Adverse Meteorological Phenomena in Northeast Brazil

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Edited by

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CONTENTS

List of Abbreviations and Acronyms

BNE – Brazilian Northeast
EBNE – Eastern BNE
NH – Northern Hemisphere
SH – Southern Hemisphere

Names of the BNE states:

RN – Rio Grande do Norte,
PB – Paraiba,
PE – Pernambuco,
AL – Alagoas,
SE – Sergipe,
BA – Bahia.

Cities in the BNE.

south of the BNE:
Salvador city (13.01°S, 38.51°W) (Bahia State).
middle of the BNE:
Maceio city (9.55°S, 5.77°W) (Alagoas State).

Meteorological Centers

INPE (Instituto Nacional de Pesquisas Espaciais) – Nacional Institute of Space Research
CPTEC (Centro de Previsão de Tempo e Estudos Climáticos) – Center for Weather Forecasting and Climate Studies
INMET (Instituto Nacional de Meteorologia) – National Institute of Meteorology
ECMWF – European Centre for Medium-range Weather Forecast
NCEP – National Centers for Environmental Prediction

Synoptic systems

L – Low/cyclone
H – High/Anticyclone
ITCZ – InterTropical Convergence Zone
UTCV – Upper Tropospheric Cyclonic Vortex
UTT – Upper Tropospheric Trough,
MTCV – Middle Tropospheric Cyclonic Vortexes
SACZ- South Atlantic Convergence Zone

JS – Jet Stream
SJS – Subtropical Jet Stream
PJS – Polar Jet Stream
PJSSH – polar jet stream of Southern Hemisphere
PJSNH – polar jet stream of Northern Hemisphere
STJSSH – subtropical jet streams of Southern Hemispheres
STJSNH – subtropical jet streams of Northern Hemispheres
BNEJS – Brazilian Northeast Jet Stream

FZ – Frontal Zone
TW – Trade Winds
WDTW – Wave Disturbance in Trade Winds
MCC – Mesoscale Convective Complexes
EW – Easterly Waves
Wave – cyclonic curvature at streamlines
WDTW – Wave Disturbances on the Trade Winds
SASH – South Atlantic Subtropical High
SASR – South Atlantic Subtropical Ridge
SAD – South Atlantic Dipole

Variables

u – zonal wind component ($m.s^{-1}$)
v – meridional wind component ($m.s^{-1}$)
u_g – **x** component of geostrophic wind
v_g – **y** component of geostrophic wind
ω – **p** component of wind (vertical motion in p- coordinates; ($hPa\ s^{-1}$)
w – vertical component of wind ($m\ s^{-1}$)
g – gravitational acceleration
ς – vorticity
RV – relative vorticity

CRV – cyclonic relative vorticity
ρ – air density
t – time
Z – geopotential (height in geopotential meters, gpm)
Thickness 500-1000 hPa (dam)
f – Coriolis parameter
SLP – surface level pressure (hPa)
MSLP – Mean Sea Level Pressure (hPa)
SST – Sea Surface Temperature (°C)
Stl – streamlines
Q – omega (Pas^{-1})
Conv – convergence of air current
Div – divergence of air current
T – temperature (°C)
AdvT – temperature advection
Ttr – temperature transformation
OLR – Outgoing Long Wave Radiation (Wm^2)

γ – vertical temperature gradient, lapse rate of temperature
γ_d – vertical temperature gradient for dry adiabatic processes, adiabatic lapse rate of temperature
Tmax – maximum temperature
Hmax – layer heights with Tmax (hPa)
H – diabatic term
R – universal gas constant
Cp – heat capacity of air at constant pressure
RH – relative humidity
P – precipitation
Pw – precipitable water (mm)
SH – Specific humidity (gkg^{-1})
Mdiv – moisture flux divergence ($10^{-5}gkg^{-1}s^{-1}$)

Sp – simulated profile
Fp – forecasted or predicted profile.

