Probabilistic forecast verification

Caio Coelho

Centro de Previsão de Tempo e Estudos Climáticos (CPTEC)

Instituto Nacional de Pesquisas Espaciais (INPE)

Plan of lecture

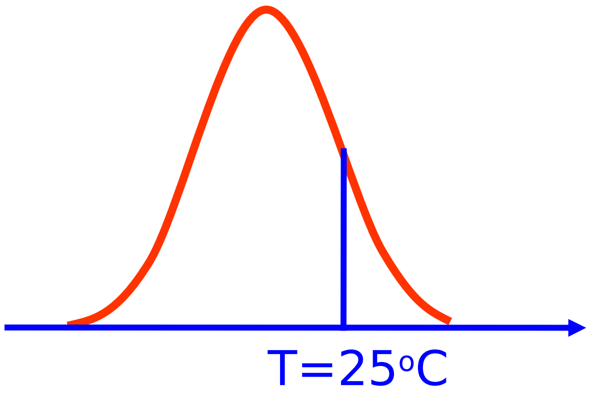
- **Examples of probabilistic forecasts and common verification practice**
- **How to construct a reliability diagram**
- **Exercise on Brier score, its decomposition and reliability diagram**
- **ROC: discrimination**
- **Exercises on ROC**

7th International Verification Methods Workshop

Tutorial on forecast verification methods

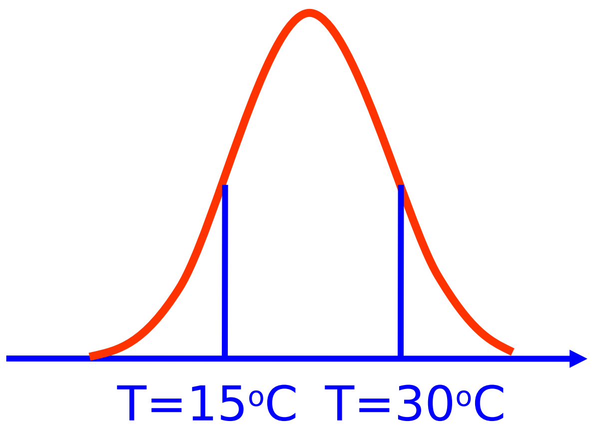
Berlin, Germany, 3-6 May 2017

Examples of probabilistic forecasts: Temperature



F is a set of probabilities
for the discrete values of O

F: 0.4, 0.3, 0.5, 0.1, 0.6, 0.2
O: 1 , 1 , 0 , 1 , 0 , 0



F is a probabilistic interval
of values for O (interval forecast)

F: 0.7, 0.6, 0.5, 0.8, 0.7, 0.5
O: 0 , 1 , 0 , 1 , 1 , 0

Common verification practice:

- **Compare forecast probability and occurrence (or non-occurrence) of event using a probabilistic score (e.g Brier score)**

- **Construct a reliability diagram**

Forecast attributes assessed with the Brier score and reliability diagram

- Reliability: correspondence between forecast probabilities and observed relative frequency (e.g. an event must occur on 30% of the occasions that the 30% forecast probability was issued)

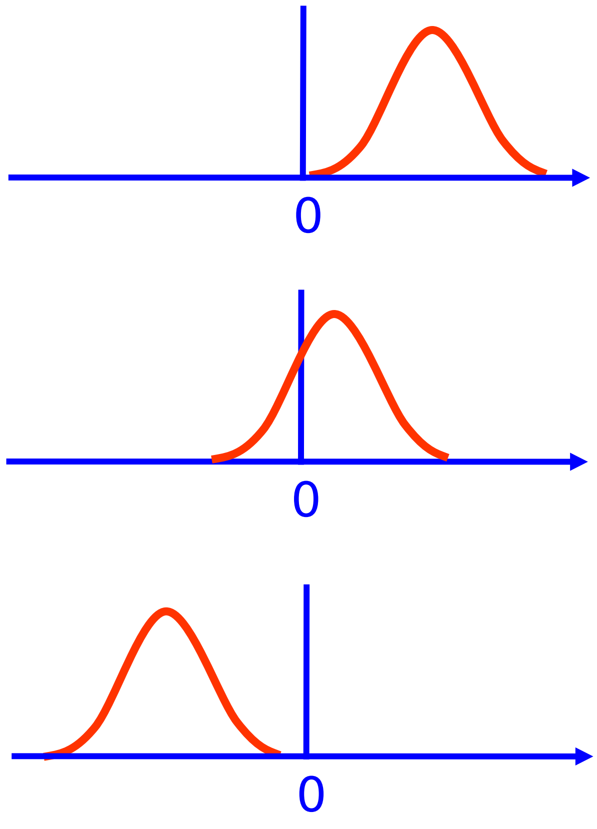
- Resolution: Conditioning of observed outcome on the forecasts
- Addresses the question: Does the frequency of occurrence of an event differs as the forecast probability changes?
- If the event occurs with the same relative frequency regardless of the forecast, the forecasts are said to have

Example of how to construct a reliability diagram

Sample of probability forecasts:

22 years x 3000 grid points = 66000 forecasts

How many times the event (T>0) was forecast with probability p_i?



Forecast Prob.(p_i)	# Fcsts. N_i	"Perfect fcst." OBS-Freq.($\overline{o}_i$)	"Real fcst." OBS-Freq($\overline{o}_i$)
100%	8000	8000 (100%)	7200 (90%)
90%	5000	4500 (90%)	4000 (80%)
80%	4500	3600 (80%)	3000 (66%)
….	….	….	….
….	….	….	….
….	….	….	….
10%	5500	550 (10%)	800 (15%)
0%	7000	0 (0%)	700 (10%)

Courtesy: Francisco Doblas-Reyes

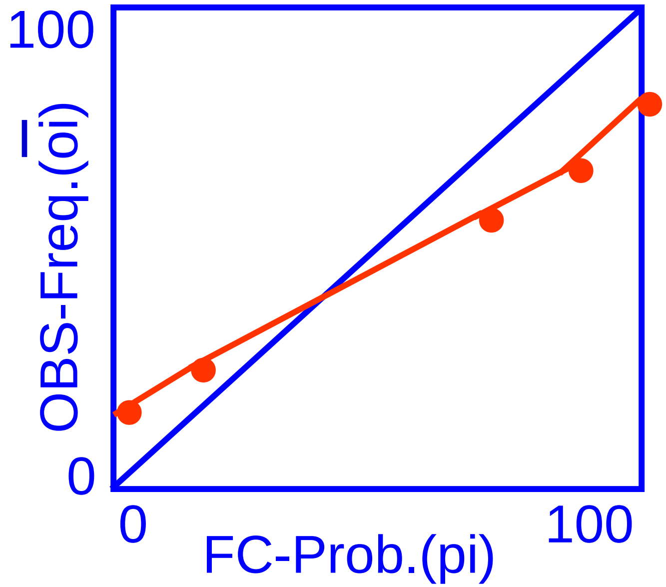
Example of how to construct a reliability diagram

Sample of probability forecasts:

22 years x 3000 grid points = 66000 forecasts

How many times the event (T>0) was forecast with probability p_i?

Forecast Prob.(p_i)	# Fcsts. N_i	"Perfect fcst." OBS-Freq.($\overline{o}_i$)	"Real fcst." OBS-Freq($\overline{o}_i$)
100%	8000	8000 (100%)	7200 (90%)
90%	5000	4500 (90%)	4000 (80%)
80%	4500	3600 (80%)	3000 (66%)
….	….	….	….
….	….	….	….
….	….	….	….
10%	5500	550 (10%)	800 (15%)
0%	7000	0 (0%)	700 (10%)

