The WInd VElocity Radar Nephoscope (WIVERN) a candidate mission for the ESA Earth Explorer 11

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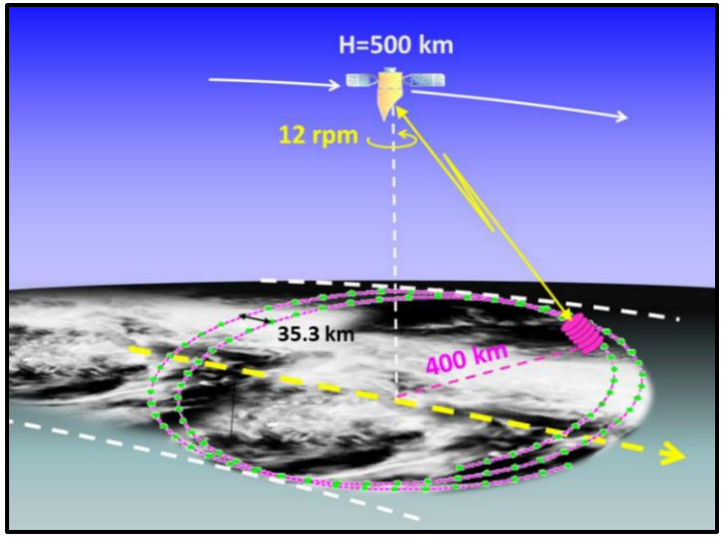

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➔ The **first space-based mission to provide in-cloud winds**, and hence to contribute to **NWP and climate research**

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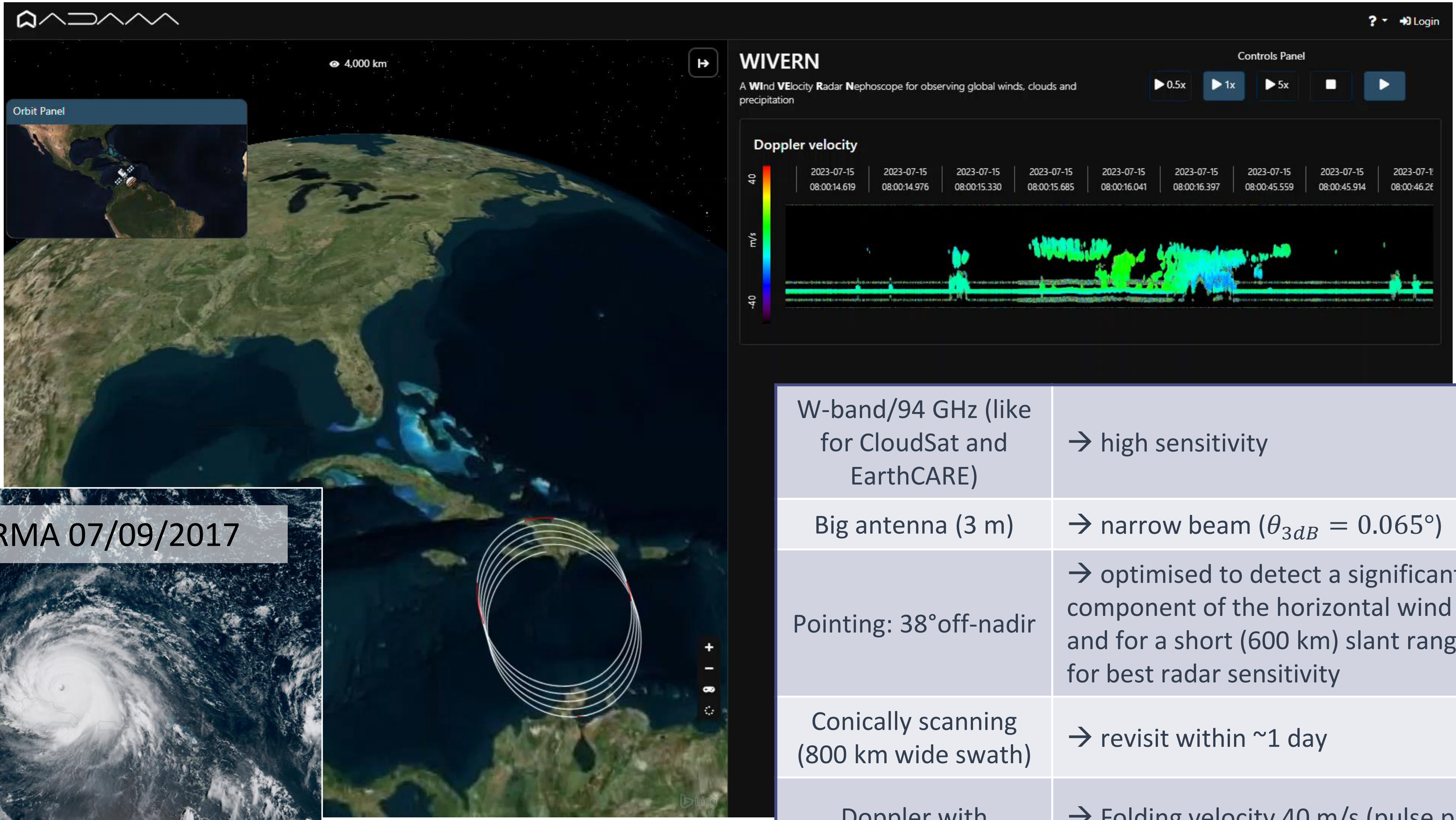
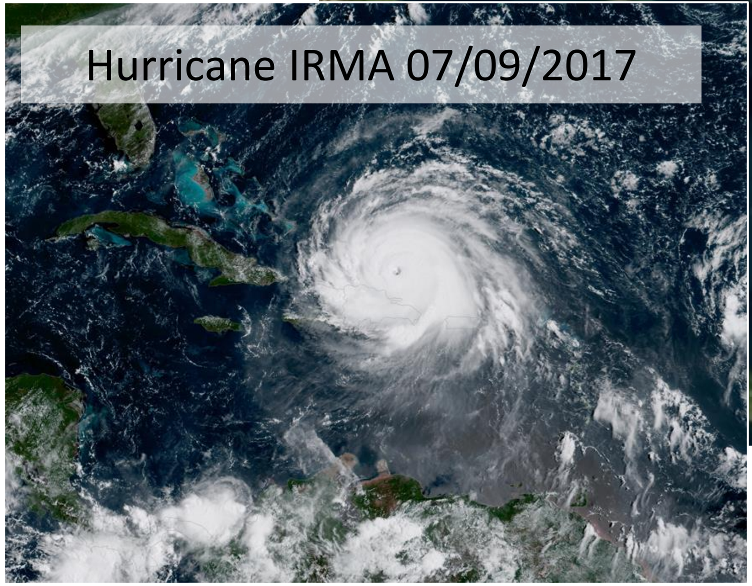
WIVERN radar instrument concept