Satellite

IR – infrared satellite imagery
WV – water vapor satellite imagery
VIS – visible imagery

INTRODUCTION

Geographical conditions of the Brazilian Northeast

The continent of South America consists of four regions (Figure 1) with different weather conditions and processes of formation (Cavalcanti, 2012). These regions are: 1) Amazonia, 2) Northeast Brazil or Brazilian Northeast (BNE), 3) Southeast Brazil and 4) La Plata Basin. This book is dedicated to region 2, the Brazilian Northeast (BNE).

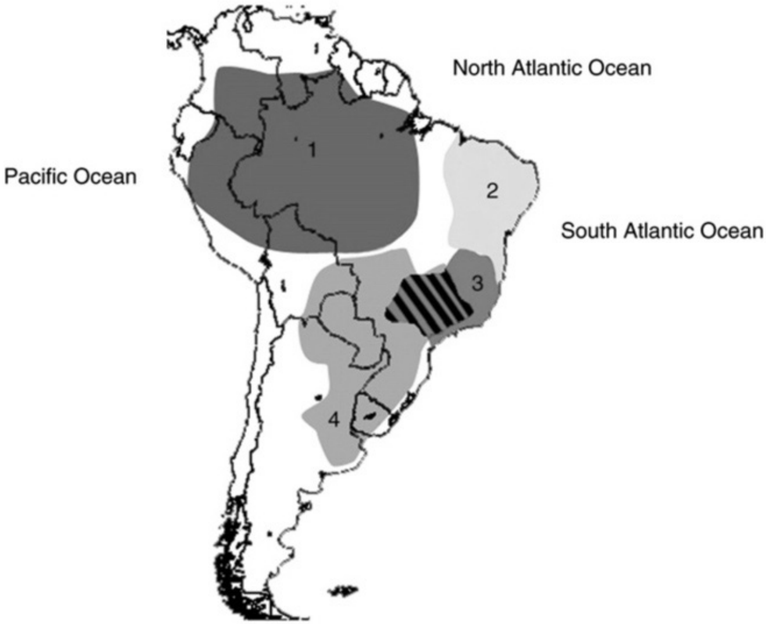

Figure 1- Regions of South America:
1 — Amazonia, 2 — Brazilian Northeast, 3 — Southeast Brazil, 4 — La Plata Basin (stripes indicate common areas of La Plata Basin and Southeast Brazil).
Source: Cavalcanti (2012)

Northeast South America is a very important agricultural region and one of the most important tourist regions in Brazil. Correct weather forecasting plays a key role in the economic success of this region. The location of this region can be seen on the map of Brazil (Figure 2). The BNE includes the following states (from north to south along the coast): Maranhao, Piaui, Ceara, Rio Grande do Norte, Paraiba, Pernambuco, Alagoas, Sergipe and Bahia.

a)

b)

Figure 2- Location of the BNE region (dark grey) on the map of Brazil (a) and the BNE States with capitals (b).
Source: wikipedia.org; Google, maps

Relief of the BNE

The BNE relief (Figure 3) is characterized by the presence of 1) coastal plains close to the northeastern beaches, 2) the Borborema Plateau, located in the interior of the region in the east, 3) the Parnaiba River Basin in the west, and 4) some uplands such as the plateau, in the south.

