Climate Change in Micronesia: What Can We Expect?

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Guam

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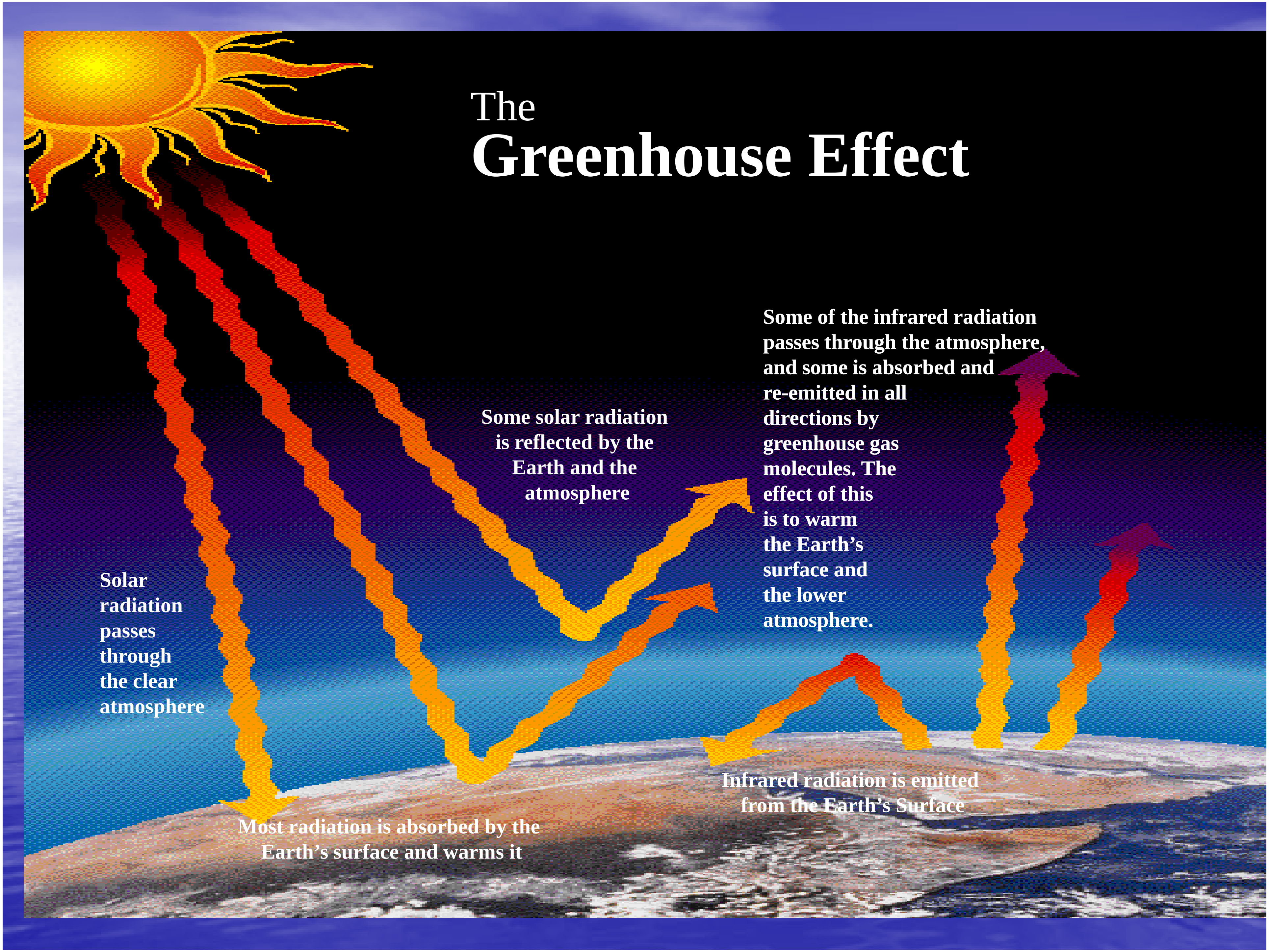
OBJECTIVES

- **Provide a Short Summary of Past Climate Change in Micronesia**
- **Illustrate the Importance of the ENSO Cycle on Key Climate Parameters in Micronesia**
- **Illustrate the Most Likely Effects of Climate Change on the ENSO Cycle**
- **Illustrate the Most Likely Societal Impacts Due to ENSO & Likely Climate Change**


The
Greenhouse Effect
Some solar radiation is reflected by the Earth and the atmosphere
Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.
Solar radiation passes through the clear atmosphere
Infrared radiation is emitted from the Earth's Surface
Most radiation is absorbed by the Earth's surface and warms it

Greenhouse Gases (GHG)

GHGs that warm the earth

- Carbon dioxide (CO_2)—burning of fossil fuels; long lifetime
- Methane (CH_4)—agriculture, cows, decomposed organic material; long lifetime
- Nitrogen oxides (N_2O)—fossil fuels, fertilizer; long lifetime

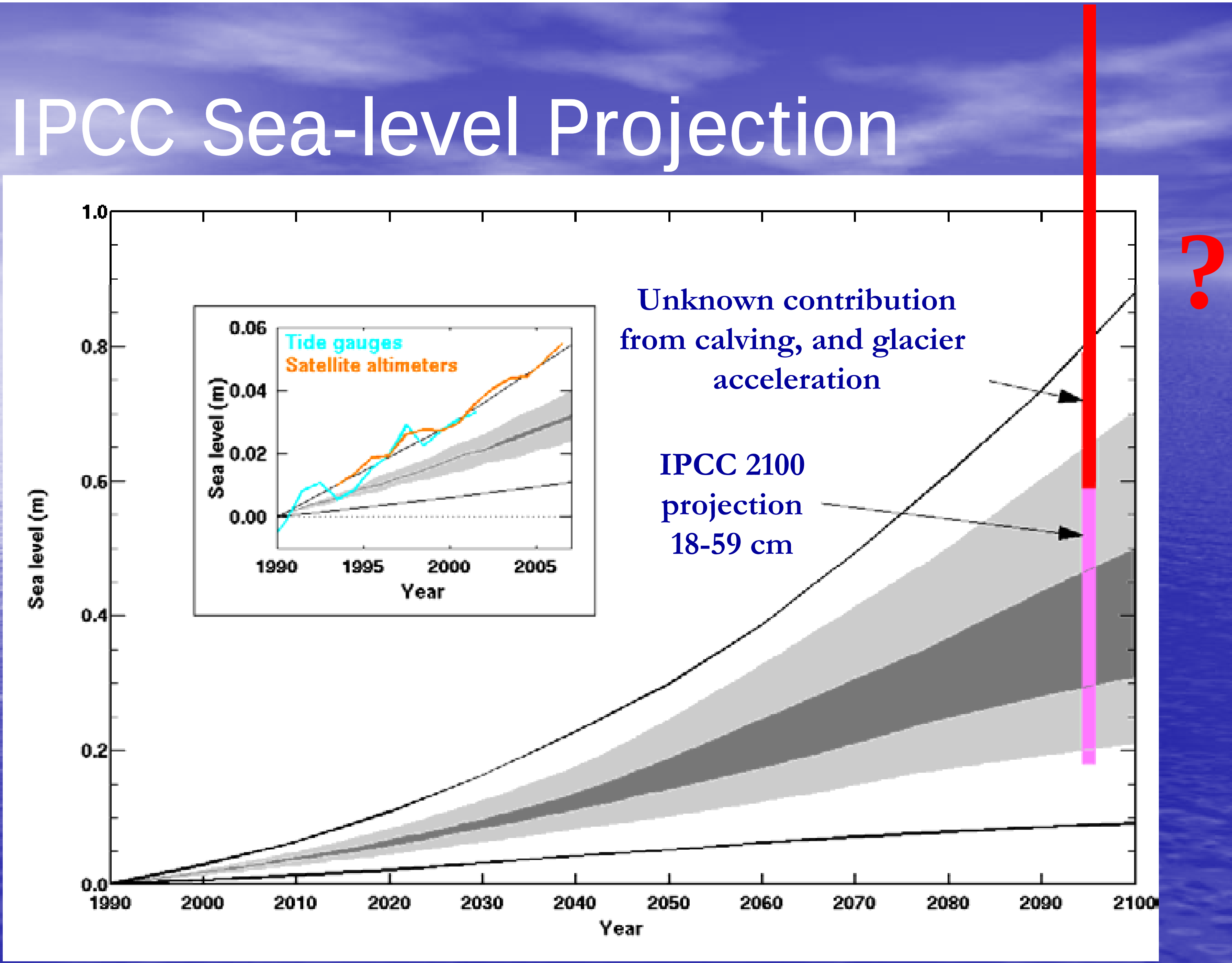
GHGs that cool the earth

- Sulfates (SO_4)—burning vegetation, volcanoes; short lifetime (washed out after a few days to years)
- Particulates (dust, volcanic ash, smoke)—short lifetime

GHGs that can warm or cool the earth

- Water vapor (H_2O)—largest GHG; oceans, soils; short lifetime (recycles after 2 weeks); this recycling is very complex and the net effect of water vapor is not known

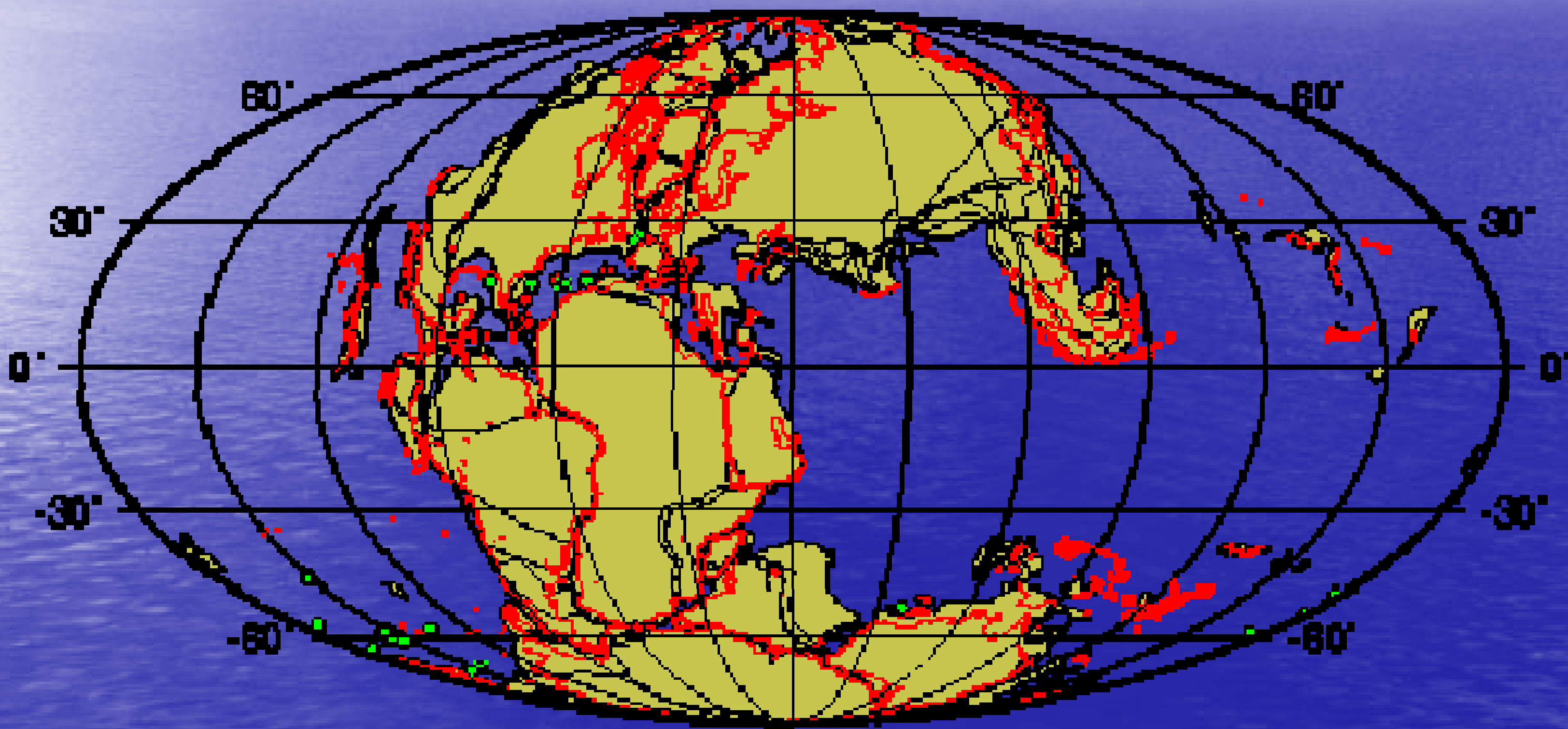
IPCC Sea-level Projection



Pacific Basin History

4-2 ka Late Holocene sea level decline
~ 4 ka Mid-Holocene highstand
Holocene 0.01 Ma
15-4 ka 110-m Holocene sea-level rise
125-20 ka Sea level decline to LGM, -109 m
125 ka Last interglacial highstand, + 6 m
0.9 Ma 100 ka-cycle sea level fluctuations
Pleistocene 2 Ma
2 Ma 41 ka-cycle sea level fluctuations
3 Ma Central American seaway closes
Pliocene 5 Ma
15 Ma Major expansion of Antarctic ice sheet
Miocene 24 Ma
Early-Middle Oligocene Caroline Basin forms
Oligocene 34 Ma
30 Ma East Pacific Rise subducts under NA
35 Ma Antarctic glaciation begins
Late Eocene-Miocene New Zealand splits, rotates, converges
40 Ma Emperor-Hawaiian shift in Pacific Plate rotational pole
Middle Eocene SW Pacific arcs and basins: Coral Sea, New Hebrides, west Fiji, Norfolk
40 Ma Indo-Asian collision
45-37 Ma West Philippine Basin opens
53 Ma Australia moves north
Eocene 55 Ma
60 Ma Tasman Sea opens
Paleocene 65 Ma
81-63 Ma East and West Antarctica separate
80 Ma Pacific-Antarctic Rise opens
80 Ma New Zealand splits from W. Antarctica, starts north
Cretaceous 144 Ma
180 Ma Pangaea breaks up into Laurasia and Gondwana
Jurassic 206 Ma

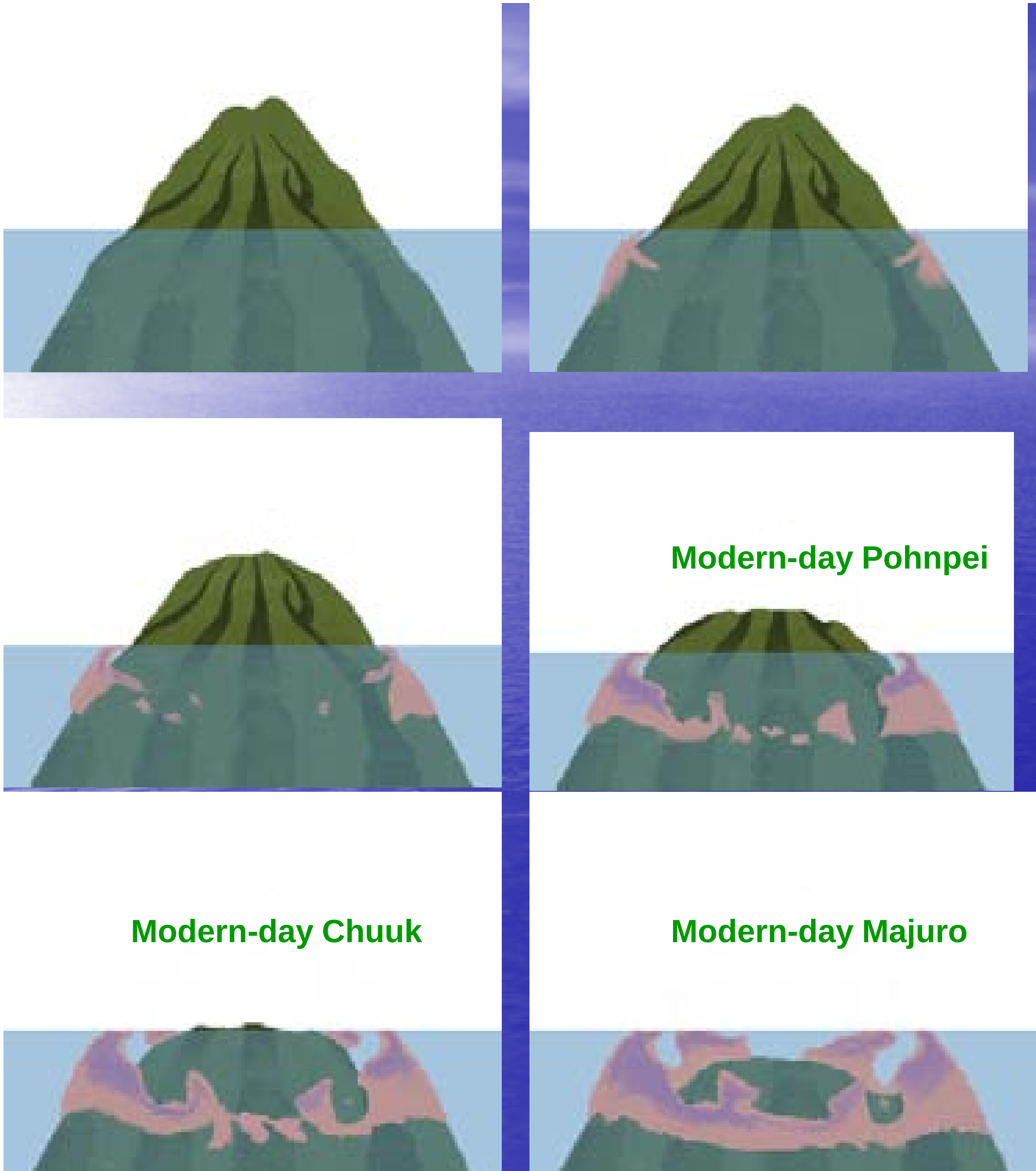
www.scotese.com/jurassic.htm Courtesy Dr Mark Lander

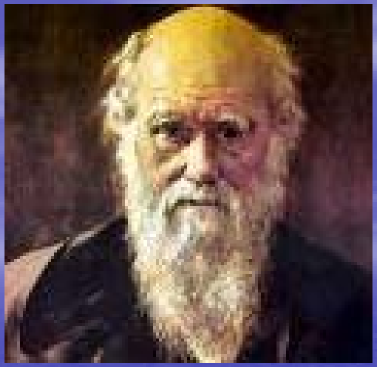


150 My Reconstruction

UMATAC BAY: RELIC OF THE ICE AGE

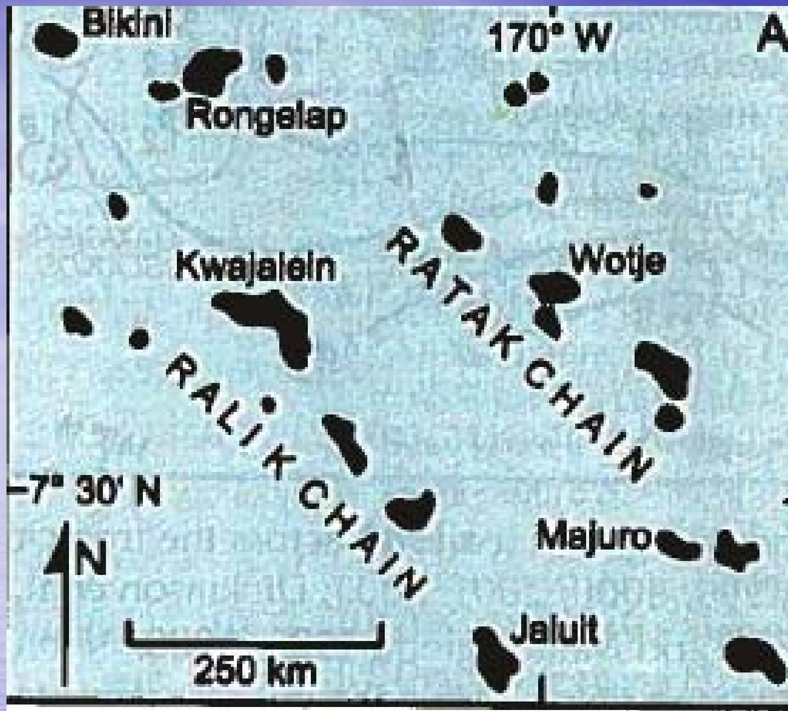
Stream-cut valley when sea level was 450 feet lower!



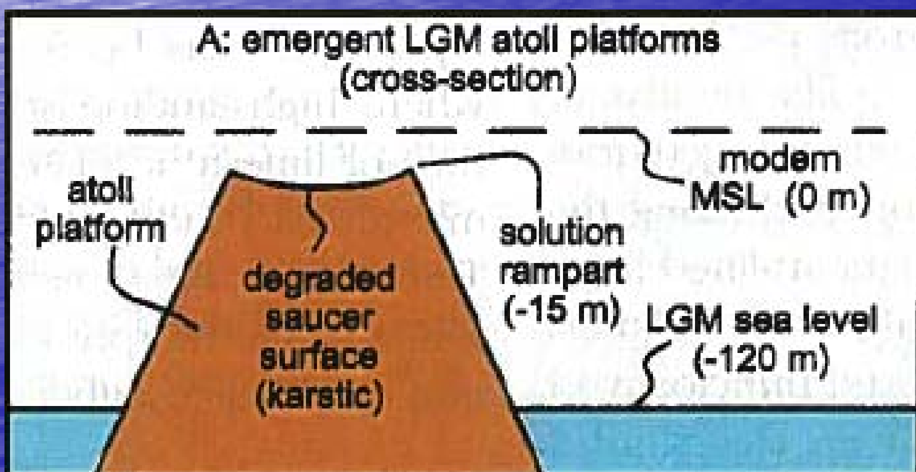


Atoll Formation

Charles Darwin



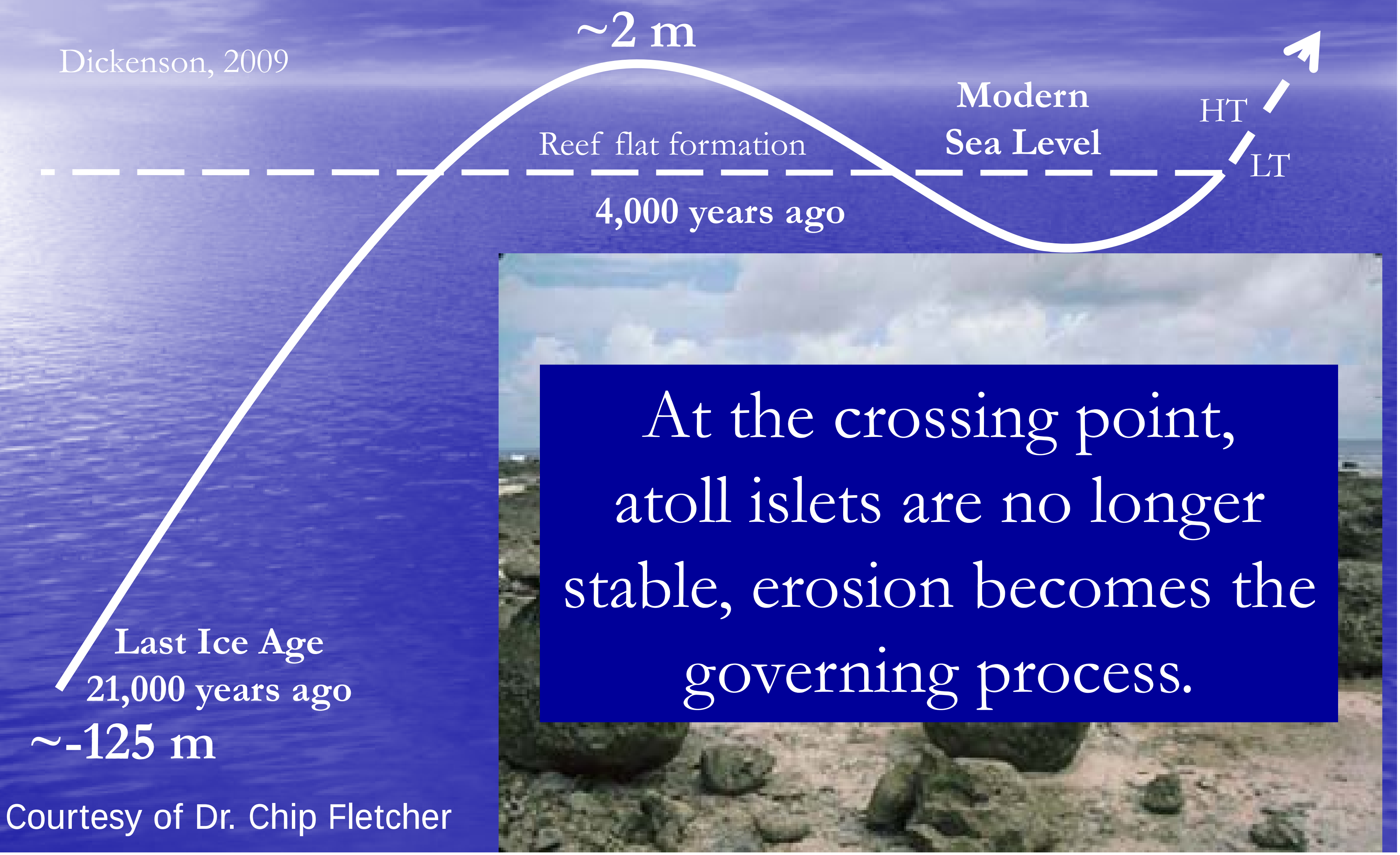
During the last ice age,
The Marshall Islands
and other Pacific atolls
were giant islands, with
100 m sea cliffs. Modern
day Niue and northern Guam
are reasonable analogs (Note:
Guam and Niue are far above
sea level today for other reasons).



