STATISTICAL PERFORMANCE MEASURES OF THE HWM-93 AND MSISE-90 EMPIRICAL ATMOSPHERIC MODELS

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ABSTRACT

An enforceable Comprehensive Nuclear-Test-Ban Treaty (CTBT) regime will require accurate detection and location of low-yield (1 kT or less) nuclear detonations. For reliable infrasonic detection and location of candidate events, a thorough knowledge of the upper atmosphere and advanced modeling techniques is required. Currently, a near-real-time global specification of the atmosphere extends to only about 55 km from the surface. This is insufficient for CTBT monitoring purposes. A near-real-time global specification will have to be developed that covers the region that is 45 ±10 km to 150 ± 20 km above the surface for infrasonic detection and location of nuclear detonations.

The Naval Research Laboratory maintains both the Mass Spectrometer and Incoherent Scatter Radar Model (MSISE-90) and Horizontal Wind Model (HWM-93). These empirical models employ meteorological data assimilation techniques and draw upon a forty-year, multi-instrument database of satellite- and ground-based research measurements. These models produce global atmospheric state estimates in the region of interest from day-of-year, time-of-day, latitude, longitude, altitude, and solar and geomagnetic activity indices using a set of harmonic coefficients. These models provide a framework for organizing and disseminating measurements of density, temperature, and wind data.

It is important to have statistical performance measures of the MSISE-90 and HWM-93 models to evaluate their performance, determine potential error, and enable adjustment for that error. The models' limitations stem from two types of uncertainties – statistical and systematic errors. Statistical errors are introduced by unresolved random fluctuations in the upper atmosphere. Systematic errors are introduced by observation and modeling biases. The measurement database that was used to construct the models and seven newer comprehensive data sets are used in calculating these statistical performance measures. Limitations of the models can be quantified and understood through this methodology. A database of standard deviations and mean biases is being developed for these models. The database will be organized to facilitate assessment of the models and validation of current source location error ellipses. The resulting data will then be made available to the infrasound community for use in error correction.

Key Words: infrasound, atmospheric models, statistical performance

OBJECTIVES

Source location algorithms require global winds and temperatures from the ground to approximately150 km. Currently, operational near-real time global specification of the atmosphere is only available for the region below 55-km. Above this region near-real time atmospheric specification remains an active scientific research topic. The purpose of this task is to advance Naval Research Laboratory (NRL) upper atmospheric empirical models; the Mass Spectrometer and Incoherent Scatter Radar (MSISE-90) model and Horizontal Wind Model (HWM-93) for infrasonic measurement applications. The objective of this work is to understand and reduce uncertainties in the models using newly available upper atmospheric observations in order to provide the best information possible for infrasound source location and characterization.

RESEARCH ACCOMPLISHED

Our models (henceforth HWM/MSIS) provide an elegant solution for infrasound monitoring applications and research. They are publicly available at http://uap_www.nrl.navy.mil/models_web. Given day-of-year, time-of-day, latitude, longitude, altitude, and solar and geomagnetic activity indices the end-user FORTRAN subroutines produce global atmospheric state estimates from the ground to 500 km using a set of harmonic coefficients that have been optimally estimated from the database of historical measurements. Dr. Alan Hedin of the NASA Goddard Spaceflight center developed the HWM/MSIS models over a twenty-year period. They employ meteorological data assimilation techniques and have been produced from a forty-year, multi-instrument database of satellite and ground-based research measurements. Mathematical details of the models and the underlying measurement databases can be found in Hedin *et al.* (1991, 1996) and references therein. These models and our supporting software tools provide an extremely powerful and readily available framework for organizing and making widely available measurements of density, temperature, and wind data from satellite missions, rocket flights, and ground-based observations. Furthermore, now that global near-real time measurements are becoming available above 35 km, these tools are being considered for adaptation to produce near real-time specifications of the atmosphere from the ground to 120 km for use in infrasound monitoring activities.

It is important to consider the uncertainties in the background atmospheric field in order to understand uncertainties in infrasound propagation solutions. Uncertainty estimates and model bias are currently not provided as standard model output. The subsequent production and distribution of these statistical measures will serve two very important purposes for the CTBT and infrasound community. First, these statistical measures can be used to effectively assess the overall performance of the models and the subsequent impact and infrasound source location and characterization. Secondly, once this statistical knowledge is obtained it can be used to upgrade the models.

Data Collection and Organization

The data sets collected for model analysis and improvement effort are shown in Table 1. This table also illustrates the regions of parameter space covered by the data. It is important to note that while certain data sets may extend over several years, observations may have only been collected a small fraction of the time. Each of these diverse data sets was provided different format. Therefore, an investment has been made to reformat, organize, and understand them. A sets of software routines was developed so that each data set can be read from disk and stored in common database format for subsequent analysis.

Statistical Model Performance

The majority of the dominant fluctuations in the upper atmosphere, which are driven by solar heating and periodic wave processes, are generally repeatable from day-to-day and year-to-year and are parameterized in the empirical models. There are, however, some classes of waves and fluctuations that are purely random or even pseudo-random, which cannot be resolved or predicted given the current set of historical

Table 1. Upper atmospheric data sets collect to evaluate HWM/MSIS model performance.

