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Global Climate Change: Myth or Reality?

B. N. Goswami

As reported by the World Meteorological Organization recently (WMO press release no. 15, 14th November, 2016), the year 2016 is heading towards being the hottest on record taking the global mean surface temperature (T_{gm}) and the global warming relative to pre-industrial level to approximately 1.2°C (Fig.1B), the myth about so called 'global warming hiatus' has been busted. The global warming of ~1°C is already considered 'dangerous' (Hansen et al. 2006) and its impact on global sea level rise, increase in both temperature and precipitation extremes (Hansen et al. 2012, Goswami et al. 2006) and several ecosystems (Scheffers et al, 2016) is clear and evident. The global warming and human induced environmental changes have led to an accelerated loss of many species leading us to a potential 'Sixth Mass Extinction' (Ceballos et al. 2015).

Human activity on the planet over the past couple of hundred years has also affected the balance between production and consumption of earth resources (e.g. production and consumption biomass) leaving geological markers that led geologists to conclude that 'the Earth has been pushed out of the Holocene Epoch by human activities, with the mid-20th century a strong candidate for the start date of the Anthropocene, the proposed new epoch in Earth history' (Steffen et al.2016, Williams et al. 2016). Therefore, 'climate change' is not a myth but is a reality and poses clear and present danger!

Skeptics have questioned whether the rapid increase in the T_{gm} during the past 100 years (Fig.1A) represents a 'change' or it is just part of natural climate variability. What is responsible for the accelerated rate of change of the T_{gm} during the past hundred years, is the other important question. What is the confidence that it is due to the accelerated increase in the greenhouse gases (GHGs, primarily CO_2 and CH_4) in recent years? Skeptics also raise the question that the climate models are not reliable as different climate models give slightly different answers to the same GHG forcing. While we shall address these questions here, going to the other extreme, we shall also raise the following question. With the current atmospheric concentration of CO_2 and CH_4 at 400 ppm and 1800 ppb respectively compared to 280 ppm and 700 ppb of the same during the interglacial period over the past eight glacial cycle (~ 1 million years), has the earth's climate reached a 'tipping' point?

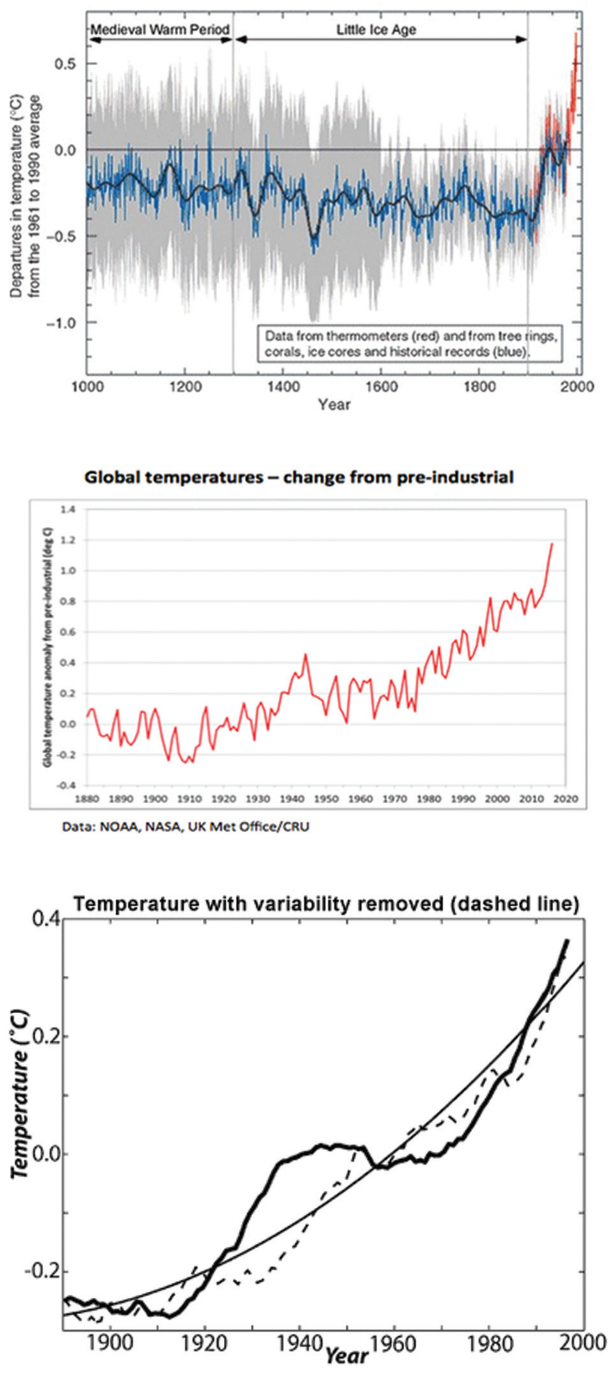


Fig.1: (A) Global mean temperature anomaly (°C) over the past 1000 years with respect to mean over 1961-1990, (B) The same expanded (°C)over the instrumental period between 1880 and 2016. (C) Underlying trend in the presence of multi-decadal variability of global mean temperature (°C).

As seen from Fig.1A, the rate of increase of Tgm of ~0.1°C /decade is much larger than anything that happened during the past one thousand years. This increasing 'trend' of Tgm over the past 100 years may be considered a 'change' as over the any other 100 year period in the past this trend would be more than one order of magnitude smaller. Thus, on a millennium time scale, this variation of temperature qualifies to be termed as a 'change'. However, we may get confused if we examine trends on a much smaller period, as a multi-decadal natural variability may be superimposed on the climate change signal (say, a linear trend over 100 years) of the Tgm (Fig.1C). The so called 'climate change hiatus' is nothing but a decreasing phase of the multi-decadal variation while the longer term trend (the climate change signal) is clear and present. This 'change' of Tgm could indeed be part of a much larger time scale variability of the climate. Therefore, it is always a time scale over which we should define a 'change'. Due to poor temporal resolution and accuracy of reconstruction of paleo-climate, such change Tgm (~1°C over 100 years) has been difficult to document for past climate. While level of present Tgm is not unprecedented in the past and this rate of change of Tgm may have happened in the past, its impact on the environment and ecosystems is far greater today than any time in the past. The over exploitation of the natural resources and the environment by the unprecedented human population (~7.5 billion by the latest count!) has left various ecosystems highly vulnerable where the large rate of change in Tgm , is accelerating the ecosystem changes (Scheffers et al, 2016) potentially leading to the Sixth Mass Extinction (Ceballos et al. 2015). This is why the current climate change is far more dangerous than any changes in the past!

The greenhouse effect of water vapor, carbon dioxide, methane and a few other minor constituents (GHGs) make the earth's climate habitable by increasing Tgm by ~33°K to current value of 288°K compared to the radiative equilibrium temperature at the top of the atmosphere (255°K, in the absence of the GHGs). Any increase in GHGs without increasing the earth's albedo would increase longwave radiation absorbed by the atmosphere requiring larger Tgm so that incoming and outgoing radiations are balanced. Increased Tgm would increase water vapor in the atmosphere and increase the greenhouse effect and further increase in Tgm . The global warming driven by more than 40% increase of CO_2 and about three times increase in CH_4 compared to pre-industrial levels could, in principle, lead to a significantly accelerated water vapor greenhouse feedback.

However, increase in cloud cover (or increase in clouds that reflect more solar radiation) leads to an increase in albedo that could offset the water vapor greenhouse effect. Therefore, the global warming temperature as result of certain levels of increase in CO_2 and/or CH_4 (e.g. doubling of CO_2) would depend on the distribution of clouds and frequency of occurrence of different clouds in the increased water vapor state. In climate models, the formulation of cloud is necessarily simplified leaving climate models having difficulty in simulating the observed distribution and frequency of occurrence of different cloud types. This is what leads to an uncertainty in the increase of Tgm as a result of certain level of increase in CO_2 and/or CH_4 (i.e the climate sensitivity). Different climate models have slightly different formulations of clouds and as a result lead to slightly different estimate increase in Tgm for the same level of increase in CO_2 and/or CH_4. Therefore, our estimate of Tgm as a result of some GHG forcing must be probabilistic. Since the formulation of clouds in climate models have a large number of 'parameters' with a range of uncertainties, the probability distribution of climate sensitivity to a given GHG forcing could be estimated in a series of 'perturbed physics' experiments giving the most probable estimate. Different climate models could also be considered (approximately) as different members of 'perturbed physics' ensemble and hence an ensemble of climate model simulations may also provide the probability distribution of climate sensitivity. Based on various such considerations, IPCC Fourth Assessment Report (Solomon et al. 2007) concluded that there is 'high confidence' that the recent large change in Tgm is due to the increase in anthropogenic GHGs.

