Mystery of El Niño and Hurricanes

Overview of Present, Distant Past and Future

Wind Research Laboratory Paper 249

Not for Sale or Distribution

January 1998

Tetsuya T. Fujita and Sumiko Fujita

PREFACE IN JAPANESE

今世紀最大のエルニーニョの年1997年の12月、メキシコの北部からアメリカ南部の暖かいはずの南国に何度も雪が降り道が凍結して死者が出た。 一方アメリカ東海岸は異常に暖かく、98年1月9日にワシントンの桜が咲き始めたので、春の桜祭りにもう一度咲くだろうかと心配。僅か600km北のニューヨークからカナダ南部では強い雨氷が降り続き、大木が倒れ300万戸が停電、住民は暖房の入らない暗い家で一週間も生活し、やがて氷が解けると洪水が起こり、停電中の家屋が多数浸水した。

一方太平洋上では季節はずれの台風が大あばれ。 97年12月ハワイの南に発生したハリケーン パカが西進し、日付変更線通過と共にパカ台風と改名。12月17日にグアム島に上陸後秒速106ﾒｰﾄﾙの強風を測定した（38ﾍﾟｰｼﾞ)。 又98年1月の上旬には、タヒチ島とオーストラリアの間の海上に熱帯低気圧が4個並んで発生。 97年末の北太平洋上の雲の形と動きは千差万別で、南北に長い長方形の雲が非常な速さで日本からハワイの方向に、気象衛星の画像上を走っていた。その翌日、ジェット機が乱気流のために降下し、一人が死亡したと報道された。

この様な地球規模の異常気象は「エルニーニョのせいだ」と濡れ衣を着せるのは不当だと思う。又エルニーニョを起こす暖水が、ダーウィンとタヒチの気圧差で吹く西風で、西太平洋から東太平洋側に移動する説は不自然であり、冷水のラニーニャ現象は説明できない。世の中の万物は必ず変動し、経済の世界では、毎年少しずつ物価が上昇する（ノーバング）型と急にバブルが弾ける（ビックバング）型がある。前者は地球温暖化の様に目立たないが、後者はエルニーニョだから無視すると被害を受ける。バブルもエルニーニョも発生原因、その強度、継続期間等を早めに又正確に予報してほしいものである。

エルニーニョは地球規模の海流が地球を取り巻く大気の流れとの相互作用で変動して起こり、ペルー沖の寒流が非常に弱まるとエルニーニョ、又強まるとラニーニャが発生する海面温度のビッグバンである（47ﾍﾟｰｼﾞと50ﾍﾟｰｼﾞ)。

1998年 1月 11日　　藤田哲也

Mystery of El Niño and Hurricanes

Overview of Present, Distant Past and Future

Wind Research Laboratory Paper 249

<u>Not for Sale Distribution</u>

January 1998

Tetsuya T. Fujita and Sumiko Fujita

Mystery of El Niño and Hurricanes

エルニーニョと台風の神秘

Printed in the United States of America

Published by the Wind Research Laboratory
Department of the Geophysical Sciences
The University Of Chicago
5734 Ellis Avenue
Chicago, Illinois 60637

WRL Research Paper Number 249

This book was written in appreciation of the cooperation and support to the author's teaching and research during the past 54 years at Kyushu Institute of Technology, Japan and The University of Chicago, U.S.A. Book is not for sale.

本書は、日本とアメリカで行った著者の研究に協力および援助された方々に進呈するために出版したもので、非売品です。再版はしません。

エルニーニョと台風の神秘

現在及び遠い昔と未来への展望

強風研究室　研究報告　２４９号

非売品

平成十年　　１月

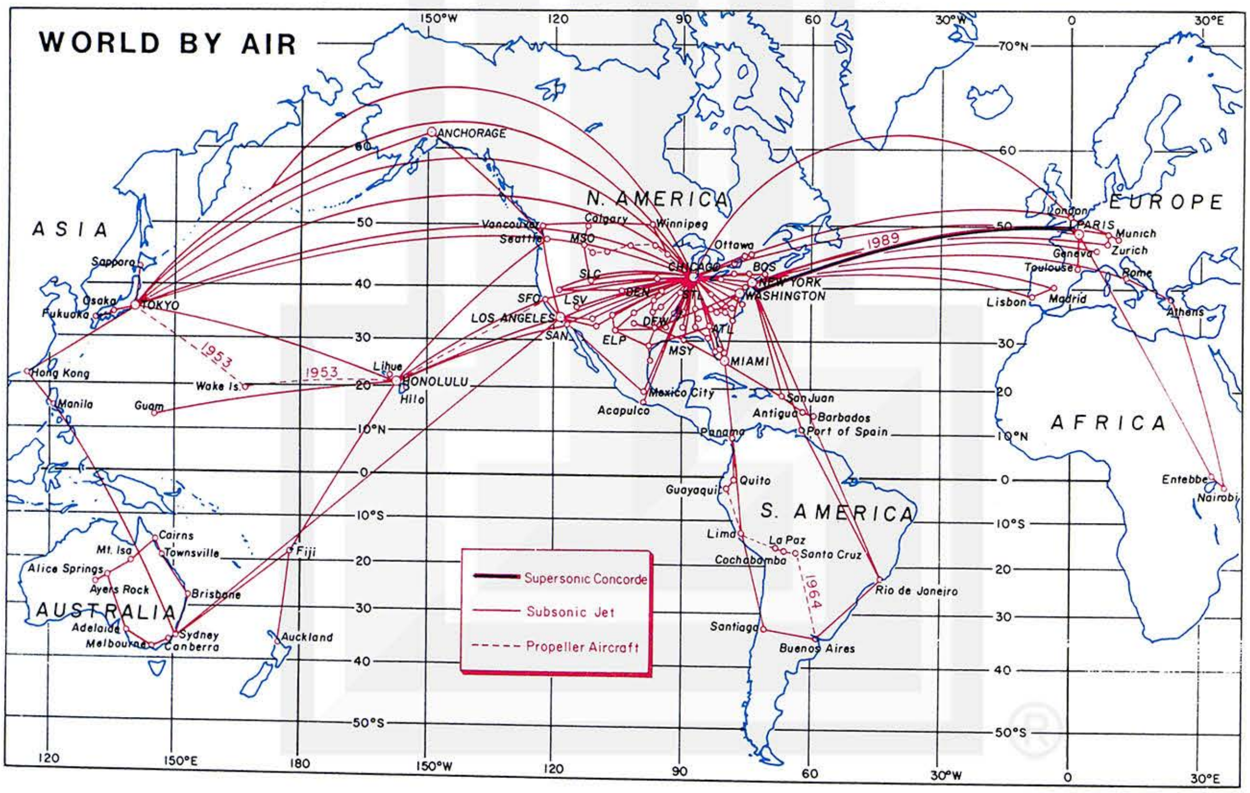
藤田哲也・藤田すみ子　共著

INTRODUCTION

I was wondering why no penguins live in the Arctic? Now the answer is simple. Should polar bears invade Antarctica, penguins could disappear within one year, leaving behind a kingdom of fat bears. Most penguins live in large groups on Antarctica and neighboring islands away from land predators.

In 1963, I learned in Santiago that medium-size penguins live on the offshore islands of southern Chile. I was also informed in Lima, Peru that small penguins live on Galapagos Islands on the equator, 8,000 km north of the Antarctic Circle. Galapagos penguins migrated northward with cold Peru Current and lived comfortably when the current was normal or cold (La Niña). Unexpectedly, sea-surface temperature of the current increased in El Niño years, starving many penguins in Chile and Galapagos. Although the penguins did not keep records of El Niño years, annual change of the Lake Titicaca water level and accumulation of the ice caps of high Andes suggest the temperature change of Peru Current.

Fujita's Travel Around the World by Air



Let us overview both sea-surface temperature above 18°C and SST anomaly above -3°C together. El Niño and La Niña phenomena can be explained as being the simple variation of Peru Current (p 47). The warm SST and cold SST may be regarded as the less cooling and more cooling of Peru Current. In this context, El Niño and La Niña turn into a single phenomenon stemmed out of the cooling power of the current.

In my view, the major Branch-Off Currents (BOCs) are driven by the anticyclonic winds of Hadley Cells over the cold ocean surface half-circled by BOCs (p 44). Due to the feedback mechanism, the colder the BOC, the stronger the anticyclone and vice versa. This concept leads to a conclusion that the General Circulation of the Atmosphere is the driving force of the BOCs around the world.

Under this concept, it will be possible to determine the El Niño / La Niña changeover in various oceans of the world based on the Central Pressure of Anticyclone (CPA) which drives the specific BOC. Test computations of the Pacific and Atlantic situations based on the CPA alone revealed that both oceans were normal in 1996. When the 1997 El Niño was in the Pacific, the Atlantic was near normal to weak La Niña (p 46).

Detailed investigation of the Percent Change of hurricanes around the world revealed a startling change of -50% to +100% in El Niño years (p 37). The change is so extensive that it could not possibly be caused by the Pacific El Niño alone. The global change in hurricanes and that of cold and warm currents of the world should be investigated in relation to the General Circulation of the Atmosphere, the principal driving force of the circulation of fluid on the earth.

シカゴ新報
THE CHICAGO JAPANESE AMERICAN NEWS

１９９７年（平成９年）　12月12日（金）

エルニーニョに関する新説

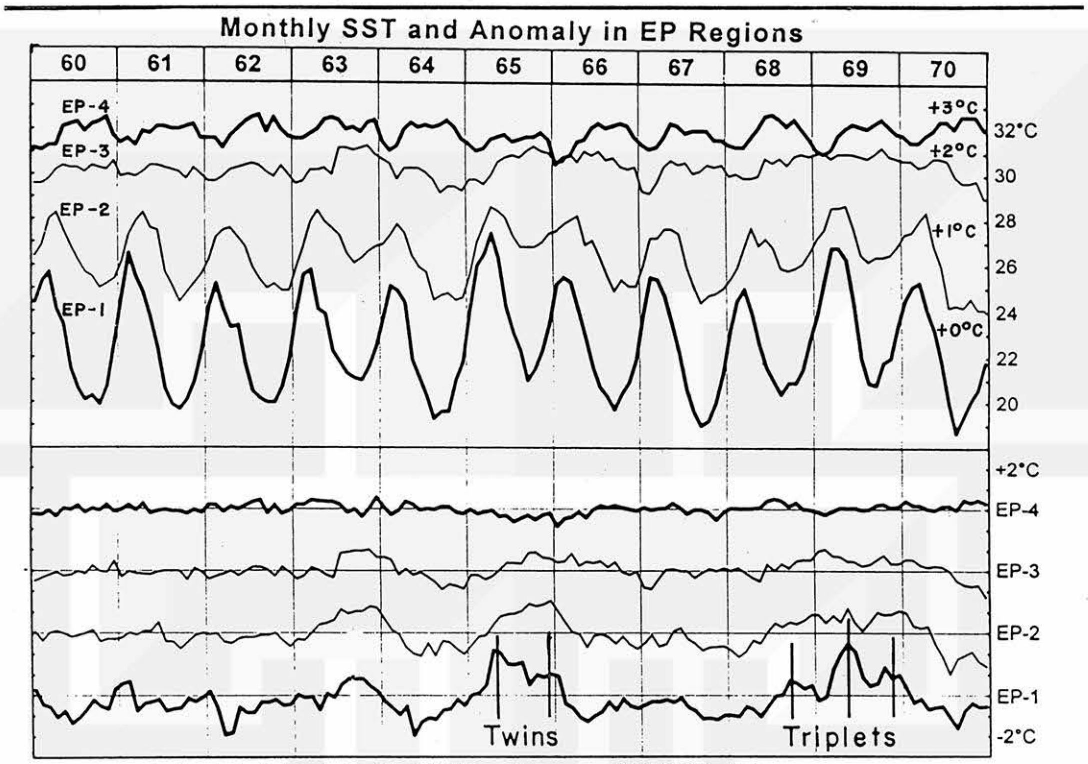
藤田哲也シカゴ大学名誉教授

エルニーニョはスペイン語で男の子を意味し、東太平洋の海水温が異常に上昇する。逆に水温が下がるときはラニーニャ女の子と言う。今年は世紀最悪のエルニーニョが発生したので、マスコミは人間生活に害を及ぼす現象はすべてエルニーニョのせいだと報道。各国が海洋観測船で数百㍍の深さまでの水温を測定して異常値の行方を追って、エルニーニョの早期発見と予報に努力しているがそれは高価で時間がかかる。

今回、私は気象庁から提供された過去四十八年間の月別海面温度を使って海水の指紋を作成。海水の生まれ故郷を推定する方法を開発した。又水温の異常上昇を男の子一人とすればエルニーニョの年には、一つ子、双子、三つ子が生まれるが四つ子はまだ発見されていない。

平成九年十月二十三日私の喜寿（77）の誕生日を祝ってくださったシカゴ新報社長の菅野昭子氏に「やがて、エルニーニョの新理論を出す積もりです」と打ち明けた後研究を始めた。私が薬の副作用からと思われる痛みに悩んでいるので、妻すみ子は「両足の痛みで大変でしょう。私が論文のお手伝いをします」と夫婦協力がはじまった。

赤道付近の海面は強い太陽光線を受けて昇温する。丁度、走行中の車と同様に冷却水が弱ければオーバーヒートする。大自然は巧く出来ていて、冷水がペルー沖から赤道海域へと流入してオーバーヒートを防いでいる。



上半分　一九六〇年から七〇年までの気象庁のエルニーニョ監視海域の水温
海域毎のカーブが重複しないように線毎に水温を少しずつ上げている。
下半分は水温の異常値で一九六五年に双子、一九六九年には三つ子のエルニーニョが見える。

その海流が弱まれば赤道付近が異常に暖かくなってエルニーニョ、強まると異常に冷えてラニーニャが起る。この研究で海水温度の年内変化を利用して海水の生まれ故郷を推定する方法を開発した。その結果、太平洋東部の赤道付近の海水は西太平洋から東進したのではなく、全く方向違いの南太平洋から北進したものだと判明した。又その海流の本籍地は南極海であると言う想像も及ばない結論に達した。

エルニーニョが何万年前から発生しているのかは分からないが、過去数億年の間に地球上の大陸分布は大きく変わった。大陸移動説によると、約二億年前、多数の大陸が南極にくっついていてパンジーアと言う巨大な大陸があった。勿論、南極を取り巻く円形寒流は存在しなかった。七千万年前最後のオーストラリア大陸が南極を去り、円形寒流が発生し現在に近くなった。現在円形寒流から四つの寒流が分離しエルニーニョが発生している。中には小型で中間サイズのメソニーニョとも言えるエルニーニョがあるらしく、一九九七年の秋から冬にかけてカリフォルニア州に大雨が降った。

〔後記〕此の研究に使用した基礎のデータは 気象庁から毎月航空便で藤田に提供されたもので、日本は勿論全世界の気圧、温度、海洋の状況が規則的に又正確に記述されている。そのデータ 無しでは此の研究は出きなかった。東京とシカゴを結ぶ地球規模の空のシルクロードを開設して下さった気象庁に感謝したい。又、北九州在住の弟、藤田碩也とは毎日国際電話で連絡し日本側からみたエルニーニョ、メソニーニョについて話し会った。

この本は非売品として来年早々出版する予定だが、限定されているので一般には配布できない。無断転載を禁じられている。

Table of Contents

目　次

Chapter One Fingerprint of SST

My school teacher taught me that our world consists of Gas, Liquid, and Solid. After my 54-years of teaching and research of Geophysical Sciences since October 23, 1943 (my 23rd birthday) at Kyushu Institute of Technology, Japan and The University of Chicago, my concept of the earth changed into Atmospheric Circulation, Ocean Circulation, and Mantle Circulation. These circulations are associated, respectively with warm front and cold front, upwelling and downwelling, and spreading and subduction.

Do they have fingerprints which move with specific circulation? Magnetic reversal on the deep ocean floor could be preserved for 100 million years until disappearing into a subduction zone. While atmosphere does not have a natural fingerprint which can be traced for months, the interannual variation of the Sea-Surface Temperature(SST) could be traced for months as a current travels around the ocean of the world.

Japan Meteorological Agency maintains EP(Equatorial Pacific) 1 through 4 regions of El Niño Watch and I located EA(Equatorial Atlantic) 1 through 4 data points (Fig. 1.1). The purpose of the EP and EA is to compare the interannual variations of SSTs over the equatorial Pacific and Atlantic oceans (Fig. 1.2).

Difference of the SST at the same latitudes over the eastern and western ocean **(E-W difference)** is of great interest. In August 1996, a normal anomaly month, the E-W difference off the coast of Peru was -12°C. One year later when the El Niño of the century was in progress in August 97, the difference increased by 5°C to -7°C (Figs. 1.3 and 1.4).

1. Fingerprint of SST

Upwelling of the wind-driven, west coast current increases with the driving windspeed and also with the decrease of latitude toward the equator. Since the latitude remains unchanged, the dramatic increase in the E-W difference from 1996 to 1997 must be due to the weakening of the driving winds. Although the weakening of the southeast trade winds prior to El Niño has not been confirmed, the 5°C increase cannot be explained otherwise.

Unexpectedly, the interannual variations of the SST at EP1, 2, 3 and EA1, 2, 3 in 1996 are very similar to each other. In 1997, EA1 and 2 in the Atlantic remained practically the same while EP1 and 2 in the Pacific increased significantly due to El Niño of the century (Fig. 1.5).

Finally, an attempt was made to determine the SST difference (1997 minus 1996) along the nine(9) locations on the Branch Off Currents(BOCs). Results revealed that SST increased 5.5°C in the Pacific, but decreased 3.5°C in the Atlantic, 1.6°C in South Indian Ocean and inconclusively cool in Tasman Sea (Figs. 1.6 - 1.10)

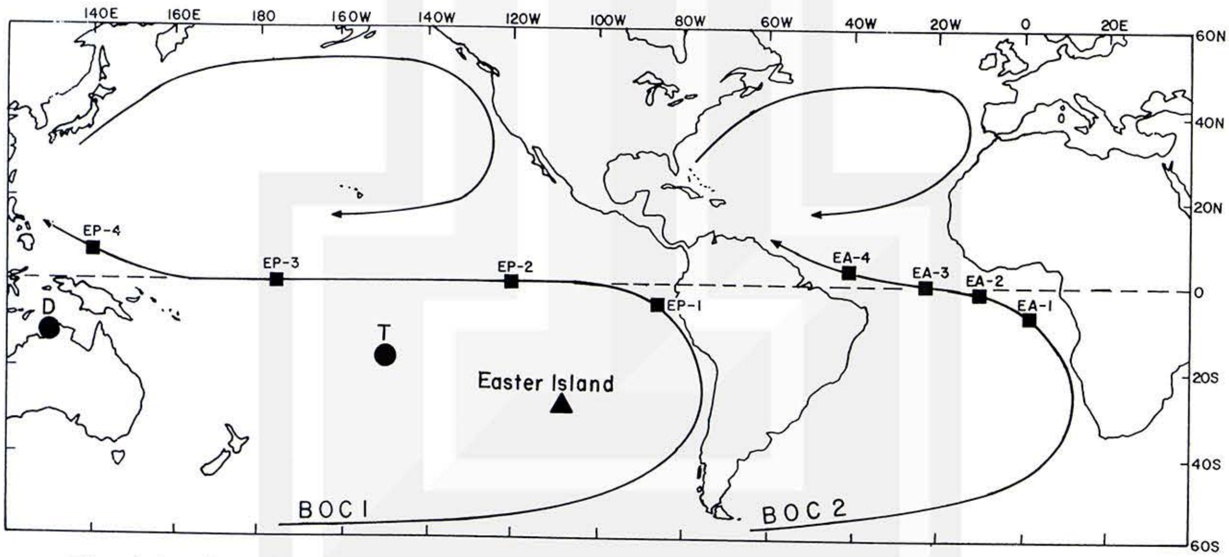


Fig. 1.1 Sampling areas of the sea-surface temperature used in this research. EP denotes equatorial Pacific and EA, equatorial Atlantic Ocean.

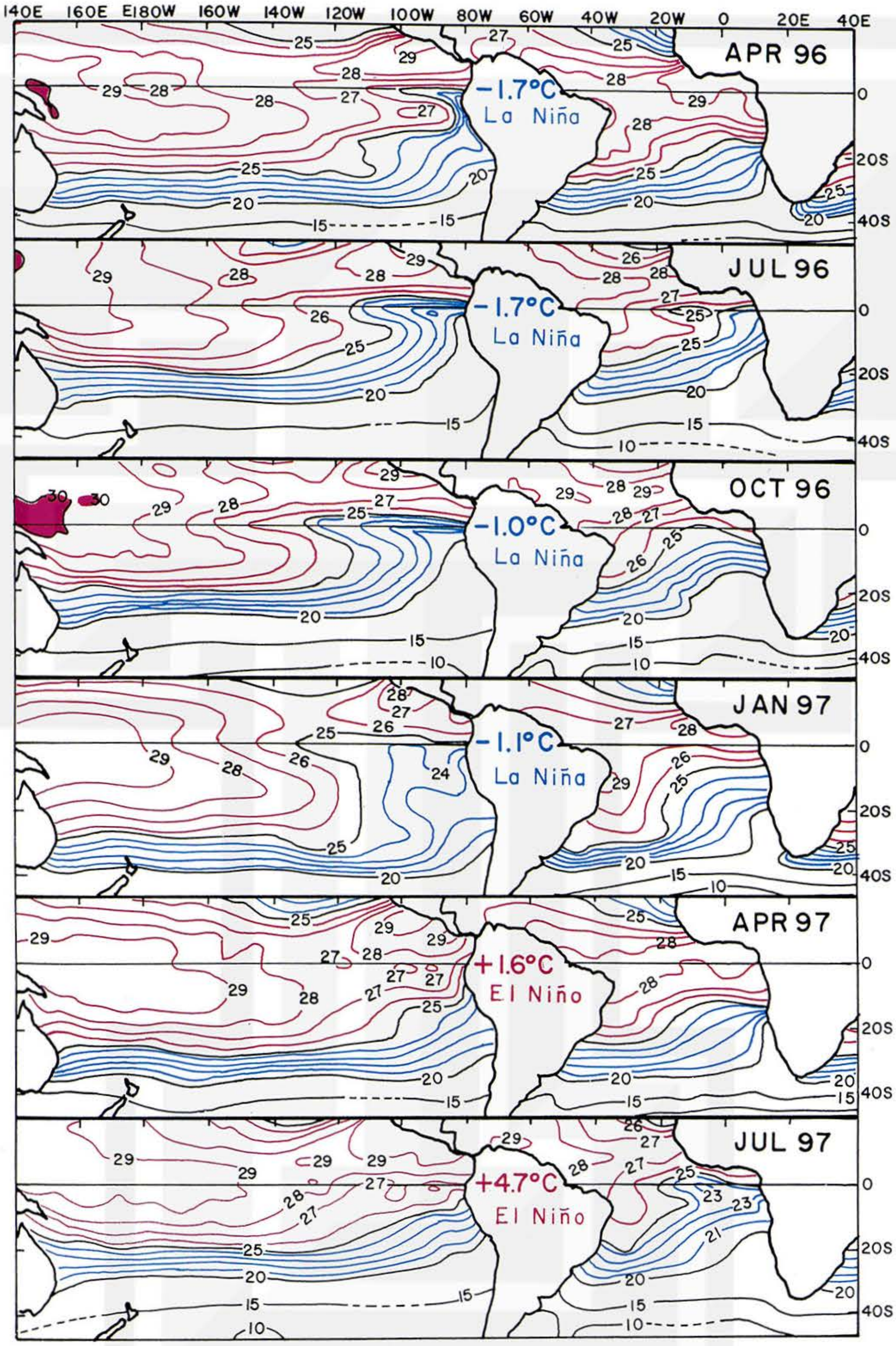


Fig. 1.2 Cooling of the equatorial water 13,000 Km long and 1,500 Km wide in weak La Niña months, April to October. Insignificant cooling is seen in July 1997 when El Niño is in progress. Data from JMA.

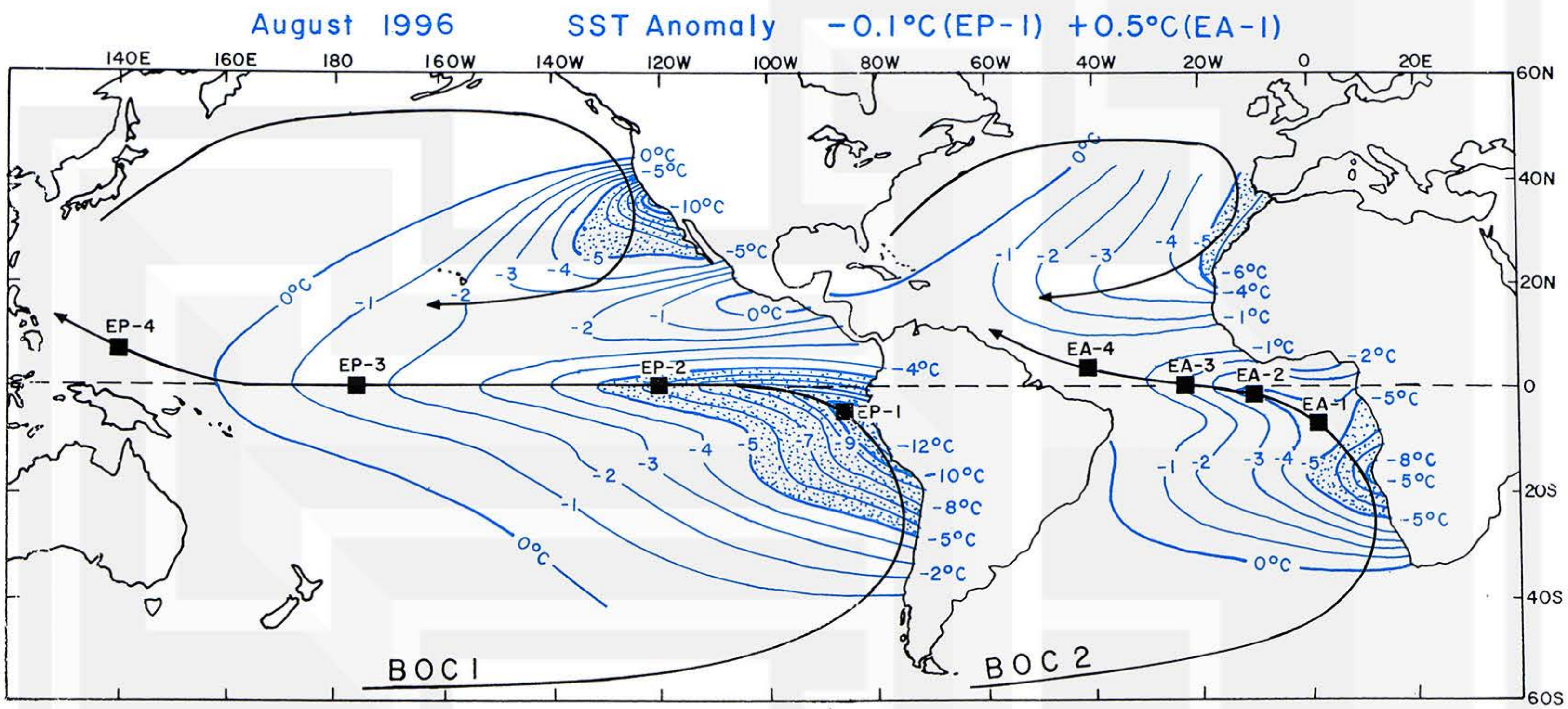


Fig. 1.3 The E-W difference of sea-surface temperature. In August 1996, a weak (-0.1°C) La Niña month in the Pacific, the Peru current was cooled by 12°C. If the current, acting as a giant coolant, dies down completely, the equatorial ocean will experience a +12°C anomaly resulting in a super giant El Niño. Basic Data form JMA.

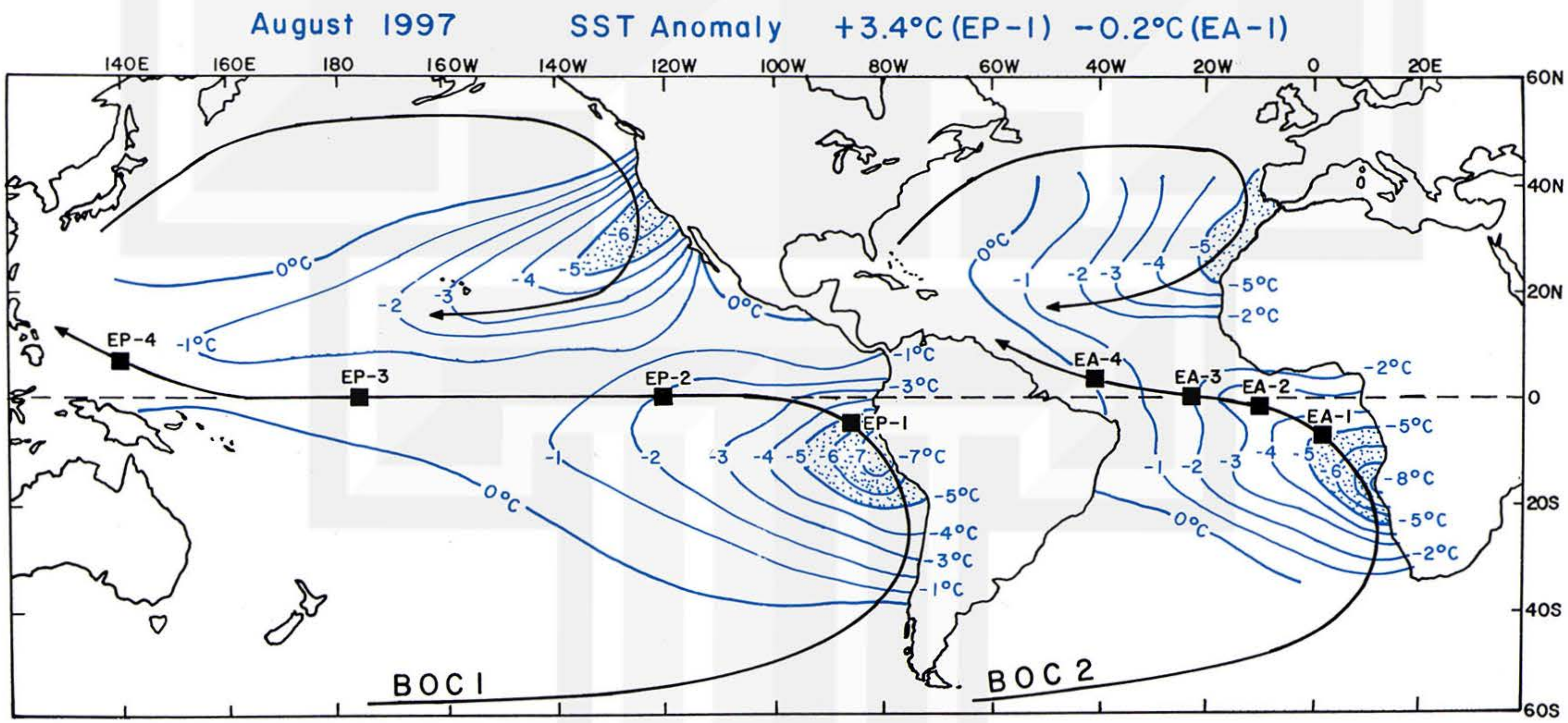


Fig. 1.4 One year later in August 1997 when the SST anomaly was +3.4°C at EP1, the E-W difference increased from -12°C to -7°C. This evidence leads to a conclusion that El Niño is caused by **less cooling** and La Niña, by **more cooling**. El Niño may be explained by the shift of warm water from the western to eastern Pacific. La Niña cannot be initiated, however, by shifting cold water from **somewhere** to the eastern equatorial Pacific Ocean. The alternate explanation of both El Niño and La Niña together will be the **less cooling and more cooling** by the Peru current due to its variations.

1. Fingerprint of SST

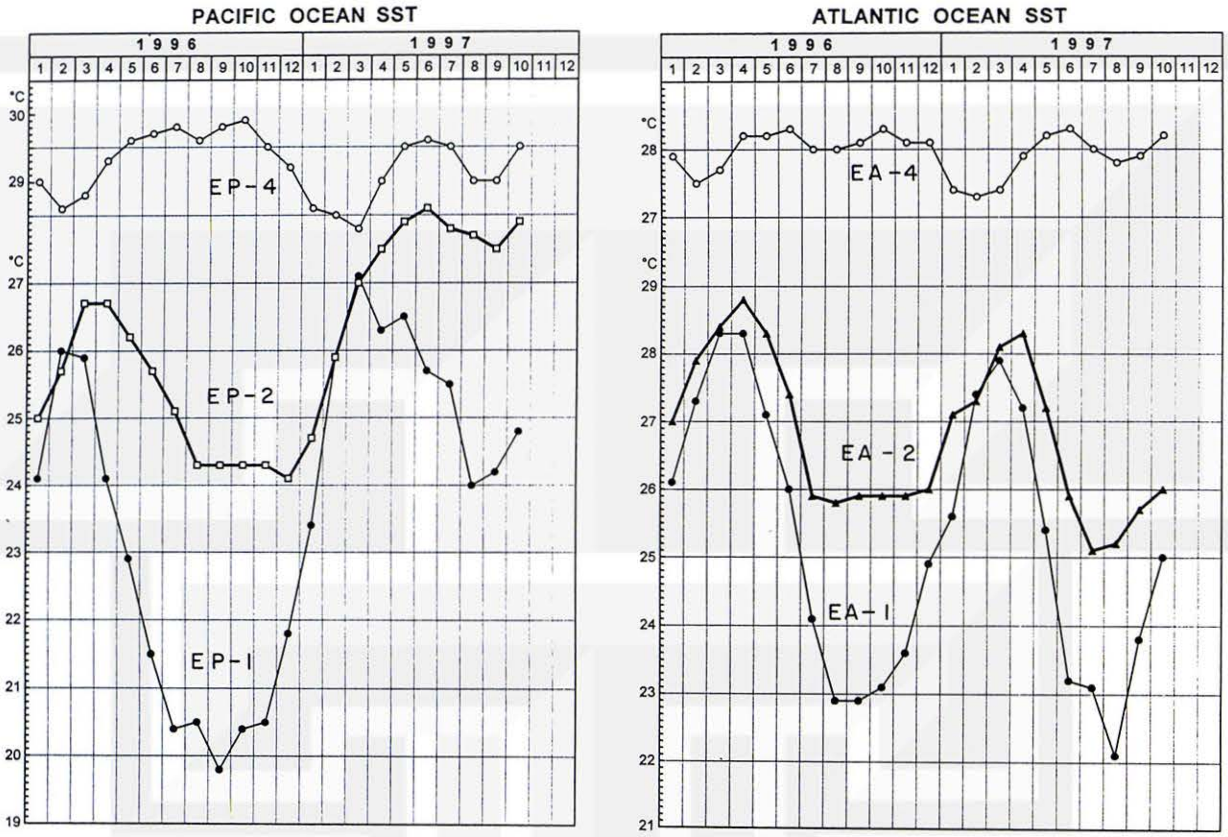


Fig. 1.5 Change in the variation of sea-surface temperature(SST) at EP1, EP2, and EP4 in the equatorial Pacific and at EA1, EA2, and EA4 in the equatorial Atlantic at comparable locations.

