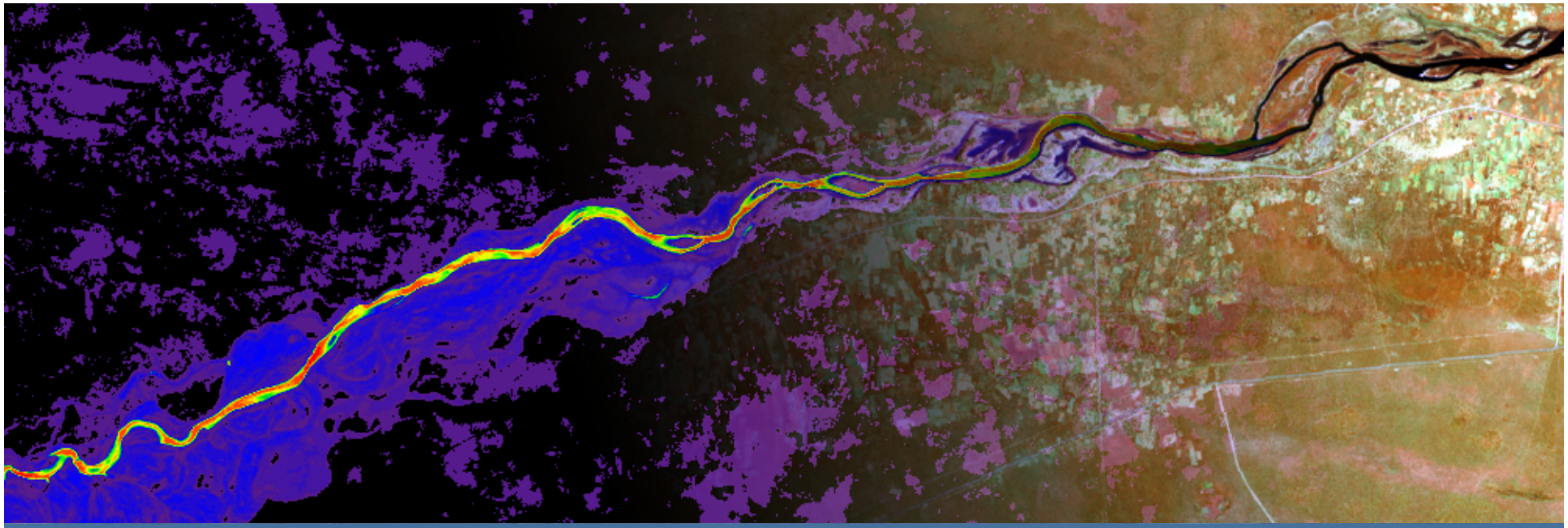


On the usage of a pixel-based dark-object database for the estimation of aerosol optical depth and its incorporation in a large area Landsat processing framework

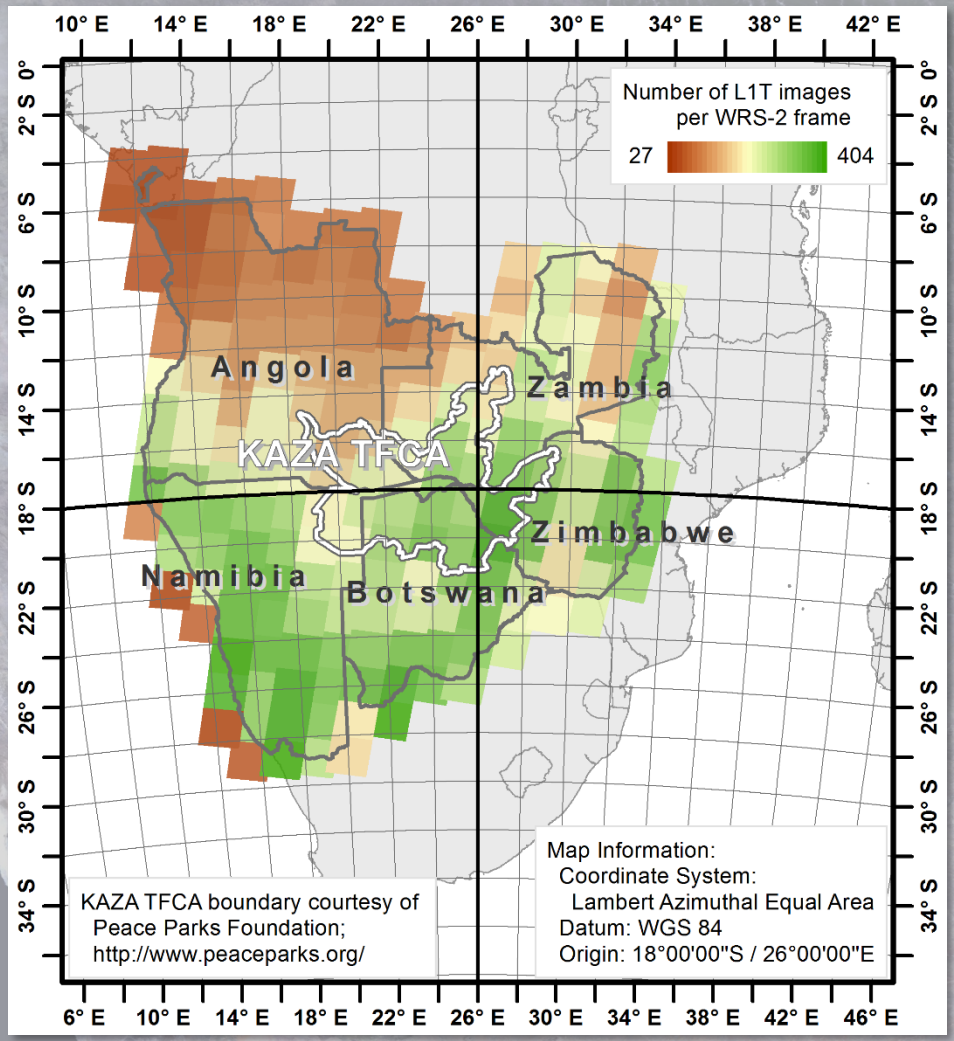
MultiTemp 2015
8th International Workshop on the Analysis of Multitemporal Remote Sensing Images
July 22-24, 2015 – Annecy, France

David Frantz, Achim Röder, Marion Stellmes & Joachim Hill
Department of Environmental Remote Sensing & Geoinformatics,
FB VI Regional and Environmental Sciences,
Trier University

Universität Trier
Environmental Remote Sensing & Geoinformatics

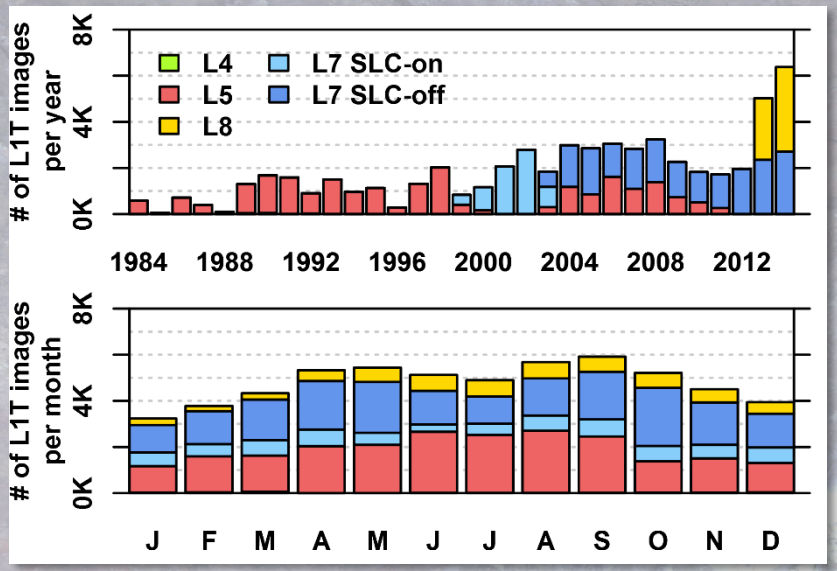
SPONSORED BY THE
Federal Ministry of Education and Research
SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management

