POLarization-diversitY Doppler Radars On Satellites (POLYDOROS)

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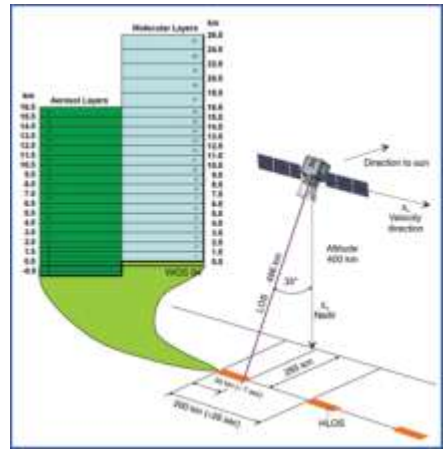
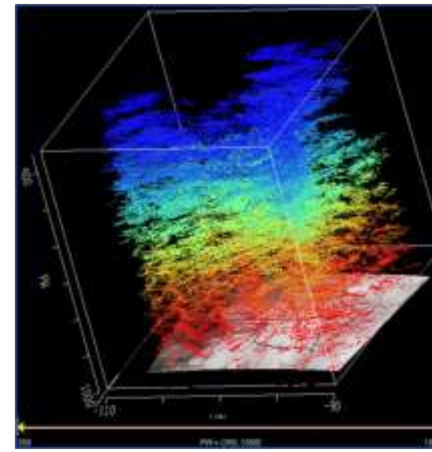
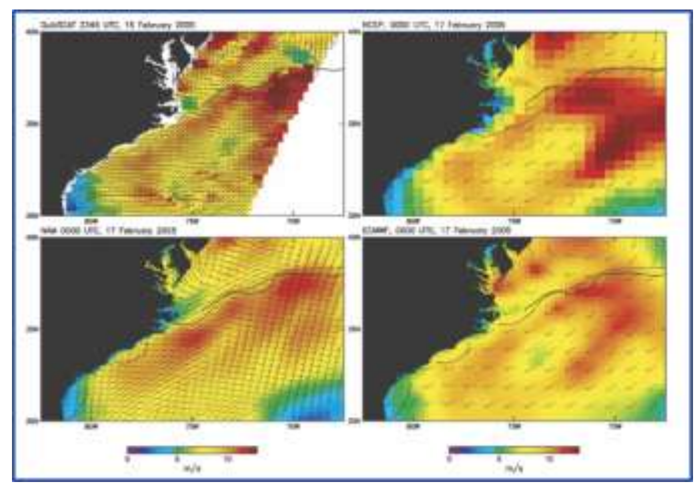
Requirement for wind field observations

- Three user communities with requirement for improved wind field observations (particularly spatial and temporal coverage):
  - NWP and data assimilation
  - Hurricanes
  - Cloud modelling
- Current/proposed observation techniques:
  - ADM-Aeolus: Doppler lidar, provides global coverage but low frequency of observation, unable to observe within clouds
  - Visible/IR (spectral) imaging from GEO, e.g. from GOES: infer wind speeds from movement of clouds in successive images (every 7.5 minutes), altitude determination is problematic… spectral imaging (e.g. from MTG-IRS) would improve this whilst maintaining high frequency of observation and good spatial resolution, albeit over only one portion of the globe
  - Scatterometers, e.g. QuikSCAT: active radar (14 GHz) technique measures wind speeds just above the ocean surface under clear and cloudy conditions

