EE-11 candidate WIVERN

Science and System development (Objectives, critical requirements, and key technology aspects)

Anthony Illingworth (U. Reading) and the WIVERN MAG, Anne Grete Straume (ESA), Michel Tossaint (ESA)

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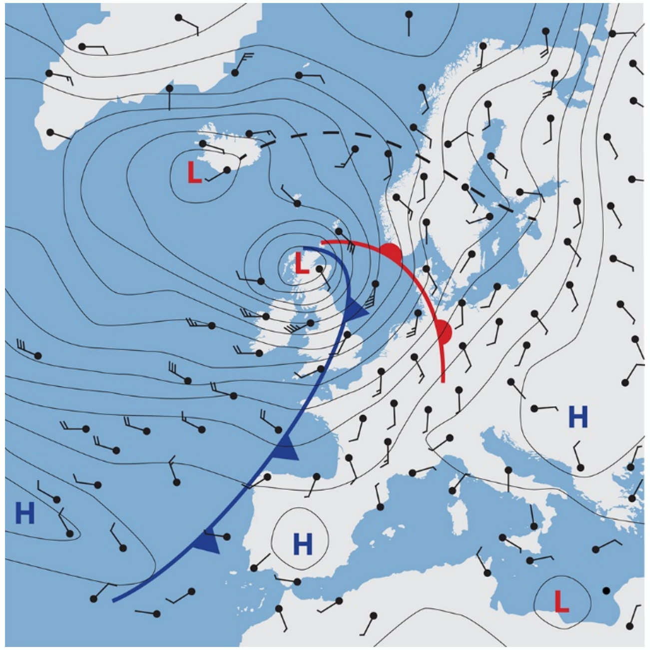
Science development (A. Illingworth)

Scientific goals

WIVERN: A Satellite Providing Global in-cloud Winds, Precipitation and Cloud Properties



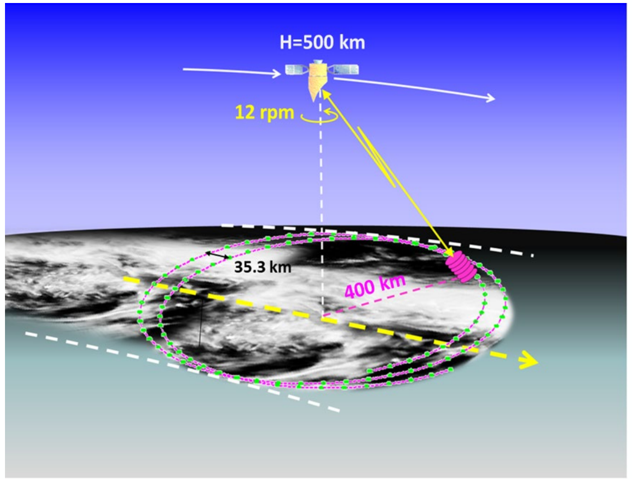
- Extend lead-time and predictive skills of high-impact weather
- Benchmark for global cloud profile climate records of solid/light precipitation
- Improve weather and climate model parameterization

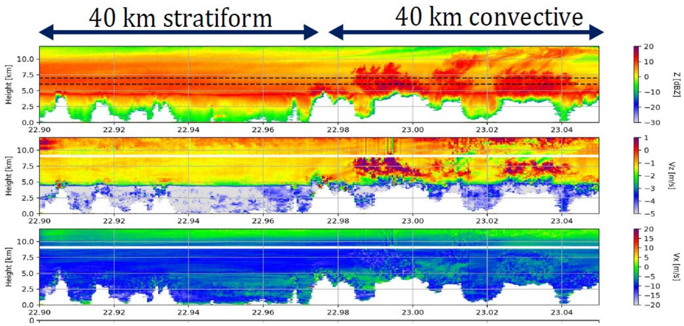
- Application areas:
    - Numerical Weather Prediction (NWP) at short to medium range, tropical cyclone track prediction, atmospheric reanalysis, (climate) model validation, air quality predictions, quantification of Earth's hydrological cycle and energy budget
- Complementarity and continuation of other wind and cloud missions:
    - Wind: Aeolus, DWL/Aeolus-2 Doppler wind lidar missions, air motion vectors from imagers and sounders, scatterometers, etc.
    - Clouds: CloudSat and EarthCARE

Mission Objectives

Global 3D in-cloud horizontal wind, cloud and precipitation observations

- In-cloud horizontally projected line-of-sight (HLOS) winds (including tropical and mid-latitude cyclones), sampling profiles of zonal and meridional wind components
- Detection of convective motion
- Liquid Water Path (LWP) and profiles of Ice Water Content (IWC)
- Rain rates (experimental product, not driving the mission requirements)





- These advances in observational capabilities will be used to address the WIVERN scientific goals (see previous slide), with immediate application and societal benefits.
  - Recall the large impact of the Aeolus Doppler Wind Lidar and the plans for an operational follow-on in 2030 based on user needs/requests e.g. to WMO and CGMS

