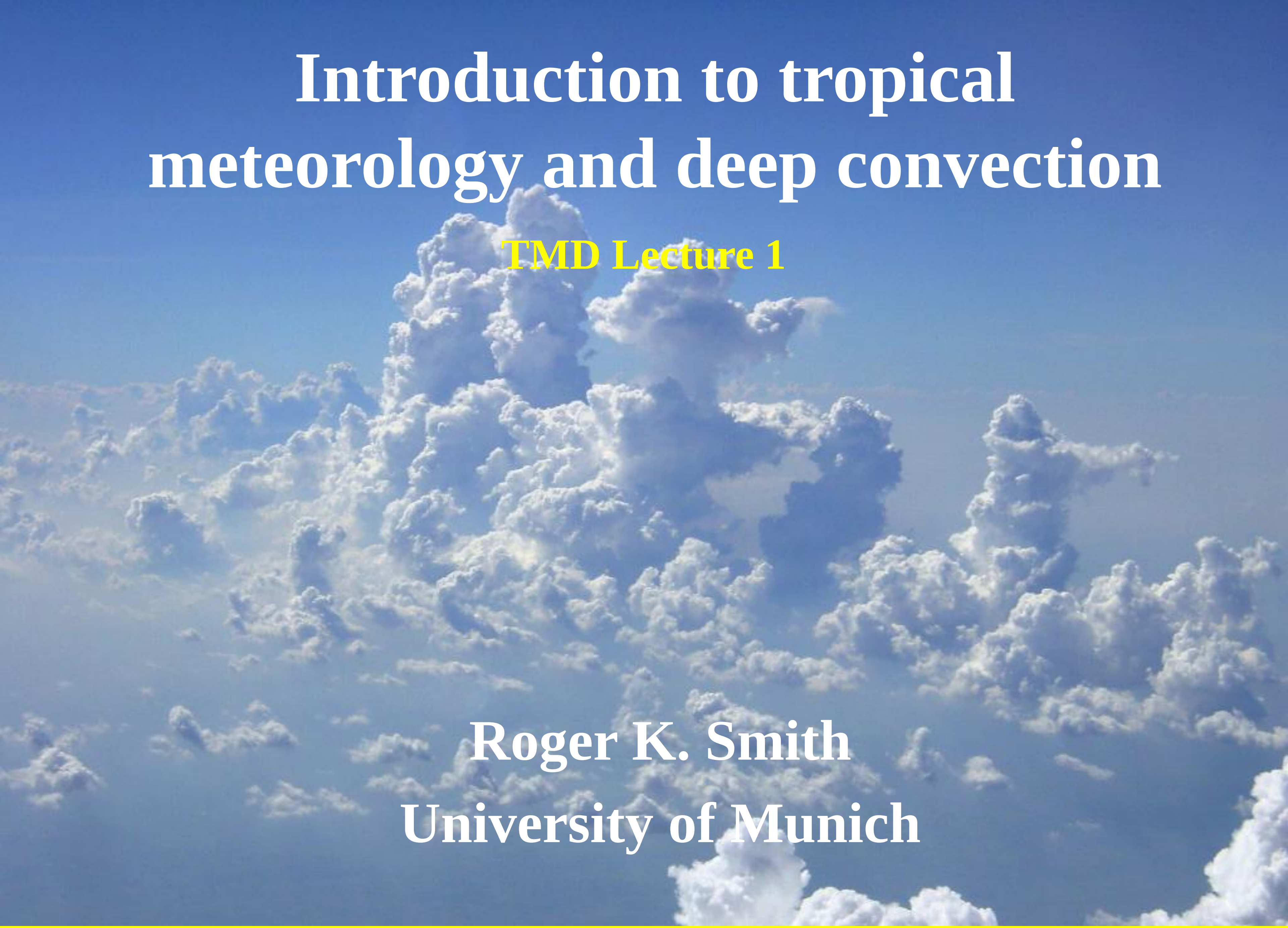

Introduction to tropical meteorology and deep convection

TMD Lecture 1

Roger K. Smith

University of Munich

http://www.meteo.physik.uni-muenchen.de/~roger/Lectures/TropicalMetweb/TropicalMeteorology.html

Topics

- A satpix tour of the tropics
- The zonal mean circulation (Hadley circulation), Inter-Tropical Convergence Zone (ITCZ)
- Field experiments
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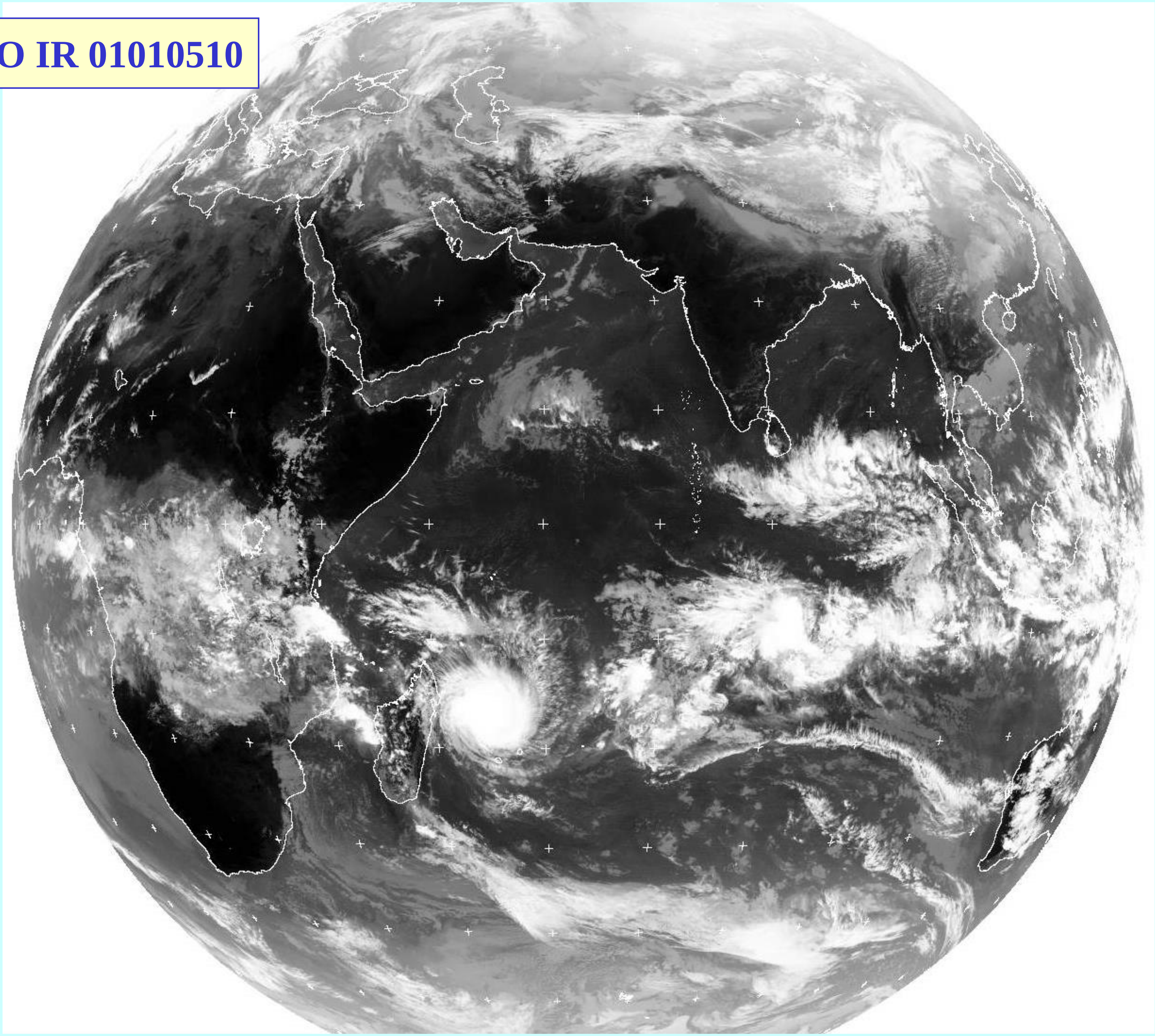
- Concluding remarks

INDO IR 01010510



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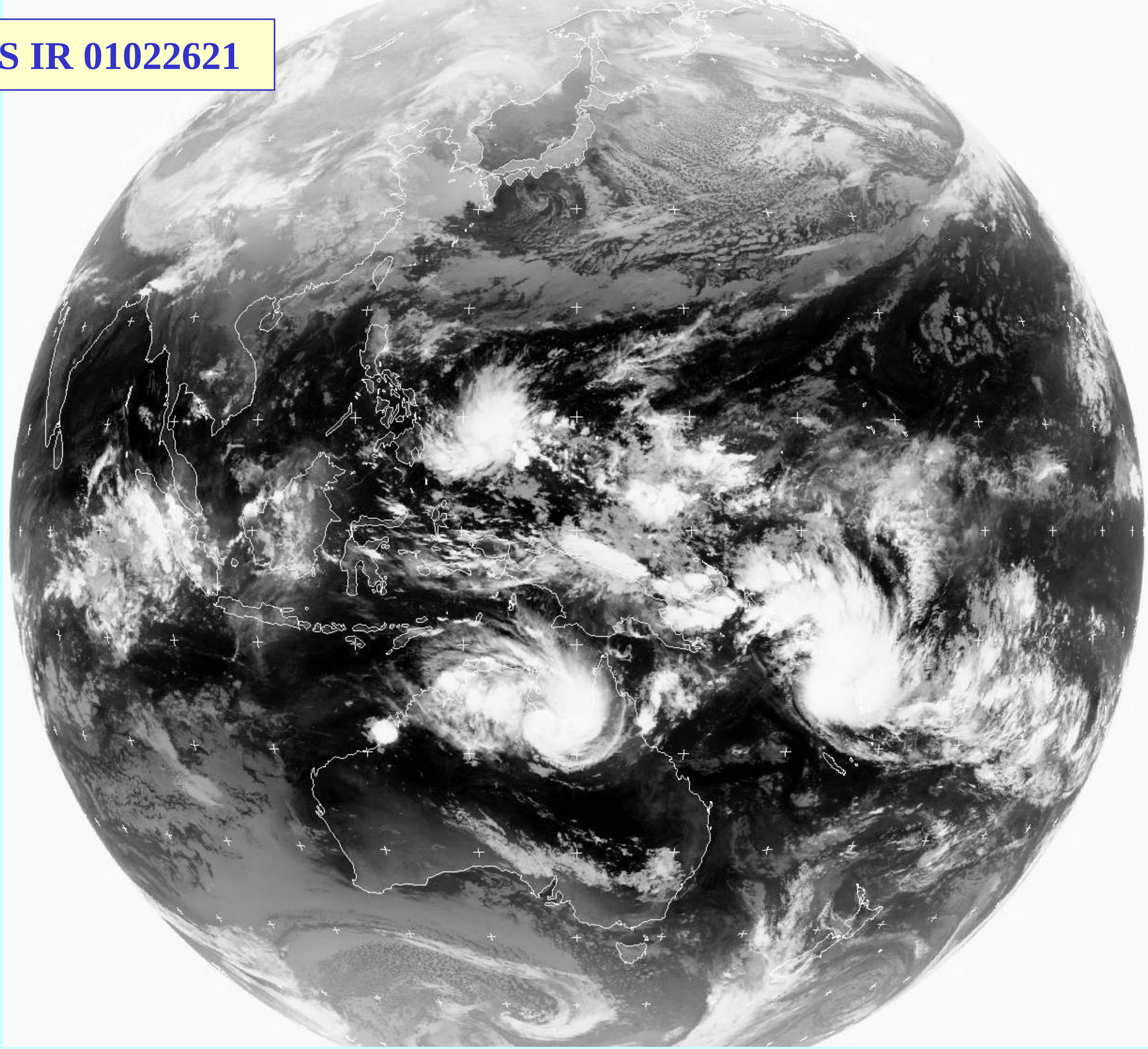
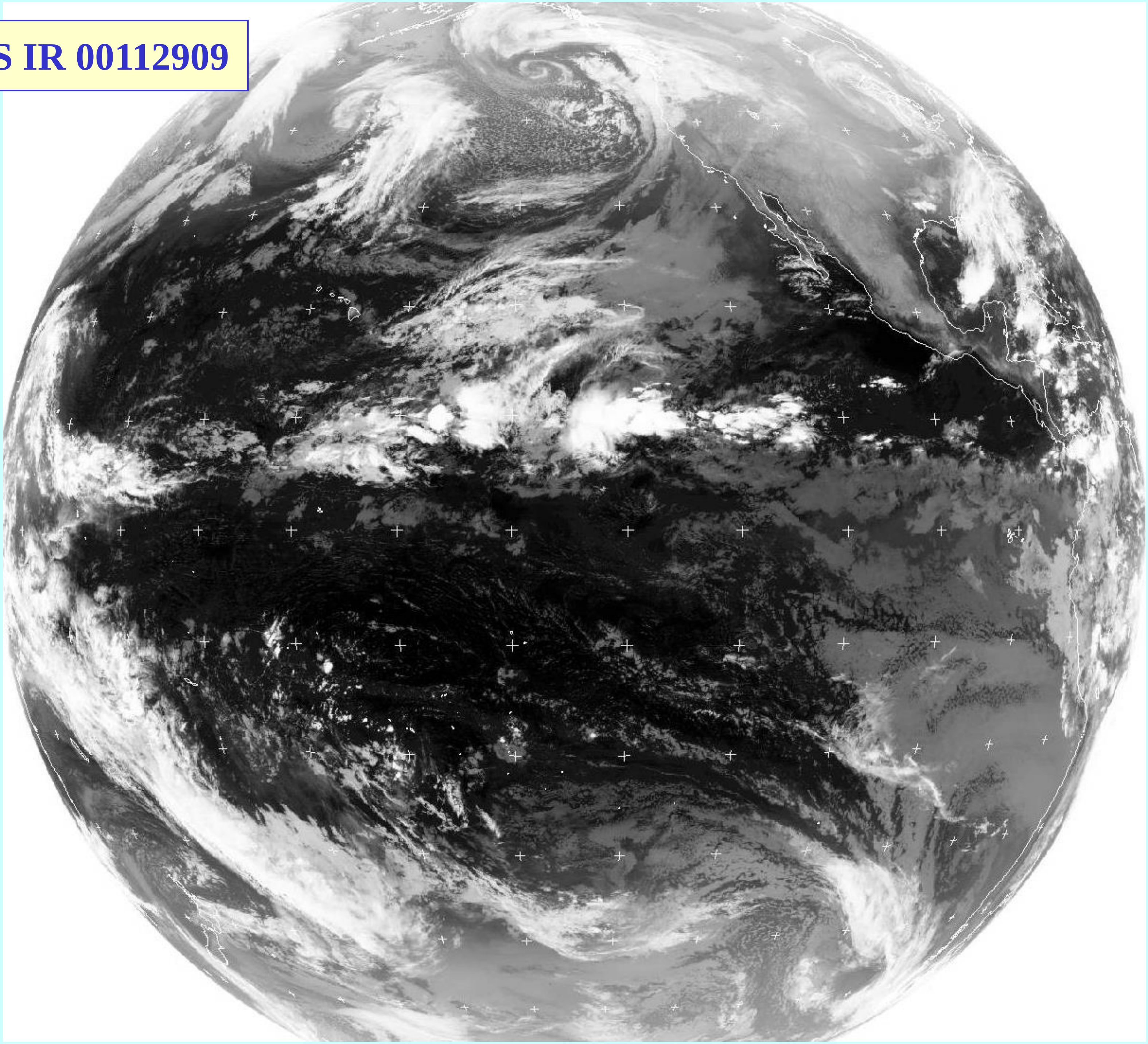
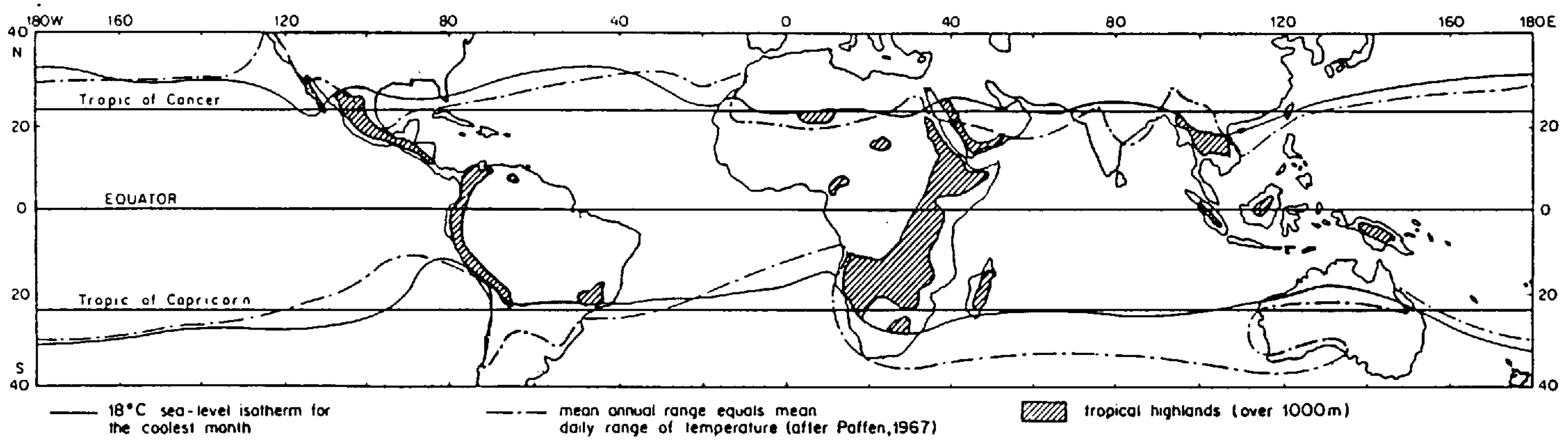


GOES IR 00112909



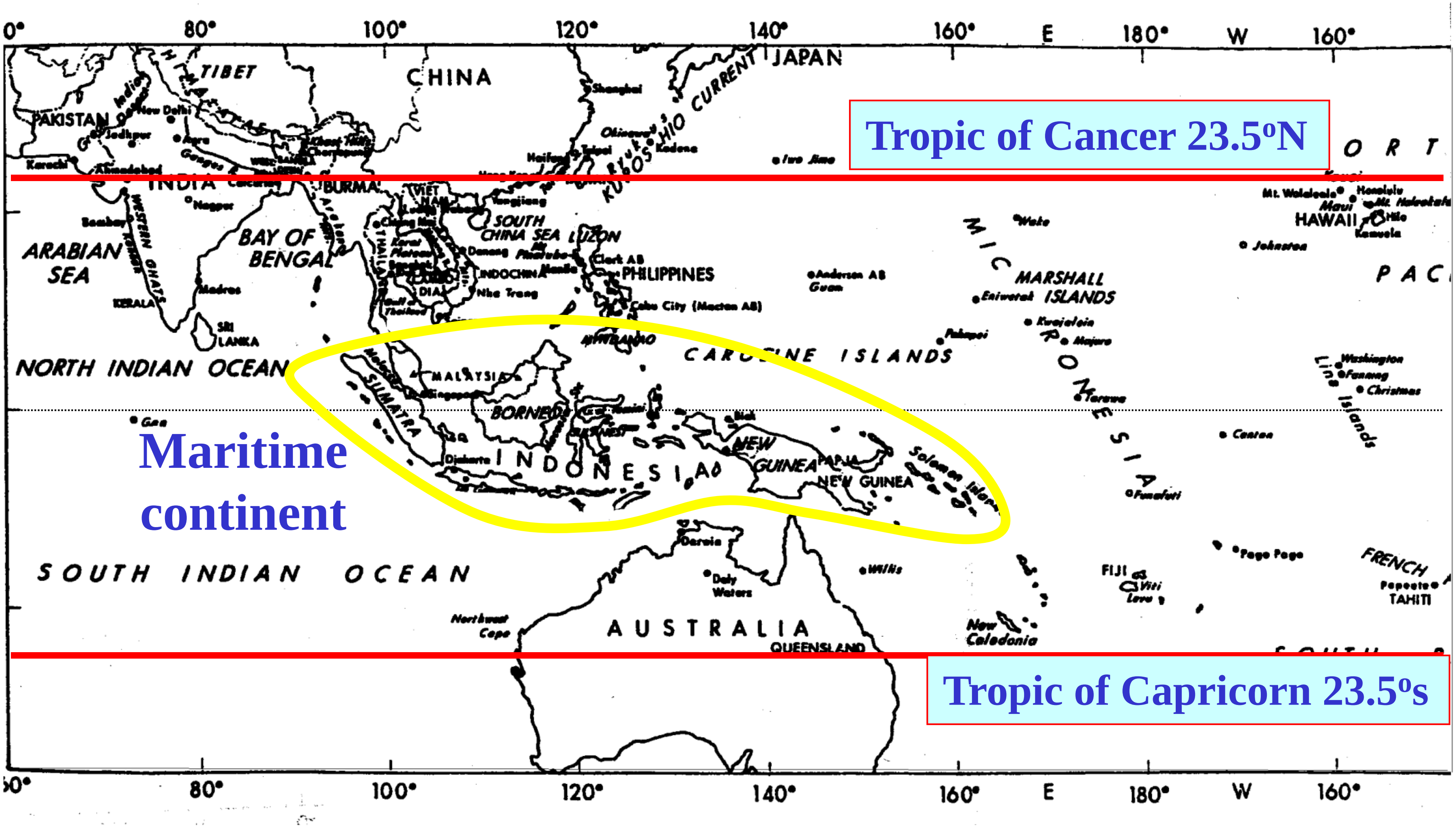
EUMETSAT Movie



Principal land and ocean areas between 40°S and 40°N. The shaded areas show tropical highlands (over 1000 m).

From Nieuwolt (1977)

How does one define the tropics?



