The Abdus Salam International Centre for Theoretical Physics

2138-16

Joint ICTP-IAEA Workshop on Vulnerability of Energy Systems to Climate Change and Extreme Events

19 - 23 April 2010

HYDROMETEOROLOGICAL HAZARDS IN THE GULF OF CALIFORNIA AND VULNERABILITY OF THE COASTAL CITIES OF GUAYMAS-EMPALME, SONORA, MEXICO, DURING CYCLONE JIMENA IN SEPTEMBER, 2009

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Mexico

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Trieste, Italy, April, 9-13

WHY THIS EVENT AND WHY THIS REGION?

• OBJECTIVES

- To show you a very special hydrometeorological event.
- How to reduce the vulnerability of a region with an unexpected event?
- Attention on warnings and forecasting, because:

  The role of hurricanes in the global climate system has gained interest ever since scientists suggested that strong hurricanes have become more frequent in recent decades and might continue to do so as the planet warms.

ABOUT THE REGION

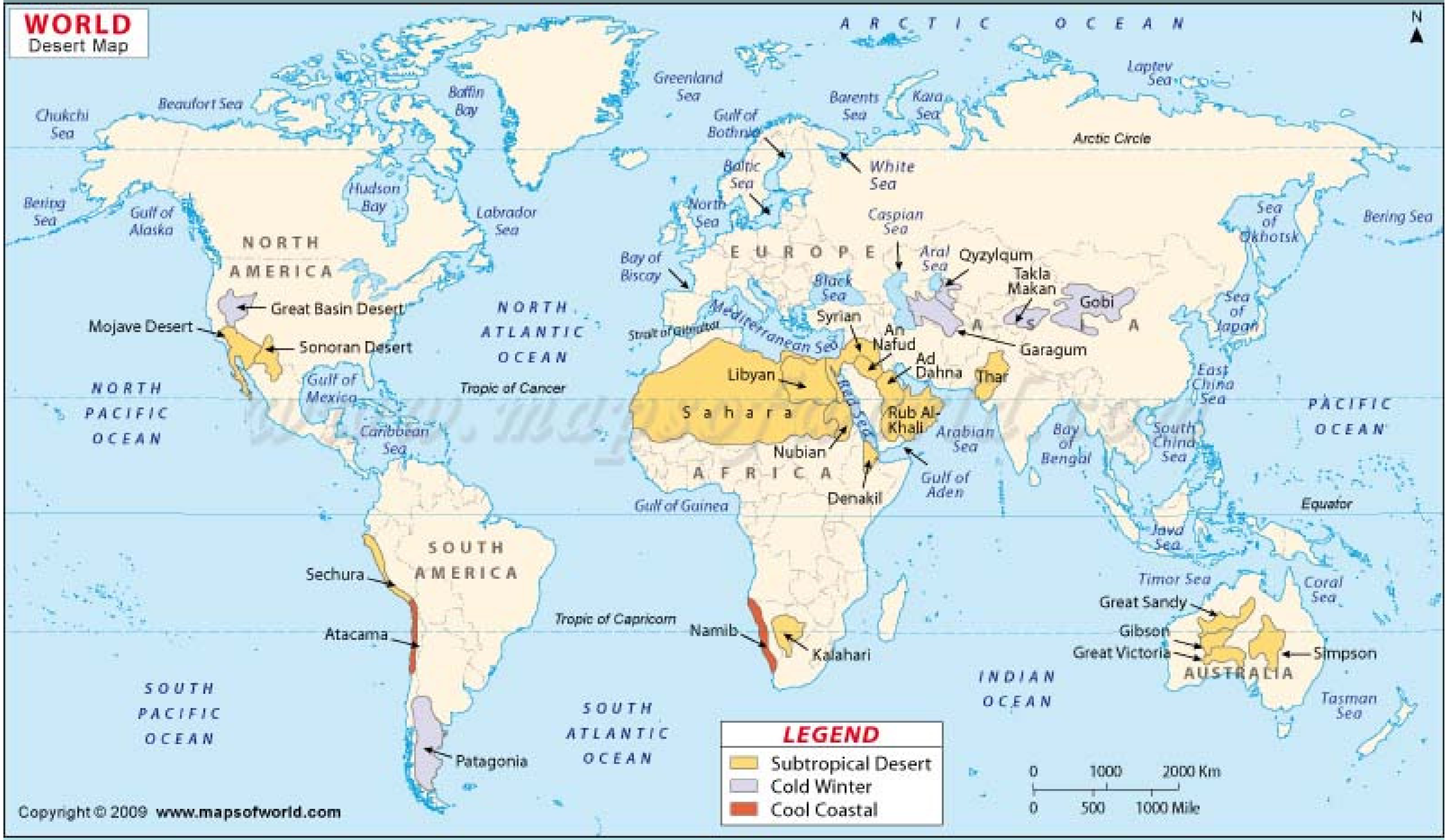
NORTHWEST OF MEXICO

(GULF OF CALIFORNIA)

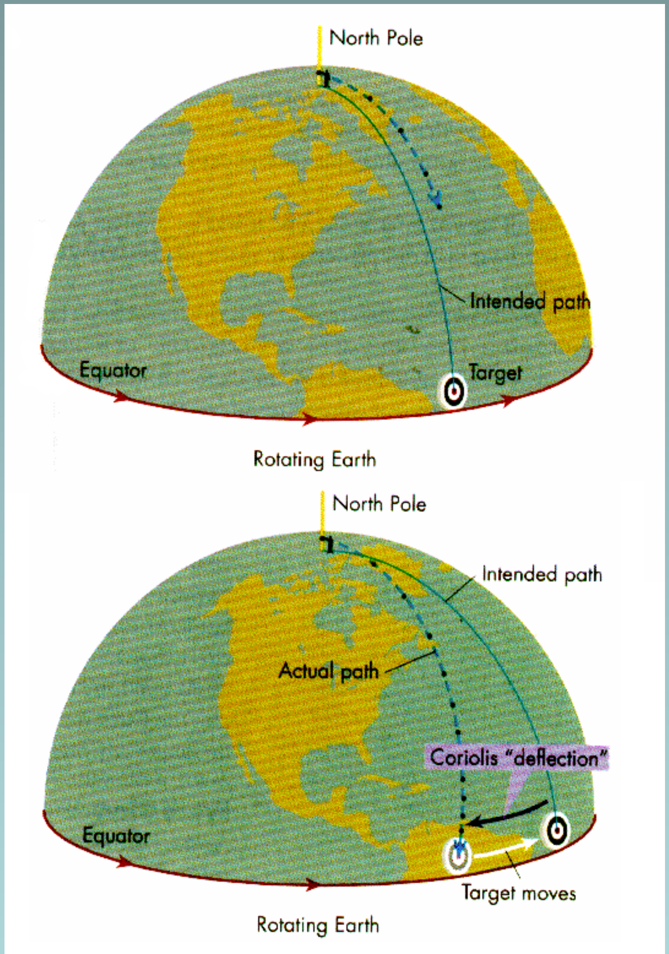
AND

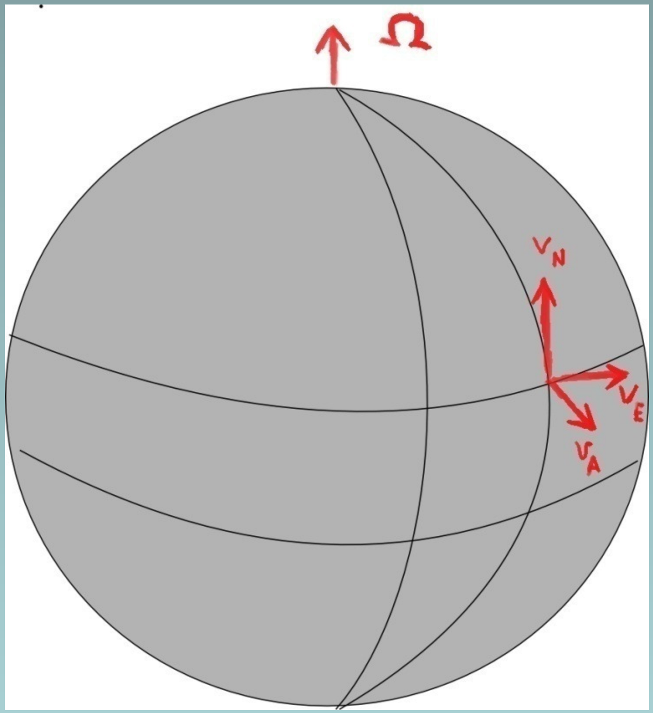
ORIENTAL PACIFIC OCEAN

GLOBAL FRINGE OF DESERTS



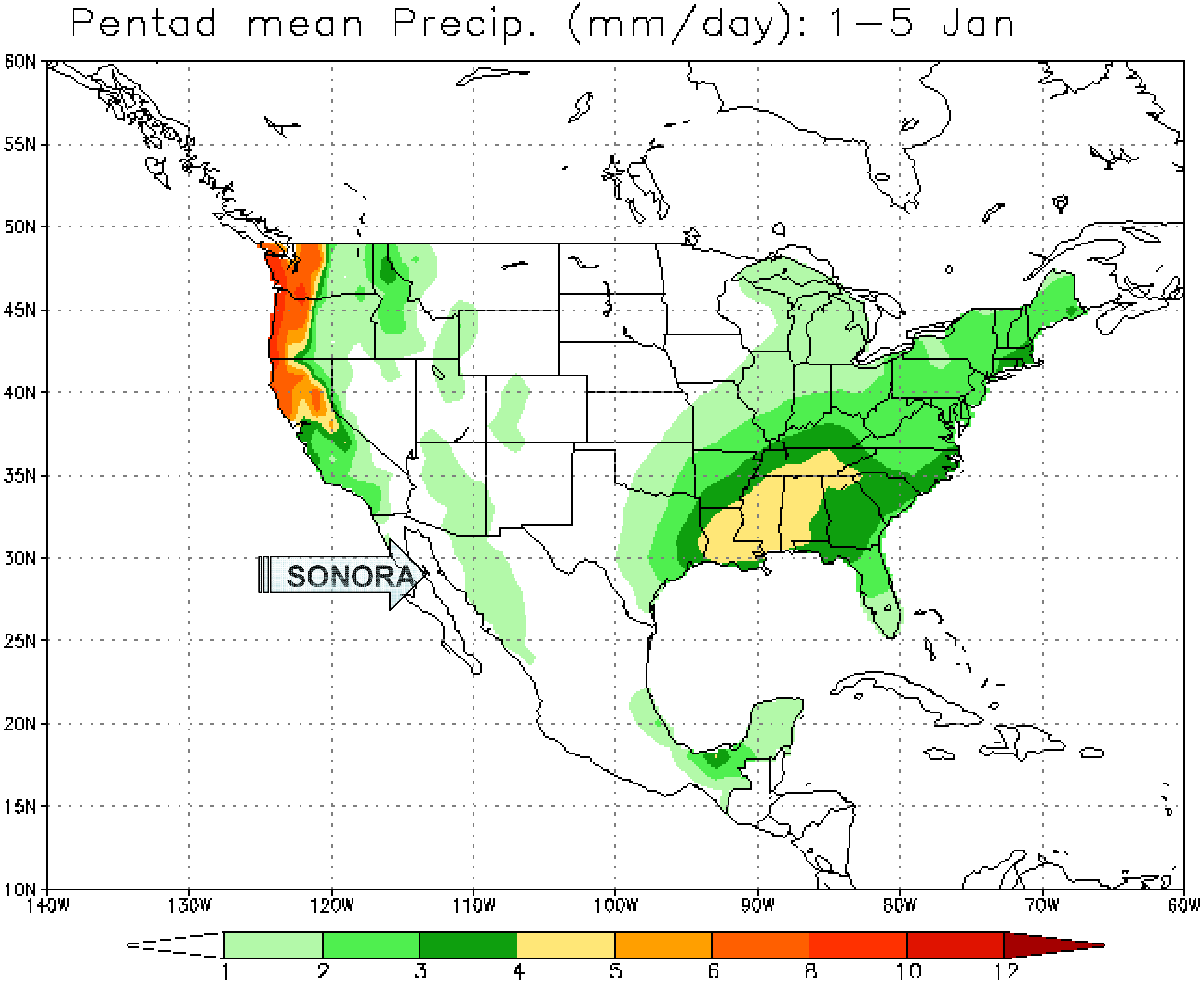
The hurricanes: a consequence of the Coriolis force modeled by means of a cycle of Carnot





It influences in the speed of an air molecule of the atmosphere (rotating sphere)

RAINFALL ANNUAL DISTRIBUTION IN MEXICO-USA REGION



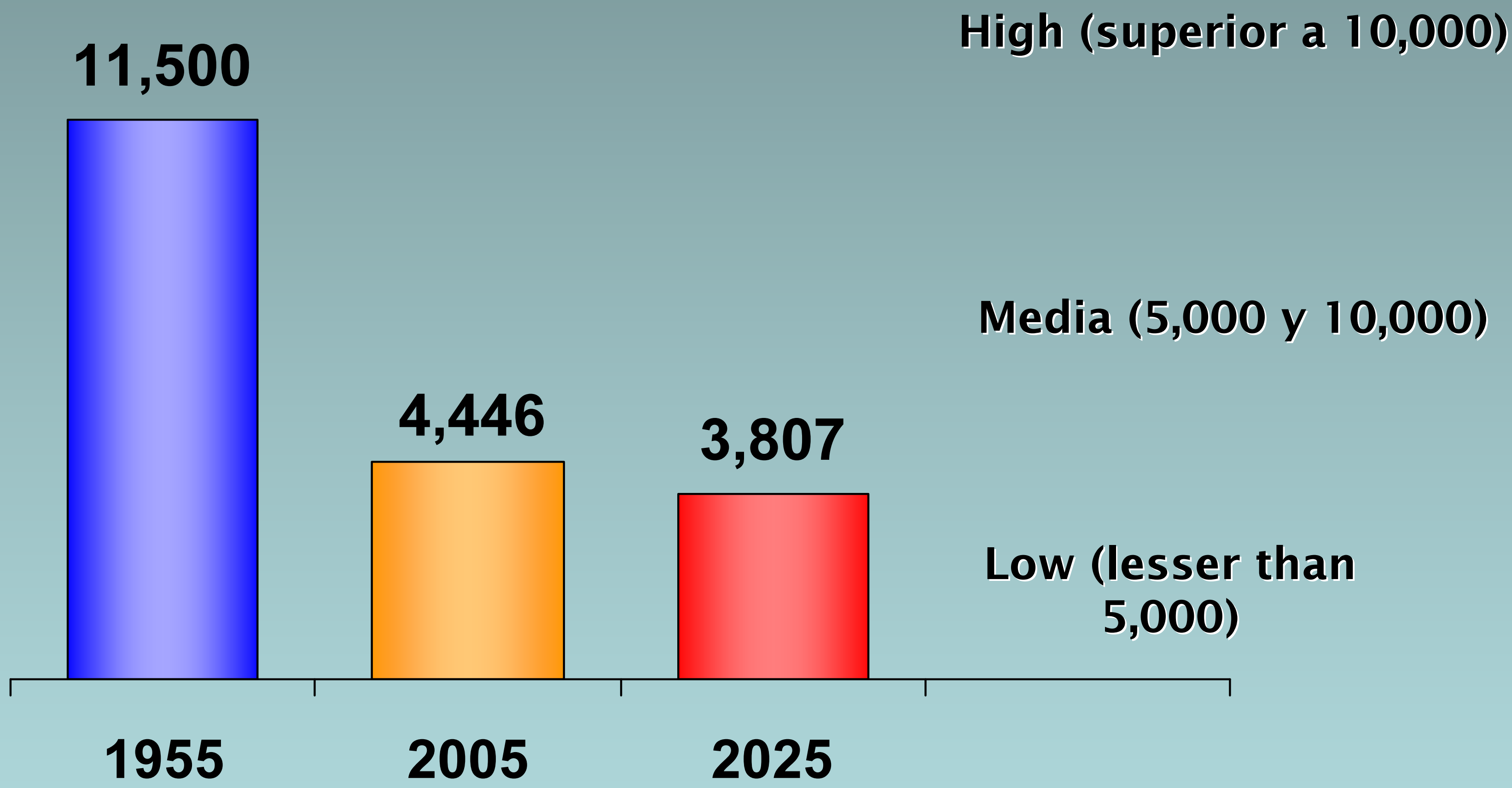
OUR REGION

Area
205,291 km2

Population
2.41 million inhabitants
(2008)
2.4% of Mexico´s population.

Evolution of the water availability in Mexico

Cubic meters/inhabitant/year



ACTUAL AVAILABILITY

- **NORTHWESTERN OF MEXICO 3,172**

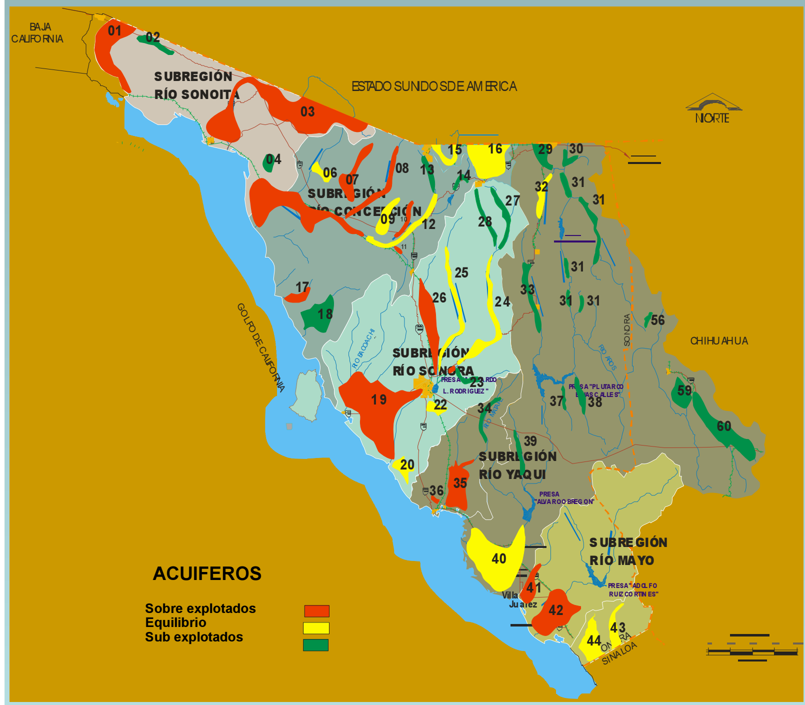
(CONAGUA, 2009)

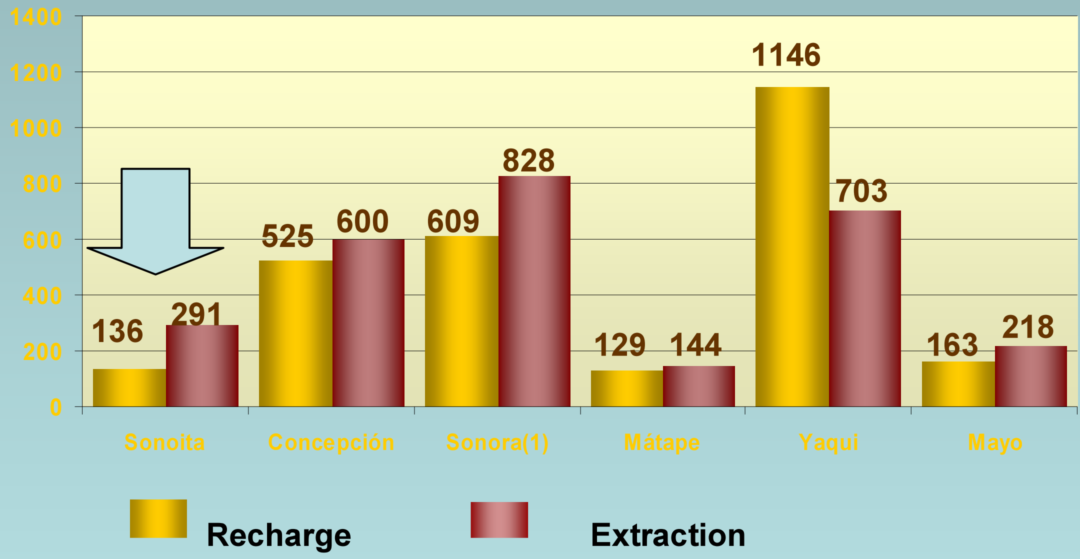
GROUNDWATER

The average charge is of 2707,08 hm3/year and the extractions are of the order of 2784,91 hm3/year. Regional deficit of -77,83 hm3/year.