The link between variation of atmospheric CO_2 (as well as CH_4) and variations of the earth's climate has always been very strong. For example, it is strongly correlated with glacial and interglacial variations of the climate (Fig.2B) which extends to even in the recent 1000 years (Fig.2C). While CO_2 evolves through complex interactions and feedbacks involving the cryosphere and ocean biogeochemistry (Sigman and Boyle, 2000, Sigman et al, 2010) and while may not be the primary driver for these climate variations, plays an important role in maintaining and amplifying these glacial-interglacial cycles (Gildor and Tziperman, 2001). However, it is noteworthy that in the absence of the human influence of modifying

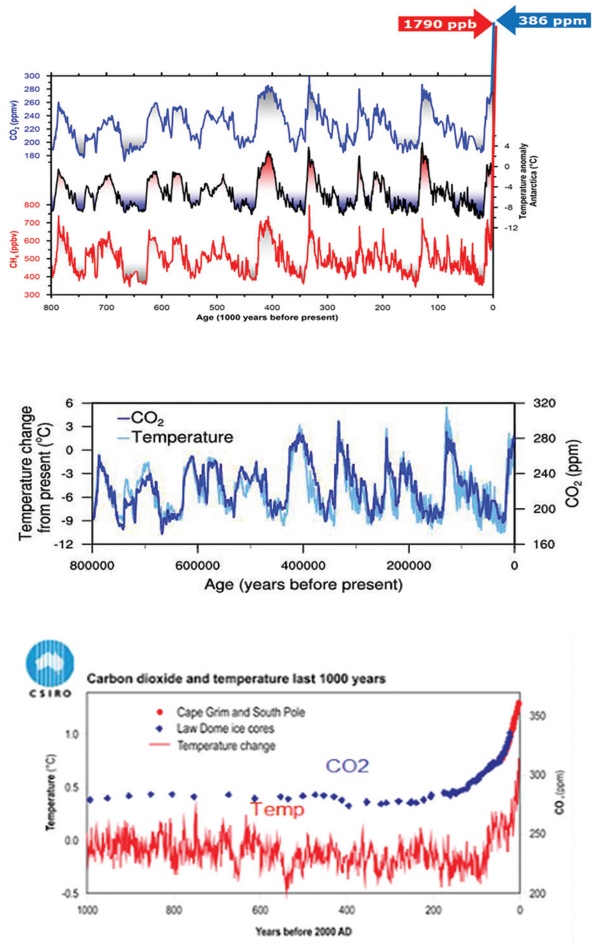


Fig.2: (A) Atmospheric CO_2 , CH_4 and surface temperature variations in Antarctica ice core (EPICA) over eight hundred thousand years. (B) Coherency in variations of CO_2 and temperature over the same period. (c) Coherency in variations of CO_2 and temperature during the past 1000 years.

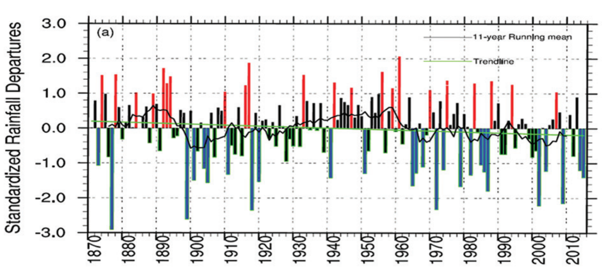
atmospheric CO_2, the upper limit of concentration of atmospheric CO_2 (CH_4) was bounded to 280 ppm (700 ppb) even when the climate went through large glacial-interglacial excursions of approximately 10°C. Therefore, the human induced current level of CO_2 (400ppm) and CH_4 (1800 ppb) represents a GHG forcing unprecedented in the past one million years! As, the earth's climate is a highly non-linear system with the equilibrium climate depending on several non-linear feedbacks, such a large perturbation could trigger new feedbacks and potentially 'tip' the climate to a new equilibrium state (Lenton et al., 2008). Recent assessments have indicated increased probability of several elements of the climate system reaching a tipping point (Lenton, 2011). The 'water vapor greenhouse effect' is a strong positive feedback and while a 'runaway greenhouse' is unlikely, it could not be completely ruled out (Goldblatt and Watson, 2012). Our understanding of the dynamics, thermodynamics, radiative transfer and cloud physics of hot and steamy atmospheres remains rather weak.

The climate models are the only tools to quantitatively assess climate sensitivity to a specified GHG forcing or projection of climate under different GHG scenarios. Climate models, however, would always have some limitations as no climate model can represent all physics/chemistry, dynamics and thermodynamics of all scales involved in the multi-component climate system. However, modern climate models are adequate to address these questions as they can simulate the large scale mean present day climate and associated weather statistics with a high degree of fidelity. However, as mentioned earlier, the climate sensitivity as well as projections to the future must be done with an ensemble of simulations to estimate the highest probability. With availability to high power supercomputers, this has become feasible as seen in many results presented in IPCC 4th Assessment Report (Solomon et al. 2007). Apart from the challenge of representing the chaotic multi-scale interactions in climate models, they also face the challenge of representing both natural and anthropogenic aerosols and their interactions with radiation and clouds. Depending on their physical and chemical properties, aerosols could absorb and/or scatter/reflect solar radiation thereby directly affecting the radiation balance at surface and at the top of atmosphere (and the climate). They could also affect the radiation balance indirectly by affecting the statistics and type of cloud formation, which in turn affects the radiation balance and the albedo. Acting as cloud condensation nuclei, often the aerosols lead to increase in small size water drop and delay formation of deep clouds, while at other times they could invigorate formation of deep clouds (Rosenfield et al. 2008.). In most places, the space-time variability of concentration and their physical and chemical properties is so large that making estimation of time mean and its spatial pattern becomes sampling dependent. It is, therefore, not surprising that aerosol chemistry models in climate models (earth system models) have large biases in simulating the 'observed' aerosol concentrations of different types.

Nonetheless, over the past two decades, while great progress has been made in realistically representing the aerosols and their influence on climate in climate models, it still remains the largest source of uncertainty in estimating the climate sensitivity as well as climate projections. Without an Earth System Model (ESM) model of our own and necessary computing infrastructure, India refrained from participating in modeling exercise in the past four IPCC Assessments. However, this is going to change shortly. An ESM developed by the Indian Institute of Tropical Meteorology, Pune (Swapna et al. 2015) is going to fully participate in the next IPCC assessment with all the model integrations as planned for the Coupled Model Intercomparison Project, Phase VI (CMIP6).

How the Indian summer monsoon (ISM) responds to the climate change and what may happen to it in the coming 50-100 years is critical to the Indian farmers as well as the policy makers of the country. IPCC models (Chaturvedi et al. 2012) indicate that with increased GHG concentrations, the seasonal mean ISM rainfall is likely to increase by 8-10% by the end of this century, consistent with the expectation that increasing moisture content in the atmosphere would lead to increased rainfall. In this context, it is rather counterintuitive that the ISM rainfall does not have an increasing trend over the past 100 years (may even have a small decreasing trend, Fig.3A!). It is particularly interesting to note that the ISM rainfall has a significant decreasing trend over the past sixty years when the increase of the GHGs has been steepest. While some like to believe that aerosols are responsible for this decreasing trend of ISM rainfall in recent years (Bollasina et al, 2011), there are many issues with the aerosol theory. Could this decreasing trend of ISM rainfall in recent years be part of a natural variability? To answer this question, we examined more than one high resolution paleo-climate reconstructions of ISM rainfall over the past 2000 years and discovered that the ISM rainfall has a strong 50-80 year multi-decadal 'mode' of variability (Goswami et al. 2015). Our study indicates that, on the time scale of interest (~ 1000 years), the multi-decadal natural variability ISM is dominant and the recent decreasing trend appears to be associated with a negative phase of this multi-decadal variability. It has also been shown that the decreasing trend of ISM rainfall is driven by the increasing trend of tropical Indian Ocean (IO) temperature (Roxy et al. 2016) while the increasing trend of IO temperature is driven by the weakening winds associated with the weakening ISM (Swapna et al., 2013). To bring ISM rainfall from the decreasing trend back to normal (or to the positive side) would require a negative feedback to counter the positive feedback arising from the above mentioned regional air-sea interactions, identifying which remains an open science question. In the future too, I believe that the projections of increase of ISM under different GHG scenarios is over estimated by climate models as the models tend to produce too much convective and too little stratiform precipitation compared to observations (Sabeerali et al. 2013).

