Exploring Innovations in Space Science to promote a Sustainable Planet

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Abstract: The advancement of space technology plays an important role for earth in long term sustainability modern innovations like satellite monitoring, space-based data analysis and interplanetary research are being used to solve environmental and resource challenges on our planet. The technological improvement driven by spaceflight programs can be used to drive sustainability as well. Spaceflight missions require careful handling of the resources that is minimizing waste, similarly on earth on a sustainable way of life requires careful handling of resources. This paper discuss how both pathways relate to each other and how they can help each other for a bright and sustainable future Development in space-based solar power, reusable launch systems, and eco- friendly technologies aim to reduce carbon emission and dependence on non-renewable resources.

Keywords Space Technology, Sustainable Development, Earth Observation, Space-Based Solar Power, Reusable Launch Systems, Climate Action

I. INTRODUCTION

The space is vast and even unimaginable, from around a century, humanity has focused and invested on Space technology. Which include interplanetary mission, human spaceflights, communication and whether telecast satellites, space station etc. some of very famous & trusted spaced agencies like Indian Space Research Organization (ISRO), National Aeronautics and Space Administration (NASA) European Space Agency (ESA) etc. have made major contributions to human space Exploration, scientific discovery satellite technology etc. some of the very important missions like ISRO`s Chandrayan-1, India`s first mission to moon, which discovered water molecules on the moon`s surface, Mangalyaan also known as mars orbiter mission, which made India the first Asian country to reach mass orbit, and first nation to do it on its first attempt also with very low budget. NASA`s Apollo program which helped humans to land on moon and return safely. ESA`s Rosetta mission, the first mission to orbit and land on a comet etc. All these missions have helped humanity to understand our surroundings and how our whole universe is different from our Earth. And all these missions off course have taught us about resources and how we can use them for Earth sustainability.

II. INTERSECTION OF SPACE TECHNOLOGY AND SUSTAINABILITY

Space Technology was originally developed for exploration beyond our planet, but it has become a critical tool for understanding and protecting the planet itself. Now we will understand how space technology has influenced our planets sustainability through some important missions. Let us study about it through examples that is through several space missions.

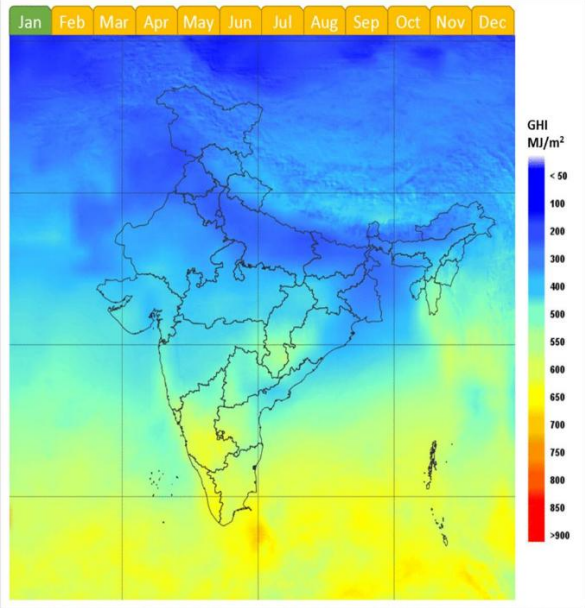
a. Environmental monitoring and climate action:

NASA's Landsat 9 mission, launched on September 27, 2021 is a mission designed to monitor the earth's surface changes over time. Its main goal is to provide accurate high resolution images that help scientist and to understand deforestation and forest growth, urban expansion, agricultural productivity, water resource management, glacier and ice sheet dynamics etc.

The image of Buccaneer Archipelago captured by the operational land imager of landsat- 9 https://www.nasa.gov/image-article/landsat-9-sees-buccaneer-archipelago/

b. Disaster Management and Reslliense:

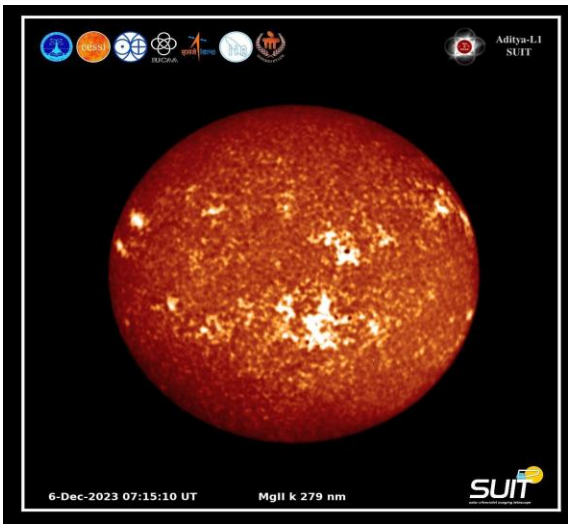
ISRO's INSAT -3D & its successor INSAT – 3DR both satellite are part of India`s Indian national satellite (INSAT) system, operated by ISRO for meteorology, weather forecasting and disaster monitoring, it is designed to provide real – time data for weather forecasting, storm tracking and disaster warning.



