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TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

WIVERN:A MISSION FOR OBSERVING GLOBAL IN-CLOUD WINDS, CLOUDS & PRECIPITATION

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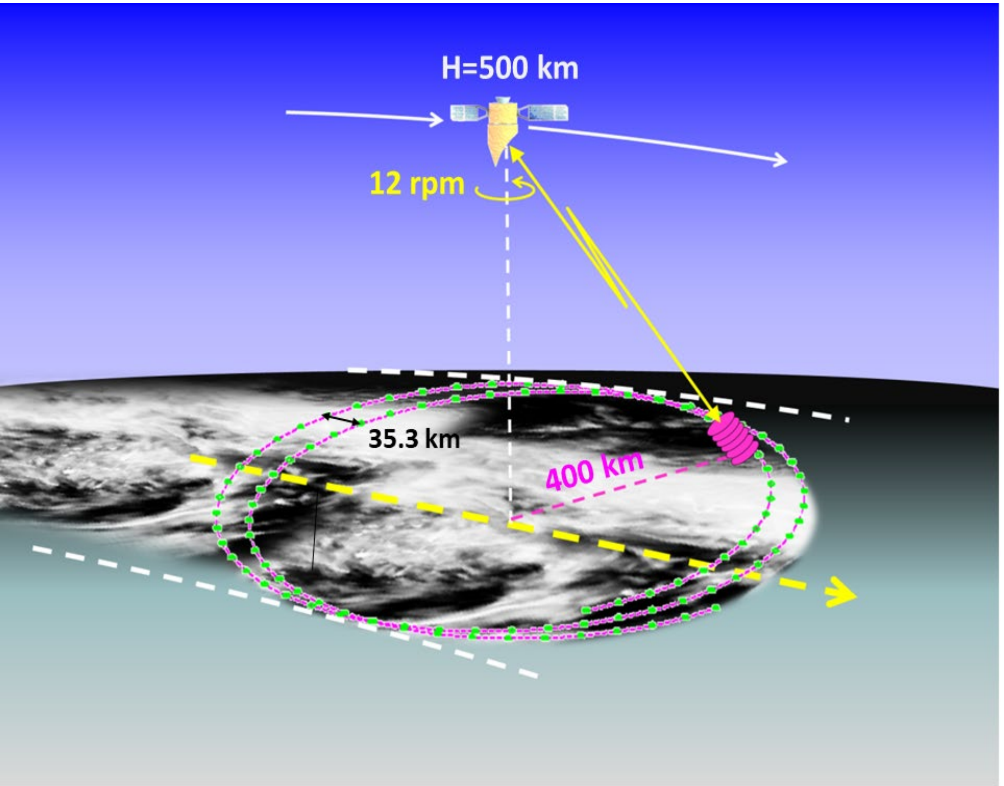
25/5/2022

WIVERN: a conically scanning Doppler 94GHz radar



CONICALLY SCANNING 94 GHz DOPPLER RADAR

Optimised to detect a significant component of the horizontal wind and a short (600 km) slant range for radar sensitivity.

94 GHz radar - high sensitivity. 42° off-zenith angle at the surface

800 km wide ground track ➔ daily revisit within ~ 1 day

3 m ∅ antenna (max for VEGA C) for narrow beam (1 mrad)

3.3μs transmit pulse - 500 m slant path resolution

From the phase of the return ➔ Doppler and hence winds

From the magnitude of the return ➔ clouds and precipitation

ROTATION SPEED 12 rpm

For one revolution of the antenna the "cycloid" ground track advances 35 km along the sub-satellite track

PRF=4kHz ➔ Pulse pair separation distance 37 km ➔ only one pulse pair in the atmosphere at a time

Footprint moves 500 km/s ➔ one sample every 125 m ➔ 8 Doppler radar and reflectivity estimates every km

Why Global In-Cloud Winds, Clouds and Precipitation?

WIVERN- Wind Velocity Radar Nephoscope

GLOBAL IN-CLOUD WINDS

- Aeolus lidar measures clear air & cloud top winds. The single instrument making the biggest contribution in reducing ECMWF forecast errors. WIVERN’s in-cloud winds would complement Aeolus follow on (~2030).
- In Europe, windstorms are the biggest contributor to economic losses caused by weather related hazards.

