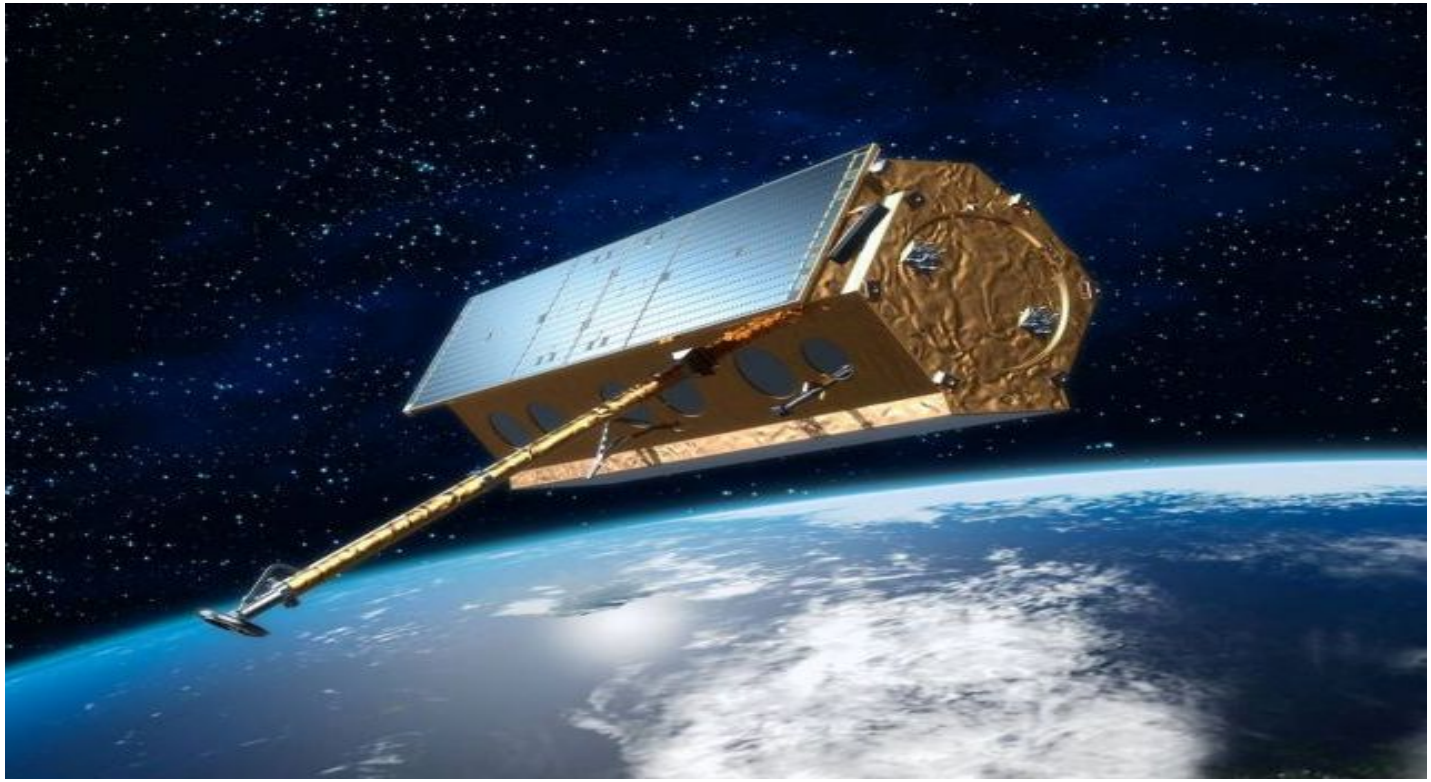
PAZ Neutral Atmosphere Radio Occultation Retrieval Processing



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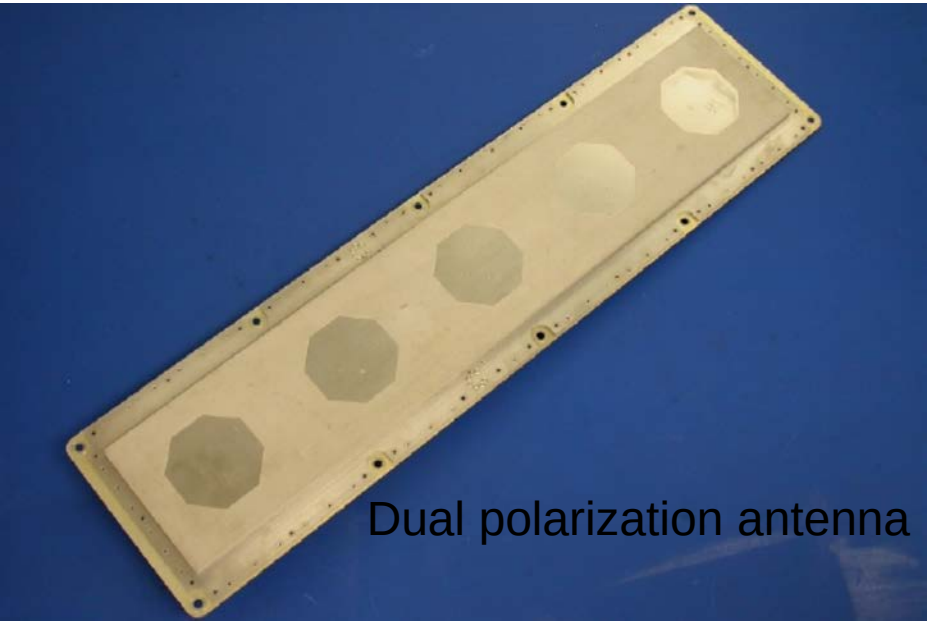
Paz Background

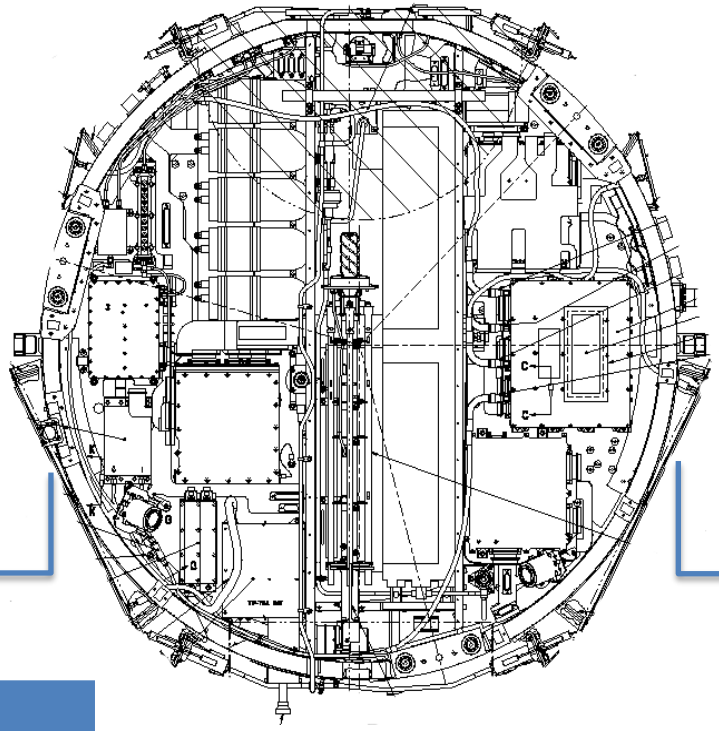
- Launched Feb 22 2018
- Spanish SAR satellite based on TerraSAR-X
- Radio Occulation Heavy Precipitation (ROHP) IGOR instrument a secondary payload
- JPL heritage instrument
- Special purpose multiple patch antenna has separate outputs for Horizontal and Vertical polarizations
- These outputs are processed by the IGOR as separate antenna inputs, similar to fore and aft antennas on other spacecraft
- This approach is a simple change to IGOR firmware, but adds complexity to ground data processing due to separate time stamps for each polarization
- The separate H and V channels are intended for rain detection, but can use this extra information to enhance normal radio occultation (RO) processing.


