

A CRISE HÍDRICA BRASILEIRA 2014

A crise da água e suas consequências no século XXI

Augusto José Pereira Filho
Departamento de Ciências Atmosféricas
Instituto de Astronomia, Geofísica e Ciências Atmosféricas



26º Encontro Técnico AESABESP
Expo Center Norte em São Paulo
04 a 06 de Agosto de 2015

MUDANÇAS CLIMÁTICAS

Geleiras - 10 % da área da Terra, principais Antártica e Groenlândia
18.000 anos atrás se estendiam sobre latitudes médias.

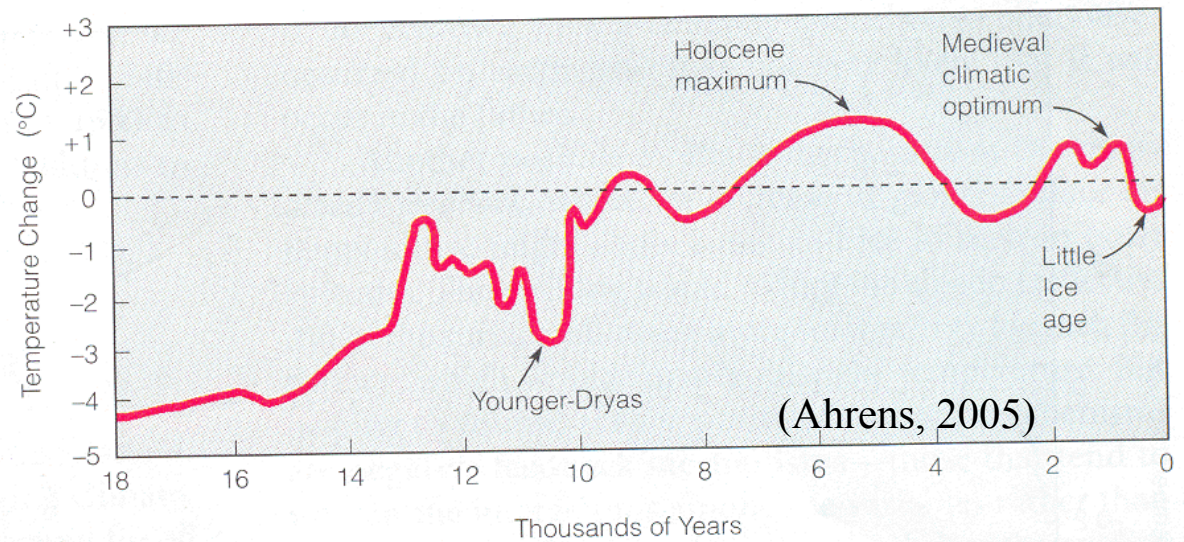
Avanço das geleiras - idade do gelo - períodos mais frios

Avanços e recuos das geleiras -> evidência geológica -> constante
mudança do clima global

Evidências: sedimentos terrestres e oceânicos, e geleiras.

FIGURE 18.4

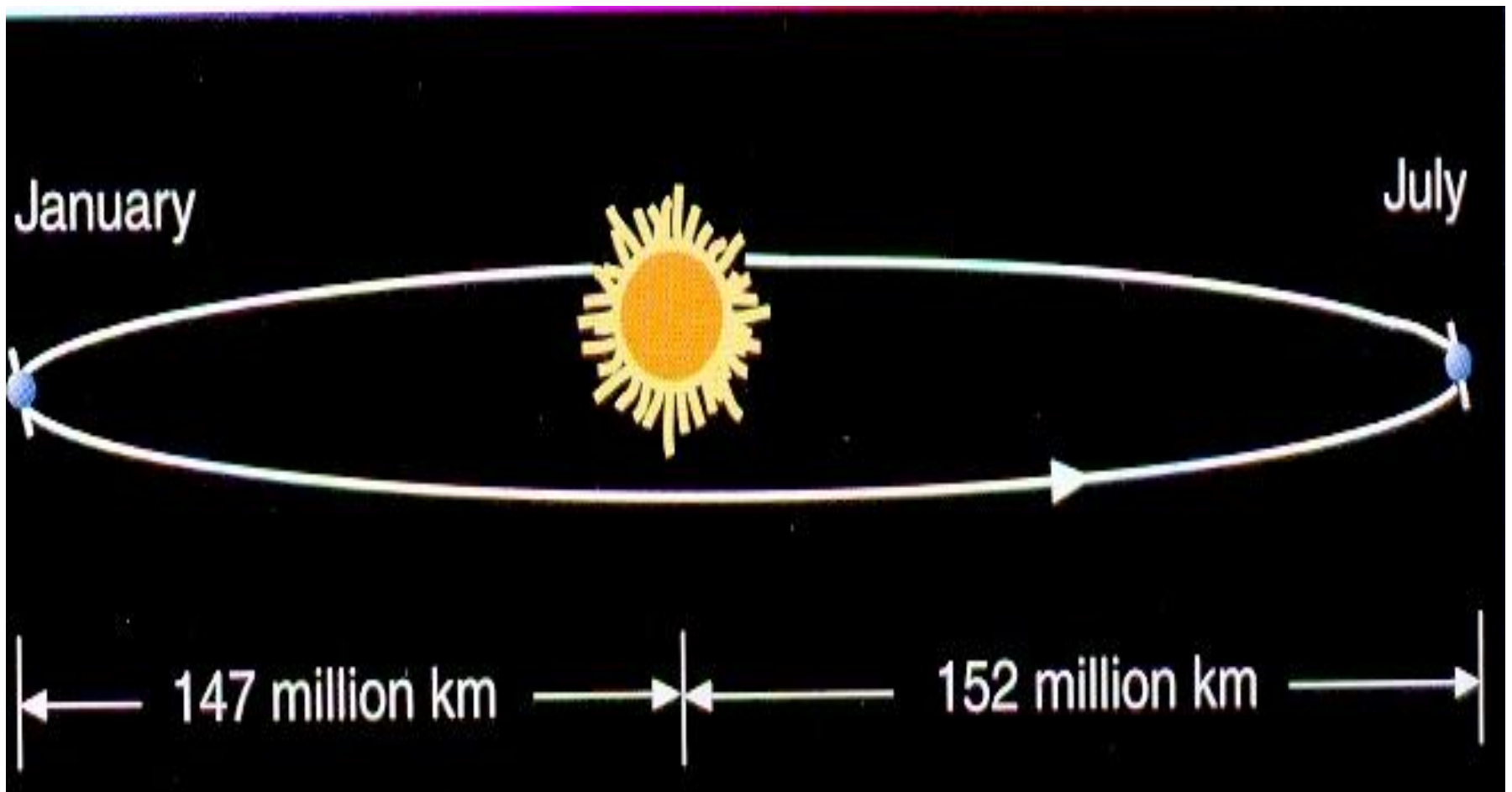
The average air temperature variations for the past 18,000 years. (Modified from J. T. Houghton et al., *Climate Change: The IPCC Assessment*, Cambridge University Press, Cambridge, England, 1990.)



Possíveis Causas das Mudanças Climáticas

Interações complexas entre atmosfera, hidrosfera, criosfera, litosfera e biosfera determinam o clima.

- Mecanismos de feedback
- Teoria da Tectônica de Placas
- Órbita Terrestre - Teoria de Milankovitch
 - Excentricidade 100.000 anos
 - Precessão 23.000 anos
 - Obliquidade 41.000 anos



(Ahrens, 2005)

Figure 3.1 The elliptical path (highly exaggerated) of the earth about the sun brings the earth slightly closer to the sun in January than in July.

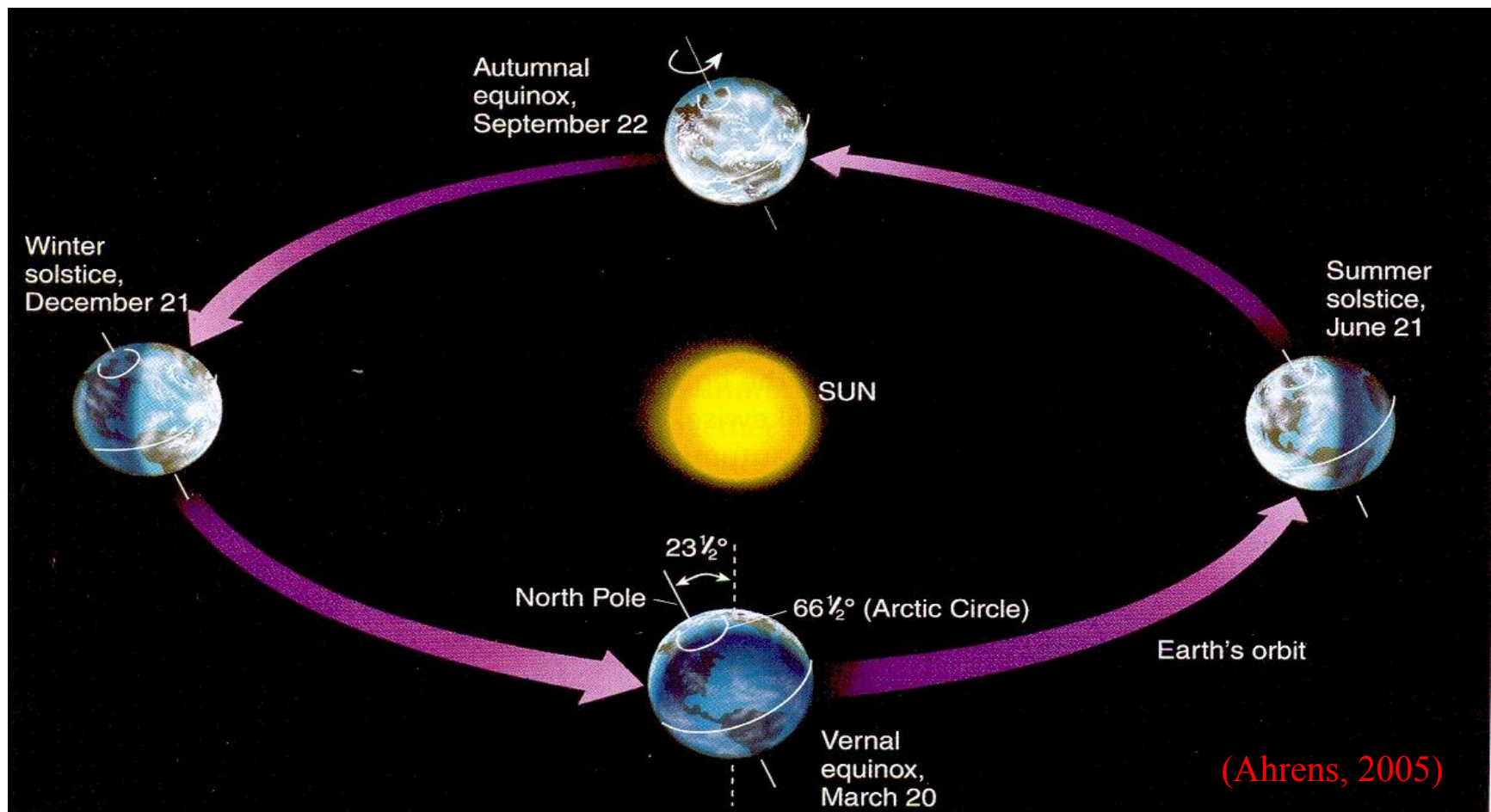


Figure 3.2 As the earth revolves about the sun, it is tilted on its axis by an angle of $23, 5^\circ$. The earth's axis always points to the same area in space (as viewed from a distant star). Thus, in June, when the Northern Hemisphere is tipped toward the sun, more direct sunlight and long hours of daylight cause warmer weather than in December, when the Northern Hemisphere is tipped away from the sun.

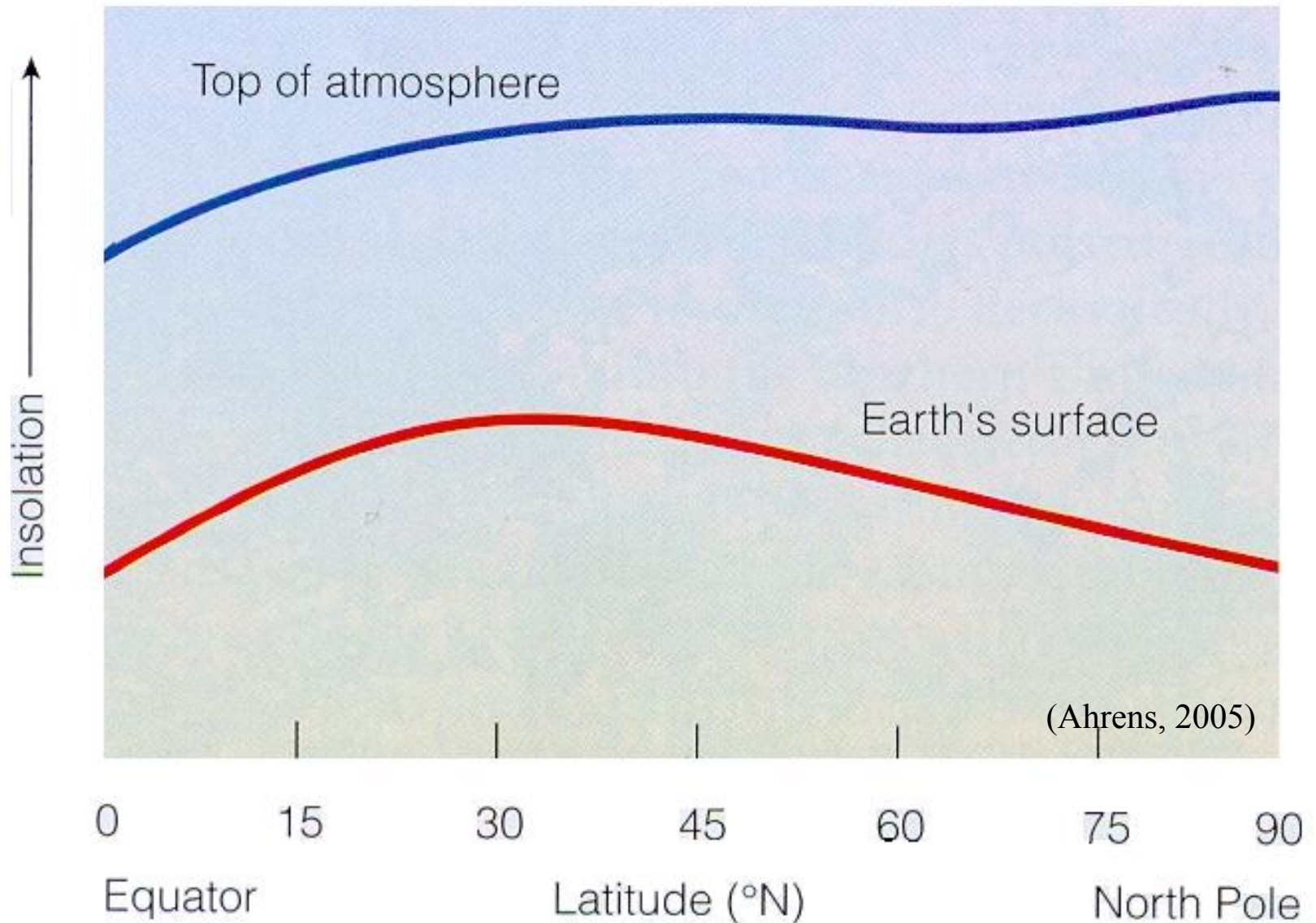
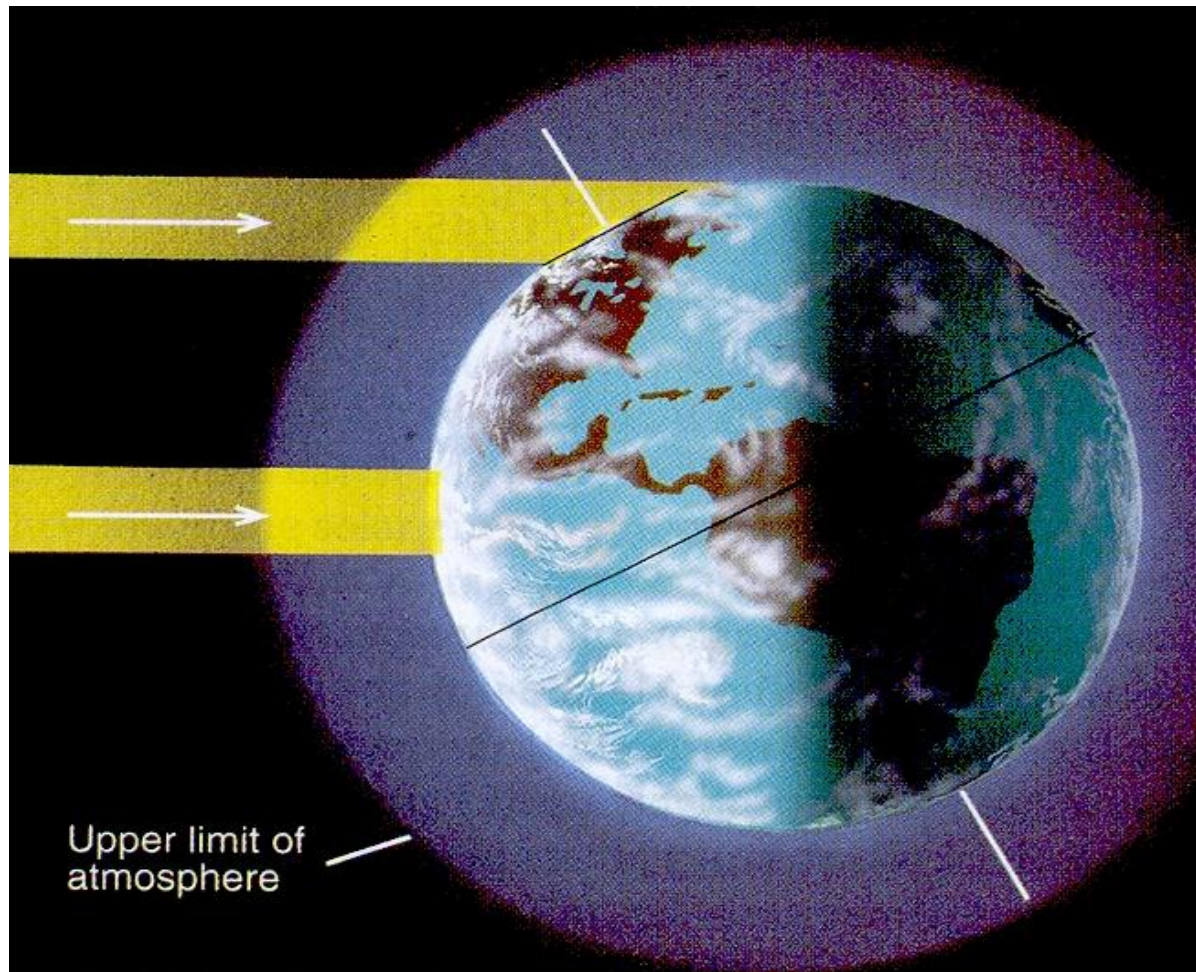
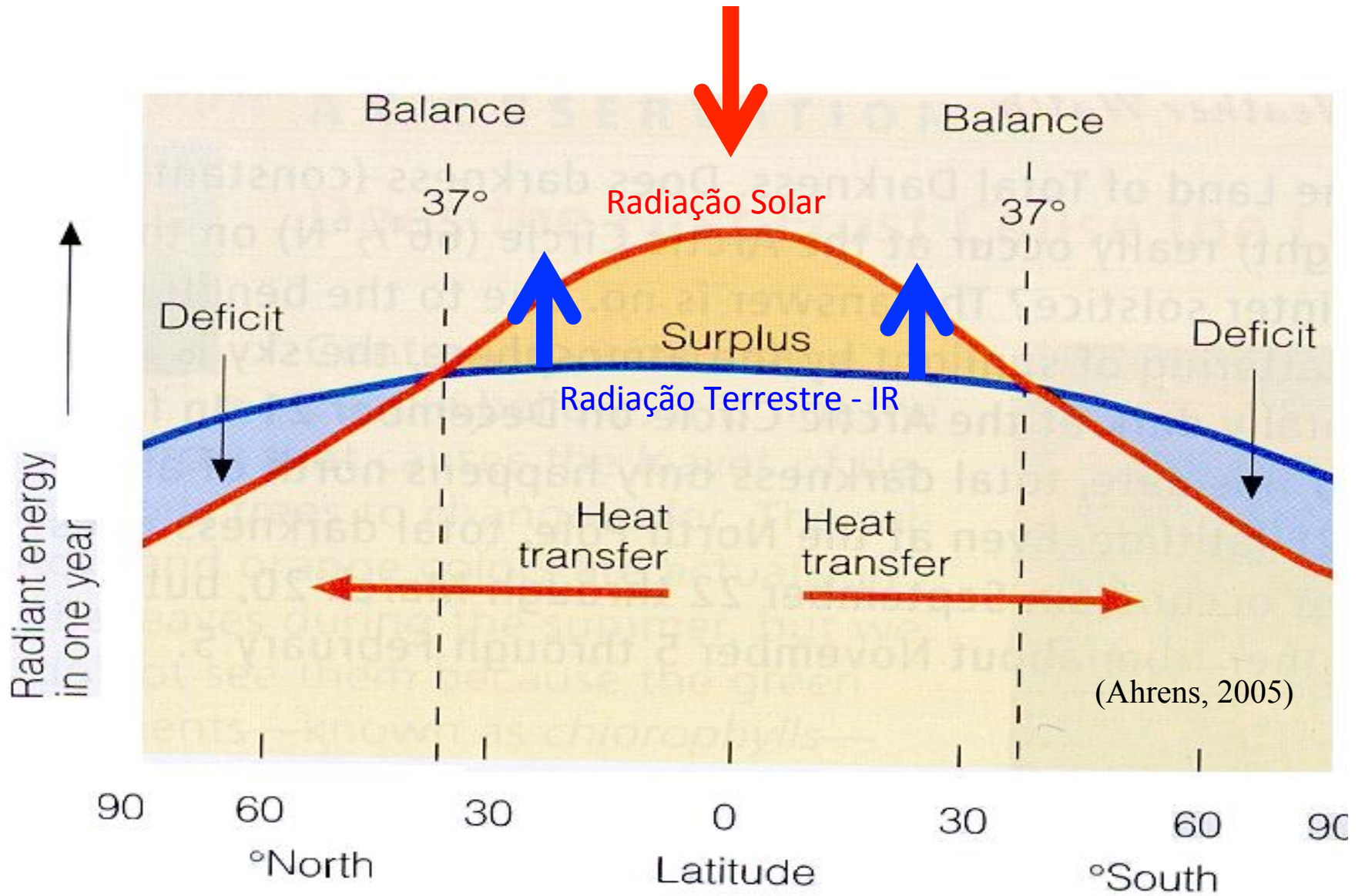


Figure 3.3 The relative amount of radiant energy received at the top of the earth's atmosphere and at the earth's surface on June 21 – the summer solstice.

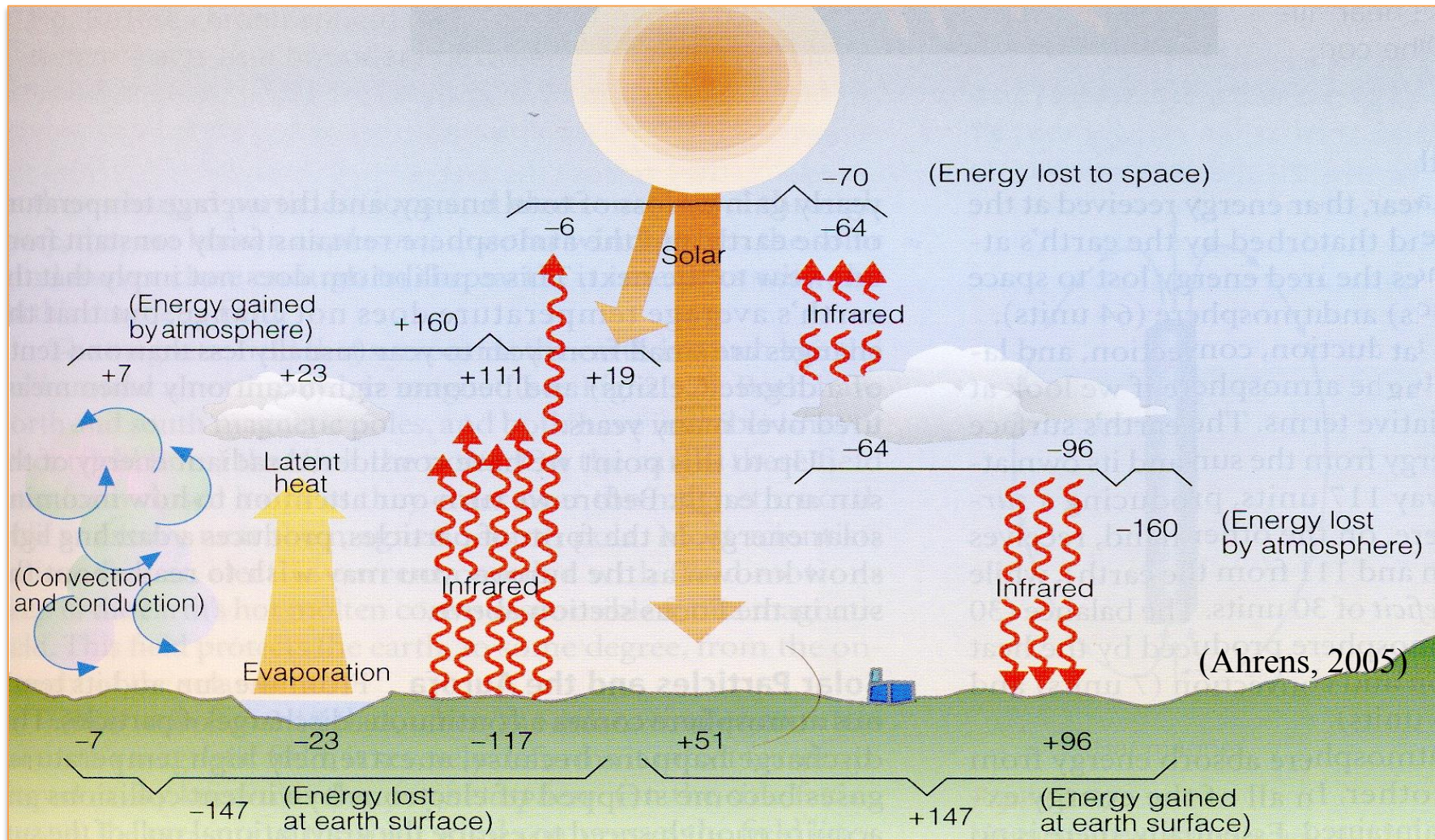


(Ahrens, 2005)

Figure 3.4 During the Northern Hemisphere summer, sunlight that reaches the earth's surface in far northern latitudes has passed through a thicker layer of absorbing, scattering, and reflecting atmosphere than sunlight that reaches the earth's surface farther south. Sunlight is lost through both the thickness of the pure atmosphere and by impurities in the atmosphere. As the sun's rays become more oblique, these effects become more pronounced.



Efeito Estufa



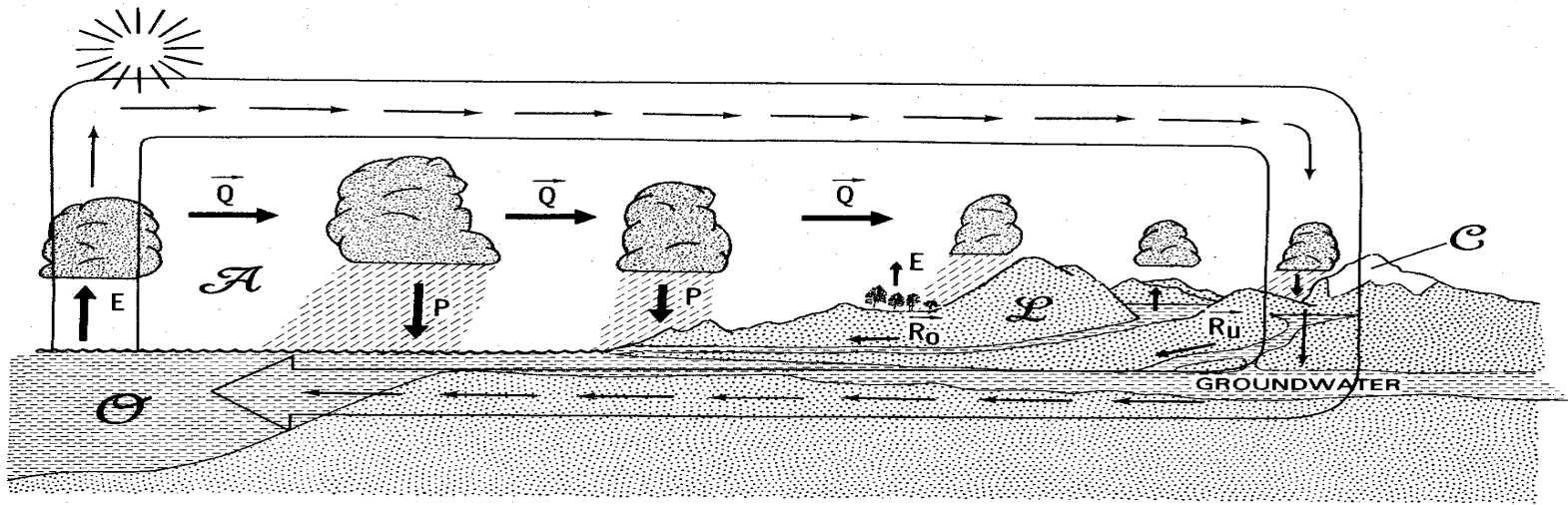


FIGURE 12.1. Schematic diagram of the atmospheric and terrestrial branches of the hydrological cycle showing the importance of evaporation E , advection of water vapor in the atmosphere \bar{Q} , precipitation P , river runoff R_0 , and underground runoff R_u .

