CHAPTER 6

RELATIONSHIPS BETWEEN SST, LARGE-SCALE ATMOSPHERIC CIRCULATION, AND CONVECTION OVER THE TROPICAL OCEANS

The overall long-term means of the SST, OLR and DIV are shown in Figs. 6.1a-c. The mean SST values range between 15.7°C and 29.1°C, the mean OLR values range between 201.4 Wm^{-2} and 292.9 Wm^{-2}, and the mean DIV values range between -3×10^{-6} s^{-1} and 7×10^{-6} s^{-1}. The positive (negative) DIV values are associated with the rising (sinking) motions. Comparison of Fig. 6.1a and 6.1b reveals obvious similarity between the spatial patterns of SST and OLR, with deep convection located over the warm waters (SST ≥ 27°C). However, there are some significant differences between the SST and OLR patterns. For example, the spatial gradients of the OLR patterns are much stronger than the SST patterns. Also, within the convective zone in the western Pacific, secondary maxima of deep convection are found over Kalimantan. Such conditions are not found in the SST field, but in the DIV field (Fig. 6.1c).

6.1 SST-OLR Relationships

Figures 6.2a-f show the scatterplots of collocated monthly SST vs OLR grid point values for the Indian, western Pacific, central Pacific, eastern Pacific, Atlantic, and global tropical oceans, respectively. Superimposed are the mean of OLR values at every 0.5°C SST bin and the associated standard errors given as error bars. The most noticeable feature from each domain is the elbow-like pattern marked by the rapid up-turn of the