Dual polarization antenna


IGOR GPS receiver

Photo credit: Estel Cardellach, ICE CSIC

Multi-antenna High Rate Data Packaging



COSMIC-1

Antenna 3 (Occultation)

Antenna 2 (Occultation)

High rate data, antenna 3	
Time	1233014435 .0000254
PRN	23
Phase	...
SNR	...

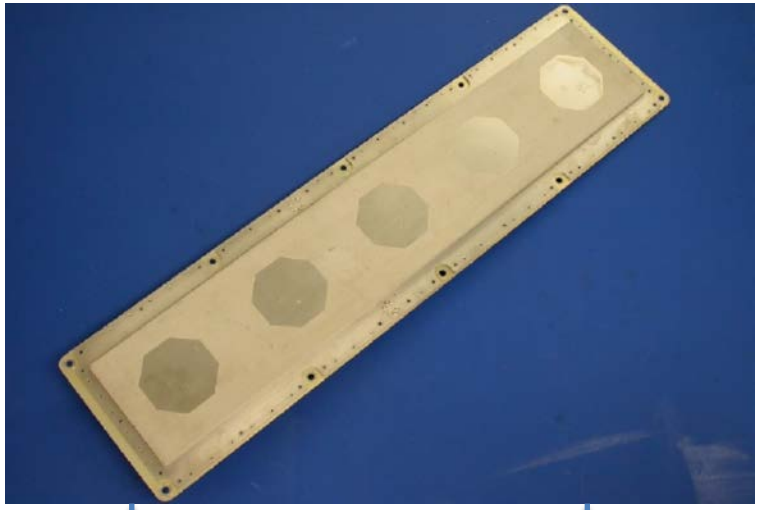
Separate data packets per antenna

Different times

Different PRNs

High rate data, antenna 2	
Time	1233014435 .0000255
PRN	24
Phase	...
SNR	...

Paz High Rate Data Packaging



Paz

H polarization antenna input

V polarization antenna input

High rate data, antenna 2	
Time	1233014435 .0000254
PRN	23
Phase	...
SNR	...

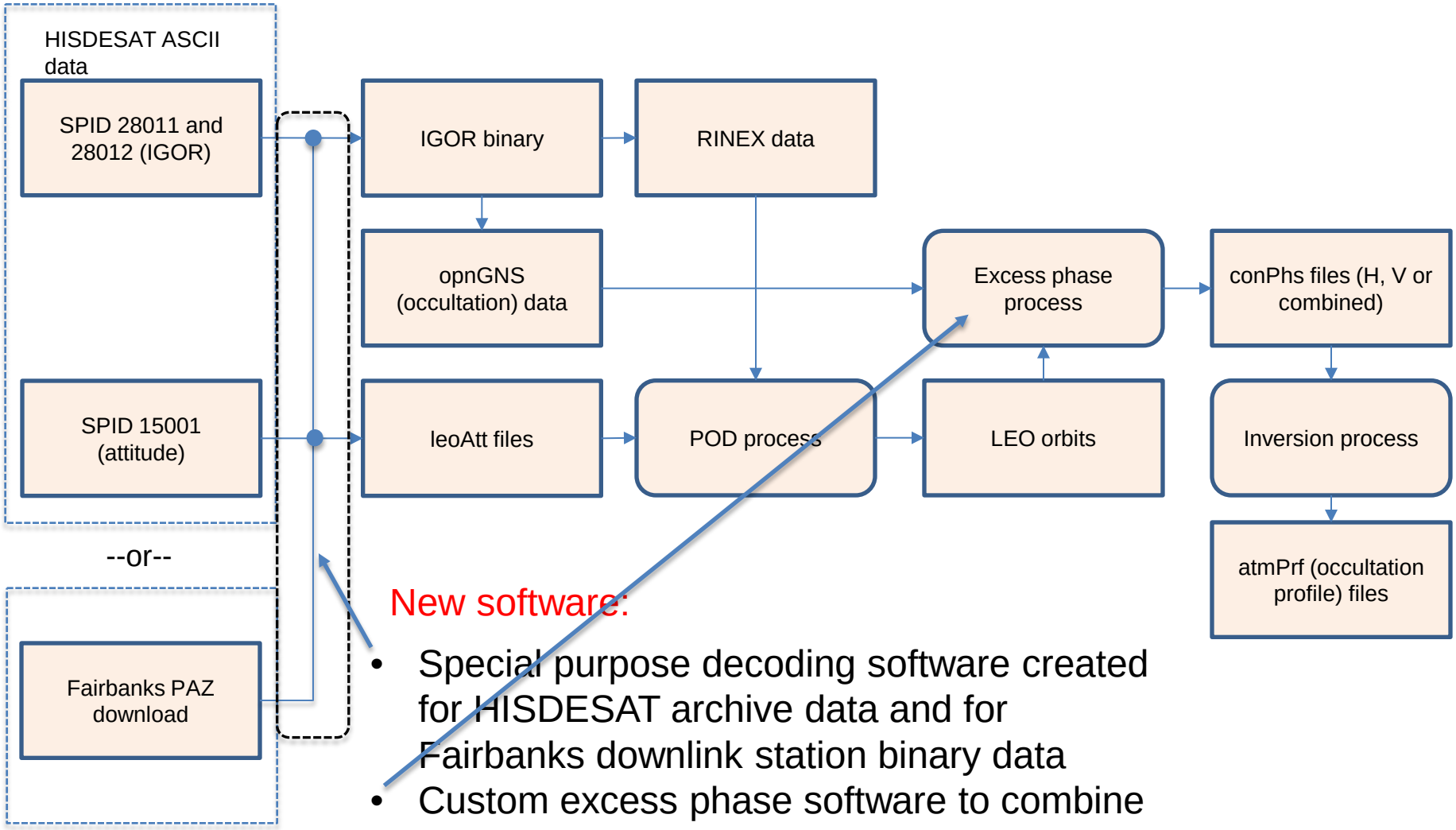
Separate data packets per polarization, same antenna

Different times

Same PRN

High rate data, antenna 3	
Time	1233014435 .0000255
PRN	23
Phase	...
SNR	...

