P1.4 **DATA ASSIMILATION INTO A LES MODEL: RETRIEVAL OF IFN AND CCN CONCENTRATIONS**

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1. INTRODUCTION

This abstract presents the basic configuration of an aerosol retrieval method based on assimilating vertically integrated quantities into a microscale model. The Large Eddy Simulation (LES) version of the CSU Regional Atmospheric Modeling System (RAMS@CSU) and a Maximum Likelihood Ensemble Filter algorithm (MLEF, developed at CSU) were chosen to examine the feasibility of retrieving cloud-nucleating aerosol by assimilating real observations.

Data assimilation into a micro-scale model introduces several unique problems. Among them, allowing each ensemble member a (spin-up) time to develop an eddy distribution (stable turbulence statistics) physically consistent with the new (perturbed) optimal model state after each assimilation cycle, and taking into account aspects not resolvable within the framework of a LES model such as large-scale (L-S) tendencies.

We performed numerous experiments assimilating real observations to analyze the response of cloud-nucleating aerosol concentrations to the potential optimization of the model state. The state vector was configured to include the concentrations of different types of aerosol (prognostic variables within RAMS@CSU), and the number concentration and mixing ratio of all water species

The aerosol retrieval method is being evaluated for different boundary-layer (BL) cloud cases. Results indicate that data assimilation enhanced several aspects of the LES model performance in simulating the microstructure of the BL clouds. The most encouraging result was that model successfully reproduced the observed presence of a polluted air mass above the inversion for a well-documented mixed-phase Arctic BL cloud when only liquid and ice water paths were assimilated.

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2. THE COUPLED MODEL

2.1 *Selection and Implementation of the Data Assimilation Algorithm*

The MLEF algorithm (Zupanski 2005; Zupanski and Zupanski 2005) has been selected for this study. The algorithm calculates optimal estimates of the model state, error (bias) and empirical parameters, employing a maximum likelihood approach. It also calculates uncertainties of all estimates in terms of analysis and forecast error covariance. This algorithm presents an important advantage (compared to the classical ensemble Kalman filter) as it does not make any assumption about the shape in the probability density function of the model state (e.g., symmetry).

In order to include the LES version of RAMS@CSU into the MLEF algorithm, several interface routines have been developed. On the one hand, routines to consider as model state variables, the concentrations of ice forming and cloud condensation nuclei (IFN and CCN), giant CCN (GCCN) and the number concentration and mixing ratio of all eight water species considered by RAMS@CSU (cloud droplets, drizzle drops, rain drops, pristine ice crystals, snow crystals, aggregates, graupel, and hail). On the other hand, several routines had to be added to deal with algorithmic issues related to the specifics of the LES model (see subsection 2.2). The algorithm can assimilate various types of real observations: vertically integrated ice and liquid water paths (IWP, and LWP, respectively), and long wave and short-wave downwelling radiative fluxes at the surface (LWDN, and SWDN, respectively), and/or radiances.

2.2*) Configuration of Retrieval Method*

The basic approach used to retrieve cloud-nucleating aerosol concentrations can be described as follows:

● From a selected location at which the concentrations want to be estimated, we simulate *backward* trajectories over regions where BL clouds prevail (using a mesoscale model).

● Collect observational data to be assimilated along the trajectories.

● Run ensembles of *forward* LES simulations with a domain that moves along the trajectory, considering the large L-S tendencies provided by the *backward* simulations, and periodically assimilating observations.

● Aerosol concentrations are retrieved at the end of the *forward* simulations (the selected location).

As mentioned in the previous section, each ensemble member needs a spin-up time to develop stable turbulence statistics. During these spin-up periods preceding the forecast runs (FCST), the horizontally averaged model state vector is not allowed to change. A Newtonian relaxation technique (nudging) is used to preserve this 1-D version of the state vector while the 2-D/3-D model develops perturbations consistent with these updated vertical profiles. The L-S scale tendencies and the changes induced by the motion of the LES domain (e.g., surface properties, solar angles, SSTs, etc) are taken into account only during the FCST runs. The resulting configuration can be described as follows:

I) The *first* ensemble of LES simulations is randomly designed.

II) L-S tendencies (and surface changes) are applied to each member till an assimilation time is reached.

III) Observational data is assimilated, and an *optimal* state of the model computed by minimization of a cost function. If it is not the last cycle continues with **IV)**.

IV) A new ensemble of LES simulations is generated adding to the optimal state perturbations based in error covariance matrices.

V) Each ensemble member has its spin-up period to allow the model developing an eddy distribution physically consistent to the new (perturbed) optimal state.

