USA weather and climate. Many earlier studies (Hurrell et al., 2003; Kenyon, J. & Hegerl, G. C.,2008; Myoung et al., 2015) have noted that NAO weakly influences the weather over the eastern USA. But the recent proclivity of NAO towards positive phase can have serious implications for the USA weather. Further NAO can have an indirect effect on the USA weather through large scale changes in Northern Hemisphere. The Indian monsoon is a highly energetic system and its variability can influence tropical circulation and precipitation patterns elsewhere. The coupled experiment could shed some light on the causes of the recent prolonged Californian drought and help clarify if NAO-Indian monsoon interactions are responsible for it. The following figure summarizes the main objectives:



Outcomes: The proposed research will help understand in a mechanistic way if and how the NAO can influence the Indian monsoon, both in terms of its seasonal total precipitation and intraseasonal variability. Seasonal predictive skills of the Indian monsoon remain poor. By shedding light on antecedent conditions at a global scale, this work might reveal new predictors and new mechanisms that might eventually lead to improved monsoon predictions. By extending our analyses to global scales, this work might also shed light on mechanisms of precipitation variability in remote regions over North America. All these expected outcomes address challenges that are at the core of NOAA mission and would result in significant societal impacts.

References

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Banerjee, A. et al., (1978), On foreshadowing southwest monsoon rainfall over india with midtropospheric circulation anomaly of april, Indian journal of Meteorology Hydrology and Geophysics, 29, 425–431.

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Delworth TL et al., (2016) The north atlantic oscillation as a driver of rapid climate change in the northern hemisphere. Nature Geoscience 9:509, DOI 10.1038/ngeo2738

Goswami, B. N. et al., (2006), Increasing trend of extreme rain events over india in a warming environment, Science, 314(5804), 1442–1445, doi:10.1126/science.1132027.

Hahn, D. G., and J. Shukla (1976), An apparent relationship between eurasian snow cover and indian monsoon rainfall, Journal of the Atmospheric Sciences, 33(12), 2461–2462, doi:10.1175/1520-0469(1976)033h2461:AARBESi2.0.CO;2.

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Statement of Relevance

Life in India is closely intertwined with the seasons, be it festivals, new beginnings, sowing or harvest of crops. Weather has been a favorite topic for all the age groups, with monsoons raising the highest curiosity, and I am no exception. I am simply amazed at how deeply it affects the Indian society and its food security and economy. Similarly, monsoon systems all over the globe strongly affect not just the socio-economic conditions of the region but also the regional flora and fauna. However, our changing climate poses a great threat to these regional monsoon systems and their variability. Here, I want to emphasize how changes in climate variability are maybe a more impactful threat than changes in the mean climate: in a warmer climate, theoretical considerations suggest an increase in the number and intensity of extreme events, both in terms of temperature and precipitation. Changes in these extreme events are already starting to be observed across the world.

As I have discussed in my research proposal, the North Atlantic Oscillation (NAO) and Indian monsoon variability could be strongly related, and trends have been noted for both of these weather patterns in recent decades. The NAO has shown proclivity towards positive phase, which can significantly influence the weather in Eurasia and also modulate the intra-seasonal variability of the Indian monsoon. Additionally, many studies have shown a weak but significant influence of NAO on the weather and extreme events over North America. Increase in daily maximum and minimum temperatures have been noted over North America in association with changes in NAO phase during the last three decades. The Indian monsoon, being one of the most energetic and largest-scale circulations in boreal summer, could be responsible for amplifying the climate variability related to the NAO and thus affect regional weather across the globe in the subsequent months after the monsoon. This is possible through mid-latitude circulations as these circulations closely connect the Northern Hemisphere continents. Thus, it is important to understand how the NAO influences the seasonal mean and variability of the Indian monsoon and to investigate if these influences extend to North America. Preliminary results look promising and show the potential connection between them.

The objectives of my proposed research are well aligned with the research goals of the NOAA Climate Program Office. A better understanding of the current climate variability and its effects on regional weather will be helpful in planning adaptation and mitigation policies for the affected regions. It will also help in improving the predictive skills of the model. In addition to the desire of tackling scientific questions that still await definite answers, I am equally motivated to answer questions that have direct societal impacts. In fact, this was one of the reasons I chose a career in Atmospheric Sciences. My PhD thesis also deals with topics that are highly relevant to the Indian monsoon. I hope that by the end of my postdoctoral fellowship, I would have contributed significantly to the understanding of the Northern Hemisphere climate variability. And on a personal level, this postdoctoral opportunity will be extremely beneficial to my career in research. It will give me the required platform to learn and interact with the scientific community and help me in achieving my professional aspirations.