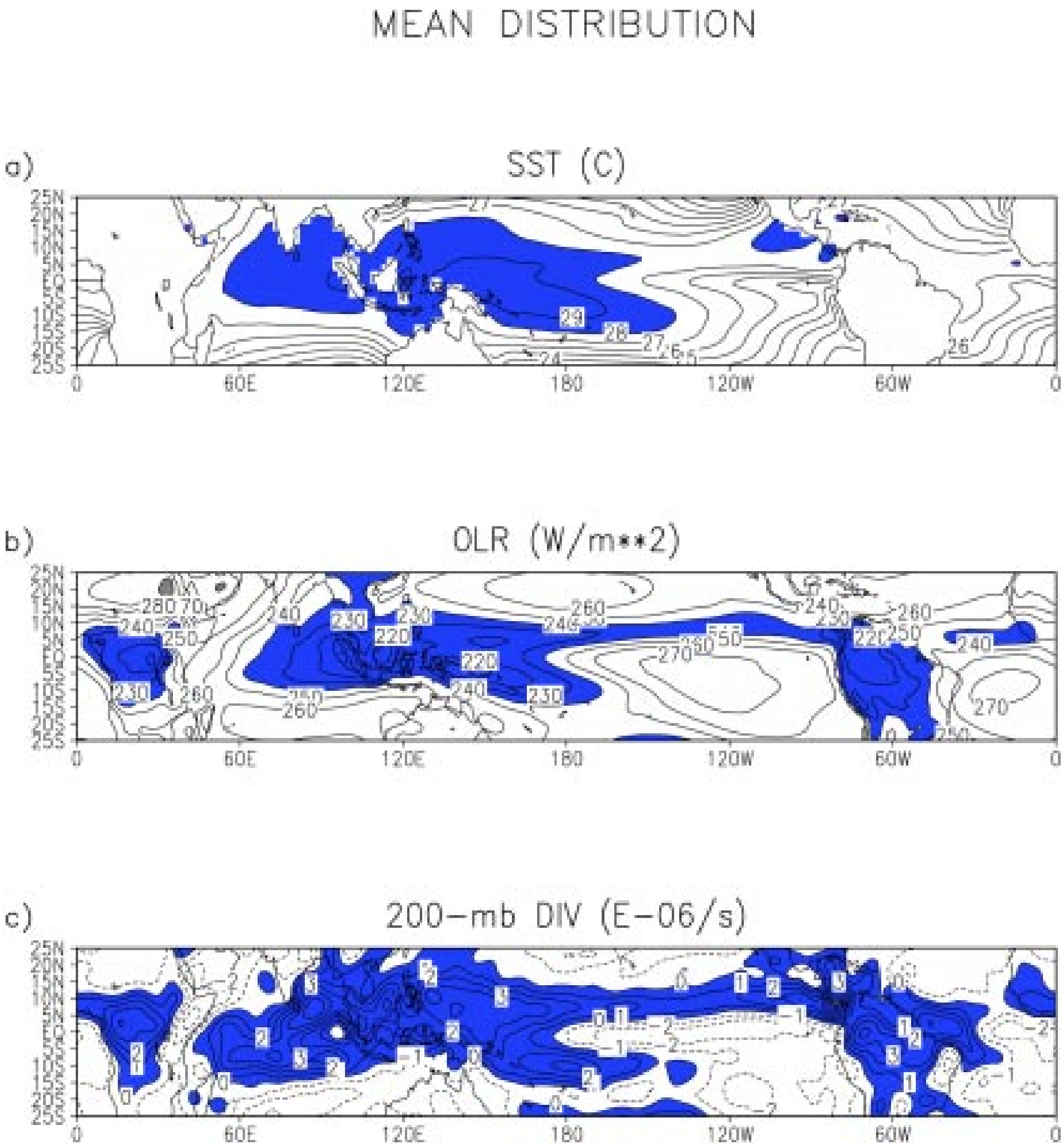

Figure 6.1. The overall long-term mean a) SST (°C), b) OLR (Wm^{-2}), and DIV (s^{-1}) data over the tropics. The areas with SST ≥ 28°C, OLR ≤ 240 Wm^{-2}, and DIV ≥ 0 s^{-1} are shaded.

