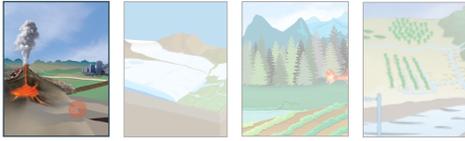




## Proposed NASA-ISRO SAR Mission

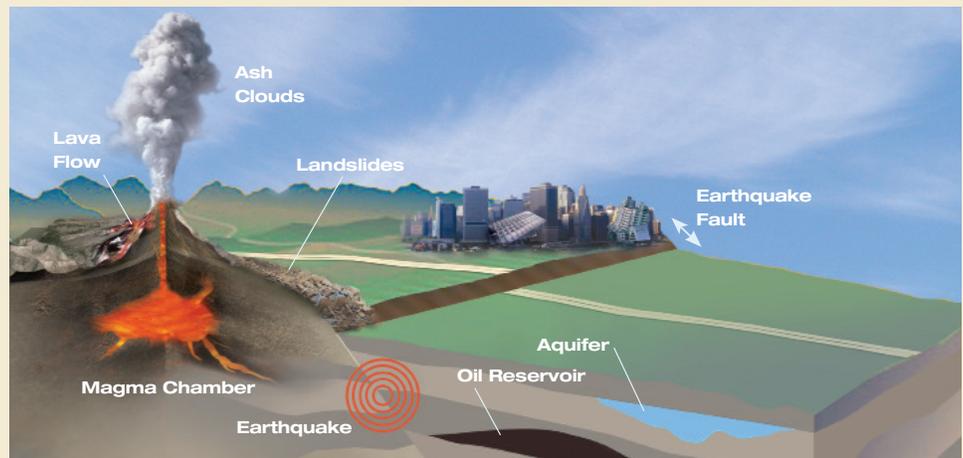


# Illuminating Earth's Dynamic Surface and Interior

NISAR will measure surface deformation to determine the likelihood of earthquakes, volcanic eruptions, and landslides, and monitor groundwater, hydrocarbon, and geothermal reservoirs.

### Earth's Hazards and Resources

Why does our planet sometimes threaten us with earthquakes or volcanic eruptions? Can I depend on fresh water to flow from my tap each morning? Do we have the best possible information needed to manage our resources and potential disasters? We are often reminded that disasters occur unexpectedly, but extraordinary measurements of processes leading to disasters would help us address these questions, prepare for natural disasters, and sustainably manage Earth's resources.



### Addressing an Increasing Exposure to Natural Disasters

Society's exposure to natural hazards is rapidly increasing. Overdue large earthquakes will be costly and threaten densely populated regions on the U.S. western coast, home to about 50 million citizens. Volcanic eruptions also endanger many areas of the Earth and often disrupt air travel. Water is an increasingly scarce resource, and water storage and distribution systems must be safe and resilient for current and increasing needs.

Many hazards subtly change and deform the land surface preceding catastrophic events such as earthquakes and volcanic unrest. The best way to properly prepare for, mitigate, and respond to nature's disasters is to detect, measure, and understand these slow-moving processes before they either trigger a major disaster or compromise our natural resources. This requires relevant, comprehensive, detailed, and accessible observations collected over time of subtle but detectable motions.

*continued on back page*



Artist's concept

### The Proposed NISAR Mission — All-Weather Day and Night Imaging

Orbiting radar captures the movements of the Earth over time and with enough detail to reveal what is happening below the surface. Radar penetrates clouds and operates day and night. It produces images with resolution to see local changes and has broad enough coverage to measure regional events. The proposed NASA-ISRO Synthetic Aperture Radar (NISAR) mission, a collaboration between the National Aeronautics and Space Administration (NASA) and the Indian Space Research Organization (ISRO), will acquire images of surface changes globally with millimeter accuracy and meter-scale resolution. Rapid sampling over years to decades will allow for understanding processes leading to disasters and for rapid response following them. NISAR's unprecedented coverage in space and time will reveal forces acting within the Earth and on its surface far more comprehensively than any other measurement method. The detailed observations will reveal information about the evolution and state of the Earth's crust, allowing us to better manage resources and prepare for and cope with hazards.

## Mitigating Disasters and Sustaining Resources

Natural disasters often occur abruptly and without notice. Earthquakes, volcanoes, and landslides are sudden events that can cause billions of dollars in damage and extensive loss of life. Subsidence from water, oil, or gas withdrawal, faulting, or underground dissolution of limestone can have major impacts on agriculture, levees, and our built environment.

Forces deep within the Earth drive the tectonic plates, causing earthquakes and volcanoes while shaping our landscapes. Withdrawal, injection, and movement of fluids at depth also cause small but detectable motions of the Earth's surface.

