The Diurnal Cycle of Mature Tropical Cyclones

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Master Literature Seminar

Topic suggestion: **Prof. Dr. Roger K. Smith**

LITERATURE

Gray, W. M. and R. W. Jacobson. 1977: Diurnal Variation of Deep Cumulus Convection. *Mon. Wea. Rev.*, **105**, 1171-1187.

SEPTEMBER 1977 W. M. GRAY AND R. W. JACOBSON, JR. 1171

Diurnal Variation of Deep Cumulus Convection

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Dunion, J. P., C. D. Thorncroft and C. S. Velden. 2014: The Tropical Cyclone Diurnal Cycle of Mature Hurricanes. *Mon. Wea. Rev.*, **142**, 3900-3919.

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The Tropical Cyclone Diurnal Cycle of Mature Hurricanes

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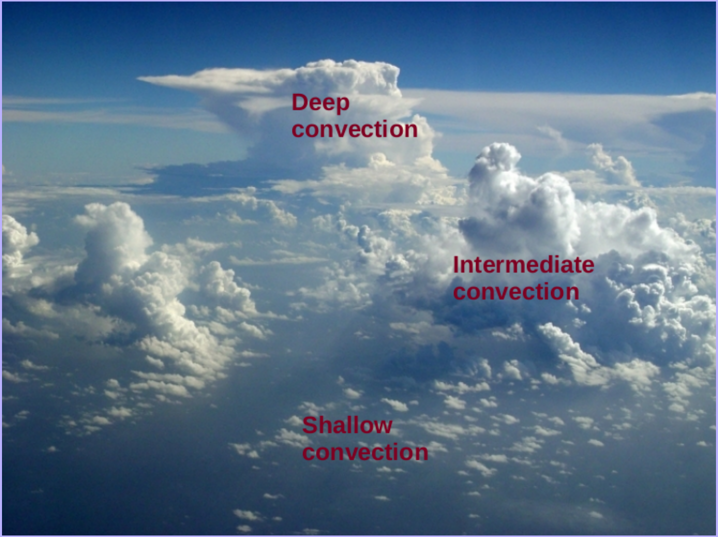
Deep Convection



Photograph taken by Roger K. Smith.

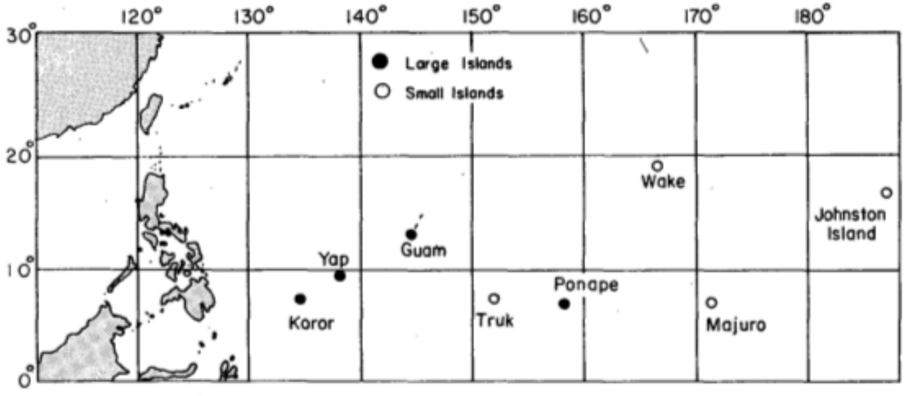
Gray and Jacobson (1977): Diurnal Variation of Deep Cumulus Convection

- The paper presents observational evidence in support of the existence of a large **diurnal cycle** (one daily maximum and one daily minimum) of **oceanic, tropical, deep cumulus convection.**
- The more intense the deep convection and the more associated it is with organized weather systems, the more evident is a diurnal cycle with a **maximum in the morning.**
- At many places over tropical oceans **heavy rainfall** is 2-3 times greater in the morning than in the late afternoon.

Diurnal variation of oceanic deep cumulus convection

Example: Analysis of tropical oceanic precipitation for 8 stations in tropical west Pacific.

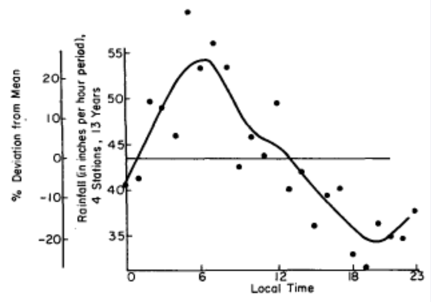
- Dataset: Hourly precipitation data from National Climatic Center for the period 1961-1973.



