Multi-source Imaging of Infrastructure and Urban Growth using Landsat, Sentinel and SRTM

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Objectives

Develop, calibrate and validate a continuous optical+microwave index to map the continuum of human settlements worldwide.

Apply the index to Landsat+SRTM circa 2000 and Landsat+Sentinel circa 2015 to map changes in spatial structure of settlement networks.

Quantify spatiotemporal co-evolution of settlement networks and other complementary land cover networks.

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COLUMBIA UNIVERSITY | EARTH INSTITUTE

NASA JPL Jet Propulsion Laboratory California Institute of Technology

Challenges of Urban Mapping

Many Definitions of Urban - *Application dependent*

Multiple Scales - *Occurs at meter scales - Mapped at global scale.*

Many Manifestations - *Modification of land cover takes many forms.*

Spectral Non-Uniqueness - *Natural materials are often used.*

Spatial Continuity - *Rarely spatially contiguous. Generally fractal.*

Strategy

Challenge

Definition - Varying non-physical definitions of a continuum of settlement types.

Heterogeneity – Compositional heterogeneity both among and within settlements
Violates the principal assumptions of discrete thematic classification

Spectral Ambiguity – Spectral inseparability of pervious soils and many impervious substrates

Solution

Definition - Represent continuum of settlement types with continuous fields of physical properties
Map distinctive physical properties common to all settlement types.
Impervious surfaces *Persistent Shadow* *Corner Reflectors*

Heterogeneity – Represent land cover as mixtures of spectrally distinct materials
Unmix to give sub-pixel fractions of impervious substrates and shadow.

Spectral Ambiguity – Use SAR to map areas of high corner reflector density
Use multi-season spectral variability to map impervious surface & shadow

Spectrally Stable Impervious Substrates vs Spectrally Variable Pervious Soils

Spectrally Variable Building Shadow vs Spectrally Stable Water Bodies.

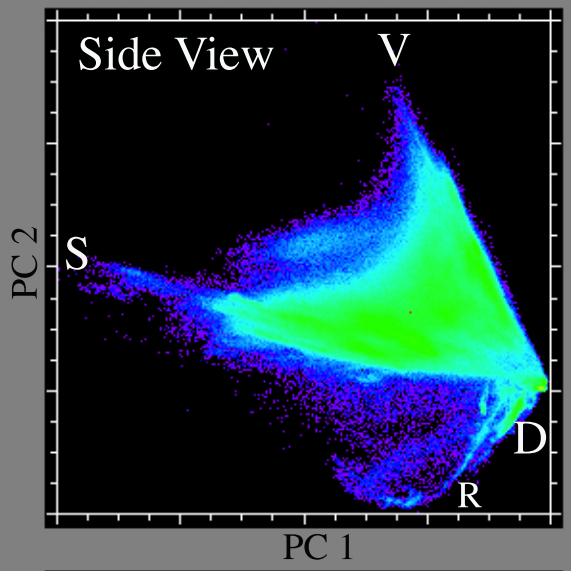
Continuous index based on physical properties calibrated across wide range of settlement types.

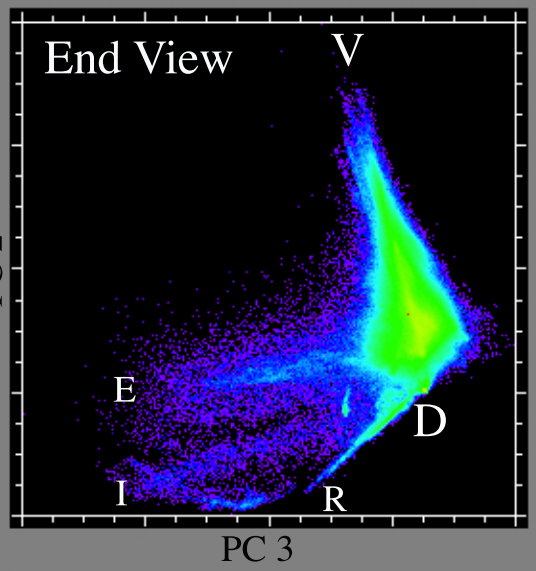
The Global Spectral Mixing Space

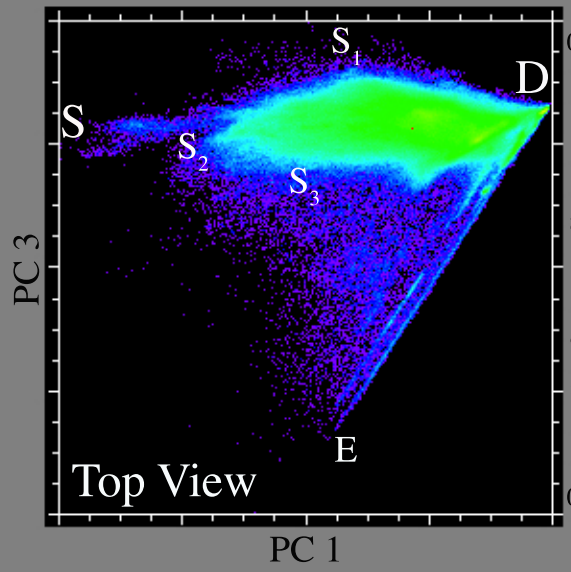
Spectrally, most land surfaces are composed of a few common reflectances:

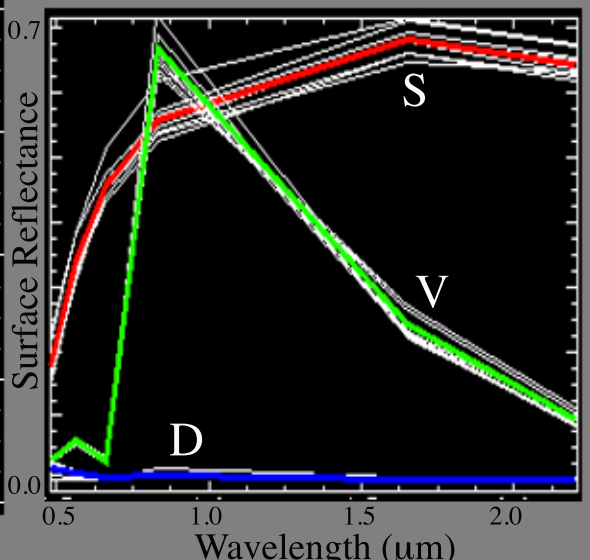
Substrate, Vegetation and Dark surfaces

100,000,000 Landsat spectra worldwide *97% have < 0.05 misfit to SVD mixture model*









Small & Milesi (2013) *Sousa & Small (2017)*

Substrate

The Rock - Soil continuum
Plane of Substrates D S_1 S_2 S_3
High albedo (when dry)
SWIR bright

Vegetation

Similar spectral features:
Vis - Chlorophyll Absorptive
NIR - Mesophyll Reflective
SWIR - H_2O, Lignin,Absorptive

Dark surfaces:

Transmissive: e.g. clear water
Absorptive: dark rocks & soils
Non-illuminated: shadow

