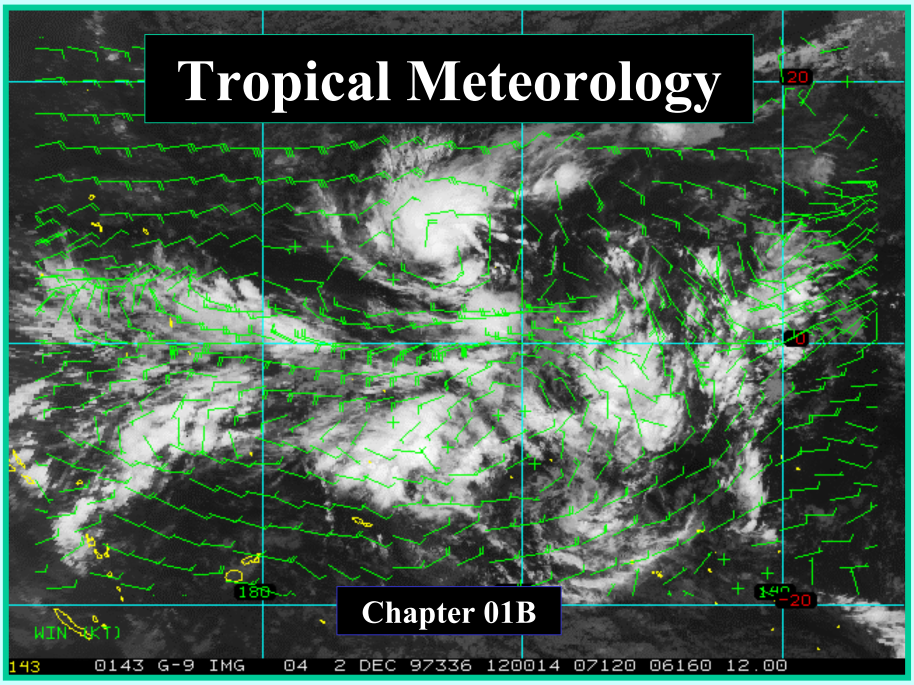
Tropical Meteorology



Chapter 01B

Topics

- El Niño – Southern Oscillation (ENSO)
- The Madden-Julian Oscillation
- Westerly wind bursts

The Southern Oscillation

- **There is considerable interannual variability in the scale and intensity of the Walker Circulation, which is manifest in the so-called Southern Oscillation (SO).**
- **The SO is associated with fluctuations in sea level pressure in the tropics, monsoon rainfall, and wintertime circulation over the Pacific Ocean and also over North America and other parts of the extratropics.**
- **It is the single most prominent signal in year-to-year climate variability in the atmosphere.**
- **It was first described in a series of papers in the 1920s by Sir Gilbert Walker and a review and references are contained in a paper by Julian and Chervin (1978).**

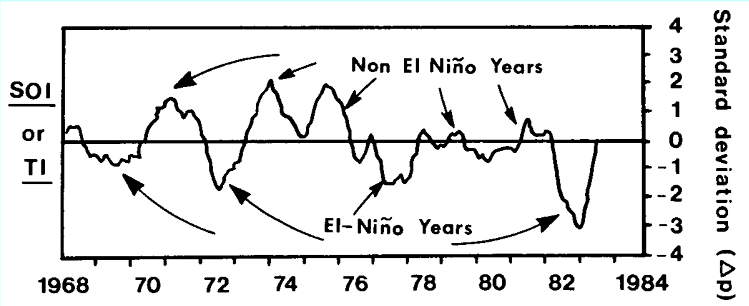
The Southern Oscillation

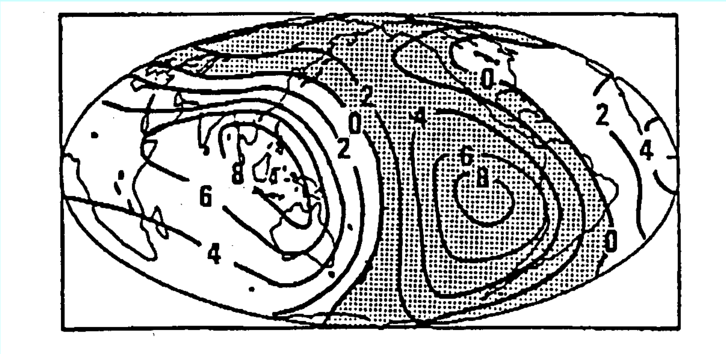
- **Julian and Chervin (1978) use Walker´s own words to summarize the phenomenon.**

"By the southern oscillation is implied the tendency of (surface) pressure at stations in the Pacific (San Francisco, Tokyo, Honolulu, Samoa and South America), and of rainfall in India and Java... to increase, while pressure in the region of the Indian Ocean (Cairo, N.W. India, Darwin, Mauritius, S.E. Australia and the Cape) decreases...“

and

"We can perhaps best sum up the situation by saying that there is a swaying of pressure on a big scale backwards and forwards between the Pacific and Indian Oceans...".





The Southern Oscillation

- Bjerknes (1969) first pointed to an association between the SO and the Walker Circulation, but the seeds for this association were present in the studies by Troup (1965).
- These authors noted the presence of interannual changes in the upper troposphere flow over the tropics associated with the SO and indicated that the anomalies in the flow covered a large range of longitudes.

The Southern Oscillation

- **Bjerknes stated:**

"*The Walker Circulation.... must be part of the mechanism of the still larger ´Southern Oscillation´ statistically defined by Sir Gilbert Walker... whereas the Walker Circulation maintains east-west exchange of air covering a little over an earth quadrant of the equatorial belt from South America to the west Pacific, the concept of the Southern Oscillation refers to the barometrically-recorded exchange of mass along the complete circumference of the globe in tropical latitudes. What distinguishes the Walker Circulation from other tropical east-west exchanges of air is that it operates a large tapping of potential energy by combining the large-scale rise of warm-moist air and descent of colder dry air*".

The Southern Oscillation

- **In a subsequent paper, Bjerknes (1970) describes this thermally-direct circulation oriented in a zonal plane by reference to mean monthly wind soundings at opposing "swings" of the SO and the patterns of ocean temperature anomalies.**

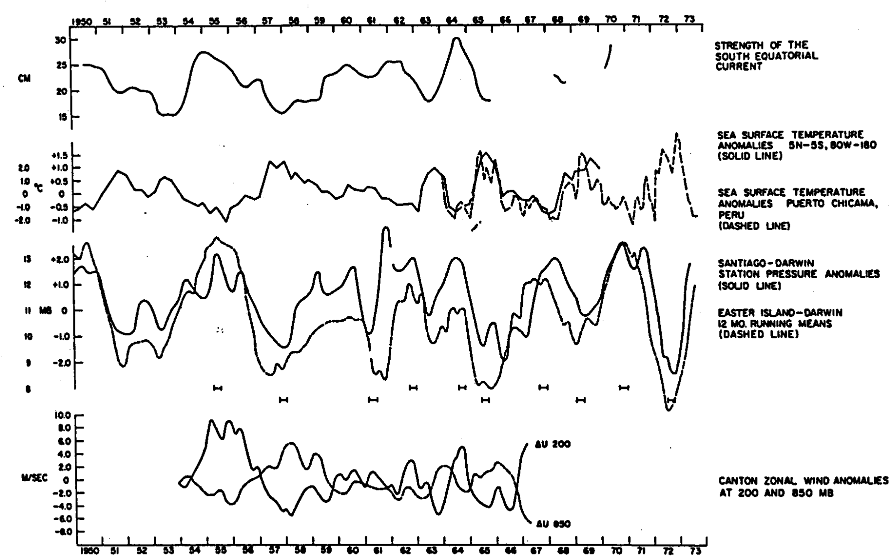
El Niño

- **El Niño** refers to the appearance of anomalously warm surface water off the South American coast, a condition which leads periodically to catastrophic downturns in the Peruvian fishing industry by severely reducing the catch.
- The colder water that normally upwells along the Peruvian coast is rich in nutrients, in contrast to the warmer surface waters during El Niño.
- The phenomenon has been the subject of research by oceanographers for many years, but again it seems to have been Bjerknes (1969) who was the first to link it with the southern oscillation (SO) as some kind of air-sea interaction effect.

The Southern Oscillation

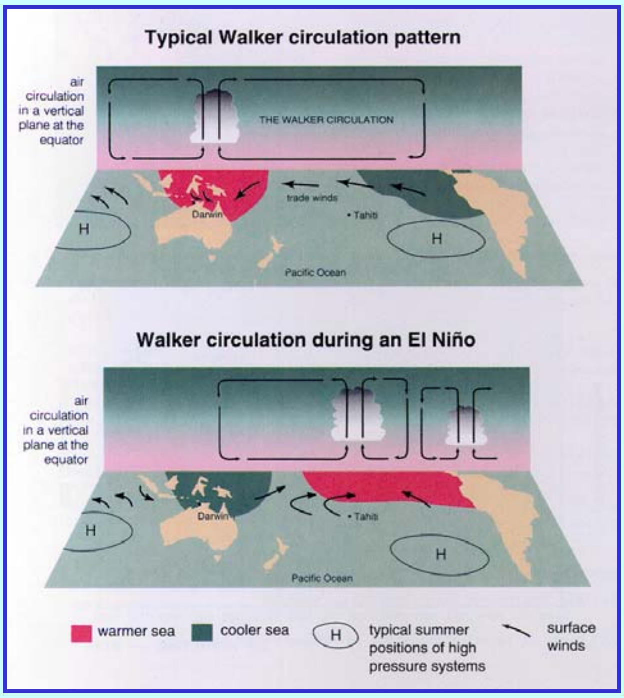
- Bjerknes used satellite imagery to define the region of heavy rainfall over the zone of the equatorial central and eastern Pacific during episodes of warm SSTs there.
- He showed that these fluctuations in SST and rainfall are associated with large-scale variations in the equatorial trade wind systems, which in turn effect the major variations of the SO pressure pattern.
- The fluctuations in the strength of the trade winds can be expected to affect the ocean currents, themselves, and therefore the ocean temperatures to the extent that these are determined by the advection of cooler or warmer bodies of water to a particular locality.

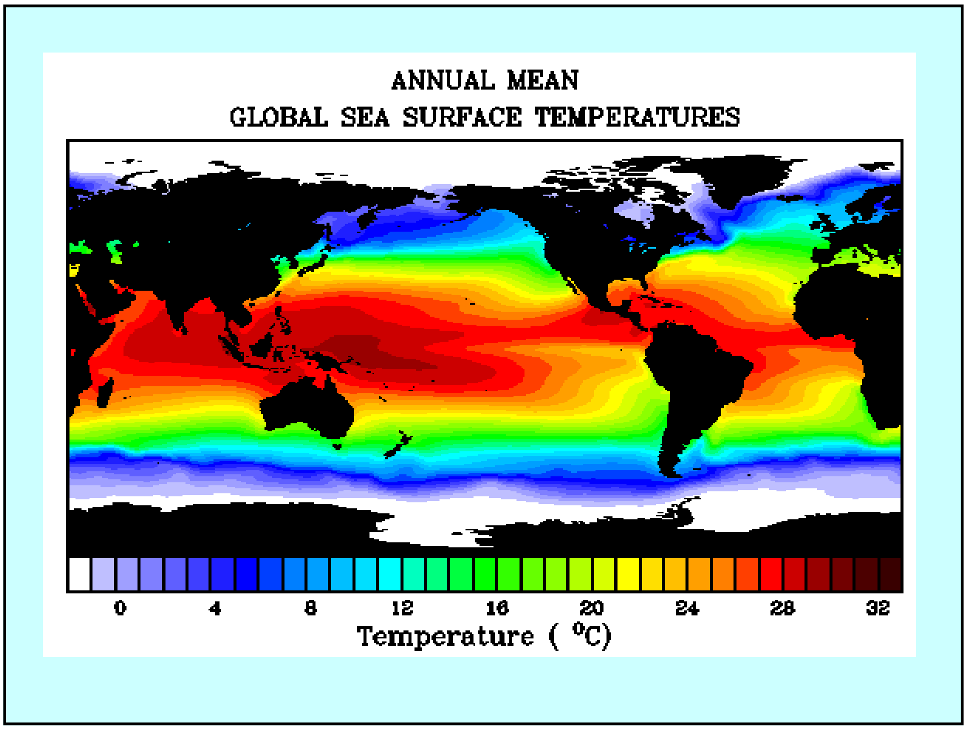
- ➢ The next figure shows time-series of various oceanic and atmospheric variables at tropical stations during the period 1950 to 1973 taken from Julian and Chervin (1978).
- ➢ These data include:
  - the strength of the South Equatorial Current;
  - the average SST over the equatorial eastern Pacific;
  - the Puerto Chicama (Peru) monthly SST anomalies;
  - the 12 month running averages of the Easter Island-Darwin differences in sea level pressure;
  - and the smoothed Santiago-Darwin station pressure differences.
- ➢ The figure shows also the zonal wind anomalies at Canton Island (3°S, 172°W) which was available for the period 1954-1967 only.

