Spin Axis Attitude Determination (SAAD) Package

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What's to come...

- Overview of spin axis attitude determination
  - When? Why? How?
- Spin axis attitude determination algorithms
  - Brief intro to those used in SAAD
- Solution of a sample case
  - Data generated, noise and biases added
  - Highlight features of the package from data entry through final solution

Spin Axis Attitude Determination

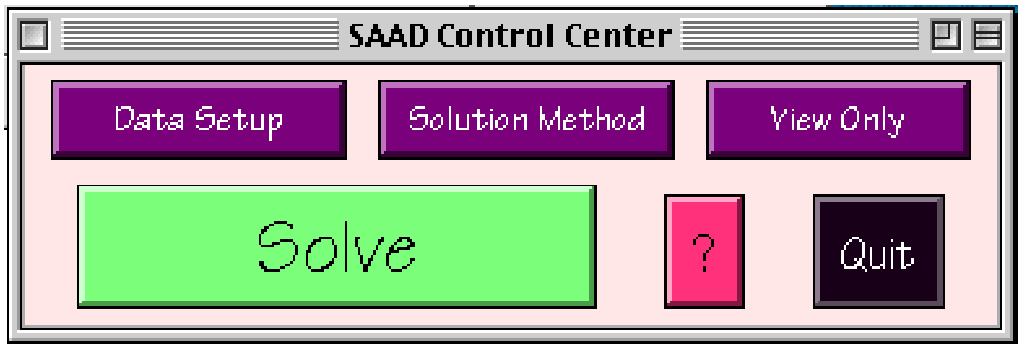
- Used in spinning geosynchronous transfer orbit
- Need to point the spacecraft accurately for the solid rocket apogee firing, which circularizes orbit
- A few tenths of a degree error in declination will have significant effect on the life of the spacecraft
- Measurements taken using sun sensor and horizon sensors
- Typically, very large data sets of noisy data with numerous systematic errors
- Problem is poorly conditioned

SAAD Methods

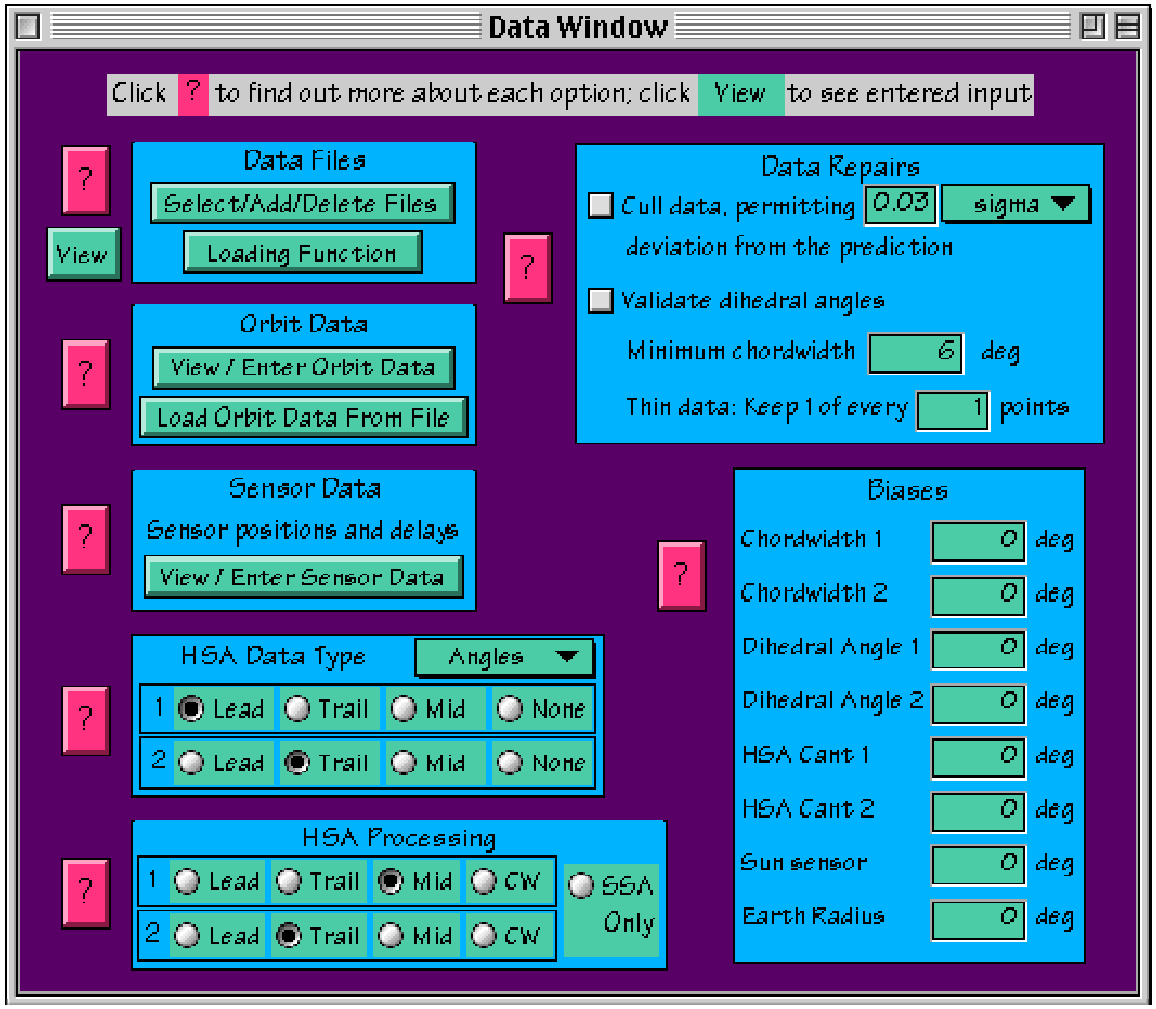
- Two types of algorithms - closed form and numerical
- Closed Form - solve analytically
  - Single Frame and Batch Shuster
  - Cone Intercept
- Numerical - solve iteratively
  - Differential Corrector
  - Conjugate Gradient
  - Kalman
  - Nelder-Mead

