A Proposed Satellite to Provide Global Winds, Ice Water Content and Rainfall

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+ STFC (Chilbolton) + Airbus

WIVERN:

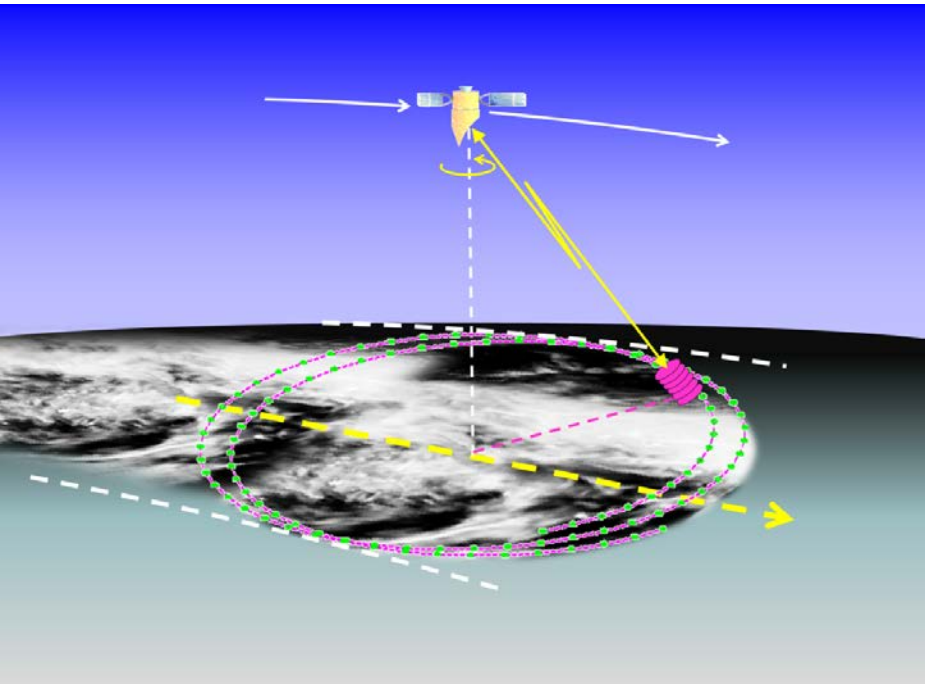
A WInd Velocity Radar Nephoscope:

Earth Explorer 10 Candidate

WIVERN should provide in-cloud global winds to ± 2m/s, rain, snow and cloud ice water content with 50km horizontal and 1km vertical resolution and daily visits poleward of 50°

NCEO-CEOI: ANNUAL CONFERENCE
Bath: 28 June 2017

2. WIVERN – RADAR CONCEPT



800km wide ground track:
Slant range 651km
Conical scan 37.9° off-nadir
(41.4° off zenith at surface)

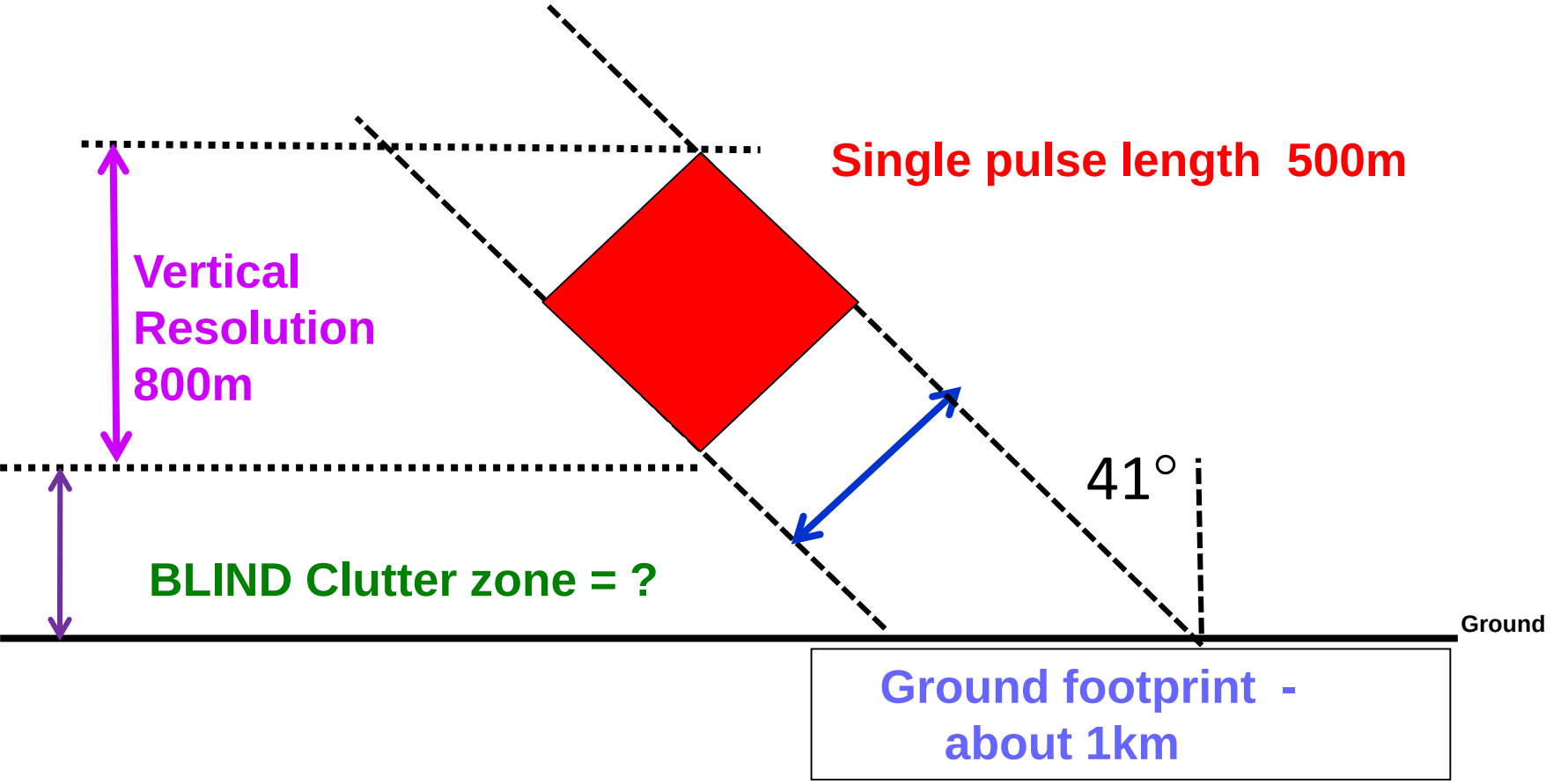
Scan every 7 seconds
- move 50km along track
- sample every 50km along arc

94GHz: 2.9m elliptical antenna: 1.23mrad: NARROW BEAM (800m)
Pulse length 500m (3.3μsec): 1km vertical resolution

Doppler shift of cloud return + precipitation rate + ice water content.
Detect line of sight winds - can assimilate into NWP forecast models -
COMPLEMENTS: ADM lidar - CLEAR-AIR winds: launch Jan 2018.
SCATTEROMETERS – WINDS AT THE SEA SURFACE.
WIND OBSERVATIONS VERY USEFUL IN REDUCING FORECAST ERRORS.

