Effects of a Ship's Motion on the Measurements of Vertically Pointing Radars: The Scientific Basis and Development of Radar-Based VAPs on the MAGIC AMF Deployment

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Background: The second ARM Mobile Facility was created with the intent to include deployments in marine environments. The year-long MAGIC campaign – beginning in October 2012 – is the first ship-board deployment of the AMF. Among the many challenges associated with this field campaign is determining the impact of the ship's motion on the measurements of the vertically pointing radars. The two radars placed on the ship are the Ka-band ARM Zenith Radar (KAZR) and the Marine W-band ARM Cloud Radar (MWACR). Development of two post-processing VAPs – 'kazrshipcor1' VAP and the 'mwacrshipcor1' VAP – is necessary to provide adjustments for the movement of the ocean-going vessel. This poster presents the scientific basis and algorithm designed to create the proper alignment corrections required for the specific radar. Second versions of these VAP (kazrshipcor2 and mwacrshipcor2) will have a more robust horizontal wind input that may involve interpolated ship-launched radiosonde measurements, wind profiler, and other sources of wind information.

Characteristics of Ship-Board KAZR and MWACR Instruments During the MAGIC AMF Deployment

	Ka-band ARM Zenith Radar (KAZR)	Marine W-band ARM Cloud Radar (MWACR)
Platform	Unstabilized	Stabilized
Vertical Beam	Typically Off-Zenith	Zenith Pointing
Observed Mean Doppler Velocities	Not Vertical Velocities	Vertical
Radar Range Coordinates	Differ from Earth-Based Vertical Height above Radar	Identical to Earth-Based Vertical Height above Radar
Ship Motion Variables (from SeaNAV files)	Pitch, Roll, Yaw, Heave, Heave Velocity	Heave, Heave Velocity
Horizontal Winds (TBD)	U-Wind, V-Wind	None
Output Files	kazrshipcor1	mwacrshipcor1

Transformation Equations

Conversion of unstablized vertical velocity (v_3^s) to Earth-based velocity (v_3) is done using equation (1):

(1) $v_3 = \{ v_3^s + [\cos(\phi) \sin(\theta) \cos(\psi) + \sin(\phi) \sin(\psi)] v_1 + [\cos(\phi) \sin(\theta) \sin(\psi) - \sin(\phi) \cos(\psi)] v_2 \} / [\cos(\phi) \cos(\theta)]$

where, v1 and v2 are the horizontal wind components and ψ, ϕ, θ are the yaw, roll, and pitch angles, respectively.

If the horizontal winds are ignored (as they are difficult to determine), equation (1) becomes

(2) $v_3 = v_3^s / [\cos(\phi) \cos(\theta)]$

While (2) is more simple, it is not sufficient to capture the complete transformation (see Table 2).

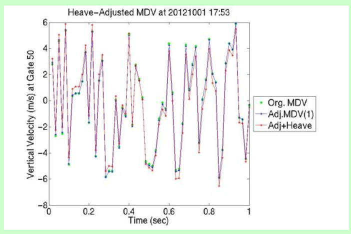
Transformation Equations (Cont.)

Both the stabilized instrument (MWACR) and unstablized instrument (KAZR) require an adjustment to velocity related to the relative motion of the ship. To make this adjustment, heave_velocity is added to the adjusted mean doppler velocity.

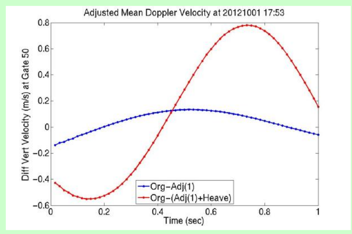
(3) $w3 = \text{heave\_velocity} + v_3$

Note: If the stabilized platform of the MWACR fails, the change from ship coordinates to Earth-based coordinates is accomplished by applying equation (1).

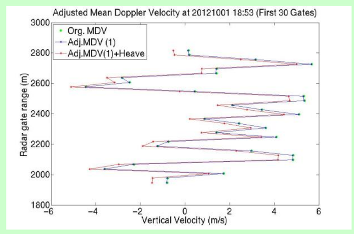
Heave Velocity Adjustment By Radar Range at 18:53 on 10/01/2012