(Peixot & Oort, 1992)

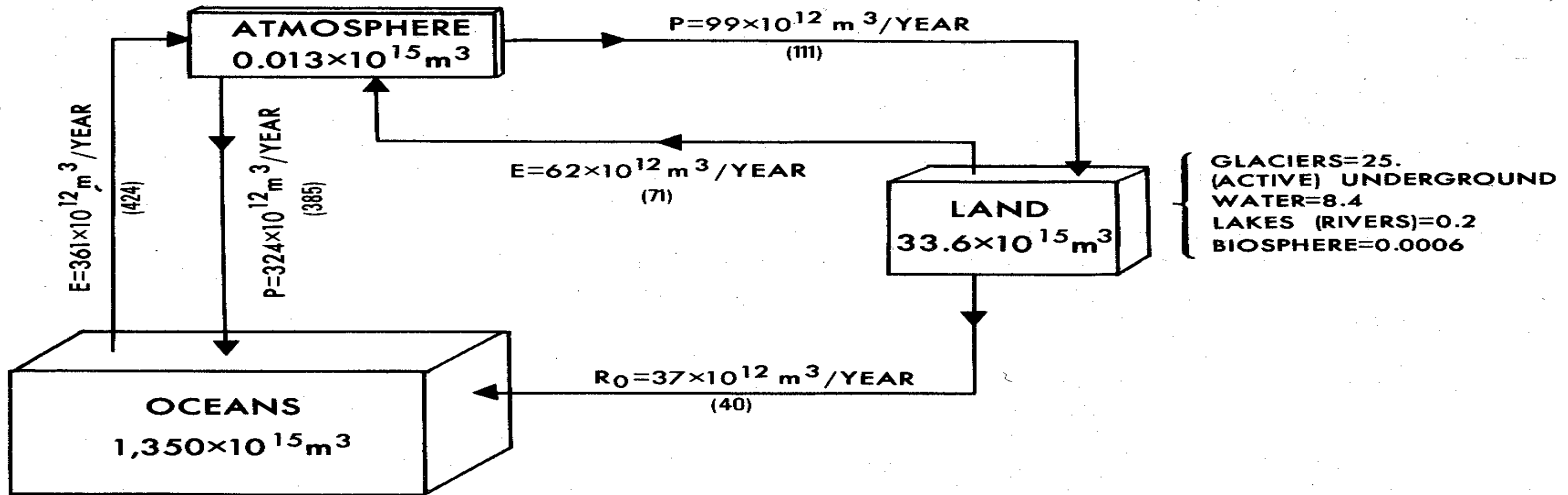


FIGURE 12.2. The amounts of water stored in the oceans, land, and atmosphere, and the amounts exchanged annually between the different reservoirs through evaporation, precipitation, and runoff (estimates are from Peixoto and Kettani, 1973, and, in parentheses, from Baumgartner and Reichel, 1975).

Divergência do vapor d'água – média zonal $0,01 \text{ m ano}^{-1}$

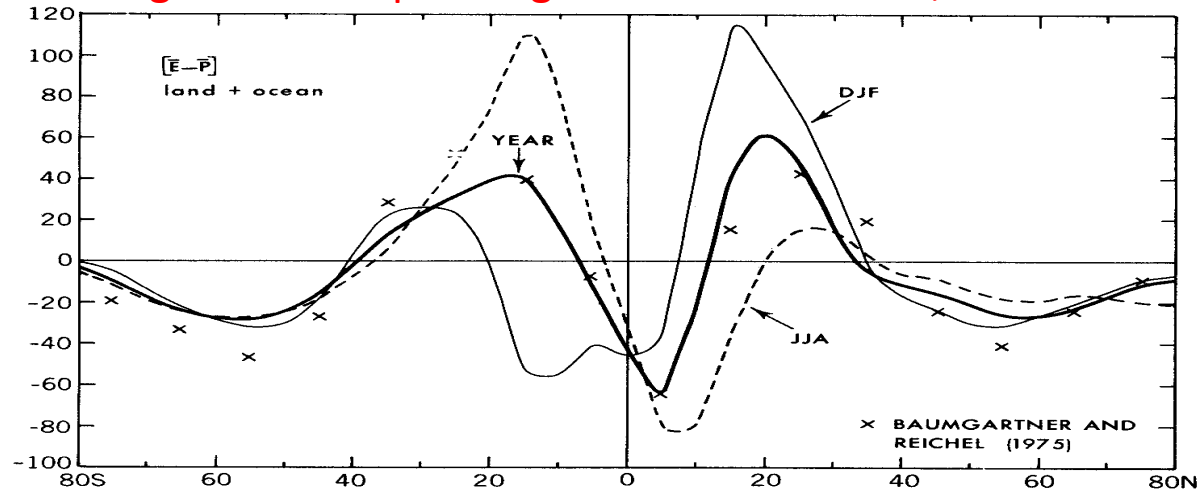


FIGURE 12.16. Meridional profiles of the zonal-mean divergence of the total water vapor transport $[\text{div } \mathbf{Q}] \approx [E - P]$ in 0.01 m yr^{-1} for annual, DJF, and JJA mean conditions. Some annual-mean estimates of $E - P$ by Baumgartner and Reichel (1975) are added for comparison (see also Table 7.1).

(Peixot & Oort, 1992)

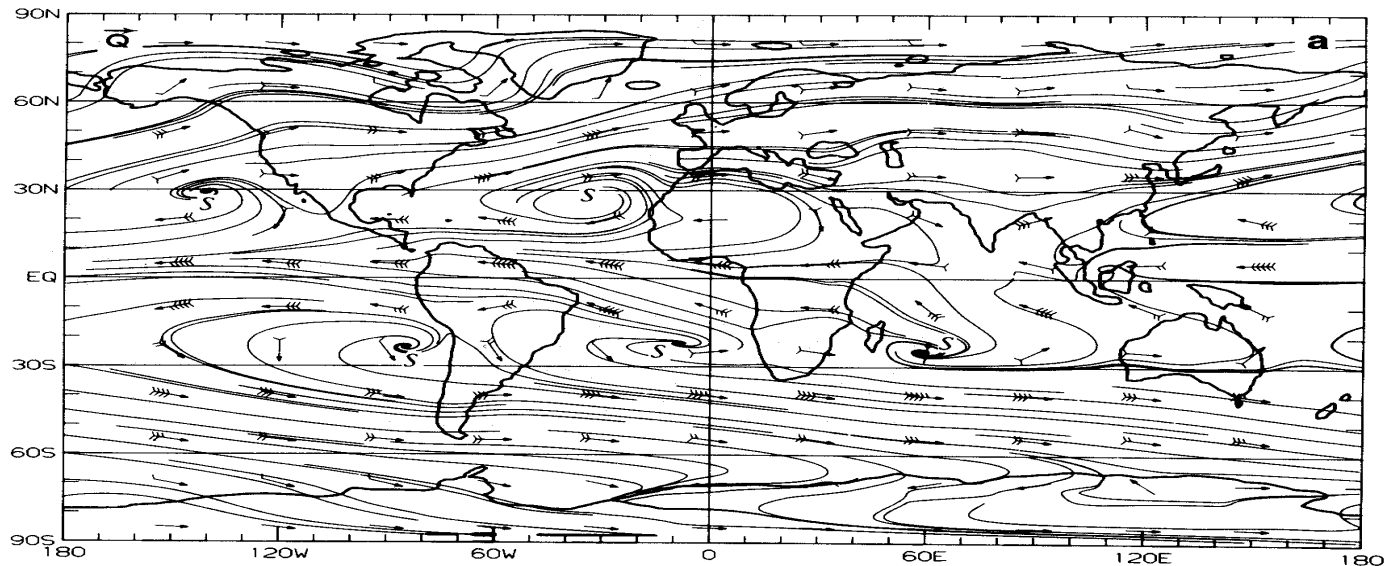


FIGURE 12.17a

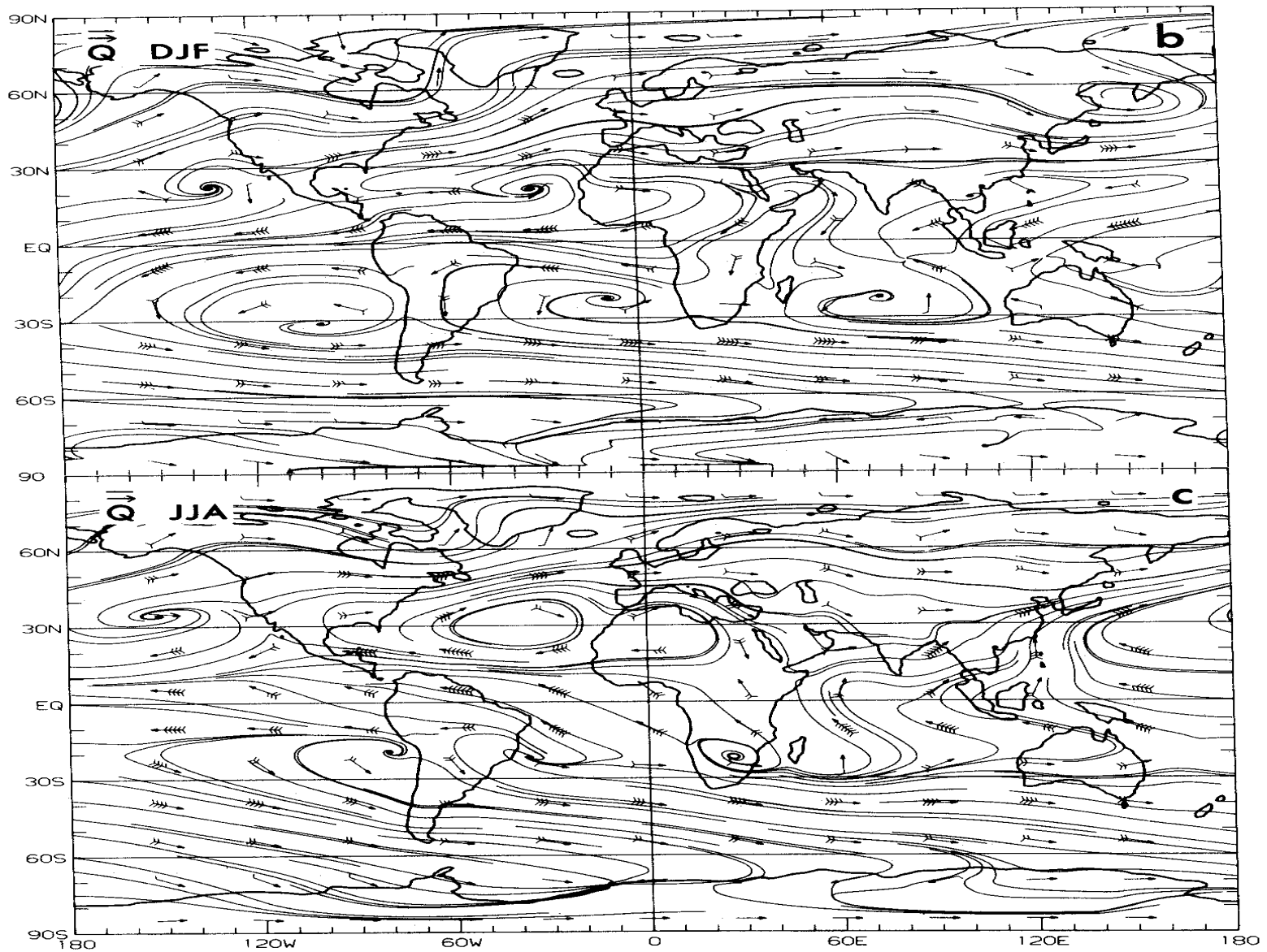
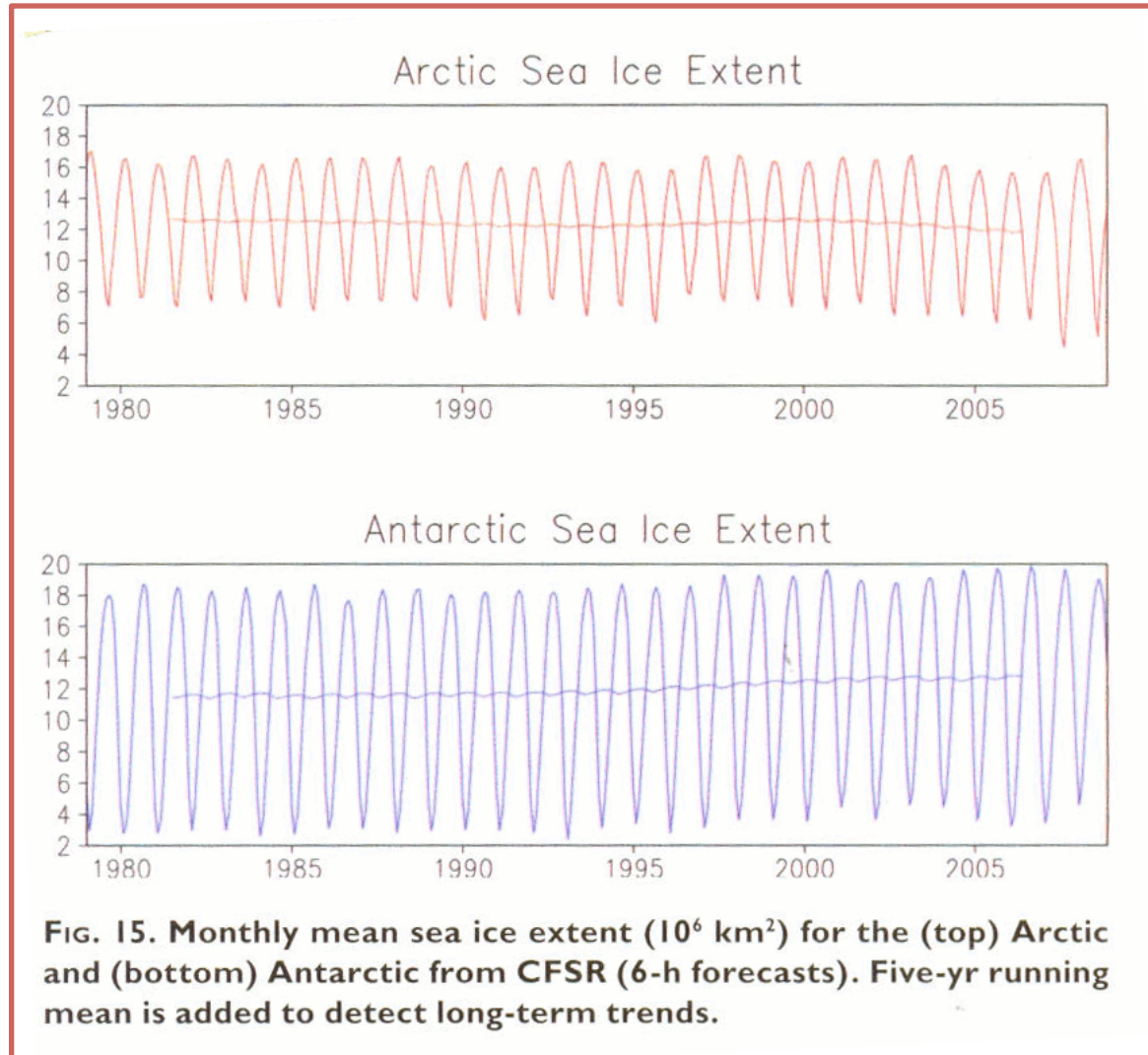


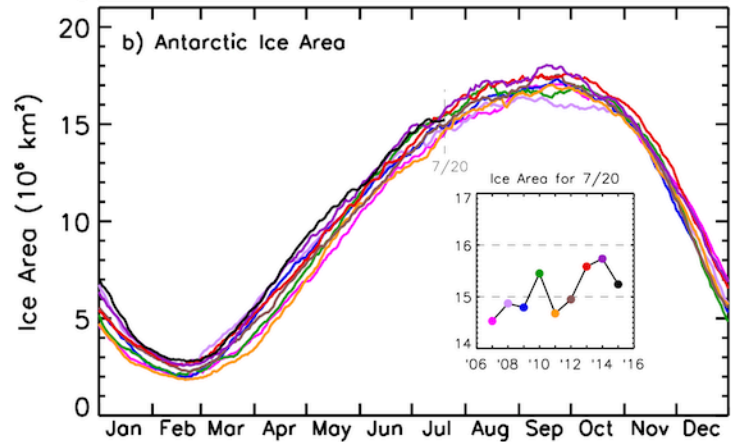
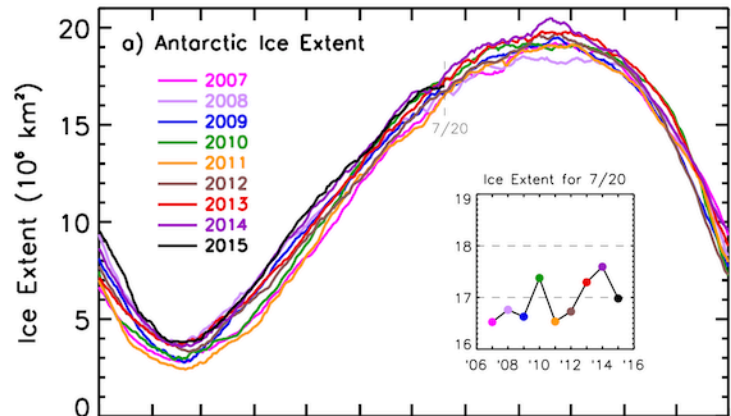
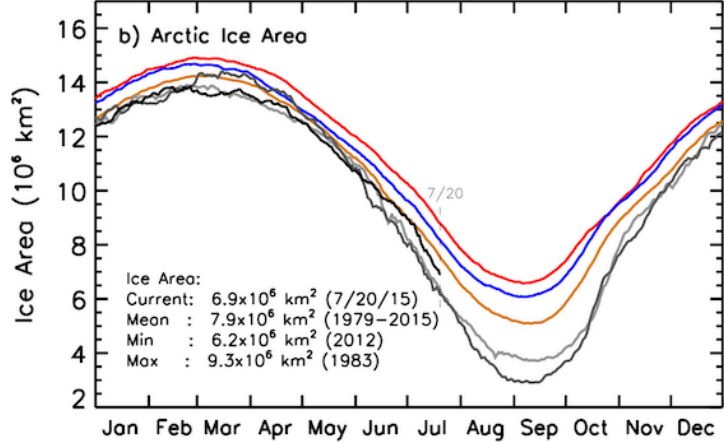
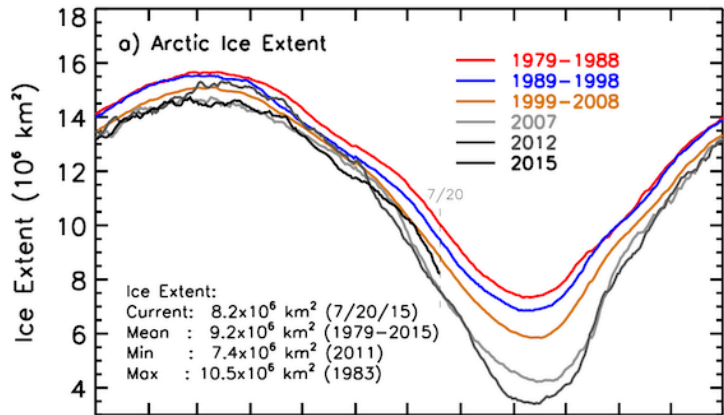
FIGURE 12.17. Global distributions of the total aerial runoff Q and some corresponding streamlines for annual (a), DJF (b), and JJA (c) mean conditions. Each barb on the shaft of an arrow indicates a value of $2 \text{ m s}^{-1} \text{ g kg}^{-1}$ (from Peixoto and Oort, 1983).

(Peixot & Oort, 1992)

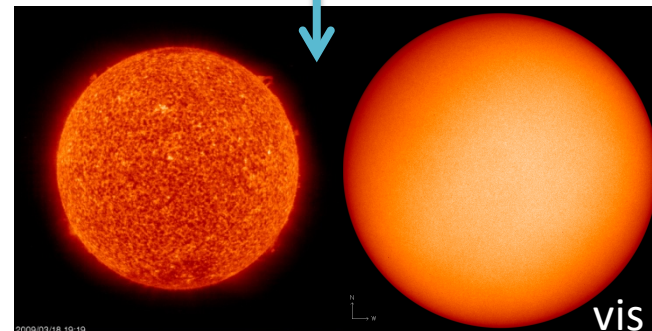
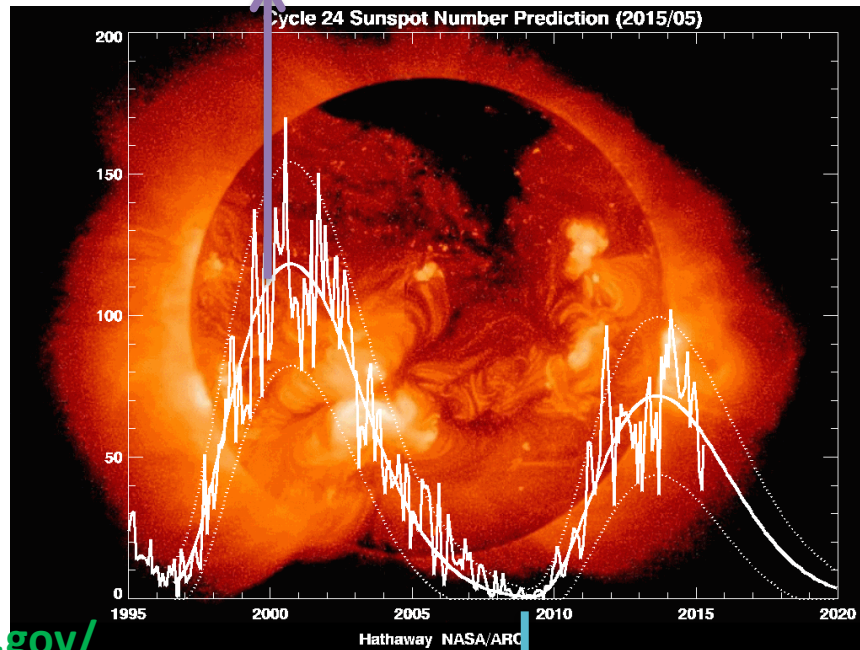
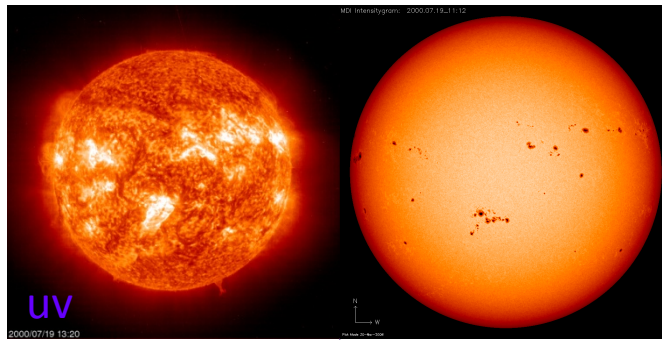
Resultados NCEP 2010

(Saha et al. 2010)





<http://neptune.gsfc.nasa.gov/csb/>



FONTE: <http://solarscience.msfc.nasa.gov/predict.shtml>

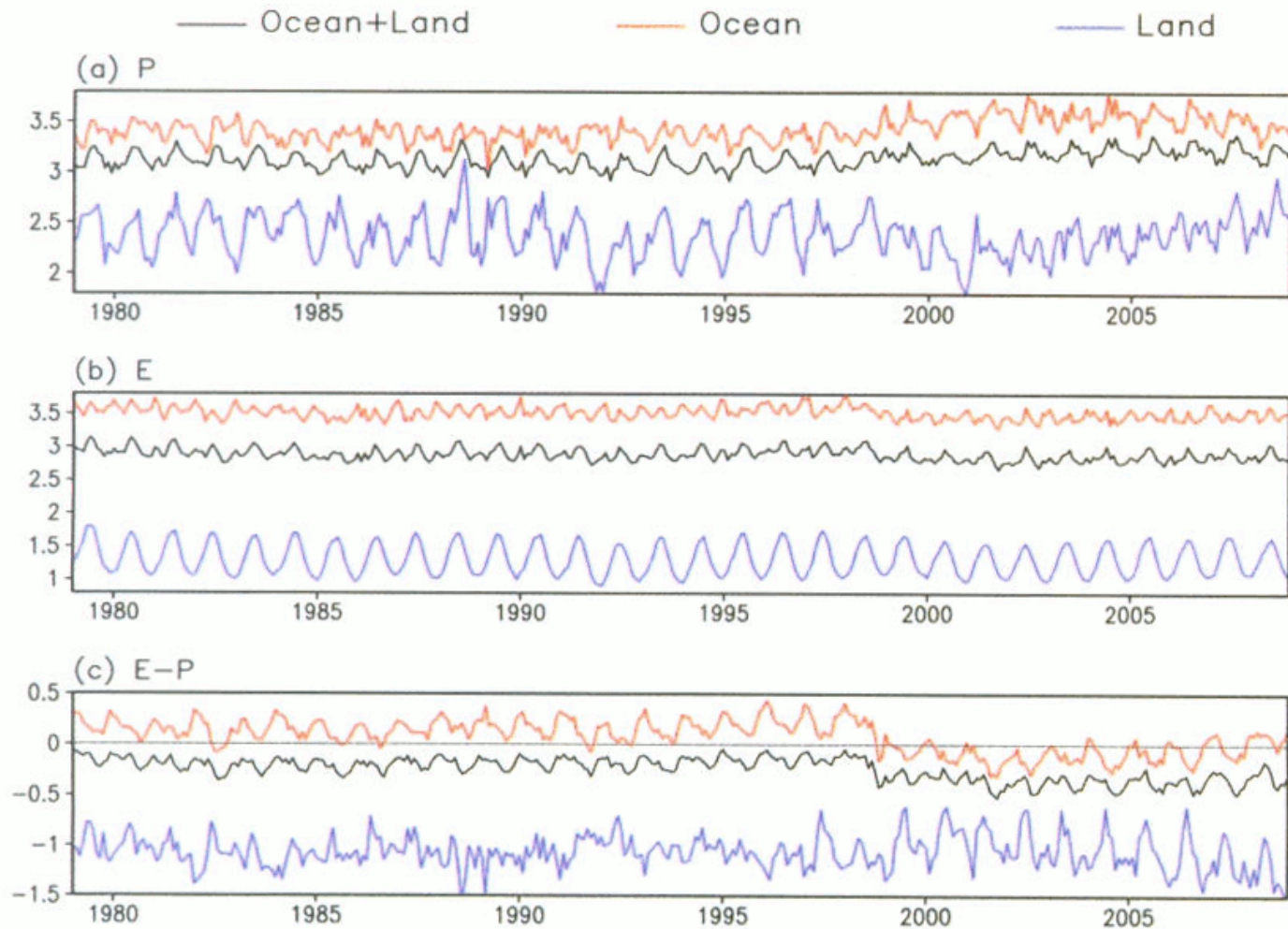


FIG. 21. Global average of monthly mean (a) precipitation, (b) evaporation, and (c) evaporation minus precipitation. Averages over ocean (red), land (blue), and ocean plus land (black) are plotted. (Units: mm day⁻¹)

(Saha et al. 2010)

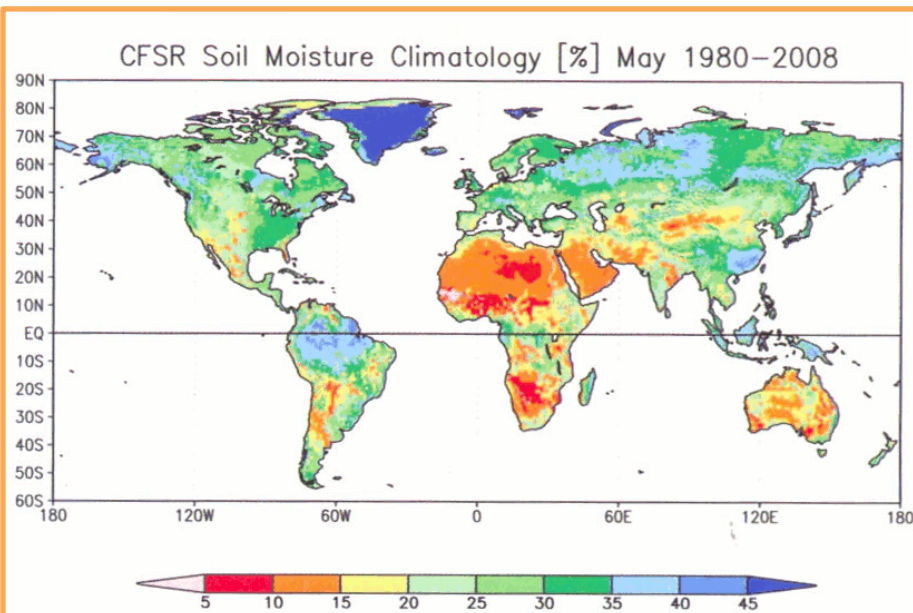


FIG. 17. The 2-m volumetric soil moisture climatology of CFSR for May averaged over 1980–2008.

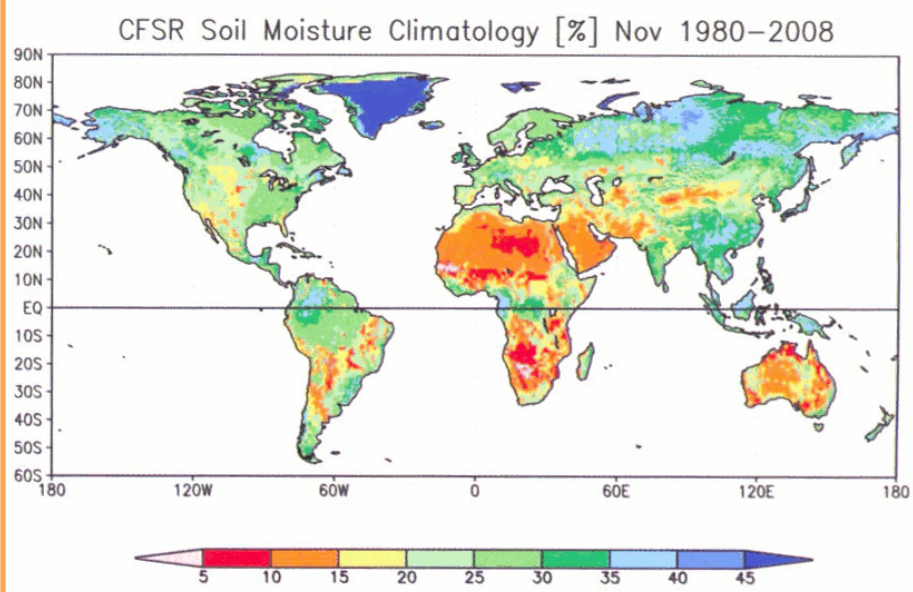
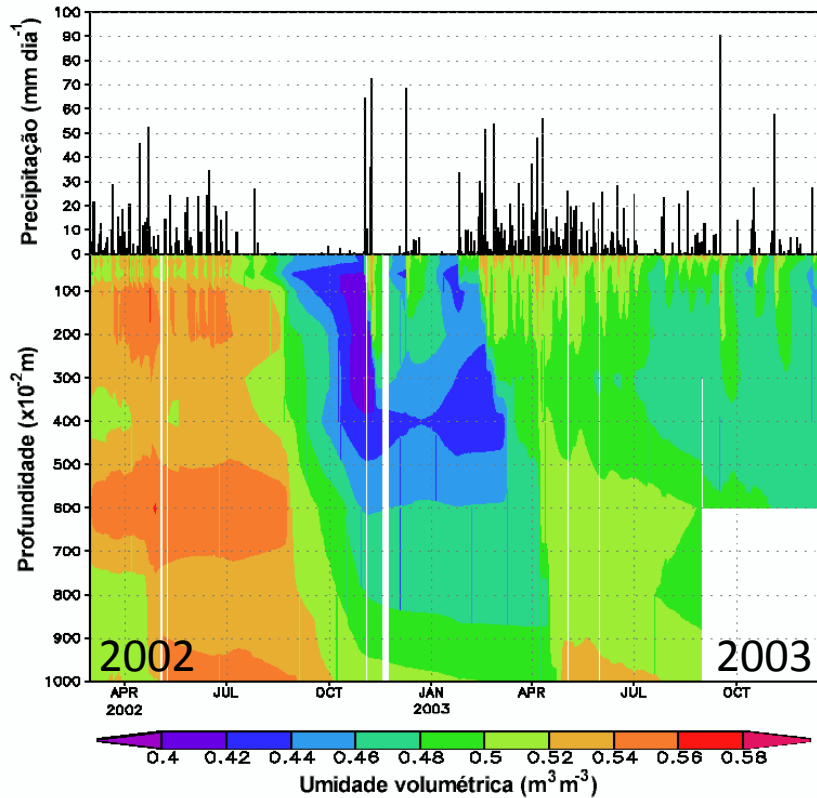


FIG. 18. As in Fig. 17, but for Nov.

