The MJO, Equatorial Waves, and TCs over the South Indian Ocean: Their Associations and use for Prediction

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Introduction and motivation

The importance of the MJO and convectively-coupled equatorial waves (CCEWs) for modulating tropical convective activity has become increasingly apparent.

(e.g. Takayabu 1994; Wheeler and Kiladis 1999; Masunaga et al. 2006; TOGA-COARE experiment; TRMM-KWAJEX; MISMO)

Strong modulation of tropical cyclones (TCs) by the MJO and CCEWs is also often apparent in many ocean basins.

- But, how strong is this modulation, in general, for the south Indian Ocean basin?
- Which waves show a statistically-significant connection?
- How may this information be used for prediction?

Contents

We investigate these questions using observations, as described in the papers:

Bessafi, M., and M.C. Wheeler, 2006 (**BW06**): Modulation of south Indian Ocean tropical cyclones by the Madden-Julian oscillation and convectively-coupled equatorial waves. *Mon. Wea. Rev.*, 134, 638-656.

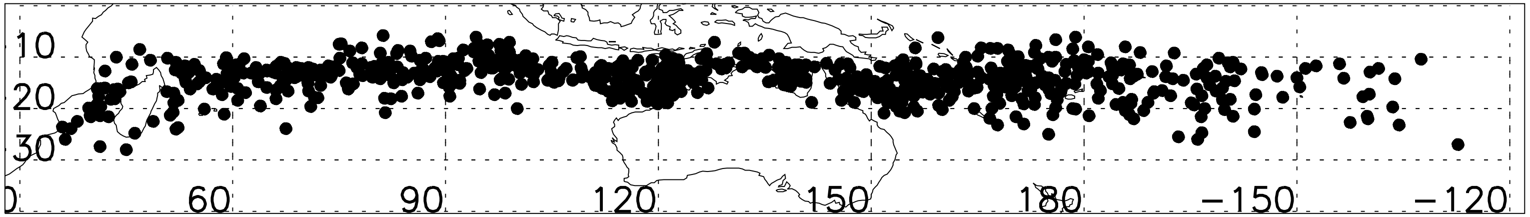
Leroy, A., and M.C. Wheeler, 2008 (**LW08**): Statistical prediction of weekly tropical cyclone activity in the Southern Hemisphere. *Mon. Wea. Rev.*, 136, 3637-3654.

BW06 was the first to document the MJO's modulation of TCs in the south Indian ocean, and also considered the role of convectively-coupled equatorial Rossby (ER) waves, Kelvin waves, and mixed Rossby-gravity (MRG) waves.

LW08 is the first to show the feasibility of intraseasonal TC activity prediction using the MJO, and apply it in real-time.

TC Data

TC genesis locations for TC season from 1 Nov to 30 Apr, 1969-2004.

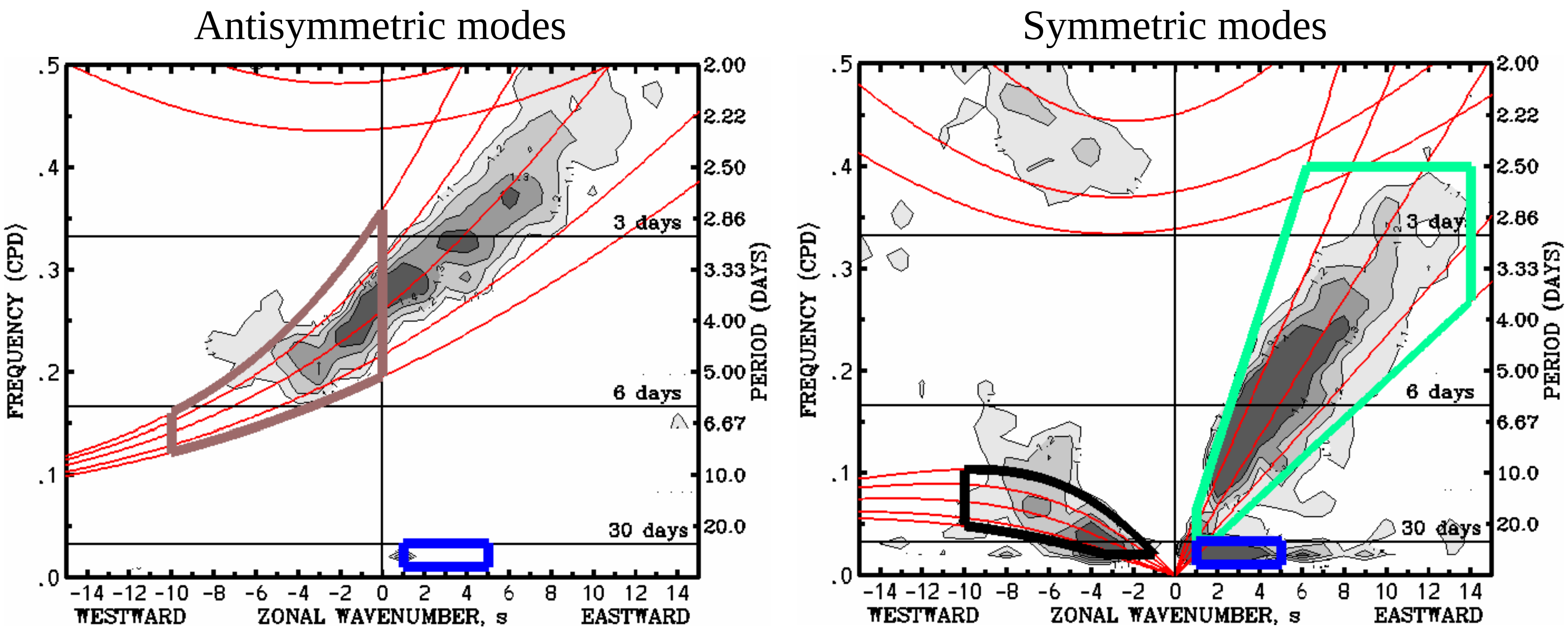


BW06 used subset of this data west of 100°E and 1979-2004.

LW08 used entire southern hemisphere.

Identification of the MJO and CCEWs

Step 1: Wavenumber-frequency filtering of symmetry-specified OLR.