PAZ data flow at CDAAC



New software:

- Special purpose decoding software created for HISDESAT archive data and for Fairbanks downlink station binary data
- Custom excess phase software to combine H and V polarizations

Single-polarization processing

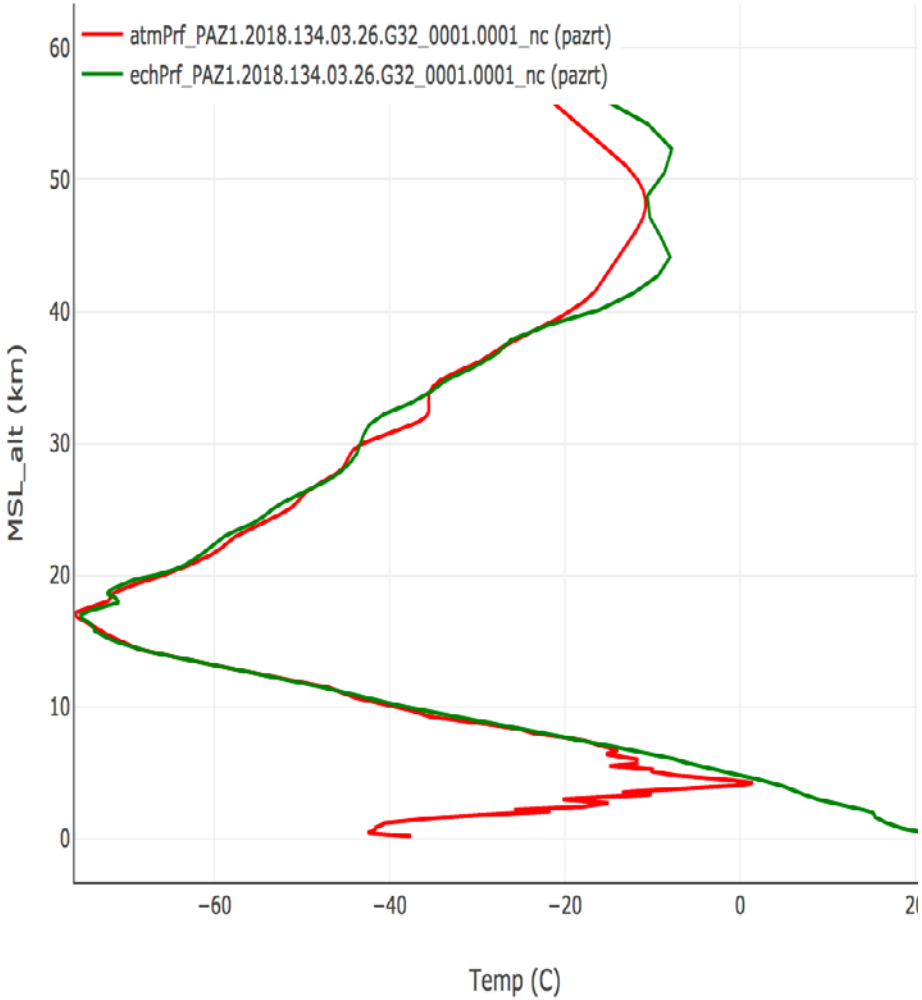
Normal RO processing

1. Start with high rate opnGns occultation data
2. Remove orbital motion (LEO and GNSS POD data), GNSS clocks (e.g. IGS products), and LEO clocks (via differencing with a high elevation (reference) satellite)
3. Compute an atmospheric Doppler model from climatology
4. Integrate this model to get a phase model, then difference it with the observed (excess) phase computed above
5. This phase angle $\Delta\theta$ is now rotating slowly enough to generate meaningful I and Q components: $I = SNR * \cos(\Delta\theta), Q = SNR * \sin(\Delta\theta)$
6. Apply navigation bits to the open-loop portion of I and Q
7. Stitch open- and closed-loop I's and Q's together
8. Compute phase via $atan2(Q, I)$
9. Fix full cycle slips by adding or subtracting 2π to minimize the difference between samples
10. Add the phase model back in to get connected excess phase
11. These connected L1 and L2 phases are then submitted to the *inversion process* to compute bending angle, refractivity, and finally temperature and pressure profiles.

