SHORT-TERM FORECASTING OF CLOUD CEILING CATEGORIES AT KENNEDY SPACE CENTER FOR THE SPACE SHUTTLE PROGRAM

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BACKGROUND
- Cloud ceiling over the Shuttle Landing Facility (SLF) at Kennedy Space Center (KSC) is a critical element in determining GO/NO-GO forecasts for Space Shuttle landings.
- Spaceflight Meteorology Group (SMG) forecasters have found that cloud ceiling is a challenging parameter to forecast, even in the short-term (6-9 hours).
- The AMU was tasked to develop a statistical cloud ceiling forecast technique.

DATA
- Data analysis to determine climatologies, trends, relationships between data types.
- Ceiling heights are preferred values.
- Only regular hourly obs used – no specials.
- 3 data quality control routines used.
- Various stadistics used.
- Temperature
- Dewpoint Depression
- Wind Speed
- Wind Direction

EXPLORATORY DATA ANALYSIS
- Time period restricted to days with minimum ceiling of 10,000 ft.
- Data from Cloud Ceiling Analysis System (CCAS) at KSC.

DATA LOCATIONS
- Bary, ravine, most surface stations eliminated.
- Surface data grouped into cool season stratified by time of year.
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DATA PRE-PROCESSING
- Only regular hourly obs used – no specials.
- 3 data quality control routines used.
- Various stadistics used.
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DATA STRATIFICATION
- 20-year dataset stratified into warm (April – September) and cool (October – March) season.
- Cool season used for equation development due to large number of events, few events in warm season.
- Cool season dataset separated into dependent (16 seasons) and independent (3 seasons) datasets for development and testing, respectively.

EQUATION DEVELOPMENT
- Initial lead times:
  - Space Shuttle landings occur around the clock: need equations for all times at highest temporal resolution possible.
  - Hourly means highest temporal resolution is hourly.
  - Equation lead-times are 1-, 2-, and 3-hours.
  - Valid and initial times: Each hour of day.

PREDICTANDS
- Binary observations of Shuttle Flight Rule ceiling thresholds:
  - Ceiling B ins (meters)
  - Minimum in June, July, and August.
  - Maximum low ceiling frequencies from October to March.

PREDICTORS
- Two methods: Observations-based (OBS) and Persistence (PCL).
- OBS – event occurred at SLF.
- Number of predictors per equation ranged from 1 to 9.
- Most important predictors were ceiling or cloud cover obs.

TESTS
- Hypothesis Testing
  - Null hypothesis: MISE = MISE = 0.
  - Distribution of MISE differences similar to chart below.
  - Used nonparametric Wilcoxson Signed rank test.

HYPOTHESIS TESTING
- p-values < 1e-7, null hypothesis rejected with > 99% confidence.
- Distribution of 24 OBS and PCL MISE differences for 2-hour forecasts of ceilings < 8000 ft. Value of bin is upper bound.

PROBABILITY CUTOFF
- Previous POD/FAR calculated with 0.5 as probability cutoff.
- Wilks (1995) suggests using Threat Score (TS) and Bias (B) to determine best cutoff value when TS is mun and B=1.

SUMMARY AND CONCLUSIONS
- 216 OBS and 216 PCL equations for 3 ceiling categories/3 lead times valid each hour of day during cool season.
- Calculate probability for violation of Shuttle FR ceiling thresholds.
- Final Conclusion:
  - OBS equations performed very well on independent dataset.
  - OBS equations are more accurate forecasts than PCL.
  - OBS method: 9-15% improvement over PCL.
  - Improvement statistically significant beyond 99% confidence.
  - For 1-hour equations smallest; PIs increase with lead time; decrease with lower height category.
  - PODs higher than FARs indicating good performance.
  - Highest PODs were for 2-hour forecasts, degrade with increased lead time, but PODs higher than FARs.
  - TS, HR, and NSS values indicated large percentage of correct forecasts (TS and HR), unbiased (B = 1), and superior to random forecasts (KSS < 0).

TEST RESULTS
- Equations explained no more than 60% of variance in data.
- Only surface observations used, upper-air data from rawinsondes, satellite, radar, 50 and 915 MHz profilers, or radiosonde may be needed.
- Surface data grouped into cool season stratified by day. Phenomological stratification may be more useful.
- MLR may not be appropriate model.

OTHER STUDIES
- Accurate cloud ceiling forecasts also intend to aviation.
- Several studies funded by FAA, DOD, and other groups underway, e.g. Wilson and Clark (2000), Fett et al. (2000).
- Results will be monitored to determine if they could be applied to Space Shuttle FR ceiling forecasts.

OPERATIONAL USE
- Equations developed to improve forecast for requirement to visually track the Shuttle solid rocket boosters through 8000 ft.
- Equations provide another tool to improve ceiling forecasts when combined with other observational model and data forecaster experience.