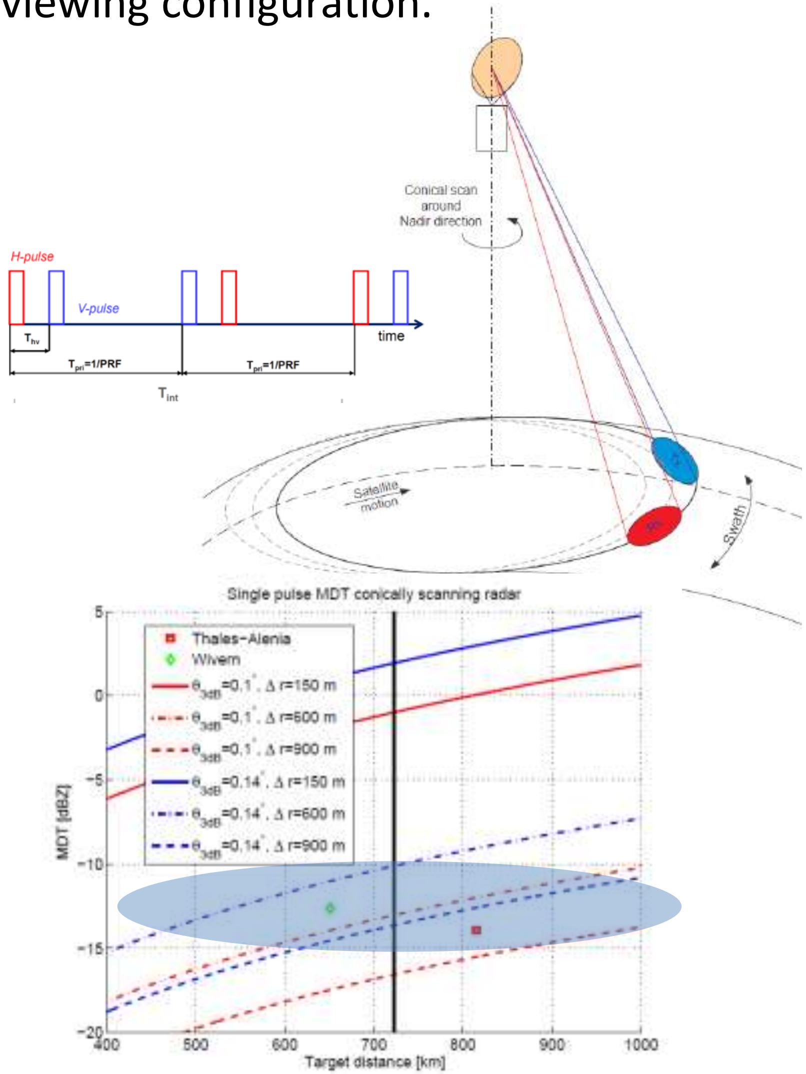






Conically scanning W-band radar

Different conically scanning W-band polarization diversity radars concepts have been previously studied by ESA (Thales-Alenia and Wivern study). Only slight differences in viewing configuration.



Frequency	94 GHz
Peak power	1 kW
Satellite height	$\mathbf{550}(500-600)$ km $(v_{sat} = 7.7\ \mathrm{kms}^{-1})$
Incidence angle	$\mathbf{42.5}[41.7° - 45°]$(scanning angle $= \mathbf{38.5}[37.8 - 40.2]°$)
Swath	$\mathbf{900}(800-1050)$ km
Distance from ground	$\mathbf{723}(651-815)$ km
Antenna rotation velocity	8.6/13 RPM Footprint velocity 354/612.3 km/s
Antenna diameter	$1.59-2.23$ m $(\theta_{3dB} = 0.14° - 0.1°)$
Antenna side lobes	$<$ 30 dB
Pulse-length	$3-6\ \mu$sec $(\Delta r = 450 - 900\mathrm{m})$
Pair separation	$TBD(V_{Nyq}$ accordingly)
PRF_{pairs}	3000-3600Hz [50-41.6 km slant-range ambiguity]
Total system losses	6dB
Integration time	TBD
Receiver bandwidth	according to pulse-length
Noise figure	6.5 dB

In this project: 1) in-depth error budget study

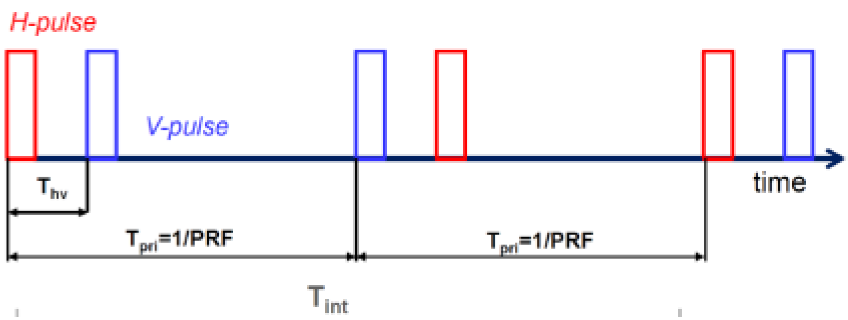
2) Advantage of adding pulse compression

Error budget

Doppler measurements are affected by a variety of errors, ranging from noise to multiple scattering, non uniform beam filling, aliasing, and pointing errors.

$$\epsilon^2_{TOT} = \epsilon^2_N + \epsilon^2_{NUBF} + \cancel{\epsilon^2_{aliasing}} + \epsilon^2_{MS} + \epsilon^2_{pointing}$$

Total quadratic error

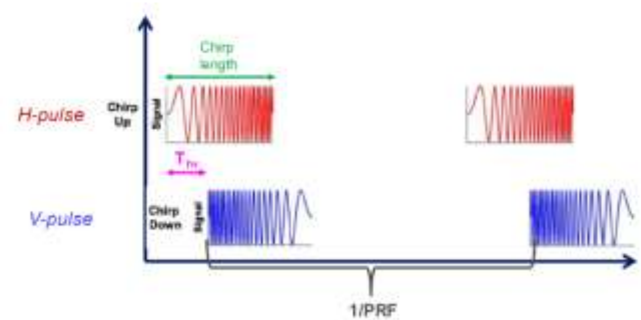


PD ensures that we get rid of aliasing!

