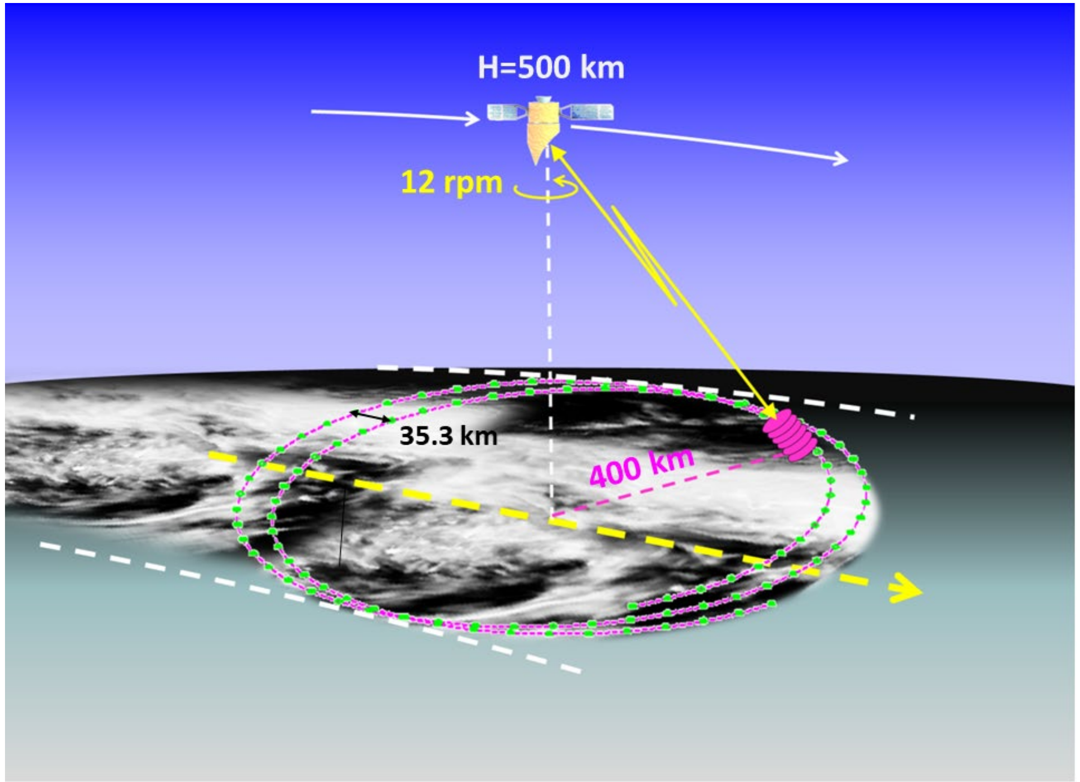
UK EO week: EE11 WIVERN Mission - 6 Sep 2021

A Satellite Providing Global In-Cloud Winds, Precipitation and Cloud Properties. - selected for phase 0 studies of ESA Earth Explorer 11 programme.

