Final Report (November 2016)

Project Title: Multiscale Variability of the Tropopause Transition Layer During AMIE
Project ID: 0018528
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Executive Summary

An investigation has been carried out of the influence of the Madden-Julian Oscillation on the tropical tropopause layer (TTL) using data from the ARM MJO Investigation Experiment (AMIE) during the period October-November 2011. A variety of data from the ARM Mobile Facility deployed during AMIE on Gan Island have been used in the study: 3-hourly atmospheric soundings, the Ka-band ARM Zenith Radar (KAZR) radar reflectivity fields, and the ARM PI-Product CombRet (Combined Retrieval, Microphysical Retrievals, and Heating Rates) produced by PNNL. Additional data used in the study are from CALIPSO, ERAi reanalyses, DYNAMO (Dynamics of the MJO) sounding network observations, the S-PolKa radar on Gan Island, and the DOE ARM sites at Manus and Nauru.

Principal findings of the research are as follows:

1. The MJO and its convective elements have been found to excite a spectrum of gravity wave activity in the TTL and lower stratosphere, including prominent Kelvin waves that impact both the depth of convection and cirrus distribution across the MJO.
2. Kelvin wave momentum fluxes into the lower stratosphere estimated from the sounding data from AMIE Gan, Manus, and Nauru have been found to be greatest during the easterly phase of the QBO and found to be directly linked to the descent of the westerlies. There is only a weak indication of a modulation of the momentum fluxes by the MJO.
3. CombRet data from Gan Island indicate an important role of cloud-radiation interaction in the buildup of MSE prior to the convectively active phases of the two MJO events observed during AMIE/DYNAMO.
4. The diurnal cycle of convection during the suppressed phase of the MJO has been found to be important in moistening the lower troposphere during the pre-onset phase of the MJO.

Final Report

Observations from the ARM MJO Investigation Experiment (AMIE) have been used to study the influence of the Madden-Julian Oscillation on the tropical tropopause layer (TTL) during the period October-November 2011. During this period, two prominent

MJOs passed through the observational network over the Indian Ocean, one in October and one in November. Data and other products used in the study have been obtained from the ARM Mobile Facility deployed during AMIE on Gan Island. They include 3-hourly atmospheric soundings, the Ka-band ARM Zenith Radar (KAZR) radar reflectivity fields, and the ARM PI-Product CombRet (Combined Retrieval, Microphysical Retrievals, and Heating Rates) produced by PNNL. Additional data used in the study are from CALIPSO and the ERAi reanalysis.

Erin Dagg, a student in the Department of Atmospheric Science at Colorado State University, completed her M.S. degree in 2015 under this project.

Research highlights

1. MJO impact on TTL

Results from AMIE show that the MJO has a significant impact on the tropical tropopause layer (TTL). AMIE observations have provided a documentation of this impact in a detail heretofore not possible (Dagg 2015). Disturbances in the TTL have been analyzed by decomposing the temperature and wind fields into three frequency bands: 20-80 days (representing the MJO), 7-20 days (Kelvin waves), and < 7 days (higher frequency equatorial disturbances, including the bulk of the gravity wave spectrum). Prominent anomalies are observed on all time scales. Observations from AMIE radars on Gan Island, soundings, and CALIPSO data show that the warm and cool anomalies associated with the Kelvin waves directly influence the depth of convection within the MJO active phase as well as the distribution of cirrus in the AMIE/DYNAMO region.

Dagg, E., 2015: Tropical tropopause layer variability associated with the Madden-Julian Oscillation during DYNAMO. M.S. thesis, Colorado State University, 93 pp.

Birner, T., E. Dagg, R. H. Johnson, 2016: Tropical tropopause and lower stratospheric wave activity associated with the Madden-Julian Oscillation during DYNAMO. In preparation.

2. Kelvin wave momentum fluxes in lower stratosphere

Sounding data from the AMIE/DYNAMO field campaign (the Gan Island and Manus sites) as well as an eleven-year period (2003-2013) from the DOE ARM sites at Manus and Nauru have been used to infer Kelvin wave momentum fluxes into the lower stratosphere (Sjoberg et al. 2016). These momentum fluxes are notoriously hard to estimate from observational data. Our estimated time series of the momentum fluxes show the a clear annual cycle signal and the expected variations of the fluxes in association with the QBO. Specifically, momentum fluxes are greatest during the easterly phase of the QBO and found to be directly linked to the descent of the westerlies. While there is some indication of a modulation of the

momentum fluxes by the MJO, this variability is not statistically significant (possibly due to the insufficient length of the available time series).