Starting SAAD Package

- Start by typing SAAD at the Matlab prompt
- Main control window (below) gives access to
  - Data entry and setup functions
  - Solution method selection and setup
  - Commands to solve or view the data
  - Help

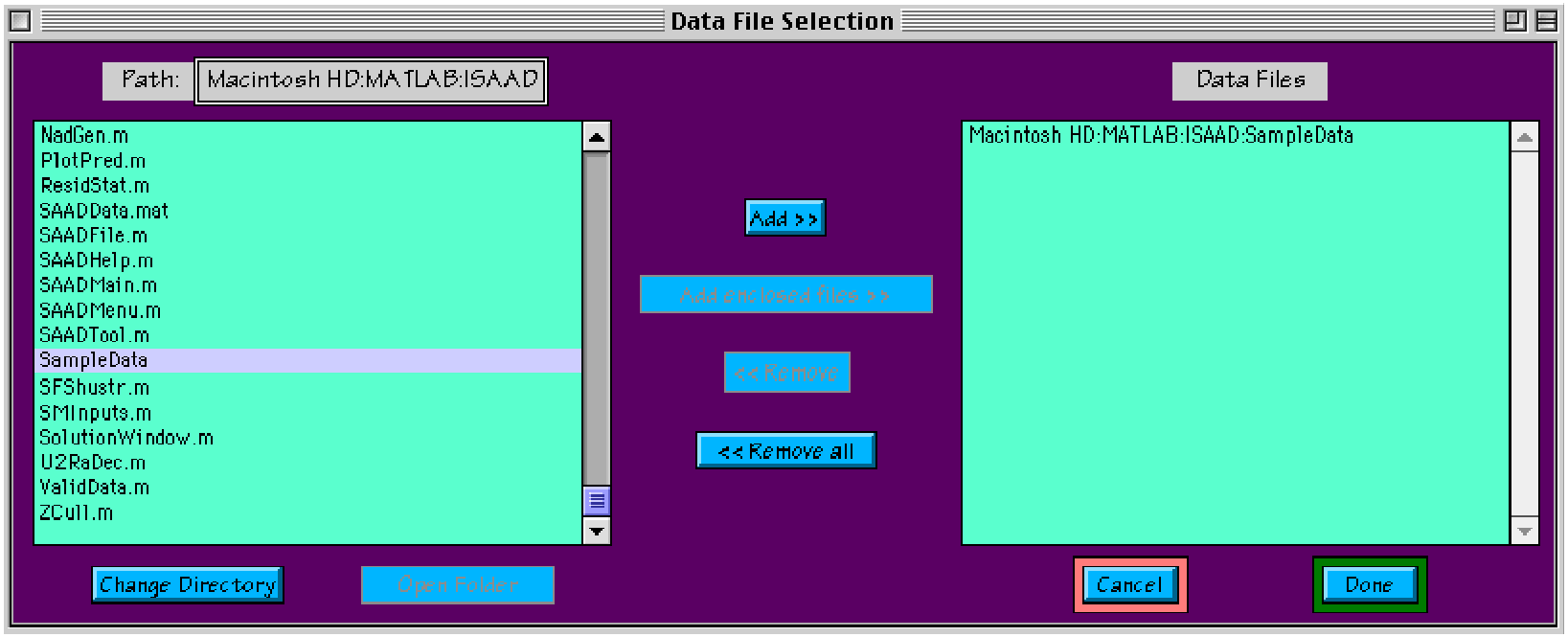


Data Setup Window



Data File and Loading Function Selection

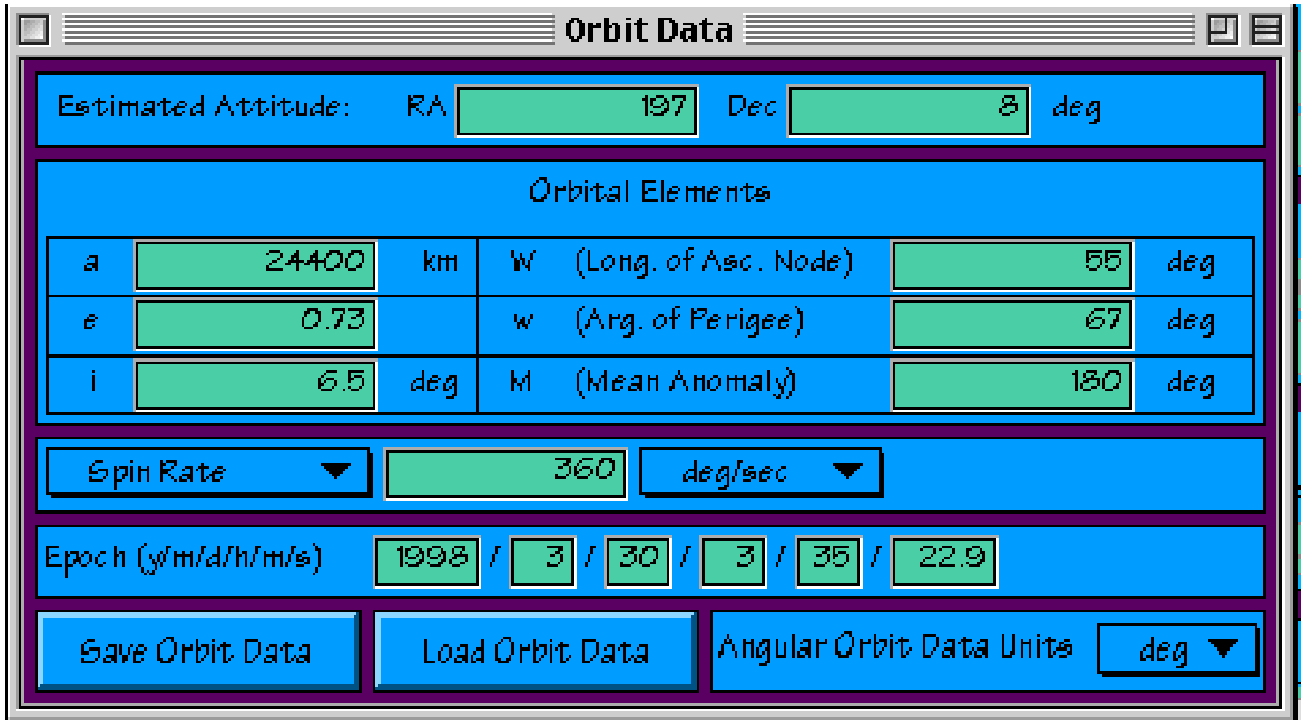
- GUI allows unlimited number of data files



- File dialog used for loading function selection. Loading function is customized for data format.

