List of Figures

1.1 Annual cycle of convection,winds and SST in the Indian Ocean are shown. Seasonal means from daily climatology of TMI SST (℃; shaded; *Wentz* et al. 2000),QuikSCAT wind stress (Nm^{-2}; vectors) and NOAA interpolated outgoing longwave radiation (OLR,Wm^2 ; contours; *Liebmann* and *Smith*, 1996), computed for the period 1998-2007. OLR < 240 Wm^2 is contoured with dash curve to highlight the region of strong convection during particular season. 3

1.2 Ocean temperature difference between surface and 100m (°C, shaded), 20°isotherm depth (d20, m, dark contour) and wind stress curl ($10^{-8}Nm^{-3}$, red dash contour) for a)winter and b)Summer are shown. Dark orange color indicate the shallowest region possibly having strong upper temperature gradient. 5

1.3 A schematic picture of the air sea interaction processes associated with eastward propagating MJO. [Adapted from Lecture notes on Intraseasonal Oscillation by Sengupta D., IISc, India] 6

1.4 Intraseasonal amplitude of a) OLR and b) TMI SST variability is shown as the standard deviation (SD) of daily intraseasonal anomalies of these two fields in the 20-100 days band. Regions of strong variability have been outlined. 9

2.1 Bar diagrams-showing validation of 5-day average turbulent fluxes for the 2000-2007 period. NCEP/NCAR is shown in blue, NCEP2 in red, ERA-I in yellow, OAFlux in green and TropFlux in purple. . 13

2.2 Bar diagrams-showing validation of 5-day average radiative fluxes for the 2000–2007 period. NCEP/NCAR is shown in blue, NCEP2 in red, ERA-I in yellow, ISCCP in green and TropFlux in purple. The orange bar shows the near-realtime reconstruction of SWR from OLR data and LWR from the Clark empirical formula [*Clark* et al. 1974]. 15

3.1 Time series of 30-90 day band pass TMI (black) and Model SST anomaly (Red) in ℃ over the TRIO location, (b) 30-90 day band pass Net heat flux from OA (black) and model (red) in Wm^{-2} averaged over the TRIO region. The correlation coefficient (CC) and Standard Deviation (SD) of model with observations are illustrated on the respective panels. 24

3.2 The January diabatic heating (x 10^{-5} K/s, shaded) and zonal-vertical circulation (vectors) averaged over 10°S and 5°N and mean (left panels) and anomaly (right panels) for (a) 1999, (b) 2002 and (c) 2007. The u, ω fields are plotted after applying scale correction. 26

3.3 Time longitude plot of interannual variability of SLA(cm) averaged over the latitude 10°S to 5°S during (a) 1998-99, (b) 2001-02 and (c) 2006-07. They show the strong interannual variability of ocean subsurface structure (ocean state) in this region. 27

3.4 Temperature profiles of upper 130 meter averaged over SCTR region, MLD (black line) and D20 (red dash line) are plotted over it, and the unusual deepening in the MLD for anomalous event is highlighted with circle. 28

3.5 Observed TMI SST anomalies (shaded, ℃) and Pentad Wind anomalies (vectors, ms^{-1}) centered on (a) 18 January 2002, (b) 27 January 2002, (c) 05 February 2002, and the respective OLR anomalies (contours, Wm^{-2}) with a lead time of 10 days (left panels). The peak-cooling phase over TRIO corresponds to 27 January 2002, whereas other periods are chosen to show the growth and decay of the event. The right panels correspond to the model simulation of the SST anomalies for different cooling phases as similar to TMI. The red box indicates the TRIO region. 29

3.6 Scatterplot between observed amplitude of SST intraseasonal response each year (computed as the December-March standard-deviation of 30-90 day filtered SST) and amplitude of 30-90 day time-integral of the heat flux perturbation 31

3.7 Mixed layer temperature tendency (dark line) for 2002 event (Upper panel) and 1999 event (lower panel) and its contributing terms are represented as Atmospheric Flux (red), Horizontal advection (pink), Subsurface processes (blue). 32

3.8 Mixed layer temperature (MLT) tendency (black) and its contributions from Net heat flux (red), vertical processes (blue) and horizontal advection (green), for a) CTL and b) Similar as a) but for NO_SUB_STRESS_SW. Components of Vertical processes: entrainment term (blue), Ekman Pumping(red) for c) CTL and d) NO_SUB_STRESS_SW. The vertical turbulence term is considered to be negligible. 33
3.9 The observed intraseasonal (30-90 day band passed) SST anomalies (blue) and model SST anomalies (red) along with surface chlorophyll concentration (chl-a, mgm^{-3}) for events in (a) 1999 (b) 2002. 34
3.10 Scatterplot between observed amplitude of intraseasonal SST (30-90 day band) amplitude of 30-90 day time integral of Ekman pumping 35