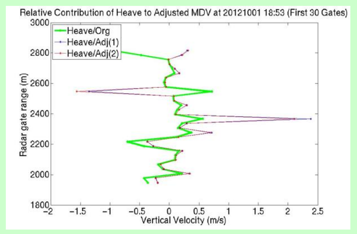
Heave Adj. MDV
Radar Gates 50



MDV Differences
At Gate 50

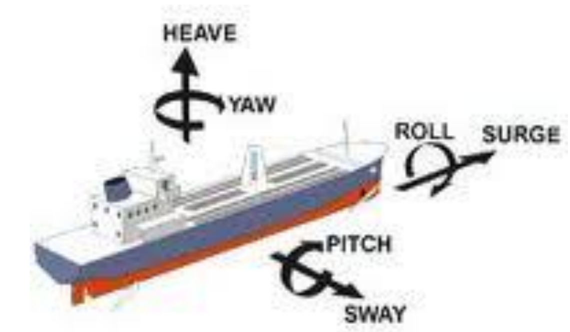


Heave Adjusted MDV
Radar Gates 1-30



Rel. Heave Contribution
Radar Gates 1-30

Primer on Ship Motion Terms



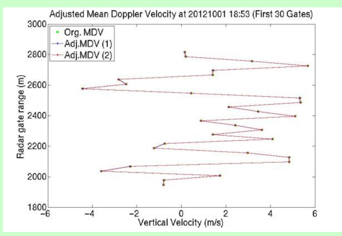
The ship motion terms used within these two VAPs are all found in the SeaNAV datafiles:

Yaw angle (ψ): Rotation of ship about its vertical axis (degrees)
Pitch angle (θ): Rotation of ship about its transverse axis (degrees)
Roll angle (ϕ): Rotation of ship about its longitudinal axis (degrees)
Heave: Linear vertical (up and down) motion (meters)
Heave velocity: Rate of heave (meter / second)

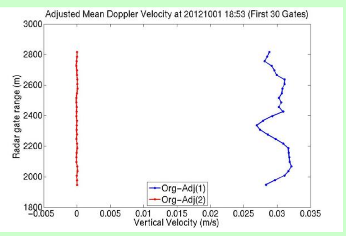
Motion terms in the SeaNav files, but not used in these VAPs:

Sway: Linear lateral (side to side) motion (meters)
Surge: Linear longitudinal (front to back) motion (meters)

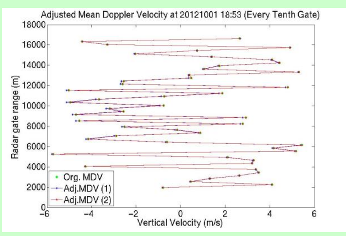
Ship- and Earth-Based Vertical Velocities by Radar Ranges at 18:53 on 10/01/2012



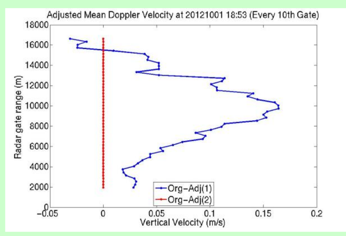
MDV (v3)
Radar Gates 1-30



MDV Differences
Radar Gates 1-30

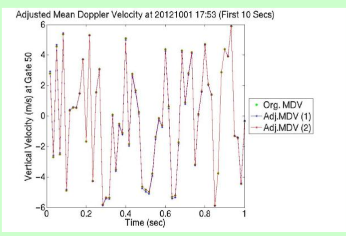


MDV (v3)
Radar Gates 1-500 (10th)

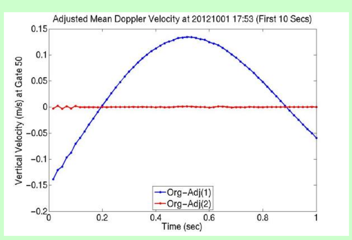


MDV Differences
Radar Gates 1-500 (10th)

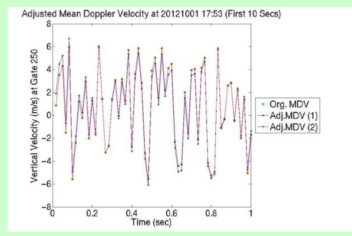
Ship- and Earth-Based Vertical Velocities by Time at Gates 50 and 250 on 10/01/2012