Key Mission Requirements, HLOS wind

	Random error	Systematic error	L2 observation horizontal resolution	L2 observation vertical resolution	Vertical domain
Threshold	2 m/s	1 m/s (TBC)	20* km / 1** km	1 km	-5 to 20 km altitude
Breakthrough	-	0.5 m/s (TBC)	-	500*** m	-
Goal	-	-	-	200 m	-

*For reflectivities above -15 dBZ

**For reflectivities above 0 dBZ, and needed to detect convective motion

*** 650 m vertical sampling currently considered as baseline

- Dynamic range: +/- 150 m/s (TBC) requiring unfolding in on-ground data processing (see slide 10)
- The breakthrough and goal vertical resolution needed for future higher resolution NWP models
  - **200 m vertical resolution needed to resolve high wind shear, common in active weather systems**
  - Use shorter pulse, but unacceptable 8 dB loss of sensitivity?
  - **NEED TO INVESTIGATE IF THIS CAN BE ACHIEVED USING PULSE COMPRESSION**

Key Mission Requirements, cloud microphysical products

	IWC	LWP	L2 observation horizontal resolution	L2 observation vertical resolution	Vertical domain
Threshold	50%	30 g m^{-2}	1 km	1 km	-5 to 20 km altitude
Breakthrough	-	-		500* m	
Goal	-	--		200 m	

* 650 m vertical sampling currently considered as baseline

- IWC (Ice water content) is derived from radar reflectivity, Z, and temperature, T.
- LWP (liquid water path) from 94GHz brightness temperature (noise level of empty radar gates over sea)
- **Rain rates**
    - Key parameter but challenging from space. CloudSat rainfall data led to changed estimates of Earth's radiation balance by 2 W m^{-2}
    - Suggest to derive rain rate from the gradient of Z. Would work over the land as well as the sea.
    - Use pulse compression for more Z samples in the rain
    - Current assessment indicate that WIVERN could provide rain rate estimates of 1 mm/hr accuracy per km along track

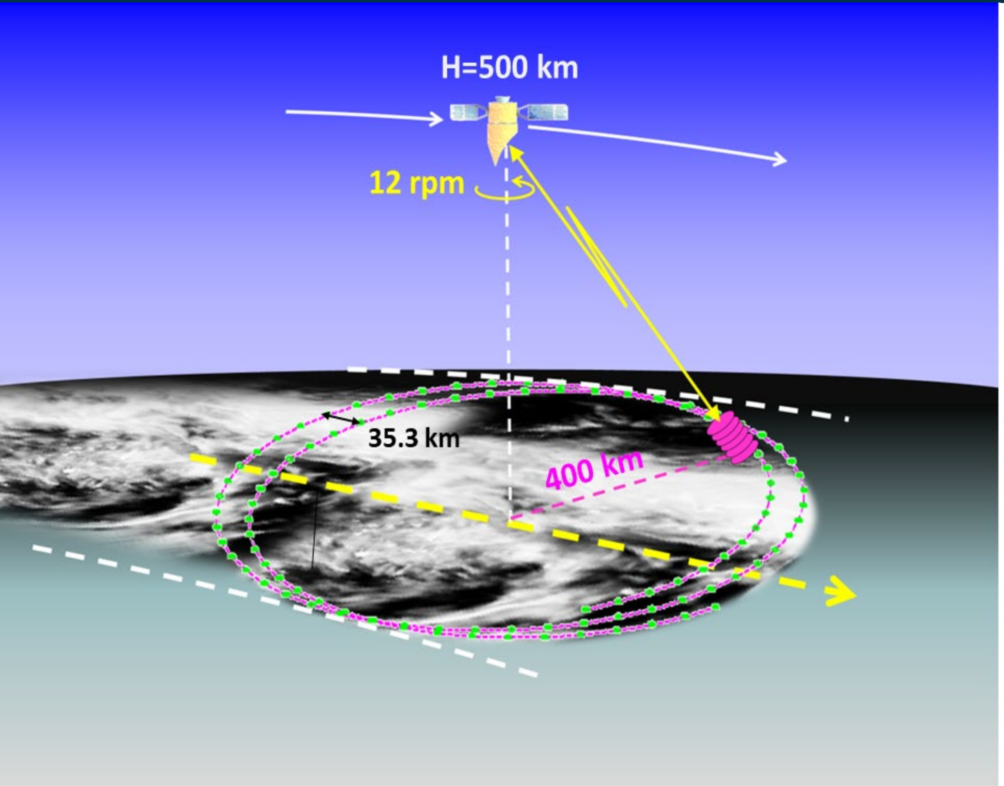
Key Mission Requirements, timeliness, sampling, and key parameters

- **TIMELINESS, TEMPORAL AND LOCAL SAMPLING TIME**
  - < 180 minutes, to be confirmed in parallel science study and based on MAG advice
  - Global revisit within 1 – 1.5 days, sun-synchronous dawn/dusk orbit needed to ensure pointing stability?

