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esa EUROPEAN SPACE AGENCY

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Retrieval and Climatology of Hydrometeor Sedimentation Velocity from EarthCARE Cloud Profiling Radar Observations

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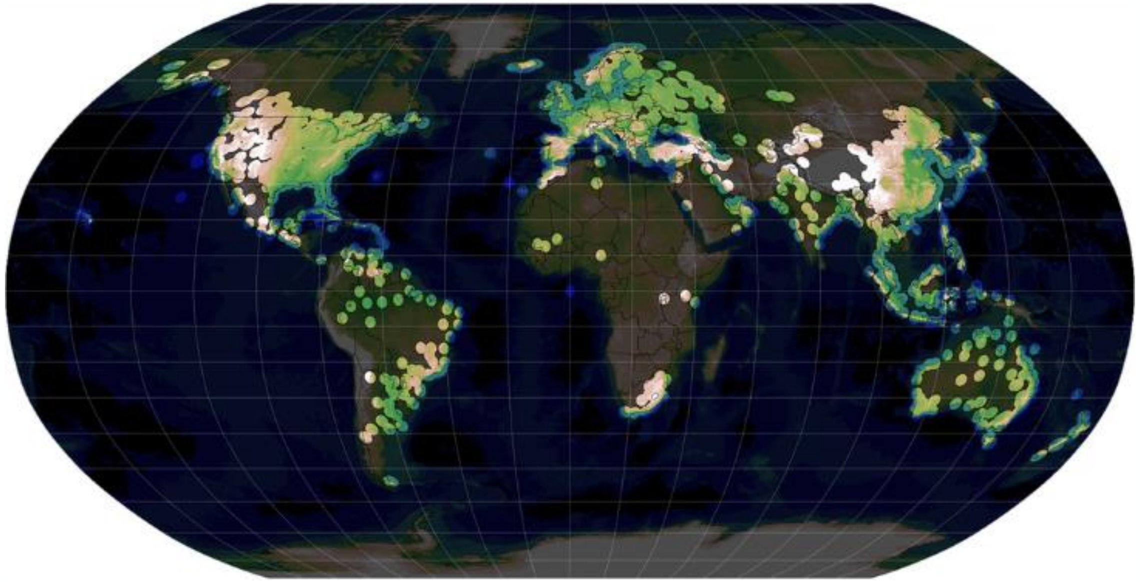
Why sedimentation velocity matters?

Hydrometeor sedimentation velocity controls cloud evolution, precipitation formation, and radiative effects, and remains a major source of uncertainty in weather and climate models
Sanderson et al. (2008); Waliser et al. (2009); Wang et al. (2020)

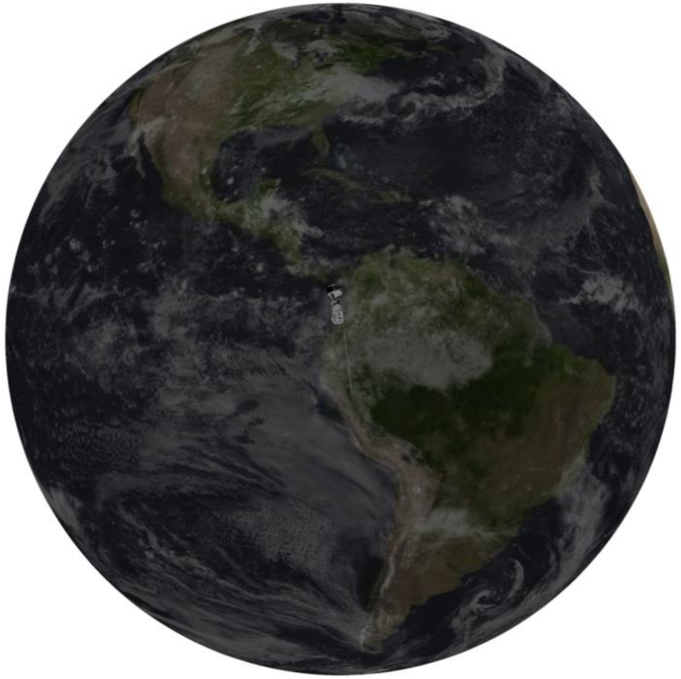
Doppler radars can provide information on the fall speed of hydrometeors, but observations remain limited at the global scale, especially over oceans and the Southern Hemisphere

Timelapse of storm clouds gathering over Halifax, Canada



Weather radar coverage in the world *Saltikoff et al. (2019)*

CPR measurements



Animation of EarthCARE in action

The **EarthCARE CPR** provides an unprecedented global record of Doppler velocity observations, creating a **new opportunity** to **retrieve sedimentation velocity and constrain microphysical parameterizations**

The observed **CPR Doppler velocity** (V_D) is a composite signal that includes **hydrometeor fall speed** (V_{sed}), **vertical air motion** (V_{air}), and measurement **noise and instrumental effects** (ϵ)

$$V_D = V_{sed} + V_{air} + \epsilon$$

How can we retrieve V_{sed} from the measured V_D ?

