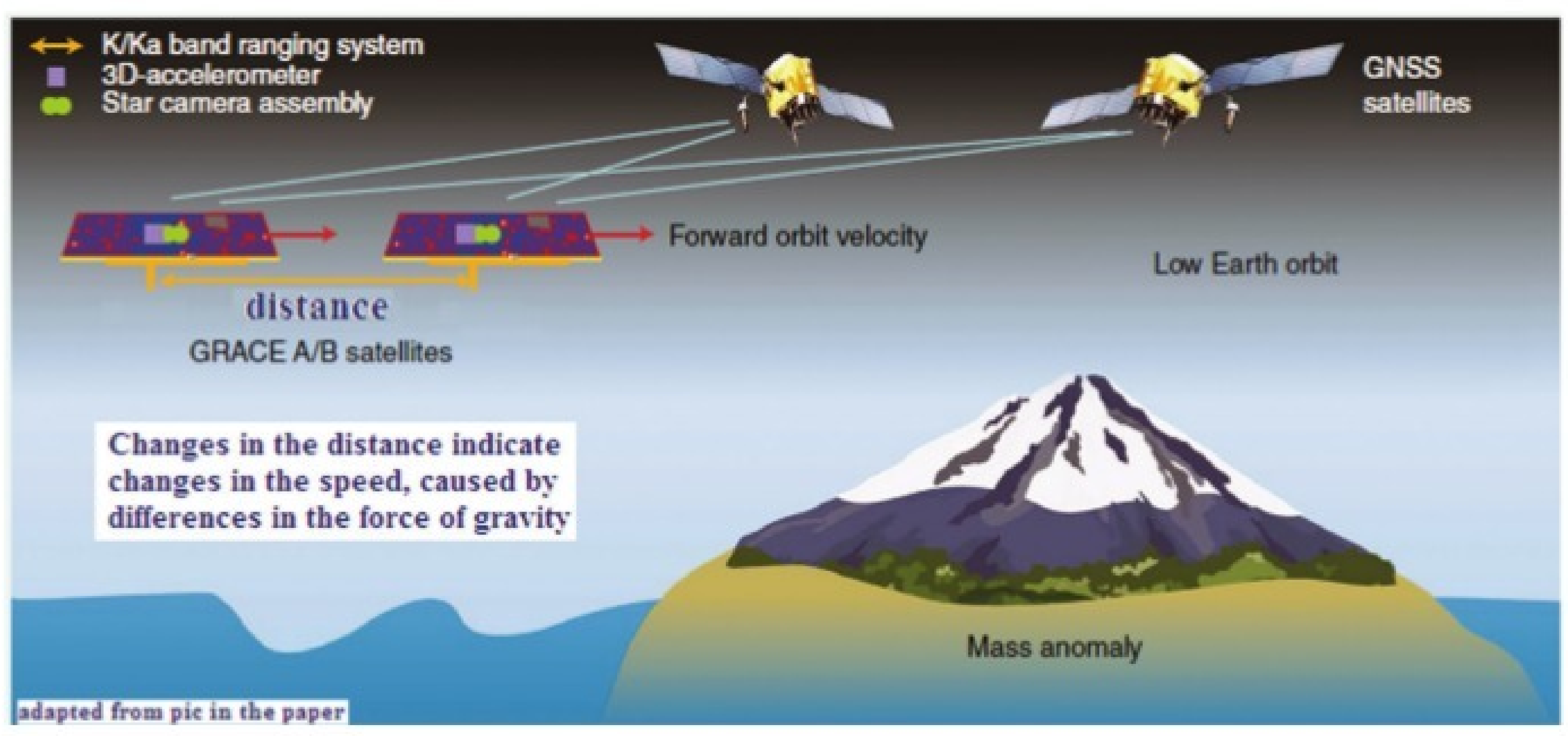
Measuring global warming

Variations in the Earth's gravity can reveal how the planet's bulk is shifting

S ANANTHANARAYANAN

The material of the Earth, including the water in the oceans, and the atmosphere, has been in movement and flux all through its history. These movements affect the Earth's climate, and changes in the climate, in turn, affect the movements.

