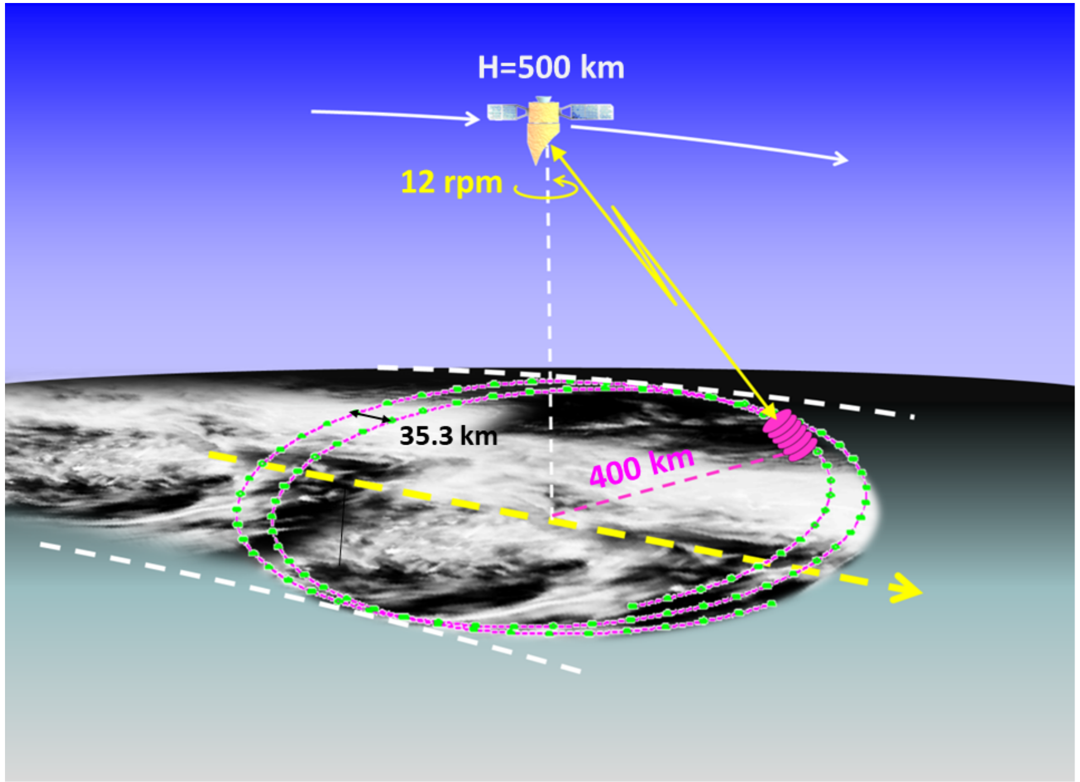
ATMOS-2021 22 Nov 2021 I.6 Earth Explorer Candidate Missions