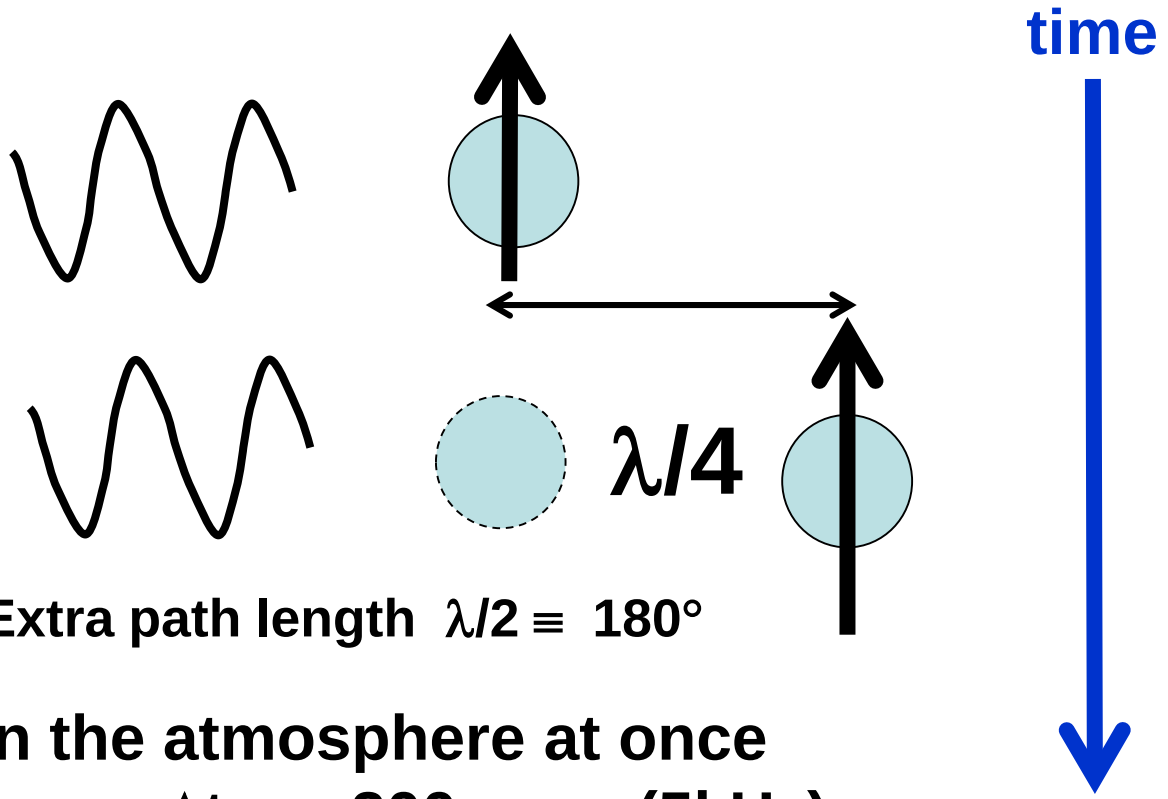
3. MAJOR DRIVER: VERTICAL RESOLUTION <1km

800km SWATH – 500km orbit – range 650km,
2.9m by 1.8m elliptical antenna; 0.07°/ 1.23mrad,
beam width 800m



UKNOWN DEPTH OF THE CLUTTER ZONE at 94GHz?
Affects the minimum height that winds can be measured

4. CAN WE GET DOPPLER TO WORK IN SPACE?
PULSE-PAIR DOPPLER



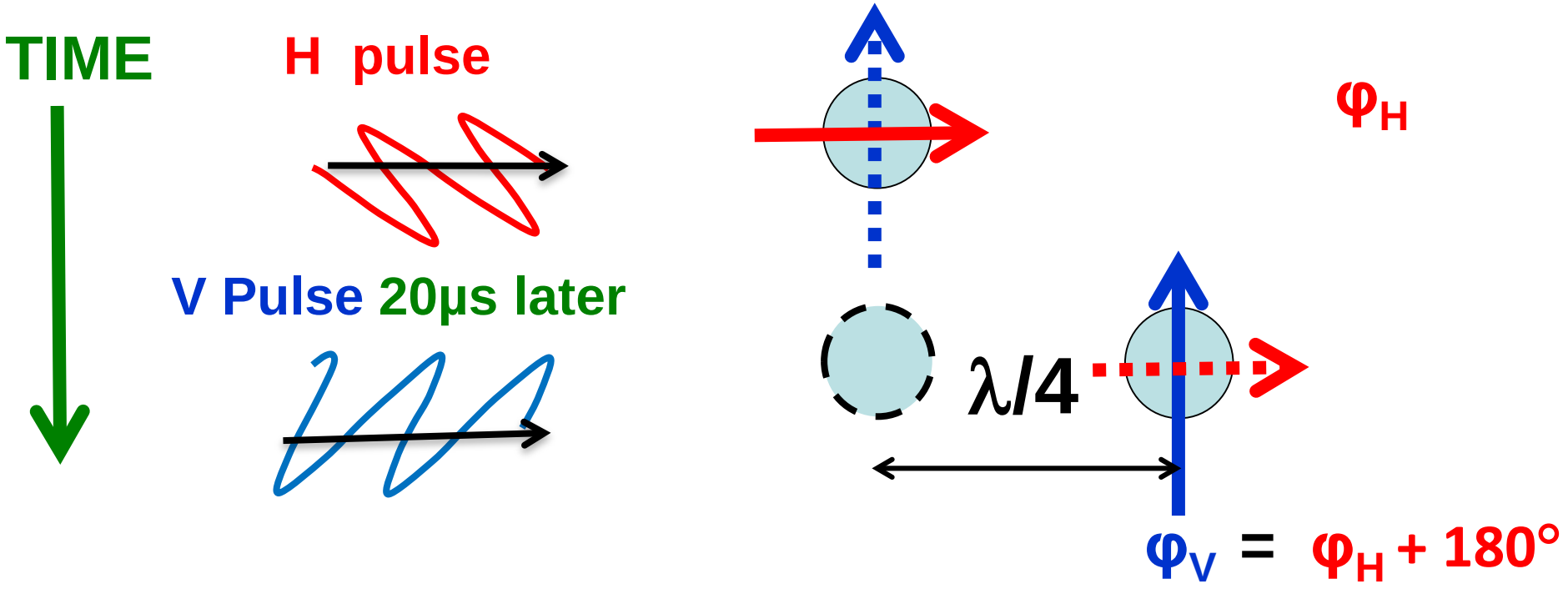
Move λ/4=800μm: Extra path length λ/2 ≡ 180°

Only one pulse in the atmosphere at once
– 30km separation, Δt = 200μsec (5kHz)

FOLDING VELOCITY = 800μm in 200μsec = ±4m/s
BUT WE NEED TO MEASURE UP TO 80m/s!!

5 . SOLUTION: CLOSELY SPACED PAIR OF H AND V PULSES

The two H & V pulses are effectively ‘labelled’:
they transmit, scatter and are received independently



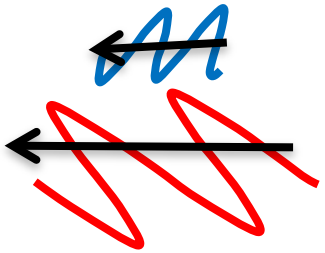
(Pazmany et al., J Tech, 1999) H and V dipoles are coincident in space.
FOLDING VELOCITY: 800μm in 20μsec = ±40m/s and 1m/s IS ABOUT 4°

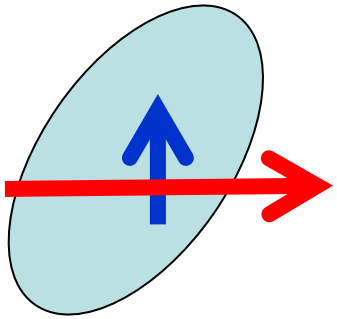
20μsec pulse separation for H and V pulses

(3km slant path: 2km in vertical)

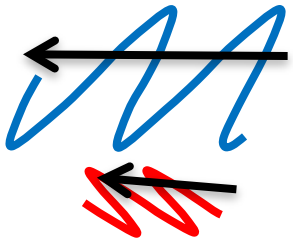
6. PROBLEM: OBLATE (WET) ORIENTED HYDROMETEOR (AND THE GROUND) DEPOLARISE – CROSS TALK H &V

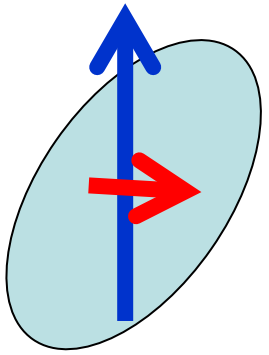
H pulse
Also excites
Small V
dipole





V pulse
excites
Small H
dipole





1. ‘Ghost echoes’ ± 2km above or below a high Z echo.
2. Depolarising surface (land/ocean) will also give ‘ghost echo’ 2km above the surface (affects the blind layer)

SOLUTION? TRANSMIT SOME SINGLE H OR V PULSES AND MEASURE CROSS-POL RETURN. FLAG AS ERROR PRONE.

