

LES Modeling of Aerosol and Drizzle Effects in Marine Stratocumulus

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LONG-TERM GOALS

The development and improvement of cloud microphysical and radiative parameterizations for use in cloud scale models

OBJECTIVES

Investigation of marine stratocumulus clouds microphysics and radiative processes using the CIMMS LES model with explicit microphysics and radiation. The model simulations based on data from ASTEX and MAST field programs will be used to improve our understanding of the interactions between microphysical, radiative, and thermodynamical processes and to refine parameterizations of microphysical and radiative processes.

APPROACH

The modeling part of the research is based on the CIMMS 3-D LES model of boundary layer stratocumulus clouds with explicit formulation of aerosol and drop size-resolving microphysics. The model has been thoroughly verified against observations from ASTEX and other field programs. The University of Oklahoma PhD student, Mr. Alexei Belochitski, will use the model to generate 3D data fields and to calculate the rates of various microphysical processes needed to find relations between bulk variables that can be forecasted in numerical weather prediction models. Dr. Mikhail Ovtchinnikov will use the 3D drop size distributions to calculate the optical properties of clouds and study radiative transfer in inhomogeneous cloud media based on a 3D Monte Carlo radiative transfer model.

WORK COMPLETED

1. We are developing a conceptually new parameterization of cloud physics processes based on the full moments of drop size distributions (DSD) as opposed to partial moments used in Kessler-type parameterizations. At present, we have completed the most difficult part of the parameterization, which is derivation of coagulation rates based on non-linear regression analysis of explicit coagulation rates provided by the LES model.
2. In a separate study we are investigating the effect of CCN shape on cloud drop microstructure using LES experiments based on data from ASTEX field program.
3. We have developed a new parameterization of cloud drop effective radius for use in precipitating marine stratocumulus.
4. The optimal time frequency of radiation calculations in marine stratocumulus has been evaluated.

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RESULTS

1. The new parameterization of cloud physics processes

The new parameterization is based on the full moments of the DSD (N – drop concentration, S – drop total geometrical cross-section, Q – liquid water, P – precipitation flux and Z – radar reflectivity). Under this approach, there is no need to artificially divide microphysical parameters into cloud and precipitation part. As a result, the coagulation rates obtained by non-linear regression analysis of the explicit rates are defined with an error less than 8% (see Fig 1). This is an order of magnitude more accurate than autoconversion or accretion rates in conventional Kessler type parameterizations (Khairoutdinov and Kogan, 1999).

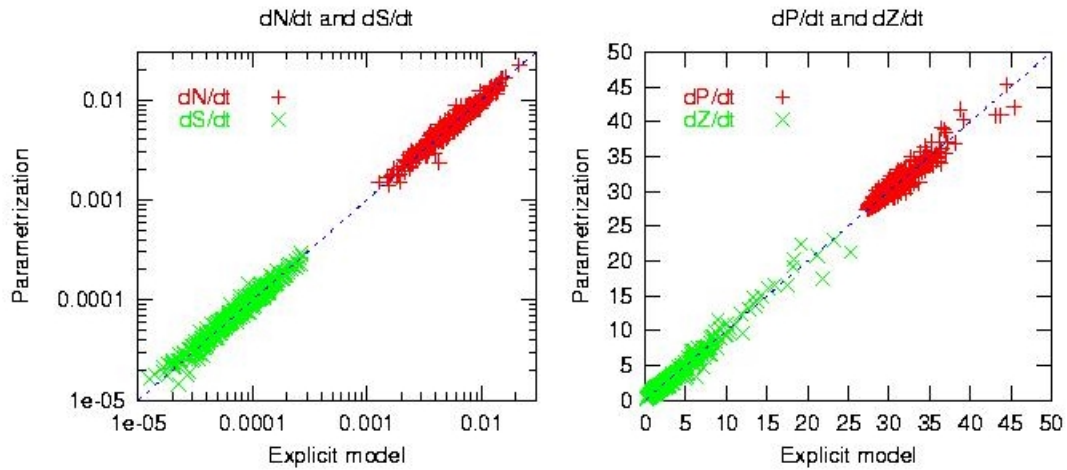


Fig. 1. Parameterized coagulation rates for N , S , P , and Z compared with the exact ones obtained by explicitly solving the coagulation equation.