64 aquifer systems in the región.

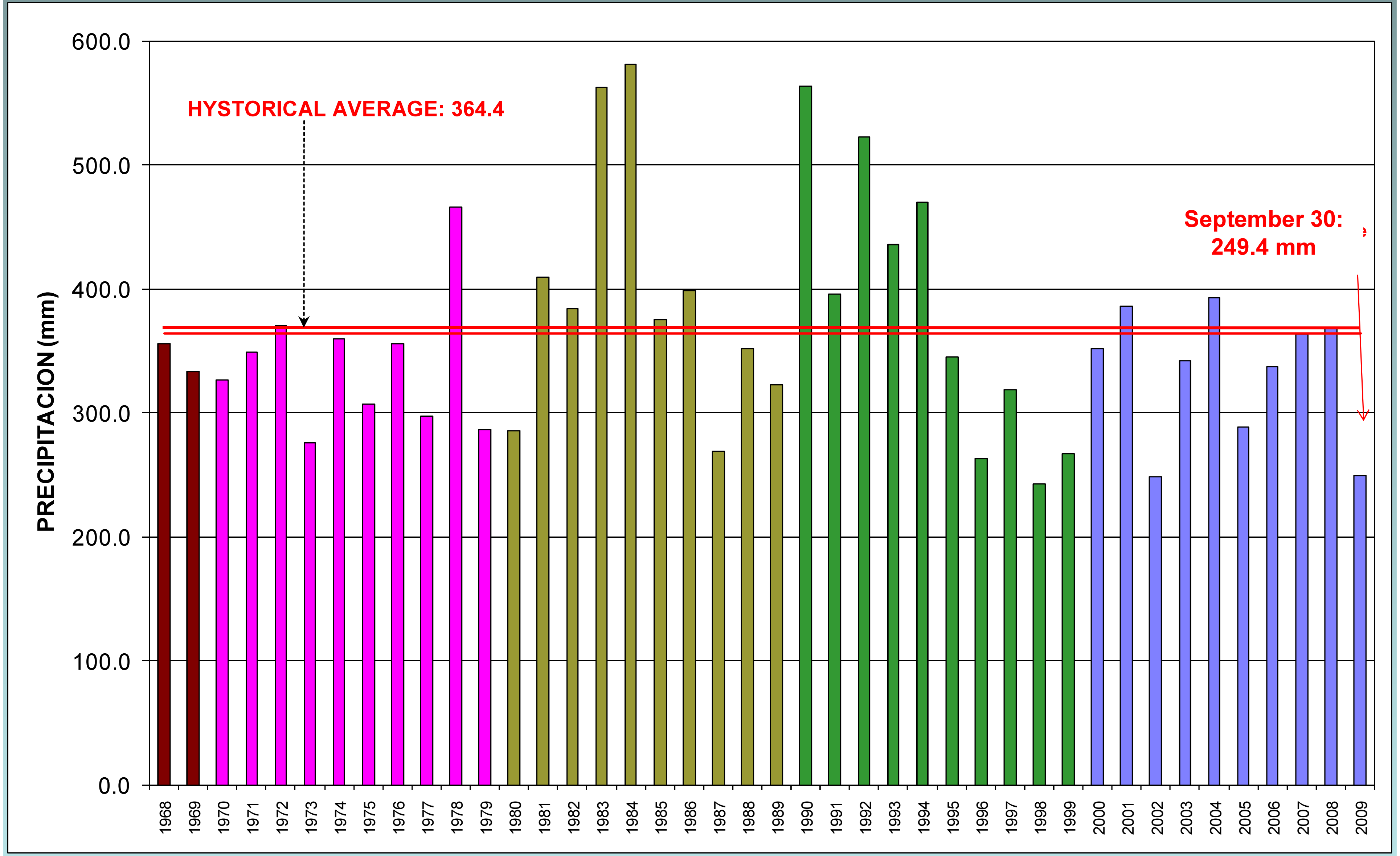
15 under overexplotation,





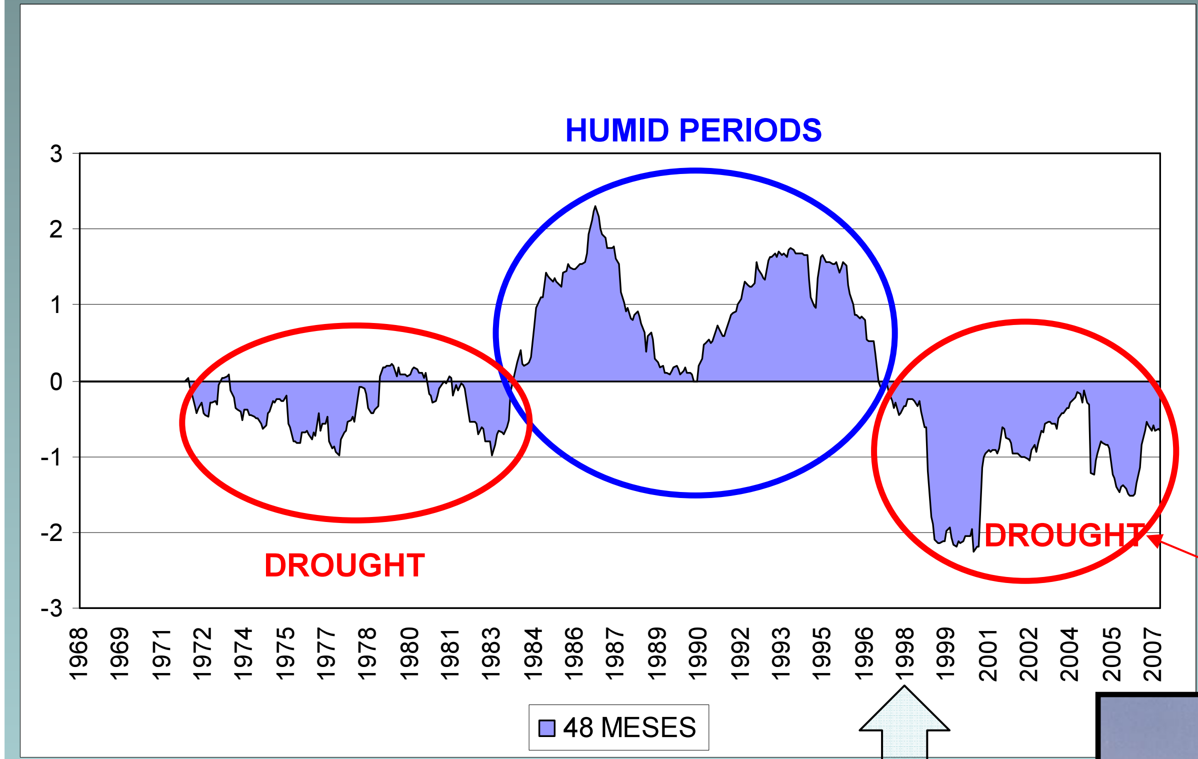
PRECIPITATION IN THE REGION

41 YEARS (1968-2009)



SONORA RIVER BASIN

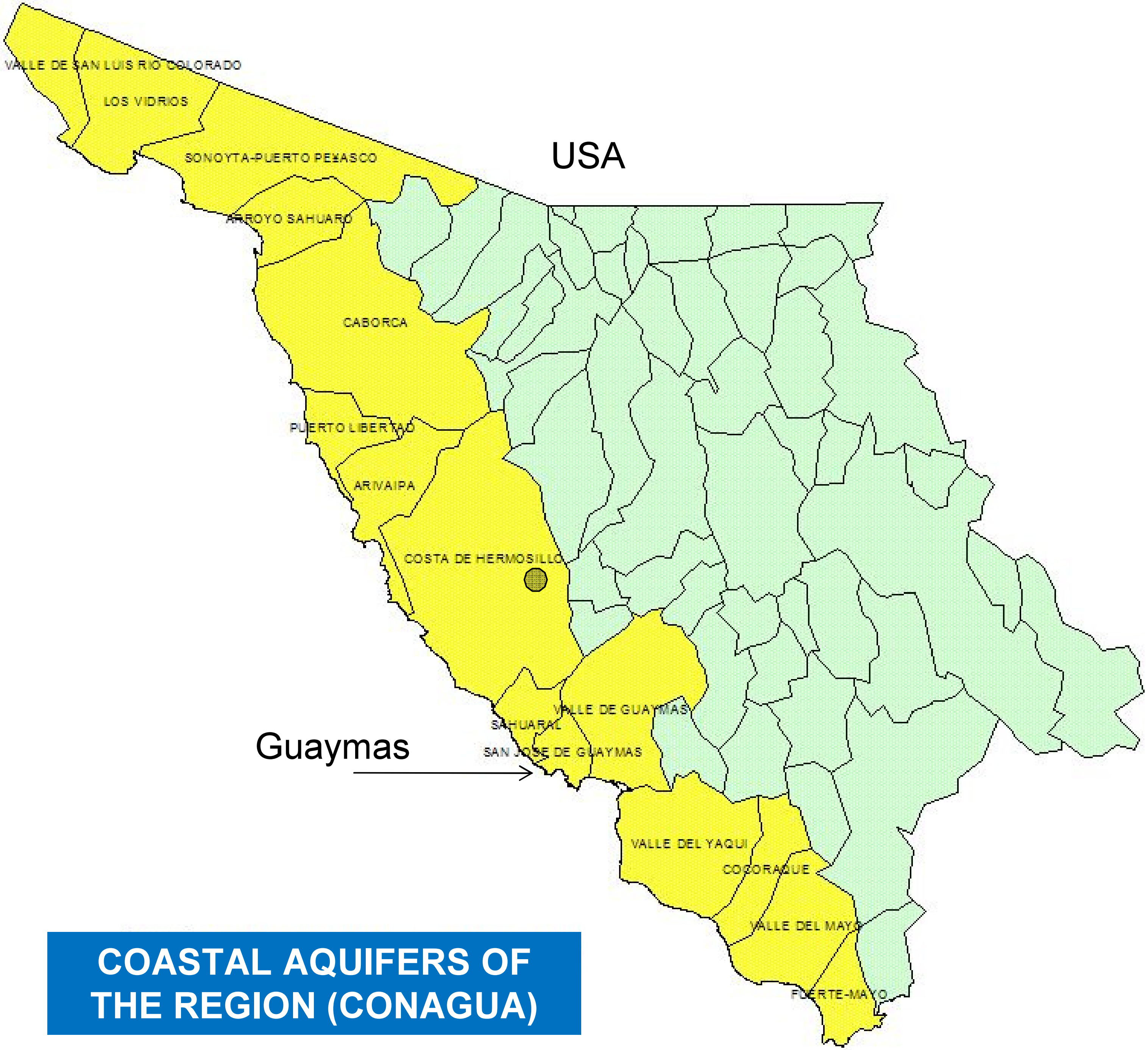
STANDARD PRECIPITATION INDEX (SPI)



STORAGE ZERO

Hermosillo's Dam

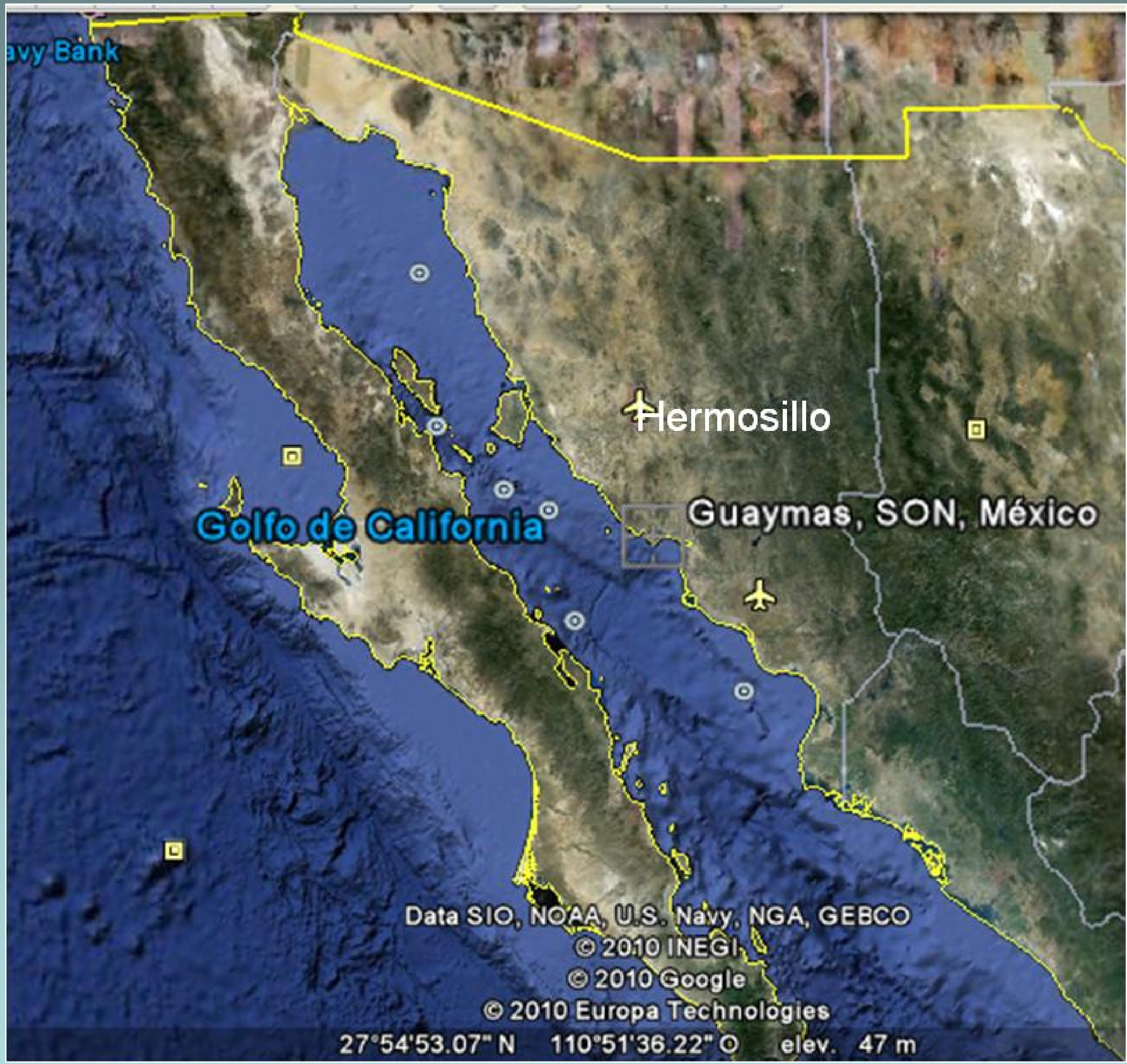
Abelardo Rodríguez Dam
río Sonora Basin
Hermosillo, Sonora



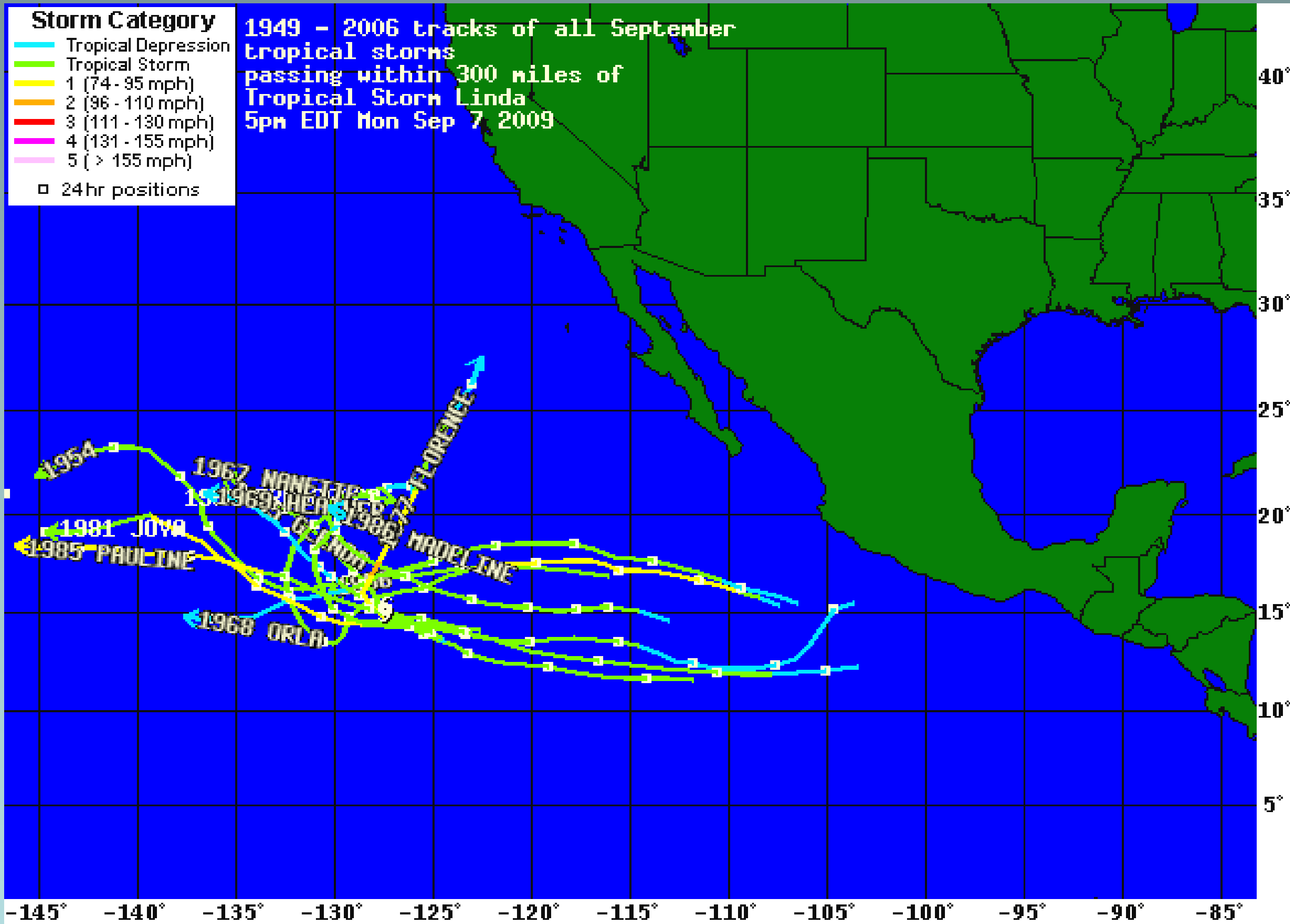
COASTAL AQUIFERS OF THE REGION (CONAGUA)

HURRICANES IN THE GULF OF CALIFORNIA

Hystorical conditions

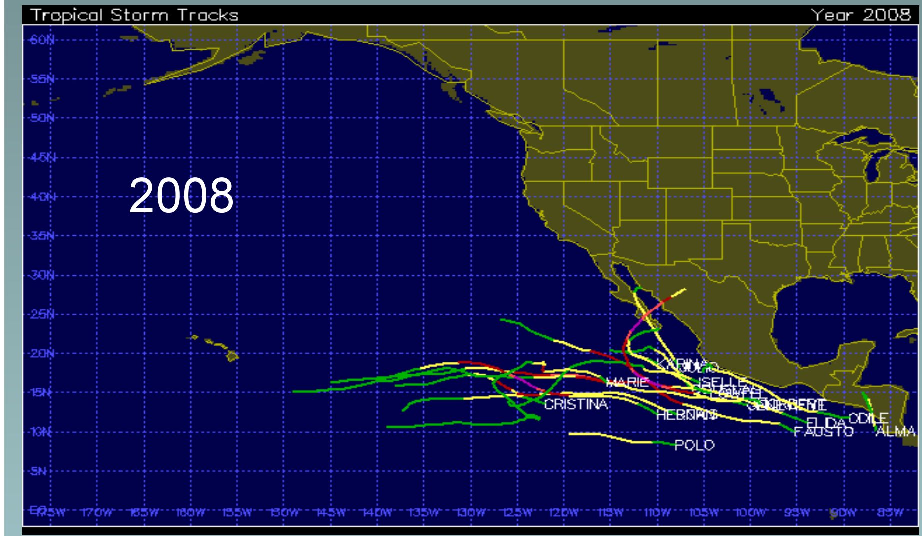

avy Bank
Hermosillo
Guaymas, SON, México
Golfo de California
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2010 INEGI
© 2010 Google
© 2010 Europa Technologies
27°54'53.07" N 110°51'36.22" O elev. 47 m