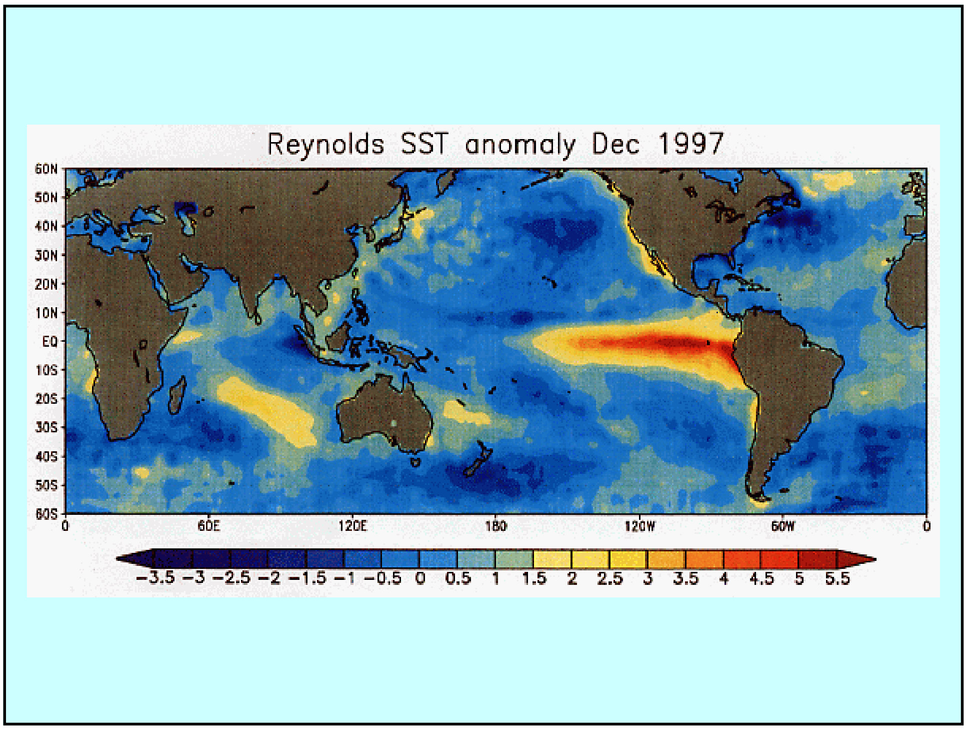


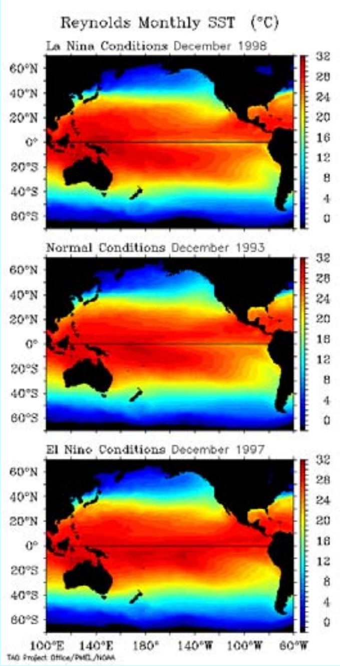
ENSO

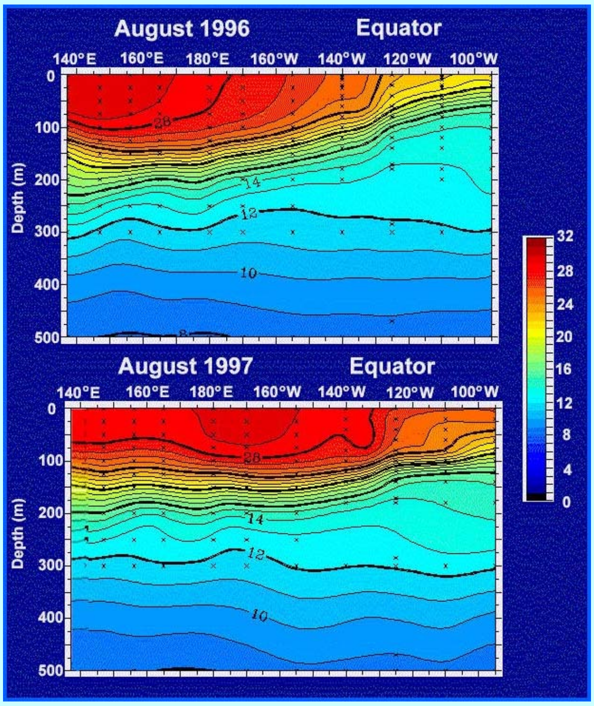
- The mutual correlation and particular phase association of these time series is striking and indicate an atmosphere-ocean coupling with a time scale of years and a spatial scale of tens of thousands of kilometres involving the tropics as well as parts of the subtropics.
- This coupled ocean-atmosphere phenomenon is now referred to as ENSO, an acronym for El Niño-Southern Oscillation.

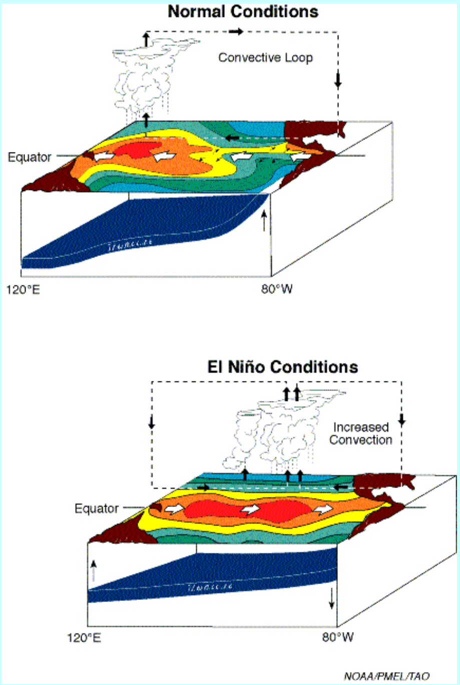


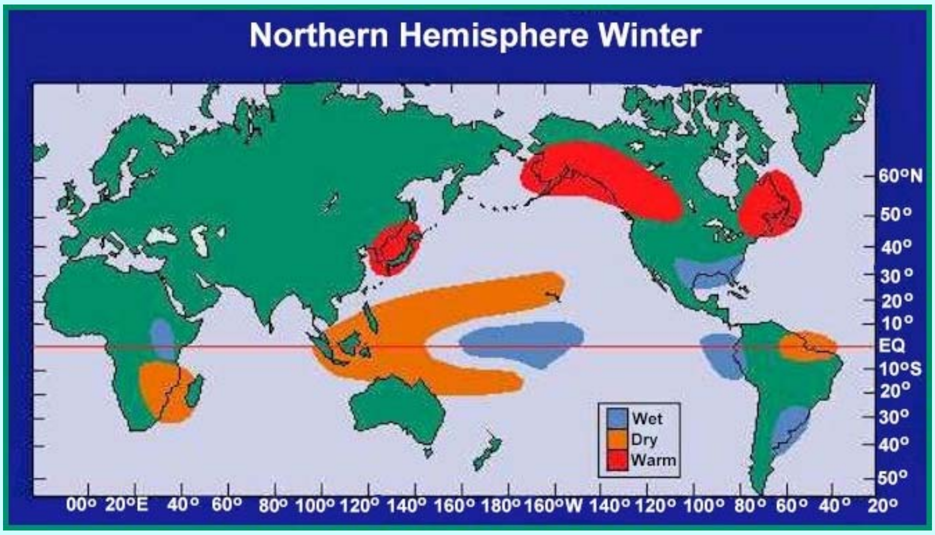

ANNUAL MEAN
GLOBAL SEA SURFACE TEMPERATURES
0 4 8 12 16 20 24 28 32
Temperature (°C)

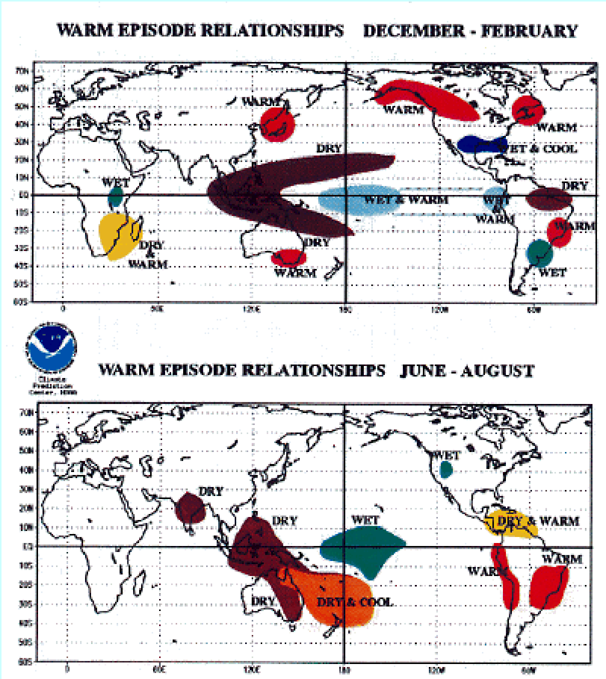

Reynolds SST anomaly Dec 1997
60N 50N 40N 30N 20N 10N EQ 10S 20S 30S 40S 50S 60S
0 60E 120E 180 120W 60W 0
−3.5 −3 −2.5 −2 −1.5 −1 −0.5 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5


Reynolds Monthly SST (°C)
La Nina Conditions December 1998
Normal Conditions December 1993
El Nino Conditions December 1997
60°N
40°N
20°N
0°
20°S
40°S
60°S
100°E 140°E 180° 140°W 100°W 60°W
32
28
24
20
16
12
8
4
0
TAO Project Office/PMEL/NOAA


August 1996 Equator
August 1997 Equator
140°E 160°E 180°E 160°W 140°W 120°W 100°W
Depth (m)
0
100
200
300
400
500
28
14
12
10
32
28
24
20
16
12
8
4
0


Normal Conditions
Convective Loop
Equator
120°E
80°W
El Niño Conditions
Increased Convection
Equator
120°E
80°W
NOAA/PMEL/TAO


Northern Hemisphere Winter
Wet
Dry
Warm
60°N
50°
40°
30°
20°
10°
EQ
10°S
20°
30°
40°
50°
00° 20°E 40° 60° 80° 100° 120° 140° 160° 180° 160°W 140° 120° 100° 80° 60° 40° 20°



Madden-Julian Oscillation

- As well as interannual fluctuations, the Walker Circulation appears to undergo significant fluctuations on intraseasonal timescales.
- This discovery was made by Madden and Julian (1971, 1972) who found a 40-50 day oscillation in time series of sea-level pressure and rawinsonde data at tropical stations.
- They described the oscillation as consisting of global-scale eastward-propagating zonal circulation cells along the equator.
- The oscillation appears to be associated with intraseasonal variations in tropical convective activity as evidenced in time series of rainfall and in analyses of anomalies in cloudiness and outgoing long-wave radiation (OLR) as measured by satellites.

Madden-Julian Oscillation

Description of Global-Scale Circulation Cells in the Tropics with a 40–50 Day Period

ROLAND A. MADDEN AND PAUL R. JULIAN

National Center for Atmospheric Research,[1] Boulder, Colo. 80302

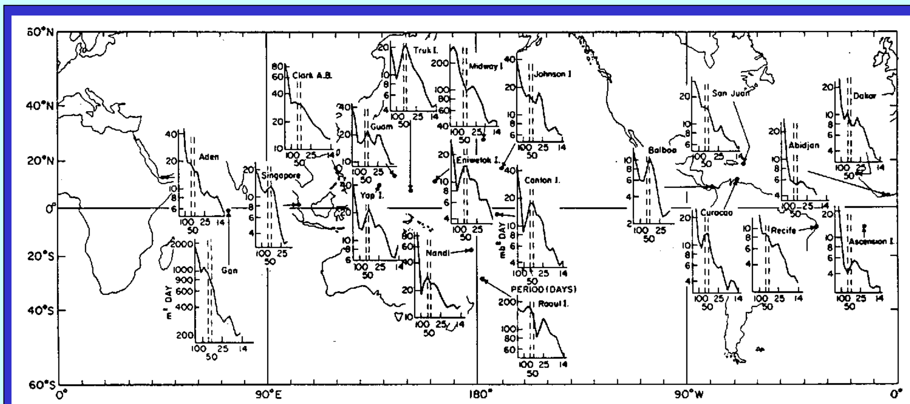
(Manuscript received 6 April, in revised form 15 May 1972)

ABSTRACT

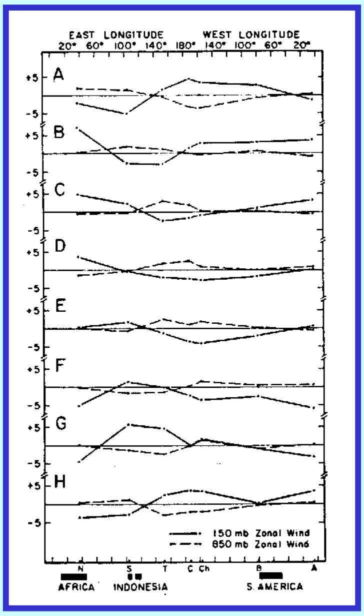
Long time series (5–10 years) of station pressure and upper air data from stations located in the tropics are subjected to spectral and cross-spectral analysis to investigate the spatial extent of a previously detected oscillation in various variables with a period range of 40–50 days. In addition, time series of station pressure from two tropical stations for the 1890's are examined and indicate that the oscillation is a stationary feature. The cross-spectral analysis suggests that the oscillation is of global scale but restricted to the tropics: it possesses features of an eastward-moving wave whose characteristics change with time. A mean wave disturbance, constructed with data from the IGY, provides additional descriptive material on the spatial and temporal behavior of the oscillation. The manifestation in station pressure consists of anomalies which appear between 10N and 10S in the Indian Ocean region and propagate eastward to the Eastern Pacific. Zonal winds participate in the oscillation and, in general, are out-of-phase between the upper and lower troposphere. Mixing ratios and temperatures are also investigated. The sum total of evidence indicates that the oscillation is the result of an eastward movement of large-scale circulation cells oriented in the equatorial (zonal) plane.