Caltech

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Division of Geological and Planetary Sciences Simona Bordoni
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Pasadena, CA 91125
(626) 395-2672

April 2 2018

Cooperative Program for the Advancement
of Earth System Science
NOAA Climate & Global Change
Postdoctoral Fellowship Program

Dear Members of the Selection Committee,

With this letter, I want to express my strong interest in hosting Shubhi Agrawal as a NOAA Postdoctoral Fellow at Caltech. Shubhi is currently a PhD student at the Centre for Atmospheric and Oceanic Sciences at the Indian Institute of Science in Bangalore, India. She has submitted her PhD thesis last December and will obtain her PhD by June 2018. For her PhD, Shubhi has been working on several aspects of the South Asian monsoon, including its intra-seasonal variability and the role of land-atmosphere coupling on its strength and variability. She is now applying to one of your fellowships and is proposing to study under my guidance how the NAO influences the variability of the South Asian monsoon from both an observational and modeling perspective. This is both a natural and important progression of her previous work, as it addresses a question that remains outstanding in the literature and that connects with and expands core research activities already ongoing in my research group. This project is of strong scientific and societal relevance. From a scientific perspective, it will advance our understanding of the fundamental dynamics, in present and future climates, of monsoon variability. From a societal perspective, it has the potential of improving seasonal forecasting skills that to these days remain limited.

The research plan Shubhi is proposing fits nicely with current research activities in my group, which are primarily focused on studying monsoons in the Earth's atmosphere from both a large-scale and a regional perspective. We use a variety of tools, including observations, and idealized and comprehensive GCMs, and have extensive experience in monsoon dynamics, extratropical-tropical interactions and large-scale climate modeling. Shubhi's expertise and interests would complement and bring novel expertise to the group, thanks to her familiarity with regional scale dynamics in the monsoon region.

If she were to be supported, Shubhi would join the very vibrant scientific community working on many aspects of the climate system at Caltech. She would be working in one of the relatively few groups in the US led by a female atmospheric dynamicist. She would be hosted at the recently established Linde Center for Global Environmental Science, where scientists from a broad range of disciplines collaborate to generate a comprehensive understanding of our global environment, including impacts of human activities on it. The Linde Center is located within the unique Linde+ Robinson Laboratory, one of the most energy-efficient laboratory buildings in the country. We have access to a number of state-of-the-art facilities, including a high-performance computing

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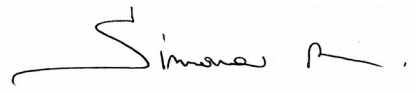
cluster. We are also engaged in active collaborations with scientists at the Center for Climate Sciences at JPL.

In summary, I strongly support Shubhi's application to the NOAA Climate & Global Change Postdoctoral Fellowship Program and I would be delighted to see her proposal funded. If you need any further information, please do not hesitate to contact me.

Sincerely,



Simona Bordoni
Professor of Environmental Science and Engineering

SIMONA BORDONI'S CV

Professional Preparation

University of Rome, Tor Vergata	Physics (Magna cum Laude)	Laurea (M.S.), 1996
University of California, Los Angeles	Atmospheric and Oceanic Sciences	M.S., 2003
University of California, Los Angeles	Atmospheric and Oceanic Sciences	Ph.D., 2007
California Institute of Technology	Large-scale atmospheric dynamics	Postdoc, 2007
National Center for Atmospheric Research	Atmospheric Sciences	Postdoc, 2008 – 2009

Professional Appointments

California Institute of Technology	Professor	2017 – present
California Institute of Technology	Assistant Professor	2009 – 2017
National Center for Atmospheric Research	Postdoctoral Fellow	2008 – 2009
California Institute of Technology	Postdoctoral Fellow	2007
Eurelettronica Icas S.r.l., Rome (IT)	Meteorological Systems Engineer	1997 – 2001