It is crucial for our society and economy to mitigate losses from disasters. We need informed decisions in order to carry out effective mitigation and make the most of our resources sustainably and economically. By measuring motions and other changes of the Earth's surface, we can understand processes occurring at depth and their impacts.

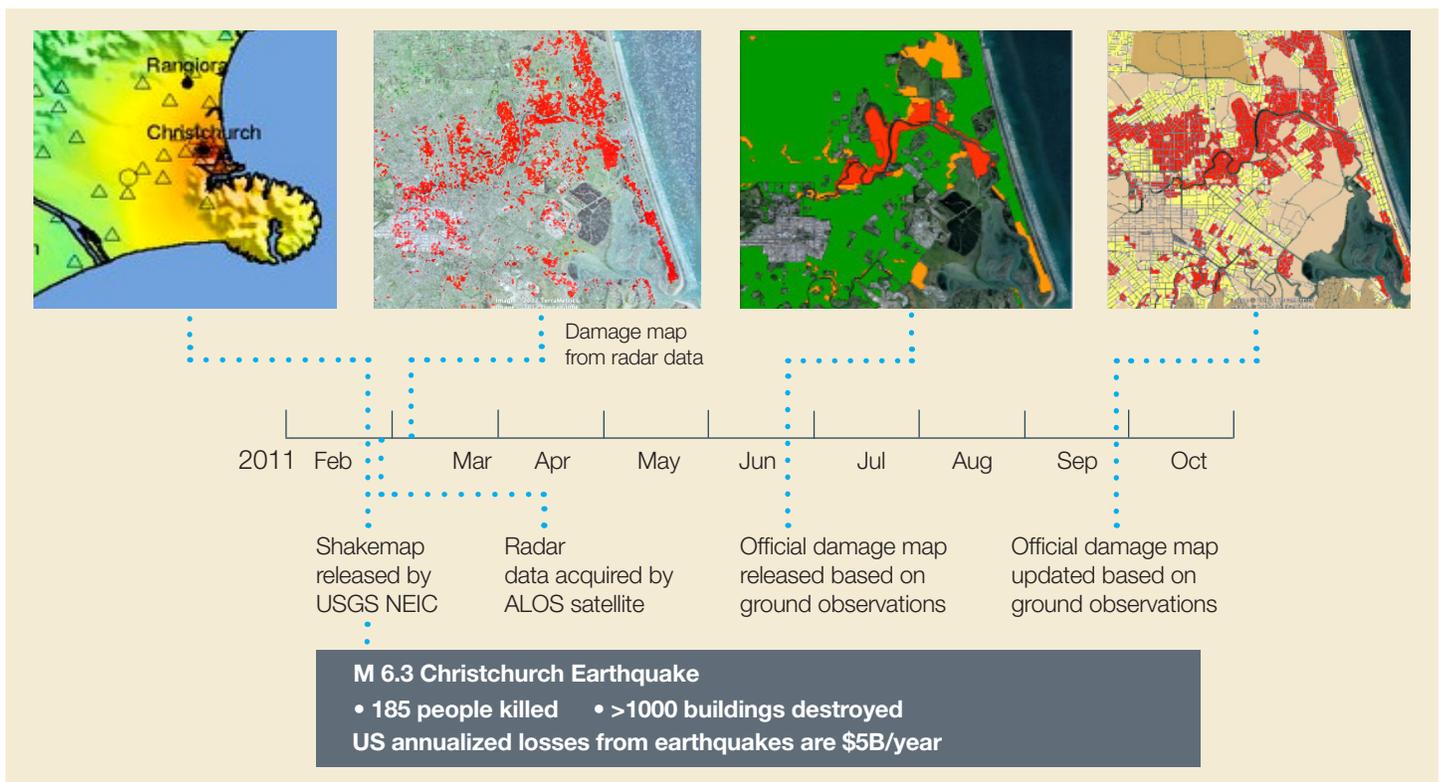
## Benefiting Forecasting, Response, and Resource Management

Natural hazards will continue to threaten densely populated regions of our country. NISAR's global and rapid coverage will provide unprecedented opportunities to mitigate or assess widespread damage. Detecting Earth surface motions of our planet and its resources will help illuminate the processes occurring deep within.

A mission with open access to data adds flexibility to meet far more scientific, societal, and commercial goals. Science-based management and storage of fresh water and energy sources will allow us to use the available resources more efficiently and sustainably.

### Rapid Building-Scale Damage Assessment

Following the February 2011 earthquake in Christchurch, New Zealand, a damage map was produced by comparing before and after radar images from the Japanese Advanced Land Observing Satellite (ALOS) satellite. This method detected building damage, liquefaction, and a small landslide. The results compare favorably to official maps, which were produced later. NISAR maps will allow initial damage estimates to guide ground inspection damage assessment.