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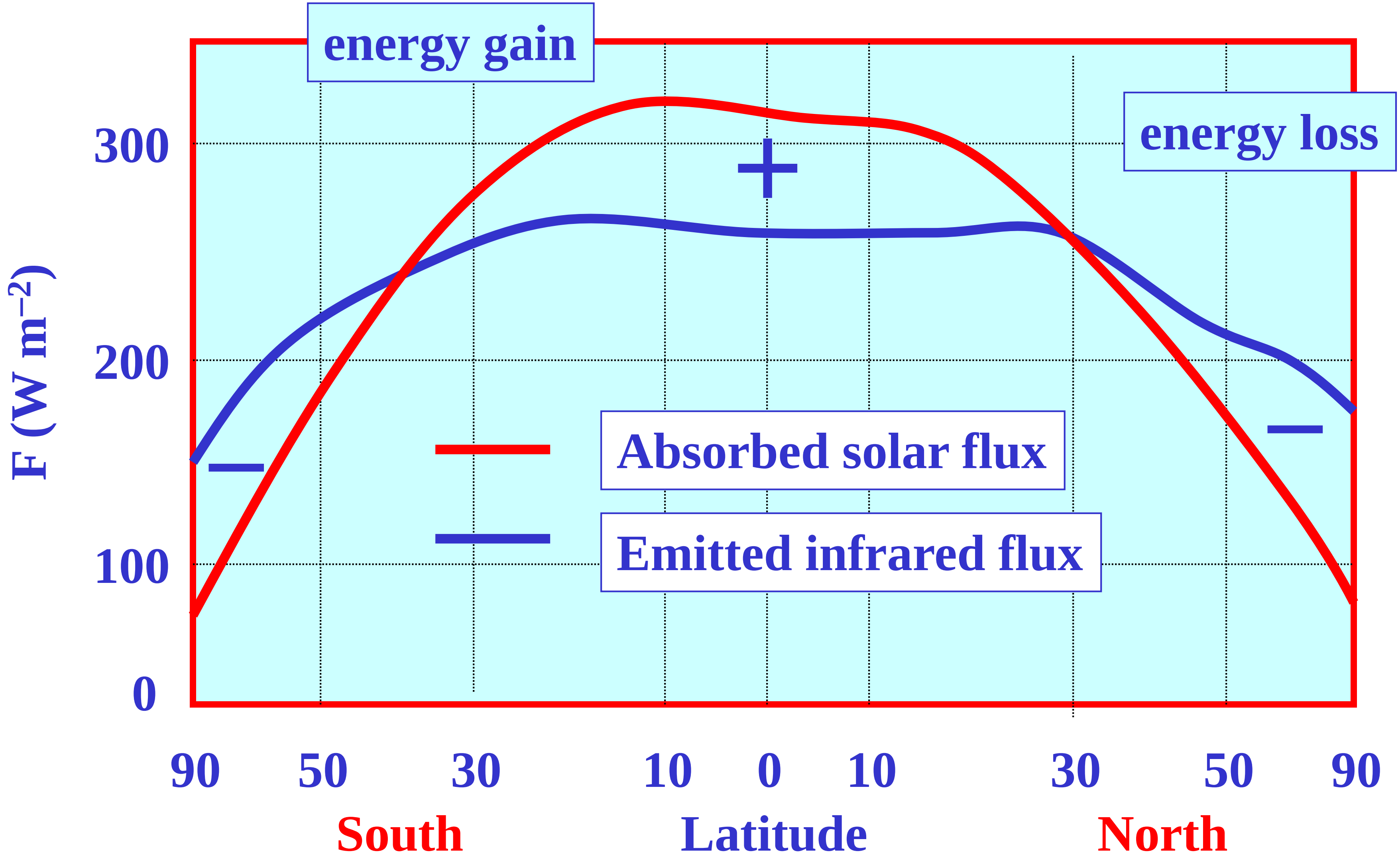
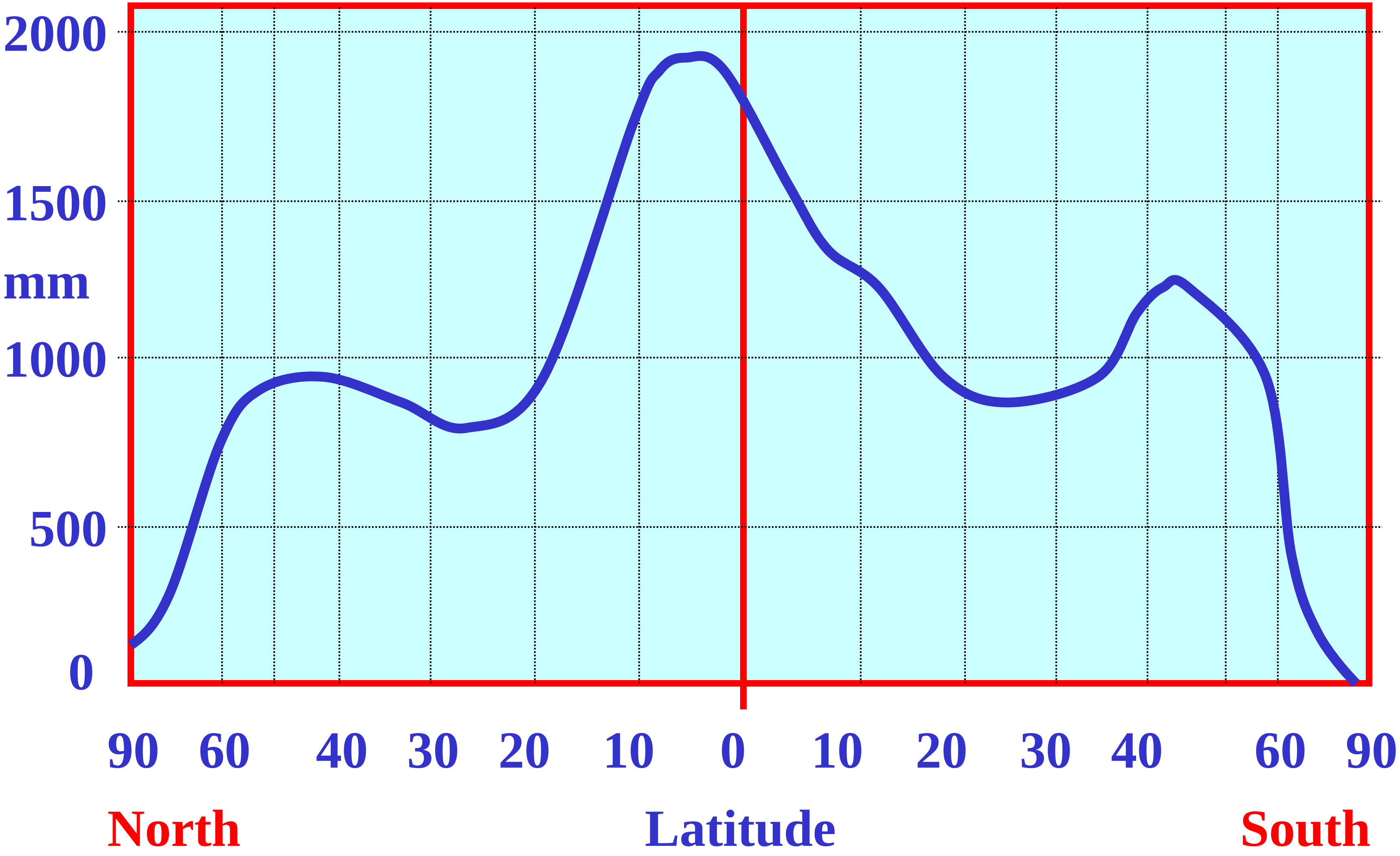


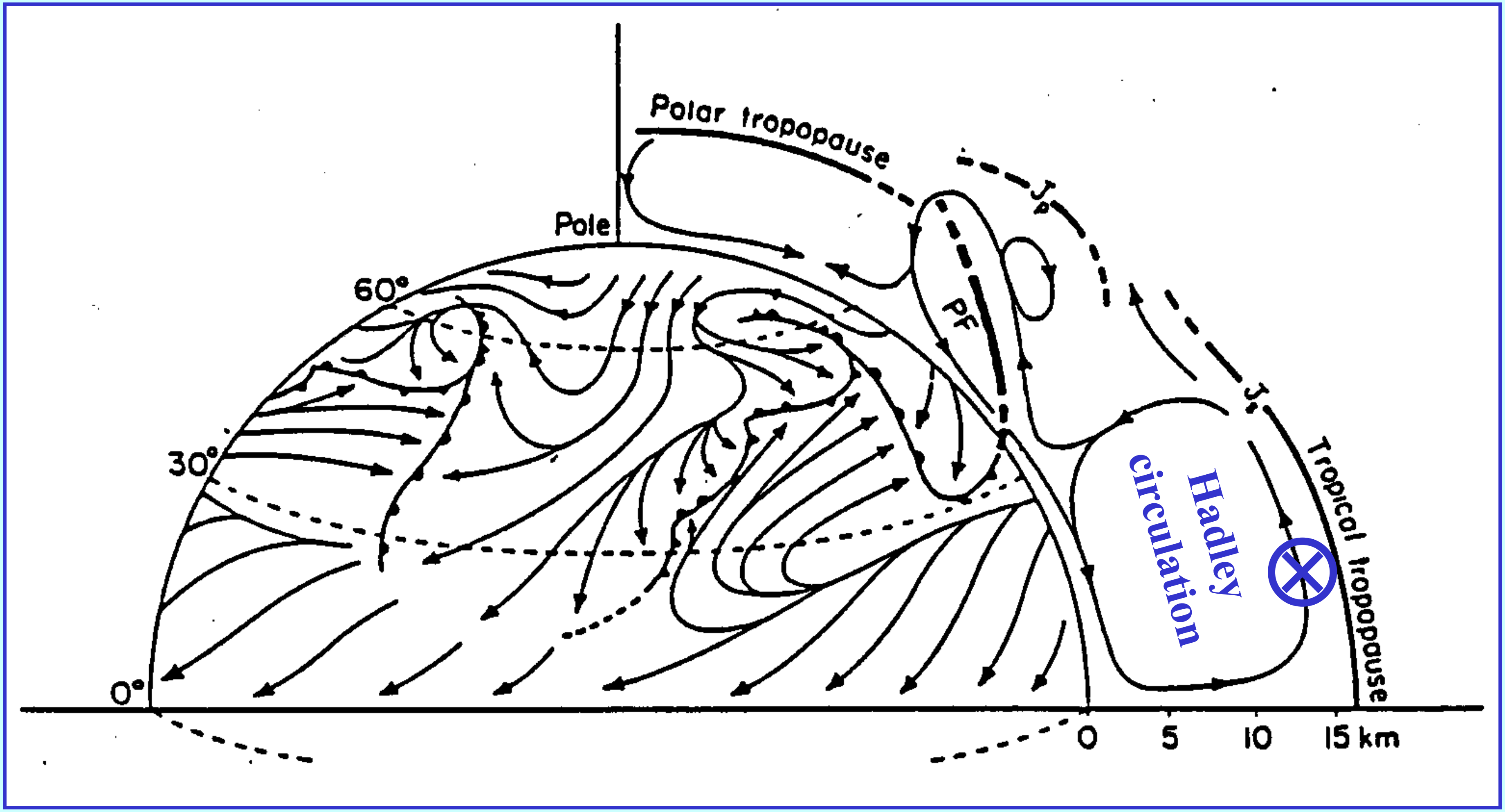
Zonally averaged components of the absorbed solar flux and emitted thermal infrared flux at the top of the atmosphere.

(after Vonder Haar and Suomi, 1971, with modifications)



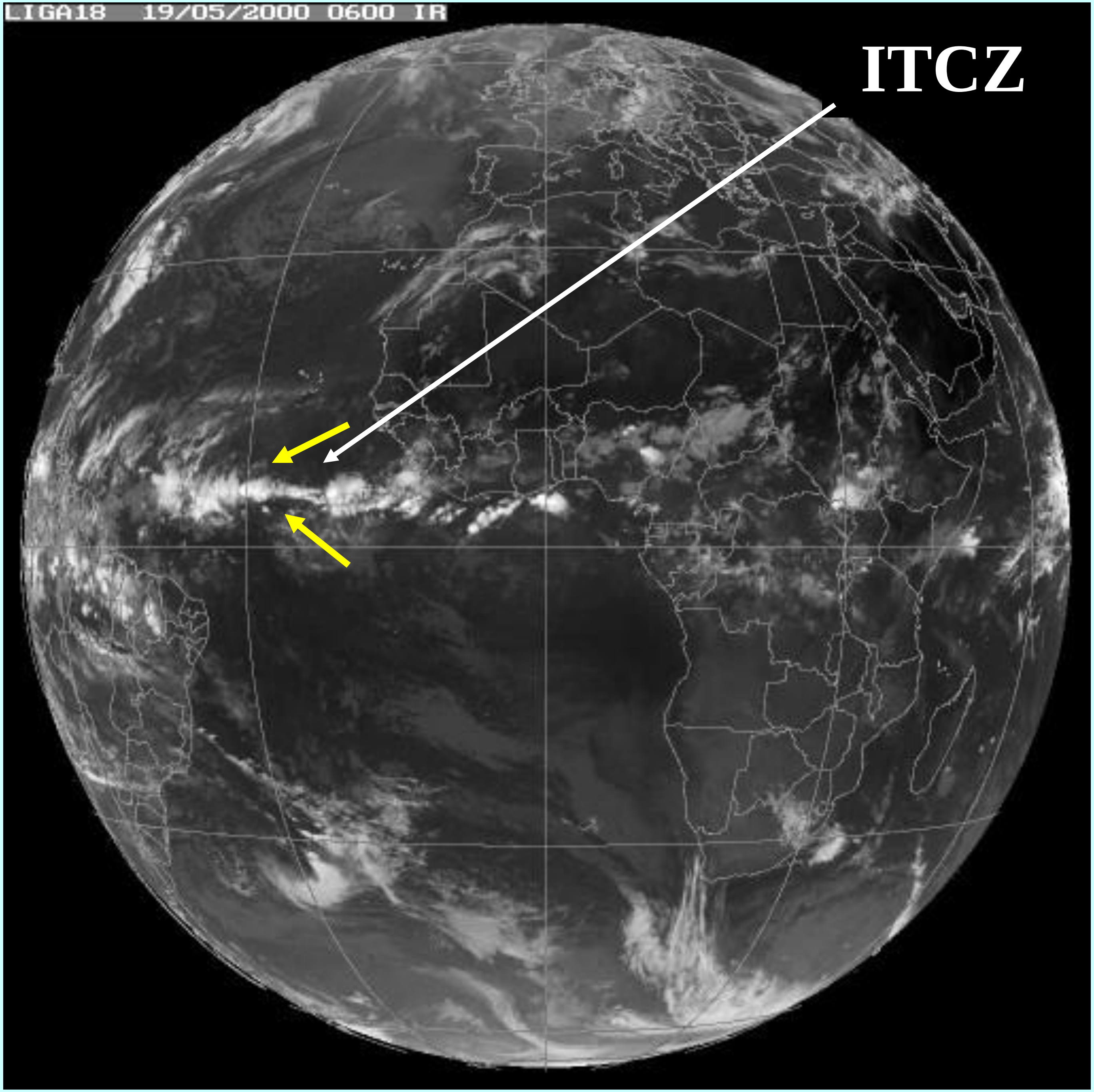
Mean annual precipitation as a function of latitude.

(after Sellers, 1965)

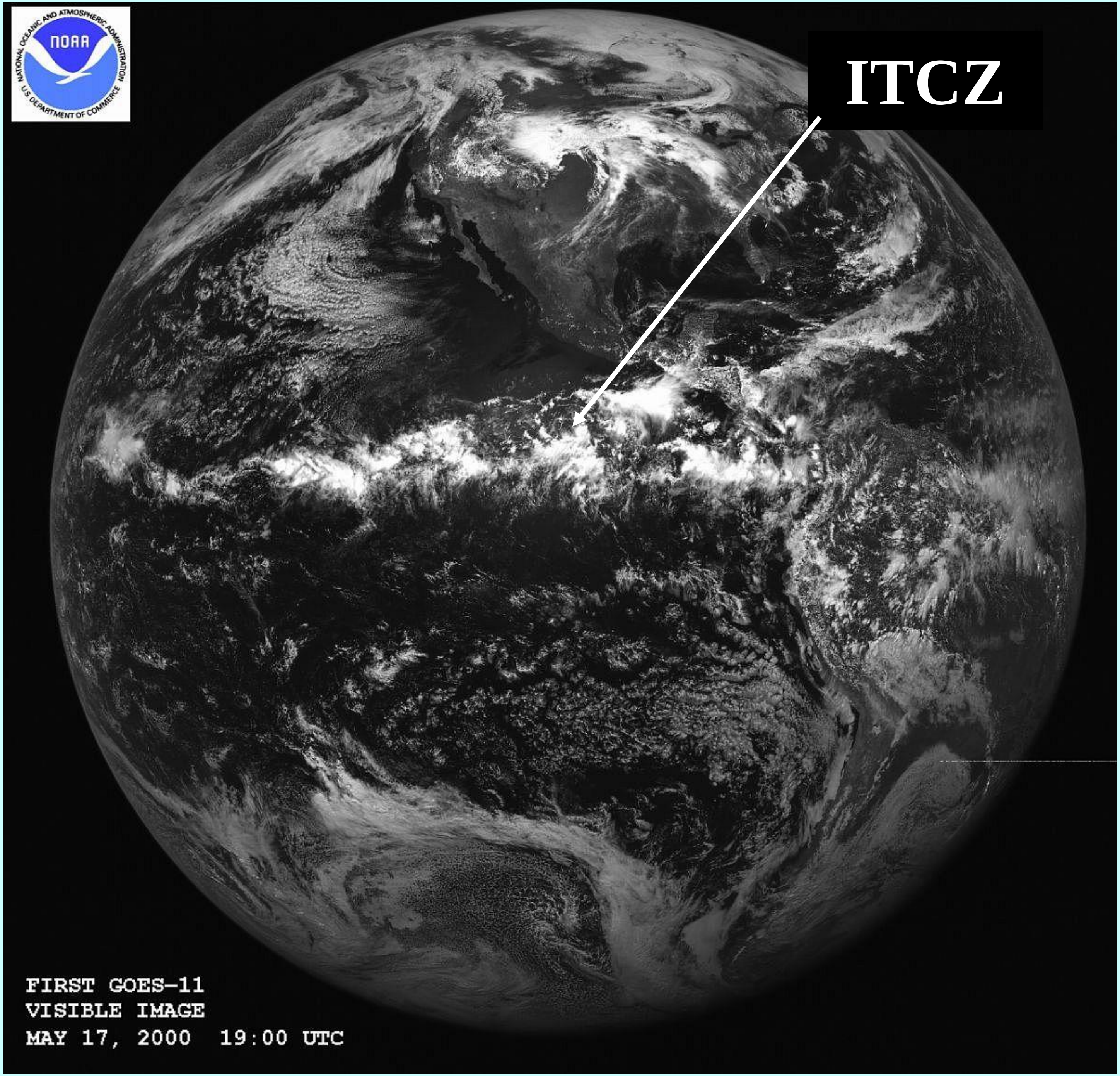


The mean meridional circulation and main surface wind regimes.

after Defant, 1958



ITCZ



ITCZ

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Field Experiments in the Tropics

- Global Atmospheric Research Programme (GARP) Atlantic Tropical Experiment (GATE) July 1974
- The MONsoon EXperiment (WMONEX December 1978, SMONEX May – August, 1979)
- Australian Monsoon EXperiment & Equatorial Mesoscale EXperiment (AMEX, EMEX) January – February 1987
- Tropical Oceans Global Atmosphere Couple Ocean Atmosphere Response Experiment (TOGA COARE) November 1992 – February 1993
- DYNAMO (Dynamics of the MJO)/CINDY(Cooperative Indian Ocean Experiment on Intraseasonal Variability in Year 2011)