While the global warming may not have a significant impact on the seasonal mean ISM rainfall amount, it has a large impact on the probability distribution of daily rainfall. We show that increased water vapor in the atmosphere makes the atmosphere more unstable leading to propensity of stronger rain events (fattening the tail of the distribution) at the expense of weaker and moderate rain events (weakening the middle part of the distribution) over central India (Goswami et al. 2006). Consistent with this, the extreme rain events over central India has a strong increasing trend while the weak and moderate events have a significant decreasing trend (Fig.3B) over the past 5-6 decades.



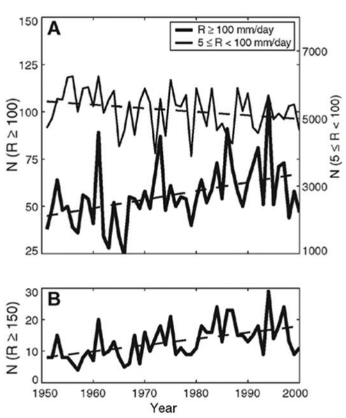


Fig.3 (a) Deviations of June to September all India rainfall from its long term mean normalized by its own standard deviation between 1871 and 2015. (A) Temporal variation (1951 to 2000) in the number (N) of (A) heavy (R ≥ 100 mm/day, bold line) and moderate (5 ≤ R < 100 mm/day, thin line) daily rain events and (B) very heavy events (R ≥ 150 mm/day) during the summer monsoon season over Central India.

The compensating contributions to the mean from the two types of rain events seem to explain why simply increasing water vapor in the atmosphere may not lead to increase of the seasonal mean rainfall. Interestingly, we also find that the extreme events over the eastern India have a significant decreasing trend over the same period (Goswami et al. 2010) as against that over the central India. This initially puzzling result could be understood in terms of spatial pattern of mean conditions associated with multi-decadal variability of ISM such that the convective available potential energy (CAPE, dependent of vertical distribution mean temperature and humidity) is increasing over central India while it is decreasing over eastern India.

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Clouds

Amit Apte and Rama Govindarajan

Look up at the sky. You are likely to see clouds pretending to be large gentle puffs of cotton, standing still or moving lazily. Fly through, and you feel the turbulent, and even violent, dynamics within. A simple yet revealing experiment is to take a video of a cloud, say for an hour, and play it fast.

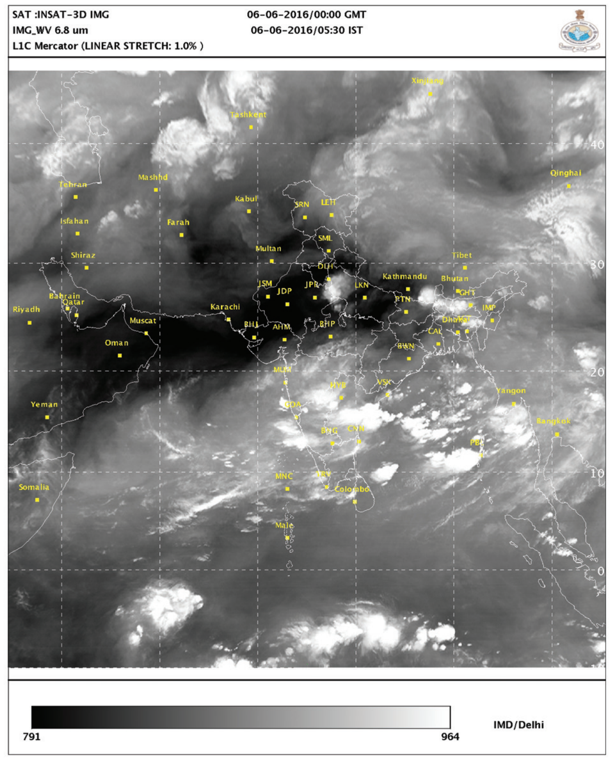
High clouds probably form by a miraculous circumstance that Roddam Narasimha calls volumetric heating [1]. Imagine a plume of smoke coming out of a chimney. The plume is hotter than its surroundings, and therefore lighter and buoyant, so it rises through the air. Close to the mouth of the chimney, its colour is dark grey, due to the soot it carries. Moving up, its colour becomes lighter and lighter and then practically vanishes. This is because surrounding air is entrained into the plume, i.e., the plume fluid drags along some surrounding air and mixes with it, effectively sharing its soot concentration, its heat, as well as its momentum with it. So along with the colour, the temperature and the upward velocity of the plume reduce with height as well, until the plume is extinguished at a height which scales, by an as yet unexplained factor for turbulent shear flow, with its initial diameter. This argument leads us to expect that a cloud too should meet the same fate. A cloud begins life as a parcel or plume of air which, instead of soot, carries water vapour that has evaporated from the ocean or land surface. It must quickly lose its water vapour as well as its upward momentum to the surrounding air and become incapable of causing rain. On the contrary, a monsoon cloud forms, and stands several kilometers tall. How?

Every parcel of air which contains some water vapour will not become a rain cloud, obviously, so let us call it a cloud-aspirant. It is not understood yet how to characterize surface conditions leading to local cloud formation. Cloud-aspirants must, of course, have sufficient initial buoyancy or upward momentum to begin their rise. The latter occurs in regions of convergence. Now the temperature in the atmosphere falls by about 7 degrees Kelvin per kilometre of height, see e.g., [2]. Correspondingly, the saturation vapour pressure falls, i.e., the partial pressure of a given parcel of air, if it contains sufficient water vapour, will equal the saturation vapour pressure at some height. This height is known as the lifting condensation level. As the cloud-aspirant rises past this height, volumetric heating can spring to action. At every height, some water vapour within the parcel condenses to liquid water. The latent heat of condensation gives additional buoyancy to the parcel, enabling it to rise further and allow the process to continue. For reasons not understood yet, entrainment seems to be far lower in a volumetrically heated plume than in a normal one where no phase change occurs. Entrainment, even in a simple turbulent shear flow is not understood quantitatively. When fluid flow and thermodynamics coevolve, things are much more complicated.

For significant condensation to take place, the cloud aspirant needs a significant density of aerosol particles within it, which can act as cloud-condensation nuclei. Aerosol is crucial to this process, because in the absence of solid or liquid surfaces for the water vapour to condense on to, one needs a super saturation of several hundred percent for spontaneous condensation to take place, whereas supersaturations rarely exceed a couple of percent in a cloud. For the droplet to grow bigger, its radius needs to be larger than what is called a Kohler radius, for reasons we will not go into now.

The next step is the formation of rain drops. A small droplet grows if it continues to live in a supersaturated environment, by a simple diffusion of water vapour towards its surface. A bigger droplet grows so slowly by this process, however, that it would take several days to create a rain drop by diffusion alone, whereas the life-time of a cloud is less than a day, and rain can happen within an hour. Diffusion can bring droplets to a size of the order of ten micron within the permitted time. Droplets bigger than fifty microns can undergo gravity-induced coalescence at sufficient frequency to become rain drops, i.e., millimeters in size. This is because differential downward velocity among droplets due to size can cause collisions, some of which will result in droplet coalescence. What makes droplets grow in a matter of ten minutes, from 10 to 50 microns, is not sorted out yet, and is termed the "droplet growth bottleneck".

Flow at high inertia such as in a cloud-aspirant is usually turbulent. Turbulence has a counter-intuitive effect on inertial droplets and solid particles, i.e., objects of finite size whose density is different from that of the surroundings. When we put milk into tea and stir it, turbulence mixes the milk in, until the concentration of milk is uniform everywhere in our tea. On the other hand, if we start with a uniform concentration of inertial particles, turbulence actually demixes this suspension and creates stringy regions of high particle-concentration, with practically no particles elsewhere. It is believed that turbulence has an important role to play in bridging the droplet growth bottleneck, by creating regions of extremely



Cloud bands over the Indian subcontinent and the surrounding seas during monsoon 2016 (INSAT image from imd.gov.in)

high droplet density where frequent collisions and coalescence can take place, but this has not been shown quantitatively. We in the ICTS group believe that caustics, that is, places where droplet dynamics cannot be described as a field, are a crucial component in getting past the bottleneck.