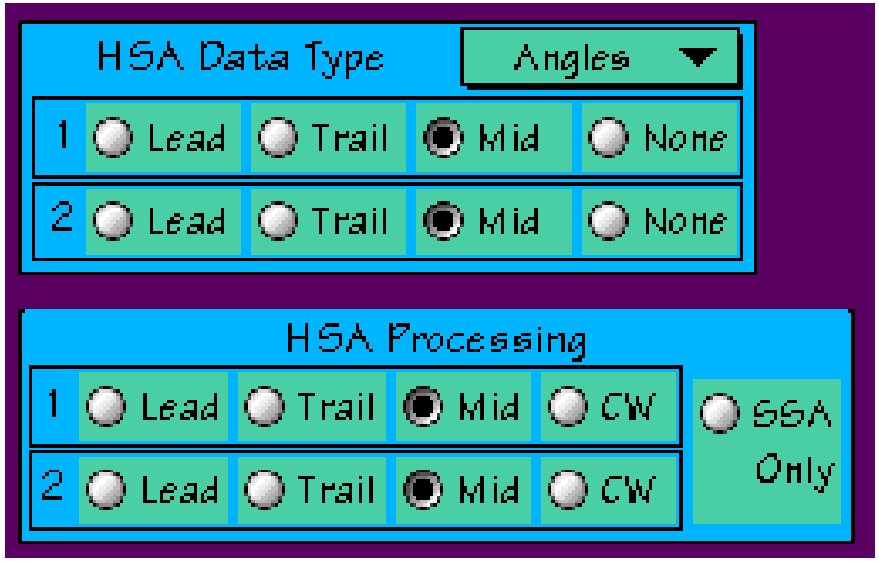
Load the Orbit Data

- Orbital elements from the current apogee must be used
- Estimated attitude is required



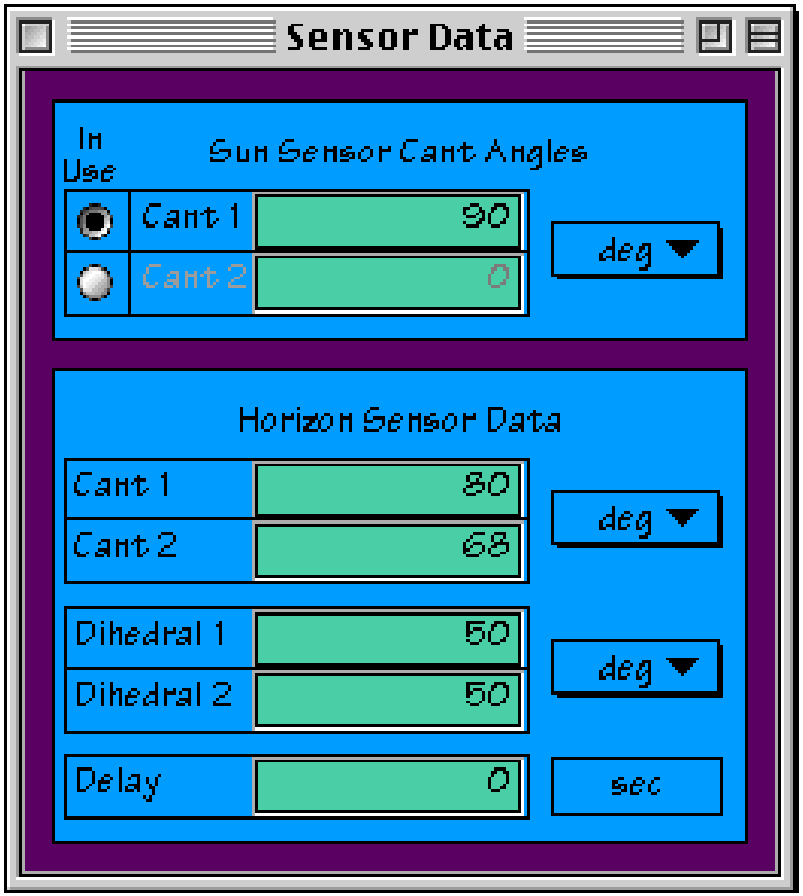
HSA Data and Processing

- HSA data can be input in a number of forms
- Processing usually done with midscan dihedral angles
- Other processing options allow attitude solution when full measurements are not available