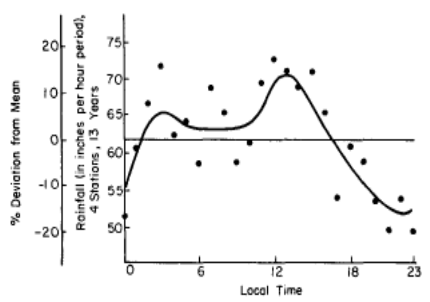
Diurnal variation of oceanic deep cumulus convection

Hourly distribution of the 13-year average precipitation for the **spring season** (March-May):

Precipitation curve for SMALL ISLANDS



Precipitation curve for LARGE ISLANDS



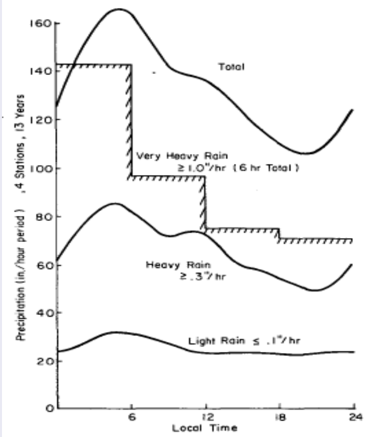
- **Early morning maximum** occurs between 03:00 and 06:00 LT.
- The larger stations experience an **afternoon heat island influence** which is not present in the smaller atolls.

Diurnal variation of oceanic deep cumulus convection

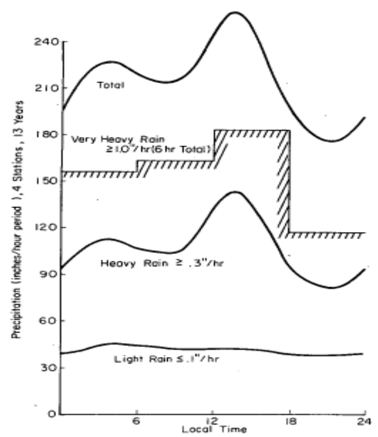
Rainfall by intensity (13-year average, March-October):

- Light rain: ≤ 0.1 inch h^{-1} (≤ 2.5 mm h^{-1})
- Heavy rain: ≥ 0.3 inch h^{-1} (≥ 7.6 mm h^{-1})

SMALL ISLANDS



LARGE ISLANDS



Physical mechanism?

Main finding:

Small islands, which are best representatives of oceanic conditions, show a strong diurnal variation in heavy rainfall with a maximum at night / in the early morning.

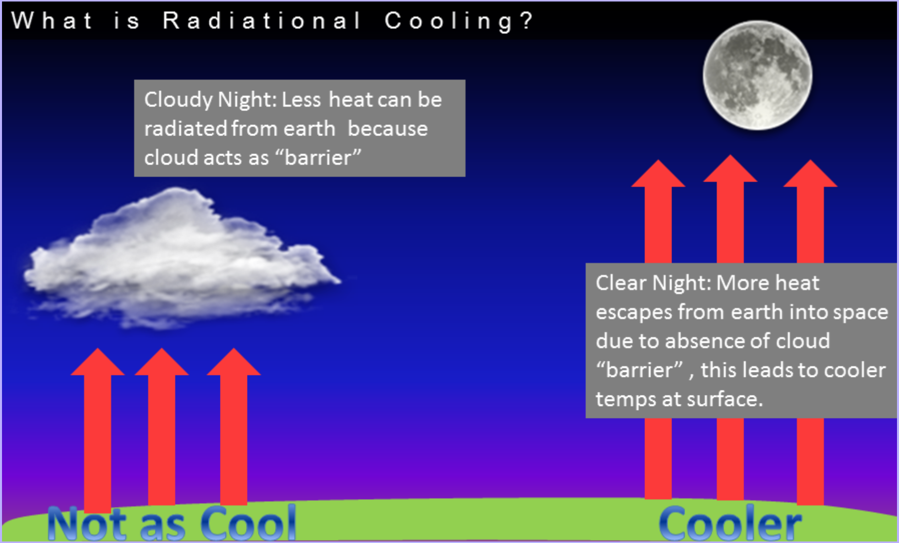
Question:

Which physical mechanism causes this nighttime / early morning maximum?

