The Mesoscale Characteristics of Tropical Oceanic Precipitation During Kelvin Waves and Mixed Rossby-Gravity Wave Events

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1. Motivation

- ❖Kelvin and mixed Rossby-gravity (MRG) waves are convectively-coupled equatorial waves with distinct signatures in outgoing longwave radiation (OLR) frequency-wavenumber spectra. They account for a significant percentage of tropical OLR variance.
- ❖Previous equatorial wave studies examined their *large-scale* dynamical and convective structures.
  - This study extends the work of Swann et al. (2006, GRL). These are among the first studies to use radar data to examine the 3D *mesoscale* structures of open ocean tropical precipitation associated with Kelvin and MRG waves.
- ❖As numerical models improve to better represent tropical oceanic mesoscale precipitation structures, quantification of observed structures is needed to evaluate model output.

2. Data and Methods

- ❖ Wheeler and Kiladis (1999) OLR spectral analysis method is used to identify Kelvin and MRG waves near Kwajalein (**FIG. 1**) for the 1999-2003 rainy seasons.
  - Wave event = At least 24 h where negative wave-filtered OLR anomalies (suggestive of wave trough) exceed 1.5σ of the 1997-2005 OLR dataset mean OLR anomaly.
- ❖ 23 Kelvin events (3609 radar volumes) and 16 MRG events (2028 radar volumes) are identified.
- ❖ Kwajalein S-band weather radar data (volumes every 10 min) are used to characterize mesoscale precipitation structures during wave events.
  - ❖Visual examination of low-level reflectivity patterns is used to identify precipitation structure organization (**FIG. 2**).
  - ❖Individual contiguous rain areas, and 'pores' within MCSs where reflectivity is weak, are identified using a blob detection algorithm (**FIG. 2d**)
  - ❖Low-level reflectivities are classified into convective and stratiform regions following Yuter et al. (2005, JAM).
  - ❖Echo top heights and contoured frequency-by-altitude diagrams (CFADs) are computed for convective and stratiform precipitation regions within each wave type.

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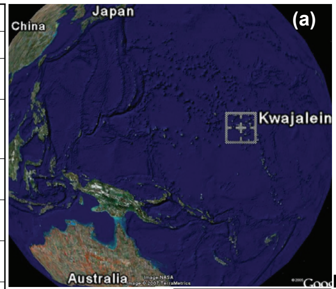
TABLE 1

Organizational Statistics		KELVIN	MRG
Isolated Cells	% radar volumes with isolated activity	92 %	91 %
	% radar volumes with *only* isolated activity	54 %	49 %
MCSs	% radar volumes with MCSs	18 %	19 %
	# wave events with MCSs	19 of 23	14 of 16
	Median MCS size	10 814 km²	7 072 km²
	% MCSs with porosity > 0.05	18 %	12 %
	% MCSs with porosity > 500 km²	35 %	15 %
Convective Lines	% radar volumes with convective lines	9 %	3 %
	# individual lines	24 (across ~28 total days)	6 (across ~16 total days)
	# wave events with lines	17 of 23	14 of 16
	Typical line length	< 150 km	< 150 km
	Average line lifespan within radar domain	2.1 h	1.7 h

TABLE 2

Blob Statistics		KELVIN	MRG
Number per scan	Freq. Dist.	Pos. Skew. Gaussian	Pos. Skew. Gaussian
	Mode	28	37
Rain area	Freq. Dist.	Logarithmic	Logarithmic
	Mode	32 km²	32 km²
Distance Between	Freq. Dist.	Logarithmic	Logarithmic
	Mode	12 km	12 km
Orientation Clockwise from North	Freq. Dist.	Nearly Uniform	Nearly Uniform
Minor:Major Axis Aspect Ratio	Freq. Dist.	Gaussian	Gaussian
	Mean	0.61	0.58
Reflectivity	Freq. Dist. Of Blob Modal Reflectivity	Logarithmic	Logarithmic
	Mode	16 dBZ	16 dBZ
	Max	58 dBZ	62 dBZ



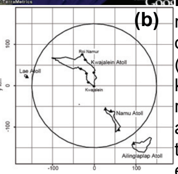


FIG 1. Kwajalein Atoll (8.7 ºN 167.7 ºE) is part of the Marshall Islands. Kwajalein hosts an operational weather radar and upper-air sounding site. (a) was created from Google Earth. (b) focuses on the Kwajalein area, with the 157-km radar volume scan radius shown.

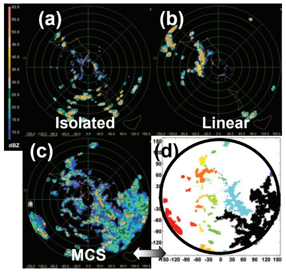


Fig 2. Radar reflectivity images of three major types of horizontal precipitation organization. Radar range rings are shown (radius=157 km), with horizontal scale in km. (d) is how (c) appears when individual rain areas are identified using the 'blob' algorithm, with the MCS in (c) highlighted as the black blob. There are many scattered embedded convective areas within the MCS (visible in (c)). This MCS also has holes of reflectivity <15 dBZ (which we call pores) that are visible as white space within the black-shaded MCS in (d). About 9% of the area of this MCS is covered by such holes, totaling 919 km².

