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Warming SST Raises the Bar for Tropical Cyclogenesis

Jenni L. Evans

Collaborators: Jeffrey Waters, Casey Webster, Chris Forest

US CLIVAR Workshop, 5 June 2013

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Favorable Environmental Conditions for Tropical Cyclogenesis

1. SST in excess of 26°C to a depth of 60 m (SST > 26°C)
2. Conditional instability
3. High mid-level relative humidity (RH > 80% at 500 hPa)
4. Weak vertical wind shear (850 – 250 hPa vector shear)

5. Distant from the equator ($|\varphi| > 5°$ latitude)
6. Anomalous cyclonic low-level relative vorticity (taken at 850 hPa – above the PBL)

Gray (1968)

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Incipient disturbance

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Gray (1968)

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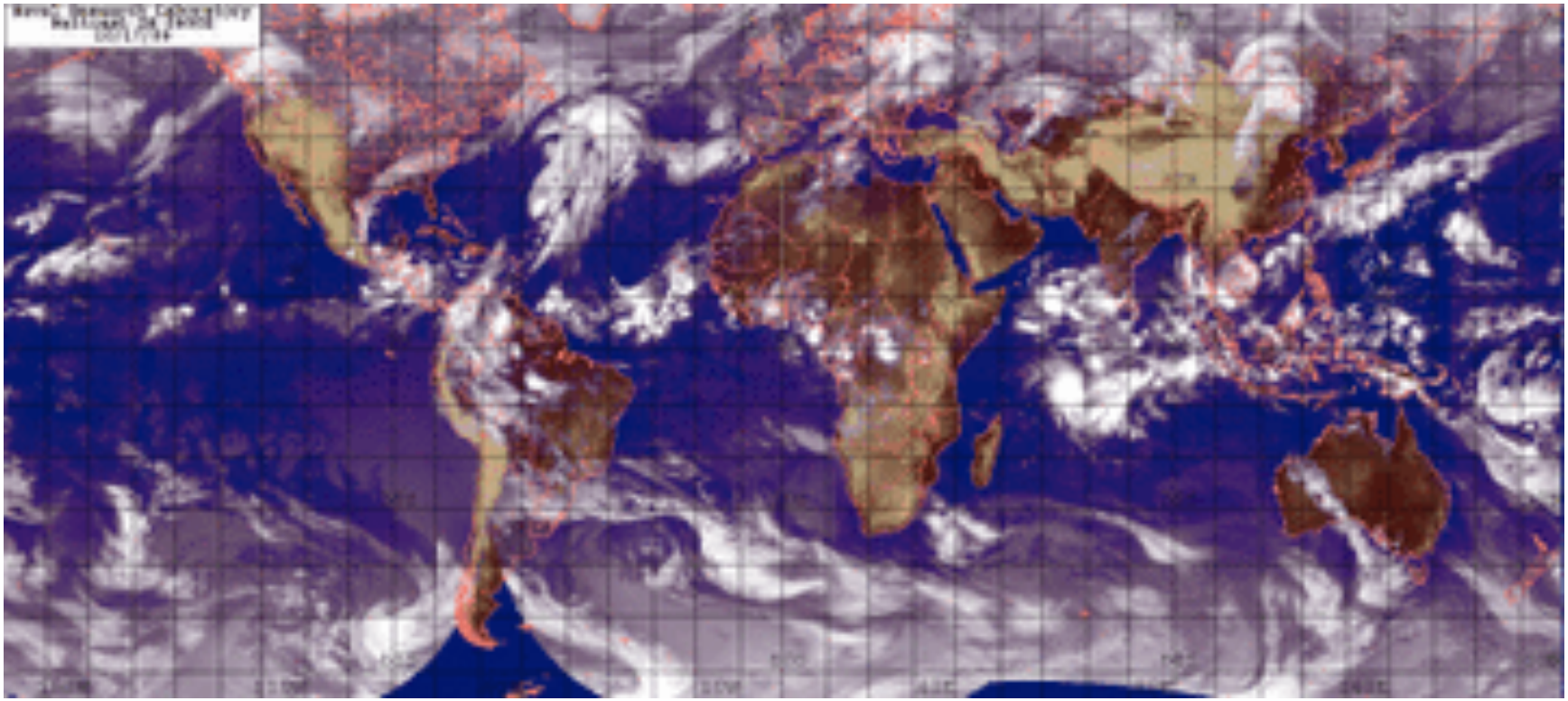
Tropical cyclones develop from a pre-existing disturbance of oceanic deep tropical convection



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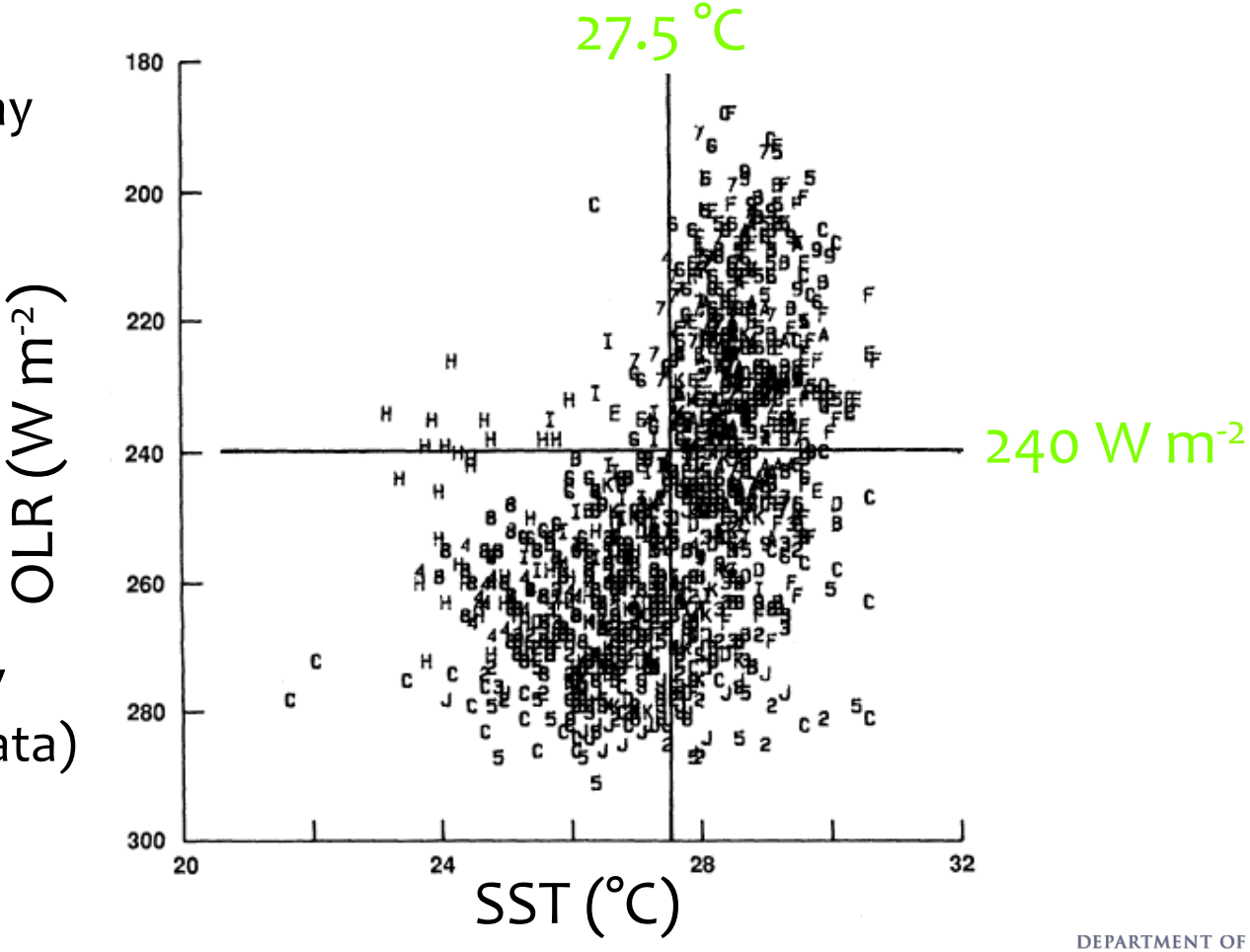
Observed tropical SST and deep convection (1974-1979)

OLR: 5°×5°, 5-day averages from polar orbiter

SST: 4°×4°, daily COADS (ship data)



Graham and Barnett (1987)