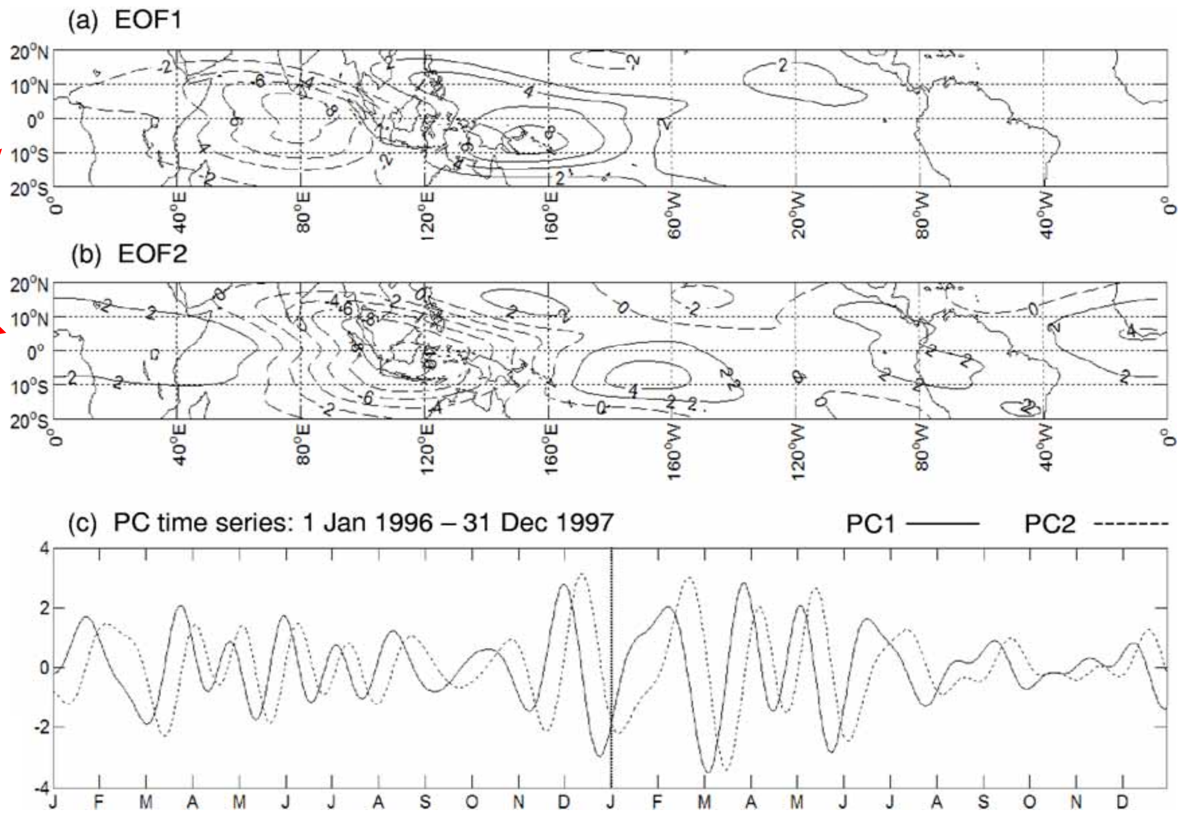
Identical to *Wheeler and Kiladis (1999)*

Step 2: EOF analysis applied over restricted domain.

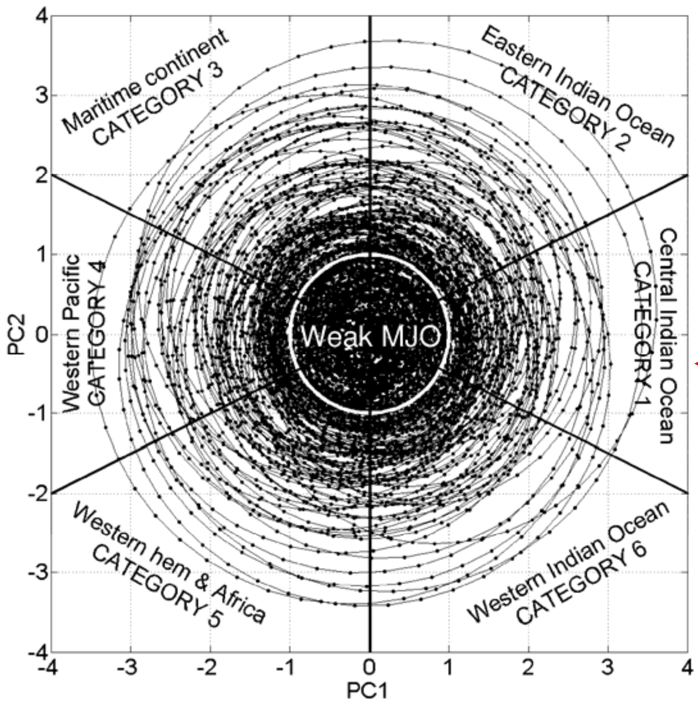
The Principal Component (PC) time series are then used as an index to provide category definitions for each wave.

