Does the MJO Influence Aerosol Variability?

Baijun Tian

Joint Institute for Regional Earth System Science and Engineering (JIFRESSE)
University of California, Los Angeles (UCLA)
Jet Propulsion Laboratory (JPL), California Institute of Technology (Caltech)
http://www.gps.caltech.edu/~btian


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OUTLINE

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The MJO is characterized by slow eastward-propagating oscillations in tropical deep convection and large-scale circulation.

It is the dominant form of intra-seasonal variability in the Tropics.

It impacts a wide range of phenomena.

It is predictable within 2-4 weeks.

Our weather & climate models have a relatively poor representation.

A comprehensive theory for the MJO is still lacking.

Madden & Julian [1971; 1972], Lau and Waliser [2005], Zhang [2005]
• Composite rainfall maps derived from merged satellite and in-situ measurements are separated by 10 days.

• Rainfall anomalies propagate in an eastward fashion and mainly affect the tropical eastern hemisphere.

• These anomalies are accompanied by anomalies in wind, solar radiation, sea surface temperature, etc.

A Typical MJO in N.H. Winter (Nov-Apr)

Courtesy of D. Waliser
• Composite rainfall maps derived from merged satellite and in-situ measurements are separated by 10 days.

• Rainfall anomalies propagate in a northeast fashion and mainly affect the Tropical eastern hemisphere.

• These anomalies are accompanied by anomalies in wind, solar radiation, sea surface temperature, etc.

Courtesy of D. Waliser
Interactions of the MJO and other parts of the physical weather & climate system are significant, in many cases well documented, and in a few cases understood.
**Motivation**

However, the impacts of the MJO on chemical components of our climate system are not understood and in most cases not even (well) documented. Thus, more studies are definitely needed in this area.

The main benefit of such studies is to expand the socially relevance of prediction of atmospheric composition and air quality given the potential predictability of the MJO within 2-4 weeks.
Tropical Total Ozone Variability

Tian et al. [2007]
MJO and Total Ozone Variability

Tian et al. [2007]

Subtropical UT anticyclones lift the tropopause and O3-poor tropospheric air to decrease the total ozone

Subtropical UT cyclones lower the tropopause and O3-rich stratospheric air to increase the total ozone

The cloud symbol indicates the convective center. Arrows represent anomalous winds at 850 and 200 hPa and the vertical motions at 500 hPa. “A” and “C” mark the anticyclonic and cyclonic circulation centers, respectively. Dashed lines mark troughs and ridges. From Rui and Wang [1990].
Aerosols: Influences on Climate, Clouds, Air Quality

www.pmel.noaa.gov
Due to sampling issues, aerosol type discrimination, and other measurement challenges, the spatial and temporal variability of aerosols has not yet been comprehensively documented.

Liu et al. [2005]
AEROSOL VARIABILITY

In particular, to the best of our knowledge, the spatial and temporal patterns of intra-seasonal (30–90 day) aerosol variability and its connection to the MJO have not yet been explored.
Objective

- Using the available satellite aerosol data to document the spatial and temporal patterns of intra-seasonal (30–90 day) variability of aerosol and its connection to the MJO.
- Does the MJO influence the aerosol variability?
- If yes, how?
AEROSOL DATA

TOMS Aerosol Index (AI):
The AI is based on 2-UV radiances and can detect the elevated UV-absorbing aerosols over both ocean and land, above clouds.

MODIS Aerosol Optical Thickness (AOT):
L3, V4, MOD08, 1.0° x 1.0°, daily, 02/2000-12/2005.
The MODIS AOT is based on calibrated clear-sky radiances with different visible/FIR bands/schemes for land versus ocean.

Global Aerosol Climatology Project (GACP)/AVHRR AOT
1.0° x 1.0°, 0.55 µm, daily, ocean only, 01/1982-06/2005.
Derived from calibrated clear-sky radiances in AVHRR channel 1 & 2.

