An Assessment of Reprocessed GPS/MET Observations Spanning 1995-1997

Anthony J. Mannucci[1]
Chi Ao[1]
Byron A. Iijima[1]
Panagiotis Vergados[1]
E. Robert Kursinkski[2]
Sean Healy[3]
Andras Horanyi[3]
William S. Schreiner[4]

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]Space Sciences and Engineering, LLC
[3]European Centre for Medium-Range Weather Forecasts, Reading, UK
[4]University Corporation for Atmospheric Research

Session 2: Climate
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The trove of GPS/MET data spanning 1995-1997 is underutilized

Testing GPS/MET data in ERA5

From S. Healy, A. Horányi and A. Simmons “Assessing the impact of GPS radio occultation measurements in ERA5”

- New data set: reprocessed data with anti-spoofing encryption (AS-ON) available at CDAAC

Positive impact despite higher noise of AS-ON data

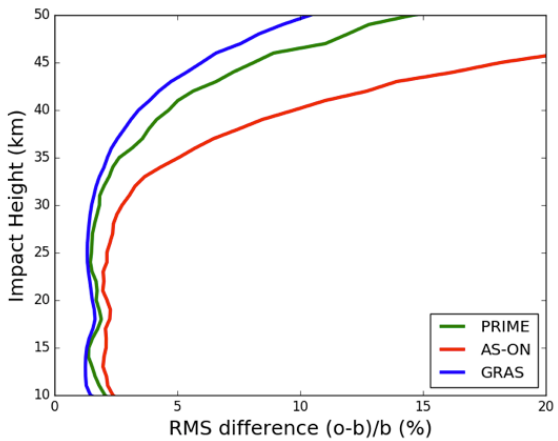
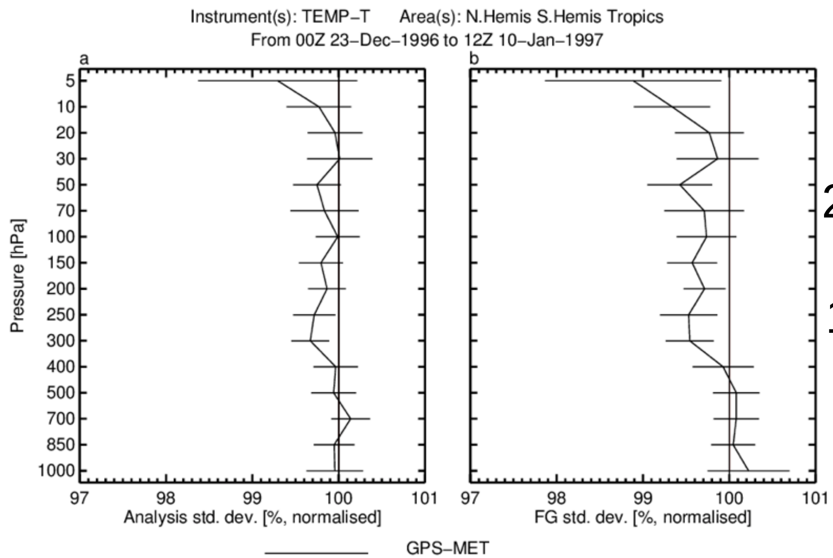


Figure 7: Global GPS/MET and operational GRAS bending angle statistics for reference.



23-Dec-1996
to
10-Jan-1997

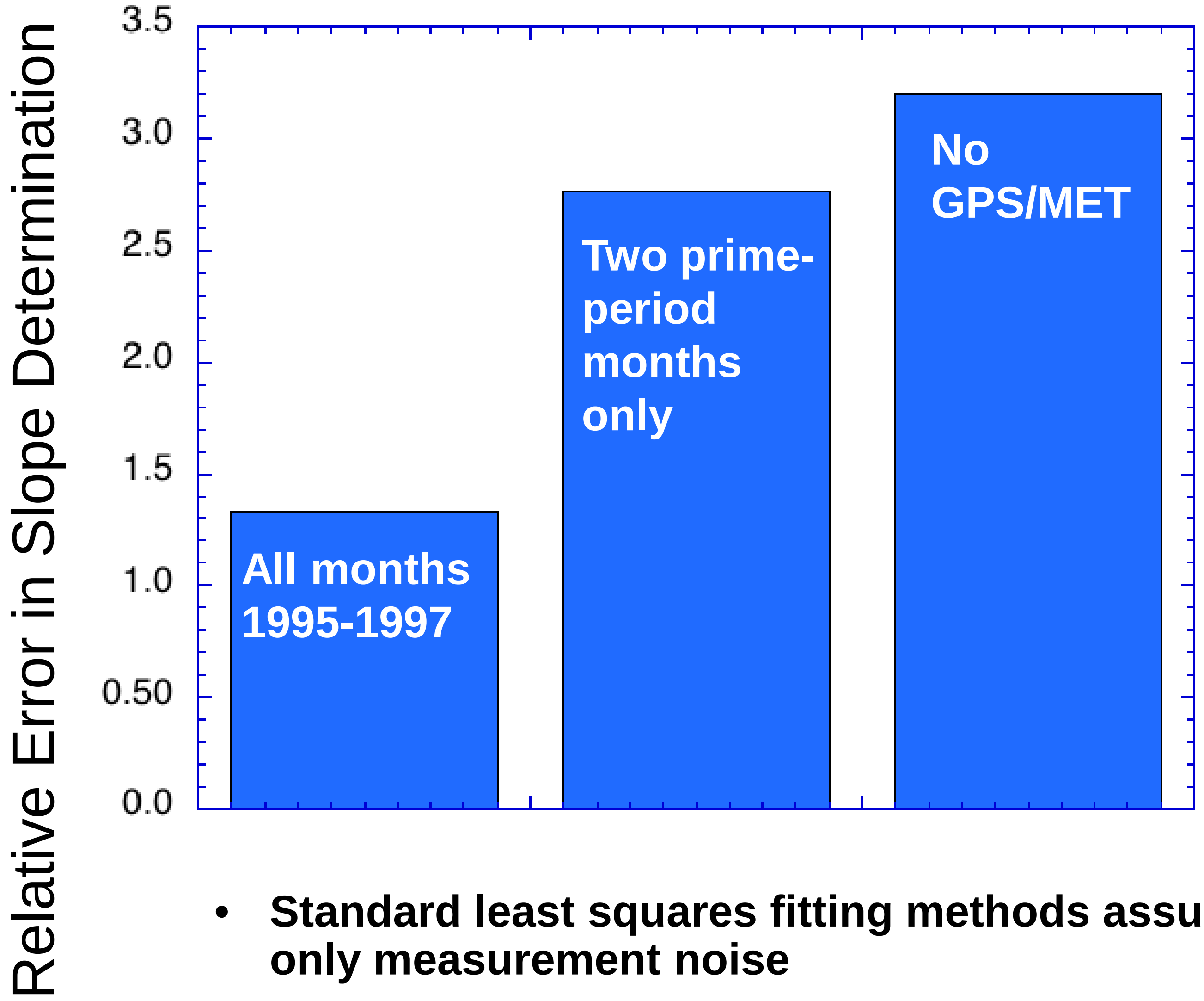
Figure 8: The percentage reduction in the first-guess (FG) and analysis departure statistics for radiosonde temperature measurements, as a result of assimilating GPS/MET AS-ON data.

Why are we concerned with data as far back as 1995?

(~25 years ago!)