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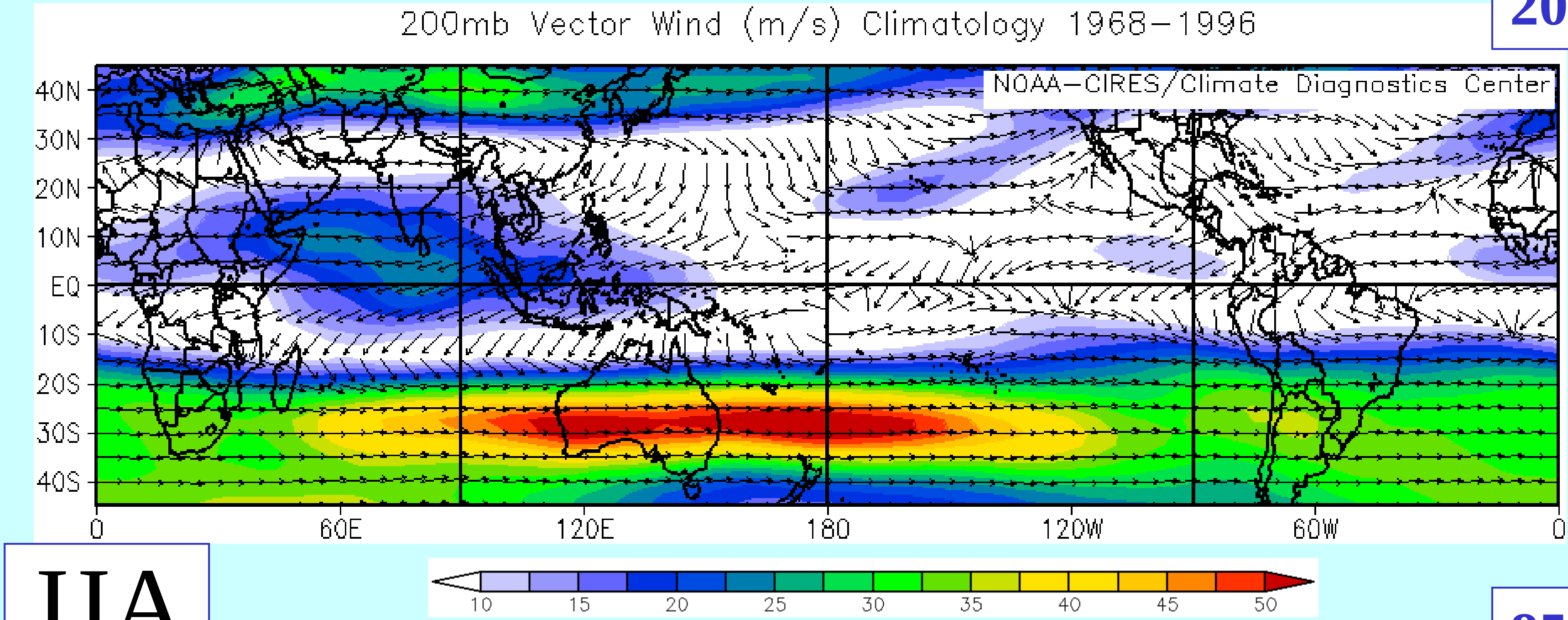
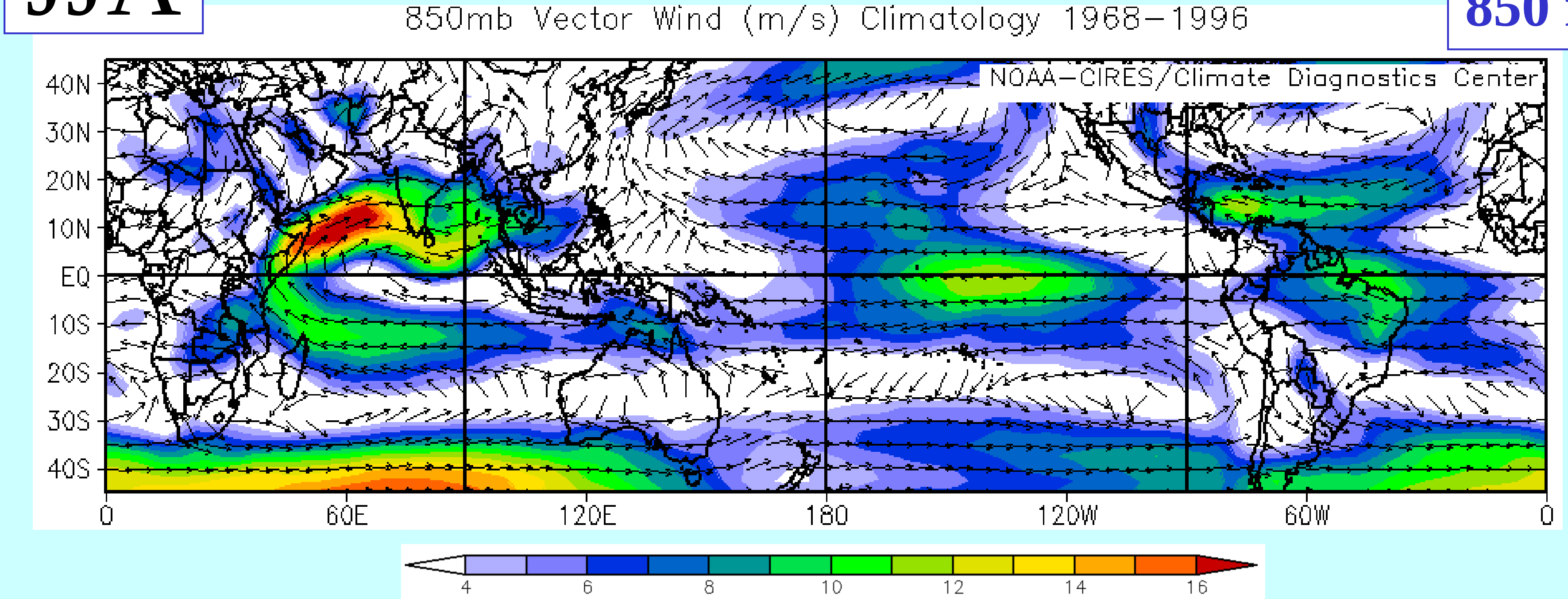
200 mb

JJA



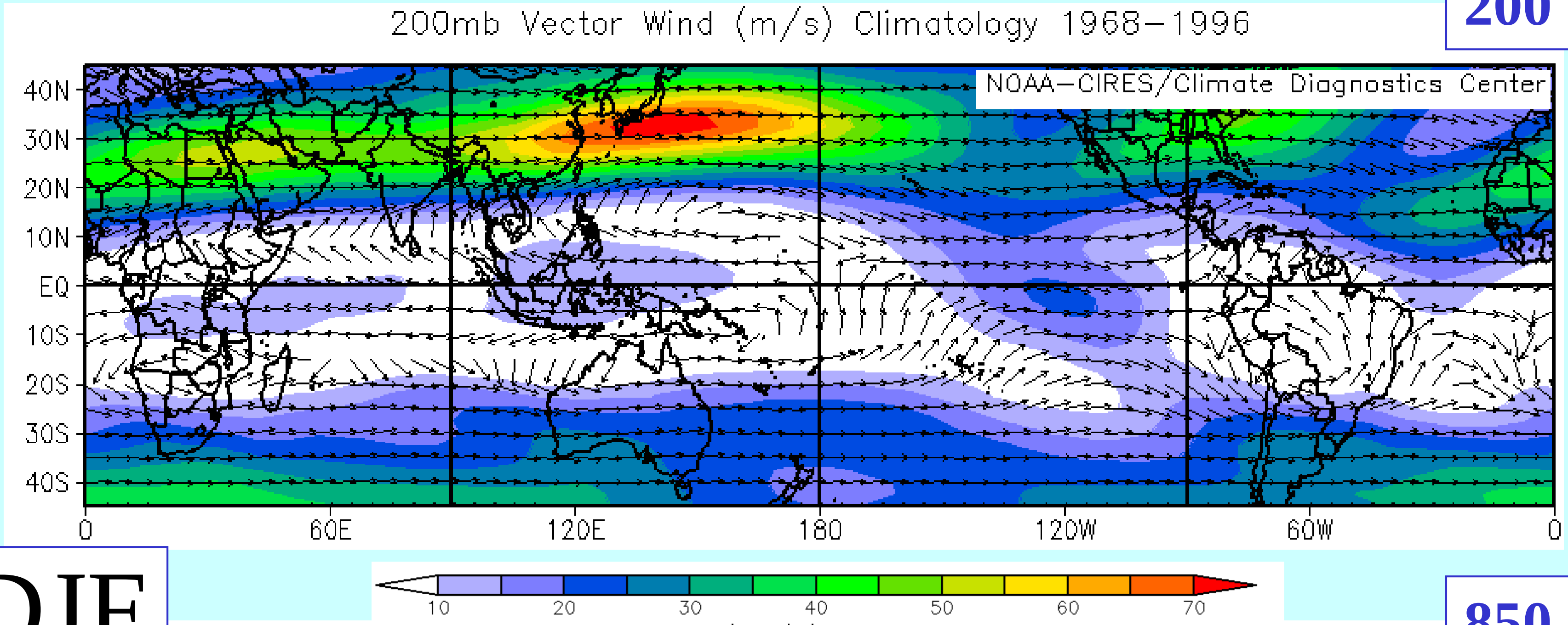
200mb Vector Wind (m/s) Climatology 1968–1996

850 mb



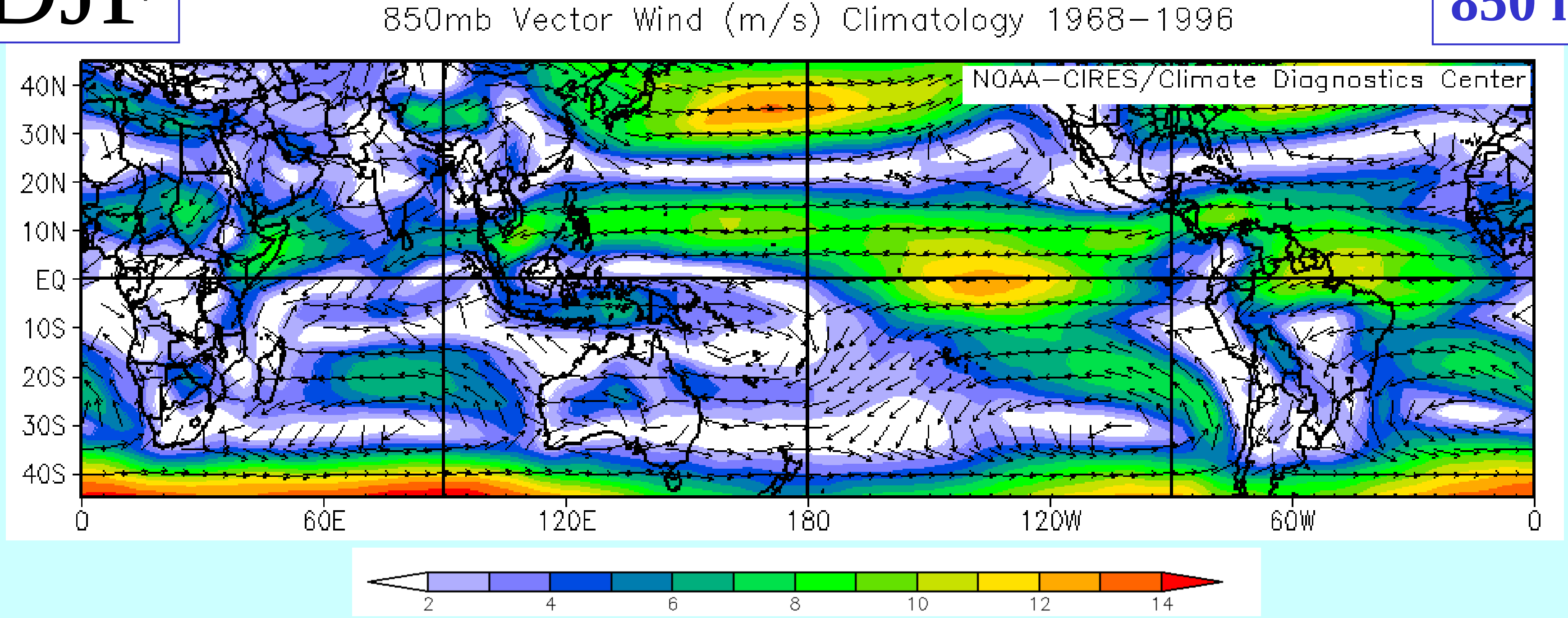
850mb Vector Wind (m/s) Climatology 1968–1996

200 mb



DJF

850 mb



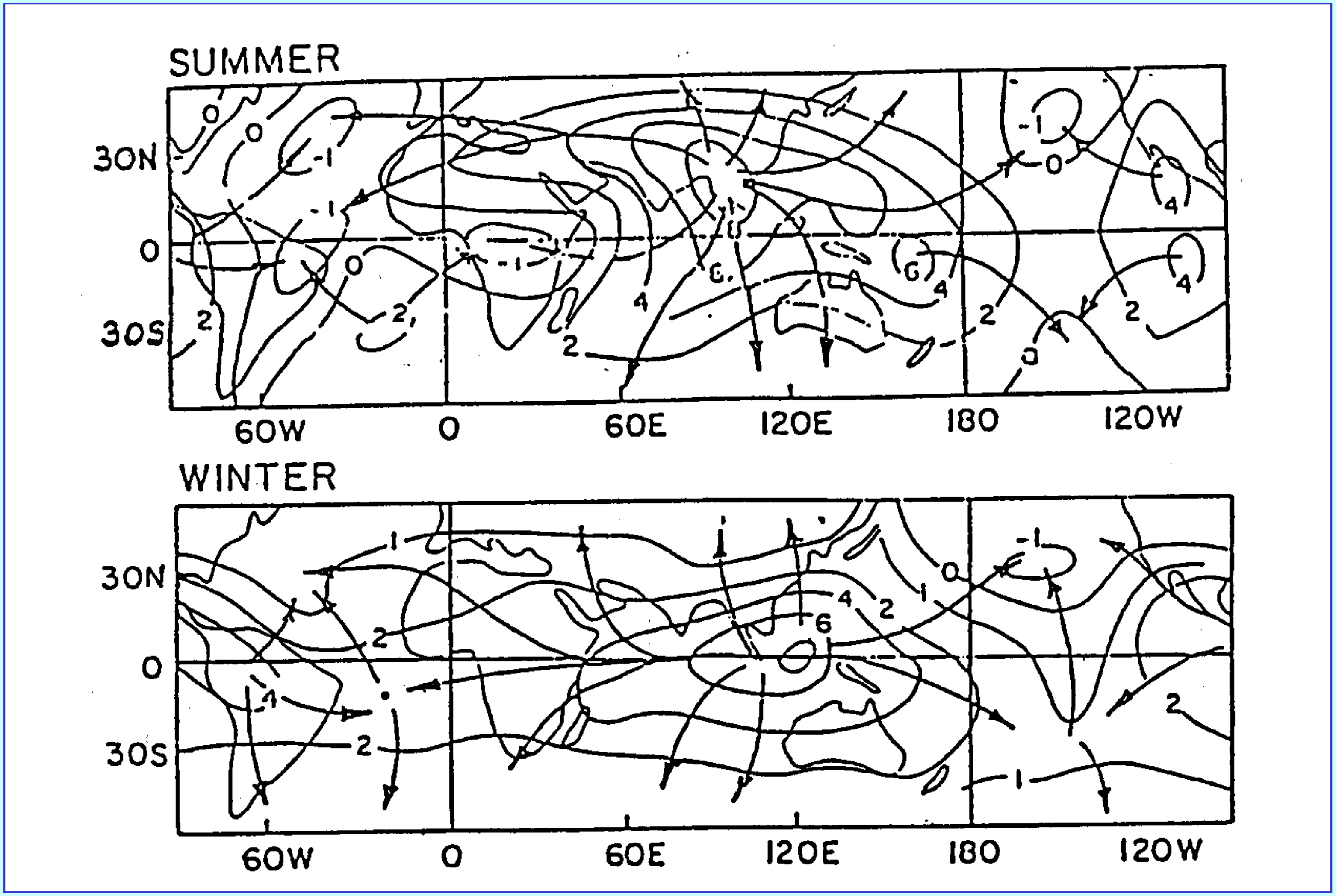
Velocity potential

We can separate the three-dimensional velocity field into a rotational part and a divergent part (see e.g. Holton, 1972, Appendix C.)

$$\mathbf{V} = \underbrace{\mathbf{k} \wedge \nabla \psi}_{\text{rotational nondivergent}} + \underbrace{\nabla \chi}_{\text{irrotational divergent}}$$

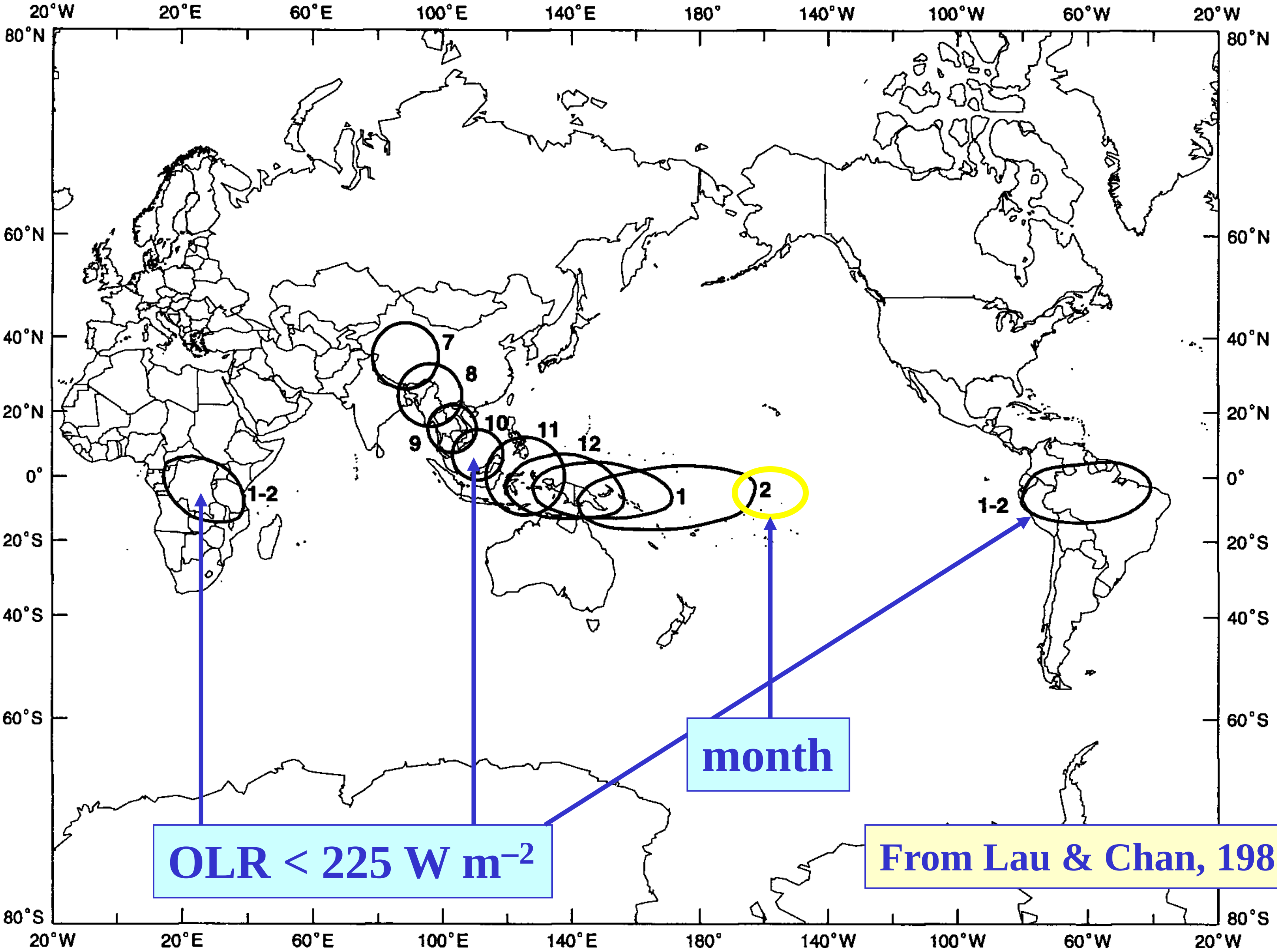
$$\nabla \wedge (\mathbf{k} \wedge \nabla \psi) = \mathbf{k} \nabla^2 \psi \qquad \nabla \wedge (\nabla \chi) = \mathbf{0}$$

$$\nabla \cdot (\mathbf{k} \wedge \nabla \psi) = 0 \qquad \nabla \cdot (\nabla \chi) = \nabla^2 \chi$$



Upper tropospheric (200 mb) mean seasonal velocity potential indicating the divergent part of the mean seasonal wind which is proportional to χ.

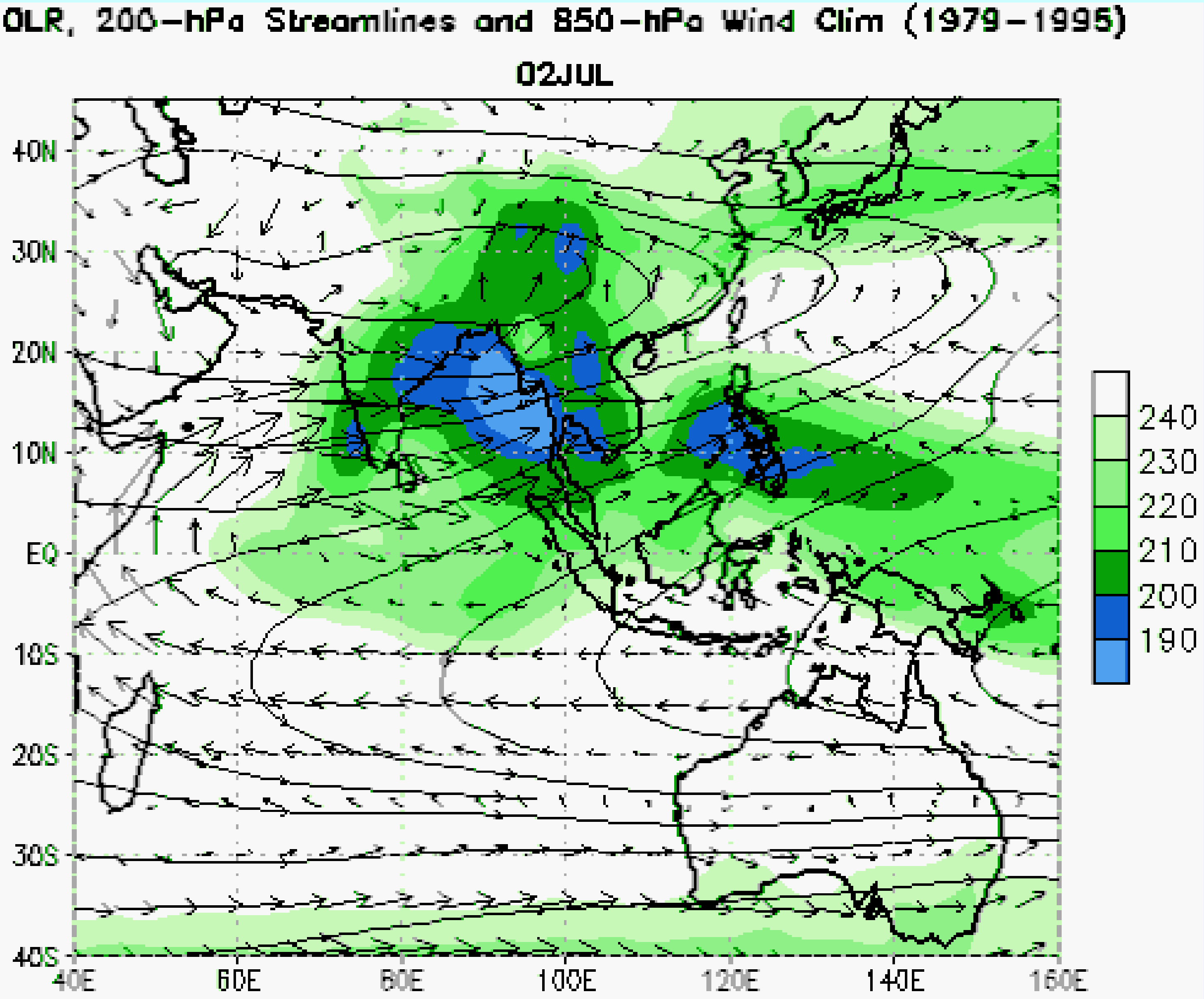
(Adapted from Krishnamurti *et al*., 1973).