Sjoberg, J. P, T. Birner, and R. H. Johnson, 2016: Intraseasonal to interannual variability of Kelvin wave momentum fluxes as derived from high-resolution radiosonde data, submitted to Atmos. Chem. Phys.

3. MJO convective structures and cloud-radiation interaction

Radiative heating rate estimates based on AMIE measurements (CombRet data prepared by Zhe Feng et al.), along with sounding data, have been used to determine the distributions convective heating and moistening as well as the vertical eddy flux of moist static energy MSE) for the October and November MJO events (Johnson et al. 2015). Results indicate an important role of cloud-radiation interaction in the buildup of MSE prior to the convectively active phases of the two MJOs.

Johnson, R. H., and P. E. Ciesielski, 2013: Structure and properties of Madden-Julian oscillations deduced from DYNAMO sounding arrays. *J. Atmos. Sci.*, **70**, 3157–3179, doi:10.1175/JAS-D-13-065.1.

4. Role of diurnal cycle of convection in MJO preonset

Atmospheric soundings, radar from S-PolKa on Gan Island (data acquisition assisted by Zhe Feng of PNNL), and air–sea flux measurements collected during DYNAMO have been used to study MJO convective onset (i.e., the transition from shallow to deep convection). The findings indicate that moistening of the low–midtroposphere during the light-wind preonset stage of the MJO has a strong diurnal signal, which is associated with enhanced midday surface fluxes in response to frequent diurnal warm layers (2-3°C increases in afternoon SST). Modeling studies show that the diurnal cycle accelerates the moistening of the lower troposphere prior to the active phase of the MJO.

Ruppert, J. H., Jr., and R. H. Johnson, 2015: Diurnally modulated cumulus moistening in the preonset stage of the Madden–Julian oscillation during DYNAMO. *J. Atmos. Sci.*, **72**, 1622–1647, doi:10.1175/JAS-D-14-0218.1.

Conference Presentations

(Invited) Gravity wave and Kelvin wave activity in the tropical lower stratosphere, SPARC Gravity Symposium, State College, PA, USA, May 2016. (talk by Co-I Birner)

TTL variability associated with the Madden-Julian Oscillation during DYNAMO, CT3LS workshop, Boulder, CO, July 2015. (talk by Co-I Birner)

(**I**nvited) Multiscale dynamics in the TTL, Strateole-2 workshop, Paris, France, March 2015. (talk by Co-I Birner)

Diurnal Cycle of the Atmospheric Mixed Layer during DYNAMO/CINDY/AMIE. Third Symposium on Prediction of the Madden-Julian Oscillation: Processes, Prediction and Impact; AMS Annual Meeting, Phoenix, AZ, 5 January, 2015 (talk by PI Johnson).

Influence of the Madden-Julian Oscillation on the tropical tropopause layer during the 2011-12 DYNAMO field campaign, AMS Middle Atmosphere Meeting, Phoenix, AZ, January 2015. (talk by MS student Dagg)

MJO Dynamics Deduced from CINDY/DYNAMO/AMIE Sounding Data. Symposium on Progress of the MJO Research Through the Field Campaigns, Sapporo, Japan, 23-25 July 2014 (talk by PI Johnson).

Multi-scale variability of tropical tropopause layer characteristics during the 2011 DYNAMO field campaign, EGU General Assembly, Vienna, Austria, May 2014. (talk by MS student Dagg)

MJO Moistening Processes Deduced from DYNAMO Sounding and Radar Data. Tropical Dynamics Workshop, East-West Center, University of Hawaii, 14-16 January 2014 (talk by PI Johnson).

Characteristics of MJOs observed during CINDY2011/DYNAMO. Davos Atmosphere and Cryosphere Assembly (DACA), Davos, Switzerland, 8-12 July, 2013 (talk by PI Johnson).

Modulation of tropical tropopause layer characteristics by the Madden-Julian Oscillation
during the DYNAMO/AMIE field campaigns, AMS Middle Atmosphere Meeting, Newport, RI, USA, June 2013. (poster by MS student Dagg)

(Invited) Structure of the tropopause region from high-vertical resolution radiosonde (HVRR) observations, Workshop on research applications of HVRR data, SUNY Stony Brook, New York, USA, May 2013. (talk by Co-I Birner)