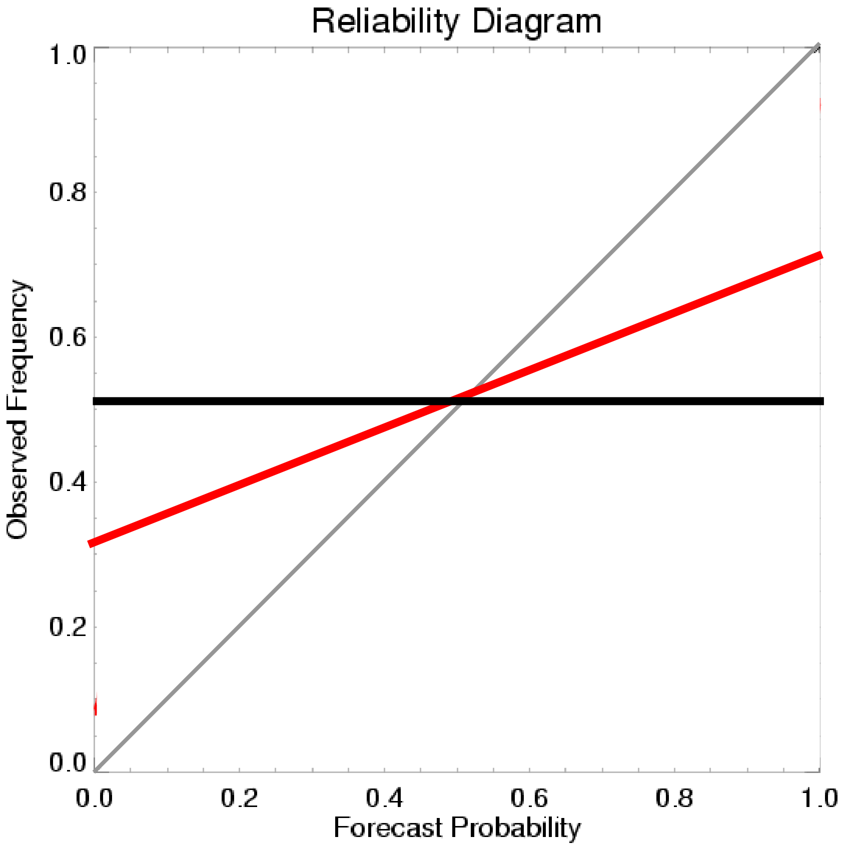


Courtesy: Francisco Doblas-Reyes

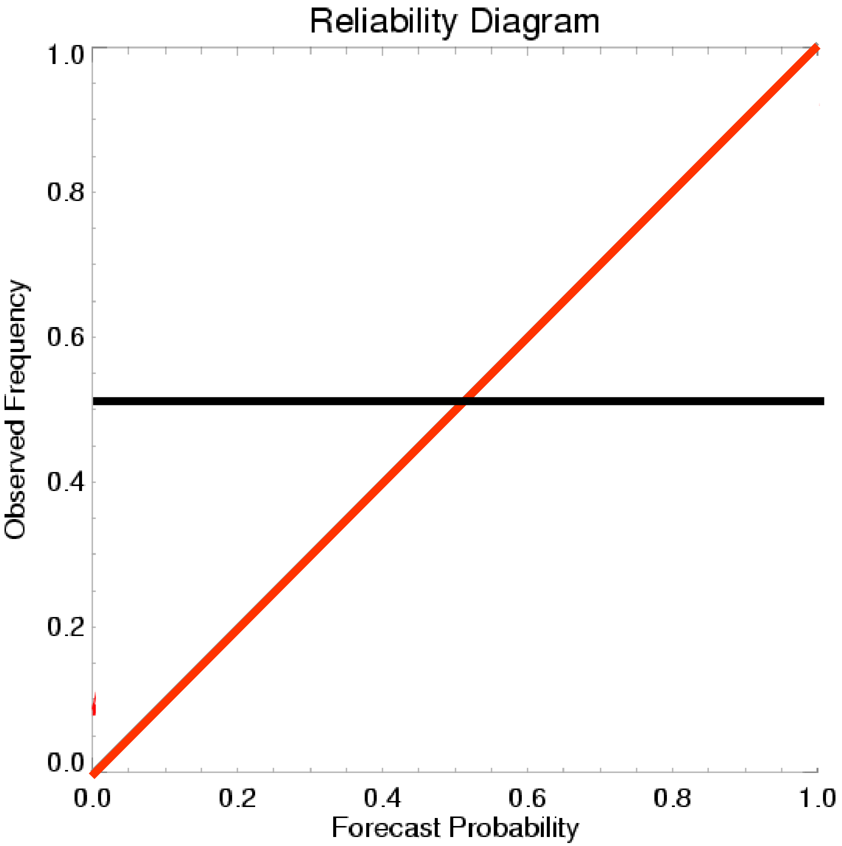
Reliability diagram

Over-confident forecasts,

with poor resolution



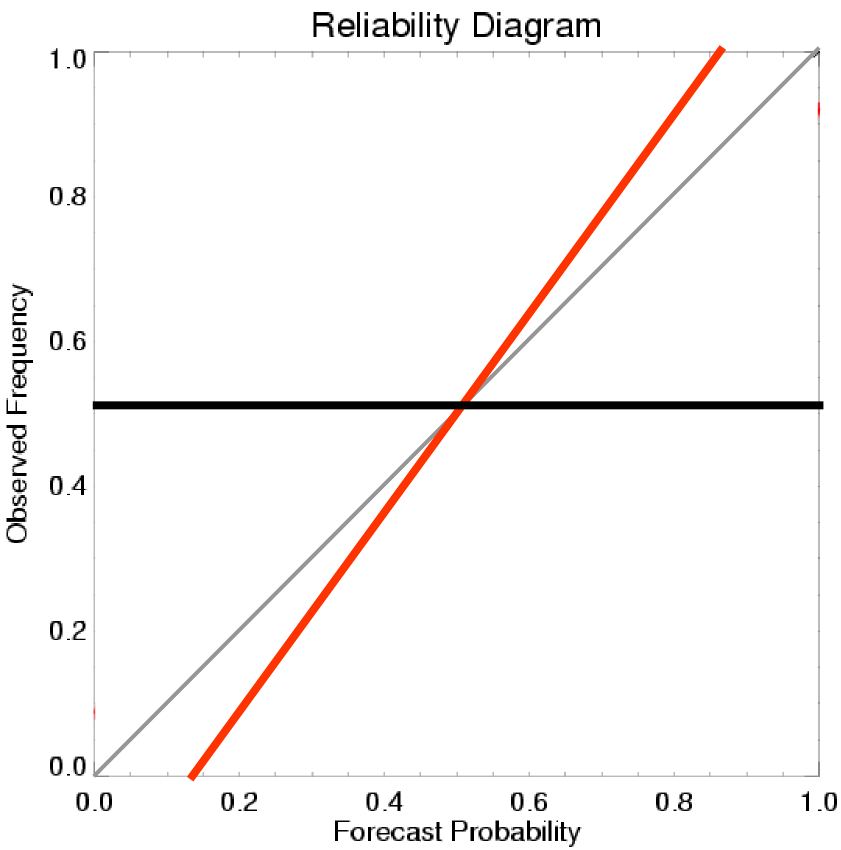
Perfect forecasts



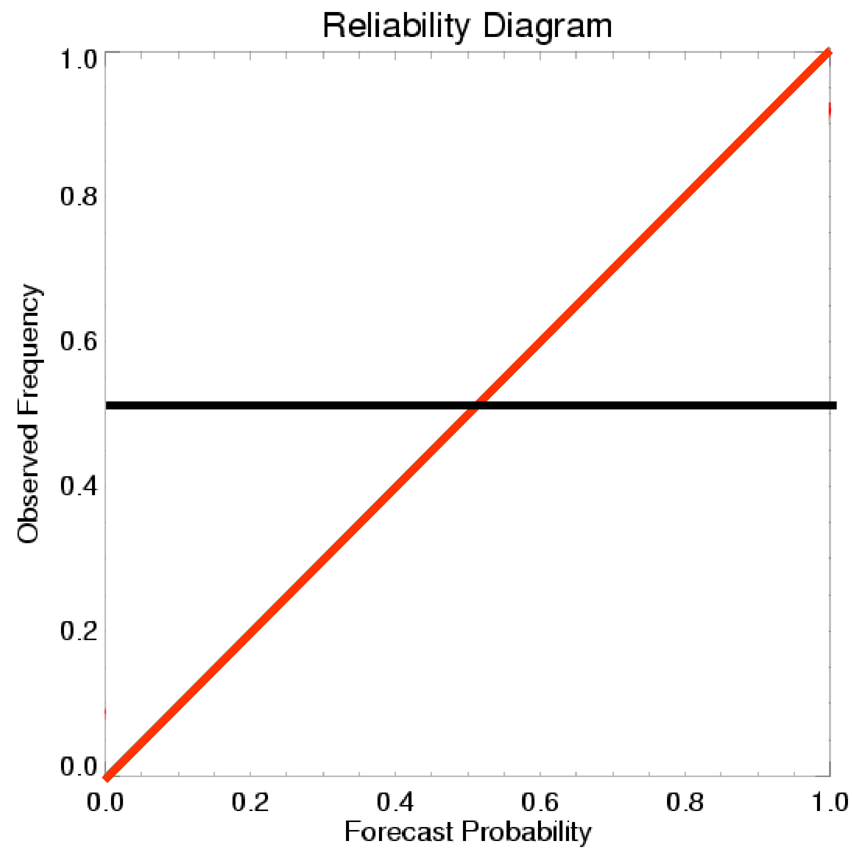
Reliability diagram

Under-confident forecasts,

with good resolution

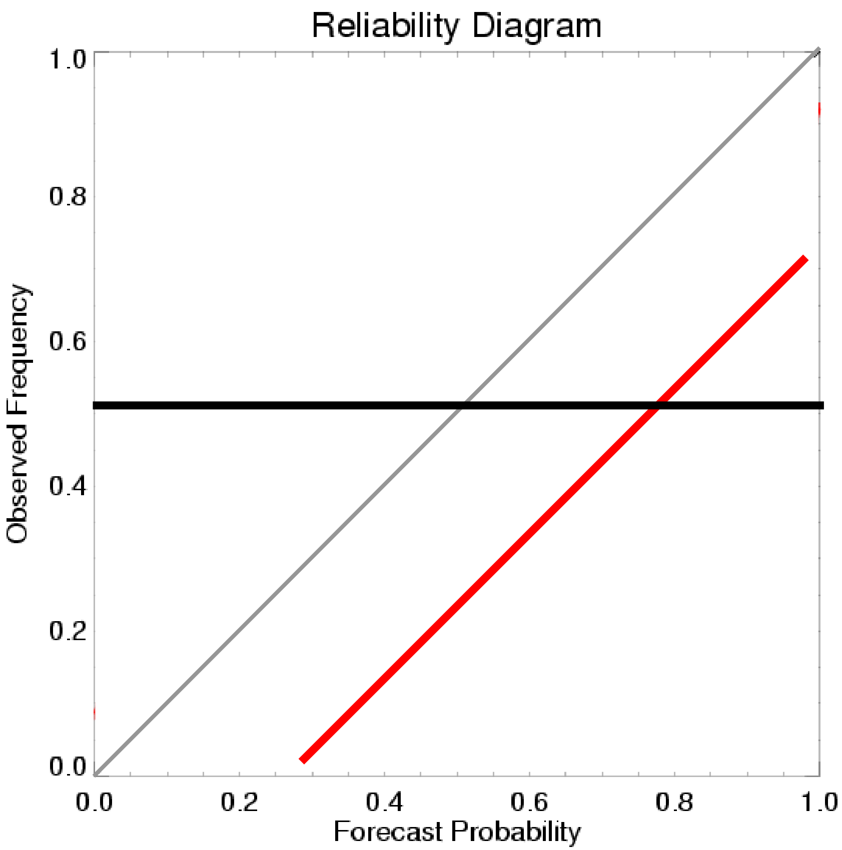


Perfect forecasts

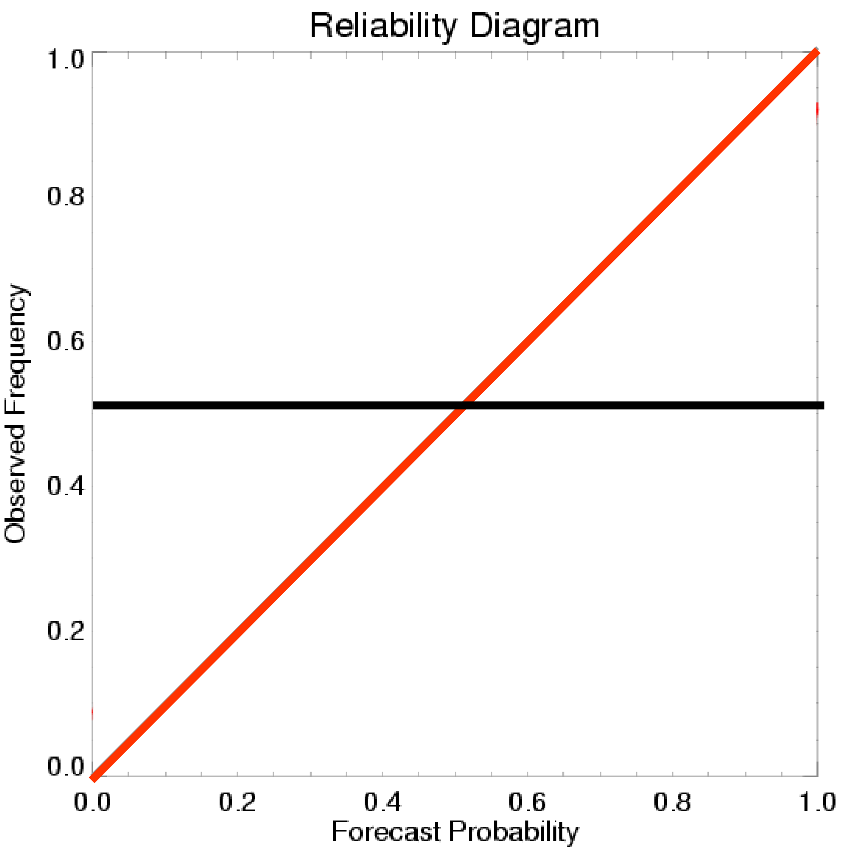


Reliability diagram

Over forecasting

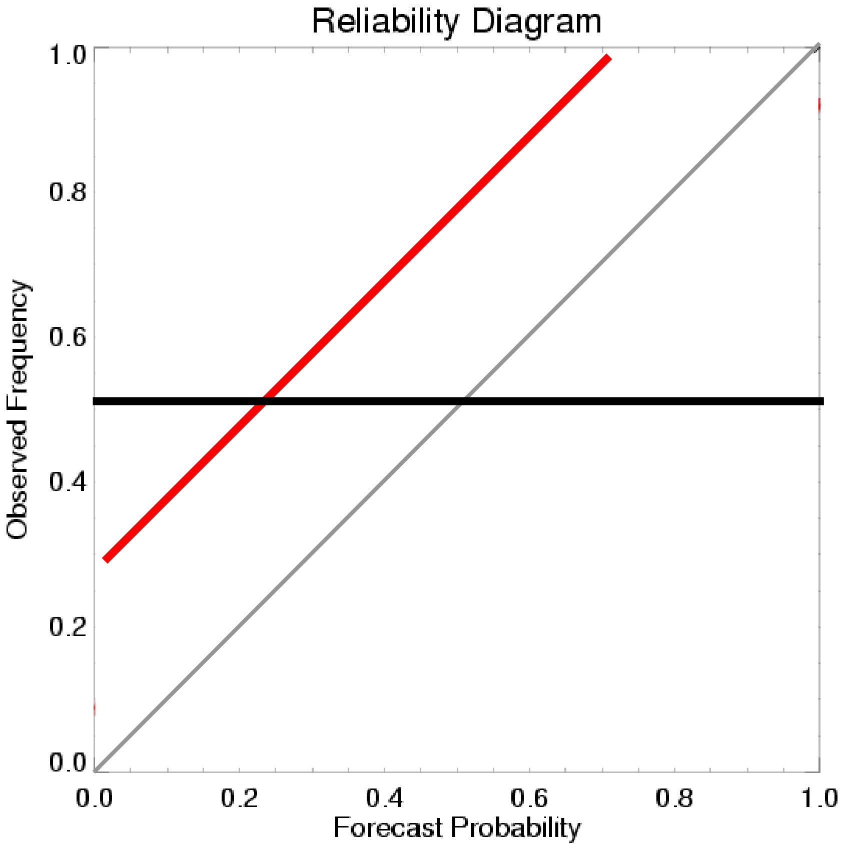


Perfect forecasts

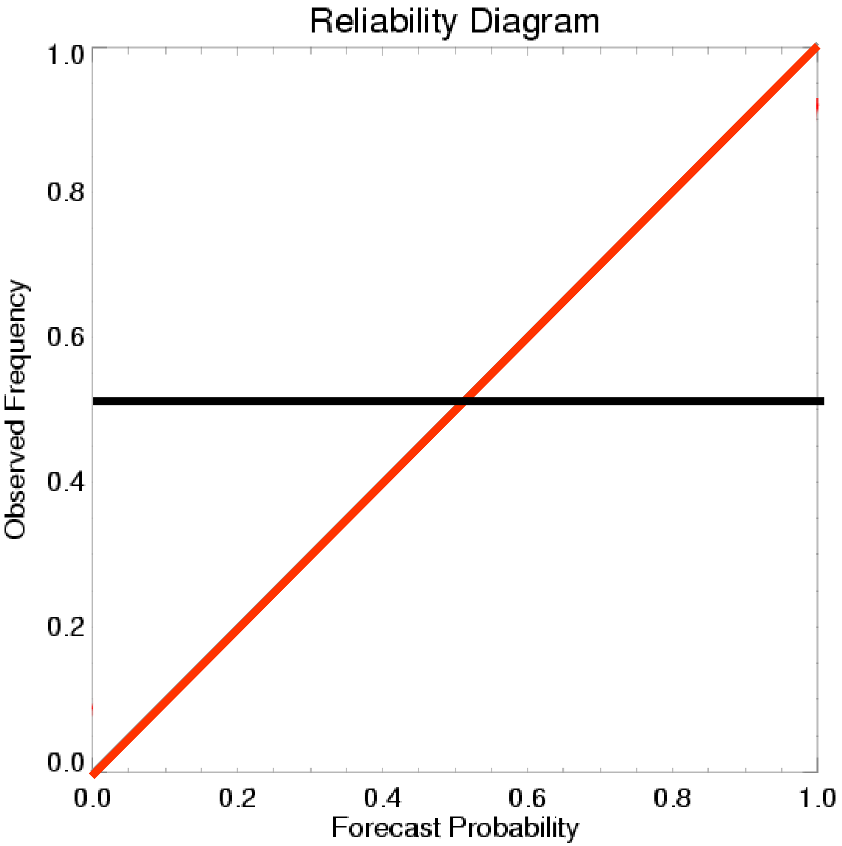


Reliability diagram

Under forecasting



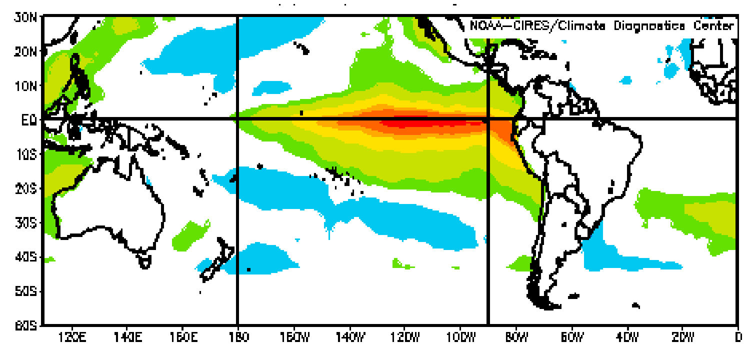
Perfect forecasts



Example:Equatorial Pacific SST

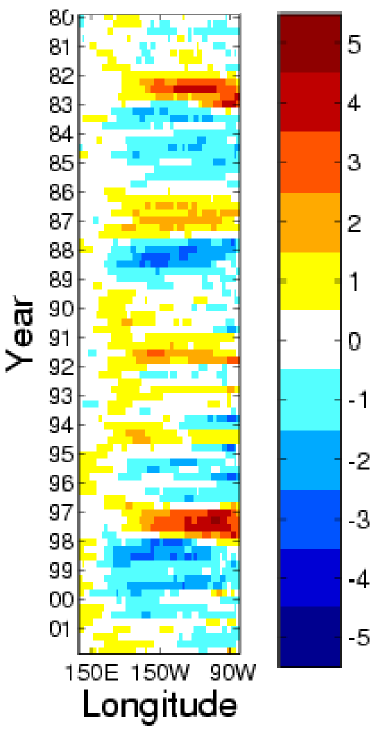
88 seasonal probability forecasts of binary SST anomalies at 56 grid points along the equatorial Pacific. Total of 4928 forecasts.

6-month lead forecasts for 4 start dates (F,M,A,N) valid for (Jul,Oct,Jan,Aug)

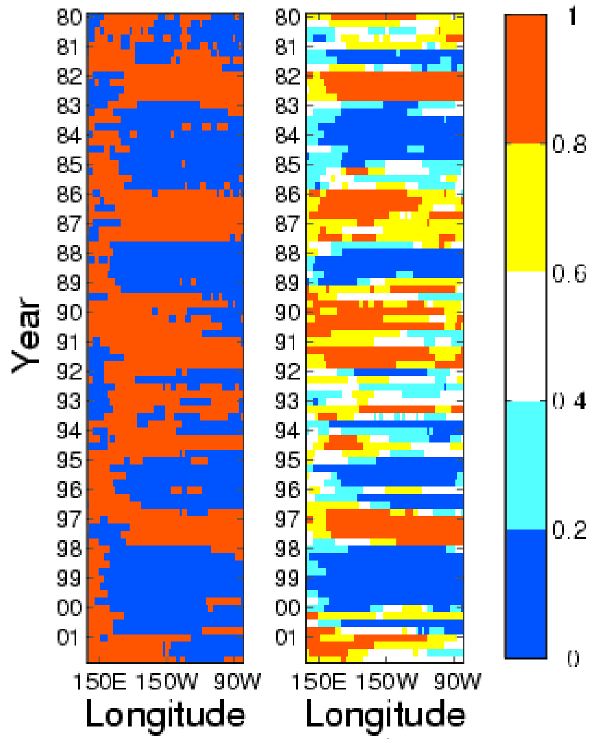


SST $\quad o = (SST > 0) \quad f = \Pr(\hat{o})$

OBS



OBS ENS



SST anomalies (°C)

Forecast probab

The probability forecasts were constructed by fitting Normal distributions to the ensemble mean forecasts from the 7 DEMETER coupled models, and then calculating the area under the normal density for SST anomalies greater than zero

Exercise 1:

Read data file equatorialpacificsst.txt which contains forecast probabilities for the event Eq. Pac. SST>0 and the corresponding binary observations

```
data<-read.table(“equatorialpacificsst.txt”)

#1st column contains forecast probabilities
probfcsts<-data[,1]

#2nd column contains binary observation
binobs<-data[,2]
```

```
#Compute the climatological frequency of the event
 obar<-mean(binobs)

#Compute the Brier score for the climatological frequency
#(i.e. the climatological forecast)
bsclim<-mean((obar-binobs)^2)

#Compute the variance of binary observation
var(binobs) *(length(binobs)-1)/length(binobs)

#Compute the uncertainty component of the Brier score
obar*(1-obar)
#How does this compare with the Brier score computed
#above? What can you conclude about the reliabilty and
#resolution components of the Brier score for the