STUDY AREA

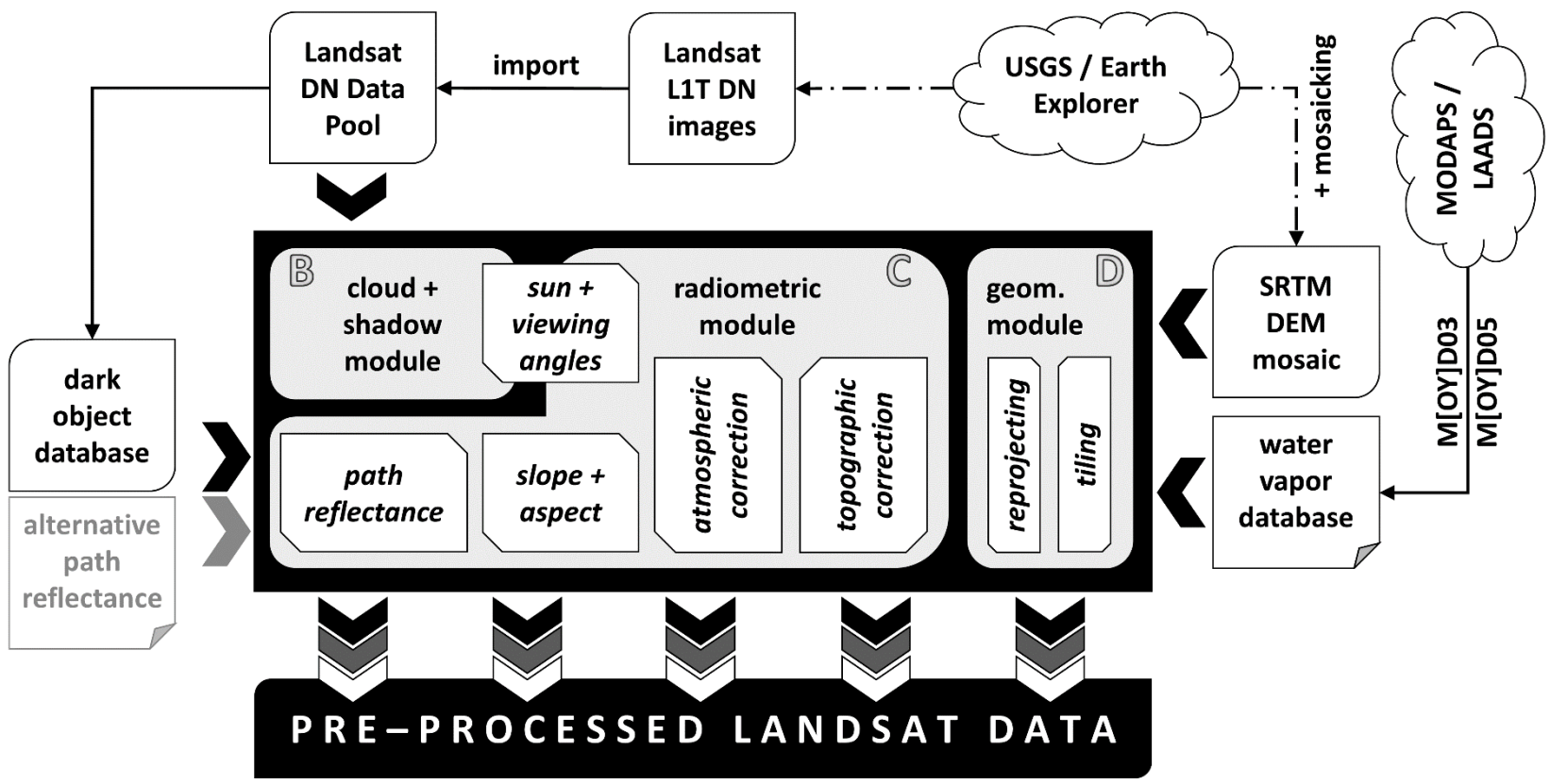


Centered at the upcoming Kavango-Zambezi Transfrontier Conservation Area (KAZA TFCA)

- ~ 3.7 Mio. km²
- 194 WRS-2 frames
- 57,371 L1T Landsat images
- ~ 15 TB

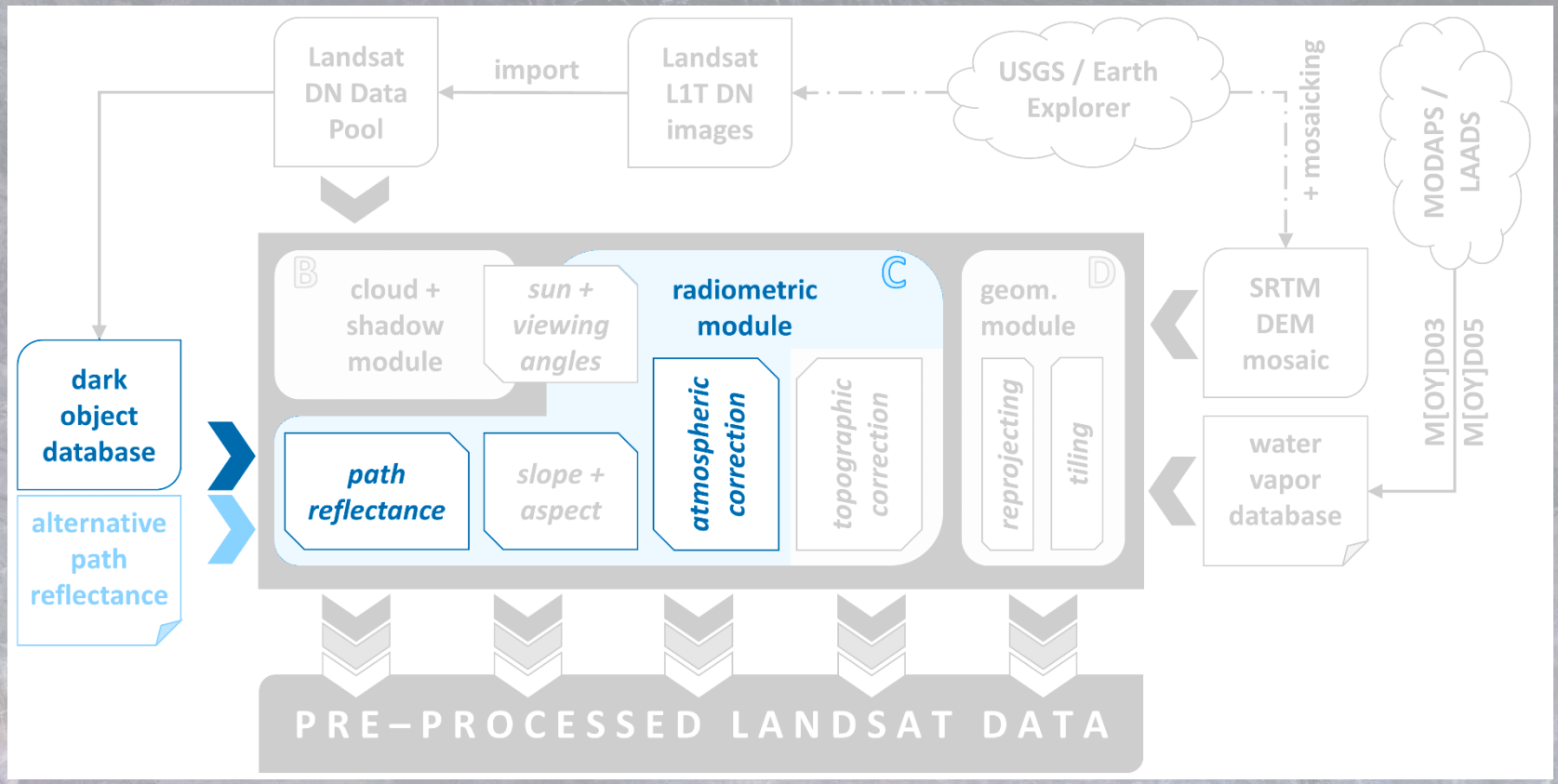


LANDSAT PRE-PROCESSING



Frantz, D., A. Röder, M. Stellmes, and J. Hill. "An Operational Radiometric Landsat Pre-Processing Framework for Large Area Time Series Applications." In Submission.

LANDSAT PRE-PROCESSING



Frantz, D., A. Röder, M. Stellmes, and J. Hill. "An Operational Radiometric Landsat Pre-Processing Framework for Large Area Time Series Applications." In Submission.

AOD FROM DARK OBJECTS

Histogram-based method

→ **Path reflectance ρ_p** over the darkest targets in image

Assumption:

signal over the darkest pixels is mainly composed of scattered radiation, i.e.

- Molecular scattering (Rayleigh scattering $\tau\downarrow r = 0.0088 \cdot \lambda\uparrow -4.15+0.2\lambda$)
- Forward and backward scattering at aerosols $\tau\downarrow a$, i.e. AOD

→ Total optical depth: $\tau = \tau\downarrow a + \tau\downarrow r$

AOD FROM DARK OBJECTS

Histogram-based method

→ **Path reflectance ρ_p** over the darkest targets in image

Assumption:

signal over the darkest pixels is mainly composed of scattered radiation, i.e.