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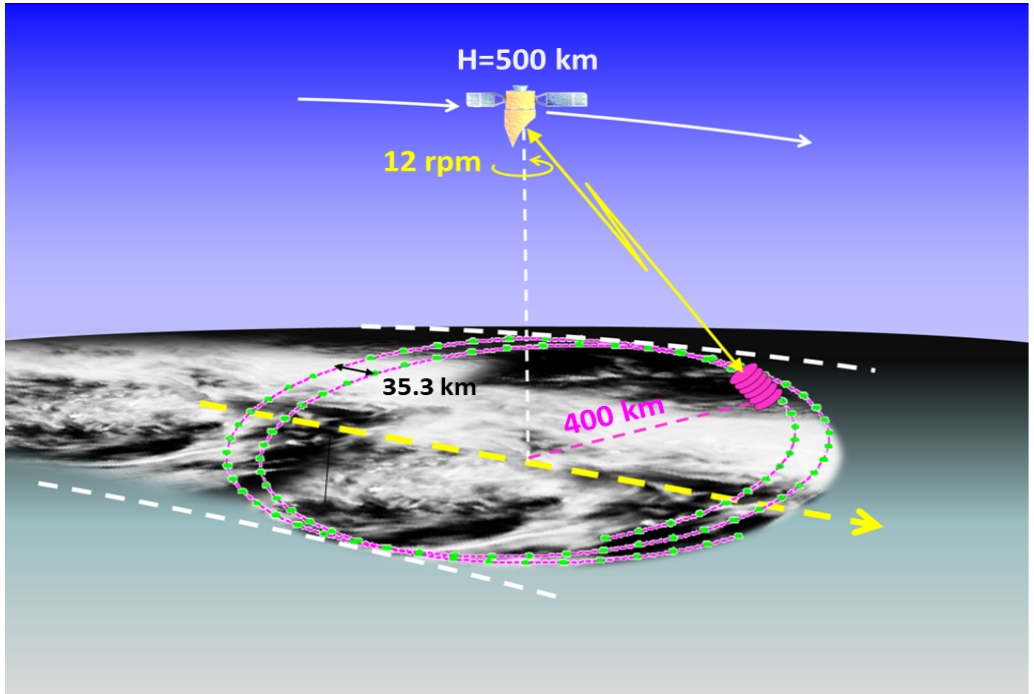
+ science team including those currently responsible for assimilating Aeolus winds at 1) ECMWF, 2) UKMO, 3) Environment Canada, 4) DWD, 5) MeteoFrance



WIVERN – RADAR CONCEPT

500km orbit 800km wide ground track:
41.6° off zenith at surface

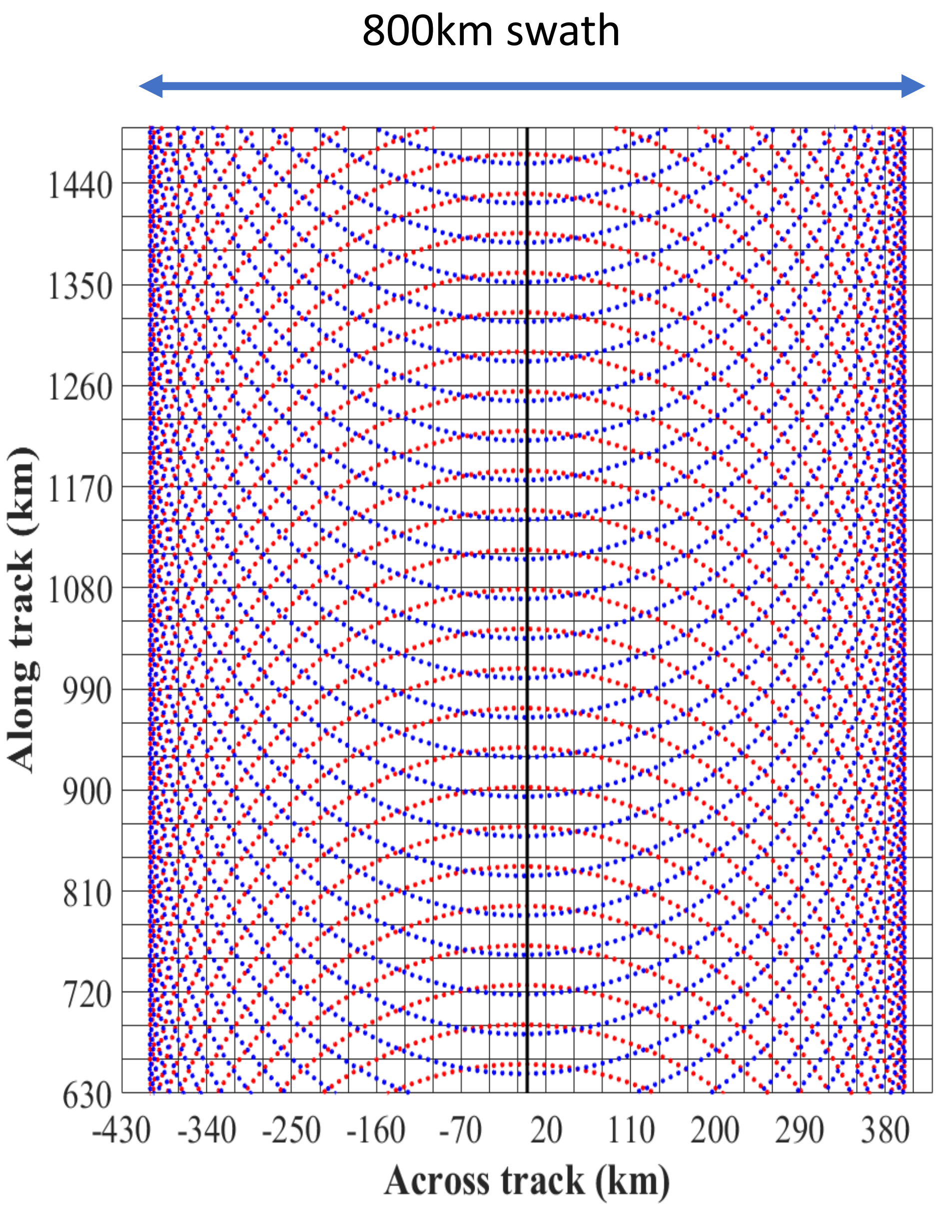
One rotation in 5 seconds (12 rpm)
- move 35km along track