#climatological forecast?
```

```
#Compute the Brier score for the SST prob. forecasts
#for the event SST>0
bs<-mean((probfcsts-binobs)^2)

#How does this compare with the Brier score for the
#climatological forecast? What can you conclude about the
#skill of these forecasts (i.e. which of the two are more
#skillfull by looking at their Brier score values)?

#Compute the Brier skill score
bss <- 1-(bs/bsclim)

#How do you interpret the Brier skill score obtained
#above? I.e. what can you conclude about the skill of the SST
#prob. forecasts when compared to the climatological
#forecast?
```

```
#Use the verification package to compute the Brier score and
#its decomposition for the SST prob. forecasts for
#the event SST>0
library(verification)
A<-verify(binobs,probfcsts, frcst.type="prob",obs.type="binary"
summary(A)

#Note: Brier score – Baseline is the Brier score for the
#reference climatological forecast
#Skill Score is the Brier skill score
#Reliability, resolution and uncertainty are the three
#components of the Brier score decomposition

#What can be conclude about the quality of these forecasts
#when compared with the climatological forecasts?
```

```
#Construct the reliability diagram for these forecasts using
#10 bins
nbins<-10
bk<-seq(0,1,1/nbins)
h<-hist(probfcsts,breaks=bk,plot=F)$counts
g<-hist(probfcsts[binobs==1],breaks=bk,plot=F)$counts
obari <- g/h
yi <- seq((1/nbins)/2,1,1/nbins)

par(pty='s',las=1)
reliability.plot(yi,obari,h,titl="10 bins",legend.names="")
abline(h=obar)

#What can you conclude about these forecasts by examining
#the feature of the reliability diagram curve?
```

```
# Compute reliability, resolution and uncertainty components
# of the Brier score
n<-length(probfcsts)
reliab <- sum(h*((yi-obari)^2), na.rm=TRUE)/n
resol <- sum(h*((obari-obar)^2), na.rm=TRUE)/n
uncert<-obar*(1-obar)
bs<-reliab-resol+uncert

#How does the results above compare with those obtained
#with the verify function?
```

Discrimination

- Conditioning of forecasts on observed outcomes
- Addresses the question: Does the forecast (probabilities) differ given different observed outcomes? Or, can the forecasts distinguish (discriminate or detect) an event from a non-event?

