LT Todd Barnhill
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Comparison of Atmospheric Refractive Conditions based on Rawinsonde Data, ETA Model Analysis and Forecasts, and the Statistical Refractivity Model

1. Background:

Over recent years, many have debated whether Navy units, such as, Carrier and Amphibious Ready Group OA division or Mobile Environmental Teams (MET) need to launch Rawindsondes in order to provide accurate atmospheric refractivity forecasts. Most debates have been sparked due to the rising cost of the Rawinsondes and their falling reliability as the new GPS Rawinsondes came on the market. Additionally, operational concerns in the fleet have limited the opportunities to launch Rawinsondes when they are most useful and have restricted them to non-flight hours or on a not to interfere basis. Another problem is that over eager proponents for Mesoscale models have tried to convince others that these models can accomplish things far beyond their current capabilities. Although developments in Mesoscale models have truly been revolutionary, some have been lead to believe that model output would be just as useful in describing the 3-D operating space as in-situ data sources. In order to better understand the issues within this debate, this project was created to compare output from traditional Rawinsonde balloon data to the analysis and forecast output from the ETA model and the Statistical Refractivity Model (SRM) (Helvey and Rosenthal, 1983). The two primary issues that will be compared are whether ETA and the SRM produce ducting conditions that match the Rawindsonde data and whether the duct height information from ETA and the SRM match the Rawindsonde data. If these models can be shown to describe the atmosphere with similar results to the Rawindsonde data, then many thousands of dollars can be saved in operating costs for the Navy's OA divisions and MET's.

2. Procedures:

Collection of the Rawindsonde data was conducted during a survey cruise off the CA coast from 28 February to 04 March. During the cruise, multiple launches were conducted (21 in all) at various times of the day in order to characterize the atmospheric conditions. Rawinsondes were launched in two configurations, the standard configuration was used to measure the atmosphere from the surface to 100 mb, while the up/down configuration was used to measure atmospheric conditions from the surface to 500-700 mb. The up/down configuration was launched with an open syringe located in the nozzle of the balloon. Helium would escape during the ascent of the balloon. When sufficient helium had been lost, the balloon would begin to fall. Atmospheric conditions were measured during the entire flight path of the balloon. For this particular study, the downward path of data was eliminated since the profiles were very similar to the upward path. From the original 21 profiles, 15 cases will be considered.

The raw data files required processing in order to get the data into the Advanced Refractive Effects Prediction System (AREPS) to produce both M profiles and the duct graphic product. AREPS programming requirements mandated that a file had to have at least 4 levels, but no more than 400. In most cases, the data files that were collected contained nearly 1200 lines and many had over 1500. In order to process the data, missing data needed to be removed and then plotted using a MATLAB code which was produced by several of the students in the class. To eliminated unnecessary levels, only level of significant changes were pulled from the original flies and saved in a separate data file. These files were then imported into AREPS for later analysis.

Using the shipboard launch times and positions as reference, the closest ETA model analysis or forecast times were used to produce synthetic vertical profiles. In the case of the ETA model, which has 39 vertical levels, these files were easily imported into AREPS in order to produce the M profile and duct graphic. The following is a list of available levels and associated height measurements:

LEVEL (mb)	HGHT (ft)	LEVEL (mb)	HGHT (ft)
1000	230.01	500	5701.36
975	439.73	475	6076.36
950	654.8	450	6466.65
925	874.6	425	6873.12
900	1099.61	400	7298.54
875	1330.49	375	7744.69
850	1567.02	350	8213.75
825	1809.7	325	8709.82
800	2058.9	300	9237.72
775	2314.83	275	9804.88
750	2577.88	250	10423.02
725	2848.57	225	11109.51
700	3127.23	200	11882.28
675	3414.03	175	12758.4
650	3709.73	150	13763.38
625	4014.83	125	14936.12
600	4329.85	100	16348.74
575	4655.28	75	18169.92
550	4991.6	50	20736.73
525	5340.08		

The Statistical Refractivity Model did not provide standard atmospheric output, but rather provided a qualitative assessment of whether the formation of a duct was “Unlikely”, “Possible”, “Probable”, or “Very Likely”. Additionally, if a duct was possible, than a predicted duct base height was provided. For statistical purposes, any prediction, which had an assessment of unlikely or possible, was considered not to have a duct and an assessment of probable or very likely was considered to have a duct. An interface to the Statistical Model was created by LCDR Tony Miller and placed on the NPS web server at http://www.oc.nps.navy.mil/~hamiller/duct. Many inputs are required for this model to perform its calculations. Model analysis, Satellite imagery and shipboard observational data were used to provide these inputs (Table 1).