7.WIVERN: CURRENT SITUATION:EE10 CANDIDATE

NWP REQUIREMENT: Observations reduce (24h) forecast errors :

50% of reduction: Microwave and IR sounders (Temp and Humidity)

20% of reduction: Winds: AMVs (Atmospheric Motion Vectors)

from successive satellite images and aircraft winds. (ECMWF, UKMO, MeteoFrance)

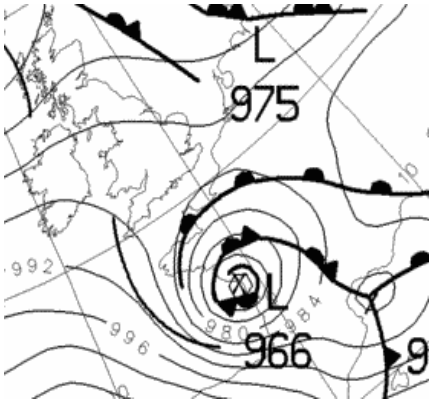
Daily visits – so only for long lived systems.

NOT FOR SHORTLIVED THUNDERSTORMS

GOOD FOR 1-2 DAY FORECAST OF

DEVELOPING WIND STORMS + tropical cyclones…

Most weather damage in Europe is from winds: "Klaus" 1999: 26 deaths.



Data assimilation: ECMWF thin AMVs to 100km,

Winds must not be biased, but represent the mean flow.

ANALYSE THE RETURNS FOR 20km ALONG THE CONICAL ARC

Avoid convective up/down draughts: look for steady winds.

Reject 20km arcs where there is vigorous convection.

Convection -problems for WIVERN winds:

Can't get accurate horizontal winds from line of sight if big up/downdrafts.

Problems with Doppler if non-uniform beam filling and multiple scattering.

8. HERITAGE

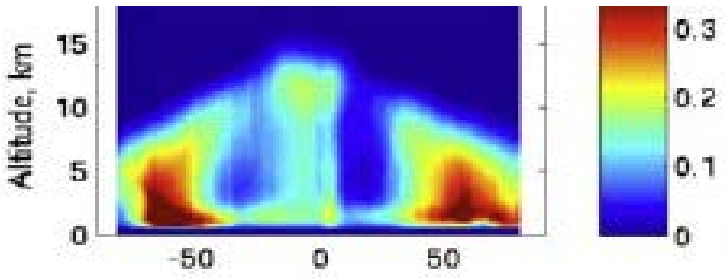
CloudSat first 94GHz radar in space: 1.2km swath.

Tube lifetime was a worry, but since launch 2006, power loss <0.5dB.
Sensitivity and ability to detect clouds now known from CloudSat.
Transmits high power pulses – duty cycle 1.2% - mean power 20W

HAS OPERATED FLAWLESSLY FOR TEN YEARS
LOST <1dB of POWER. SPARE TUBE YET TO BE USED

Transmit 600 pulses every 1km along track: detect -30dBZ
Single pulse will have SNR =0dB for -16dBZ (down by 14dB or $\sqrt{600}$)

Cloudsat – Zonal average of fraction of the time with clouds with Z >-25dBZ



DJF S N

PREDICT WIVERN DOPPLER CAPABILITY

Bigger antenna, lower orbit + 3dB
Can detect single pulse SNR 0dB for -19dB
Only 200 pulses per 20km

Doppler theory well known for 60 years:
20km sample: H-V separation 3km/20μsec
2m/s for -23dBZ

PROBLEMS? H-V CROSS TALK (GHOSTS);
BLIND ZONE FROM SURFACE CLUTTER?

9: MAIN TECHNOLOGY DEVELOPMENTS

CEOI funded: upgrade UK radar fast H-V switch to measure high velocities + validate accuracy of these velocities

ESA funding 94GHz H-V radar on Canadian aircraft.

ESA funding study of rotating antenna and feed.

TRL level estimated to be at TRL6. (Antenna may be less)

➢**Current Science status: SRL level 5**

1. From CloudSat reflectivity data and proven Doppler performance we predict that for clouds > -23dBZ WIVERN should measure wind velocities to ± 2m/s.

2. Weather services are ready for ADM winds so using the in-cloud WIVERN winds will be a small step.

Studies in progress:

3. CEOI: frequency of ghost (cross-talk) echoes at Chilbolton

4. ESA study using 94GHZ H-V radar on Canadian aircraft to establish ocean/land backscatter at 41° incidence

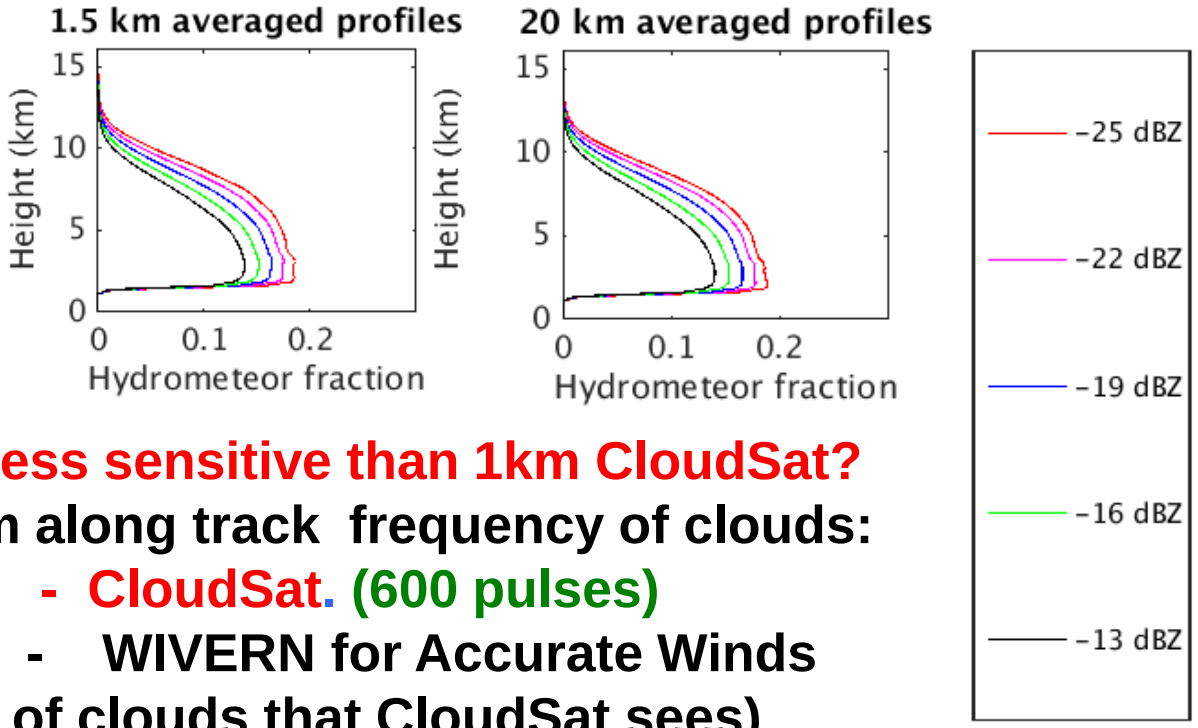
10. How many clouds will WIVERN detect?

