94GHz Polarisation Diversity Doppler Radar to Observe Global In-Cloud Winds

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+ STFC + Airbus + NRC Canada (Wolde)

WIVERN:

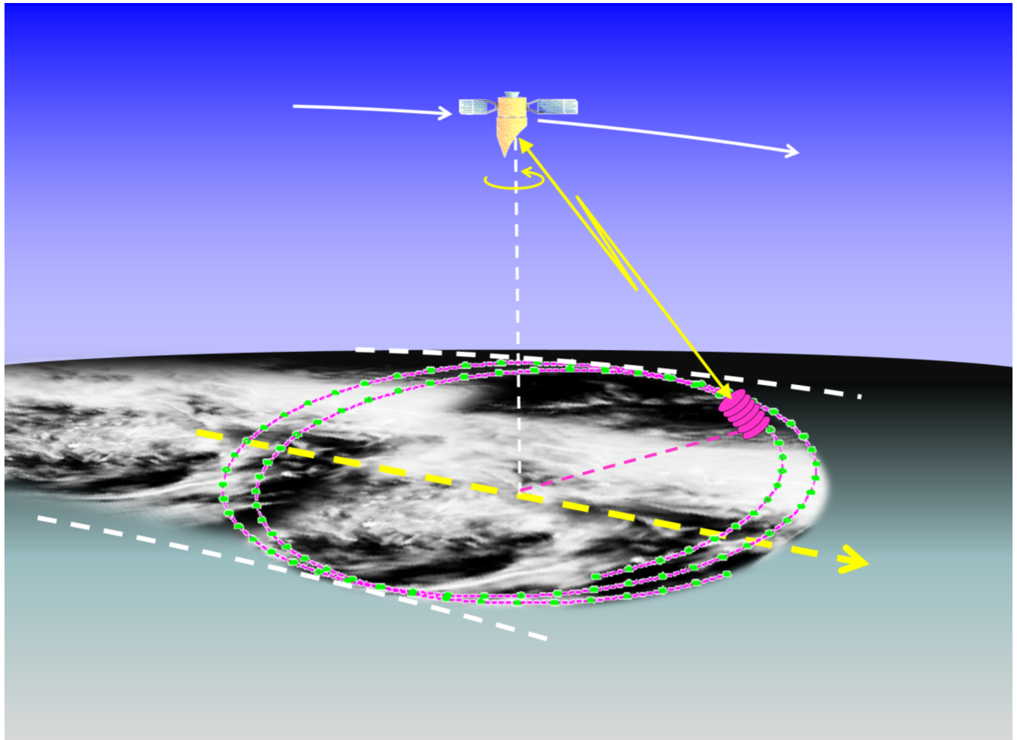
A WInd VElocity Radar Nephoscope:

Earth Explorer 10 Candidate

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

CEOI: EMERGING TECHNOLOGIES WORKSHOP
Cosener's House: 3-4 May 2017

2. WIVERN – RADAR CONCEPT



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

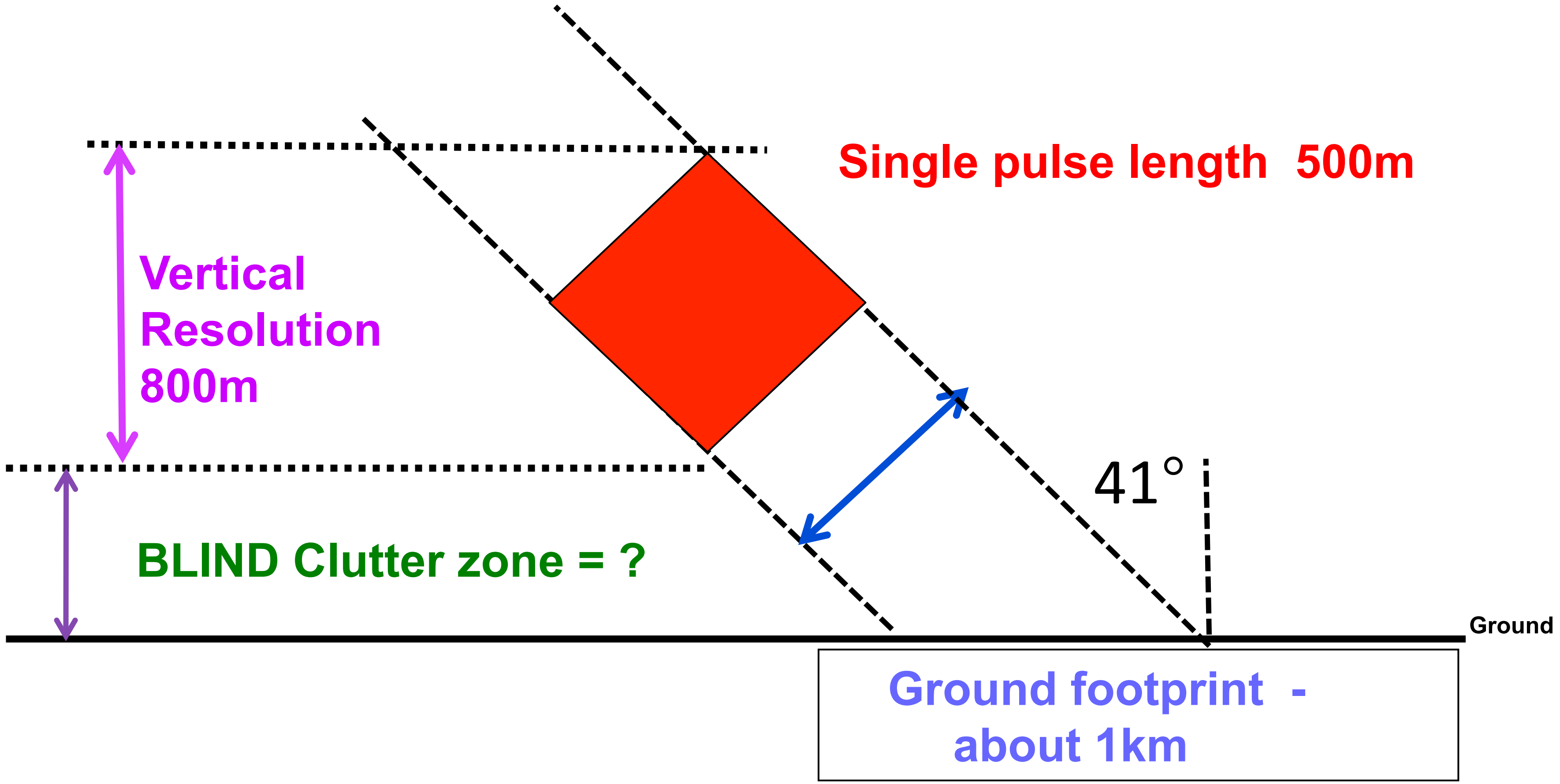
Scan every 7 seconds
- move 50km along track
- sample every 50km along arc

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 2017;
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

