Simulating Virtual Terminal Area Weather Data Bases for Use in the Wake Vortex Avoidance System (Wake VAS) Prediction Algorithm

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1. Summary of the Research

During the research project, sounding datasets were generated for the region surrounding 9 major airports, including Dallas, TX, Boston, MA, New York, NY, Chicago, IL, St. Louis, MO, Atlanta, GA, Miami, FL, San Francisco, CA, and Los Angeles, CA. The numerical simulation of winter and summer environments during which no instrument flight rule impact was occurring at these 9 terminals was performed using the most contemporary version of the Terminal Area PBL Prediction System (TAPPS) model nested from 36 km to 6 km to 1 km horizontal resolution and very detailed vertical resolution in the planetary boundary layer (e.g., note Appendix A). The soundings from the 1 km model were archived at 30 minute time intervals for a 24 hour period and the vertical dependent variables as well as derived quantities, i.e., 3-dimensional wind components, temperatures, pressures, mixing ratios, turbulence kinetic energy and eddy dissipation rates were then interpolated to 5 m vertical resolution up to 1000 m elevation above ground level. After partial validation against field experiment datasets for Dallas as well as larger scale and much coarser resolution observations at the other 8 airports, these sounding datasets were sent to NASA for use in the Virtual Air Space and Modeling program. The application of these datasets being to determine representative airport weather environments to diagnose the response of simulated wake vortices to realistic atmospheric environments. These virtual datasets are based on large scale observed atmospheric initial conditions that are dynamically interpolated in space and time employing a numerical simulation model based on a comprehensive hydro-thermodynamical equation set. The 1 km nested-grid simulated datasets providing a very coarse and highly smoothed representation of airport environment meteorological conditions. Details concerning the airport surface forcing are virtually absent from these simulated datasets although the observed background atmospheric processes have been compared to the simulated fields and the fields were found to accurately replicate the flows surrounding the airport where coarse verification data were available as well as where airport scale datasets where available at Dallas (e.g., note Appendix A). The simulated profiles of atmospheric dependent variables can be viewed online at the following links:

Appendix A

Simulating Virtual Terminal Area Weather Data Bases for Use in the Wake Vortex Advisory System – Dallas-Fort Worth Wake-VAS Preliminary Simulation Experiments

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1. Task Overview

This report summarizes research on the development of virtual atmosphere sounding data sets for the Wake-Vortex Advisory System (Wake-VAS) during the summer of 2004. During this period the focus was on generating virtual sounding data sets at Dallas-Fort Worth International Airport (DFW) during the September 1997 AVOSS deployment. Soundings generated by the NHMASS 6.2 model, i.e., the Terminal Area PBL Prediction System (TAPPS), where directly compared to MIT Lincoln Laboratory synthesized observed soundings of u and v wind components as well as observations of 40 m eddy dissipation rate and turbulence kinetic energy at DFW. The comparison would represent evaluations of potential control simulations in anticipation of more complex future simulation studies. This represents precursor analyses in preparation for future simulation experiments in which local observations would be assimilated into the predictive system. These simulated soundings have highly detailed vertical structure for use in diagnosing realistic vertical wind shears, temperature lapse rates and, therefore, potential turbulence generating features in the planetary boundary layer at the DFW airport. The simulations were validated against the MIT observations to diagnose the status of their existing utility as components of a future Wake-VAS predictive system.

2. Modeling System/Numerical Simulation Experiments

The numerical model, NHMASS 6.2, is a nonhydrostatic and terrain following simulation model. This is a nonhydrostatic version of the Terminal Area PBL Prediction System (TAPPS) (Kaplan et al. 2000). The model lid was set at 100 hPa with focused vertical resolution below 1000 m elevation above ground level (AGL). The version of NHMASS employed for these simulation experiments included a 1.5 order prognostic turbulence kinetic energy planetary boundary layer formulation after Therry and Lacarrere (1983) and a convective parameterization scheme after Kain and Fritsch (1992). A comprehensive surface energy budget and soil moisture predictive scheme is utilized in the numerical model so that diurnal radiative forcing of the earth’s surface and hydrological forcing is included in the surface layer of the simulated atmosphere (Mahrt and Pan 1984). Surface soil moisture was set at a climatological value for September in Dallas and land use/land cover databases as well as surface albedo where also generated based on prescribed datasets (Anderson et al. 1976; Noilan and Planton 1989). The eddy dissipation rate formulation ($\epsilon$) employed in diagnostic calculations is consistent with that utilized in the turbulence kinetic energy boundary layer formulation. It is represented by the following expression from Bougeault and Lacarrere (1989) and Therry and Lacarrere (1983):

$$\epsilon = C \varepsilon^{3/2}/\lambda \varepsilon$$  \hspace{1cm} (1)

where:
$e =$ first guess turbulence kinetic energy derived from the full time dependent equation

$C^* =$ a first order numerical coefficient

$\ell =$ a characteristic length scale of the energy-containing eddies

The value of this characteristic length scale ($\ell$) is primarily a function of Richardson number wherein numerous thresholds exist for differing stability and shear regimes in order to differentiate the mixing length of eddies in stable, convective and transitional boundary layers.

