Tracking Fresh Water from Space
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Fresh water is a basic requirement for terrestrial life, yet knowledge of changes in the volume of water stored and flowing in rivers, lakes, and wetlands is poor. Recent developments in satellite remote sensing promise more accurate monitoring of freshwater resources and better prediction of floods and droughts.

Stream flow is traditionally estimated by measuring the water level and converting it to river discharge using an empirical relationship of level versus discharge. Similarly, water level in lakes and reservoirs is converted to storage volume via level-volume relationships. Gauge measurements have helped to quantify flow in river channels. However, the gauging networks used for the level measurements are in decline globally, and gauges are particularly sparse outside of industrialized regions (1).

Furthermore, estimates of the amount of surface water leaving a drainage basin assume that all the runoff generated upstream flows past a single downstream point. This is often not the case: Many river basins are marked by extensive wetlands and floodplains in which flow is diffuse and not flowing in a channel (see the first figure). Braided rivers are also problematic because their multiple, intertwined channels are constantly shifting, resulting in new channels with ungauged flows. Costs and logistics prohibit the installation of numerous gauges to characterize the flow dynamics in these environments.

Without comprehensive measurements of surface water storage and discharge, the availability of freshwater resources cannot be predicted with confidence. The performance of climate models with respect to land surface hydrology also cannot be evaluated. Comparison of model-derived flows with observations typically shows large modeling errors, sometimes greater than 100% (2). Such comparisons are only possible where there are stream gauges to verify discharge. Yet, in many areas—including much of Africa and the Arctic—surface water flow is not measured (1).

Knowledge of flow through nonchanneled environments such as wetlands and floodplains is particularly poor. Wetlands cover at least 4% of Earth’s land surface (3)
The Amazon floodplain near Manaus, Brazil. Nearly 100% of the area is inundated, despite the lack of visible open water. Furthermore, much of the flow occurs outside the channel (photo center), making a single gauge nearly useless for measuring discharge. A series of water surface elevation maps would show how the volume of stored water changes with time.

and up to 20% of humid basins such as the Amazon, but are represented poorly or not at all in most global climate models. In addition, these models generally ignore the effects of water management on the redistribution of water over much of the populated part of the globe.

The need for better knowledge of the global distribution of surface water resources is particularly acute, given population growth and the uneven distribution of water supplies (4). Furthermore, changing weather and climate may accelerate the hydrologic cycle, with unknown effects on freshwater resources (5).

Satellite measurements may enable hydrologists to move beyond the point-based observations provided by gauge networks to basin-wide measurements of discharge and storage. For example, areas inundated by floodwaters have been measured with Landsat imagery (6). However, clouds and vegetation can easily mask the underlying water, a problem that is common to all systems operating in the visible spectrum (see the first figure). Microwave radar [such as synthetic aperture radar (SAR)] overcomes this problem by penetrating clouds and canopy (7).

Remotely measuring surface water area is much easier than monitoring changes in the water volume over space and time. There are three different satellite-based approaches to calculating volume changes. The most straightforward method is to simultaneously measure water surface area and elevation; from a series of such maps, one can then calculate the volume gained or lost. A first step toward such measurements is to use radar altimeters, which were originally designed for use over the open ocean or ice sheets (see the second figure) (8).

Altimeters measure the elevation of the water surface relative to a reference ellipsoid. Over the ocean surface, the elevation accuracy is on the order of a few centimeters, but two factors reduce the accuracy to tens of centimeters over terrestrial water bodies. First, terrestrial water bodies do not provide a sufficiently large surface area for averaging the multiple radar pulses used in ocean applications. Second, the shape of the returned radar pulse from the water surface deviates from the shape of a typical ocean-like echo. Today’s altimeters provide only an elevation profile, yet ideal future instruments would also include area. Radar altimetry has been used to measure river surface slopes (8), which should be related to velocity and hence discharge.

A second approach provides simultaneous measurements of water surface area and elevation change to yield temporal variations in water storage. A first step toward such simultaneous imaging has recently come from interferometric SAR (9). This method is commonly used to generate maps of seismic deformation and glacial flow. Because water is highly reflective, microwave pulses from off-nadir imaging SARs reflect away from the SAR antennae, unless intercepted by vegetation. Thus, subtle height fluctuations across a floodplain’s water surface can be mapped interferometrically with centimeter-scale accuracy. Such accuracy is required for understanding flow volumes across lowland floodplains. For example, an elevation change of only a few centimeters in the Amazon can be equivalent to flows greater than the average discharge of the Mississippi River.

Instead of directly measuring spatial and height changes of a water surface, one may also measure the change in mass resulting from volumetric gains or losses in terrestrial water. Starting in 2004, the Gravity Recovery and Climate Experiment (GRACE) satellites will provide monthly global measurements of Earth’s gravity field (10). On this time scale, most gravitational variations over the land surface result from mass changes in the total water column (11, 12). The column total is the sum of atmospheric, surface, soil, and ground water volumes. However, because a mass’s gravity field decreases rapidly with observing distance, GRACE is only sensitive to basins greater than about 200,000 km² (11, 12).