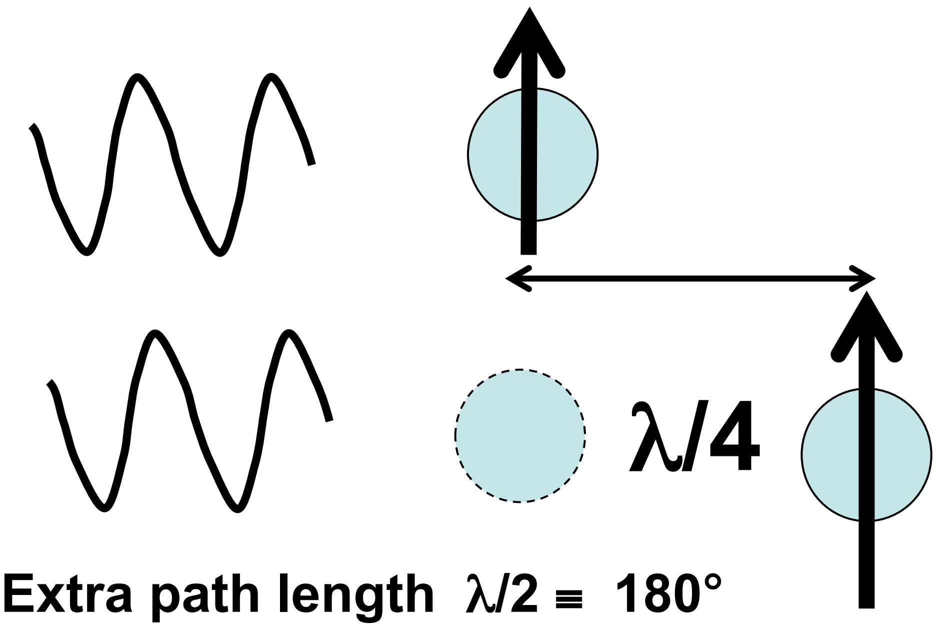


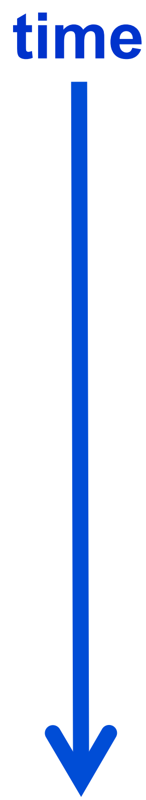
UKNOWN DEPTH OF THE CLUTTER ZONE at 94GHz?
Affects the minimum height that winds can be measured

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

Pulse one

Pulse two
Δt later





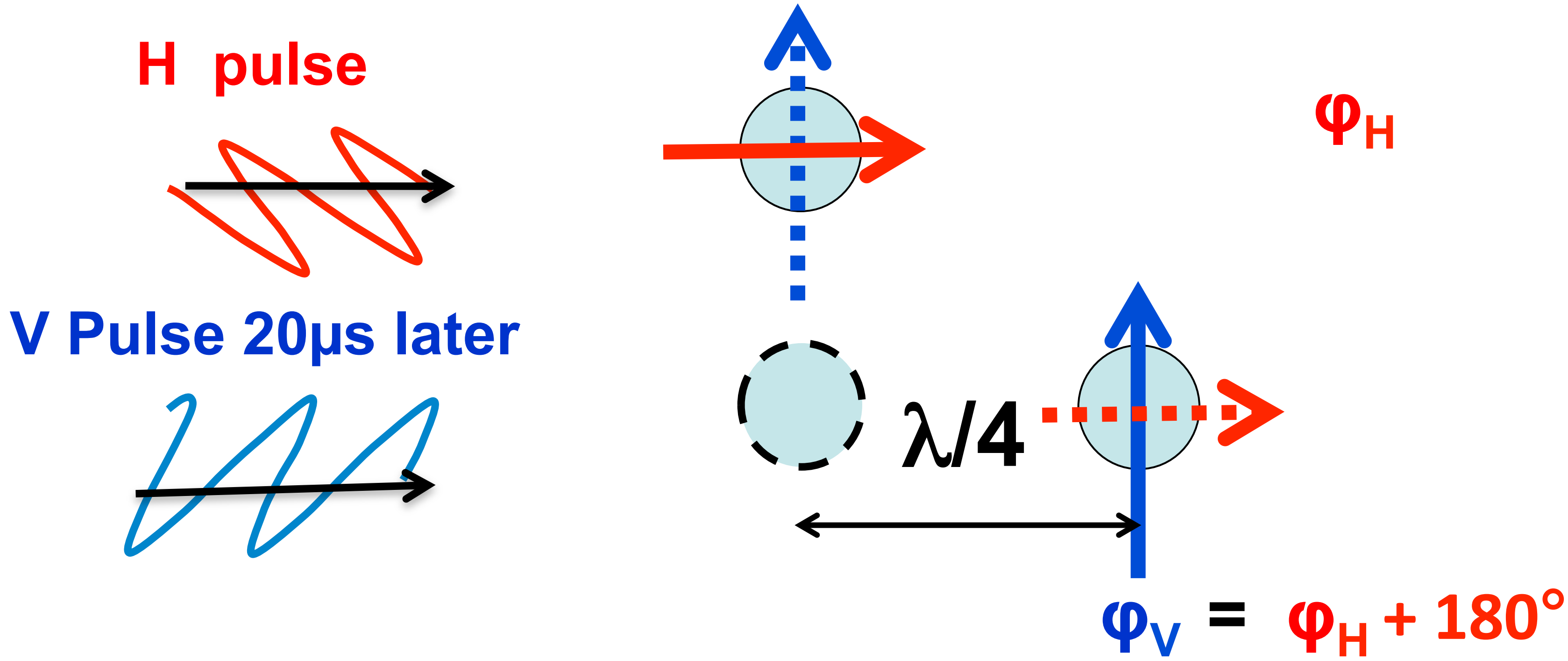
Move λ/4=800μm: Extra path length λ/2 ≡ 180°

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



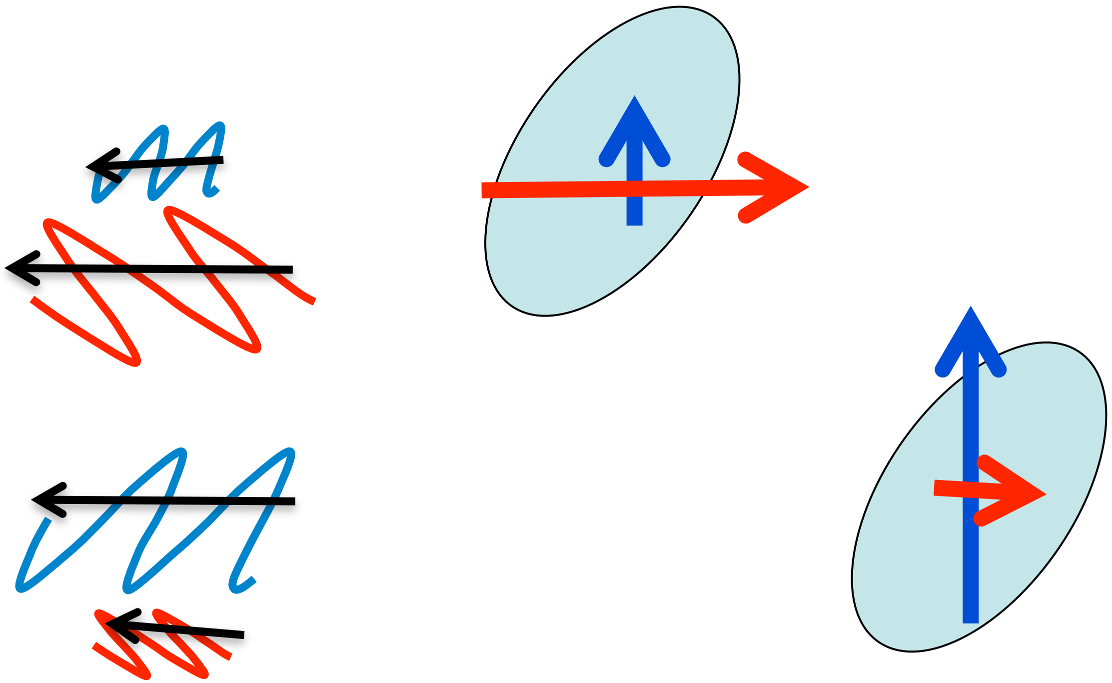
(Pazmany et al., J Tech, 1999) H and V dipoles are coincident in space.
FOLDING VELOCITY: 800µm in 20µsec = ±40m/s and 1m/s IS ABOUT 4°

