# Evidence for Hydrometeor Storage and Advection Effects in DYNAMO Budget Analysis of the MJO

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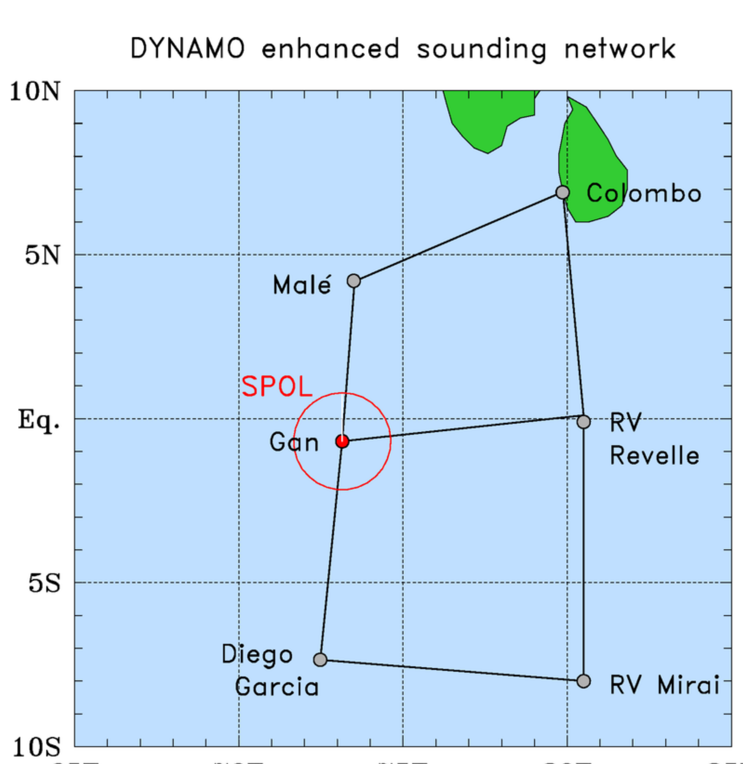
## Introduction

Since the pioneering work of Yanai et al. (1973), heat and moisture budget analyses computed from an array of radiosonde stations have been used to examine the effects of convection on large-scale atmospheric motions. This conventional budget method (CBM), which computes precipitation using only storage and advection of water vapor, is well suited for use with the radiosonde observations which provide all the needed fields. Using observations from the DYNAMO field campaign, conducted over the Indian Ocean from October to December 2011, this presentation demonstrates the limitations of the CBM approach when the large-scale cloud field is rapidly evolving.

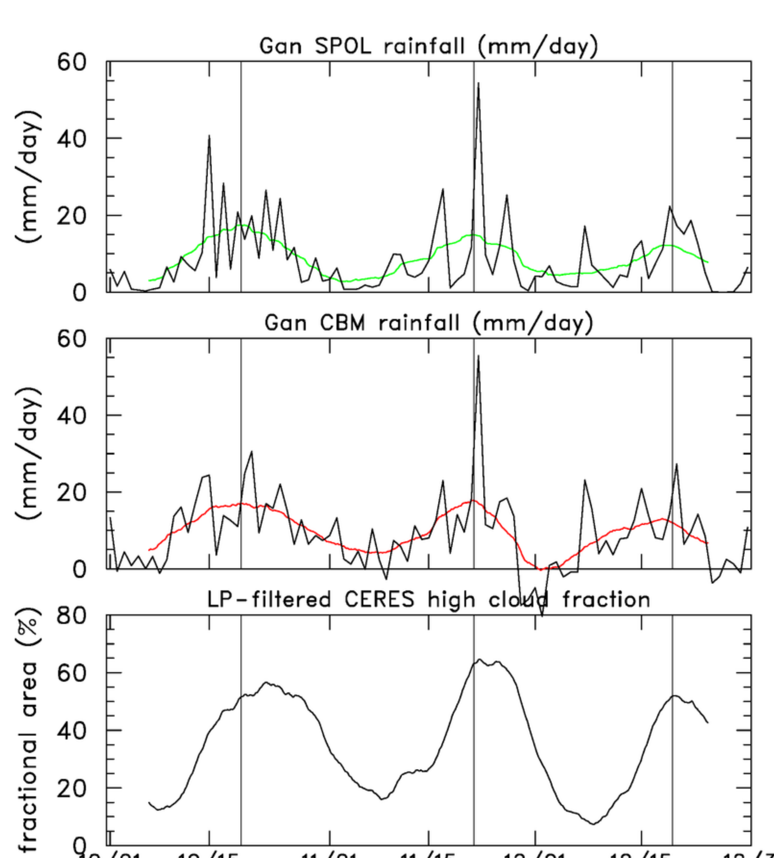
## Procedure

- Use CBM with an objectively analyzed gridded dataset based primarily on sounding data to compute large-scale budgets.
- Examine veracity of CBM analysis against a constrained variational analysis (CVA) which used SPOL rainfall as primary constraint.
- Compute precipitation ($P_0$) as a budget residual (see Eq. 1) and compare to that derived from SPOL radar operated on Gan Island.
- Low-pass filter $P_0$ time series and create a MJO composite based on time of maximum $P_0$ for the 3 MJOs observed during DYNAMO.
- Compare MJO-composite budget-derived $P_0$ to that from the SPOL radar.