  Example: Event (Positive SST anom. observed)
  Non-event (Positive SST anom. not obs)
- If the forecast is the same regardless of the outcome, the forecasts cannot discriminate an *event* from a *non-event*
- Forecasts with no discrimination ability are useless because the forecasts are the same regardless of what happens

ROC: Relative operating characteristics

Measures discrimination (ability of forecasting system to detect the event of interest)

Forecast	Observed		
	Yes	No	Total
Yes	a (Hit)	b (False alarm)	a+b
No	c (Miss)	d (Correct rejection)	c+d
Total	a+c	b+d	a+b+c+d=n

Hit rate=a/(a+c)
False alarm rate=b/(b+d)
ROC curve: plot of hit versus false-alarm rates for various prob. thresholds

Important points to remember

- The area under the ROC curve will tell us the probability of successfully discriminating an event from a non event. In other words, how different the forecast probabilities are for events and non events
- As events and non-events are binary (i.e have 2 possible outcomes) the probability of correctly discriminating (distinguishing) and event from a non-event by change (guessing) is 50% and is represented by the area below the 45 degrees diagonal line in the ROC plot
- ROC is not sensitive to biases in the forecasts
- Forecast biases are diagnosed with the reliability diagram

Example: 3 category probabilistic forecasts

October NIÑO3 forecasts from five DEMETER models produced in the precious May, together with observed anomalies for the 20 years, 1982-2001. The observed NIÑO3 anomalies are indicated in column 2 and classified as El Niño (E), neutral (N), and La Niña (L).

•The forecasts are presented as probabilities based on a simple count of five DEMETER models.
• Sum of fcts probs E+N+L is 100%.
• Forecast probabilities for each category are assessed separately (i.e. each column of forecast probabilities for El Niño, Neutral and La Niña is assessed separately).
• Each fcst probability column is compared to obs column

			Probabilities of October NIÑO3 produced in the previous May		
Year	Observed		El Niño (E)	Neutral (N)	La Niña (L)
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥0

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥0

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥0

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =5/5=1

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	Observed		El Niño	Neutral	La Niña
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥0

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =5/5=1

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

F =15/15=1

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥20

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥20

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =4/5=0.8

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥20

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =4/5=0.8

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

F =5/15=0.33

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥40

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥40

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =4/5=0.8

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	Observed		El Niño	Neutral	La Niña
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥40

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =4/5=0.8

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

F =3/15=0.2

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥60

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥60

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =3/5=0.6

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥60

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =3/5=0.6

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

F =0/15=0

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥80

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥80

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =3/5=0.6

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	Observed		El Niño	Neutral	La Niña
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥80

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =3/5=0.6

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

F =0/15=0

			Probabilities of October NIÑO3		
Year	Observed		El Niño	Neutral	La Niña
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥100

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥100

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

H =2/5=0.4

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed El Ninos: 5

Non Obs El Ninos: 15

Prob≥100

$$H = \frac{\text{Hits}}{\text{Observed El Ninos}}$$

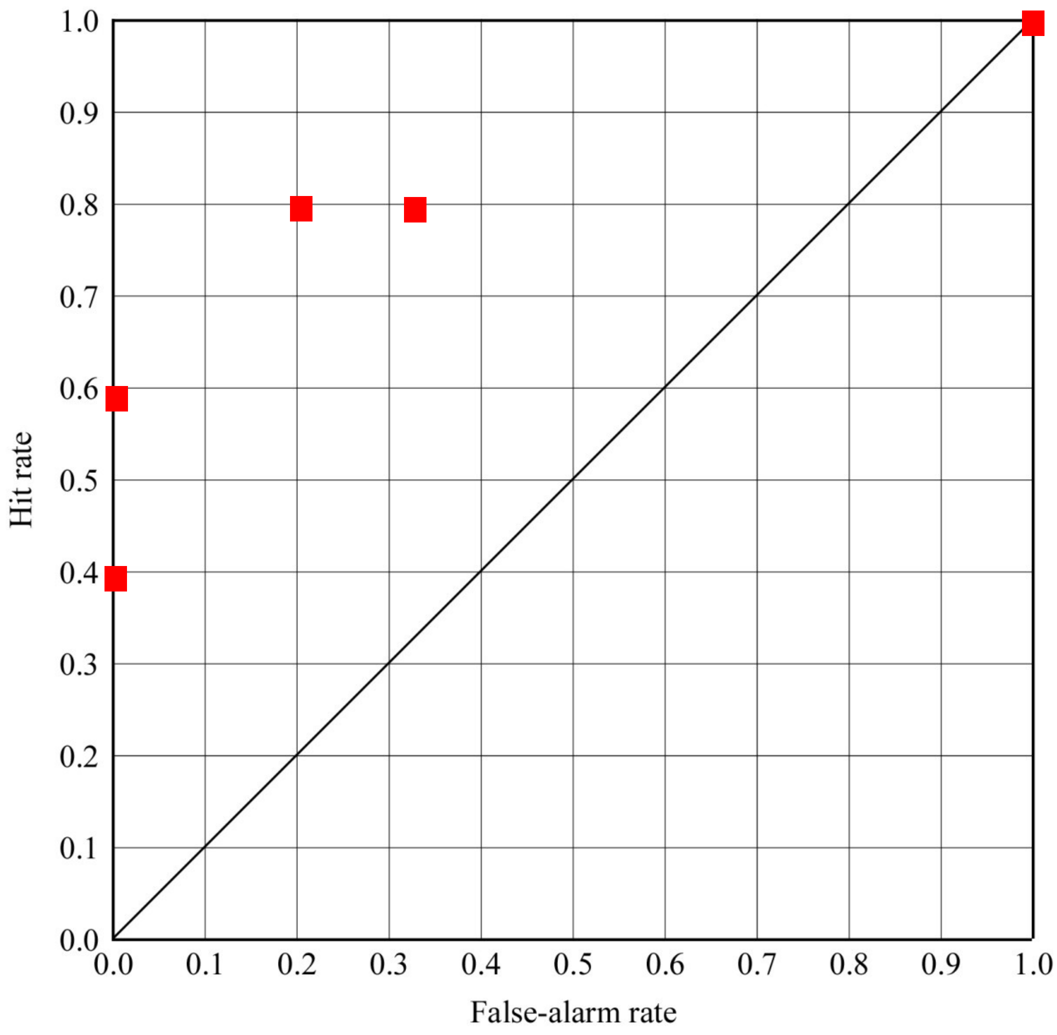
H =2/5=0.4

$$F = \frac{\text{False alarms}}{\text{Non Obs El Ninos}}$$

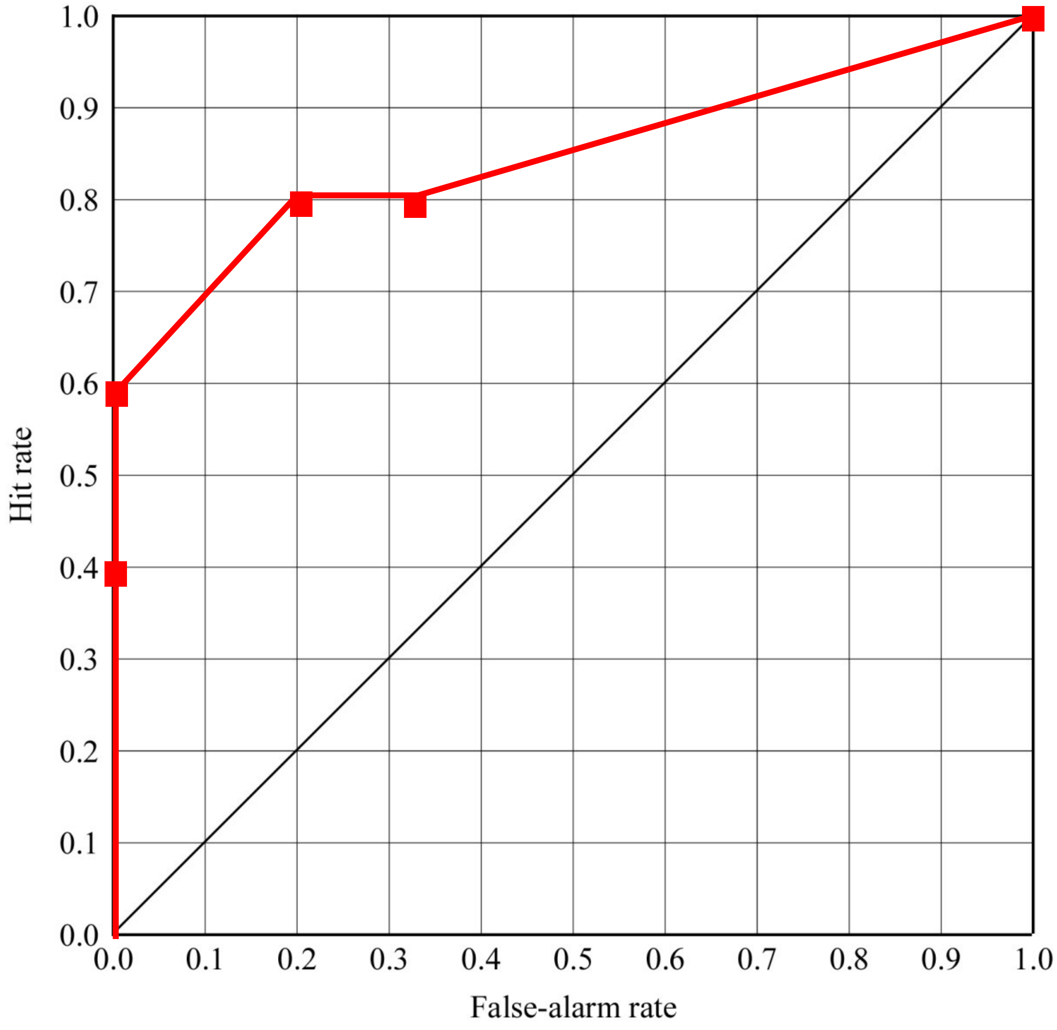
F =0/15=0

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Warning	El Niño		Neutral		La Niña	
	H	F	H	F	H	F
≥ 100%	2/5=0.4	0/15=0	0/10=0	0/10=0	0/5=0	2/15=0.13
≥ 80%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	2/5=0.4	6/15=0.4
≥ 60%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	5/5=1	10/15=0.66
≥ 40%	4/5=0.8	3/15=0.2	2/10=0.2	3/10=0.3	5/5=1	11/15=0.73
≥ 20%	4/5=0.8	5/15=0.33	5/10=0.5	5/10=0.5	5/5=1	13/15=0.86
≥ 0%	5/5=1	15/15=1	10/10=1	10/10=1	5/5=1	15/15=1