https://dev.explorer.wivern.adamplatform.eu/





Hurricane IRMA 07/09/2017

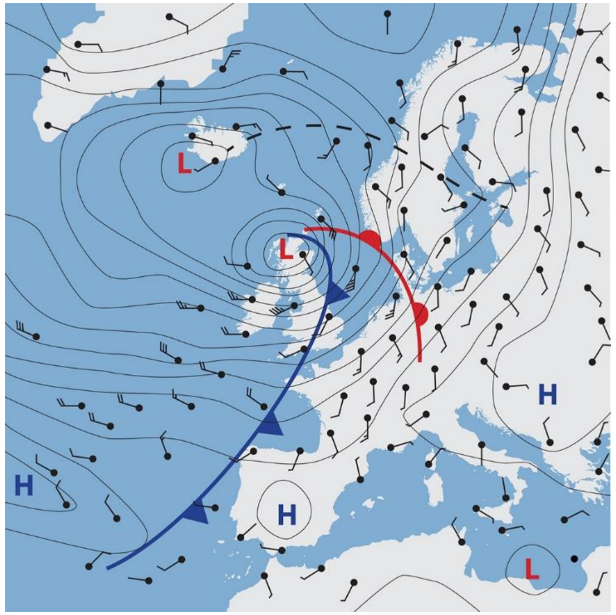
W-band/94 GHz (like for CloudSat and EarthCARE)	→ high sensitivity
Big antenna (3 m)	→ narrow beam ($\theta_{3dB} = 0.065°$)
Pointing: 38°off-nadir	→ optimised to detect a significant component of the horizontal wind and for a short (600 km) slant range for best radar sensitivity
Conically scanning (800 km wide swath)	→ revisit within ~1 day
Doppler with polarization diversity	→ Folding velocity 40 m/s (pulse pair separation: 37 km)

WIVERN scientific goals and products

1) **Extend lead-time and predictive skills of NWP models** (including high-impact weather)

→ Vertically resolved in-cloud winds

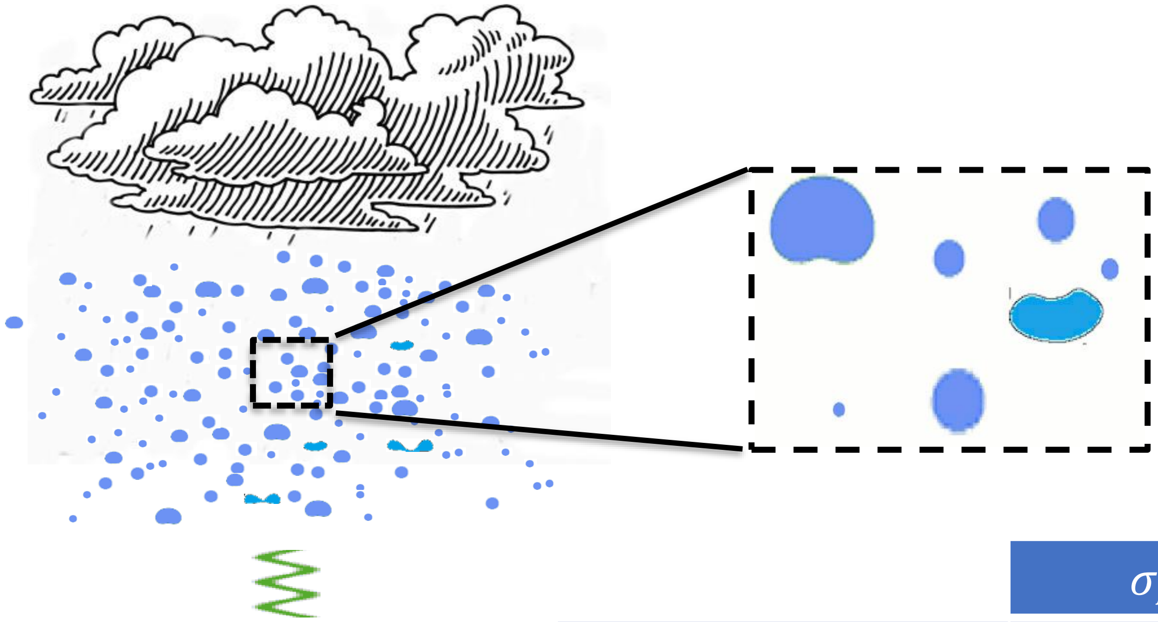
Help in filling a critical gap in the global observing system, by providing near real-time wind observations in cloudy stratiform conditions



2) Benchmark for the **climate record of cloud profiles and solid/light precipitation** in the 2030s (continuation of CloudSat and EarthCARE global datasets)