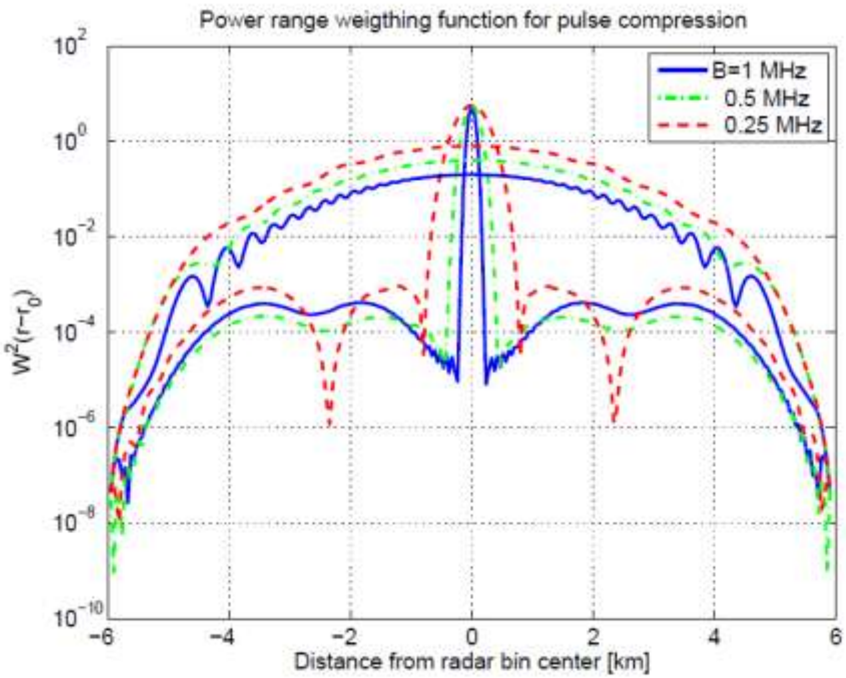
T_{hv}=5µsec ➔ v_{Ny}=160 m/s

T_{hv}=20µsec ➔ v_{Ny}=40 m/s (no aliasing for wind up to 203 km/h)

But cross-talk introduced by multiple scattering, depolarizing atmospheric targets, ground clutter, instrument cross talk must be reduced ➔ V and H signal transmitted with opposite slopes



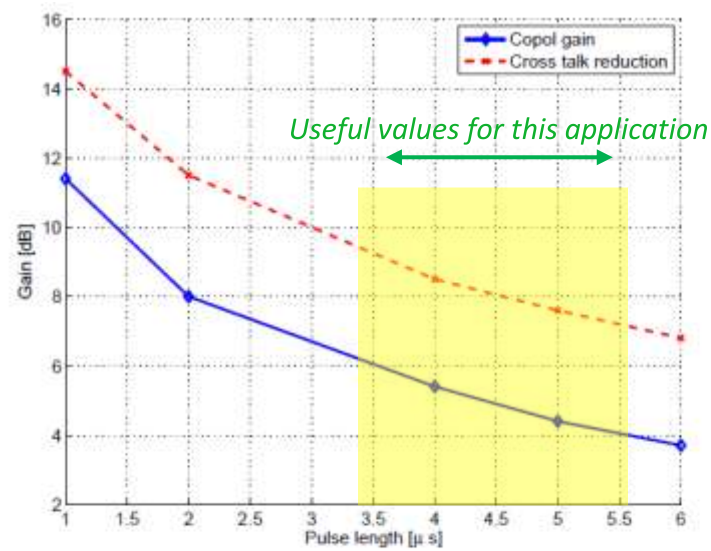
Range sidelobes for pulse compression



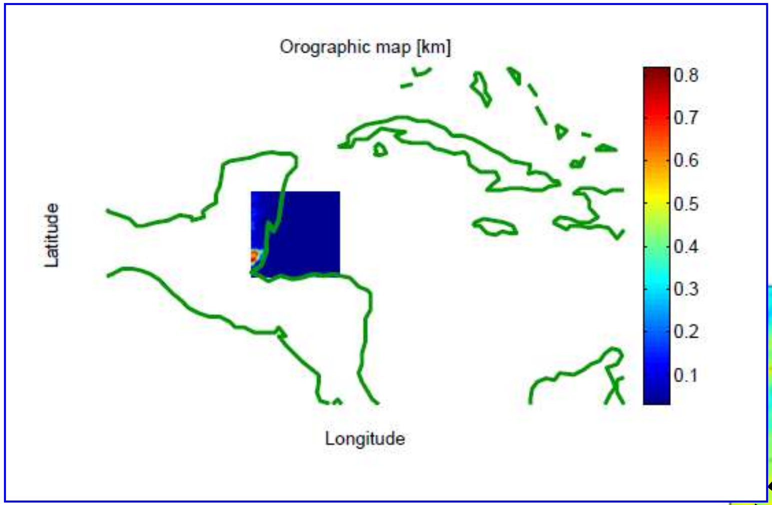
Pulse compression with sidelobe suppression approaching 40 (50) dB for a 0.25 (1) MHz chirp bandwidth can be achieved. This is adequate for this application, especially over sea surfaces characterized by very low σ_0.

