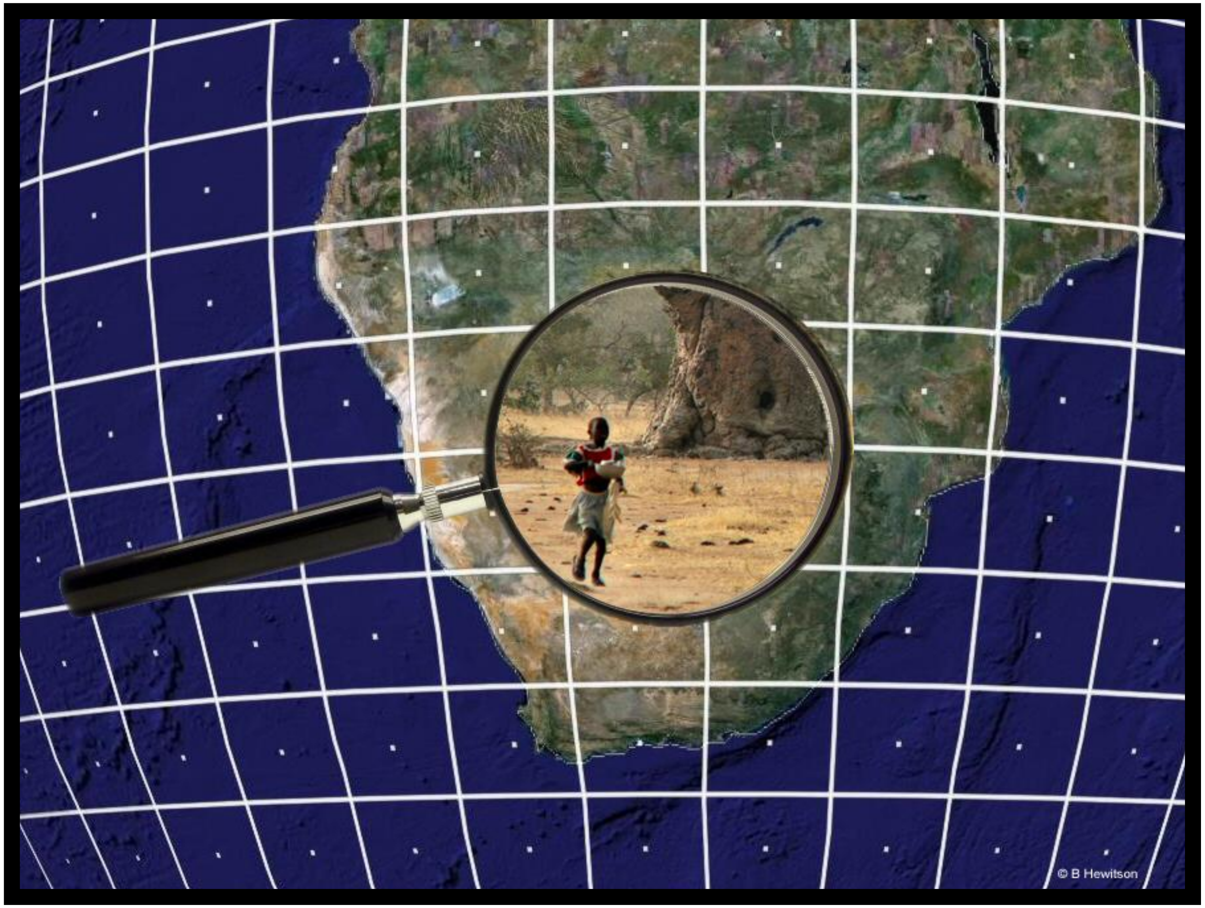
Climate modeling and downscaling:
A flying commentary with WRC at the centre

- History
- Systems
- Processes
- Coupling
- Feedbacks
- Scales
- Uncertainty
- Methods
- Capacity
- Applications
- Challenges



Climate System Analysis Group
CSAG
University of Cape Town

Bruce Hewitson
University of Cape Town

A brief aside: this talk is not about climate change!

a) If you wish to discuss climate change, I am very happy to talk with you in the appropriate context

b) Statements that climate change is a distraction, debatable, or of little relevance, are irresponsible, and have no foundation in the overwhelming body of evidence supported by fundamental physics with consistent signals across multiple lines of evidence.

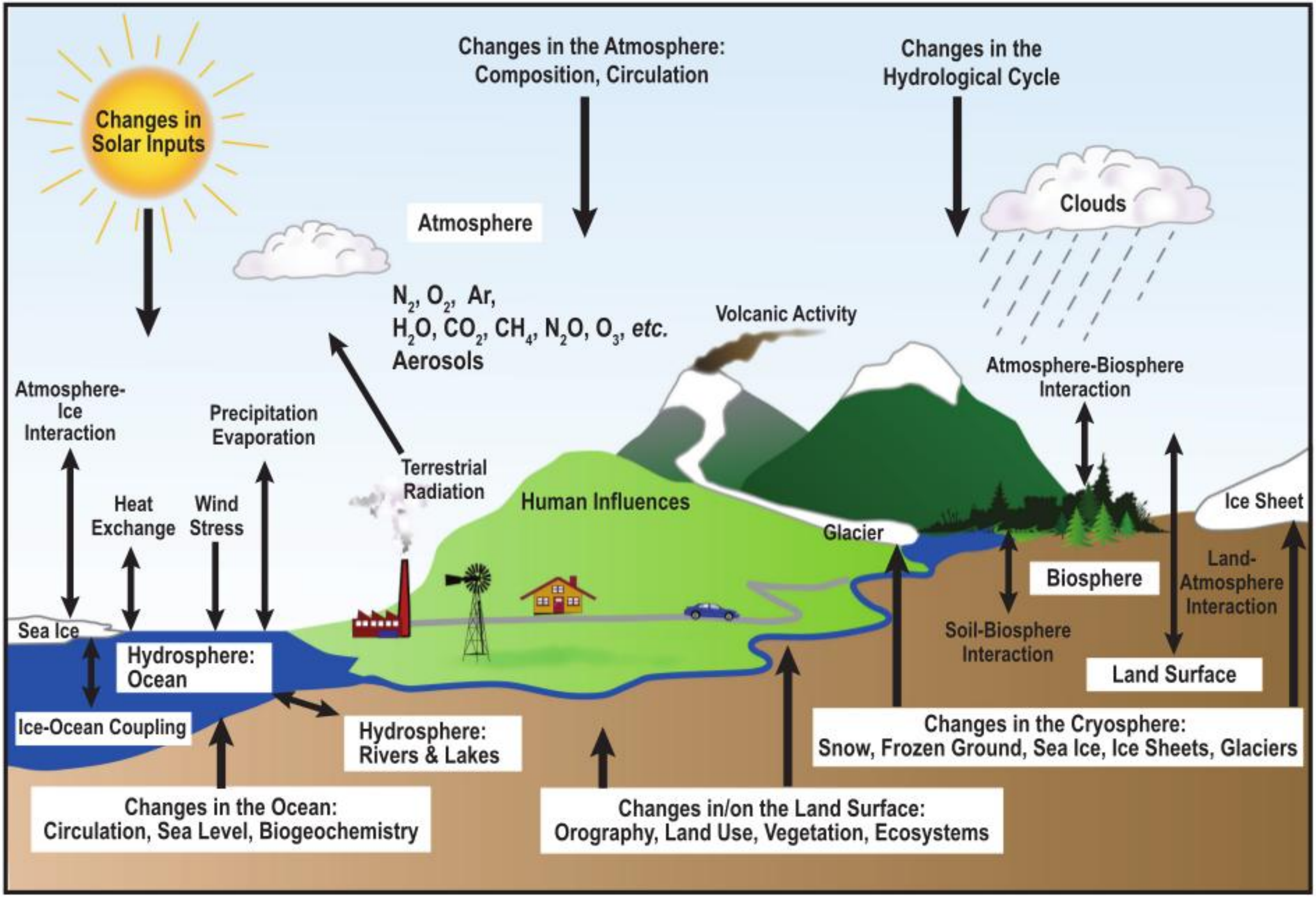
c) Cycles in climate are, by definition, quantifiable. The current historical change cannot be accounted for by cycles.

All models are “wrong” – they are not an exact representation of reality

Climate models, hydrological models, vegetation model, (your investment!) financial models, health models, ecosystem models, etc., etc., are imperfect, because they are reduced complexity

