Severe Convective Storms

A White Paper in response to the Initial RFI for the 2017-2027 Decadal Survey

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Primary theme: Severe convective storms

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?

In just 10 years, from 2004 to 2013, the United States suffered 3500 fatalities and $500B in economic losses from hurricanes and severe storms. New storm-penetrating observations are urgently needed to improve our nation's capability to predict the path and intensity of these extreme weather events, to give people enough time to safeguard property and get out of harm's way. Convective storms in particular, such as tropical cyclones, mesoscale convective systems (i.e. large thunderstorm complexes), and extratropical cyclones (typically, large midlatitude winter storms) need urgent attention. Monsoons and atmospheric rivers – systems that play a large role in transporting water from oceans to continents – are also in this category. Such storms can undergo very rapid and unexpected intensification and have the potential for causing great harm to life and property from wind, floods and related hazards.

Although we have made great progress in predicting the tracks of such storms (but still not well enough), predicting intensity is still a major challenge. There are many recent examples of that. Improved track forecasts are likely the result of significant progress in recent years in observing, modeling and predicting global circulation, but intensity forecasts are thought to lag behind because the models do not capture storm-scale convective processes well nor the underlying microphysics. The modeling of convection is a particular problem that must be addressed.

The problem of severe storms may be growing as a consequence of climate change. While there is in general a strong need to address near-term climate consequences that affect society, from people's daily lives to the economic activities of nations, severe storms are a particularly threatening consequence. We have an inadequate understanding of the underlying earth system processes in many such "applications" areas, which results in poor predictions. We must therefore carry out research, based on observations, to improve our understanding of the processes, which will in turn lead to better models and predictions. This approach should urgently be applied to the key science questions around severe storms, such as the ones identified by a recent NASA Weather workshop:

- How do convective-scale and large-scale circulations interact?
- What determines the mesoscale organization, internal structure and dynamics, and life cycle of convective systems?
- What modulates the rate at which convective storms (of all types) intensify to produce severe weather, tornadic storms, lightning, and other hazards?

- What processes and interactions control the type, onset, rate, and accumulation of precipitation?

We need good observations of a) storm-scale macro-physical moist thermodynamic processes, b) sub-stormscale macro- and micro-physical processes, and c) interactions between storm-scale, mesoscale and large-scale processes. These observations need to be made simultaneously, under all weather conditions, in full context and continuously, covering all phases of a storm's life cycle in three dimensions. It is not sufficient to observe "snippets" of limited aspects of storms and stitch them together from an ensemble of case studies – at least not until we have a clear understanding of how the "cases" may be separable. Above all, the observations must be valid in all weather conditions, i.e. in the presence of full cloud cover and precipitation.

The key variables are i) thermodynamics (temperature and water vapor profiles), ii) water phase and phase transitions (cloud liquid and ice, evaporation, condensation and precipitation), iii) dynamics (horizontal and vertical wind vectors, and iv) microphysics (hydrometeor particle size/shape/distribution) – all continuously with high temporal resolution and in 3 dimensions. We must be able to determine both horizontal and vertical transport of mass, momentum, and latent and sensible heat, as well as their rates of change.

Why are these challenge/questions timely to address now especially with respect to readiness?

Many projected or hypothesized climate change consequences are at the threshold of detectability with current or near-mature observing technology and capabilities, and focusing on them now may give society enough time to adapt or mitigate. This is the case with severe storms, which are predicted to become more intense as a consequence of a warming climate. In particular, the predicted intensification or speedup of the hydrologic cycle may lead to more intense and possibly more frequent convective storms. It has become clear in recent years that vulnerability to such storms has grown, both because of societal trends and because of effects related to known climate change (e.g., sea level rise). This is therefore a particularly timely and urgent challenge.

Increased efforts in observing, understanding, modeling and predicting severe convective storms are therefore urgently needed, and this need will only grow more urgent over time. Severe storms affect nearly all applications areas, from agriculture to transportation to security – with consequences spreading from local to regional to national and global. In the last decadal survey nearly 10 years ago this was already recognized as a priority, when the NRC recommended the PATH mission, a geostationary microwave sounder to be focused on tropical cyclones and severe storms, and it is arguably even more urgent and timely now.

NASA has invested significantly to mature the technology required for PATH. This development has now been successfully completed, and, as a result, a PATH mission is ready to be implemented at this time. PATH will have the capability to measure all key storm parameters at storm-scale and above, except for vertical velocity and microphysics. Despite these two gaps, just a single geostationary microwave sounder, operating in conjunction with existing sensors in a multi-sensor/multi-platform virtual constellation, will lead to rapid progress in the science of severe storms - observing, understanding, modeling and predicting. The

Sensor system	Continuous	Targeted obs	All-weather	TC/MCS/XTC	Coverage	Temp, humid	Precipitation	Wind
Ground radar (NEXRAD)	+		+	O	+		+	O[1]
GEO imagers (GOES)	+	O		+	+		O	O[2]
LEO MW-sounders (AMSU etc.)			+	+	O	+	+	
LEO MW-imagers (SSM/I etc.)			+	+	O		+	O[3]
LEO IR-sounders (AIRS etc.)				O	O	O		
LEO radar (GPM)			+	+	O		+	
GEO MW-sounders (PATH)	+	+	+	+	+	+	+	+

+ = capable; O = partially capable; O[1]: radial only; O[2]: uncertain height; O[3]: speed only
TC = Trop. cyclone; MCS = mesoscale conv. Sys.; XTC = extratrop. cyclone

table summarizes capabilities of existing sensors vs. a GEO MW sounder in the context of severe storms and illustrates both the singular contribution PATH will make, the inadequacy of existing systems to solve the storm problem alone (due to inadequate temporal sampling, inability to penetrate clouds and rain or incomplete funcionality), and the value of using all of them in a complementary way. We also note that a geostationary sensor will provide real-time nowcasting capabilities, and important addition to disaster response planning and resource management.

Other future storm sensor systems are being explored but do not have the level of readiness that PATH now has.

Why are space-based observations fundamental to addressing these challenges/questions?

Severe storms are currently not well sampled. That is because they typically are narrowly concentrated in time and space, i.e. evolving and moving rapidly and spatially highly heterogeneous. Ground based observing systems are not dense enough or capable enough to capture key processes. This is especially true in ocean areas, where many severe storms (e.g., tropical and extratropical cyclones) develop and intensify. And it is nearly impossible to have mobile observing systems (e.g., field campaigns) positioned at the right time and place. Although it is possible to accumulate enough “coincident” data from such sources to build statistical models, the great variety of processes, interacting at multiple scales, that determine the evolution of individual storms cannot be modeled from such statistics. Rather, it is necessary to observe the entire individual life cycle of constituent storm processes, storm elements and storm systems to gain a full understanding that can be incorporated into high fidelity models that are valid under all circumstances. Doing so is only possible from space.