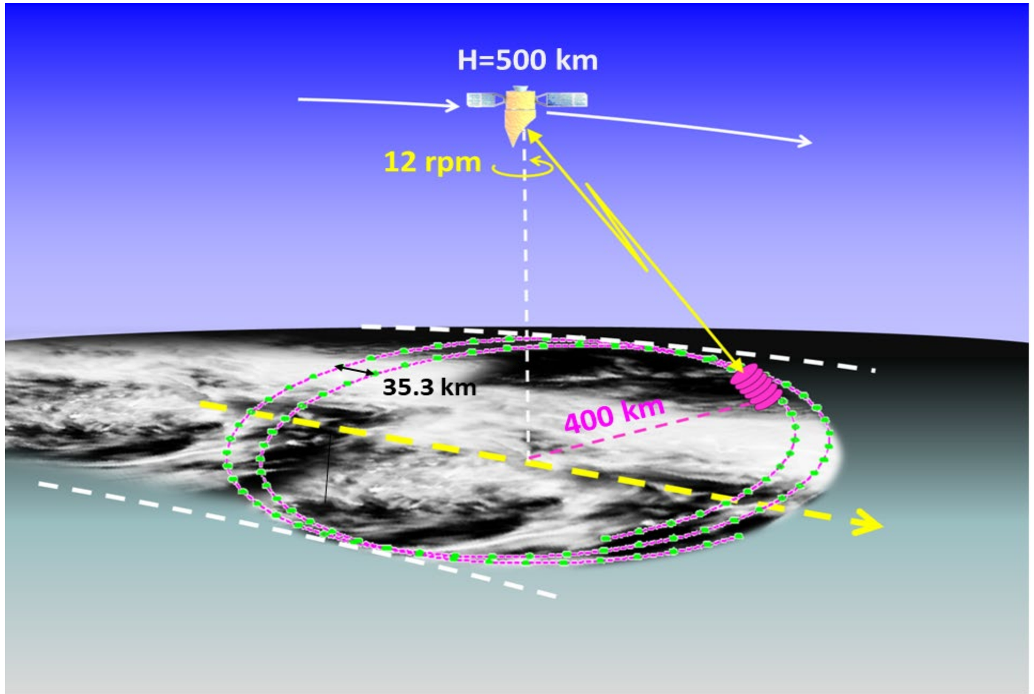
WIVERN: A WInd Velocity Radar Nephoscope Single instrument: 94GHz/3.2mm Doppler radar conically scanning with an 800km swath for global coverage each day.

PRIMARY OBJECTIVE:
In-cloud winds using cloud particles as tracers.
SECONDARY OBJECTIVE:
Global rainfall from radar reflectivity (Z)
PLUS snow, cloud water content, cloud depth



Anthony Illingworth, U of Reading:
Alessandro Battaglia, U of Leicester/Politecnico Torino.

+ science team including those currently responsible for assimilating Aeolus winds at 1) ECMWF, 2) UKMO, 3) Environment Canada, 4) DWD, 5) MeteoFrance



