Vulnerability and Adaptation Assessment Hands-on Training Workshop
for the Africa Region

- Climate Change Scenarios -

Maputo, Mozambique
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climate change secretariat

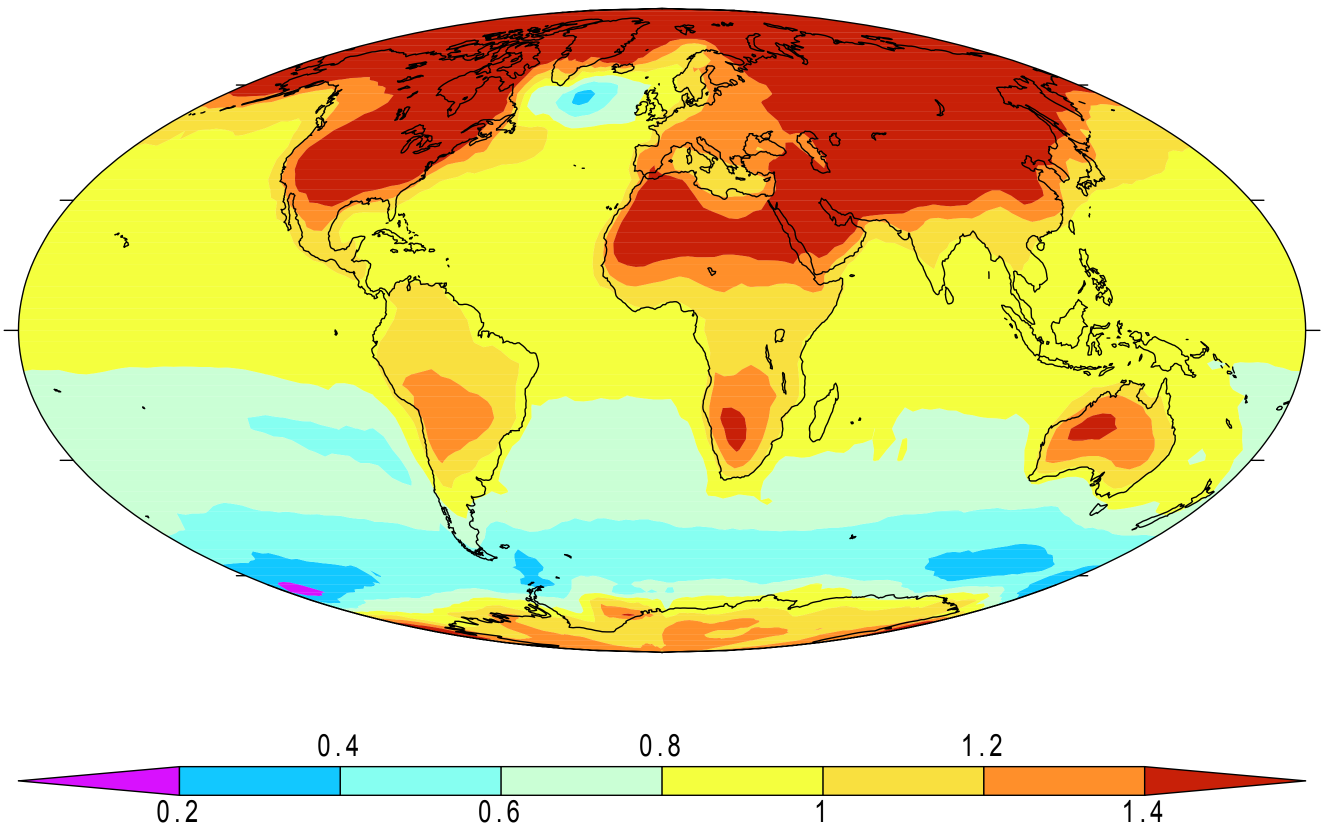
Outline

- Brief review of climate change
- Why we use scenarios
- Review of options
  - Incremental
  - Analogue
  - Models
    - GCMs
    - Use of GCMs
    - Downscaling options
- Techniques for understanding range of regional climate change
- What to do
- Obtaining data

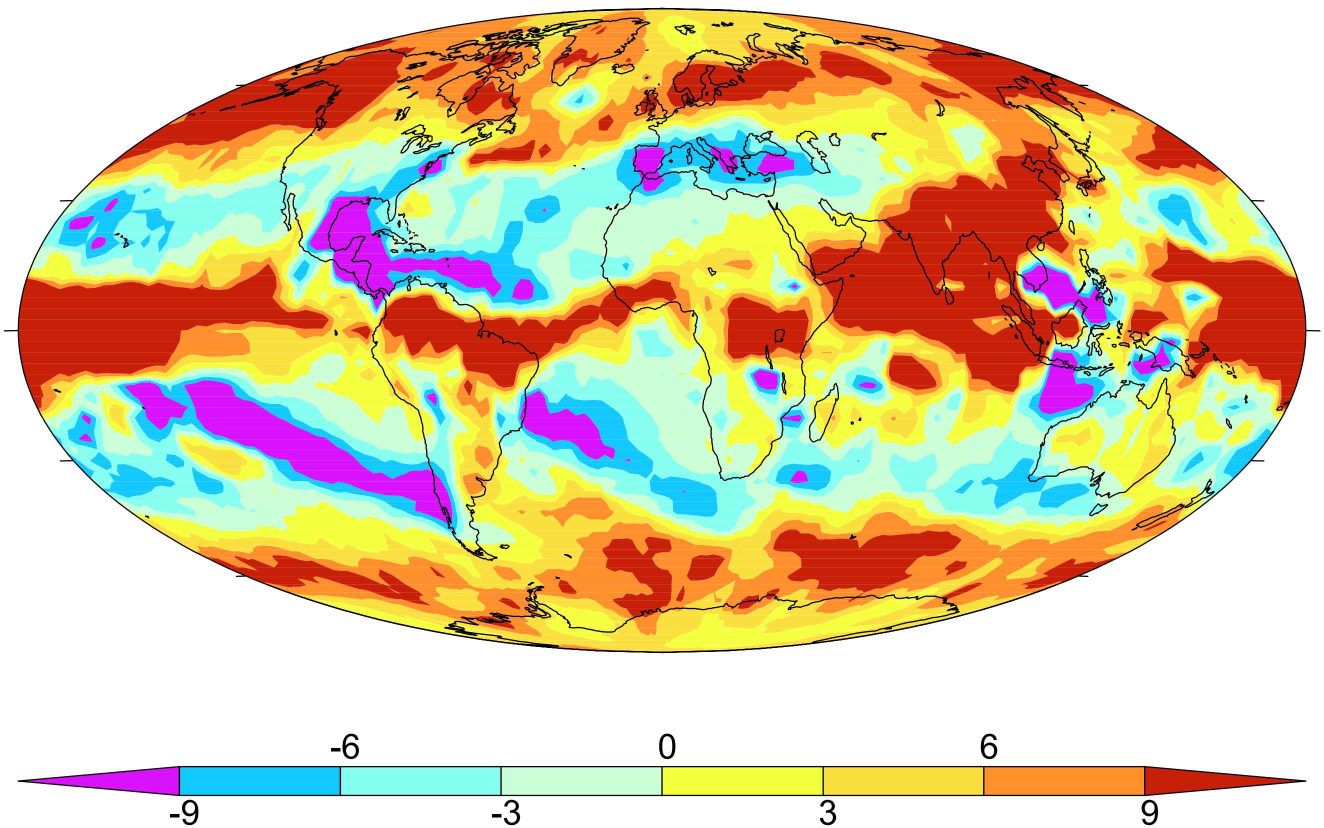
Brief Primer on Regional Climate Change

- Temperatures over most land areas likely to rise
  - Other factors, e.g., land use change, also have importance
  - Increase in heat waves and evaporation
- Rise in mean sea level: 0.1 to 0.9 m
  - Local subsidence/uplift
- Precipitation will change; increase globally
  - Local changes uncertain: critical uncertainty
  - Increase in storm intensity in some regions

Normalized Annual-Mean Temperature Changes in CMIP2 Greenhouse Warming Experiments



Normalized Annual-Mean Precipitation Changes in CMIP2 Greenhouse Warming Experiments



Why Use Climate Change Scenarios?

- We are unsure exactly how regional climate will change
- Scenarios are plausible combinations of variables consistent with what we know about human induced induced climate change
- One can think of them as prediction of a model, contingent upon the greenhouse gas emissions scenario
- Since estimate of regional change by models differs substantially, an individual model estimate should be treated more as a scenario

What are Reasonable Scenarios?