Rainfall and vegetal growth created
conditions that eroded the interior
of the island faster than the edges,
producing a saucer shaped top.
During the ice age emergence, the
islands eroded about 12 m below the
current sea level

When the rising sea level overtopped
these limestone plateaus, new reef
began to grow on the rims, and the
flooded lagoons filled with detritus
and patch reefs

Crossing point



Crossover dates (past and future)

TABLE 1. INFERRED CROSSOVER DATES FOR PACIFIC ATOLL CLUSTERS*

Atoll cluster†	highstand magnitude§ (m)	highstand termination# (BCE or CE)	tidal range (m)	past crossover date** (CE)	earliest future crossover date†† (CE)	latest future crossover date§§ (CE)
western Caroline Islands##	1.6	100 CE	1.2	400	2050	2100
central Caroline Islands	1.2	100 BCE	0.6	500	2060	2120
eastern Caroline Islands	1.4	200 BCE	0.9	600	2050	2100
Marshall Islands	2.4	600 BCE	1.6	700	2080	2160
Kiribati-Tungaru chain	2.2	300 BCE	1.5	1000	2070	2140
Tuvalu	2.3	200 BCE	1.6	1100	2070	2140
Tokelau##	1.8	100 BCE	1.0	1000	2080	2160
Phoenix Islands##	1.7	100 BCE	1.0	900	2070	2140
northern Cook Islands	1.1	400 CE	0.6	900	2050	2100
Line Islands (Kiritimati)	0.9	300 CE	0.4	800	2050	2100
northern Tuamotu Archipelago	1.0	500 CE	0.3	900	2070	2140
Society Islands (Tupai)	1.0	100 BCE	0.3	500	2070	2140
southern Tuamotu Archipelago	1.2	600 CE	0.4	900	2080	2160
Gambier Archipelago (Temoe)	1.5	300 CE	0.7	900	2070	2140
Cook-Austral chain (Aitutaki)	1.3	200 BCE	0.8	800	2050	2100

Note: BCE—before common era; CE—common era.

*All elevations ± 0.1 m (observational uncertainty) and past dates ± 100+ yr (owing to sparse age control and/or uncertainties in radiocarbon calibrations).

†See Figure 2 for location (islands in parentheses are relevant individual atolls or almost-atolls).

§From Figure 5.

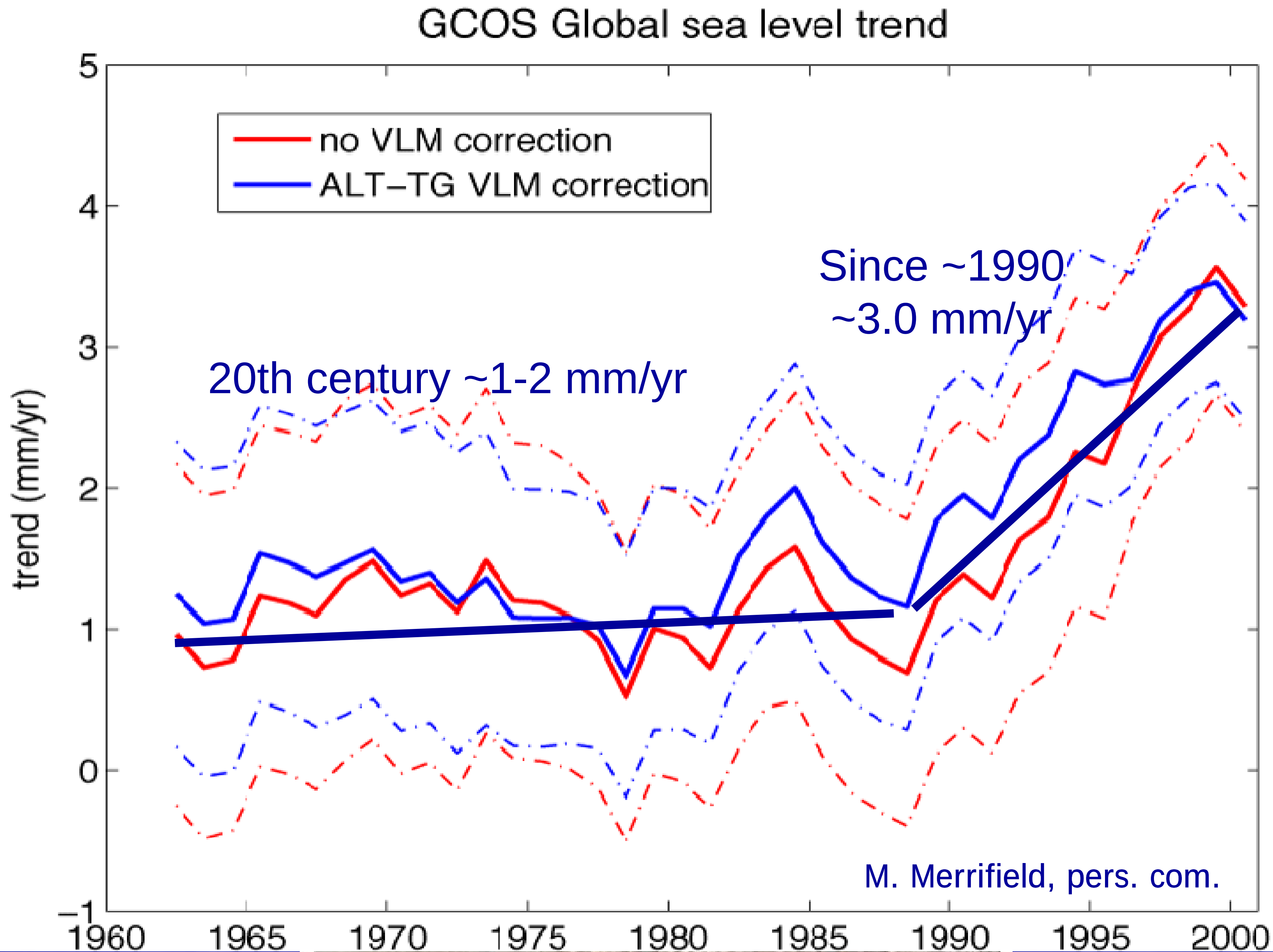
#Adapted from Dickinson (2003).

**Date when declining high tide fell below paleoreef flats built to mid-Holocene low-tide level (adapted from Dickinson, 2003).

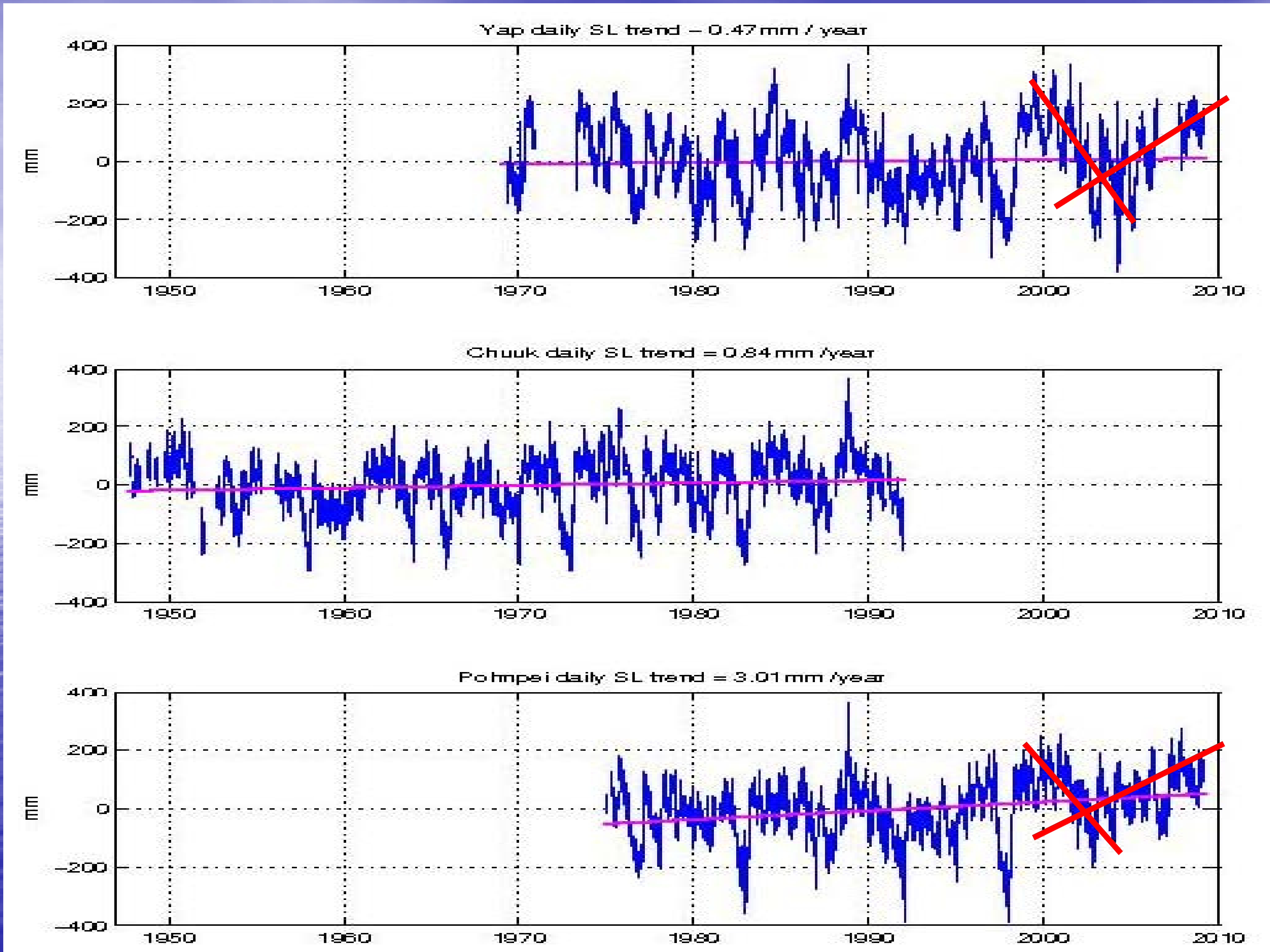
††Date when rising high tide will submerge mid-Holocene paleoreef remnants if global sea level rises ~1.0 m by 2100 CE.

§§Date when rising high tide will submerge mid-Holocene paleoreef remnants if global sea level rises only ~0.5 m by 2100 CE (and continues to rise thereafter at the same rate).

##Data interpolated from neighboring island groups (no internal data available).

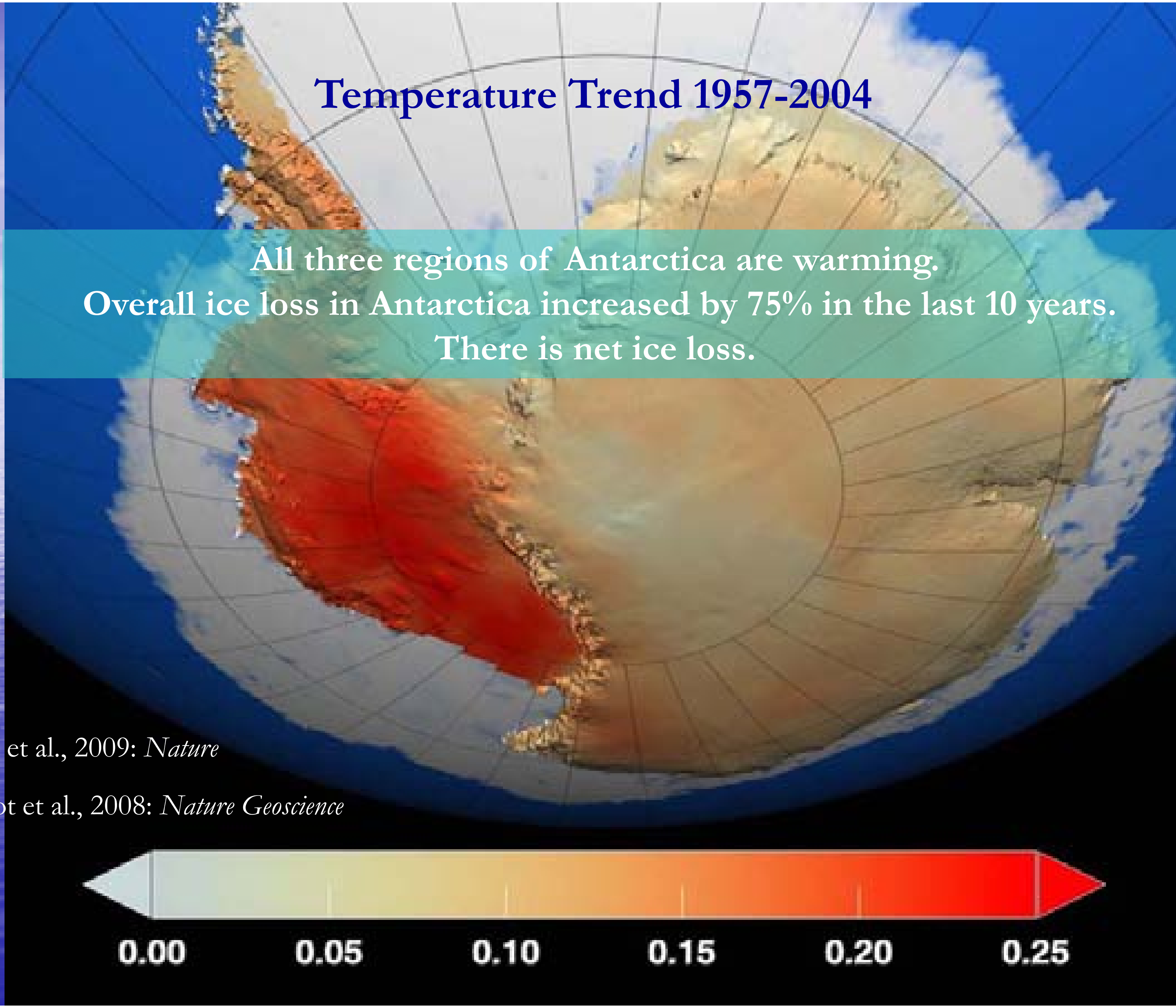


GCOS Global sea level trend
no VLM correction
ALT−TG VLM correction
Since ~1990
~3.0 mm/yr
20th century ~1-2 mm/yr
trend (mm/yr)
5
4
3
2
1
0
−1
1960
1965
1970
1975
1980
1985
1990
1995
2000
M. Merrifield, pers. com.


Yap daily SL trend – 0.47 mm / year
Chuuk daily SL trend = 0.84 mm /year
Pohnpei daily SL trend = 3.01 mm /year
mm
400
200
0
–200
–400
1950
1960
1970
1980
1990
2000
2010

Temperature Trend 1957-2004

All three regions of Antarctica are warming.
Overall ice loss in Antarctica increased by 75% in the last 10 years.
There is net ice loss.

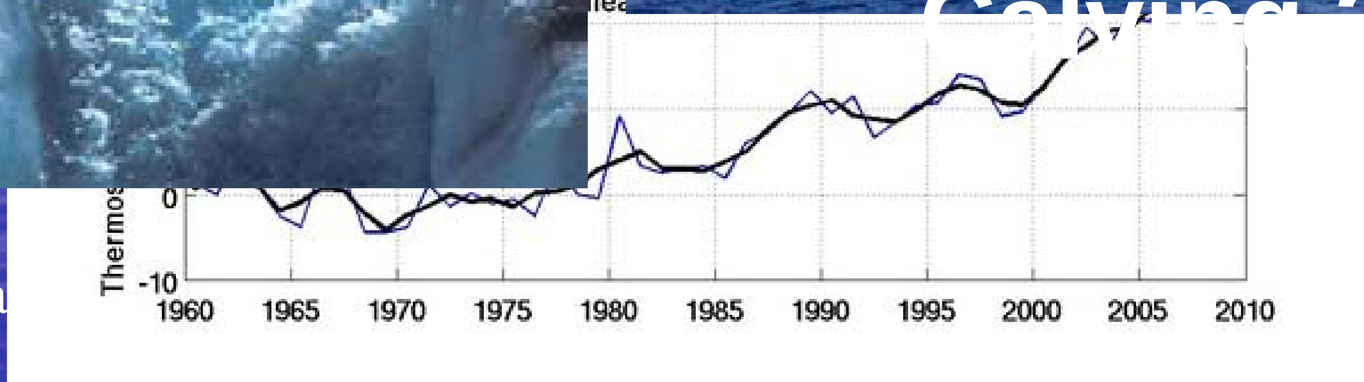


Steig, et al., 2009: *Nature*

Rignot et al., 2008: *Nature Geoscience*

Major components

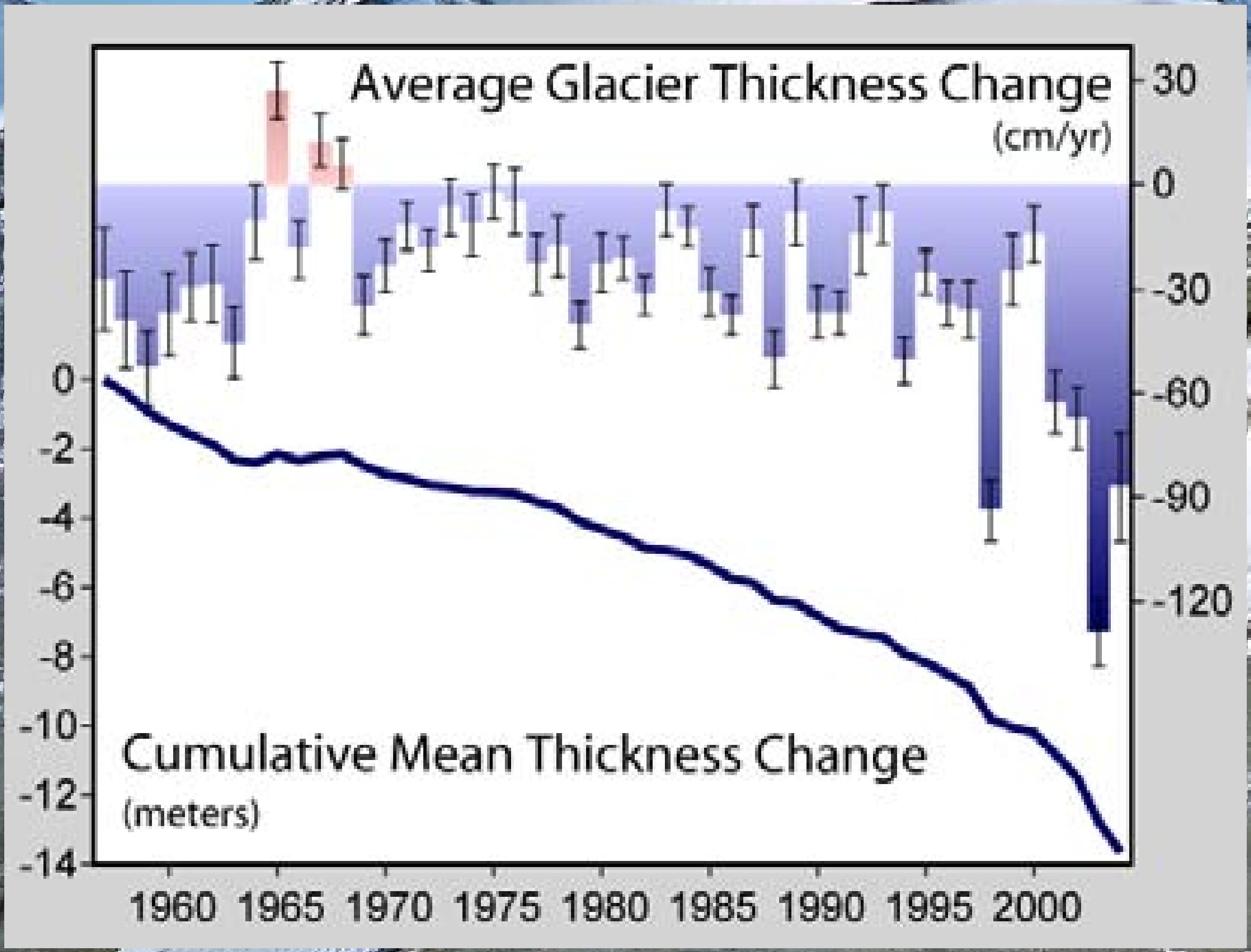
- Thermal Expansion and Ice Loss (melting and



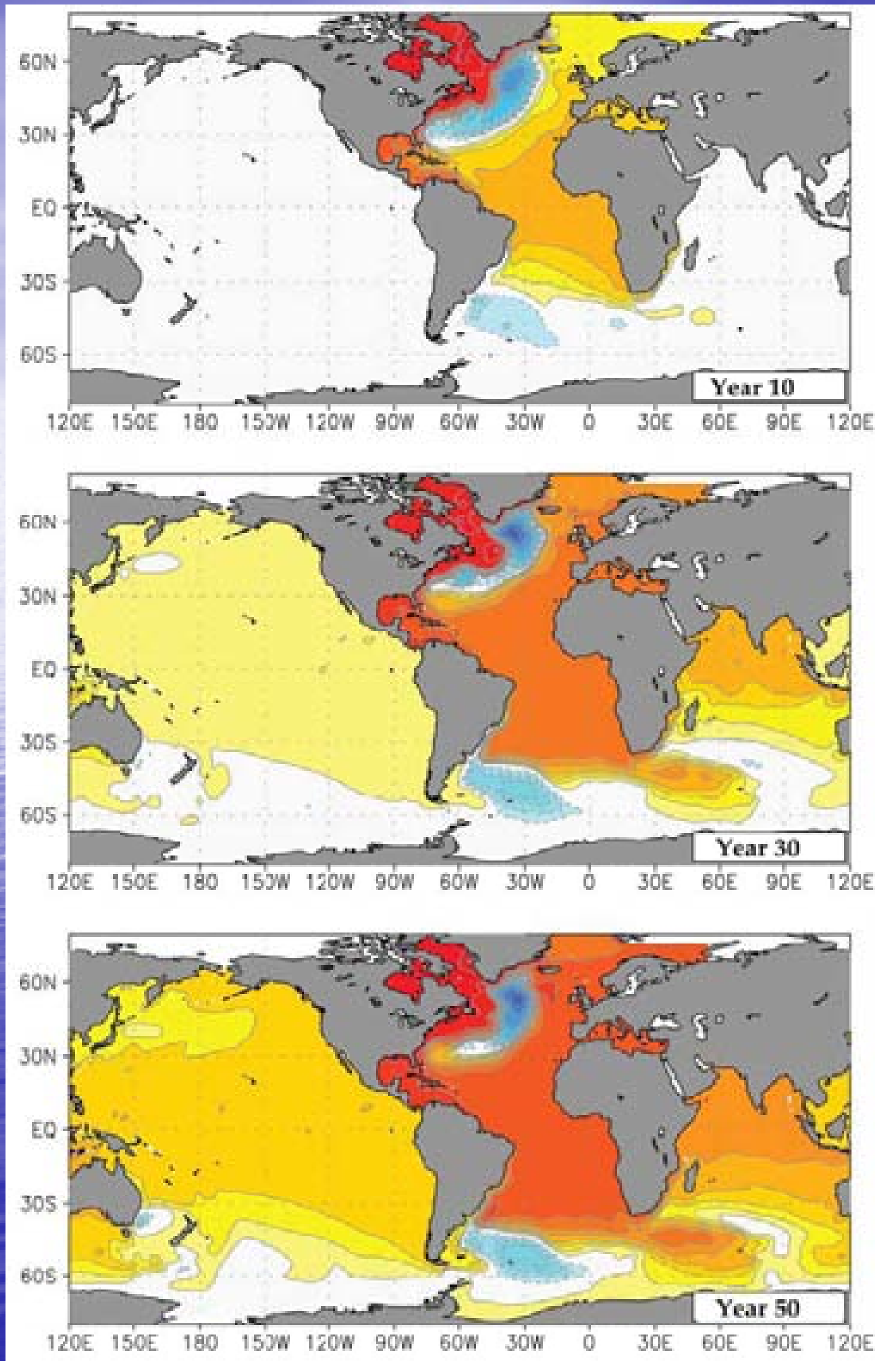
Calving ?

