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Seasonal Variability Of Latent Heat Flux Over The Arabian, And Bay Of Bengal Sea During 1990-2018.

[1]Dr. Krishna Dora Babu. Kotti, [2]Dr. V.Lakshmana Rao.

1. Department of Geography, School of Distance Education, Andhra University, Visakhapatnam, India.

2. Department Meteorology and Oceanography, Andhra University, Visakhapatnam, India.

Abstract

The latent heat flux at the ocean's surface plays a key role in the atmospheric hydrological and energy cycles. Here we discuss the spatial distribution of Latent Heat flux climatology from (1990-2018) over the Bay of Bengal and Arabian Sea. Throughout the beginning of the South-West monsoon season, especially June, the South- West side of both the Arabian and Bay of Bengal show a high latent heat flux. In the month of October, Bay of Bengal, and the Arabian Sea are showing the least latent heat flux (60 W/m^2). The latent heat flux has a great influence on the Arabian Sea**.** From 1990 to 2000 during the monsoon the latent heat flux was minimum (40wm2) along the west Arabian Sea and maximum along the north Arabian Sea. In the overall 28 years of the study, the maximum latent heat flux is observed in the Arabian Sea rather than the Bay of Bengal.

Key words: Latent heat flux, climatology, monsoon, energy cycles.

1. Introduction

Latent heat: All pure substances in nature are able to change their state. Solids can become liquids (ice to water) and liquids can become gases (water to vapor) but changes such as these require the addition or removal of heat. The heat that causes these changes is called latent heat. Latent heat however, does not affect the temperature of a substance –for example, water remains at 100°c while boiling. The heat added to keep the water boiling is latent heat. Heat that causes a change of state with no change in temperature is called latent heat.

Latent heat flux is the flux of heat from the Earth's surface to the atmosphere that is associated with evaporation of water at the surface and subsequent condensation of water vapor in the troposphere. It is an important component of Earth's surface energy budget**.** Latent heat is the amount of energy that is either absorbed or released during a phase transition at a constant temperature.

Latent heat of evaporation: The latent heat of vaporization is the amount of "heat required converting a unit mass of a liquid into vapor without a change in temperature". Energy is required to change from solid to liquid, liquid to gas (evaporation), or solid to gas (sublimation). Latent heat of evaporation is the energy used to change liquid to vapor. The temperature does not change during this process, so heat added goes directly into changing the state of the substance.

Wind speed: An equation of state (EOS) is a thermodynamic expression that relates pressure (P), temperature (T), and volume (V). Many attempts have been made to describe the thermodynamic behaviour of fluids to predict their physical properties at given conditions. Wind speed is the speed of weather-related air movement from one place to the next. High wind speeds can cause unpleasant side effects, and strong winds often have special names, including gales, hurricanes, and typhoons.

Saturated specific humidity: Saturation specific humidity is the specific humidity of the atmosphere when it is saturated. It expresses the mass of water vapor relative to the air mass. The maximum mixing ratio is the saturation mixing ratio. Specific humidity, mass of water vapour in **Latent heat of evaporation**: The latent heat of vaporization is the amount of "heat required converting a unit mass of a liquid into vapor without a change in temperature". Energy is required to change from solid to liquid, liquid to gas (evaporation), or solid to gas (sublimation). ... Latent heat of evaporation is the energy used to change liquid to vapor. The temperature does not change during this process, so heat added goes directly into changing the state of the substance.

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Saturated specific humidity: Saturation specific humidity is the specific humidity of the atmosphere when it is saturated. It expresses the mass of water vapor relative to the air mass. The maximum mixing ratio is the saturation mixing ratio. Specific humidity, mass of water vapour in **Latent Heat Change during summer:** With the rapid development of urbanization, more than half of the world's population lives in cities. According to a report by the Intergovernmental Panel on Climate Change of 2014, human activities are almost certainly the cause of global warming. The heat island phenomenon, accelerated by global warming, has become a serious problem in major cities around the world, recently. It is particularly severe in the metropolitan area of Tokyo in Japan. Natural greening systems such as growing grass and plants on rooftops can convert the heat into latent heat (Evapotranspiration). It is one of the attractive ways to reduce heat island phenomena and can also contribute to a substantial reduction in electric power consumption to cool the house in urban areas.

Latent Heat Change during Post-Monsoon: It is well known that tropical Indian Ocean (IO) acts as the major source of heat and moisture in supplying the necessary energy to drive and maintain the large-scale summer monsoon circulation and associated rainfall over the Indian subcontinent. Therefore, understanding of the air-sea interaction processes over the tropical IO and its association with Indian Summer Monsoon (ISM) deficit is of importance. The knowledge of the heat loss from the ocean surface to the atmosphere, both in terms of Latent Heat Flux (LHF) is of paramount importance for the study of air-sea energy exchange. Bengal (BoB). Webster (1972) found that both latent heat and the orography are important in forcing the mean circulation in the tropics and sub-tropics. The changes in the thermal conditions over the tropical IO are mainly contributed by changes in the LHF.

Latent Heat Change during winter:

Latent heat flux for the winter (DJF) (a) and sensible heat flux for the summer season (JJA) (b). Time averaged differences between the data assimilated and the control run are shown in W m À2 . Heat flux differences which are not statistically significant at the 90% level are not drawn. Reconstructions of past climates show notable temperature variability over the past millennium, with relatively warm conditions during the Medieval Climate Anomaly (MCA) and a relatively cold Little Ice Age (LIA). Multimodal simulations of the past millennium are used together with a wide range of reconstructions of the Northern Hemispheric mean annual. . In terms of climate, this century encompassed the DM, which was a period of anomalous coldness (van der Schrier and Barkmeijer, 2005, and references cited therein).

Drag coefficient: The drag coefficient is a number those aerodynamicists use to model all of the complex dependencies of shape, inclination, and flow conditions on aircraft drag. The drag coefficient then expresses the ratio of the drag force to the force produced by the dynamic pressure times on the area. The latent heat flux is in SI units is measured in W/m^2.