From JAS, Sept. 1972

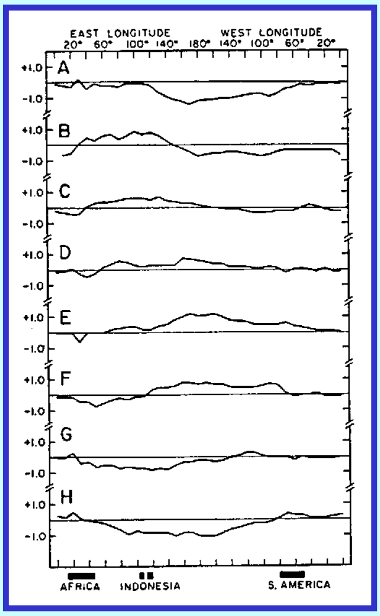
Variance spectra for selected surface stations



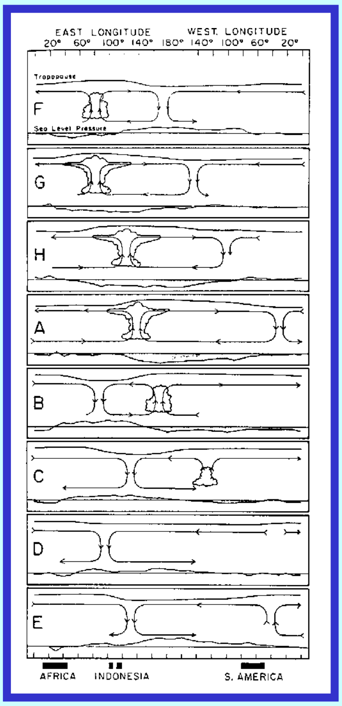
Mean zonal wind



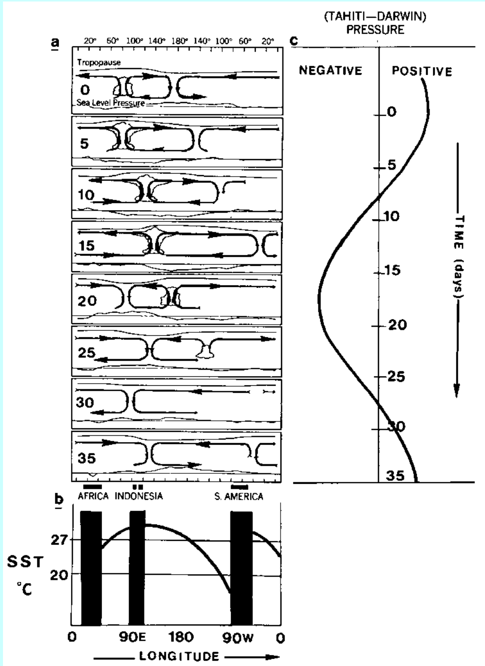
Mean surface pressure



Madden-Julian Oscillation



MJO



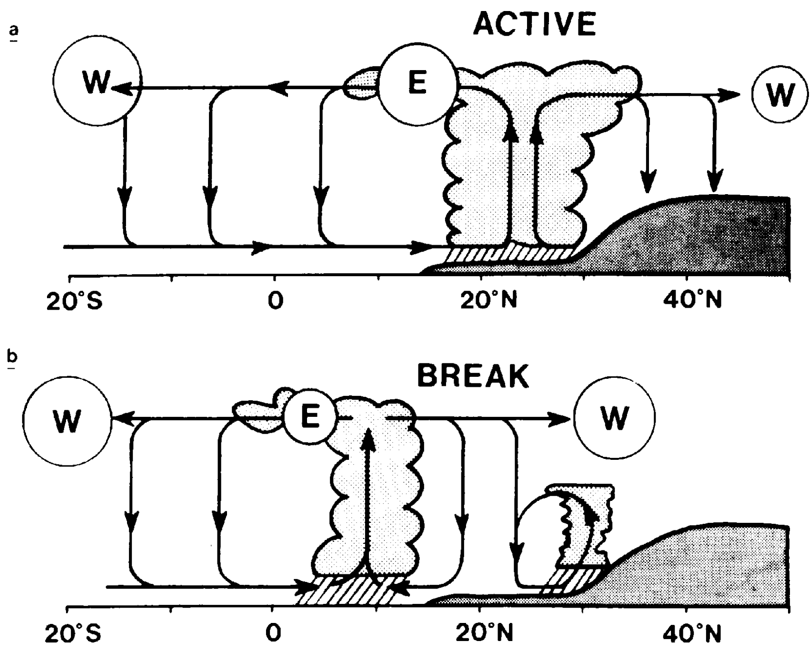
From Webster 1987

Madden-Julian Oscillation

- The results of various studies to the mid-80s are summarized by Lau and Peng (1987).
- They list the key features of the intraseasonal variability as follows:
  - There is a predominance of low-frequency oscillations in the broad range from 30-60 days;
  - The oscillations have predominant zonal scales of wavenumbers 1 and 2 and propagate eastward along the equator year-round;
  - Strong convection is confined to the equatorial regions of the Indian Ocean and western Pacific sector, while the wind pattern appears to propagate around the globe.

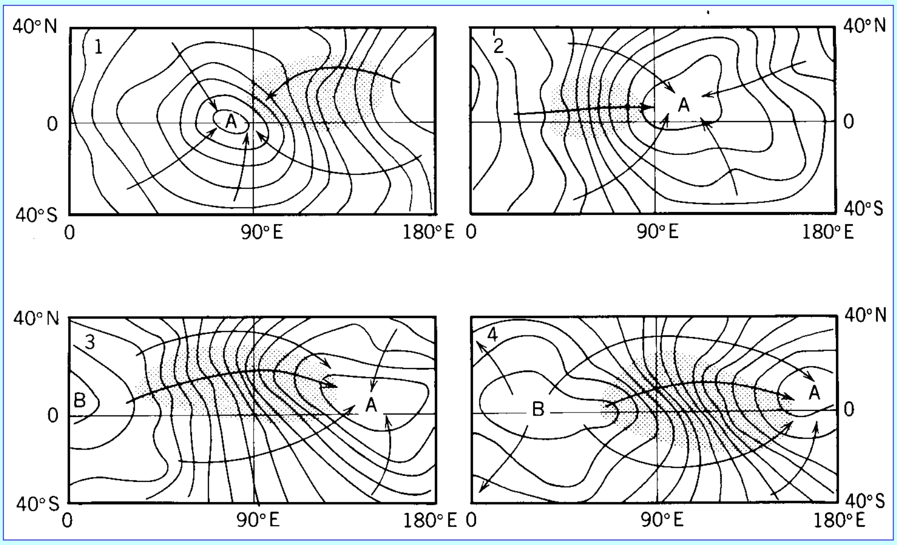
Madden-Julian Oscillation

- There is a marked northward propagation of the disturbance over India and East Africa during the summer monsoon season and, to a lesser extent, southward penetration over northern Australia during the northern winter.
- Coherent fluctuations between extratropical circulation anomalies and the tropical 40-50 day oscillation *may* exist, indicating possible tropical-midlatitude interactions on the above time scale.
- The 40-50 day oscillation appears to be phase-locked to oscillations of 10-20 day periods over India and the western Pacific. Both are closely related to monsoon onset and break conditions over the above regions.



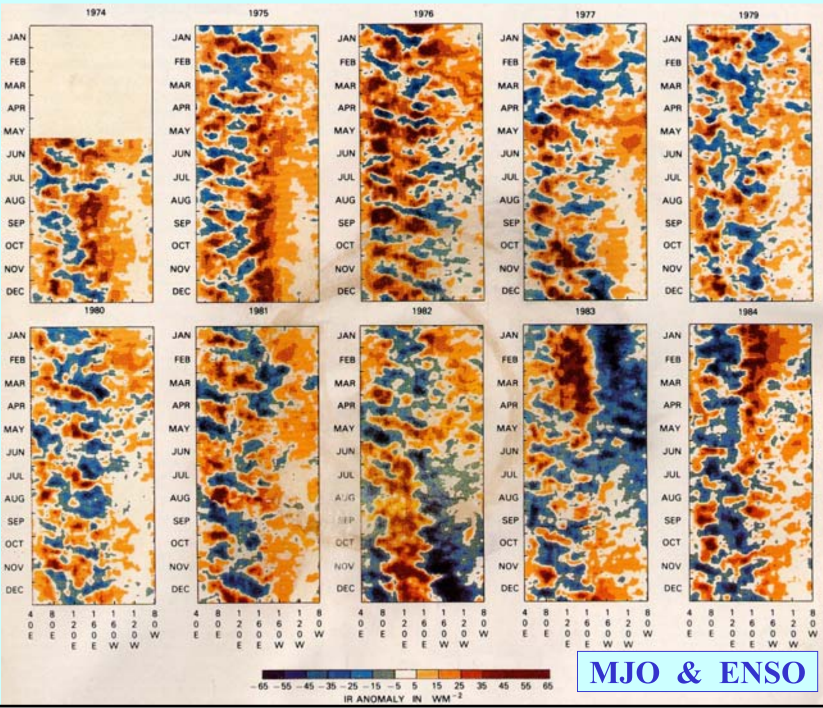
- According to Lau and Peng, the most fundamental features of the oscillation are the perennial eastward propagation along the equator and the slow time scale in the range 30-60 days.
- To date, observational knowledge of the phenomenon has outpaced theoretical understanding, but it would appear that the equatorial wave modes to be discussed later play an important role in the dynamics of the oscillation.
- Because of the similar spatial and relative temporal evolution of atmospheric anomalies associated with the 40-50 day oscillation and those with ENSO, it is likely that the two phenomena are closely related (see. e.g. Lau and Chan, 1986).
- One might view the atmospheric part of the ENSO cycle as fluctuations in a longer-term (e.g. seasonal average of the MJO).

Velocity potential changes with the MJO



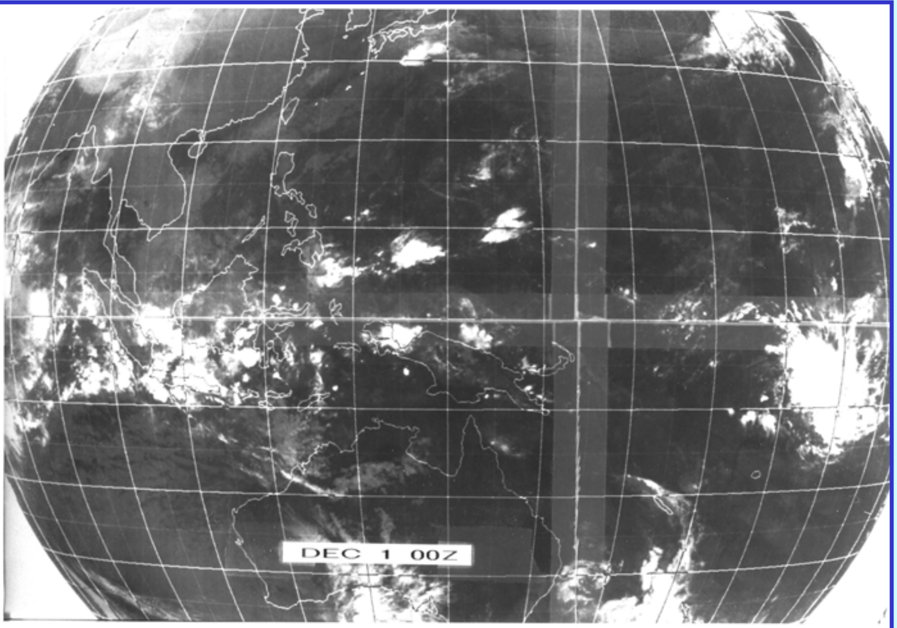
Literature on the MJO

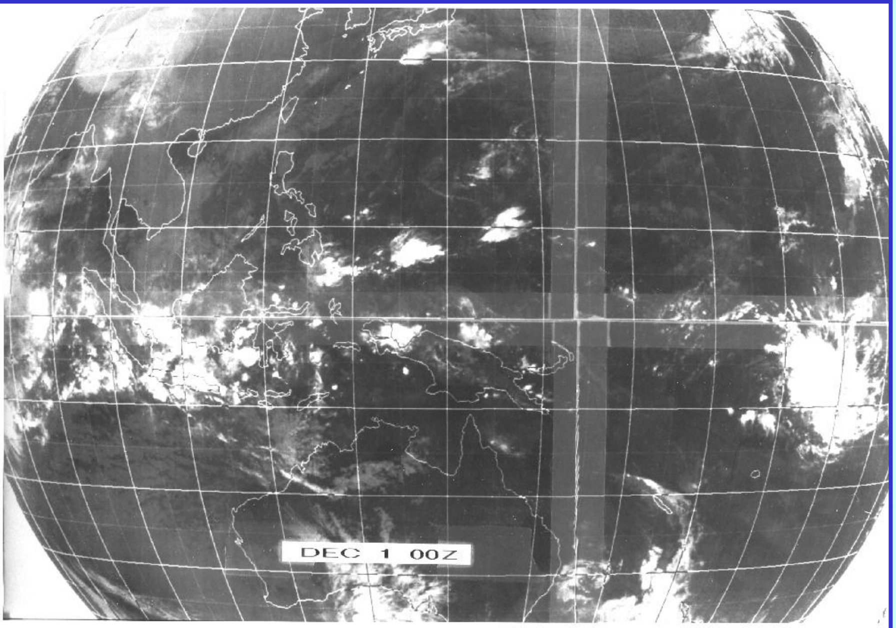
- Two recent observational studies of the MJO are those of Knutson *et al*., (1986) and Knutson and Weickmann (1987).
- A recent review of observational studies is included in the paper by Madden and Julian (1994).
- A recent review of theoretical studies is included in the paper by Bladé and Hartmann (1993).