Other Stuff

Evaporites, **I**ce/snow **R**eefs

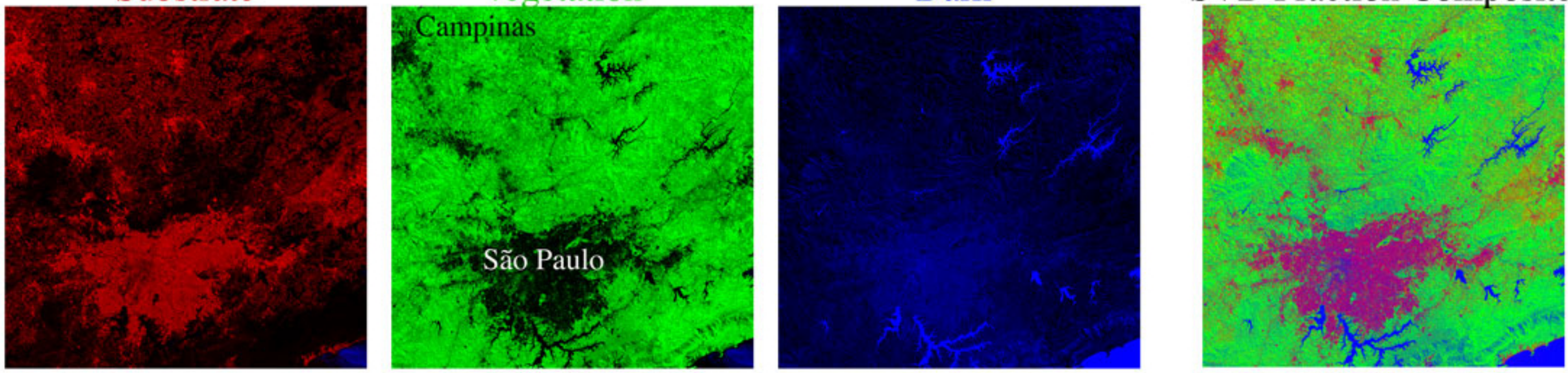
Substrate

Vegetation

Dark

SVD Fraction Composite

120 km



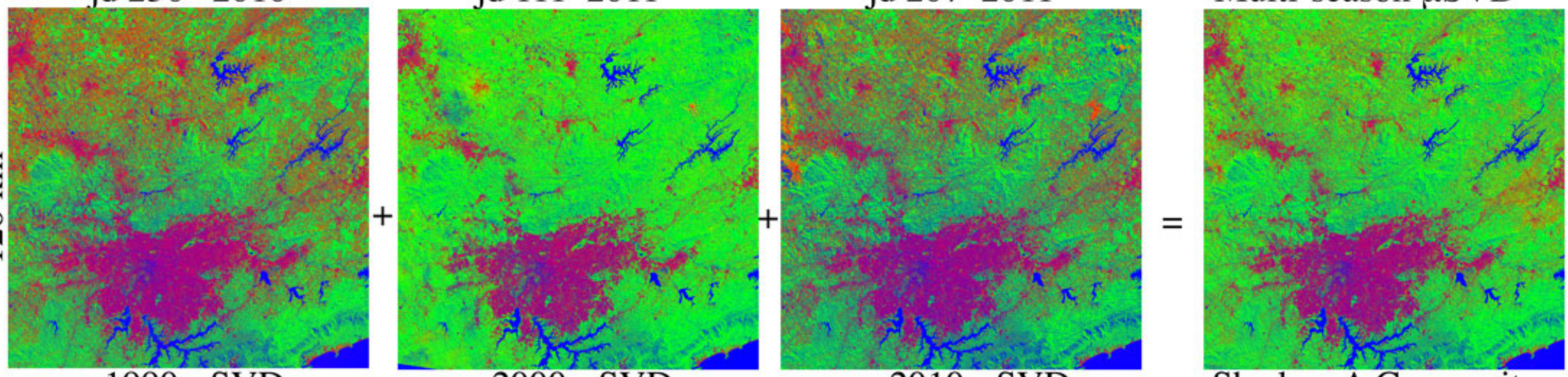
jd 236 2010

jd 111 2011

jd 207 2011

Multi-season μSVD

120 km



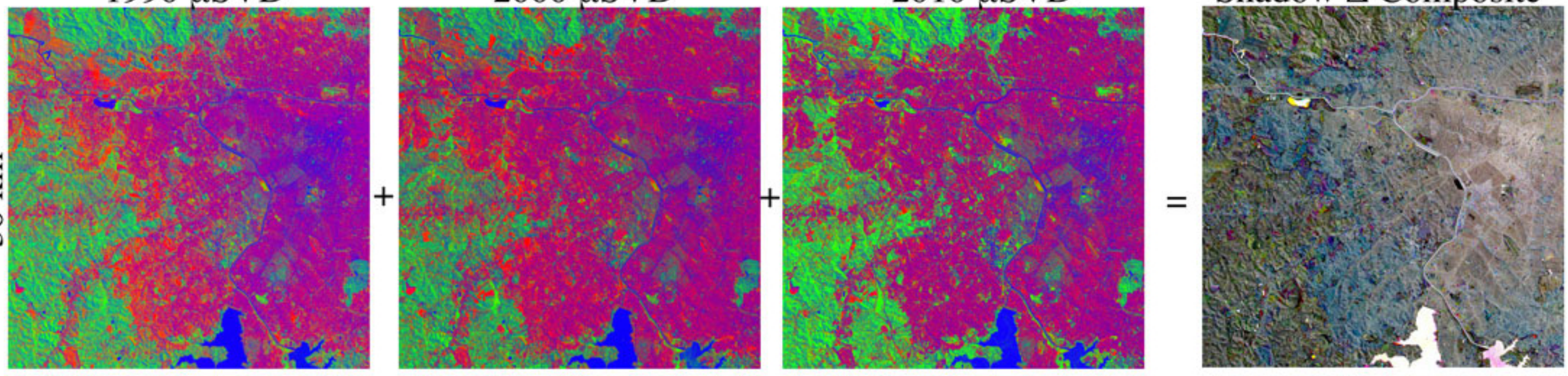
1990 μSVD

2000 μSVD

2010 μSVD

Shadow Δ Composite

30 km



Continuous Field Multi-Season Spectral Properties

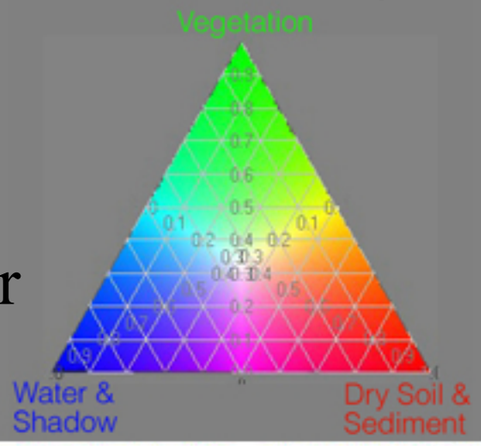
Continuous Field - *Accommodates subpixel heterogeneity*
Multi-Season - *Incorporates temporal variability & spectral stability*
Spectral Properties - *Projects 6D reflectance onto 3D land cover*

Mixture model inversion uncertainty & scaling accuracy 2m to 30 m

Represent landscape as continuous fields of physically & functionally distinct land cover while incorporating temporal variability/stability information.

Unmix

6D reflectance → 3D land cover fractions



Temporal Stability → Standardized Moment

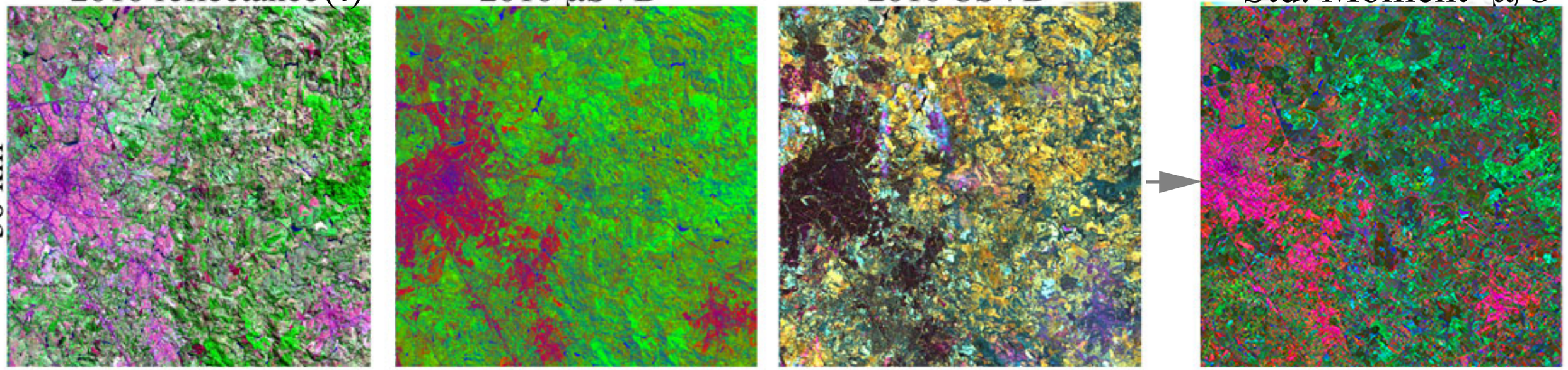
2010 reflectance (t)

