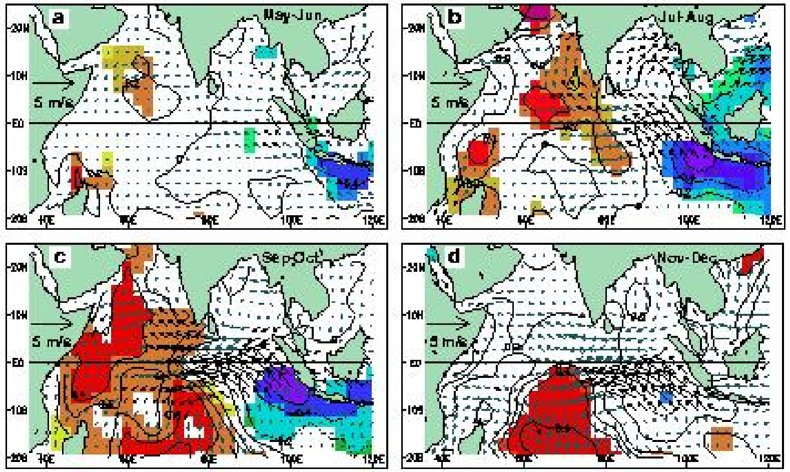
The Australian Winter Rainfall: Response to the IOD SSTA

(* Koica Training Material)

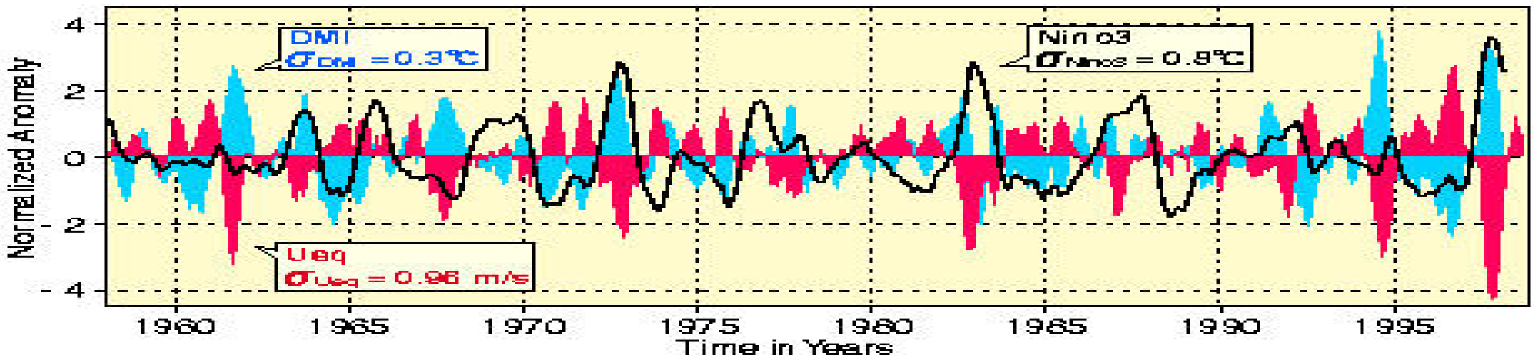
Karumuri Ashok

Background of IOD

- Dipolelike SST anomalies
- equatorial wind anomalies
- sea level low(high) in the east(west)
- suppressed(enhanced) rain in the east(west)
- ocean dynamics may play a significant role

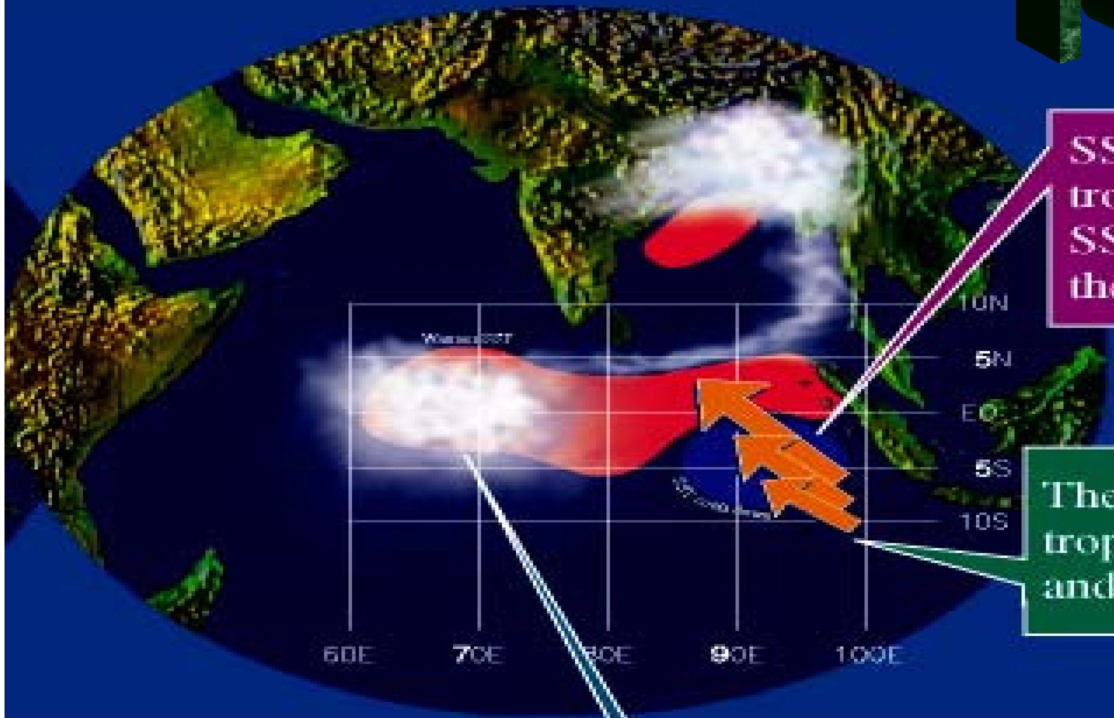


- strong cross correlation between all the variables mentioned above



- *Saji et al. (2001)'s IODMI: SSTA(-10°S-10°N, 50°-70°E)-SSTA (10°S-Equator,*
- *90°E-110°E).*

Positive IOD



SST cools down in the southeast tropical Indian Ocean, making the SST distribution asymmetric about the equator.

The southeast trades at the southeast tropical Indian Ocean has strengthened and extended across the equator.

The OTCZ has disappeared; convection has strengthened over the tropical western Indian Ocean where the SST is warmer than usual.

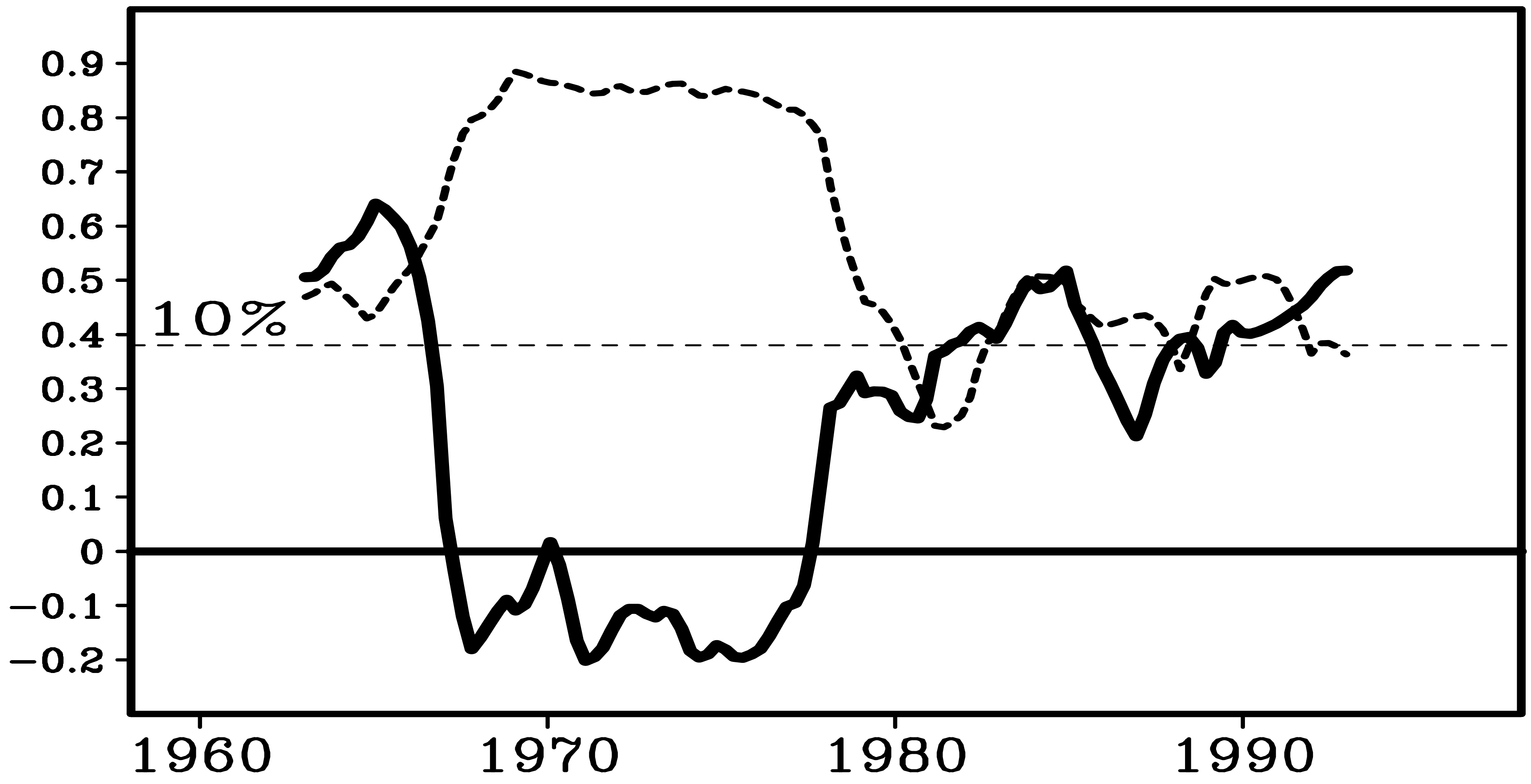
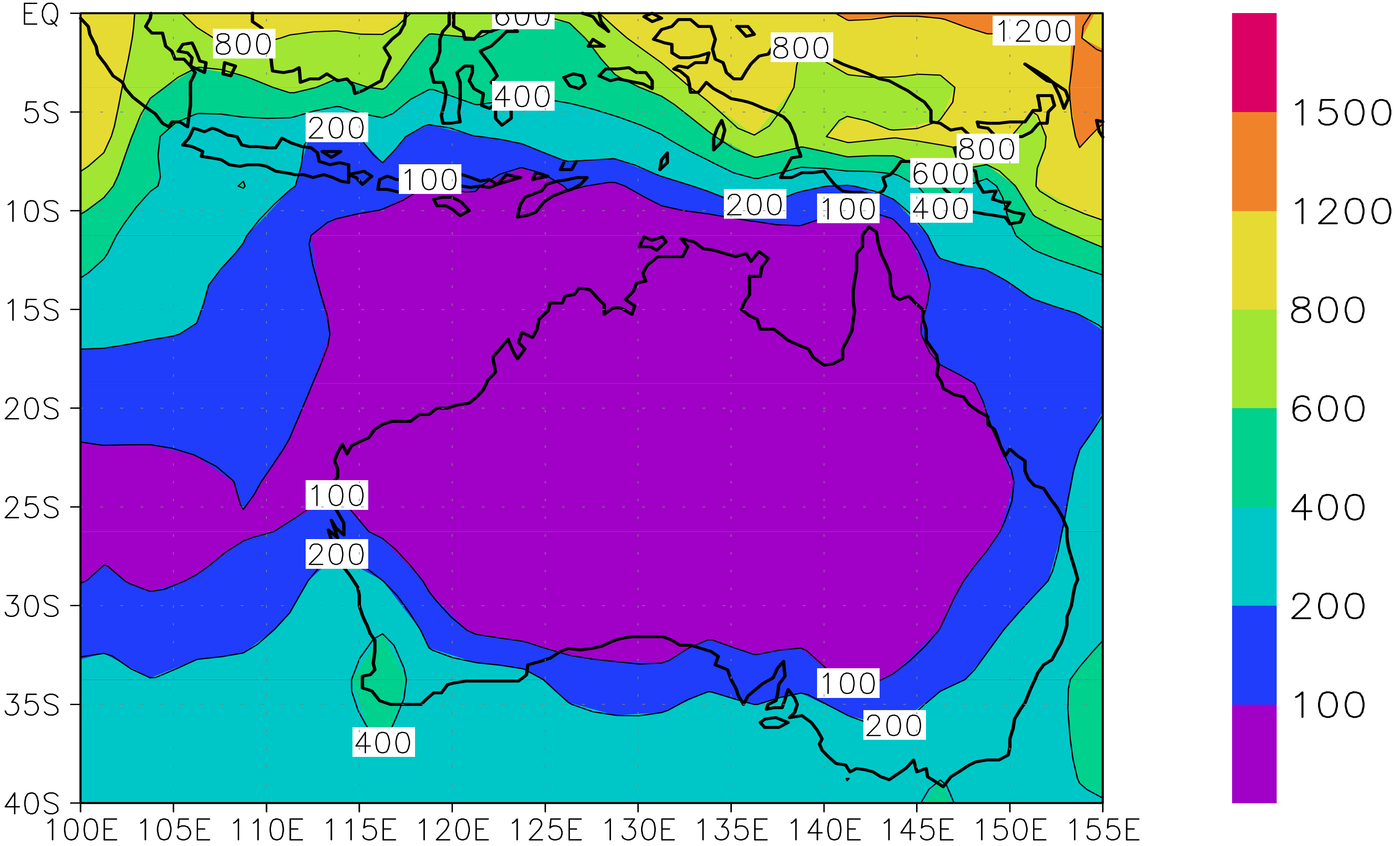


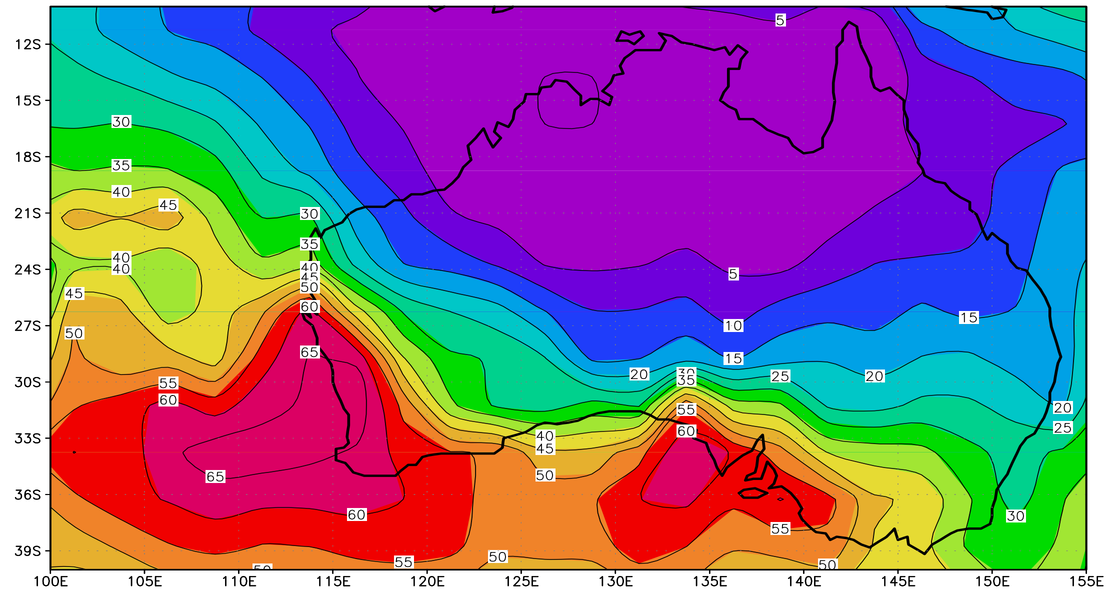
Figure The 41-month sliding correlation coefficients between ISMR and IODMI (solid), and those between monthly ISMR and NINO3 Index (dashed; to be multiplied by –1) during 1958-1997. The significant correlation value at 90% confidence level is 0.38 (verified by 1,000 randomized time series, using the Monte-Carlo simulations)

From Ashok et al., GRL (2001)

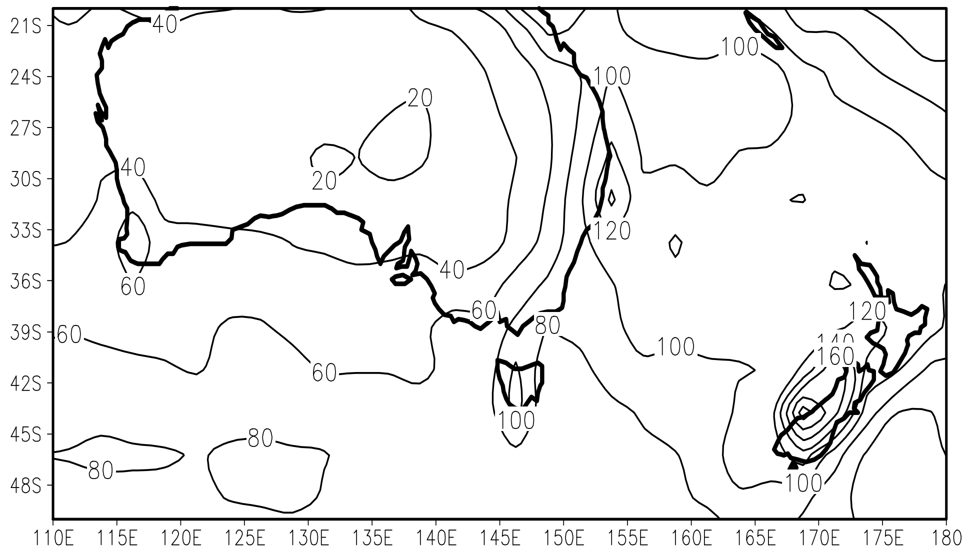
mean JJAS raintall (mm)
(Xie–Arkin data 1979–1999)