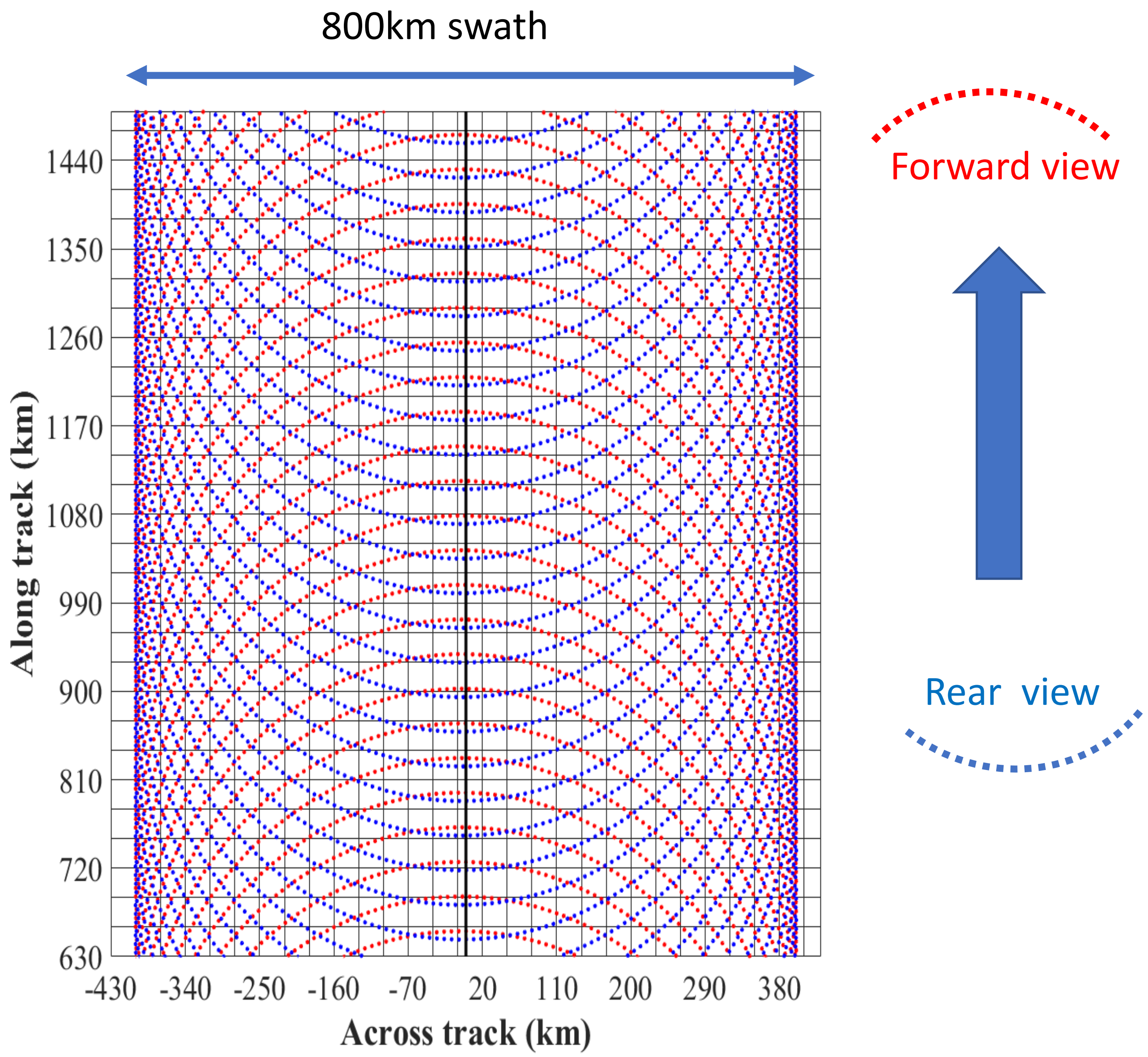
WIVERN – RADAR CONCEPT

500km orbit 800km wide ground track:
41.6° off zenith at surface
One rotation in 5 seconds (12 rpm)
- move 35km along track
For winds accurate 2m/s
average 20km along footprint track

3m antenna 94GHz for a narrow beam: Beamwidth at the surface 800 m.
Pulse length 500m (3.3μs)

1. **DOPPLER line of sight winds** – using cloud particles as tracers.
   Winds inside tropical cyclones + deepening Atlantic (and Mediterranean) depressions
2. **RADAR REFLECTIVITY precipitation rate,** cloud profiles, cloud ice water content
3. BENCHMARK for climate record of cloud profiles, global precipitation.
   (continuation of CloudSat record since 2006, and EarthCARE 2023 onwards + winds)

SAMPLING: EACH 30 km BOX IS VISITED WITH A "CURTAIN" OF RADAR DATA CROSSING IT EACH DAY (ON AVERAGE) UP TO +/-82DEG LATITUDE



Ground track 7km/s.

35km per circular scan (5 secs/12rpm)

On the average each 30km by 30km box has at least one track across it.

DOPPLER RADARS ON THE GROUND HAVE BEEN USING PULSE-PAIR "PP" TECHNIQUE TO ESTIMATE VELOCITIES OF PRECIPITATION FOR MOR THAN FIFTY YEARS

Transmit a pair of pulses: Detect change in phase shift, $\Delta\phi$, from the two returns.
The maximum unambiguous velocity (V_{FOLD}) occurs when $\Delta\phi = +/- 180^\circ$
and the particles have moved +/- $\lambda/4$.

Ground base radar: if $\lambda = 5.6$cm $\lambda/4 = 14$mm
Pulse every 0.5 msec (so max unambiguous range is 75km).
Folding velocity 14mm/ 0.5msec +/- 28m/s or +/- 100km/hr