- Molecular scattering (Rayleigh scattering $\tau_r = 0.0088 \cdot \lambda^{-4.15+0.2\lambda}$)
- Forward and backward scattering at aerosols τ_a, i.e. AOD

→ Total optical depth: $\tau = \tau_a + \tau_r$

$$\tau_a = (\boldsymbol{\rho_p} \cdot 4\mu_v \mu_s - \tau_r P_r)/P_a$$

single scattering approximation

$$P_r = 0.75 \cdot (1 + cos^2 \psi_-)$$

$$P_a = (1-g_1^2) \cdot \alpha / [1+g_1^2 - 2g_1 \cos\psi_-]^{1.5} + (1-g_2^2) \cdot (1-\alpha) / [1+g_2^2 + 2g_2 \cos\psi_-]^{1.5}$$

$$\psi_- = \cos^{-1} \{-\mu_v \mu_s - [(1-\mu_v^2)(1-\mu_s^2)]^{0.5} \cos(\phi_v - \phi_s)\}$$

J. Hill and B. Sturm, "Radiometric correction of multitemporal Thematic Mapper data for use in agricultural land-cover classification and vegetation monitoring," International Journal of Remote Sensing, vol. 12, no. 7,pp. 1471-1491, Jul., 1991

AOD FROM DARK OBJECTS

Histogram-based method

→ **Path reflectance ρ_p** over the darkest targets in image

Assumption:

signal over the darkest pixels is mainly composed of scattered radiation, i.e.

- Molecular scattering (Rayleigh scattering $\tau_r = 0.0088 \cdot \lambda^{-4.15+0.2\lambda}$)
- Forward and backward scattering at aerosols τ_a, i.e. AOD

→ Total optical depth: $\tau = \tau_a + \tau_r$

$$\tau_a = (\rho_p \cdot 4\mu_v \mu_s - \tau_r P_r)/P_a$$

single scattering approximation

$$P_r = 0.75 \cdot (1+\cos^2 \psi_-)$$

$$P_a = (1-g_1^2)\cdot\alpha/[1+g_1^2 - 2g_1 \cos\psi_-]^{1.5} + (1-g_2^2)\cdot(1-\alpha)/[1+g_2^2 + 2g_2 \cos\psi_-]^{1.5}$$

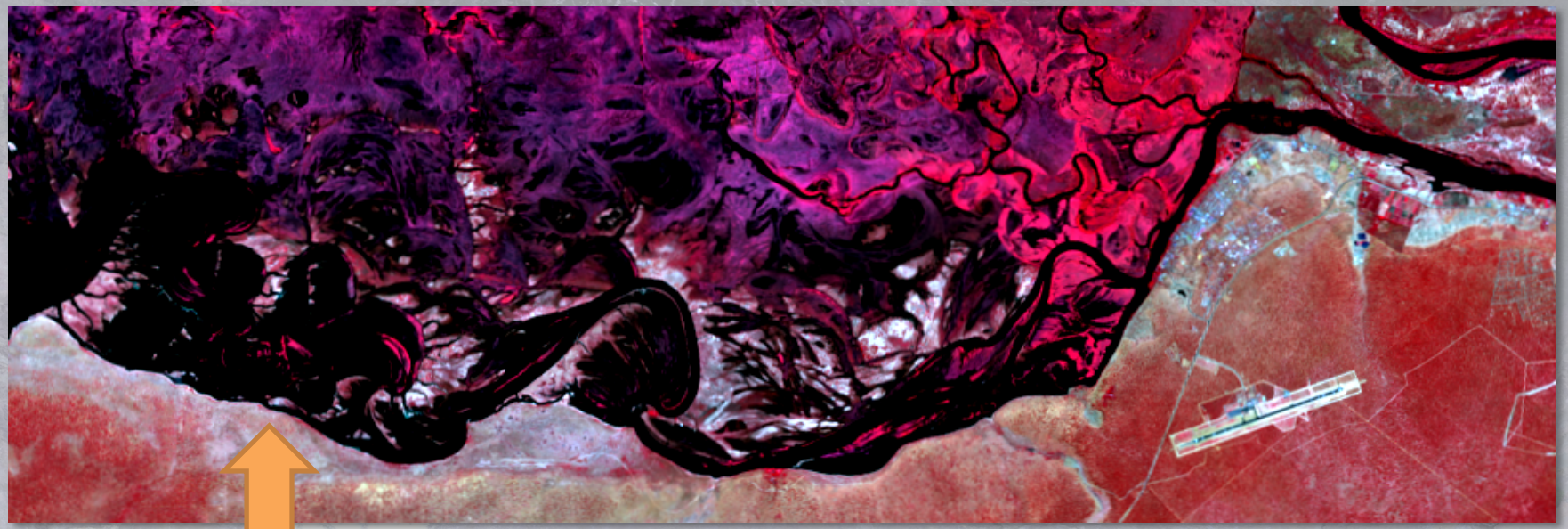
$g_1 = 0.836$
$g_2 = 0.537$
$\alpha = 0.968$
→ continental aerosol model

$$\psi_- = \cos^{-1}\{-\mu_v \mu_s - [(1-\mu_v^2)(1-\mu_s^2)]^{0.5} \cos(\phi_v - \phi_s)\}$$

J. Hill and B. Sturm, "Radiometric correction of multitemporal Thematic Mapper data for use in agricultural land-cover classification and vegetation monitoring," International Journal of Remote Sensing, vol. 12, no. 7,pp. 1471-1491, Jul., 1991

DARK OBJECT DATABASE

SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management



flood water

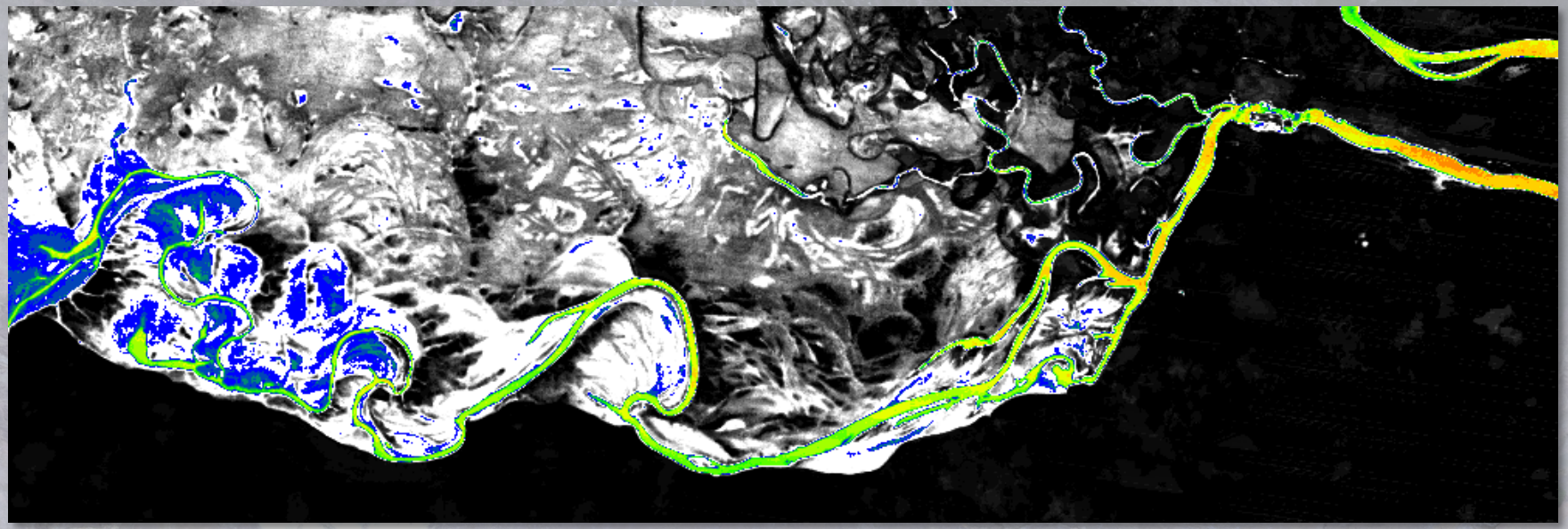
Wet Season [24 March 2013]

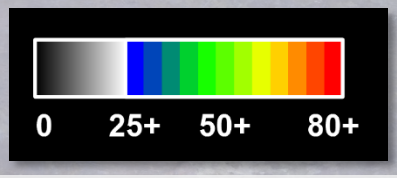
DARK OBJECT DATABASE

SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management

Dry Season [17 October 2013]

DARK OBJECT DATABASE





Dark Object Persistency
]2005,2015]

