Variability and Seasonal Predictions

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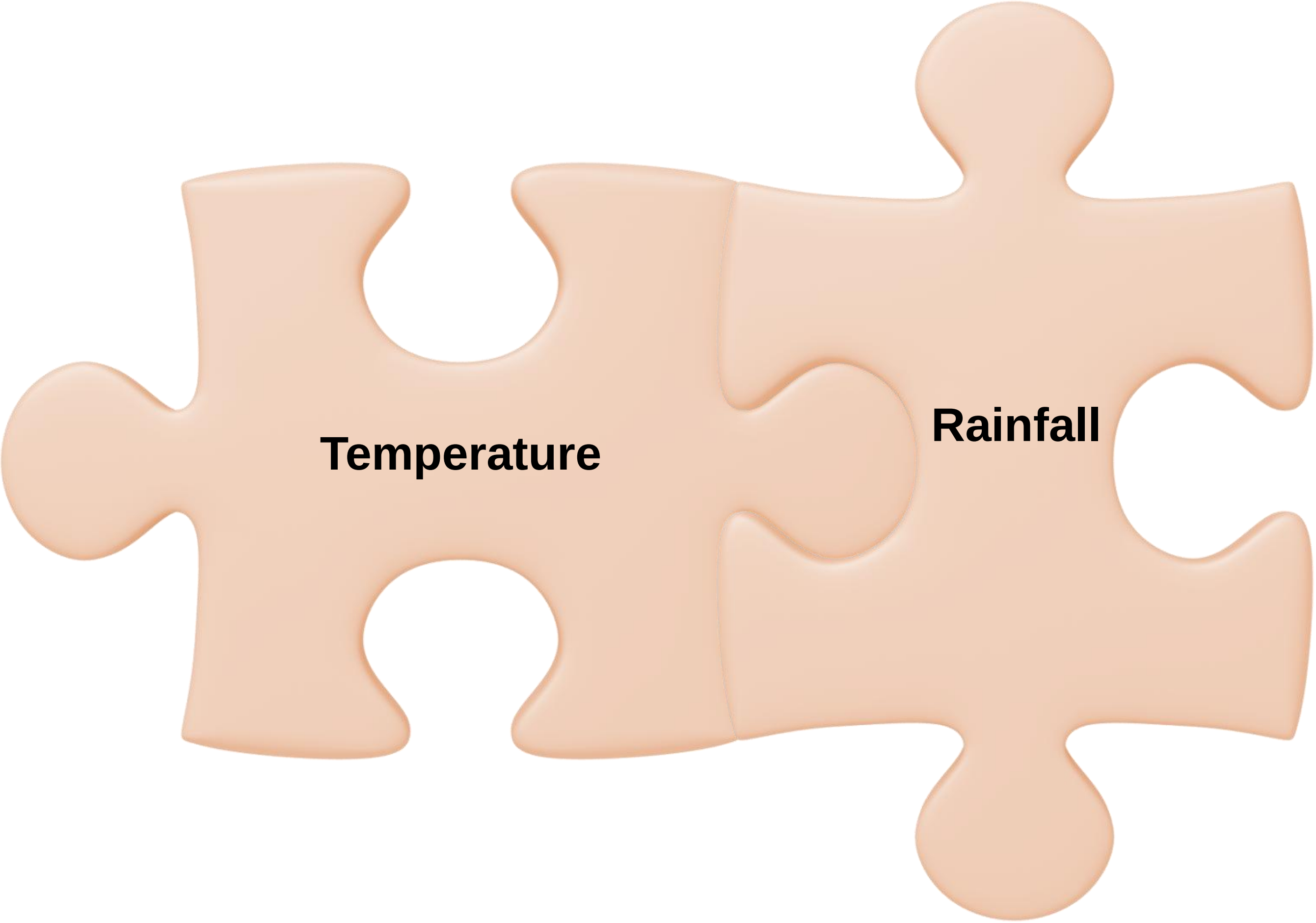
Part 1: Climate Variability

‘Piecing it together’

PIECING IT TOGETHER



Piecing Temperature

Temperature

- Over most of the region the annual temperature range [difference in temperature between the warmest and the coldest month], is about 2°C or 3°C, except over certain parts of Cuba where the range can be greater than 5°C.

- The diurnal temperature range [difference between daily maximum and minimum temperature] far exceeds the mean annual temperature range, with values greater than 5°C.

Piecing Temperature

Temperature

- The difference is influenced by such factors as the prevailing wind, topography, altitude, nature of the underlying surface, and cloudiness.

- Smaller diurnal ranges are experienced near coastal regions.

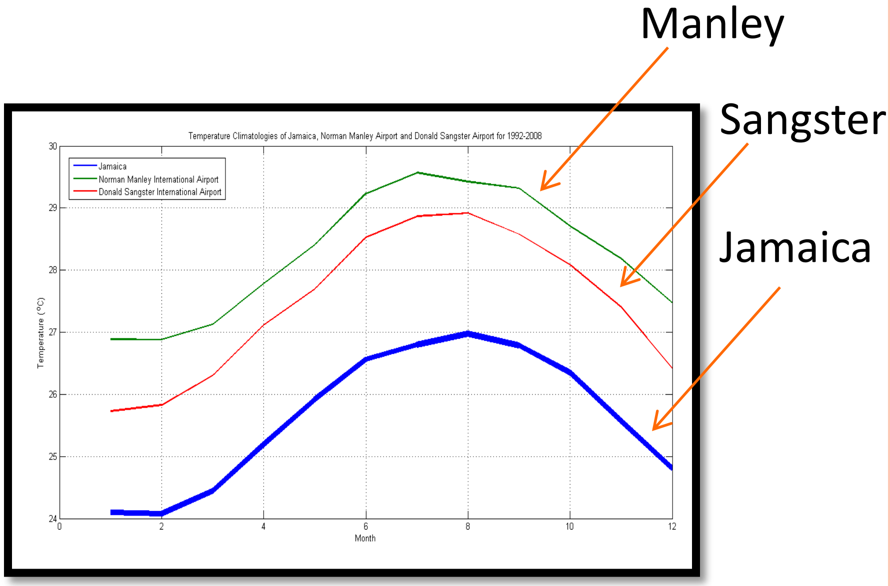
- Temperatures are generally rather constant over the region.

TEMPERATURE

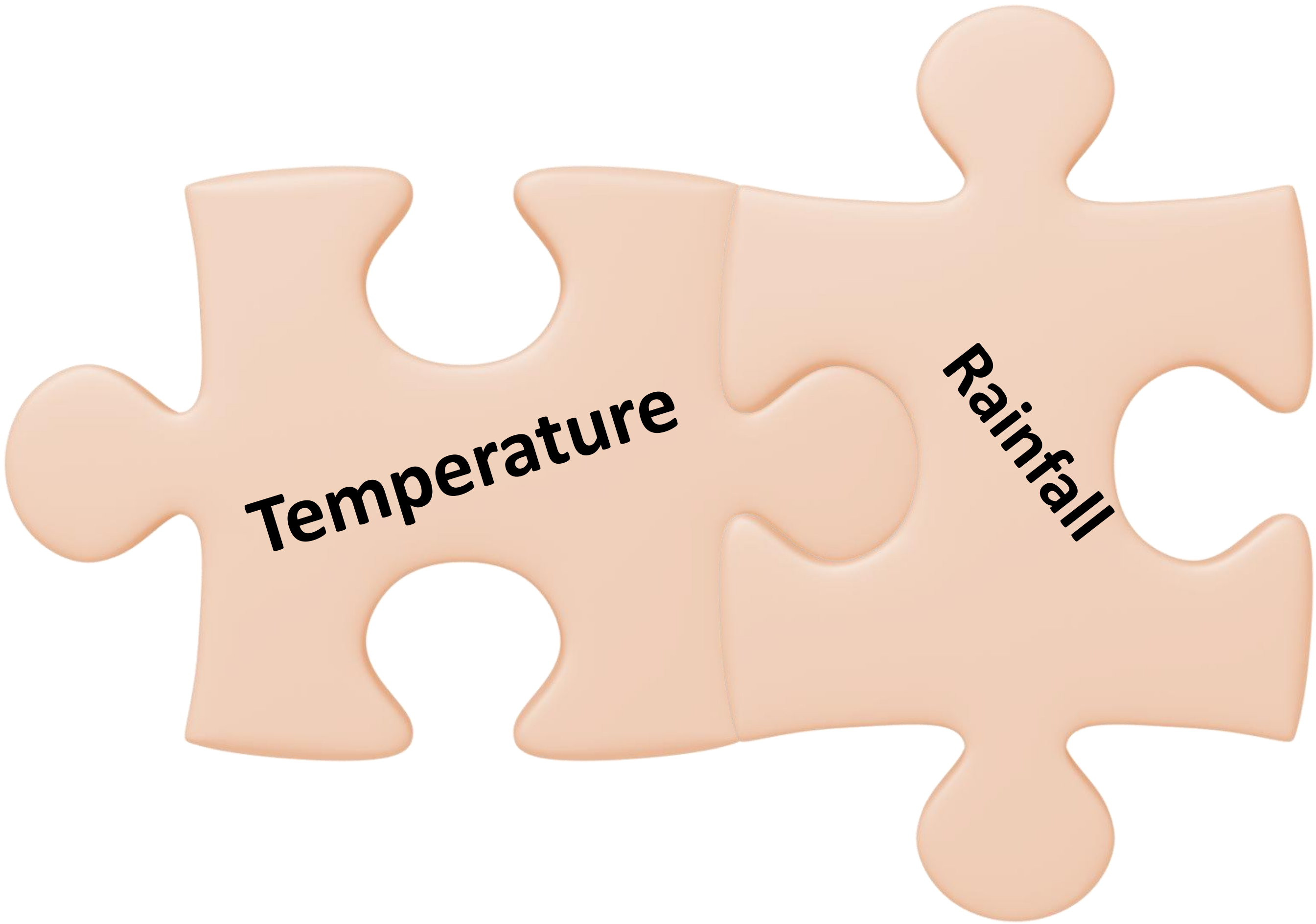
- The mean annual temperature range is small close to the equator and increases towards higher latitudes.

