EarthCARE's Cloud Profiling Radar: Assessment of Doppler products

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November 30, 2025

Expectations about ECPR **pre-launch** (based on simulations)

- Expected performance of ECPR:

	Quality	Comment
Z	✓✓✓	$V_{\mathrm{SAT}} > 7$ km/s $\Longrightarrow \nearrow$ (I,Q) decorrelation
V	✓	$V_{\mathrm{SAT}} > 7$ km/s $\Longrightarrow$ aliasing, *NUBF, noisiness*
S	☒	$V_{\mathrm{SAT}} > 7$ km/s $\Longrightarrow$ *broadening, noisiness*

- Thanks to NASA's ES-USPI pgm, collaborators @ NICT & ESA, we developed algorithms
  1. *mean Doppler velocity*: NUBF, noisiness (aliasing);
  2. *Doppler width*: broadening, noisiness.

Burning question

- All these algorithms validated successfully (*pre-launch*) with idealized simulations,
- How do they fare when applied (*post-launch*) to real spaceborne Doppler measurements?

Corrections developed for ECPR **pre-launch** (based on simulations)

	Problem	Proposed algorithm	References
V	NUBF	*Gradient-based*: $V_{\mathrm{cor}} = V_{\mathrm{obs}} - \alpha \nabla_x Z$	Art'14a, Art'23
V	NUBF	*CConDoR*[1]: Deconvolution of R_1, then V_{cor} from $\arg(R_{1,\mathrm{dec}})$	JPL'12, Art'22
V	noisiness	*Adaptive filters*	Art'14b
S	broadening	*ExpliSyT*[2]: $S^2_{\mathrm{cor}} = S^2_{\mathrm{obs}} - \left[\beta f(\nabla_x Z, \partial^2_x Z) - \gamma g(\partial_x V)\right]$	Art'23
S	broadening	*CConDoR*: Deconvolution of R_1, then S_{cor} from $\lvert R_{1,\mathrm{dec}} \rvert$	Art'22

[1] CConDoR: *Complex Convolution Doppler Resampling* correction for NUBF & spectral broadening
[2] ExpliSyT: *Explicit Sy-Tanelli* correction for spectral broadening

Example of rain in Indian ocean (25 Aug 2025): differential corrections ($\nabla_x Z$, ExpliSyT)

Z_{EC}

Measured V_{EC}

Corrected V_{EC}

☺

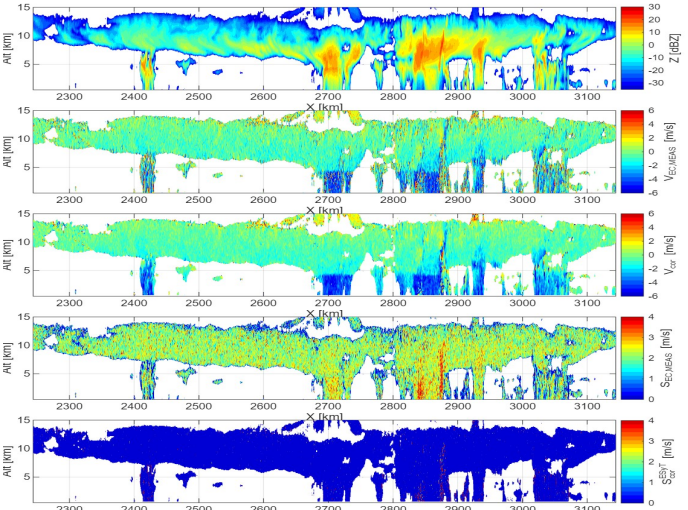
$\nabla_x Z$ filter

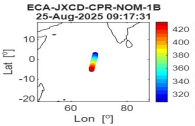
Measured S_{EC}

"too hot"

Corrected S_{EC}

☹





Example of rain in Indian ocean (25 Aug 2025): spectral corrections (CConDoR deconvolution)

Z_{EC}

Measured V_{EC}

Corrected V_{EC}

☺

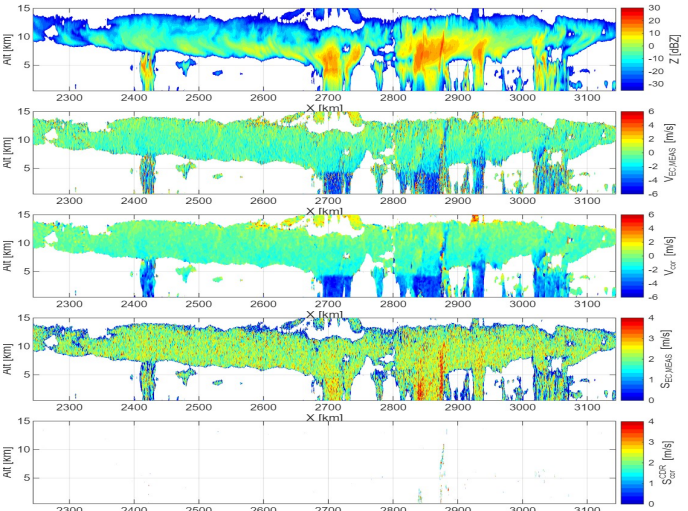
deconvolution filter

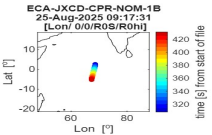
Measured S_{EC}

"too hot"

Corrected S_{EC}

☹





Status

Mean Doppler

- ✓ Gradient-based and deconvolution methods work.
- ✓ Adaptive filtering removes noise.

