CHANGING CLIMATE VARIABILITY AND ITS IMPACTS ON AFRICAN SAVANNA ECOSYSTEMS

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Presenting here only a small portion from a much larger, NASA funded project also involving: Dr. Brian Child, Dr. Mike Binford, Dr. Eric Keys, Dr. Youliang Qiu, Dr. Greg Kiker, Dr. Rafa Muñoz-Carpena, Dr. Lin Cassidy, Jing Sun, Andrea Gaughan, Forrest Stevens, Gloria Perez-Falcon, Jessica Steele, Sanjiv Jagtap, Caroline Staub, Patricia Mupeta, Shylock Muwenga, Tim Fullman, Luke Rostant, Narcisa Pricope






Overarching research agenda

THE LARGER PROJECT:

- “**how does climate variability and climate change influence land use and land cover change** as it works through socio-economic institutions?”

SPECIFICALLY WE WILL :

- develop a temporally and spatially multi-scale understanding of the relationships between land-cover and land-use change (LCLUC) and climatic shifts in three watersheds that lie in four southern African nations (800,000 km^2 = bigger than Texas!).
- determine how such shifts, once identified, can be expressed in terms of resilience and savanna ecology perturbations and persistence.

SO THAT WE CAN THEN:

- test the resilience of the socio-ecological systems of southern Africa, enhance the use of remote sensing, and provide models for climate scenario planning.

Study Region:
Tightly coupled social-ecological system

Okavango-Kwando-Zambezi Catchments

- Link climate-vegetation variability to social –economic processes

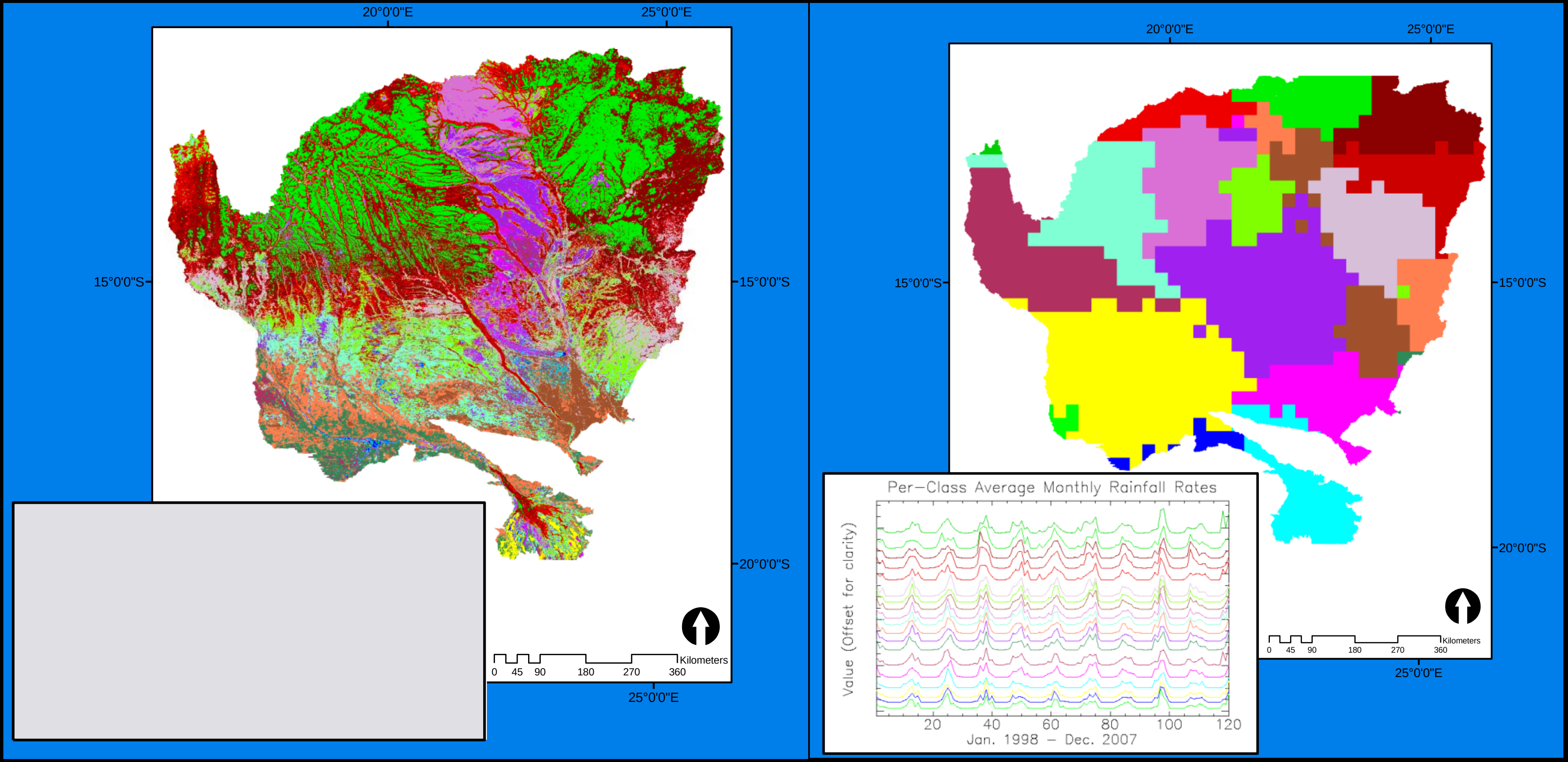
This talk

- Apply time-series analyses to address climate vegetation dynamics under climate shifts
  - Remotely sensed data
  - Precipitation analysis
  - Test relationships across scales and across land cover types

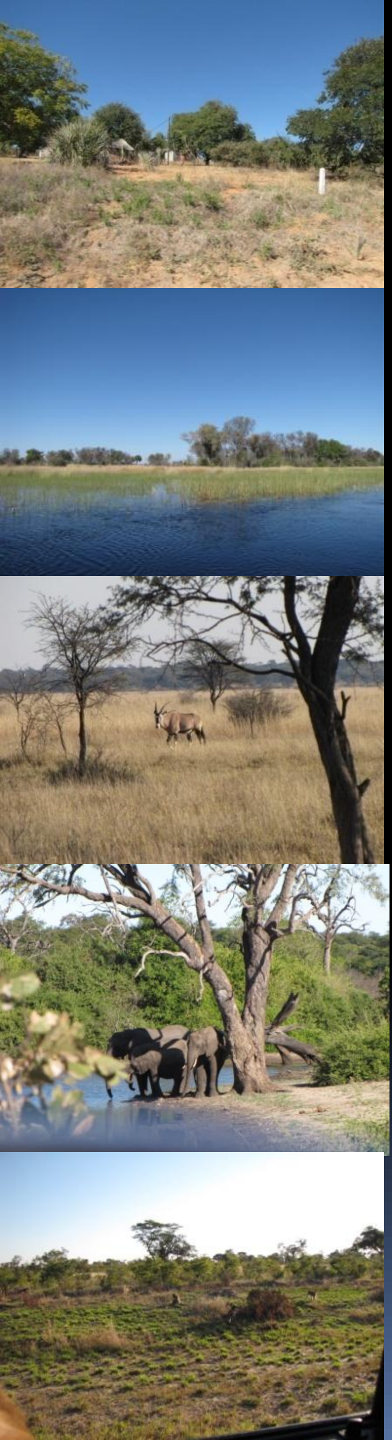
Preliminary Analysis – research basis

Figure : a) 20 Class land cover classifications based on MODIS monthly NDVI data, 1999-2007, and b) 20 class precipitation clusters based on TRMM monthly precipitation data, 1999-2007, for the study region, with associated spectral graphs of each class. These images how clear clustering and spatial groupings within the datasets which will provide some basis for this research approach.

(a) *(b)*



- From Forrest Stevens, Andrea Gaughan and Cerian Gibbes, 2008



Savanna Ecology

- 'semi-arid savanna' refers to those regions of the world, which, in their natural state, have a predominant continuous grass cover, with scattered to numerous trees and shrub
  - Gradations in landscape relate to composition
    - i.e. amount grass-tree-shrub
- Comparison of the dynamics of various savanna and other natural systems leads to the conclusion that the resilience of the systems decreases as their stability increases
- So highly heterogeneous landscape = resilient
    - Walker et al. 1981

Landscape dynamics

Grasses dominate



Increasing vegetation amount

Shrubs dominate



Increasing vegetation amount

Woodland dominates



Methods

Remote Sensing is great tool to study landscape change over time

- We focus on NDVI initially
  - so first look at overall vegetation changes
  - NDVI performs well in this study region

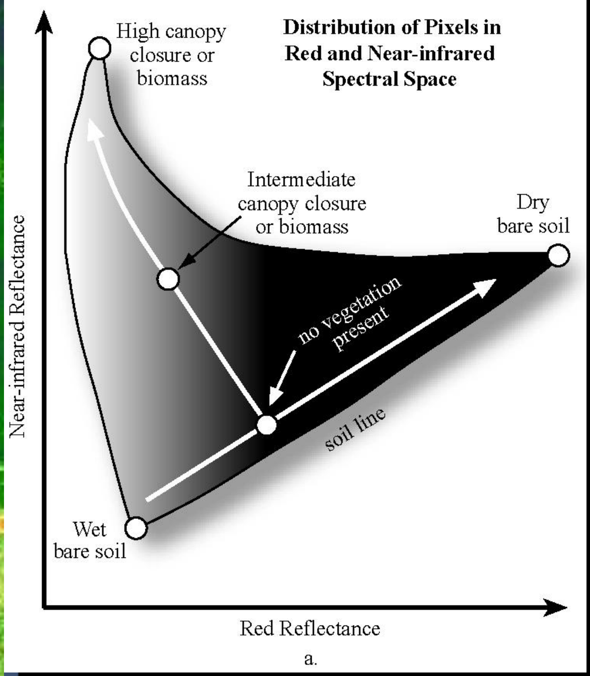
- Multi temporal and spatial level analysis: 1982-2009, annual series
  - AVHRR/MODIS we obtain a monthly time series
  - Precipitation monthly time series data (0.5° gridded dataset – Uni of Delaware,)
  - Study identified April and May as ideal months for studying long-term change

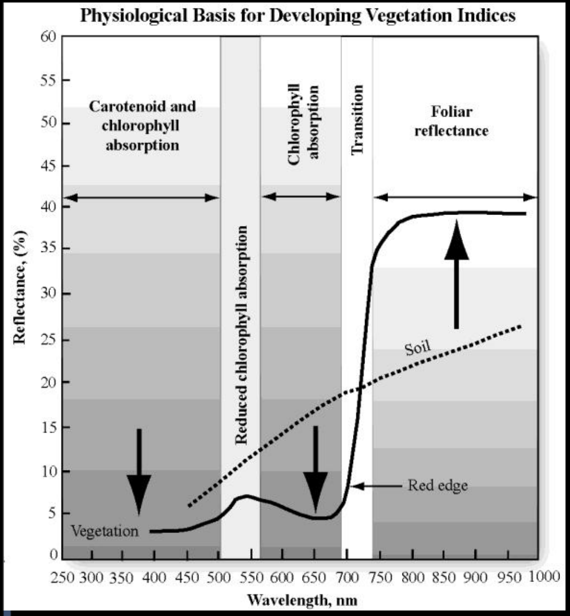
- As such we can pull climate AND vegetation history into our landscape level studies – so providing CONTEXT, PERSPECTIVE and therefore potentially a useful FRAMEWORK for the larger research.