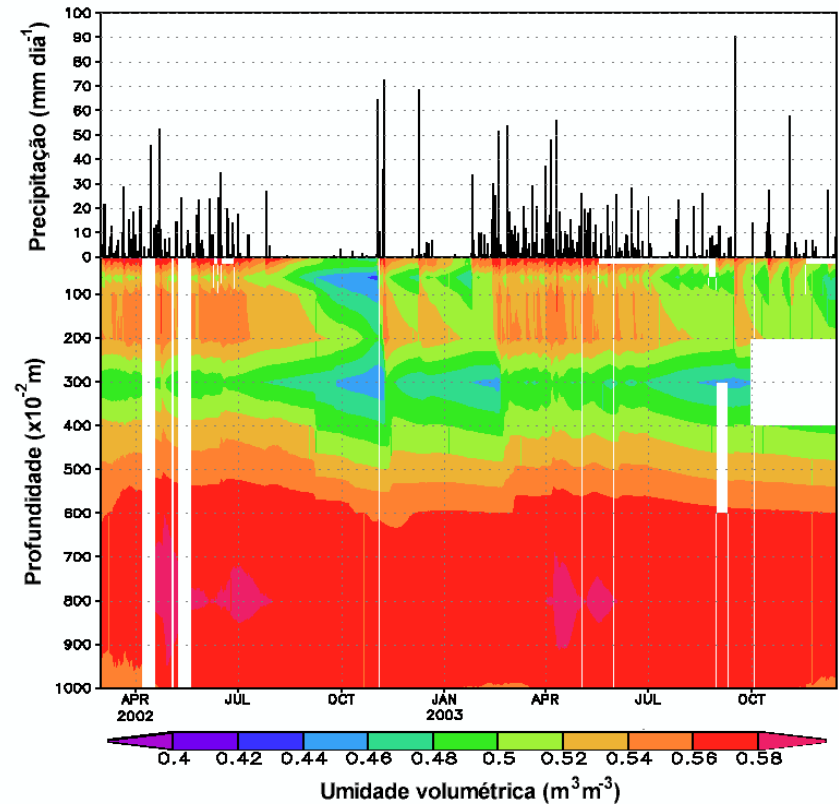
(Saha et al. 2010)

Floresta Amazônica

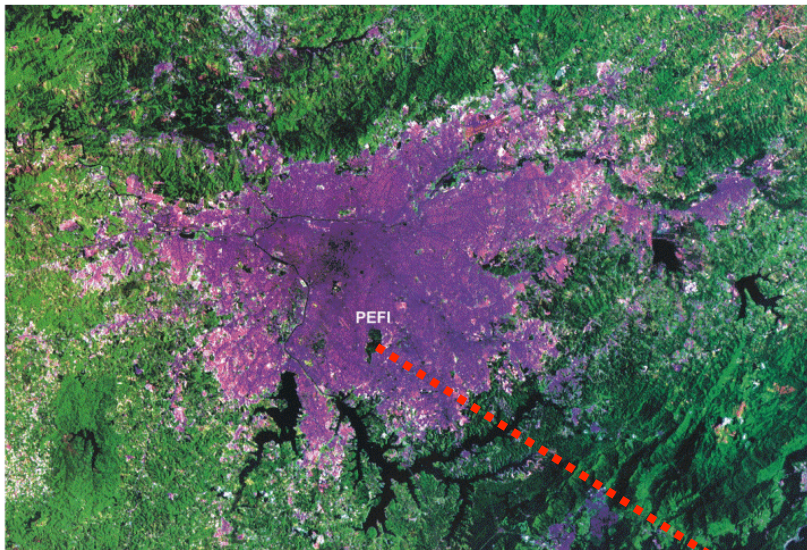
Floresta Tropical Úmida (não perturbada)
FLONA Tapajós, Santarém/PA



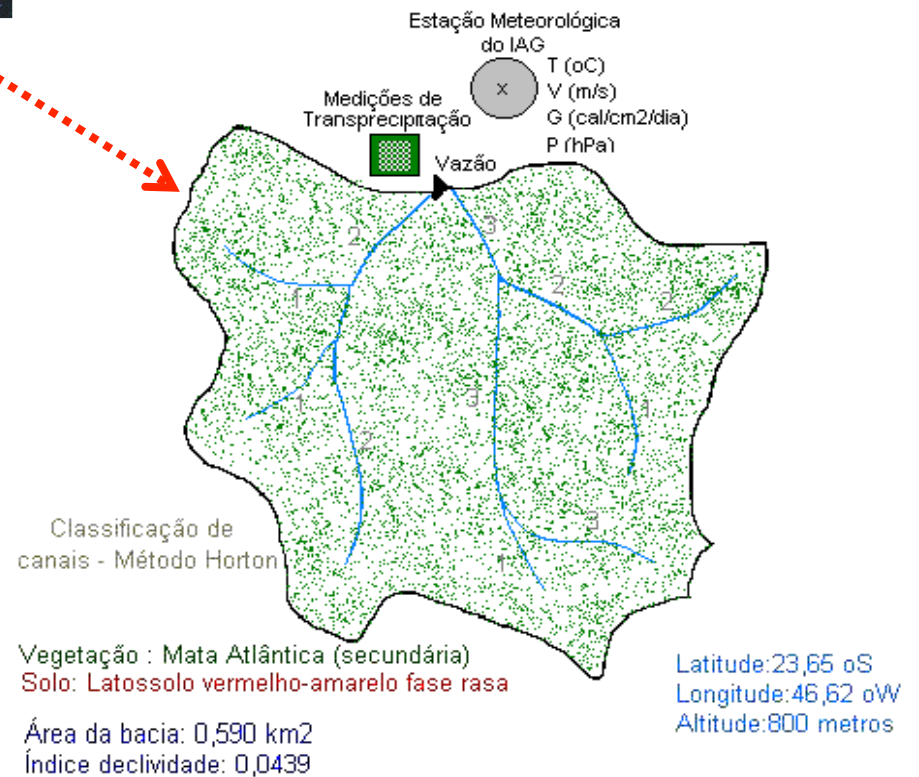
Floresta Tropical Úmida (clareira)
FLONA Tapajós, Santarém/PA



Bruno e Rocha (2004)

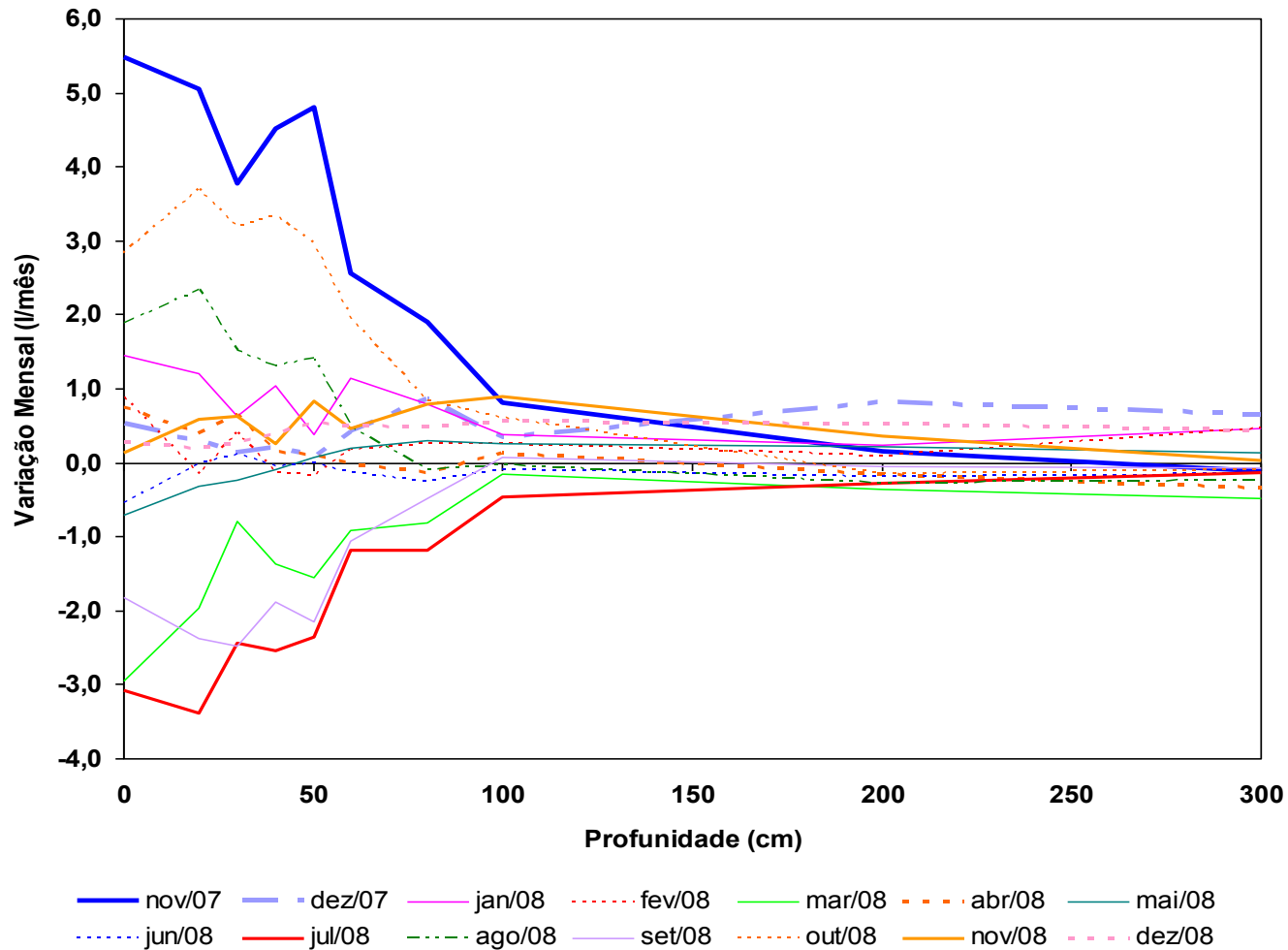


Bacia do IAG



(Pereira Filho et al., 2002)

Variação da Umidade do solo - PEFI



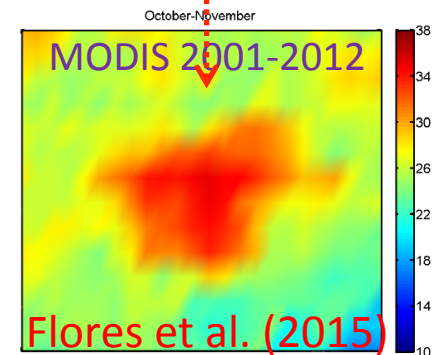
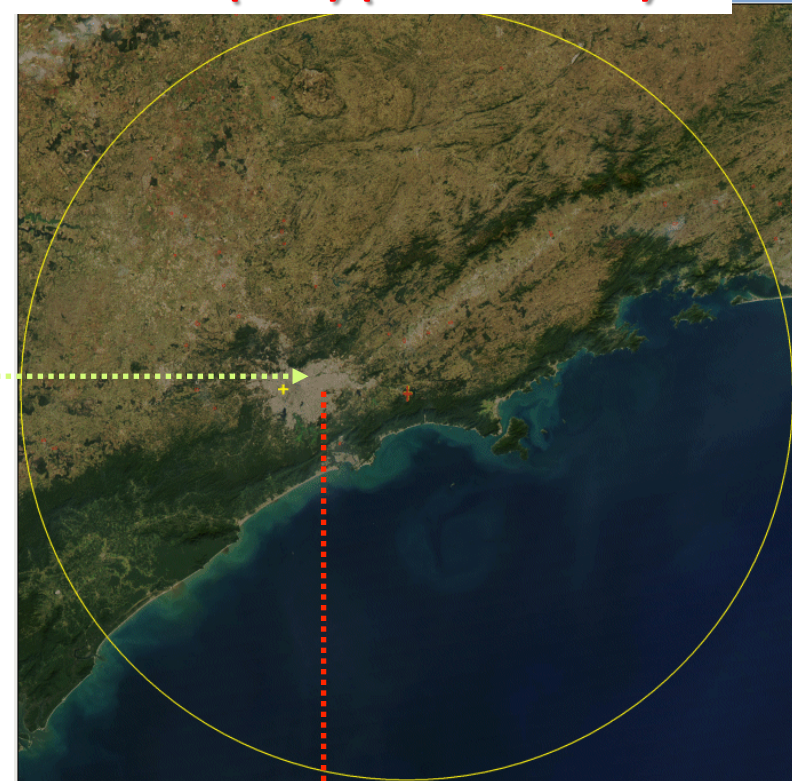
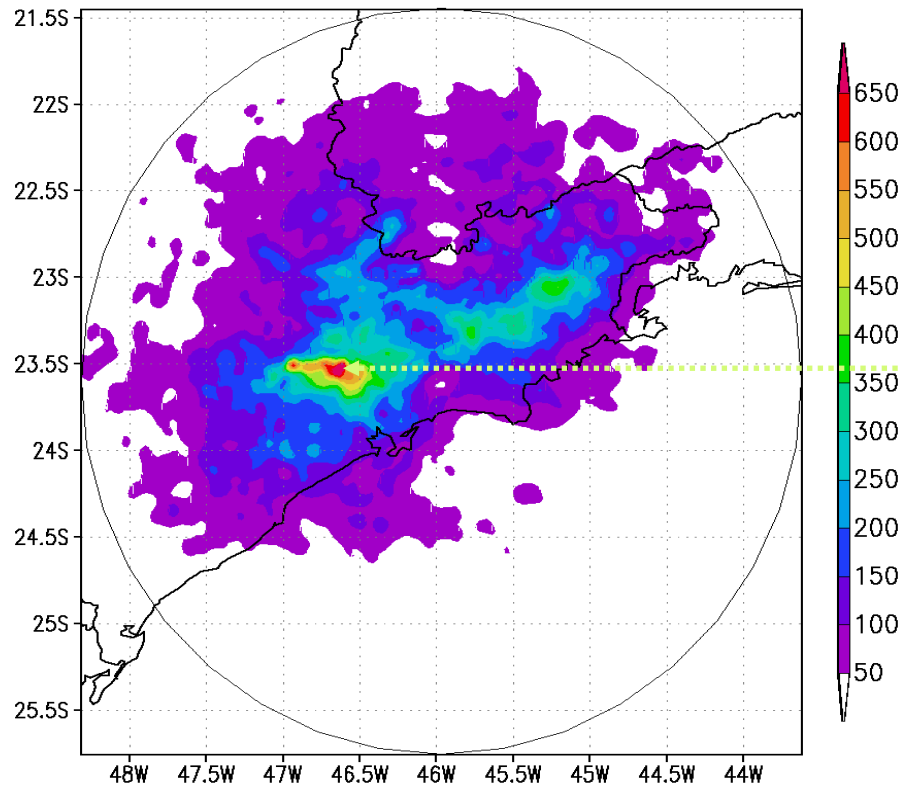
(Pereira Filho, 2010)

Balanço Hídrico - PEFI (mm)

Precipitação (P)	1290,5
Transprecipitação (T)	1002,1
Interceptação (I)	288,4
Vazão (Q)	285,6
Evapotranspiração (ETo)	1004,9

(Pereira Filho et al., 2002)

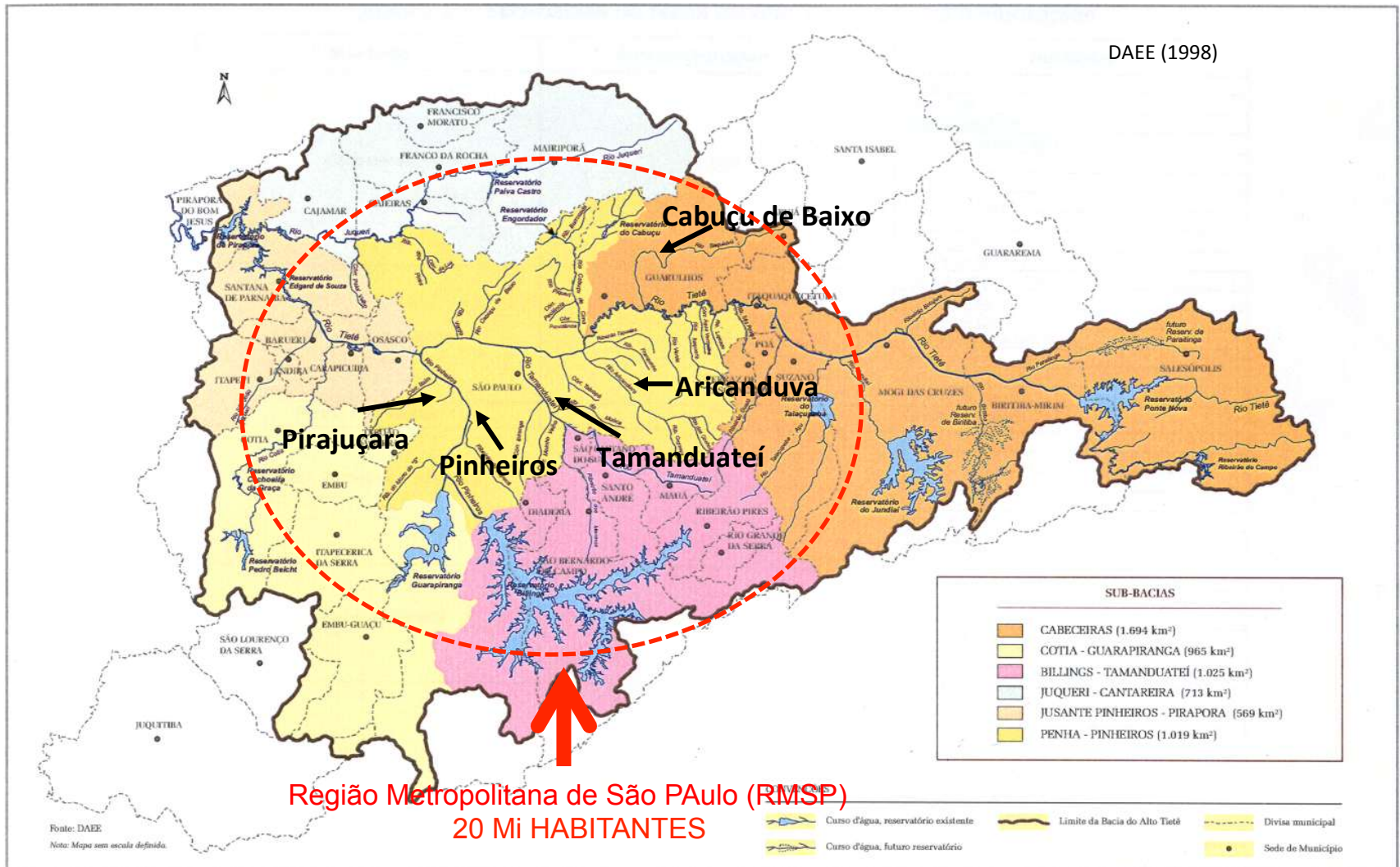
Efeitos Ilha de Calor e Brisa na Distribuição de chuva (mm) (2002 – 2004)



BRASIL – SÃO PAULO - RMSP



BACIA DO ALTO TIETÊ (6,000 km²)



CRESCIMENTO URBANO 1905 - 2005

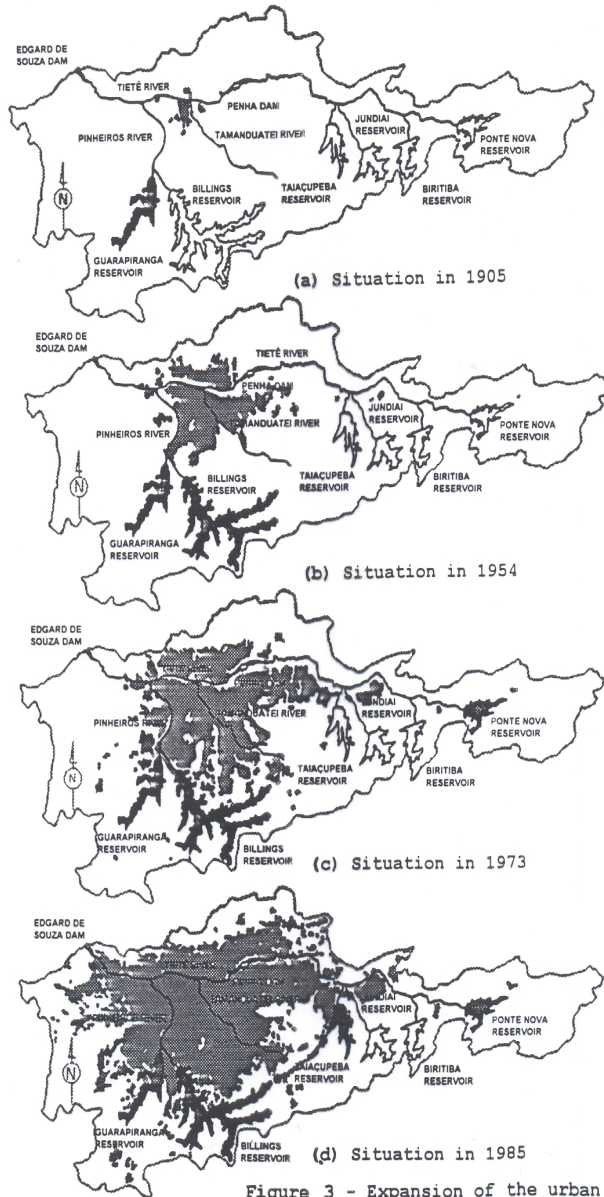
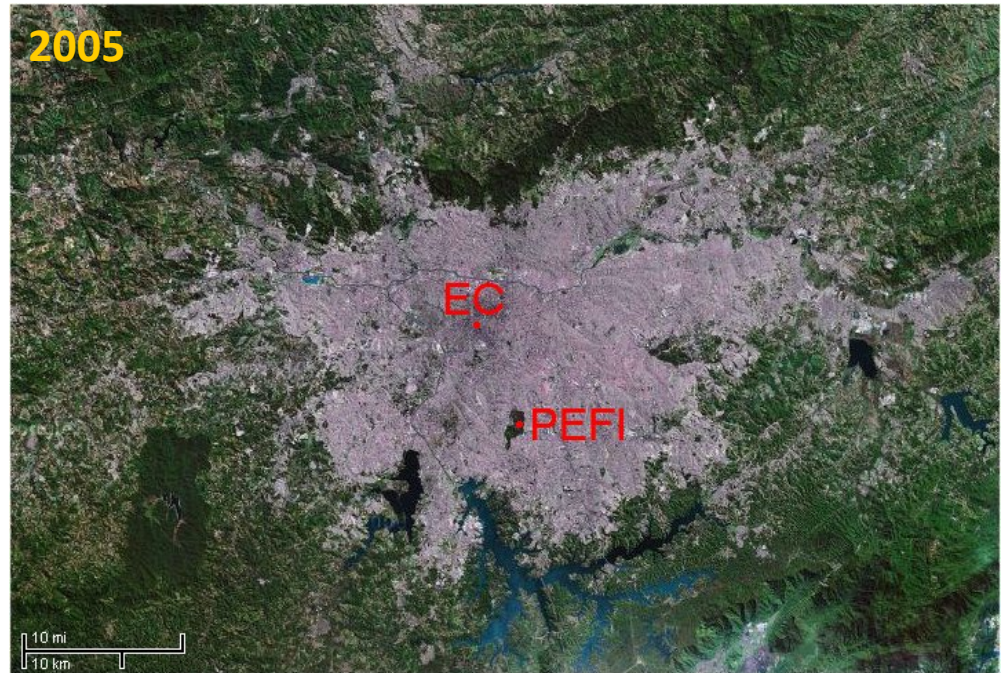


Figure 3 - Expansion of the urban area.



REPRESA DE GUARAPIRANGA - 1933



SANTO AMARO, RIVIERA PAULISTA

REPRESA DE GUARAPIRANGA - HOJE



AEROPORTO DE CONGONHAS - 1950



AEROPORTO DE CONGONHAS HOJE



SÃO PAULO, TERRA DA GAROA - 1954



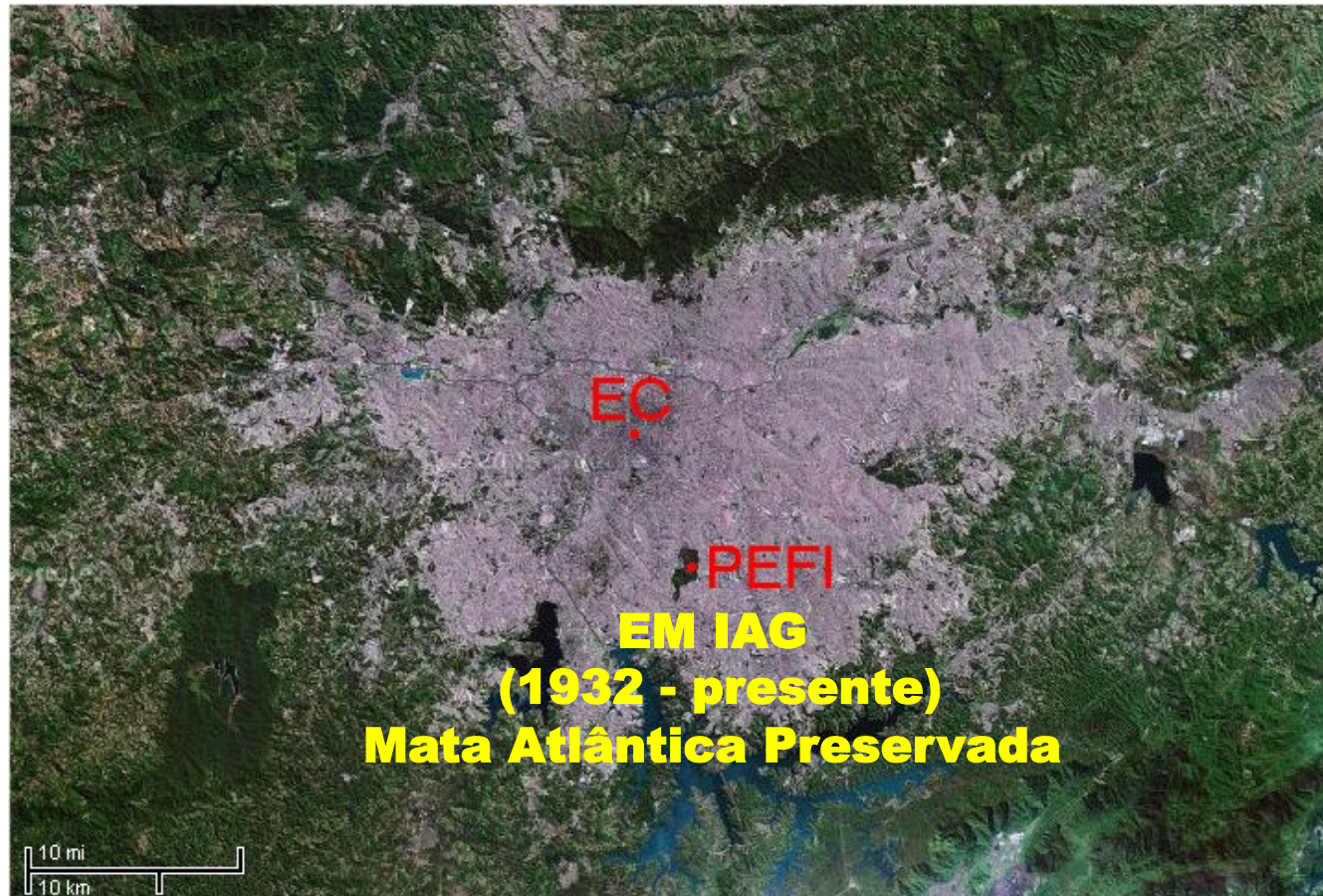
SÃO PAULO, DESERTO URBANO - HOJE



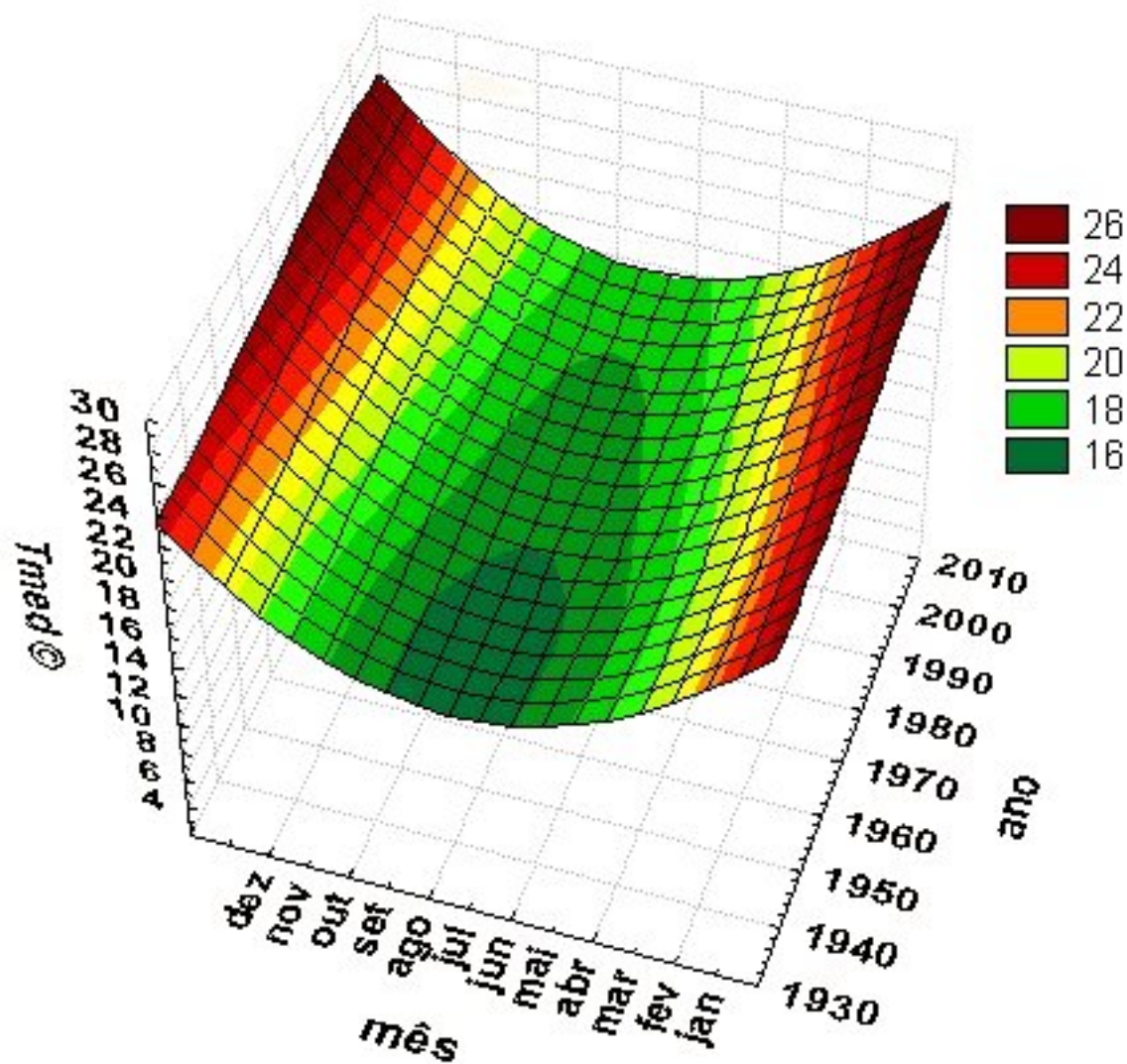
(FSP ,2011)