→ Liquid Water Path, profiles of Ice Water Content, precipitation/snow rates at **unprecedented spatial and temporal resolution**

The challenge of Doppler from space



Doppler estimate from two radar pulses separated by time τ

- ☐ τ not too short to get large enough unambiguous range → $r_{max} = \frac{c\tau}{2}$
- ☐ τ not too long so that the medium maintains coherency between two pulses (targets do not reshuffle too much, i.e. their relative motion is ≤ λ) → $\tau < T_{dec}$

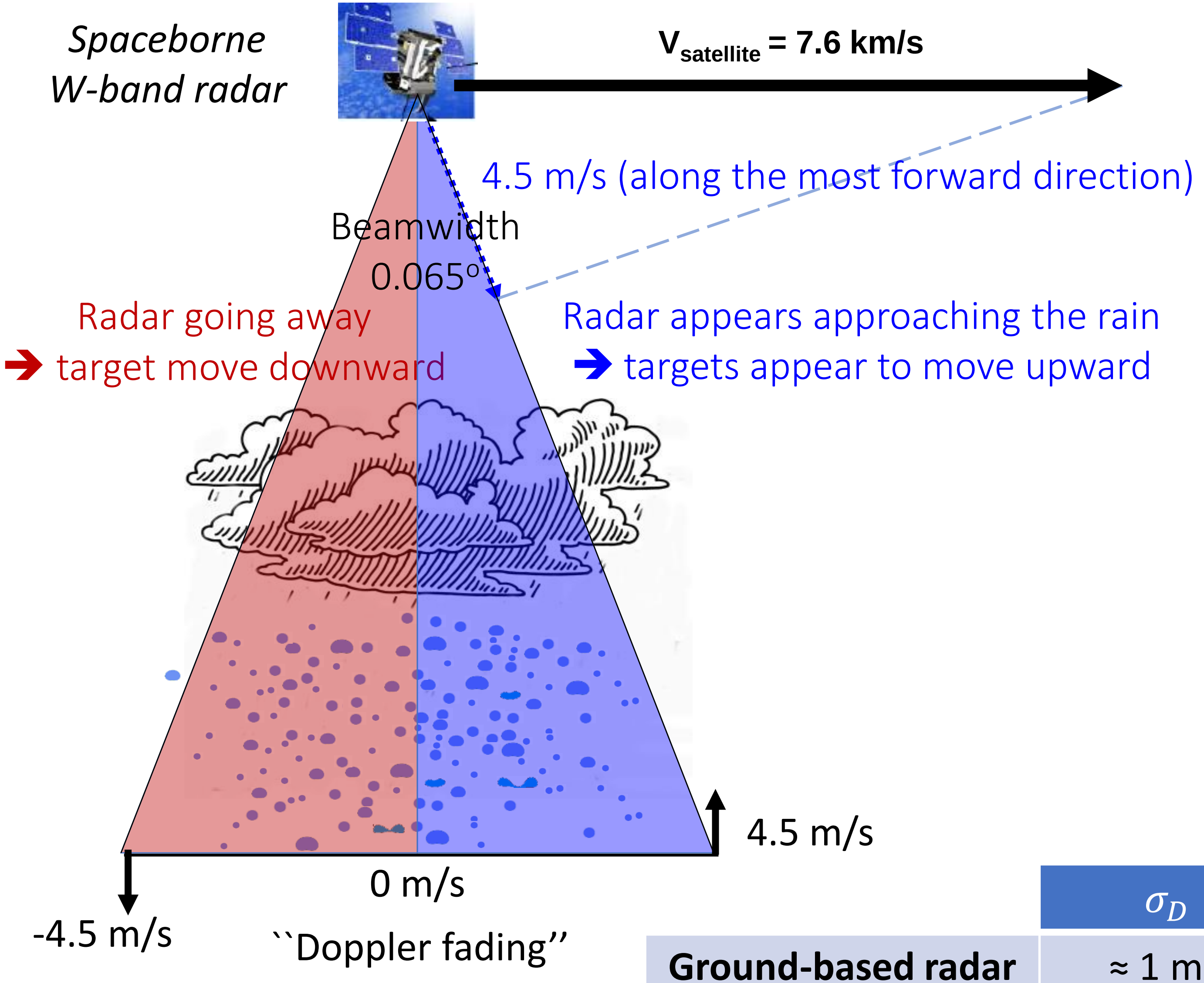
$$T_{dec} = \frac{\lambda}{4\sqrt{\pi}\sigma_D}$$

where σ_D is the standard deviation of the vertical velocities of drops in the radar volume

	σ_D	T_{dec}	PRF	r_{max}
Ground-based radar	≈ 1 m/s	360 μs	> 3 kHz	50 km

Ground based W-band radar

The challenge of Doppler from space



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	σ_D	T_{dec}	PRF	r_{max}
Ground-based radar	≈ 1 m/s	360 μs	> 3 kHz	50 km
Spaceborne radar	≈ 3-4 m/s	100 μs	> 10 kHz	15 km

The solution: polarization diversity

- Two nearby H and V pulses separated by τ_{HV}
  - The isolation between H and V signals prevents range ambiguity
  - Doppler is derived from the phase shift between H and V pulse
- Long waiting time τ_{pri} before the next pulse pair
  - Max range is restricted by the time between 2 H-V pairs