Use CloudSat climatology of Z profiles.

Occurrence of cloud of a given Z as f(height).

Statistics for mid-latitudes from CloudSat

Radiatively significant clouds have Z values above -25dBZ



WIVERN 800km 'swath': less sensitive than 1km CloudSat?

1.1- 5 km height; for 1.5km along track frequency of clouds:

18% if Z > -25dBZ - CloudSat. (600 pulses)

13% if Z > -13dBZ - WIVERN for Accurate Winds

(i.e. detect 72% of clouds that CloudSat sees)

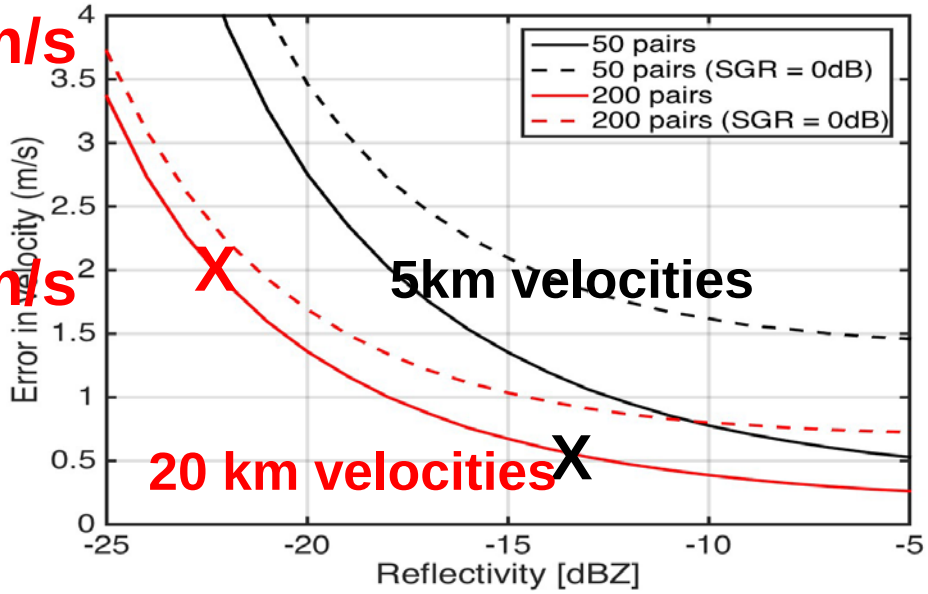
2.For 20km along track frequency changes by <1%

OK to consider 20km arcs of the conical scan for representative winds. (200 pulse pairs)

11. How many winds will Wivern detect?

Error in wind as f(dBZ)

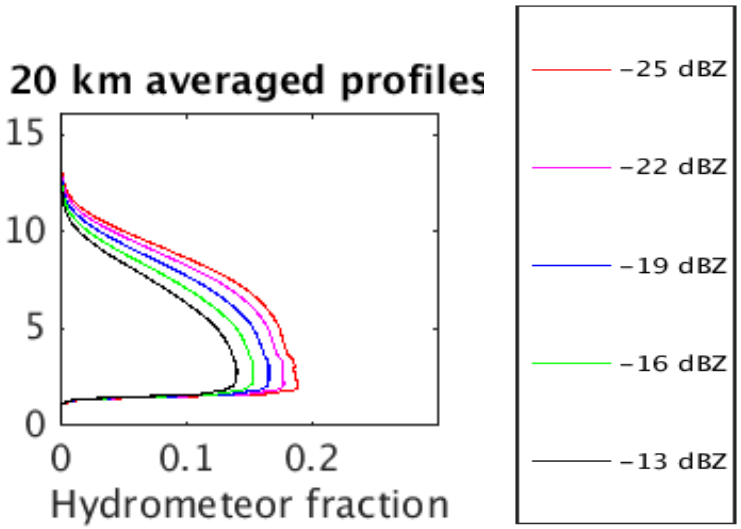
5km (50pulses) and 20km (200pulses)
Remember folding velocity 40m/s



-25dBZ **-15dBZ**

1. **LOOK AT 5km along track VELOCITIES**
If changing by >3m/s
and if big Z changes every km
REJECT AS CONVECTIVE.

CloudSat dBZ climatology

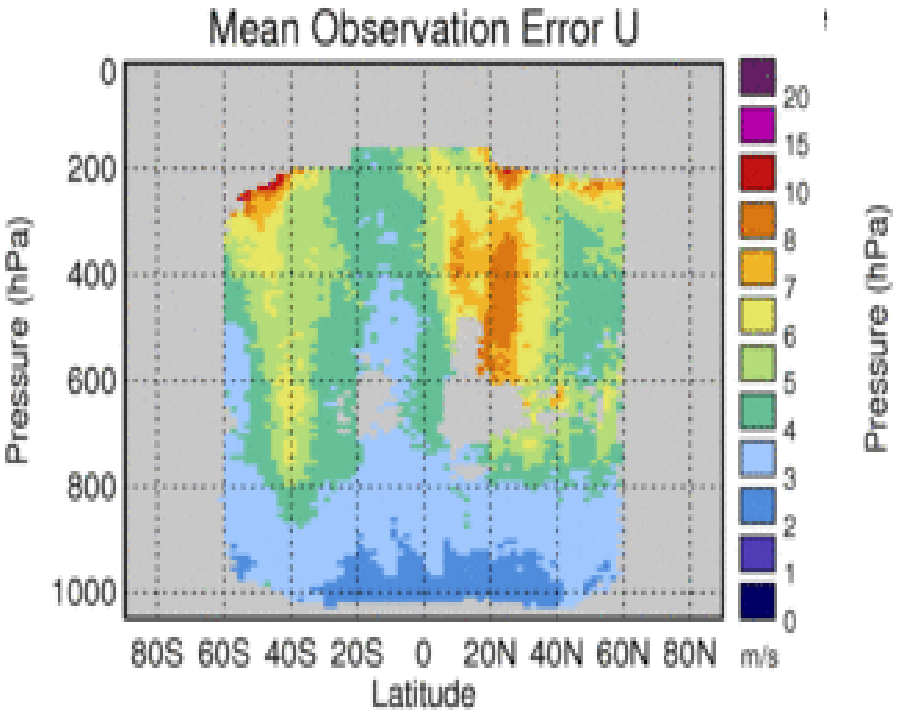


2. **20km accepted as non-convective:**

At -23dBZ V accurate to 2m/s
-13dBZ V accurate to 0.5m/s
(OK for 72% of profiles)
{but accuracy limited due to antenna pointing uncertainty and non-uniform beam filling}.

12. Statistics of AMV winds from Met Office. (December 2016)

Above 800hPa
AMVs are assigned errors of 5 -8m/s.
Difficult to know the height of the clouds from geostationary Satellites.