Answer: to determine climate trends

Benefit of GPS/MET Data to Trend Determinatio



- **Standard least squares fitting methods assuming only measurement noise**
- **Assumes monthly data of unit variance (up to 2015)**

Natural Variability Affects Trend Determination

- **Natural variability reduces the benefit of GPS/MET data in slope determination**

Uncertainty in slope

"Noise" due to natural variability

Measurement noise

$$\langle(\delta m)^2\rangle \simeq 12\,(\Delta t)^{-3}(\sigma_{\mathrm{var}}^2\tau_{\mathrm{var}} + \sigma_{\mathrm{meas}}^2\tau_{\mathrm{meas}})$$

Time period of observations

Benefit of GPS/MET reduced by 30% using assumptions in Leroy et al., 2008 (e.g. CLARREO mission)

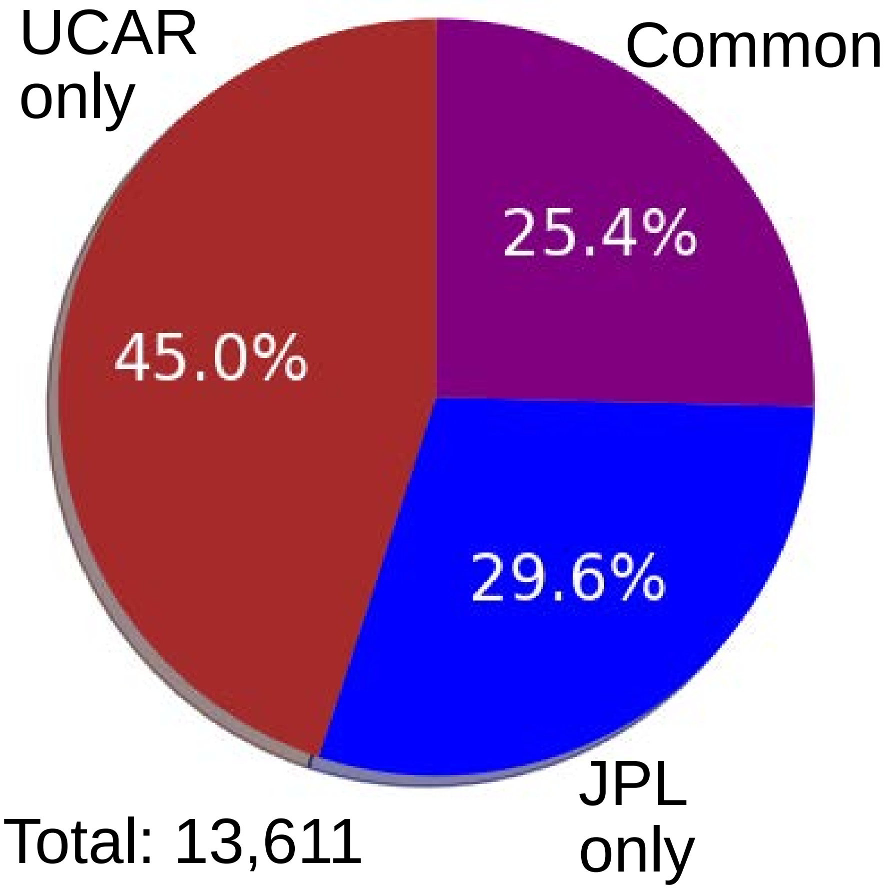
The “New” GPS/MET Data Sets

Reprocessed GPS/MET data including encryption ON (CDAAC)

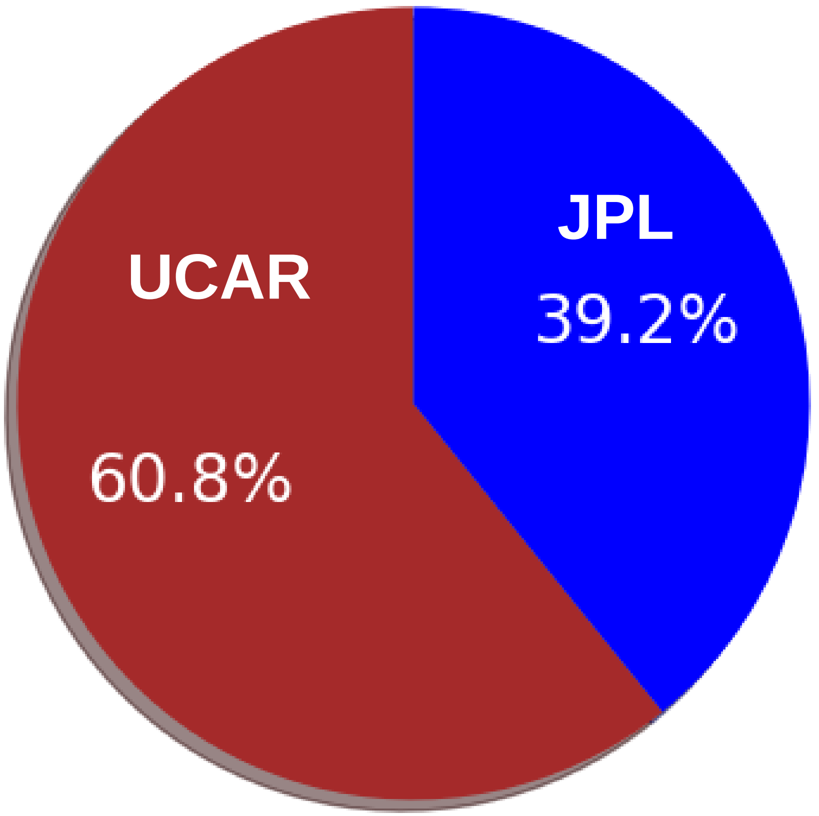
Dated to 2007

Single-frequency retrievals (JPL)

New Data Sets



Total: 13,611
unique profiles

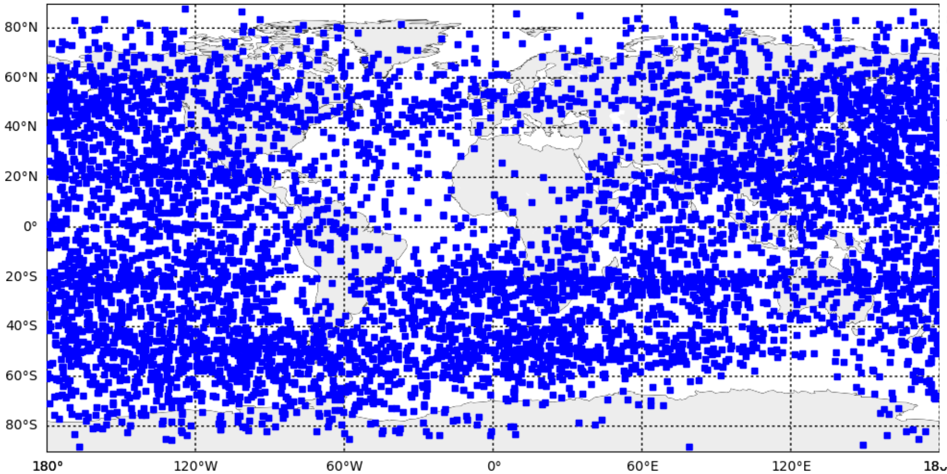


15,752 profiles
including overlap

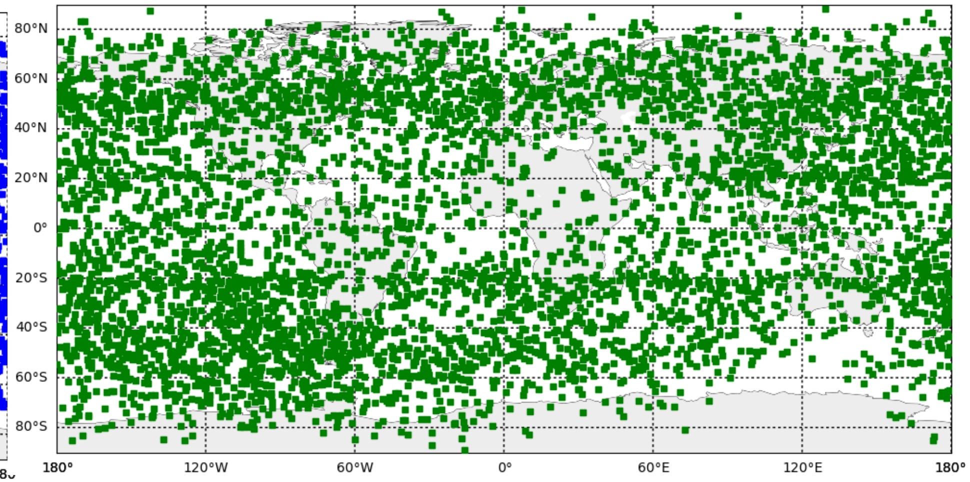
Data set used in previous studies: 2,890 total profiles