Relevant Publications

1. Feldl, N.[†], B. Anderson, and **S. Bordoni**, 2017: "Atmospheric eddies mediate lapse rate feedback and Artic amplification". *J. Climate*, **30**, 9213-9224.
2. Pascale, S.[†], W. R. Boos, **S. Bordoni**, T. L. Delworth, S. B. Kapnick, H. Murakami, G. A. Vecchi and W. Zhang, 2017: Weakening of the North American monsoon with global warming, *Nature Climate Change*, **7**, 806–812, doi:10.1038/nclimate3412.
3. Bhattacharya, R.[†], **S. Bordoni**, and J. Teixeira, 2017: "Tropical precipitation extremes: Response to SST-induced warming in aquaplanet simulations". *Geoph. Res. Lett.*, **44**, DOI: 10.1002/2017GL073121.
4. Walker, J. M.[†], and **S. Bordoni**, 2016: "Onset and withdrawal of the large-scale South Asian monsoon: A dynamical definition using change point detection". *Geoph. Res. Lett.*, **43**, 11,815-11,822. DOI: 10.1002/2016GL071026.
5. Feldl, N. [†], and **S. Bordoni**, 2016: "Characterizing the Hadley circulation response through regional climate feedbacks", *J. Climate*, **29**, 613 – 622.
6. Walker, J.M, **S. Bordoni**, and T. Schneider, 2015: "Interannual variability in the large-scale dynamics of the South Asian summer monsoon", *J. Climate***, 28**, 3731-3750.
7. Chen J. [†] and **S. Bordoni**, 2014b: "Intermodel spread of East Asian summer monsoon simulations in CMIP5", *Geophys. Res. Lett*., **41**, 1314 – 1321, doi: 10.1002/2013GL058981.
8. Chen J. [†] and **S. Bordoni**, 2014a: "Orographic effects of the Tibetan Plateau on the East Asian Summer monsoon: An energetic perspective", *J. Climate*, **27**, 3052 – 3072.
9. Merlis, T. M., T. Schneider, **S. Bordoni**, I. Eisenman, 2013c; "The tropical precipitation response to orbital precession", *J. Climate*, **26**, 2010 – 2021.
10. **Bordoni, S.** and T. Schneider, 2008: "Monsoons as eddy-mediated regime transitions of the tropical overturning circulation", *Nature Geoscience*, **1**, 515 – 519, doi: 10.1038/ngeo248.

Selected Honors and Awards

- Black, Gold and Green Lecture Series, Hixon Center for Sustainable Environmental Design, Harvey Mudd College, April 2017
- 2014 ISSNAF Young Scientist Award in Environmental Sciences
- 5th Indo-American Frontier of Science Symposium (invited participant by the National Academy of Sciences), Agra, India, Apr. 2013
- AGU James R. Holton Junior Scientist Award, 2009
- Advanced Study Program Postdoctoral Fellowship, NCAR, 2008 – 2009
- NASA Graduate Student Fellowship in Earth System Science, 2003 – 2006

Selected Professional services

Npj, Climate and Atmospheric Science, Editorial Board (2017 – present)

Science Organizing Committee, Comparative Climatology of Terrestrial Planets Conference 3 (CCPT-3), Houston, TX, August 2018

TRACMIP: Tropical Rain belts with an Annual Cycle and a Continent Model Intercomparison Project, contributor, 2016

Panelist for the Office of Biological & Environmental Research (BER) within the Department of Energy (DOE) Office of Science, Water Cycle and Climate Extreme Modeling (WACCEM), August 2015

Lead of the Linde Center Workshop "Monsoons: Past, present and future", May 2015, Caltech

Member of the CLIVAR Climate Dynamics Panel (2015 – present)

UCAR Member representative for Caltech (2012 – present).

UCAR President's Advisory Committee on University Relations (PACUR) (2011– 2018).

Organizing Committee, Workshop on Equation Hierarchies for Climate Modeling. Institute for Pure and Applied Math (IPAM), UCLA (2009 – 2010)

Reviewer: UK Natural Environment Research Council, National Science Foundation, Journal of the Atmospheric Sciences, Journal of Climate, Nature Geoscience, Climate Dynamics, Monthly Weather Review, Ocean Modeling, Meteorology and Atmospheric Physics, Geophysical Research Letters, Journal of Geophysical Research (Atmospheres), Atmospheric Research, Earth Interactions.

AMS, AGU member since 2002.

