MEETING REPORT

Clouds, microphysical processes and small-scale simulations*

An international workshop on cloud dynamics, micro-physics and small-scale simulations was held recently. This four-day event included 27 lectures, poster presentations and an open panel discussion.

Sessions on first day include the large and mesoscale simulations with weather models, highlighting the challenges and future opportunities. The workshop began with an invited talk by W. W. Grabowski (National Center for Atmospheric Research, USA). He suggested a new methodology called 'piggy backing', which allows confident assessment of the impact of cloud microphysics on cloud simulation and identifies the dynamic basis of convective invigoration in polluted environments.

Representing clouds and microphysical processes, and challenges therein in climate models were discussed by P. Mukhopadhyay and Anupam Hazra (Indian Institute of Tropical Meteorology (IITM), Pune). They highlighted the recent developments in stochastic multi-cloud modelling with emphasis on improving the simulations of variance of tropical waves and the fidelity of Indian summer monsoon, with specific emphasis on reduction of biases in NCEP CFSv2. The focus next shifted to mesoscale convective systems (MCS).

Ravi S. Nanjundiah (IITM) proposed a mechanism responsible for southward propagation of MCSs over the Bay of Bengal based on gravity currents. He emphasized the importance of microphysics for simulation of MCS which could not be captured using cumulus parameterization.

G. S. Bhat (IISc, Bengaluru) also discussing MCS showed that while the growth stage of an MCS is characterized by rapid increase in the number of storms, there is a reduction in number and average area in the dissipation stage. He also pointed out that there is no clear variation in average area and height of storms during cloud system growth and mature stages.

Yangang Liu (Brookhaven National Laboratory, USA) highlighted that due to unrealistic assumptions and closely related buffering processes such as dispersion effect, regime dependence, entrainment-mixing processes, coupling, etc., GCM estimation is characterized by high levels of uncertainties and over-estimation of the AIE (aerosol indirect effects) cooling. He described that LES cannot capture the observed cloud mixing type accurately and concluded that consideration of spectral shape poses new challenges to parameterize entrainment-mixing processes.

Continuing on large-scale models, Suryachandra A. Rao (IITM) discussed the state-of-the-art of prediction models, their limitations and how direct numerical simulations (DNS) or large eddy simulations (LES) could help in improving them. He mentioned that small-scale simulations should be focused towards decreasing the uncertainties in the sub-grid level parameterizations. According to Rao, a detailed process-based analysis of systematic model biases could be carried out in future with a view to improve the parameterization scheme.

S. K. Murthy (Defense Institute of Advanced Technology, Pune) delivered a talk on the basics of mathematical modelling, framework and its different applications.

The emphasis on the second day was on small-scale simulations, specifically on DNS and the gap between LES and DNS, and on laboratory experiments to understand cumulus cloud droplets.

Steven Krueger (University of Utah, USA) described an economical model called explicit mixing parcel model (EMPM), which combines the linear eddy model with the parcel model, and includes stochastic entrainment events and bulk or droplet microphysics. He showed that the suggested model closely reproduces DNS results at a much lower cost, especially for coalescence growth of sedimenting droplets.

Using a new approach, viz. Markov random field (MRF) model, Amit Apte (ICTS, Bengaluru) highlighted identification of the pattern of the Indian monsoon rainfall. The model uses a Bayesian non-parametric method and while it is built from eight years of data, it fits well for 100 years of observations.

V. D. Narasimhamurthy (IIT, Madras) showed that DNS is an important tool for solving partial differential equations without any parameterization and described the sensitivity of DNS simulations to initial conditions.

Ravichandran (JNCASR, Bengaluru) discussed the feasibility of using DNS for cumulus clouds simulations. He used Megha-5, a state-of-the-art DNS software, to model cumulus clouds and identified a boundary in the lapse rate–relative humidity phase-space plot.

David Richter (University of Notre Dame, USA) discussed DNS simulations using graphics processing units (GPUs). He briefly explained that GPU acceleration is a powerful tool for enhancement of simulations to hundreds of millions of particles and sub-stepping to resolve fast microphysics. He described the Lagrangian statistics of cloud droplets and concluded that DNS of point particles is an important tool for understanding the thermodynamics, droplet microphysics and Lagrangian histories.

This was followed by talks on observations and lab experiments. Roddam Narasimha (JNCASR) pointed out in his talk that computational methods (such as LES or DNS) are expensive and aircraft/radar observations are not feasible at all the times. Therefore, lab experiments are needed to shed light on the happenings within a cloud. K. R. Sreenivas (JNCASR) emphasized the significant impacts of aerosol on fog formation. He showed that fog intensity was inversely proportional to wind speed and concluded that fog formed in the presence of aerosol particles which enhanced the minima in the temperature above the ground layer.