CLIMATOLOGIA DA RSMP

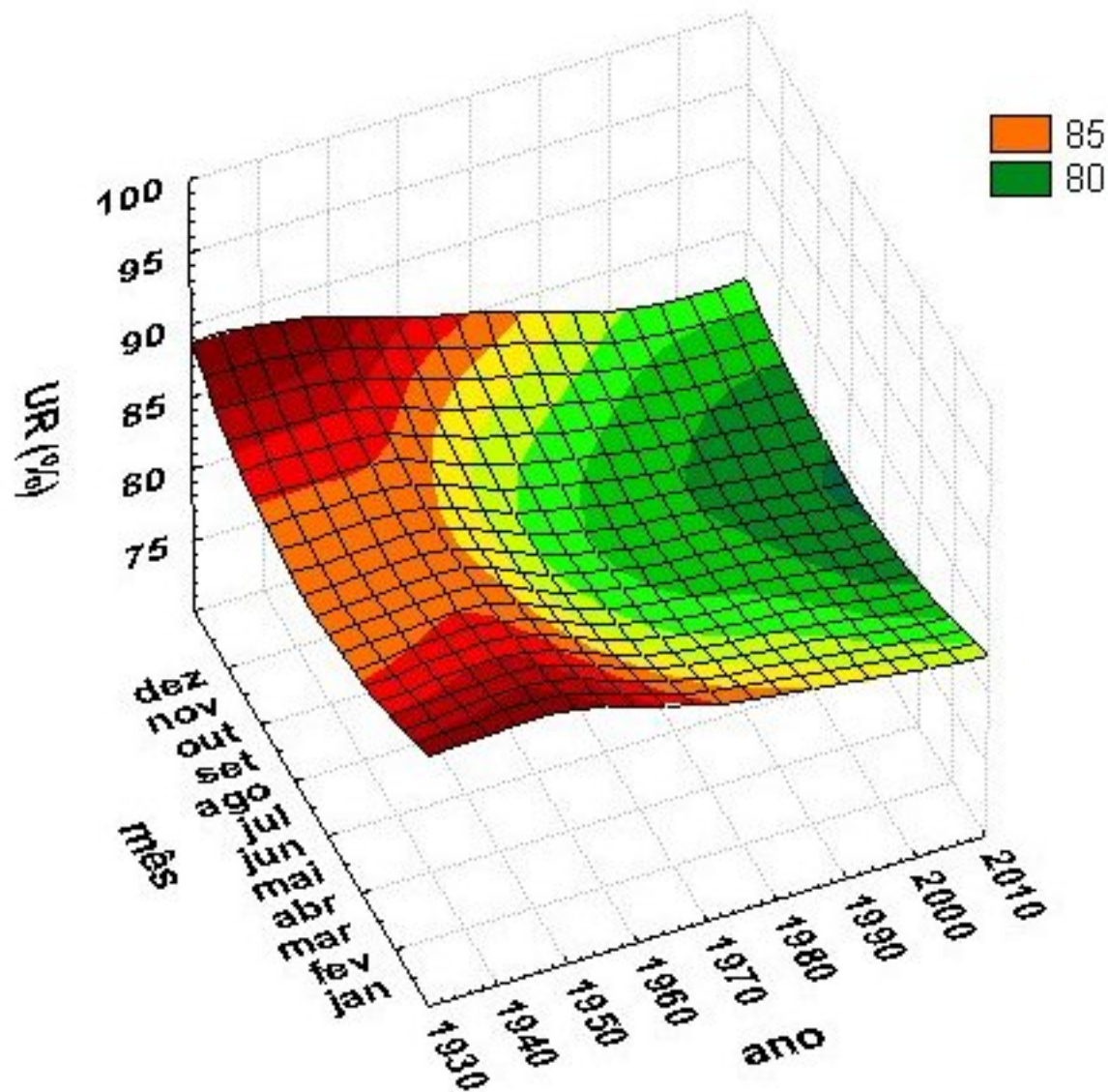
1936 - 2005



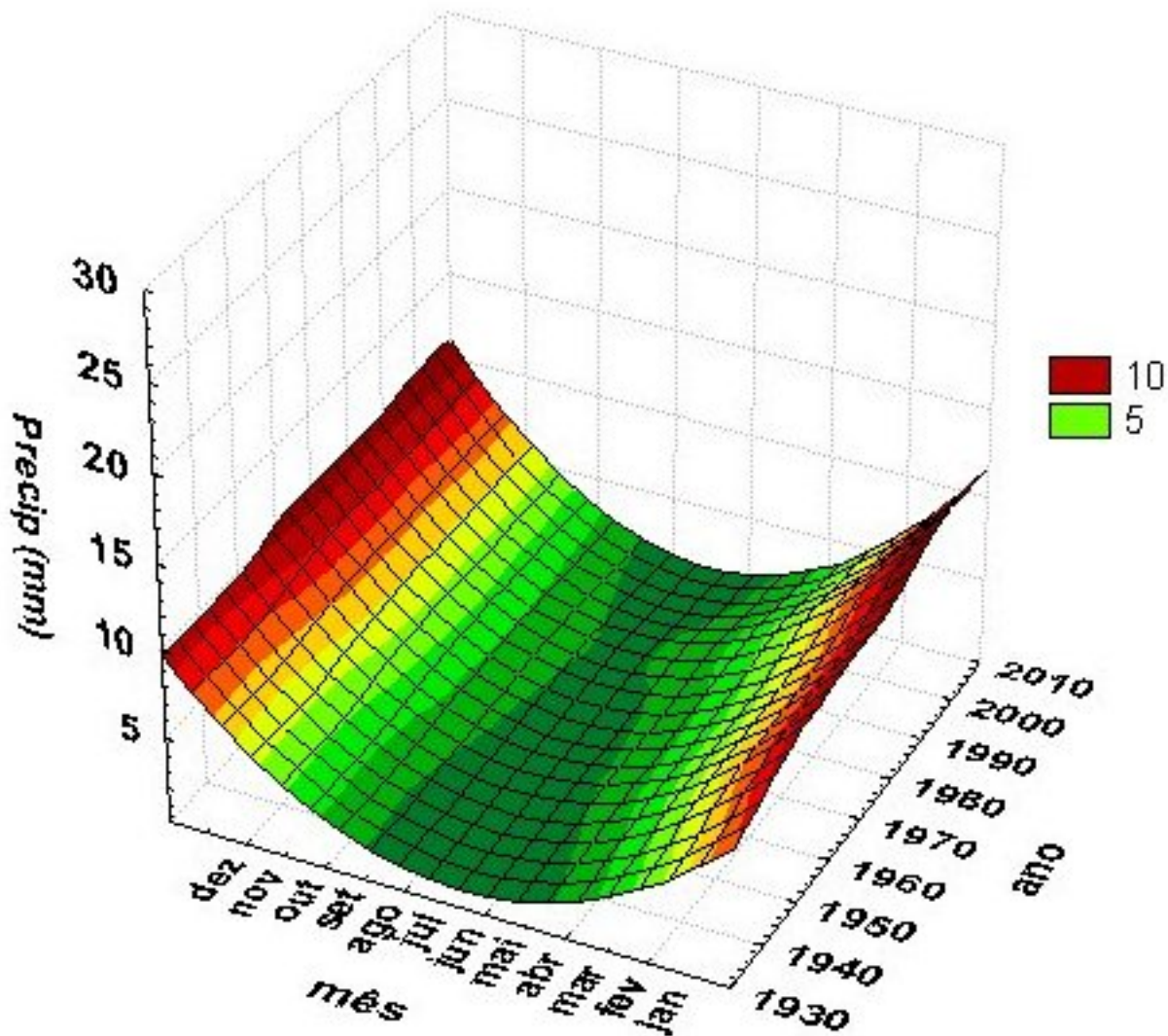
TEMPERATURA DO AR DIÁRIA 1936 - 2005



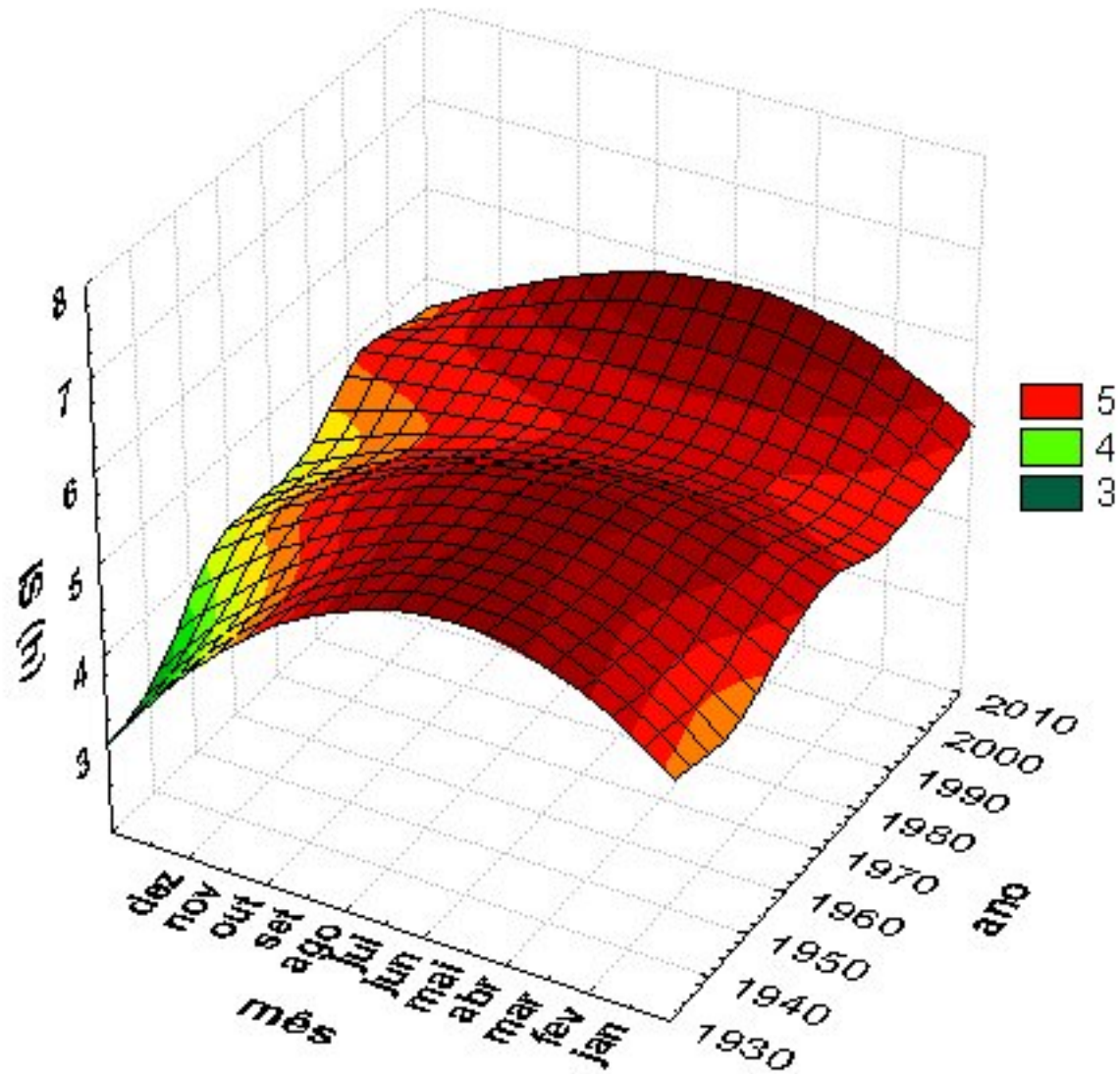
UMIDADE RELATIVA DIÁRIA 1936 -2005



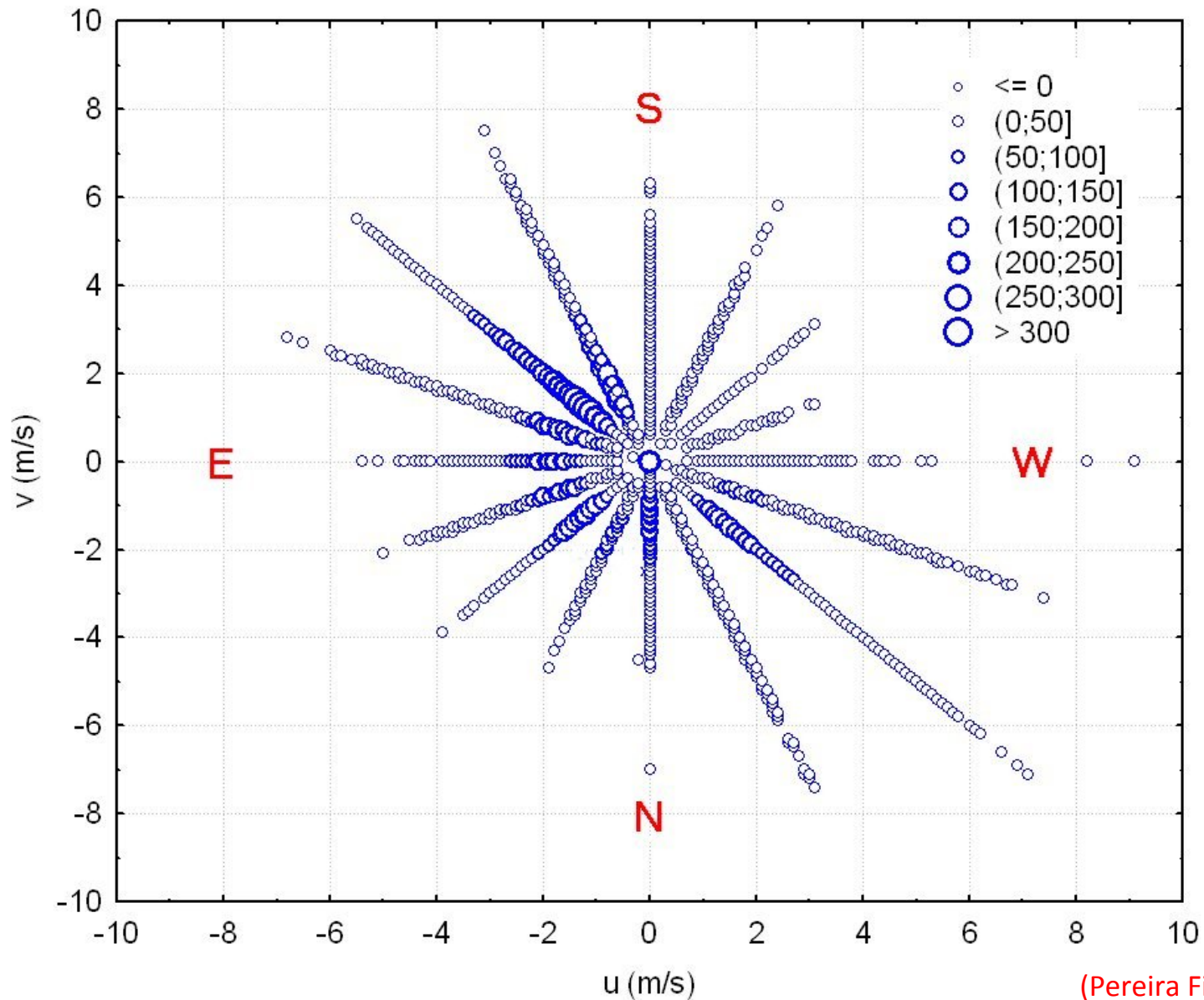
CHUVA DIÁRIA 1936 -2005



INSOLAÇÃO DIÁRIA 1936 -2005



ROSA DOS VENTOS 1936 -2005



MUDANÇAS CLIMÁTICAS NA RMSP:

MAIS QUENTE

SECO

MAIS TEMPESTADES

MENSO GAROA

MAIS POLUIÇÃO DO AR

**AS MUDANÇAS CLIMÁTICAS
SÃO LOCAIS OU GLOBAIS?**

TAR & UR 1936 -2005

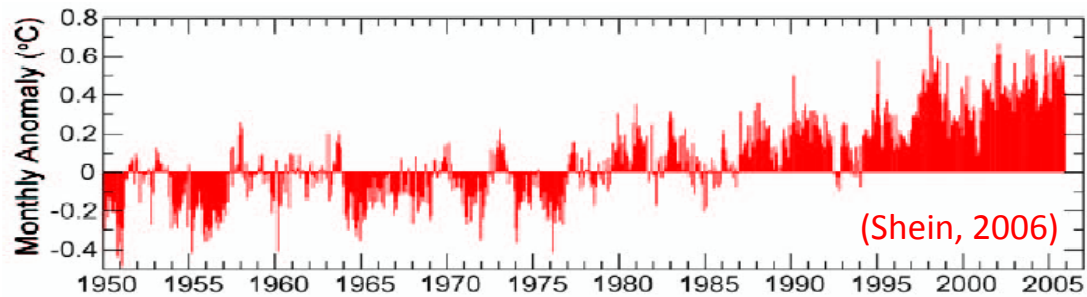
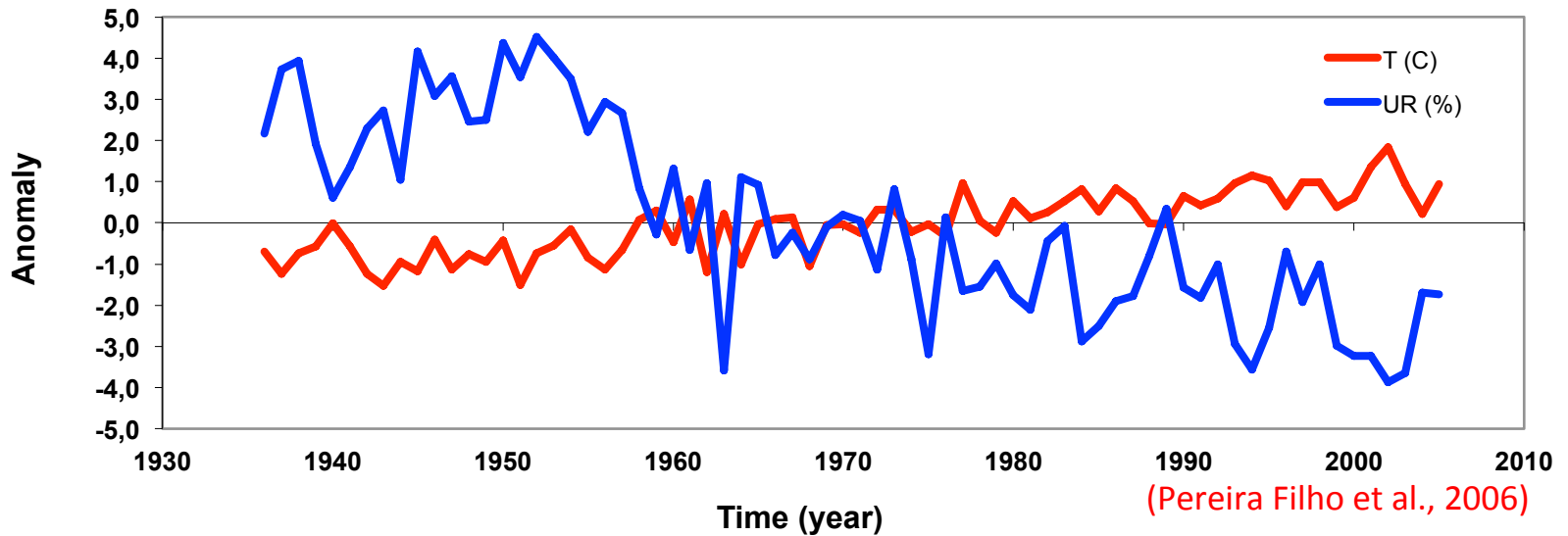


FIG. 2.2. Serial monthly surface temperature anomalies (°C) relative to a 1961–90 base period, based on Quayle et al. (1999). [Source: NOAA/NCDC]

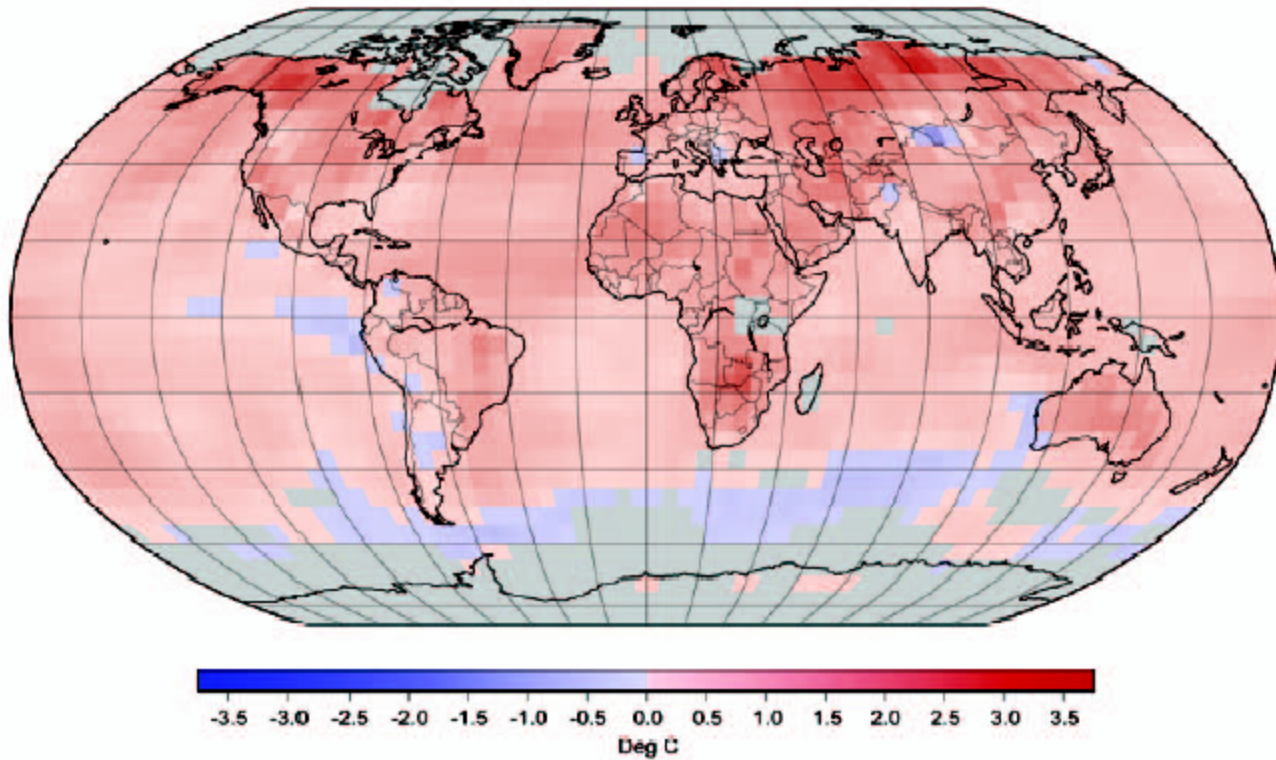
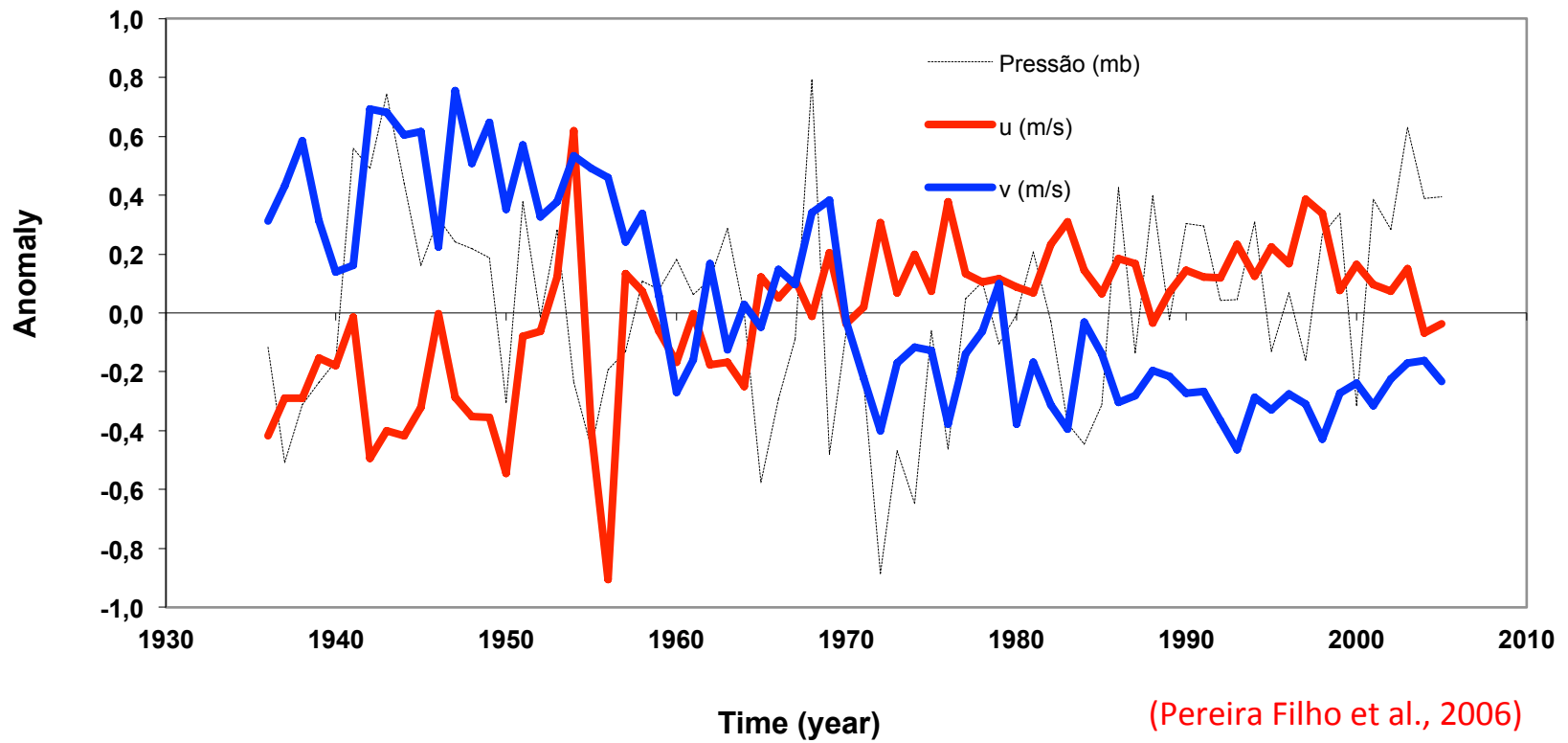
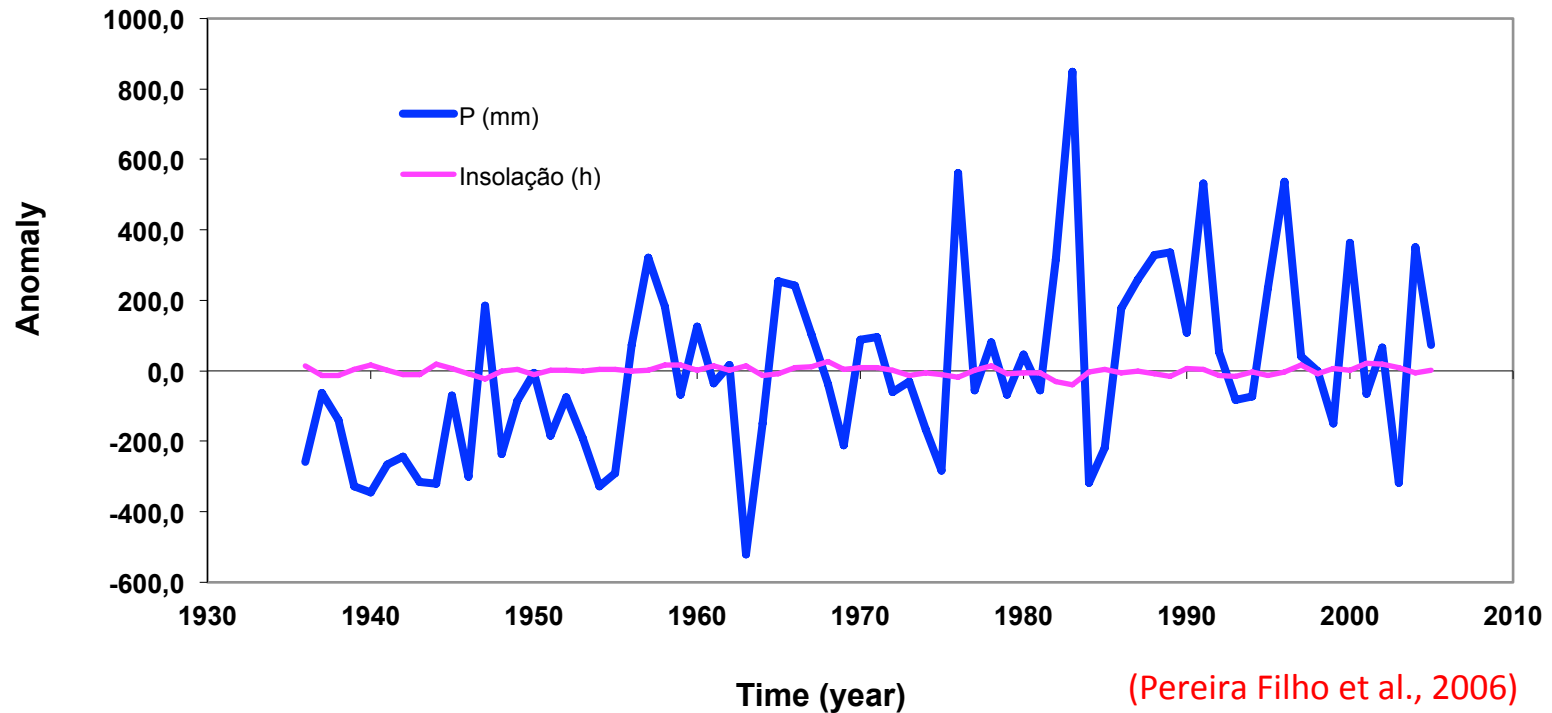