2. The effect of CCN shape on drizzle and cloud microstructure

LES case studies using CCN spectra in environments with different surface winds showed that drop concentrations depend strongly on surface winds, as well as parameters of the accumulation mode of the spectra comprised of non sea-salt nuclei (nss). We found that, contrary to common belief that clouds with less drop concentration produce more drizzle, the presence of large and giant sea-salt nuclei formed under strong surface wind conditions can lead to increase in drop concentration, as well as increase in drizzle amount (Fig. 2).

3. Parameterization of cloud drop effective radius for drizzling marine boundary-layer clouds

At present, operational forecast models use a variety of formulations for the effective radius. The simplest one prescribe R_e a constant value (8-10 μ over the oceans and 5-6 μ over the land), while the more sophisticated define R_e as a function of $(Q/N)^{1/3}$ (see, e.g., Martin et al. 1994). All parameterizations are based on data from non-drizzling clouds and, to the best of our knowledge, no parameterization exists for precipitating boundary-layer clouds. The goal of the study was to derive such parameterization using LES studies of ASTEX drizzling stratocumulus. Our results show that a parameterization based on three variables: N – drop concentration, Q – liquid content,

Z – radar reflectivity has almost perfect correlation ($r \sim 0.98$) with the exact value (Fig.3). It is given by the expression: $(R_e)_{par} = 33.4Q^{0.26}N^{0.37}(Z+50)^{0.21}$

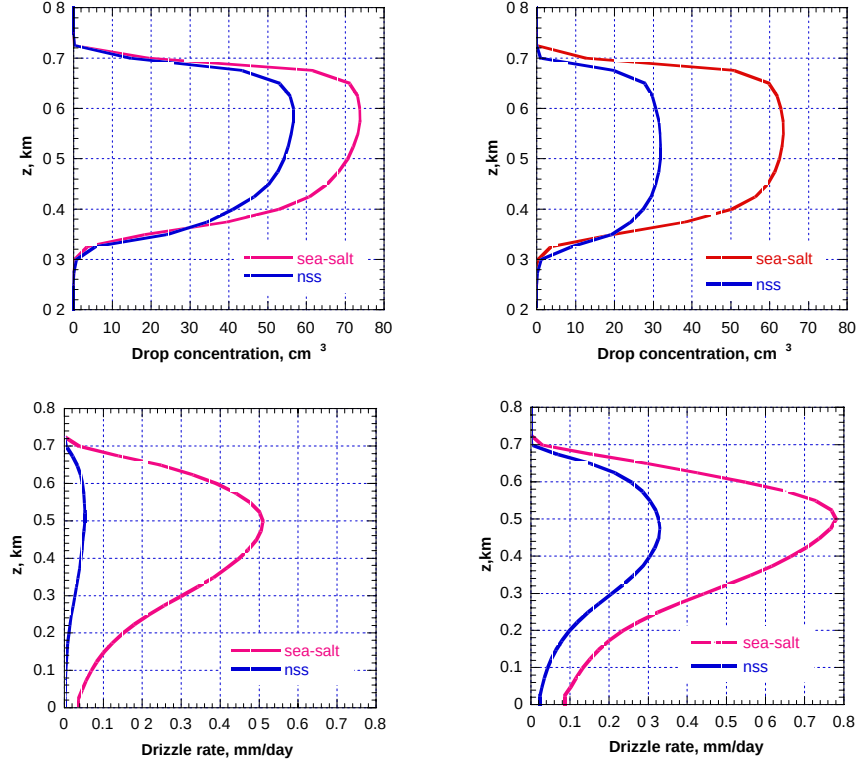


Fig. 2. The effect of adding sea-salt CCN on profiles of drop concentration and drizzle rates in environments with nss concentrations of 55 cm^{-3} (left) and 30 cm^{-3} (right panels).

