Input to NRC Decadal Survey from a Broad Audience of Remote Sensing Scientists – Land-Ocean Themes

Q.1 What are the key challenges or questions for Earth System Science in the coming decade?

Key challenges/questions identified by respondents not-associated with a particular geographic region are presented below (not listed in order of priority). Responses are presented verbatim, with minor editing to improve understanding and to combine similar comments.

Biodiversity

1. Habitat monitoring for wildlife
2. What are the environmental drivers of the distribution and abundance of organisms?
3. How is the biodiversity of ecosystems and vegetation communities changing?
4. How does biodiversity contribute to societal benefits?
5. How is climate change impacting ecosystem dynamics through changes in vegetation species composition and structure, and what is the resulting impact on the hydrological cycle?

Ecosystems

6. Invasive species growth
7. How can we best place a value on ecosystem services?
8. How are ecosystem loss of services being monitored over time?
9. Can we develop integrated observation and modeling systems to predict ecosystem change?
10. Response of ecosystems to changes in climate, migration, population concentrations, and land use.

Disasters

11. Disaster mitigation/risk reduction
12. Real-time forecasts for typhoon-driven storm surge, worldwide

Land Surface

13. How to improve elevation data (beyond SRTM), especially in steep terrain and heavy canopy areas?
14. Improved vegetation mapping capabilities. Where is forest cover, where is it not?
15. How and where is land cover changing? Need to establish data record that captures long-term land cover dynamics.
16. Where is land use changing, how does this contribute to climate change locally and globally, and how will land use be impacted by climate change?
17. How are land management practices and climate change affecting soil-water-vegetation interactions?
18. How are anthropogenic changes in land use/land cover, which occur at ~100 m scale, integrated over the landscape to affect water, energy and carbon cycles at watershed and regional scales?
19. How does the intensity and extent of the urban heat island effect relate to human health outcomes?
20. How do changes in land surface properties impact human health and behavior?

21. What are the current rates of deforestation and reforestation globally?
22. Response of the carbon cycle to changes in climate over time
23. Where are the major carbon sources and sinks and how do they vary in time?
24. How can Earth observations be used to develop a global carbon monitoring system?

Oceans

25. Sea level rise
26. Pollution of coastal waters
27. Ocean atmosphere coupling
28. How are ocean evaporation, and associated moisture transports, changing on intraseasonal, interannual, decadal, and longer time scales?
29. How is the ocean's surface energy budget changing, and what are the roles of radiative and turbulent heat fluxes?

Glaciers

30. Melting glaciers
31. How does ice-loss vary seasonally and annually around the globe?

Q.2 Why are these challenge/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 ones.

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

- ICESaT-2 – relevant to ice, glaciers, Arctic, Antarctic
- Landsat – Number 1 priority would be to ensure the continuity of Landsat.
    - The world now relies on Landsat for the bulk of Earth observations including mapping and monitoring.
    - Relevant to Earth resources management, land use/land cover change, climate impacts, invasive species, etc.
    - Critically important for understanding change through time.
- Suomi-NPP, Terra, Aqua (workhorses of NASA)
    - Support a wide range of applications: climate, urban development, energy, catastrophic event decision-making, etc.
- The NASA A-train is proving to be one of the best satellite platforms for scientific and applied research communities. The use of multiple sensors so close together in temporal space has proven to be a distinct advantage for ocean, land, and atmospheric measurements, which can be applied together to provide a more complete picture than any one sensor can provide.

- High temporal, moderate resolution (<=250 meters) multi-spectral observations of the globe (e.g., MODIS, VIIRS) to support land, atmosphere and ocean science applications and information needs.
- Forest health – Satellite observations and derived products that improve capabilities to detect forest disturbance earlier (pests and pathogens) and monitor.
- MODIS, VIIRS, Landsat 8 and 9 for land use
- GEDI LIDAR for vegetation structure
- Land cover type delineation such as vegetation and urban growth
- Change monitoring for climate, deforestation and afforestation efforts
- Fluorescence – key insight into plant productivity
- NDVI – long-term record of plant greenness
- Net radiation – key energy driver for ecosystem processes
- The growing list of Essential Biodiversity Variables (EBVs) are key to continue measuring.
- Any and all data/observations which provide valuable soils, oceanographic, vegetation, climatic, geologic, etc. information that can help decision-makers face the environmental and social challenges ahead.