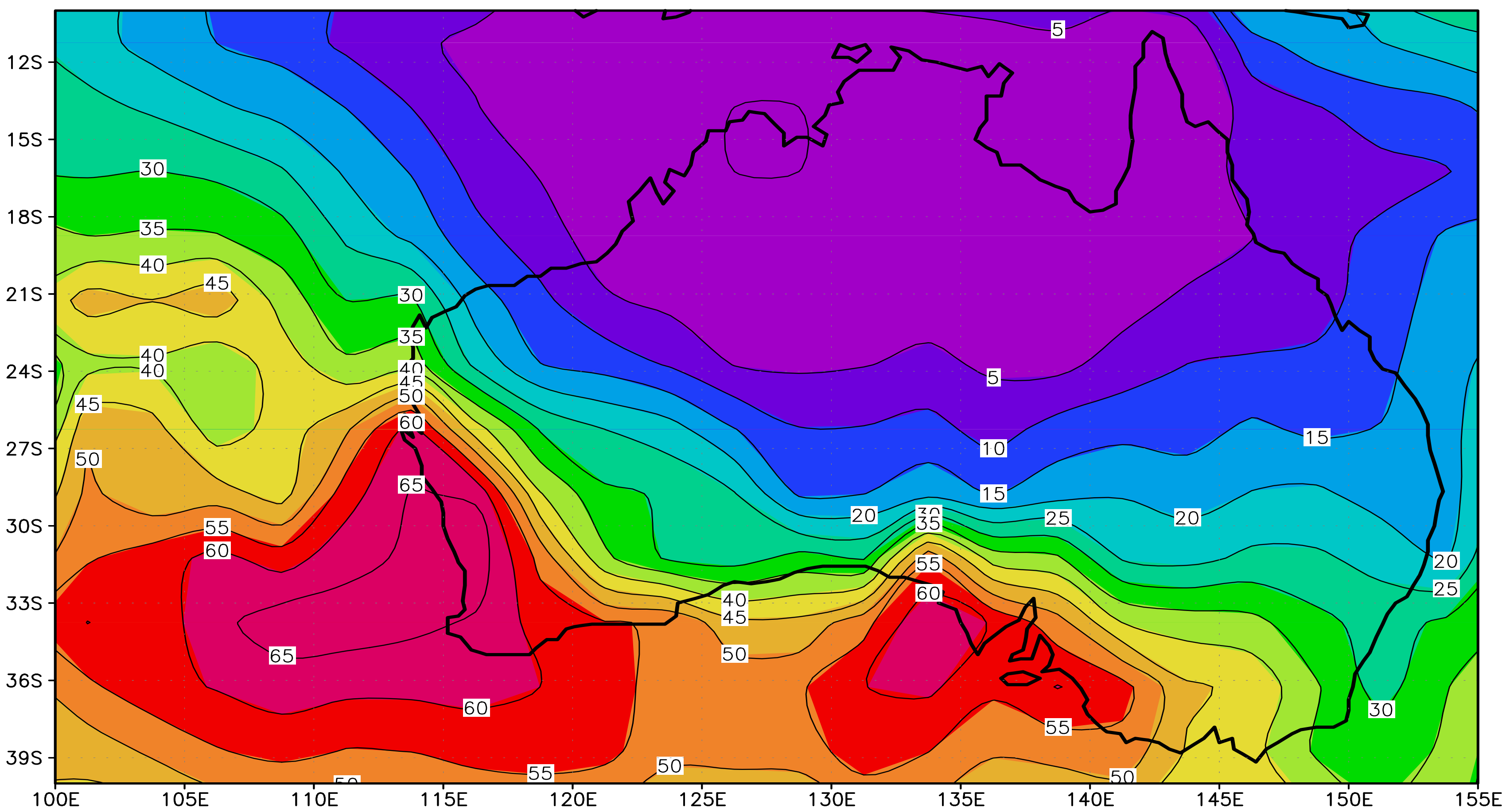
%age of JJAS rainfall in the annual rainfall

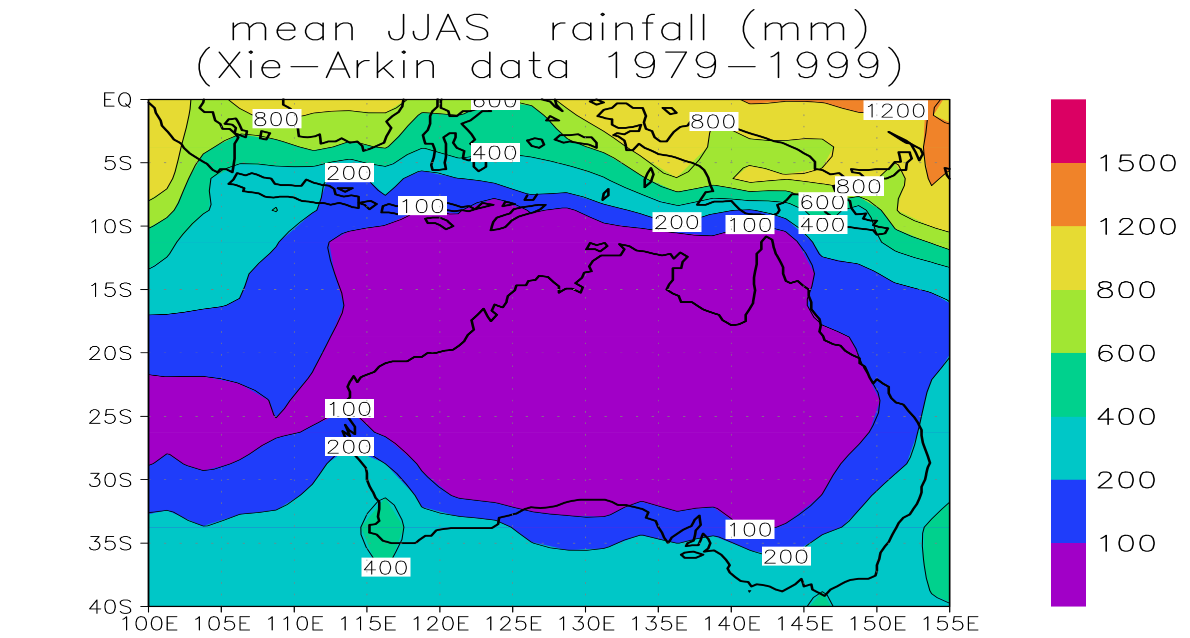


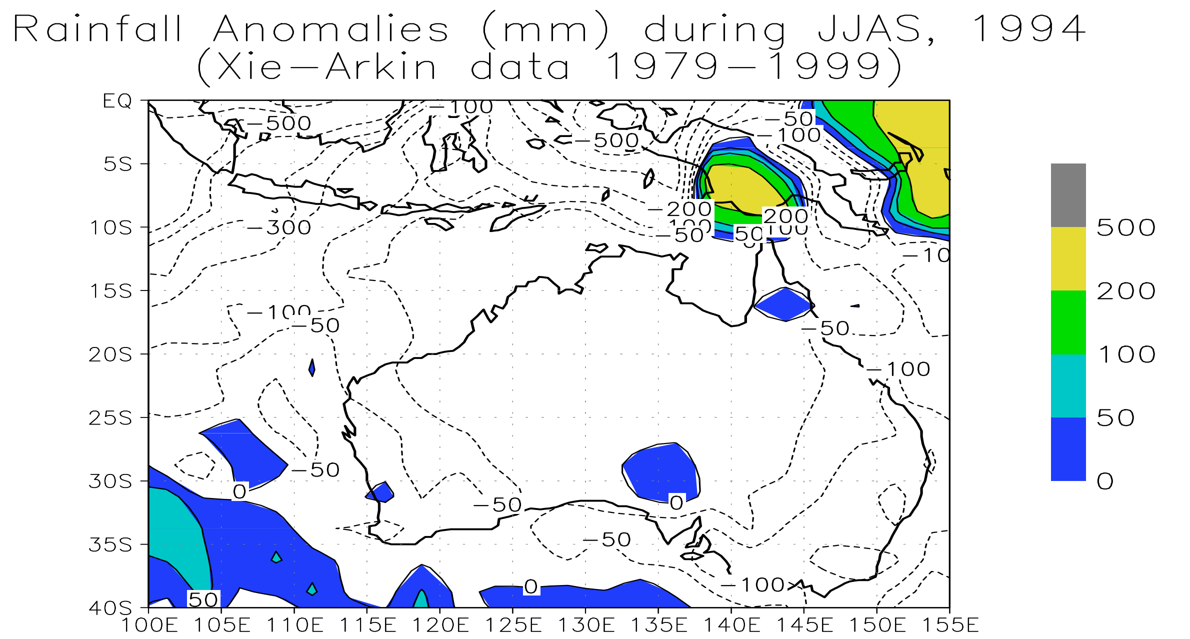
Annual aggregate rainfall →



%age of JJAS rainfall in the annual rainfall

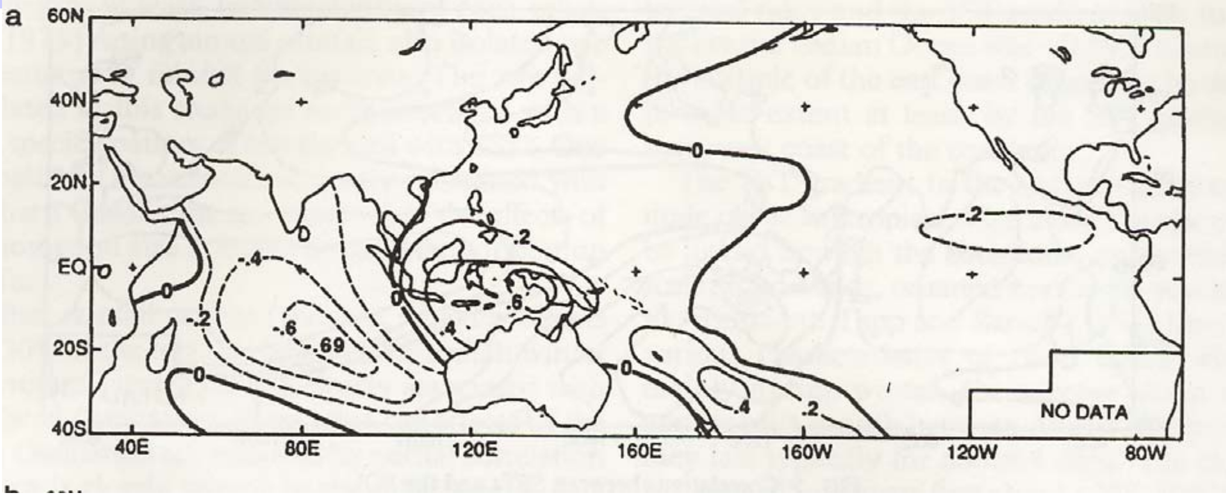



mean JJAS rainfall (mm)
(Xie–Arkin data 1979–1999)
EQ
5S
10S
15S
20S
25S
30S
35S
40S
100E 105E 110E 115E 120E 125E 130E 135E 140E 145E 150E 155E
1500
1200
800
600
400
200
100


Rainfall Anomalies (mm) during JJAS, 1994
(Xie–Arkin data 1979–1999)
EQ
5S
10S
15S
20S
25S
30S
35S
40S
100E 105E 110E 115E 120E 125E 130E 135E 140E 145E 150E 155E
500
200
100
50
0

Background

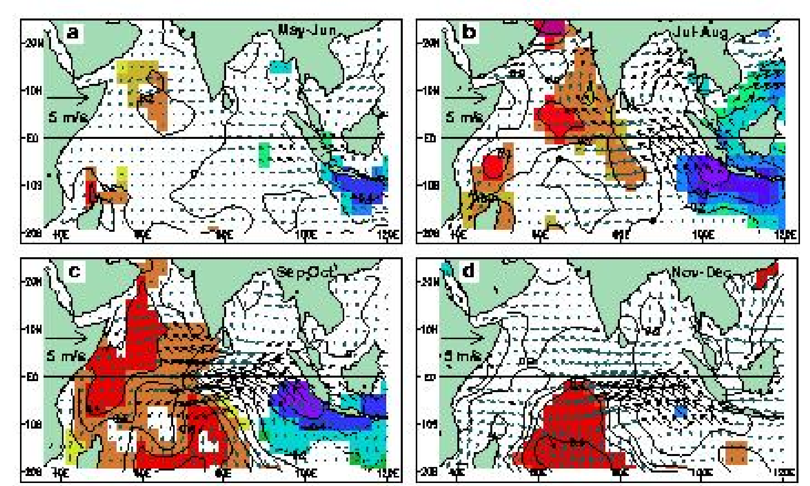
- *Streten* [1981, 1983] claimed that years of extensive Australian droughts are linked to the negative sea surface temperature anomalies (SSTA) over the eastern Indian Ocean.



- *Nicholls* [1989] found strong negative correlations between the first rotated principal component of Australian winter rainfall and the sea surface temperatures in the central Indian Ocean. Strongest negative correlation values are centered in the box of 10°-20°S, 80°-90°E). He found positive correlations around the Indonesia, in agreement with earlier studies [e.g. *Streten*, 1981, 1983; *Kep* 1984; *Whetton*, 1986].

Background (Continued)

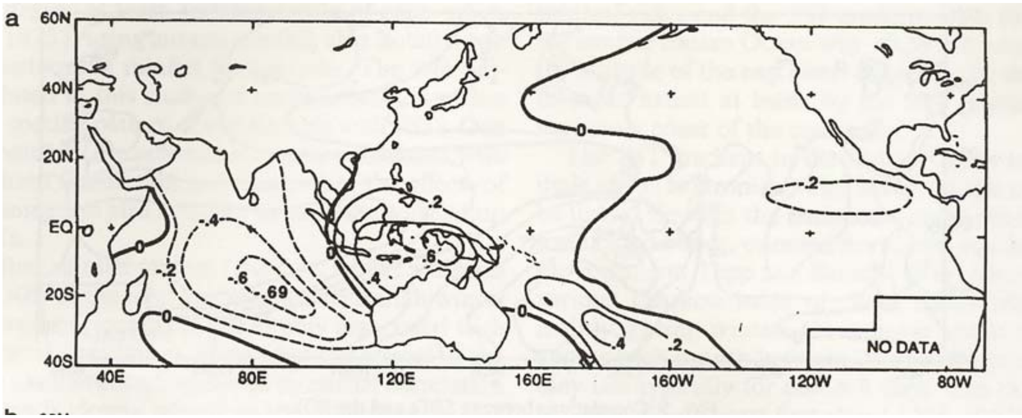
- *Nicholls* [1989] also found that the first rotated principal component of Australian winter rainfall has a correlation coefficient of 0.75 with the SST difference between the Indonesian region (0°–10°S, 120°E–130°E) and the central Indian Ocean (10°–20°S, 80°–90°E), even after the ENSO related component was removed from the SST through partial correlation technique.



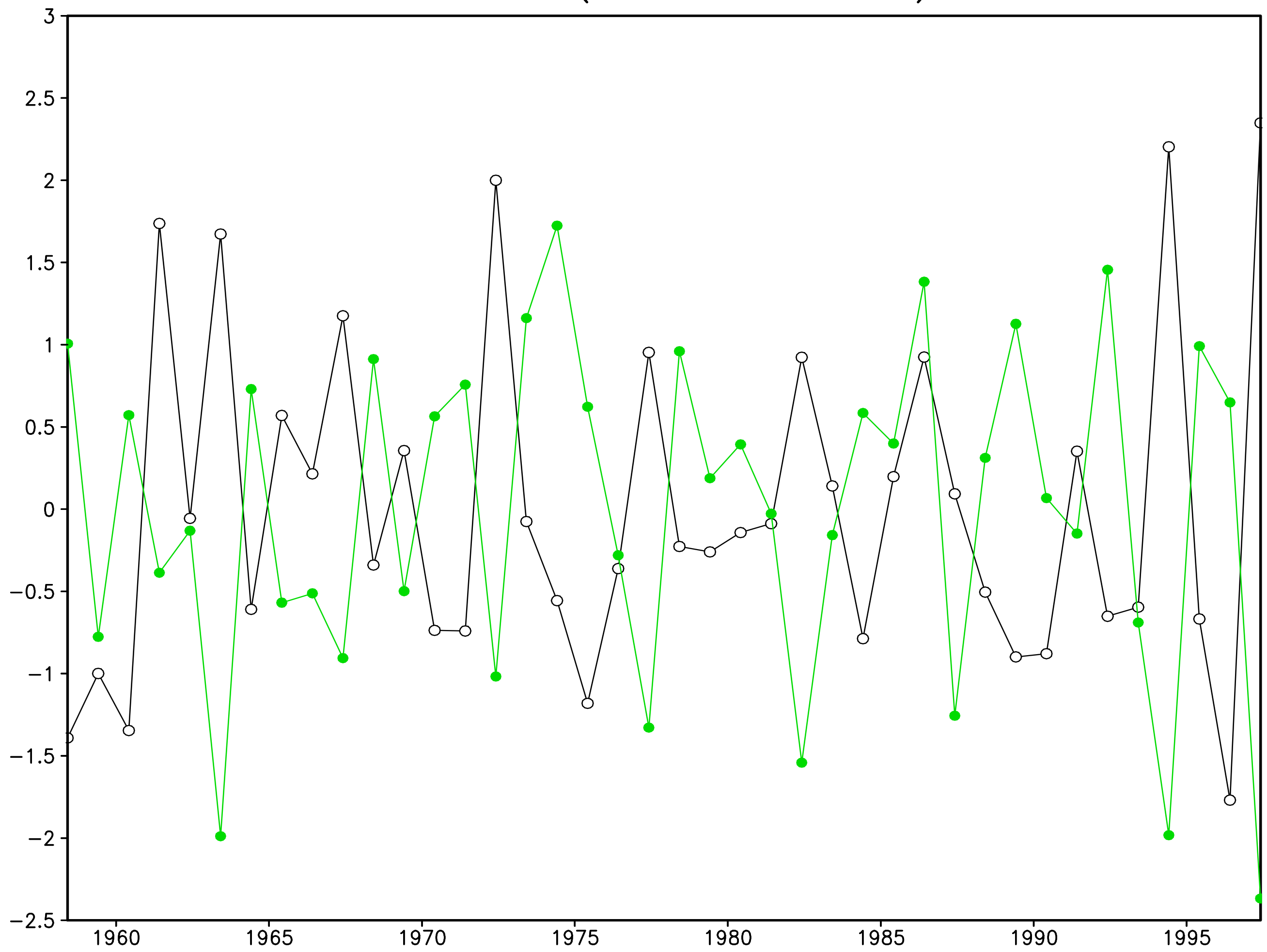
Saji et al. (2001)'s IODMI: SSTA(-10°S-10°N, 50°-70°E)-SSTA (10°S-Equator, 90°E-110°E).