Data type	Measurement kind	Altitude Range	Instrument Name	Dates	Location	Time Coverage
Meteorological Analysis Products	Wind, Temperature Geopotential Height	1000 - .35 mb (0 - 55 km)	United Kingdom Meteorology Office (UMKO) – UARS correlative analysis	1993 – 1994 1996 – 1997	Global 2.5º x 2.5º Grid	12:00 UTC
		10 - .4 mb (35 – 55 km)	Navy Fleet-Numeric STRATOI	Spring 1999	Global 1º x 1º Grid	0:00 and 12:00 UTC
NASA Upper Atmosphere Research Satellite (UARS)	Winds and Temperature	10 – 35 km and 50 – 110 km	High Resolution Doppler Imager (HRDI) (level 2b and 3a version 11)	1991 to present	Near Global +/- 60º	Daytime and 93 km during nighttime
MF Radars	Winds	70 – 110 km	Christmas Island	1993 - 1994	2 N – 157 W	24-hr coverage
			Briebe Island	1996	28 S – 153 E	
Airglow Interferometers	Wind and Temperature	87 and 97 km	Peach Mountain, MI	1995 to 1996	40 N - 83 W	Night
LIDAR	Temperature	80 – 100 km	Colorado State	1993 to present	41 N - 105 W	Night (No cloud cover)
			Urbana, IL	1997 - 1998	40 N - 88 W	

observations. Thus current limitations of the HWM/MSIS models stem from two types of uncertainties – statistical and systematic errors. The statistical occurrence of these fluctuations can however, be estimated given our current models and the newly collected data sets. At times these waves represent a significant source of uncertainty in our models. Several examples of statistical comparisons with the underlying historical data sets are given in Hedin *et al.* (1991, 1996). Several recent papers have also focused on HWM/MSIS model biases using newly collected scientific data sets (see for example Fleming *et al.*, 1996). To date, however, there are no published studies directly involving the calculation of comprehensive statistical measures for these models and the subsequent impact on infrasound source estimation.

Figure 1 shows a histogram analysis of hourly Medium Frequency (MF) radar wind measurements and HWM model predictions for a 3-month period over Christmas Island during spring at an altitude of 90 km. The solid lines indicate the distribution of HWM model predictions. The dashed line indicates the measurement distribution of the zonal wind component. Variance in the HWM model predictions is due to the modeled climatological changes in zonal mean flow and the dominant diurnal and semi-diurnal tidal wind components. The differences in the mean value of the histogram distribution indicate a systematic bias between the MF radar measurements and the HWM model. During this period the HWM model under predicts the magnitude of the zonal mean wind component by approximately 20 m/s. This comparison does not imply that the model is biased everywhere. Furthermore, Figure 1 shows that the MF radar winds exhibit a much broader range of values. This is due to the inability to deterministically model fluctuations on time scales less than 8 hours. The magnitude these short time scale fluctuations in the atmosphere depends highly on altitude, latitude, and season.

To access model performance a variety statistical measures will be calculated. These include model bias, standard deviation, and anomaly correlation (error covariance). Together these measures determine the limitations of the models and parameterize the natural variability of the upper atmosphere.

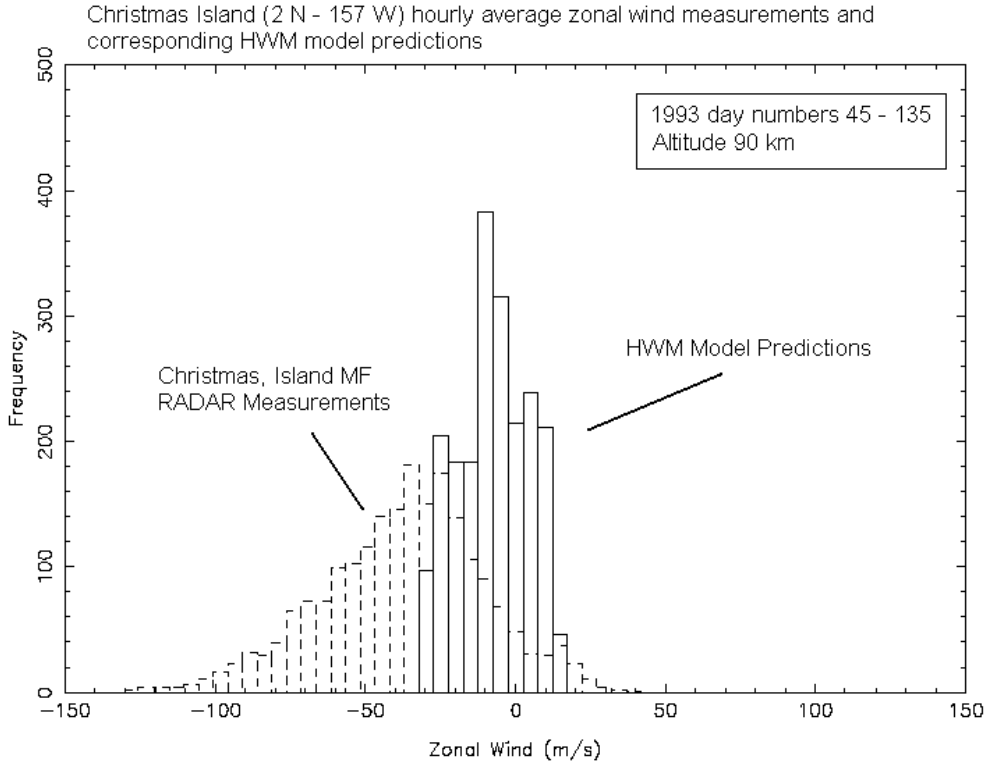

Figure 1. Hourly average wind measurement made at Christmas, Island and the corresponding HWM predictions over a 3-month period indicating a region where model improvement is needed.

CONCLUSIONS AND RECOMMENDATIONS

Application of our models and the pending statistical performance database requires careful consideration, because there are many regions where knowledge may be incomplete. Bias in the current HWM/MSIS models are known to exist. Additional work is needed to understand the impact of atmospheric estimate uncertainties on infrasound source location and characterization. Using the data recently collected for this effort, a better characterization of departures of the HWM/MSIS empirical models from the true state of the atmosphere is being made.

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