Geographic Distribution

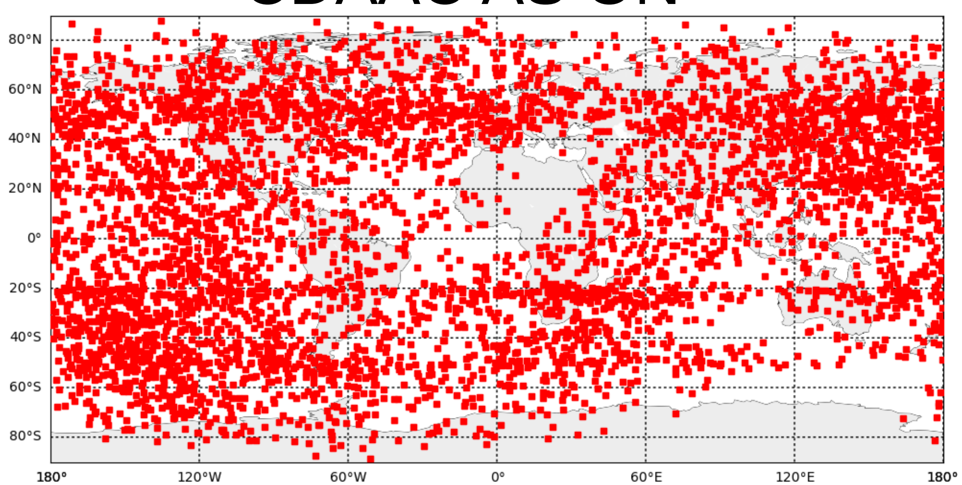
JPL



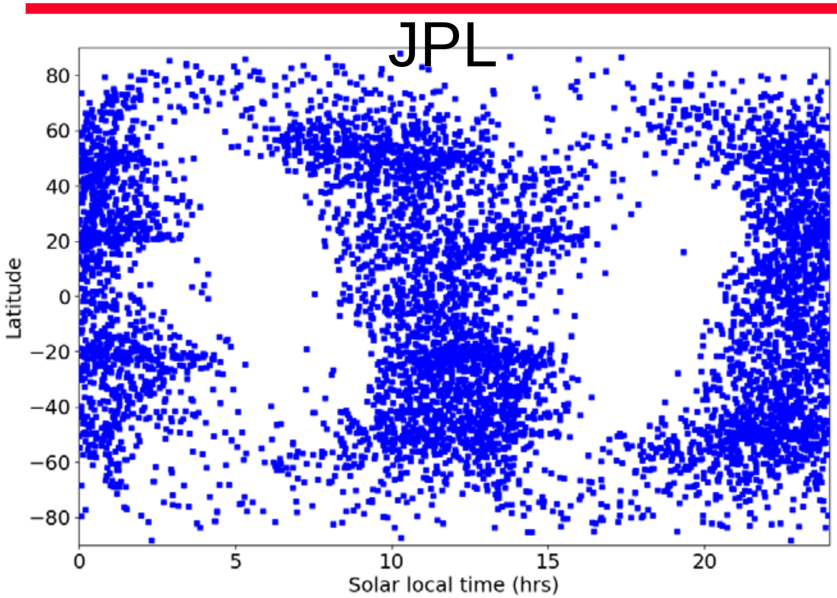
CDAAC AS OFF

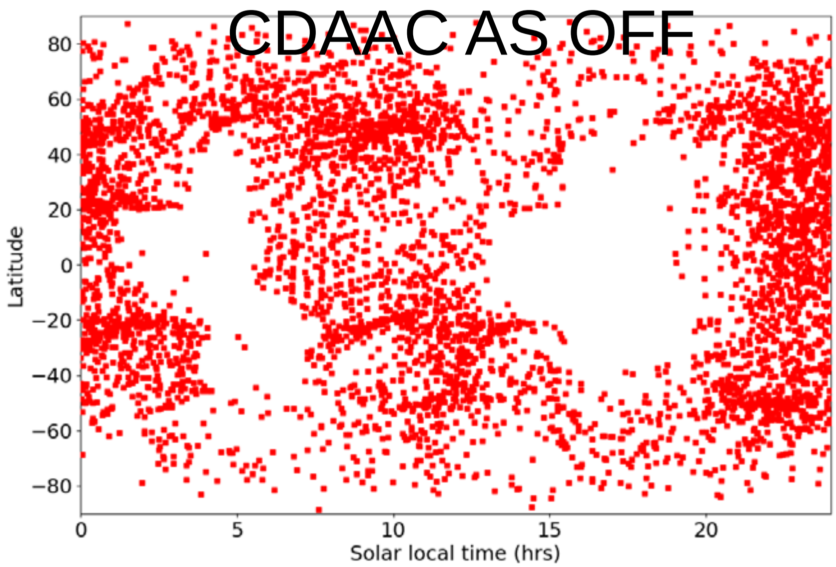


CDAAC AS ON

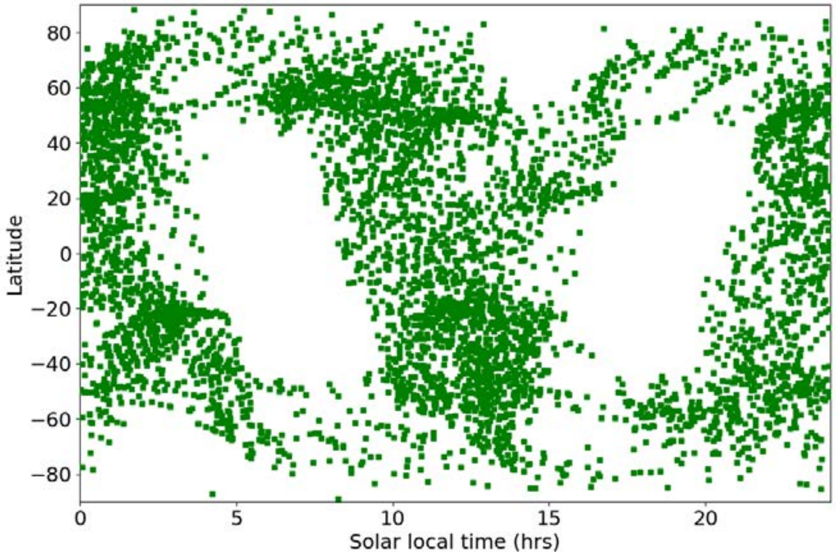


Solar Local Time Distribution



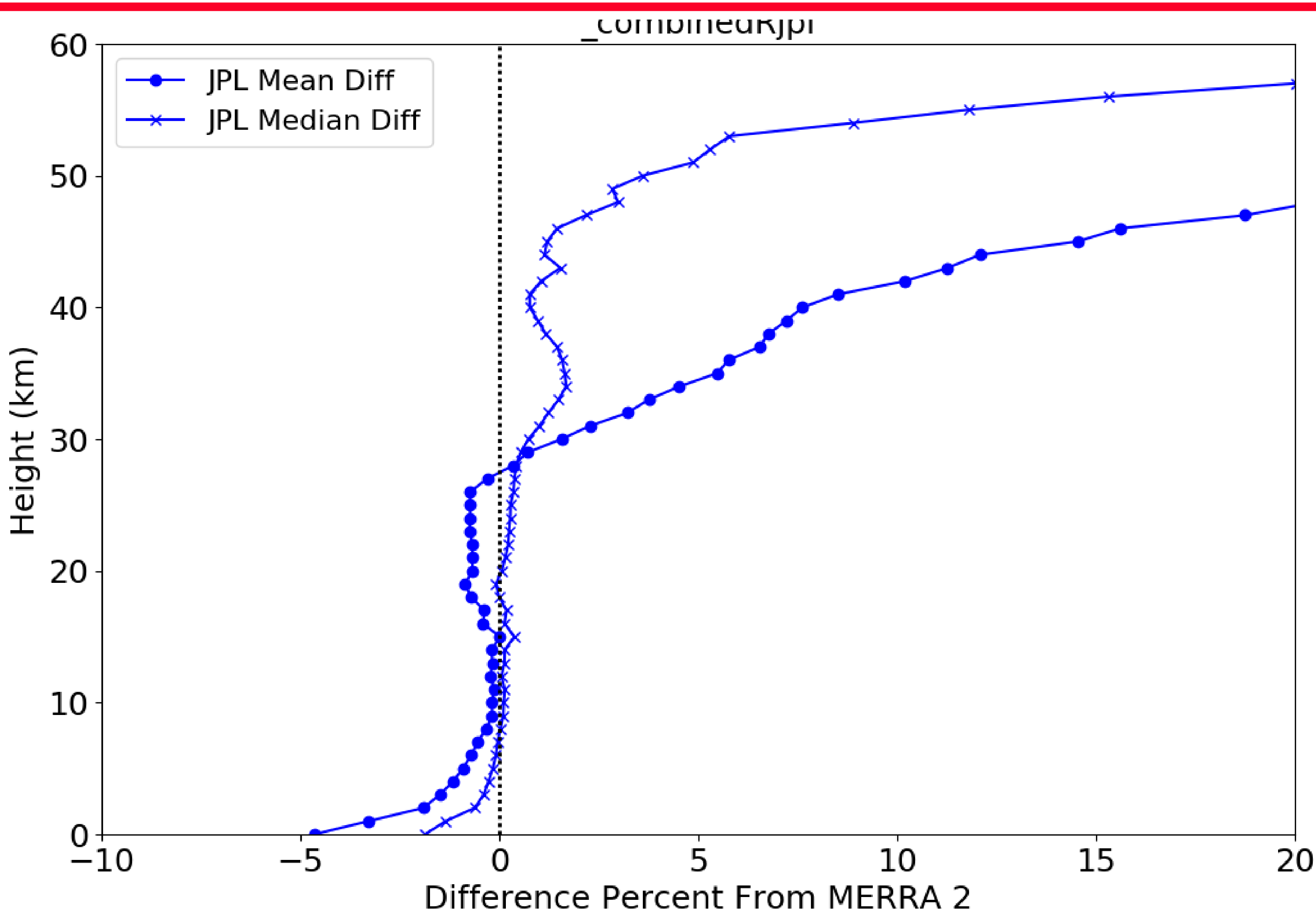


CDAAC AS ON

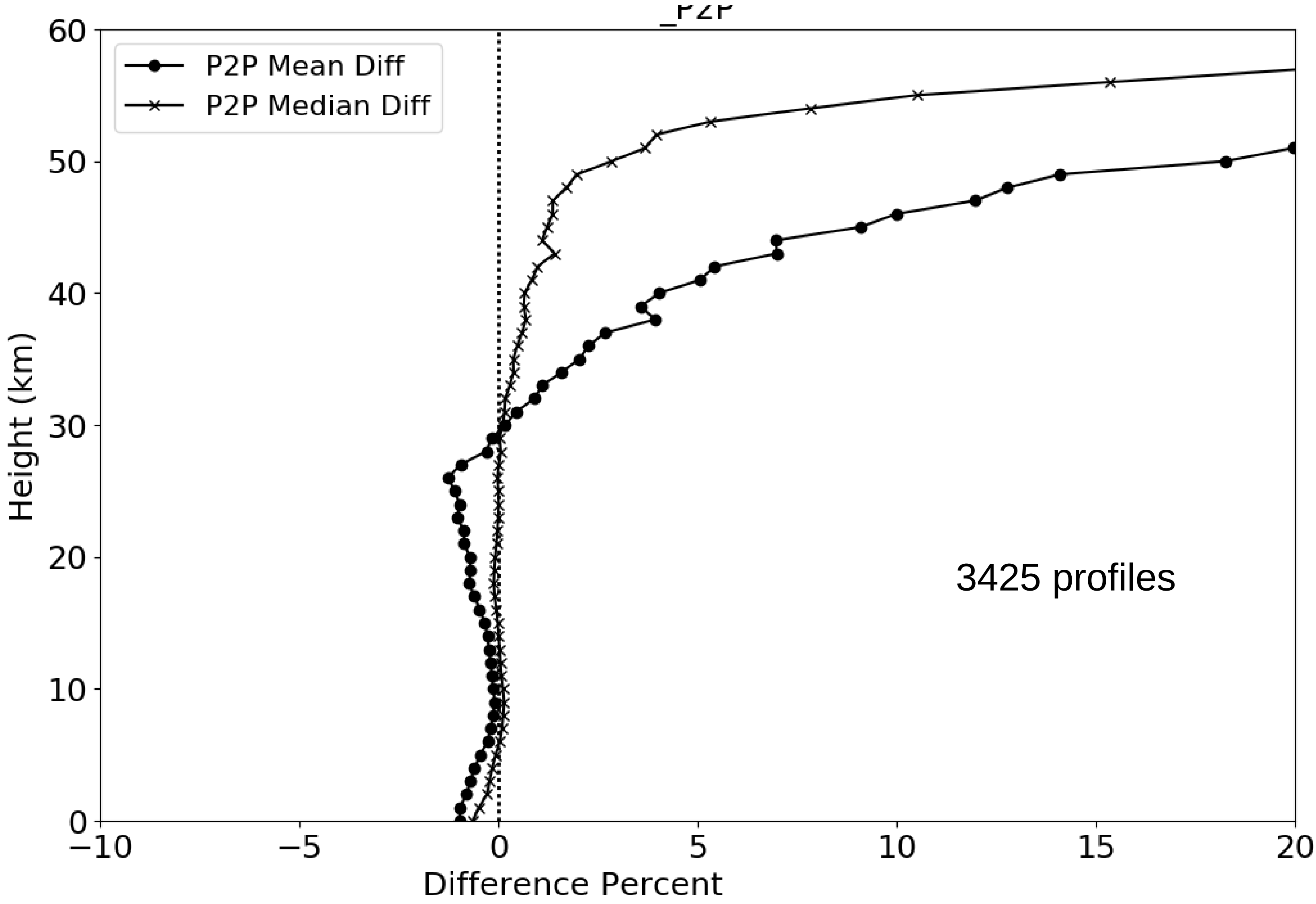