The numerical experiments consisted of performing several one-way doubly-nested numerical simulations with NHMASS 6.2 during the September 1997 AVOSS deployment in the Dallas-Fort Worth, Texas metropolitan region. The simulations were centered on DFW. Three numerical grids were employed for these experiments: 1) 36 km horizontal resolution, 2) 6 km horizontal resolution and 3) 1 km horizontal resolution. Matrices included a 100 x 100 x 59, 50 x 50 x 59 and 25 x 25 x 59 grid, respectively, with very detailed and identical vertical resolution within the first 1000 m AGL of the numerical model for all 3 grids. The time periods of integration for the 3 grids were 24 hours, 24 hours and 30 minutes regenerated for the entire 24-hour period, respectively. This means that every 30 minutes a 1 km horizontal resolution simulation was performed from the 6 km simulated initial and lateral boundary condition data. The 6 km initial and lateral boundary conditions were derived from the 36 km simulation, which, in turn received its initial and lateral boundary conditions from NWS ETA gridded analyses, which were reanalyzed with synoptic scale rawinsondes as well as ASOS surface observations. No local (special AVOSS) DFW observations were utilized in the numerical simulations. The initial and lateral boundary condition datasets were solely derived from the NWS ETA analyses gridded fields as well as reanalyzed standard rawinsonde and aviation surface datasets. The simulations were initialized at 8 different time periods, i.e., 0000 UTC 16, 17, 18 and 19 September 1997 (group #1) and 1200 UTC 16, 17, 18 and 19 September 1997 (group #2). The groupings would allow statistical comparisons of the relative accuracy of the simulations comparing 0000 and 1200 UTC initialization times. Vertical soundings were constructed centered on DFW every 30 minutes from the 1 km simulations and interpolated to 5 m vertical resolution for comparison to the available observed fields at 200 levels up to 1000 m AGL. These simulated soundings included the following variables: 1) pressure (hPa), 2) height (m AGL), 3) temperature (K), 4) dew point temperature (K), 5) u wind component (m/s), 6) v wind component (m/s), 7) w wind component (m/s), 8) turbulence kinetic energy (m$^2$/s$^2$) and 9) eddy dissipation rate (m$^2$/s$^3$). These were sent to NASA-Langley for potential use in the Virtual Air Space Modeling Program. Figure 1, below, represents an example of one of these 384 soundings.
Figure 1 – Simulated 5-meter vertical resolution DFW virtual soundings of pressure (hPa), height AGL (m), temperature (K), dew point temperature (K), u wind component (m/s), v wind component (m/s), w wind component (m/s), turbulence kinetic energy (m$^2$/s$^2$), and eddy dissipation rate (m$^2$/s$^3$) valid at 1200 UTC 18 September 1997.

3. Simulation Validation

The validation datasets include DFW synthesized wind soundings, which represented a synthesis of DFW wind profiler, lidar, sodar and anemometer observations, as well as 5 m and 40 m observed eddy dissipation rate estimates prepared by the MIT Lincoln Laboratory (e.g., Dasey et al. 1998). The validation procedure included calculating both absolute errors and root mean square errors at times and levels where direct validation data from MIT where available. This required interpolating MIT Lincoln Laboratory sounding datasets to the same vertical resolution as the TAPPS simulated virtual soundings.

Figures 2-13, below, depict tables of averaged absolute errors (absolute values of errors) of u and v wind component up to 600 m AGL, eddy dissipation rate at 40m AGL and turbulence kinetic energy at 40 m AGL over each group of 4 case studies, i.e., the 1200 UTC and 0000 UTC initialized simulations. Only two time periods of observed data were employed to initialize these simulations, which are validated out through 24 hours. These errors are for a very small sample of case studies and represent a point verification for a group of similar weakly-forced large scale environments. Additionally, the MIT profiles may have systematic biases as they represent a synthesis of numerous sensor-derived observations with their own intrinsic biases and errors. The u and v wind component versus height validation (Figures 2-5) represent direct comparison of averaged observations versus averaged simulated fields over each group of 4 case studies at specific heights for all times. The u and v wind component versus time validation (Figures 6-9) represent averaged observations versus averaged simulated fields over each group of 4 case studies for all heights at specific times. Note that the observed datasets were missing at times specified on each diagram. Only 40 m turbulence kinetic energy and eddy dissipation rate errors could be calculated since the 5 m simulated fields were not available due to their being below the first model level of ~7 m AGL.