3. Results:

The Rawinsonde data and synoptic analysis showed the cruise began in a somewhat unstable atmosphere, which produced normal refractive conditions with no ducting. From 21Z on the 30th of January to 15Z on the 2nd of February, conditions transitioned to a more stable atmosphere and ducts formed, dissolved, and reformed over the period. Finally, from 18Z on the 2nd until the end of the cruise, several strong ducts formed. The strongest ducts formed on the morning of the 3rd with surface based ducts of 150 meters and elevated ducts of 500 meters (see Table 2 for summary, representative temperature, dew point and M profile plots at end of paper).

Each of the 15 vertical profiles from the ETA model produced normal refractive conditions with few variations in the Temperature, Dew Point or M profiles. No ducting conditions were seen in any of the runs and no visible changes were seen in any of the profiles.

The SRM did provide results that changed over time. For the first two launches, during the unstable atmosphere, the SRM predicted unlikely conditions with a possible during the third launch. During the transition period, SRM maintained a probable or very likely assessment that it continued through the end of the cruise. The results showed that the SRM was capable of predicting when a duct would be or would not be present getting 10/15 assessments correct. Although this result was encouraging, the duct height forecast was not. In most cases, duct heights of 800 or 1300 meters were predicted, however ducts at this level were never observed. Only during one occasion did the forecasted duct height actually match the Rawindsonde data (Table 2).

4. Discussion:

The results from this study were very disappointing to say the least. Although the sample size of this data set is very small, the problems, which arose, do not have any near-term solutions. Analysis of the ETA fields and subsequent conversations with Prof Miller provided insight that make the author believe that the era of Rawindsondes will not be over for many, many years. One issue that may be correctable in future studies is that NPS currently receives a smoothed form of the ETA model. This data is provided to NPS in this smoothed format to facilitate timely bandwidth transfers from the National Weather Service to its customer. When this smoothing occurs, both horizontal and vertical features are lost. With additional planning and resource management, full versions of the model may be able to be pulled for short period work.

Another issue that caused problems with the data was that the bottom layer of the vertical profiles was at 1000 mb. During the cruise, surface pressures increased from 1015 mb to 1026 mb. The strongest ducts existed during the period of max surface pressure and this caused the models to miss the first 100 to 150 meters of atmosphere. When ducts were present, many of them contained ducts from the surface to 200-meter range and would have been missed in the ETA analysis.

Another reason that the model does not produce an accurate vertical profile is that the vertical resolution of the model is not sufficient to resolve the small changes in the atmosphere. In most cases, many hundreds of feet separate one level from the next. During this study, most of the changes in temperature and dew point changed over only 25 or 50 feet (figure (1)).