Models are useful to understand & predict systems

Models are absolutely **central** in contemporary research



FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

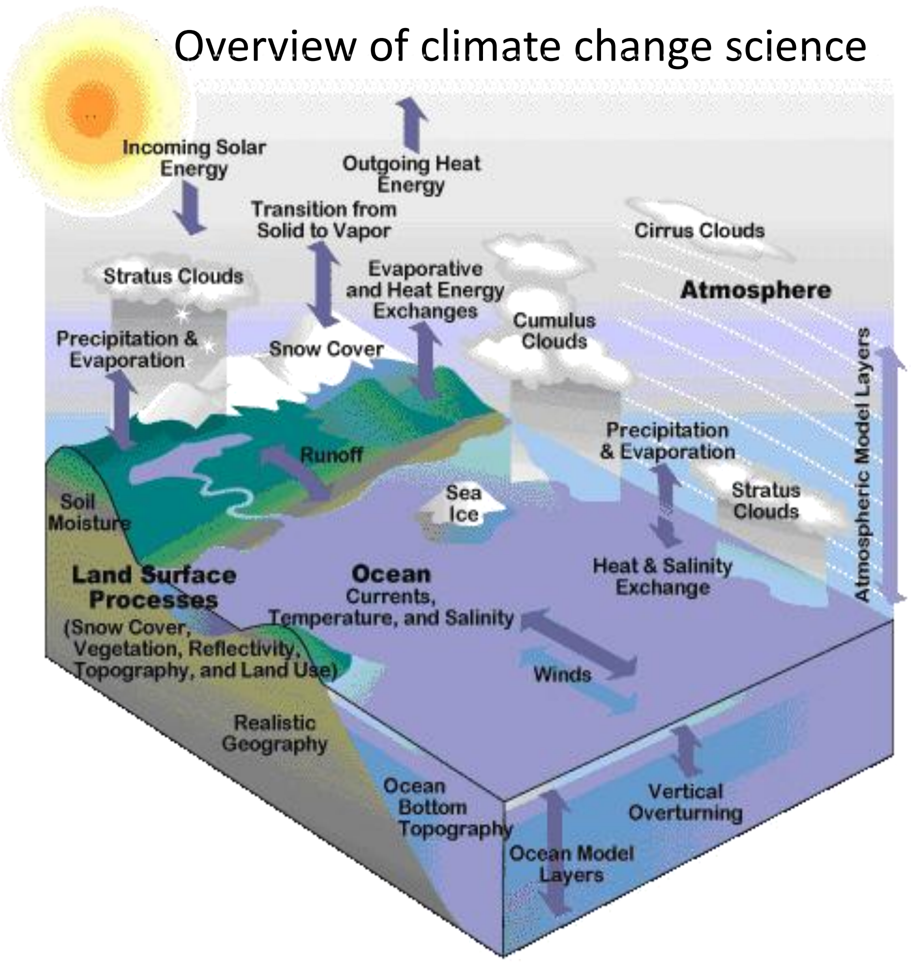
IPCC Ar4 Ch 1

Climate models are built on fundamental physics

Global Climate Models

The basis of (large scale) projections

Overview of climate change science



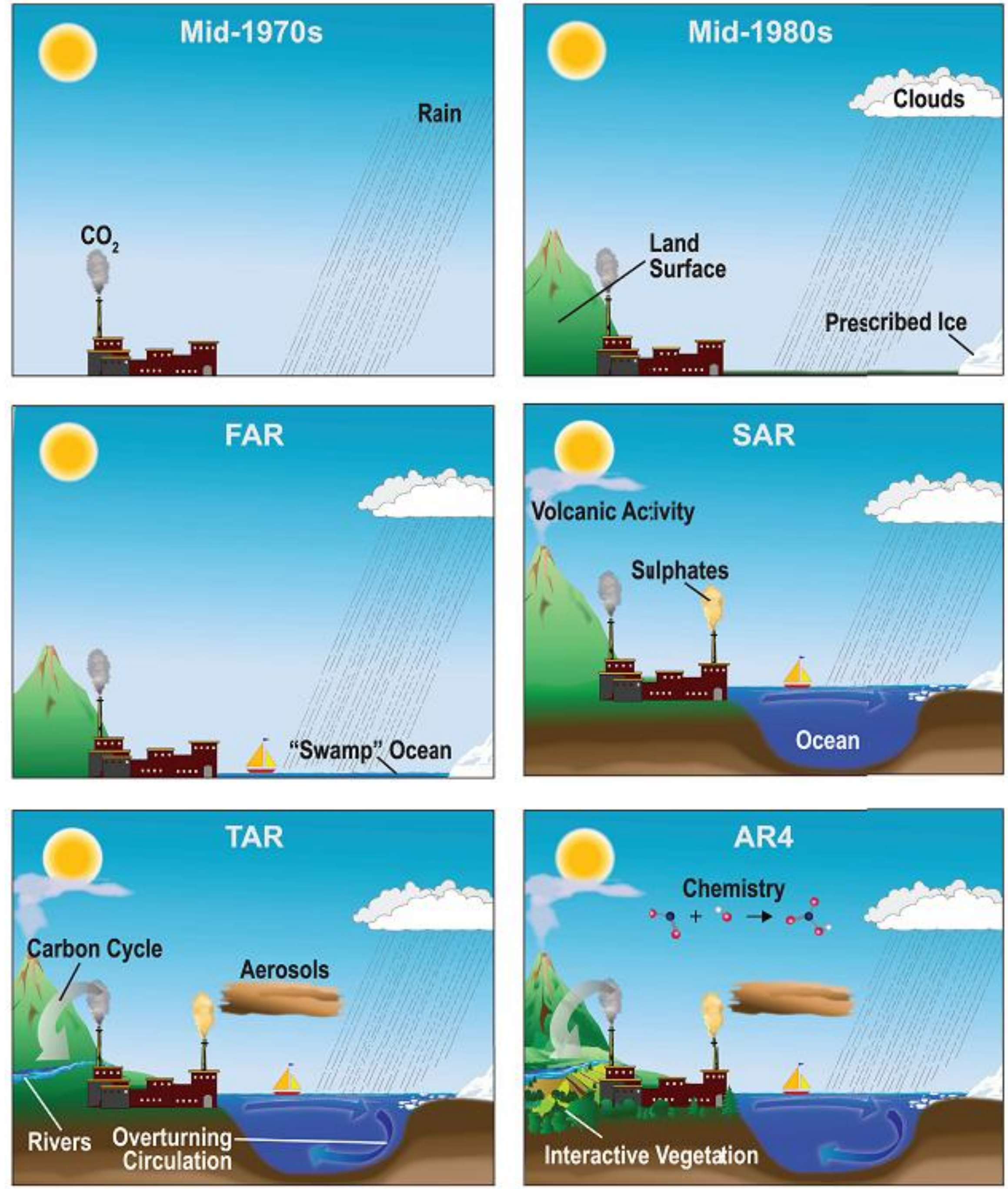
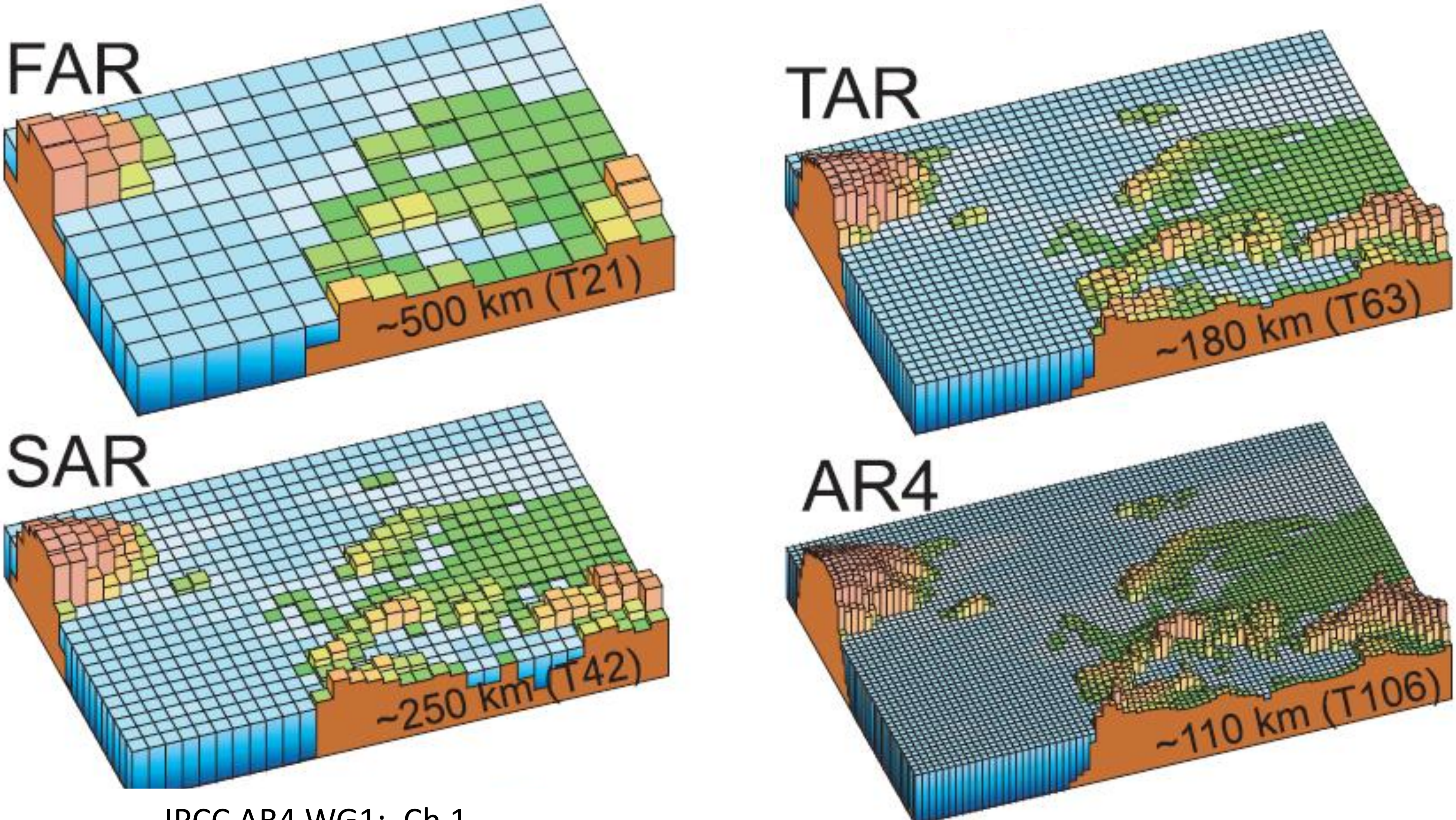


Figure 1.2. *The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.*

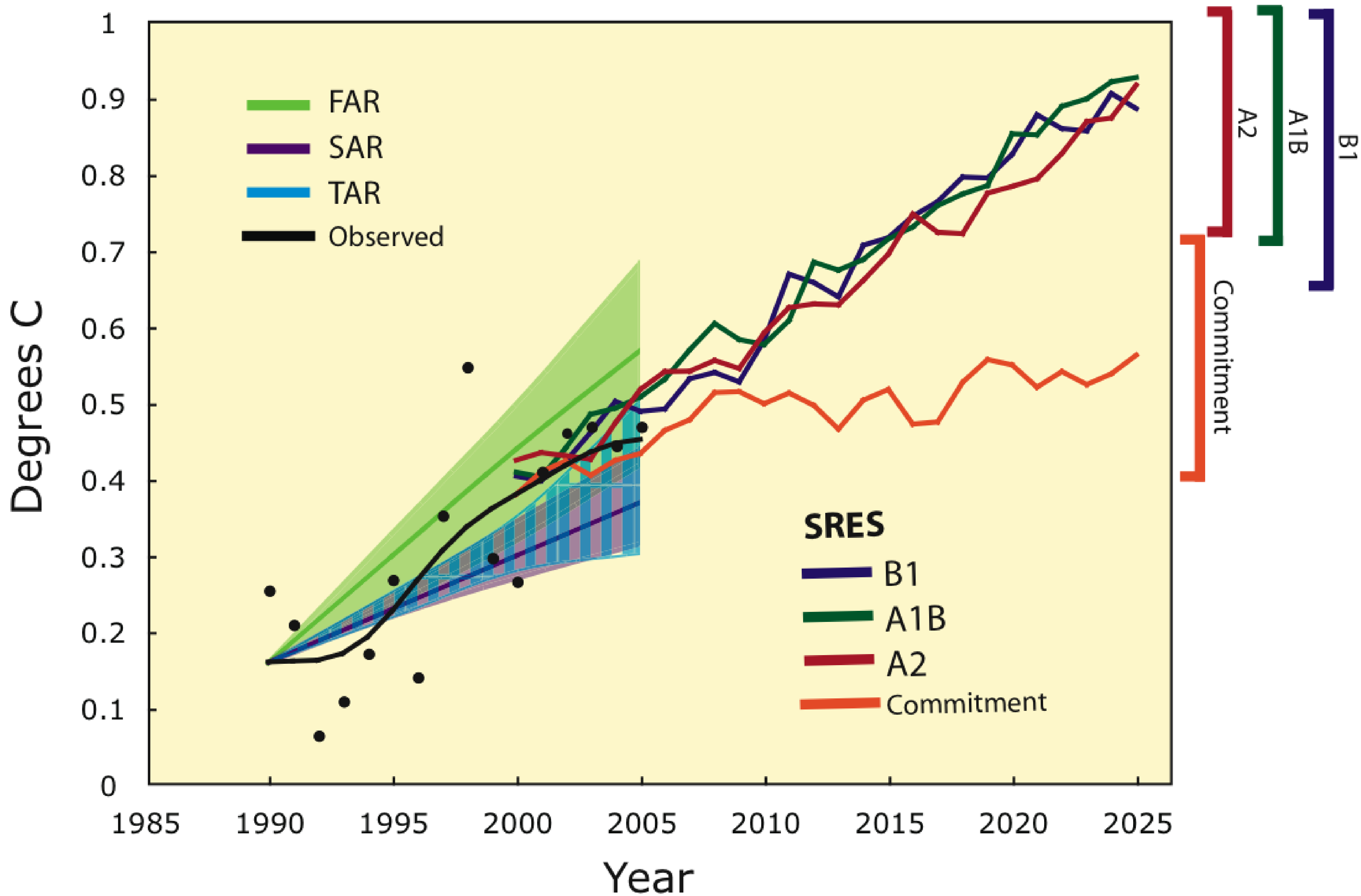
The (implied?) improvement of regional projections



IPCC AR4 WG1: Ch 1

How well do models do?