Keeping track or accounting for the changes can be challenging. One way, however, is to scan and record undulations in gravitational forces, which are affected by large masses on and within the Earth. Byron D Tapley, Michael M Watkins, Frank Flechtner, Christoph Reigber, Srinivas Bettadpur, Matthew Rodell, Ingo Sasgen, James S Famiglietti, Felix W Landerer, Don P Chambers, John T Reager, Alex S Gardner, Himanshu Save, Erik R Ivins, Sean C Swenson, Carmen Boening, Christoph Dahle, David N Wiese, Henryk Dobslaw, Mark E Tamisiea and Isabella Velicogna, from University of Texas, Caltech, Nasa Goddard Space Flight Center, University of Saskatchewan, University of South Florida, National Center for Atmospheric Research, Boulder, the German Research for Geosciences, Potsdam, Alfred Wegener Institute, Bremerhaven, and Technical University, Berlin, describe in the journal, *Nature Climate Change*, the measurements of the Earth's gravitational field made by the sensors of the Gravity Recovery And Climate Experiment (GRACE) in orbit around the Earth.



There have been several assessments of the pattern of the Earth's gravity, in the vicinity of mountains, underground features, et al by different methods, generally of measuring the force of gravity itself. The GRACE arrangement does it differently — it uses a pair of satellites that measure not the force of gravity, but the effect that changes in gravity have on the distance between them. While the distance between the satellites should normally remain unchanged, slight variations in the Earth's gravity could momentarily slow down or speed up one or the other satellite.

The distance between the two satellites is monitored by radio signals of frequency some 20 billion cycles a second. This arrangement is able to make out changes of the order of a micron in the distance of 220 km that separates the satellites, and the result is an exceedingly sensitive measurement of the force of gravity. The two satellites orbit the earth 500 km above its surface and in a plane almost along the poles. The plane of orbit slowly rotates, so that the satellites overfly all parts of the Earth every month.

During the last half century, when global warming has become the critical concern, there is great interest in sensitive monitoring of the sea level. While records of the high tide mark can give us a general picture, there is more confidence in measurements made by radar beams from satellites. The results, however, are not good enough because of the moving nature of the surface of the sea. A more sensitive measure that was adopted is to measure variations in the speed of the Earth's rotation. This speed of rotation, like that of any spinning object, is affected when its parts are spread out or drawn in.

On the one hand, the Earth's speed of rotation is known to be slowing, at just 1.8 milliseconds a day, every century, as a result of the energy lost due to the tides. Apart from this, are the changes due to redistribution of mass. As the movement due to rotation is fastest at the equator, the Earth shows a bulge around its middle, and this would have slowed the spin. Shifting of masses on and within the Earth also affects the rate of spin. During cool periods, like the ice ages, sea water was collected as ice at the poles and sea levels fell. While this would have led to speeding up of the rotation, the extra load of ice at the poles caused more bulging at the equator. In the current period of warming, the melting of polar ice and the expansion of sea water cause rising of sea levels, slightly mitigated by relieving of load at the poles. It is worked out that every 1mm increase in the diameter would slow the Earth down by half a second per year every century. The actual sea level rise during 1900-1990 was 1.8 mm every year, or 18 cm over the century. As it is now possible to time the length of the day with great accuracy, this timing has become an important and sensitive means of monitoring changes in the sea level.

Detailed observation

While the sea level is one indicator of the progress of global warming, it has now become important to understand the mechanics of warming in much greater detail. As the paper in Nature Climate Change says, "Global observations of water and ice mass redistribution in the Earth system at monthly to decadal time scales are critical for understanding the climate system and investigating its changes." Together with other observations, it is this level of detail, the

> "Sea-level rise is a profound and direct consequence of a warming climate: within this century global mean sea-level rise may accelerate to 10 mm a year, a rate unprecedented during the last 5,000 years." Understanding the dynamics of what is happening to our planet is the key, both to try and retard the process as well as to adapt to the inevitable. GRACE is an important tool for this understanding.

paper says, that can "provide information on the Earth's energy storage, ocean heat content, land surface water-storage, and ice-sheet response to global warming. Interactions between the different climate system components involve mass variations in continental surface and sub-surface water storage (rivers, lakes, ground water, snow cover, polar ice sheets and mountain glaciers), as well as the mass redistribution within and between ocean and atmosphere. These mass movements are inherent to the evolution of droughts, floods, large-scale ocean currents, ice-sheet and glacier changes, and sea-level rise."

