6.7 VERIFICATION OF WORLD-WIDE SPACE STATION EMERGENCY LANDING FORECASTS: CHALLENGES AND RESULTS

Timothy D. Oram*
NOAA/NWS Spaceflight Meteorology Group and Cimarron

1. INTRODUCTION

The United States, Russia and other international partners launched the first components of the International Space Station (ISS) in 1999. The first crew occupied the ISS in November 2000. In the event of an emergency, the crew can enter a Russian-made Soyuz spacecraft attached to the ISS and de-orbit to one landing site per orbit. These landing sites are located in the Northern Hemisphere at various longitudes in North America, Europe, Asia, and the Sea of Japan. The Soyuz capsule returns to earth in a ballistic trajectory with little capability to maneuver. A parachute is deployed to reduce the descent speed. Rockets are fired just above the surface to further reduce the speed for the final landing. During the descent through the atmosphere, the Soyuz capsule is subject to certain weather conditions that may pose a threat to either the integrity of the vehicle or the safety of the crew.

The National Weather Service Spaceflight Meteorology Group (SMG) has been issuing emergency landing forecasts for the Soyuz spacecraft since the first crew occupied the ISS. The Johnson Space Center's Mission Operations Directorate (MOD) requested the Spaceflight Meteorology Group issue forecasts for the emergency landing locations. Weather forecast criteria were established in collaboration with the MOD and the Russian Space Agency (RSA).

This paper discusses the challenges and results associated with the forecast verification. Section two describes the landing site locations and forecasts. Sections three and four describe the verification methods and results. Conclusions are presented in Section five.

2. LANDING-SITE FORECASTS

The MOD and RSA Flight Control Teams agreed that SMG would issue forecasts of the occurrence (yes or no) of specific weather conditions for the Soyuz emergency landing sites. The two most significant weather hazards to the capsule and crew are surface winds greater than 15 meters per second and thunderstorms. High winds can cause the parachute to drag the capsule after landing producing a threat of injury to the crew. Thunderstorms create both wind and electrical hazards to the vehicle and crew. The forecast of the occurrence of a specific weather condition does not mean that the landing location cannot be used. Rather, the weather forecast would be used with other information to make a determination of which landing location will provide the best opportunity to safely recover the crew for the particular emergency encountered.

NASA has implemented a method for automating the transfer of the emergency landing site information. An electronic file sent from the Russian Control Center in Moscow to the Johnson Space Center Mission Control Center contains the pre-planned landing point for upcoming orbits as well as the de-orbit time required to reach this point. The pre-planned locations are selected from a set of general landing locations based on the exact orbit the ISS and Soyuz capsule. The general locations of the landing areas are: United States, Canada, Russia, Kazakhstan, France, Khabarovak, and the Sea of Japan. There is, however, an expected uncertainty on the order of 100 km between the pre-planned landing point and the actual location the Soyuz would touch down in the event of an actual landing.

SMG issues the forecasts once per day at about 1800 UTC for a 24-hour period beginning at approximately 2200 UTC. The forecast includes the emergency landing sites for all orbits in this 24-hour period. Prior to weekends and holidays, the forecasts for subsequent days may also be issued. These extended forecasts cover the orbits for periods from about 24 hours to 72 hours when the SMG forecast office may not be staffed. In the event of an actual emergency, SMG could be called upon to provide updated weather information.

3. VERIFICATION METHODS

Corresponding author address: Timothy Oram, JSC/ZS8, Spaceflight Meteorology Group, 2001 NASA Road 1, Houston, TX 77058, e-mail: tim.oram@jsc.nasa.gov

Verification of the forecasts presents several challenges. First, SMG forecasters issue a forecast that attempts to account for the uncertainty in the landing location described above. The verification, therefore, must attempt to determine the conditions throughout the probable landing area rather than at a particular point. Second, the availability of observed weather data for verification depends greatly on the landing location. The wealth of observed data (surface observations, satellite, weather radar, and National Lightning Detection Network cloud-to-ground flash locations, for example) in the United States and Canada makes verification for these landing sites relatively easy. In Europe, SMG also has access to a relatively large amount of surface observation data as well as lightning location data from the United Kingdom Meteorological Office (Lee, 1986) and the Spanish National Institute of Meteorology cloud-to-ground lightning detection system. However, the verification of both winds and thunderstorms over Russia, Kazakhstan, Khabarovak , and the Sea of Japan is hampered by the limited data available. In order to overcome the limitations in the data void areas, non-traditional verification data sources such as satellite derived low-level winds, satellite imagery, and the Global Atmospherics Long Range Lightning Data (available to US government users from the Aviation Weather Center) are used to supplement the surface observations. However, the use of this data introduces a measure of subjectivity into the verification process.

