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

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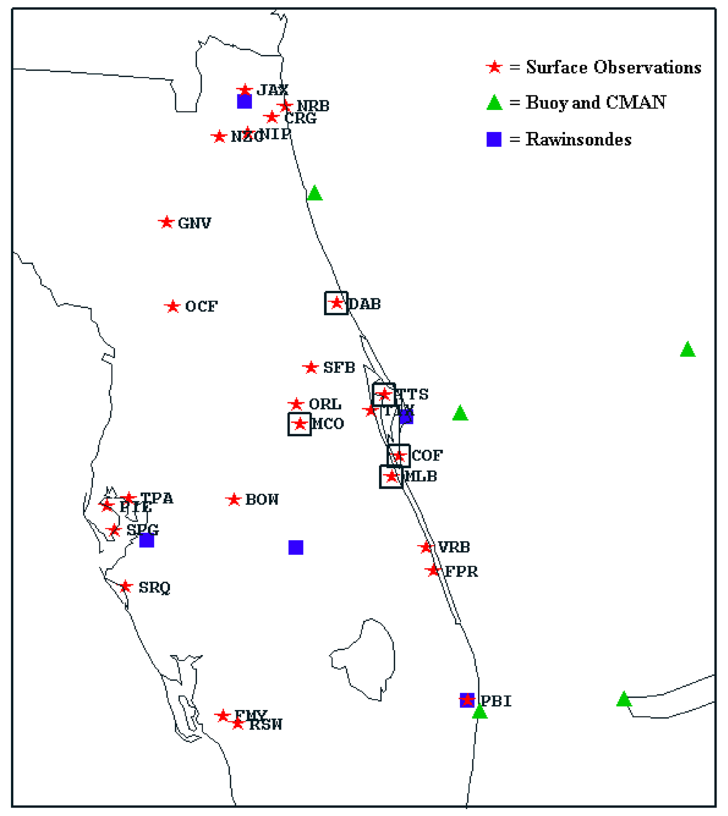
BACKGROUND

- 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 (0-6 hours).
- The AMU was tasked to develop a statistical cloud ceiling forecast technique.
- Two recent studies provided guidance: Vislocky and Fritsch (1997), Hilliker and Fritsch (1999).

DATA



Map of Florida and station locations. Data from stations surrounded by boxes used in development.

DATA LOCATIONS

- Period of Record (POR): January 1978 – March 1997.
- Buoy, rawinsonde, most surface stations eliminated – insufficient POR, excessive missing data.

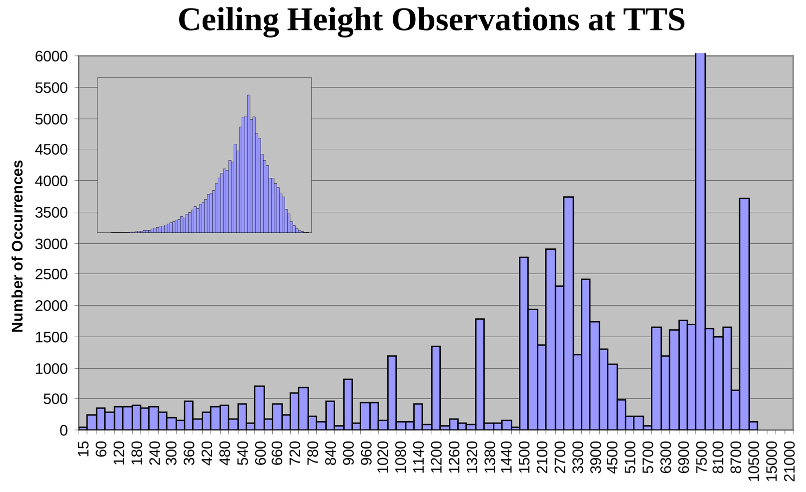
DATA PRE-PROCESSING

- Only regular hourly obs used – no specials.
- 3 data quality control routines used.
  - -Impossible value
  - -10 standard deviations within mean
  - -Temporal consistency
- Missing data not filled in – ceilings not continuous in time/space in central Florida.