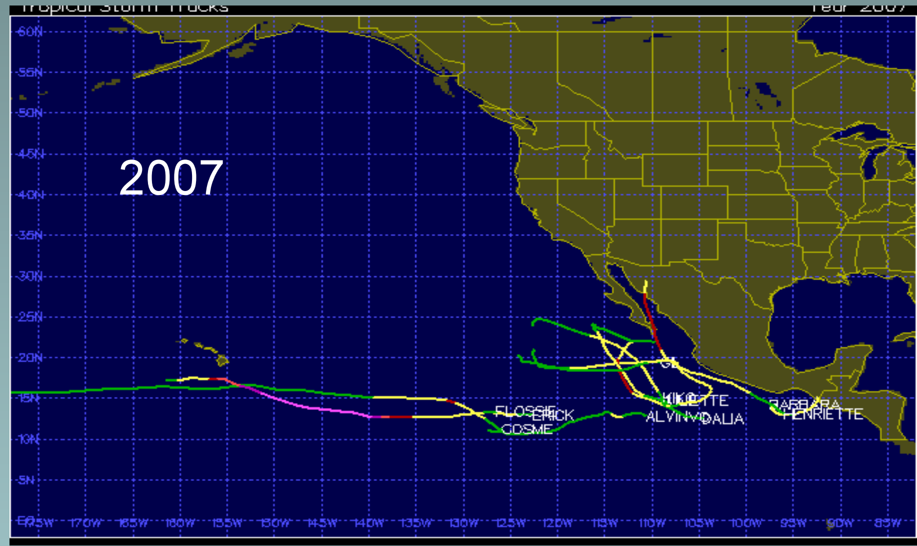
Trajectories in the oriental Pacific

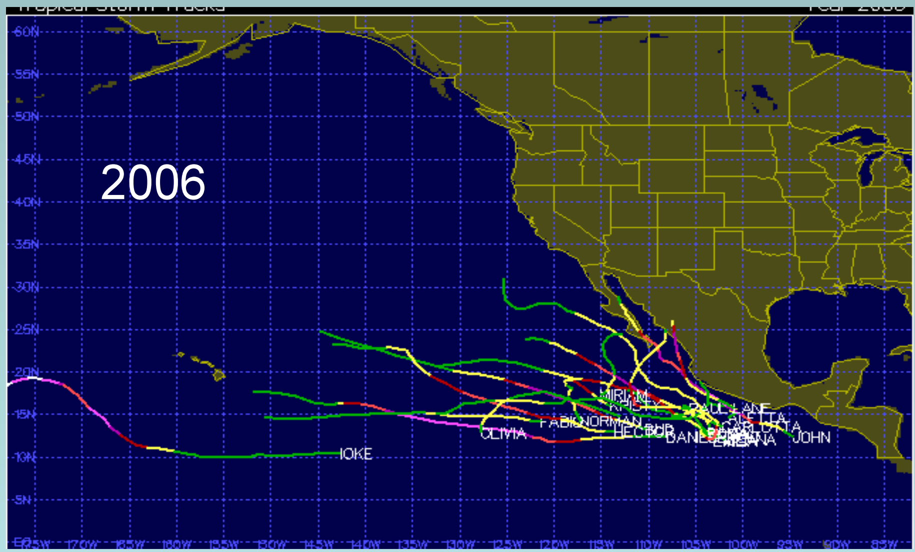


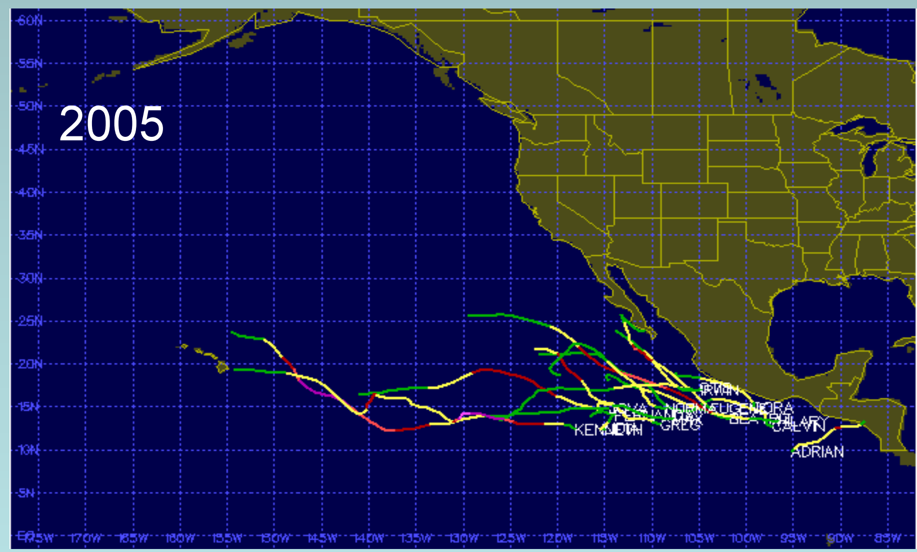
Source: http://www.wunderground.com/hurricane/hurrarchive.asp

Trajectories oriental Pacific



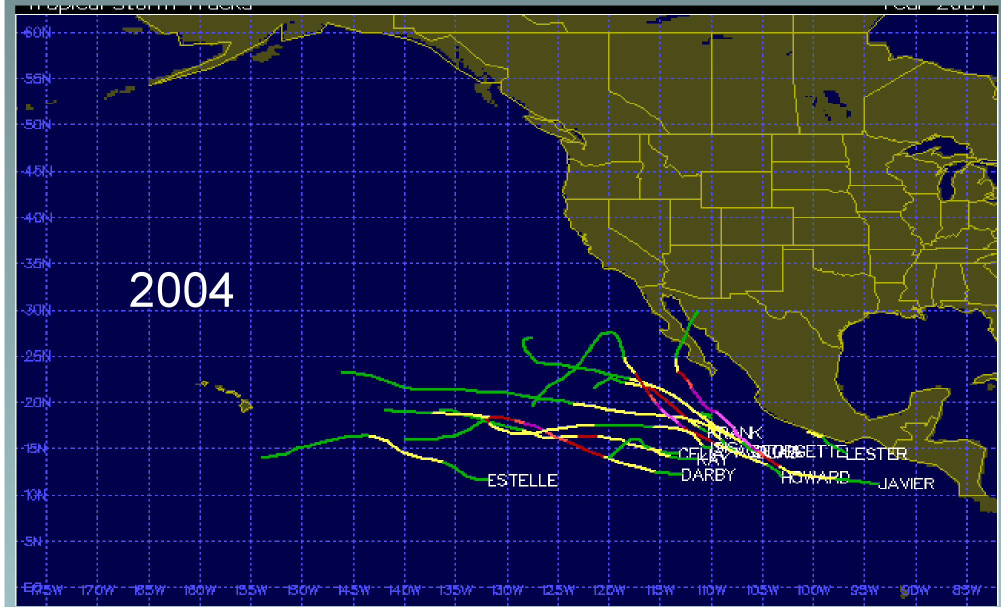


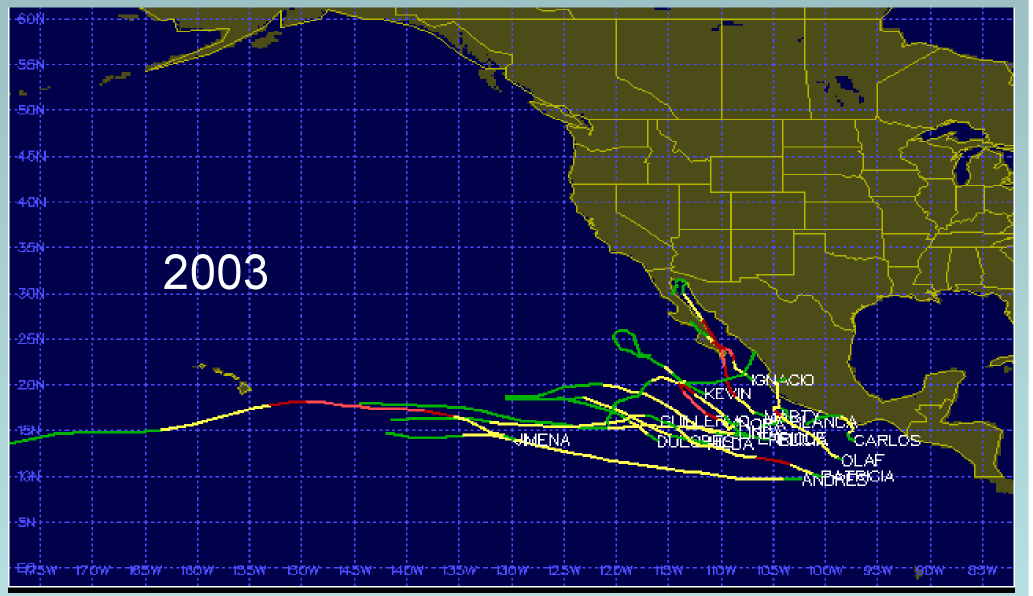




Fuente: http://weather.unisys.com/hurricane/e_pacific/index.html

Trajectories oriental Pacific

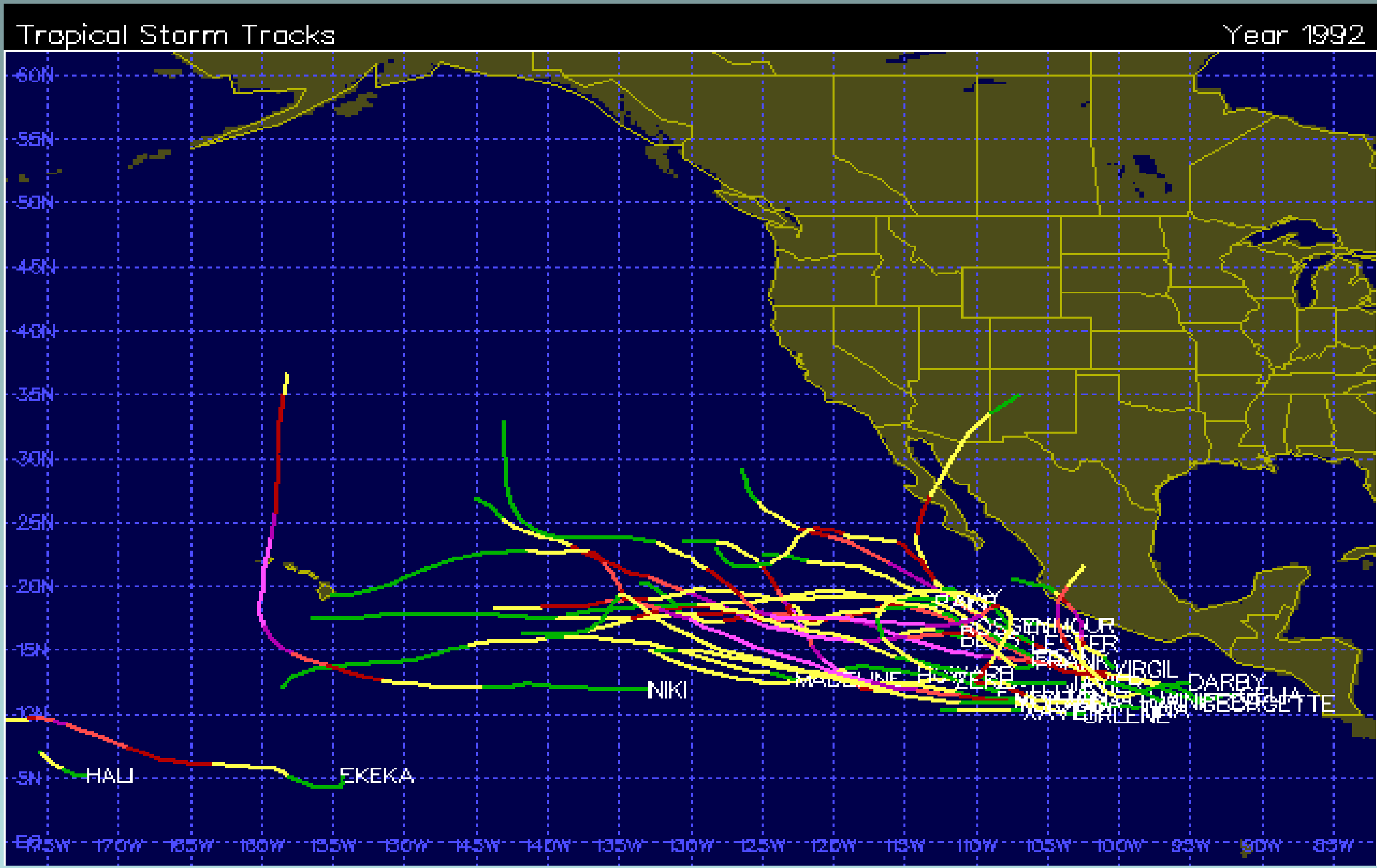




Fuente: http://weather.unisys.com/hurricane/e_pacific/index.html

Hurricane Lester (23/08/1992)

Hurricane 1 (Gulf of California) to Tropical Depression (Sonora)



Fuente: http://weather.unisys.com/hurricane/e_pacific/index.html

Hurricanes in the Gulf of California

- The cyclones formation in the oceans are usually favored when the upper layer of the water surface in the oceans reaches 26ºC.

- Winds from all directions will trend to flow to the low pressure zone.

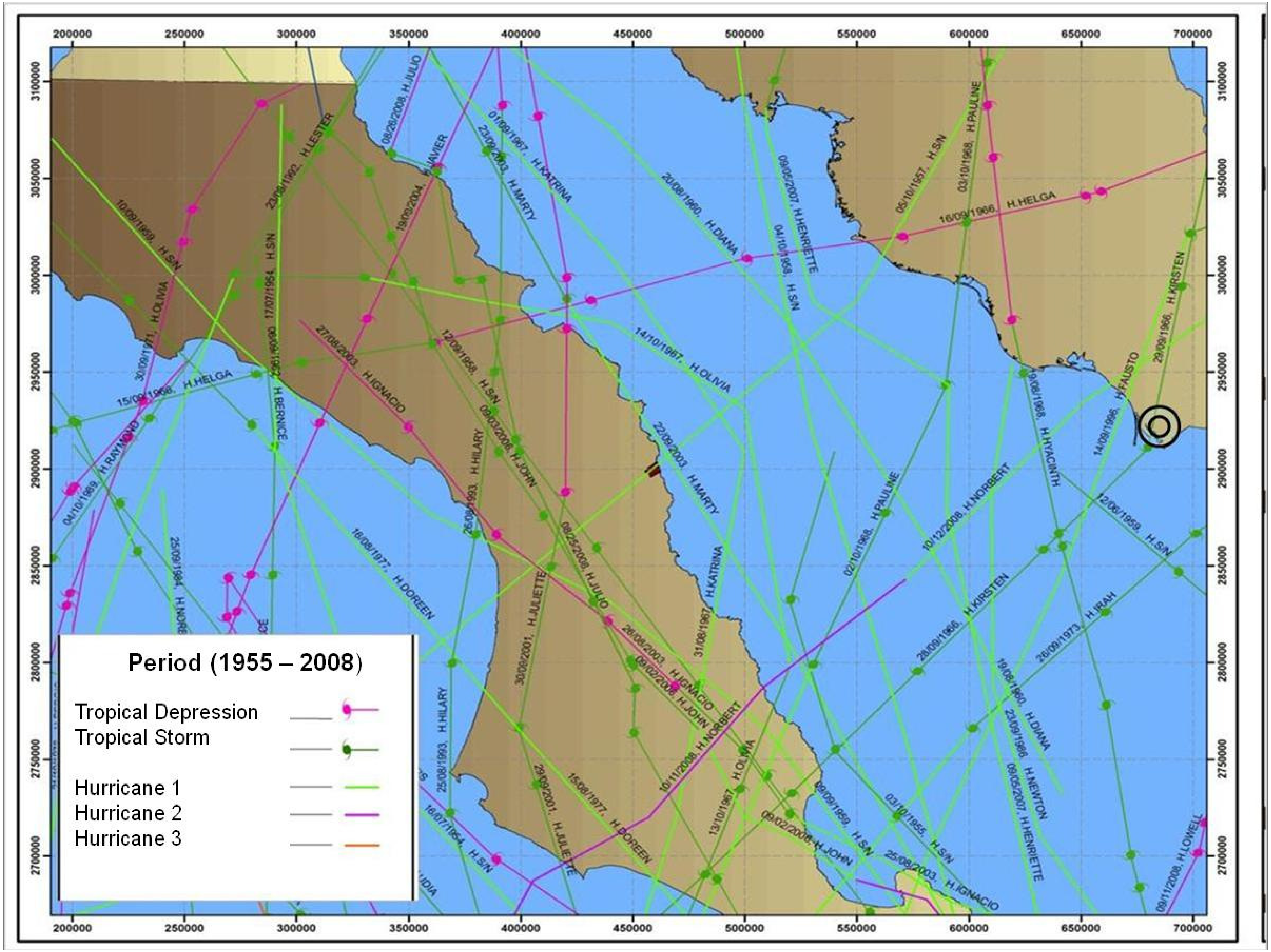
- The atmospheric, oceanic and the latitude conditions expose the Gulf of California to the effect of tropical cyclones from the Pacific ocean.