Observed Temperature change versus IPCC projections



IPCC AR4 TS

Modeling climate in SA: A brief time line

Early 1990's: Weather forecasting modeling (SAWS)

Mid 1990's: Early regional climate modeling (RCMs)
Early learning with statistical downscaling (SD)

Late 1990's: Improved statistical downscaling
Explorations with global models
Increased confidence that robust results will emerge

Early 2000's: Large project work with GCMs, RCMs, & SD
Emerging understanding of uncertainty and limits

Mid-late 2000's: Increased understanding on model limits, model development, new investigative lines on uncertainty / probability, and multi-model ensemble analysis

Present: International collaboration on multi-model multi-method analysis, advances in developing scale relevant messages

WRC 594-1-97

Thus by using the anomaly map one represents the CO_2 forced synoptic response of the local climate within the context of the GCM climate simulation. Figures 14-16 show the anomaly maps for the seasonal mean precipitation and temperature changes.

4. Discussion

4.1 Downscaling functions

The downscaling functions show evident ability to represent the regional climate as a function of synoptic scale forcing. The ANN represents the *generalised* response of regional precipitation and temperature to the current and antecedent circulation to the extent that circulation alone is the dominant control. In this regard the aspects that the ANNs miss are the peak events. Thus while the circulation indicates a given state of synoptic forcing, and hence the regional value for the downscaled variable, there is still variability unaccounted for due to other features, for example, atmospheric water vapour.

Nonetheless, the ANN captures the temporal behaviour of the system well. When considering the seasonal mean values and their close resemblance to the observed data it is apparent that the extreme positive and negative values missed by the ANN lead to little bias in the mean, and this at present tends to generate only a nominal under-prediction. As such the downscaling can be accepted as a valid representation of regional climate response to the larger atmospheric system.

The significance of these results are important in the context of future climate change work for South Africa. While this study is preliminary and uses only one GCM simulation set, the validity of the approach is demonstrated and holds promise for further extension to newer simulation data sets from different models. In doing so an evaluation of model consensus between model simulations may be derived which is important for building a basis of credibility for a particular scenario's implications.

4.2 GCM control simulation

Application of the downscaling demonstrates that the Genesis GCM v1.02 simulates synoptic scale forcing with reliable accuracy as shown by the comparison of the downscaled values with respect to those derived from the observed circulation patterns.

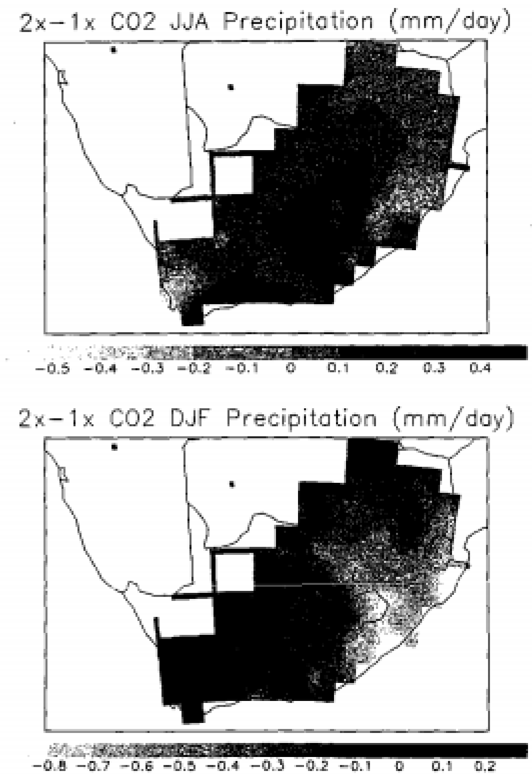


Figure 14: $2xCO_2$ - $1xCO_2$ circulation-predicted anomaly precipitation.

Early project on <u>statistical downscaling</u> from a single GCM produced results (in hindsight, wrong), but revealed valuable methodological understanding (and with bad quality figures)

Climate System Analysis Group
CSAG
University of Cape Town

WRC 806-1-01

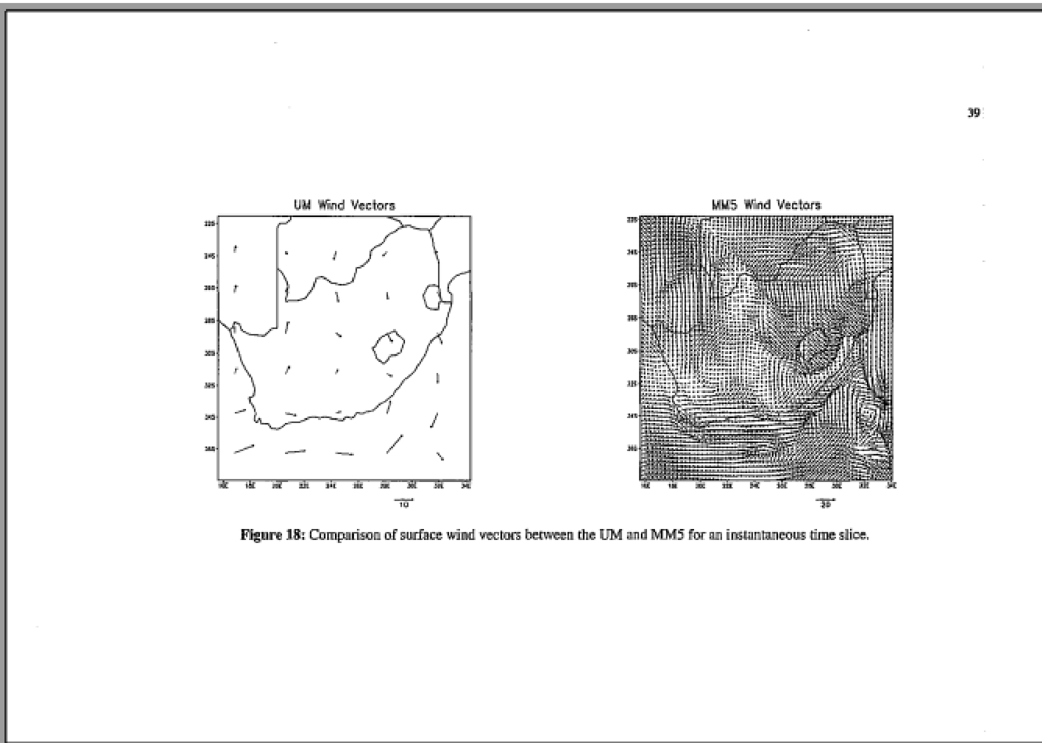

39

Figure 18: Comparison of surface wind vectors between the UM and MM5 for an instantaneous time slice.

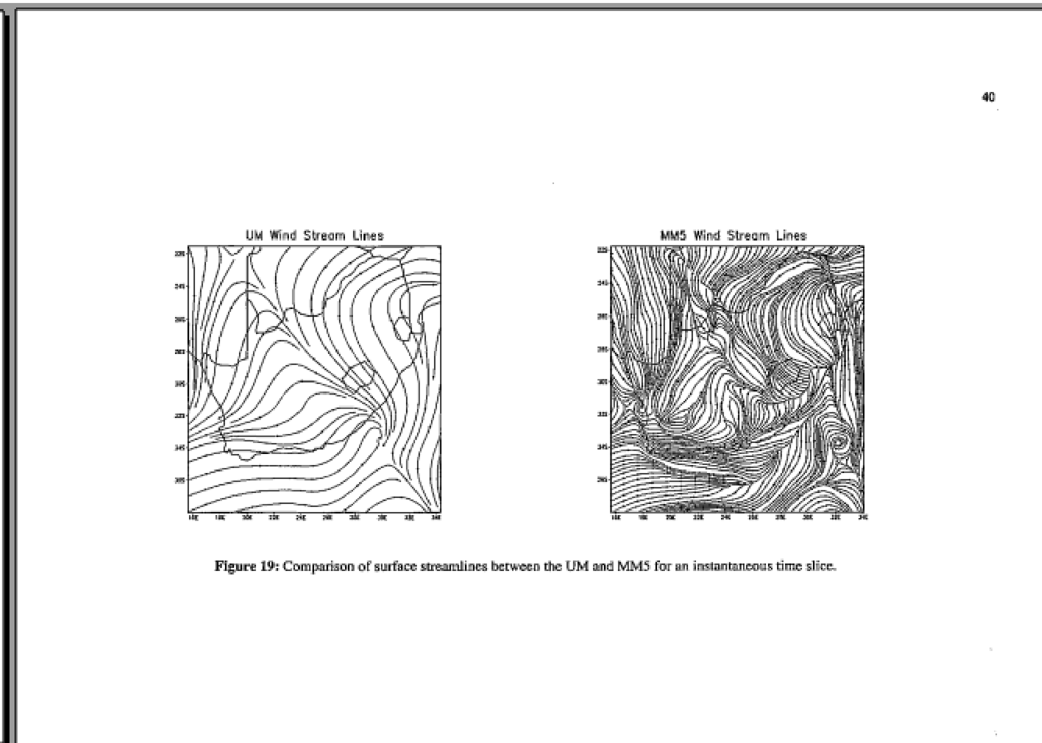

40

Figure 19: Comparison of surface streamlines between the UM and MM5 for an instantaneous time slice.