20µsec pulse separation for H and V pulses
(3km slant path: 2km in vertical)

6. PROBLEM: OBLATE (WET) ORIENTED HYDROMETEORS (AND THE GROUND) DEPOLARISE

H pulse
Also excites
Small V
dipole

V pulse
excites
Small H
dipole



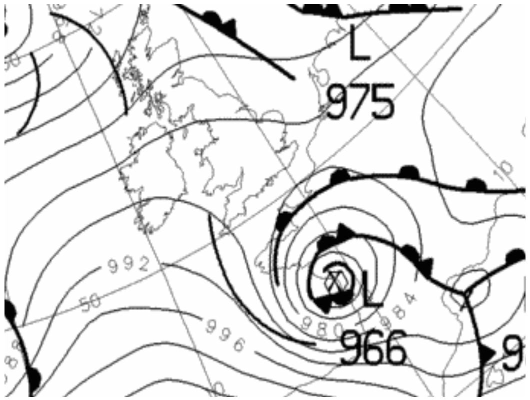
1. **'Ghost echoes' ± 2km above or below a high Z echo.**
2. **Depolarising surface (land/ocean) will also give 'ghost echo' 2km above the surface (affects the blind layer)**

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.
(EMWF, UKMO, MeteoFrance)

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



Daily visits – so only for long lived systems.
NOT FOR SHORTLIVED THUNDERSTORMS
GOOD FOR 1-2 DAY FORECAST OF DEVELOPING WIND STORMS
Plus tropical cylcones…

HERITAGE: WIVERN will use a 94GHZ transmitter based on the single pulse nadir-pointing CloudSat radar launched 2016. Still working OK.

8 ➢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

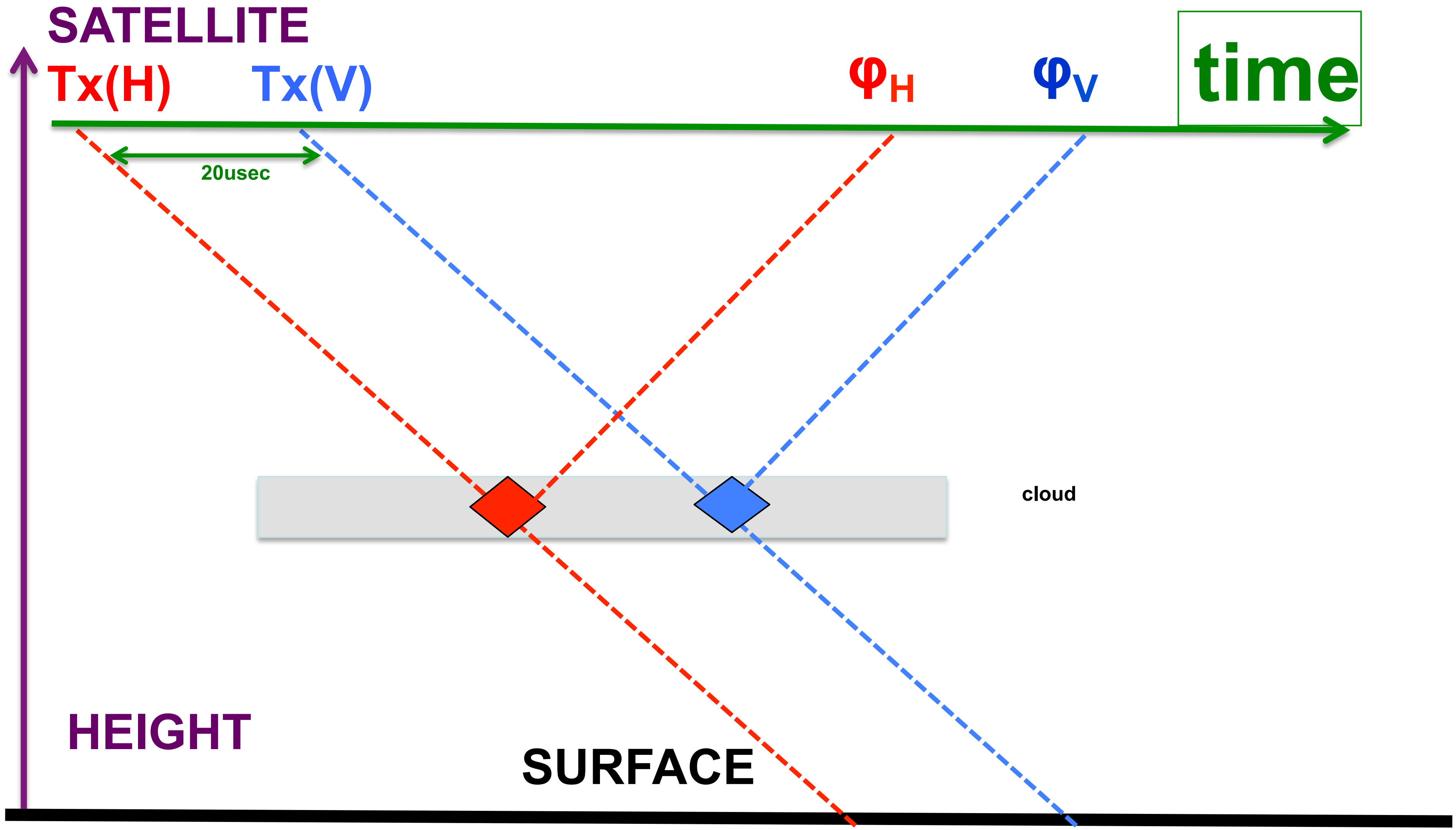
1. From CloudSat reflectivity data and proven Doppler performance we predict that for clouds > -18dBZ WIVERN should measure wind velocities to ± 2m/s.
2. Weather services are ready for ADM winds so using the in-cloud WIVERN winds will be a small step.