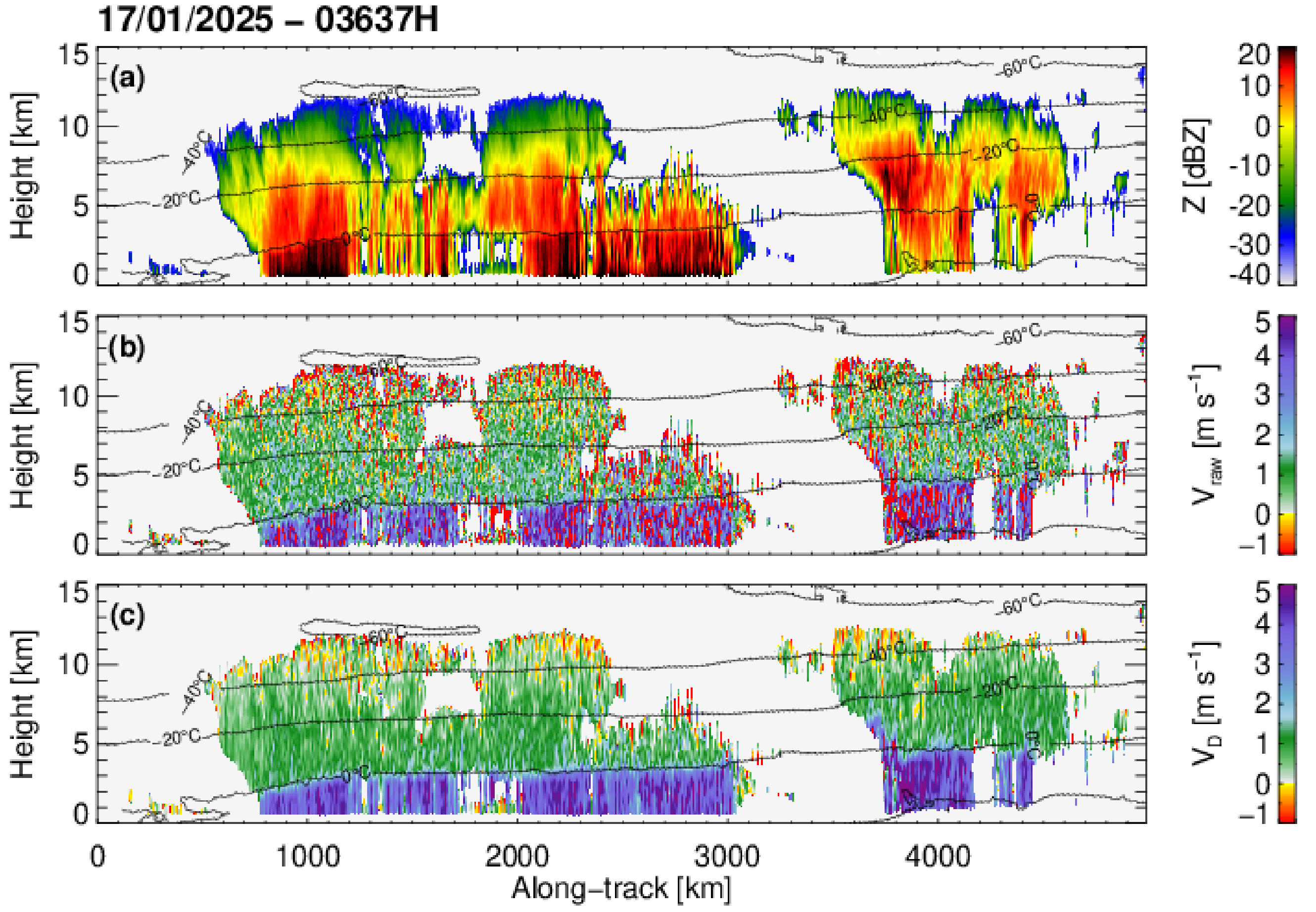
From Doppler to sedimentation velocity

Retrieval concept

Assuming that nearby observations with similar Z and T are likely to share similar microphysical and thermodynamical conditions,

We average their V_D to suppress V_{air} and ϵ contributions to estimate V_{sed}

$$V_D = V_{sed} + \underbrace{V_{air} + \epsilon}_{\text{Zero mean}}$$

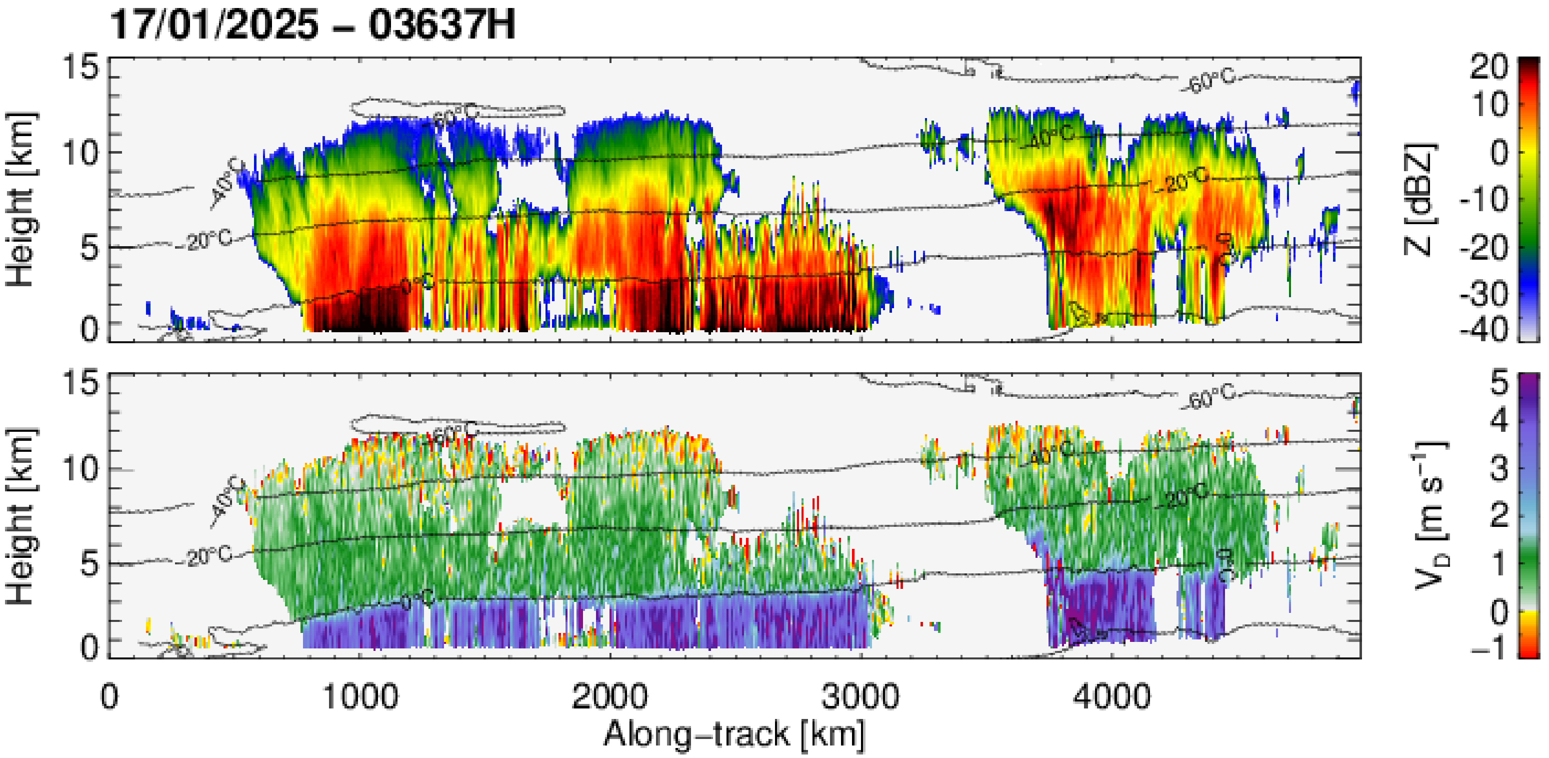


(a) CPR L2a radar reflectivity corrected for attenuation (PIA)
(b) CPR L1b Doppler velocity
(c) CPR L2a Doppler velocity best estimate