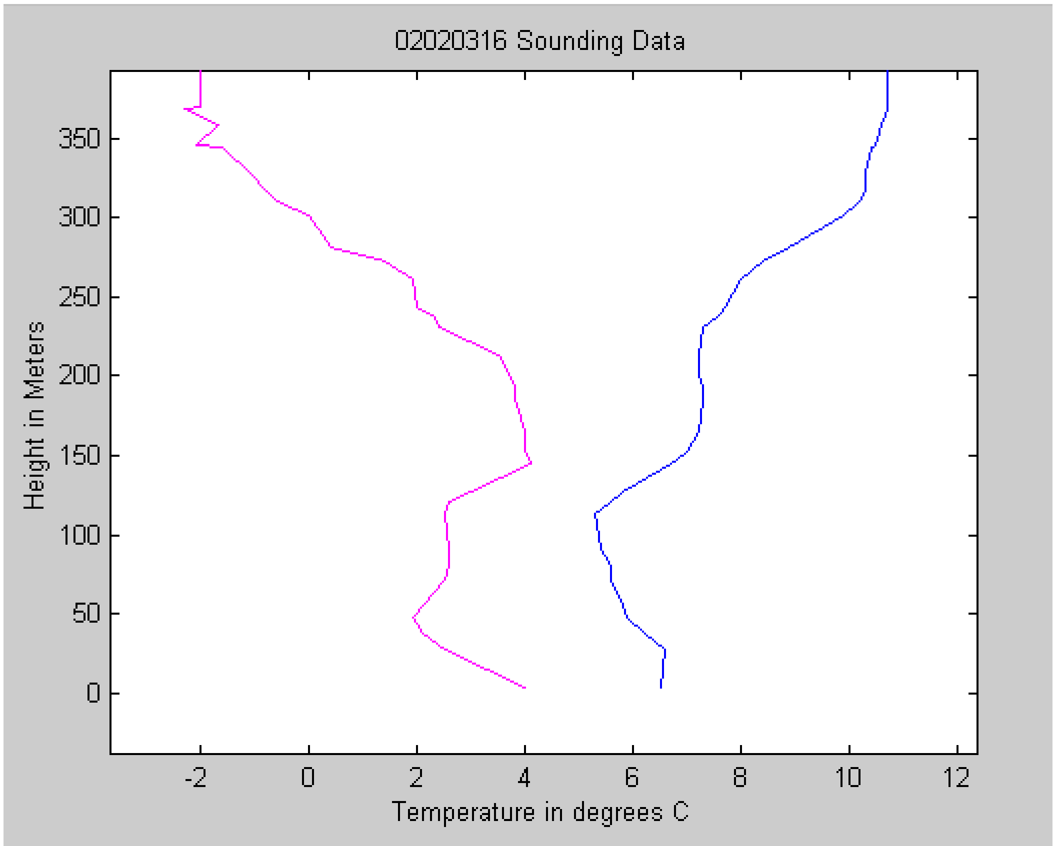


Figure 1: Blow-up of lower 350 meters of Sounding 02020316

The last issue that needs to be considered is where these models get the information to create a prediction. Since models receive their information from the observation networks that have been developed to support them. If we take these networks away the model will fail. In many of the areas that the Navy operates, it is the Navy METOC teams are the only observation points to provide to the model. If we stop taking observations, then what initialization field is the model using to do its predictions, climatology?

In this case, the SRM demonstrated its ability to reasonably predict when conditions are correct for the formation of an atmospheric duct. Although the information required for the model is more observational than forecasted, model input can be used to make predictions. More reliable predictions are achieved from SRM when accurate inversions heights, height of cloud bases or the cloud types are known. In most cases, SRM is much more reliable during completely unstable or stable conditions and tends to over predict ducting conditions during transition periods such as the one during the middle of our cruise. SRM also seems to heavily weight the distance to the nearest high pressure systems or fronts as indicators for its predictions. When the distance to the high is twice as far as the front, then predictions favor “Unlikely” development. However, when the opposite is true than predictions favor “Very Likely”. The problem occurs when the distances are roughly the same. This is when an accurate accounting of inversion height or cloud base height makes the largest difference.

Although the predictive capabilities for the presence of the duct seem to be on track, the ability for the model to calculate the duct height is not accurate by any means. As stated previously, in only one case was the duct height predicted correctly (18 Z, 02 Feb) where the duct was predicted to be at the surface and according to the Rawindsonde the duct was at the surface. In every other case where a duct was confirmed, SRM predicted a much higher duct height than was observed. No observed inversion layers where used in these predictions and accurate cloud base heights were not available. If this data was available the predicted values my have been more reasonable.

