Long term forecasting of climate & rainfall – the importance of current data

W. Durand

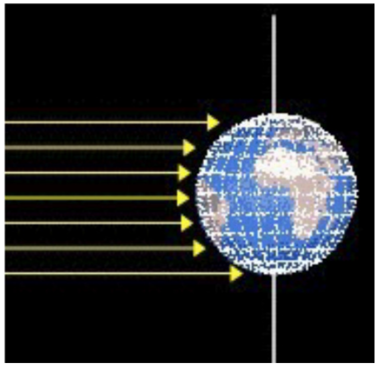
AgBIZ Grain Mini Symposium

Centurion Country Club

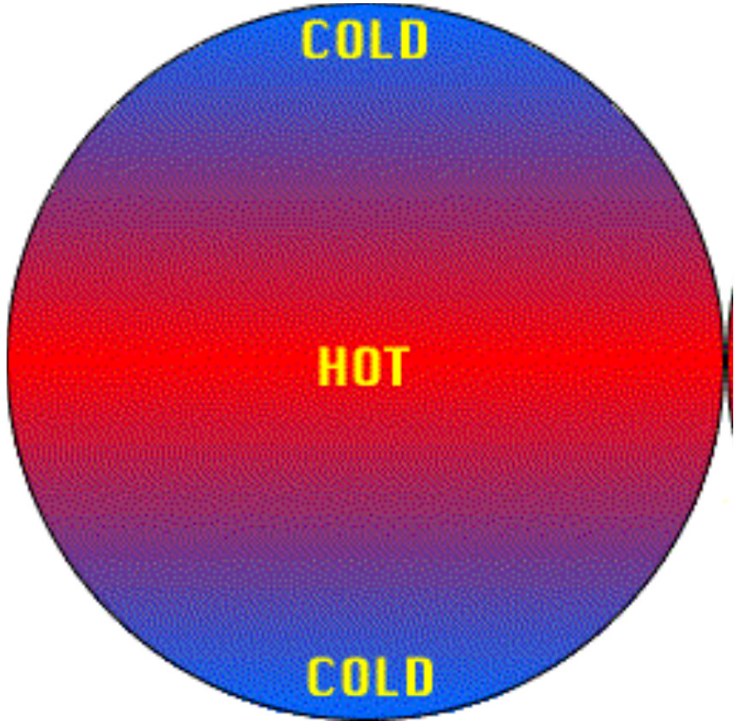
10 August 2016

WEATHER AND CLIMATE

Why do we have weather at all?



Differential heating of the globe results in energy transfer which together with the spin of the earth and position of the continents gives rise to our weather systems as we know them.

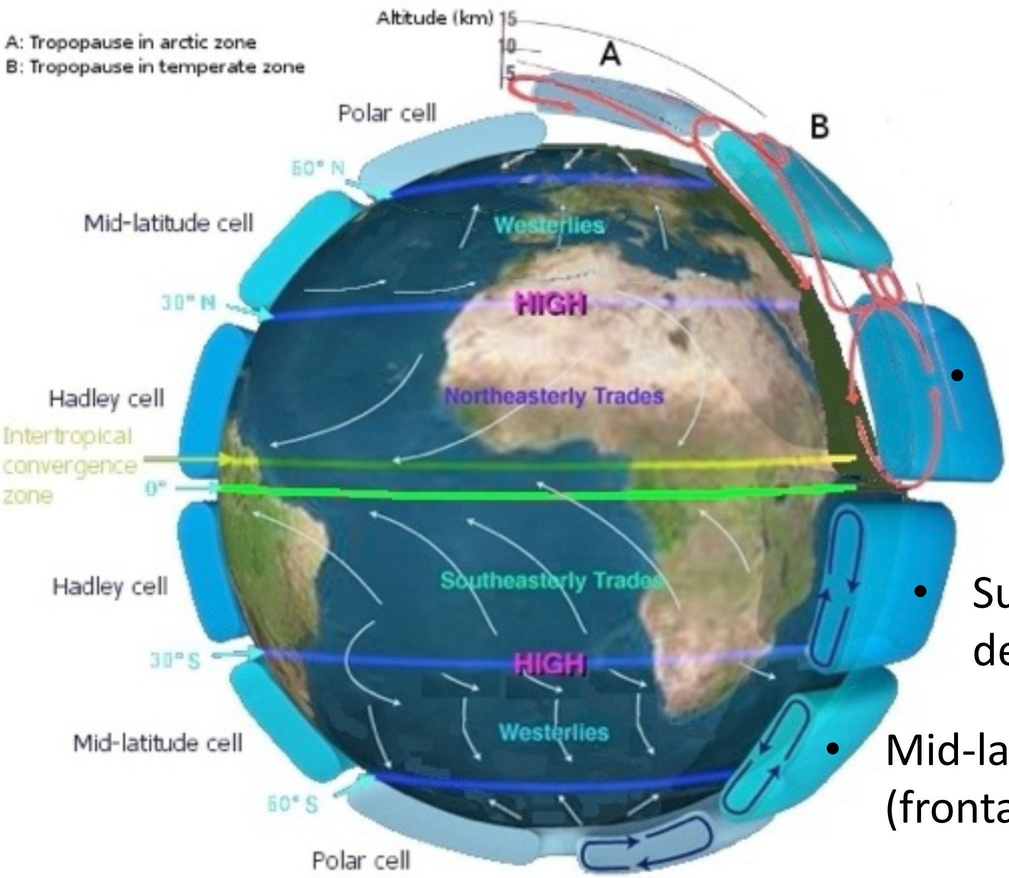


If energy were not redistributed in this way the Equator would be about 14 degrees hotter and the Poles about 25 degrees colder!!

From Chris Lennard Winter School 2014

WEATHER AND CLIMATE

Why do we have weather at all?



- Tropics characterized by rising air and convection
- Sub-tropics characterized by descending air (dry)
- Mid-latitudes are high energy zones (frontal systems)

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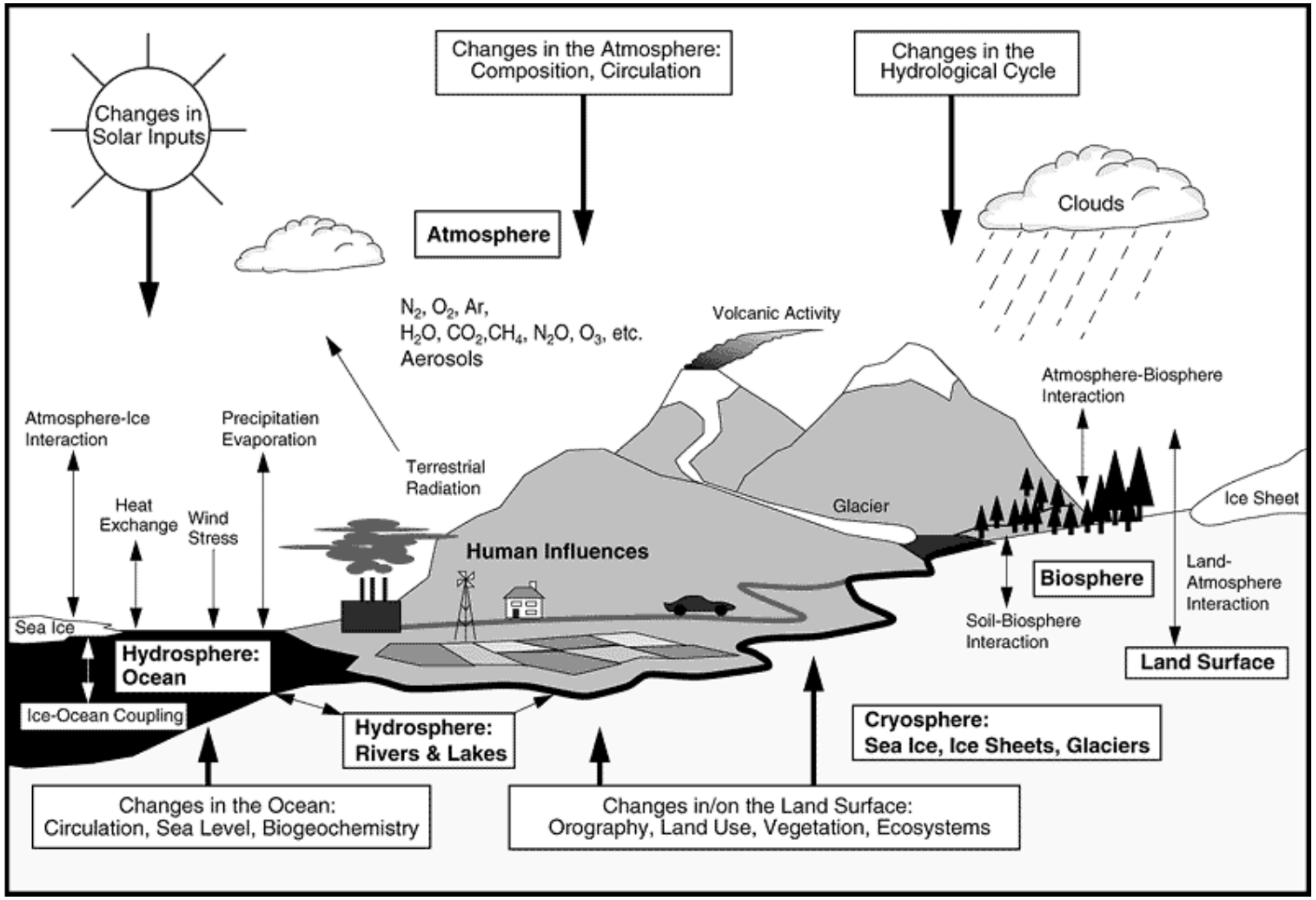
Why do we have weather at all?

Not just the climate.....
interaction through physical, chemical and biological processes



From Chris Lennard Winter School 2014

WEATHER AND CLIMATE

Are Weather and Climate the Same?

Weather is defined as the state of the atmosphere at some place and time, usually expressed in terms of temperature, air pressure, humidity, wind speed and direction, precipitation, and cloudiness. Meteorologists study weather.

WEATHER
the state of the atmosphere at some place and time

Climate is defined in terms of the average (mean) of weather elements (such as temperature and precipitation) over a specified period of time (30 years according to the World Meteorological Organization).

CLIMATE
the average of weather elements over a specified period of time

It is important to understand the difference between weather and climate:

Climate is what we expect, weather is what we get!

WEATHER AND CLIMATE

Are Weather and Climate the Same?

Weather is about events and observations
Weather includes sunshine, cloudiness, rain, snow, temperature, atmospheric pressure, humidity, winds, severe weather, the approach of a cold or warm front, heat waves, lightning strikes, and a whole lot more. The state of each of these is communicated to us through **weather forecasts**.

Climate is about event and observation trends
Climate also includes many of the above mentioned weather conditions except their measurements are averaged over a number of years (usually 30 years). So, instead of telling us how many days Bothaville in the Free State got rainfall , climate data will tell us on average how many rain-days Bothaville experiences per year, how many mm of rain it generally gets during the summer season, or when the first frost occurs so farmers will know when to plant or harvest. Other examples of climate-related products include weather patterns (El Niño/La Niña, etc.) and **seasonal outlooks**.

Forecasting Weather vs. Predicting Climate

Forecasting Weather vs. Predicting Climate

Meteorologists actually use similar tools, known as **models**, for both.

The models used to forecast weather incorporate air pressure, temperature, humidity, and wind observations to produce the best estimate of the atmosphere's future conditions. A weather forecaster then looks at this model output data and adds in his personal forecasting know-how in able to figure out the most likely scenario.

Unlike weather forecast models, climate models cannot use observations because future conditions aren't known yet. Instead, climate predictions are made using **Global Climate Models** (GCMs) that simulate how our atmosphere, oceans, and land surfaces might interact.

WEATHER AND CLIMATE

Forecasting Weather vs. Predicting Climate

Nowcasts: 0 to 6 hours. Forecasters use the latest radar, satellite, and current observations to issue nowcasts in the near real-time (almost "live").
Short Range: Short range forecasts detail the weather that's expected over the next 72 hours (3 days).
Medium Range: The National Weather Service's medium range forecasts detail weather conditions over the next 3 to 7 (10) days.

Outlooks: Monthly and 3-monthly (90 days) time-frames. Outlooks are forecast maps that express how likely it is that weather conditions, like temperature and precipitation, will be normal, above normal, or below normal.

- **Extended Range Outlooks:** Extended range outlooks detail weather anomalies, or departures from normal, for 6 to 10 days and 8 to 14 days out.
- **Long Range Outlooks:** Forecasts 30+ days into the future are known as long range outlooks.

Climate projections (Climate Change): A climate projection is usually a statement about the likelihood that something will happen several decades to centuries in the future if certain influential conditions develop. In contrast to a prediction, a projection specifically allows for significant changes in the set of boundary conditions, such as an increase in greenhouse gases, which might influence the future climate. As a result, what emerge are conditional expectations (if this happens, then that is what is expected). For projections extending well out into the future, scenarios are developed of what could happen given various assumptions and judgments.