2010 μSVD

2010 σSVD

Std. Moment μ/σ

30 km



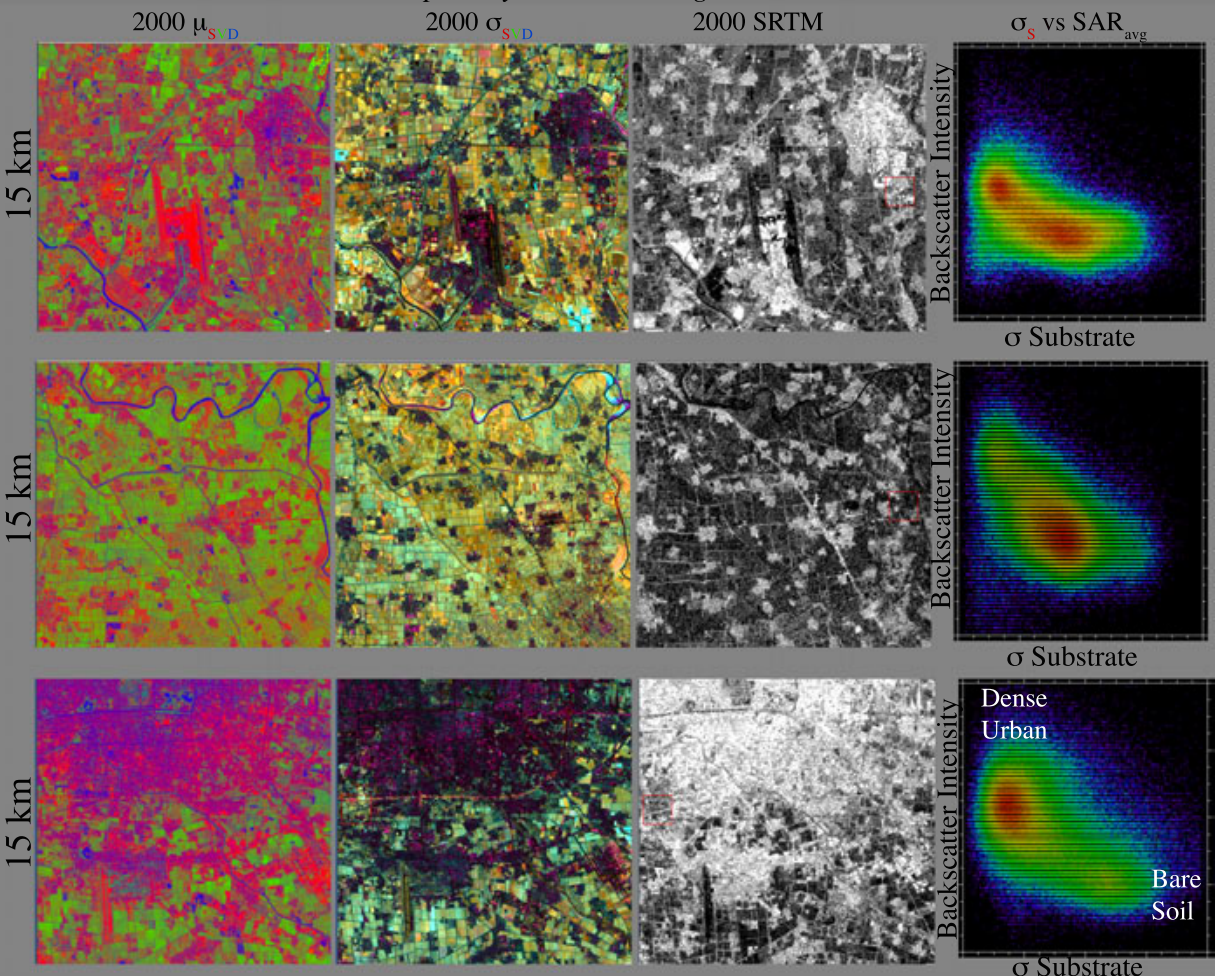
660 nm 800 nm 2200 nm

μ_S μ_V μ_D

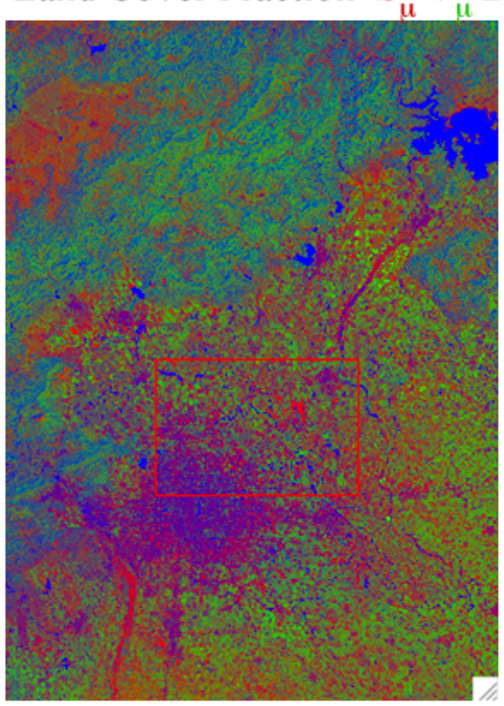
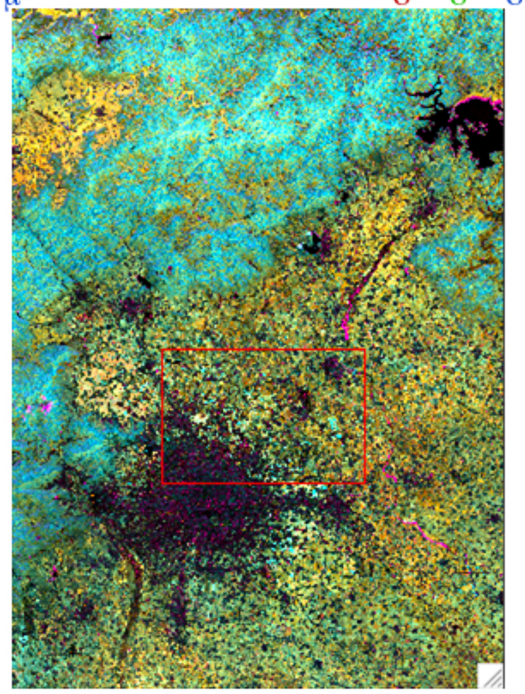
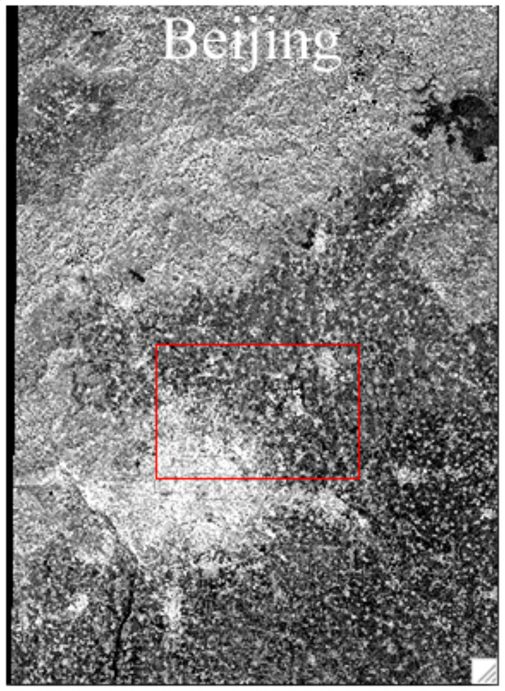
σ_S σ_V σ_D

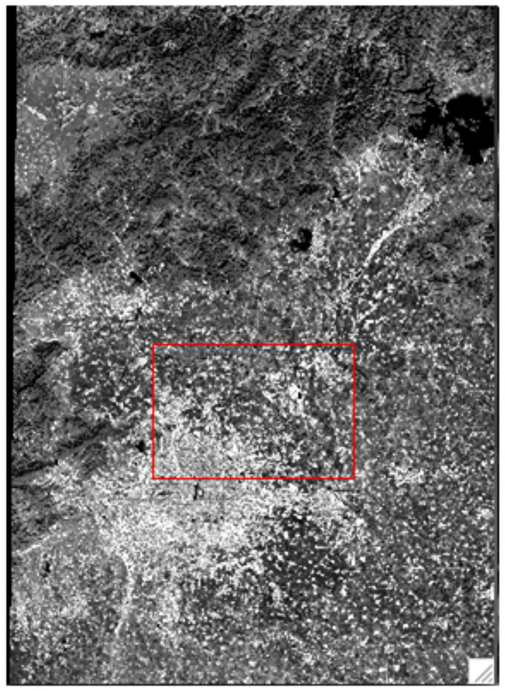
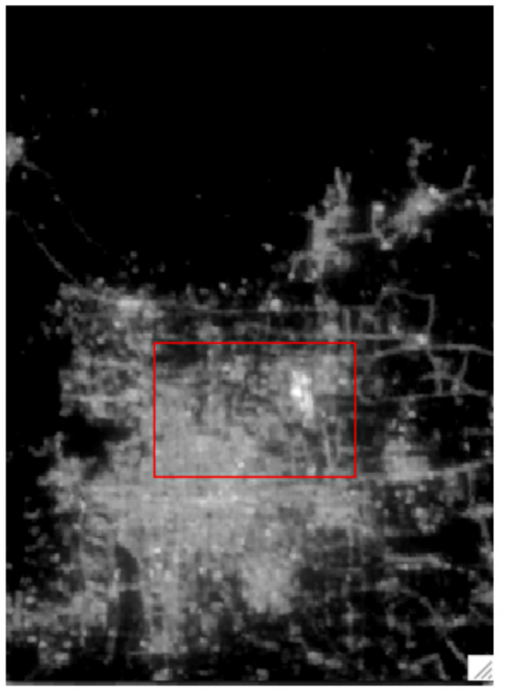
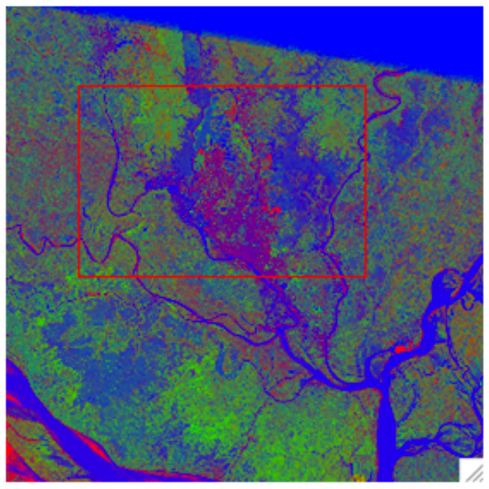
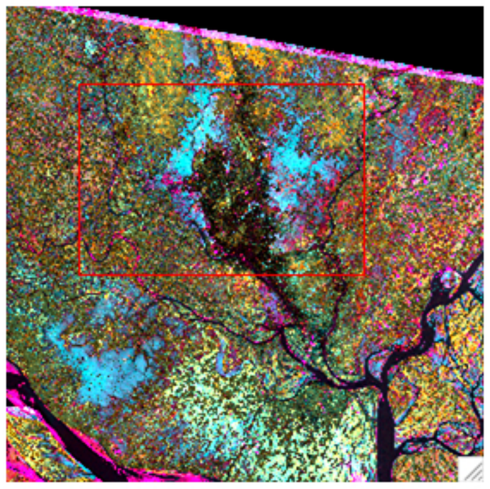
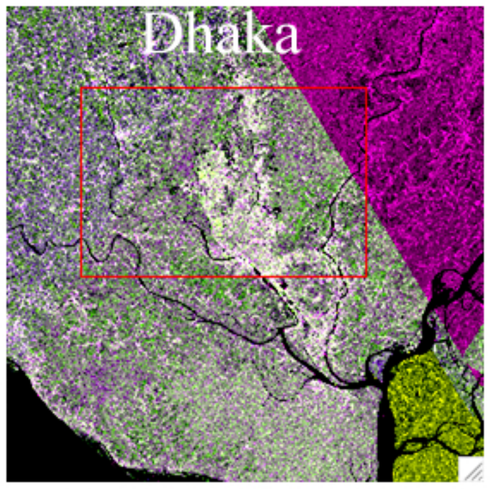
LC Fraction Stability - Backscatter Characterization

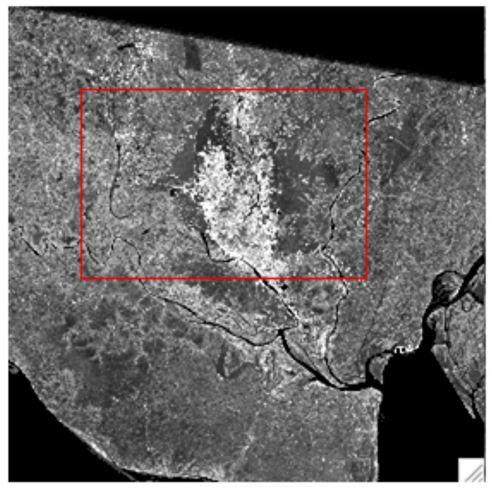
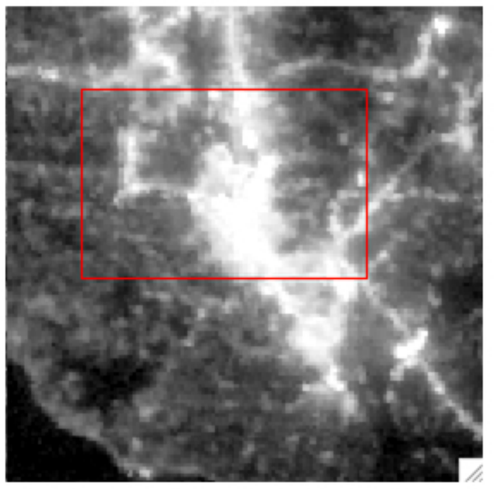
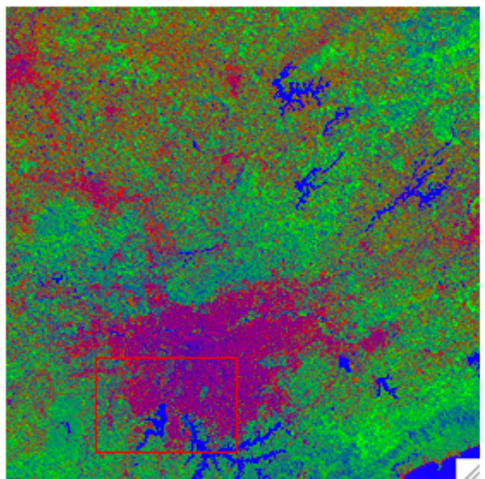
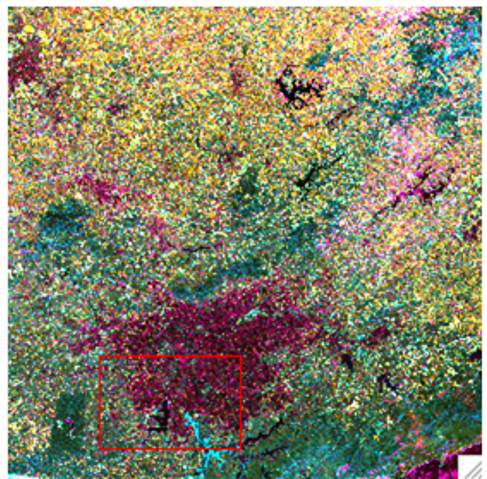
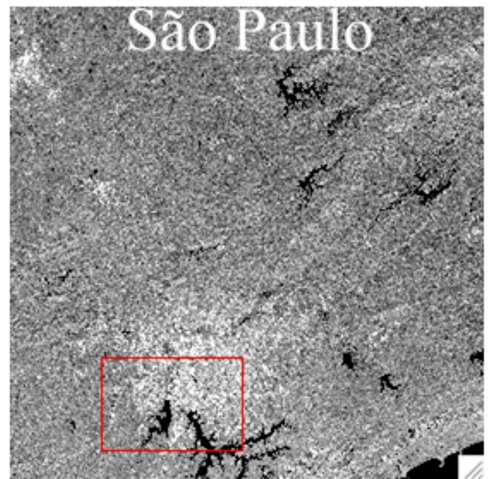
Substrate + Shadow *Temporally Stable* *High Backscatter*