Amazingly, interannual variations of SST in non-El Niño years are very similar. Years are 1996 and 1997 in the Atlantic and 1996 in the Pacific. This evidence signifies that the cooling mechanisms of the equatorial Pacific and Atlantic oceans are very similar, if not identical. In both oceans, southern-hemisphere currents were at EP1 and EA1 with peak SST in August to September.

When the current reached EP2 and EA2, the minimum temperature increased by 2 to 3°C, suggesting that the cold current warmed up, just like the coolant of a running automobile, which warms up while engine cools off. There is practically no change in SST at EP4 and EA4, because the cold current did not reach these remote oceanic locations.

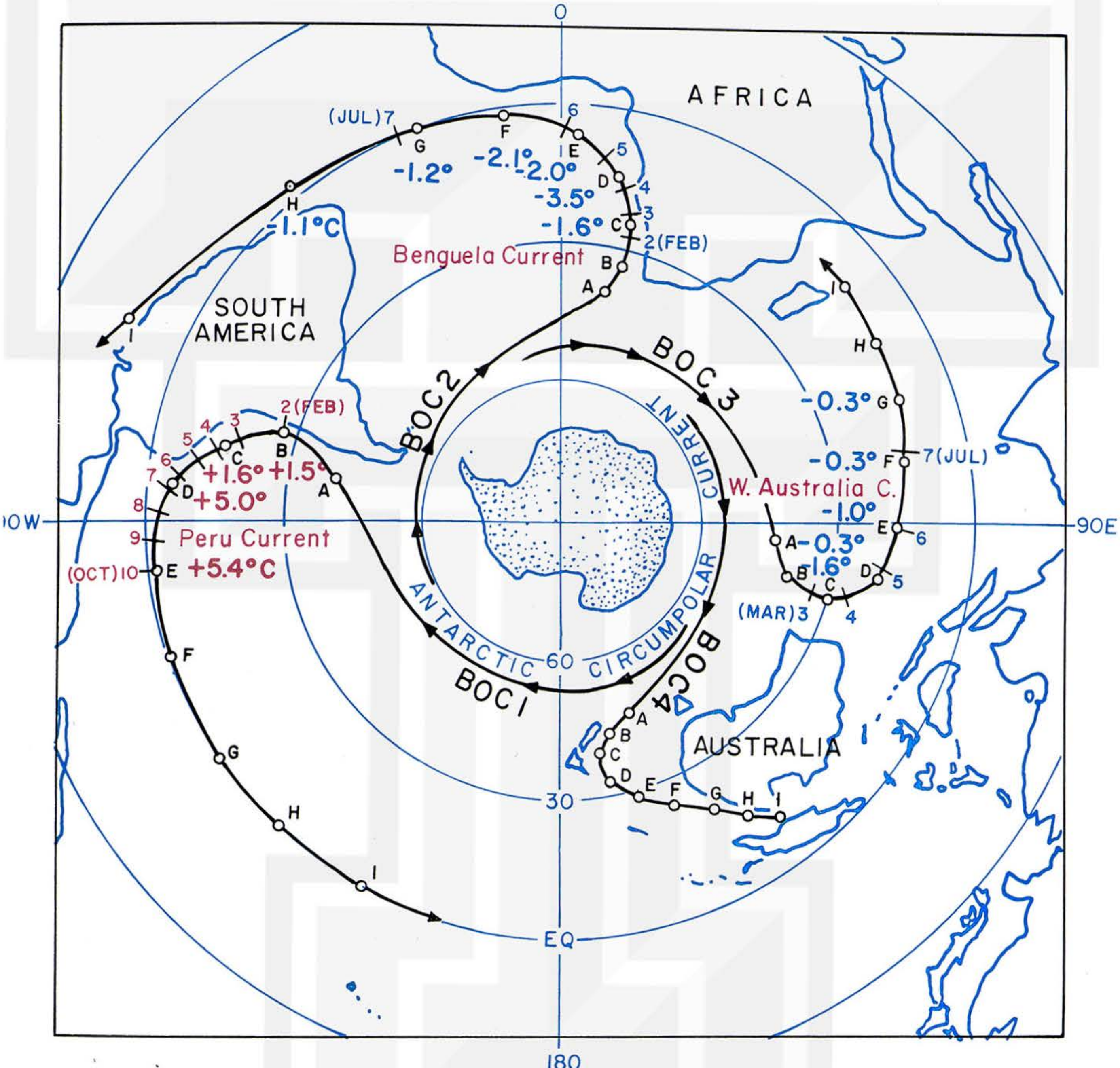
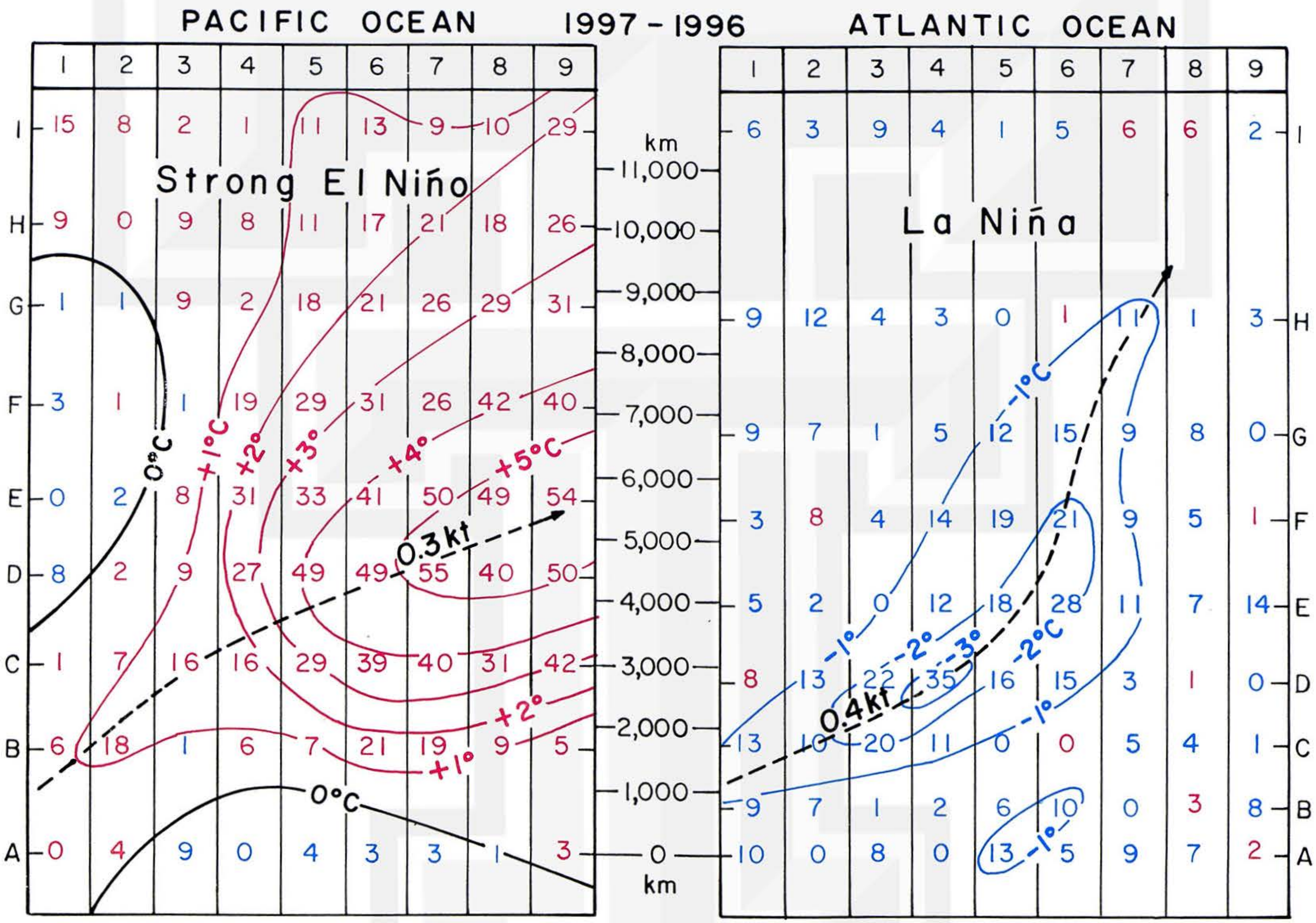
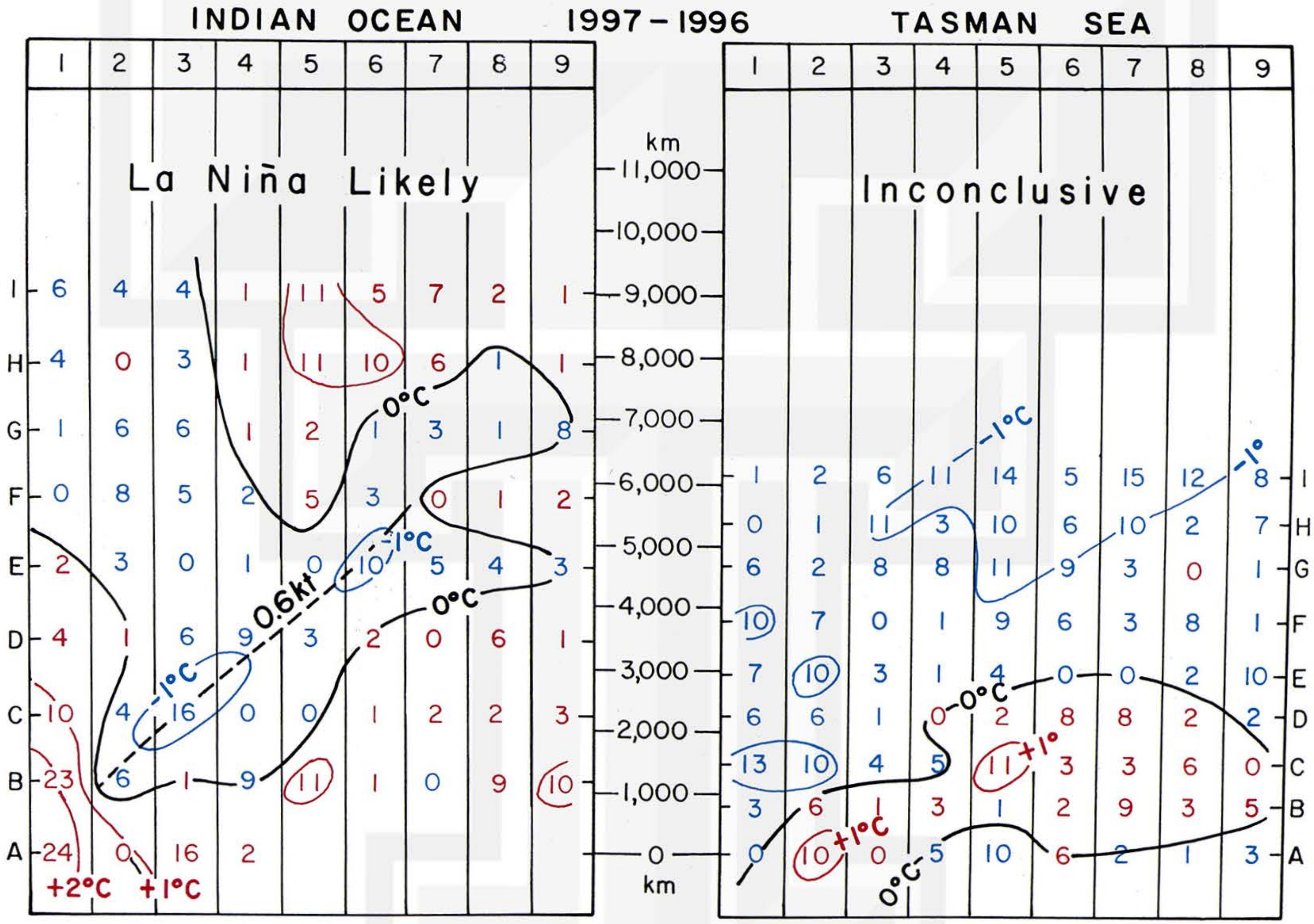


Fig. 1.6 Being impressed by the unexpected similarity of the cold currents, BOC1 and BOC2 in the Pacific and Atlantic Oceans, the difference (1997 SST - 1996 SST) was computed at nine(9) locations along the four BOCs 1, 2, 3, and 4.



Figs. 1.7 and 1.8 In the Pacific Ocean the largest difference was +5.5°C. A positive difference of 1.8°C was detected at location B as early as February 1997. On the contrary, the Atlantic Ocean was colder in 1997 showing the -3.5°C difference.



Figs. 1.9 and 1.10 West Australia Current (BOC 3) in South Indian Ocean was 1.6°C colder at C in March 1997. Whereas, Tasman Sea north of location D was cold, where South Pacific hurricanes are up to 70% less in El Niño years.

Chapter Two Tropicalization of SST

Long-term variation of SST at four JMA regions, EP1, 2, 3, and 4 (JMA identification: NINO 1+2, NINO 3, NINO4, and NINO WEST) reveals that the 5.9°C amplitude of the SST at EP1 decreases to 2.5°C at EP2. Amplitude at EP3 is only 0.6°C while bi-annual, camel-back variation with 1.0°C amplitude is seen at EP4. These are very important fingerprints of the SST (Figs. 2.1, 2.2, 2.3, 2.4). On the other hand, the variation of SST anomalies is hard to follow from one EP station to the next.

The 48 years of SST and anomaly data were enlarged to find that one or more anomaly peaks exist within the overall period of an El Niño (male child). These peaks are identified as the births of multiple children. Within the 48 years, 1950 to 1997 there were 2 single children, 8 twins, and 1 triplet. The 1997 El Niño is expected to be either twins or triplets (Figs. 2.7 to 2.11).

The current from EP1 to EP2 flows westward because the dates of the peak SST increase from EP1 to 2. The current flows under the tropical sun which crosses the equator twice a year on 21 March and 23 September (Fig. 2.12). Computed incoming solar radiation at the top of the atmosphere peaks in June in northern hemisphere and in December in southern hemisphere (Fig. 2.13). During the flow of the El Niño current from southern to northern hemisphere, the interannual variation of SST changes from the southern mode to the tropical mode (Fig. 2.14).

Change of the mode is identified as the **Tropicalization of SST**. The SST variation during the near-normal, 15-yr average (Fig. 2.15) was compared with the computed incoming solar radiation (Fig. 2.16). After the time-lag shifts of 2 to 3 months, they are very similar to each other. A comparison of the 15-yr average of the LOW, MID, and HIGH SST years at EP1 shows that the fingerprints of these average SST are not influenced by the difference of the peak SST at EP1 (Figs. 2.17, 2.18 and 2.19).

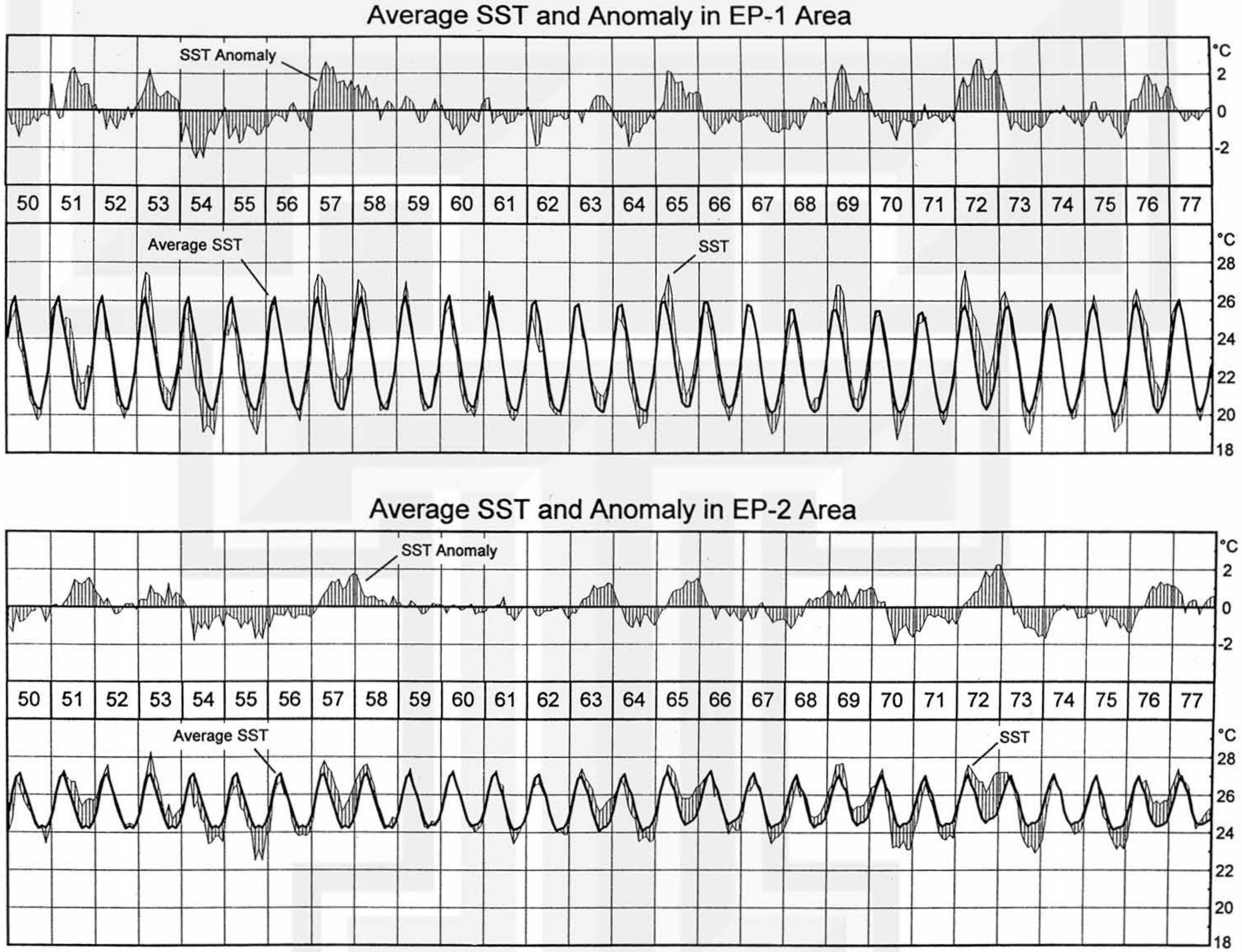


Fig. 2.1 SST anomaly shown by a thin line with vertical shade (top line). SST in a thin line with vertical shade above and below the 10-yr ending mean SST shown with heavy line. 10-yr ending mean SST is used throughout this report in computing the SST anomaly.

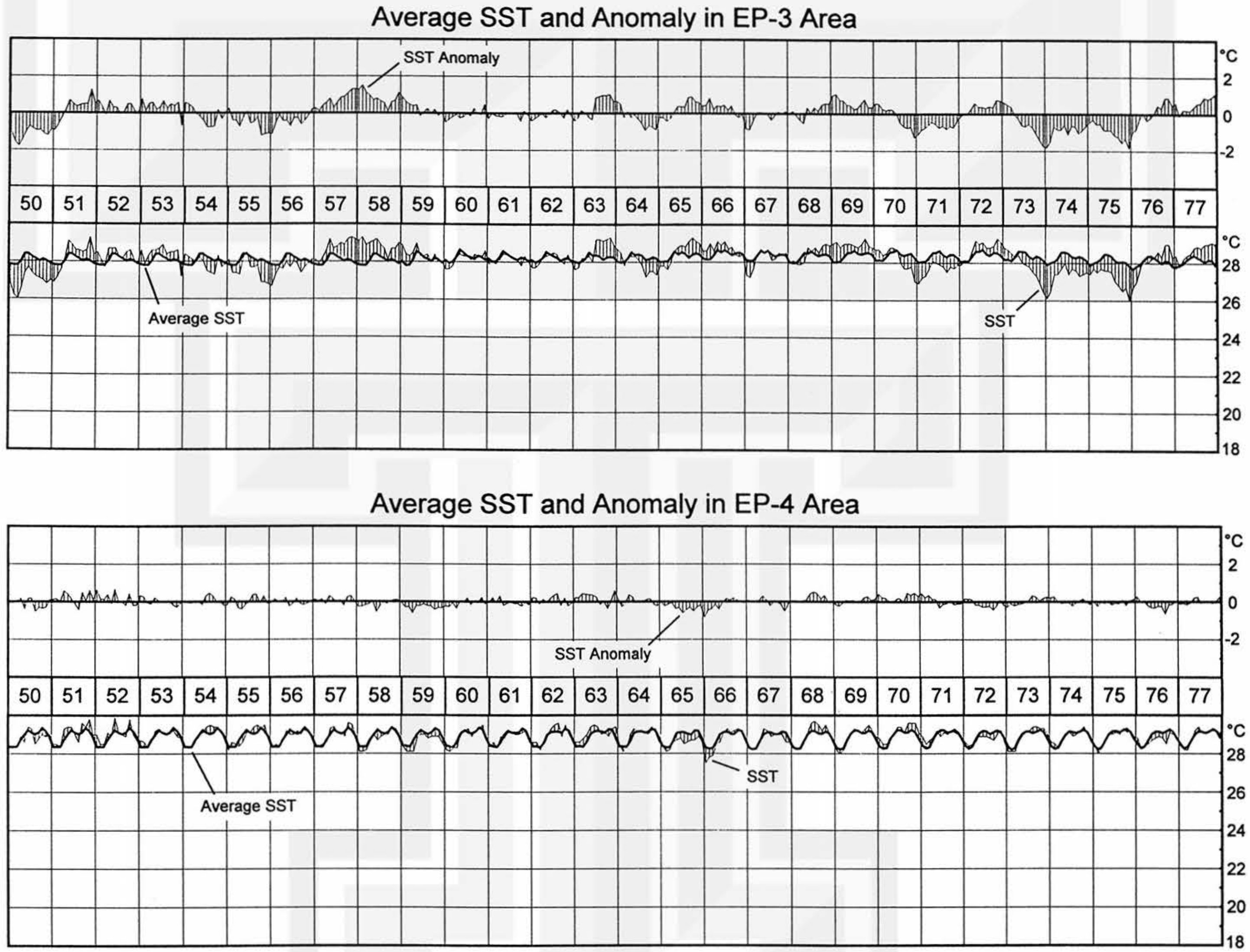


Fig. 2.2 Average SST (10-yr ending mean SST) and SST anomaly at EP3 and EP4. It is hard to relate SST with its anomaly at EP4, in particular.

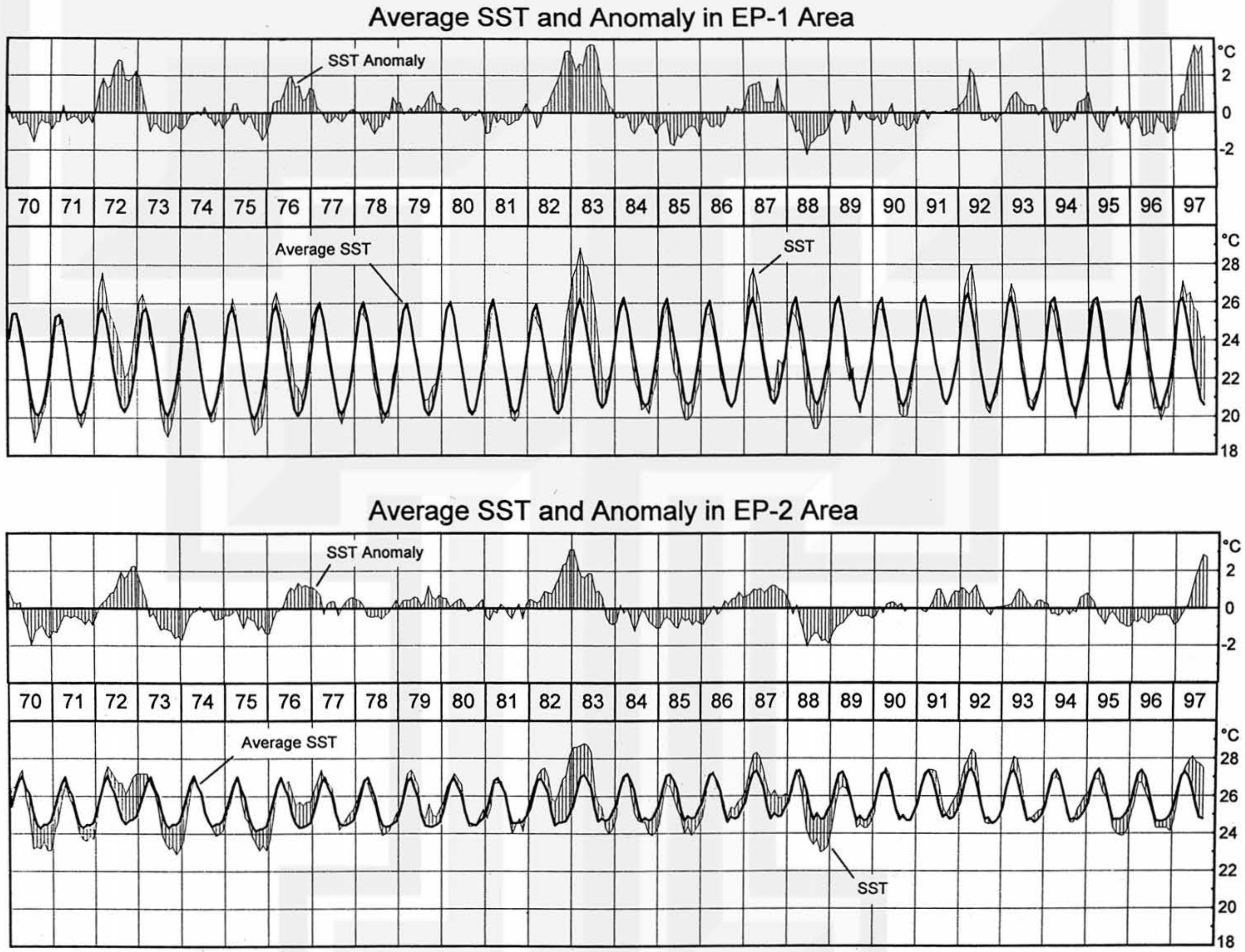


Fig. 2.3 SST at EP1 and EP2 in the 1970-97 period show that the peak months of anomaly and SST are often quite different. Although both SST and average SST are often in phase, anomaly in 1982-83 at EP1 shows two peaks, while the maximum SST anomaly is located between two SST peaks.

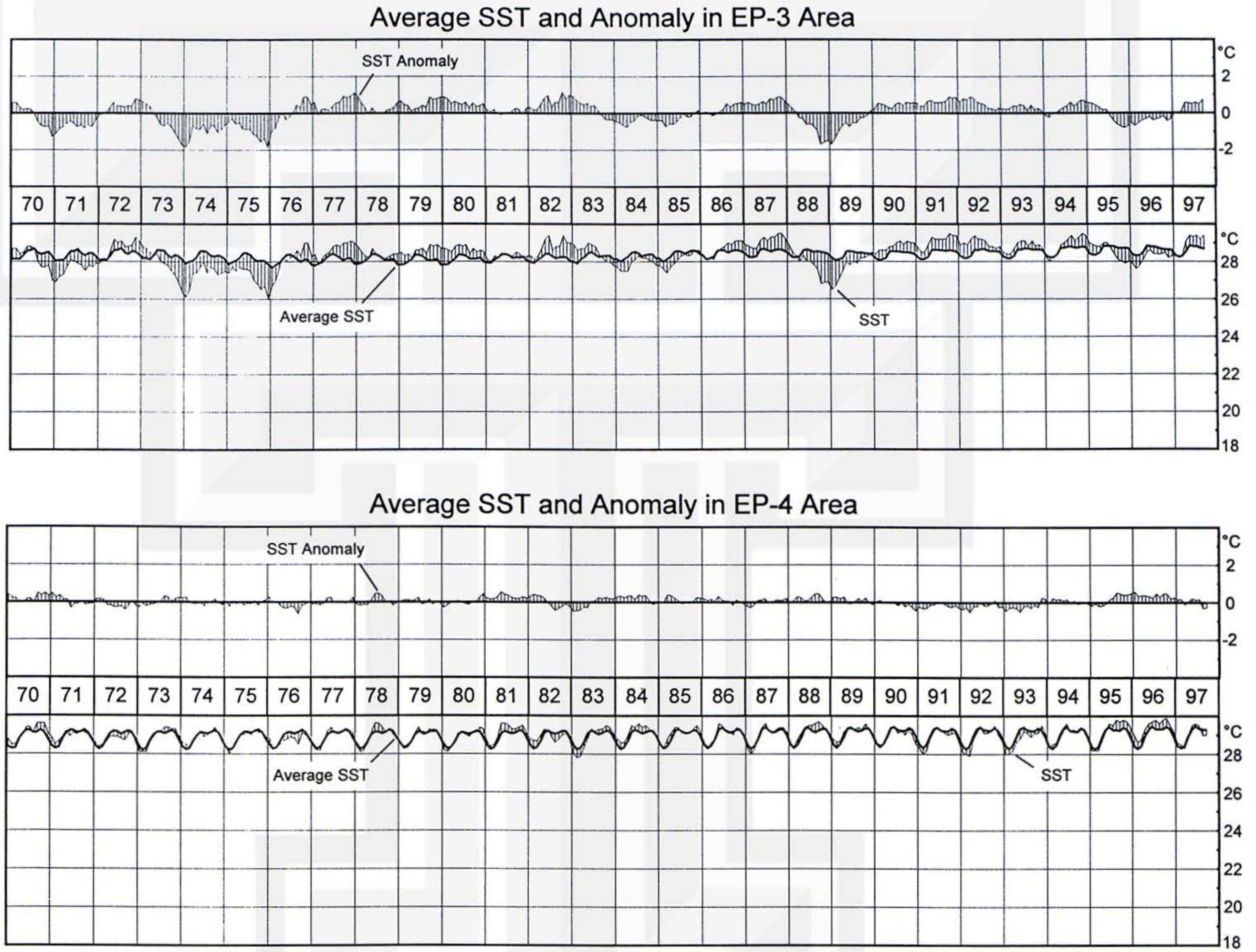


Fig. 2.4 Frequently, SST anomaly and SST at EP3 and EP4 are unrelated. When the eastward advection of warm water occurs, the pattern of SST and SST anomaly should be similar to each other.

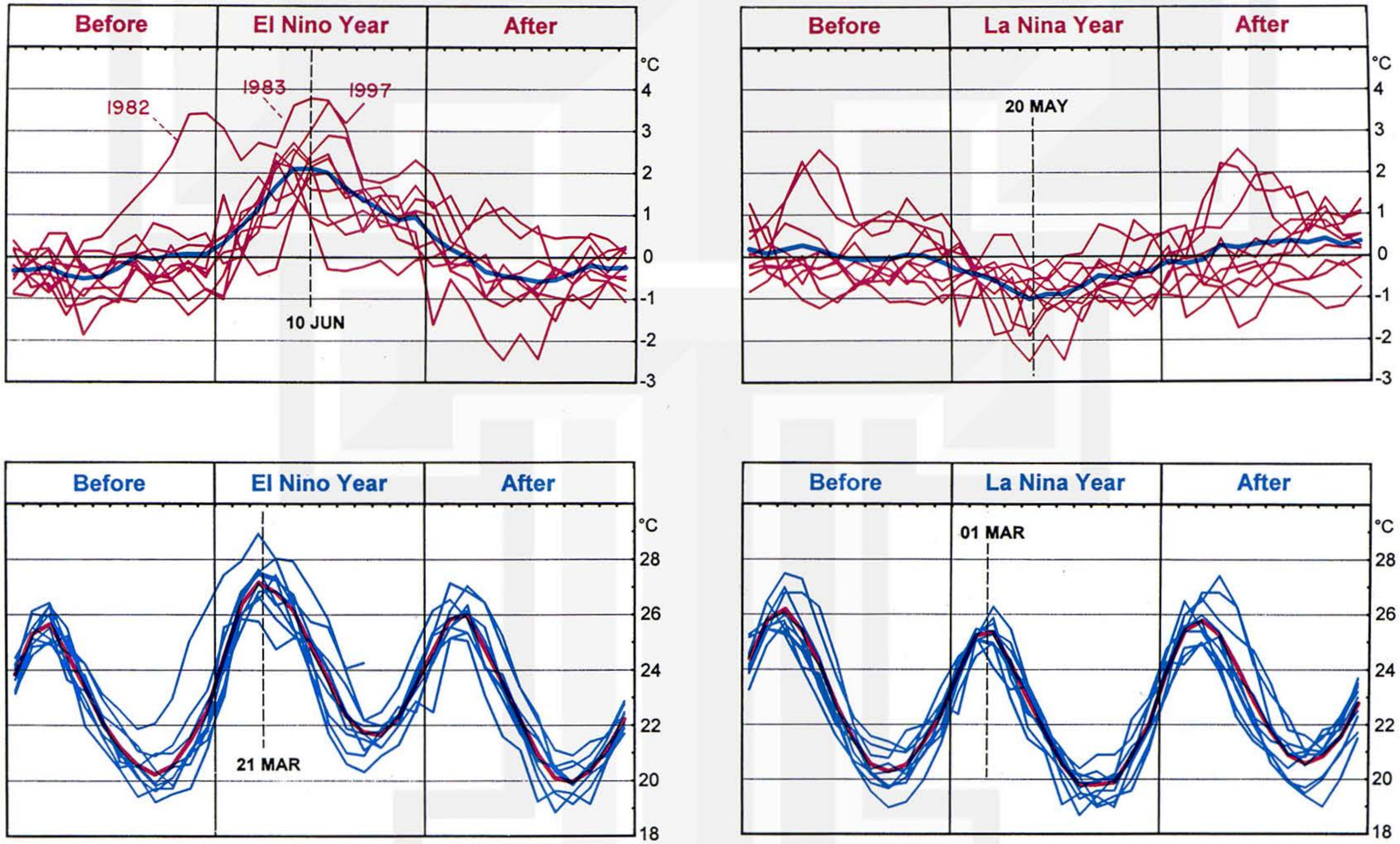


Fig. 2.5 (left) and Fig. 2.6 (right) Composite variation of SST anomaly (above) and SST (below) of the top 10 El Niño (left) and top 10 La Niña (right) years. The **mean El Niño period is two years** while the period of SST variation is one year. The peak date of SST anomaly is 10 JUN (20 MAY) which is 82 (80) days later than the peak date of SST. ( ) denotes La Niña years. I wonder why La Nina peak occurs 20 days earlier than the El Niño peak.