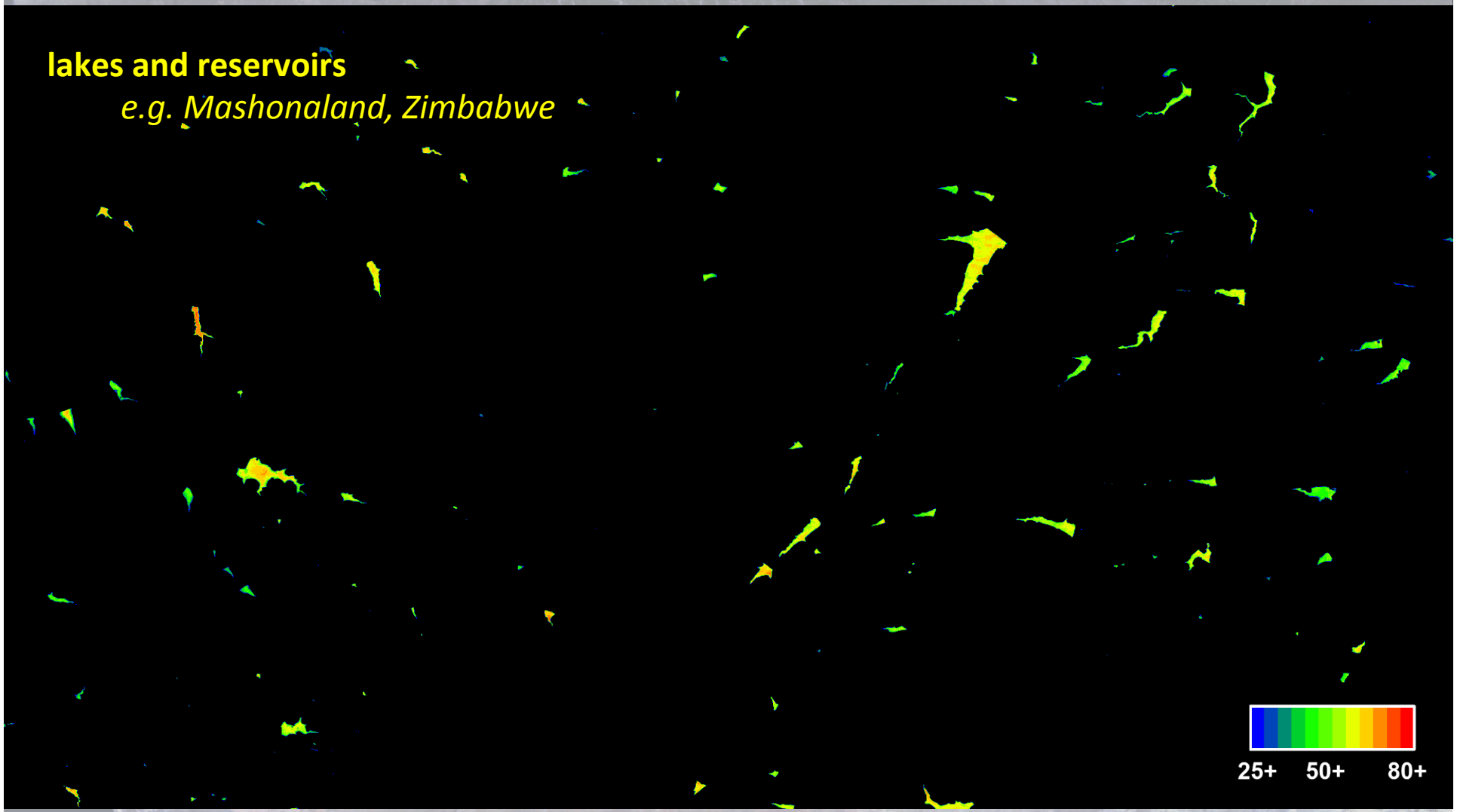
Pre-analysis of all available Landsat DN images

- Find darkest pixels in each image
- Determine the dark object persistency (DOP), i.e. the percentage of the time a pixel is dark

Atmospheric correction: ρ_p is determined from the most persistent available pixels

DARK OBJECT DATABASE

SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management



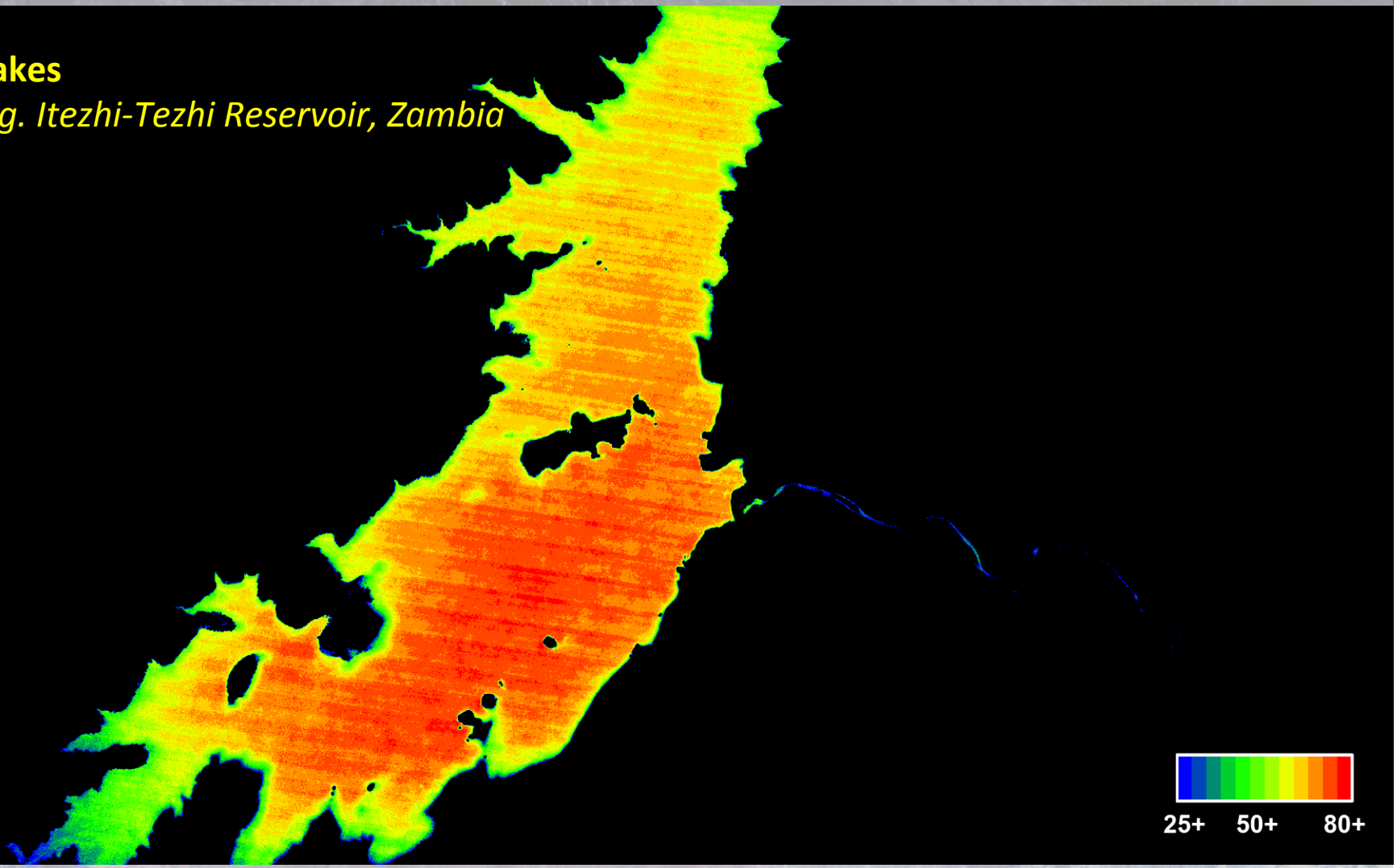
Using a pixel-based dark-object database for AOD estimation in large area Landsat pre-processing

