Evaporation Duct:
A Comparison Study Between Bulk Methods and Kite Profiles

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INTRODUCTION

An over the water surface duct which increases distances of radar transmissions is likely to form when there are significant temperature and humidity gradients. Having typical depths of around two to thirty meters, evaporation ducts are more persistent over the ocean because low level moisture is always present and large semi-permanent air masses reside over the ocean. The evaporation duct occurs because of a large vertical decrease in refractivity directly over the ocean surface due to a humidity gradient. The humidity changes from near 100% at the ocean surface to 80-90% in the atmosphere above the ocean. In case of significant upward motion and mixing sharp vertical gradients are disrupted and evaporation ducts will be destroyed. Since humidity is a first order term in the approximation of refractivity, the layer is called the evaporation duct. However, three parameters must be examined when determining duct height. Refractivity and the duct are strongly dependent on pressure (p), temperature (T), and the partial pressure of water vapor (e). Using surface parameters, bulk methods are the standard method used to calculate evaporation duct height. In the past, it has been difficult to get accurate surface measurements of temperature and humidity possibly affecting the accuracy of the duct predictions. Either a weather balloon launched from the ship or a ship's sensor is inside the envelope of the ship experiencing the disrupting effects of the ship to the air, thus reducing the gradients.

OBJECTIVES

There were three objective of this project. The first was to calculate M directly using a rawinsonde suspended from a kite. The second objective was to calculate M profiles using bulk methods from ship's sensors and kite data. The final goal was to compare profiles and associated duct heights.

MOTIVATION

Due to the thickness of the evaporation duct, the affected frequency range is above upper UHF affecting radar frequencies relevant to the Navy. Detection ranges from ships radar would change depending on the environment, which would change the "picture" of the battle space. It is important for the Navy to know the environment for exploitation and limitation when applicable.

Using a kite to collect environmental measurements is an idea for resolving the duct for the first few meters off the surface. Strong temperature and humidity gradients cannot be measured near the surface from weather balloons because the duct elevations are to low for the balloon/rawinsonde to resolve. The balloon rises at four meters per second and the rawinsonde takes measurements every 2 seconds. Alternatively, a kite can resolve the temperature and humidity gradients coming within one meter of the surface and slowly gaining or losing altitude multiple times using one rawinsonde.

BACKGROUND

The index of refraction, n, characterizes the scattering (radiating) of an electromagnetic wave passing through a specified medium. Index of refraction and refractivity, N, for VHF/UHF/microwave frequencies are related in the following equation: $N = 10^6(n-1)$

(typically n~1.0003 or 1.0004 and N~ 300-400)

Refractivity is a function of atmospheric parameters: P, T, and e. The concern for wave propagation is not the absolute value of refractivity, but its vertical gradient, $\frac{dN}{dz}$.

Demonstrated below:

Class	$\frac{dN}{dz}$	Distance to Horizon	$\frac{dM}{dz}$
Subrefraction	$0\ m^{-1} < \frac{dN}{dz}$	reduced	$0 > \frac{dM}{dz}$
Normal	$-.079\ m^{-1} < \frac{dN}{dz} < 0\ m^{-1}$	normal	$0 > \frac{dM}{dz}$
Superrefraction	$-.157\ m^{-1} < \frac{dN}{dz} < -.079\ m^{-1}$	increased	$0 > \frac{dM}{dz}$
trapping(ducting)	$\frac{dN}{dz} < -.157\ m^{-1}$	greatly increased	$0 < \frac{dM}{dz}$

Another variable called the modified refractivity, M, was made to help easily identify regions of ducting. $M = N_z + (.157 m^{-1}) * z$ where z is any height in m and N is the refractivity at that height. $\frac{dM}{dz} = \frac{dN}{dz} + .157 m^{-1}$. By substituting the appropriate $\frac{dN}{dz}$

values into the above equation, it is apparent ducting will occur when $0 < \frac{dM}{dz}$. An important point is that refractivity is also frequency dependent. The following equation of modified refractivity is valid for frequencies between 100MHz and 80 GHz:

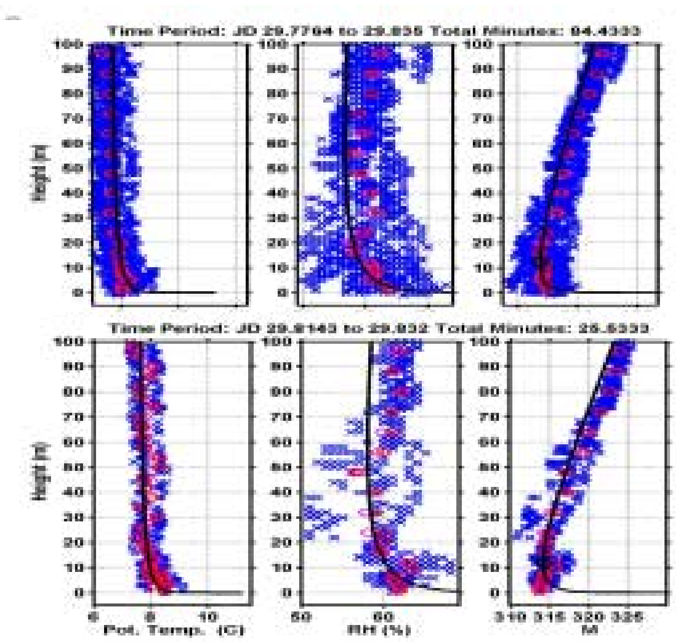
$$M = 77.6\frac{p}{T} - 5.6\frac{e}{T} + 375000\frac{e}{T^2} + 0.157z$$