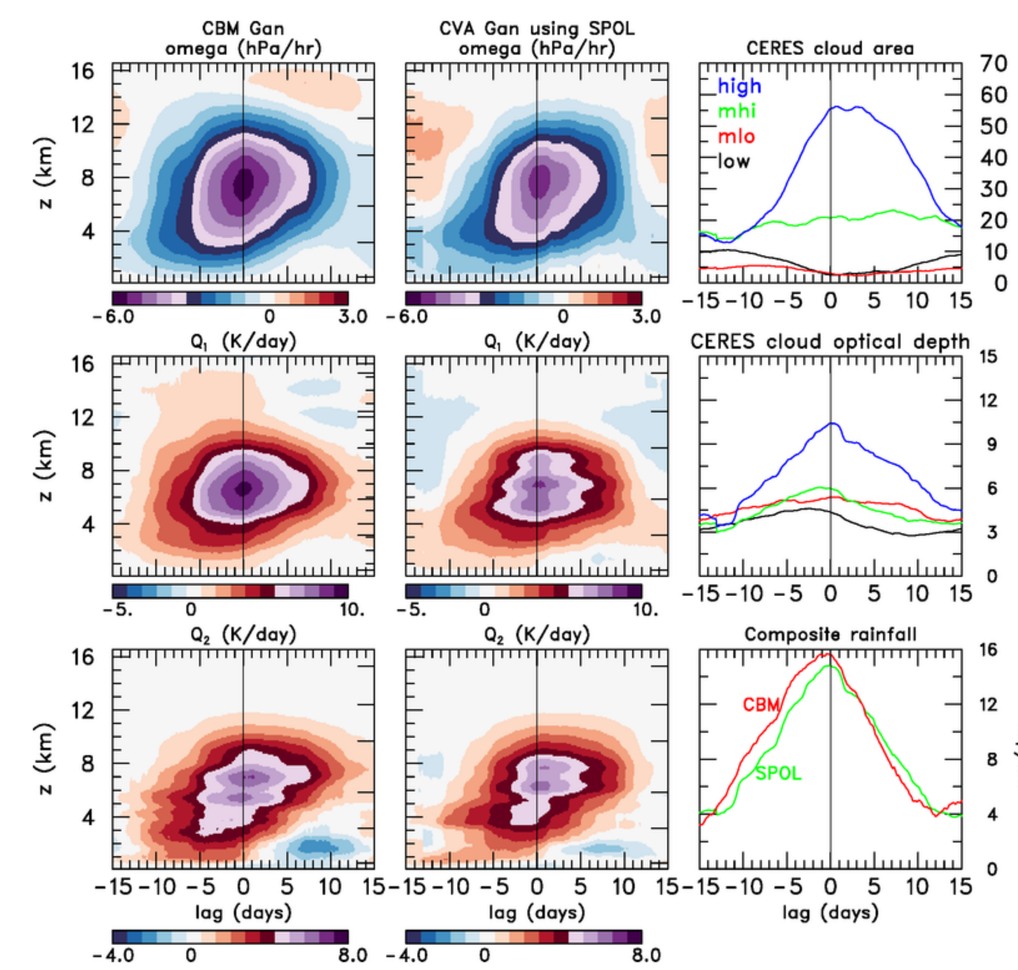



- Map over central Indian Ocean showing sounding network during the DYNAMO experiment.
- Budget-derived $P_0$ averaged over 150 km radius SPOL radar domain shown on map.
- CVA computed over SPOL domain used SPOL derived rainfall as main constraint.
- Sounding and radar data are from DYNAMO legacy data archive.

- Time series of daily-averaged (DA, black) and low-pass (LP) filtered rainfall (color) for SPOL (top) and CBM (middle).
- Vertical lines indicate time of maximum LP-filtered rainfall for each of the three MJO events.
- Good correlation between these time series (r=0.78 for DA, and 0.89 for LP) provides confidence in CBM estimates.
- Bottom panel shows LP-filtered CERES high cloud fraction.