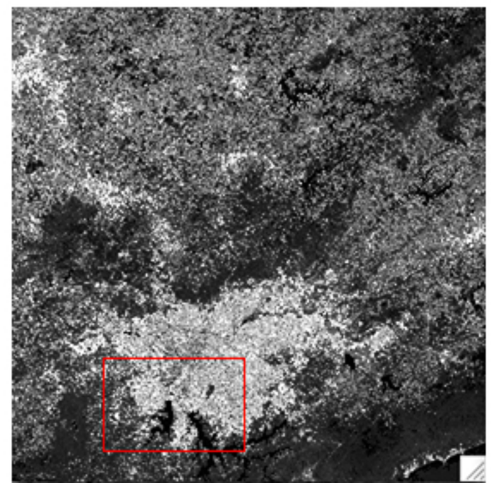
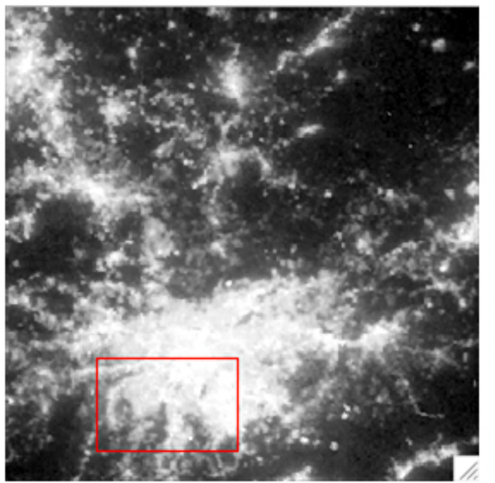


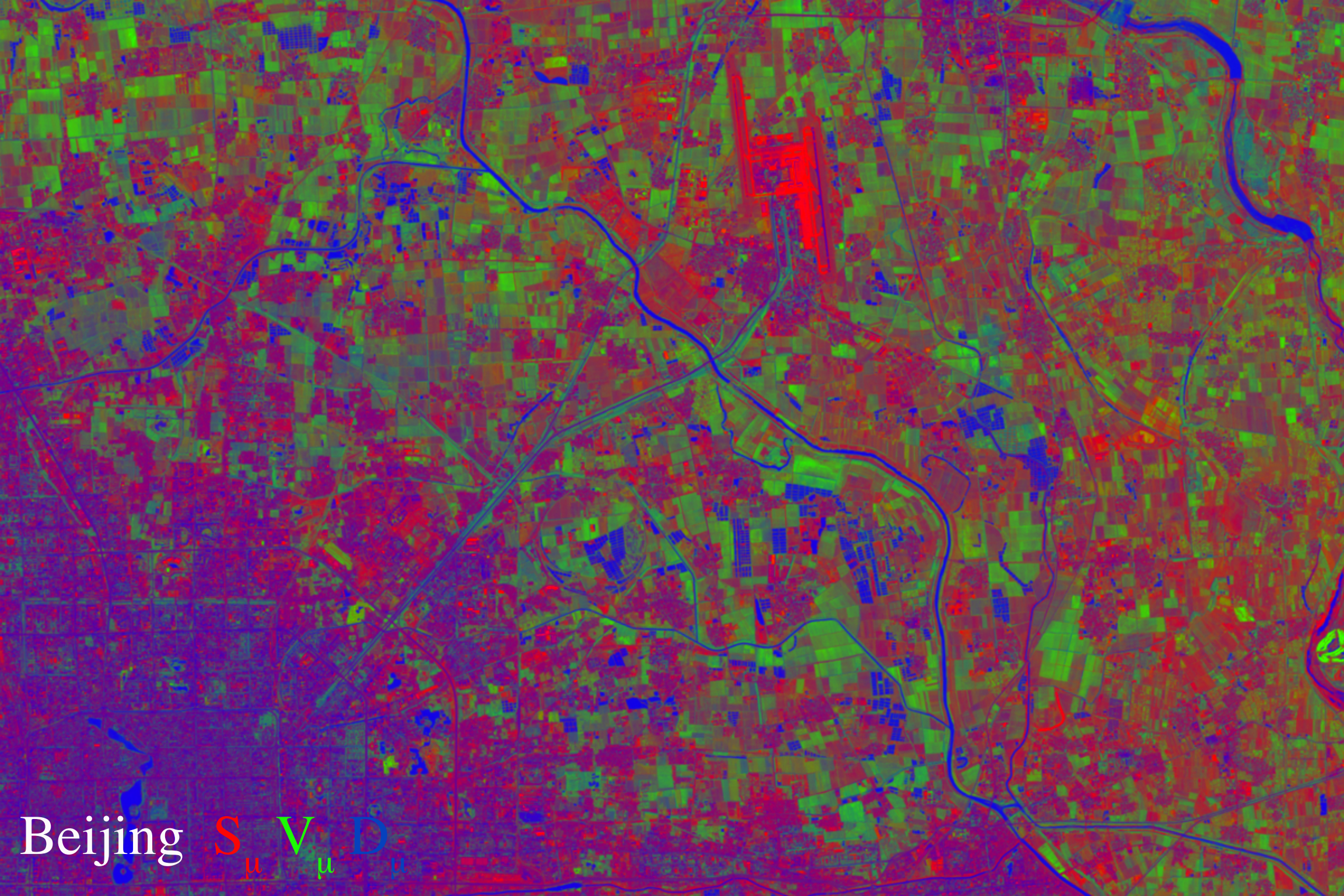
Land Cover Fraction S_μ V_μ D_μ | Spectral Variability S_σ V_σ D_σ | SRTM Backscatter | Infrastucture Index | VIIRS Night Light