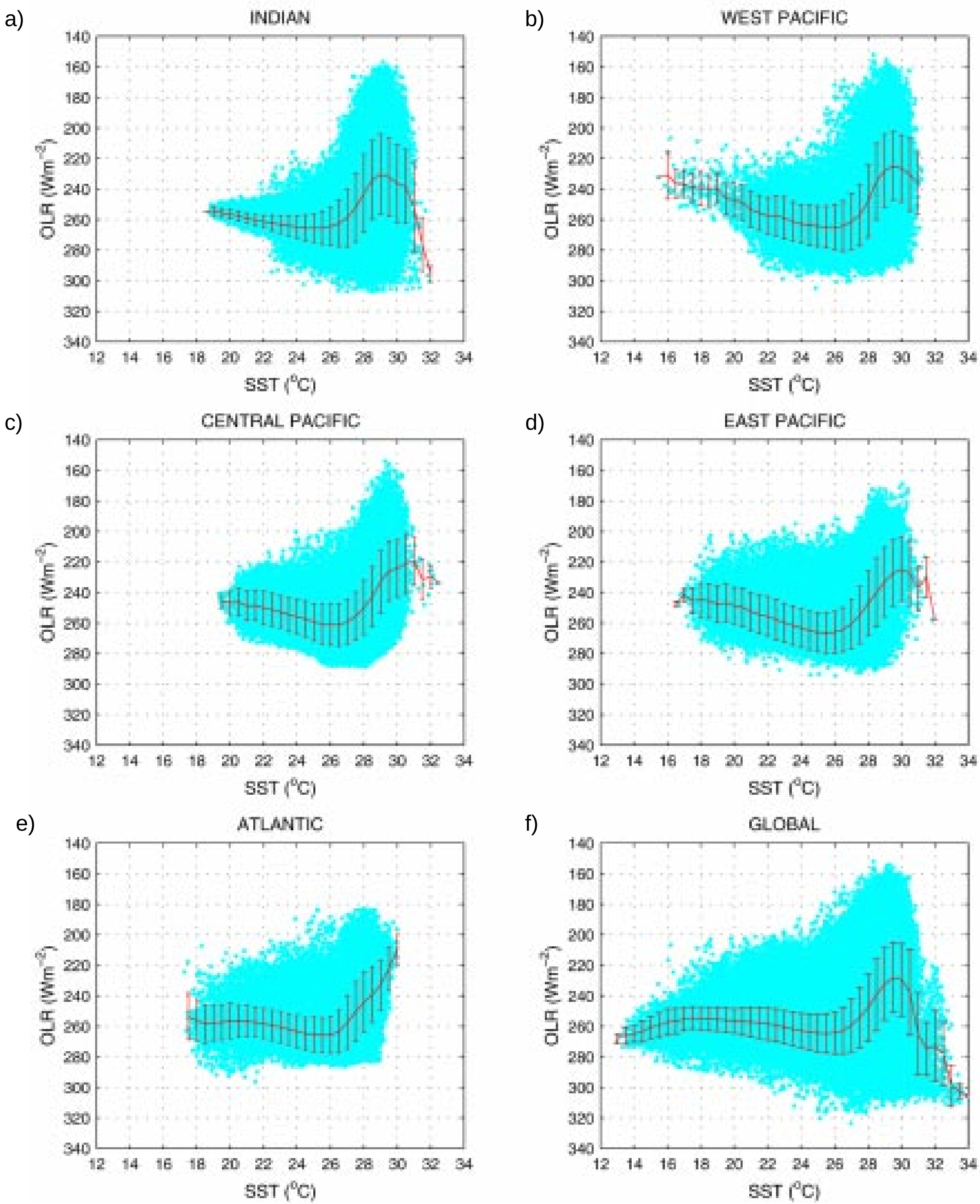

Figure 6.2. Scatterplots of collocated SST and OLR grid points values for the a) Indian, b) western Pacific, c) central Pacific, d) eastern Pacific, e) Atlantic, and g) global tropical oceans. Superimposed are the mean OLR values as a function of every 0.5°C SST bin.

SST-OLR curve at about 26°C-30°C. Based on the mean OLR values, the SST-OLR regimes for each domain are, furthermore, identified as:

SST-OLR1 regime : an increasing OLR with increasing SST

SST-OLR2 regime : a steep decreasing OLR with increasing SST

SST-OLR3 regime : a drop-off of OLR with increasing SST

Previous studies (e.g. Lau et al. 1997) have demonstrated that the increase in OLR with SST in the SST-OLR1 regime is primarily due to the increasing SST minus the opposing effects of increasing water vapor under clear-sky /subsidence conditions. In the SST-OLR2 regime, the steep increase in the SST-OLR relationship can be attributed to the rapidly increasing occurrence of deep convection over warm waters or to large-scale moisture convergence. The SST-OLR3 regime is associated to the presence of hot spots in isolated regions of forced subsidence particularly over the warm pool region.

Due to different dynamic and thermodynamic forcings, it is found that the SST range in the SST-OLR2 regime is different for different domains (Table 6.1). For example, the Indian Ocean has a rapid decrease of OLR (increase of convection) for SST between 25°C and 29°C. Meanwhile, a sharply skewed OLR distribution in the western Pacific Ocean occurs over warmer SST range from 26°C to 29.5°C. It should be noted that the statistics of high SSTs (SST ≥ 30°C) over the central and eastern Pacific oceans are contributed by relatively small number of data points, and hence may be affected by sampling errors. In the Atlantic Ocean, the SST-OLR2 regime is characterized by SST between 25.5°C and 29.5°C and there is no evidence of an increasing OLR for SST > 29.5°C.

Table 6.1. The SST ranges within each SST-OLR regime.

Domain	SST-OLR1	SST-OLR2	SST-OLR3
Indian	SST ≤ 25°C	25°C < SST ≤ 29°C	SST > 29°C
Western Pacific	SST ≤ 26°C	26°C < SST ≤ 29.5°C	SST > 29.5°C
Central Pacific	SST ≤ 26.5°C	26.5°C < SST ≤ 31°C	SST > 31°C
Eastern Pacific	SST ≤ 25.5°C	25.5°C < SST ≤ 30°C	SST > 30°C
Atlantic	SST ≤ 25.5°C	SST > 25.5°C	-
Global	SST ≤ 25.5°C	25.5°C < SST ≤ 29.5°C	SST > 29.5°C

Table 6.2 shows the partial rate of change of OLR with respect to SST ($\partial OLR / \partial SST$) in each domain for each SST-OLR regime. Under the subsidence and clear-sky conditions (SST-OLR1 regime), a near constant slope of SST-OLR relationship can be found in all domains with a minimum rate of 1.8 Wm^{-2} $°C^{-1}$ occurs in the Indian Ocean and a maximum rate of 3.4 Wm^{-2} $°C^{-1}$ in the eastern Pacific Ocean. In this regime, increased occurrence of clear sky conditions will allow more insolation to reach the ocean leading to warmer SST. Over the eastern Pacific Ocean, this slope is more representative of the subsidence branch of the Walker circulation.

In warm SST regions (SST-OLR2 regime), there is a large decrease in OLR with respect to SST associated with increase in deep convection, with a minimum rate of -10.4 Wm^{-2} $°C^{-1}$ in the eastern Pacific Ocean and a maximum rate of -15.2 Wm^{-2} $°C^{-1}$ in the western Pacific Ocean. Most of the net decrease in OLR can be attributed to the increased occurrence of deep convection overshadowing the background radiation. The sensitivity of convection to local SST is strongly enhanced by the rising motion associated with the large-scale circulation. In the central and eastern Pacific oceans, the highest OLR sensitivity to SST is found during ENSO events. The migration of convection from the western Pacific to the central and eastern Pacific oceans is responsive to changes in the entire ocean-atmosphere structure.