- Scenarios should be:
  - Consistent with understanding of anthropogenic effects on climate
  - Internally consistent
    - e.g., clouds, temperature, precipitation

- Scenarios are a communication tool about what is known and not known about climate change
  - Should reflect plausible range for key variables

Scenarios for Impacts Analysis

- Need to be at a scale necessary for analysis
- Spatial
  - e.g., to watershed or farm level
- Temporal
  - Monthly
  - Daily
  - Sub-daily

Options for Creating Scenarios

- Past climates: analogues
- Spatial analogues
- Arbitrary changes; incremental
- Climate models

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Past Climates

- Options
  - Instrumental record
  - Paleoclimate reconstructions

- Instrumental record
  - Pros
    - Can provide daily data
    - Includes past extreme events
  - Con
    - Range of change in climate is limited

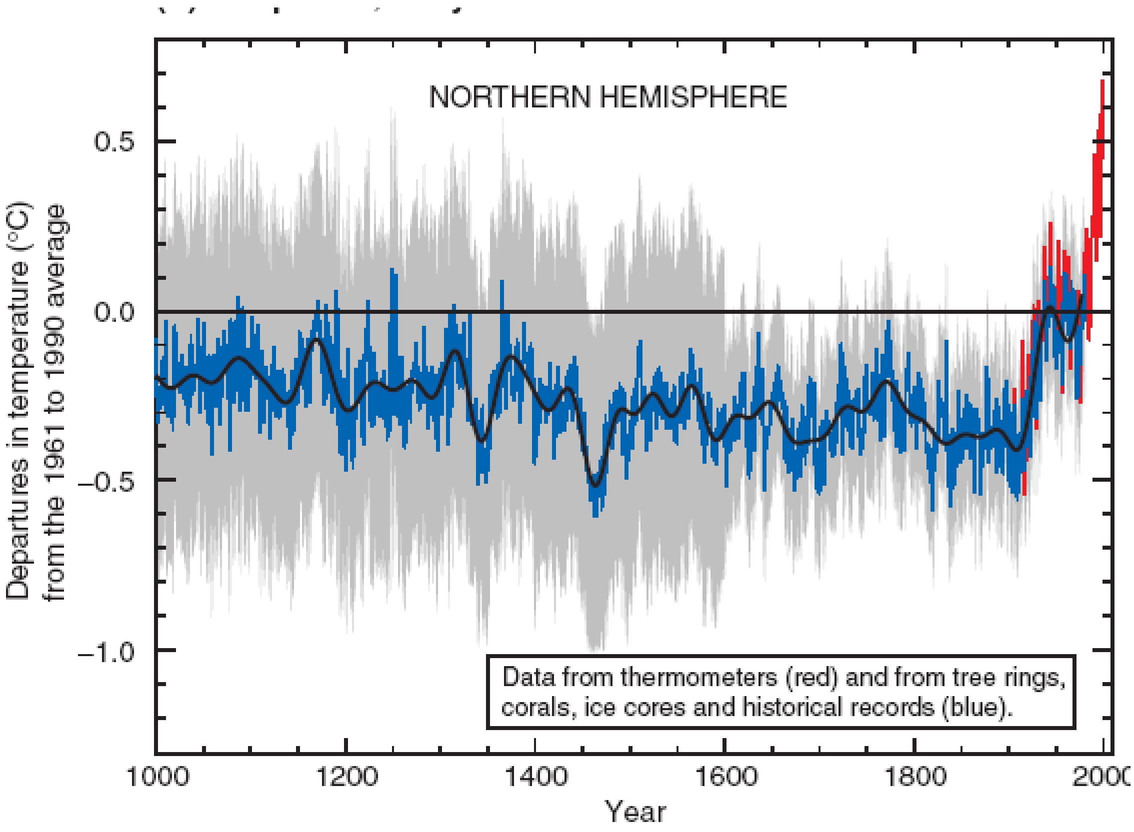
Past Climates (continued)

- Paleoclimate reconstructions
  - From tree rings, boreholes, ice cores, etc.
  - Can give annual, sometimes seasonal climate
  - Can go back hundreds of years

- Pro
  - Wider range of climates

- Cons
  - Incomplete data
  - Uncertainties about values

Mann et al. Reconstruction of N. Hemisphere Temperatures



Spatial Analogues

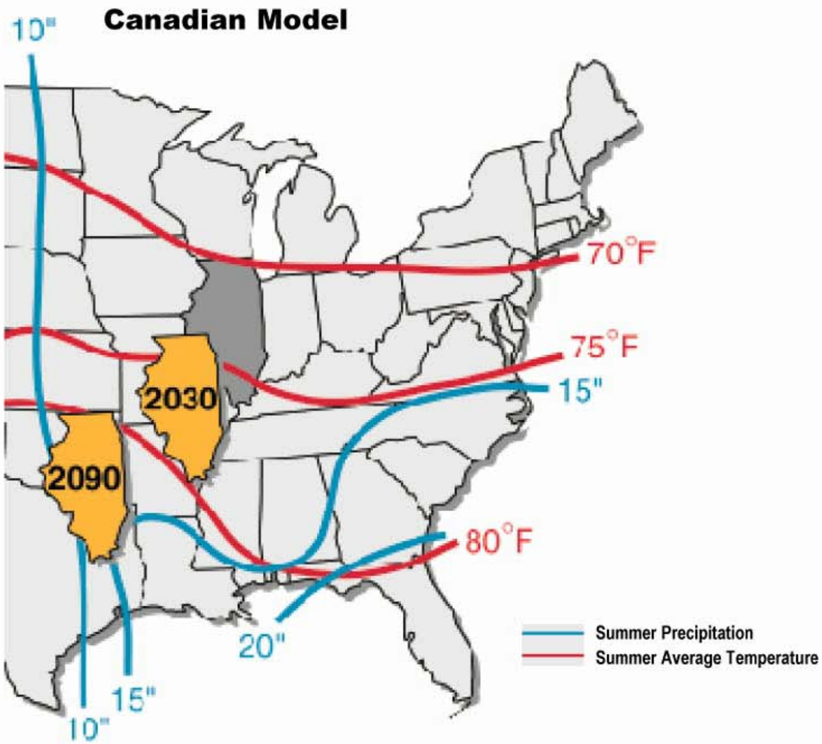


Illustration of how the summer climate of Illinois would shift under the Canadian and Hadley model scenarios. Under the Canadian scenario, the summer climate of Illinois would become more like the current climate of southern Missouri in 2030 and more like Oklahoma's current climate in 2090. The primary difference in the resulting climates of the two models relates to the amount of summer rainfall.

Spatial Analogues (continued)

- Advantages
  - Communication tool: perhaps easier to understand

- Disadvantages
  - Change in climate may be different from what spatial analogue shows
  - Don’t capture changes in variability

Arbitrary/Incremental

- Assume uniform annual or seasonal changes across a region
- + 2°C; +4°C
- +/- 10%, 20% change in precipitation
- Can also make assumptions about changes in variability and extremes

Arbitrary/Incremental

- Pros
  - Easy to use
  - Simulate wide range of conditions
- Cons
  - If assume uniform annual change or spatial change, do not capture temporal or spatial variance
  - Combinations of changes in climate variables can be physically implausible

Climate Models

- Mathematical representations of the climate

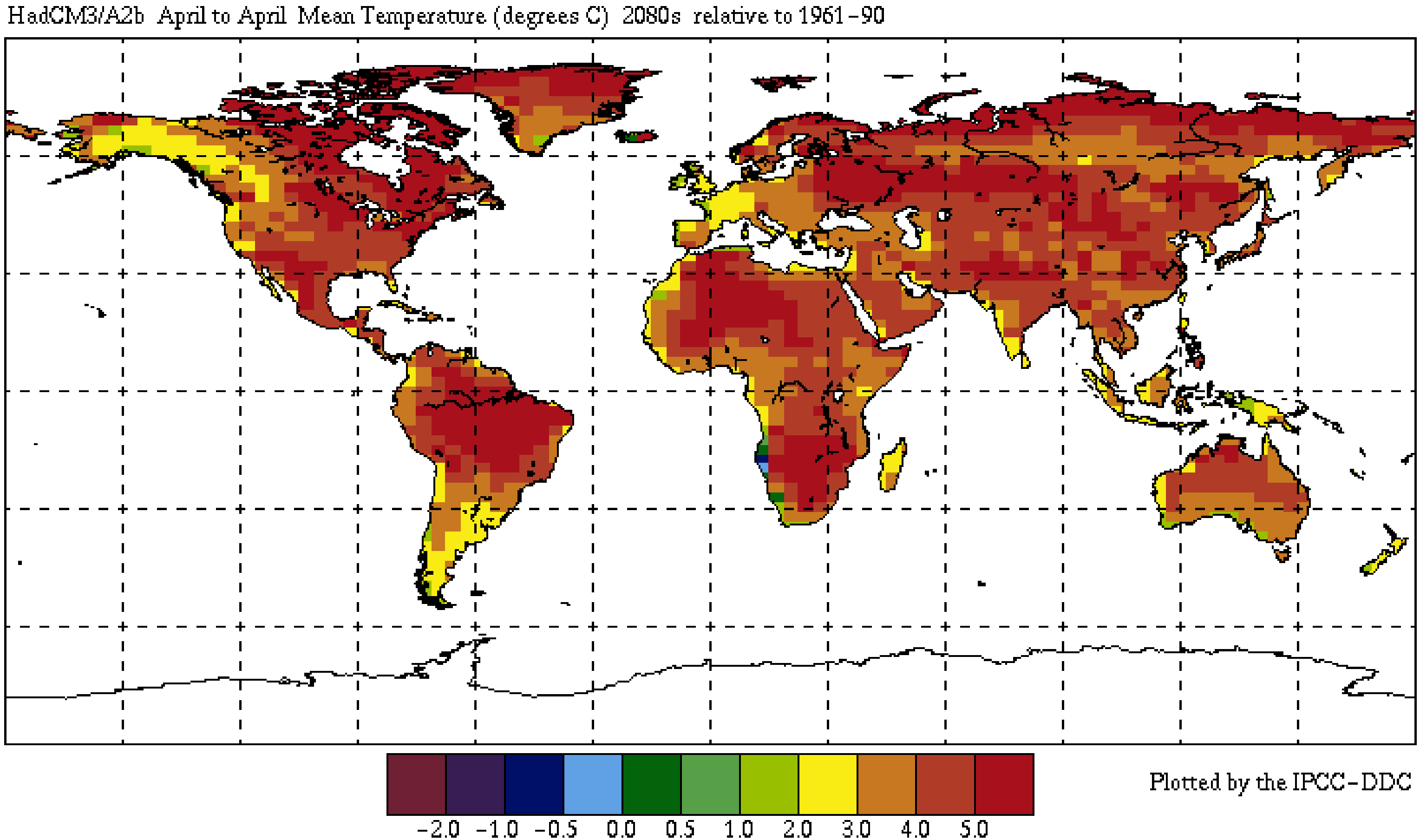
- Can be run with different forcings, e.g., higher GHG concentrations

