General knowledge expectations for materials taught by Dr. Xue

You should clearly understand the concepts of data assimilation and the analysis/assimilation methods covered in this course. You should know the main characteristics and the strength and weaknesses of these schemes, and be able to compare and contrast them, including solution accuracy, physical meaning, practical implementation issues and cost.

You are not expected to memorize or derive in the exam complete solutions of various analysis schemes in matrix form, but you should be able to do so for the equations in scalar form and apply the solution to simple examples.

You should understand fully the matrix-form equations and solutions, and be able to recognize the terms in standard notations. You should be able to interpret the meaning of each term and each variable in the equations, and their role in and effect on the solutions.

You should know the procedure by which various analysis solutions are obtained and how such solutions are implemented computationally in practical data assimilation systems. You should be able to perform basic matrix operations, and know the general rules of such operations.

More specifics:

- Know and be able to use the standard notion of data assimilation
- Understand the concept and role of observation operator
- Know the underlying assumptions of and the procedure by which OI solution is obtained, and the physical meaning of the solution
- Know the definition of errors and error covariance matrix
- Know various concepts/terminologies such innovation, incremental, background, first guess, weight.
- Given the OI solution, be able to describe the numerical procedure for obtaining the solution
- Know common practices, such as observations election/domain partitioning to make OI solution more tractable and issues/problems involved
- Be able to apply the OI solution to simple problems and be able to interpret the results
- Know common methods to estimate static background error covariance statistics, and commonly used simplifications/approximations, and issues involved
- Understand the role and effects of background error covariance

- Understand and be able to interpret the 3DVAR cost function
- Understand the 3DVAR solution, and how it's analytical solution is obtained and the relation to the IO solution
- Understand the probabilistic framework, including the underlying assumptions, for the choice of the 3DVAR cost function, and the physical meaning of the 3DVAR solution.
- Understand and be able to describe the typical procedures of 3DVAR minimization, and know the issues involved in numerically finding the minimizing solution of 3DVAR for realistic atmospheric data assimilation systems that involve nonlinear observation operators.
- Know incremental 3DVAR, and its formulation, and the reasons for using the incremental form, including issues it addresses.
- Have some idea about the preconditioning, via variable transform, of 3DVAR systems.
- Know the use of filter to model and achieve the effect of background error covariance

- Understand the 4DVAR, concept, formulation, procedures, underlying assumptions, as well as advantages as compared to simpler schemes such as 3DVAR.
- Understand the role of tangent linear model and joint in 4DVAR systems.
- Know the procedure of incremental 4DVAR and the use of double-loop procedure

- Know the importance and effects of flow-dependent background error covariances.
- Know the general steps and characteristics of extended Kalman filter (EKF).
- Know the general methodology of ensemble-based data assimilation, in particular, the ensemble Kalman filter (EnKF) and how it calculates flow-dependent error covariances.
- Know two commonly used algorithms of ensemble Kalman filter, their general methodology, though not necessarily memorizing their equations.
- Know the practical issues involved in using EnKF

- For all of the above methods, know their strengths and weaknesses, in terms of both accuracy and cost, and know how the different methods are inter-related to each other.