We have discussed the life of a single cloud and a few among the host of unanswered questions in that process alone. But instead of looking up at single clouds, if we see the planet earth from high above, as satellites now regularly do [year-video], we will see large aggregates, such as the band of clouds around the equator known as the Inter-Tropical Convergence Zone (ICTZ). In fact, such planetary scale structures are closely related to a phenomenon of great importance to the Indian subcontinent: the monsoon rains. The northward migration of the ITCZ is generally accepted to bring India its summer monsoon, and the ICTS monsoon group, and a host of others, are asking why.

The Indian monsoon is a dramatic event which takes place every year between June and September. Its onset is sudden and beautiful, and it has been a preoccupation of scientists, poets, musicians, economists, farmers, and the rest of us water-drinkers for at least twenty-five centuries to our knowledge. The pattern is similar every year, although variations of over a mere ten percent do occur and result in prosperity or great distress depending on their sign. Understanding this majestic phenomenon is one of the great unsolved problems in earth sciences, and needs to be studied with a sense of urgency because of its poorly understood relation to man-made climate change.

Clouds are but a small part of what determines the Earth's climate. But they are among the most difficult. A majority of the Earth's surface, at any given time, is covered by clouds. Clouds are acknowledged to form the biggest uncertainty in climate predictions. Whether clouds will aggravate global warming or make it milder is not known yet, though it is believed that increased sea surface temperatures will increase convective activity and probably cloud formation. The reigning dogma is that low clouds reflect more and therefore cool the Earth's surface, whereas high clouds act like blankets to keep heat in. Monsoon clouds are thin and tall, and do both, and how the monsoons react to the changing climate is not known at all.

Global circulation models (GCM) are unable to predict the Indian Monsoon even in present climate, for reasons that include our inadequate knowledge of clouds, our inadequate understanding of many unique processes in the Bay of Bengal, our inability to resolve spatial scales due to computer limitations, and many other things. These problems will challenge us for the next decade at the very least.

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'There is no such thing as a risk-free future'

Interview with Freeman Dyson

Freeman Dyson retired as a professor of physics from the Institute for Advanced Study, Princeton. His several path breaking contributions to theoretical physics include the unification of the three versions of quantum electrodynamics invented by Feynman, Schwinger and Tomonaga. He is a fellow of the American Physical Society, a member of the US National Academy of Sciences, and a fellow of the Royal Society of London. He was awarded the Templeton Prize in 2000, and the Henri Poincaré Prize in 2012.

There is a general worry that the increase of carbon dioxide content due to human activity can have undesirable effects on the climate system. However you have pointed out that the increased carbon dioxide concentration also has beneficial consequences. Could you elaborate on this?
Yes, the beneficial effects of CO2 on plant growth are more substantial, more certain, more measurable and better understood, than the undesirable effects on climate.

Is it true that the world has become greener on the average over the last few decades? What is the evidence for this claim? Is there good reason to believe that this is a consequence of increased carbon dioxide in the atmosphere?
Yes, the world has become greener as a result of increased CO2. This effect is not easy to measure locally but is clearly visible in images of the whole planet seen from space.

The well-publicized predictions for carbon induced temperature rise over the next century or so are obtained using computer models of climate evolution. Are these computer simulations a reliable guide for future expectations of the climate?
Computer simulations are good tools for understanding climate because they allow us to vary one thing at time and see the effect. They are bad tools for predicting climate because they ignore all the hundreds of messy processes in the real world that cannot be calculated.

Is it possible to use the rich historical archive of ice core data to quantify the correlation between carbon dioxide content in the atmosphere and temperature and use this to make tentative predictions for the future independent of climate change models?
The ice core data is full of valuable information about ice-ages. It does not answer the big question: why do ice-ages happen? The data can measure correlations but it cannot measure causality.

The ice core record indicates that, while ice ages last for tens of thousands of years, the transitions between ice ages and warmer phases occurs over decades. Does this suggest that the climate system undergoes sharp phase transition? Should we be worried that increasing carbon content might push us past a tipping point?
The words 'phase transition' have a precise meaning in physics but only a vague meaning in meteorology. All we know is that big changes in climate can occur rapidly. The same is true in economics and politics. Whatever we decide to do, either to increase carbon dioxide emissions or to decrease them, has big unpredictable consequences. There is no such thing as a risk-free future. The big mistake is to imagine that we can avoid risks by government regulation.

[Interview by Ananya Dasgupta]

'Global warming will benefit some but hurt many more'

Interview with J. Srinivasan

J. Srinivasan was the former chairman of the Divecha Centre for Climate Change, Indian Institute of Science, Bangalore. He was the lead author of the Intergovernmental Panel on Climate Change (IPCC) second and fourth assessment report. He was also the review editor of the third assessment report of IPCC on climate change.

Available data clearly establishes that surface and sea temperatures on the earth have risen significantly over the last hundred years. The concentration of greenhouse gases in the atmosphere – especially the concentration of carbon dioxide – has also risen very significantly over this period. Has it conclusively been established that the second effect (increase in greenhouse gas concentrations) is the cause of the first effect (increase in temperatures)? What is the evidence?
The evidence comes from coupled ocean-atmosphere climate models that are run with and without human induced CO2 increase. These simulations show clearly that the increase in global mean surface air temperature during the past 50 years is primarily on account of increase in CO2.

Many studies claim that if greenhouse gas emissions continue unchecked then that would result in a warming of the earth by 1-4 degrees Celsius over the next hundred years. It seems these predictions are made with the aid of computer simulations of the climate. How reliable are these simulations? How seriously can we take their results?
The climate models mentioned above are quite reliable for the prediction of global mean temperature but not reliable for regional rainfall changes. There is some uncertainty in the predictions of global mean temperature because for our inability to predict how clouds will change in the future.

How can a change of one or two degrees in global average temperatures have an impact on our lives?
When the global mean temperature increases by 2 C, the polar regions will have changes in the range for 4 to 6 and hence impact on the polar regions will be dramatic(large scale ice melting). Even a small increase in global mean temperature has a large impact on extreme events like heat waves. The number of these events will double or treble.

Continuing on the last question, it seems that the ice core record shows that ice ages – which last for tens of thousands of years begin and end over much shorter periods (decades) suggesting that the climate system sometimes undergoes 'phase transitions'. Some climate scientists have suggested that the fact that carbon emissions appear to be pushing atmospheric parameters into uncharted territory means that we are risking triggering truly horrific phase transitions – like the switching off of the monsoon. How plausible are such scenarios? What are they based on?

The rapid transitions in earth's climate are called tipping points. We do not know whether the tipping point is 2 C or 1.5 C or 3 C. The risk of monsoon switching off is low. The rainfall zones in India can however shift and this can have serious impact in a highly populated country like India. The steady decline in summer rainfall over Kerala during the past 50 years is most probably on account of global warming.

Apart from curtailing emissions of greenhouse gasses, are there other steps human society can take to combat global warming? Is the spraying of aerosols into the atmosphere a plausible solution?

My colleague Prof Bala Govindasamy works on Geoengineering which looks at ways to cool the earth by spraying aerosols. Since we do not understand the earth climate system (especially clouds) this approach is fraught with dangers.

The reputed scientist Freeman Dyson has claimed that the beneficial effects of carbon dioxide on plant growth are more substantial, more certain, more measurable and better understood than their undesirable effects. In particular Prof. Dyson has claimed that the increased Carbon Dioxide concentration over the last few decades has led to a measurable greening of the planet. How would you respond to these statements?

Global warming on earth will benefit some but hurt many more. All the work done so far shows that the damages far outweigh the benefits. Economists like Lord Nick Stern have provided a detailed account of the adverse impact of global warming. Prof. Dyson's comments are not based on a detailed study of the impact of global warming. In similar vein many people argue that human being survived that last ice age and hence can survive global warming. This comment fails to account for the fact that the human population was less than 5 million during the last ice age while the population today exceeds 7000 million. The population today does not have the option of migration which was available to our ancestor during the ice age.