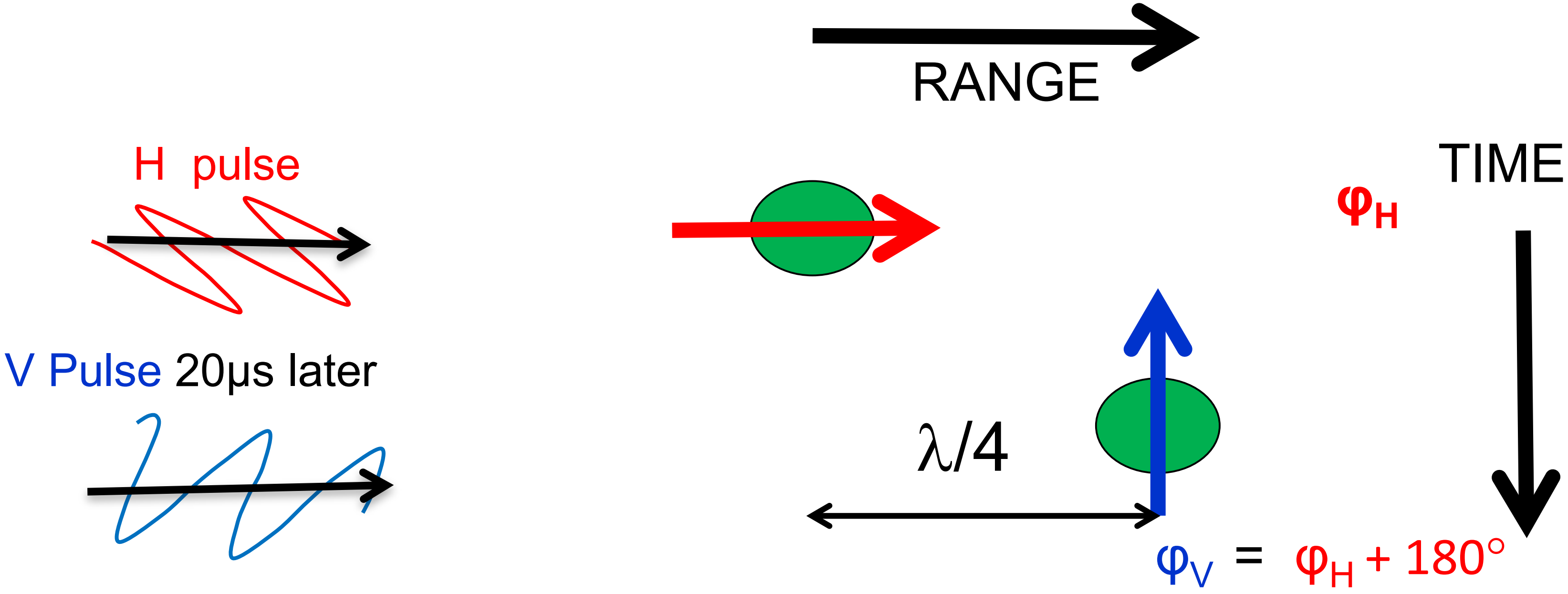
FROM SPACE MUST USE 94 GHz/3.2mm to have a 1km footprint on the surface:
$\lambda/4$ = 800µm so need pulse separation of just 20µsec
for a folding velocity of 800µm/20µsec = +/ 40m/s or +/-144km/hr
20µsec pulse separation is just 3km in range
– so how do you know which pulse you are receiving?

DOPPLER FROM SPACE? POLARISATION DIVERSITY PULSE PAIR "PDPP"

Use two H & V pulses separated by just 3km/ 20µsec are effectively 'labelled': they transmit, scatter and are received independently.

PULSE SEPARATION
20µsec OR
3km slant path
(2.3km in the vertical

In that 20µsecs
the target moves
λ/4 in range



FOLDING VELOCITY: 800µm in 20µsec = ±40m/s

ESA has funded two PDPP (Polarisation Diversity Pulse Pair) systems:
one on the NRC (Canada) Convair aircraft and one on the ground at Chilbolton (UK).
They transmit H-V 20µs pulse pairs AND 250µsec H-H pulse pairs as "truth".

Extensive observations confirm the PDPP velocity is the same as PP velocity.
EXACTLY THE SAME SYSTEM WILL BE USED ON THE WIVERN SATELLITE

HERITAGE

CloudSat: first 94GHz radar in space. Launch 2006.
Radar transmitter performed beyond expectations since launch in 2006 and after 15 years is not yet using the spare tube! **Nadir pointing: 1.4km wide swath**.
CloudSat measured radar reflectivity (Z) profiles (no Doppler) and has provided a global climatology of cloud reflectivity profiles