Latent heat mainly depends on insulation, the water vapor flux between ocean and atmosphere, sea surface temperature, the clouding and the level of moisture in the atmosphere. It is quite clear that the latent heat flux increases over the oceans if the atmosphere is relatively dry or of low moisture content. The latent heat flux is mainly the transfer of heat from the ocean to the atmosphere in a latent from that is by way of evaporation. The latent heat included in water vapor can be freely moved from one place to another. This characteristic is closely related to the distribution of heat energy is global climate system.

Relation between SST and LHF: The surface latent heat flux is an important quantity in atmosphere and ocean interaction, of which studies show the surface evaporation-sea surface temperature (SST) feedback, could contribute to the development of several climate modes. It has been increasingly used for various climate studies.

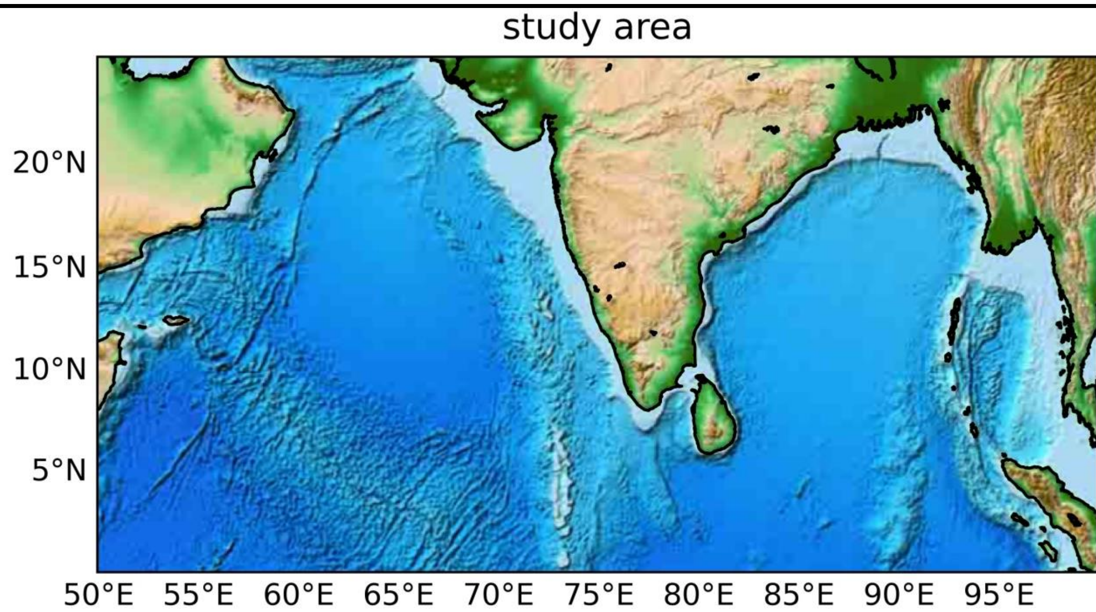


Figure 1: Geographical study area of North Indian Ocean (Arabian Sea and Bay of Bengal) 0N:25N/50E:100E.

The Indian Ocean is the third-largest of the world's five oceanic divisions, covering 70,560,000 km^2 (27,240,000 sq mi) or 19.8% of the water on Earth's surface. It is bounded by Asia to the north, Africa to the west and Australia to the east. To the south, it is bounded by the Southern Ocean or Antarctica, depending on the definition in use. Along its core, the Indian Ocean has some large marginal or regional seas such as the Arabian Sea, the Laccadive Sea, the Somali Sea, Bay of Bengal, and the Andaman Seas. The Arabian Sea and the Bay of Bengal come under the north Indian Ocean. And these are vital a role play in Indian sub-continent climate change.

Arabian Sea: The Arabian Sea is a region of the northern Indian Ocean bounded on the north by Pakistan and Iran, on the west by northeastern Somalia and the Arabian Peninsula, and on the east by India. Historically the sea has been known by other names including the Eritrean Sea and the Persian Sea. Its total area is 3,862,000 km2 (1,491,000 sq mi) and its maximum depth is 4,652 meters (15,262 ft). The Arabian Sea 26 years average SST remains below than 28°C which creates favorable conditions for convective activities.

Bay of Bengal: The Bay of Bengal, the largest bay in the world, forms the northeastern part of the Indian Ocean. Roughly triangular, it is bordered mostly by India and Sri Lanka to the west, Bangladesh to the north, and Myanmar (Burma) and the Andaman and Nicobar Islands (India) to the east. The Bay of Bengal occupies an area of 2,172,000 square kilometers. The BOB’s 26 years average SST remains higher than 28°C which creates favorable conditions for convective activities and severe cyclonic events in this area.

2. Objectives of the study

1. Understand the spatial distribution of Latent Heat flux climatology (1990-2018) over the Bay of Bengal and Arabian Sea.
2. Understand the seasonal variability of latent heat flux (LHF) and wind speed over the Arabian Sea, and Bay of Bengal.
3. To derive the Monthly climatology of Latent Heat Flux over the Arabian Sea, and Bay of Bengal from 1990 to 2018.
4. To identify and detect the Monthly climatology of sea surface temperature (SST) over Arabian Sea and Bay of Bengal from 1990 to 2018.

3. Data and Methodology

For this study from 1991-2018 period data has been taken from the Indian National center for Ocean Information Services (INCOIS) followed by the parameters Latent Heat Flux (LHF). Seasonal averaged Tropflux Latent heat flux data from 1991-2018 utilized to analyze the spatio-temporal variability of LHF over Arabian Sea and Bay of Bengal, Climatology also analyzed here. Monthly Sea Surface Temperature data taken from the Advanced Very High-Resolution Radiometer (AVHRR) which have the high spatial (1km) resolution. Monthly wind speed data taken from APDRC, ASCAT Advanced Scatterometer and ECMWF ERA-Interim. Here trying to analyze seasonal and climatological variations of wind speed and LHF.