Natural Variability

Natural Variability of the Climate System

At Different Scales in Space and Time

Notice:
The Variability in the system occurs at a number of <u>scales</u>:

- **Time** (minutes to millennia)
- **Space** (meters to 1000's KM)

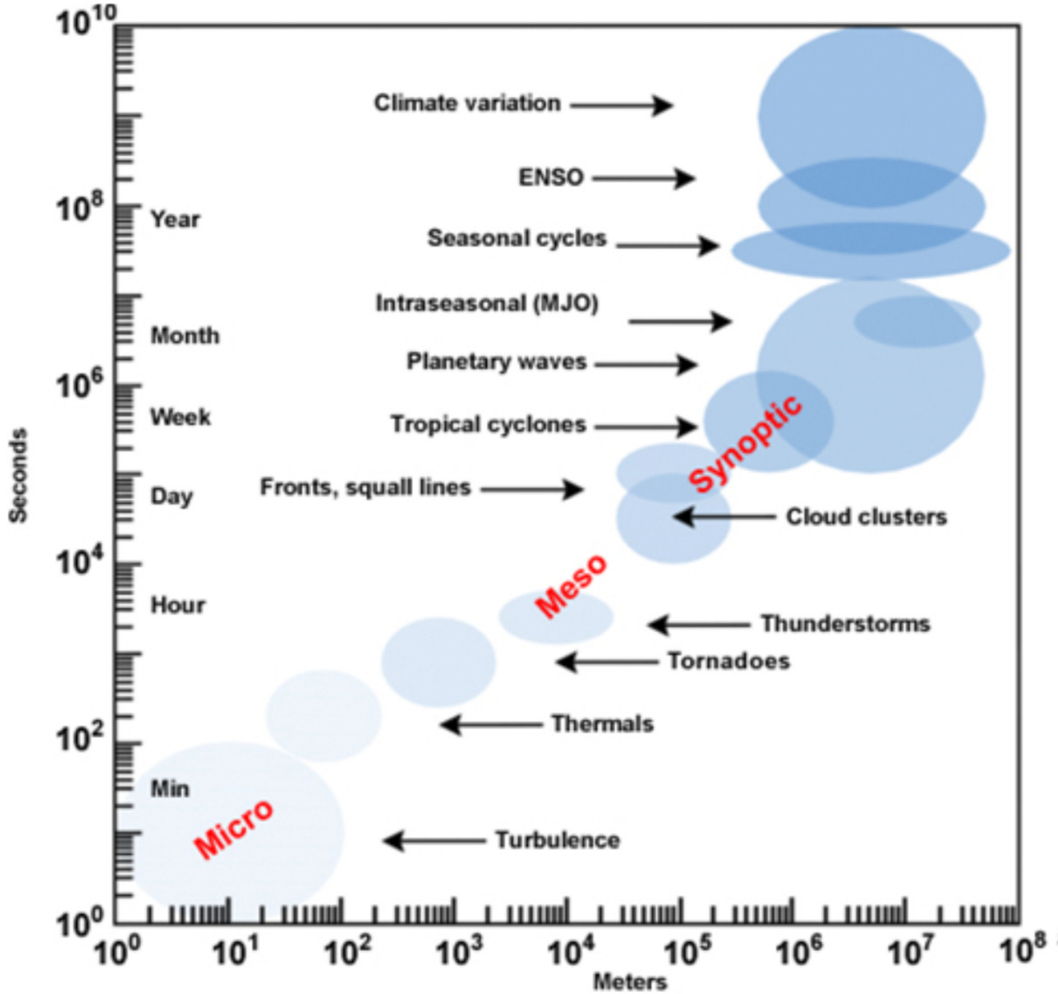


Image courtesy of MetEd, The COMET Program, UCAR. Natural Variability

Natural Variability

Seasonal Cycle

Start with one we all know – **Seasonal cycle**

Other seasonal cycles: **Monsoons**
It is most often applied to the seasonal reversals of the wind direction

Seasons are:

- Large source of variability
- Dominant driver of human activities

Seasonal cycle

Results from the oscillating tilt of the earth

Latitude of most intense heating moves north and south

Tropical variability tied to Inter-tropical Convergence Zone (ITCZ) which moves north and south – bi-modal seasons.

Sub-tropical variability linked to the descending high pressure cell variations.

Mid-latitude variability linked to the north-south shift of mid-latitude frontal systems.

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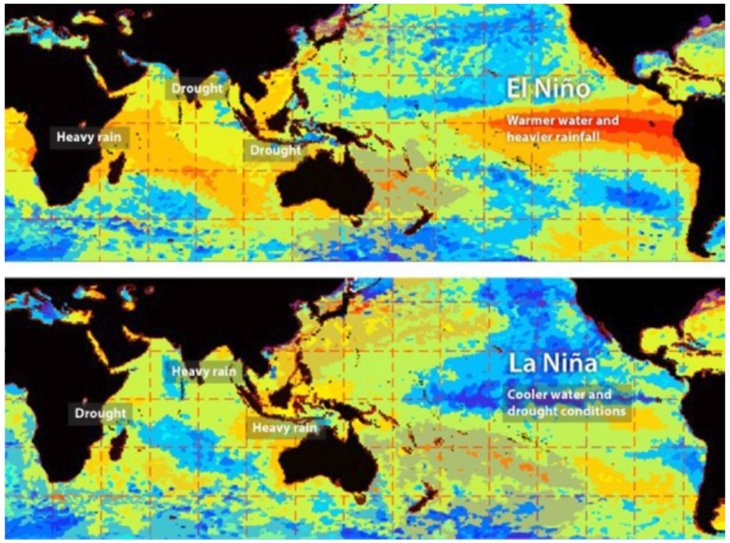
Intra- and Inter- Seasonal variation

Modifying the seasons: Intra- and Inter- Seasonal variation

Longer time period (3 – 10+ years) variability often linked to slower changing ocean oscillations

- **El-Ninõ Southern Oscillation (ENSO) (3-6 years)**
- **Southern Annular Mode (SAM) (weeks to years)**

  Due to the southward shift of the storm track, a high SAM index is associated with:
  - Anomalously dry conditions over southern South America, New Zealand and Tasmania
  - Wet conditions over much of Australia and South Africa.
  - Associated with warming trends over Antarctic peninsula, Argentina, Tasmania and the south of New Zealand in summer and autumn.
- **Indian Ocean Dipole (IOD) (4-6 years)**
- **North Atlantic Oscillation (NAO)**
- **Volcanic eruptions!**
- **Solar cycle (~11-12 years)**



Decadal and longer........

- **Pacific Decadal Oscillation (15-30 years)**
- **Atlantic multi-decadal oscillation (70 year cycle)**
- **Milankovitch cycles (Thousands of years)**

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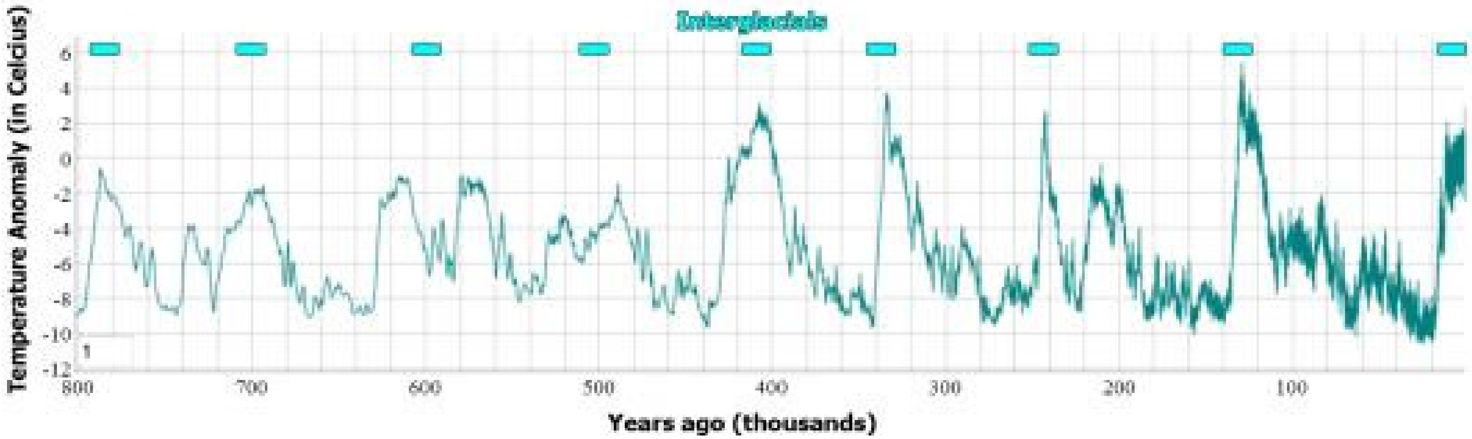
Temperature change in the atmosphere over the past 800,000 years



The planet's climate has changed many times over Earth's long geologic history. Over the past million years, Earth has experienced several glacial periods interspersed with interglacial (warmer) periods.

The relatively constant and favorable interglacial period of climate experienced over the past 8,000 years has made human civilization's advancement possible.

What is the difference between climate variability and climate change?

Climate Variability

Climate variability signifies any **deviation from the long-term expected value**. It is an entirely natural phenomenon, is reversible and nonpermanent.
An example would be the droughts in southern Africa which are associated with the El Niño-Southern Ocean phenomenon.

Climate Change

Climate change is **irreversible and permanent**, where a trend over time (either positive or negative) is superimposed over naturally occurring variability. The most common cited contemporary example of climate change is anthropogenically forced global warming, and the associated trends in increased temperature which result from the enhanced greenhouse effect through increased atmospheric emissions of greenhouse gases.

Summary of natural variability

In summary.......

- There is a lot of natural variability in the earth-atmosphere-ocean system
- These occur on many time scales and they modulate each other
- So climate change is constant..... and complex.
- We do not understand the mechanisms of many of the natural oscillations

Challenges:

- Are there cycles we have not discovered yet?
- How do we filter the effects of natural cycles in our weather from those
- Effects caused by greenhouse gas emissions?
- How do these cycles change through an enhanced greenhouse effect?

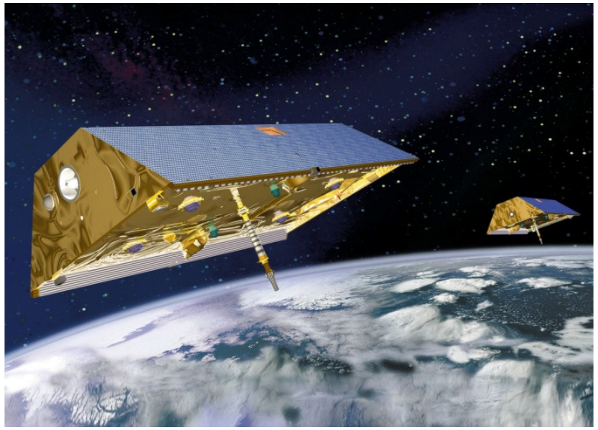
Tools

Tools Used to Forecast Weather and Climate

Weather balloons, satellites, specially designed airplanes, and radar and other **ground-based data** collection instruments are used to

- measure wind speed,
- precipitation,
- air temperature,
- humidity levels, etc.

Reliable records have been kept since 1800s and provide accurate weather forecasts (weekly and daily).

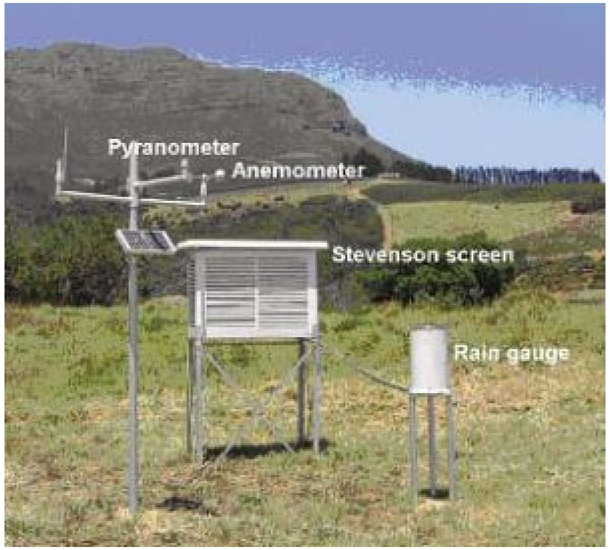


Sophisticated **Earth-observing satellites** equipped with remote-sensing equipment circle the globe to

- record sea surface and other temperatures,
- measure atmospheric gases and rainfall amounts,
- take visible and infrared photos of Earth's surface, and
- calculate Earth's outgoing infrared and reflected solar radiation.

Tools

Ground based data: weather station



Station Data

- Weather stations
  - Manual
  - Automatic
- Limited by Resources
- Multiple sources (Different quality control and station coverage)
  - South African Weather Service (SAWS)
  - Agricultural Research Council (ARC)
  - South African Sugarcane Research Institute (SASRI)
  - Number of municipalities, private companies and individuals
- Human Induced error
  - Recording error
  - Archiving error
- Instrument error
- Location specific error

Tools

Ground based data: weather station

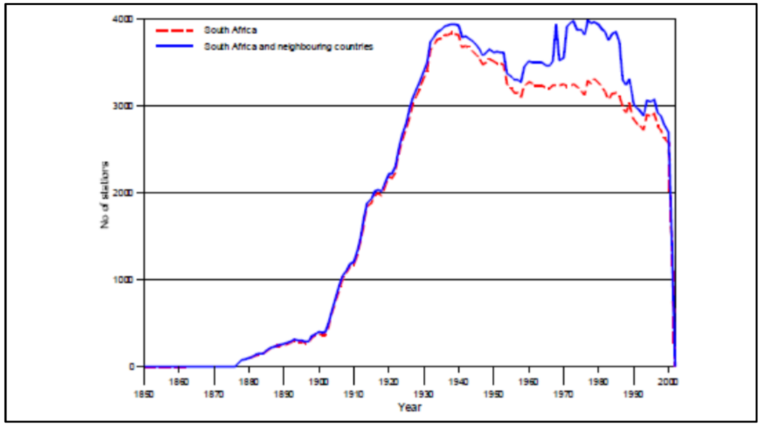
Did you know……..

- One of the first accounts of heavy rain in South Africa, from Jan van Riebeeck's journal, dates back to 22 - 23 July 1652 when the garden at the fort in Cape Town was washed away and the packing shed in the fort was 150 mm under water.
- The earliest systematic recording station was the Royal Observatory in Cape Town, with records dating back to 1850.
- By 1880 the region which now comprises South Africa had more than 100 active daily recording stations and this number increased to a maximum of 3 841 in 1938, with a steady decline in the number of rainfall stations since then, but particularly since 1960.