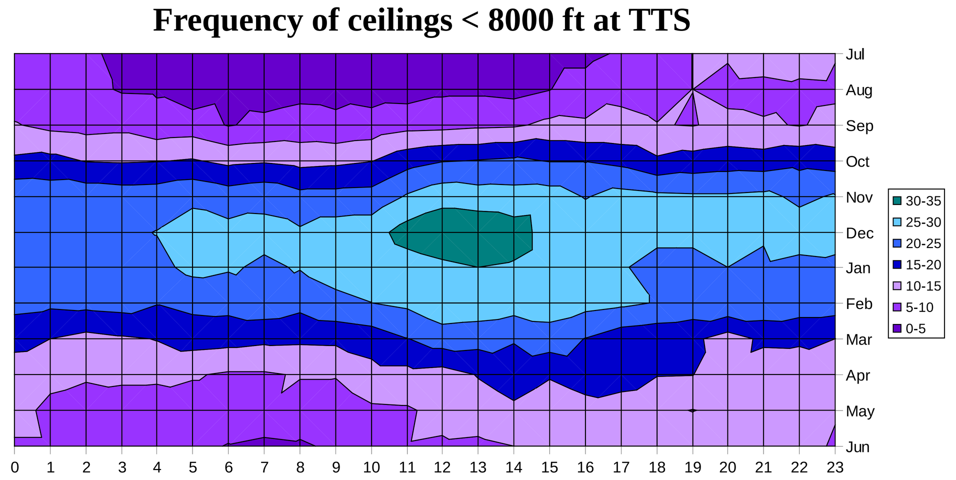
EXPLORATORY DATA ANALYSIS

- Data analyzed to determine climatologies, trends, relationships between data types.
- Ceiling heights are preferred values.
- Reported ceiling heights estimated, not measured, prone to error.
- Uneven distribution of ceiling heights difficult to analyze statistically.

Ceiling Height Observations at TTS



Frequency of ceilings < 8000 ft at TTS



- Maximum low ceiling occurrence in December and January, 11-14 UTC (local sunrise: ~12 UTC).
- Minimum in June, July, and August between 02-15 UTC.
- Ribbon of higher frequencies from October to March.

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/VALID TIMES

- Space Shuttle landings occur around the clock: need equations for all times at highest temporal resolution possible.
- Hourly data 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 Threshold	*Shuttle Flight Rule*
< 5000 ft	Return to Launch Site (RTLS)
< 8000 ft	End of Mission (EOM)
< 10 000 ft	Navigation Aid Degradation

PREDICTORS

- Two methods : Observations-based (OBS) and Persistence Climatology (PCL).
- OBS performance compared to PCL benchmark.
- OBS: data from TTS and surrounding stations at intial time.
- PCL: TTS initial time ceiling ob, valid time ceiling climatology.

27 Potential Predictors per Station for OBS Equations

Variable	*Binary Threshold*
Ceiling Height	< 10 000, < 8000, or < 5000 ft
Total Cloud Cover	> 1/10, > 5/10, or > 9/10
Wind Direction	N (315-45°), E (45-135°), S (135-225°), and W (225-315°)
Precipitation	Yes
1st Cloud Deck Base	< 10 000, < 8000, or < 5000 ft
2nd Cloud Deck Base	< 10 000, < 8000, or < 5000 ft
3rd Cloud Deck Base	< 10 000, < 8000, or < 5000 ft
4th Cloud Deck Base	< 10 000, < 8000, or < 5000 ft
Wind Speed	Actual Value
Temperature	Actual Value
Dewpoint	Actual Value
Dewpoint Depression	Actual Value

2 Predictors at TTS for PCL Equations

Variable	*Binary Threshold*
Ceiling Height	< 10 000, < 8000, or < 5000 ft
Ceiling Climatology	Actual Value

DEVELOPMENT

3 Predictands x 3 Lead Times x 24 Hours = *216 Equations/Method*

- Statistical model for both methods is Multiple Linear Regression:

$$P = C_o + C_1x_1 + C_2x_2 + \ldots C_nx_n$$

- OBS predictors chosen using forward stepwise technique, stopped when new predictor did not explain > 0.5% of variance.

