Questions	Answer
Danang Eko Nuryanto Do you have any opinion about relationship between IOD with Rainfall?	**Dr. Tim Cowan**: With respect to Australia, the IOD has a strong association with austral winter and spring rainfall, particularly over central and southeast Australia. The IOD decays as the Australian summer monsoon (AUSM) arrives, meaning there is not a strong relationship with AUSM rainfall. In saying this, the IOD is correlated to AUSM onset, although a positive IOD tends to delay AUSM onset more than a negative IOD expedites onset. A nice paper on this is Lisonbee & Ribbe 2021 (https://doi.org/10.5194/wcd-2-489-2021).
Saumyendu De I have a question regarding regional inter seasonal variability of monsoon rainfall. why kerala has got small rain during past few years why Marathwada has received more rainfall during monsoon season? Although climatogically, Kerala should get more rain and Marathawada less rain	**Prof. B. N. Goswami**: You may recall that the monsoon intraseasonal oscillation is an oscillation between the continental ITCZ and the Oceanic ITCZ. When the continental one is strong the oceanic one is weak and vices versa. When there is an 'active' condition over central India there an 'break' condition' over equatorial Indian Ocean extending to Kerala. Kerala is close to the oceanic ITCZ while Marathwada is on the continental ITCZ. To understand this observation, we need to keep in mind the meridional structure of the MISO.
Aditi Deshpande What is the role of synoptic scale variability in heavy to very heavy rainfall events?	**Dr. Tim Cowan**: For Australia, synoptic scale variability plays a big role in heavy to extreme rainfall events, mostly in the form of cold fronts, monsoon depressions and tropical cyclones. For northern Australia, extreme rainfall variability is strongly related to local weather systems, which are often associated with pulses in the MJO or equatorial Rossby waves. Systems like depressions and TCs account for between 10 and 40% of the wet season rainfall for northern Australia. As I said in my presentation, the AUSM is really just a series of rainfall bursts punctuated by breaks – these are mostly synoptic scale events.
Mohan Thota From the past few decades in other words since CMIP3 to CMIP6 the systematic biases in rainfall over Indian ocean is still persist. Though we are improving technologically why these biases are still there, are we missing anything regarding monsoon physical processes?	**Dr. Gill Martin**: As emergent phenomena, the representation of monsoons (rainfall, winds, temperatures) and their many scales of variability relies on the correct representation of many individual processes on many time and space scales combing together correctly in our models, and this is clearly an ongoing challenge. We do make continual improvements to how the fundamental processes are represented, both through better physical parametrisations and increased model resolution, but there's no guarantee that biases will be reduced everywhere. Also, global climate simulations necessarily involve some bias compensation, so it is often found that improving the representation of one process reduces model skill by removing compensation against another source of bias. **Prof. B. N. Goswami**: As mentioned by Dr. Martin, technology by itself cannot solve this problem. But technology could help in better understanding the processes and thereby in improvement of parametrizations. Since you raised the biases over the Indian Ocean specifically, I would like to add that the Indian Ocean with very low surface salinity is a special place in the tropics. Due to the stratification,

	vertical mixing is week in the region and the mixed layer over the Bay of Bengal is very shallow (e.g. 5-10 m). But most models mix too much tending to make the mixed layer too deep and colder surface temperature. Surely, parametrizations of vertical mixing are inadequate for the India Ocean. This problem is like that of improving the parametrizations of convection in the atmosphere. Unfortunately, progress in improving vertical mixing parametrizations in ocean models has been slow. Under our Monsoon Mission we had project called 'Monsoons to Mixing' in collaboration with Woods Hole Institute, University of Massachusetts, IISC, NIO, INCOIS to study the processes related to mixing over north Indian Ocean such as sub-mesoscale eddies, sub-mesoscale salinity fronts, inertial waves etc. Under this program we had Woods Hole mooring over north Bay of Bengal for more than a year with turbulent flux measurements and gliders to make sections in addition to several research ships making simultaneous measurements. For the first time, we have enough length of fine scale data to understand the sub-mesoscale systems. See **Oceanography** Vol. 29, No. 2, Special Issue on the Bay of Bengal: From Monsoons to Mixing (JUNE 2016) For several articles describing some initial results. More interesting findings have been published later. However, to convert these unique observations to improvement of parametrizations of mixing is still a huge task and still awaited. Also biases in the India Ocean is a coupled process. While SST influences the monsoon rainfall, monsoon winds influence SST and mixing. Therefore, some of the Ocean biases may also be related to teleconnection biases such as the ENSO-monsoon relationship.