EXPERIMENT

This project consists of three flights that were conducted using a rawinsonde attached to a kite. Specifically Jan 29 at 18z, Jan 29 at 22z, and Feb 02 at 22z. First the rawinsonde was initialized. Then the kite was flown off the ship with the kite line attached to a fishing pole. After flying the kite approximately 50 meters away from the ship, a series of vertical profiles were taken by flying the kite to one meter above the ocean to 100 meters in the air. Finally, if all went well, the kite and rawinsonde were retrieved onboard after approximately two hours of data collection. This kite data was collected to make an M profile from the kite's rawinsonde data. These profiles will be compared to M profiles made from measurements taken from ships sensors. The R/V Point Sur's Serial ASCII Interface Loop (SAIL) system was used to measure air temperature, wind speed (port true wind speed), relative humidity, pressure, and sea surface temperature (from boom probe). The data was received after being averaged over 52 to 58 second intervals. All of the instruments (excluding the boom probe) were mounted 17 meters above the sea surface. A rawinsonde attached to a kite was used to collect air temperature, relative humidity, and pressure. Dew point temperature and height were derived from that data.

RESULTS

Each rawinsonde flight data set was examined with a few different analysis techniques. The data when the kite was closest to the ship was removed due to possible ship contamination. For almost every test, the few meters above the surface showed lower relative humidity and higher potential temperatures than predicted by the bulk method. The temperature was closer to the bulk method prediction than the relative humidity. As observed by Lt. Mabey's OC3570 project, relative humidity has the greatest impact of the three parameters on the M profile. How did the profiles and duct heights compare? The profiles varied depending on how the data was manipulated when averaging and eliminating data. To compare the profiles, all the kite plots will be compared to the bulk method profile. It appears one average period for the time series fits the bulk method profile better than having more, smaller averaging periods.



29 Jan 1800

One average period for the entire time series

x –rawinsonde data
o – averaged data
| - Bulk Method

One of three average periods for the entire time series

It is important to remember when averaging the whole time series stationality is lost due to ship movement. Another way to examine the data is by averaging heights. The kite data was averaged in bins. For example, between zero and ten meters of elevation the data was averaged every two meters. Ten to twenty meters was averaged every four meters. Finally, twenty to 200 meters was averaged every eight meters. Changing the averaging to one, two, and four meters for the respective elevations did not significantly change the profiles for a time series averaged one time. When the time series was divided up, the number of points to be averaged decreased, then the larger averaging heights of two, four, and eight meters did a better job replicating the bulk method profile. Each kite flight had multiple up/downs. One idea was that the data near the bottom of the down leg, when the kite is closer to the ship, could be contaminated due to atmospheric mixing. When editing out the very bottom of the down segment it is possible to improve the kite profiles as seen for the 29 Jan 2200 flight. However, there were not enough tests to show this was a conclusive result. There could also be more accuracy for a specific kite up/down. When a time was identified where the humidity is higher than average, a good representation of the M profile was the result. Possibly where there is higher relative humidity recorded could be where the kite was actually closer to the ocean surface and good data was recorded for the first few meters of elevation.

Three averaging periods, with number three having the highest RH.

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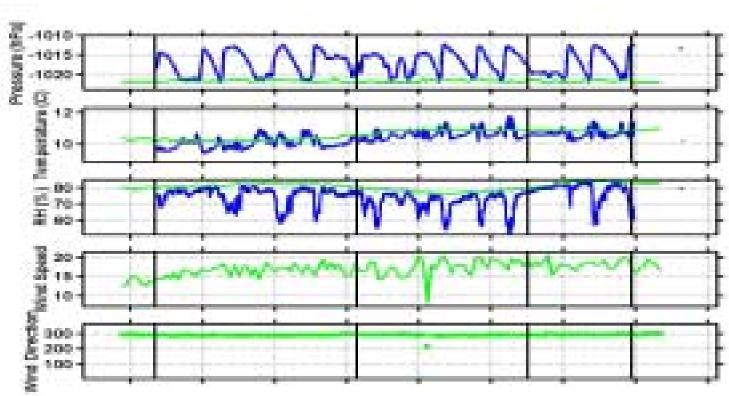