From Doppler to sedimentation velocity

Retrieval concept

$$V_{sed}(\hat{x}, \hat{y}) = \frac{\sum_i w_i V(x_i, z_i)}{\sum_i w_i}$$



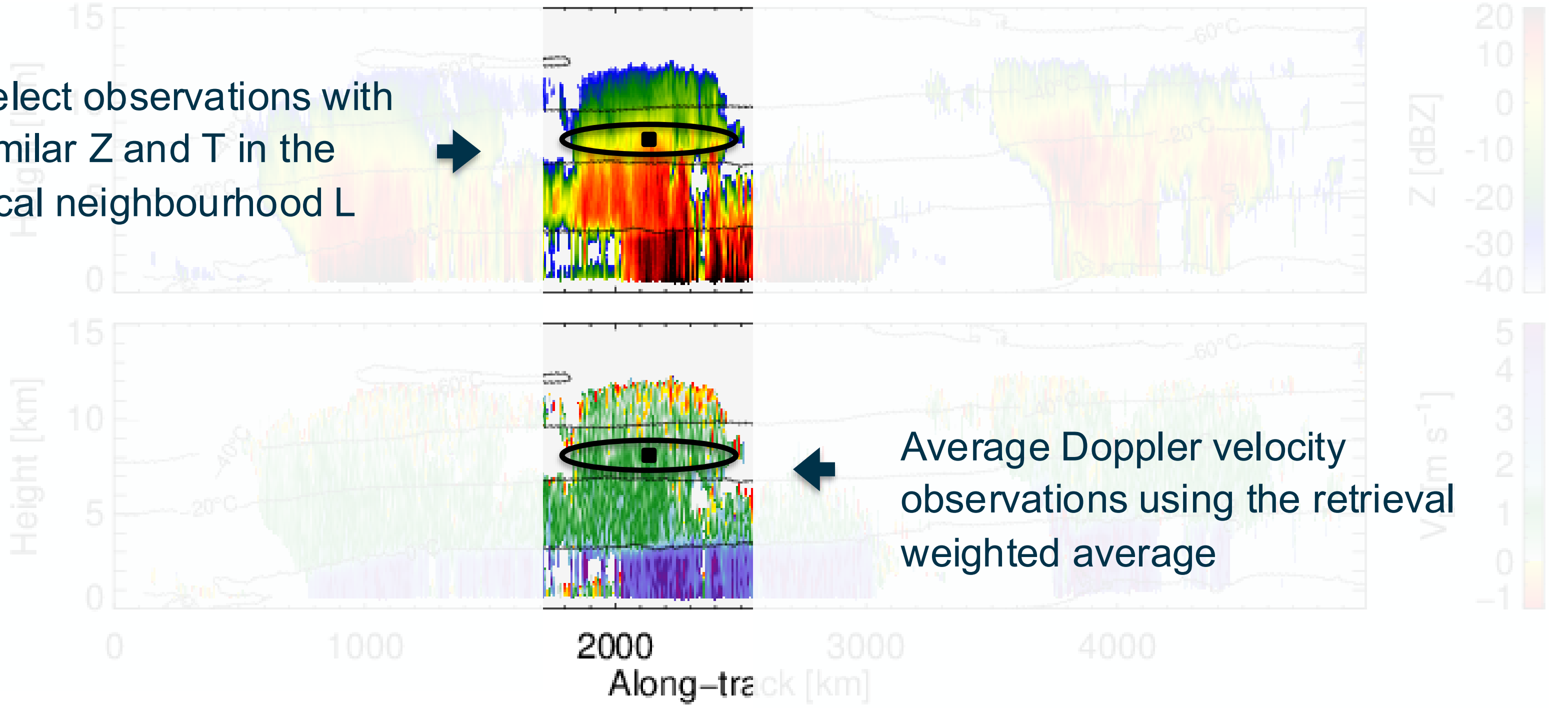
From Doppler to sedimentation velocity

Retrieval concept

$$V_{sed}(\hat{x},\hat{y}) = \frac{\sum_i w_i V(x_i, z_i)}{\sum_i w_i}$$

17/01/2025 – 03637H

Select observations with similar Z and T in the local neighbourhood L



Average Doppler velocity observations using the retrieval weighted average

From Doppler to sedimentation velocity

Retrieval concept

$$V_{sed}(\hat{x},\hat{y}) = \frac{\sum_i w_i V(x_i, z_i)}{\sum_i w_i}$$

Local-similarity averaging kernel

$$w_i = \exp\left[-\frac{(Z_i-\hat{Z})^2}{2Z_{\text{bin}}^2} - \frac{(T_i-\hat{T})^2}{2T_{\text{bin}}^2} - \frac{(x_i-\hat{x})^2}{2L^2}\right]\cdot\frac{1}{\sigma_{VD,i}^2}$$