The GRACE programme, with its continuous, fine-grained and long-term data of the presence and changes in the land, water or ice masses, adds a crucial component to the remaining information, to understand the interactions and transitions that influence the evolution of climate. Each month, when the Grace satellites complete a scan of the Earth, "collected measurements allow an estimate of a global spherical harmonic model of the Earth's gravity field, which is then used to estimate mass change on the Earth's surface," the paper says.

An important component of the data that climate scientists need is the mass of ice covering the poles. Conventional methods, like radar altimetry, only yield the surface height, without regard to compaction or composition. The net mass change is thus an indirect assessment. With GRACE, on the other hand, we obtain a direct mass assessment, and a reading every month for every part of the planet.

Another unique item of data that we get from GRACE is about hidden masses, particularly, groundwater or subterranean water bodies. GRACE has been able to estimate the Earth's changing fresh water resources, with implications for human access to water and food and security, the paper says. And then, GRACE has been able to detect groundwater depletion in major aquifer systems, confirming excessive rates of depletion the world over, attributable to natural variations, changes caused by human activity or water management practices, the paper says.

The writer can be contacted at
response@simplescience.in

Bridging divides

Leonardo da Vinci combined art with engineering and laid the foundation of integrative learning across disciplines. His trailblazing example has inspired researchers down the years

BEN SHNEIDERMAN

Leonardo da Vinci's remarkable capacity for careful observation made him an astonishing artist and a brilliant scientist. He was able to compare the speed of a bird's wing movement downwards and upwards. He noticed the differences between arteries carrying blood from the heart and the veins bringing the blood back, so as to draw accurate models of the human circulatory system. His portrait paintings were groundbreaking because da Vinci was the first to show accurate musculature in the face and neck.

Beyond applying his artist's perceptual capabilities to scientific topics, da Vinci took on artistic and engineering challenges that built on his knowledge of geology, weather, hydrology, botany and much more. His natural state of mind was to integrate art, design, engineering and science. That integrative spirit inspired other legendary artist-scientists, such as John James Audubon, Louis Pasteur, Ada Lovelace and Buckminster Fuller.

However, in the 20th century, scholars began focusing on specialties, fragmenting academic disciplines. More recently, though, researchers are rethinking that approach, drawing attention to the value of bridging disciplines to inspire discovery and innovation.

At a 2018 meeting that I organised for the National Academy of Sciences, a diverse group of academics talked about examples of how scholars of art, design, engineering and science can work together for mutual benefit, as da Vinci found in his day. There are several good starting points for those who want to understand, teach and benefit from an integrative approach.

Arts training helps scientists excel

Da Vinci's celebrated perceptual skills made him a compelling artist. They also improved his science, enabling him to draw accurate representations of water swirling around objects and the movements of clouds. This tradition is apparent in Audubon's bird paintings and the anthropology drawings of Mary Leakey.

Medical professionals may also find that training in the visual arts can help them in their jobs. For instance, after dermatologists were asked to study museum paintings they had improved their capacity to spot and describe features in skin lesions. Art training also improves clinician skills such as patient examination and reading medical images.

Similarly, musically trained doctors are better at hearing the nuances in heartbeats when they use their stethoscopes. Nursing students who got musical training were able to more accurately identify sounds from patients' stomachs, hearts and lungs.

Louis Pasteur's training in making portraits probably helped him understand chirality, the mechanism by which molecules can take left-handed and right-handed forms.