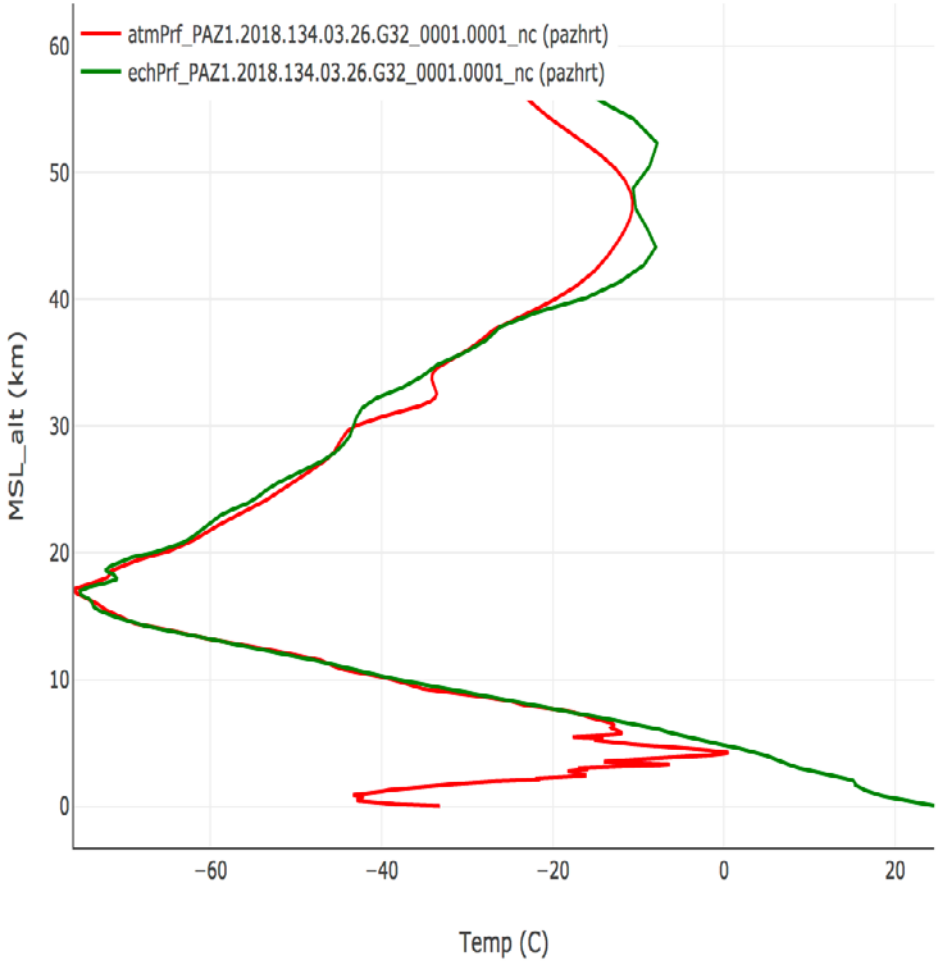
V and H compared

Single-polarization processing generates reasonable results

Vertical



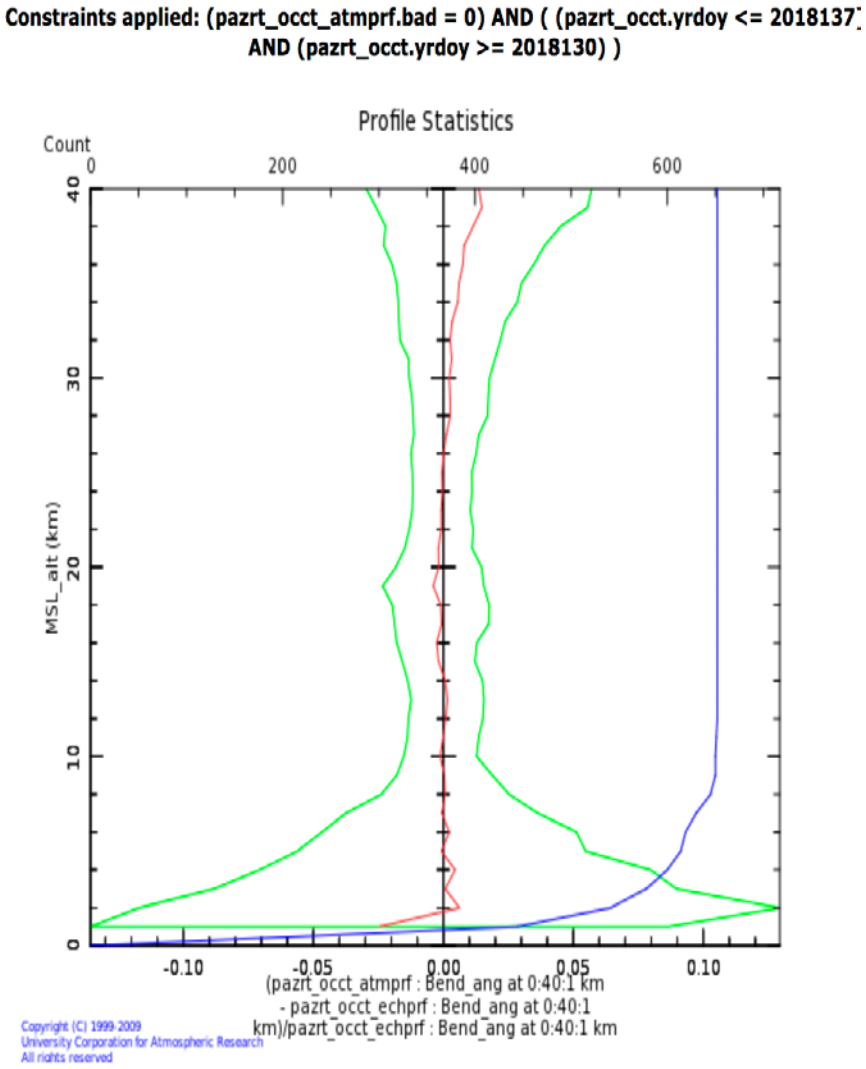
Horizontal



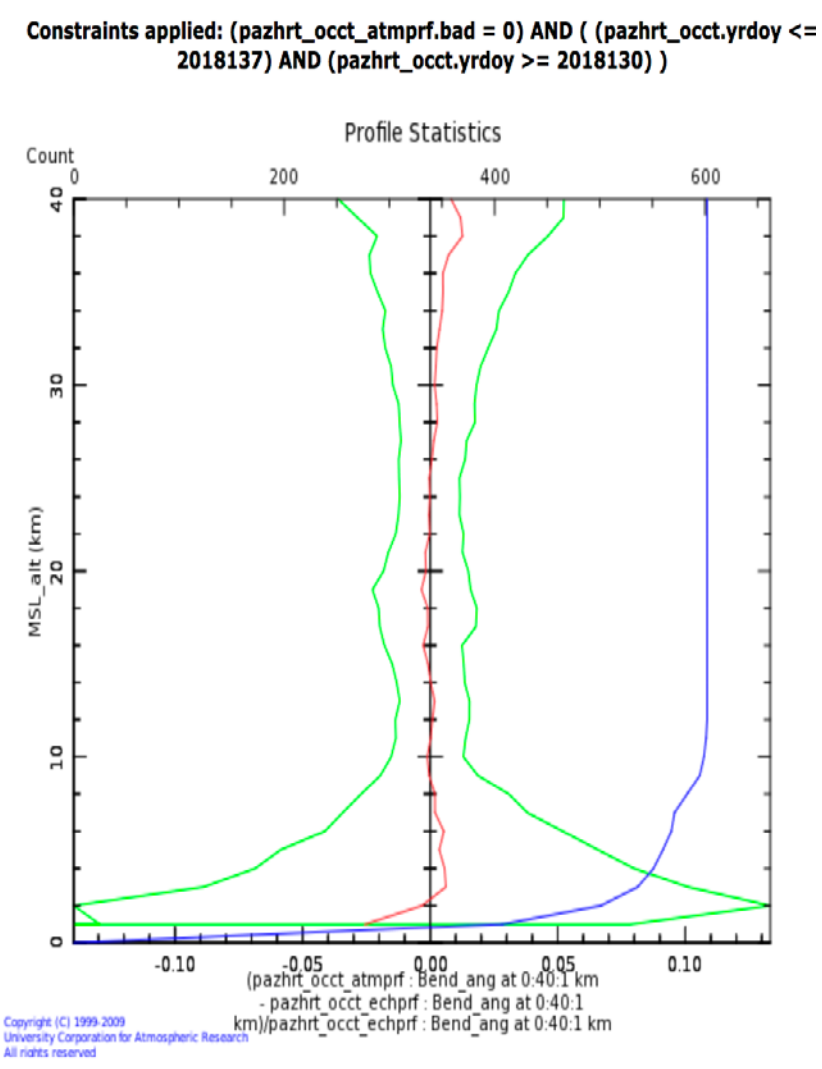
V and H compared

Single-polarization statistics similar