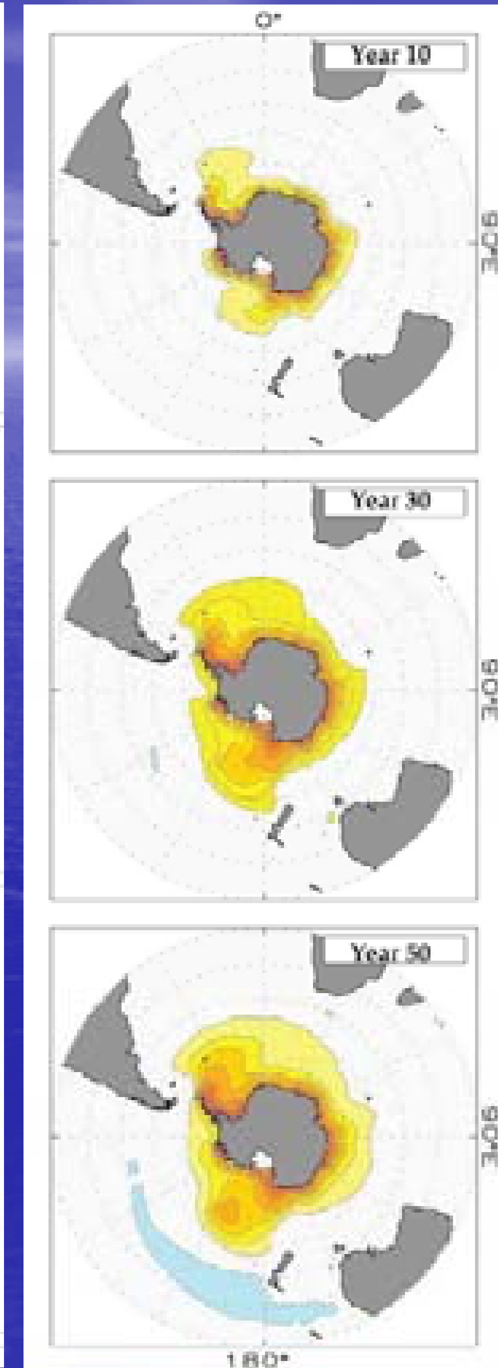
Therma … m

Alpine glaciers are in a state of global collapse



Meier, et al. 2007 Science





Meltwater from Greenland and Antarctica takes decades to impact the Pacific

Greenland meltwater is trapped in the Atlantic for decades.

Stammer, JGR v.113, 2008

Summary of Atoll Evolution

- At tectonic time scales reefs may be significant carbon sinks
  - Not known for certain how quickly oceans and reefs might respond to change in atmospheric CO_2
- Modern atolls are a <u>transient</u> morphology
- Annular reefs atop carbonate platforms
  - Underlain by 8-28 m of Holocene LS
  - Underlain by weathered Pleistocene LS (karst)
  - Lagoons uniformly <85 m deep, with 9-23 m of sediment on bottom
- Carbonate platform surfaces spent most of the past 125 ka (indeed, most of past 2 ma) above sea level
- Modern atoll reef caps grew after ~9 ka, when overtopped by rising sea level
- Stayed submerged as reefs grew to sea level in Mid-Holocene, 6-4 ka
  - High stand at 1.0-2.6 m
- Atoll islands exposed when ambient high tide dropped below Mid-Holocene low tide level ("cross-over") <1-2 ka

Sea level components

global and local

- Glacio-eustatic component
  - Global water volume change due to glacial growth & decay
  - Regional gravitational effects: mantle anomalies, continental mass and ice sheet mass
    - Time scale: 100 ka to 1 ka
- Hydro-isostatic component
  - Global ocean basin volume change due to isostatic adjustment of ocean floor and/or continental subsidence or rebound in response to change in load
    - Time scale: 100 ka to 1 ka
- Tectonic components
  - Global: Change in ocean basin volume due to tectonic process, e.g., sea-floor spreading, crustal flexture, continental rifting, collision, uplift and subsidence, etc.
    - Time scale: 10 ma to 100 ka
  - Local: uplift and subsidence
    - Millions of years to instantaneous
- Climatic components
  - Regional in effect: ENSO, regional wind patterns, storms
    - Mellinea, Centuries to decades to years and months to days and hours

Summary 2 (Dickinson, 2009)

Relevant climate statistics:

20th Century sea level rise:
Persistent 1.7 – 1.9 mm/yr (0.67-0.75 in/yr)

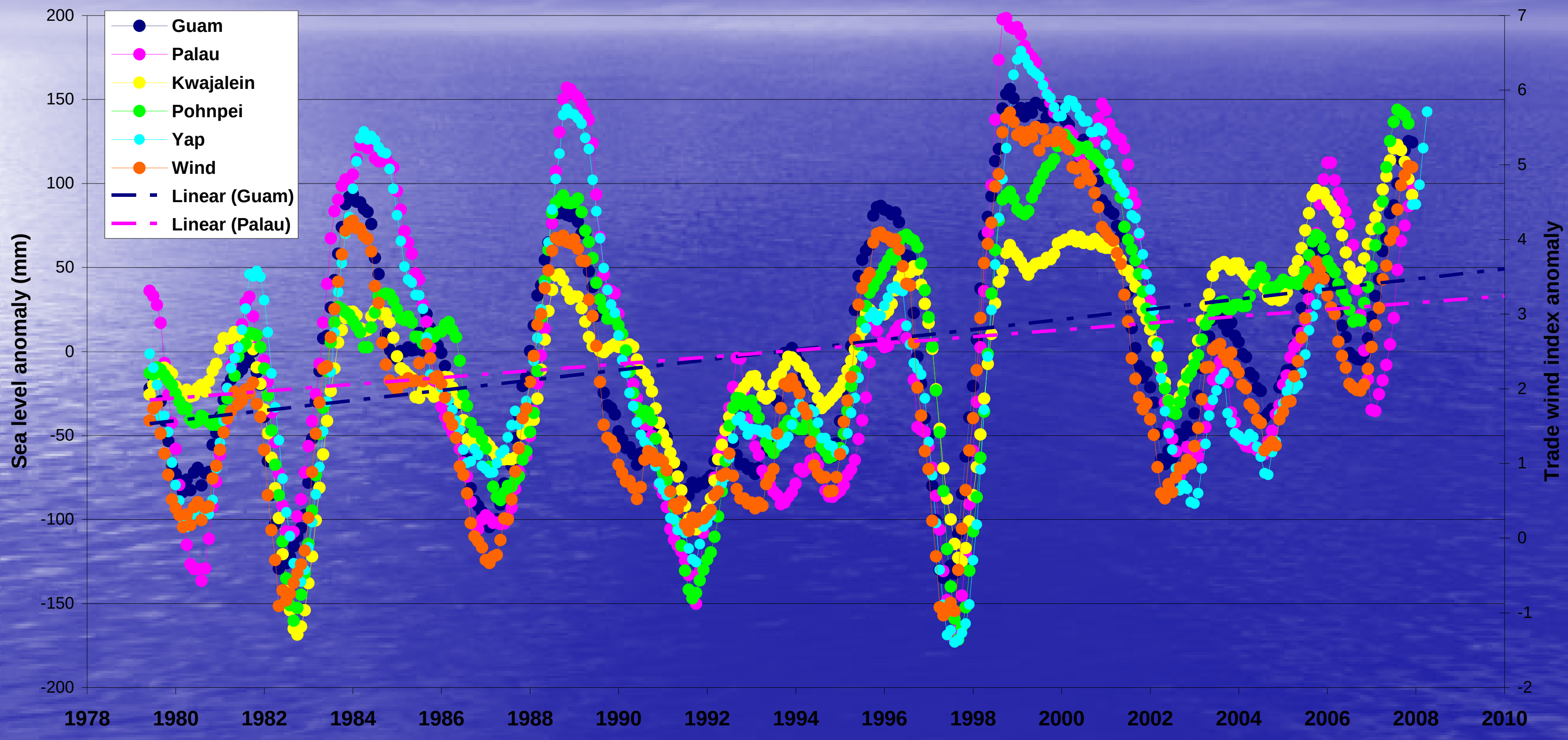
Rise of the sea from 1908 to 1999 = 180 mm (7 inches)

Sea level rise 2.5 mm/yr during 1990s (0.1 in/yr)

Sea level rise 4 mm/yr present decade !? (0.16 in/yr)

Crossover dates
Later half of 21st Century 10 mm/yr (0.4 in/yr)
First half of 22nd Century 5 mm/yr (0.2 in/yr)

Pacific Island Sea Level 1978-2008

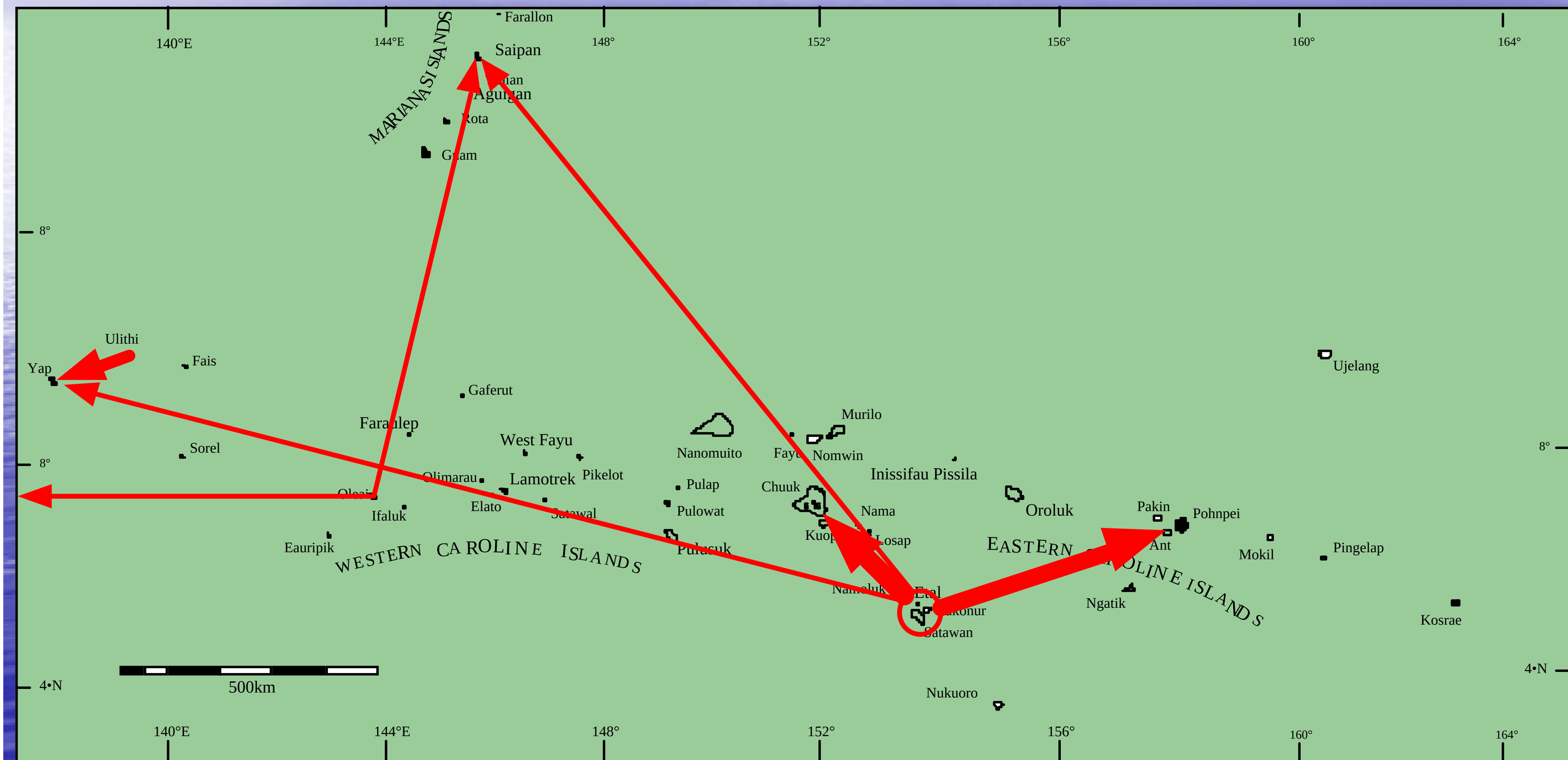


Courtesy of Dr Mark Lander & Dr John Jensen

BACKGROUND

- ENSO Affects Three Important Parameters
  - Rainfall
  - Monsoon Trough Activity
  - Sea Level Height
- Rainfall Amount Determines Floods and Droughts
- Monsoon Trough Activity Determines Tropical Cyclone Activity
- Sea Level Height Determines Salt Water Inundation
- Typhoons and Droughts are the Primary Reasons for Migrations in Micronesia
- All Three Parameters Lead to Island Erosion

Relocation



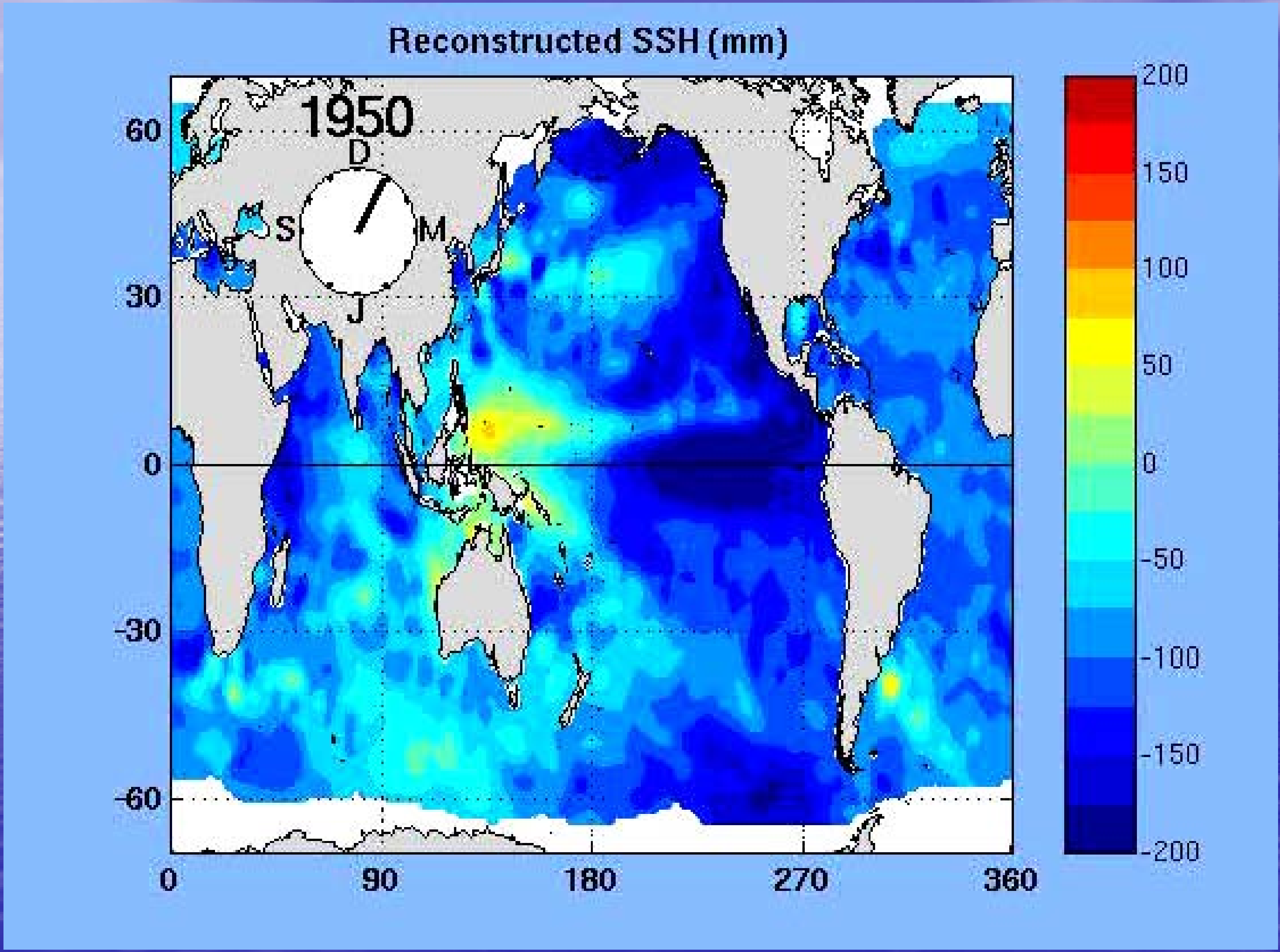
Farallon
Saipan
Aguijan
Rota
Guam
MARIANAS ISLANDS
140°E
144°E
148°
152°
156°
160°
164°
8°
Ulithi
Yap
Fais
Gaferut
Faraulep
Sorel
West Fayu
Pikelot
Lamotrek
Olimarau
Elato
Ifaluk
Eauripik
Pulap
Pulowat
Pulusuk
Nanomuito
Murilo
Nomwin
Chuuk
Nama
Losap
Inissifau Pissila
Oroluk
Pakin
Pohnpei
Ant
Mokil
Pingelap
Ngatik
Ujelang
Kosrae
Satawan
Nukuoro
WESTERN CAROLINE ISLANDS
EASTERN CAROLINE ISLANDS
4•N
500km

Photo Fritz Collection MARC

Tropical Weather Basics

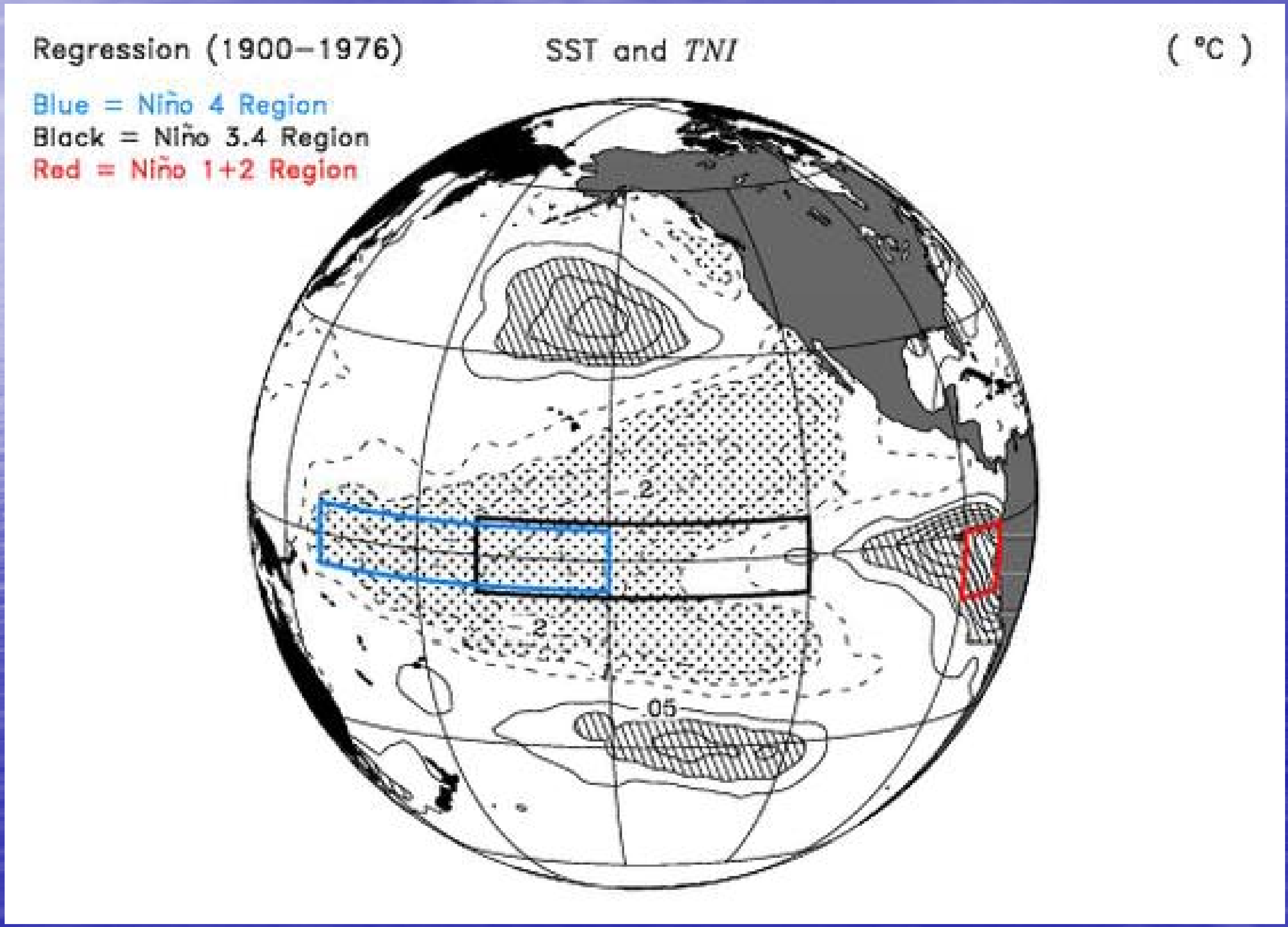
- All tropical weather systems have a basic in-up-out-down structure
- Up = upward motion, condensation, rain
- Down = downward motion, drying, little rain
- This applies at all scales—small and large—from the small rain shower to the thunderstorm to the typhoon to the monsoon to El Nino
- Wind blows from high pressure to low pressure
- Land heats and cools much faster than the ocean
- The amount of water vapor the air can hold increases with increasing temperature
- The earth balances incoming and outgoing radiation; if more radiation comes in than goes out, it gets warmer