DARK OBJECT DATABASE

SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management

large lakes

e.g. Itezhi-Tezhi Reservoir, Zambia



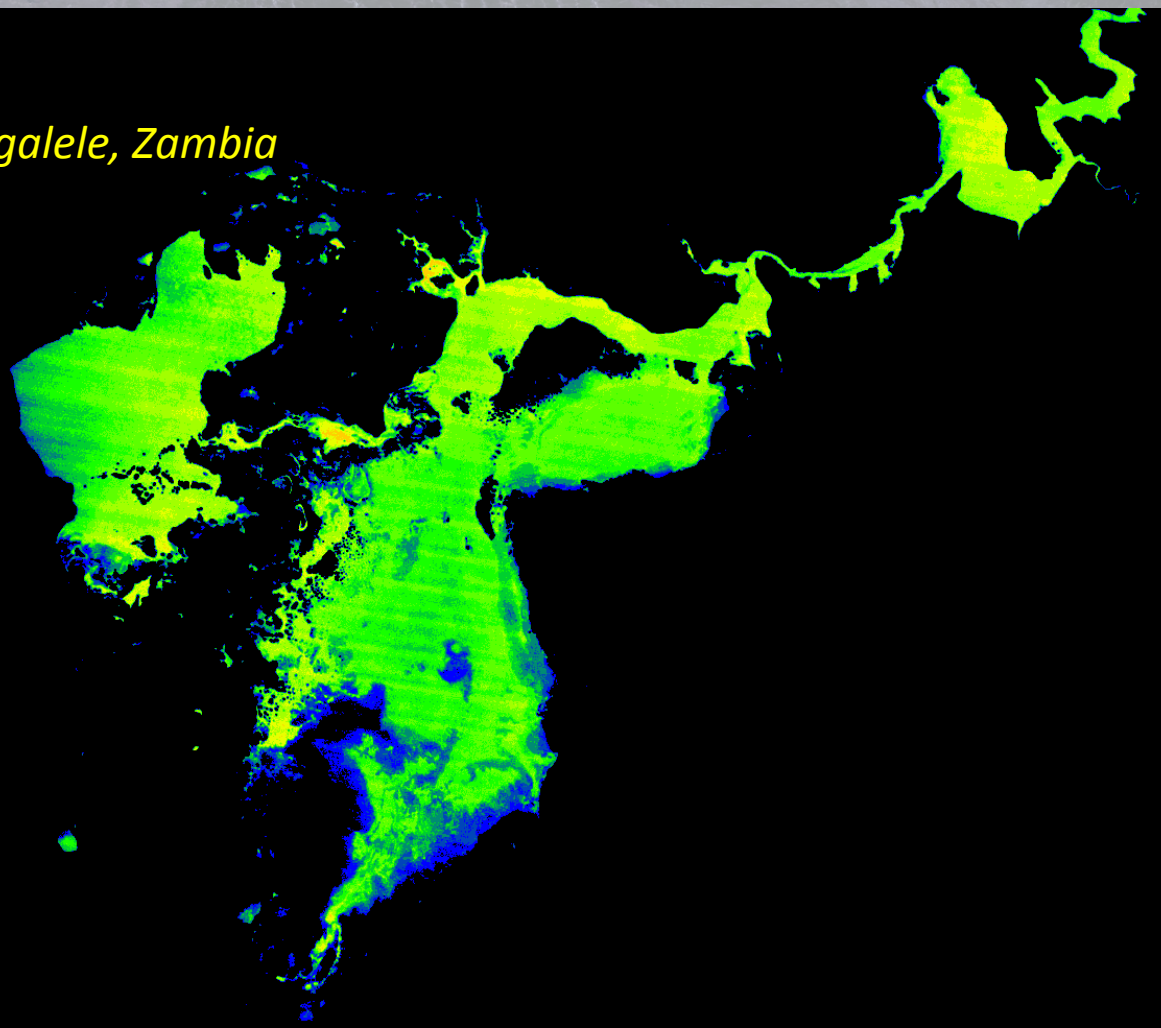
Using a pixel-based dark-object database for AOD estimation in large area Landsat pre-processing

DARK OBJECT DATABASE

SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management

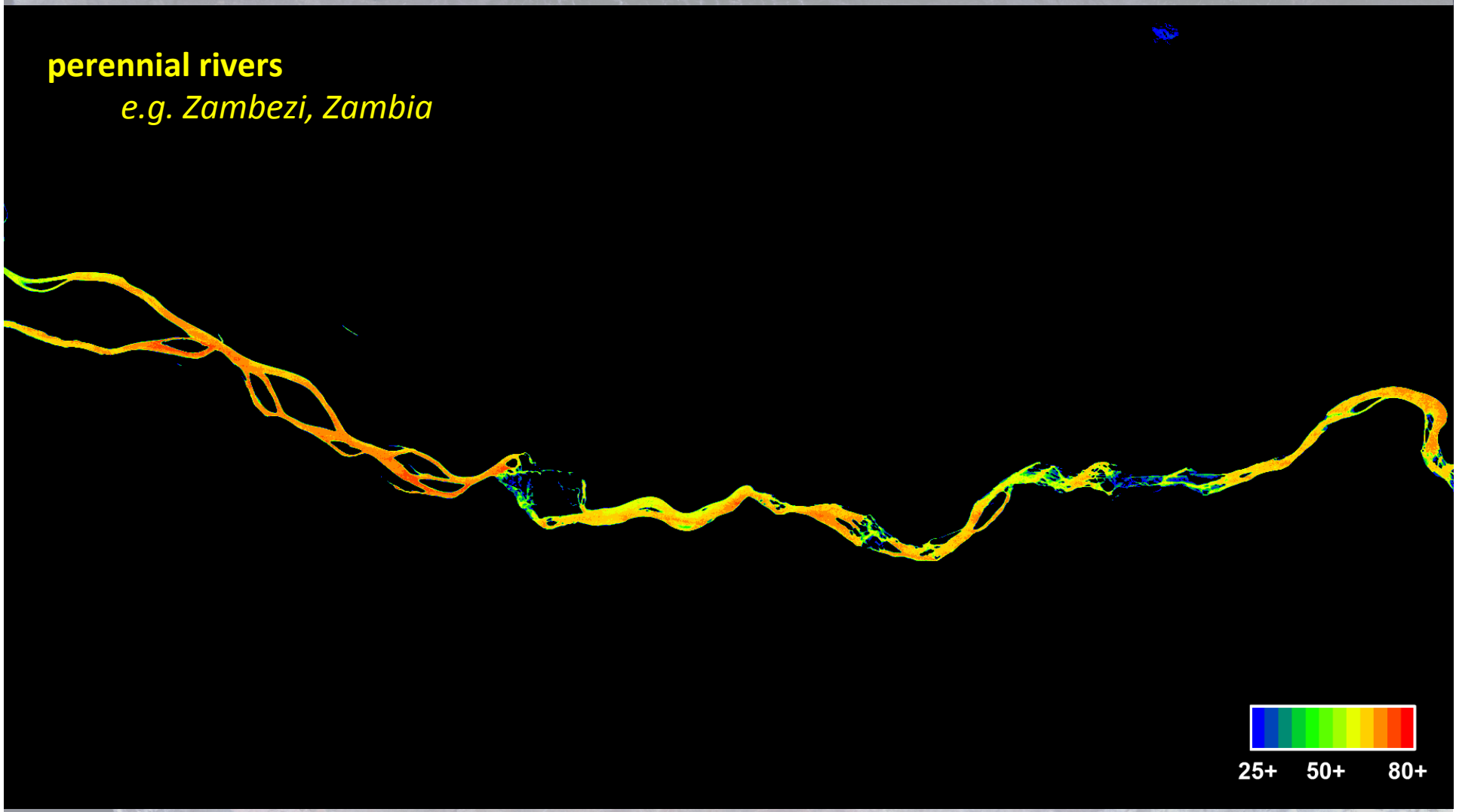
swamps

e.g. Lake Tshangalele, Zambia



DARK OBJECT DATABASE

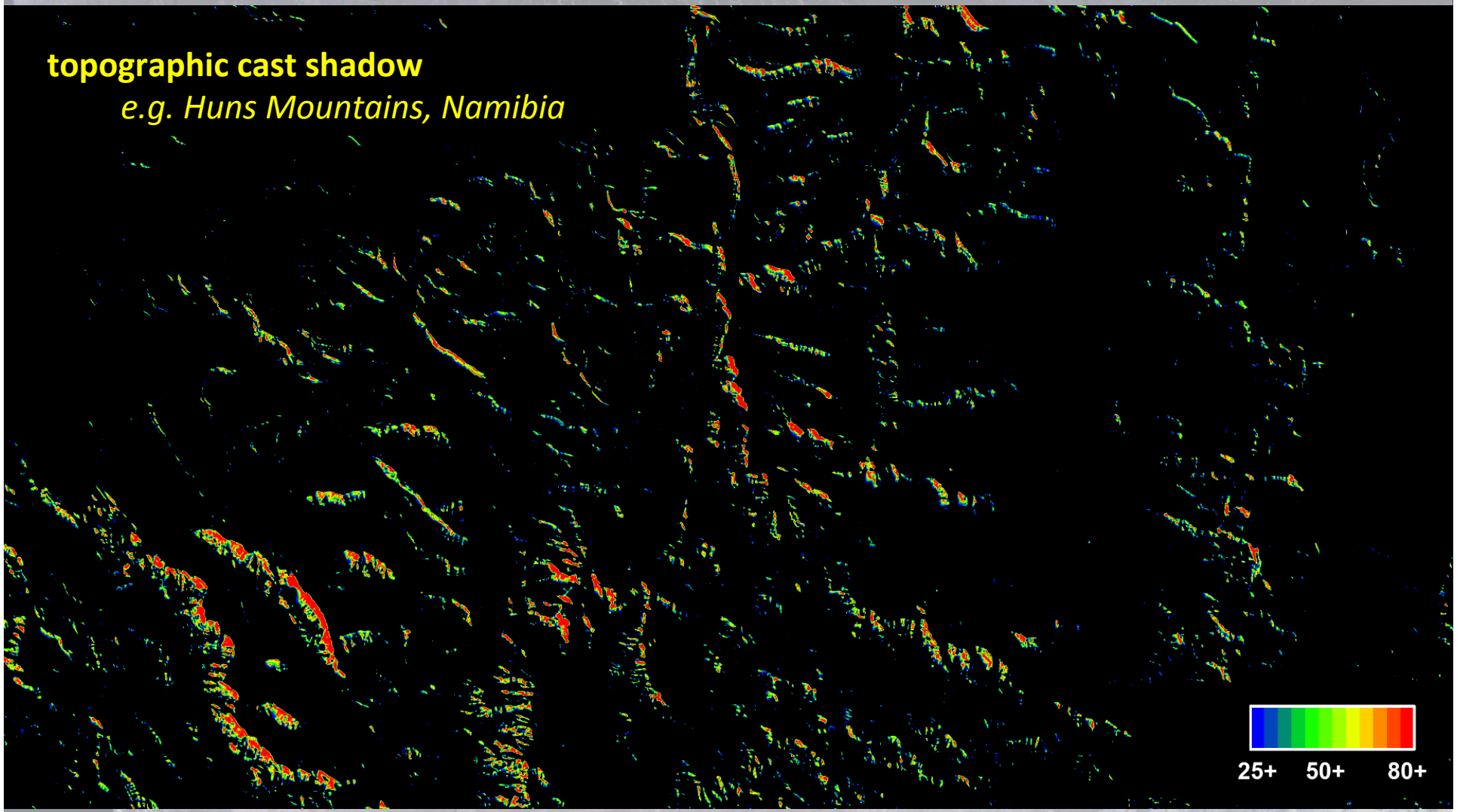
SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management