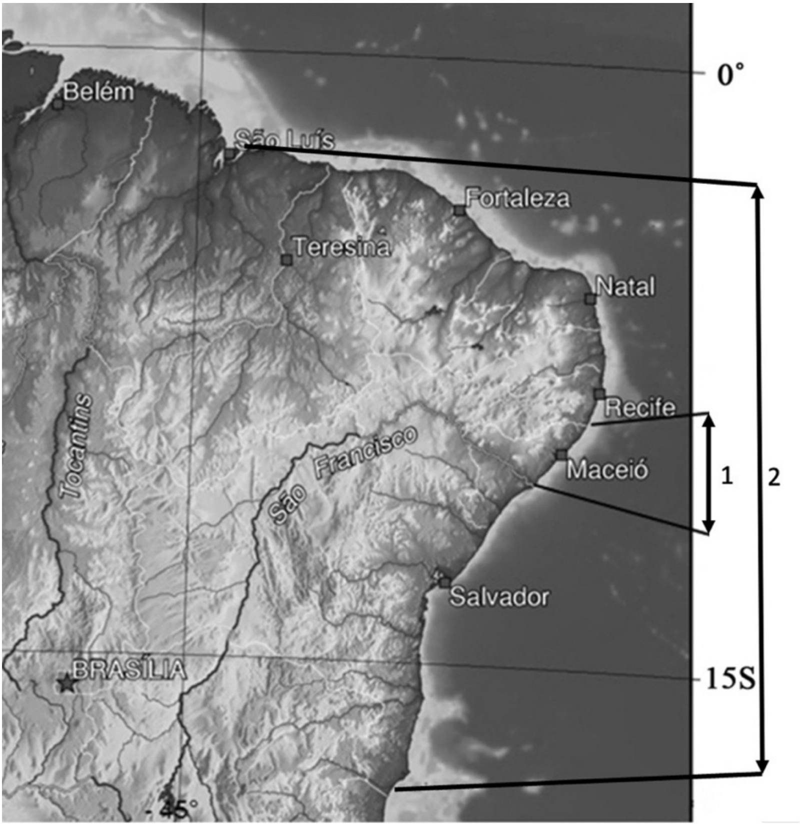

Figure 3- Relief in the BNE: 1- central region and 2 - all BNE
Source: IBGE (2006); Kulikova et al. (2014)

Geoclimatic regions and precipitation in the BNE

Four geoclimatic regions with meridional distribution are distinguished in the BNE: 1– *Meio-Norte*; 2 – *Sertao*, 3 *–Agreste,* 4 – *Zona da Mata* (Figure 4). Region 1, Meio-Norte, furthest from the Atlantic Ocean. Region 2, *Sertao*, is located in the highest regions. Two regions stretch along the coast of the Atlantic Ocean, one close to the coast, *4- Zona da Mata*, and the other *3 –Agreste* on the slope.