2. Tropicalization of SST

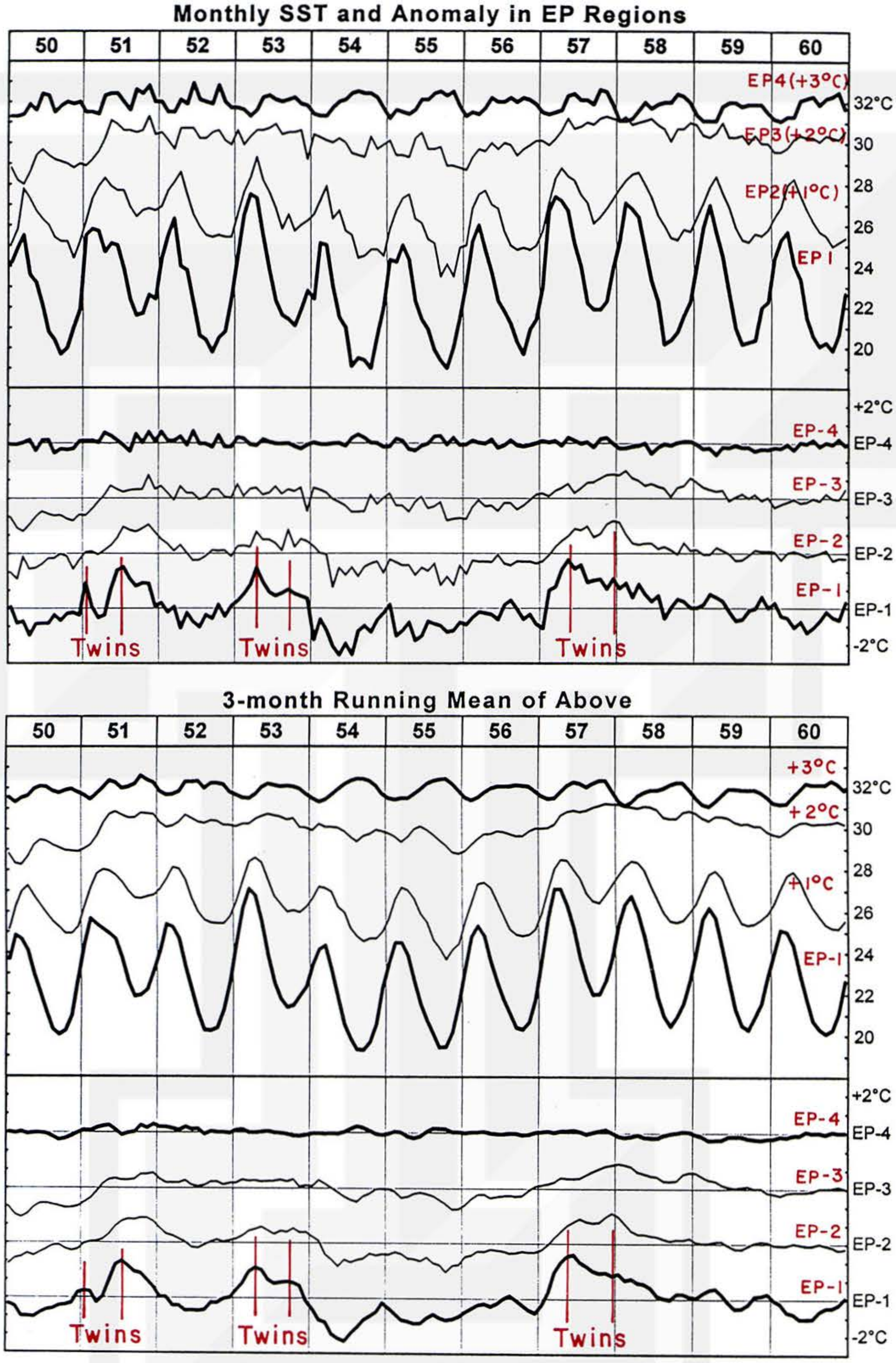


Fig. 2.7 Variation of SST and anomaly in 1950 through 1960. SST at EP locations is shifted 1°C per location to avoid overlaps.

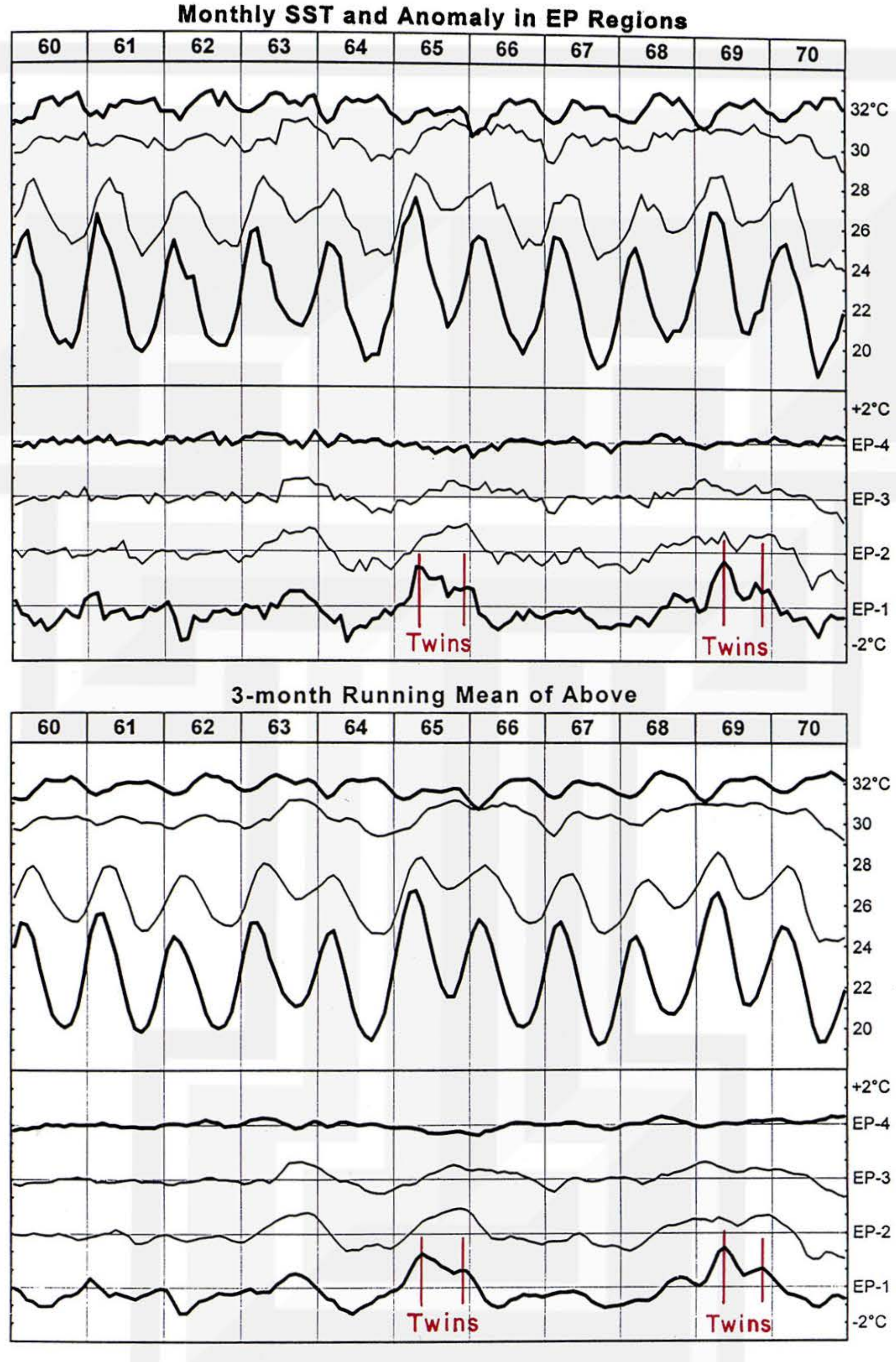


Fig. 2.8 1960 through 1970. More than one SST peak within a one-year period of El Niño are identified as Twins or Triplets.

2. Tropicalization of SST

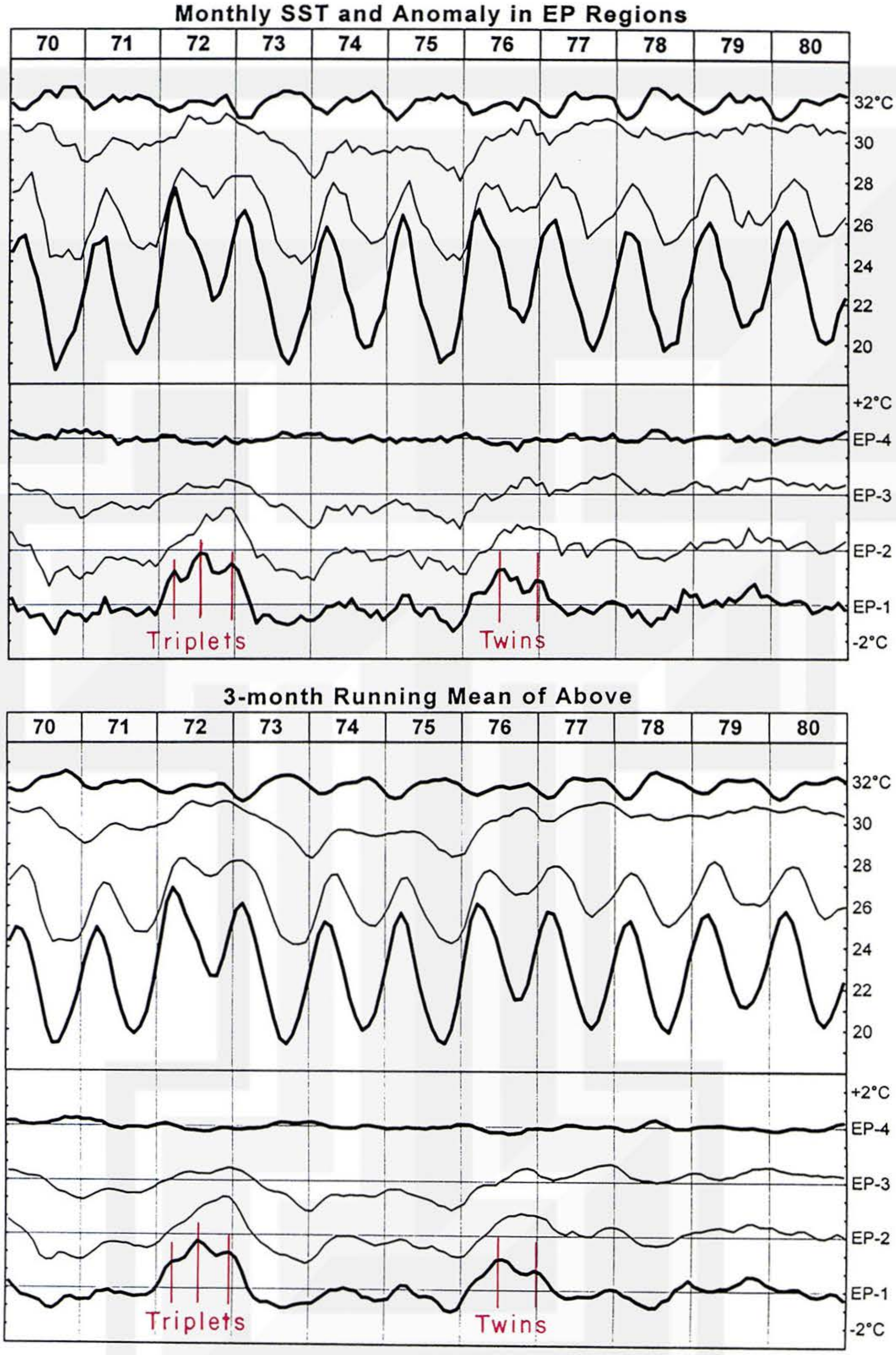


Fig. 2.9 Variation of SST and anomaly in 1970 through 1980. Note the Triplets in the 1972 El Niño.

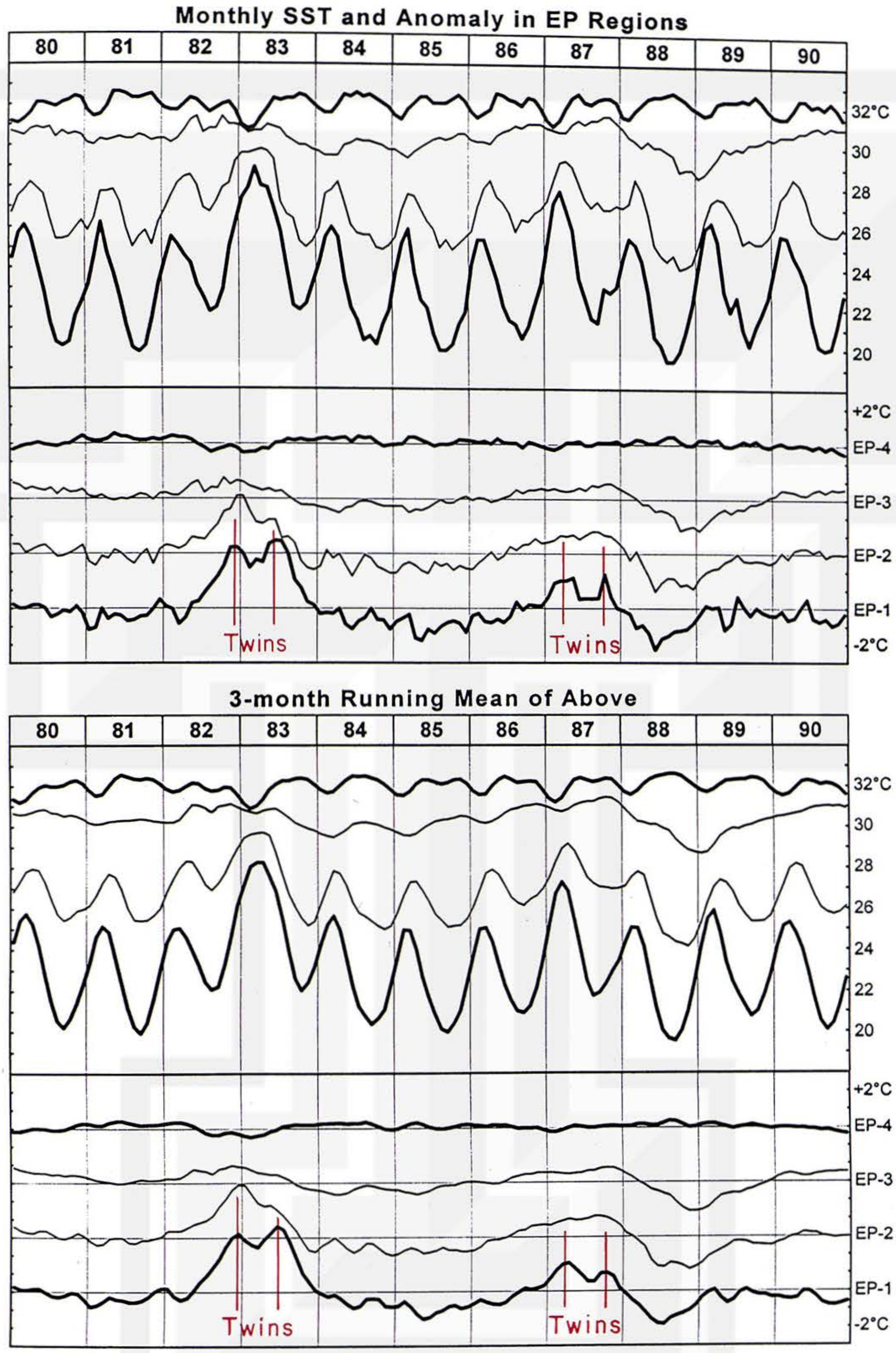


Fig. 2.10 Variation of SST and anomaly in 1980 through 1990.

2. Tropicalization of SST

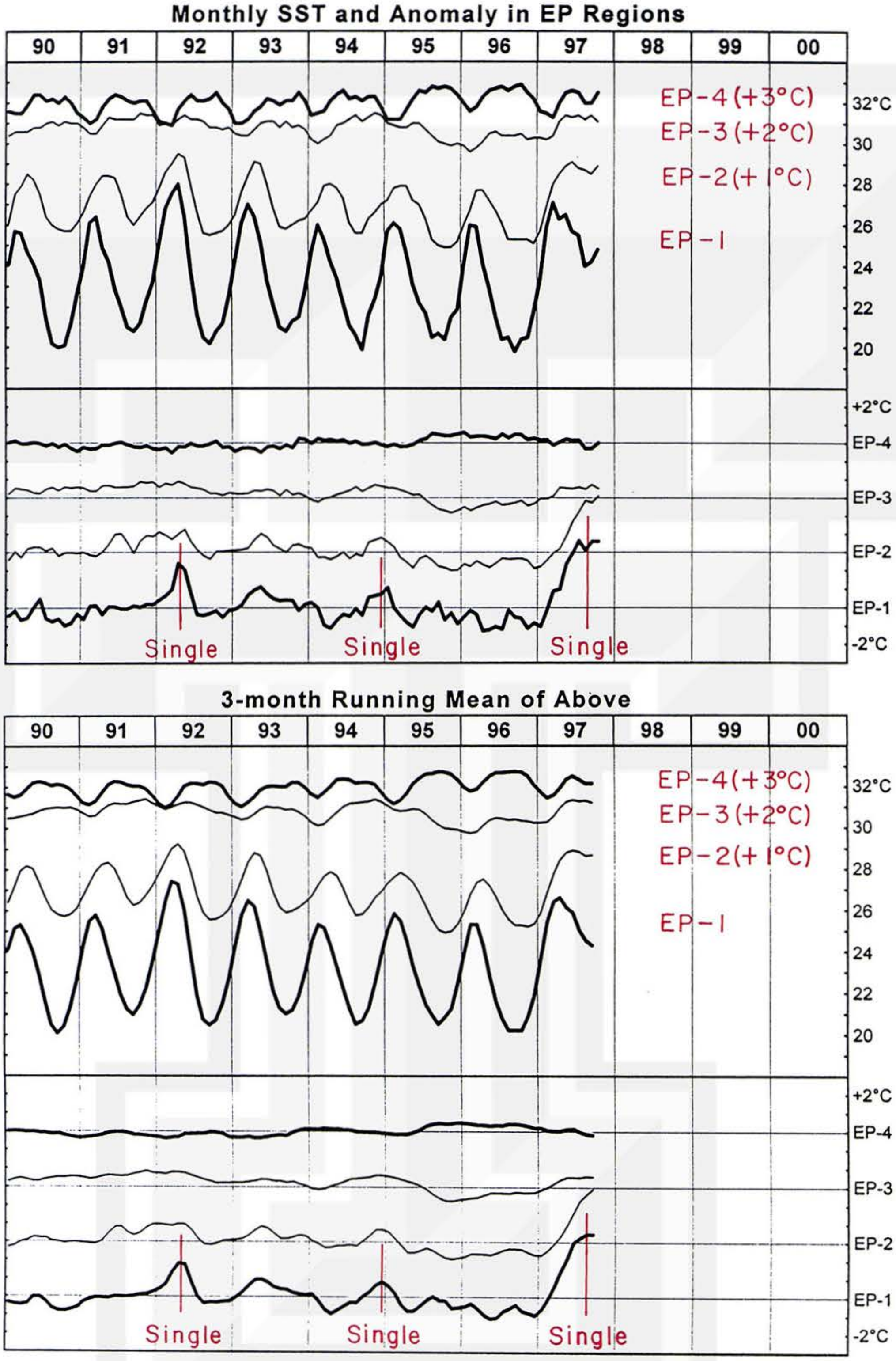


Fig. 2.11 Variation of SST and anomaly in 1990 through OCT 1997.

Incoming solar radiation at the **top of the atmosphere**(TOA) reaches the sea surface after losing 20% by atmospheric absorption and 30% by reflection and scattering back to space by the atmosphere and clouds. Finally the ocean surface reflects the energy to space 5 to 20% (specular reflection at low sun). Less than 50% descends into the ocean warming the thermocline, 50 to 200 m deep, the depth of the upwelling.

The incoming solar radiation at TOA was computed by integrating the radiation from sunrise to sunset at various latitudes. Spherical trigonometry was used in computing the radiation every 15 days.

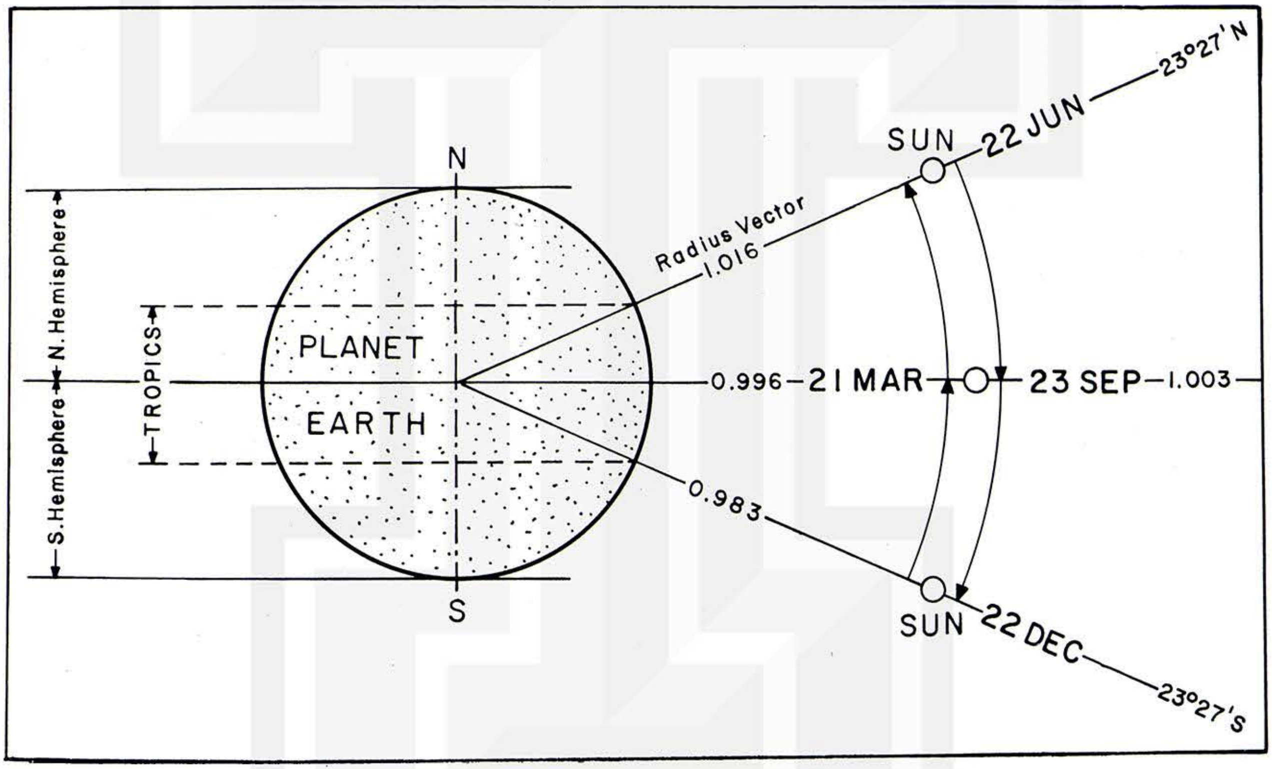


Fig. 2.12 Showing the annual movement of the sun crossing the equator twice a year. In computing the solar radiation at TOA, 1.000 radius vector was assumed.

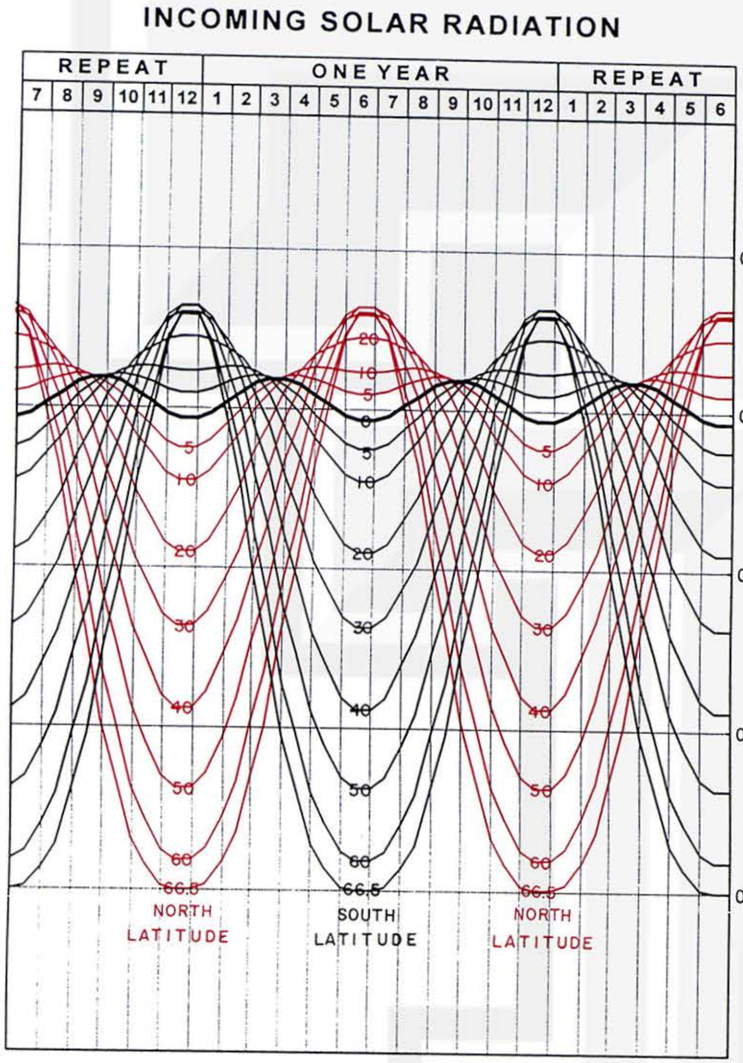


Fig. 2.13 Incoming solar radiation at various latitudes. Black curves denote south latitude and red curves, north latitude.

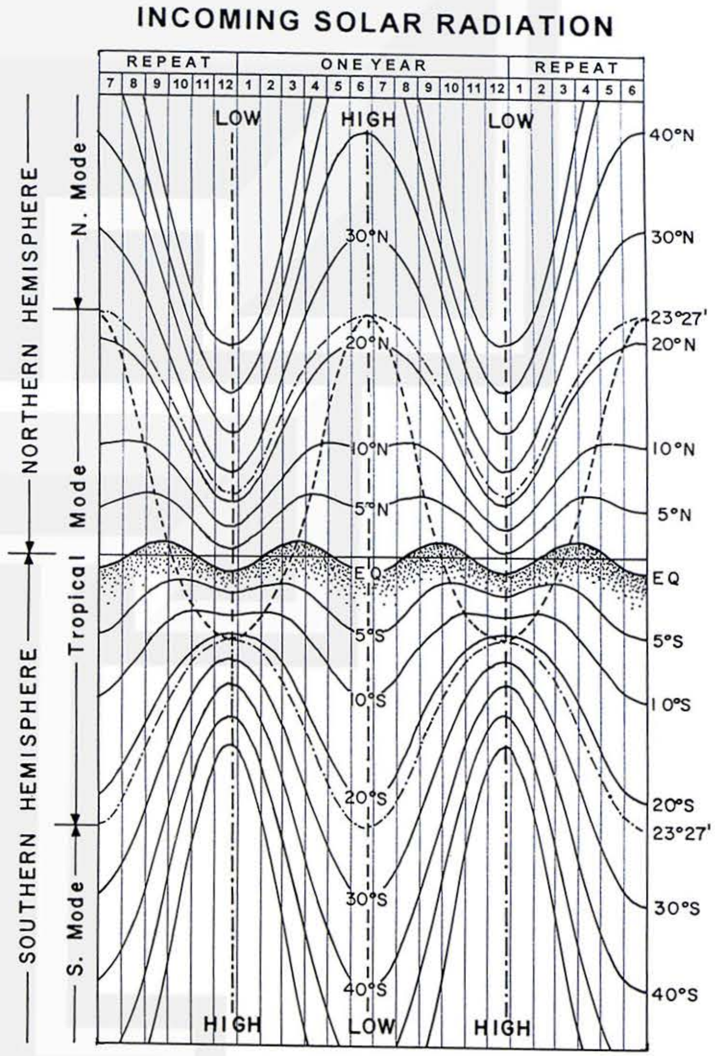
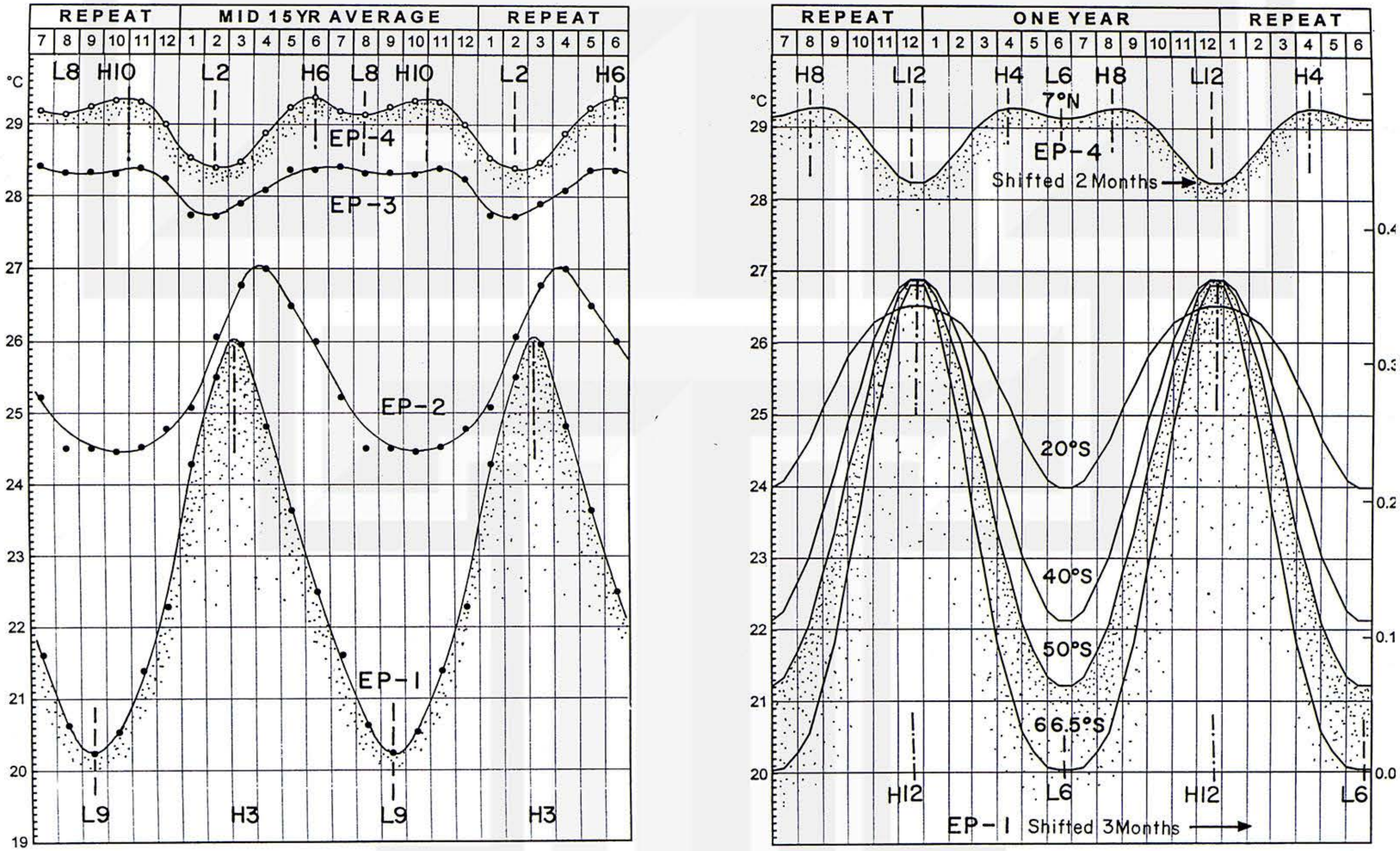
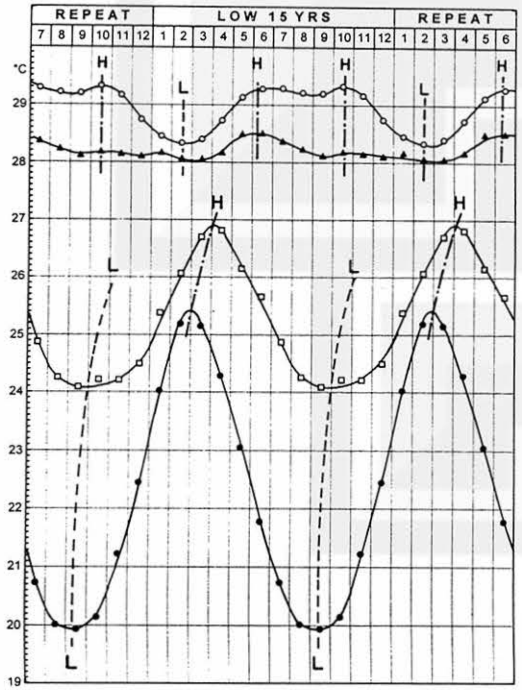
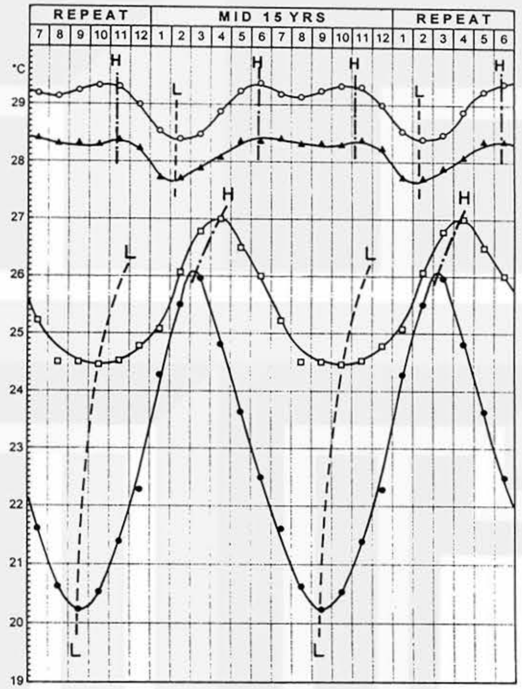


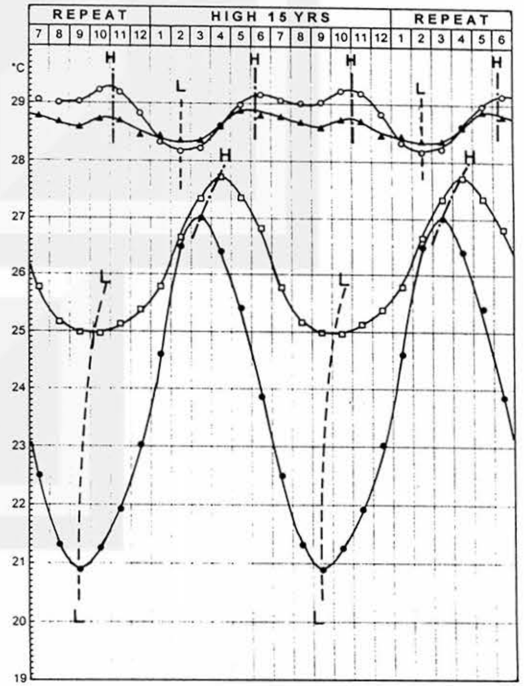
Fig. 2.14 Incoming solar radiation shown by shifting curves upward in avoiding overlaps. The change of SST from the southern mode to the tropical mode is called the tropicalization.



