Results of Flight testing of a Differential Absorption Microwave Sensor for the Remote Sensing of Atmospheric Pressure

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The surface barometric pressure is one of the most important meteorological parameters in the prediction and forecast of the intensity and track of tropical storms and hurricanes. To improve predictions and forecasts of the intensity and track of tropical storms, large spatial coverage and frequent sampling of sea surface barometry are critically needed for use in numerical weather models. These needed measurements of sea surface barometric pressure cannot be realized by in-situ buoy and aircraft dropsonde techniques. One approach to obtain barometry in large spatial and temporal scales over oceans is from remote sensing techniques including those on board manned aircraft, unmanned aerial vehicles (UAVs), and satellite platforms.

Recently, researchers have considered a technique that uses a dual-frequency, O2-band radar to measure the differential O2 absorption to estimate the total oxygen and infer the surface air pressure [1]. The technique uses dual wavelength channels with similar water vapor (WV) and liquid water (LW) absorption characteristics, as well as similar footprints and sea surface reflectivities, over the range of measurement frequencies. The microwave absorption effects due to LW and WV and the influences of sea surface reflection should be effectively removed by use of the ratio of reflected radar signals of the two channels. Simulated results suggest that the accuracy of instantaneous surface pressure estimations from the ratio of the radar return at two frequencies could reach 4–7 millibars (mb) [1]. The potential improvement of storm intensity and storm track predictions possible with such and instrument have also been studied. In fact, numerical simulations of hurricanes Ivan and Fran indicate that adding surface pressure with resolution and spatial sampling consistent with the differential absorption radar concepts presented here could significantly improve 24-hour storm intensity predictions and landfall predictions [1]

In this paper, we will present a description of a demonstration radar concept based on the differential absorption measurement concept that could provide the surface pressure measurements, and enable the improved severe storm predictions. Test results and measured performance of this Differential Absorption Microwave Radar (DAMR) instrument will be described, and results from flight-testing of the radar will be presented. Finally, we will describe modifications to the instrument concept to improve the measurement precision of the surface level pressure measurement.

1. DAMR measurement of Sea Surface Barometry

The DAMR instrument is based on the retrieval of the differential absorption near the O2 line complex (frequencies: 50–56 GHz). This selection of frequencies provides large changes in absorption for the reflected radar signals as a function of the frequency of the radar due to the different atmospheric O2 path lengths (or microwave optical depths of the atmospheric O2 absorptions). In the atmosphere, O2 is generally uniformly mixed with other gases. The column O2 amount is proportion to column air mass and the column air mass is proportional to the surface air pressure and the measured reflected power measured by the radar can be approximated as:

$$P_r(f) = \left(\frac{\mathrm{P_T G_t G_r} \lambda^2}{(4\pi)^3} \right) \left(\frac{\sigma^0(f)}{r^2} \right) \exp\left(-\frac{2\alpha_o M_o P_o}{g} - 2\alpha_L L - 2\alpha_v V \right) \tag{1}$$

Where the first term in equation 1 includes frequency dependent characteristics of the radar, which must be well determined by calibration: PT is the transmitter power and G represents the transmitter and receiver antenna gain. The second term includes changes in the surface reflectivity over the radar frequency, and the last term represents the atmospheric absorption, where M0 is the mixing ratio of O2 to total air and Po is the surface pressure. Thus, if the spectral response of the radar is will characterized from 50 -56 GHz, and the effect of LW and WV absorption characteristics and spatial resolution of the radar are similar over this range frequencies, then the ratio of the radar received powers from two frequencies then, is:

$$\frac{P_r(f_1)}{P_r(f_2)} = \left(\frac{C(f_1)}{C(f_2)} \right) \exp\left(-\frac{2(\alpha_o(f_1) - \alpha_o(f_2)) M_o P_o}{g} \right) \tag{2}$$

C(f) is the frequency dependent radar characteristics. This ratio is dominantly decided by the surface air pressure. The temperature and pressure dependences of the effective O2 absorption coefficients have secondary influences on the spectrum power ratio. Further, we define the differential absorption index, Ri(f1, f2), as the logarithm of the radar return and defining terms C0(f1, f2) and C1(f1, f2) for a linear relationship between Ri and Po, as the radar frequency response at frequencies f1 and f2, as,

$$P_o = C_0(f_1, f_2) + C_1(f_1, f_2) Ri(f_1, f_2) \tag{3}$$

The differential absorption index, Ri(f1,f2), is the logarithm of the ratio of the radar return exclusive of the frequency response of the radar, C0 includes residual calibration errors and variations in the instrument spectral response not corrected by the proportionality constant, C1. Simulated results presented elsewhere suggested a similar linear relationship between Ri and surface level pressure [1].

2. DAMR Flight Testing

The demonstration DMAR instrument was on installed on a helicopter for several test flights over water in varying sea conditions. The installation is shown in figure 1. Data was collected at various altitudes from 500 to 8000 feet for each sea state. Our analysis indicates that for the expected RAOBS demonstration radar performance, the data for 3000 to 4000 feet altitude may provide the optimum tradeoff between difference in O2 absorption and SNR at higher frequencies. The low altitude measurements for each flight was used to provide correction for sea surface reflectivity changes and spectral calibration of the instrument. The differential absorption for various altitudes was used to provide validation of the model results and the overall measurement concept. The initial results of these tests indicate that the demonstration DAMR instrument is as expected. The measurements over the Chesapeake Bay agree with the model predicted increased O2 loss, and measured differential absorption appears consistent with changes in barometric pressure during the flight testing.

These flight test data and the predicted performance of the DAMR will be presented in detail. Results of additional higher altitude flight testing planned for this spring will also be presented. Finally, an instrument concept based on this measurement approach utilizing adaptive measurement frequency selection will be presented.

Figure 1: DAMR Instrument Installed in vehicle for initial flight tests.

[1] Lin, B. and Y. Hu, Numerical Simulations of Radar Surface Air Pressure Measurements at O2 Bands, IEEE Geosci. and Remote Sensing Letter, 2, 324-328, 2005.

[2] Lawrence, R., et.al, Differential Absorption Microwave Radar Measurements for Remote Sensing of Atmospheric Pressure, Proceedings IGARSS, July 2003

[3] Liebe, H., MPM--An atmospheric millimeter-wave propagation model. Int. J. Infrared and Millimeter Waves, 10, 631-650, 1989.