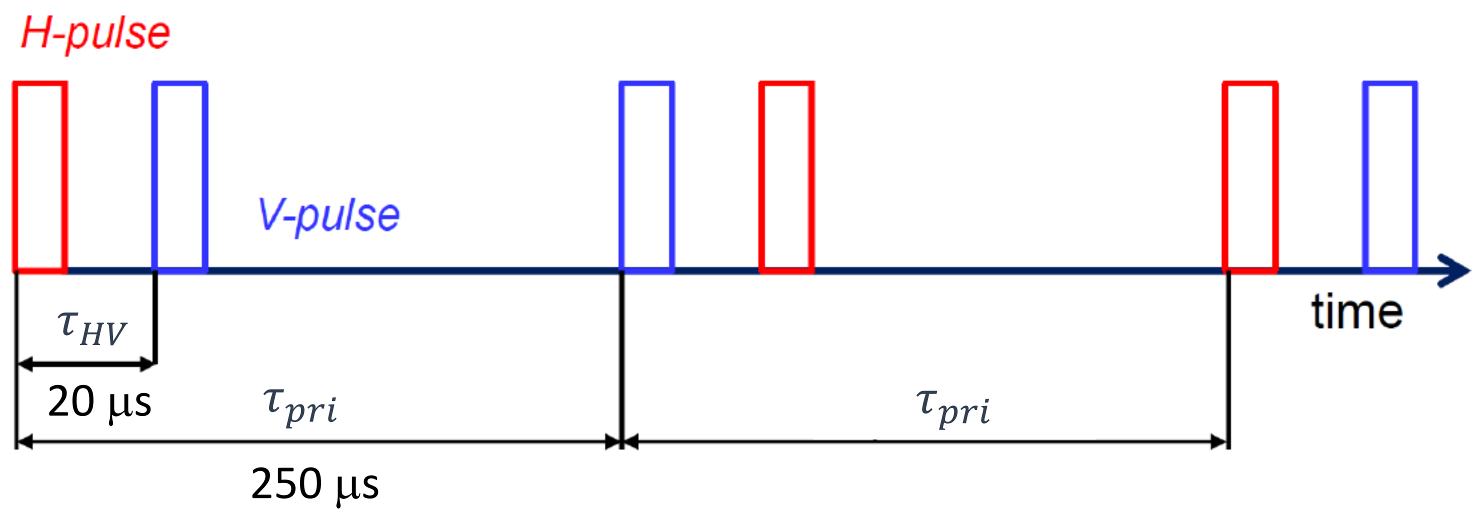
Velocity interval

$$v_N = \frac{\lambda}{4\tau_{HV}} = \pm\, 40 \text{ m/s}$$

Range interval

$$r_{max} = \frac{c\tau_{pri}}{2} = 37.5 \text{ km}$$

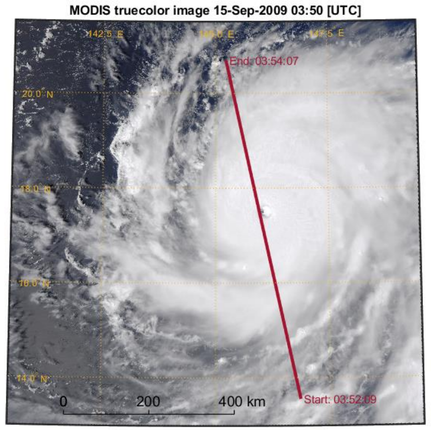
decoupled!!



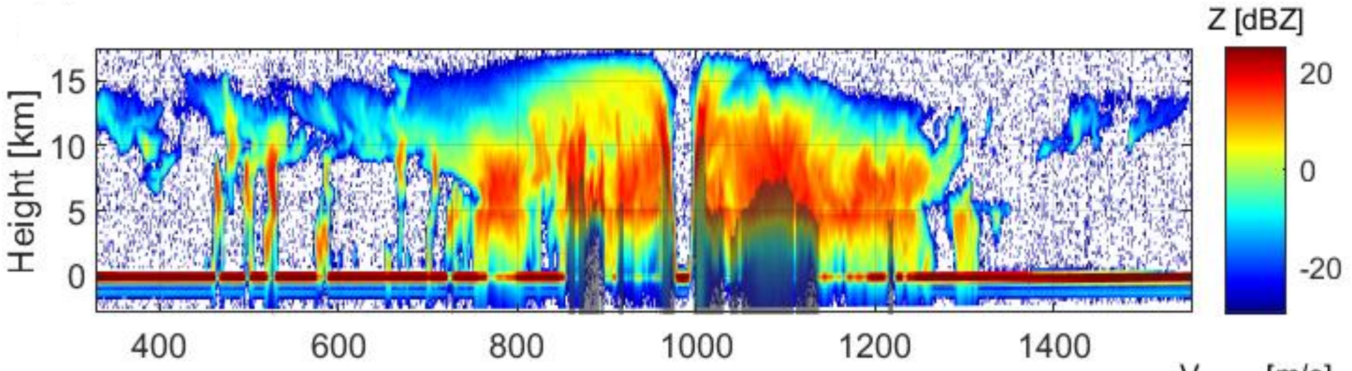
Best proxy for simulating WIVERN: CloudSat observations

