Input to NRC Decadal Survey from a Broad Audience of Remote Sensing Scientists – Water, Agriculture, and Food 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.

Water Resources

1. How is the global water budget changing?
2. Partitioning of evaporation and transpiration
3. Response of the water cycle to changes in climate over time
4. Water cycle extremes – Monitoring, early warning/prediction system
5. Strategic implementation options for extremes
6. Accuracy of evaporation, transpiration, and evapotranspiration (ET) models using mass/volume balance instead of indirect micrometeorological methods
7. How can we monitor more efficiently (less uncertainty) regional water budgets?
8. How well do existing water resources support demand, and how do limitations and constraints vary geographically?
9. Can we close the remotely sensed water balance in mountainous basins? At present, systematic problems in both rainfall and ET estimates make this difficult.
10. Where are the greatest changes in groundwater and soil moisture, and at what rate are these changing? Are these trends expected to continue?

Agriculture / Food Security

11. Rangeland condition
12. Natural resource limitations on food
13. Tradeoffs between food and energy and the use of water to produce these
14. Can the new agriculture be sustainable?
15. How are changes in agricultural production impacting water resources at watershed and regional scales?
16. How is climate change influencing agricultural management practices, particularly in irrigated agriculture, which consumes 70-80% of the world's freshwater (both surface and groundwater)?
17. Can spatial and temporal resolution be increased to enable effective decision-making for agriculture?
18. How to improve or create spectral libraries of the main types of crops, either annual or fruit-bearing.
19. How is agricultural production impacted by extreme weather events and the associated vulnerabilities?
20. What satellite constellation is needed to provide early detection of significant crop failure due to drought for early famine warning, particularly in third-world countries with no or very limited ground information on crop condition or weather data?

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>:

- Landsat – Number 1 priority would be to ensure the continuity of Landsat.
  - The world now relies on Landsat for the bulk of Earth observations.
  - ET maps derived from Landsat data have potential to be used in decision-making regarding water resources management such as irrigation scheduling and regional water planning, which require ET estimates over an individual field or entire region.
  - ET estimates are critical for managing water resources and agriculture.
- CloudSat
- GCOM-W1
- GEOS (All)
- GPM
- GRACE-FO and GRACE2
  - The GRACE mission has revolutionized our understanding (and society's appreciation) of trends in water storage across the planet.
- MODIS, VIIRS, Landsat 8 and 9
- Precipitation, groundwater – important for water resources
- SMAP and other soil moisture at high resolution and high accuracy
- Suomi-NPP, Terra, Aqua
- SWOT
- To reliably monitor/assess water resources, climate change impacts, agriculture production and ecosystem health, satellites are needed to provide estimates of radiation, land use, vegetation biomass/cover and structure, land surface temperature and vegetation phenology
  - Provides a means to determine the energy, water, and carbon fluxes
  - Resolutions required vary from field to regional scales depending on whether the question being addressed relates to agriculture, hydrology, weather or climate.
- AMSR-E, AMSR-2, GPM 37 GHz microwave emission data over land surface, globally – exceptionally valuable for river discharge measurements and monitoring (the longer the period of record, the more valuable current information is). Applications include immediate assessment of flood magnitude/recurrence intervals, as events are underway.
- Continue the distribution of multispectral images and/or finished products relevant to agriculture, since it would enable in the near future the practice of precision farming of annual crops and fruit trees by providing improvements in field productivity and ensuring the

traceability of agricultural production, thereby saving water and supplies and ultimately improving returns by obtaining better sale prices.

- Critical components of the Earth's energy and water cycles, which are also critical to providing initial and boundary conditions (including radiative and turbulent heat fluxes) to coupled GCMs:
    - sea surface temperature
    - ocean surface wind vectors
    - vertical profiles of atmospheric temperature
    - vertical profiles of atmospheric humidity
    - top of atmosphere shortwave and longwave radiation
    - cloud properties (fraction, temperature/height, thickness)
- Any and all data/observations which provide valuable soils, atmospheric, vegetation, climatic, geologic, hydrologic, etc. information that can help decision-makers face the environmental and social challenges ahead.