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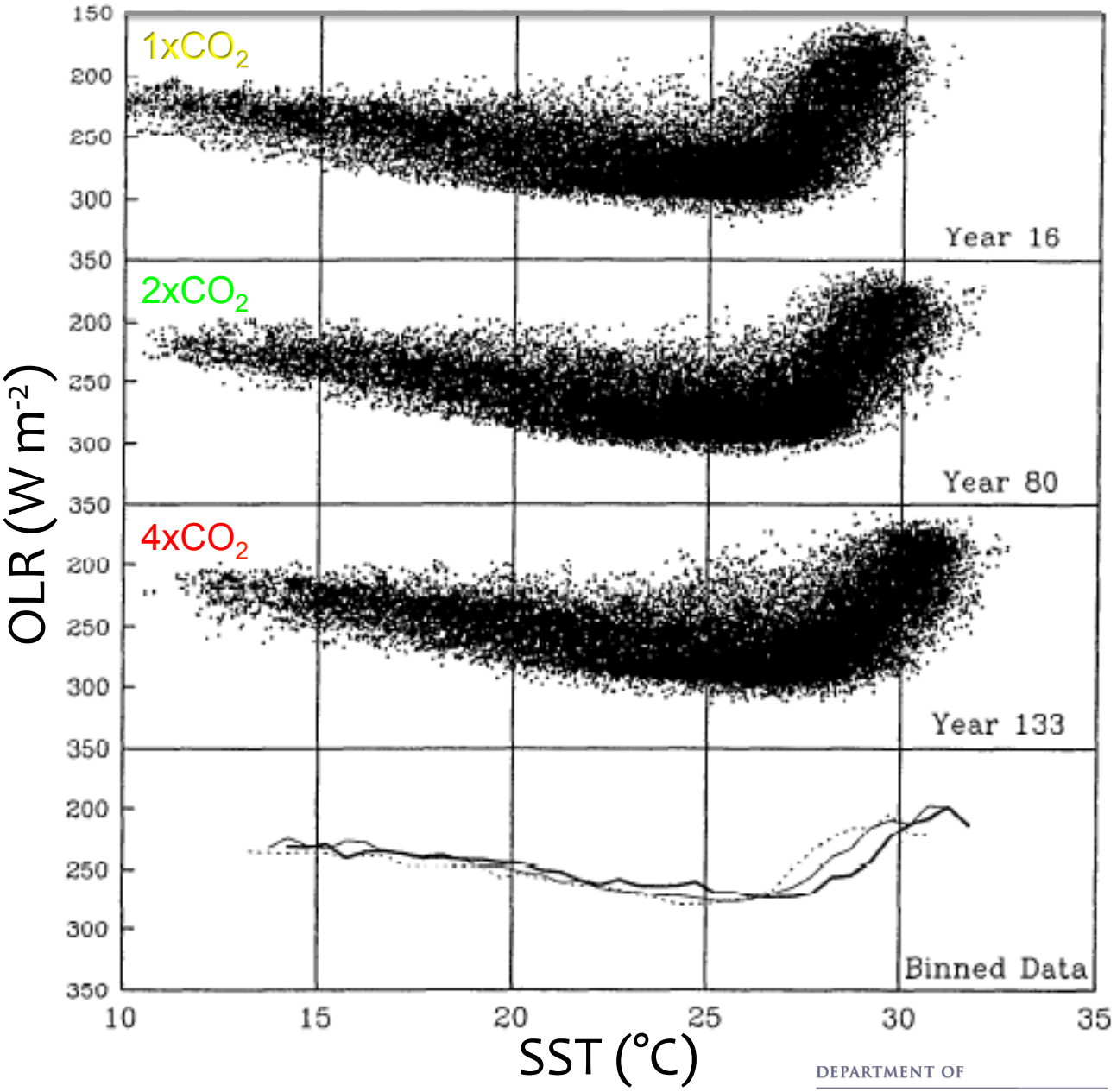
Climate change simulation

CSM1 coupled AOGCM with 1% annual CO_2 increase

Analyses for 40° S to 40° N



Dutton, Poulsen and Evans (2000)

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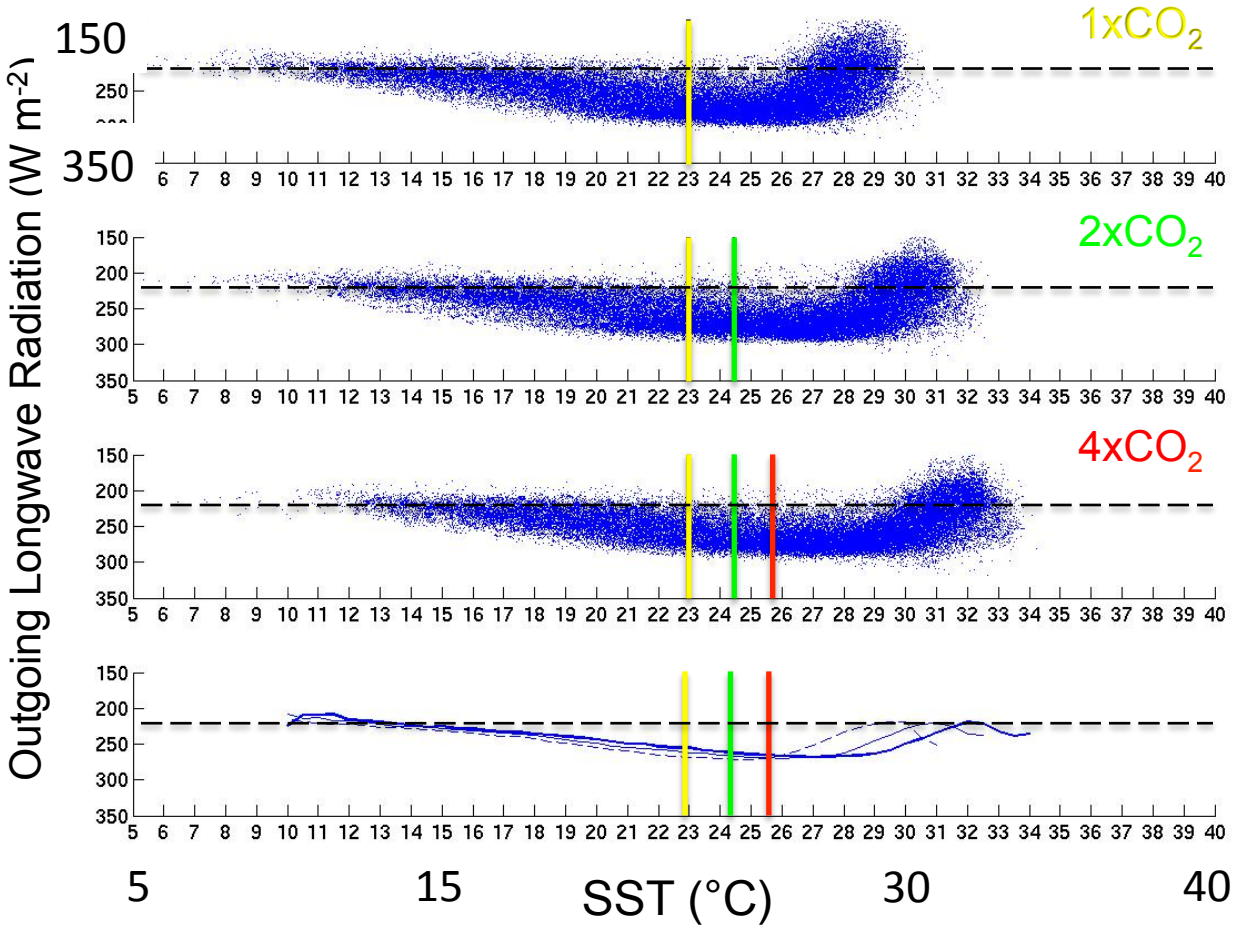
AOGCM transient CO2 SST threshold behavior for tropical convection



OLR variation with SST (40°N-40°S) GFDL-CM2.0

355 ppmv
710 ppmv
1210 ppmv

Evans and Waters (2012)

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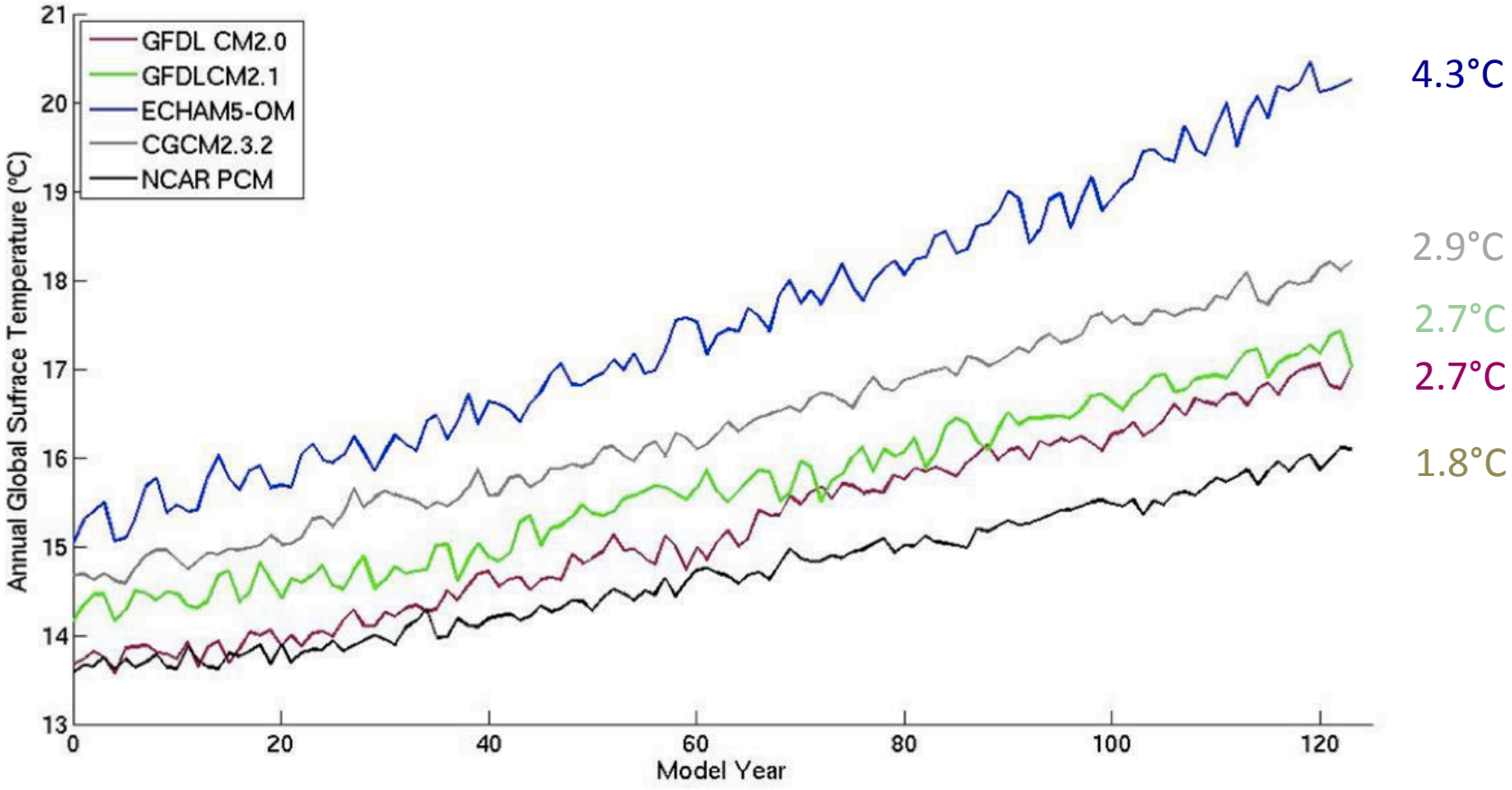
Transient CO_2 global average surface temperature (IPCC4)