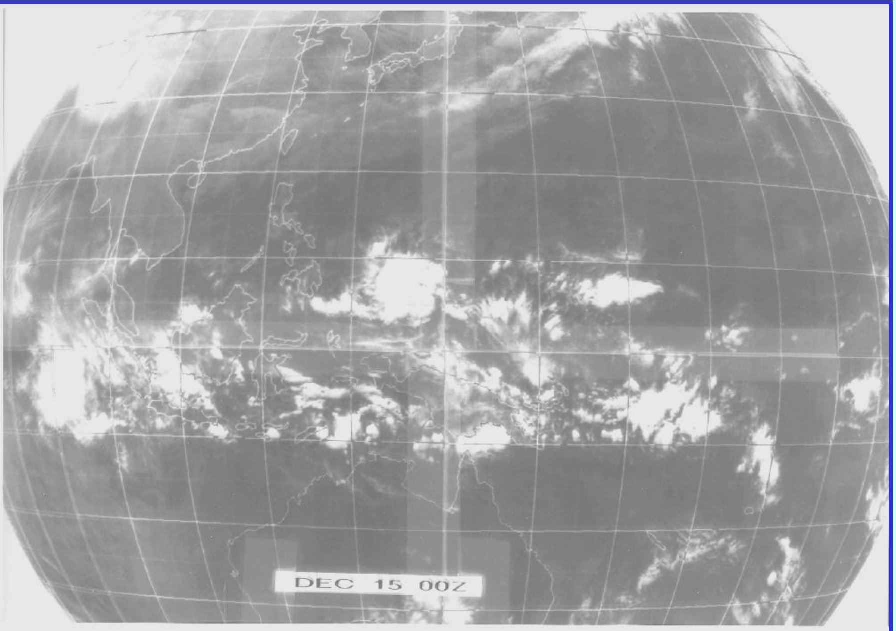


MJO & ENSO

A well-marked Madden-Julian Oscillation




DEC 1 00Z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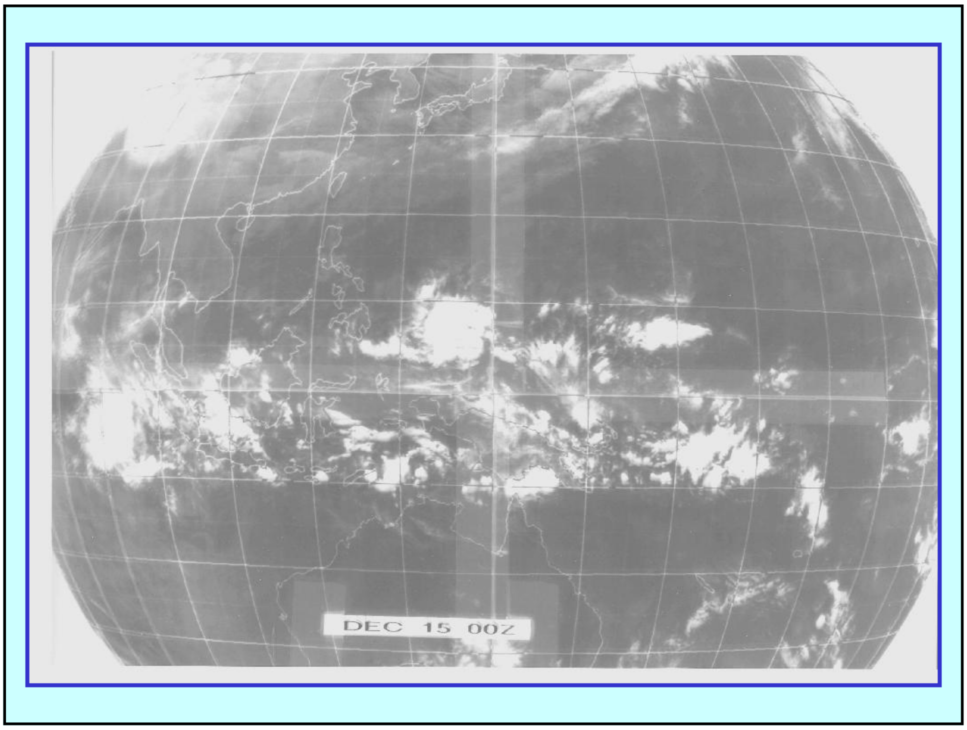
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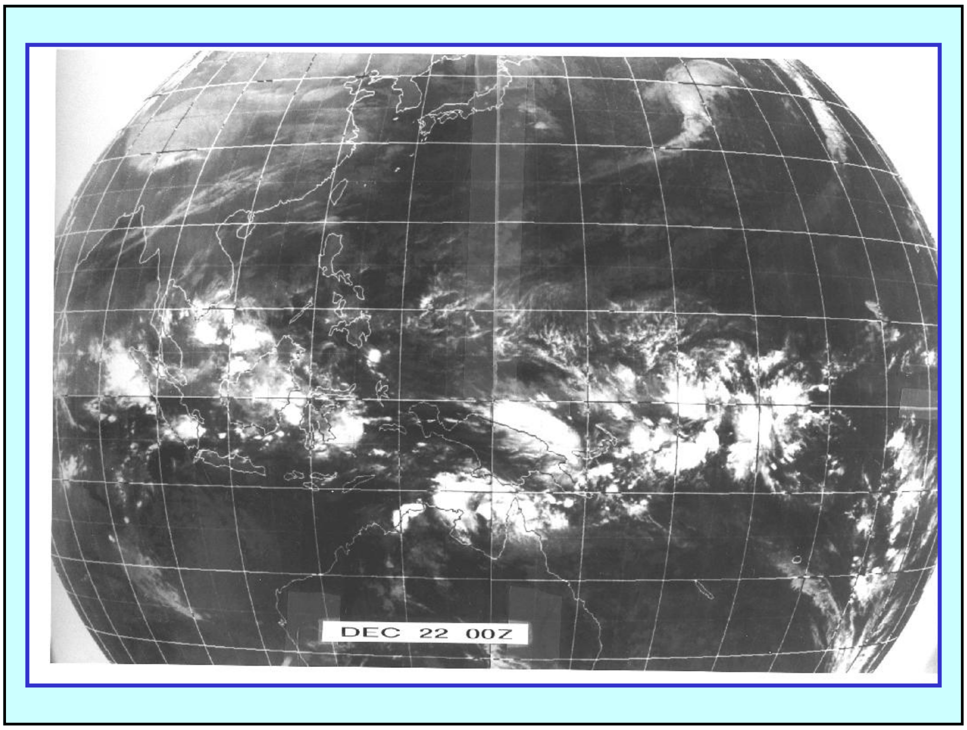
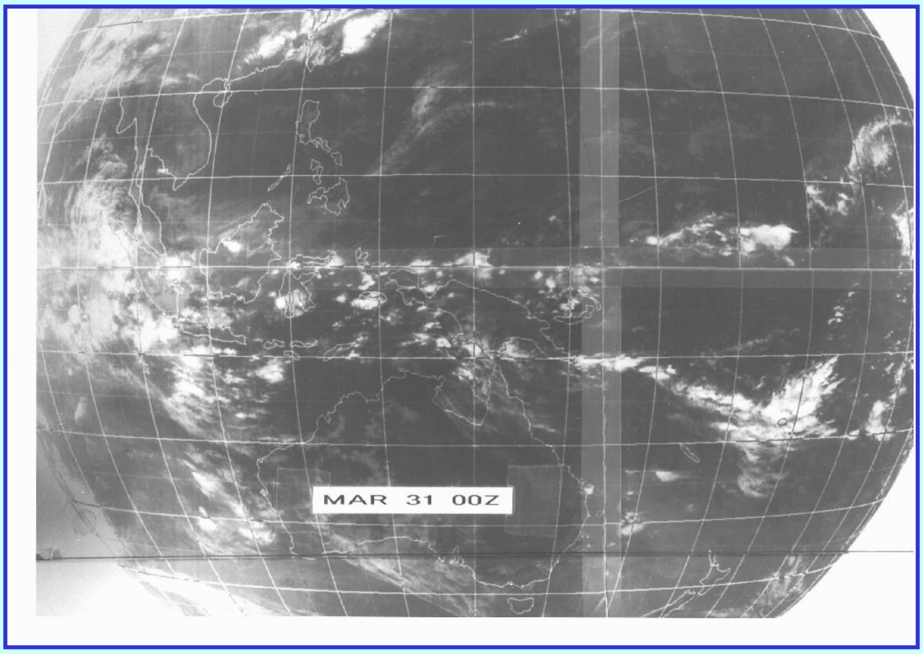

DEC 22 00Z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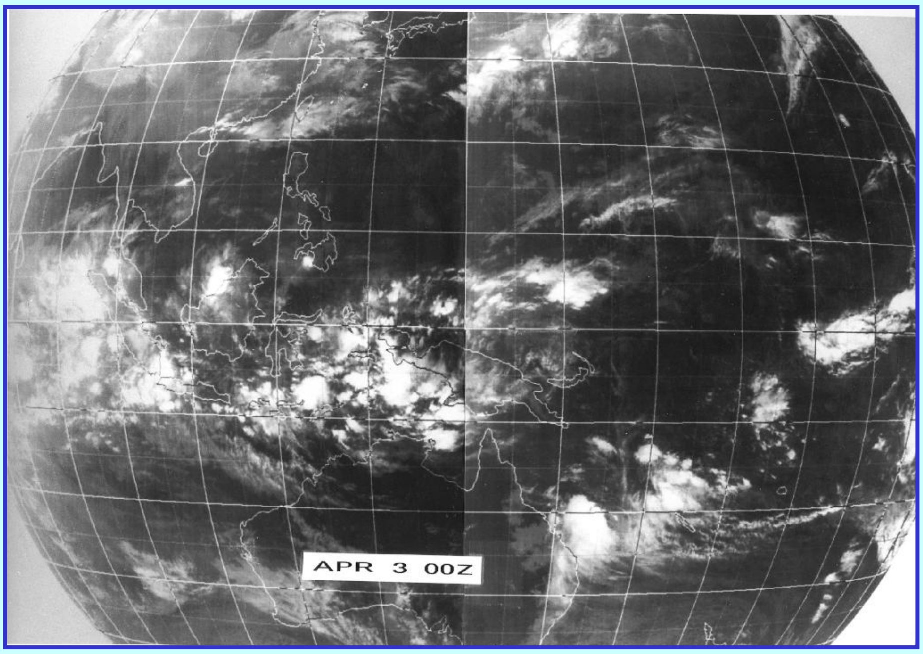
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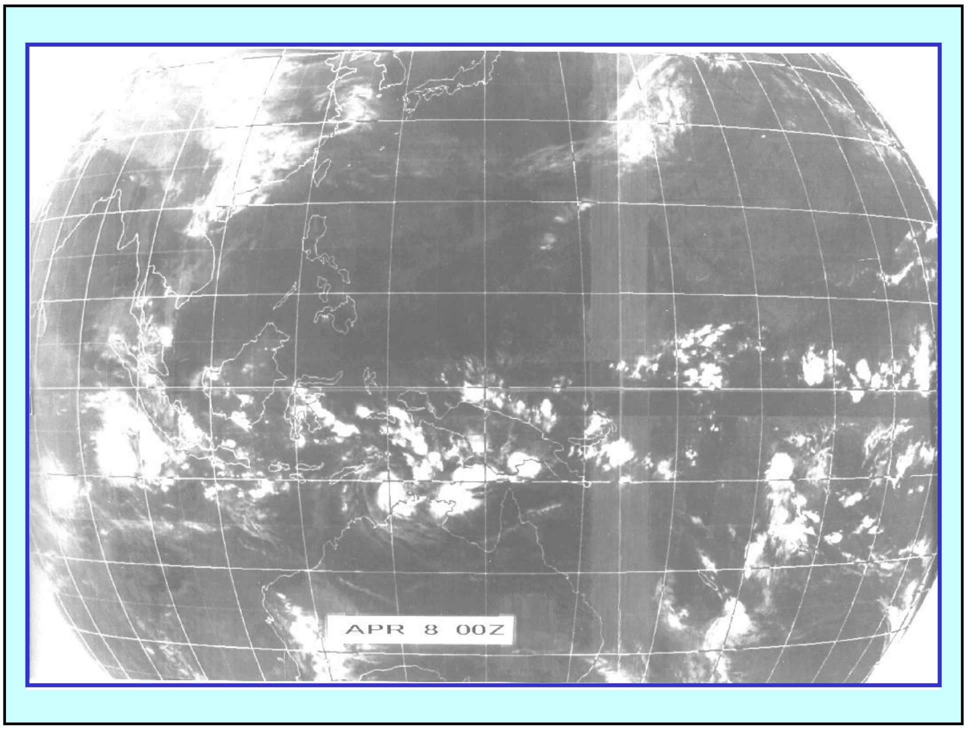
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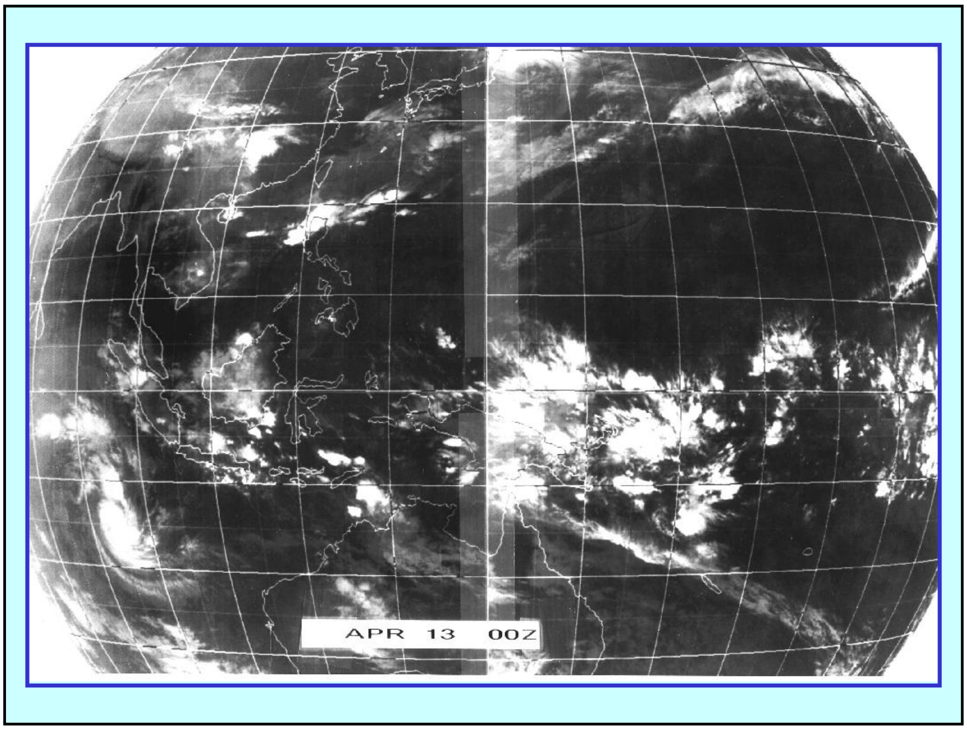
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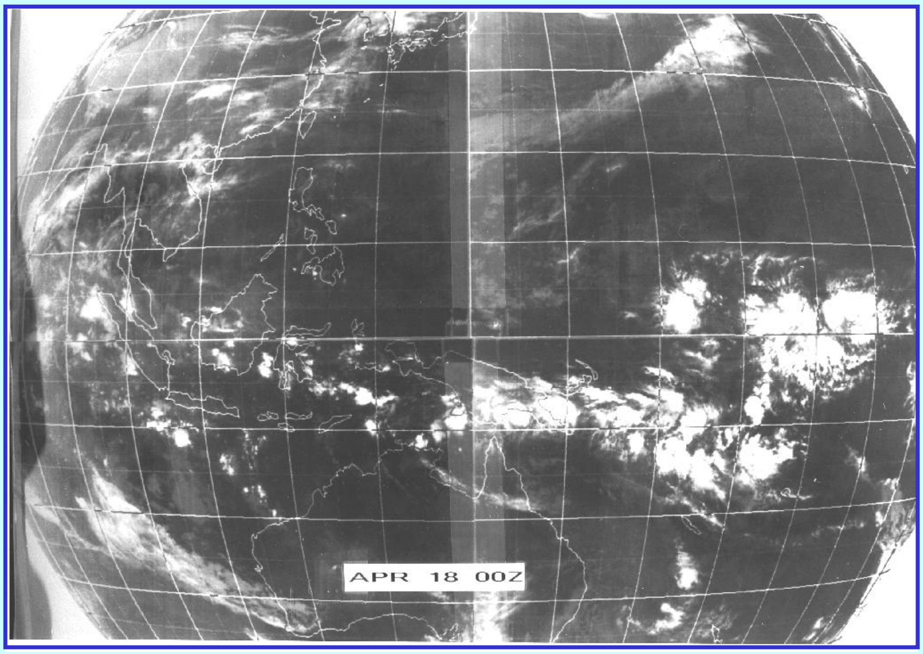
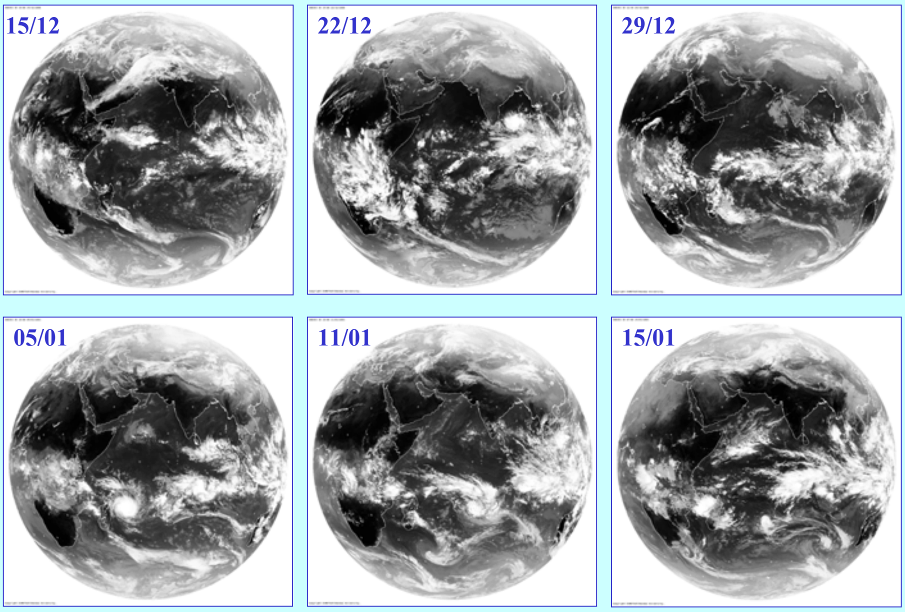