BACKGROUND

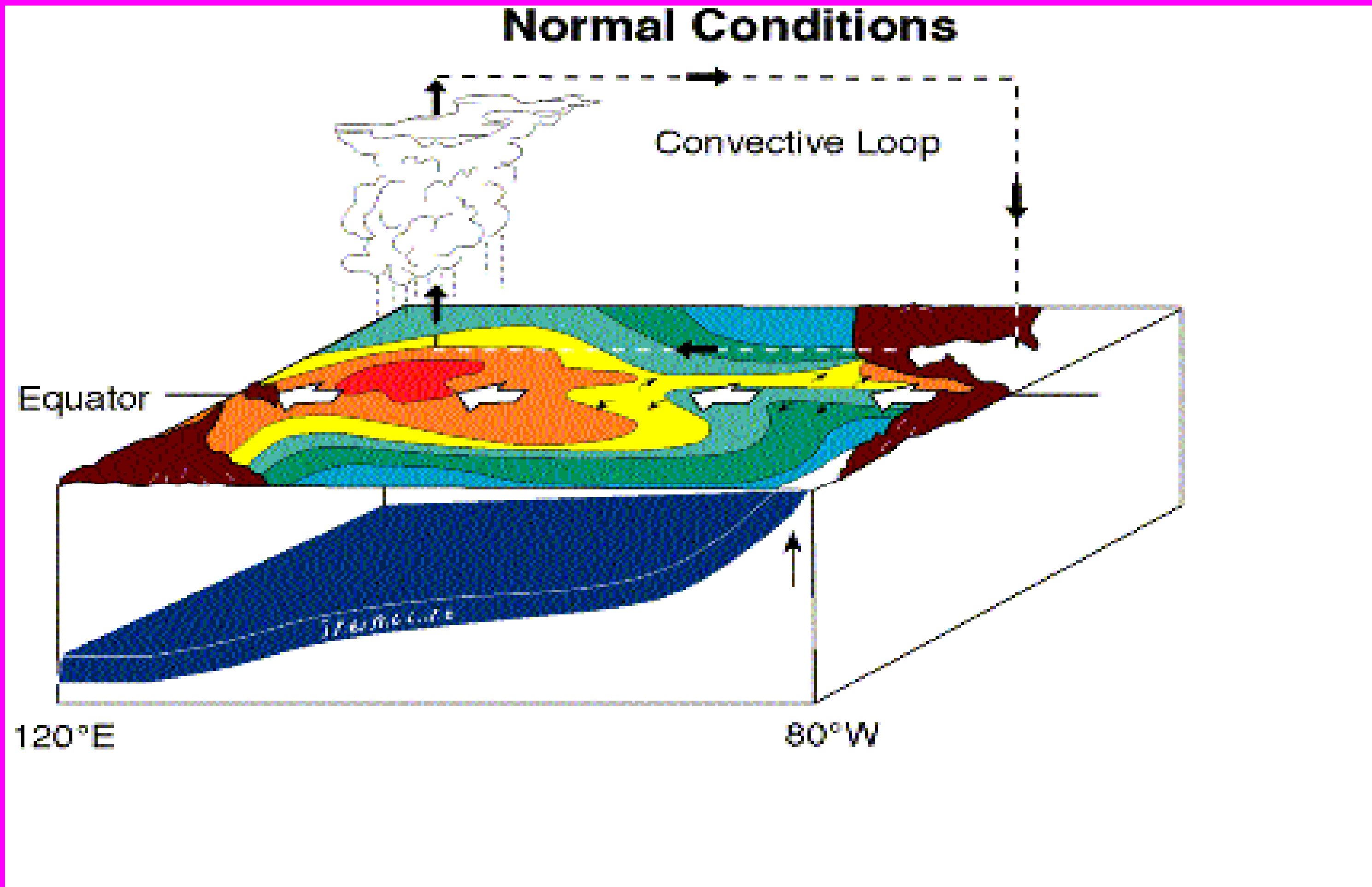


Reconstructed SSH (mm)
1950
D
S
M
J
60
30
0
-30
-60
0
90
180
270
360
200
150
100
50
0
-50
-100
-150
-200

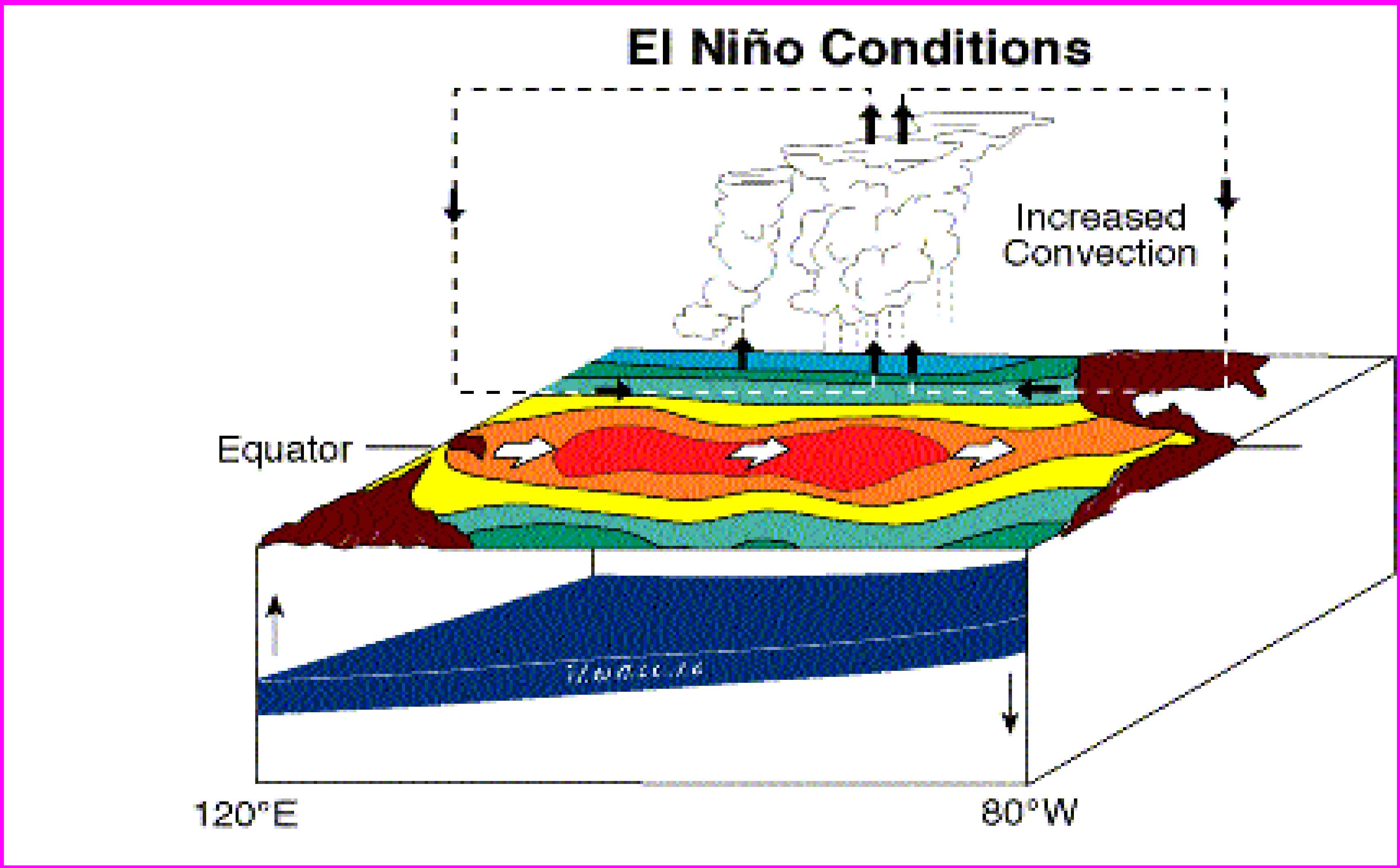
EL NINO MONITORING REGIONS



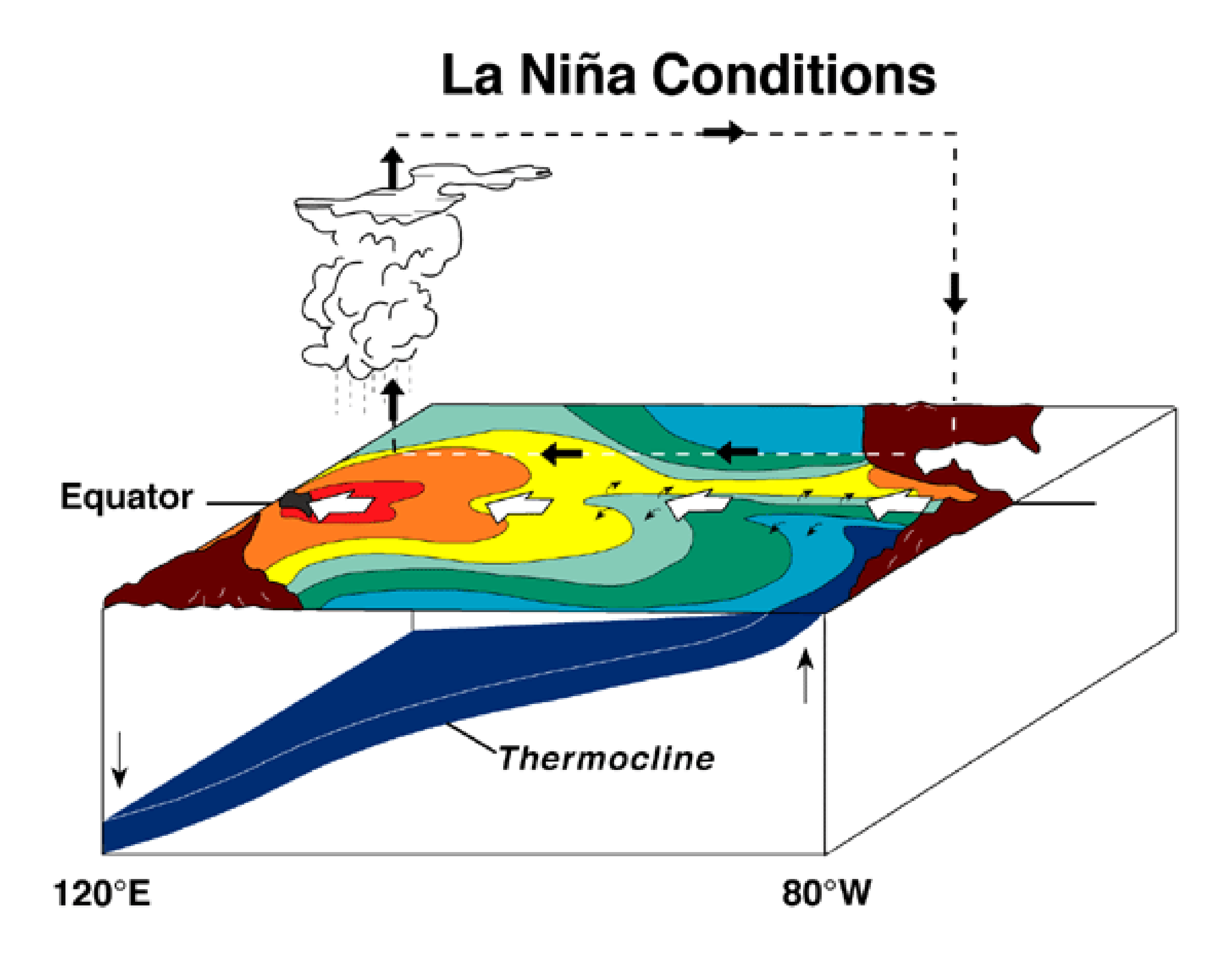
NORMAL CONDITIONS ACROSS THE EQUATORIAL PACIFIC



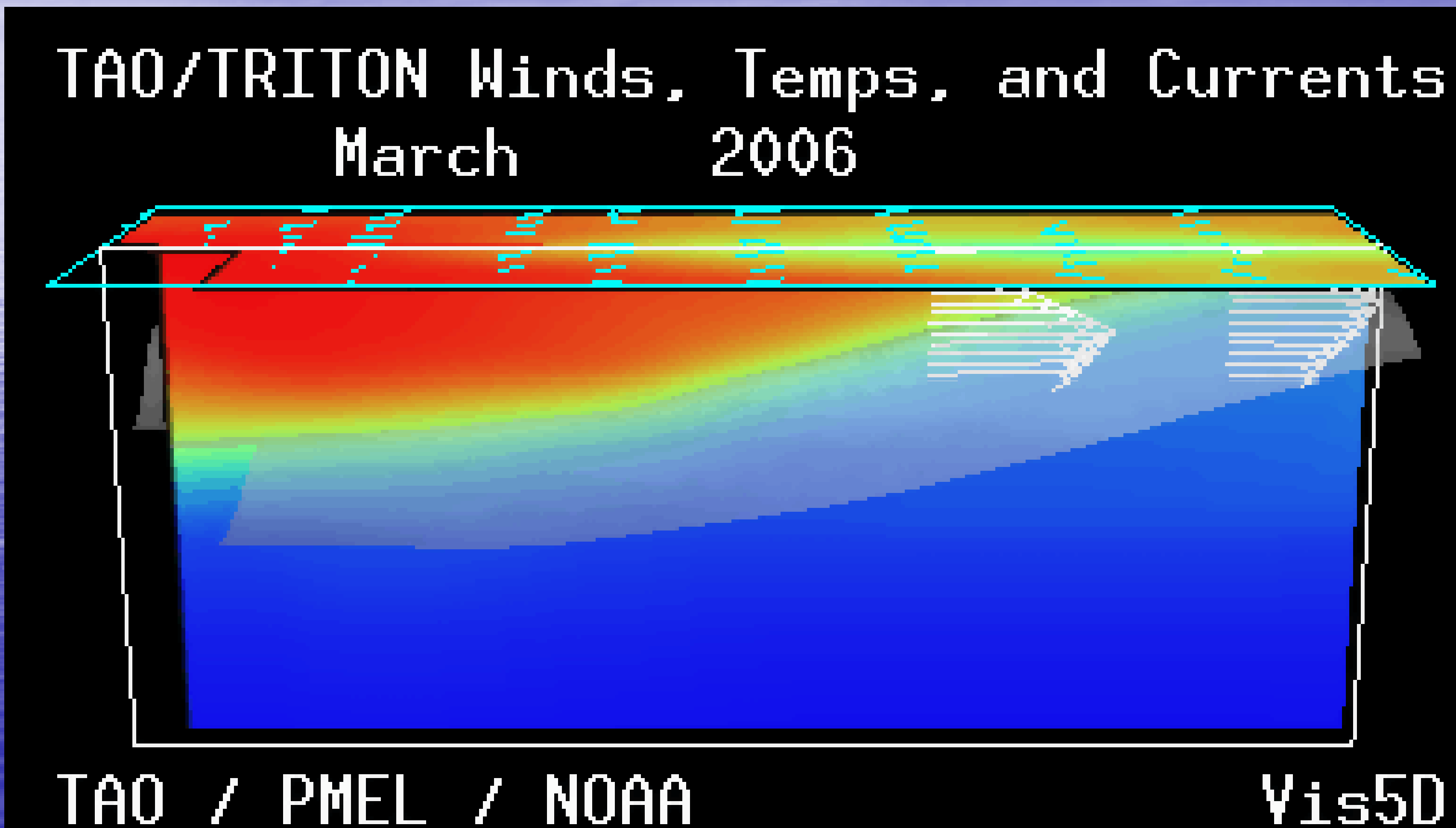
EL NINO ONSET CONDITIONS ACROSS THE EQUATORIAL PACIFIC



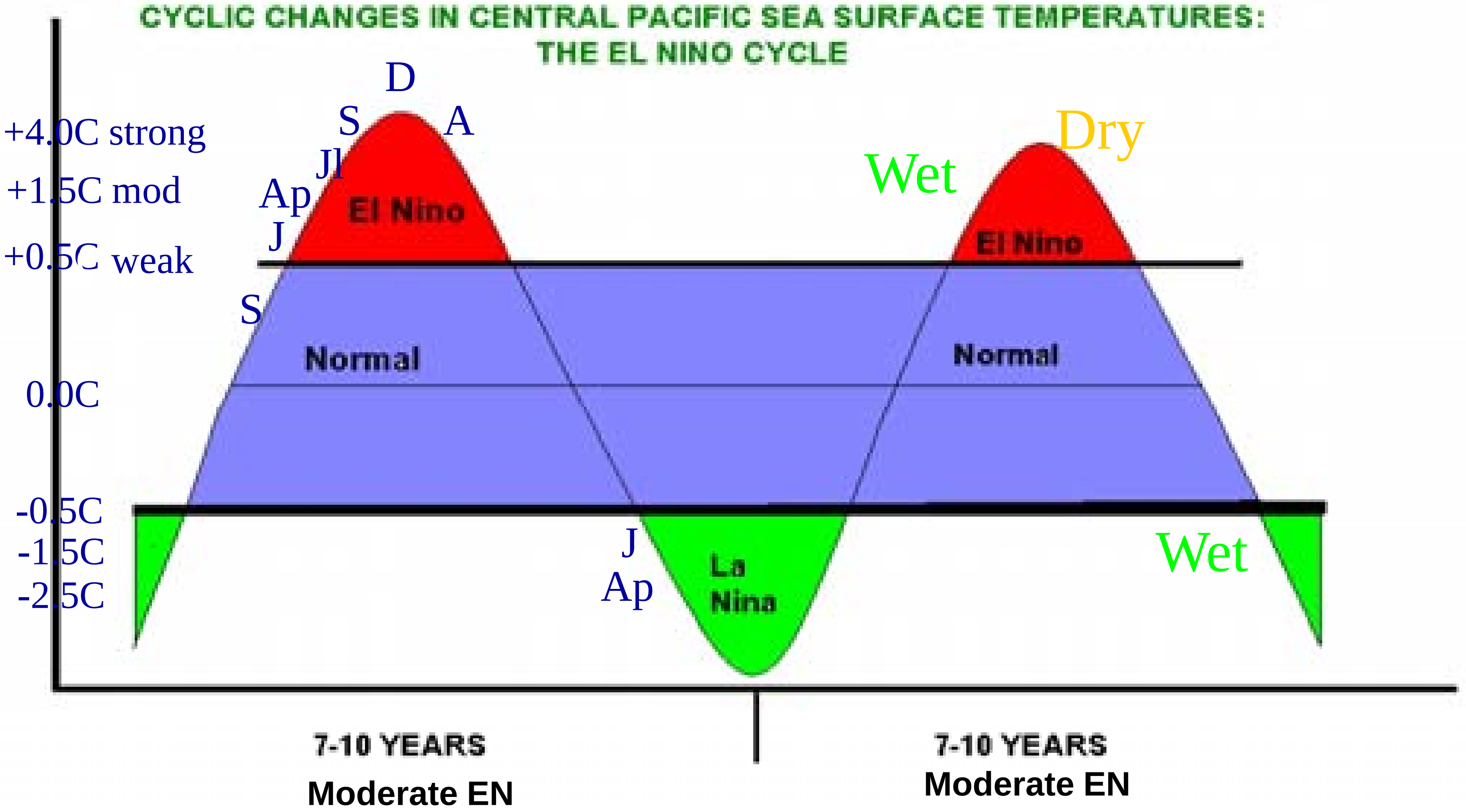
LA NINA CONDITIONS IN EQUATORIAL PACIFIC



Winds, Temperatures, Currents



EL NINO CYCLE



Weak—every 3-5 years
Moderate—every 7-10 years
Strong—every 15-20 years

TWO TYPES OF ISLANDS

- High Islands
- Low Islands

- Each type of island has specific drought-related problems, but low islands are most harshly affected

HIGH ISLAND

LOW ISLAND

LOW ISLAND

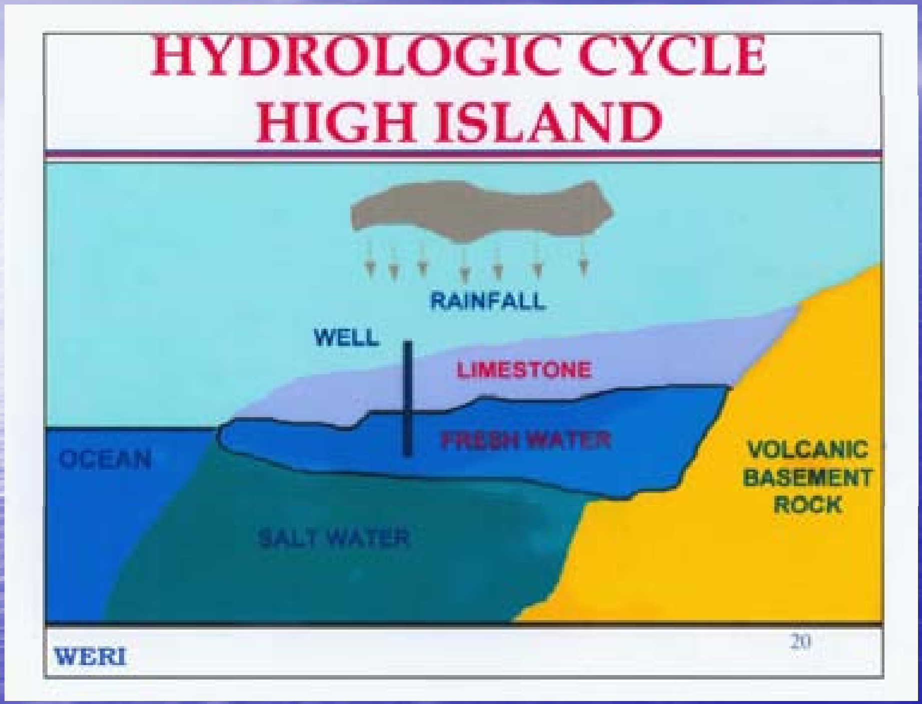
EL NINO EFFECTS AND IMPACTS ON PACIFIC ISLANDS—WET PERIODS

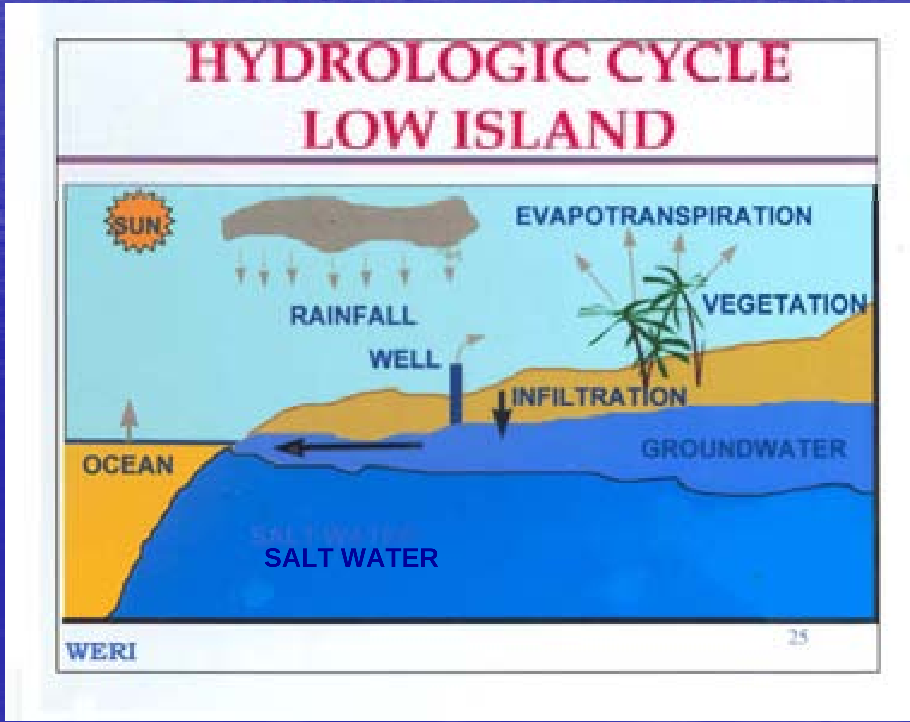
- Enhances westerly winds along equator—**coastal flooding and erosion; some wind damage**
- Enhances monsoon activity across Micronesia—**flooding, mudslides, and coastal erosion**
- Shifts tropical cyclone development eastward, increasing risk to the Marshall Islands, eastern FSM, the Mariana Islands, and American Samoa—**wind damage, storm surge, flooding, destruction of food crops**
- Causes sea levels to fall, exposing coral reefs to the sun and bleaching

EL NINO EFFECTS AND IMPACTS ON PACIFIC ISLANDS—DRY PERIODS

- Drought occurs in all of Micronesia in Jan-Apr following a strong El Nino event; it starts in late Fall in Palau; Yap & Chuuk States usually dry in moderate El Ninos; the Marianas can be wet or dry.
  - Water resources greatly reduced or disappear
  - Health can be drastically affected
  - Fire danger greatly enhanced
  - Trade winds increase, raising sea levels and causing coastal flooding
  - Food sources may not return for 8-10 months

EL NINO EFFECTS AND IMPACTS ON PACIFIC ISLANDS—DRY PERIODS





EL NINO EFFECTS AND IMPACTS ON PACIFIC ISLANDS—DRY PERIODS

- Drought occurs in all of Micronesia in Jan-Apr following a strong El Nino event;
  - Water resources greatly reduced or disappear
  - Health can be drastically affected
  - Fire danger greatly enhanced
  - Trade winds increase, raising sea levels and causing coastal flooding and inundation
  - Food sources may not return for 8-10 months
- Rains return to: Kosrae in Apr; Majuro, Pohnpei, Chuuk & Palau in May; Yap & Kwajalein in Jun; Guam in Jul; Saipan in Aug.