E.g., for the MJO

EOFs computed for global tropical domain

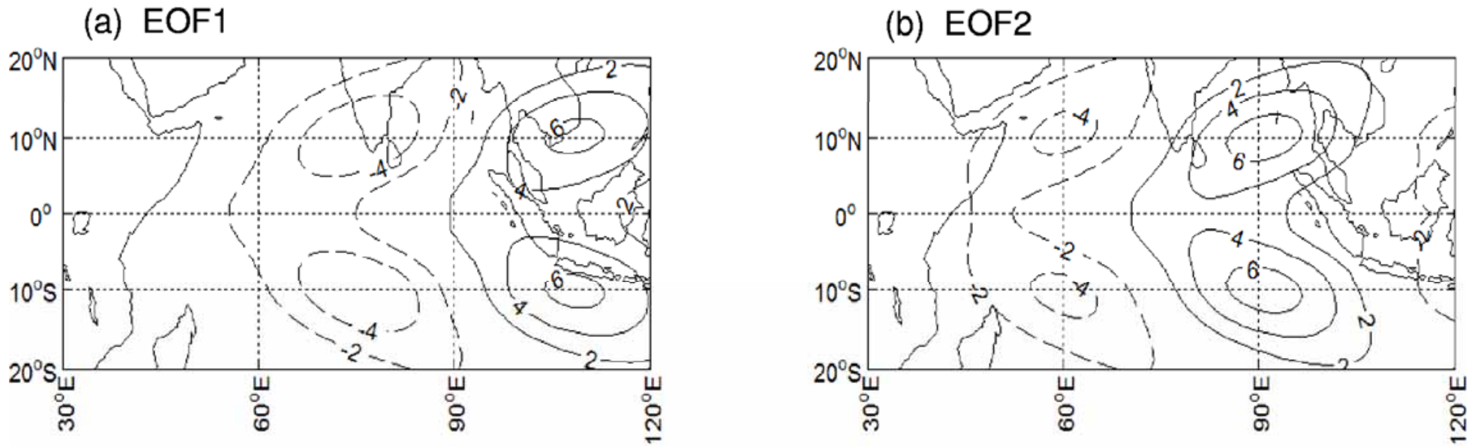


PC time series used to define 6 different MJO categories

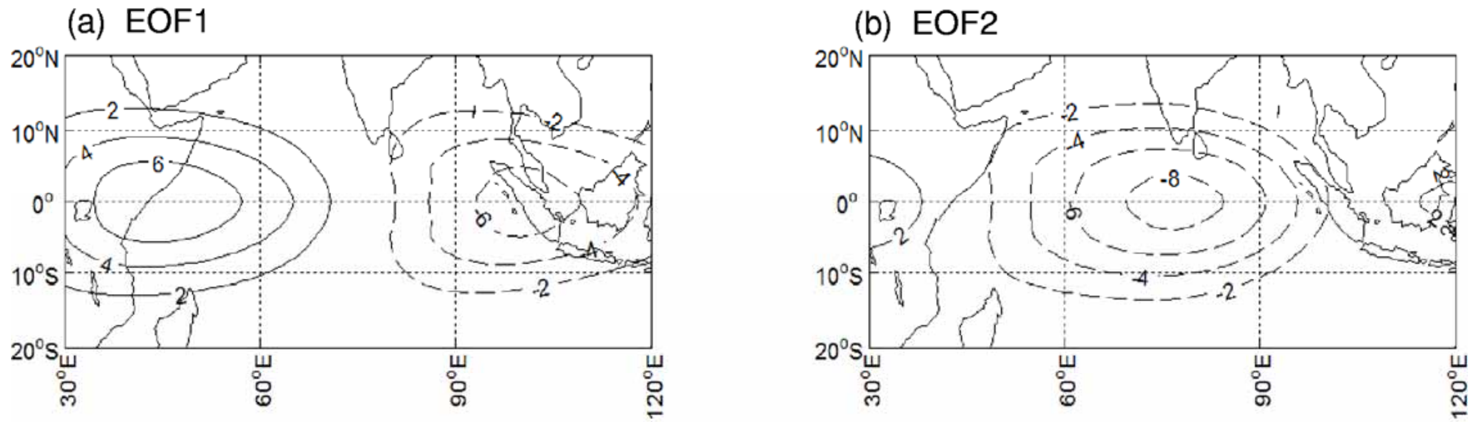


EOFs computed over Indian Ocean only for the other waves

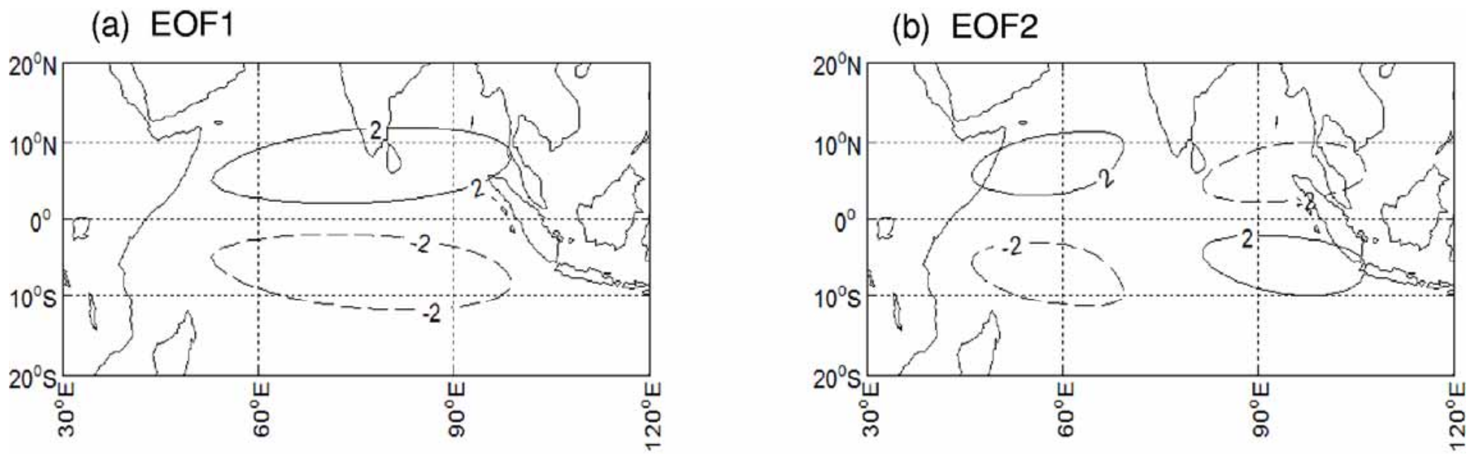
n=1 ER



Kelvin



MRG



Modulation results for south Indian Ocean region - BW06

MJO: large (~3:1) and significant

ER: large (~3:1) and significant

Kelvin: small (~2:1) but significant

MRG: not significant

MJO Category	MJO day Number	MJO day Percentage	TCs genesis Number	TCs genesis Percentage
1	523	11.4	25	4.8
2	566	12.3	40**	7.1**
3	528	11.5	19	3.6
4	519	11.3	22	4.2
5	515	11.2	14¤¤	2.7¤¤
6	508	11.1	24	4.7
0	1432	31.2	77	5.4
Total	4591	100	221	4.8

ER Category	ER day Number	ER day Percentage	TCs genesis Number	TCs genesis Percentage
1	463	10.1	35**	7.6**
2	441	9.6	18	4.1
3	460	10.0	19	4.1
4	462	10.1	13¤¤	2.8¤¤
5	457	10.0	19	4.2
6	455	9.9	20	4.4
0	1853	40.4	97	5.2
Total	4591	100	221	4.8

Kelvin Category	Kelvin day Number	Kelvin day Percentage	TCs genesis Number	TCs genesis Percentage
1	378	8.2	19	5.0
2	463	10.1	32**	6.9**
3	478	10.4	24	5.0
4	355	7.7	13	3.7
5	498	10.8	17	3.4
6	485	10.6	18	3.7
0	1934	42.1	98	5.1
Total	4591	100	221	4.8

MRG Category	MRG day Number	MRG day Percentage	TCs genesis Number	TCs genesis Percentage
1	430	9.4	19	4.4
2	439	9.6	25	5.7
3	442	9.6	26	5.9
4	442	9.6	22	5.0
5	442	9.6	21	4.8
6	444	9.7	19	4.3
0	1952	42.5	89	4.6
Total	4591	100	221	4.8

Categories where TC genesis numbers were significantly above (below) average at the 95% level are indicated by ** (¤¤).

Attribution of TC modulation

In BW06 we also considered the attribution of this TC modulation by studying the wave-composite fields of low-level vorticity, vertical wind shear, and OLR.

For the MJO, the vorticity and shear fields appeared most important.

For the ER wave, the OLR and vorticity fields appeared most important.