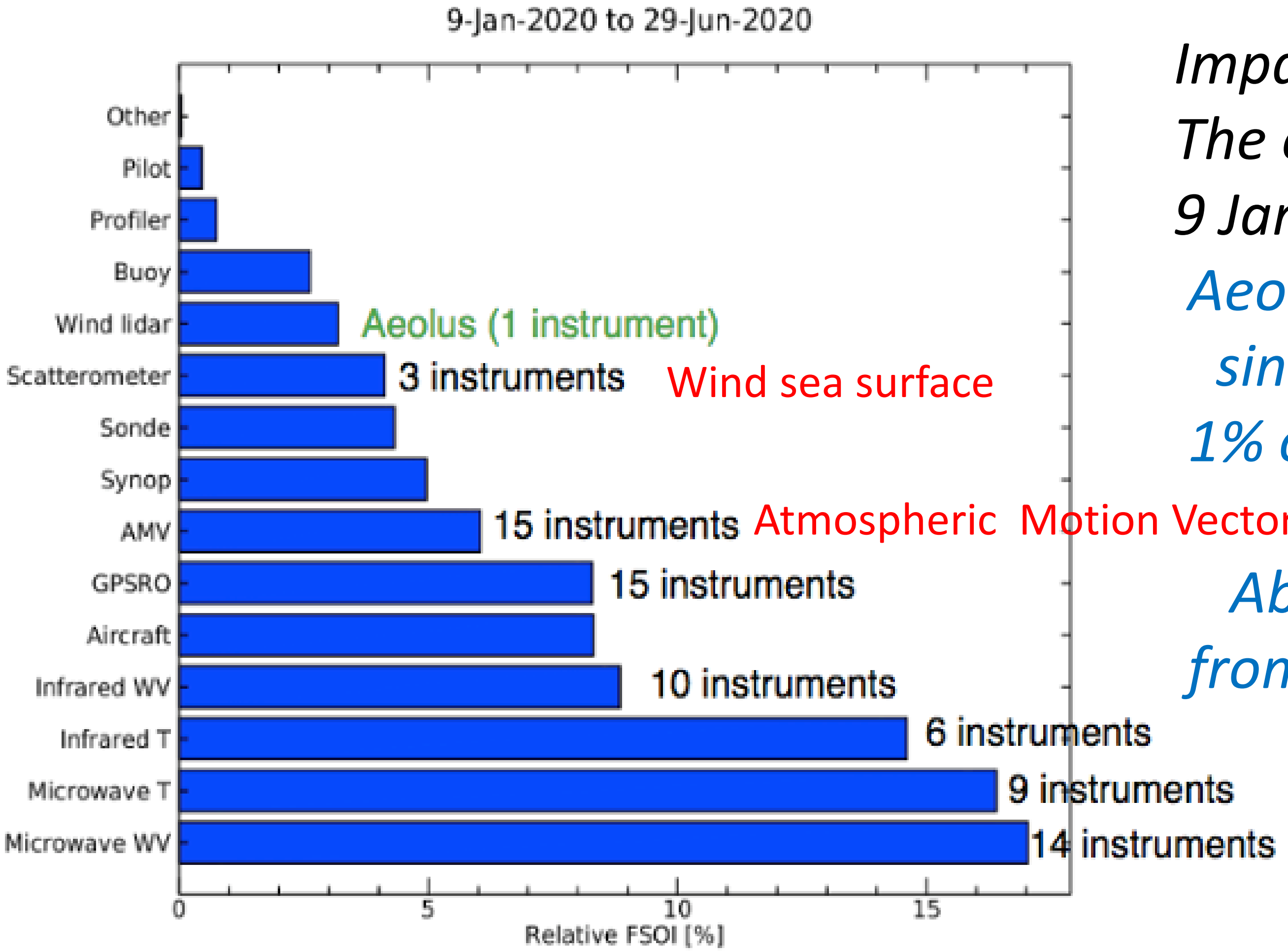
WIVERN is low risk – will use the same 94GHz klystron, same prf (4kHz) same pulse power, same pulse length (3.3us/500m) as CloudSat. Use two klystrons: one for H, one for V

DOPPLER PERFORMANCE OF WIVERN

ESA funded studies using H-V PDPP polarisation radar both ground-based and aircraft have established that the wind accuracy is as predicted by well established Doppler theory.
Expect that we can measure the horizontal component of the line of sight (HLOS) wind speed with a precision of 2m/s for 20 km along track integration for targets with Z > -20dBZ
Using a) the known climatology of global profiles from CloudSat
we can predict WIVERN should measure > 1 million winds per day

Impact of winds from Aeolus in reducing forecast errors

The Aeolus 355nm wind-lidar launched by ESA in August 2018 Predominantly clear-air winds from the Doppler shift of the molecular returns



Impact of each type of observation on reducing The error in the forecast for ECMWF model from 9 Jan to 29 June 2020.

