WRSM and Future NASA Missions

by

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Why WRSM?

- Due to lack of spectrum at X-band (8.41 GHz) NASA's Deep Space missions are switching to higher frequencies (32 GHz Ka-band and optical) for their primary science downlink. While these frequencies have higher average capacity than X-band for the same amount of power spent on the spacecraft, the maximum average capacity is achieved at a lower weather reliability for them. WRSM is an attempt to use weather forecasting to increase the weather reliability of the link and to reduce its uncertainties at higher frequencies.

WRSM: Goals and Challanges

- Goal: To convert meteorological forecasts to relevant parameters for link design at the frequencies of interest (Ka-band and optical) and provide them on a timely basis to the missions.
- Challenges:
  - Defining the conversion algorithm.
  - Getting mission to use forecasts in a timely manner (requires change of mission operations philosophy).
  - Modifying the link design methods if necessary.

WRSM: Missions that may need it

Mission	Downlink
MRO	Prime X-band, Experimental Ka-band
Kepler	Prime Ka-band
SIM	Prime Ka-band
MTO	Prime Ka-band, Experimental Optical
JWST	Prime Ka-band (near-earth)
JIMO	Prime Ka-band

WRSM: A Closer Look at Challenges for the Missions

- Currently mission planning cycle time is about four weeks (MRO) for the background sequence with weekly updates through mini-sequences.
- Forecasts are good for at most four days in advance.
- In order for missions to use forecasts effectively they need to reduce their telecom planning cycle time.
- Some proposed solutions (brain-storming):
  - Separate sequencing for telecom with near real time commanding
    - Problem: Requires modifications to the data management system on the spacecraft with effective automatic handshaking between the spacecraft data management system and the telecom system.
  - Multiple data rate profile programming for the spacecraft. At the regular planning cycles program multiple data rate profiles for the same pass and based on the forecast select the most appropriate profile during the pass.
    - Problem: Requires additional planning resources by the mission. May not improve the performance much.

WRSM: Current Status

- Ka-band:
  - Developed an algorithm that converts meteorological forecasts from Space Flight Meteorological Group in NOAA into link design parameters for Goldstone DSCC (Slobin and Shambayati, JPL).
  - Developed the link design algorithm for Ka-band that uses the parameters generated by the forecasting algorithm.
  - Developed plans for MRO Ka-band demonstration to explore operational use of forecasting.
  - Obtained preliminary results for the performance of the forecasting algorithm.
- Optical:
  - No work has been done at this time.

Ka-band Forecasting: A Closer Look

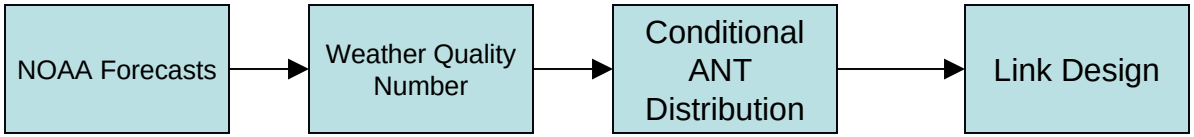
- RF link design requires an assumed value for the atmospheric noise temperature.
  - Traditionally, this value is the 90-percentile zenith atmospheric noise temperature.
  - The distribution of the zenith atmospheric noise temperature is obtained by collecting statistics of the atmospheric noise temperature from sky brightness measurements made by Water Vapor Radiometers (WVRs) and Advanced Water Vapor Radiometers (AWVRs).
- Forecasting at first attempted to convert meteorological forecasts directly to zenith atmospheric noise temperature values (Dr. Stephen D. Slobin, JPL).
  - These values were compared to AWVR measurements at the time of forecast and they were found to be off when cloudy conditions were forecast. This was due to lack of precise data about the cloud coverage.
  - However, it was found that these values do measure quality of the weather in that higher values indicate, in general, worse weather.

Ka-band Forecasting: A Closer Look (cont.)

- Since the predicted zenith atmospheric noise temperature was a good measure of the weather quality, the distribution of forecasts values were obtained and for every 5-percentile bin of forecast values, conditional atmospheric noise temperature distributions were obtained from AWVR measurements.
- These conditional atmospheric noise temperature distributions are used for the link design.
  - Obtaining the conditional distributions is called the calibration of the algorithm and requires significant amount of forecasts and concurrent WVR observations (at least 3 years).

Ka-band Forecasting: A Closer Look (cont.)

- Algorithm for Ka-band Forecasting:
  - Obtain the meteorological forecast from NOAA.
  - Convert the NOAA forecast to a weather quality number.
  - Find the conditional atmospheric noise temperature distribution associated with the weather quality number.
  - Design the link according to the conditional distribution.