Studies in progress:

3. CEOI study of frequency of ghost echoes at Chilbolton
4. ESA study using 94GHZ H-V radar on Canadian aircraft to establish ocean/land backscatter at 41° incidence

9. 'BOUNCE' DIAGRAM
DOPPLER FROM H-V pulse pair:

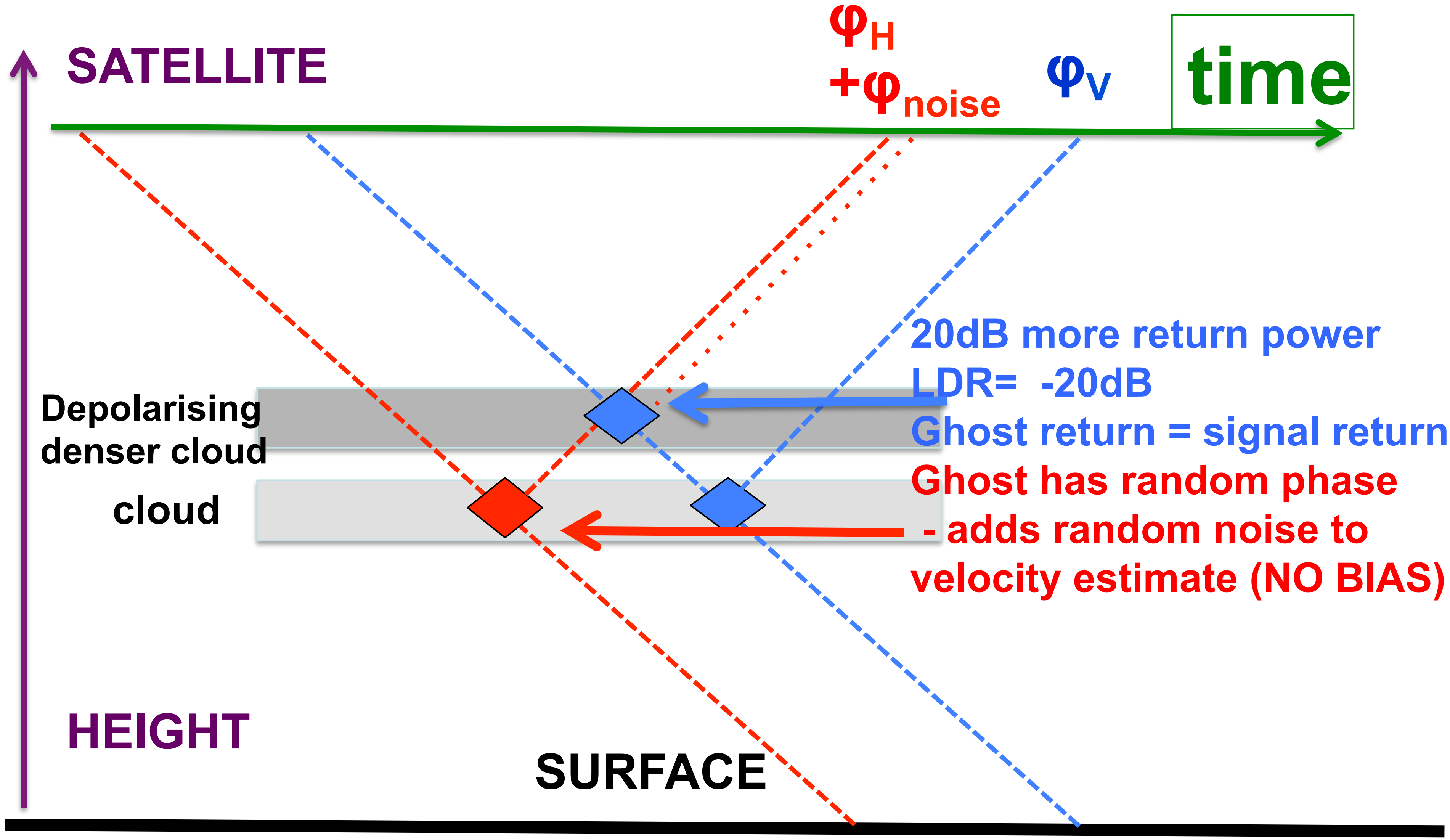
Velocity from $\{\varphi_V - \varphi_H\}$



10. H-V pulse pair

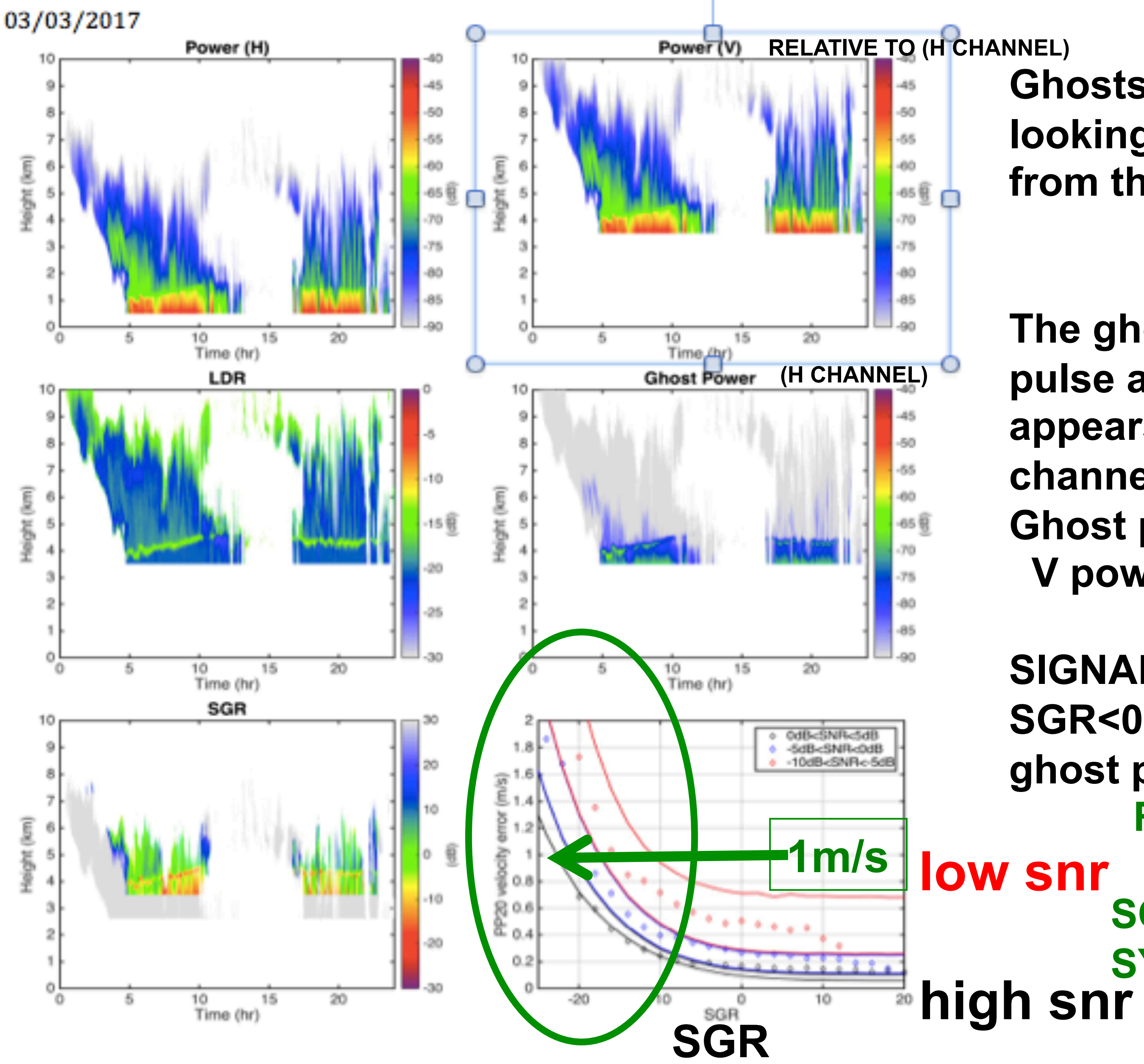
GHOST FROM BLUE TARGET IN THE H CHANNEL

Velocity from $\{ \varphi_V - \varphi_H \}$



WORSE PROBLEM WHEN RED PULSE HITS DEPOLARISING GROUND

11.CHILBOLTON OBSERVATIONS OF INCREASED RANDOM WIND ERRORS ASSOCIATED WITH GHOSTS



Ghosts are common looking upwards from the ground

The ghost from the V pulse at 1km height appears in the H channel at 4km height.
Ghost power =
V power* LDR