Aeolus has the largest impact (~3%) of any single instrument although it has just in 1% of the total number of observations.

Atmospheric Motion Vectors from successive satellite images.

About 200k winds a day are being assimilated from Aeolus with a precision is 4-5 m/s.

WMO REPORT 31 AUG 2021

The number of disasters has increased by a factor of five over the last 50-year period, driven by climate change, more extreme weather and improved reporting. But, thanks to improved early warnings and disaster management, the number of deaths decreased almost three-fold.

WIVERN – CHALLENGE –ANTENNA POINTING KNOWLEDGE

THE ROTATING ANTENNA induces a COMPONENT of the SATELLITE MOTION (7.6 km/s) with an amplitude of 5,000 m/s superposed on the OBSERVED DOPPLER.

Need antenna pointing knowledge to 200µrad to reduce the component to 1m/s.
(i.e. position of the 800m footprint on the ground to 200m)

For EE10 in SEPT 2018, WIVERN was initially recommended for selection by the Scientific Panel but this was rescinded by the ACEO – (Advisory Committee on Earth Observation)

Worries over pointing knowledge.

In 2018 we really didn't have the expertise to justify a pointing knowledge of 200**µ**rad.

CEOI to the rescue – grant autumn 2020 – money for industry who analysed the TED (Thermo-Elastic Deformation) Vibration of 3m/45kg antenna, star trackers, gyros……

OK to 40µrad (0.2m/s) over 10 secs (three sigma)

THANK YOU MICK JOHNSON AND CEOI !!!

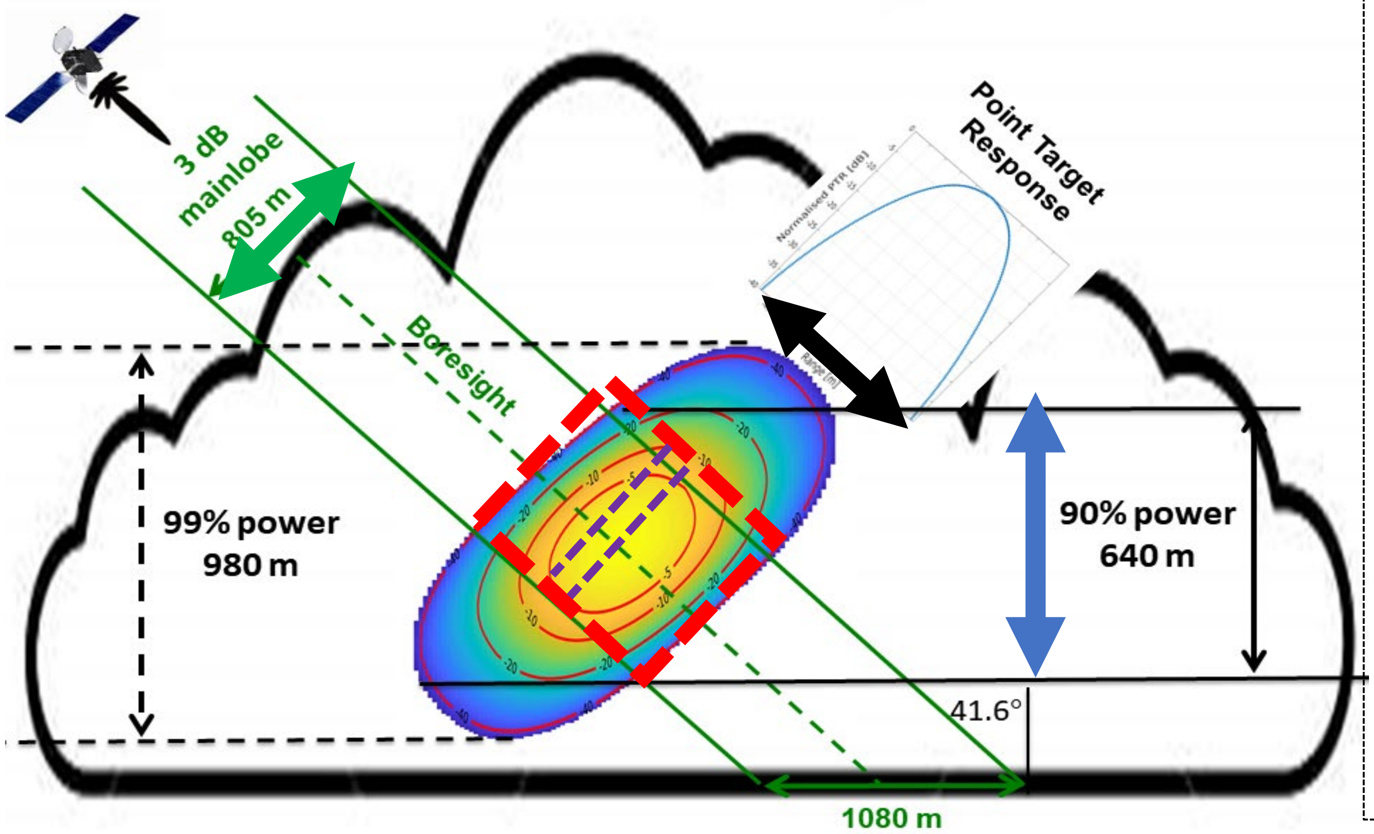
WHAT ABOUT ESTIMATING RAINFALL?

