## Input to NRC Decadal Survey from NASA SERVIR Himalaya Hub Region

**Q.1 What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?**

Key challenges/questions identified by approximately 8 respondents living or working in the Hindu-Kush Himalaya (HKH) NASA SERVIR hub region are presented below (not listed in order of priority). Respondents represented academic institutions (3 respondents), intergovernmental organizations (3 respondents), and other sectors (2 respondents). Responses are presented verbatim, with minor editing to improve understanding and combine similar comments.

Data Accessibility, Dissemination, and Challenges

1. How can NASA better communicate its research?
2. How can we better access real time or near real-time satellite data?
3. How can non-scientists best utilize (and understand) the plethora of NASA data available?
4. How can NASA data and applications address the needs of under-served populations, ranging from STEM needs in schools to the needs of poor farmers or slum dwellers around the world?
5. What are the gaps, challenges, and practices to be addressed to better connect satellite-based science products with end users/decision-makers to achieve meaningful utilization of services?
6. What research and value-added systems are needed to move toward a “services” mode that offers societal benefits as a market-based commodity?
7. How can we achieve a situation like GPS or internet today that originally started as defense projects where the business model succeeds and sustains the NASA Earth Observation (EO) capability?
8. How do we empower nations and agencies so that they can maintain and afford EO systems of their own based on NASA Pathfinder missions?
9. How to calculate return on investments in Earth science and satellite applications within multiple timeframes (e.g., yearly and decadal).
10. Assimilation of remotely sensed products (e.g., AOD) with products that are necessary from a regulatory-mitigation perspective (e.g., $PM_{2.5}$).

Food/Water/Energy Security

11. What new advances in EO systems can be made to address increasing needs and challenges of food/water/energy security?

Challenges in Mountain Areas

12. What kind of customization and new package of EO systems are required to understand the geophysical and biophysical complexities of mountain systems?
13. Resolving orographic precipitation in mountain areas.

Climate Change

14. How will NASA deal with government and popular attacks on the merits of climate change, considering their access to so much relevant data?

15. Addressing uncertainty in seasonal climate projections and applications using seasonal climate model outputs, especially in low-flow and high-flow conditions (droughts and floods).
16. Understanding complex positive and negative feedback loops in the global climate system, especially the role of water vapor and clouds in dampening or increasing GHGs' influence on global climate change.
17. How could EO systems enhance climate measurements and forecast systems?

**Q.2 Why are these challenges/questions timely to address now especially with respect to readiness?**

Respondents were not asked to comment on the timeliness of proposed key questions/challenges. Considering the extended time horizon of the Decadal Survey (2017-2027), timeliness of proposed key questions/challenges was not considered a critical factor.

**Q.3 Why are space-based observations fundamental to addressing these challenges/questions?**

To address proposed key challenges/questions, respondents offered several suggestions for continuing existing satellite observations or implementing new satellite observations, and facilitating the use of satellite data.

Existing observations that should be continued to support decision-making or application development include:

- Landsat, PATH, SWOT, TRMM, GPM, MODIS, JASON-3, ICESAT-2, SMOS
- EO-1 Optical imagery (tasking is very important during disasters)
- EOS for air quality and weather are extremely beneficial; singling out one is doing injustice to others.

Global land observation missions, such as the Landsat series, are crucial to providing a long-term, consistent perspective on global to local changes.

Hyperspectral and SAR continue to be research areas for NASA, but the immediate benefits range from better water quality and ecosystem service assessment to situational awareness of hazards when awareness is needed the most (not waiting for clouds to clear).

It is important to continue remote sensing in difficult terrain, such as the mountains and cryosphere. These are places where in-situ measurements are lacking and where huge knowledge gaps exist. Cross collaboration between different thematic groups is also important to develop better products.

Suggestions for additional investments include:

- A global, data-driven indication of poverty to be used in connecting other environmental/ climate data to communities.
- Air quality and weather related application for the HKH – model/satellite assimilated products. The HKH is an extremely poor in-situ observation data region yet in dire need of information. HKH is an aerosol pollution hotspot, impacting the cryosphere and monsoon, which affects not only mountain people but almost a billion people downstream.
- More near-real time weather monitoring applications to enhance early warning.
- More vertical profile data like Calipso/MISR, or additional spatial and temporal resolutions from them.