FIG. 2.4. Geographic distribution of surface air temperature anomalies (°C) in 2005 relative to the 1961-90 mean. [Source: NOAA/NCDC]
(Shein, 2006)

PRESSÃO DO AR E VENTO 1936 -2005



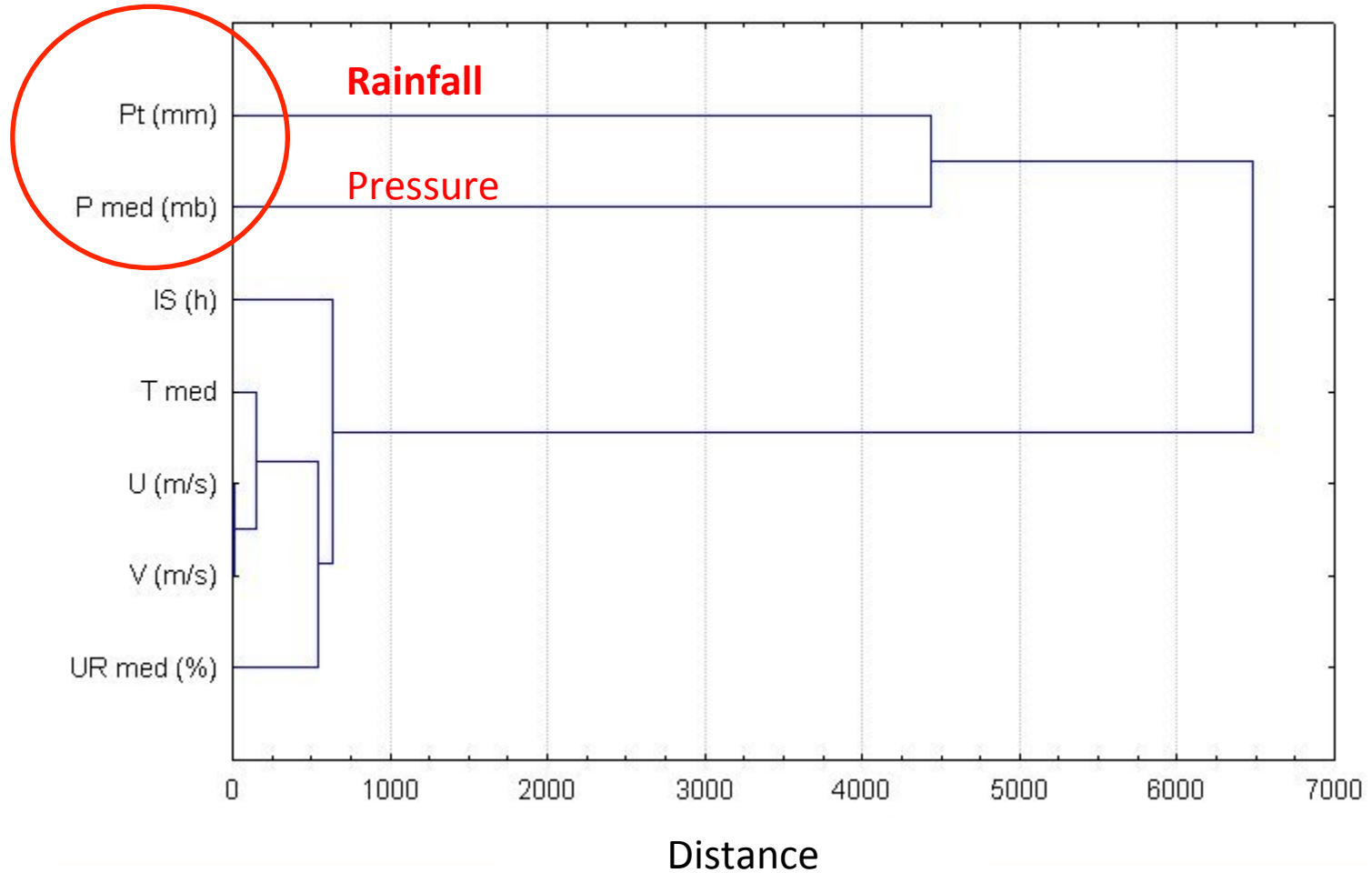
CHUVA E INSOLAÇÃO 1936 -2005



**MUDANÇAS NO CLIMA
LOCAL (+) E GLOBAL (-)**

ANÁLISE DE AGRUPAMENTO (ANUAL) 1936-2005

Seven Variables
Euclidean Distances

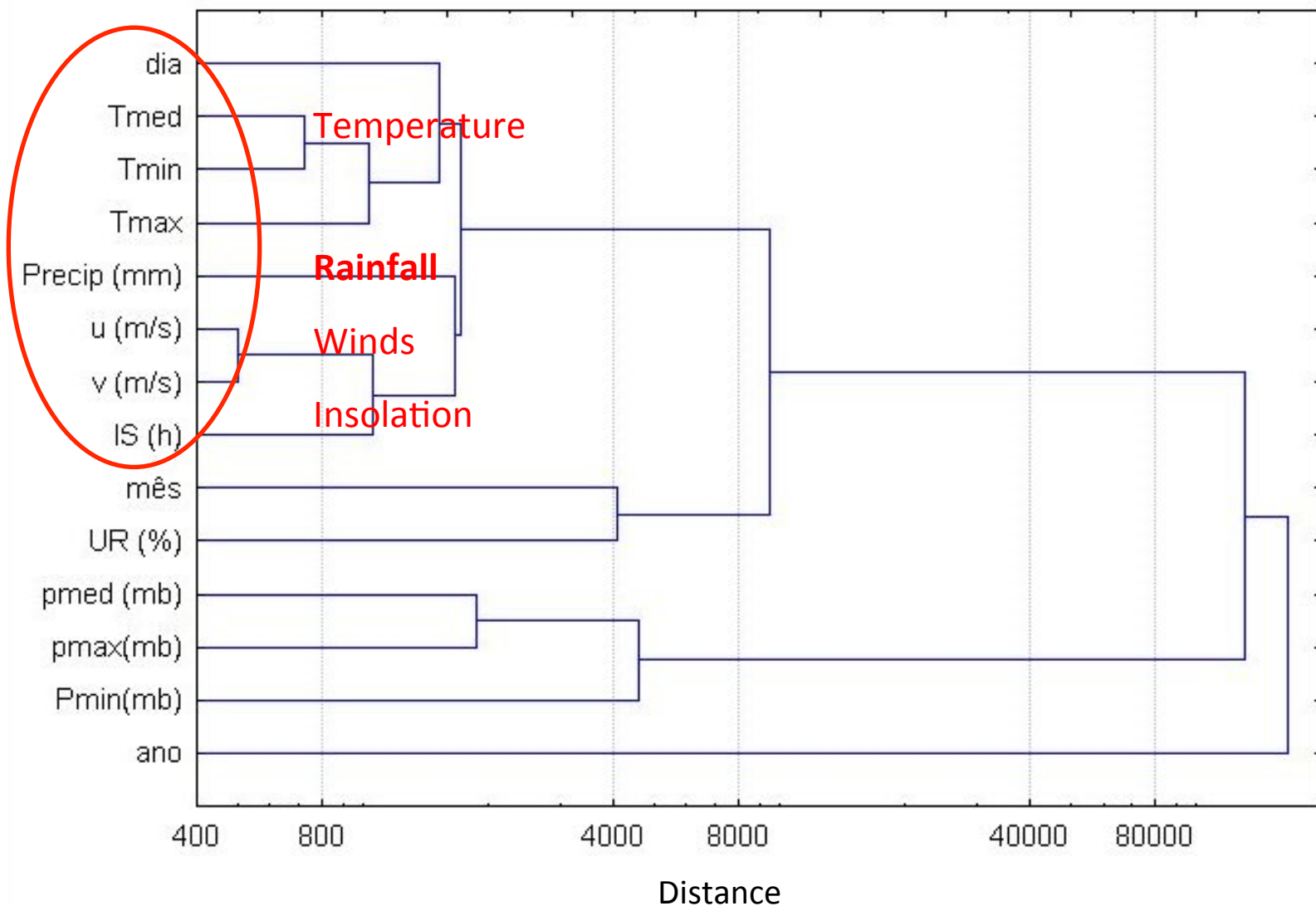


ANÁLISE DE AGRUPAMENTO (DIÁRIA)

1936-2005

Fourteen Variables

Euclidean Distances

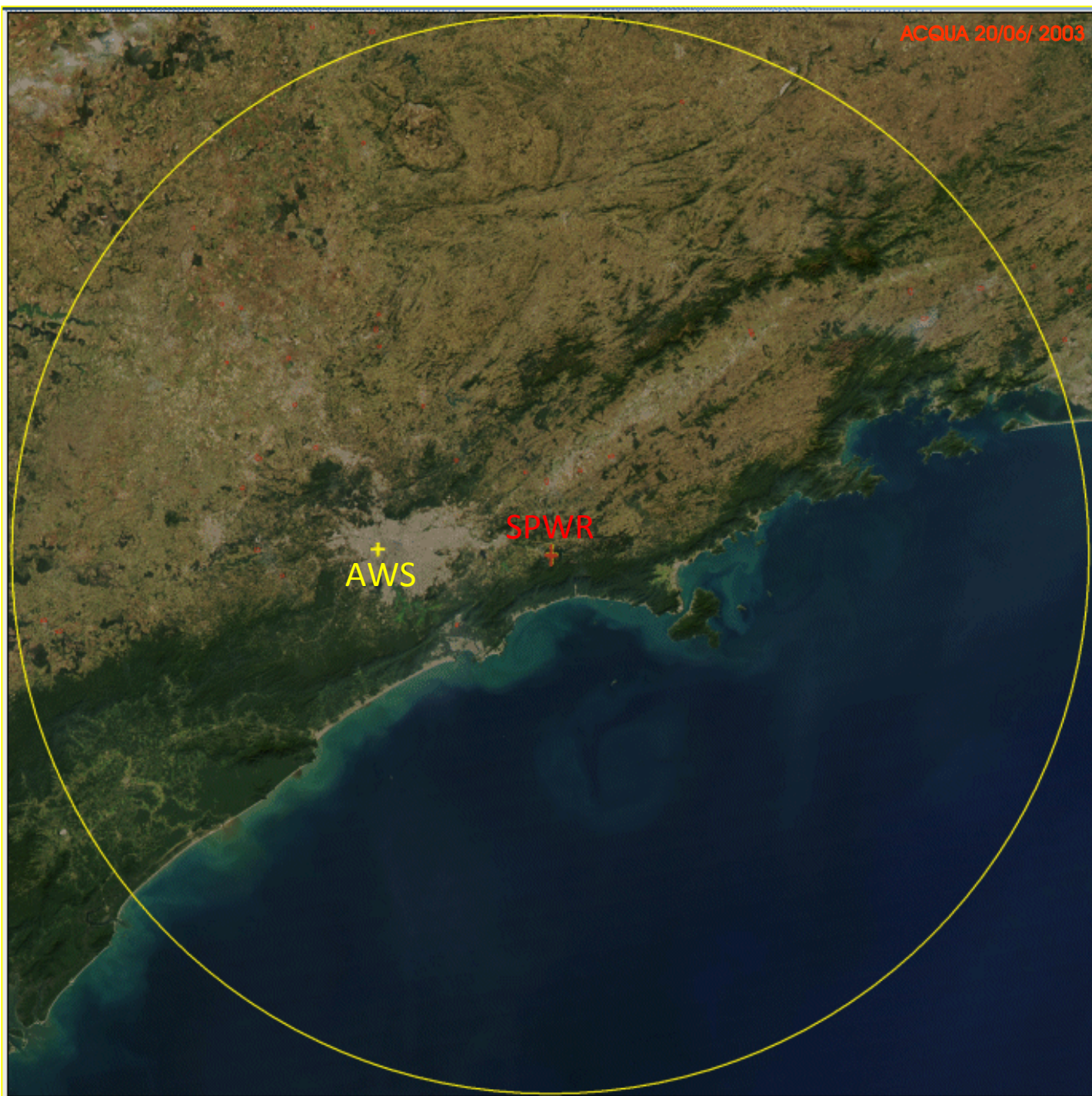


IMPACTOS DAS MUDANÇAS CLIMÁTICAS LOCAIS NA CHUVA SOBRE A RMSP

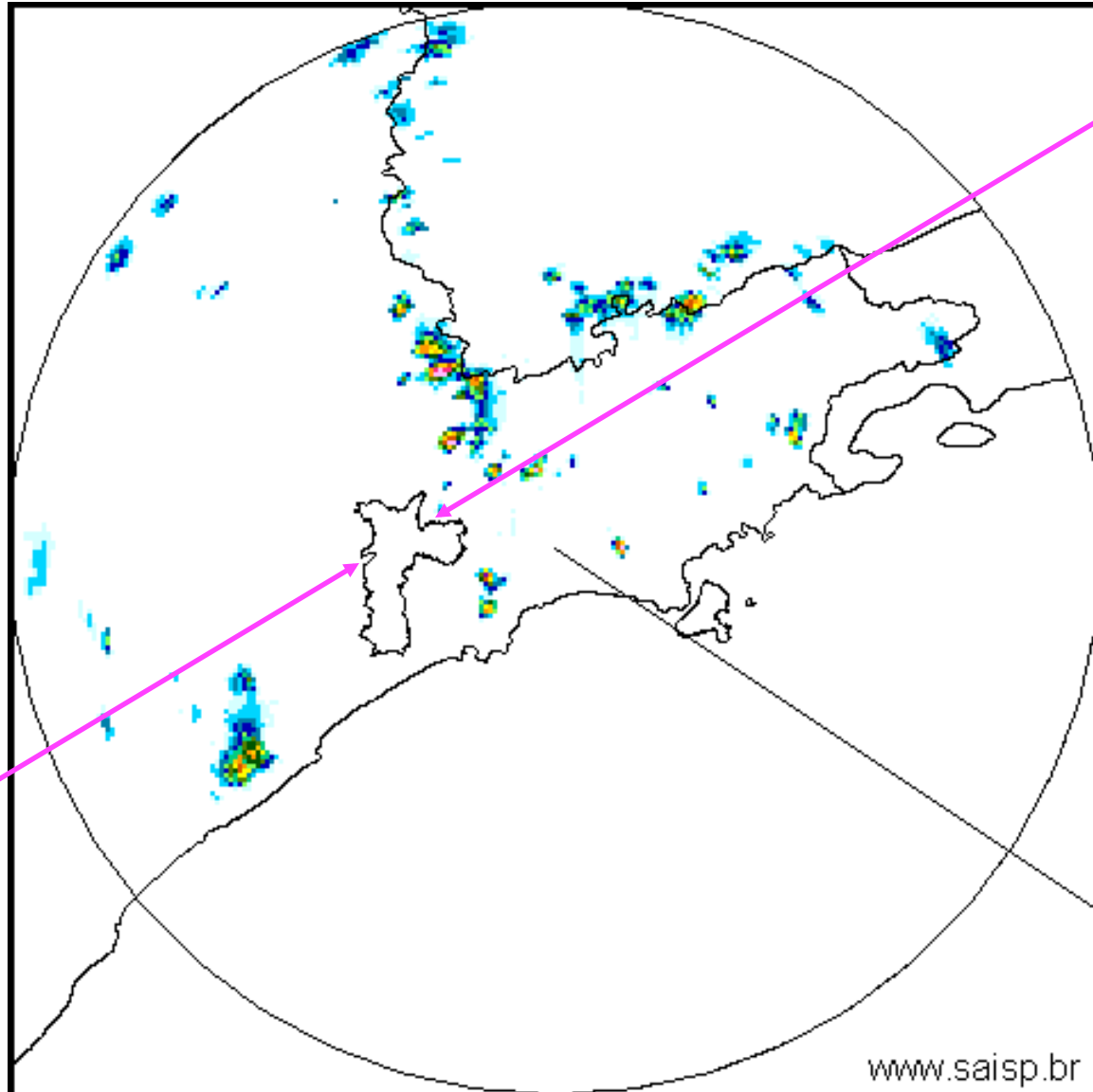
ACQUA 20/06/ 2003

+
AWS

+
SPWR



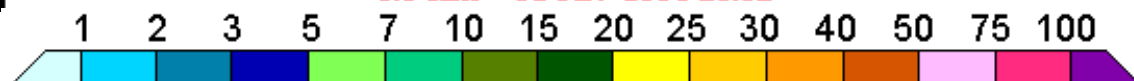
ZONA SUL



ZONA LESTE

www.saisp.br

3.0 Km - 02 FEV 2004 18:01

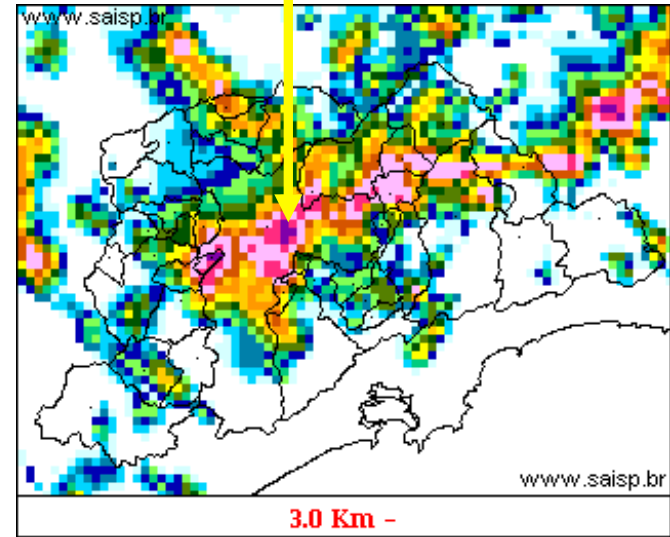


(mm h⁻¹)

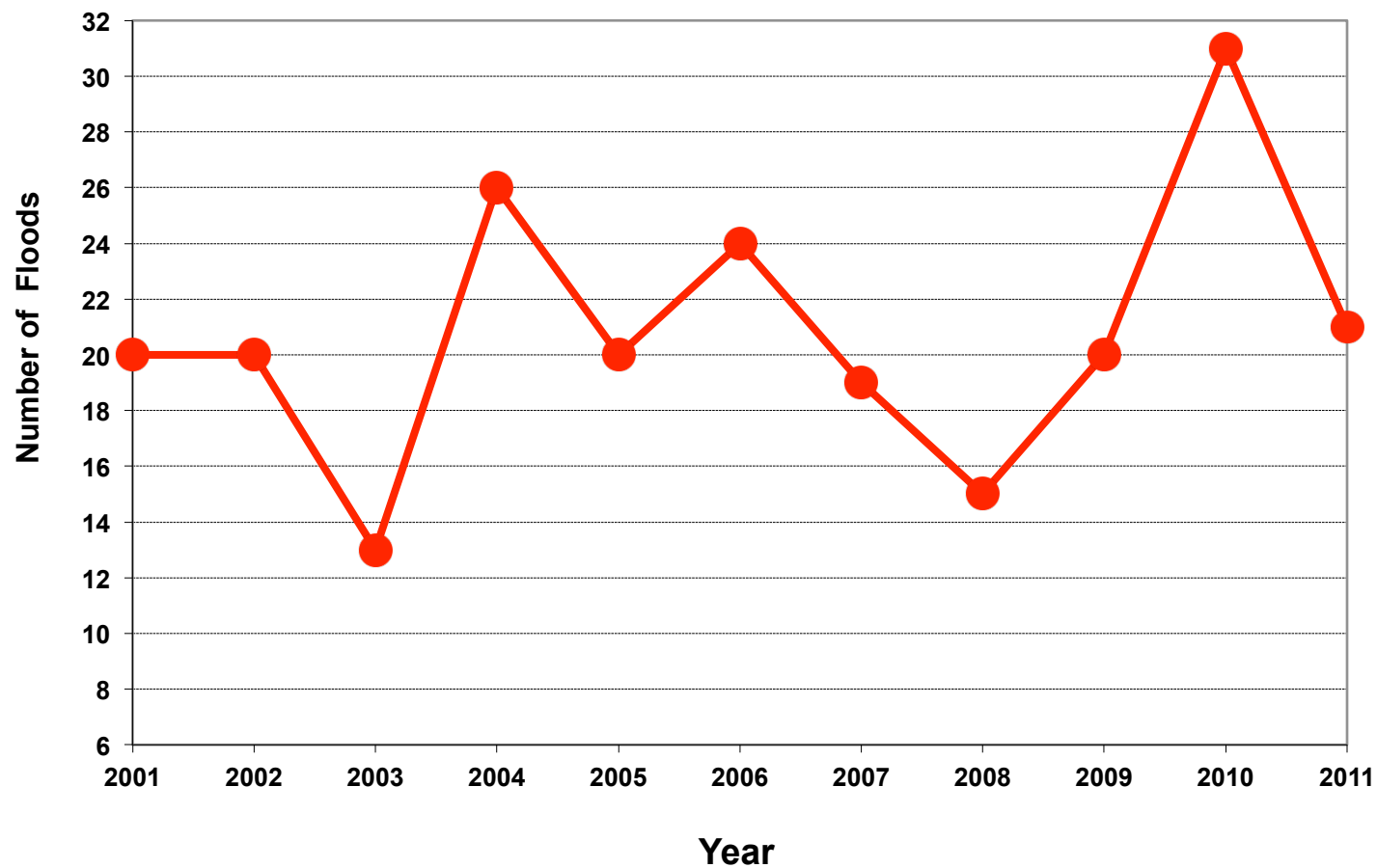
ENCHENTES



RIO ARICANDUVA



NÚMERO DE ENCHENTES NA CIDADE DE SÃO PAULO 2001 A 2011

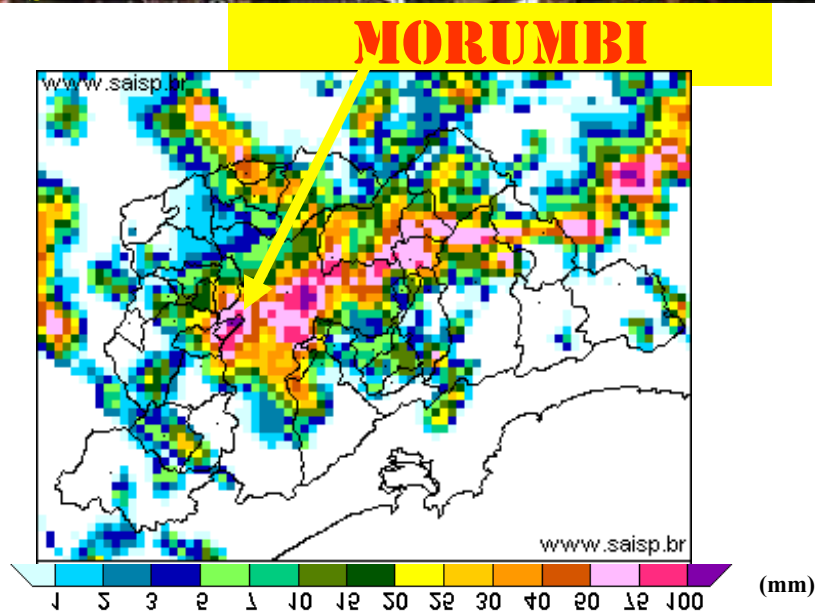


Inundação

02-02-2004

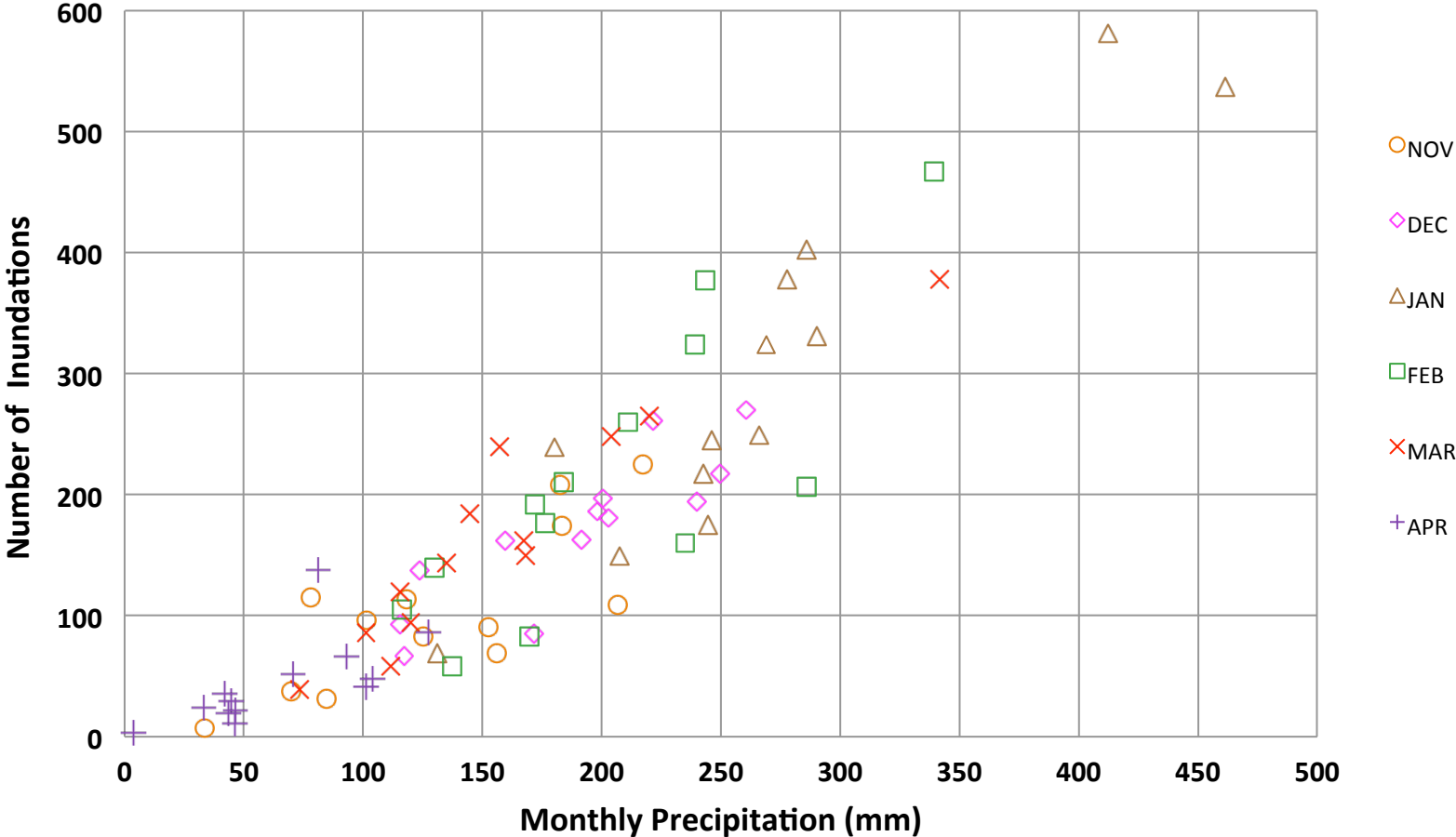


Fonte: OESP

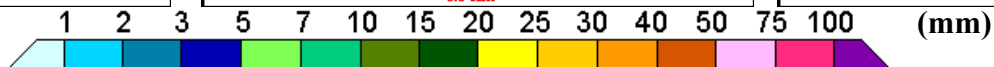
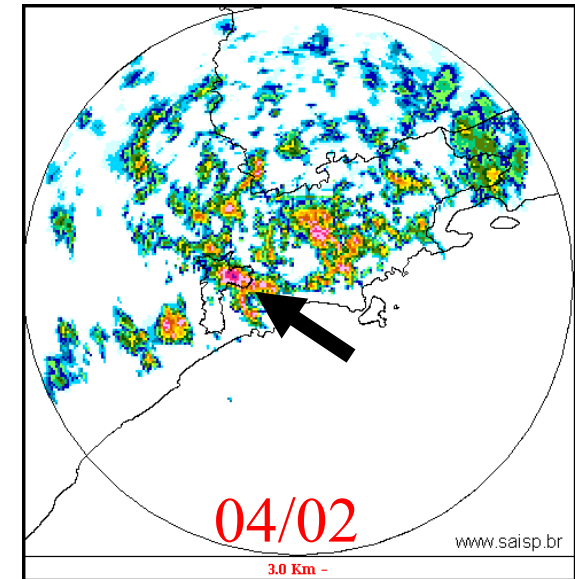
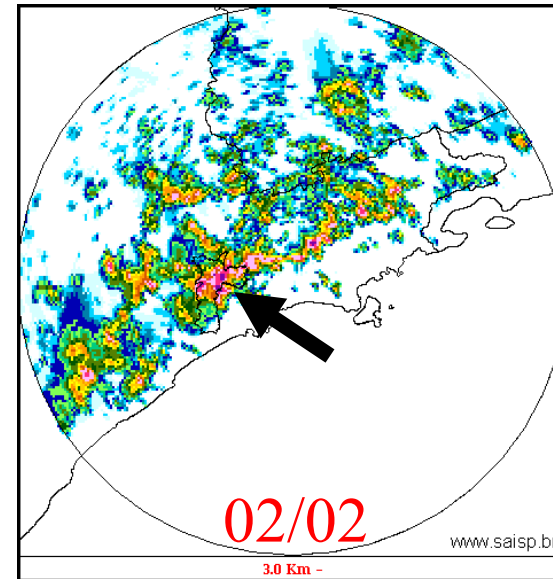
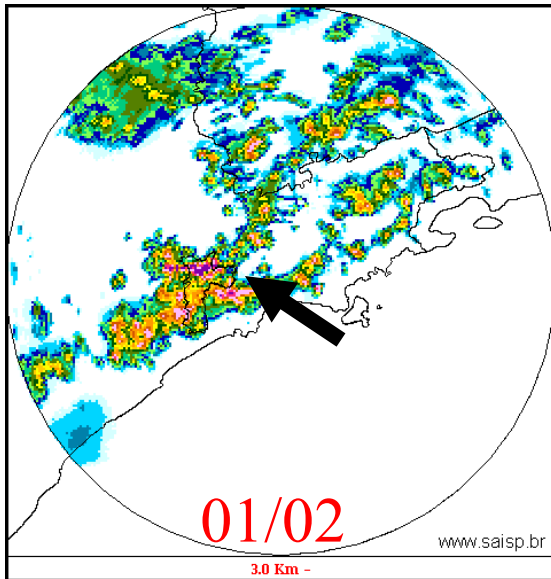
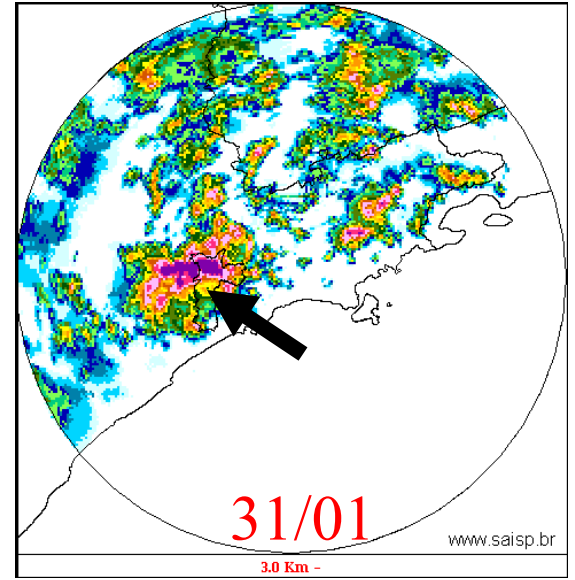
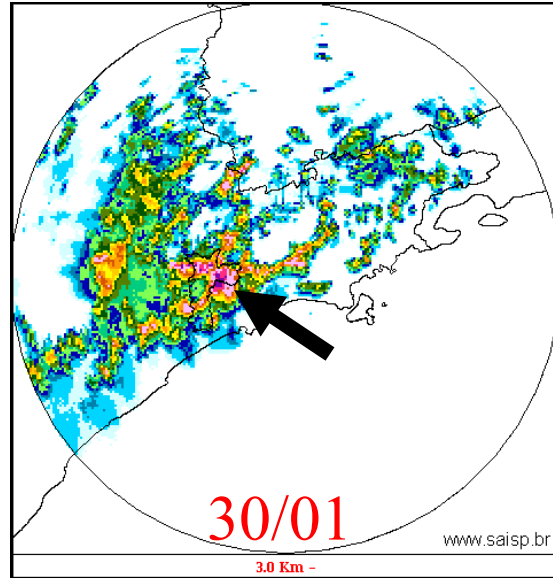
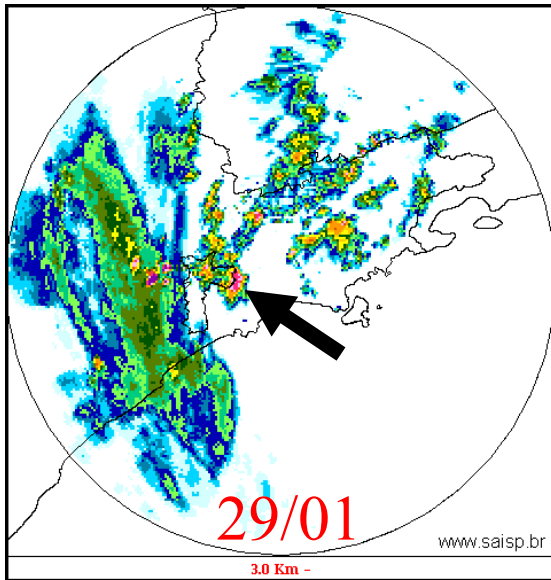