Z Reflectivity

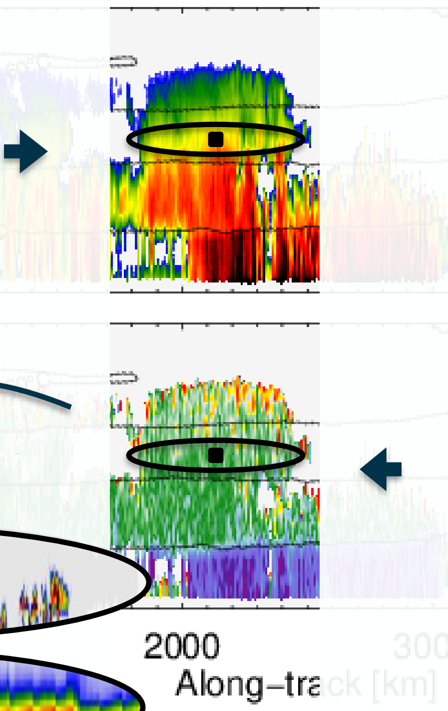
T Temperature

L Distance

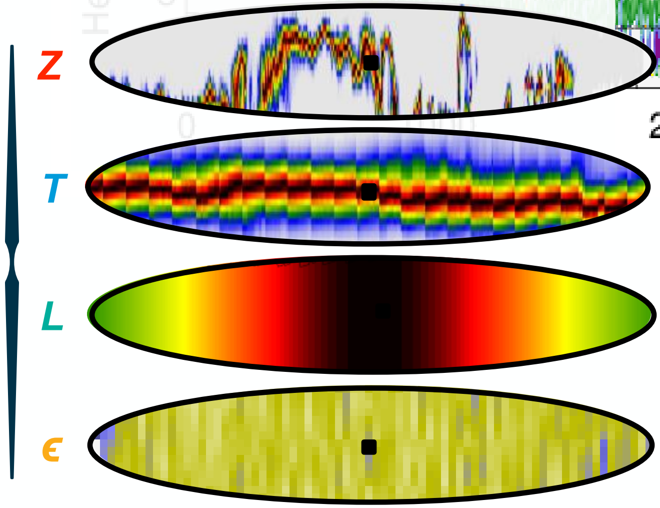
ϵ Error

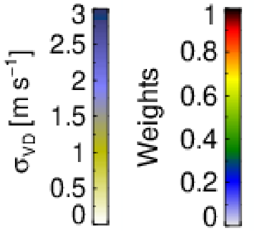
17/01/2025 – 03637H

Select observations with similar Z and T in the local neighbourhood L



Average Doppler velocity observations using the retrieval weighted average



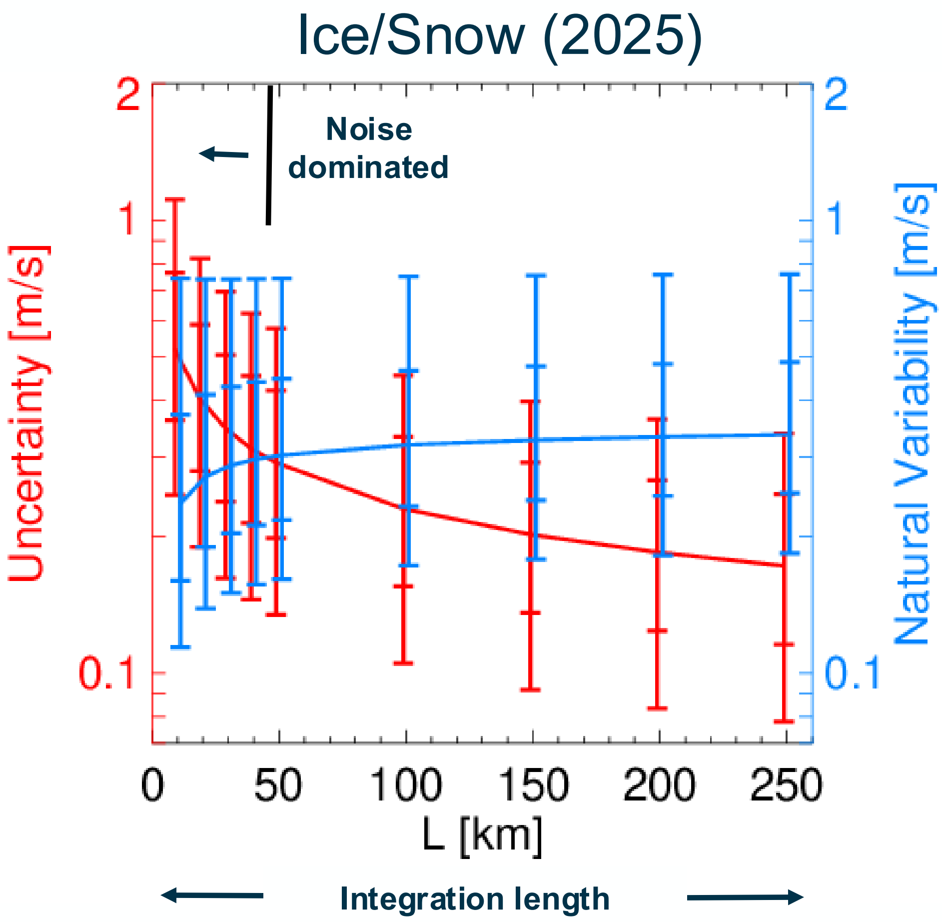


Higher weights are assigned to samples with similar Z and T, and closer proximity to the target volume

Noisier measurements are down-weighted using inverse-error variance

Adaptive sampling strategy

The retrieval is applied to several along-track integration window lengths and statistics are retained



The **Uncertainty** is the **standard error of the mean**, propagated from individual Doppler errors

The **Natural Variability** is the **weighted standard deviation of the averaged samples**. It defines the **goodness-of-fit,** used as a measure of homogeneity

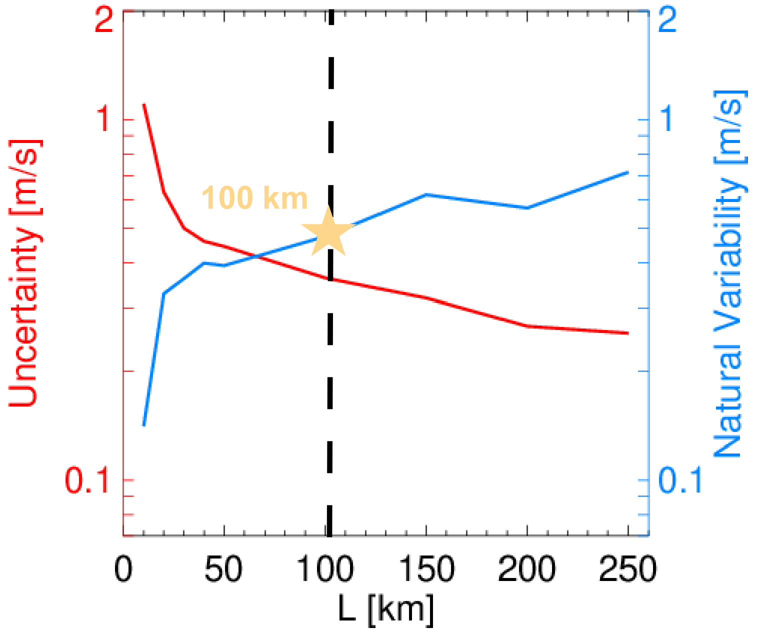
Small windows are noise-dominated (Uncertainty > Natural Variability)

As L increases, the variability reaches a stable plateau, where the minimization can identify the optimal integration window

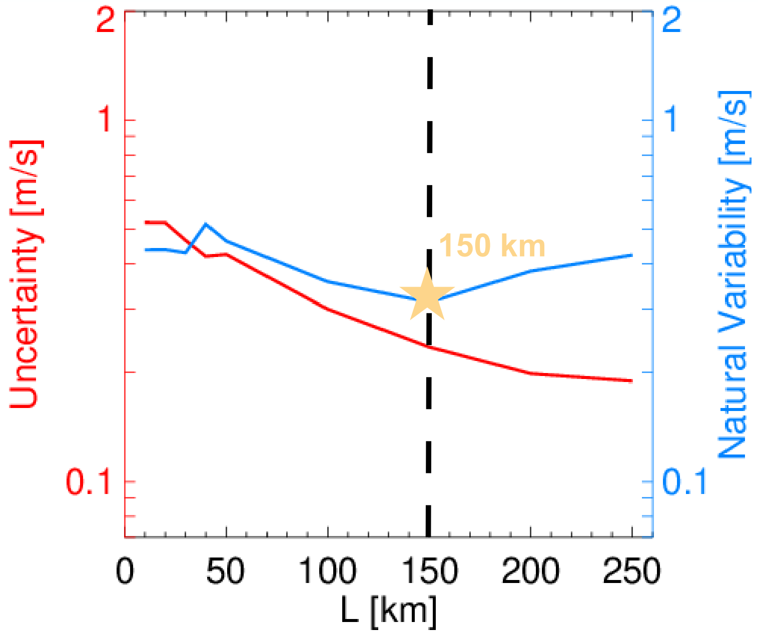
Adaptive sampling strategy

The best integration length is selected by balancing uncertainty reduction and natural variability

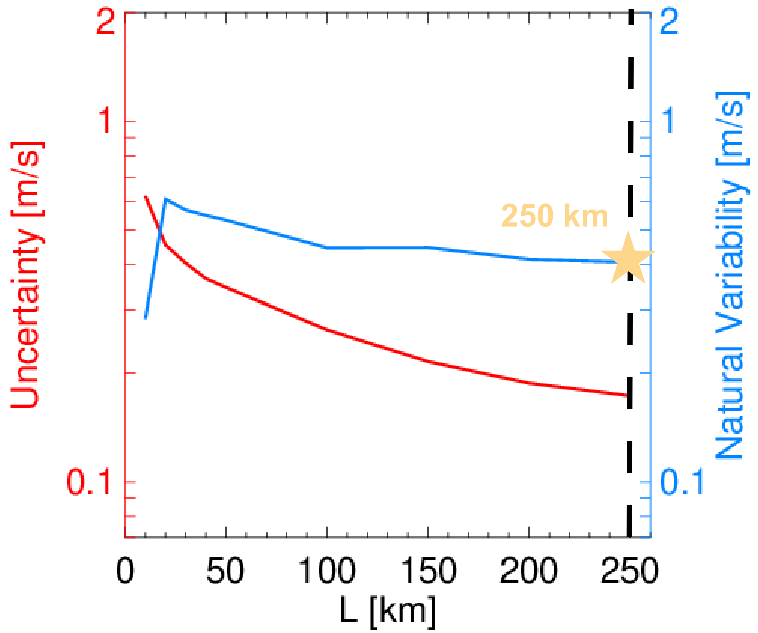
Increasing variability limits the window length