Comparisons to MERRA-2 Reanalysis

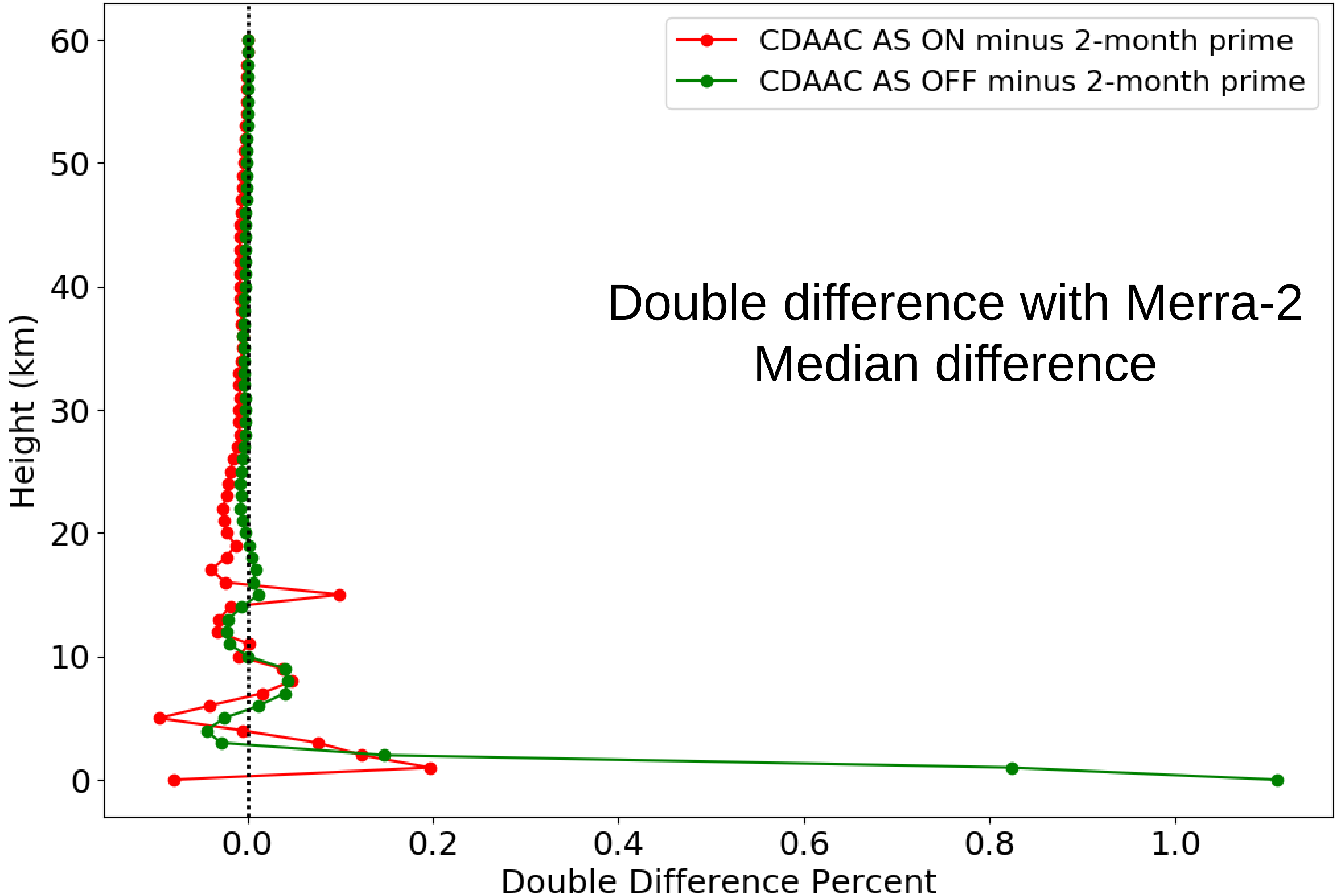
Aggregate Comparison to MERRA 2



JPL-CDAAC Common Profile Comparison



CDAAC: Two-Month Prime versus CDAAC Data Sets



Aggregate Comparison to MERRA 2

No evidence that ”standard”2-month GPS/MET data set differs in bias from this new, larger data set