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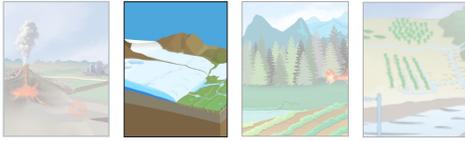
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## Proposed NASA-ISRO SAR Mission

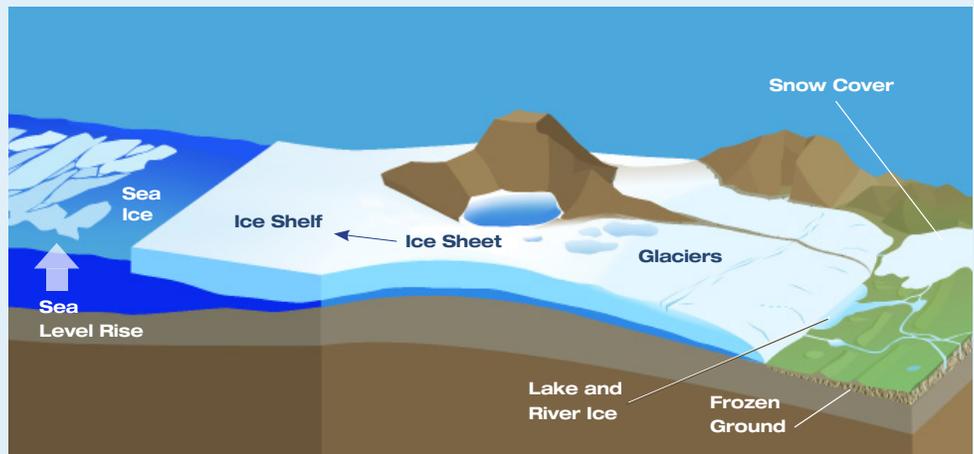


# Understanding Earth's Cold Regions

NISAR will measure changes in glacier and ice sheet motion, sea ice, and permafrost to determine how global climate and ice masses interrelate and how melting of land ice raises sea level.

### Impacts of Earth's Remote Ice

Perhaps you imagine the polar ice sheets as icy white blankets at the ends of the Earth, static and majestic, but far removed from your daily life. In reality, these areas are among the most dynamic and rapidly changing places on Earth, where wind and currents move ice over the seas, and the forces of gravity disgorge huge icebergs to the ocean. These distant changes have very real local consequences of climate feedbacks and rising sea level.



### Assessing Society's Exposure to Diminishing Ice

For over a hundred years, scientists have considered diminishing glaciers and sea ice to be an early indicator of climate change. At the same time, ice sheets and glaciers are already melting fast enough to be the largest contributors to sea level rise, with a potential to raise sea level by several tens of centimeters or more in the coming century. Satellite observations collected over the past three decades now show that the summer sea

ice cover is decreasing drastically and may vanish entirely within the next decades. The loss of sea ice cover will have a profound effect on life, climate, and commercial activities in the Arctic, while the loss of land ice will impact an important source of water for millions of people. Collectively, these effects mean that despite its remote location, changes in ice have global economic and health implications as climate changes.

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Artist's concept

### The Proposed NISAR Mission — All-Weather Day and Night Imaging

Orbiting radar captures extent and motions of land and sea ice over time and with enough detail to reveal subtle changes. Radar penetrates clouds and operates day and night. It produces images that are detailed enough to see local changes, and has broad enough coverage to measure regional trends. The proposed NASA-ISRO Synthetic Aperture Radar (NISAR) mission, a collaboration between the National Aeronautics and Space Administration (NASA) and the Indian Space Research Organization (ISRO), will acquire images of ice sheets, glaciers, and sea ice globally. Rapid sampling over years to decades will allow for understanding flow and changes over time. NISAR's unprecedented coverage in space and time will reveal response of ice masses far more comprehensively than any other measurement method. The detailed observations will reveal information that will allow us to better manage resources and prepare for and cope with global change.

## Improving Sea Level Projections

Disintegrating ice sheets and retreating glaciers raise sea level, yet predicting future sea level changes is difficult at present. Rising sea level will displace millions of people and adaptation will be costly. Recent observations provide only isolated snapshots of ice sheet velocity and changes, and current missions map large-scale ice sheet changes while missing many fast moving glaciers with large thinning rates. NISAR will provide systematic measurements allowing short-term variations and long-term trends to be measured. NISAR will provide a time history of ice sheet and glacier behavior including flow and conditions at the base of the ice. It will provide precise measurement of the changing ice sheet grounding lines. Understanding ice sheet and glacier behavior, changes, and stability will improve projections of sea level rise from melting glaciers and ice sheets. Accurate sea-level projection will improve planning of sea walls, dikes, and other adaptation and mitigation strategies.

