ABSTRACT: State and local agencies involved in emergency response to natural disasters such as hurricanes have explicitly indicated they need imagery covering the disaster area within three days of the event; and more desirably within 24 hours of the event. Airborne image collections have often been used but suffer from several problems, most noticeably the collection time (days or week) required for larger areas. The use of remote sensing satellites carrying high spatial resolution sensors has often been touted as the logical response for rapidly collecting post-disaster event imagery for emergency response. Unfortunately, satellites are maintained on fixed orbits. The repeat interval for remote sensing satellites carrying high spatial resolution sensors, even with pointable sensors, is on the order of several days, depending on the latitude for the disaster event. Fortunately, more than one satellite carries high spatial resolution imagery. This combination of requirements and restrictions may result in either a relatively high (or low) likelihood of collecting imagery within the three-day window of opportunity. This research investigated the likelihood of collecting imagery over a hurricane disaster area based on the orbital cycles of three high spatial resolution imaging satellites. Using the spatial-temporal distribution of historic hurricane landfall locations as a proxy for the probability distribution of future hurricanes by latitude, the “visibility” of each landfall location to future satellite imaging opportunities was determined. The results indicate that the likelihood of collecting imagery within one day of the event varied between 17 and 39 percent by relying on one satellite image provider. However, if either of three satellite imagery sources (i.e., Ikonos-2, Quickbird-2, and Orbview-3) could be used, then the likelihood increased to 61 percent. By relying on three satellite imagery providers there is a likelihood of between 94 and 100 percent of collecting imagery within two or three days, respectively, after the event.

KEYWORDS: Satellite remote sensing, disaster response, orbit, modeling

Introduction

The natural disaster paradigm is often portrayed as a cycle—from the warning stage as the event approaches, the event followed by the response stage, subsequent recovery, and then a relatively more leisurely planning and mitigation stage. Considerable GIScience research has been conducted for the warning, recovery, or mitigation stages. A highly “visible” yet poorly understood or researched problem is the use of remotely sensed imagery during the short response stage. The emergency response stage for most natural disasters is very short. State and local agencies involved in emergency response to natural disasters such as hurricanes have explicitly indicated they need imagery covering the disaster area within three days of the event; and more desirably within 24 hours of the event (Hodgson et al. 2010). During the post-event disaster response remotely sensed derived damage information becomes less important as time passes and in situ data (deemed more accurate) becomes available (Hodgson et al. 2010). Airborne image collections have often been used but suffer from several problems, most noticeably the long collection time required for larger areas. The use of remote sensing satellites carrying high spatial resolution sensors has often been touted (Visser and Dawood 2004; Zhang and Kerle 2008) as the logical response for rapidly collecting post-disaster event imagery for emergency response. While more coarse resolution
satellite sensors may provide some information that is useful in emergency response, agencies typically desire high spatial resolution (e.g., 1 m or less) to assess structural and transportation feature damages. Thus, this article focused on the use of satellite imaging opportunities with high spatial resolution sensors on the order of 1.5 × 1.5 m or less.

Satellite image coverage area within a swath (e.g., >8 km width by an infinite length) is much larger than the footprint of airborne (except the U-2 high altitude aircraft) imaging sensors. Collection times for most remote sensing satellites are ~7.5 km/sec, allowing for impact areas to be imaged in a few seconds. The downlink and initial post-processing by satellite image providers can be within a few hours, compared to six to eight hours (or much longer for post-processing and geometric rectification) for airborne imagery collection, processing, and transmittal.

Unfortunately, satellites are maintained on fixed orbits. The repeat interval for remote sensing satellites carrying high spatial resolution sensors, even with pointable sensors, is on the order of several days, depending on the latitude of the area of interest. It may be that the next available overpass is two or more days after the disaster event. Fortunately, more than one operational satellite carries high spatial resolution imagery. The availability of multiple collection platforms may provide the appropriate set of opportunities to collect imagery over disasters at any time. However, these satellites are still on fixed orbits. No known study has examined the collection opportunities provided by high spatial resolution satellites for disaster response. The problem is not simple. Such satellites carrying high spatial resolution satellites are not on systematic repetitive tracks whereby future passes can be made from path-row maps, such as Landsat or SPOT. The pointable (off-nadir in particular) sensor systems onboard many earth resources satellites today offer somewhat flexible collection opportunities. Prediction of future collection opportunities would require modeling satellite orbital trajectories and somehow incorporating unsystematic maneuvers where the satellites are repositioned. Furthermore, the observational record of many high-impact but low-frequency events, such as hurricanes and earthquakes, is weakly suited to developing well-fitted spatial/temporal probability functions for predicting future occurrences.