✓ **Combined CDAAC+JPL data set**

Numbers: 13,611 vs 2890

Conclusions

- **A significantly expanded GPS/MET data set has been assessed against MERRA-2 reanalyses**
- **Reprocessed CDAAC data and new single-frequency data from JPL are included**
  - **13,611 profiles in the new set versus 2,890 profiles used in previous studies (10/1995 and 2/1997)**
- **No significant differences found between the older and newer data sets in aggregate compared to MERRA-2**
  - **More detailed analysis is warranted and in progress**

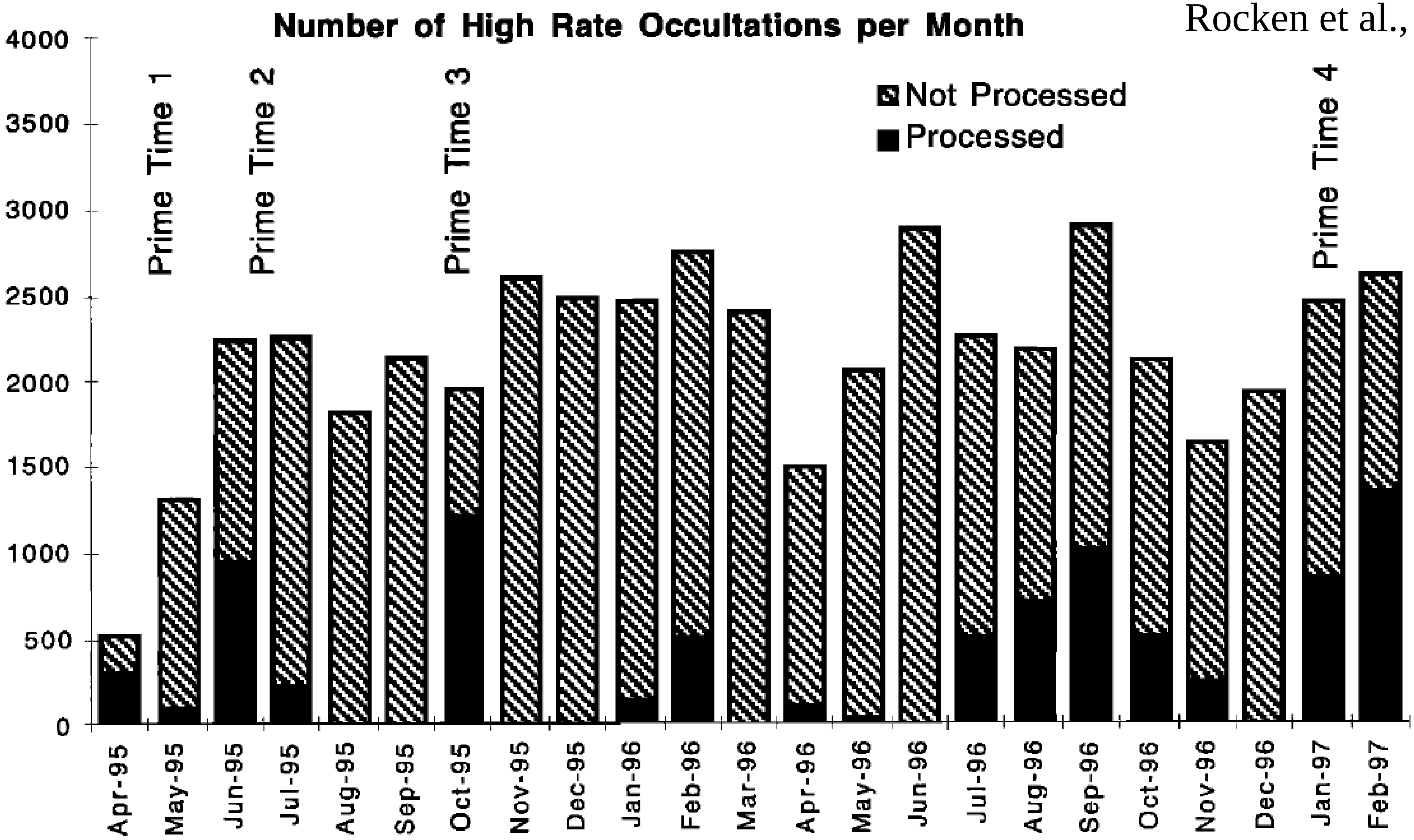
Bonus Slide: Possible Uses of Single Frequency Processing

- **Single frequency processing is a viable technique**
- **There are significant data sets where the L2 frequency is problematic that could benefit**
- **Possibility to provide independent assessment of ionospheric error**
- **Alternative to extrapolating dual-frequency correction to lower altitudes**