By themselves, none of these technologies supply the water volume measurements needed to accurately model the water cycle and to guide water management (13). However, they provide a conceptual framework for a surface water satellite mission that could provide the required information.

Such a mission—assuming it passes careful model-based evaluation—would need to have the following attributes: (i) sufficient spatial resolution (~100 m) to resolve channels, floodplains, and lakes contributing most of a basin’s discharge; (ii) sufficient temporal resolution (a few days) to capture short flood events; and (iii) sufficient vertical resolution (a few centimeters) to measure subtle height changes responsible for significant discharge. Surface velocities might be helpful, but surface slope could be used as a surrogate, especially because surface velocity observations are often corrupted by wind ef-

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The Power of Speech

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In the next few decades, advances in communications will radically change the way we live and work. The concept of “going to work” will change from commuting to a particular place to get things done, to “getting things done” no matter where you are. Life at home will also change radically as communications between individuals become multimodal (using voice, visual, and tactile modes) and multimedia (with sharing of text, data, audio, images, video, and other forms of information). For example, you will be able to control virtually any device in the home—such as the family home entertainment center—by pointing to it with your finger and issuing voice commands such as “find me a good classical music station.”

The driving force for these changes is the seamless integration of real-time communications (voice, audio, video, virtual reality) and data (text, images, files) into a single network that can be accessed anywhere, anytime, and by a wide range of devices. Speech and language processing plays a crucial role in this network by enabling enhanced services and providing seamless access to new services (1).

Traditional speech and audio coding and compression will remain important even as bandwidth increases dramatically to the home, to the office, and in wireless environments. The need for high-quality, low-delay streaming of voice, CD-quality audio, and HDTV-quality video is a driving force for advanced coding research. Advanced coding and compression technologies enable networks to provide high signal quality at low delays without requiring excessive network resources.

Speech and language processing is also crucial for seamless user access to new and advanced services. As communication devices become ever smaller, the ability to provide and use keyboards and pointing devices (such as the mouse) becomes limited and problematic, and voice access to services becomes an essential component of the user interface. To access services on such devices, we will increasingly rely on speech recognition and speech understanding to command and control machines, and on speech synthesis to respond back to the user.

A third opportunity for speech processing is in user authentication. Speaker verification technology is a convenient and accurate method for authenticating the claimed identity of a user for access to secure or restricted services. It has the potential to be much more robust and reliable than conventional log-ons and passwords.

Finally, the opportunities for speech and language processing in services and operations are almost limitless. Voice commands may be used to access movie schedules or airline schedules or to add new people to a teleconference, whereas text-to-speech synthesis can be used to convert a text message to a voice message. At help desks or in customer care, voice processing can act as a surrogate for an attendant or an operator in handling routine transactions.

The speech dialog circle (see the figure) illustrates the speech-processing technology that enables voice communications between humans and machines. Its major elements are speech recognition, spoken-language understanding, dialog management, and text-to-speech synthesis. In addition to these basic speech-processing technologies, two other key technologies, speech coding and speaker verification, are used in multimedia communications.

Speech Coding

Speech coding has existed for more than 60 years, beginning with the classic work of Dudley on the “vocoder” (2). The original goal of speech coding was to provide a compression technology that would enable existing copper wires to handle the continual growth in voice traffic without having to continuously add new lines. Recently, the need for speech coding has grown because of the rapid growth in wireless systems and in the transmission of voice signals over data networks, where speech is just one (very important) data type.

The goal of speech coding (3) is to compress the speech signal—that is, to reduce the bit rate necessary to accurately represent the speech signal—without distorting it excessively. Two main techniques have been used in speech coding. Waveform coding tries to match waveform characteristics directly, whereas model-based coding tries to match spectral and source-excitation characteristics of speech.

Today, speech can be coded down to bit rates of about 8000 bps, with intelligibility and quality approaching that of telephone-bandwidth speech (which has a bit rate of about 64,000 bps). The challenge for the next few years is to lower the bit rate by a factor of 2 without seriously lowering the quality of the resulting speech. Achieving this goal requires improved signal processing for accurately representing the excitation source and the short-time spectrum properties of the time-varying speech signal.

Text-to-Speech Synthesis

Text-to-speech synthesis aims to convert an ordinary text message into an intelligible, natural-sounding speech utterance, thus giving machines the ability to “speak” (4, 5). Two approaches have been proposed

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References and Notes
7. An outstanding effort to map inundated areas throughout the world has been constructed by the Global Rain Forest Mapping project using SAR images collected by the Japanese Earth Resources Satellite (JERS-1) (15).
10. B. Tapley, personal communication.
14. An instrument that matches these requirements has been sketched by E. Rodriguez of NASA’s Jet Propulsion Laboratory, based on the Shuttle Radar Topography Mission (SRTM).
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