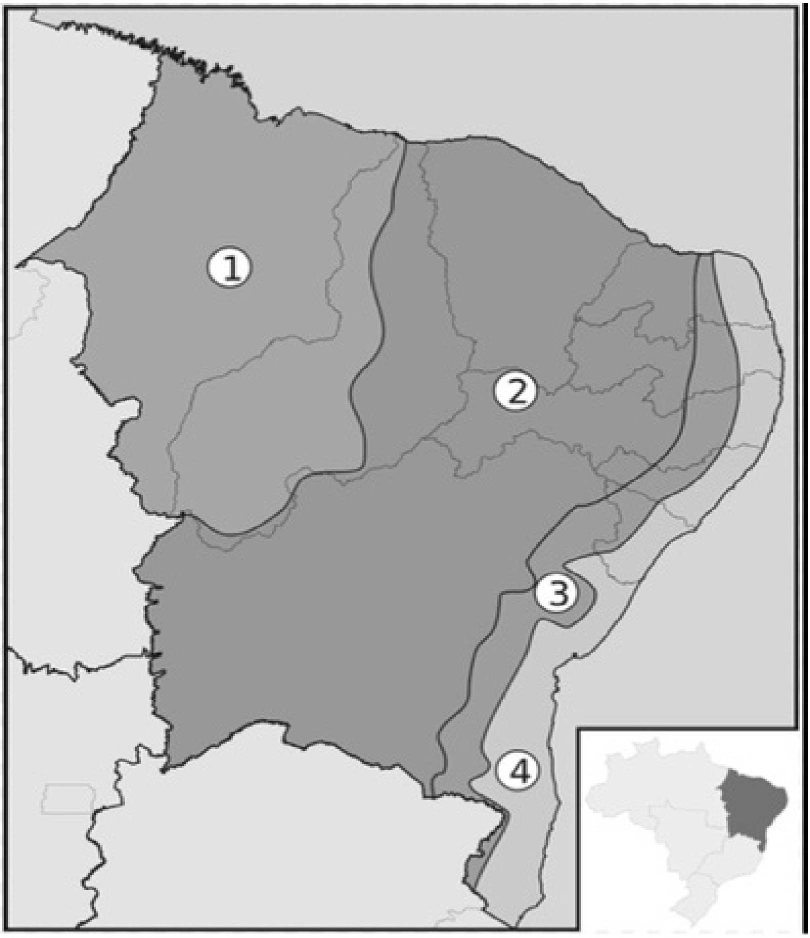

Figure 4 – Map of the geoclimatic subregions of the BNE:
1– Meio-Norte; 2 – Sertao, 3 –Agreste, 4 – Zona da Mata
Source: wikipedia.org; Matheus (2018); Fedorova et al. (2019)

Three precipitation patterns are described in the BNE (Molion, Bernardo, 2002): 1) The northern region has a humid season from February to May 2) The southern region has a humid season from November to February and 3) the coastal region has a rainy season from April to July. The rainy season in the central part of the coastal region usually occurs in May-July (precipitation ≥ 150 mm per month) or April-August (precipitation ≥ 100 mm per month) (Pontes Da Silva, 2008, 2011). Heavy precipitation in the central part of the coastal region usually fell in the autumn/winter period, and convective rains in January (Pontes Da Silva, 2011). The spatial distribution of precipitation in the central part showed the presence of two regions: semi-arid in the west (500 - 700 mm per year) and humid along the coast (2000 mm per year) (Molion & Bernardo, 2002, Pontes Da Silva, 2011).

The spatial and temporal characteristics of precipitation make their diagnostics and forecasting extremely difficult. The precipitation formation mechanisms and their evolution are associated with dynamic and thermodynamic processes interacting from large scales to cloud microphysics scale (Schwerdtfeger, 1976). This book will describe the dynamic and thermodynamic process in the BNE.

Objectives

The book analyzes the formation and forecast of adverse meteorological phenomena in the tropical region of the *Brazilian Northeast* (*BNE*). This book is a *Short-Range Weather Forecasting Guide* for the Tropical Region of Northeast Brazil. In addition, the main methods of forecasting can be used, after special additional verification in other tropical regions.

The meteorological systems of the tropical and extra-tropical regions of both hemispheres influence the phenomena formation in the BNE. The physical processes of these phenomena formations differ from the processes in other regions. Adverse phenomena (heavy and weak rain, thunderstorms, low visibility, fog, and mist) create many problems for the safety of the population and for transport (road and aviation). Therefore, the main purpose of this book is to combine information about the physical processes of adverse phenomena formation with practical methods for short-term forecasting. Synoptic and thermodynamic methods will be used together with the results of numerical models. This information is essential to improve weather forecasting and thus save lives.

The book contains information on both well-known and recently described synoptic-scale systems such as the Middle Tropospheric Cyclonic Vortexes, Brazilian Northeast Jet Stream, and Frontal Zones in the tropical region. The interactions between the hemispheres are also described, as well as the influence of tropical cyclones of the Northern Hemisphere on the BNE. In addition, the book presents practical methods for short-term weather forecasting in Northeast Brazil using thermodynamic analysis, satellite data and numerical models.

This book is intended primarily for undergraduate, graduate, and postgraduate students of meteorology. Also, this book will be useful to professionals in meteorology, such as professors, researchers, and operational meteorologists. In addition, even experts from another field can use it if they want to better understand the topic. This book will form part of the main text of courses in synoptic meteorology and operational meteorology at Brazilian Federal Universities.

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PART I

SYNOPTIC AND MESOSCALE SYSTEMS AFFECTING THE WEATHER FORMATION IN BRAZILIAN NORTHEAST

CHAPTER I.1

INTERTROPICAL CONVERGENCE ZONE

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DAVIDSON LIMA DE MELO AND
VLADIMIR LEVIT

1. Identification

The Intertropical Convergence Zone (ITCZ) is the most important weather system in the tropical region that can be seen around the globe. The ITCZ is characterized by a band of low pressure, convergence of the trade winds (TW, Chapter I-2), and a cloudiness band on satellite imagery. TW convergence defined the classical method of ITCZ identification: TW confluence at low levels and difluence at high levels. This difluence/convergence creates air lifting and therefore the ITCZ controls precipitation formation (Schneider, 2014). In some books, the ITCZ is also referred to as the *Intertropical Front* (Djuric, 1994).