Beijing S_μ V_μ D_μ

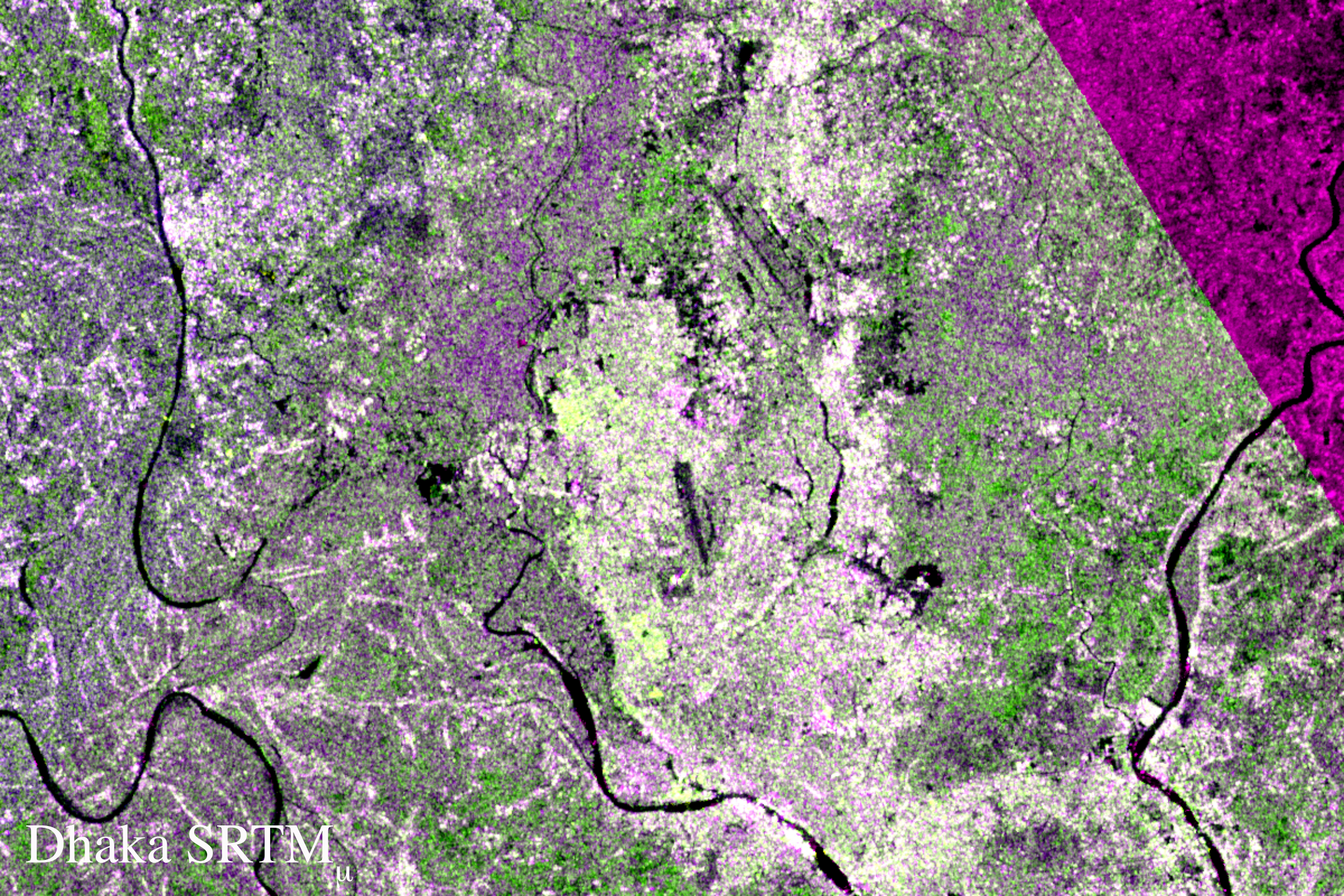
Beijing
S_σ V_σ D_σ

Beijing SRTM$_{\mu}$

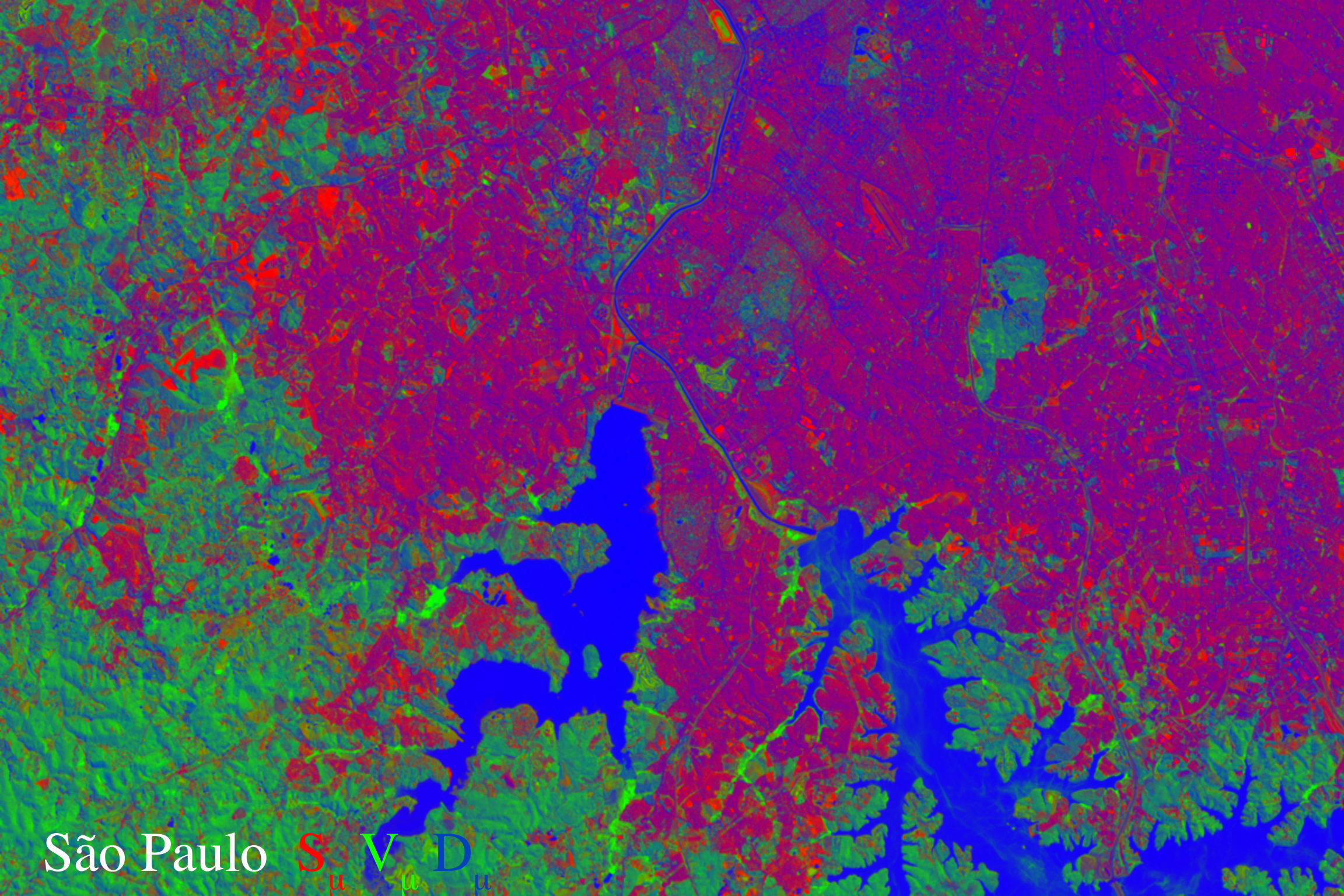
Beijing II

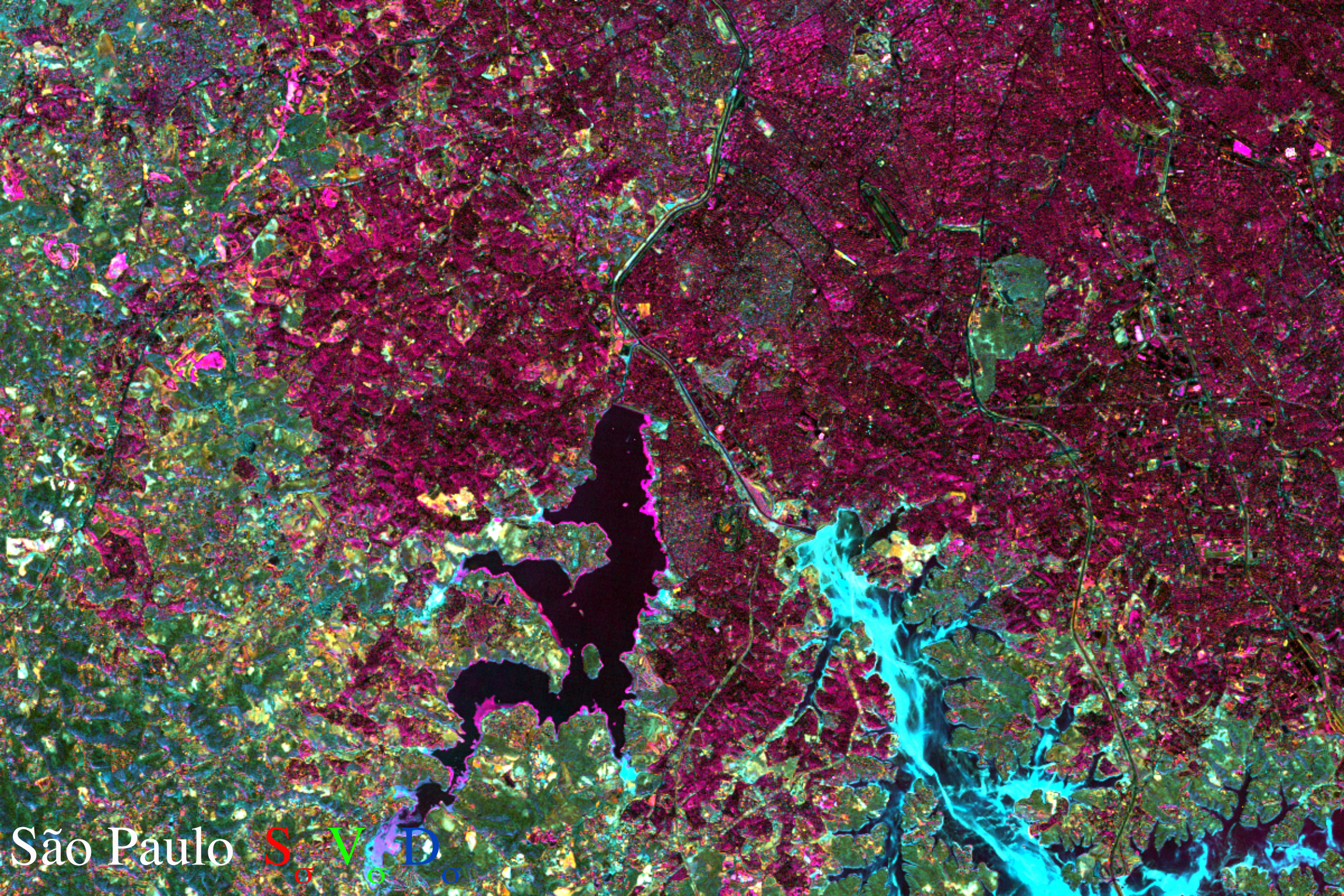
Dhaka S_μ V_μ D_μ

Dhaka $S_\sigma V_\sigma D_\sigma$


Dhaka SRTM

Dhaka II


São Paulo
S_u V_u D_u

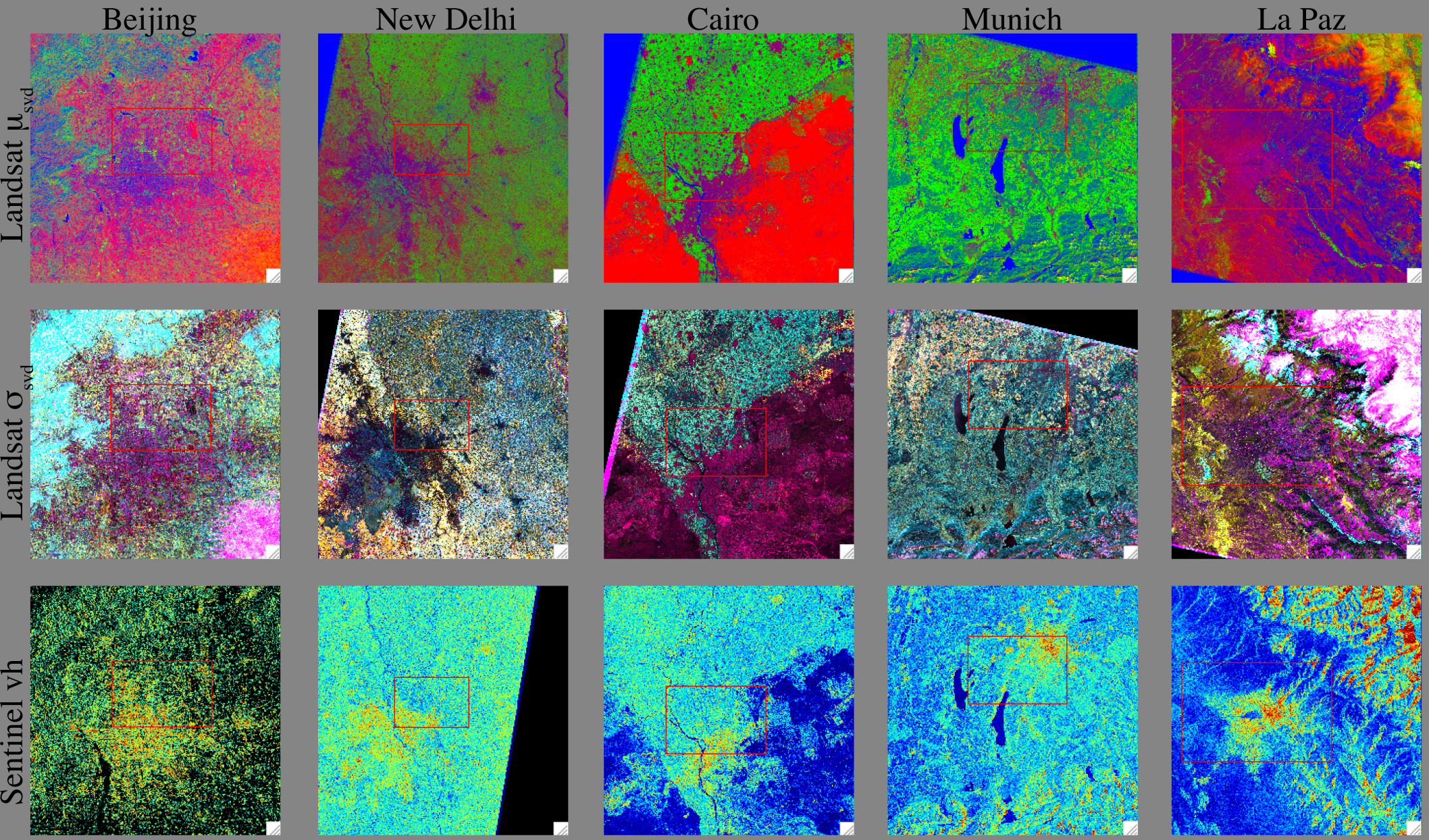