Hurricanes in the oriental Pacific Ocean

PERIOD	HURRICANES CATEGORY 1, 2 AND 3	HURRICANES CATEGORY 4 Y 5	TOTAL
1970-1979	63	18	81
1980-1989	73	23	96
1990-1999	59	36	95
2000-2009	51	17	68

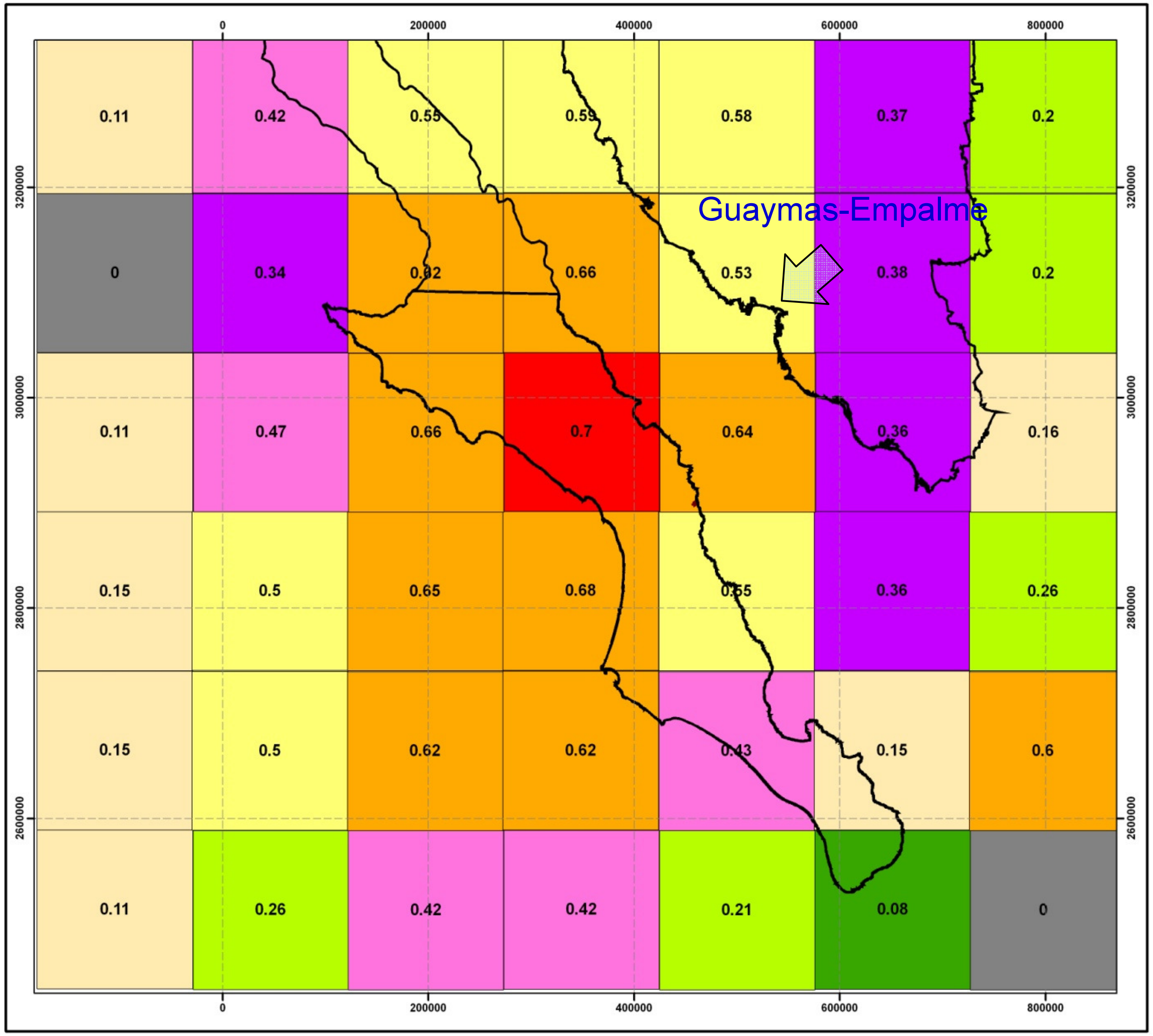
Nine Hurricanes Category 5 in the Period 1970-2009

NOMBRE	MES	AÑO
AVA	JUNIO	1973
EMILIA	JULIO	1994
GILMA	JULIO	1994
JOHN	AGOSTO	1994
GUILLERMO	JULIO	1997
LINDA	SEPTIEMBRE	1997
HERNAN	AGOSTO	2002
KENNA	OCTUBRE	2002
RICK	OCTUBRE	2009

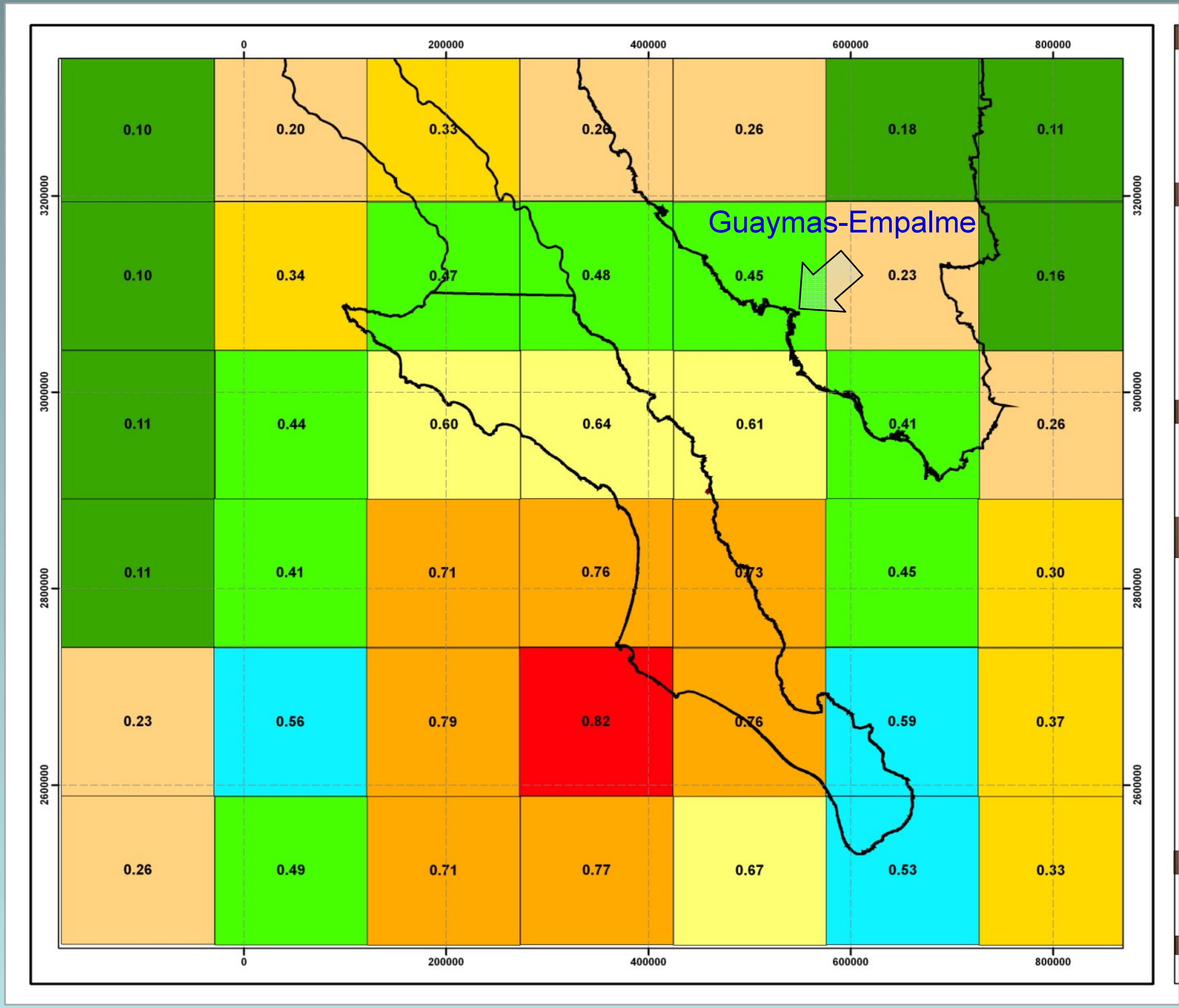


Period (1955 – 2008)
Tropical Depression
Tropical Storm
Hurricane 1
Hurricane 2
Hurricane 3

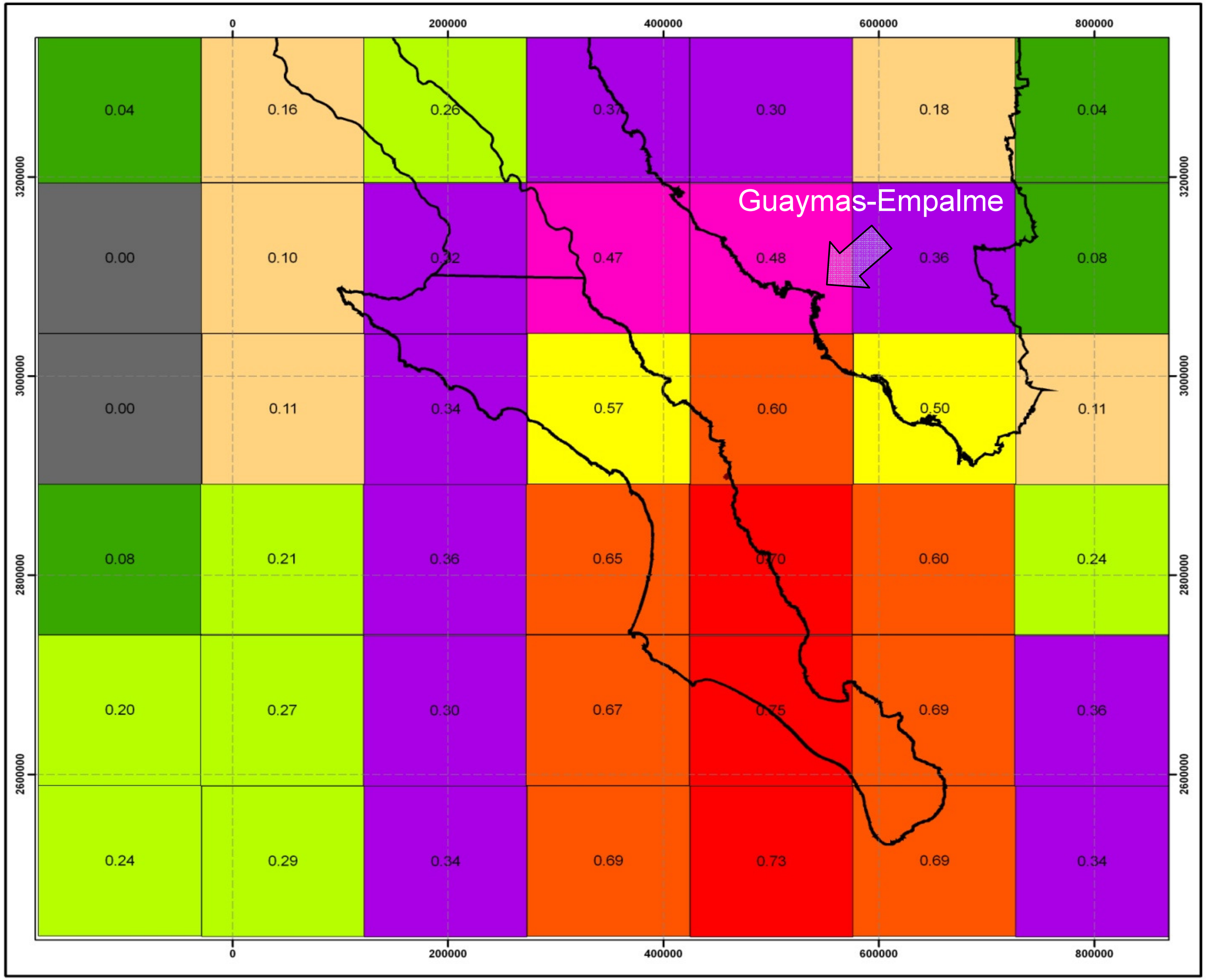
Tropical Depression
Probability in the Gulf of California



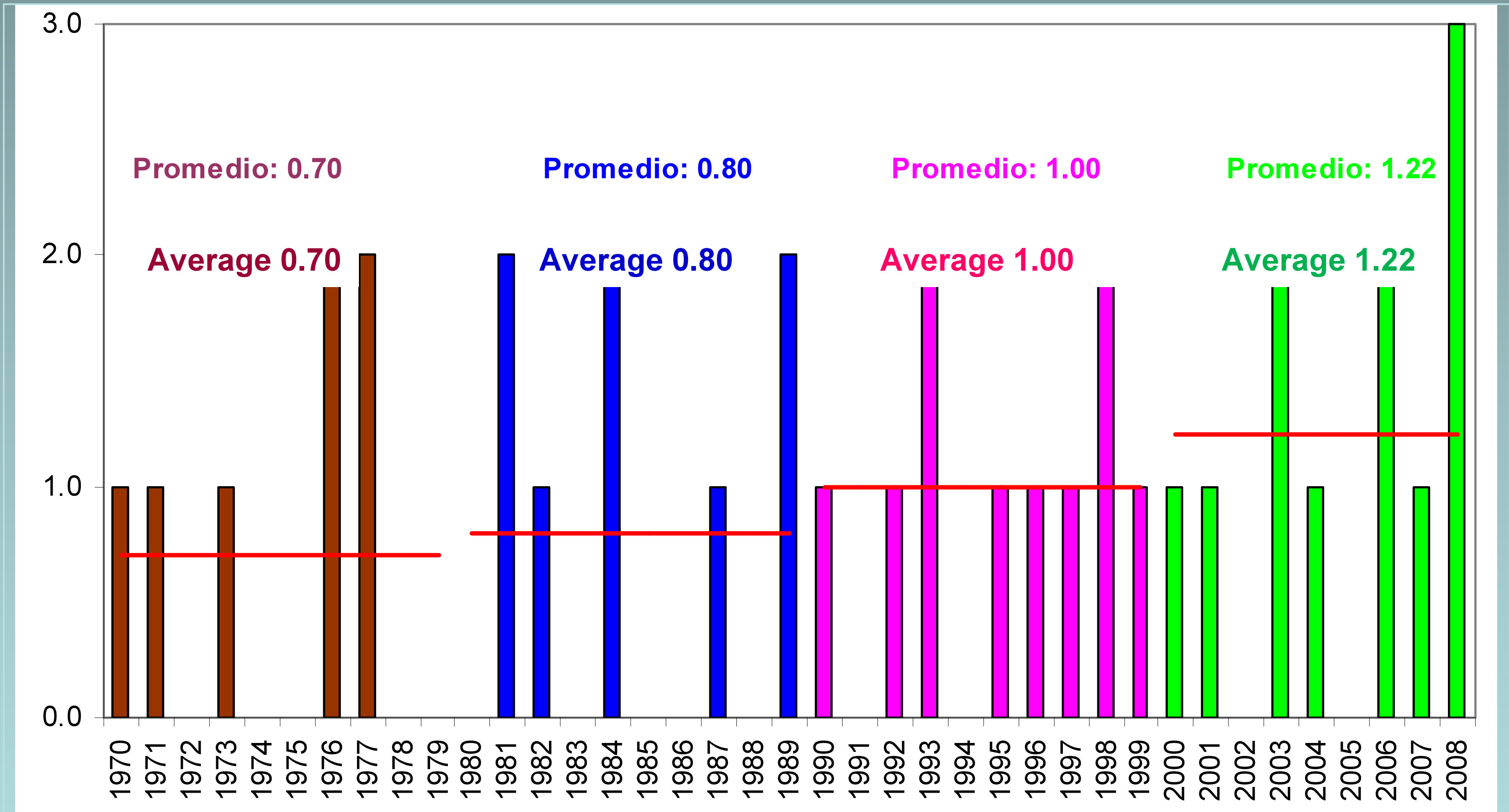
Tropical Storm
Probability in the Gulf of California



Hurricane category 1
Probability in the Gulf of California

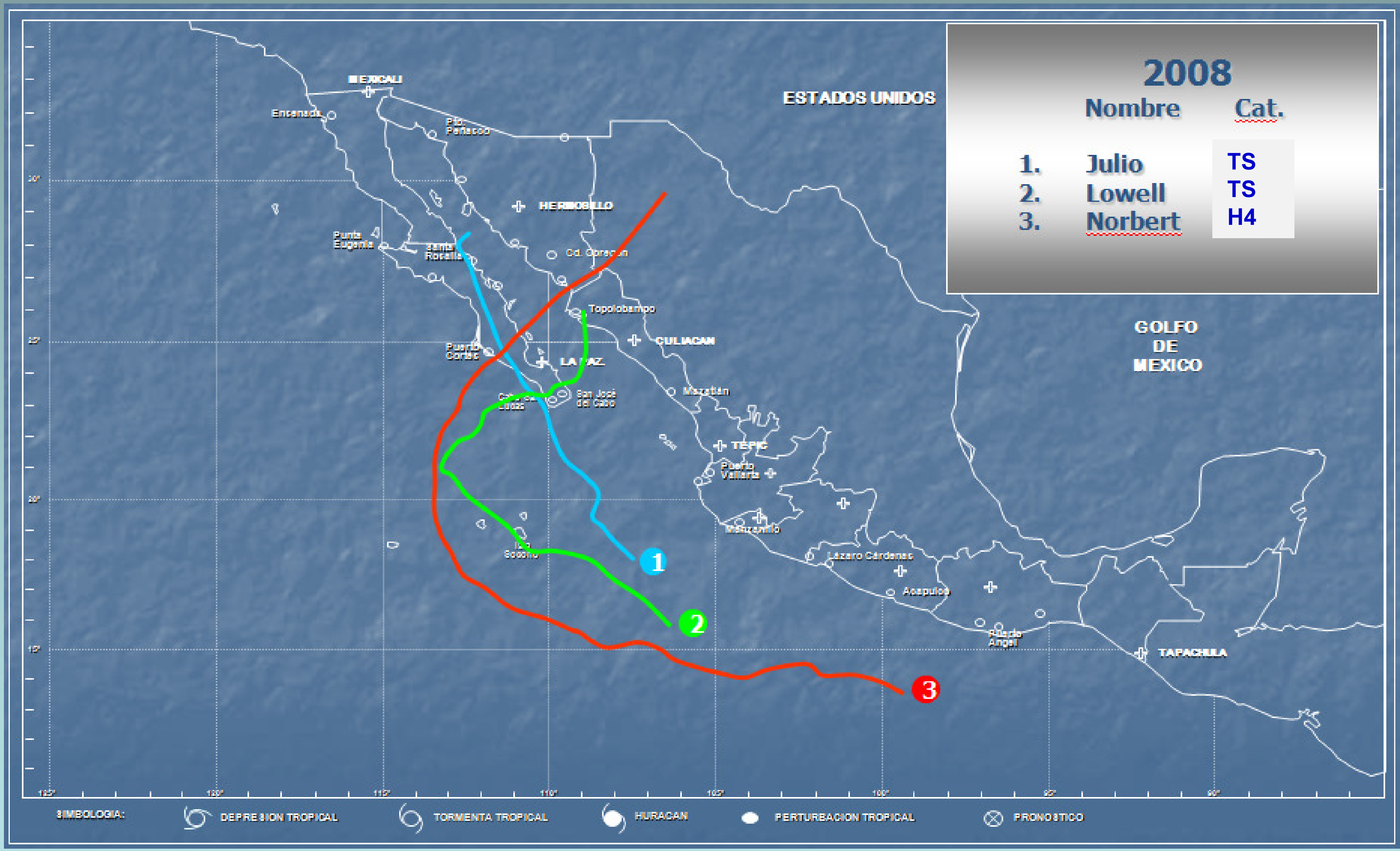


Evolution of cyclones presence in the Gulf of California (1970-2008)



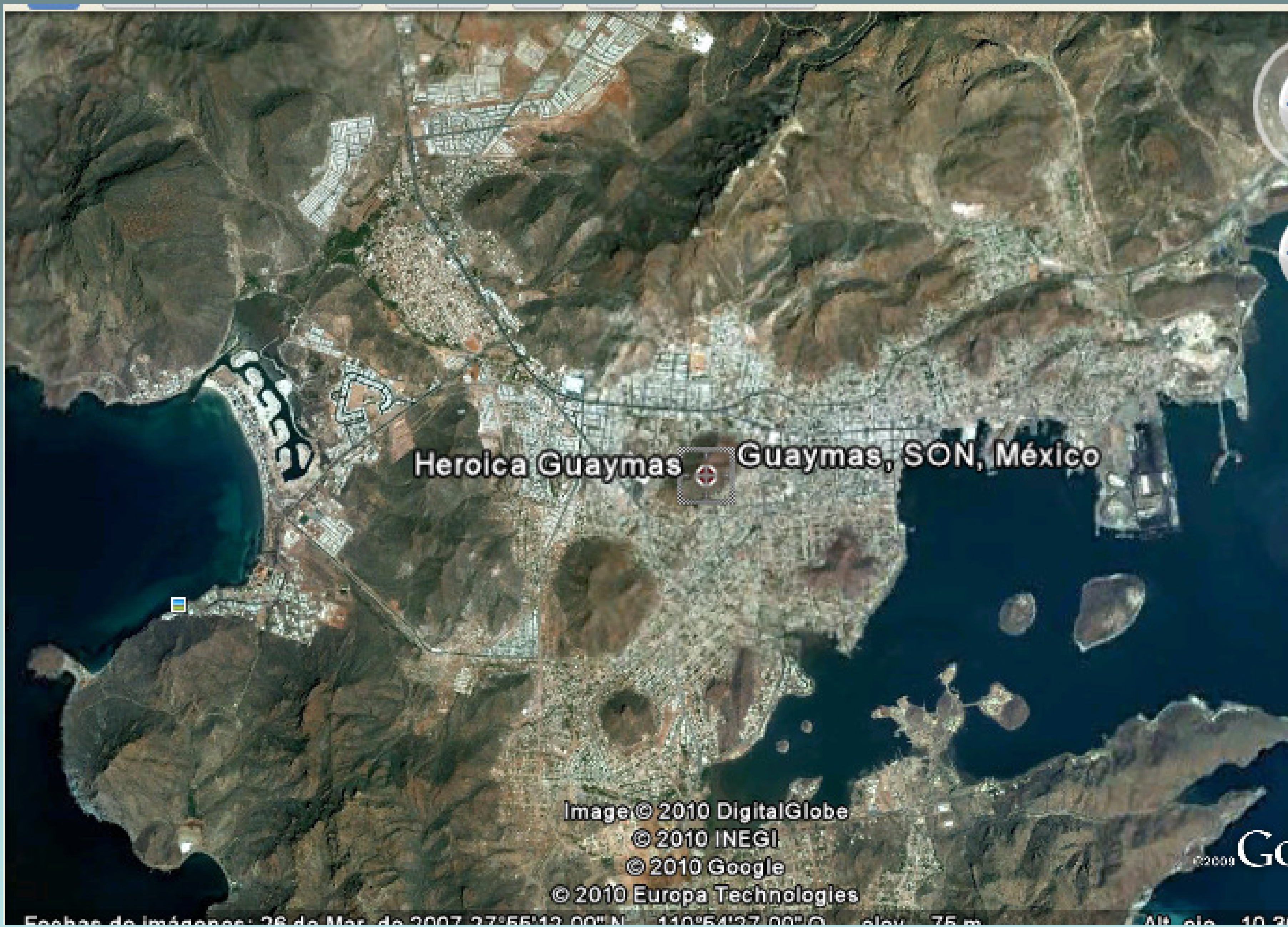
Hurricanes are known to influence the oceans and overall climate system, the consequences of the increase in the frequency of hurricanes could go further.