Latent heat fluxes cannot be directly measured, but they can be calculated using the temperature and moisture content of the air at the Earth's surface and just above it along with the wind speed just above the surface. The latent heat flux flows of energy are in terms of loss/gain to the Earth's surface. So, a positive latent heat flux means water is condensing onto the surface. A negative latent heat flux means water is evaporating from the surface.

The general latent heat flux indicated in bulk parameterization formula of the determination of latent heat flux. According to this formula the latent heat flux (f) can be computed as.

$$f = \rho CdVL\ (Qs-Qa)$$

Where þ=is the density 1.29 ($kg.m^{-3}$) of the surface air computed from the equation of state.
Cd=drag coefficient 1.3×10^{-3},V=wind speed (m/s),L=latent heat of evaporation,Qs=saturated specific humidity, Qa= specific humidity at the surface.

Air -sea interaction process, like changes in heat transfer from ocean to atmosphere and shifts of wind stress pattern over the ocean, are responsible for variations in climatic behavior. major parts of heat transfer from ocean to atmosphere are carried out by evaporation in the form of latent heat and sensible heat. In this study used the python version 3.10 software. Python is an interpreter, object-oriented, high-level programming language with dynamic semantics.

By using Latent heat flux calculated the climatological change (Saji et.al (1999)). During the study period (1990-2018) seasonal variations of latent heat flux identified using python software version 3.10. While the wind speeds movement identified with seasonally and observes the climatological movement from 1990 to 2018. In the study Analise the monthly charges of latent heat flux and sea surface temperature and detect the maximum & minimum changed regions.

5. Results & Discussions

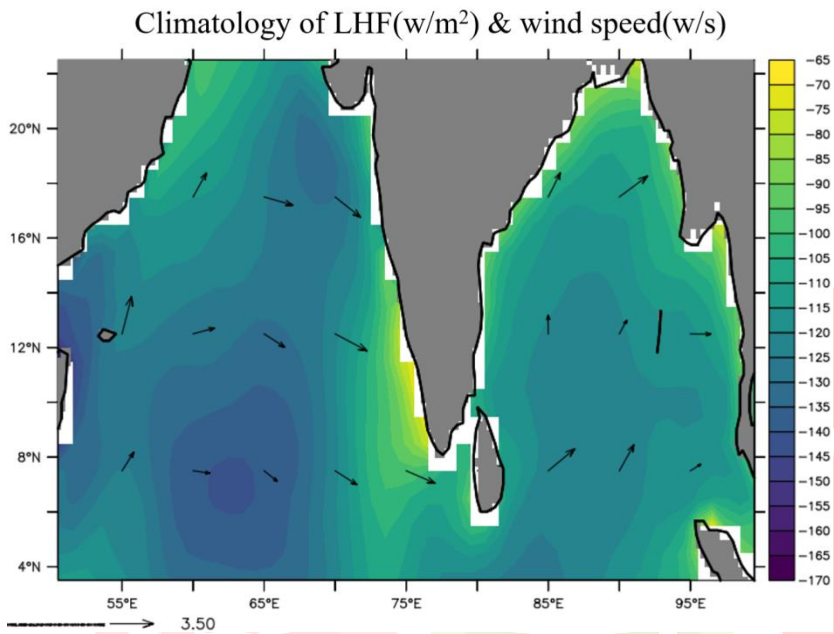


Figure4: The total 28 years latent heat flux average (1990 -2018) over the bay of bengal and Arabian sea.

Using INCOIS troplex data we observed over bay of bengal and Arabian sea highest LHF 150W/m^2 (1990-2018) in central Arabian sea. In over all 28 years the maximum LHF observed in the same place. According to the above analasys latent heat flux performance high in arabian sea than Bay of Bengal. Because upper BOB freshwater discharge is believed to cause the creation of the high variability of LHF in the northern Bay of Bengal. While the average wind speed is 3.50m/s around the study area. This study has attempted to clearly point out that larger spatial variability of LHF for both seasonal and climatological time scales and that this fact has been overlooked in previous literatures. LHFA is found to be mostly influenced by air sea differences in the before monsoon period.