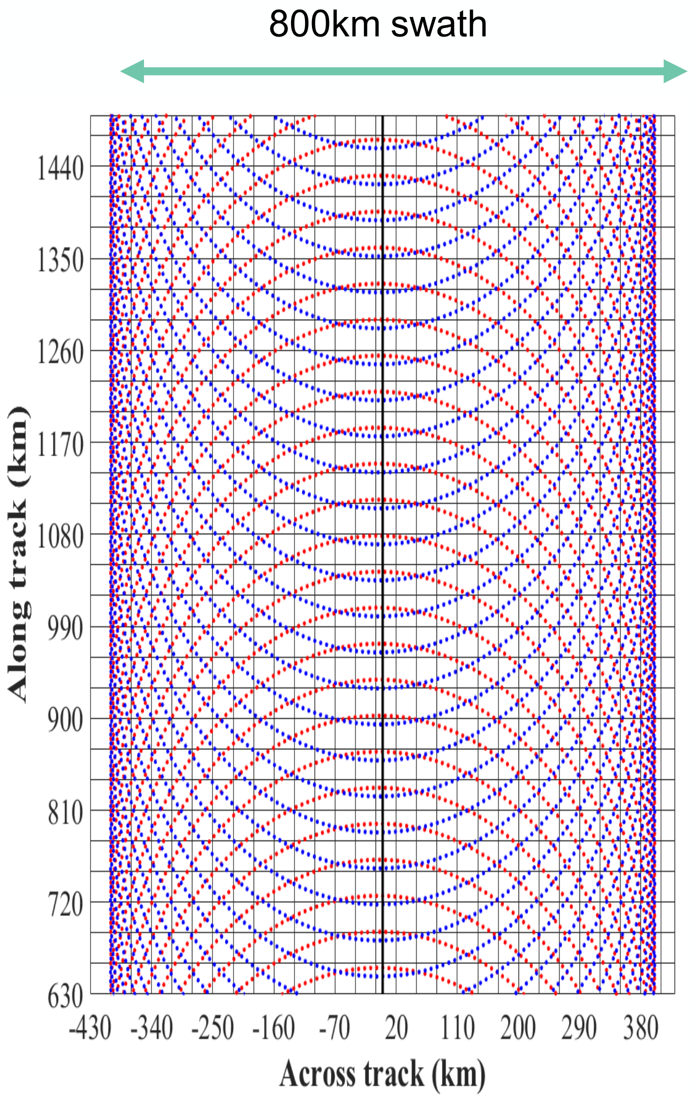
GLOBAL CLOUDS

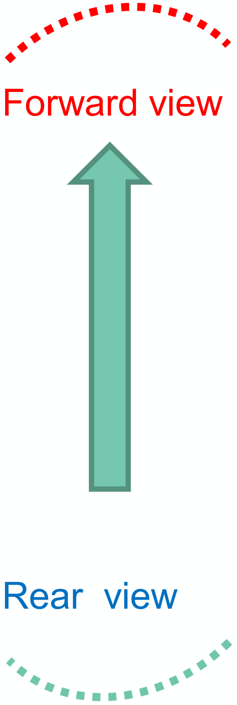
- Largest uncertainty in predictions of global warming is due to unknown cloud feedbacks in a warmer world.
- Global observations of clouds needed to inform and evaluate the new generation of km resolution global models for both weather forecasting and climate models expected by 2030.
- Assimilation of the reflectivity of clouds into NWP forecast models.

GLOBAL PRECIPITATION

- Passive techniques need many assumptions (e.g. vertical profile of the rain). Active radar challenging.