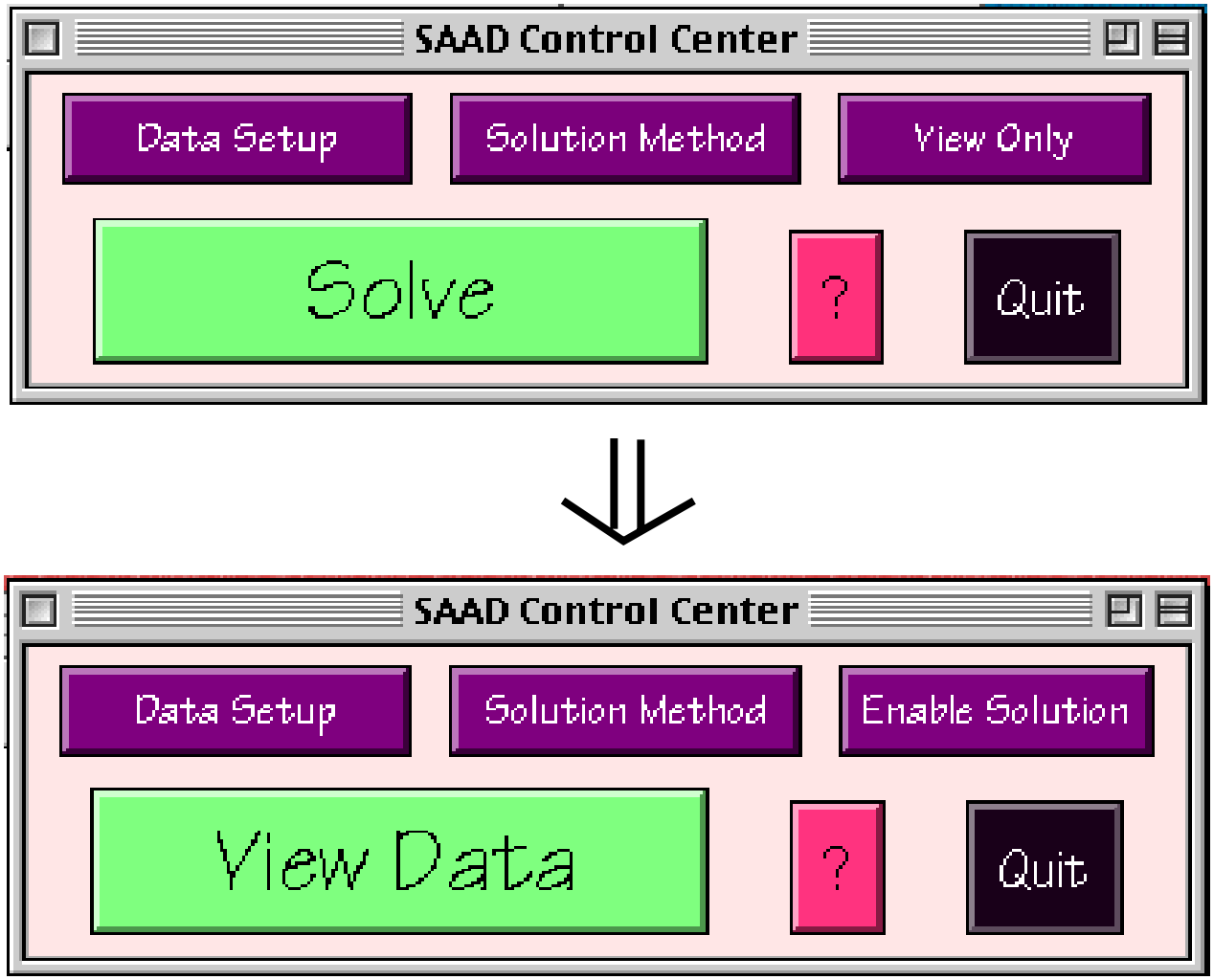


Sensor Data

- Need to enter sensor positions on the spacecraft
- HSA time delay will create a dihedral angle bias that varies with spin rate



Viewing the Data



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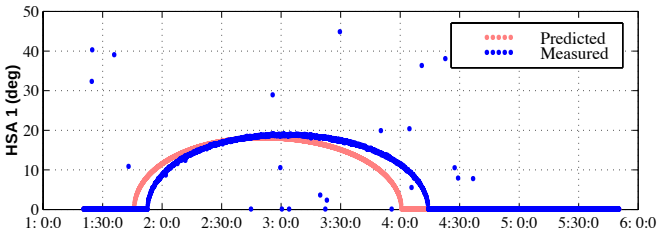
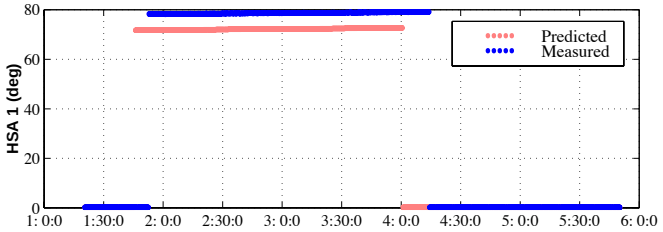
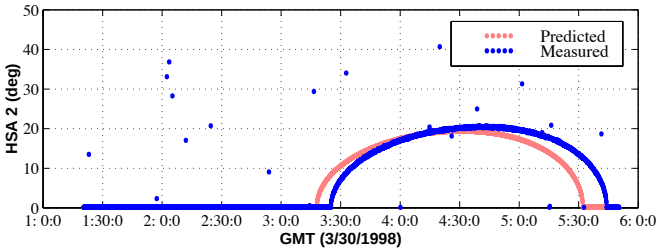
The Sample Data

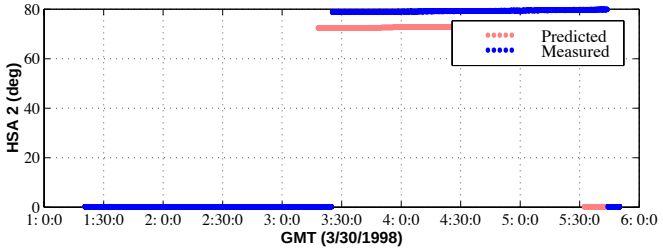
- Viewing the data produces
  - —plots of predicted vs. measured data
  - —residual plots (measured-predicted) and a
  - —residual statistics, consisting of the mean and standard deviation of each measurement. Separate statistics are computed for each HSA.
- Predicted vs. Measured plots for each sensor are shown next.

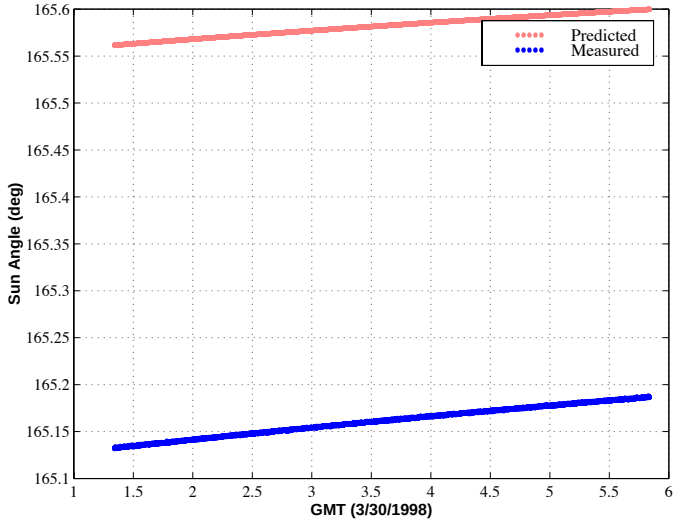
The Sample Data (cont.)