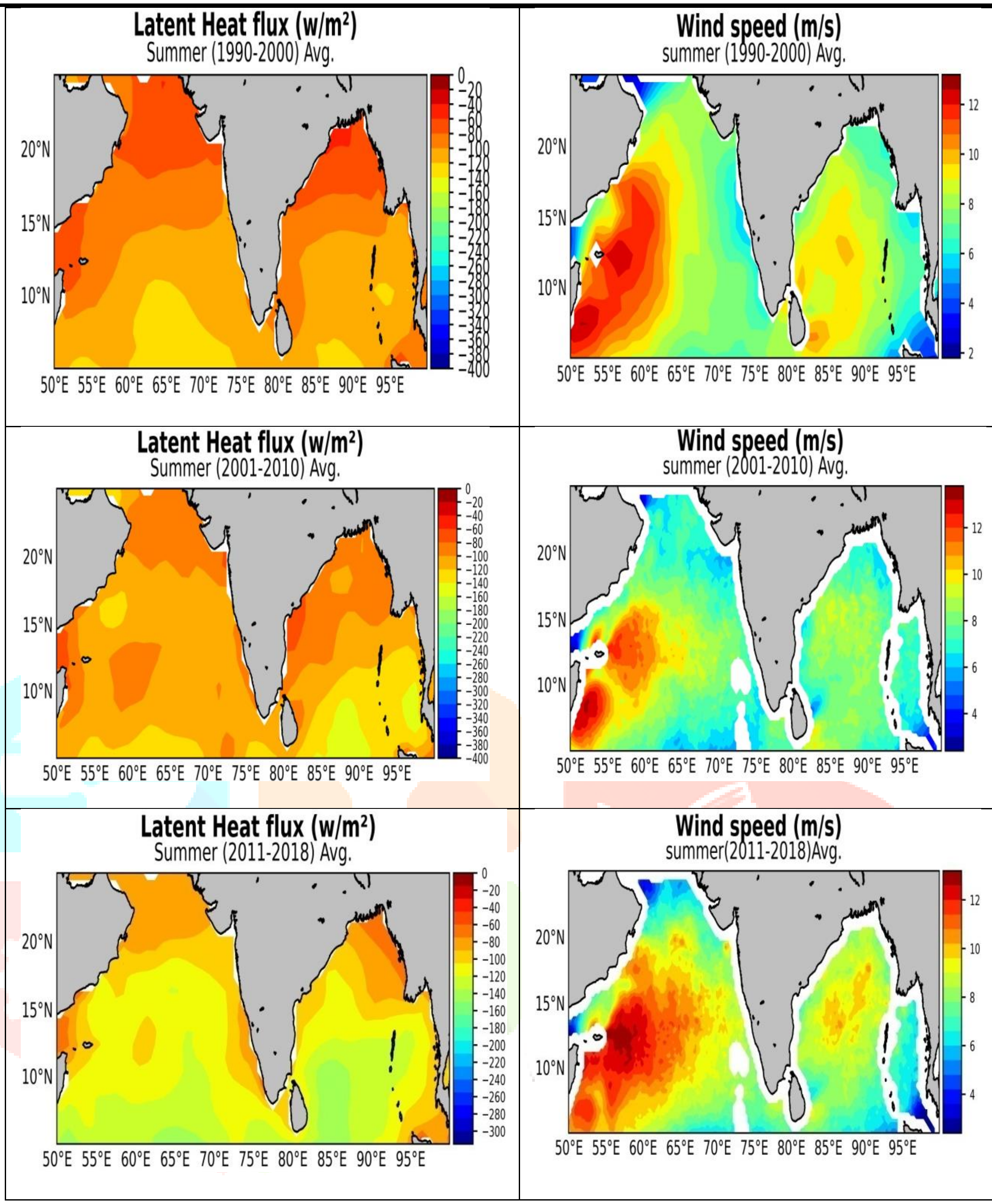


Figure 5: **Latent heat flux and wind speed change variability along Bay of Bengal and Arabian Sea during summer from 1990 to 2018.**

The latent heat flux within the surface energy balance directly relates to evaporation, which moistens the atmosphere. The drying of the atmosphere is accomplished by precipitation, which releases the latent heat into the atmosphere, causing a strong heating source and moist convection *(*Axel Kleidon et.al.2019). The zonal variation in evaporation follows strongly the zonal variation of solar radiation, but precipitation occurs more concentrated in the tropics and mid-latitude regions. Particularly in Asian subcontinent effect peak summer from April to May. As shown in the above the figure**,** from 1990 to 2000 both Arabian and Bay of Bengal Sea les effected by latent heat flux. The LHFis slightly decreasing as it moves from south to north. While the wind speed is maximum 14m/s along Arabian Sea and minimum along east Arabian Sea. Coming to next 10 years

(2000-2010) the LHF behaves like same and here observe 140w/m2 along Bay of Bengal. And from 2010 to 2018, we observe the 160w/m2 in south Arabian and Bay of Bengal sea.at the same time wind sped is maximum at west Arabian sea around 12m/s and 10m/s along central BOB.