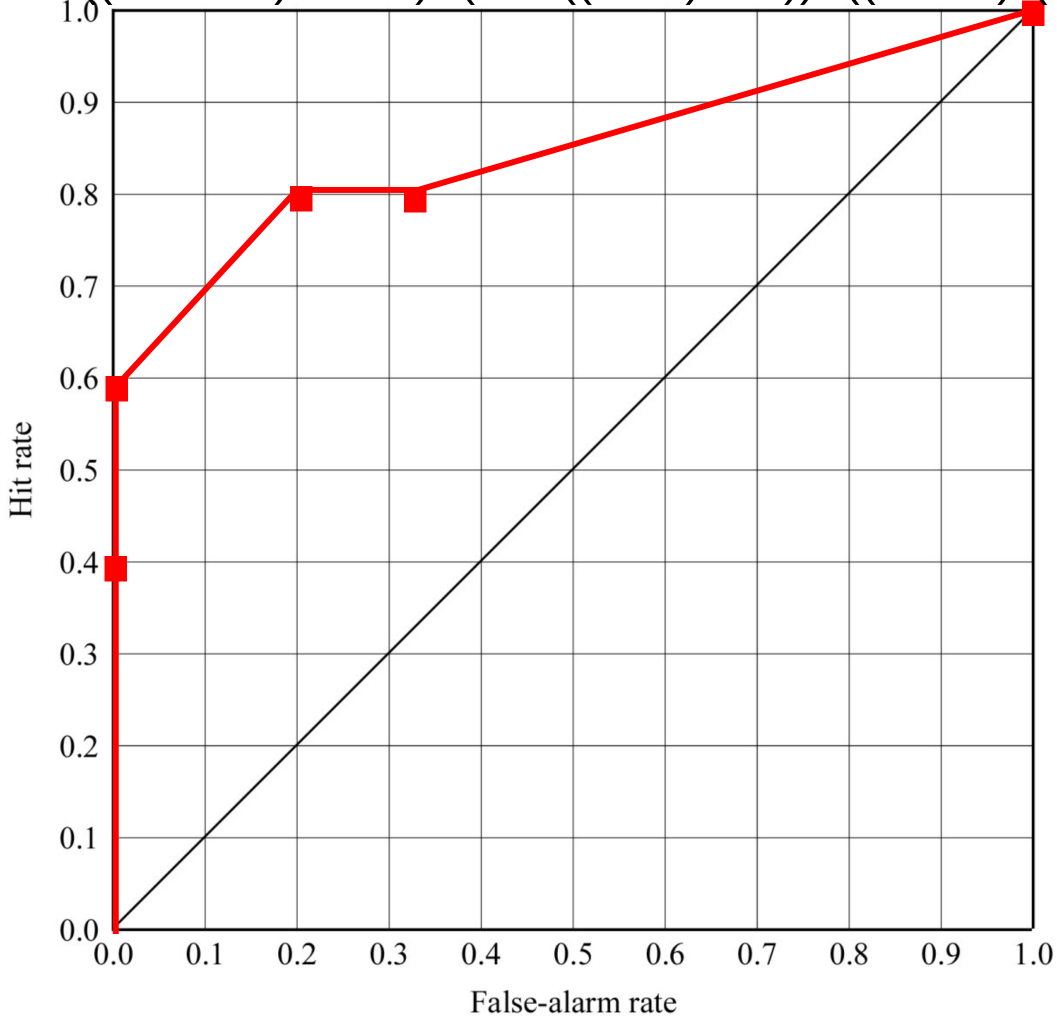


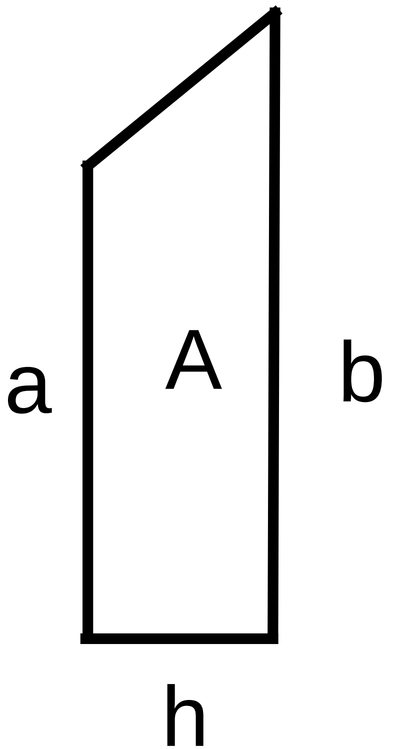
Warning	El Niño		Neutral		La Niña	
	H	F	H	F	H	F
≥ 100%	2/5=0.4	0/15=0	0/10=0	0/10=0	0/5=0	2/15=0.13
≥ 80%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	2/5=0.4	6/15=0.4
≥ 60%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	5/5=1	10/15=0.66
≥ 40%	4/5=0.8	3/15=0.2	2/10=0.2	3/10=0.3	5/5=1	11/15=0.73
≥ 20%	4/5=0.8	5/15=0.33	5/10=0.5	5/10=0.5	5/5=1	13/15=0.86
≥ 0%	5/5=1	15/15=1	10/10=1	10/10=1	5/5=1	15/15=1



Warning	El Niño		Neutral		La Niña	
	H	F	H	F	H	F
≥ 100%	2/5=0.4	0/15=0	0/10=0	0/10=0	0/5=0	2/15=0.13
≥ 80%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	2/5=0.4	6/15=0.4
≥ 60%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	5/5=1	10/15=0.66
≥ 40%	4/5=0.8	3/15=0.2	2/10=0.2	3/10=0.3	5/5=1	11/15=0.73
≥ 20%	4/5=0.8	5/15=0.33	5/10=0.5	5/10=0.5	5/5=1	13/15=0.86
≥ 0%	5/5=1	15/15=1	10/10=1	10/10=1	5/5=1	15/15=1

ROC area=((0.8+0.6)*0.2/2)+(0.8*((5/15)-0.2))+((1+0.8)*(1-(5/15))/2)=0.85





Area A = (a+b)*h/2

Observed Neutral: 10

Non Obs Neutral: 10

Prob≥0

$$H = \frac{\text{Hits}}{\text{Observed Neutral}}$$

H =10/10=1

$$F = \frac{\text{False alarms}}{\text{Non Obs Neutral}}$$

F =10/10=1

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed Neutral: 10

Non Obs Neutral: 10

Prob≥20

$$H = \frac{\text{Hits}}{\text{Observed Neutral}}$$

H =5/10=0.5

$$F = \frac{\text{False alarms}}{\text{Non Obs Neutral}}$$

F =5/10=0.5

			Probabilities of October NIÑO3		
Year	Observed		El Niño	Neutral	La Niña
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed Neutral: 10

Non Obs Neutral: 10

Prob≥40

$$H = \frac{\text{Hits}}{\text{Observed Neutral}}$$

H =2/10=0.2

$$F = \frac{\text{False alarms}}{\text{Non Obs Neutral}}$$

F =3/10=0.3

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed Neutral: 10

Non Obs Neutral: 10

Prob≥60

$$H = \frac{\text{Hits}}{\text{Observed Neutral}}$$

H =1/10=0.1

$$F = \frac{\text{False alarms}}{\text{Non Obs Neutral}}$$

F =0/10=0

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed Neutral: 10

Non Obs Neutral: 10

Prob≥80

$$H = \frac{\text{Hits}}{\text{Observed Neutral}}$$

H =1/10=0.1

$$F = \frac{\text{False alarms}}{\text{Non Obs Neutral}}$$

F =0/10=0

			Probabilities of October NIÑO3		
Year	Observed		El Niño	Neutral	La Niña
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed Neutral: 10