São Paulo
S
σ
V
σ
D
σ

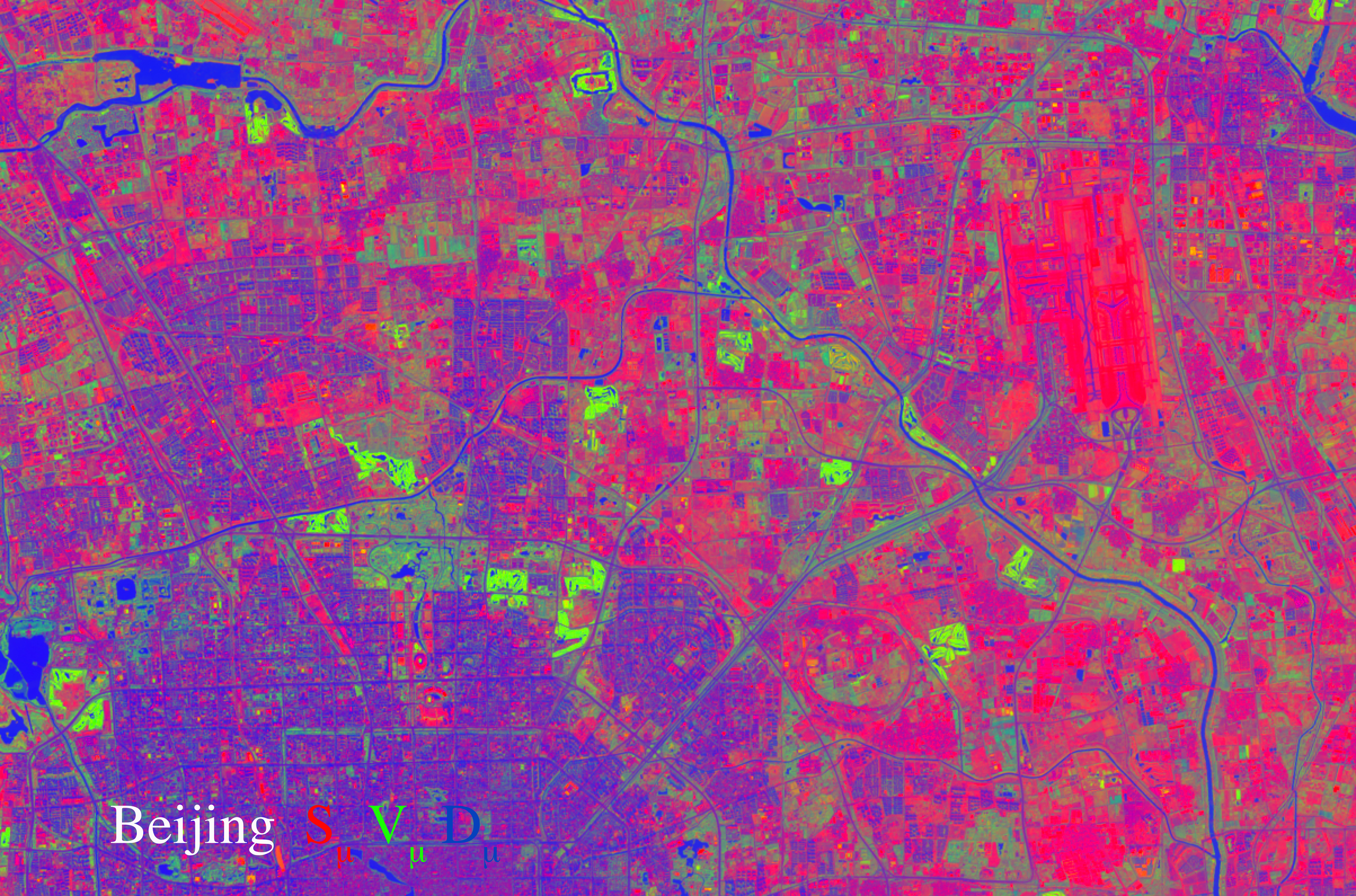
São Paulo SRTM

São Paulo II

2016 Landsat 8 + Sentinel 1a

Complications: Terrain Effects, Clouds, Arid Substrates, S1a geometry




Beijing
S
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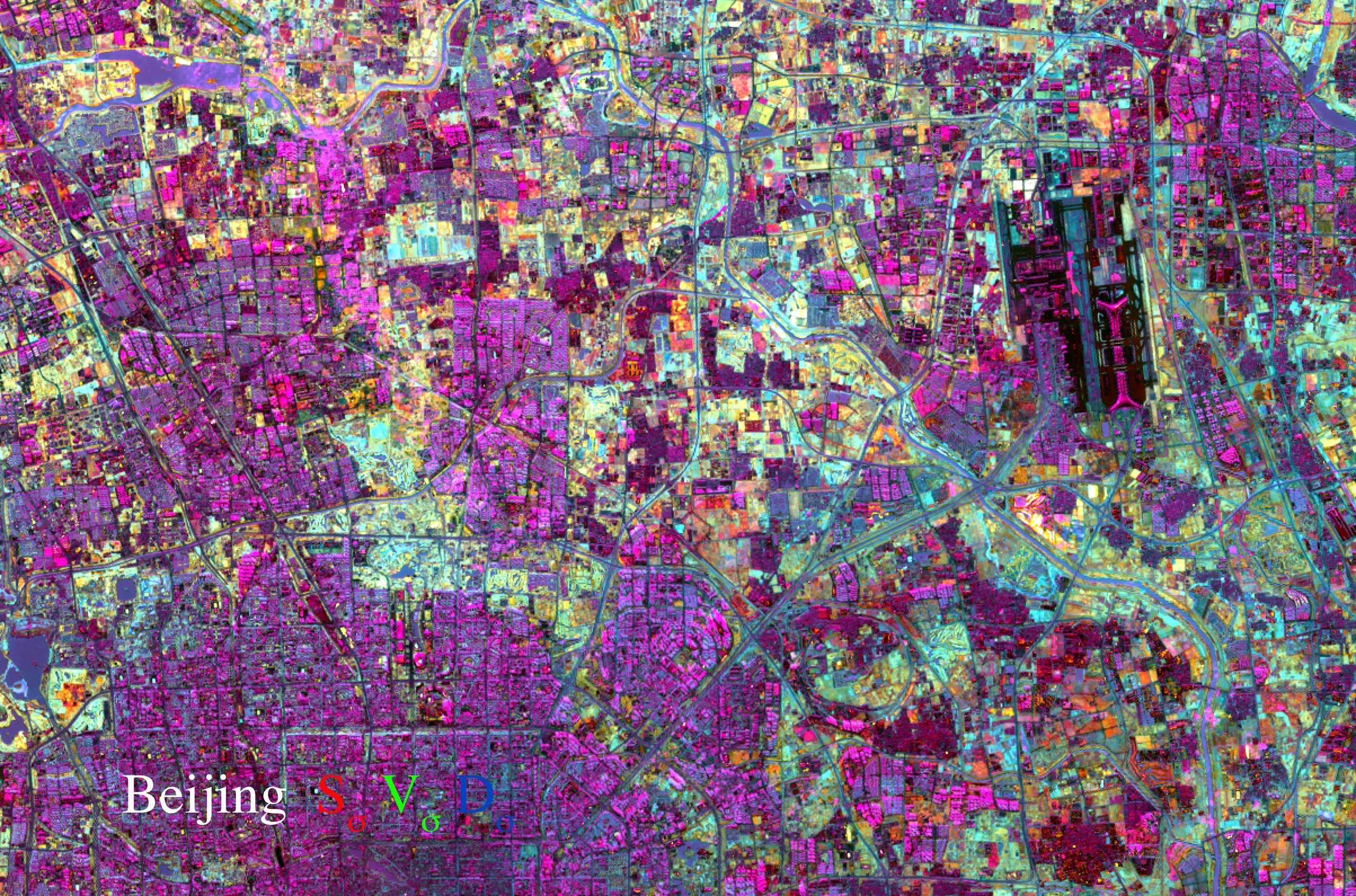
μ