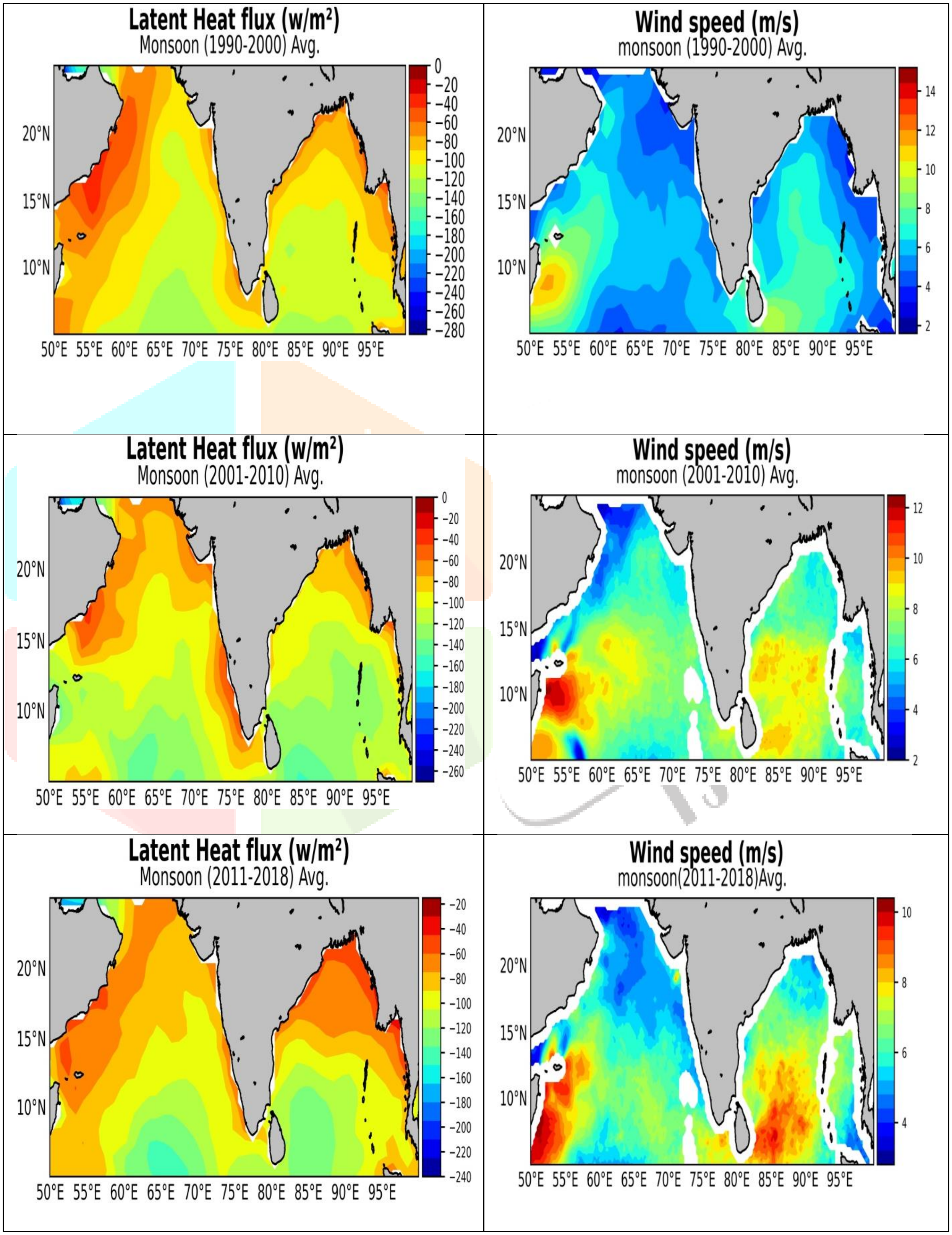
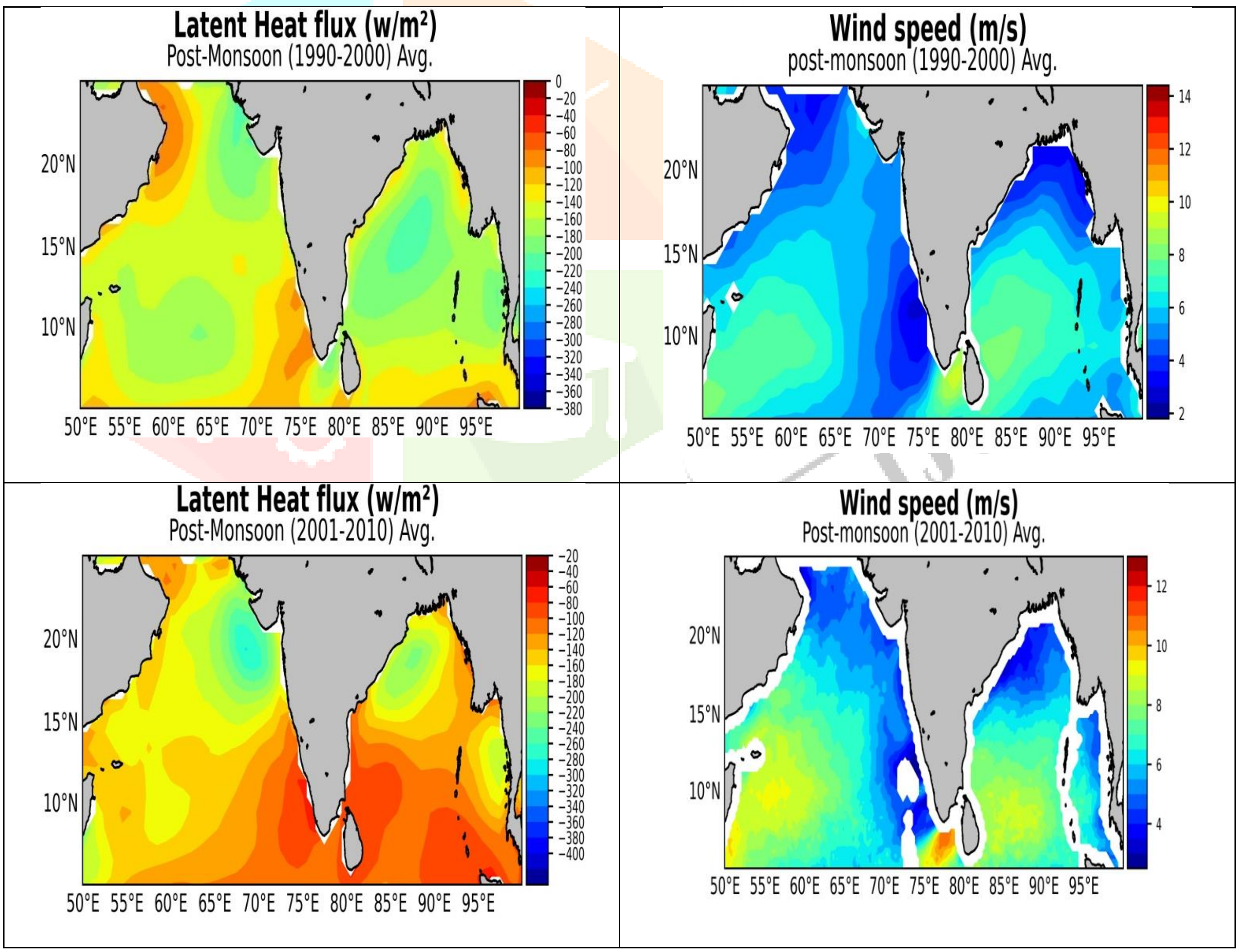


Figure 6: latent heat flux and wind speed change variability along Bay of Bengal and Arabian Sea during monsoon from 1990 to 2018.

Indian monsoon systems are driven by air-sea interaction. The southeast trade wind belt of west Australia, the Bay of Bengal and the Arabian Sea are of particular interest in the Indian Ocean regime. The predominant phenomenon found in the Indian Ocean region is the annual monsoon reversal. In general, the summer monsoon in the lower atmosphere is dominated by strong westerly and southwesterly flow. Strong cross-equatorial flow is observed along the east coast of Africa in association with the low-level Somali jet.

As shown in the above figure, during monsoon season, the latent heat flux high influence in Arabian Sea**,** from 1990 to 2000 during monsoon latent heat flux minimum (40wm2) along west Arabian Sea and maximum along north Arabian Sea. The LHF is slightly decreasing as it moves from south to north. While wind speed is maximum 14m/s along south -west Arabian sea and minimum along north-east Arabian. And next 10 years (2000-2010) the LHF behaves like same and here observe 140w/m2 along Bay of Bengal. And from 2010 to 2018, we observe the 160w/m2 in south Arabian and Bay of Bengal sea.at the same time wind speed is maximum at west Arabian sea around 12m/s and 10m/s along central BOB.