For the Kelvin and MRG waves, there was also consistency between their TC modulation and vorticity and OLR fields respectively.

Thus there appears to be no single factor that controls all subseasonal TC variability.

How may this information be used for TC prediction?

Showing that there is a contemporaneous relationship between the waves and TC activity is not enough. We must also take into account the predictability of the waves themselves.

The predictability limits suggested are:

MJO 20 days *(Waliser et al. 1999; Lo & Hendon 2000; Wheeler & Weickmann 2001…..)*

ER 7 days *(Wheeler & Weickmann 2001)*

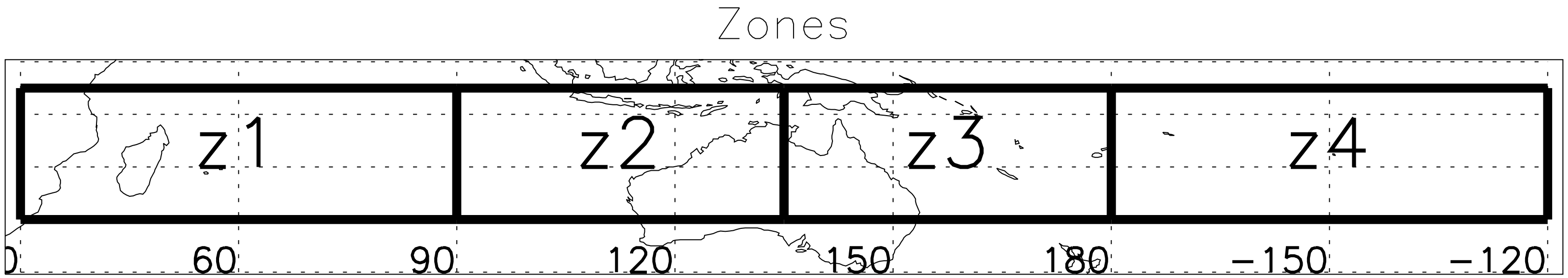
Kelvin 4 days *(Wheeler & Weickmann 2001)*

Thus, BW06 concluded that the MJO and ER waves were worthy of further examination for prediction on the weekly time scale.

Hence the motivation for our work in *Leroy and Wheeler (2008)* to predict the probability of TCs occurring in coming weeks.

Method of LW08

We examine the probability of formation (i.e. genesis) or occurrence (i.e. including the whole track) during each week (week 1, week 2, week 3, etc) in the following regions:



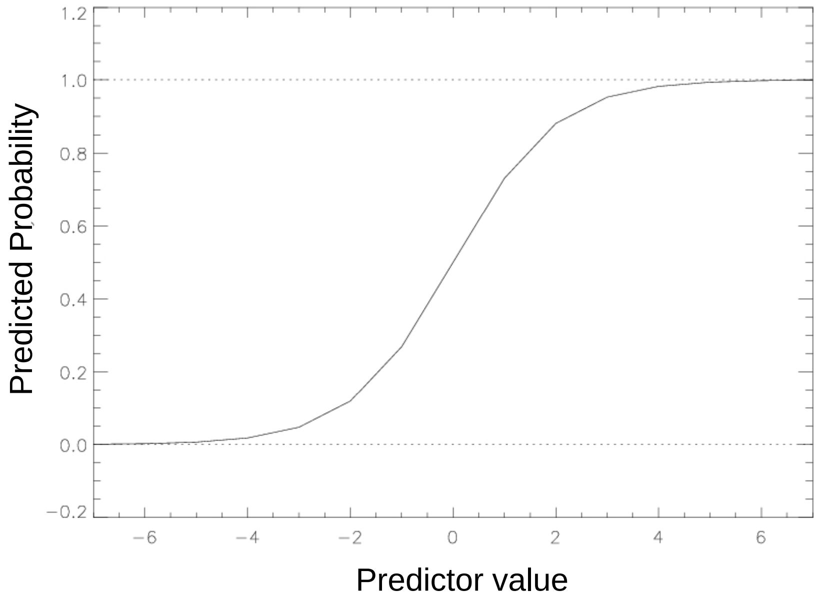
Method (continued)

We employ logistic regression:

$$\hat{P} = \frac{e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\ldots+\beta_m x_m}}{1+e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\ldots+\beta_m x_m}}$$

where $\hat{P}$ is the predicted probability of TC formation, and $(x_1,x_2,x_3,\ldots,x_m)$ are the multiple predictors.

Input observations are in the form of a binary probability that is assigned to be 0 if no TC genesis is observed during the week of interest, and 1 if a TC does form. The fitted coefficients (i.e. $\beta_0,\beta_1,\ldots,\beta_m$) are computed iteratively.



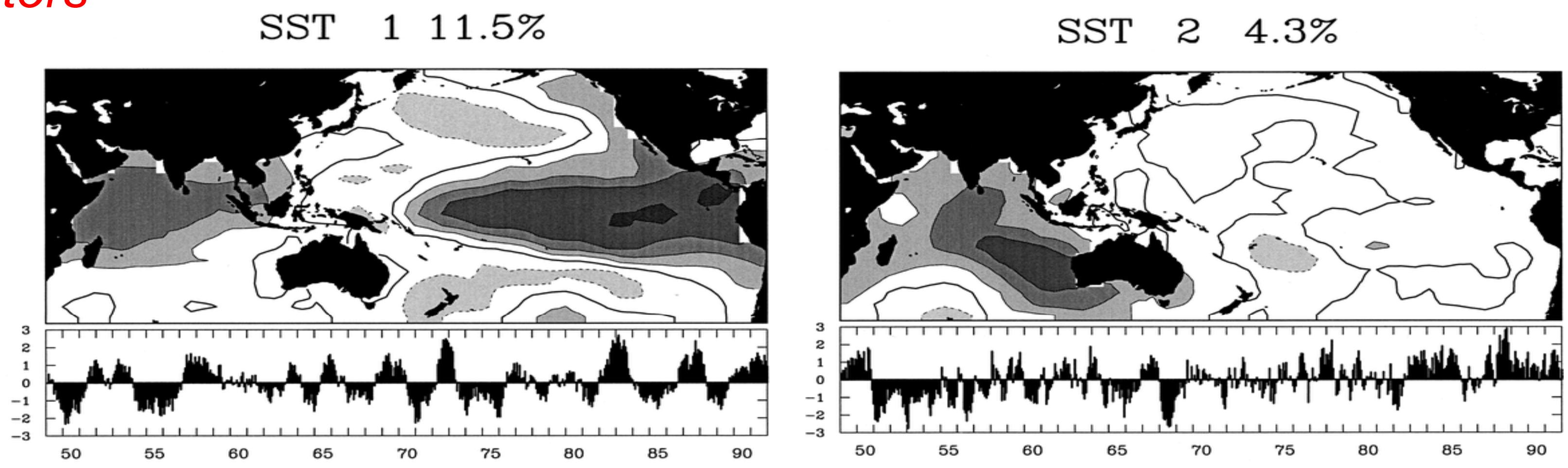
Predictors are selected from:

- MJO – Use the Real-time Multivariate MJO indices (RMM1 and RMM2).