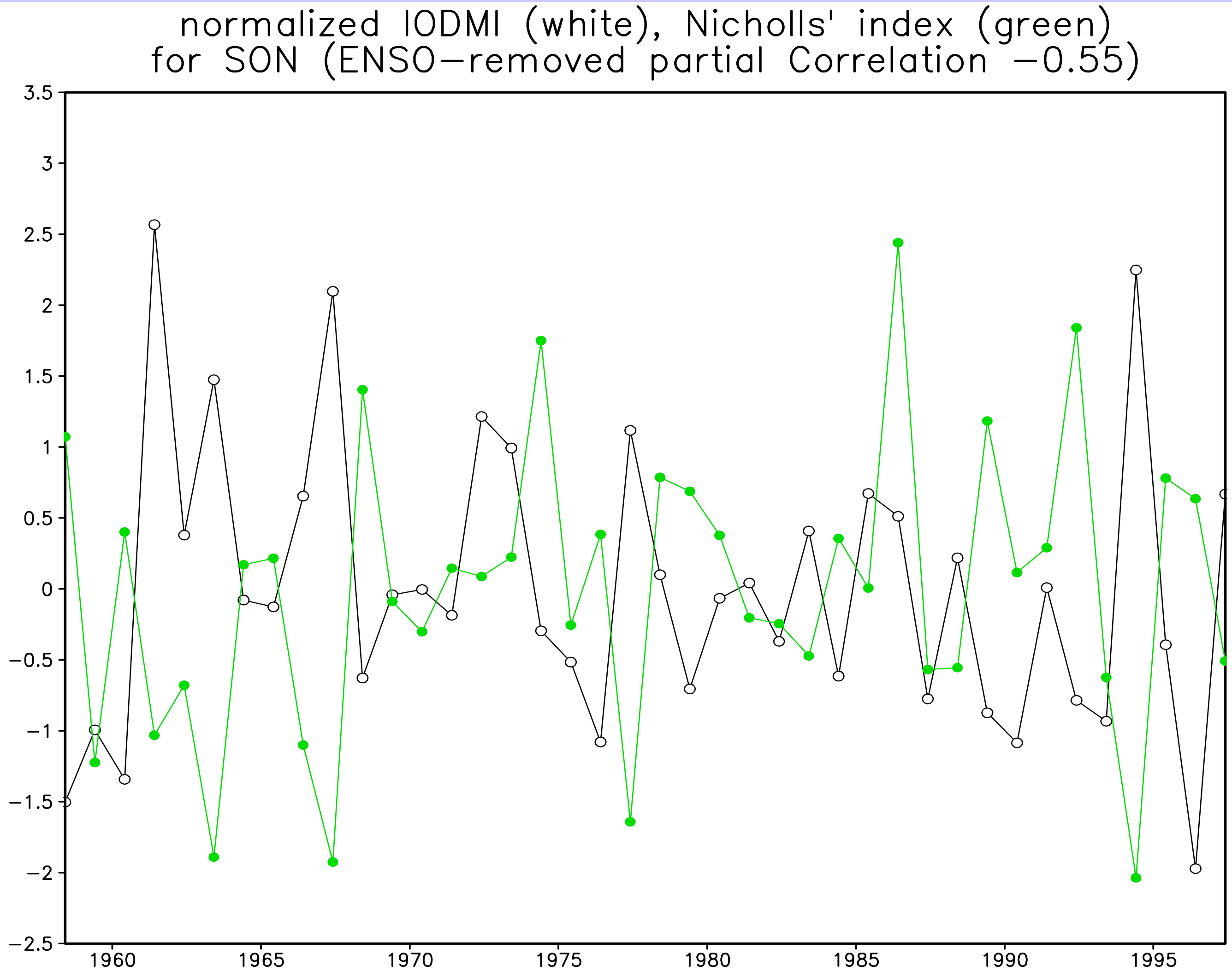
Nicholls' Index (1989): the SST difference between the Indonesian region (0°-10°S, 120°E-130°E) and the central Indian Ocean (10°-20°S, 80°-90°E)

----extends into West Pacific



normalized IODMI (white), Nicholls' index (green)
for SON (Correlation −0.7)



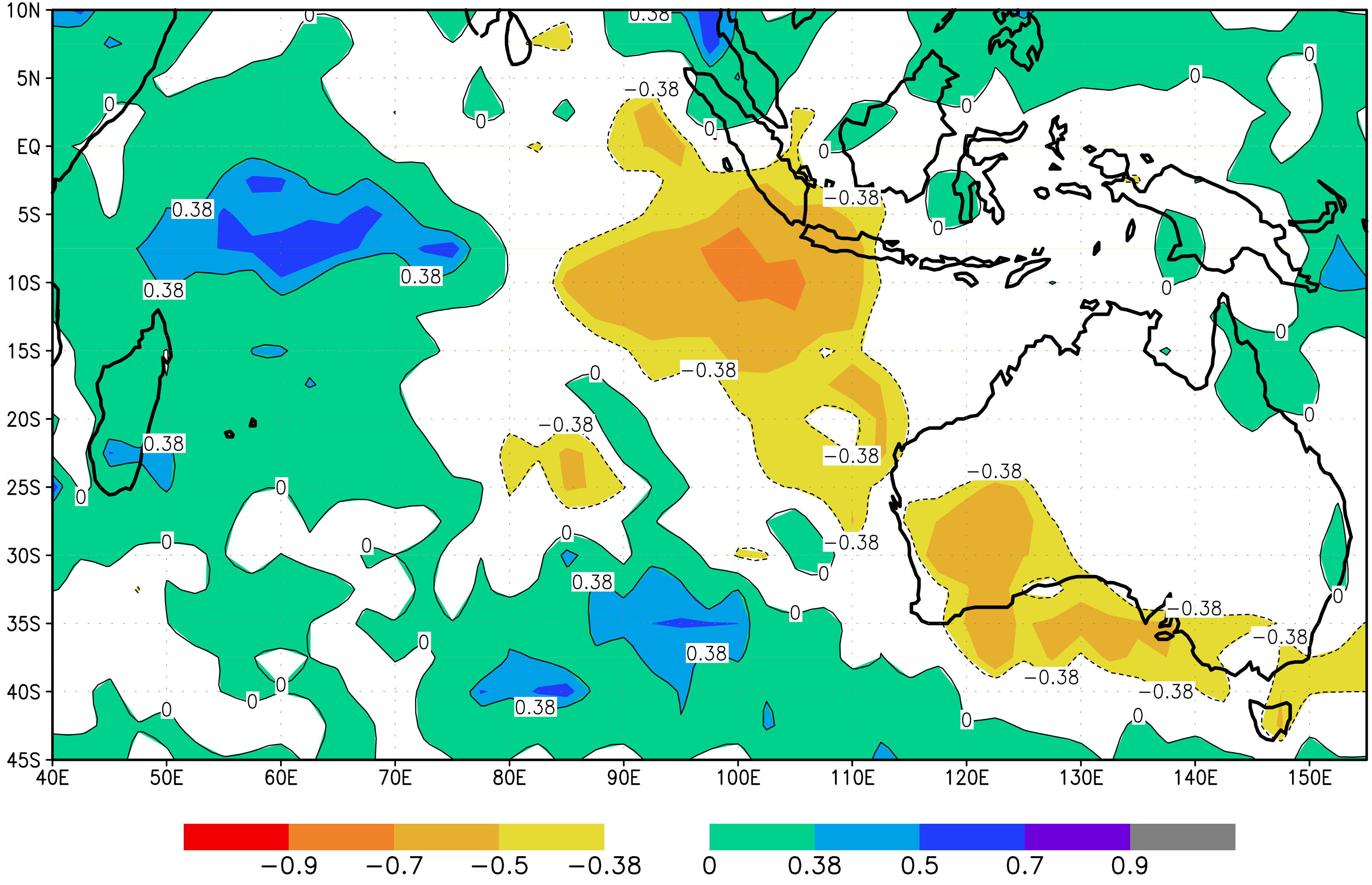


Annual Correlation -0.31

Data (1979-1997)

- GISST Data (Rayner et al., 1996)
- CMAP rainfall data (Xie-Arkin, 1996)

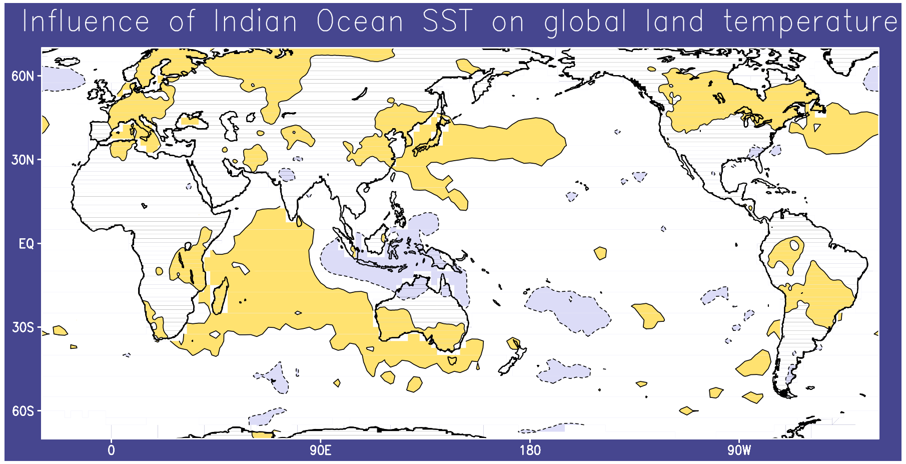
significant partial correlation (90% conf.) between IODMI and Xie-Arkin Rainfall (JJAS season; 1979-1997)

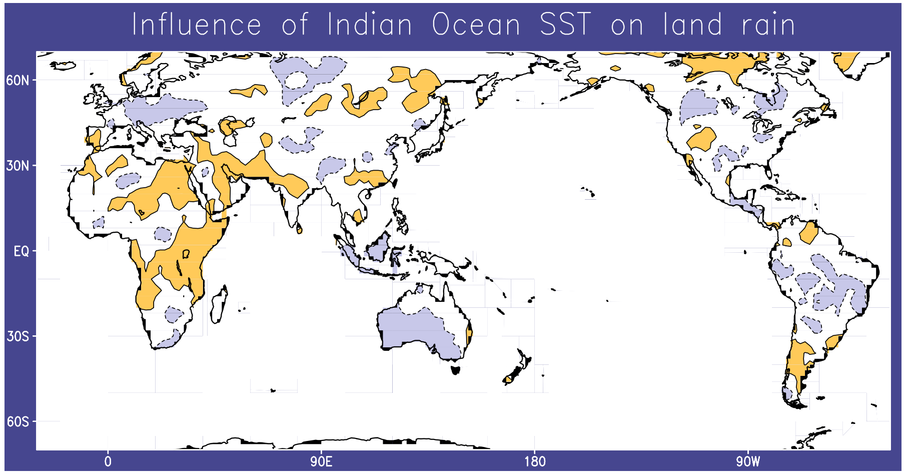


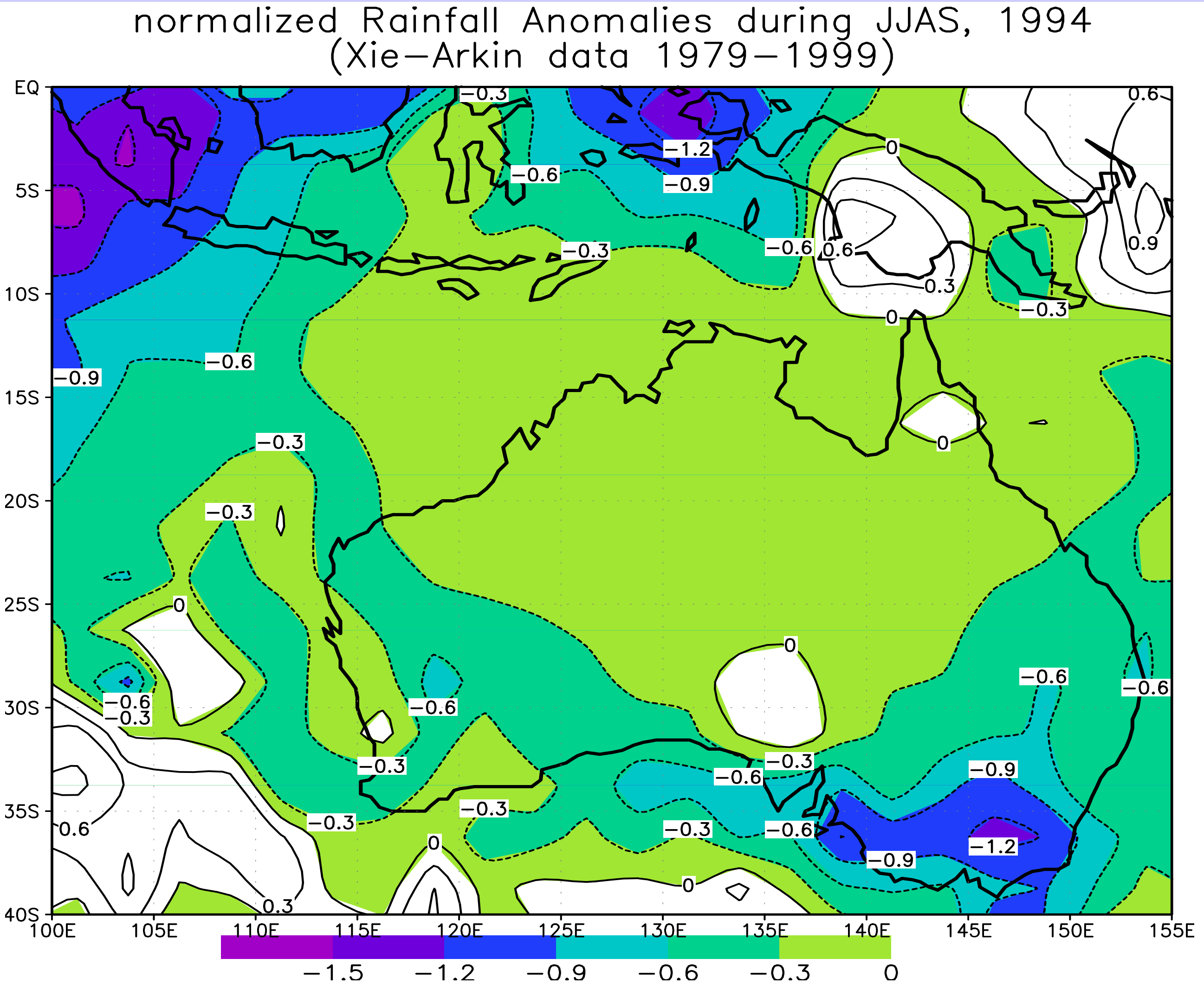
Correlation with land rain,temperature

From Saji & Yamagata, 2003

- Floods to the west, droughts to the east.
- Floods over the monsoon trough
- warmer temperatures and droughts over extratropics







normalized Rainfall Anomalies during JJAS, 1994
(Xie–Arkin data 1979–1999)
EQ
5S
10S
15S
20S
25S
30S
35S
40S
100E
105E
110E
115E
120E
125E
130E
135E
140E
145E
150E
155E
−1.5
−1.2
−0.9
−0.6
−0.3
0

The Frontier Atmospheric General Circulation Model version 1.0

(FrAM 1.0)

- · ***T42***
- · ***Hybrid Vertical Co-Ordinates; 28 layers***
- · ***Cumulus convection (Kuo, 1974)***
- · ***Long Wave Radiation (Shibata and Aoki, 1989), Shibata (1989)***
- · ***Short Wave Radiation (Lacis and Hansen, 1974)***
- · ***Vertical Mixing (Miller and Yamada, 1974)***
- · ***Land surface Model (Viterbo and Beljaars, 1995)***