Intense instability creates convective clouds along the ITCZ. Therefore, the second method of ITCZ determining is based on the identification of the band of the convective cloud on satellite imagery (Xavier et al., 2000; Uvo, 1989).

The ITCZ is located over the oceans with positive anomalies of Sea Surface Temperature (SST) and negative anomalies of the surface level pressure (SLP) (Hastenrath, 1991). ITCZ oscillated on average between ~8 ^{o}N during summer of the Northern Hemisphere (July) and ~1 ^{o}N during summer of the Southern Hemisphere (January) (Citeau et al., 1988).

2. Annual and seasonal frequencies.

ITCZ around the globe

The annual variation of the ITCZ location is different around the globe (Figure I-1) (Lockwood, 1974; Hastenrath, 1984, 1991; Weninger, 2014).

The ITCZ usually migrates towards the warming hemisphere (Schneider et al., 2014). The average ITCZ location is north of the Equator because the Northern Hemisphere is warmer than the Southern Hemisphere. Over the Atlantic, the ITCZ is located north of the equator from July to December and near the equator from January to May (Xavier et al., 2000; Hastenrath and Lamb, 1977).

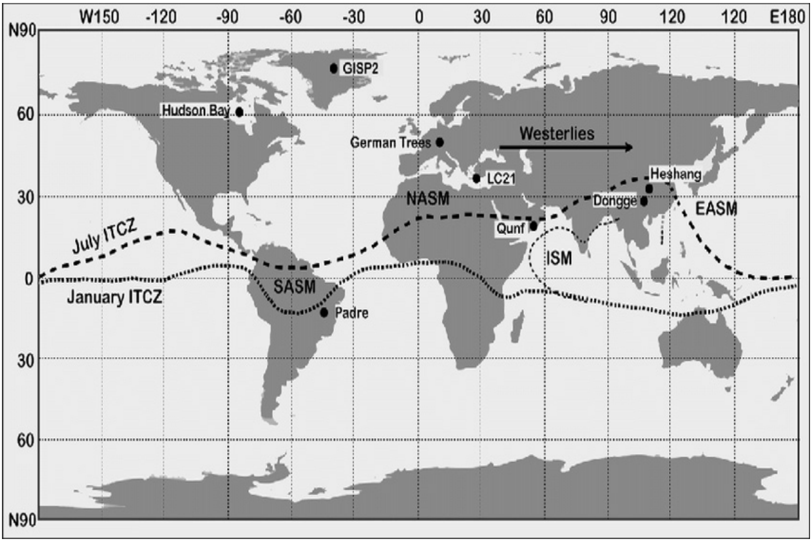
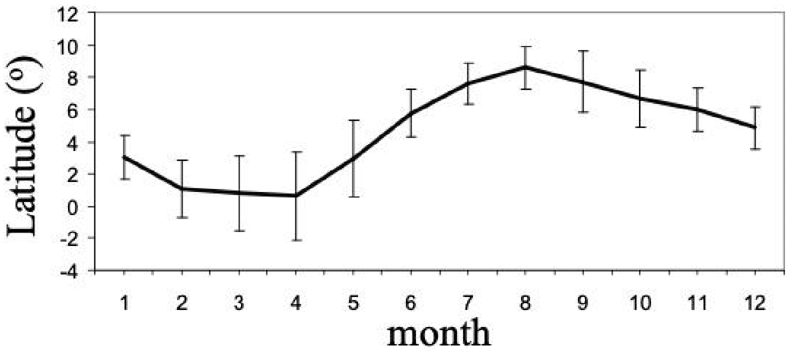