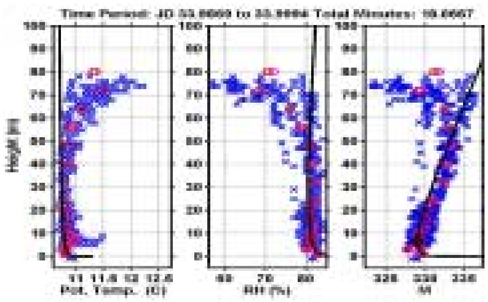

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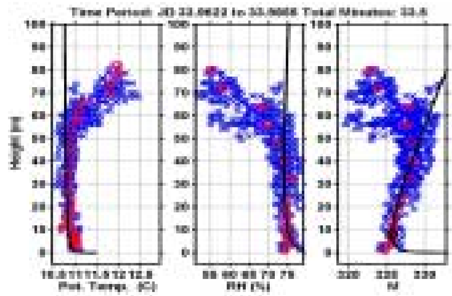

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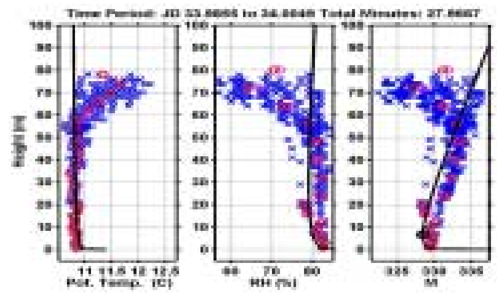

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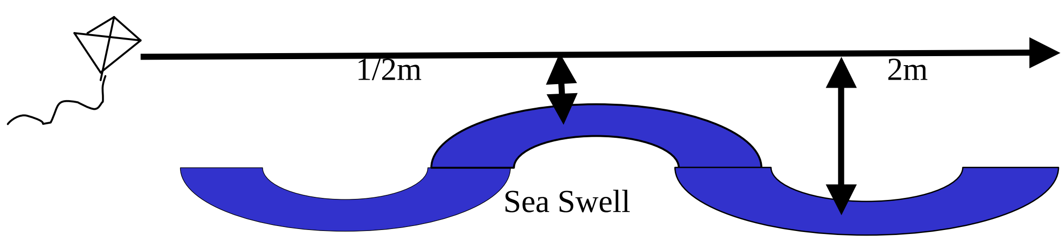
CONCLUSION

In the future it would be important to try to isolate and eliminate errors in the measurements. It was difficult to isolate a specific aspect of the project to determine if that piece affected the profile because there were so many situation that where subjective. Whether it was writing down how high the kite was off the ocean, clicking that adjusted height on the pressure profile to adjust for horizontal pressure change, determining the average periods and what data to eliminate, or even picking the correct sea surface temperature (when there were five different measurements to choose from). I am not sure any one test could be duplicated, let alone any one variable isolated. Errors could also be found in the uncertainty of data collection associated with height. The swell could add some uncertainty to height. As the kite is let out, it ideally skims one meter over the mean sea level. However, the kite is actually going over troughs and crests altering the height being measured to something other than one meter.



Also, the rawinsonde is a sensitive instrument and might not have responded fast enough to the changing environment. Another concern is the rawinsonde only collected data every two seconds. A suggestion is to change the sampling rate of the rawinsonde to a desired rate less than two seconds and compare the results to stadard rawinsondes or the bulk method profile. Any uncertainty between zero and three meters is critical for evaporation duct prediction. Consistently the bulk method showed a higher duct height than kite data. Averaging over the entire time series matched the bulk method more closely than averaging shorter periods. Also, making the bin averaging heights smaller did little to change the profile over one long averaged time period but degraded the profile when the time period was broken into smaller averaging periods. Isolating times of higher relative humidity showed M profiles more closely matching the bulk method. For this study the bulk profile was assumed to represent the real environment. In actuality the bulk method was derived empirically and might not show the environmental variability that could be occurring at the time of the experimental kite flight. The bulk method has not been verified for evaporation duct predictions leaving uncertainty about the first ten meters above the surface. This is the same problem with the kite profile. The bottom ten meters are in question. The bottom line is no one knows for sure what the truth is. To resolve this issue of method accuracy and duct evaporation height, follow-on research is suggested. An experiment measuring the environment and radar propagation must be conducted.

REFERENCES

Davidson, K.L., *Atmospheric Factors in Electromagnetic and Optical Propagation,* MR4416 Manual.

Mabey, D. L., *Evaporation Duct Profile Comparisons Using Kites and Bulk Methods*, OC3570 Project, 22 March 2001.

Phillips, R. L., *The Use of Tethered Balloons to Measure the Evaporation Duct*, OC3570 Project, September 2001

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