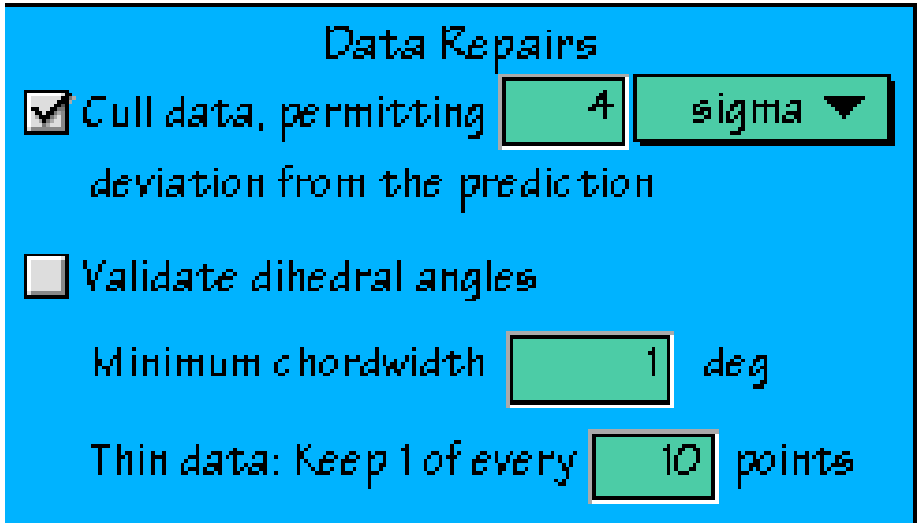






Data Validation

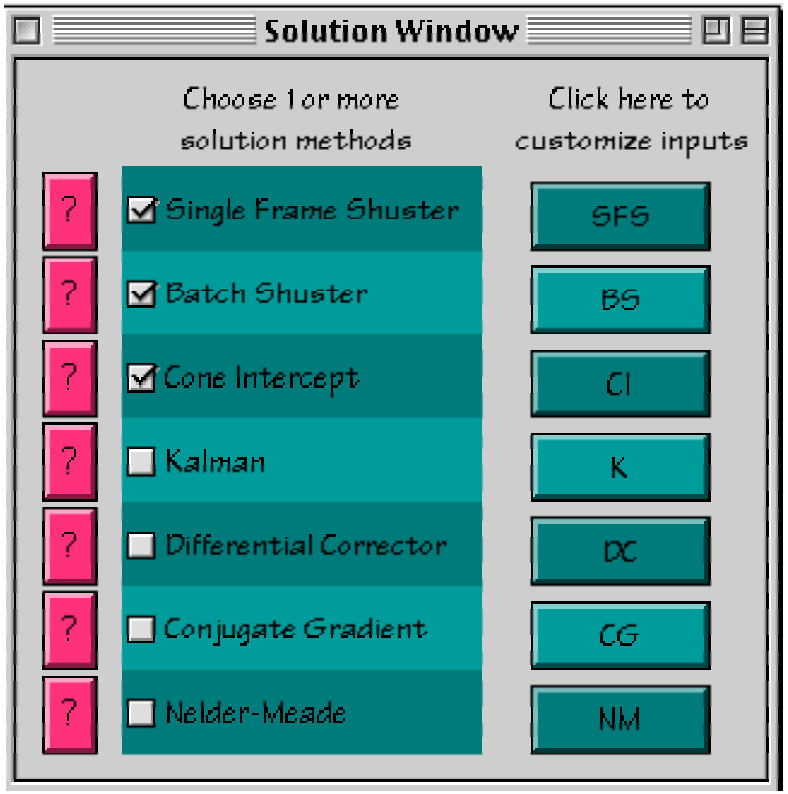
- SAAD includes a number of tools for validating and conditioning the data
  - —Culling
  - —Validating dihedral angles
  - —Minimum chordwidth
  - —Thinning the data



