Proposal title: Investigation of the relationships between DCS cloud properties, lifecycle, and precipitation with meteorological regimes and aerosol sources at the ARM SGP Site

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1. Scientific goals

In this proposed research, we will investigate how different meteorological regimes and aerosol sources affect DCS properties, diurnal and life cycles, and precipitation using multiple observational platforms (surface, satellite, and aircraft) and NARR reanalysis at the ARM SGP site. The Feng et al. (2011, 2012) DCS results will serve as a starting point for this proposed research, and help us to address some fundamental issues of DCSs, such as convective initiation, rain rate, areal extent (including stratiform and convective regions), and longevity. Convective properties will be stratified by meteorological regime (synoptic/mesoscale patterns) identified by reanalysis. Aerosol information obtained from the ARM SGP site will also be stratified by meteorological regimes to understand their effects on convection. Finally, the aircraft in-situ measurements and various radar observations and retrievals during the MC3E campaign will provide a "cloud-truth" dataset and are an invaluable data source for verifying the findings and investigating the proposed hypotheses in Objective 1.

Objective 1: Relationship between DCS properties, meteorological regimes, and aerosol sources

For this proposed objective, we will provide statistical information and individual cases of the classified DCS three components (CC, SR, AC) through our newly developed hybrid classification method over the ARM SGP region during the period 2009-2012, including the formation and dissipation processes of DCS, the life and diurnal cycles of three DCS components, and their associated precipitation. The goal is to investigate the relationships between the classified DCS properties, meteorological regimes, and aerosol sources through the Self Organizing Map (SOM) technique. There are two hypotheses: (1) the DCS properties at the scale of climate models will vary by meteorological regimes (i.e., large-scale thermodynamic and kinematic parameters); (2) Aerosol occurrence is directly linked to meteorological conditions favorable for enhanced convection. In order to investigate these hypotheses, this proposed research will take advantage of the recently developed objective classification techniques using both radar/satellite data (Feng et al. 2011 and 2012) and reanalysis data (Kennedy et al. 2011 and Kennedy 2011). Aerosol data will be provided by CCN data collected at the ARM SGP site.

Objective 2: Case studies during MC3E

Although Objective 1 can provide statistical information for climate modelers from years of observations and research results, it is still necessary to understand more details and verify the findings in Objective 1 with intensive and independent observations. The aircraft in-situ measurements and various radar observations and retrievals during MC3E field experiment provide a "cloud-truth" dataset and are an invaluable data source for reaching this goal. Through the way of case studies during MC3E, we will perform detailed comparisons of convective cloud properties observed by the ARM new instrumentation and aircraft with the Feng et al. (2011, 2012) results, and further validate the findings and investigate the hypotheses in Objective 1.

2. Working Progress

During the four years of this project, Dr. Dong's group has made the following progress under either fully or partially support from DOE ASR funding:
(1) 22 papers have been published/submitted.
(2) The hybrid NEXRAD radar and GOES product during MC3E has been generated and provided for ASR/ARM community. The UND aircraft in situ measurements have been processed and analyzed, which are available for ASR/ARM community. The MBL clouds at ARM ENA site have been processed and submitted to ARM as PI product.
(3) Dr. Dong's group has attended the ASR 2012-2016 annual and fall working group meetings, presented more than 20 talks (including 6 invited talks) and organized the MC3E section.