Trajectories of tropical cyclones to the Gulf of California (2008)



HURRICANE JIMENA

DURING THE EVENT


Heroica Guaymas
Guaymas, SON, México
Image © 2010 DigitalGlobe
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THE HISTORICAL RECORD

The state of Sonora is a region semi arid to arid with an annual average of 364mm/year (1968-2008). But by this time these cities got a new historical record of rainfall.

Previous record in maximum rainfall in 24 hours: Hermosillo city 152.6 mm (November 11th, 1994).

Total rainfall in Guaymas from16:00 hours September 2th to14:00 hours of September 4th: 712.5 mm

Total rainfall in Guaymas from 16:00 hours September 2th to 14:00 hours September 4th (46 hours): 712.5 mm

TROPICAL DEPRESSION THIRTEEN-E DISCUSSION NUMBER 1 NWS **TPC/NATIONAL HURRICANE CENTER MIAMI FL**

EP132009 800 PM PDT FRI AUG 28 2009

“CONVENTIONAL SATELLITE IMAGERY INDICATES THAT THE AREA OF LOWPRESSURE LOCATED SOUTH-SOUTHWEST OF ACAPULCO HAS ACQUIRED SUFFICIENT ORGANIZED CONVECTION TO BE CLASSIFIED AS A TROPICAL DEPRESSION”.

“THE OFFICIAL FORECAST INDICATES INTENSIFICATION AT A CLIMATOLOGICAL RATE AND SIMILAR TO THE INTENSITY MODEL CONSENSUS ICON. **A GRADUAL WEAKENING NOTED AT DAY 5** AS THE SYSTEM BEGINS TO MOVE OVER SLIGHTLY **COOLER WATER SOUTHWEST OF THE COAST OF BAJA CALIFORNIA”**.

Jimena’s Evolution

The tropical depression was located in the Mexican South Pacific. This depression was **400km** south-southwest of Acapulco, Mexico.

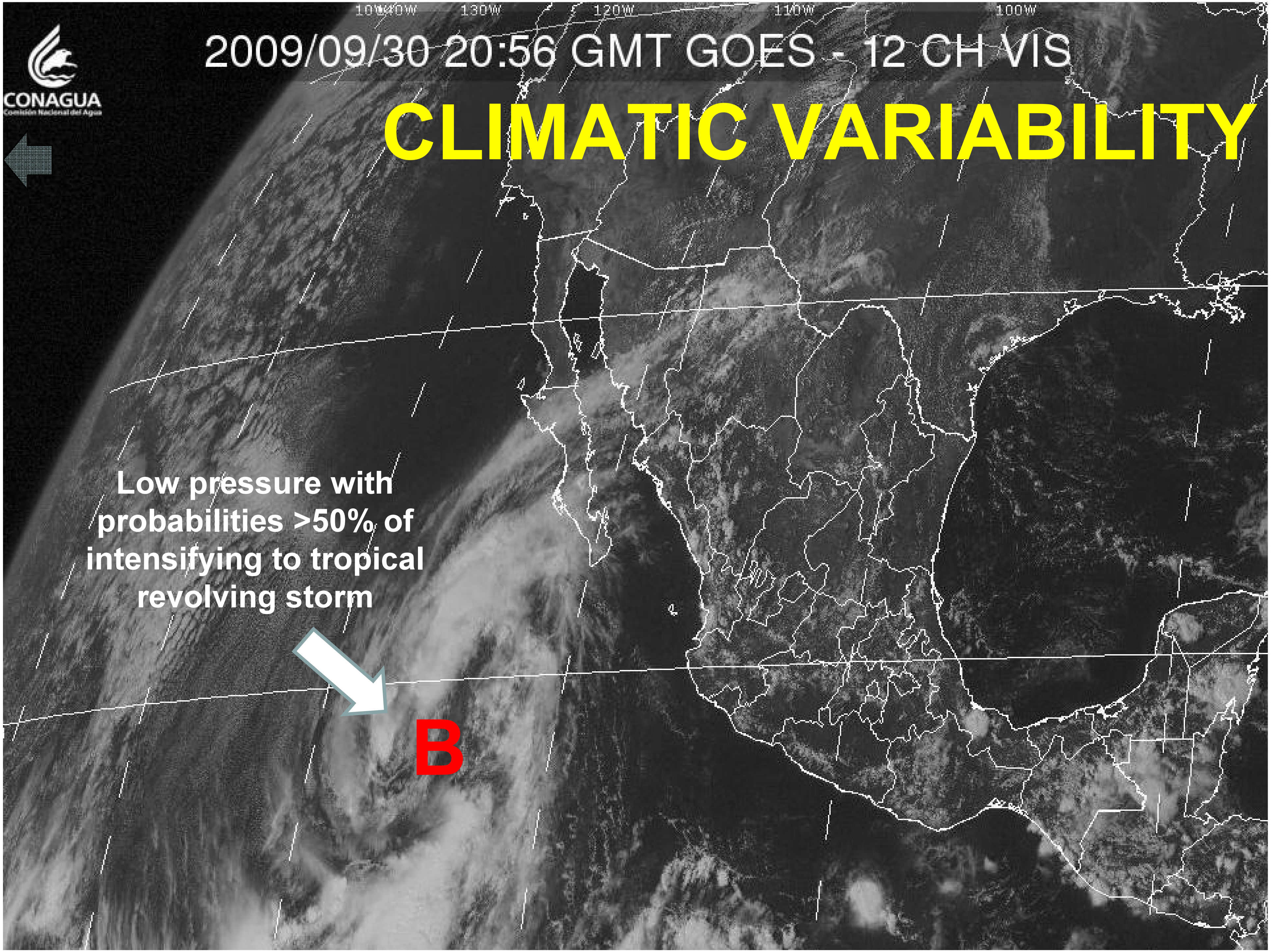
On 29th the storm has been growing and the new warning indicated Hurricane category I.

24 hours later the category was IV.

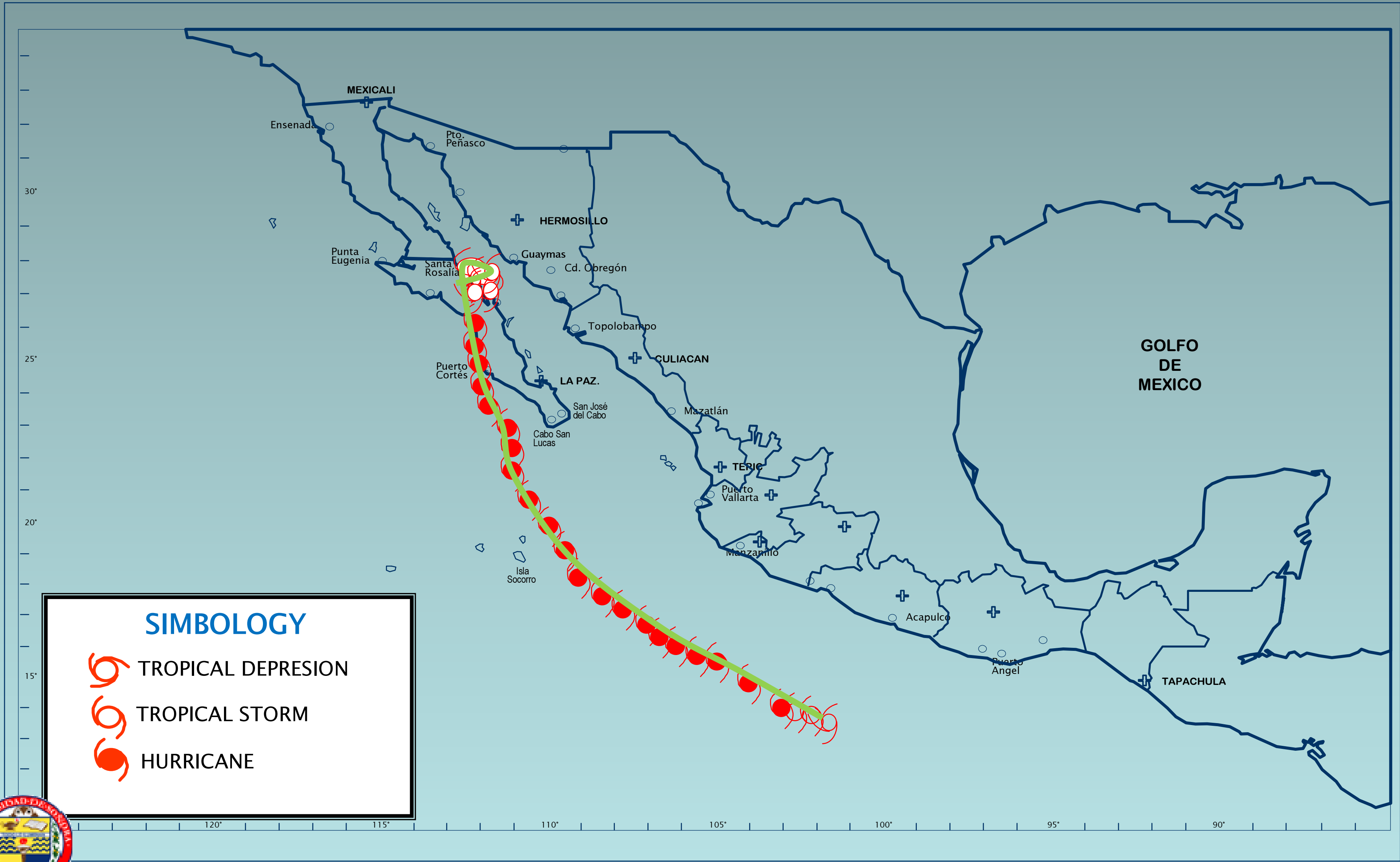
The total time of life for this event was 162 hours,

54 hours as category 4.

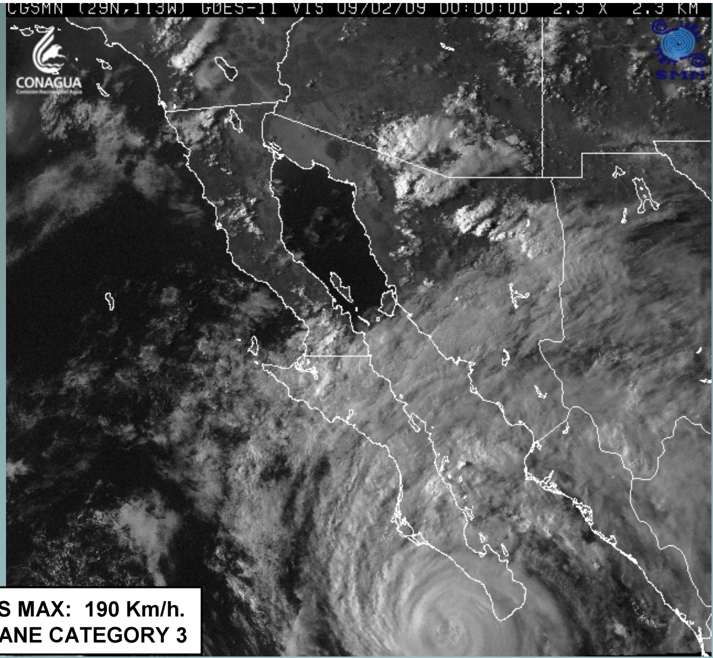
CLIMATIC VARIABILITY



TRAJECTORY OF CYCLONE "JIMENA"
Period: August 28 to September 04 2009

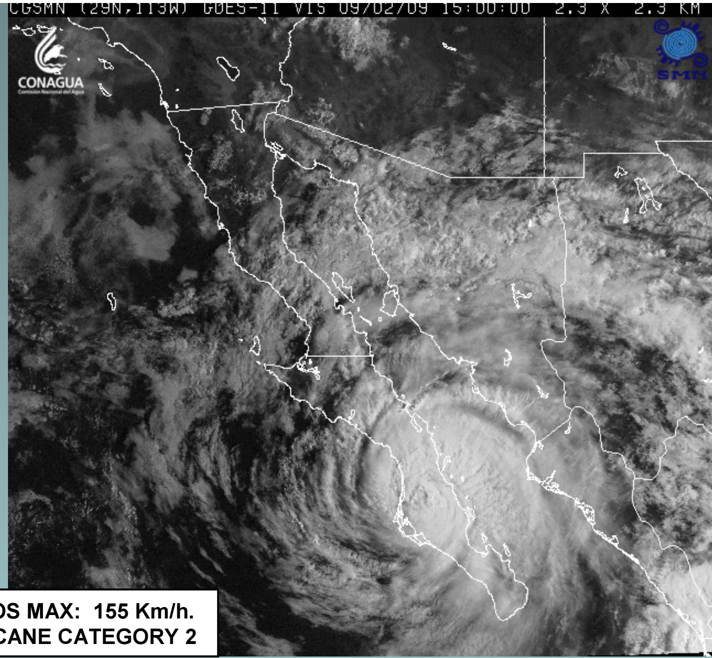


Date SEPTEMBER 1ST, 2009 LOCAL HOUR: 17:00



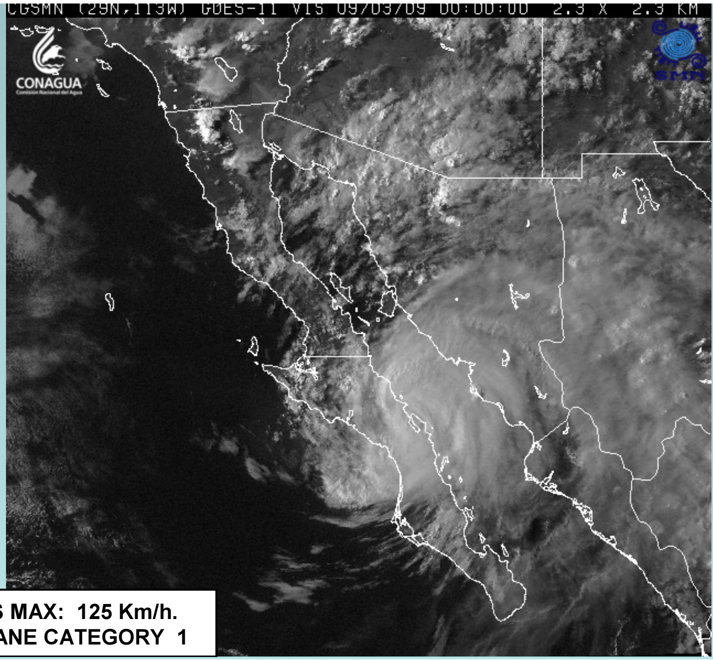
VIENTOS MAX: 190 Km/h.
HURRICANE CATEGORY 3

Date: SEPTEMBER 2, 2009 LOCAL HOUR: 08:00



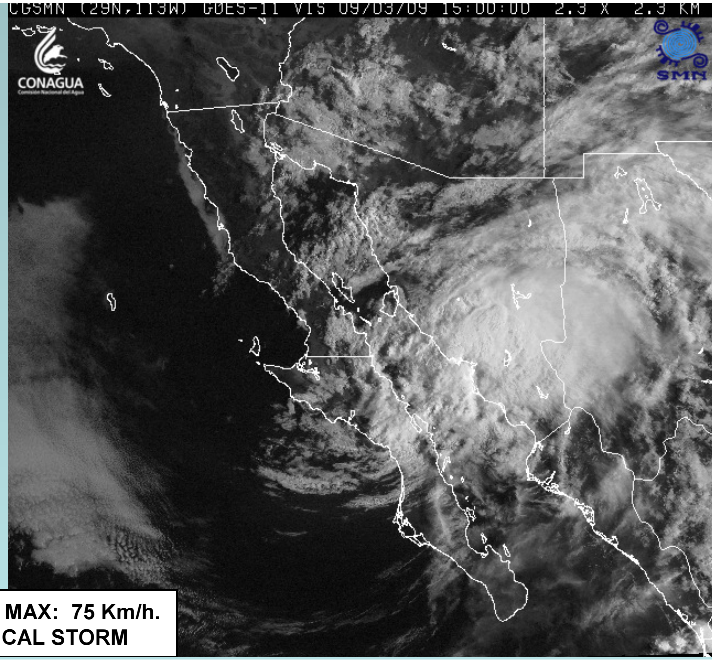
VIENTOS MAX: 155 Km/h.
HURRICANE CATEGORY 2

Date: SEPTEMBER 2, 2009 LOCAL HOUR: 17:00



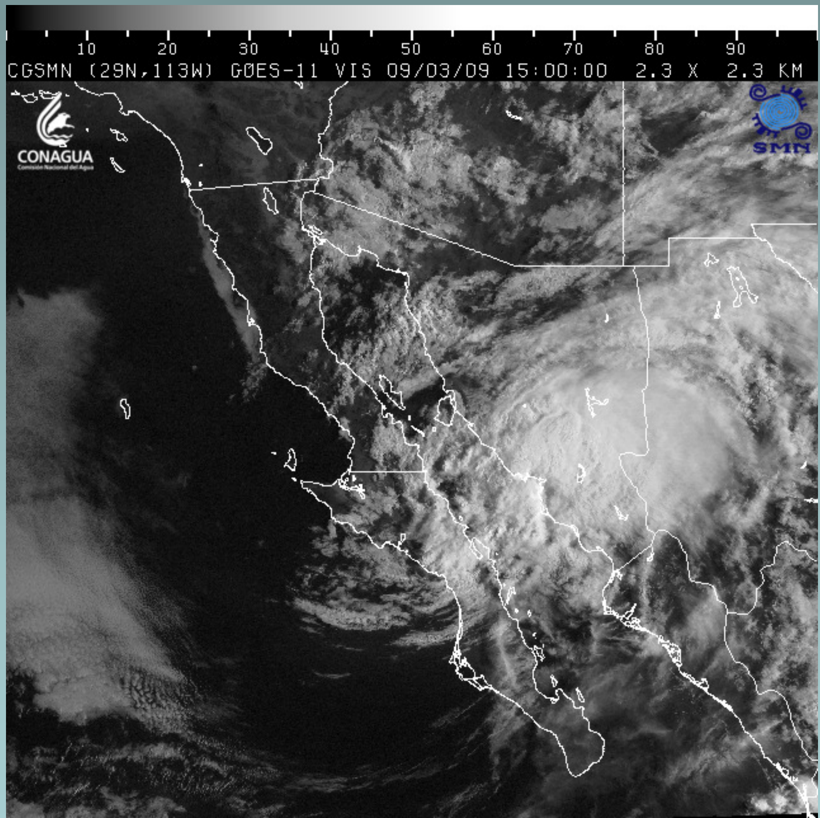
VIENTOS MAX: 125 Km/h.
HURRICANE CATEGORY 1

Date : SEPTEMBER 3, 2009 LOCAL HOUR: 08:00



VIENTOS MAX: 75 Km/h.
TROPICAL STORM

ACTIVITIES DURING THE EVENT



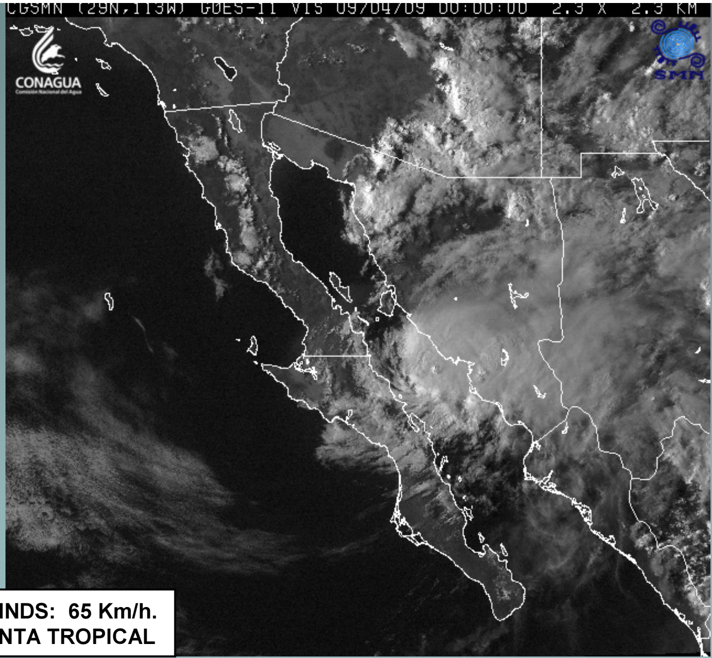
Observations during the event in Guaymas and Empalme during the event.