The goal of this research was to develop a generic approach for empirically assessing the likelihood of collecting satellite imagery given a spatial/temporal distribution of disaster locations. The focused context of this research is on the response phase for land-falling hurricanes along the Eastern United States. The three commonly used high spatial resolution sensors from U.S. commercial satellites (and thus, more easily acquired imagery by U.S. federal and state agencies) at the time of this research were Ikonos-2, Quickbird-2, and Orbview-3. The key questions examined in this research were:

- What is the probability that an image collection could be made with ‘n’ days of a disaster event with one satellite?
- What is the probability that an image collection could be made with ‘n’ days of a disaster event with three satellites?

Relying on one satellite–sensor system is often desirable for several reasons. First, only one contract needs to be established to rapidly task and collect the imagery. For disaster response applications such contracts would need to be pre-established for facilitating rapid response. Second, the image specifications (spectral bands and spatial resolution) will be very similar for different study areas, providing uniformity in processing and interpretation approaches by the image analysts. But how many high spatial resolution satellite providers need to be considered? An ideal research question might be: Given the spatial/temporal variation in cloud cover, what is the joint probability that a cloud-free image over the impact area could be collected within one or ‘n’ days after the hurricane event? Remote sensing satellite collection opportunities are, from a statistical perspective, independent of cloud cover. In this article, the focus is on assessing satellite image collection opportunities as an independent likelihood. The joint probability of cloud cover—a very problematic source to evaluate empirically—could be added from future work.

**Methodology**

In this article, we develop an approach for empirically determining the likelihood of obtaining high spatial resolution imagery for a disaster. We implement and evaluate the approach for “future” hurricane disasters and empirically determine the likelihood based on single- and

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1 Since this research was completed, Orbview-3 satellite has ceased communication and is deemed inoperable. The Ikonos 2 satellite was renamed to simply Ikonos after Orbview acquired Space Imaging, Inc.}
three-satellite vehicles. The probability distribution of future hurricane landfall locations was developed based on historic landfalls from 1850 through to 2004. Modeling future satellite viewing opportunities was accomplished using a satellite orbit propagation model and a sensor viewing model.

The assumptions in the modeling approach were:
- The spatial and temporal distribution of historic hurricane landfall locations represents the future distribution in space and time;
- The area to be imaged is represented by the landfall point location; and
- Atmospheric conditions during the three days after the hurricane visit will not obscure collections.

Historic/Future Hurricane Landfall Locations

The temporal and spatial distribution of future hurricane landfall locations was assumed to be the same as the historic record. The historic record of hurricane landfall locations on the eastern United States coast was extracted from the North Atlantic Tropical Cyclone database (Jarvinen et al. 1984; and it included observations from 1850 through 2004 (Figure 1). The database was developed from ground-based human observers strictly from 1850 until the TIROS satellite was placed in orbit in the 1960s. The first land-falling hurricane in the U.S. imaged by TIROS was hurricane Camille in 1969. Prior to satellites, hurricane observations were strictly from land or sea vessels. In the early record, the landfall locations were less precise spatially, and some events may even have been missed altogether. Ship logs, plantation logs, and other fugitive sources utilized by ongoing research have been used to fill in the historic hurricane record (e.g., Mock 2008), but they were not used in this research. The hurricane tracks in the North Atlantic Tropical Cyclone (NATC) database are averaged locations of the hurricane generalized on a lineal path with 6-hr observations. Despite these data observation limitations, the NATC database is regarded as the best record of past hurricane events.

