TERC Project H24-2003

Meteorological Model Improvements Using the Ensemble Kalman Filter: Final Report

December 14, 2004

John Nielsen-Gammon, Fuqing Zhang, Amy Stuart, Altug Aksoy and Naifang Bei
Department of Atmospheric Sciences
Texas A&M University
College Station, Texas

Contact Information:
John W. Nielsen-Gammon (PI)
Dept. of Atmospheric Sciences
Texas A&M University
3150 TAMU
College Station, TX 77843-3150
n-g@tamu.edu
979-862-2248
979-862-4466

1. Introduction

The primary goal of project H24-2003 is to investigate the potential of the Ensemble Kalman Filter (EnKF) as a tool for improved Houston air quality forecasts. A second goal is to apply the filter in MM5 to assess observing network siting configurations and to assess the potential effectiveness of targeted observations during air quality field projects in preparation for the upcoming TexAQS II field study.

The Ensemble Kalman Filter is a flexible data assimilation technique designed to combine (1) observational data over time, (2) knowledge of the physical and chemical behavior of the atmosphere (as represented by predictive models), and (3) information on the error in both the observed information and the model representation. Through combining this information, the EnKF can provide a more accurate description of the state (e.g. multidimensional information on wind speeds, wind directions, temperatures, and chemical concentrations) of the atmosphere and its expected evolution in time. The technique also provides information on the uncertainty in the predicted state. The EnKF has been applied successfully to improve forecasts for large-scale weather systems and small-scale convective systems, but has largely been untested for systems, including Houston air quality forecasting, for which nonlinear error growth fundamental to the dynamics of the system does not drive the system variability (uncertainty). However, due to its ability to incorporate uncertainty information, the EnKF has promise for improving Houston air quality forecasts for which the largest sources of uncertainty are errors in both initial condition information and model parameterizations. Due to its prediction of multidimensional uncertainty information, the EnKF also has promise as tool for determining locations where additional information will decrease model uncertainty most, and hence should be obtained through appropriate network siting configuration and targeted observations.

In this report, we will discuss the current progress of our investigation of the use of the EnKF for improved Houston air quality forecasts and observational network siting. We will discuss our progress on several fronts of the project in turn. These fronts include application of the ensemble MM5 modeling system to Houston air pollution meteorology to understand the error dynamics and covariance structure for the sea breeze circulation, application of the EnKF for one-time assimilation with synthetic observations to determine the improvement offered by the filter, and proof-of-concept tests for parameter estimation and concentration observational network siting with the EnKF in a two-dimensional model.

7. Project Summary

Under the support of this project, we have successfully designed and implemented an EnKF data assimilation system based on MM5 and applicable to Houston which uses a synthetic observations to understand the error dynamics and covariance structure for the sea-breeze scenario (Task 1).

We have built the observation operator to assimilate profiler data and surface observations during the 2000 episode through nudging (Task 2). Due to the rearrangement of priorities resulting from interesting unexpected avenues that have arisen during the pursuit of the project goals, especially those on evaluating the importance of meteorological uncertainties through photochemical ensemble forecasting, a quantitative comparison to gauge the accuracy of the EnKF technique relative to the standard nudging technique has not been completed.

Also, we have performed numerous experiments to refine and improve the EnKF assimilation of profiler and surface data via proof-of-concept tests (Task 3). With the development of a 2-D seabreeze model, we have the ability to do parameter estimation simultaneously with state estimation, which has the great potential to estimate and correct parametric model errors. We also successfully built a CO tracer into the 2-D model to examine the effect of meteorological model errors on tracer concentrations.

Furthermore, we successfully implemented the EnKF technique, with some combination of simple chemical transport, and parameterization modification, in an application to the assessment of observing network siting issues and potential effectiveness of targeted observations during air quality field programs (Task 4).

In addition to continued progress on the above tasks, we now have the capability to perform ensemble modeling with photochemical models. This enables us to investigate the relative sensitivity of photochemical model output to meteorology and emissions uncertainties. It also enables us to determine correlations between predicted quantities, such as ozone, and precursor emissions, such as particular hydrocarbons.

The successes of the project have led to three papers which are soon to be submitted to leading journals, one on nudging and two on model parameter estimation. A couple of other papers are also planned, one on the impact of meteorological uncertainties on ozone prediction and the other on proof of concept CO tracer study.