2 predictors

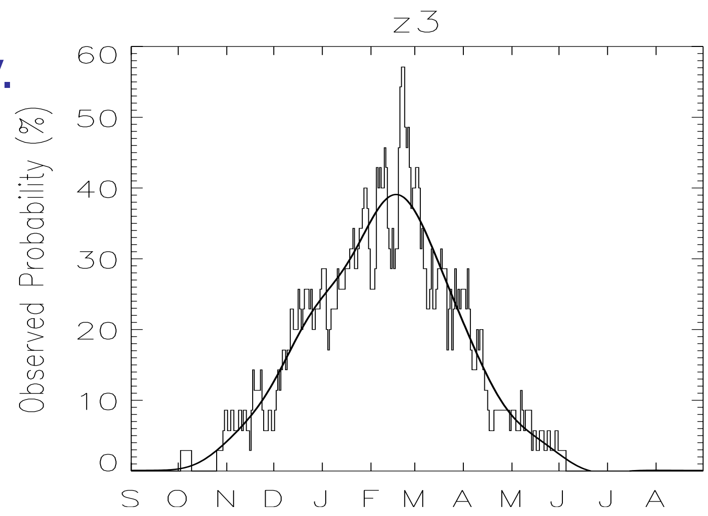
- The leading two patterns of Indo-Pacific SST variability (SST1 and SST2).

2 predictors



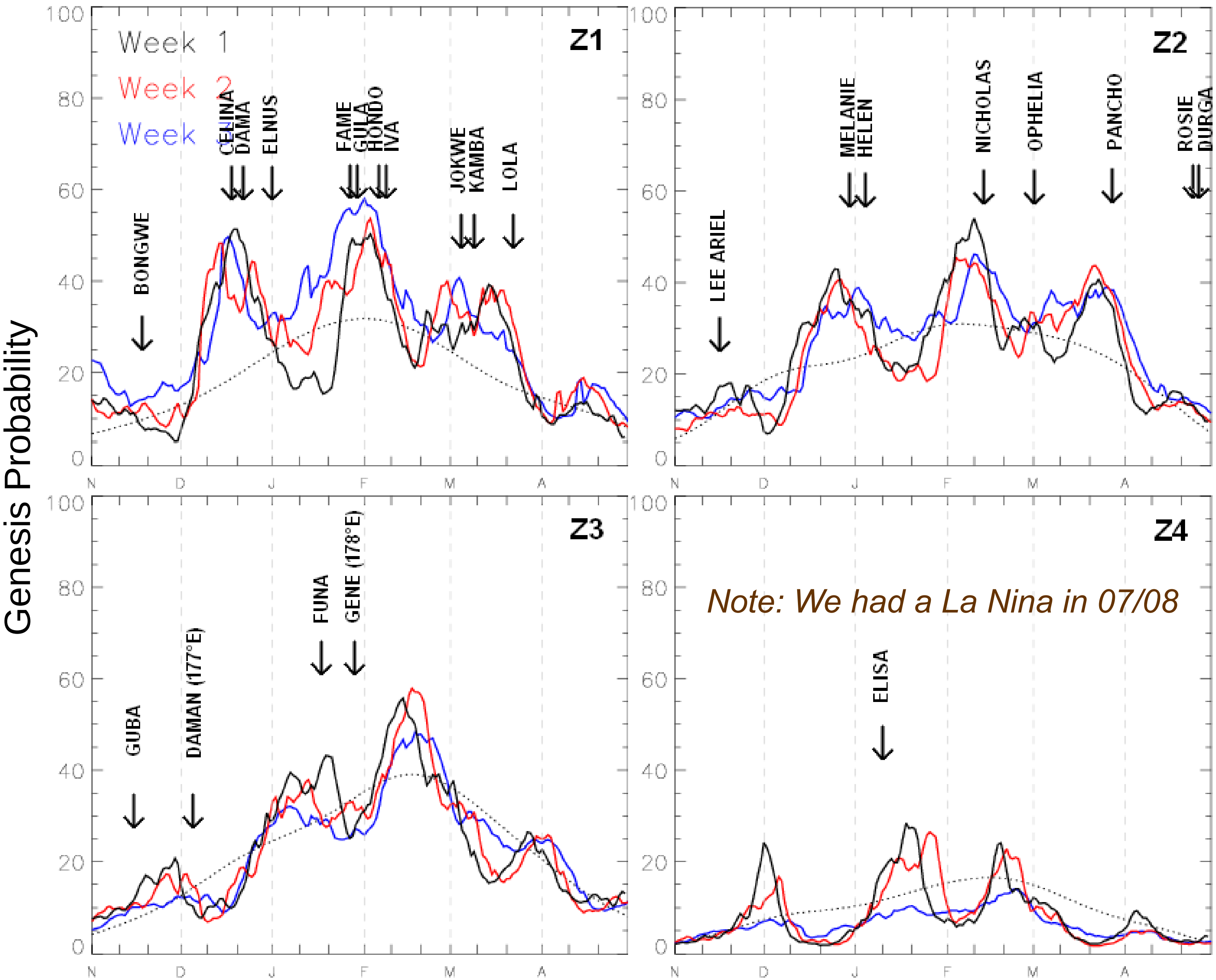
- Climatological seasonal cycle of TC activity.

1 predictor



A formal stepwise predictor selection procedure is employed, which selects which predictors to use for each lead and zone.