OBS Equation Stats:

- -In 212 of 216 equations, ob of predictor at initial time explained most of variance.
- -Number of predictors per equation ranged from 1 to 9.
- -Number of predictors per equation increased with lead time.
- -Most important predictors were ceiling or cloud cover obs.

PCL Equation Stats

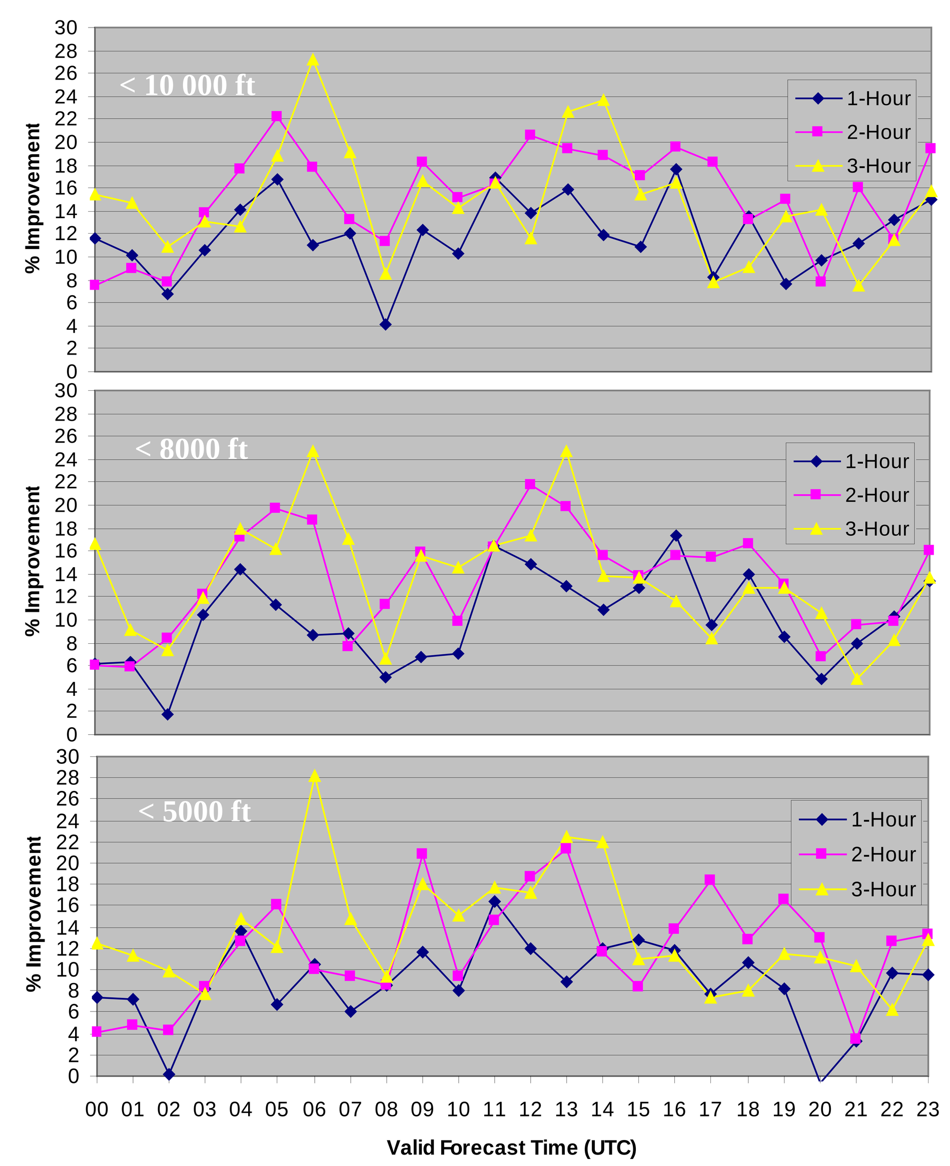
- -1-Hour equations: ob of predictor at initial time explained most of variance.
- -2-Hour equations: climatology more important predictor, sometimes explaining most of variance.
- -3-Hour equations: climatology term explained most of variance in more than half.