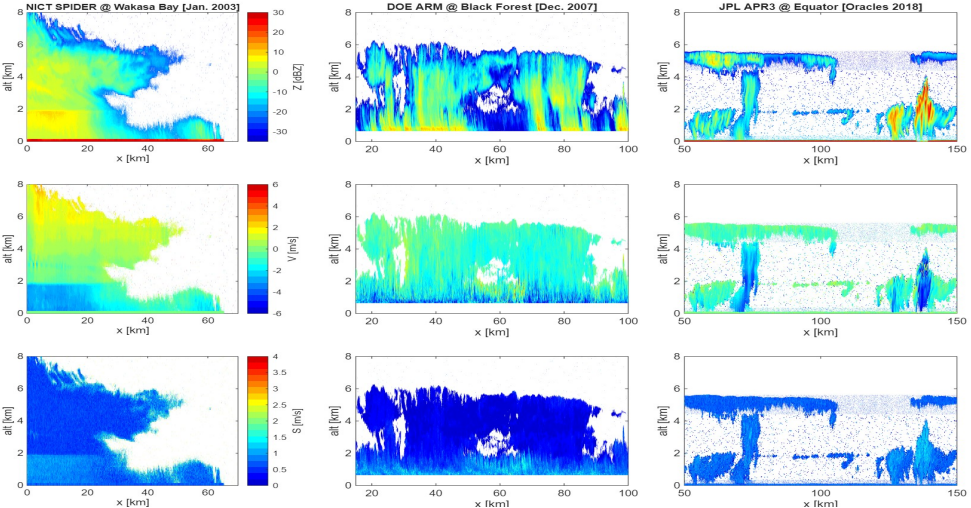
Doppler width: neither correction seems to work

- ☹ After ExpliSyT & CConDoR, $S^2_{\mathrm{cor}} < 0$ invalid.

Problems

1. Our correction algorithms expect to start from the *uncorrected* Doppler width.
2. The S_{EC} *(posted)* is the result of a correction, but we couldn't find which one.
3. The S_{EC} *(posted)* is *still too high*.

"*posted S_{EC} still too high*"? from experience (NICT SPIDER, DOE ARM, JPL's APR3)



Z_W

v_W

s_W

All W band data

airborne data are from "slow movers" (e.g. P3 Orion)

Special Thanks

NICT:
Pr. Takahashi,
Dr. Ohno,
Dr. Horie

Special Thanks

McGill U.:
Pr. Kollias & team

Our correction algorithms start from an uncorrected width

1. ExpliSyT: $S^2_{\rm cor} = S^2_{\rm EC} - \left[\beta f(\nabla_x Z, \partial^2_x Z) - \gamma g(\partial_x V)\right] < 0$, i.e. invalid
   Solution? Add a term to posted $S^2_{\rm EC}$ until $S^2_{\rm cor} > 0$?
   $\Rightarrow$ arbitrary & biases the analysis.

2. CConDoR: deconvolved $|R_{1,\rm dec}| \gg |R_0 - R_{0,\rm noise}| \Rightarrow S^2_{\rm cor} < 0$ invalid.
   Solution
   - deconvolve R_1 into $R_{1,\rm dec}$; then compute

$$S^2_{\rm dec} = \frac{2V^2_{\rm Nyq}}{\pi^2} \ln\left(\frac{R_0 - R_{0,\rm noise}}{|R_{1,\rm dec}|}\right), \tag{1}$$

   - since this formula acts on the *noise-subtracted spectrum*, *the value of $S_{\rm dec}$ in noise should be 0*, i.e.

$$S^2_{\rm cor,A} = S^2_{\rm dec} - \text{median}\left[S^2_{\rm dec}(\text{noise})\right], \tag{2a}$$

$$S_{\rm cor} = S_{\rm cor,A} - \text{median}\left[S_{\rm cor,A}(\text{noise})\right]. \tag{2b}$$

Example 1: Rain in Indian ocean (25 Aug 2025)