Vertical



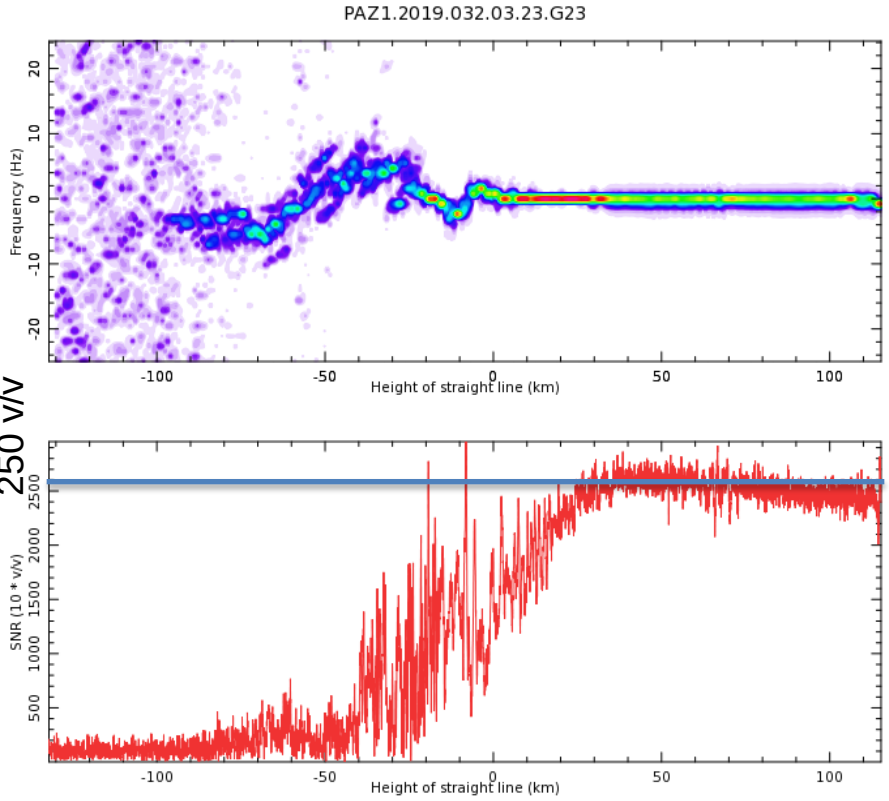
Horizontal



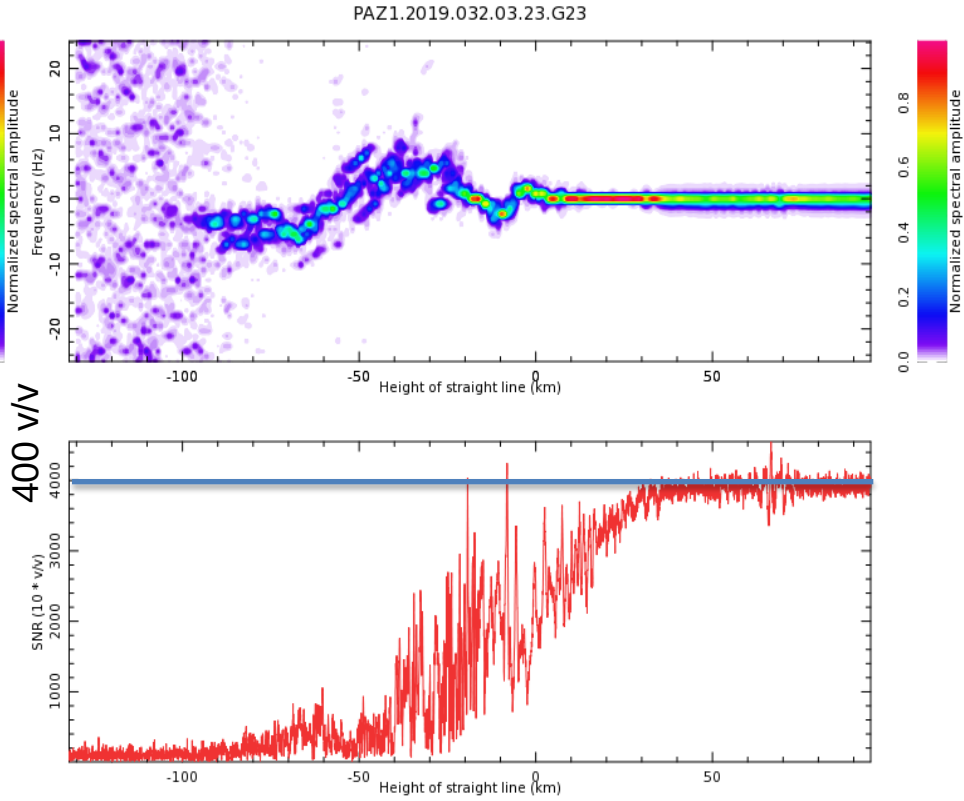
Spectrogram comparison

Note the larger SNR for the horizontal polarization case. In other cases, vertical polarization has higher SNR. Both can be combined to yield higher SNR.