Evans and Waters (2012)

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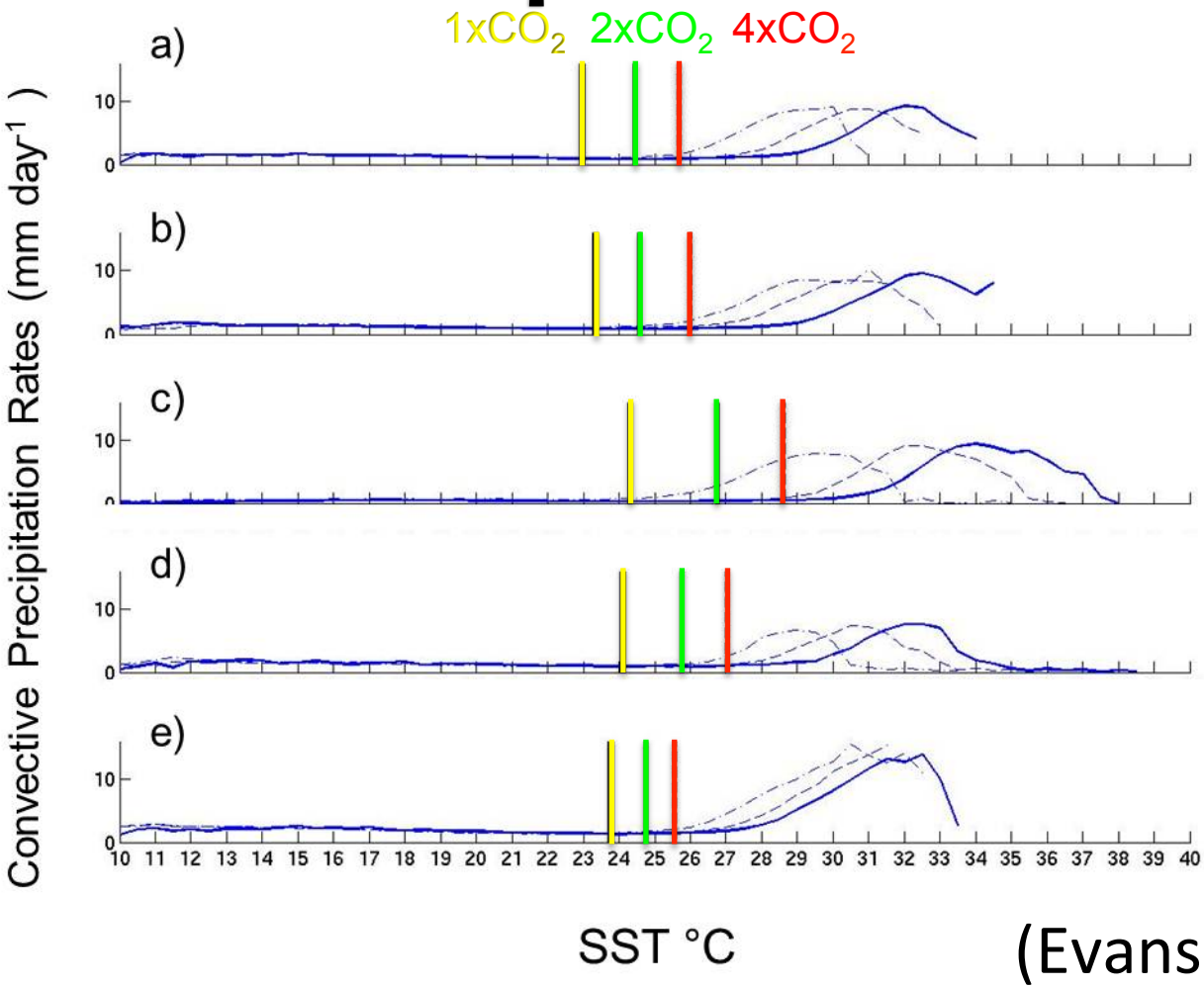
Precipitation rate and SST



GFDL CM2.0

GFDL CM2.1

ECHAM5/MPI-OM

MRI CGCM2.3.2

NCAR PCM

(Evans and Waters 2012)

355 ppmv
710 ppmv
1210 ppmv

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An SST Threshold for Deep Convection

- Threshold SST exists for deep tropical convection
- Evidence from AOGCMs that this threshold will increase in value under global warming

- How does this relate to tropical cyclones?

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A threshold SST is also observed for tropical cyclogenesis

- Palmén (1948)
  - identified a 26.5° C SST threshold for tropical cyclogenesis
- Gray (1968)
  - relates 26.5° C threshold to other environmental conditions
  - linked SST directly to convective support for TCG
- Dare and McBride (2011)
  - re-examine the SST threshold value

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A threshold SST is also observed for tropical cyclogenesis

Global TCs

- 1981-2008
- 35° S to 35° N
- NOT ST or ET

2217 TC events

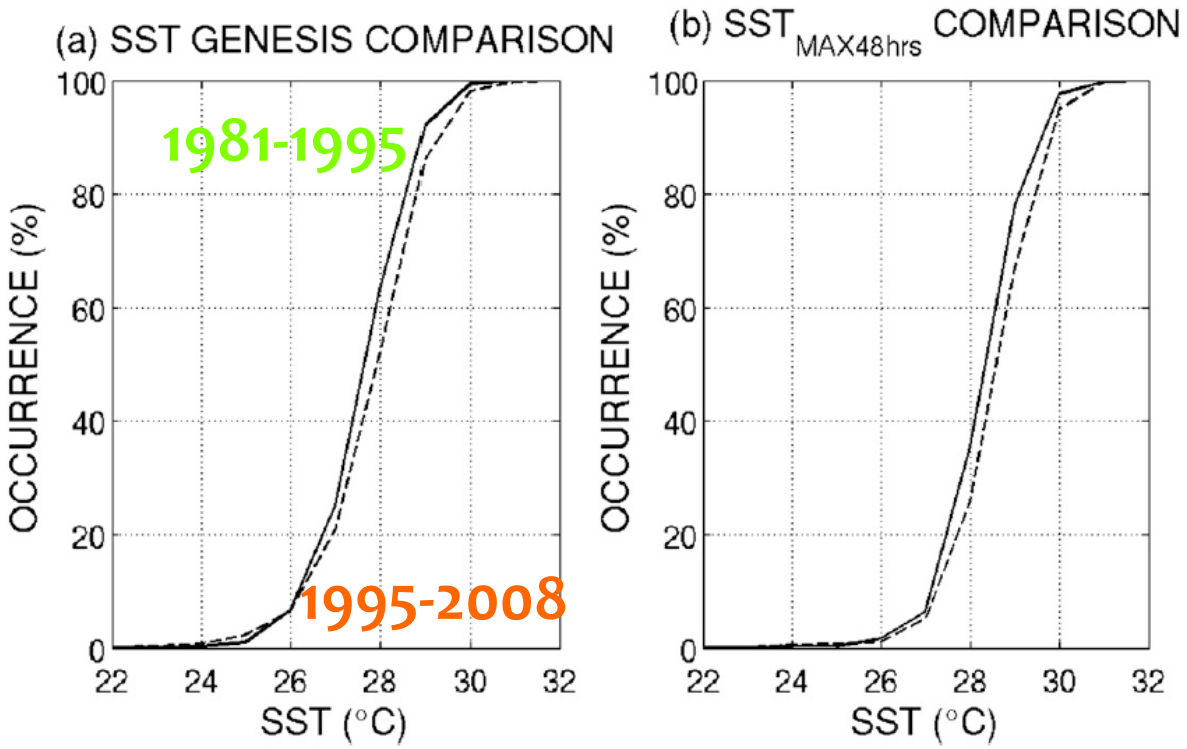

FIG. 5. (a) Accumulated percentages of SSTs at the point of TC genesis corresponding to each 1°C bin for TCs that occurred during the period September 1981 to June 1995 (solid line) and during July 1995 to December 2008 (dashed line). (b) As in (a), but with the SST48s.