5. Conclusions:

The overall results from this study show that in-situ data received from Rawindsondes are vital for producing reliable, accurate atmospheric refraction predictions which our customers rely on for adjusting radar parameters, mission guidance and planning. To date, the current operational models do not have the necessary horizontal, but more importantly, vertical resolution to accurately depict the microscale changes that affect refractive conditions. Small changes in surface heating or mid-level cooling can make major changes to the M profile that cannot be seen by even mesoscale models.

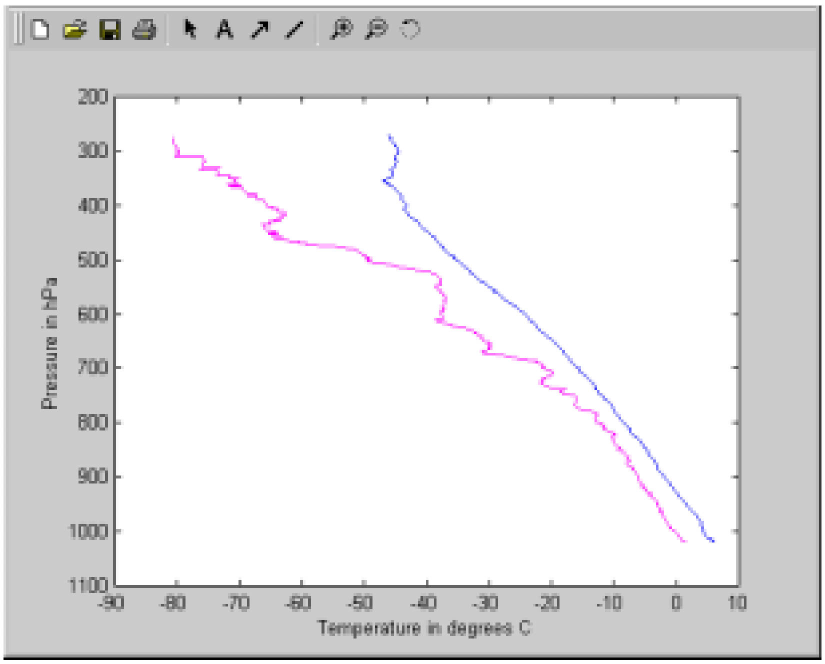
The SRM shows promise in predicting the formation of ducts in regions of strong stability or instability. Results are suspect in regions of transition and tend to overestimate the presence of ducts. The duct height predictions are very unreliable and should not be used operationally.

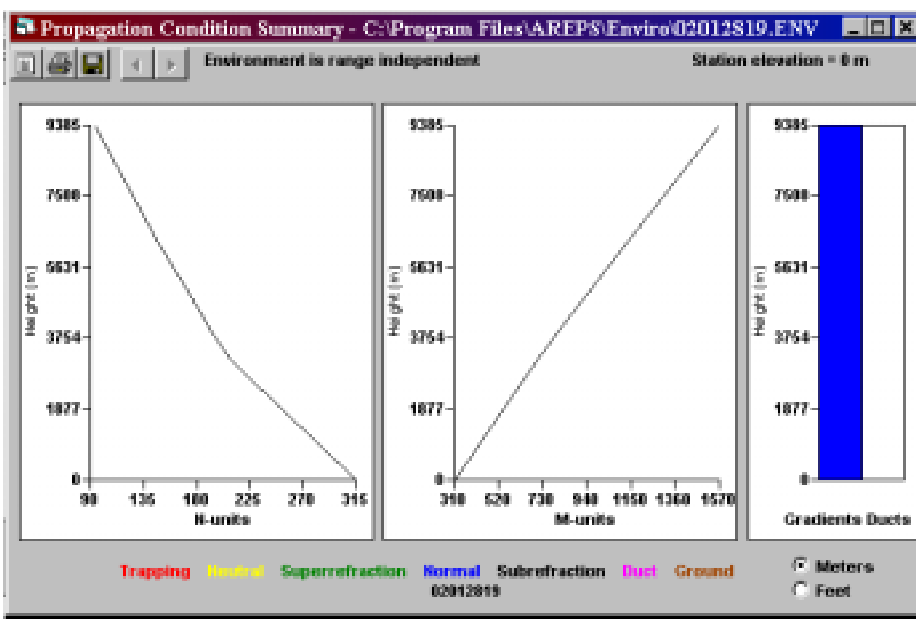
References

Helvey, R.A. and J.S. Rosenthal, 1983: Guide for inferring refractive conditions from synoptic parameters. Technical Report, Pacific Missile Test Center, 36pp.