TESTS

COMPARISON TO BENCHMARK

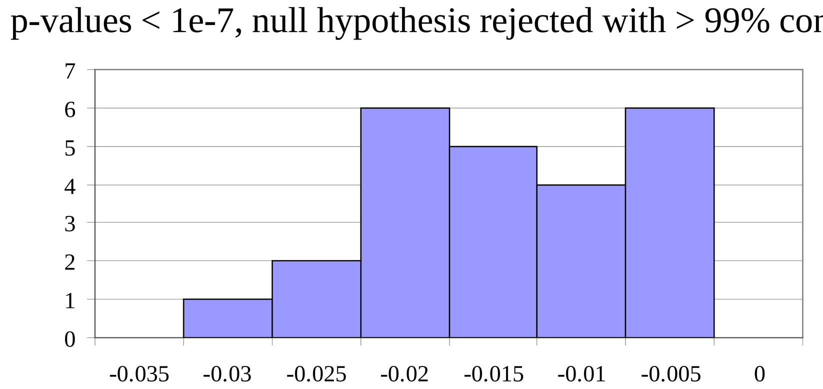
- OBS performance compared to PCL performance
- % Improvement (PI) calculated from Mean Square Errors (MSE) of OBS and PCL forecasts using independent data:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(o_i - f_i)^2 \qquad PI = \frac{(MSE_{obs} - MSE_{pcl})}{(MSE_{perfect} - MSE_{pcl})} \times 100$$



HYPOTHESIS TESTING

- Null hypothesis: $MSE_{OBS} - MSE_{PCL} = 0$.
- Distribution of MSE differences similar to chart below.
- Used nonparametric Wilcoxon Signed Rank test.
- p-values < 1e-7, null hypothesis rejected with > 99% confidence.



Distribution of 24 OBS and PCL MSE differences for 2-hour forecasts of ceilings < 8000 ft. Value of bin is upper bound.

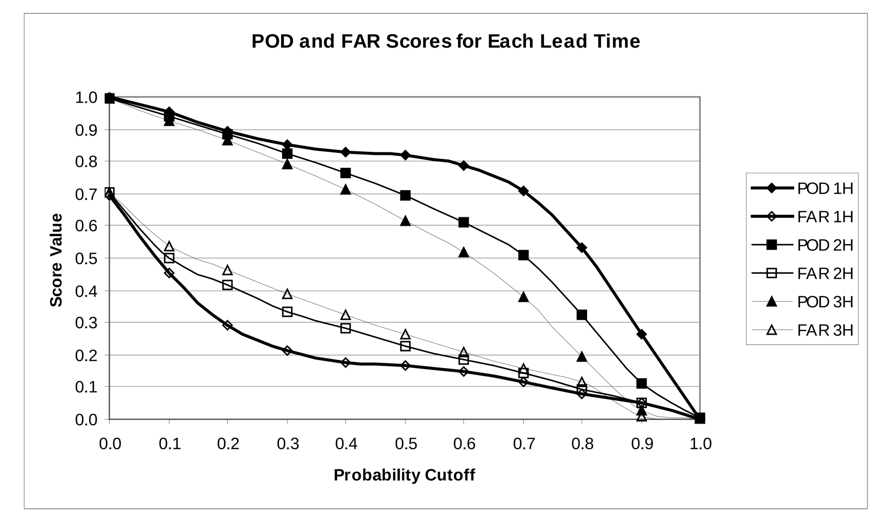
EQUATION PERFORMANCE

OBS POD and FAR scores using independent data. Values are averaged over 24 valid times in each ceiling height/lead time category.