The Hurricane stops just in front of the cities

Monitoring of precipitation and evolution in rivers and levels in dams.

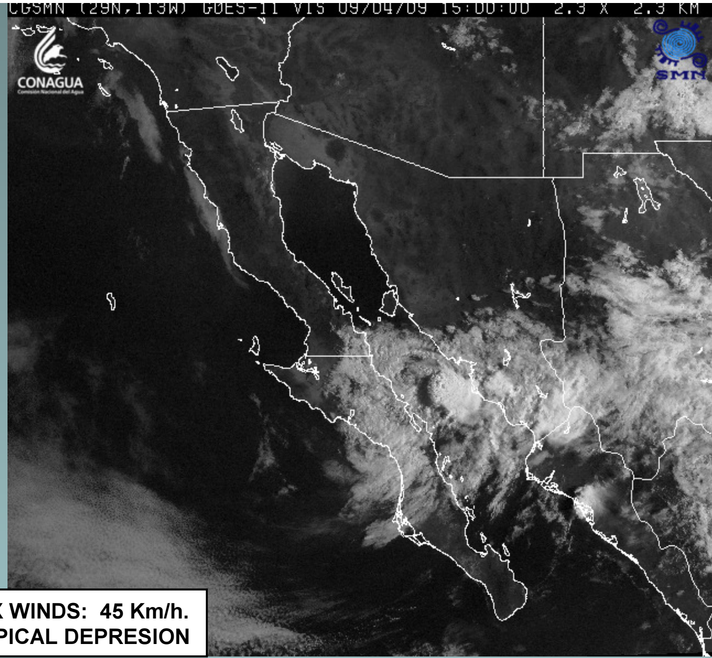
Warnings to the population during the event.

Date: SEPTEMBER 3, 2009 LOCAL HOUR: 17:00



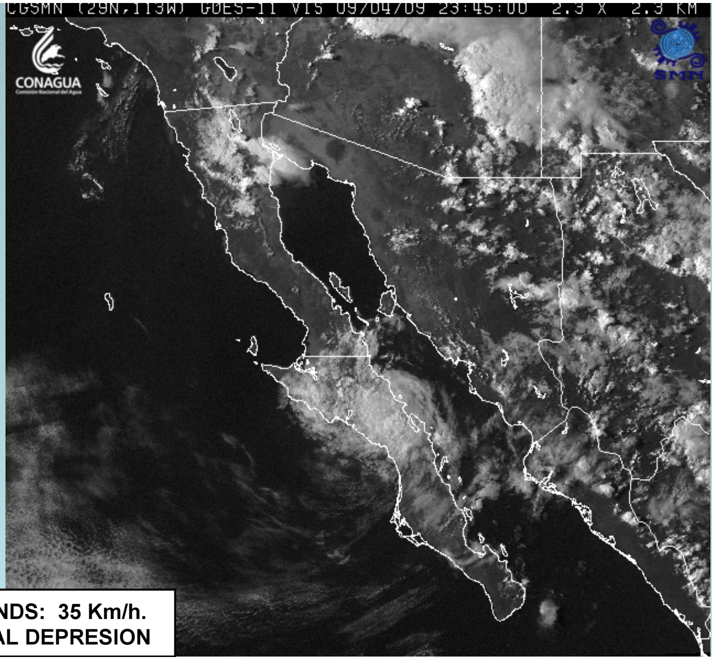
MAX WINDS: 65 Km/h.
TORMENTA TROPICAL

Date : SEPTEMBER 4, 2009 LOCAL HOUR: 8:00



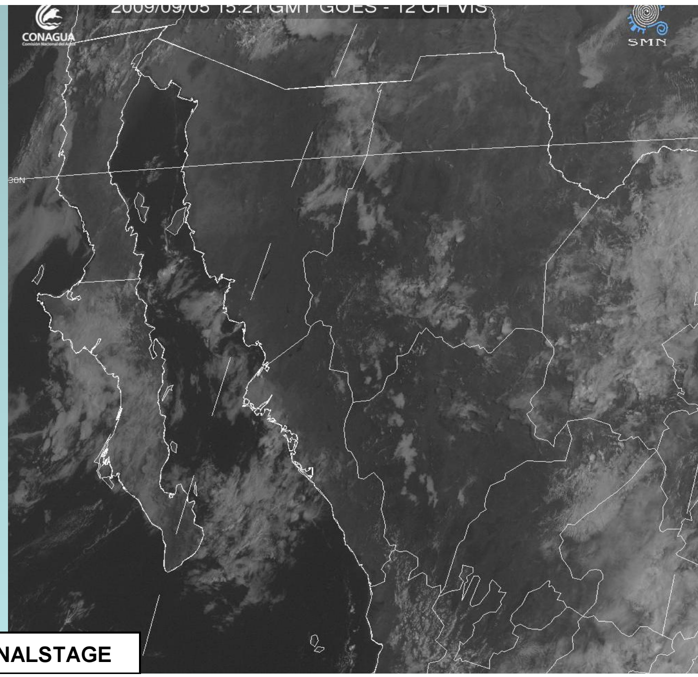
MAX WINDS: 45 Km/h.
TROPICAL DEPRESION

Date: SEPTEMBER 4, 2009 LOCAL HOUR: 16:45



MAX WINDS: 35 Km/h.
TROPICAL DEPRESION

Date : SEPTEMBER 5, 2009 LOCAL HOUR: 8:21

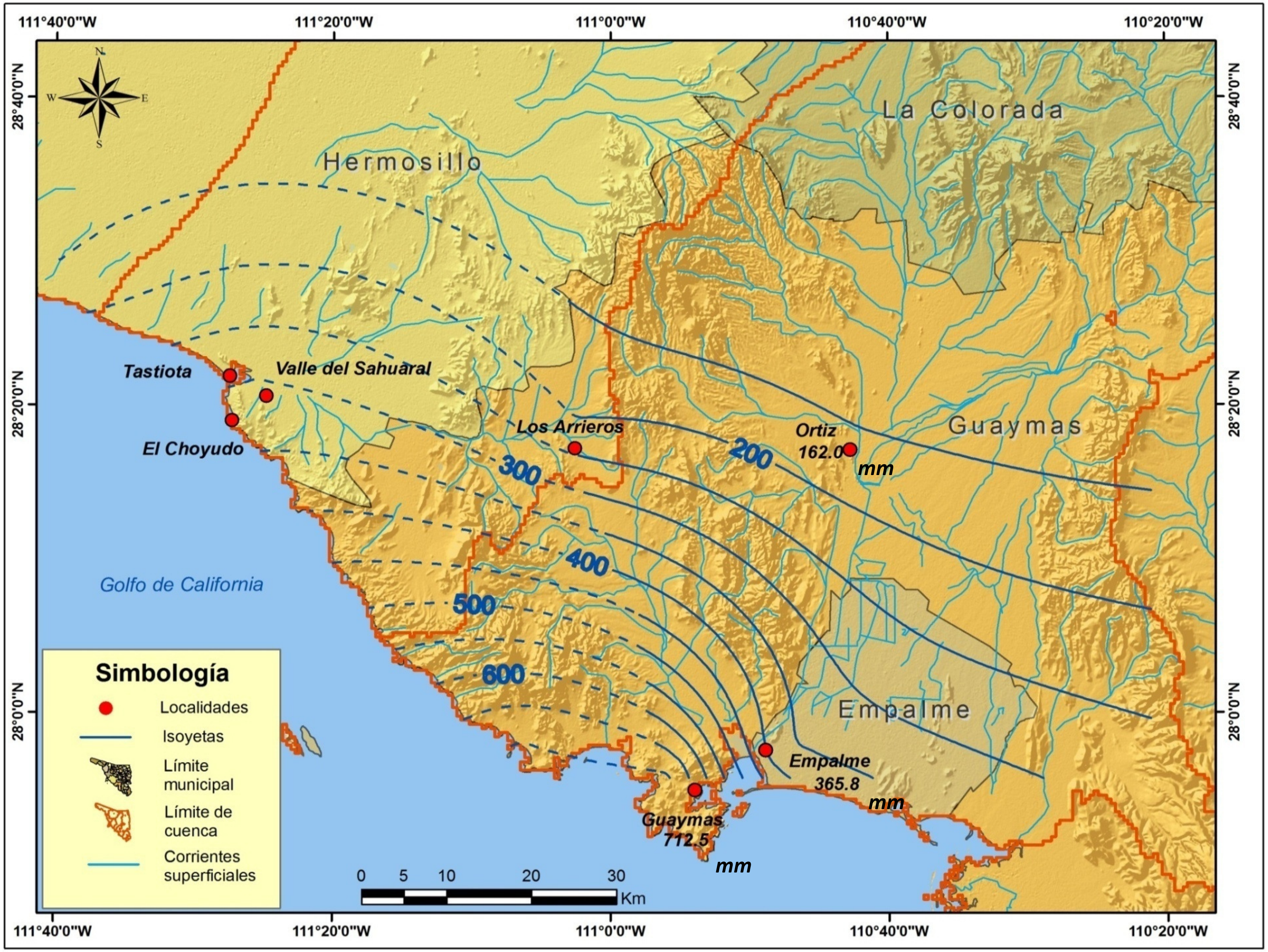


FINALSTAGE

PRECIPITATION
TROPICAL CYCLONE STAGES "JIMENA"
28 august to 4 september 2009

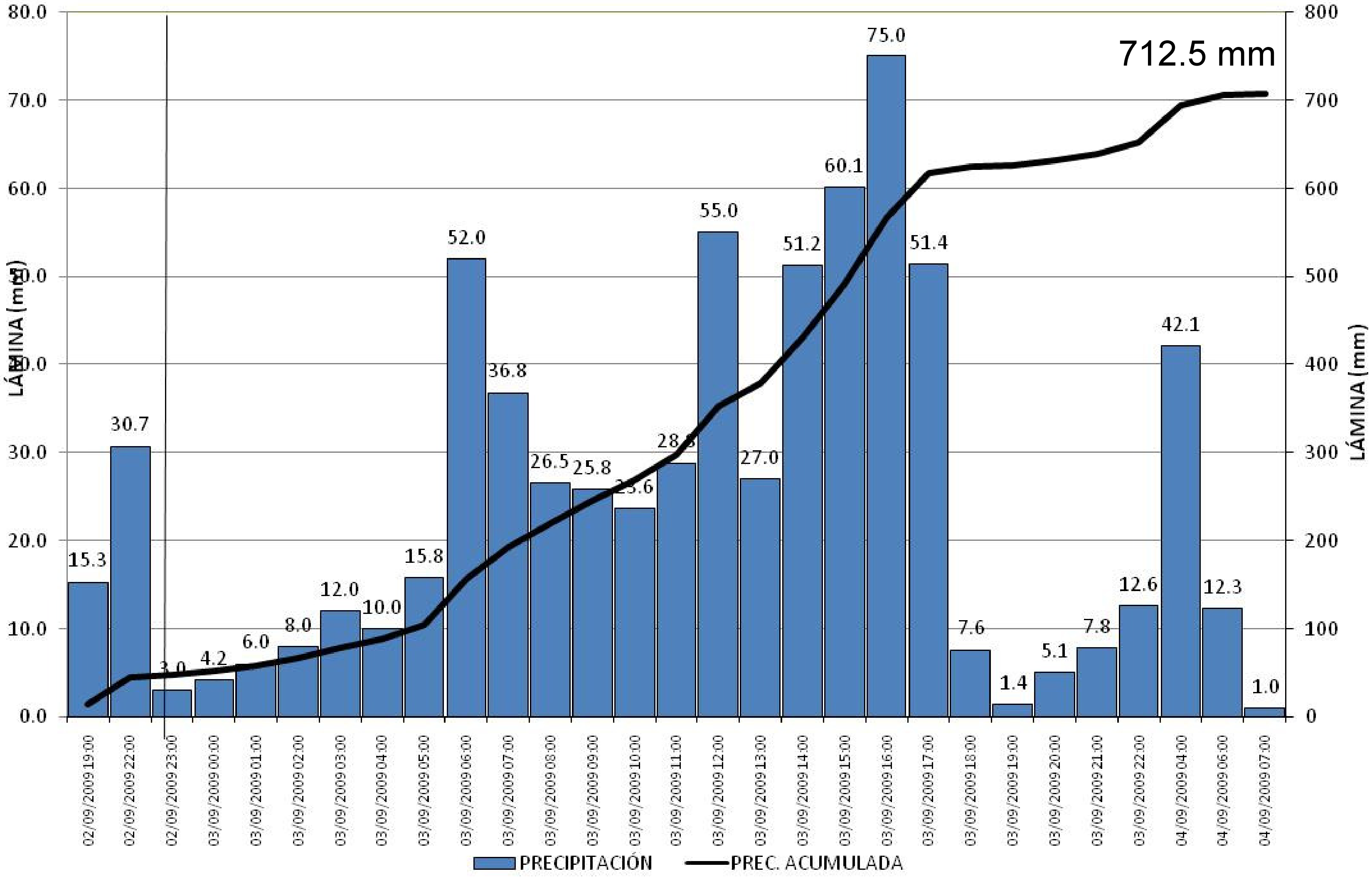
DATE	TIME	STAGE	LONG	PRECIPITATION (mm)	
				GUAYMAS	EMPALME
AUGUST 28	20:00	TROPICAL DEPRESSION	6 HOURS		
AUGUST 29	02:00	TROPICAL STORM	6 HOURS		
AUGUST 29	08:00	CATEGORY 1 HURRICANE	6 HOURS		
AUSUST 29	14:00	CATEGORY 2 HURRICANE	12 HOURS		
AUGUST 30	02:00	CATEGORY 3 HURRICANE	6 HOURS		
AUGUST 30	08:00	CATEGORY 4 HURRICANE	54 HOURS		
SEPTEMBER 1	14:00	CATEGORY 3 HURRICANE	9 HOURS		
SEPTEMBER 1	23:00	CATEGORY 2 HURRICANE	12 HOURS		
SEPTEMBER 2	11:00	CATEGORY 1 HURRICANE	9 HOURS		
SEPTEMBER 2	20:00	TROPICAL STORM	4 HOURS	30.0	8.0
SEPTEMBER 3	00:00	TROPICAL STORM	24 HOURS	53.2	30.6
SEPTEMBER 4	00:00	TROPICAL STORM	2 HOURS	670.0	343.0
SEPTEMBER 4	02:00	TROPICAL DEPRESSION	12 HOURS	682.0	345.0
SEPTEMBER 4	14:00	DISSIPATION		712.5	365.8
		TOTAL	162 HOURS	712.5	365.8