Figure I-1-1 – ITCZ location in July and January
Source: Weninger, 2014

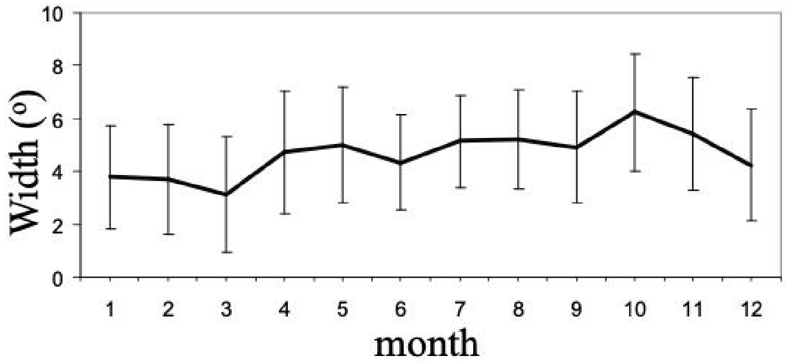
The mechanisms of interannual climate variability, global circulation and, hence the ITCZ location are determined by annual cycles (Hastenrath, 1984). Its position coincides with areas of the ocean with positive SST anomalies, which indicates the relationship between the ocean and the atmosphere (Hastenrath, 1984; Asnasi, 1993).

ITCZ over the Atlantic

In the north of South America, the change in ITCZ location is small, from 2^{o}N in July to 2^{o}S in January (Weninger, 2014). More detailed information shows that ITCZ annual variation over the Atlantic is approximately 7^{o} of latitude (Figure I-2a) (Carvalho & Oyama, 2013). Its displacement ranged from 1^{o}N in April to 8^{o}N in August. The width varied from 3^{o} in March to 6^{o} in October (Figure I-2b). The ITCZ reaches its southernmost position from February to April and tends to decrease in width and intensity during this period. The ITCZ position coincides with the region of a positive SST anomaly (Hastenrath, 1991; Asnani, 1993). On average, positive width anomalies are related with negative SST anomalies and positive convergence of surface winds.



a)



b)

Figure I-1-2 – ITCZ over the Atlantic: a) location per latitude and b) width.
Source: Carvalho & Oyama, 2013

The sea surface temperature (SST) with a negative anomaly or cooling SST in North Atlantic (28-12°N) triggered strong meridional processes (Foltz et al., 2012). During one intense event, SST was 18° C colder than normal, and Equatorial Atlantic was 0.5° C warmer than normal. This very intense SST gradient created anomalous northern trade winds and an anomalous southward shift of the ITCZ. This cooling was initiated by stronger trade winds in January and February 2009. All these processes were associated with an anomalous intense Subtropical High (Chapter I-2). Unusually strong trade winds cooled the ocean due to wind-induced evaporation and deepened the mixed layer by 5-20 m. Near the equator, the wind responded to the anomalous SST gradient between the hemispheres and became northwesterly.

3. Vertical and horizontal structure

Idealized ITCZ

The idealized ITCZ model represents a warm core at the low and upper levels, while a cold core at the middle levels (Figure I-3, Estoque, 1975). Large moisture content is observed through all levels in the central core. Relatively low humidity was found near 700 hPa (Figure I-4). The wind was relatively calm at low levels and significantly disturbed at middle levels. Similar results were obtained for two sources of information: Atlantic Trade Wind Experiment (ATEX) and Line Island Experiment (LIE).