SAWS
- 231 Automatic weather stations
- 1180 rainfall stations
- 153 Automatic rainfall stations
- 12 Climate stations

ARC
- 530 Automatic weather stations
- 100 manual stations

SASRI
- 120 rainfall stations



Analysis of active rainfall stations in South Africa and neighboring countries (Lynch, 2004)

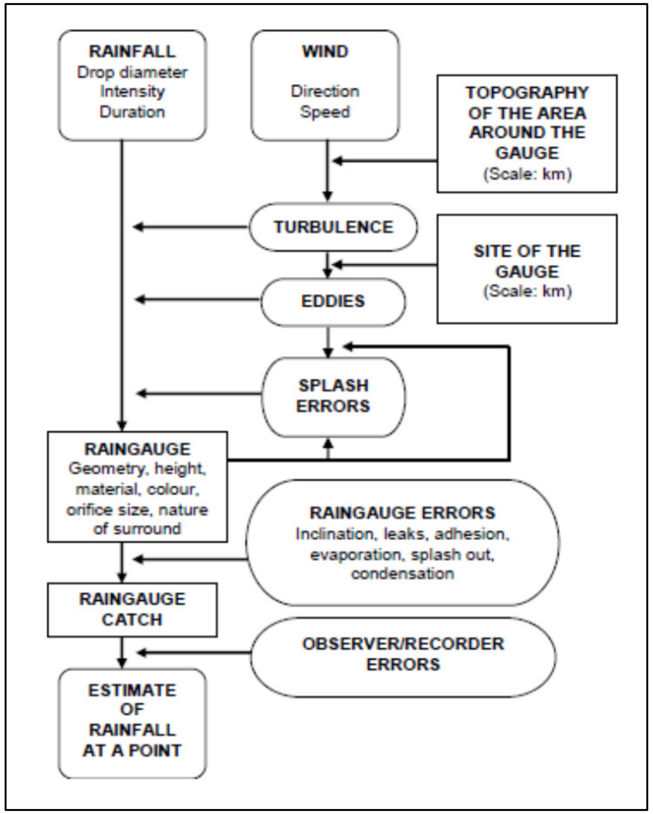
Lynch, S.D. and Schulze, R.E. 2007. Rainfall Database. In: Schulze, R.E. (Ed). 2007. South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 2.2.

Tools

Ground based data: weather station

Did you know……..

- The actual sample of measured rainfall is minute. A standard South African 127 mm diameter raingauge, for example, takes a **0.00000001267 sample per km²**.



Factors giving rise to catch deficiencies in point rainfall measurements (After Rodda, 1967)

- Daily rainfall has, historically, been recorded at approximately 12 000 stations in southern Africa.

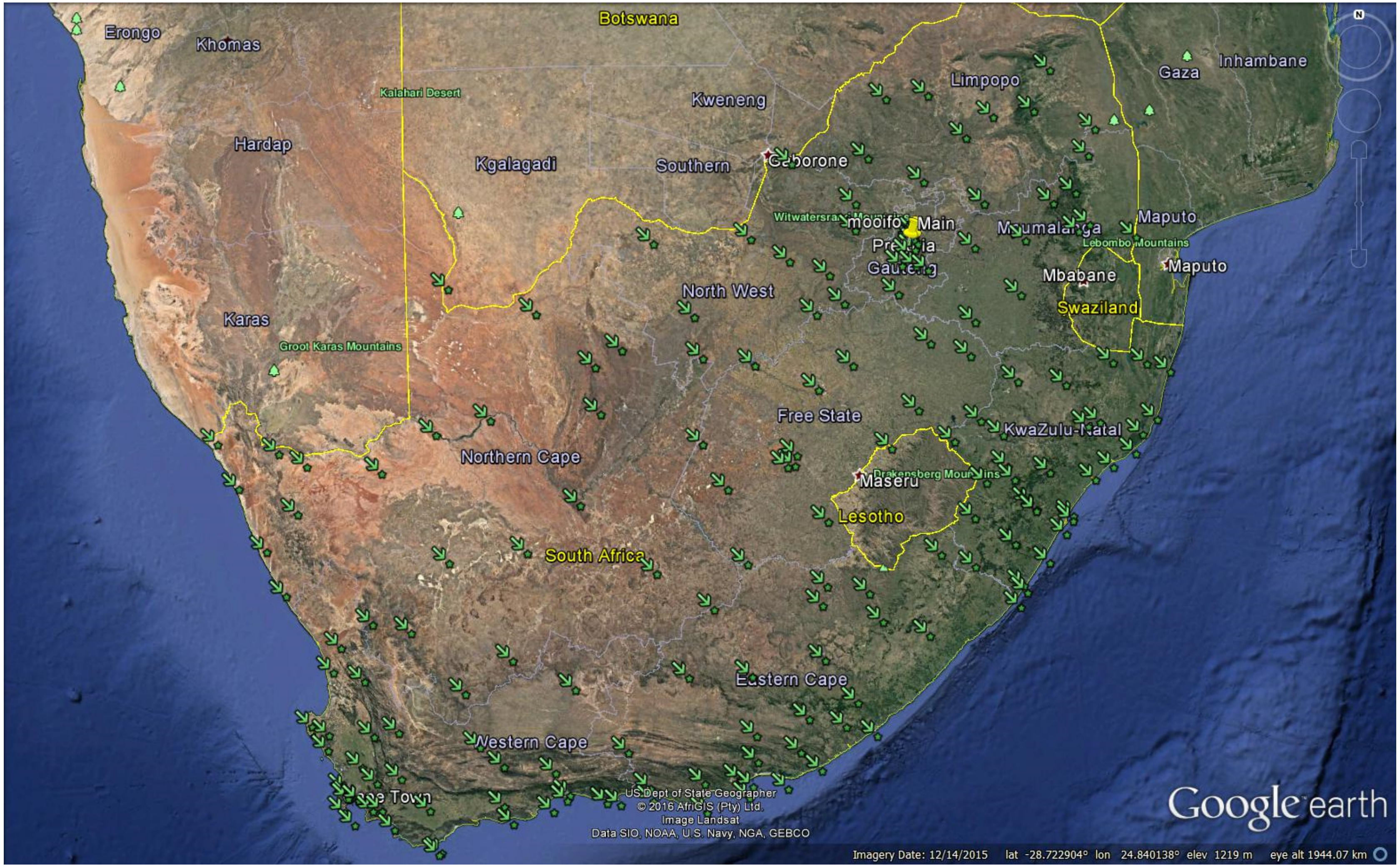
- Up to the year 2001 these rainfall data were collated, quality controlled and disseminated by the Computing Centre for Water Research (CCWR). With the closure of the CCWR **no common point of rainfall data access** is any longer available in South Africa.

Schulze, R.E. 2007. Rainfall: Background. In: Schulze, R.E. (Ed). 2007. South African Atlas of Climatology and Agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report 1489/1/06, Section 6.1.

Tools

Automatic weather station

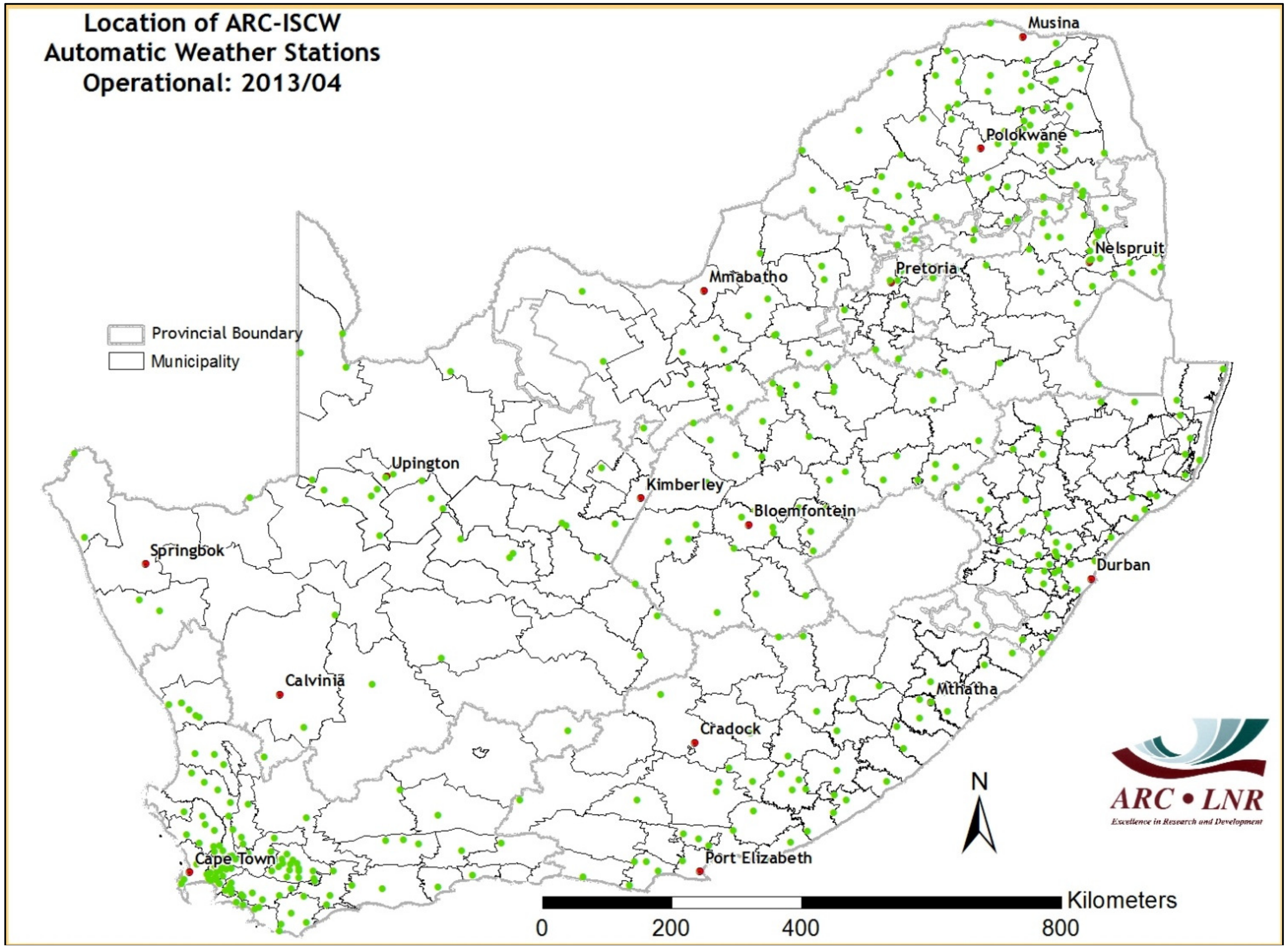
South African Weather Service (SAWS)



Tools

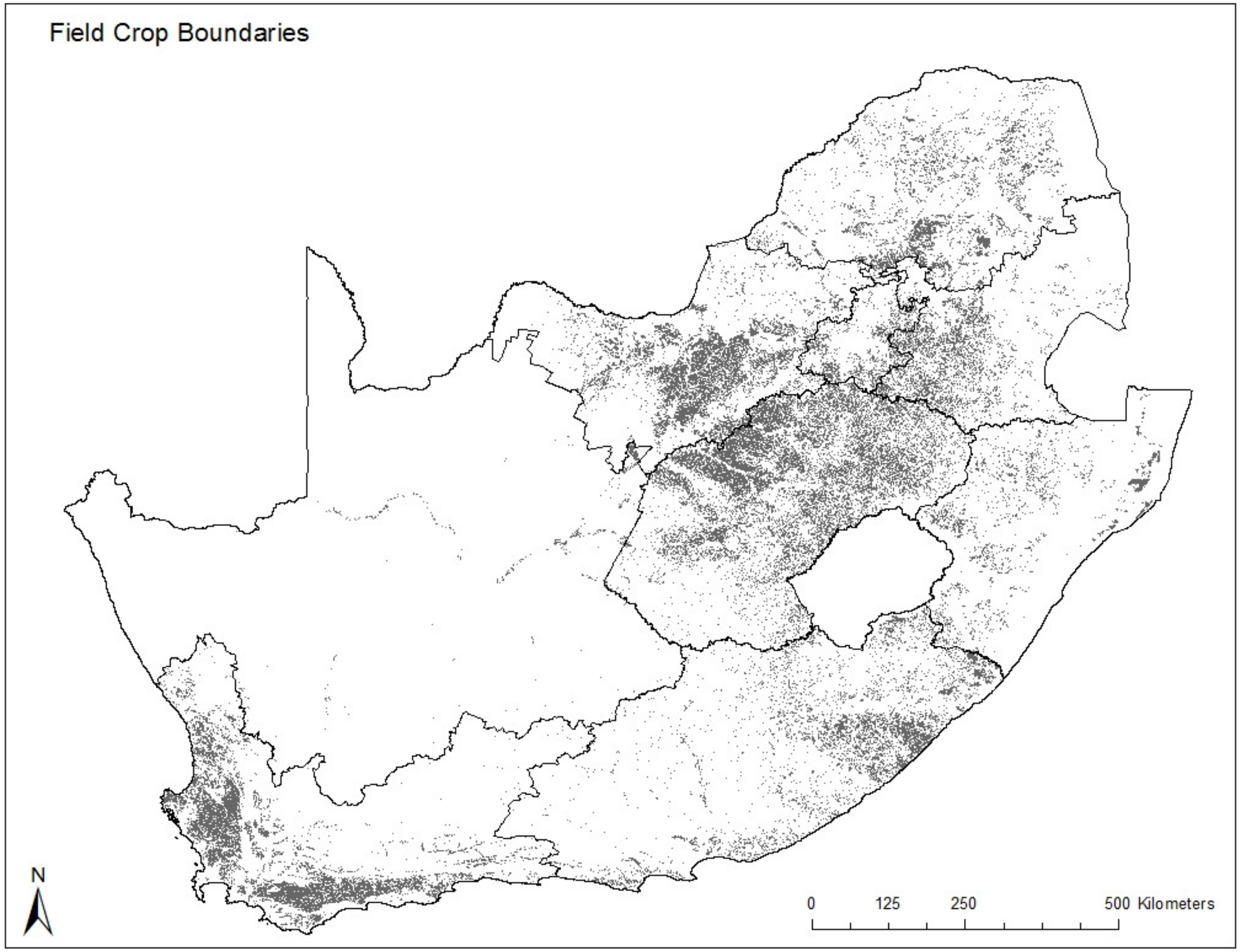
Automatic weather station

Agricultural Research Council (ARC)



Tools

Automatic weather station



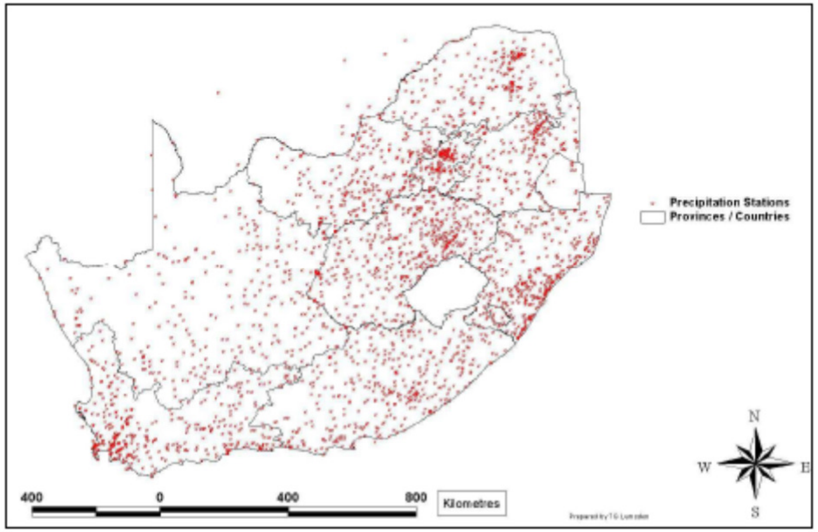
Problem:

Weather stations are often not located where the crops are.