- Accessed through the Data Repairs block of the Data Window

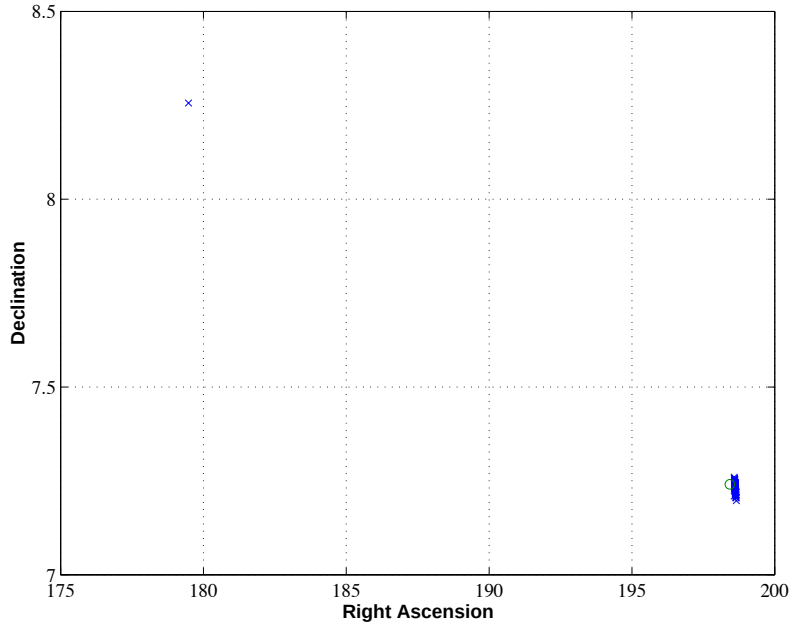
Getting an Attitude Estimate

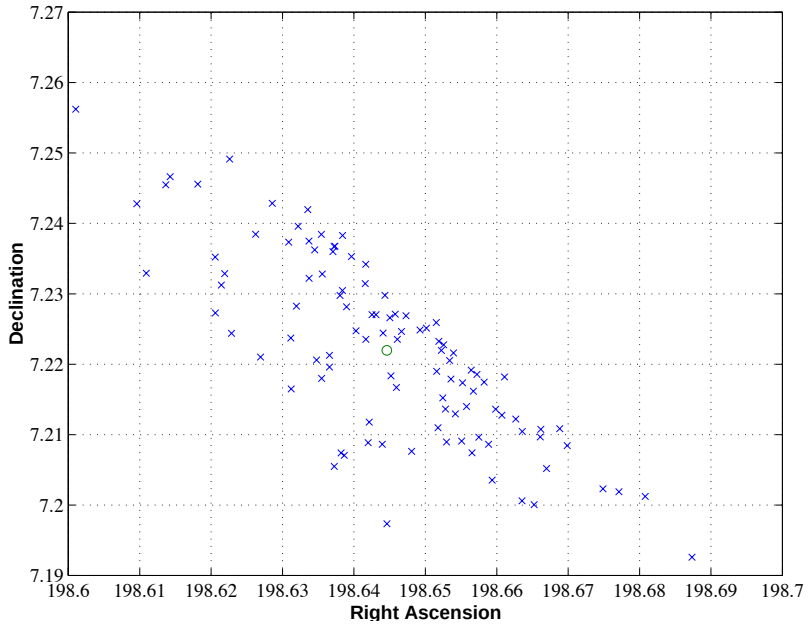
- Use closed form methods
- Methods are selected using the Solution Window
- Results should be nearly the same from each, differences may indicate dihedral and/or earth radius biases
- Single Frame Shuster and Cone Intercept produce plots of the algorithm results



Single Frame Shuster Results

- Results show each of the Shuster solutions for HSA 1 (left) and HSA 2
- Notice the spurious data point on the HSA 1 plot





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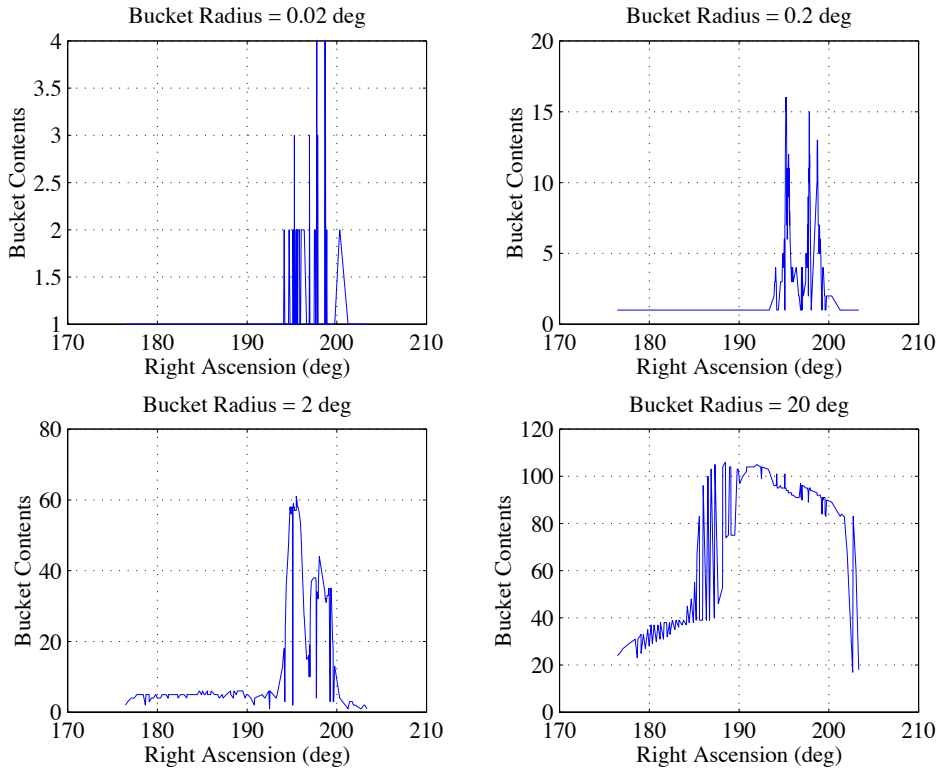
Numerical Results

Solution Method	HSA	Right Ascension	Declination
Single Frame Shuster	1	198.43	7.24
	2	198.64	7.22
Batch Shuster	1	198.41	7.25
	2	198.65	7.22
Cone Intercept	1	195.49	-16.79
	2	197.84	7.89

- Difference between Shuster and Cone Intercept indicates likely dihedral and/or earth radius biases
- Cone intercept 1 result indicates possible problem

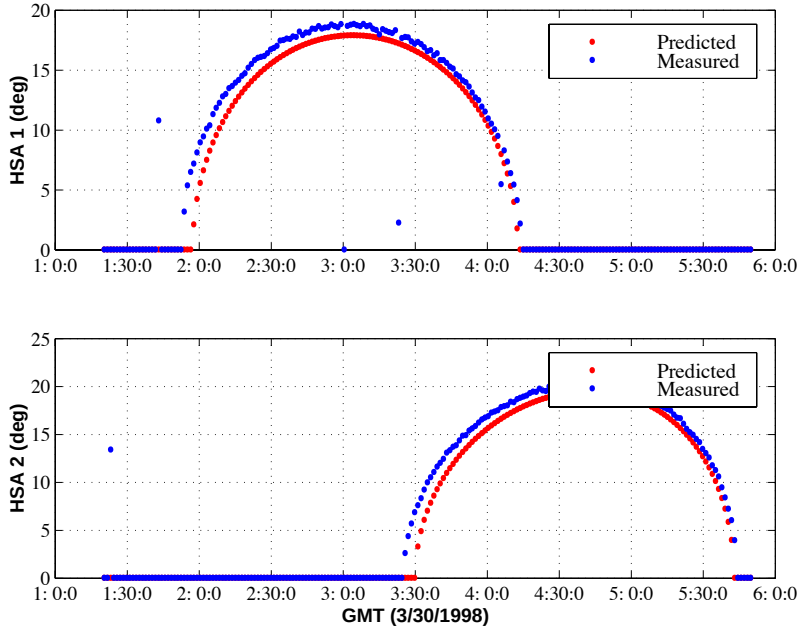
Cone Intercept Results

- Plots show a tie in the 0.02° buckets (upper left).
- Algorithm moves to next larger bucket to break the tie, in this case an error results.
- Possibly too little data being used.