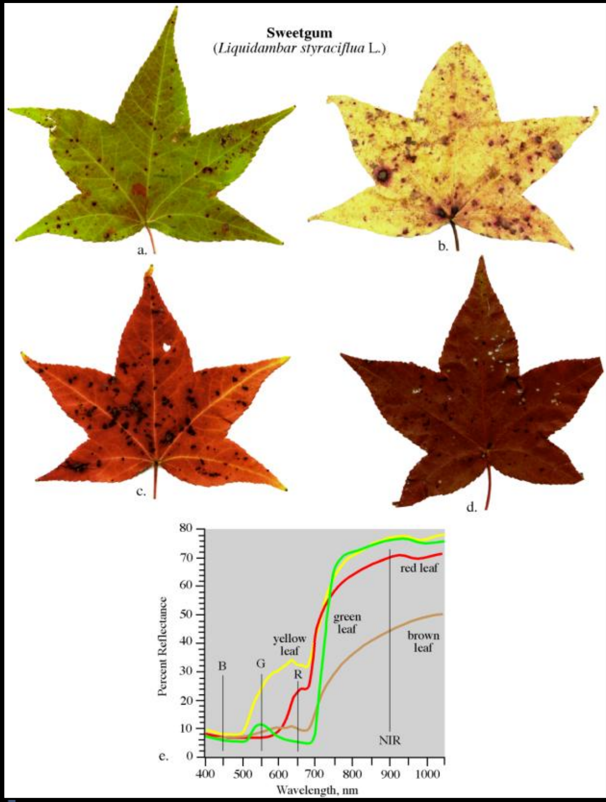
NDVI: Normalized Difference Vegetation Index

- AVHRR Monthly data 1982-2000 (1.1km)
- MODIS Monthly data 2000-2009 (500 m)