Dare and McBride (2011)

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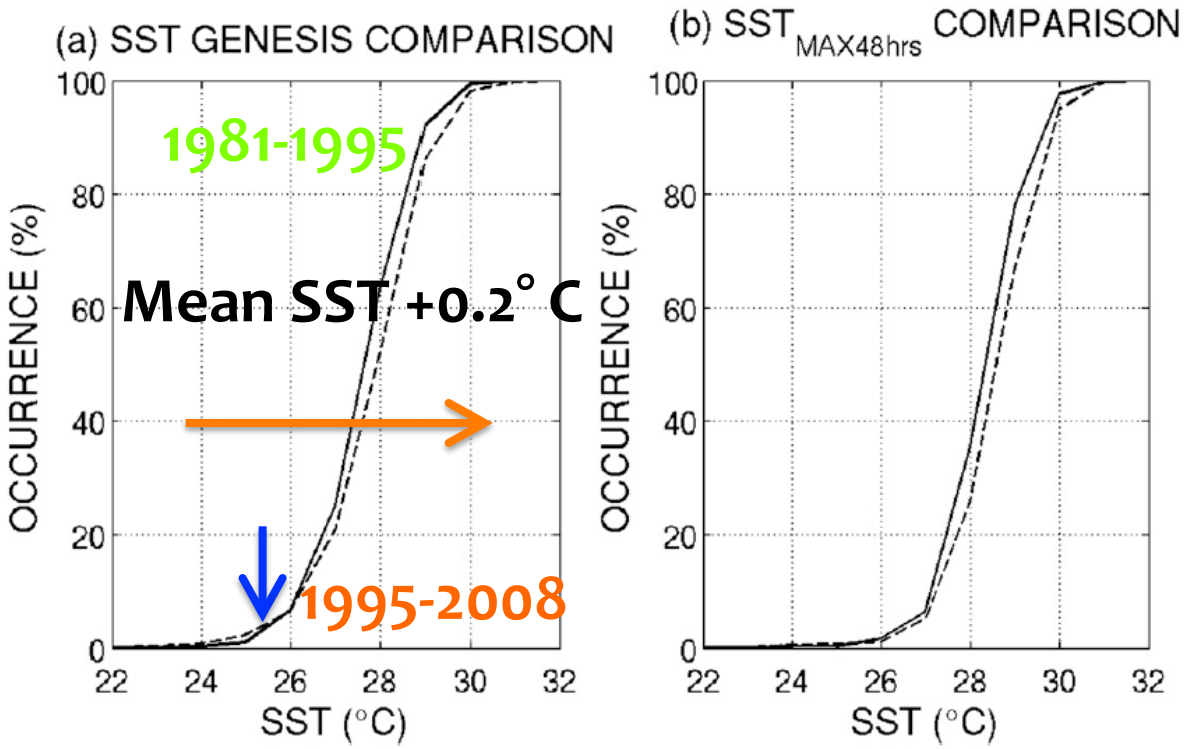
A threshold SST is also observed for tropical cyclogenesis

More systems form at SST< 25.5° C in later epoch

No change in threshold SST for TCG



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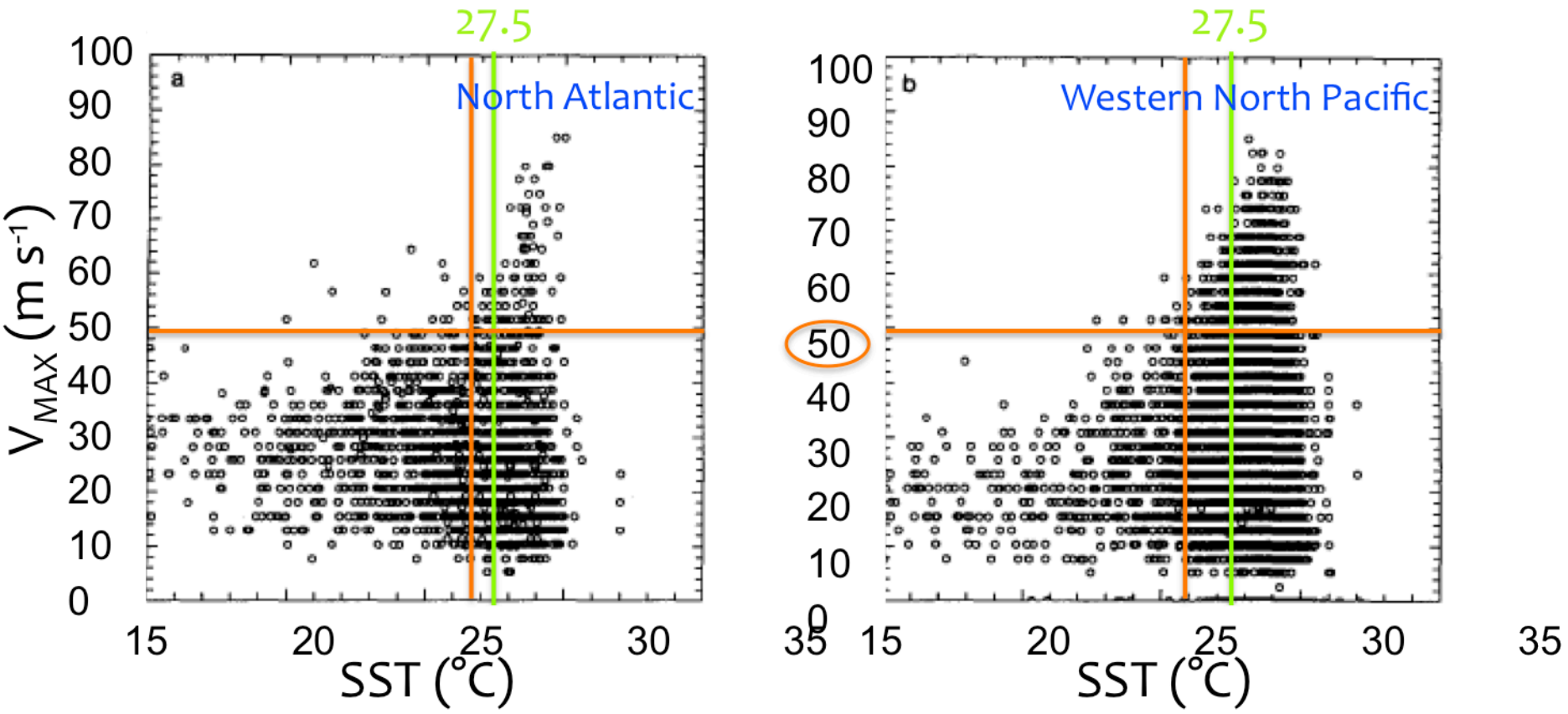
Observations of SST and TC intensity



TC intensities: Worldwide TC Dataset (NOAA 1988)

SST: 2°×2°, daily COADS (ship data)

Evans (1993)

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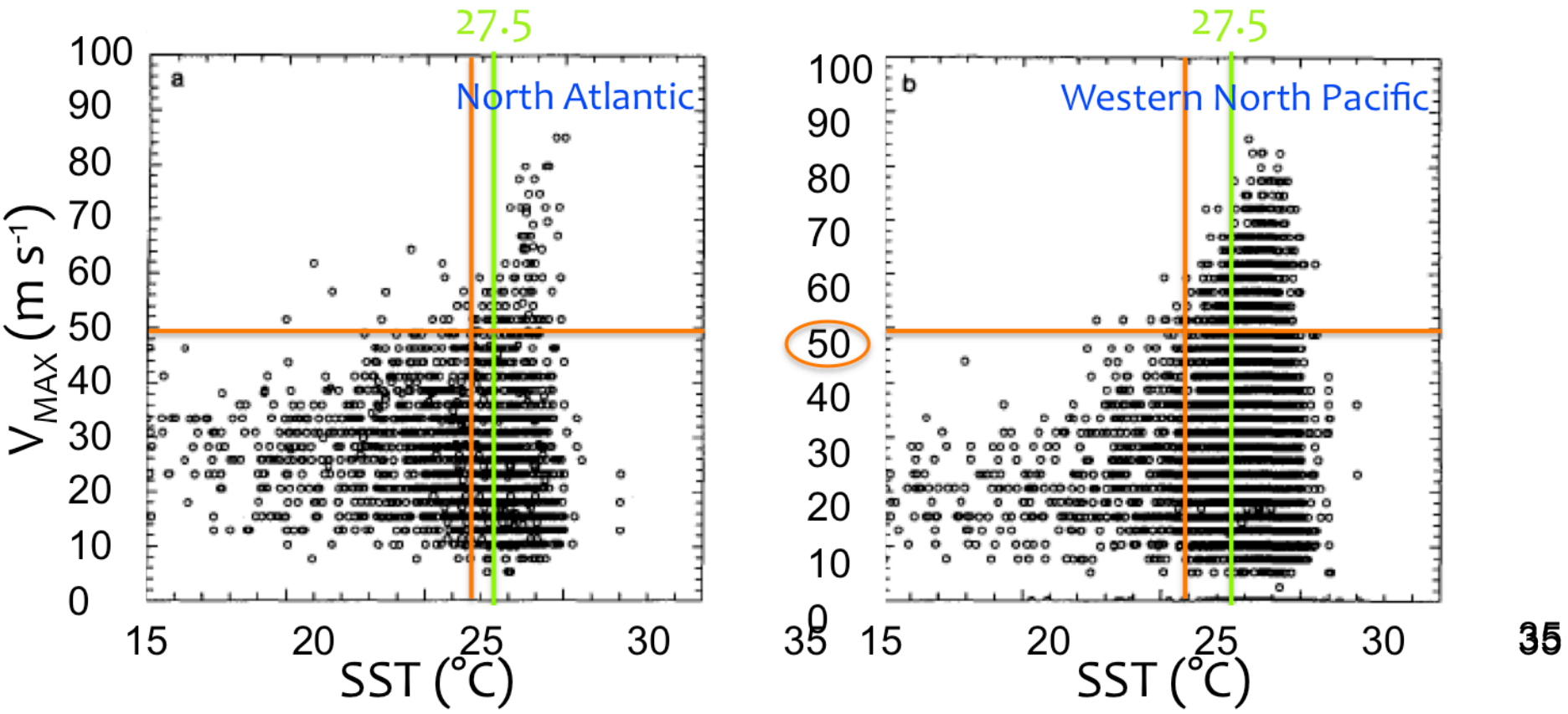