The assumption that the “area” to be imaged can be empirically evaluated as a single point location is, on one hand, a simplification of the collection area problem (Figure 2). Hurricane impact areas can be quite large, resulting in structural damage across tens of miles or coastal flooding across a hundred or more miles. Creating an empirical model of whether the impact area could or could not be imaged first requires assumptions about what impact characteristics are of interest. For instance, are only catastrophic (i.e., complete building destruction) damage areas important to be imaged? Are all areas with 50 percent structural damage or greater to be imaged? In an actual disaster event, imagery over the entire impact area with all levels of damage would be nice but very expensive. Thus, other strategies are used by federal agencies which focus on the expected areas of intense damage, or on areas that are less accessible, or where cloud-free conditions allow collection. One major question immediately facing response agencies is to simply define the impact area. Coarse resolution remote sensing of the hurricane eye and physical modeling of the cyclonic winds and associated surge are often used as an initial

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![Figure 1. Spatial distribution of hurricane “best tracks” in the eastern United States between 1850 and 2004.](image1)

![Figure 2. Spatial distribution of hurricane landfall locations in the eastern United States between 1850 and 2004.](image2)
estimate defining the geographic distribution of damage. Subsequent fly-overs by response aircraft and ground observations begin to provide geographic samples of the damage landscape. It is from this combination of sources that emergency response officials determine where to focus satellite or airborne remote sensing efforts.

The approach used here with the land-falling point essentially assumes the highest impact areas (Figure 3). It may be that other locations (e.g., to the right of the hurricane centerline along the forward direction) are more important, as the winds and storm surge will be somewhat higher at these locations.

Our use of the hurricane land-falling points is to represent the spatial variation in the probability density function (PDF) for the historic hurricane record. With regard to satellite remote sensing, the major factor influencing collection opportunities is latitude. With respect to the remote-sensing polar-orbiting satellites, locations at higher latitudes move less with respect to the Earth’s center than do latitudes nearer the Equator. Since the meridians converge with increasing latitude, the opportunities for collecting imagery at higher latitudes are obviously more likely (Figure 4). For example, The Ikonos satellite, with a 45-degree off-nadir pointing capability and a 98.1° orbit inclination, can collect imagery over any area above 82° north latitude daily (Dial et al. 2003). However, the Ikonos satellite/sensor can only collect imagery over the equatorial region every ~2.5 days. The historic set of land-falling points is clearly not random with respect to latitude (Figure 5). This historic set of latitudinal positions (and longitude implicitly) represents the future distribution of hurricane impact areas (as an aggregate set).

Estimating the likelihood of collecting imagery over a disaster area could include the probability of cloud cover during the days after the event. Unfortunately, this cloud cover estimation question suffers from several problems. It is often assumed that the skies are relatively clear the day (or days?) after the intense low cell passes over. If this assumption is true, cloud cover is correlated temporally with hurricane landfall. Having discussed this with numerous individuals in the meteorological community we conclude at this time the cloud probability after a hurricane problem is still a research hypothesis without empirical evidence. We have worked for several years on developing a suitable methodology for evaluating this cloud cover–hurricane passing relationship. An adequate reference data source for cloud cover during the days after a hurricane event is problematic due to 1) limited record of historical observations, 2) changes in observational methods over time, and 3) the seemingly forgotten problem of instrument damage in the aftermath of a hurricane event.

To develop a large sample size of hurricane landfalls and associated post-event cloud cover would require a lengthy historic record. Assuming the postulated relationship is also influenced by hurricane intensity, forward momentum, contextual weather systems, and geographic location, a sizeable set (perhaps 50-100 events) of hurricane events would be required for any empirical evaluation. To obtain this many observations in the United States would require some 50 or more years of record. This need of a long temporal record results in the related problem of changes in the observational method over time. The historic record is very inconsistent in observations and methods used. Observations are for different quadrants in the sky, different heights, and different cloud types, and for different times of the day. Early human observations are gradually being replaced by automated methods of cloud observations (e.g., the ASOS network).

Finally, few good records of cloud cover at/near the hurricane landfall location will exist in such a catastrophic context due to damage to automated instruments or human-observer problems. The historic record is filled with missing data in the days after a hurricane event.

Given the working assumption that cloud cover will decrease the likelihood of collecting imagery...
over a landfall location, our analysis will identify the maximum likelihood of collection opportunities. Incorporating a probability density function for cloud cover both temporally and geographically would only decrease likelihood of collection opportunities.