- This increase is partly due to the incursion of mid-latitude systems into the tropics.

- For example: JAMAICA
- Annual Temperature Range of 3˚C
- Spatial variation in mean temperature across island.



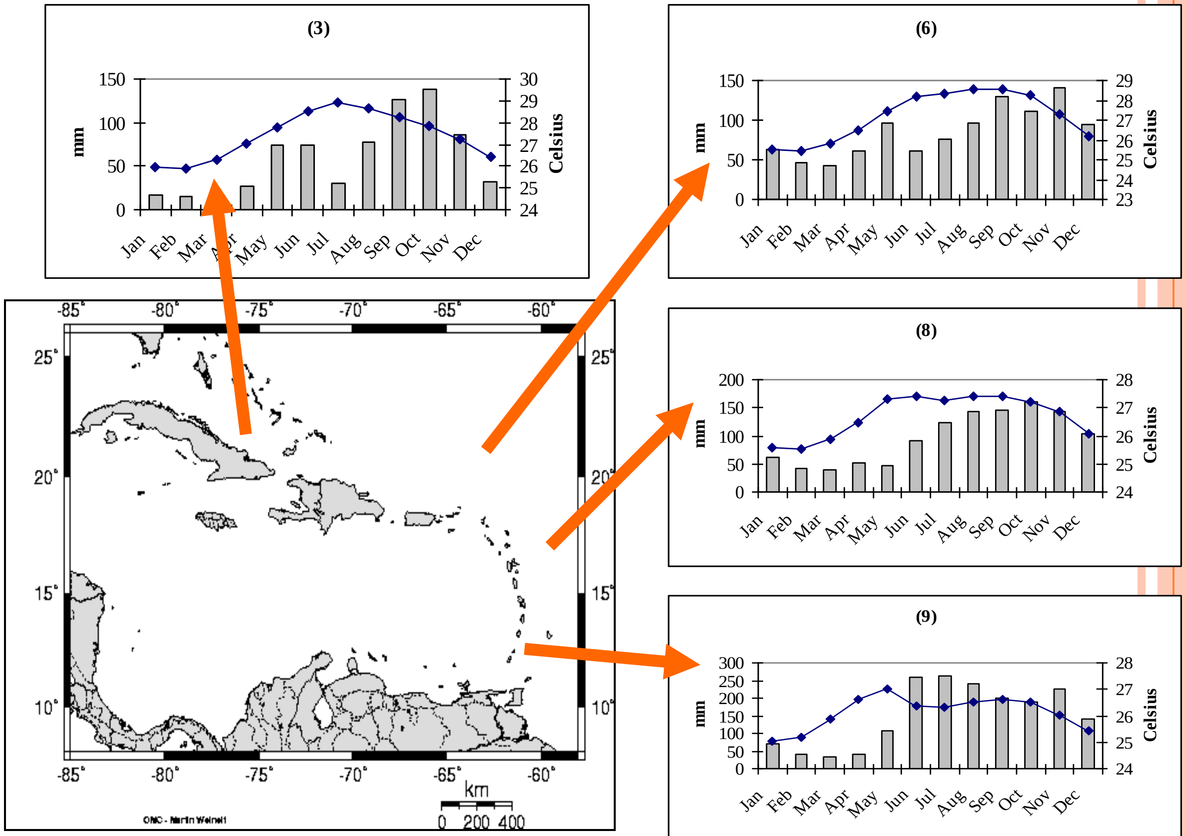
Piecing it together



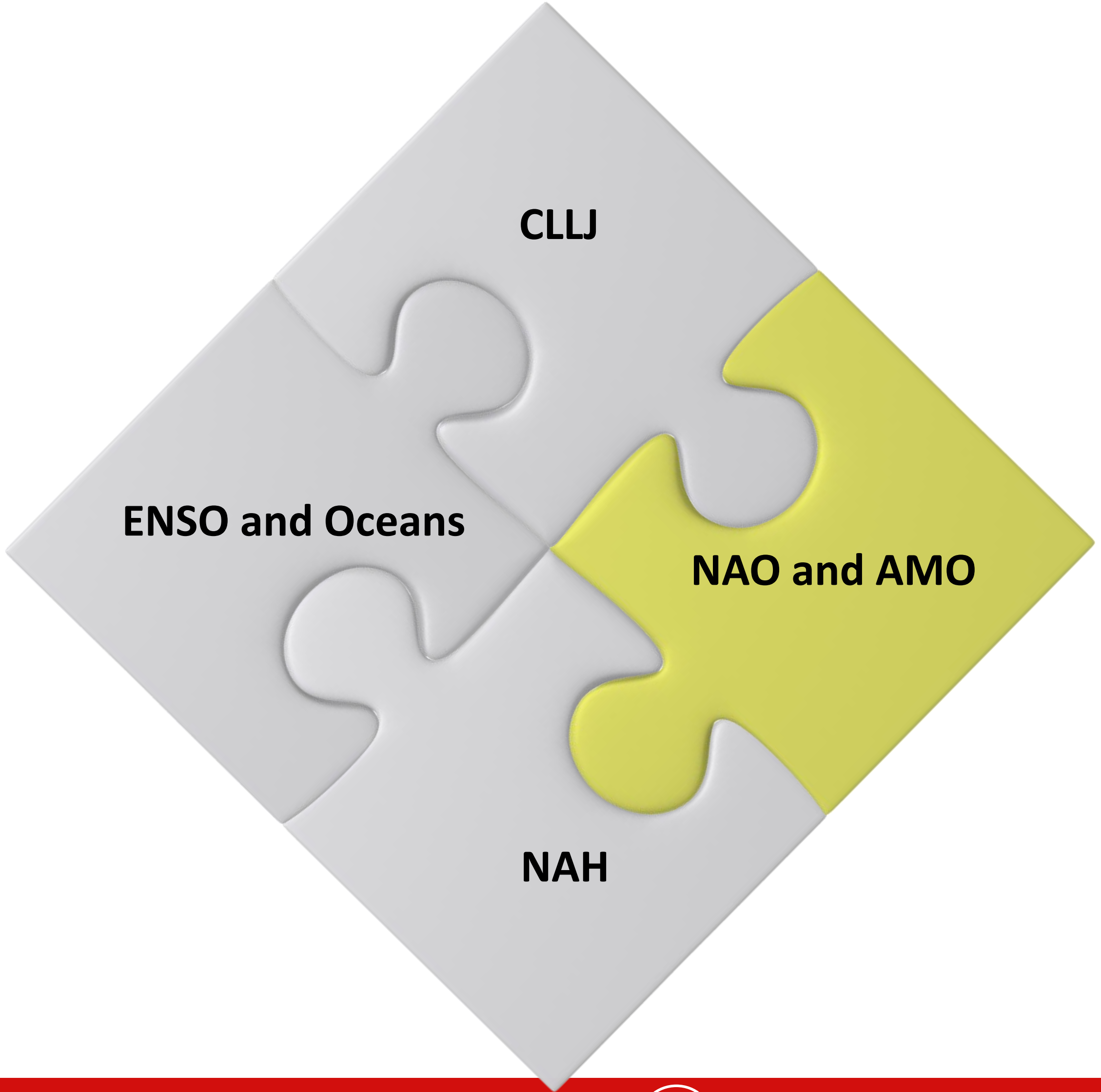
PIECING RAINFALL

"Most of the Caribbean islands exhibit common pattern of seasonal variability"

- **Dry season** early in year (January – April)
- **Wet season**: May – November
- Bimodal (early rains and late rains) or dry period interrupts rainy season
- Peak rain SON
  - Coincides with peak hurricane activity