- **KEY LEVEL 1 PRODUCTS**
  - I and Q data for each radar pulse pair (4kHz) per range for Doppler, power for reflectivity
    - 100 m oversampling along slant path, power and frequency per Tx pulse to be recorded
  - Reflectivity calibration and correction for molecular attenuation using aux. humidity and pressure data
  - Phase correction for satellite motion using precise antenna boresight pointing knowledge

- **KEY LEVEL 2 PRODUCTS**
  - LOS (Line-of-Sight) winds at each range gate for adjustable pre-defined horizontal integration lengths
  - HLOS (Horizontally projected Line-of-Sight) winds, LOS wind corrected for terminal velocity of precipitation particles
  - Ice water content at each gate, liquid water path for the profile, rain rate estimate

Measurement concept major trade-offs



CONICALLY SCANNING 94GHz DOPPLER RADAR

- 800 km wide ground track –> daily revisit within 1.5 days
- 500 km orbit altitude, with 42° off-zenith angle at the surface
- *Optimised to detect a significant component of the horizontal wind and a short (600 km) slant range for radar sensitivity*

LOW RISK

94GHz radar - high sensitivity: 3 m ∅ antenna (max for VEGA C)

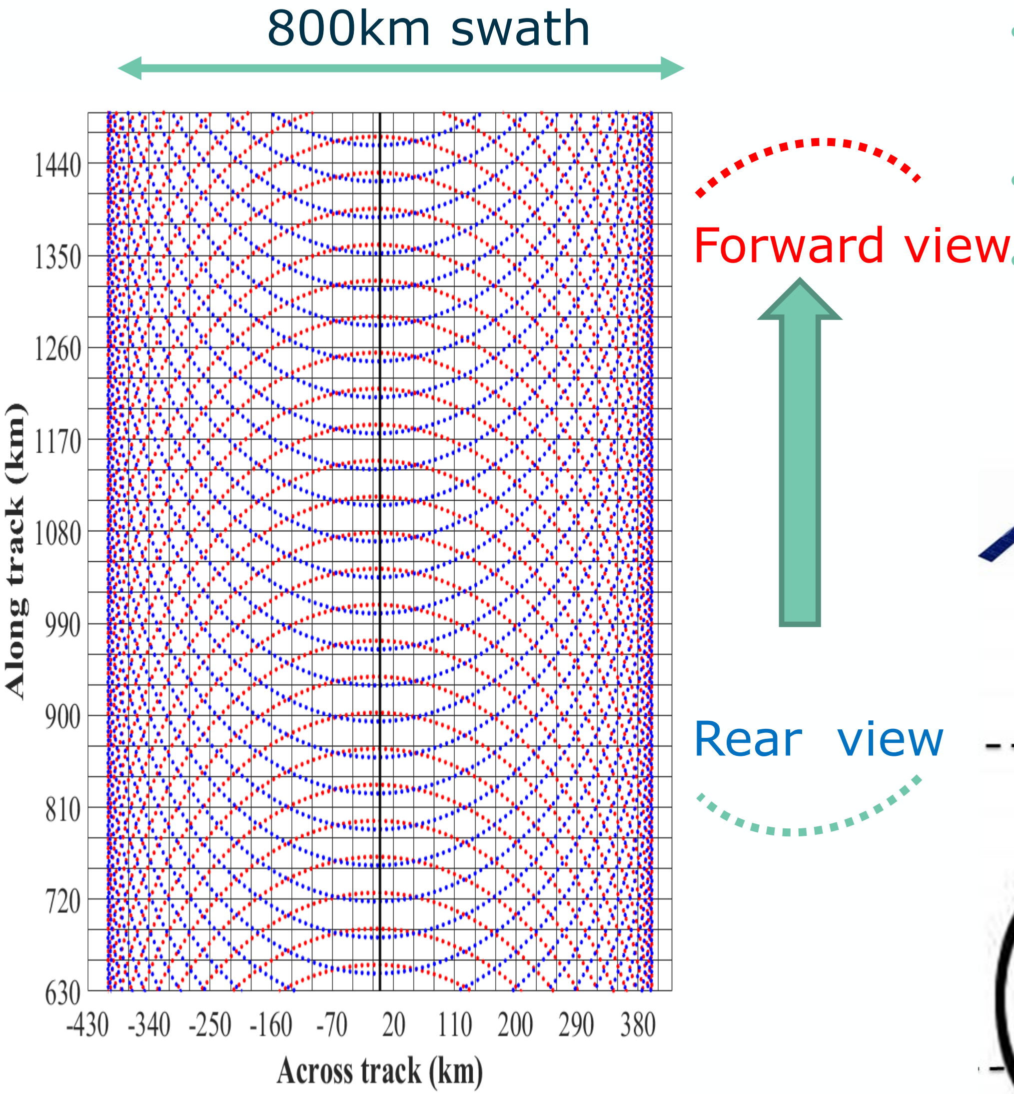
- Narrow beam (1 mrad): 805 m diameter at the surface
- 3.3µs transmit pulse (500 m slant path resolution), 1700W

Same EIK specification as successfully used by CloudSat recommended

ROTATION SPEED 12 rpm (5 secs)