[Interview by Ananya Dasgupta]

BETWEEN THE SCIENCE

P. AJITH was named the PI of the 'Indo–U.S. Center for the Exploration of Extreme Gravity' that is funded by the Indo-US Science and Technology Forum (US PI: B.S. Sathyaprakash, Penn State)

SUBHRO BHATTACHARJEE has been awarded a grant from the Max Planck Society, Germany, to set up a new Max Planck Partner Group in to study the physics of strongly correlated condensed matter systems at the ICTS-TIFR. Roderich Moessner, Director, Max Planck Institute for the Physics of Complex Systems (MPI-PKS), Dresden, will be the German host of the partner group from the MPI side.

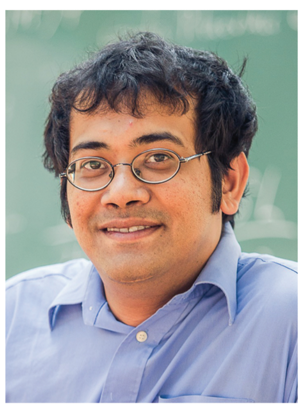
MANAS KULKARNI was awarded the prestigious Ramanujan fellowship of the DST/SERB.

ANINDA SINHA, Associate Professor at CHEP, Indian Institute of Science, Bengaluru and Associated Faculty at ICTS has been awarded the 2016 ICTP Prize (in honour of Kenneth Wilson) for his key contributions to aspects of quantum field theory using the AdS/CFT correspondence.

SPENTA R. WADIA has been awarded the TIFR Alumni Association (TAA) Excellence Award 2016 for his distinguished contributions to science and for conceptualizing and founding the International Centre for Theoretical Sciences.

The Intermittent Nature of Turbulent Flows

SAMRIDDHI SANKAR RAY



Amongst the many intriguing, unanswered questions in the natural sciences, the ones related to turbulence are, arguably, some of the oldest. Different aspects of turbulent flows must have fascinated us since time immemorial because they are ubiquitous and hence a part of our shared and every day experiences. In a manner of speaking, it did not need the technological advances of the last centuries to be aware that flows can often be complex and unpredictable; in nature this is all too common, be it in the plumes of smoke, an unexpected gust of wind, or the 'sudden sally' and 'eddying bays' of a brook. In fact our familiarity with disorder and chaos extends beyond the natural sciences to social and human behavior. It is no wonder then that the word turbulence derives from the old Latin word turbulentia for the disorganized movement of a crowd (turba) .

For scientists, turbulence describes the rather complex and irregular behavior which emerges in flows under suitable – and very common – situations which range from the depths of our oceans to the outer reaches of our atmosphere and beyond. And like Banquo's ghost, the effect of turbulence – often via mixing – appears in unexpected places such as in the sweetening of our coffee (through stirring), the cleansing of pollution in our cities or the rate at which droplets in clouds coalesce leading to precipitation. As a result of this wide span of its application and complexity, which include length and time scales ranging from the laboratory to the astrophysical, present day study of turbulence is really a collection of several important problems ranging from mathematics, physics, engineering, geo and astrophysics, as well as atmospheric and climate sciences. Here we will revisit an old puzzle and a universal feature of all turbulent flows, namely intermittency.

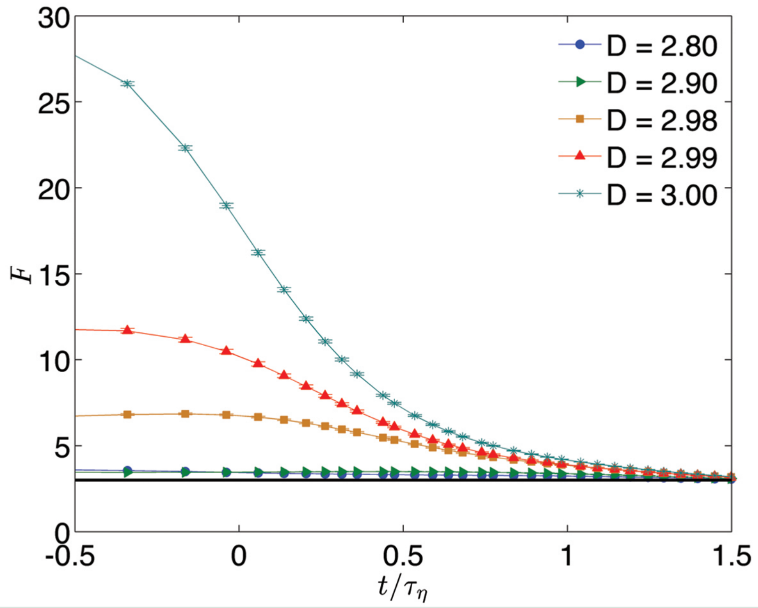
The starting point for a modern scientific framework to understand turbulence goes back to Leonhard Euler in 1757 when he wrote the equations of motion for an incompressible, idealized (no viscosity) fluid. For real fluids, with viscosity, an additional term (to account for viscous damping) was included several decades later (in the early nineteenth century) and the celebrated Navier-Stokes equation emerged as the complete description of all fluids . Technically, these equations are non-local, non-linear partial differential equations whose solution (for given initial conditions and geometry) is the velocity u of the fluid at any given point in time and space. When the Navier-Stokes equations have an energy input (as in nature or the laboratory) via a forcing term, solutions are typically statistically steady but non-equilibrium. Unfortunately, for almost all cases, an analytical, complete solution of such equations are elusive because of its non-linearity. Indeed, whether the Euler and the Navier-Stokes equations have smooth and regular solutions for all time still ranks as one of the most important, unsolved problems of mathematics .

It is useful now to have a qualitative – albeit non-rigorous – picture of a turbulent flow. Consider a fluid coming out of a pipe or a tap. When the speed is sufficiently low, or the fluid is very viscous (e.g., oil instead of water), the flow is laminar: featureless and without any structure. As the speed increases (or the viscosity decreases) however, irregular structures of different sizes (scales) seem to emerge out of the blue. The flow is then said to be turbulent. Therefore, a flow can make a transition from laminar to turbulent either by an increase in its velocity or a decrease in the viscosity of the fluid. A convenient way to quantify this is to introduce a non-dimensional combination of the viscosity and the velocity of the fluid (along with the typical size of the flow); this non-dimensional quantity is known as the Reynolds number and it allows us to uniquely control the different regimes (laminar and turbulent) of the flow without worrying about the details of the fluid: high Reynolds number corresponds to turbulent flow and low Reynolds numbers to a laminar one . Mathematically, the solution to the Navier-Stokes equations become turbulent when the viscosity is small enough for non-linearity to dominate linear, viscous dissipation (it is easy to show that the Reynolds number is the ratio of the non-linear term to the linear viscous term). Qualitatively speaking – and strictly for three-dimensional flows – the energy injected at large scales (e.g., injected at the scale of the blades of the fan in a wind tunnel) is transferred (cascade) via the non-linear term to smaller and smaller scales till the energy is lost through molecular dissipation (viscosity). This phenomenological picture, proposed by Richardson, of the transfer of kinetic energy from large to small scales is beautifully illustrated and draws inspiration from Jonathan Swift's satire (On Poetry: a Rhapsody):

So, naturalists observe, a flea.
Hath smaller fleas that on him prey;
And these have smaller still to bite 'em;
And so proceed ad infinitum.