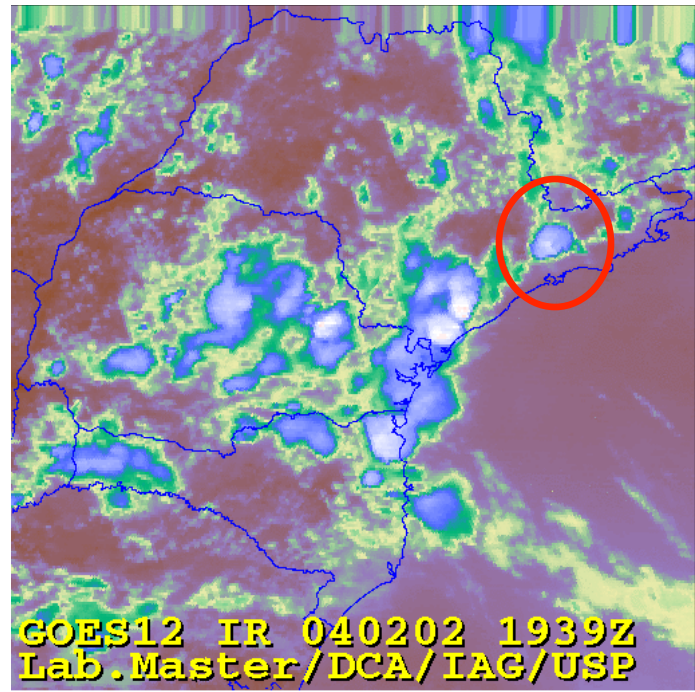
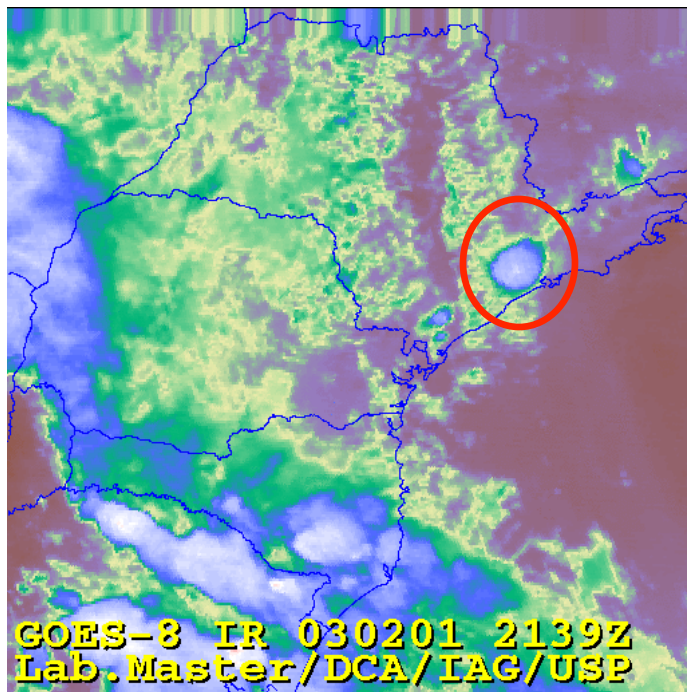
Fonte: OESP

Inundações na Cidade de São Paulo 1999 to 2011

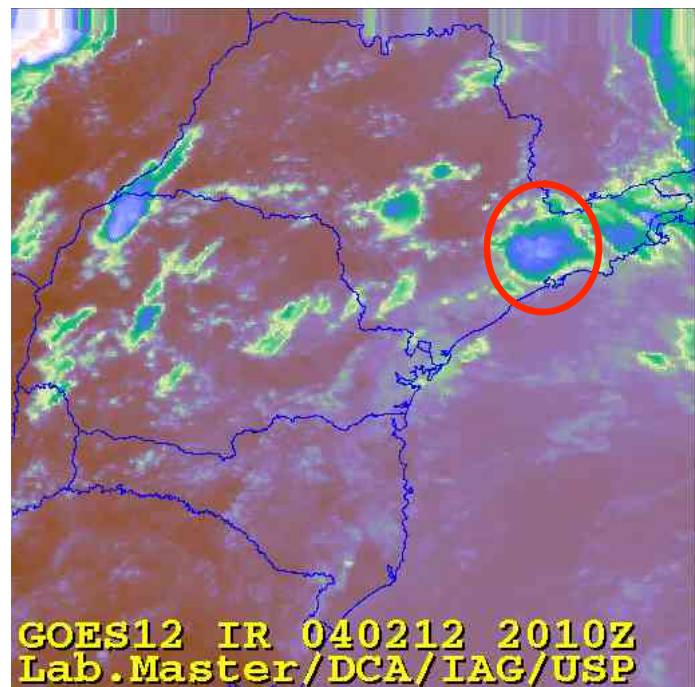
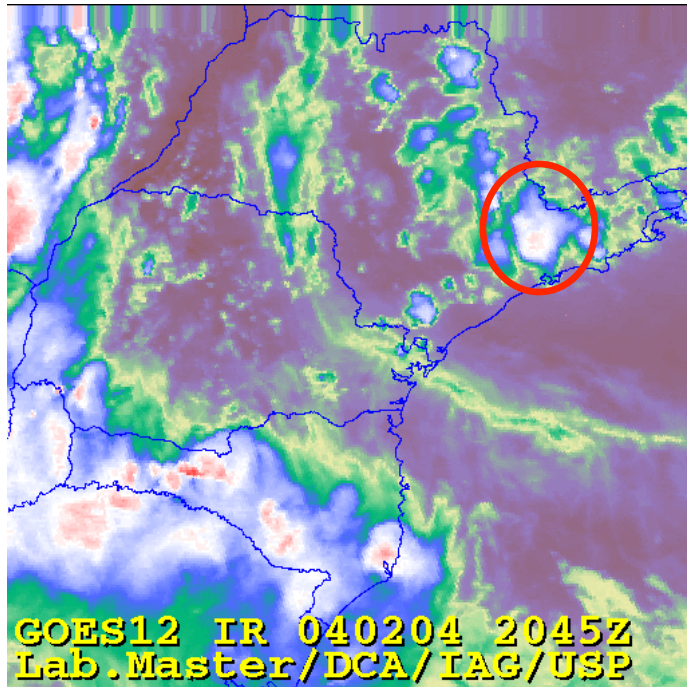


CHUVA DIÁRIA NA RMSP - ENCHENTES DE 2004

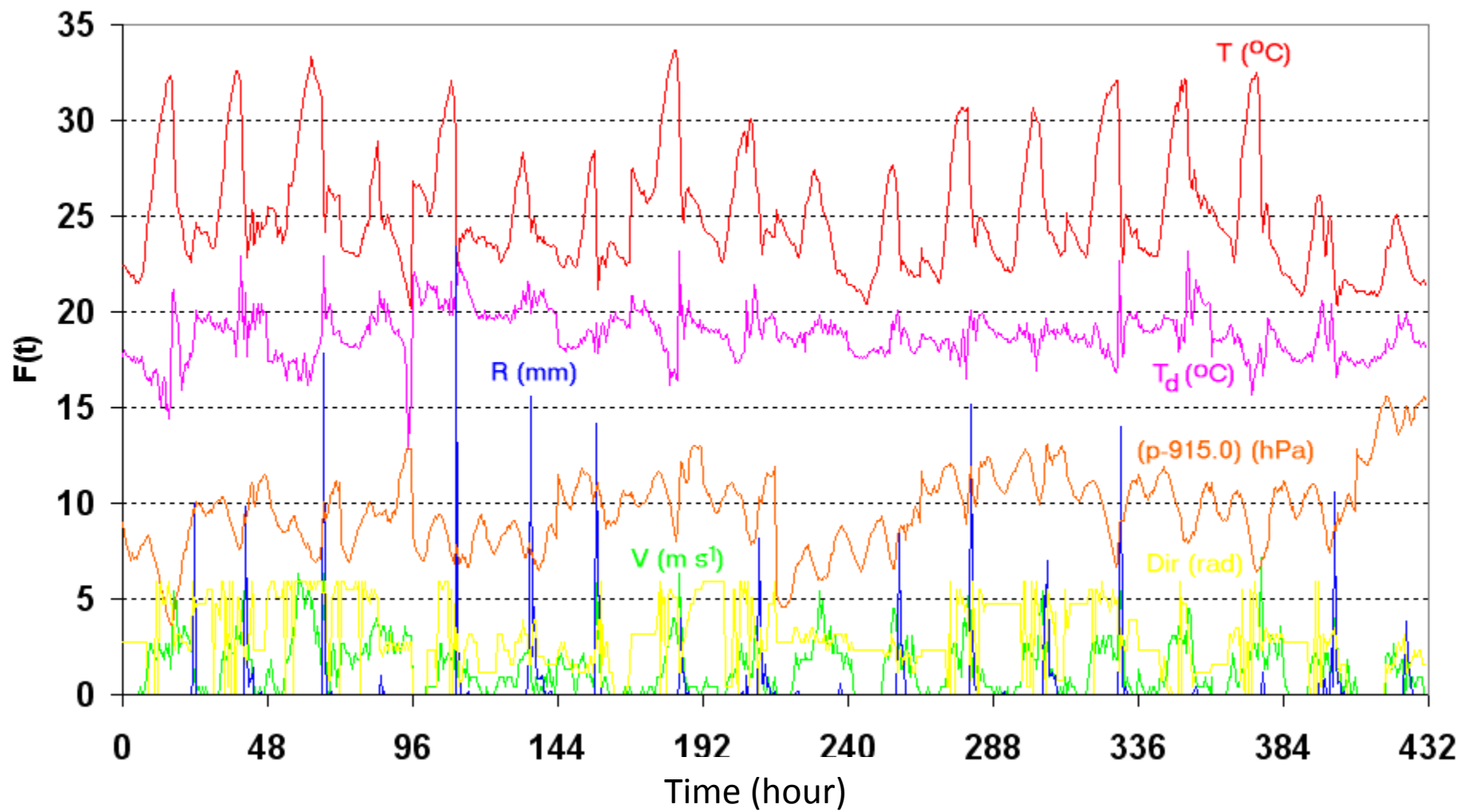




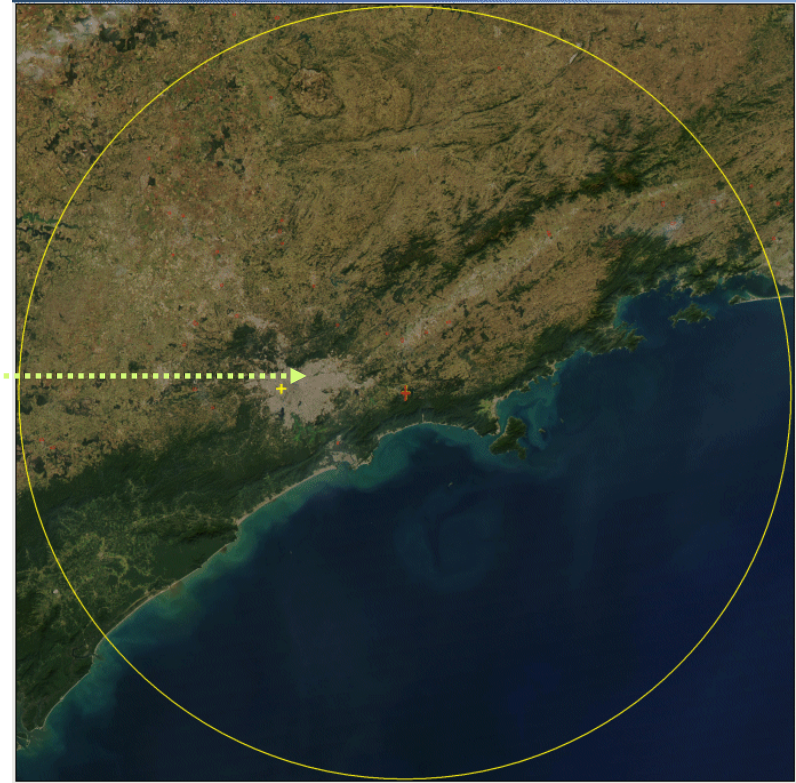
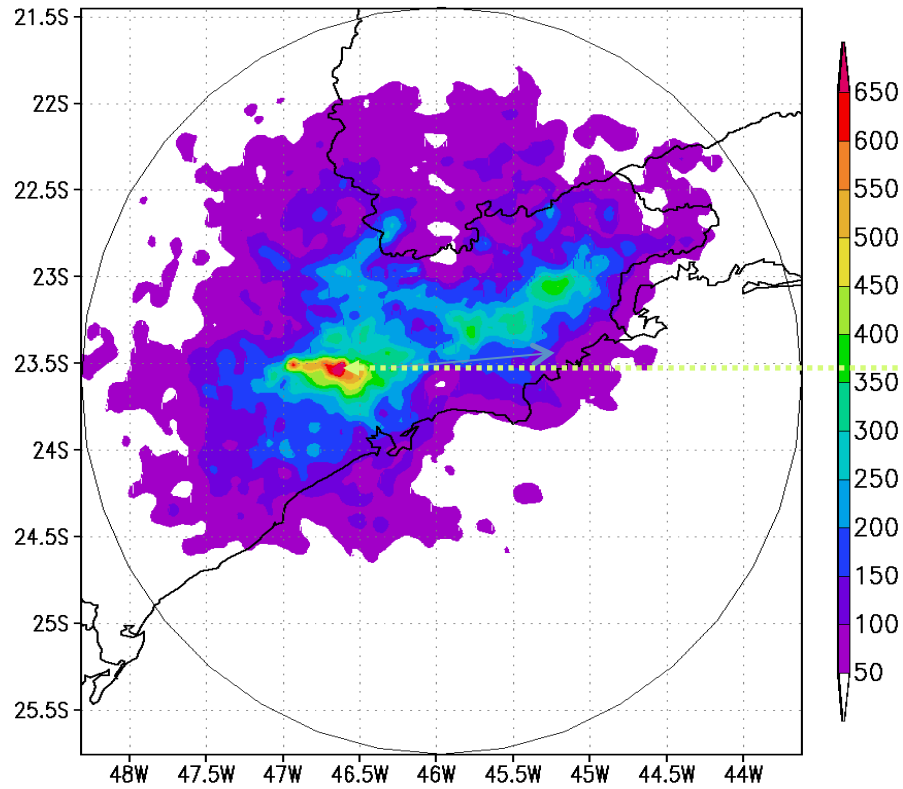
GOES-12 IR



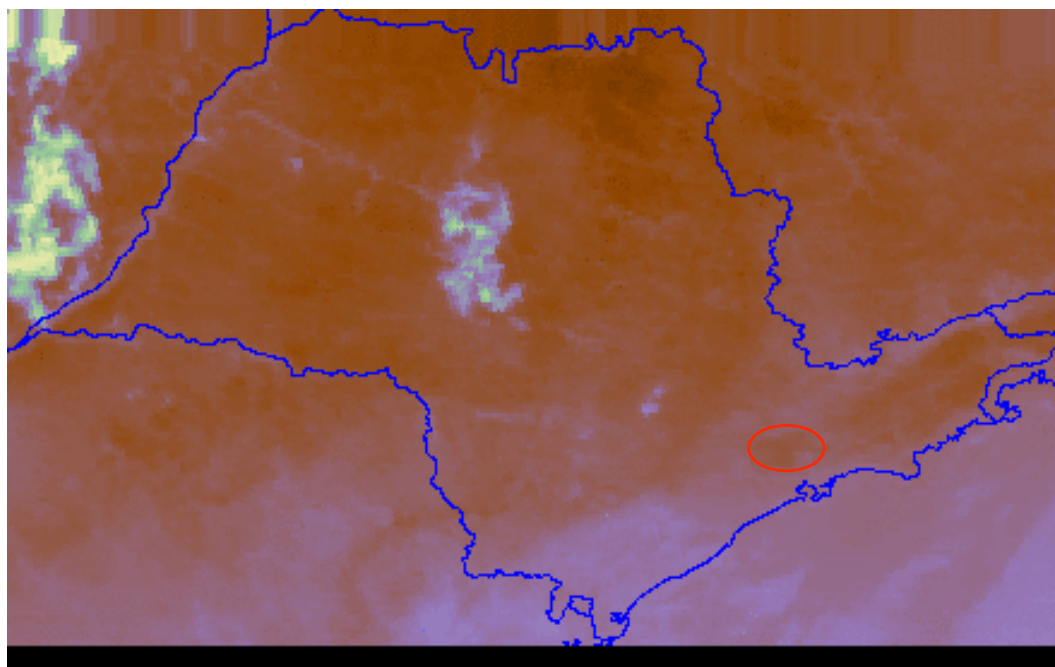
ENCHENTES CAUSAS PELA ILHA DE CALOR E BRISA MARINHA 2002 A 2004



CHUVA TOTAL (mm) – BRISA & IC (2002 – 2004)

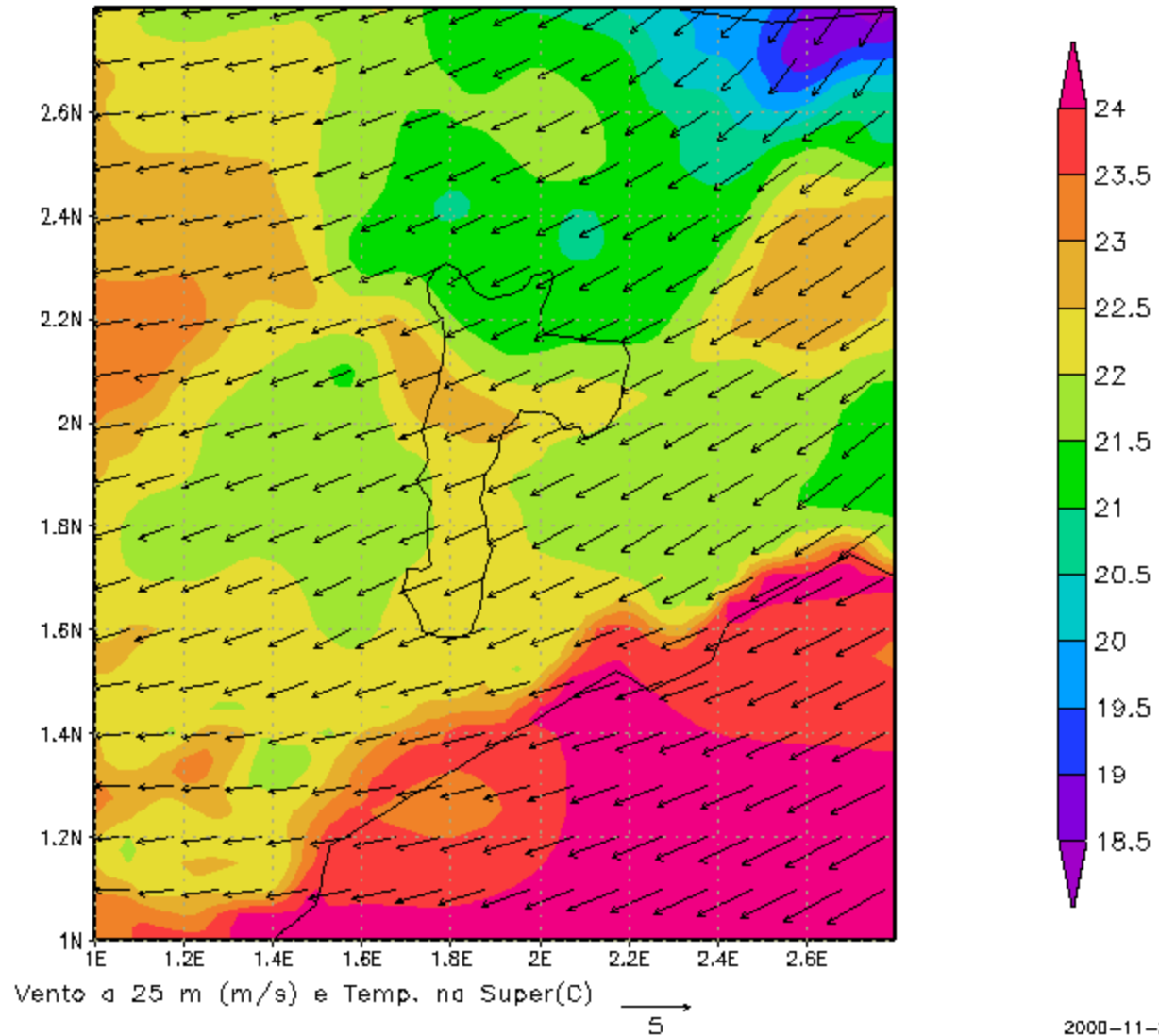


ILHA DE CALOR NA RMSP



Brisa do Mar simulada com ARPS

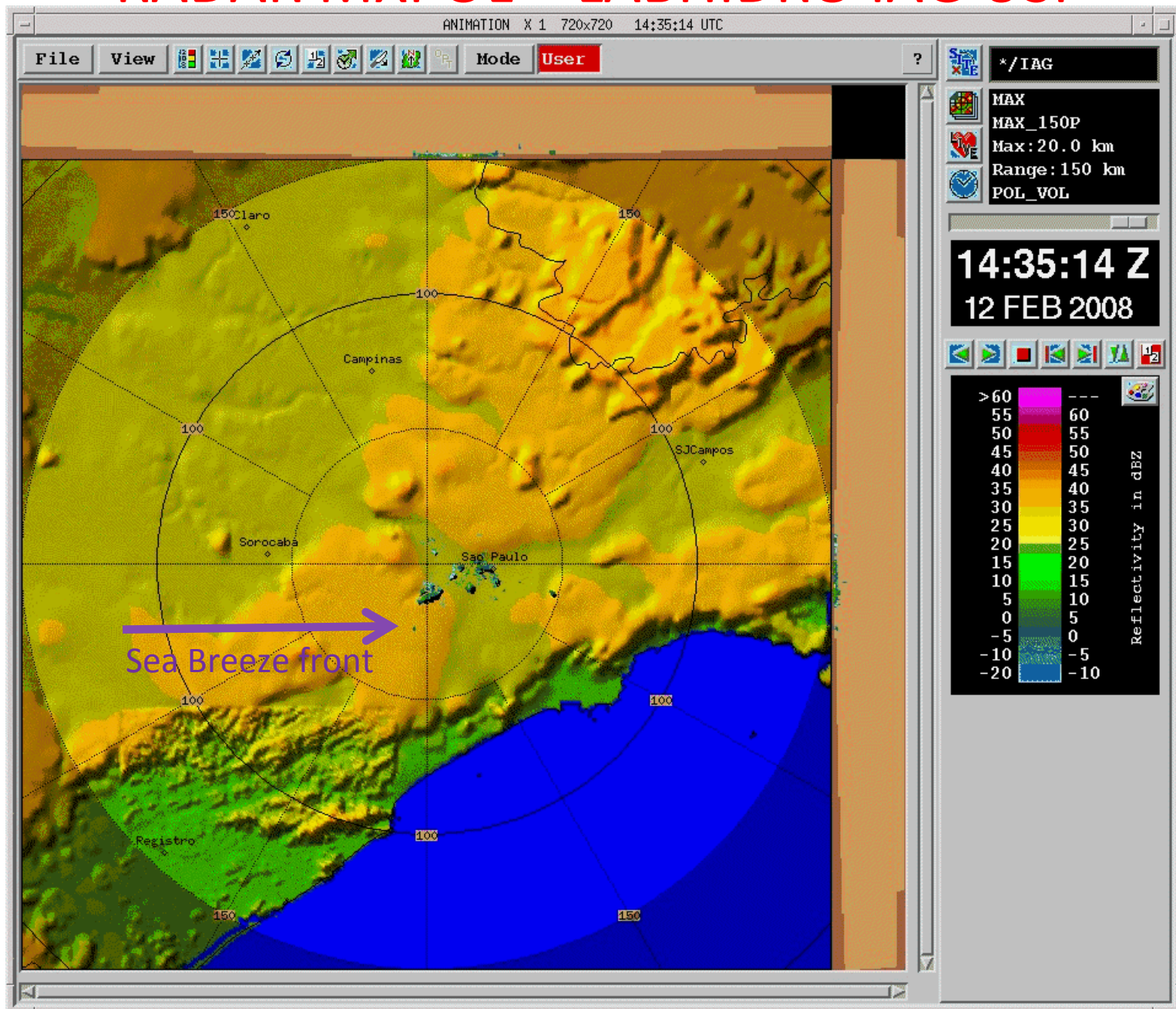
Horario: 1 Z



GrADS: COLA/IGES

(Pereira Filho et al., 2002)