  - Only way to capture complexities of increased GHG concentrations

General Circulation Models

- Pros
  - Can represent future climate conditions
  - Can maintain internal consistency
- Cons
  - Low spatial resolution
  - May not accurately represent climate parameters

Example of GCM Output



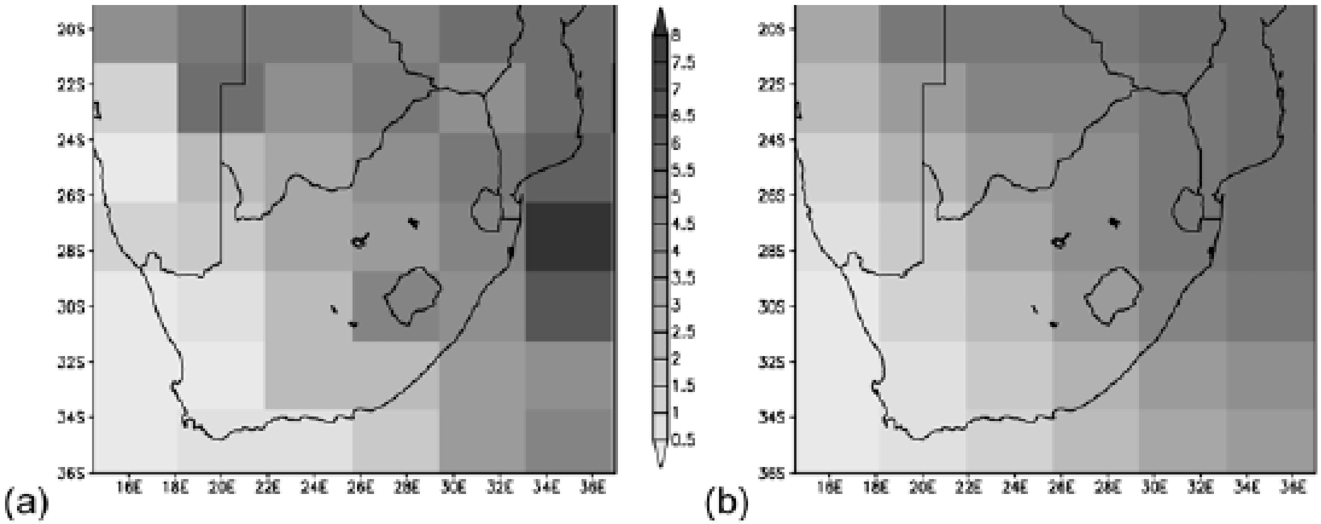
Downscaling from GCMs

- Downscaling is a way to obtain higher spatial resolution output based on GCMs
- Combine monthly GCM output with observations
- Statistical downscaling
  - Easier to apply
  - Assumes fixed relationships
- Regional Climate Models (RCMs)
  - High resolution
  - Captures more complexity
  - Limited applications
  - Computation very demanding

Combine Monthly GCM Output with Observations

- An approach that has been used in many studies
- Typically, combine average monthly change from GCMs
  - 30 year average, if possible
  - Hewitson (2003) recommends rather than using individual grid box, average the nine grid boxes surrounding and including the study area grid box

From Hewitson (2003)



Combining Monthly GCMs and Observations

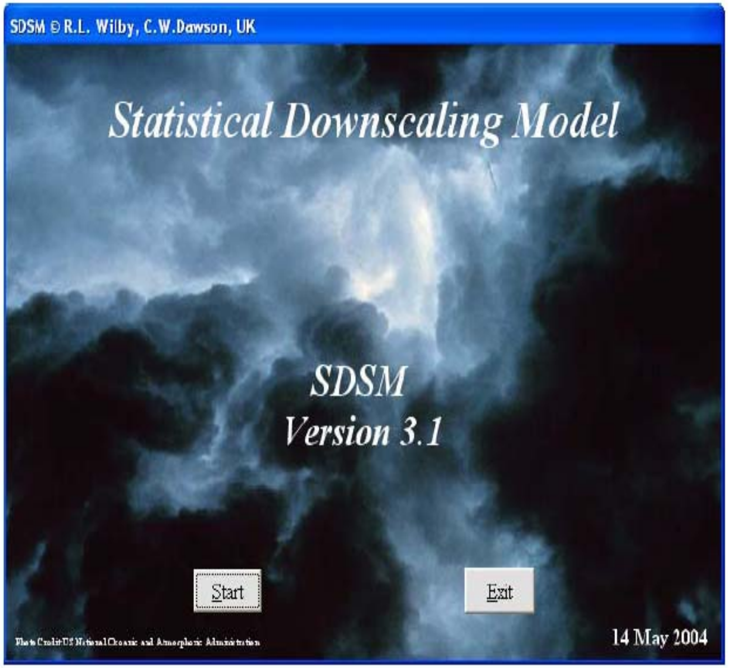
- Use a 30 year recent record of climate
  - 1961-1990
  - 1971-2000
  - Make sure baseline from GCM consistent with choice of observations
  - Recent baselines include warming, in particular 1990s
- Can provide daily data with resolution of weather observation stations
- Assumes uniform changes within grid box and month
  - No spatial or daily/weekly variability

Statistical Downscaling

- Is most appropriate for
  - Sub-grid scales (small islands, point processes, etc.)
  - Complex/heterogeneous environments
  - Extreme events
  - Exotic predictands
  - Transient change/ensembles
- Is not appropriate for
  - Data-poor regions
  - Where relationships between predictors and predictands may change.

Statistical Downscaling Model (SDSM)

- Currently, only feasible based on outputs from a few GCMs



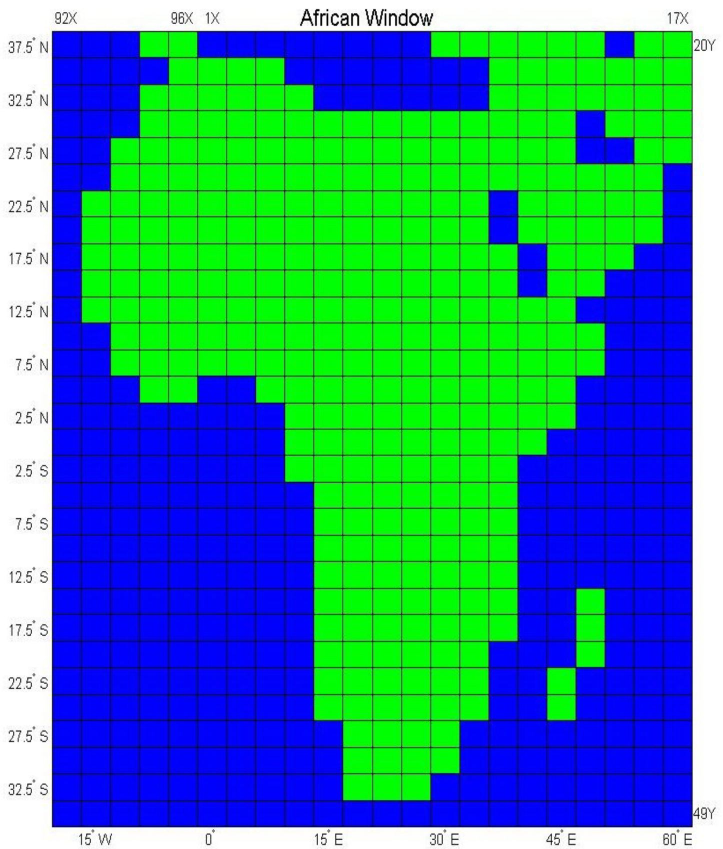
User Manual

Robert L. Wilby[1] and Christian W. Dawson[2]

