Towards a new understanding of monsoon depressions

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Financial support:
What is a monsoon low pressure system?

- Vortex embedded in larger scale monsoon
- Diameter ~ 2000 km, moderate winds, abundant precipitation
- Transit and even form over land
- Observed in northern and southern Indian Ocean, western Pacific
Indian monsoon depressions have well-known genesis and propagation characteristics.
Cold-core cyclonic vortices

Indian monsoon depression composite mean anomalies of potential temperature (colors, K) and zonal wind (contours, m/s)

Hurley & Boos 2014, QJRMS
Why are monsoon low pressure systems important?

- Produce about half the rainfall of much of monsoonal India, Australia
- Precursors for many tropical cyclones
- Create intense floods
Pakistan floods
July/August 2010
related to depression
from Bay of Bengal

about 2000 dead,
$10-30 billion loss
(Aon Benfield disaster report)

NASA MODIS images
Previous theory

• Growth: Like mid-latitude weather systems, monsoon depressions thought to obtain energy from equator-to-pole temperature gradient

• Propagation: westward propagation thought to be controlled by low-level dynamics
  • Rao and Rajamani 1970, Sanders 1984, Chen et al. 2005
Not dry baroclinic instability

composite mean Ertel’s Potential Vorticity (colors), potential temperature (contours)
Downshear tilt of PV column in all phases of life cycle is inconsistent with moist baroclinic growth.
Monsoon synoptic vortices and TCs have similar genesis statistics

- Poisson regression of observed genesis points on climatological mean variables, after Tippett et al. (2011) for TCs

\[ \mu = \exp(\mathbf{b}^T \mathbf{x}) \]
where the structure is embedded.

The climatological mean flow in which the relative vorticity confirms that the observed northwestward propagation is upstream of each storm's track and then over all storms. This composite standard here, averaging first over all times in the middle third wind climatology centered on each track position and then, as is mean eastward wind (Fig.3). The zonal wind shown in Fig.3 is and is contained almost entirely within the layer of climatological relative vorticity that has peak amplitude in the lower troposphere.

The composite mean Indian MD consists of a column of positive 3.2. The relevance of low-level vortex stretching quasigeostrophic control of storm motion. To resolve these and propagation mechanism but might still be thought of as low-level, substantially different from that due to downshear stretching other terms in the vorticity budget could produce storm motion could allow for different directions of propagation than might be inconsistent with the idea that MD propagation is primarily domain (Fig.2b), the distribution of propagation vectors seems

variability and points to the northwest almost nowhere in the image, The right-hand side of (3) has a horizontal distribution that qualitatively matches the distribution of the right-hand side of (3) was computed for every 6-hourly period, African easterly waves (also see discussion in Davies-Jones 1991).

Given that the vector vertical wind shear (defined as the 200

speed at each grid point is statistically significant at the 5% level by a two-tailed t-test. b) June-Sept. climatological mean vertical shear vector, defined as the 200 hPa -

pressure (hPa) interval 2 m s

vortex moves upstream in mean eastward flow ... why?
Potential vorticity structure tells a different story

suggests propagation may be governed by nonlinear mid-tropospheric dynamics

Boos et al. 2014, QJRMS
Propagation by self-advection (“beta drift”)

schematic of beta gyres in a tropical cyclone

composite Indian monsoon depression: 500 hPa PV (colors) and azimuthally asymmetric streamfunction (contours)

vectors show:
- total wind
- mean wind
- vortex propagation
Propagation by self-advection ("beta drift")

Schematic of beta gyres in a tropical cyclone

Composite Indian monsoon depression: 500 hPa PV (colors) and azimuthally asymmetric streamfunction (contours)

Boos et al. 2014, QJRMS
A big story: declining storm count trends in India

Supplemental Fig. 5: Sensitivity test for the synoptic KE count. Panel (a) shows the summer mean synoptic KE storm count as a function of the synoptic KE threshold. The dashed lines correspond to the summer mean monsoon depression in the Yale (blue) and IMD (red) datasets. The cross-cutting points are used in panel (b) to tune the synoptic KE threshold to produce KE count that will have the same summer mean as in the Yale and IMD datasets. In panel (b) the tuned KE counts are shown in the dashed and dotted black lines. For comparison we show also the original Yale and IMD monsoon depression count. The nonlinear regression fits to the tuned KE counts is also shown.

Supplemental Fig. 6: Monsoon depression frequency over Bay of Bengal using the IMD dataset (black) for 1891-2012, and its smoothed trend using 11-year centered moving average (red).

Cohen & Boos 2014, GRL
But that record is missing some depressions

ERA-Interim sea level pressure (colors), surface winds (vectors)
Scatterometer surface wind (WindSat), surface wind speed (colors, SSM/I), TRMM 40 mm/day rain contour (magenta)

Figure 3. Three monsoon depressions observed in the Yale and NYUAD datasets during the summers of 2002, 2010 and 2012. In all panels storm tracks (from the Yale dataset) are shown by blue lines with vortex center marked with a black star. Left column: ERA-Interim sea-level pressure (in hPa) is shaded and black arrows show the ERA-Interim surface wind vector field. Right column: SSM/I surface wind speed is shaded, while arrows show surface wind vector from QuikSCAT (Fig. 3b) and WindSat (Figs. 3d and 3f) scatterometers. The thick magenta contour shows the 40 mm day$^{-1}$ daily TRMM precipitation. Precipitation, winds, and the vortex center position are shown for the dates indicated above each panel.

Cohen & Boos 2014, GRL
Trend estimates

The traditional datasets:
- IMD (Fig. 1b)
- SIKKA (Fig. 1b)
- ERA-Interim Yale (Fig. 1c)
- MERAA NYUAD (Fig. 1c)
- ERA-Interim NYUAD (Fig. 1c)
- Averaged Reanalysis data (Fig. 1c)

1979-2012 trends
- Scatterometer KE (Figs. 4c and 4d)
- ERA-Interim Yale (Fig. 4c)
- IMD (Fig. 4c)
- Summer average KE (Fig. 4d)

1989-2012 trends

Linear and nonlinear Poisson regression coefficients

Figure 2. Linear regression and nonlinear Poisson regression fits [Solow and Moore, 2000; Wilks, 2011] to the data presented in Figures 1b, 1c, 4c, and 4d. Here, only the slope coefficients (i.e., the gradient of the regression fits) are shown and error bars represent the 95% confidence interval for these coefficients. Units are year\(^{-1}\). More information, including the y-intercepts, can be found in the supporting information to the text (Supplemental Table 1).

Cohen & Boos 2014, GRL
Summary

• “Low pressure systems” (e.g. monsoon depressions) are very important, yet are poorly understood and little studied since 1980s

• Steep downward trend reported in number of Indian monsoon depressions

We have shown:

• Indian monsoon depressions propagate westward by beta drift (not by QG lifting in easterly shear)

• PV structure is inconsistent with baroclinic instability/growth

• There are problems with the only dataset that shows downward trend in depression counts

There is great need for community assessments of monsoon synoptic variability in observations and models (both climate & NWP)