In 1941, Kolmogorov set-up the first theoretical framework (popularly known as K41) for statistically homogeneous and isotropic three-dimensional turbulence in the large Reynolds numbers limit. Key to Kolmogorov's theory is the assumption (validated by numerous experiments and numerical simulations) that the mean energy dissipation has a non-vanishing limit as the Reynolds number tends to infinity (or the viscosity goes to zero). This is the celebrated dissipative anomaly of turbulence. By assuming statistical scale invariance (over length scales smaller than the scale of energy injection and larger than the scales at which viscosity dominates) and universality (independent of the specific fluid and away from boundaries), K41 yields (dimensionally) cubic root dependence for the velocity difference (at a fixed time) δu between points separated by a distance r, i.e., δu ⊠ r1/3. (This is reminiscent of increments in the position of a Brownian particle which scales as the square root of the time increment; in turbulence, the spatial increments of the velocity scale as the cubic root of the separation.) An immediate consequence of Kolmogorov's theory is that the average p-th power (we gloss over the technical details of this definition) of the increment δu – the p-th order moment of the velocity increments known, historically, in turbulence as structure functions – scale as rζ p , where ζp = p/3. However, over the last many decades all experimental, observational and numerical data show that the measured exponent ζp deviates (strongly for p ≥ 4) from the dimensional prediction p/3 of Kolmogorov. In fact, measurements suggest that ζp is a nonlinear, convex, monotone-increasing functions of p with ζp > p/3 for p < 3 and ζp < p/3 for p > 3. This behavior is commonly known as multiscaling in contrast to the simple linear scaling p/3 a la Kolmogorov. These exponents, so far, have proved universal and independent of the exact fluid or the mechanism which drives the flow turbulent. For p = 3, the exponent is exactly 1 (as suggested by dimensional arguments) and can be proved analytically to be so from the Navier-Stokes equation. (In fact this is the only exact result in fluid turbulence; similar calculations for other values of p fail because of the usual closure problem.)
All of this suggests that the self-similarity implicit in Kolmogorov's theory may well be broken. The reasons for this may well lie in the Swift-inspired Richardson picture of energy transfer:

Big whorls have little whorls
That feed on their velocity;
And little whorls have lesser whorls
And so on to viscosity.



A representative plot of the kurtosis of the Lagrangian structure function versus time (normalised by the Kolmogorov time scale) for different values of the fractal decimation (see legend). With increasing decimation, the value of the kurtosis tends to 3 -- a signature of Gaussian, non-intermittent statistics.

In reality, the transfer of energy from scale to scale (whorl to whorl) is patchy and not as efficient as the fleas of Swift. Such clumps in the hierarchy of scale-to-scale transfer suggests objects which are irregular or fractal and energy, at small scales (where it dissipates), concentrates on fractal sets with dimensions less than three . This breaking of self-similarity and (with increasing Reynolds number) fluctuating energy transfers at small scales is known as intermittency . Unfortunately, we do not have a microscopic theory, starting with the Navier-Stokes equation, to explain this or the multifractal nature of turbulence.

The fact that turbulent flows are intermittent is not in doubt. In almost every measurable, either in experiments or in numerical, simulations of the Navier-Stokes equation, evidence of intermittency rears its fascinating head. Thus a time series of the energy dissipated in turbulence has irregular, intermittent spikes with values much larger than the typical values of dissipation. The distribution of the acceleration or velocity increments over a scale r in the flow also show large excursions from typical values. Technically, this means that the probability distribution function of such quantities are non-Gaussian with fat tails showing a finite probability of having large fluctuations from the root-mean-square values.

Many would argue that understanding this phenomenon – which seems to be most conspicuous feature of all turbulent flows – remains the Holy Grail for turbulence theory. A major theoretical breakthrough came in the nineties when it was shown that for a related problem – the Kraichnan model – of a scalar (such as temperature) field advected by a random but Gaussian velocity field (with some features common to turbulent fluids), intermittency in the scalar field could be proved analytically from the primitive equations themselves. By using techniques from field theory, this model was shown to have zero modes leading to a breakdown of self-similarity. Unfortunately, unlike the passive-scalar advection-diffusion equation, the fully non-linear Navier-Stokes equation is not amenable to such techniques. Hence an explanation for intermittency has relied heavily on the use of phenomenological models with, typically, fractal dissipation and multifractality in the statistics of the velocity field. Often these phenomenological models are based on the statistics of the dissipation, such as the multifractal dissipation model, the random cascade models or the lognormal model. From a theoretical point of view the most appealing of such models are the ones based on the velocity field, such as the β and bifractal model, which incorporate a form of intermittency by assuming that successive generations of energy carrying eddies in the Richardson picture are non space filling. By using such ideas, it is easy to show the existence of more than one scaling exponent. Such ideas culminated beautifully in the celebrated Frisch-Parisi multifractal model [1] whence the turbulent velocity field possesses a (bounded) range of scaling exponents and a fractal set with a fractal dimension associated with each such exponent. Starting with this, the multifractal model yields the exponent ζp which multiscale in way real fluids do. We should remember, though, that despite the success of the Frisch-Parisi model to explain turbulence, it is still remains a theoretical framework to rationalise observations.

The Frisch-Parisi model remains our best bet in explaining intermittency and the multifractal properties of turbulence. However, its starting point is not quite the Navier-Stokes equation. Very recently a new approach to understand intermittency is taking shape in the form of the Fourier-decimated Navier-Stokes equation. Introduced in 2012 [2], decimation reduces the effective degrees of freedom of the flow, in Fourier space, by solving the Navier-Stokes equation on a restricted set of modes which are obtained as a projection on a fractal or homogeneous Fourier set. In results reported recently [3], such a microsurgery on the Fourier space shows a sharp drop in the intermittency (suitably quantified) of the turbulent flows and a tendency towards quasi-Gaussian statistics. Decimation results in a depletion of the strength of stretching and a modification of the triad-to-triad nonlinear energy transfer; these in turn lead to a suppression of anomalous fluctuations – hence a convergence to Gaussian statistics – and intermittency.

Technically, decimation is achieved via a generalized Galerkin projector and hence, mathematically, the form of the decimated Navier-Stokes is precise. This raises hope of possible analytical approaches – guided by numerical results – to understand why intermittency goes away as soon as we tinker around a little with the degrees of freedom and the non-linearity in the system. And if we were able to do so, we would go a long way in solving the riddle of intermittency. It, of course, remains to be seen if this is just another siren for us who are fascinated by the world of flows.

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Constructing Science and Institutions

A discussion with Spenta Wadia (Avinash Dhar, Rajesh Gopakumar, Shiraz Minwalla)

A few excerpts:

String Theory at TIFR...

Rajesh Gopakumar: Soon TIFR had a large string theory faculty?

Spenta Wadia: Oh I see! You want to know how the string theorists got hired at TIFR?

Shiraz Minwalla: Yes, like Ashoke.

RG: And there was a growing international visibility... you mentioned the 1989 conference. Can you say a little bit about that?

SW: Yes. I knew I had to bring Sumit Das back because I knew him well and had a very high opinion of him. Sumit was the first person I wanted to attract back. TIFR hired Avinash also... for all the work he had done in perturbative QCD. Then after some time we also hired Gautam because he was excellent and I knew that we needed a critical size to begin with. I had some difficulty with the induction of Gautam because he was my student. I knew from my Chicago days that hiring your own students is not something you do. But our circumstances were very different.

I visited Sumit in Fermilab. Both Sumit and Ashoke were post-docs there. I met Ashoke and spoke to him at length about coming to TIFR. By then he had already done some very beautiful work. I still remember - he was sitting in his office and his desk was almost empty. At that time there was the general impression that getting a job at the Tata Institute was difficult. He said, 'Now I will have to work harder.' This was the first conversation I had with Ashoke Sen. I really urged him and I told Sumit as well to urge him to join TIFR. Sumit knew him very well – they were college friends. So it started like that. Then at the Institute [IAS], I overlapped with Sandip Trivedi who was a postdoc at that time. Atish Dabholkar was a postdoc at nearby Rutgers University. I urged both of them to come back [to India and TIFR]. I also met Shubha Tole with Sandip and encouraged her too to return to India after her post-doc.

This is how it was and I think we got really lucky. It was our good luck that people were working on string theory and related problems, and were interested in coming back. Then the next hire was Shiraz. He was in Harvard then. And I was in correspondence with Harvard. Shobo had asked me to do this. The correspondence was basically with Andy Strominger. They didn't want to let him go. Then there was the issue of a joint appointment, and while Harvard was agreeable we had to get it approved at TIFR. We managed that.

I knew more or less that once this guy is here he will not go back. I had that intuitive feeling somehow, just by talking to him. True, right?

SM: Yes true.

SW: Salam played a key role in the early years. When we wrote our string theory paper, he invited me to give talks at the ICTP summer school in 1985. The other lecturers included David Gross, Curt Callan, and Lars Brink. After 1985, I went to ICTP almost every summer for many years.

What was great about being associated with ICTP was that Salam was very encouraging and would also facilitate my travel from ICTP to other places. So when I was invited to give a talk at the Berkeley meeting on High Energy physics and I didn't have any source of money for travel, ICTP gave me the travel money. I still remember that when I went to the conference they asked me for my registration fee but fortunately for me Salam was coming that way. I told him about the registration fees. He said to them, 'this is daylight robbery'. He had a presence, with his coat and his hat. I thought that was amazing!