OLR < 225 W m^{-2}

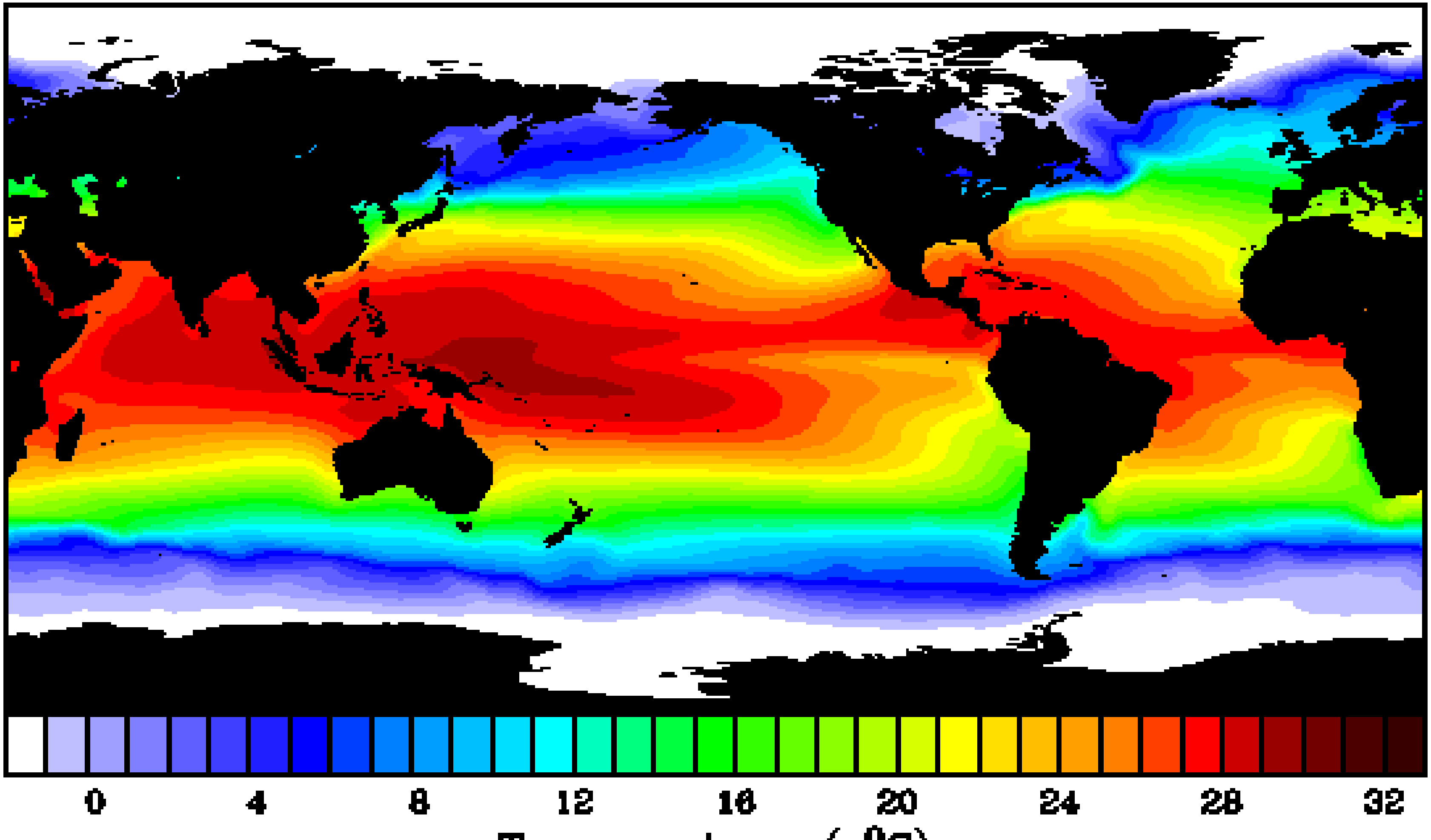
month

From Lau & Chan, 1983

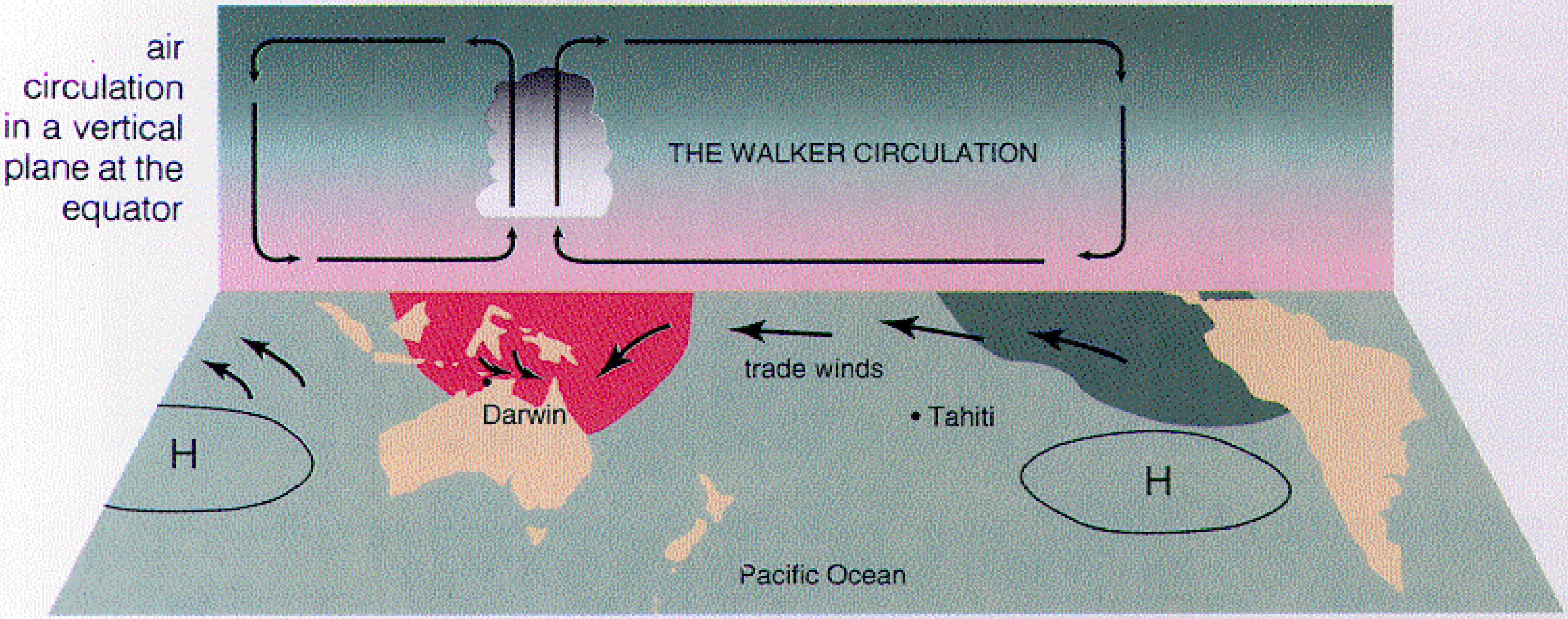


Data Sources: OLR – NESDIS/ORA, Winds – NCEP CDAS/ Reanalysis

ANNUAL MEAN
GLOBAL SEA SURFACE TEMPERATURES



Typical Walker circulation pattern



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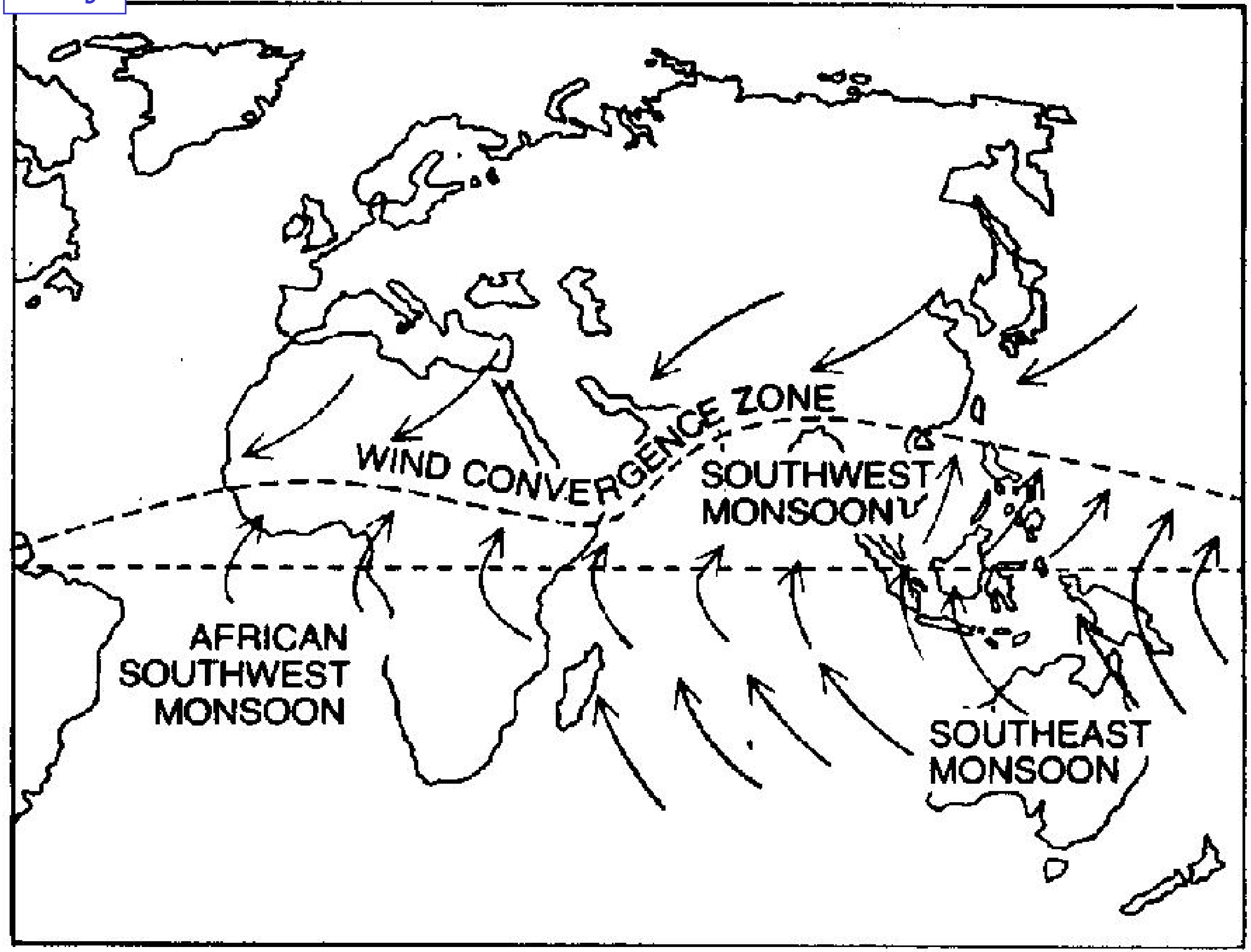
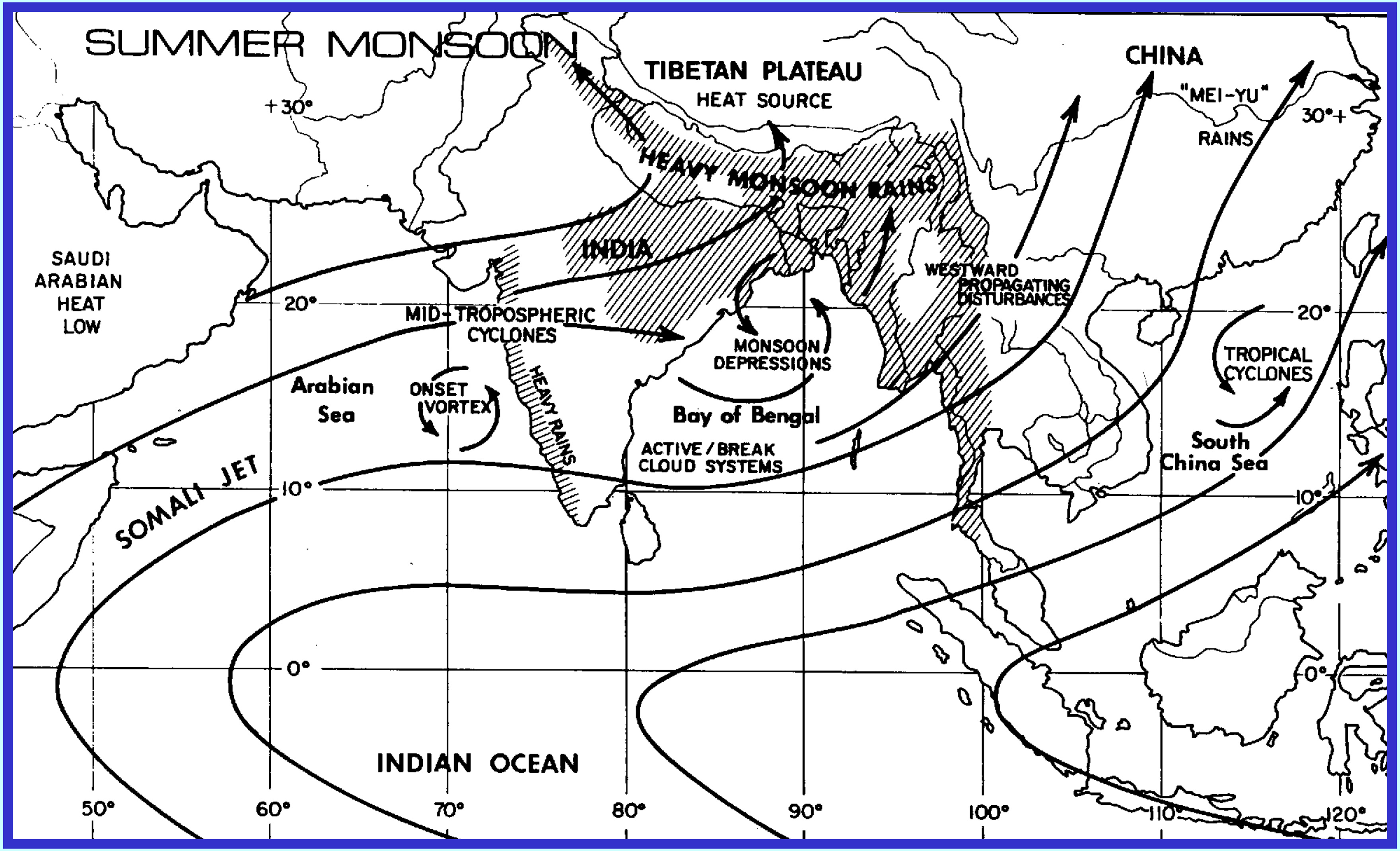
Monsoons