Vertical polarization

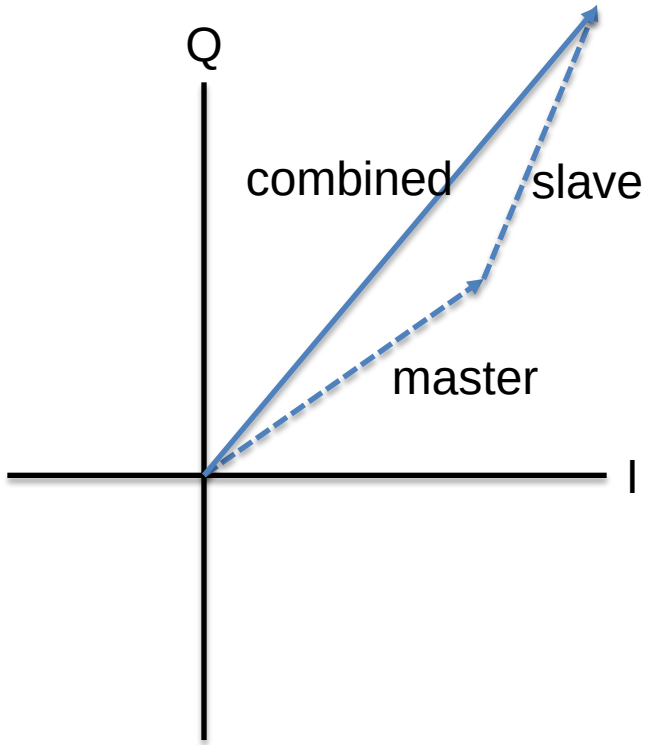


Horizontal polarization



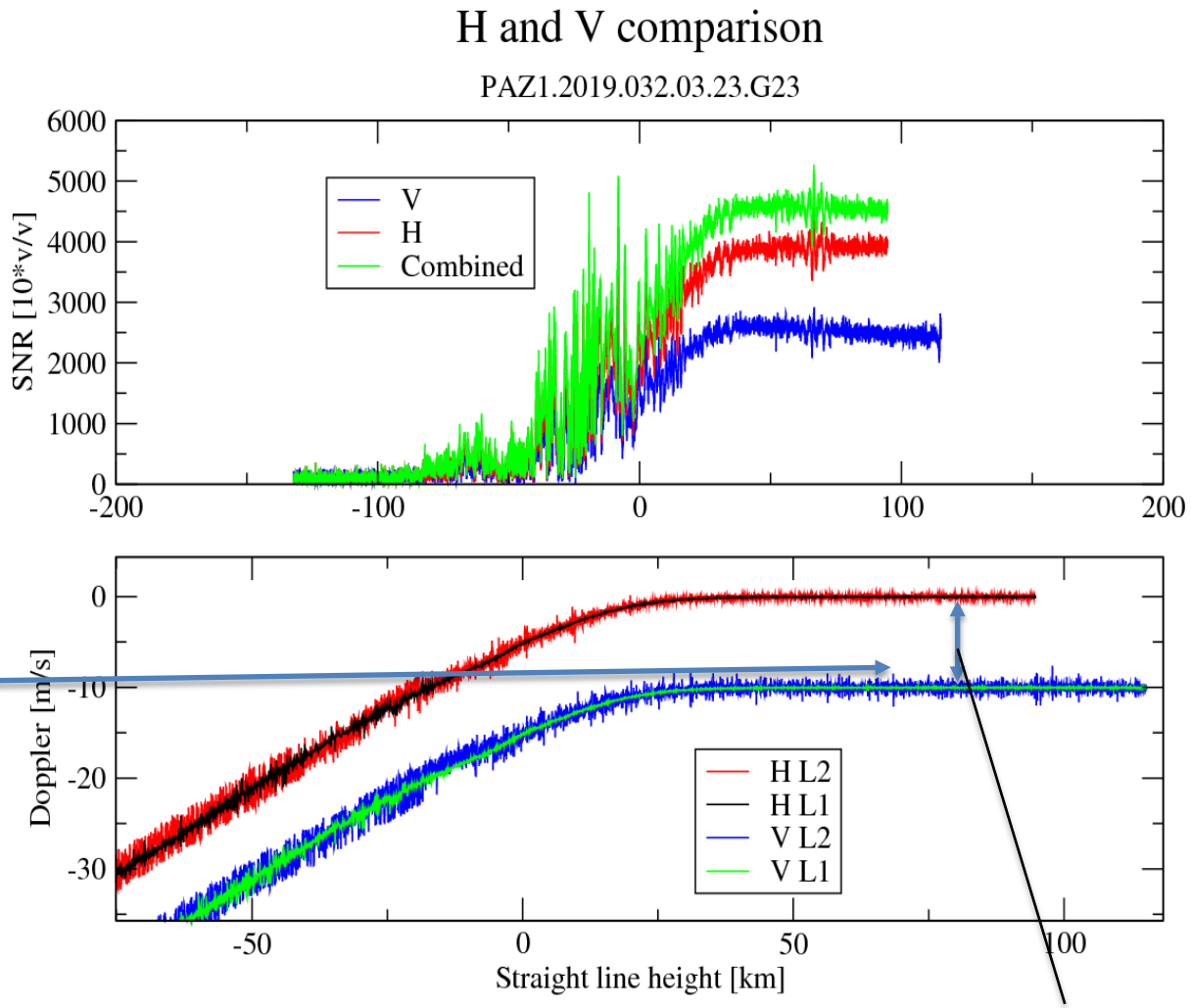
Dual polarization processing via vector sum of I and Q

1. Determine a ‘master’ polarization for this occultation. We use higher SNR to choose between H and V
2. Compute separate Horizontal and Vertical I and Q values as in the single-polarization example
3. Determine the phase alignment between H and V
4. Line the I’s and Q’s up and use the ‘master’ to fix ½ cycle slips in the ‘slave’
5. Find the point at which the slave polarization signal descends into noise. This is the point at which to stop the vector combination
6. Perform a vector sum of the lined up I and Q values from the master and slave: $I = I_s + I_m$, $Q = Q_s + Q_m$
7. Assemble the combined excess phase (as in steps 9-11 in the single polarization processing)
8. Compute the SNR of the combined signal as $\frac{\sqrt{I^2+Q^2}}{\sqrt{2}}$ (assumes equal noise on H and V channels)



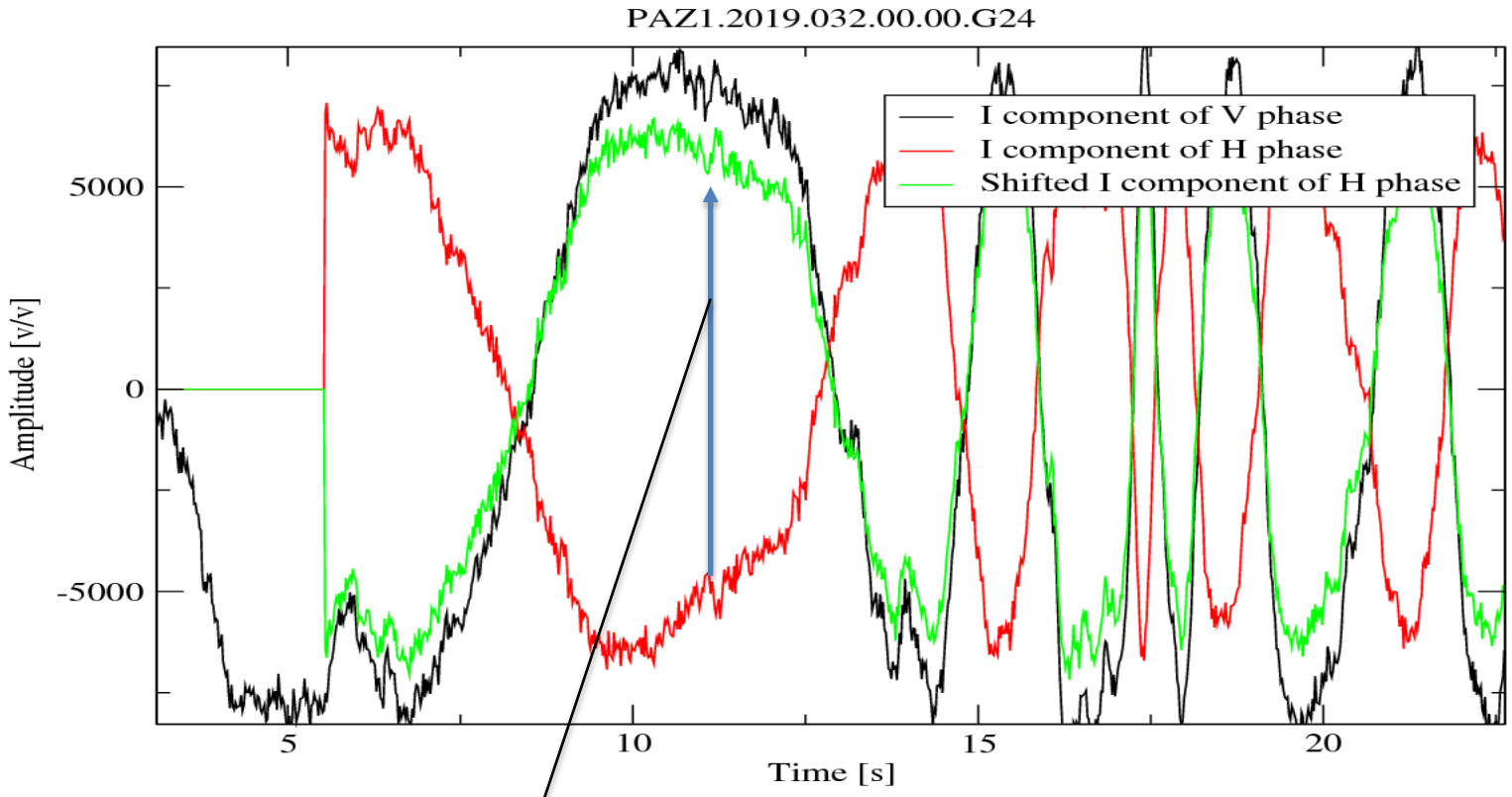
Choosing V or H for master polarization

- Originally I always chose V for the ‘master’ polarization, but found that in many cases H worked better
- In this occultation, the single-polarization H processing passed QC, whereas the V processing did not.
- Note the higher L2 Doppler noise for V
- Master polarization is chosen by higher average SNR, so for this occultation H is chosen over V