VI) During spin-up period: time and sun angles "freeze", no L-S tendencies are applied, and a 1-D version of the state is nudged.

VII) When spin-up period ends, *time* starts evolving and returns to step **II)**.

VIII) Aerosol concentrations are retrieved from last cycle's optimal model state.

Schematic representations of the proposed aerosol retrieval method and the maximum likelihood ensemble filter are given in Figs. 1 and 2, respectively.

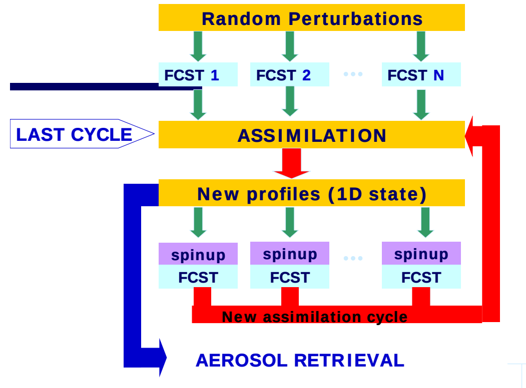

Figure 1. Aerosol retrieval method.

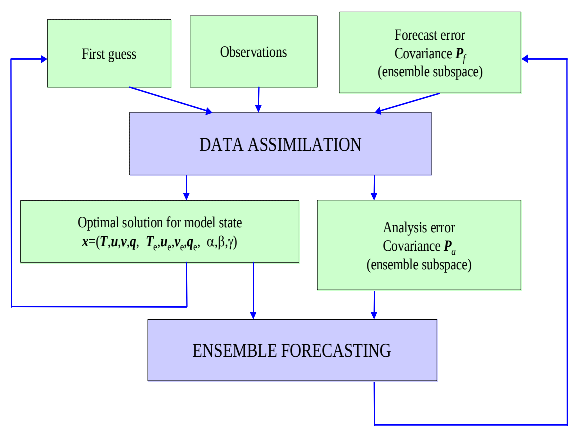

Figure 2. Maximum likelihood ensemble filter.

3. ASSIMLIATION OF REAL OBSERVATIONS

3.1 *May 4 1998 Arctic BL Cloud Case*

We are particularly interested in this SHEBA field experiment because of several reasons: it was a mixed-phase cloud, both IN and CCN vertical profiles have been documented, and we previously studied this case (Carrió et al., 2005a and b). The CCN concentrations (obtained using the instantaneous CCN spectrometer of the Desert Research Institute) were approximately 100 and 250 cm^{-3} below and above the inversion, respectively (Yum and Hudson, 2001) . The IFN vertical profile derived from the CSU continuous flow diffusion chamber ice nucleus counter data, exhibited relatively large concentrations above the boundary layer with a maximum value of

85.6L^{-1}, while below the inversion the vertical average is approximately 3L^{-1} (Rogers et al., 2001). Finally, the presence of this moderately polluted air mass above the inversion, makes this case of Arctic boundary layer cloud case of particular interest to examine feasibility of retrieving cloud-nucleating aerosol by assimilating real observations into a LES model.

3.2 *Simulation Conditions*

All experiments have been performed within a 2-D framework (Nx=100, Nz=100). Model domain was approximately located at ~ 76N, 165W. A horizontal resolution of 50m, a vertical resolution of 30m, and a timestep of 2s were used. The lateral boundary conditions were cyclic and the domain top is a rigid lid. High-resolution SHEBA soundings were used for initialization and L-S tendencies. Ensemble simulations were initialized at 18:00 UTC May 2 1998 (no cloud observed at this time). IFN and CCN concentrations were homogeneously initialized with typical clean values ([IFN]=4L-^{1}, [CCN] =100cm^{-3}) both below and above the inversion. Two-moment microphysics was used for all water species.

Observed LWP/IWP and/or SWDN/LWDN were assimilated with a frequency of 2h. Simulations cover a period of 54 hours, although, no assimilation is performed during the first 8 hours (23 cycles). We performed several experiments considering different ensemble sizes: 50, 100, 200, and free run (control).

3.3 *Main Results*

Figure 3 compares the model simulated LWP for the control run (purple), 50 (green) and 100 (red) ensemble members, and the observed values (black). This figure shows how the model rapidly corrects the underprediction of liquid water in the simulated cloud.

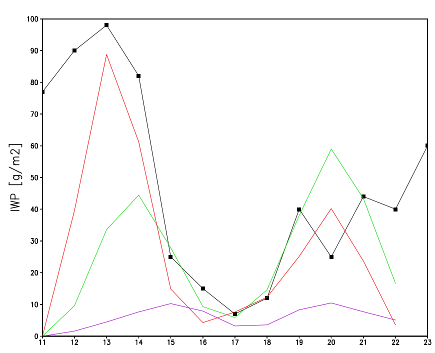

Figure 3. Comparison of observed liquid water paths and values simulated for different ensemble members.