Experimental Design

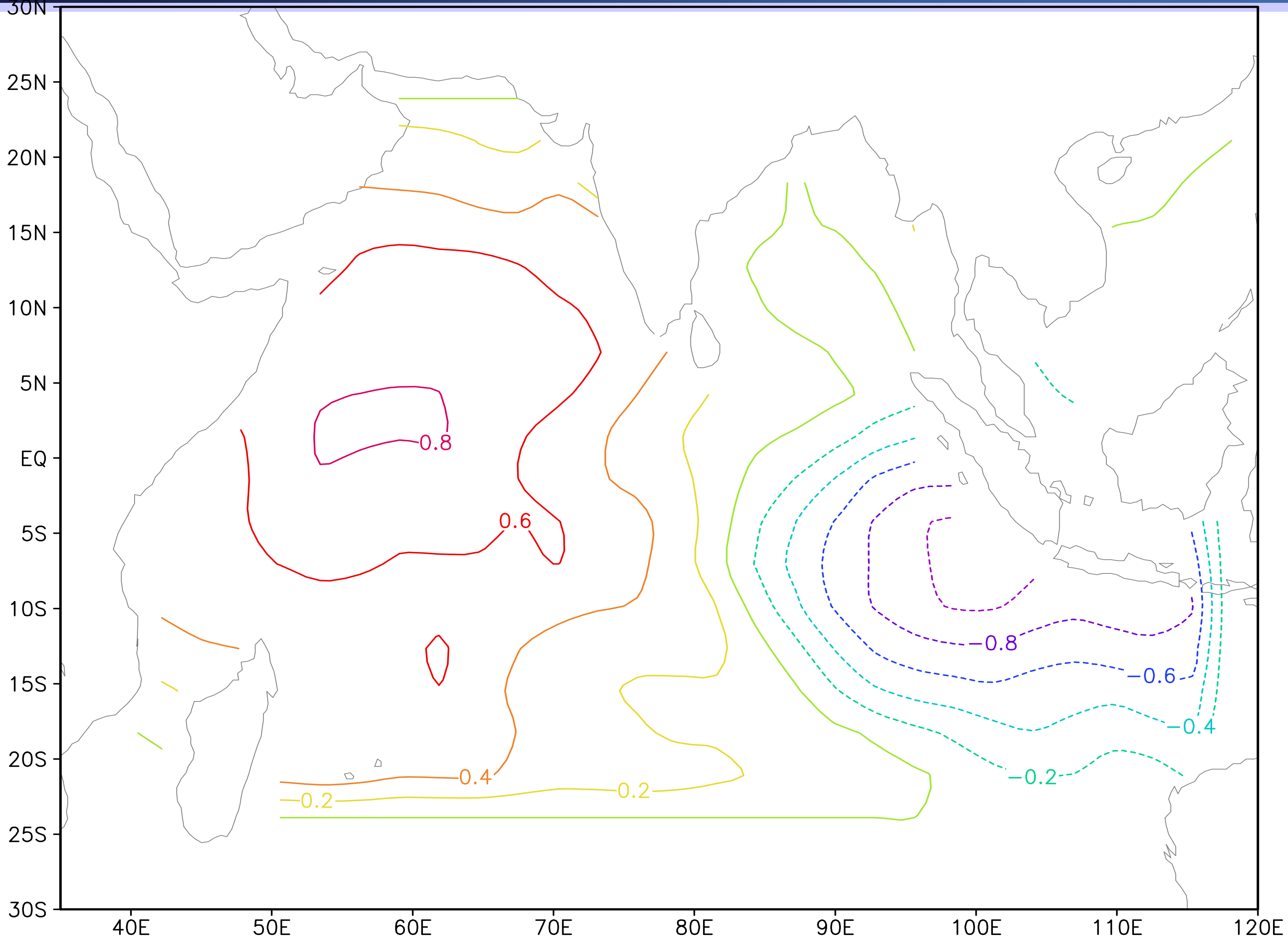
- 2 expts – each with sixteen member ensembles, and run for a full calendar year (January-December).

(i) with seasonally varying Climatological SST

(ii) Positive IOD type SSTA imposed on Clim. SST from April (peak in October)

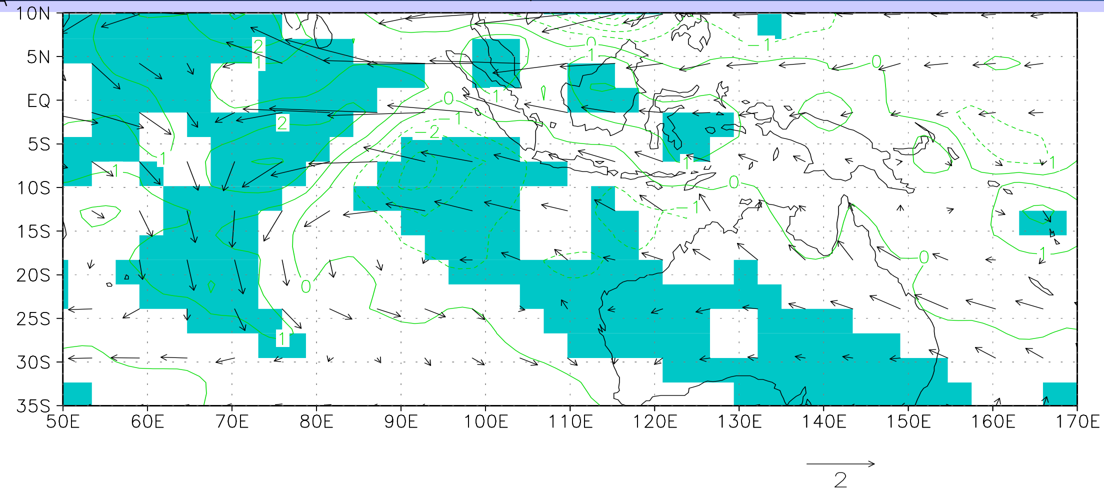
* *Initial conditions picked from a long integration.*

SSTA (C) imposed in the IOD experiment during September



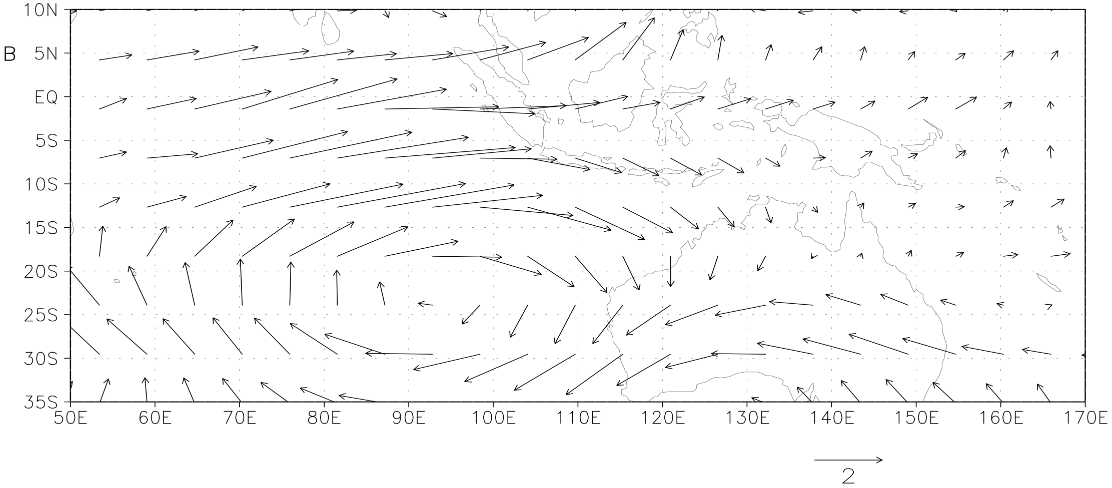
JJAS rainfall and wind at 850 hPa (m/s)
IOD expt.–Control

A

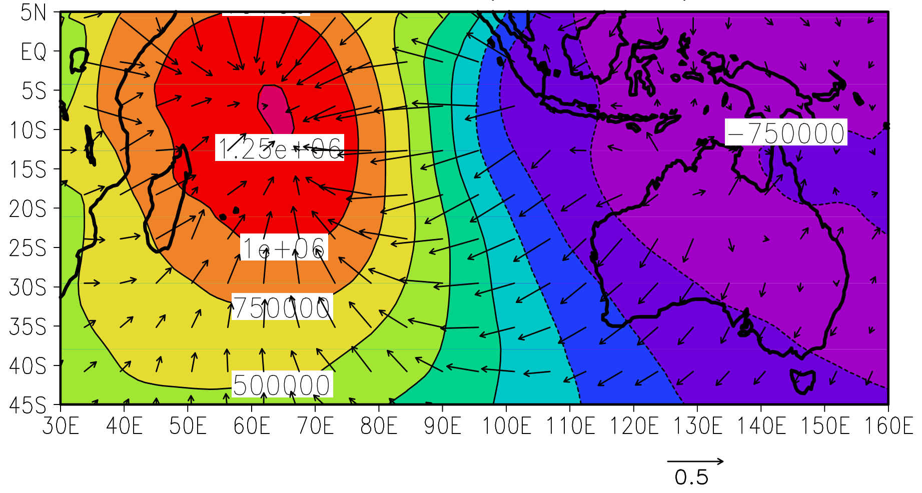


JJAS wind at 200 hPa (m/s)
IOD expt.–control

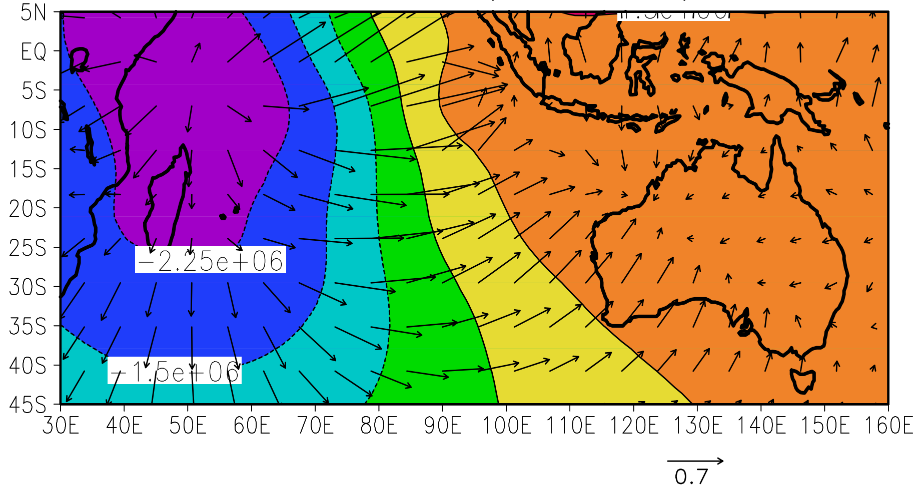
B



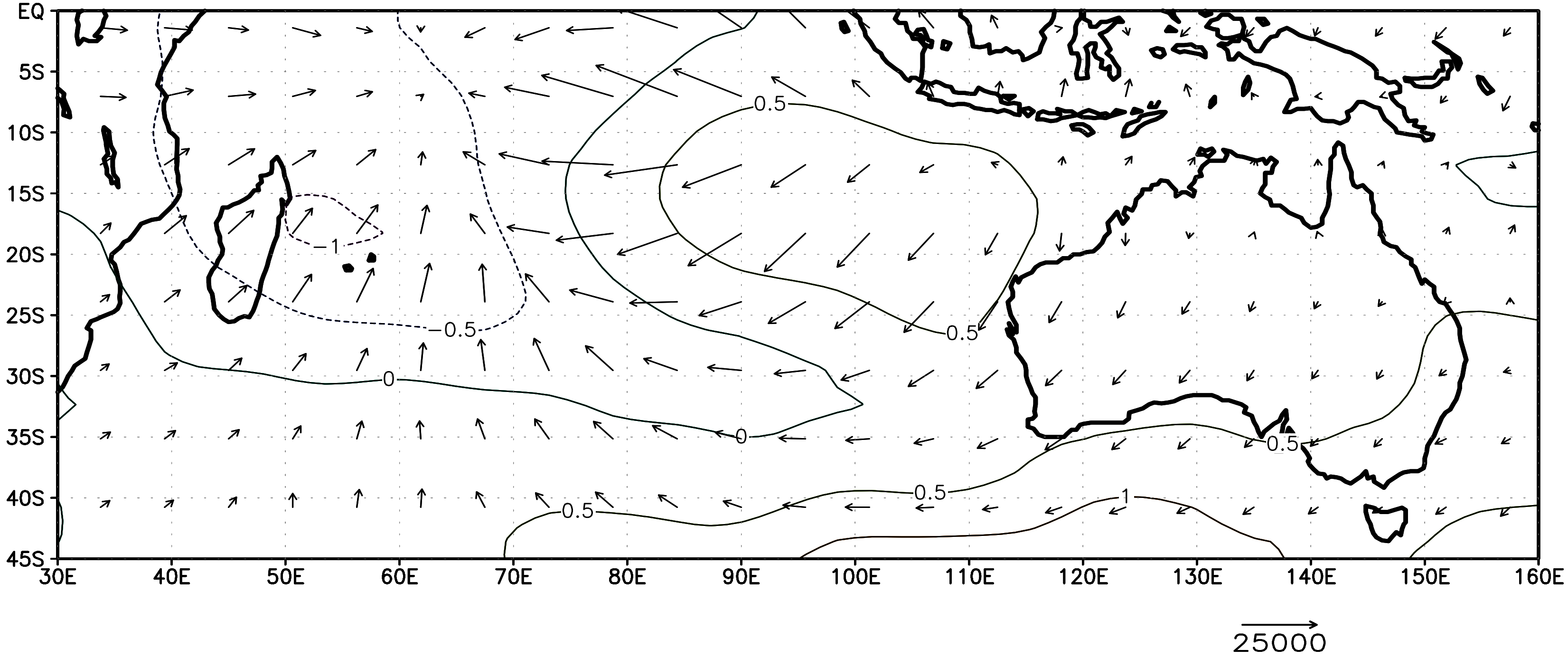
JJAS velocity potential and divergent winds
850 hPa; IOD Expt.–Clim. Expt.



JJAS velocity potential and divergent winds
200 hPa; IOD Expt.–Clim. Expt.



Anamolous SLP (hPa) and Vertically integrated moisture flux
(IOD Expt.−Cntrl Expt.)

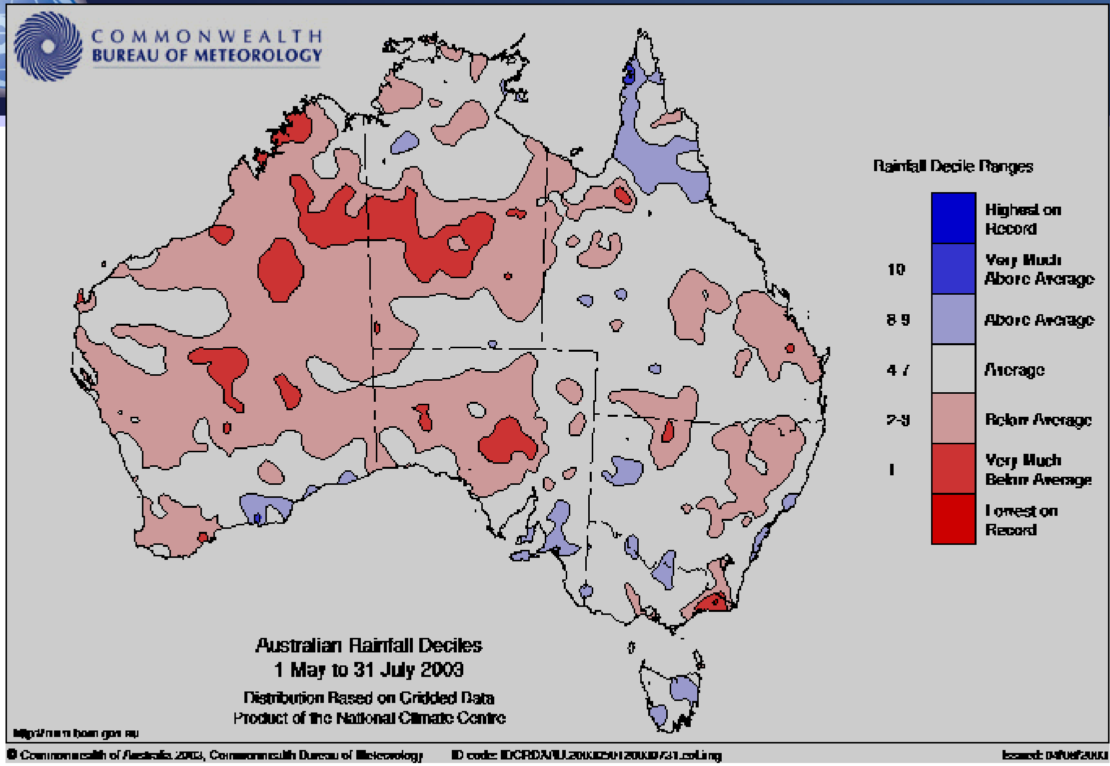


Summary & Conclusion

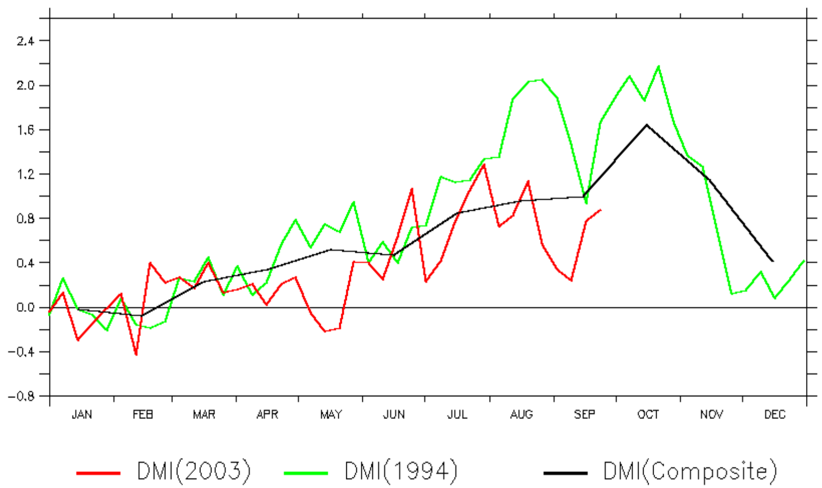
- In this paper, the impact of the IOD on the Australian winter rainfall was studied using the different observational data sets and the FrAM1.0 AGCM. The results from this study can be summarized as follows:
- During the intense IOD years such as 1961, 1967, 1972, 1994 and 1997 etc., large negative rainfall anomalies are observed over many parts of the southern half of the Australian continent.
- We have computed partial correlations between the IODMI and the rainfall over Australia after removing the influence of the NINO3 index, the second predictor that represents the influence of the ENSO events in the Pacific. the IOD has significant impact on the winter rainfall of western and southern Australia. Significant negative partial correlations extend southeastward from Indonesia all the way to southeast Australia.