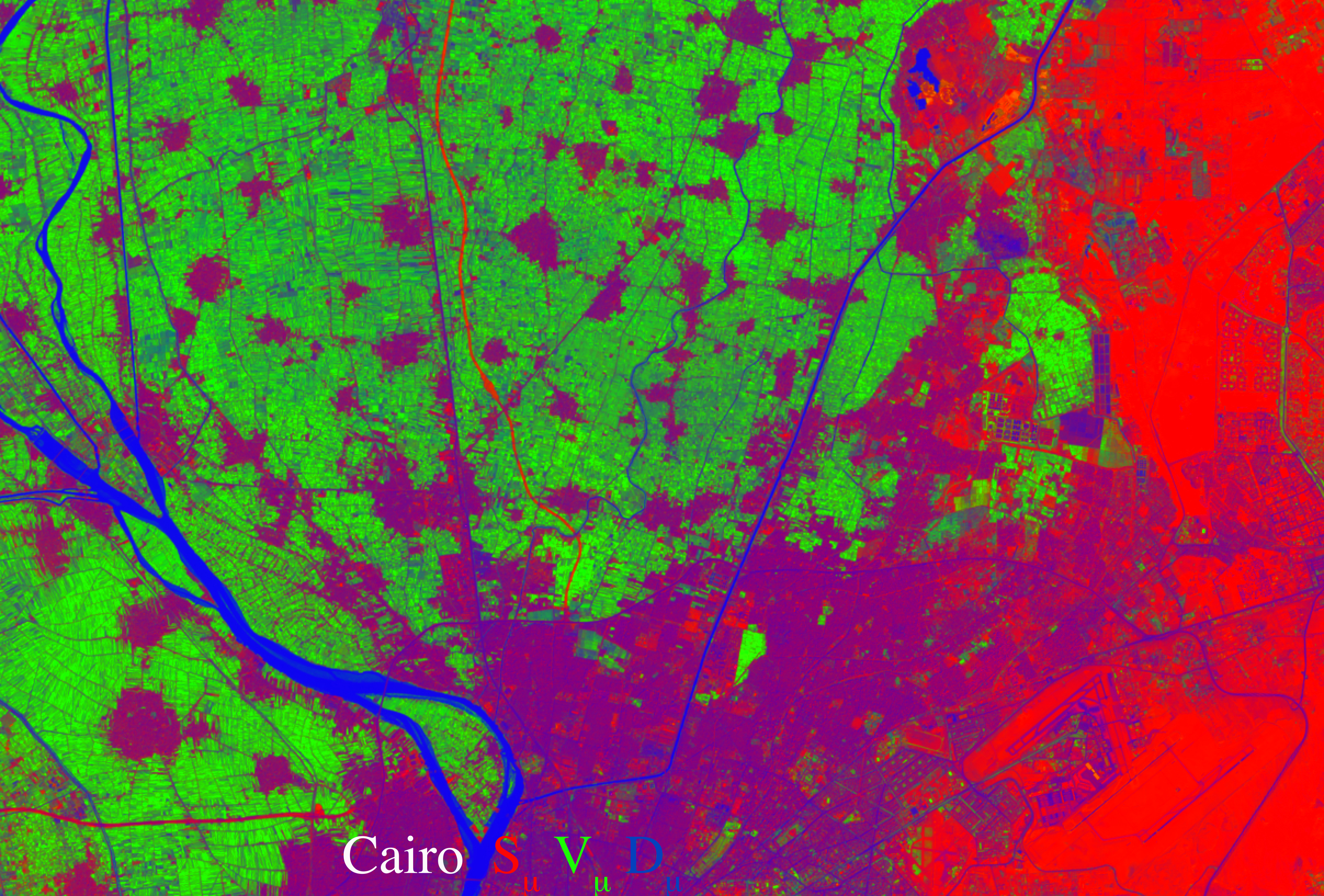

Beijing S_σ V_σ D_σ

Beijing S1a vh

New Delhi S_{μ} V_{μ} D_{μ}

New Delhi S_σ V_σ D_σ

New Delhi S1a vh


Cairo
S
μ
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μ
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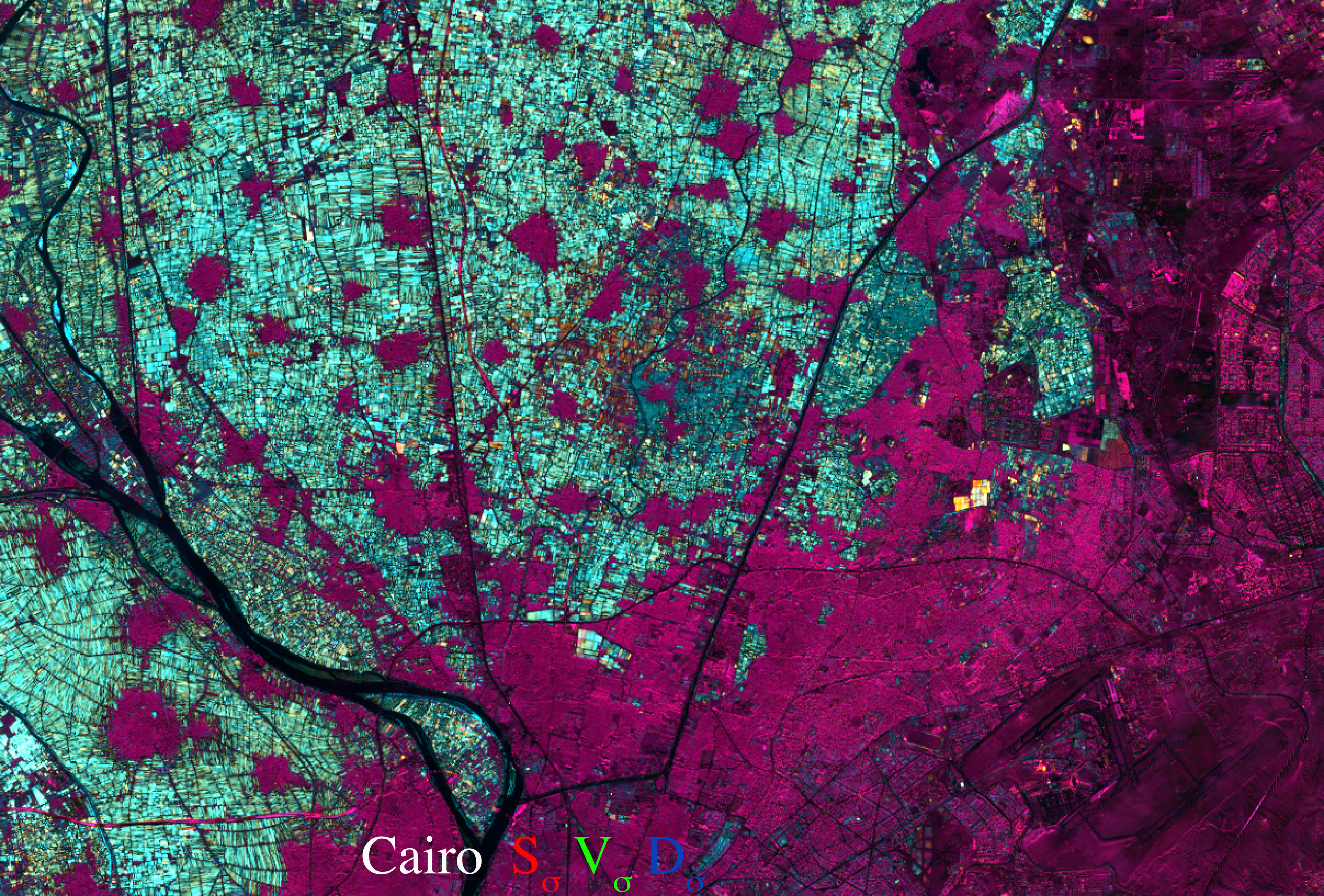
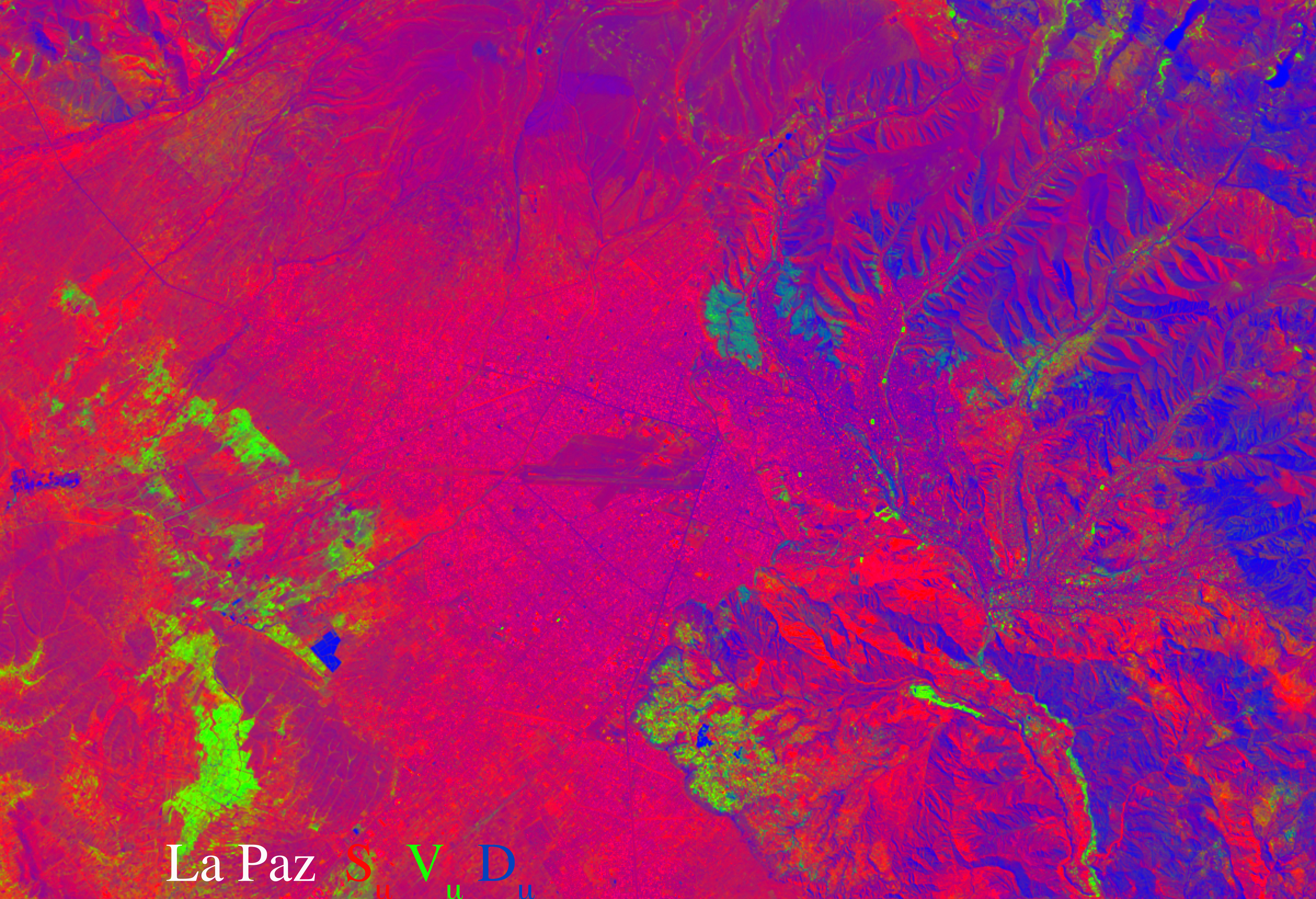