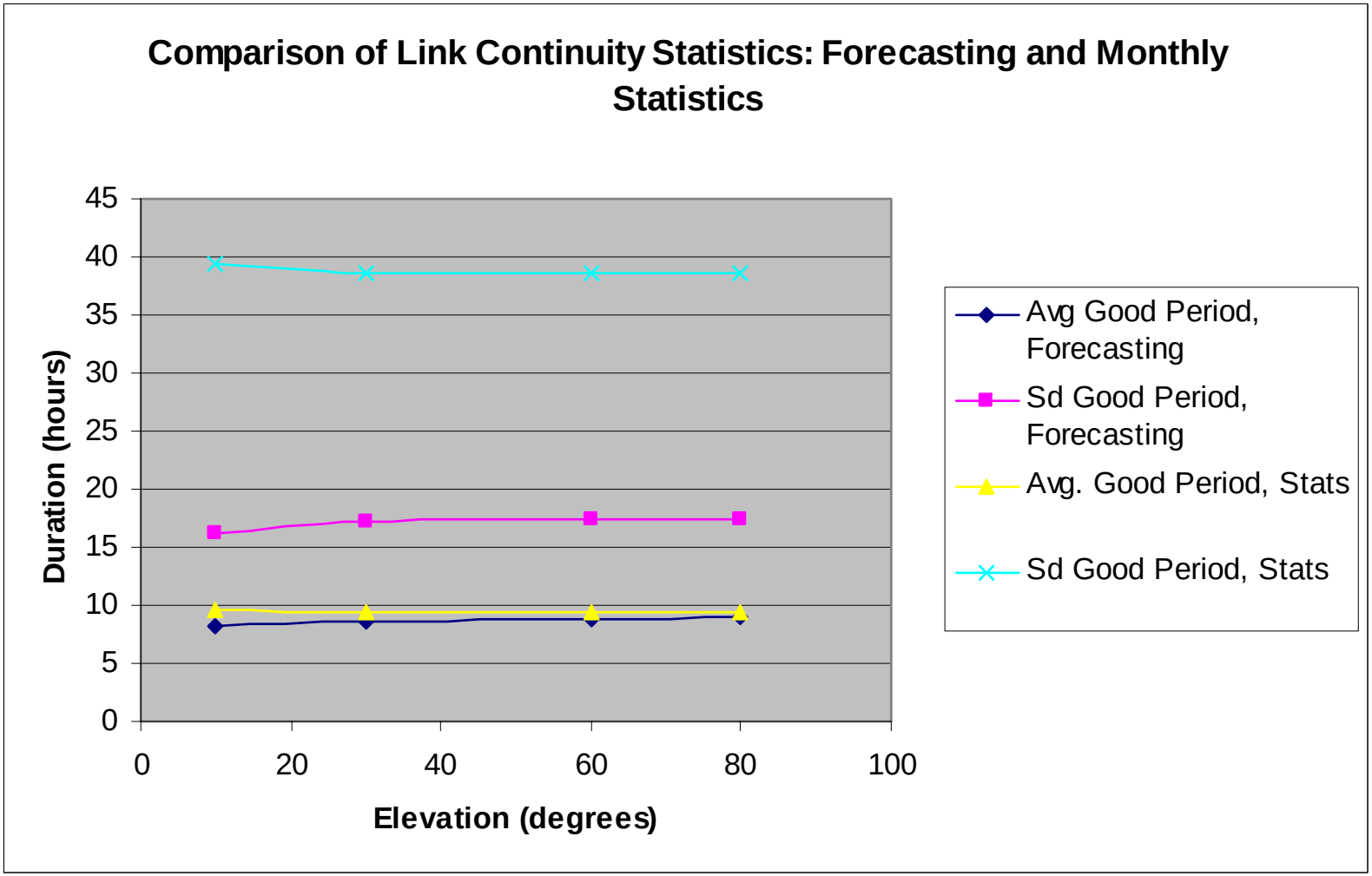


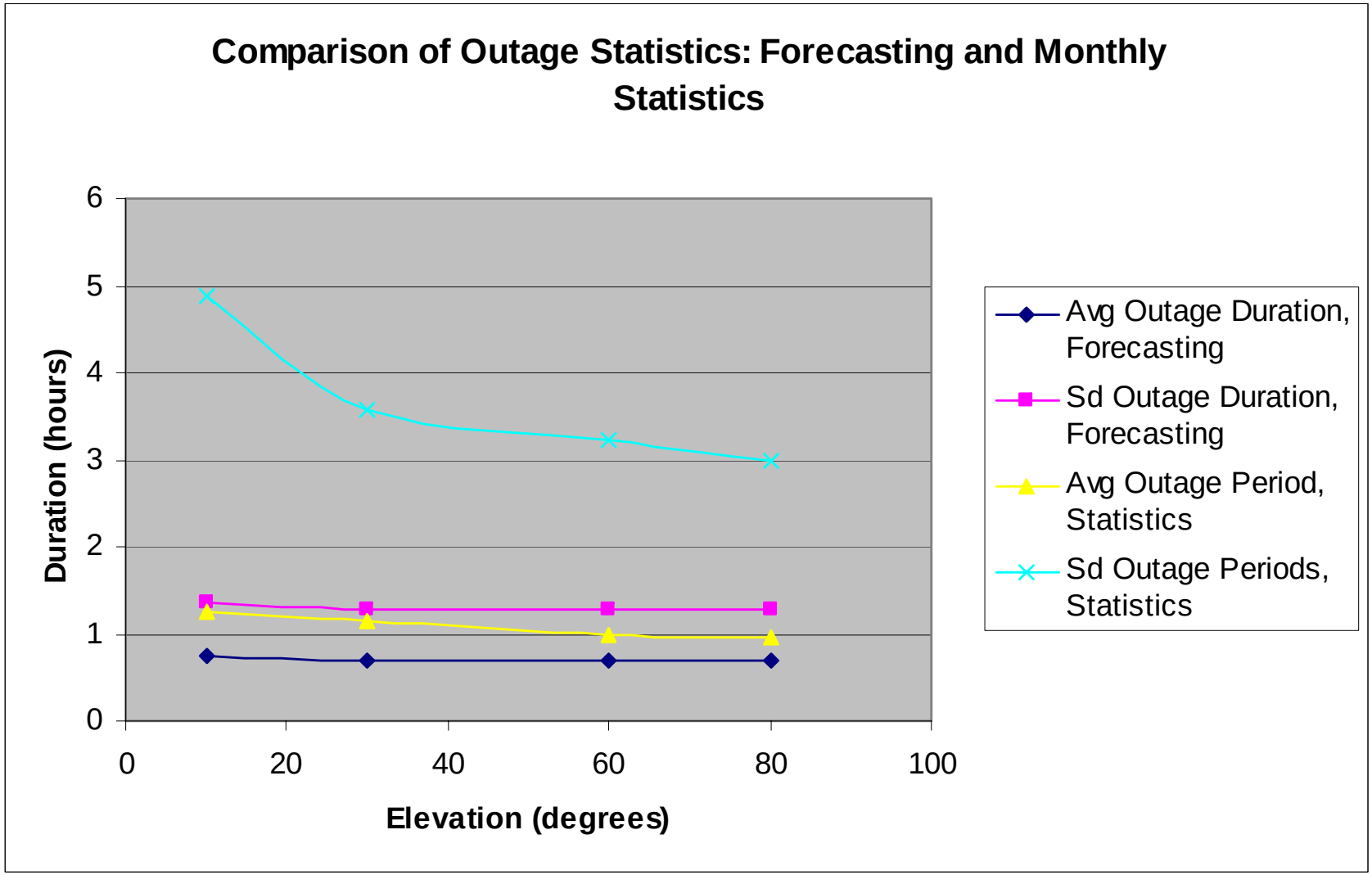
WRSM: Reducing Uncertainty for the Missions

- Uncertainty on the link is associated with the outage and good period durations (continuity) of the link. If the outage period is too long, the spacecraft buffer could overflow. To avoid such a scenario, missions have to carry large buffers. Similarly, if good periods are too short, completeness of the data may be affected.
- WRSM could help reduce the maximum length of outage periods and increase the number of good period with long enough durations.

WRSM: Example of Uncertainty reduction

- The continuity statistics at different elevations with and without forecasting were obtained for a time period from September 2003 through April 2004. Forecasting Reduced both the mean and the standard deviation of outage periods while slightly reducing the mean of good periods and significantly reducing their standard deviations.


Comparison of Link Continuity Statistics: Forecasting and Monthly Statistics
Duration (hours)
45
40
35
30
25
20
15
10
5
0
0
20
40
60
80
100
Elevation (degrees)
Avg Good Period, Forecasting
Sd Good Period, Forecasting
Avg. Good Period, Stats
Sd Good Period, Stats


Comparison of Outage Statistics: Forecasting and Monthly Statistics
Duration (hours)
0
1
2
3
4
5
6
0
20
40
60
80
100
Elevation (degrees)
Avg Outage Duration, Forecasting
Sd Outage Duration, Forecasting
Avg Outage Period, Statistics
Sd Outage Periods, Statistics

WRSM: Making it Useful for Future Missions

- Ka-band:
  - Improve the forecasting algorithms.
  - Extend the algorithms to Canberra and Madrid DSCC (requires 3 to five years of WVR data collection for these sites simultaneously with NOAA forecasts).
  - Work out an operational methodology acceptable to future missions to maximize the benefits of forecasting (MRO Ka-band demo).
- Optical:
  - Identify link budget parameters that are affected by the weather.
  - Devise algorithms to estimate these parameters from meteorological forecasts.
  - Identify possible optical ground tracking station sites and collect statistics (both in terms of link parameter measurements and forecasts) for those sites.
  - Etc. (?)