Hypothesis:

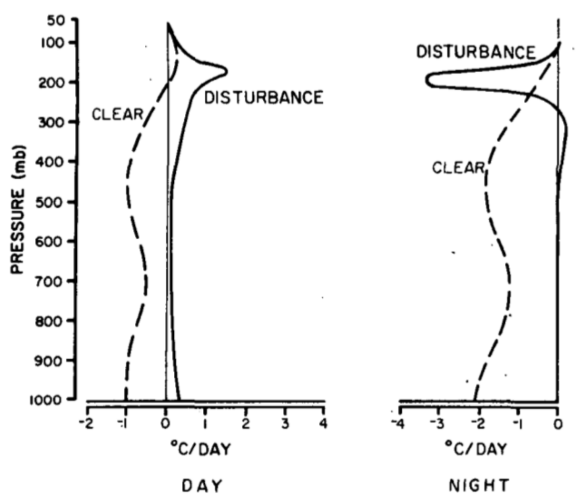
The diurnal cycle of oceanic deep convection with a morning maximum likely results from day versus night variations in **radiational cooling** between the weather system and its surrounding cloud-free region.

CLOUDY NIGHT vs. CLEAR NIGHT radiational cooling

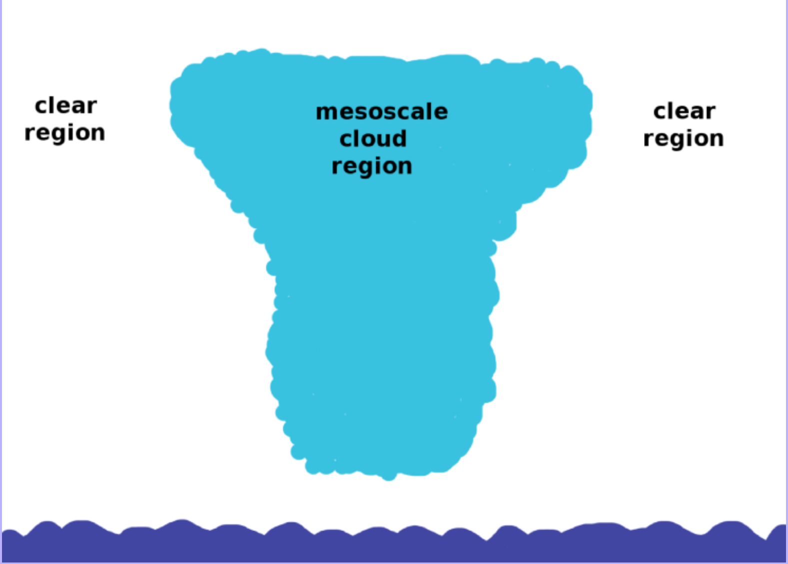


Radiation-induced temperature changes

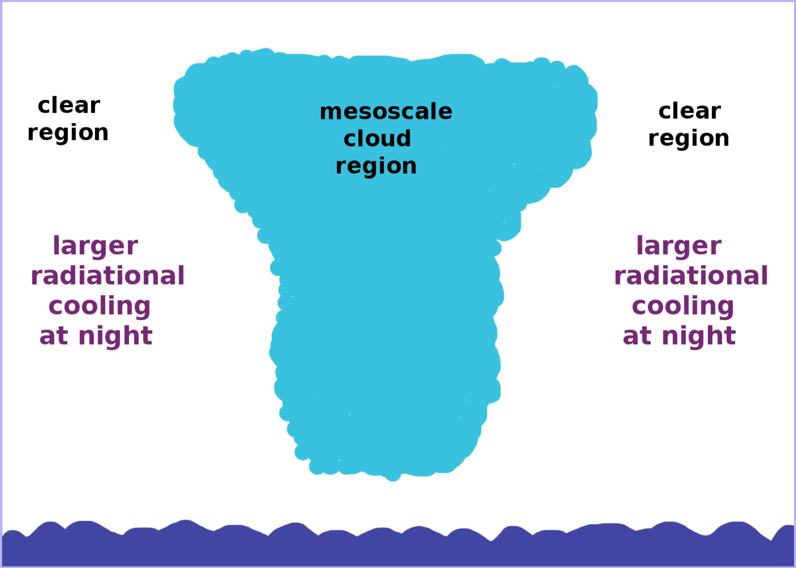
- Tropical disturbance vs. surrounding clear regions ?