Sociologist of science Robert


Leonardo Da Vinci

Root-Bernstein, who has long researched the sources of extreme success in science, studied the avocations of Nobel Prize winners. He found them to be polymaths who were far more proficient in producing art, sculpture, music, literature, poetry, theatre and other creative activities than other prominent researchers or the general public.

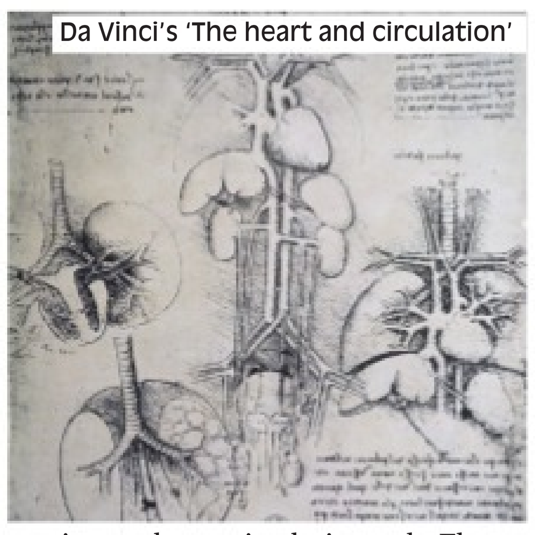
Artistic innovation challenges scientists

Some creative ideas can't be executed without science. For instance, engineer Karlheinz Brandenburg wanted to enable audio recordings to be digitally recorded in a compact way that would allow songs to be transmitted over slow communications lines. He developed the hugely successful mp3 audio format, whose compressed data formats enabled the digital music revolution, while at the same time revolutionising computing algorithms research.

Artist Lillian Schwartz, who carefully studied da Vinci's work, was a participant in the 1960s group Experiments in Art and Technology. While at Bell Labs, she worked with computer graphics innovator Ken Knowlton to develop computer animation techniques that laid the foundation for Hollywood special effects and the computer games industry.

Play expands engineers' thinking

Training in making art, design and craft work can help scientists and

Da Vinci's 'The heart and circulation'


engineers better in their work. Flourishing design schools, like the Rhode Island School of Design, Savannah College of Design or Canada's OCAD University, as well as design departments at many universities, are demonstrating that they teach skills that accelerate work in many fields. Their students learn important lessons from the experience of wrestling with design problems, trying multiple approaches with sketches and drafts and getting feedback during studio reviews. These lessons appear to improve performance in science and engineering research.

The growing movement known as "practice-based research" in the art and design community generates new knowledge, which can lay the foundation for further discovery and invention. A favoured technique for combining art/design with science/engineering is to create long-term collaborations so as to get past the early stages of learning new language and methods. A study of 118 such collaborations, supported by the Wellcome Trust, demonstrated ample benefits.

Art can inspire scholars in other disciplines

While it is difficult to track, it seems reasonable to assume some artistic productions like paintings or sculpture or performances of music or theatre triggered a scientist or engineer to make a connection or think in a fresh way about a problem that they are working on. Einstein claimed that music underpinned the insights that led to his theory of general relativity.

Seeing an Escher print of fish


Needle Tower by Kenneth Snelson

arranged in a grid stimulated NYU chemist Nadrian Seeman to produce the first DNA-based nanotechnologies. He writes that art can "generate or help illustrate structural ideas — possibly new structural ideas — about DNA."

Superstar engineer Buckminster Fuller's ideas of tensegrity were put to work in Kenneth Snelson's innovative constructions, which combined steel cables and aluminum cylinders, creating large visually engaging public sculptures. These sculptures also helped molecular biologists understand the structure of large molecules.

Other stories describe how a Miro painting, a Calder mobile or a Stravinsky symphony inspired 20th-century researchers. How do the works of painter Jean-Michel Basquiat, space artist Trevor Paglen, or dance choreographer Liz Lerman inspire 21st-century researchers?