Assessment of solar energy from geostationary satellite INSAT 3D & 3DR https://www..gov.in/RenewableEnergy.html

c. Clean Energy and Innovation:

ISRO's very famous satellite mission Aditya -L1, helps scientist understand solar activity and its impact on earth's climate and energy systems. It supports innovation in solar energy technologies, by helping optimize placement of solar forms and predict energy fluctuations due to solar variability, it also aids in protecting power grids and satellite systems from solar storms, ensuring sustainable energy infrastructure.



The Solar ultraviolet imaging telescope (SUIT) instrument on board the ADITYA-L1 spacecraft capturing NB3 (Mg II K) showing chromosphere, sunspots, plages and filaments https://suit.iucaa.in/

III. EMERGING TRENDS IN SPACE TECHNOLOGY

Space Technology is advancing rapidly, driven by innovation, sustainability goals. The emerging trends are transforming how humanity explores space and uses it to solve earth – based challenges like climate change, resources scarcity and connectivity gaps.

a. Reusable Launch Vehicles:

A Reusable launch vehicle is a type of spacecraft a rocket that can be launched, recovered and reused Multiple times. This concept reduces the cost of access to space, minimizes space debris and suppose sustainable space exploration by cutting down on waste and manufacturing resources.

Ex: ISROS`s RLV-TD (technology demonstrator), LEX (landing experiment), ESA`s Prometheus project.

b. Green propulsion and eco-friendly space craft:

Green propulsion refers to rocket and spacecraft propulsion system the use non-toxic, environmentally safe propellants instead of traditional fuels which are highly toxic and hazardous to handle.

Ex: Electric or Ion propulsion which uses electric fields to accelerations and generate thrust instead of burning chemicals, used in ISRO's Chandrayaan-2

orbiter for fine orbital adjustments.

C. Satellite Constellations & Global connectivity:

A satellite constellation is a group of satellites working together in coordinated orbits to provide continuous, wind-area coverage of earth. These are used for internet and telecommunication services, earth observation and environmental monitoring. These can provide high speed internet and communication access anywhere on earth

Ex: Bhartiya Antariksh Saneha Nigam (BAS) is planned to deploy constellation of small satellite for broadband internet.

d. Artificial Intelligence CAD and Automation:

AI is the use of computer algorithms that can analyse data, learn pattern and make decisions without explicit human instructions & Automation is the use of systems that perform tasks with minimal or no human intervation.

Applications:

1) Autonomous operation
2) Fault detection
3) Data prioritization

Ex: NASA`s earth observing satellites, ISRO`s NISAR mission (NASA – ISRO synthetic Aperture radar).

e. Space Resources Utilization:

SRU, also called IN-Situ Resource Utilization (ISRU), Involves harvesting and using materials found in space instead of transporting everything from, earth like water Ice (on moon, mars, asteroids), metals and solar energy.

Applications:

a) Propellant production
b) Habitat construction
c) Mining of asteroids
d) Life support

Ex: ISRO`s Chandrayan-3, ESA lunar resource initiative.

IV. OBSTACLES FACED IN SPACE TECHNOLOGY FOR EARTH'S SUSTAINABILITY

1. Environmental and Sustainability Challenges:
   Space Debris & Orbital Pollution
   -> Mining, processing and transporting materials in space can generate debris, including broken parts, leftover materials which can increase the risk of collisions with satellites
2. Over exploitation and ethical use of space resources:
   As commercial and national interests in mining asteroids, the moon, there is a risk of over exploitation of extra terrestrial which could lead to conflicts over access and raise ethical questions about humanity`s right to exploit other celestial bodies.
3. Energy consumption and carbon footprints:
   High energy requirements like in launching satellites, probes or humans into space requires massive amount of energy.
   Rocket propellants release CO2, water vapour, black carbon and other gases directly into the upper atmosphere.

V. RECOMMENDATION FOR ACTIONS

Adopt green propulsion technologies:

Develop and implement eco- friendly fuels ex: Hydrogen, Methane, to reduce CO2 and soot emissions.

1) Encourage research and innovation:

Invest in advanced materials, lightweight structures and energy efficient technologies for spacecraft, support missions that monitor climate change, track pollution and measure earth`s resources.

2) Increase awareness in both communities i.e. human spaceflight and sustainable development for common research areas and efforts.

3) Communicate the similarity of challenges and especially derivation of solution for sustainability challenges from space technology to make use of human spaceflight popularity for acceptance of sustainability measures.

4) Respect the Integrity of celestial bodies by preventing biological or chemical contamination and follow strict planetary protection guidelines to presence the scientific value and natural state of other planets.

5) Promote fair and equitable access to Space technology benefits, including earth observation, global connecting and resource utilization and prevent disparities where only wealthy nation or corporations

control space resources or climate -monitoring.

VI. CONCLUSION

This paper discusses the contribution human spaceflight technology development can have sustainable development. It has includes how space technology and earth sustainability interacts for a better future, emerging trend to solve earth-based challenges, and the problems we faced. It actually showed some recommendations have been made on how to Integrate the two research communities with each other to maximize the results of the respective technology developments that is those of space community and of the science and technology for sustainability community.

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