Figs. 2.15(left) and 2.16(right) Mean SST curves of the 15 normal years at EP1, 2, 3, and 4. The amplitude of the EP4 curve in °C was used in converting the radiation unit to the temperature unit used in these figures. With the exception of a 2 to 3 month time lag, the SST curve at EP1 is similar to that of the 50°S radiation. The SST peak in March at EP1 and April at EP2 suggests the westward movement of the peak SST which tropicalized before reaching EP3.







Figs. 2.17(left), 2.18(middle), and 2.19(right) The 45-year period was divided into 15-year periods each of the low, middle, and high SST years. The average SSTs during these sub-periods show that the pattern of the SST variation is not influenced by the low (La Niña), middle (Normal), and high (El Niño) SST at EP1. This evidence proves the change of the SST at EP1, being the primary cause of El Niño and La Niña. In all three cases, the southern mode of SST is tropicalized between EP2 and EP3 while moving westward along the equator.

Chapter Three Distance (x) - Time (t) Diagram

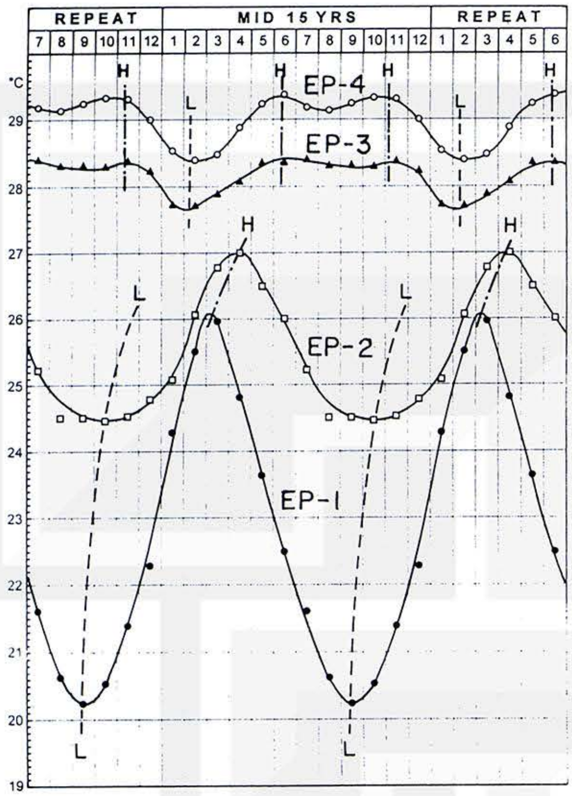
The distance(x) - time(t) diagram is the x-t diagram used in detailed **mesoanalysis** in Mesometeorology. The diagram converts the time sequence of events into a spatial map. As an example, average SSTs at EP1, 2, 3 and 4 during the 15 normal years were converted into an x-t diagram (Figs. 3.1 and 3.2). The axes of both high(ridge) and low(trough) SST reveal the transformation of the southern mode into the tropical mode. In principle, the tangent of the axis represents both direction and speed of the movement of the peak SST.

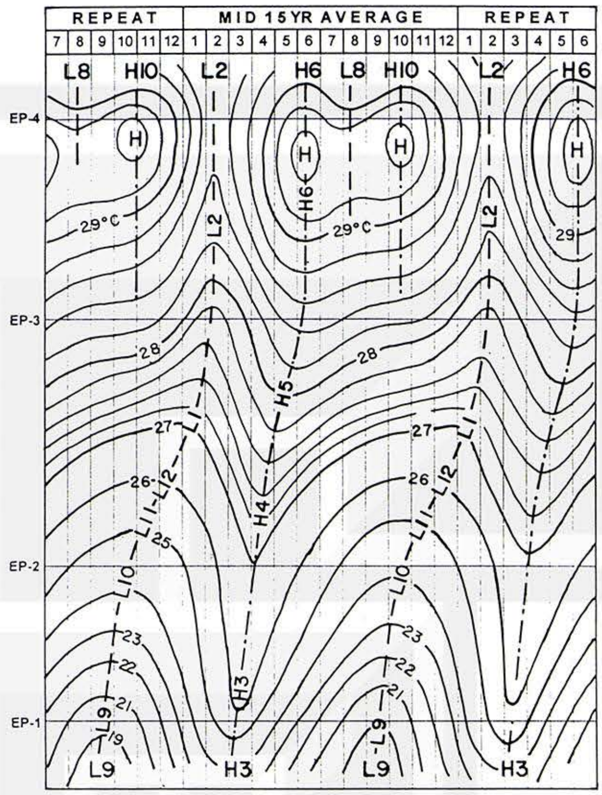
The x-t diagram of the 1988 La Niña reveals the **significant cooling power of the La Niña current** which transports cold SST beyond the EP3 region. La Niña current is wide in time, with a huge rounded bottom trough (Figs. 3.3 and 3.4).

In contrast to the 1988 La Niña case, high temperature ridges of the strong 1982-83 El Niño are very small. The twin El Niño are seen on both sides of the small ridge (Figs. 3.5 and 3.6). Even the 1997 El Niño of the century is characterized by a small, narrow high ridge of SST preceded by a wide, low SST trough (Figs. 3.7 and 3.8). These x-t diagrams give an impression that the negative disturbance(La Niña) is more impressive than its counterpart, El Niño disturbance.

A summary table of PTI, PDI, RTI, and MAD in the 48 years, 1950-1997 at EP1 and EP2 reveals interesting statistical parameters on El Niños (p 31). In particular, the ratio of temperature increase from EP1 to EP2 in top 13 El Niño years are all less than 1°C per month, suggesting that strong El Niños are not contributing much to the increase of the already overheated equatorial SST in the easternmost equatorial Pacific Ocean (Figs. 3.10 and 3.11).

3. Distance (x) - Time (t) Diagram

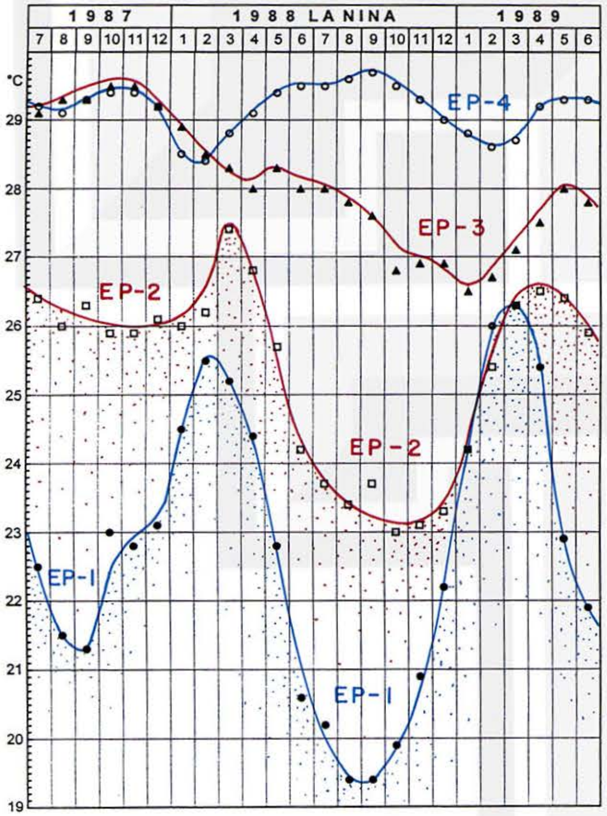




Figs. 3.1(left) and 3.2(right) Variation of SST in Fig. 3.1 reveals the similarity between SST and incoming solar radiation at various latitudes.

Sampling Locations (Reference)	EP1	EP2	EP3	EP4
Sampling latitude (JMA)	EQ to 10°S	4°N to 4°S	4°N to 4°S	EQ to 14°N
Radiation mode (Fig. 2.14)	50°S	25°S	3°N	8°N
Month of high SST (Fig. 3.1)	MAR	APR	JUN & NOV	FEB
Month of low SST (Fig. 3.2)	SEP	OCT	FEB	FEB

This table clarifies the time sequence of the event that the surface water at EP1 from deep south tropicalized while moving westward. Eastward movement of tropical surface water will not accumulate the genuine southern-mode water. Furthermore the direction of the bulk movement must be westward. The x-t diagram shows the tropicalizing process and direction which cannot be reversed (Fig. 3.2).



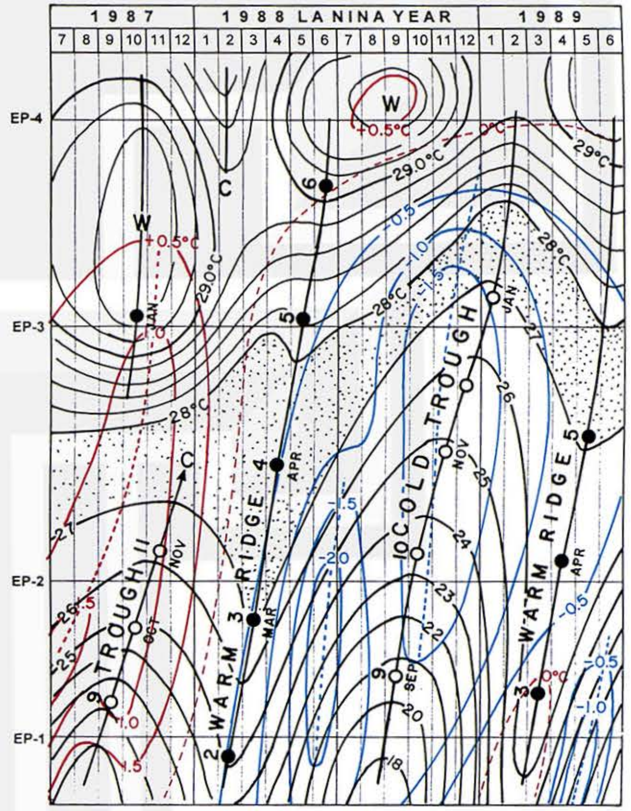
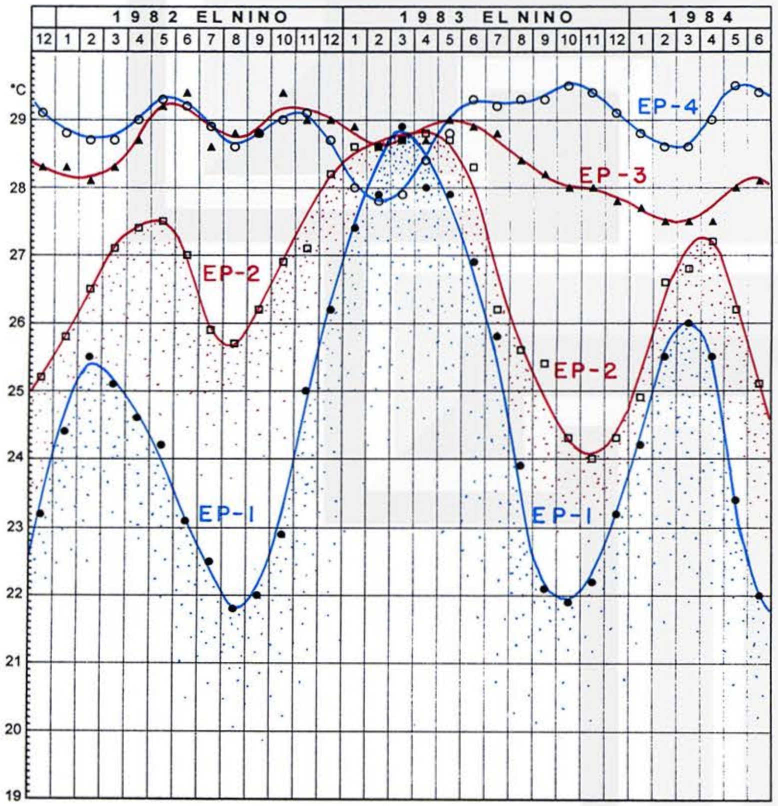
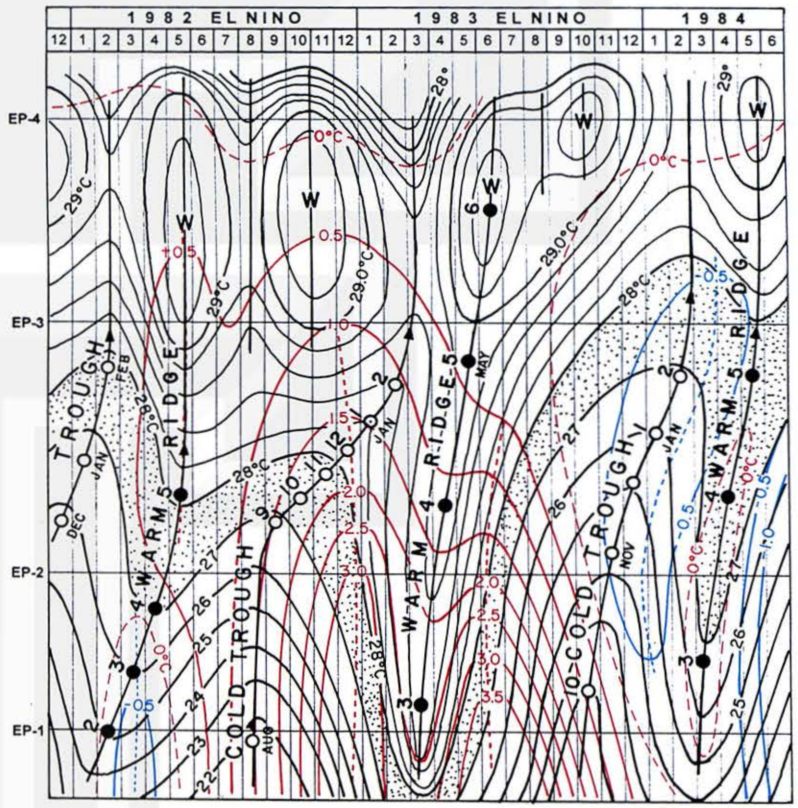


Fig. 3.3(left) and 3.4(right) SST curve and x-t diagram of the 1988 La Niña case reveals the broad trough of the low SST axis. Two ridges of high SST on both sides of the trough are practically dwarfed by the mighty advance of the cold, southern water to EP4. The minimum SST anomaly in 1998 was -2.3°C which is the second lowest in 48 years.

Twin El Niño of 1982-83

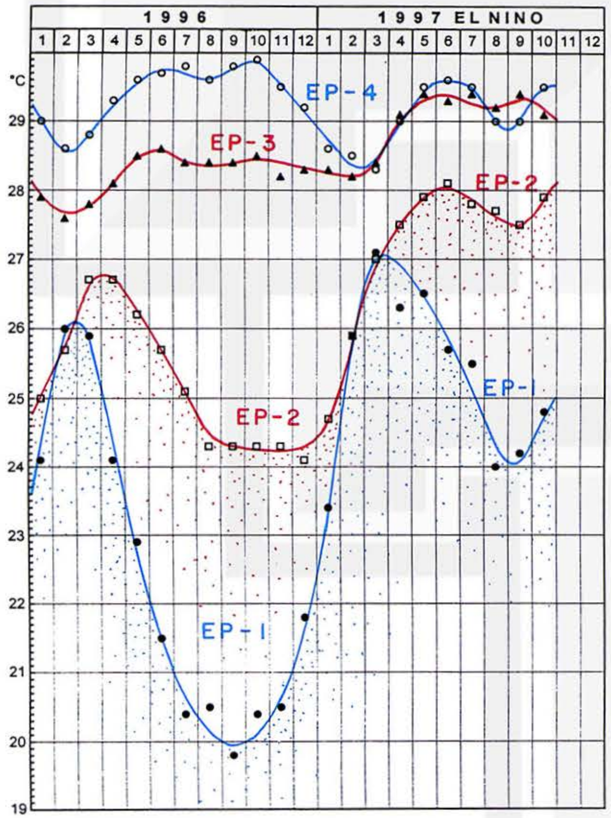


Twin El Niño of 1982-83

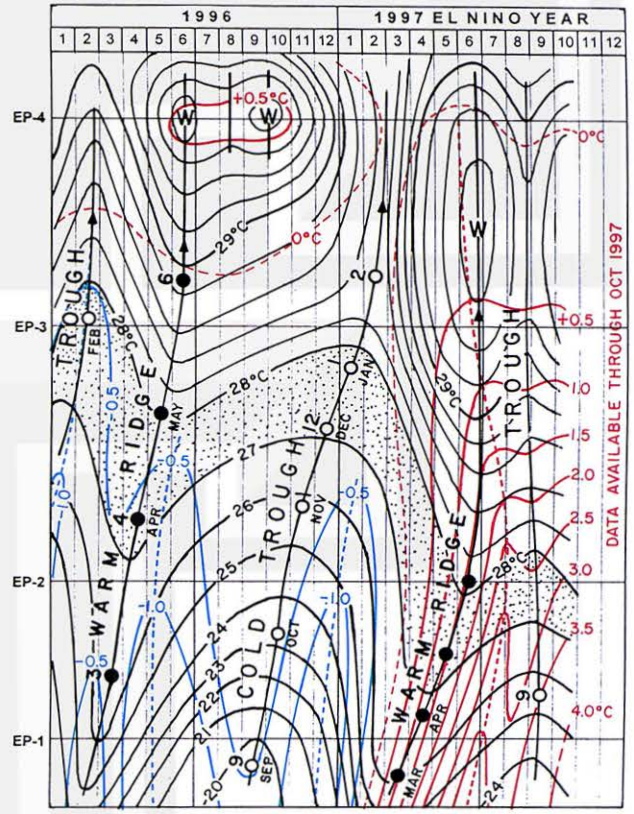


Figs. 3.5(left) and 3.6(right) The twin El Niño of 1982-83 shows a huge single SST peak with the warm SST ridge from March to May 1983. The SST anomaly had two peaks approximately 3 to 4 months before and 2 months after the warm SST ridge. It is very difficult to relate the pattern of SST and SST anomaly of this twin El Niño (one El Niño with twins inside). It should be noted that x-t diagrams are very useful in determining the SST vs SST anomaly relationships.

The Worst El Niño in the Century



The Worst El Niño in the Century



Figs. 3.7(left) and 3.8(right) The 1997 El Niño is rated as the worst in the century. The large positive anomaly is seen in the area of the warm SST ridge. The EP1 SST in August was 24°C, the warmest winter SST in 48 years, 1950-97 (Fig. 5.7) suggesting that either “Twins” or “Triplets” anomaly may appear. It should be noted that both EP1 and EP2 showed La Niña (negative) anomaly until February 1996, which is quite different from the twin El Niño of 1982-83 (p 28). Analysis with x-t diagram clearly reveals the difference.

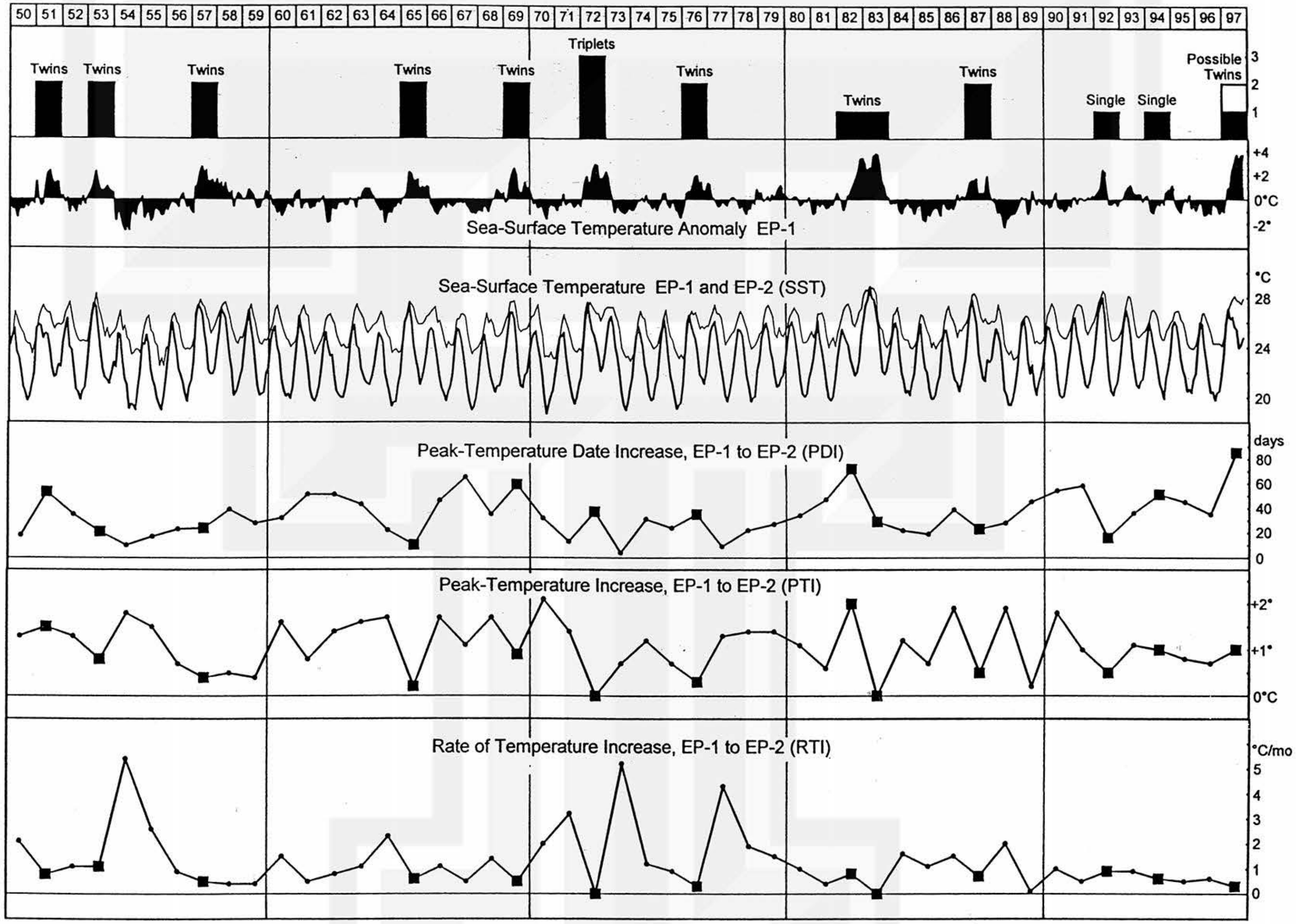


Fig. 3.9 A summary of El Niño and La Niña in 48 years. There were two singles, eight twins and one triplet. After examining all parameters in the Table (p 31) the Rate of Temperature Increase(RTI) turned out to be the best indication of all El Niños in the 48 years.

3. Distance (x) - Time (t) Diagram

	Peak SST			Date of Peak SST				
Year	EP 2	EP 1	P T I	EP 2	EP 1	P D I	R T I	M A D
1950	26.8	25.5	1.3	3-23	3-5	18	2.1	-0.8
51	27.3	25.8	1.5	4-15	2-22	53	0.8	2.3
52	27.6	26.3	1.3	4-10	3-5	35	1.1	-1.1
53	28.3	27.5	0.8	4-14	3-23	21	1.1	2.2
54	26.9	25.1	1.8	3-7	2-27	10	5.4	-2.5
1955	26.5	25.0	1.5	4-3	3-16	17	2.6	-1.7
56	26.7	26.0	0.7	4-5	3-12	23	0.9	0.4
57	27.8	27.4	0.4	4-16	3-22	24	0.5	2.7
58	27.6	27.1	0.5	4-3	2-24	39	0.4	1.3
59	27.4	27.0	0.4	4-11	3-13	28	0.4	-0.7
1960	27.3	25.7	1.6	4-7	3-5	32	1.5	-1.3
61	27.3	26.5	0.8	4-11	2-20	51	0.5	0.7
62	26.6	25.2	1.4	4-5	2-14	51	0.8	-1.9
63	27.4	25.8	1.6	4-15	3-2	43	1.1	0.8
64	26.8	25.1	1.7	3-16	2-24	22	2.3	-1.9
1965	27.6	27.4	0.2	4-23	4-13	10	0.6	2.1
66	27.2	25.5	1.7	4-3	2-17	46	1.1	-1.3
67	26.6	25.5	1.1	5-1	2-26	65	0.5	-1.2
68	26.7	25.0	1.7	4-15	3-10	35	1.4	0.7
69	27.7	26.8	0.9	5-2	3-3	59	0.5	2.5
1970	27.4	25.3	2.1	4-5	3-3	32	2.0	-1.6
71	26.6	25.2	1.4	4-16	4-3	13	3.2	-0.6
72	27.6	27.6	0.0	4-20	3-13	37	0.0	2.8
73	27.2	26.5	0.7	2-15	2-11	4	5.2	-1.1
74	26.9	25.7	1.2	4-17	3-16	31	1.2	-0.8
1975	27.0	26.3	0.7	4-10	3-16	24	0.9	-0.5
76	26.9	26.6	0.3	4-18	3-13	35	0.3	1.9
77	27.4	26.1	1.3	3-14	3-5	9	4.3	-0.6
78	26.9	25.5	1.4	3-18	2-26	22	1.9	-1.2
79	27.4	26.0	1.4	4-10	3-13	27	1.5	1.1
1980	27.2	26.1	1.1	4-16	3-12	34	1.0	-0.5
81	26.8	26.2	0.6	5-3	3-16	47	0.4	-0.7
82	27.5	25.5	2.0	5-3	2-21	72	0.8	3.4
83	28.9	28.9	0.0	4-15	3-16	29	0.0	3.7
84	27.2	26.0	1.2	4-7	3-15	22	1.6	-1.1
1985	26.6	25.9	0.7	3-24	3-5	19	1.1	-1.8
86	27.3	25.4	1.9	4-10	3-1	39	1.5	-0.8
87	28.3	27.8	0.5	4-5	3-12	23	0.7	1.7
88	27.4	25.5	1.9	3-20	2-22	28	2.0	-2.3
89	26.5	26.3	0.2	4-20	3-5	45	0.1	-1.2
1990	27.5	25.7	1.8	4-20	2-26	54	1.0	-0.9
91	27.4	26.4	1.0	5-1	3-3	58	0.5	-0.4
92	28.5	28.0	0.5	4-21	4-5	16	0.9	2.1
93	28.1	27.0	1.1	4-24	3-18	36	0.9	1.1
94	27.0	26.0	1.0	4-10	2-19	51	0.6	-1.1
1995	26.9	26.1	0.8	4-1	2-16	45	0.5	1.1
96	26.7	26.0	0.7	4-1	2-26	35	0.6	-0.1
97	28.1	27.1	1.0	6-12	3-17	85	0.3	3.6

Table of parameters in 48 years, 1950-97.

P T I .... Peak-Temperature Increase, (EP2 - EP1)°C

P D I .... Peak-Date Increase, (from EP1 to EP2) days

R T I. ... Rate of Temperature Increase (C°/month)

MAD... Maximum Anomaly Deviation (°C)

3. Distance (x) - Time (t) Diagram

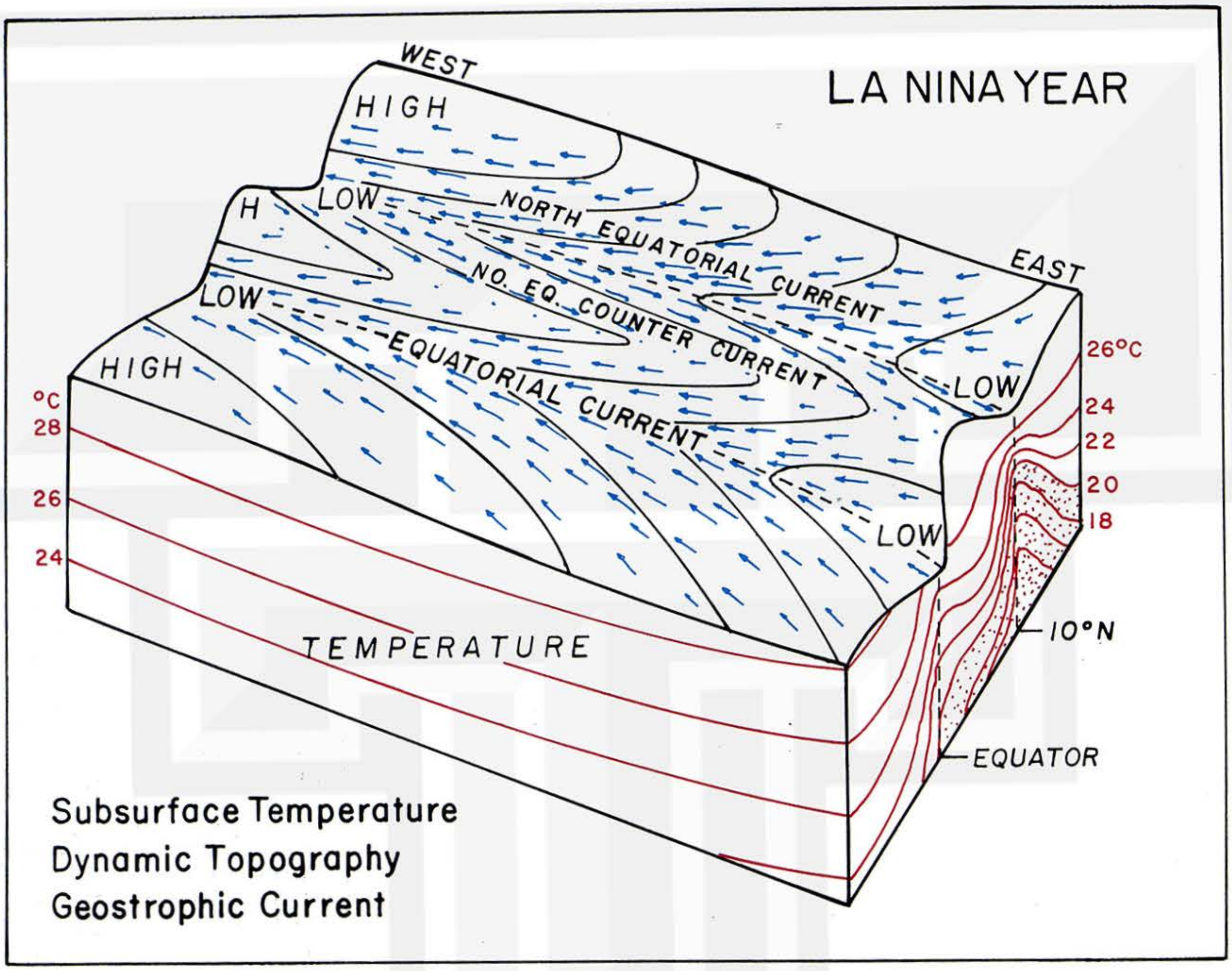


Fig. 3.10 The ocean surface is not flat. The height varies with time and location. However, the ocean surface topped by the atmosphere with 1/1000th density of the ocean is like the 200mb surface (not level) of the atmosphere. The airflow and current at 200mb surface and ocean surface, respectively, are regarded as **geostrophic**. Meanwhile, the height of these surfaces is determined by the density of air or water below these upper boundaries.

During La Niña years, cold Peru Current lowers the sea-level height, resulting in the trough of so-called dynamic topography. Due to the reversal of coriolis force at the equator, the opposite height gradient on both sides of the equator produces the strong westward current called **Equatorial Current**.

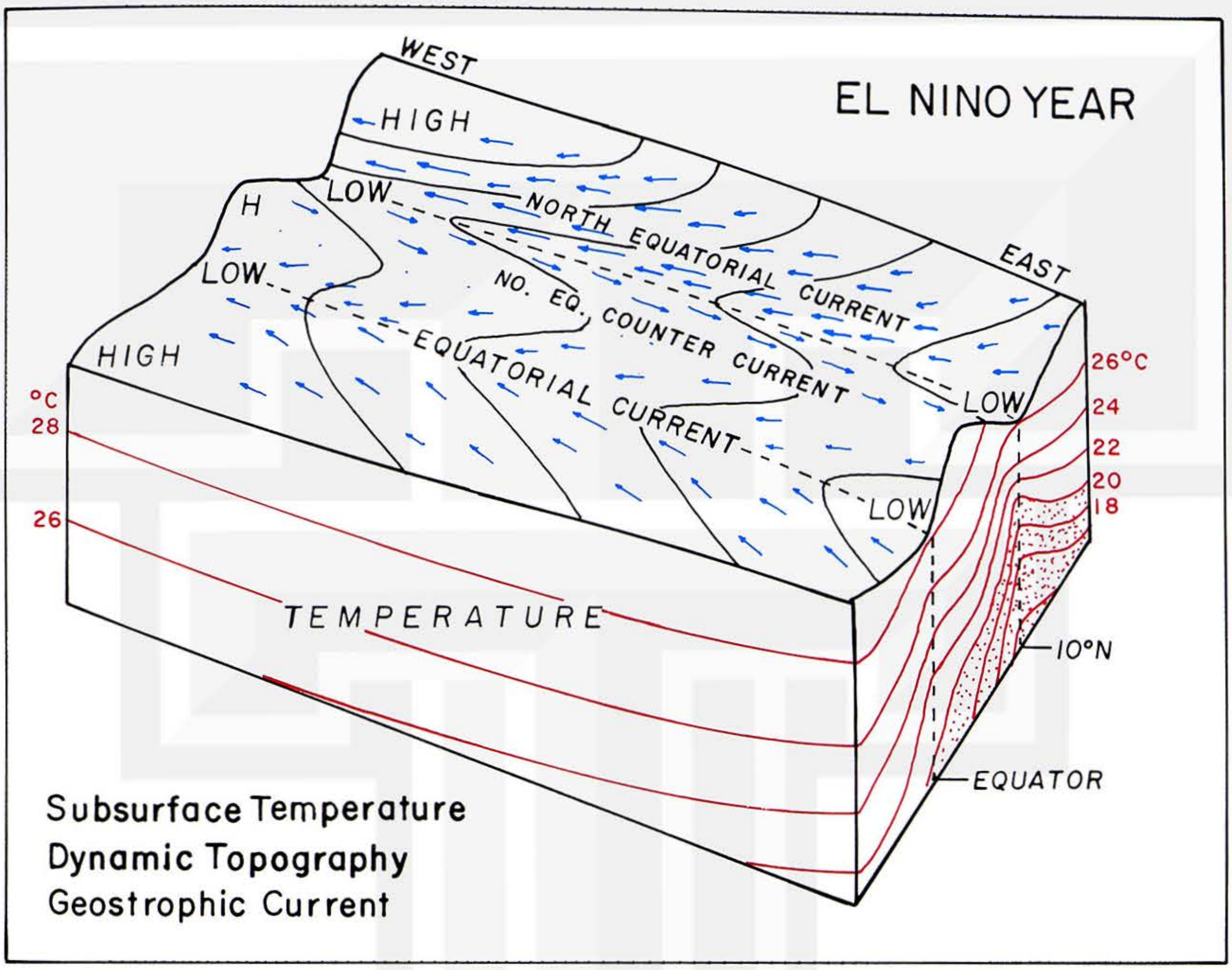


Fig. 3.11 Warming of Peru Current in El Niño year results in the warming of the cold-to-be Peru Current. The sea surface (not level) rises and height gradient decreases. Low dynamic topography along the equator does not change from low to high because the thickness between the ocean surface and the 100 dbar (decibar) is not large enough to reverse the east-west height gradient. At least a 12°C super warming may be required for reversing the east-west gradient (Fig. 1.3).