Evans (1993)

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So far

- Tropical cyclones develop from pre-existing complex of deep tropical convection
- Threshold temperature for existence of deep tropical convection
- Tropical cyclogenesis also has threshold SST
- Tropical cyclone maximum (possible) intensity also dependent on SST

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Remainder of talk

- Two recent contributions to this problem
  - Diagnostics of TC activity in climate model incorporating environment variability metrics (Waters, Evans, Forest. *J. Climate*, 2012)
  - Further examination of structure of SST-threshold for deep convection in current climate (Webster and Evans 2013)

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Gray's Seasonal Genesis Parameter (SGP) for climate change projections

Values are (2xCO2 / 1xCO2) by SGP component

Seasonal Genesis Parameter Component (SGP)	Interpretation	JFM	AMJ	JAS	OND
$\zeta_{850}\, f / \lvert f \rvert^{-1} + 5$	Cyclone relative vorticity anomaly	0.99	0.96	0.99	1.00
$(\partial v/\partial z + 3)^{-1}$	Weak vertical wind shear	0.98	1.01	1.02	1.09
E	SST > 26°C	2.13	2.01	2.10	2.18
$(\partial \theta_e/\partial p + 5)$	Conditionally unstable	1.27	1.27	1.27	1.25
$(RH_{500} - 40)/30$	High mid-level RH	1.09	1.08	1.06	1.07

Ryan, Watterson and Evans (1992)

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Inferring tropical cyclogenesis likelihood from larger scales

- More recent TC indices – Camargo and Sobel, Nolan and Emanuel, …
- Thermodynamic envelope for TCG varies slowly over large scales and long times
- Hypothesis: must capture short term dynamic and thermodynamic variability to capture TCG signatures

Waters, Evans and Forest (2012)

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Inferring tropical cyclogenesis likelihood from larger scales

- Deviation anomalies: how anomalous is *this* 15 days?

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Inferring tropical cyclogenesis likelihood from larger scales

- Deviation anomalies: how anomalous is *this* 15 days compared to other 15 day periods?

$$\sigma'_i = \frac{\sigma_i - \bar{\sigma}}{\sigma(\text{All } \sigma_i)}$$

- Sub-monthly variability (also 5 and 10 days)
- Develop logistic (Y/N) and Poisson (#) TCG regression models
- Build models on EOFs of deviation anomalies

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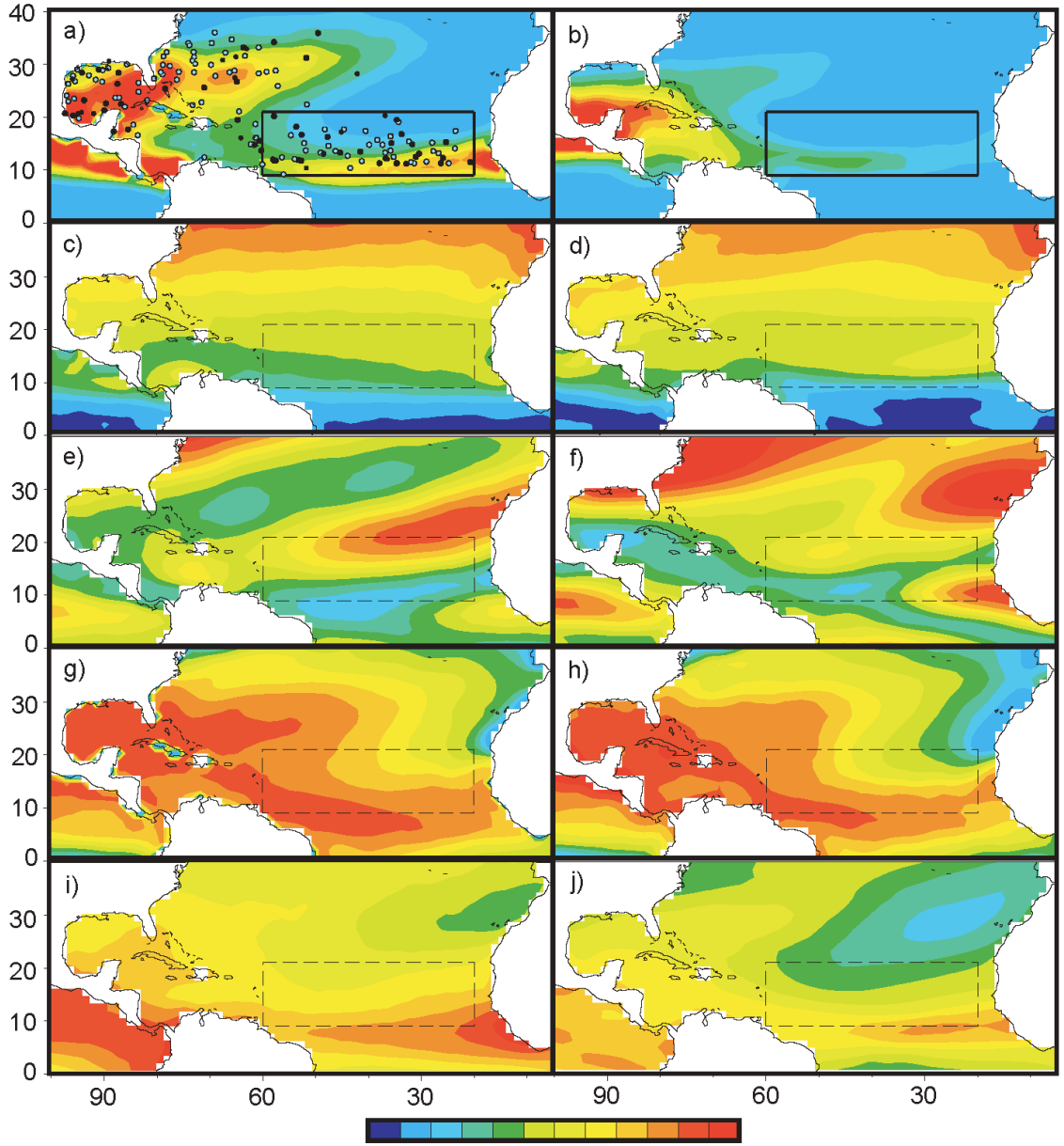
ERA-40 CAM3.1 (1.4° x 1.4°)



GPI (0 – 10 events)

850 hPa ζ_a

Potential Intensity

850–200 hPa shear

700 hPa RH

Waters, Evans and Forest (2012)

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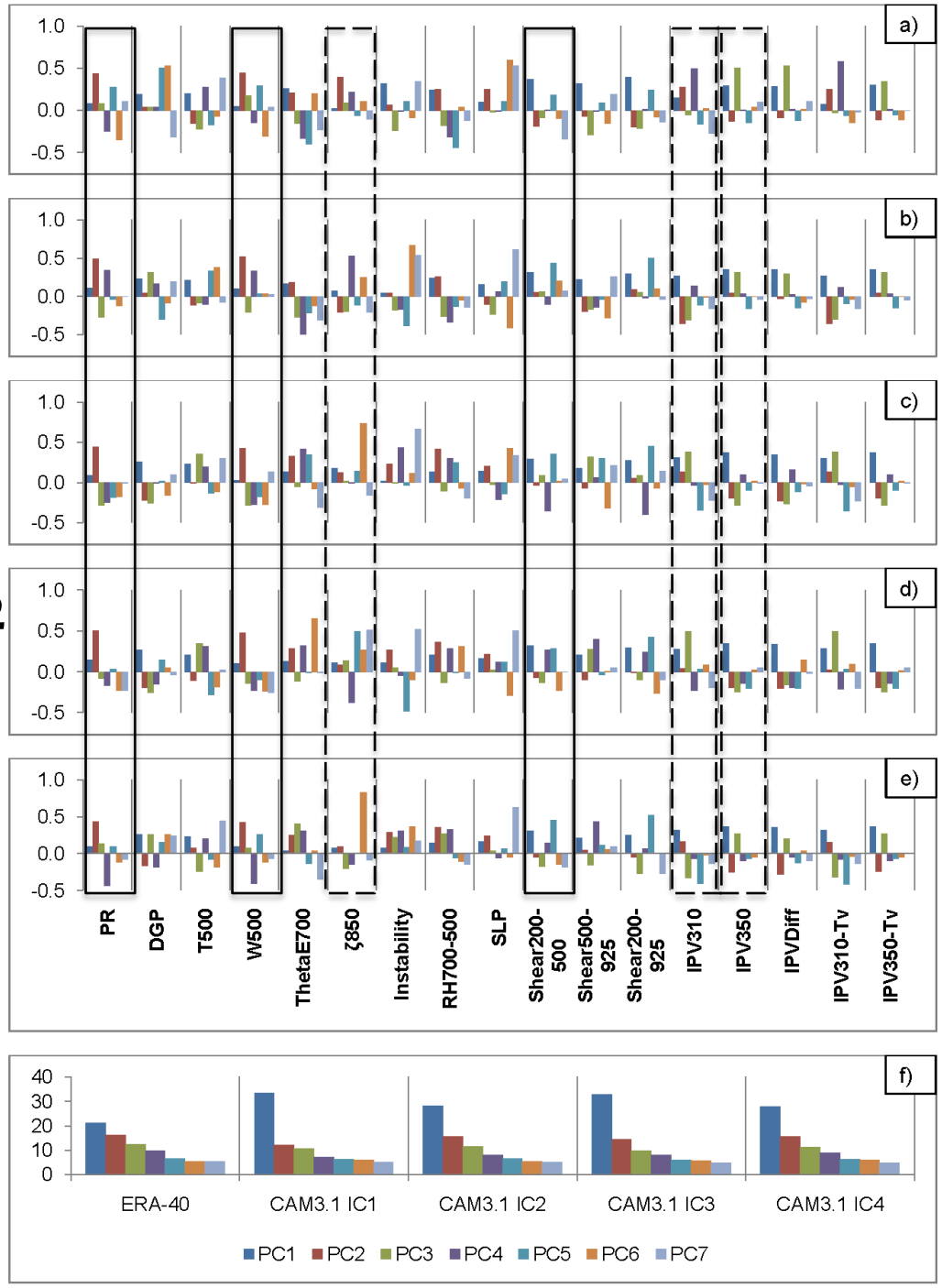
ERA-40 PC1