HIETOLINESDISTRIBUTION IN THE LOW BASIN RIO MATAPE
SEPTEMBER 2 - SEPTEMBER 4, 2009

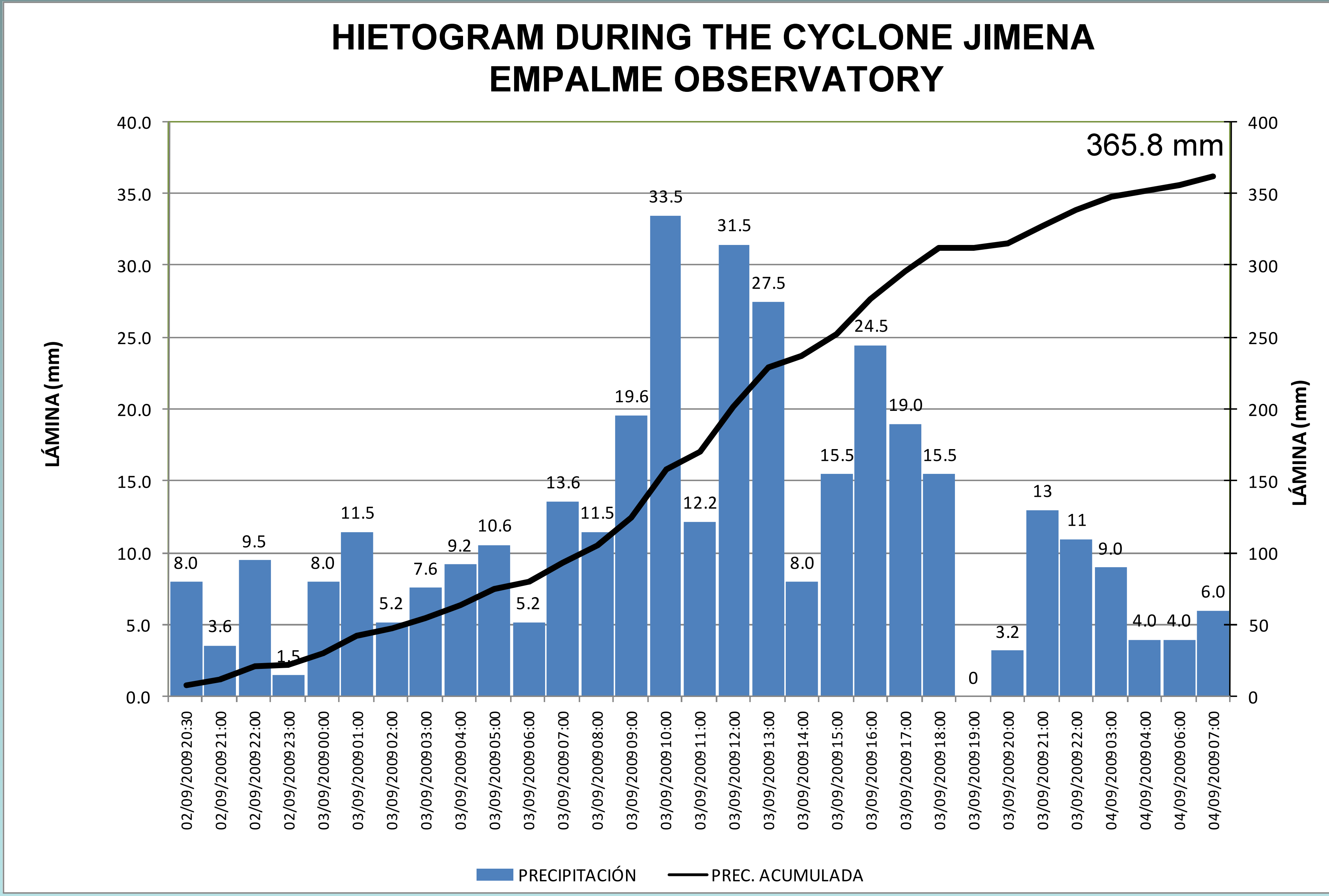


PRECIPITATION IN THE LOW BASIN RÍO MÁTAPE
SEPTEMBER 2 - SEPTEMBER 4, 2009

HIETOGRAM DURING THE CYCLONE JIMENA
GUAYMAS OBSERVATORY

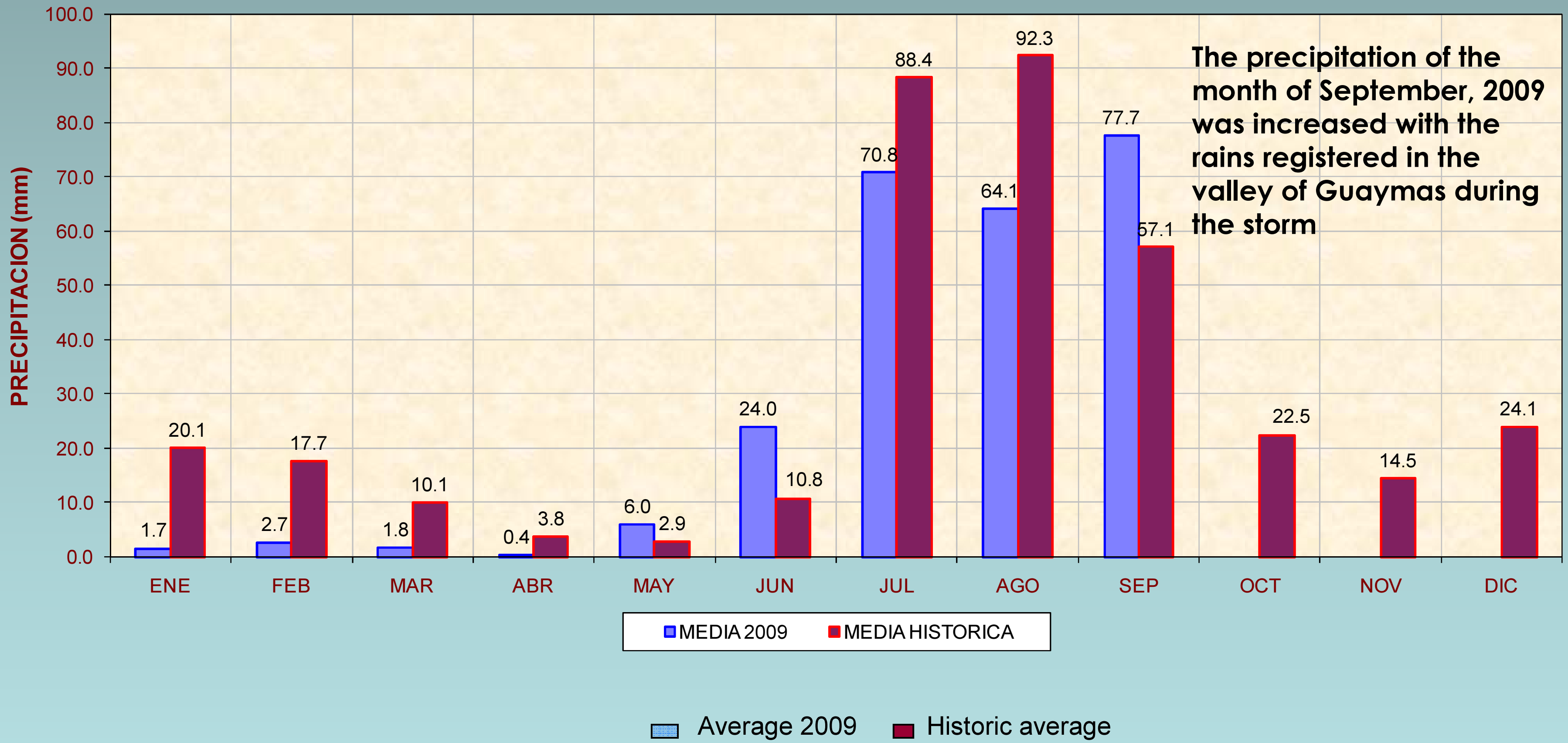


PRECIPITATION IN THE LOW BASIN RÍO MÁTAPE
SEPTEMBER 2 - SEPTEMBER 4, 2009



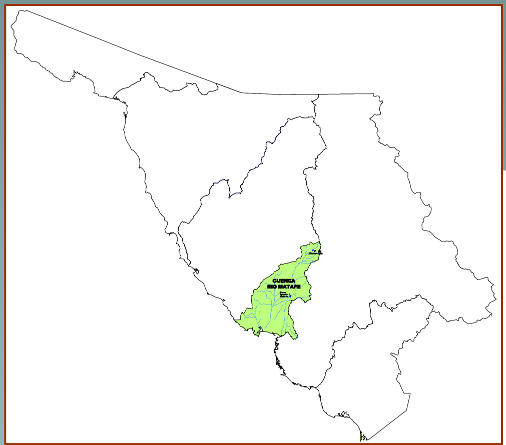
Precipitation average in the northwest of Mexico.

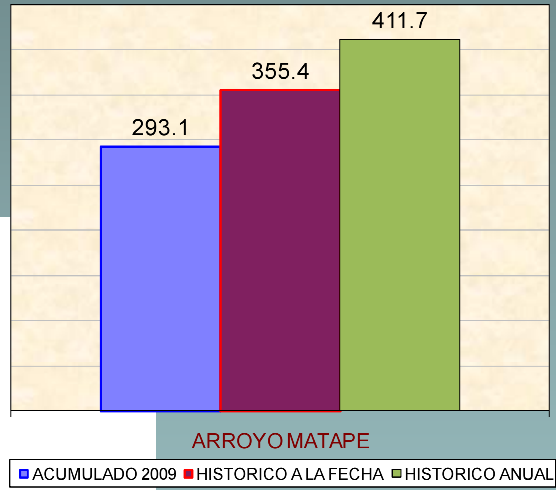
Comparative monthly to the 30 of September of 2009 and historical average

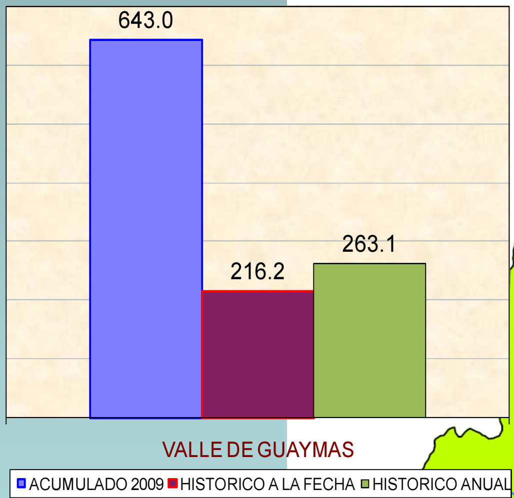


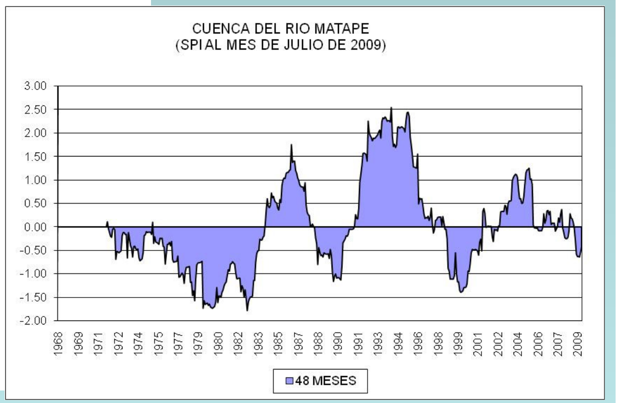
RIO MATAPE BASIN

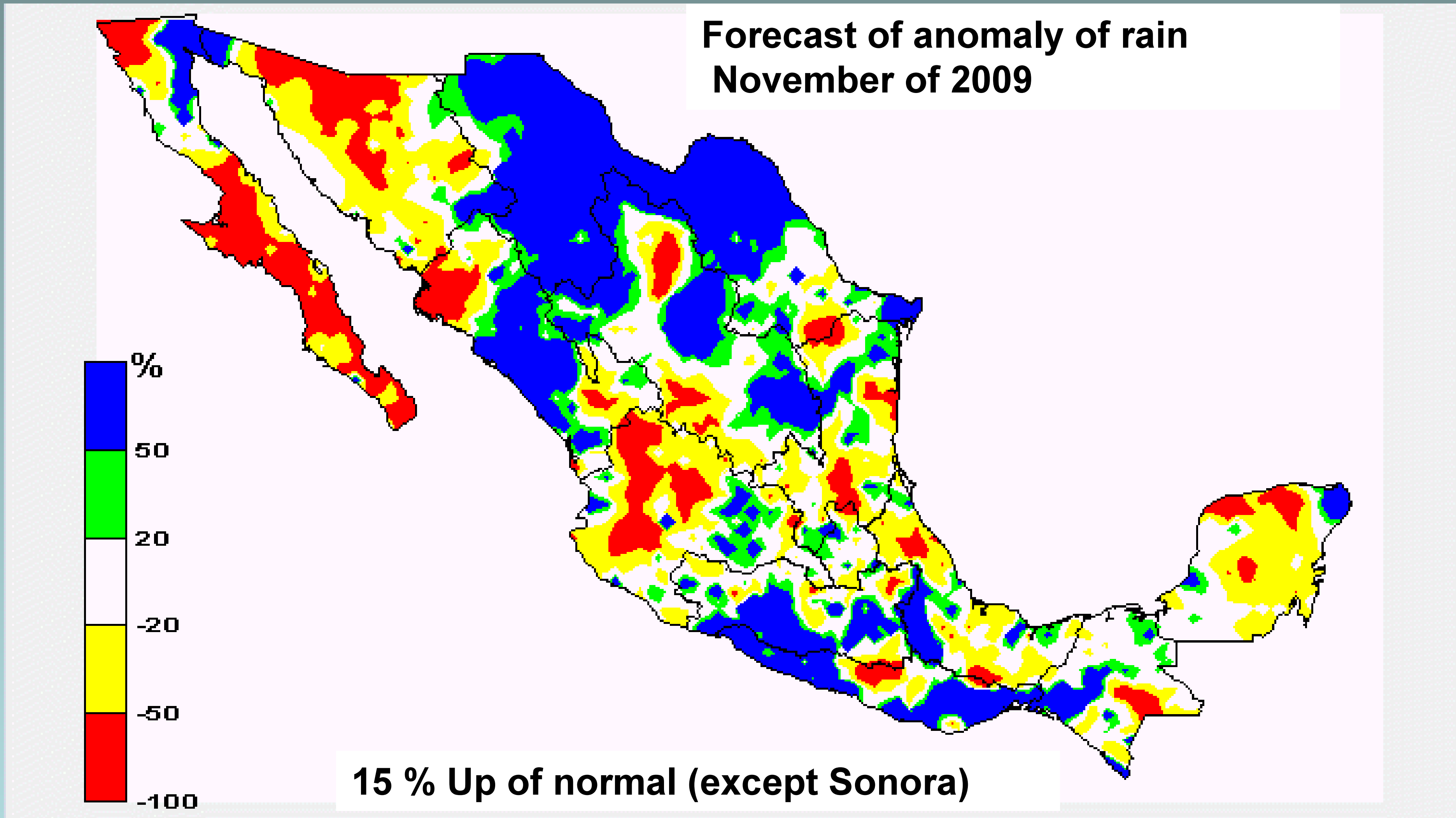
September 2009



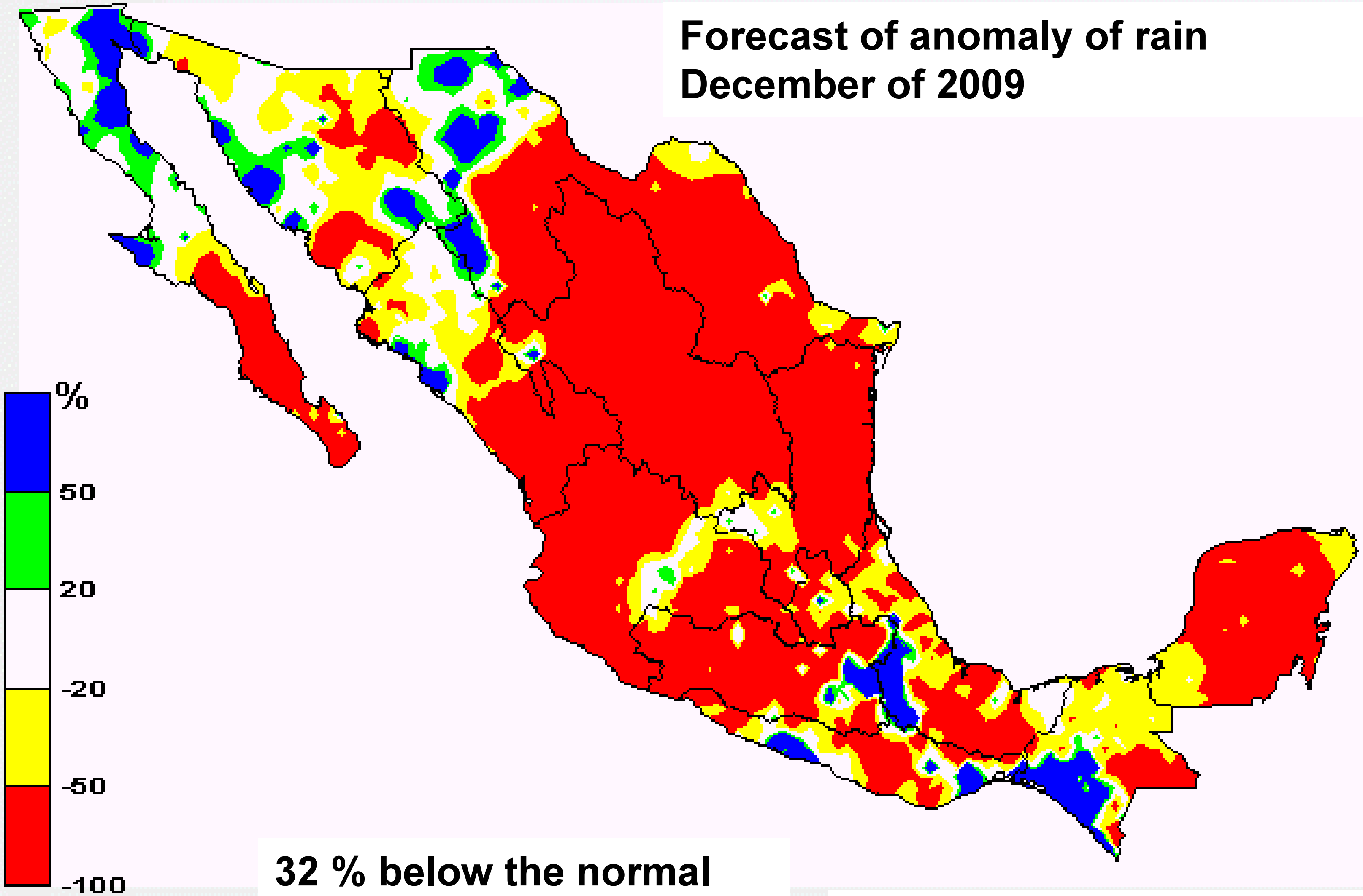







Forecast of anomaly of rain
November of 2009
%
50
20
-20
-50
-100
15 % Up of normal (except Sonora)

Forecast of anomaly of rain December of 2009



32 % below the normal

Taking analogy with years:

1957, 1997, 2002 y 2004

DURING THE EVENT

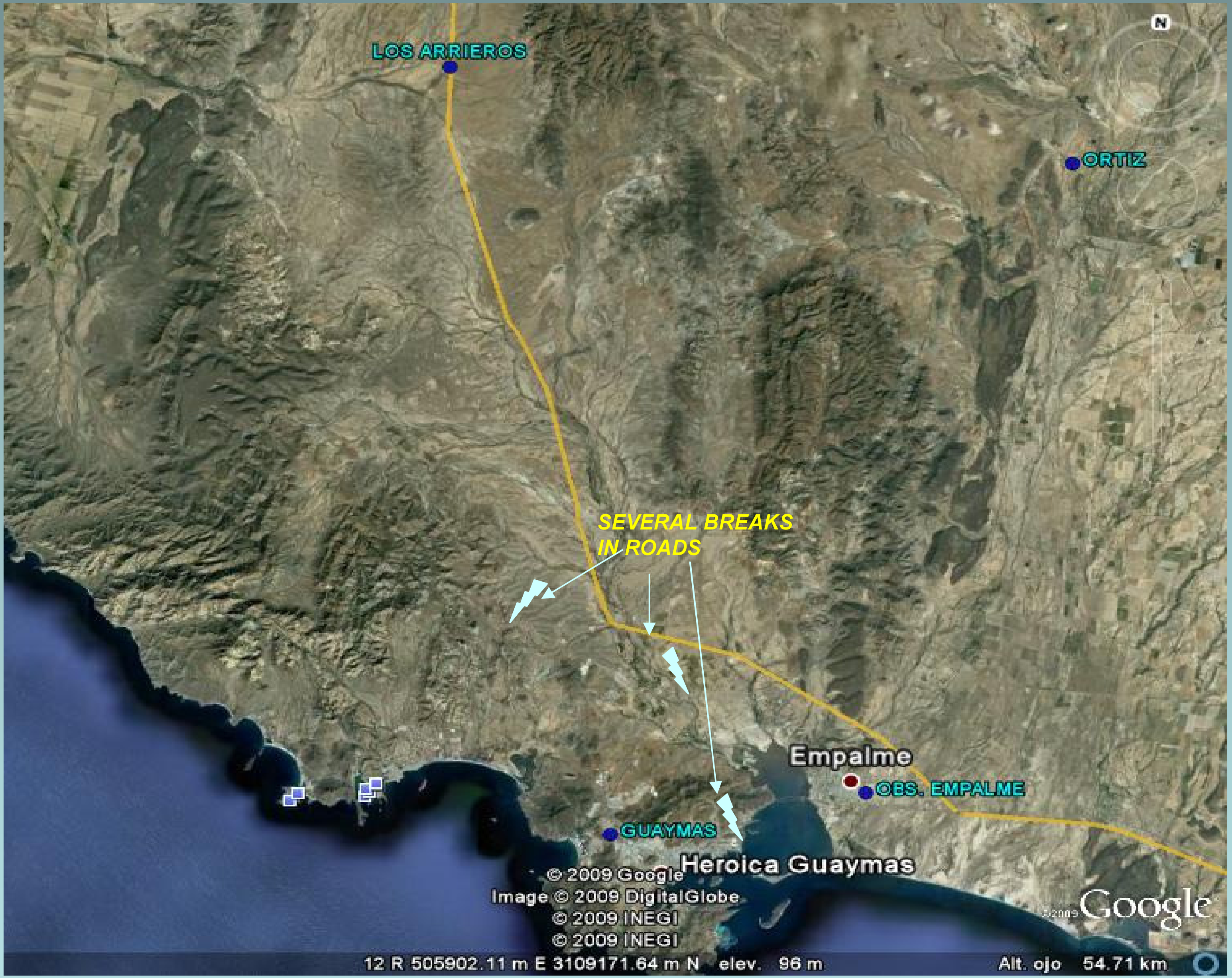
INFRAESTRUCTURE AND CIVIL PROTECTION

DAMS 200 KM AROUND THE REGIONAL CENTER OF THE EVENT

- **Dams located in the region were observed since** 6:00 hours of **August 31th, the mean capacity was 76.8%**.

- Rio Yaqui Dam were at **87.3%**, (145 km)
- Rio Mayo were at **71.7%** (200 Km)

INFORMACIÓN DE DAÑOS A LAS 7:00 HORAS DEL DÍA 4 DE SEPTIEMBRE DE 2009




TOTONAKA RV
FREE WiFi
RV

San Carlos beach

BATUECAS
water supply
SAN JOSÉ Pumping
system
SAN
CARLOS
beaches
PEDRO G. MORENO
wast e water colector
LA SALADA
Waste water
treatment plant
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2009 DigitalGlobe
Google

“LA SALADA”LAGOON

The system is formed by four lagoons:

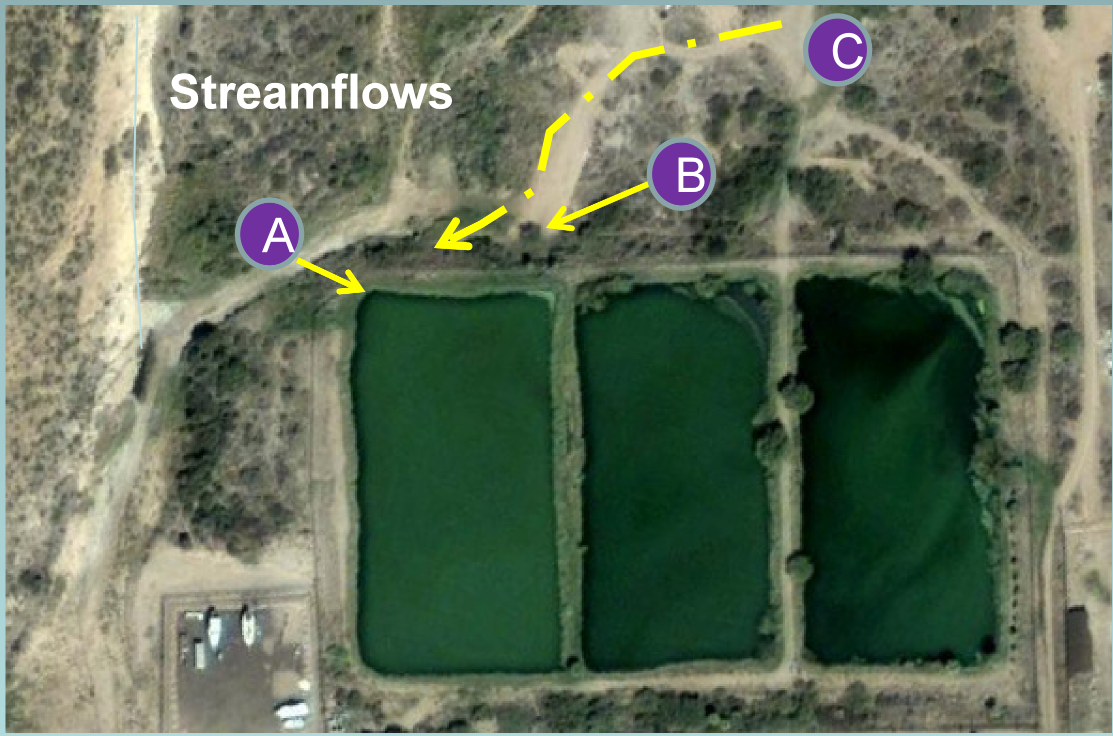
Q rate of design 483 l/s

Q rate of operation 235 l/s.