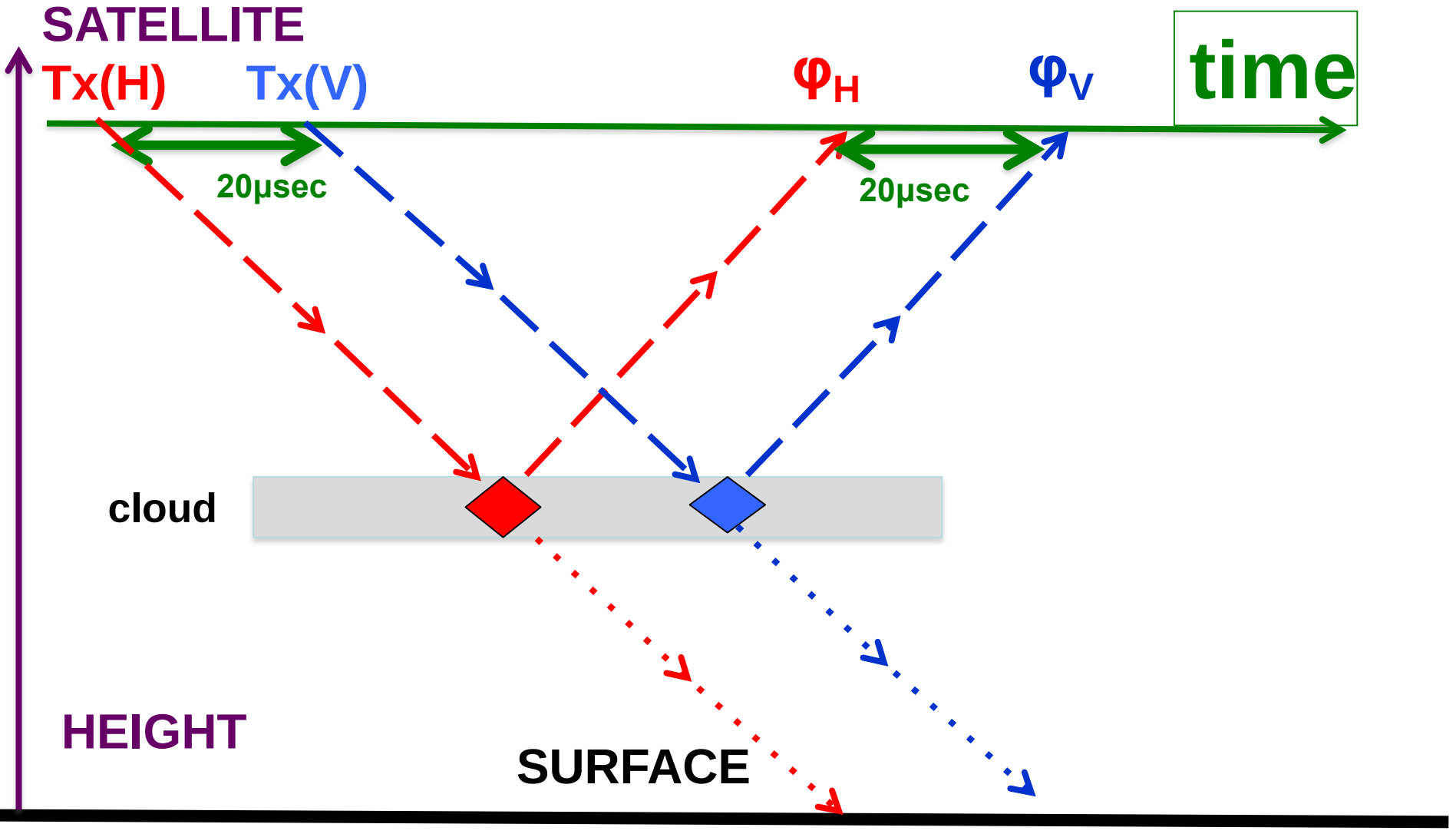


WIVERN – errors 2m/s and also from radar the height errors are not spatially correlated.
Thin to 80km as is planned for ADM – AEOLUS?

13. GHOSTS: 'BOUNCE' DIAGRAM

DOPPLER FROM H-V pulse pair:

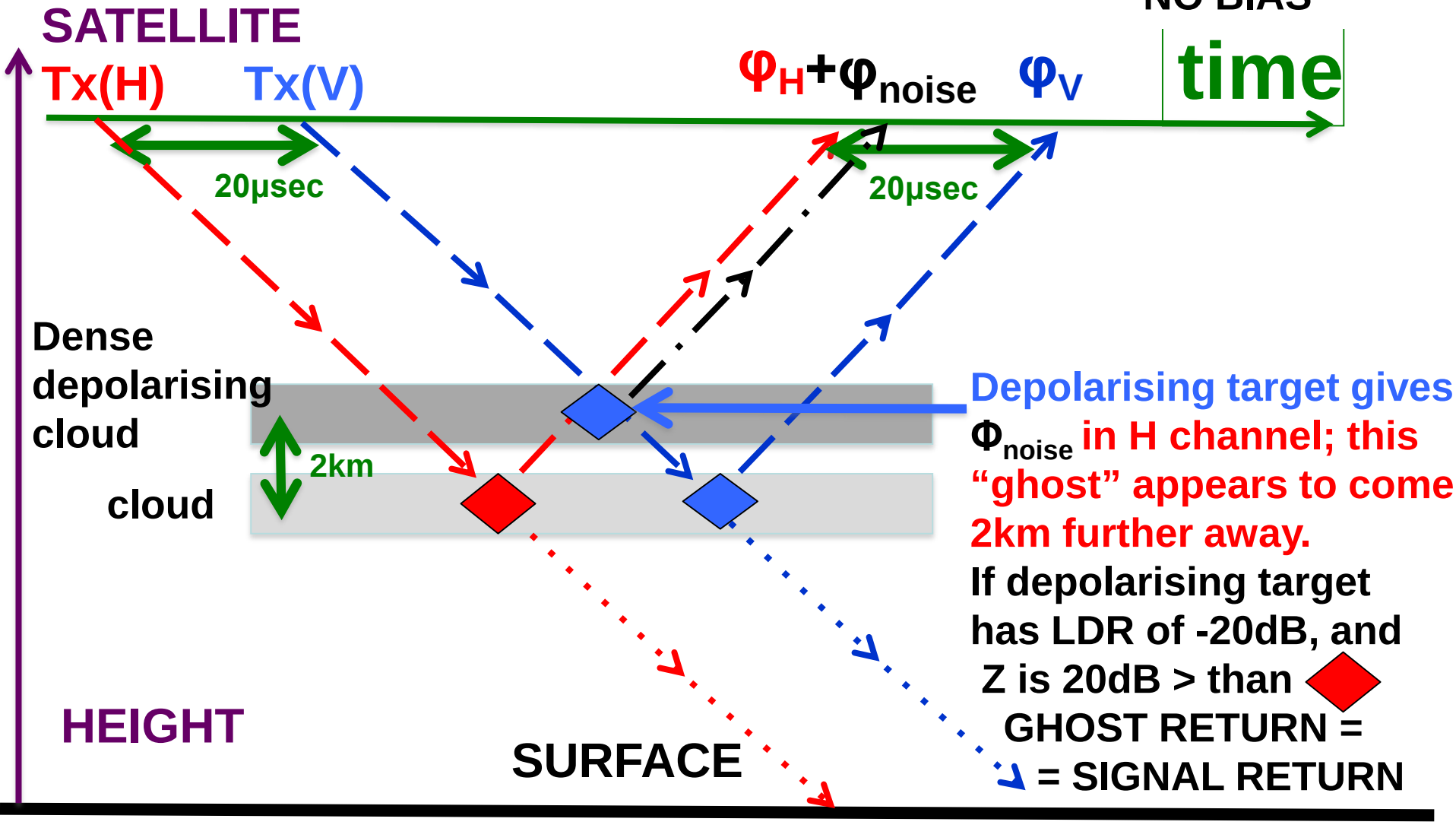
Velocity from
{ φ_V - φ_H }



13. GHOSTS: 'BOUNCE' DIAGRAM

DOPPLER FROM H-V pulse pair:

Random error in velocity from $\{\varphi_V - \varphi_H + \varphi_{noise}\}$ NO BIAS

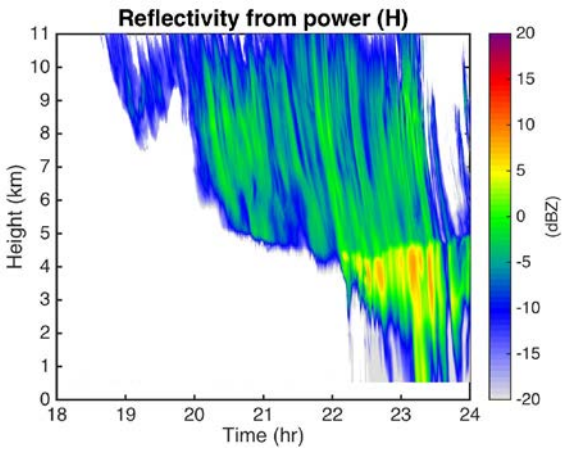


WORSE PROBLEM WHEN RED PULSE HITS DEPOLARISING GROUND

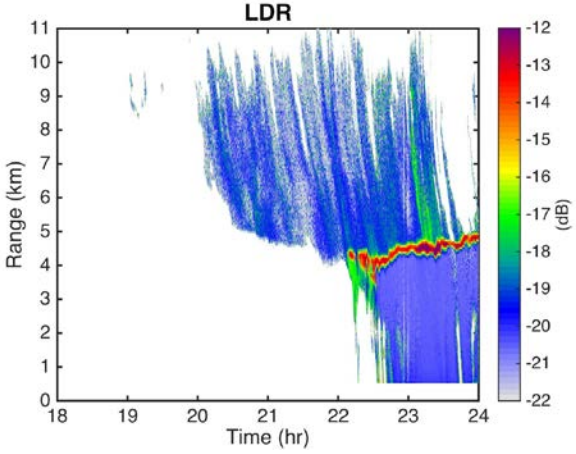
14. Ghosts observed from ground 45deg incidence: 9 JUNE 17

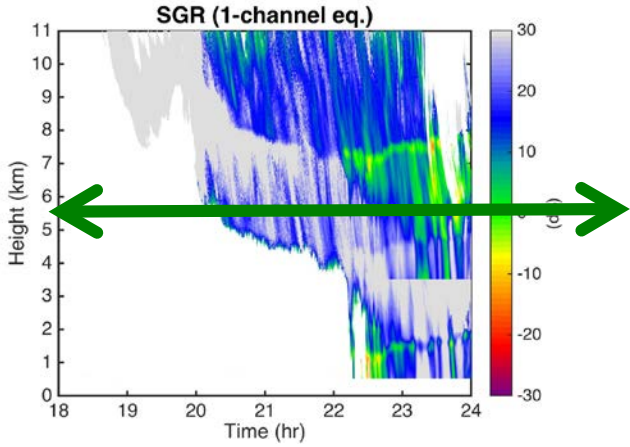
Signal to Ghost Ratio(SGR)
green is negative
Ghosts +/-3km of 4km height

Reflectivity dBZ

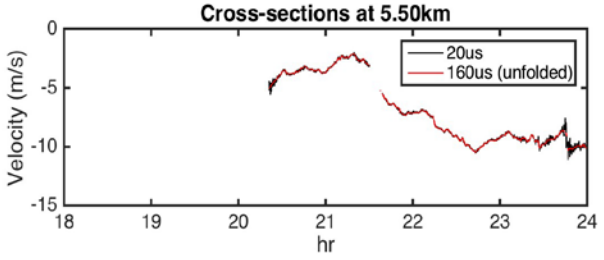


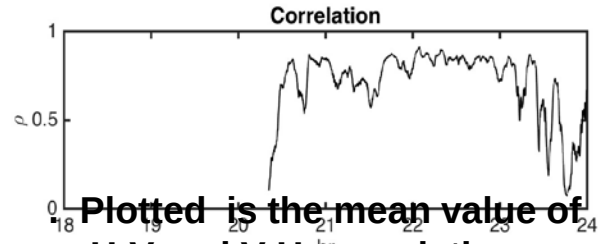
LDR in dB



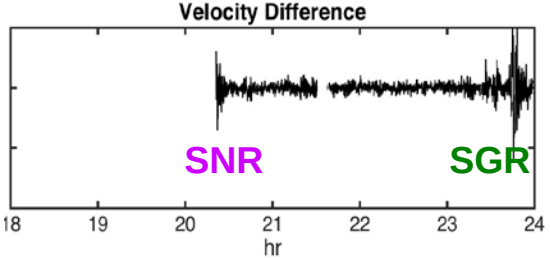


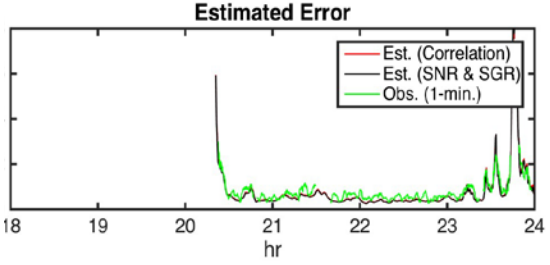
HEIGHT 5.5km RED true H-H and
Black the H-V velocity





Plotted is the mean value of H-V and V-H correlation





H-V velocity: any errors due to SGR (or SNR) is random (noise in phase) – NO BIAS (ESSENTIAL FOR DA)

GREEN – OBSERVED ERROR AGREES WITH ERROR PREDICTED by theory from observed H-V CORRELATION;
NOT NEED LDR ON SATELLITE?

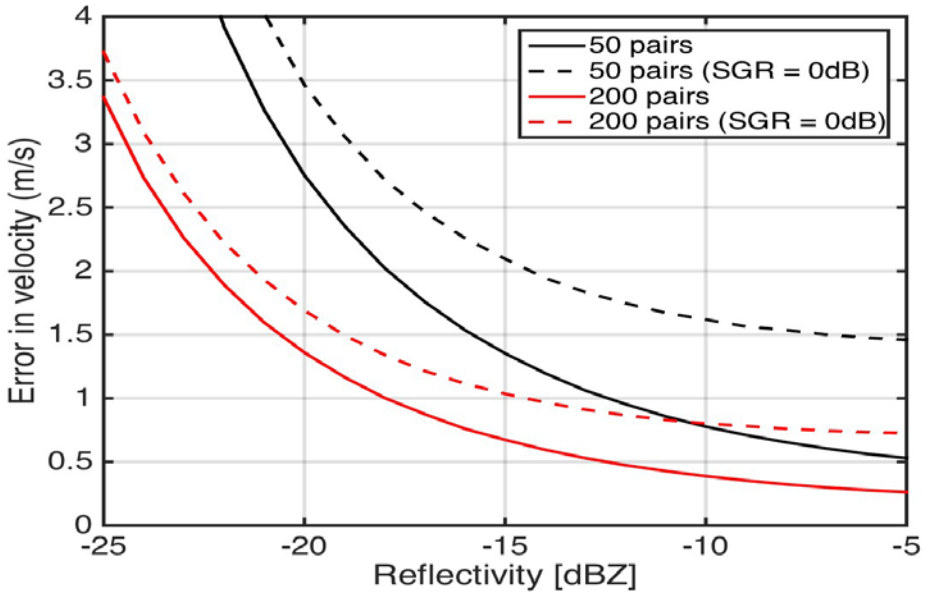
14. How many ghosts from CloudSat climatology?