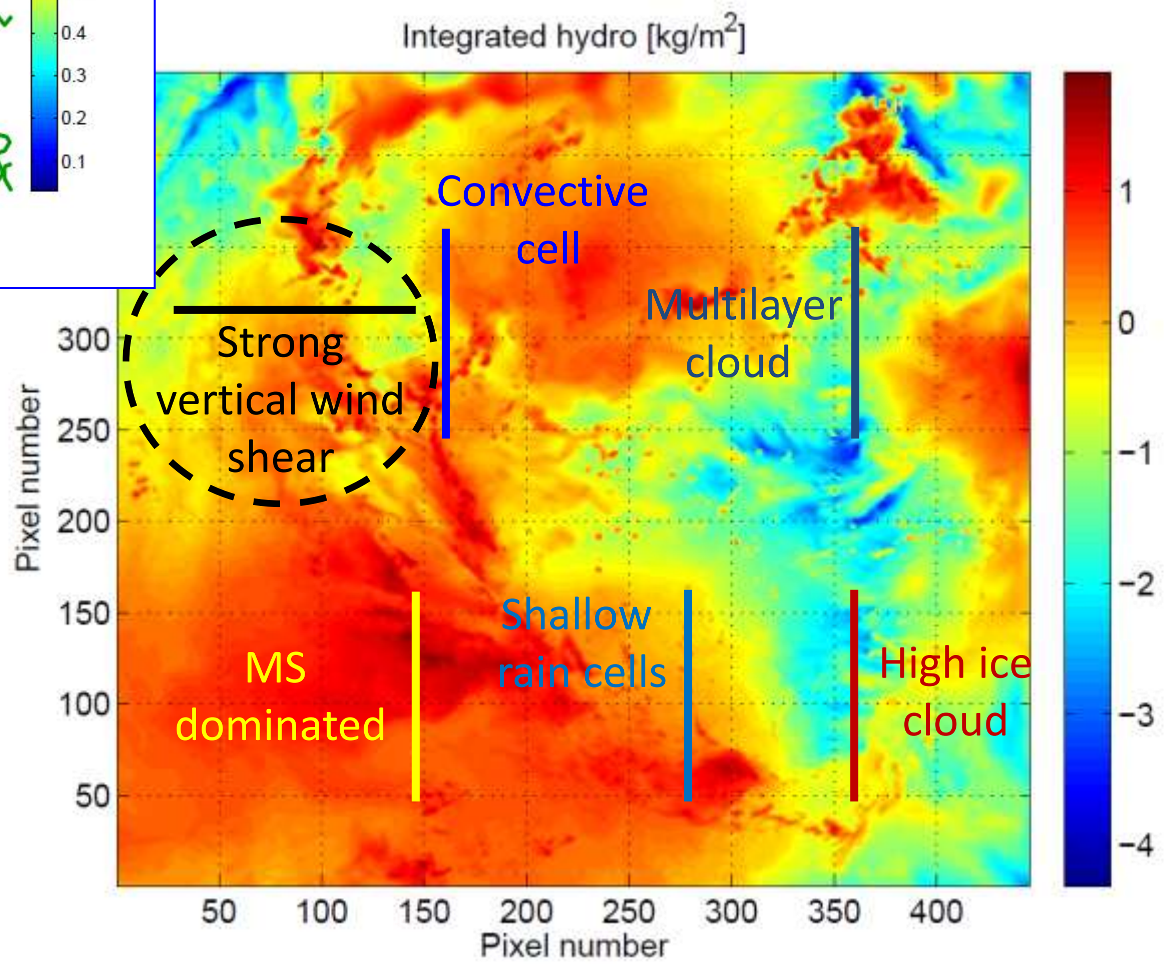
The 2 chirp mode offers some improvement in Doppler accuracy by reducing crosstalk between H and V -polarized channels

Surface type	Cross section	Range sidelobe level
Land, typical	-10 dB	-39 dB
Land, worst case	-5 dB	-44 dB
Sea, typical	-15 dB	-34 dB
Sea, worst case	-10 dB	-39 dB
Snow, typical	0 dB	-49 dB
Snow, worst case	3 dB	-52 dB