Intermediate window gives the best trade-off

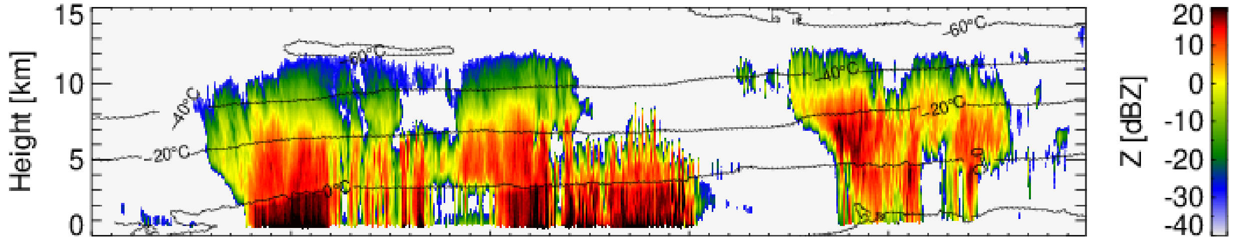


Stable variability allows longer integration

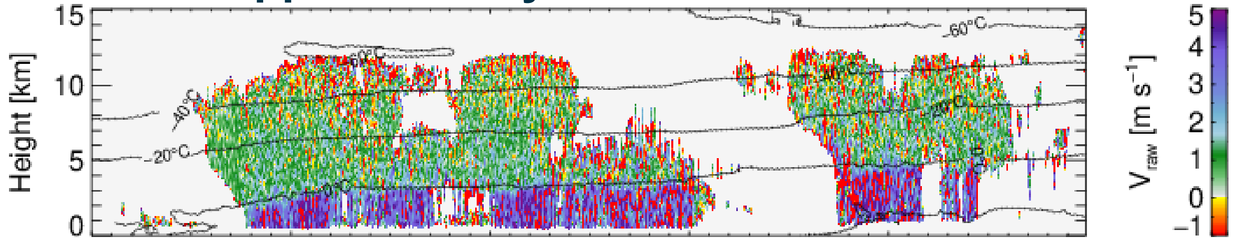


Case study: 17 Jan 2025, frame 03637H

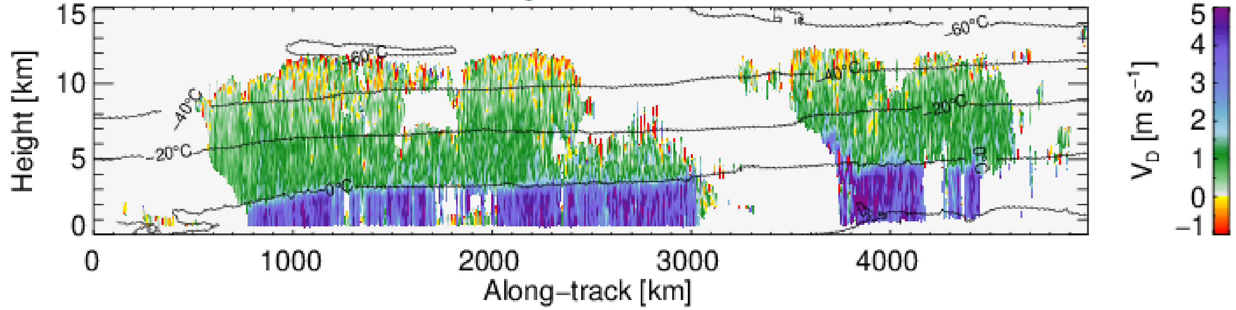
Reflectivity corrected for attenuation



L1b Doppler velocity



L2a Doppler velocity



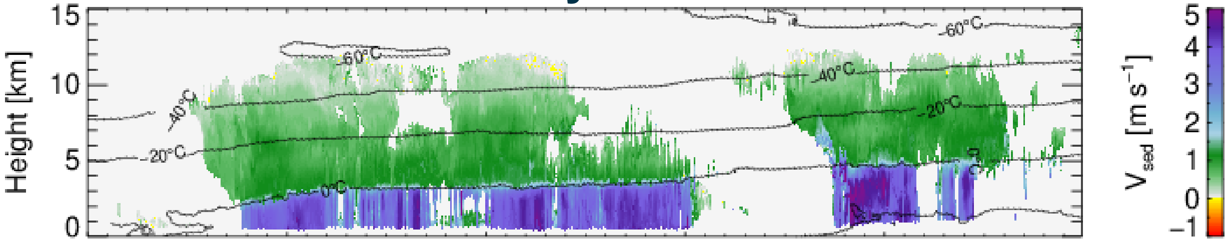
Attenuation-corrected reflectivity and Temperature define similar microphysical and thermodynamic environments

Raw measurements are affected by pointing, noise and folding effects

Quality-controlled (*V_D*) reduce known effects, but gate-to-gate and along-track variability remain

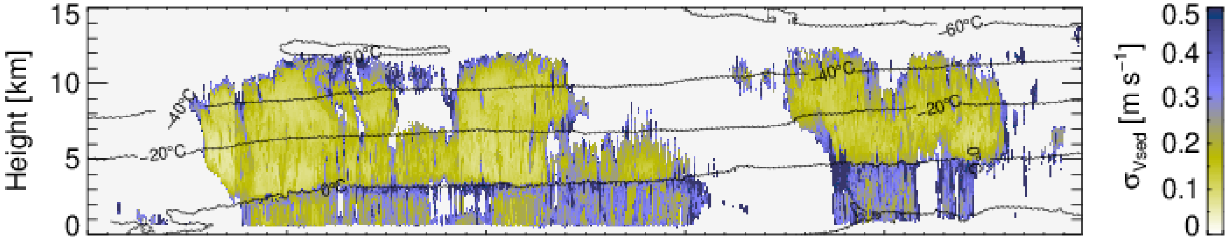
Case study: 17 Jan 2025, frame 03637H

Sedimentation velocity



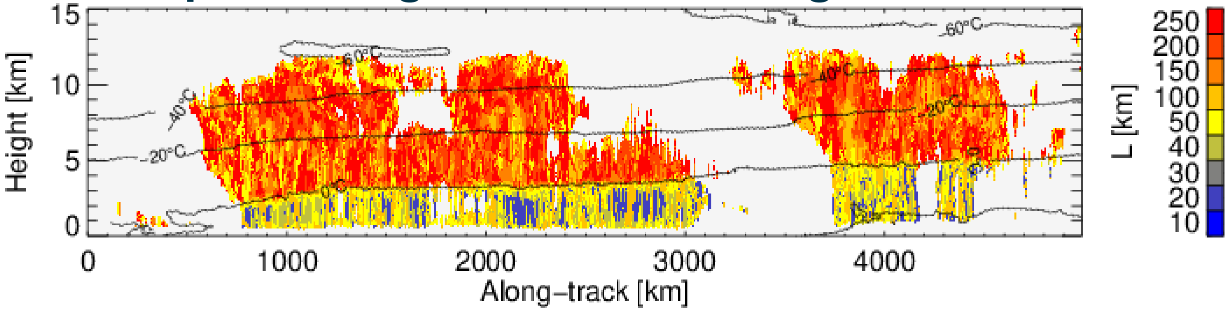
Coherent V_{sed} field after suppressing V_{air} and ϵ variability