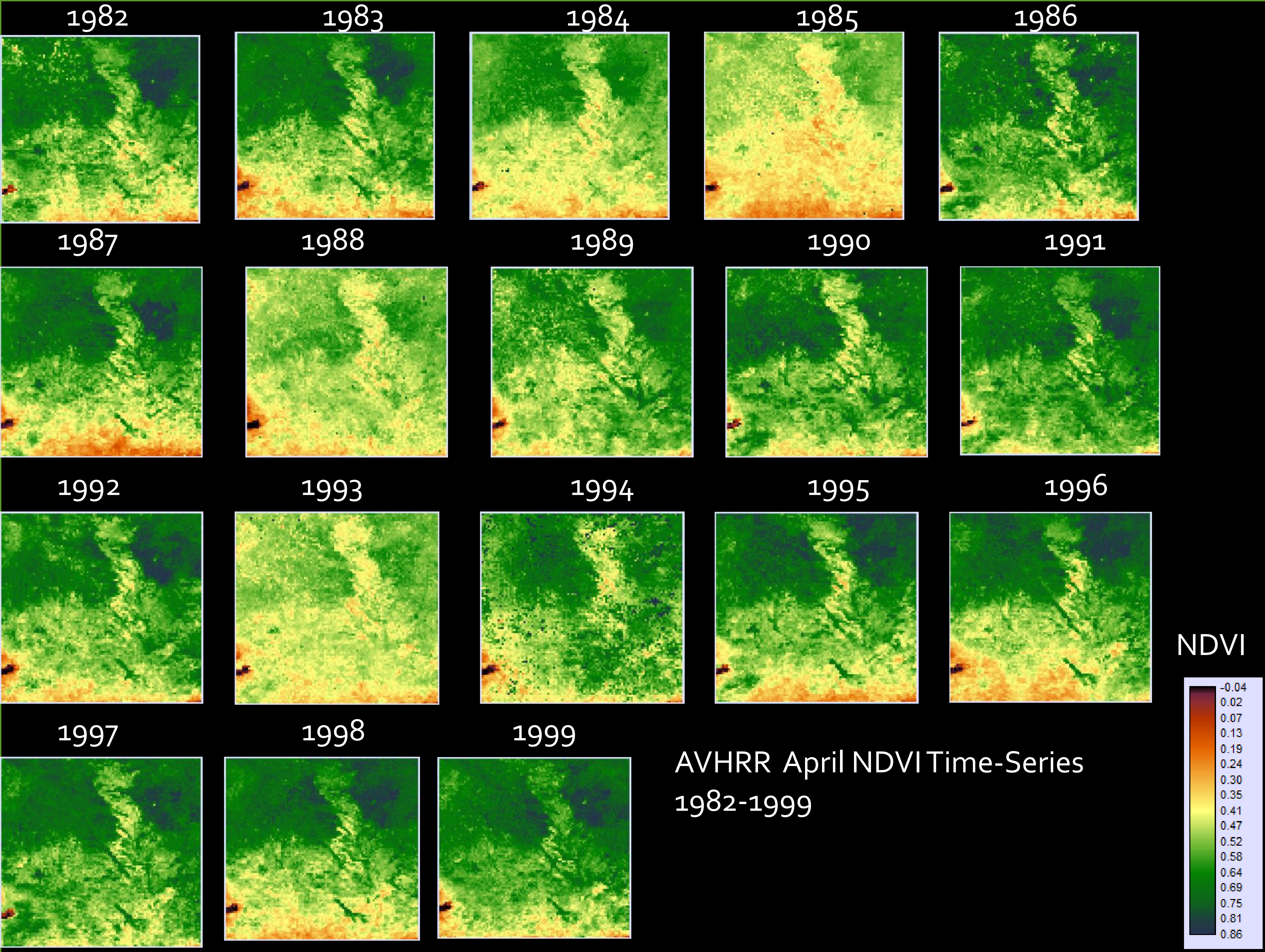
$$NDVI = \frac{NIR - red}{NIR + red}$$







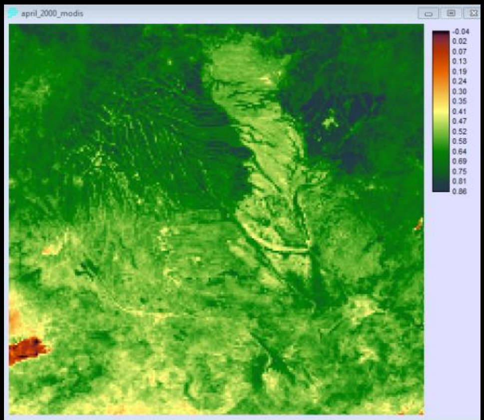
Source: Jensen, 2004



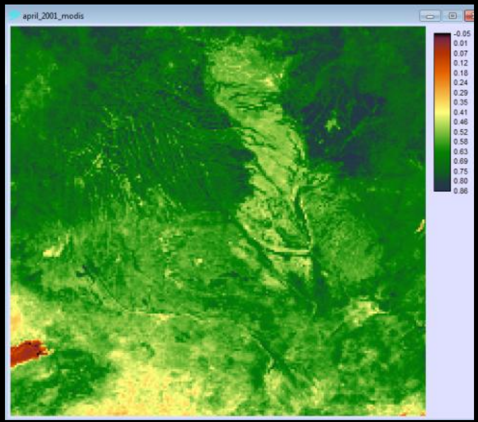
AVHRR April NDVI Time-Series 1982-1999

MODIS NDVI April

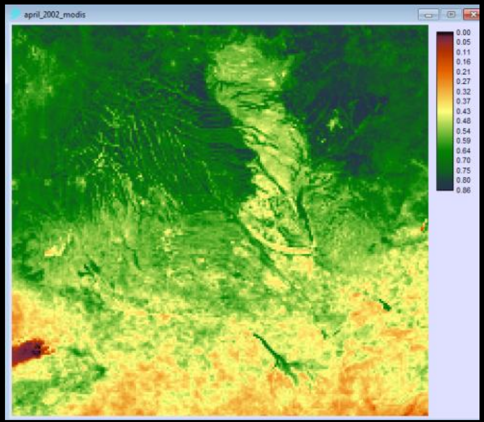
2000



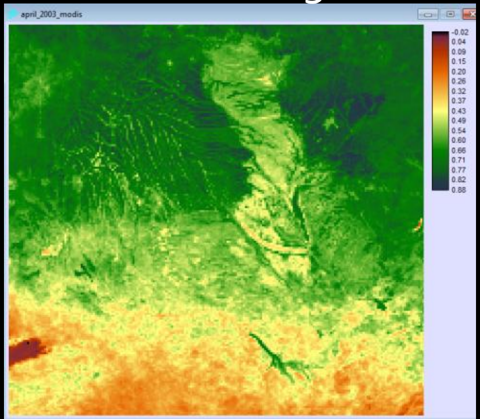
2001



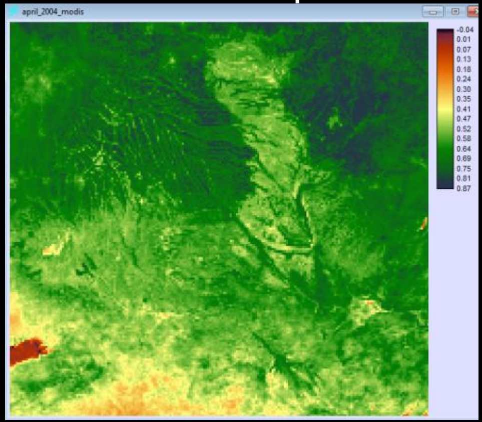
2002



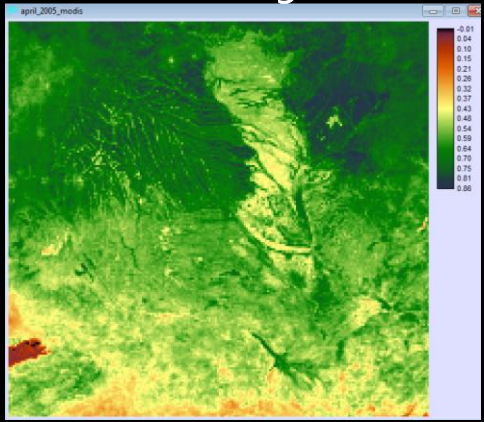
2003



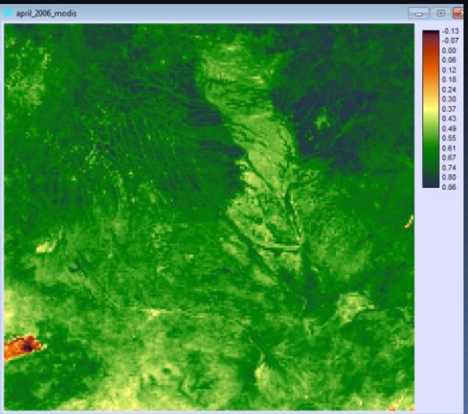
2004



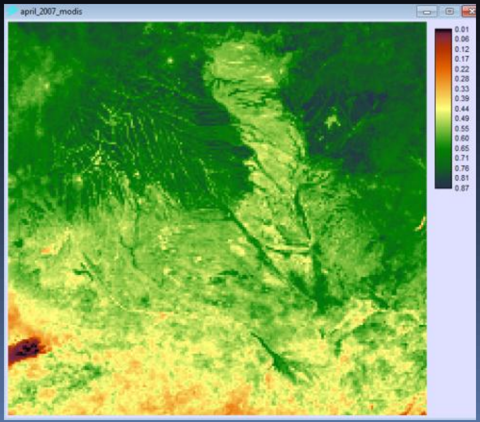
2005



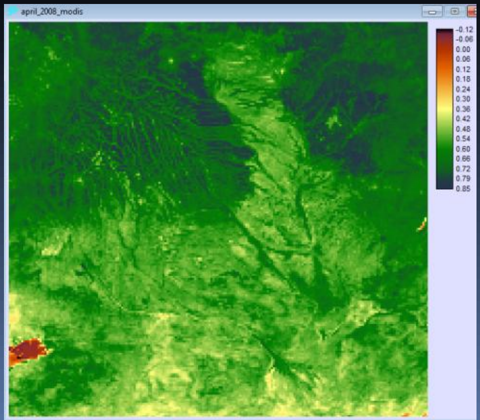
2006



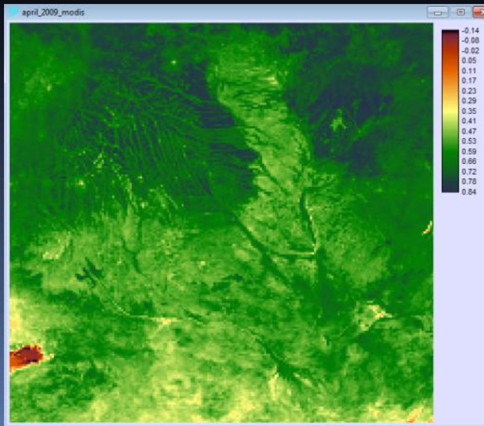
2007



2008



2009



Mean-Variance Analysis

- To characterize the spatio-temporal behavior of the RS vegetation index
- Can describe seasonal or inter-annual response of vegetation to climate and disturbance
  - Mean = amount of vegetation
  - Variance = degree of landscape heterogeneity
- Post-event recovery can be assessed via malleability

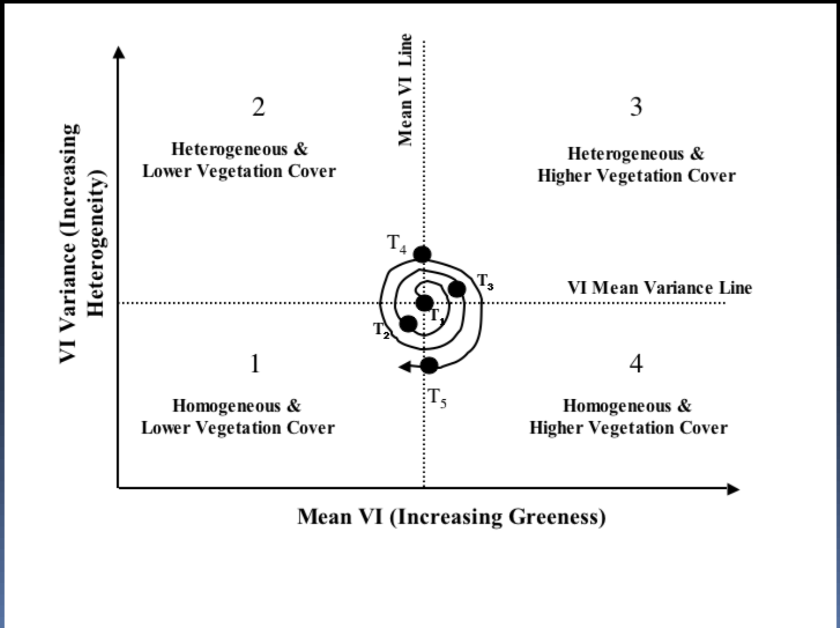
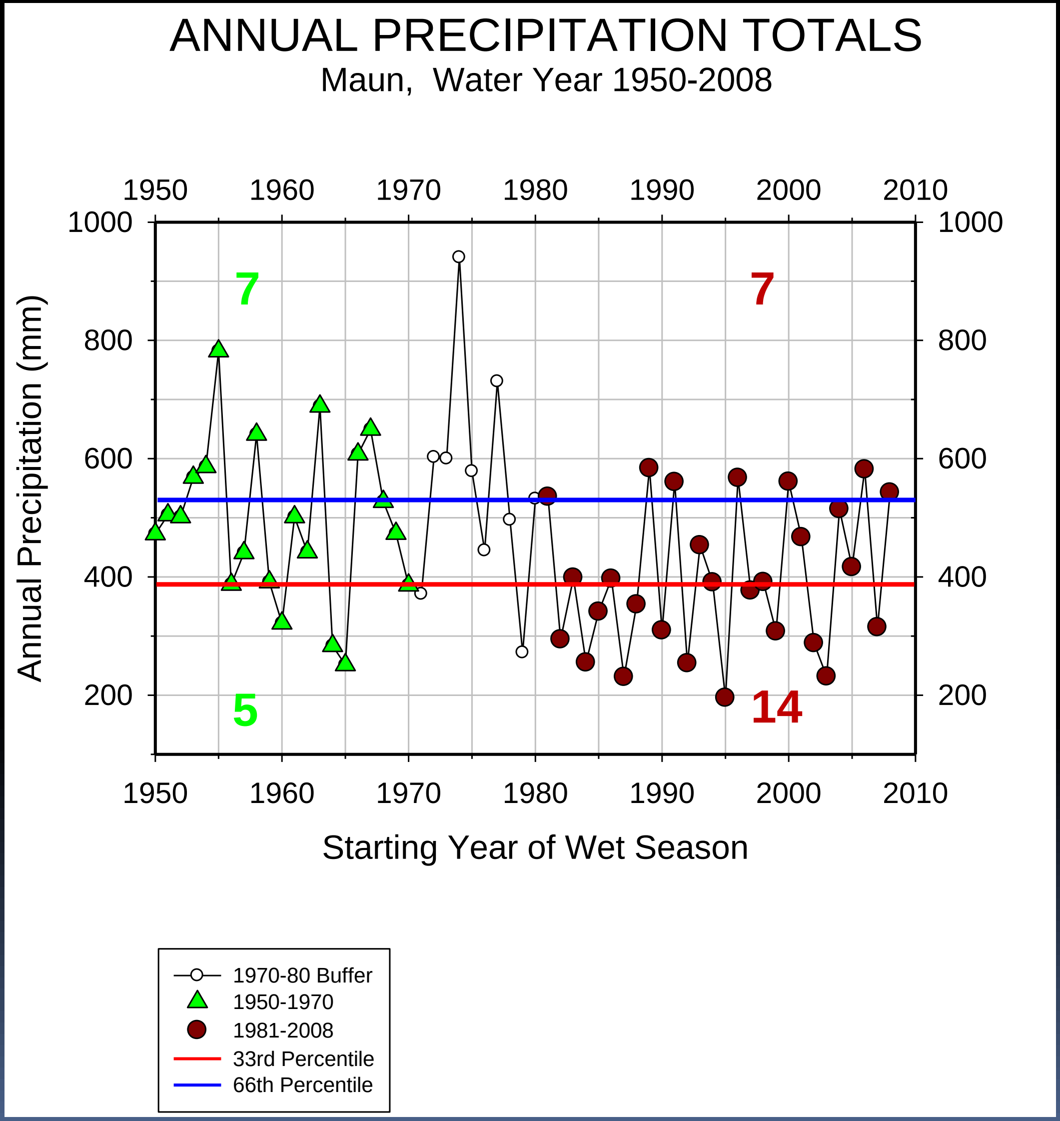


Figure: Hypothetical statistical phase portrait of the interannual mean-variance dynamics of an agricultural landscape's vegetation index (VI). T = time.

Source: Washington-Allen et al. 2008

Main driver in this region = Precipitation

- Major climatic shifts have been found since the mid to late 1970's
  - A global climate shift
- Long term change, has 5 and 7 year cyclical events also, e.g., El Nino, Benguela current
  - Nicholson (2000).
- We treat this shift as a shock, ecologically
- We study post-shock landscape and changes by looking at NDVI, new equilibrium?

