Operational Seasonal Forecast System Development in South Africa

Willem A. Landman
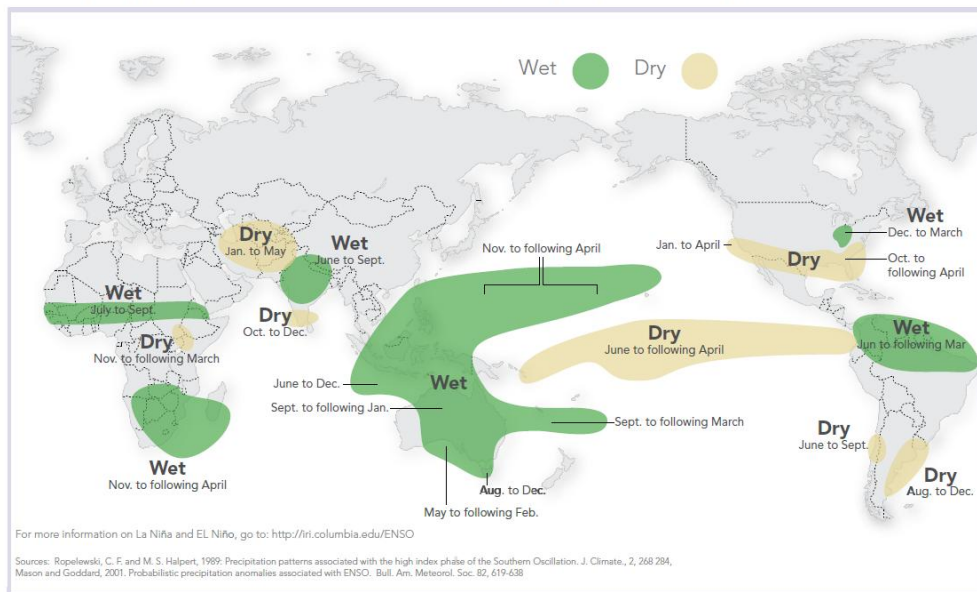
**Asmerom Beraki**

La Niña and Rainfall

La Niña conditions in the tropical Pacific are known to shift rainfall patterns in many different parts of the world. Although varying somewhat from one La Niña to the next, the strongest shifts are fairly consistent in the regions and seasons shown on the map below.

Wet ● Dry ●

Dry Jan. to May

Wet June to Sept.

Wet July to Sept.

Dry Oct. to Dec.

Dry Nov. to following March

Wet Nov. to following April

June to Dec.

Sept. to following Jan.

Wet May to following Feb.

Aug. to Dec.

Nov. to following April

Dry June to following April

Sept. to following March

Wet Jun to following Mar

Wet Dec. to March

Dry Oct. to following April

Jan. to April

Dry June to Sept.

Dry Aug. to Dec.

For more information on La Niña and EL Niño, go to: http://iri.columbia.edu/ENSO

Sources: Ropelewski, C. F. and M. S. Halpert, 1989: Precipitation patterns associated with the high index phase of the Southern Oscillation. J. Climate., 2, 268 284, Mason and Goddard, 2001. Probabilistic precipitation anomalies associated with ENSO. Bull. Am. Meteorol. Soc. 82, 619-638

The evolution of the science of seasonal forecasting in southern Africa

- Model/system development started in early 1990s – SAWS, UCT, UP, Wits (statistical forecast systems)
- South African Long-Lead Forecast Forum
- SARCOF started in 1997 – consensus through discussions
- Late 1990s – started to use AGCMs and post-processing
  - At SAWS (COLA T30, then ECHAM4.5)
  - At UCT (HadAM3)
  - At UP (CSIRO-II/III, then CCAM)
- Global Forecasting Centre for Southern Africa – 2003
- Objective multi-model forecast systems – 2008
- Coupled model considerations – 2010 onwards

Deterministic statistical model (antecedent SST as predictor):
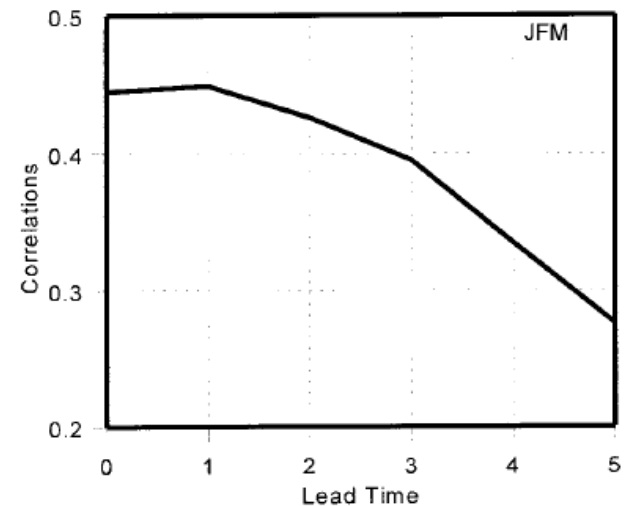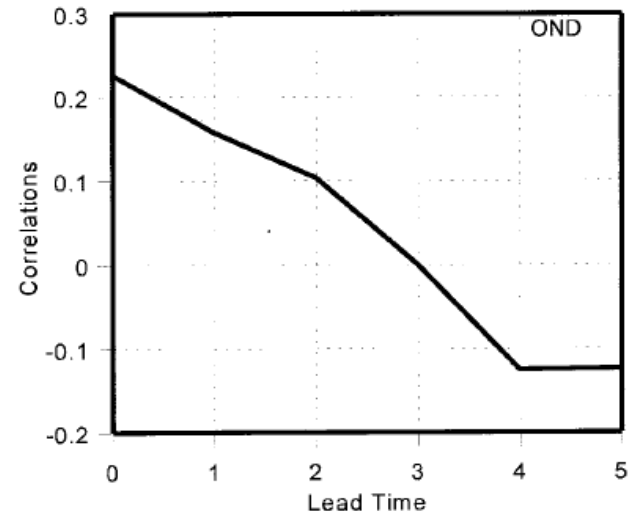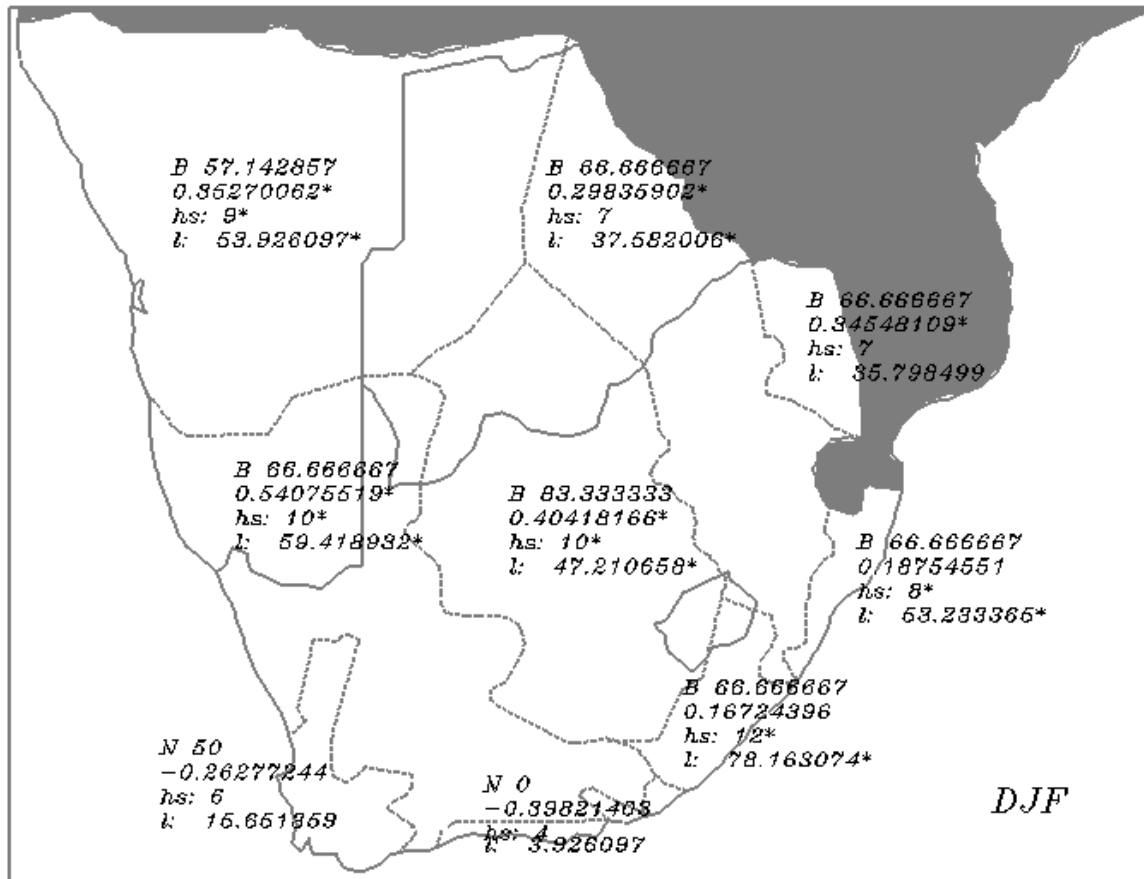
The seasonal forecast systems of the SAWS use the slow evolution of SSTs to make forecasts. In fact, improvements in the forecast systems have occurred owing to the better understanding of the **coupled ocean-atmosphere system** obtained through research at the SAWS and elsewhere.
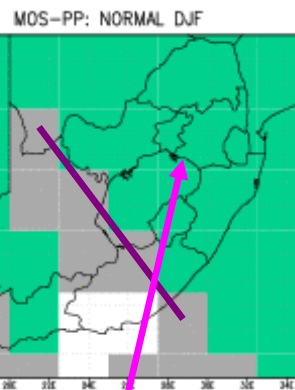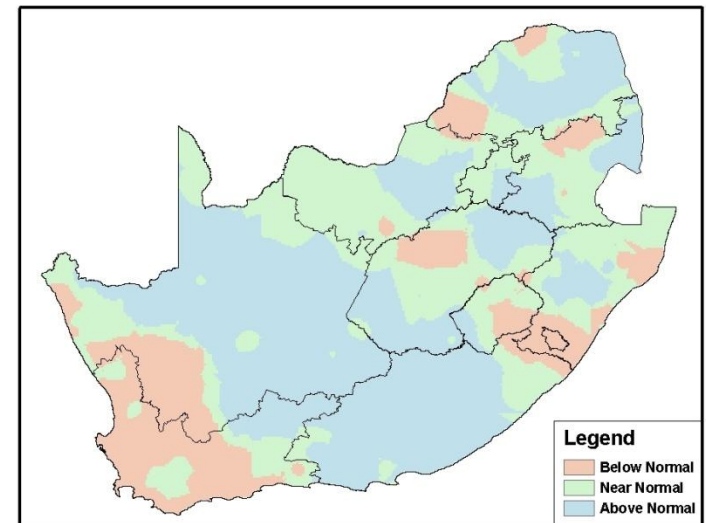

