Assessment of ecosystem diversity and urban boundaries:

Preliminary findings, exploring surface reflectance and emissivity

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Background

Problem: With the increase in the population density, the effect of ever expanding conversion of land from rural to urban has become a problem of critical importance. *With increasing urbanization, land cover type and land surface temperature (LST) in urban and rural areas display significant differences, such as higher LST and lower moisture content.*

Hypotheses: The distribution, and spectral and spatial characteristics of optical and thermal data co-vary, in significantly different way in natural and anthropogenic environments; The combination of high spectral resolution optical and thermal infrared imagery will provide a powerful capability for more precise land cover type discrimination and ecosystem monitoring than possible using current satellite systems.

Science Questions

- How do natural environmental characteristics change under the effects of urbanization, affecting vegetation composition and function, and ecosystem health?

- How do natural vs. anthropogenic ecosystem compositions compare (similar environmental conditions) with regard to land cover types, diversity, function, and spectral properties?

- How do natural ecosystems respond to impinging environmental changes, particularly to urban growth and land cover change and the associated impacts of urbanization?

Goals

1. Using together VSWIR and TIR measurements, to assess the differences in natural and anthropogenic ecosystem composition and their vegetation bio-physical parameters.

2. Provide data that can elucidate how urbanization impacts the environment. Seeking common spectral trends associated with vegetation function, induced by natural and anthropogenic factors such as effects of urbanization and UHI, we would contribute toward improving the current capabilities for vegetation assessments.

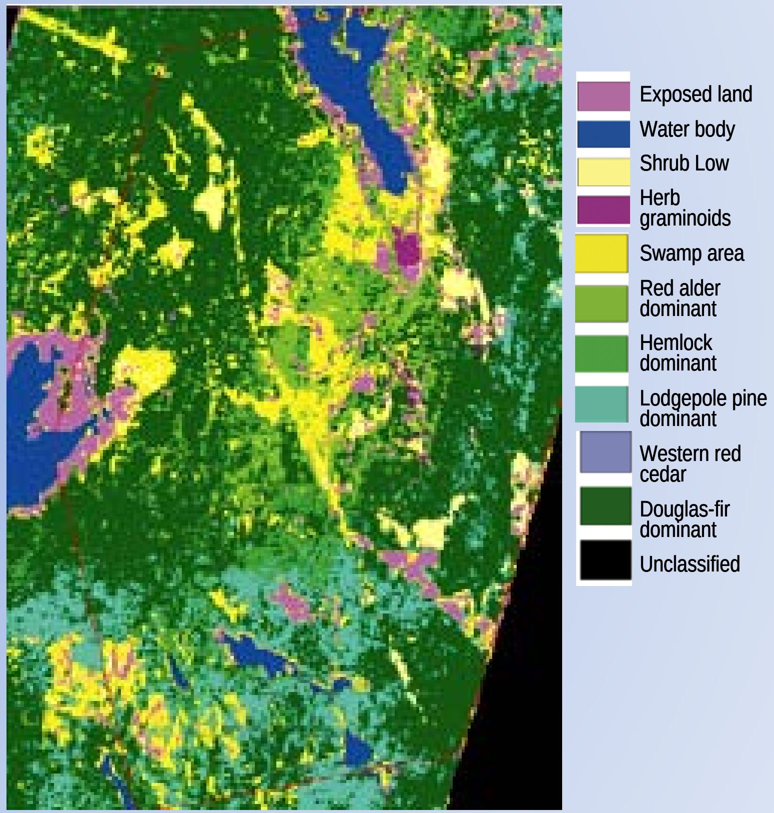
3. Generate HyspIRI-like datasets and tools for work with the data.