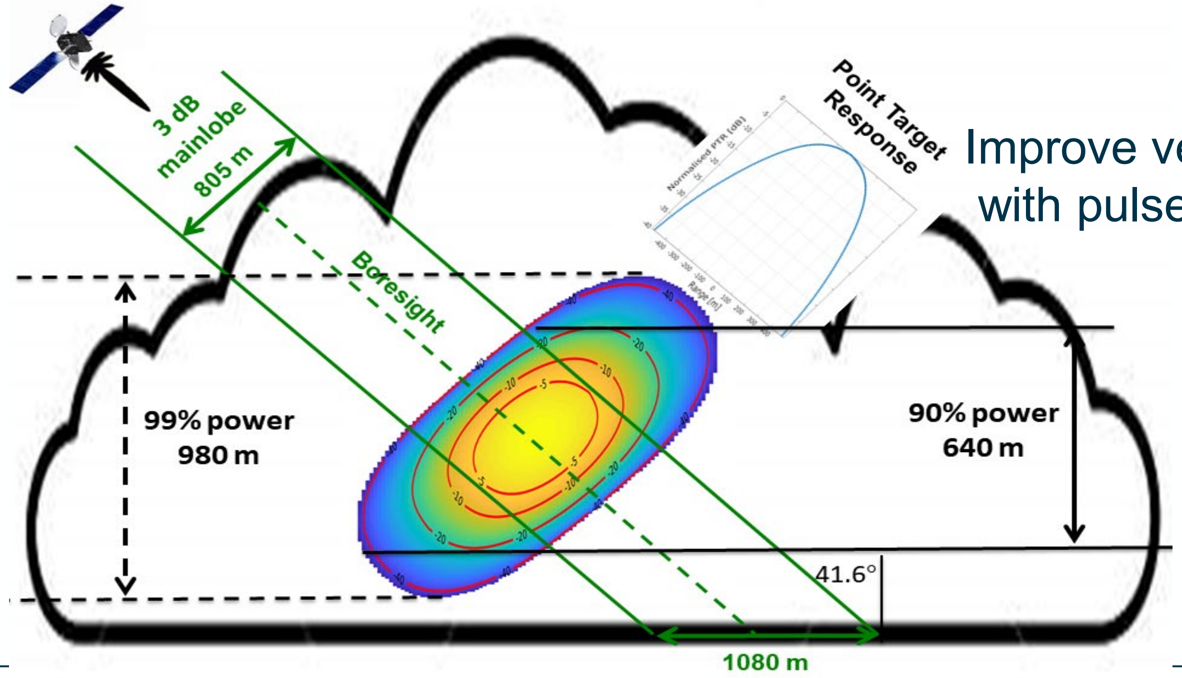
- For one revolution of the antenna the “cycloid” ground track advances 35 km along the satellite track
- Footprint moves 500 km/s. PRF 4kHz (every 250 µsec – 37 km) yielding one pulse in the atmosphere at a time
- One radar sample every 125 m along the footprint track, yielding 8 radar reflectivity estimates every km

Measurement concept trade-offs – global sampling



- 1 km radar footprint sampled along 800 km swath by the rotating antenna, superposed on a grid of 30 km by 30 km boxes
- Each box on average traversed by one radar footprint track
- WIDER SWATH? Greater range leads to loss of sensitivity for the Doppler and a wider beam with loss of vertical resolution

RESOLUTION OF WIVERN PULSE: 640 m (V) 1080 m (H)



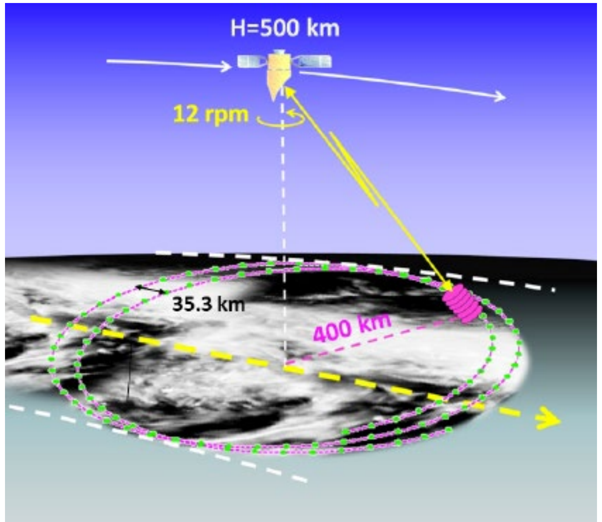
Improve vertical resolution with pulse compression?