Tropical cyclones which were hurricanes during their life history were identified in the NATC database. A subset of this selection was created for those hurricanes which maintained hurricane strength (64-knots) at landfall. By modeling the paths of historic tropical cyclones using interpolated locations between the six-hour averaged positions in the NATC database, 388 locations were identified where the tropical cyclone was at hurricane strength at landfall. To avoid multiple counting of hurricanes, “landfall” points on islands were removed, resulting in 342 landfall points (Figure 2). A few hurricanes made mainland landfall twice, and both landfall observations were included. For example, hurricane Andrew in 1992 made landfall in south Florida and a few days later in Louisiana. Using the spatial and temporal (within the year) distribution of hurricane landfall locations for a 155-year period (1850 - 2004), this distribution represents the probability density function for where (most importantly, the latitude) and when (within the year) a hurricane landfall location could occur for any single year in the future. For an empirical assessment of probabilities, we selected the year 2005 as the “standard” year representing satellite orbits. For instance, hurricane Camille made landfall at midnight on August 17, 1969. To estimate the satellite viewing likelihood, the observation of Camille’s landfall was assessed as if the hurricane made landfall on August 17, 2005.

None of the high spatial resolution satellites examined were in an orbit for collecting imagery over the Camille landfall at this same day in 2005 (Figure 4). We note that, for many geographic areas in particular, the frequency of observations is low and may not adequately represent future probabilities. It may thus be inappropriate to impart probabilities for any small area (e.g., Norfolk, Virginia). However, for the purpose of assessing the likelihood of obtaining imagery for any future hurricane event (an average assumption for the entire U.S.), in general, this distribution is appropriate.

Satellite Orbit Propagation

Modeling satellite orbit propagation can be accomplished from a deterministic model or a statistical model of numerous orbital ephemeris. Because the deterministic approach is so well known in classical physics, we do not seek to repeat the equations and algorithms. While fundamental in nature, these equations would still take some ten pages or so for presentation and more for explanation. The deterministic approach is well grounded but complex (Hoots and Roehrich 1980). One of the earliest works...
on deterministic modeling of satellite orbits around the Earth was by Brouwer (1959). A brief history of the fundamentals of Brouwer’s research and the subsequent modifications by others is presented by Hoots (1981). Tapley et al. (2004) provide a thorough discussion of statistical approaches for modeling satellite orbit propagation. Notable works by others (e.g., Emery et al. 1989) for specific sensors on remote sensing satellites have also been conducted. Those interested in developing their own satellite propagation or sensor models are encouraged to consult these fundamental works.

The orbital propagation solution and sensor viewing geometry developed for the Remote Sensing Hazard Guidance System (Hodgson and Kar 2008) was used in this research. We have built our model based on these works but modified it for efficiency and accuracy. The age of the satellite ephemerae (i.e., the location and trajectory of a satellite observed at one moment) is one of the major factors influencing satellite orbit propagation accuracy. Predictions of near-future satellite locations (e.g., hours later) are trivial and very accurate, while predictions for months ahead require greater complexity and numerous additional factors. Our model was based on other demanding applications but was used in a very ideal context here. For this research, we used orbital ephemerae that were collected nightly and thus are less than 24 hours old. Our orbital predictions for day ‘n’ used the ephemerae from day ‘n’ – 1 (i.e., the preceding day). By using daily ephemerae, we can obviate the major sources of error in satellite orbit prediction, such as satellite maneuvers.

The first step in the orbital propagation process is to obtain the orbits of all the satellites of interest. The orbital ephemereides are obtained on a nightly basis for all remote sensing satellites. The satellite orbits are converted into a Cartesian Earth centered state vector at the particular epoch of interest. The Cartesian state vectors are used to compute classical orbit elements for each of the satellites. These classical orbit elements may be used to propagate the satellite trajectory forward or backward in time from the epoch specified. In addition, the time and state vector for a particular satellite may be determined using angles from the satellite location at the epoch of interest. For example, the state of a satellite when it reaches its northern most position may be determined from the angle measured from the initial position to the point in the orbit where the true anomaly plus argument of periapsis is 90 degrees. Using these classical orbit elements, the parts of the orbit where the spacecraft is on the dark side of the Earth or too far north to be imaged may be quickly eliminated.

The search algorithm then finds the point on the orbit where the satellite is closest to the landfall point defined on the surface. At this point, the range rate is zero and transitioning from negative to positive. These geometrical parameters may be easily computed from the landfall point location and state vectors of the satellite obtained from orbit element propagation. Various geometrical parameters, such as sun elevation angle or range, may be examined to determine if they satisfy the constraints specified. If they are out of tolerance, the satellite will not have an opportunity to collect imagery at this location.

Once the minimum-range point is found, as determined from conic orbit elements, a new initial epoch is computed. The ephemerae database is interrogated for a new satellite state vector for the date/time calculated using the conic orbit element. The entire search algorithm is then repeated using precision satellite state vectors at the exact time of overflight. This insures that the most accurate results are obtained, and conic orbit propagation is only used for relatively short distances.