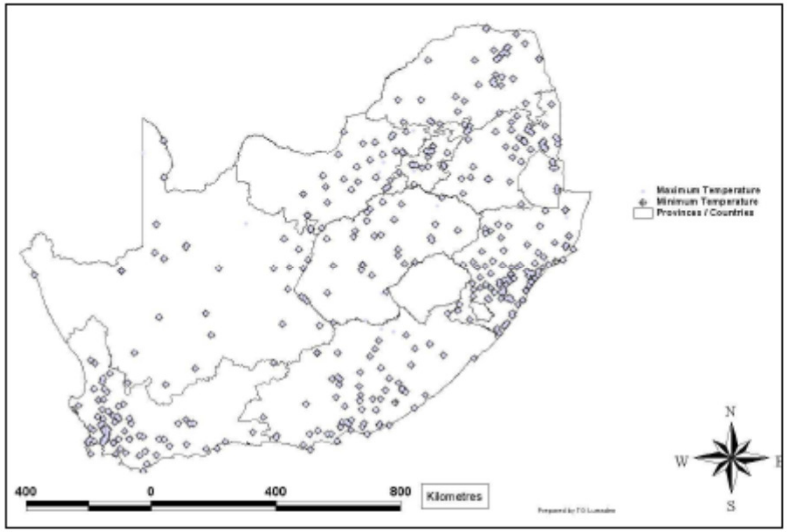
Tools

Weather station network
Rainfall, temperature, solar radiation

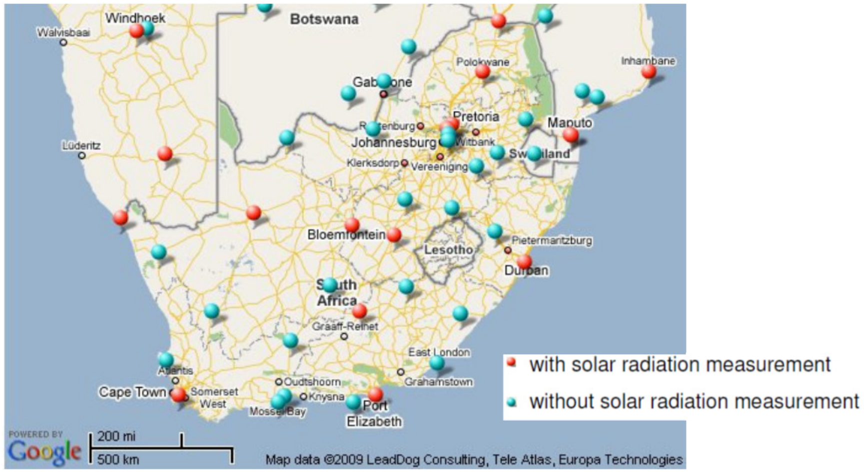
Rainfall



Minimum and Maximum Temperature



Solar radiation



Problem:

- Rainfall: most abundant data
- Temperature: few stations measure temperature
- Solar radiation: Even less stations measure solar radiation

Tools

Remote sensed products

- Commercial high resolution and multi-spectral satellite systems are delivering an unprecedented quantity of Earth observation data in very short timescales after acquisition.
- The satellites, the images, the delivery systems and the value-added information providers and products are all now components of a well-established industry.

➢ **Use satellite based instruments based on different frequencies**

- Infrared
- Visible
- Microwave

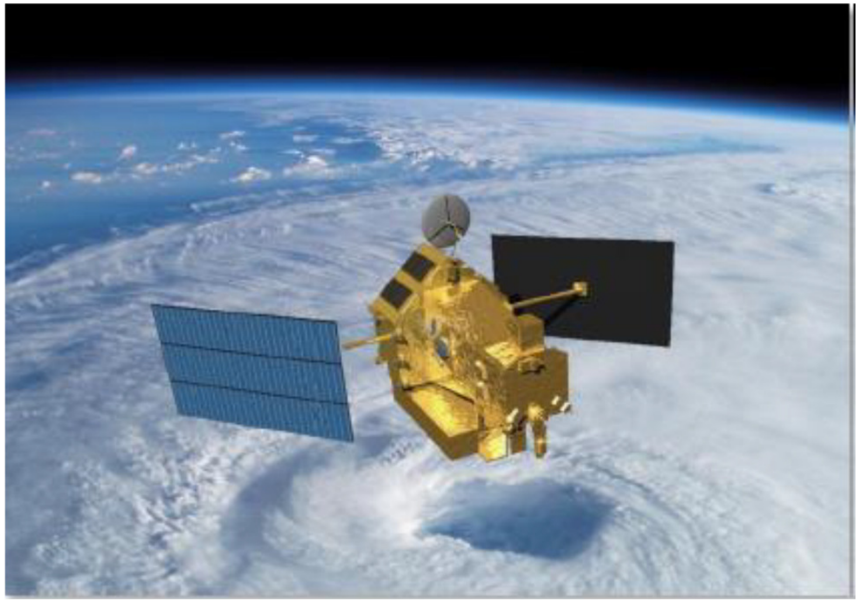
➢ **Post processed to estimate**

- Rainfall
- Temperatures
- Wind speed and direction
- Waves
- Moisture

➢ **Relatively short history** (e.g., 15 years for TRMM)

➢ **Calibration problems**

➢ **Often merged with station data**



Why climate info?

How is all this Weather and climate information distributed?

Weather and climate services

Data Portals/Platforms

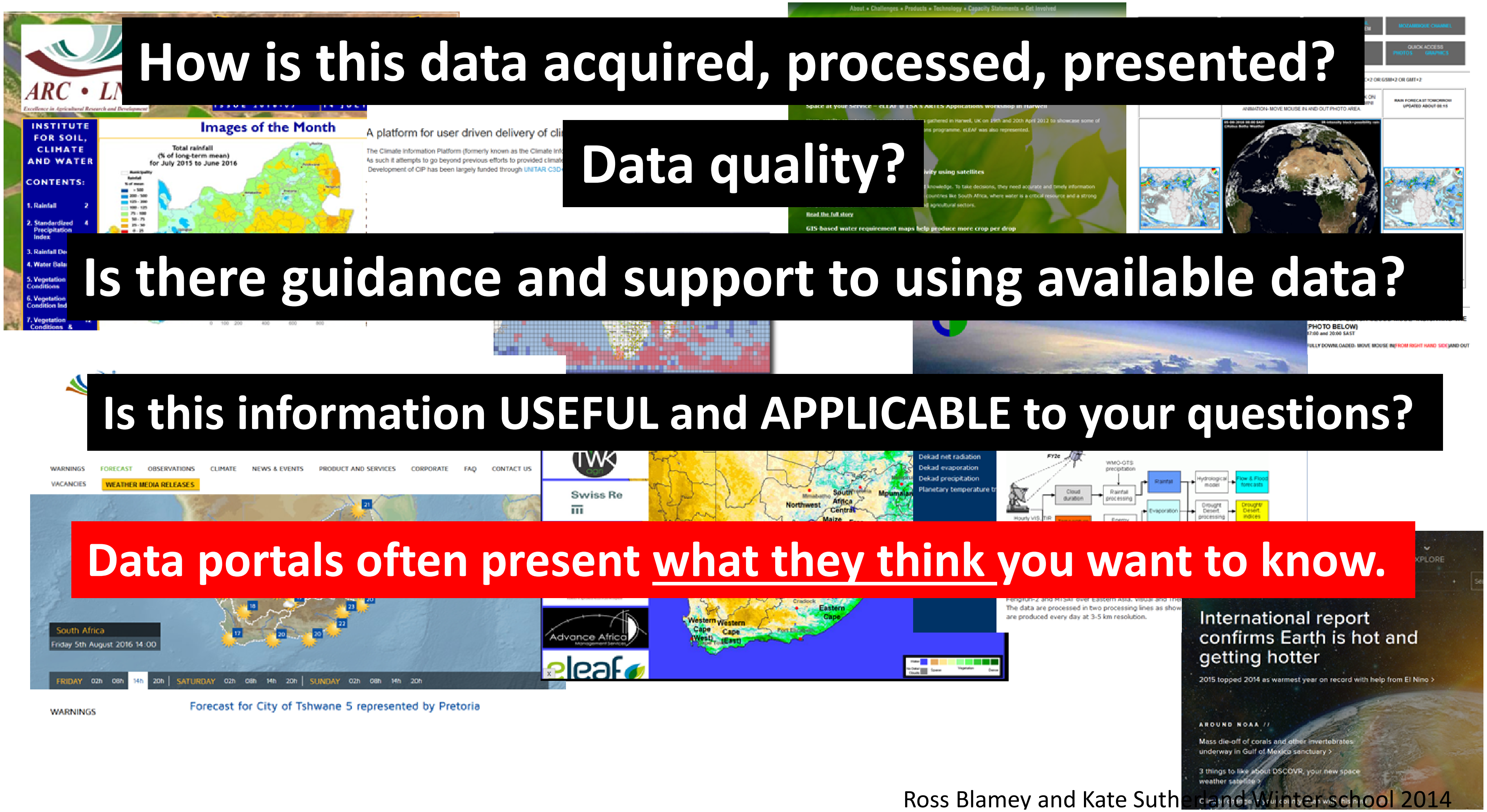
Ahhhhhhhhhhh…..?!?!#@?

Why climate info?

How is all this Weather and climate information distributed?

Weather and climate services

Data Portals/Platforms



How is this data acquired, processed, presented?

Data quality?

Is there guidance and support to using available data?

Is this information USEFUL and APPLICABLE to your questions?

Data portals often present <u>what they think</u> you want to know.

Why climate info?

Critical thinking
climate services

In using climate information, the questions that producers and users need to collectively address:

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?)

- Motivation for producing climate information and services is different for everyone.

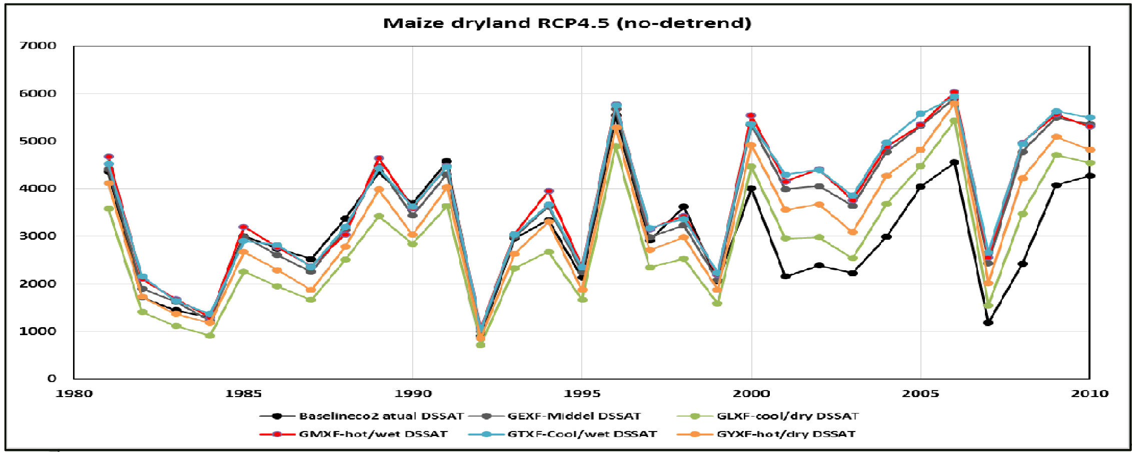
- Who is monitoring the production and delivery of this service?

- Users need to ensure they have a baseline understanding of how climate information is produced, distributed, displayed and communicated to ensure the users correct understanding, use and application of this information.

Why climate info?