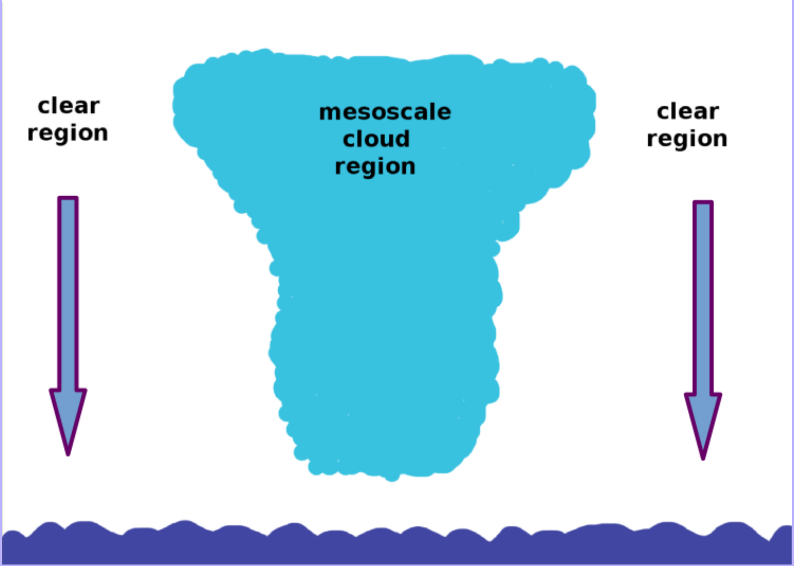
Radiation hypothesis



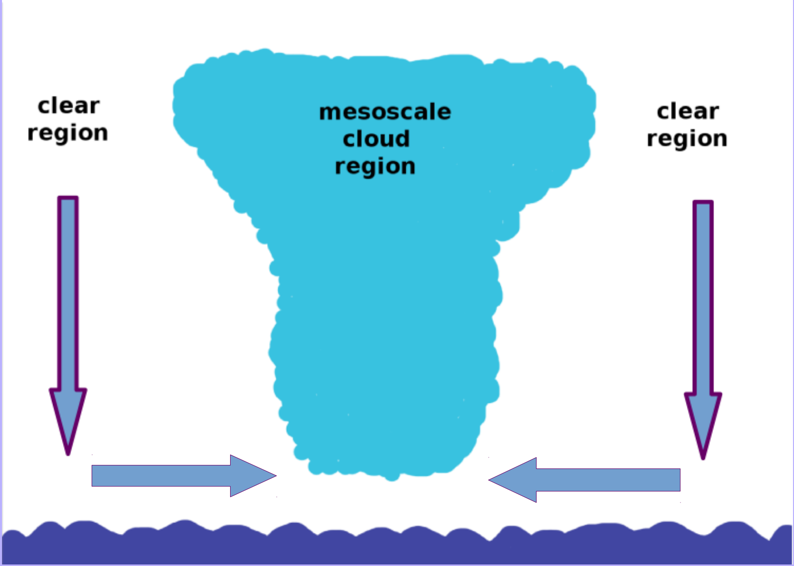
Radiation hypothesis



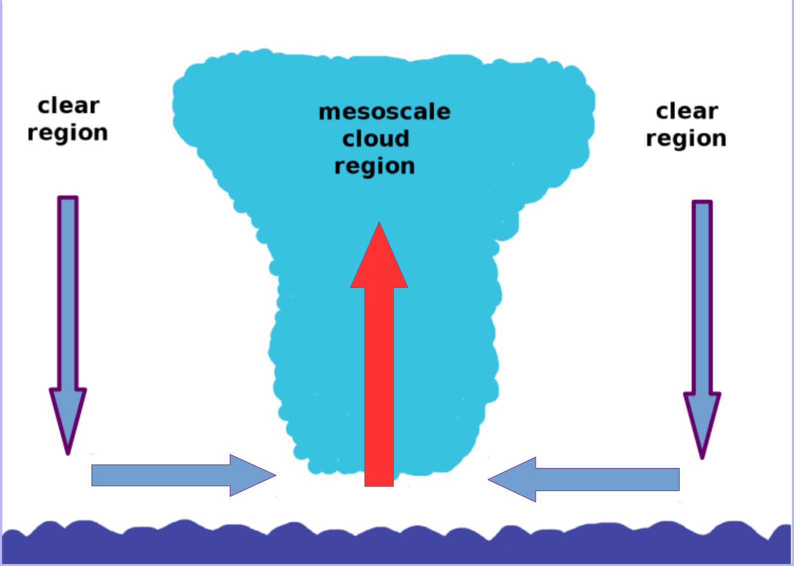
Radiation hypothesis



Radiation hypothesis



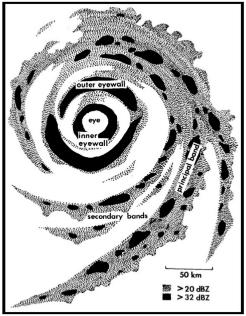
Radiation hypothesis

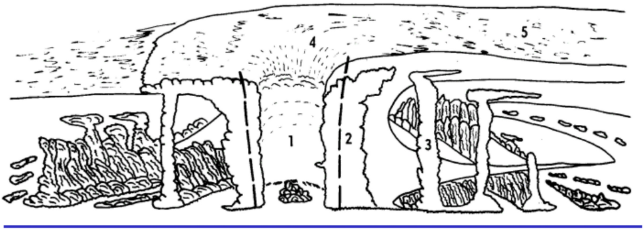


Summary: Radiation hypothesis

- **Radiational cooling** of clear regions is **larger** than that of areas underneath the disturbance.
- Comparatively large nocturnal cooling of clear regions drives **subsidence**.
- This extra nighttime subsidence within clear regions increases **low-level (moisture) convergence** into the adjacent cloud regions.
- This leads to **higher convective activity** (i.e., higher precipitation intensity) at night.
- Large nighttime radiational cooling of upper-level cirrus cloud shield acts in a complementary fashion with conditions at lower levels.