RADAR MXPOL – LABHIDRO IAG USP

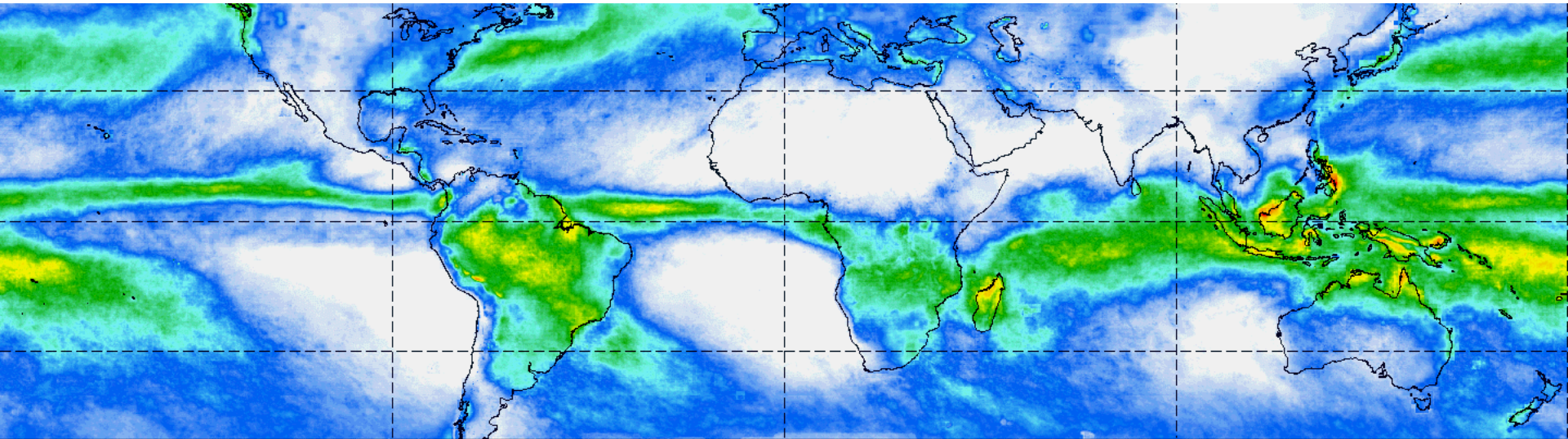


CONCLUSÃO

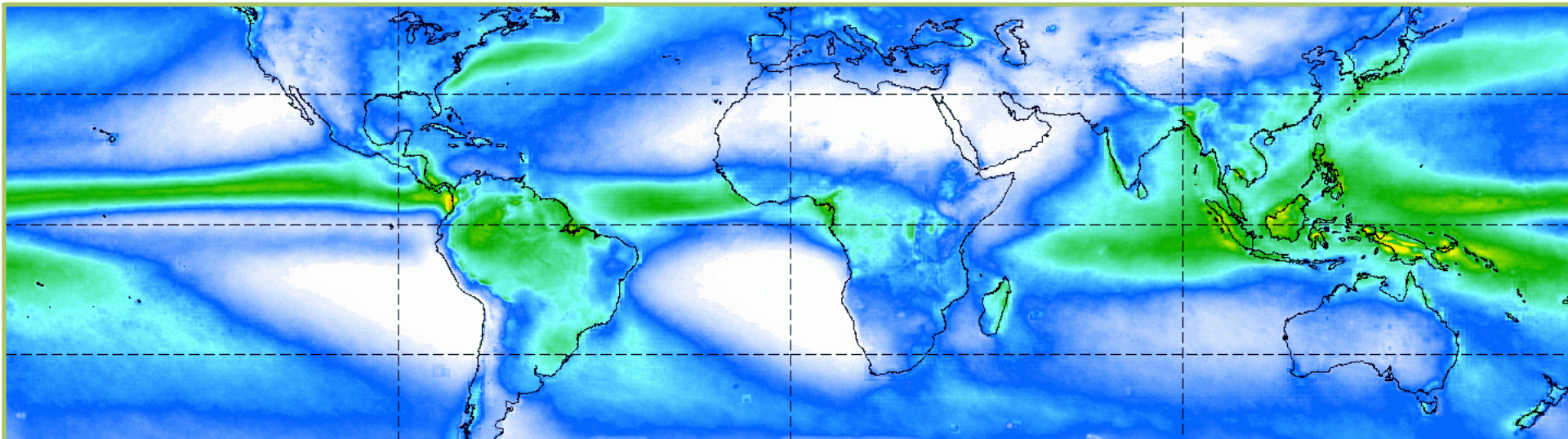
- **CAUSAS DAS MUDANÇAS CLIMÁTICAS LOCAIS:**
REDUÇÃO DA VEGETAÇÃO
CRESCIMENTO URBANO
POLUIÇÃO DO AR (INVERNO)
EFEITOS GLOBAIS MENOR IMPACTO;
- **$T_{AR} + 2,1^{\circ} C$; ↑**
- **CHUVA + 395 MM; ↑**
- **VENTO ZONAL (E) + 0,5 M S⁻¹; ↑**
- **VENTO MERIDIONAL (S) - 1,0 M S⁻¹; ↓**
- **UMIDIDADE RELATIVA - 7%. ↓**

- **CICLOS DE 2 A 11 ANOS, 21 ANOS E MAIS LONGOS NA PRESSÃO DO AR, VENTOS, UMIDADE RELATIVA, INSOLAÇÃO E CHUVA.**
- **TEMPERATURA DO AR TEM CICLOS DE 2 A 7 YEAR POR CAUSA DO EL NIÑO, LA NIÑA E OSCILAÇÃO SUL.**
- **ALTA DO ATLÂNTICO SUL CONTROLA A CHUVA ANUAL + OESTE (- LESTE) –(+) CHUVA.**

CLIMATOLOGIA TRMM

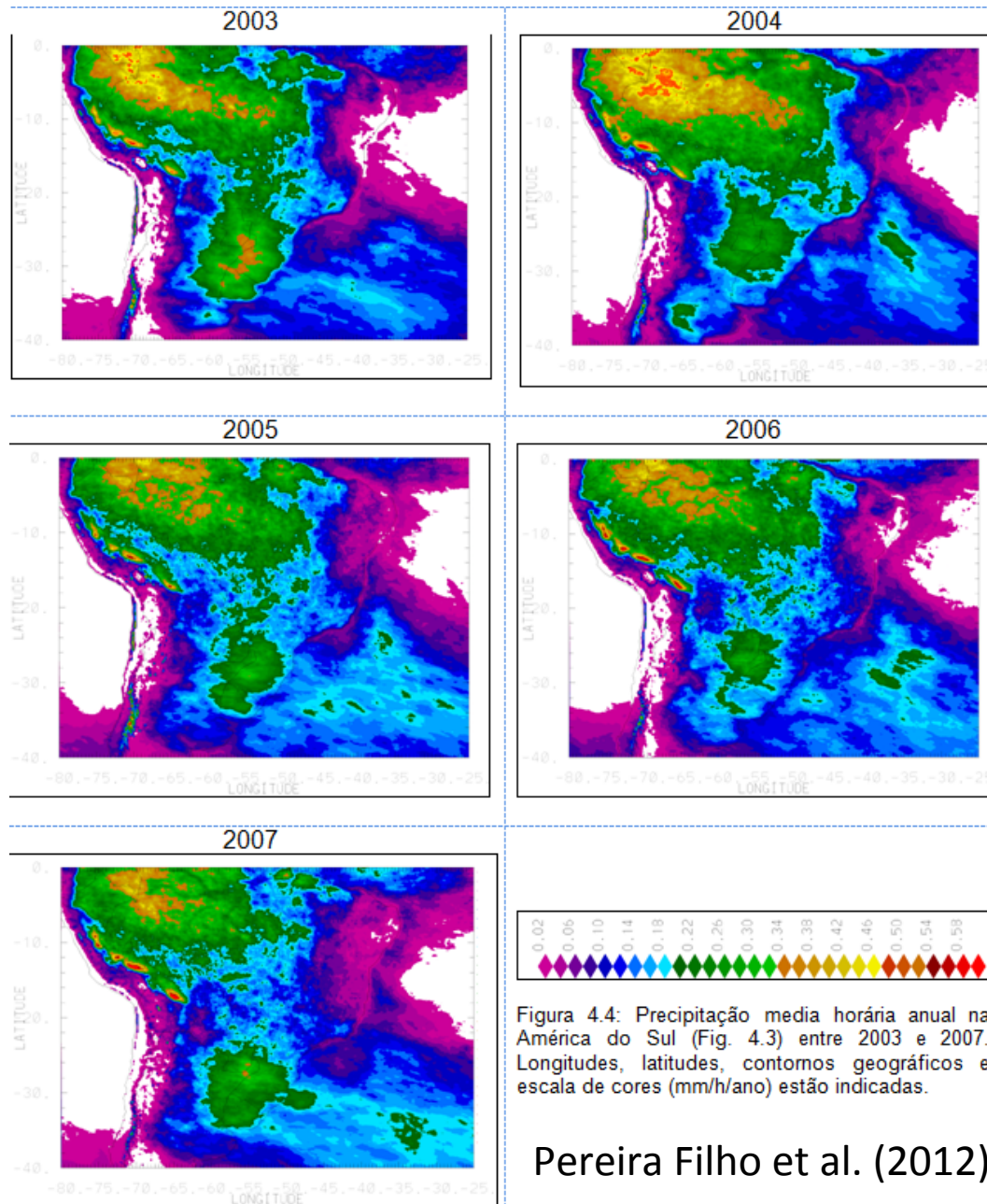


JANUARY Average Rainfall mm/dd (3B43) 1998 to 2011



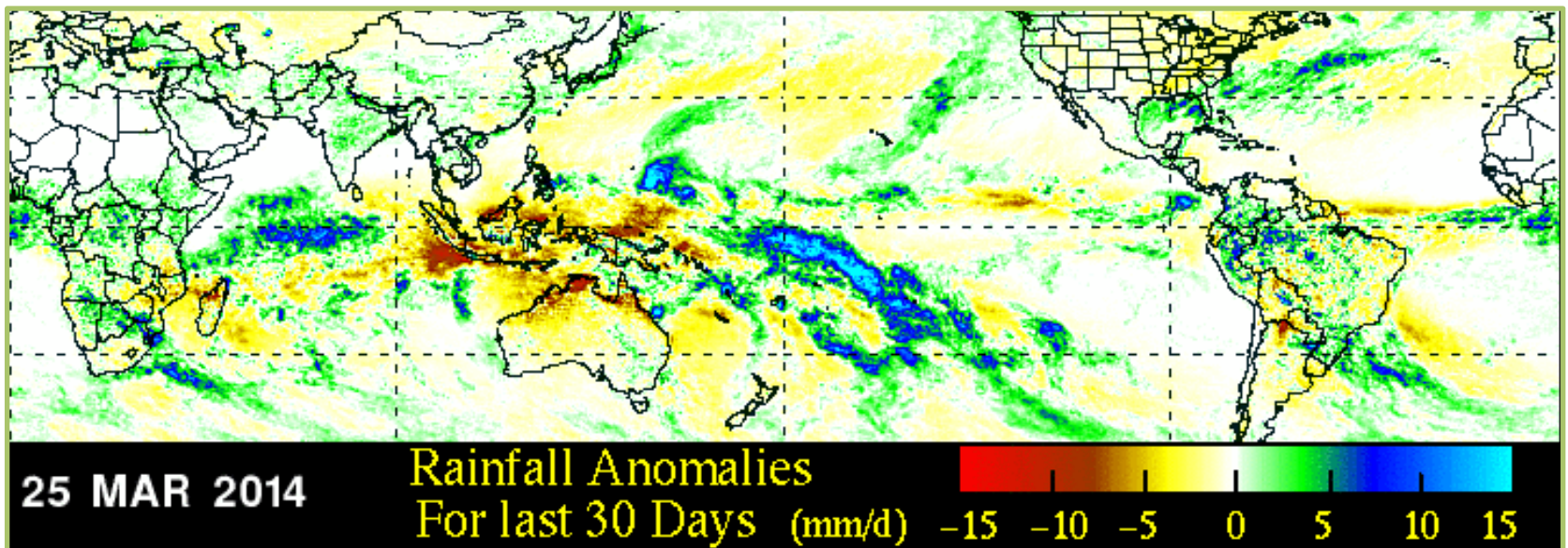
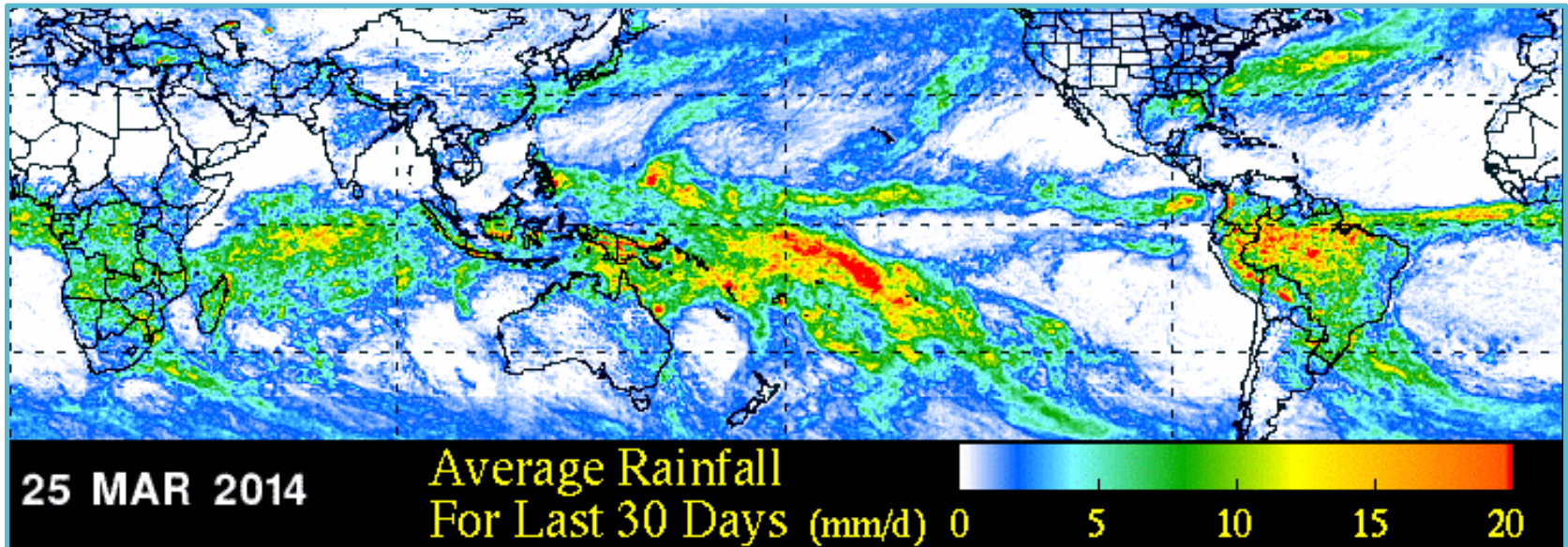
Average of ALL AVAILABLE Rainfall mm/dd (3B43) 1998 to 2011





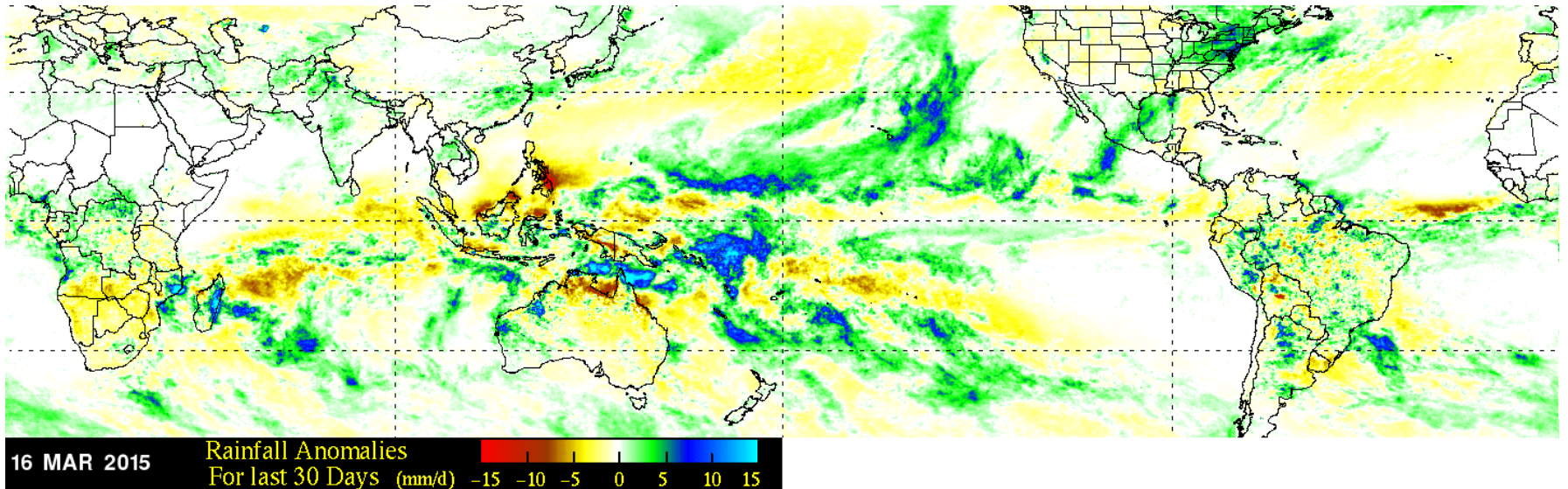
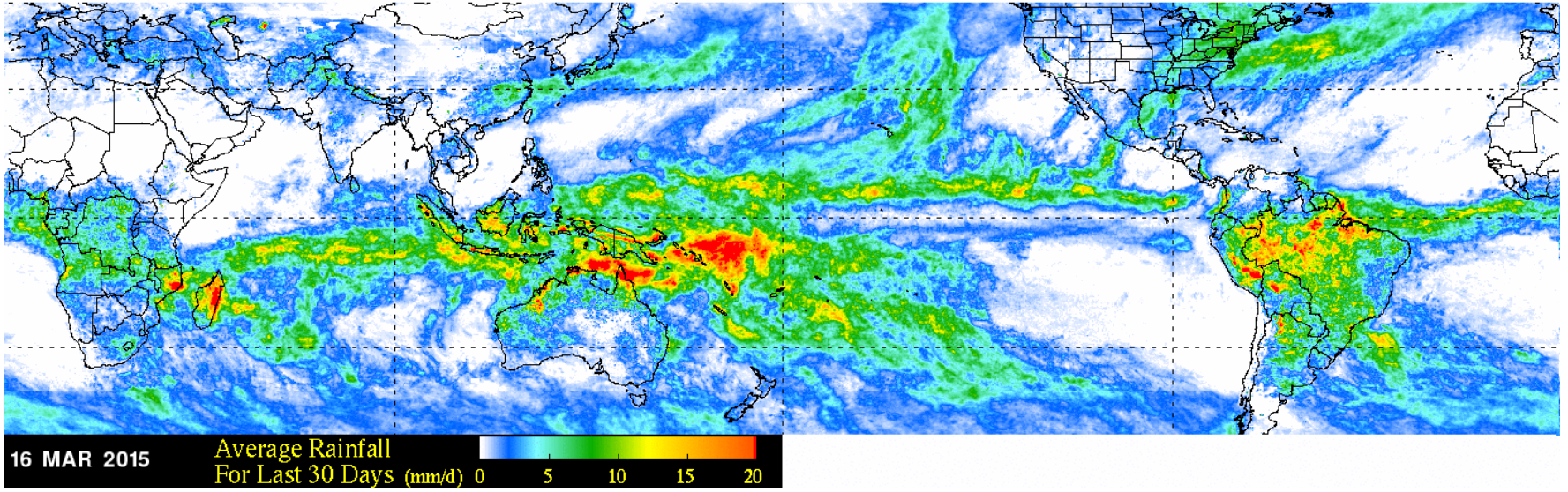
Pereira Filho et al. (2012)

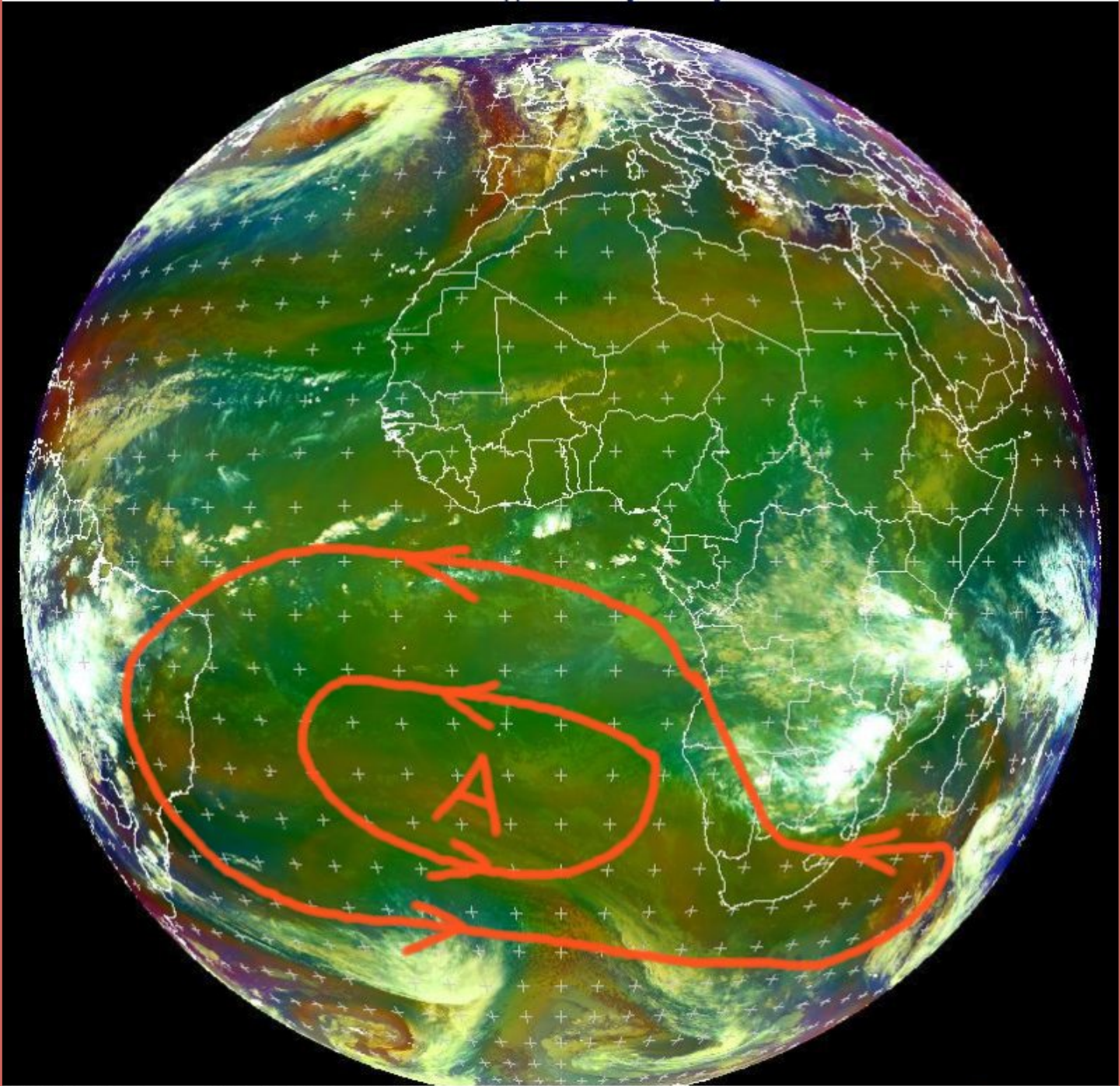
PRECIPITAÇÃO 30 DIAS -03/2014



PRECIPITAÇÃO 30 DIAS - 03/2015

http://trmm.gsfc.nasa.gov/trmm_rain/Events/thirty_day.html

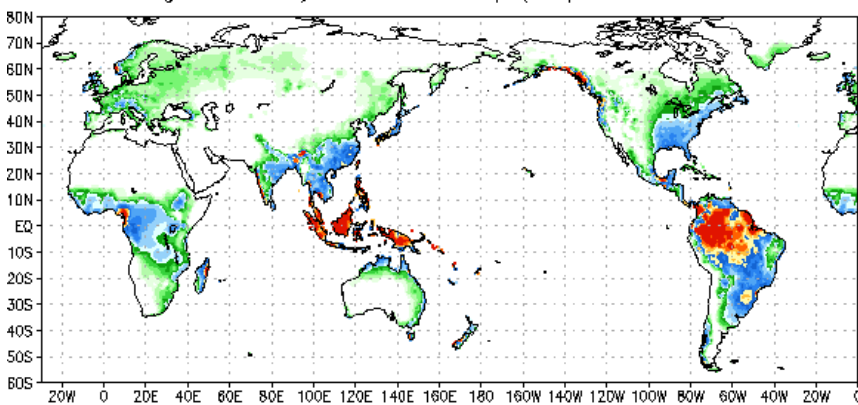




MET10 RGB-Airmass 2014-02-07 01:00 UTC

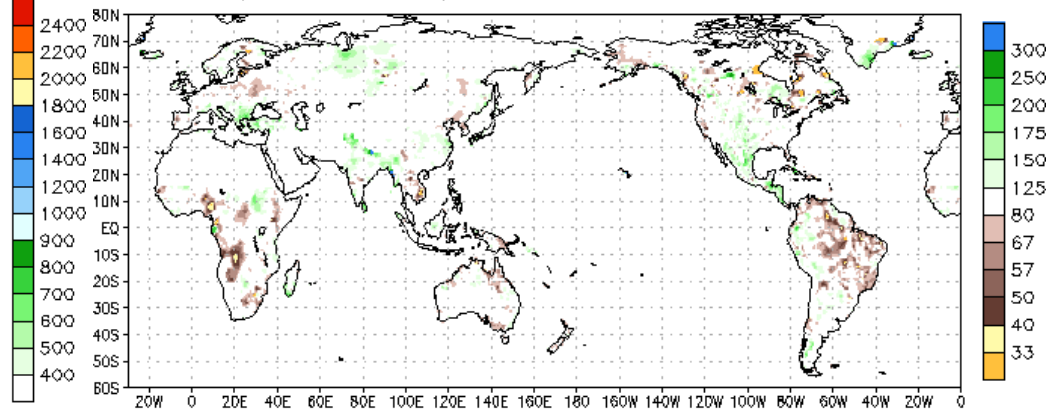
PRECIPITAÇÃO 365 DIAS

Climatological 365-day Accumulated Prep (mm) 23JUL2014–22JUL2015



Data Source: CPC Unified (gauge-based) Precipitation
Climatology (1981–2010)

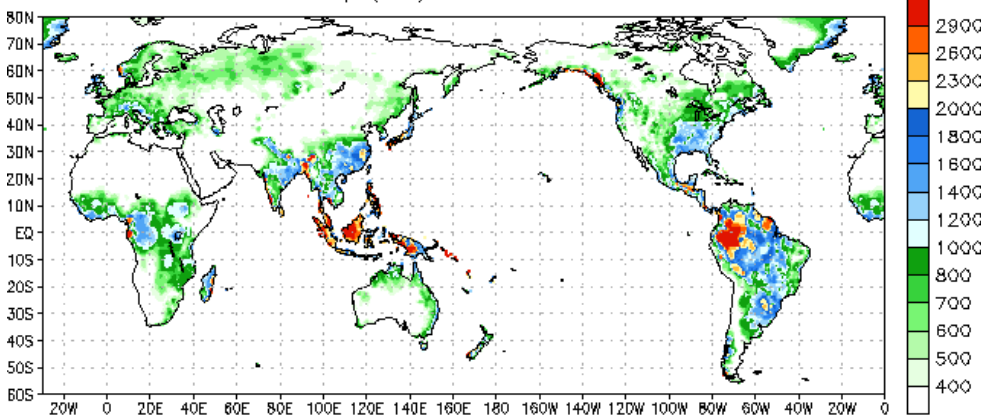
365-day Accumulated Prep % of Normal 23 JUL 2014 – 22 JUL 2015



Data Source: CPC Unified (gauge-based) Precipitation
Climatology (1981–2010)

Note: Areas which receive on average 1mm/day are masked out.