It should be noted that Equatorial Current is not just a wind-driven current. The reversal of coriolis force and sub-surface cooling are playing the important role.

3. Distance (x) - Time (t) Diagram

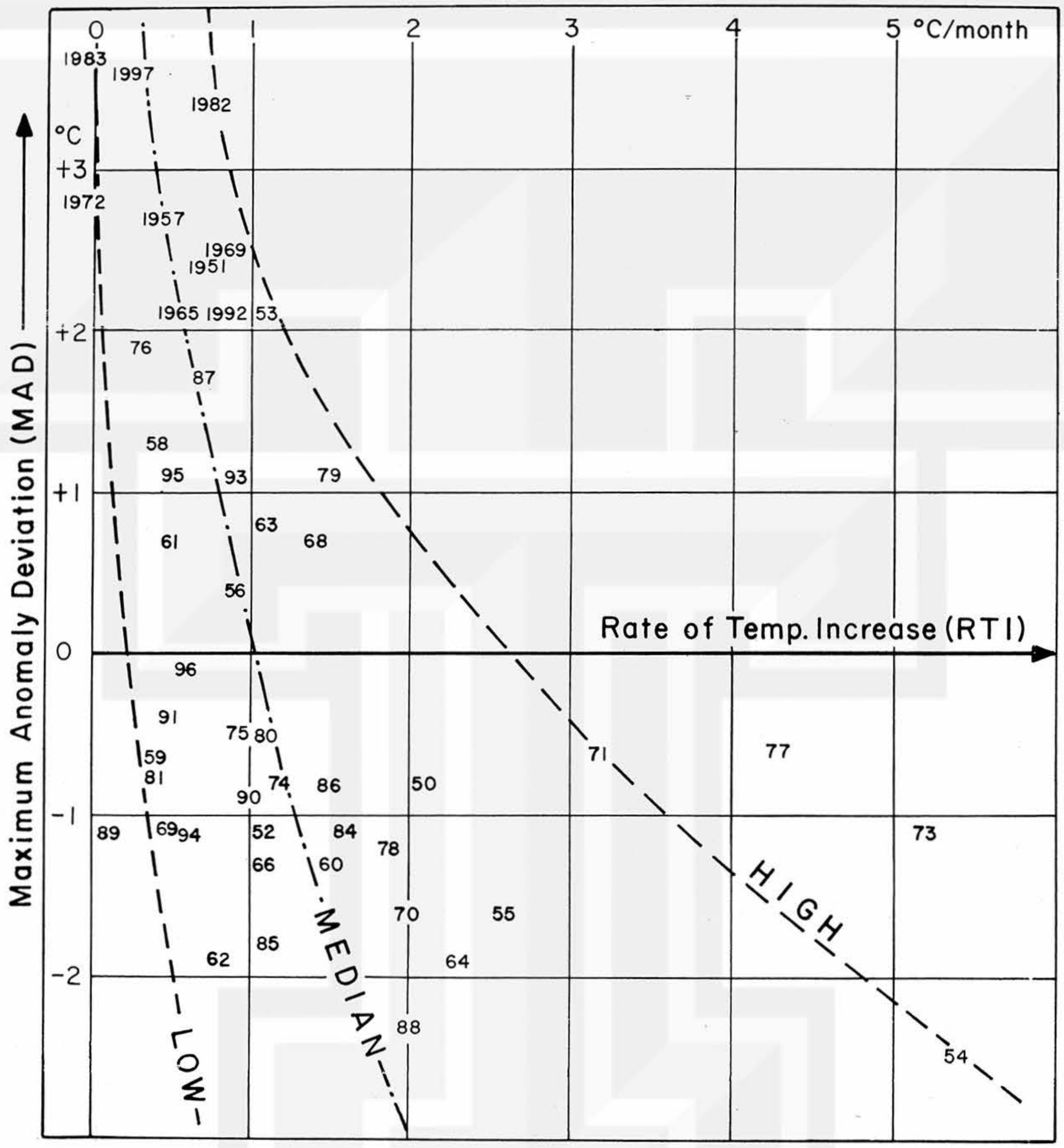


Fig. 3.12 Year of Maximum Anomaly Deviation(MAD) plotted on the MAD - RTI coordinates. RTIs of the 9 El Niños in the 48 years during 1950-97 are all less than 1.0°C/month. The SST of these El Niños does not increase much while current probably moved slowly from EP1 to EP2.

Chapter Four   Hurricane and El Niño

It should be noted that no tropical storm ever formed inside the 15-degree wide zone I call the **Intertropical Irrotational Zone**. It is due to the near zero coriolis parameter required to initiate the rotation of storms. West Pacific typhoons with a top PPC of 92 are the most extensive in the world. However, the East Pacific hurricanes have the highest PPC of 113, the highest density in the world (Fig 4.1).

No storm has been reported from South Atlantic Ocean and South Pacific Ocean east of 130°W longitude, which are half-circled by the **Branch Off Current (BOC)** of the Antarctic Circumpolar Current. Unexpectedly, hurricanes around the world are influenced by El Niño far more than we had expected; 42% decrease occurred at Puerto Rico while there were large increases at various locations: 52% at Guam, 70% at Tahiti, and 100% increase at Kwajalein in the equatorial Pacific.

On the contrary, a low percent band extends 14,000 km from south of Hawaii toward the west coast of Africa. Since incipient hurricanes do not develop under strong wind shear, the band appears to be the combined areas of tropical jets induced by El Niño (Figs. 4.2, 4.3, and 4.4).

x-t diagrams of the SST difference, 1997 minus 1996 along the Peru Current increased from +1.8°C(JAN) to +5.5°C(JUL) preceding the 1997 El Niño. Along the Benguela Current the difference decreased from -1.3°C(JAN) to -3.5°C(APR), resulting in the cold Atlantic while the 1997 El Niño was in progress. The percent change of hurricanes in South Indian Ocean and Tasman Sea suggests a possible cooling of BOC 3 and 4 along with BOC 2, while Peru Current (BOC 1) was very warm. Interaction of these four BOCs should be studied under international cooperation.

Paths of Hurricanes Around the World During the 45-year Period, 1951-95

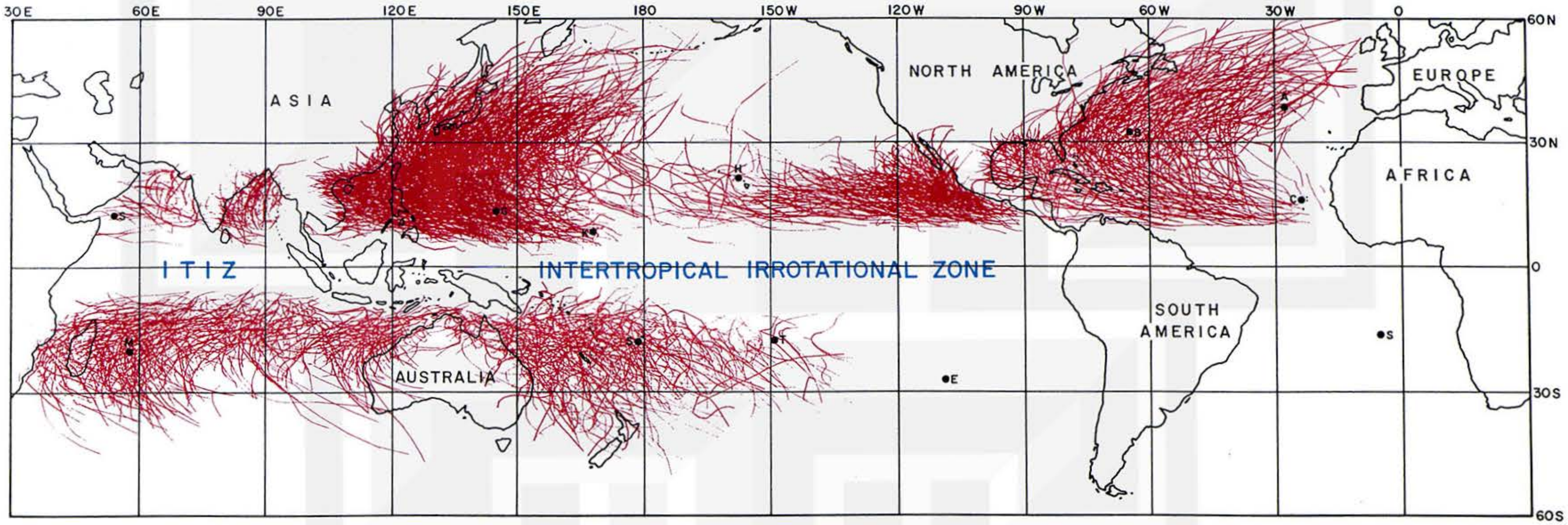


Fig. 4.1 Hurricanes around the world. Thin lines are the paths of tropical storms with sustained windspeeds, 35 to 64 kts and heavy lines, those with 65 kts or faster. Heavy damage in hurricane winds is caused by the peak gust, rather than sustained winds. The Fujita Tornado Scale(F-scale) can be used in assessing the damaging wind in hurricanes. Table on the right shows the F-scale windspeeds and periods of the fastest ¼ mile gust.

F-Scale	Kts	m/s	mph	Gust Period
0.0	35-49	17-25	40-57	19 (sec)
0.5	50-63	26-31	58-42	14
1.0	64-82	32-41	73-94	11
1.5	83-97	42-49	95-112	9
2.0	98-119	50-61	113-137	7
2.5	120-136	62-69	138-157	6
3.0	137-160	70-82	158-185	5
3.5	161-179	83-91	186-206	4
4.0	180-206	92-105	207-237	4
4.5	207-226	106-115	238-260	3
5.0	227-254	116-130	261-293	3
5.5	255-276	131-141	294-318	3
6.0	277-329	142-170	319-380	2

Percent Change of Hurricanes in the Top 10 El Niño Years During the Same 45-year Period

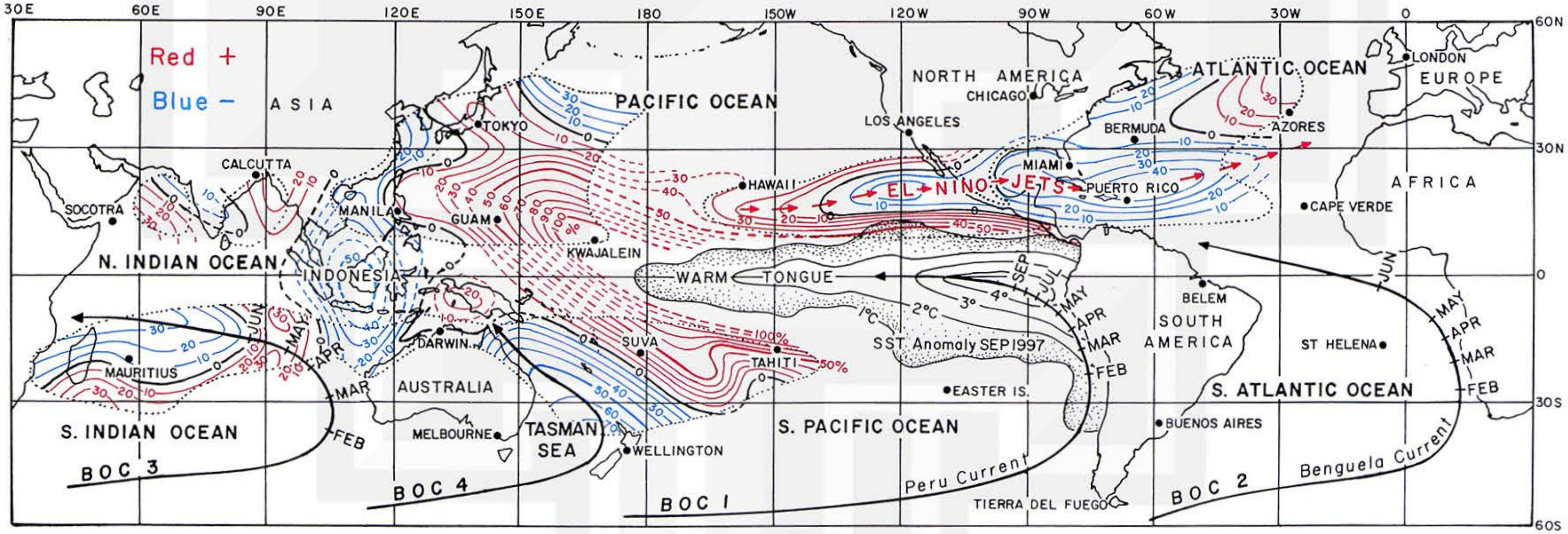


Fig. 4.2 Percent change (+ in red and - in blue) of hurricanes due to El Niño turned out to be much larger than anticipated. The percent change was computed by the simple formula,

$$\frac{E - \frac{1}{2}(E + L)}{\frac{1}{2}(E + L)} = \frac{E - L}{E + L}$$

where E and L are the Prorated Position Counts(PPC) in El Niño and La Niña years respectively, per 1° equatorial square per 100 years. PPC is the number of 6-hourly storm positions within any area on the earth prorated to 100 years per 1° (111 km) square area. Top 10 El Niño years and top 10 La Niña years were used in computing PPCs at about 500 grid points. Both E and L can be applied to other parameters such as tornado frequency, rainfall amount, snow cover, drought index, and many others.

Percent Change of Typhoons in the Eastern Hemisphere

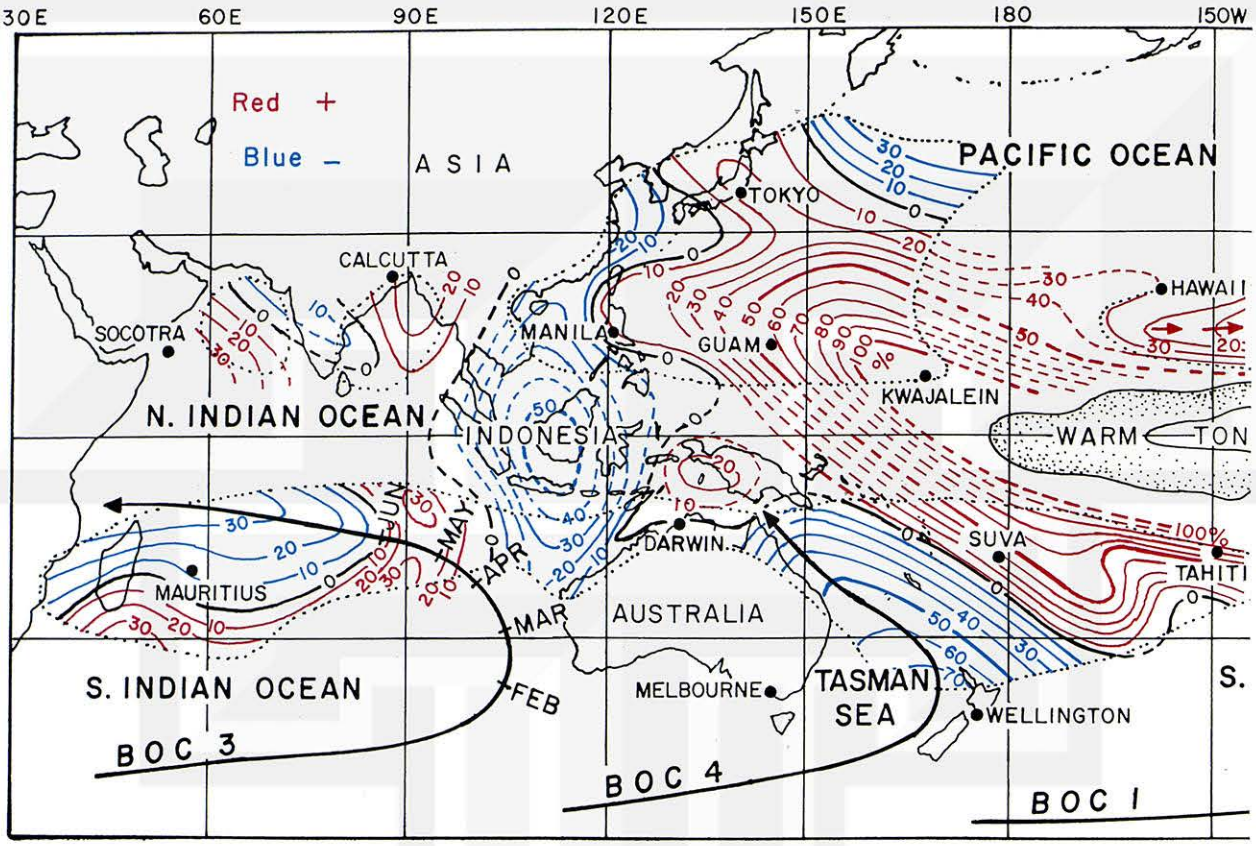


Fig. 4.3 In December 1997, a tropical storm was borne near Hawaii. The storm developed into hurricane Paka and moved west. Upon crossing the date line, the storm turned into typhoon Paka. On 17 December the eye moved west passing north of Anderson AFB in Guam where the record high, 236 mph (105.5 m/s) gust (F4.5) was measured. The rare storm was borne at the +50% area and moved through the up to 100% area and hit Guam in the +52% area.

Apparently, the percent change in Indonesia area is very low, suggesting suppressed convection and drought. Percent change is also low in Tasman Sea and South Indian Ocean, affected by BOC 3 and BOC 4. Why are they colder in El Niño years?

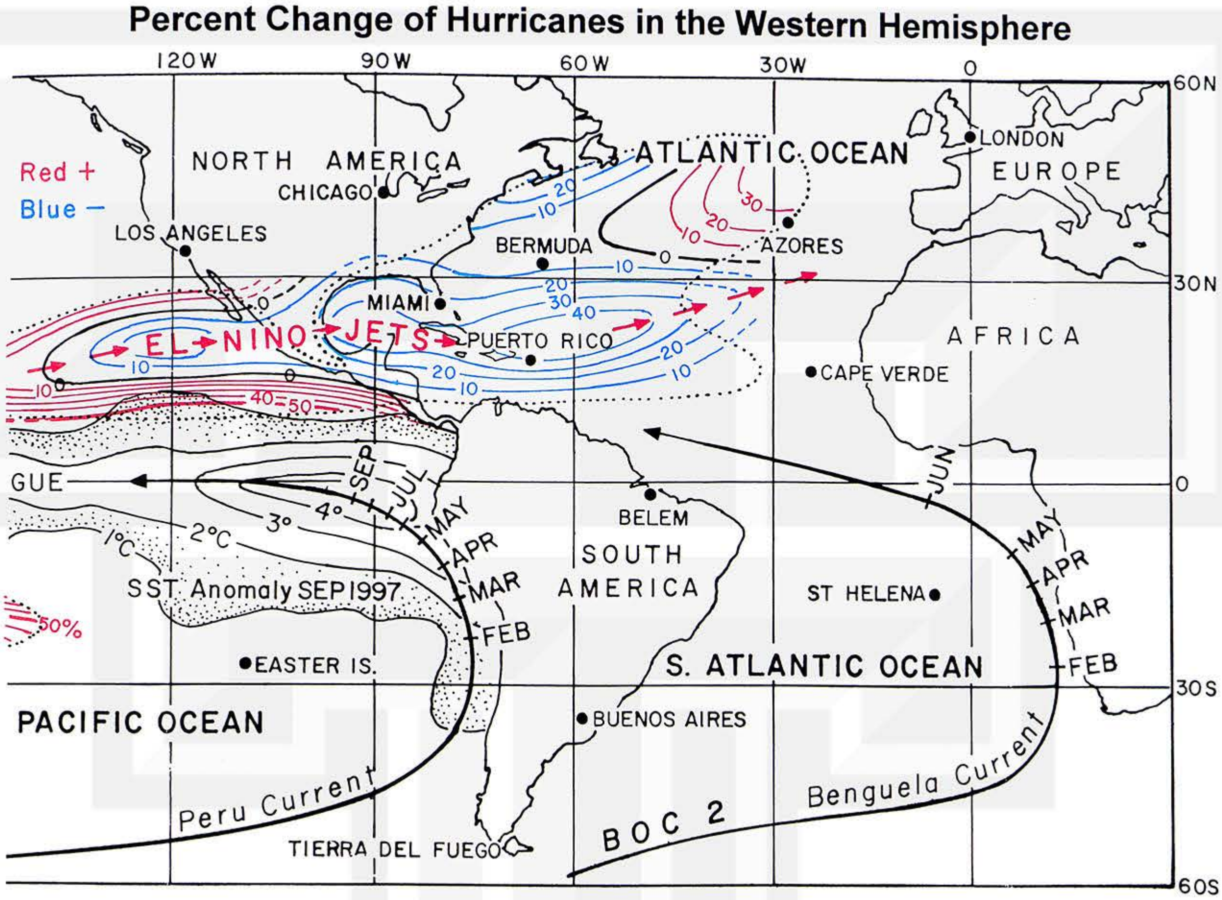


Fig. 4.4 In the Western Hemisphere, the percent change of hurricanes in El Niño years are mostly negative. Since incipient hurricanes do not develop beneath jet stream due to excessive vertical windshear, storms could be suppressed by the jet stream or jet streak which forms on the north side of the warm, equatorial sea surface.

Another unconfirmed evidence is the interaction of BOC 1 and BOC 2. In 1997, a weak La Niña was in the Atlantic while strong El Niño was in progress in the Pacific. The fast movement of the SST peak from FEB to JUN in the Atlantic and the slower movement during the same months in the Pacific could be the important clue in solving the interaction of BOC 1 and 2.

Chapter Five Cause of Global El Niño

Now, the **chicken and egg relationship** went beyond my passing interest, because the probability of a chicken laying an egg in 24 hours is much higher than that of an egg turning into an egg-laying bird within 24 days.

Anomaly of surface winds in the tropics may imply the eastward movement of warm surface water (Fig. 5.1). However, the surface water must be driven by ocean-relative winds, not by anomaly winds (Fig 5.2). Drift vectors of buoys are inconclusive in believing the eastward movement of the surface water prior to and during the development stage of the 1997 El Niño (Fig 5.3). Now, I wonder which is the chicken.

In 1997, the **E-W difference** off the coast of Peru increased from -12°C to -7°C due to the 1997 El Niño. Now, my interpretation of El Niño is less cooling and that of La Niña, more cooling. Namely, the simple expressions are **EL Niño = less cooling** and **La Niña = more cooling** which could occur in global scale. Since it is rather hard to explain both warming and cooling by the pressure difference of Darwin and Tahiti we have to look for something else. Note that the pressure difference alone is not able to transport both warm or cold water in generating El Niño or La Niña.

Analysis of the anticyclones by month revealed the weakening of the Pacific anticyclone prior to and during the 1997 El Niño (Fig 5.5). Then a simple equation was developed to compute the El Niño/La Niña anomalies from the central pressure of the anticyclone (Fig. 5.6).

Finally, the relationship between the Branch-Off Currents(BOCs) and the PPC pattern of hurricanes around the world was established, concluding that both hurricanes and El Niños are global phenomena to be investigated together with the variation of the **General Circulation of the Ocean and Atmosphere** (Fig. 5.7).

Monthly Anomaly of Surface Winds

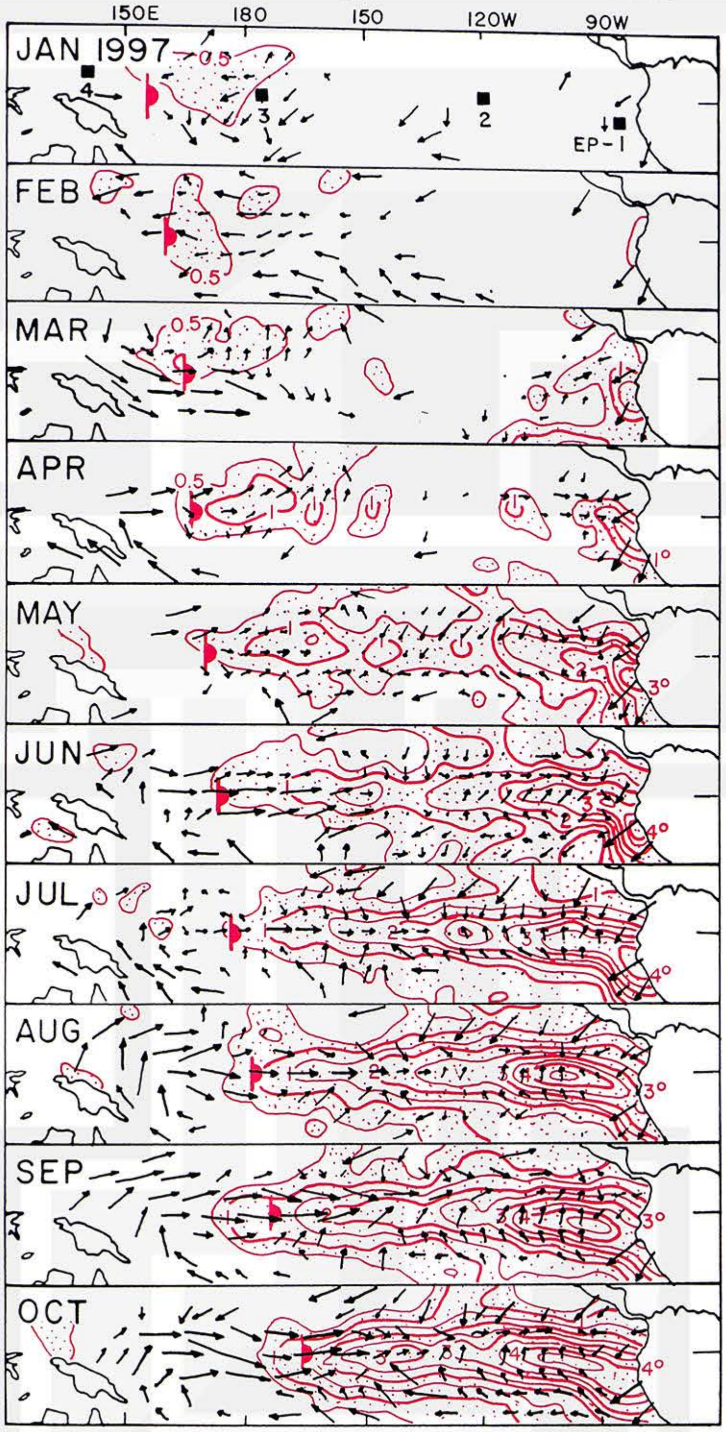


Fig. 5.1 Anomaly winds and SST anomaly in relation to the eastward movement of the oceanic warm front moving eastward. Basic data from JMA.

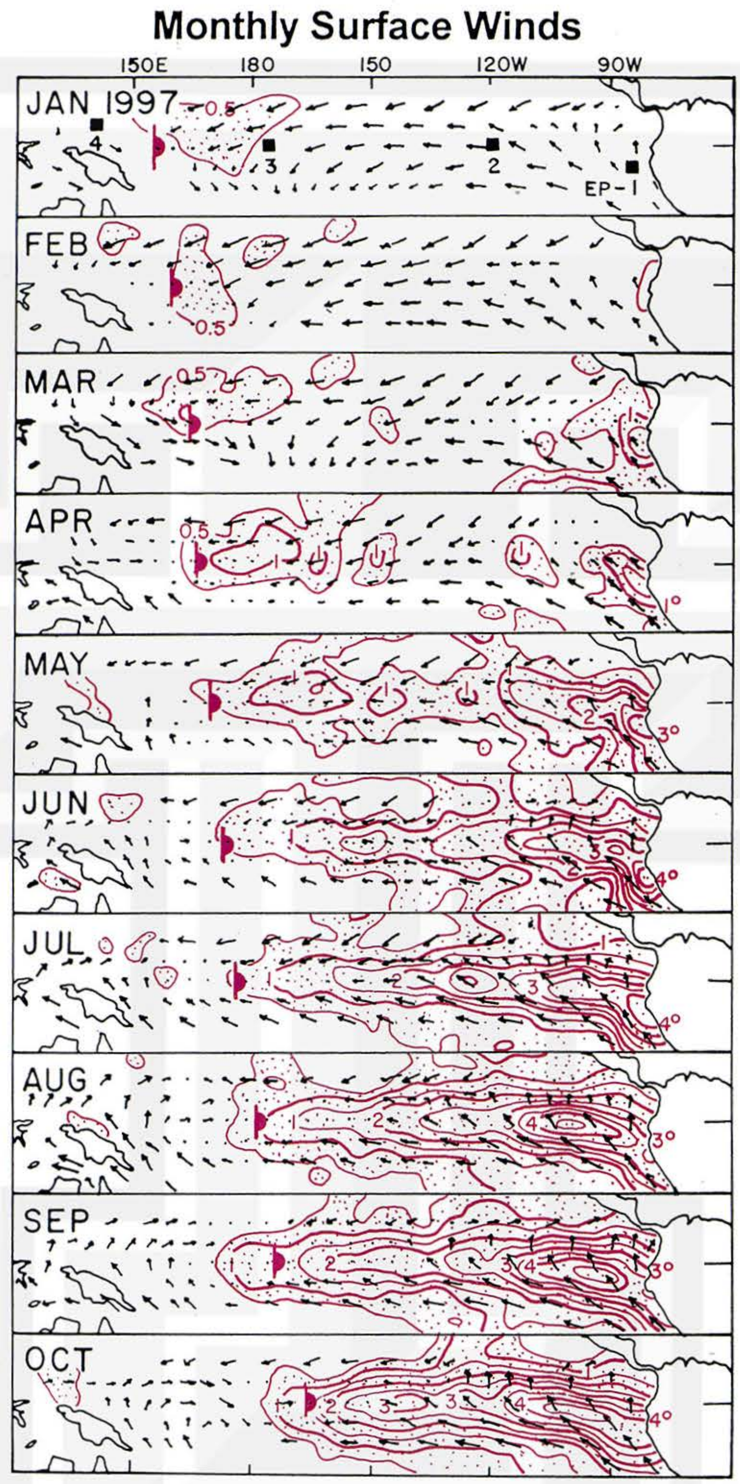


Fig. 5.2 Surface winds and oceanic warm front. No wind is blowing eastward across the warm front. However, the front and wind should be unrelated. Basic data from JMA.

Drift Vectors of Bouys by Month

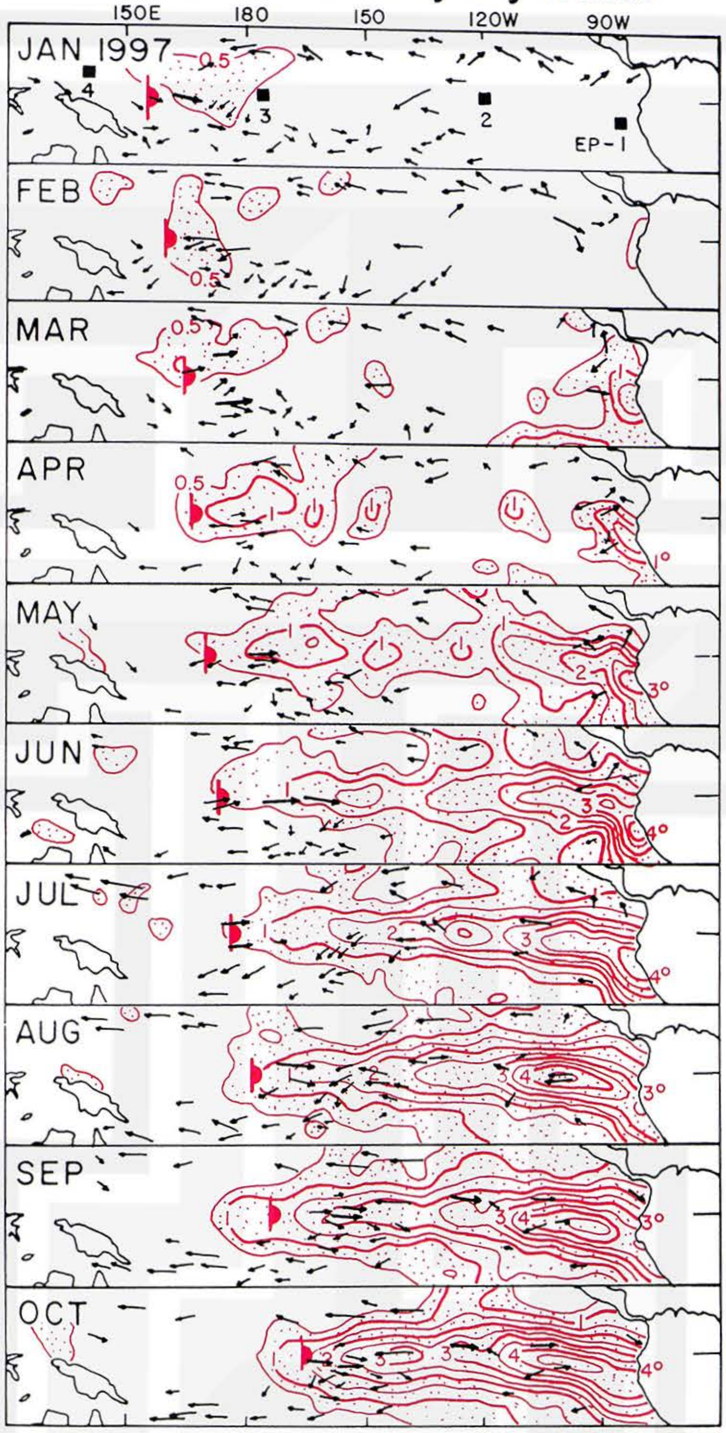


Fig. 5.3 Some buoys on the eastside of the front are drifting eastward. Front is moving eastward at 4 to 24 cm/sec. Basic data from JMA.