- Access to commercial high-resolution imagery for disasters.
- More real-time and higher resolution soil moisture measurements could provide better inputs into drought, crop productivity, and hydro-meteorological hazards nowcasting and forecasting.
- Improved access and interpretability of SAR for rapid response.
- More assimilation of satellite data with model products, packaged into readily usable, timely service systems, such as turnkey products/services addressing biodiversity, ecosystem services, vegetation stress, productivity (food security).
- A system to rapidly ingest EO data and provide easy access to the community (a range of products exist, but there are few centralized ways to summarize capabilities, resulting in a piecemeal approach and tools/data that are hard to find).
- Altimetry provides key inputs into global circulation models as well as riverine flood forecasting. Expansion of inland bodies of water covered would result in greater immediate benefit where ground data are lacking.
- Global DEMs that are updated every few years, at least 30 m spatial resolution; myriad hydrological and surface process applications in agriculture, water management, and disaster management.
- Repeat dual or quad pole SAR will greatly enhance ecosystem monitoring, agricultural and rangelands health, and situational awareness during disasters such as floods, oil spills, landslides.
- More customization and strengthening to address snow/ice depth, which helps to identify precursors of hydrological dynamics, disaster vulnerability, upstream/downstream dynamics across nations (water availability, life security).

A more dynamic and global digital elevation product will contribute to many of the thematic areas that we address. At the global and macro-levels, elevation has been treated as a constant, but it is dynamic. Looking at surface changes give us insight into groundwater levels for water resource management and food security, surface deformation gives us insight into hazards that could turn into disasters, and DTM and DSM can give us a better picture of carbon and biomass in critical ecosystems.

Future satellites launched should reflect NASA's technologically innovative nature and push the 'envelope' of space missions – such as ones that yield higher resolution DEM (LIDAR scale), 24/7 microwave-accuracy precipitation from GEO platforms (PATH), good insight of surface water bodies and its changes that we know so little about (SWOT).

Regarding tools, products, and datasets, NASA should not be in the business of trying to do everything, but should provide easy access to remote sensing observations and the geophysical variables estimated from them. It's the job of scientists and end users to build systems/tools of their own within their framework to ensure sustainability. Taxpayer money should not be used trying to satisfy every single product/tool that the wide range of users need. A self-sustaining ecosystem of users is required.

The mountains across the world serve natural resource regimes and control climate systems as well as oceans and main land do. In the context of climate change and transboundary issues, the understanding of mountain ecosystems requires utmost priority and importance. There is an urgent need to orient EO efforts to characterize, monitor, and model mountain systems in the same way that oceans and atmosphere are studied. The mountains support poverty ridden and ecologically vulnerable communities. Current satellite based EO systems and associated products do help, to a limited extent, to understand cryosphere dynamics and associated hydrology regimes, and erosion of ecosystem services. To improve the ability of current ground sensor networks to monitor high altitude climatology, atmospheric chemistry, and dispersion, the following improvements are suggested:

- Improved satellite-based stereogramatic capabilities to understand /quantify snow and ice depth.
- Orient and customize sensors and products to better monitor and forecast mountain climate.
- Satellite constellation systems to enhance repetitive cover to address disaster and resources monitoring related aspects.
- Short-term experimental, small satellites to study geophysical and biophysical mountain complexities.
- Sensor-satellite webs to address problems like flash floods and glacier melts.
- High radiometric and increased spectral channels based systems to monitor ecosystem processes like invasive species, stress, water quality, and productivity.
- Synthesize, integrate, and develop operational Mountain Essential Variables similar to Essential Climate Variables.

To increase the value of data and enable end users to fully understand satellite data and how it can be used, it would be useful to provide:

- Metadata (geographic scope, time series length)
- Information on the uncertainty of satellite data
- Customization for national needs