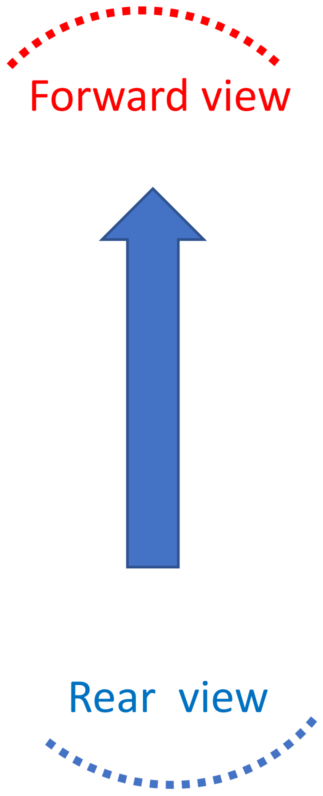
For representative winds suitable for data assimilation accurate 2m/s averaged 20km along footprint track.

3m antenna (maximum possible with current launcher) 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
   Complementing Aeolus Doppler lidar clear-sky and cloud top winds (+ Aeolus follow on)
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)

GLOBAL 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 movement along track per circular scan (5 secs/12rpm)

On the average each 30km by 30km box has at least one track across it each day to provide wind profiles and rain rates.

BUT HOW TO MEASURE A DOPPLER SHIFT OF 1m/s ?

Speed of light is $3\ 10^8$ m/s

Round trip so:

Need to measure change in frequency of return to 1 part in $1.5\ 10^8$

ONE PART IN 150 MILLION. SOUNDS TRICKY.

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

FROM THE GROUND:

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 weather 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