Using a pixel-based dark-object database for AOD estimation in large area Landsat pre-processing

DARK OBJECT DATABASE

SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management



Using a pixel-based dark-object database for AOD estimation in large area Landsat pre-processing

SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management

Violation of assumptions

Dark objects are not available in every scene

1. General brightness of the study area
   especially in the savannas in Namibia and Botswana

2. Increasing effect in the dry season
   - landscape brightness is increasing
   - water availability is decreasing

Violation of assumptions

Dark objects are not available in every scene

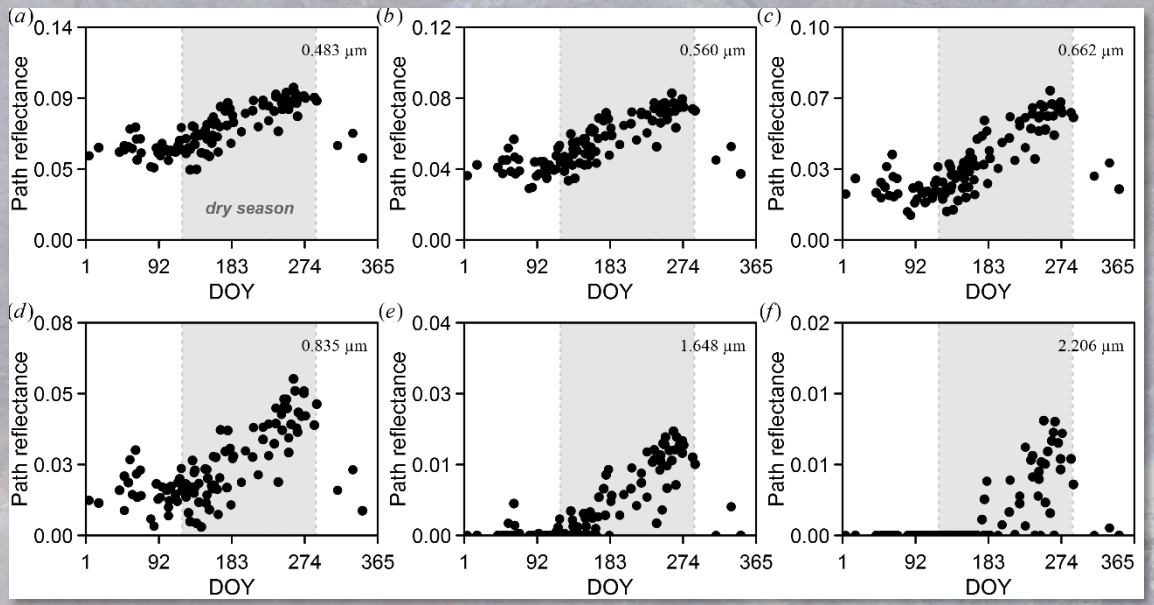
1. General brightness of the study area
   especially in the savannas in Namibia and Botswana

2. Increasing effect in the dry season
   - landscape brightness is increasing
   - water availability is decreasing

Environmental settings

Aerosol loading is not constant and inhibits a strong variability

1. Pronounced seasonality



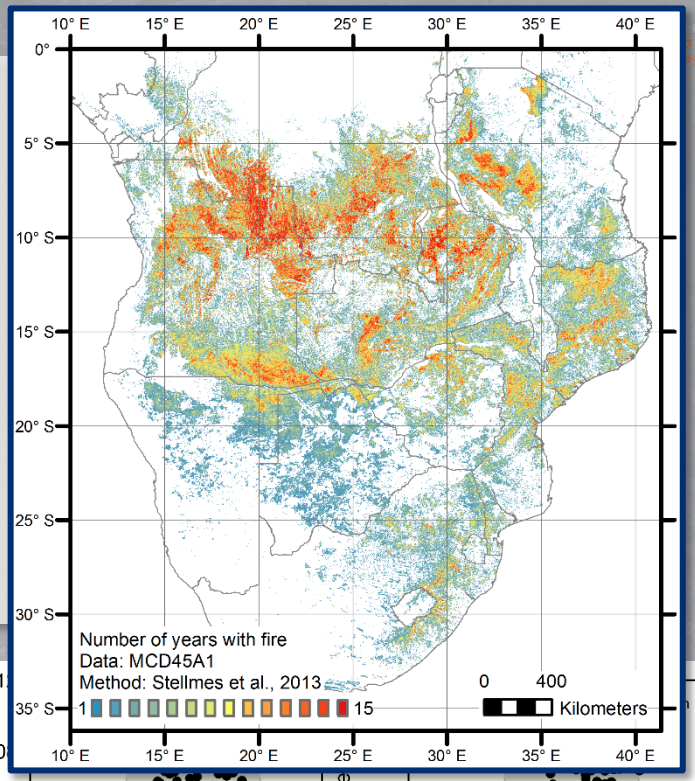
SASSCAL

Violation of assumptions

Dark objects are not available in every scene

1. General brightness of the study area
   especially in the savannas in Namibia and Botswana

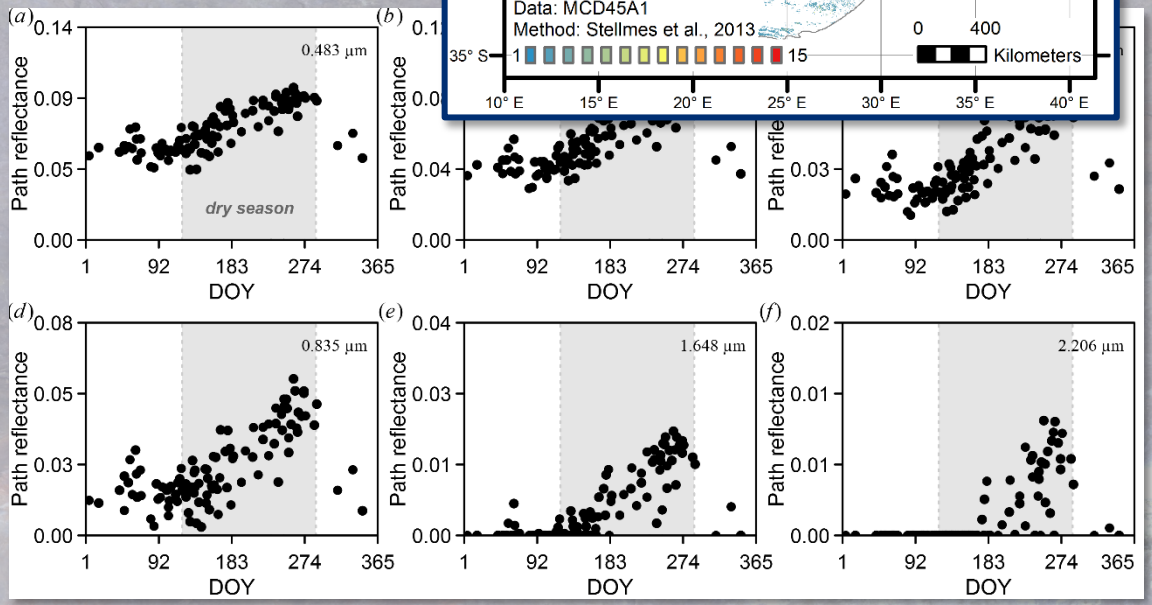
2. Increasing effect in the dry season
   - landscape brightness is increasing
   - water availability is decreasing