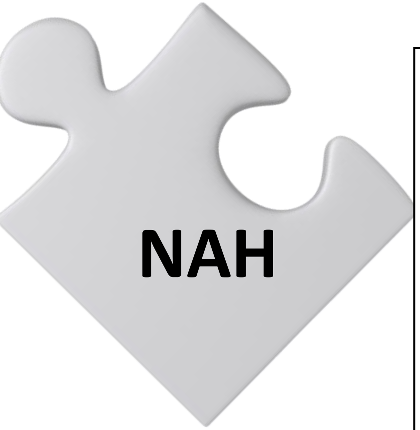
Piecing Rainfall



Piecing Rainfall

Piecing Rainfall

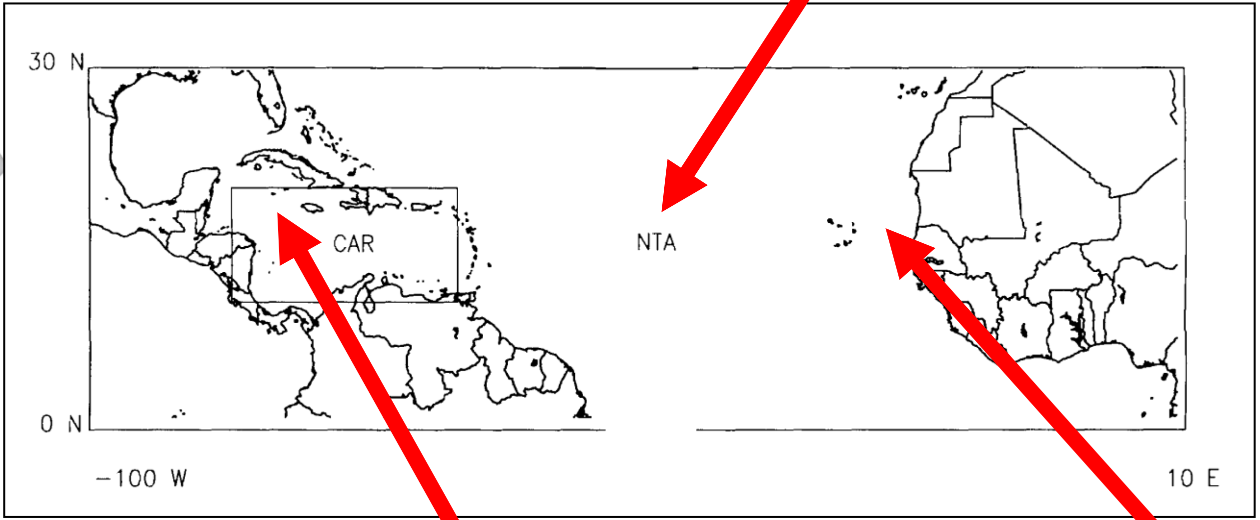
North Atlantic High (NAH)



Movement of North Atlantic High (NAH)

•April - November

•Reduced vertical shear + low pressures



Sea surface warms

•April-October (peak)

•>27^{o}C

Easterly/Tropical Waves

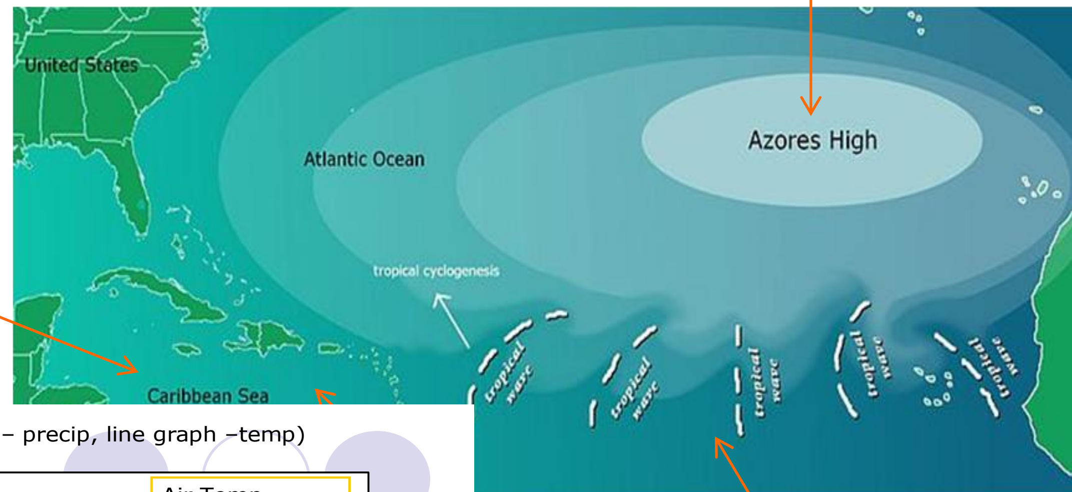
•Late May-November

•3-5 days

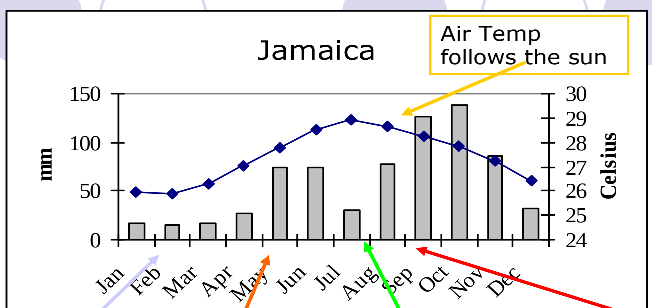
PIECING RAINFALL: NAH

High Pressure

SSTs



Climatology (Bar graph – precip, line graph –temp)



Easterly Waves

Trade Wind Strength
+ vertical shear

NAH moves closer to equator

Stronger trades

Low SST

Mid-lat fronts

NAH starts Northward migration

Weaker trades

SST begins to increase

NAH temporarily retreats Southward

'Mid-Summer Drought'

NAH return Northward

High SST

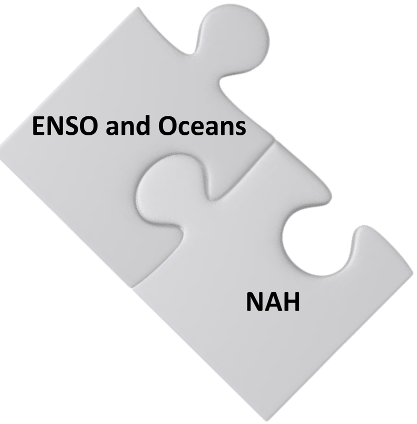
Easterly waves

ITCZ North

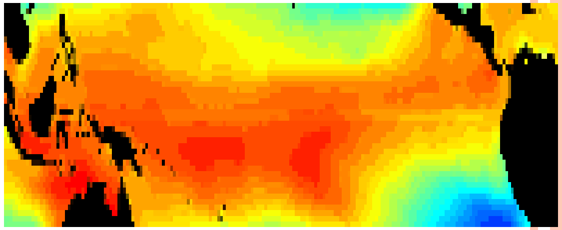
Piecing Rainfall

Piecing Rainfall

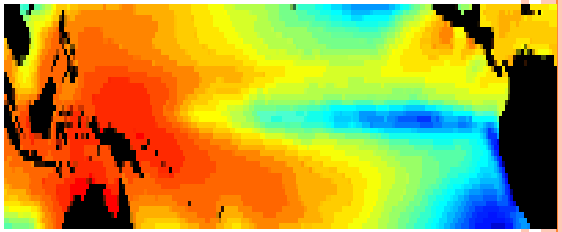
ENSO - El Niño-Southern Oscillation



- Is a global coupled ocean-atmosphere phenomenon.
- El Niño (La Niña) is an unusual warming (cooling) of the tropical Pacific Ocean.
- The Southern Oscillation is an accompanying fluctuation in the air pressure difference between Tahiti and Darwin, Australia.
- Prompts changes in weather patterns across the globe.
- Occurs irregularly at approximately 3-6 year intervals.