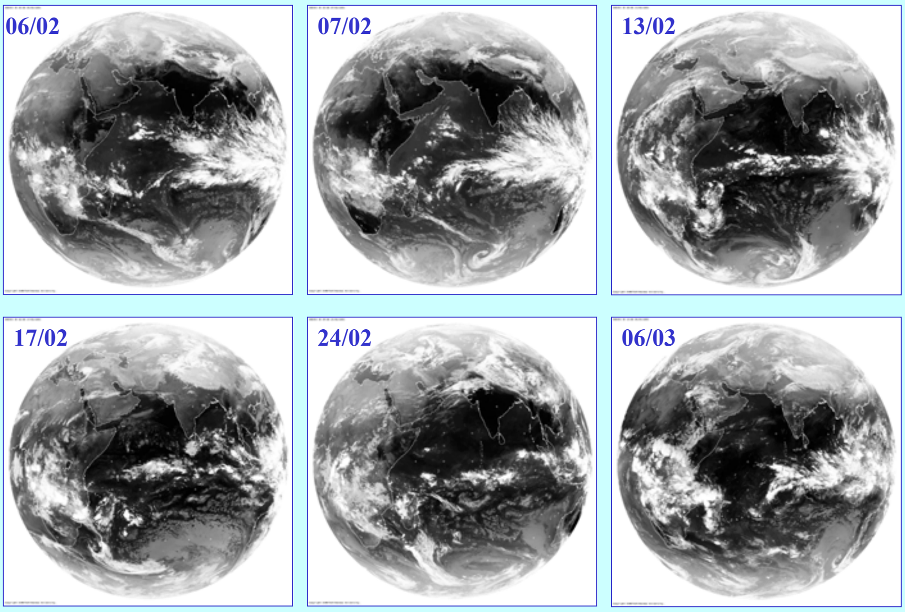
Madden-Julian Oscillation

Jan – Feb 2001

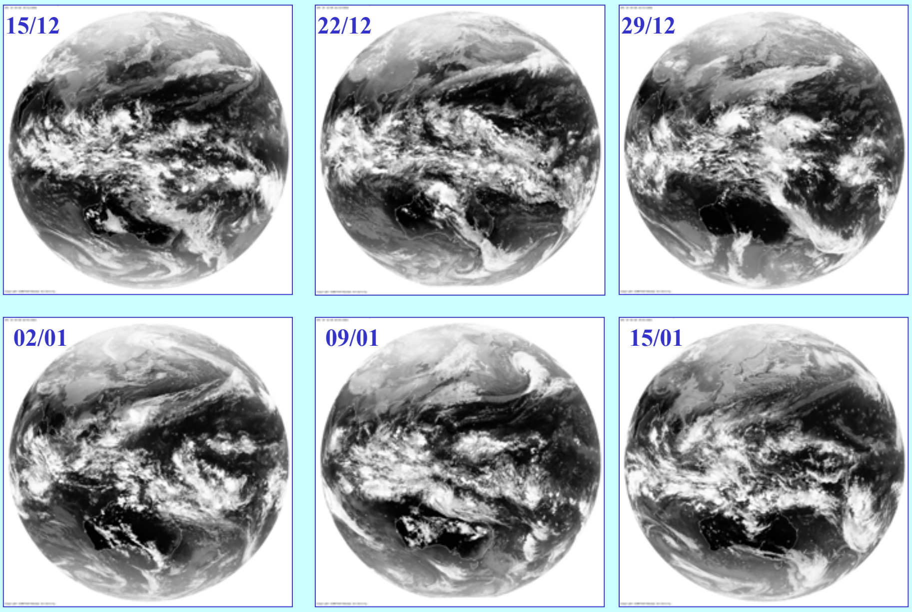
Indian Ocean Dec 2000/Jan 2001



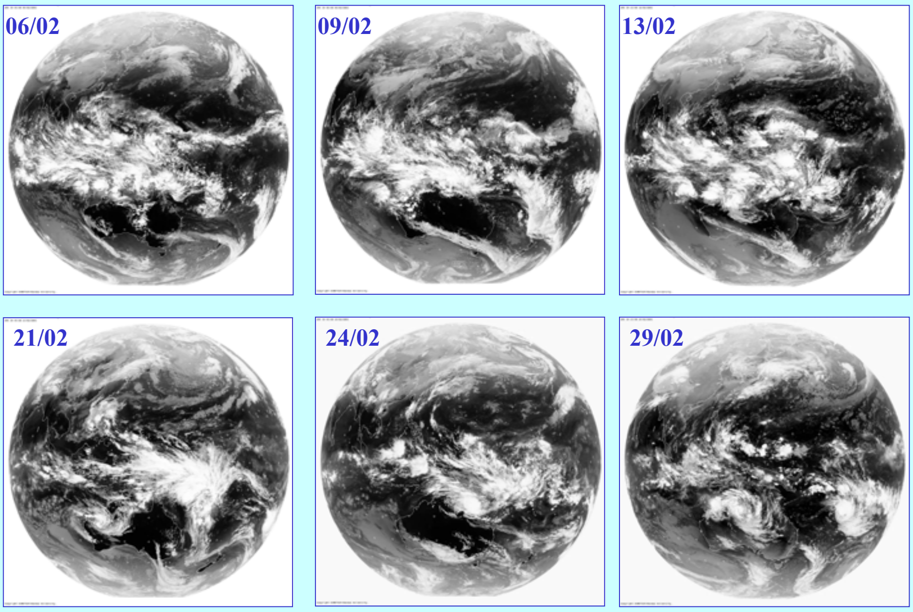
Indian Ocean Feb/Mar 2001

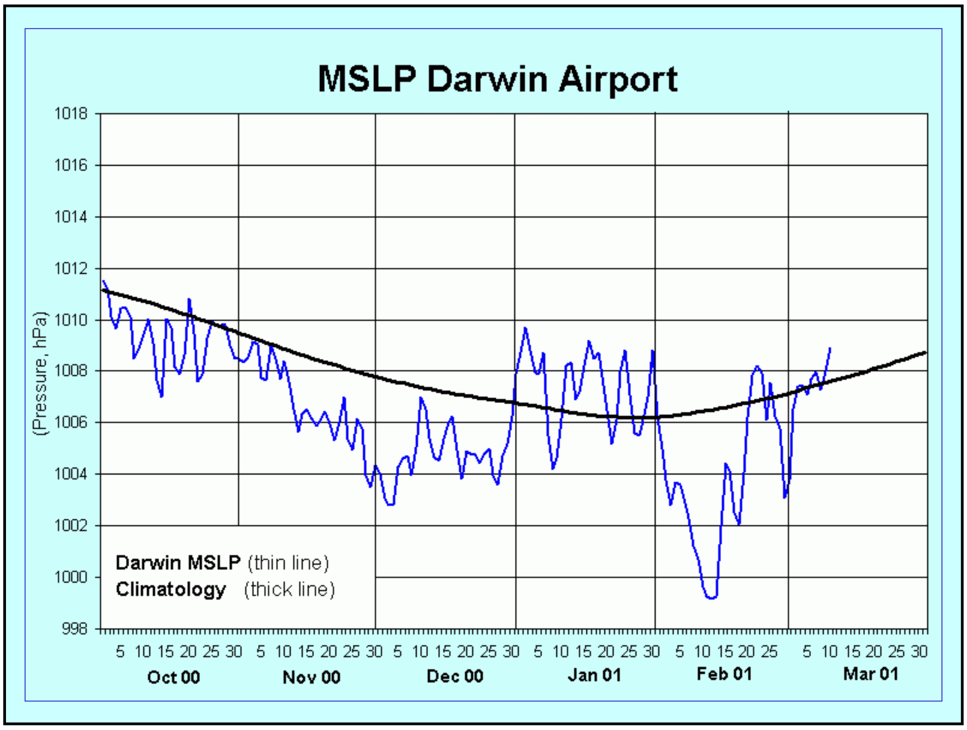


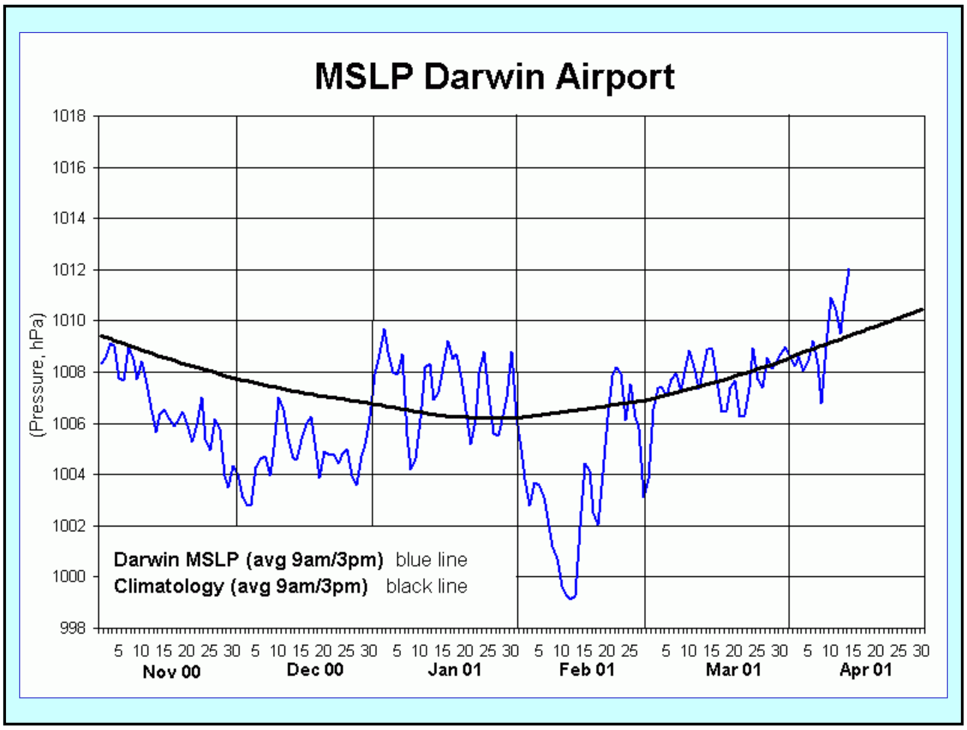
West Pacific Ocean Dec 2000/Jan 2001

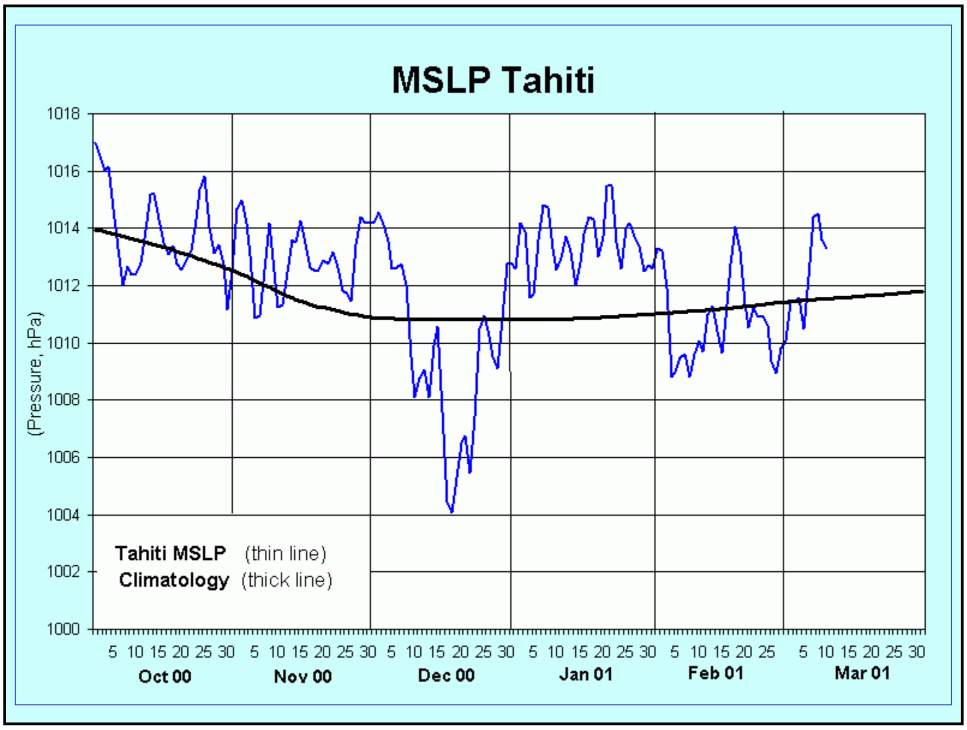


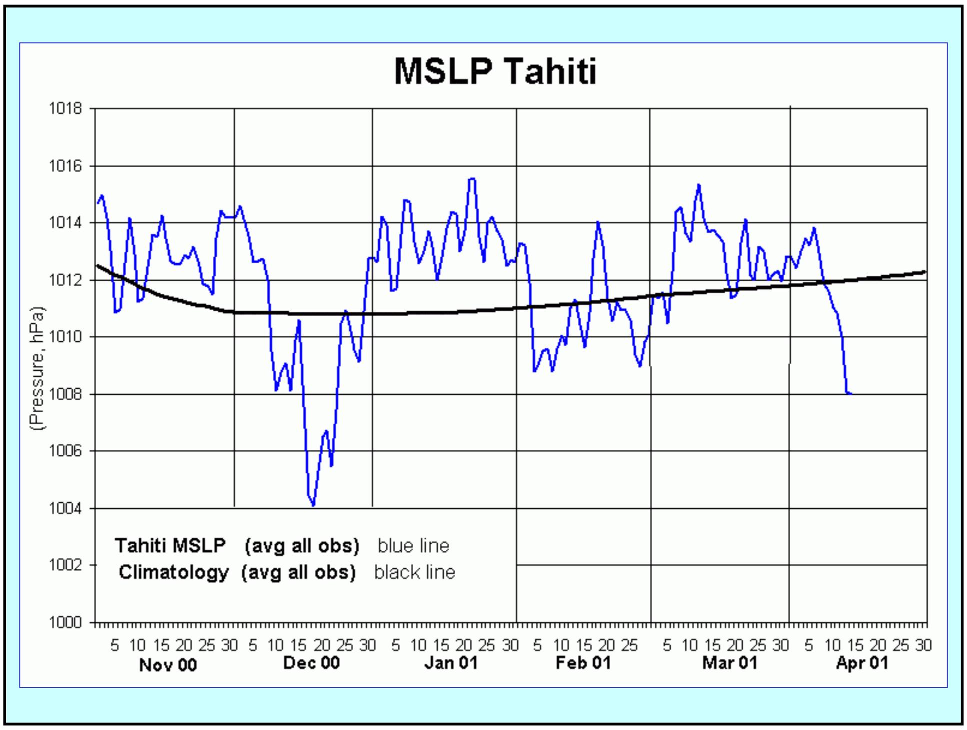
West Pacific Ocean – Feb 2001

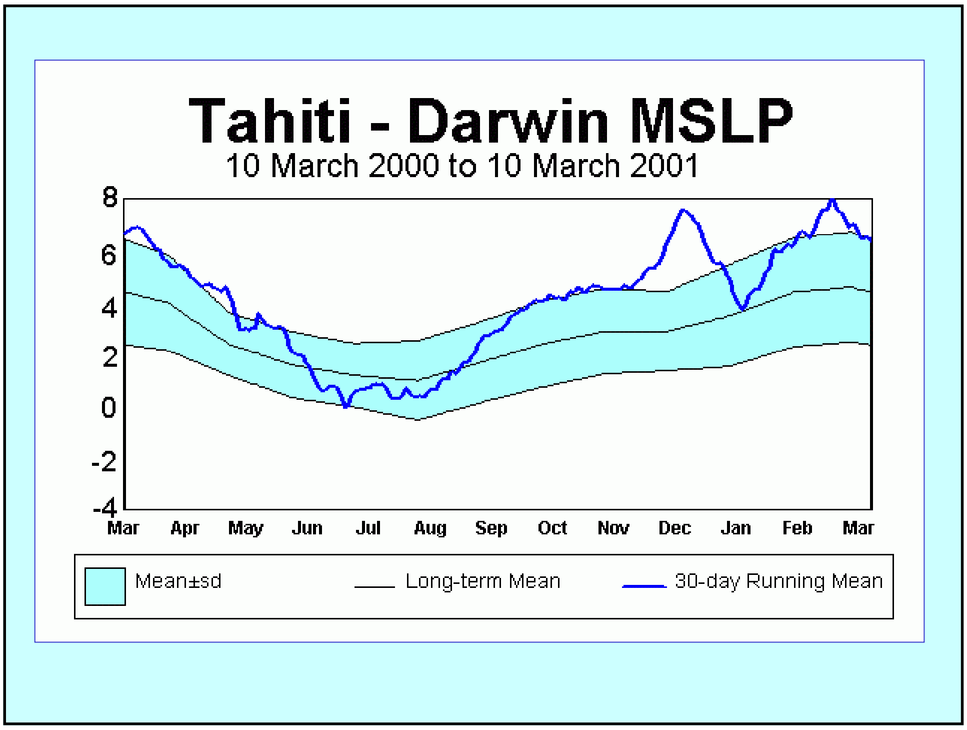


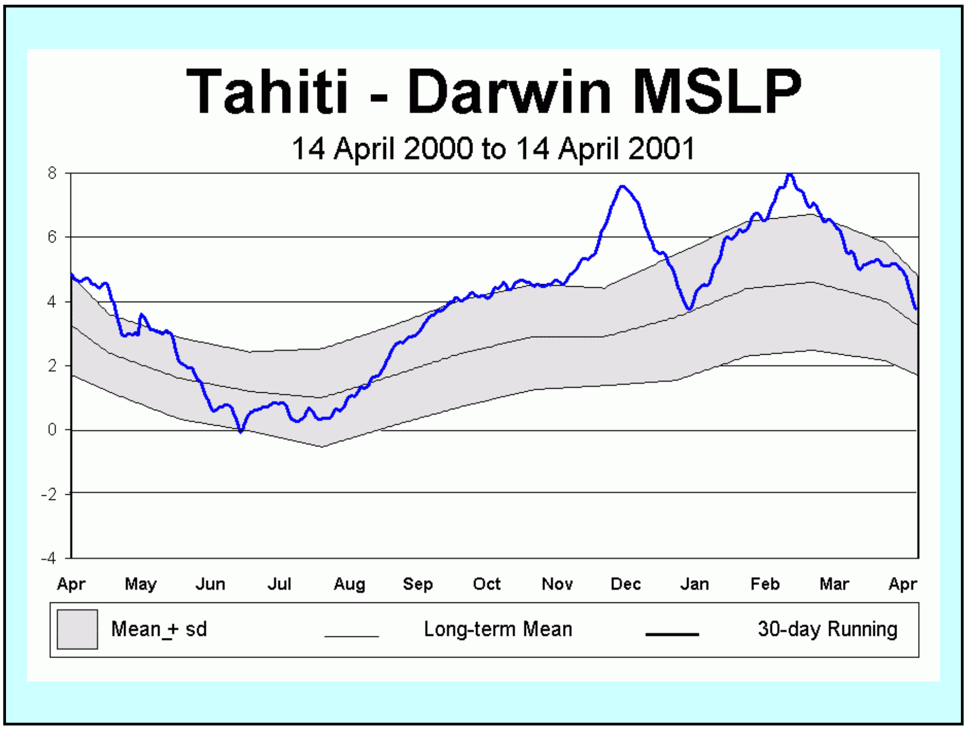

MSLP Darwin Airport