Projects working with GCMs and nested RCMs were pivotal in catalyzing new researcher capacity, building experiential knowledge, and led to insights into the model limitations with simulating southern Africa climate (figures now at least readable)

WRC 904-01-03

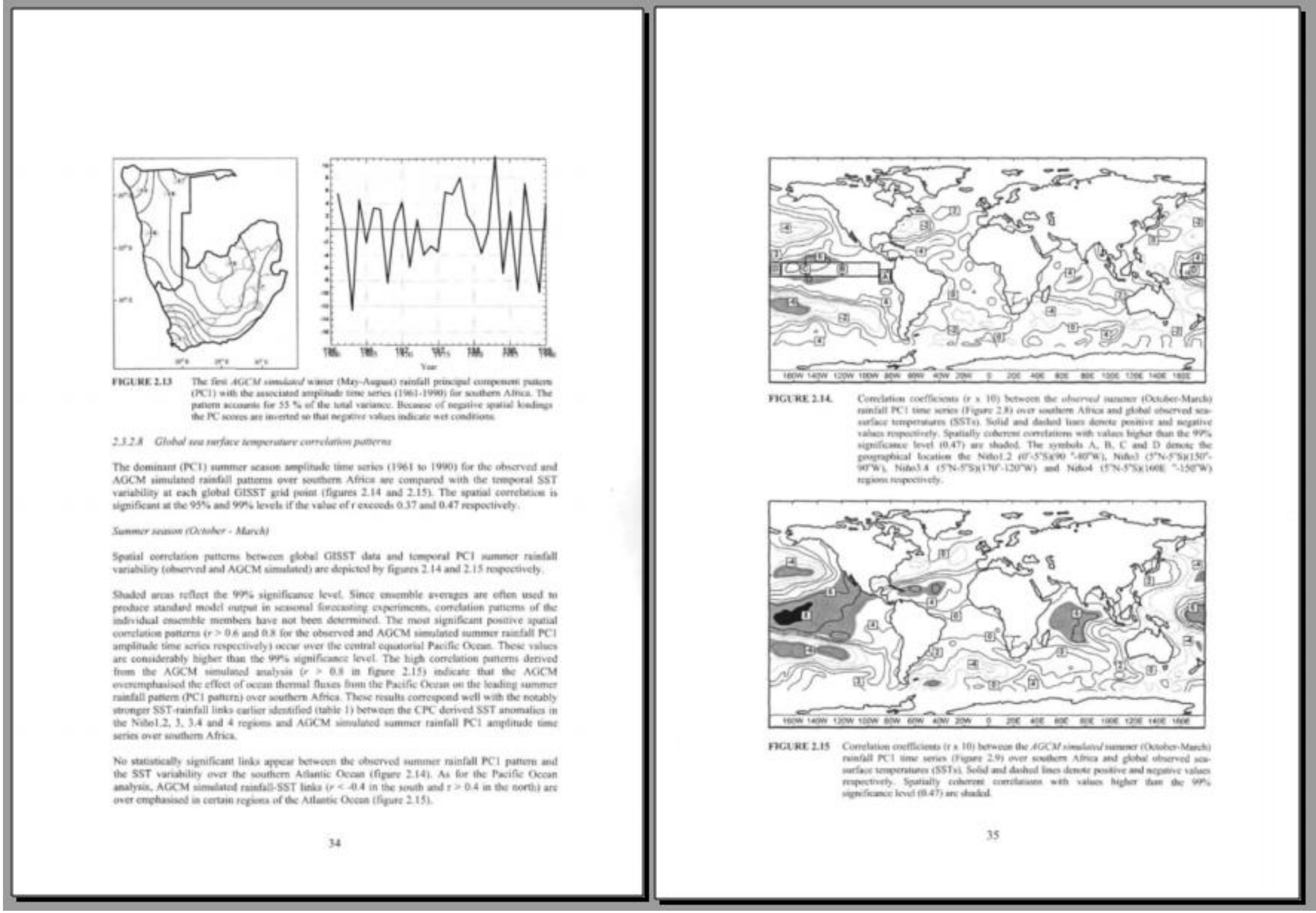


FIGURE 2.13 The first *AGCM simulated* winter (May-August) rainfall principal component pattern (PC1) with the associated amplitude time series (1961-1990) for southern Africa. The pattern accounts for 55 % of the total variance. Because of negative spatial loadings the PC scores are inverted so that negative values indicate wet conditions.

2.3.2.8 Global sea surface temperature correlation patterns

The dominant (PC1) summer season amplitude time series (1961 to 1990) for the observed and AGCM simulated rainfall patterns over southern Africa are compared with the temporal SST variability at each global GISST grid point (figures 2.14 and 2.15). The spatial correlation is significant at the 95% and 99% levels if the value of r exceeds 0.37 and 0.47 respectively.

Summer season (October - March)

Spatial correlation patterns between global GISST data and temporal PC1 summer rainfall variability (observed and AGCM simulated) are depicted by figures 2.14 and 2.15 respectively.

Shaded areas reflect the 99% significance level. Since ensemble averages are often used to produce standard model output in seasonal forecasting experiments, correlation patterns of the individual ensemble members have not been determined. The most significant positive spatial correlation patterns ($r > 0.6$ and 0.8 for the observed and AGCM simulated summer rainfall PC1 amplitude time series respectively) occur over the central equatorial Pacific Ocean. These values are considerably higher than the 99% significance level. The high correlation patterns derived from the AGCM simulated analysis ($r > 0.8$ in figure 2.15) indicate that the AGCM overemphasised the effect of ocean thermal fluxes from the Pacific Ocean on the leading summer rainfall pattern (PC1 pattern) over southern Africa. These results correspond well with the notably stronger SST-rainfall links earlier identified (table 1) between the CPC derived SST anomalies in the Niño1.2, 3, 3.4 and 4 regions and AGCM simulated summer rainfall PC1 amplitude time series over southern Africa.

No statistically significant links appear between the observed summer rainfall PC1 pattern and the SST variability over the southern Atlantic Ocean (figure 2.14). As for the Pacific Ocean analysis, AGCM simulated rainfall-SST links ($r < -0.4$ in the south and $r > 0.4$ in the north) are over emphasised in certain regions of the Atlantic Ocean (figure 2.15).

34

FIGURE 2.14. Correlation coefficients (r x 10) between the *observed* summer (October-March) rainfall PC1 time series (Figure 2.8) over southern Africa and global observed sea-surface temperatures (SSTs). Solid and dashed lines denote positive and negative values respectively. Spatially coherent correlations with values higher than the 99% significance level (0.47) are shaded. The symbols A, B, C and D denote the geographical location the Niño1.2 (0°-5°S)(90°-80°W), Niño3 (5°N-5°S)(150°-90°W), Niño3.4 (5°N-5°S)(170°-120°W) and Niño4 (5°N-5°S)(160E°-150°W) regions respectively.

FIGURE 2.15 Correlation coefficients (r x 10) between the *AGCM simulated* summer (October-March) rainfall PC1 time series (Figure 2.9) over southern Africa and global observed sea-surface temperatures (SSTs). Solid and dashed lines denote positive and negative values respectively. Spatially coherent correlations with values higher than the 99% significance level (0.47) are shaded.

35

<u>Multi-institutional collaboration</u> on seasonal forecasting opened possibilities and raised expectations of major developments (but still no colour figures!)

WRC 1154-1-04

(Colour figs!)

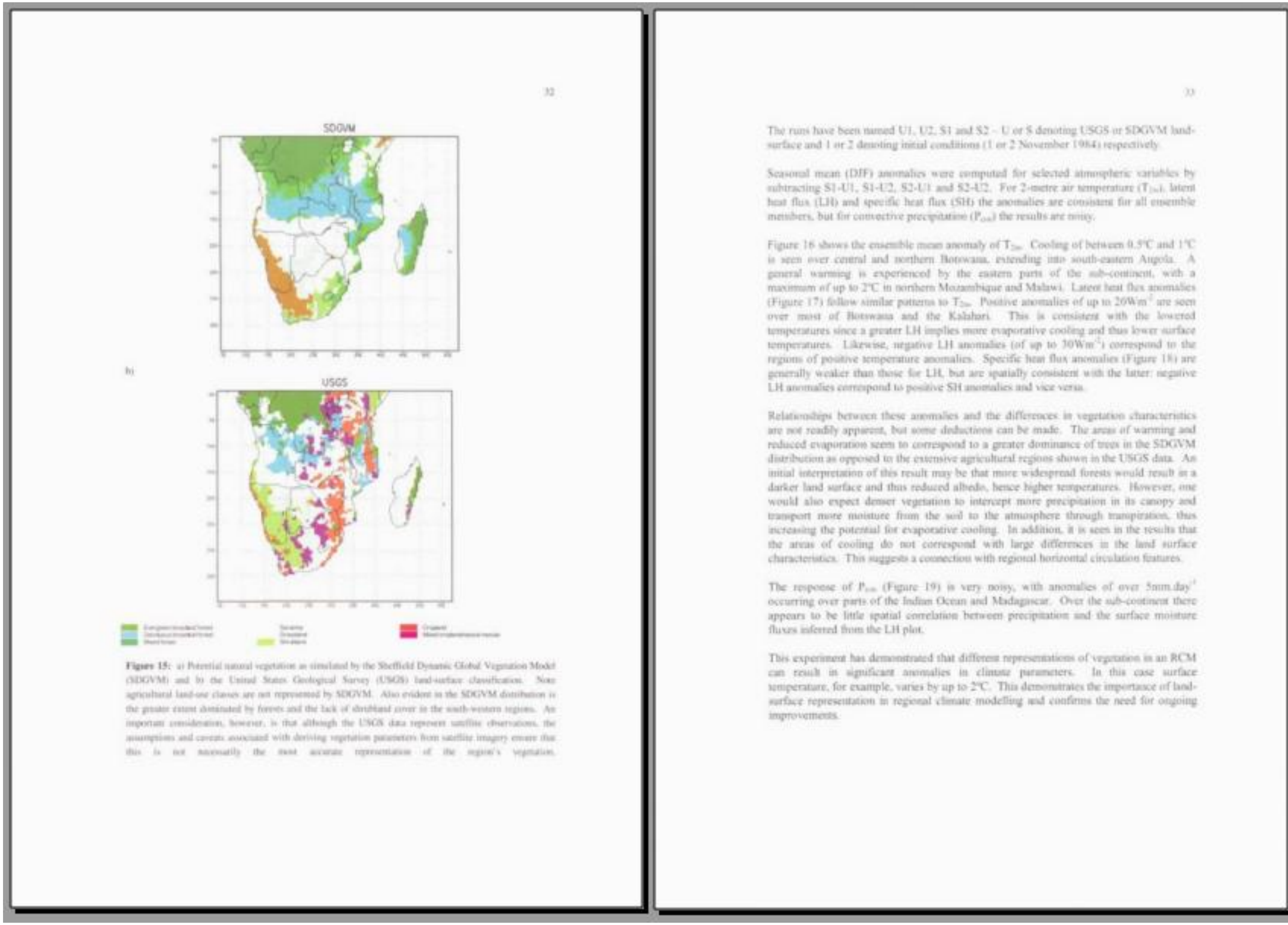


Figure 15: a) Potential natural vegetation as simulated by the Sheffield Dynamic Global Vegetation Model (SDGVM) and b) the United States Geological Survey (USGS) land-surface classification. Note agricultural land-use classes are not represented by SDGVM. Also evident in the SDGVM distribution is the greater extent dominated by forests and the lack of shrubland cover in the south-western regions. An important consideration, however, is that although the USGS data represent satellite observations, the assumptions and caveats associated with deriving vegetation parameters from satellite imagery ensure that this is not necessarily the most accurate representation of the region's vegetation.

The runs have been named U1, U2, S1 and S2 – U or S denoting USGS or SDGVM land-surface and 1 or 2 denoting initial conditions (1 or 2 November 1984) respectively.

Seasonal mean (DJF) anomalies were computed for selected atmospheric variables by subtracting S1-U1, S1-U2, S2-U1 and S2-U2. For 2-metre air temperature (T_{2m}), latent heat flux (LH) and specific heat flux (SH) the anomalies are consistent for all ensemble members, but for convective precipitation (P_{cnv}) the results are noisy.

Figure 16 shows the ensemble mean anomaly of T_{2m}. Cooling of between 0.5°C and 1°C is seen over central and northern Botswana, extending into south-eastern Angola. A general warming is experienced by the eastern parts of the sub-continent, with a maximum of up to 2°C in northern Mozambique and Malawi. Latent heat flux anomalies (Figure 17) follow similar patterns to T_{2m}. Positive anomalies of up to $20Wm^{-2}$ are seen over most of Botswana and the Kalahari. This is consistent with the lowered temperatures since a greater LH implies more evaporative cooling and thus lower surface temperatures. Likewise, negative LH anomalies (of up to $30Wm^{-2}$) correspond to the regions of positive temperature anomalies. Specific heat flux anomalies (Figure 18) are generally weaker than those for LH, but are spatially consistent with the latter: negative LH anomalies correspond to positive SH anomalies and vice versa.