August 2004

Global Data to Use in Downscaling with SDSM

- Canadian site
  - Go to scenarios, then SDSM
- Only has HadCM3
- Get output for individual grid



Regional Climate Models

- High resolution models “nested” within GCMs
  - 50 km grids
    - Some are higher resolution
  - Run with boundary conditions from GCMs

- Give higher resolution output
  - Much greater sensitivity to smaller scale factors such as mountains, lakes

RCM Limitations

- Cannot correct for errors in GCMs
- Typically applied to one or only a few GCMs
- In many applications, just run for a simulated decade, e.g., 2040s
- RCMs still need to parameterize many processes
- May need further downscaling for some applications

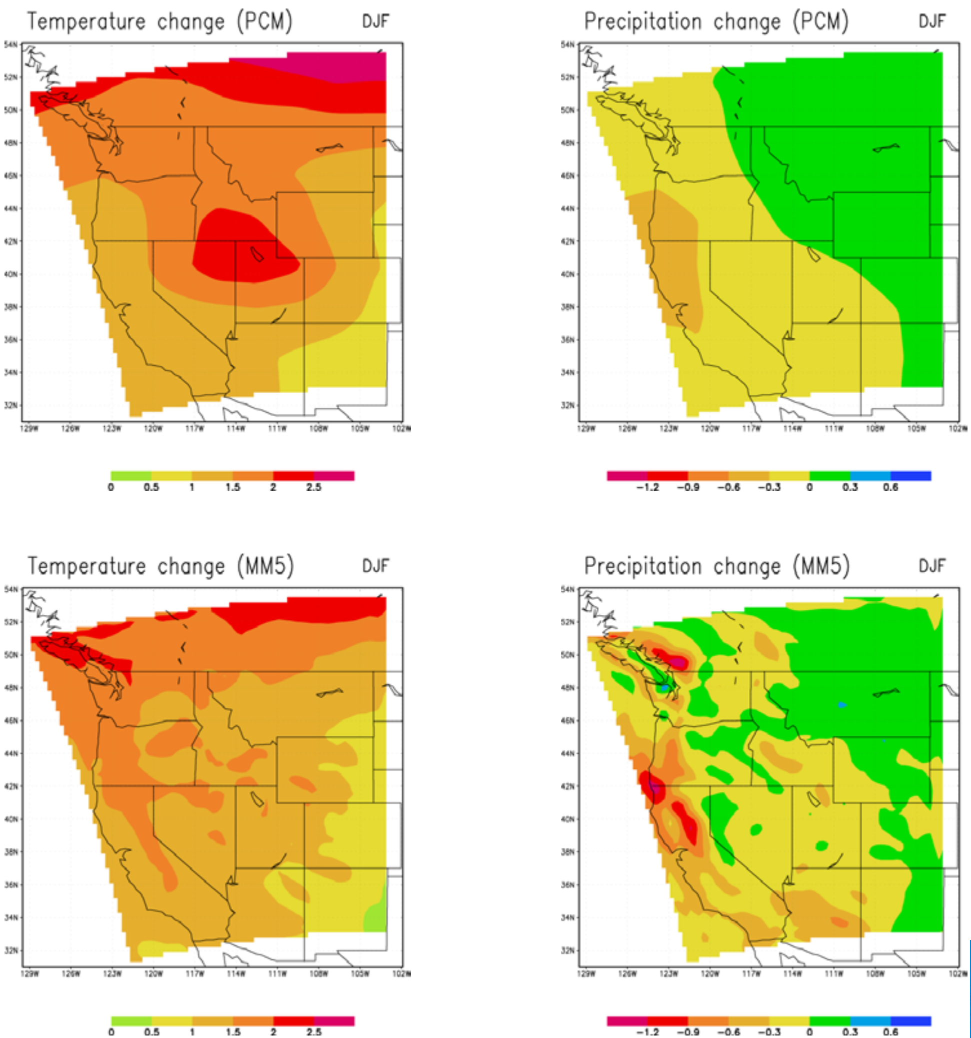
GCM vs. RCM Resolution

Temperature

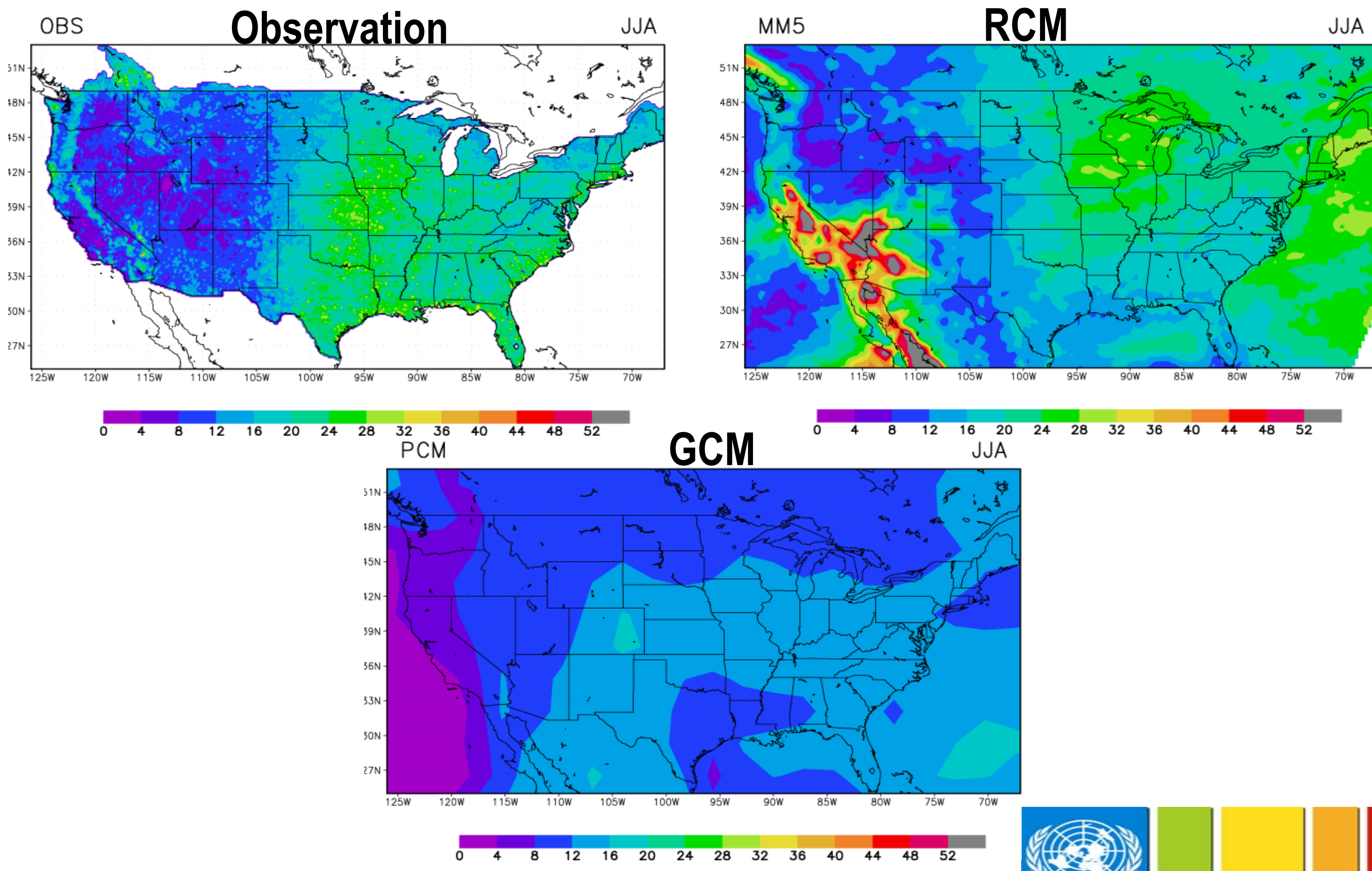
Precipitation

GCM

RCM



Extreme Precipitation (JJA)



RCM Coming Soon

- Data from two RCMs (PRECIS model developed by Hadley Centre, MM5 nested within 3 GCMs) and statistical downscaling
- A2 Scenario
- 10 years of control (simulating current climate)
- 10 years in the future
- Available later this spring from Climate Systems Analysis Group (CSAG), University of Cape Town (www.csag.uct.ac.za)

By Now You May Be Confused

- So many choices, what to do
- First, let’s remember the basics
  - Scenarios are essentially educational tools to help:
    - see ranges of potential climate change
    - provide tools for better understanding sensitivities of affected systems
- So, we need to select scenarios that enable us to meet these goals

Tools for Surveying Regional Model Output

- Survey results of many GCMs
- Model results are normalized so the relative regional changes can be compared
- Can analyze degree to which models agree about change in direction and relative magnitude
  - A measure of GCM uncertainty
- But, still rely on climate models to capture range
  - What if all or most models repeat the same mistakes?
- Technique useful for selecting scenarios