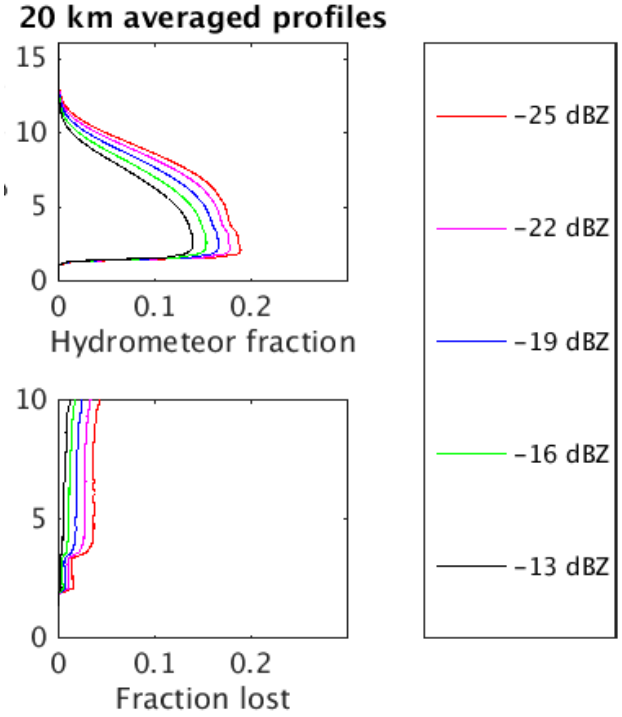
H-V separation 20usecs,

Ghost formed if there is an echo 2km above or below that is 20dB higher in Z, and that as an LDR of -20dB:

This will form a ghost with a signal-to-ghost ratio, SGR of 0dB.

Dotted lines show increased random error in velocity if we have an SGR of 0dB





Average fraction of echoes affected is

4% for Z > -25dBZ

2% for Z > -19dBZ

Same value for 1.5km or 20km integration

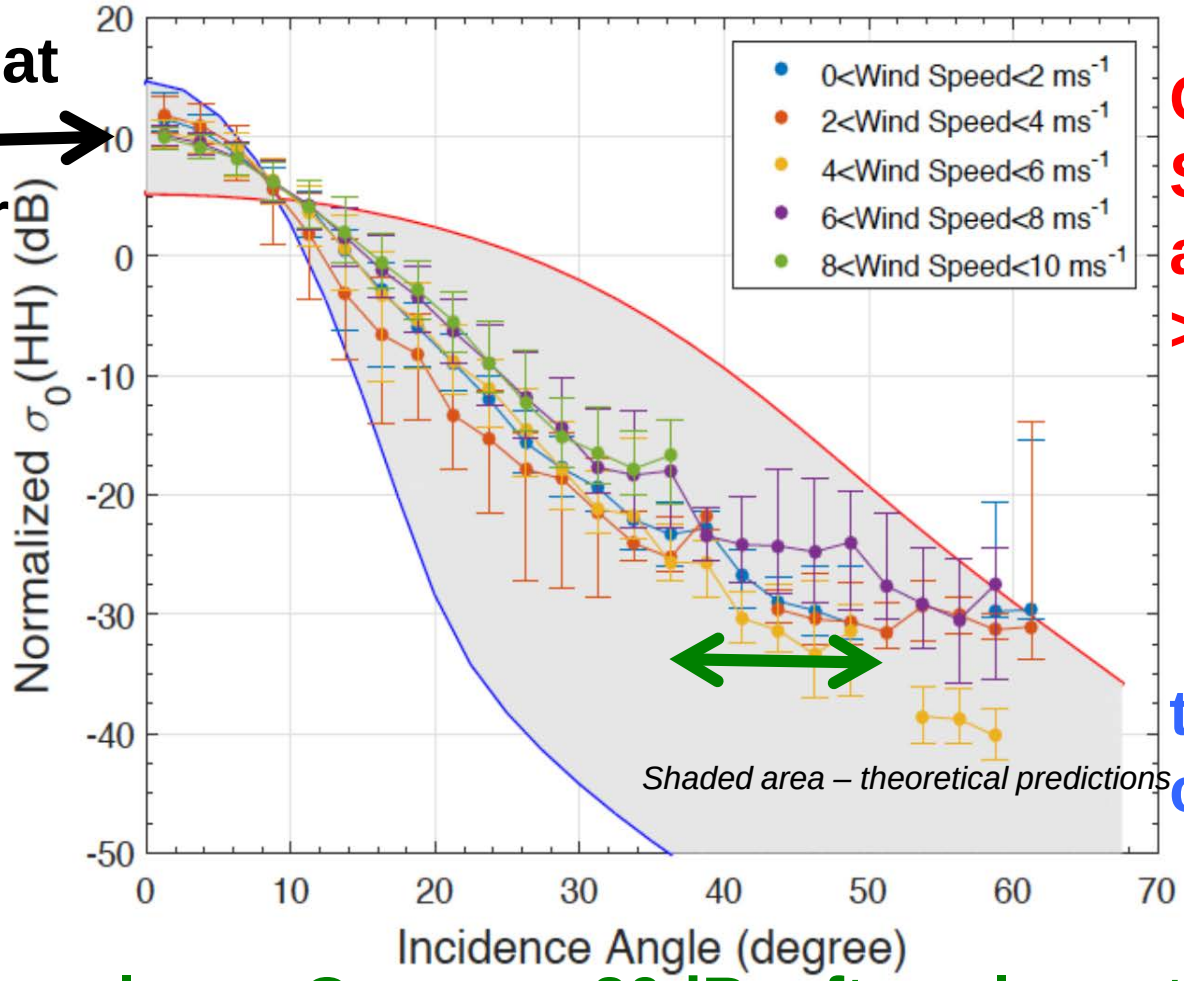
CONCLUDE

– GHOSTS VERY RARE.

15. Aircraft campaign 2016-7: sea-surface return.

FIRST MEASURMENTS OF 94GHz radar cross section, σ_0, of oceans and land at high angles of incidence above 25°.

CloudSat +10dB at nadir



Good news! Surface return at 40deg is >1000 times less than at nadir

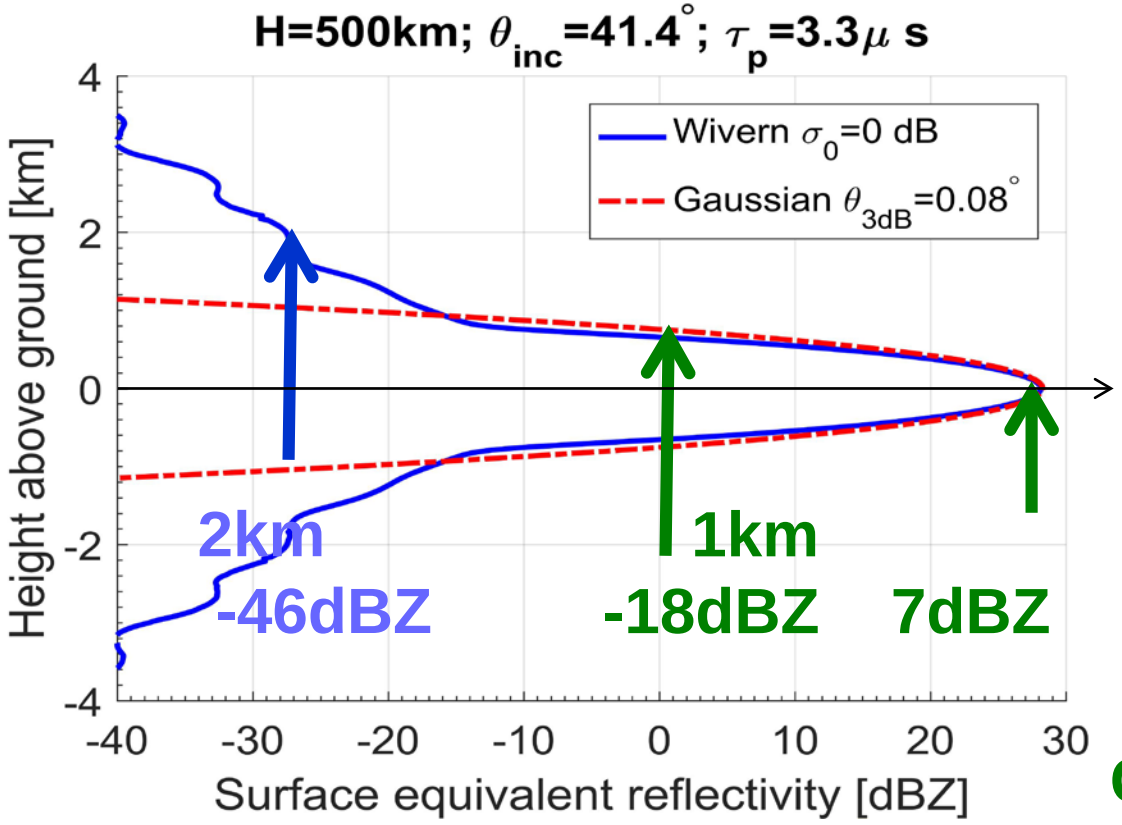
- how deep is the blind clutter zone?