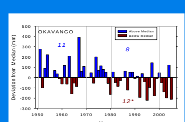


Theoretical Framework and Research Methods

CLIMATE

Measurables:
Precipitation
- Monthly mean
-Standard deviation

Precipitation Trajectory



Time Series of Precipitation 1950-2009

Time-series analysis, moving averages, spatial variability,

Qu. *What is the impact of this precipitation regime shift on the vegetation?*

VEGETATION

Measurables:
Land Cover
Vegetation Amount-**NDVI**
Spatial variability

Vegetation Trajectory

Time Series of NDVI 1982-2009

Mean-variance analysis, time-series analysis, moving averages

Established relationship between climate variability and vegetation dynamics – *Analysis of Change*

Vegetation shifts in drylands ecosystem

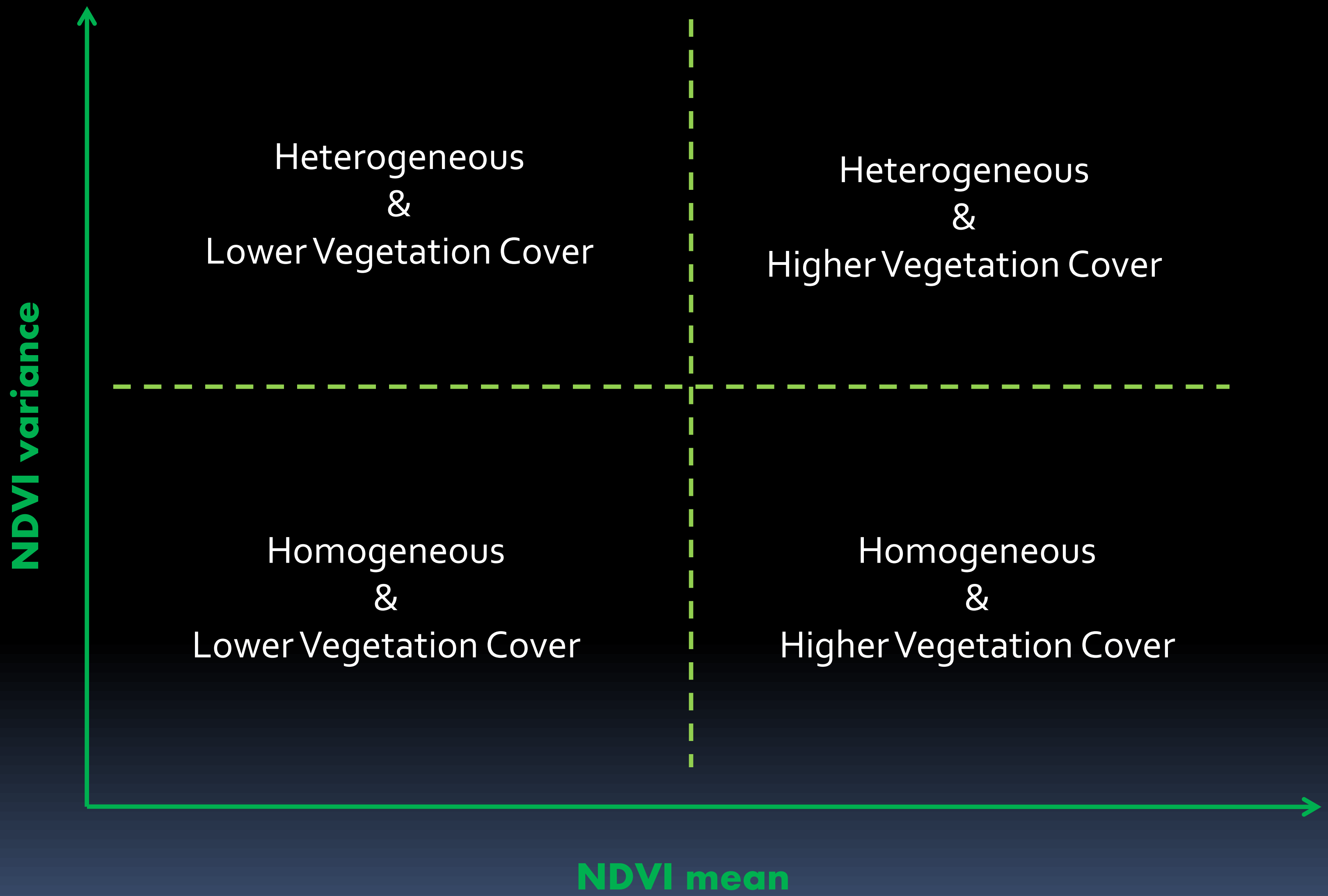


Figure based on Washington –Allen et al. 2009

Vegetation shifts in drylands ecosystem
- possible vegetation states across our region

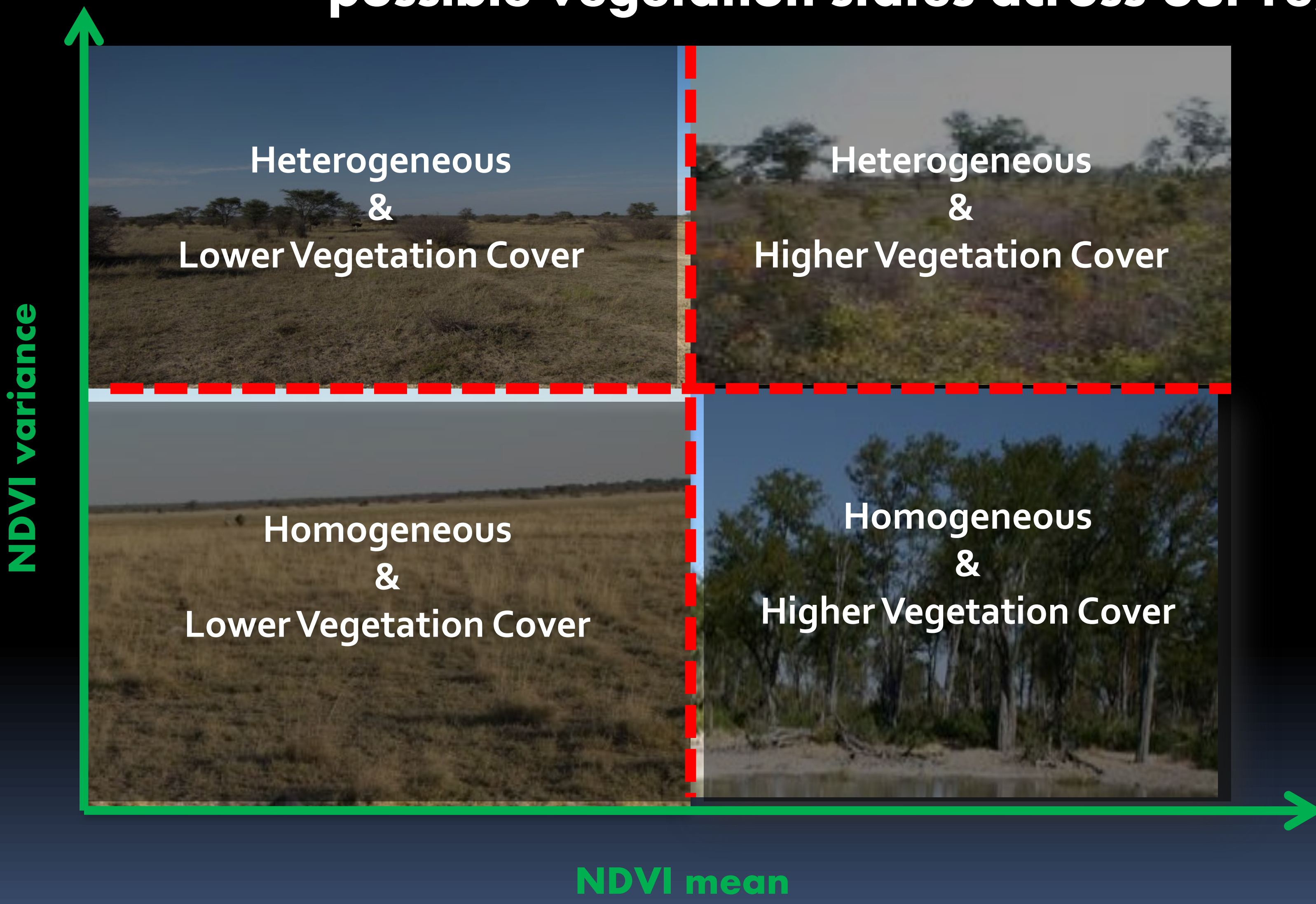
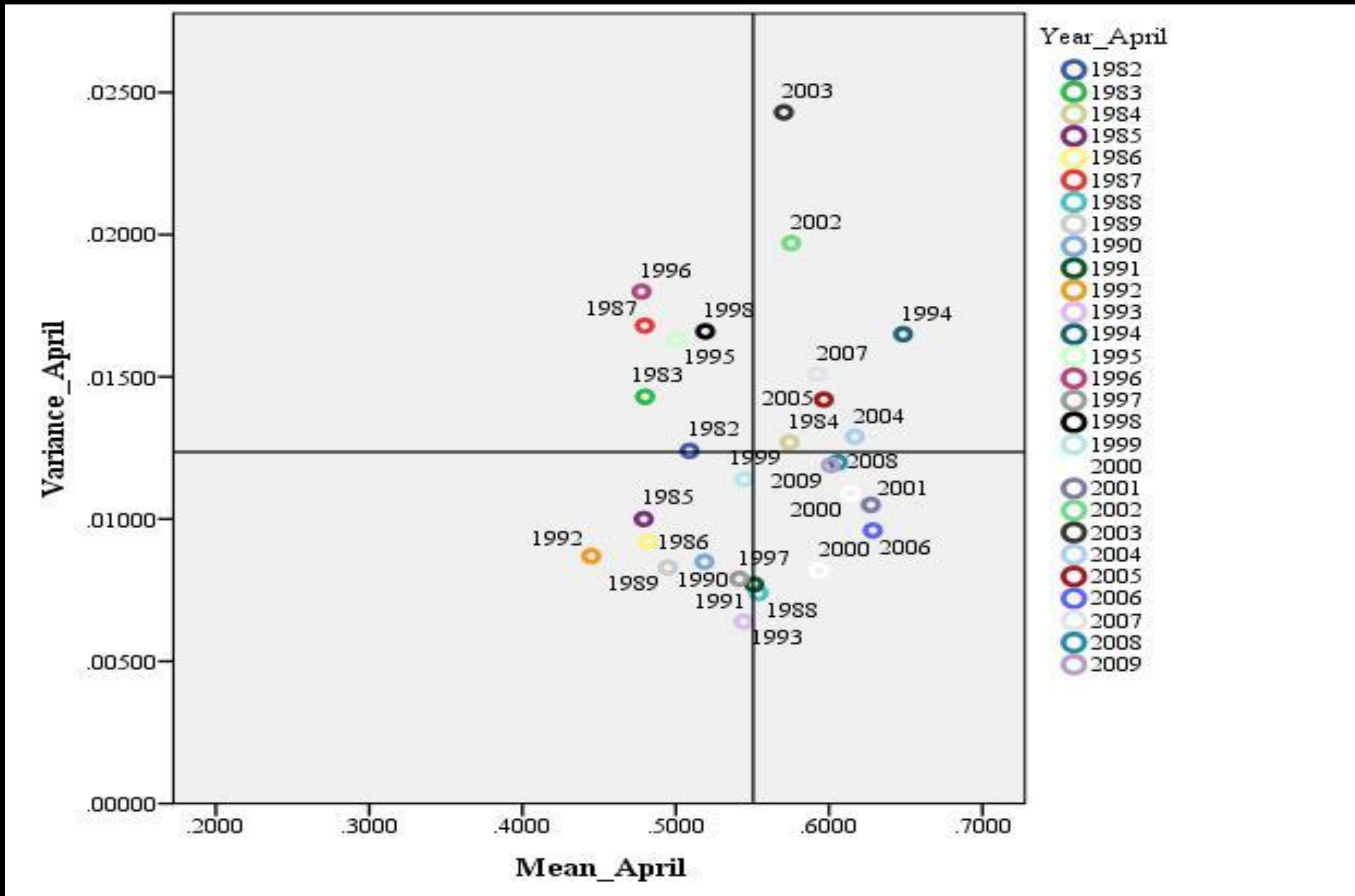
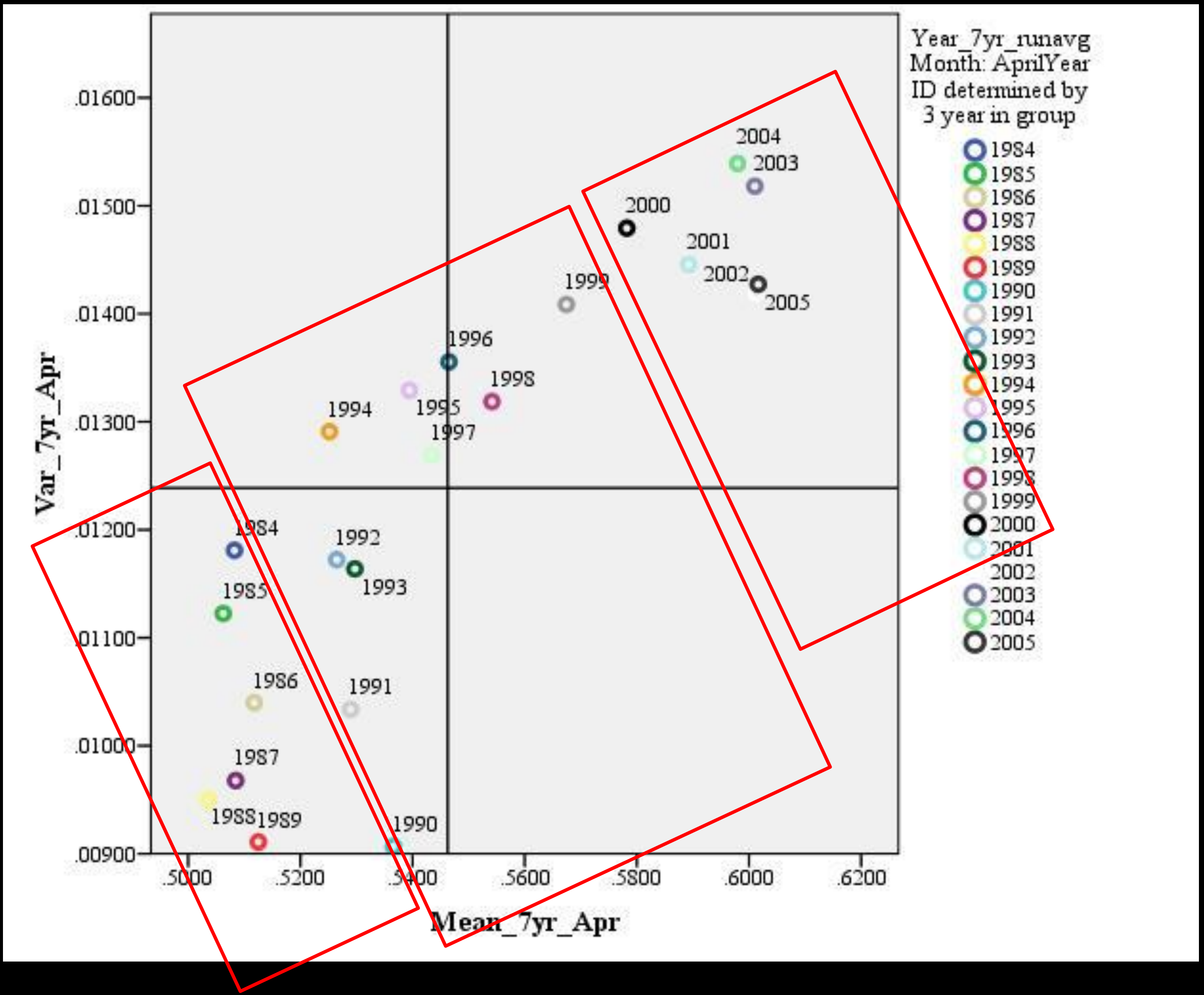