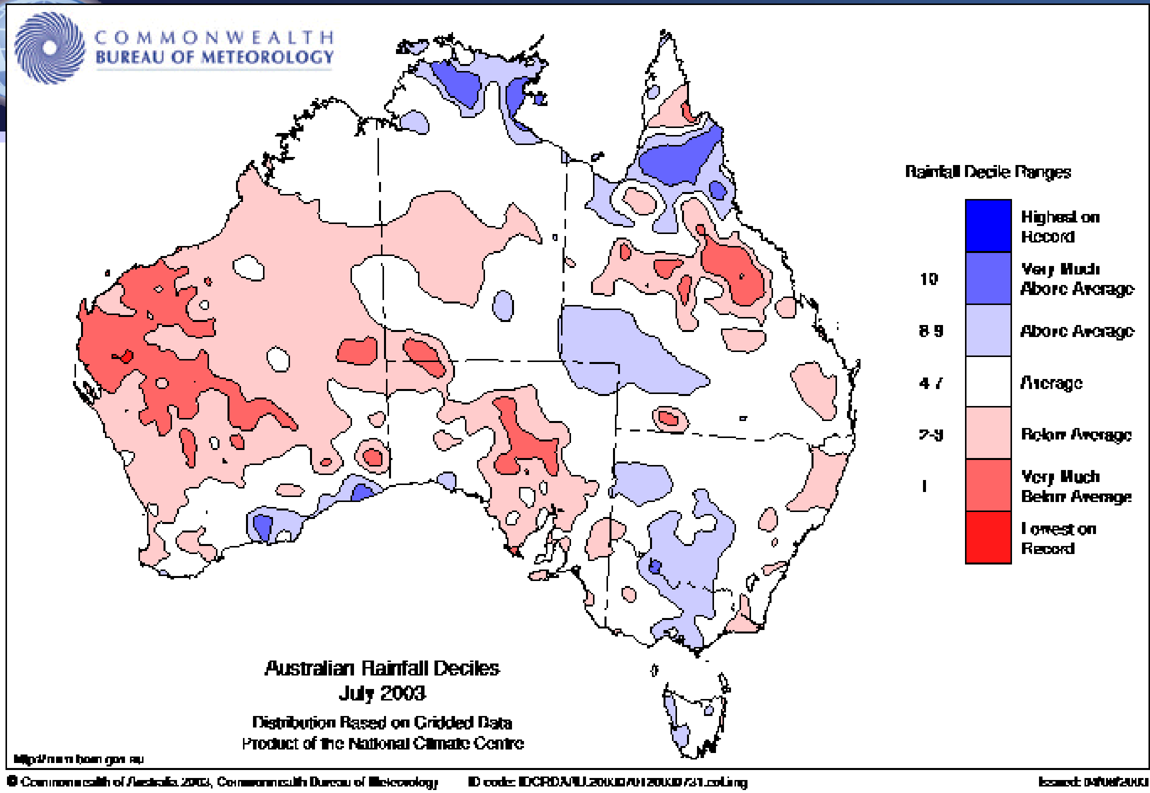
Summary & Conclusion (Continued)

- Using the FrAM1.0 AGCM, we conducted two sets of sensitivity experiments to understand the mechanism behind the IOD-Australian winter rainfall relationship. The simulations reasonably agree with observations. The mechanism behind how the positive IOD events influence the Australian winter climate can be derived from the results of these experiments: the relatively cold SSTA to the west of the Indonesian archipelago during a positive IOD event introduce an anomalously anticyclonic circulation at lower levels over the eastern tropical and subtropical Indian Ocean as well as much of the Australian continent, consistent with the Matsuno-Gill theory [*Matsuno* 1966, *Gill* 1980, *Wang et al.* 2003, *Guan et al.,* 2003]. The response of the atmosphere in this region is baroclinic. This results in anomalous subsidence over regions of western and southern Australian continent and also reduces the rainfall.

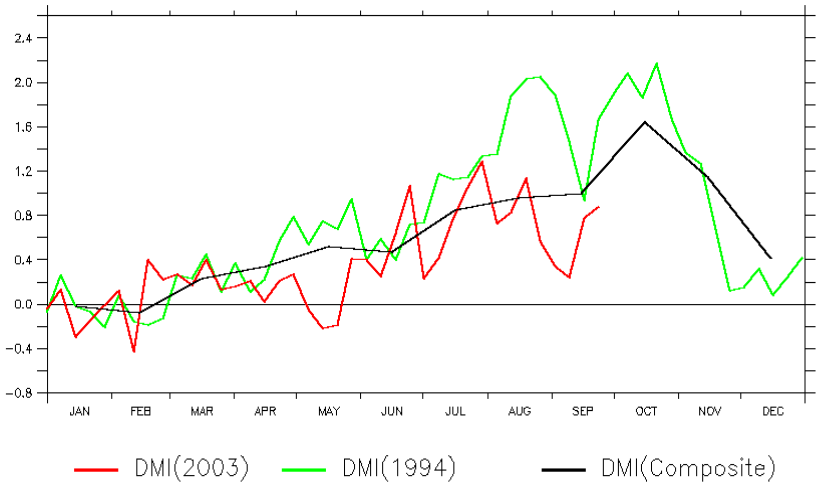


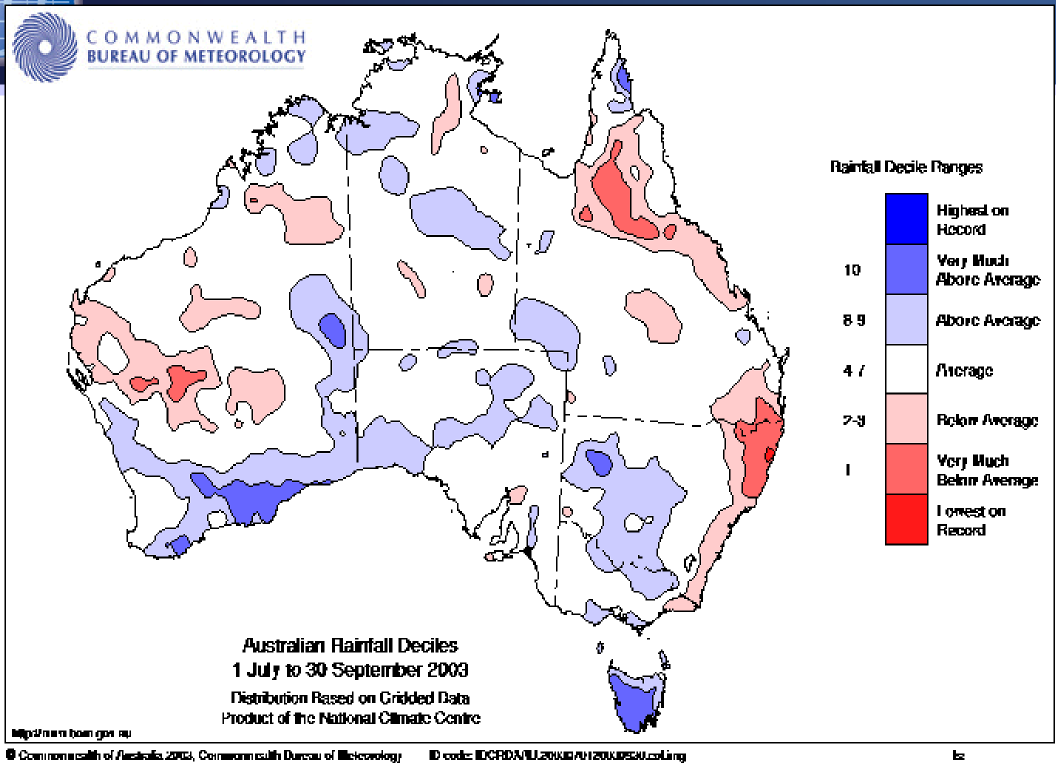
DMI evolution (Weekly)

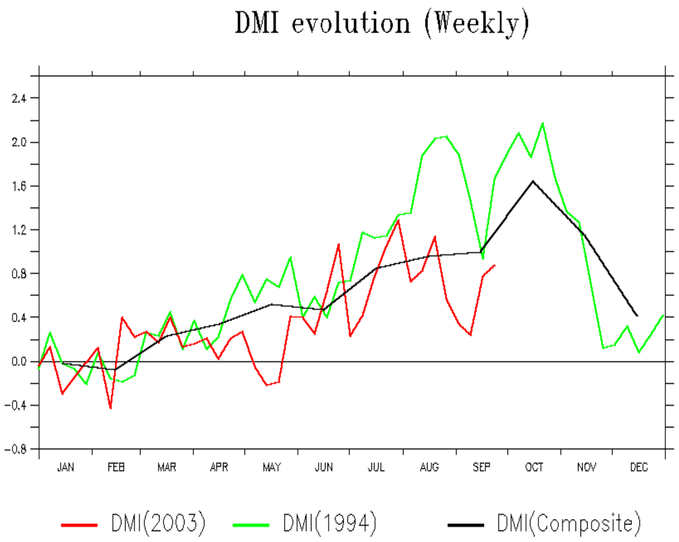




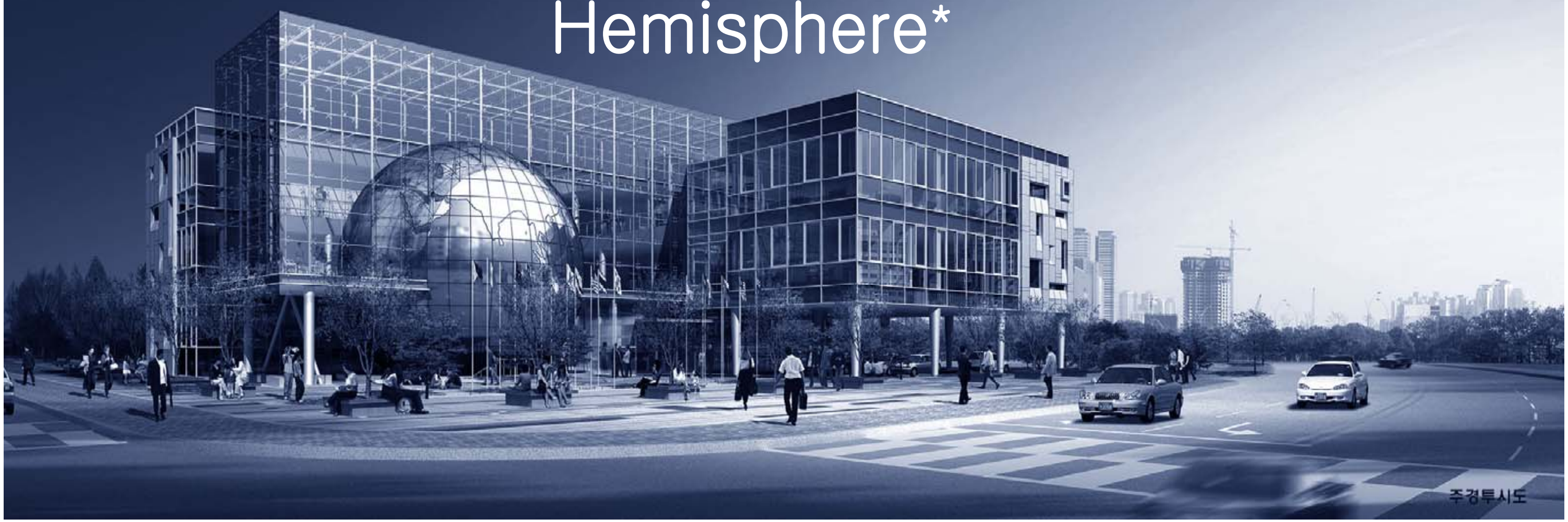
DMI evolution (Weekly)




COMMONWEALTH
BUREAU OF METEOROLOGY
Rainfall Decile Ranges
Highest on Record
10 Very Much Above Average
8-9 Above Average
4-7 Average
2-3 Below Average
1 Very Much Below Average
Lowest on Record
Australian Rainfall Deciles
1 July to 30 September 2003
Distribution Based on Gridded Data
Product of the National Climate Centre


DMI evolution (Weekly)
2.4
2.0
1.6
1.2
0.8
0.4
0.0
−0.4
−0.8
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
DMI(2003)
DMI(1994)
DMI(Composite)

ENSO and IOD impacts on the winter storm track activity in the Southern Hemisphere*



Introduction

- Trenberth (1991) has first studied the seasonal characteristics of the storm track activity in the Southern Hemisphere (SH) comprehensively, based mainly on zonally averaged statistics of sub weekly eddies and their relationship with the zonal mean circulation.
- Several other studies that addressed the group velocity propagation of synoptic scale eddies : Lee and Held 193; Berberry & Vera 1996; Chang 1999; Rao et al. 2002). Study of synoptic and regional aspects of storm activity by tracking centers of moving cyclones & anticyclones over SH – Sinclair (1994, 1995, 1996), Simmonds and Keay (2000).

Seasonality, & association with Jet streams

- In the absence of the developed STJ during austral summer, a single, well-defined circumpolar storm track forms along a deep polar-front (or sub polar) jet stream (PFJ).

- In contrast, During austral winter, the main upper-level storm track over the South Pacific forms along the intense STJ, while the low-level storm track with vigorous baroclinic eddy growth forms along a surface baroclinic zone off the Antarctic coast.

- Trapping upper-level eddy activity into its core away from a surface baroclinic zone (Nakamura and Sampe, 2002), an intense STJ as over the South Pacific acts to suppress the mid latitude storm track activity (Nakamura and Shimpo 2004; Nakamura et al. 2004).

- Another important factor that influences the SH storm track activity is the presence of a pronounced surface baroclinic zone over the South Indian Ocean anchored by an intense oceanic frontal zone along the Antarctic Circumpolar Current (Nakamura and Shimpo 2004; Nakamura et al. 2004; Inatsu and Hoskins 2004).

From Tropics to higher latitudes

- ENSO events affect the SH storm tracks by changing the strengths of anomalous convective activity in the tropics (Trenberth et al., 1998). The anomalous convection can influence the STJ via an anomalous divergent wind (Sardeshmukh & Hoskins, 1985), while PFJ tends to be influenced through stationary Rossby waves generated in response to anomalous tropical convection (Kidson et al., 2002).
- Guan et al. (2003), Ashok et al. (2003), Saji & Yamagata 2003, Saji et al. (2005), – IOD impacts.

Data Period (1979-2003)

NCEP/NCAR reanalysis based storm track parameters
(* courtesy Dr. T. Sampe)
GISST
CMAP rainfall datasets
Willmott-Matsuura rain gauge-based rainfall datasets

Indices of Storm track activity

- Upper level activity index: Local instantaneous upper-level storm track activity is measured by what may be called "envelope function" (*Ze*; Nakamura and Wallace 1990; Nakamura and Shimpo 2004), which is defined locally as twice the smoothed time series of the squared high-pass-filtered 300-hPa height; the smoothing has been performed with an 8-day low-pass filter. Then, the square root of this quantity was taken before multiplied by a factor [sin (45°S)/sin (latitude)] to mimic eddy amplitude in geostrophic stream function. At each grid point, *Ze* represents local instantaneous amplitude of 300-hPa height fluctuations with periods shorter than 8 days.