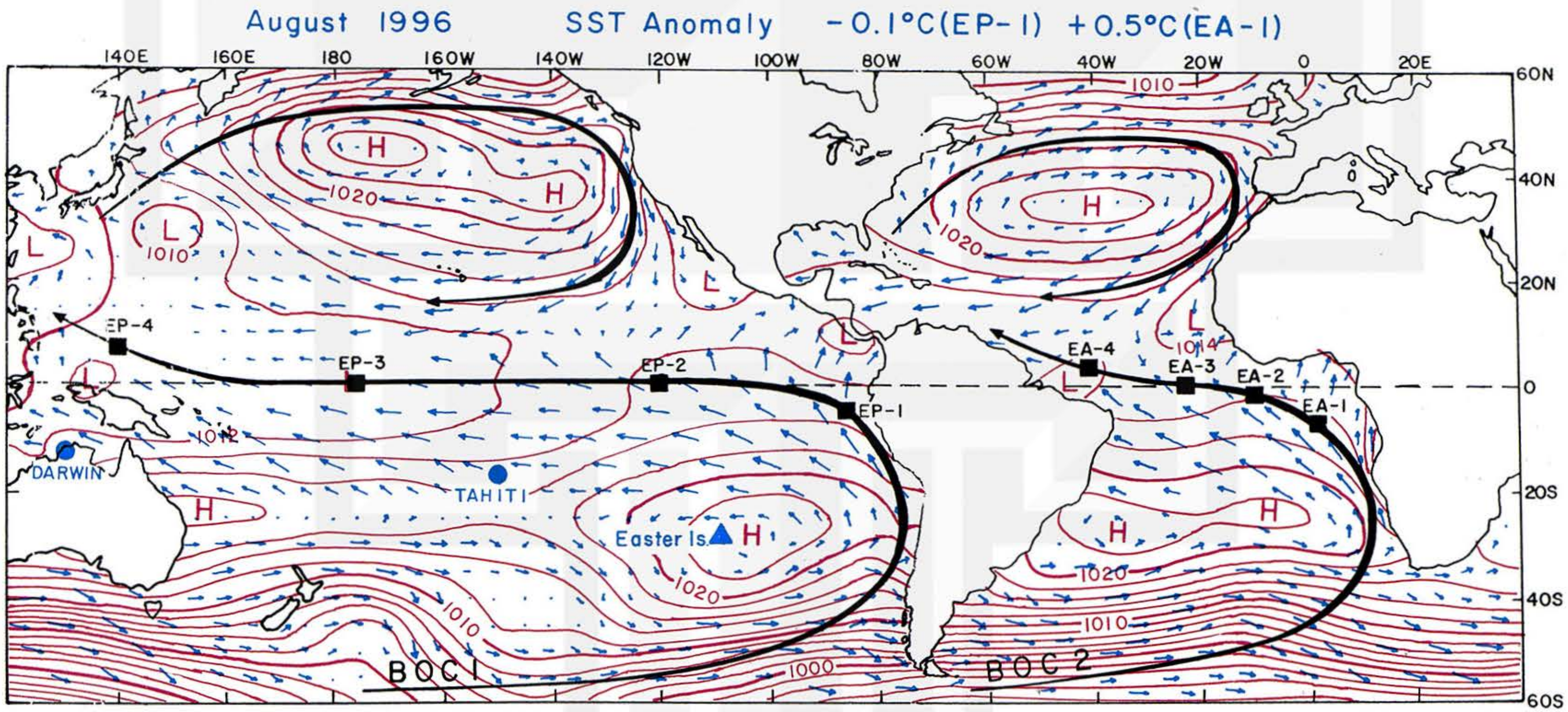


Fig. 5.4 Hadley cell circulation is the major component of the global circulation of the atmosphere, in which thermally driven air from equatorial region descends to the middle latitude zones at about 30° on both sides of the equator. High pressure cells (anticyclones) develop inside the zones over cold ocean areas half-circled by cold currents. The colder the current, the stronger the anticyclone and vice versa.

This figure shows that cold currents in the eastern oceans in both hemispheres are driven by the swirling outflow winds of the anticyclones. We may assume that a long-term intensification of an anticyclone could cause a La Niña and weakening, an El Niño, although nature maintains normal intensity of anticyclones in most years. Basic maps from JMA.

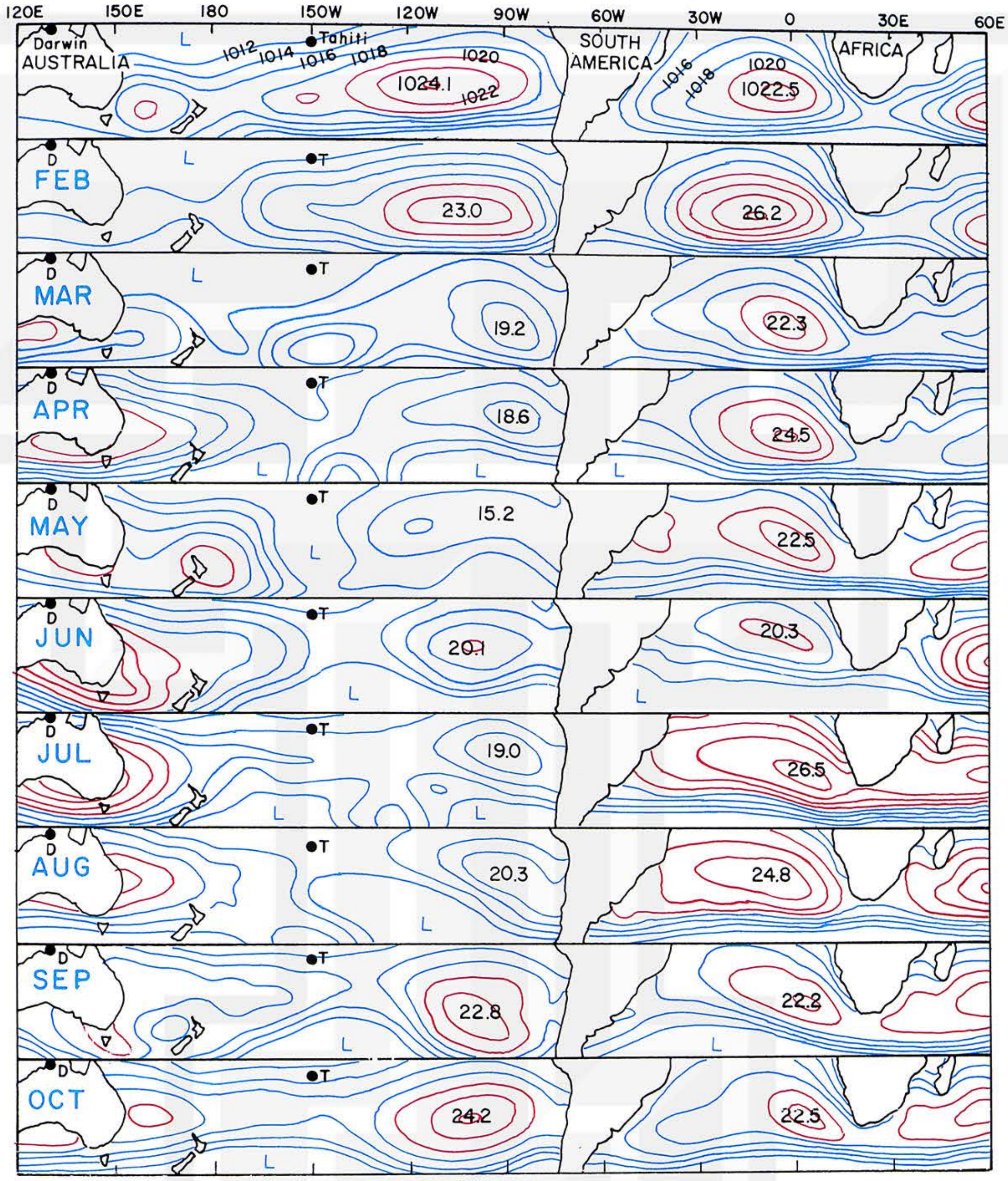


Fig. 5.5 In March 1997, The Hadley cell anticyclone off the west coast of Chili weakened to the 1019.2 mb central pressure and stayed weak for six months. On the other hand, another anticyclone over South Atlantic remained unchanged. Strangely, Atlantic remained cool while Pacific turned into the El Niño of the century.

5. Cause of Global El Niño

SLP ANOMALIES of BOC I and EASTER ISLAND

1996												1997												
1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	
	1	1	1	0	1	1	1	1	0	0	1	1	1	2	1	1	1	1	1	2	1	1		5S 85W
	0	0	1	0	1	2	1	0	0	0	0	0	0	2	0	1	1	1	0	2	0	0		10S 79W
	1	1	0	0	0	1	1	0	0	0	0	1	0	3	0	2	0	1	0	1	0	0		15S 76W
	0	1	1	1	1	1	1	0	0	1	0	1	0	3	0	2	0	1	1	0	1	0		20S 74W
	1	2	2	2	1	2	1	1	1	0	0	1	1	2	2	3	1	0	0	0	0	0		25S 73W
	0	2	3	1	1	2	1	2	1	2	0	2	2	2	3	3	1	0	1	0	0	1		30S 73W
	1	2	2	1	1	2	0	3	1	0	0	1	3	1	4	0	3	2	0	0	1	0		35S 76W
	2	1	1	2	1	3	2	4	0	2	1	1	3	1	5	5	5	4	1	0	5	1		40S 80W
	0.5	1.3	1.4	0.9	0.9	1.8	1.9	1.4	0.4	0.1	0.3	0.8	1.3	2.0	1.6	0.9	1.0	1.3	0.3	0.6	1.0	0.1		AVERAGE

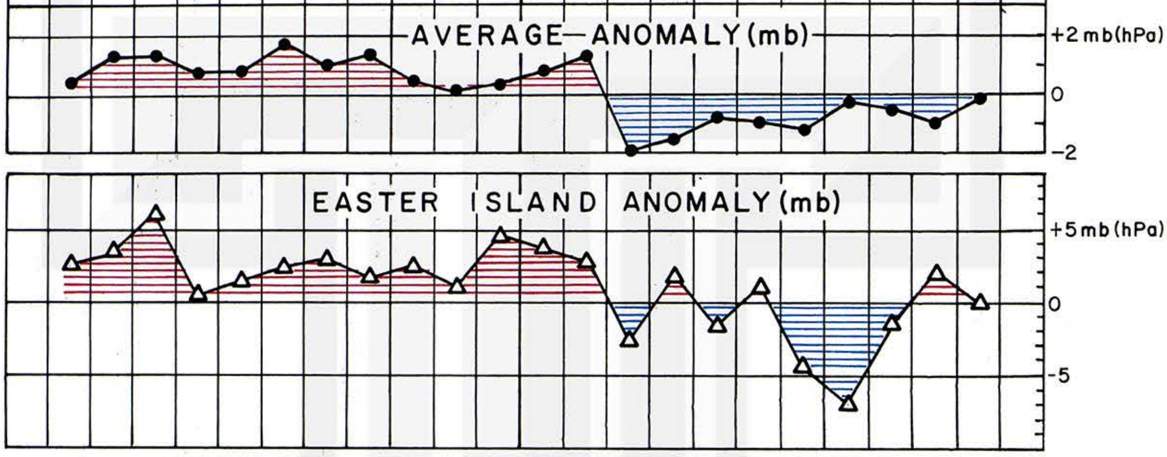


Fig. 5.6 Sea-level Pressure (SLP) anomalies at Easter Island and along the Branch-Off Current (BOC 1) north of 40°S latitude. This chart was made from the monthly **SLP maps of southern hemisphere in the FEB 1996 through NOV 1997 issues of Monthly Report on Climate System** provided by Japan Meteorological Agency. Location of Easter Island is shown on pp 2, 44, and 50. SLP anomalies along BOC 1 were determined at 8 locations for every 5° latitude intervals and averaged. The average SLP decreased sharply by 3.3 hPa(mb) in March 1997, suggesting the onset of the 1997 El Niño. At the same time, SLP anomaly at Easter Island decreased by 6 hPa(mb) changing the 13 month positive anomalies into negative anomaly. It should be noted that JMA computed these anomalies using the base period for Normal: 1979 to 1990. As years go by the Normal SLP will improve. THIRD PREDICTION METHOD (p 61) will become a low-cost and accurate in years to come.

Due to high sea-surface temperature, El Niño causes more troubles than its counterpart, La Niña. On the other hand, we must explain the cause(s) of both El Niño and La Niña together as much as possible. A historical summary (1950-97) in Fig. 3.9 reveals that El Niño and La Niña are like two sides of a coin, which can be flipped into the two faces of a cold current.

A comparison of the SST anomaly (painted above -3°C) and the interannual minimum SST (painted above +18°C) suggests, beyond doubt, that both variations can easily be explained by the multi-annual change of the volume transport of the Peru Current in Sv(10^6 m^3/s), for instance. From natures point of view, it will be very difficult to maintain the constant volume transport of a wind-driven, cold current year after year. A low transport will cause increase of SST with fast tropicalization, while a high transport, a decrease of SST with slow tropicalization (Fig. 5.7).

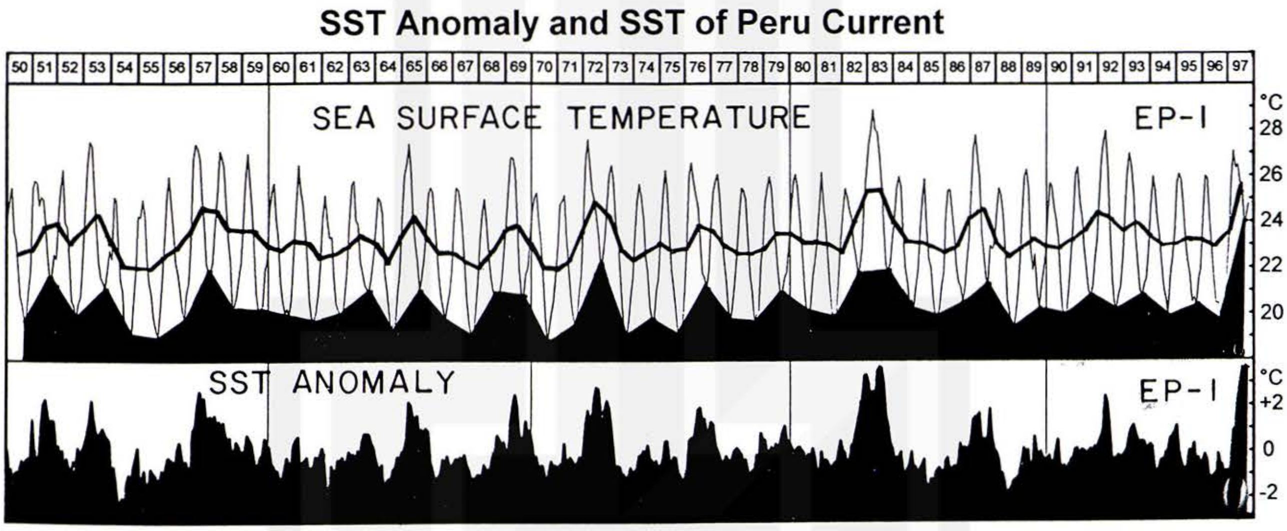


Fig. 5.7 SST by month (thin line), average SST (heavy line), minimum SST by year (above 18°C painted) and SST anomaly by month (above -3°C painted). It is rather amazing to find in this diagram that the El Niño/La Niña phenomena and the temperature variation of Peru Current are closely related.

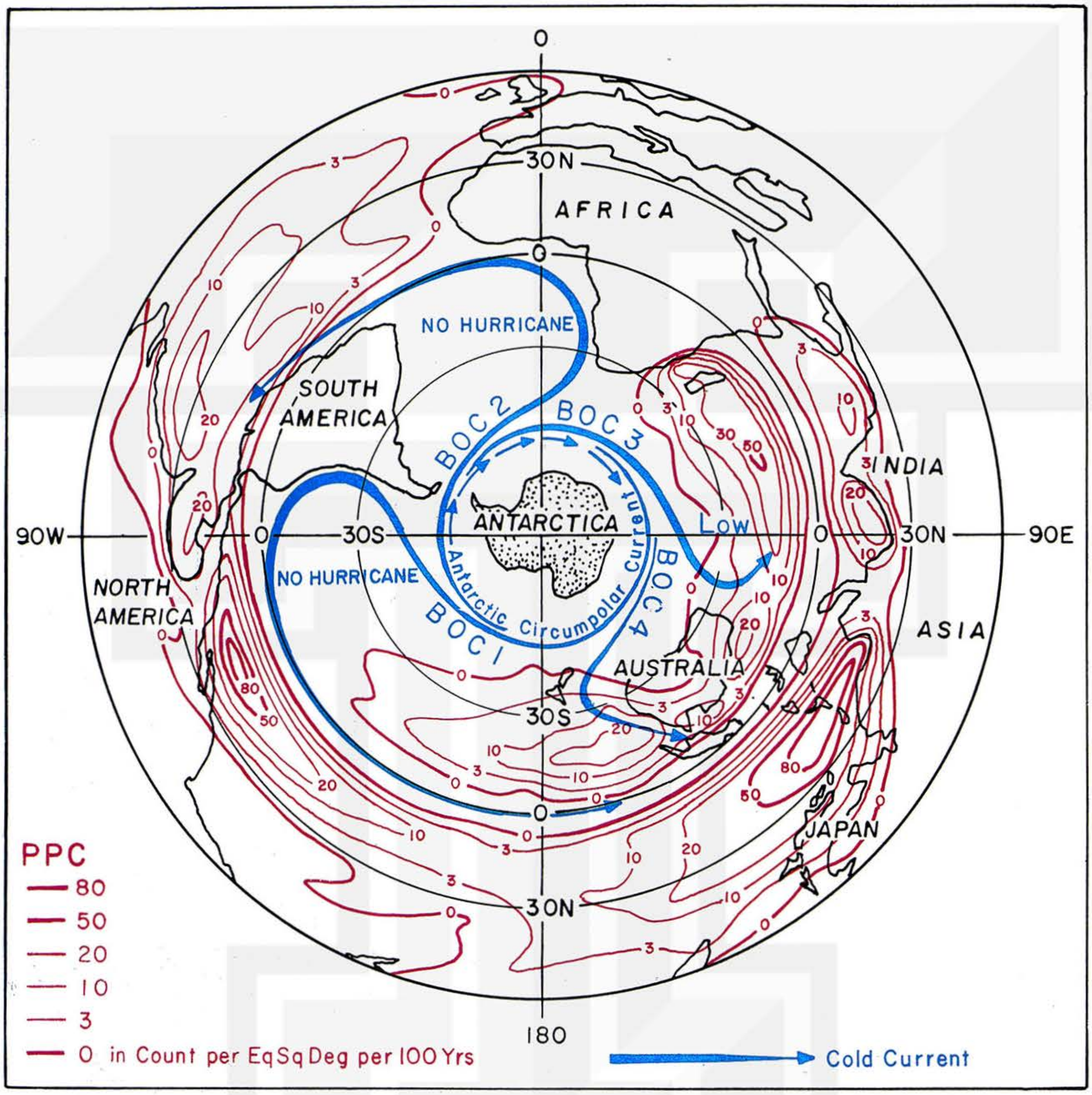


Fig. 5.8 Four BOCs superimposed upon the PPC distribution of hurricanes in the 45-yr period, 1951-95. It is of interest to find that hurricanes decrease significantly on the west side of BOCs, BOC 1 and BOC 2 in particular.

Chapter Six Triple Prediction of El Niño

It has been concluded that the Old Penguin Passage (migration route of penguins to Galapagos Islands) and the Equatorial Current are a combined single current (p 50). The sea-surface temperature of the cold current increases from near 15°C to 29°C during the long journey from 40°S to 140°W through the distance of 19,000 km, one half of the circumference of the earth.

In accordance with the variation of incoming solar radiation and 3-month time lag of SST variation, (p 23), the minimum SST, while in southern hemisphere, occurs in September (p 52). During the westward flow along the equator, SST of the cold current tropicalizes warming to about 29°C.

It is of particular interest to find that the westward water dives suddenly, 100m to 200m before reaching the boundary (frontal) surface, between the cold water from the east and the warm water from the west. The boundary has been called **The Equatorial Front (p 57)**. By definition, the front becomes a cold front while moving east to west and a warm front while moving from west to east. Downflows on both sides of the equatorial front result in the downward transport of warm water, thus causing a band of warm water along the frontal surface. The front at -50 to -150m depth can be depicted by the isotherms above 29°C drawn at 0.2 to 0.5°C intervals (pp 54-56).

Although no special data are available, practically the identical variation of SST is occurring in the Atlantic Ocean along the BOC 2, extending from off the coast of South Africa to off the north coast of Venezuela (pp 2, 6, 7 and 52).

6. Triple Prediction of El Niño

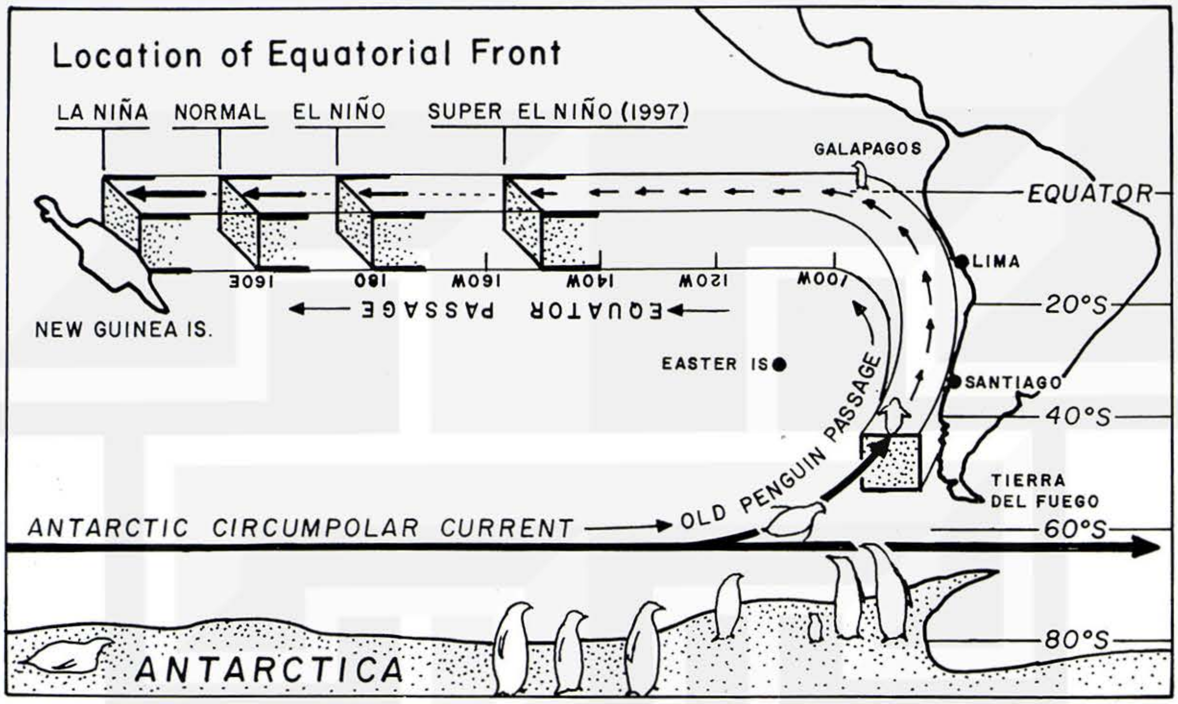


Fig. 6.1 A schematic view of the passage of branch-off current (BOC) of the Antarctic Circumpolar Current all the way to New Guinea Island. The passage is divided into the Old Penguin Passage and the Equator Passage which cannot be separated artificially into two. Fig 6.6 clearly shows a sign of the 1997 El Niño as early as JAN 96. On the other hand, Fig. 6.7 along with Figs. 6.14 and 6.15 show an unnatural termination or initiation of the equatorial water at the coast of Ecuador. Furthermore, the tilt of both cold trough and warm ridge (Fig. 6.14) reveals the westward transport of the cold surface water which should be originating deep in southern hemisphere. The SST maximum at 79°W in JAN-MAR and minimum in JUL-SEP also imply the southern hemisphere origin. Figs. 6.3 and 6.4 also reveal the flow from southern hemisphere to the equator both in the Pacific and Atlantic oceans. Technically, Old Penguin Passage in this figure should read "Branch-Off Current (BOC 1)".

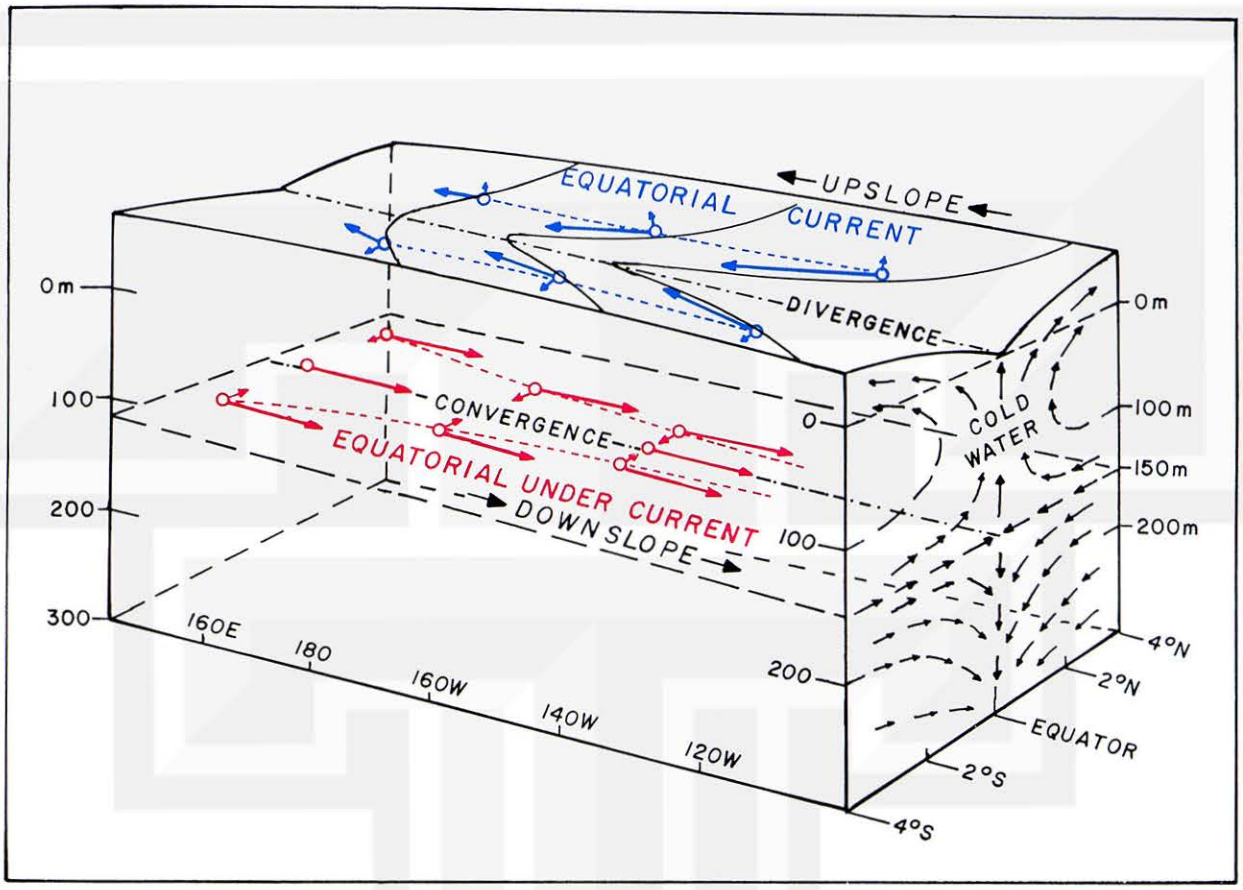
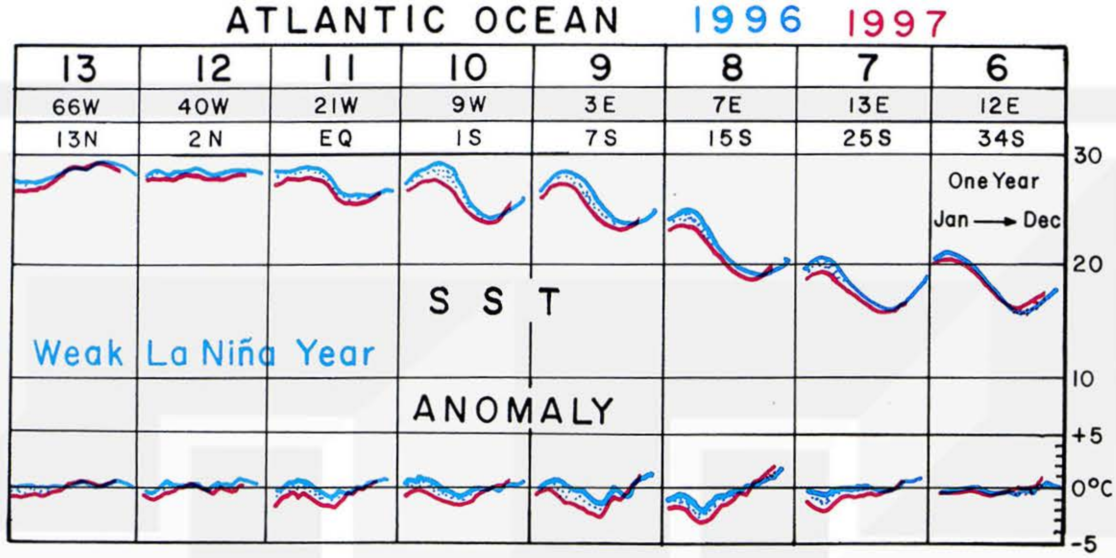
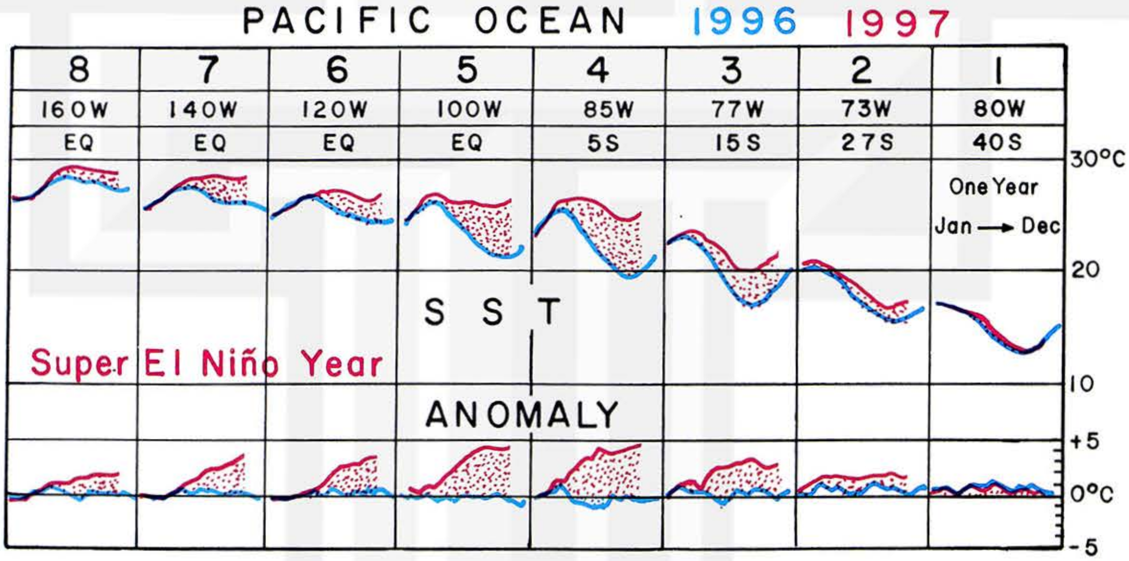


Fig. 6.2 Schematic view of the Equatorial Current and the Equatorial Under Current. In spite of the fact that the equatorial sea surface slopes up toward the west, the Equatorial Current flows upslope from east to west. It is due to the coriolis force which reverses at the equator. The reversal results in the diverging flow at the equator causing the upwelling of cold water beneath the surface (pp 32 and 33).

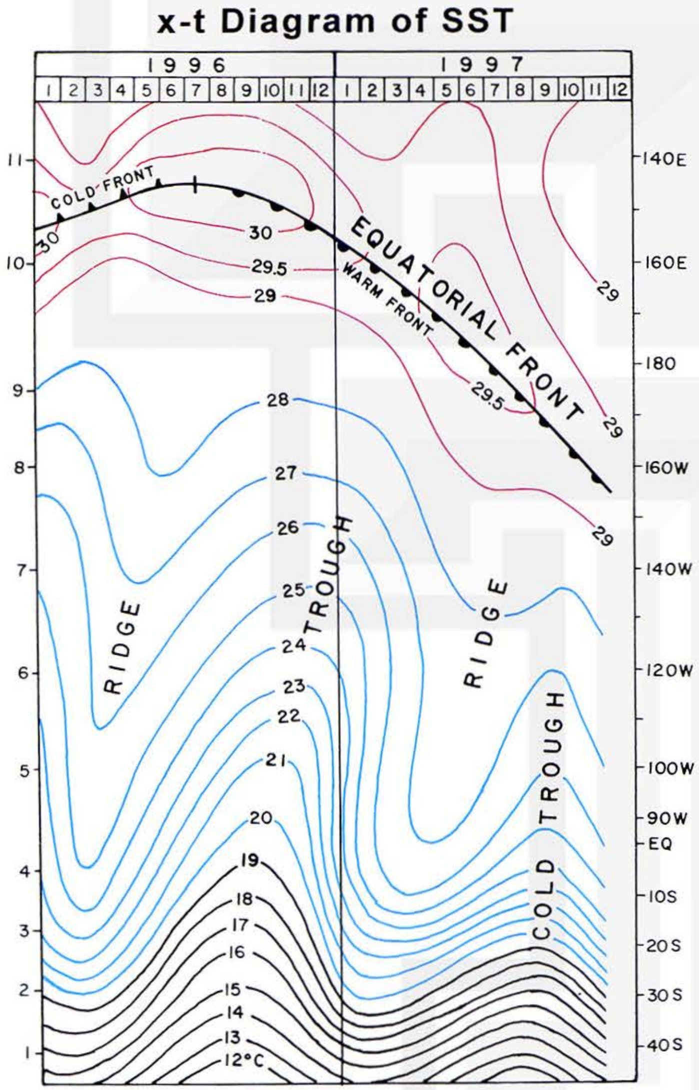
The Equatorial Under Current flows downslope from the westernmost equatorial Pacific Ocean. Due to the reversal of the coriolis force, downslope flow is constantly pulled toward the equator resulting in the convergence. The under current flows very fast, 100 to 150 cm/sec. During the 1982-83 El Niño the current somehow surfaced and weakened considerably.