Figure based on Washington-Allen et al. 2009

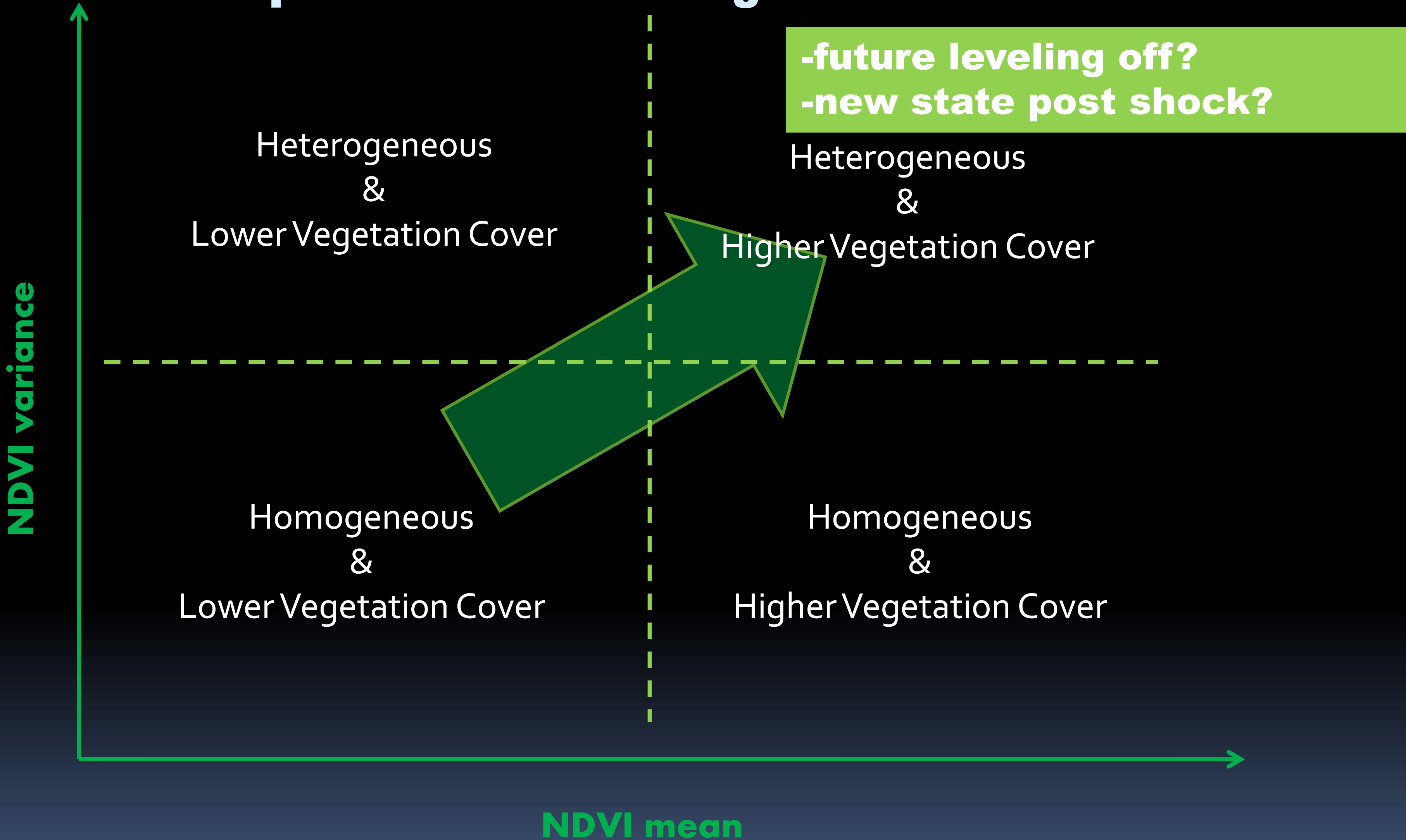
April NDVI mean-variance relationship over time - highly variable inter-annual patterns



Precipitation on known 5-7 years cycles, so to determine the long-term changes produced a 7-year running mean of the NDVI input



Overall trend is one of increasing vegetation cover and increased spatial variance of vegetation



Spatial Variability of Precipitation

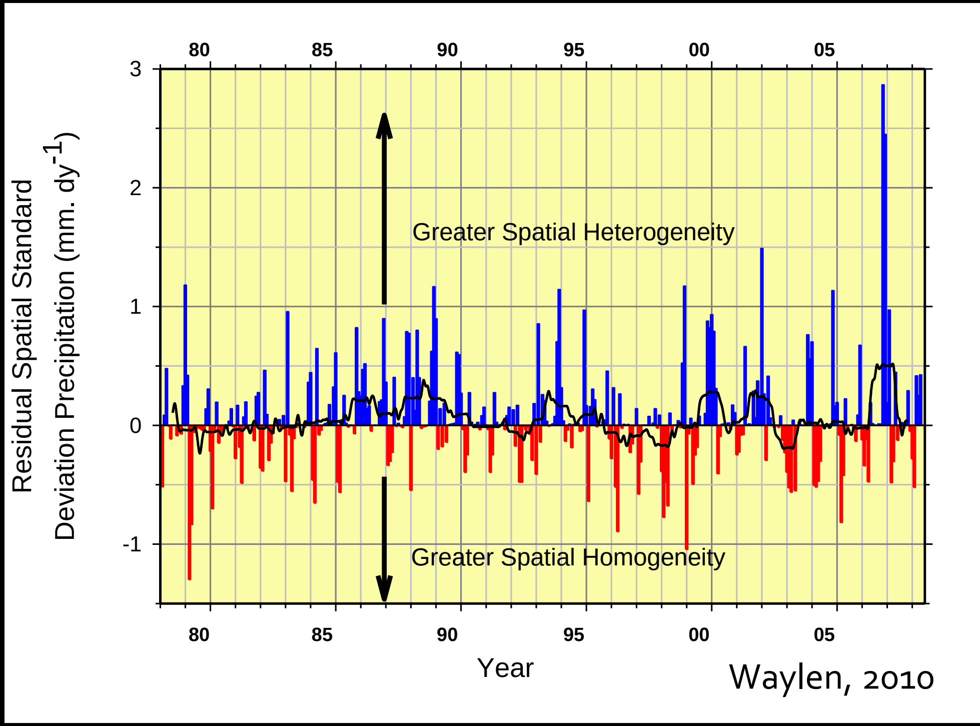


Figure: Monthly precipitation residuals where positive residuals (blue) indicate a higher measure of deviation (variability) of monthly precipitation within the study area than simply suggested by the changing variability found in association with the mean, whereas negative residuals (red), indicate lower measures of spatial variability within the study area. [black line shown on next graph = 12 month moving average)