Introduction of GCMs…
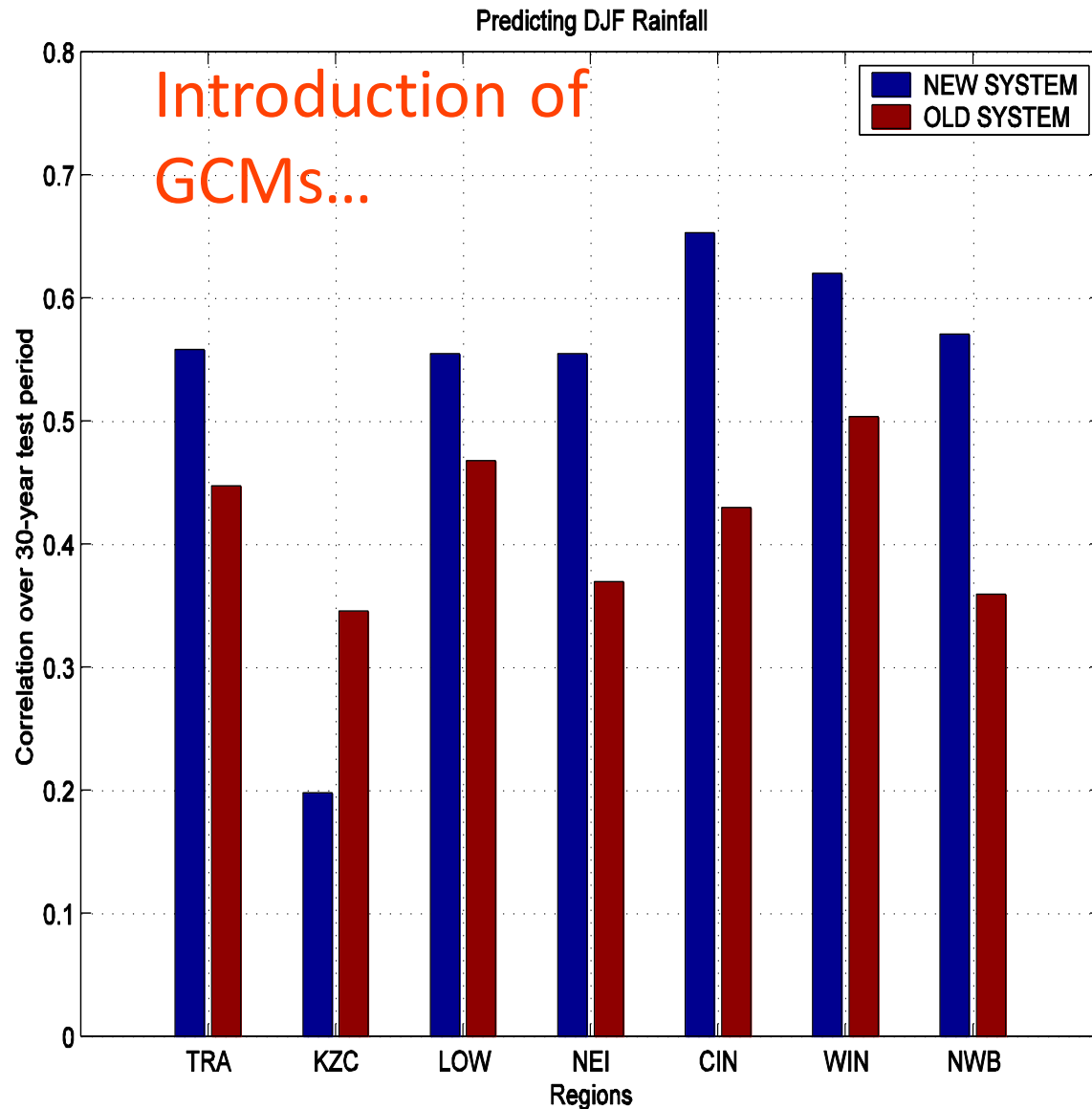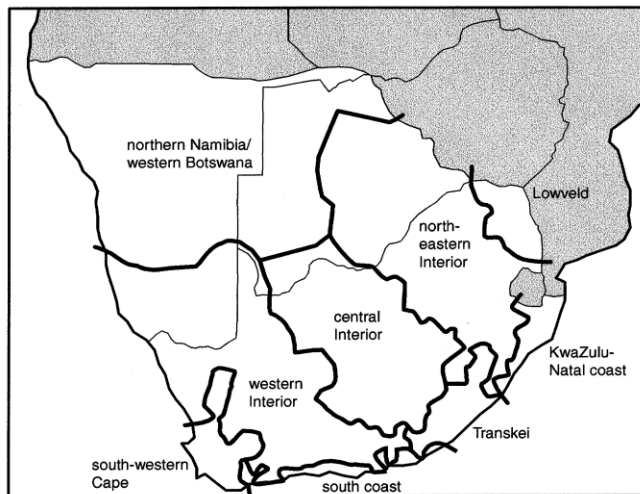
DJF 2005/06 forecast made early December

MOS-PP: ABOVE DJF
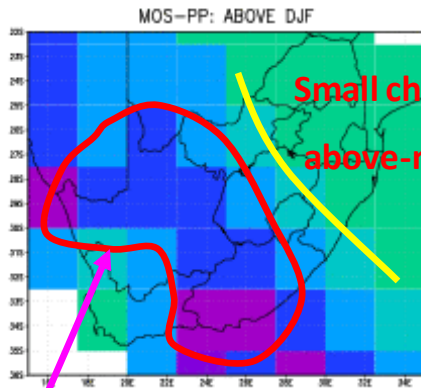
Small chance of above-normal

Enhanced probabilities

MOS-PP: NORMAL DJF

MOS-PP: BELOW DJF

Assessment of Rainfall for December 2005 to February 2006

South African Weather Service

**Legend**
- Below Normal
- Near Normal
- Above Normal

"Normal to below-normal" most likely
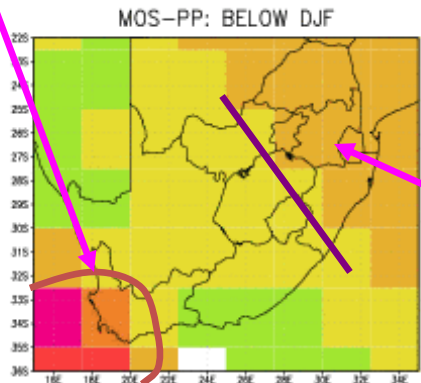
The MOS-PP-ECHAM4.5 system was successful in predicting enhanced probabilities of above-normal over the central-western parts and enhanced probabilities in below-normal over the south-western parts, but predicted only small probabilities of above-normal over the north-eastern parts
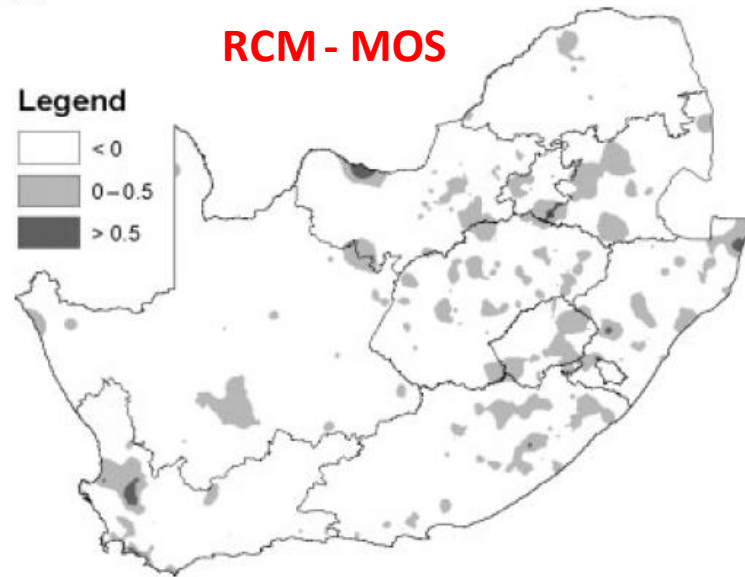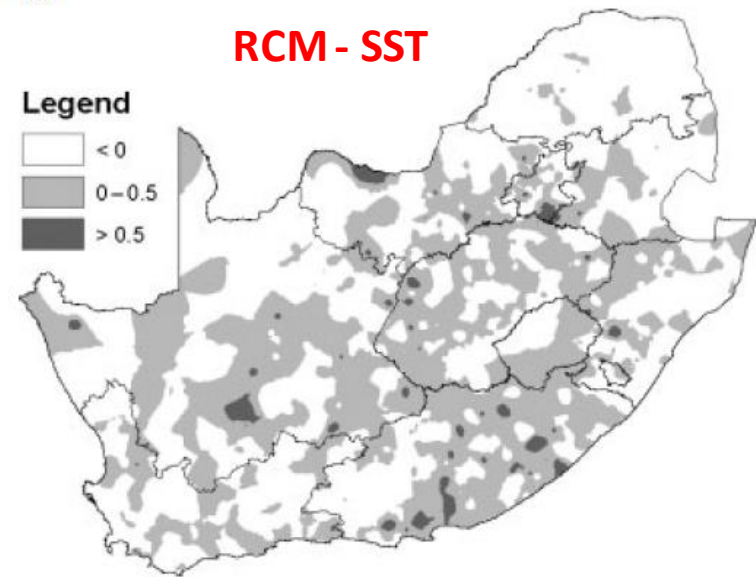
DJF forecasts using RCM
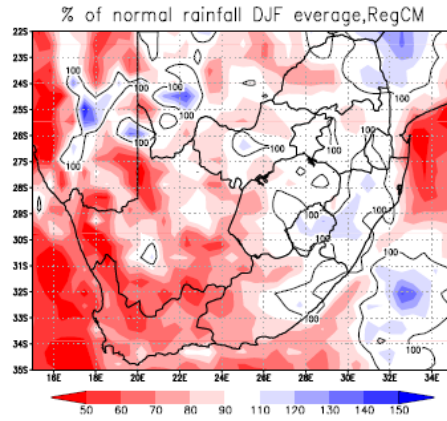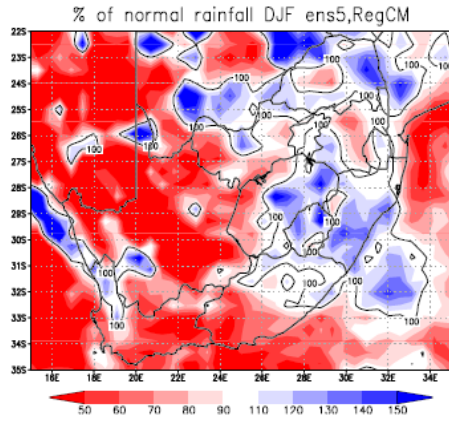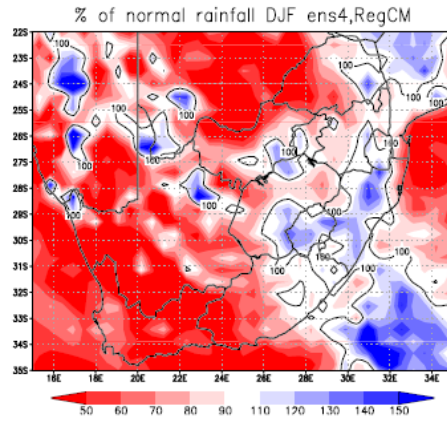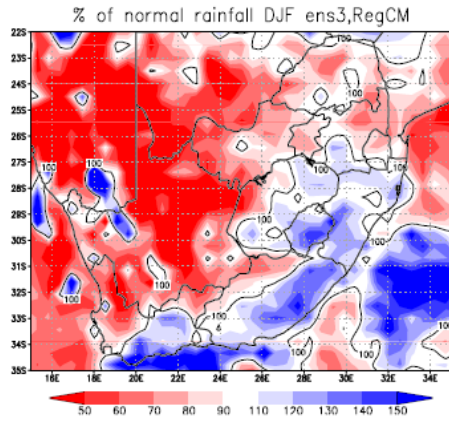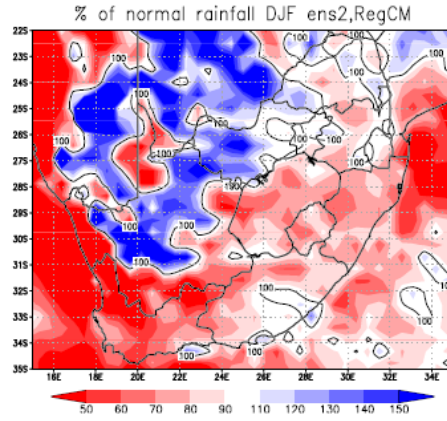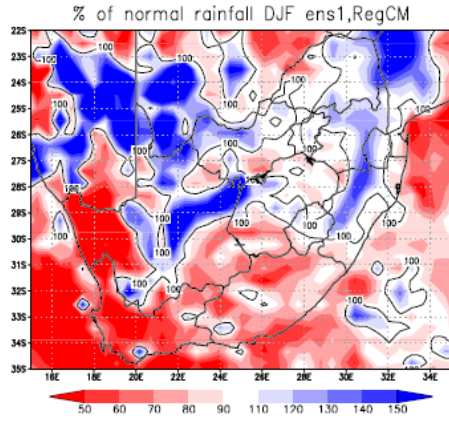
- First ever <u>operational</u> *regional climate model* forecast for southern Africa