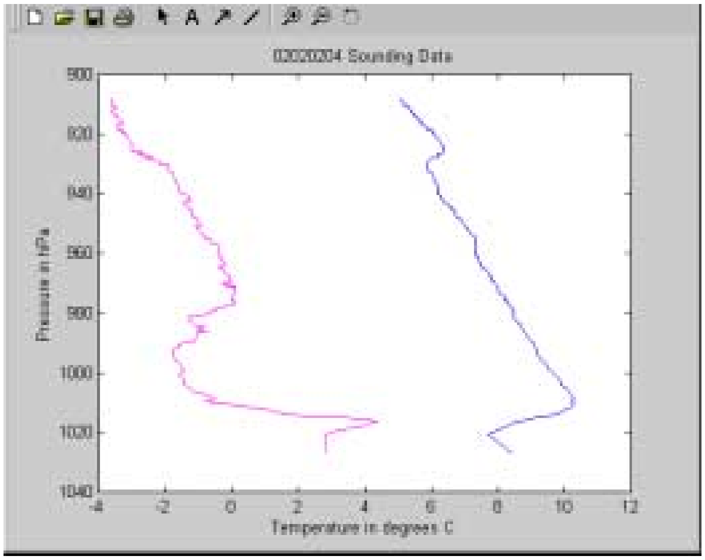
Representative Temperature (Blue), Dew point (Red) and M Profile plots for 02012819 (No Duct), 02020404 (Surface Duct), 02020316 (Surface and Elevated Duct) and Model output for 02020316.

02012819:

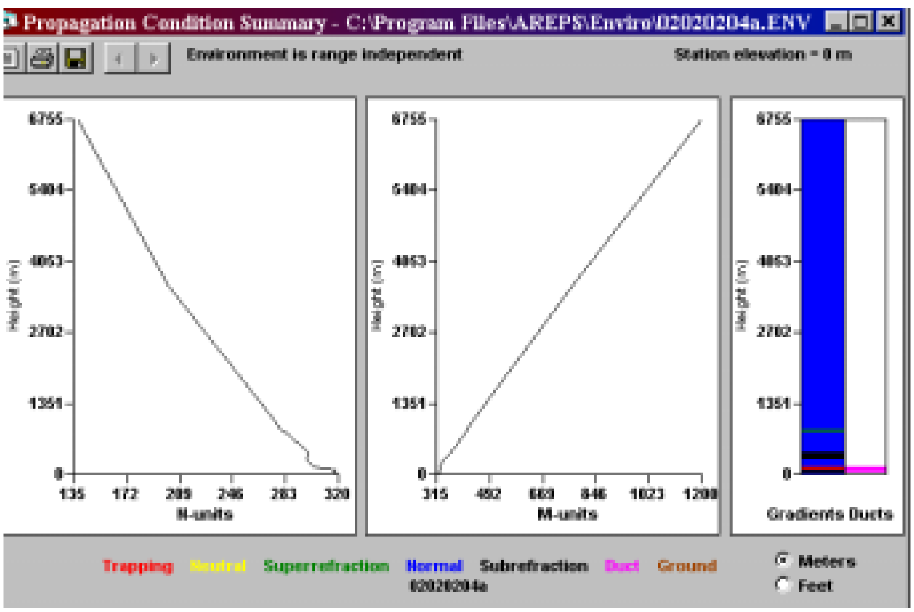




02020404:

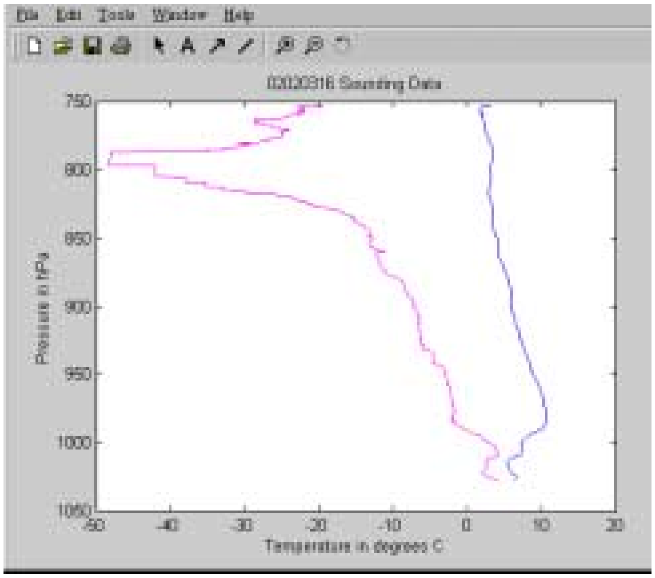


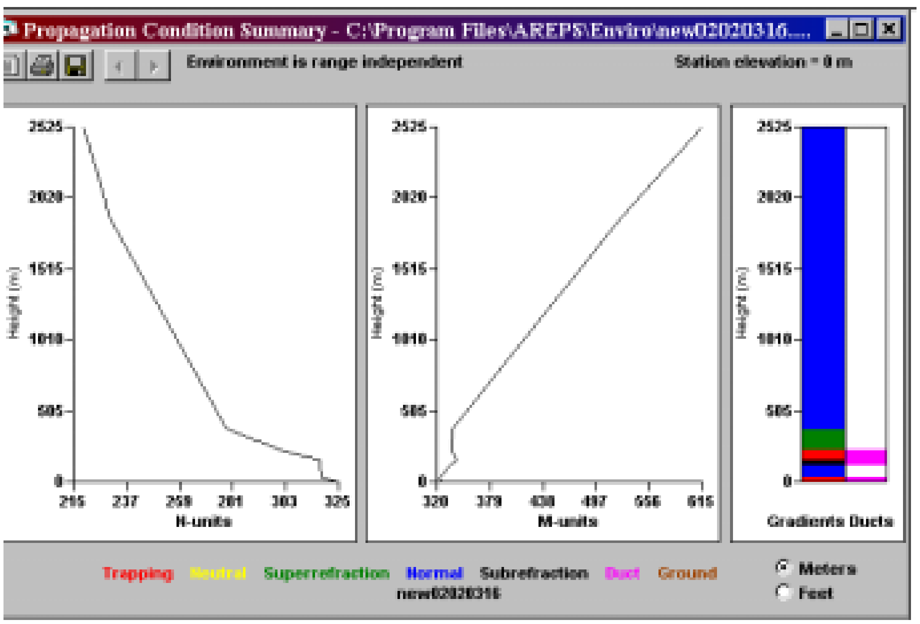
02020204 Sounding Data
Pressure in hPa
Temperature in degrees C



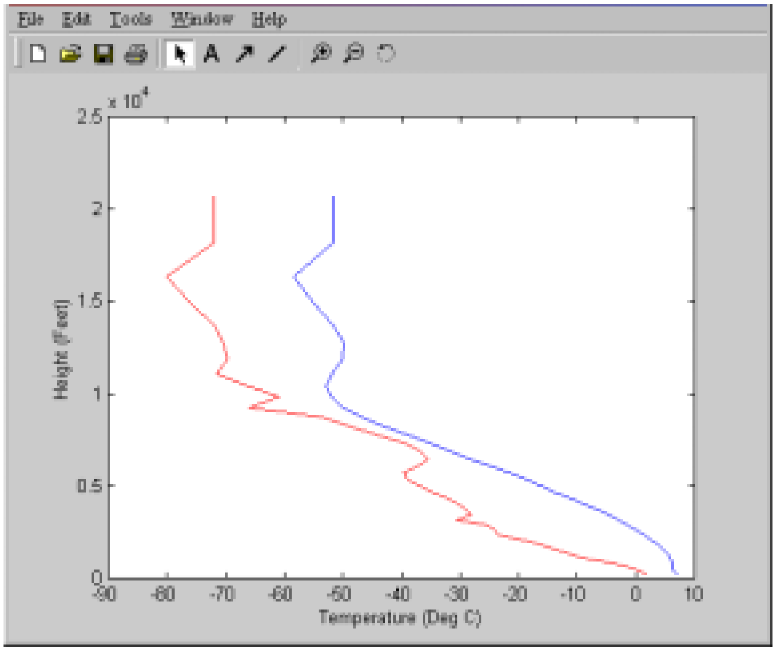
Propagation Condition Summary - C:\Program Files\AREPS\Enviro\02020204a.ENV
Environment is range independent
Station elevation = 0 m
Height (m)
N-units
M-units
Gradients Ducts
Trapping
Neutral
Superrefraction
Normal
Subrefraction
Duct
Ground
02020204a
Meters
Feet