SM: They waived the fees?

SW: Yes of course. ***Read more***

I think he [Virendra Singh] played a very important role. The buck stopped with him. It is important to mention that he played a crucial role.

SM: Was it just intellectual appreciation? Or was it that string theory has its roots in S-matrix theory, did that play a role?

SW: I think both. He was the smartest guy and he knew what was going on. I remember in one of the Puri meetings we had invited John Schwarz, and Virendra Singh as the Director of Tata Institute gave the opening remarks. After the talk, John said, 'it's amazing. I don't know of any other director who can give this type of a talk.' So he was very good. I think it is important to record that if he hadn't agreed and appreciated we could not have built the string theory group... he also had enormous confidence in me.

Now let me talk a bit about Strings 2001. String theory in India before and after that event is different. It gave enormous visibility to the string theory effort in India. That was an amazing meeting. Mainly Atish, Sunil and I organized it, and it was a truly backbreaking experience. David Gross strongly suggested, 'get Stephen Hawking'. So we wrote to Hawking and he agreed to come. ***Read more***

The idea of an international level campus in India...How ICTS happened?

After Strings 2001 in Mumbai, we organized a talk by Ed Witten in the Indian Academy of Sciences in Bangalore. I accompanied Chiara and Ed to Bangalore. They were staying in the Academy guesthouse. Any special attention given to them was met with a response 'don't worry about all that...we are very simple people'. I asked him if he wanted to visit the temples in Belur and Halebid. Ed said no, he wanted to visit the `temples of modern India'. He would like to visit the Infosys campus. Shibulal very kindly arranged this visit. We went to the Infosys campus and met Nandan Nilekani. This visit to the Infosys campus was a stunning experience for me. Have you ever been to the Infosys campus in Bangalore? This was of course in 2001.

SM: When it was more surprising.

SW: Yes. This visit made the point that it was possible to imagine that we too can create an international level campus in India?

Between January and May I sent a proposal to Mr Narayana Murthy for setting up a new type of institute in India. I did not hear from him. In 2004 I mentioned to David Gross, about not getting a reply from Narayana Murthy. He told me, 'You don't get this kind of money from private companies. This institute has to be funded by the government.' I still have his comments and edits on the proposal to Murthy. Then we had two full days of discussions in Santa Barbara where he told me how to go about it. His understanding of these matters is just amazing:

'the first thing you do is to have all the well-known Indian scientists support your proposal. [Laughs] Then carry all the people in the institute with you'. I knew that would be the biggest block. So slowly somehow I managed this.

In the last Council meeting of Shobo Bhattacharya as Director in October 2006, Prof CNR Rao asked me to make a presentation for a National Centre for Theoretical Sciences in the Tata Institute. Even before I started my presentation... CNR said, 'India needs a centre like this'.

In the August 2007 meeting of the TIFR Council I presented the financial and other requirements for the Centre. During the presentation Prof Rao said, that the Centre must pay for business class air travel to distinguished scientists, and hence the travel budget needs to be enhanced. He also suggested that we call the Centre an International Centre. The Council approved the creation of the `International Centre for Theoretical Sciences of TIFR' at a suitable location in India. It would be a Centre like the NCBS with a Centre Director and the management structure would include a Management Board, Advisory Council and Program Committee.

After this approval we faced the question of where to set up the Centre. Now you are interacting with your `Motherland' for a piece of land! By now Avinash was already on board. We set out looking for places in India.

This was 2007-08. The Hyderabad campus was a possibility. The first team that went to investigate the possibility of TIFR Hyderabad included Ramky, BJ Rao, Chari and I. We met the additional secretary in government and then the vice-chancellor of Hyderabad University. After that visit I took a decision that Hyderabad was not the place where ICTS could be because Hyderabad did not have the ecosystem to sustain a centre like ICTS.

So we were again trying in Bangalore. Then I met somebody who helped me a lot. And this was Dr Kasturirangan. He told me exactly what to do, whom to meet etc. He put me in touch with Mr Baligar Principal Secretary to Chief Minister who was an IIT Powai graduate, and he understood our cause and took us step-by-step forward.

Then we went to the Atomic Energy Commission of the Govt of India. I made a presentation in the AEC. There was a long and involved discussion. Prof CNR Rao was not present that day. The Commission was in favor of approving a Centre like ICTS in India but we needed to answer the question: why Bangalore? They told me to come back with a justification as to why ICTS should be located in Bangalore.

For my next presentation to the AEC, I made sure that Prof CNR Rao was there. So he came and it was amazing. He said to the Commission, 'how can you look a gift horse in the face? Chief Minister [of Karnataka] has told me that he has given land to ICTS as a present.' So this is how the ICTS was approved by the AEC.

Transit campus at IISc...

So in 2010 we began activities in Bangalore at the TIFR Centre in the Indian Institute of Science, much like Bhabha had started TIFR in the same institute in June 1945. Prof Balaram, the then IISc Director supported our temporary stay in the IISc campus.
The next few challenges were building the campus and its infrastructure, organizing programs in Bangalore, creating the ICTS faculty and admitting students and postdocs. I thought that beyond the buildings and architecture, the most important core of ICTS would be its faculty. Without the faculty there would be no ICTS. So most of my mental energies were spent there. How to attract people in diverse areas and convince them that ICTS has a great future, which in turn will depend on them. Slowly, slowly we built up the faculty.

While we were in the IISc, we were initially greatly helped by the NCBS and TIFR-CAM with regard to the management of administration and finance. I would like to put on record the enormous support provided by Prof. K. VijayRaghavan, Director, NCBS to the fledgling institution. The IISc Physics Department was a source of tremendous help and encouragement. Prof H. R. Krishnamurthy, then the Chair of the Physics Department and Prof. Rahul Pandit, the divisional chairman for Physics and Mathematics at IISc were strong supporters of the ICTS.

I constituted the International Advisory Board of ICTS in consultation with David Gross. That was one of the most important things I did, because I felt that when you do new things advice from outstanding people is very important. Clearly it paid off very well and David Gross was always there, advising me about everything. I always felt there was someone non-trivial as a saathi in a difficult and unknown terrain.

Thoughts about the future...

My dream is that the ICTS will become a big institution. It is doing very well and hence it should grow and grow and grow. It should augment all these facilities and do big things.

Why don't we create more big institutions in the country? If they [institutions] are capable of doing it, then why not? It's a tough job but is not impossible. I also feel the NCBS should grow into something much bigger. It should get out of its pure biology mode and get into systems science, big data science. Biology is a complex system, which needs ideas and tools from all across science and engineering to make sense of it. And I know that this is happening in some of the best institutions in the United States. As an example people who are working in neuroscience are thinking of similar mathematical problems as those who are trying to explore the `landscape' in cosmology and spin glass. People working in computer science and neuroscience ask about efficiency of computing and analysis of big data. One approach is using random matrix theory and this is something we also work on. You see the connection? Between statistical mechanics, computer science, biology, neuroscience? I (and VijayRaghavan) wanted ICTS to be next door to the NCBS, which is mainly a place for experimental biology. But this did not work out.

Also, NCRA should grow big. All these small 'start-ups' should become big institutions that would train a large number of students and postdocs. In this way Tata Institute would have given rise to many big institutions in India. And that's the way it should be.

It's a grand dream, but why not? You started something – it should grow, right? It doesn't remain small all its life. If it's doing well then you have to let it grow.

The off-springs of the Tata Institute should be allowed to grow to their fullest potential. That way we can serve the institute and the nation better.

In the new model, which also reinvents the composition and role of the TIFR Council there could be a 'Director General' looking after the overall well-being of the institute. With renewed enthusiasm we can excel and we can even attract private funding and do a lot of good things.

Ananya Das Gupta: I guess the private money is a very important part of this.

SW: Yes. But there are also others who support science but mainly research in chemistry and biology that is closer to immediate applications. But that is very different from us. We are doing science in which we value the serendipity of discovery, not necessarily a discovery made with an intention. Most important discoveries in science have been serendipitous, including the discovery of the electron that is the basis of the chemical bond and chemistry. I think very few people appreciate this and are always asking for deliverables.

There have to be some parts of science that deliver. But you also have to encourage people who engage in fundamental research, without any intention of application. History has shown us that these correlations are weak. Maxwell did not complete his equations with the intention of predicting light, thinking that some electricity company will benefit. It's amazing that what the human mind creates and understands about nature somehow becomes useful. Today we use General Relativity for the GPS! This is the amazing thing about science and the logical structures we create to understand the world around us.