Aerosol Robotic Network (AERONET) AOT
L2.0 (cloud-screened and quality-assured), V2.0, daily AOT at 0.55 µm.
Kaashidhoo (73.5E, 4.9N), 02/20/1998 to 07/11/2000;
Nauru (167E, 0.5S), 06/15/1999 to 06/11/2006
### Key Differences Among Satellite data

<table>
<thead>
<tr>
<th>Retrieval Methods</th>
<th>TOMS AI</th>
<th>MODIS/AVHRR AOT</th>
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<tbody>
<tr>
<td></td>
<td>UV absorption</td>
<td>Scattered visible/FIR light</td>
</tr>
<tr>
<td>Aerosol Type</td>
<td>Absorbing aerosols</td>
<td>Both absorbing and non-absorbing aerosols</td>
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<tr>
<td>Vertical Level</td>
<td>Upper troposphere</td>
<td>Whole troposphere</td>
</tr>
<tr>
<td>Field of View (Pixel)</td>
<td>Very coarse (50 km)</td>
<td>Much finer (0.5 km for MODIS and 1 km for AVHRR)</td>
</tr>
<tr>
<td>Cloud Contamination</td>
<td>Unscreened sub-pixel clouds</td>
<td>(i) The existence of sub-pixel-sized clouds or very thin cirrus in pixels identified as cloud-free</td>
</tr>
<tr>
<td></td>
<td>above any absorbing aerosol layers would scatter light, homogenize the radiation field, reduce the particle UV absorption signal, and produce an anomalously low AI value.</td>
<td>(ii) enhanced illumination of the cloud-free column through the reflection of sunlight by nearby clouds (cloud adjacency effect)</td>
</tr>
</tbody>
</table>
General Analysis Methodology

(1) All the data were binned into pentad (5-day) values.
(2) Intraseasonal anomalies were obtained by removing the annual cycle and data filtering through a 30–90-day band pass filter.
(3) Perform an Extended EOF (EEOF) analysis on band-passed (30-90 day) rainfall data (e.g., CMAP).
(4) Identify MJO events from the EEOF amplitude time series.
(5) Composite MJO events in band-passed rainfall and target quantity (e.g., aerosols).

Tian et al. [2006a; 2006b; 2007; 2008]
**Spatial-temporal Pattern of the 1st EEOF Mode of Rainfall Anomaly MJO Event Selection**
MJO Events in Aerosol Time Series

26, 13, and 48 MJO events were selected for TOMS, MODIS, and AVHRR.
Aerosol Anomalies in TOMS

- Enhanced MJO convection (solid contours, positive rainfall and cloud cover anomaly)
- Suppressed MJO convection (dashed contours, negative rainfall and cloud cover anomaly)
- Large AI Anomalies over Indian and western Pacific oceans
- Large AI Anomalies over Atlantic and Africa
- Positive TOMS AI anomaly (red color)
- Negative TOMS AI anomaly (blue color)

-20 Days
-10 Days
0 Days
+10 Days
+20 Days

Comp TOMS Aerosol Index MJO Anom (>95%) (Winter)
Contours: CMAP Rainfall MJO Anom; Solid: Pos; Dashed: Neg;
Contours start at +/-0.5 with interval of 1 mm day
AEROSOL ANOMALIES IN MODIS

-20 Days

Large AI Anomalies over Atlantic and Africa

-10 Days

Negative MODIS AOD anomaly (blue color)

0 Days

Enhanced MJO convection (solid contours, positive rainfall and cloud cover anomaly)

+10 Days

Positive MODIS AOD anomaly (red color)

+20 Days

Large AI Anomalies over Indian and western Pacific oceans

Suppressed MJO convection (dashed contours, negative rainfall and cloud cover anomaly)
Zero-lag Correlation btw the Composite Rainfall & Aerosol MJO Anomalies

Correlation btw MJO Rainfall and Aerosol Anomalies

-0.6 -0.4 -0.2 0.0 0.2 0.4 0.6
There exists a strong positive correlation (corr coef=+0.70 for Kaashidhoo and +0.90 for Nauru) between the MJO composite AERONET AOT and rainfall anomalies.

This seems to support the weak positive correlation between the MODIS/AVHRR AOT and rainfall anomalies.
**Result Summary**

- Large aerosol variations are found over the equatorial Indian and western Pacific Oceans where MJO convection is strong. Over this region, the zero-lag correlation between aerosol and rainfall anomalies is negative for TOMS AI but positive for MODIS/AVHRR/AERONET AOT.

- Large aerosol variations are also found over the equatorial Africa and Atlantic Ocean where MJO convection is weak but the background aerosol level is high.