- This type of diurnal radiation response occurs only with **organized mesoscale weather systems** (i.e., cloud clusters, tropical cyclones).
- Only organized mesoscale weather systems posses **sufficient lifetime and size** to make the radiation processes significant.

Structure of mature tropical cyclones





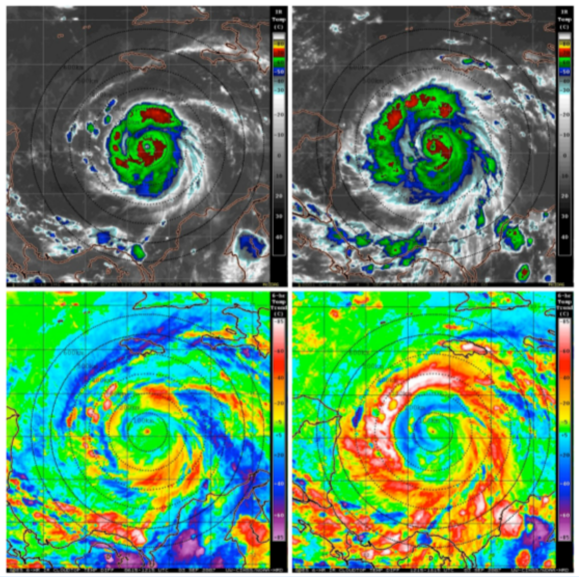
— — —	Maximum wind belt	3	Spiral bands
1	Eye	4	Cirrus overcast
2	Wall cloud	5	Cirrus outflow

Dunion et al. (2014): The Tropical Cyclone Diurnal Cycle of Mature Hurricanes

- Goal of the study: To document the observational aspects of tropical cyclone (TC) diurnal cycle characteristics.
- Dataset: All North Atlantic major hurricanes from 2001 to 2010 (36 hurricanes).
- Methodology: This work presents a **new technique that uses IR satellite image differencing** to examine the evolution of the TC diurnal cycle.