Non Obs Neutral: 10

Prob≥100

$$H = \frac{\text{Hits}}{\text{Observed Neutral}}$$

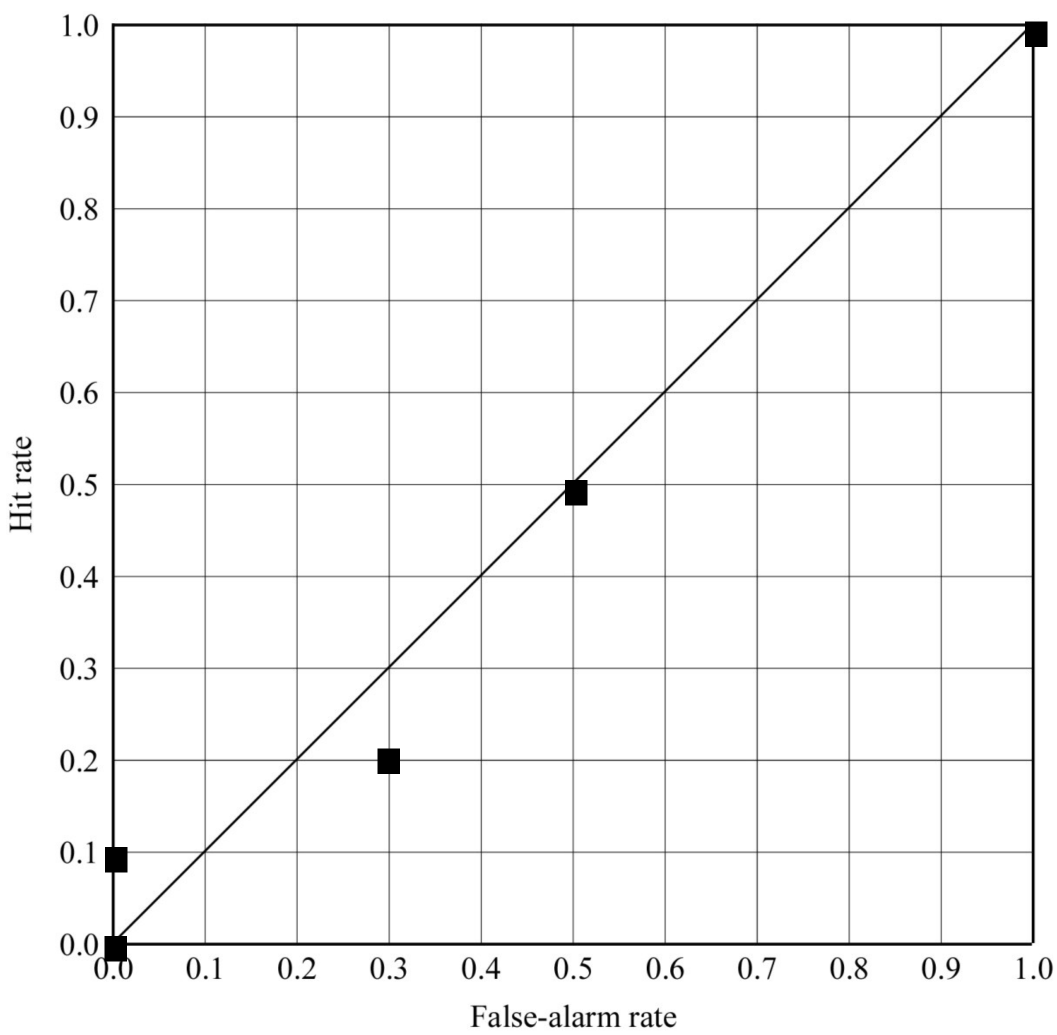
H =0/10=0

$$F = \frac{\text{False alarms}}{\text{Non Obs Neutral}}$$

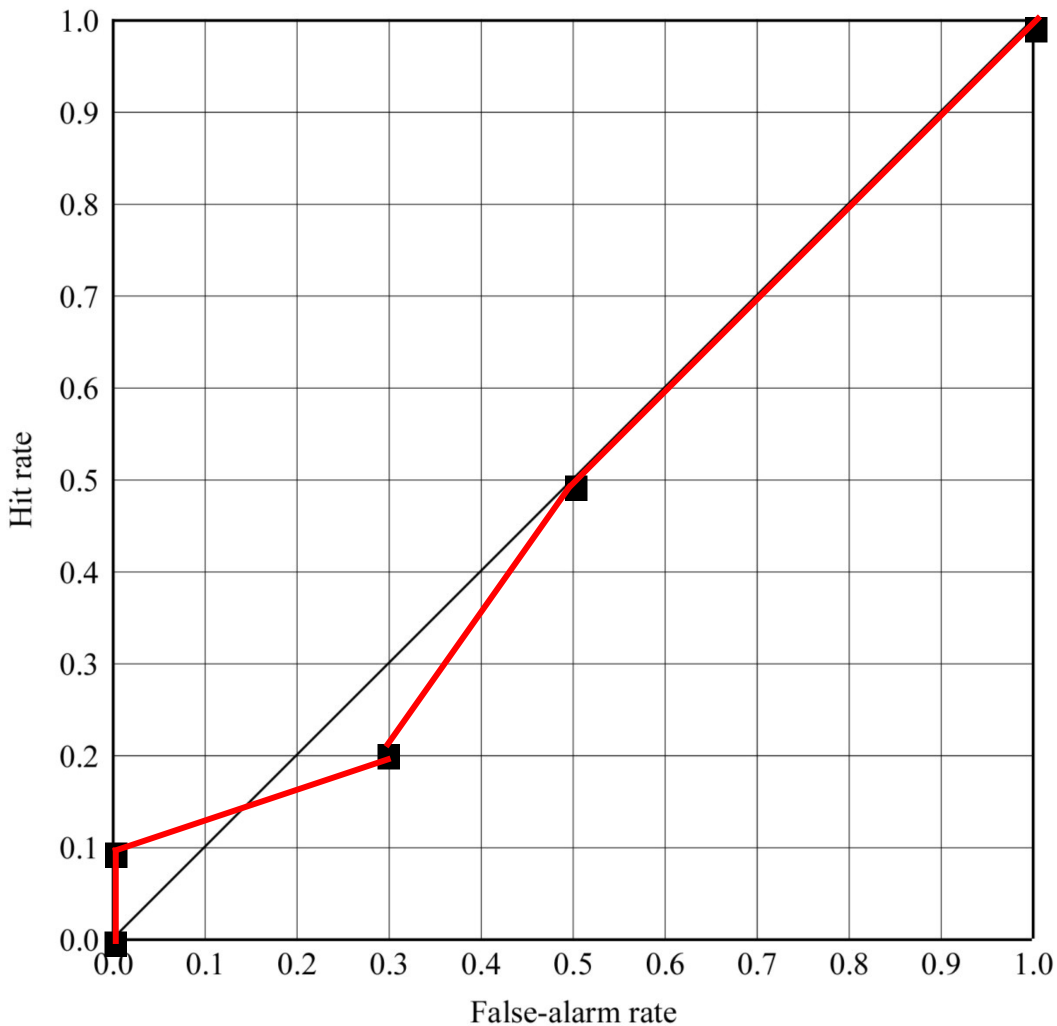
F =0/10=0

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Warning	El Niño		Neutral		La Niña	
	H	F	H	F	H	F
≥ 100%	2/5=0.4	0/15=0	0/10=0	0/10=0	0/5=0	2/15=0.13
≥ 80%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	2/5=0.4	6/15=0.4
≥ 60%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	5/5=1	10/15=0.66
≥ 40%	4/5=0.8	3/15=0.2	2/10=0.2	3/10=0.3	5/5=1	11/15=0.73
≥ 20%	4/5=0.8	5/15=0.33	5/10=0.5	5/10=0.5	5/5=1	13/15=0.86
≥ 0%	5/5=1	15/15=1	10/10=1	10/10=1	5/5=1	15/15=1

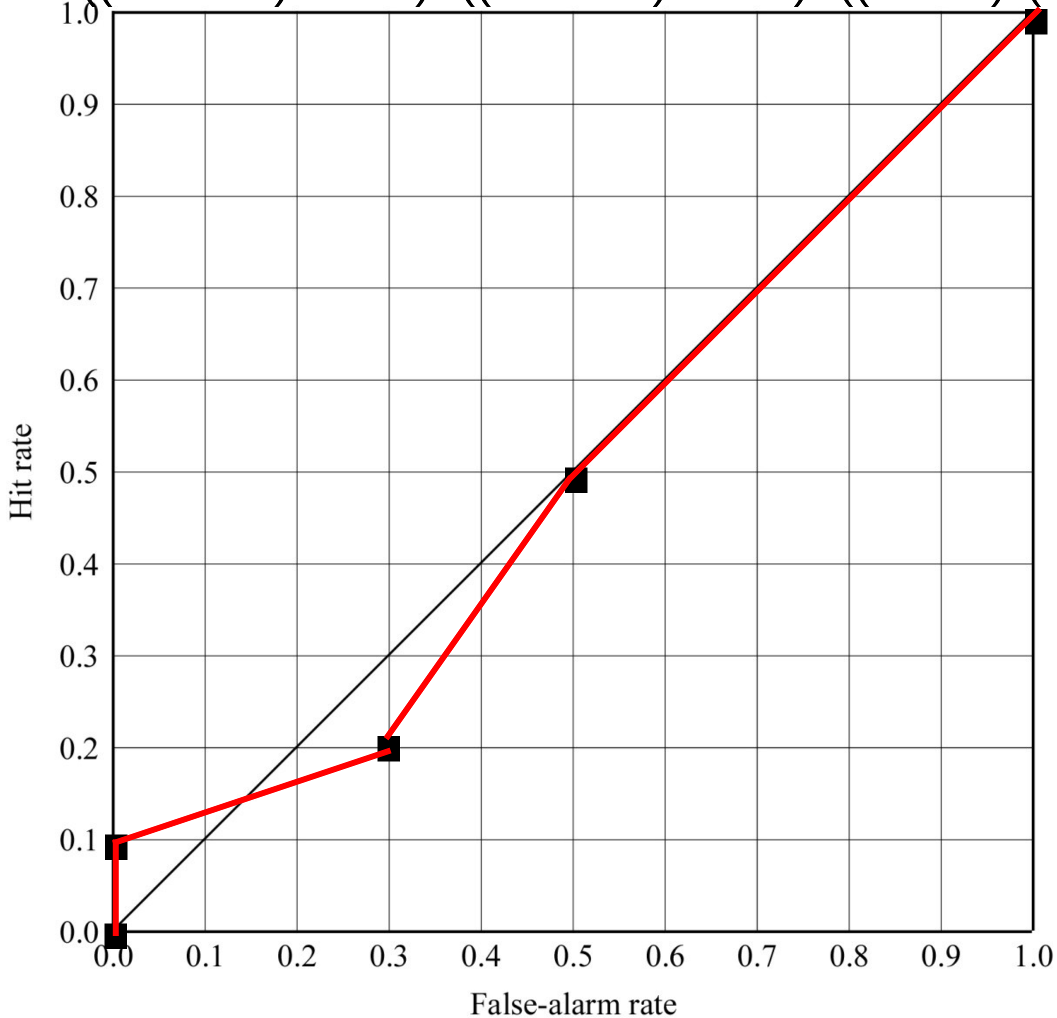


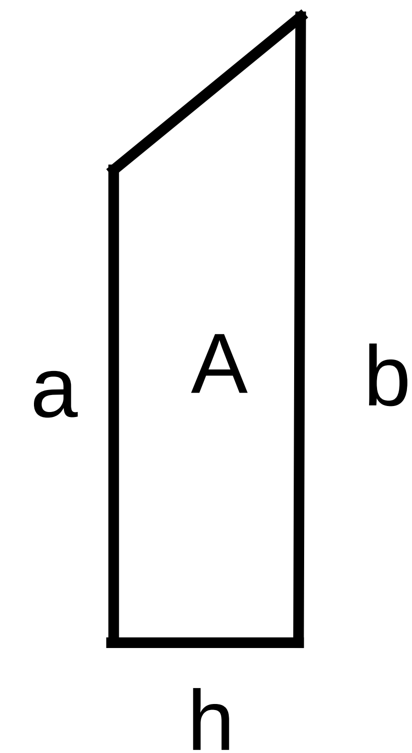
Warning	El Niño		Neutral		La Niña	
	H	F	H	F	H	F
≥ 100%	2/5=0.4	0/15=0	0/10=0	0/10=0	0/5=0	2/15=0.13
≥ 80%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	2/5=0.4	6/15=0.4
≥ 60%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	5/5=1	10/15=0.66
≥ 40%	4/5=0.8	3/15=0.2	2/10=0.2	3/10=0.3	5/5=1	11/15=0.73
≥ 20%	4/5=0.8	5/15=0.33	5/10=0.5	5/10=0.5	5/5=1	13/15=0.86
≥ 0%	5/5=1	15/15=1	10/10=1	10/10=1	5/5=1	15/15=1



Warning	El Niño		Neutral		La Niña	
	H	F	H	F	H	F
≥ 100%	2/5=0.4	0/15=0	0/10=0	0/10=0	0/5=0	2/15=0.13
≥ 80%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	2/5=0.4	6/15=0.4
≥ 60%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	5/5=1	10/15=0.66
≥ 40%	4/5=0.8	3/15=0.2	2/10=0.2	3/10=0.3	5/5=1	11/15=0.73
≥ 20%	4/5=0.8	5/15=0.33	5/10=0.5	5/10=0.5	5/5=1	13/15=0.86
≥ 0%	5/5=1	15/15=1	10/10=1	10/10=1	5/5=1	15/15=1

ROC area=((0.2+0.1)*0.3/2)+((0.5+0.2)*0.2/2)+((1+0.5)*(0.5/2))=0.49





Area A = (a+b)*h/2

Observed La Nina: 5

Non Obs La Nina: 15

Prob≥0

$$H = \frac{\text{Hits}}{\text{Observed La Nina}}$$

H =5/5=1

$$F = \frac{\text{False alarms}}{\text{Non Obs La Nina}}$$

F =15/15=1

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed La Nina: 5

Non Obs La Nina: 15

Prob≥20

$$H = \frac{\text{Hits}}{\text{Observed La Nina}}$$

H =5/5=1

$$F = \frac{\text{False alarms}}{\text{Non Obs La Nina}}$$

F =13/15=0.86

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed La Nina: 5

Non Obs La Nina: 15

Prob≥40

$$H = \frac{\text{Hits}}{\text{Observed La Nina}}$$

H =5/5=1

$$F = \frac{\text{False alarms}}{\text{Non Obs La Nina}}$$

F =11/15=0.73

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed La Nina: 5

Non Obs La Nina: 15

Prob≥60

$$H = \frac{\text{Hits}}{\text{Observed La Nina}}$$

H =5/5=1

$$F = \frac{\text{False alarms}}{\text{Non Obs La Nina}}$$

F =10/15=0.66

			Probabilities of October NIÑO3		
Year	Observed		El Niño	Neutral	La Niña
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed La Nina: 5

Non Obs La Nina: 15

Prob≥80

$$H = \frac{\text{Hits}}{\text{Observed La Nina}}$$

H =2/5=0.4

$$F = \frac{\text{False alarms}}{\text{Non Obs La Nina}}$$

F =6/15=0.4

			Probabilities of October NIÑO3		
Year	**Observed**		**El Niño**	**Neutral**	**La Niña**
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Observed La Nina: 5