Relationships between these anomalies and the differences in vegetation characteristics are not readily apparent, but some deductions can be made. The areas of warming and reduced evaporation seem to correspond to a greater dominance of trees in the SDGVM distribution as opposed to the extensive agricultural regions shown in the USGS data. An initial interpretation of this result may be that more widespread forests would result in a darker land surface and thus reduced albedo, hence higher temperatures. However, one would also expect denser vegetation to intercept more precipitation in its canopy and transport more moisture from the soil to the atmosphere through transpiration, thus increasing the potential for evaporative cooling. In addition, it is seen in the results that the areas of cooling do not correspond with large differences in the land surface characteristics. This suggests a connection with regional horizontal circulation features.

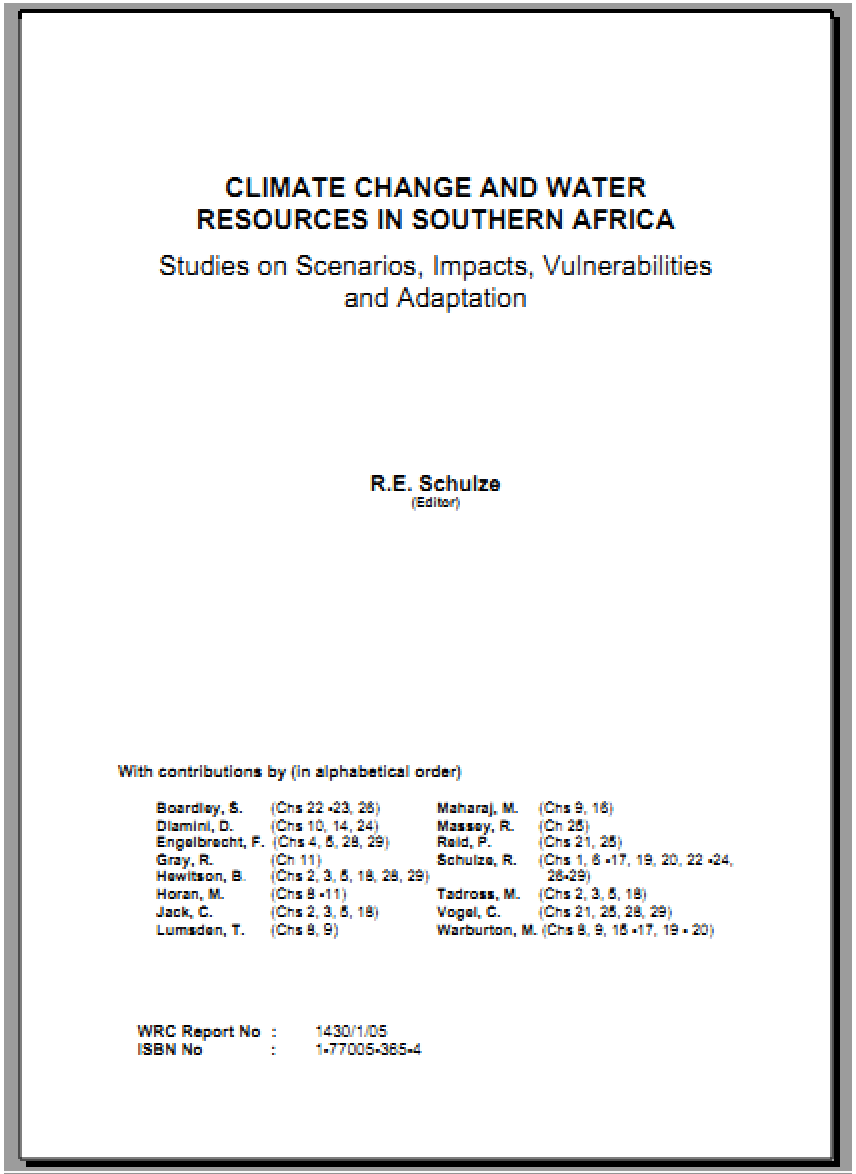
The response of P_{cnv} (Figure 19) is very noisy, with anomalies of over $5mm.day^{-1}$ occurring over parts of the Indian Ocean and Madagascar. Over the sub-continent there appears to be little spatial correlation between precipitation and the surface moisture fluxes inferred from the LH plot.

This experiment has demonstrated that different representations of vegetation in an RCM can result in significant anomalies in climate parameters. In this case surface temperature, for example, varies by up to 2°C. This demonstrates the importance of land-surface representation in regional climate modelling and confirms the need for ongoing improvements.

Large project teams use the models to explore fundamental dynamics of the climate system, including feedbacks, scale dependencies, high resolution simulations, multi-model responses, and extreme events

WRC 1430-01-05

(Many colour figs!)



CLIMATE CHANGE AND WATER RESOURCES IN SOUTHERN AFRICA

Studies on Scenarios, Impacts, Vulnerabilities and Adaptation

R.E. Schulze
(Editor)

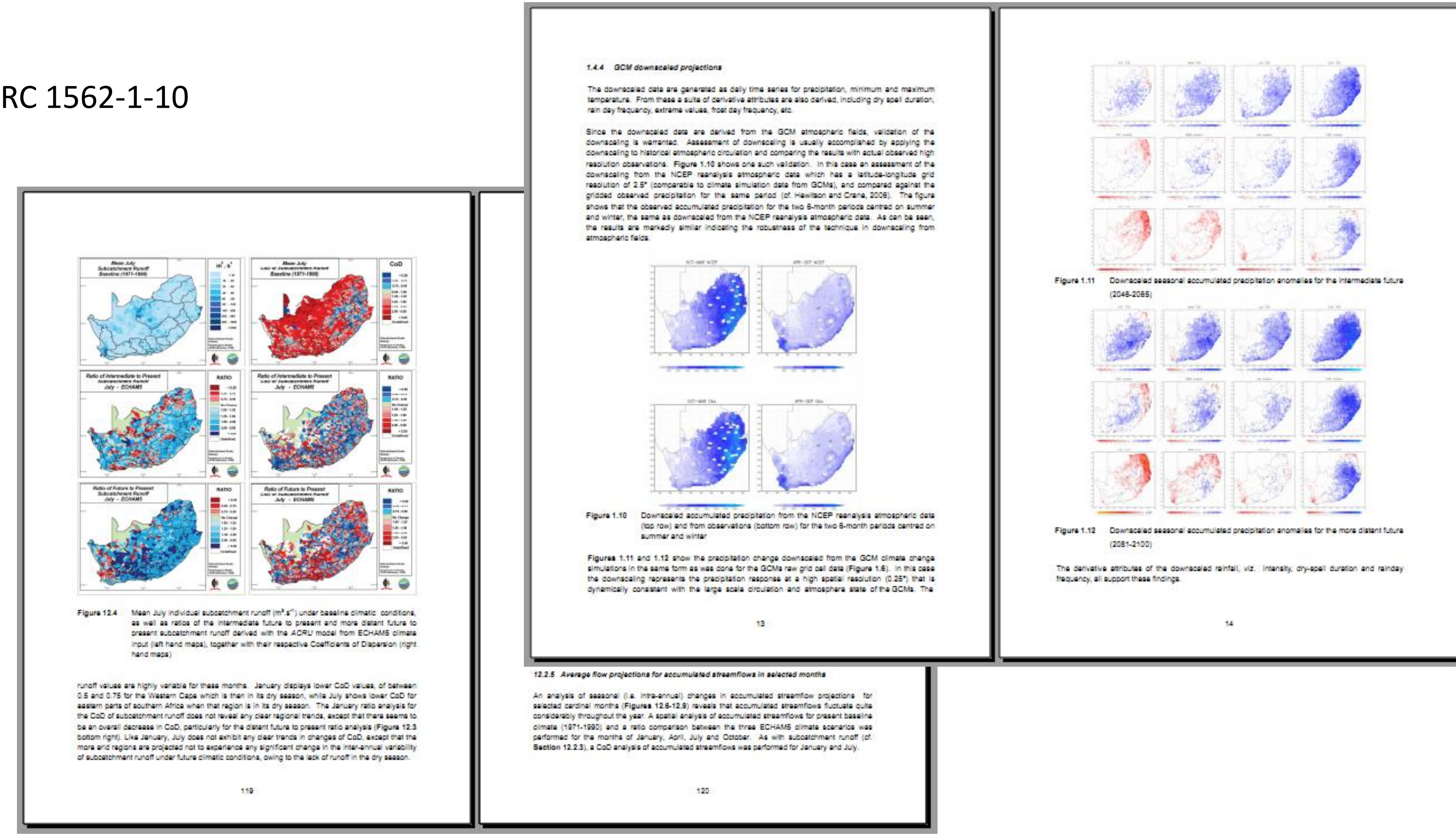
With contributions by (in alphabetical order)

Boardley, S.	(Chs 22 -23, 26)	Maharaj, M.	(Chs 9, 16)
Dlamini, D.	(Chs 10, 14, 24)	Massey, R.	(Ch 25)
Engelbrecht, F.	(Chs 4, 5, 28, 29)	Reid, P.	(Chs 21, 25)
Gray, R.	(Ch 11)	Schulze, R.	(Chs 1, 6 -17, 19, 20, 22 -24, 26-29)
Hewitson, B.	(Chs 2, 3, 5, 18, 28, 29)		
Horan, M.	(Chs 8 -11)	Tadross, M.	(Chs 2, 3, 5, 18)
Jack, C.	(Chs 2, 3, 5, 18)	Vogel, C.	(Chs 21, 25, 28, 29)
Lumsden, T.	(Chs 8, 9)	Warburton, M.	(Chs 8, 9, 15 -17, 19 - 20)

WRC Report No : 1430/1/05
ISBN No : 1-77005-365-4

Multi-institutional large project teams expand to more in-depth exploration of coupling global models, downscaling, and impact models. This was a period of a shift in the centre of gravity of research to explore coupling with impacts.

WRC 1562-1-10



Extensive exploration of the emerging robust messages and their <u>regional eco-hydrological responses</u> to South African climate using coupling of GCMs, downscaling, and hydrological modeling

WRC 1566-1-09
WRC 1681-1-10

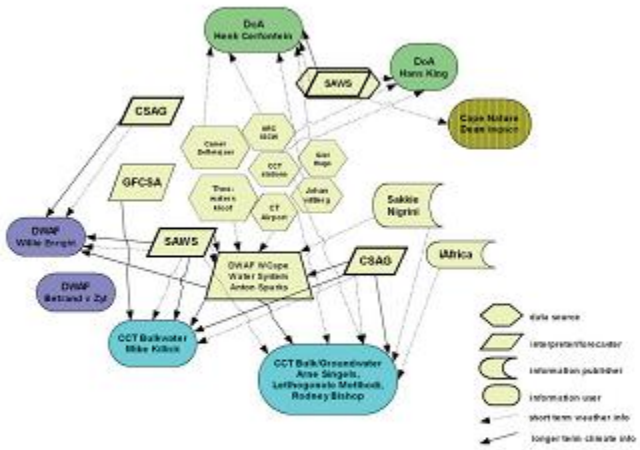


Figure 3: Stakeholder networks emerging from Cape Town interviews

CCT water managers

CCT bulk water managers used shorter term (daily to fortnightly) forecasts to manage the water in dams. Forecasts informed their decisions on which dam(s) to draw on at that time to supply Cape Town as well as on movement of water from one dam to another. Forecasts were used to inform the water managers in their planning decisions sent to operations, were discussed with others (especially DWAF), and were reported in water liaison meetings and to politicians. The most important aspect of the forecast was rainfall intensity and thus runoff.