Typhoon Choi-Wan
15/09/2009

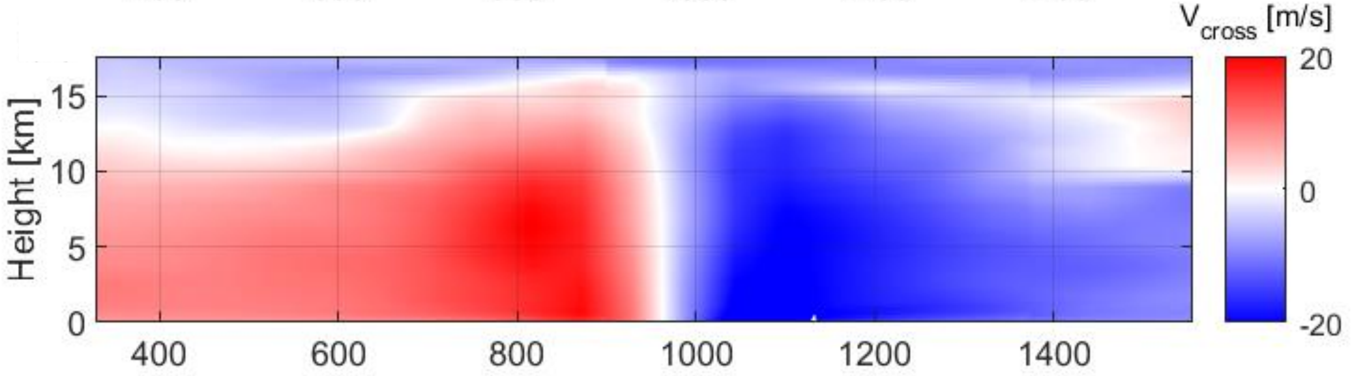
CloudSat trajectory



CloudSat reflectivity curtain with shading where attenuation cannot be corrected



ECMWF cross-track winds

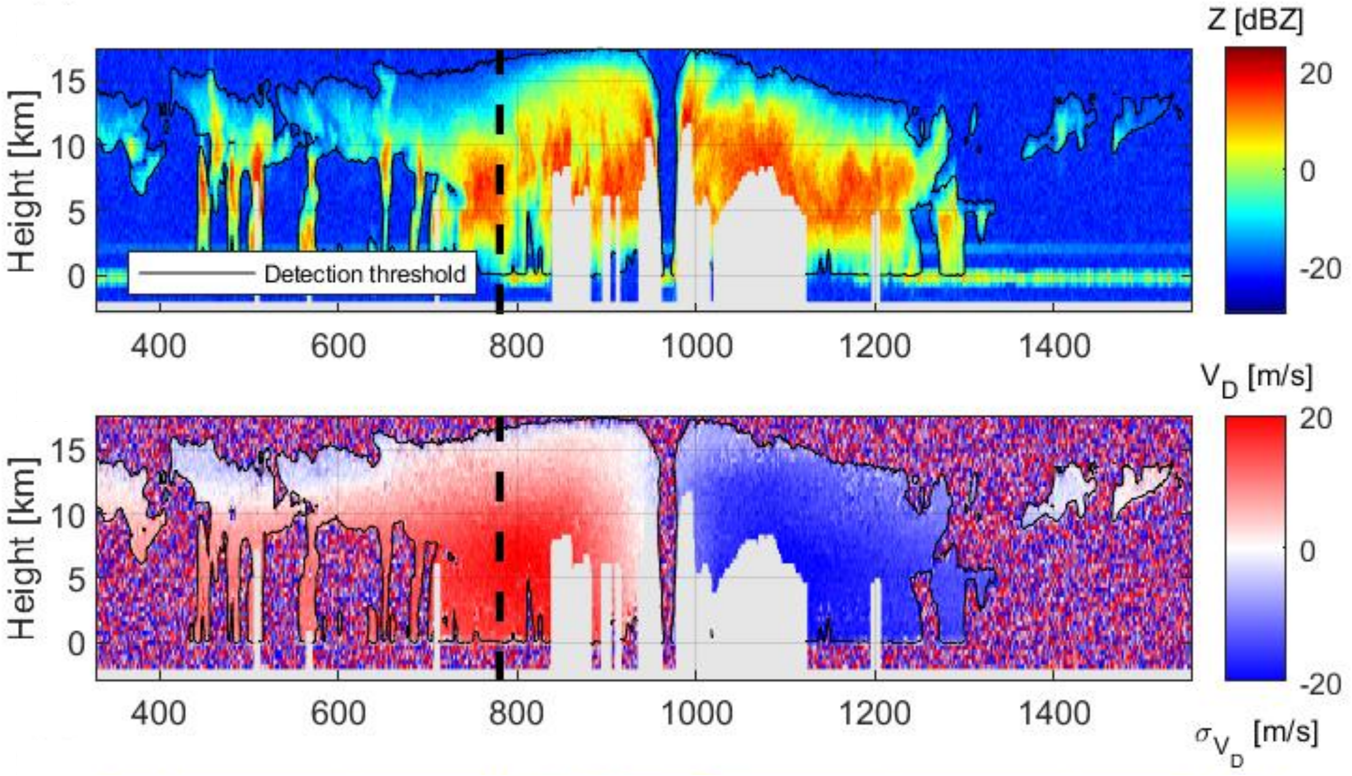


WIVERN end-to-end simulator

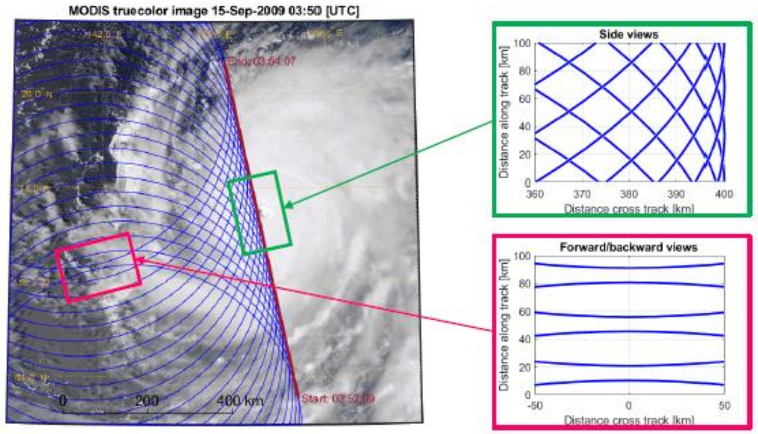
Typhoon Choi-Wan
15/09/2009

WIVERN reflectivity curtain with no data where attenuation is unknown

Doppler velocity