Forecast examples from 2007/08 (these were produced in real time)

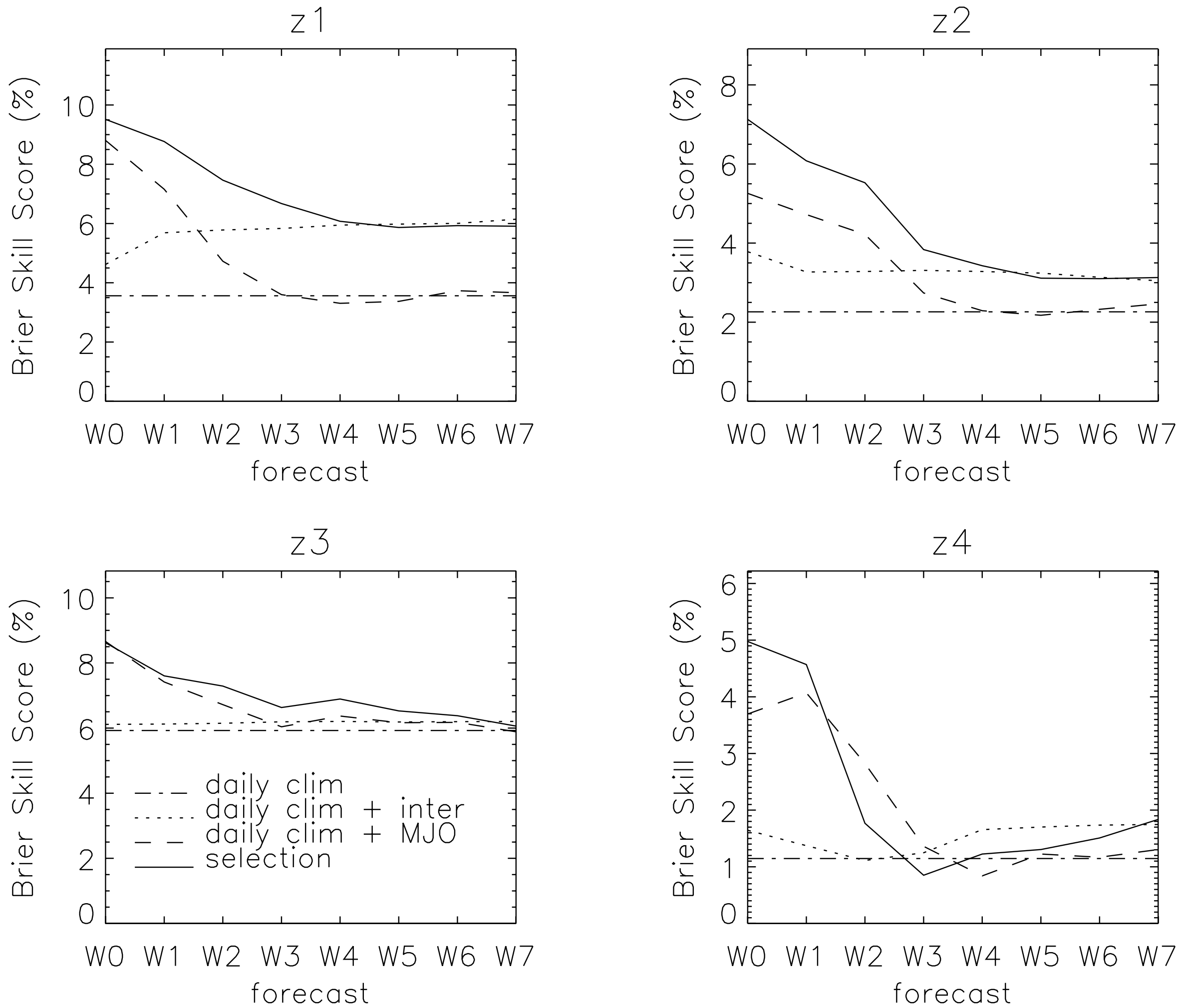


Hindcast skill (cross-validated hindcasts for 69/70-03/04)

Brier skill scores (BSS), expressed as a percentage improvement over a reference forecast strategy that predicts a constant climatology.

Using all forecasts

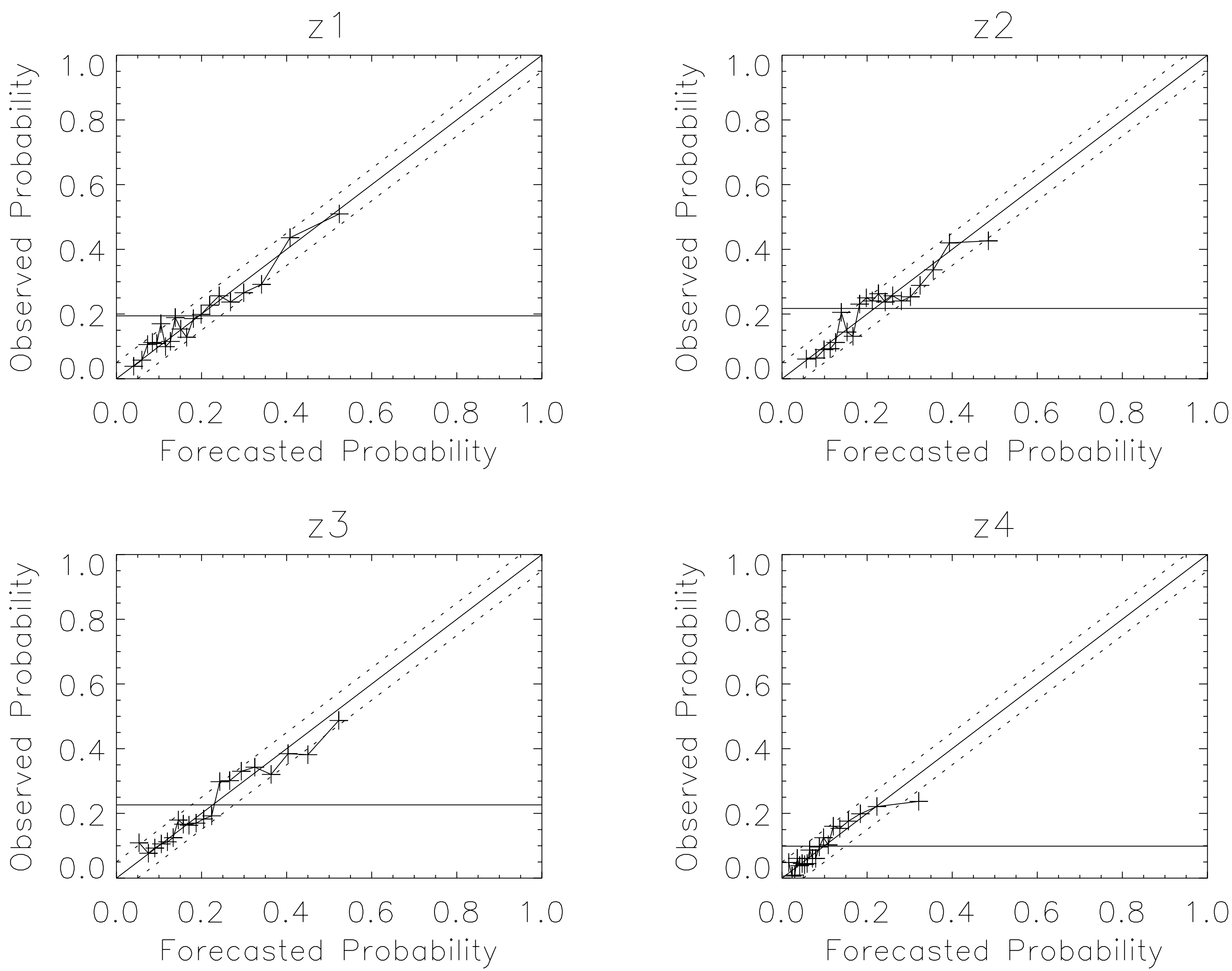
(note different scales)



and using forecasts from periods of strong MJO activity only, skill is even greater……