Specific findings of these small numbers of case studies can be summarized by the following general conclusions concerning u and v wind component errors versus height and time:

1) The u component errors exhibited little height dependence while the v component errors exhibited significant relative height dependence from both groups.
2) The 1200 UTC initialized u and v component errors were much smaller than the 0000 UTC initialized u and v component errors versus height and time.

3) The u and v component errors are similar in magnitude when initialized at 1200 UTC but the v component is much larger than the u component wind error initialized at 0000 UTC.

4) The maximum error with respect to height for both groups and both components is at ~400 m +/- ~100 m AGL.

5) The maximum error with respect to time for both groups is during the midafternoon period.

6) Both the u and v wind components exhibited double temporal error maxima from the 0000 UTC initialized simulations but only a single temporal maxima from the 1200 UTC simulations.

7) The u and v components exhibited a double temporal minima in the 1200 UTC simulations but not in the 0000 UTC simulations where a single temporal minima occurred.

As far as eddy dissipation rate and turbulence kinetic energy errors are concerned (note Figures 10-13):

1) Eddy dissipation rate errors peak ~10^{-2} m^2/s^3 after the first 30 minute period but then drop to ~10^{-3} m^2/s^3 for the remainder of the simulation for both groups.

2) Turbulence kinetic energy errors are consistent with wind component errors in terms of their temporal variation.

The most important general and preliminary findings to be derived from these experiments are the following:

1) 1200 UTC initial data enabled a much more accurate simulation of nocturnally-forced boundary layer jets as well as, possibly, the background synoptic flow regime at DFW. This is likely because the 1200 UTC large scale analyses contained more of a signal of these boundary layer features, in particular, which had not developed at 0000 UTC and where, therefore absent from the larger scale initial datasets at 0000 UTC. May also be, in part, a result of the times of the availability of observations.

2) The v wind component variance is much more pronounced in the lower troposphere for nocturnal boundary layer jets than is the u wind component variance.

3) The simulation of stable boundary layer may lend itself to deterministic simulation better than the convective boundary layer does as errors tended to peak during the period of most significant surface sensible heating and convective overturning within the boundary layer.

4) Eddy dissipation rate simulation is likely very sensitive to the initial data and initial data adjustment processes employed in a deterministic numerical model as these
errors peaked right after model initialization. Overall these errors were very large but are likely highly sensitive to the formulation employed for both the observations and simulations reflecting differences in these formulations.

5) The most frequent level of the nocturnal boundary level jets at DFW is ~400 m AGL.

Figure 2 – Simulated averaged u wind component errors (m/s) versus height (m AGL) from the 1200 UTC initial data.
Figure 3 – Simulated averaged u wind component error (m/s) versus height (m AGL) from the 0000 UTC initial data.
Figure 4 – Simulated averaged v wind component error (m/s) versus height (m AGL) from the 1200 UTC initial data.

Figure 5 – Simulated averaged v wind component error (m/s) versus height (m AGL) from the 0000 UTC initial data.
Figure 6 – Simulated averaged u wind component error (m/s) versus time (hr) from the 1200 UTC initial data.
Figure 7 – Simulated averaged u wind component error (m/s) versus time (hr) from the 0000 UTC initial data.

Figure 8 – Simulated averaged v wind component error (m/s) versus time (hr) from the 1200 UTC initial data.
Figure 9 – Simulated averaged v wind component error (m/s) versus time (hr) from the 0000 UTC initial data.
Figure 10 – Simulated averaged eddy dissipation rate error (m$^2$/s$^3$) versus time (hr) at 40 m AGL from the 1200 UTC initial data.

Figure 11 – Simulated averaged eddy dissipation rate error (m$^2$/s$^3$) versus time at 40 m AGL from the 0000 UTC initial data.
Figure 12 – Simulated averaged turbulence kinetic energy error (m²/s²) versus time at 40 m AGL from the 1200 UTC initial data.
Figure 13 – Simulated averaged turbulence kinetic energy error (m$^2$/s$^2$) versus time at 40 m AGL from the 0000 UTC initial data.

4. References


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