- IPV350
- Shear

ERA-40 PC2

- PR
- W500



ERA-40

CAM3.1 #1

CAM3.1 #2

CAM3.1 #3

CAM3.1 #4

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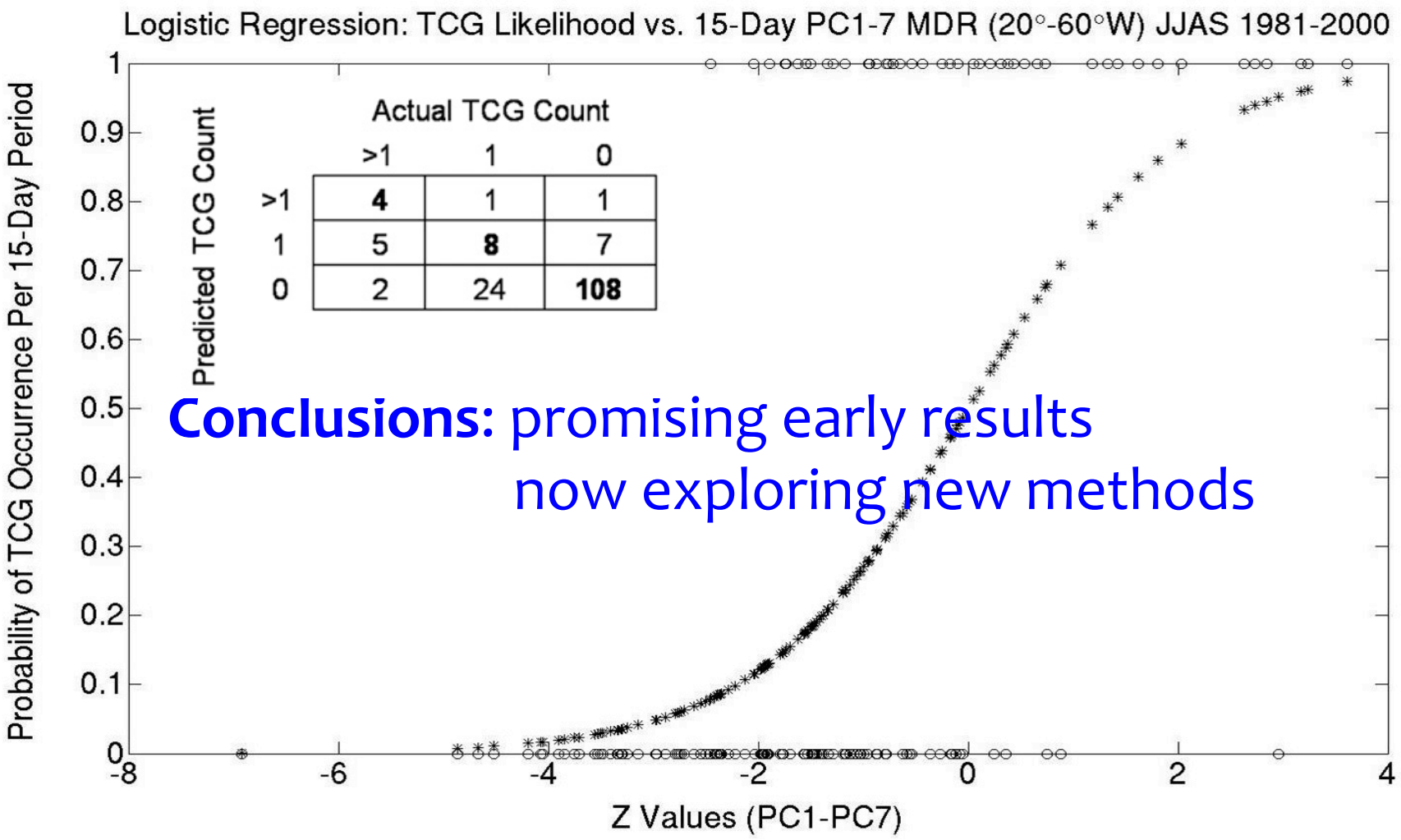

Predicted TCG Count	Actual TCG Count >1	Actual TCG Count 1	Actual TCG Count 0
>1	**4**	1	1
1	5	**8**	7
0	2	24	**108**

Conclusions: promising early results
now exploring new methods

Waters, Evans and Forest (2012)

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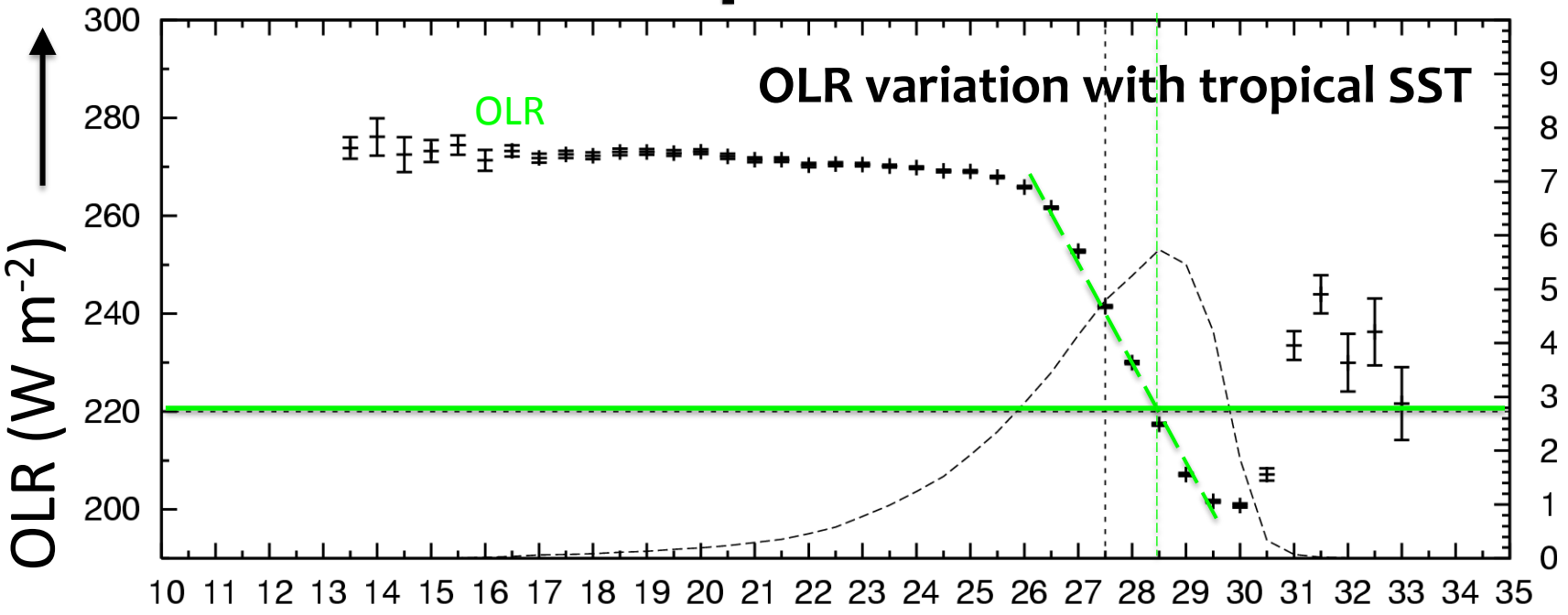
Observed SST threshold behavior for tropical convection



SST (°C) in band 22°S – 22°N

July 2002 – October 2005

Threshold SST 28.5°C

Webster and Evans (2013)