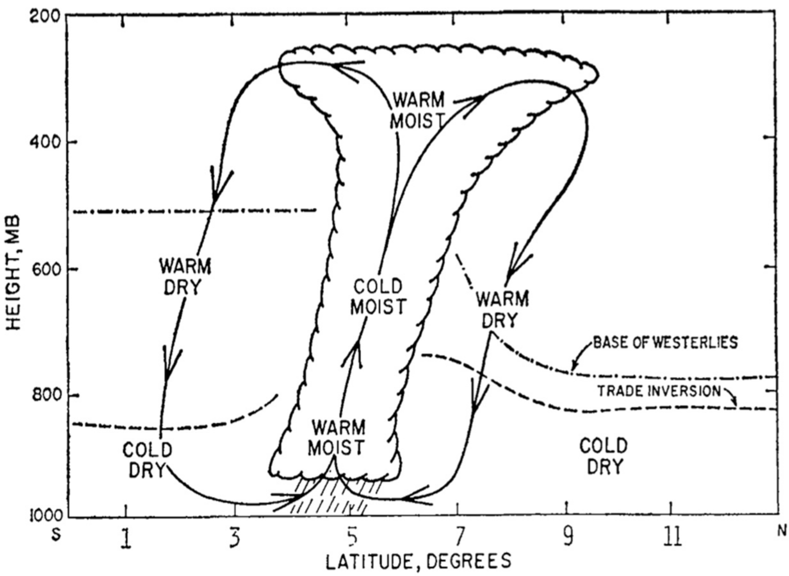


Figure I-1-3 – Schematic diagram of an idealized ITCZ model.
ITCZ: cloud-shaped outline
Source: Estoque, 1975

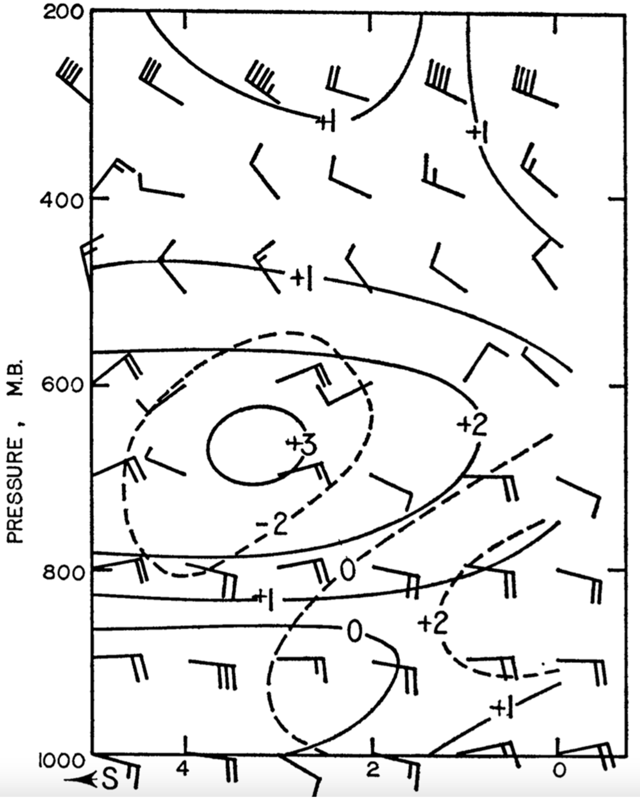


Figure I-1-4 – Vertical structure of the ITCZ along a meridional cross-section based on the Line Island Experiment (LIE) observations.
Temperature (ºC) - full lines, maxing ratio (g/kg) - dashed lines, wind - convectional form (full barb=10 knots)
Source: Estoque, 1975

The absence of any significant temperature maximum at any ITCZ levels was confirmed by various studies by Estoque (1975) and Estoque and Douglas (1978). This conclusion shows that condensational heating is a secondary mechanism for the development and maintenance of the ITCZ. Conversely, the same authors found that the ITCZ of the Central Atlantic presents a warm core at high levels (Estoque & Douglas, 1978). The main mechanisms of ITCZ formation are barotropic instability or "pressure energy flux" from extratropical regions (Estoque & Douglas, 1978).

Double Band

Double bands in the Atlantic were more frequent in March and April (Teodoro et al., 2019). The climatological position of the single ITCZ bands is along 2ºN, and the double bands are along 2ºS. The two bands are 4º latitude apart from each other. Low-level mass convergence and outgoing longwave radiation (OLR) represent the double bands better than the other variables.

When a cold-water current enters the warm ocean around the ITCZ, dividing it, two ITCZ bands or Double Band are formed (Lietzke et al., 2001). The cloudiness band bifurcates, forming two bands visible on the satellite image. The longer its duration, the more precipitation is recorded in the affected region (Uvo, 1989).