Z_{EC}

Measured V_{EC}

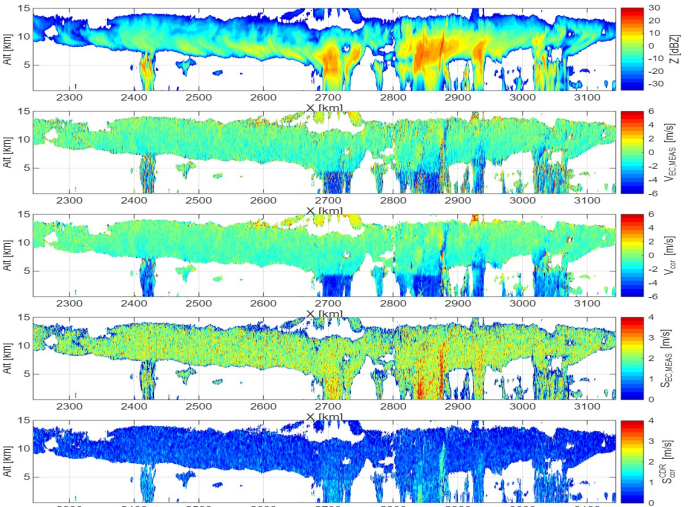
Corrected V_{EC}

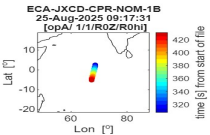
deconvolution filter

Measured S_{EC}

Corrected S_{EC}

☺





Example 2: Precipitation South of Japan (27 Nov. 2025)

Z_{EC}

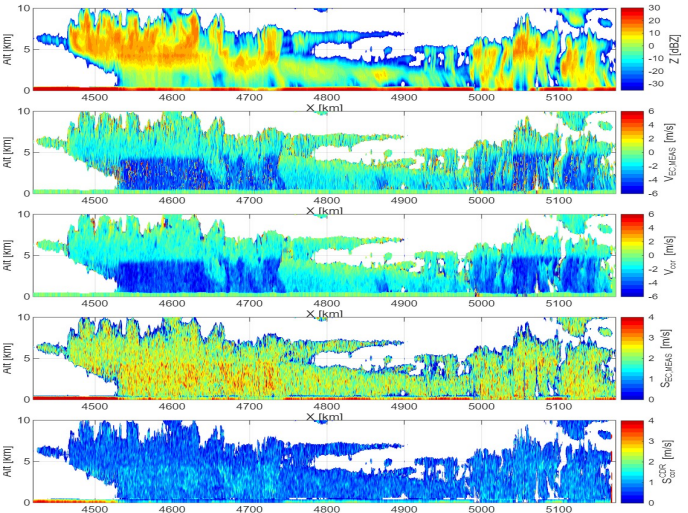
Measured V_{EC}

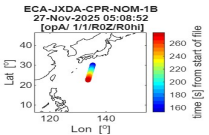
Corrected V_{EC}

deconvolution filter

Measured S_{EC}

Corrected S_{EC}





Take-away message

1. Corrections successfully applied to ECPR data.
2. Corrected S calls for validation by co-located suborbital measurements.
3. *Uncorrected data* help validate/invalidate forward models; especially with *novel measurements* like ECPR's Doppler.
4. Thanks to the support from ES-USPI program, this work benefited
   - *NASA*: ECPR Wiener deconvolution ('12) $\rightsquigarrow$ RainCUBE's deconvolution ('18-'22)
   - *from NASA*: INCUS's deconvolution ('24) $\rightsquigarrow$ ECPR (V, S) deconvolution ('25)
5. Details of algorithms all published in literature (see next slide).
   Application to ECPR measurements summarized in article (*to be submitted*)
   "Doppler corrections applied to EarhCARE's radar products".

Thank you for your attention

REFERENCES

1. JPL'12: *"Non-Uniform Beam-filling corrections for atmospheric spaceborne Doppler radars: Reflectivity-based methods"*; JPL Postdoc research day **2012**; **Sy & Tanelli**
2. Art'14a: *"Simulation of EarthCARE Spaceborne Doppler Radar Products Using Ground-Based and Airborne Data: Effects of Aliasing and Nonuniform Beam-Filling"*, IEEE TGRS **2014**; **Sy, Tanelli, Takahashi, Ohno, Horie & Kollias**
3. Art'14b: *"Application of Matched Statistical Filters for EarthCARE Cloud Doppler Products"*, IEEE TGRS **2014**; **Sy, Tanelli, Kollias & Ohno**
4. Art'22: *"Dynamic Retrievals from Spaceborne Doppler Radar Measurements: the CConDoR Approach"*, IEEE TGRS **2022**; **Sy & Tanelli**
5. Art'23: *"Recovering the Elusive Spectral Width From Spaceborne Doppler Profiling Radar Measurements: The "ExpliSyT" Approach"*, IEEE TGRS **2023**; **Sy & Tanelli**