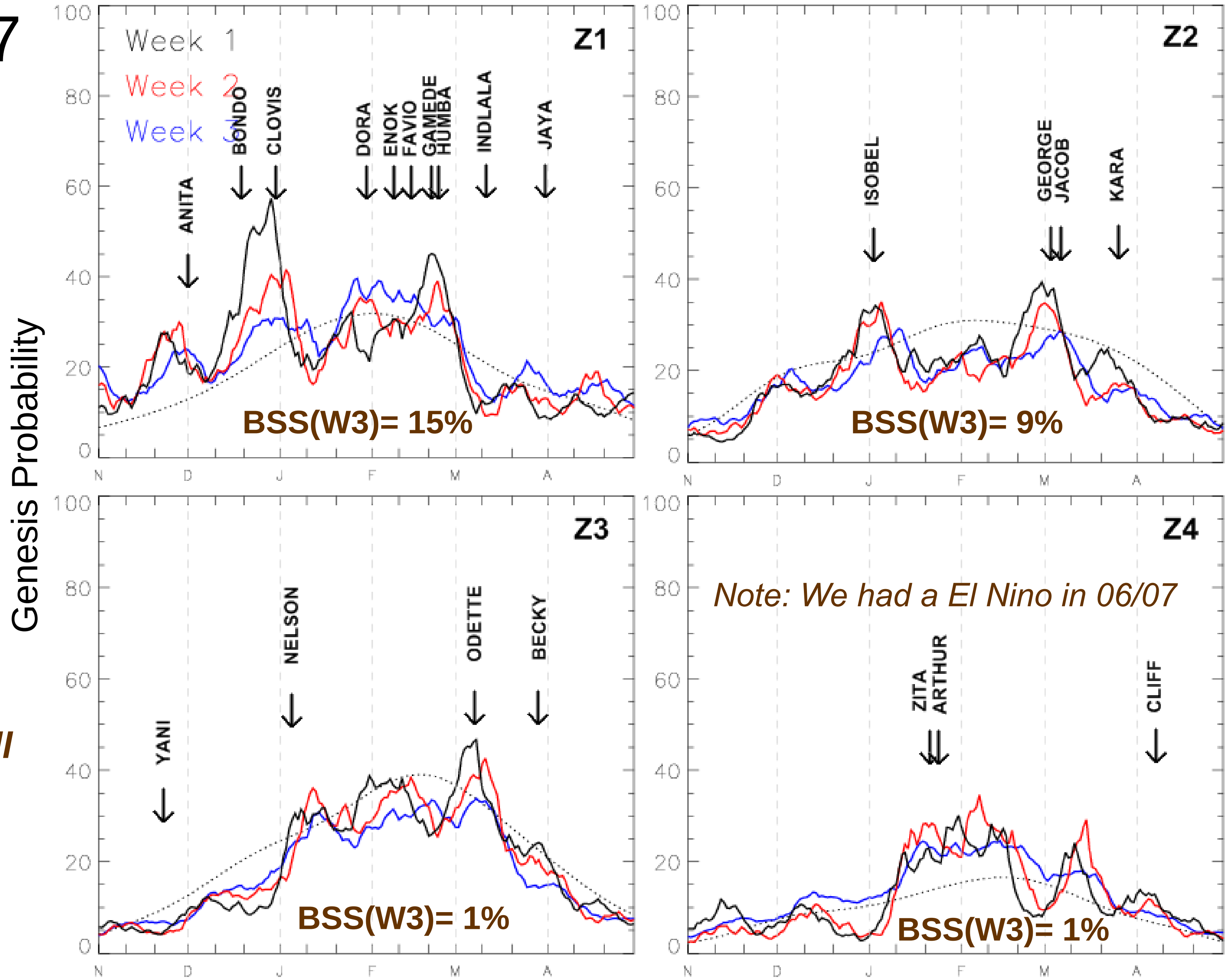
<u>**Hindcast reliability**</u> (cross-validated hindcasts for 69/70-03/04)

