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Satellite meteorology plays a significant role in support of commercial aviation, with impacts on all phases of flight from pre-flight operations to taxiing to the final gate. With many flights operating over oceans or sparsely populated land masses, there is a lack of conventional meteorological observations throughout large portions of many commercial aviation flight paths, especially along less-travelled routes. For a significant fraction of all aircraft in the air at any given moment, satellites remain the primary source of information about atmospheric conditions along their routes. However, the meteorological community is currently experiencing a generational shift with respect to the capabilities of its geostationary satellite platforms. With the recent launches of Himawari-8 by Japan and GOES-16 by the United States, and the forthcoming launch of the third generation of Meteosat by the European Space Agency, improved temporal, spatial, and spectral resolution facilitates the development and operational use of new algorithms that will greatly improve the ability of airlines to plan for and react to a variety of atmospheric concerns over all parts of the globe. The impacts of these new algorithms are further amplified by improvements in air/ground communications, which enable greater access within the cockpit to real-time and forecasted weather conditions than has ever been possible before. The present work explores the ways that satellite products are currently being used for aviation support and provides a look forward to how the new generation of data and products may revolutionize the way that commercial aviation implements weather information into their operations.

![Image](image.png)

**Figure 1:** ProbSevere forecasts of the probability of severe weather in a developing cell in the central part of the Florida Panhandle in the southeastern United States. This cell later produced damaging winds and a possible tornado.
A key factor in operational forecasting for any weather-sensitive industry is situational awareness. For the aviation sector, this includes recognizing the location and intensity of hazards that can impact the safety of passengers and crew.

Severe convection is one of these major hazards. The finer spatial and temporal resolution of the new generation of geostationary satellites enables forecasters to monitor the evolution of convective activity in far greater detail than has even been possible, with scans as frequently as every 30 s in certain environments. These data are also used as inputs into products like the Cooperative Institute for Meteorological Satellite Studies (CIMSS)-produced ProbSevere (Cintineo et al. 2014), a statistical analysis that combines remotely sensed data with numerical weather prediction output to predict the probability of severe weather in a given location with up to an hour of extra lead time over conventional forecast methods. An example of a ProbSevere analysis is shown in Figure 1. In this case, a developing storm cell has already been identified and probabilities of the development of a tornado, damaging wind, and large hail are shown at 14%, 77%, and 91%, with damaging winds (possibly from a tornado) reported about 30 min later. ProbSevere is now being used regularly within the United States National Weather Service, but could also be optimized for private sector and international use as well. Several other major operational hazards for commercial airplanes include icing and volcanic ash, the latest satellite technology provides valuable insight as well. Because different cloud types (including mixed phase, liquid, and supercooled water) have different spectral responses at different infrared wavelengths, multispectral imagers are now capable of identifying clouds with supercooled liquid water droplets. Similar techniques are used to identify the position, height, and mass loading of ash plumes; the results from this can be used to identify regions for aircraft to avoid, as well as to accurately initialize dispersion models to forecast the evolution of the plume.