BACKUP

Achieving a Climate Record to 1995

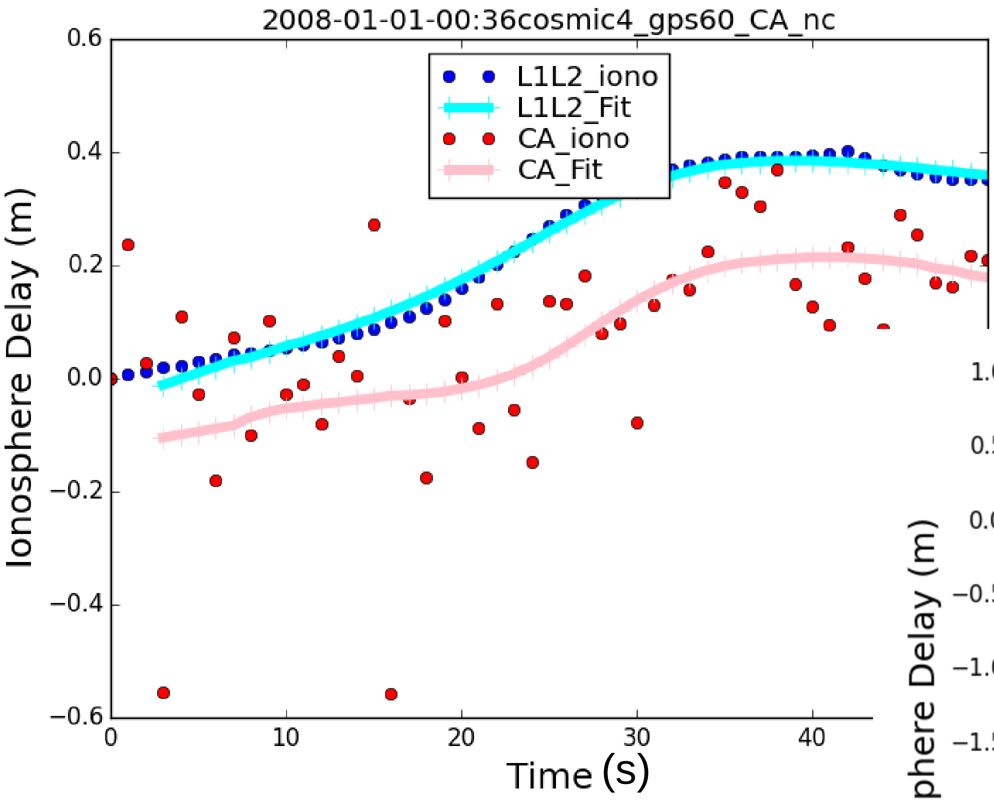
Rocken et al., 1997



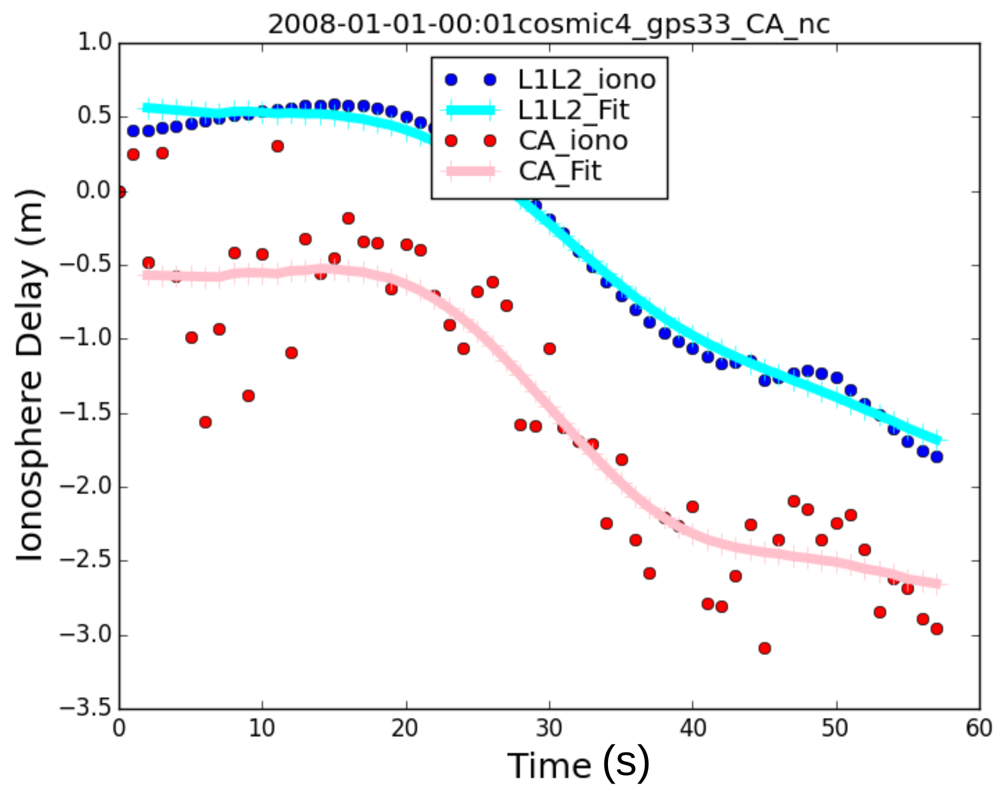
Processed in Steiner et al., 2009

Different trends found for October than February

Ionospheric Estimates of Delay – COSMIC

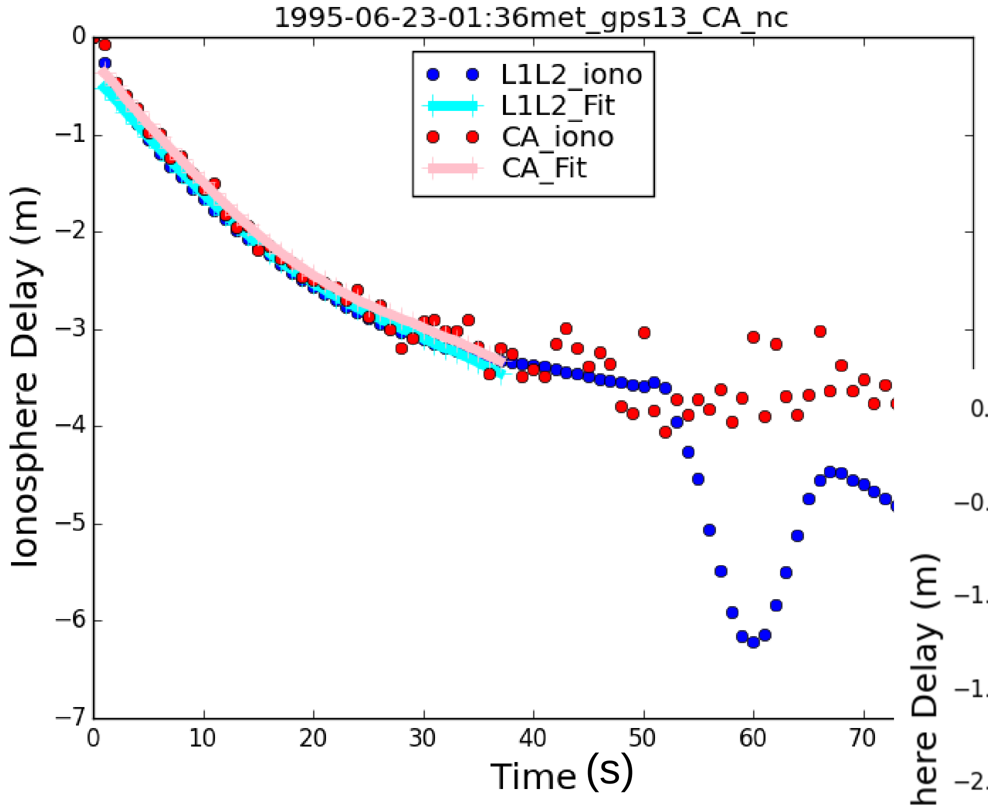


- Two examples from 2008
- CA is pseudorange
- Multiple linear fits

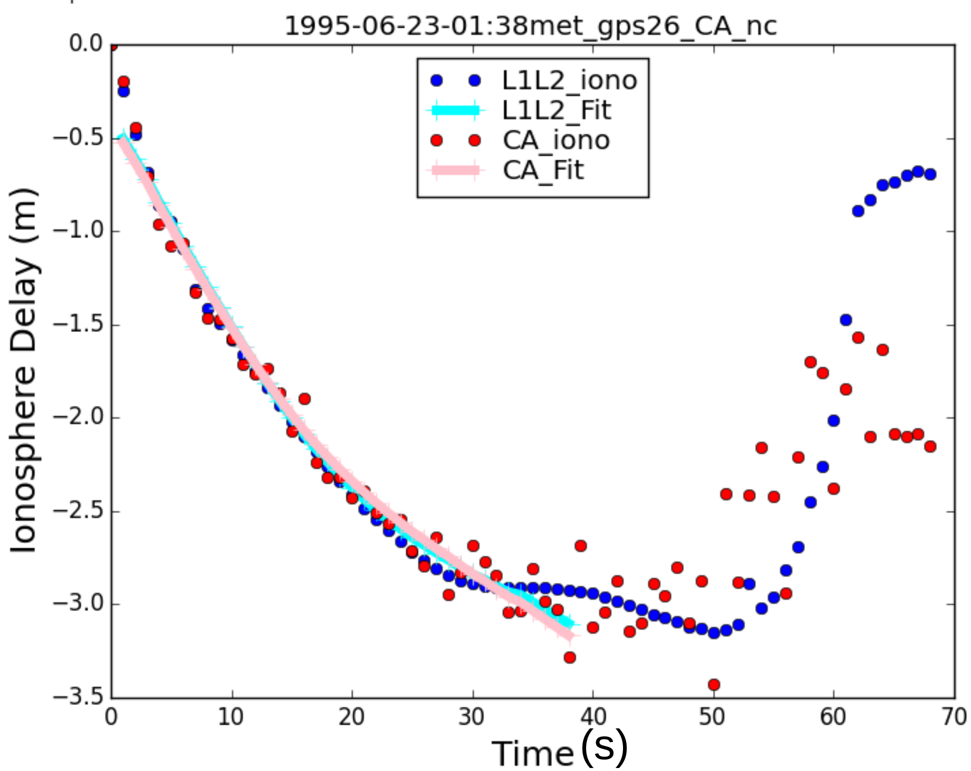


- These examples obtained when two frequencies are available
- Testing and algorithm refinement

Estimates of Ionospheric Delay – GPS/MET



- Two examples from 1995
- Setting occultations
- Multiple linear fits
- Lower pseudorange noise



- These examples obtained when two frequencies are available
- Testing and algorithm refinement

Smoothing Algorithm – What Problem am I Trying to Solve?