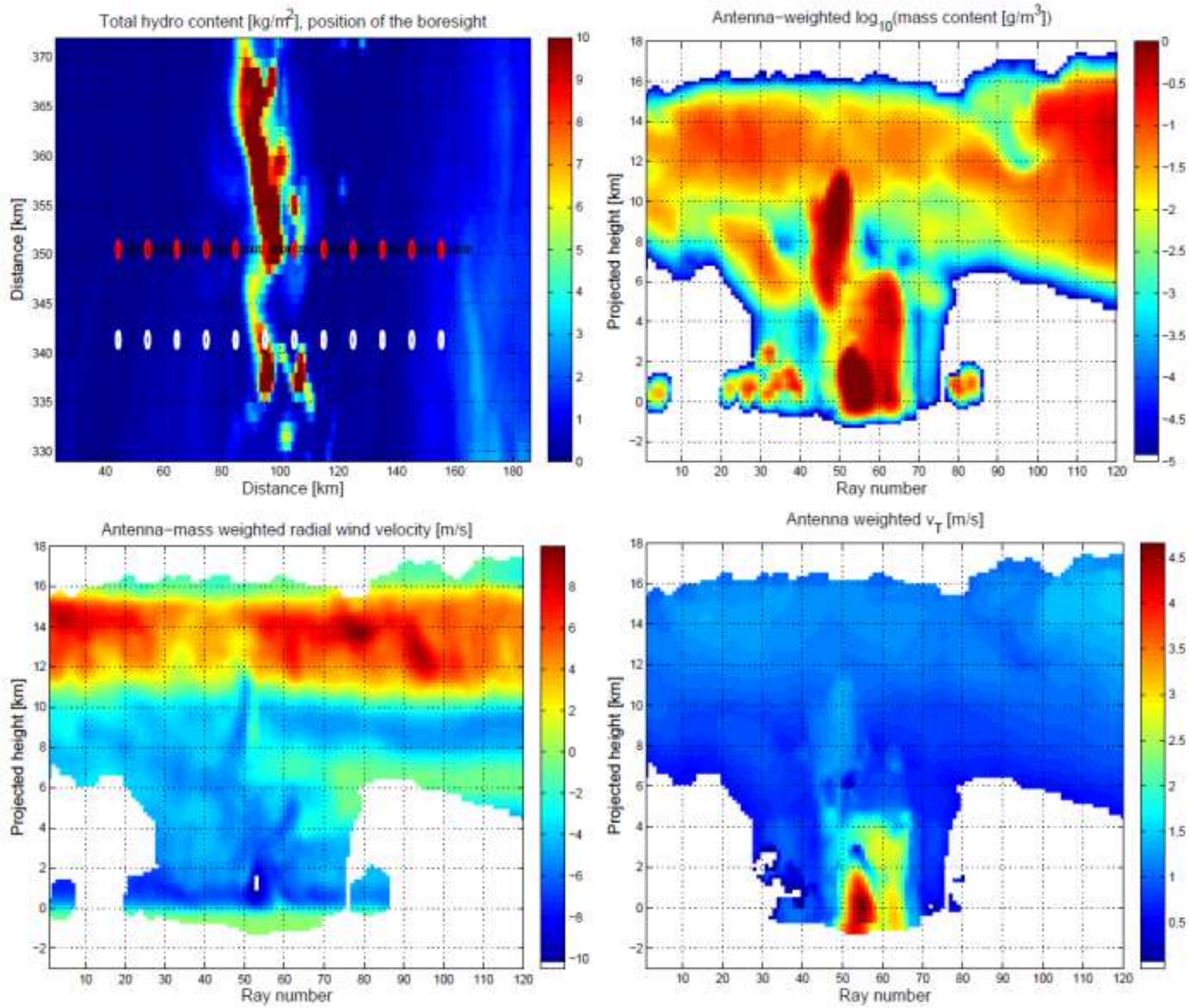


Hurricane Karl simulation



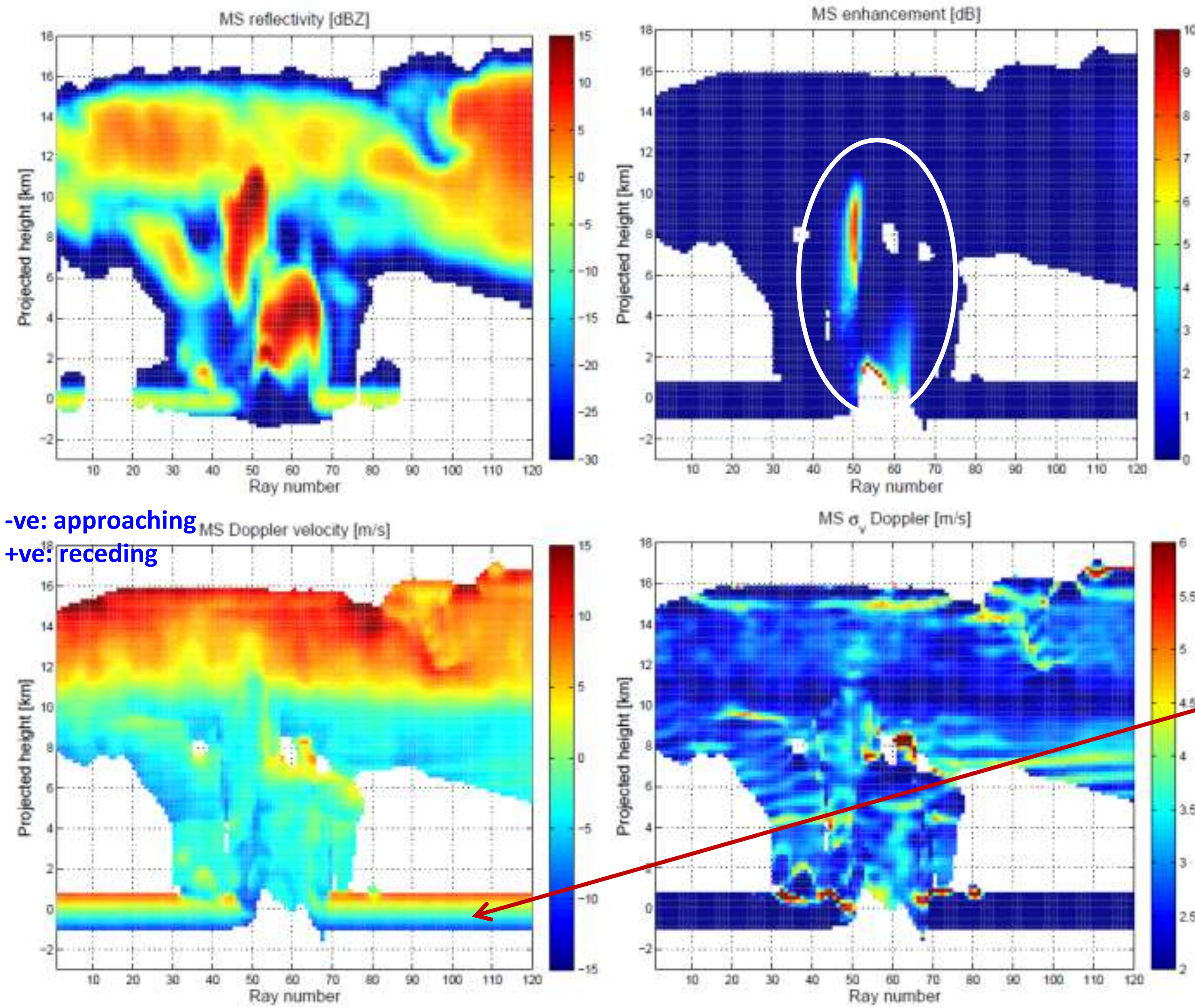


Forward view: strong vertical wind shear



-ve: approaching
+ve: receding

Forward modelling



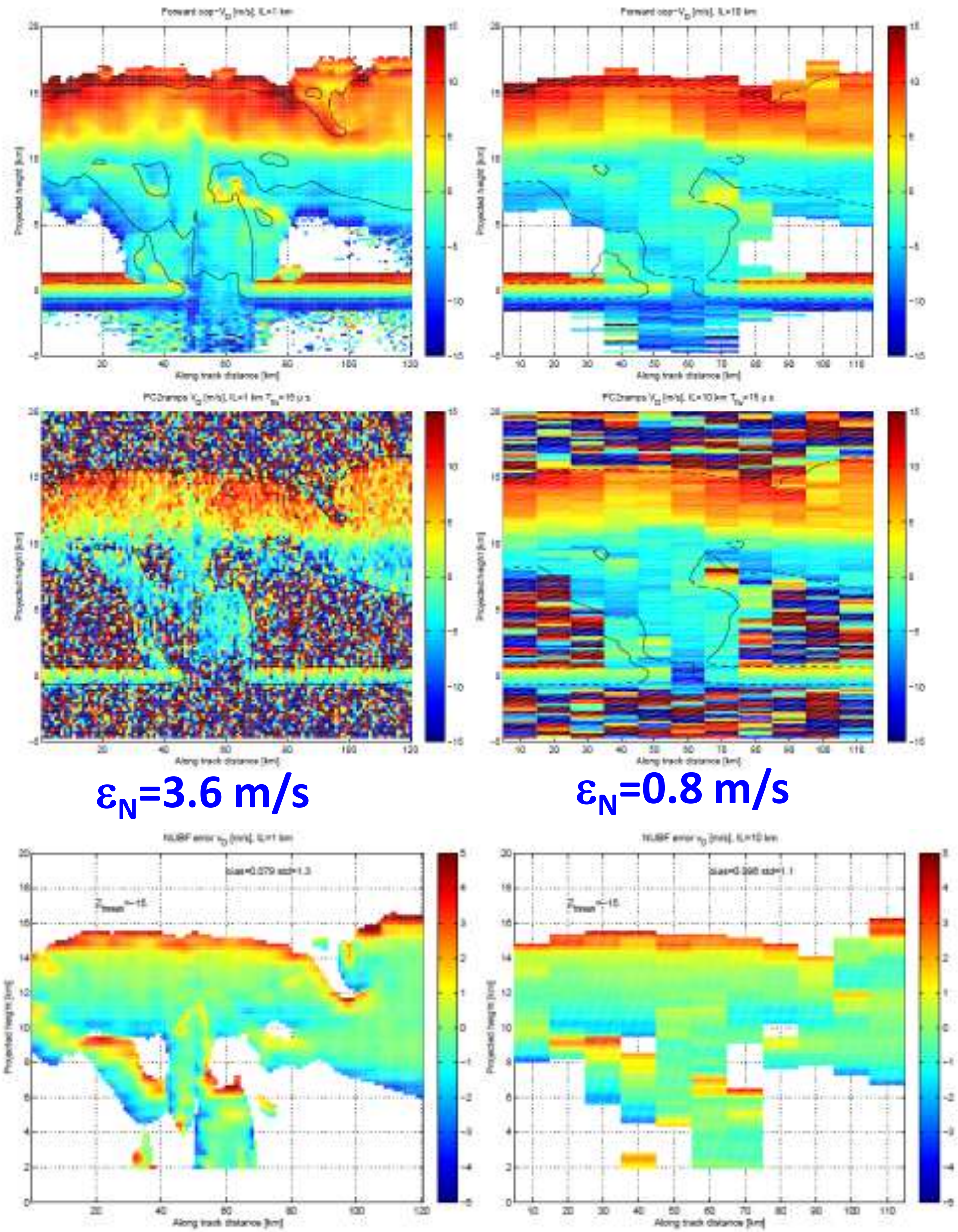