Accumulated Prep (mm) 23 JUL 2014 – 22 JUL 2015



Data Source: CPC Unified (gauge-based) Precipitation

Período chuvoso Outubro/ano a Março/ano seguinte

Dados EM-IAG/USP 1933-2014

+ SECOS (mm)

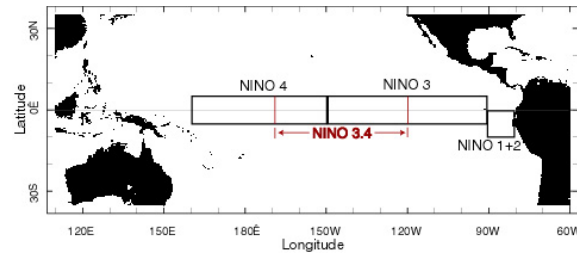
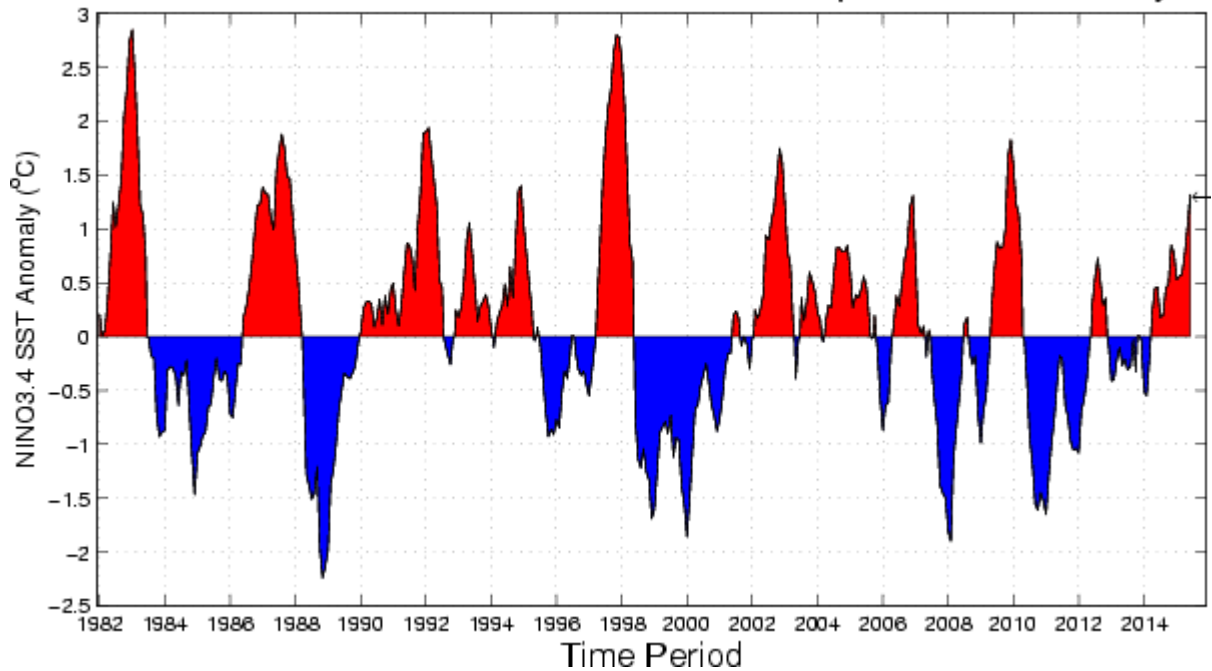
670,5	1941
697,7	1934
730,7	1964
740,9	1943
760,5	1955
798	1954
800,7	1937
803,6	1936
814,6	1969
824	1953
837,5	1939
850,2	1938
887,2	2014
900,5	1946
901,6	1945
913,2	1957
914,7	1935
915,71	1975
916,7	1994
920,1	1985

+ CHUVOSOS (mm)

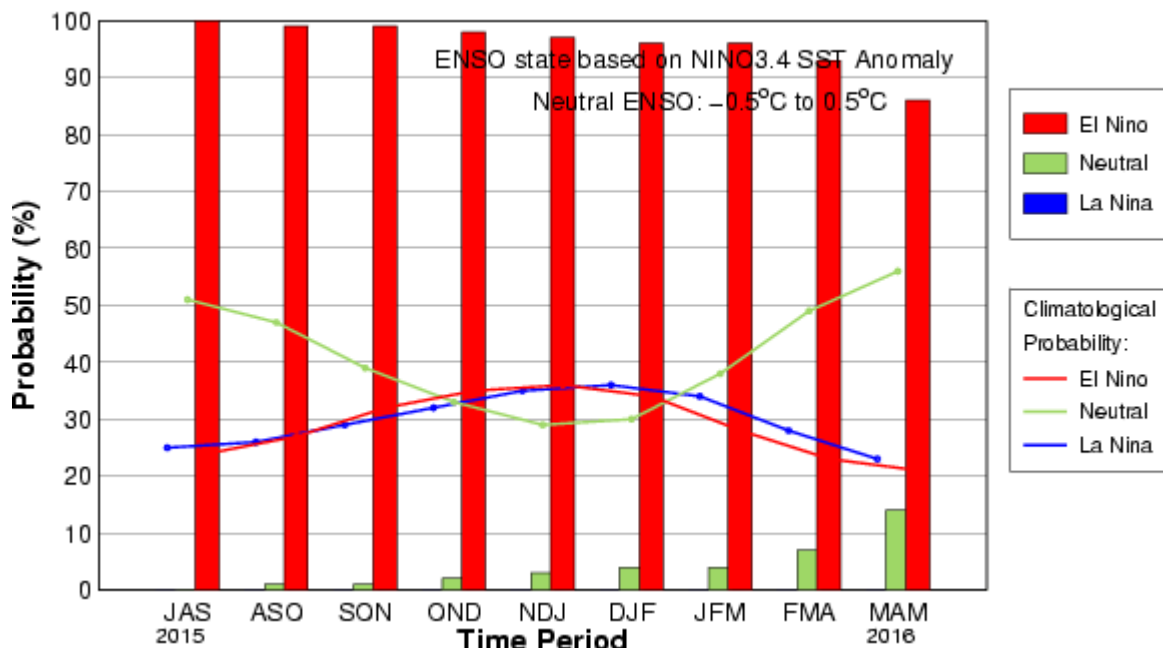
1259,9	2013
1260,4	2012
1296,8	1970
1339,6	1989
1363,8	1995
1380,2	1983
1385,8	1991
1401,7	2011
1443,1	1996
1775,8	2010

PROGNÓSTICO CLIMÁTICO INVERNO 2015

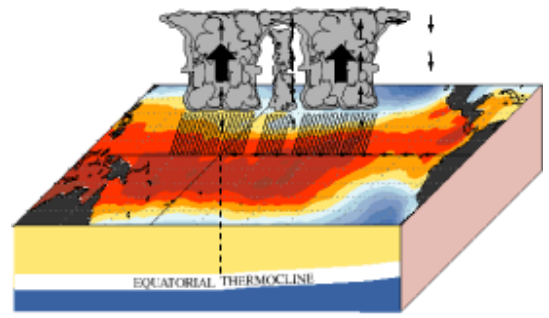
Historical NINO3.4 Sea Surface Temperature Anomaly



Mid-Jul IRI/CPC Plume-Based Probabilistic ENSO Forecast



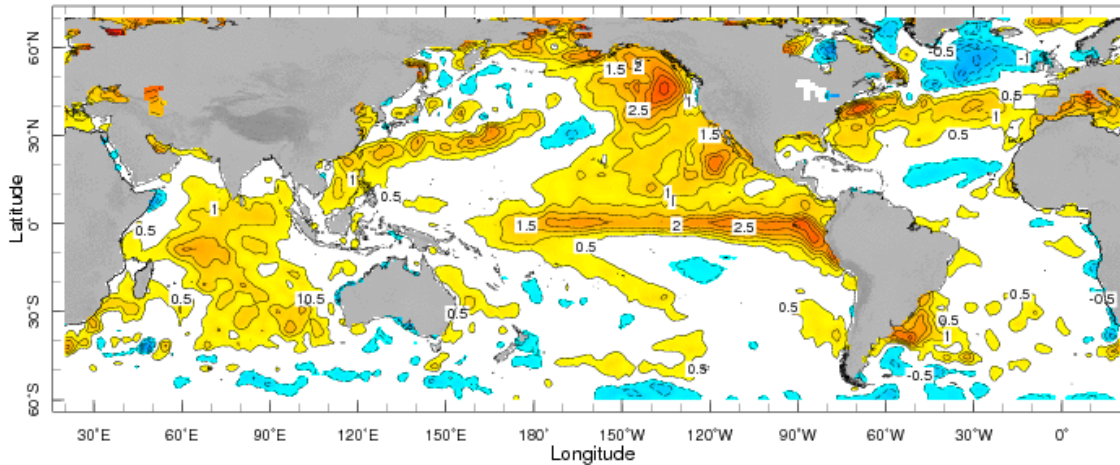
December - February El Niño Conditions



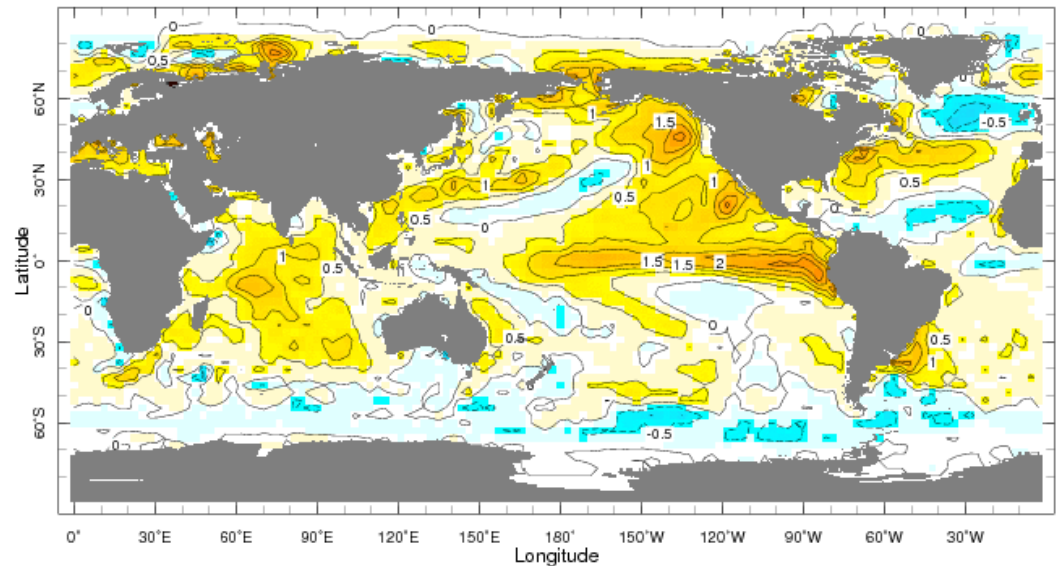
TSM ATUAL E PREVISTA

<http://iridl.ldeo.columbia.edu/maproom/Global/Forecasts/SST.html>

Jun 2015

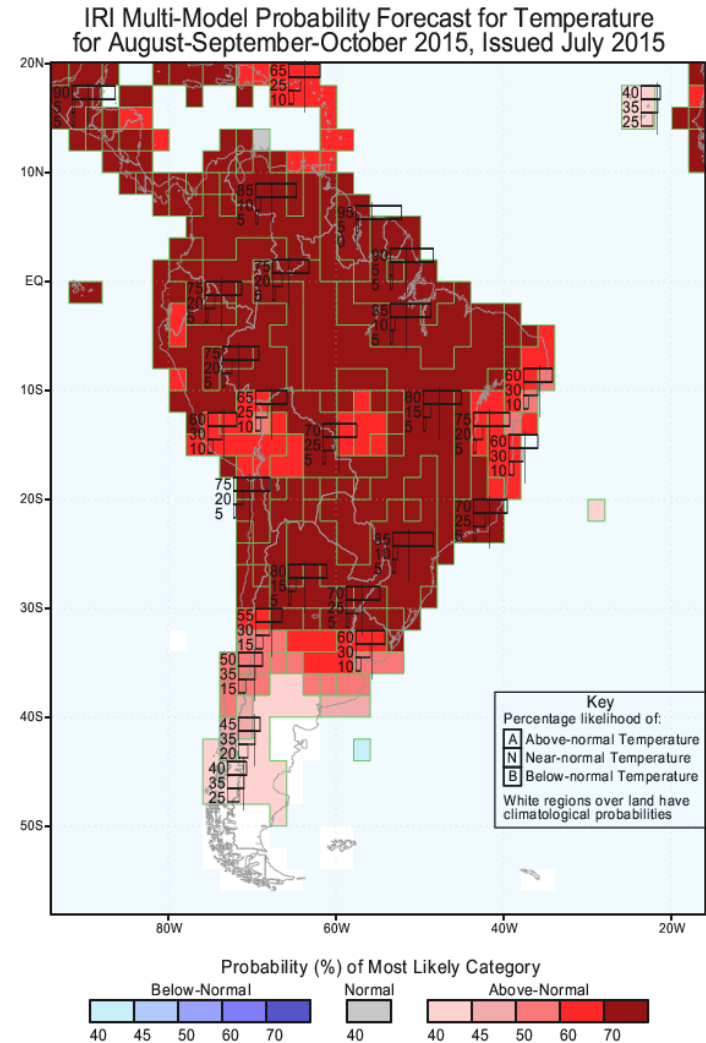
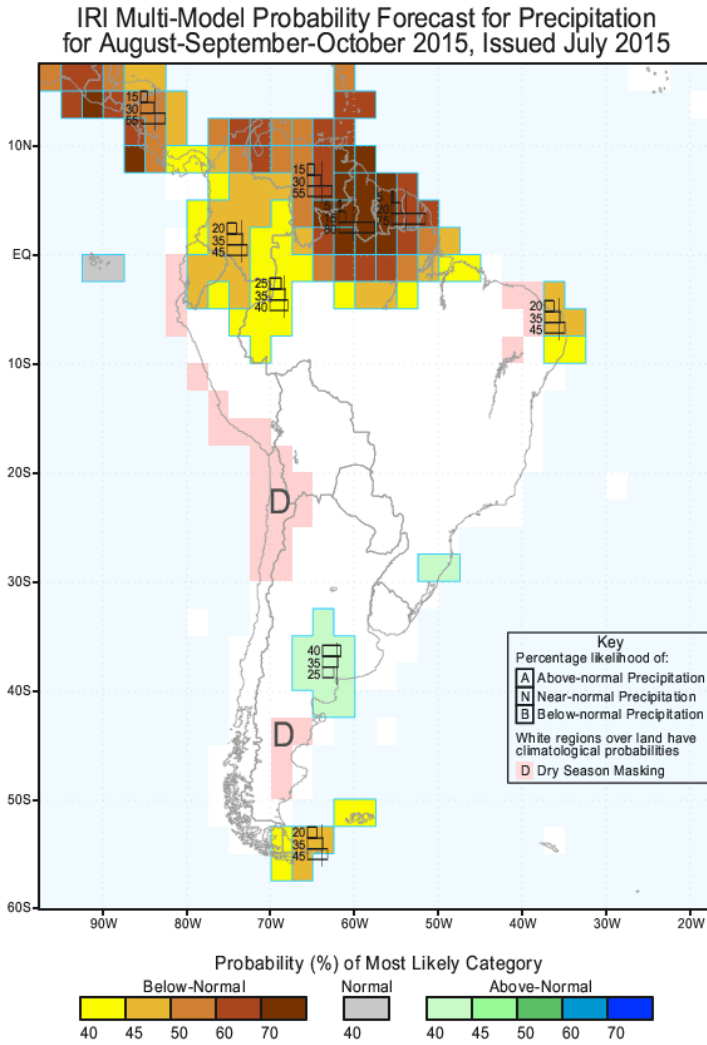


Jul-Sep 2015 IRI seasonal Forecast SSTA issued 0000 1 Jul 2015



PROGNÓSTICO IRI

<http://iri.columbia.edu/our-expertise/climate/forecasts/seasonal-forecasts/>



REGIÃO	PLANALTO		SERRA DO MAR		SERRA DA MANTIQUEIRA		GERAL	
PARÂMETRO	\bar{x}	σ	\bar{x}	σ	\bar{x}	σ	\bar{x}	σ
MES								
JANEIRO	220	34	278	87	262	47	248	68
FEVEREIRO	196	23	237	64	233	38	217	50
MARÇO	150	23	227	88	182	31	185	70
ABRIL	68	12	150	87	87	18	104	69
MAIO	54	10	103	53	54	14	75	43
JUNHO	43	10	71	35	41	8	55	28
JULHO	37	12	69	40	32	9	51	32
AGOSTO	35	7	75	43	42	13	53	35
SETEMBRO	64	12	111	65	63	12	84	50
OUTUBRO	130	15	173	84	147	27	150	60
NOVEMBRO	145	22	173	72	175	27	160	52
DEZEMBRO	209	29	228	78	258	37	221	58
ANUAL	1370	141	1920	754	1569	258	1620	572

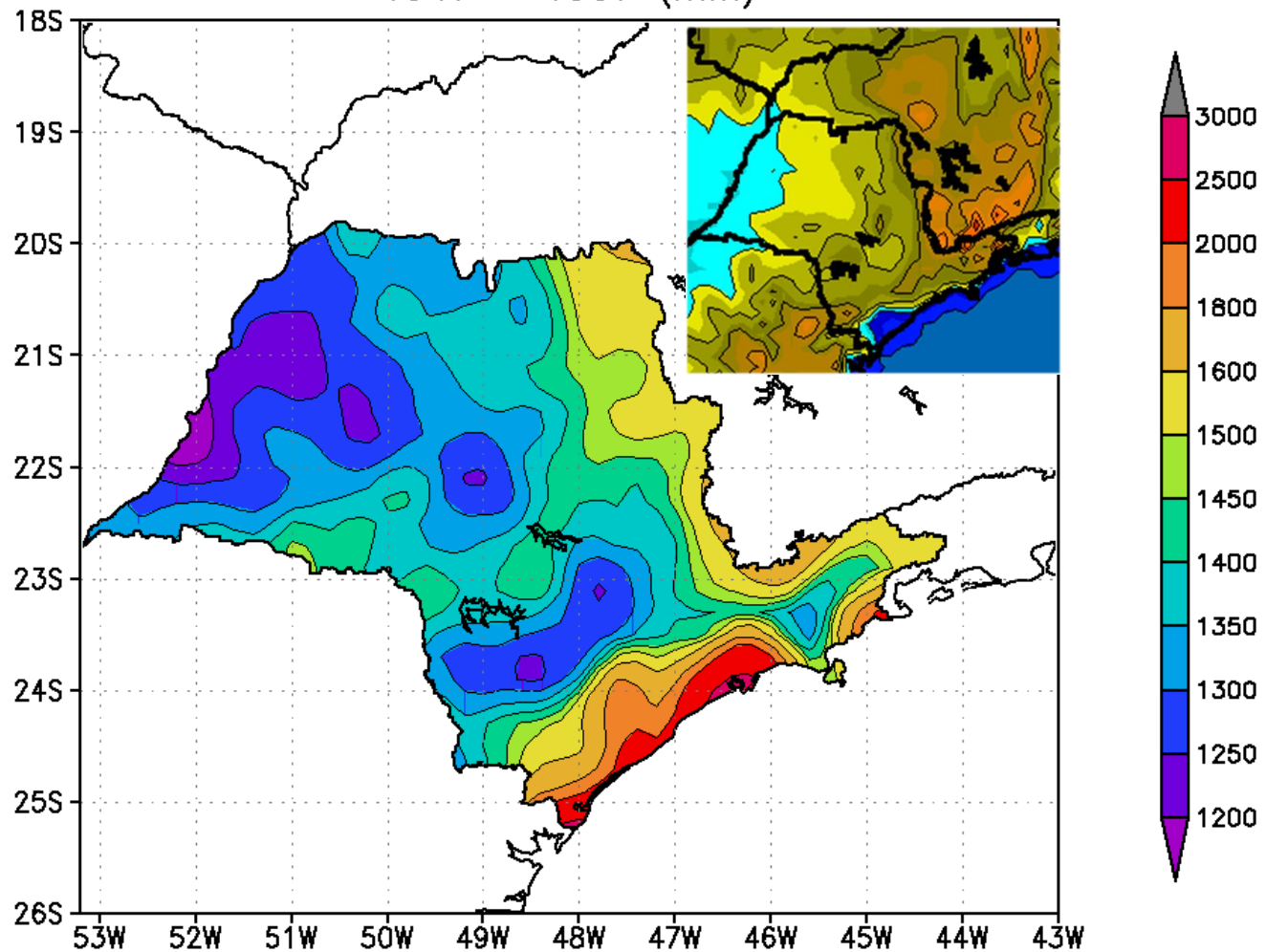
TABELA 3.1. - Precipitação média mensal nas áreas cobertas pelo radar meteorológico de Ponte Nova. \bar{x} é a precipitação média e σ é o desvio padrão dos totais médios mensais, em mm.

PRECIPITAÇÃO - SÃO PAULO

Prado, Pereira Filho e Hallak (2006)

PRECIPITAÇÃO ANNUAL SP (mm)

Precipitacao media climatologica
1947 - 1997 (mm)



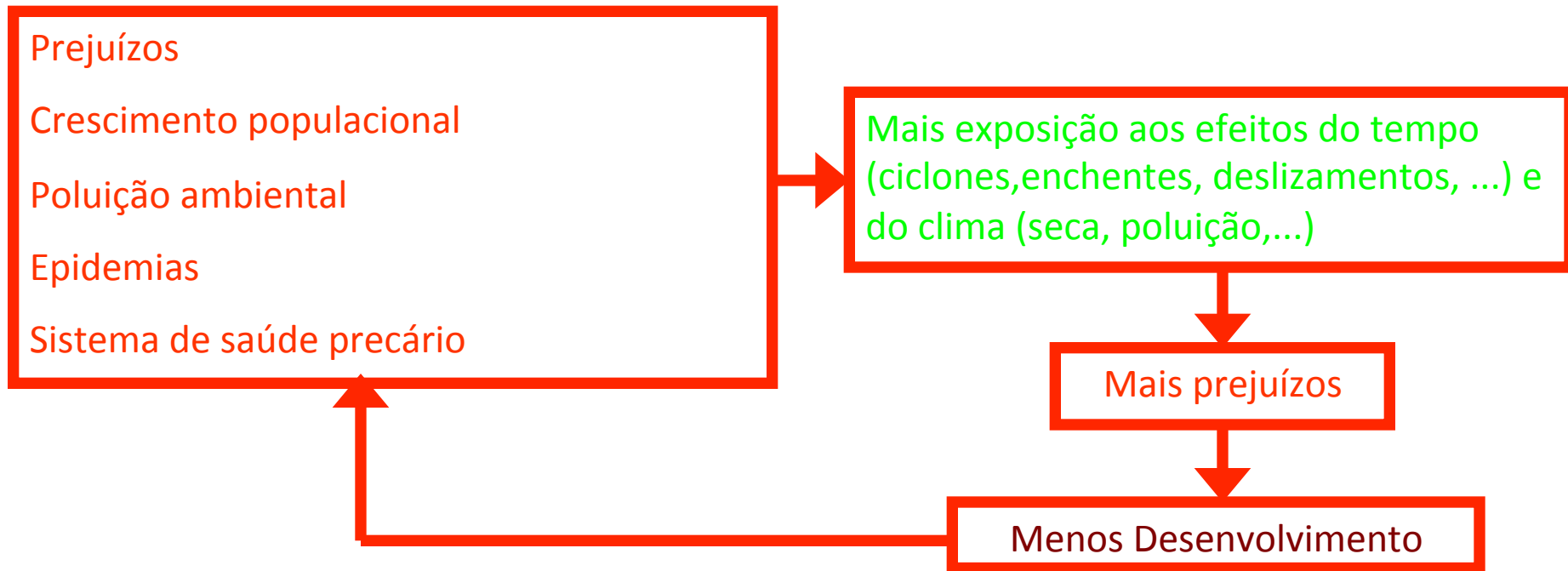
Frequência de anomalias de precipitação média espacial para eventos de El Niño, La Niña e neutros entre 1947 e 1997.

	Evento		
Anomalias	El Niño	La Niña	Neutro
Positivas	19,6%	9,8%	23,5%
Negativas	11,8%	11,8%	23,5%

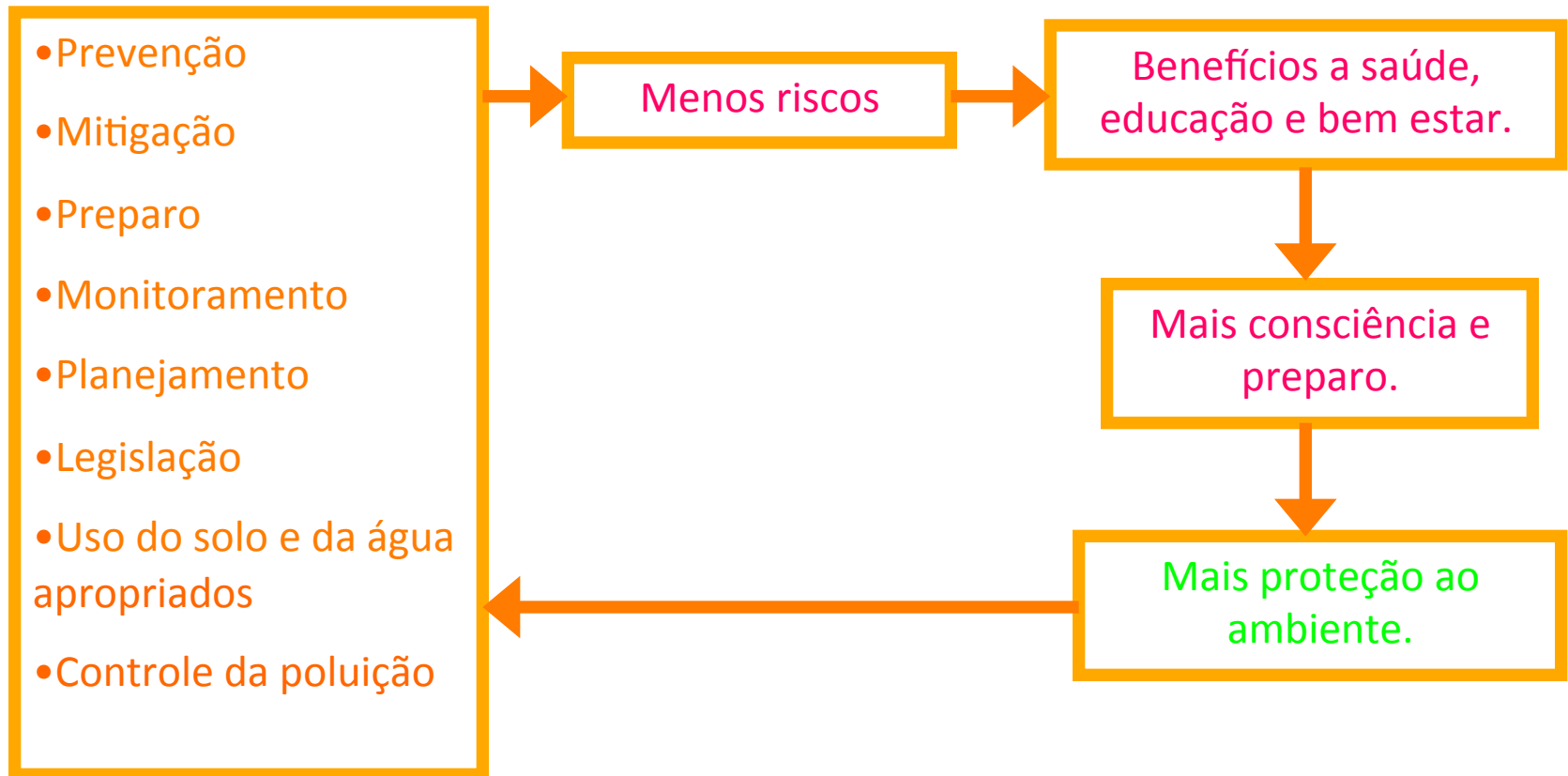
**METEOROLOGIA E
DESASTRES NATURAIS
CENÁRIO GLOBAL**

“As mudanças climáticas devem causar desastres naturais mais frequentes e mais graves”

RETRO-ALIMENTAÇÃO POSITIVA DOS PROBLEMAS



GESTÃO AMBIENTAL – FATOR PARA O DESENVOLVIMENTO SUSTENTÁVEL



Evolução do Consumo na RMSP e Projeção para 20 anos

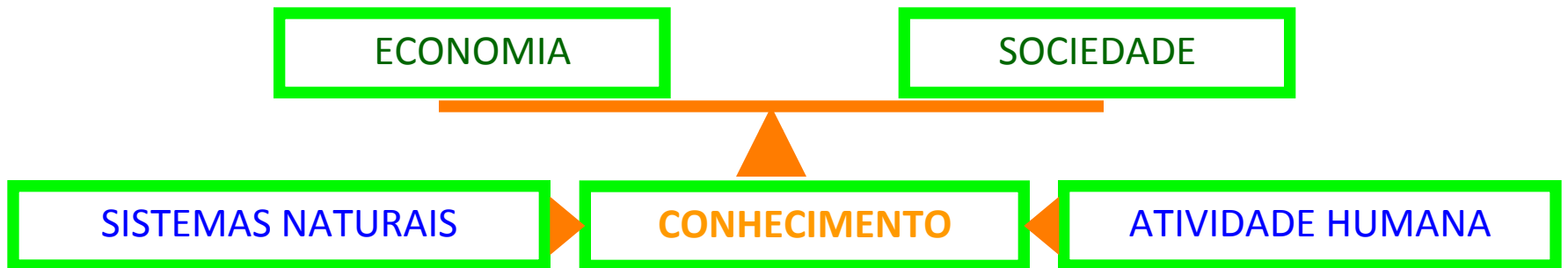
Ano	CHA (m ³ /ano)	PROD (10 ⁹ m ³ /ano)	CT (10 ⁹ m ³ /ano)	CT/PROD	HAB (mi)
2003	52,3	1.96	0.93	0.46	18.5
2013	59,9	2.18	1.21	0.55	20.1
2033	78,0	3.27	1.80	0.55 (1)	22.3
2033	78,0	2,33	1.80	0.73 (2)	22.3

Soluções :

Novas fontes para suprir demanda de + um Cantareira (cenário 1)

Aumentar a razão consumo/produção (cenário 2)

CIÊNCIA DA SUSTENTABILIDADE



OBSERVAÇÃO DA TERRA E DA ATMOSFERA

(Essenciais para a sustentabilidade)



FERRAMENTAS DE PREVISÃO

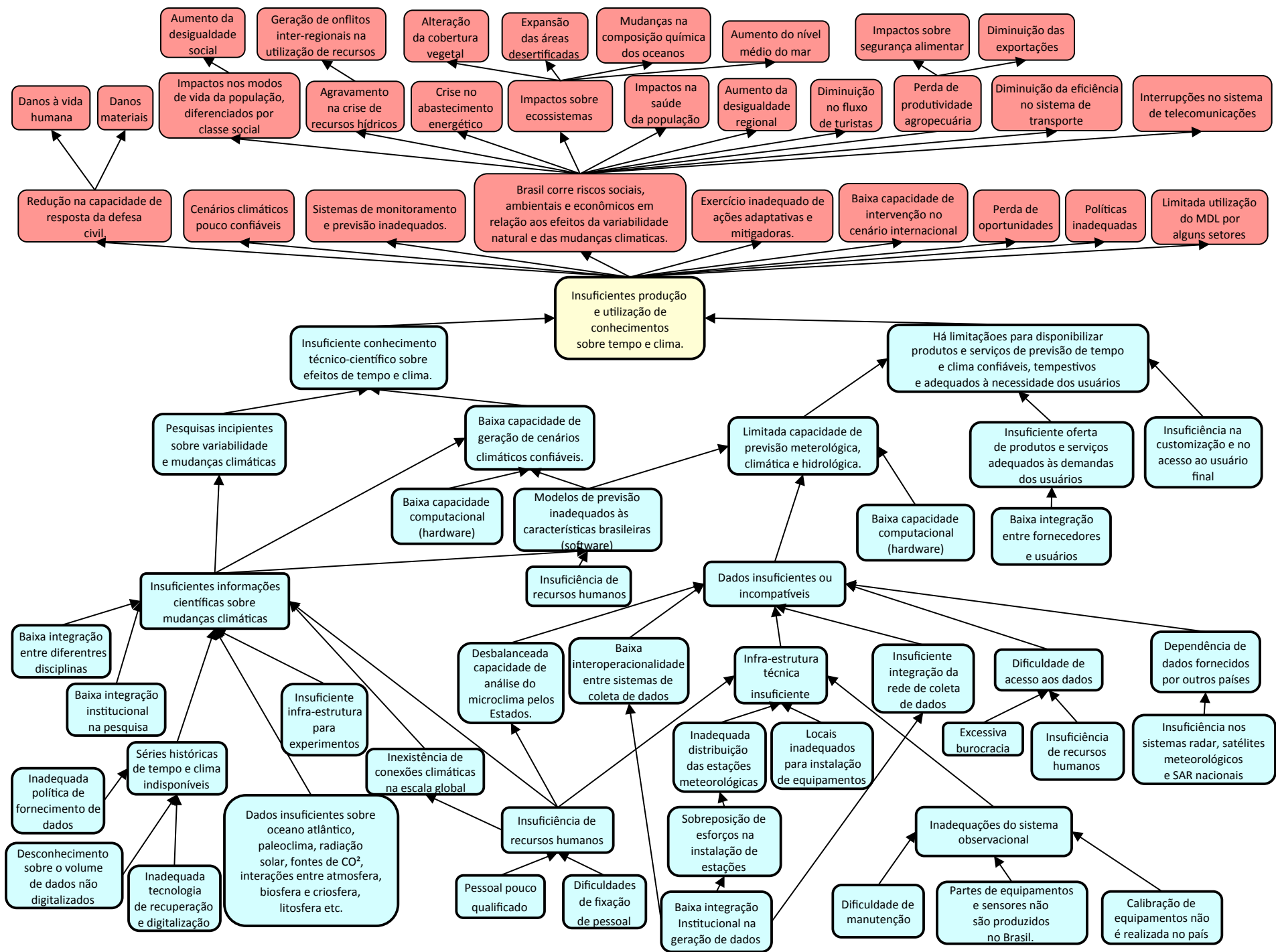
SISTEMAS DE ALERTA

ENTENDIMENTO DO TEMPO E DO CLIMA

INFORMAÇÃO



REDUÇÃO DE RISCOS



MUITO OBRIGADO!

apereira@model.iag.usp.br