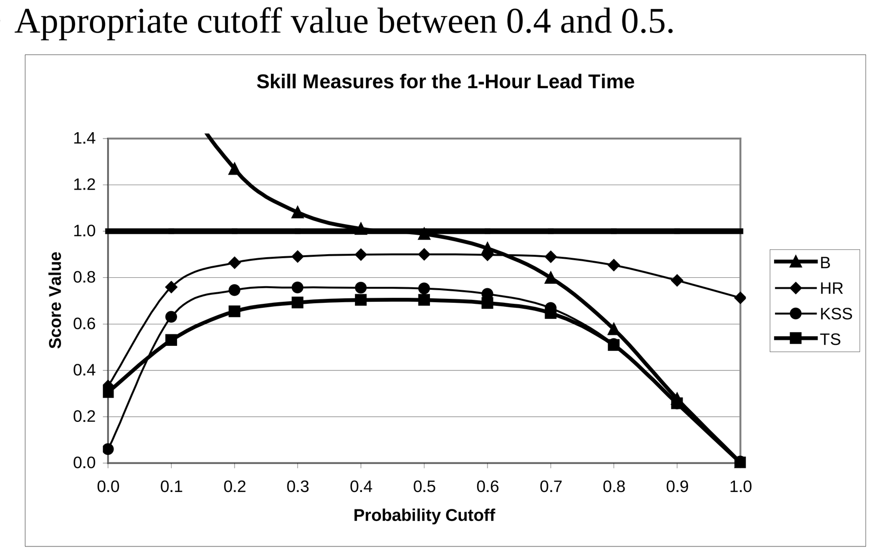
Lead Time by Score	*< 10 000 feet*	*< 8000 feet*	*< 5000 feet*
POD (Probability of Detection)			
1-Hour	0.83	0.83	0.80
2-Hour	0.73	0.70	0.65
3-Hour	0.67	0.63	0.54
FAR (False Alarm Rate)			
1-Hour	0.16	0.17	0.18
2-Hour	0.21	0.23	0.24
3-Hour	0.25	0.27	0.27

PROBABILITY CUTOFF

- Previous POD/FAR calculated with 0.5 as probability cutoff between Yes/No forecast
- Appropriate value needed for operations



- Wilks (1995) suggests using Threat Score (TS) and Bias (B) to determine best cutoff value where TS is max and B=1.
- Hit Rate (HR), Kuipers Skill Score (KSS) used to confirm.
- Appropriate cutoff value between 0.4 and 0.5.



SUMMARY AND CONCLUSIONS

SUMMARY

- 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.

TEST RESULTS

- **Final Conclusion:**
  - **-OBS equations performed well on independent dataset**
  - **-Indicates good performance in operations**
  - **-Produce more accurate forecasts than PCL**
- **OBS method: 9 - 15% improvement over PCL.**
- **Improvement statistically significant beyond 99% confidence.**
- PIs for 1-hour equations smallest; PIs increase with lead time; decrease with lower height category.
- **PODs higher than FARs indicating good performance.**
- Highest PODs/lowest FARs for 1-hour forecasts; degrade with increased lead time, but PODs higher than FARs.
- **TS, B, HR, and KSS values indicated large percentage of correct forecasts (TS and HR), unbiased (B = 1), and superior to random forecasts (KSS > 0).**

TEST RESULT ISSUES

- Equations explained **no more than 60% of variance** in data
- 3 possible explanations:
  - -Only surface observations used, upper-air data from rawinsondes, satellite, radar, 50 and 915 MHz profilers, or models may be needed.
  - -Surface data grouped into cool season stratified by time of day. Phenomenological stratification may be more useful.
  - -MLR may not be appropriate model.

OTHER STUDIES

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

OPERATIONAL USE

- **Equations to be used only in the cool season from October to March and only at the SLF.**
- All equations require input that is readily available from standard METAR code.
- Although developed for SMG, 45th Weather Squadron may use them to 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 and model data and forecaster experience.