A reduction in deep convection begins to occur for higher SSTs (SST-OLR3 regime) with a minimum rate of 7.4 Wm^{-2} $°C^{-1}$ in the Indian Ocean and a maximum rate of 12.6 Wm^{-2} $°C^{-1}$ in the eastern Pacific Ocean. However, as described earlier, the occurrence of relatively higher SSTs (SST > 30°C) in the eastern Pacific Ocean is highly rare and questionable. A possible explanation of this behavior is that increased subsidence induced from nearby and remote convection provides warming and drying of the atmosphere above the boundary layer through adiabatic processes. In the Indian and western Pacific oceans, these conditions may be due to the formation of 'hot spots' (Waliser 1996). In the eastern Pacific Ocean, these may be influenced by the insolation that warms the ocean and the vigorous ocean dynamics that cools it by upwelling.

Table 6.2. The partial rate of change of OLR w.r.t. SST ($\partial OLR / \partial SST$) over different SST-OLR regimes.

Domain	$\frac{\partial OLR}{\partial SST}$ $\left(Wm^{-2\,o}C^{-1}\right)$		
	SST-OLR1	SST-OLR2	SST-OLR3
Indian	1.8	-11.6	7.4
Western Pacific	2.6	-15.2	8.2
Central Pacific	2.7	-13.1	10.3
Eastern Pacific	3.4	-10.4	12.6
Atlantic	2.0	-10.8	-
Global	1.0	-12.1	10.3

Table 6.3 shows the $(\partial OLR / \partial SST)$ values in the SST-OLR2 regime after the linear dependence of the SST-OLR relationship on DIV is removed. The increased convection is found to be a strong function of the large-scale motion field, particularly in the Indian and western Pacific oceans. Under condition of weak large-scale circulations (DIV2 regime), the $(\partial OLR / \partial SST)$ values are -3.5 $Wm^{-2}\ {}^{\circ}C^{-1}$ and -8.1 $Wm^{-2}\ {}^{\circ}C^{-1}$ in the Indian and western Pacific, respectively. In contrast, under the influence of large-scale rising motions (DIV3 regime), the $(\partial OLR / \partial SST)$ values can enhance to -12.5 $Wm^{-2}\ {}^{\circ}C^{-1}$ and -12.8 $Wm^{-2}\ {}^{\circ}C^{-1}$ or increase by about 257% and 58% for the Indian and western Pacific oceans, respectively. Meanwhile the effect of the rising motion in increasing deep convection is relatively much smaller in the central Pacific (35%) and eastern Pacific (11%) oceans. In the Atlantic Ocean, the effect of large-scale circulation does not increase convection. This means that the SST-OLR relationship is mainly due to local SST in this region.

Table 6.3. The $(\partial OLR / \partial SST)$ at constant DIV categories for the SST-OLR2 regime.

Domain	$\frac{\partial OLR}{\partial SST}$ $\left(Wm^{-2\,o}C^{-1}\right)$			
	DIV1	DIV2	DIV3	DIV4
Indian	4.9	-3.5	-12.5	-12.4
Western Pacific	-	-8.1	-12.8	-3.7
Central Pacific	10.5	-8.7	-11.7	-
Eastern Pacific	-	-7.5	-8.3	-
Atlantic	-	-9.2	-8.0	-6.4
Global	5.5	-5.6	-9.9	-10.4

6.2 DIV-OLR Relationships

Figures 6.3a-f display the scatterplots of collocated monthly DIV vs OLR grid point values for the Indian, western Pacific, central Pacific, eastern Pacific, Atlantic, and global tropical oceans, respectively. The mean OLR values and the associated standard errors for every $0.5\text{x}10^{-5}$ s^{-1} DIV bin are also shown in these figures. Unlike the SST-OLR relationship, the relationship between DIV and OLR for all domains generally appears to be quite linear, particularly for $-0.5\text{x}10^{-5}$ s^{-1} $\leq$ DIV $\leq$ $1\text{x}10^{-5}$ s^{-1} range indicating an increase in rising motion results in an enhance in convection.