Indices of Storm track activity (con'd)

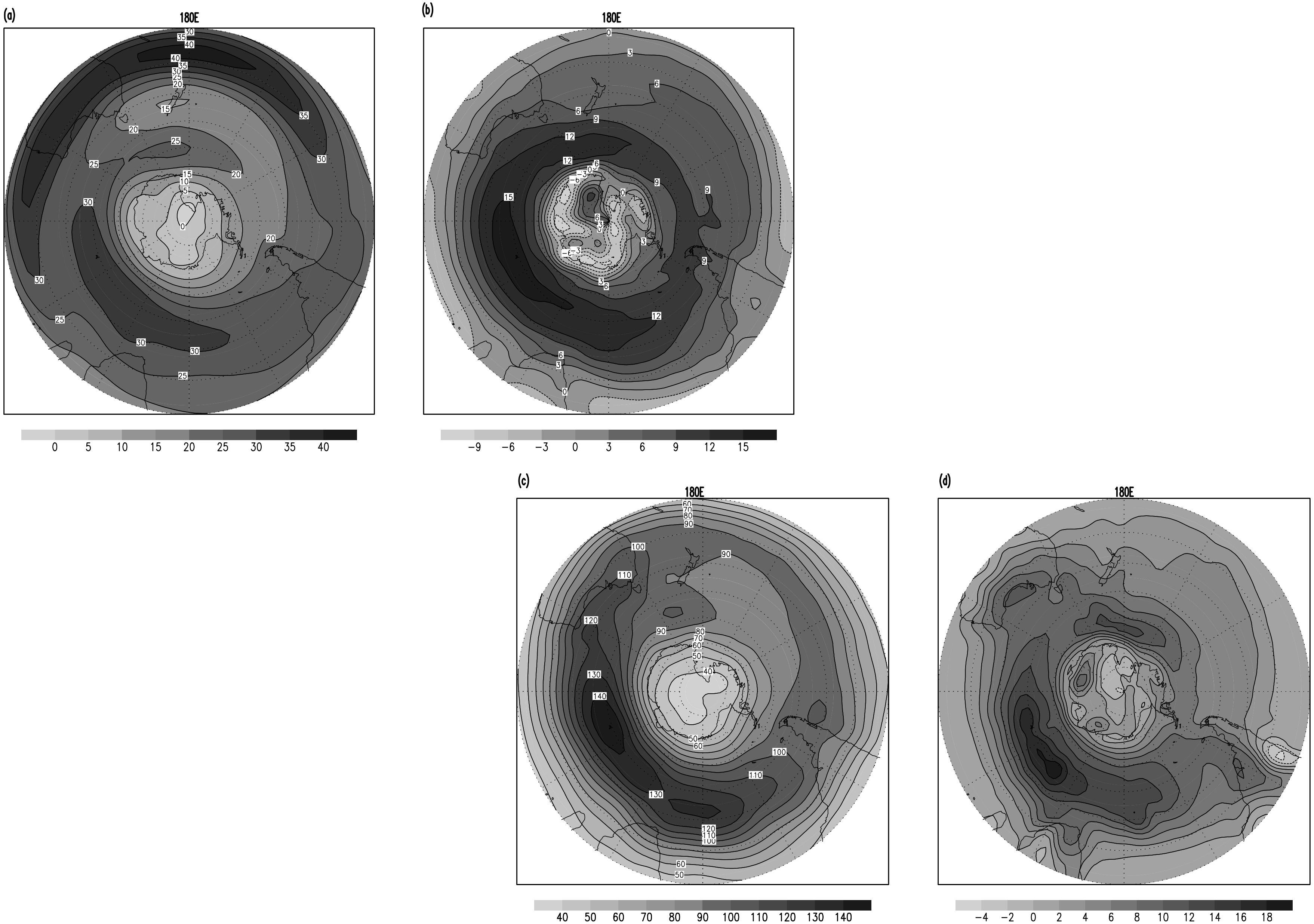
- **Lower level activity index:** As an index of low-level storm track activity, a poleward heat flux ($\overline{v'T'}$) associated with sub weekly disturbances was obtained as a product of the high-pass-filtered time series of the meridional velocity and temperature at the 850-hPa level. This flux was subsequently subject to an 8-day low-pass filter, to represent systematic transport of heat and momentum by the transient disturbances.

Indices of Storm track activity (Cont'd)

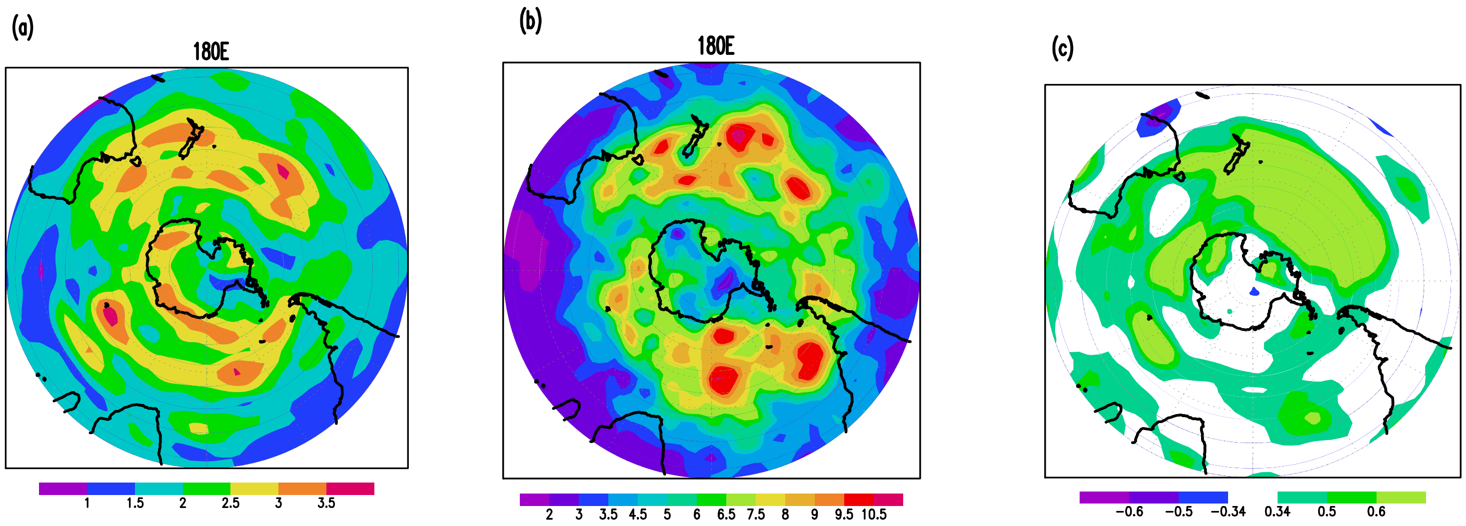
In addition, barotropic feedback forcing by synoptic scale eddies migrating along a storm track has been evaluated as a local tendency in 250-hPa height (*dz*250) that would be induced due solely to 250-hPa anomalous vorticity flux convergence associated with those eddies (Nakamura et al. 1997). The vorticity flux was calculated from the high-pass-filtered velocity fields, before smoothed with the low-pass filter. Compensated by the corresponding tendency due to eddy heat transport at lower levels, the barotropic feedback (*dz*250) should be regarded as an upper bound of the net feedback forcing by those eddies on quasi-stationary circulation (Lau and Nath 1991). In the following, we focus primarily on the eddy feedback forcing in terms of the equivalent westerly acceleration at the 250-hPa level (*dU*250).

Indices of Storm track activity (Cont'd)

Since we are interested in the remote influence of the tropical interannual variability on the SH storm tracks, we use monthly mean fields of SH circulation including those for eddy statistics of Ze, and *dU*250. Their anomaly fields are defined as monthly departures from their corresponding climatological-mean fields for a given calendar month for the period of 1979-98.



Climatology of zonal wind velocity (m/s) for winter (June-October) at the (a) 300-hPa and (b) 850-hPa levels. (c) Same as (a), but for 300-hPa *Ze* (m). (d) Same as (a), but for 850-hPa poleward heat fluxes associated with sub weekly eddies (; K m s–1). Based on the NCEP/NCAR reanalysis data for 1979-1998.



(a) (b) (c)

300-hPa distribution of wintertime (a) standard deviation of zonal wind anomalies (m.s.-1) (b) standard deviation of Ze (m.) anomalies. (c) local anomaly correlations between the zonal winds and Ze; significant correlations (at 90% confidence level from a two-tailed Student's t-test) are shaded.

ENSO impact on winter Storm tracks – A case study

- Nakamura et al. (2004) have carried out a case study to examine the impacts of the 1997 El Niño and 1998 La Niña events on the wintertime*** SH storm track activity. They found that in the 1997 winter the meridional bifurcation of the storm track activity over the South Pacific was even more distinct than in the climatological mean, while in the 1998 winter the bifurcation was diminished, and a single circumpolar storm track formed as in the normal summer. They also found that the bifurcation between the STJ and PFJ was also enhanced in the 1997 winter, whereas the STJ was diminished in the following winter.

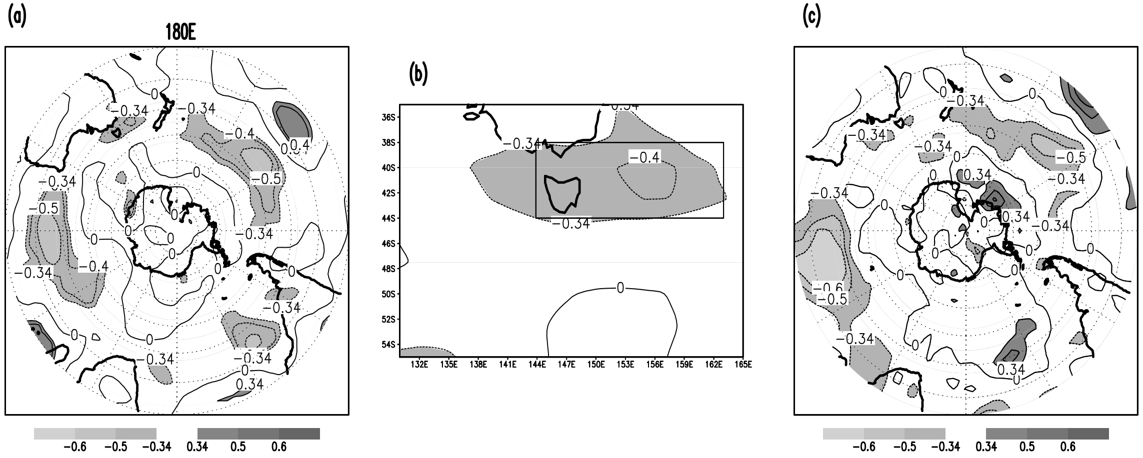
*** Bhaskaran & Mullan (2003) examined the ENSO impacts on SH storm track activity during Austral summer.

ENSO impact – A case study (Con'd)

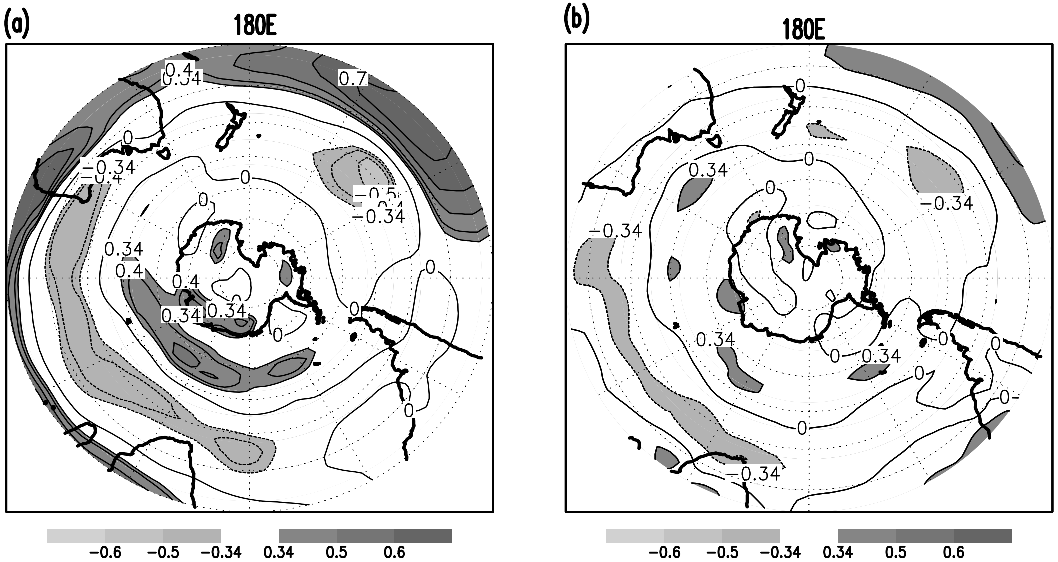
- They hypothesize that the enhanced (diminished) storm track activity along the STJ in the 1997 (1998) winter was due to the stronger (weaker) trapping effect of upper-level eddy activity by the intense (diminished) STJ core. Since the correlation between the southern oscillation index and the degree of the jet bifurcation over the South Pacific is not particularly high (Bals-Elsholz et al. 2001), it is our interest to examine whether the hypothesis is valid, in general, for ENSO events during the analysis period that spans from 1979 till 1998.

$v'T'$

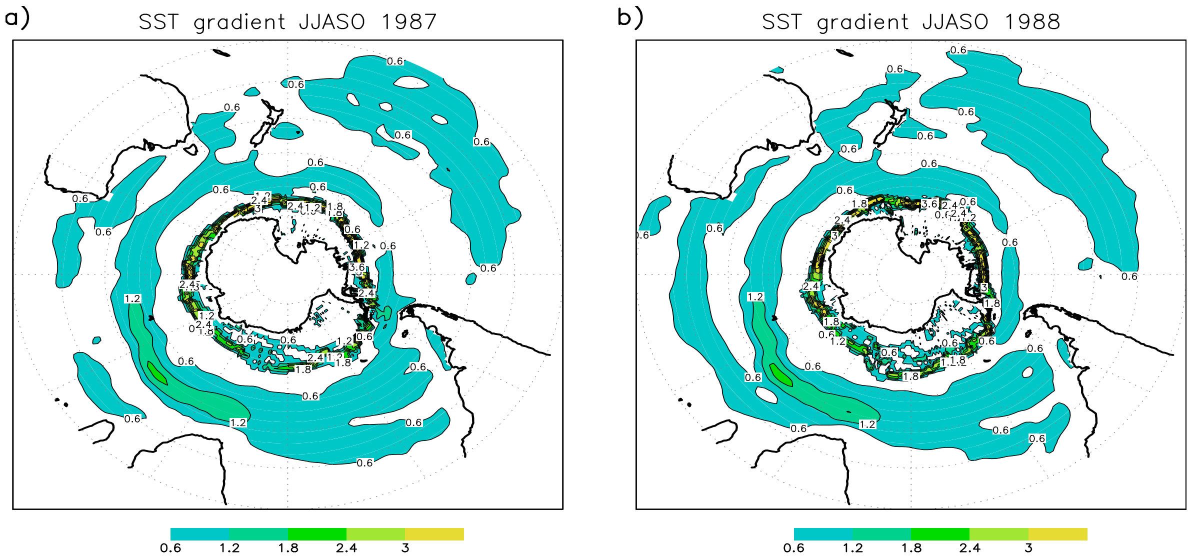
ENSO Impacts



Distribution of the winter partial correlation coefficients over the SH for (a) 300-hPa Ze anomalies with an enlarged format around southeastern Australia in (b), and (c) 850-hPa $\overline{v'T'}$ anomalies with NINO3 SSTA. Shading denotes correlations significant at the 90% or higher confidence level. The box in Fig. 3b is the domain for the “ENSO-sensitive” index, as a measure of the ENSO-related anomalous activity of the local storm track (see text for its definition).

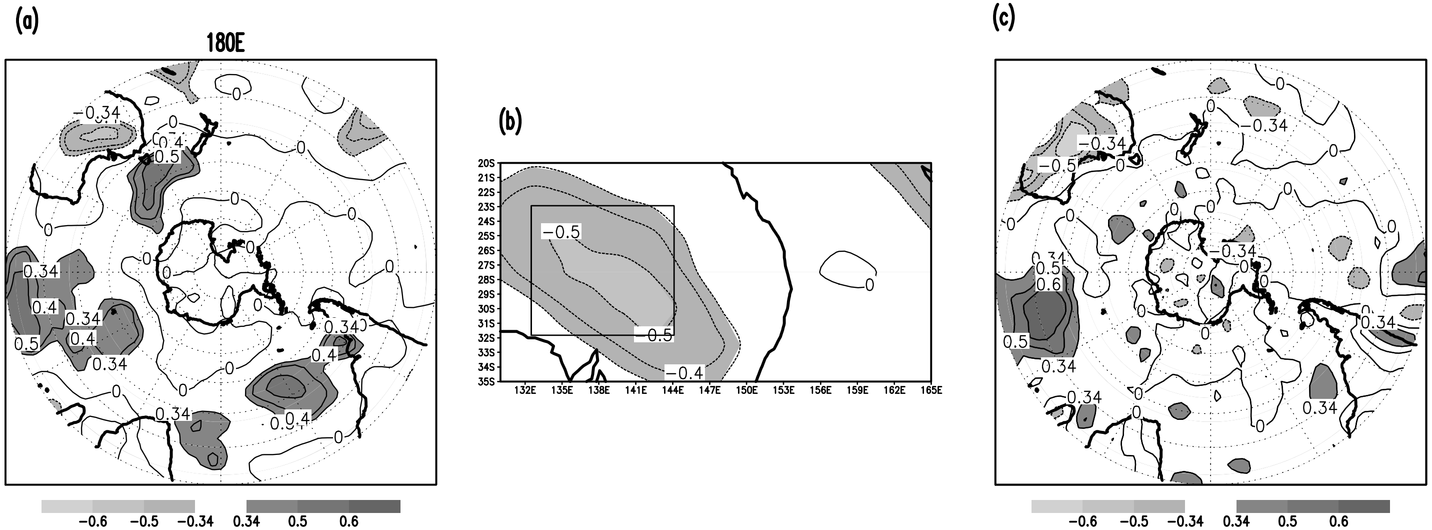


Distribution of the wintertime partial correlation coefficients for zonal wind anomalies at (a) 300-hPa and (b) 850-hPa levels with NINO3 SSTA.



