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Indian summer monsoon rainfall: Dancing with the tunes of the sun

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HIGHLIGHTS

- The purpose of this article is to find a physical linkage between solar activity and the summer monsoon rainfall.
- Hydrodynamical equations are used to derive an equation for the rate of precipitation.
- The equation for the rate of precipitation is similar to a forced harmonic oscillator.
- Forcing variables are cloud and rain water mixing ratios.
- Numerical solution captures very well the variability of Indian summer monsoon rainfall.

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ABSTRACT

There is strong statistical evidence that solar activity influences the Indian summer monsoon rainfall. To search for a physical link between the two, we consider the coupled cloud hydrodynamic equations, and derive an equation for the rate of precipitation that is similar to the equation of a forced harmonic oscillator, with cloud and rain water mixing ratios as forcing variables. Those internal forcing variables are parameterized in terms of the combined effect of external forcing as measured by sunspot and coronal hole activities with several well known solar periods (9, 13 and 27 days; 1.3, 5, 11 and 22 years). The equation is then numerically solved and the results show that the variability of the simulated rate of precipitation captures very well the actual variability of the Indian monsoon rainfall, yielding vital clues for a physical understanding that has so far eluded analyses based on statistical correlations alone. We also solved the precipitation equation by allowing for the effects of long-term variation of aerosols. We tentatively conclude that the net effects of aerosols variation are small, when compared to the solar factors, in terms of explaining the observed rainfall variability covering the full Indian monsoonal geographical domains.

1. Introduction

Indian agriculture and hence its thriving economy crucially depend upon both occurrence and intensity of the summer monsoon rainfall. It is remarkable to note that the Indian peninsular spans the range of subtropical latitudes more typical for desert environments (see Wu et al., 2009 for an in-depth perspective from atmospheric dynamics) than a motherland that sustains over 1 billion human population. Vagaries of floods and droughts related to extreme opposite ends of monsoonal rainfalls have caused immense loss of human lives, valuable cattle population and loss of agricultural outputs valued in billions of dollars. That is why a clear understanding of variability of Indian summer monsoon has remained a high priority for scientific research and breakthroughs.

It is generally accepted that summer monsoon rainfall is driven primarily by overall differential temperature gradient between the mainland and the sea that are ultimately heated and modulated by incoming sunlight. In fact, with century-long rainfall data recorded by instrumental rain gauges, a rather convincing set of analyses are suggesting that the varying sun's activity indeed influences the Indian monsoon rainfall (Bhalme and Mooley, 1980; Ananthakrishnan and Parthasarathy, 1984; Reddy et al., 1989; Kailas and Narasimha, 2000; Higginson et al., 2004; van Loon et al., 2004; Kerr, 2005; Badruddin et al., 2006; Hiremath, 2006a,b; Kodera et al., 2007; Perry, 2007; Claud et al., 2008; Hiremath, 2009a; Meehl et al., 2008; Meehl et al., 2009; Agnihotri et al., 2011; van Loon et al., 2012 and references therein). Our sun's influence on the Indian monsoon rainfall, especially on multidecadal to centennial timescales, can also be studied and deduced from a variety of paleoclimatic records (Nigam et al., 1995; Neff et al., 2001; Agnihotri et al., 2002; Agnihotri and

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Dutta, 2003; Higginson et al., 2004; Gupta et al., 2005; Tiwari et al., 2005; Wang et al., 2005; Thamban et al., 2007; Agnihotri et al., 2011). The general topic of solar forcing on Earth's climate has been recently reviewed by Gray et al. (2010); Soon and Legates (2013); Soon et al. (2014) and references therein.

Although sun's radiant energy is considered to be the main cause for the genesis of monsoon winds and the seasonal (i.e., the wet monsoonal versus dry non-monsoonal seasons) reversal of near-surface wind flows, that are sustained by the differential heatings of land and ocean masses, presently it is not understood how the sun's energy outputs are linked with the Indian summer monsoon rainfall changes from decade-to-decade nor even from year-to-year. We interpret a plausible influence of the magnetic sun on the summer monsoon rainfall as follows. Radiant energy by sun received by the ocean and land masses, either locally within the Indian ocean and subcontinent or remotely elsewhere, controls the amount of atmospheric water vapor that is ultimately connected to precipitation-and-cloud fields. If our proposed scenario is reasonable (see the work of Lim et al. (2006) for a similar proposal for the key role of atmospheric water vapor for the solar-activity-induced decadal variability over tropical Atlantic), owing to quasi-periodic solar activity, water vapor in the Earth's atmosphere might vary periodically in response to the different sun-originated periodic activities. As a consequence, it is therefore not too surprising to find hints of several quasi-periodic signals from time-series analyses of Indian summer monsoon rainfall records (Vines, 1986; Kailas and Narasimha, 2000; Hiremath and Mandi, 2004; Ma et al., 2007; Hiremath, 2009a; Agnihotri et al., 2011) and its proxies (Yadava and Ramesh, 2007; Ramesh et al., 2010; Knudsen et al., 2012; Maitra et al., 2014) that correspond to those natural periods from the sun's activity.