For verification purposes, a significant wind event is defined as a gust in excess of 15 mps or an average wind greater than 11 mps in the absence of a reported gust. The threshold for the average wind was determined assuming a 1.4 gust factor. An average wind criterion was needed due to two facts. First, although surface METAR observations may have a gust reported, a gust is not reported in the majority of the world unless the peak wind exceeds the average wind by 5 mps (WMO, 1995) as opposed to the United States convention of peak wind exceeding the lull (FMH-1, 1995). Second, the synoptic surface observations do not contain a reported gust (WMO, 1995). A thunderstorm occurrence is defined as the report of a thunderstorm (thunder heard or lightning observed) or a remotely sensed lightning location within the probable landing area.

Only surface stations located within the probable landing area are used for verification, when possible. Each station's routine and special observations within 30 minutes of the predicted landing time are used to determine whether a significant event occurred. NLDN and Spanish lightning information was limited to lightning events that occurred within 15 minutes of the predicted landing time since this information has a time resolution of seconds and a high time accuracy. Sferics locations were determined using the information in the SFUK30 and SFUK31 weather bulletins (WMO, 1995). The sferic bulletins include all locations within a 30-minute interval with no specific information regarding the time of occurrence of lightning at a particular point. Therefore, sferic locations within the two bulletins nearest in time are used for verification. In spite of these efforts, some subjective merging of information over the remote areas of the world is still required when verifying the forecasts. Table 1 lists the order in which data are preferred for determining the observed conditions. A significant problem remains regarding the lack of information for observing thunderstorms in Russia and Asia.

4. VERIFICATION RESULTS

Although SMG began issuing forecasts for ISS operations when the crew first occupied the station, an automated verification program was not available until November 2001. Systematic forecast verification began at that point in time. As a consequence, the results presented in this paper represent the period from November 2001 to January 2002 totaling 1323 forecasts (orbits).

Forecasters issued 17 forecasts of thunderstorm occurrence (1.3%) and 71 forecasts of significant wind occurrence (5.4%). This compares to the observed totals of 11 thunderstorm (0.8%) and 40 significant wind (3.0%) occurrences. Overall, thunderstorm forecasts are correct 98.8% of the time and wind forecasts are correct 96.5% of the time. The Probability of Detection (False Alarm Rate) was 0.6 (0.7) for thunderstorms and 0.8 (0.6) for winds. The forecast biases are 1.6 and 1.8 for thunderstorms and winds, respectively, indicating a tendency for forecasters to over-forecast both events. The over-forecasts result in the relatively high numbers for both the Probability of Detection and False Alarm Rate.

The Heidke Skill Score and the Critical Success Index (CSI) were chosen as the measures of forecast skill. Doswell et al. (1990) discuss the advantages of the Heidke Skill Score in verification of rare event forecasting. Given the relative infrequency of thunderstorm and wind events in this study, the use of this measure would seem appropriate. The CSI provides a measure of the instances of forecast or observed significant weather events ignoring the “null-null” cases. The Heidke skill score was 0.5 for thunderstorms and 0.7 for winds while the CSI was 0.3 for thunderstorms and 0.4 for winds. The Heidke skill score indicates the SMG forecasters have demonstrated skill compared to random forecasts. The CSI also shows skill particularly considering this score is biased against high scores in rare event verification (Schaefer, 1990).

Subjective review of the data has shown only one area for improvement. A tendency to over-forecast the wind speed in Asia was noted. However, the database is still too small to show any other significant regional trends.

5. CONCLUSIONS

A systematic method for issuing and verifying emergency landing forecasts for the International Space Station has been implemented at the Johnson Space Center. Significant challenges exist in verifying forecasts in remote areas of the world, but every effort is made to make the verification as objective as possible. Preliminary evaluation of the forecasts has shown the forecasts are accurate and have skill. One area for improving wind forecasts in Asia was noted. Future work will focus on continuing to expand the database and identifying trends and regional biases.

6. REFERENCES

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Table 1. Order of precedence for verification of weather conditions.

Wind	**Thunderstorms**
Surface METAR Observation	National Lightning Data Network
Synoptic Observation (average wind only)	Spanish Lightning Detection Network
Ship and buoy data (average wind)	Sferic locations
QuikScat Winds (average wind)	Surface METAR observation
Aviation Model Data (average wind)	Synoptic Observation