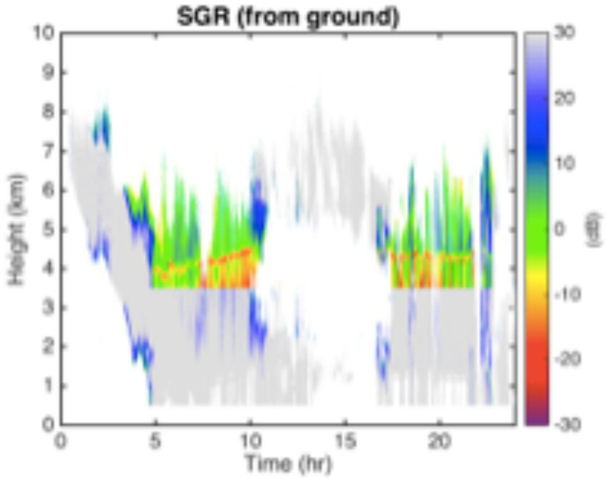
SIGNAL TO GHOST RATIO
SGR<0dB: (red/-yellow)
ghost power > signal

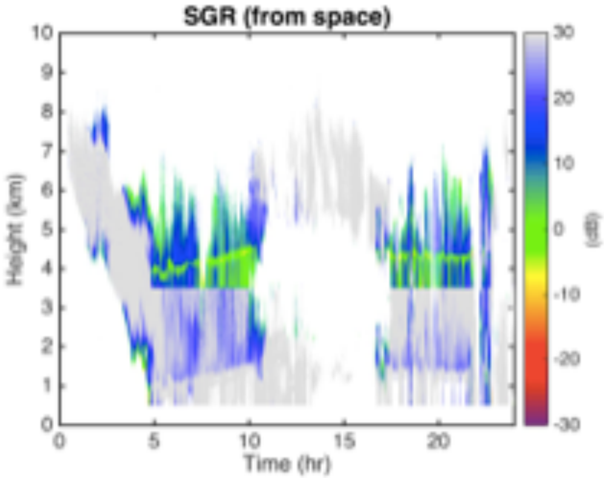
Random error in velocity > 1m/s
SOLID lines - theory
SYMBOLS - observvns

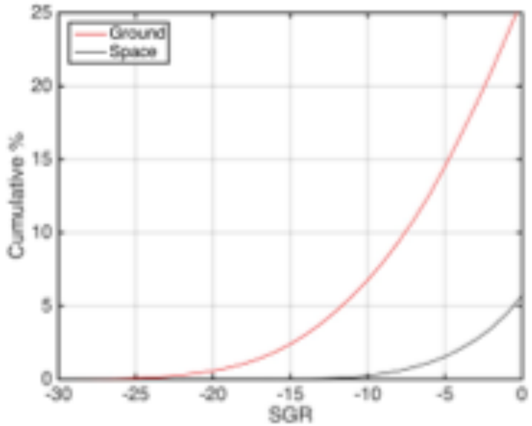
12.PREDICTED GHOSTS FROM SPACE.

SGR FROM GROUND
- RED/YELLOW NEGATIVE

SGR FROM SPACE
RANGE OF TARGETS APPROX CONSTANT
- SGR MOSTLY POSITIVE







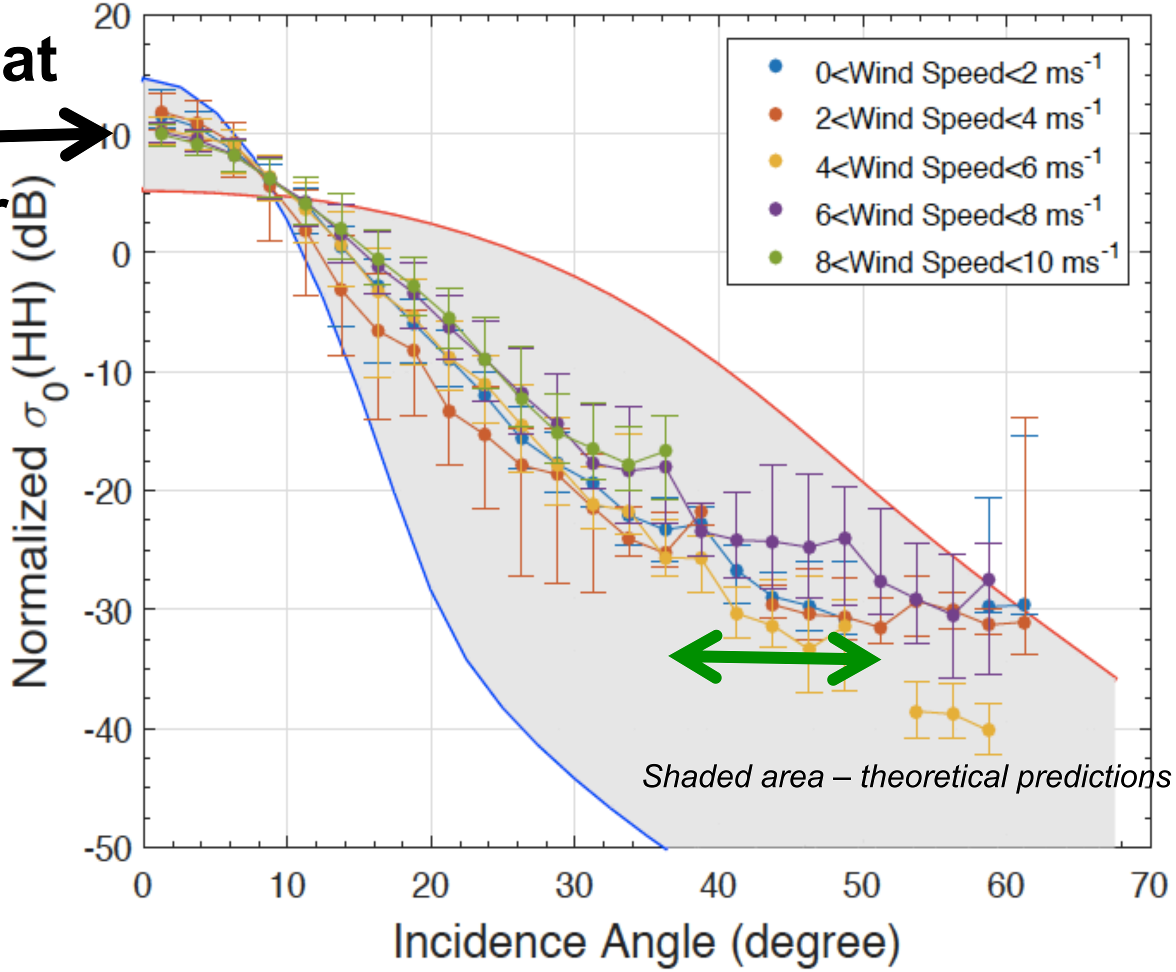
RED CUMULATIVE OCCURRENC OF GHOST FROM THE GROUND AS f(SGR)
BLACK - FROM SPACE

Ghosts add noise to Zh and Zv,
So can predict wind error from drop in observed correlation of Zh and Zv.
Maybe don't need to observe 'LDR'