Graduate and Postdoctoral Advisors

Bjorn Stevens, Max Planck Institute for Meteorology, Hamburg, Germany (Graduate Advisor)

Tapio Schneider, California Institute of Technology (Graduate co-Advisor and Postdoctoral Sponsor)

Graduate and Postdoctoral Advisees

Jinqiang Chen, Asian Development Bank, Manila, Philippines (Graduate Advisee, 2011 – 2015)

Anne Laraia, McKinsey & Company (Graduate Advisee, 2010 – 2015)

Jennifer Walker, University of British Columbia, Vancouver, Canada (Graduate Advisee, 2010 – 2015)

Ho-Hsuan Wei, California Institute of Technology (Graduate Advisee, 2012 – present)

Ana Lobo, California Institute of Technology (Graduate Advisee, 2015 – present)

Katrina Hui, California Institute of Technology (Graduate Advisee, 2016 – present)

Siraput Jongaramrungruang, California Institute of Technology (Graduate Advisee, 2016 – present)

Sean Faulk, University of California at Los Angeles, (Graduate co-Advisee, 2013 – 2015)

Jane Baldwin, Princeton University (Graduate co-Advisee, 2016 – present)

Hyo-Seok Park, KIGAM, Korea (Postdoctoral Advisee, 2010 – 2012)

Joan Ballester, Barcelona Institute for Global Health, Barcelona, Spain (Postdoctoral Advisee, 2013 – 2015)

Nicole Feldl, University of California at Santa Cruz (Postdoctoral Advisee, 2013 – 2016)

Salvatore Pascale, GFDL/Princeton (Postdoctoral Advisee, 2015 – 2017)

Ritthik Bhattacharya, Goethe University, Frankfurt, Germany (Postdoctoral Advisee, 2015 – 2017)

Spencer Hill, Caltech/UCLA (Postdoctoral Advisee, 2016 – present)

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April 2 2018

Mentoring Plan for Shubhi Agrawal

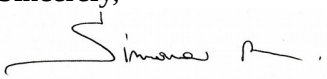
I am writing this statement in support of Shubhi Agrawal's application to one of your postdoctoral fellowships. I hereby certify that I will be delighted to act as the scientific sponsor for her project. Shubhi is currently a PhD student at the Centre for Atmospheric and Oceanic Sciences at the Indian Institute of Science in Bangalore, India, planning to complete her PhD by June 2018. For her PhD, Shubhi has been working on several aspects of the South Asian monsoon, including its intra-seasonal variability and the role of land-atmosphere coupling on its strength and variability. She is now applying to one of your fellowships and is proposing to study under my guidance how the NAO influences the variability of the South Asian monsoon from both an observational and modeling perspective.

Throughout the project, Shubhi's training and professional development will be advanced through a combination of individual mentoring by myself, interactions with other scientists and students in my group, and participation in structured activities at Caltech and other institutions. The following mentoring plan will be implemented:

- Scientific and technical mentoring will be provided through regularly scheduled individual group meetings;
- Weekly group meetings will help Shubhi make frequent informal presentations and will encourage group interactions;
- I regularly teach graduate level classes in Atmosphere Dynamics, including an advanced graduate student course (ESE132) on Tropical Atmosphere Dynamics on modern theories of tropical large-scale circulations, which Shubhi will be invited to attend and participate to;
- Shubhi will be encouraged to present her research at two conferences or workshops per year. Likely venues will be the American Geophysical Union (AGU) Fall Meeting and the American Meteorological Society (AMS) Conference on Hurricanes and Tropical Meteorology;
- Shubhi will have the opportunity to attend workshops at Caltech on career development, and grant writing. She will also be encouraged to apply to attend the annual workshop "Preparing for an Academic Career in the Geosciences", which is sponsored by NSF.
- Career advising and support will be provided through individual meetings whenever necessary at every stage of Shubhi's professional, academic and personal development. Being a female scientist myself, I am very sensitive to the importance of adequate role models for younger generations of women scientists, and I will strive to provide such a role model for Shubhi.

The division of Geological and Planetary Sciences at Caltech is committed to serve as Shubhi's host institution if her proposal were to be funded. We will provide her with office space, access to a high-performance computing cluster and any other resource she will need for a successful completion of her project.