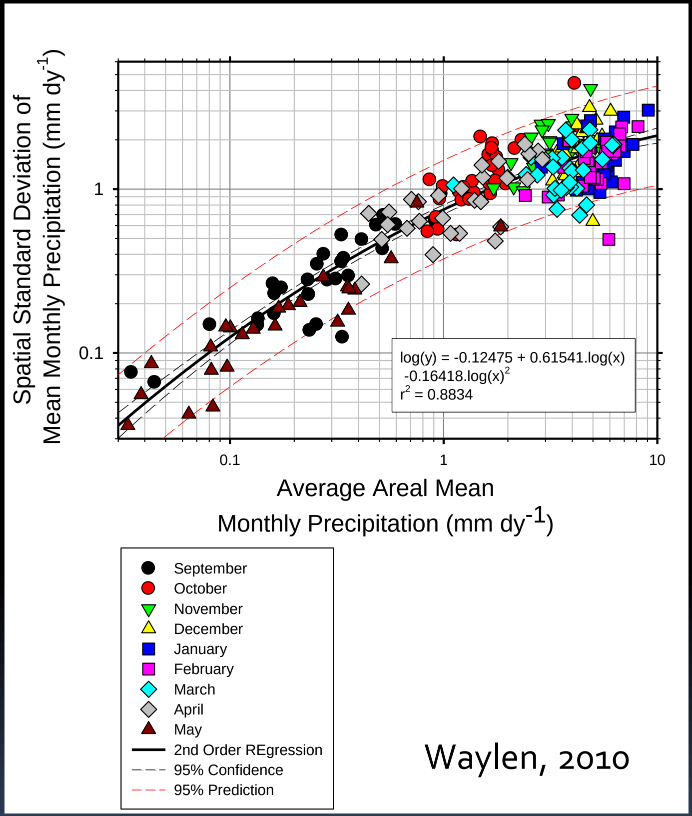
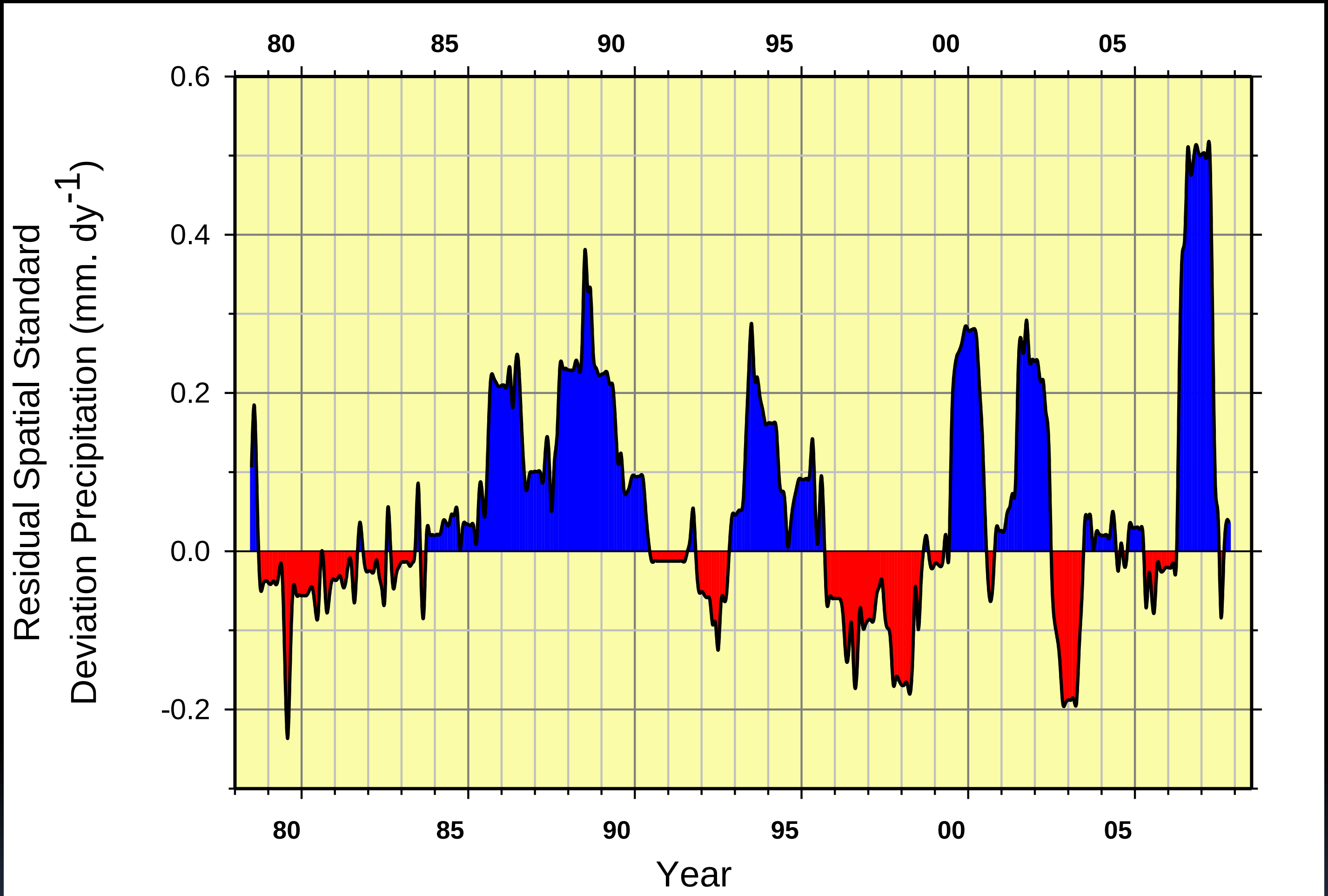


Figure: Relationship between the mean monthly precipitation across the study area, and the standard deviation of the stations/cells about that mean for 1979-2009, with the 2^{nd} order polynomial regression shown.

12-month moving average of residual time series



- This seems to indicate that some of the increased spatial variance in NDVI since the 1980s may be attributable to an increased spatial heterogeneity in precipitation over that time
  - Remainder? Ecological shifts most likely?

Does the pattern hold over spatial scales?