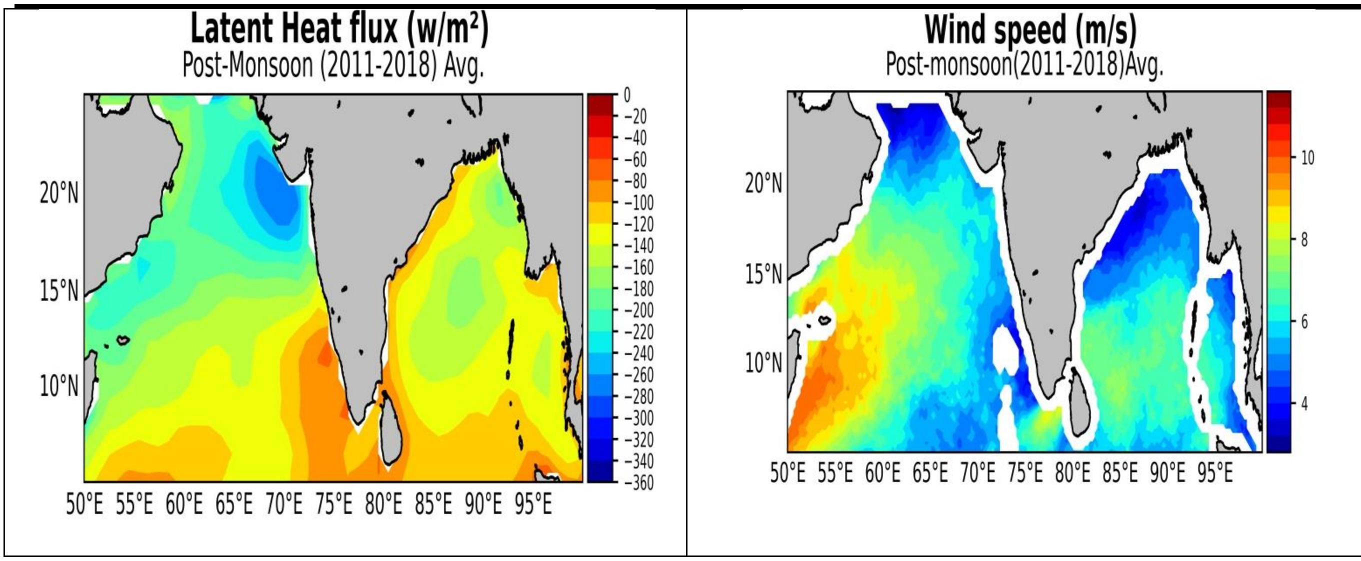
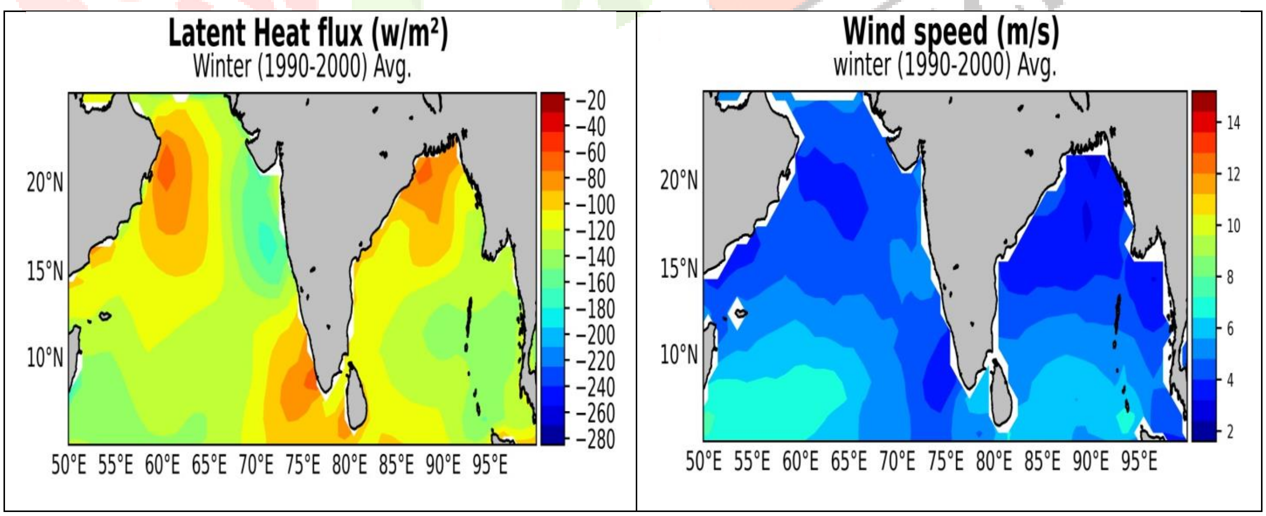


Figure7: Latent heat flux and wind speed change variability along Bay of Bengal and Arabian Sea during post-monsoon from 1990 to 2018.

As shown in the above figures, during the post-monsoon season the latent heat flux is at the maximum. LHF influence over the north-east Arabian Sea. From 1990 to 2000, in the Arabian Sea, maximum LHF was observed along the north-east region around 220w/m2 and in the central Bay of Bengal Sea in maximum LHF 240w/m2 was observed. The LHF is slightly decreasing as it moves from south to north. While the wind speed is maximum 14m/s along the Arabian Sea and minimum along the east Arabian Sea. From 2000 to 2010, we observed 260w/m2 along the north-east Arabian Sea while 220w/m2 along the Bay of Bengal. From 2010 to 2018, we observed 260w/m2 in the north-east Arabian Sea. At the same time, the Bay of Bengal Sea is 200w/m2. At that same time, wind speed is maximum in the west Arabian Sea around 12m/s and 10m/s along the central BOB.