Satellite Viewing Opportunities

To empirically determine the likelihood of future collection opportunities, the spatial and temporal distribution of historic landfall points were assumed to occur in the year 2005. The year 2005 is arbitrary but was convenient for this research as we had a complete daily collection of the satellite orbital ephemerae needed to predict the orbital tracks of each satellite and, subsequently, the satellite viewing opportunities. As noted earlier, using daily orbital ephemerae allows for very high spatial/temporal accuracy. The use of any other year may change the collection opportunities for a single hurricane event but not for the set of landfall events, unless the orbits of the satellites were temporally correlated.

For each day and geographic landfall location of a hurricane, the viewing opportunity for each of three satellites (i.e., Ikonos-2, Quickbird-2, and Orbview-3) was modeled. Determining if the geographic location can be imaged is solved by first propagating the satellite vehicle orbit during the days following the hurricane landfall, and modeling the viewing geometry for the sensors onboard the satellite vehicle (Table 1). Most satellites with high spatial resolution sensors have a similar orbital...
period (90-100 min) resulting in similar repeat intervals on the ground (satellite image providers routinely advertise a 2-3 day repeat visit).

Imaging opportunities vary among satellite sensors with variations in altitude and off-nadir viewing. The OSA sensor on Ikonos-2 and Orbview-3 can point 45-degrees off-nadir as compared to the 28-degrees of the BGIS200 on Quickbird-2. For most mapping applications (except for stereoviewing applications), off-nadir viewing angles of less than 26 degrees are desirable. At greater angles, the ground surface obscured by the sides of land cover features (buildings, vegetation, etc.) is problematic. The potential swath coverage (e.g., Figure 4) depicts the possible image collection opportunities; however, it does not represent the area-field-of-view (e.g., Figure 3), also called swath width, which would be imaged by most high spatial resolution sensors. The swath width is always smaller (e.g., 16.5-km in width for Quickbird-2 at nadir) than the potential swath coverage.

The likelihood of satellite imagery collection was examined under several scenarios. First, we assumed a single image provider, and a maximum viewing angle of 26 degrees off-nadir was permitted. Historically, remote sensors in a hurricane disaster context have sought imagery from near-nadir views rather than oblique imagery. The 26-degree criterion has been used informally in emergency operations centers. Second, any of the three satellites were allowed but still imposing a 26-degree off-nadir limit. Finally, collection opportunities from 1) single satellites and 2) all three satellites were examined with the maximum viewing angle allowed by the sensors.

**Findings**

**Restricted Viewing Angles**

If an emergency response agency relied on a single satellite provider to collect imagery over the hurricane landfall area, the likelihood of obtaining imagery within the first 24 hours ranges from 16 to 18 percent (Table 2). The likelihood increases to 37 to 42 percent during the first 48 hours and from 53 to 67 percent in the first three days. Even with the restriction of 26 degrees maximum viewing angle, the Ikonos-2 satellite-sensor combination has a higher likelihood of collection as its altitude is higher (i.e., 679 km versus ~450 km for the other two). A higher altitude allows the sensor to point at farther planimetric distances with the same viewing angle. Relying on one satellite–sensor combination with this 26 degree off-nadir viewing limit results in an image collection during the first

<table>
<thead>
<tr>
<th>Satellite-Sensor</th>
<th>Altitude at Apogee (km)</th>
<th>Orbital Period (min)</th>
<th>Sensor Swath Width at Nadir (km)</th>
<th>Sensor Off-Nadir Viewing Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ikonos 2 – OSA</td>
<td>679</td>
<td>98.33</td>
<td>11</td>
<td>45</td>
</tr>
<tr>
<td>Quickbird 2 – BGIS2000</td>
<td>448</td>
<td>93.52</td>
<td>16.5</td>
<td>28</td>
</tr>
<tr>
<td>Orbview 3 – OHRIS</td>
<td>458</td>
<td>93.73</td>
<td>8</td>
<td>45</td>
</tr>
</tbody>
</table>

* Orbital altitude and orbital period are observations in 2005 and vary slightly temporally.