Seasonal forecasts were mainly used in drought management. Longer-term forecasts were seen as less skilful than short-term forecasts. Long-term predictions such as climate change scenarios informed their thinking of future resources along the line of diversification.

> *"If I take note of climate change it doesn't necessarily tell me what to do with water management."*

DWAF water managers

DWAF water managers use 1-7 day, monthly and 3-monthly forecasts from CSAG and SAWS as part of their decision-making, but use Ninham Shand's bulletin especially.

21

precipitation are accompanied by changes in clouds as represented by the cloud mixing ratio (Figure 47c) and regions of convergence in 745 hPa winds (Figure 47d). Differences in convergence and winds at these lower levels are consistent with the anticyclonic anomaly demonstrated in Figure 46, resulting in areas of divergence over Namibia and southwest South Africa.

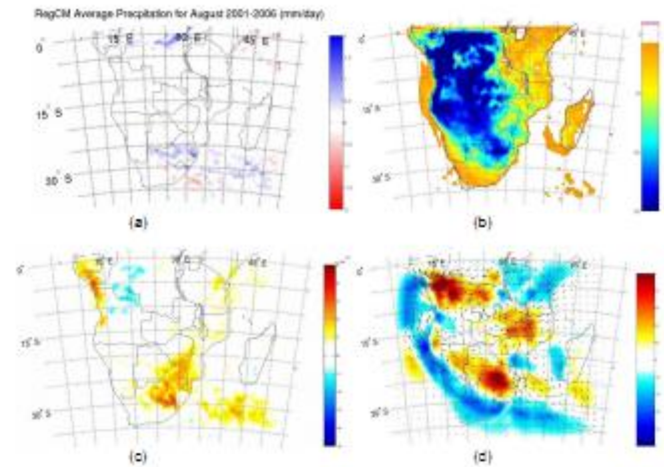


Figure 47: Simulated mean differences (aerosol – no aerosols), during August for (a) precipitation (mm day^{-1}), (b) plantary boundary layer height (m), (c) cloud mixing ratio (kg/kg) and (d) 745 hPa winds (ms^{-1}).

2.7 Summary of modelling experiments

The modelling work shown here will continue and form the basis of student research beyond the lifetime of this project. There has been great diversification in the approach to the modelling during the last 12 months. The inclusion of the aerosol modelling has made some initial inroads to fill a significant knowledge gap in our modelling of the known terrestrial forcings of southern African climate during the early summer season. Whilst all these modelling results provide a sound basis for understanding how these terrestrial forcings of climate work individually, there is plenty of scope for future work to understand how the climate may change when these forcings act together e.g. biomass burning produces aerosols but also reduces vegetation and alters the land surface at the same time.

Several clear messages are discernible from these modelling experiments:

- Soil moisture perturbations affect the lower boundary layers, more so in early spring than later in summer. Dry/wet soil moisture conditions have positive feedbacks with similar (wet/dry) synoptic forcings of the regional climate. The evidence in these experiments is that a dry forcing persists for longer and promotes a larger change in the regional circulation;

48

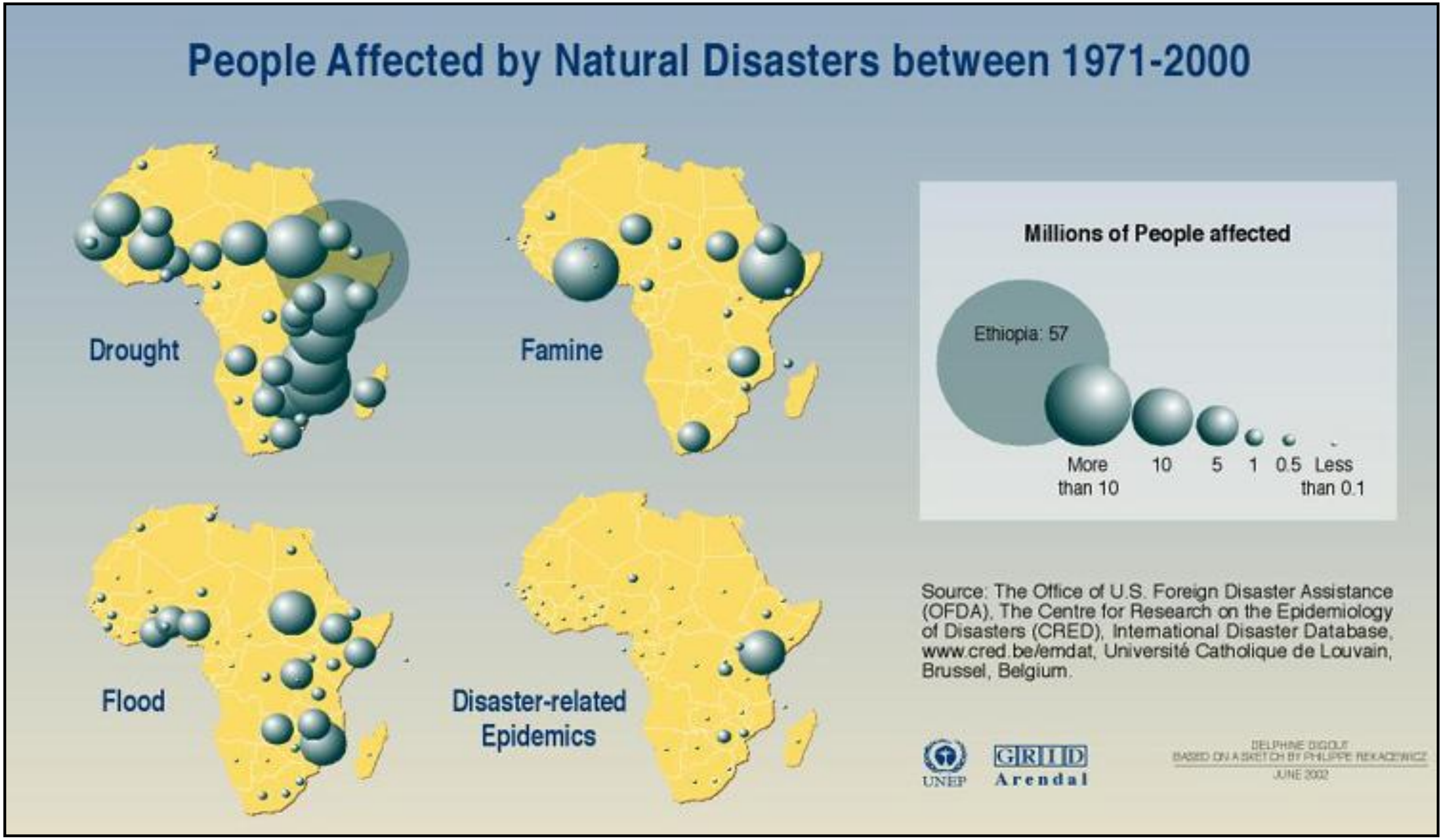
<u>Expansion of activities</u> into diverse research areas, including exploring climate information relevant to stakeholder's decision-space, and digging into fundamental physical process issues such as the role of aerosols.

Questions we need to stop and periodically ask

- Why model … what is the imperative behind this approach?
- What is our goal in modeling?
- Which are the current priority knowledge gaps that relate to advancing the value of our research?

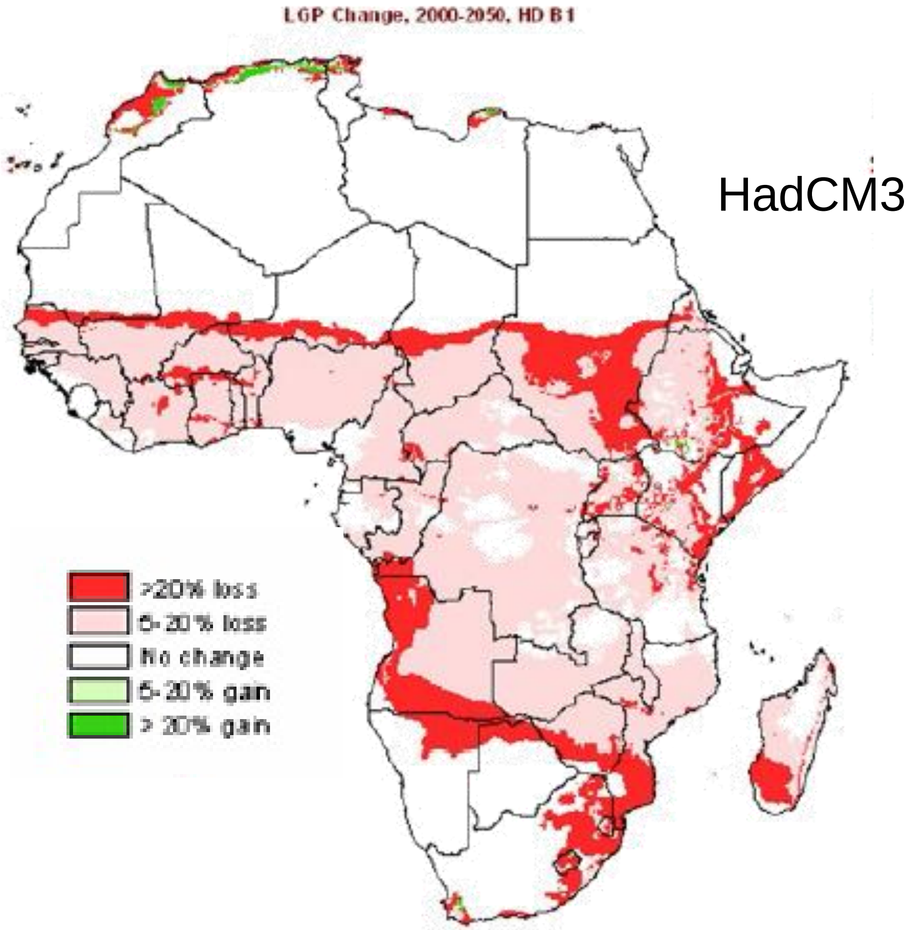
<u>Why</u> are we focusing on modeling?