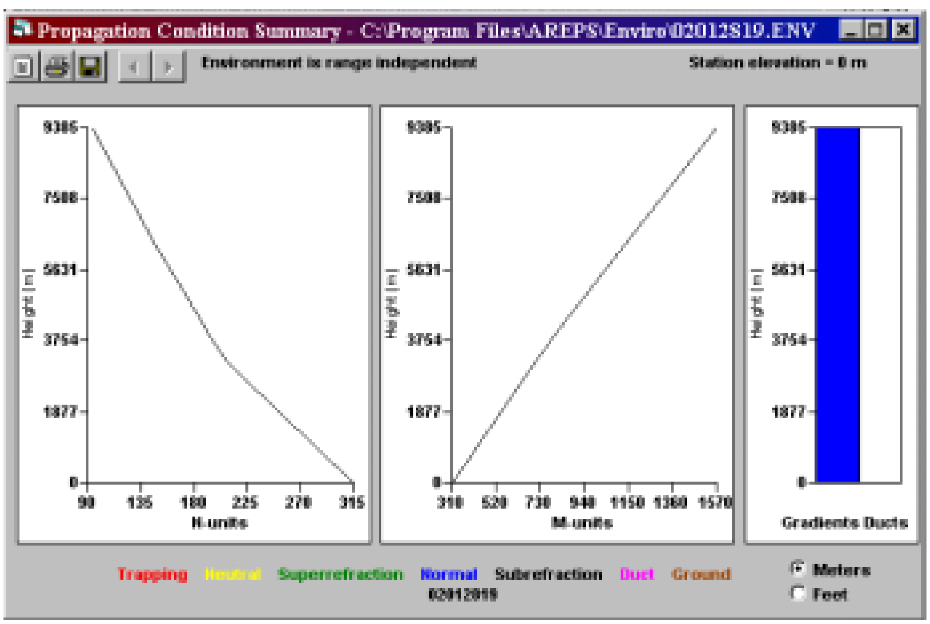
02020316:


File Edit Tools Window Help
02020316 Sounding Data
Pressure in hPa
Temperature in degrees C


Propagation Condition Summary - C:\Program Files\AREPS\Enviro\new02020316....
Environment is range independent
Station elevation = 0 m
Height (m)
N-units
M-units
Gradients Ducts
Trapping
Neutral
Superrefraction
Normal
Subrefraction
Duct
Ground
new02020316
Meters
Feet

Model Output:





	2012819	2012900	2013000	2013021	2013023	2013117	2013119	2020119
Sfc. Press (mb)	1015	1018	1022	1026	1026	1026	1026	1025
Isobaric Curvature	neutral	cyc	cyc	anti	anti	anti	anti	anti
Center of High (NM)	>20	>20	540.5405405	311.3513514	324.3243243	135.6756757	135.6756757	127.027027
Dist to Sfc Front (NM)	291.8918919	close	324.3243243	756.7567568	>1500	>1500	>1500	>1500
Location	Eastern Pacific	Eastern Pacific	Eastern Pacific	Eastern Pacific	Eastern Pacific	Eastern Pacific	Eastern Pacific	Eastern Pacific
Wind Direction	330	280	345	30	345	120	120	340
Inversion Present	no	no	no	no	no	no	no	no
Sfc. Air Temp (0C)	8	6	7	4	4	6	6	10
700 mb Air Temp	-13	-15	-15	-7	-7	-7	-7	-6
Warm, dry offshore flow	no	no	no	no	no	no	no	no
Daytime	yes	no	no	yes	yes	yes	yes	yes
SST	12	12	12	12	12	12	12	12
Cloud Appearance	stcu dense	stcu dense	clear/cu	clear	clear	clear	clear	clear
Forecast/Duct	Unlikely	Unlikely	Possible/800m	Very Likely, 800 m	Very Likely, 800 m	Probable, 1300 m	Probable, 1300 m	Probable 1300m
Position: 36.8N 121.9W								

	2020204	2020215	2020218	2020302	2020316	2020320	2020404	2020408
Sfc. Press (mb)	1025	1024	1024	1023	1026	1026	1026	1026
Isobaric Curvature	anti	anti	anti	anti	anti	anti	anti	anti
Center of High (NM)	467.027027	467.027027	467.027027	405.4054054	162.1621622	162.1621622	540.5405405	540.5405405
Dist to Sfc Front (NM)	540.5405405	310.8108108	310.8108108	162.1621622	810.8108108	810.8108108	648.6486486	648
Location	Eastern Pacific	Eastern Pacific	Eastern Pacific	Eastern Pacific	Eastern Pacific	Eastern Pacific	Eastern Pacific	Eastern Pacific
Wind Direction	350	90	90	345	90	90	10	10
Inversion Present	no	no	no	no	no	no	no	no
Sfc. Air Temp (0C)	9	8	7	10	8	8	12	11
700 mb Air Temp	-5	-3	-3	-3	-3	-3	-3	-3
Warm, dry offshore flow	no	no	no	no	yes	no	no	no
Daytime	no	yes	no	no	yes	yes	no	no
SST	12	12	12	12	12	12	12	12
Cloud Appearance	no sat	no sat	clear	no sat	strat layer to south	clear		
Forecast/Duct	Very Likely, 800 m	Very Likely, 0 m	Very Likely, 0 m	Probable, 1300 m	Very Likely, 1300 m	Very Likely, 1300 m	Very Likely, 800 m	Very likely, 800 m

Table 1: Data Inputs to the Statistical Refractive Model

Data Summary

	2012819	2012900	2013000	2013021	2013023	2013117	2013119
Statistical Refraction Model	Unlikely	Unlikely	Possible/800m	Very Likely, Base 800 m	Very Likely, 800 m	Probable, 1300 m	Probable, 1300 m
Rawinsonde Data	No Ducting	No Ducting	No Ducting	Duct, Base 1300m, 200 m Thick	No Ducting	Duct, Base 450 m, 150 m Thick	No Ducting
ETA Model Data	No Ducting	No Ducting	No Ducting	No Ducting	No Ducting	No Ducting	No Ducting

	2020119	2020204	2020215	2020218	2020302	2020316	2020320
Statistical Refraction Model	Probable 1300m	Very Likely, 800 m	Very Likely, 0 m	Very Likely, 0 m	Probable, 1300 m	Very Likely, 1300 m	Very Likely, 1300 m
Rawinsonde Data	No Ducting	Duct, Base 50m, 100 Thick	No Ducting	Duct, Base Surface, 24m Thick	Duct, Base: Surface, 500m Thick	Duct: 2 Ducts 1: Base Surface, 50m Thick 2. Base 364, 400m Thick	Duct: 2 Ducts 1: Base Surface, 33m Thick 2: Base 260m, 150m Thick
ETA Model Data	No Ducting	No Ducting	No Ducting	No Ducting	No Ducting	No Ducting	No Ducting

	2020404						
Statistical Refraction Model	Very Likely, 800 m						
Rawinsonde Data	No Ducting						
ETA Model Data	No Ducting						

Table 2: Summary of all Comparisons for each time.