4.1 Average forcing fields of the CTL (black line) and 120-day low passed sensitivity experiments (blue line) within the TRIO region. The red line on a, b indicates our best guess of actual stresses (from ERS and Qscat scatterometers) and net heat fluxes (from the TropFlux product). a) Zonal wind stress for CTL and NO_ISO_STRESS experiment. b) net heat flux for CTL and NO_ISO_ FLUX experiment and c) shortwave heat flux for CTL and ISO_SW experiment. Only the December-March values have been plotted to focus on the period with the strongest SST intraseasonal events. Grey bars separate the different years in this plot. 41
4.2 CTL experiment (a) and *de Boyer* et al., (2004) observed (b) December-March mixed layer depth climatology (m). CTL experiment (black) and WOA05 [red, *Locarnini* et al. 2006] December-March climatological temperature profile within the TRIO region (outlined in panels a,b) 42
4.3 Standard deviation of 30-100 day band-passed SST for the December-March period during 1998-2006 (°C) for a) TMI SST observations and b) CTL experiment. The black box indicates the TRIO (60°E-90°E, 10°S-5°S) region used in this study. 44

4.4 Observed 30-100 day bandpassed a) TMI SST (the blue curve shows the expected response of a slab ocean mixed layer to air-sea flux perturbations in b; the numbers under show the regression coefficient of the blue curve to the black one for each year). The TMI SST is also shown in green in panels b, c and d. b) net surface heat flux, c) QuikSCAT zonal wind stress and d) QuikSCAT Ekman pumping in the TRIO region. Only the December-March values have been plotted to focus on the period with the strongest SST intraseasonal events. e) December-March average observed sea-level interannual anomaly in the TRIO region. Grey bars separate the different years in this plot. 47

4.5 Intraseasonal (30-100 day) surface perturbations in the TRIO region regressed to 30- 100 day band-passed SST in the TRIO region in December-March: a) zonal (full line) and meridional (dashed line) wind stress; b) Net heat flux (black) and its components and c) SST. The blue curve in c) shows the SST response of a slab ocean mixed layer to the net heat flux perturbation in b). 48

4.6 Scatterplot between observed amplitude of SST intraseasonal response each year (computed as the December-March standard-deviation of 30-100 day filtered SST) and a) amplitude of 30-100 day time-integral of the heat flux perturbation, b) amplitude of 30-100 day time integral of the cube of friction velocity (see text for details), c) amplitude of 30-100 day time integral of Ekman pumping and f) December-march average sea level anomaly in the TRIO region. d) scatterplot of 30-100 day cubed fiction velocity against heat flux. e) scatterplot of 30-100 day surface shortwave against latent heat flux. The black line in figures 7a and 7f indicate the y=x curve. The correlation and significance value are indicated at the bottom of each scatterplot. 49

4.7 Standard deviation of December-March 30-100 band-passed SST for the 1999-2006 period: a) Total variability in CTL experiment and contributions from b) total heat flux, c) shortwave heat flux, d) wind stress , e) residual (representing both internal variability and filtering error due to spectral leaks from adjacent frequencies; see text for details) and f) error (mostly due to nonlinearities, see text for details). e) and f) can be combined to represent the overall uncertainty on the estimates of b), c), d). 50

4.8 a) 30-100 day band-passed SST for CTL (black), wind stress contribution (blue) and heat flux contribution (red). b) 30-100 day band-passed SST for CTL (black) and sum of heat flux and wind stress contributions (blue). c) 30-100 day band-passed SST for CTL (black) and expected response from a slab ocean mixed layer (blue). In a) and c), the number indicated below each year are the regression coefficients of the 30-100 day SST in each experiment to the CTL experiment (i.e. the contribution of each process to total SST variability for each year). Only the December-March values have been plotted to focus on the period with the strongest SST intraseasonal events. Grey bars separate the different years in this plot. . 54

4.9 30-100 day band-passed SST for total heat flux contribution (red) and ISO _shortwave contribution (blue). The numbers indicated below each year are the regression coefficients of the 30-100 day shortwave contribution to the total heat flux contribution experiment (i.e. fraction of heat flux induced SST variability due to shortwave for each year). Only the December-March values have been plotted to focus on the period with the strongest SST intraseasonal events. Grey bars separate the different years in this plot. 55

4.10 Observed sea level anomaly (red) and CTL-CLIM_TAU sea level in the TRIO region (black). The December-march average values are indicated by dots. b) CTL (black) and CLIM_TAU (red) 30-100 day band-passed SST in the TRIO region. The numbers indicated below each year are the regression coefficients of the 30-100 day SST in NO_INT_STRESS to the CTL experiment (i.e. an estimate of the impact of subsurface interannual variability on the SST response to the MJO). In b), only the December-March values have been plotted to focus on the period with the strongest SST intraseasonal events and grey bars separate the different years. . . . 56