WIVERN GLOBAL SAMPLING

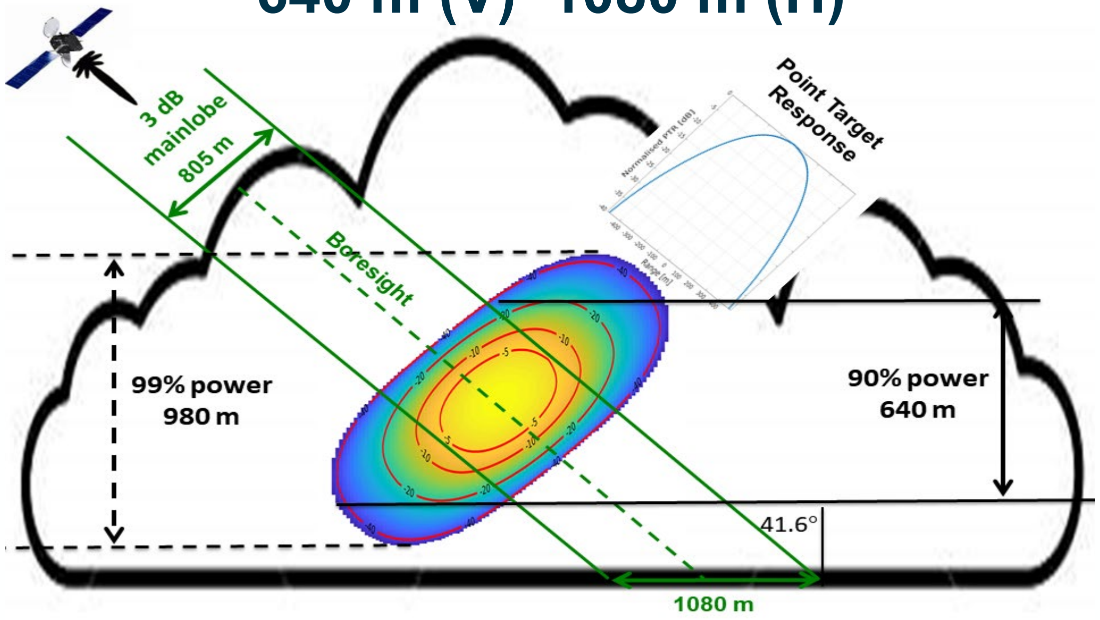




Each 30 km by 30 km box on average traversed by at least one 1km radar footprint track

Low altitude and large antenna essential to achieve sensitivity for the Doppler and fine vertical resolution

RESOLUTION OF WIVERN PULSE:
640 m (V) 1080 m (H)



HOW WIVERN TACKLES DOPPLER FROM SPACE

- **DOPPLER:** Transmit a PULSE PAIR (PP) and measure the change in phase of the two returns.

  If the phase shift is 180° then the target has moved a distance λ/4

- **CHALLENGE FROM SPACE**: 94 GHz (3.2 mm), λ/4 = 800 μm.

  To measure high winds need a folding velocity 40 m/s

  λ/4 is 800 μm so need a pulse separation of only 20 μs (800 μm/ 20 μs = 40m/s)

  20 μs pulse separation at 94 GHz ➔ pulses only separated by 3 km in space

- **Polarisation Diversity Pulse Pair (PDPP)**: To distinguish between the returns, label one pulse H the other V

  PDPP system, tested on radars on the ground in the UK and on an aircraft in Canada, performs as predicted by theory:

DOPPLER PDPP Demonstration and Evaluation

ESA has funded 2 PDPP systems: One ground based at Chilbolton and on the Canadian Convair 850

- They transmit H-V 20μs pulse pairs alternating with a conventional H-H "pulse pair"
- H-H pairs with separation 250μsec used operationally for past 30 years (assumed as "truth")

Extensive observations confirm the PDPP velocity is identical to the traditional PP velocity.

THE PDPP SYSTEM WILL BE USED ON THE WIVERN SATELLITE

GROUND BASED- CHILBOLTON UK

CANADA NCR CONVAIR 850 AIRCRAFT

HERITAGE – SAME KLYSTRON “EIK” AS CLOUDSAT

SAME EIK AS CLOUDSAT – still performing 16 years after the 2006 launch.

- WIVERN: Same peak power 1700W, pulse length 3.3μs and prf 4kHz.
- Use two EIKs – one for the H pulse for the V pulse. **LOW RISK**.