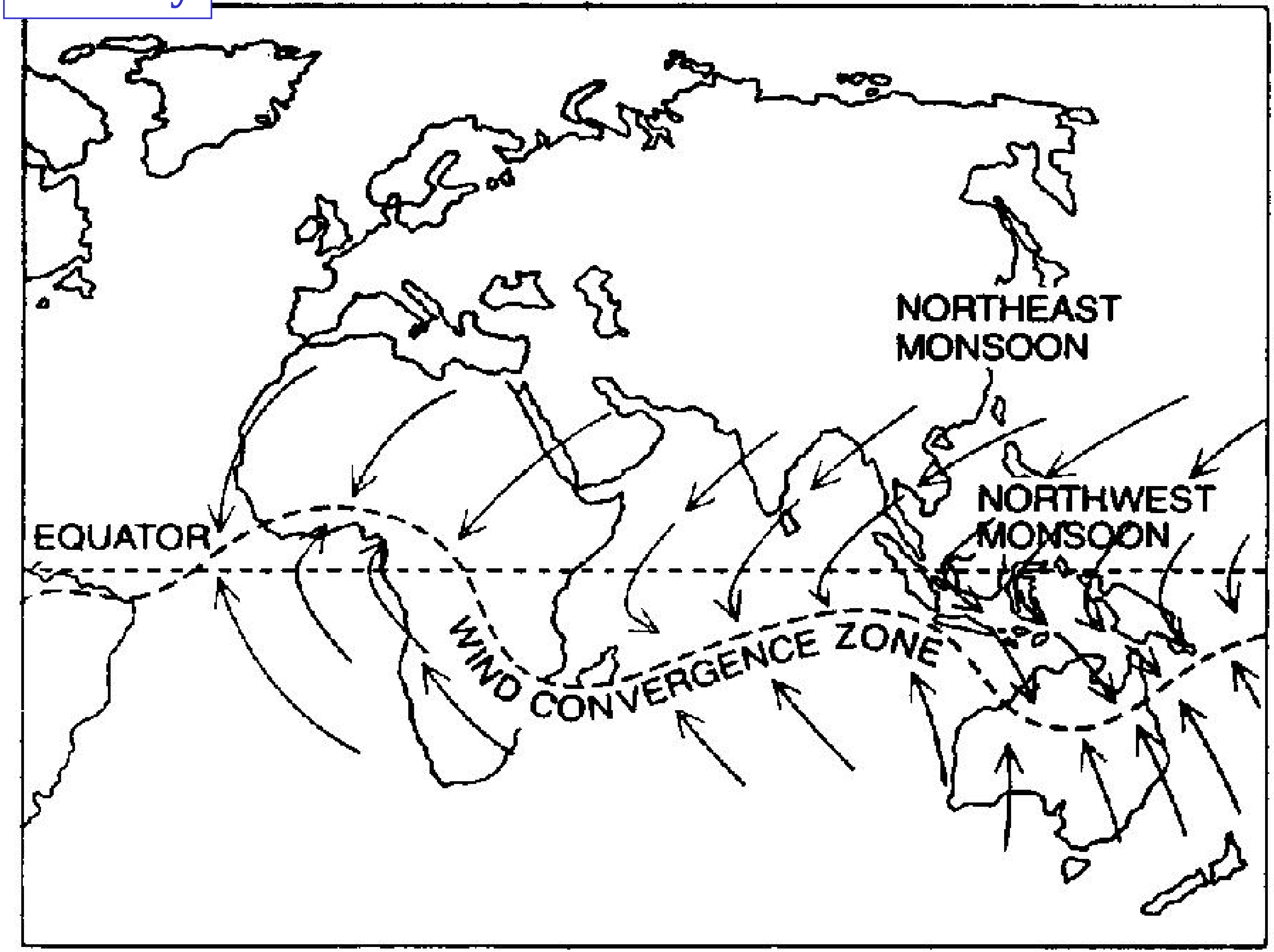
July



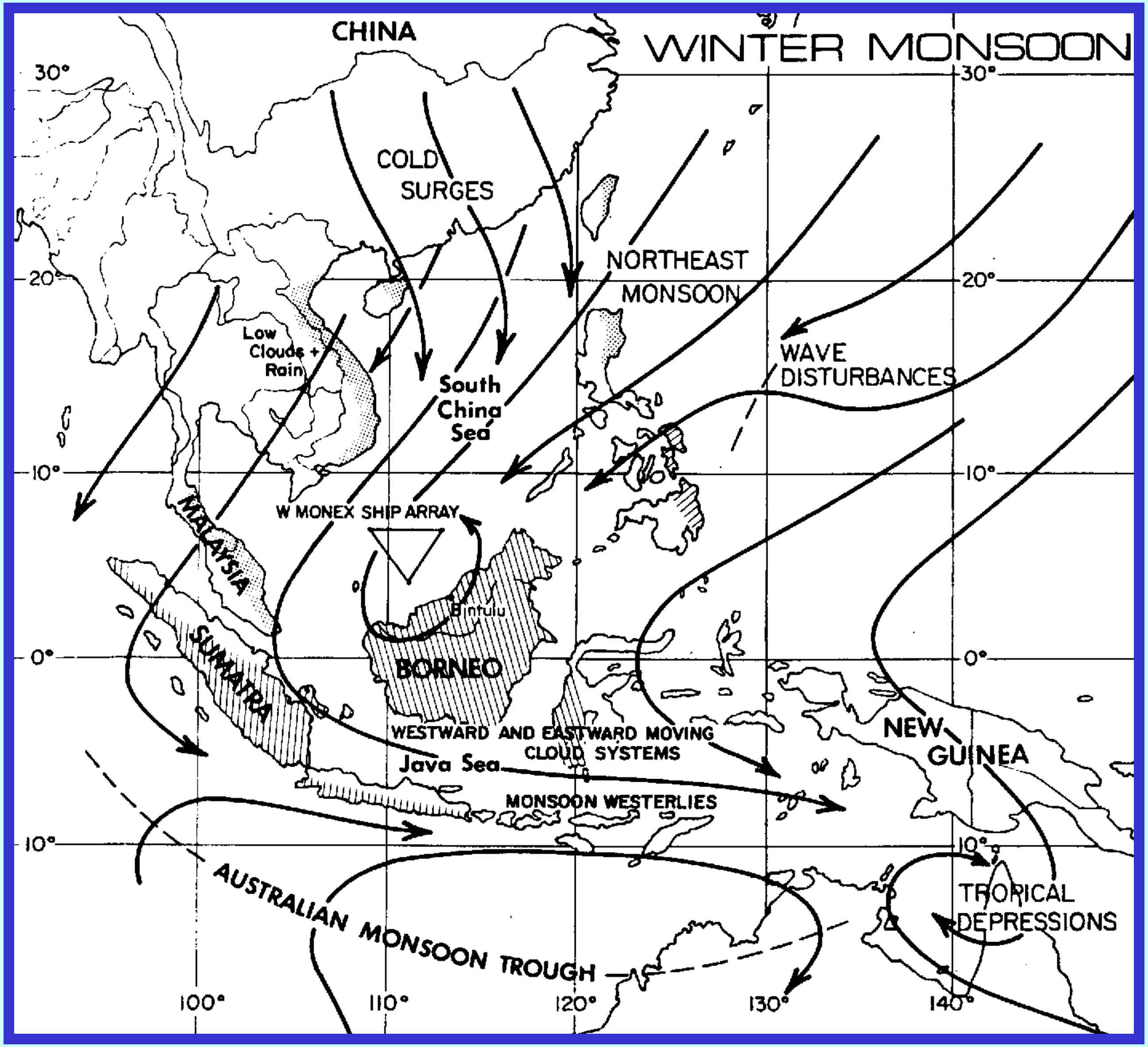
SE Asian Monsoon



January

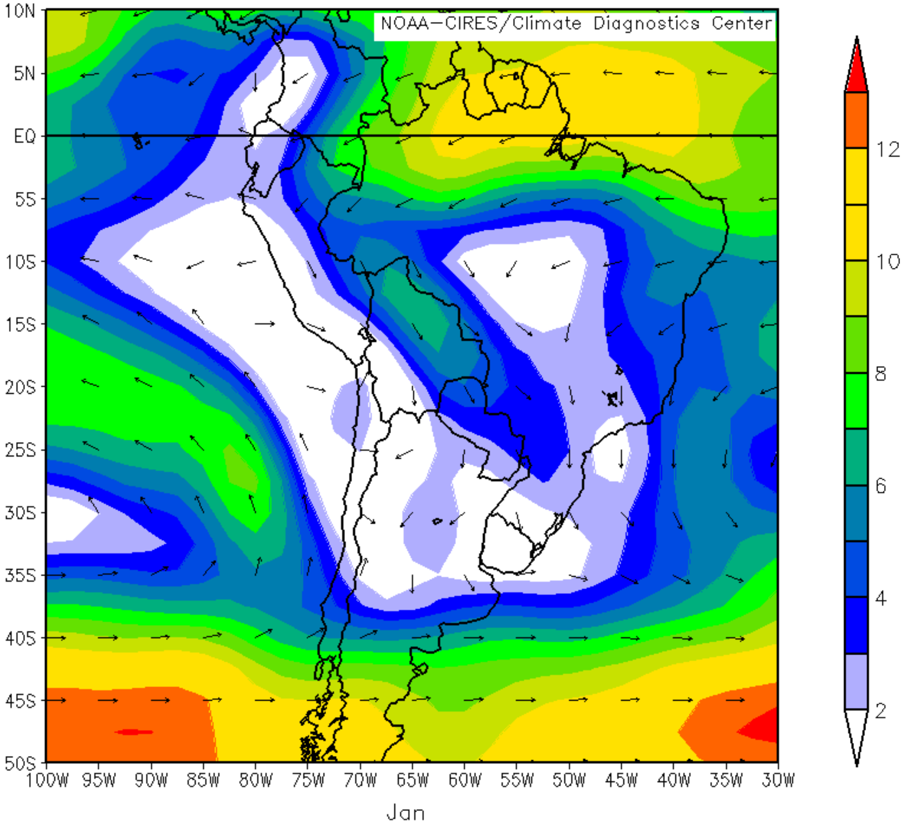

NORTHEAST MONSOON
NORTHWEST MONSOON
EQUATOR
WIND CONVERGENCE ZONE

Australasian Monsoon

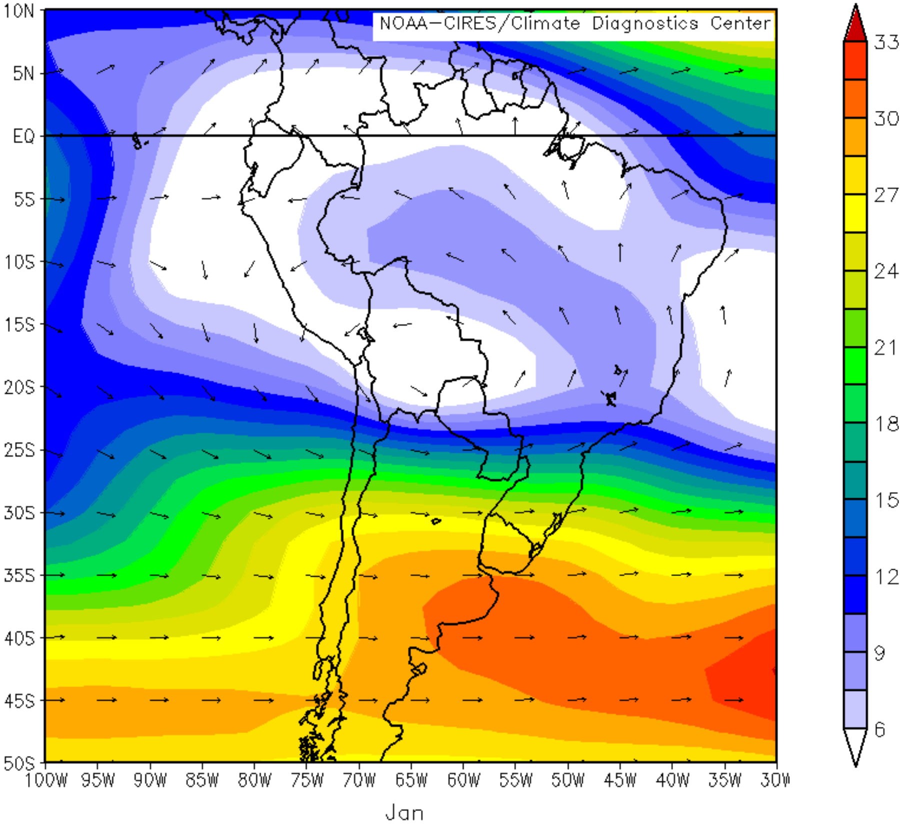


South America: January climatology

850 mb wind

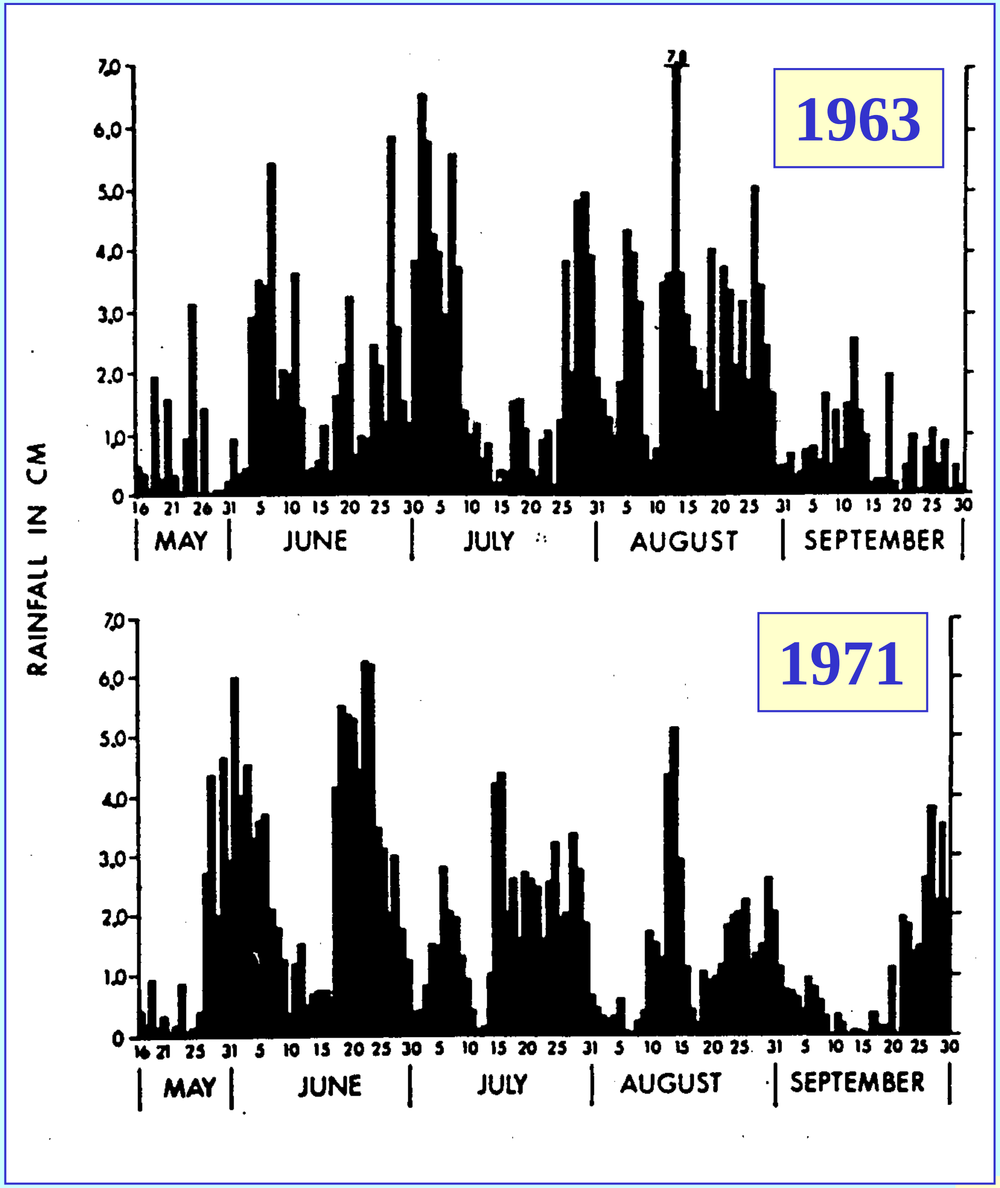


200 mb wind



An example of monsoon variability

West coast of India



(From Webster, 1983)

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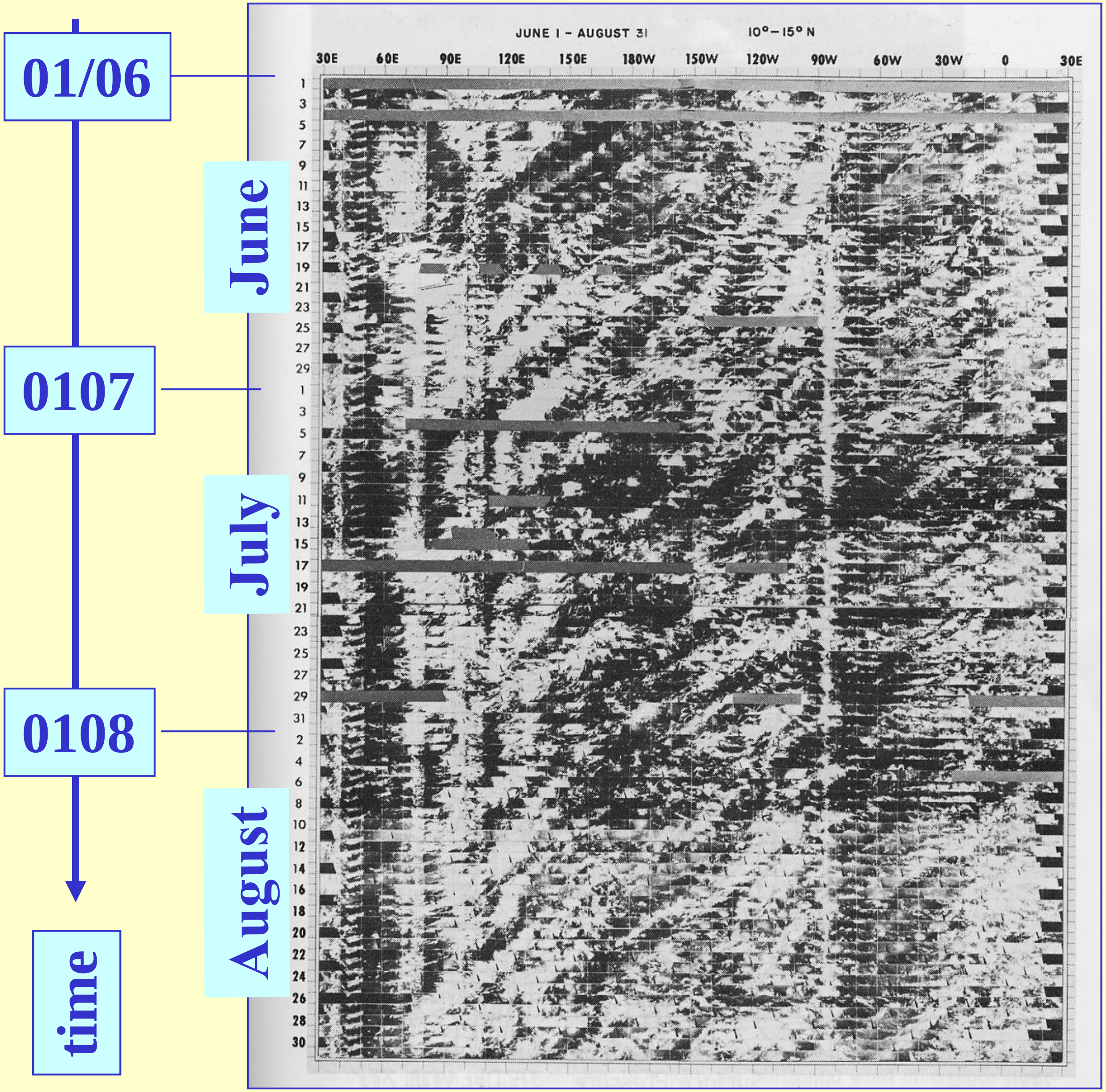
Time-longitude section of vis imagery - latitude band 10 -15 N