EL NINO EFFECTS AND IMPACTS ON PACIFIC ISLANDS—DRY PERIODS

- Summary
  - Drought occurs in all of Micronesia in Jan-Apr following a strong El Nino event
  - Rains return to:
    - Kosrae in Apr
    - Majuro, Pohnpei, Chuuk & Palau in May
    - Yap & Kwajalein in Jun
    - Guam in Jul
    - Saipan in Aug

- On many islands, drought is not an inconvenience, but **a life or death issue**

LA NINA EFFECTS AND IMPACTS ON FSM PACIFIC ISLANDS

- Many locations can have a wet spring (Mar-May)
  - Islands from 4N-8N can get 60-80 inches of rain in Jan-Mar; the Marianas can be wet or dry
  - Tropical cyclone activity pushed to the west; reduced threat for Islands East of 140E
  - Strong trade winds can elevate sea levels, causing increased coastal erosion and coastal inundation

EL NINO—SOUTHERN OSCILLATION ASSESSMENT TOOLS

OCEANIC PARAMETERS

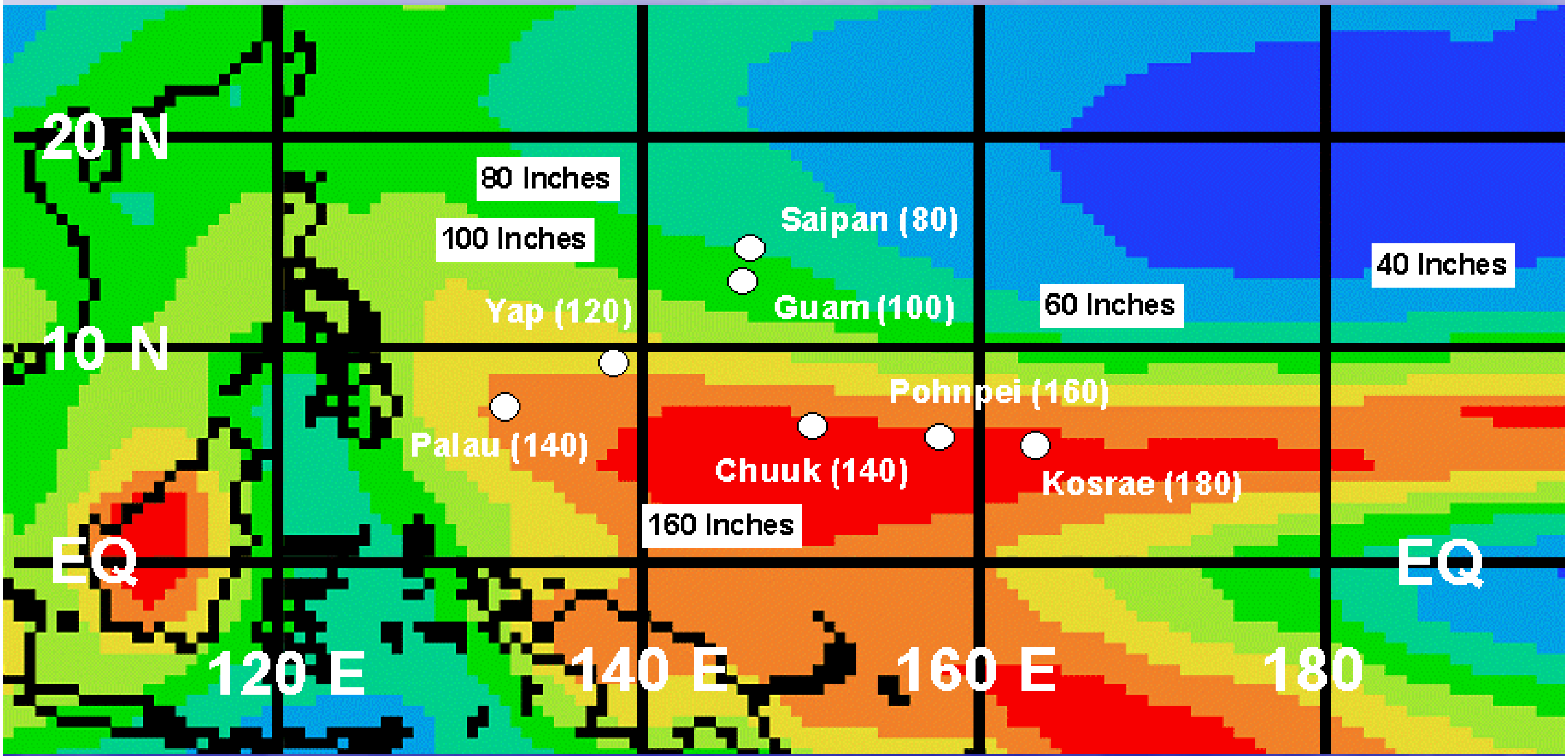
- Equatorial sea surface temperature anomalies
- Equatorial sub-surface ocean temp anomalies
- Sea level heights
- Climate model predictions

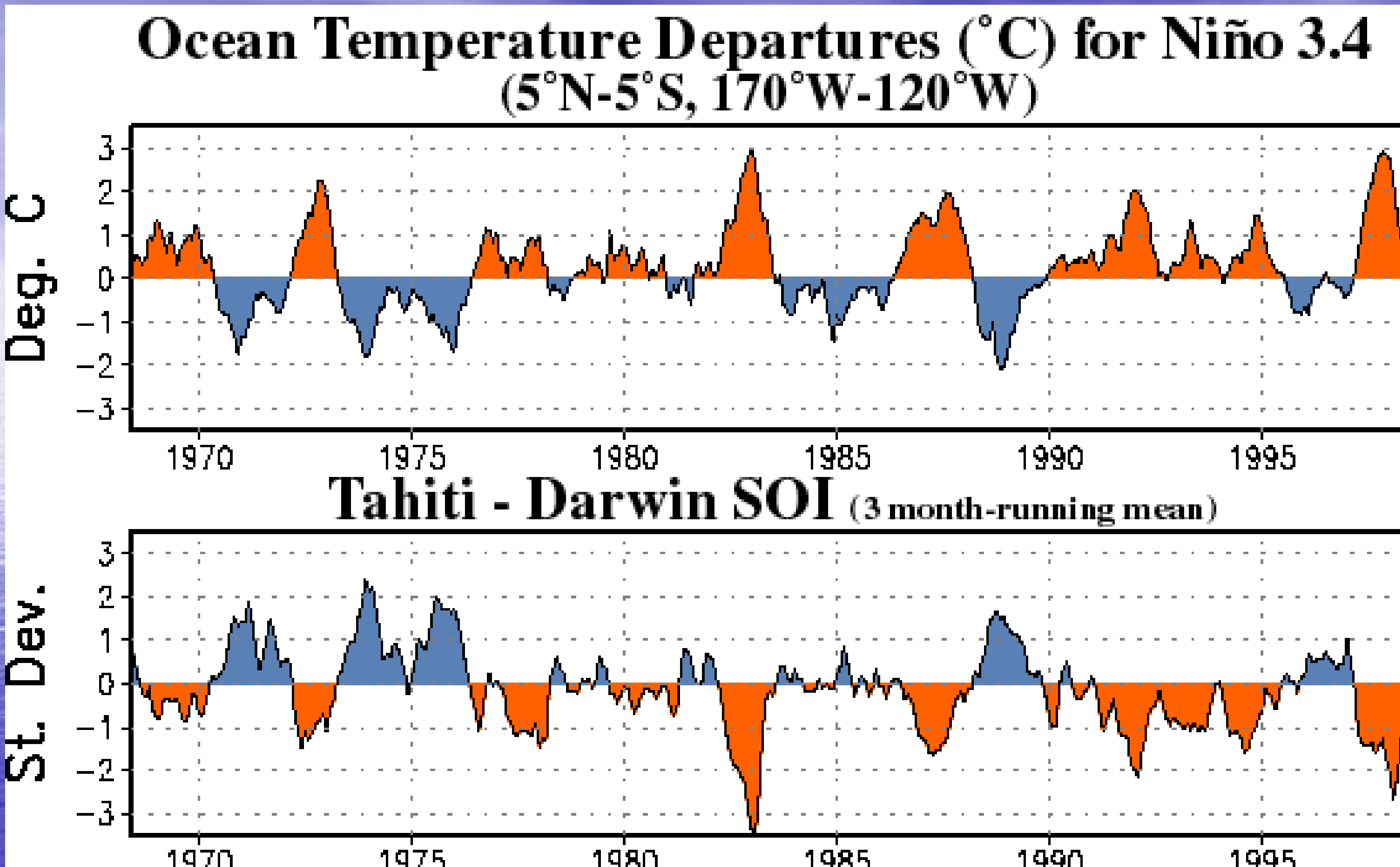
EL NINO—SOUTHERN OSCILLATION ASSESSMENT TOOLS

ATMOSPHERIC PARAMETERS

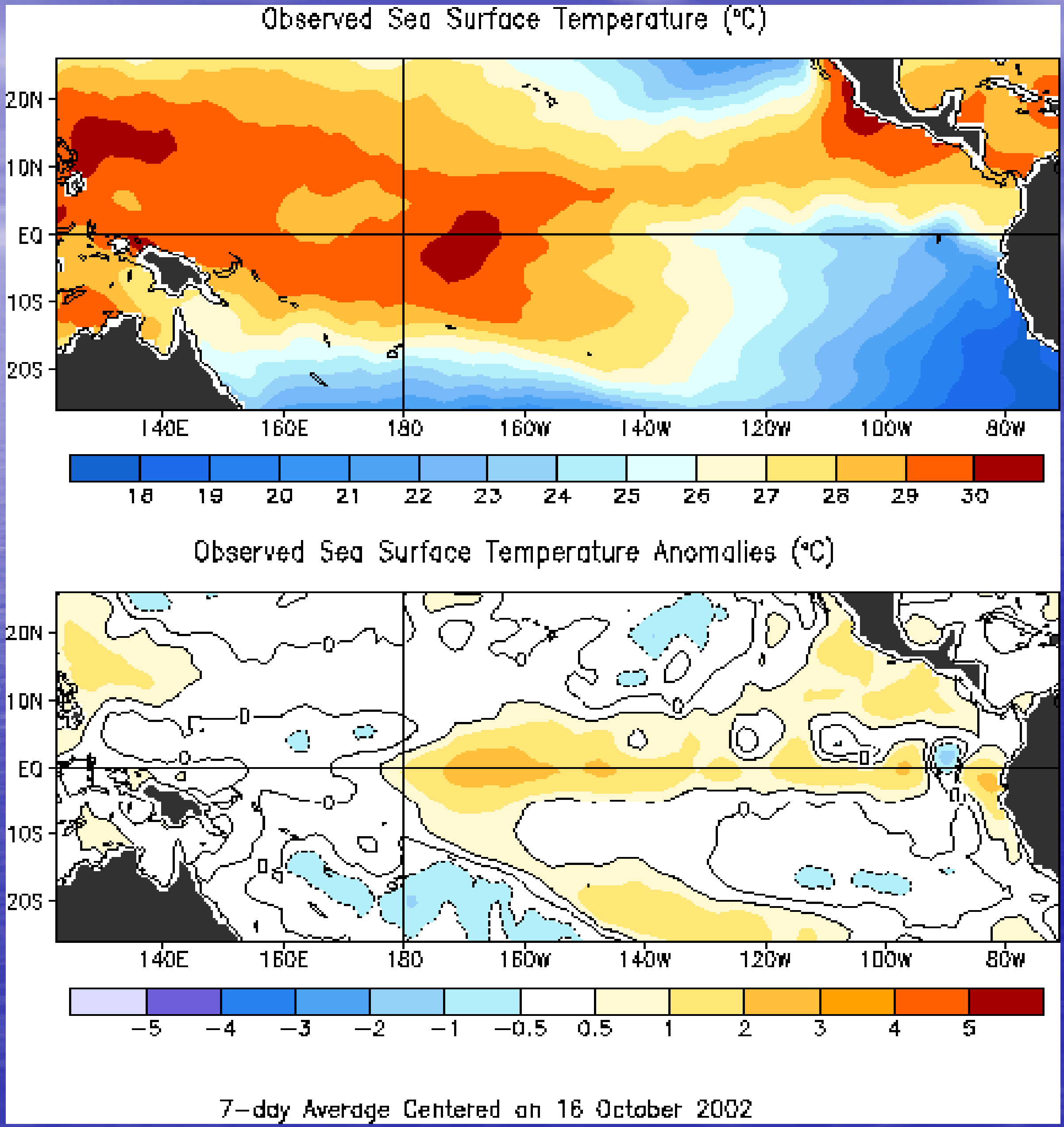
- Southern Oscillation Index
- Equatorial wind anomalies
- Near equatorial vertical motion fields
- Rainfall and tropical cyclone patterns
- Climate model predictions

AVERAGE ANNUAL TROPICAL PACIFIC RAINFALL PATTERNS

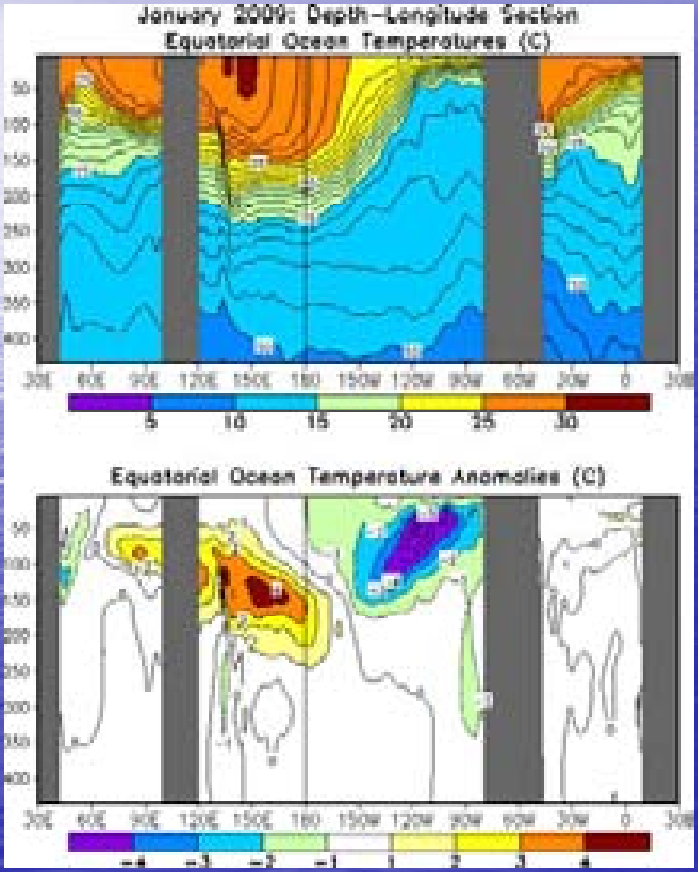


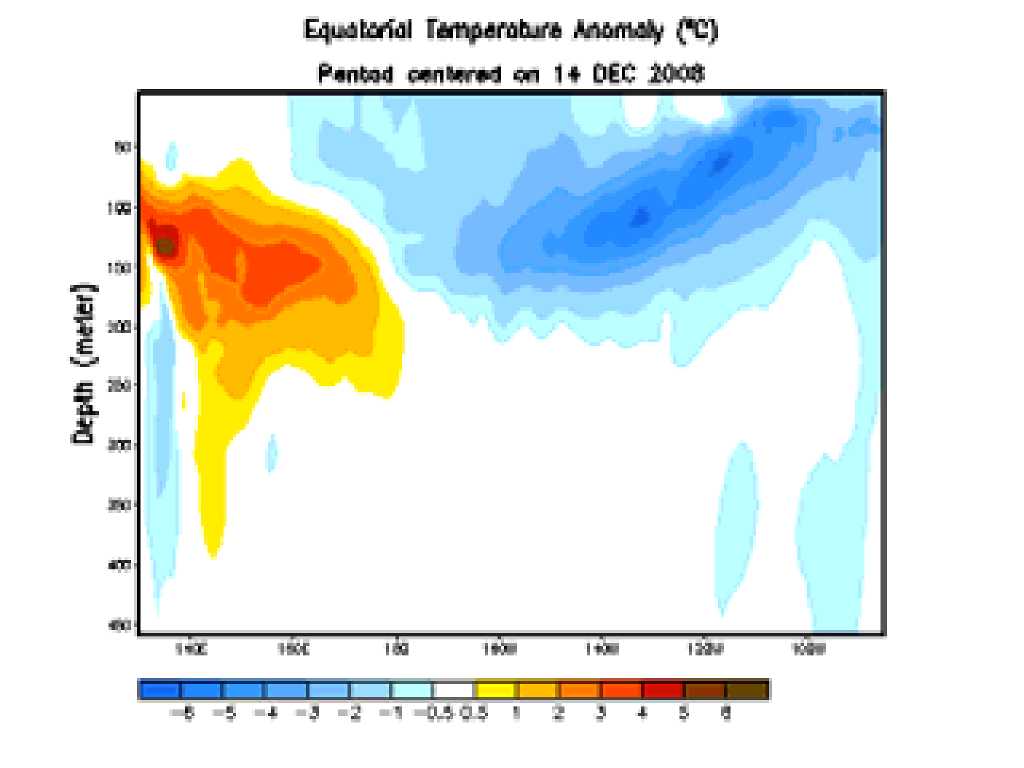

Ocean Temperature Departures (°C) for Niño 3.4
(5°N-5°S, 170°W-120°W)
Deg. C
3
2
1
0
−1
−2
−3
1970
1975
1980
1985
1990
1995
Tahiti - Darwin SOI (3 month-running mean)
St. Dev.
3
2
1
0
−1
−2
−3
1970
1975
1980
1985
1990
1995