Use CloudSat’s demonstrated performance to calculate WIVERN sensitivity

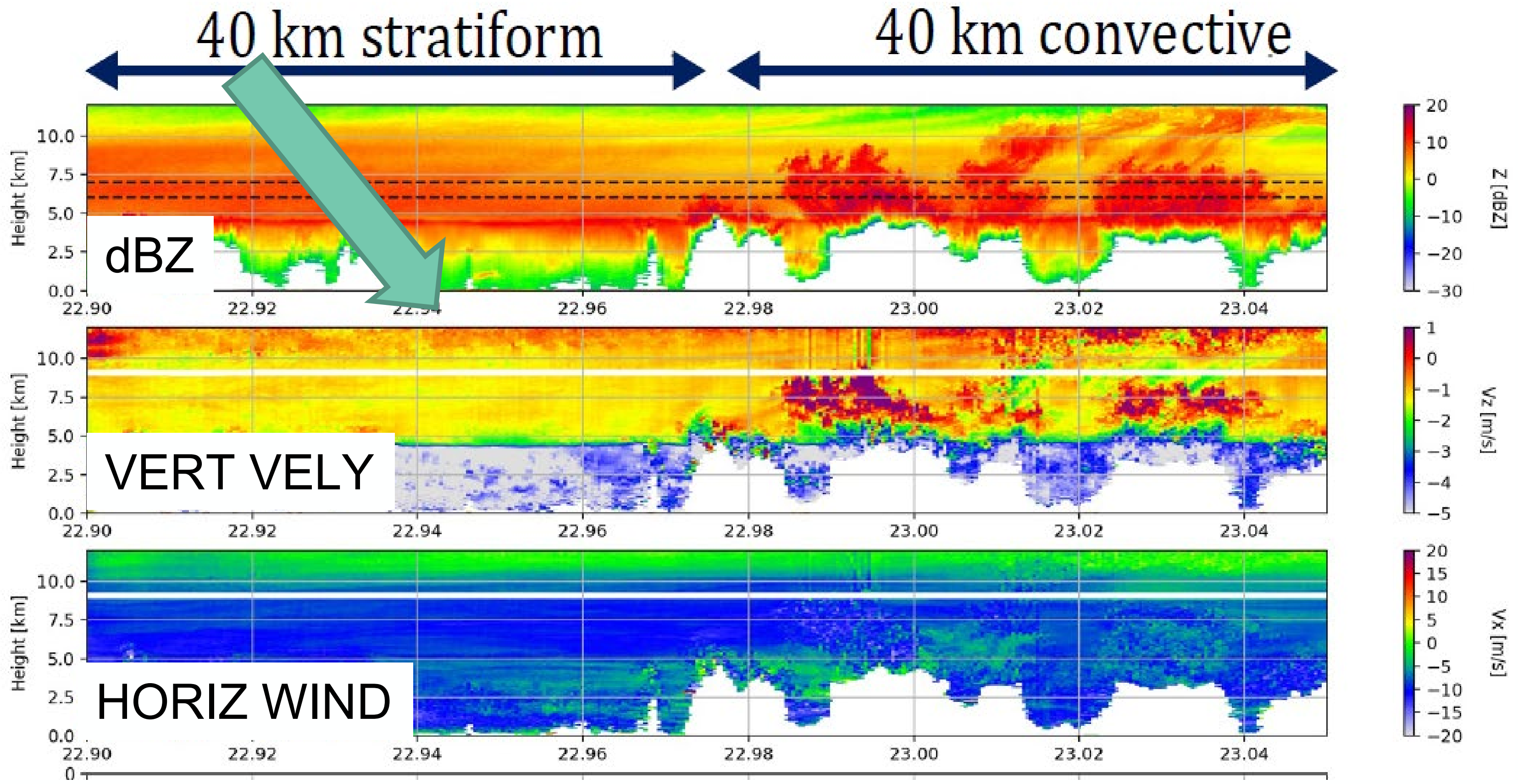
- Use well established Doppler theory to calculate accuracy of the derived winds.
- Wind precision < 2m/s for 20km integration and target reflectivities above -15dBZ
- Need 20km wind averages for data assimilation. Representative of the mean flow.