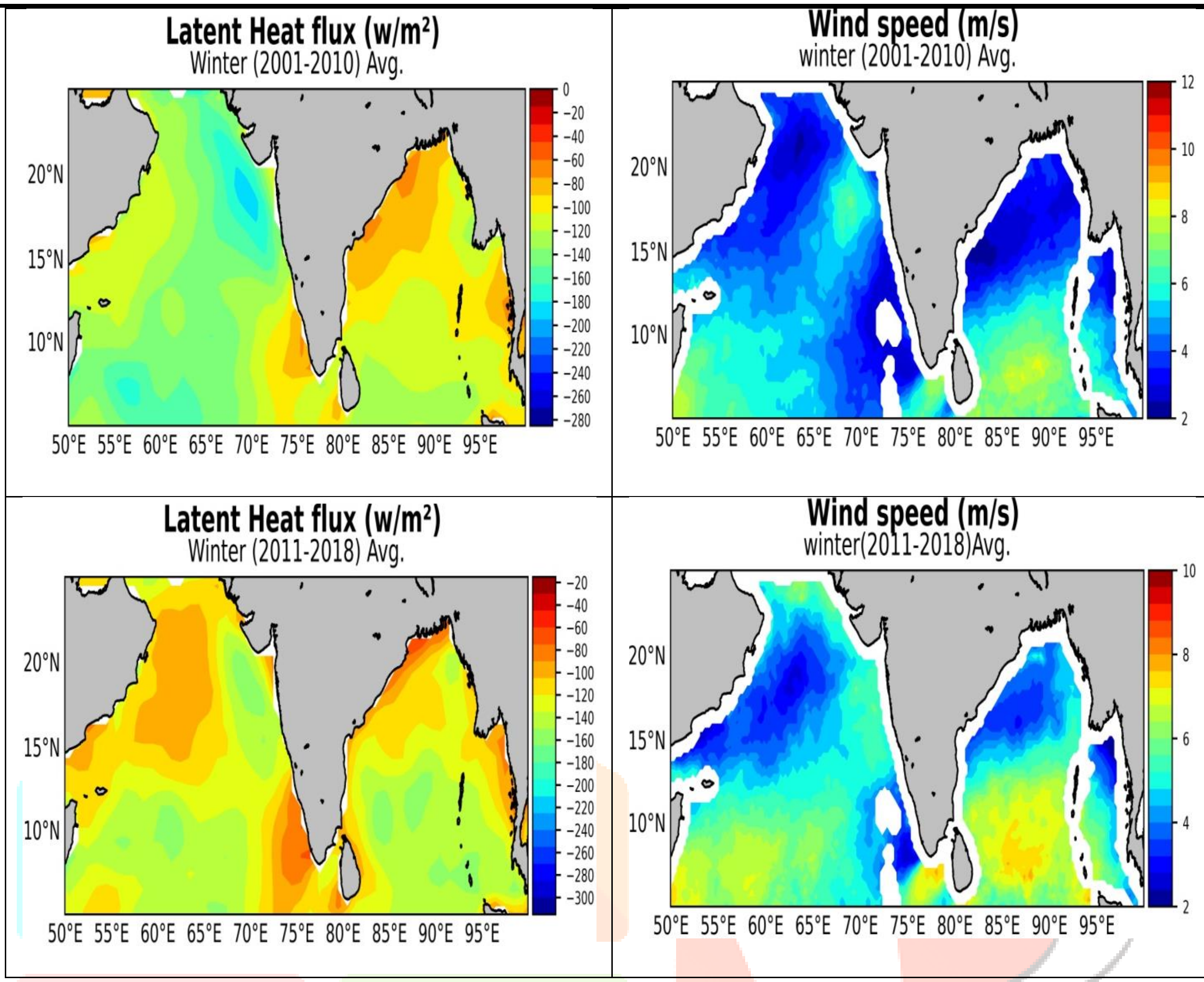


Figure 8: **Latent heat flux and wind speed change variability along Bay of Bengal and Arabian Sea during winter from 1990 to 2018**.

As shown in the above figure, during winter from 1990 to 2000, both the Arabian and Bay of Bengal Seas were affected by latent heat flux. The LHF is slightly decreasing as it moves from south to north. While the wind speed is maximum 14m/s along the Arabian Sea and minimum along the east Arabian Sea. Coming in the next 10 years (2000-2010) the LHF behaves the same and here was observed 140w/m2 along the Bay of Bengal. And from 2010 to 2018, we observed 160w/m2 in the south Arabian and Bay of Bengal seas. At the same time, wind speed is maximum in the west Arabian Sea around 12m/s and 10m/s along the central BOB.