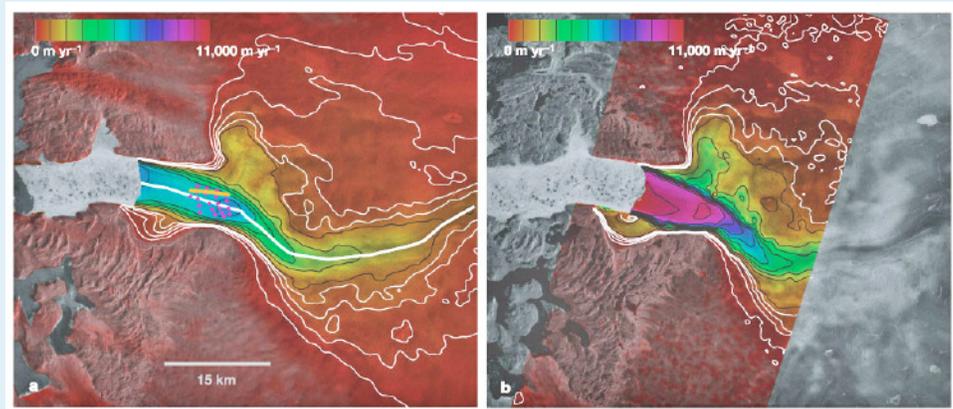
## Tracking Sea Ice and Monitoring Permafrost

Arctic sea ice has thinned and its summer extent has reduced by as much 50 percent over the last several decades. By contrast, sea ice extent in the Southern Ocean may be increasing, but there is very little information regarding its deformation and thickness distribution. The thinning and retreating Arctic ice cover is changing the economy of local communities by causing a shift in the patterns of marine ecology and an increase in winds and waves, as well as stimulating interest in petroleum development and shipping. NISAR will provide key data necessary to make informed environmental and economic decisions. NISAR will provide the most complete measurements of rapidly changing sea ice motion and estimates of thickness of both polar regions. Understanding the causes and mechanisms of its loss requires knowledge of sea ice dynamics, ice thickness distribution, and sea ice types. Melting permafrost releases methane to the atmosphere, erodes soil, and impacts surface water distribution and stability of infrastructure. NISAR will measure heave and thaw in the near-surface active layer of permafrost.

### Mapping Ice Sheet Flow

Radar measurements from the Canadian RADARSAT mission show the rapid speed up of Jakobshavn Isbræ in Greenland between February 1992 and October 2000. Over the last decade, glaciers in Greenland have sped up on average by more than 30 percent. NISAR will allow monitoring of ice sheets in Antarctica and Greenland as well as glaciers throughout the world.

The images are from Ian Joughin, Waleed Abdalati, and Mark Fahnestock, "Large Fluctuations in Speed on Greenland's Jakobshavn Isbrae Glacier," *Nature* 432 (2004): pp. 608–610.



**The economic impact of sea level rise on the US will exceed \$20B.**



## Proposed NASA-ISRO SAR Mission

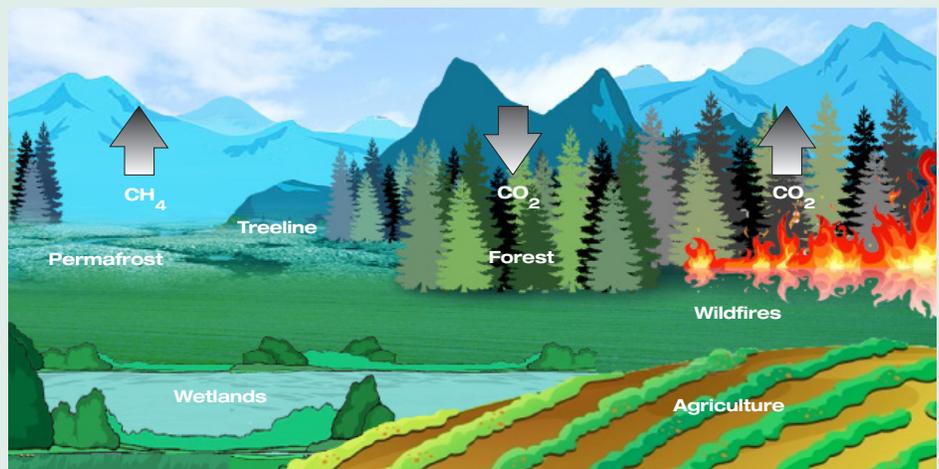


# Monitoring and Managing Our Terrestrial Ecosystems

NISAR will determine the contribution of Earth's biomass to the global carbon budget and characterize ecosystem disturbance and impacts on biodiversity.