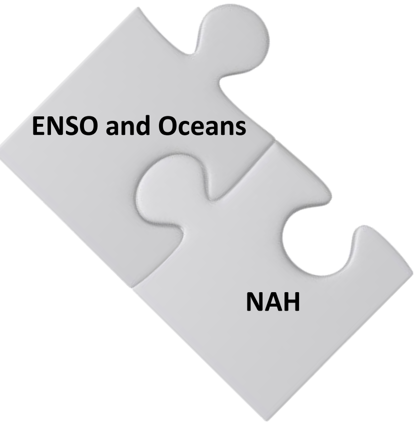
El Niño

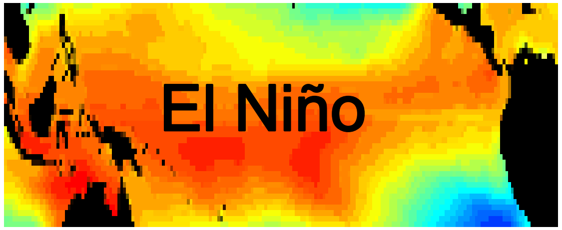


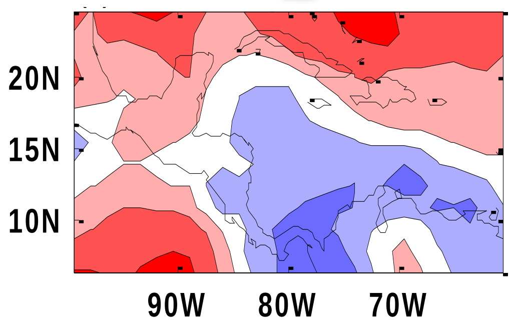
La Niña

Piecing Rainfall

El Nino Southern Oscillation

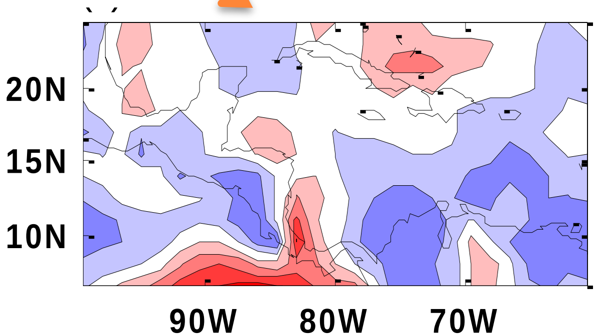




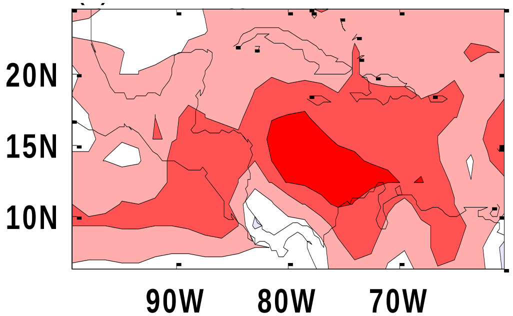


1. Dry season drier in south Caribbean

3. Early Wet season wetter in most of the Caribbean

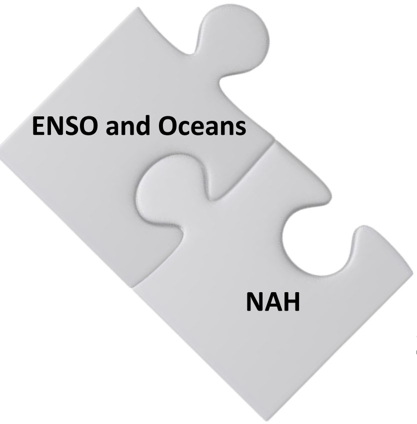


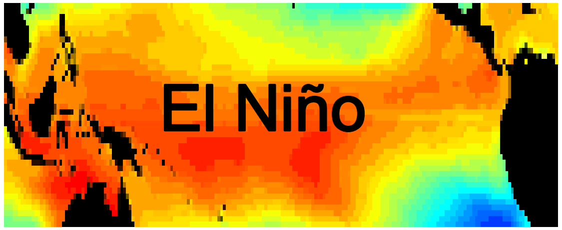
2. Late wet season drier in most of the Caribbean

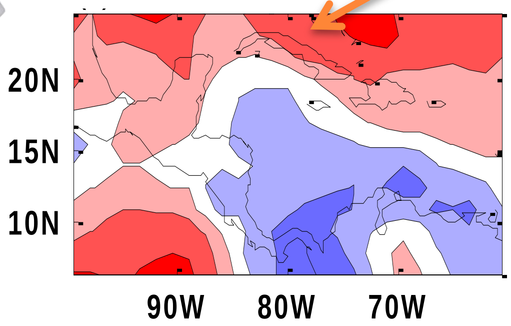


Piecing Rainfall

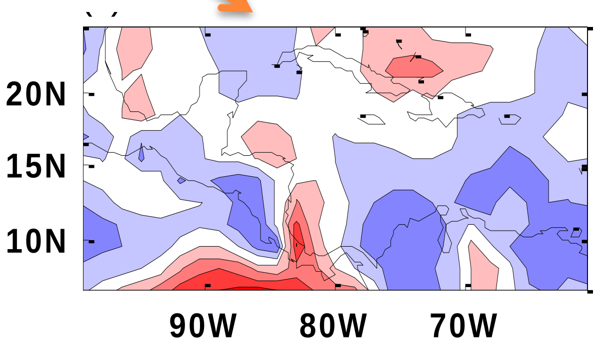
El Nino Southern Oscillation







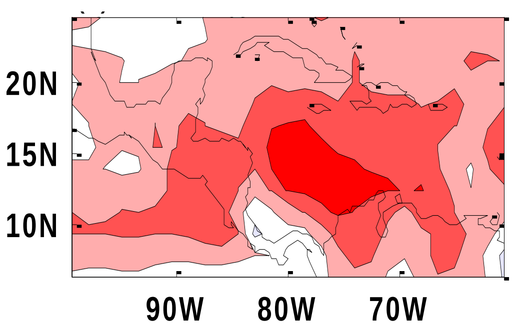
3. Early Wet season wetter in most of the Caribbean



Warms Caribbean Sea

1. Dry season drier in south Caribbean

Changes large scale circulations



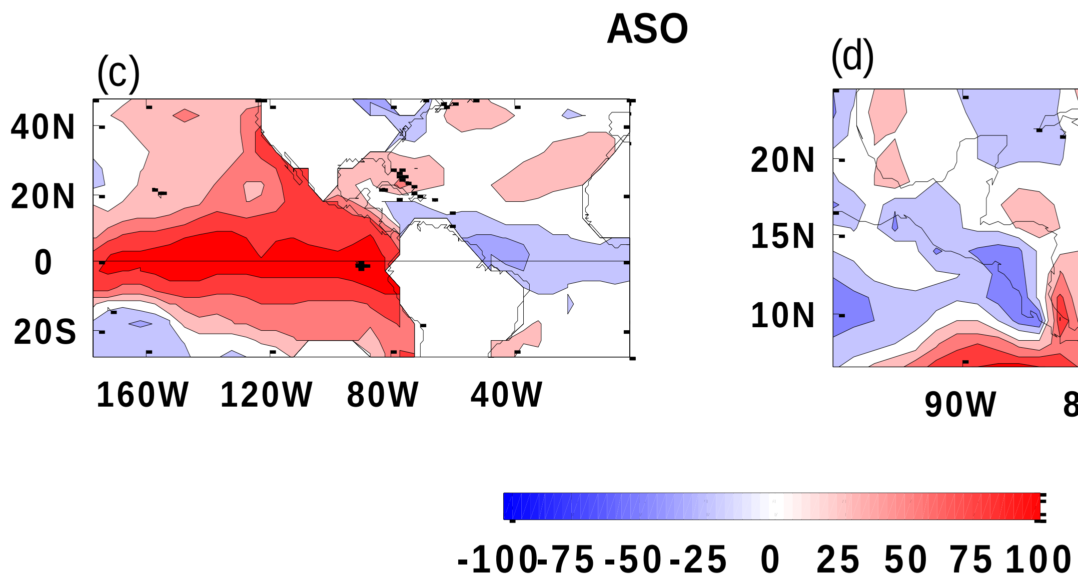
2. Late wet season drier in most of the Caribbean

Increases shear

Piecing Rainfall

Differences in SSTS between the Pacific and Atlantic

Gradients in SSTs between Equatorial Pacific and Tropical Atlantic



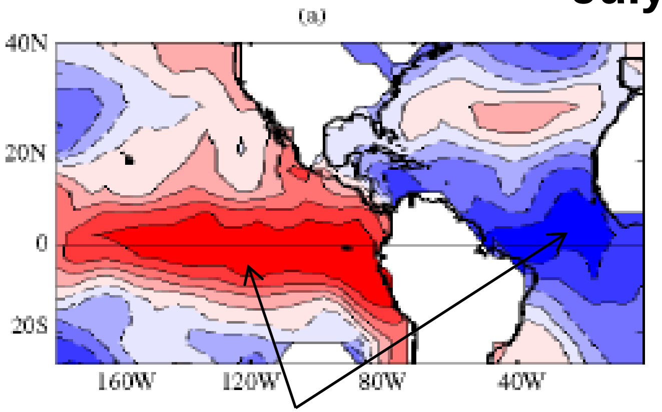
Dry Caribbean basin

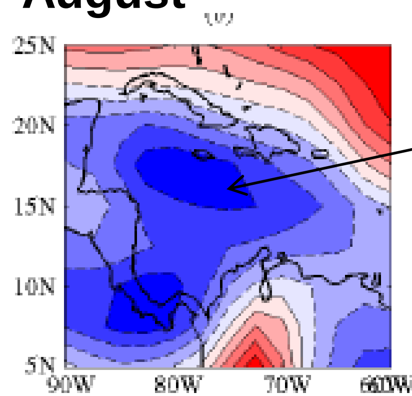
Drought 1997-1998

Piecing Rainfall

Differences in SSTS between the Pacific and Atlantic

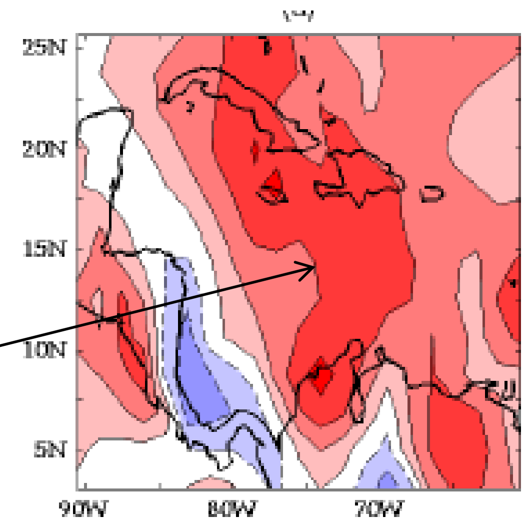
July-August



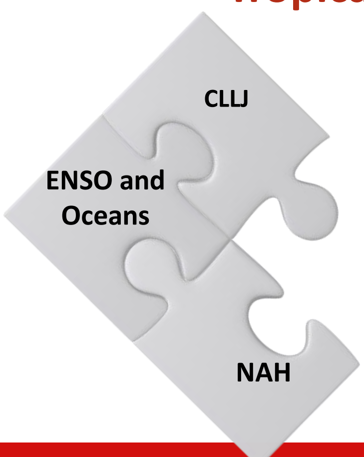


Low level wind strengths (CLLJ)