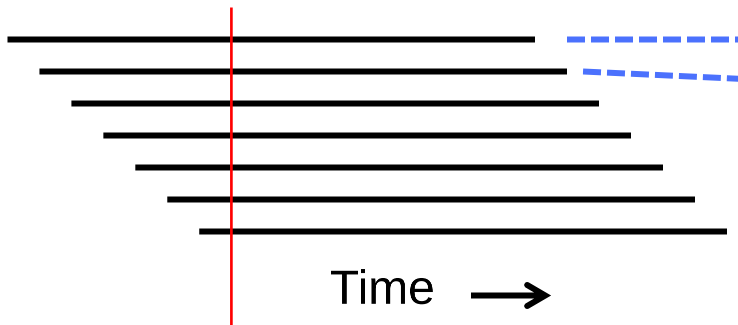
- **More smoothing – low order fit over many data points – can create a bias!**

- **Less smoothing – higher order fit over fewer data points – increased noise!**

Smoothing Algorithm

Fits are to CA range – L1 phase

1. Define overlapping time intervals



2. Perform polynomial fit over each interval

$\{a_1, b_1\}$
$\{a_2, b_2\}$
etc.

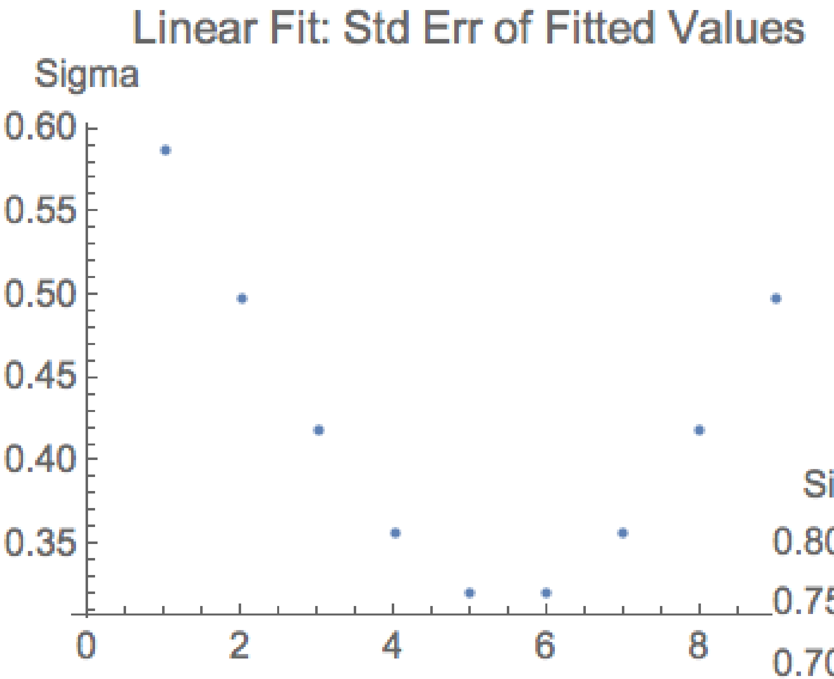
$$f(t) = a_i + b_i\, t$$

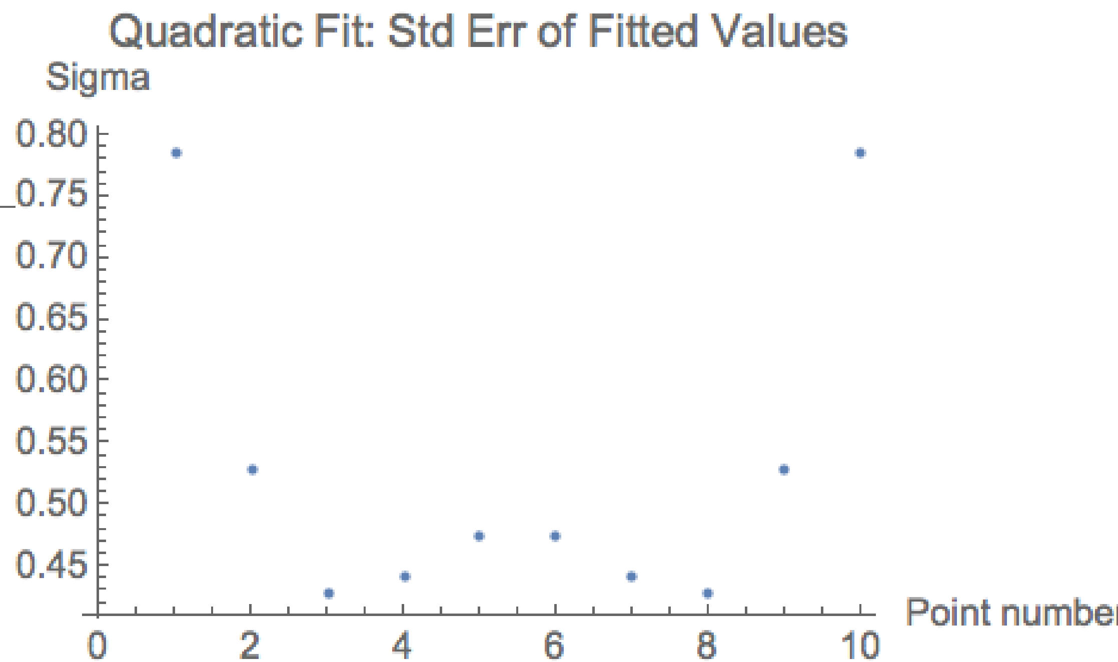
Linear case

3. Evaluate each fit at a particular time. The final result is a weighted sum of all the applicable fits.
   - The weighting function depends on distance from center of each fit
   - Each fit contains some unique information

Precision of Polynomial Fits

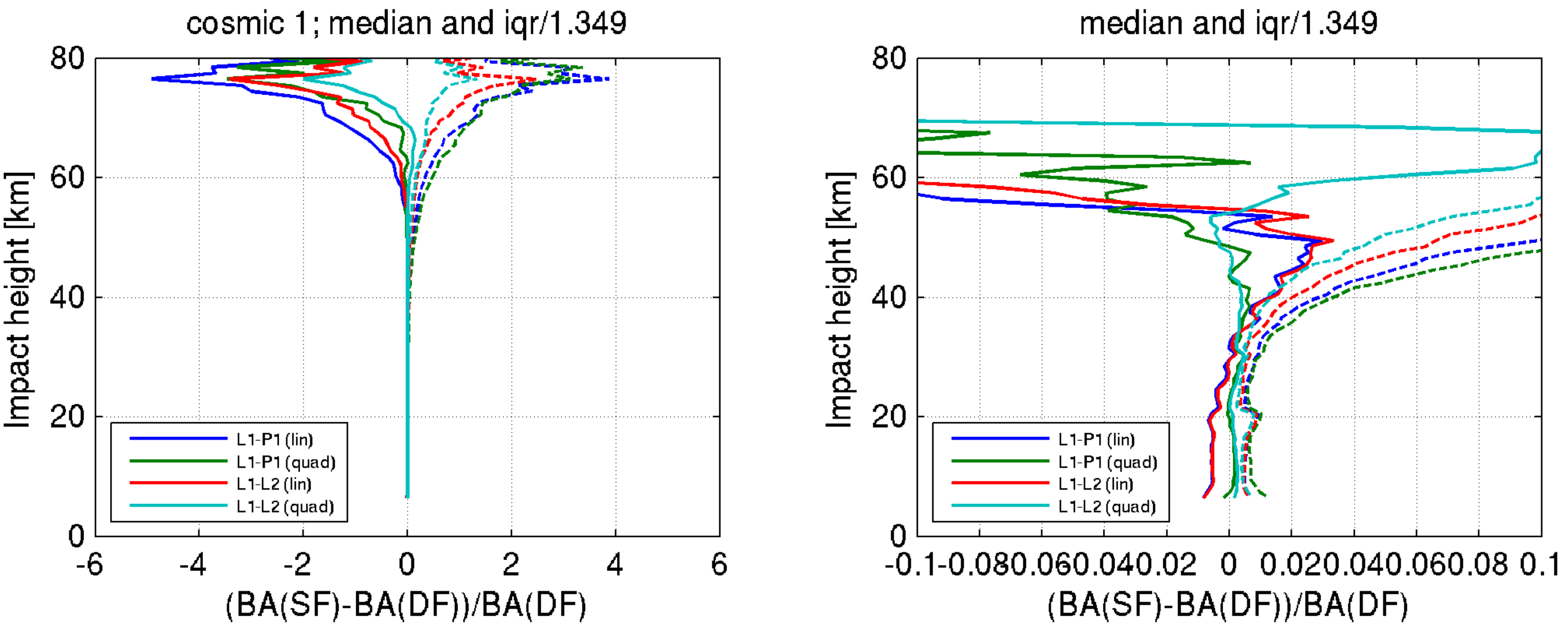
- N = 10
- Each data point has unit variance