### Landscapes Under Pressure

We depend on our forests, agricultural landscapes, and freshwater systems, but our landscapes are under increasing pressure. Large-scale global deforestation is causing increases in greenhouse gas fluxes. Farmers are converting patches of forests to agriculture. Urban areas are expanding into surrounding natural forests. It is imperative to fully understand the connections between human natural resource management and ecosystem responses. To protect Earth and our future, we urgently need a local-to-global-scale assessment of Earth's landscapes.

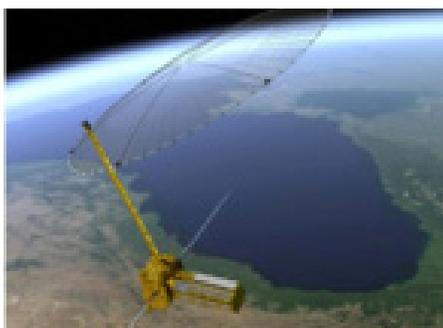


### Monitoring Ecosystems for Managing Natural Resources

The world's growing population is experiencing unprecedented changes to our climate through intensifying events such as floods, droughts and wildfires, hurricanes and tornadoes, and insect infestations and related health effects. These impacts are putting pressure on our landscapes and ecosystems

that generate food, fiber, energy, and living spaces for a growing global population. It is imperative to understand the connections between natural resource management and ecosystem responses to create a sustainable future.

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Artist's concept

### The Proposed NISAR Mission — All-Weather Day and Night Imaging

Orbiting radar captures forest volume and biomass over time and with enough detail to reveal changes on hectare scales. Radar penetrates clouds and operates day and night. It produces images that are detailed enough to see local changes, and has broad enough coverage to measure regional trends. The proposed NASA-ISRO Synthetic Aperture Radar (NISAR) mission, a collaboration between the National Aeronautics and Space Administration (NASA) and the Indian Space Research Organization (ISRO), will acquire images of ecosystem changes globally. Rapid sampling over years to decades will allow for understanding disturbance, degradation, and response. NISAR's unprecedented coverage in space and time will reveal biomass variability far more comprehensively than any other measurement method. The detailed observations will reveal information that will allow us to better manage resources and prepare for and cope with global change.

## Tracking Global Carbon to Improve Climate Change Projections

NISAR measurements will have a major impact on projections of climate change. Ecosystems are sources and sinks for carbon. The total mass of living matter within an environmental area, called biomass, stores carbon and links directly to the carbon cycle. Characterizing biomass globally will refine estimates of the spatial distribution of carbon. The removal of biomass, known as disturbance, can happen abruptly or gradually and can be due to human or natural causes such as forest fires, logging, acid rain, and insect infestations. Recovery or the reestablishment of forests and woody vegetation follows disturbance.

It is not known how Earth's terrestrial biomass is changing and interacting with climate variability. NISAR will be ideally suited to measure woody plants and forest, which make up 80 percent of living terrestrial biomass. NISAR's global, detailed map of aboveground woody biomass density will halve the uncertainty of estimated carbon emissions from land use change.

## Understanding the Consequences of Land Use and Climate Change on Ecosystems

Global wetlands and permafrost, which cover nearly a quarter of the northern hemisphere land surface, can have major impacts on and responses to climate change. Wetlands are one of the most significant natural sources of increased atmospheric

methane. When permafrost melts, it releases carbon dioxide and methane, creating further feedback of warming and melt.

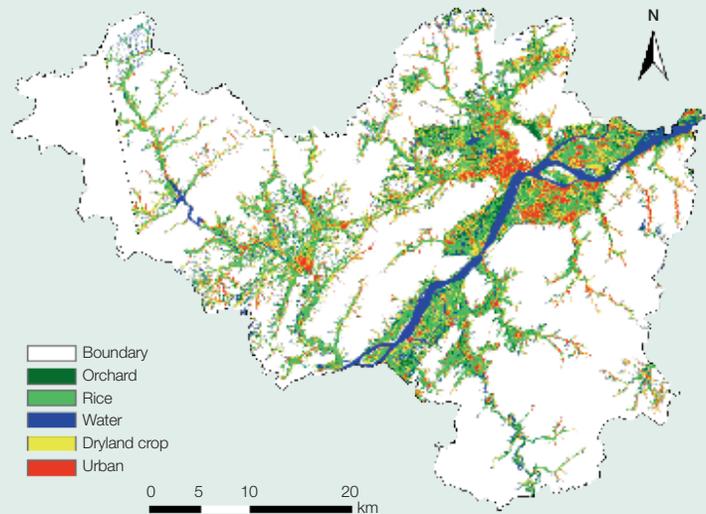
Human-induced disturbances have dramatically altered the terrestrial ecosystems by converting old-growth and carbon-rich forests into permanent croplands and urban landscapes and incurring extensive losses of wetlands (up to 50 percent). These disturbances are also changing the climate with increasing atmospheric CO<sub>2</sub> concentrations, which increases the probability of natural disturbances such as fire, droughts, hurricanes, and storms.