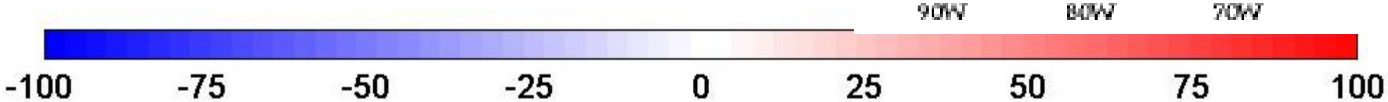
Gradients in SSTs between Equatorial Pacific and Tropical Atlantic



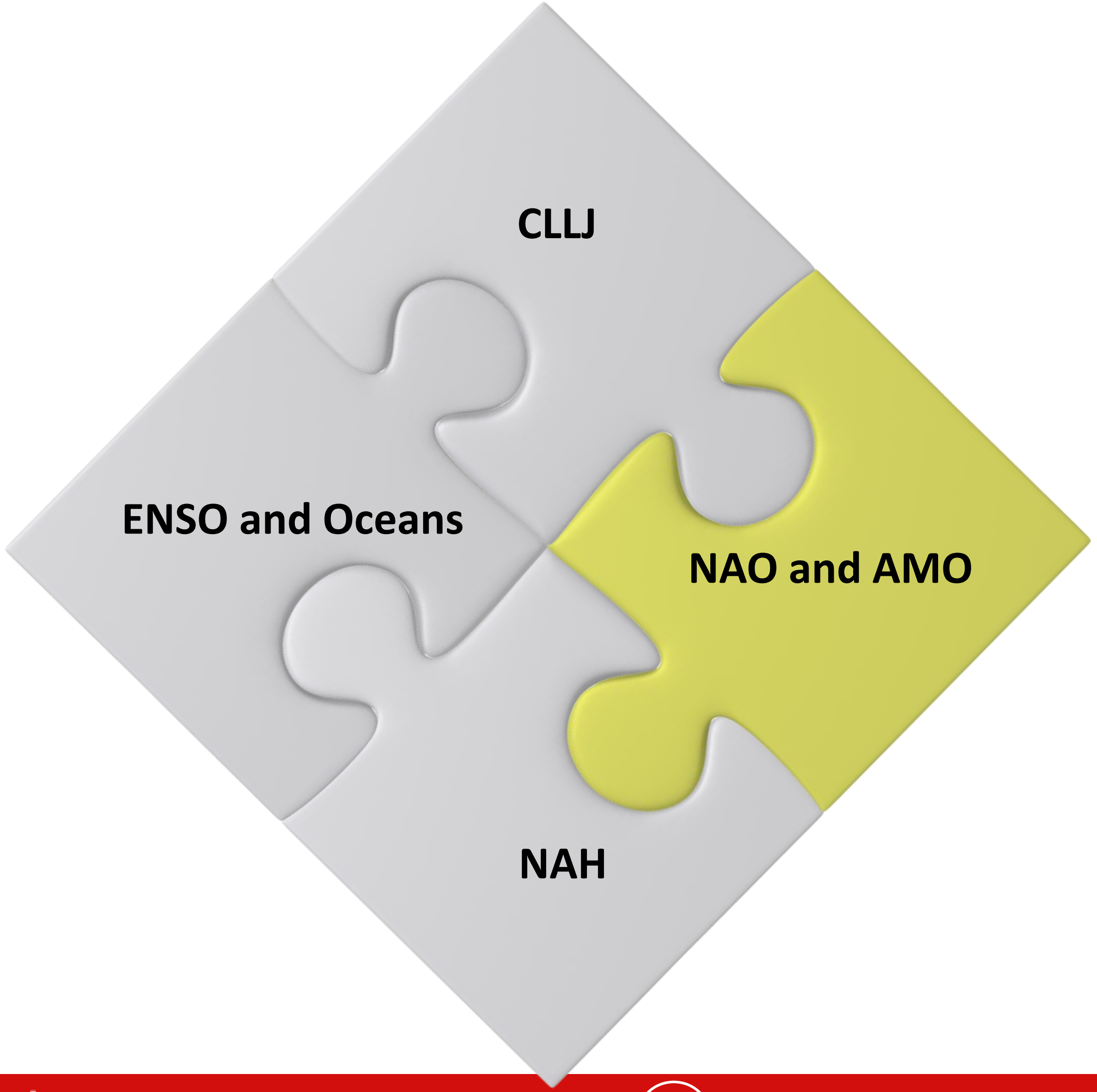
Drier than normal Caribbean basin during midsummer drought



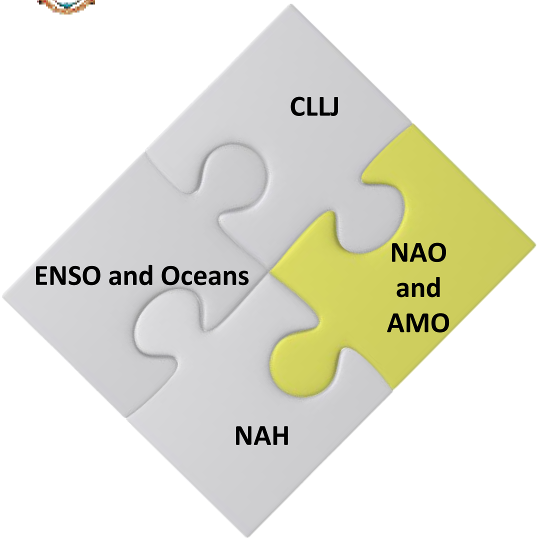
Drought 1997



PIECING RAINFALL

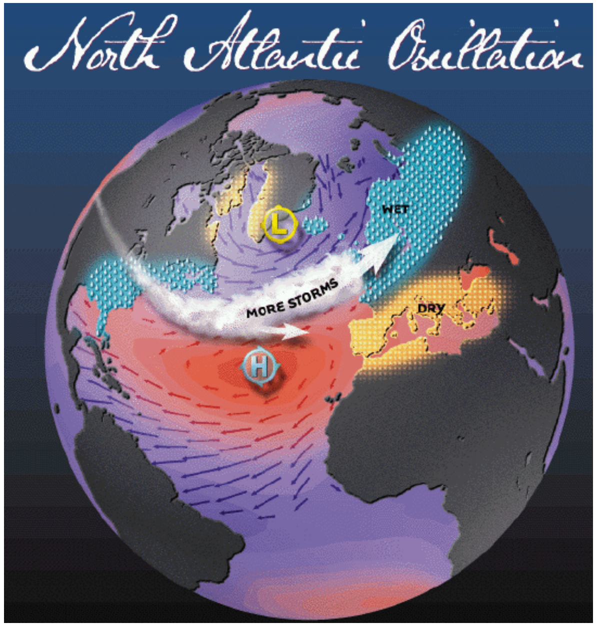


North Atlantic Oscillation (NAO)

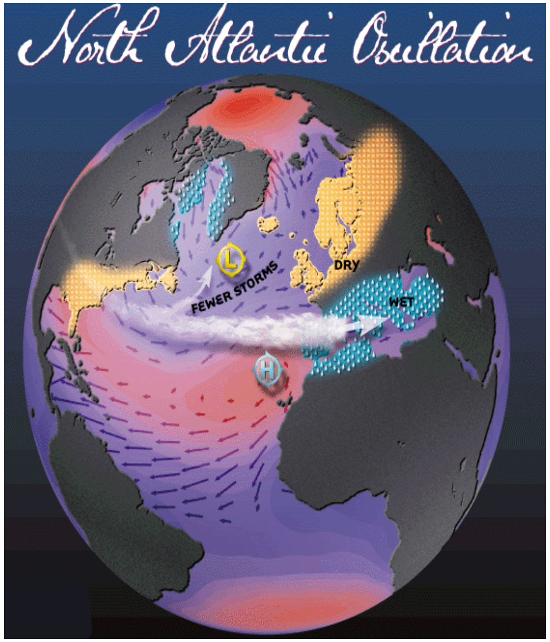


The NAO is the dominant mode of winter climate variability in the North Atlantic region ranging from central North America to Europe and much into Northern Asia.