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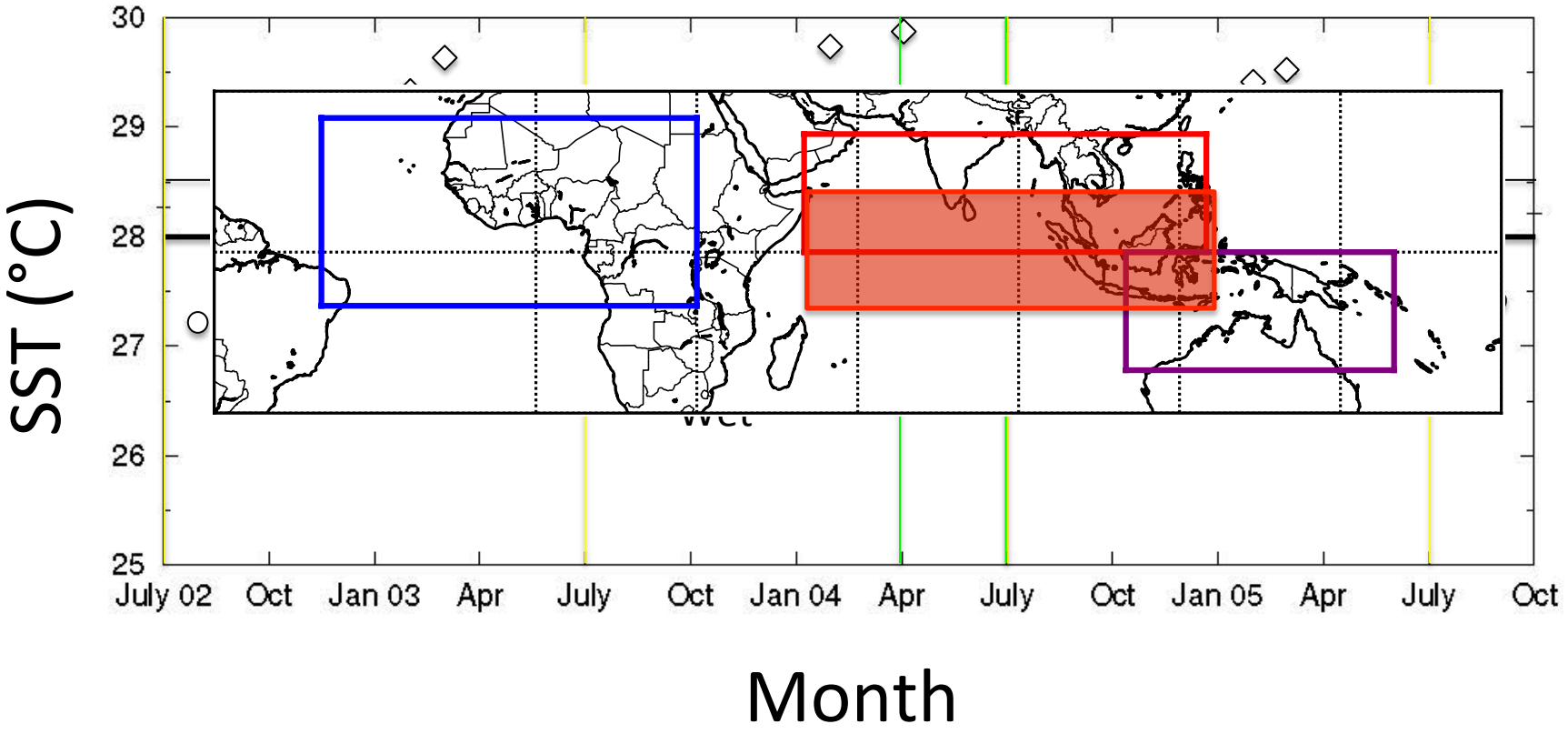
Temporal variation of SST threshold in Asian monsoon region



Webster and Evans (2013)

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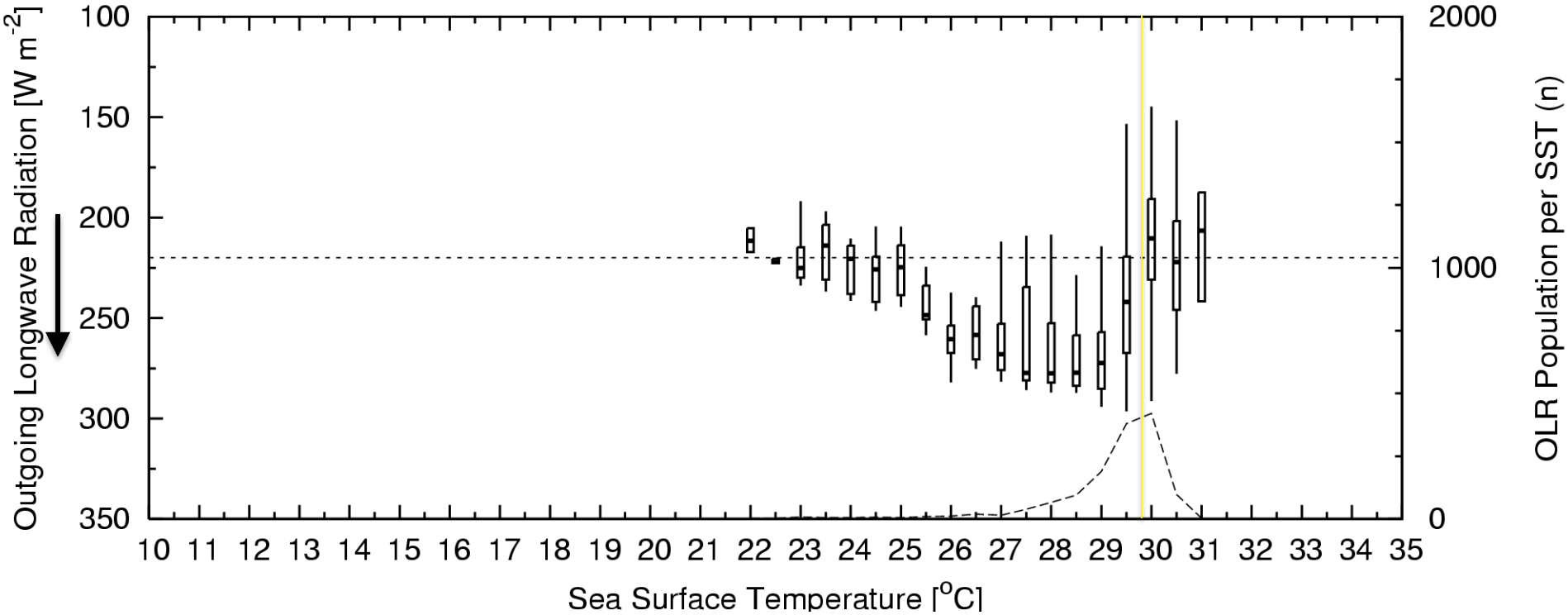
SST threshold variation in Asian monsoon: April 2004 (dry)



Threshold SST ~30°C

Webster and Evans (2013)

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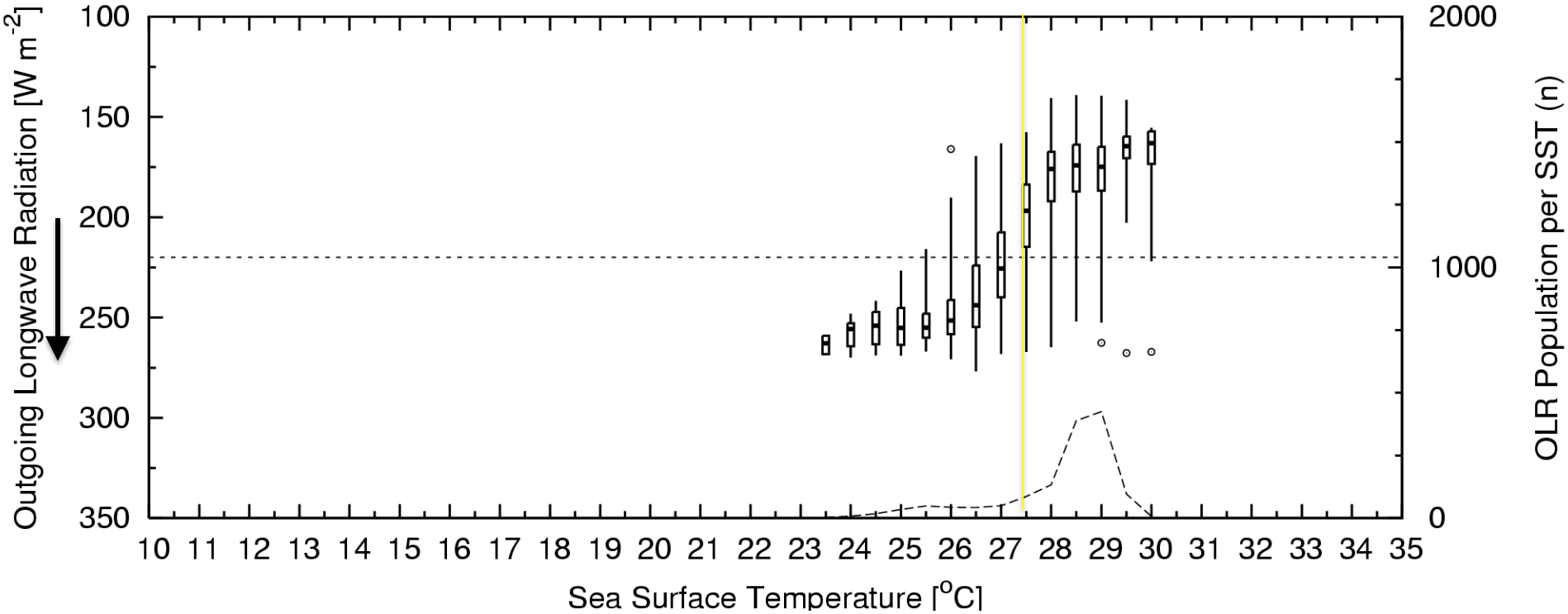
SST threshold variation in Asian monsoon: July 2004 (wet)



Threshold SST~27.5°C

Webster and Evans (2013)

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SST threshold from observations

- Increase in average SST in a tropical region ⇔ SST threshold for deep convection increases!
- Link is via large-scale dynamical structure of the atmosphere
- Thermodynamics are fundamental to TC development, but dynamics are the limiting factor