4.11 Scatterplot between December-March average mixed layer depth in the control experiment and a) December-March average sea level anomaly in the TRIO region in the CTL experiment and b) December-March average mixed layer depth in the CLIM_TAU experiment. c) Scatterplot between December-March average of temperature jump at the bottom of the mixed layer against sea level anomaly in the TRIO region.The slope of the regression (β) and linear correlation coefficient (r) are indicated in each plot. 58

5.1 June-September climatological values of (a) depth of the 20°C isotherm from WOA05 database [*Locarnini* et al. 2006] and (b) the mixed layer depth [*de Boyer Montegut* et al., 2004]. Panels c and d show the same quantities for the CTL experiment. 66

5.2 June-September standard deviation of 30-90 day bandpass-filtered net surface flux from Tropflux dataset (a) [*Praveen Kumar* et al. 2010], and (b) ERS and QuikSCAT scatterometers-derived (see text for details) wind stress module . Panels c and d show the same quantities for the CTL experiment. 67

5.3 Standard Deviation of 30-90 day band passed 1998-2006 SST during JJAS (o C) for a) TMI SST observation and b) CTL experiment. The black boxes show the various regions selected in this paper: OMAN (58°E-65°E, 17°N-22°N), NBOB (80°E-95°E, 15°N-23°N), SOMALIA (52°E-60°E, 7°N-15°N) and STI (75°E-80°E, 5°N-8°N). 70

5.4 Average 30-90 day band passed SST for TMI SST observation (red) and CTL experiment (black) for the four regions displayed in Fig. 1: a) OMAN, b) NBOB, c) SOMALIA and d) STI. The correlation coefficient (r) and the standard deviation of observations and the model for the JJAS period are indicated in each panel. 71

5.5 Regression of 30-90 day June-September TMI SST (℃, colors), QuikSCAT wind ($m.s^{-1}$, vectors) and Tropflux surface net heat flux ($W.m^{-2}$, contours) to a normalized active/break monsoon index (see text for details) at a) 20 day before , b)10 day before, c) 0 day before, d) 10 day after and e) 20 day after a break monsoon phase. 73

5.6 a) average of the regressed SST shown in Fig.5.5 over the four reference regions: OMAN (red), NBOB (black), SOMALIA (green) and STI (blue). b) average of the corresponding correlation (of correlation of SST to active/break phase index). The maximum SST perturbation is at lag -8, 2, 11 and 15 days before/after a break phase for STI, SOMALIA, NBOB and OMAN, respectively. 74

5.7 June-September intraseasonal (30-90 day) a) TMI SST, b) NOAA OLR and c) QuikSCAT wind speed associated with typical SST perturbations in the four reference regions: OMAN (red), NBOB (black), SOMALIA (green) and STI (blue). Each 30-90 day filtered variable is averaged over the region and regressed to the normalized 30-90 day SST over the same region. 75

5.8 June-September intraseasonal (30-90day) net heat flux (black) perturbation and its four components (shortwave radiation in red, latent heat flux in green, sensible heat flux in blue and long wave radiation in purple) regressed to normalized average 30-90 day SST for : a) OMAN , b) NBOB, c) SOMALIA and d) STI. 77

5.9 a) Standard deviation of June-September intraseasonal (30-90day) SST variability estimated from a slab-ocean approach in observations (using climatological mixed layer depth as in Fig. 1b and Tropflux net heat fluxes). b) Regression of this SST to 30-90 day observed (TMI) SST. . . 78

5.10 Panels a) and b) are similar to Fig. 5.9, but computed from CTL experiment outputs. Panel c shows the standard deviation of 30-90 day filtered mixed layer depth in the CTL experiment. 79

5.11 a) Standard deviation of JJAS 30-90 band-passed SST for the 1996-2006 period in CTL experiment and contributions from b) intraseasonal heat fluxes, c) intraseasonal shortwave fluxes, d) intraseasonal wind stress, e) internal variability and f) residual. See text for details on how each component is evaluated. The contributions in b-f are computed as the correlation to the total SST variability, multiplied by its standard deviation (as in panel a). With such a normalization, panels b), d) e) and f) add up to panel a). 80

5.12 Time series analysis of average 30-90 days band passed SST from CTL experiment (black), and the component associated with heat flux (red) and wind stress (blue) intraseasonal variability for : a) OMAN , b) NBOB, c) SOMALIA and d) STI. The number indicated below each year are the regression coefficients of the 30-90 day SST for heat flux (red) and wind stress (blue to the CTL experiment (i.e. the contribution of each process to total SST variability for each year). Only the June- September values have been plotted to focus on the period with the strongest SST intraseasonal events. Grey bars separate the different years in this plot. . 83