Uncertainty



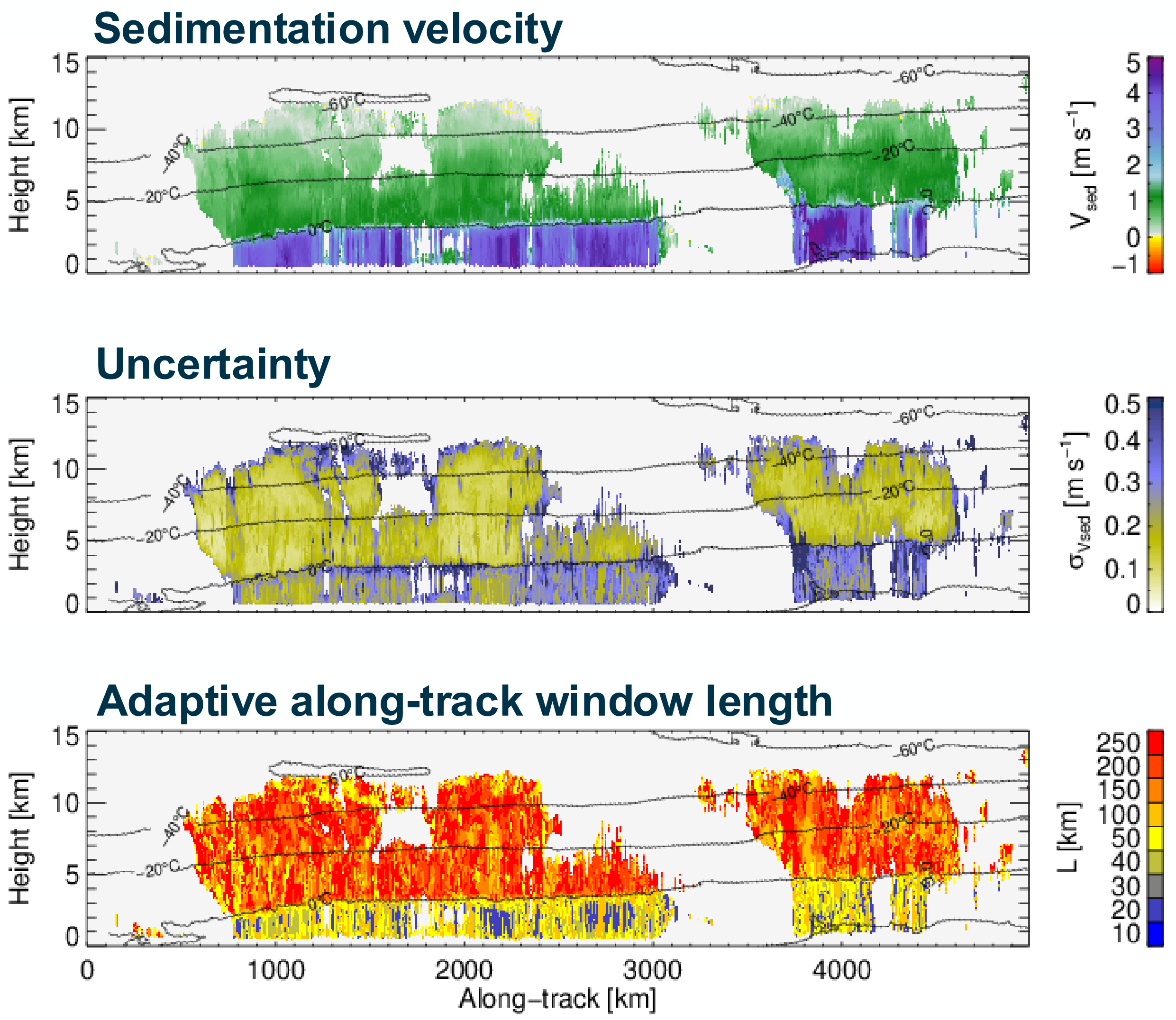
Small values indicating that the retrieval is well constrained

Adaptive along-track window length



Broader windows for ice/snow low-SNR conditions; narrower windows for rain to limit attenuation-correction uncertainty

Case study: 17 Jan 2025, frame 03637H

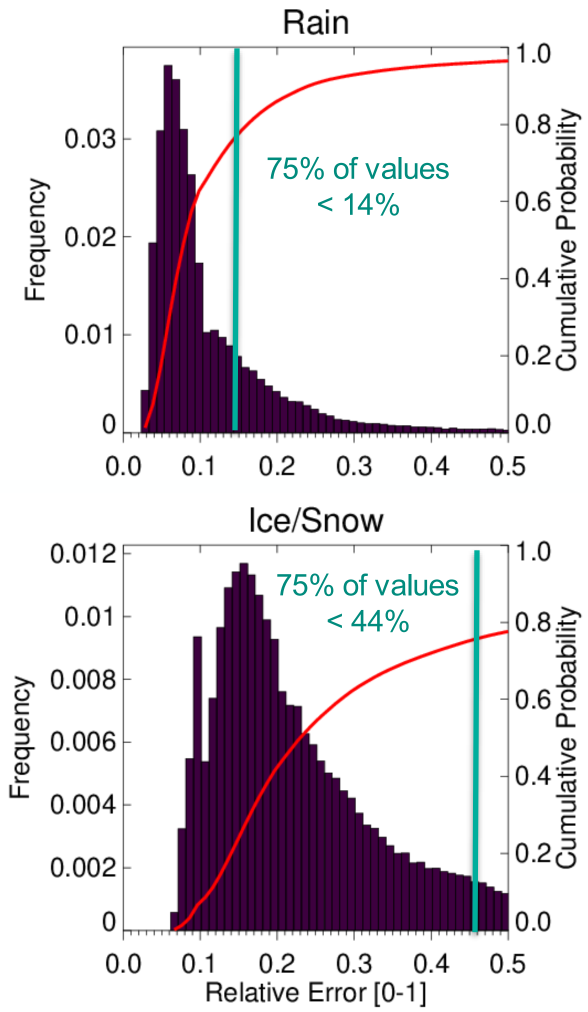


Coherent V_{sed} field after suppressing V_{air} and ϵ variability

Small values indicating that the retrieval is well constrained

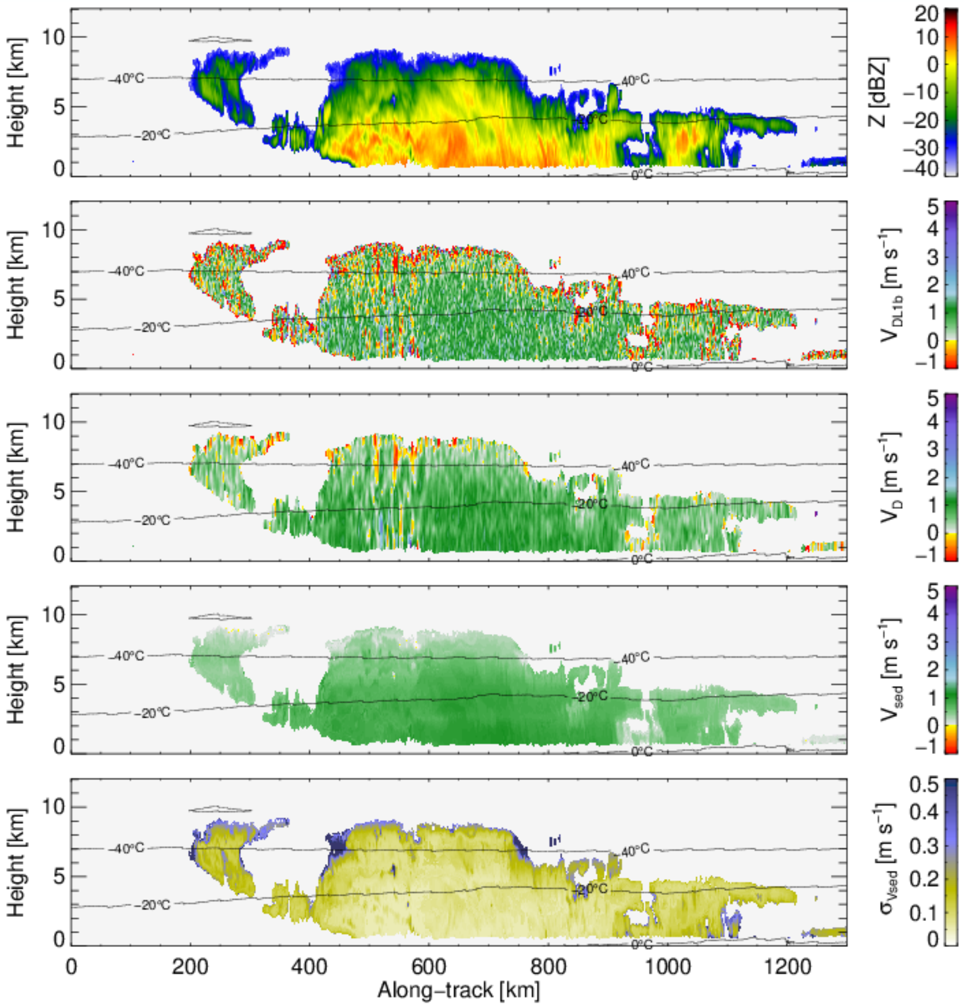
Broader windows for ice/snow low-SNR conditions; narrower windows for rain to limit attenuation-correction uncertainty