Using CloudSat global climatology of reflectivity (Z) profiles :

- **PREDICTS OVER ONE MILLION IN-CLOUD WINDS A DAY FROM WIVERN**

Horizontal winds from WIVERN? What about convection?

THE 3 D WIND FIELD ALONG A 2D CURTAIN CAN BE RETRIEVED FROM 94GHz AIRCRAFT OBS USING MULTIPLE ANTENNAS. (Courtesy Julien Delanoe)



IDENTIFY STRATIFORM
If V(wiv) doesn't vary from km to km DERIVE HORIZ WIND ASSUMING TERM VELOCITY is a f(Z, T) for ice/rain. WORKS V WELL

IF CONVECTIVE - Transitory, so wind is no good for data assimilation BUT can we characterise convection from the fluctuations in V(wiv)?

Global Clouds: Reflectivity

CONTINUATION OF THE CLOUDSAT REFLECTIVITY OBSERVATIONS

- CloudSat footprint moves at 7km/s with a 1km swath.
- WIVERN footprint moves at 500km/s sampling a swath width of 800km
- 70 times more data.
- Assimilating CloudSat reflectivities leads to a small reduction in forecast errors.
- WIVERN reflectivities should have a much greater impact in improving forecasts.

Pulse Compression (PC) & Rainfall (work in phase zero)

PULSE COMPRESSION (PC) of 3.3 μs pulse (500m) to 0.33 μs (50m) should:

Improved range resolution + more independent Z samples AND almost factor of ten extra gain

In phase zero: update PC system at Chilbolton and implement PC on the Canadian aircraft.

BENEFITS FOR NWP

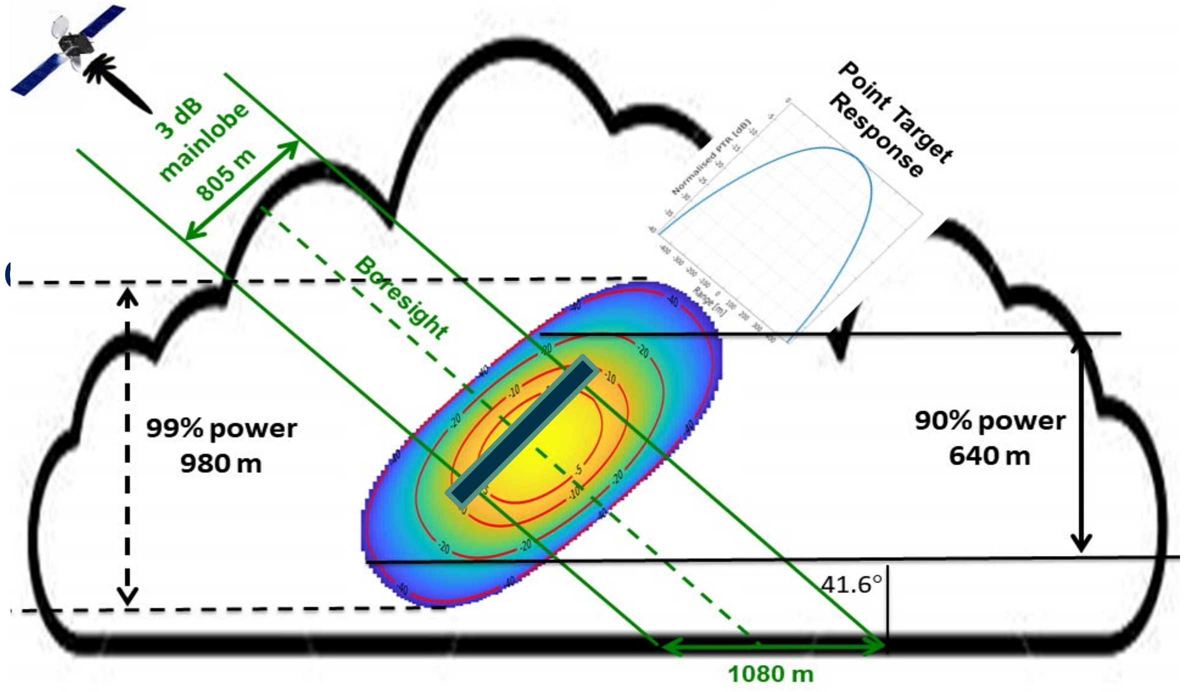
Resolve regions of high shear in active weather.