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

Water Resources

- Systematic water level databases and flooded area such as provided already somewhat by MODIS and potentially by SWOT. However, these data need to be provided systematically and not on a "research base" as has been more traditionally the case.
- SWOT for surface water
- GRACE-FO for groundwater
- Water resources management would benefit most from a satellite with moderate resolution (100 m or less) and daily acquisition frequency. The biggest hurdle for producer-level remote sensing use is having good resolution data, including thermal, on a daily basis.
- Higher spatial/time resolution groundwater observations (e.g., weekly at 100 km).
- Microwave-domain river monitoring is proceeding at just several institutions but is proving useful in operational settings (e.g., for assimilation into flood forecasting models). The 37 GHz channel is nearly ideal for water/land discrimination, but was designed mainly to provide background upwelling microwave signal for use in precipitation, other atmospheric variable retrieval. A very useful satellite would optimize such microwave information for land/water discrimination, and perhaps as coupled with a low-resolution SAR imager. Overall, something like SMAP, but designed for surface water, not soil moisture, would extend and complement the SWOT mission, and could use the same river mask for data acquisition.
- To obtain daily water use/evapotranspiration monitoring of natural and agro-ecosystems at the scale to resolve individual fields and fragmented ecosystems, NASA needs to build future satellites to support water resources management by maintaining or improving the present Landsat-standards of 30 x 30 meter pixel size ifr the visible and short-wave infrared bands, and must have thermal infrared pixels no larger than 120 x 120 meters.
- Consider launching a thermal free-flying satellite having at least the standards of the Landsat 8 thermal infrared sensor, placed in orbit in close proximity to the present and future European Sentinel 2-type satellites, which do not have thermal-sensing capabilities.
    - As a backup for potential failure of and as mitigation for the TIRS thermal imager on-board Landsat 8, should it fail prior to the short-wave OLI sensor of the satellite.

- At watershed and regional scales, a satellite having visible, near-infrared, thermal and microwave (K-band) sensors would provide near-continuous monitoring of water, energy and carbon cycles critical for assessing climate change impacts on ecosystem health and water resources.
- Evapotranspiration observing strategy and a supporting observational system (global)
- Soil moisture – higher frequency, daily
- Water cycle extremes – Monitoring, early detection
- Essential water cycle variables
    - PRIMARY: precipitation, evapotranspiration, snow cover (& depth, freeze/thaw margins), soil moisture, soil temperature, groundwater, runoff/streamflow/river discharge, lake/reservoir levels and terrestrial water storage, water quality (nitrates, phosphates, dissolved oxygen, algal blooms), water use/demand
    - SUPPLEMENTARY: surface meteorology, surface and atmospheric radiation budget, clouds, land cover, vegetation and land cover, land use, permafrost, elevation/topography, geological stratification, surface altimetry, aerosols

Agriculture / Food Security

- A high-resolution thermal sensor with at least 4 satellite passes per day and global cover, which can be used to monitor water consumption for water crisis and food security.
- An evaporation, transpiration, and evapotranspiration product with specifications: US coverage, 1 m spatial resolution, daily repeat frequency, +/- 0.5 mm accuracy and precision. To provide real-time feedback for on-farm irrigation management and stream flow prediction in mountainous regions that feed irrigated valleys below. This is urgently needed to improve crop water productivity, which is central to addressing food-water-energy security.
- Incorporate multispectral sensors for high temporal, spatial and radiometric resolution data, primarily to address issues more specifically, e.g., scales of 1:5 or less, a pixel size of 1 m, and a frequency of a few days.
- Improve monitoring in mountain areas to continuously evaluate the volume of snow fall, accumulated as a reserve of water in watersheds in the spring, and thus be able to better plan the agricultural year.
    - Improved multispectral data, spatial and temporal resolution, and quality of data to better understand the availability of snow fall, especially in arid and semiarid areas, will improve predictive models related to water availability, resulting in social and economic benefits by increasing crop production.
- Add spectral bands for the Cellulose Absorption Index (CAI) to allow regional collection of crop residue data.
    - Regional mapping of crop residue helps reduce soil erosion.
    - $CAI = 100[0.5(R2.0 + R2.2) - R2.1]$ where R2.0, R2.1, and R2.2 are the reflectance values in 10-nm bands centered at 2031, 2101, and 2211 nm, respectively.
- Find ways to add other vegetation and water-sensitive sensors to Landsat missions, such as L-band – important for food-water-energy security.