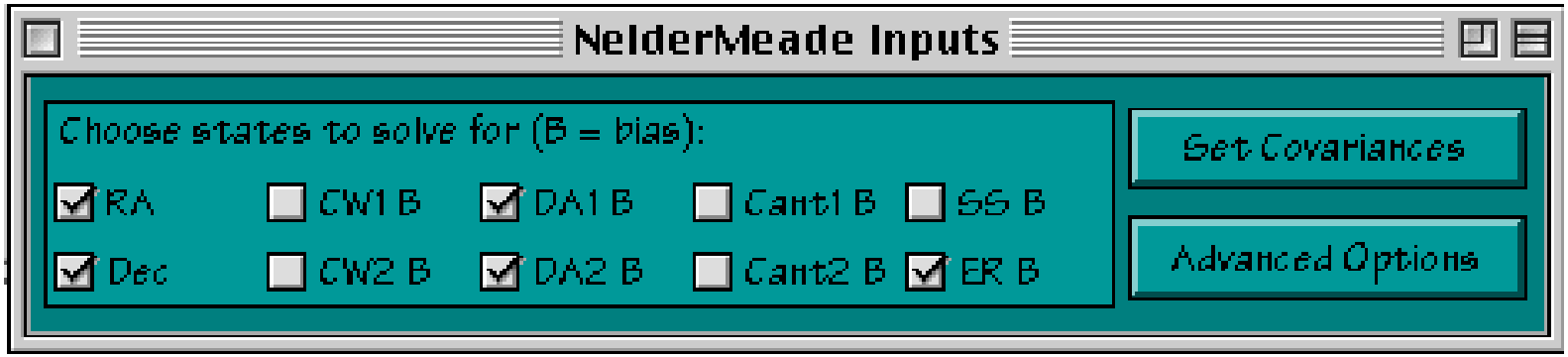
Adjust Estimated Attitude

- Enter new attitude in orbit window: RA = 198.5, Dec = 7.23
- View data again
- “Fat” chordwidths indicate earth radius bias



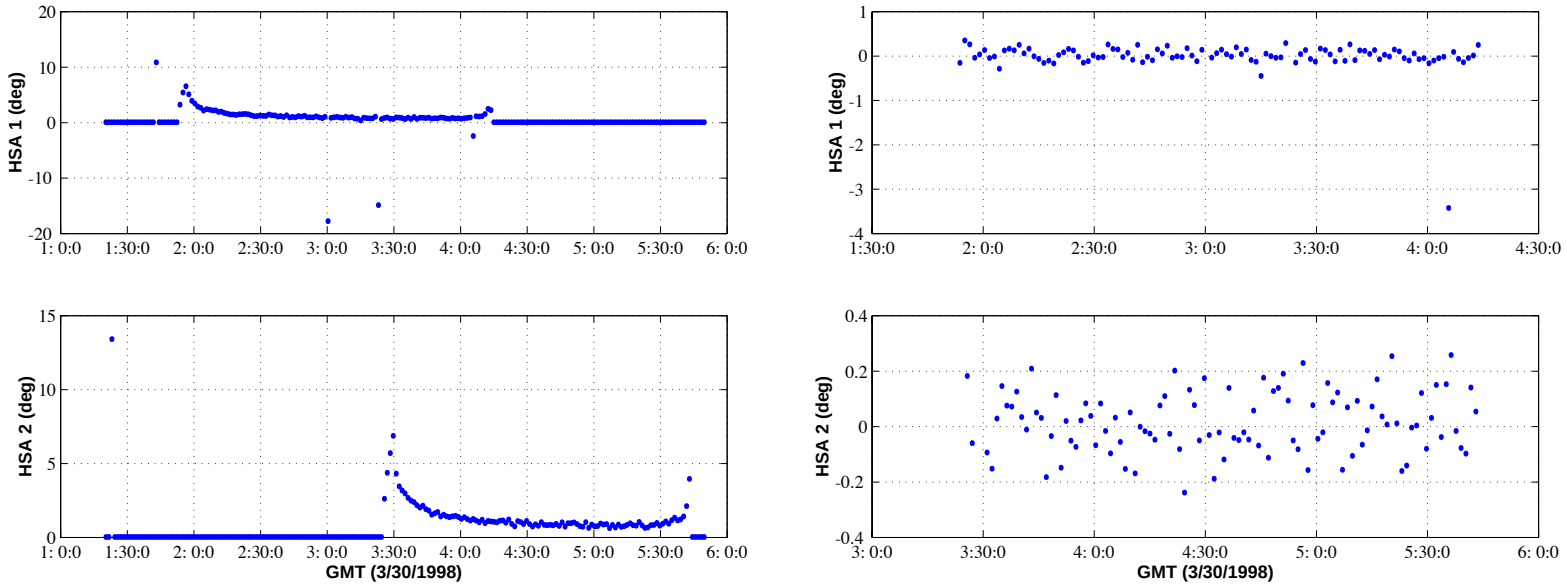
Least Squares Solution

- Start with Nelder-Mead
- Deselect closed form methods in the solution window, select Nelder-Mead
- Select states to be solved for