Doppler from Space: Polarization Diversity Pulse Pair

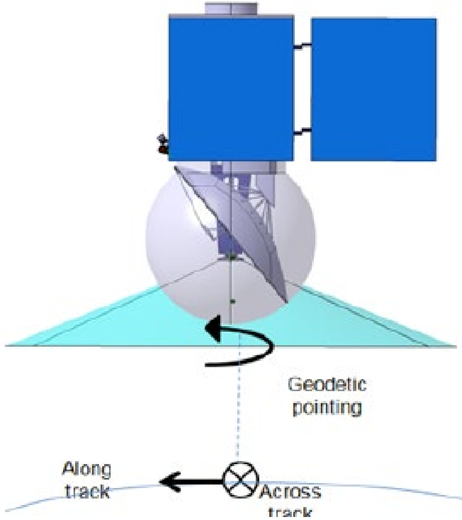
- **DOPPLER:** Measurement of phase shifts from successive pulses (phase shift is 180 deg if target moves λ/4)
- **CHALLENGE FROM SPACE**: 94GHz (3.2 mm), λ/4 = 800 um. Folding velocity 40 m/s (i.e. 800 um / 20 us)
    - Need 20us pulse separation at 94GHz. Pulse separation only 20 μs or 3 km in space
- **PDPP: Polarisation Diversity Pulse Pair**: To distinguish between the returns, label one pulse H the other V
    - PDPP system has been tested on radars on the ground in the UK and on an aircraft in Canada
    - Performs as predicted by theory
    - Cross-talk by depolarizing targets (e.g. ground, melting snow in bright band) leads to “ghost” echoes 3 km above or below the depolarizing target
        - The phase of the ghost is random -> increased random errors but no bias
        - Ghost of 10dB > true return => degrade 2 m/s LOS wind to 4 m/s precision (rare events)
- **FOLDING VELOCITY**
    - Wind statistics (NWP models and Aeolus cloud top winds) show tropospheric HLOS winds up to and slightly above 130 m/s
    - WIVERN velocity folds at 40 m/s LOS, or 60 m/s HLOS -> one fold will be encountered by WIVERN
        - Experience with ground-based radar networks shows unfolding a single fold unproblematic / robust

System development (M. Tossaint)

Key System and Payload Specification



- Conical scanning dual polarization pulse pair Doppler radar 94 GHz for multi-view direction line-of-sight (LOS) winds, to be projected to the horizontal (HLOS)
  - HLOS random error <2 m/s (20 km integration along scan, Z=-15dBZ (incl. 3 dB margin)
- Radiometer channel for liquid water and large ice particles in silent radar intervals
    - Noise level 3-5 K integrated over 8 PRIs (~1 km along-scan averaging)
- Orbit altitude ~500km for sensitivity, coverage and lifetime
- Global revisit: approximately daily
- Satellite to be launched in VEGA-C, estimated at ~1.5 ton wet mass incl adapter



- Transmit Peak Power ~1.7kW, pulse duration ~3µs, PRF ~4kHz both H and V (20 us pulse separation)
- Antenna aperture size ~3m (limited by fairing and precision)
- Cross polar discrimination < ~30dB for H and V
- Resulting resolution: 640 m H and 1080 m V, Radiometer Bandwidth: 500 MHz (TBC)
- Radiometer sensitivity 3K (on-board and/or NWP model calibration)

Key technologies

- **Mechanical Equipment:**
  - Rotating antenna, feed, sub-reflector, mechanism and APCE with sufficient precision (30 µm), low micro-vibration and thermoelastic deformation for the 94GHz frequency
  - Antenna counter rotation mechanism (at low TRL today), if not possible with reaction wheels

- **RF Equipment:**
  - High power amplifiers + power converters (one for each H and V to avoid high power switch) for sufficient peak power, low thermal dissipation and lifetime (technology worked > 15yr on CloudSat)
  - Rotary joints and switches (at low TRL today)
  - High power output isolator with ESA member state supplier
  - LNA @ 94GHz (TBC)
- **Electronics:**
  - Onboard processing (incl. range compression TBC)
  - RFI Mitigation for radiometer (TBC) due to fact that some systems might operate in 500MHz band (only 100MHz allocated by ITU)

Summary and Conclusions

- WIVERN shall improve weather forecasts, extend satellite wind and cloud data records, and improve model parameterization
- HLOS Doppler concept from space already demonstrated by Aeolus, including positive weather forecast impact
- Space-based HLOS Doppler demonstrated by Aeolus and reflectivity profiles by CloudSat
- WIVERN mission requirements being drafted
    - To be provided in draft in ITT, and further updates in July 2022 and end Phase 0
- Proposed to use same EIK specifications, and similar PRF, pulse length and peak power as CloudSat
- Propose conical scanning to achieve global coverage in 1.5 days and sampling of zonal and meridional winds

CHALLENGES:

- Rotating antenna need boresight radar pointing knowledge better than 40 µrad (3**σ**)
- H and V pulses to be fed to rotating antenna with minimal loss (low TRL!)
- Can pulse compression help to achieve the goal vertical resolution?
    - Demonstrated by NASA RainCube mission. Could improve isolation between the H and V returns?
- Calibration of radar reflectivity challenging due to off-nadir viewing geometry, how can this best be done?