- These results indicate that the MJO DOES influence the aerosol variability.
Questions Raised

Over the equatorial Indian and western Pacific Oceans, why is the correlation between aerosol and rainfall anomalies negative for TOMS AI but positive for MODIS/AVHRR/AERONET AOT?

Are these aerosol-rainfall relationships physical, or is one or more of them a result of the aerosol sampling and/or retrieval artifacts?

How does the MJO influence the aerosol over the equatorial Atlantic? How about summer? Does the MJO influence the Saharan air layer (SAL) giving its important role on Atlantic hurricane genesis?

Do our chemistry-transport models represent these relationships and can they be used to help unravel the issues?
Aerosol-Rainfall Relationship

Similar aerosol-cloud cover relationships, at time scales other than intra-seasonal, have been reported in the literature, such as Ignatov and Nalli [2002], Ignatov et al. [2004], Jeong and Li [2005a, 2005b], Jeong et al. [2005], Kaufman et al. [2002, 2005], Lau and Kim [2006], Loeb and Manalo-Smith [2005], Lin et al. [2006], Matheson et al. [2005], Myhre et al. [2004, 2005], and Zhang et al. [2005]. However, the reasons for this aerosol-rainfall (cloud cover) relationship are still unclear.
Hypotheses

- Aerosol humidity effect may contribute to the MODIS/AVHRR relationship (a measure of aerosol scattering) but would have a negligible effect on the TOMS pattern (which only measures absorbing aerosol).
- Wet deposition could contribute to the negative correlation between TOMS AI and rainfall, but it cannot explain the positive correlation in MODIS/AVHRR.
- Low-level wind variability including both wind advection and wind speed associated with the MJO may contribute to the MODIS/AVHRR pattern, albeit no influence on the TOMS pattern.
- The MJO may influence the aerosol variability, especially the scattering one detected by MODIS and AVHRR, through its influence in oceanic biological production.
- These aerosol-rainfall relationships are also likely a result of the aerosol sampling artifact associated with different sensor sensitivities (absorbing versus non-absorbing, upper- versus lower-level aerosols), cloud-clearing procedures, and cloud contamination effects.
AERONET AOT and Rainfall MJO Anomalies at Kaashidhoo

✓ Upper: 3-sample variability cloud-clearing method;
✓ Lower: symmetry in sky-scan radiances, more strict cloud-clearing method.
✓ The positive correlation is much weaker in the more strict cloud-cleared AERONET data.
✓ This indicates that cloud contamination in the aerosol retrievals is likely to be a major contributor to the observed relationships, although we cannot exclude possible contributions from other physical mechanisms.
AEROSOL ANOMALIES IN MODIS

-20 Days
-10 Days
0 Days
+10 Days
+20 Days

Large AOT Anomalies over Atlantic

6/11/2008
Atlantic MODIS AOT & 850hPa NCEP Wind
Does the MJO Influence Aerosol Variability?

Yes!

How?

Very complex and more research is needed.
Future Research

Combine aerosol from MODIS/OMI/AIRS/MISR/CALIPSO, temp and moisture profiles from AIRS and dynamics from NCEP reanalysis to better understand how the MJO influences the aerosol variability over the Atlantic Ocean including the role of the low-level wind in the aerosol transport, the seasonal dependence, dynamic and thermodynamic structure change of the SAL associated with the MJO.

Analyzing the MISR/CALIPSO aerosol data to better understand the role of aerosol vertical distribution (upper versus lower troposphere), aerosol types (absorbing versus non-absorbing aerosols), physical mechanism versus sampling issues and cloud contamination in the complex aerosol-rainfall relationship.

Analyze and evaluate the CTM simulation of aerosol intraseasonal variability.
Thank You!
MADDEN-JULIAN OSCILLATION
(a.k.a. INTRASEASONAL OSCILLATION)

- Intraseasonal Time Scale: 30-60 days
- Slow Eastward Propagation: ~5 m/s Phase Speed
- Strong Coupling Between Deep Convection and Large-Scale Circulation
- Planetary Scale (Zonal Wavenumber 1-3)
- Vertical Baroclinic Wind Structure
- Equatorially Trapped
- Strong Geographic Preference: The Tropical Indian and West Pacific Oceans ("Warm Pool")
- Strong Seasonal Dependence:
  - NH Winter: Eastward Propagation
  - NH Summer: Northeast Propagation
- Significant Interannual Variability
- Potential Role of Ocean/SST Feedback
- Convection Has Multi-Scale Structure
- Significant Remote and Extra-Tropical Impacts