Environmental settings

Aerosol loading is not constant and inhibits a strong variability

1. Pronounced seasonality
   Dry season = **Fire**



AEROSOL CLIMATOLOGY

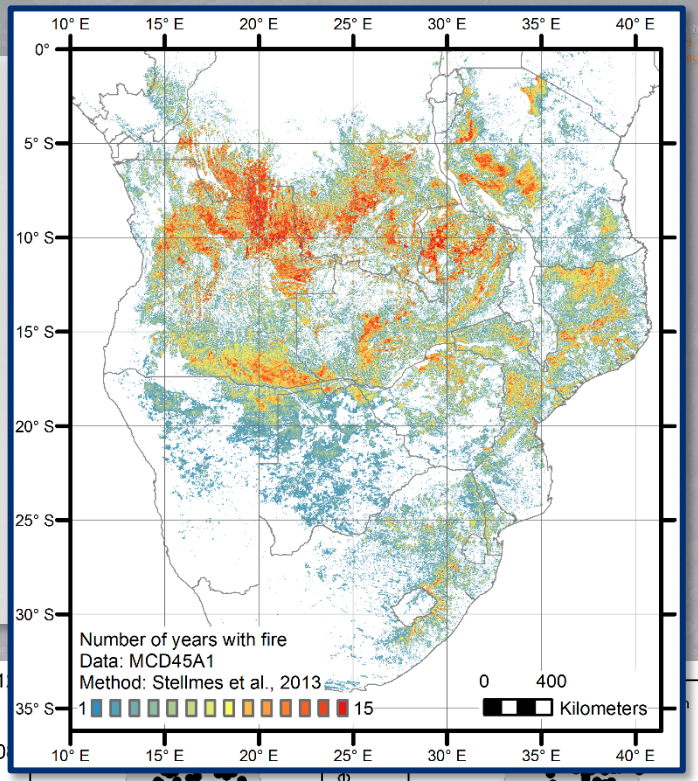
SASSCAL

Violation of assumptions

Dark objects are not available in every scene

1. General brightness of the study area
   especially in the savannas in Namibia and Botswana

2. Increasing effect in the dry season
   - landscape brightness is increasing
   - water availability is decreasing

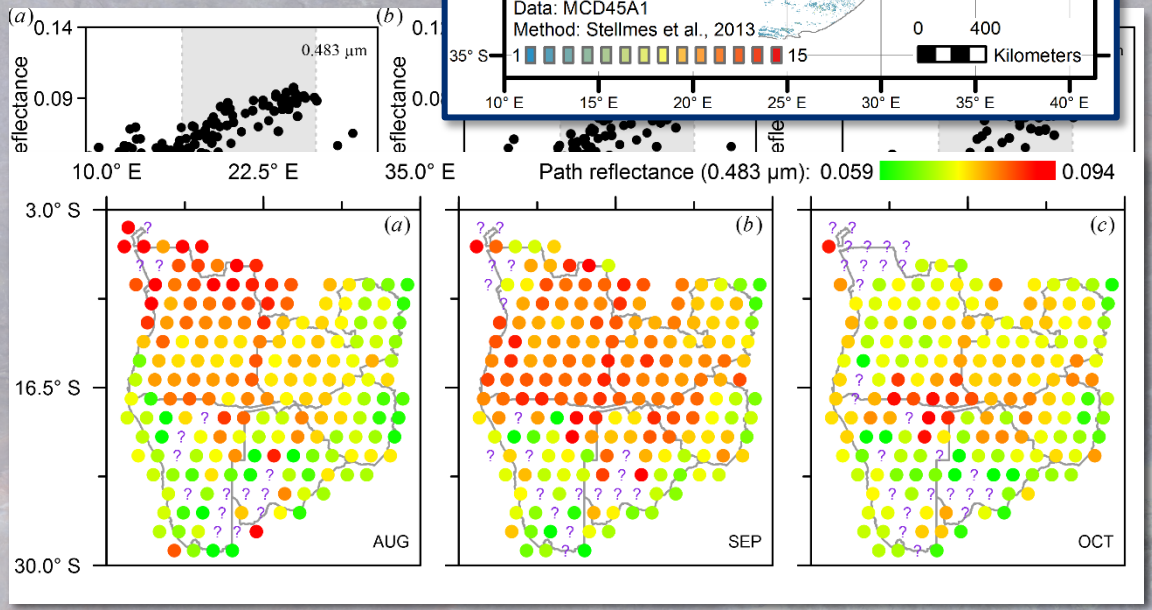


Environmental settings

Aerosol loading is not constant and inhibits a strong variability

1. Pronounced seasonality
   Dry season = **Fire**

2. Spatial variability
   Fire regime (fuel, climate, etc.)



Modelling

→ Spatio-temporal ρ_p climatology

- On basis of the succesful ρ_p retrievals
- **Fallback** strategy when actual AOD cannot be retrieved from dark targets

$$\rho_{\mathbf{p},b} = c_0 + c_1 X + c_2 Y + c_3 XY + c_4 X^2 + c_5 Y^2 + c_6 (\mathrm{DOY}) + c_7 (\mathrm{DOY})^2 +$$

$$c_8 X \sin(2\pi(\mathrm{DOY})/365) + c_9 X \cos(2\pi(\mathrm{DOY})/365) +$$
$$c_{10} Y \sin(2\pi(\mathrm{DOY})/365) + c_{11} Y \cos(2\pi(\mathrm{DOY})/365) +$$
$$c_{12} X \sin(4\pi(\mathrm{DOY})/365) + c_{13} X \cos(4\pi(\mathrm{DOY})/365) +$$
$$c_{14} Y \sin(4\pi(\mathrm{DOY})/365) + c_{15} Y \cos(4\pi(\mathrm{DOY})/365) +$$
$$c_{16} X \sin(6\pi(\mathrm{DOY})/365) + c_{17} X \cos(6\pi(\mathrm{DOY})/365) +$$
$$c_{18} Y \sin(6\pi(\mathrm{DOY})/365) + c_{19} Y \cos(6\pi(\mathrm{DOY})/365)$$

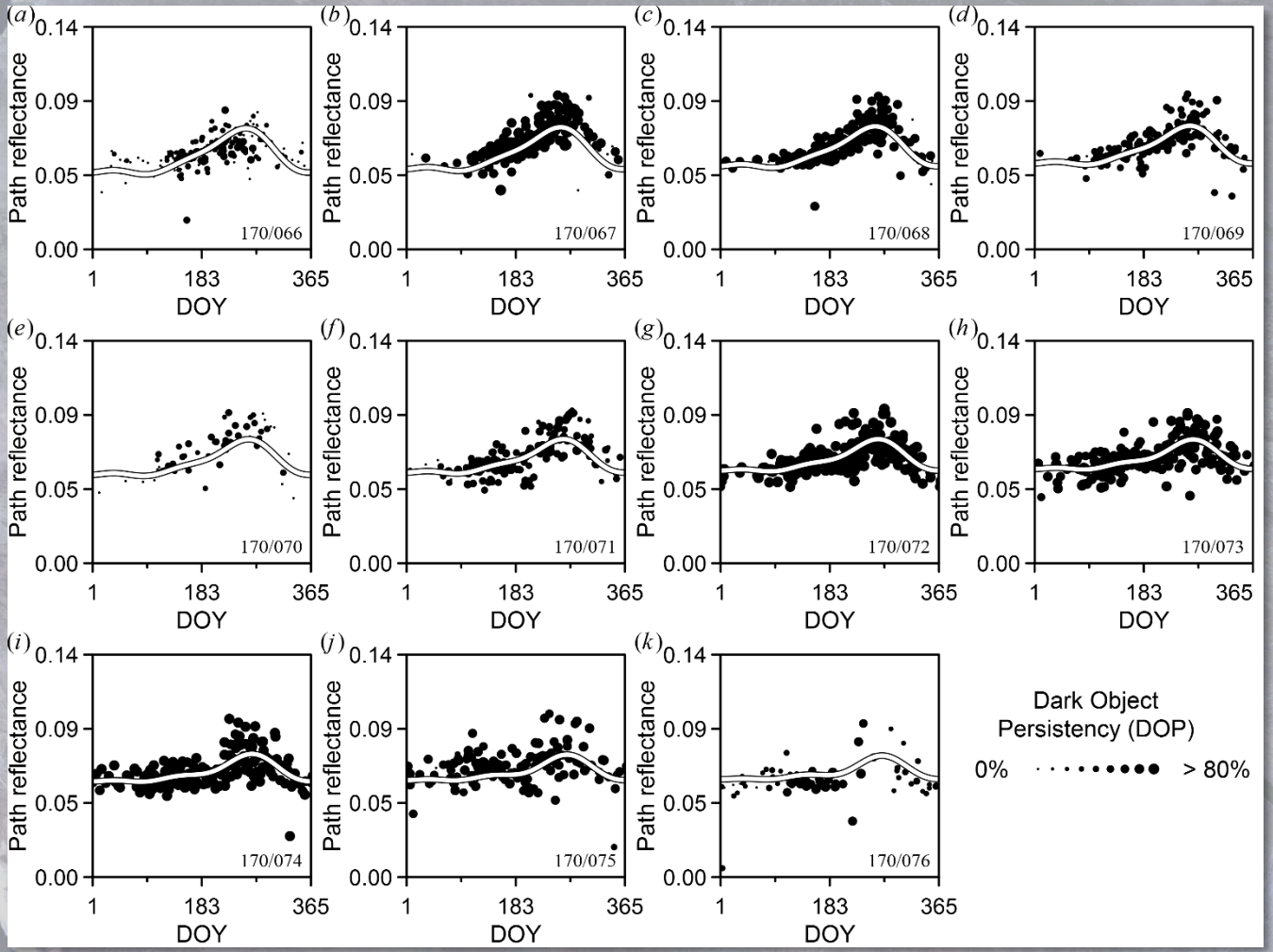
Geolocation **(X,Y)**

Acquisition **DOY**

Weighted least squares fitting; cylic prediction; weights: Dark Object Persistency (DOP) of input ρ_p