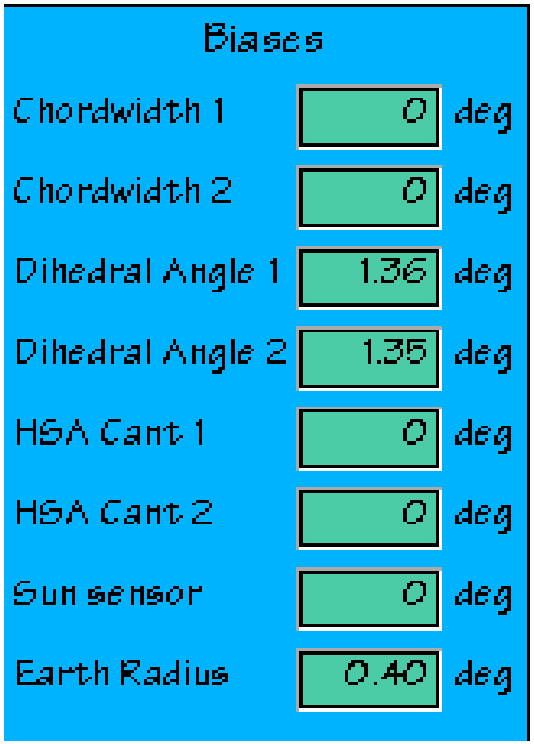
Nelder-Mead Results

- Residual statistics and plots indicate a much improved solution
- Chordwidth residuals before and after



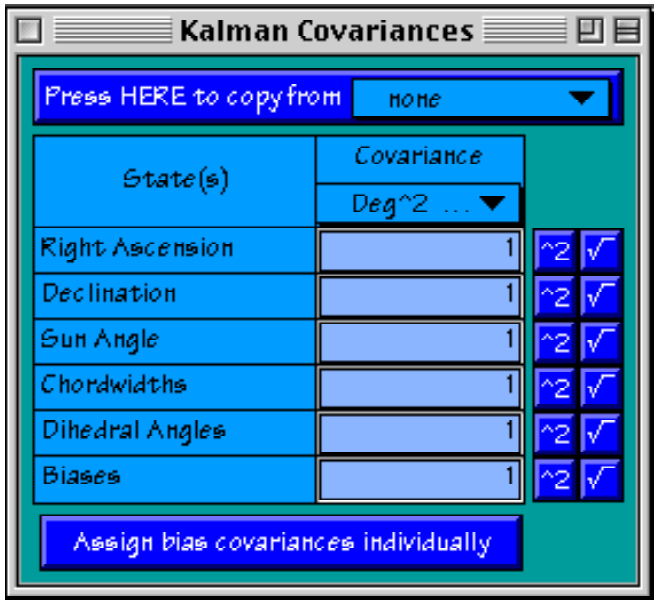
Further Refinement of the Solution

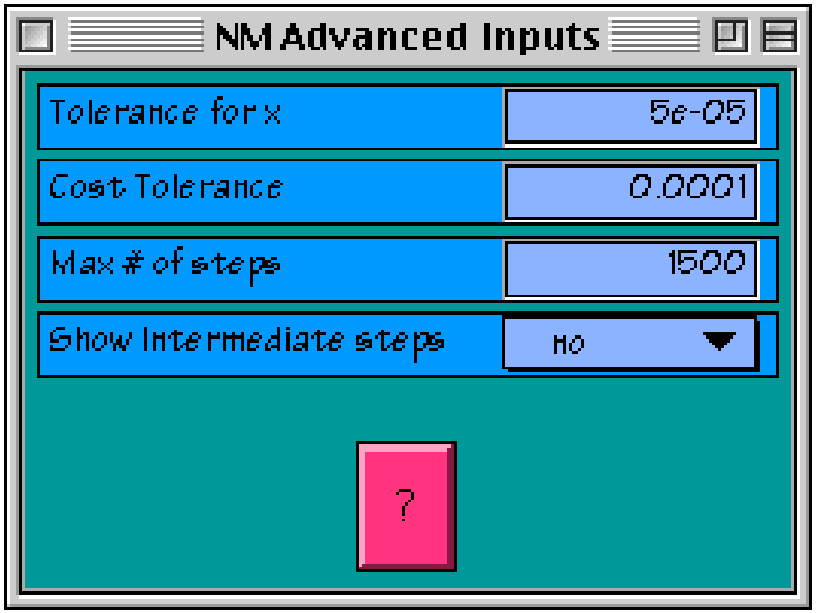
- Enter biases and attitude solution and rerun Nelder-Mead
- Run other numerical methods
- Solve for additional, or fewer, biases
- Adjust data thinning value
- Adjust culling threshold



Advanced Input Options

- All numerical methods use initial state covariance values
- A flexible covariance entry window exists for each method
- Other advanced options include maximum iterations and ending tolerances





Final Attitude Solution

- To reach the final solution
  - —Reran Nelder-Mead with new attitude and biases
  - —Added sun sensor bias
  - —Reduced culling threshold from 4 sigma to 3° (~1.6 sigma)
  - —Ran all other method using results from above, which are shown at right

State	Value (deg)
Right Ascension	198.29
Declination	7.48
Dihedral Angle Bias (HSA 1)	1.42
Dihedral Angle Bias (HSA 2)	1.42
Earth Radius Bias	0.40
Sun Sensor Bias	-0.02

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Final Attitude Solution (cont.)

Solution Method	HSA	Right Ascension	Declination
Single Frame Shuster	1	198.29	7.48
	2	198.29	7.48
Batch Shuster	1	198.29	7.48
	2	198.29	7.48
Cone Intercept	1	198.31	7.46
	2	198.29	7.49
Kalman	Both	198.30	7.48
Differential-Corrector	Both	198.30	7.48
Conjugate Gradient	Both	198.29	7.48
Nelder-Mead	Both	198.30	7.48
True Attitude		198.30	7.50

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Conclusion

- GUI features make SAAD much easier to use
- Tools allow visual and numeric validation and conditioning of data
- Variety of algorithms enhances reliability of the solution
- Bias calculation and use made much simpler
- Advantages in speed because data is only read from file once, but can be processed an unlimited number of times