1018
1016
1014
1012
1010
1008
1006
1004
1002
1000
998
(Pressure, hPa)
Darwin MSLP (thin line)
Climatology (thick line)
5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 5 10 15 20 25 30
Oct 00
Nov 00
Dec 00
Jan 01
Feb 01
Mar 01

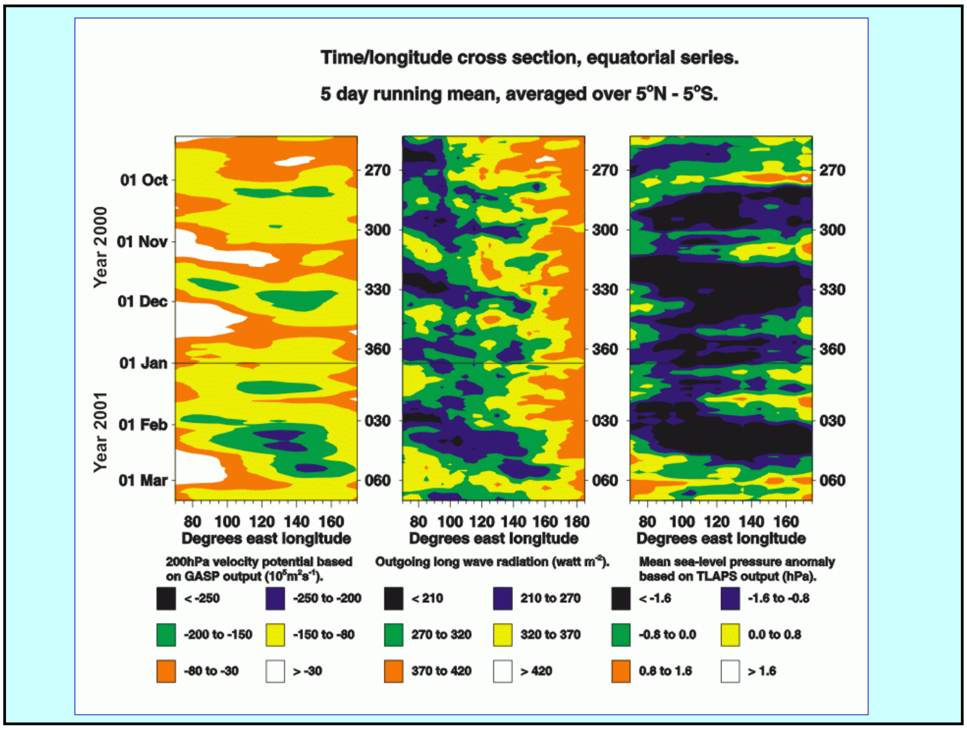

MSLP Darwin Airport
1018
1016
1014
1012
1010
1008
1006
1004
1002
1000
998
(Pressure, hPa)
Darwin MSLP (avg 9am/3pm) blue line
Climatology (avg 9am/3pm) black line
5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 5 10 15 20 25 30 5 10 15 20 25 30
Nov 00
Dec 00
Jan 01
Feb 01
Mar 01
Apr 01