Study Sites

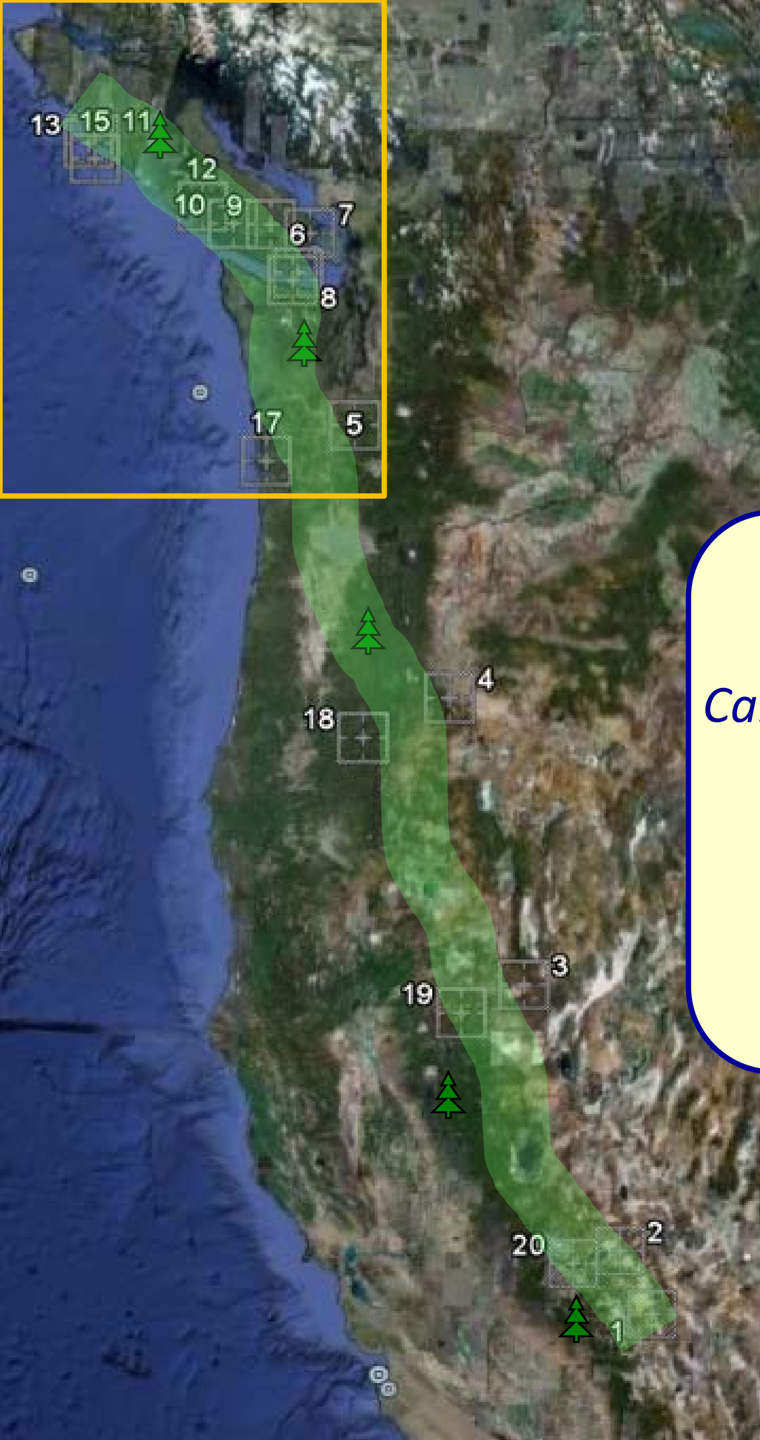
The study includes two independent locations with different regional climate and ecosystem types. Data aggregated to higher and lower spatial scales will be compared for the same locations.

Vancouver Island, Canada/Hoquiam, WA: includes portions of unique natural ecosystems such as the Great Victoria Watershed (GVWD) test site on Vancouver Island, BC and rural, sub-urban and urban environment associated with the city of Victoria, BC.