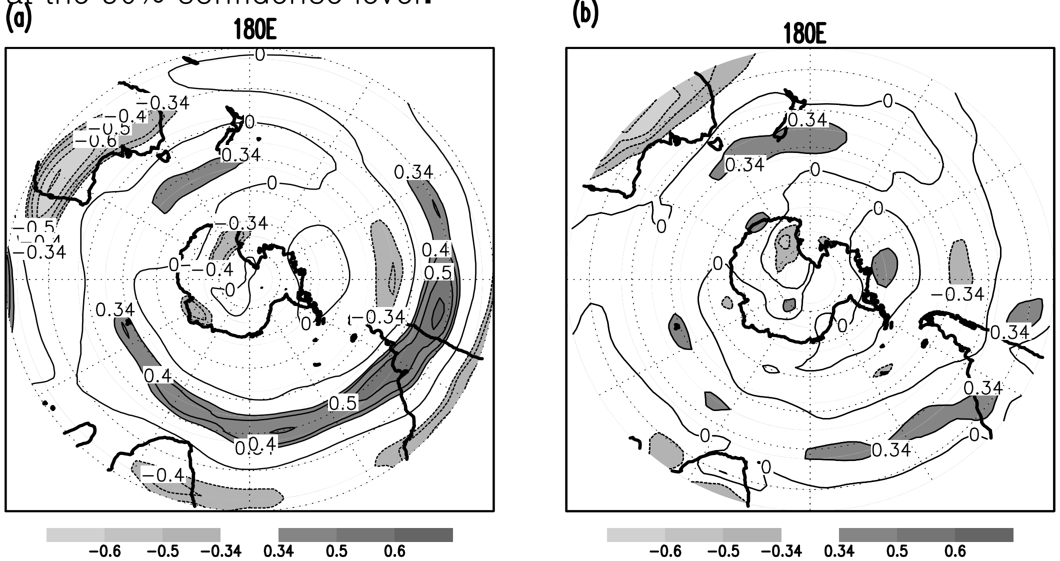
Distribution of the meridional gradient of sea surface temperature (ºC/110 km) during the winters of (a) 1987 and (b) 1988. Colored where the gradient exceeds 0.6, and the color convention is indicated at the bottom.

Oceanic sub-arctic frontal zone, just as in ENSO cases, seems to be located in the same place during positive (negative) IOD years such as 1994 (1992) – fig. not . shown



Distribution of the wintertime partial correlation coefficients for (a) 300-hPa Ze anomalies and (b) 850-hPa $\overline{v'T'}$ anomalies with IODMI. Shading denotes the correlation significant at the 90% confidence level.

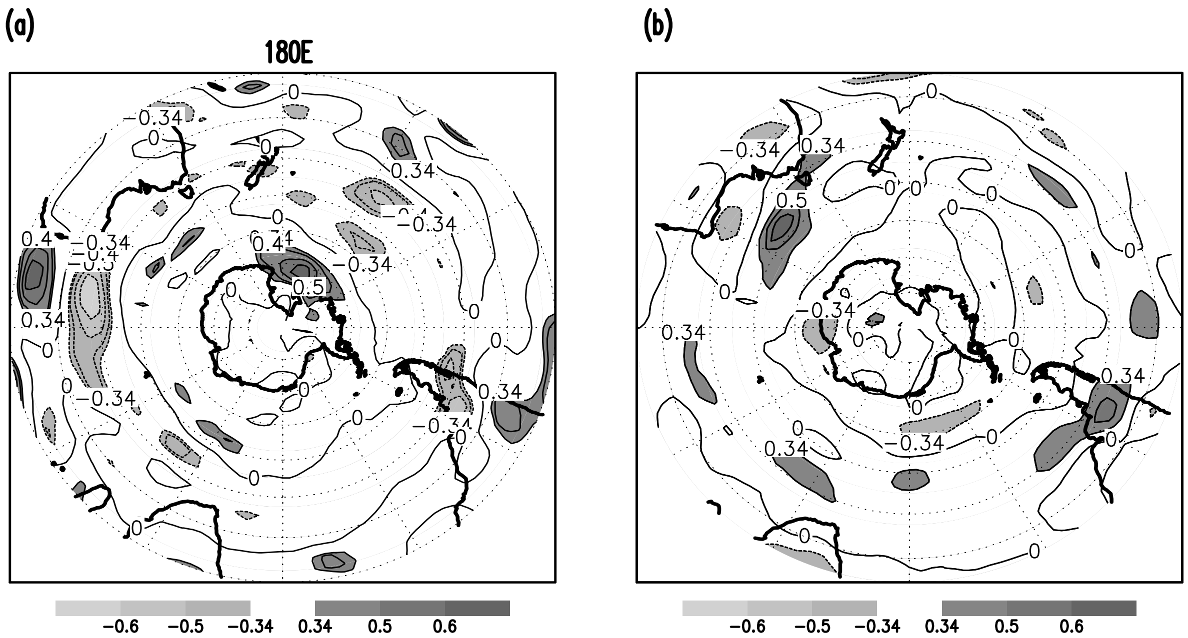
IOD Impacts



Distribution of the wintertime partial correlation coefficients for zonal wind anomalies at (a) he 300-hPa and (b) 850-hPa levels with IODMI.

As shown, both ENSO and IOD tend to generate stationary atmospheric Responses over the SH including the anomalous westerlies, leading to systematic changes in the midlatitude storm track activity. The anomalous storm track activity changes the westerly momentum transport, which in turn acts to maintain the anomalous westerlies. This positive feedback can be represented as the anomalous westerly acceleration at the 250-hPa level (*dU*250) due solely to the anomalous convergence of eddy vorticity fluxes (e.g., Nakamura et al. 1997).

To confirm whether the eddy feedback forcing is indeed operative in the SH response to each of the ENSO and IOD, we show maps of the wintertime partial correlation of *dU*250 with the NINO3 index and IODMI.

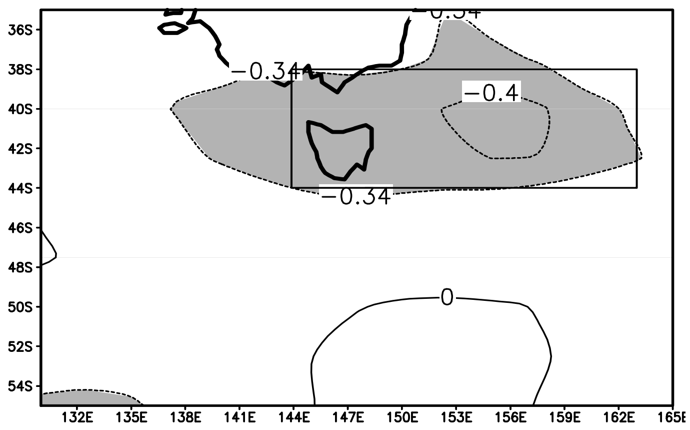


Distribution of the wintertime partial correlation coefficients for the eddy feedback forcing in terms of the anomalous westerly acceleration at the 250-hPa level (dU_{250}) with (a) NINO3 SSTA and (b) IODMI. Shading denotes the correlation significant at the 90% confidence level.

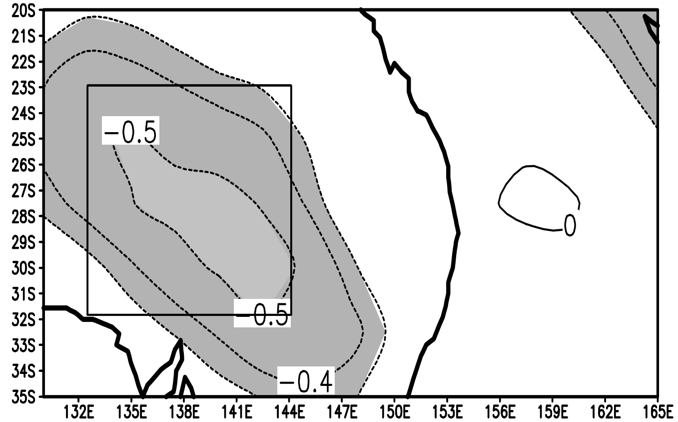
The feedback forcing is positive in the sense that it acts to reinforce and maintain the ENSO and IOD-related anomalous westerlies in which eddies are embedded. Our findings are consistent with the previous studies that have highlighted the importance of the anomalous storm track activity in shaping up the extratropical stationary response to ENSO over the wintertime Northern Hemisphere (e.g., Hoerling and Ting 1994).

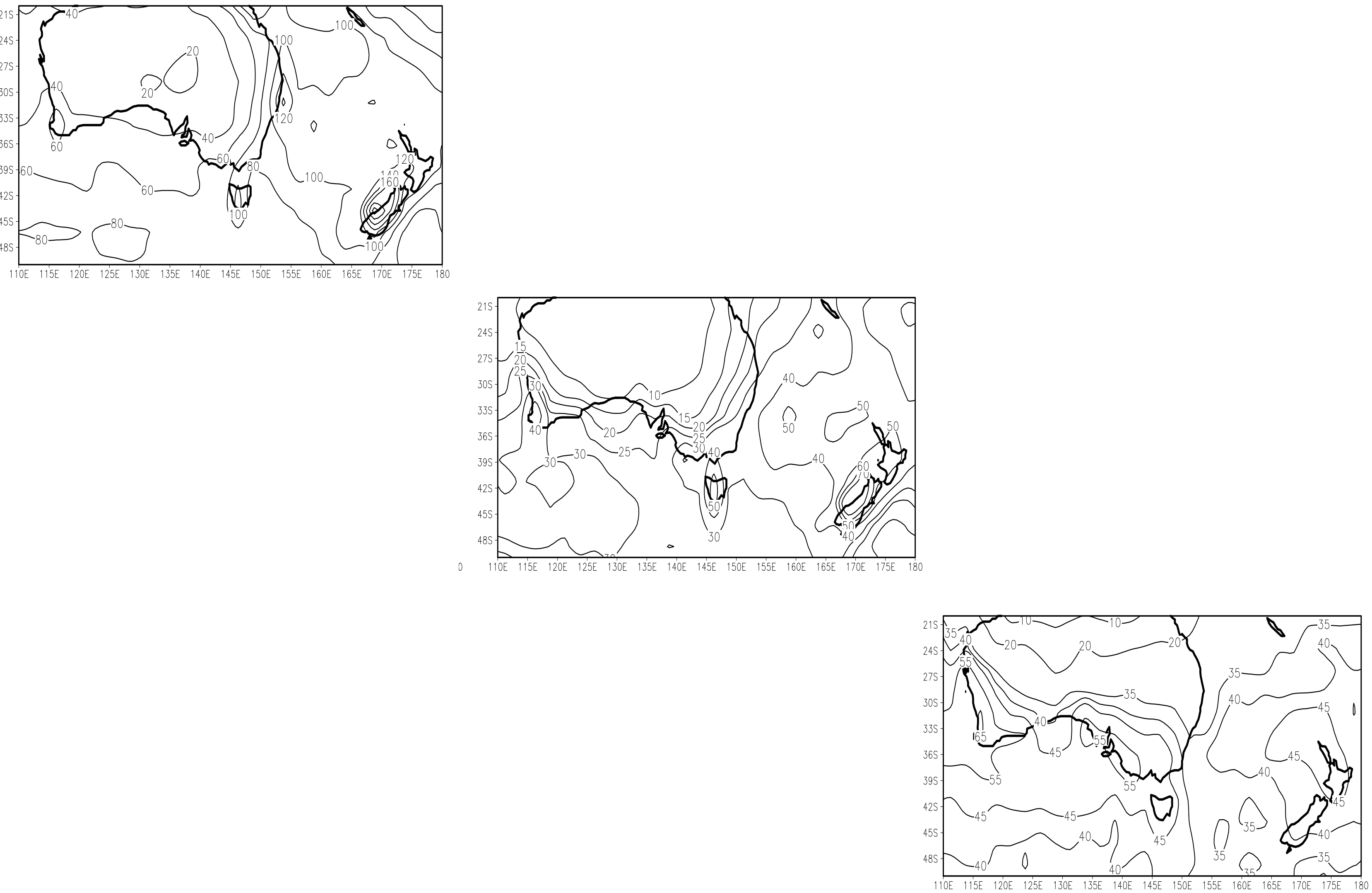
Potential impact-prone regions

- ENSO impact index: an index of the local storm track activity as the wintertime 300-hPa Ze anomaly averaged over the "ENSO-sensitive" region [38ºS~44ºS, 144ºE~163ºE; see figure to right], in which the ENSO impact on the eddy activity is strongest; multiplied by −1.0 to facilitate easy understanding.



- IOD impact index: 300-hPa *Ze* anomaly averaged over [23ºS~32ºS, 133ºE~144ºE ; see figure to right]. Multipled by −1.0





(a) Aggregate annual precipitation (cm), and (b) aggregate wintertime precipitation (cm) over the Australian-New Zealand sector. (c) Percentage of the wintertime amount in (b) over the annual amount in (a). Based on the CMAP data for 1979-1997.

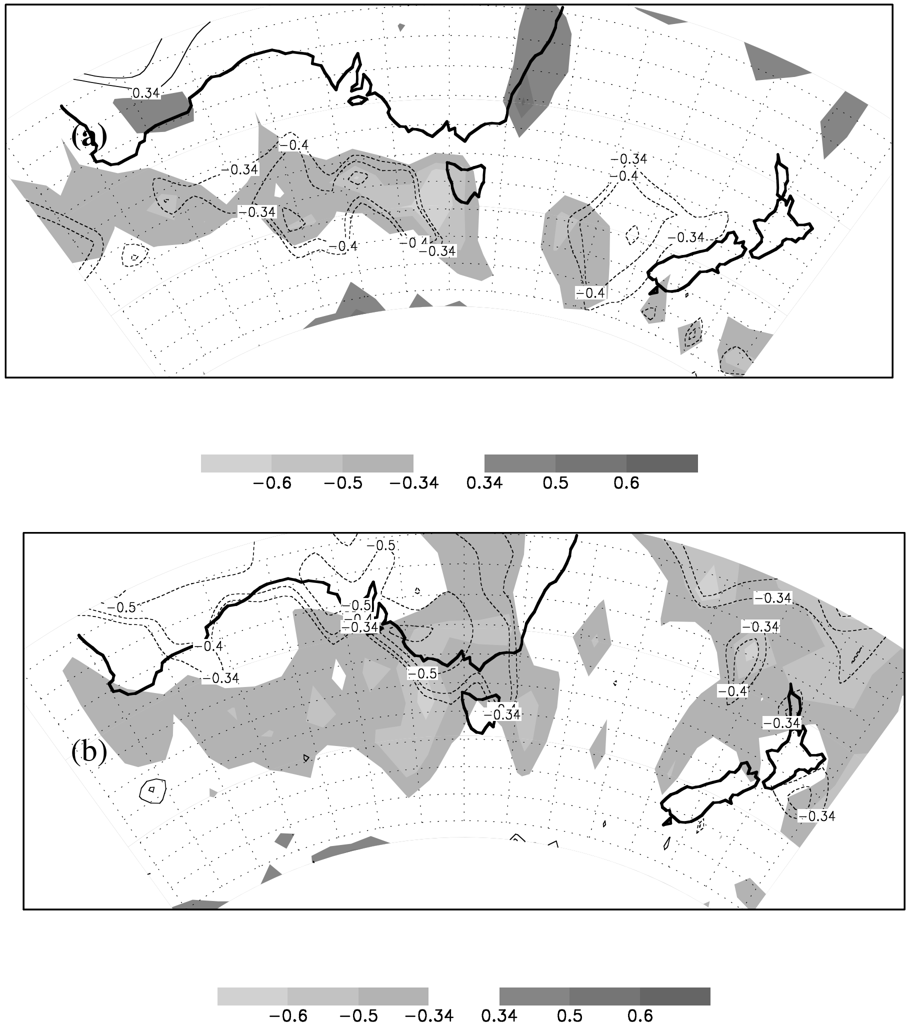
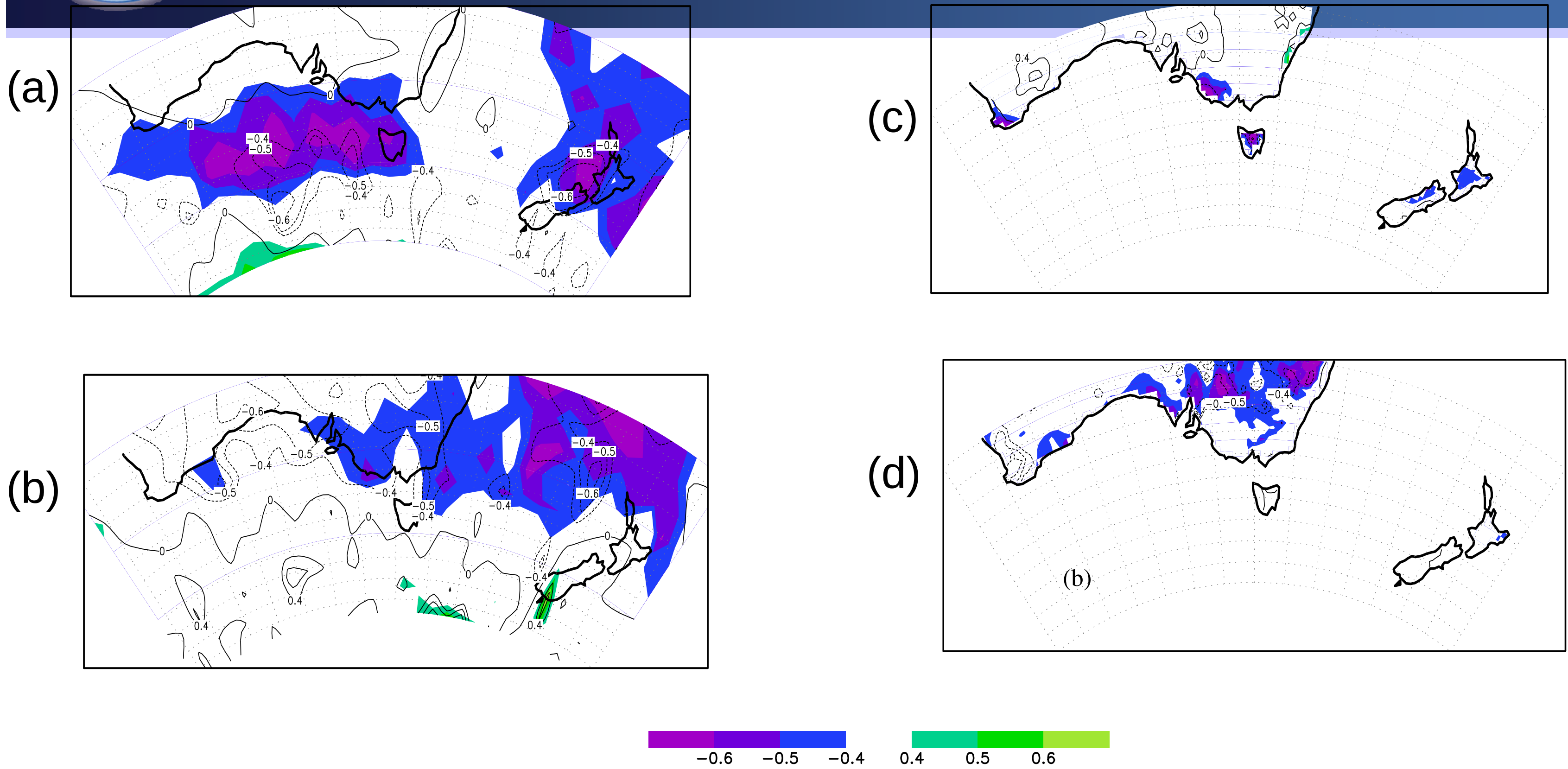


Fig. 9 (a) Distribution of the significant correlations between winter local CMAP precipitation and the “ENSO-sensitive” index for eddy activity (shaded) after removing the influence of the “IOD-sensitive index”. The correlations below 90% confidence level are omitted for clarity. Likewise, the significant partial correlation between the local precipitation and NINO3 SSTA after removing the IODMI influence is superimposed with contour lines (dashed for the significant negative correlation). (b) Same as in (a), but with the “IOD-sensitive” index for eddy activity after removing the influence from “ENSO-sensitive” index (shaded), and partial correlations between local precipitation and IODMI after removing the influence of NINO3 index.