Alpine and mangrove ecosystems respond to change in climate quickly, serving as climatic indicators. Mangroves are a critical coastal ecosystem under severe threat from climate change. Similarly, shifts in vegetation are occurring, especially in high-altitude regions where alpine tree lines are advancing. These changes have important implications for the global carbon cycle and its climate feedback, yet there remains large uncertainty in the global extent and magnitude of these changes in the terrestrial component. NISAR will quantify biomass and track ecosystem changes.

### Classifying and Monitoring Crops Using Radar

Radar is effective for classifying crops and has the unique ability to see through clouds. In this image, the Japanese Advanced Land Observing Satellite/Phased Array-type L-band SAR (ALOS/PALSAR) radar imagery was used to produce this crop classification map. The map separates dry and wet crops from forests and urban areas. NISAR can also be used for agricultural monitoring. It can be used to measure changes over the growing season as well as seasonal changes.

The image is from Yuan Zhang, Cuizhen Wang, Jiaping Wu, Jiaguo Qi, and William A. Salas, "Mapping Paddy Rice with Multitemporal ALOS/PALSAR Imagery in Southeast China," *International Journal of Remote Sensing* 30, no. 23 (2009): pp. 6301–6315.



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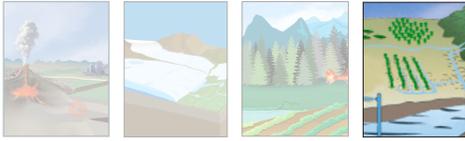
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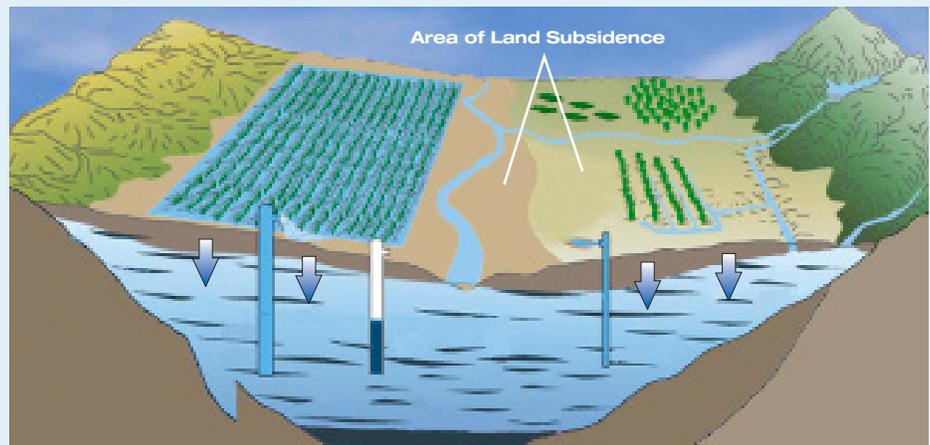


# Water: Sustaining Life

NISAR will measure changes in groundwater over the Earth's vulnerable arid regions.

### Understanding Aquifer Dynamics

Mapping and monitoring changes in land surface elevation with interferometric synthetic aperture radar (InSAR) may help fill in the gaps between monitoring wells. The ability to map surface deformation of a few millimeters monthly over large areas at resolutions of a few tens of meters has opened up new possibilities for remote monitoring of groundwater resources.



### Managing Water Resources

Water is necessary for life, both for drinking and for growing food. In the more arid parts of the world, rainfall and surface water can't satisfy the growing demands of the people who live in those regions. Groundwater makes up the difference, acting as a reservoir that can be tapped through wells. Unfortunately, climate change coupled with growing populations is causing increasing stress on groundwater resources around the world.

Over-exploitation of groundwater leads to lowering of the water table and, in alluvial basins, compaction of aquifers leading to sinking of the land surface (subsidence). Subsidence is often the first indication of over-exploitation and can also cause problems for infrastructure such as aqueducts, flood-control projects, highways, bridges, and railways. If subsidence continues for too long, it can lead to irreversible collapse of the aquifer system, reducing its ability to recharge when water is available.

