Sea surface air pressure measurements for reliable longer-term storm track and intensification predictions

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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?

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Hurricanes, such as Katrina and recent Super-storm Sandy, produce dangerous winds, torrential rains and floods, all of which result in the loss of lives, tremendous property damages and economic losses. It is estimated that hurricane Katrina and Sandy resulted in 108 and 68 billion dollars in damages, respectively. More accurate forecasts of the track and intensity well ahead of the landfall of such powerful storms can better pinpoint the time and location of landfall and corresponding strength of the storm. This not only diminishes public risk, but also reduces the economic loss of unnecessary evacuations. Every mile of improved forecast accuracy would bring considerable savings and public peace of mind. Therefore, improved weather forecasts, especially longer-term, more reliable storm track and intensification predictions of hurricanes are extremely important not only to earth sciences but also to public safety and national security.

The underlying processes that drive severe weather (e.g., hurricanes) are neither fully understood nor adequately characterized in weather prediction models, so high priority is placed on measurements that will contribute to successful forecasts of such events. As atmospheric pressure gradients are the primary driving force of atmospheric motions that transport mass, moisture and momentum, numerical weather prediction (NWP) models are critically dependent on accurate estimates of the pressure field. Surface pressure observations makeup the backbone of modern weather forecasting. Without the hundreds of surface observing stations across the US, the accuracy of the 5-10 day forecast relied upon daily by the public and commerce would be considerably compromised. Unfortunately, the spatial coverage of surface observing stations on land is not feasible over the ocean. Pressure information is provided by buoys which for economic and practical reasons are sparsely deployed across the ocean -- hundreds to thousands of miles apart, especially away from shipping lanes or coasts. But this is precisely where is needed to improve hurricane forecasts. Hence, the proper specification and analysis of sea surface pressure are important prerequisites of accurate numerical weather prediction (NWP) for improving tropical storm track and intensification forecasting. **Sea surface pressure measurements are pone of key challenges for Earth System Science, particularly for reliable longer-term storm track and intensification predictions, as discussed in the last Decadal Survey.**

Why are these challenge/questions timely to address now especially with respect to readiness? Why are space-based observations fundamental to addressing these challenges/questions?

The devastation of Katrina and Super-storm Sandy compels action to improve public safety and reduce the risk of economic loss from hurricanes. Accurate, precise, all-weather, high-temporal-resolution, and high-spatial-resolution global profiles of pressure, temperature, wind and water vapor are basic requirements of a sustained global observing system to support the understanding and prediction of virtually all aspects of weather, including such high-impact phenomena as hurricanes and heavy precipitation events. However, scientific applications are severely limited by the lack of directly measured those key meteorology fields over the oceans, the tropics, and the polar regions, where meteorological observations are scarce. Space-based remote sensing instrumentation is the only effective means in obtaining sufficient coverage of the vast oceans to improve forecast accuracy. Currently, satellites provide information on sea surface temperature and to some extent sea surface winds. But **such information is not presently provided on sea surface pressure, the most important key ingredient needed for accurate forecasts**.

To address this weakness in the current global forecast system, the development of a new satellite radar system is needed and has been proposed to provide highly accurate and spatially dense information on surface pressure over the ocean. As the total extinction of radar echoes from surfaces at the 50~55 GHz O_2 absorption band is strongly correlated to atmospheric column O_2 amounts, thus, atmospheric path lengths and surface air pressures, the novel technique is to use the absorption difference from the echoes of a dual-frequency O_2-band radar to estimate the surface pressure. The two adjacent frequencies are selected such that the microwave absorption effects of liquid water and water vapor can be effectively removed from the ratio of reflected radar signals of the two channels. A critical feature of this technology is that it can make observations from space through thick clouds which is challenging for alternative technologies of sea surface pressure. Analyses show that the accuracy of surface air pressure from this technology are comparable to conventional state-of-art buoy measurements, with the advantage of being provided at much **greater spatial density under all-weather conditions** across the ocean addresses the weakness in the global forecast system. The proposed system is a novel concept for surface pressure barometry and can be developed using existing commercial off the shelf technologies. It is a high return in the potential societal benefits but low risk in terms of the cost of development as compared to other technologies. Currently a research team led by NASA Langley Research Center has improved this differential absorption barometric radar (DiBAR) concept with limited resources. A space DiBAR system design has been developed, a prototype DiBAR has been built, and laboratory, ground and low altitude flight tests of the instrument have been conducted, which leads to multiple peer-reviewed journal publications and an award of US patent. The DiBAR system assessment and flight test results both show that the accuracy in surface pressure measurements is comparable to in-situ measurements and thus, these measurements can be directly used in NWP models.