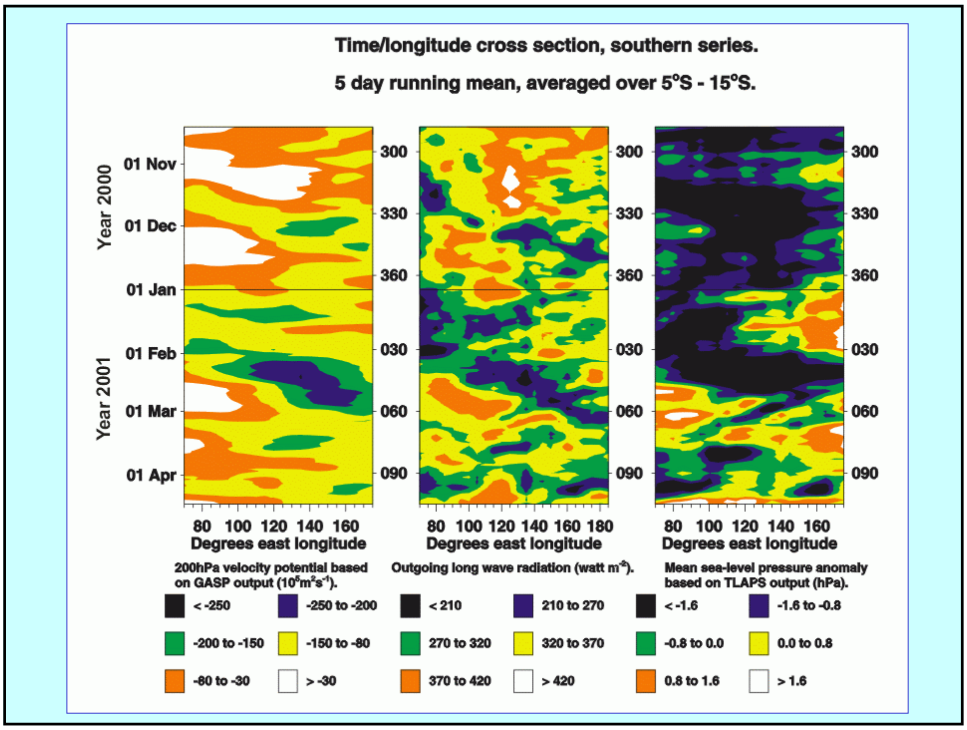

MSLP Tahiti
(Pressure, hPa)
1018
1016
1014
1012
1010
1008
1006
1004
1002
1000
Tahiti MSLP (thin line)
Climatology (thick line)
5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 5 10 15 20 25 30
Oct 00
Nov 00
Dec 00
Jan 01
Feb 01
Mar 01

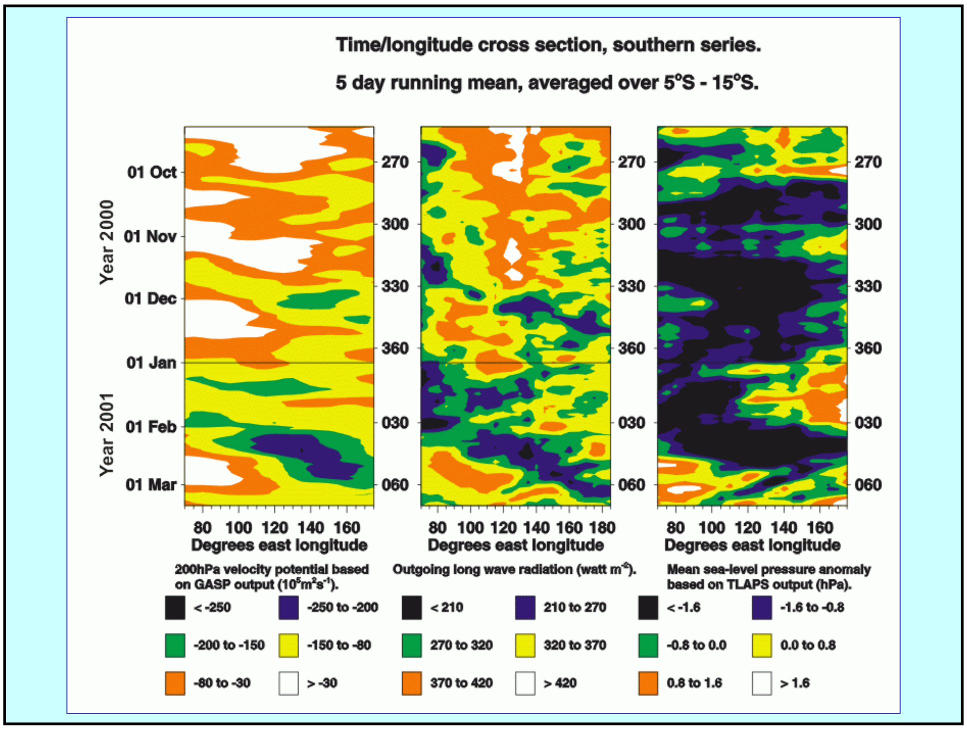

MSLP Tahiti
(Pressure, hPa)
1018
1016
1014
1012
1010
1008
1006
1004
1002
1000
Tahiti MSLP (avg all obs) blue line
Climatology (avg all obs) black line
5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 5 10 15 20 25 30 5 10 15 20 25 30
Nov 00
Dec 00
Jan 01
Feb 01
Mar 01
Apr 01

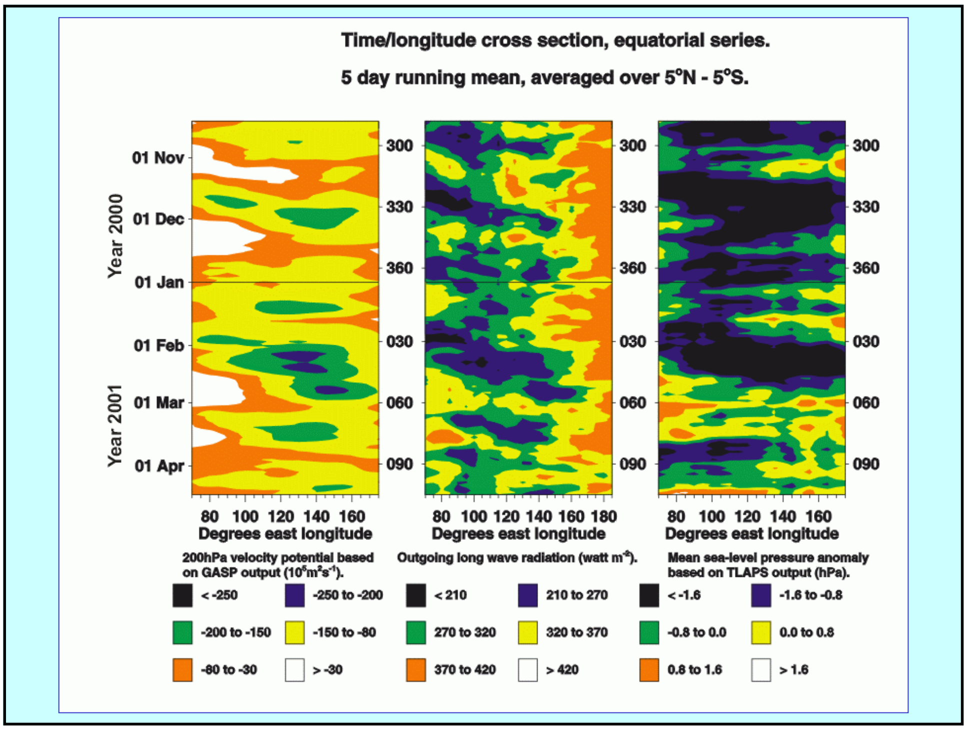

Tahiti - Darwin MSLP
10 March 2000 to 10 March 2001
8
6
4
2
0
-2
-4
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Mean±sd
Long-term Mean
30-day Running Mean

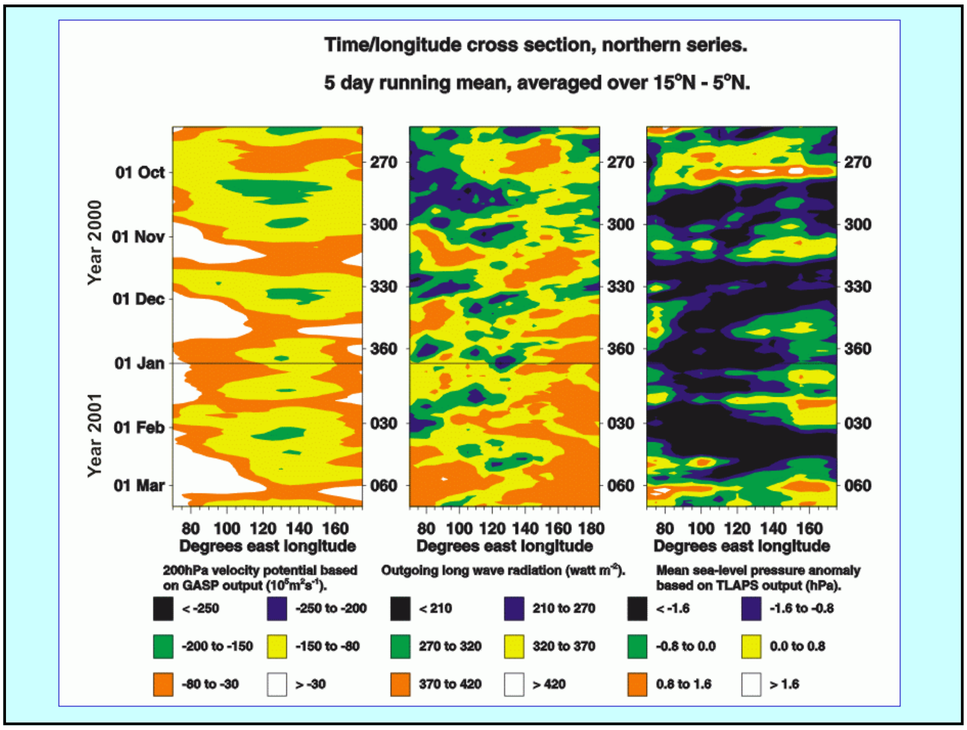

Tahiti - Darwin MSLP
14 April 2000 to 14 April 2001
8
6
4
2
0
-2
-4
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
Mean_+ sd
Long-term Mean
30-day Running

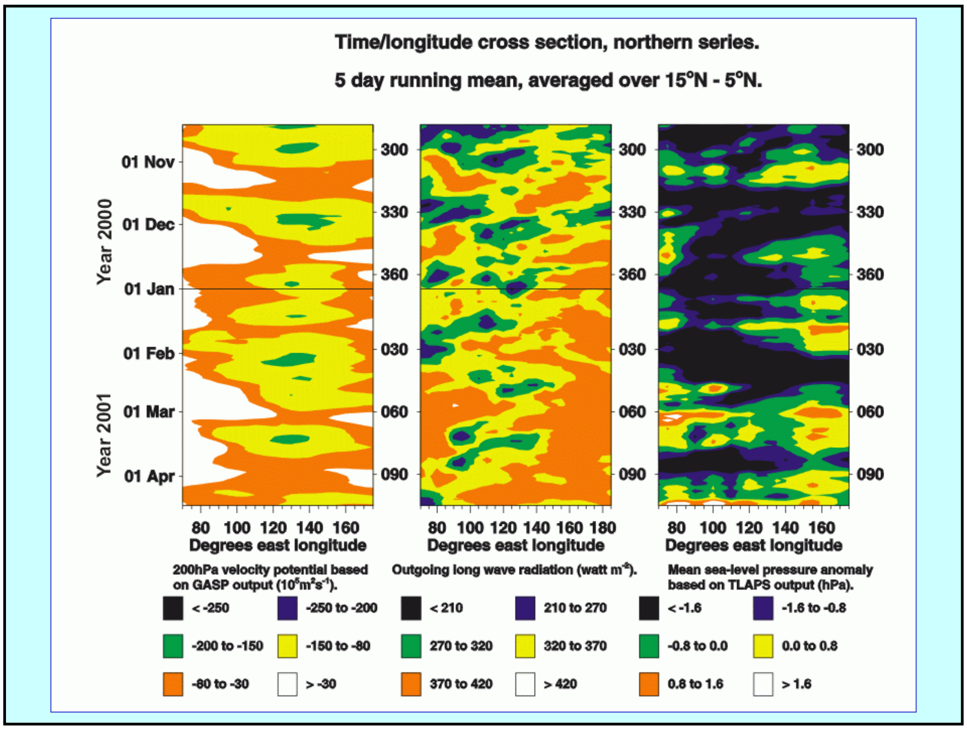

Time/longitude cross section, equatorial series.
5 day running mean, averaged over 5°N - 5°S.
Year 2000
Year 2001
01 Oct
01 Nov
01 Dec
01 Jan
01 Feb
01 Mar
270
300
330
360
030
060
80 100 120 140 160
Degrees east longitude
80 100 120 140 160 180
Degrees east longitude
80 100 120 140 160
Degrees east longitude
200hPa velocity potential based on GASP output (10⁶m²s⁻¹).
< -250
-250 to -200
-200 to -150
-150 to -80
-80 to -30
> -30
Outgoing long wave radiation (watt m⁻²).
< 210
210 to 270
270 to 320
320 to 370
370 to 420
> 420
Mean sea-level pressure anomaly based on TLAPS output (hPa).
< -1.6
-1.6 to -0.8
-0.8 to 0.0
0.0 to 0.8
0.8 to 1.6
> 1.6

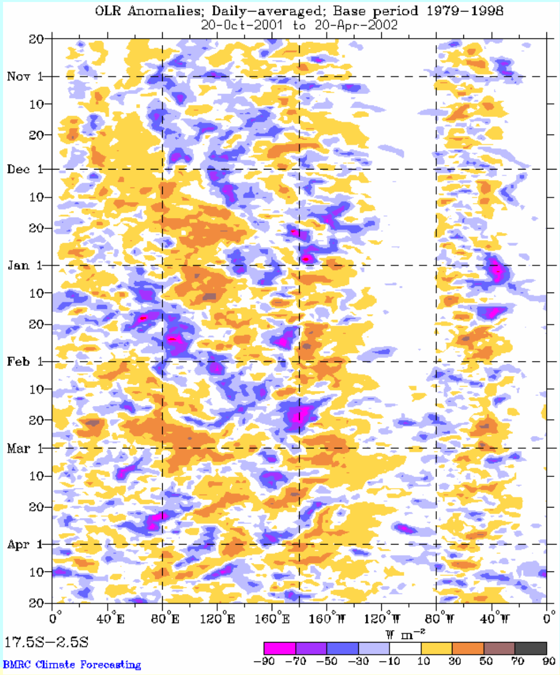

Time/longitude cross section, southern series.
5 day running mean, averaged over 5°S - 15°S.
Year 2000
Year 2001
01 Nov
01 Dec
01 Jan
01 Feb
01 Mar
01 Apr
300
330
360
030
060
090
80 100 120 140 160
Degrees east longitude
80 100 120 140 160 180
Degrees east longitude
80 100 120 140 160
Degrees east longitude
200hPa velocity potential based on GASP output (10⁶m²s⁻¹).
< -250
-250 to -200
-200 to -150
-150 to -80
-80 to -30
> -30
Outgoing long wave radiation (watt m⁻²).
< 210
210 to 270
270 to 320
320 to 370
370 to 420
> 420
Mean sea-level pressure anomaly based on TLAPS output (hPa).
< -1.6
-1.6 to -0.8
-0.8 to 0.0
0.0 to 0.8
0.8 to 1.6
> 1.6