Pratibha Gautam Do you think over monsoon core zone, the soil moisture has play a role in maintaining the land ITCZ?	**Dr. Gill Martin**: Land-atmosphere interactions have been shown to be important to rainfall on a range of spatial and temporal scales, although their relative contribution varies and can be hard to ascertain without careful sensitivity experiments due to coupled feedbacks.
Mohan Thota another one over the Indian subcontinent vertical profiles of moisture and temperature are still sparse (except for reanalysis data). How to overcome this issue (lack of high quality and continuous observations) if we validate our model forecasts?	**Dr. Gill Martin**: We should certainly promote to funding bodies the continuation and advancement of observing systems (quality, quantity and frequency) over the monsoon regions, over both land and ocean. Making and demonstrating good use of these in our model validation and development will help add weight to such promotion.
Ashis Mitra 'How reliable is the Historical runs compared to Obs ? Any Publication on that for	**Prof. B. N. Goswami**: If we talk about simulation of the Indian monsoon, there is notable improvement of the coupled models in simulating the Indian monsoon. However significant biases still exit. See Choudhury, B.A., Rajesh, P.V., Zahan, Y. and B. N. Goswami. Evolution of the

Monsoon ?	Indian summer monsoon rainfall simulations from CMIP3 to CMIP6 models. Clim Dyn (2021). https://doi.org/10.1007/s00382-021-06023-0 As for reliability, no model could ever be 'perfect'. Thus, reliability is a relative term. However, we are making progress as CMIP6 models are certainly more reliable.
Raghavendra Ashrit Whether the westward shifting of monsoon is driven only by air sea interaction, Any role of Land surface changes in it?	**Prof. B. N. Goswami**: On the continental scale, it is primarily driven by large-scale air-sea interactions in the following way, Global warming is driving ISMR increase @3%/K➔ leads to stabilization vertical profile of temperature in the region➔ weakening of low-level winds ➔weakening of upwelling and mixing leads to warmer SST in western Indian Ocean➔ westward expansion of the warm pool ➔ westward expansion of the Oceanic ITCZ➔ westward expansion of the continental ITCZ. As for the role of the land-surface processes on this phenomenon, my guess is that it plays a secondary role. Having said that, nobody has studied it so far as the phenomenon has been established only recently. We need to study this aspect.
Aditi Deshpande What is our current understanding of the role of synoptic variability to heavy and very heavy rainfall events?	See answer to similar question above.
Sachin Deshpande During the historical era and in the projections, ISMR show strong presence over the N-W India. In these periods, what could have been the contributions form synoptic scale disturbances and how their tracks moved?	**Prof. B. N. Goswami**: The synoptic disturbances form and intensify in the environment provided by the ITCZ (e.g. horizontal wind shear). Therefore, if the ITCZ extends towards the west, you expect synoptic disturbances to intrude further to the west. Although I could not show due to time restrictions, in our paper we have a figure (Fig.S4) showing that during the historical period there is an increase in the number of lows and depressions reaching northwest India associated increase in LPD days and LPS rainfall over the northwest India.
Raghavendra Ashrit What is the impact of climate change on physics of monsoon (beyond the changes in mean and variability)? Do we need to rebuild the models?	**Dr. Gill Martin**: I'm not sure we'd expect the fundamental physical processes in the atmosphere, land or ocean to change, but how they manifest and combine into the emergent phenomenon that is the monsoon may change, so we should continue to pursue understanding on this.