My own example

climate services

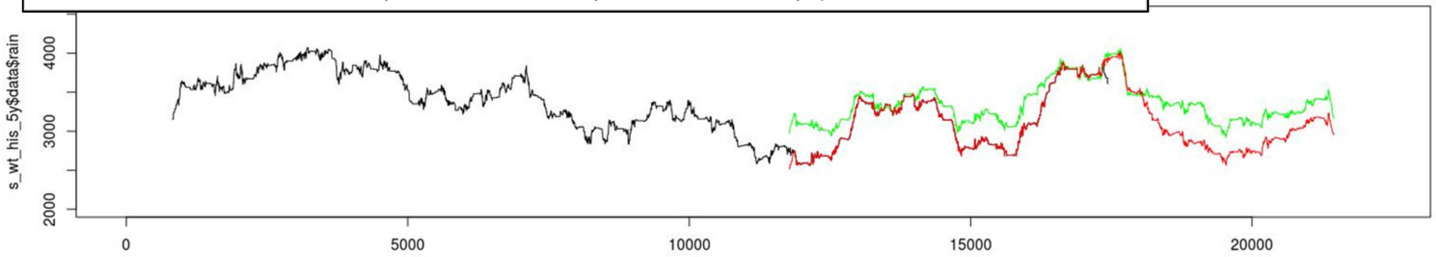


First 19 years based on observed data : future is worst than baseline because:

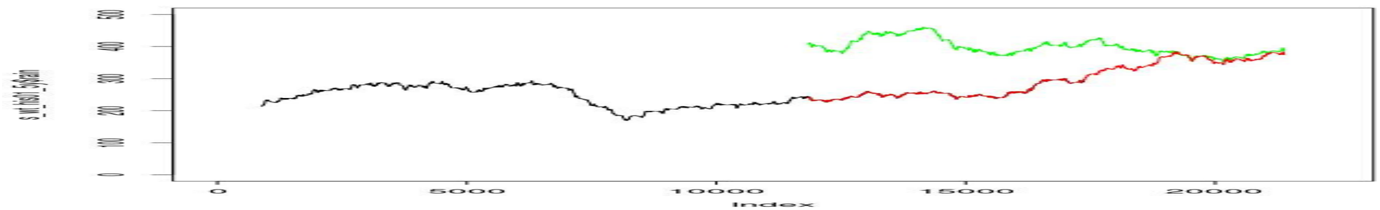
- Higher amount per rainy day but lower number of rainy days (same total)

11 last years based on AgMERRA : future is better than baseline because

- Lower amounts per rainy day but higher number of rainy days (same total)



Running 5 years (approx. 1826 days) of **rainfall totals** over period plotted in the middle of the period (hence first value at 1826/2 = 913 days)



Running 5 years (approx. 1826 days) **Total number of rainy days (>2mm)** over period plotted in the middle of the period (hence first value at 1826/2 = 913 days)

BLACK -- Historical 1950-001 (0) to 1999-365 (18262)
GREEN -- AgMERRA 1980-001 (10958) to 2010-365 (22280)
RED – Baseline 1980-001 to 2010-365

Why climate information?

Weather services and climate services

Information allows one to:

- weigh the evidence,
- understand context,
- consider the risk,
- assess resources,
- evaluate what’s possible, etc

….**then decide** (including “do nothing”).

Climate information services prepare users for the weather they will actually experience.

Why climate information?

How does this affect me?

We operate in decision spaces at different scales of variability

TYPE OF DECISION	WEATHER	Intermediate	CLIMATE
	Short term (0 - 7 days)	Medium Term (6 - 9 months)	Long Term (10 - 50 years)
	Real Time → Week	Seasonal Forecasts	Decadal Changes
Operational			
Tactical			
Strategic			

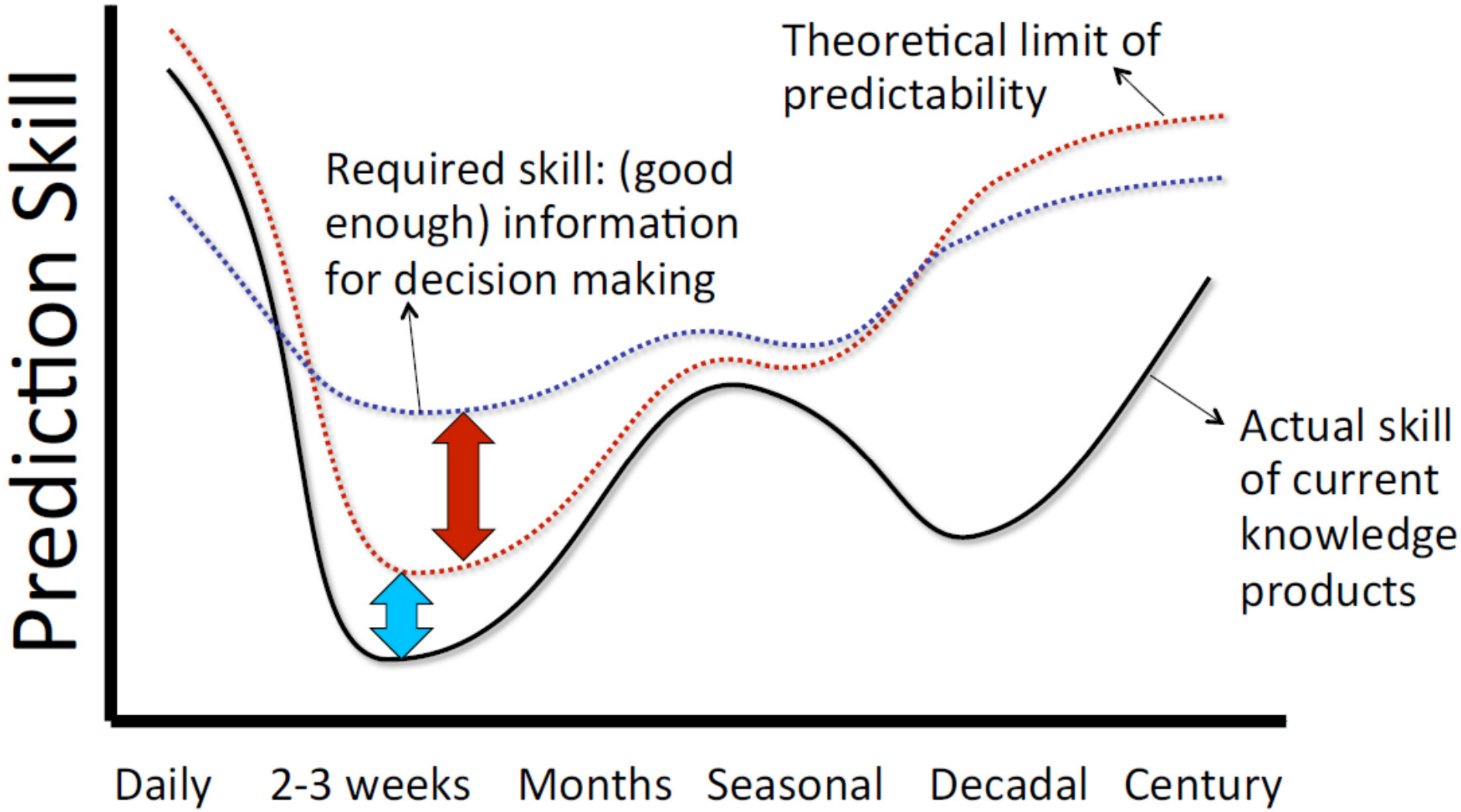
Why climate info?

How good are we at the different scales?

Weather services and climate services

What are we really trying to achieve?

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



Ross Blamey and Kate Sutherland Winter school 2014

Why climate info?

The knowledge chain approach to climate services

Delivered by science

Needed by society

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

↓

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

↓

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

↓

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

First order derivatives
Annual/monthly/daily/hourly temperature
Maximum temperature
Minimum temperature
Heat waves
Cold spells
Annual/monthly/daily/hourly precipitation
Rainfall concentration
Rainfall seasonality

↓

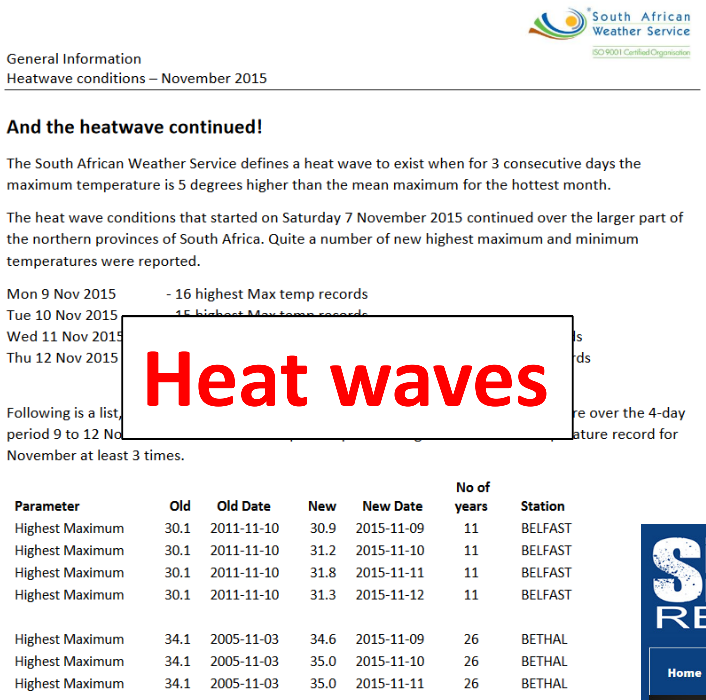
Second order derivatives
Heat units
Positive chill units
Crop evapotranspiration
Climate zones
Crop suitability zones

↓

Third order derivatives
Soil water stress
Yields and yield forecast
Net irrigation demand
Planting dates for optimum yields
Pest and disease outbreaks

Why climate info?

First order derivatives



South African Weather Service

General Information
Heatwave conditions – November 2015

And the heatwave continued!

The South African Weather Service defines a heat wave to exist when for 3 consecutive days the maximum temperature is 5 degrees higher than the mean maximum for the hottest month.

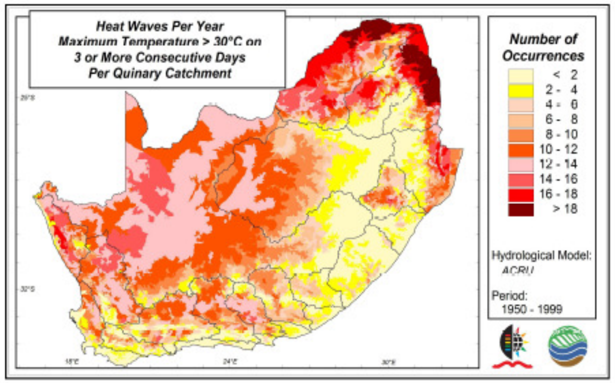
The heat wave conditions that started on Saturday 7 November 2015 continued over the larger part of the northern provinces of South Africa. Quite a number of new highest maximum and minimum temperatures were reported.

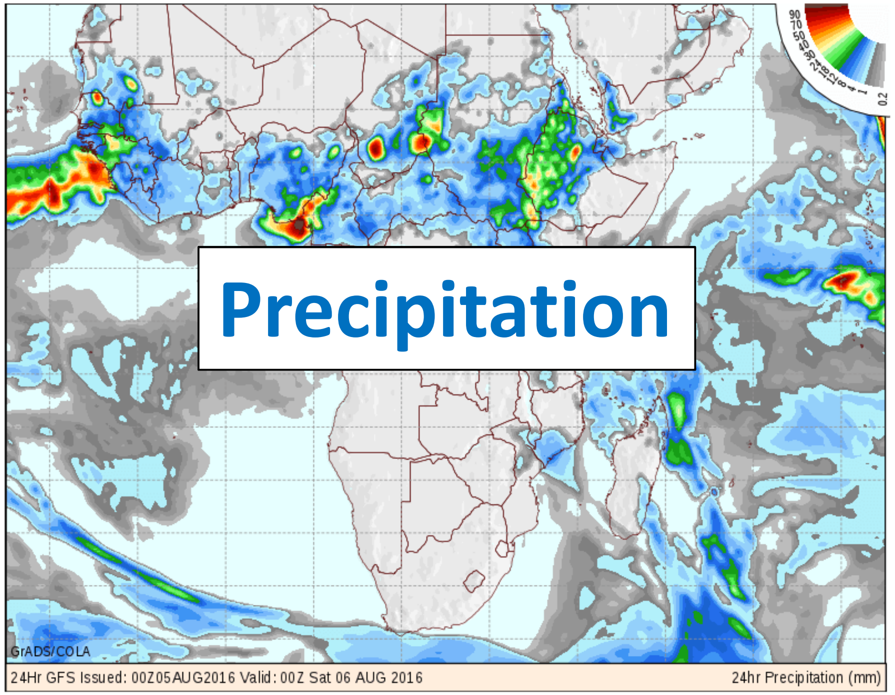
Mon 9 Nov 2015 - 16 highest Max temp records
Tue 10 Nov 2015
Wed 11 Nov 2015 ... s
Thu 12 Nov 2015 ... ds

Following is a list, ... e over the 4-day period 9 to 12 No... ature record for November at least 3 times.