- ECHAM4.5-RegCM3

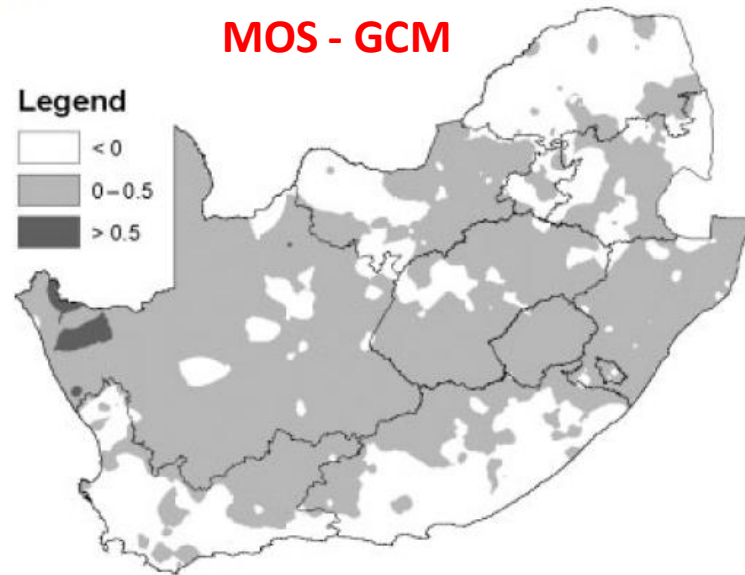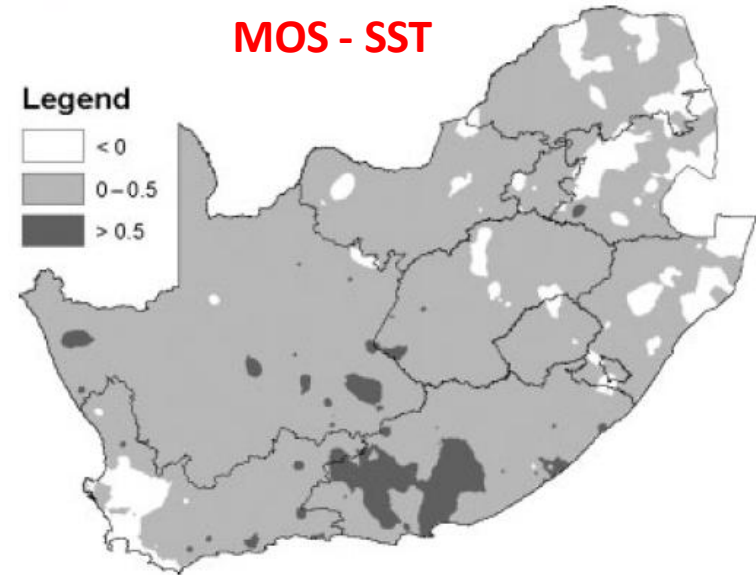**Initiative lead by Mary-Jane Bopape**

and Maluta Mbedzi

Figure 12. Correlation differences between the (a) ECHAM4.5-RegCM3 system and the ECHAM4.5-MOS system (24-member mean), the (b) ECHAM4.5-RegCM3 system and the baseline model (using SSTs to simulate rainfall), the (c) ECHAM4.5-MOS and the raw ECHAM4.5 systems (24-member mean), and the (d) ECHAM4.5-MOS (24-member mean) and the baseline system (using SSTs to simulate rainfall) over the 10-year test period. Negative values are masked out.
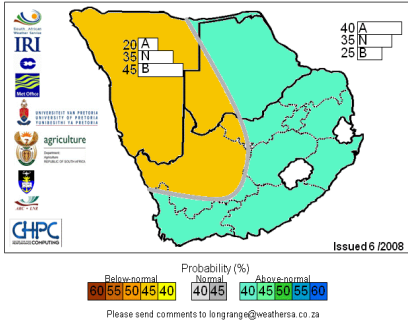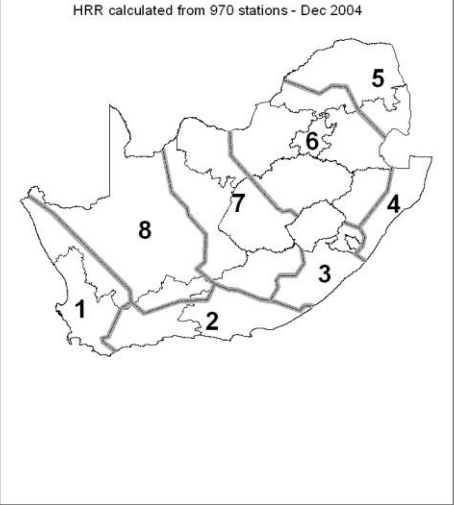
Operational Forecast Skill
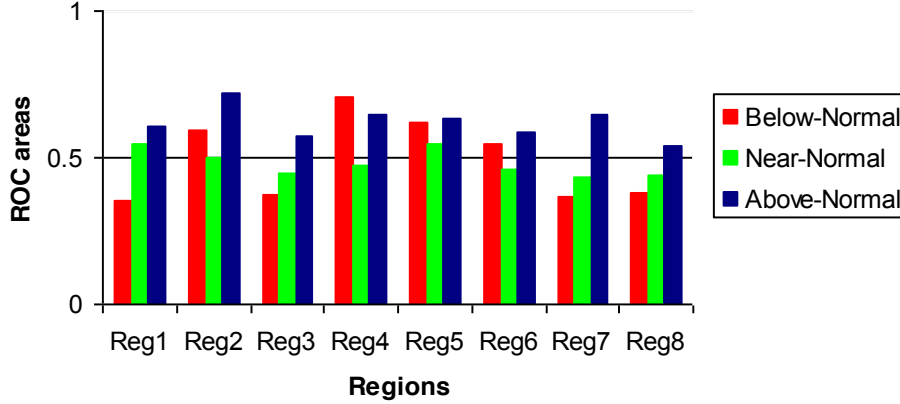
From CONSENSUS discussions

Verification work by Peggy Moatshe

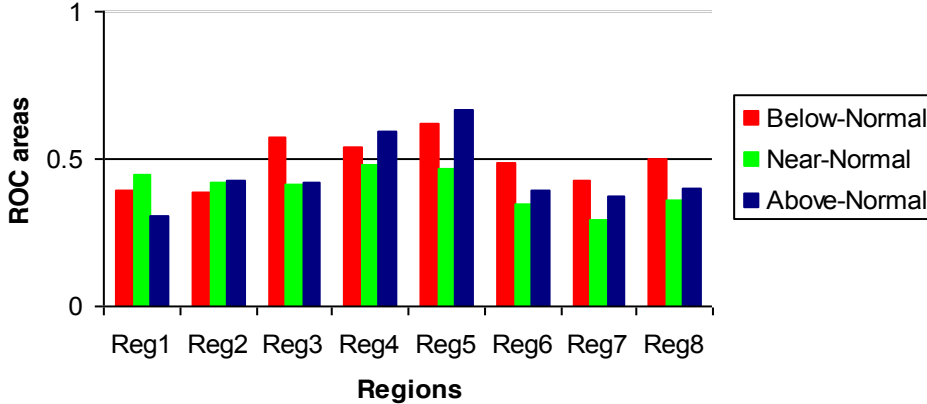**Verification over 7 years of consensus forecast production**

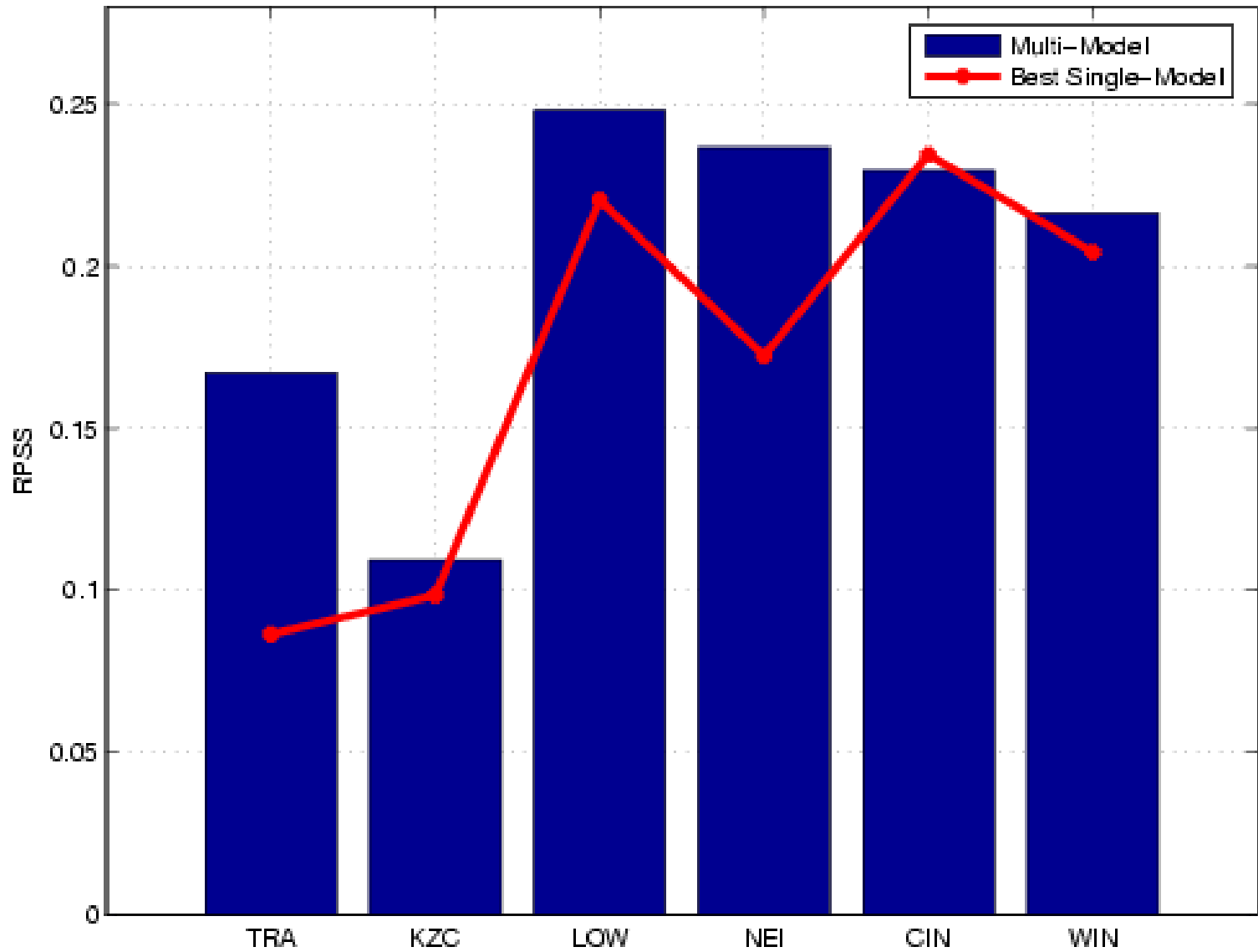Expected Total Rainfall for the period
August-September-October 2008

Issued 6 /2008

Probability (%)
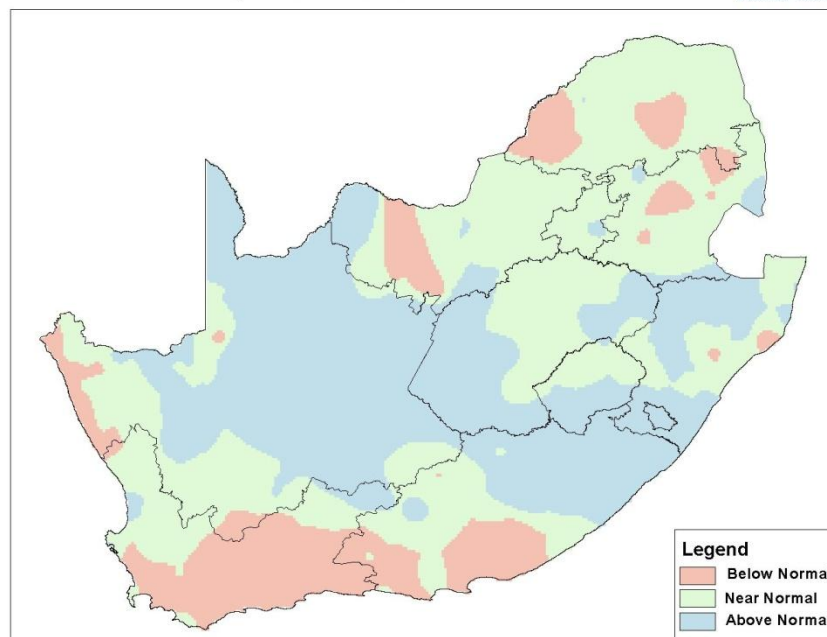
Below-normal | Normal | Above-normal
60 55 50 45 40 | 40 45 | 40 45 50 55 60

Please send comments to longrange@weathersa.co.za

HRR calculated from 970 stations - Dec 2004

SON ROC analysis

DJF ROC analysis

Multi–Model vs Single–Model Simulation Skill of DJF Rainfall

New objective multi-model forecast

Probability Rainfall Forecast for ABOVE-normal for April-May-June 2008

Legend:
- 33 – 40
- 40 – 50
- 50 – 60
- 60 – 70
- > 70

Assessment of Rainfall for April to June 2008

South African Weather Service

Legend
- Below Normal
- Near Normal
- Above Normal
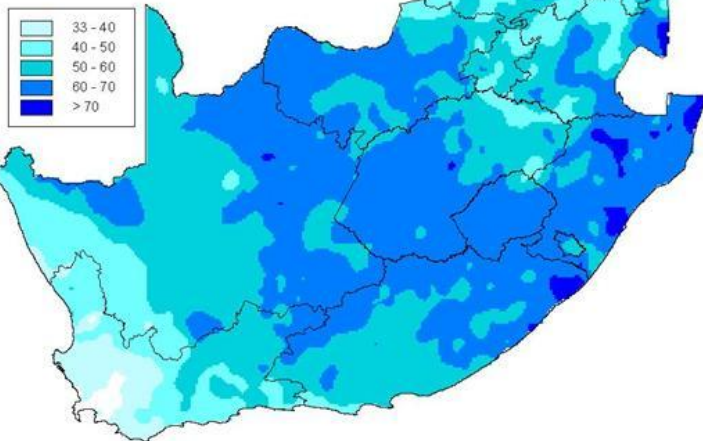
Probability Rainfall Forecast for BELOW-normal for April-May-June 2008