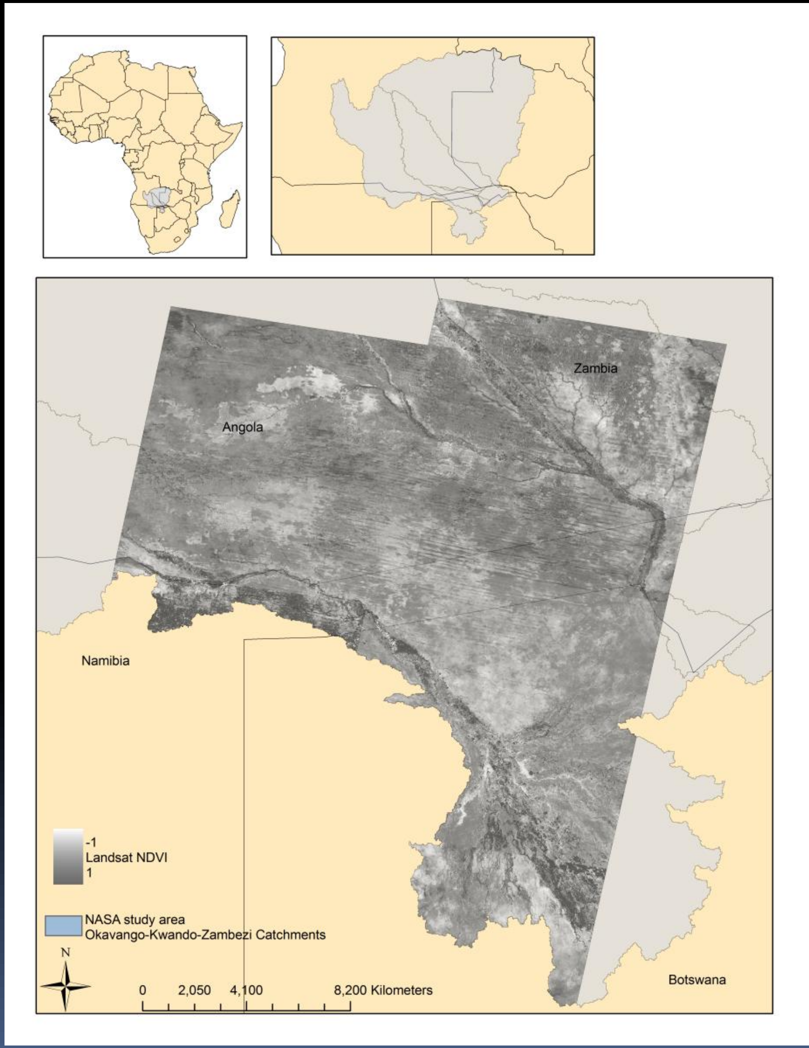
Meso-scale study

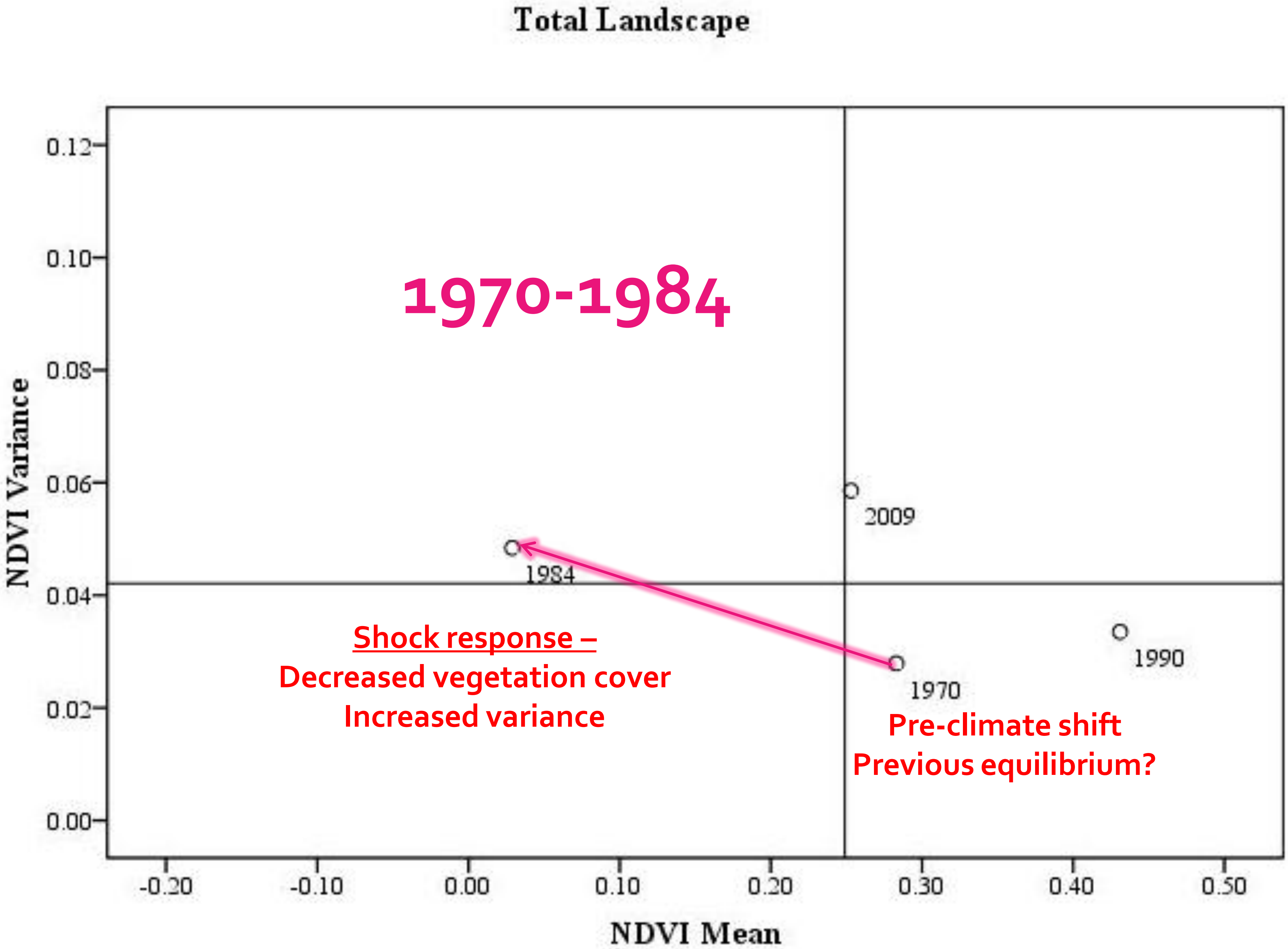
5 Landsat images
1970s, 1980s, 1990s, 2000s

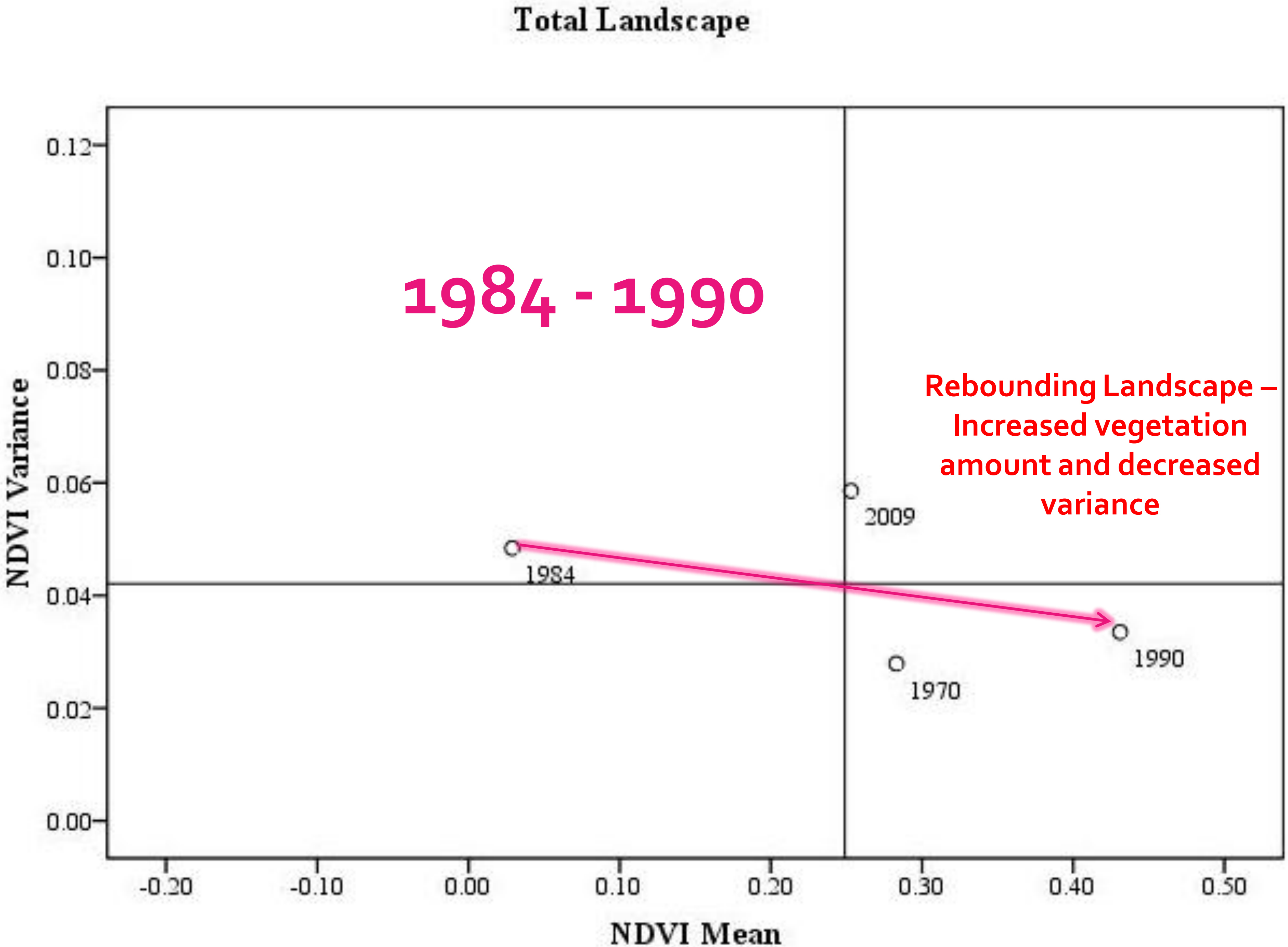
Shock of changing precipitation regime should be evident here from pre-shock (1970), through the response to this shock

"Hysteresis" – will the system return to the same state and along the same trajectory and can we 'see' this (given 1970s data we may follow this)?

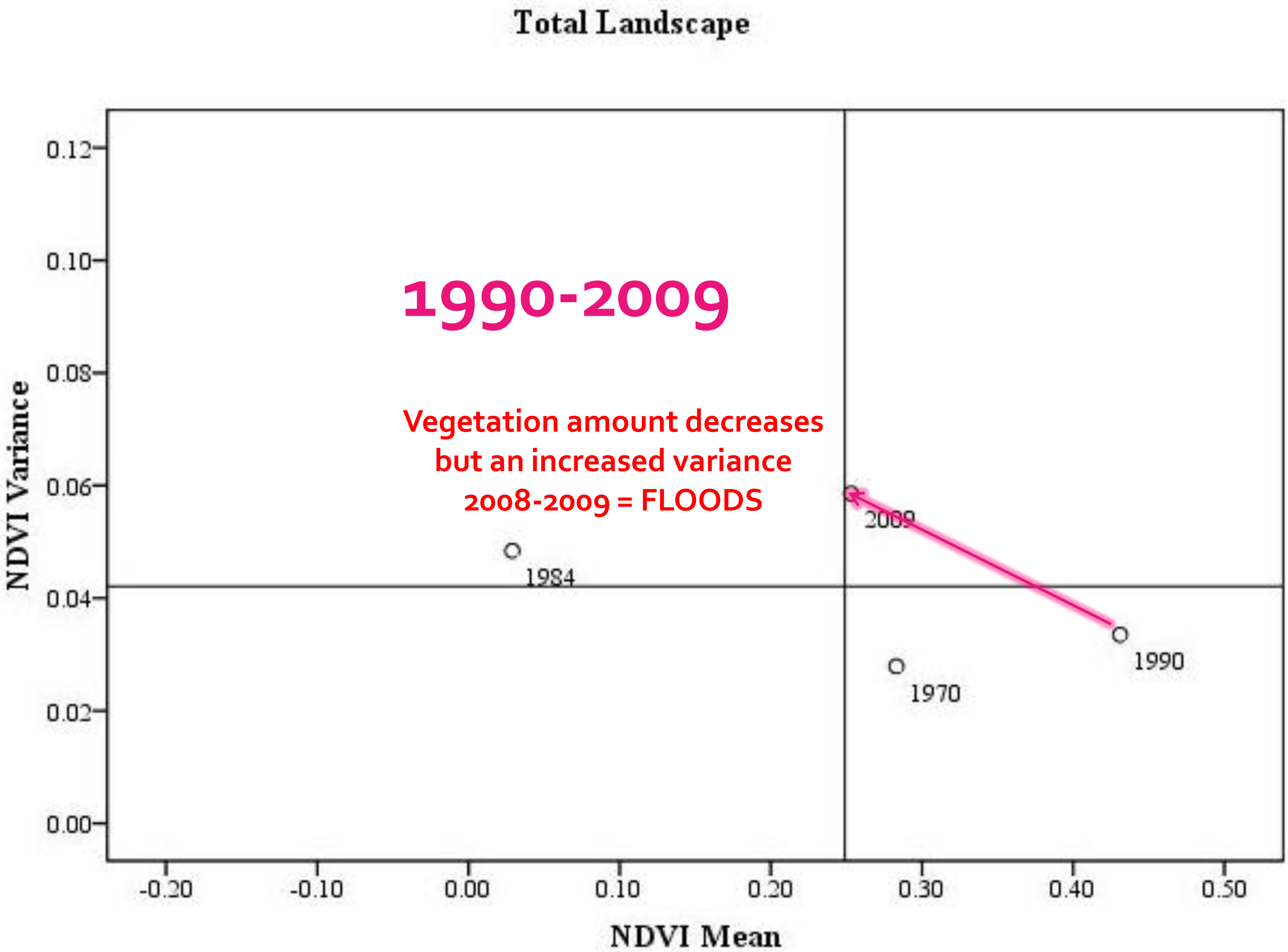
At finer spatial scale can look across land cover classes (IGBP) and see responses by land cover type – SAVANNA, Wetland etc.