Parameter	Old	Old Date	New	New Date	No of years	Station
Highest Maximum	30.1	2011-11-10	30.9	2015-11-09	11	BELFAST
Highest Maximum	30.1	2011-11-10	31.2	2015-11-10	11	BELFAST
Highest Maximum	30.1	2011-11-10	31.8	2015-11-11	11	BELFAST
Highest Maximum	30.1	2011-11-10	31.3	2015-11-12	11	BELFAST
Highest Maximum	34.1	2005-11-03	34.6	2015-11-09	26	BETHAL
Highest Maximum	34.1	2005-11-03	35.0	2015-11-10	26	BETHAL
Highest Maximum	34.1	2005-11-03	35.0	2015-11-11	26	BETHAL

Heat waves





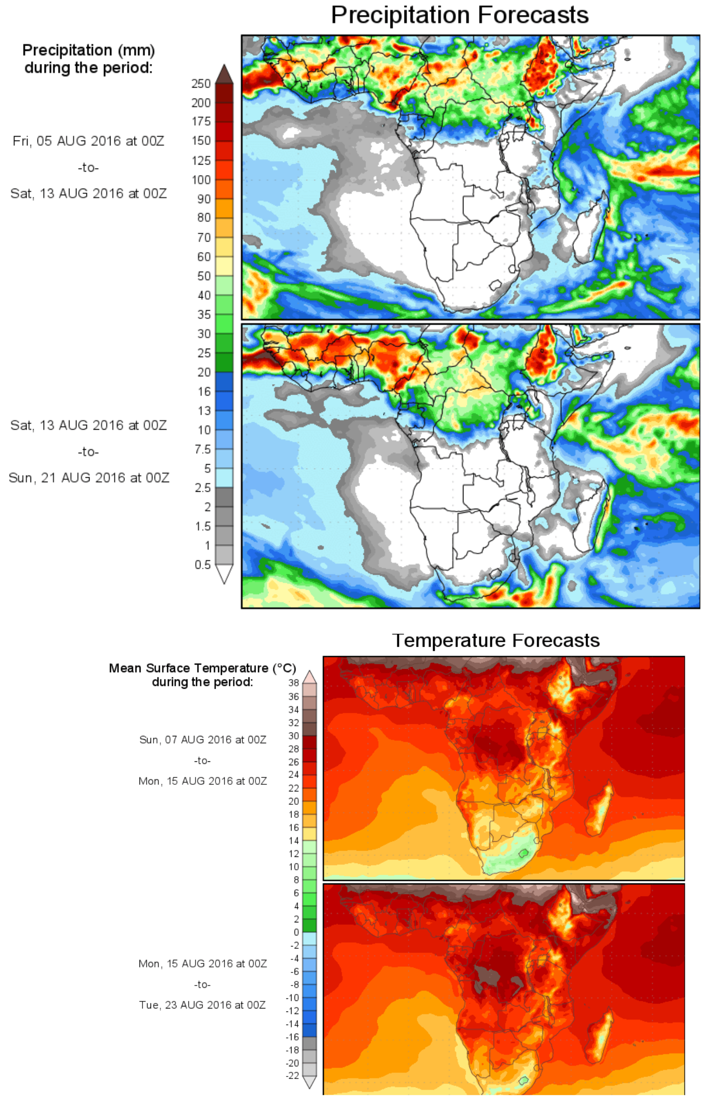
Precipitation

Cold spells

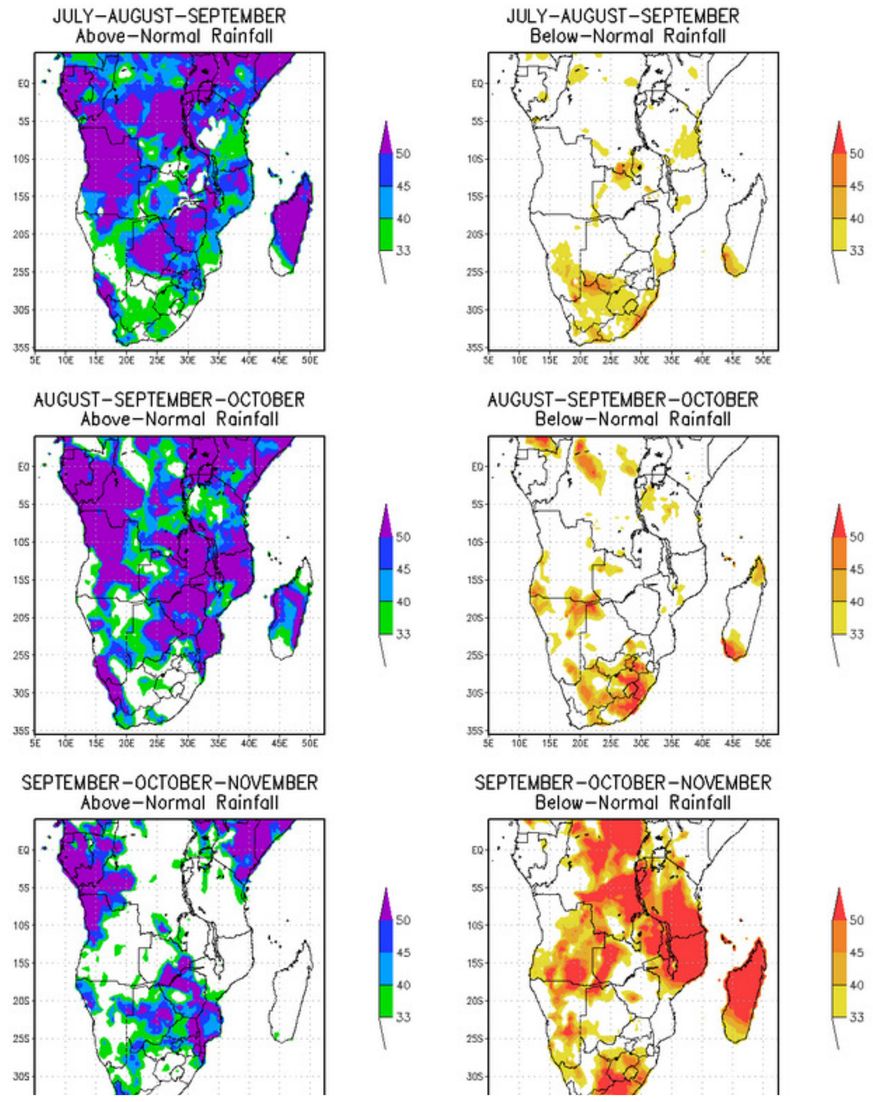
Why climate info?

First order derivatives

http://wxmaps.org/outlooks.php

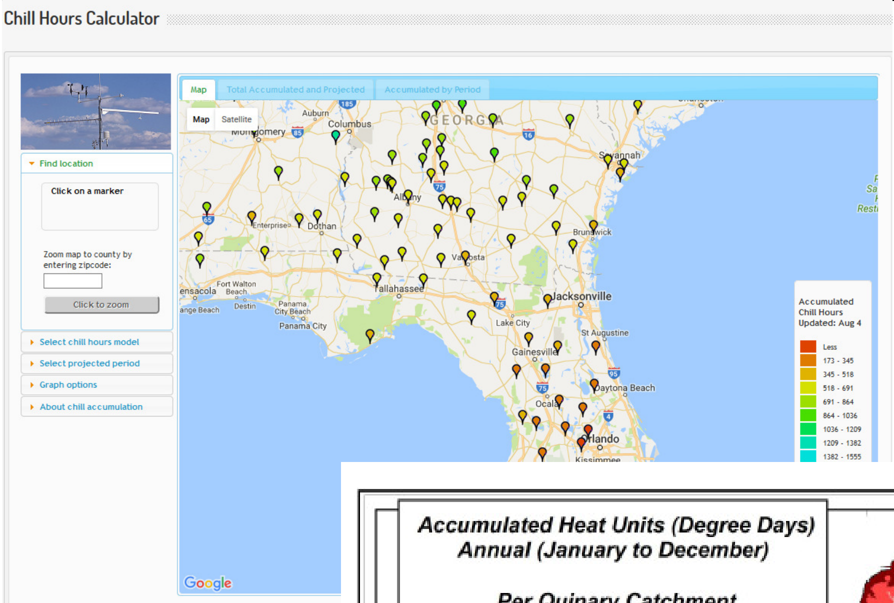


http://www.weathersa.co.za/media/data/longrange/gfcsa/PCP_SEA.gif



Why climate info?

Second order derivatives



http://www.agroclimate.org/

Schulze, R.E. 2010. ***Atlas of Climate Change and the South African Agricultural Sector: A 2010 Perspective***. Department of Agriculture, Forestry and Fisheries, Pretoria, RSA. pp 391.

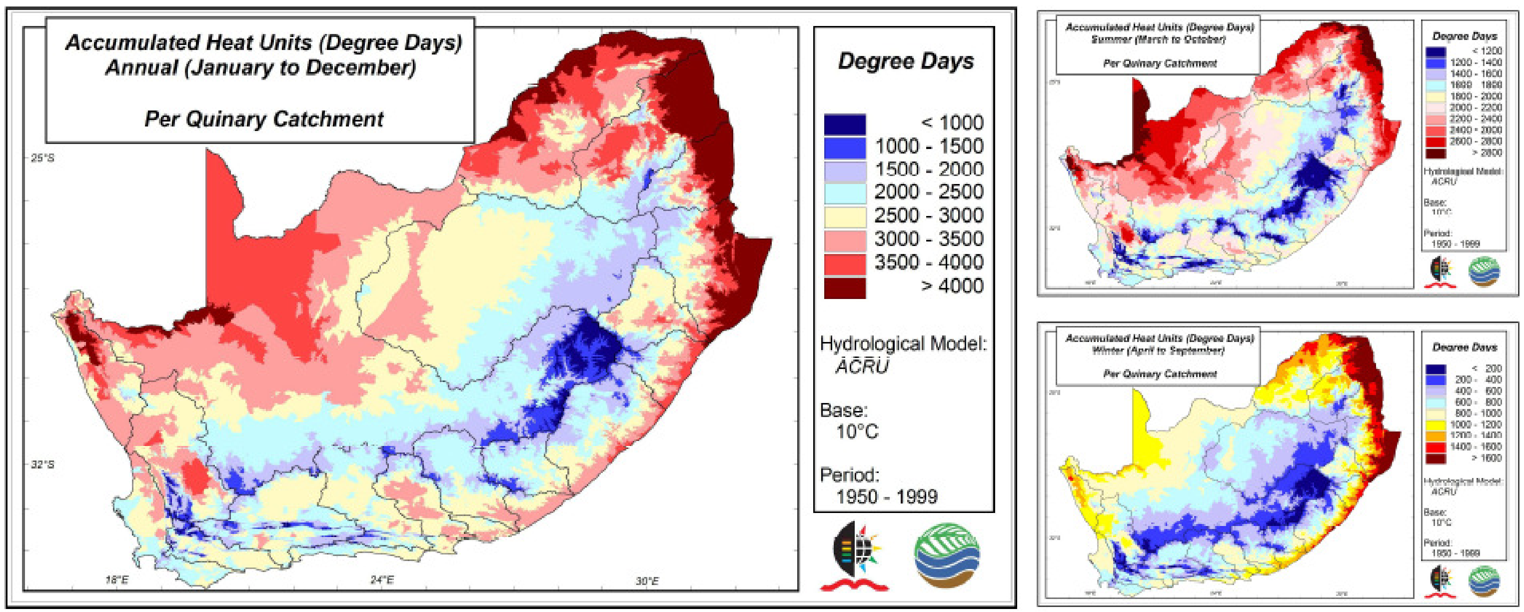


Figure 4.1.1 Accumulated annual (left), as well as summer (top right) and winter (bottom right) heat units over South Africa under baseline (historical;

Second order derivatives

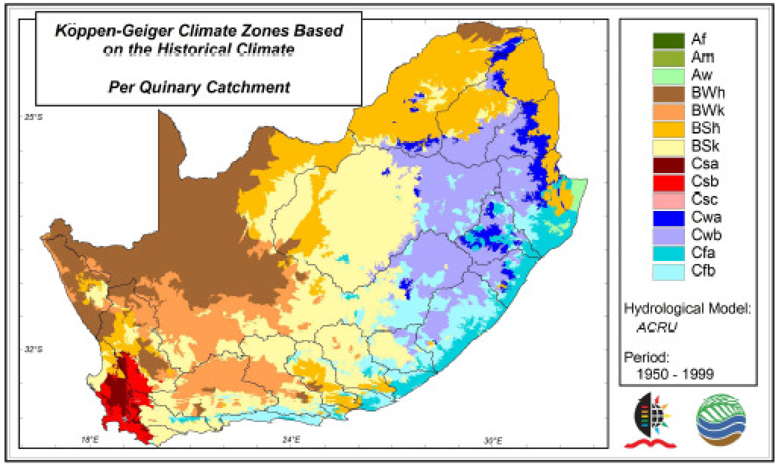


Figure 4.4.1 Köppen-Geiger climate zones over South Africa, derived from baseline (historical; 1950 - 1999) climatic conditions

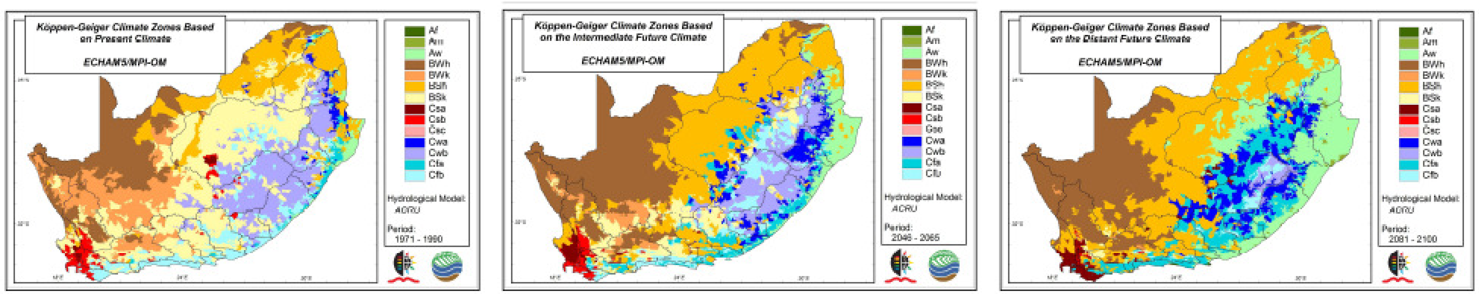


Figure 4.4.2 Köppen-Geiger climate zones over South Africa for present (left), intermediate future (middle) and more distant future (right) climate scenarios, derived from output from the EHAM5/MPI-OM GCM

Schulze, R.E. 2010. ***Atlas of Climate Change and the South African Agricultural Sector: A 2010 Perspective***. Department of Agriculture, Forestry and Fisheries, Pretoria, RSA. pp 391.

Why climate info?