Twice as many winds (detect thin cirrus in jet stream)

RAIN RATE ESTIMATES

directly from the gradient of the 94GHz radar return

(attenuation is ~ 1.7 dB/km per mm/hr of rain).

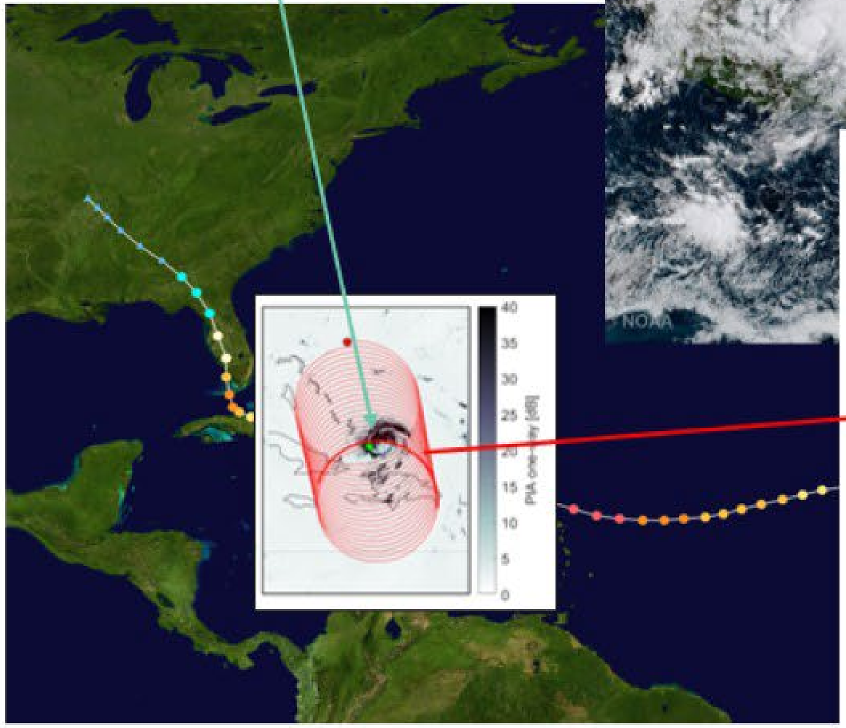


Predicted Performance – Winds in Hurricane IRMA

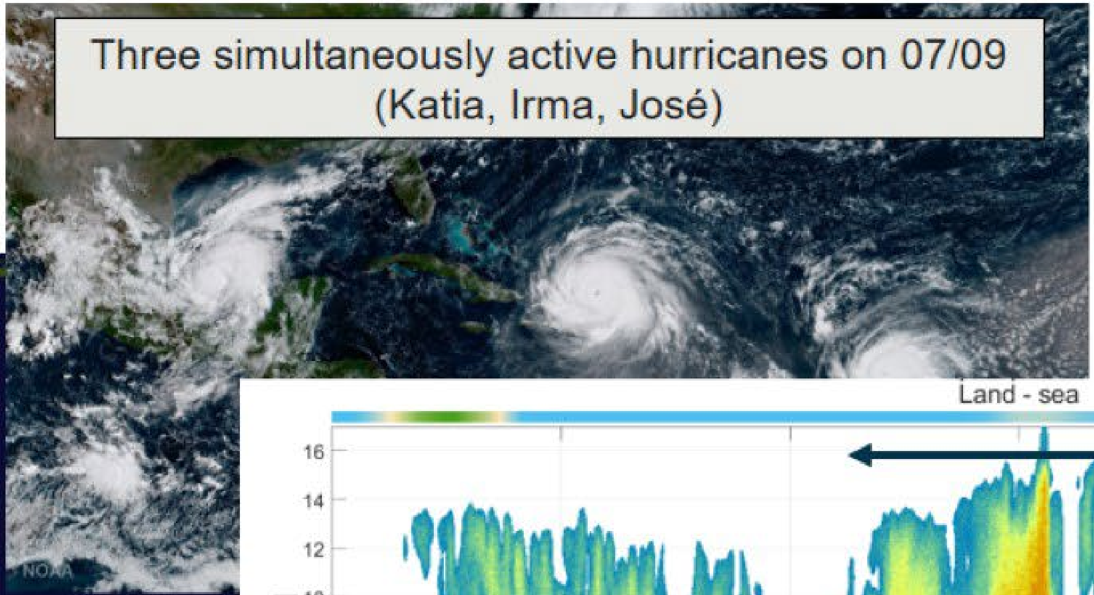
Full end-to-end simulator has been developed