Phases offset by 10 Hz for visibility

Aligning V and H polarization phases

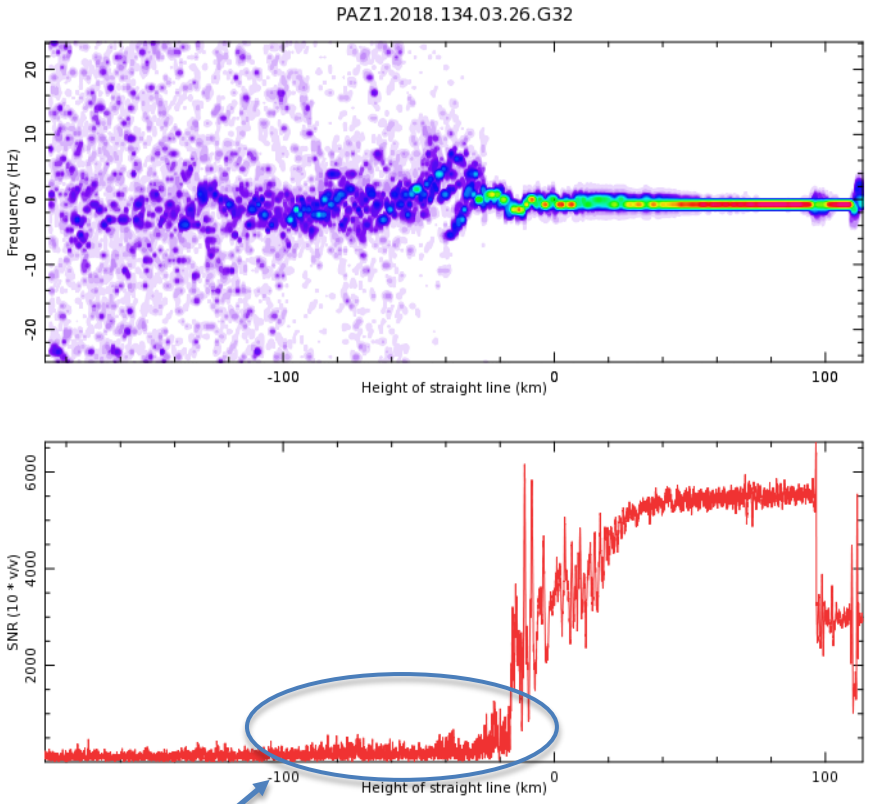


H phase is shifted 2.9 radians to align with V phase

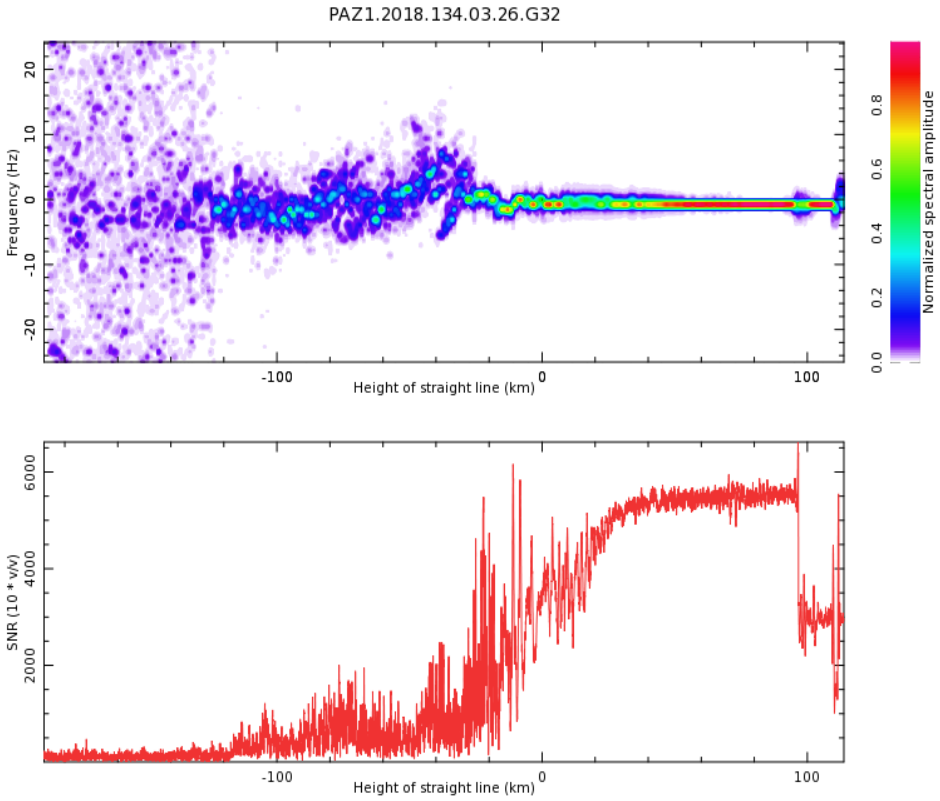
Now I and Q components of H and V can be added constructively