The NAO is a large scale seesaw in atmospheric mass between the subtropical high and the polar low

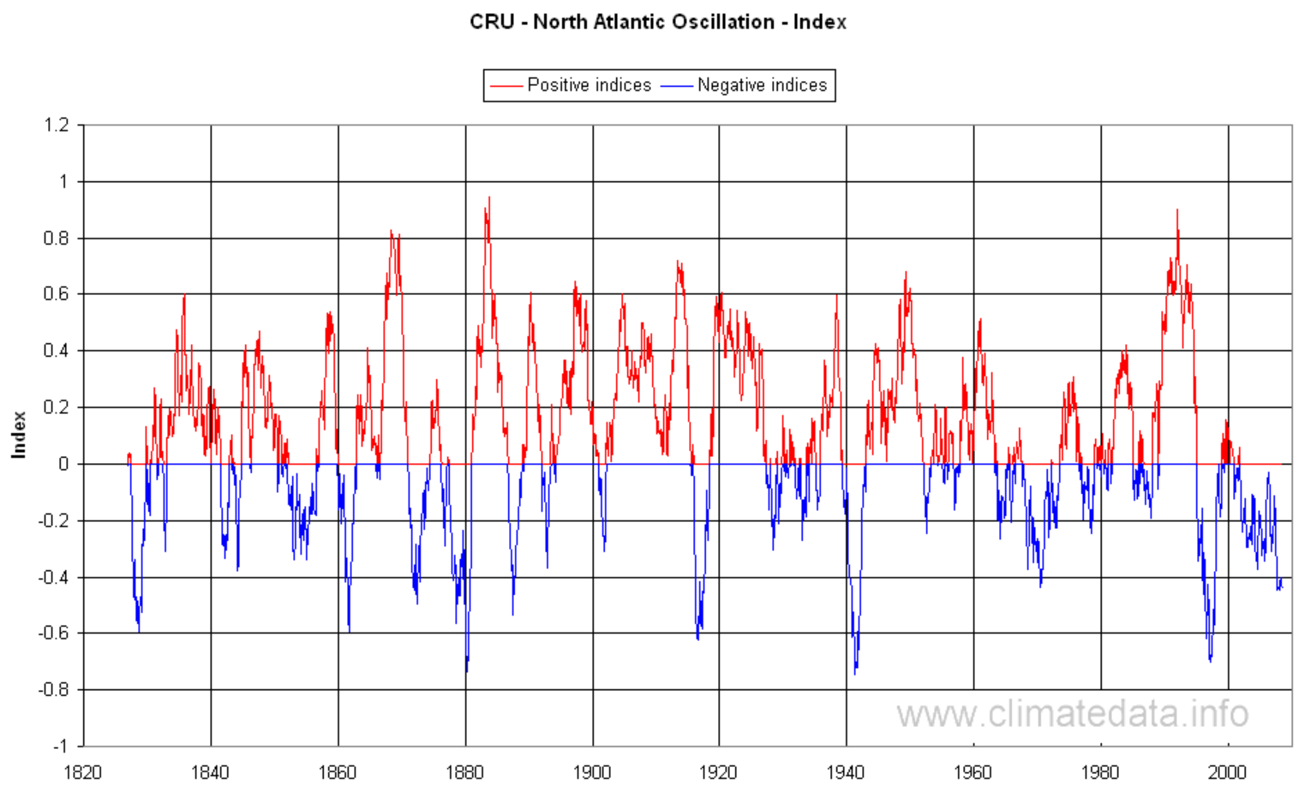


Positive phase => Drier Caribbean (particularly eastern Caribbean)



Negative phase => Wetter Caribbean (particularly eastern Caribbean)

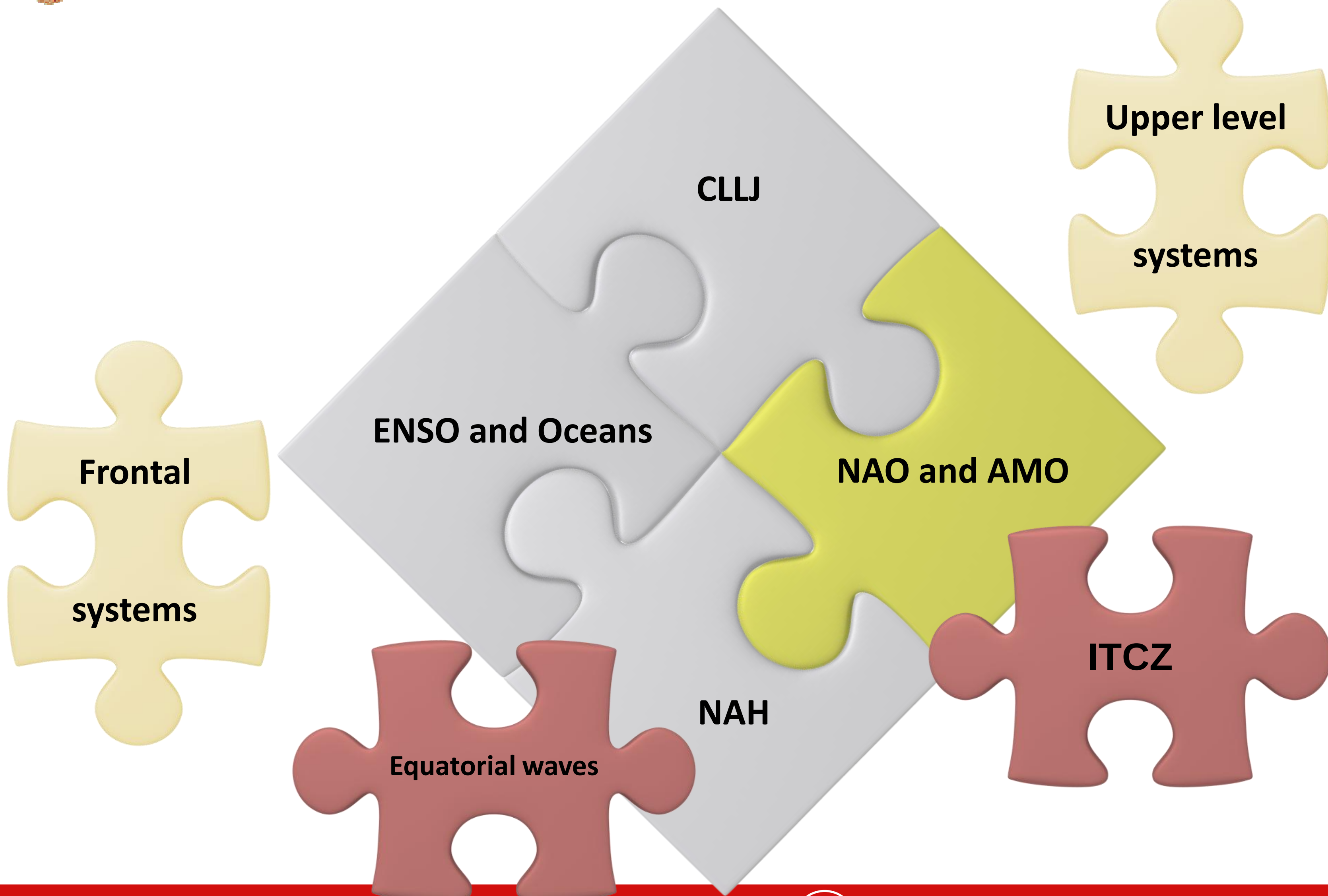
NAO



Background conditions Caribbean to be dry/wet

10-14 year cycle

Piecing together Rainfall



Review (Match making)

A. Annual Temperature Range

B. Diurnal Temperature Range

C. North Atlantic High

D. El Nino

E. Caribbean low level jet

F. North Atlantic Oscillation

1. Its movement towards the south causes increased trade winds, lower sea surface temperatures and decreased rainfall
2. Warming over the Pacific; influences rainfall over the Caribbean
3. Main driver of winter climate variability over the North Atlantic
4. Typically 2-3°C
5. Wind maximum below Jamaica that is associated with the mid-summer drought
6. Typically greater than 5°C

Part 2: Seasonal Prediction

THE SCIENTIFIC BASES

- The evolution of the atmosphere is partly driven by the evolution of external forcing conditions (SST and continental surfaces).

- The evolution of external forcings is often slow and predictable. It gives a slow memory to the atmosphere ; the evolution of the latter becoming partly predictable.

The evolution of external forcing conditions

- **Evolution of Sea Surface temperature (SST)**
  - Interannual variability (like ENSO)
  - Decadal variability (like NAO)

- **Evolution of continental surface conditions**
  - Intraseasonal variability (notably soil moisture),

- **Mutual influences**
  - Decadal/ENSO
  - ENSO/Intraseasonal

The fundamentals of seasonal forecasting

- The climatic variability → slow variation in the Atmosphere (e.g. NAO)

- The forecasting models
  - Statistical models
  - SST forced Atmospheric General Circulation Models
  - Ocean/Atmosphere Coupled General Circulation Models

- The verifications
  - Verification of the forecast
  - Verification of the usefulness of the forecast

Statistical Models

- Many problems in seasonal climate prediction start by trying to establish some relationship (linear) between two sets of variables.
- An example would be to try and see whether the (SST) over any of the global oceans (variable one) is related to rainfall (variable two) at a certain given location of the globe.

Statistical Models

- The Knowledge of such a relationship would be useful in that the expected rainfall of the given location can be predicted if the SSTs of the global Oceans are known in advance.

- The strength of the two relationship can be determined by computing the correlation coefficient.

Statistical Models

- A simple linear regression equation gives the functional relationship between two variables such as:

  $$Y = \alpha + \beta x$$

  where x is the independent variable (predictor) and Y the dependent variable (response or predictand).