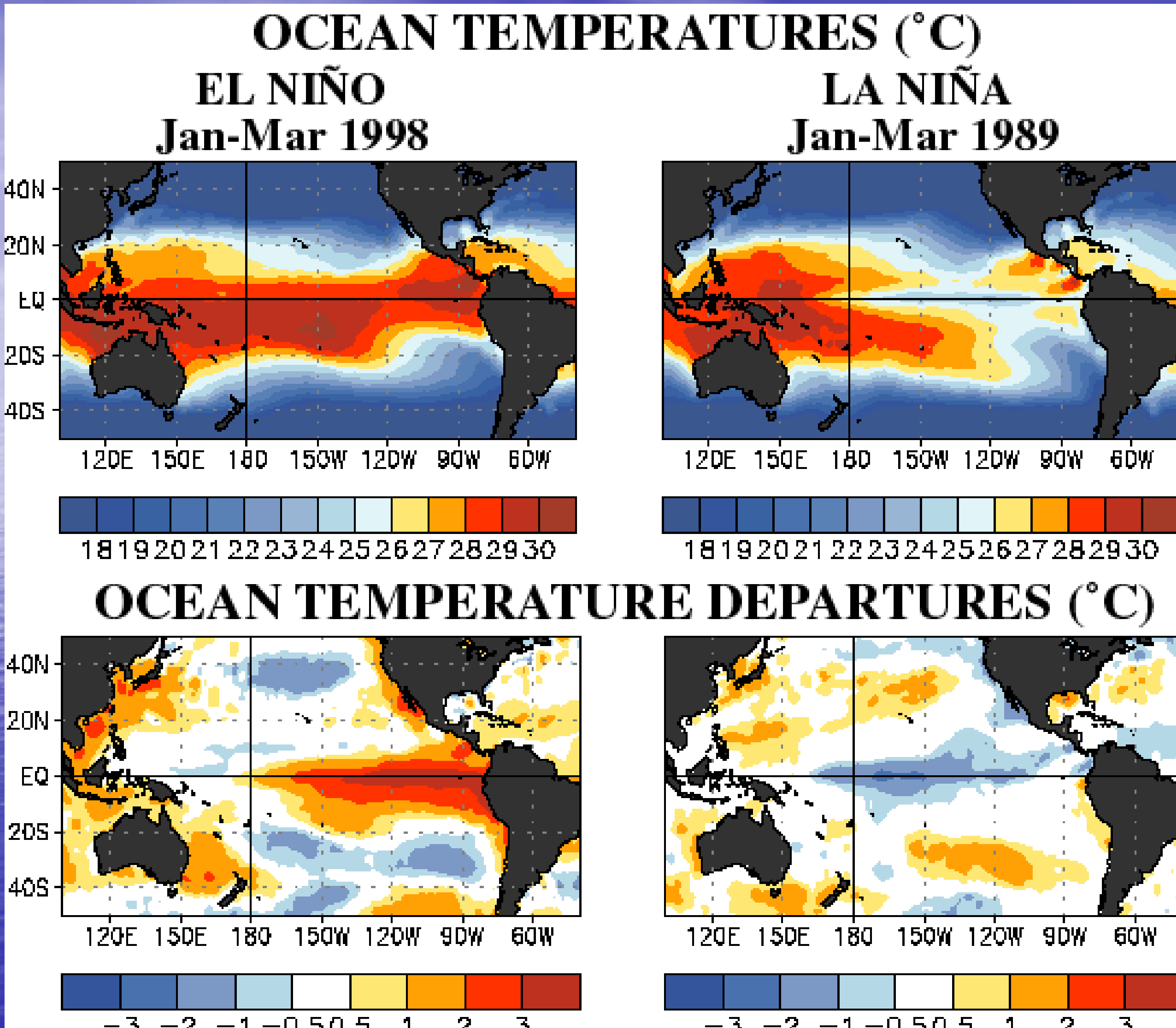
El Nino SST and Anomaly



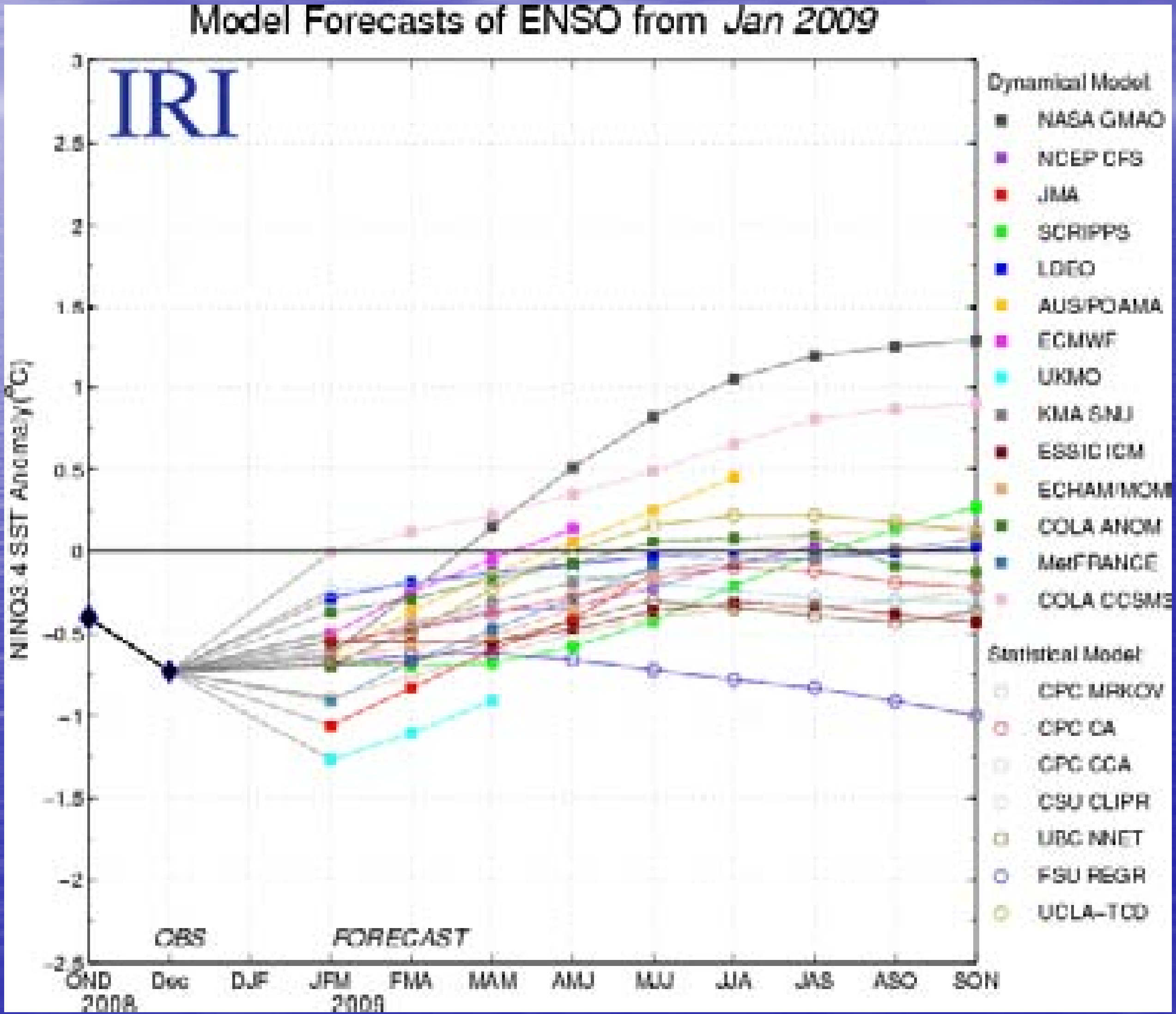
SUB-SURFACE OCEAN TEMPERATURES IN THE EQUATORIAL PACIFIC



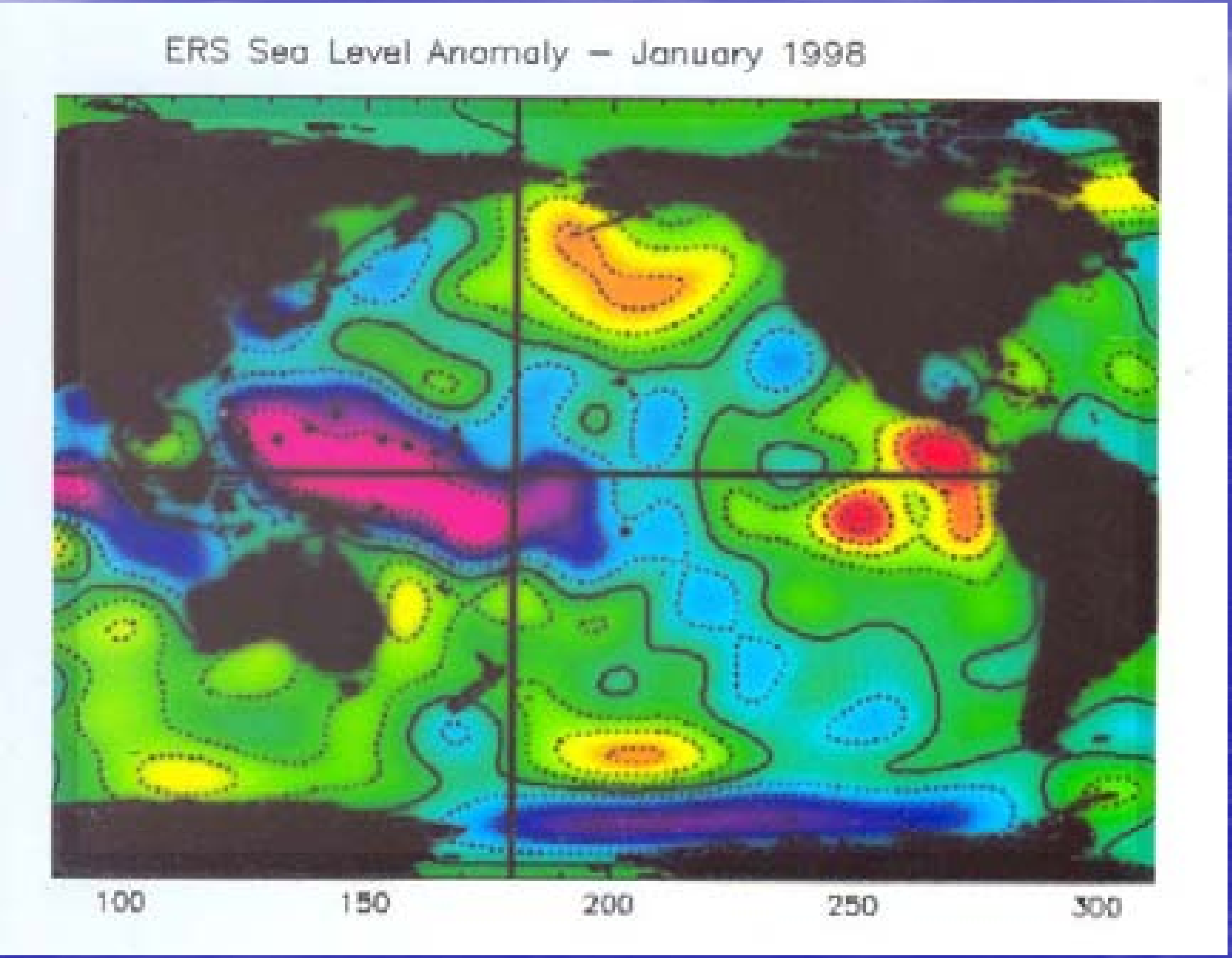



OCEAN TEMPERATURES (°C)
EL NIÑO
Jan-Mar 1998
LA NIÑA
Jan-Mar 1989
40N
20N
EQ
20S
40S
120E 150E 180 150W 120W 90W 60W
18 19 20 21 22 23 24 25 26 27 28 29 30
OCEAN TEMPERATURE DEPARTURES (°C)
−3 −2 −1 −0.5 0.5 1 2 3

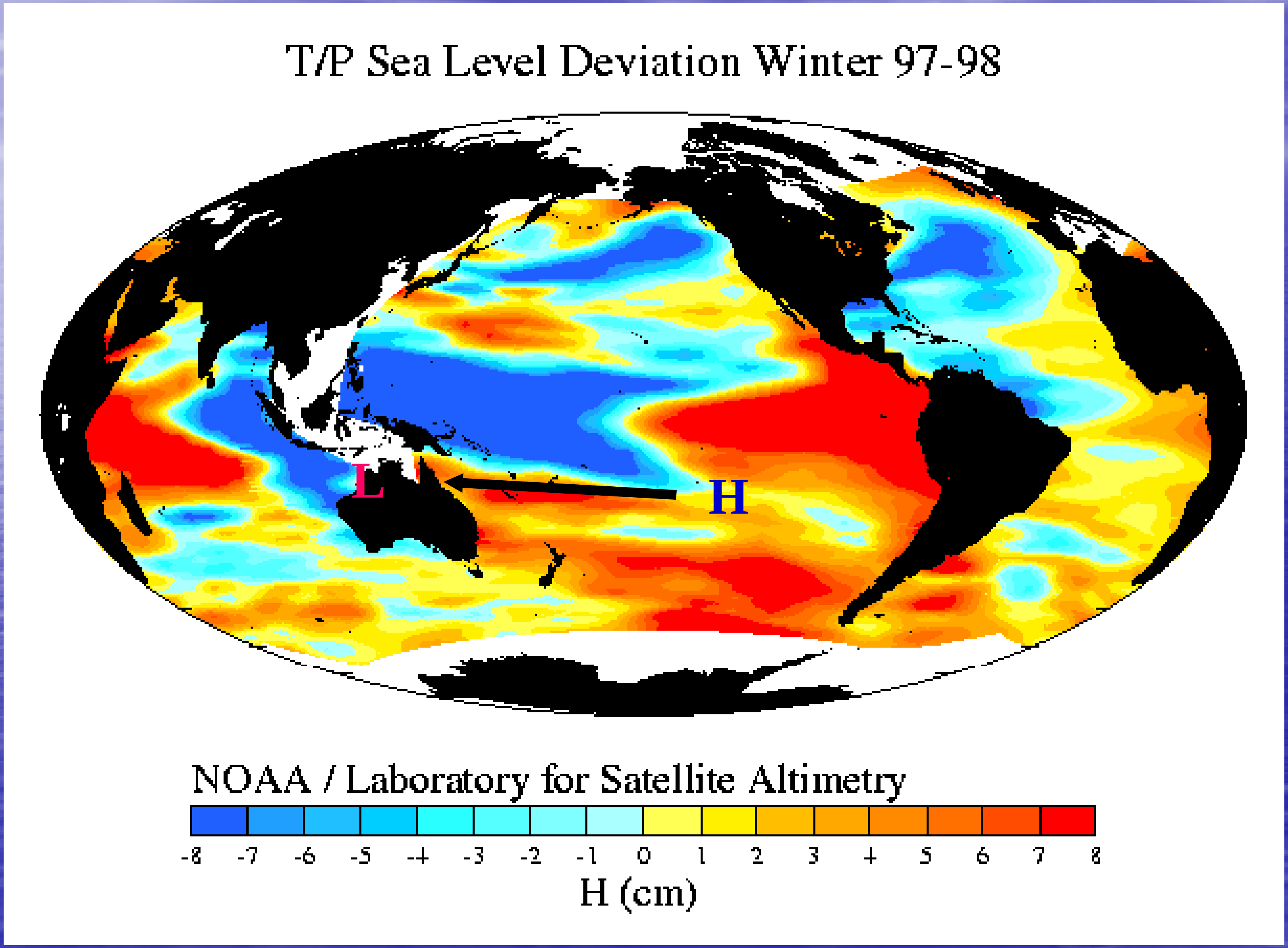
PREDICTION MODEL ANOMALIES



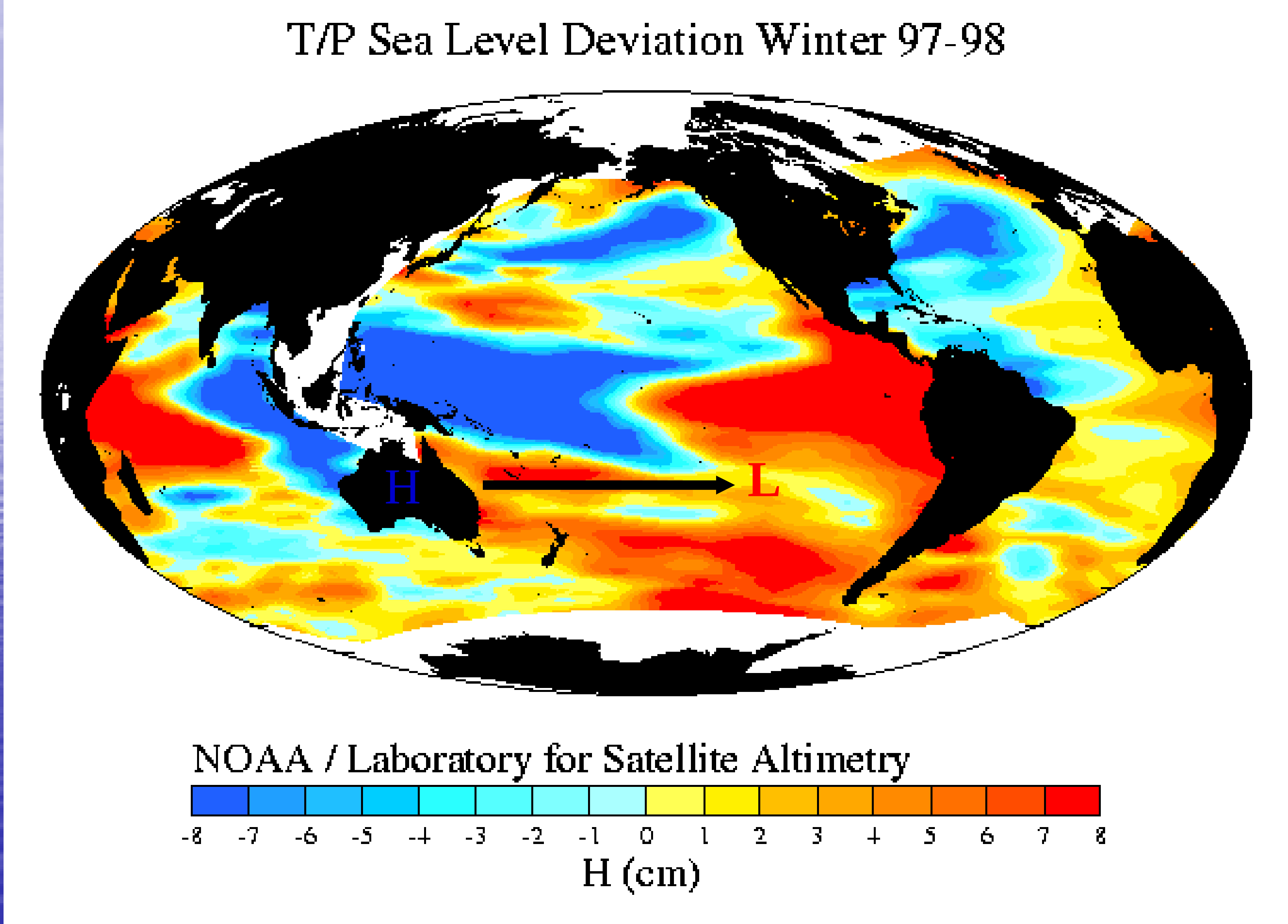
SEA LEVEL CHANGE



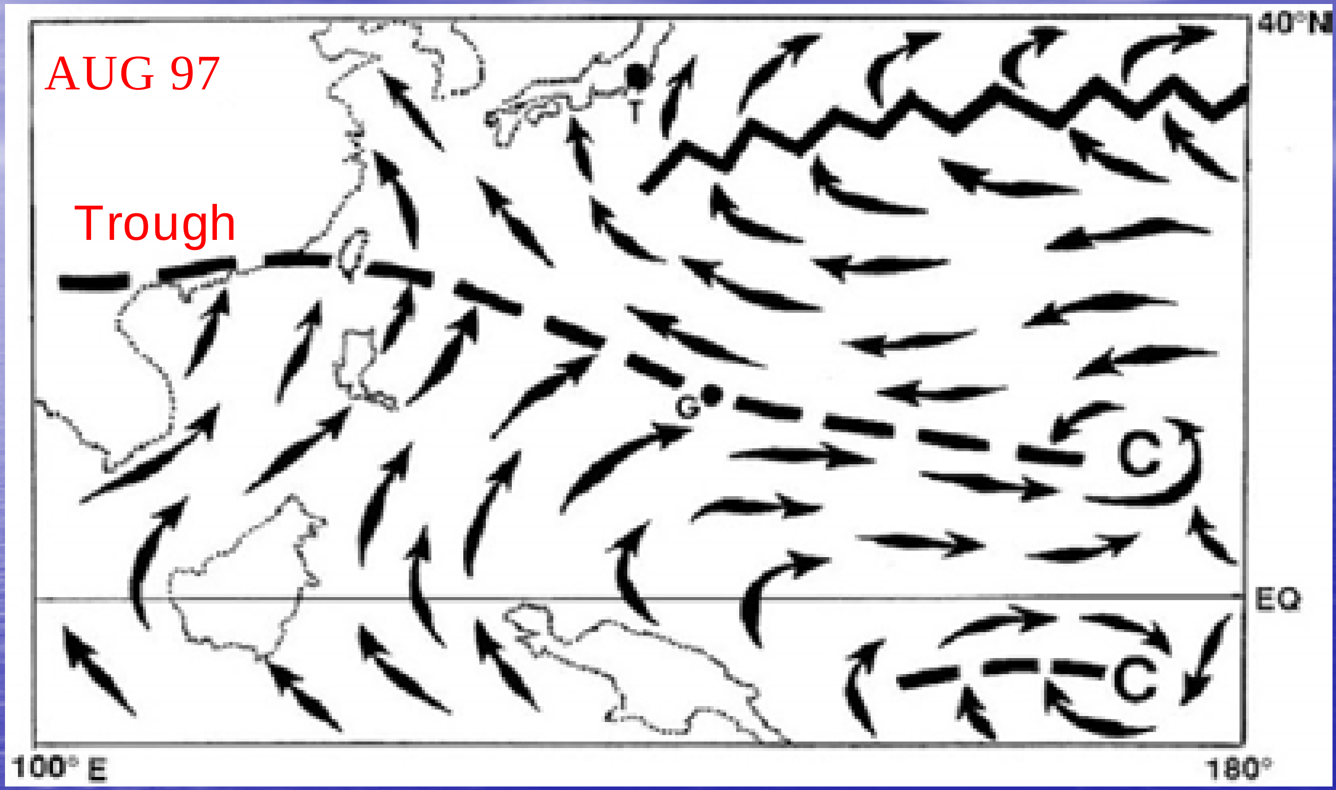
Normal Southern Hemisphere Flow



Southern Oscillation Flow



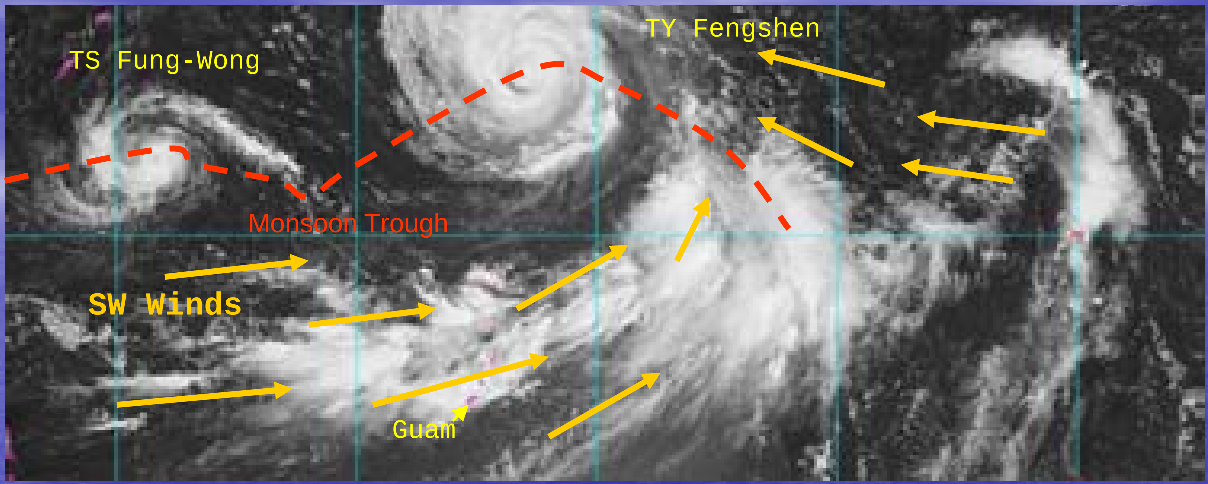
The Monsoon and Monsoon Trough



- East winds north of the trough axis; west or southwest winds south of the axis.
- Tends to produce inclement weather—heavy showers, gusty winds and low ceilings.
- Acts as a focus for tropical cyclone formation.
- Associated with monsoon surges and monsoon depressions.