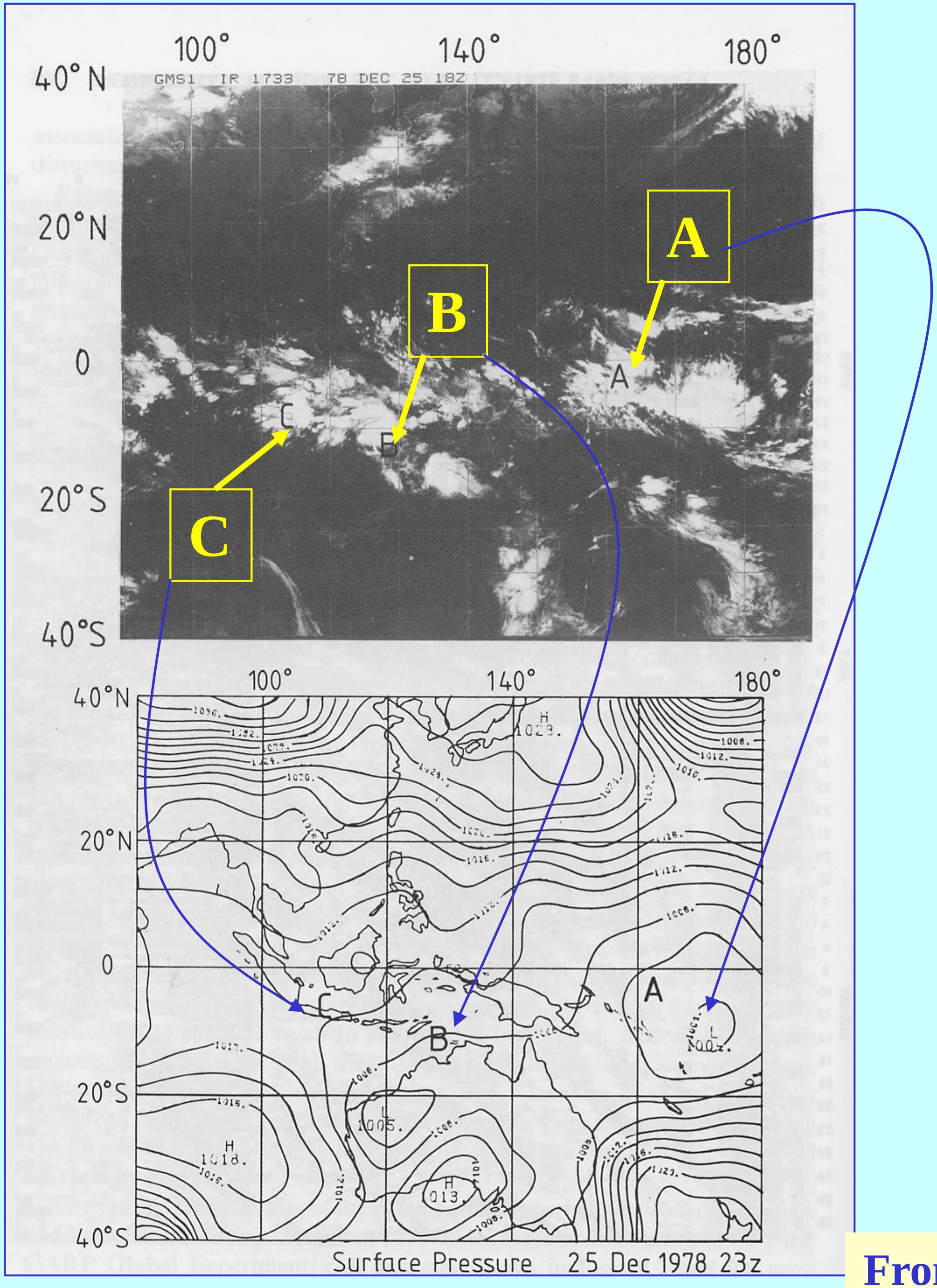


From Wallace, 1970

Winter MONEX

GMS – IR
25 Dec 1978

MSLP
25 Dec 1978

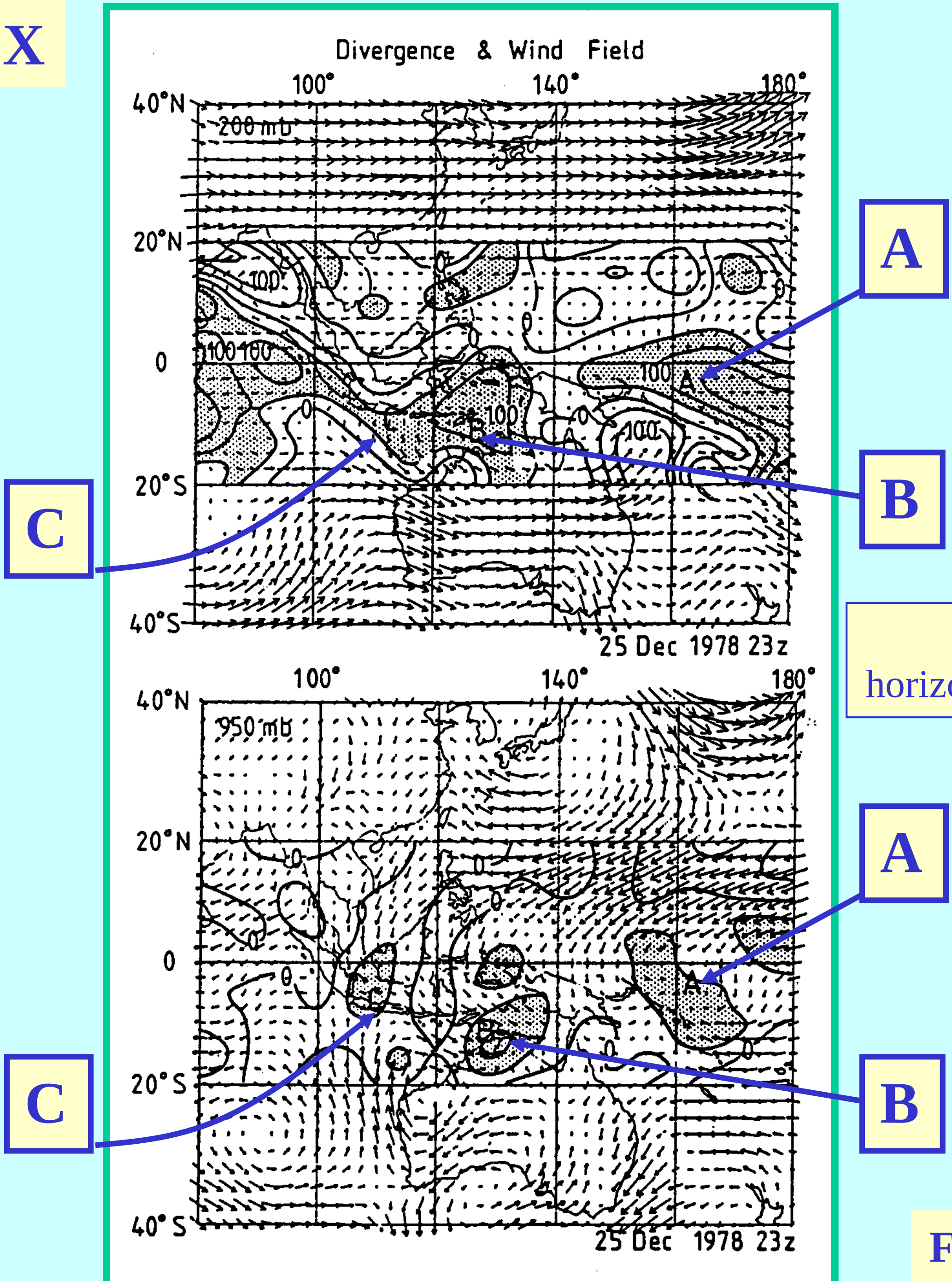


From Webster, 1983

Winter MONEX

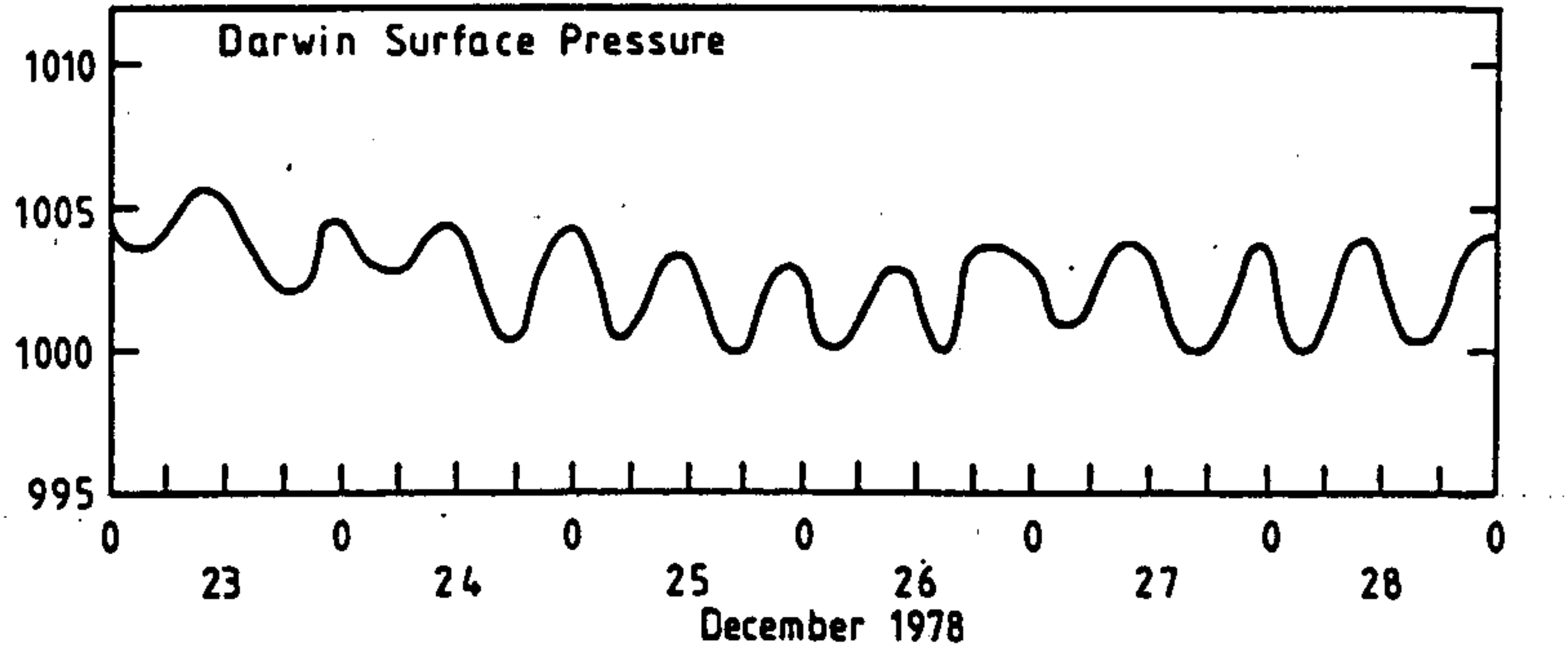
250 mb
25 Dec 1978

850 mb
25 Dec 1978



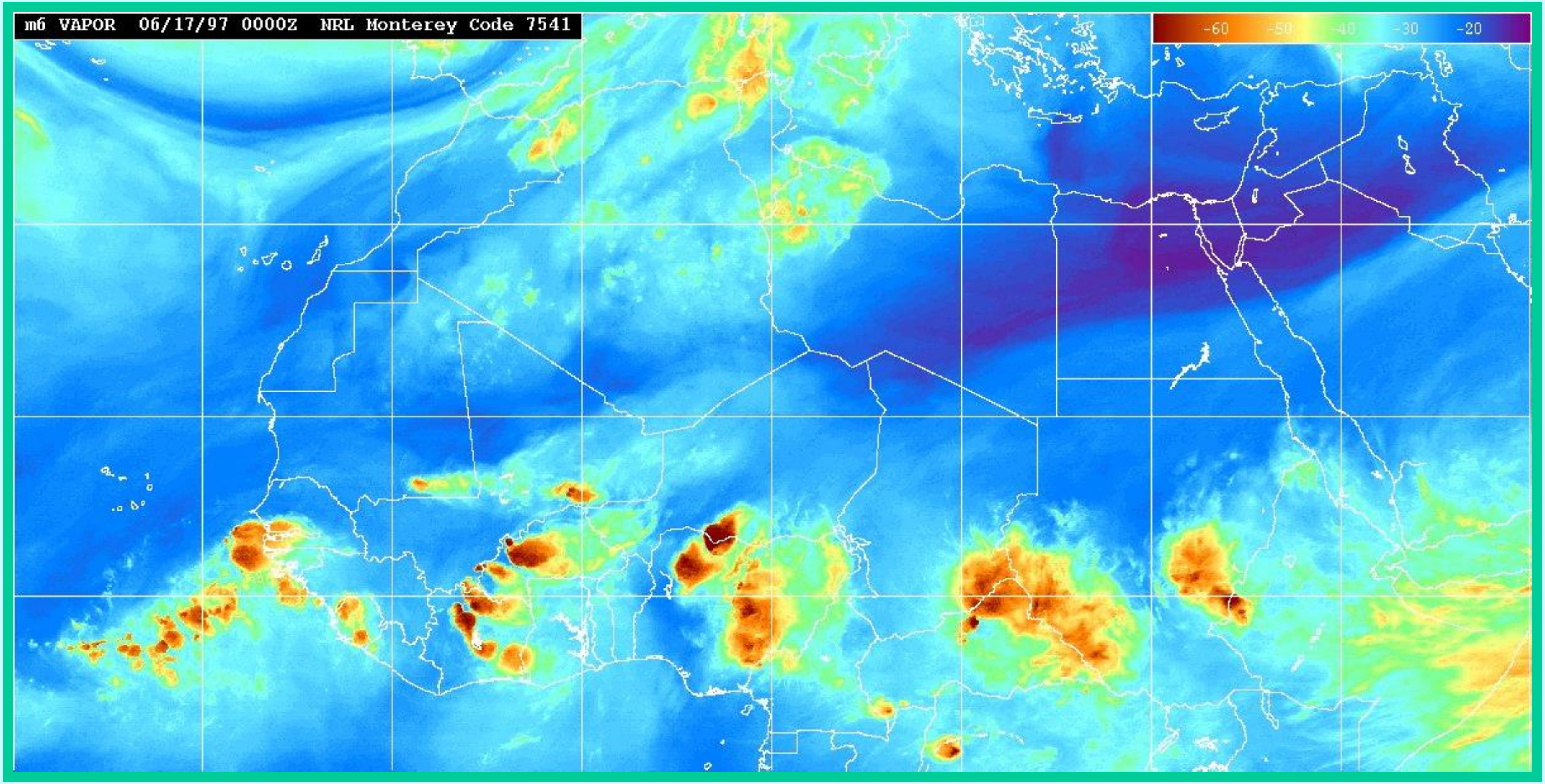
shaded
horizontal wind divergence

From Webster, 1983



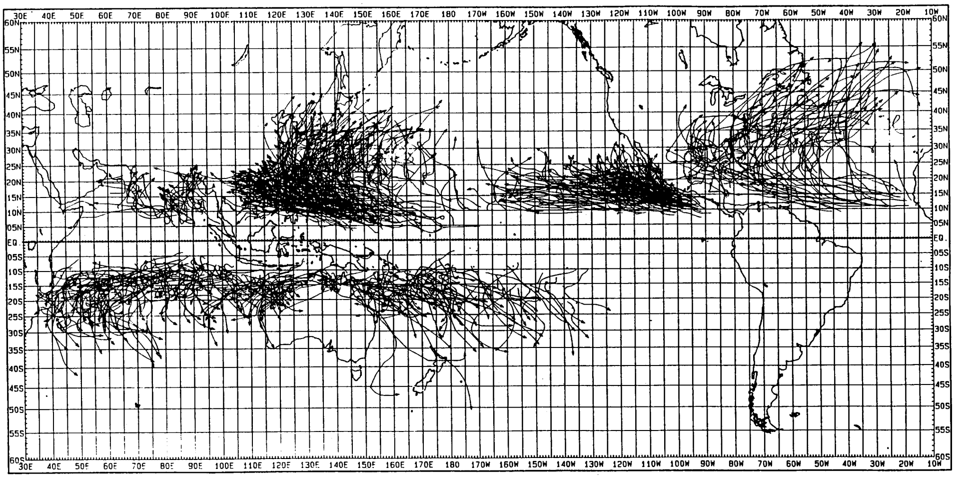
The variation of surface pressure at Darwin for the period 23 - 28 Dec. 1978.

Easterly waves over Africa

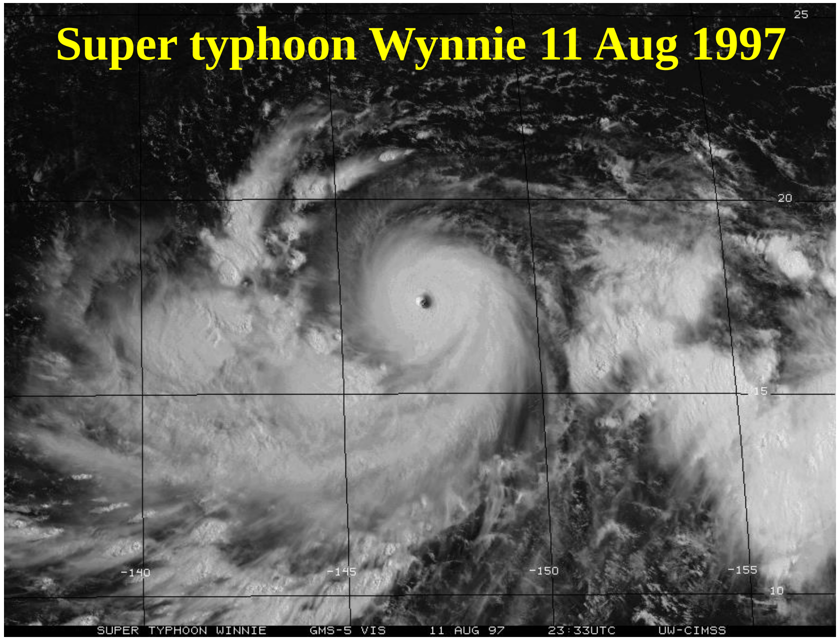


WV Imagery 17 June 1997 00Z

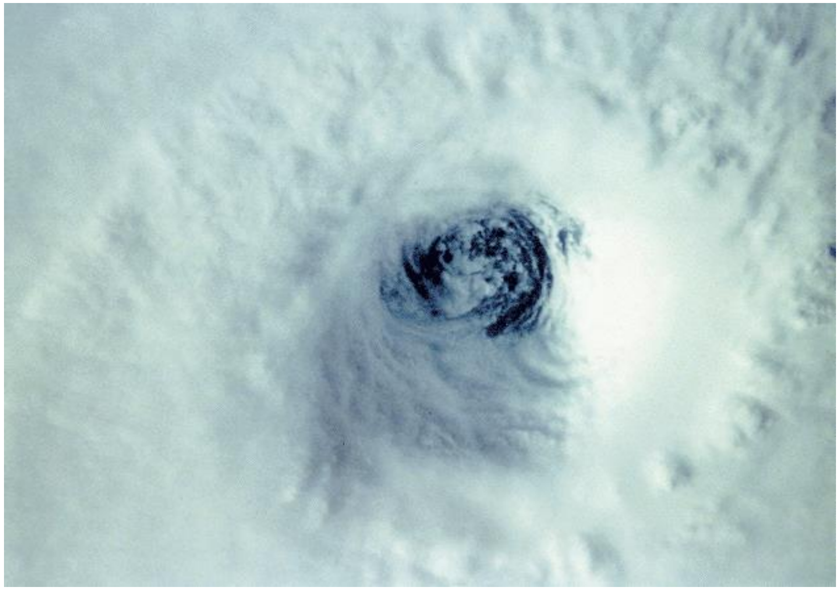
Tropical cyclones



TC tracks (1979-1988)



Super typhoon Wynnie 11 Aug 1997



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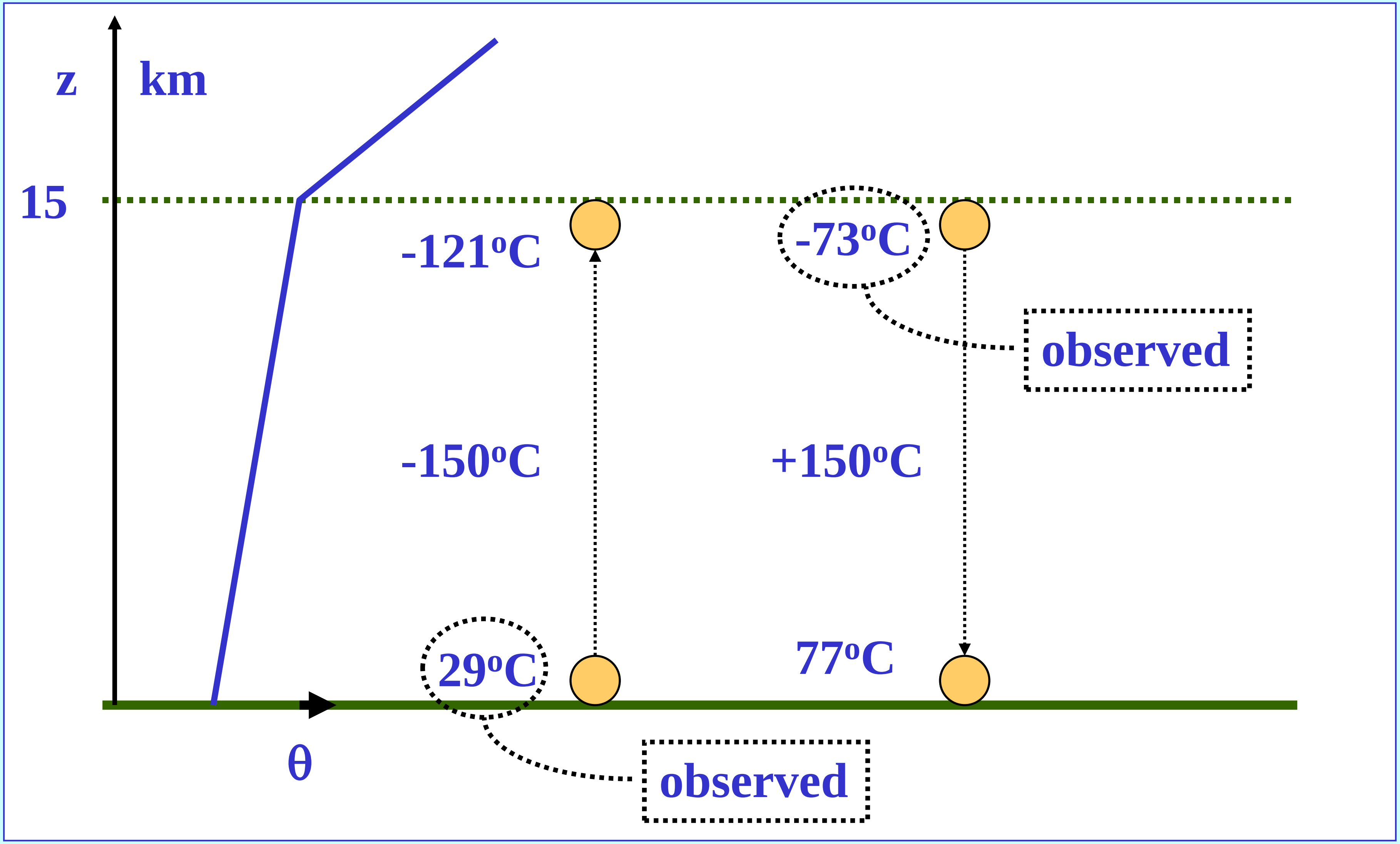
Moist Convection