Read more

STRING THEORY: PAST AND PRESENT

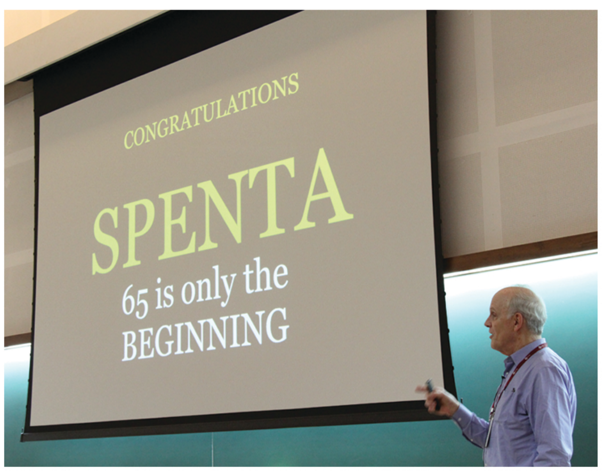
JANUARY 11-13, 2017

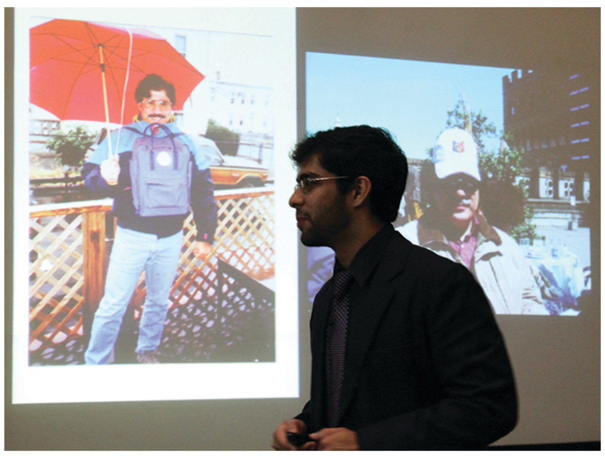
The meeting 'String Theory: Past and Present' was held from January 11-13, 2017, to celebrate Spenta Wadia's contributions to theoretical physics and the building of scientific institutions in India and around the world.

Thirty seven academic talks were presented at this meeting on topics ranging from gravitational scattering amplitudes, string perturbation theory, the conformal bootstrap and quantum field theory, black hole physics and the recent SYK model, string cosmology, non-equilibrium dynamics and hydrodynamics, random matrix models, glacier physics and theoretical biology.

A special session devoted to talks by Prof. Wadia's ex-students had six of the most diverse talks in the conference. Avinash Dhar presented a summary of Prof. Wadia's most important contributions to theoretical physics.

A celebratory banquet was also held at which speakers recounted Spenta's contributions to the development of science around the world, including in ICTP Trieste, Korea, Japan, Israel and Greece. These speeches were followed by several personal reminiscences about Spenta, including snapshots of Spenta as a father from his children Neha and Varun.





PROGRAMS

US-INDIA ADVANCED STUDIES INSTITUTE: CLASSICAL AND QUANTUM INFORMATION

ORGANIZERS

Bulbul Chakraborty, Anupam Kundu and Albion Lawrence

DATES

26 December 2016-7 January 2017

VENUE

Madhava Lecture Hall, ICTS-TIFR, Bengaluru

THEORETICAL AND COMPUTATIONAL ASPECTS OF THE BIRCH AND SWINNERTON-DYER CONJECTURE

ORGANIZERS

Chandrakant Aribam, Somnath Jha, Narasimha Kumar and Sujatha R

DATES

12-22 December, 2016

VENUE

Madhava Lecture Hall, ICTS-TIFR, Bengaluru

ICTP-ICTS WINTER SCHOOL ON QUANTITATIVE SYSTEMS BIOLOGY

ORGANIZERS

Antonio Celani, Stefano Di Talia and Carl-Philipp Heisenberg

DATES

05 December 2016 to 16 December 2016

VENUE

ICTP, Trieste, Italy

FUNDAMENTAL PROBLEMS OF QUANTUM PHYSICS

ORGANIZERS

Angelo Bassi, Sougato Bose, Saikat Ghosh, Tejinder Singh, Urbasi Sinha and Hendrik Ulbricht

DATES

21 November-10 December, 2016

VENUE

Ramanujan Lecture Hall, ICTS-TIFR, Bengaluru

GROUP THEORY AND COMPUTATIONAL METHODS

ORGANIZERS

Manoj Kumar and NSN Sastry

DATES

5-14 November, 2016

VENUE

Ramanujan Lecture Hall, ICTS-TIFR, Bengaluru

DISCUSSION MEETINGS

INDIAN STATISTICAL PHYSICS COMMUNITY MEETING 2017

ORGANIZERS

Ranjini Bandyopadhyay, Abhishek Dhar,

Kavita Jain, Rahul Pandit, Sanjib Sabhapandit, Samriddhi Sankar Ray and Prerna Sharma

DATE

17-19 February, 2017

VENUE

Ramanujan Lecture Hall, ICTS-TIFR, Bengaluru

JETS @ LHC

ORGANIZERS

Gobinda Majumder, Sreerup Raychaudhuri, Vikram Rentala, Tuhin S. Roy, Rishi Sharma and Seema Sharma

DATE

21-28 January, 2017

VENUE

Madhava Lecture Hall, ICTS-TIFR, Bengaluru

LECTURES

ABDUS SALAM MEMORIAL LECTURES

Photochemical and Thermochemical Generation of Hydrogen by Water Splitting

SPEAKER

C.N.R. Rao (Honorary President and Linus Pauling Research Professor, Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru)

DATE

30 December 2016

VENUE

ICTS-TIFR

DISTINGUISHED LECTURE

What is Science?

SPEAKER

Pierre Hohenberg (New York University)

DATE

28 December 2016

VENUE

ICTS-TIFR

Moduli of Vector Bundles on Compact Riemann Surfaces

SPEAKER

M.S. Narasimhan (NMI, Indian Institute of Science and TIFR-CAM, Bangalore)

DATE

20 December 2016

VENUE

ICTS-TIFR

PUBLIC LECTURES

Remarkable Lives and Legacy of Sofia Kovalevskaya and Emmy Noether

SPEAKER

Leon Takhtajan (Stony Brook University, NY)

DATE

10 January 2017

VENUE

ICTS-TIFR

EINSTEIN LECTURES

Undreamt by Einstein: The Discovery of Gravitational Waves

SPEAKER

Parameswaran Ajith (ICTS-TIFR)

DATE

28 February 2017

VENUE

T K M College of Engineering, Kollam, Kerala

Ligo Detectors Observe the First Binary Black Hole Merger

SPEAKER

Archana Pai (IISER, Trivandrum)

DATE

17 February 2017, 13:00 to 15:00

VENUE

RIT, Kottayam, Kerala

The End of Space-Time and Beyond

SPEAKER

Spenta R. Wadia (ICTS-TIFR)

DATE

2 December 2016

VENUE

Christ University, Bangalore

VENUE

Jawaharlal Nehru Planetarium, Bangalore

KAAPI WITH KURIOSITY

Footloose on a Tiled Trail - Exploring Repeating Patterns

SPEAKER

C S Aravinda (TIFR-CAM, Bangalore)

DATE

19 February 2017

VENUE

Jawaharlal Nehru Planetarium, Bangalore

My Life in Physics: From Quarks to Strings

SPEAKER

David Gross (KITP, Santa Barbara)

DATE

14 January 2017

VENUE

Christ University, Bangalore

Insects as Architects - How Insects Engineer their Ecosystems

SPEAKER

Sanjay Sane (NCBS, Bangalore)

DATE

11 December 2016

VENUE

Jawaharlal Nehru Planetarium, Bangalore

Vagaries of the Monsoon

SPEAKER

Sulochana Gadgil (CAOS, IISc, Bangalore)

DATE

26 November 2016

VENUE

Visvesvaraya Industrial & Technological Museum, Bangalore

The Universe: Big and Small

SPEAKER

Ashoke Sen (HRI, Allahabad)

DATE

23 October 2016

VENUE

Jawaharlal Nehru Planetarium, Bangalore