Avoiding turbulence has long been an area of concern for commercial airlines due to negative impacts on crew and passenger safety, as well as airframe durability. Clear air turbulence has been a particularly difficult problem due to the fact that these events are difficult to identify from visible or infrared satellite views or from the cockpit. In the past, water vapor imagery has shown promise to indicate turbulent regions in the absence of clouds, but the low spatial resolution of water vapor channels often made it difficult to discern where turbulence was taking place. Today, however, the fine resolution enables the identification of regions with standing waves and large eddies. An example of this is shown in Figure 2. Fine-scale features present in water vapor imagery from Himawari-8 are enhanced with a high-pass filter to enhance the edges of the identified turbulent elements, which are coincident with high eddy dispersion rates reports from an airplane passing through the turbulent region, providing a validation of this technique. It is important to note that this particular image was taken at night, and thus visual inspection of clouds would be difficult to determine if turbulence is occurring. Imagery like this can be used by flight planners and by pilots in the cockpit in order to avoid such regions, and it can be used by pilots to allow passengers and flight crews to anticipate imminent turbulence if it cannot be avoided.
Because of the unique environments in which commercial aircraft operate, they are exposed to harsh operating conditions that can affect the efficiency of their operations and the safety of their passengers and crew. These include extreme temperatures, lightning, elevated ozone concentrations, and intense radiation. Satellite observations can assist with the identification of all these features with low enough latency and widespread enough coverage to be useful for aircraft operations. For example, soundings retrieved from hyper-spectral infrared radiometers can identify and predict altitudes with temperatures that are cold enough to affect fuel flow. New lightning products observed from space can identify regions of intense convection far away from any land-based network, enabling safe traverses of the ITCZ and other regions with significant convection. The identification of tropopause folds and areas of increased ozone concentration by satellite help planners to avoid these areas which may be hazardous to passenger and longer-term crew health. Solar-pointing satellites identify solar flares and assist space weather forecasters in determining if polar regions will have elevated levels of harmful radiation.
Aviation also benefits indirectly from the assimilation of satellite observations into forecast models. The overwhelming majority of data assimilated by models comes from satellite, which has spatial and temporal continuity, that ground-based observation systems lack. This is especially true over the oceans, where satellites provide nearly all of the available information about atmospheric conditions. Numerous observation impact studies across many different domains and time scales have indicated that satellite data outpace other observation systems in terms of forecast impact. For example, impact tests for both the United States Global Forecast Systems (GFS) ensemble and the European Centre for Medium-range Weather Forecasting (ECMWF) model showed that microwave soundings from the Advanced Microwave Sounding Unit (AMSU) mounted aboard polar orbiting satellites have a greater impact than any other observation, including radiosondes and surface measurements (Oto et al. 2013, Dahoui et al. 2017). More recent work utilizing the UKMET model indicates that the assimilation of satellite-derived atmospheric motion vectors is becoming increasingly important for accurate forecasts. These model forecasts are the backbone of the forecasting process and crucial for airline operations.

Armed with these products and imagery, airline forecasters and flight planners will be better equipped to deal with all phases of flight operations, from when passengers arrived at their departure airport until they arrive at their final destination. Improved forecasts brought about by assimilation of higher quality satellite data means that airlines will better anticipate the adverse weather conditions that induce irregular operations, shift flight crew schedules and change aircraft to other, less impacted locations, resulting in fewer passengers being impacted by cancellations and misconnections a well as better fleet management. Enhanced forecasts also result in reduced fuel use as upper-level winds are better characterized in part due to the greatly enhanced observations of winds over the oceans. The improvements in short-term forecasting and situational awareness facilitate flight plans that avoid significant storms, turbulence, and other hazards to people and property, while enhanced cockpit displays and air-to-ground communications mean that pilots will be better informed about situations that they will encounter during flight.

Satellites will also play an important role in the far future of aviation, such as assisting autonomous cargo aircraft. Currently, CIMSS supports high-altitude, long duration tropical storm observations with the NASA Global Hawk airframe. CIMSS forecasters use GOES-16 and other satellite data to identify cloud top height, overshooting tops, lightning, and other conditions to ensure safe operation of the aircraft in a difficult environment. As autonomous operations continue to grow, these kinds of flight decisions will need to increasingly rely on satellites to be the proverbial “eye in the sky” without a pilot in the air. Some work has also been done to use aircraft to select flight levels with enhanced moisture content in order to reduce (or selectively generate) contrails in response to climate change. Satellite soundings will often be needed to help identify these moist layers.
Over the next several decades, the aviation industry will rely ever more heavily on satellite-based observations for its planning and operational needs. As part of this, it is important that there be ongoing dialogue between the industry and the satellite meteorology community. The researchers and scientists developing the products used in aviation support need to know how those products are being used, what changes need to be made, and what future tools need to be developed. With continuous communication between industry, government, and academia, the efficiency of the airlines and the safety of the billions of airline passengers worldwide will continue to improve.

References