- The estimation of the regression constants, α (Y-intercept) and β (slope of the line), are possible through the method of *least-squares.*

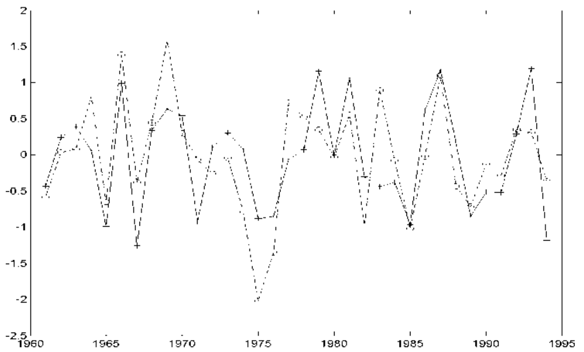
Examples of Statistical models

The Caribbean Model

MJJ RAIN =

– 0.0610 + 0.3111 NINO3(FMA)
– 0.0675 SLP2(FMA)
– 0.0299 SLP4(FMA)
+ 0.1187 VSH4(FMA)

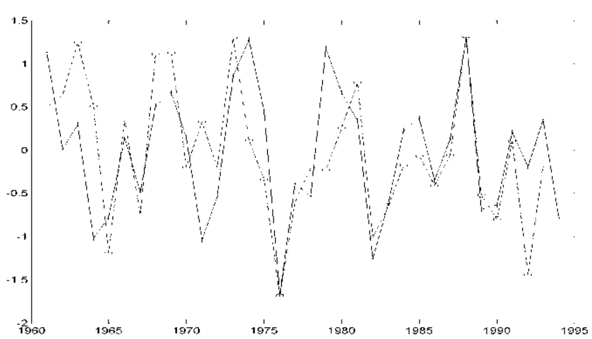
$R^2 = 0.76$



ASON RAIN =

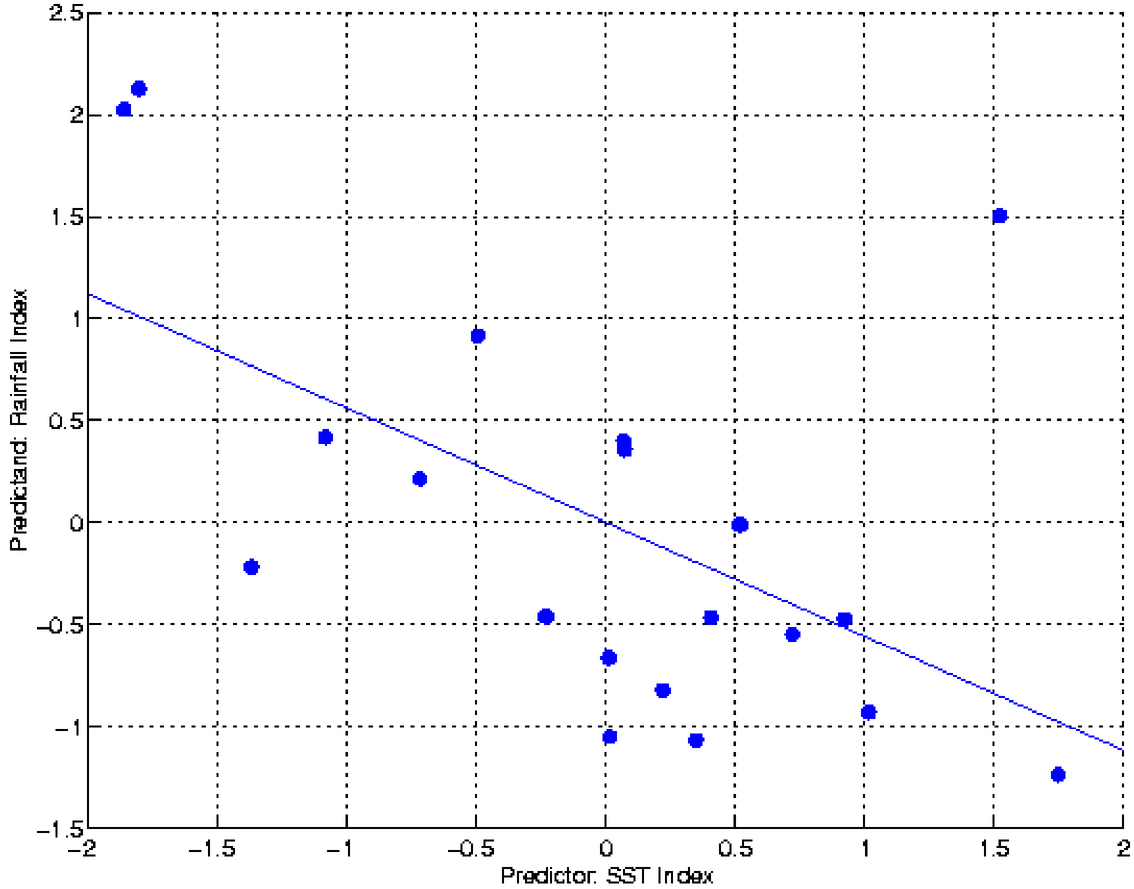
– 0.0280 + 1.5822 CSST(MJJ)
– 0.7227 PACEq(MJJ)
– 0.5739 PACTNA(MJJ)

$R^2 = 0.70$



Statistical Models

Scatter Plot and Line of Best Fit



Anomalies

Linear Regression Fit

- It can be seen that the relationship is linear but negatively, i.e. when the SST index increases (decreases), the rainfall index decreases (increases).

- Using this type of relationship, it is possible to make a qualitative statement regarding the expected rainfall for a coming season if knowledge of the seasonal lag SST index can obtained just before the beginning of the season to be forecasted.

- So if for 2012 the SST was above normal, what would you expect to happen to rainfall?

Statistical Models

- In a multiple linear regression model, a single predictand, *Y*, (e.g. SOND rainfall) has more than one predictor variable, i.e, it can be influenced by ENSO, QBO, SSTs over the Indian Ocean AND/OR the Atlantic Ocean, etc.

- For K predictors: $Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k$
- The procedure for estimating the regression coefficients is the same as those for simple linear regression models.

Stepwise Regression analysis

- **Forward Selection**: In this procedure, only the best potential predictors that improves the model the most, are examined individually and added into the model equation, starting with the one that explains the highest variance, etc.

- **Backward Elimination**: The regression model starts with all potential predictors and at each step of model construction, the least important predictor is removed until only the best predictors remain.
- A stopping criteria should be selected in both cases.

CREATING THE MODELS

- A number of methods can be used.
- The simplest is Linear Regression.
- Some other methods include:
  - Discriminant Analysis
  - Neural Networks
  - Canonical Correlation Analysis

CREATING THE MODELS

- A number of tools are available
  - Climate Predictability Tool
  - R (climpact package)
  - MATLAB
  - SPSS

Forecast Skill Estimation (Contingency Table)

	O_A	O_N	O_B
F_A	R	S	T
F_N	U	V	W
F_B	X	Y	Z

O: Observed
F: Forecast

A: Above-normal
N: Near-normal
B: Below-normal

Accuracy Measures of Multicategory Forecasts (1)

- Hit Score (HS): Number of times a correct category is forecast

- $HS = R+V+Z$

Accuracy Measures of Multicategory Forecasts (2)

- False Alarm Ratio (FAR): The fraction of forecast events that failed to materialize
- Best FAR=0; worst FAR=1
- For Above-Normal=(S+T)/(R+S+T)
- For Near-Normal=(U+W)/(U+V+W)
- For Below-Normal=(X+Y)/(X+Y+Z)

EXAMPLE

- Predicting May-June-July Caribbean rainfall
  - Step 1: Identify predictors.
    - based on understanding of factors affecting MJJ rainfall (e.g. El Nino, Tropical North Atlantic surface temperatures . . .)

Step 1

Table 1. The predictors and predictands for the Caribbean rainfall models. Predictors are deduced from diagnostic analysis of the general circulation (See Section 2)

	Description	References
a) Predictors		
Pool A: Atmospheric Variables		
LAT	Latitude of the central maximum of the North Atlantic Sub-tropical High	
LON	Longitude of the central maximum of the North Atlantic Sub-tropical High	
VSH1	Area averaged vertical shear anomaly for 40 W–17.5 W, 2.5 N–10 N. Calculated using 850 and 200 hPA levels.	
VSH2	Area averaged vertical shear anomaly for 17.5 W–17.5 E, 2.5 S–2.5 N. Calculated using 850 and 200 hPA levels.	
VSH3	Area averaged vertical shear anomaly for 50 W–77.5 W, 15 N–20 N. Calculated using 850 and 200 hPA levels.	
VSH4	Area averaged vertical shear anomaly for 2.5 W–35 W, 15 N–20 N. Calculated using 850 and 200 hPA levels.	
SLP1	Area averaged sea level pressure anomalies for 60 W–22.5 E, 7.5 N–22.5 N	
SLP2	Area averaged sea level pressure anomalies for 45 W–65 W, 15 N–27.5 N	

EXAMPLE

- Predicting May-June-July Caribbean rainfall
  - Step 1: Identify predictors.
    - based on understanding of factors affecting MJJ rainfall (e.g. El Nino, Tropical North Atlantic surface temperatures . . .)
  - Step 2: Test predictors.
    - Determine the strength of the relationship between MJJ rainfall and our predictors (e.g. calculating the correlation)

EXAMPLE

- Step 2

Table 2. Correlation coefficients between Pool A and Pool B predictors and the early season (MJJ) time series' of CPINDX and DCPINDX (*italicized*). Concurrent correlations are shown (column 2) as well as for predictors leading the early season rainfall indices by up to 3 seasons (columns 3 through 5). Significant correlations are in bold