The partial rate of change of OLR with respect to DIV $(\partial\text{OLR}/\partial\text{DIV})$ in $-0.5\text{x}10^{-5}$ s^{-1} $\leq$ DIV $\leq$ $1\text{x}10^{-5}$ s^{-1} regime for each domain is shown in Table 6.4. As expected, the smallest $(\partial\text{OLR}/\partial\text{DIV})$ value is found in the Atlantic Ocean (-3.3 $\text{Wm}^{-2}/10^{-6}$ s^{-1}) and the largest in the western Pacific Ocean (-6.1 $\text{Wm}^{-2}/10^{-6}$ s^{-1}). In the eastern Pacific and Atlantic oceans, the ocean-atmosphere interactions are most effective because of prevailing easterly trade winds and thus shallow thermocline. The ocean-atmosphere interactions are ineffective in the Indian and western Pacific oceans whereas cross-equatorial monsoon winds are more prominent than the trade winds. Therefore, the large-scale circulations have relatively stronger control than local SST in these regions.

Table 6.5 presents the $(\partial\text{OLR}/\partial\text{DIV})$ at constant SST categories derived using same regression procedure. In general, the relationship between DIV and OLR is nearly independent of SST. For example, over the Indian and western Pacific oceans, the

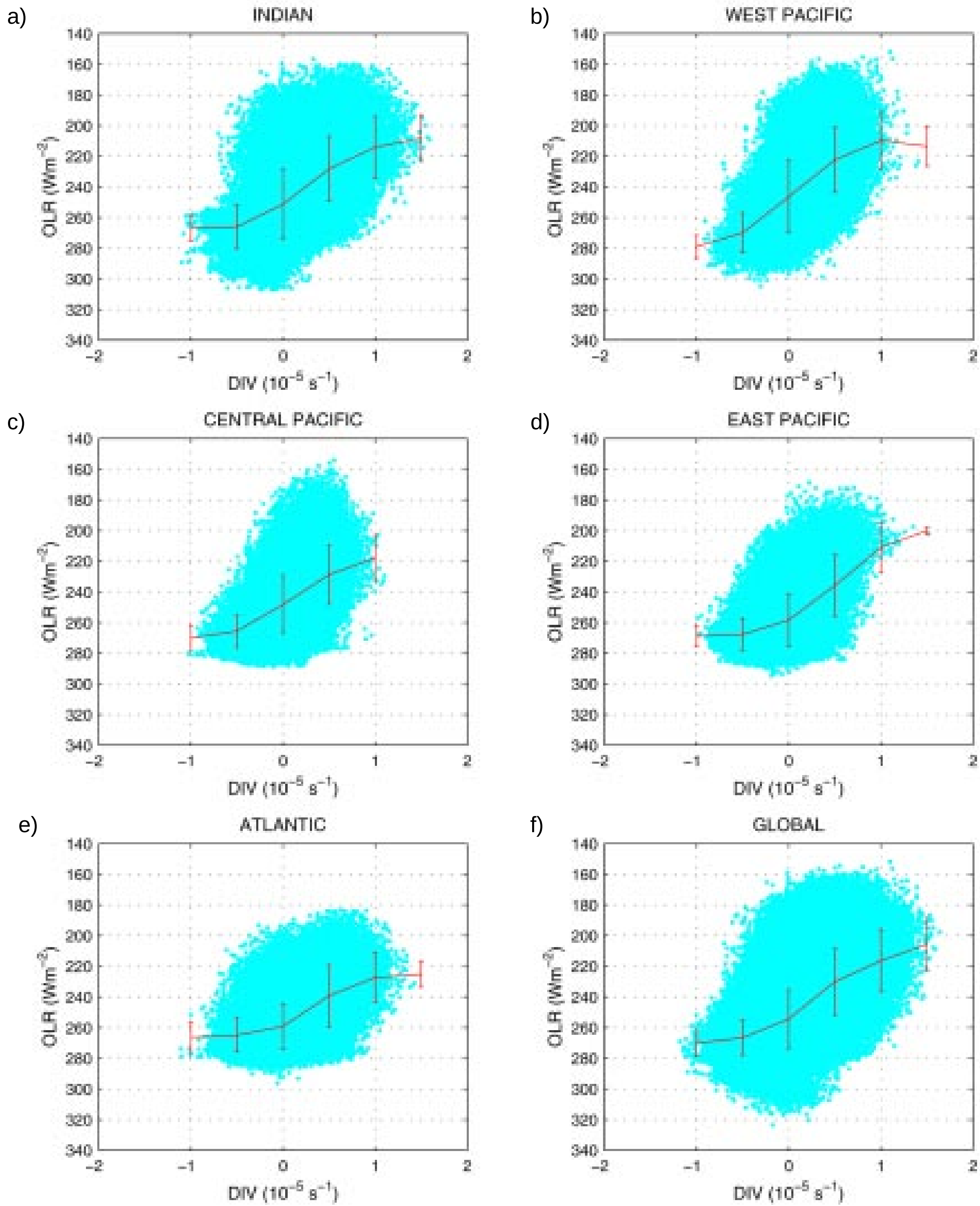

Figure 6.3. Scatterplots of collocated DIV and OLR grid points values for the a) Indian, b) western Pacific, c) central Pacific, d) eastern Pacific, e) Atlantic, and g) global tropical oceans. Superimposed are the mean OLR values as a function of every $0.5x10^{-5}$ s^{-1} DIV bin.

Table 6.4. The partial rate of change of OLR with respect to DIV ($\partial OLR / \partial DIV$) in $-0.5 \times 10^{-5}\ s^{-1} \le DIV \le 1.0 \times 10^{-5}\ s^{-1}$ regime.

Domain	$\frac{\partial OLR}{\partial DIV}\ \left(Wm^{-2} / 10^{-6} s^{-1}\right)$
Indian	-4.8
Western Pacific	-6.1
Central Pacific	-5.1
Eastern Pacific	-4.3
Atlantic	-3.3
Global	-4.9

Table 6.5. The ($\partial OLR / \partial DIV$) at constant SST categories in $-0.5 \times 10^{-5}\ s^{-1} \le DIV \le 1.0 \times 10^{-5}\ s^{-1}$ regime.

Domain	$\frac{\partial OLR}{\partial DIV}\ \left(Wm^{-2} / 10^{-6} s^{-1}\right)$				