It is equally clear there may be various non-solar factors of the Indian monsoonal rainfall variability, both deterministic and stochastic, that may contribute to the phenomenon we are attempting to study. But we shall prescribe an underlying solar-Indian monsoon relation through a parametric modeling of the physically relevant solar activity and monsoonal rainfall quantities in order to see how well we can emulate the measured Indian summer monsoonal rainfall from 1871 through 2005. If the outcome is negative, then one can suggest that the proposed hypothesis for solar-monsoon rainfall correlation can be strongly rejected. In contrast, if the simulation may turn out to be positive, then one may at least diagnose and identify some of the relevant physical quantities involved. We proffer such an avenue of parametric modeling approach in order to reach the ultimate physical understanding of any solar-monsoonal rainfall connection. It is important to acknowledge that our proposed minimal parametric modeling approach (as discussed in more details below) is partly motivated by and is consistent with the findings of van Loon et al. (2012) where those authors found that the net solar radiation and latent heat flux indeed control the near-surface energy budget in the relatively cloud-free part of the southern Indian ocean (0–15°S; 60–100°E) on decadal solar oscillation timescale. Our pursuit of solar-Indian monsoon relation should ultimately be sought in terms of how solar activity may modulate the linkages and interconnection among the southern Indian Ocean anticyclones, Indian Ocean Dipole and El-Nino-Southern Oscillation from the perspective of coupled atmosphere–ocean dynamics as sketched by previous studies (Gadgil et al., 2004; Kodera et al., 2007; Claud et al., 2008; Agnihotri et al., 2011).

It is well known that sunspot activity is the most obvious manifestation of the solar magnetic phenomena that in turn is related to a host of other solar magnetic features and dynamic phenomena including the solar faculae and plages, solar flares, coronal mass ejections, etc. Recent observations from the satellites, especially in the high energy X-ray and UV windows, brought the hitherto less well known solar magnetic disturbing regions, *viz.*, coronal holes (Wang, 2009; Cranmer, 2009) as also one of the prominent solar activity phenomena. The solar coronal hole (CH) is now identified as the source of fast solar wind that creates disturbances in the Earth's atmosphere (Soon et al., 2000; Sykora et al., 2000; Lei et al., 2008; Choi et al., 2009; Shugai et al., 2009; Sojka et al., 2009; Ram et al., 2010; Verbanac et al., 2011; Mannucci et al., 2012; Hiremath and Hegde, 2013). During a particular solar activity cycle, activity of the coronal holes occur in advance and hence there is a phase lag (Bravo and Stewart, 1997) for the occurrence of sunspot activity. In terms of spatial domain, sunspot variability is primary a phenomenon around middle to low solar latitudes while the coronal hole activity is largely a phenomenon covering the polar and mid-latitude regions of the sun. Thus we suspect that the Earth probably receives the combined effect of sunspot and coronal hole disturbances and hence the consideration of energy outputs from the sun must include both these effects. It may be pointed out that the physical motivation for including coronal hole indices (area or other derived properties including sources of fast solar winds) for a sun-climate study can be found in the earlier statistical correlation study (Soon et al., 2000).

The sun is a variable star whose activity and hence its energy outputs vary on time scales of few minutes to months, years to decades and perhaps even on century time scales. Recent observations of a persistent 5-min global oscillations – due to pressure gradient variations in the interior of the sun – yielded rich dividends on the internal dynamic, thermal and magnetic field structures of the sun. Other manifestations of sun's periodic oscillations are: 9, 13 and 27 days; 1.3, 5, 11 and 22 years. Although physics of 5-min oscillations of the sun is well understood (Hiremath, 2013), however, the physics for the rest of the longer period oscillations is not understood completely (Hiremath, 2010).

Presently, there are indeed many studies focusing on the simulations and predictions of Indian summer monsoon rainfall that mainly concentrate on the local micro and macro physics as well as several locally and remotely inter-connected circulation phenomena of the coupled ocean–atmosphere. Such studies are conducted using the most sophisticated general circulation models (Kripalani et al., 2007; Preethi et al., 2010; Sabade et al., 2011; Rajeevan et al., 2012; DelSole and Shukla, 2012; Gadgil and Srinivasan, 2012; Krishnamurty and Shukla, 2012; Krishnan et al., 2012) with a range of successes and unsatisfactory outcomes in terms of a comprehensive understanding of all co-varying factors for the Indian monsoon rainfall variations. Among the currently unresolved issues is the lack of long-term trend in the measured Indian summer monsoon rainfall when compared to some of the simulated series as forced by increased atmospheric CO_2 (Kripalani et al., 2007; Sabade et al., 2011). This is why we consider our present approach is an important alternative avenue for scientific research with the ultimate aim of learning more about both the nature of solar magnetic variations and its associated physical linkages to the underlying Indian monsoon rainfall variability.

In the present study, from the coupled cloud hydrodynamic equations, we derive an equation of rate of precipitation that is similar to equation of a forced harmonic oscillator with cloud and rain water mixing ratios as the forcing variables. These forcing variables in turn are parameterized in terms of combined effect of external forcing due to sunspot and coronal hole activities with the well known solar periodicities. Next the derived equation for the rate of precipitation is numerically solved and compared with the observed Indian summer monsoon rainfall activity. We find that the solution of precipitation variability matches very well with the observed Indian rainfall variability yielding insights regarding a physical link between the Indian summer monsoon rainfall and the sun's activity. We also evaluated the effects of aerosol forcing on simulated Indian monsoon rainfalls, although this effort needs