Non Obs La Nina: 15

Prob≥100

$$H = \frac{\text{Hits}}{\text{Observed La Nina}}$$

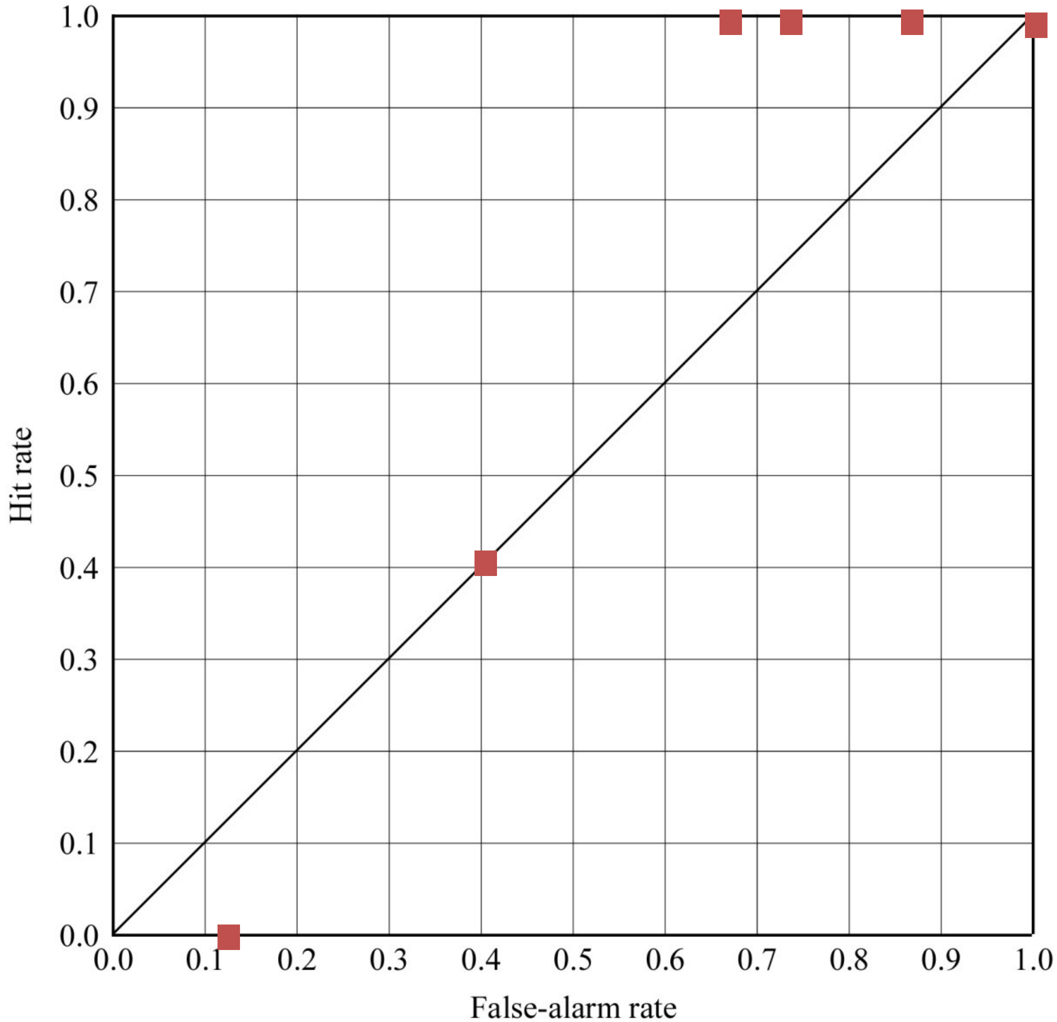
H =0/5=0

$$F = \frac{\text{False alarms}}{\text{Non Obs La Nina}}$$

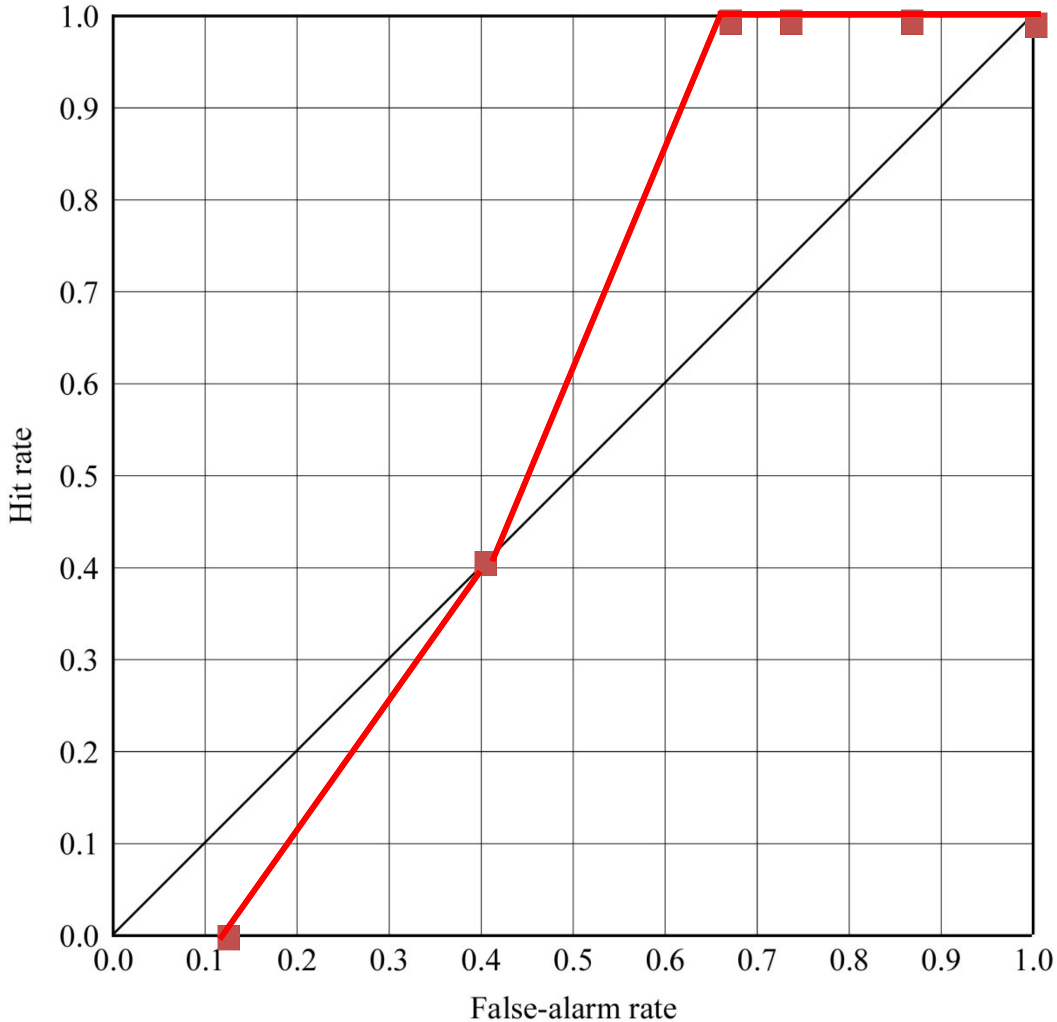
F =2/15=0.13

			Probabilities of October NIÑO3		
Year	Observed		El Niño	Neutral	La Niña
1981	-0.23	N	0	40	60
1982	2.07	E	100	0	0
1983	-0.21	N	0	0	100
1984	-0.84	L	0	20	80
1985	-0.82	L	0	20	80
1986	0.55	E	0	0	100
1987	1.28	E	80	0	20
1988	-1.62	L	0	40	60
1989	-0.41	N	20	0	80
1990	-0.10	N	40	20	40
1991	0.62	E	40	0	60
1992	-0.33	N	40	0	60
1993	0.24	N	40	0	60
1994	0.47	N	0	20	80
1995	-0.86	L	0	40	60
1996	-0.49	N	0	20	80
1997	3.02	E	100	0	0
1998	-0.71	N	0	80	20
1999	-1.09	L	0	40	60
2000	-0.54	N	20	0	80

Warning	El Niño		Neutral		La Niña	
	H	F	H	F	H	F
≥ 100%	2/5=0.4	0/15=0	0/10=0	0/10=0	0/5=0	2/15=0.13
≥ 80%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	2/5=0.4	6/15=0.4
≥ 60%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	5/5=1	10/15=0.66
≥ 40%	4/5=0.8	3/15=0.2	2/10=0.2	3/10=0.3	5/5=1	11/15=0.73
≥ 20%	4/5=0.8	5/15=0.33	5/10=0.5	5/10=0.5	5/5=1	13/15=0.86
≥ 0%	5/5=1	15/15=1	10/10=1	10/10=1	5/5=1	15/15=1