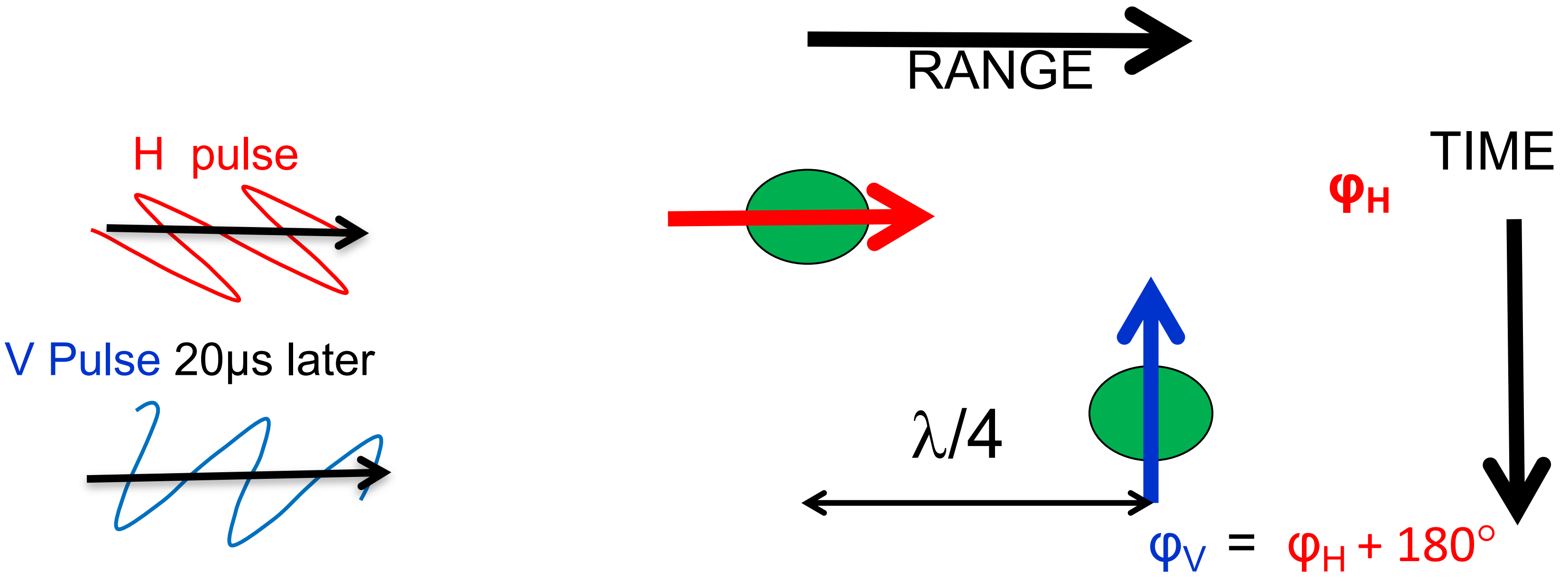
– so how do you know which pulse you are receiving?

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.
Can measure phase 1deg accuracy , better than 0.25m/s

Very simple technique for radar. Why won't it work for lidar (Aeolus?)

Aeolus: λ = 0.355um 10,000 times smaller

folding velocity for 20usec pulse separation 4mm/sec

ESA has funded two PDPP (Polarisation Diversity Pulse Pair) systems:
one on the (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

GROUND BASED- CHILBOLTON UK

CANADA NCR CONVAIR 850 AIRCRAFT

MANY HOURS OF DATA TO CHECK H-V DOPPLER GIVES RELIABLE WINDS

CROSS TALK. DEPOLARISING TARGETS, PULSES 3km APART, VERY LARGE CHANGE IN Z OVER 3km, the return from the high Z regions will give a GHOST ECHOES IN THE LOW Z REGION

