Recent Ensemble Simulations for Data Assimilation and Photochemistry Sensitivity to Meteorology

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This poster presents abstracts from recently-published papers dealing with the numerical simulation of air quality in idealized circumstatnces or for TexAQS-2000 case study analysis.

Ensemble Kalman Filter and Parameter Estimation

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Ensemble-based data assimilation for thermally forced circulations

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Abstract

The effectiveness of the ensemble Kalman filter (EnKF) for thermally forced circulations is investigated with simulated observations. A two-dimensional, nonlinear, hydrostatic, non-rotating, and incompressible sea breeze model is developed for this purpose with buoyancy and vorticity as the prognostic variables. Model resolution is 4 km horizontally and 50 m vertically. Forcing is maintained through an explicit heating function with additive stochastic noise. Pure forecast experiments reveal that the model exhibits moderate nonlinearity. The strongest nonlinearity occurs along the sea breeze front at the time of peak sea breeze phase. Considerable small-scale error growth occurs at this phase for vorticity, while buoyancy is dominated by large-scale error as the direct result of the initial condition uncertainty. In the EnKF experiments, simulated buoyancy observations (with assumed error of 10_3 ms_2) on land surface with 40-km spacing are assimilated every 3 hours. As a result of their resolution, the observations naturally sample the larger-scale flow structure. At the first analysis step, the filter is found to remove most of the large-scale error resulting from the initial conditions and the domain-averaged error of buoyancy and vorticity is reduced by about 83% and 42%, respectively. Subsequent analyses continue to remove error at a progressively slower rate and the error ultimately stabilizes within about 24 hours for both variables. At later model times, while mostly large-scale buoyancy errors due to the stochastic heating uncertainty are effectively removed, the filter also performs well at reducing smaller-scale vorticity errors associated with the sea breeze front. This is an indication that observations also contain useful small-scale information relevant at the scales of frontal convergence.

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Keywords: data assimilation; ensemble Kalman filter; forced circulations.

Index Terms: 3307 Atmospheric Processes: Boundary layer processes; 3315 Atmospheric Processes: Data assimilation; 3329 Atmospheric Processes: Mesoscale meteorology; 3355 Atmospheric Processes: Regional modeling.

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Ensemble-based simultaneous state and parameter estimation with MM5

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Abstract

The performance of the ensemble Kalman filter (EnKF) under imperfect model conditions is investigated through simultaneous state and parameter estimation for a numerical weather prediction model of operational complexity (MM5). The source of model error is assumed to be the uncertainty in the vertical eddy mixing coefficient. Assimilations are performed with a 12-hour interval with simulated sounding and surface observations of horizontal winds and temperature. The mean estimated parameter value nicely converges to the true value within a satisfactory level of variability due to sufficient model sensitivity to parameter uncertainty and detectable (relative to ensemble sampling noise) correlation signal between the parameter and observed variables.

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Ensemble-Based Simultaneous State and Parameter Estimation in a Two-Dimensional Sea-Breeze Model

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ABSTRACT

The performance of the ensemble Kalman filter (EnKF) in forced, dissipative flow under imperfect-model conditions is investigated through simultaneous state and parameter estimation where the source of model error is the uncertainty in the model parameters. A two-dimensional, nonlinear, hydrostatic, nonrotating, and incompressible sea-breeze model is used for this purpose with buoyancy and vorticity as the prognostic variables and a square root filter with covariance localization is employed. To control filter divergence caused by the narrowing of parameter variance, a "conditional covariance inflation" method is devised. Up to six model parameters are subjected to estimation attempts in various experiments. While the estimation of single imperfect parameters results in error of model variables that is indistinguishable from the respective perfect-parameter cases, increasing the number of estimated parameters to six inevitably leads to a decline in the level of improvement achieved by parameter estimation. However, the overall EnKF performance in terms of the error statistics is still superior to the situation where there is parameter error but no parameter estimation is performed. In fact, compared with that situation, the simultaneous estimation of six parameters reduces the average error in buoyancy and vorticity by 40% and 46%, respectively.

Several aspects of the filter configuration (e.g., observation location, ensemble size, radius of influence, and parameter variance limit) are found to considerably influence the identifiability of the parameters. The parameter-dependent response to such factors implies strong nonlinearity between the parameters and the state of the model and suggests that a straightforward spatial covariance localization does not necessarily produce optimality.