Legend:
- 33 – 40
- 40 – 50
- 50 – 60
- 60 – 70
- > 70
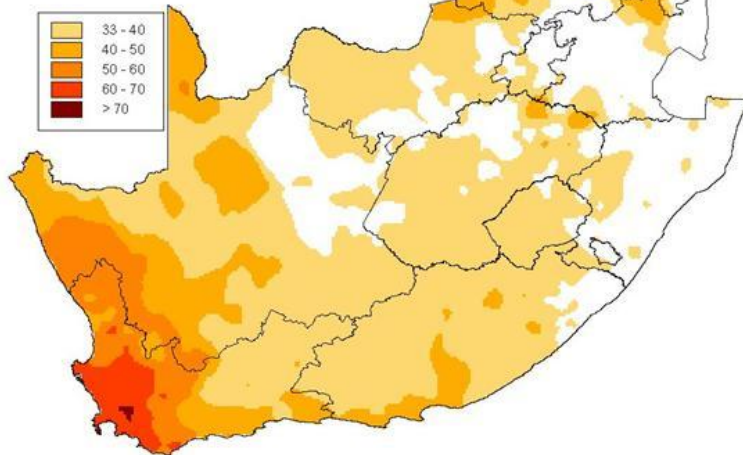
Old subjective consensus forecast

Expected Total Rainfall for the period April-May-June 2008

IRI
Met Office
UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
agriculture
Department Agriculture REPUBLIC OF SOUTH AFRICA
CHPC

| 40 A |
| 35 N |
| 25 B |

| 45 A |
| 35 N |
| 20 B |

| 40 A |
| 35 N |
| 25 B |

Issued 3/2008

Probability (%)

Below-normal: 60 55 50 45 40
Normal: 40 45
Above-normal: 40 45 50 55 60

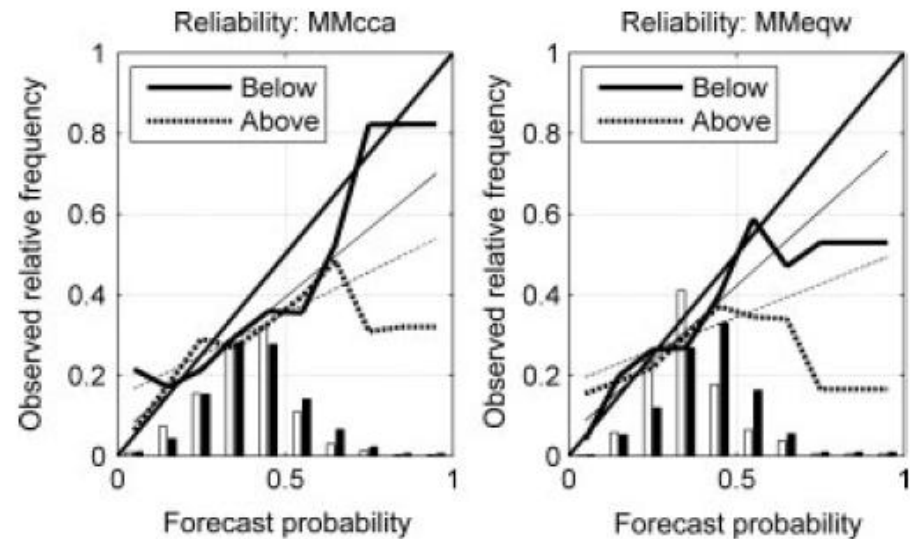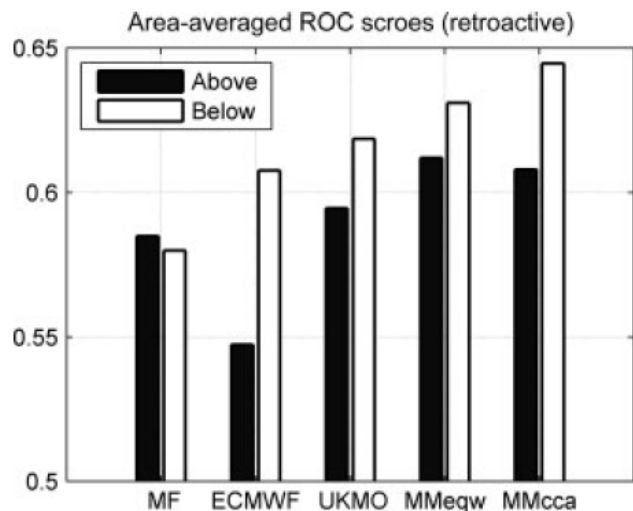Please send comments to longrange@weathersa.co.za
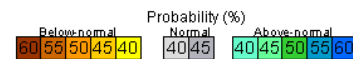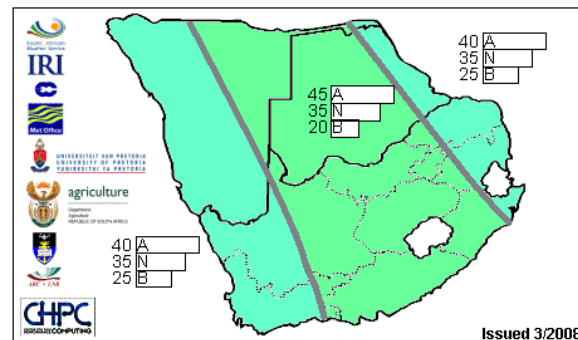
Figure 3. ROC scores, averaged over the southern African domain, for the above-normal and below-normal rainfall categories. Scores for the single models and for the two multi-models are shown.

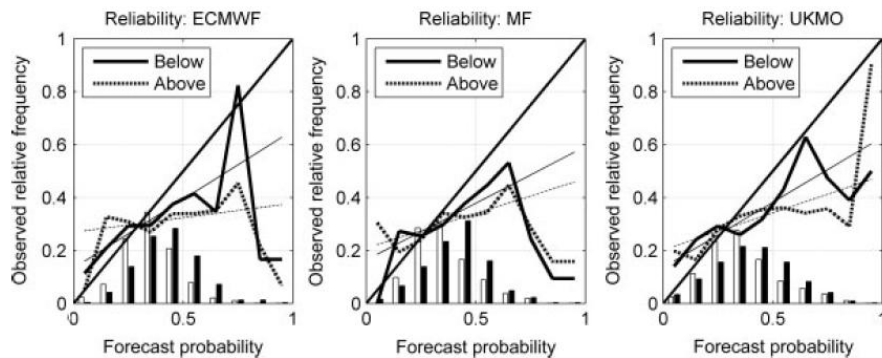Figure 6. As in Figure 5, but for the two multi-models.

Figure 5. Reliability diagrams and frequency histograms for above- and below-normal DJF rainfall forecasts produced by the single models. The thick black curves and black bars of the histogram represent the below-normal rainfall category, while the thick black dotted curves and white bars of the histogram represent the above-normal rainfall category. For perfect reliability the curves should fall on top of the thick black diagonal line. The thin solid and dotted lines are respectively the weighted least-squares regression lines of the above-normal and below-normal reliability curves.
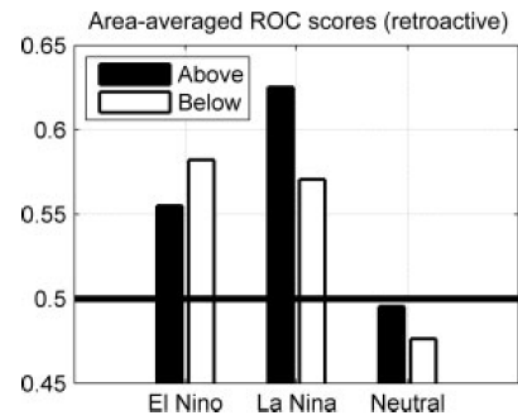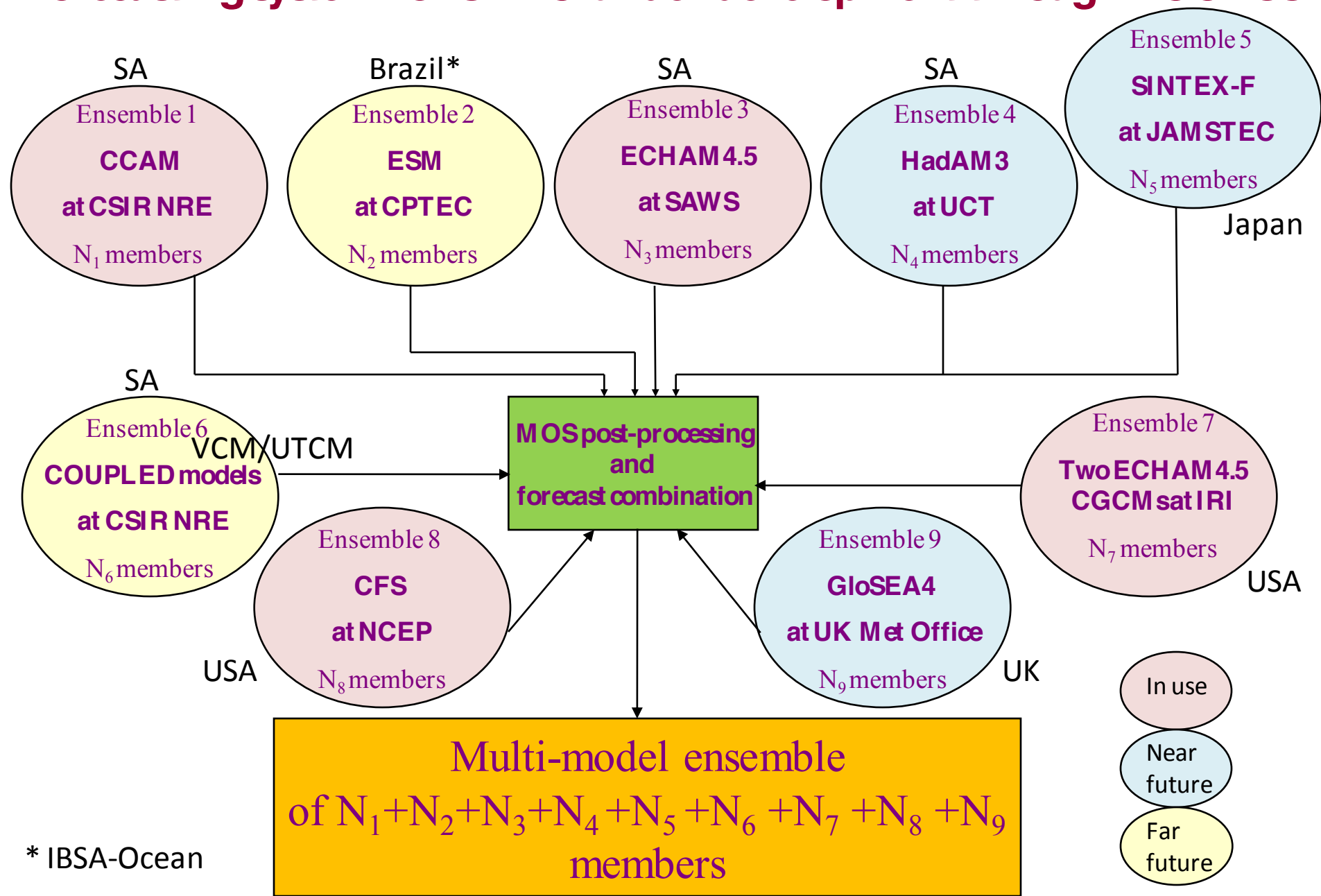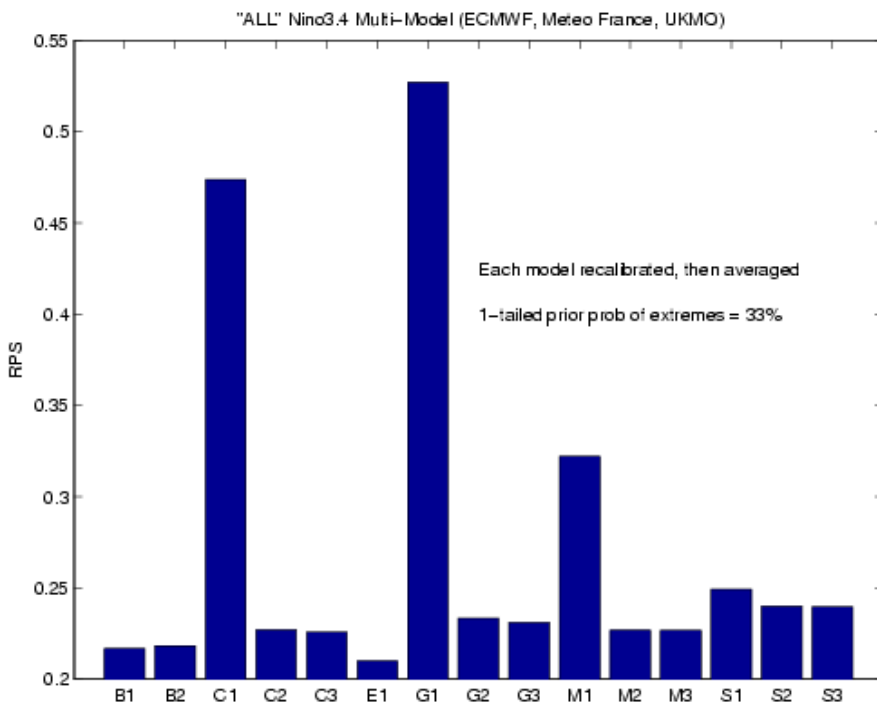

Figure 7. ROC scores, averaged over the southern African domain, for the above-normal and below-normal rainfall categories during El Niño, La Niña and neutral seasons. Scores for the MMcca multi-model are shown.