Courtesy Frederic Tridon

SAM simulation on 06/09 shortly after peak intensity
Simulate WIVERN Orbit → slice through the hurricane core

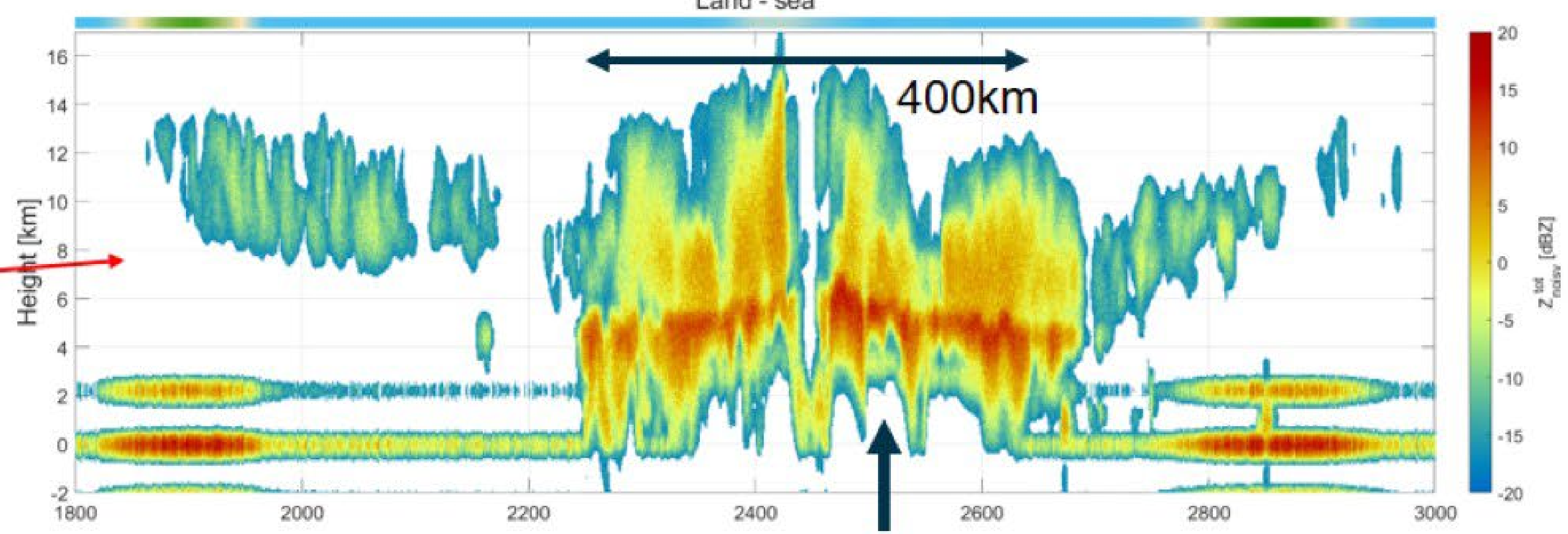


Three simultaneously active hurricanes on 07/09 (Katia, Irma, José)



- use NWP model values of ice water content and rain rates
- to forward model the reflectivities and attenuation at 94GHz