6.1 Standard deviation of 120 days low pass filtered on SSTA (shaded, °C) for interannual variability overlaid with the intraseasonal SSTA (120 days High pass, red contour) from December to February (DJF). The black box indicates the TRIO and EEIO (95°E-115°E, 10°S-5°S) region used in this study. 89

6.2 The time series of (a) chl-a anomalies (mgm^{-3}) and SLA (m), (b) SLA from Topex (black) and Model (red), (c)SSTA (°C) from TMI(black) and Model (red) (d) Ekman pumping anomaly (EPA) $\times 10^{-6}$ (ms^{-1}) and $\tau_{alongshore}$ (Nm^{-2}) calculated from model wind stress over EEIO. 90

6.3 Same as Fig. 6.2 but for TRIO with labeling Remote forcing anomaly (RFA) instead of $\tau_{alongshore}$. Anomalies of chl-a over TRIO is multiplied by 10 for better illustration. 93

6.4 Time series of chl-a over a) EEIO b) TRIO overlaid with Model Sensitivity experiments. 30–100 day bandpassed CTL-NO_ISO_STRESS (red) indicate the impact of intraseasonal wind stress and CTL-NO_INT_STRESS (black) gives the idea of interannual anomalies of thermocline depth over both region. 94

6.5 TMI SST anomalies (shaded), and wind anomalies (vectors) in the left panels (a, c, e) and the 30-100 day band passed filtered respective fields in right panels (b, d, and f) of 2002. The intraseasonal variability events are taken as the pentad average with the corresponding dates (for Jan, May and Jun intraseasonal variability events are 28 January, 9 May and 20 June respectively) as the centre. The red boxes in Fig 8(a) correspond to the Somalia-Oman upwelling region (52°E-57°E, 7°N-12°N) and the TRIO region. 96

6.6 Observed SST anomaly (SSTA,°C) and zonal wind stress anomaly (TAUXA, Nm^{-2}) and its intraseasonal components (30-90 day bandpass)averaged over TRIO and Somalia-Oman upwelling region are shown in panel (a) and (b), anomaly of specific humidity (QA x 1000, gkg^{-1}) and wind speed(WSA, ms^{-1}) (15 day smoothing) are plotted in panels (c) and (d) for the same regions 97

6.7 Correlation between interannual SLA and wind stress curl (shaded) for a) 1996-2001 and b) 2002-2007. Low pass (120 days) filter is applied on SLA and wind stress curl to remove the high frequency signals. Contours are depicting the region where the correlation is statistically significant at 90% from a t-test. 98

7.1 (a) The diurnal cycle observed at 67°E, 8°S [RAMA] (black solid line) and Model estimated diurnal cycle in shortwave flux at same location (red solid line). (b) Daily averaged short wave flux from RAMA (black solid line), LY (red) and OA Flux (blue). This indicates the most of the high frequency components smoothed out. (c) The RAMA (black dash) and CTL hourly SST (red dash) overlaid in the daily mean SST (black solid line) and the model simulated CTL SST (red solid line). The TMI (blue) satellite observation is overlaid in the same panel. The TMI overestimates the cooling event as it gives the subskin temperature with the high wind condition (observed Dora cyclone). (d) MLD calculated from the RAMA (black solid line) and the model simulated MLD (red solid line). The deepening of MLD to a 35 meter corresponds to the cyclone period (SWF and wind forcing) is simulated in the model also. 104

7.2 (a) The scattered plot of the NSWR (LY) with NSWR (RAMA) overlay with the regression line (black). (b) NSWR calculated using *Shinoda* et al., (1998) based on OLR with NSWR (RAMA) (c) Similarly NSWR from OA flux with NSWR (RAMA). The Root Mean Square error (RMS) and correlation (Cor) for LY and OLR derived flux with reference to RAMA is illustrated in the above panels respectively. 105

7.3 a) Composite of intra seasonal SSTA from (a) CTL and (b) Diurnal_fix. The events are selected based on SSTA (30-120 day band passed) showing value less than 1.5 Standard Deviation. The box indicates the TRIO region used in this study. 106

7.4 a,d) Mixed layer depth (b, e) Surface heat flux available in the mixed layer (Q) normalized by MLD variability and (c, f) Entrainment heat flux for 2001 (left panels), and 2002 (right panels) ISV events are respectively based on CTL (black) and Diurnal_fix (red)(daily averaged). 108

7.5 30-120 day SST from CTL minus NO_ISO_SW (black), Diurnal_fix minus CTL (red) and Diurnal_relax minus CTL (green) 109