The multi-model seasonal **rainfall and surface temperature** forecasting system for SADC under development through ACCESS

SA

Ensemble 1

CCAM

at CSIR NRE

N_1 members

Brazil*

Ensemble 2

ESM

at CPTEC

N_2 members

SA

Ensemble 3

ECHAM 4.5

at SAWS

N_3 members

SA

Ensemble 4

HadAM3

at UCT

N_4 members

Ensemble 5

SINTEX-F

at JAMSTEC

N_5 members

Japan

SA

Ensemble 6

COUPLED models

at CSIR NRE

N_6 members

VCM/UTCM

MOS post-processing and forecast combination

Ensemble 7

Two ECHAM 4.5 CGCMs at IRI

N_7 members

USA

Ensemble 8

CFS

at NCEP

N_8 members

USA

Ensemble 9

GloSEA4

at UK Met Office

N_9 members

UK

Multi-model ensemble
of $N_1 + N_2 + N_3 + N_4 + N_5 + N_6 + N_7 + N_8 + N_9$ members

In use

Near future

Far future

* IBSA-Ocean

Some MM Combination Schemes

"ALL" Nino3.4 Multi-Model (ECMWF, Meteo France, UKMO)

Each model recalibrated, then averaged

1-tailed prior prob of extremes = 33%

RPS

B1 B2 C1 C2 C3 E1 G1 G2 G3 M1 M2 M3 S1 S2 S3

- Bayesian optimal weighting (B1)
- Bayesian sequential optimal weighting (B2)
- Canonical variate analysis
  - using members (C1)
  - using PCs (C2)
  - using moments (C3)
- Equal weighting (E1)
- Generalized linear model
  - using members (G1)
  - using PCs (G2)
  - using moments (G3)
- Multiple linear regression
  - using members (M1)
  - using PCs (M2)
  - using moments (M3)
- Stepwise regression
  - using members (S1)
  - using PCs (S2)
  - using moments (S3)

1. **Models recalibrated and combined at the same time**

2. **Each model recalibrated, then averaged**

With assistance from Simon Mason

Seasonal forecast examples: *Issued Nov 2010*
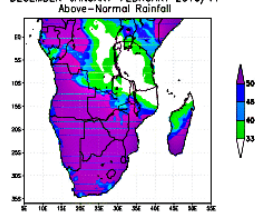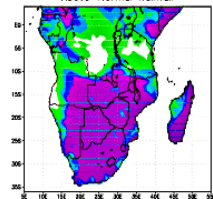
www.GFCSA.net (Est. 2003)

long-range forecasts for southern Africa

Global Forecasting Centre for Southern Africa
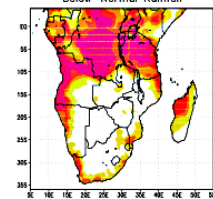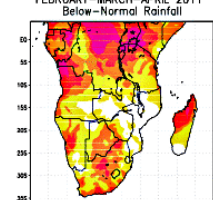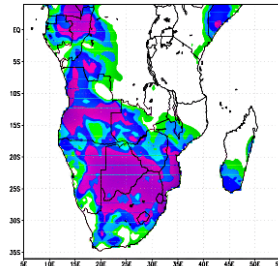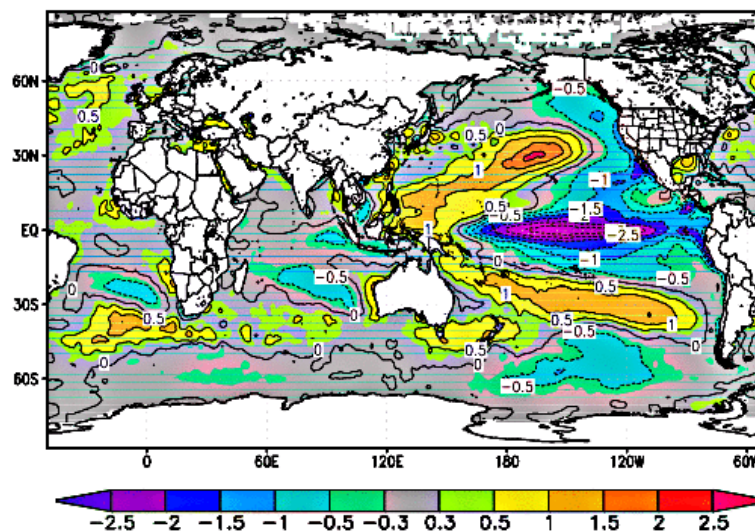
ToR 1: To facilitate cooperation between the centres within southern Africa that run an operational global scale long-range forecasting (LRF - from 30 days up to 2 years) system

ToR 2: To produce global forecasts from dynamical forecasting systems

ToR 3: To establish a web based environment for non commercial product dissemination

ToR 4: The consortium will be managed by a committee

ToR 5: To compile archived hindcasts

ToR 6: To apply standard verification tools

ToR 7: To assist in training and capacity building for LRF

ToR 8: To actively pursue the development and improvement of global scale LRF techniques

UCT: HadAM3
SAWS: ECHAM4.5 (AGCM and CGCM)
CSIR: CCAM, VCM, UTCM

**"ToshioGeorge"
(multi-node machine)**

Example of coupled model work:
The state-of-the-art
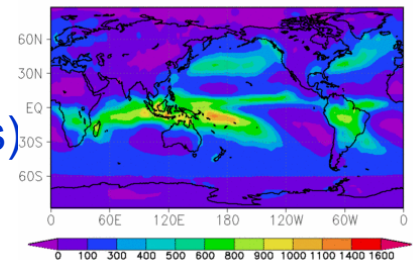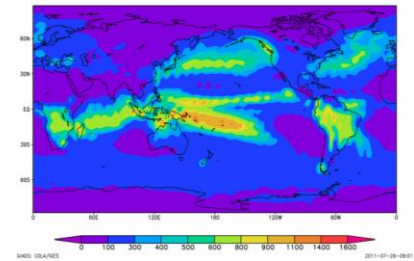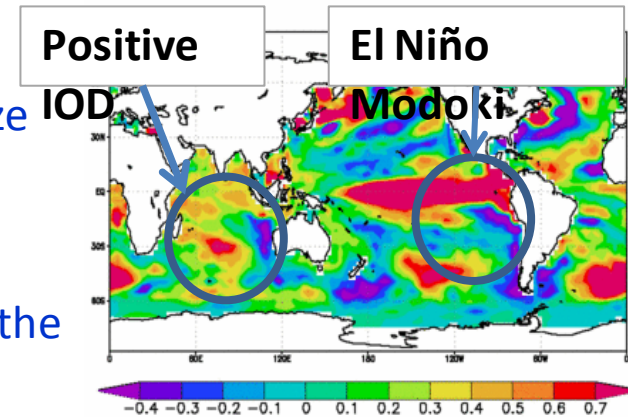
Coupled GCM Implementation:

- **ECHAM4.5-MOM3** running at the CHPC with 10 ensemble size

- Ready for operational use (pending for suitable HPC)

Coupling procedure:

- Anomalously coupled to the AGCM side and fully coupled to the OGCM side

- OGCM SST relaxed toward climatology at high latitudes in order to suppress spurious ice (no sea-ice model)

- AGCM and OGCM are coupled using the *multiple-program multiple-data (MPMD)* paradigm.

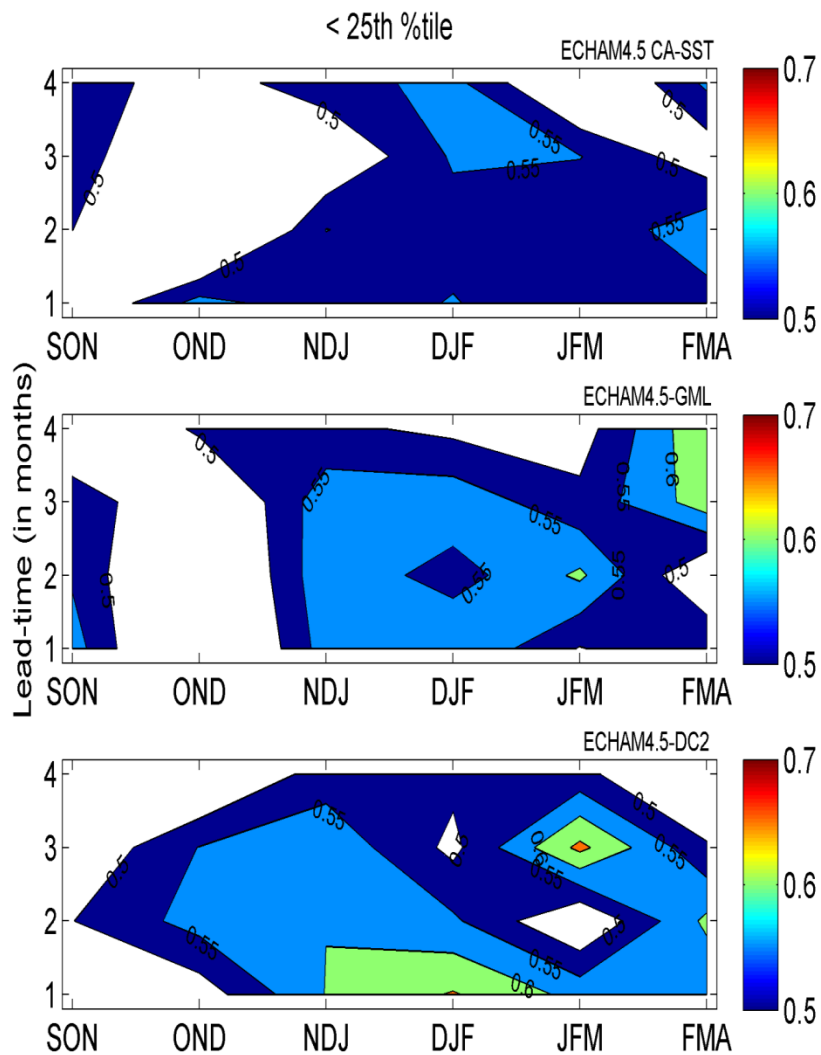- Exchange information via data files *every model simulation day*.
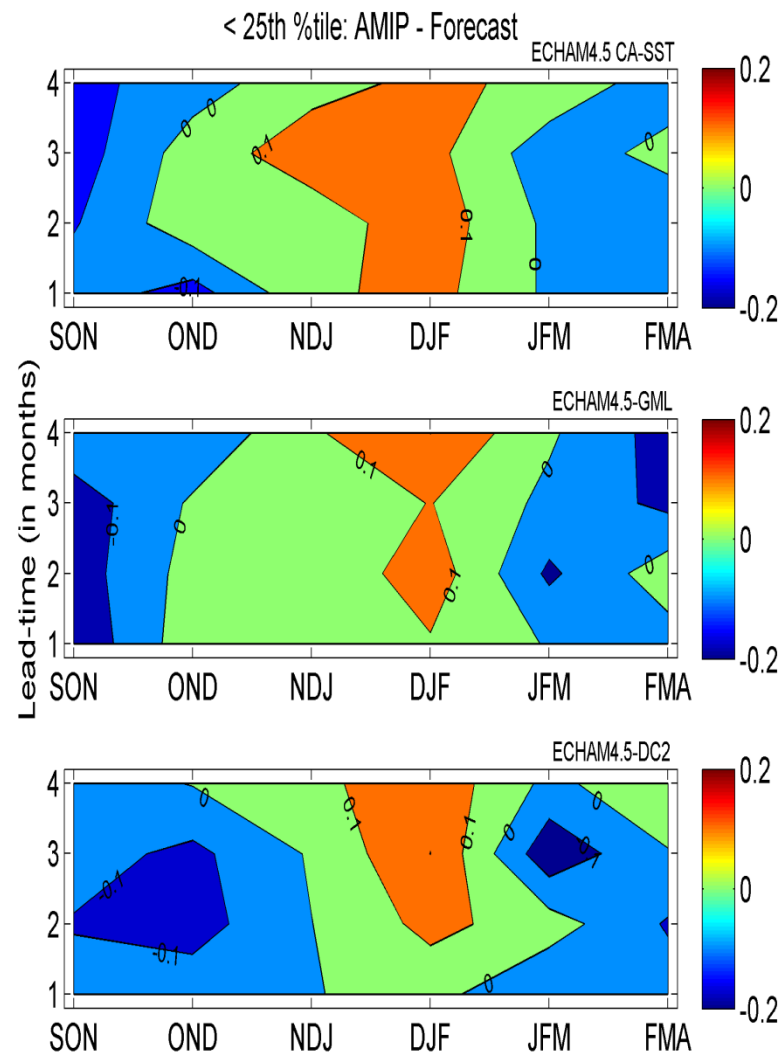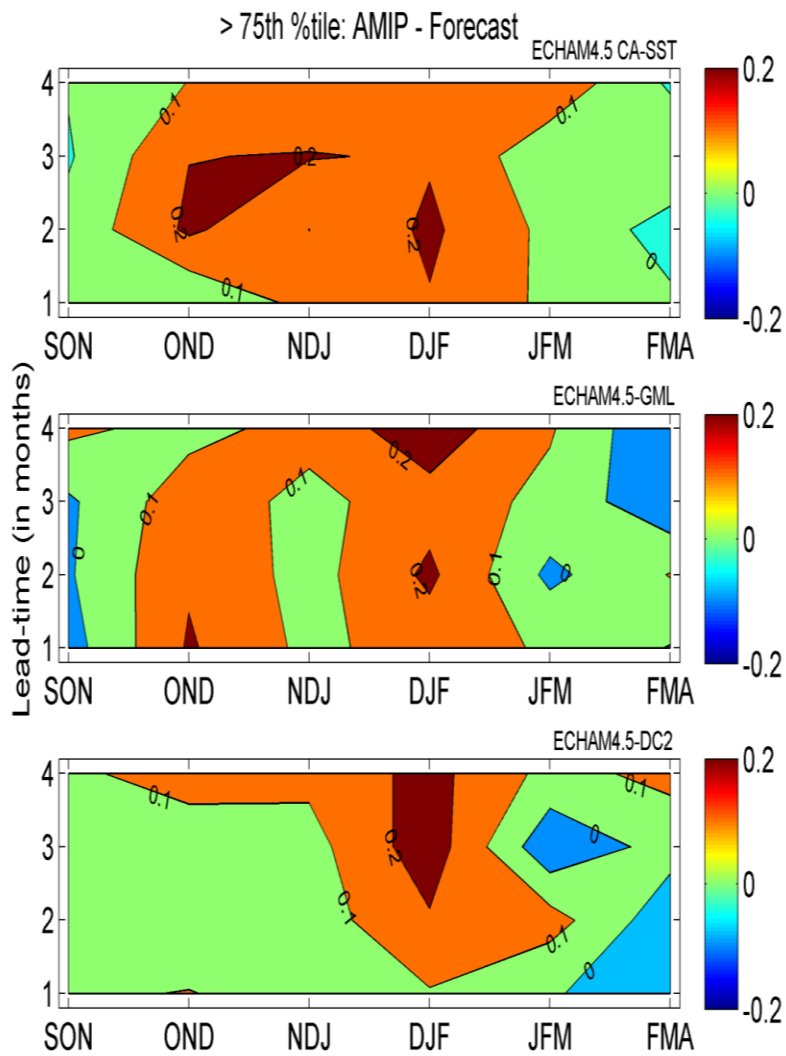
Initialization strategy:

- Initialized using best available information of the ocean and atmosphere state

- Each hindcast run involves 9 months integration (0-8 lead times) and mimics truly **operational** set-up

Significant support from Dave DeWitt

Positive IOD

El Niño Modoki

ROC Scores: Coupled vs. 2-tiered systems

> 75th %tile: AMIP - Forecast

ECHAM4.5 CA-SST

ECHAM4.5-GML

ECHAM4.5-DC2

Lead-time (in months)

< 25th %tile: AMIP - Forecast
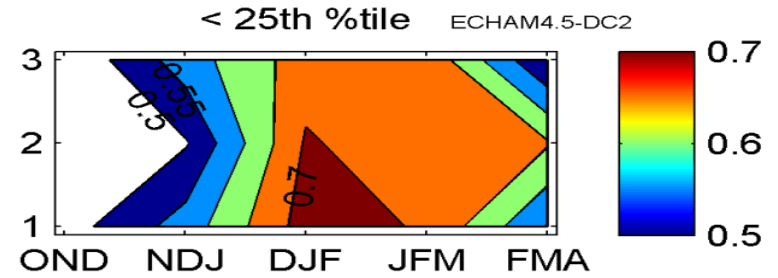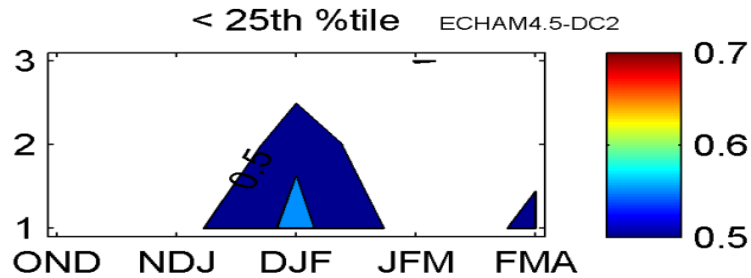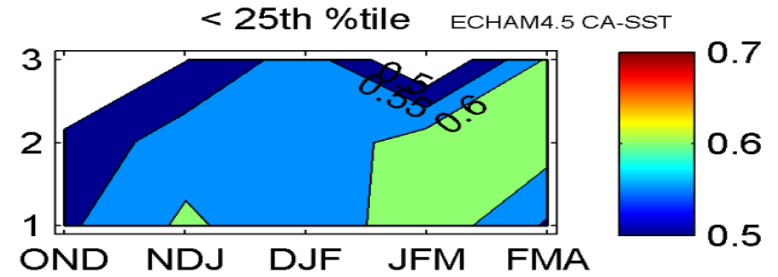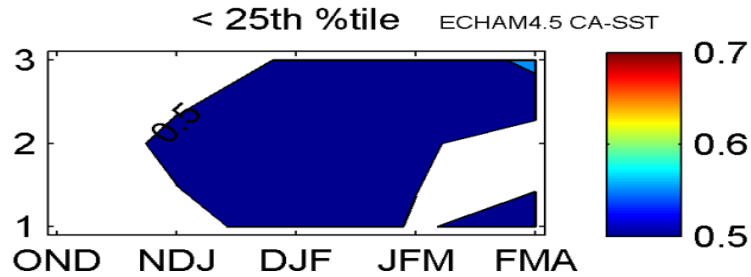
ECHAM4.5 CA-SST

ECHAM4.5-GML

ECHAM4.5-DC2

Lead-time (in months)
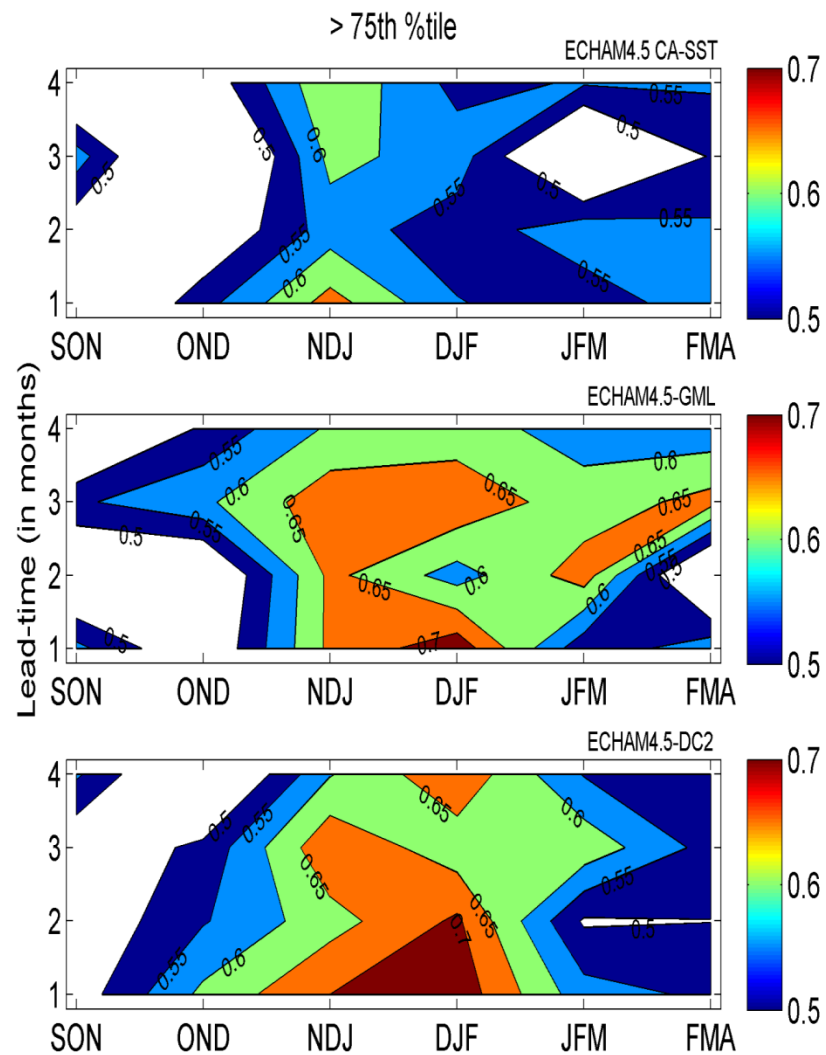
Minimum temperatures   ROC Scores   Maximum temperatures
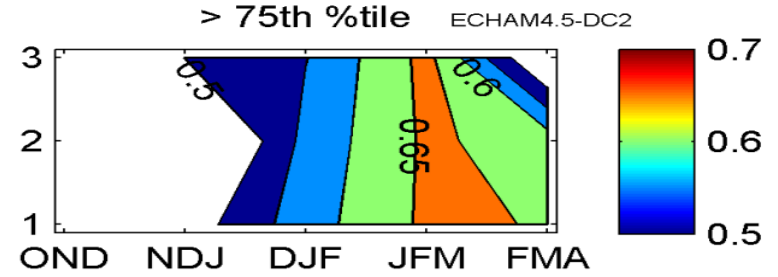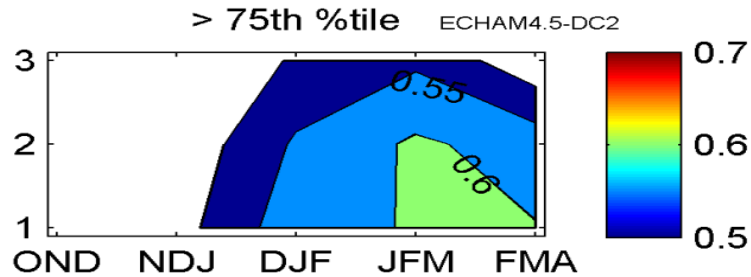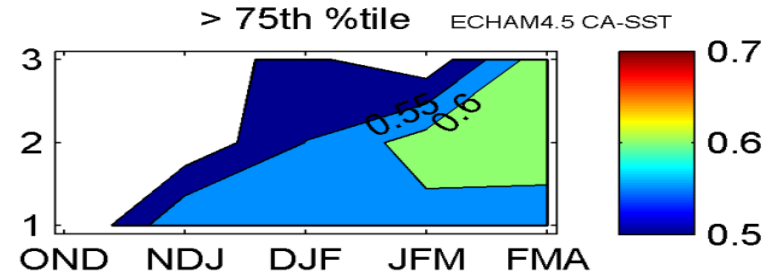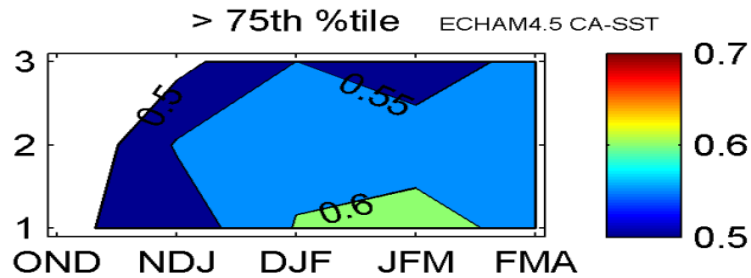
Initiative lead by Melissa Lazenby

Model data supplied by Dave DeWitt

SST configuration strategy
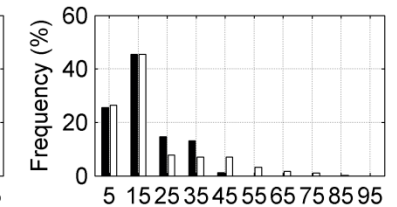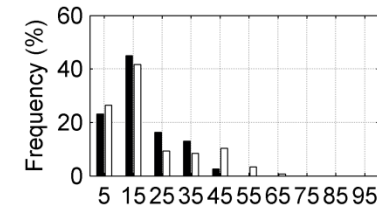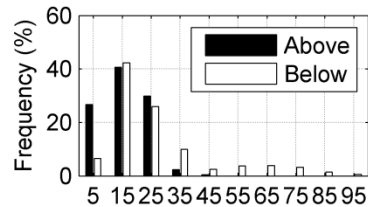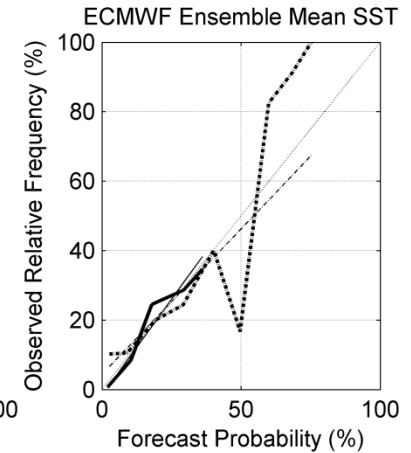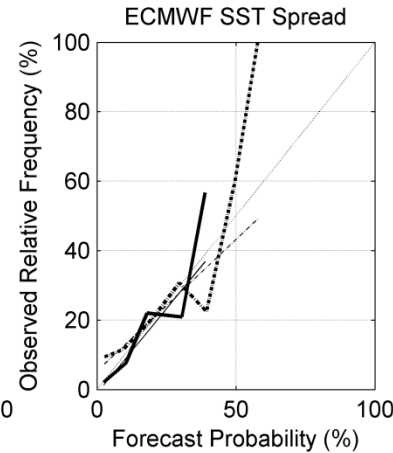
JANUARY NINO3.4 MULTI-MODEL