**Table 1.** Satellite-orbital characteristics and sensor projected geometric characteristics.

<table>
<thead>
<tr>
<th>Satellite–Sensor</th>
<th>Day 1 (0 – 24 hours)</th>
<th>Days 1-2 (0-48 hours)</th>
<th>Days 1-3 (0 – 72 hours)</th>
<th>Days 1-4 (0 – 96 hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ikonos 2 – OSA</td>
<td>18%</td>
<td>42%</td>
<td>67%</td>
<td>82%</td>
</tr>
<tr>
<td>Quickbird 2 – BGIS2000</td>
<td>16</td>
<td>36</td>
<td>53</td>
<td>69</td>
</tr>
<tr>
<td>Orbview 3 – OHRIS</td>
<td>17</td>
<td>37</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Using all 3 satellites</td>
<td>38%</td>
<td>74%</td>
<td>91%</td>
<td>97%</td>
</tr>
</tbody>
</table>

* Hurricane landfall was assumed to be the same as the historic location and at the same day as the historic event.

**Table 2.** Probability of satellite image collection ‘n’ days after hurricane landfall (maximum 26° viewing angle).
three days of, at best, only 2 out of 3 (∼67 percent) hurricane disasters. However, if satellite imagery from any of the three satellites were permitted, then the likelihood increases to 38 percent, 74 percent, and 91 percent within the first 24, 48, and 72 hours after hurricane landfall.

Maximum Viewing Angles

Not surprisingly, when more extreme viewing angles are allowed (e.g., when the agency must have some imagery regardless of whether portions of the landscape are obscured), the likelihood of collecting imagery increases. Ikonos-2 and Orbview-3 can point off-nadir at angles of 45 degrees (Table 3). The likelihood of collection in the first 24 hours increases to 39 percent using either of these satellites. The likelihood increases to 97 percent for either Ikonos-2 or Orbview-3 within the first 72 hours after landfall. By relying on all three satellite image providers, the likelihood of collecting in the first 24 hours is 61 percent.

**Discussion**

This research estimated the likelihood of using one or more (up to three) satellite imagery sensors for collecting post-hurricane event imagery in the first 24, 48, and 72 hours of landfall. Relying on a single satellite provider would result in only a 39 percent chance of collecting in the first 24 hours, if using maximum off-nadir viewing angles. To improve the collection likelihoods for post-event imagery, multiple satellite providers must be relied upon. In the concept of operations (CONOPS) model, this would inevitably require pre-existing contracts (pre-existing to enable a rapid agreement to collect and pay for the collection) with multiple satellite image providers.

Since the completion of this research, Orbview-3 satellite imaging sensor has malfunctioned and is considered inoperable. However, GeoEye-1, with a .41cm spatial resolution and a 681-km altitude and off-nadir viewing angle of up to 61 degrees is operational. Using the GeoEye-1 satellite in lieu of Orbview-3 would result in likelihood estimates slightly better than Ikonos-2. Other high spatial resolution satellite–sensors, such as Worldview-1, have recently been launched, providing viewing opportunities from at least four different U.S. commercially controlled satellites.

A logical planning scenario might be to use multiple satellite–sensor contracts and stratify the potential damage area into image collection priorities. An image collection with a near-nadir (low off-nadir angles) vantage might be used for the high-priority areas, while greater off-nadir angle opportunities are used for low-priority areas. Focusing on large-impact areas would further increase the likelihood of collecting imagery across a disaster area.

A final probing scenario for response agencies might be to use both aerial and satellite imaging platforms in a well defined and coordinated approach. By quickly modeling (e.g., GIS-based without imagery) the likely damage area, the collection area could be spatially defined, stratified, and prioritized. Available airborne and satellite–sensors could be utilized in a stratified (both temporally and spatially) approach to collect imagery as part of the post-event response.

**ACKNOWLEDGMENTS**

This research was supported by a National Aeronautics and Space Administration (NASA)

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<td>39%</td>
<td>78%</td>
<td>97%</td>
<td>100%</td>
</tr>
<tr>
<td>Quickbird 2 – BGIS2000</td>
<td>17%</td>
<td>38%</td>
<td>56%</td>
<td>73%</td>
</tr>
<tr>
<td>Orbview 3 – OHRIS</td>
<td>39%</td>
<td>77%</td>
<td>97%</td>
<td>100%</td>
</tr>
<tr>
<td>Using all 3 satellites</td>
<td>61%</td>
<td>94%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

* Hurricane landfall was assumed to be the same as the historic location and at the same day as the historic event.

Table 3. Probability of satellite image collection ‘n’ days after hurricane landfall (up to maximum pointing angle of sensor).
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