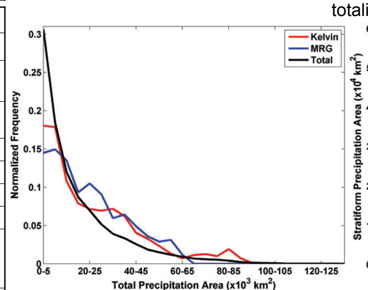


FIG 3. Frequency distributions of total rain areas across the whole Jul-Dec 1999-2003 dataset, and of the subsets of Kelvin and MRG data. These rain areas are based on the long-range scan dataset (radius=240 km, domain area approx. 180 000 km²). The rain areas within our Kelvin and MRG troughs are generally larger than is typical near Kwajalein.

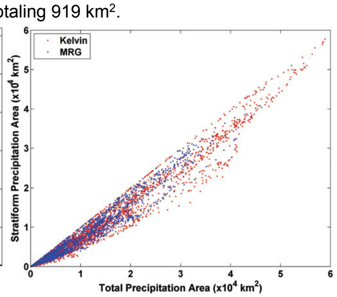


FIG 4. Scatter plot of stratiform precipitation areas and total precipitation area across all Kelvin and MRG radar volumes (domain area = 76 752 km²). Large stratiform rain areas are more frequently associated with Kelvin troughs than MRG troughs.

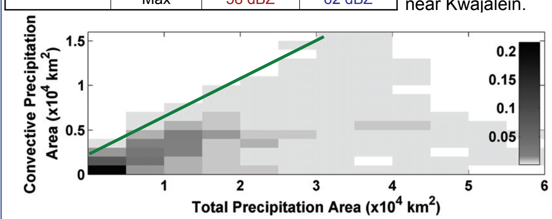


FIG 5. Density plot of frequency of convective precipitation area per total precipitation area for all Kelvin and MRG trough radar volumes together. A line is drawn to indicate the approximate maximum convective area observed for a given total rain area.

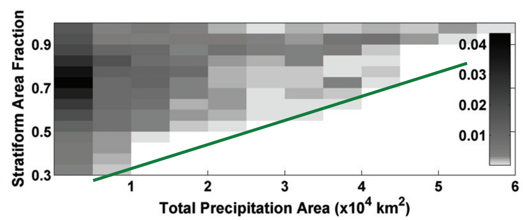


FIG 6. As in Fig. 5, but with stratiform area fractions. A line is drawn to indicate the approximate minimum stratiform fraction observed for a given total rain area.

3. Results

(Radar domain radius = 157 km, area = 76,752 km²)

❖Small, isolated convection is the most common mesoscale precipitation structure near Kwajalein

- ❑Total rain area frequency distributions are logarithmic (**FIG. 3**). Typical total rain areas cover ~3% of the radar domain
- ❑Radar scans typically contain 20-50 individual blobs, typically <15 km apart and <50 km² in area (**TABLE 2**)
- ❑Frequency distributions of other blob characteristics, such as orientation, aspect ratio, and reflectivity, are very similar between the Kelvin and MRG trough datasets (**TABLE 2**)
- ❑Most precipitating clouds at Kwajalein are mixed. Freezing level height is 4.5 km altitude and echo top height mode is 7 km altitude. The frequency distribution of echo top height varies with blob size -- smaller blobs have a wider range of observed echo top heights, while rain areas larger than about 10 000 km² always have echo heights > 5 km

❖Larger rain areas, which are associated with MCSs, are more frequent in wave troughs than overall Kwajalein climatology (Fig. 3)

- ❑The average trough rain area is 1.3x larger than the climatological mean rain area at Kwajalein
- ❑MCSs occur about 19% of the time during wave troughs (**Table 1**) -- 4x more often than outside of troughs

❖Kelvin troughs more frequently contain larger mesoscale precipitation structures than MRG

- ❑Kelvin radar volumes tend to contain fewer rain blobs and larger MCSs than MRG volumes (**Table 2**)
- ❑Larger stratiform precipitation areas are more frequently associated with Kelvin troughs than MRG troughs (**Fig. 4**)
- ❑Convective lines are infrequent, but occur 3-4x more often in the Kelvin trough dataset than MRG (**Table 1**)

❖Kwajalein MCS typically do not have leading line/trailing stratiform organization

- ❑MCSs often have many convective rain areas embedded throughout the stratiform region (**Fig. 2c**)
- ❑Many MCSs are 'porous', meaning they contain many areas of weak (<15 dBZ) reflectivities (**Table 1**, **Fig. 2d**).
  - ❑28% of all trough MCSs contain pores which altogether total at least 500 km²
- ❑Little to no hydrometeor growth within ice layer of stratiform regions is indicated by a nearly vertical mode in CFADs of reflectivity (not shown).

❖There are clear thresholds that separate observed and unobserved values of convective precipitation area and of stratiform precipitation area fraction

- ❑Convective rain area is poorly correlated with total area, with a limit to convective area per total rain area and a max convective area of ~20% of the radar domain (**Fig. 5**)
- ❑Stratiform rain area fractions vary widely for small total rain areas; as total areas increase, the stratiform area fraction increases towards 1.0 (**Fig. 6**)