Hurricane Felix (2007)

Diurnal cycle of hurricane Felix (September 3, 2007)



GOES IR (10.7 μm) imagery:

Left: 12:15 UTC (07:15 LST)

Right: 18:15 UTC (13:15 LST)

Note: Arc of cold cloud tops (**from −50°C to −70°C**) propagating radially outwards;

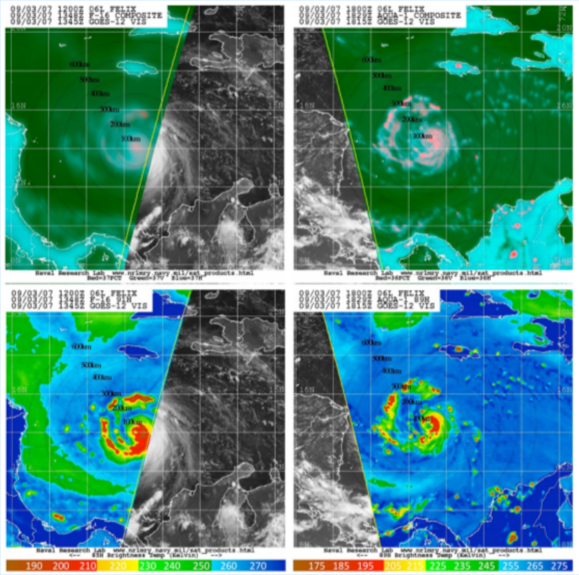
6-h GOES IR differencing imagery:

Left: 06:15-12:15 UTC

Right: 12:15-18:15 UTC

Note: Ring of cooling cloud tops (**−10°C to −85°C IR cooling tendencies**) propagating radially outwards (DIURNAL PULSE);

Diurnal cycle of hurricane Felix (September 3, 2007)



37-GHz microwave images:
Left: 13:48 UTC
Right: 18:29 UTC

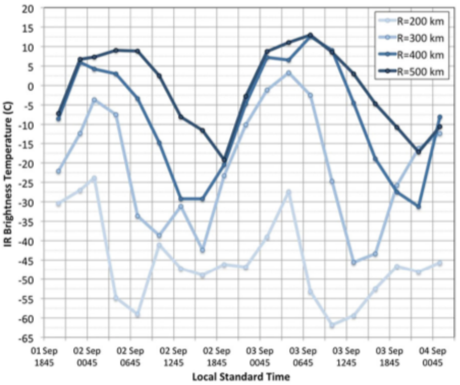
This channel is sensitive to low-level rain and cloud liquid water.

89-91 GHz microwave images:
Left: 13:48 UTC
Right: 18:29 UTC

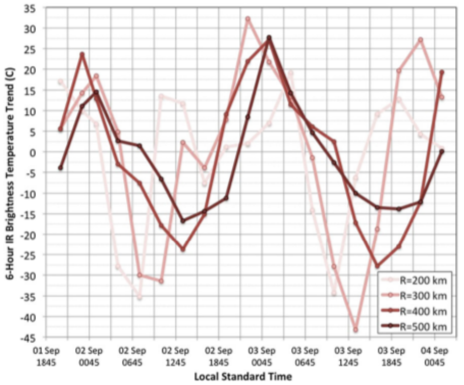
Ideal channel for examining TC inner-core and rainband structures in the middle to upper levels.

Diurnal cycle of hurricane Felix

Azimuthally-averaged **IR brightness temperatures:**



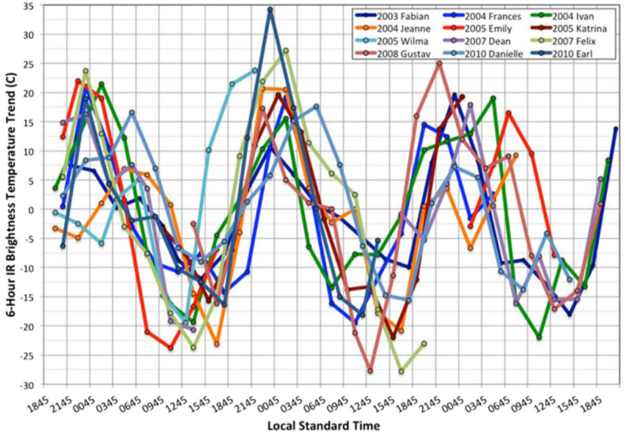
Azimuthally-averaged **6-h IR brightness temperature trends:**



$\Longrightarrow$ At a given radius, a period of cooling is followed by a period of warming. The period of this oscillation: $\sim$ **1 day**.

$\Longrightarrow$ There is a **phase shift** in the timing of the diurnal cycle at the various radii (i.e., the peak cooling/warming progress radially outward over time).