Third order derivatives
Soil water stress

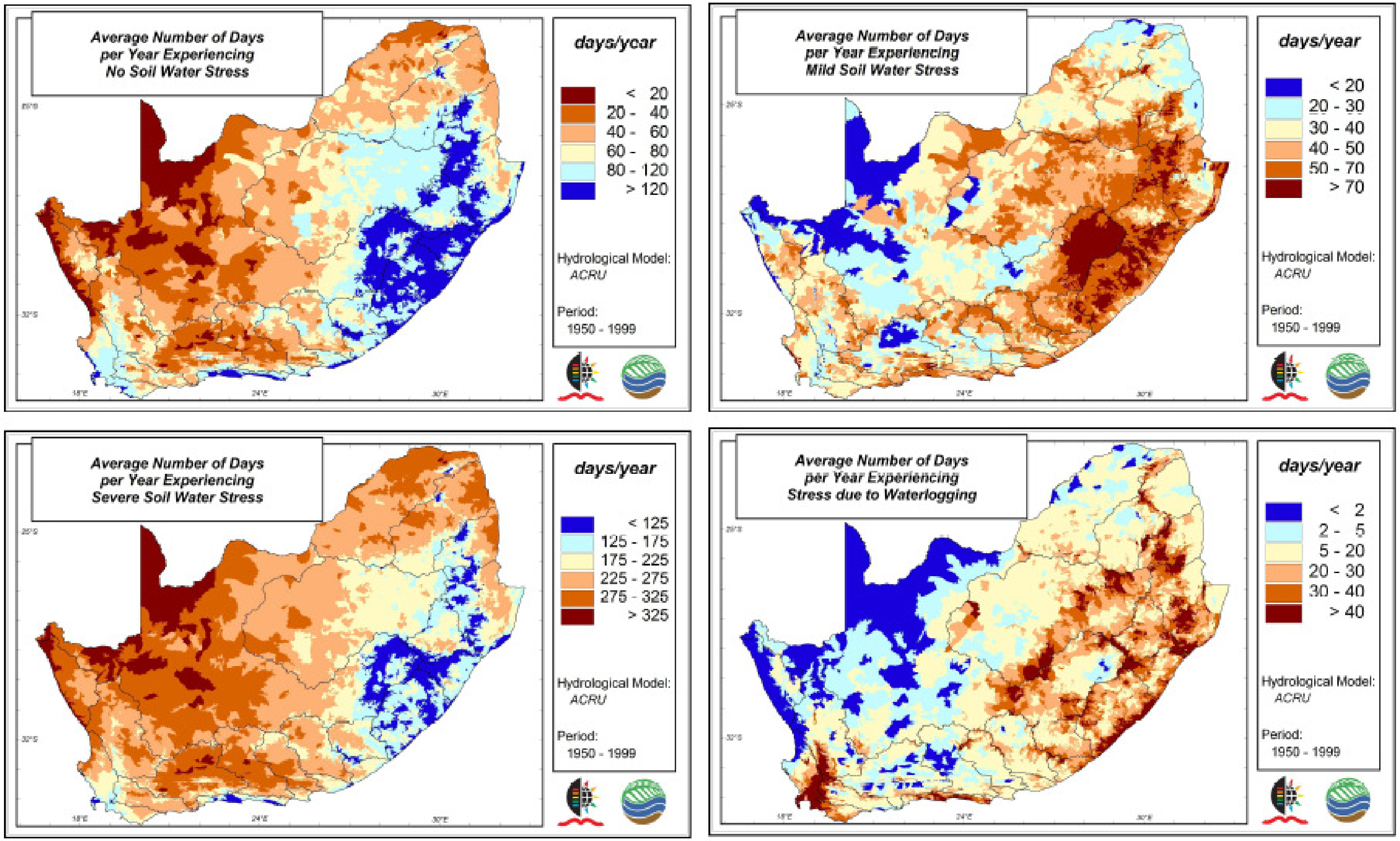


Figure 5.1.2 Average number of days per year experiencing no soil water stress (top left), mild stress (top right), severe soil water stress (bottom left) and stress due to waterlogging (bottom right) for current (1950 - 1999) climatic conditions

Schulze, R.E. 2010. ***Atlas of Climate Change and the South African Agricultural Sector: A 2010 Perspective***. Department of Agriculture, Forestry and Fisheries, Pretoria, RSA. pp 391.

Why climate info?

Third order derivatives
Pest and diseases

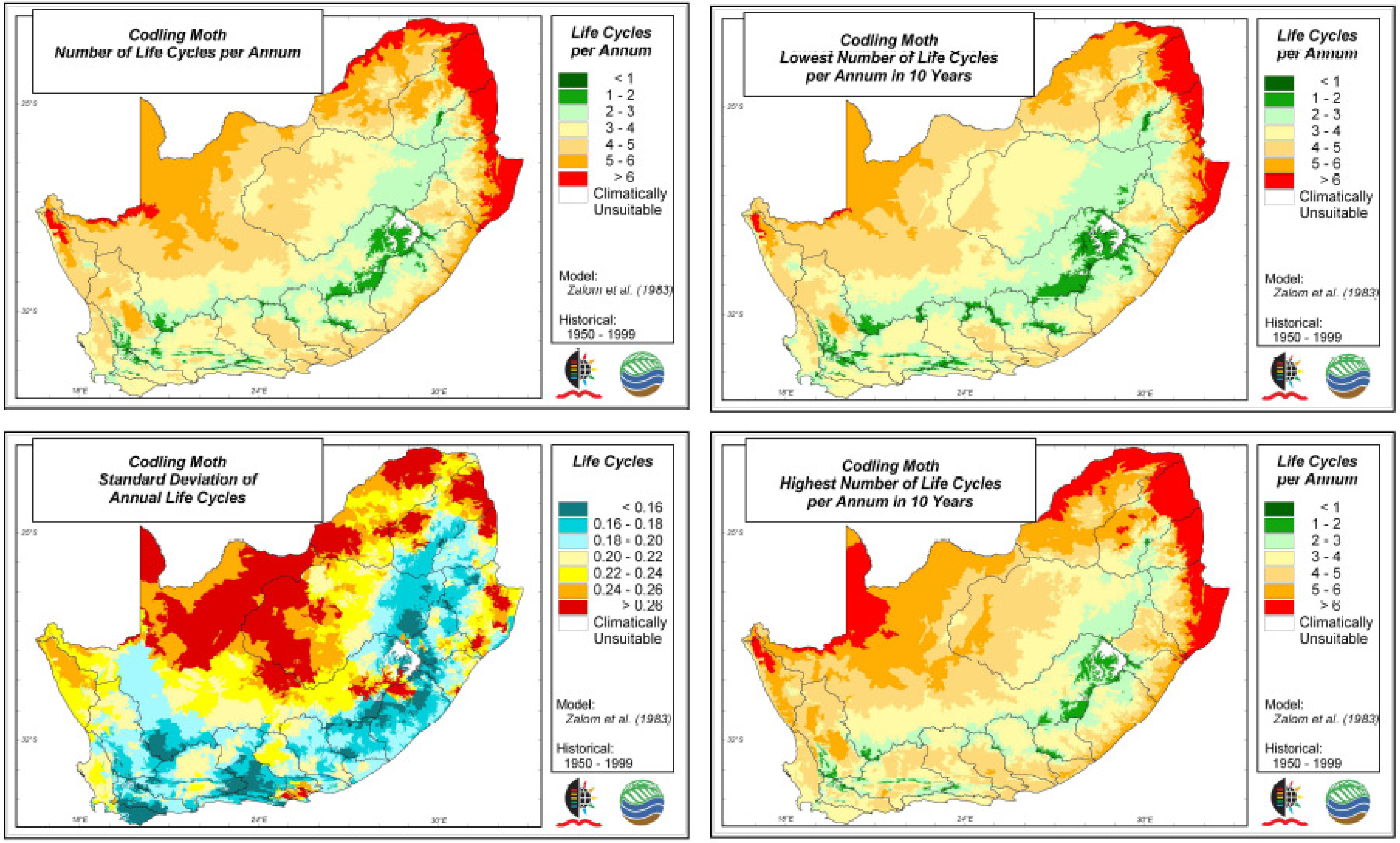


Figure 8.4.1 Mean number of life cycles per annum of codling moths (top left), the inter-annual variability in annual life cycles (bottom left) and lowest and highest numbers of life cycles in 10 years (top and bottom right), simulated with the Zalom *et al.* model under baseline (historical; 1950 - 1999) climatic conditions

Schulze, R.E. 2010. ***Atlas of Climate Change and the South African Agricultural Sector: A 2010 Perspective***. Department of Agriculture, Forestry and Fisheries, Pretoria, RSA. pp 391.

Why climate info?

Third order derivatives
Crop yield forecasting

Long term predictions (climate change)

Two historic climate data sources were used:

- **National scale**: Data from the University of KwaZulu-Natal. Based on quinary catchments (1950-1999) used 1980-1999.
- **AgMERRA**: Climate Forcing Datasets for Agricultural Modelling, NASA. Used 2000-2010.

Future climate data based on Global Circulation Models (GCMs) with no downscaling using mean and Daily Variability as the future creation method.

Data contained daily:

- minimum and maximum temperature,
- precipitation and
- solar radiation.

Historical Climate Conditions
1980-2010
CO_2 360 ppm

Future Climate Scenario's
2040-2070
CO2 571 ppm
RCP 4.5 and 8.5

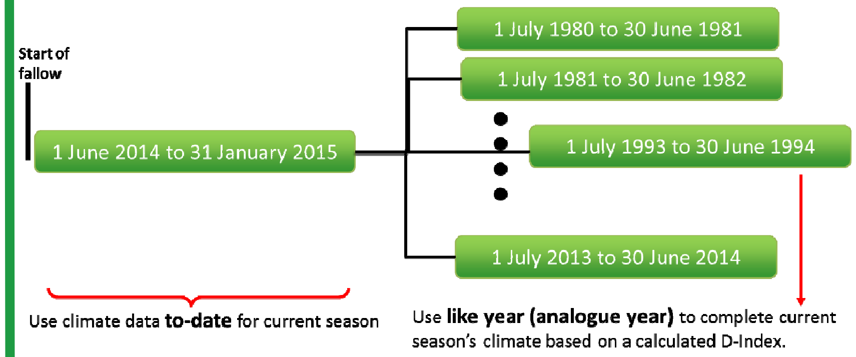
- GCM's: CCSM4, IPSL-CM5A-LR, IPSL-CM5A-MR, NorESM1-M and HadGEM2-AO.
- Mid-century (2040-2070) under RCP4.5 and 8.5.
- Baseline CO_2 level 361 ppm and future 571 ppm.

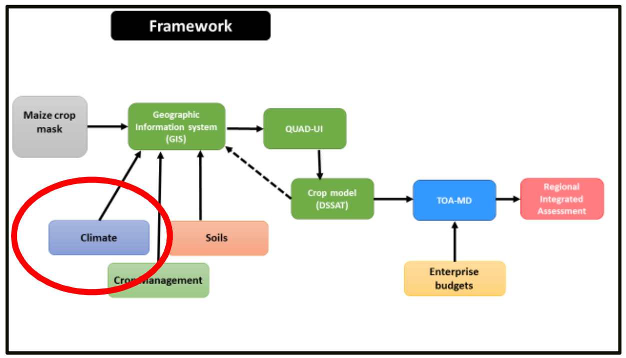
Short term predictions (in season)

Single season up-to-date and projected climate using an analogue model (Crop estimates)