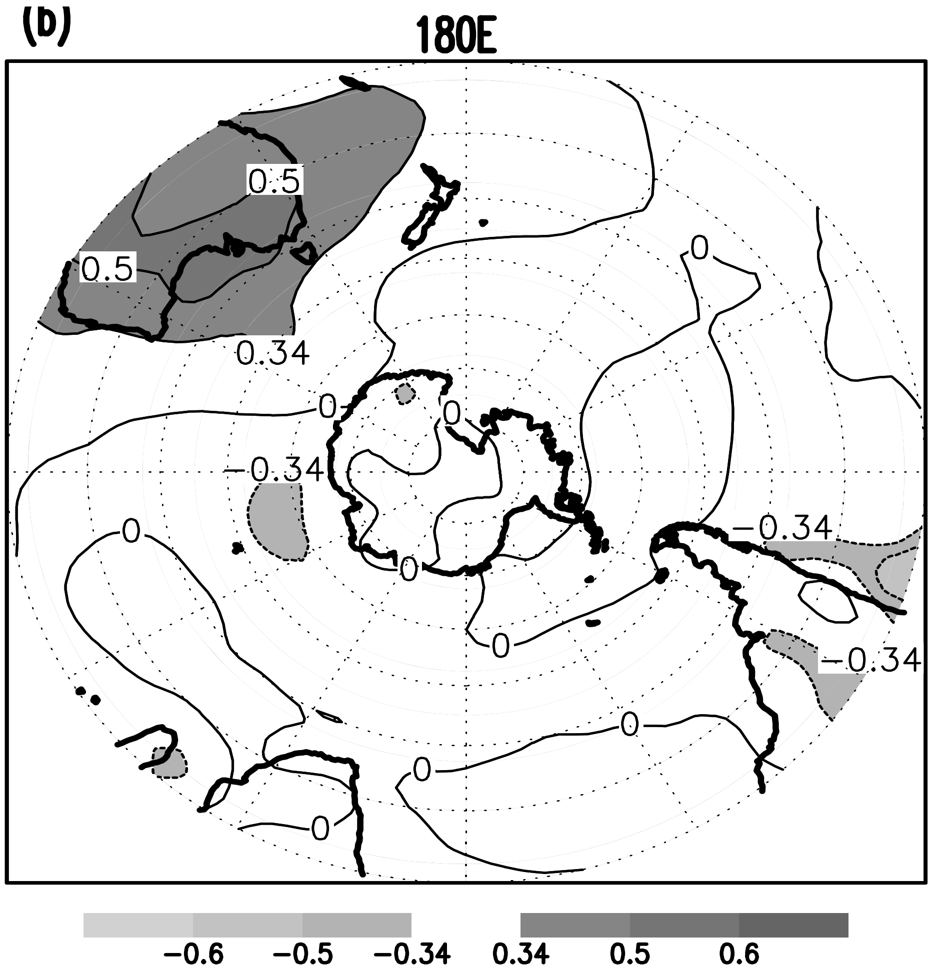
With CMAP Data

With Wilmott-Matuura Data

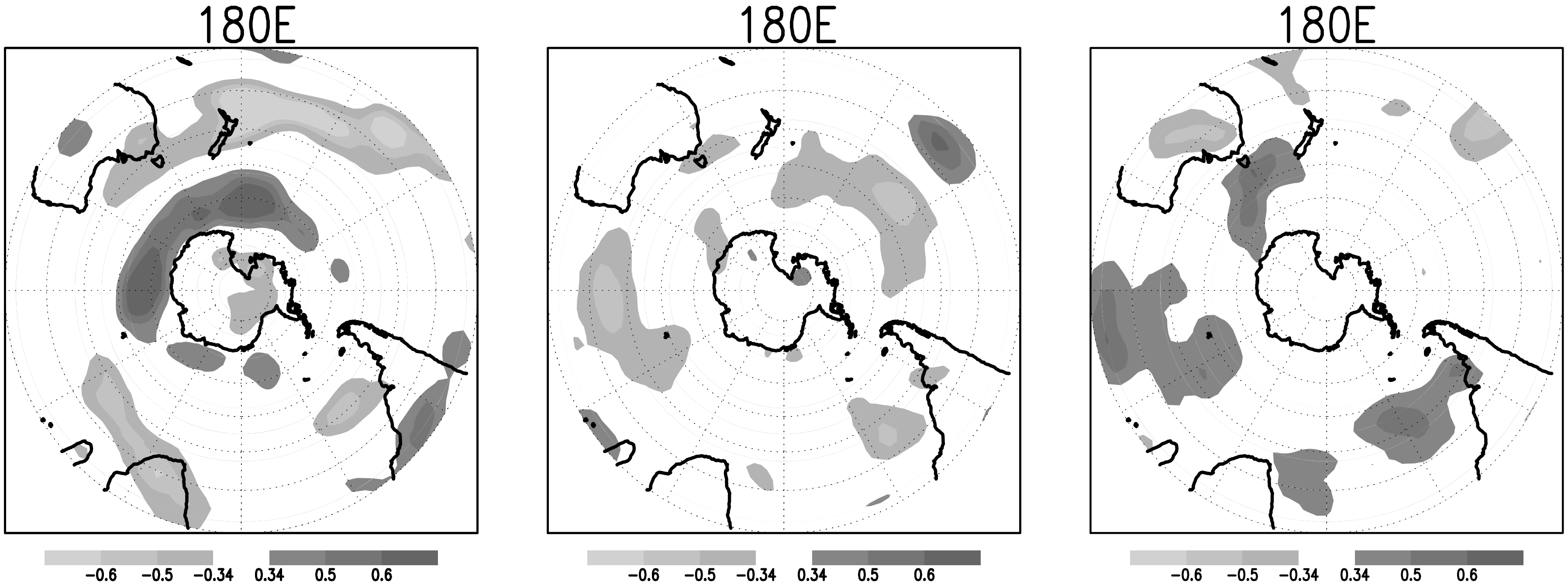


(a) Distribution of the correlation between wintertime local CMAP precipitation and the ENSO impact index, a measure of the ENSO-related anomalous activity of the local storm track. Only the correlation significant at the 90% confidence level is color shaded (as indicated at the bottom). Likewise, the significant partial correlation between the local precipitation and NINO3 SSTA is superimposed with contour lines (dashed for the negative correlation). (b) Same as in (a), but with IOD- impact index.

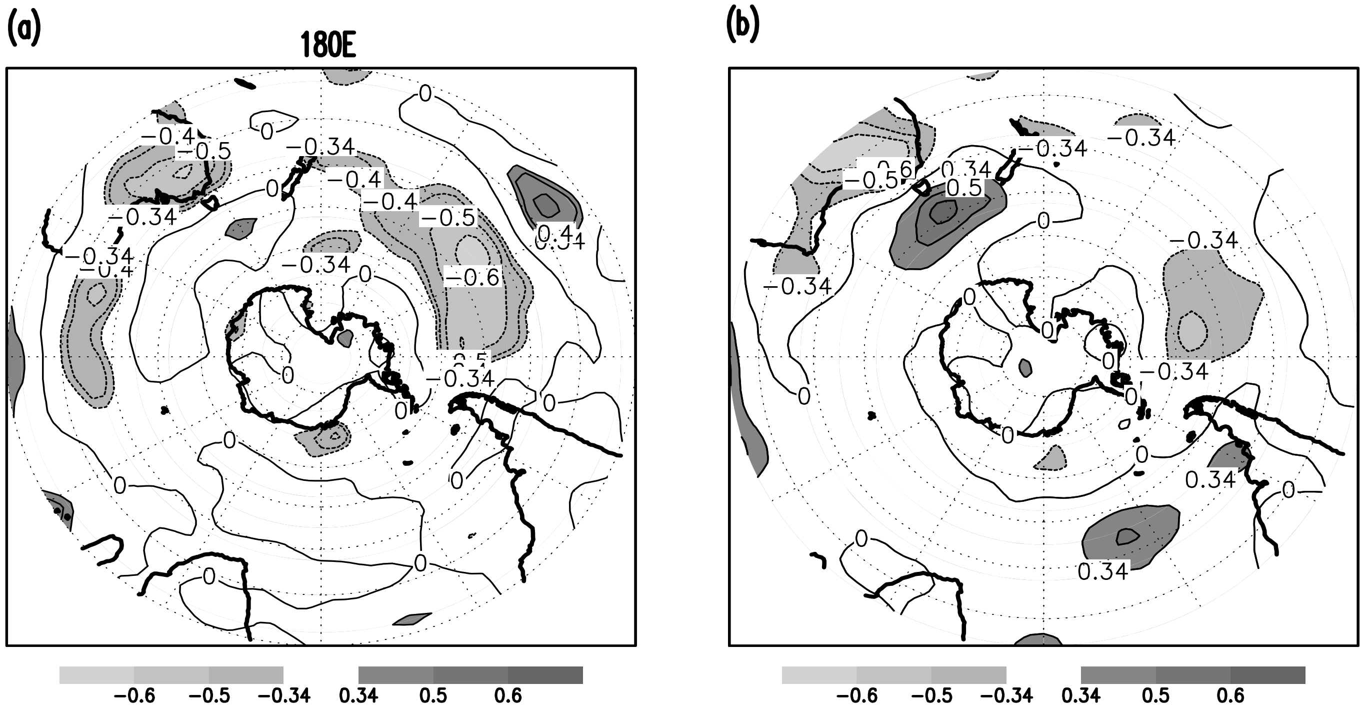
(c) & (d) are same as (a) and (b), but with Wilmott-Matsuura rain gauge network derived data.



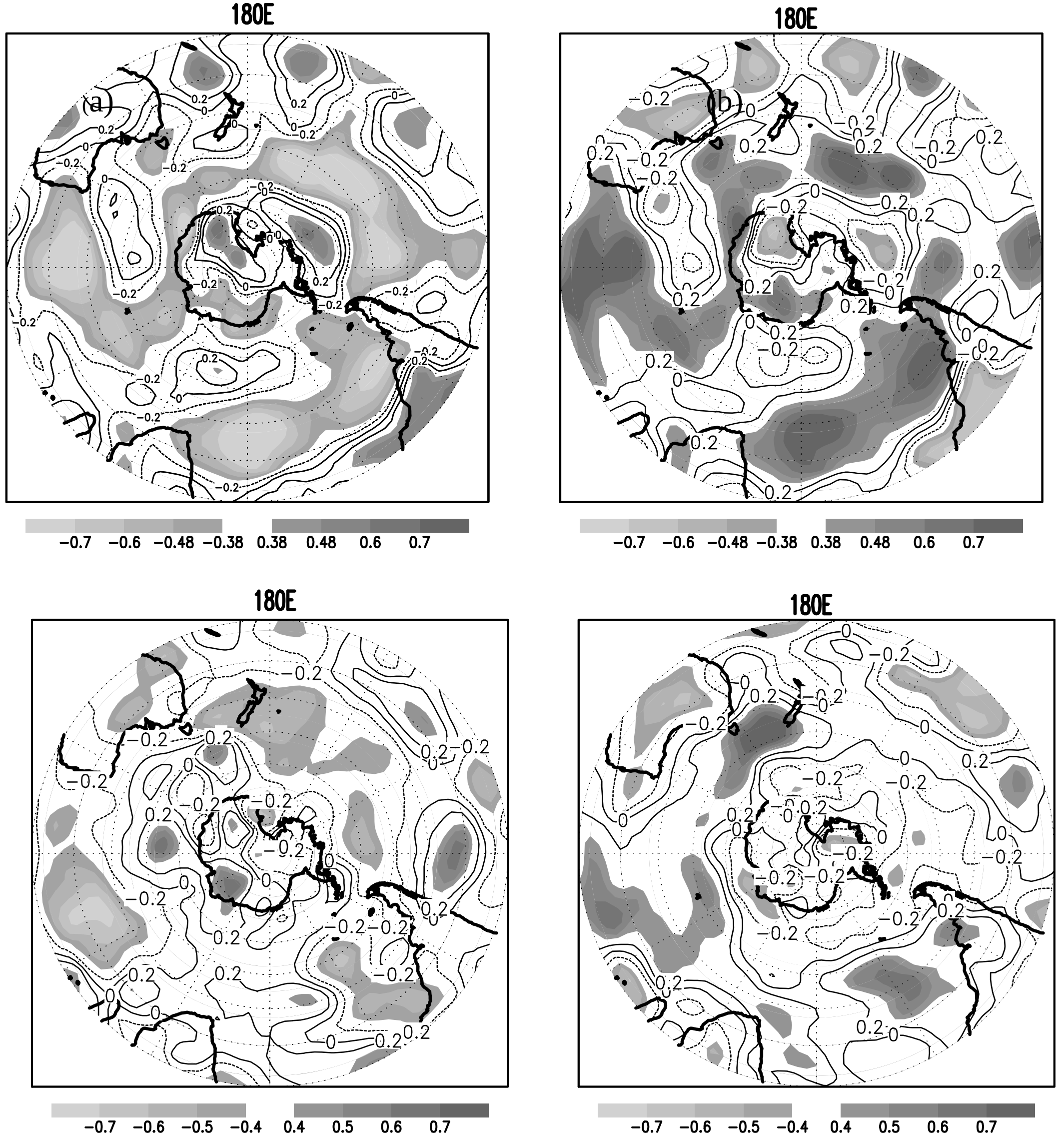
Distribution of the winter partial correlation coefficients for the sea level pressure anomalies (SLPA) with IODMI after removal of the ENSO impact. Shading denotes the correlation significant at the 90% or higher confidence level.



Distribution of the winter partial correlation coefficients for 300-hPa Ze anomalies with (a) the 300-hPa and SAM, after removing the influences of the IOD and ENSO (b) NINO3 index after removal of the influences of the IOD and SAM (c) IODMI after removing the influences of ENSO and SAM.



Distribution of the winter partial correlation coefficients for 300-hPa Ze anomalies with (a) the 300-hPa and SAM, after removal of the influence from SAM index with (a) NINO3 SSTA and (b) IODMI. Shading denotes the correlation significant at the 90% or higher confidence level.



(a) Same as in Fig. 3a, but for 13 odd-numbered years (1979, 1981, ···, 2003) . (b) Same as in Fig. 5a but for the odd-numbered years. In (a) and (b), 0.38 (0.48) are the significant correlations at 80% (90%) confidence levels from 1000 randomized Monte Carlo simulations. (c) Same as in Fig. 3a, but for 12 even-numbered years (1980, 1982, ···, 2002). (d) Same as in Fig. 5a but for the even-numbered years. In (c) and (d) 0.4 (0.5) are the significant

Summary

- The impact of the ENSO and IOD phenomena on wintertime storm track activity over the Southern Hemisphere is examined on the basis of the observed data for 1979–2003. The partial correlation technique is utilized to clearly distinguish the impact of each of the phenomena from that of the other.

Summary (Con'd)

- During an El Niño event, the STJ tends to strengthen substantially, while the midlatitude westerlies and storm track activity tend to weaken significantly over Australia and the South Pacific. During a positive IOD event, the westerlies and storm track activity weaken over Australia and enhance to its south. Thus, both the positive IOD and El Niño events act to shift the local storm track away from the Australian continent and thereby reduce wintertime rainfall significantly around the southern coast, although the cyclone-related precipitation over the southeastern portion of the continent is more sensitive to IOD.

Summary (continued)

- Significant reduction in precipitation associated with an El Niño event tends to spread more widely over New Zealand than that with a positive IOD event, whereas the latter event tends to enhance precipitation in the extreme south part of that country. Over the mid-latitude South America, in contrast, the enhancement of the westerlies and storm track activity tend to be more significant in a positive IOD even than in an El Niño event.
- The ENSO/IOD-related anomalous storm track activity mentioned above in turn acts to maintain the associated westerly wind anomalies via anomalous eddy transport of vorticity.