Inspiring examples from the Science, Engineering, Art, and Design website tell the stories of how collaborations work. High school and university instructors who give their students the experience of working in team projects will better prepare them for a life of successful creative partnerships. Another indication of the growing appreciation of integrative ideas is that design thinking has gained recognition for its benefits to business in product and service development. For the long term, I propose the development of a US National Academy of Design, to join the National Academies of Science, Engineering, and Medicine. This won't be easy, but it would restore prominence to the power of integrative thinking that da Vinci still exemplifies.

The writer is professor of computer science, University of Maryland, US. This article first appeared on www.theconversation.com

PLUS POINTS

Massive 'lion'

Some old bones found in a drawer in Kenya have turned out to be fossils from a new species of meat-eating mammal larger than any big cat stalking the world today.

Paleontologists at Ohio University have announced the discovery of *Simbakubwa kutokaafrika*, a gigantic carnivore, bigger than a polar bear and with a skull as large as that of a rhinoceros but with massive piercing canine teeth. Though it bears almost no relation to big cats today, the species name *Simbakubwa*, is Swahili for "big lion" because the animal was likely at the top of the food chain in Africa, as lions are in modern African ecosystems, the research team said. The 22-million-year-old fossils were unearthed in Kenya decades ago as researchers combed the region for evidence of ancient apes.

Specimens including the animal's jaw, portions of its skull, and parts of its skeleton were placed in a drawer at the National Museums of Kenya and not given a great deal of attention until Ohio University researchers Nancy Stevens and Matthew Borths rediscovered them, apparently immediately recognising their significance. "Opening a museum drawer, we saw a row of gigantic meat-eating teeth, clearly belonging to a species new to science," lead author of the study, Borths said.

The research team calculated the species would have weighed up to 1.5 metric tonnes, and could have fed on elephant-like creatures. "Based on its massive teeth, *Simbakubwa* was a specialised hyper-carnivore that was significantly larger than the modern lion and possibly larger than a polar bear," he told *AFP*.

The species comes from a group known as the hyaenodonts, which were the first mammalian carnivores in Africa, and lived around 22 million years ago. For about 45 million years after the extinction of the non-avian dinosaurs, hyaenodonts were the apex predators on the continent.

The second part of the new species' name, *kutokaafrika*, is Swahili for "coming from Africa" because *Simbakubwa* is the oldest of the gigantic hyaenodonts, suggesting this lineage of giant carnivores originated on the African continent and slowly moved northward to flourish for millions of years.

But despite the species longevity, hyaenodonts eventually went extinct across the world. As global ecosystems changed between 18 and 15 million years ago with grasslands replacing forests, new mammalian lineages diversified. "We don't know exactly what drove hyaenodonts to extinction, but ecosystems were changing quickly as the global climate became drier. The gigantic relatives of *Simbakubwa* were among the last hyaenodonts on the planet," Borths said.

The Independent

Elusive molecule

In the beginning, more than 13 billion years ago, the Universe was an undifferentiated soup of three simple, single-atom elements. Stars would not form for another 100 million years. But within 100,000 years of the Big Bang, the very first molecule emerged, an improbable marriage of helium and hydrogen known as a helium hydride ion, or HeH+.

HeH+ had also been studied in the laboratory, as early as 1925. But detected HeH+ in its natural habitat had remained beyond their grasp.

The problem was that the electromagnetic waves given off by the molecule were in a range — far-infrared — cancelled out by Earth's atmosphere and thus undetectable from the ground.

So Nasa and the German Aerospace Centre joined forces to create an airborne observatory with three main components — a massive 2.7m telescope, an infrared spectrometer, and a Boeing 747, with a window-like square cut away from it fuselage — big enough to carry them. From a cruising altitude of nearly 14,000m, the Stratospheric Observatory for Infrared Astronomy, or Sofia, avoided 85 per cent of the atmospheric "noise" of ground-based telescopes.

Data from a series of three flights in May 2016 contained the molecular evidence scientists had long sought, interlaced in the planetary nebula NGC 7027 some 3,000 light years away.

"The discovery of HeH+ is a dramatic and beautiful demonstration of Nature's tendency to form molecules," said Neufeld.

The straits times/ann