Relative Error



Other examples

Gravity waves 07/04/2016 - 10552D



The retrieval is able to remove the variations in vertical air motion caused by gravity waves

Other examples

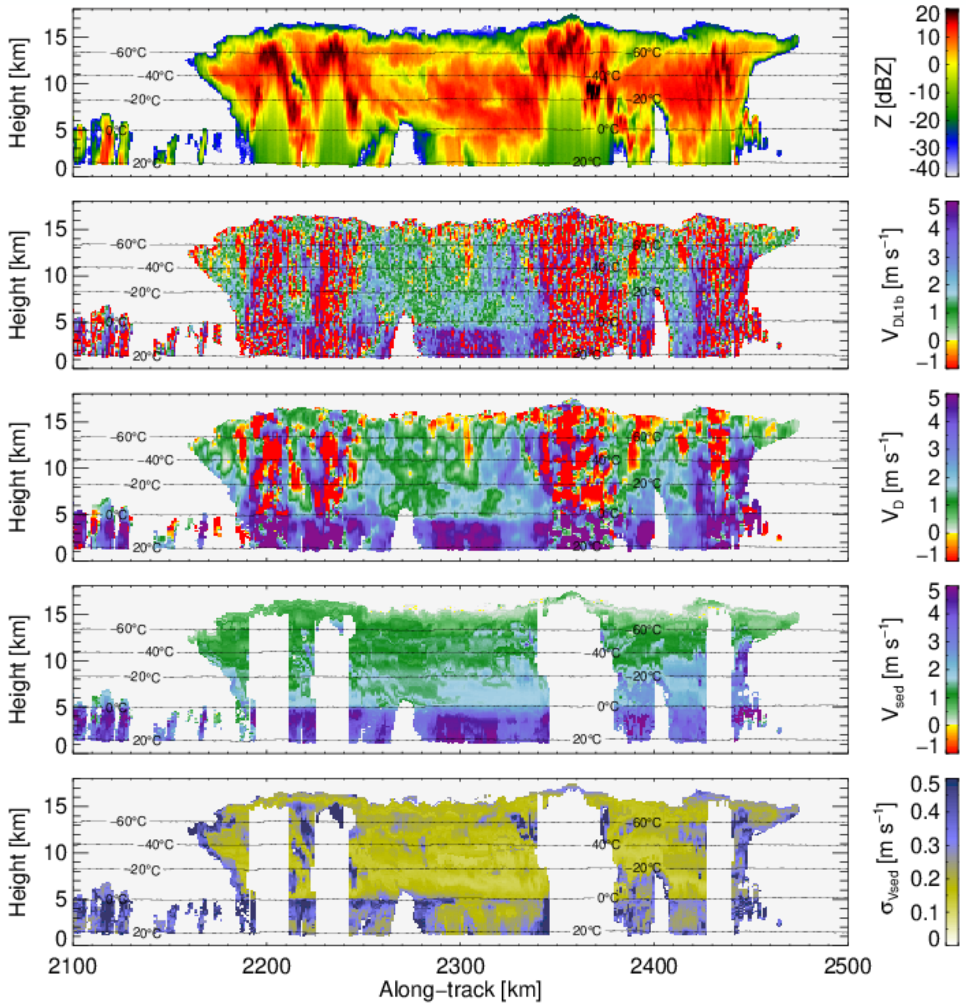
Gravity waves 07/04/2016 - 10552D

The retrieval is not intended for convective regions, where multiple scattering, rapid microphysical transitions, and coherent vertical motions break the uniformity assumptions behind the technique

The technique avoids convective cores but challenges remain in the nearby regions

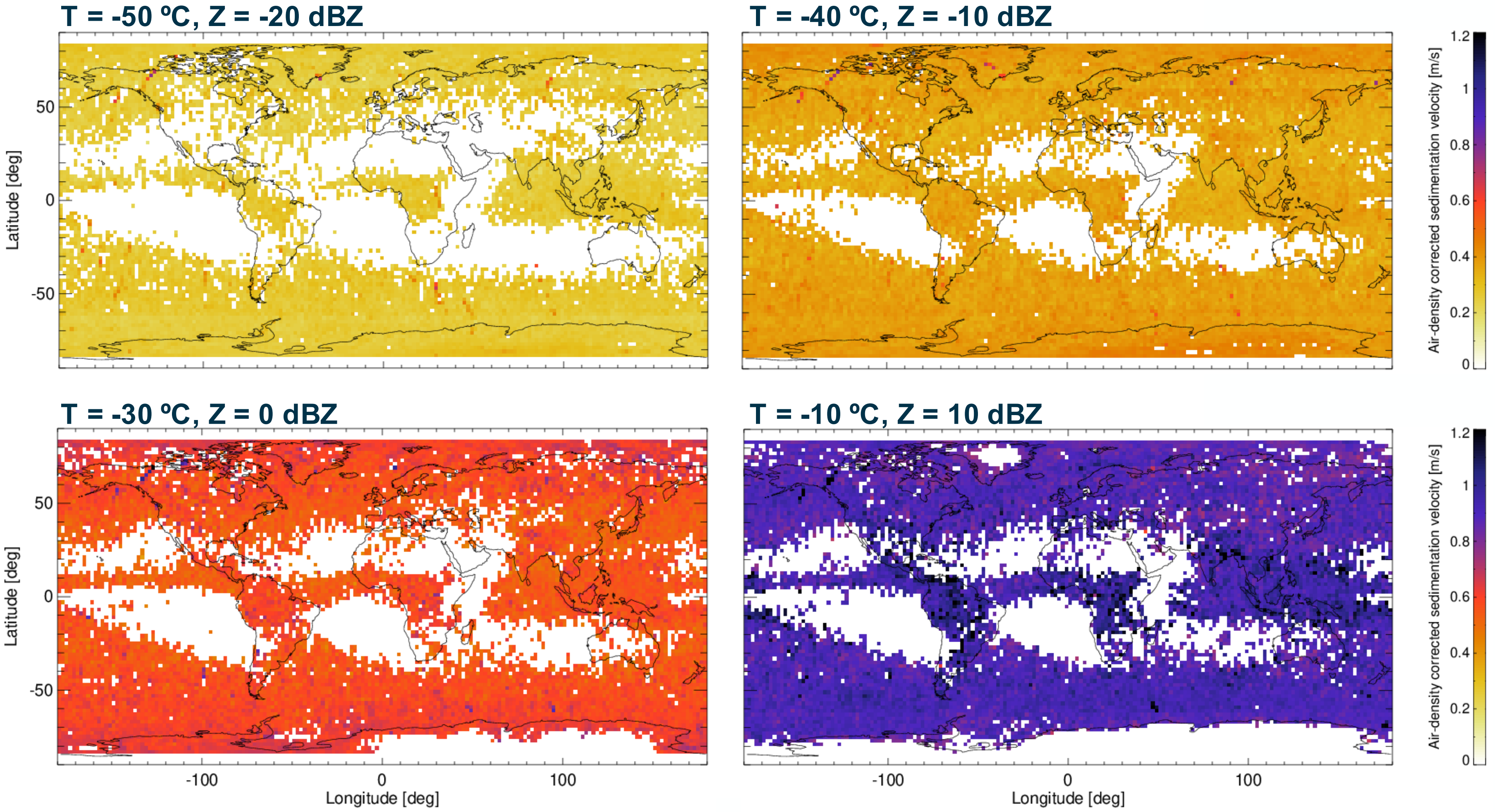
The retrieval is able to remove the variations in vertical air motion caused by gravity waves