The *Eastern Pacific* ITCZ pattern shows a synoptic-scale precipitable water (PW) dual structure, in which "*the southern and northern bands straddled at the ITCZ*" (Chen et al., 2014). This structure produces meridional dipoles, which propagate zonally. These dipoles are observed in summer and autumn. The vertical structure of the meridional wind is baroclinic, and the vertical motion has two peaks at 850 and 300 hPa. Shallow convection within deep convection forms east of the dipoles. Deep convection tends to be suppressed by the intrusion to the west of the dipole of dry cold air at middle levels. The dual band can be related to wind divergence and humidity advection. Strong meridional dipoles are closely associated with ITCZ distortion and breakdown. For the Atlantic region, such information has not yet been received.

4. ITCZ formation

Thermic theory

The scheme of the global circulation and, as a result, the ITCZ formation, was originally based on climatological maps. Thermal convection within the equatorial depression was defined as the main force of the Global Circulation (many books are cited in Pedelaborde, 1958). The example shows a map of the radiation balance per year; almost identical values are visible on this map in a wide band between 20ºN and 20ºS, approximately (Figure I-5). Many other maps show similar results, such as global radiation (Lockwood, 1974), surface temperature (Fedorova, 2001, 2008). All these maps show a contradiction with thermic theory, since the highest values are observed not only along the equator, but also in a wide band around the globe. Therefore, according to this theory, thermal convection should be observed in this large band, but this is not confirmed by observational data.

On the other hand, according to Pedelaborde (1958, with reference to Rossby), there is no thermal lifting in the equatorial region. This is due to strong cloud cover in the equatorial region, which reduces surface heating. Compared to anticyclones in the subtropics, where the highest temperature and subsidence of air masses are observed in cloudless areas (Chapter I-2, SASH). As a result, the lifting in the equatorial region is the result of dynamic processes due to trade winds confluence. Additional evidence of the predominance of the dynamic process is the frequent absence of the antitrade wind at the upper levels. But in the thermal theory, the presence of the antitrade wind at the upper levels is necessary for the SASH formation (Pedelaborde, 1958).

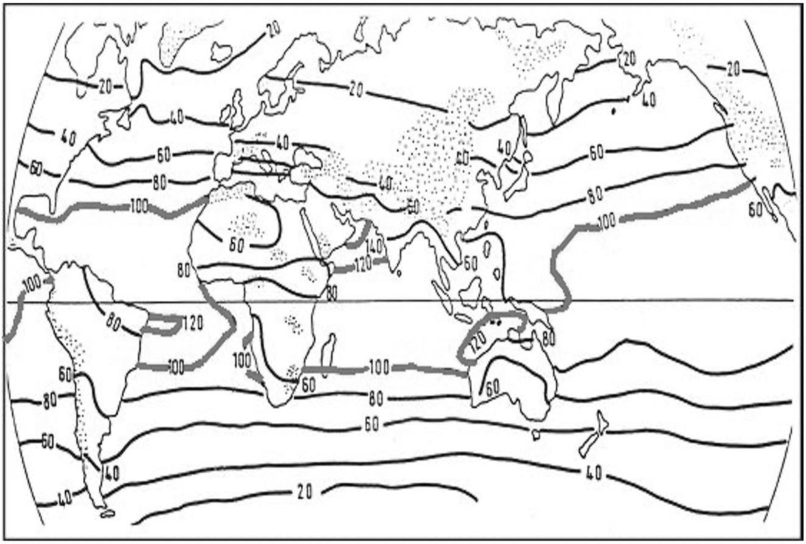


Figure I-1-5 – Radiation balance at the surface per year (Kcal cm^{-2}/year)
Source: Lockwood, 1974

Many authors (for example, Djuric, 1994) refer to the ITCZ as the *Intertropical Front* (Figure I-6). It is located between the trade winds of both hemispheres, usually within 10^o of latitude, but may cross the equator. Often the ITCZ is difficult to distinguish, and it expands into a large transition zone between the northern and southern trade winds.