G. Pandithurai (IITM) shed more light on the effect of atmospheric aerosol on cloud microphysics. He described the set-up of the High Altitude Cloud Physics Laboratory (HACPL) at Mahabaleshwar. It is an experimental set-up to study warm and cold cloud microphysical processes and aerosol chemistry. He concluded that cloud condensation nuclei could be modelled better if the aerosol chemistry is considered.

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Presentations on DNS, LES and lab experiments (related to cloud droplet and aerosols) continued on the fourth day. In his invited talk, M. K. Yau (University of McGill, Canada), described the results of DNS based on two types of experiments. His first experiment was on effect of turbulence on droplet collisions. He concluded that motion of droplets is mainly affected by small-scale turbulence and insensitive to large-scale turbulence. In the second set of experiments, he added droplet condensational growth and noted that condensation alone does not produce large droplets.

Kamal Kant Chandrakar (Michigan Technological University, USA) described the structure of pi-chamber experiment and the turbulence mixing cloud formation in it. He showed that clouds formed via isobaric mixing in a turbulent, moist Rayleigh–Benard convection and concluded that cloud cleansing enhanced through supersaturation fluctuations. Jaywant Arakeri (IISc) presented his lab experiments focused on different scaling techniques applied for turbulent flow. The laboratory set-up consisted of a tube with hot and cold reservoir that acts as a moist tube convective system, and studied droplet formation and growth in a convective turbulent environment.

The effect of turbulence on rainfall and rain drop was discussed by Rama Govindarajan (ICTS). She theoretically explained the raindrop formation using Basset history scheme, which justifies the time required for the formation of large rain drops, and concluded that Basset history acts as a drag and explains the bigger droplet formation.

Ryo Onishi (Japan Agency for Marine-Earth Science and Technology, Japan) provided detailed description of direct Lagrangian tracking simulation technique for droplet growth in clouds. Using this technique one can directly analyse multi-scale phenomena without separating the macro and micro scales, and thus new kind of information regarding statistical fluctuation can be retrieved.

Shin-Ichiro Shima (University of Hyogo, Japan) explained the superdroplet method (SDM) developed by him, as a novice method of probabilistic simulation of cloud microphysics. This method is not only accurate (as good as bin parameterization scheme), but also computationally inexpensive (like bulk parameterization scheme).

The last talk of the day, delivered by Seong Soo Yum (Yonsei University, South Korea) focused on studying cloud microphysical relationships during aircraft measurement campaigns. Yum stated that the cloud microphysical relationships represented by mixing diagrams and linear correlation coefficients suggest homogeneous mixing for the maritime stratocumulus clouds (VOCALS, ACE-ENA, MASE), and more so for the continental stratocumulus clouds (RACORO). According to him, the crucial reason of these dominant homogeneous mixing traits is vertical circulation.

The lectures on the final day of the workshop focused on DNS and tools for the simulation of DNS and LES. Lian-Ping Wang (University of Delaware, USA) delivered his talk on the collision efficiency based on point-droplet hybrid DNS. He described the collision efficiency based on droplet-resolving DNS and also introduced an interface-resolved DNS approach to simulate coalescence of cloud droplets.

B. V. Rathish Kumar (IIT Kanpur) introduced MicroHH, a CFD set-up, for simulation of turbulent flow in periodic domains with a focus on atmosphere. The main advantage is MicroHH supports both DNS and LES on a common MPI–OMP–CUDA platform with more than 1000 cores.

DNS of turbulent mixing and entrainment of clear and cloudy air was described by Bipin Kumar (IITM). He highlighted the visualization of mixing phenomenon in a $(2m)^3$ domain and explained the importance of 3D visualization of such data.

The workshop ended with a special lecture by Grabowski, who described the impact of cloud turbulence growth from DNS to LES and beyond. Cloud droplets grow by the diffusion of water vapour and by collision/coalescence. For both growth mechanisms, cloud turbulence and entrainment phenomenon play significant and still poorly understood role. He explained the limitations of DNS and concluded that small scales needed to allow hopping from one large eddy to another, whereas large scales are needed to provide different droplet activation/growth histories.

At the end of the workshop, an open discussion and feedback session was organized. New ideas, techniques and their challenges about the parameterization from smallest scale were discussed.

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