2.1. Published papers

1) Wu, P., **X. Dong**, B. Xi, Y. Liu, M. Khaiyer, and P. Minnis, 2016: Effects of Environment Forcing on Marine Boundary Layer Cloud-Drizzle Processes. Submitted to JGR.
2) Fan, J., et al., 2016: Cloud-Resolving Model Intercomparison of a MC3E Squall Line Case – Properties of Convective Cores. Submitted to JGR.
3) Fridlind, A.M., et al., 2016: Use of observation-based aerosol profiles in simulations of a mid-latitude squall line during MC3E: Similarity of microphysics regime to tropical conditions. Submitted to ACP.
4) **Dong, X**., B. Xi, S. Qiu, P, Minnis, S. Sun-Mack, and F. Rose, 2016: A Radiation Closure Study of Arctic Cloud Microphysical Properties using the collocated satellite-surface data and Fu-Liou Radiative Transfer Model. *J. Geophys. Res. Atmos*., 121,10,175-10,198, doi:10.1002/2016JD025255.
5) Wang, J., **X. Dong**, B. Xi and A.J. Heymsfield, 2016: Investigation of liquid cloud microphysical properties of deep convective systems: 1. Parameterization of rain drop size distribution and its application for stratiform rain estimate. *J. Geophys. Res. Atmos*., 121, 10,739-10,760, doi:10.1002/2016JD024941.
6) Tian, J., **X. Dong**, B. Xi, J. Wang, C.R. Homeyer, G.M. McFarquhar, and J. Fan, 2016: Retrievals of ice cloud microphysical properties of deep convective systems using radar measurements. *J. Geophys. Res. Atmos.* 121, 10,820-10,839, doi:10.1002/2015JD024686.
7) Wu, P., **X. Dong**, and B. Xi, 2015: MBL drizzle properties and their impact on cloud microphysical property retrievals. Atmos. Meas. Tech., 8, 3555–3562, 2015. doi:10.5194/amt-8-3555-2015
8) **Dong, X**. A. C. Schwants, B. Xi, and P. Wu, 2015: Investigation of the Marine Boundary Layer Cloud Properties under the Coupled and Decoupled conditions over the Azores. JGR. 120, 6179-6191, DOI: 10.1002/2014JD022939
9) Qiu, S., **X. Dong**, B. Xi. J. Li, 2015: Characterizing Arctic mixed-phase cloud structure and its relationship with humidity and temperature inversion using ARM NSA Observations. JGR, 120, 7737-7746, doi:10.1002/2014JD023022.
10) Fan, J., Y.-C. Liu, K.-M. Xu, K. North, S. Collis, **X. Dong**, G. J. Zhang, Q. Chen, P. Kollias, and S. J. Ghan, 2015: Improving representation of convective transport for scale-aware parameterization: 1. Convection and cloud properties simulated with spectral bin and bulk microphysics, *J. Geophys. Res. Atmos., 120,* 3485–3509, doi:10.1002/2014JD022142.
11) Wang, J., **X. Dong**, and B. Xi, 2015: Investigation of Ice cloud microphysical Properties of

DCS using Aircraft in-Situ Measurements. JGR, 120, 3533-3552, 10.1002/2014JD022795.
12) Kennedy, A., **X. Dong** and B. Xi, 2015: Cloud Fraction at the ARM SGP Site: reducing uncertainty with self-organizing maps. Theor. Appl. Climatol. 115:91-105. DOI 10.1007/s00704-015-1384-3
13) Wood, R., **X. Dong**, and coauthors, 2015: Clouds, Aerosol, and Precipitation in the Marine Boundary Layer: An ARM Mobile Facility Deployment. 419-439, DOI:10.1175/BAMS-D-13-00180.1
14) **Dong, X**., B. Xi and P. Wu, 2014b: Investigation of the diurnal variation of marine boundary layer cloud microphysical properties at the Azores. J. Clim., 27, 8827-8835. DOI: 10.1175/JCLI-D-14-00434.1.
15) Xi, B., **X. Dong**, P. Minnis, and S. Sun-Mack, 2014: Comparison of Marine Boundary Layer Cloud Properties From CERES-MODIS Edition 4 and DOE ARM AMF Measurements at the Azores. JGR, 119, doi:10.1002/2014JD021813.
16) Logan, T., B. Xi, and **X. Dong**, 2014: Aerosol properties and their influences on marine boundary layer cloud condensation nuclei at the ARM mobile facility over the Azores, JGR, 119, doi:10.1002/2013JD021288.
17) Logan, T., B. Xi, and **X. Dong**, 2014: Biomass Burning Aerosol Properties over the Northern Great Plains during the 2012 Warm Season. Atmos. Chem. Phys. Discuss., 13, 32269-32289. www.atmos-chem-phys-discuss.net/13/1/2013/doi:10.5194/acpd-13-1-2013.
18) **Dong, X**., B. Xi, A. Kennedy, P. Minnis and R. Wood, 2014a: A 19-month record of Marine Aerosol-Cloud-Radiation Properties derived from DOE ARM AMF deployment at the Azores: Part I: Cloud Fraction and Single-layered MBL cloud Properties. J. Clim., 27, 3665-3682. DOI: 10.1175/JCLI-D-13-00553.1
19) Kennedy, A., **X. Dong**, and B. Xi, 2013: Cloud Fraction at the ARM SGP Site: Instrument and Sampling Considerations from 14 years of ARSCL. Theoretical and Applied Climatology, 112, Nos. 1-2, DOI 10.1007/s00704-013-0853-9.
20) Wu, D**., X. Dong**, B. Xi, Z. Feng, A. Kennedy, G. Mullendore, M. Gilmore, and W-K Tao, 2013, The Impact of Various WRF Single-Moment Microphysics Parameterizations on Squall Line Precipitation, JGR, 118, DOI: 10.1002/jgrd.50798.
21) Huang, D., C. Zhao, M. Dunn, **X. Dong**, G.G. Mace, M.P. Jensen, S. Xie, and Y. Liu, 2012: An Intercomparison of Radar-Based Liquid Cloud Microphysics Retrievals and Implication for Model Evaluation Studies. Atmos. Meas. Tech. 5, 1409-1424, doi:10.5194/amt-5-1409-2012.
22) Feng, Z., **X. Dong**, B. Xi, S. McFarlane, A. Kennedy, B. Lin, and P. Minnis, 2012: Life cycle of deep convective systems in a Lagrangian Framework. *JGR.* 117, D23201, doi:10.1029/2012JD018362.