	MJJ		FMA		NDJ		ASO	
Pool A: Atmospheric Variables								
LAT	0.0420	***0.3582***	0.1227	*0.1635*	**−0.4818**	*−0.1582*	−0.0926	*0.2193*
LON	0.1153	***0.4551***	−0.3101	*−0.2251*	**−0.4167**	*−0.2478*	−0.1456	*0.2263*
VSH1	**−0.7730**	–	0.0968	–	−0.2247	–	−0.0453	–
VSH2	**−0.6446**	–	−0.2369	–	**−0.3520**	–	**−0.6352**	–
VSH3	–	*0.0032*	–	*−0.2139*	–	*0.0503*	–	*0.0800*
VSH4	–	*−0.0517*	–	***0.5063***	–	***0.4017***	–	*−0.0606*
SLP1	**−0.7307**	–	**−0.7037**	–	**−0.6004**	–	−0.5574	–
SLP2	–	***−0.5841***	–	***−0.5508***	–	*0.0581*	–	*0.0559*
SLP3	–	*−0.1830*	–	***−0.3865***	–	*0.0355*	–	*0.0671*
SLP4	–	*−0.2313*	–	***−0.4278***	–	*−0.1948*	–	*−0.2809*
NAO	**−0.4189**	*−0.2029*	0.0623	*0.0275*	0.0146	*−0.1403*	**−0.2792**	*0.0911*
QBO	−0.0661	*−0.0434*	−0.1067	*−0.0596*	0.0199	*0.0148*	0.0934	*0.0550*

Correlations range from 1 to -1. Perfect relationship is indicated by 1 (-1) and no relationship is indicated by a value of 0. Positive correlations mean as the predictor increases, rainfall increases as well. Negative means as the predictor increases, rainfall decreases

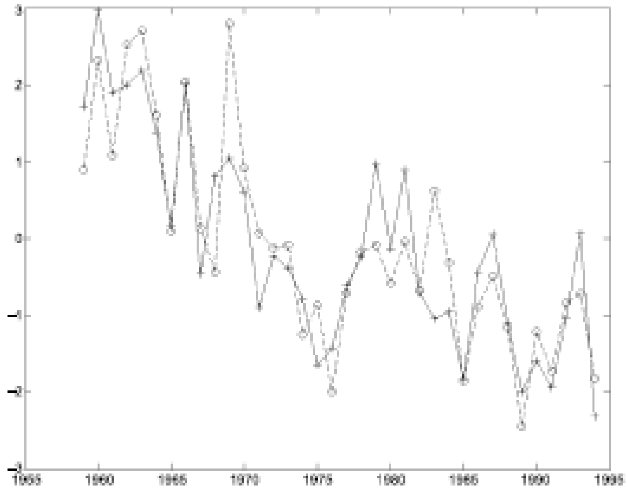
EXAMPLE

- Predicting May-June-July Caribbean rainfall
  - Step 3: Create model (using for example linear regression)

STEP 3

- Model:

$$\text{Rain (MJJ)} = -0.1361 + 1.8739\ \text{CSST (FMA)} - 0.1114\ \text{SLP1 (FMA)} - 0.2223\ \text{VSH2 (NDJ)} - 0.1737\ \text{AWP (ASO)}$$



Example

- Predicting May-June-July Caribbean rainfall

  - Step 3: Create model (using for example linear regression)

  - Step 4: Assess model
    - Evaluate the skill of the model

STEP 4

Table 3. Jackknife assessments of the early season prediction models A through G using CPINDX as the predictand. Row 2 indicates predictors retained for each regression model. S is the model skill; HR is the Hit Rate; SS is the Skill Score; LEPS is the Linear Estimation in Probability Space; FARBN and FARAN are the false alarm scores for below and above normal forecast; PODBN and PODAN are the probability scores for predicting below normal and above normal events

Models	A	B	C	D	E	F	G
Predictors	CSST (FMA), SLP1 (FMA), VSH2 (NDJ), AWP (ASO)	CSST (FMA)	SLP (NDJ)	VSH2 (NDJ)	AWP (ASO)	CPINDX (FMA)	CSST (FMA), SLP1 (FMA), VSH2 (NDJ), AWP (ASO), CPINDX (FMA)
S	0.87	0.69	0.72	0.49	0.19	0.82	0.93
R^2	0.90	0.51	0.55	0.29	0.30	0.70	0.95
HR	83.33	77.78	75.00	69.44	58.33	80.56	88.89
SS	75.00	66.67	62.50	54.17	37.50	70.83	83.33
LEPS	67.08	54.58	49.17	38.33	11.67	63.33	81.25
FARBN	16.67	8.33	25	25	41.67	0.00	0.00
FARAN	0.00	15.38	0.00	0.00	7.69	0.00	0.00
PODBN	75.00	58.33	58.33	58.33	33.33	75	83.33
PODAN	76.92	76.92	69.23	53.84	46.15	69.23	84.62

Seasonal Prediction

- Word on CARICOF

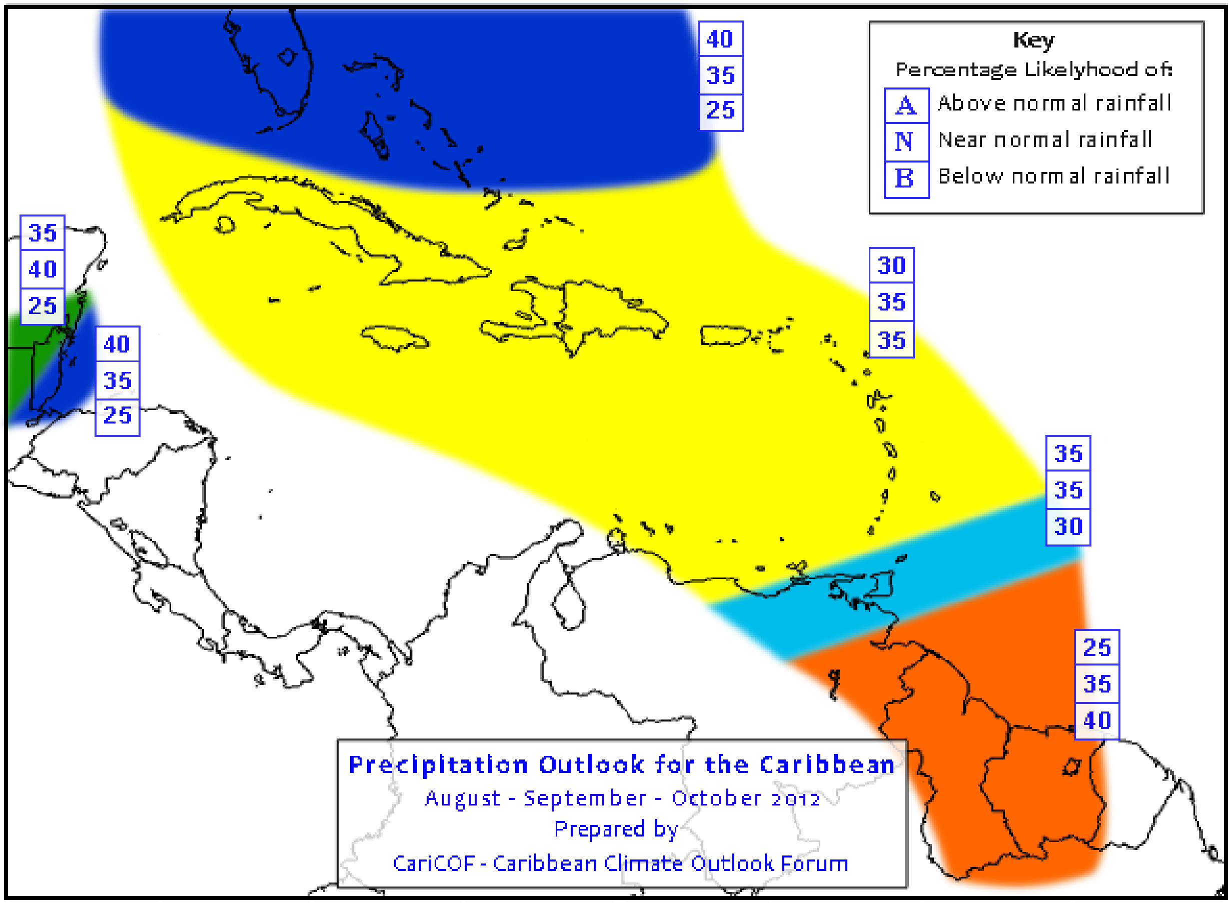
- Caribbean Climate Outlook Forum
  - Driven by CIMH
  - NMS participate
  - Run experiment using Climate Predictability tool as well as output from numerical models

Seasonal Prediction

DATA SOURCES

1) IRI multi-model probability forecast;
2) UK Met Office GCM (UKMO) probability forecast;
3) European Center for Mid-range Weather Forecast GCM (ECMWF) and EUROSIP (multi-model) probability forecasts;
4) APEC Climate Center (APCC) model probability forecasts;
5) MétéoFrance (Arpège) model probability forecasts;
6) Central American COF Word on CARICOF

ASO Precipitation Outlook



Rainfall in the Caribbean during August-September-October will likely become generally consistent with typical El Niño conditions. This means an increased likelihood of normal to above normal rainfall over the Bahamas, Belize and (possibly) some portions of the Greater Antilles whereas normal to below normal rainfall may occur in most parts of the Antilles and the Guianas, especially from the onset of the late rainy season in September.