Extra slides for Q&A

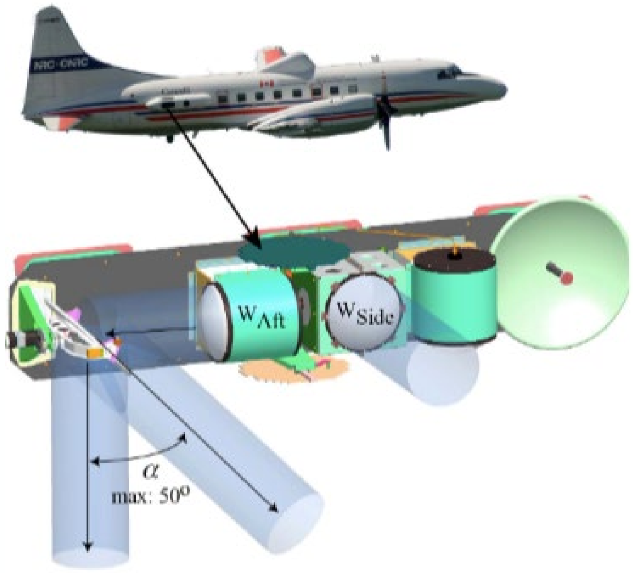
Aircraft Campaign 1

3846 IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 55, NO. 7, JULY 2017

Characterization of Surface Radar Cross Sections at W-Band at Moderate Incidence Angles

Alessandro Battaglia, Mengistu Wolde, Leo Pio D'Adderio, Cuong Nguyen,
Franco Fois, Anthony Illingworth, and Rolv Midthassel

ig. 1. Comparison of omnidirectional curvature spectra for a wind speed f 5 m/s at 10-m altitude.



ig. 2. NRC Convair-580 Airborne W- and X-band (NAWX) radar instal- ation inside a blister radome. In this paper, the W-band fixed dual-pol side- ooking antennas and the aft-looking antenna with a two-axis reflector are sed. The schematic aft antenna beam redirected to nadir and up to 50° orward along the flight direction.

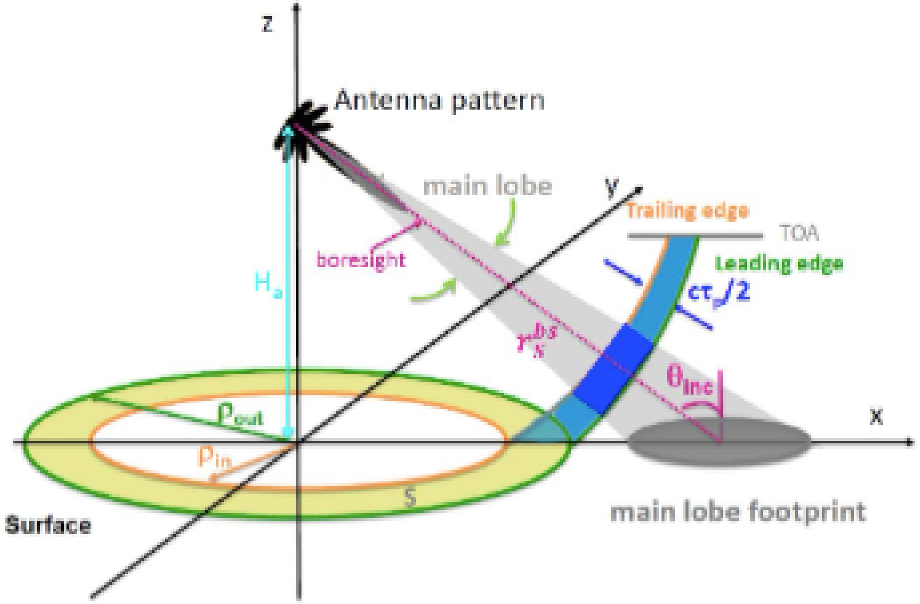
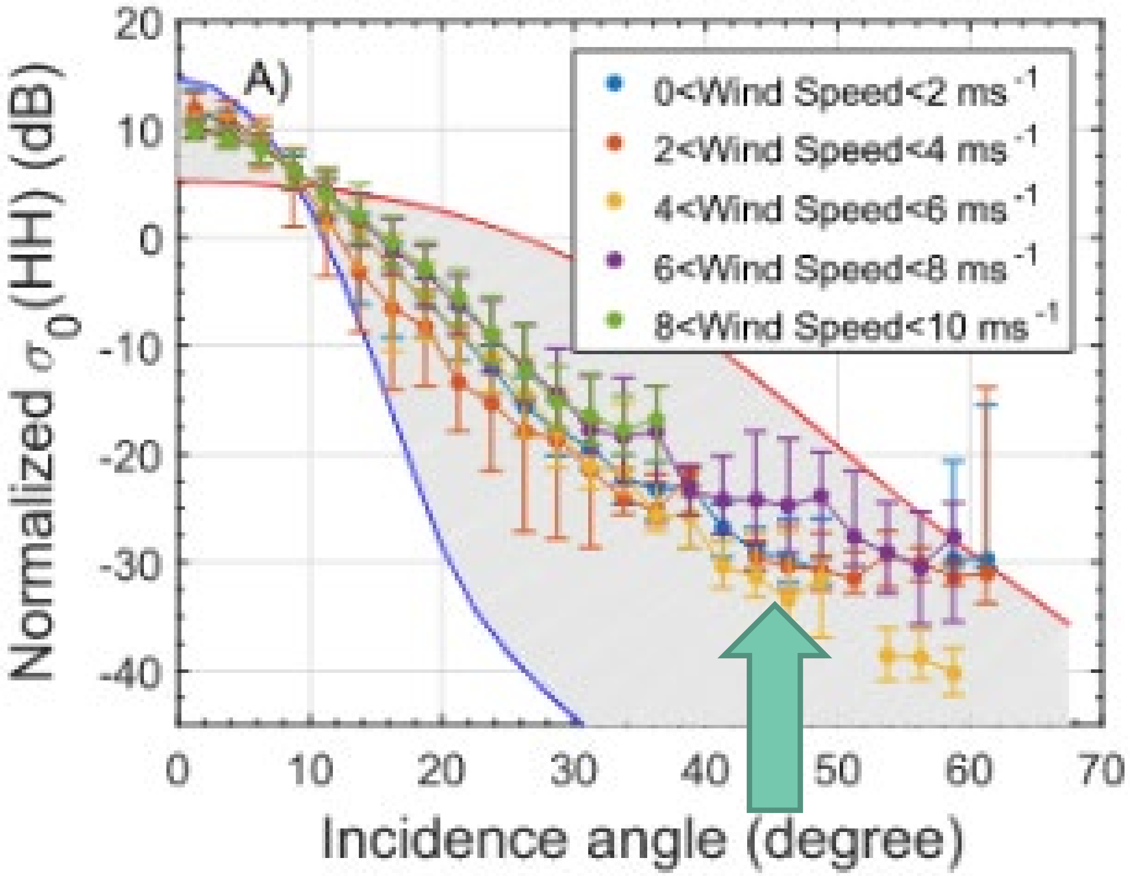