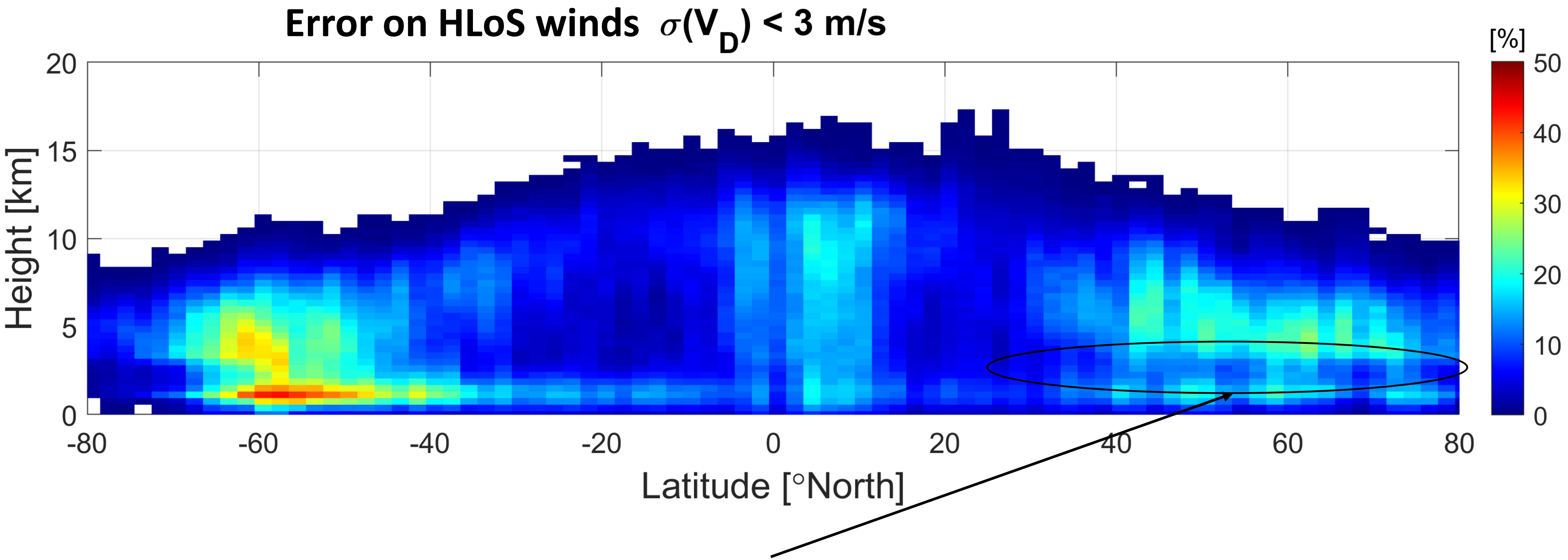
CloudSat trajectory



Wivern boresight trajectory (seeing CloudSat data in side view)

Where are we going to see winds?

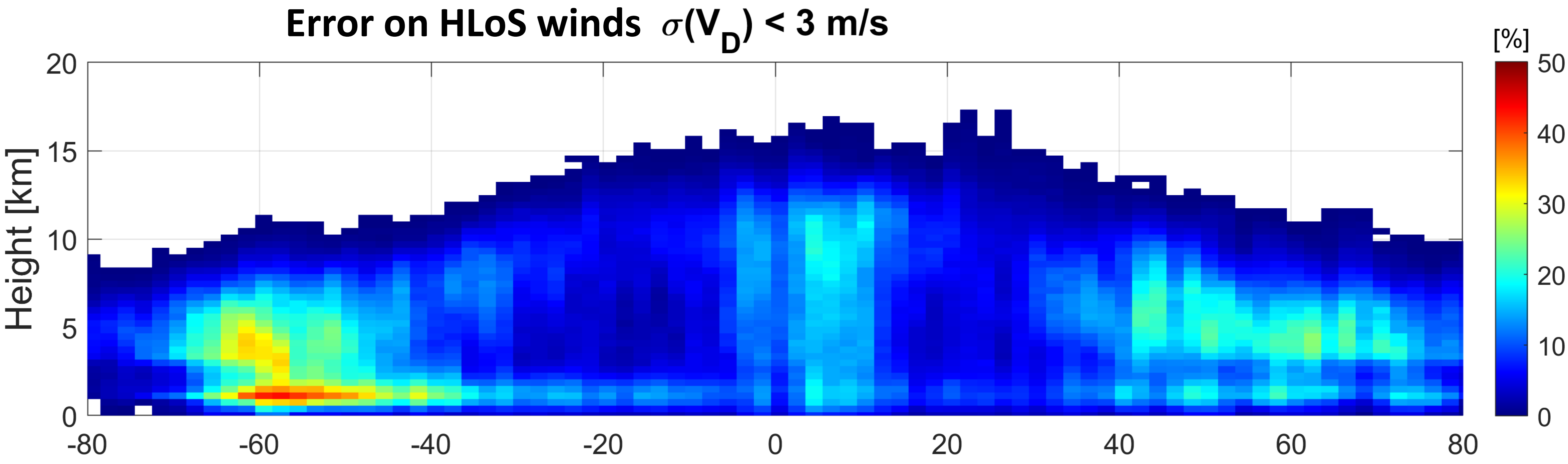
Based on 1 year of WIVERN global simulations reconstructed from CloudSat observations



Note increased noisiness in the Doppler due to contamination by cross-talk (stronger over land bright surfaces)

Where are we going to see winds?