MS effects is relevant in convective cores: in such regions it tend to produce errors of the order of 1-2 m/s even when averaging at 10 km distance (convective scale).

At forward view surface appears to have $V_D \neq 0$

Spectral widths = 3 to 3.5 m/s (smaller than at side view)

When first seen at projected height > 0 the surface appears moving downward

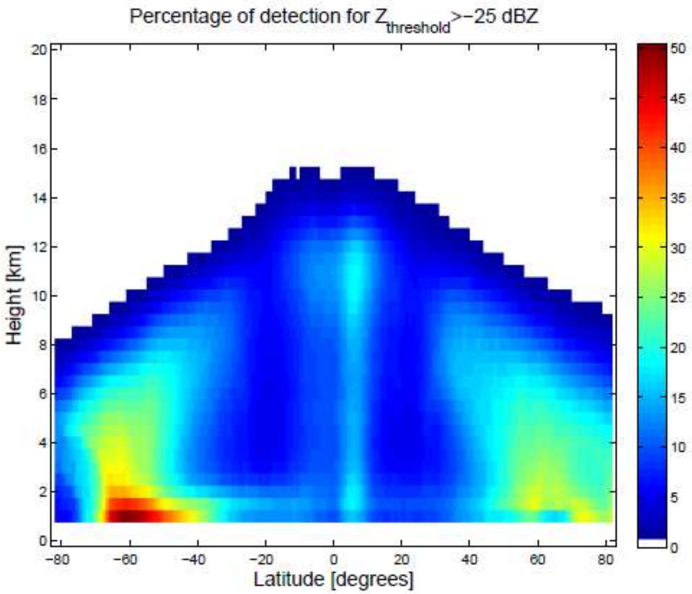
Noise and NUBF error at 1 and 10 km integration