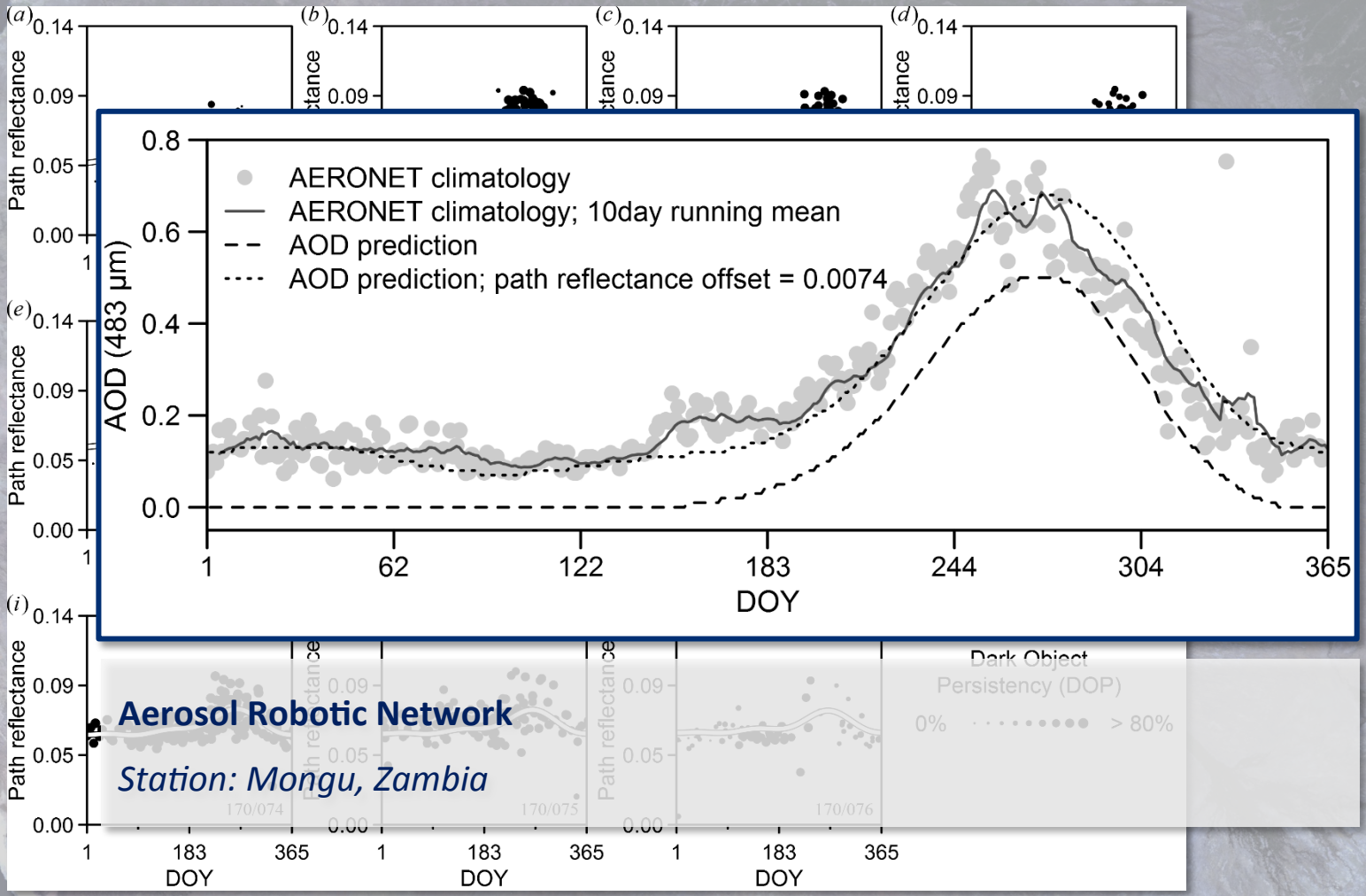
Frantz, D., A. Röder, M. Stellmes, and J. Hill. (2015). "On the derivation of a spatially distributed aerosol climatology for its incorporation in a radiometric Landsat pre-processing framework." Remote Sensing Letters 6 (8): 647-658. DOI: 10.1080/2150704X.2015.1070314

AEROSOL CLIMATOLOGY



AEROSOL CLIMATOLOGY

SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management

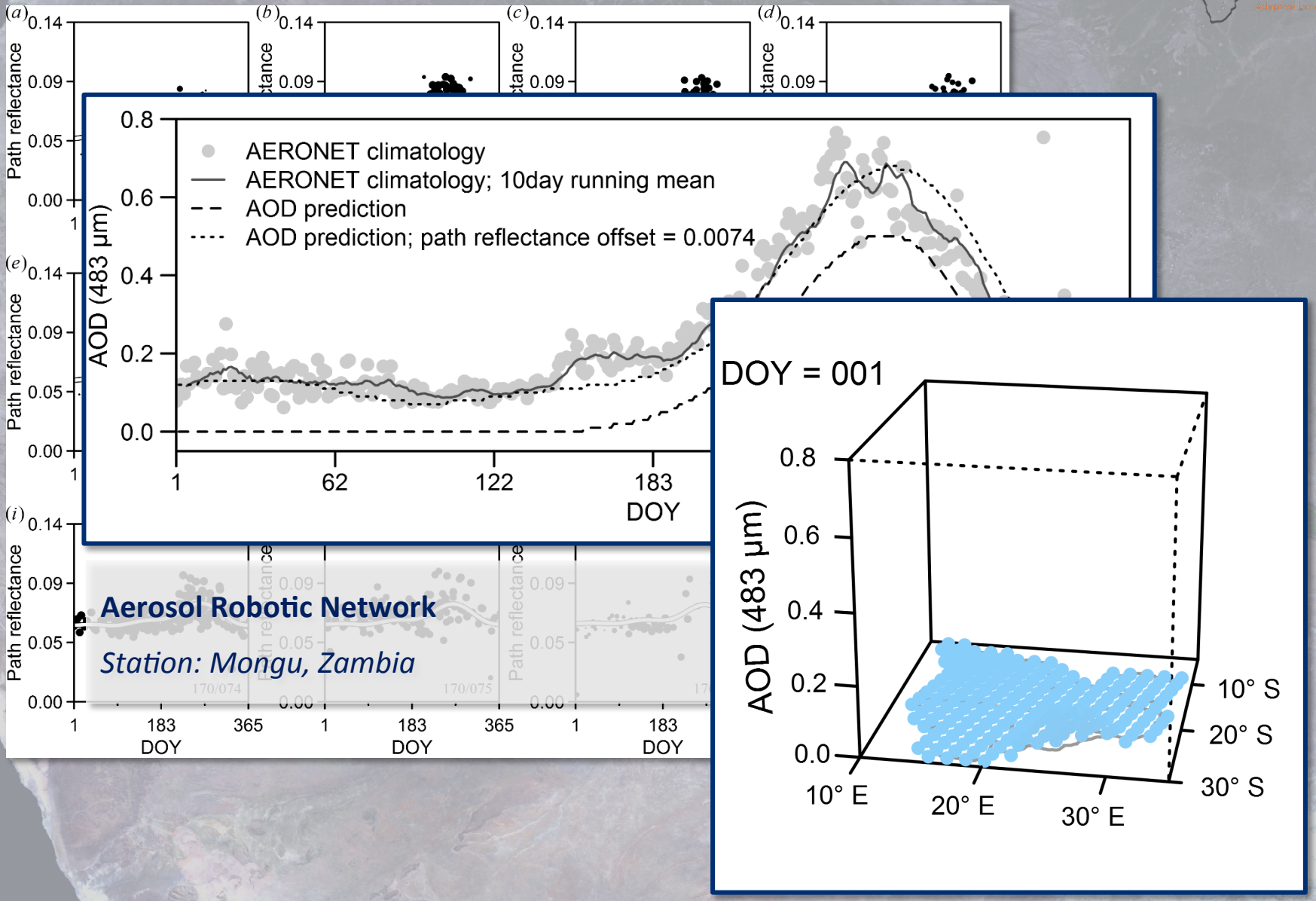


Aerosol Robotic Network

Station: Mongu, Zambia

AEROSOL CLIMATOLOGY

SASSCAL
Southern African Science Service Centre for Climate Change and Adaptive Land Management



Using a pixel-based dark-object database for AOD estimation in large area Landsat pre-processing