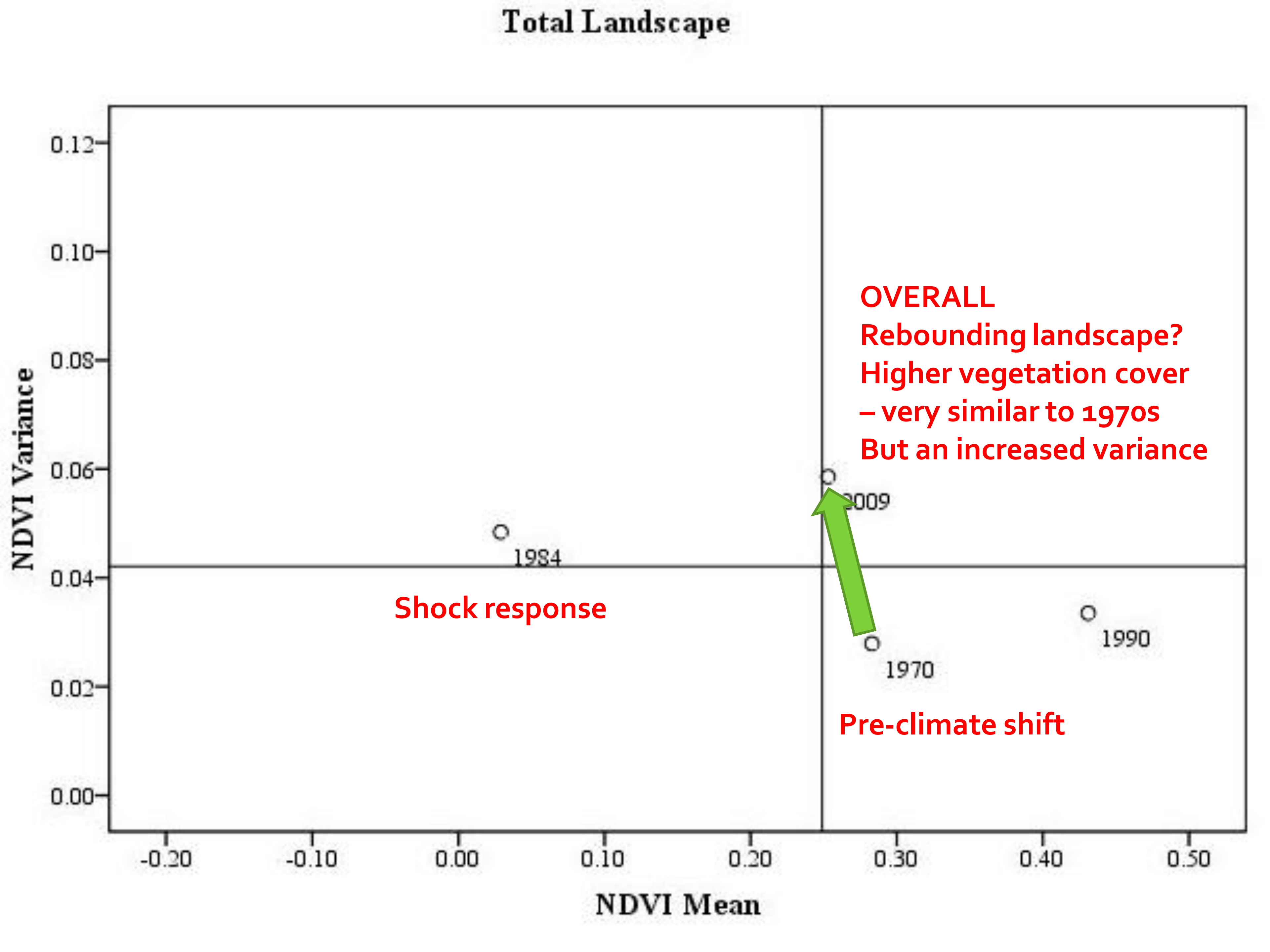

Total Landscape
1970-1984
NDVI Variance
NDVI Mean
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
0.50
2009
1984
1970
1990
Shock response –
Decreased vegetation cover
Increased variance
Pre-climate shift
Previous equilibrium?



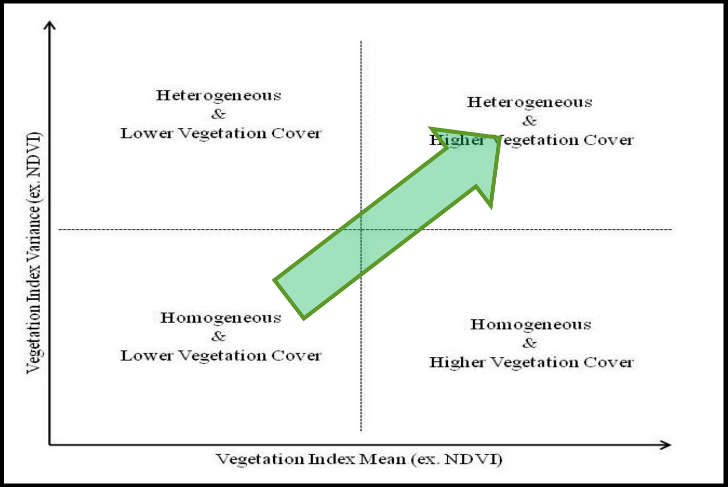
Total Landscape
1984 - 1990
Rebounding Landscape – Increased vegetation amount and decreased variance
NDVI Variance
0.12
0.10
0.08
0.06
0.04
0.02
0.00
2009
1984
1990
1970
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
0.50
NDVI Mean

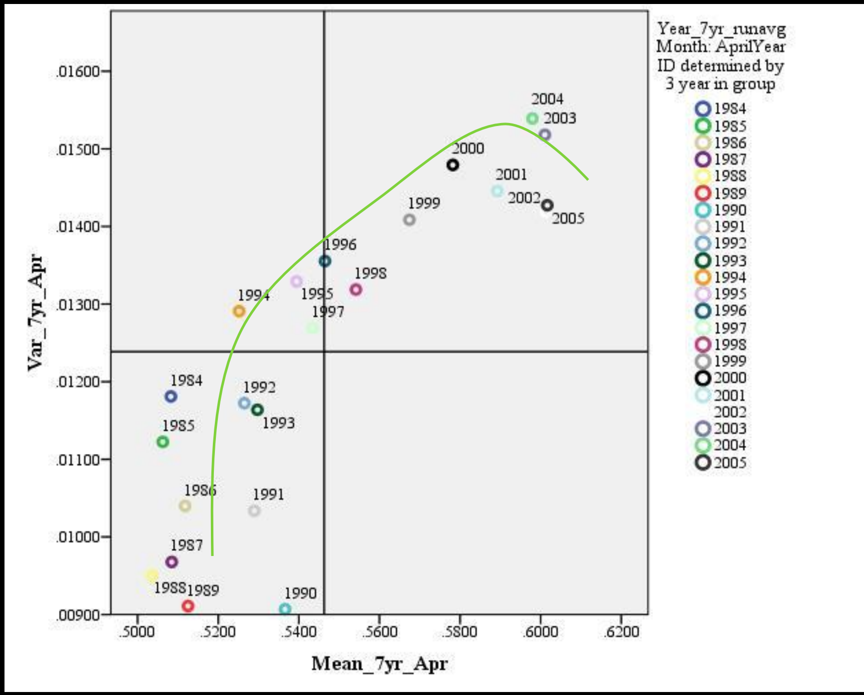


Total Landscape
1990-2009
Vegetation amount decreases
but an increased variance
2008-2009 = FLOODS
NDVI Variance
NDVI Mean
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
0.50
2009
1984
1990
1970


Total Landscape
NDVI Variance
NDVI Mean
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.20
-0.10
0.00
0.10
0.20
0.30
0.40
0.50
1984
2009
1970
1990
OVERALL
Rebounding landscape?
Higher vegetation cover
– very similar to 1970s
But an increased variance
Shock response
Pre-climate shift

So overall patterns at both study levels is one of:





So perhaps a new state of higher vegetation cover and high spatial variance – as a result of higher spatial variance in precipitation patterns and shifts ecologically in the landscape

We see this:

- **across scales**
- **across precipitation gradients**
- **across land cover classes**






Conclusions

- Significant shifts across this landscape once inter-annual variability accounted for:
  - Long-term precipitation decrease is a 'new state'
  - Resultant and significant vegetation shifts as a response to this new state
  - In terms of 'resilience' we appear to be in higher mean and variance phase for savanna in our study region overall
    - Could this equal a more RESILIENT landscape?

- Highlights need to place studies into a real landscape context in terms of spatial and temporal patterns
  - A paradigm shift for land cover change studies to time series based analysis AS WELL AS use of fewer, more discrete dates

- SAVANNA:
  - Overall more vegetation amount, but what type of vegetation?
  - Increased spatial variance in vegetation type too – link to increased precipitation variance?
  - We have to know about the grass-tree-shrub compositions
  - NDVI alone cannot do this so must move beyond

Acknowledgments

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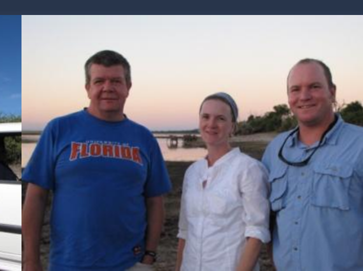
- We also thanks the Center for African Studies (UF) and the Harry Openheimer Okavango Research Center (HOORC)






Questions?

Precipitation patterns & vegetation patterns differ on 7-year moving windows