	MSESSc	Spearman	p
0	0.90588	0.96059	0
1	0.89245	0.95293	0
2	0.83959	0.91899	0
3	0.82049	0.90859	0
4	0.8513	0.896	0
5	0.82239	0.87575	0
6	0.79065	0.84839	0

Temperature Anomaly (^oC)

JANUARY NINO3.4 CCA

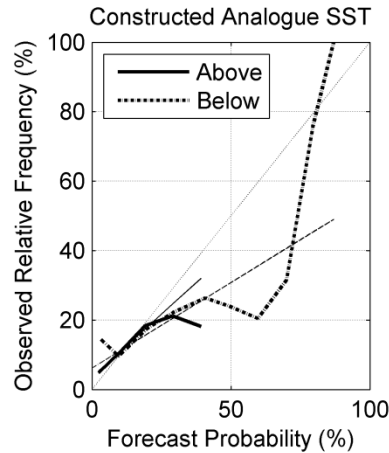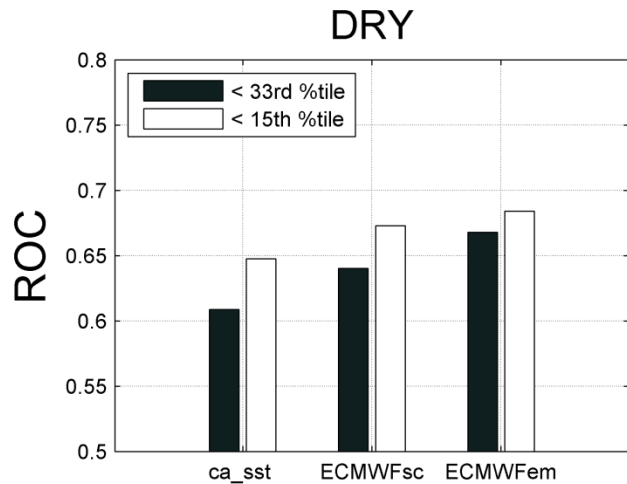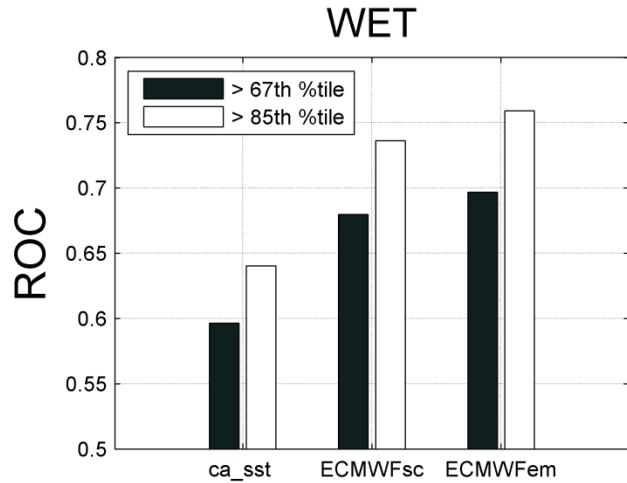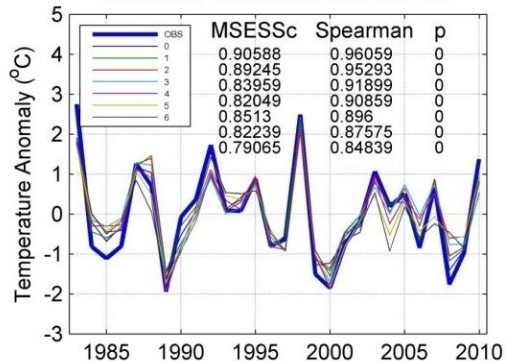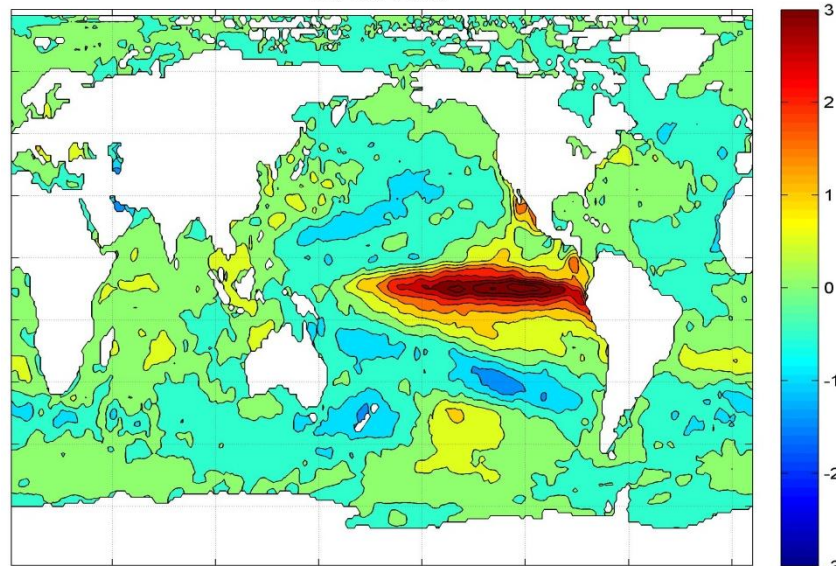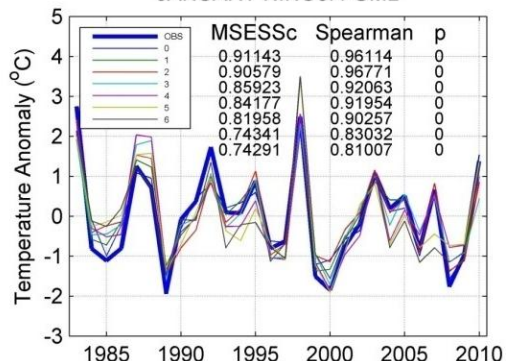|	MSESSc	Spearman	p
0	0.83953	0.93049	0
1	0.77841	0.90203	0
2	0.69544	0.85003	0
3	0.6642	0.82102	0
4	0.60958	0.75369	0
5	0.5236	0.711	0.01
6	0.51558	0.72085	0.01

JANUARY NINO3.4 GML

	MSESSc	Spearman	p
0	0.91143	0.96114	0
1	0.90579	0.96771	0
2	0.85923	0.92063	0
3	0.84177	0.91954	0
4	0.81958	0.90257	0
5	0.74341	0.83032	0
6	0.74291	0.81007	0

JANUARY NINO3.4 MOM

	MSESSc	Spearman	p
0	0.91067	0.94308	0
1	0.89788	0.94527	0
2	0.82391	0.88232	0
3	0.75065	0.81171	0
4	0.78666	0.84236	0
5	0.78633	0.8358	0
6	0.7315	0.80679	0

MM-Dec-4-1997

Spearman Rank Correlations (1983-2010) Multi-Model Feb-3

Model Predictions of ENSO from Aug 2011

IRI

DYN AVG
STAT AVG
CPC CON

Nino3.4 SST Anomaly (^oC)

OBS   FORECAST

MJJ Jul JAS ASO SON OND NDJ DJF JFM FMA MAM AMJ
2011   2012

Dynamical Model:
NASA GMAO
NCEP CFS
JMA
SCRIPPS
LDEO
AUS/POAMA
ECMWF
UKMO
KMA SNU
ESSIC ICM
ECHAM/MOM
COLA ANOM
MetFRANCE
JPN-FRCGC
COLA CCSM3
NCEP CFSv2
CSI-IRI-MM

Statistical Model:
CPC MRKOV
CDC LIM
CPC CA
CPC CCA
CSU CLIPR
UBC NNET
FSU REGR
UCLA-TCD

REAL WORLD   Vs.   MODEL WORLD

Empirical correction and verification should be part of the forecast system

DJF Rainfall Area-Average (Africa south of 10°S)

Kendalls Tau: DJF 1979/80 to 2002/03

ECHAM4.5-MOM3-DC2 for DJF at a 1-month lead

Seamless forecast products

Multi-month forecast for the Pretoria area; Forecasts were initialized using a LAF approach

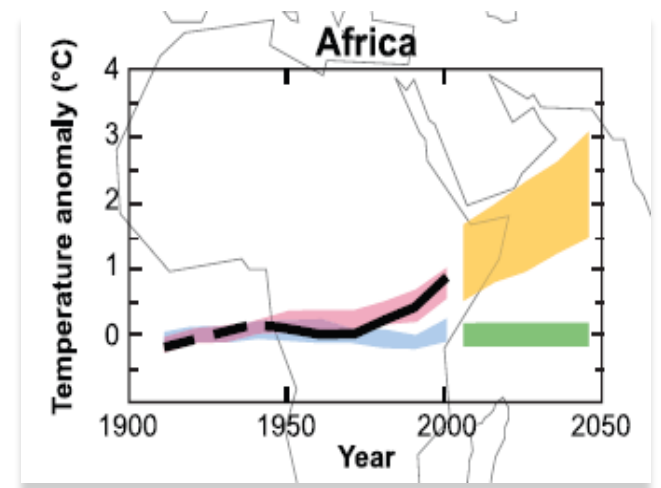## CCAM long-range forecasts are to be updated daily
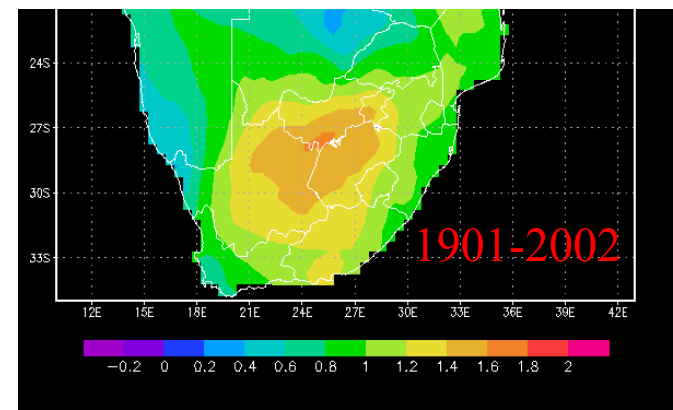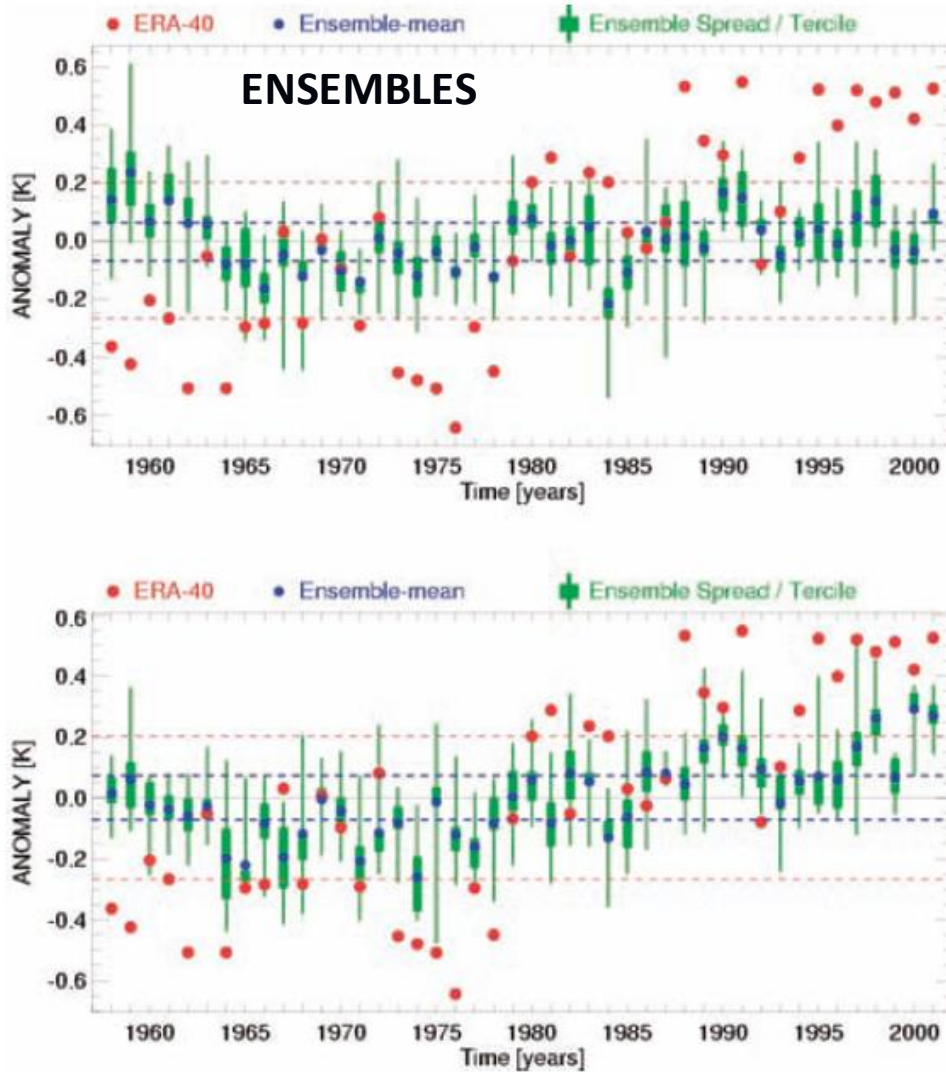
ENSEMBLES