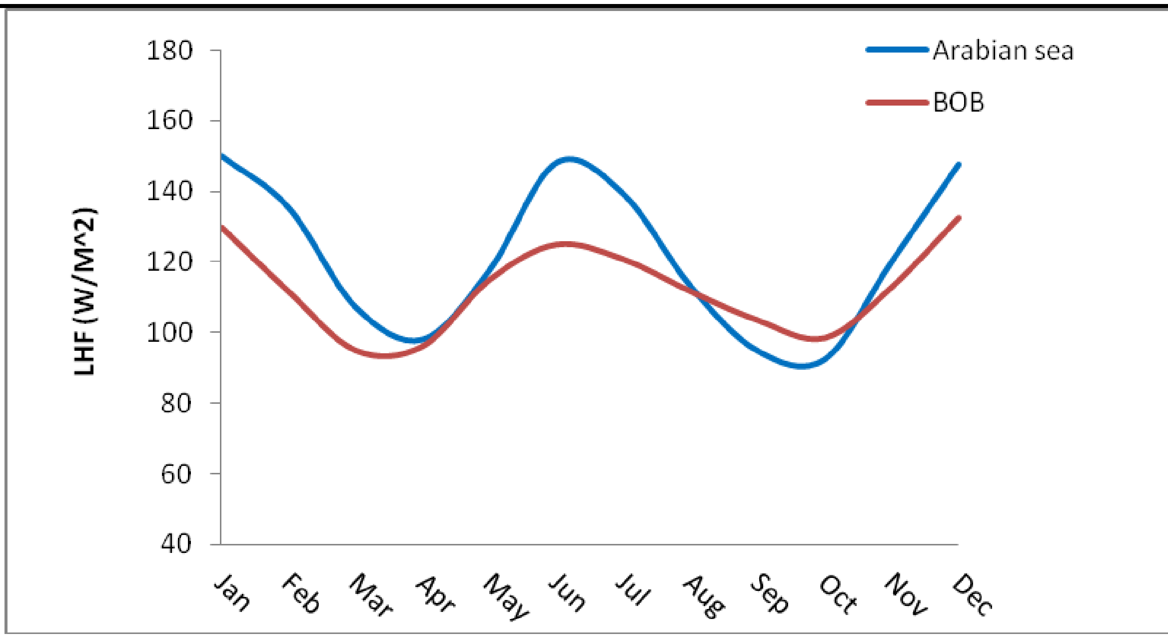


Figure 9: Monthly climatology of Latent Heat Flux over Arabian Sea and Bay of Bengal from 1990 to 2018.

From the above figure latent heat flux varies between 90w/m^2 to 151 w/m^2 over Arabian Sea, and over the Bay of Bengal 98 w/m^2 to 131 w/m^2. This part of the two bays is gain maximum heat during January, June, and December. Throughout the beginning of the South-West monsoon season especially June over the South-West side of both Arabian and Bay of Bengal show the high latent heat flux. In the month of October, BOB and Arabian Sea are showing the least latent heat flux (60 W/m^2). During December, over north-east side of the Arabian Sea and north-west part of the Bay of Bengal were shows the highest latent heat flux (220W/M^2 and 200 W/M^2) and this maintenance till the month of January. And LHF is gradually decreasing from February to April. So, the latent heat flux over both the seas attains first maximum during the month of June and the second maximum during the month of December. Here we observed the latent heat flux over the Arabian Sea is more than Bay of Bengal.

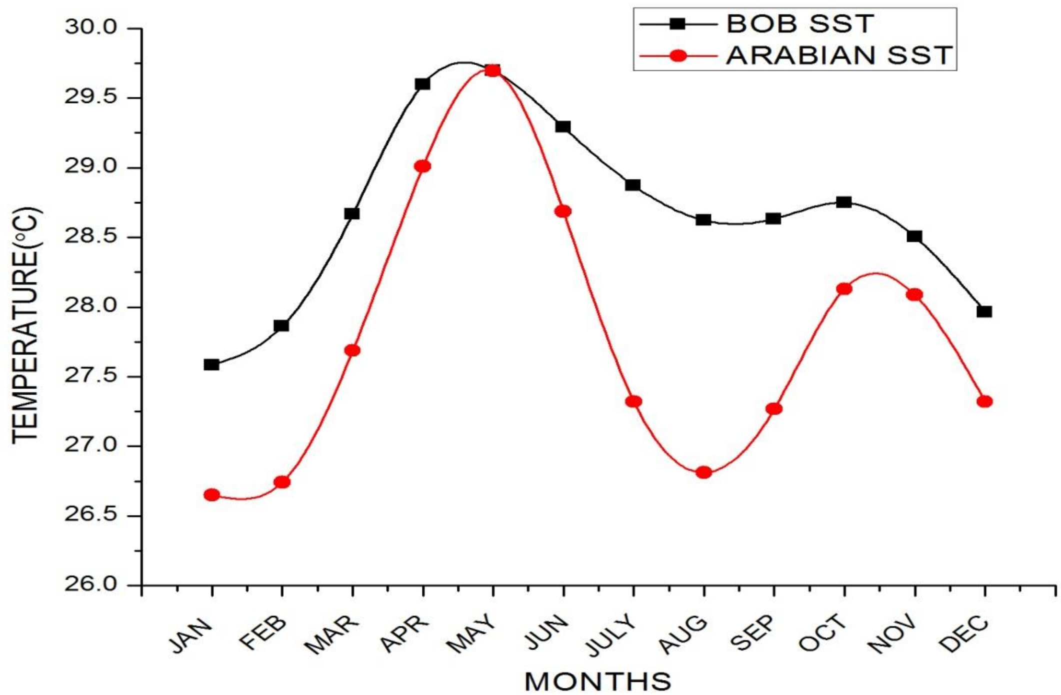


Figure 10: Monthly climatology of sea surface temperature (SST) over Arabian Sea and Bay of Bengal from 1990 to 2018.

Monthly climatology of AVHRR sea surface temperature over the Bay of Bengal and the Arabian Sea has been computed from 1991 to 2018 shown in the above figure. Here, the sea surface temperature varies between 26.5^0 C to 29.5^{0}C over the Arabian Sea and the Bay of Bengal is 27.5^0 C to 29.5^0 C. Maximum SST in Bay of Bengal and Arabian Sea is observed in May (29.5^{0}C). In both SST increases from January to May, later decreases up to August. In the Bay of Bengal, from August to September no variance observed after October gradually decrease. In Arabian Sea from August to October 1.5^{o}C increases than decreases.

6. Summary and Conclusions

This study has attempted to clearly point out that larger spatial variability of LHF both on monthly and Interannual time scales. On observation, the latent heat flux over both the sea attains the first maximum during the month of June and the second maximum during the month of December. The latent heat flux is high in the Arabian Sea compared to the Bay of Bengal. For 28 years, the monthly SST climatology SST maximum observed for the Arabian Sea and Bay of Bengal was 29.5^0 C in May. The Bay of Bengal is warmer than the Arabian Sea, maximum SST difference is 2^{o}C observed in August. Maximum LHF observed in 1999 in both the bay of

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