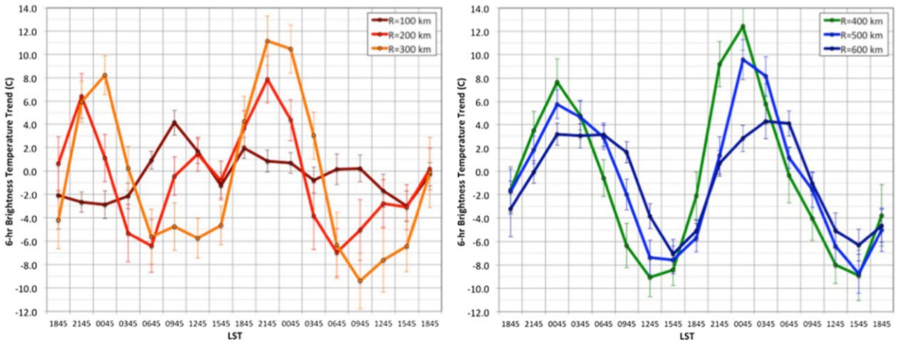
Azimuthally-averaged **6-h IR brightness temperature trends** (at R = 400 km) for several major hurricanes:



$\Longrightarrow$ A well-defined TC diurnal cycle in the satellite IR brightness temperature fields emerges, even when multiple TCs are examined!

Diurnal cycle of mature tropical cyclones: Mean statistics

Azimuthally-averaged **6-h IR brightness temperature trends** at different radii (mean statistics for 2001-2010 dataset):



- There is a **clear diurnal signal** at various radii from the storm centre.
- Diurnal pulses (i.e., peak cooling in the IR field) propagate radially outward over time.

Relation to Gray and Jacobson (1977)

- The oscillating peaks of cooling and warming evident in the IR satellite imagery may have important implications for the **timing of TC inner-core deep convection** (precipitation, intensity change etc.).
- For instance, the **diurnal pulse (peak cooling in the IR cloud field)** reaches R = 200 km between ∼04 and ∼08 LST. **Peak warming in the IR cloud field** at this radius occurs between ∼20 and ∼00 LST.

	R = 200 km
Peak IR cooling	
LST	0400–0800
Hours after sunset	9–13
Peak IR warming	
LST	2000–0000
Hours after sunset	1–5

Peak IR cooling $\Longrightarrow$ **deep convection maximum**

Peak IR warming $\Longrightarrow$ **deep convection minimum**

- This corresponds well with Gray and Jacobson's (1977) findings regarding the timing of deep convection maxima and minima over tropical oceanic regions.

Extension of Gray and Jacobson's (1977) conclusions:

- However, the diurnal pulses pass through outer radii (e.g., 300-500 km) several hours after reaching R = 200 km.

	R = 200 km	R = 300 km	R = 400 km	R = 500 km
Peak IR cooling				
LST	0400–0800	0800–1200	1200–1500	1500–1800
Hours after sunset	9–13	13–17	17–20	20–23
Peak IR warming				
LST	2000–0000	2200–0200	2300–0300	0000–0400
Hours after sunset	1–5	3–7	4–8	5–9

- This suggests that Gray and Jacobson's (1977) conclusions, although **valid for the TC inner-core region, do not adequately describe the TC diurnal cycle at all radii of a storm!**
- This relates to the fact that TC diurnal pulses propagate away from the TC center and hence, TC convective minima and maxima can be better described in terms of both **time** and **space**.

Summary and Outlook

- Gray and Jacobson (1977): The diurnal variation of oceanic deep cumulus convection exhibits an **early morning maximum.**
- This diurnal cycle likely results from day versus night variations in tropospheric radiational cooling between the weather system and its surrounding cloud-free region.
- Dunion et al. (2014) present a satellite-based examination of the diurnal cycle in mature tropical cyclones.
- The IR differencing imagery reveals a distinct **diurnal pulse** in the IR cloud field, that propagates radially outward from the storm.
- Microwave satellite imagery shows that TC diurnal pulse involves a relatively deep layer of the storm ($\sim$200-600 hPa).
- This suggests that the TC diurnal cycle may be an important element of TC dynamics and may have relevance to TC structure and intensity change.

Summary and Outlook

- The outwardly propagating diurnal pulse suggests that minima and maxima associated with the TC diurnal cycle (e.g., convection, precipitation, cirrus canopy areal coverage) cannot be adequately described in terms of time alone.

- Future work is required to provide a more complete explanation of the TC diurnal cycle.

The End