Wivern values: Ocean < -20dB, often closer to -30dB

Land (away from cities) mostly about -10dB

16. How close to the surface can we measure reflectivity?

WIVERN surface clutter for a flat surface with sigma$_o$=0 dB.
Results for a Gaussian antenna with a 3dB-beamwidth of 0.08^0
i.e. surface looks like 27dBZ to the radar.



sigma$_o$= 0 dB.

BUT: OCEAN
Surface sigma$_o$= -20dB
to radar looks like 7dBZ
and 1km above ocean
looks like -18dBZ
2km looks like -46dBZ
(Land 10dB higher)
Cross polar return 15dB
below these values

17. HOW CLOSE TO THE SURFACE CAN WIVERN MEASURE REFLECTIVITY?

FROM AIRCRAFT STUDY:

	ABOVE THE OCEAN:	ABOVE LAND 10dB Higher
2km	-46dBZ	-36dBZ
1 km	-18dBZ	-8dB
0 km	+7dBZ	+17dBZ

1km above the ocean -18dBZ should see 83% of clouds

PRECIPITATION CLOSE TO THE GOUND?

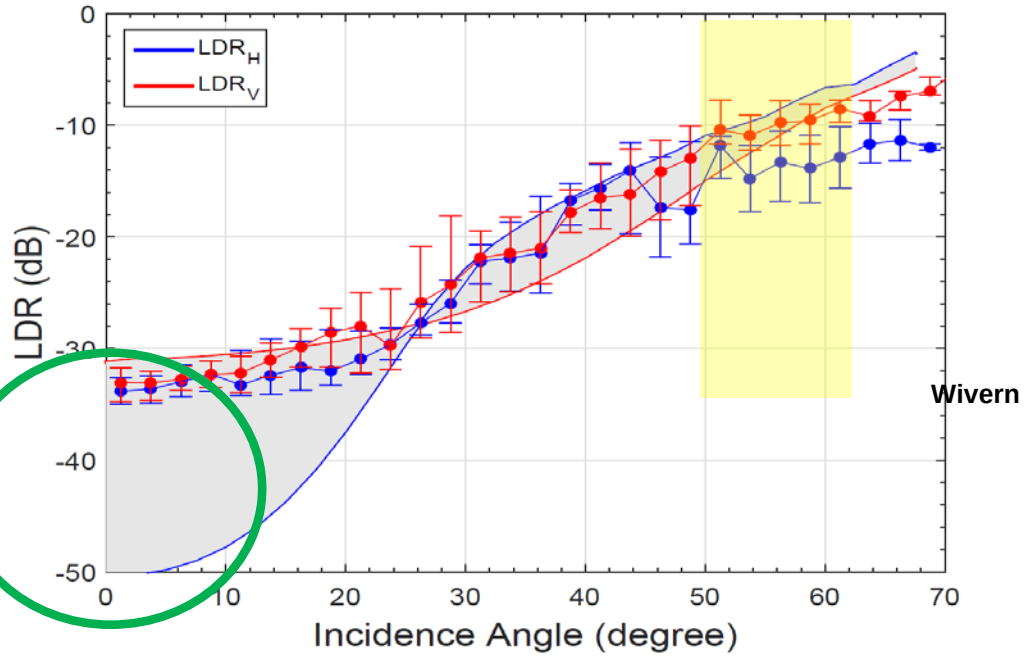
SNOWFALL: Polar regions/ANTARCTICA light snow 0dBZ; 1km over Land is -8dBZ. But what is sigma$_o$ for snow? Analysis of aircraft next week.

GLOBAL RAINFALL 1mm/hr @ 94GHz ≈ +17dB, should be possible over land (tolerate 25dB of attenuation)?

18. HOW CLOSE TO THE SURFACE CAN WIVERN MEASURE WINDS?

- Field campaign result II: sea surface LDR -15dB

Saturation effect induced by the cross isolation of the radar, which is estimated to be circa -34 dB



Wivern

LDR of surface return at 40deg: -15dB.

H-V Pulse separation 20μsecs, ghost at 2km height.

May be difficult to get winds 2km above the surface?

GLOBAL DATA ASSIMILATION CANNNOT HANDLE BOUNDARY LAYER WINDS

19. Proposed WIVERN configuration.

Parameter	Value	Units
Operating frequency	94	GHz
Pulse width	3.5	μs
Range resolution	500	m
Antenna diameter	1.8 x 2.9	m
Antenna scan rate	8	rpm
Off-zenith surface angle	41.4	degrees
Orbit height	500	km
Slant range	650	km
Height resolution	800	m
H-V pulse separation	20	μs
Folding velocity	40	$m\ s^{-1}$
Doppler accuracy (5km integration, Z>-18dBZ)	2	$m\ s^{-1}$

Winds to 2m/s for Integration of 5km along the arc, and clouds >-18dBZ

Within 2km of ocean surface.

Ghosts very rare from space – increased random error in velocity Can be recognised.

TRL6 "Model demonstrating the critical functions of the element in a real environment"

- but what about the antenna?

SRL5 - "End to end performance simulations

SRL6 - Consolidated science and products"

AOPC

22nd Session of the GCOS/WCRP Atmospheric Observation Panel for Climate
(AOPC-22)

Exeter, United Kingdom
27-31 March 2017

GCOS-207
WCRP-7/2017

20. HOW IMPORTANT ARE THE ESTIMATES OF ICE WATER CONTENT (IWC) FROM Z?

WIVERN:

IWC over a 800km wide sample and 1.5km resolution will detect all radiatively significant clouds (i.e. > -25dBZ)

- rather than 1km swath CloudSat/EarthCARE

GCOS – Global Climate Observing System: also recommend that cloud and aerosol profiling are assigned as ECVs "Essential Climate Variables"

Proposed actions:

Action : Implementation of space-based clouds and aerosols profiling

Action: Prepare and implement a follow-on lidar-radar mission to Calipso-CloudSat and EarthCare
Benefit: Monitoring and understanding of the clouds and aerosols vertical distributions and their impact on climate and weather.
Who: Space agencies
Time-frame: Launch as soon as possible to minimize the gap with EarthCare.
Performance Indicator: Long-term homogeneous satellite-based clouds profiles and aerosols profiles
Annual Cost : 100-300M US$ (tbc)