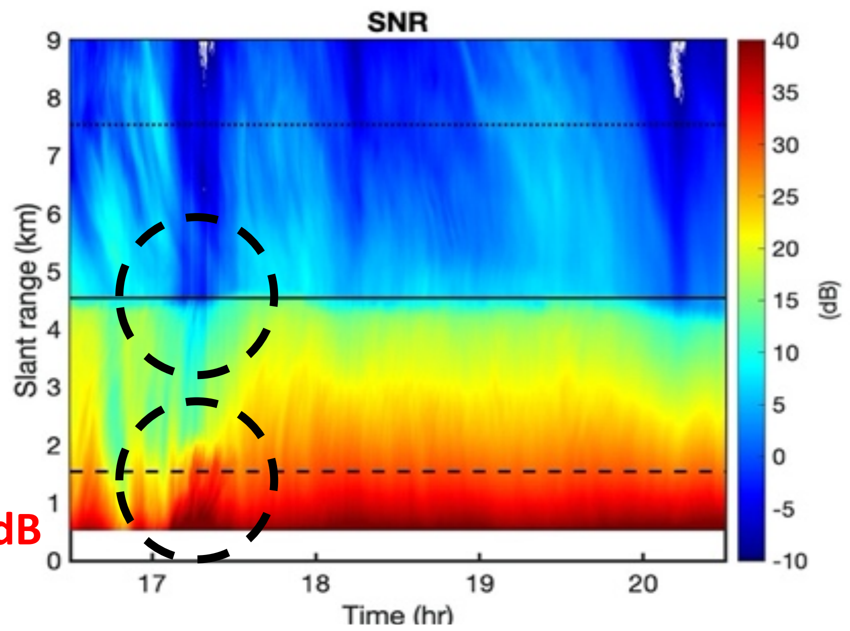
Yes, but the cross-talk signal will have random phase – MAKE WINDS NOISIER BUT NO BIAS

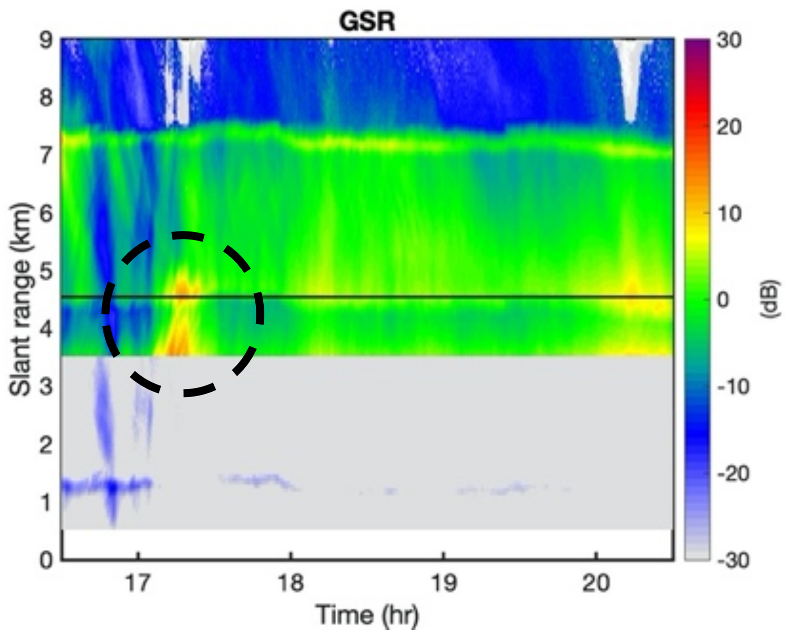
GHOST ECHO FROM THE GROUND (60m/10 Sec resolution) CONFIRMS NOISIER WINDS.