Sincerely,



Simona Bordoni

APPENDIX 2: CURRENT AND PENDING SUPPORT

Principal Investigator: Simona Bordoni

Current Support

- National Science Foundation - ATM
- Grant number: 1462544
- *Dynamics of Large-scale Monsoons and their Response to Climate Changes*
- $406,595
- Effort: 0.58 person-months/year

- GPS Division: THOR Funds
- Grant number: N/A
- *Understanding the response of large-scale monsoons to anthropogenic forcing*
- $179,000
- Effort: 0 person-months/year

- GPS Division: Davidow Funds
- Grant number: N/A
- *Fundamental dynamics of the North American Monsoon in present and future climates*
- $85,000
- Effort: 0 person-months/year

- GPS Division: Discovery Funds
- Grant number: None
- *Large-scale atmosphere dynamics of terrestrial exoplanets*
- $50,000
- Effort: 0 person-months/year

Pending Support

- NASA NESSF
- Grant Number: N/A
- *The Seasonally-Varying Earth's General Circulation in a Wide Range of Simulated Climates* (in support of Ana Lobo)
- $45,000
- Effort: 0 person-months/year

- Department of Energy – Office of Science BER
- Grant Number: N/A
- *An Energetic Framework on Circulation-precipitation Interactions in Subtropical Convergence Zones: From Improved Understanding to Robust Model Assessment*
- $868,459
- Effort: 1.0 person-months/year

INDIAN INSTITUTE OF SCIENCE

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4 April 2018

To,
Professor Simona Bordoni,
California Institute of Technology,
Pasadena

Dear Dr Bordoni,

I'm pleased to write this letter of recommendation for Ms Shubhi Agrawal, who has applied for a NOAA post-doctoral fellowship. And I understand that she plans to work on the interactive feedback between North Atlantic Oscillation and South Asian Monsoon.

Ms Shubhi was working under my guidance for her PhD dissertation since 2012. Currently, she is pursuing her post-PhD fellowship, which is closer to a postdoc position, with myself and Prof J Srinivasan.

Before going into her academic capabilities, I feel it's worth spending few lines describing the way Shubhi was ramped into the field of climate science. Shubhi did her Bachelor's in Technology and then was working for a reputed software company named WIPRO (possibly for couple of years). She found the job to be monotonous and unchallenging. Thus she applied for a Master's position in our institute and was selected. Out of her good performance during the 1st year of study, she could upgrade this Master's degree into a PhD. This entire process made Shubhi understand a few things: (1) advantage/shortcomings of an educational institution (2) advantage/shortcomings of an industry (3) and the difference between the two. This made her extremely matured in terms of thinking in practical life, which I feel is closely related to success in research field that requires good amount of judgment before pursuing something new.

When Shubhi started her research work, I was working on a joint project (with several other institutes) funded by Ministry of Earth Sciences, India and NERC, UK, on past, present and future of soil hydrology over Gangetic Plain (northern India). This was an opportunity for Shubhi to meet scientists from atmospheric science as well as hydrology background. She was also exposed to different facets of field and station data sets during workshops of our team. Finally, her PhD was a combination of observations and numerical modeling.

For her PhD, Shubhi worked on the impact of land-atmosphere interaction on onset and intraseasonal variations of Indian summer monsoon. The observational part of this work involved extensive analysis of ground based and reanalysis data sets. The analysis included interannual variations of onset, and delayed impact of winter irrigation on summer monsoon over India through North Atlantic Oscillation. On the other hand, the modeling part involved several simulations of the NCAR's CESM with interactive and prescribed soil moisture conditions. The prescription of soil moisture in the land model of CEAM (CLM) was hard-coded by Shubhi, going inside the Fortran codes. This code is able to 'nudge' another soil moisture field into the model on the fly (while running) with any nudging parameter (soft or hard nudging). I guess, this explains her capability of handling observations as well as global GCMs. This also justifies the topic she is planning to pursue as NOAA fellow, if offered.

If I need to mention any weak points about Shubhi, I'd say she gets little impatient at times. This especially happens at the final stage of a long analysis or manuscript preparation. However, those are temporary, and she understands the situation well in a short time.

Overall, I recommend Ms Shubhi the highest for the NOAA postdoctoral fellowship she has applied for.

Sincerely,

(ARINDAM CHAKRABORTY)

J.Srinivasan
Distinguished Scientist
Divecha Centre for Climate Change
Honorary Professor
Centre for Atmospheric and Oceanic Sciences
Indian Institute of Science, Bengaluru

Phone:91-80-22933068
Fax :91-80-23600865
email: jayes@.iisc.ac.in

5 April 2018

Recommendation letter for Ms.Shubhi Agrawal

I have known Ms. Shubhi Agrawal for the past 6 years. She took two graduate courses I taught in 2007-2008. Her performance in these courses was excellent. She took an active part in the weekly discussions on the progress of the Indian summer monsoon. Her research presentation were well organized and demonstrated a good grasp of the subject. The research on the impact of surface pressure on the onset of the Indian monsoon was novel. The recent work on the impact of irrigation on the Indian monsoon is interesting. She has a pleasant personality and will work well in a team. I recommend her strongly for the NOAA postdoctoral fellowship