Wet Season Rain Producers--Monsoon Surges

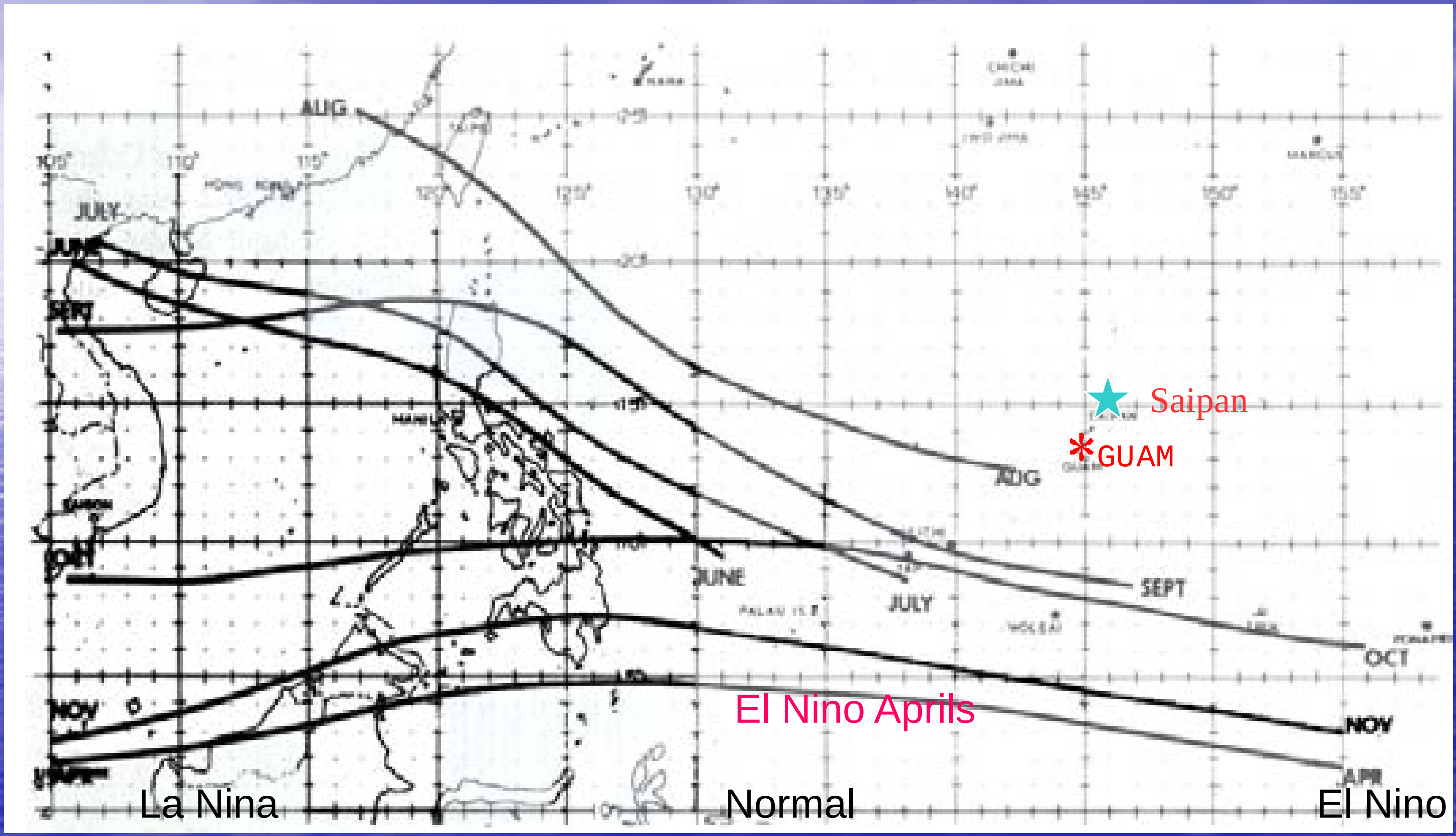
- Occur in association with the monsoon trough or a monsoon depression
- West or southwest winds south of the trough may reach gale force at times in squalls
- May produce excessive rainfall over several days
- Widespread low ceilings at times
- May produce frequent thunderstorms
- Most common from July through November



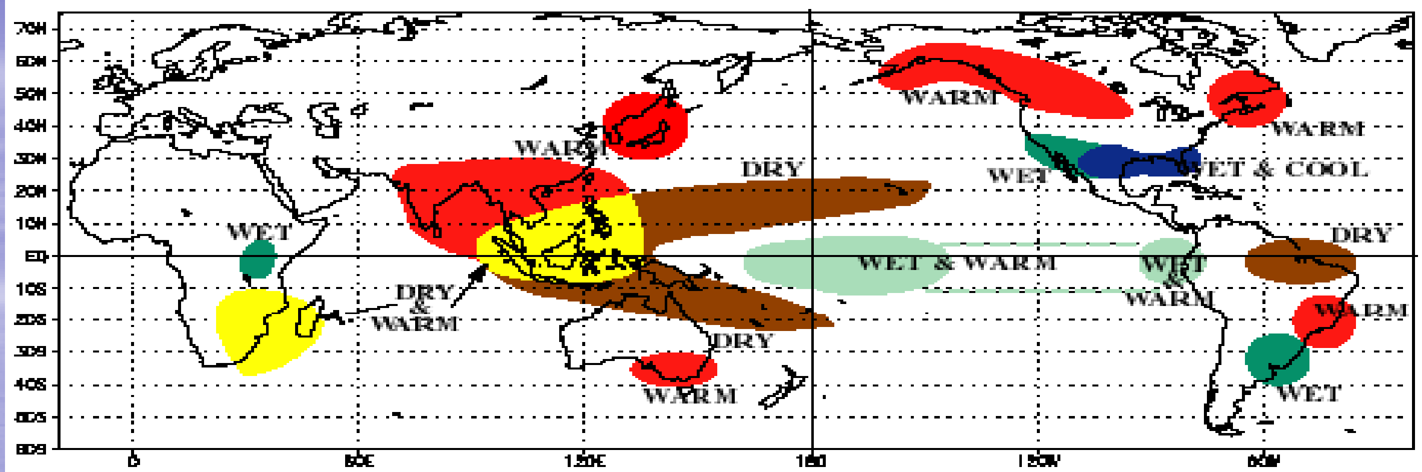
Visible Satellite Image – 23 Jul 02

Guam Doppler Radar Image – 23 Jul 02

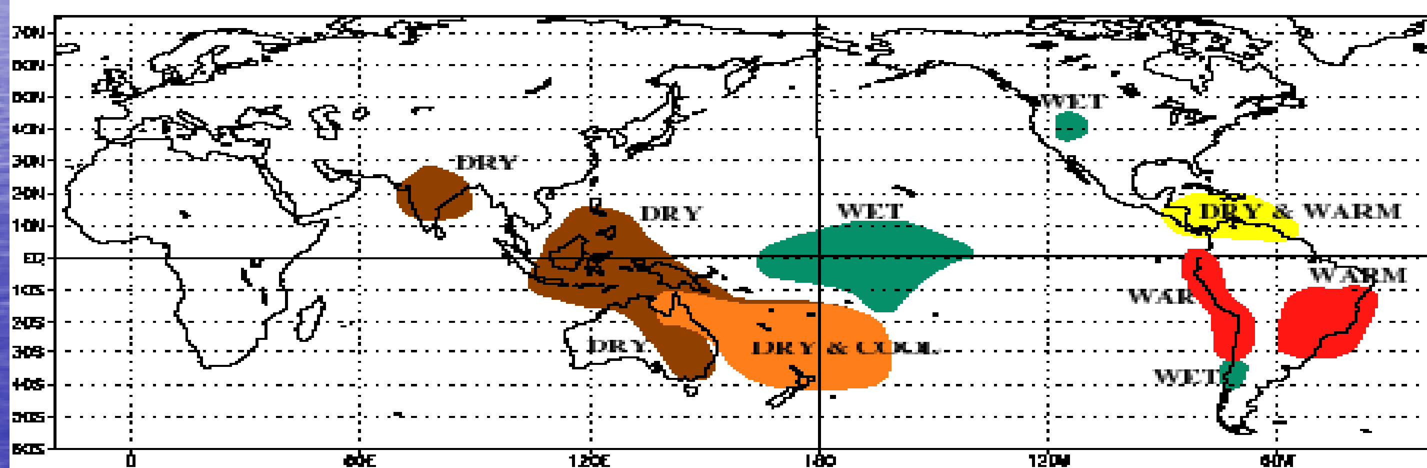
Mean Position of Monsoon Trough by Month



WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



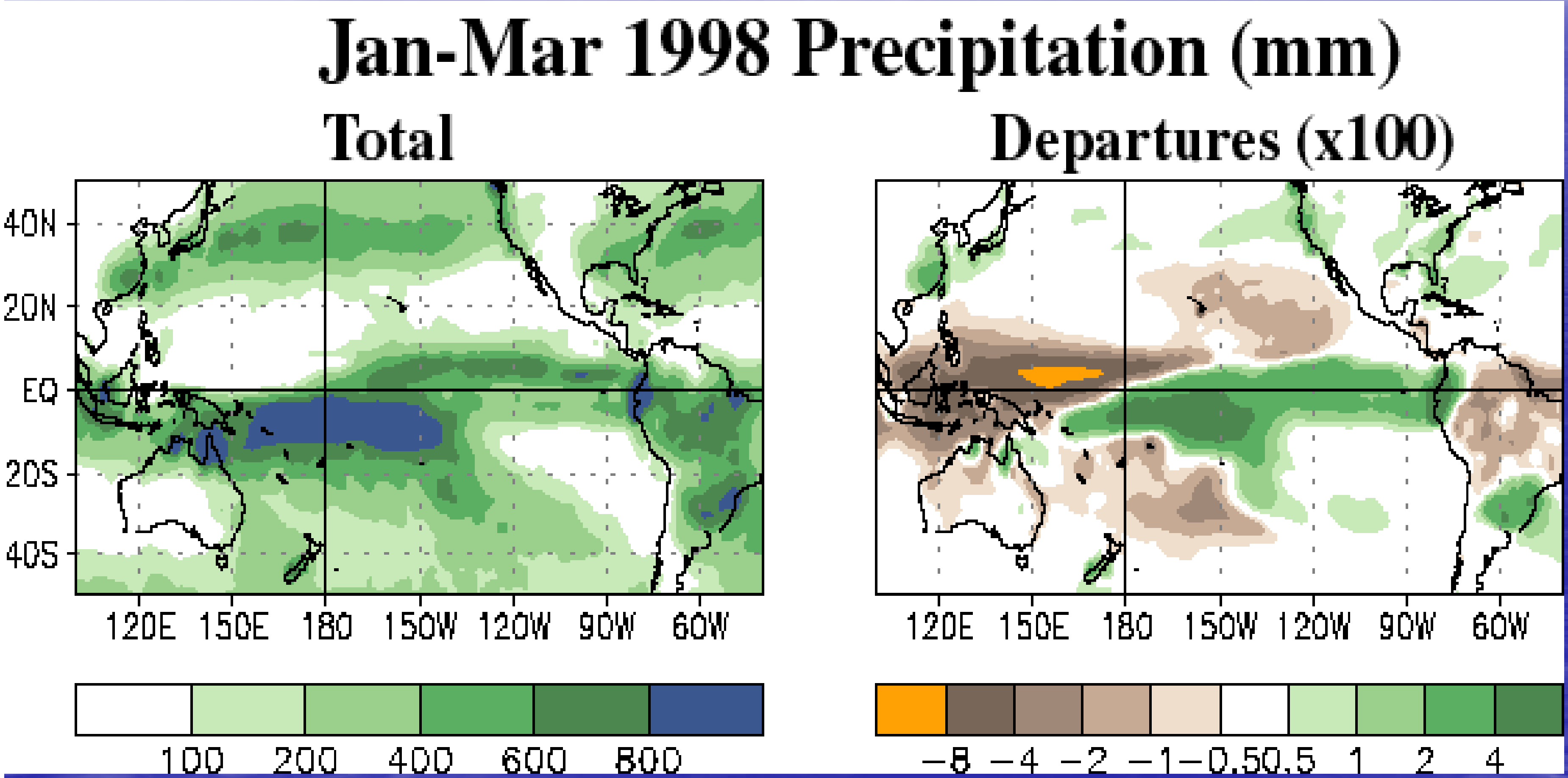
WARM EPISODE RELATIONSHIPS JUNE - AUGUST