WIVERN will provide about **2 millions accurate winds daily** at 20 km horizontal and 650 m vertical resolutions

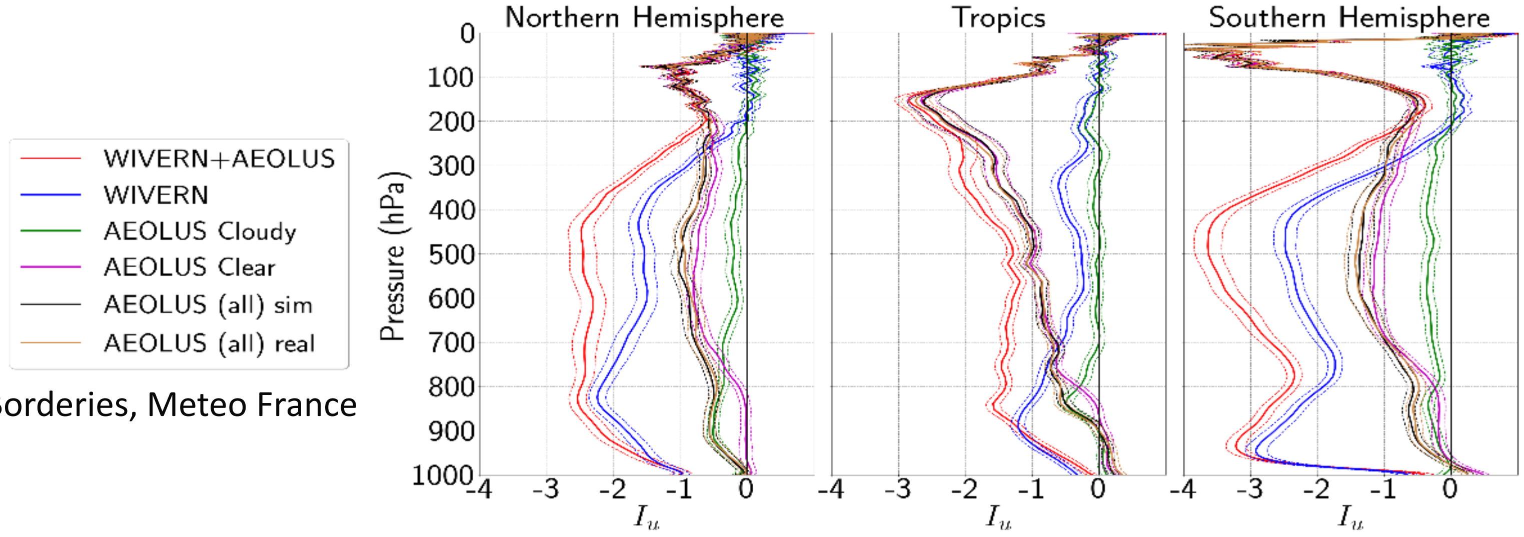


Current references

Atmospheric Motion Vectors: ~7 M/day, 300 k/day DA (error ~4 m/s)
Aircrafts: 1 M/day, 360 k/day DA (error 2 m/s)
ADM Aeolus: 130,000 clear air (89 km, error 3-4 m/s) & 50,000 cloudy (12 km, error 5-7 m/s)

Impact on data assimilation

- The recent **Aeolus mission** (spaceborne Doppler lidar for measuring winds in clear air and thin clouds in the upper troposphere/lower stratosphere) was a great success: the **assimilation of Aeolus winds significantly improved the forecasts of several NWP models** (G. George et al., 2021; Rennie et al., 2021; Laroche & St-James, 2022)
- **Assimilating the WIVERN synthetic observations** of in-cloud winds on top of Aeolus observations, can this produce a **further improvement in NWP forecast accuracy?**



Courtesy: Mary Borderies, Meteo France

Negative value → positive impact

- Impact measured by a **reduction of the operational Ensemble Data Assimilation spread** for the ARPEGE global NWP model at analysis time and other forecast ranges
- On top of Aeolus, WIVERN has a **significant positive impact on the reduction in EDA spread, especially in the lower troposphere** (below 300 hPa)

Conclusion

- WIVERN is one of the 4 ESA EE11 candidate missions, currently in Phase 0 (downselection to 2 at the end of 2023, launch in 2030)