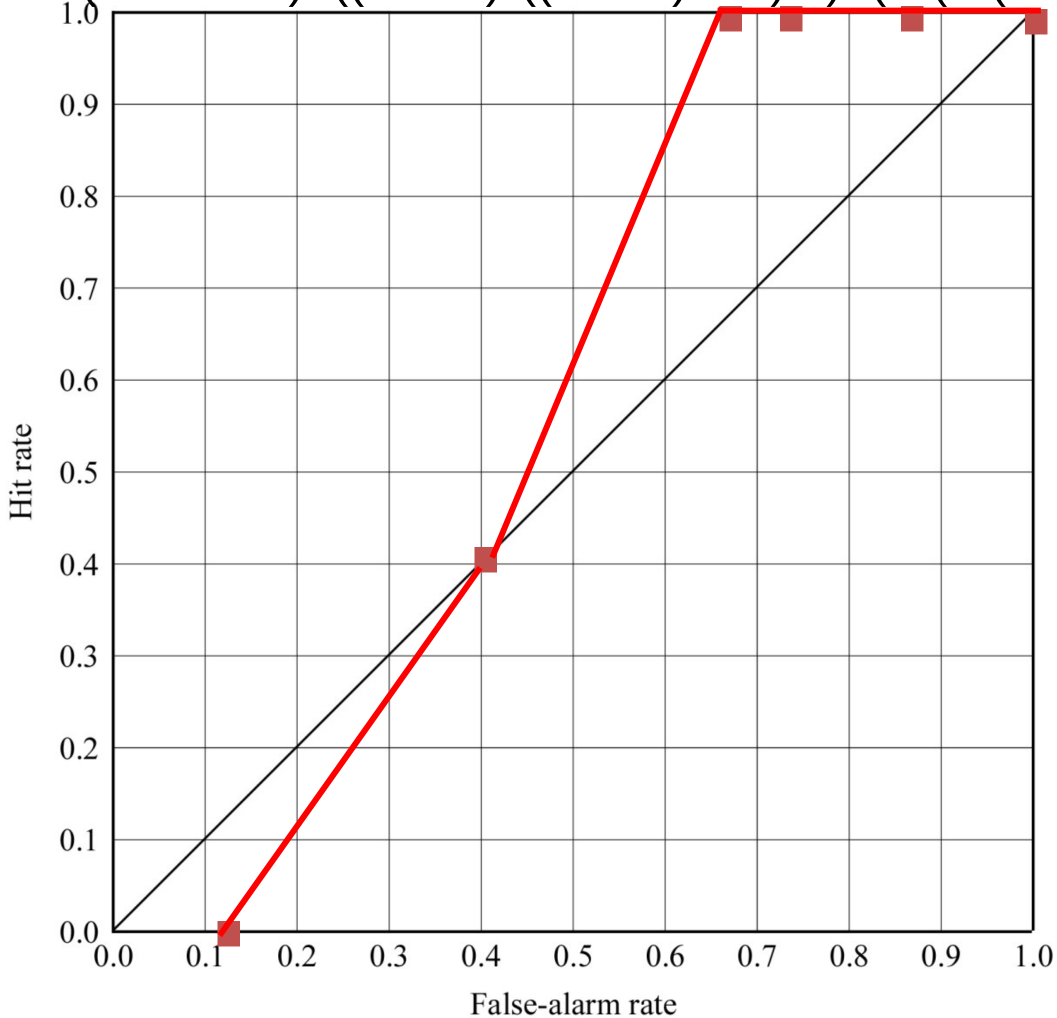


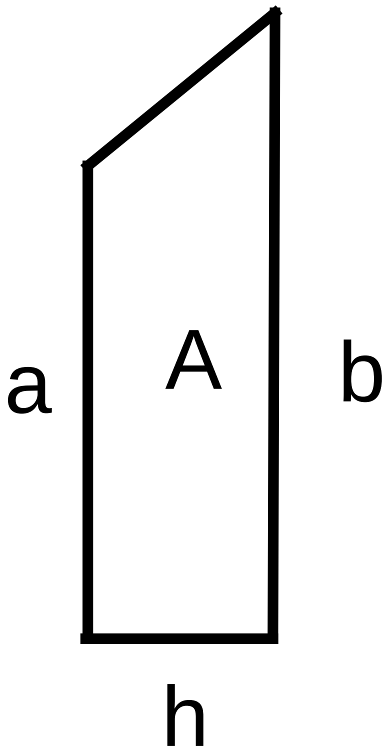
Warning	El Niño		Neutral		La Niña	
	H	F	H	F	H	F
≥ 100%	2/5=0.4	0/15=0	0/10=0	0/10=0	0/5=0	2/15=0.13
≥ 80%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	2/5=0.4	6/15=0.4
≥ 60%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	5/5=1	10/15=0.66
≥ 40%	4/5=0.8	3/15=0.2	2/10=0.2	3/10=0.3	5/5=1	11/15=0.73
≥ 20%	4/5=0.8	5/15=0.33	5/10=0.5	5/10=0.5	5/5=1	13/15=0.86
≥ 0%	5/5=1	15/15=1	10/10=1	10/10=1	5/5=1	15/15=1



Warning	El Niño		Neutral		La Niña	
	H	F	H	F	H	F
≥ 100%	2/5=0.4	0/15=0	0/10=0	0/10=0	0/5=0	2/15=0.13
≥ 80%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	2/5=0.4	6/15=0.4
≥ 60%	3/5=0.6	0/15=0	1/10=0.1	0/10=0	5/5=1	10/15=0.66
≥ 40%	4/5=0.8	3/15=0.2	2/10=0.2	3/10=0.3	5/5=1	11/15=0.73
≥ 20%	4/5=0.8	5/15=0.33	5/10=0.5	5/10=0.5	5/5=1	13/15=0.86
≥ 0%	5/5=1	15/15=1	10/10=1	10/10=1	5/5=1	15/15=1

ROC area=(0.4*0.3/2)+((1+0.4)*((10/15)-0.4)/2)+(1*(1-(10/15)))=0.58





Area A = (a+b)*h/2

Exercise 2:

Read data file equatorialpacificsst.txt which contains forecast probabilities for the event Eq. Pac. SST>0 and the corresponding binary observations

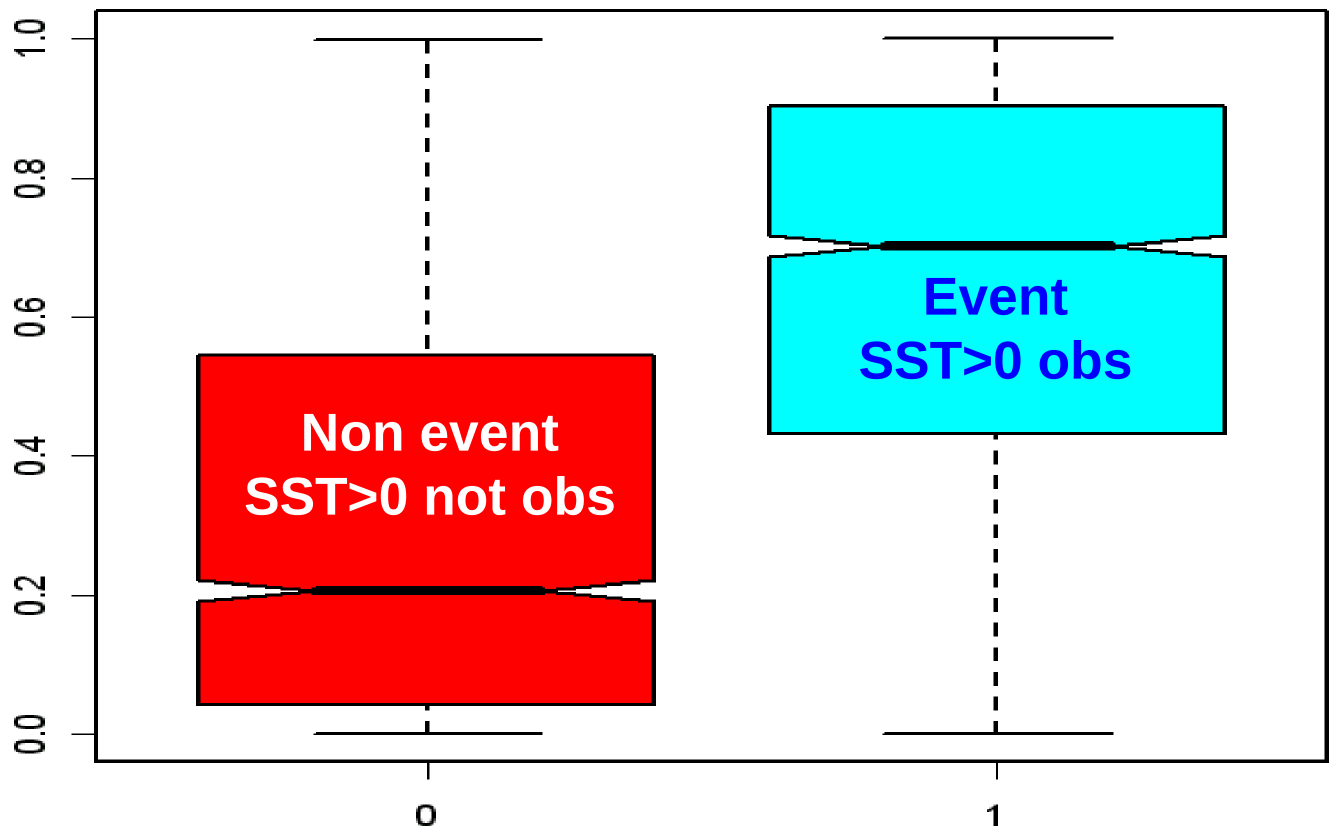
data<-read.table(“equatorialpacificsst.txt”)

#1st column contains forecast probabilities

#2nd column contains binary observations

Prob. forecasts conditioned/stratified on observations

Forecast probability Pr(SST>0)



Observed binary event X

→ Forecasts do differ given different outcomes
→ Forecast system has discrimination (distinguish eve

Reproducing the previous plot

1) Stratify forecast probabilities p (1st column of data) on observed (1) and not observed (0) binary events (2nd column od data)

```
d1 #object containing strat of p on not observed event
> d1<-data[data[,2]==0,1]
d2 #object containing strat of p on observed event
> d2<-data[data[,2]==1,1]
```

2) Produce a boxplot using the command

```
> boxplot(d1,d2,col=c(2,5),notch=T,names=c(0,1))
```

```
# extract only forecast/obs pairs with p >=0.9
p<-0.9
# forecast events
f<-data[data[,1]>=p,]
a<-sum(f[,2]==1) #forecast and observed (hit)
b<-sum(f[,2]==0) #forecast and not observed (false alarm)
# not forecast events
g<-data[data[,1]<p,]
c<-sum(g[,2]==1) #not forecast and observed (miss)
d<-sum(g[,2]==0) #not fcst and not obs (correct rejection)
n<-a+b+c+d
hr<-a/(a+c)
far<-b/(b+d)
```

```
#Plot first point of the ROC curve
par(pty='s',las=1)
plot(far,hr,type="p",pch=16,xlim=c(0,1),ylim=c(0,1),xlab="False alarm rate",ylab="Hit rate")
abline(0,1)
```

```
#repeat the same procedure for p>=0.8

#extract only forecast/obs pairs with p >=0.8
p<-0.8
# forecast events
f<-data[data[,1]>=p,]
a<-sum(f[,2]==1) #forecast and observed (hit)
b<-sum(f[,2]==0) #forecast and not observed (false alarm)
# not forecast events
g<-data[data[,1]<p,]
c<-sum(g[,2]==1) #not forecast and observed (miss)
d<-sum(g[,2]==0) #not fcst and not obs (correct rejection)
n<-a+b+c+d
hr<-a/(a+c)
far<-b/(b+d)
```

```
#Plot new point in the ROC curve
points(far,hr,pch=16)

#repeat the same procedure for p>=0.7, p>=0.6, p>=0.5,
#p>=0.4, p>=0.3, p>=0.2 and p>=0.1 adding the new points
#in the ROC curve. Try later to do this using a for loop.

#The area below the curve that joins all points (the ROC
#area) is a measure of discrimination.
#ROC area values equal 0.5 indicate no discrimination ability.
#ROC area values equal to 1 indicate perfect discrimination.
#ROC area values equal to 0 indicate perfectly bad
#discrimination.
```

```
#Constructing the empirical ROC curve

#find unique forecast probability values
p<-unique(data[,1])
#sort unique fcst prob values from largest to smallest
p<-rev(sort(p))
#define vectors to store hit and false-alarm rates
hr<-rep(NA,length(p)+2)
far<-rep(NA,length(p)+2)
#set first and last point in the ROC curve to (0,0) and (1,1)
hr[1]<-0
far[1]<-0
hr[length(p)+2]<-1
far[length(p)+2]<-1
```

```
#compute hit and false alarm rates for all fcst prob thresholds
for (i in 1:length(p)){
f<-data[data[,1]>=p[i],] #forecast events
a<-sum(f[,2]==1) #hit
b<-sum(f[,2]==0) #false alarm
g<-data[data[,1]<p[i],] # not forecast events
c<-sum(g[,2]==1) #miss
d<-sum(g[,2]==0) #correct rejection
hr[i+1]<-a/(a+c)
far[i+1]<-b/(b+d)
}
#plot empirical ROC curve
par(pty='s',las=1)
plot(far,hr,type="l",xlim=c(0,1),ylim=c(0,1),xlab="False alarm
rate",ylab="Hit rate")
abline(0,1)
```

```
#plot roc curve with verification package for comparison
x11()
roc.plot(data[,2],data[,1])

#compute area under empirical ROC curve
dif<-diff(far)
area<-sum(0.5*(hr[1:((length(hr)-1))]+hr[2:length(hr)])*dif)

#compute ROC area using the verification package
roc.area(data[,2],data[,1])

#The ROC skill score is defined as (2*ROC area)-1
#so that positive values indicate good discrimination skill
#and negative values indicate bad discrimination skill
rss<-2*area-1
```