GEOMETRY OF THE WIVERN PULSE VOLUME :

500m pulse length 805m beamwidth.

VERTICAL RESOLUTION 640m

Sample volume red box,



ACEO COMMENTS ON EE11 PROPOSAL:

"frequency modulated pulse could potentially Improve range resolution"

"RAIN-CUBE" 94GHz. Launch 2018.

Vertical incidence. Pulse compression has > -80dB range sidelobes.

Canadian colleagues (Wolde & Nguyen) have WIVERN pulse compression design.

Try it out in phase zero on their aircraft.

Potential 100m range resolution.

Purple dotted line in figure

Z value every 75m in vertical, derive rain rate from 94GHz attenuation of Z

~ 1.6dB/km per mm/hr of rainfall.

Potential for accurate global rainfall – over sea <u>and land</u>. Report next year…

WMO REQUIREMENTS FOR HORIZONTAL WINDS FOR GLOBAL WNP

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	Uncertainty	Horizontal Resolution	Vertical Resolution	Observing Cycle
Goal	2 m/s	15 km	0.5 km	1 hr
Breakthrough	3 m/s	100 km	1 km	6 hr
Threshold	5 m/s	100 km	3 km	12 hr
WIVERN	2 m/s	20 - 30 km	0.64 km	1 day (average)

WMO REQUIREMENTS SURFACE RAINFALL FOR GLOBAL WNP

THRESHOLD,	1mm/hr	50km resolution
BREAKTHROUGH,	0.2mm/hr	15km resolution
GOAL	0.1mm/hr	5km resolution

Can be achieved by rain gauges – but only at a point:

Not achieved by ground-based radar networks (UK 1km resolution every 5 mins).

What about WIVERN?

WIVERN complements Doppler wind lidar winds by observing in areas they cannot see – within optically thick clouds – thus allowing the full 3D-winds to be captured.

The WIVERN mission will provide:

i) unprecedented wind observations inside tropical cyclones and mid-latitude windstorms that will routinely reveal the dynamic structure of such destructive systems;

ii observations of convective motions to validate their representation in NWP models;

iii|) global profiles of cloud properties and precipitation over an 800 km swath that will better quantify the hydrological cycle and the atmospheric and surface energy budget;

iv) first direct observation of tropospheric dynamics to underpin predictions of transport and dispersion of trace gases and pollutants in atmospheric chemistry and air quality models.

v) *WORK IN PROGRESS: accurate estimates global rainfall over sea and land.*