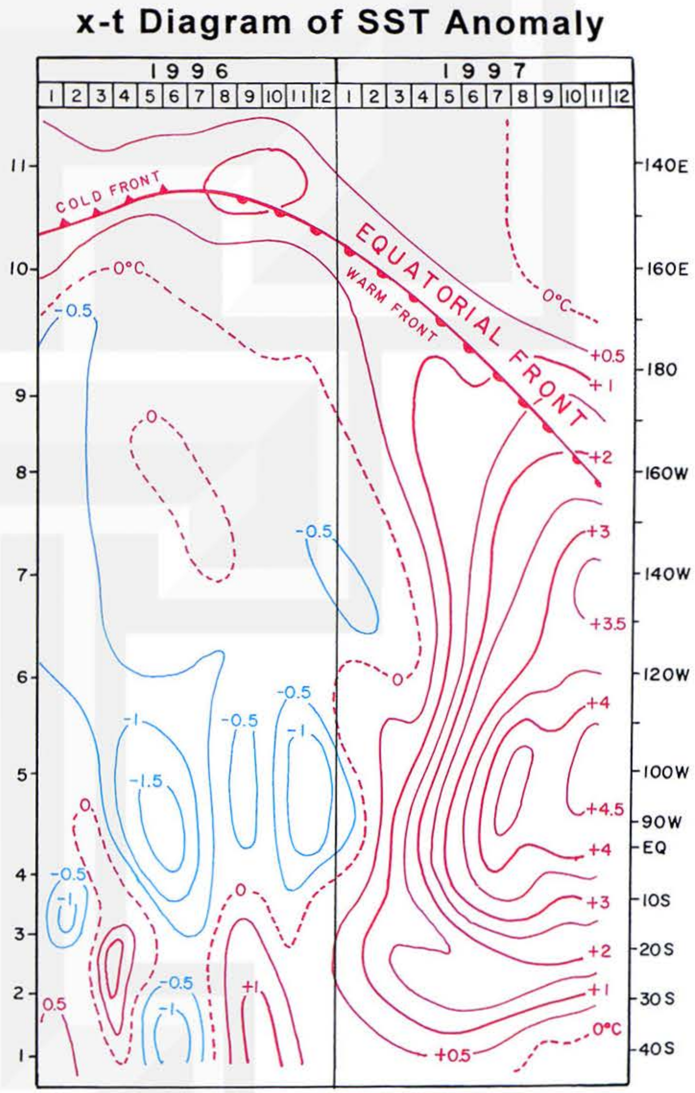
6. Triple Prediction of El Niño



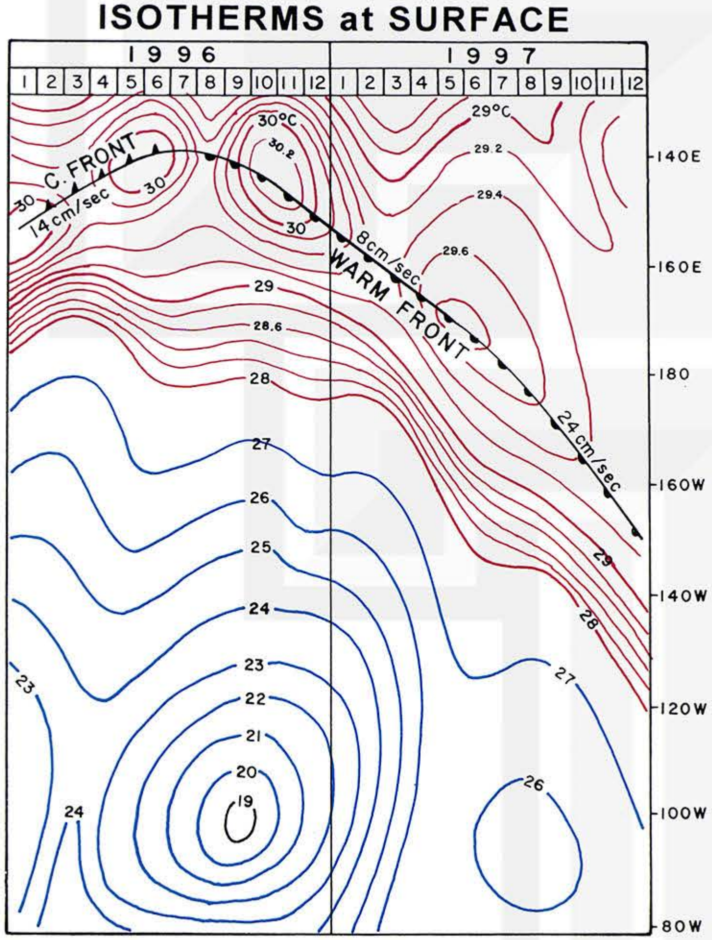


Figs. 6.3 (above) and 6.4 (below) Tropicalization of SST in 1996 and 1997 of the Atlantic BOC (Benguela Current) and the Pacific BOC (Peru Current). These currents which branch off the Antarctic Circumpolar Current are cold currents with 0 to 5°C SST at the source. As the currents flow northward, SST increases maintaining the southern mode (p 22) until reaching the equator. During the westward flow along the equator, SST will tropicalize under the equatorial solar radiation with the dual interannual peaks (pp 22 and 23). 1997 was a weak La Niña Year in the Atlantic while the Pacific was experiencing the Super El Niño Year of the Century. Early sign of the El Niño is evidenced as early as February and March 1997 (p 53).





Figs. 6.5 and 6.6 x-t diagrams of SST and anomaly obtained by determining the monthly values at 11 locations (Fig. 6.3) from Monthly Report on Climate System from JMA. Due to interpolation between contour lines, 0.1° to 0.3°C error should be expected. Nevertheless, the isobars are good enough to determine the early sign of the 1997 El Niño by February 1997.



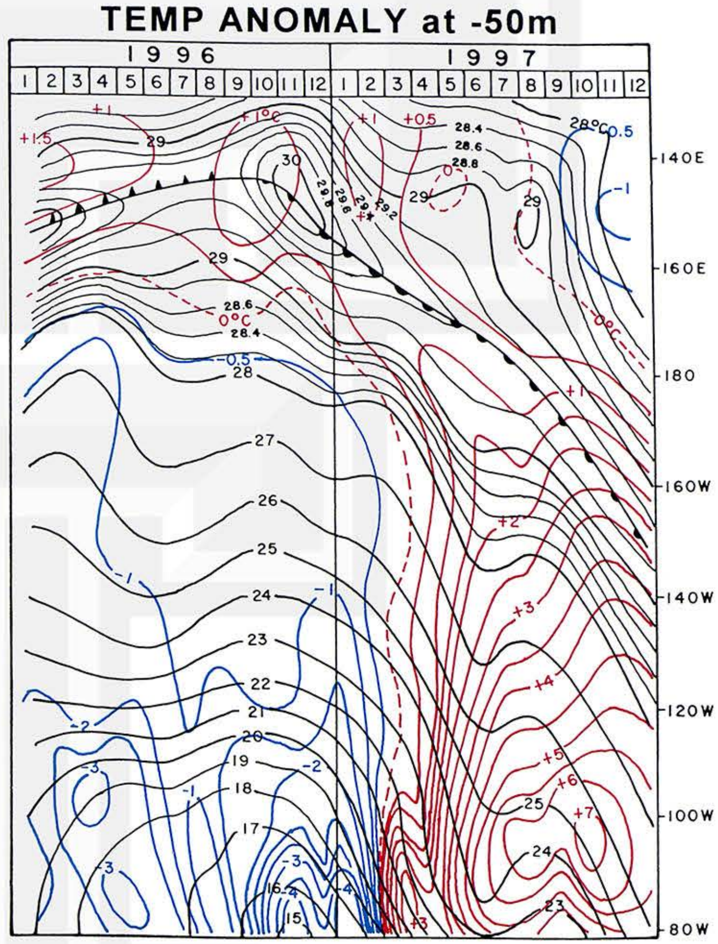
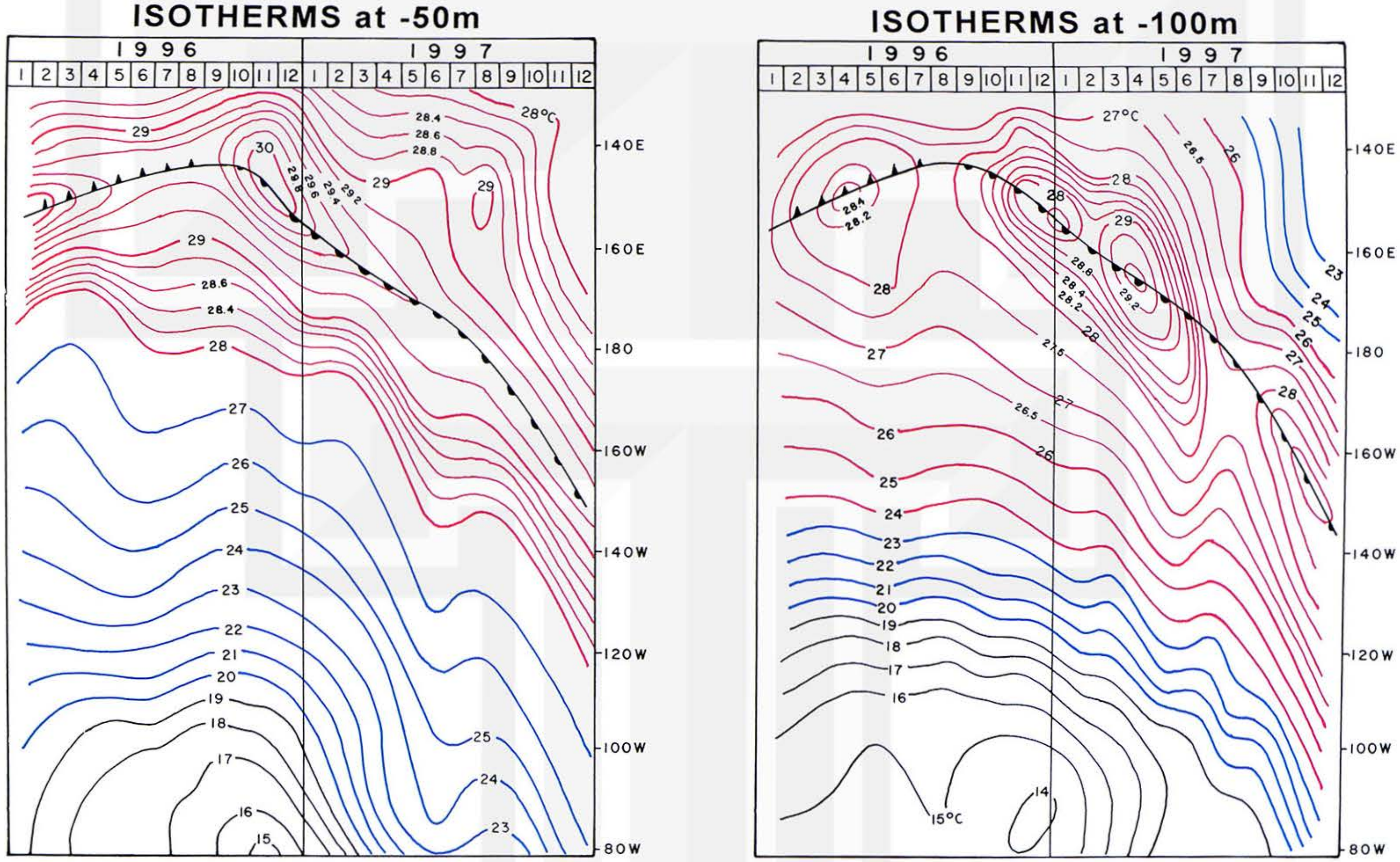
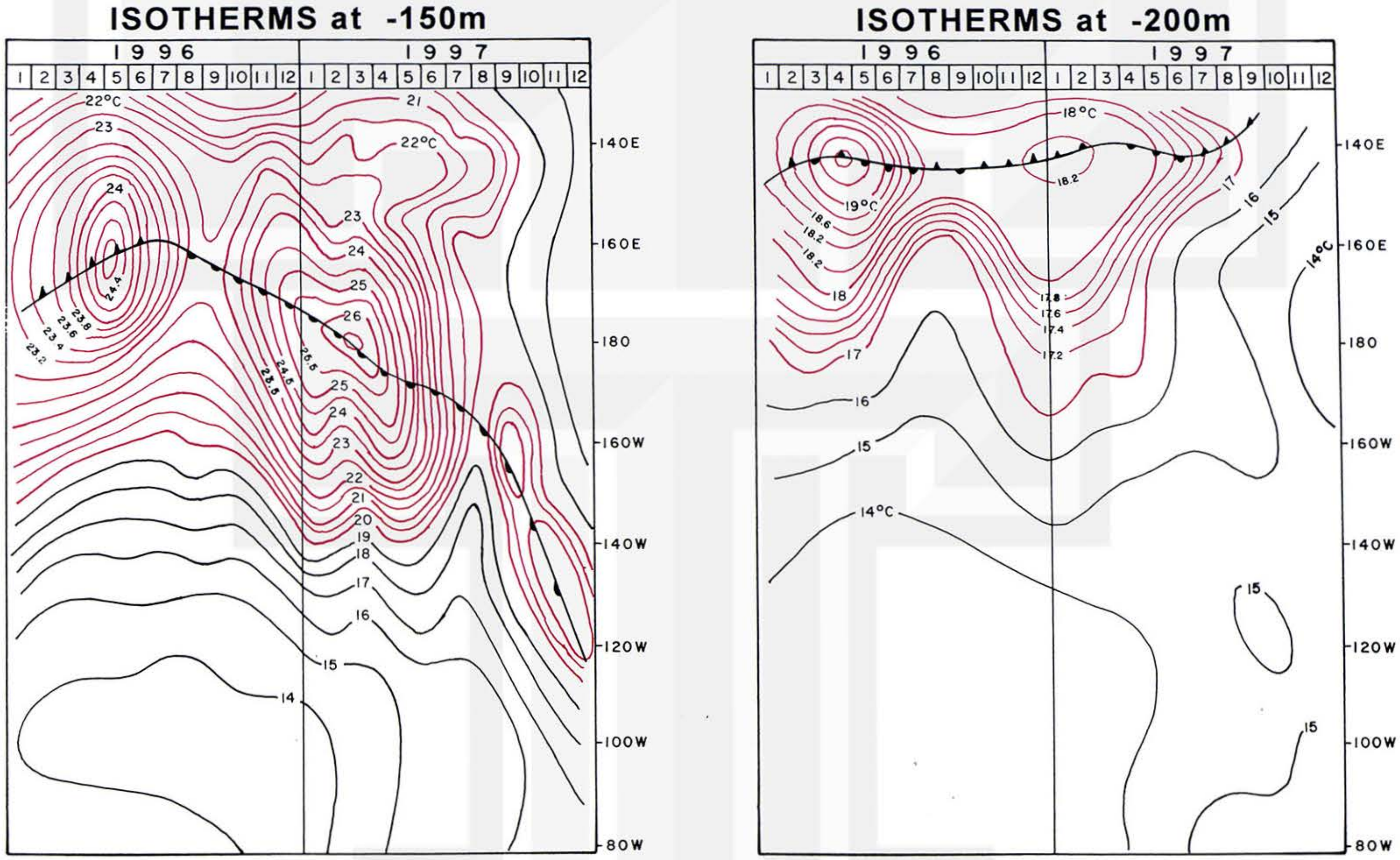


Fig. 6.7(left) Isotherms of SST drawn by plotting the depth-longitude cross sections of temperature along the equator in the Pacific Ocean by ODAS, Monthly Report (Feb 96 to Nov 97) JMA. **The equatorial front** which is subclassified into "cold front" and "warm front" according to the direction of motion. Fig. 6.8 (right) Temperature anomaly at -50m depth superimposed upon the -50m isotherms in black line. Note that no significant anomaly is seen on the warm-water (west) side of the equatorial front.



Figs. 6.9 and 6.10 Isotherms at -50m and -100m depth. Isotherms above 28°C(-50m) and 24°C(-100m) are drawn in red contours with 0.5 or 0.2°C intervals. It was noticed that a distinct ridge of isothermic topography is seen where the warm water from the west and the cold water from the east meet and sinks, resulting in the downward advection of warm water.



Figs. 6.11 and 6.12 A 4°C warming at -150m depth, suggesting a significant downwelling velocity at the front. In meteorology upward motion occurs at tropical and equatorial fronts. In equatorial ocean, however, a downward flow and warming will take place where two currents meet head on. The front is less pronounced at -200m depth where flows are weak and temperature gradient in both vertical and horizontal directions are small. Refer to Fig. 6.13.

FRONT-RELATIVE WATERFLOW ESTIMATED

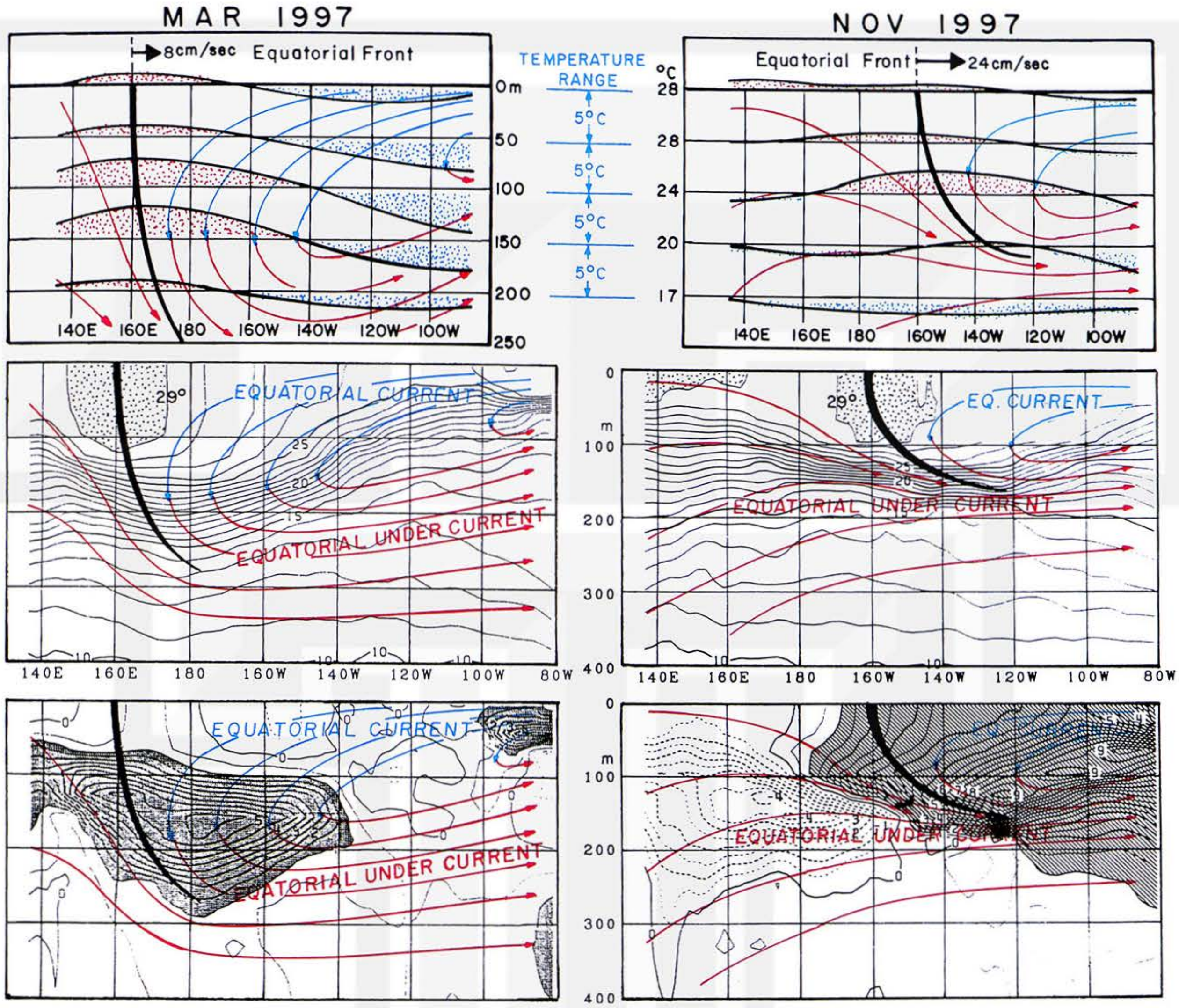


Fig. 6.13 Depth-longitude cross sections of water temperature (WAT) and anomaly from **Monthly Report on Climate System published by JMA.** Superimposed are Equatorial Current (EC) and Equatorial Under Current (EUC) shown in three-dimensional diagram (p 51). The ridge lines of WAT at various depths (pp 53-56) suggest strongly that the deeper thermocline in this figure is due to convergence and active downflow on both sides of the front which moves westward or eastward depending on the strength of EC. The front has been called the **Equatorial Front, an important Predictor.** Depth of the front in MAR 97 was 300 m and it became only 150 m in Nov 97. On the analogy of atmospheric front, examine this figure looking upside down, changing west to south and east to north. It should be noted that the speed of the front should be added to the relative flow speed in the proximity of the front to determine the earth-relative speed. For examples of prediction, refer to pp 41, 42, 43, 50, 58, 59 and 60.

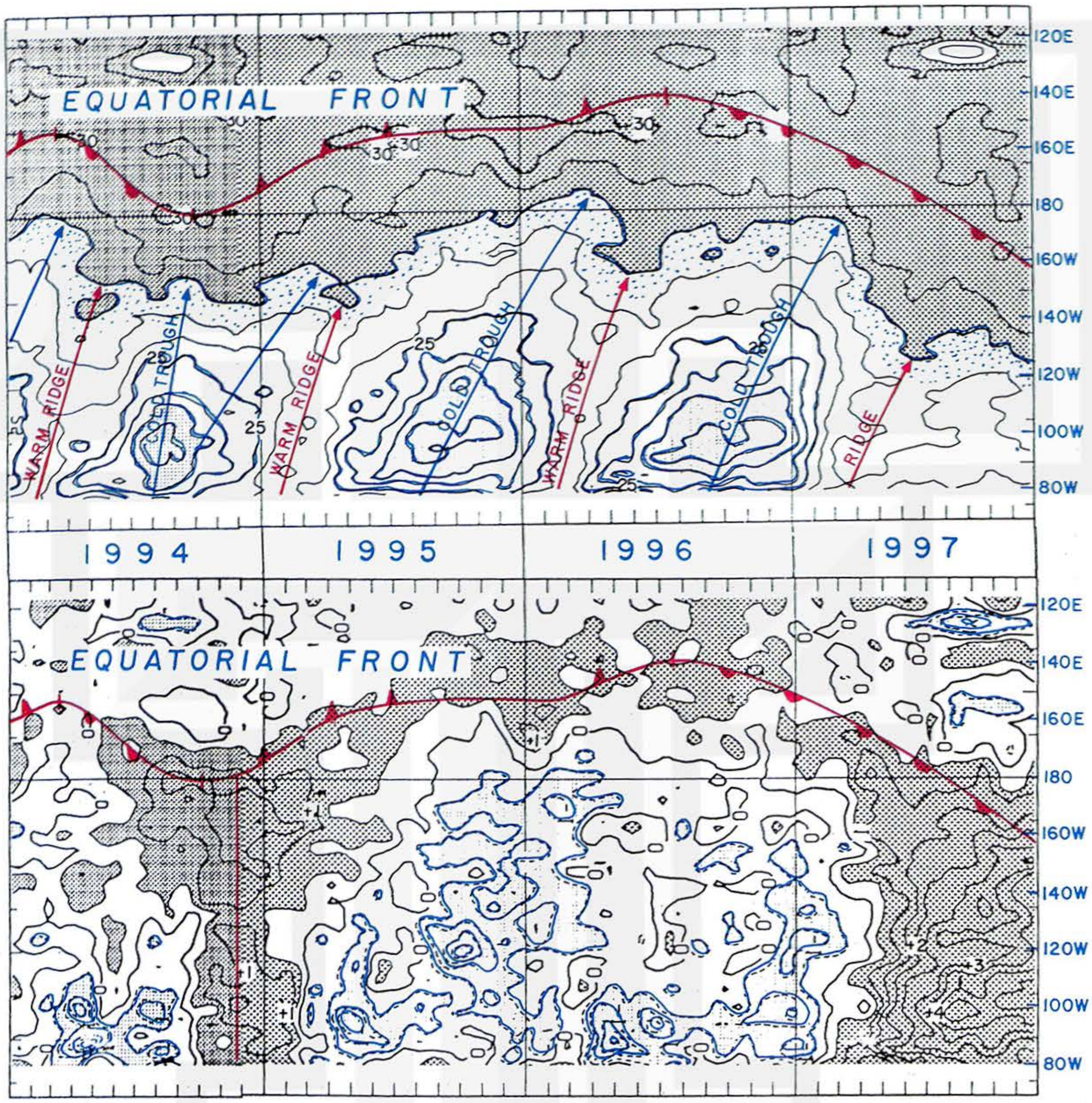


Fig. 6.14 Equatorial front superimposed upon the backward copy of Fig. 50, Time-Longitude Cross Section of SST (above) and Anomaly (below), of NOV 97 issue of Monthly Report on Climate System, JMA. The frontal position in 1996 and 1997 has been confirmed by the x-t (depth-longitude) cross sections in pp 54-56. Both 1994 and 1995 frontal position is Fujita's best estimate. Fig. 50 will be the **appropriate chart in predicting the occurrence, extent, and duration of SST anomaly**. A downward extension to -40° or -60°S (Refer to Figs. 6.5 and 6.6) will allow anyone to perform dual prediction of El Niño and La Niña as well.

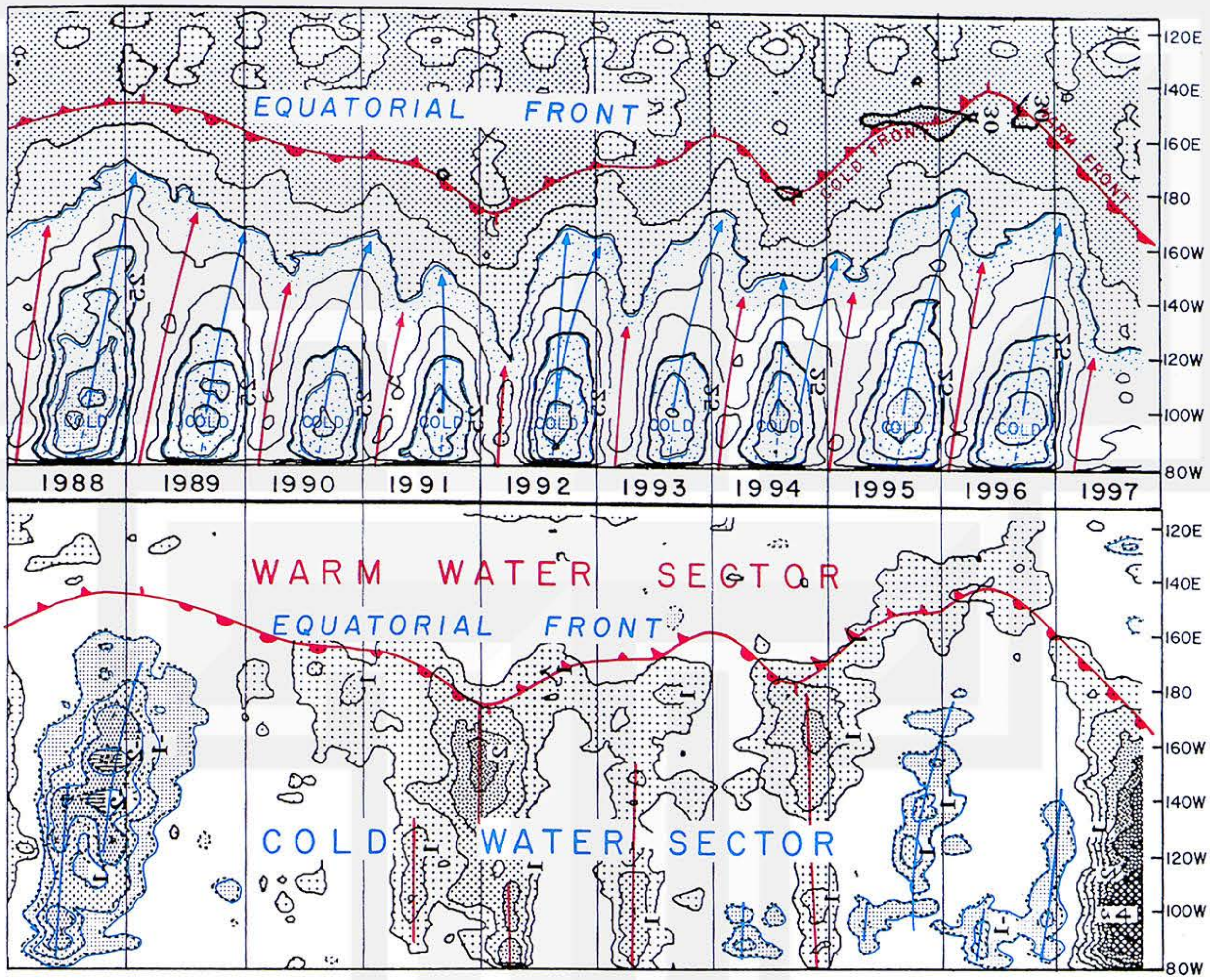


Fig. 6.15 An overview of the variation of the equatorial front during the 10-year period, 1988-1997. 1988 was the significant La Niña year analyzed with x-t diagrams (p 27). It should be noted that the equatorial front is pushed westward by cold water, eastward when the flow of cold water is weak. See the westward push as a cold front in 1995-96. During 1991-92, weak flow of cold water failed to push the front westward beyond 180°, resulting in an El Niño. Original chart is the backward copy of Fig. 77 (p 59) of the November 1997 issue of Monthly Report on Climate System from JMA. **A downward extension of these charts** along the Old Penguin Passage will be a quick and low-cost addition of the useful data **readily available to all Climate Centers around the world**.

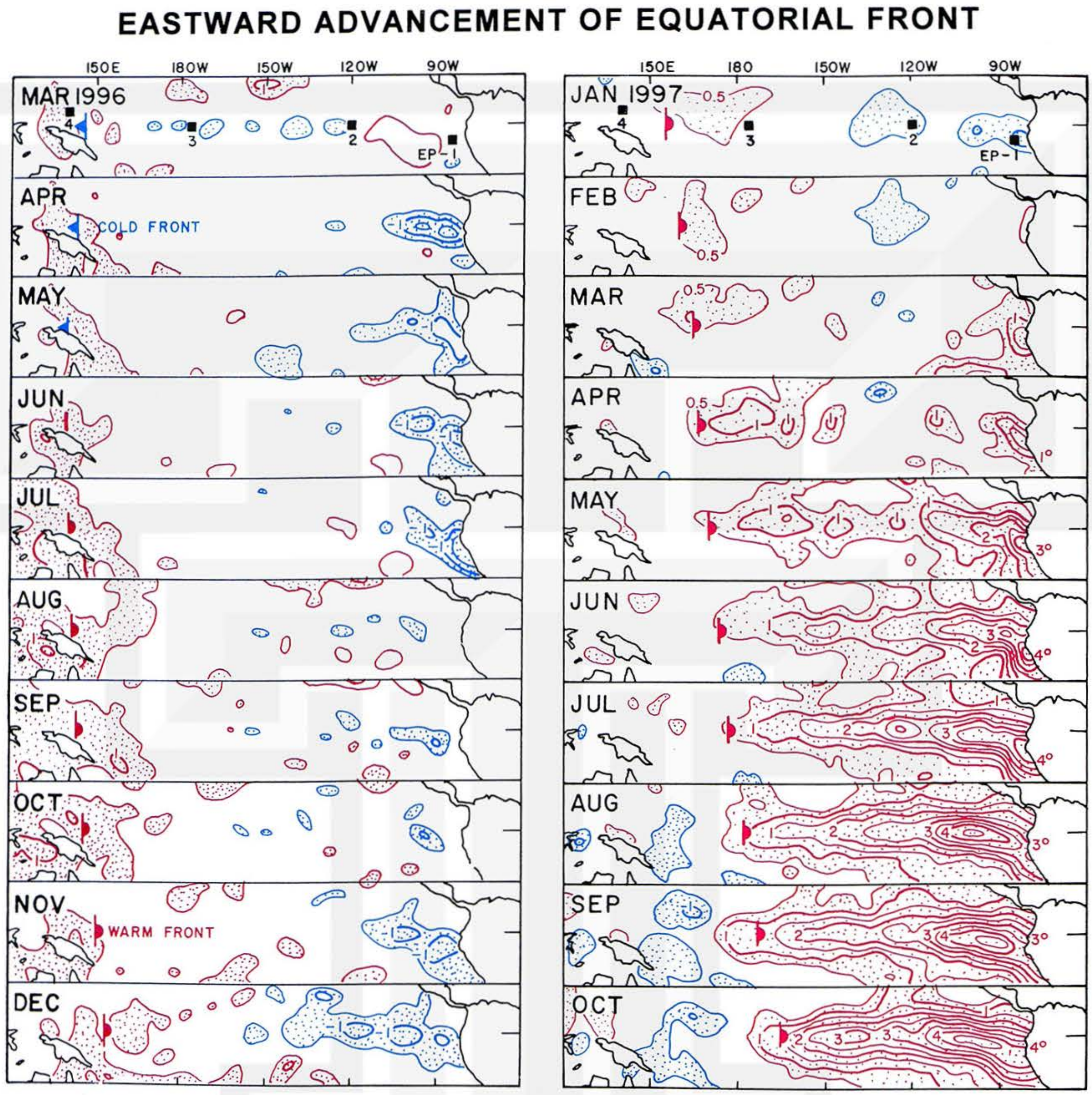


Fig. 6.16 Discovery of the Polar Front by the Norwegian School in the 1920s gave a quantum leap to the analysis of cyclones, resulting in the accurate prediction of North Atlantic storms. Early meteorologists thought that polar air from the north and tropical air from the south swirls together into a cyclone. This research, based heavily on superb data from Japan Meteorological Agency, led to the discovery of the Equatorial Oceanic Front which moves eastward or westward in response to the strength of the cold current. A combination of this diagram and the x-t diagram by JMA (pp 58 and 59) with front added, will permit us to predict El Niño/La Niña based on the longitude of the front along with the frontal movement.