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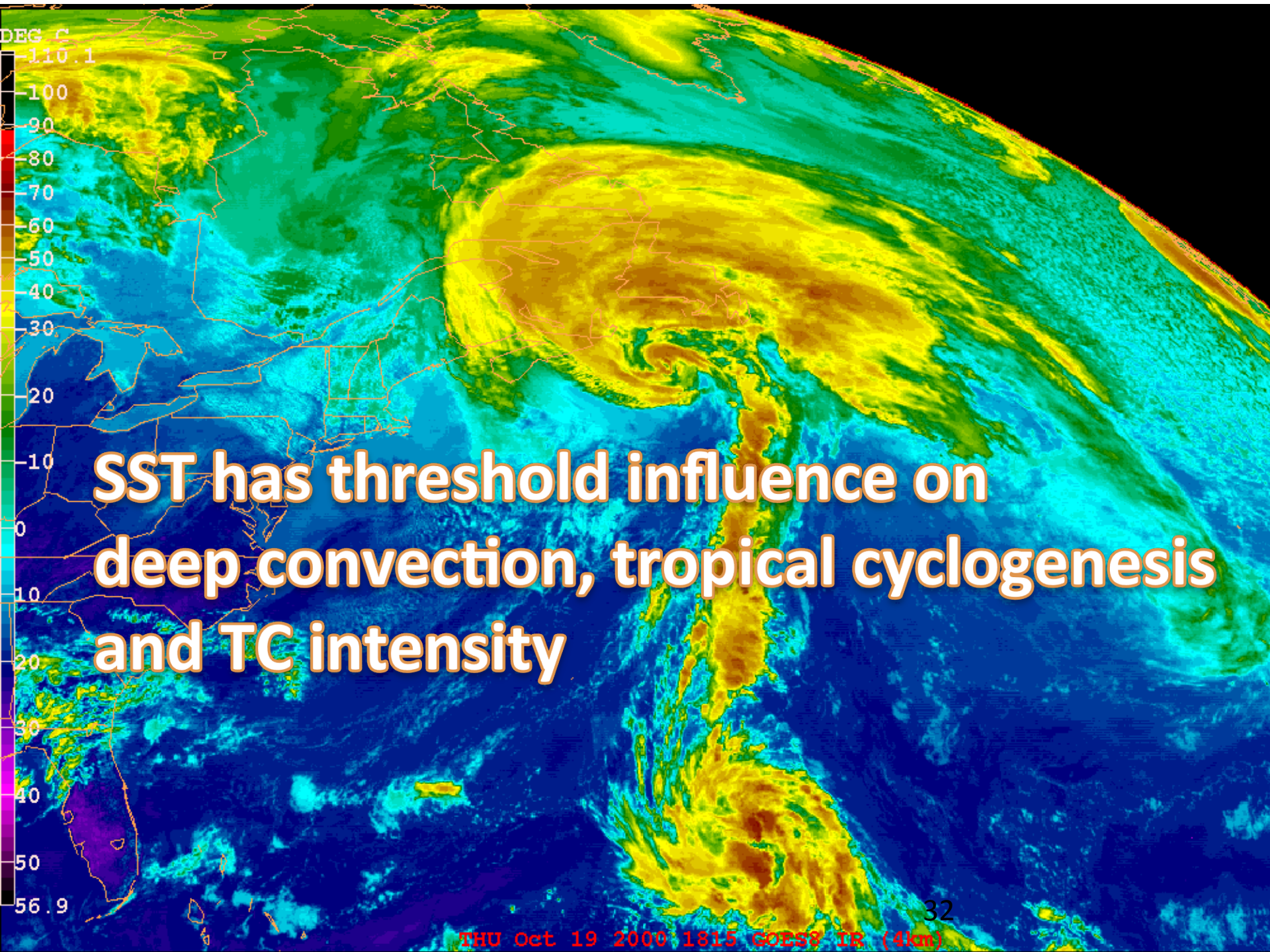
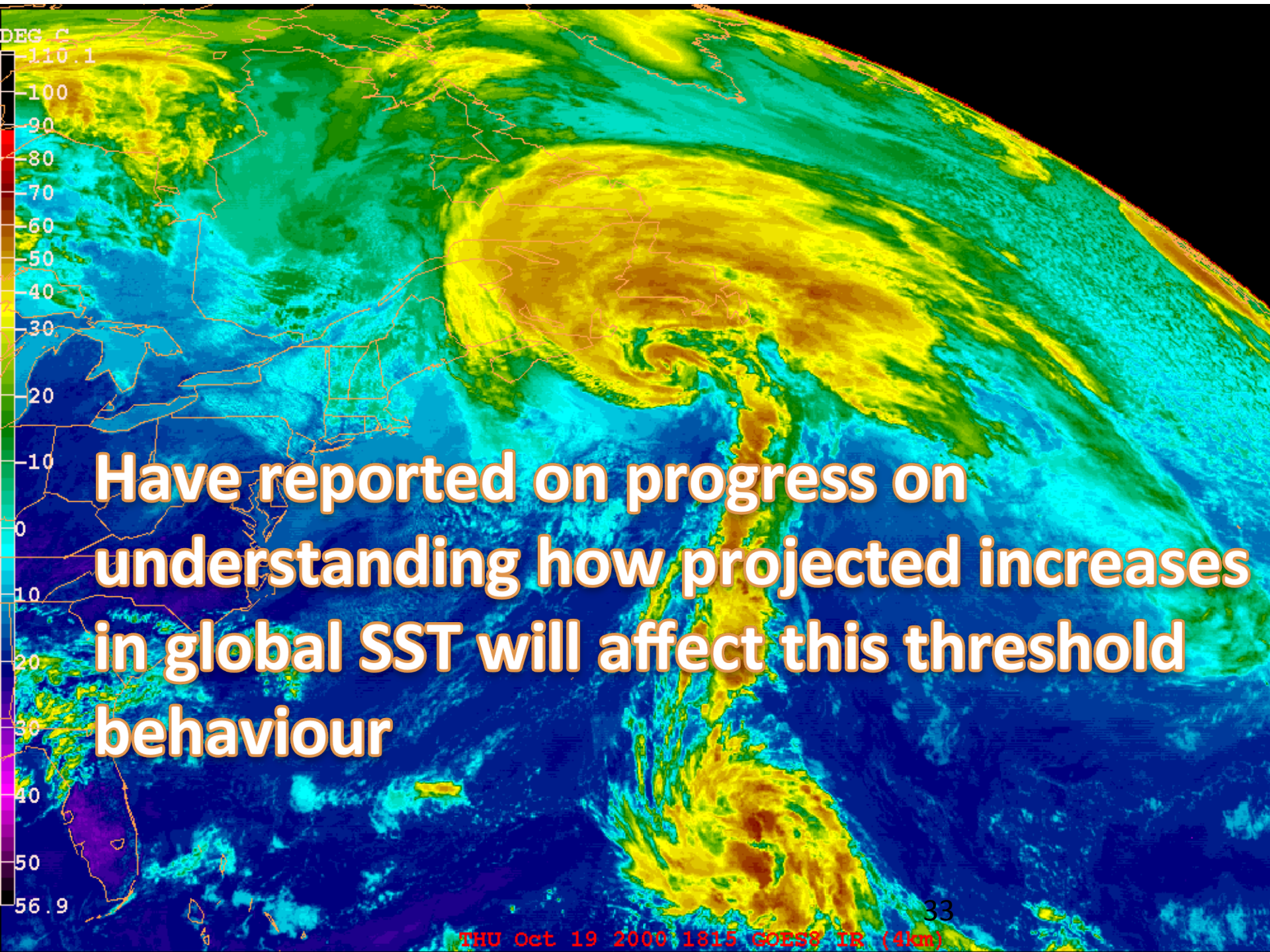

DEG C
-110.1
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
56.9
SST has threshold influence on deep convection, tropical cyclogenesis and TC intensity
THU Oct 19 2000 1815 GOES8 IR (4km)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-100
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-30
-20
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0
10
20
30
40
50
56.9
Have reported on progress on understanding how projected increases in global SST will affect this threshold behaviour
THU Oct 19 2000 1815 GOES8 IR (4km)


DEG C
-110.1
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
56.9
Questions
THANK YOU
THU Oct 19 2000 1815 GOES8 IR (4km)

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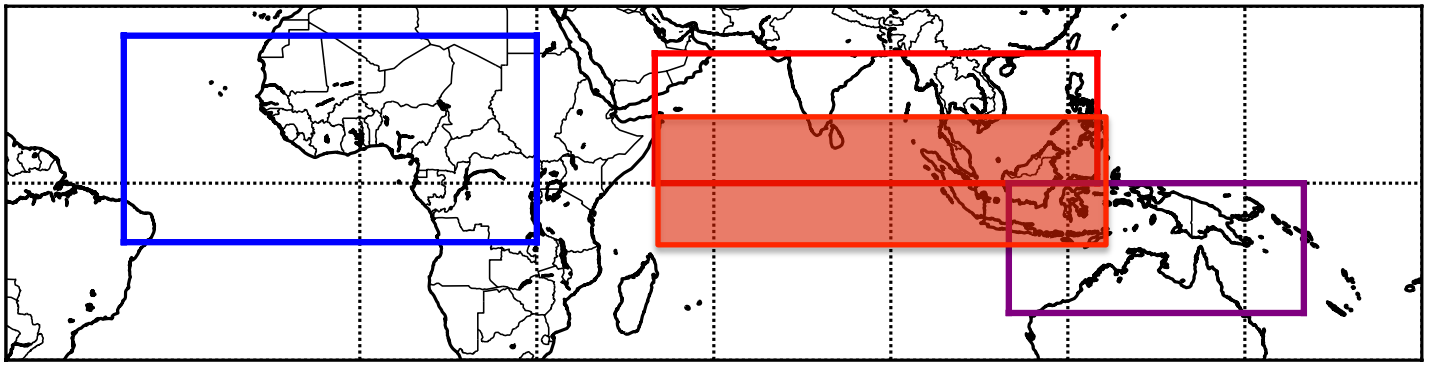
Observed SST threshold behavior for tropical convection

- Level 4 AVHRR SST – daily, 0.25° resolution
- Terra OLR – 3 hourly, 1°
- ERA-Interim reanalyses – monthly, 1.5°



- July 2002 through October 2005

Webster and Evans (2011, submitted)

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