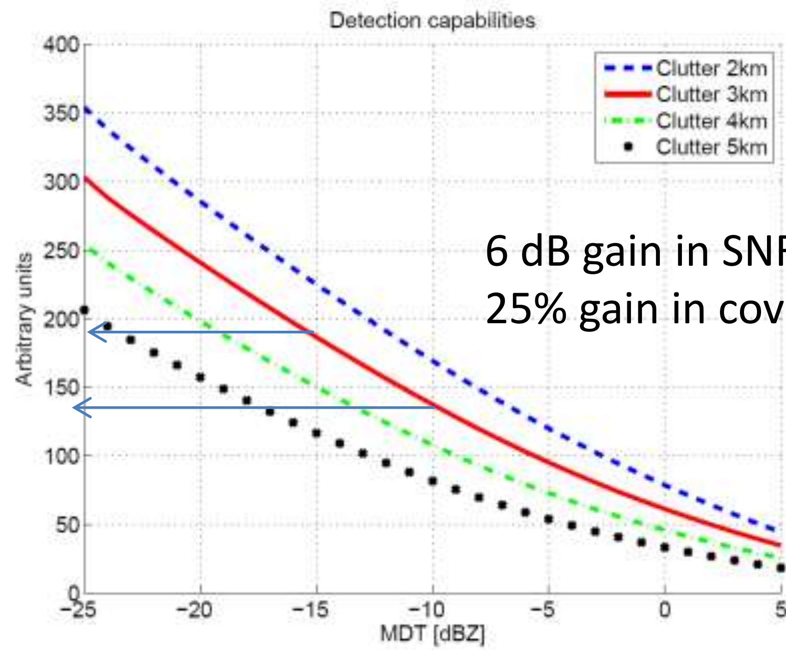


The vertical shear is well captured! There is a significant reduction of ε_N (typically below 1 m/s) when averaging for 10 km (with optimal T_{hv} around 10-20 μs).

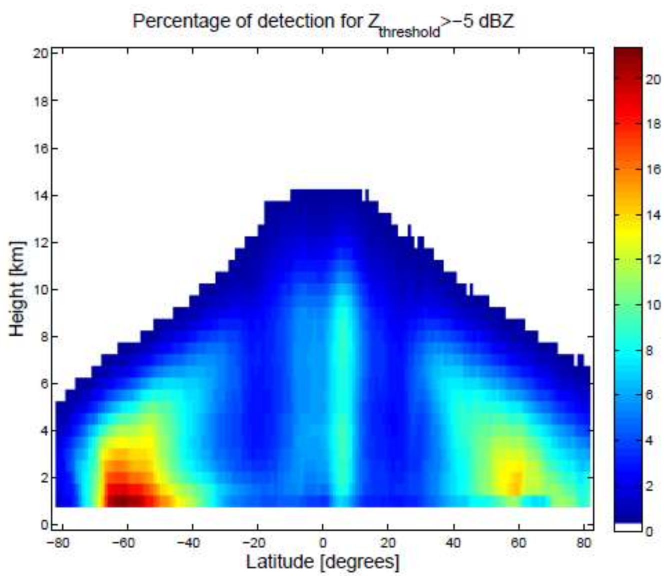
NUBF seems to be the main driver of errors with increasingly importance when moving towards the forward/backward section of the scan. Since clouds are horizontally stratified averaging along footprint track is not mitigating the problem. Biases up to 3 m/s are expected in correspondence of regions with vertical reflectivity inhomogeneity.

Gain in coverage (based on CloudSat)





6 dB gain in SNR == 25% gain in coverage



These figures assess the degradation in detection for a radar system with lower sensitivity and higher clutter height than those achieved for the CloudSat radar. Roughly speaking passing from an *MDT* value of -25 dBZ to *MDT* equal 5 dBZ reduces the detection capability by a factor of 8 to 11 (with clutter height ranging between 2 and 5 km).

Conclusions

- Obvious **benefit for larger antenna size** (but less coverage)
- NUBF seems to be the main driver of errors (bottleneck) with increasingly important effect going towards forward/backward viewing directions and with increasing sensitivity. There are no strategies in place to correct for it! **Averaging along footprint track is not a panacea**
- Noise errors can be brought down to less than 1-1.5m/s for 10 km integration (even for the 13 RPM system) for signal above -10 dBZ (preliminary analysis show that this corresponds to ~ 40% of CloudSat detection)
- Pulse compression works fine with peak to sidelobe of ~40 dB (but only ocean surfaces considered up to now).
- 2-chirp mode. Not essential but the benefit may increase in presence of larger depolarization effects (e.g. brighter surfaces/MS cells).

Pulse compression is a plausible option for a conically scanning W-band polarization diversity radar system. The key advantage of such systems is the low reflectivity of ocean surfaces at slant incidence angles, which poses less stringent constraints onto range side-lobe suppression. A system with a bandwidth of 0.25 MHz, with a chirp length of 40 µs and with T_{hv} in the range between 10 and 20 µs provides a good balance between vertical resolution, Doppler accuracy and coverage. We expect that such system will provide useful Doppler (accuracies better than 2 m/s) at 1 km vertical resolution and 10km integration on roughly half of the cloudy regions as detected by CloudSat.