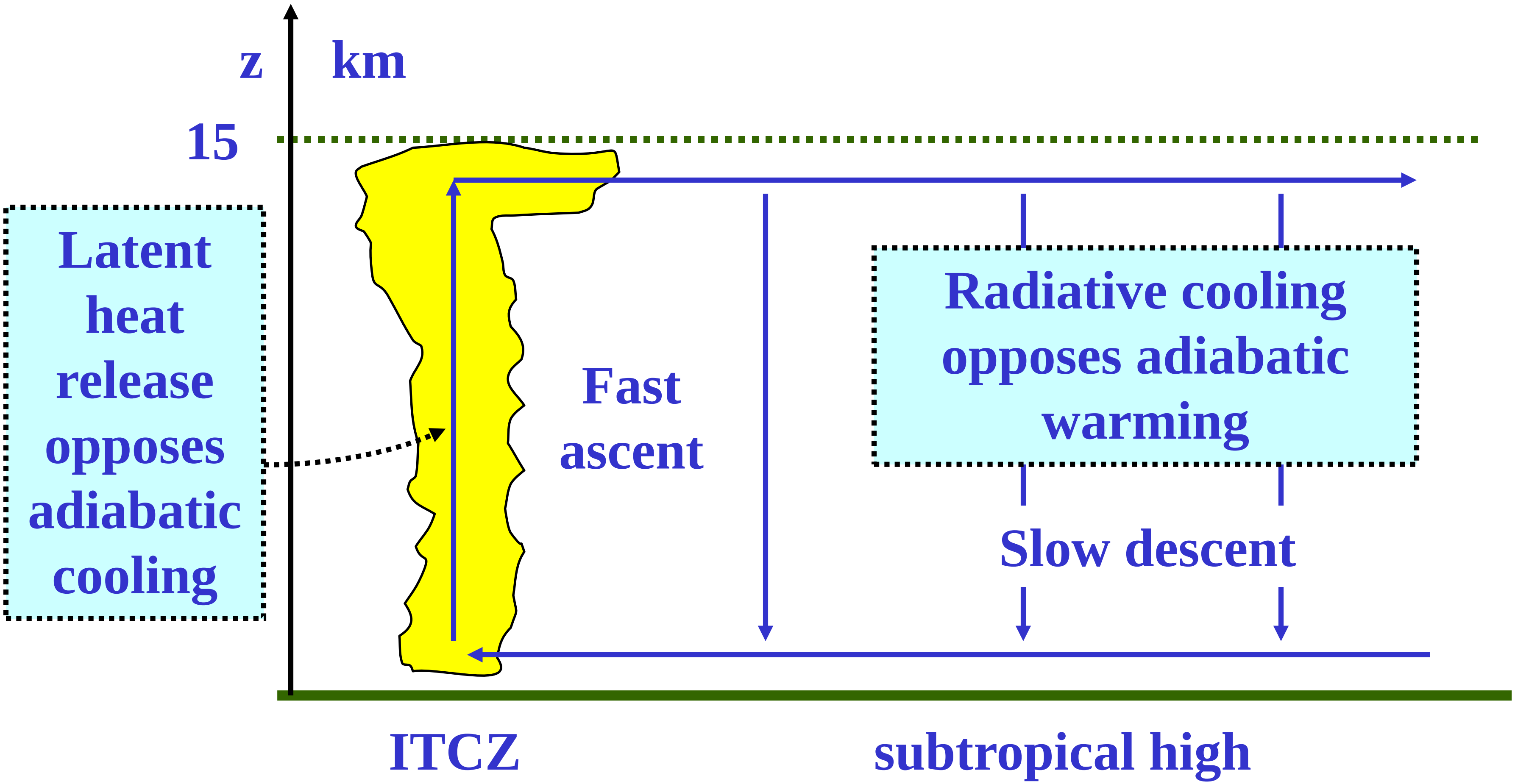
Trade Cumuli

The tropical troposphere

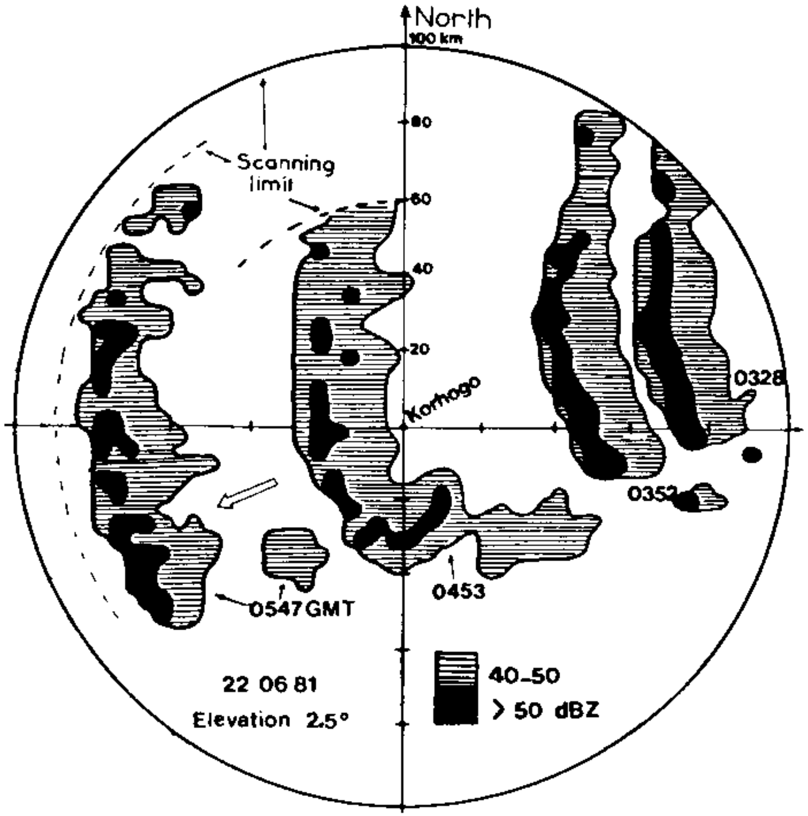


Conclusion: Deep tropical circulations cannot be dry adiabatic

The role of diabatic processes

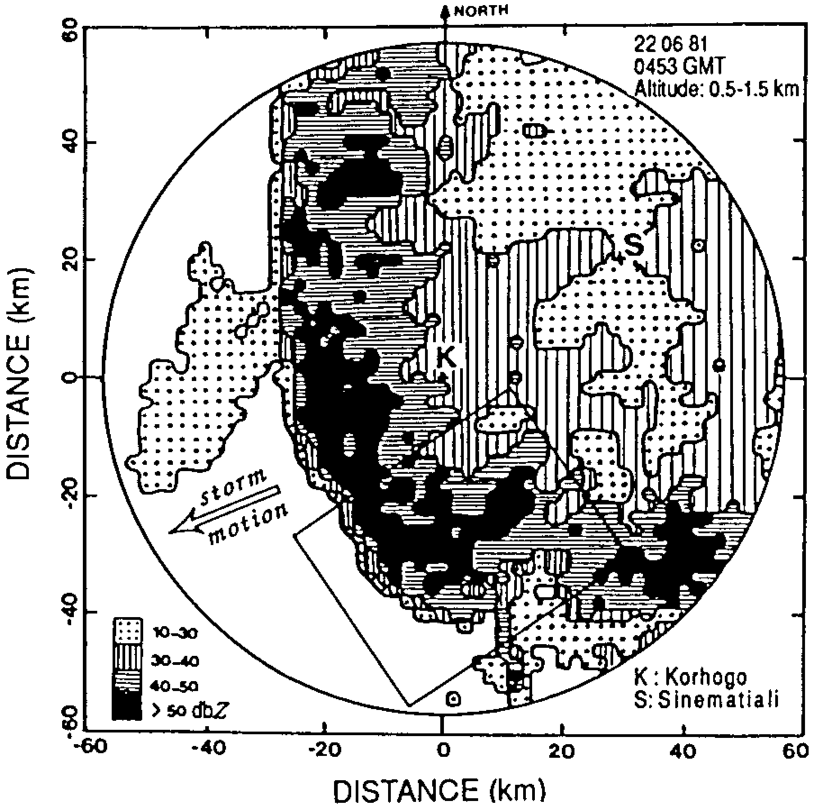


Conclusion: Deep convection occupies a small fractional area

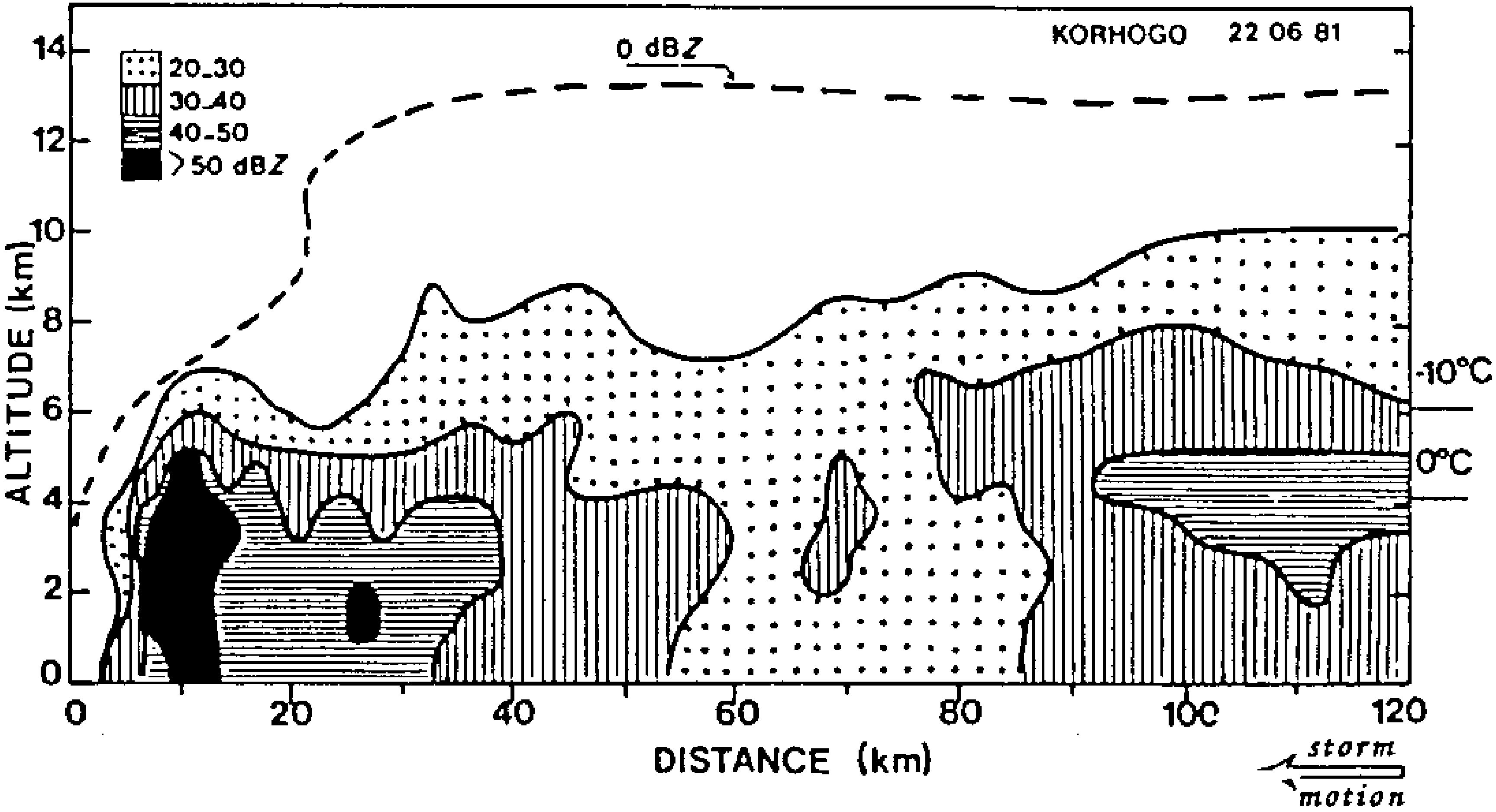


Successive locations of radar reflectivity contours in a tropical squall line.

From Chang et al. (1987)

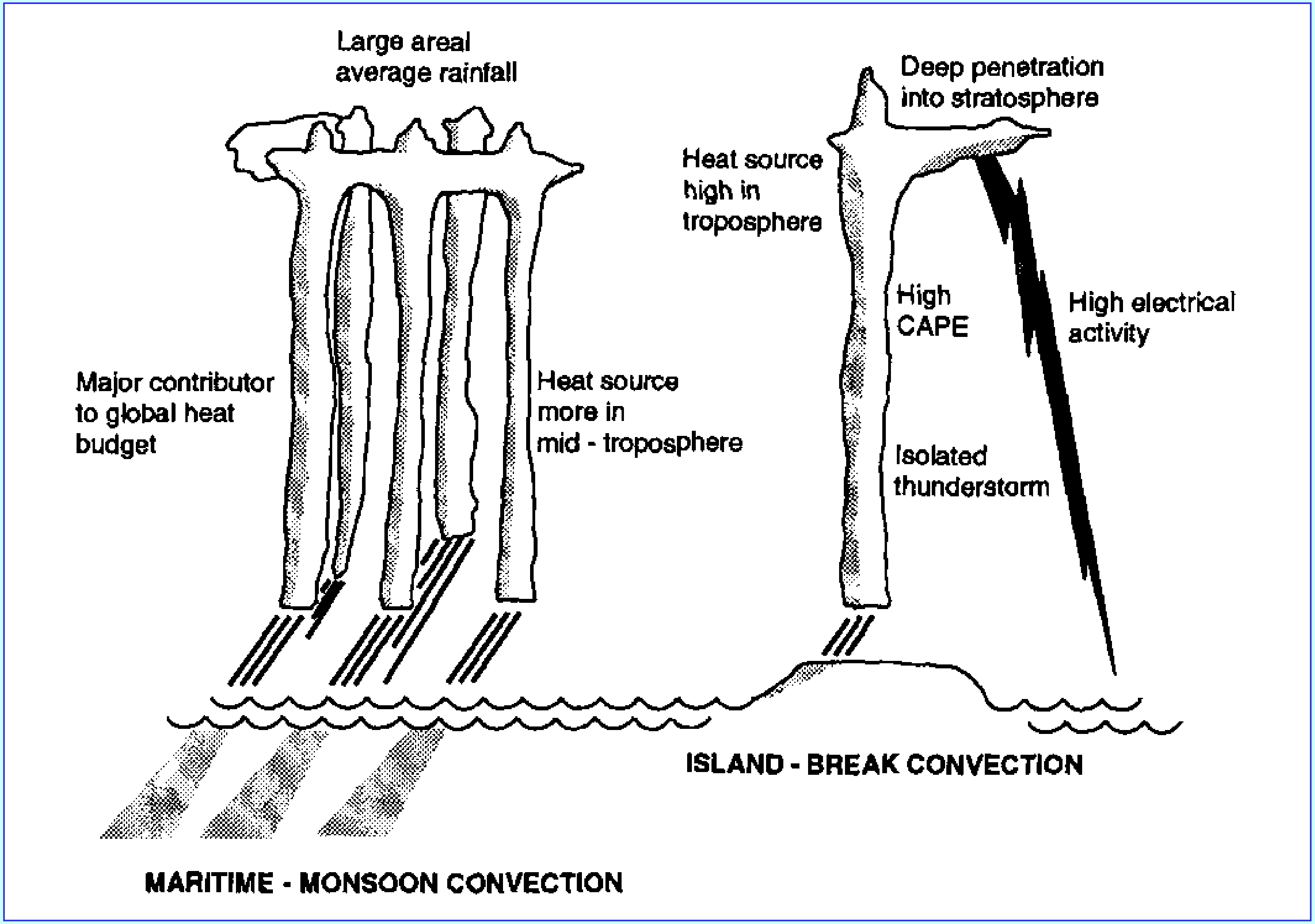


Radar reflectivity contours (dBZ) of a tropical squall line observed during COPT81 (Ivory Coast, West Africa). Horizontal cross-section at low levels (0.5 – 1.5 km).



Radar reflectivity contours (dBZ) of a tropical squall line observed during COPT81 (Ivory Coast, West Africa).
Vertical cross-section along the axis of propagation.

Types of convection



Hector Movie

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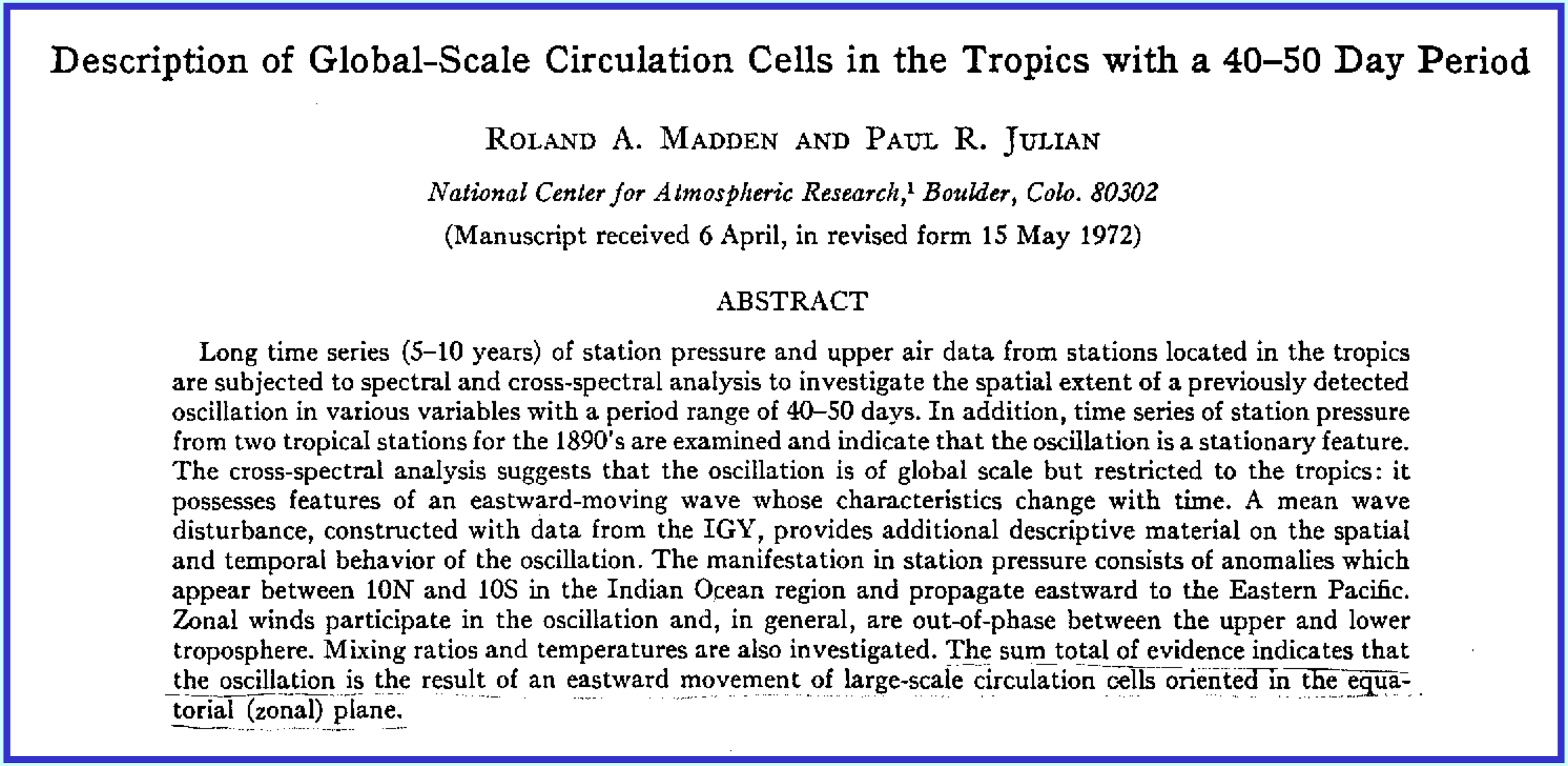
Madden-Julian Oscillation



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*

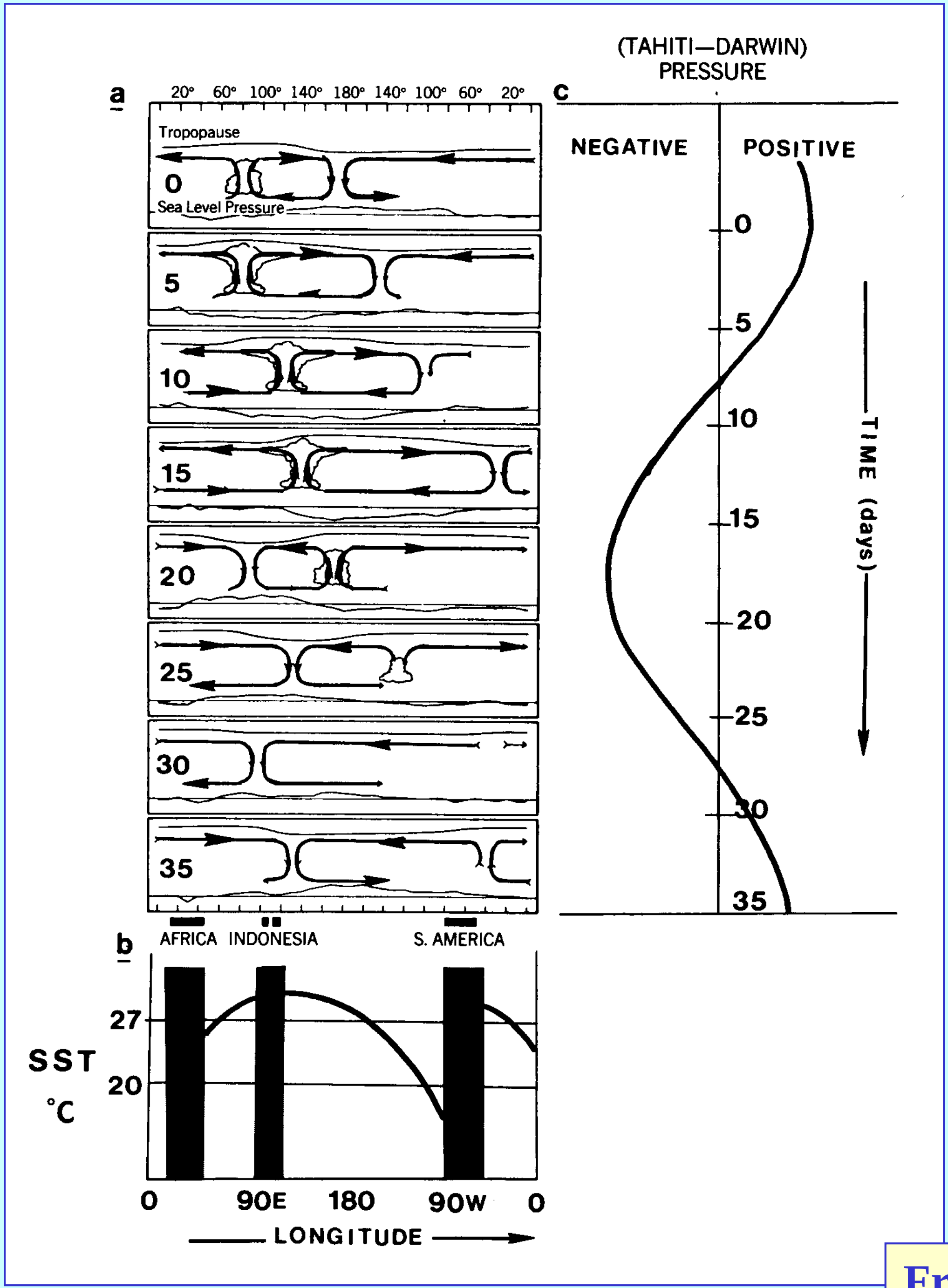
(Manuscript received 6 April, in revised form 15 May 1972)

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.

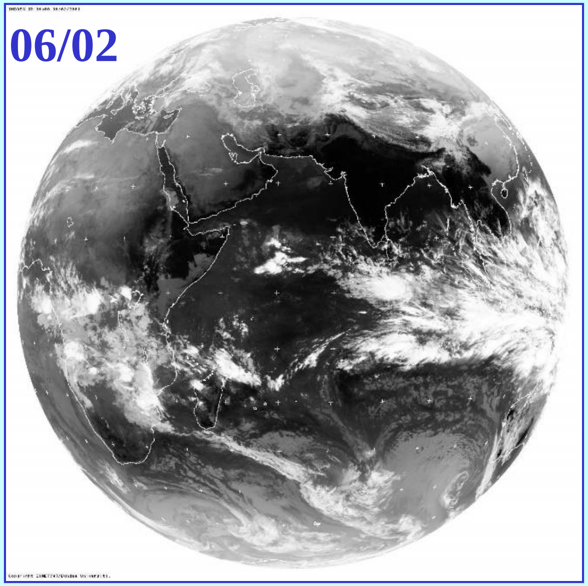
From JAS, Sept. 1972

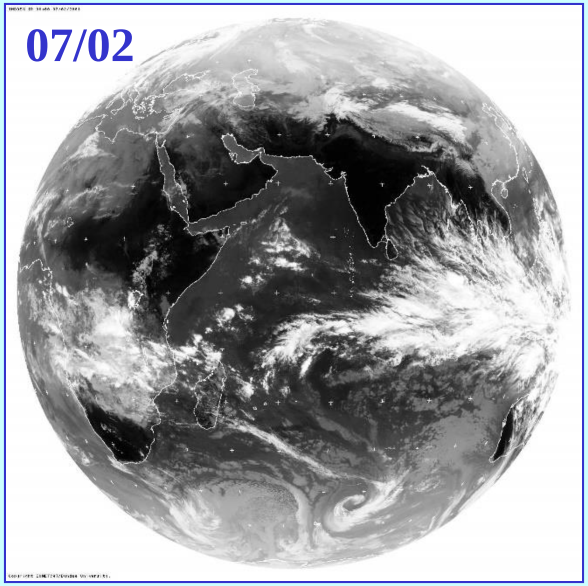
Madden-Julian Oscillation MJO



From Webster 1987

Indian Ocean Feb/Mar 2001


06/02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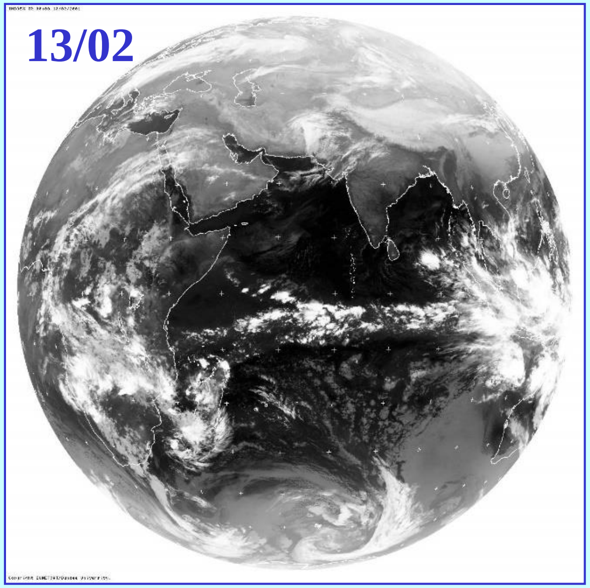
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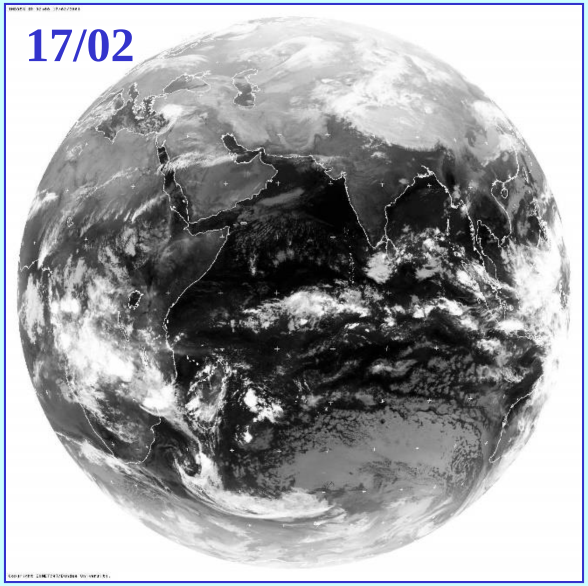
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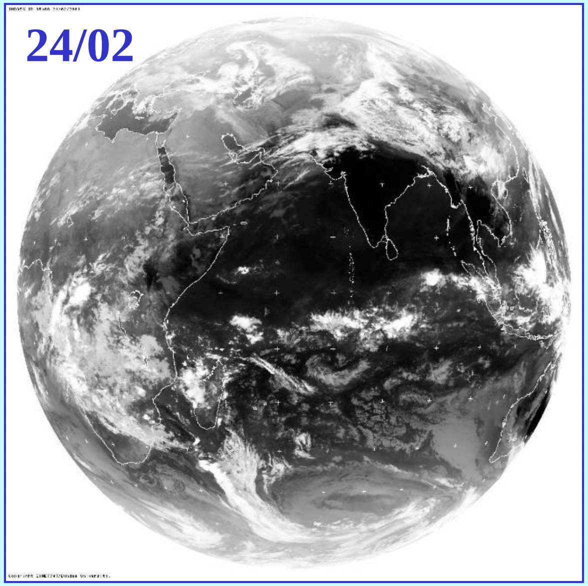
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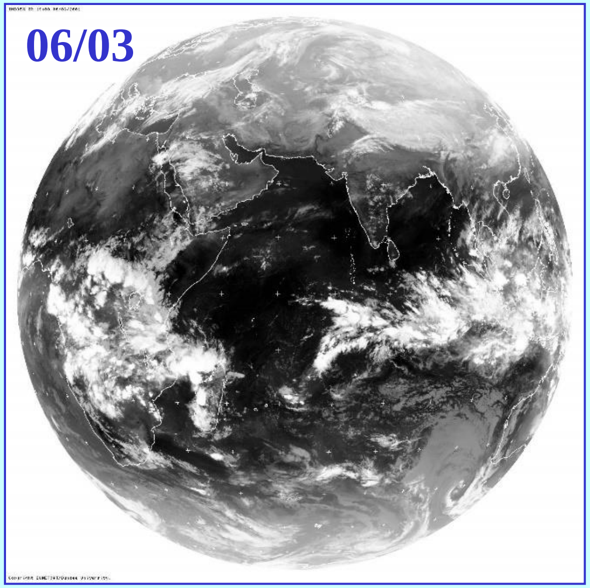
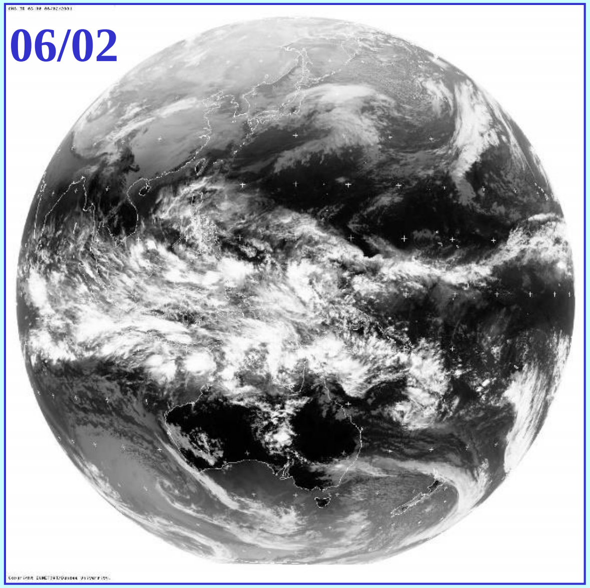