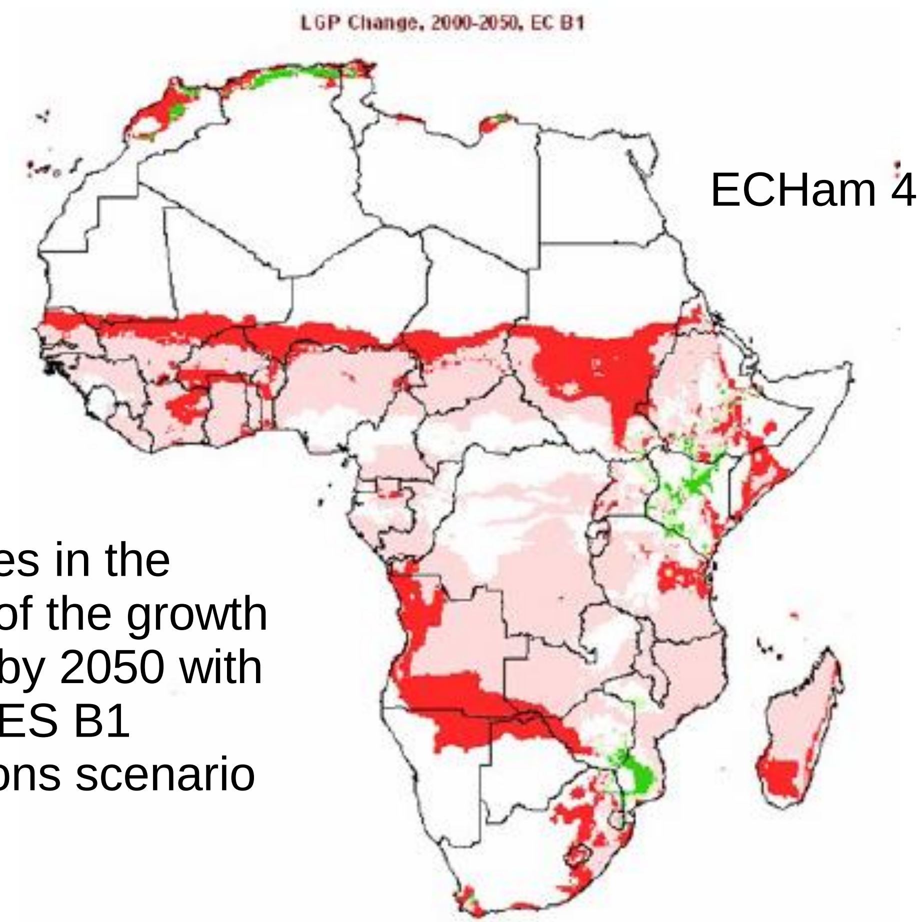
Climate is now non-stationary … a human-modulated moving target! If we cannot **<u>predict</u>**, all we can do is react.



<u>Why</u> are we focusing on this?

The changing dynamics are already beginning to exceed the operating parameters of some social and physical systems. Impact comes through <u>exceeding thresholds</u>.



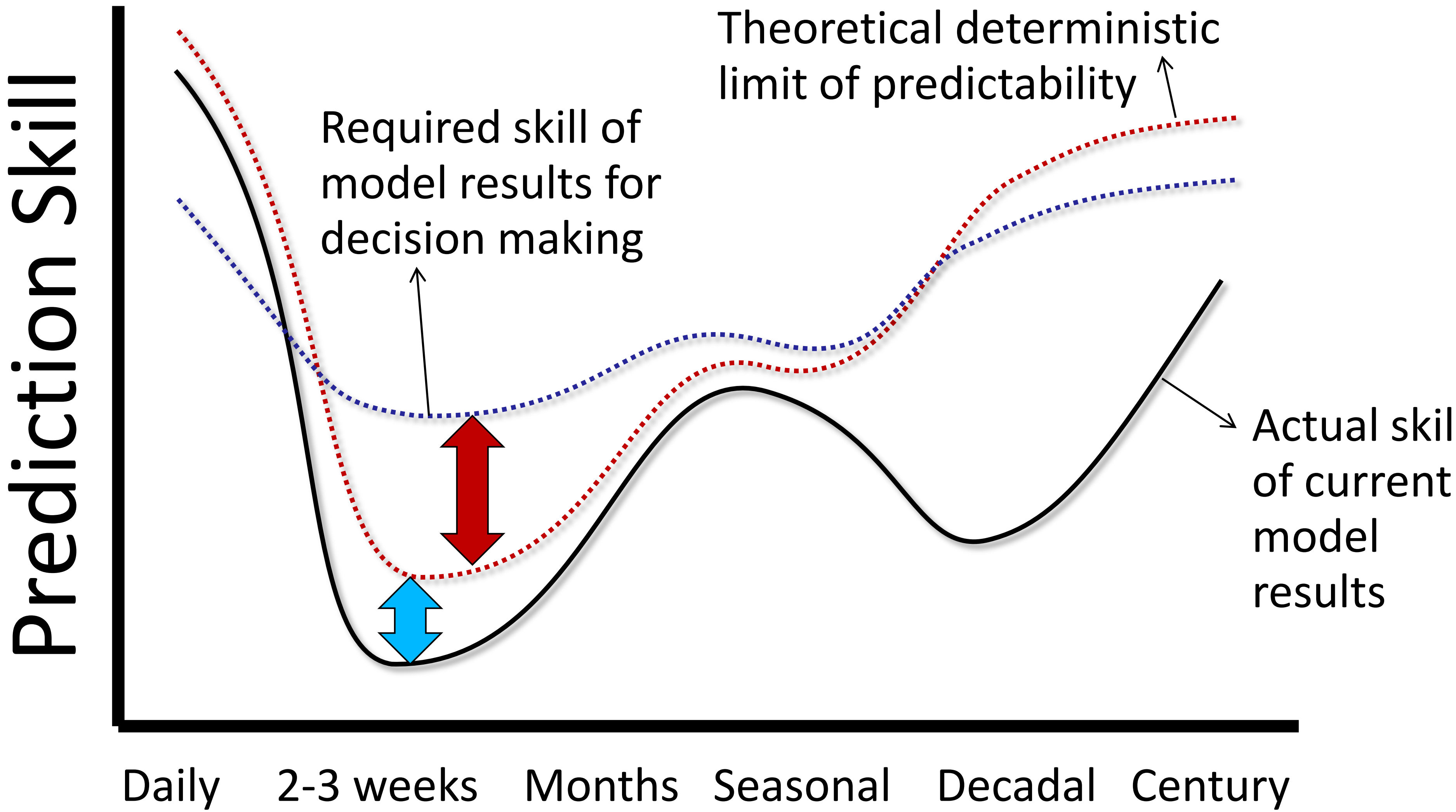


Changes in the length of the growth period by 2050 with the SRES B1 emissions scenario

Source: ILRI/TERI/ACTS, 2006

What are we trying to achieve with modeling

For a given spatial scale, variable, and application, the prediction skill is a function of time scale



The questions that producers of climate information need to answer:

1. Is the message plausible: Does it fall within the envelope of known possible variability?

2. Is the message defensible: On a regional scale, am I able to explain the understanding in terms of physical processes and dynamics?

3. Is the message actionable: at the time and space scales of user decision making, can I defend decisions based on the probabilistic climate information? (Would I spend my own money?)

Delivered by science

Needed by society

Data

Climate models, historical observations, trends, downscaling, projections, event frequency, …

→ **Generated by models, analyses, downscaling, observations …**

↓

Information

Measures of vulnerability and risk, threshold exceedence, combinatory impacts, uncertainty and confidence, regional scale variations, …

→ **We are not always sure when we have "information"**

↓

Knowledge

Assessing options, understanding consequences, evaluating responses, informing decision making, …

→ **Comes with close coupling between science and society**

↓

A basis for action

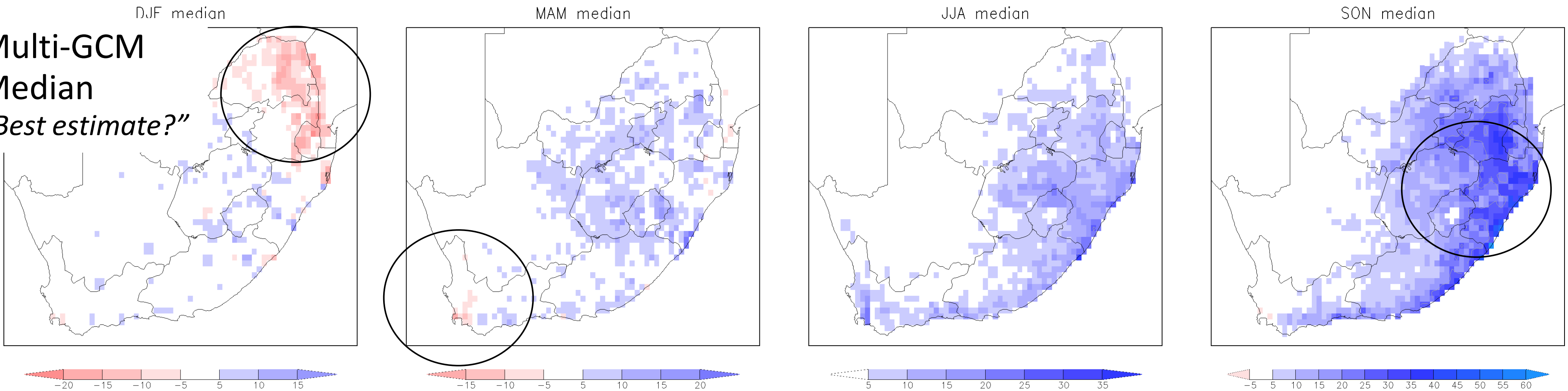
Balance competing priorities, strategic investments in adaptation and mitigation, new research avenues, coordination of response frameworks, …

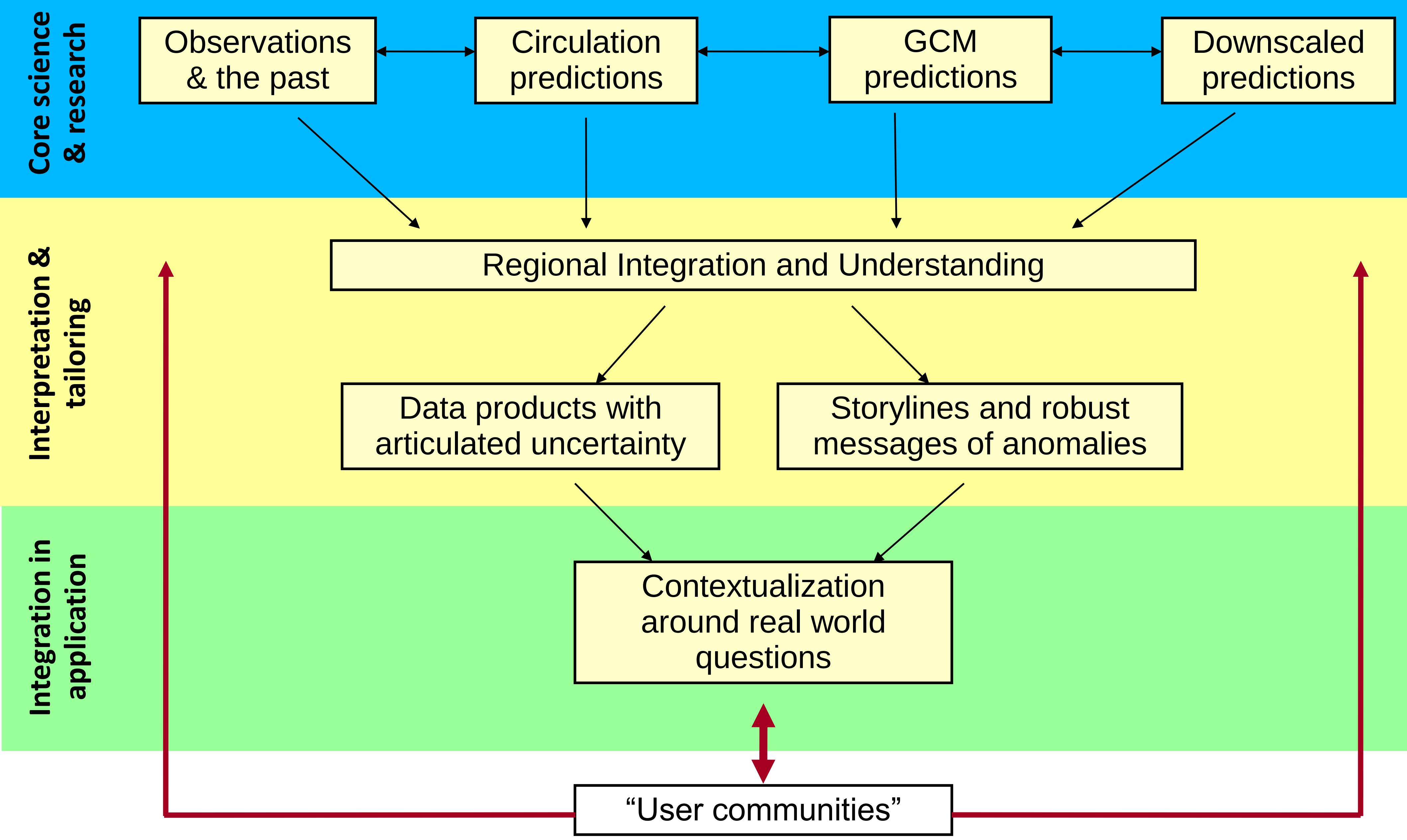
→ **Actions are risky, and takes place within a multi-stressor context**