Normalizing GCM Output

- Expresses regional change relative to increase of 1°C in mean global temperature
  - This is a way to avoid high sensitivity models dominating results
  - It allows us to compare GCM output based on relative regional change
- Normalized temperature change = $\Delta T_{RGCM}/\Delta T_{GMTGCM}$
- Normalized precipitation change = $\Delta P_{RGCM}/\Delta T_{GMTGCM}$

Pattern Scaling

- Is a technique for estimating change in regional climate using normalized change and changes in GMT

- Pattern scaled temperature chair:
  - $\Delta T_{R\Delta GMT} = (\Delta T_{RGCM}/\Delta T_{GMTGCM})\ X\ \Delta GMT$

- Pattern scaled precipitation
  - $\Delta P_{R\Delta GMT} = (\Delta P_{RGCM}/\Delta T_{GMTGCM})\ X\ \Delta GMT$

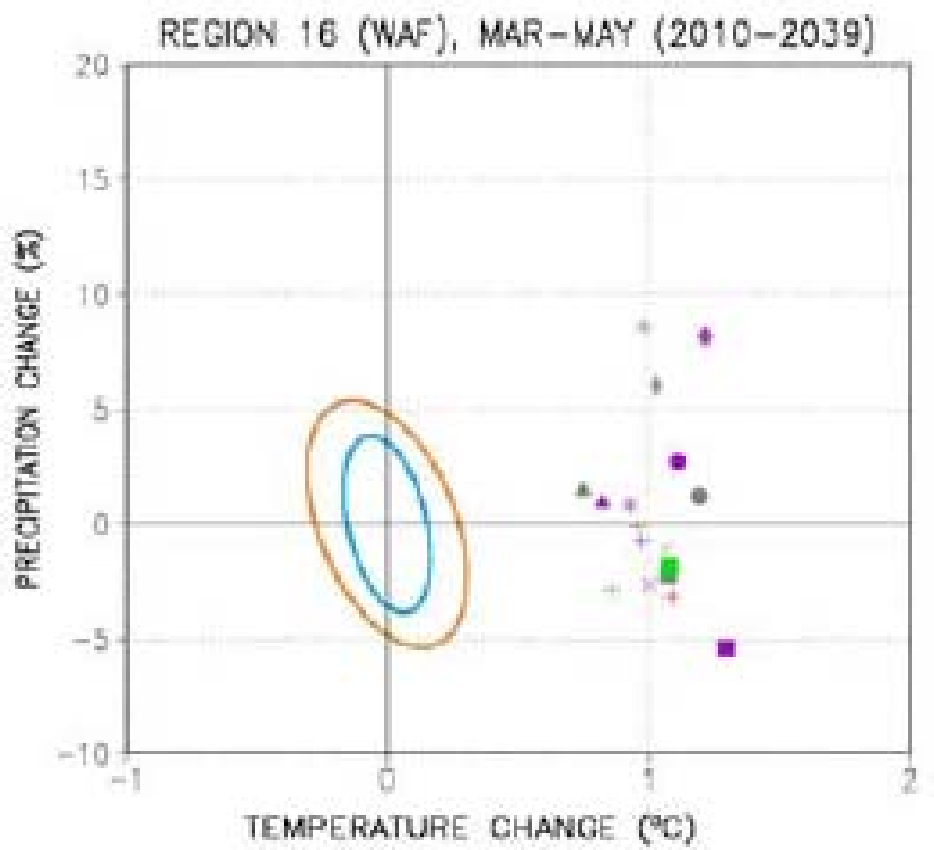
Tools to Survey GCM Results

- Finnish report: “Future climate . . .”
- COSMIC
- MAGICC/SCENGEN

Finnish Publication

- Shows regional output on temperature and precipitation for a number of models
  - For three time slices over 21st century
  - Uses some scaling
- Useful as a look-up to see degree of model agreement or disagreement
- MAGICC/SCENGEN and COSMIC provide more flexibility to users

Finnish Environment Example



COSMIC

- Developed by M. Schlesinger, R. Mendelsohn, and L. Williams
- Can choose from 28 emission scenarios
- Select individual GCM model
  - Results scaled
- Select country
  - Area or population weighted
- Yields annual change in GHGs, SO_2, SLR, and temperature

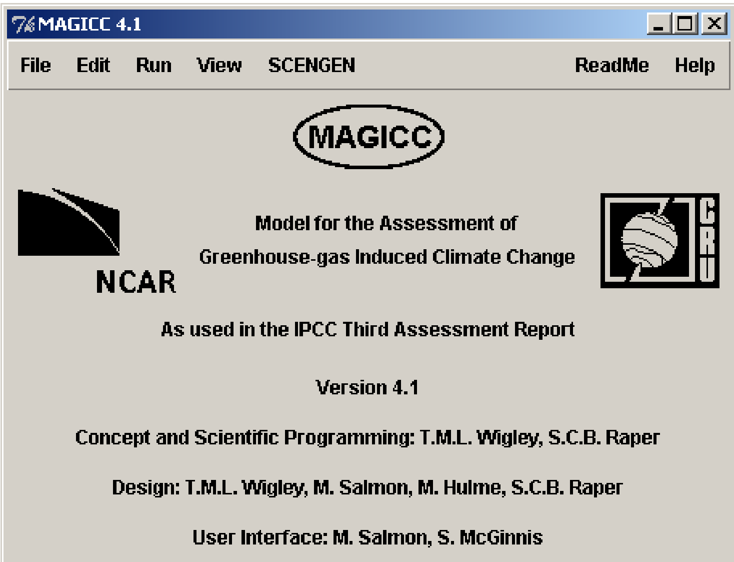
COSMIC Output

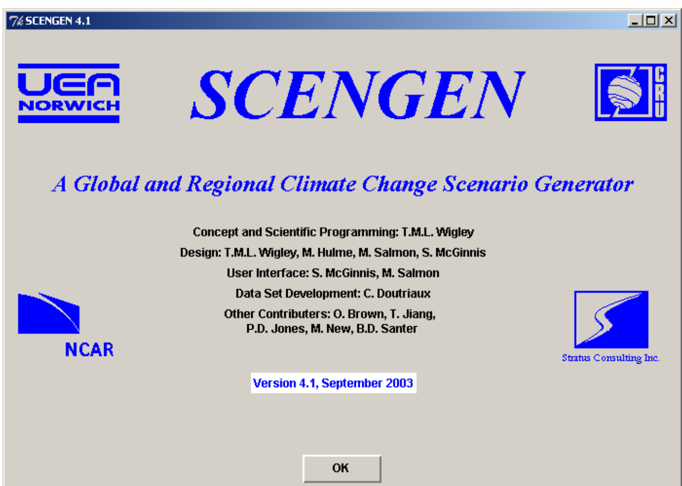
- Will give global changes in CO_2, SO_4, temperature, and sea level rise
- Will also give month-by-month temperature and precipitation at the country level
- Easy to use and obtain data
- You should not use raw output, but compute changes in temperature and precipitation

COSMIC Limitations

- Since results are scaled, change will be smooth – not reflect change in interannual variability
  - Since results are smoothed, it is OK to use a single year output as representative of average climate change
- GCMs tend to be older than in SCENGEN
  - Are 2 x CO_2; not transients
- Does not have mapping capabilities of SCENGEN

MAGICC/SCENGEN



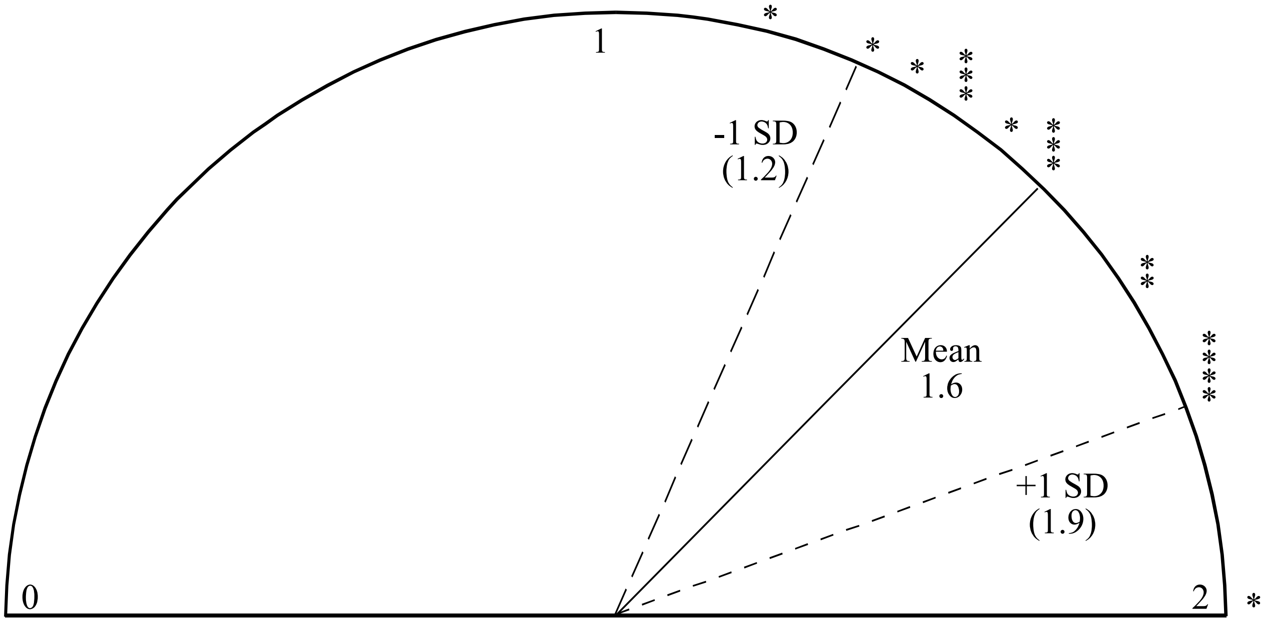


- MAGICC is 1-D model of global T and SLR
- Used in IPCC TAR
- SCENGEN uses pattern scaling for 17 GCMs
- Yield
  - Model by model changes
  - Mean change
  - Intermodel SD
  - Interannual variability changes
  - Current climate on 5 x 5°grid