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Artist's concept

### The Proposed NISAR Mission — All-Weather Day and Night Imaging

Orbiting radar captures the extent and motions of land and sea ice over time and with enough detail to reveal subtle changes. Radar penetrates clouds and operates day and night. It produces images that are detailed enough to see local changes, and has broad enough coverage to measure regional trends. The proposed NASA-ISRO SAR (NISAR) mission will acquire images of surface changes globally with millimeter accuracy and meter-scale resolution. It will capture images of the movements of the Earth over time and with sufficient detail to reveal what is happening below the surface. Rapid sampling over years to decades will allow for understanding groundwater dynamics. The detailed observations will reveal information about the migration of water and the state of aquifers.

## Subsidence As a Measure of Groundwater Depletion

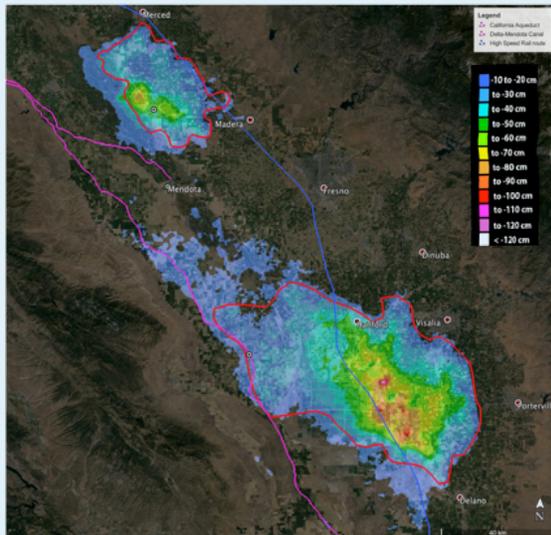
Water resource managers need to measure areas of continuing subsidence and detect new regions of compaction in order to adapt to changing water supply conditions and preserve the integrity of the aquifers for future generations. Subsidence permanently damages the aquifer, decreasing the amount of water that can be stored. Land subsidence is typically measured through periodic leveling or GPS surveys along with limited monitoring wells, but the lack of frequent measurements and the difficulty of mandating measurements at private wells result in datasets that are sparse in space and time. NISAR will provide systematic measurement across entire aquifers.

## Managing Water Globally

NISAR offers the promise of detecting and measuring changes to the land surface height above nearly every aquifer in the world. This will provide information for large segments of the global population that depend on groundwater to bridge gaps in surface and rain water supply. It may allow us for the first time to indirectly measure the volume of groundwater that is pumped and recharged around the world. This will become more important as Earth's changing climate and the growing global population outpaces the world's supply of fresh water in aquifers.

Another capability of NISAR is its ability to easily identify and map the extent of surface water in lakes and rivers. NISAR can be used to track floods, even under cloud cover and vegetation canopies. In some cases, NISAR can be used to measure changes in the water surface height as water levels change with rainfall, evaporation, and usage.

### Monitoring Subsidence



Total subsidence in the San Joaquin Valley, California, from 2007 to 2011 measured by InSAR. The subsidence bowl to the north, just south of Merced, is a relatively recent feature caused by a change from row crops to trees, which use more groundwater. Note how the California Aqueduct (purple) and the proposed High Speed Rail (blue) are both affected by subsidence. NISAR will provide this information on a regular basis.

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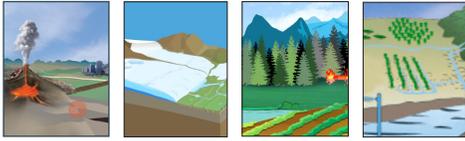
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## Proposed NASA-ISRO SAR Mission



# Sensing Our Changing Earth

NISAR will measure Earth's changing ecosystems, dynamic surface, and ice masses, providing information about biomass, natural hazards, sea level rise, and groundwater.

### Clarifying Causes and Consequences

The NASA-ISRO Synthetic Aperture Radar, or NISAR, mission will make global measurements of the causes and consequences of land surface changes for integration into Earth system models. NISAR will provide a means to measure and clarify processes ranging from ecosystem disturbances to ice sheet collapse and natural hazards including earthquakes, tsunamis, volcanoes, and landslides.



### Monitoring Earth's Changing Surface

Earth's land surface is constantly changing and interacting with its interior and atmosphere. The causes and consequences of change on the Earth's surface are complex and interrelated. Changing land use impacts the carbon cycle, which modifies Earth's climate, causing retreat of ice masses, in turn raising sea level, and resulting in altered coastlines. The impacts of a changing climate at the Earth's surface can include subsidence

from water withdrawal or melting permafrost, landslides from increased storm activity, and changes to shipping lanes from a reduction of sea ice. Natural hazards such as volcanoes and earthquakes further shape the land surface and can have devastating impacts to human populations.