Whether existing and planned U.S. and international programs will provide the capabilities necessary to make substantial progress on the identified challenge and associated questions. If not, what additional investments are needed?

Although it is one of the most important atmospheric variables, surface air pressure is currently only measured by limited numbers of in-situ observations conducted by buoys, ships or dropsondes over oceans which are sparse in spatial coverage and expensive to implement. With developments of remote sensing methods, especially in airborne and satellite remote sensing techniques, large scale and global surface pressure measurements significantly lag those for other important variables, such as temperature and humidity. There are potentials to use satellite oxygen A-band absorption characteristics (both passive and active) to measure the surface pressure. However, various difficulties in oxygen A-band systems limit their accuracy and coverage: e.g., no accurate retrievals under cloudy conditions (even optically thin clouds). There are no mature remote sensing technologies that can directly measure the dynamic fields, especially for hurricanes. The 3-D Wind Demo mission clearly shows this shortcoming: it is designed as the last DS mission and only for technology demonstration. Furthermore, Doppler wind lidars do not meet the all-weather requirements, because they do not provide data in cloudy regions. This radar system is a great complementary for wind lidars for 3-D wind observations under all-weather conditions. With direct measurements of pressure fields, wind fields can be estimated through dynamic calculations or NWP models. Therefore, a dual-frequency O_2-band radar system will fill the observational gap in atmospheric dynamics under all-weather conditions.

How to link space-based observations with other observations to increase the value of data for addressing key scientific questions and societal needs;

Reliable global observations of winds are also needed to improve scientific understanding of atmospheric dynamics, the transport of air pollution, and climate processes, and to assess the dangerous wind impacts of hurricanes and severe storms.

Satellite sounders provide good global coverage of microwave and infrared radiances, which can be assimilated directly for an accurate definition of temperature and humidity profiles. When that information is coupled with surface pressure information, the wind field can be estimated with the balance and adjustment of modeled dynamic fields in numerical weather prediction models or approximately with geostrophic and hydrostatic balance. Particularly, a dual-frequency O_2-band radar system would extend the coverage of vector winds into the rainy centers of hurricanes and storms and would provide the vector winds needed for weather forecasts. Therefore, this radar system, along with other sensors (e.g. wind lidar), will extend wind field measurements from clear skies to all-weather conditions and enhance the 3-D Wind Demo mission, especially for severe storms.

While the ability to understand and predict hurricanes and other tropical cyclones has improved, particularly with respect to storm tracking, much remains unknown concerning, such as storm dynamics, rapid intensity change, and impact on extratropical cyclones. Higher-spatial resolution observations of winds and sea level pressures under all-weather conditions can be obtained and are needed to understand and predict the effects of warm ocean regions on hurricane intensification, particularly combined with satellite observed sea surface temperature and water vapor profiles.

The anticipated scientific and societal benefits

Despite the recent advances and sophistication of modern data-assimilation methods, large analysis uncertainties remain over wide areas of the globe, especially for the pressure field. Surface pressure is a key dynamic field and is the number-one unmet measurement objective for improving weather forecasts. More accurate and reliable and longer-lead-time weather forecasts, driven by fundamentally improved tropospheric pressure and wind observations from space, would have directly measurable societal and economic impacts. Improved forecasts of extreme-weather events would also benefit public safety through disaster mitigation.

The science communities that would be involved

The science communities directly involved in the challenge of surface pressure measurements for reliable longer-term storm track and intensification predictions includes atmosphere and ocean communities.