Time/longitude cross section, southern series.
5 day running mean, averaged over 5°S - 15°S.
Year 2000
Year 2001
01 Oct
01 Nov
01 Dec
01 Jan
01 Feb
01 Mar
270
300
330
360
030
060
80 100 120 140 160
80 100 120 140 160 180
Degrees east longitude
200hPa velocity potential based on GASP output ($10^6 m^2 s^{-1}$).
< -250
-250 to -200
-200 to -150
-150 to -80
-80 to -30
> -30
Outgoing long wave radiation (watt m^{-2}).
< 210
210 to 270
270 to 320
320 to 370
370 to 420
> 420
Mean sea-level pressure anomaly based on TLAPS output (hPa).
< -1.6
-1.6 to -0.8
-0.8 to 0.0
0.0 to 0.8
0.8 to 1.6
> 1.6

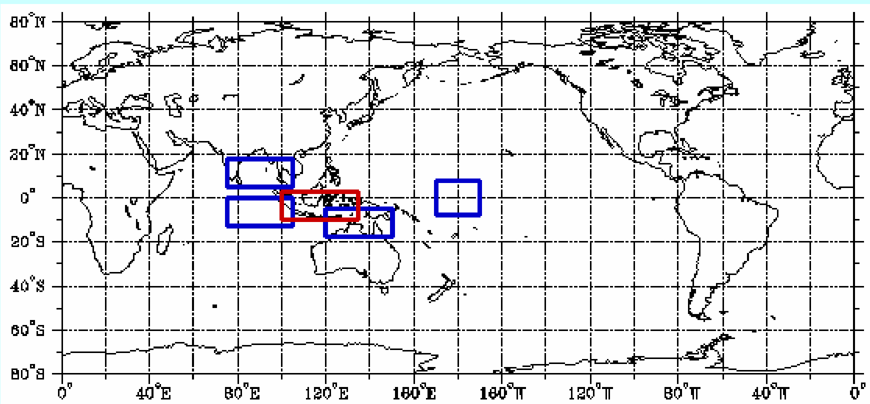

Time/longitude cross section, equatorial series.
5 day running mean, averaged over 5°N - 5°S.
Year 2000
Year 2001
01 Nov
01 Dec
01 Jan
01 Feb
01 Mar
01 Apr
300
330
360
030
060
090
80 100 120 140 160
80 100 120 140 160 180
Degrees east longitude
200hPa velocity potential based on GASP output ($10^6 m^2 s^{-1}$).
< -250
-250 to -200
-200 to -150
-150 to -80
-80 to -30
> -30
Outgoing long wave radiation (watt m^{-2}).
< 210
210 to 270
270 to 320
320 to 370
370 to 420
> 420
Mean sea-level pressure anomaly based on TLAPS output (hPa).
< -1.6
-1.6 to -0.8
-0.8 to 0.0
0.0 to 0.8
0.8 to 1.6
> 1.6


Time/longitude cross section, northern series.
5 day running mean, averaged over 15°N - 5°N.
01 Oct
01 Nov
01 Dec
01 Jan
01 Feb
01 Mar
Year 2000
Year 2001
270
300
330
360
030
060
80 100 120 140 160
80 100 120 140 160 180
Degrees east longitude
200hPa velocity potential based on GASP output (10⁵m²s⁻¹).
Outgoing long wave radiation (watt m⁻²).
Mean sea-level pressure anomaly based on TLAPS output (hPa).
< -250
-250 to -200
-200 to -150
-150 to -80
-80 to -30
> -30
< 210
210 to 270
270 to 320
320 to 370
370 to 420
> 420
< -1.6
-1.6 to -0.8
-0.8 to 0.0
0.0 to 0.8
0.8 to 1.6
> 1.6

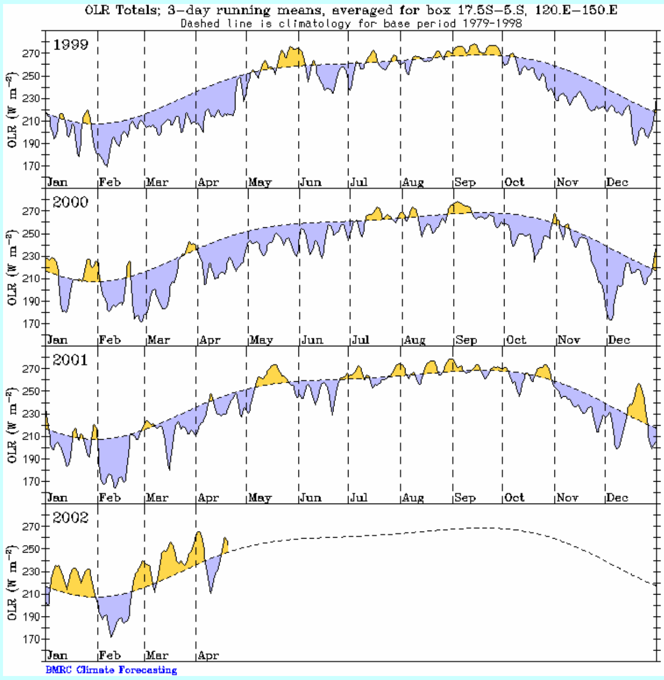

Time/longitude cross section, northern series.
5 day running mean, averaged over 15°N - 5°N.
01 Nov
01 Dec
01 Jan
01 Feb
01 Mar
01 Apr
Year 2000
Year 2001
300
330
360
030
060
090
80 100 120 140 160
80 100 120 140 160 180
Degrees east longitude
200hPa velocity potential based on GASP output (10⁵m²s⁻¹).
Outgoing long wave radiation (watt m⁻²).
Mean sea-level pressure anomaly based on TLAPS output (hPa).
< -250
-250 to -200
-200 to -150
-150 to -80
-80 to -30
> -30
< 210
210 to 270
270 to 320
320 to 370
370 to 420
> 420
< -1.6
-1.6 to -0.8
-0.8 to 0.0
0.0 to 0.8
0.8 to 1.6
> 1.6



http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/OLR/hov.last6mths.anom.S.gif



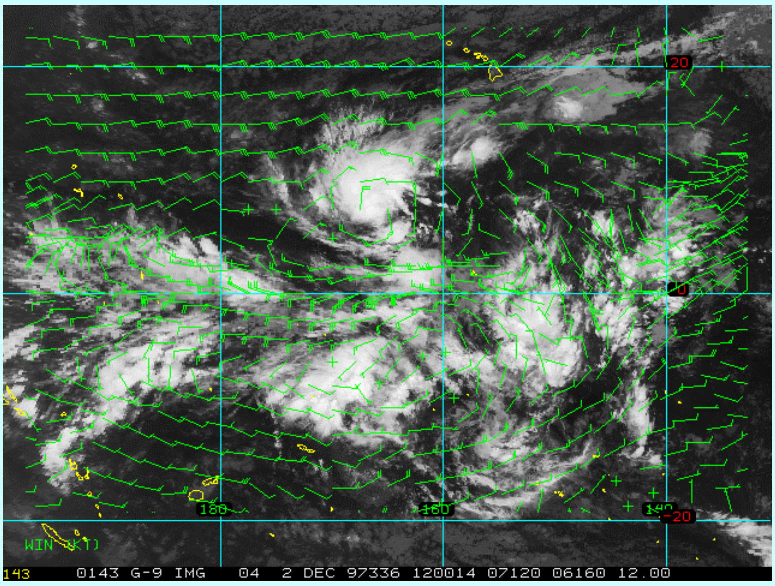
http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/OLR/ts.html



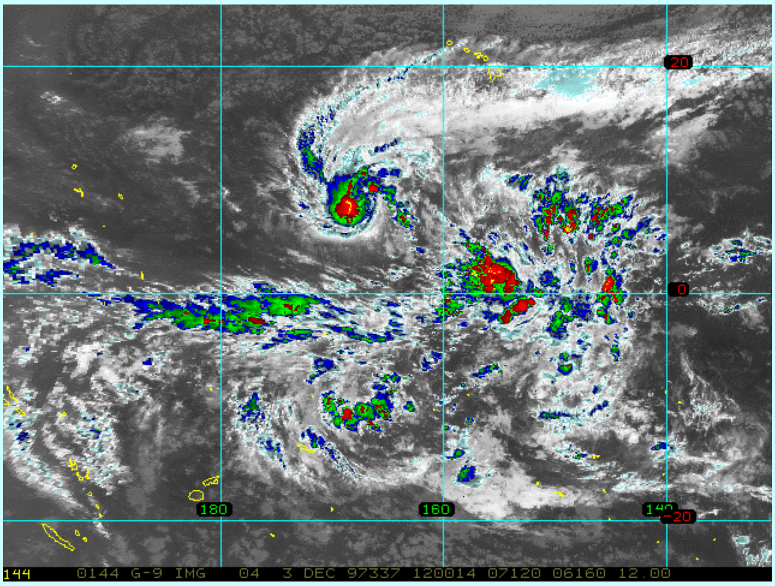
Westerly wind bursts

- Occasionally low-level westerly winds are observed along the Equator, and when those winds are particularly strong with a well defined speed maximum that propagates to the east, the phenomenon has been called a "westerly wind burst."
- This often results in the formation of tropical cyclone pairs or twins located at approximately the same longitude and the same distance on opposite sides of the Equator.
- The formation of twin tropical cyclones typically occurs in the western Pacific and Indian Ocean during the months of December through May.

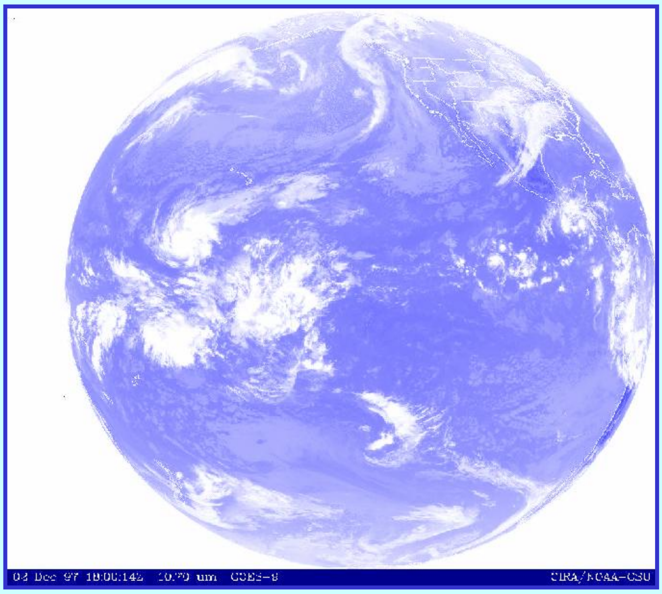
- During the first few days of December, 1997, this type weather pattern is located unusually far to the east in the central Pacific. This is likely due to the influence of the strong El Nino.
- The associated cloud pattern is seen in a series of daily GOES-9 IR images remapped to Mercator projection. One can see that a large region of the tropical Pacific is influenced by the active deep convection and cirrus.
- This can be quite spectacular with a somewhat symmetric "mirror image" cloud pattern aligned along the Equator. The formation of twin tropical cyclones is also seen in the IR images.



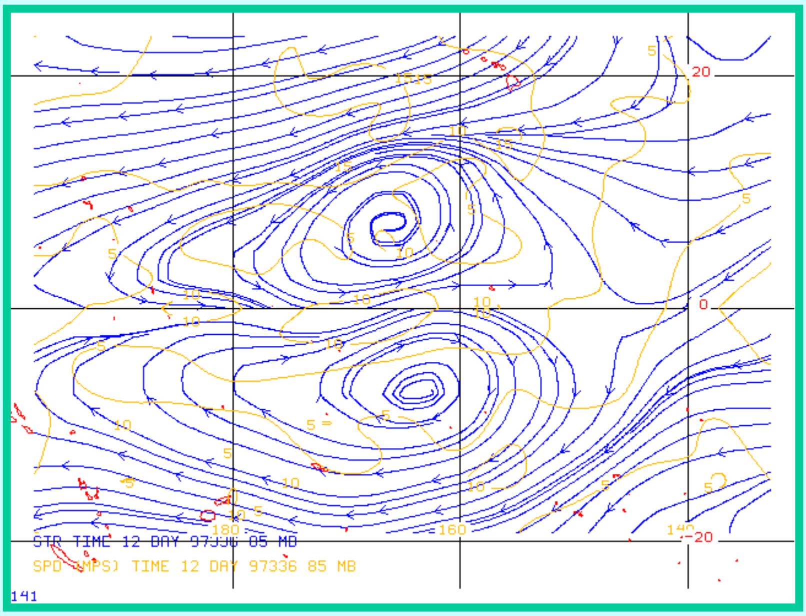
GOES-9 12 UTC 2 Dec 1997 10.7 micron image



GOES-9 12 UTC 3 Dec 1997 10.7 micron image



- Streamlines, isotachs, and wind barbs from the 850 hPa analysis of the global AVN Model at 12 UTC, 2 Dec 97, depict the low-level winds. At 1500 UTC, 3 Dec 97, Tropical Storm Paka was centred at 8.5N 167.8W, with an intensity of 45 kt, and drifting to the WNW.
- The Southern Hemisphere twin cyclonic circulation near 10S 169W had not yet intensified to a tropical storm.



AVN 12 UTC 2 Dec 1997 850 mb isotachs and streamlines

The End