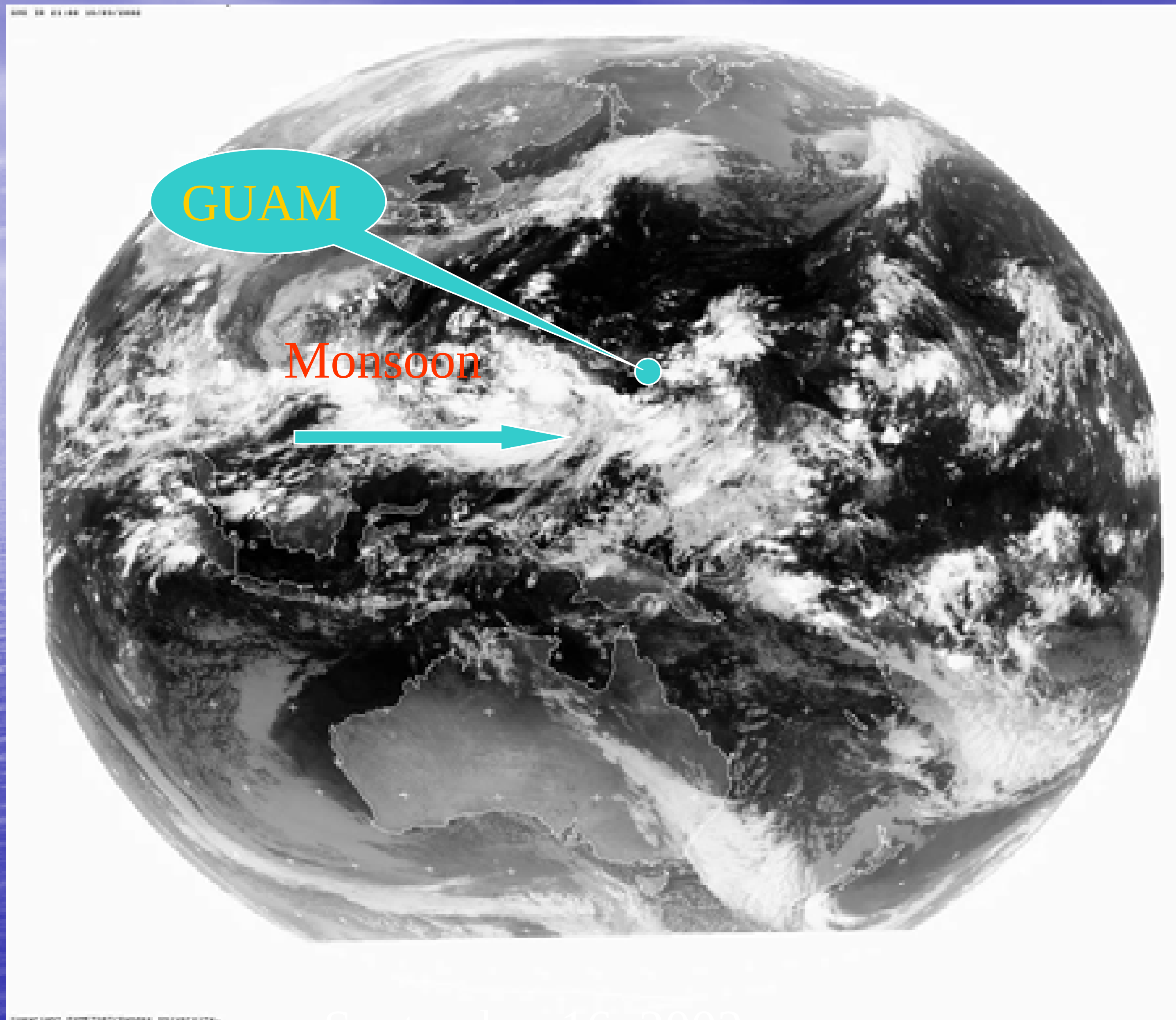


GLOBAL EFFECTS OF EL NIÑO

Climate Prediction Center
NCEP

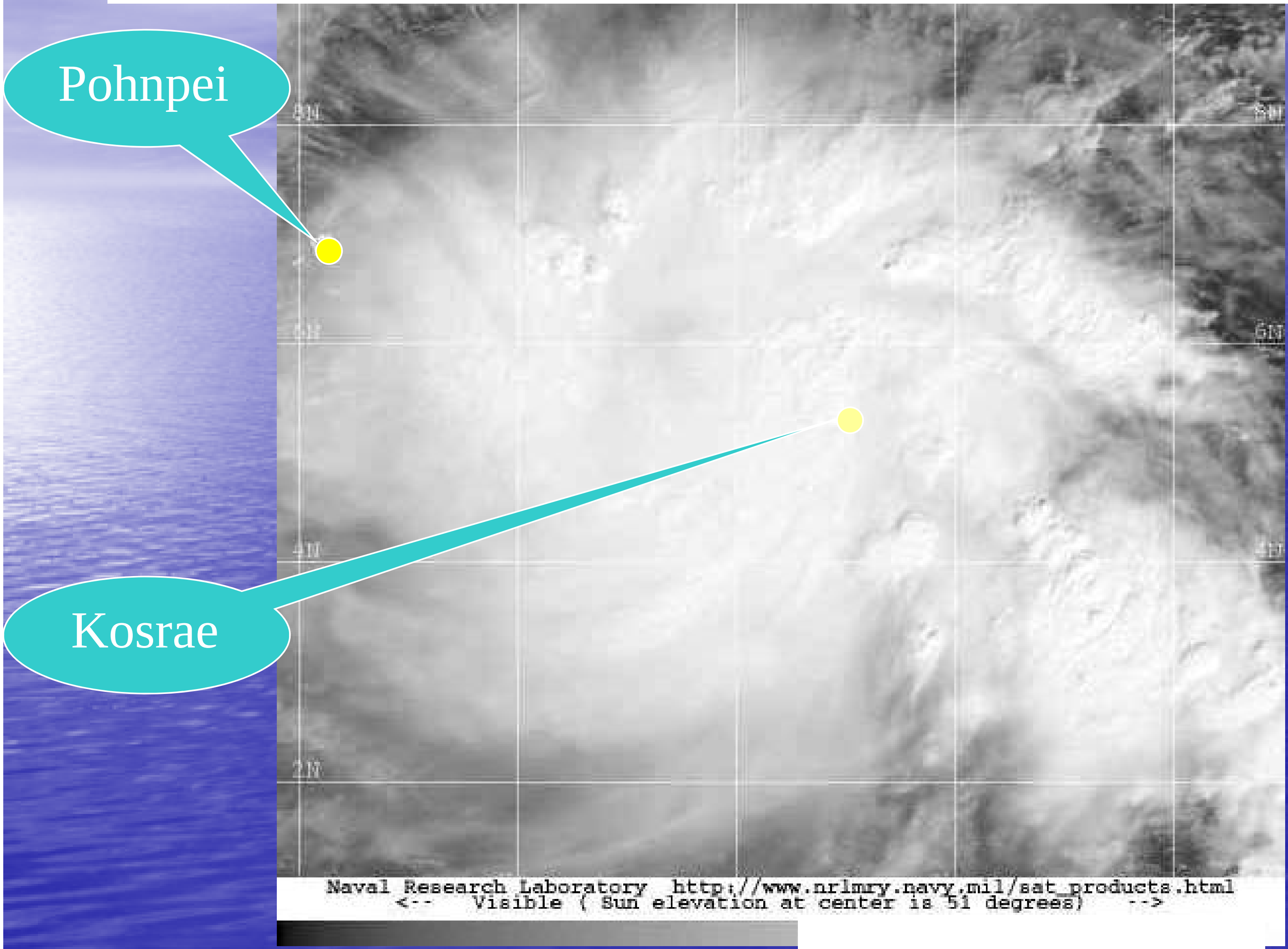
RAINFALL AND RAINFALL ANOMALY JAN-MAR AFTER MAJOR EL NIÑO



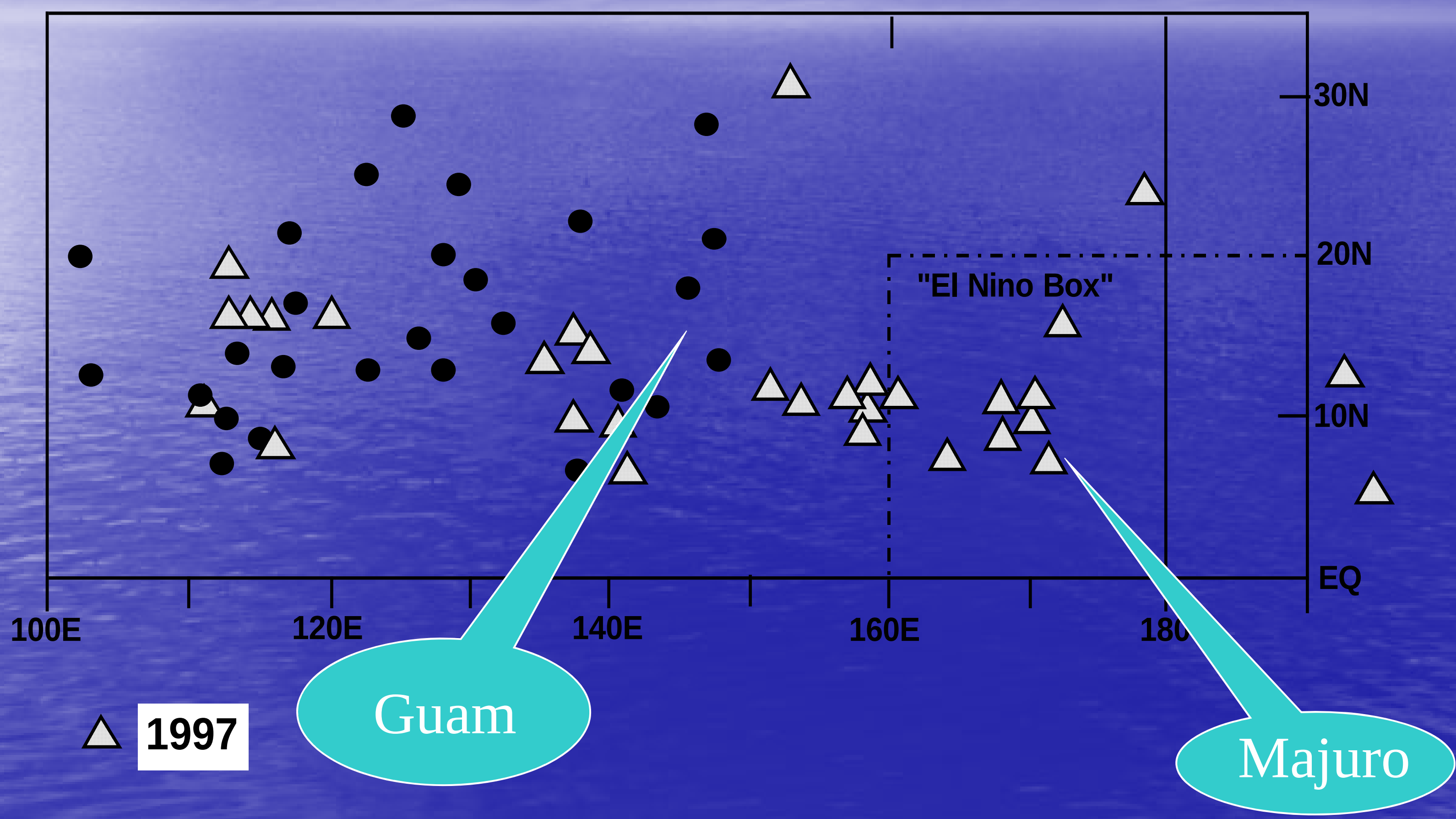


September 16, 2002

Tropical Storm Faxai



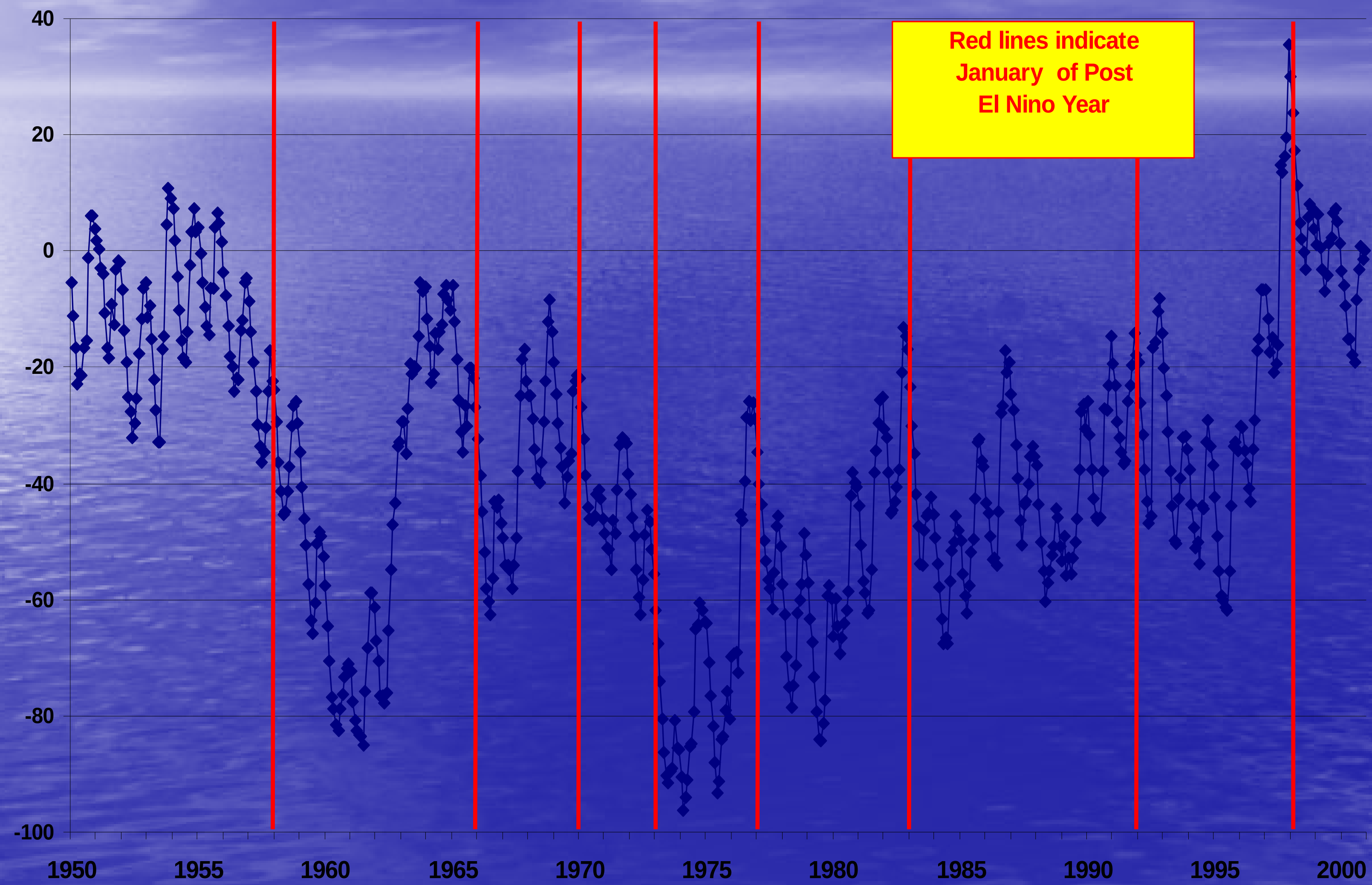
El Nino = INCREASED Threat East of 140E
La Nina = DECREASED Threat East of 140E



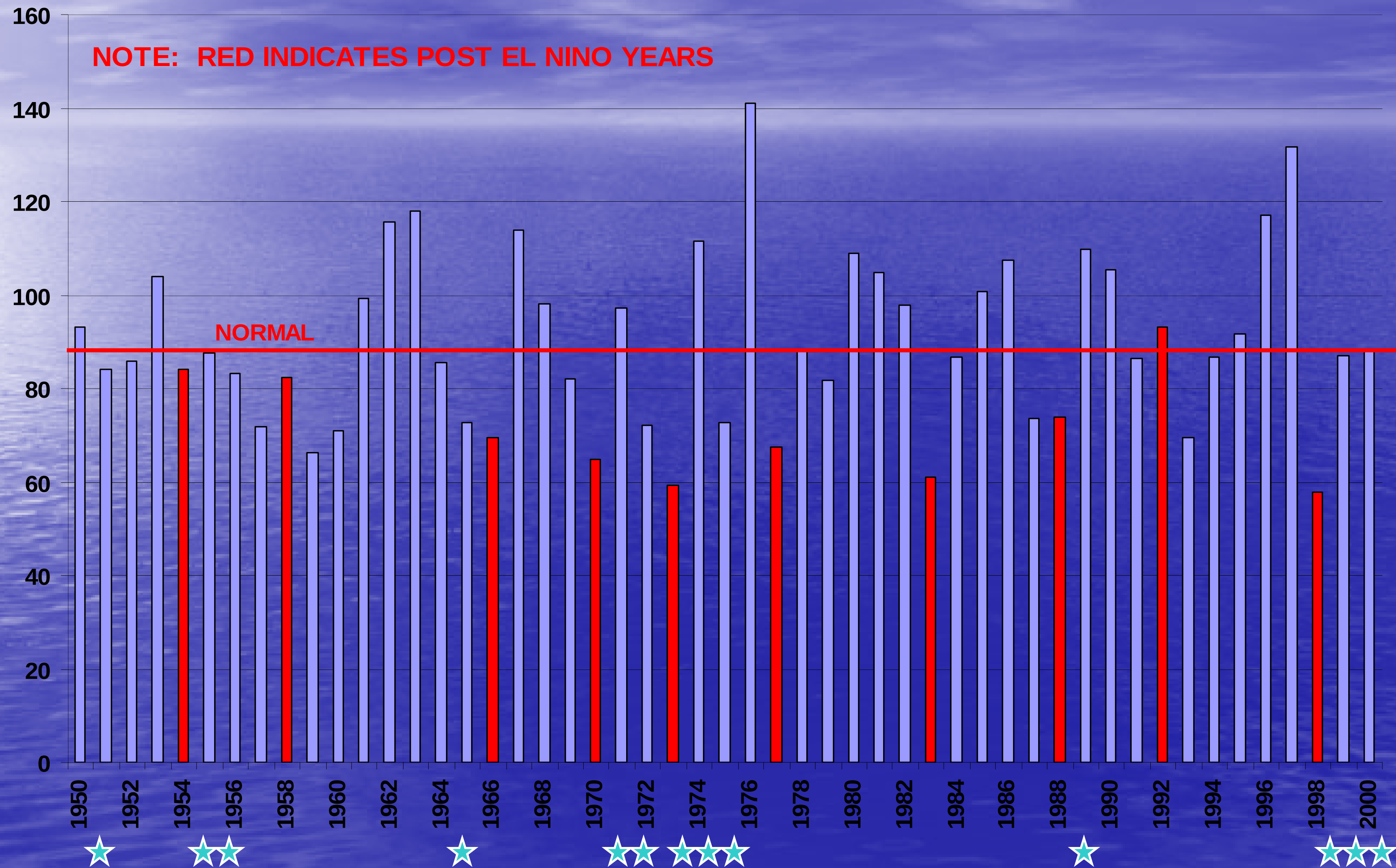
RAINFALL

- LONG-TERM TRENDS
- ISLAND DISTRIBUTIONS
- RETURN PERIODS
- SURFACE WATER RESPONSE TO RAINFALL
- DATA BASE DEVELOPMENT

LONG-TERM SURPLUSES AND DEFICITS

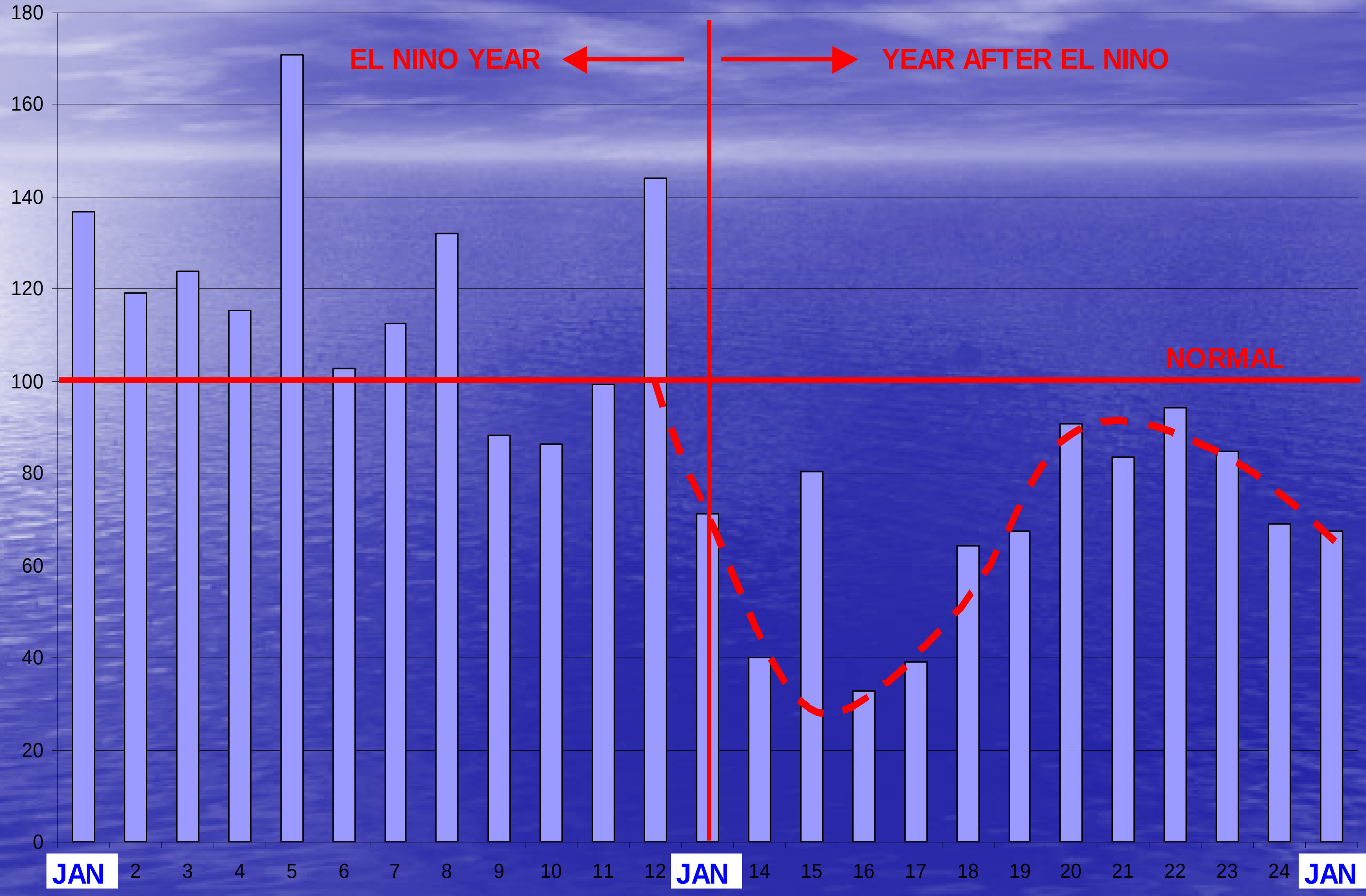


GUAM ANNUAL RAIN



NOTE: POST-EL NINO YEARS IN RED; STARS ARE LA NINA

Percent of Normal



What Will be the Effects of a Warmer World on the Tropical Pacific Islands?

Sea Level Rise

Warmer Temperatures

Drier Weather? More Droughts?

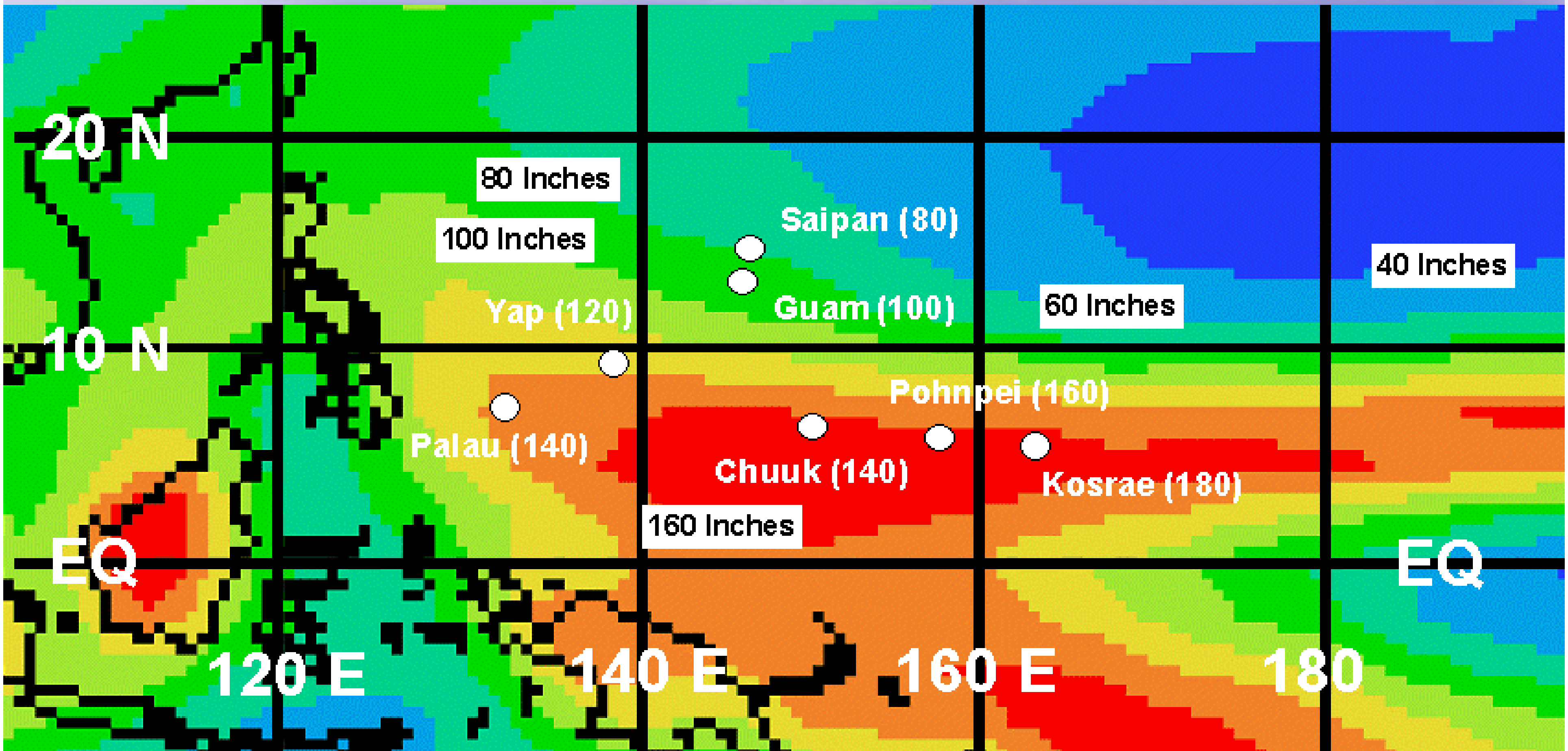
Enhanced rainfall? More Floods?

More or Less Typhoons?

Bigger or Smaller Typhoons?

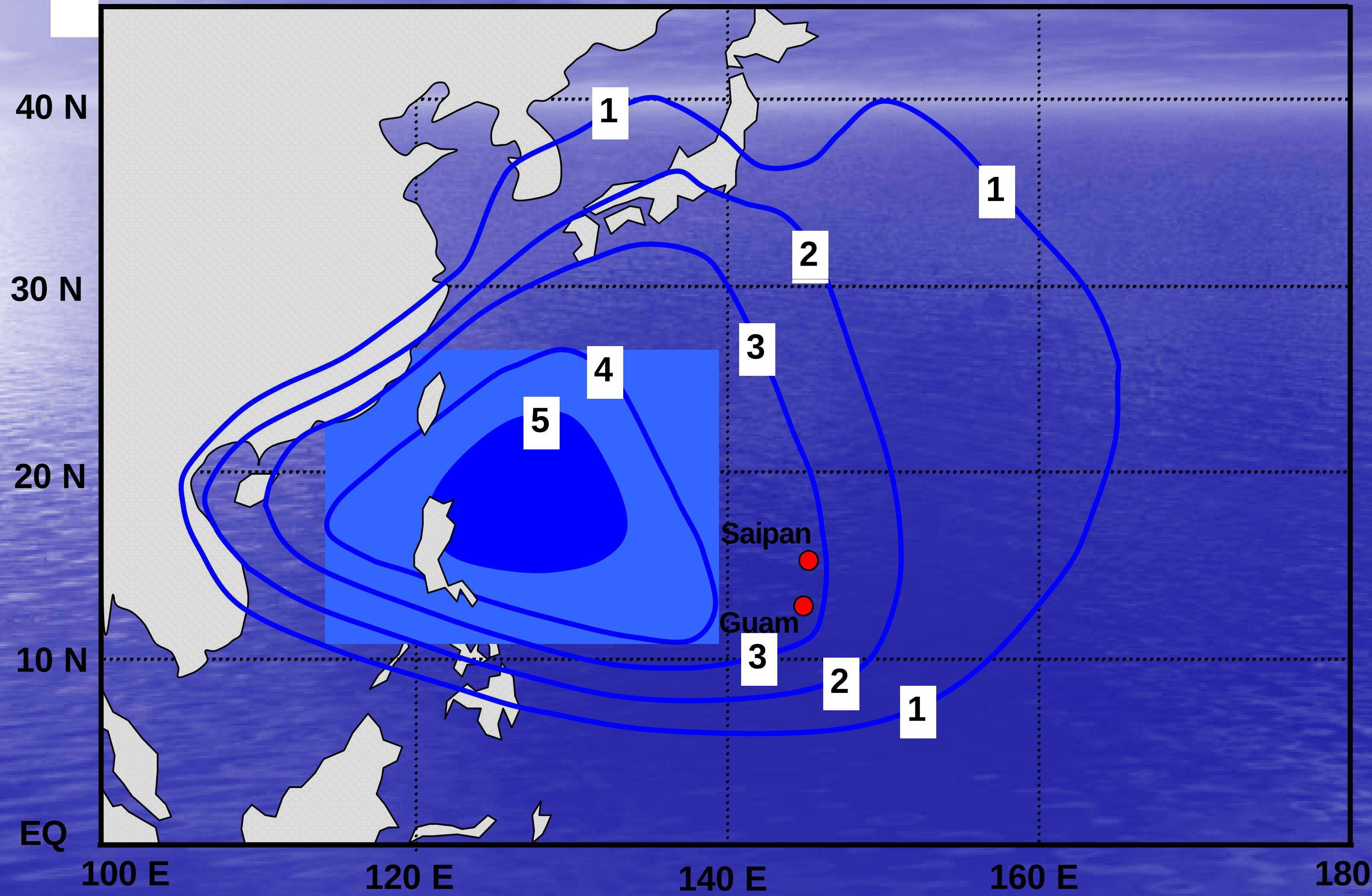
Stronger or Weaker Typhoons?

AVERAGE ANNUAL TROPICAL PACIFIC RAINFALL PATTERNS/GRADIENTS



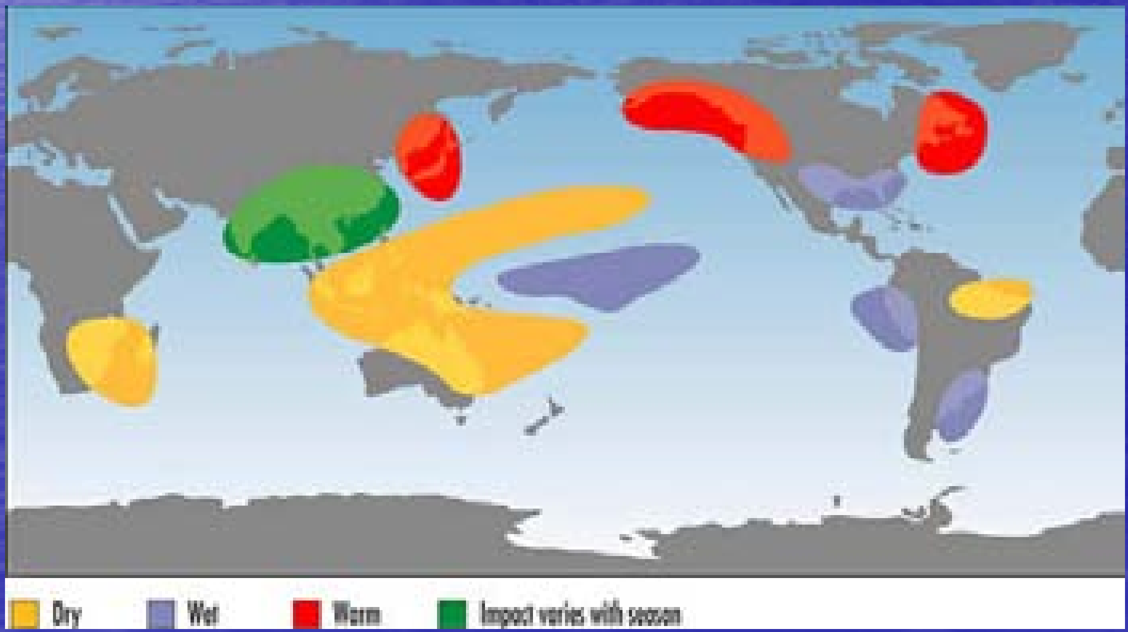
Drought

TYPHOON DISTRIBUTION



Tides and Tidal Variation

- Weather influences on sea level
  - –El Nino/La Nina—ocean heat content, wind stress, and upwelling/downwelling
    - El Nino is associated with sea level falls in WestPac
    - La Nina is associated with sea level rise in WestPac



Tides and Tidal Variation

Other Contributions—astronomical tide is superimposed on sea level

- Land Movement- we are on the Philippine Plate and are rising or at least not sinking
- Erosion—What is natural erosion?

Tides and Tidal Variation

- What contributed to the high tides in 2008 and 2009?
  - –Sun and earth were at closest point in 18 years
  - –Earth's elliptical orbit is closest to sun in winter
  - –Moderate to strong La Nina
    - ocean heat content high; ocean expands
    - wind stress—strong, persistent trade winds
  - –Several large storms near Japan produced large swells that created high surf here
- Global warming? Minimally significant at this point; probably later.

How Certain Are We About Western North Pacific Climate Impacts?

- Sea Level Rise—high confidence
- Less Rainfall—medium confidence
- More rainfall—low confidence
- More/less tropical cyclones—low confidence
- Stronger/weaker tropical cyclones—low confidence
- Larger/smaller tropical cyclones—low confidence

Conclusions for Sea Level

- **Global sea-level rise has accelerated, but is highly variable.**
- **In the Pacific:**
  - **Sea level rise will likely be the most immediate climate concern**
  - **Melt water is a greater threat in the second half of the century.**
  - **Thermal expansion and melting have increased.**
  - **There are potentially important, unknown aspects to sea-level rise.**
- **It is appropriate to plan for a 1 m rise in sea level by the end of the century.**