MAGICC/SCENGEN Output Mozambique Temperature Change per 1°C mean global temperature rise

MODEL = BMRCD2 : AREA AVE = 1.043 : SPATIAL S.D. = .204 (degC/degC)
MODEL = CCC1D2 : AREA AVE = 1.222 : SPATIAL S.D. = .149 (degC/degC)
MODEL = CCSRD2 : AREA AVE = 1.234 : SPATIAL S.D. = .329 (degC/degC)
MODEL = CERFD2 : AREA AVE = 1.262 : SPATIAL S.D. = .178 (degC/degC)
MODEL = CSI2D2 : AREA AVE = .827 : SPATIAL S.D. = .099 (degC/degC)
MODEL = CSM_D2 AREA AVE = .921 : SPATIAL S.D. = .136 (degC/degC)
MODEL = ECH3D2 : AREA AVE = 1.206 : SPATIAL S.D. = .099 (degC/degC)
MODEL = ECH4D2 : AREA AVE = 1.337 : SPATIAL S.D. = .210 (degC/degC)
MODEL = GFDLD2 : AREA AVE = .954 : SPATIAL S.D. = .053 (degC/degC)
MODEL = GISSD2 : AREA AVE = 1.048 : SPATIAL S.D. = .108 (degC/degC)
MODEL = HAD2D2 : AREA AVE = 1.274 : SPATIAL S.D. = .280 (degC/degC)
MODEL = HAD3D2 : AREA AVE = 1.263 : SPATIAL S.D. = .244 (degC/degC)
MODEL = IAP_D2 : AREA AVE = 1.010 : SPATIAL S.D. = .169 (degC/degC)
MODEL = LMD_D2 : AREA AVE = 1.046 : SPATIAL S.D. = .173 (degC/degC)
MODEL = MRI_D2 : AREA AVE = .927 : SPATIAL S.D. = .186 (degC/degC)
MODEL = PCM_D2 : AREA AVE = .762 : SPATIAL S.D. = .052 (degC/degC)
MODEL = W&M_D2 : AREA AVE = .885 : SPATIAL S.D. = .091 (degC/degC)
MODEL = MODBAR : AREA AVE = 1.072 : SPATIAL S.D. = .128 (degC/degC)
OVERALL MEAN = 1.072 degC/degC
INTER-MODEL S.D. = .172 degC/degC (FOR NORMALIZED GHG DATA)

Scengen Temperature Output for Mozambique:A1B Scenario in 2050: 1.5°C above 1990

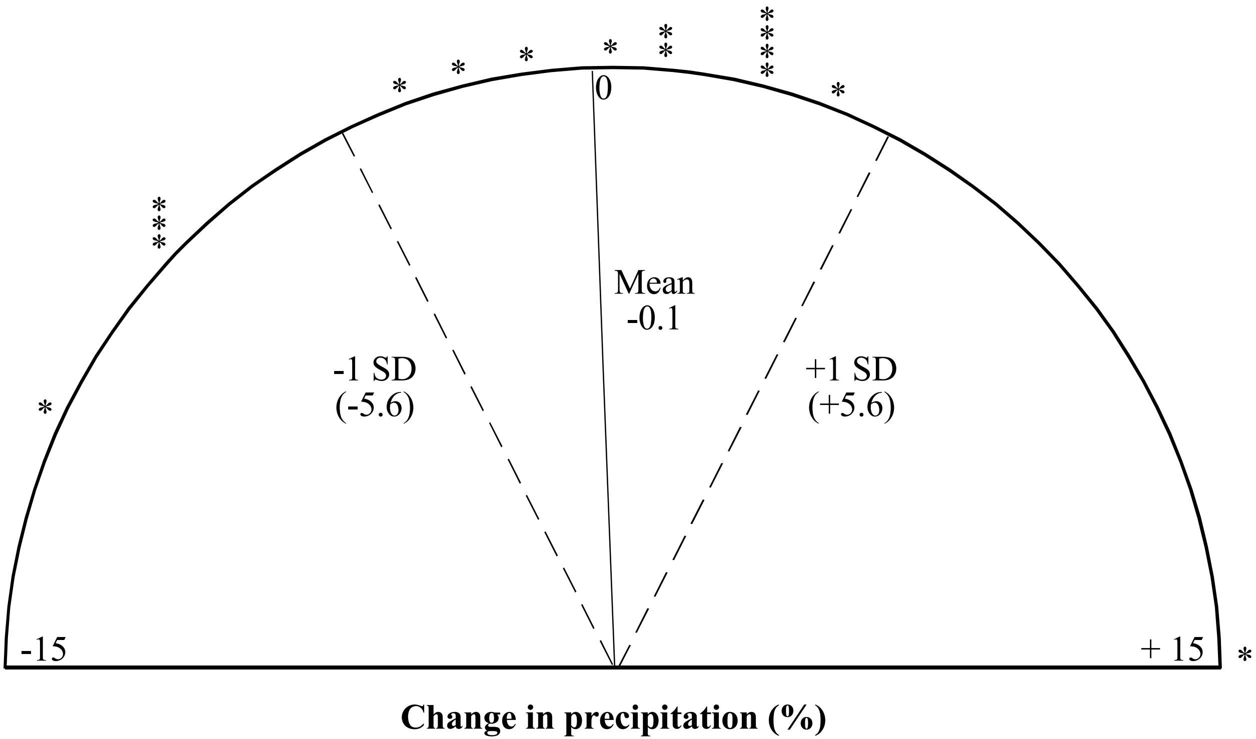


Change in temperature (°C)

MAGICC/SCENGEN Output
Mozambique Precipitation Change per 1^{o}C mean global temperature rise

MODEL = BMRCD2 : AREA AVE = .678 : SPATIAL S.D. = 2.577 (%/degC)
MODEL = CCC1D2 : AREA AVE = -4.718 : SPATIAL S.D. = 2.373 (%/degC)
MODEL = CCSRD2 : AREA AVE = -4.810 : SPATIAL S.D. = 9.762 (%/degC)
MODEL = CERFD2 : AREA AVE = 1.696 : SPATIAL S.D. = 2.917 (%/degC)
MODEL = CSI2D2 : AREA AVE = 10.275 : SPATIAL S.D. = 7.478 (%/degC)
MODEL = CSM_D2 : AREA AVE = -.352 : SPATIAL S.D. = 4.388 (%/degC)
MODEL = ECH3D2 : AREA AVE = .261 : SPATIAL S.D. = 3.557 (%/degC)
MODEL = ECH4D2 : AREA AVE = 1.699 : SPATIAL S.D. = 4.784 (%/degC)
MODEL = GFDLD2 : AREA AVE = 1.898 : SPATIAL S.D. = 1.072 (%/degC)
MODEL = GISSD2 : AREA AVE = -1.655 : SPATIAL S.D. = 1.242 (%/degC)
MODEL = HAD2D2 : AREA AVE = -4.500 : SPATIAL S.D. = 5.451 (%/degC)
MODEL = HAD3D2 : AREA AVE = -1.824 : SPATIAL S.D. = 3.928 (%/degC)
MODEL = IAP_D2 : AREA AVE = -6.436 : SPATIAL S.D. = 5.499 (%/degC)
MODEL = LMD_D2 : AREA AVE = 2.584 : SPATIAL S.D. = 6.199 (%/degC)
MODEL = MRI_D2 : AREA AVE = .999 : SPATIAL S.D. = 1.429 (%/degC)
MODEL = PCM_D2 : AREA AVE = 1.736 : SPATIAL S.D. = 4.586 (%/degC)
MODEL = W&M_D2 : AREA AVE = .979 : SPATIAL S.D. = 1.937 (%/degC)
MODEL = MODBAR : AREA AVE = -.088 : SPATIAL S.D. = .936 (%/degC)
OVERALL MEAN = -.088 %/degC
INTER-MODEL S.D. = 3.759 %/degC (FOR NORMALIZED GHG DATA)

Scengen Precipitation Output for Mozambique: A1B Scenario in 2050: 1.5°C above 1990



How to Select Scenarios

- Use M/S, COSMIC, or Finnish study to assess range of temperature or precipitation changes
- Can select models based on
  - How well they simulate current climate
    - SCENGEN has a routine
  - Representing a broad range of conditions
- Can use actual GCM data or scaled
- Can include other sources for scenarios, e.g., arbitrary, analogue

Selecting GCMs

- Some factors to use in selecting GCMs
  - Age of the model run
    - More recent tends to be better
  - Model resolution
    - Higher resolution tends to be better
  - Model accuracy in simulating current climate
    - MAGICC/SCENGEN has a routine

What to Use under What Conditions?