Madden & Julian [1971; 1972], Lau and Waliser [2005], Zhang [2005]
Subtropical negative O3 anomalies lag EQ MJO convection

Equatorial enhanced MJO convection (positive, solid, rainfall anomaly)

Lags -2 and +2 have the same pattern but opposite signs

Subtropical positive O3 anomalies lead EQ MJO convection

Equatorial O3 anomalies are small

Tian et al 2007
MODIS AOT & NCEP 850hPa Wind

2000-2005 Mean NH Winter (Nov-Apr) NCEP 850mb wind (m/s)

2000-2005 Mean NH Winter (Nov-Apr) MODIS AOT (0.01)

2000-2005 Mean NH Summer (May-Oct) NCEP 850mb wind (m/s)

2000-2005 Mean NH Summer (May-Oct) MODIS AOT (0.01)

6/11/2008
Summary

Large aerosol variations are found over the equatorial Indian and western Pacific Oceans as well as tropical Africa and Atlantic.

There is a strong negative correlation btw the TOMS AI and rainfall anomalies, but a weaker, less coherent positive correlation btw the MODIS/AVHRR AOT and rainfall anomalies.

Several physical and retrieval algorithmic factors may contribute to the observed aerosol-rainfall relationships. Preliminary analysis indicates that cloud contamination in the aerosol retrievals is likely to be a major contributor.

The large aerosol anomalies over the equatorial Atlantic are due mainly to the low-level wind anomalies associated with the MJO.

The MJO and its associated cloudiness, rainfall, and circulation anomalies can influence the aerosol variability.
Aerosol Anomalies in AVHRR

-20 Days

Suppressed MJO convection (dashed contours, negative rainfall and cloud cover anomaly)

Negative MODIS AOD anomaly (blue color)

-10 Days

0 Days

Enhanced MJO convection (solid contours, positive rainfall and cloud cover anomaly)

+10 Days

Positive MODIS AOD anomaly (red color)

+20 Days
“Chl Ratio” is the value relative to the seasonal mean, thus 1.20 means a 20% increase over the typical seasonal value.

Large-Scale systematic changes in Chlorophyll (Chl) are observed over most of the Tropical Indian and Pacific Oceans.

Waliser et al. [2005]
Phytoplankton and Cloudiness in the Southern Ocean

Nicholas Meskhidze\textsuperscript{1+}\textsuperscript{1} and Athanasios Nenes\textsuperscript{1,2}

The effect of ocean biological productivity on marine clouds is explored over a large phytoplankton bloom in the Southern Ocean with the use of remotely sensed data. Cloud droplet number concentration over the bloom was twice what it was away from the bloom, and cloud effective radius was reduced by 30\%. The resulting change in the short-wave radiative flux at the top of the atmosphere was \(-15\) watts per square meter, comparable to the aerosol indirect effect over highly polluted regions. This observed impact of phytoplankton on clouds is attributed to changes in the size distribution and chemical composition of cloud condensation nuclei.

Quality, compatibility, and synergy analyses of global aerosol products derived from the advanced very high resolution radiometer and Total Ozone Mapping Spectrometer

Myeong-Jae Jeong and Zhanqing Li\textsuperscript{1}
Department of Meteorology and Earth System Science Interdisciplinary Center, University of Maryland, USA

\[29\] High phytoplankton concentrations can lead to formation of sulfate aerosols, which have important implications for climate [Charlson et al., 1987]. Planktonic algae produce dimethylsulphide (DMS) and then, through oxidation, the DMS transforms into sulfate aerosols that are a major source of cloud condensation nuclei (CCN). It is, however, difficult to link this effect to the monthly satellite data, since the portion of such sulfate aerosols would be small compared to the total aerosol loading in the atmosphere. Besides, it is likely that the high AOT may be an artifact. Very high chlorophyll concentrations (\(\geq 2.0\) mg/m\(^3\)) and enhanced sedimentation can increase the water-leaving radiance in the visible spectrum [Siegel et al., 2000]. Since the retrieval algorithm does not account for such changes,