Convection 09/10/2025 - 07757E

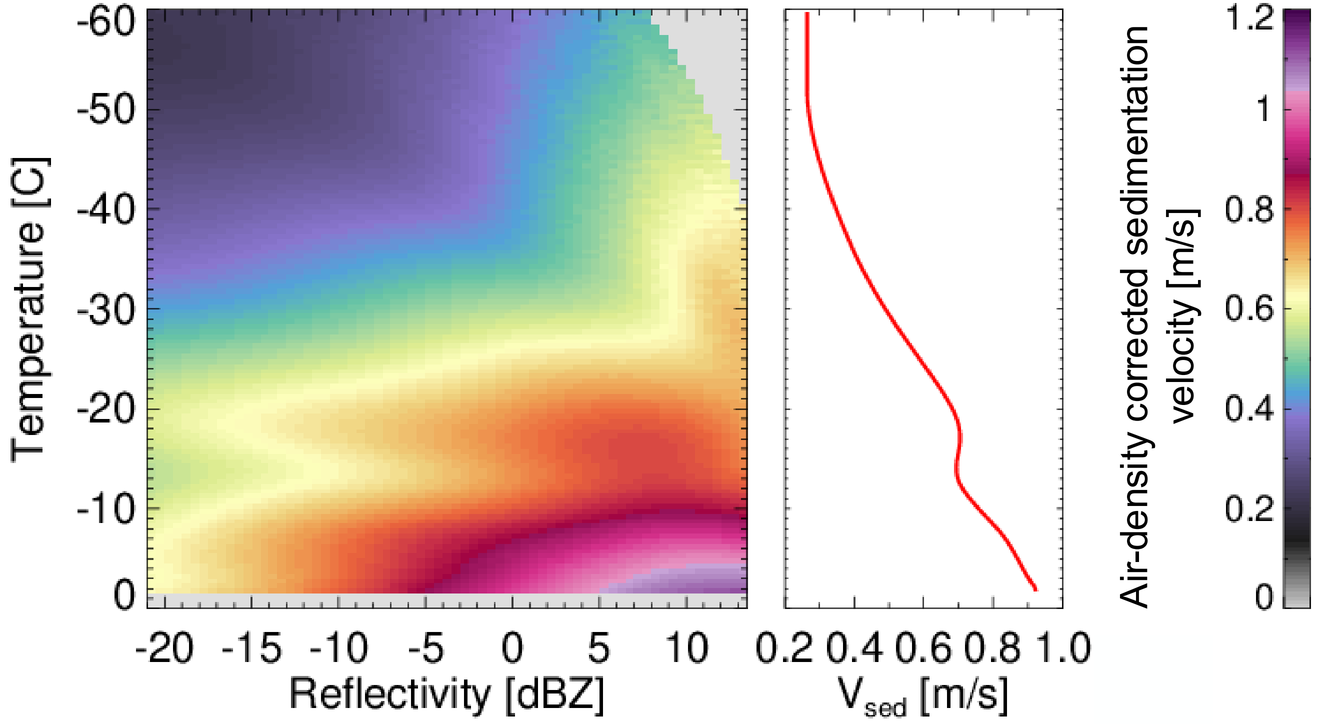


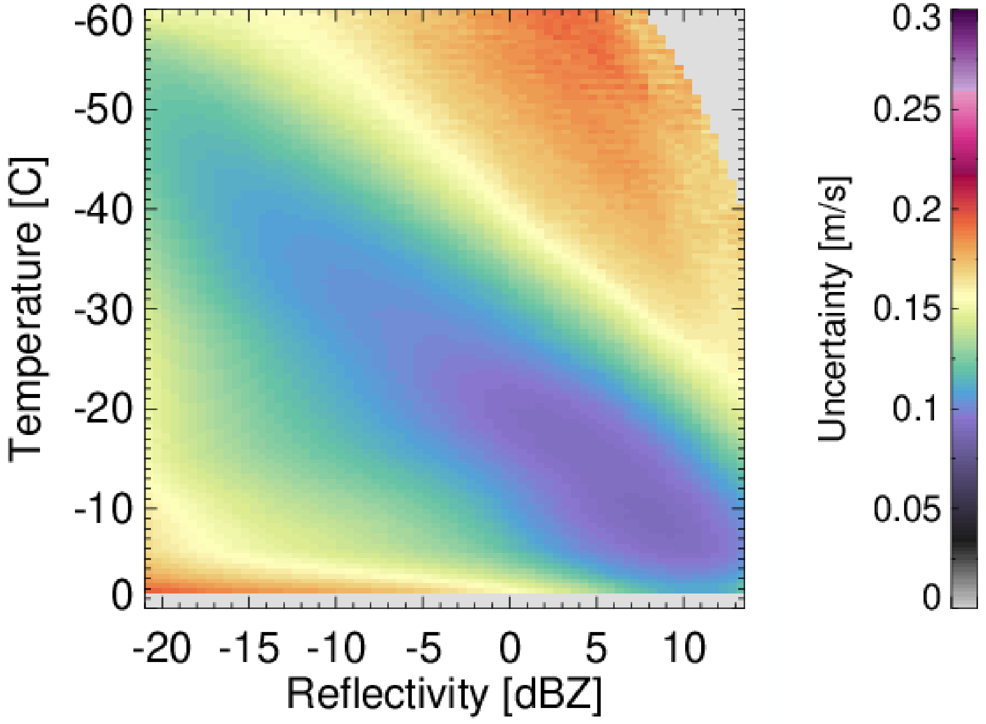
2025 Climatology

Retrieved sedimentation velocities are generally spatially coherent globally



2025 Climatology





This climatological data set provides an observation-based characterization of sedimentation processes, offering a new constraint for cloud and precipitation microphysical studies

For a practical application of the work presented here, please refer to Jiseob Kim's presentation:

Identifying Riming through Vertical Gradients of EarthCARE CPR Sedimentation Velocity in Stratiform Clouds

Summary

* EarthCARE CPR provides a new global Doppler record to characterize hydrometeor sedimentation velocity

* The retrieval uses similarity in reflectivity, temperature, and distance to suppress vertical air motion, noise and instrumental effects, and estimate sedimentation velocity

* The retrieved fields are well constrained and preserve microphysical information

* The 2025 climatology is physically consistent, and has small uncertainty, providing a new observation-based constraint for cloud and precipitation microphysical studies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Thank you