SIGNAL STRENGTH

4.5 km slant path
ICE SIGNAL 0dB

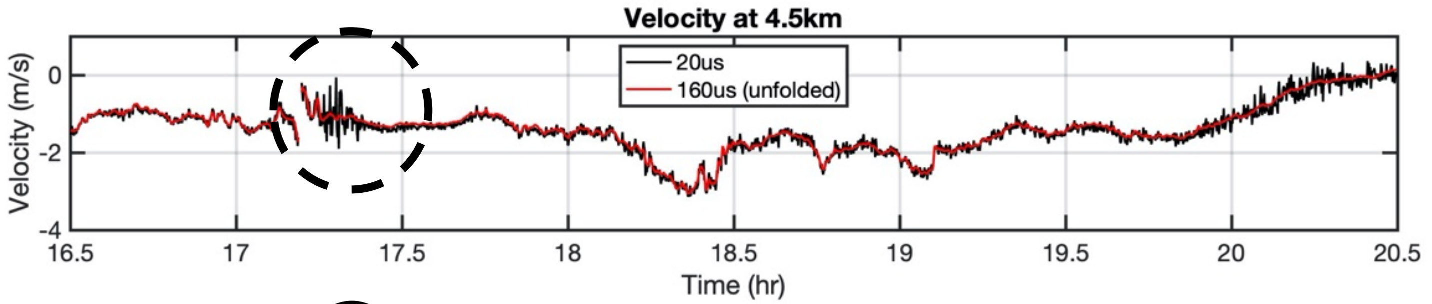
1.5Kkm slant path
RAIN SIGNAL 35dB

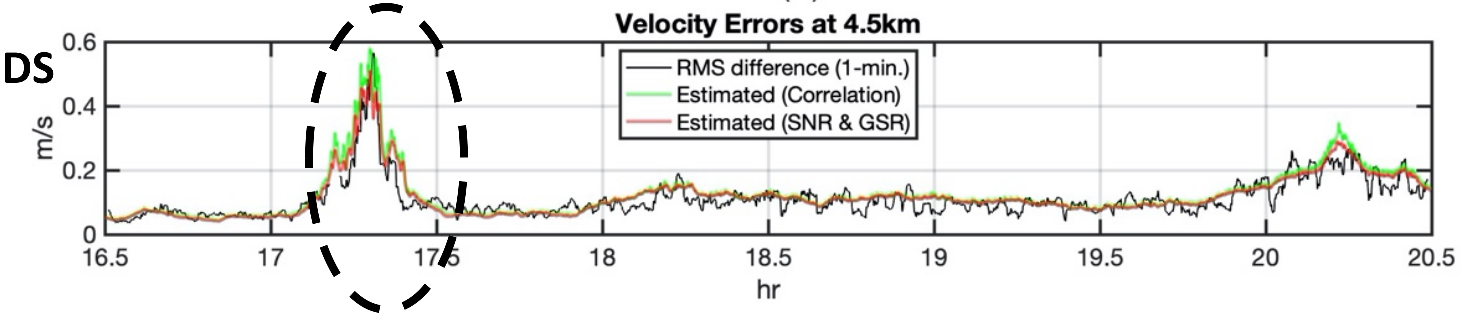




4.5 km slant path
GHOST 10dB
HIGHER than signal

WINDS
AT 4.5KM
HEIGHT
EVERY
10 SECONDS





4.5km HEIGHT WINDS

RED LINE – TRUE 250us VELOCITY

BLACK LINE H-V 20usec
noisier when 10dB ghost present

BLACK LINE RMS ERROR
UP TO 0.5m/s NO BIAS

GREEN LINE ESTIMATED RMS ERROR
FROM THE CORRELATION
OF THE OBSERVED H-V RETURNS

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

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
b) From the vertical gradients of Z ghosts will be very rare when observed from space
c) Ghost echoes from the depolarising surface will cause noisier winds at a slant path height of 3km.

NEED MORE CADNADIAN AIRCRAFT FLIGHTS IN PHASE ZERO TO QUANTIFY THIS EFFECT.

WHAT ABOUT ESTIMATING RAINFALL?