*continued on back page*



Artist's concept

### The Proposed NISAR Mission — All-Weather Day and Night Imaging

The proposed NASA-ISRO Synthetic Aperture Radar (NISAR) mission will acquire radar images of surface changes globally. Rapid sampling over the lifetime of the mission will allow for understanding Earth processes and change. Radar penetrates clouds and operates day and night, enabling reliable and continuous monitoring at all times. Orbiting radar captures images of the movements of the Earth's surface, and land and sea ice over time, revealing subtle changes in the surface as well as what is happening below the surface. It captures forest volume and biomass over time and with enough detail to reveal changes on human scales. It produces images with sufficient resolution to see local changes and has broad enough coverage to monitor regional events. Detailed observations would allow us to better manage resources and prepare for and cope with hazards and global change.

### Addressing an Increasing Exposure to Natural Disasters

NISAR will measure surface changes to determine the likelihood of earthquakes, volcanic eruptions, and landslides. Earthquakes and volcanoes cause billions of dollars in damage and loss of life. Geologists say the Pacific Northwest and California are due for large earthquakes. Populations are increasing in high-risk areas vulnerable to sea level change, land subsidence, tsunamis, volcanoes, earthquakes, and landslides. Improved forecasting and mitigation necessitates understanding these natural hazards, with measurements throughout the hazard cycle.

### Tracking Global Carbon and Understanding Land Use

NISAR will determine the contribution of Earth's most variable biomass to the global carbon budget and characterize ecosystem disturbance and impacts on biodiversity. Landscapes are rapidly changing as forests are cut down and agricultural lands are developed. Land ecosystems, which act as carbon sources and sinks, must be studied now for us to understand how they may interact with climate as atmospheric CO<sub>2</sub> increases.

### Assessing Society's Exposure to Diminishing Ice

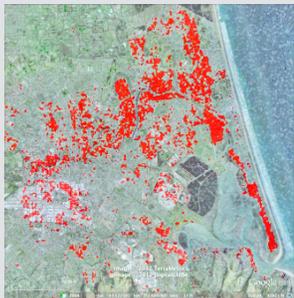
NISAR will determine how the behavior and evolution of ice masses will contribute to sea level rise. NISAR will measure changes in sea ice, snow extent, permafrost, and surface melting. Ice sheets, sea ice, and glaciers, which are key indicators of climate effects, are undergoing dramatic changes. Rising sea level from melting ice sheets poses hazards to coastal areas from storm surges and erosion. Diminishing sea ice is changing shipping lanes and availability of resources. Measurements now will be used to predict future changes.

### Monitoring Earth's Reservoirs

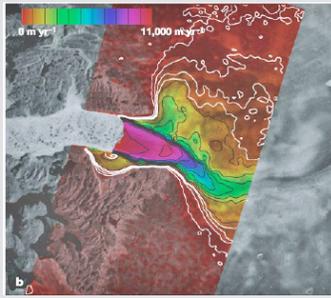
NISAR will monitor hydrocarbon and geothermal reservoirs, and measure changes in groundwater over the Earth's vulnerable arid regions. Informed decisions allow us to make the most of our resources sustainably and economically. By measuring changes of the Earth's surface, we can understand processes occurring below the surface and impacts. Subsidence is often the first indication of changes in reservoirs or over-exploitation of aquifers. Subsidence that continues for too long can lead to irreversible collapse of the aquifer system.

### Addressing Society's Needs

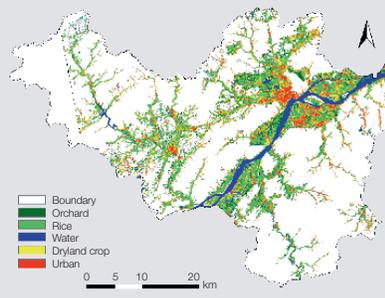
#### Earthquakes



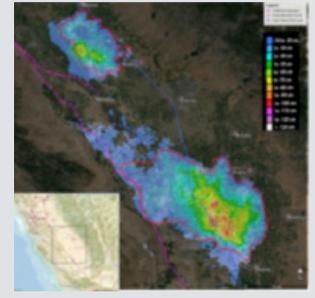
#### Glaciers



#### Crops



#### Subsidence



**U.S. losses from earthquakes are \$5B/year and the economic impact of sea level rise on the U.S. will exceed \$20B.**

Radar can be used to produce damage maps after earthquakes (left), determine the speed of glaciers (middle left), classify crops (middle right), and monitor subsidence

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