06/03

West Pacific Ocean – Feb 2001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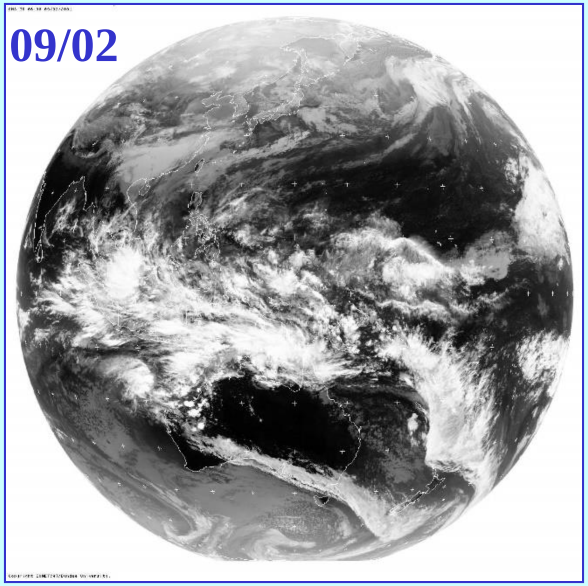
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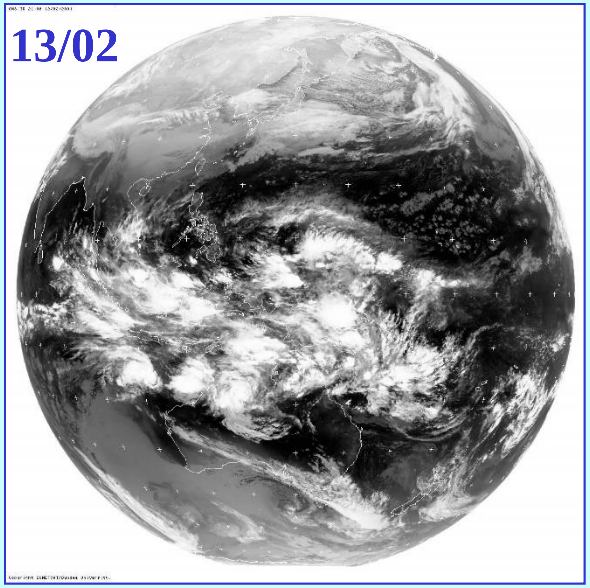
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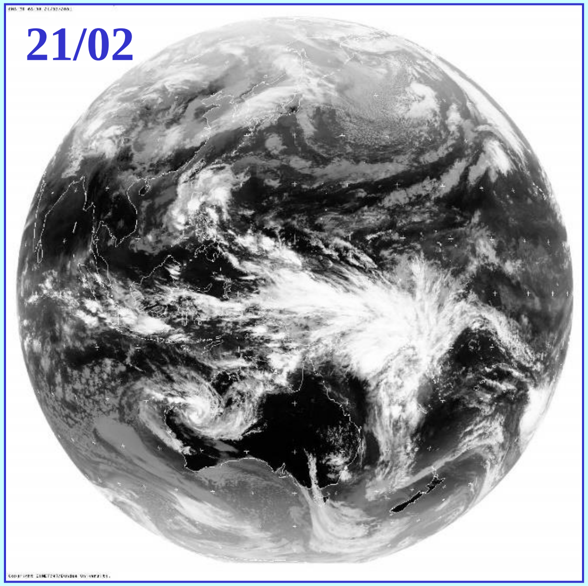
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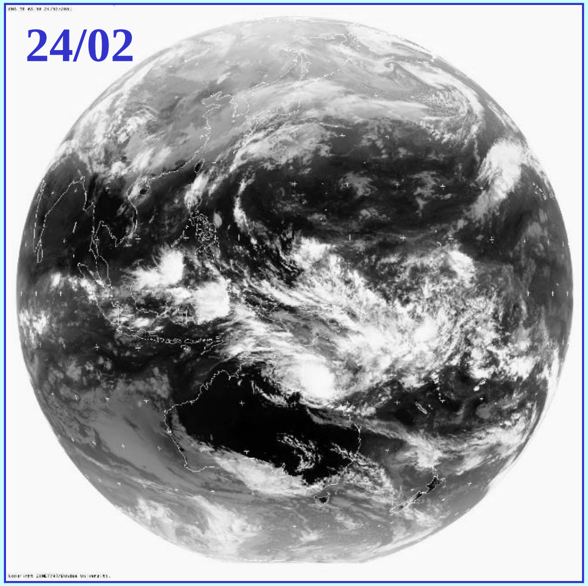
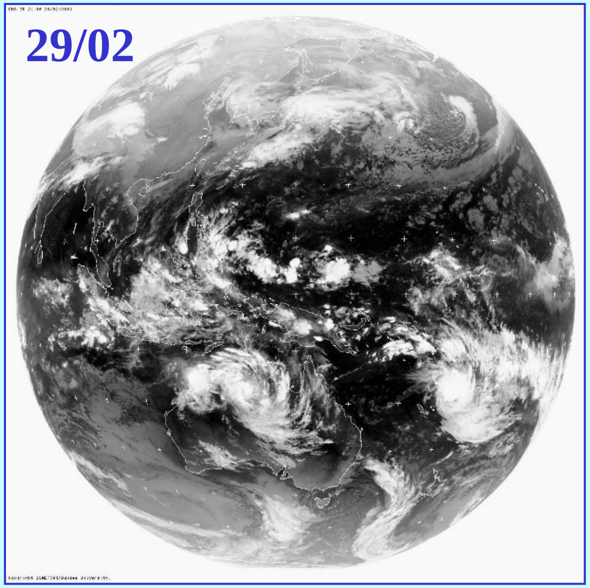
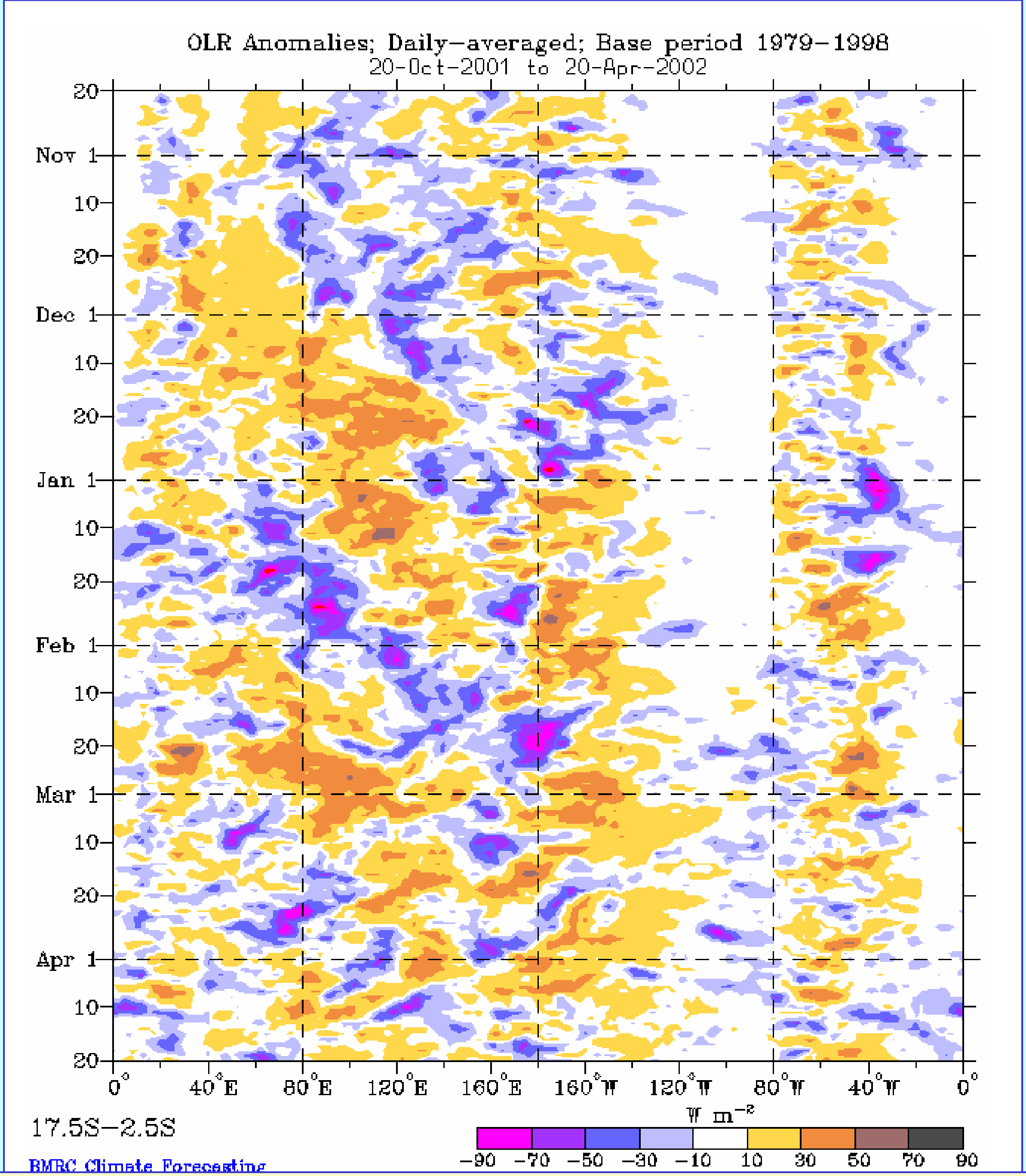
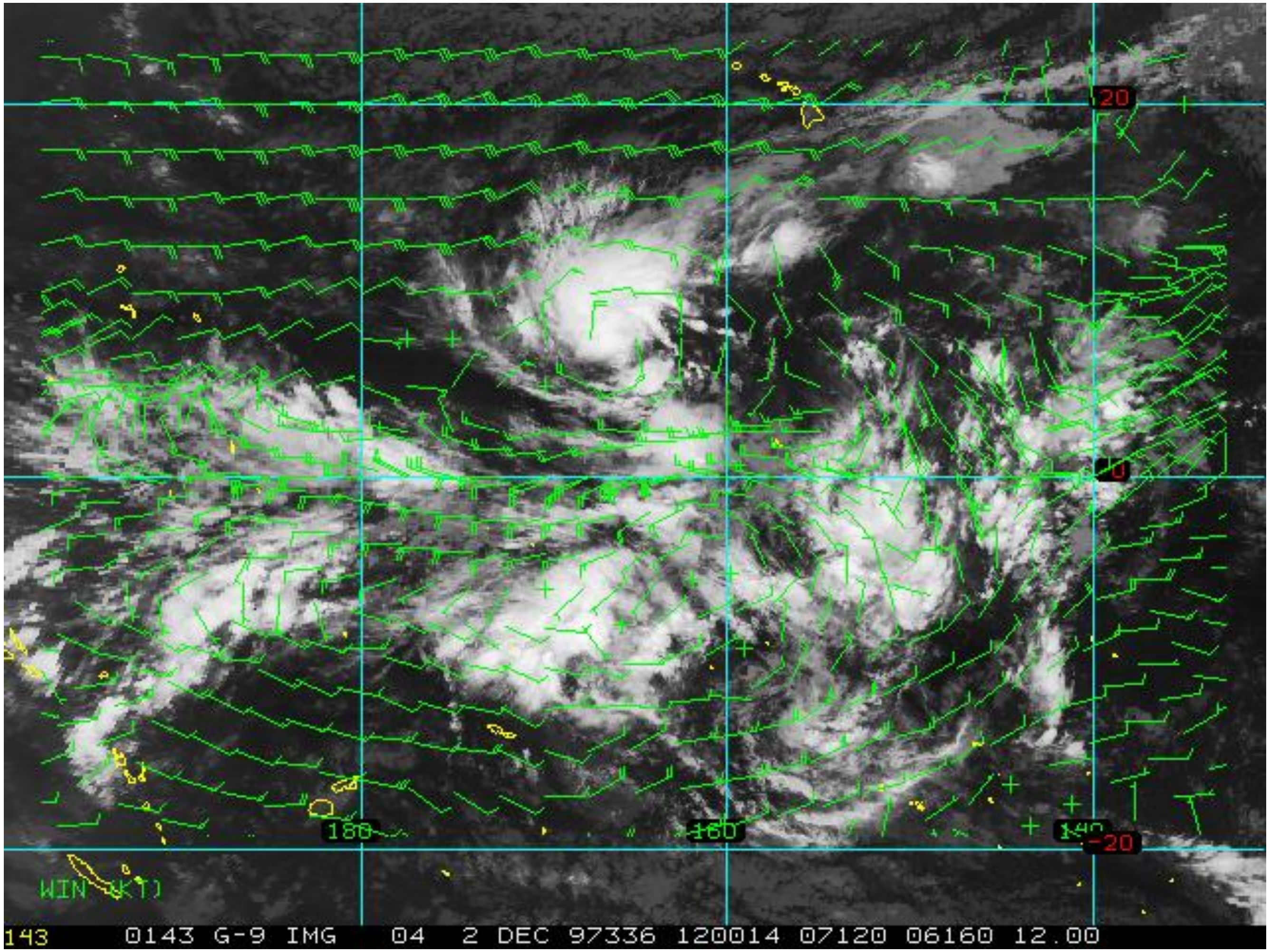

24/02


29/02



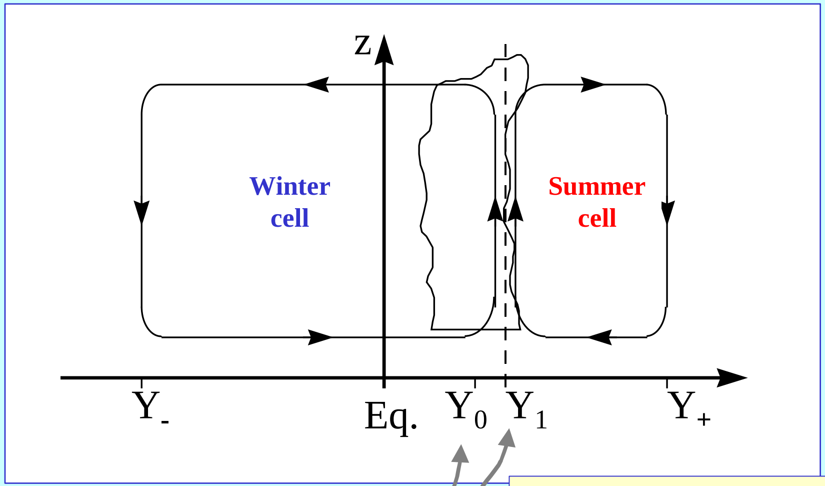
http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/OLR/hov.last6mths.anom.S.gif

Westerly wind bursts



GOES-9 12 UTC 2 Dec 1997 10.7 micron image

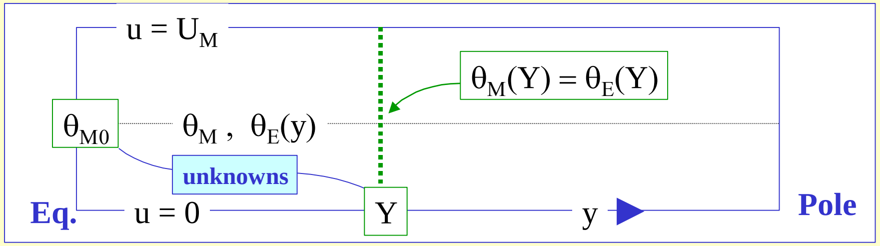
The extended Held-Hou Model



Solar heating maximum

Streamline dividing the winter and summer cells

Solution for θ_{M0} and Y



$$\theta_{M0} - \frac{\Omega^2\theta_0}{10a^2gH}Y^4 = \theta_{E0} - \frac{\Delta\theta}{3a^2}Y^2$$

$$\theta_{M0} - \frac{\Omega^2\theta_0}{2a^2gH}Y^4 = \theta_{E0} - \frac{\Delta\theta}{a^2}Y^2$$

$$\Rightarrow$$

$$Y = \left(\frac{5\Delta\theta gH}{3\Omega^2\theta_0}\right)^{1/2}$$

$$\theta_{M0} = \theta_{E0} - \frac{5\Delta\theta^2 gH}{18a^2\Omega^2\theta_0}$$

Take $\theta_0 = 255$ K, $\Delta\theta = 40$ K and H = 12 km $\Rightarrow \underbrace{Y \approx 2400\text{ km}}_{\approx \text{ in agreement with obs.}}$ and $\theta_{M0} \approx 0.9$ K cooler than $\theta_E(0)$.

Scale and put $y = L_E Y$

$$\begin{cases}\left(\nu^2-\mu^2\right)\hat{u} = \nu Y\,\hat{v} - \mu\dfrac{d\hat{v}}{dY}\\[2ex] \left(\nu^2-\mu^2\right)\hat{\eta} = \mu Y\,\hat{v} - \nu\dfrac{d\hat{v}}{dY}\end{cases}$$

Now

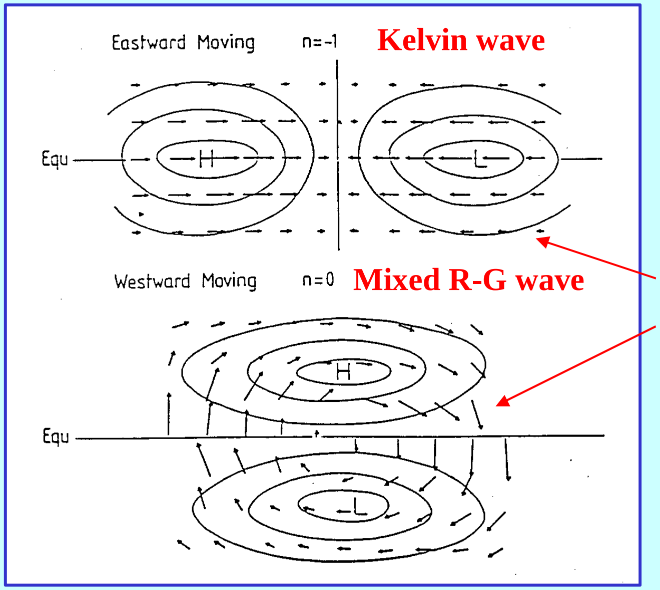
$$\hat{v}(Y) = \hat{v}_n = \exp(-\tfrac{1}{2}Y^2)H_n(Y)$$

and

$$\frac{d\hat{v}}{dY} = -Y\,\hat{v}_n + \exp\left(-\tfrac{1}{2}Y^2\right)\frac{dH_n}{dY}$$

Properties of the Hermite polynomials

$$\begin{cases}\dfrac{dH_n}{dY} = 2n\,H_{n-1}(Y)\\[2ex] H_{n+1}(Y) = 2YH_n(Y) - 2n\,H_{n-1}(Y)\end{cases}$$



Parcel motions

Horizontal structure of the Kelvin wave and of a westward propagating Mixed Rossby-gravity wave.

A few outstanding problems

- Interaction between moist convection and the large-scale flow.
- What are the controls on deep convection?
- Models usually don’t get the diurnal variation correct.
- No generally accepted theory of the Madden-Julian Oscillation.
- Weather forecasting in the tropics is still very difficult compared with that in the middle latitudes!

The End