Summary and Conclusions

Since the super El Niño of 1997, El Niño became an important phenomenon which affects various aspects of our daily life. A renewed overview of El Niño in relation to the percent change of hurricane activity around the world stimulated an extensive research of El Niño on a global scale. The superb publication of Japan Meteorological Agency, **Monthly Report on Climate System was provided to Fujita for an unbiased analysis** based on his research and teaching experiences of half a century in both Japan and United States on Meteorology, TOPEX, Astronomy, Oceanography, Geology, and Geography. It was concluded that El Niño and La Niña are caused by the insufficient and excessive cooling of the branch-off current. **Triple Independent Methods of Prediction** have been established.

PREDICTION ONE – Based on the SST anomaly near the south end of the BOC. Update monthly the flow-distance vs monthly SST and anomaly diagrams along the cold current from 40°S to 120°W. Draw 0.2° to 0.5°C isotherms above 28°C SST. Detect the earliest, growing indication of anomaly at or near the south end of the current. Make preliminary prediction in February or March each year and follow up thereafter (Refer to pp 7, 8, and 53).

PREDICTION TWO – Based on the longitude and movement of the Equatorial Front. Generate and update isotherm and anomaly charts at depths: 0m, 50m, 100m, 150m, and 200m (pp 54-56) to confirm the position and movement of the Equatorial front. Draw 0.2° to 0.5°C isotherms in the vicinity of the front. When necessary, generate vertical cross sections with excess warming and anomaly patterns (p 57). Locate the frontal positions on the monthly SST anomaly charts (p 60).

PREDICTION THREE – Based on the sea-level pressure (SLP) anomalies at Easter Island and along BOC 1 north of 40°S and 80°W (pp 44, 46, 50, and 52). Establish a barograph at Easter Island and transmit SLP daily to ???

Chapter Seven Paleo El Niño

During the 1990s, I taught **Paleo Climatology course** with Professor Fred Ziegler. He reconstructed paleo continents based on the **Theory of Continental Drift** and I reconstructed paleo climate and ocean currents. Our students enjoyed the brain exercise in the unusual course offered by both of us.

The concept of the Continental Drift was first proposed by Alfred Wegener, German astronomer/meteorologist/geologist born in Berlin on 1 November 1880. He received his PhD in 1904 at age 24. In 1912, Wegener worked out his startling interpretation of the shape of the continents on both sides of the Atlantic. On the basis of gravity measurements, Wegener assumed that the continent would float plastically on the heavier sea-floor rocks under the isostatic principle, maintaining the vertical balance.

In 1922, Wegener completed his paper **On the Origin of Continents and Oceans** by adding detailed distribution of the fossils on both sides of the Atlantic Ocean. The weakest point of his theory was the identification of the force capable of moving continents slowly but steadily in two different directions. Two years later, Harold Jeffreys, a prominent English geophysicist, argued forcefully that the gravitational force is so strong that it cannot and will not move continents horizontally no matter how long it took in geological time. Because of Jeffreys' prestige, the concept of Wegener's Continental Drift was killed in 1928. In winter 1930, Wegener undertook an expedition in Greenland and was found dead in snow and ice at age 50.

Thirty years after Wegener's tragic death, an idea of the **Sea-Floor Spreading** began. There is a mid-oceanic ridge along the center axis of the Atlantic Ocean where sea floor is generated and moves away from the spreading center. Imaginative geophysicists thought that high-temperature magma is magnetized by the earth's magnetic field as it rises and cools off below the Curie point. On 6 September 1963, Englishmen E. T. Vine and D. H. Matthews published a paper in Nature, thus redeveloping Wegener's Continental Drift into the **Plate Tectonics** dealing with the Mantle Circulation beneath the earth's crust. The atmospheric circulation, ocean circulation, and mantle circulation turned into reality thereafter.

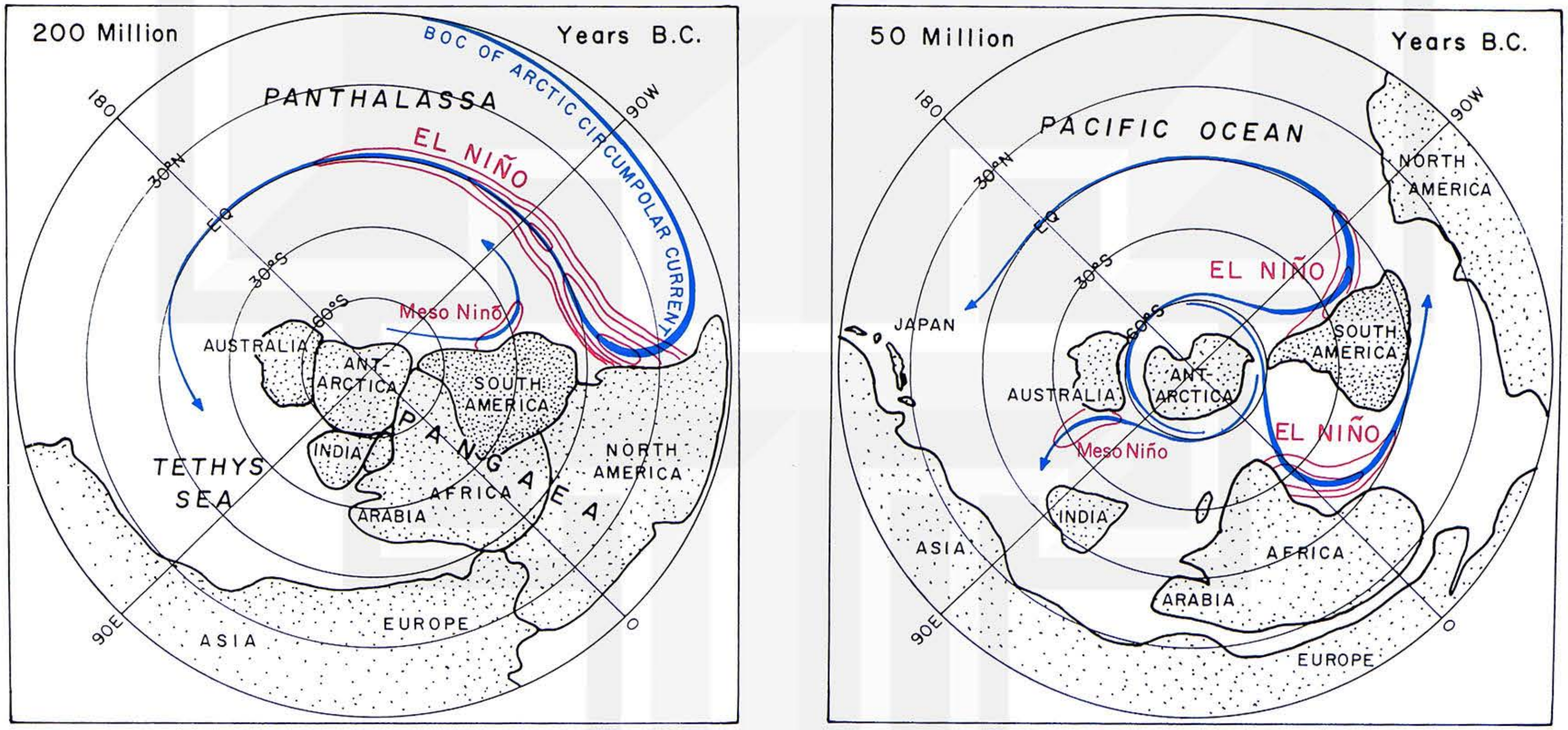


Fig. 7.1 and 7.2 Some 5 billion years ago a huge mass of gas caught by the gravitational field of the Solar System solidified into a small planet called the earth. When the surface temperature cooled below the boiling point, water accumulated slowly but steadily into the ocean, probably one billion years ago. When Jurassic Dinosaurs were dominating the world 200 million years ago, major continents of the world were connected to Antarctica. I assume that a large El Niño occurred in the equatorial Panthalassa, the largest ocean of the world. 70 million years ago, Australia broke off from Antarctica and moved northward very fast. By 50 million years ago, a channel between Australia and Antarctica became wide enough to initiate the Antarctic Circumpolar Current, a cold current circling Antarctica in the clockwise direction. El Niño could have formed over the Pacific Ocean and the Atlantic which has been widening since 180 million years ago, when the ocean split open.

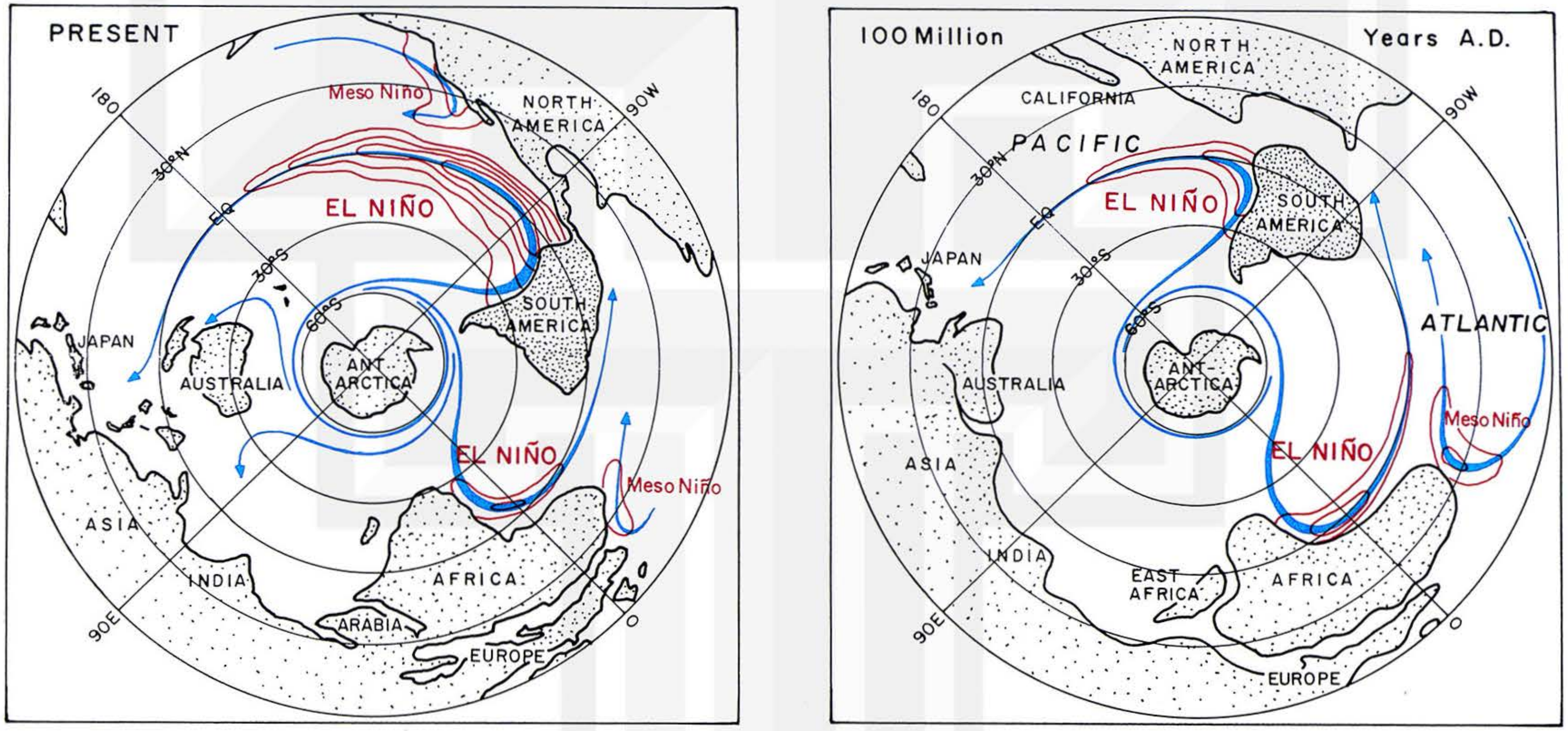


Fig. 7.3 and 7.4 Because of the huge Pacific Ocean at the present, the Peru Current (BOC 1) became the largest cold current on the earth. From the global point of view, BOC 1 is very important to prevent equatorial Pacific from overheating. When the current weakens, the ocean will become too warm, causing an El Niño. La Niña will form during the cumulative period of strong BOC 1. **Small El Niño (Meso Niño)** could develop due to the weakening of the California Current. Due to the closeness to population centers, the Meso Niño could cause additional flood damage, in particular. Although nobody will be able to confirm what could happen 100 million years from now: Global warming or global burning, meteorite impact or nuclear accident, etc. What is certain, however, is the mantle circulation which will keep widening the Atlantic and narrowing the Pacific. El Niño will adjust itself to the ocean size.

History of the Wind Research Laboratory

1943-53 **Unnamed Fujita Project, Kyushu Institute of Technology, Tobata City, Japan**

BUDGET
$2,500
(11 Yrs)

Micro-network of 88% solar-eclipse weather
Survey of Hiroshima and Nagasaki bomb damage
Discovery of downdraft in 1947. (Costs: $100)
Pressure dip in typhoon Della
Analytical study of typhoons (ScD Thesis)

1953-60 **Unnamed Fujita Project, University of Chicago** (Fujita invited by Dr. Horace R. Byers)

$289,000
(8 Yrs)

Re-analysis of Thunderstorm Project data
"MESOANALYSIS" by Fujita and Tepper
Mesoanalysis of squall lines
Precipitation and cold-air production
Use of weather radar in mesoanalysis

1961-63 **MRP, Mesometeorology Research Project, University of Chicago**

$654,000
(3 Yrs)

Dawn of Mesometeorology
Mesometeorological Network in Oklahoma
Precise analysis of Tiros satellite photos
First aerial photo of rotating thunderstorm
Identification of mesocyclone radar echo

1964-87 **SMRP, Satellite and Mesometeorology Research Project, University of Chicago**

$7,531,000
(24 Yrs)

Aerial and ground survey of tornado damage
The Fujita Tornado Scale (F-scale)
Discovery of Downburst and Microburst
Overflight of tornadic thunderstorm by Lear Jet
First Color Movie of Planet Earth by Satellite

1988-98 **WRL, Wind Research Laboratory, University of Chicago**

$3,467,000
(11 Yrs)

Mini-swirls and microbursts in Andrew and Iniki
Identification of downbursts in Japanese typhoons
Mesoanalysis of typhoon damage in Japan
Mapping of cyclone paths in northern hemisphere
Mystery of El Niño and Hurricanes
World Atlas of Typhoons and Hurricanes

Research Life of Tetsuya (Ted) Fujita

by Dr. Robert F. Abbey, Jr.

It is indeed a pleasure to provide this brief introduction to such an important work by Dr. T. T. Fujita. It is not too often that one has the privilege of both knowing and observing the work of such a magnitude as that developed by Ted Fujita. Having known Ted for the past 25 years and having had the opportunity of working closely with him for the past 23 years, Ted continues to impress not only me, but the international scientific community as well, by his dedication, insights, and seemingly endless energy in the pursuit of knowledge.

From mesoscale analysis, to tornadoes and the discovering of suction vortices, devising the Fujita Tornado Scale (F-scale) to the discovery of downbursts, to his current devotion to improving our understanding of tropical cyclones and their relationship to El Niño and La Niña phenomena, Ted always seems to drive the field, rather than being driven by it; always working at the leading edge and having the ability to extract deep insights hitherto not seen before. Never one to shrink from controversy, Ted has developed herein a new and novel way of understanding the phenomena of El Niño, ocean circulation, and the resulting impact on tropical cyclone behavior.

While enduring severe pain on his feet, Ted continued to work every day, all day, with his never-ceasing belief that **"research is my life!"** Ted is simply incapable of just simply resting and cannot wait until he has the strength to write down his thoughts and direct his staff to follow-through on his ideas and carry out his missions. Truly a man of remarkable spirit, Ted sets himself goals that only he can meet and standards that only he can achieve. The scientific community has been blessed with such an individual and the world is much the better for the contributions made by my friend and respected colleague, Ted Fujita.

January 6, 1998

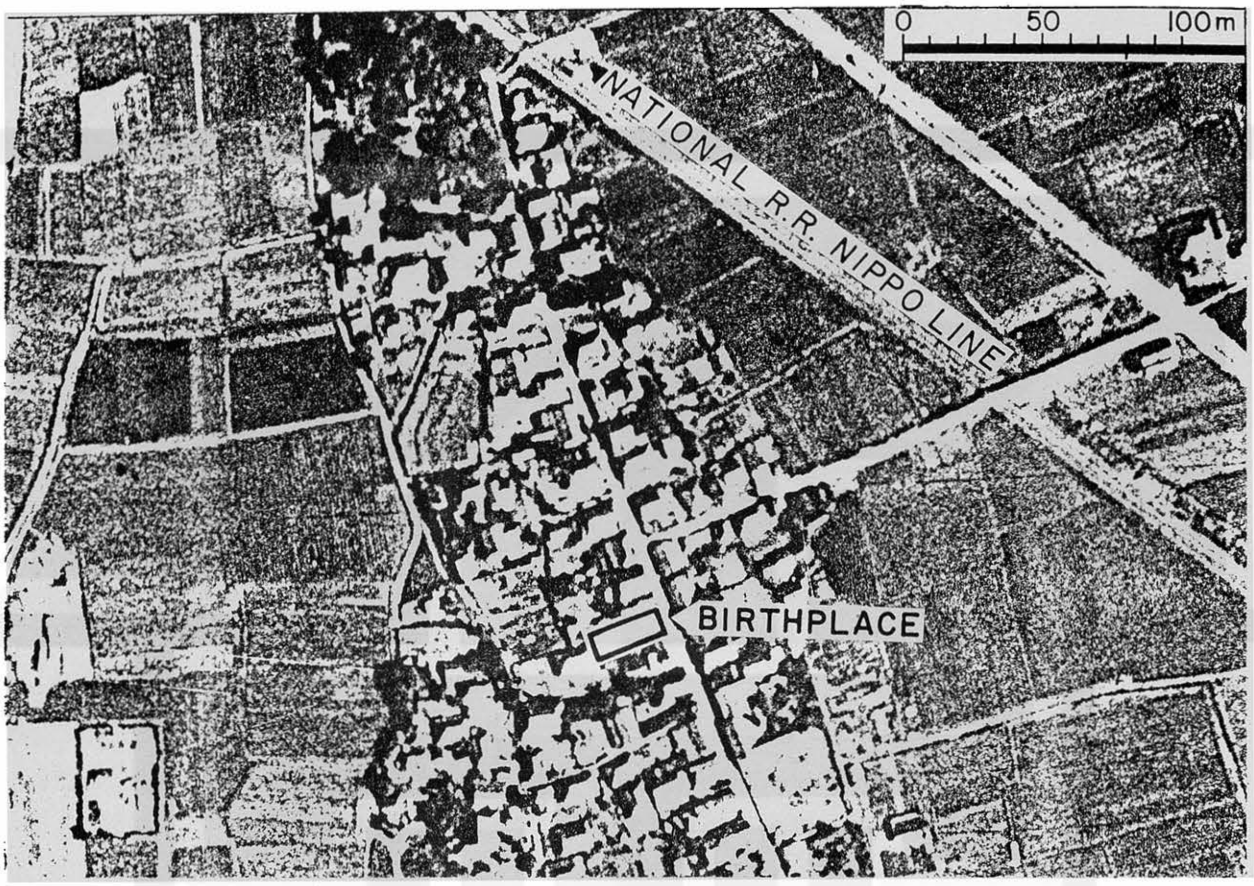
Research on El Niño with Sumiko

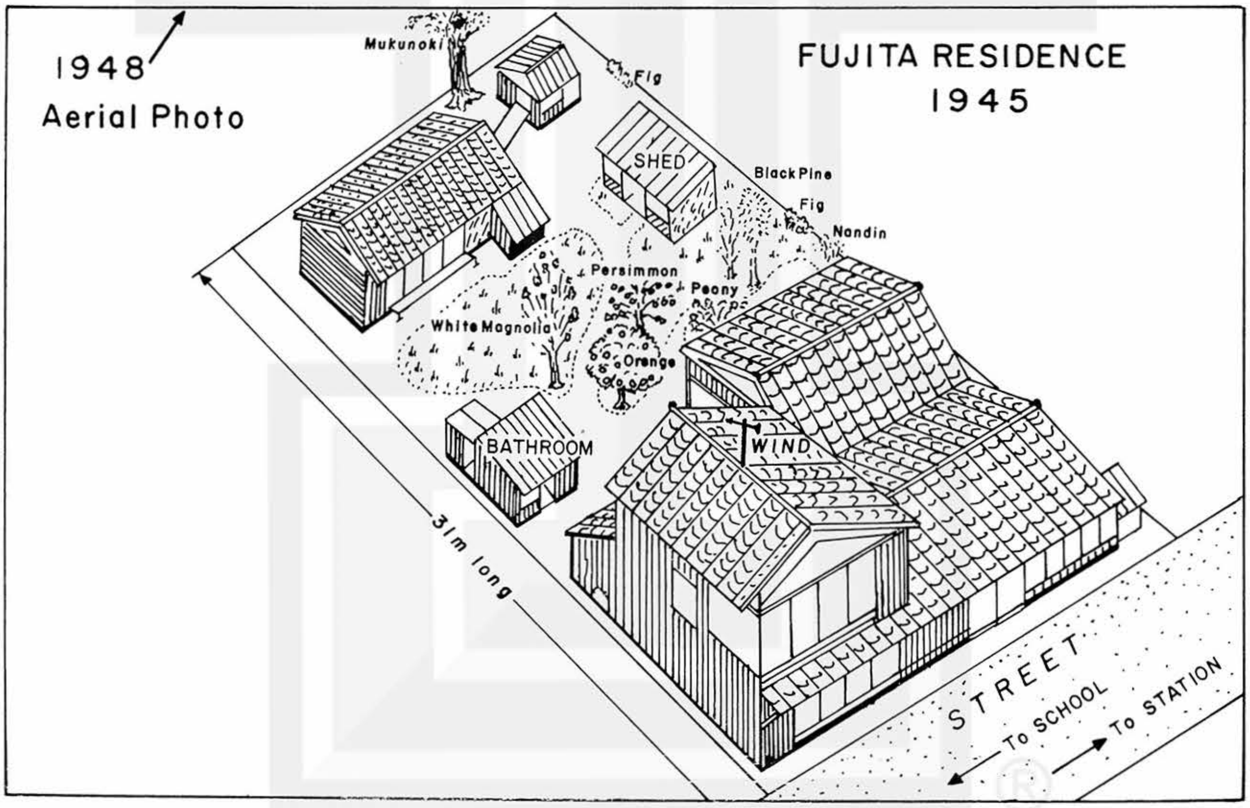
Since 18 August 1996 when pain at the base of my feet began unexpectedly, I was not able to walk to my office to conduct my promised research on **Hurricanes Around the World**. One year later, on 25 August 1997, I could no longer walk downstairs, being confined to my study adjacent to my bedroom. Sumiko carried three meals upstairs daily and my research staff, Jim Partacz and Duane Stiegler brought research materials to my study.

All of a sudden, I noticed that the memory of my specialized subjects is so vivid that I was able to pursue my research without referring again to the standard bibliography. After revealing the startling change of hurricane activity during El Niño years, I decided to undertake a new research on the cause of El Niño based on my scientific memory of the subjects.

It was my 77th birthday when I announced my plan of this El Niño research to be pursued jointly with my wife Sumiko. A number of new ideas came to my eyes one after another, completing the framework of the new ideas by 12 December 1997 and an 80-page manuscript, on 8 January 1998. The paper was completed in less than three months. I drafted every single illustration and Jim generated all computer graphics used in this paper.

Some 77 years ago, on 23 October 1920, I was born in a small village of Nakasone in northern Kyushu, Japan. I observed typhoon winds from the top of my roof. For fear of a possible accident, my father dragged me down the roof in high winds (p 68). Since 1943, I taught in Japan and moved to the University of Chicago in 1953. During these years, I felt that **Research is a Many Splendored Thing**.


0 50 100m
NATIONAL R.R. NIPPO LINE
BIRTHPLACE


1948
Aerial Photo
FUJITA RESIDENCE
1945
Mukunoki
Fig
SHED
Black Pine
Fig
Nandin
Persimmon
Peony
White Magnolia
Orange
BATHROOM
WIND
31m long
STREET
To SCHOOL
To STATION

Fujita's family picture in 1934 (Showa 9) taken in the backyard (p 68).

••• Back row, from right to left, Tetsuya 14, mother Yoshie 32, grandmother Hatsu (father's mother) 63.

••• Front row, from right to left, brother Sekiya 6, father Tomojiro 42, sister Sizuko 8.

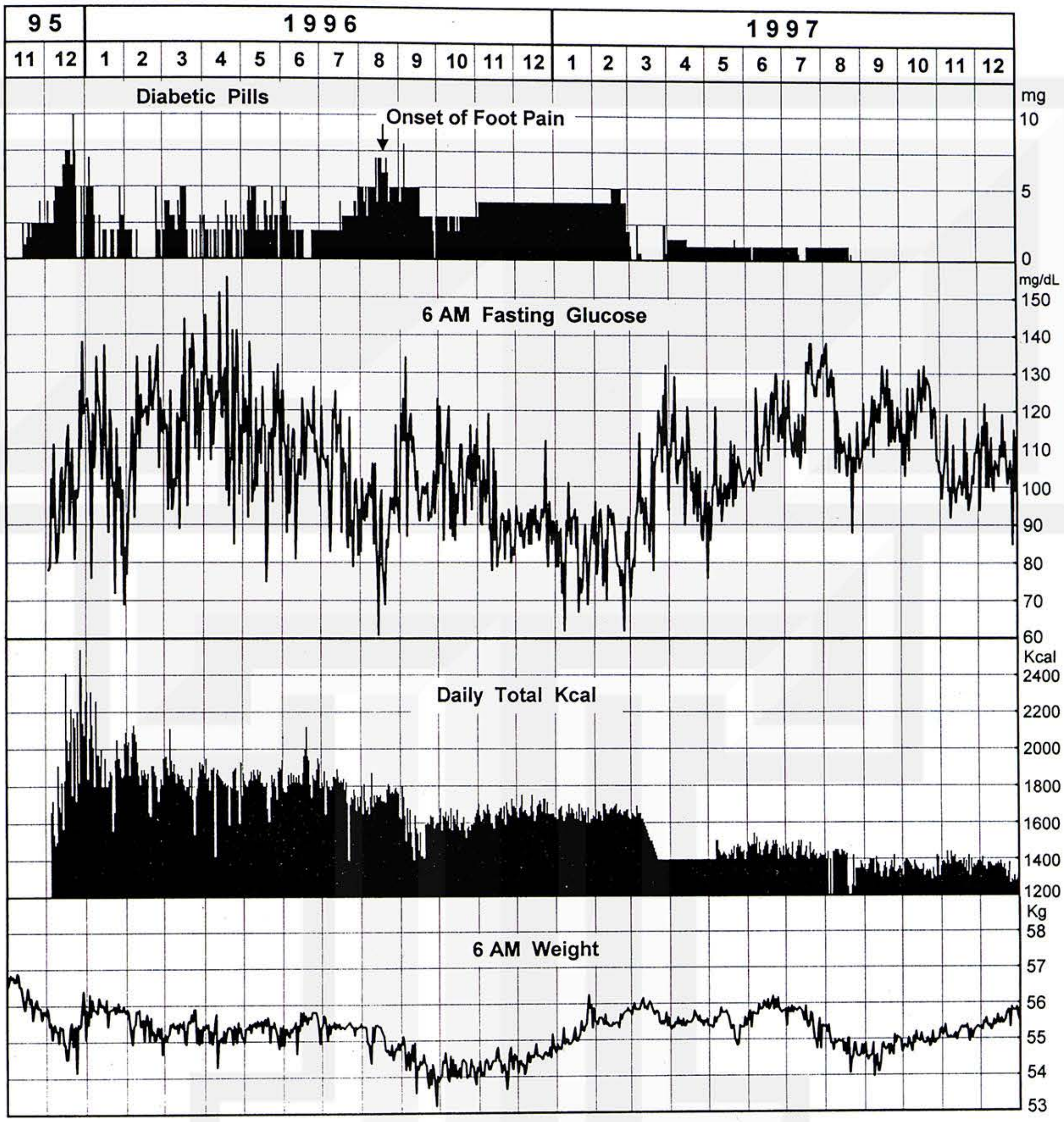
１９３４年（昭９）に撮った家族写真
••• 後列右から哲也１４才、母よしえ３２才、祖母（父の母）はつ ６３才。
••• 前列右から碩也６才、父友次郎４２才、妹閑子８才。

赤坂東急ホテルで写した
叙勲後のすみ子と私

Picture taken at Akasaka Tokyu Hotel after receiving Kun 2-tou medal at the Imperial Palace on 8 May 1991.

昭和 14 年	小倉中学　理科賞	昭和 53 年	アメリカ気象協会　応用気象学賞
昭和 34 年	日本気象学会　岡田賞	昭和 54 年	アメリカ航空宇宙局　特別貢献賞
昭和 40 年	九州工業大学　嘉村賞	昭和 57 年	アメリカ航空宇宙学会　ローシー大気科学賞
昭和 42 年	アメリカ気象学会　マイシンガー賞	昭和 60 年	アメリカ商務省　気象衛星25周年記念メダル
昭和 50 年	アラバマ州民間防衛局　特別貢献賞	昭和 63 年	アメリカ気象学会　応用気象学賞
昭和 50 年	局地性嵐会議　視覚表現最良賞	平成 元 年	フランス航空宇宙アカデミー金メダル
昭和 51 年	アーカンサス州　特別貢献賞	平成 2 年	日本気象学会　藤原賞
昭和 52 年	航空安全財団　アドミラル ルイス デ フロレス賞	平成 3 年	日本国政府　勲二等瑞寶章
昭和 52 年	航空安全財団　特別貢献賞	平成 4 年	日本国政府　交通文化賞金盃

Daily Medical Data by Fujita



During the past 16 months, Fujita has been suffering from walking difficulty. Chronological events are: Diagnosed with mild diabetes in November 1995, diabetic pills were taken since then. 6 a.m. glucose reached the lowest, 61 mg/dL on 15 August 1996. Foot pain and walking difficulty began on 18 August 1996. Glucose was between 70 and 90 mg/dL while foot pain kept increasing in proportion to the cumulative dosage of medication. Suspecting medication side effect, Fujita stopped medication completely on 25 August 1997. Since then, glucose remains between 100 and 130 mg/dL, near normal at my age 77. Severe pain with ambulatory difficulty still remains. Did I need diabetic medication?

To My Dedicated Wife, Sumiko

献身の妻すみ子に捧ぐ

１９９５年７月まで健康に恵まれ、４階の研究室まで僅か２４秒で階段を昇っていた私が降血圧剤をのみはじめてから口が渇き足が冷え、数カ月後に軽い糖尿病と診断されました。すみ子と私はリンデンバウムの歌を口ずさみながらシカゴ大学構内の菩提樹の並木道を毎日散歩。やがて、糖尿薬を日量５ｍｇのむ様に指示され血糖値を毎朝測定。その後血糖が急速に降下して最低になった１９９６年８月１８日に両足底に疼痛が発生、歩行困難になりました。

専門医の診察を受ける為、すみ子が車椅子を押して大学病院に通いました。残念ながら診断は専門医毎に異なり、糖尿からの痛みではない。靴を買い変える様に。糖尿からに違いない。などと、てんでバラバラで治療法不明。すみ子は薬５ｍｇと食事２２００ｋｃａｌは多すぎると心配し、日本式に薬をやめて１６００ｋｃａｌに減食しました。その後の血糖値は全く平常。はじめから薬の必要は無かったと痛感し、痛みの原因は薬の過剰投与の副作用による公算が強くなりました。数学的には「痛みの強さが投薬量の累計に比例している事実」に医者はノーコメント。

残念ながら、時既におそく、交感神経の障害が足底から手先に広がり、１９９７年８月末には階段を昇れなくなりました。すみ子が「二人が並んで菩提樹の並木道を歩ける様になる日まで、私が３度の食事と２度のスナックを寝室に運びます。早く治って下さいね」と階段を上下する靴音のコツコツが痛ましい。

全快を祈る妻の心を余所に私の痛みは日毎に進むので、ベッドの中で世界の台風の研究をし、寝室で研究打合せをして原稿を書き、すみ子の誕生日、１９９７年9月２８日に１６０頁の本の目次と概要を完成。両手両足の痛みに耐えながら、二人だけで、ささやかな乾杯をしました。私の栄養士、看護婦兼最愛の妻は涙をぬぐいながら「研究は貴方の生き甲斐。耐え難い痛みに耐えて良くなさいました」と咽ぶ。その内助の功がささやかな実を結び、私が夢にまで見た此の本が日の目を見ることになりました。私の研究生命の恩人すみ子に謝意を表します。

君の誕生日　平成９年9月２８日　夫　哲也

Acknowledgements

I was educated by three Mentor Professors. From my age 19 to 23, **Prof. Tadaichi Matsumoto of Kyushu Institute of Technology** taught me geology, geography, geodesy and topographic mapping while I drafted various maps and illustrations for him. "You are an excellent scientific draftsman", he said. **Prof. Sigekata Shono of Tokyo University** sponsored my ScD (only doctor's degree in Japan, then). He encouraged me to uncover microscale (mesoscale now) disturbances using barograph, wind, and temperature traces. I received ScD on Analytical Study of Typhoons on 1 August 1953. "Now I realize the importance of data analysis", he commented. **Prof. Horace R. Byers of the University of Chicago** invited me to join his Cloud Physics Laboratory immediately thereafter. I reanalyzed his Thunderstorm Project data, finding small-scale, unknown disturbances. The research developed into Mesometeorology. He fathered me saying, "I am very happy for your move from Japan to the United States".

Looking back at my research history at the University of Chicago, I am grateful to various agencies who supported my research for 45 years from 1953 to 1998. **I did not recall either excessive (El Niño) or inadequate (La Niña) funding throughout my research life**. In particular, I wish to express my sincere appreciation to NASA for supporting my El Niño/TOPEX research under Grant NAG 5-3041. This research was initiated after revealing the startling percent change of the hurricane activity around the world supported by the Office of Naval Research (ONR) under Grant N00014-91-J1136.

Sincere appreciation is due to Dr. Robert F. Abbey, Jr. of ONR, who encouraged Sumiko and I to complete this El Niño/La Niña research on global scale, which began on 23 OCT 97, my 77th (KIJYU) birthday. Without his frequent telephone calls concerning my health and research together, we could not have completed the camera-ready manuscript of this paper in 81 days on 11 January 1998.

Tetsuya T. and Sumiko Fujita 1/11/98