The temporal evolutions of IWC vertical profiles corresponding to 50, 100, and 200 members, and the radar values are given in Figure 4. Assimilation enhances both timing and vertical structure of the simulation. It is important to note that only the vertically integrated values are assimilated (IWP) and therefore vertical structure of IWC is "independent".

The horizontally averaged IFN concentrations corresponding to the control run and 48 ensemble members are given in Figs 5a and b. While all numerical simulations were initialized with low aerosol concentrations typical of a pristine Arctic environment, the LES model was successful in reproducing the observed presence of a moderately polluted air mass above the inversion (bottom panel of Fig.5).

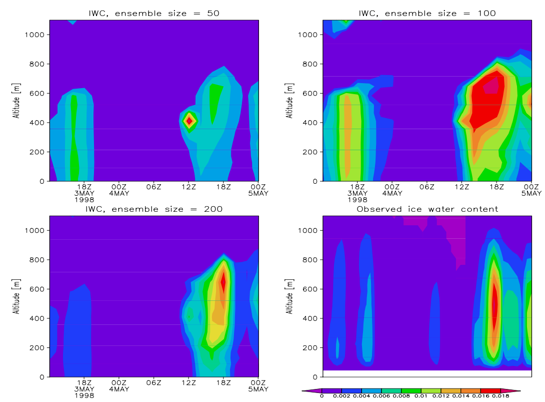

Figure 4. Observed and simulated ice water contents for different ensemble members.

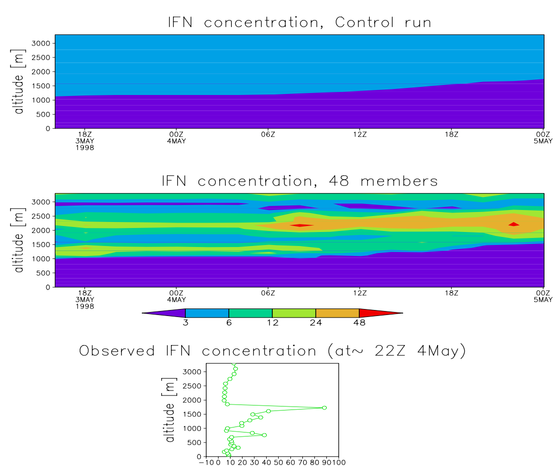

Figure 5. Temporal evolution of simulated IFN profiles (a and b). Panel c shows the observed concentrations at 22UTC.

A layer of high IFN concentrations develops above the inversion for the experiments with data assimilation, while for the control run (top panel), only a decrease below the inversion due to the activation can be observed.

Simulated CNN concentrations exhibited a similar behavior (Fig 6). As mentioned in section 3.1, observed CCN concentrations exceeded 250 cm^{-3} above the inversion, while there were significantly lower within the boundary layer.

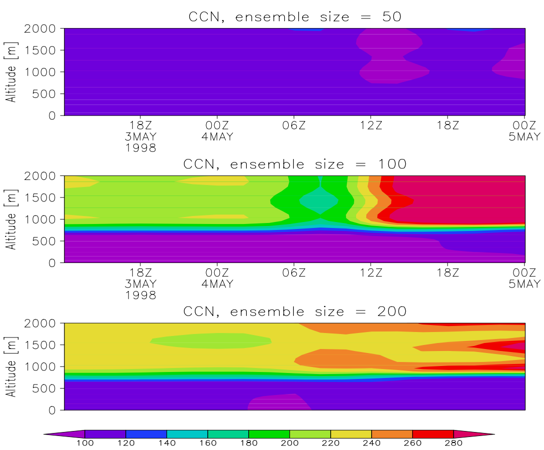

Figure 6. Temporal evolution of simulated CCN for different ensemble sizes/

It must be noted that IFN and CCN concentrations are *not* assimilated and therefore are independent observations.

5. SUMMARY AND CONCLUSIONS

The Maximum Likelihood Ensemble Filter algorithm has been adapted to assimilate data into the LES version RAMS@CSU. The proposed aerosol retrieval method was tested with simple observational operators with encouraging results, and we are now performing similar test with different BL cloud cases.

We plan to perform series of data assimilation experiments using observational operators of increasing complexity (i.e., satellite radiances) in order to find the optimal configuration of the aerosol retrieval method (e.g., observations to be assimilated (e.g. bands), number of ensemble members and minimization iterations, assimilation frequency, etc) .

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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