Fig. 4. Geometry for a slant-looking radar (see text for details). Note that for the specific range here illustrated, the surface is illuminated only by antenna sidelobes for the annulus shown. For longer ranges, the integral in (3) over the annulus will include antenna main-lobe contributions.

Aircraft Campaign 2

SEA SURFACE: 45 DEG 30dB LESS THAN AT NADIR

LAND – -10dB, URBAN HIGHER/VARIABLE



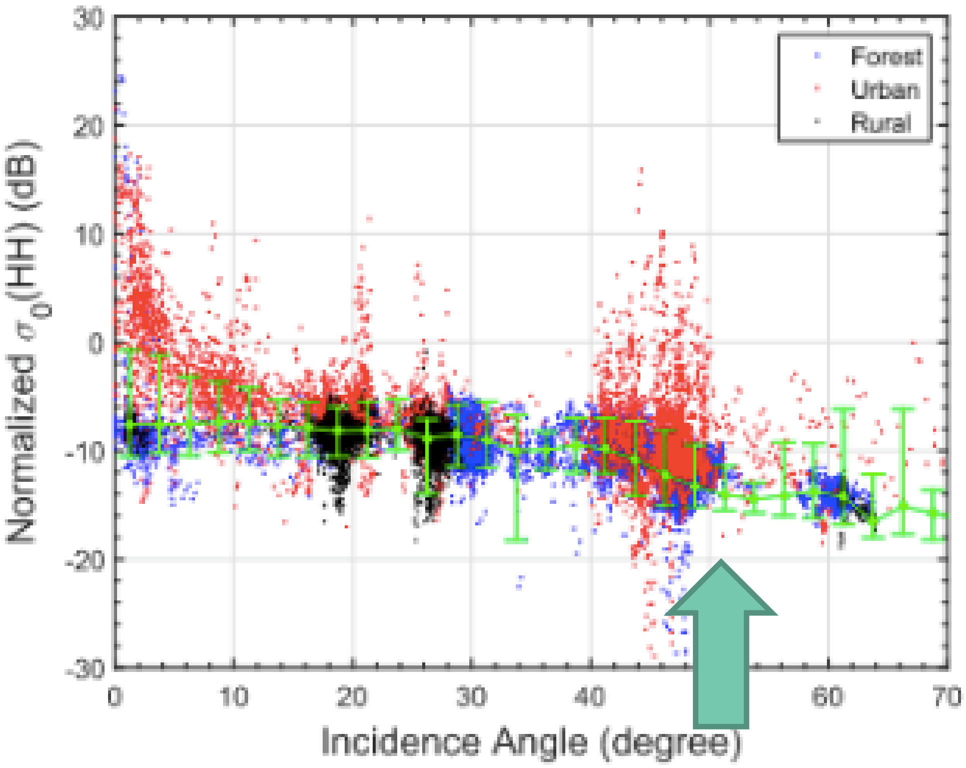


Fig. 16. Measured σ_0 for different surfaces as a function of the incidence angle for the flight of May 30, 2016 (land surfaces only). Blue, red, and black dots correspond to forest, rural, and urban surfaces, respectively.