Z (dBZ)



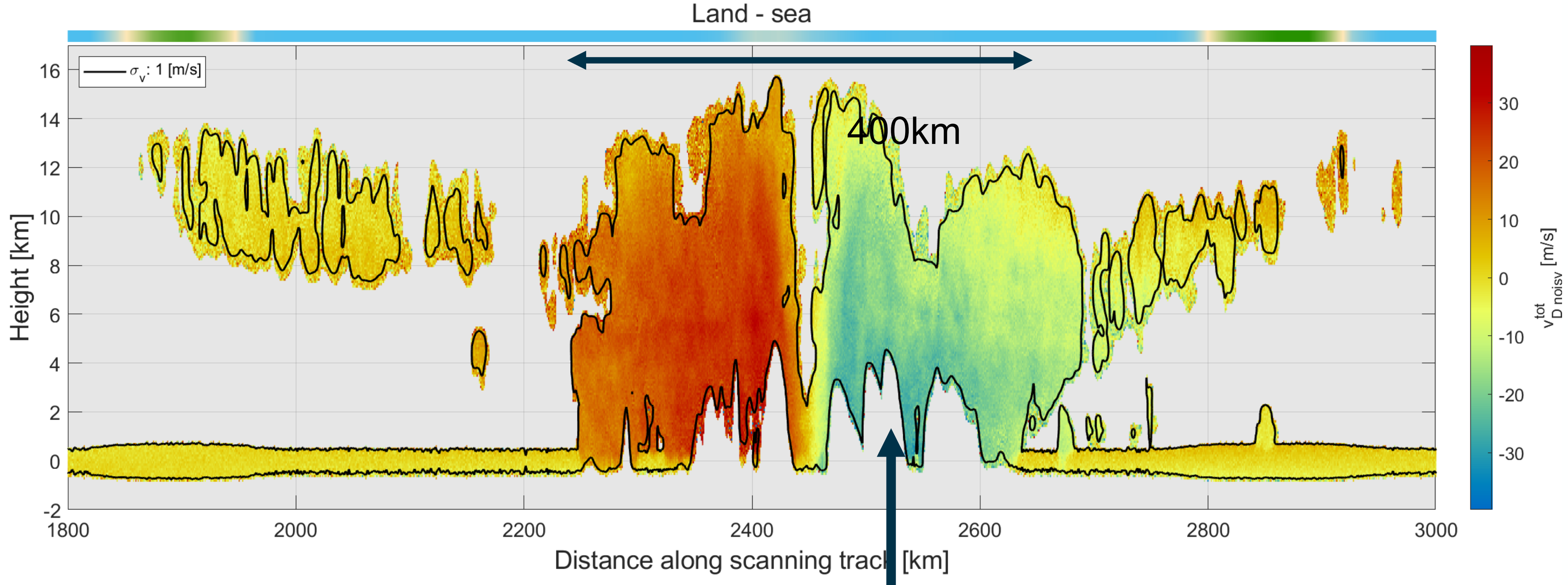
Total 94GHz attenuation by heavy tropical rain.

Performance: Winds for Hurricane IRMA overpass

Calculate the WIVERN Doppler using the reflectivity (Z) from “SAM” 4km model.

WIVERN **horizontal** **w**inds for a slice through the hurricane – thinned to 20km horizontal.

640m height resolution – 20 levels, Get a “slice” of winds for every 35km along track for each antenna rotation.



Inside the black line
The accuracy of winds
Is better than 1m/s

Courtesy Frederic Tridon

Total 94GHz attenuation by heavy tropical rain.

Technical Aspect – Industry studies for Phase Zero.

Rotating Antenna

- Feed of H and V pulses via free space rotary joint to the antenna.   Losses?

- Sinusoidal component of satellite velocity (5000m/s) as the antenna rotates superposed on LOS wind
- POINTING KNOWLEDGE OF THE ANTENNA BORESIGHT MUST BE ~ 40 μrad (3 σ)

- Drift of front-end amplifier noise for good Tb must be < 0.5K per 100km along footprint track.