## 3-MJO Composite Analysis

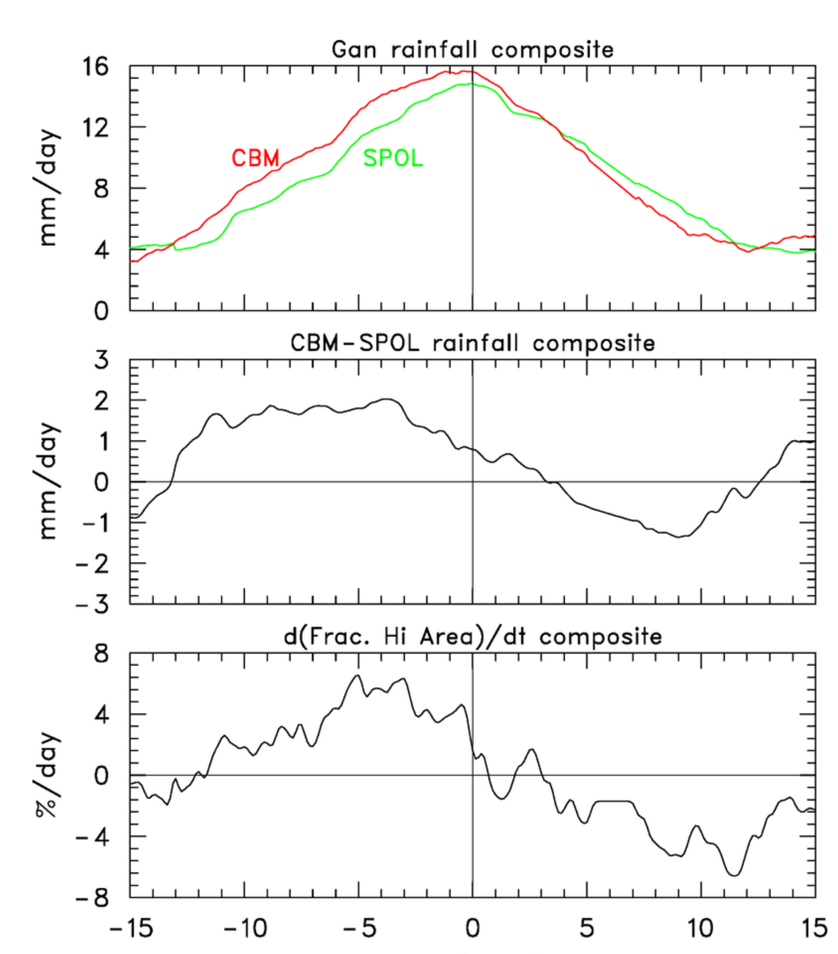



- Comparison of diagnosed fields from CBM (left) and CVA (middle).
- Right panels show CERES cloud parameters and composite rainfall.
- High clouds show rapid increase during MJO build-up and rapid decrease after day +3.
- High clouds obscure lower clouds from satellites rendering CERES low cloud estimates less reliable.

- Magnitude of derived fields is larger in CBM compared to CVA during the MJO build-up stage (prior to day 0) consistent with larger CBM-diagnosed rainfall than SPOL rainfall during this time.
- Slightly more pronounced vertical tilt is evident in CVA diagnosed fields during the MJO build-up stage.

| days | MJO stage | CBM $P_0$ (mm/day) | SPOL $P_0$ (mm/day) | CBM-SPOL $P_0$ (mm/day) |
|---|---|---|---|---|
| -12 to -1 | build-up | 11.9 | 10.3 | +1.6 |
| 4-12 | decay | 6.6 | 7.4 | -0.8 |

- CBM overestimates SPOL rainfall by ~15% during MJO build-up stage and underestimates rainfall by ~10% during MJO decay stage.




- Correlation between MJO-composite $P_0$ difference (CBM-SPOL, shown in middle panel) and time change in CERES high cloud area (bottom panel) is 0.83.
- This suggests a possible storage of condensed water in clouds in the MJO build-up phase and the opposite effect in the decay phase.

Acknowledgment: NSF Grant AGS-1853633.