Fixing ½ cycle slips in the slave by comparison with the master

Vector sum without fix



Vector sum with fix

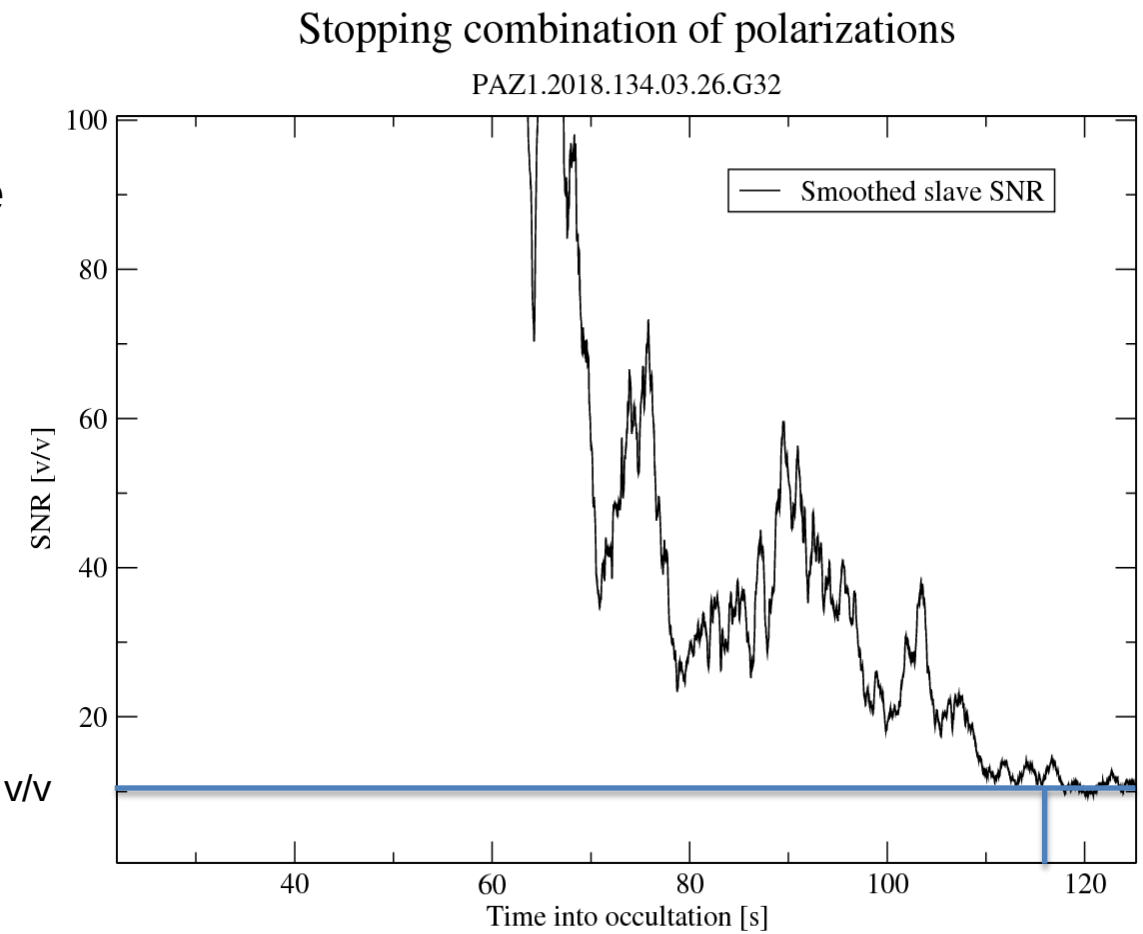


If ½ cycle slips are not fixed in the slave polarization, then there is substantial cancellation when the two are added, as shown at left.

Determining when to stop combination

The combination of polarizations no longer makes sense when the SNR gets too low—this can result in an amplification of noise.

We cut the combination off when the boxcar-smoothed slave SNR descends below 15 v/v

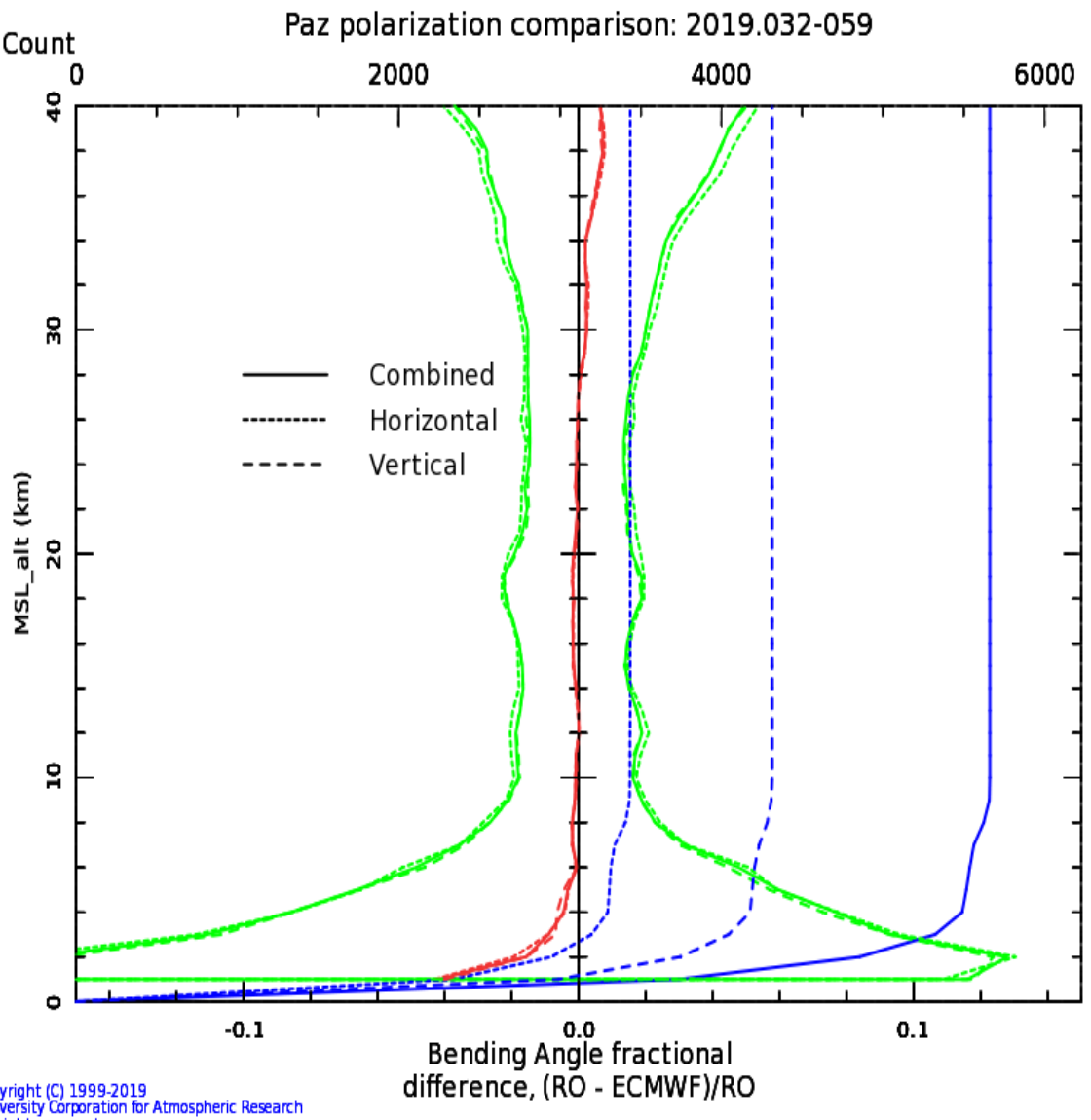


V/H combination results

Combined processing results in good statistics compared with ECMWF.

The combination results in much higher occultation counts compared with processing H or V polarization separately.

Polarization	Good occultation count
Vertical	4390
Horizontal	3493
Combined	5750



Operational Paz processing

- Fairbanks data for PAZ downlinked and processed at CDAAC since March 2019
- Near real-time processing implemented
- Leveraging COSMIC-2 data processing center infrastructure
- UCAR/CDAAC PAZ products are being provided to the NOAA Product Distribution and Access (PDA) system since July 2019
- BUFR header details recently updated, expect PAZ products on GTS soon

Conclusion

- PAZ data processed at UCAR since May 2018
- H and V processed separately for sanity check
- Several approaches tried for combining H and V
- Current approach yields similar statistics to independent H or V processing, but results in much higher quality checked data counts
- PAZ data on PDA and very close to appearing on GTS