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Ensemble-based data assimilation and targeted observation of a chemical tracer in a sea breeze model

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Abstract

We study the use of ensemble-based Kalman filtering of chemical observations for constraining forecast uncertainties and for selecting targeted observations. Using a coupled model of two-dimensional sea breeze dynamics and chemical tracer transport, we perform three numerical experiments. First, we investigate the chemical tracer forecast uncertainties associated with meteorological initial condition and forcing error. We find that the ensemble variance and error builds during the transition between land and sea breeze phases of the circulation. Second, we investigate the effects on the forecast variance and error of assimilating tracer concentration observations extracted from a truth simulation for a network of surface locations. We find that assimilation reduces the variance and error in both the observed variable (chemical tracer concentrations) and unobserved meteorological variables (vorticity and buoyancy). Finally, we investigate the potential value to the forecast of targeted observations. We calculate an observation impact factor that maximizes the total decrease in model uncertainty summed over all state variables. We find that locations of optimal targeted observations remain similar before and after assimilation of regular network observations. © 2006 Elsevier Ltd. All rights reserved.

Author Keywords

Adaptive observations; Air quality modeling; Data assimilation; Ensemble modeling

Wind Profiler Nudging

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Mesoscale model performance with assimilation of wind profiler data: Sensitivity to assimilation parameters and network configuration

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Abstract

The performance of the nudging scheme in the MM5 numerical model is evaluated for a 4-day simulation of an ozone episode during the TexAQS-2000 field study. Quality-controlled horizontal wind data from five boundary layer profilers spaced 30–50 km apart are used as input data for the nudging as well as for quantification of model errors. Observations from selected profilers are withheld to provide independent data to evaluate the performance of the model. A series of experiments are conducted to estimate the overall model performance as well as the dependence of the model performance on nudging parameters and on profiler network configuration. Within the profiler network, nudging generally reduces 4-day average biases in the wind components to less than 0.3 m s_1 and yields rms errors averaging 1.75 m s_1 to 2.08 m s_1, with the best model performance at about 500–1500 m above ground level. Rms errors without data assimilation are about twice as large. Model errors, with and without assimilation, are generally largest at night. Wind fields that are more accurate in a statistical sense can be obtained by simpler analysis schemes, but the consistent dynamical evolution of all meteorological variables, such as the pattern of temperatures associated with corrected sea breeze location and intensity, are lost. Tests with a reduced profiler network showed that a single profiler in an appropriate upstream location can produce model performance equivalent to that from a four-profiler network surrounding the validation station.

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Keywords: nudging; MM5; wind profiler.

Index Terms: 3315 Atmospheric Processes: Data assimilation; 3355 Atmospheric Processes: Regional modeling; 0345 Atmospheric Composition and Structure: Pollution: urban and regional (0305, 0478, 4251).

Ozone Sensitivity to Meteorology

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Impacts of meteorological uncertainties on ozone pollution predictability estimated through meteorological and photochemical ensemble forecasts

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Abstract

This study explores the sensitivity of ozone predictions from photochemical grid point simulations to small meteorological initial perturbations that are realistic in structure and evolution. Through both meteorological and photochemical ensemble forecasts with the Penn State/NCAR mesoscale model MM5 and the EPA Community Multiscale Air Quality (CMAQ) Model-3, the 24-hour ensemble mean of meteorological conditions and the ozone concentrations compared fairly well against the observations for a high-ozone event that occurred on 30 August during the Texas Air Quality Study of 2000 (TexAQS2000). Moreover, it was also found that there were dramatic uncertainties in the ozone prediction in Houston and surrounding areas due to initial meteorological uncertainties for this event. The high uncertainties in the ozone prediction in Houston and surrounding areas due to small initial wind and temperature uncertainties clearly demonstrated the importance of accurate representation of meteorological conditions for the Houston ozone prediction and the need for probabilistic evaluation and forecasting for air pollution, especially those supported by regulating agencies.

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Keywords: air quality modeling; meteorological and photochemical ensemble forecasts; ozone predictability.

Index Terms: 0345 Atmospheric Composition and Structure: Pollution: urban and regional (0305, 0478, 4251); 0368 Atmospheric Composition and Structure: Troposphere: constituent transport and chemistry; 3329 Atmospheric Processes: Mesoscale meteorology; 3355 Atmospheric Processes: Regional modeling.

Abstract and References