JS

J.Srinivasan

भारतीय उष्णदेशीय मौसम विज्ञान संस्थान
(पृथ्वी विज्ञान मंत्रालय, भारत सरकार का एक स्वायत्त संस्थान)
डॉ. होमी भाभा मार्ग पाषाण, पुणे– ४११ ००८
IITM
INDIAN INSTITUTE OF TROPICAL METEOROLOGY
(An Autonomous Institute of the Ministry of Earth Sciences, Govt. of India)
Dr. Homi Bhabha Road, Pashan, Pune - 411 008. India
ESSO

प्रो. रवि एस. नन्जुनडैया
निदेशक
Prof. Ravi S. Nanjundiah
Director

Reference Letter for Shubhi Agrawal

I have known Ms. Shubhi Agarwal for over five years. Initially she was a student in the courses taught by me. Later she interacted with me about her thesis work. Shubhi is an intelligent, hardworking, sincere person. Her academic record is very good. She can work well by herself and in a group. She has good problem solving skills. She would be a valuable asset to your group.

Her thesis work is on land-atmosphere interactions and the study of the same using a climate model. Her results show that the remote influence of drier-than-observed soil conditions over West Asian region causes stronger lower-level circulation leading to more moisture advection and higher rainfall during the initial phase (June) of the Indian Summer Monsoon. The simulation becomes more realistic when the dry-bias over West Asian region is removed. She has also conducted an observational study to under the relationship between West Asia and the Indian Monsoon using reanalysis data. She found that a negative surface pressure anomaly is a precursor to stronger monsoon which in turn is related to stronger inflow over the Arabian Sea into the Indian landmass. She has also studied the role of human activity viz role of irrigation in modulating the Indian monsoon. Her results show that winter-time irrigation over the Gangetic plain leads to a stronger monsoon. The changes due to this effect are analogous to the positive phase of NAO. Interestingly, she also finds that when irrigation is considered to occur both in summer and winter, the strength of the monsoon reduces.

For her studies she set up the model (CESM) herself, modified it for her experiments and conducted the analysis. She has good programming abilities, is adept at handling large model and observational datasets and has good visualization skills.

She now proposes to study the relationship between NAO and the Indian monsoon, specifically the relationship in pre and post-monsoon periods using observational data and model experiments. Her proposed work looks quite novel and interesting.

Given her excellent academic and research record I feel she is a suitable candidate for this post-doctoral program. I strongly recommend her for the same.

R.S. Nanjundiah
(Ravi S. Nanjundiah)

Date: 06 April 2018

प्रो. रवि एस. नन्जुनडैया / Prof. Ravi S. Nanjundiah
निदेशक / Director
भारतीय उष्णदेशीय मौसम विज्ञान संस्थान
Indian Institute of Tropical Meteorology,
डॉ. होमी भाभा रोड, / Dr. Homi Bhabha Road,
पाषाण, पुणे / Pashan, Pune-411008.

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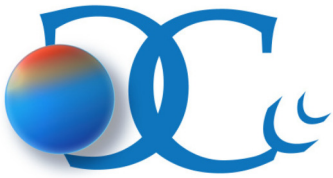
Indian Institute of Science
Bangalore-560012



DIVECHA CENTRE
FOR CLIMATE CHANGE

Letter of Reference

Dr. Shubhi Agrawal is known to me for the last five years as a graduate student in our department/centre and also as a student attended my courses. During her research, she has analyzed the effects of land-atmosphere coupling on the Indian monsoon and its multiple intricacies, like the seasonal cycle, the onset of monsoon and the mean seasonal precipitation. For the analysis, she has used a state of the art general circulation model with coupled land and atmosphere models, in addition to long-term observed and re-analysis datasets. Based on the understanding of land-atmosphere coupling, she extended her research to address a very important topic concerning the anthropogenic effect of intensified irrigation activities over the Gangetic Plains and its effect on the mean precipitation and intraseasonal variability. The results from this study are of great significance to the understanding of the role of land-atmosphere coupling in determining the seasonal mean and variability of the Indian summer monsoon.

Dr. Shubhi Agrawal is a sincere and hardworking student. She is sociable and has a broad outlook. I strongly recommend her for the prestigious NOAA Postdoctoral Fellowship Program.

Sincerely,

Satheesh