COSMIC Results – Comparing Single to Dual Frequency Bending Angle

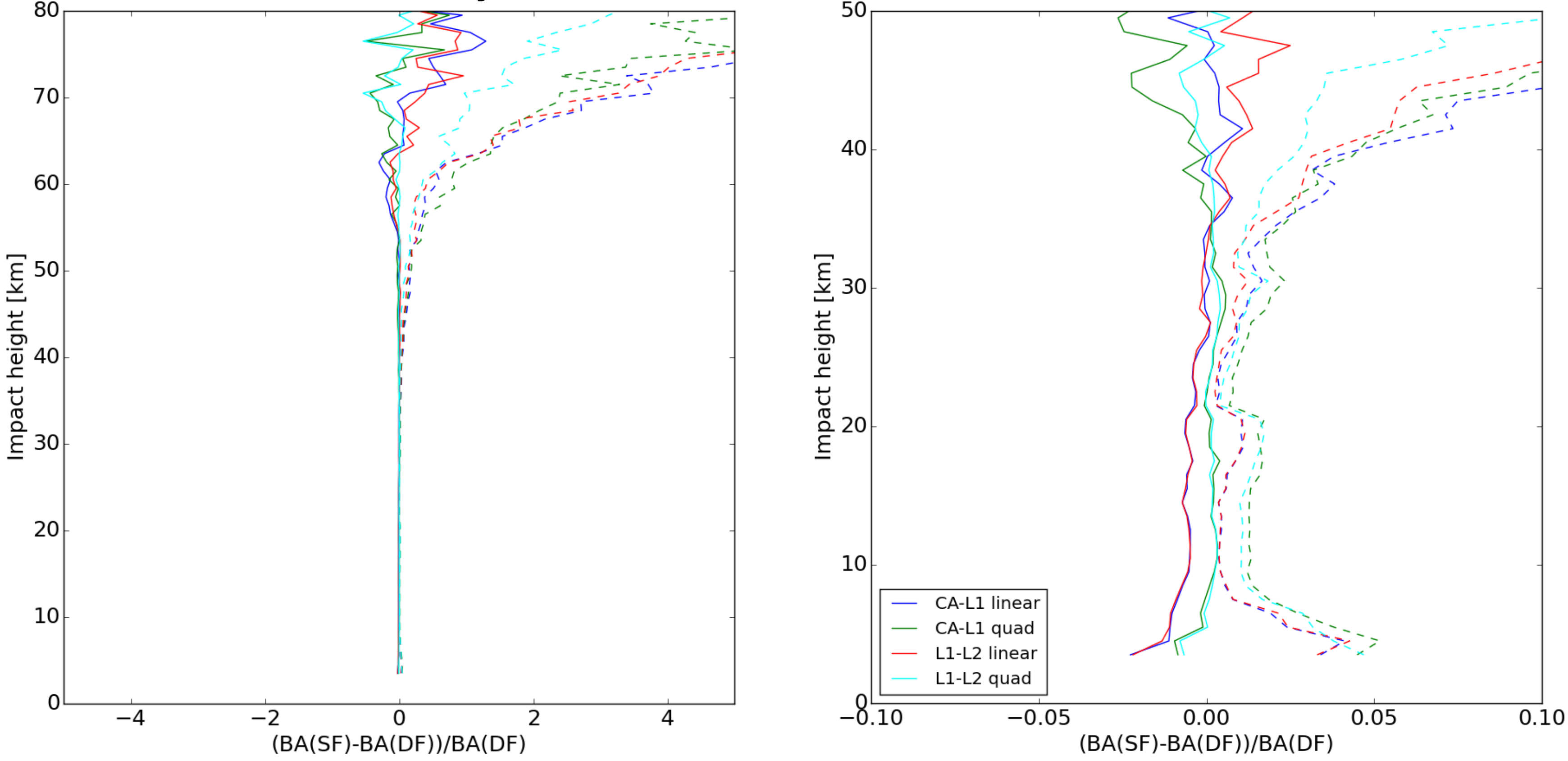
One week of COSMIC 1 data in January 2008



- Quadratic fits have the least bias
- Difference between fits to phase and range are very similar, suggesting a minimal impact of multipath error on the range

GPS/MET Results– Comparing Single to Dual Frequency Bending Angle

One day of GPS/MET data in June 1995

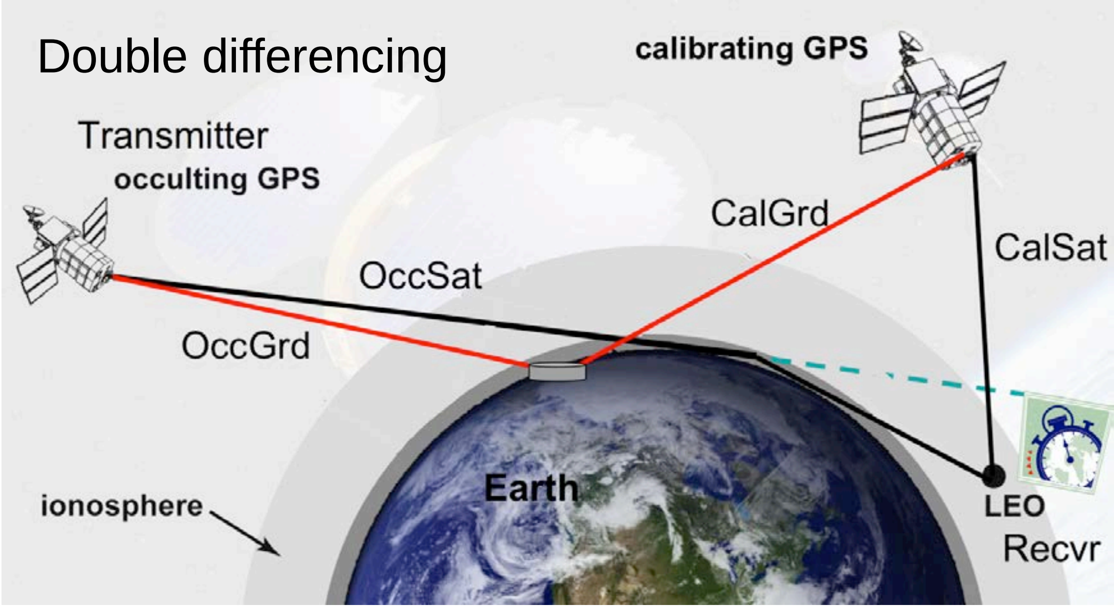


- Quadratic fits have the least bias
- Difference between fits to phase and range are very similar, suggesting a minimal impact of multipath error on the range

Towards Full Processing of GPS/MET

- **Single-frequency orbits**
- **Double differencing returns (selective availability)**

Case	H(cm)	C(cm)	L(cm)	vh(mm/s)	vc(mm/s)	vl(mm/s)
Deweight_L1	17.72	12.16	50.92	0.439	0.107	0.177
95_IF_bias	24.63	18.5	66.55	0.547	0.196	0.217
use_IONEX	21.32	12.04	51.65	0.383	0.118	0.222
phase_map	32.3	23.83	86.66	0.684	0.25	0.297
once/rev	40.45	12.28	117.09	0.958	0.156	0.371
Solarscal	45.72	13.83	142.23	1.2	0.188	0.463



These two methods use an ionospheric estimate (Bent model or IONEX)

These are solar minimum conditions

How to Best Use the GPS/MET Data

- **As the Wegener Center group [GRL, 2009] can tell you, detecting trends with even 20 years of data is a major challenge (reason: El Niño)**
- **Alternative approach: compare to trend data being generated by the microwave sounder community, who have ~40 years of data**
  - **See publications by Ben Ho, UCAR**

Summary and Conclusions

- **Using the full quantity of GPS/MET data (AS on) will significantly improve trend estimates using GPS radio occultation data**
- **A technique for processing atmospheric radio occultation data using a single frequency has been developed and is undergoing testing and refinement**
- **We will produce a GPS/MET data set that covers “non-prime” periods and make these data available**
- **Comparison with microwave upper troposphere and lower stratosphere measurements is recommended**