<u>Suggestions for additional investments include</u>:

Biodiversity / Ecosystems / Forests

- The primary need is for a combined imaging spectrometer (ranging from the UV/VIS edge into the thermal infrared) and waveform LIDAR (operating in the green and near infrared wavelengths) system. Such a system would allow us to capture ecosystem composition, structure, and function simultaneously and thoroughly.
- Build and launch additional Landsat sensors. Useful datasets would be
    - Time series-derived products at the 30-m scale, including greenup/phenology
    - Refined forest change maps
    - Updateable map of land use and ownership
    - Publicly available portal of such products across the globe.
- LIDAR collection twice a year for leaf-on and leaf-off from satellite. LIDAR is needed for road, tree, and building structural change after a large event.
- High-resolution LIDAR missions would be beneficial for looking at forest and forest structure components useful for carbon sequestration, wildlife habitat, forest inventories.
- A satellite-based imaging spectrometer similar to the capabilities provided from AVIRIS, in an orbit which regularly covers CONUS, similar to Landsat
    - Useful for species classification, plant health monitoring, and subpixel change detection, which Landsat cannot currently match.
- Soil moisture data would help when working with invasive species like cheatgrass. Comparing moisture in different environments helps researchers understand plant reactions and ecosystem development.
- Hyperspectral – critical for understanding biodiversity and biodiversity loss
- Fine-scale hyperspectral would help minimize confusion between like spectral signatures and potentially lead to a more accurate and precise understanding of local, regional, and global patterns.

- A spectral signature library for plant species would help large land cover analysis and identification of pre-fire species for land restoration decisions and large-scale land conservation efforts.
- Greater repeat cycles of high-resolution multispectral information required to compute ecosystem indicators.
- Change detection at a micro level is important for understanding local ecological impacts.
- Fluorescence – key insight into plant productivity
- An online tool (or dataset) for ecosystem risk assessments that enables monitoring of historical loss or gain in the geographic distribution and parameters of function for any ecosystem type (classification down to macrogroup level) and includes a level of present risk to future loss or gain.
- Modeled products for ecosystem services such as carbon sequestration, nutrient cycling, and primary production for ecological forecasting.
- To obtain near-continuous (daily) monitoring of the water and energy balance globally, it is essential that a satellite system be implemented that has a sensor package spanning the visible to microwave wavelengths.
    - Provides observations necessary for all-weather capabilities at the watershed and regional scales for global water, energy and carbon budget modeling and monitoring.
- Target Earth observations to the most rapidly changing human (inhabited environments) and the resources which support them – the effects of rapid urbanization, i.e., which cities are growing fastest and what that means for the surrounding ecology.

Land Surface

- Tools to improve urban areas planning to avoid overlapping of property rights.
- Land use/land cover dynamics or change monitoring, at a reasonable frequency and spatial resolution, including magnitude of change and source of change.
- Relatively low spatial resolution (~100-200 m) global coverage frequent repeat c-band or l-band SAR (synthetic aperture radar) land surface imager.
- A LIDAR topography mission (LIDAR Surface Topography) should be a high-priority mission (e.g., LIST) since the current freely and globally available SRTM topography data is 15 years old and hardly meets the accuracy requirements in the vertical for many applications. However, a LIDAR-based mission such as LIST would certainly improve the current situation for NASA in terms of topographic data needs.
- Higher-resolution infrared imagery – to see structures buried below ground level (archaeological sites)
- A 'public good' fine-resolution optical sensor to support NASA's science needs, preferably with simultaneous observation with a moderate-resolution sensor – to develop the next generation multi-scale sampling product suite and provide a validation mechanism for moderate-resolution products – relevant to Agriculture / Land Use / Carbon Monitoring.

Oceans

- Bathymetry data accurate to 3 arc-seconds, worldwide oceans

- Climate models show significant biases in their ability to represent planetary boundary layer variability over the oceans, particularly in the tropics. This limits the model’s ability to resolve convection and surface heat fluxes that are important to coupling of the atmosphere and ocean across diurnal to seasonal and longer time scales. Improving seasonal climate forecasting is challenging and will require accurate modeling of the upper ocean mixed layer on seasonal time scales; thus improvements in seasonal forecasts may be directly tied to our ability to capture the proper variability of surface fluxes.
- Ocean evaporation remains the largest component of uncertainty in the global water cycle.
    - Need ocean evaporation estimates from space, as ship and buoy measurements are too sparse for realistic climate applications.
    - Estimating evaporation from space is doable, but current space-based estimates are primarily limited by errors in near-surface estimates of air temperature and humidity, a direct result of the lack of satellite instrumentation designed for sub-boundary layer temperature and humidity profile retrievals.
    - Latent heat flux from ocean evaporation represents a substantial energy flux at the Earth's surface – critical for both ocean and atmospheric energetics.