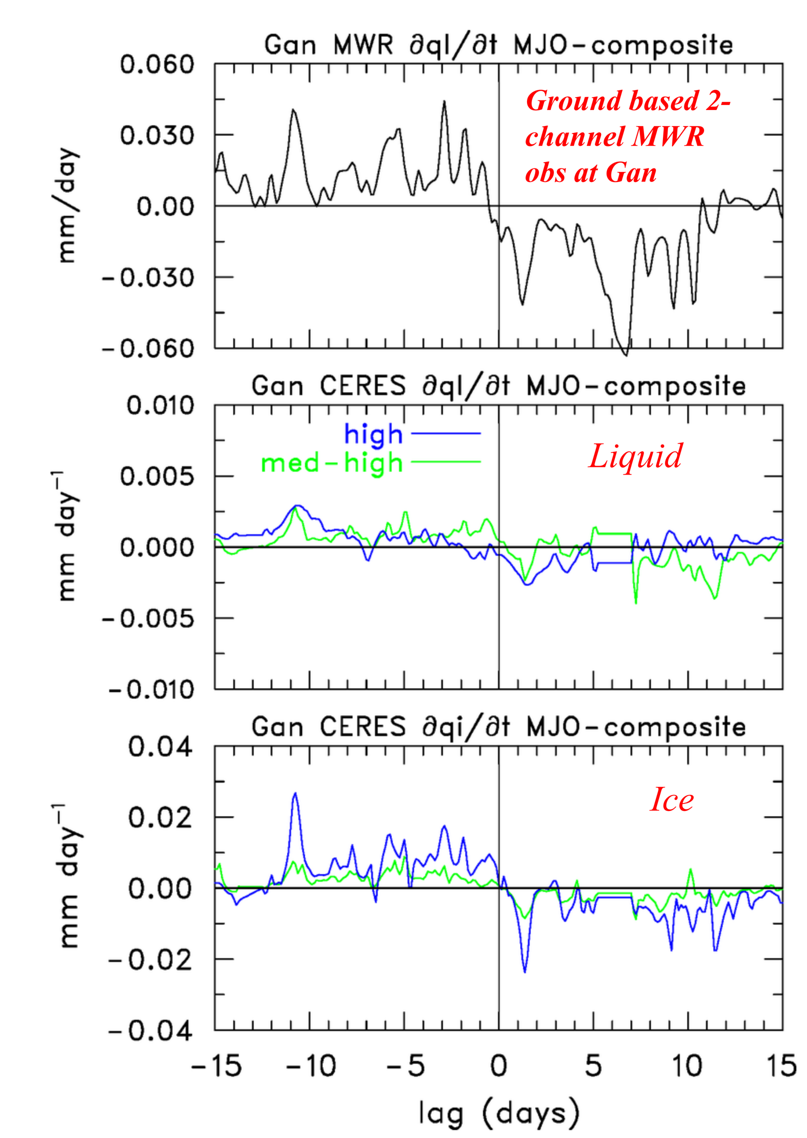
## CBM vs Improved Moist Physics (IMP)

$$P_0^{CBM} = E_0 + \int_0^{Z_T} \left( \frac{\partial \bar{q}_v}{\partial t} + \bar{u}\frac{\partial \bar{q}_v}{\partial x} + \bar{v}\frac{\partial \bar{q}_v}{\partial y} + \bar{w}\frac{\partial \bar{q}_v}{\partial z} \right) \bar{\rho}_a(z)\, dz. \quad (1)$$

$$P_0^{IMP} = E_0 + \int_0^{Z_T} \left( \frac{\partial \bar{q}_T}{\partial t} + \bar{u}\frac{\partial \bar{q}_T}{\partial x} + \bar{v}\frac{\partial \bar{q}_T}{\partial y} + \bar{w}\frac{\partial \bar{q}_T}{\partial z} \right) \bar{\rho}_a(z)\, dz. \quad (2)$$

where: $\bar{q}_T = (\bar{q}_v + \bar{q}_c + \bar{q}_r)$ is the mixing ratio of total water substance (i.e., water vapor and hydrometers)
$\bar{q}_v$ is water vapor mixing ratio
$\bar{q}_c = \bar{q}_l + \bar{q}_i$ is the airborne condensed water mixing ratio
$\bar{q}_l$ is liquid water mixing ratio
$\bar{q}_i$ is ice mixing ratio
$\bar{q}_r$ is precipitating water mixing ratio
$E_0$ is surface evaporation

- Whereas CBM computes rainfall using only the storage and advection of water vapor ($\bar{q}_v$) in (1), the IMP formulation (2) considers storage and advection of the mixing ratio of total water substance ($\bar{q}_T$).




- Temporal changes in composite fields $q_l$ and $q_i$ show good consistency with errors in CBM $P_0$ errors with cloud liquid and ice mixing ratios increasing during MJO build-up stage and decreasing during decay stage
- However, the magnitudes of their tendencies account for only a small fraction (<5%) of the rainfall differences noted in table to left (i.e. ~0.03 mm/day out of ~1 mm/day).
- Note: CVA considers effects of cloud water storage ($\partial q_l / \partial t$) when $q_l$ data exist.

## Conclusions

- In using an approximate form of moist thermodynamics the conventional budget method (CBM) estimate of rainfall is susceptible to errors when hydrometer storage and advection effects are large.
- Evidence for such systemic errors is shown with a composite MJO analysis of DYNAMO data.
- Furthermore, cloud storage effects account for only a small percentage of these errors suggesting that rainfall storage and hydrometer advective effects are likely important.
- Since observations of these effects are unavailable, models will be needed to estimate the magnitude of these effects.