Climate System Analysis Group
University of Cape Town
www.csag.uct.ac.za

Downscaled rainfall change (11 GCMs, 2050 anomaly, SRES A2)

Multi-GCM Median
"Best estimate?"





Emerging understanding of how to building regional messages

Single model sources are dangerous

Adapted from Hewitson et al., 2010

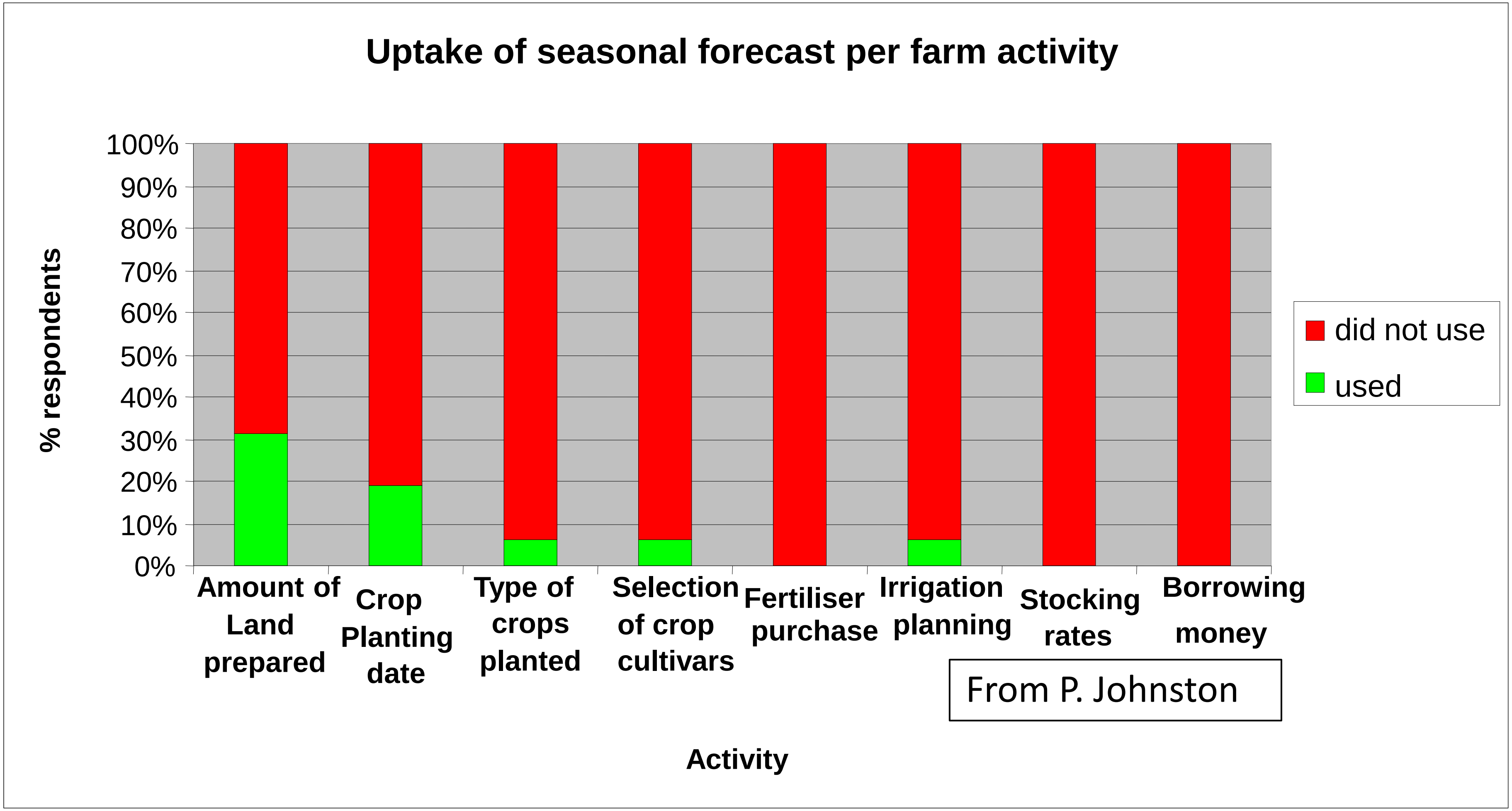
New approaches needed to find the value in the explosion of multi-model data?

Consider the following combination:

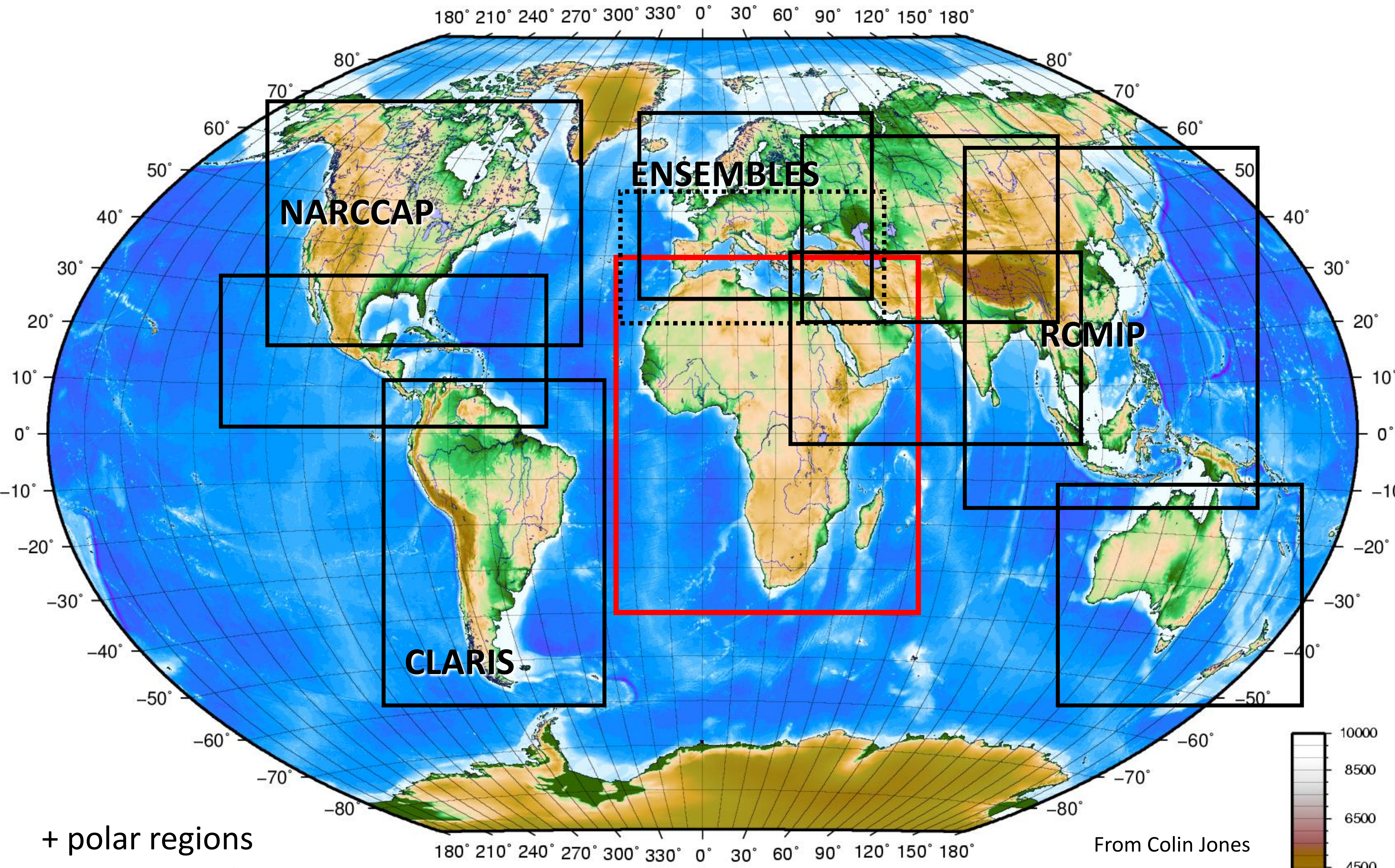
GCM-a, ~2 deg resolution, 10 ensemble members
GCM-b, ~1 deg resolution, 5 ensemble members
GCM-c, ~2.5 deg resolution, 1 simulation
RCM-a 25 downscaling of 3 ensemble members from GCM-a
RCM-b 5km downscaling 1 ensemble member from GCM-b
Statstical downscaling to point scale of all ensemble members from GCM-a and GCM-b

1. Which sources do you use, and according to what metric?
2. If you use only some sources, there will be contradictions with other sources, how do you explain the contradiction?
3. If all sources are used, how do you combine multiple models, methods and resolutions?

Communication: are we delivering the relevant information?



New unprecedented collaborative opportunities: e.g. CMIP5 and CORDEX (multi-model and multi-method)



+ polar regions

From Colin Jones

The state of play, the related challenges:

- **A strong capacity has been built;** where does this growth in scientific capacity find their career path?
- **Clearer understanding of historical change;** what is the future of the observing network of measurements, and the coordination, quality control, and sharing?
- **Solid awareness on knowledge gaps;** the relationship between change and variability, and the advance in methods, opens new avenues to address emerging grand-challenge questions.
- **New established multi-institutional partnerships;** A new modality of team research needs new structures.

Conclusion: we have moved substantially in 15 years; the need is greater than ever

- Capacity exists
- Understanding of the strengths and weaknesses is clear
- The need for predictability has rapidly expanded
- The shift is from research capacity to application
- The changing climate is an imperative