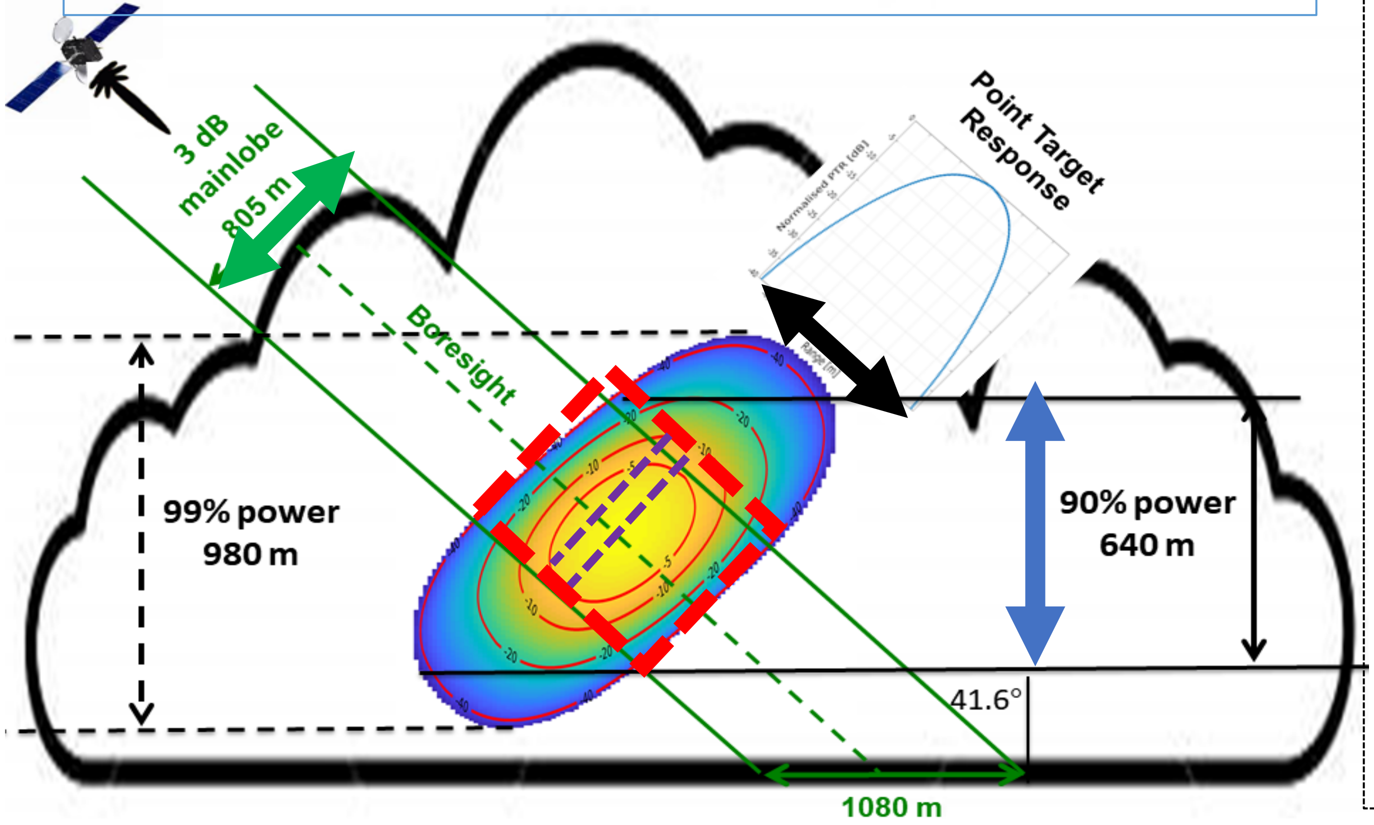
Very difficult from space – what are the errors?

GEOMETRY OF THE WIVERN PULSE VOLUME :

500m pulse length 805m beamwidth.

VERTICAL RESOLUTION 640m

Sample volume red box,



"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 on the CONVAIR 850.

(Also extra 8dB suppression of cross talk!)

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.

Simulations work really well!

Potential for accurate global rainfall – over sea <u>and land</u>.

TEST THIS in phase zero.

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 40µrad over 10 seconds (three sigma) to reduce the component to 0.2m/s .
(antenna beamwidth is about 1 mrad)

INDUSTRY HAVE TOLD US THIS CAN BE DONE!

CRUCIAL TO THE THE MISSION.

NEED MORE INDUSTRIAL STUDIES IN PHASE ZERO

WMO REQUIREMENTS FOR HORIZONTAL WINDS FOR GLOBAL WNP

	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.*