1, 2, 3 4	**Dikes were cutted and the interconnection interrupted. The holes in the dikes were from 6 to 15 meters**
5, 6	**Overflow in the pluvial channels and dikes were eroded in the lakes**
7, 8	**All sediments felt down into the last lakes and over flodded.**

SAN CARLOS LAGOONS SYSTEM

The extraordinary streamflow discharges to the lagoon colapsed the final dike loosing the perimetral contention with the overflow.



Q rate of Design 28 l/s

Q rate of Operación 15 l/s.

A	**Dike rupture in the last lagoon**
B	**Overflow and lost of the perimetral dike**
C	**Streamflows**

Destructive factors of Hurricanes

DISCUSSING CONCLUSIONS

What happened with the hurricane on September 2th?

Because when the event was again as a tropical storm, the warnings were announcing the end of hurricane activity Miami said it was finished.

Why suddenly the storm was divided in two parts? and one stopped its trajectory just in front of Guaymas and the another one crossed away over the Peninsula of Baja California and went back into the Pacific Ocean?

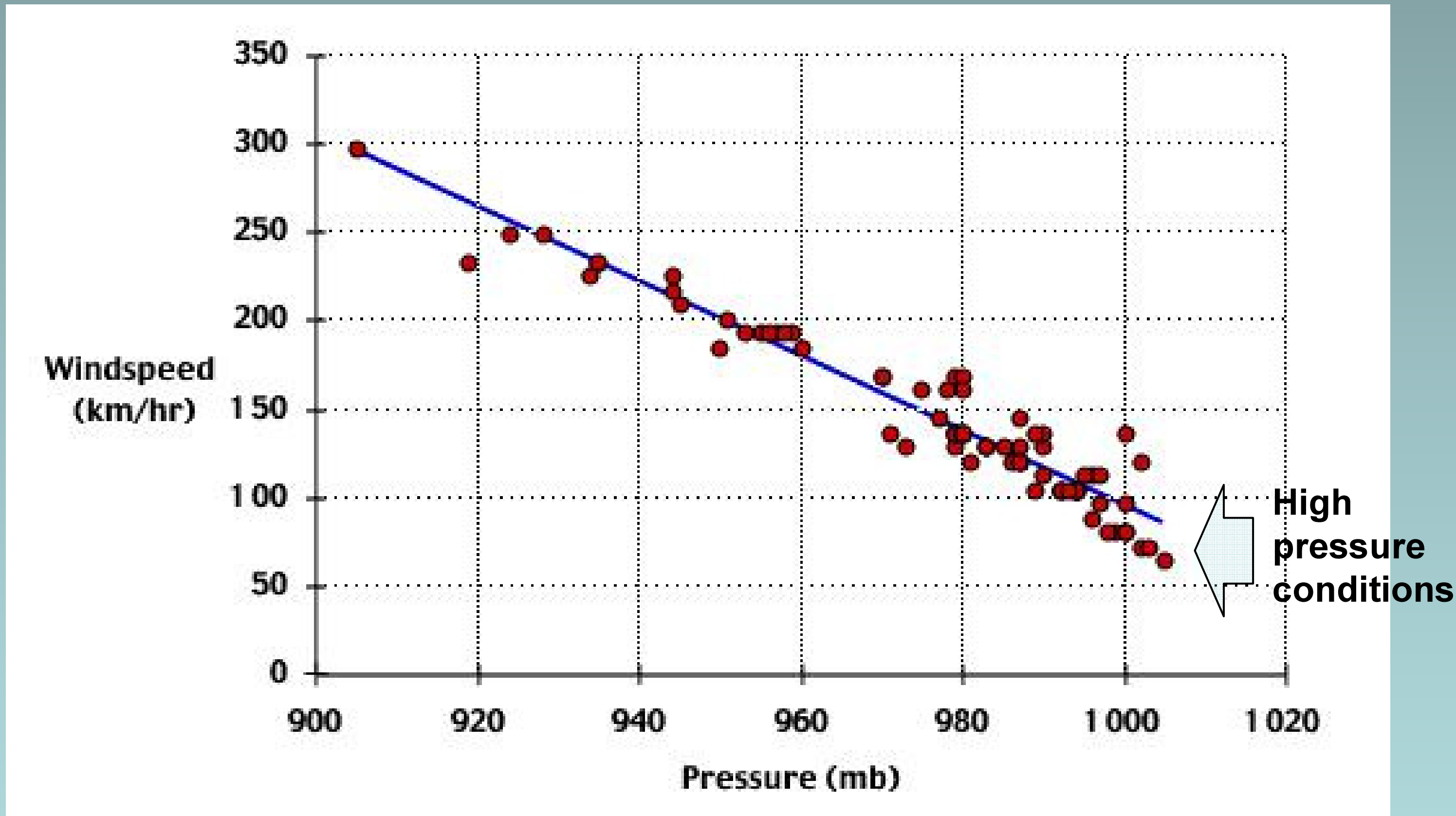
We found the answer in one of the main keys:

1. The storm stopped for more than 12 hours in a place where the cyclonal circulation maintained the generation of an intense humid air flow towards the coast.

2. This stop and almost null displacement of the tropical storm was produced by a high developed of pressure just in front of the trajectory that followed “Jimena”.

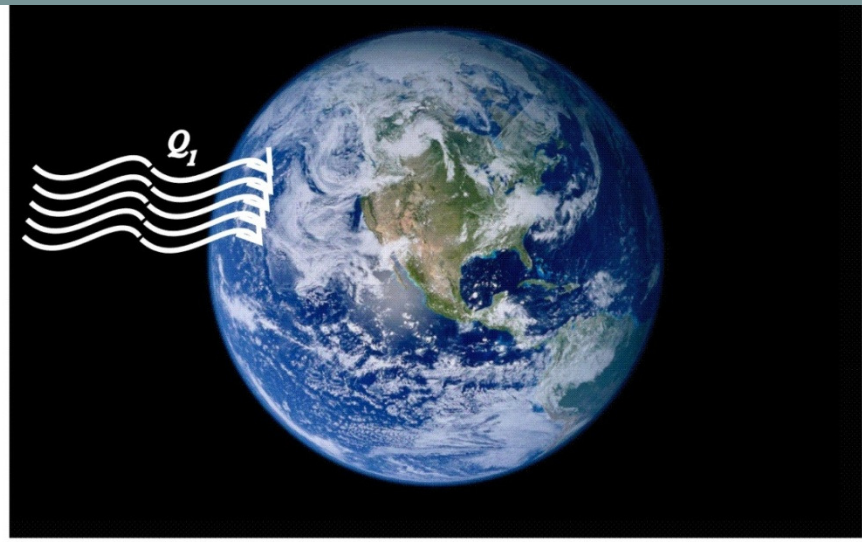
3. Due to this high pressure the favorable conditions were turned on a natural barrier and the occurrence and extraordinary rain took place.

Velocity versus pressure

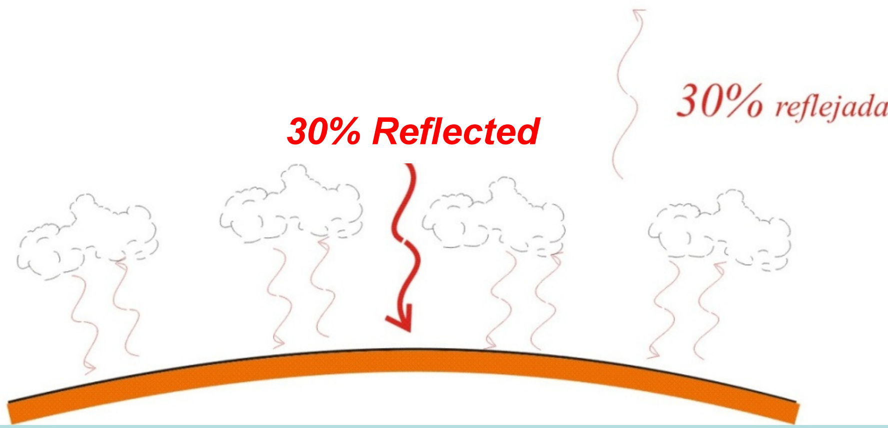


Earth

This heat is transported toward the poles by ocean currents and contributes to the ocean heat transport, the process by which oceans regulate our climate by transporting warm water away from the equator and cold water toward the equator.

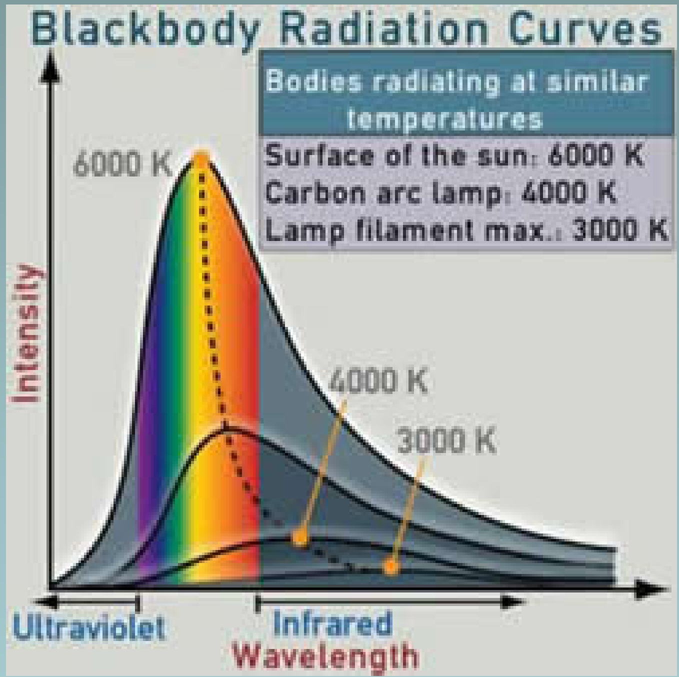


It has also been speculated that the heat pumped into the ocean by hurricanes strengthens subsequent storms that pass over the same part of the ocean, because ocean heat is the energy source that powers hurricanes.



Stronger storms would then mix even more heat into the ocean driving a positive feedback loop for hurricane intensity.

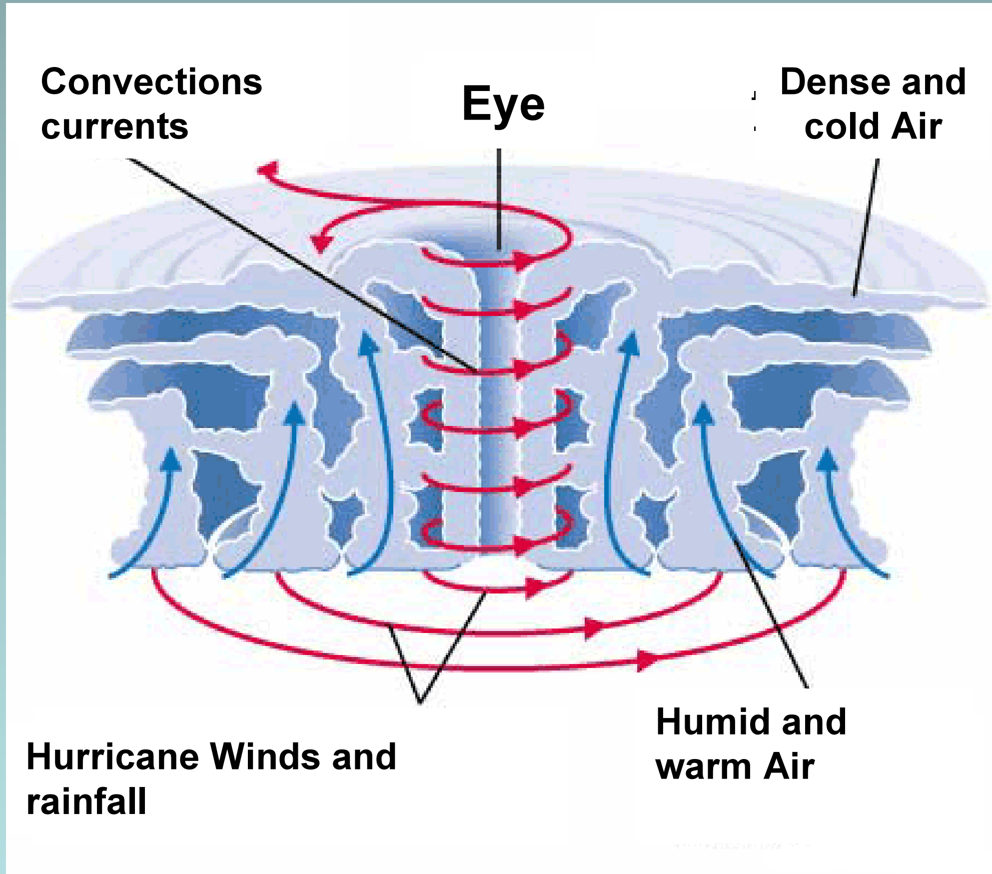
Temperature due to earth radiation



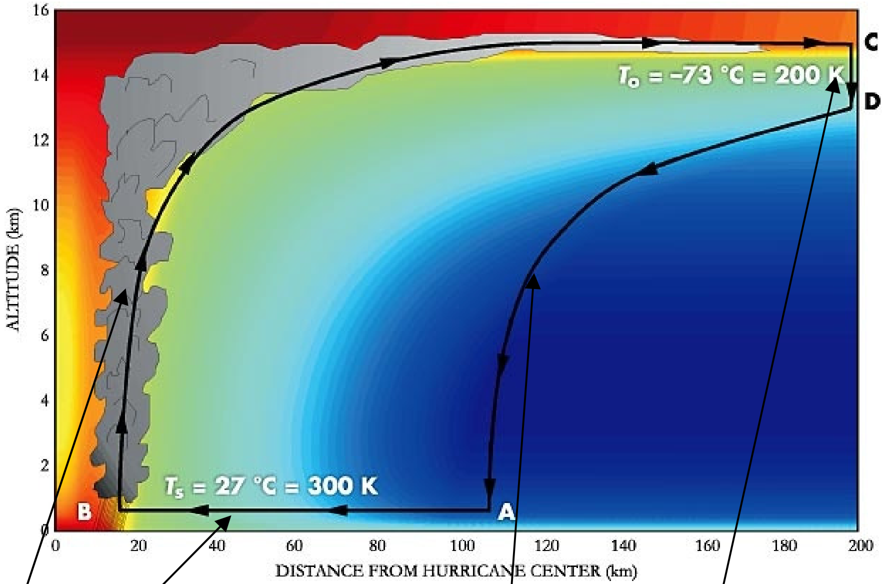
The earth radiation emission corresponds to temperatures around 35º Kelvin, and this below the real surface temperature.

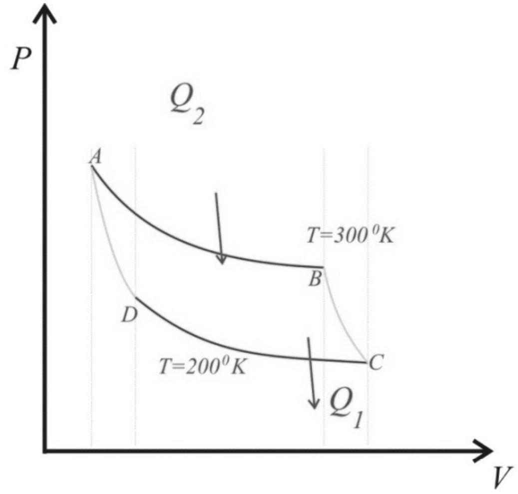
This response is due to the trapped radiation (Albedo), however this is not enough to generate hurricanes with 27ºC in the ocean water.

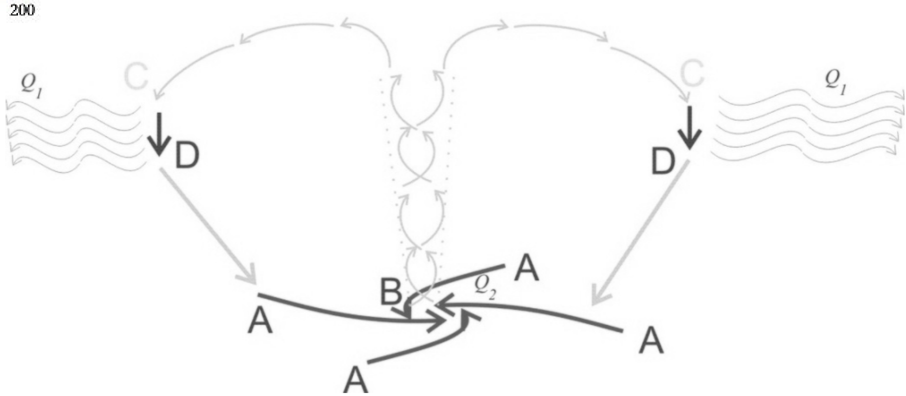
Dinamic Modelding in the Hurricane



Hurricanes are like a Carnot cycle







Isothermic Expanssion

Adiabatic expanssion

Isothermal Compression

Adiabatic compression

$Ts = T_2$ = Ocean Temperature

- $T_0 - T_2$ = Ocean temperature ± 27º C ≈ 300ºK
- $T_0 = T_1$ = Temperature in the higest point of the troposphera = -73º ≈ 200ºK
- E= Desequilibrium of the thermodinamical rate between the ocean surface and the highest point in the troposphera

- Q_2 = Transference of heating rate

- $Q_2 = \surd E$ ………………(1)

- D_e = Energy disipassion due to the friction of winds aganist the surface.

- $D_e = C_D \rho \surd^3$ .... (2)

- Cd = Surface friction coefficient
- ρ = Air density
- W = Work produced by the System (Carnot's cycle)

- $W = \epsilon Q_2$……………..(3)

Final Conclusions

The incidence and destructive power of hurricanes is thinking due to the increase of temperature of the ocean water.

1. In theory, the highest wind velocity of tropical cyclones could increase up to 5 % due to every °C (Celsius scale) as the water ocean increase its temperature.

2. With the 0.5% actually detected, the increase in velocity could be 2 - 3%. However due to the destructive potential of every hurricane (energy dissipation) the increase goes as the cubic of the velocity, and in case of 2 % the reality will get 6% of destructive capacity. In consequence the increase in 3% will give us 9% of this destructive potential.

3. Therefore the increase of the destructive capacity of the Hurricanes will grow up to the double. But we assume is due to another unknown factor.

Gracias

$$\epsilon = 1 - T_1/T_2 \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

In Equilibrium $\quad De = W, \ldots\ldots\ldots\ldots\ldots\ldots (5)$

Using (2) and (3) $\quad C_D \rho v^3 = \epsilon Q_2, \ldots\ldots\ldots\ldots\ldots\ldots (6)$

Using (1) and (6) $\quad C_D \rho v^3 = \epsilon E v,$

Solving $\quad v^2 = \epsilon\ E/\ C_D \rho, \ldots\ldots\ldots\ldots\ldots\ldots (7)$

Using (4) in (7)

$$v^2 = \left(1 - T_1/T_2\right) E/\ C_D \rho$$