2.2 ASR/ARM products

2.2a: Classified three components (CC, SR, AC) of DCS

Dr. Dong's group has collected and processed the surface, satellite and aircraft data during the MC3E IOP over the SGP (April-June 2011). We have combined NEXRAD radar observations with GOES data to generate the hybrid product and classify the DCS and its three components (CC, SR, AC) over the SGP region (Feng et al. 2012). This product has provided the ASR/ARM community, especially for modelers, such as Drs. Zhaoxia Pu, W. Tao, Jiwen Fan, Ann Fridlind, Tony Del Genio etc, to validate their simulations.

2.2b: Aircraft in-situ measurements during MC3E

Dr. Dong's group has processed the UND citation aircraft data during MC3E, developed new ice particle size distribution (PSD) and raindrop size distribution (DSD) parameterization, and provided the bulk ice and liquid cloud microphysical properties of DCSs to ARM/ASR community (Wang et al. 2015 and 2016). These in-situ results have provided a ground-truth to validate the NEXRAD radar retrieved ice cloud microphysical properties of DCSs (Tian et al. 2016) and model simulations (Jiwen et al. 2015, 2016; Tian et al. 2016, Fridlind et al. 2016).

2.2c: PI Product: Cloud Property Retrieval Products for Graciosa Island, Azores

The motivation for developing this product was to use the Dong et al. 1998 method to retrieve cloud microphysical properties, such as cloud droplet effective radius, cloud droplets number concentration, and optical thickness. These retrieved properties have been used to validate the satellite retrieval, and evaluate the climate simulations and reanalyses. We had been using this method to retrieve cloud microphysical properties over ARM SGP and NSA sites. We also modified the method for the AMF at Shouxian, China and some IOPs, e.g. ARM IOP at SGP in March, 2000. The ARSCL data from ARM data archive over the SGP and NSA have been used to determine the cloud boundary and cloud phase. For these ARM permanent sites, the ARSCL data was developed based on MMCR measurements, however, there were no data available at the Azores field campaign. We followed the steps to generate this derived product and also include the MPLCMASK cloud retrievals to determine the most accurate cloud boundaries, including the thin cirrus clouds that WACR may under-detect. We use these as input to retrieve the cloud microphysical properties. Due to the different temporal resolutions of the derived cloud boundary heights product and the cloud properties product, we submit them as two separate netcdf files.

2.3 Research highlight

During the 4-yr period, my group has submitted the following research highlights based on our publications.

a) 4D (Space-time) Ice Cloud Microphysical Properties of DCSs Retrieved from NEXRAD
b) New DSD Parameterization and SR QPE from Aircraft and Surface Distrometer
c) DCS Ice Cloud Microphysical Properties Derived from Aircraft Data during MC3E
d) A Radiation Closure Study at both Surface and TOA using RTM
e) Characterizing Arctic Mixed-Phase Cloud Structure
f) Diurnal Variation of MBL Cloud Properties over the Azores

g) MBL Aerosol Properties and Their Impact on CCN at the Azores-AMF Site
h) MBL Cloud and CCN Properties under Coupled and Decoupled Conditions
i) MBL Cloud Properties derived from the Azores-AMF Observations
j) MBL Drizzle Properties and Their Impact on Cloud Property Retrieval
k) Evaluation of WRF Microphysics Schemes in Squall Line Simulations
l) ARM Data Used to Evaluate Reanalysis Results
m) Validation of CERES-MODIS Cloud Retrievals Using the Azores Data

2.4 Presentations

During the 4-yr period, Dr. Dong's group has presented more than 20 oral and poster presentations during annual and working group meetings.