- Nothing wrong with using combinations of different sources for creating scenarios, e.g., models and arbitrary scenarios
- The climate models tend to be better for longer run analysis, e.g., beyond several decades (e.g., beyond 2050)
- Climate analogues tend to be better for near term, e.g., within several decades (e.g., 2010-2030)

Scenarios for
Extreme Events

- Difficult to obtain from any of these sources
- Options
  - Use long historical or paleoclimate record
  - Incrementally change historic extremes
    - Try to be consistent with transient GCMs
  - Are useful for sensitivity studies

DATA SOURCES

Climate models and observations

Some Climate Data Sources

- IPCC Data Distribution Centre

- Program for Climate Model Diagnosis and Intercomparison

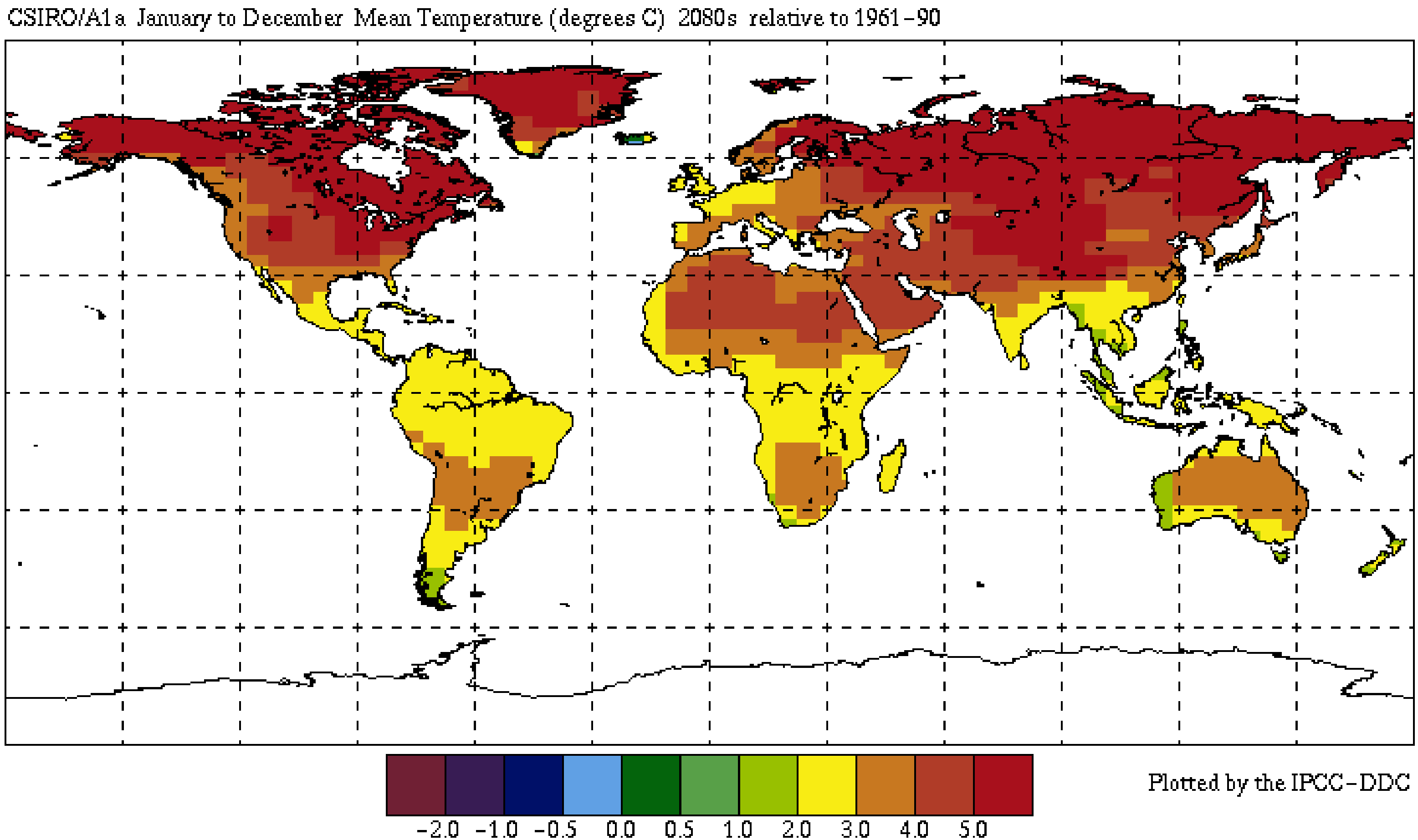
IPCC Data Distribution Center

- IPCC Data Distribution Centre appears to be the best site for climate model data
- Observed climate data 1901-1990
  - Gridded to 0.5 x 0.5°
  - 10 and 30 year means
- GCM data from
  - CCC (Canada)
  - CSIRO (Australia)
  - ECHAM4 (Germany)
  - GFDL-R30 (U.S.)
  - HadCM3 (UK)
  - NIES (Japan)
- Can obtain actual (not scaled) GCM output

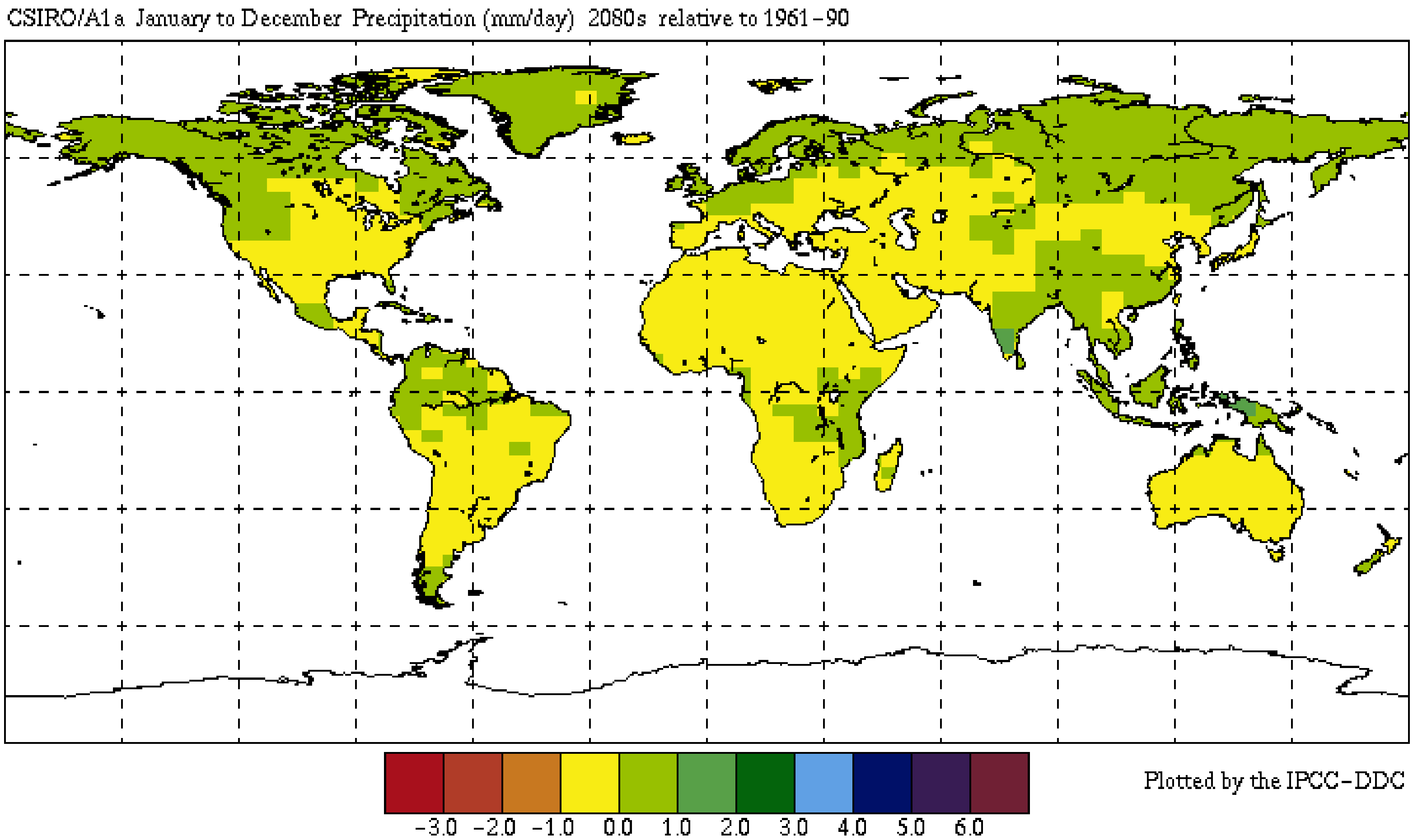
IPCC Data Distribution Center (continued)