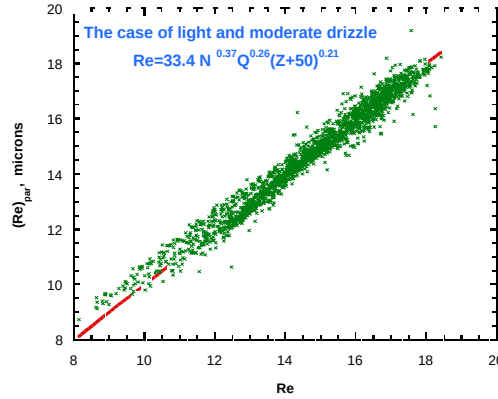


Fig. 3. The scatter plot of R_e parameterized as a function of Q , N and Z versus benchmark R_e .

4. Optimal time increments for radiative calculations in marine stratocumulus

An important and quite time-consuming part of an operational regional forecast model (such as, e.g., US Navy COAMPS model) is calculation of radiative effects. For computer efficiency, the latter are commonly calculated using rather large time steps. In order to find an optimal time increment we need to answer the question: how fast do microphysical fields change with time, or

what is the correlation between microphysical variables used in radiative transfer calculations? As an example, we have calculated the correlation coefficient for the mean volume radius, R_v , a variable closely related to the cloud drop effective radius:

$$C(\tau) = \frac{\frac{1}{N} \sum_{i=1}^N (\varphi_i(0) - \overline{\varphi(0)}) (\varphi_i(\tau) - \overline{\varphi(\tau)})}{\sigma(0)\sigma(\tau)}$$

Here $\varphi_i(0)$ is the value of $R_v(t)$ at time t and grid point i in a horizontal plane ($i=1,N$), $\varphi_i(\tau)$ is $R_v(t+\tau)$, σ is the standard deviation of R_v , τ varies from 0 to 600 s with 10 s time increments.

The isolines of the correlation coefficient shown in Fig. 4 as a function of z and τ indicate that temporal correlation is higher at cloud top and weaker at cloud base. As shortwave warming is larger near the cloud base, the variability in this region is the primary factor in defining the optimal time step. During the first 1-2 minutes the correlation is ≈ 0.9 and falls to 0.5 at 5 min. For larger time increments (≈ 10 min), the correlation is rather weak everywhere in the cloud (≈ 0.4 -0.6) and may result in large errors in calculation of radiative heating and cooling rates. We conclude that time increments for radiation calculations larger than 4-5 minutes may result in errors exceeding the errors due to simplified assumptions in radiative transfer formulation, such as, e.g., plane-parallel or two-stream approximation.

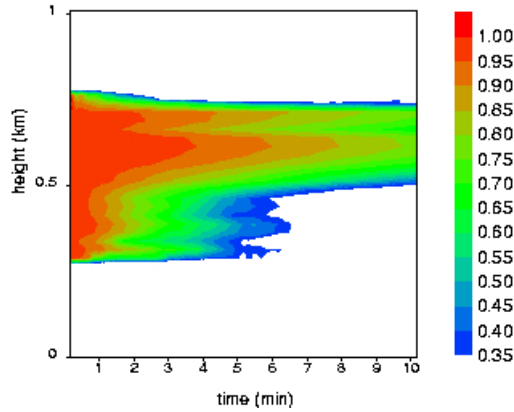


Fig. 4. The isolines of the correlation coefficient for the R_v field in the vertical cross-section through the stratocumulus cloud layer.

IMPACT

The improved parameterization of the physical processes in marine stratocumulus clouds will result in more accurate weather prediction for Navy operations. In particular, the work is aimed at improved prediction of atmospheric visibility, precipitating cloud layers, and cloud optical and radiative parameters. The approach we use to develop physical parameterizations based on LES model data verified against observations is appropriate for future investigations.

TRANSITIONS

The CIMMS drizzle parameterization is implemented into COAMPS model as part of the MURI Grant to the University of Oklahoma. Our results have been reported at three scientific meetings this year, published in conference proceedings and are known to scientific community.

RELATED PROJECTS

The current proposal is aimed at development of physical parameterizations for cloud scale (LES) models. It is related to the ONR project “Remote sensing and prediction of the coastal marine boundary layer” (N00014-96-1-1112) awarded to the University of Oklahoma under the MURI program. The latter goal is to develop and implement physical parameterizations into mesoscale prediction models, in general, and COAMPS, in particular.

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