Climate data for the season to date

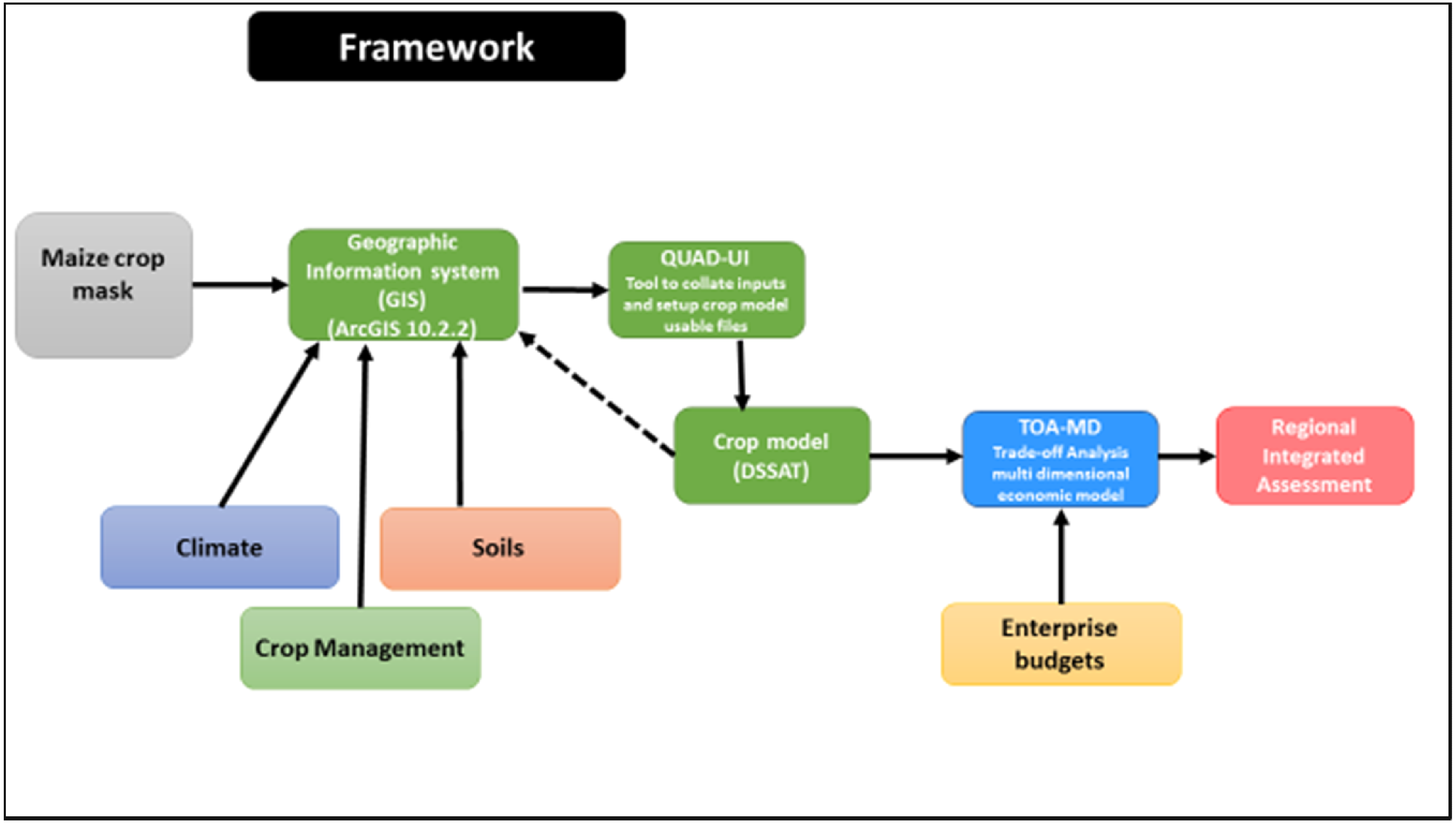
Historic climate data base





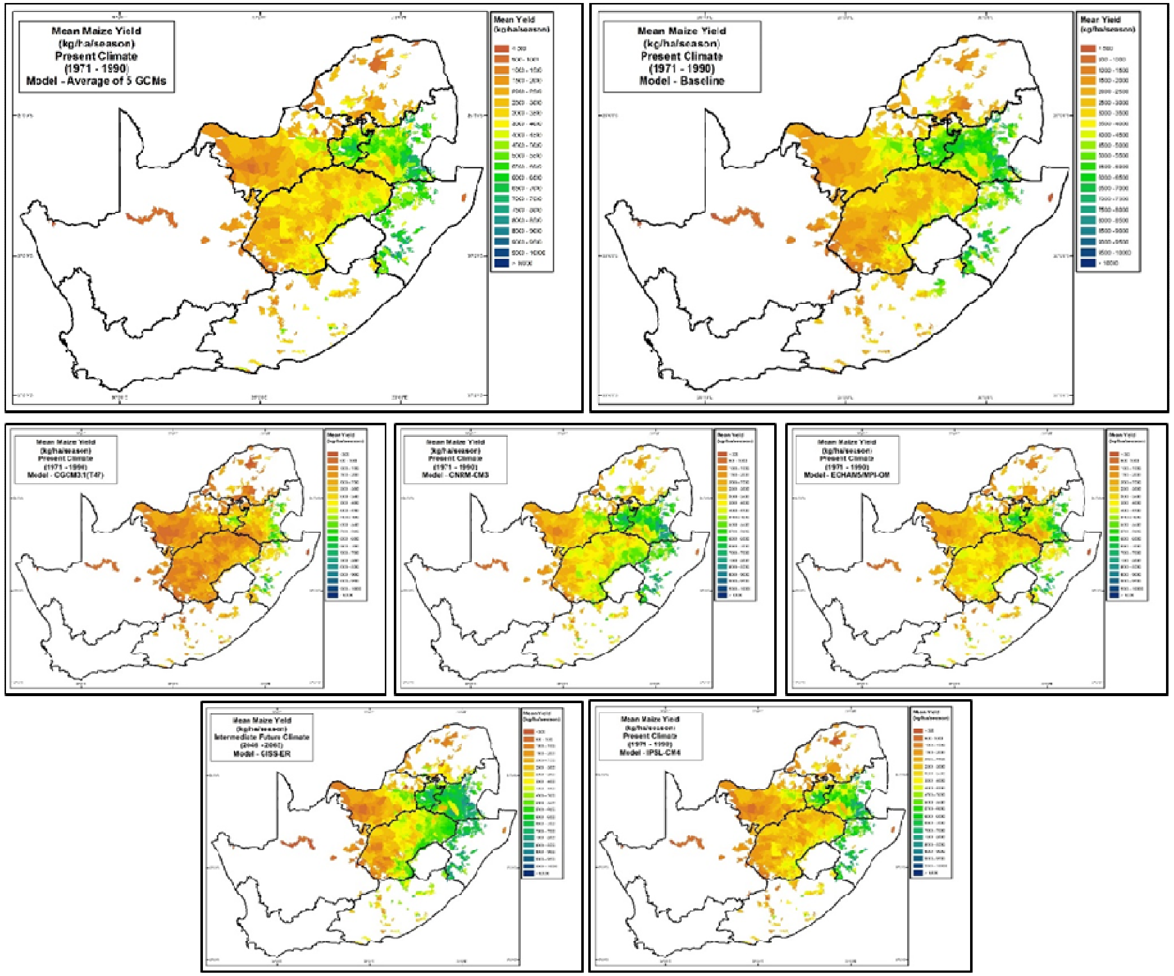
Why climate info?

Third order derivatives
Crop yield forecasting



Why climate info?

Third order derivatives
Crop yield forecasting



National Scale

Means of simulated dryland maize yields under present (1971-1990) climatic conditions, averaged from outputs of 5 GCMs (top left), from each individual GCM (bottom smaller maps) and (top right) for baseline climatic conditions (Durand and Schulze, 2014).

Why climate info?

Third order derivatives
Crop yield forecasting

	AREA	YIELD	PRODUCTION
A-line	NCSC: PICES Telephonic (subjective) survey	NCSC: Objective yield	SAGIS (end of season)
B-line	DAFF	Crop-Modelling (when updated with new variables)	SANSOR (more discussions needed)
C-line:	Agric Risk Specialists; DPO; Fertiliser Companies	Financial Institutions; Forums; Agbiz-grain	PDAs; SACOTA; Traders/ Reports

Current sources of climate data:

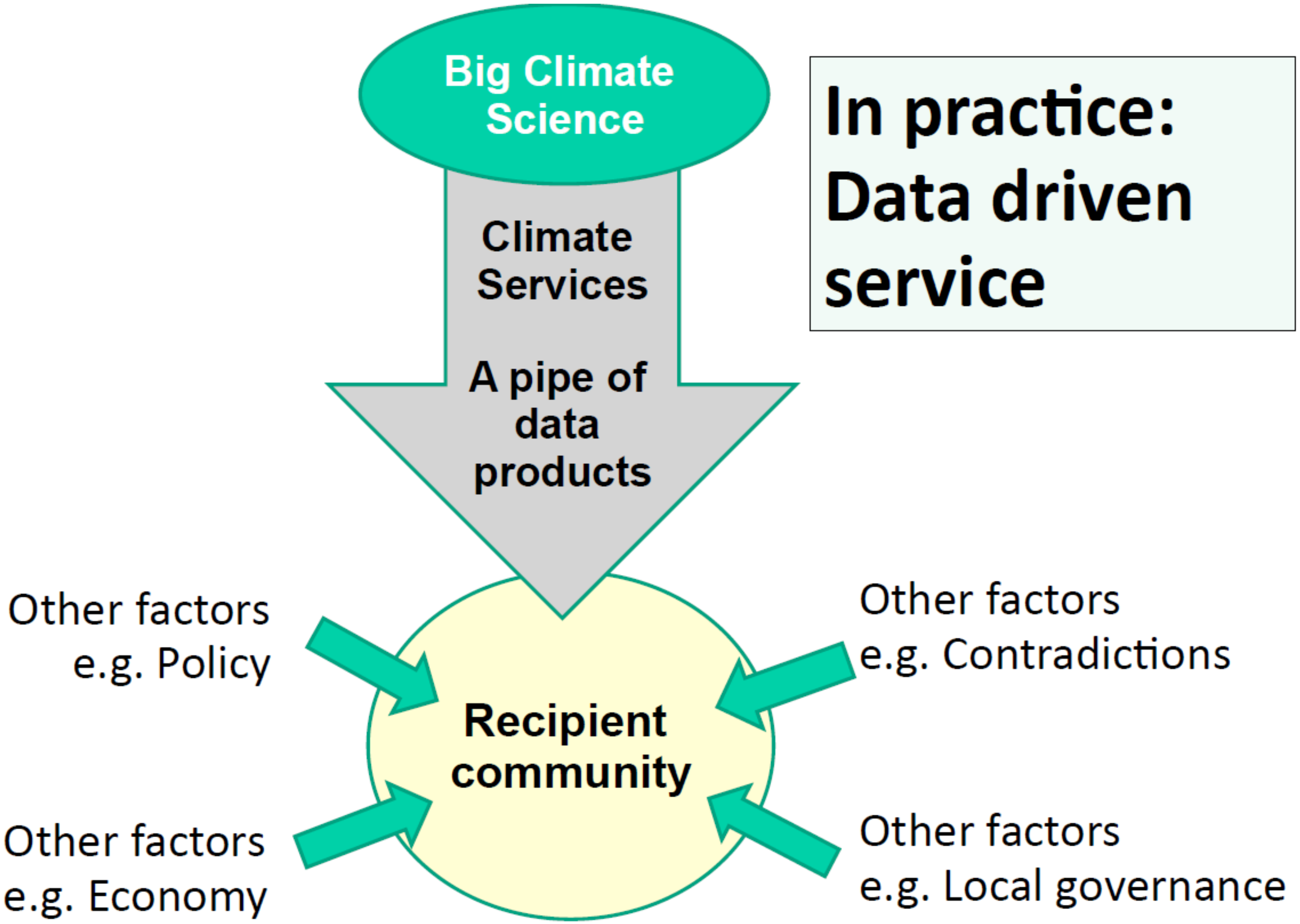
- **ARC**
- **Agribusiness**:
  - ✓AFGRI
  - ✓OVK
  - ✓NWK
  - ✓SENWES
  - ✓SUIDWES
  - ✓VKB

Current **limitations** of climate data for crop modelling:

- Spatial representation – linking the rainfall data to the fields.
- Missing rainfall data
- No measured temperature (Min and Max) data
- No measured solar radiation data.

Why climate info?

Climate science
A data driven service



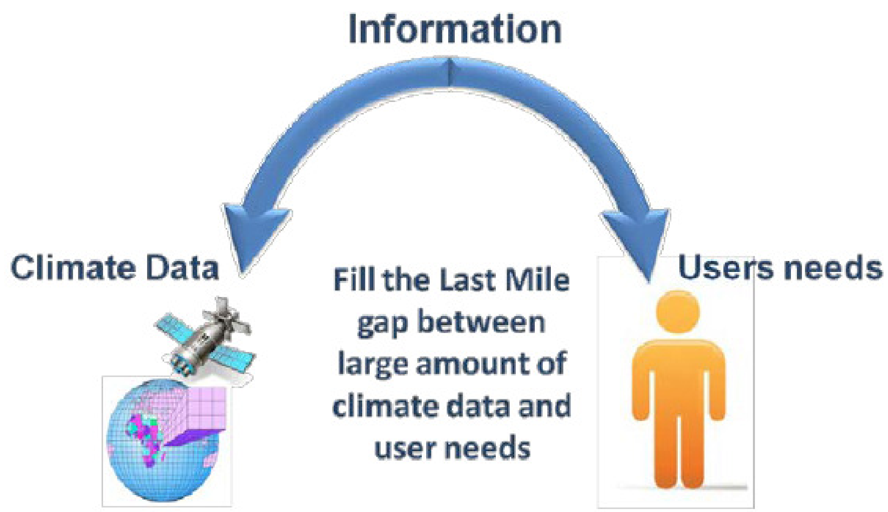
Why climate info?

Climate science
A data driven service

With the closure of the CCWR (2001) no common point of rainfall data access is any longer available in South Africa.

Consequences:

- Difficult to access data
- The cost of data
- Data quality
- Difficult for the generation of second and third order derivatives
- Difficult to collate different data sources

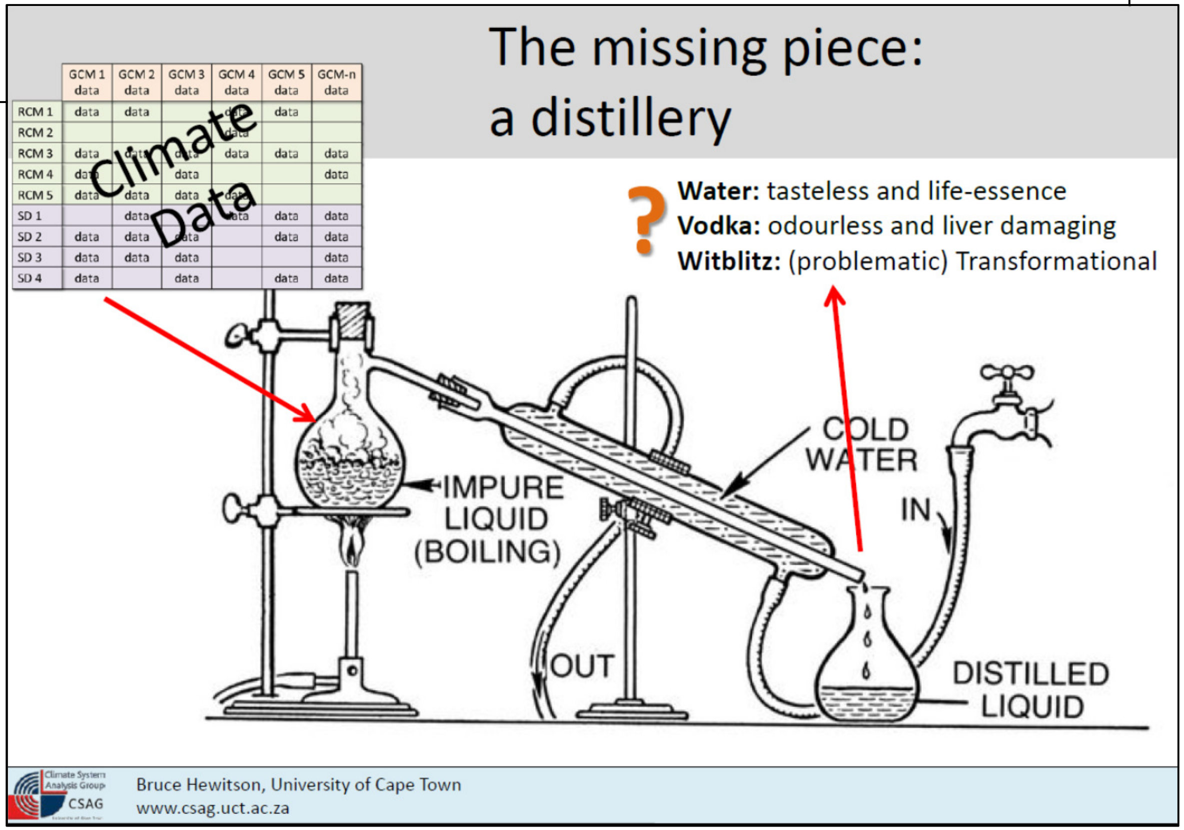


Still the **collection of data is important** and it would be nice if private/public sector partnerships could come together again to set up a common point centre for climate data.

Acknowledgements

Thank you to all the Agribusiness who have supplied rainfall data over the past 15 years for **crop estimates.**

Your data is important to us.



Thank You

CSAG Climate System Analysis Group · ARC • LNR Excellence in Agricultural Research and Development · University of KwaZulu-Natal Inyuvesi YaKwaZulu-Natali · AgMIP The Agricultural Model Intercomparison and Improvement Project · The Maize Trust