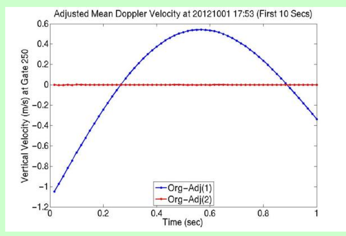
MDV (v3)
Radar Gate 50



MDV Differences
Radar Gate 50

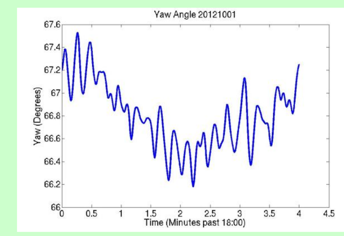


MDV (v3)
Radar Gate 250

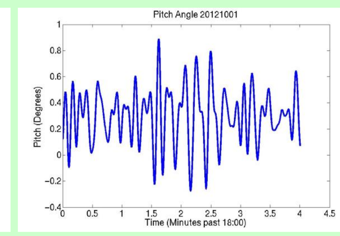


MDV Differences
Radar Gate 250

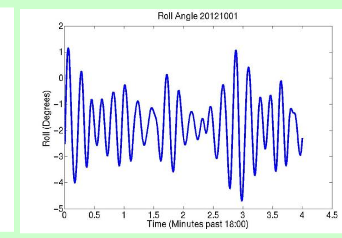
Ship Motion from SeaNAV File on 10/01/2012 for four minutes starting at 18:00



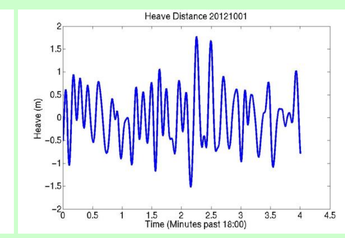
Yaw angle (ψ)
Positive values
Indicate clockwise



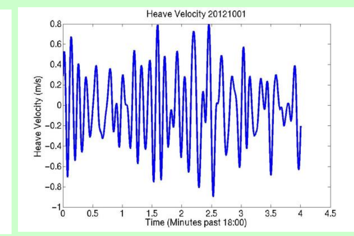
Pitch angle (θ)
Positive values
Indicate bow-up



Roll angle (ϕ)
positive values
indicate port-up

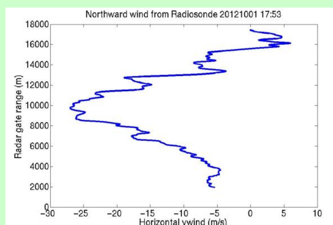


Heave
positive values
Indicate upward motion

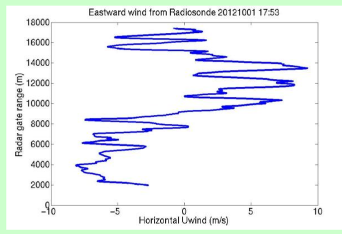


Heave velocity
positive values
indicate upward movement

Horizontal Winds from Radiosonde Launched at 17:53 on 10/01/2012

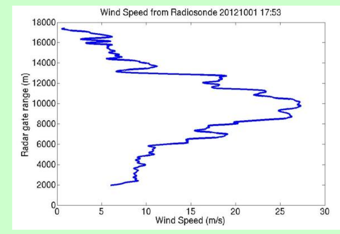


V_Wind (v1)
Northward Wind Component

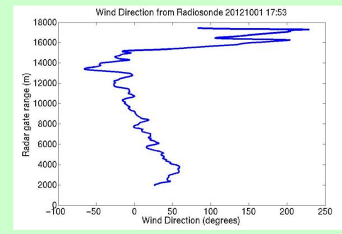


U_Wind (v2)
Eastward Wind Component

Translating the U_ and V_winds into wind speed and direction provides more context for understanding their meanings



Wind speed
(m/s)



Wind direction
0° is from the north; 90° east
-90° west and 180° south

Descriptive Statistics of Variables from 10/01/2012 (Table 1)

Variable	Mean	Min	Max	St. Dev.
Yaw	68.4	64.3	77.1	1.6
Roll	-1.8	-6.8	3.4	1.1
Pitch	0.3	-0.5	1.1	0.2
Heave Velocity	0.05	-1.2	1.1	0.3
U_wind	-2.6	-13.1	9.3	5.3
V_wind	-8.9	-27.0	6.1	9.4

Comparison of Transformations from Radial Velocity to Earth-Coordinates (Table 2)

					v3 (MDV)	v3 (MDV)	v3 (MDV)
Yaw (ψ)	Pitch (θ)	Roll (ϕ)	V wind (v1)	U wind (v2)	v-rad 2 m/s	v-rad 4 m/s	v-rad 8 m/s
	-0.5	-6.1			2.0115	4.0229	8.0459
	1.1	-6.1			2.0118	4.0235	8.0470
	-0.5	3.1			2.0030	4.0060	8.0120
	1.1	3.1			2.0033	4.0066	8.0132
68.4	-0.5	-6.1	-2.6	-8.9	2.0002	4.0117	8.0346
68.4	1.1	-6.1	-2.6	-8.9	1.7427	3.7544	7.7780
68.4	-0.5	3.1	-2.6	-8.9	2.1301	4.1331	8.1391
68.4	1.1	3.1	-2.6	-8.9	1.8726	3.8759	7.8825