Aircraft Campaign 3

DEPOLARISATION RATIO OF THE SURFACE

-15dB at 45 degs

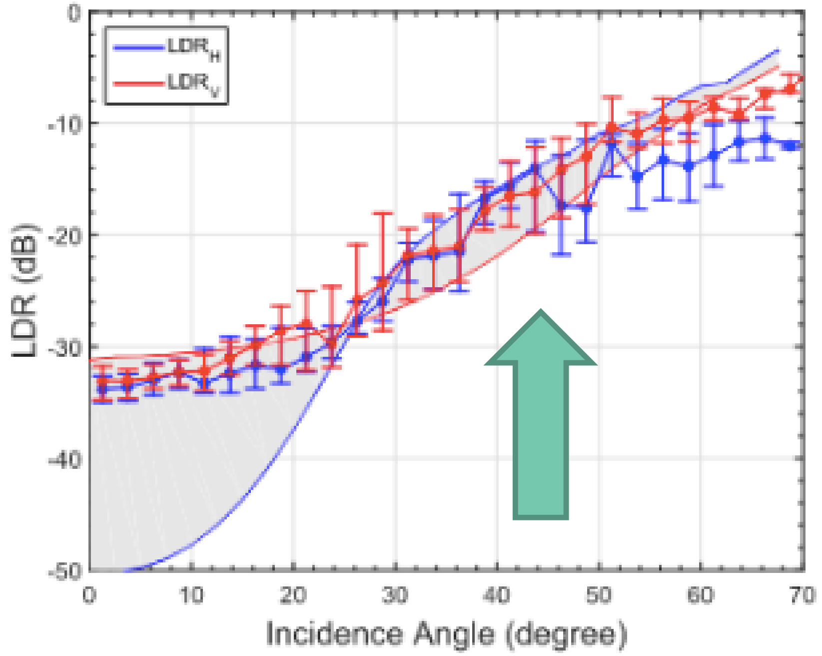


Fig. 15. Measured LDR as a function of the incidence angle for water surfaces. Measured median and the 10th and 90th percentile as a function of incidence angle for water surface. The solid blue and red line limiting the shading gray area indicate the theoretical LDR estimated for the wind speed of 5 and 15 ms^{-1}, respectively.

OCEAN SURFACE CROSS SECTION VARIES WITH RELATIVE WIND DIRECTION

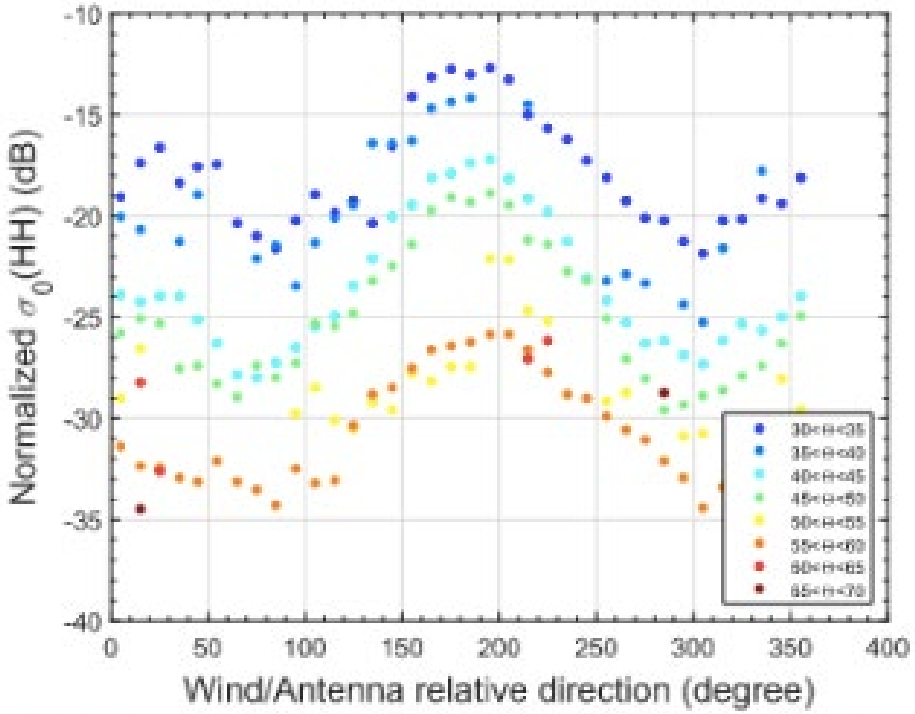


Fig. 13. Median σ_0 over water surfaces as a function of the relative direction between the radar antenna beam-pointing vector and the wind. Results have been clustered according to a 5° wide incidence angle classes (as indicated in the legend).

Further campaigns proposed with Canadian aircraft

- Surface cross section at 45deg for ice and broken ice.
- More on land, snow covered surfaces, forests, etc.
- Piggy-back existing NASA/NSF campaign Feb-March 2022

- Implement pulse compression
  - How does it perform?
  - Better slant path resolution?
  - Improved range sidelobes to suppress the surface return

(Waveform has been designed. Implement in early 2023)