13. Aircraft campaign return from sea surface 2016

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

CloudSat +10dB at nadir

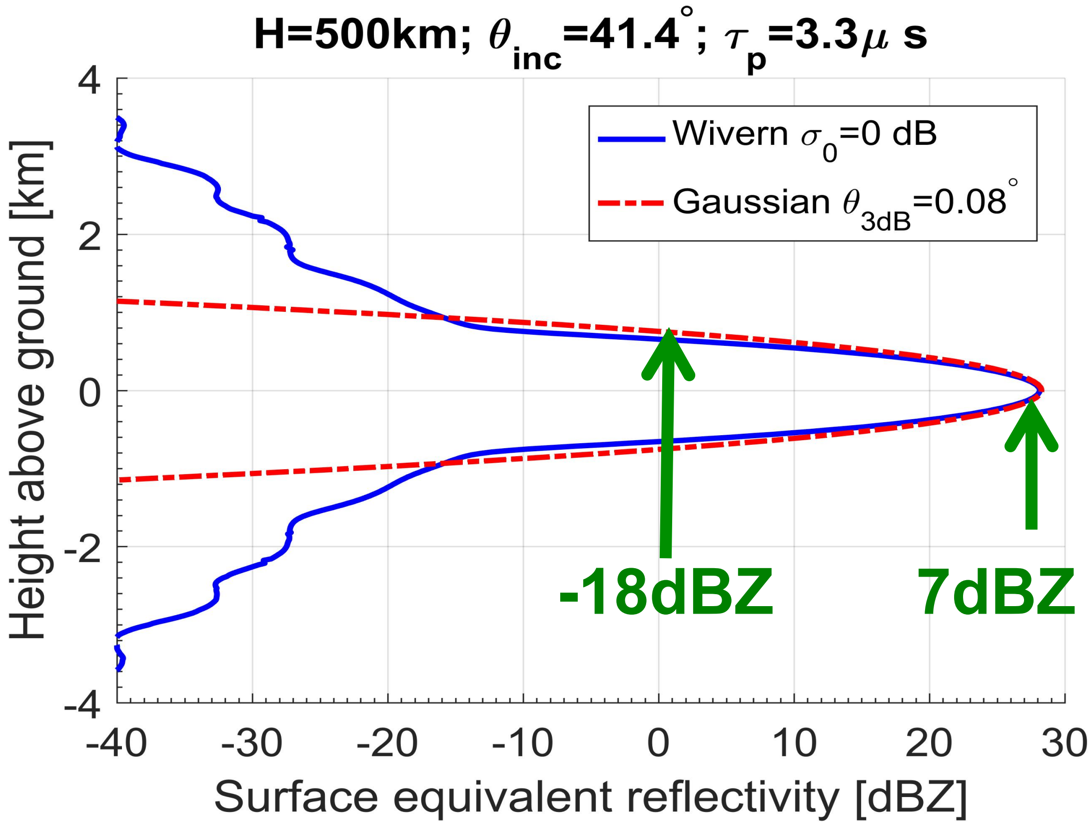


Good news! Surface return at 40deg is >1000 times less than at nadir - reduced blind zone

Wivern values: < -20dB, OFTEN AT -30dB

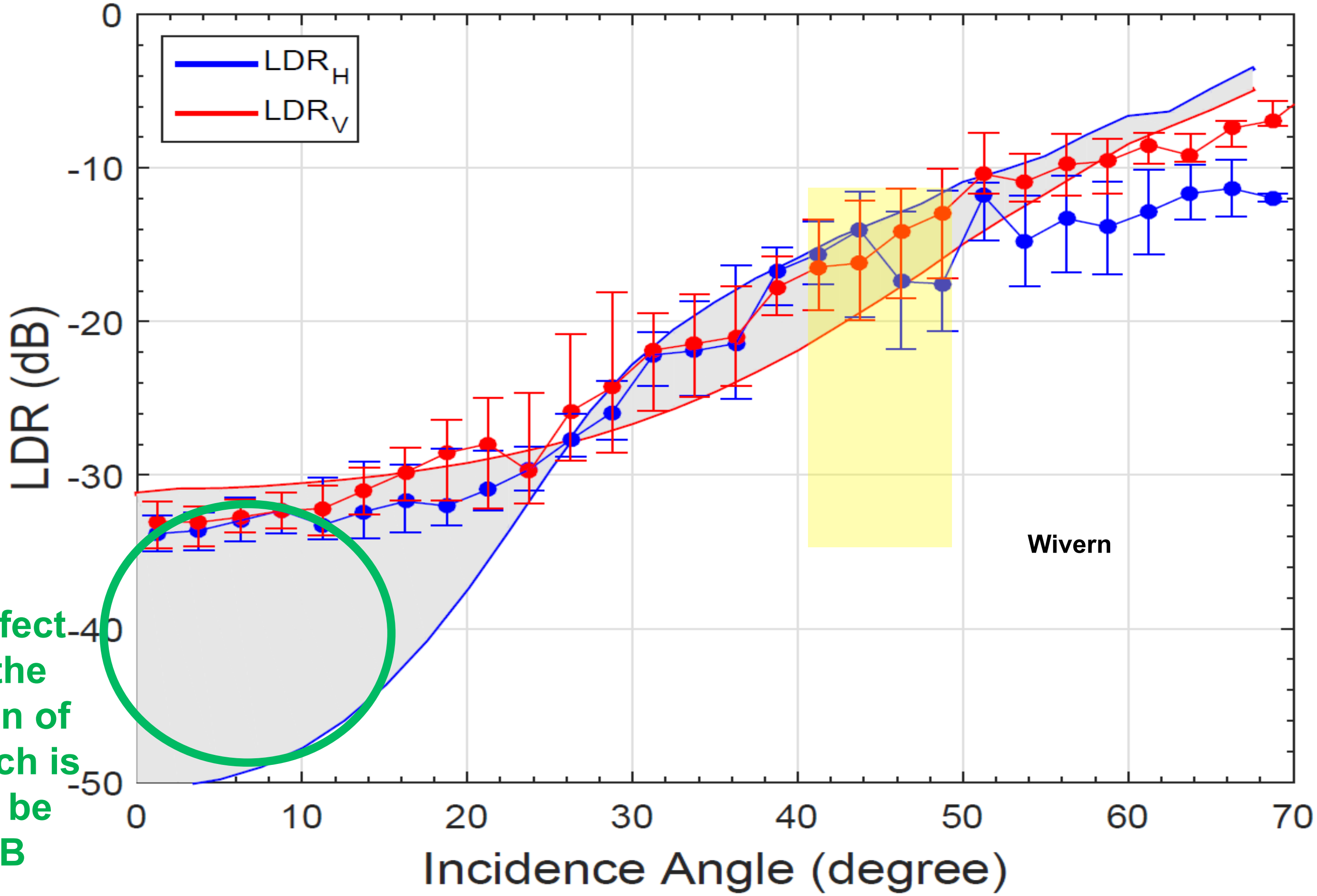
14. How close to the surface can we measure winds and reflectivity

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.