Week 1 forecasts



Independent (real time!) verification for 06/07 and 07/08

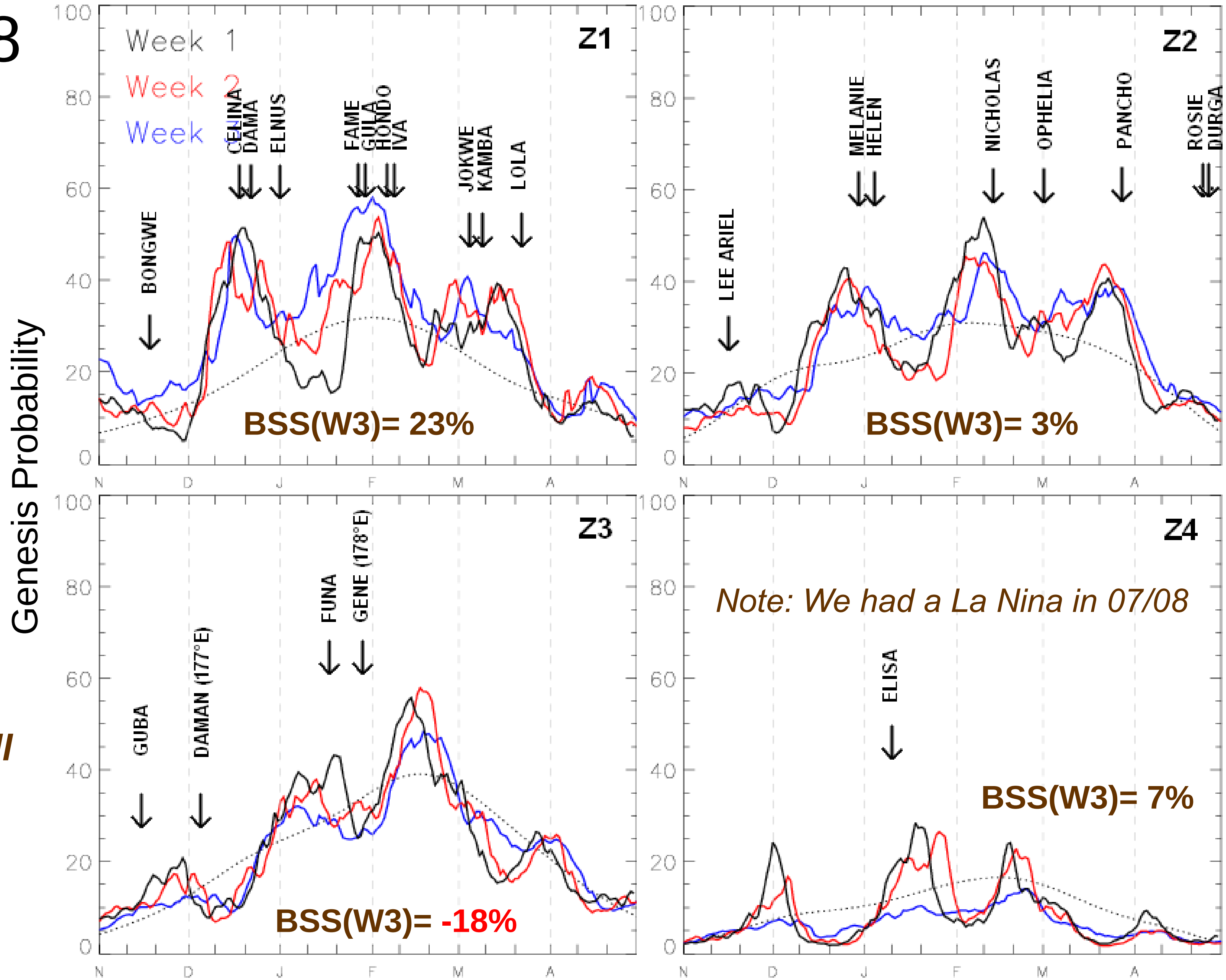
06/07



Week 3 Brier Skill Score

Independent verification:

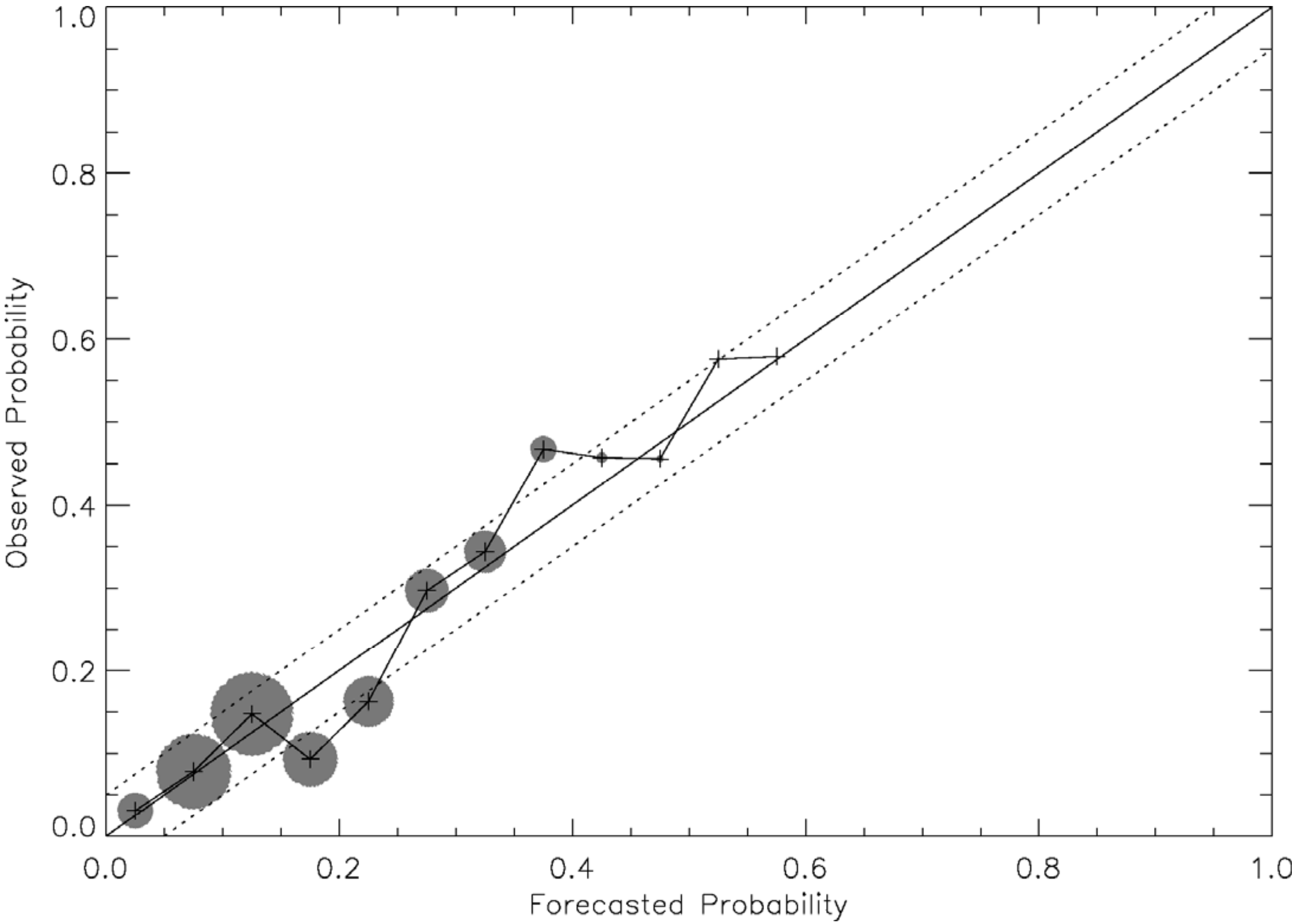
07/08



Week 3 Brier Skill Score

Independent verification:

Reliability of all forecasts (W1, W2, and W3), in all regions, for 06/07 and 07/08



- 20 categories
- Area of each dot is proportional to the number of forecasts in category

Final Conclusions

• On average, we are able to achieve positive skill out to week-3 when assessed using multiple years of hindcasts across each of the four regions.

• During the last two seasons, when real time forecasts were made, best skill has been achieved in regions z1 and z2 (Indian Ocean), but relatively poor skill (little better than climatology) in regions z3 and z4. The only negative skill was for z3 in 2007/08. But verification results in individual years are highly sensitive to individual systems!

• Real-time forecasts available from http://www.meteo.nc/espro/previcycl/cyclA.php

Future Improvements

▪ SST1 and SST2 are not optimally designed for TC prediction.

▪ The seasonal cycle of the impact of interannual variability (i.e. ENSO and Indian Ocean variability) is not taken into account.

▪ It would be interesting to look at the ability of dynamical forecast models to make weekly TC forecasts (e.g. ECMWF already issues seasonal TC forecasts).