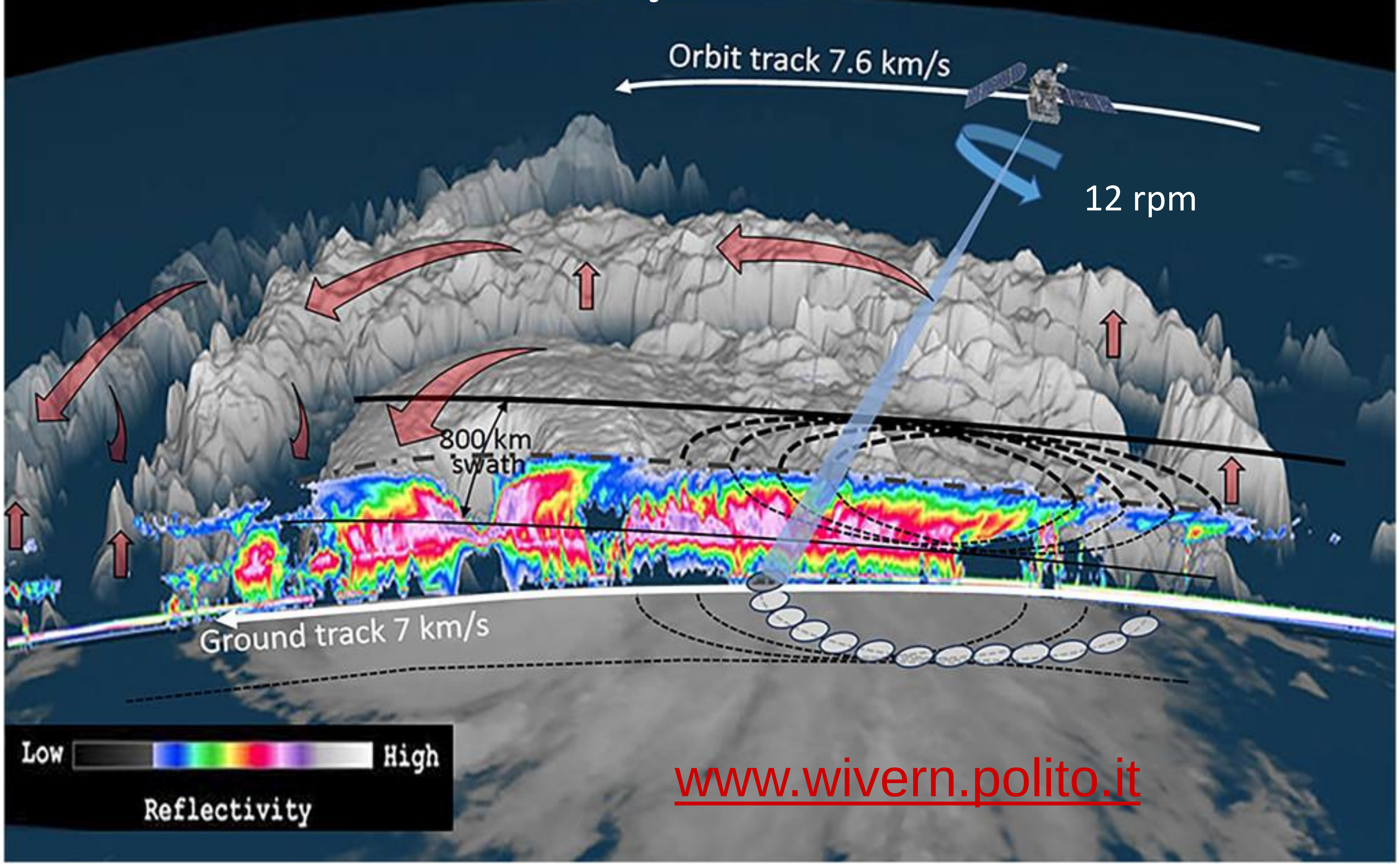
- It is based on a single cutting-edge radar instrument: **first-ever conically scanning W-band radar with Doppler capabilities**

- Flagship product: **vertically resolved in-cloud winds** over a large swath ➔ **plenty of winds are expected** including in high-impact weather such as tropical cyclones (>2 million line of sight wind measurements at 20 km resolution per day) with **a significant impact on data assimilation** (complement Aeolus in cloudy mid and low troposphere region)

- **Cloud and precipitation products:** continuity with CloudSat/EarthCARE with lower sensitivity but **30-40 times better sampling**

→ WIVERN could be ideal observing system for understanding clouds and their dynamics!

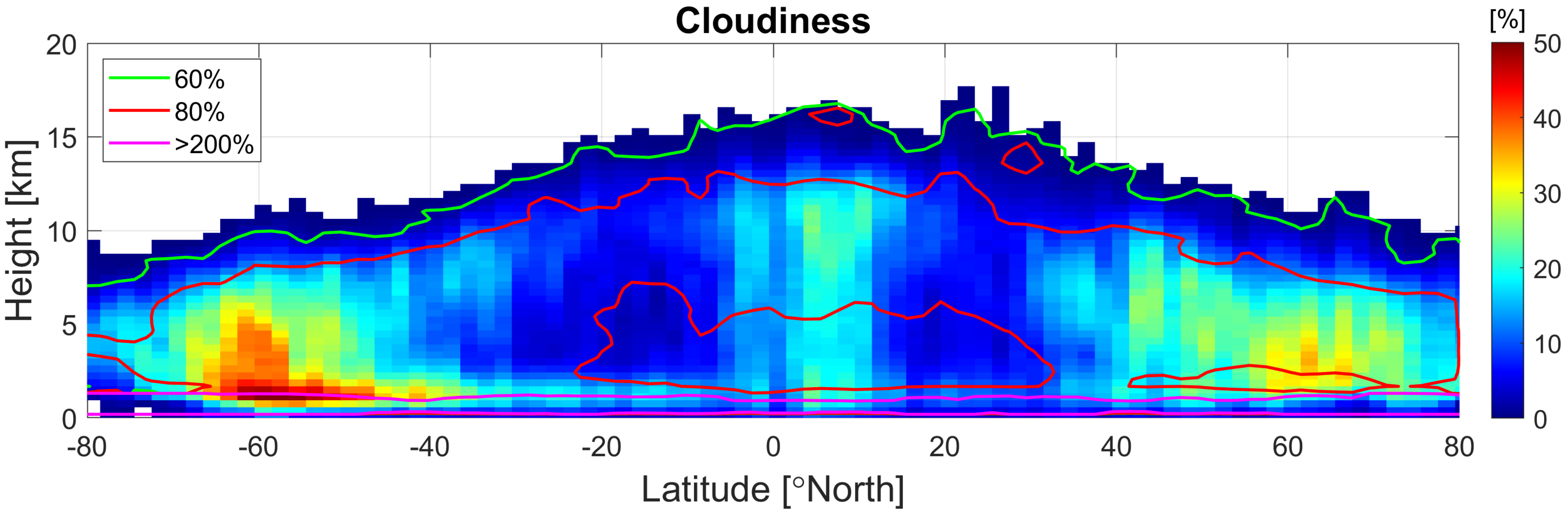
Thanks for your attention



www.wivern.polito.it

How many clouds?

WIVERN will detect about **2.5 millions clouds daily** at 20 km horizontal and 650 m vertical resolutions



Note that in the first km close to the surface the WIVERN signal to clutter ratio will be much better than for CloudSat and EarthCARE ➔ benefit for precipitation products