Aircraft measures surface sigma$_o$=-20dB
Looks like 7dBZ
To the radar
Can get Doppler for dBZ > -18dBZ
To within 1km of surface

15. 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

GOOD NEWs: LDR of surface return at 40deg: -15dB
For a pulse separation of 20usecs,
Should get winds over ocean to 2km above surface.

20. 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?

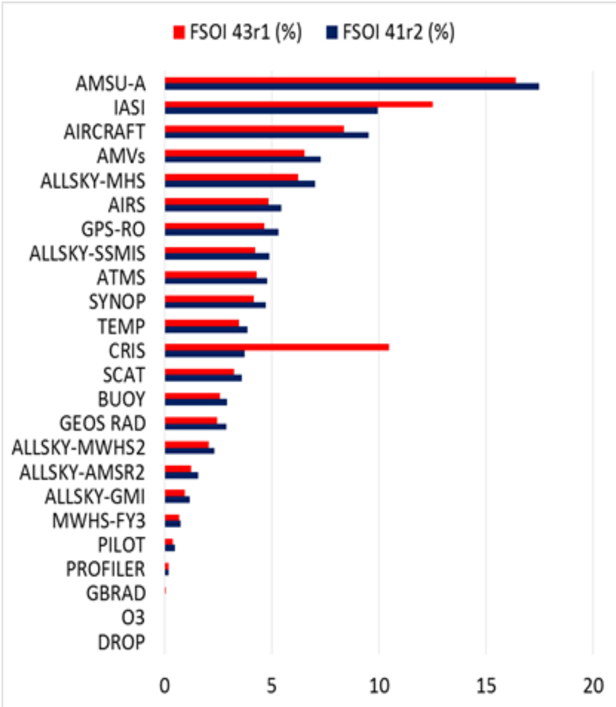
SRL5 - "End to end performance simulations

SRL6 - Consolidated science and products"

Spare slides

ECMWF
AMVs are the fourth highest in terms of FSO Impact

total FSOI (%) by instrument



May – August 2016

OBSERVATIONS FOR IMPROVING FORECASTS:

ORDER OF IMPORTANCE

1. TEMP/HUMID SOUNDERS (50-60%)

HSIR - high res infra red MWSI – microwave sounders

2. WINDS (ABOUT 20%)

AMV (atmospheric motion vectors –satellite images A/C aircraft

	Met Office (Oct 2016)		ECMWF (May-Aug 2016)		MeteoFrance (April 2015)	
1	HSIR	31.5%	MWSI	36.0%	MWSI	30%
2	MWSI	23.8%	HSIR	30.3%	HSIR	18%
3	AMV	11.9%	A/C	8.4%	A/C	13%
4	SL	8.6%	AMV	6.5%	RS	12%
5	A/C	8%	GPS-RO	4.7%	AMV	8%

RS – radio sondes T, and q : GPS-RO – GPS radio occultation:

Winds in cloudy regions, accuracy 1 to 2 m/s or better,

NOT FOR INDIVIDUAL SHORTLIVED THUNDERSTORMS

GOOD FOR 1-2 DAY FORECAST OF DEVELOPING WIND STORMS

WINDSTORMS ARE THE MOST DAMAGING WEATHER EVENT IN EUROPE

RAW AND ASSIMILATED WIND OBSERVATIONS AND AVERAGE ASSIGNED ERROR FOR 12 HOUR PERIOD (OCT 2016) IN ECWMF MODEL.

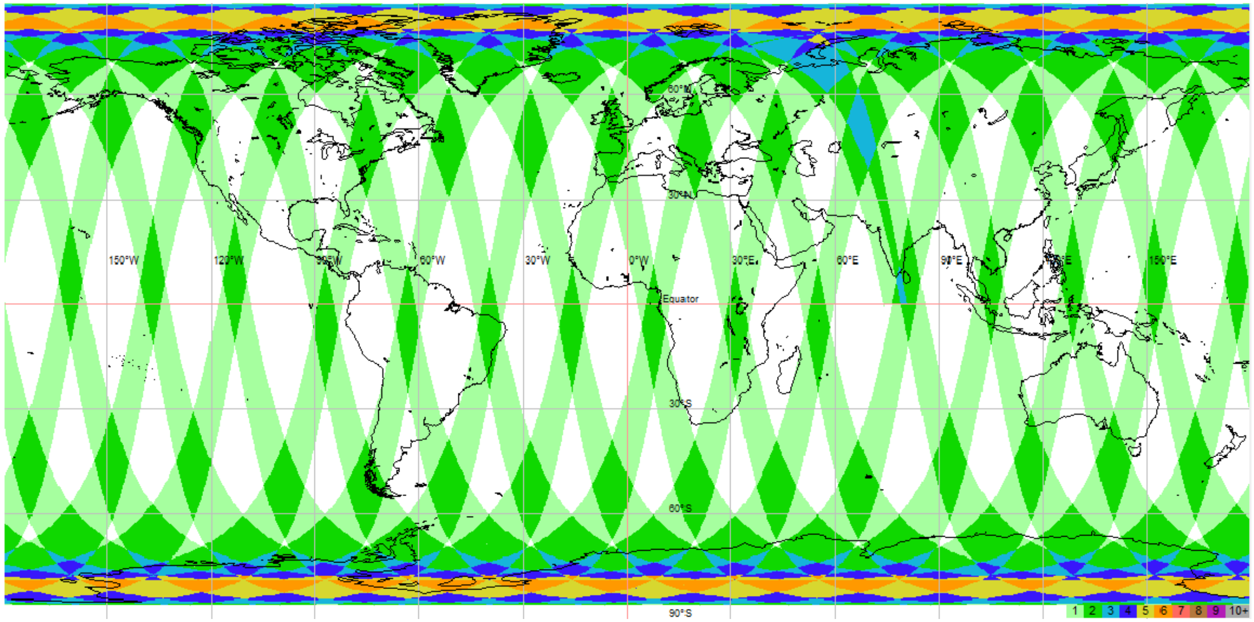
	TOTAL	AMV	A/C
Raw (pre-QC)	6,527k	3,570k 54.7%	496k 7.6%
Assimilated	424k	144k 34.0%	179k 42.3%
Assigned error (m/s)		4.61 m/s	2.27 m/s

AMV WINDS: 4.61m/s assigned error (OK if random);
This is due to height uncertainty derived from IR temp.
Error depends on vertical wind shear
- i.e. highest in areas of 'active' weather.