- Mean monthly data from GCMs on
  - Mean temperature (°C)
  - Maximum temperature (°C)
  - Minimum temperature (°C)
  - Precipitation (mm/day)
  - Vapor pressure (hPa)
  - Cloud cover (%)
  - Wind speed (m/s)
  - Soil moisture

Example Data from DDC – Temperature



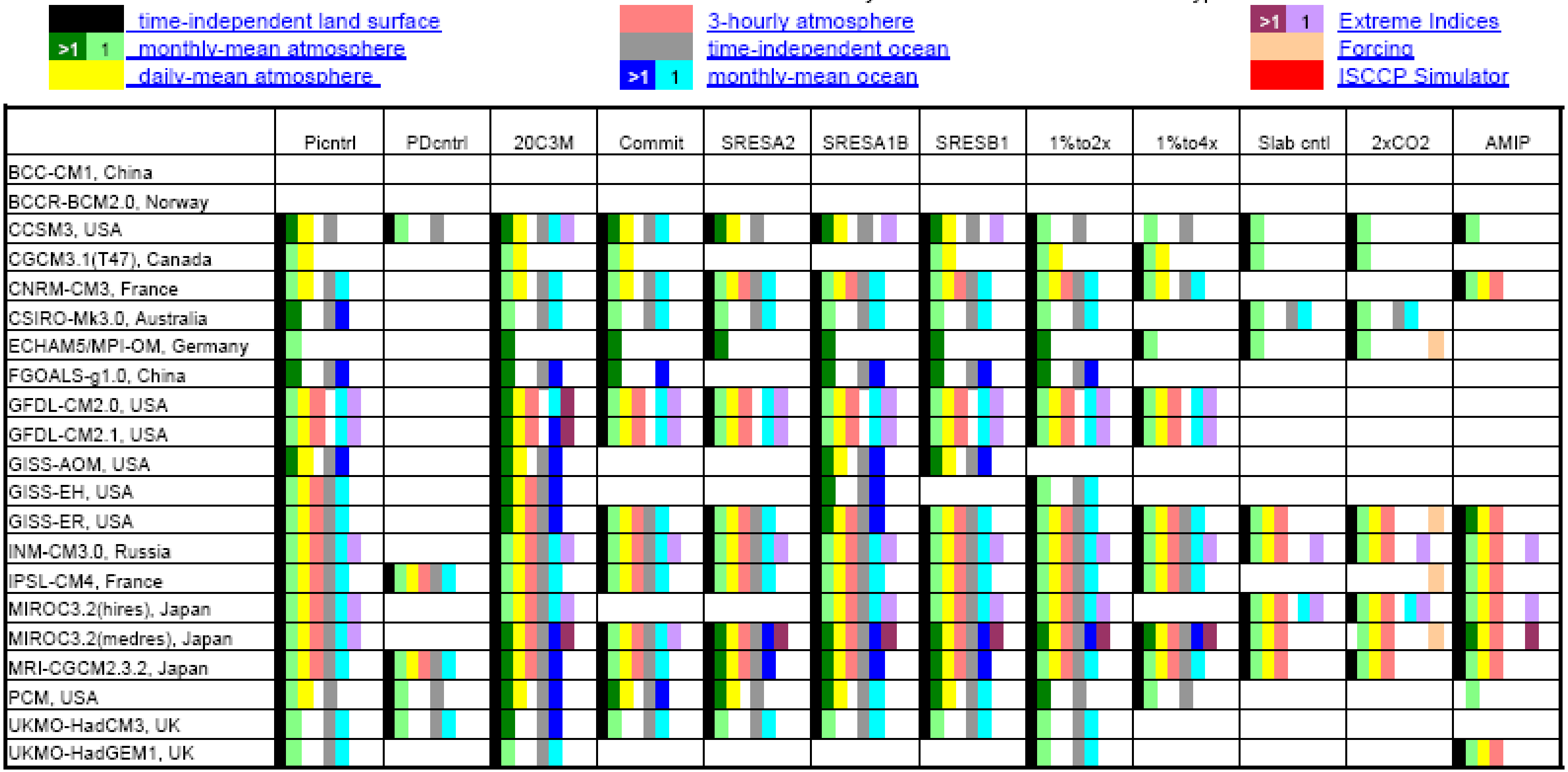
Example Data – Precipitation



PCMDI has GCM Output

Data Availability Summary **(as of 30 March 2005)**

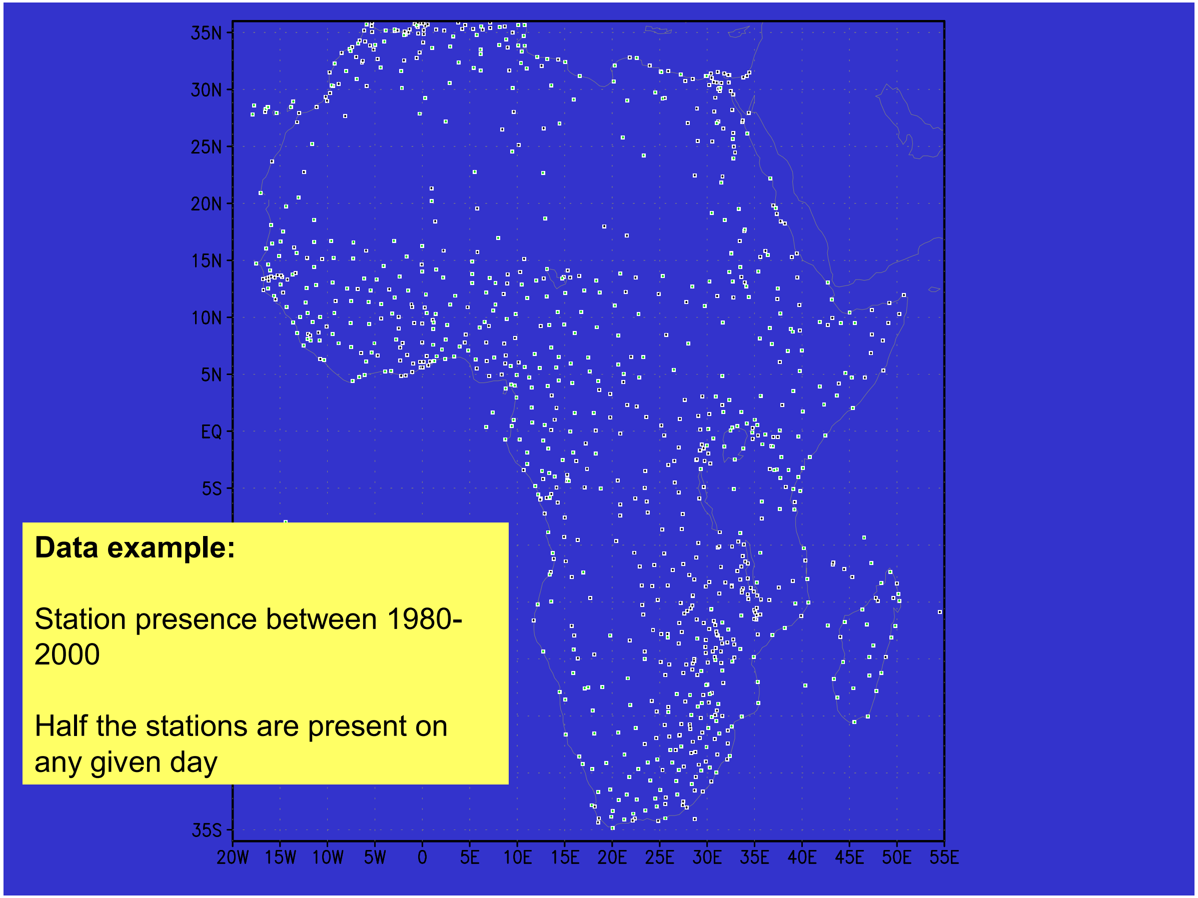
shaded area indicates that at least some but not necessarily all fields are available for data type indicated



Observational Record

- National meteorological offices
- MARA/ARMA has 1951-1995 monthly temperature and precipitation
  - Developed by Climatic Research Unit, East Anglia, UK
  - 3 minute scale

African Weather Data Sites



Data example:

Station presence between 1980-2000

Half the stations are present on any given day

Final Thoughts

- Remember that individual scenarios are not predictions of future regional climate change

- If used properly, they can help us understand and portray
  - What is known about regional climates may change
  - Uncertainties about regional climate change
  - The potential consequences

Uses

- If assessing vulnerability, ought to reflect wide range of climate change
  - Serves education purpose
- If examining adaptation, *need* to reflect wide range of climate change
  - If uncertainty range too narrow, could lead to ill-informed decision