Cairo S_σ V_σ D_σ

Cairo S1a vh

Munich S_μ V_μ D_μ

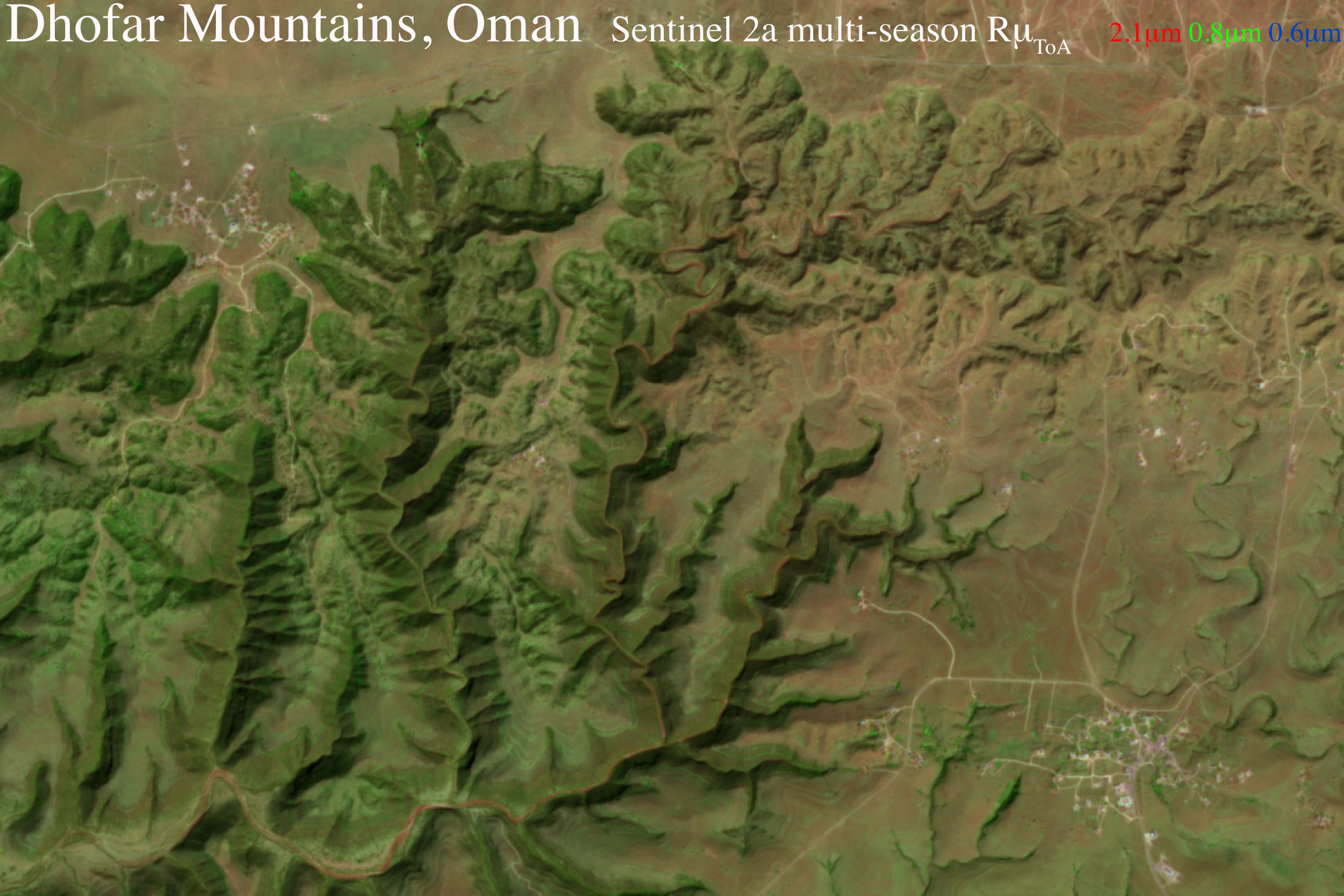
Munich S_{μ} V_{μ} D_{μ}

Munich S1a vh


La Paz
S_u V_u D_u

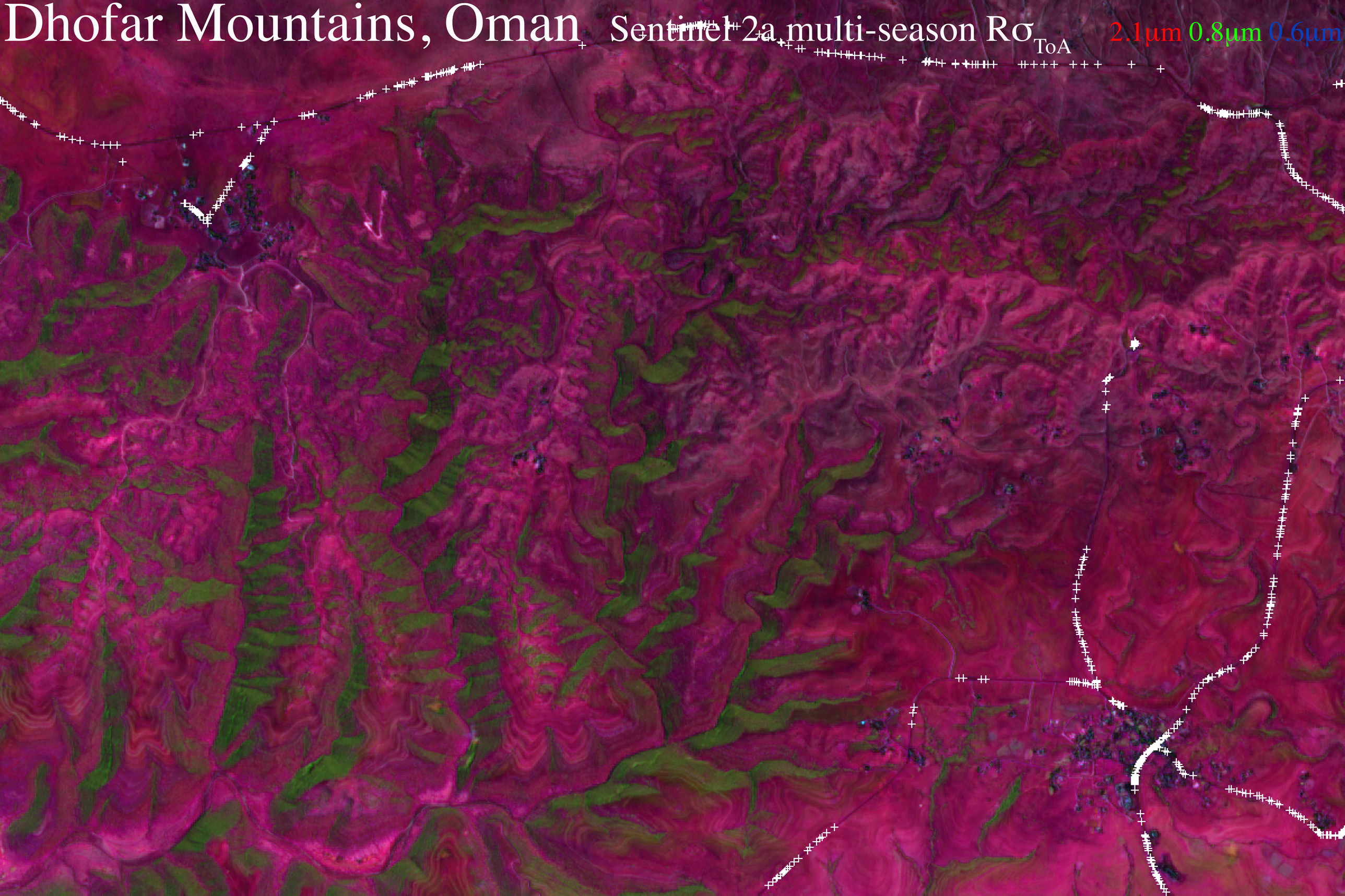
La Paz S_u V_u D_u

La Paz S1a vh


Dhofar Mountains, Oman
Sentinel 2a multi-season $R\mu_{ToA}$
2.1μm 0.8μm 0.6μm

Dhofar Mountains, Oman

Sentinel 2a multi-season $R\sigma_{ToA}$ 2.1μm 0.8μm 0.6μm



Dhofar Mountains, Oman

DLR Global Urban Footprint 2013

Remaining Challenges

Microwave

Sentinel 1 Resolution & View Geometry

Terrain Effects

Optical

Cloud Cover & Seasonality

Arid Environment Substrates

Next Steps

Multi-temporal Sentinel 1 - Seasonality & Speckle Noise Reduction

Landsat 8 + Sentinel 2 Cross Characterization - Resolution

Index Parameter Optimization - Global vs Local

Transect Validation - Bangladesh, Brazil, Germany, Oman, New Jersey