Winds thinned to 200km (correlated height errors)

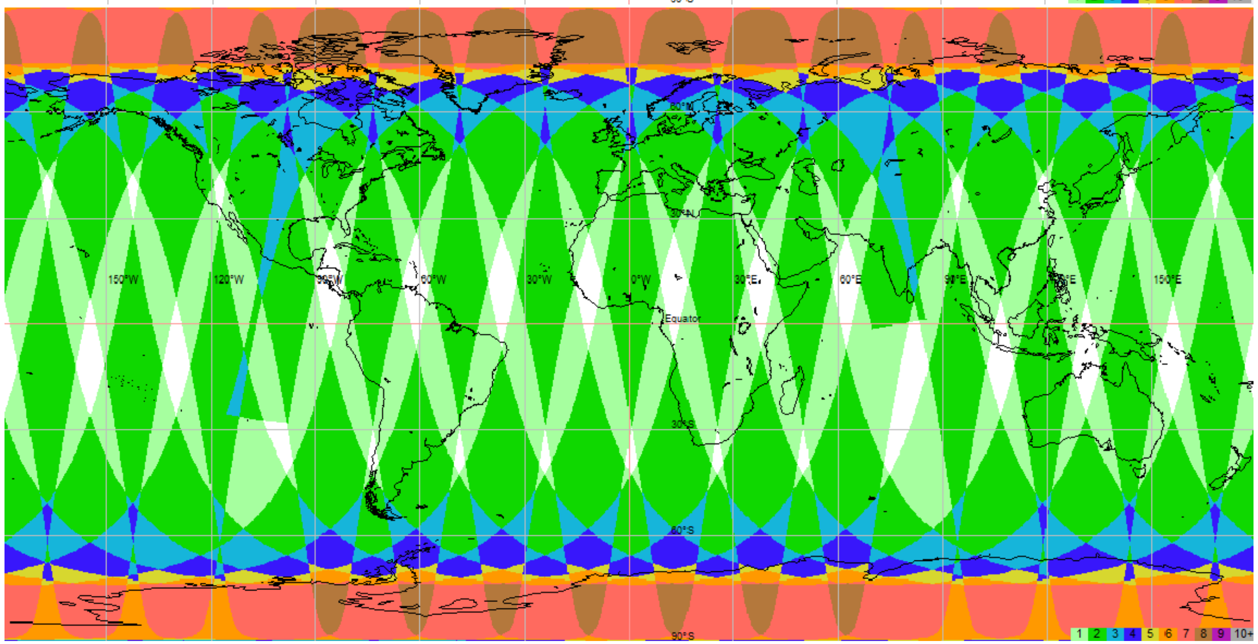
FOR A/C (in situ) and RADAR height is known to 1km.

5. REVISIT TIME and ORBIT



500km ORBIT
800km wide
ground track

Dark green twice a day
Light blue three times



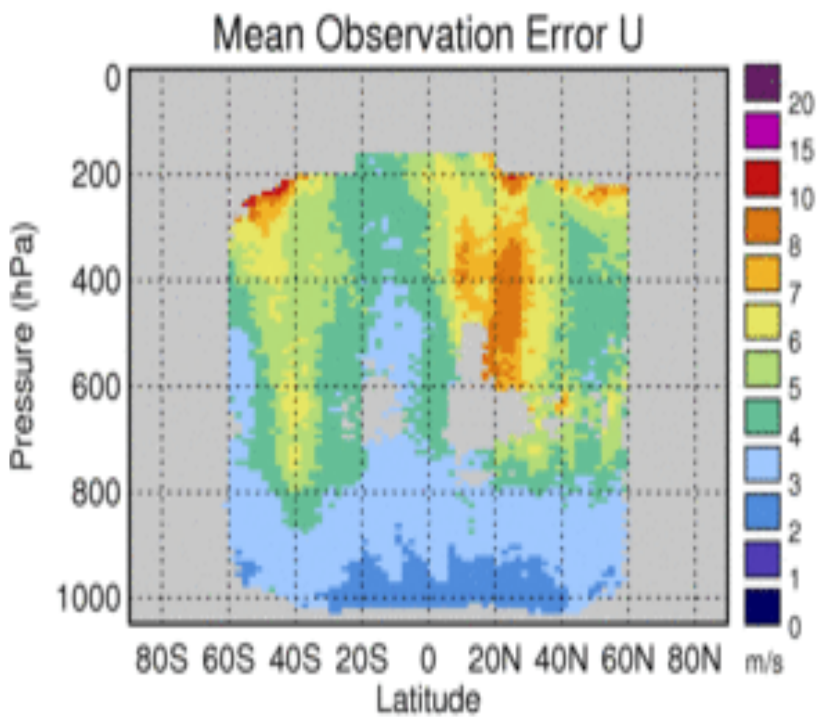
700km ORBIT
1800km GROUND
TRACK

Slant path 1178 not 651km,
BEAMWIDTH 2km
Poor v resolution
Blind zone near ground

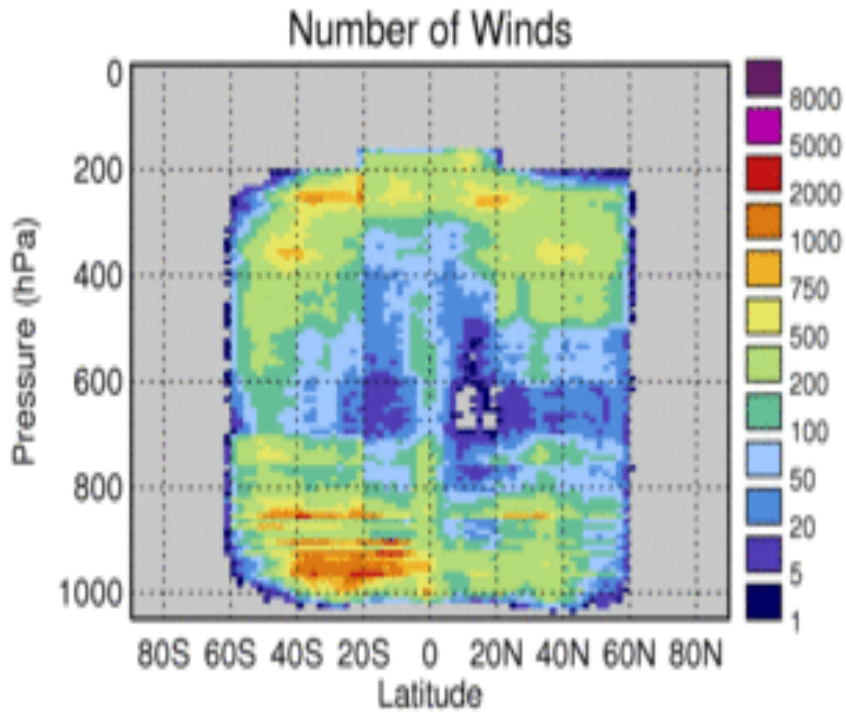
REJECT

18. December 2016 – statistics of AMV winds from Met Office.

Above 800hPa errors 5 -8m/s



Most winds S Oceans 900hPa And 200-400hPa at all latitudes



WIVERN – errors 2m/s and more winds at mid-levels???
Also height errors not spatially correlated.
Thin to 80km as is planned for ADM – AEOLUS?