	SST1	SST2	SST3	SST4	SST5
Indian	-1.5	-3.5	-4.5	-4.2	-4.4
Western Pacific	-3.3	-4.2	-4.5	-5.1	-4.9
Central Pacific	-3.6	-3.6	-4.0	-4.4	-4.3
Eastern Pacific	-3.6	-3.6	-3.2	-3.9	-4.2
Atlantic	-2.9	-3.2	-2.6	-1.4	-1.6
Global	-3.2	-3.4	-3.7	-4.2	-4.7

$(\partial \mathrm{OLR}/\partial \mathrm{DIV})$ in the SST2 category (26°C < SST ≤ 27°C) is -3.5 $Wm^{-2}(10^{-6}\ s^{-1})$ and -4.2 $Wm^{-2}(10^{-6}\ s^{-1})$, respectively. In SST4 category (28°C < SST ≤ 29°C), the $(\partial \mathrm{OLR}/\partial \mathrm{DIV})$ is -4.2 $Wm^{-2}(10^{-6}\ s^{-1})$ and -5.1 Wm-2$(10^{-6}\ s^{-1})$ or increase by only 34% and 21%, respectively. Meanwhile, a decrease in $|\partial \mathrm{OLR}/\partial \mathrm{DIV}|$ with higher SST in the Atlantic Ocean confirms the previous result. The DIV-OLR relationships suggest a fundamental link between the large-scale circulation and tropical convection that are less dependent on the spatial domains compared to the SST-OLR relationships.

In summary, depending on the strength of large-scale upward motion or SST in each domain of the tropical oceans, the transition occurs at a SST range of 25°C to 26°C. Below this SST range namely under subsidence and clear sky conditions, an increase in OLR with respect to SST is at a rate of 1.8 $Wm^{-2}\ °C^{-1}$ to 3.4 $Wm^{-2}\ °C^{-1}$. Above this SST range to about 30°C, there is a large apparent decrease in OLR (increase in convection) with SST. The SST-OLR relationship is strongly enhanced by the rising motions associated with the large-scale circulation. Under conditions of weak large-scale circulation, the rate of OLR reduction with respect to SST in the Indian and western Pacific oceans is about -3.5 $Wm^{-2}\ °C^{-1}$and -8.1 $Wm^{-2}\ °C^{-1}$, respectively. For the same SST range, under the influence of strong rising motions, the respective rate is increased to -12.5 $Wm^{-2}\ °C^{-1}$ and -12.8 $Wm^{-2}\ °C^{-1}$. On the other hand, for each domain the relationship between large-scale circulation and deep convection is nearly linear and less dependent on SST.