1901-2002
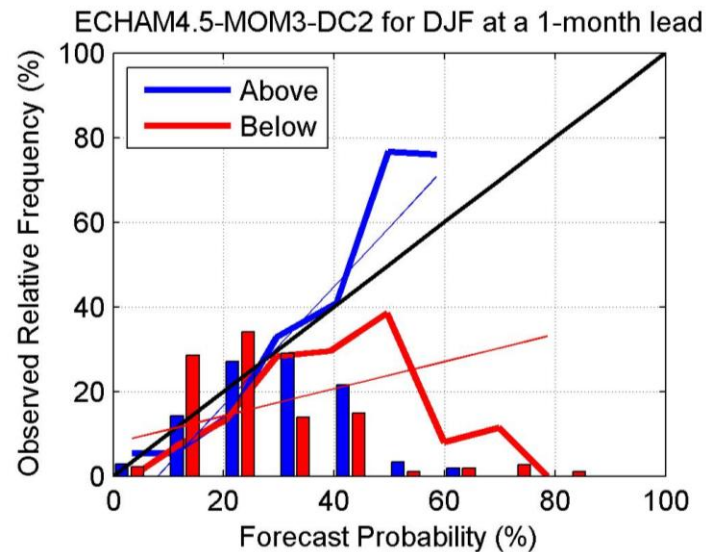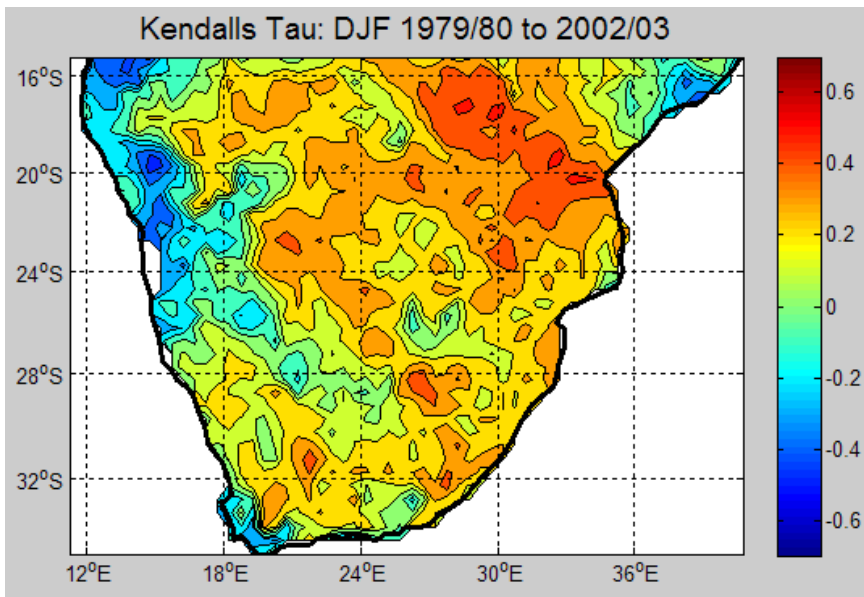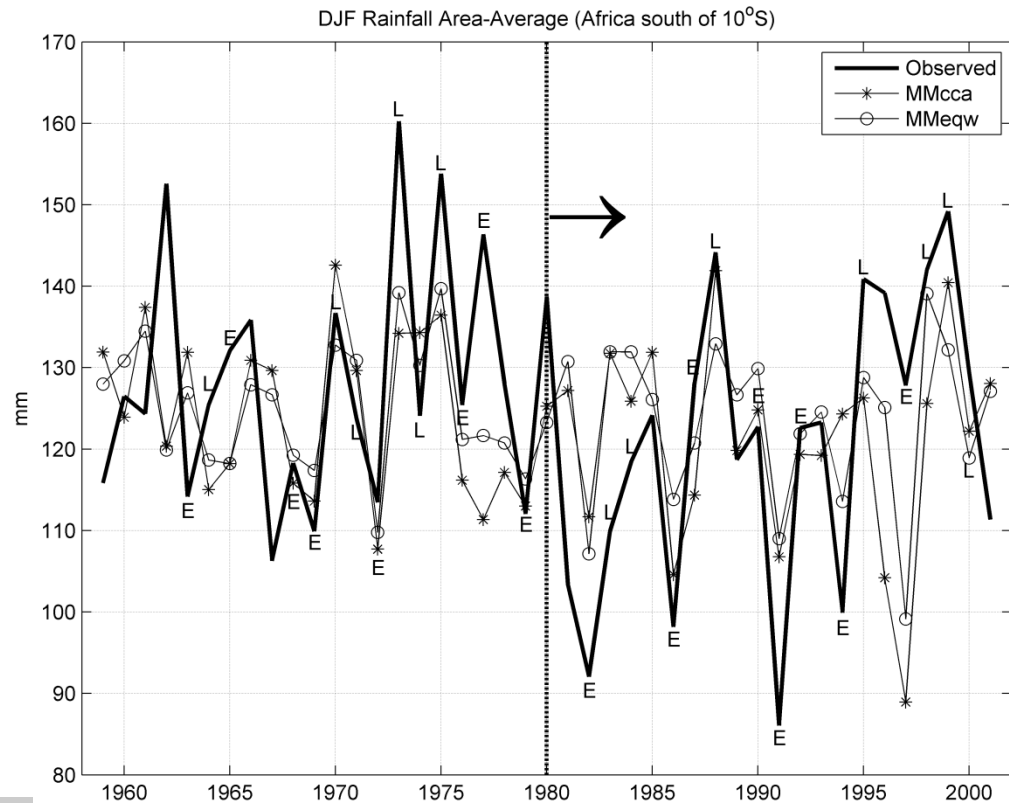
Figure 7.17: ECMWF 3-month lead time hindcasts of global 2 m temperature for August–October without (upper panel) and with (lower panel) time-varying anthropogenic greenhouse gases (GHG). In the upper panel the correlation between the ensemble mean and the observations is only 0.29, whereas this increases to 0.68 with variable GHGs, indicating that including variable greenhouse gas concentrations improves the seasonal forecast/hindcast skill of global mean surface air temperature (after Doblas-Reyes et al., 2006).

Strong anthropogenically forced warming trends have been observed over southern Africa and are projected to continue to rise, consequently justifying the investigation into how the annual update of greenhouse gas (GHG) concentrations in a global model may affect seasonal forecast performance over the region.
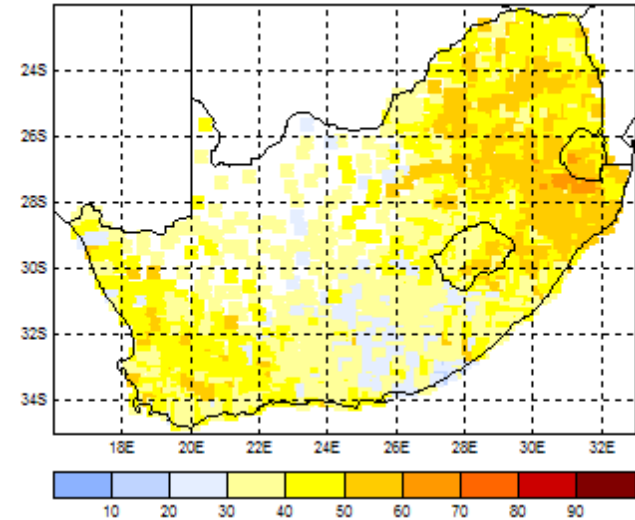
Applications Modelling
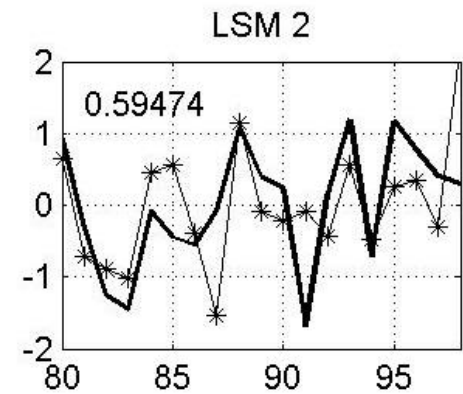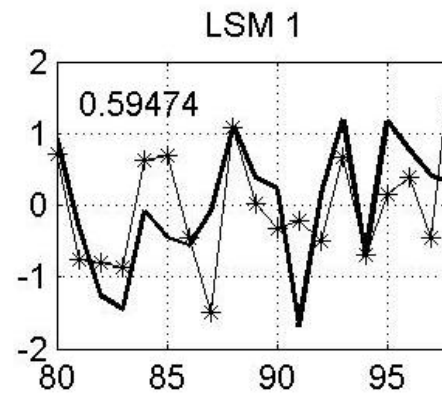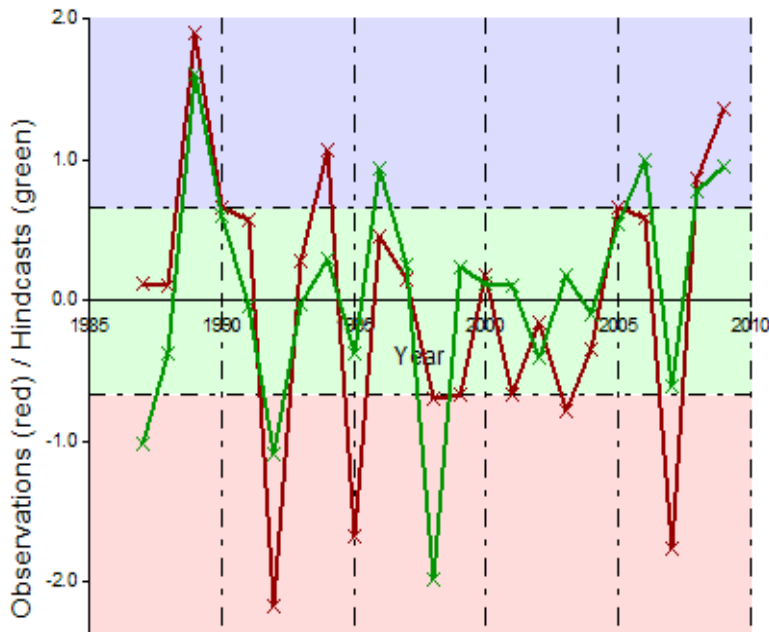

FEBRUARY – MARCH - APRIL 2011

EXTREMELY Above – Normal Accumulated Streamflow
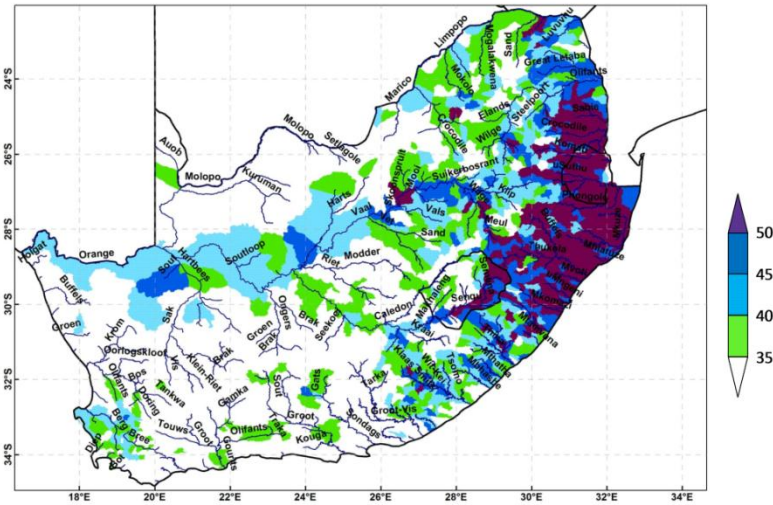
EXTREMELY Above-Normal Accumulated STREAMFLOW

DJF 1999/2000 flooding; ECHAM4.5-MOM3-DC2 fully coupled model forecast late October 1999

LSM 1

0.59474

LSM 2

0.59474

Simulated crop production for growing season

To summarize

- From empirical to physical
- MOS > RCM
- Objective combination > subjective consensus
- CGCMs have great potential
- AGCMs should continue to be optimized
- Downscaling and verification important components of forecast system
- System improvement still continuing, including applications model development