Jasper Ridge Biological Preserve (JRBP), CA: provides Mediterranean-type climate, with five major vegetation types: evergreen forest, deciduous forest, chaparral shrublands, herbaceous perennial wetlands, and annual grasslands



Hyperion land cover classification of the Greater Victoria Watershed (GVWD) test site on Vancouver Island (September 10 2001, Goodenough et al. 2003).



Area 1:
Vancouver Island
Canada/Hoquiam, WA

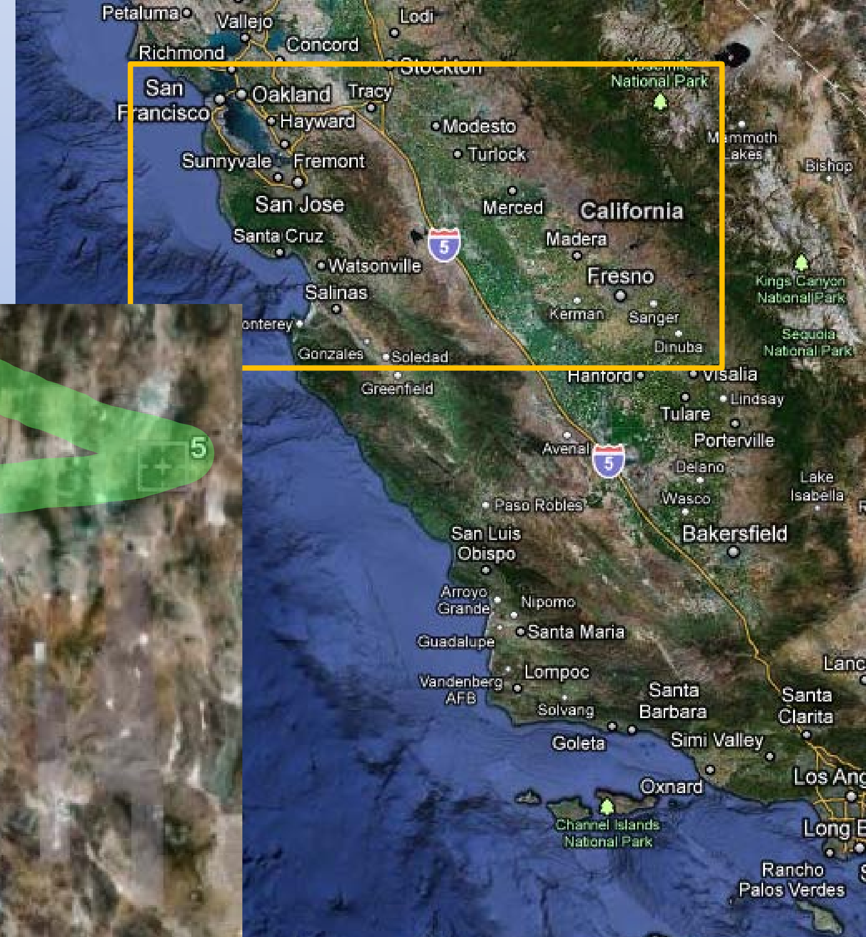
Data:

MASTER & AVIRIS

ASTER

EO-1 Hyperion

Area 2:
Jasper Ridge Biological Preserve (JRBP), CA



Data:
MASTER & AVIRIS
Hyperion

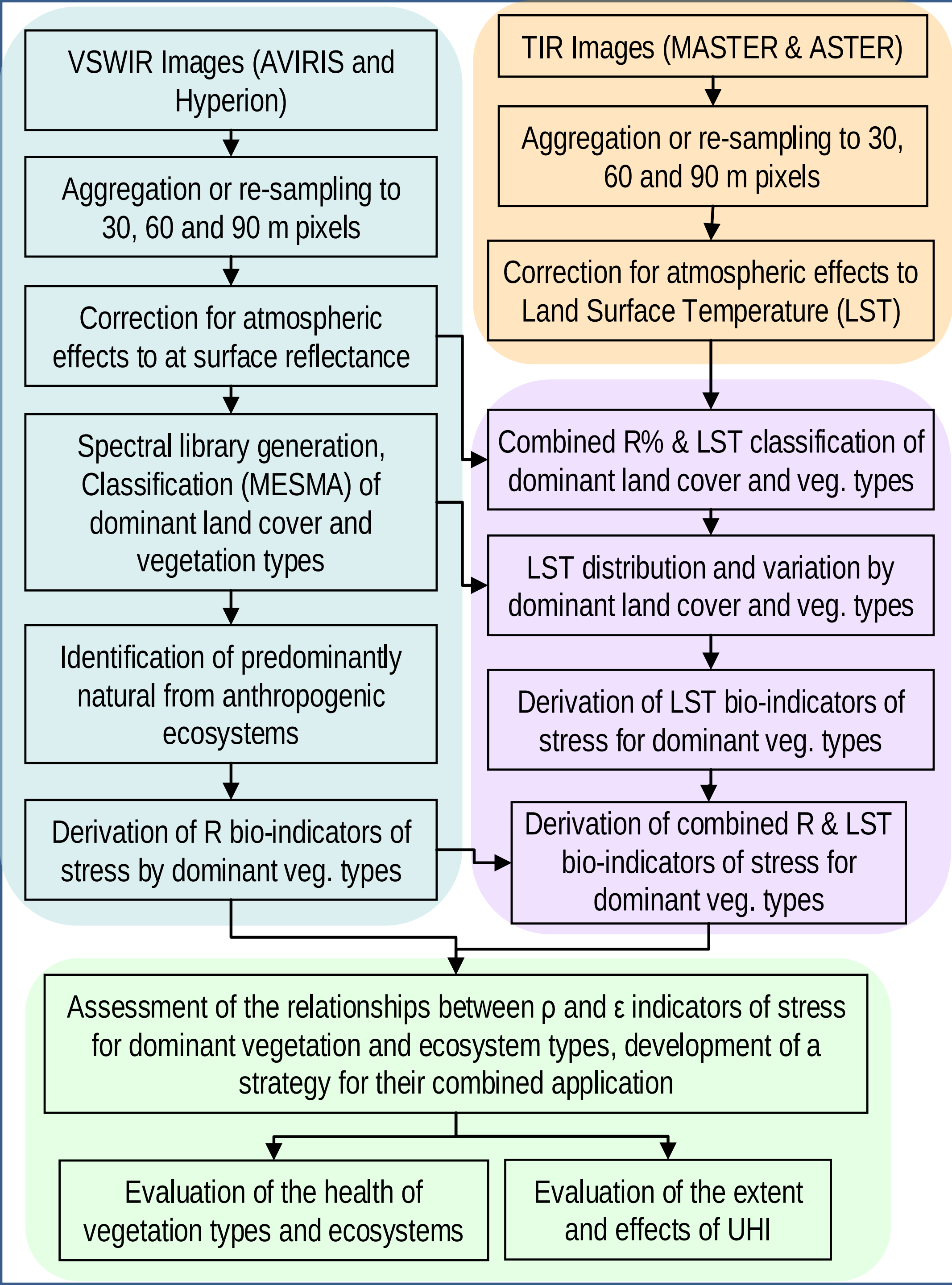
Calibration of TIR and VISWIR data

Lake Tahoe is a high-altitude, large-sized lake on the California-Nevada border near Reno, Nevada.

The *Ivanpah Playa* test site is approximately 3 km by 7 km in size with excellent spatial uniformity, hence its use for the vicarious calibration of reflective bands.

Sample MASTER imagery from the Ivanpah test site, reflectance (left), vegetation in green; thermal (right) side.

Capability of HyspIRI data for assessments of vegetation type and function



The analysis will be conducted using the native data resolution (~ 30 m), and aggregated to 60 and 90 m images, comparing the results.

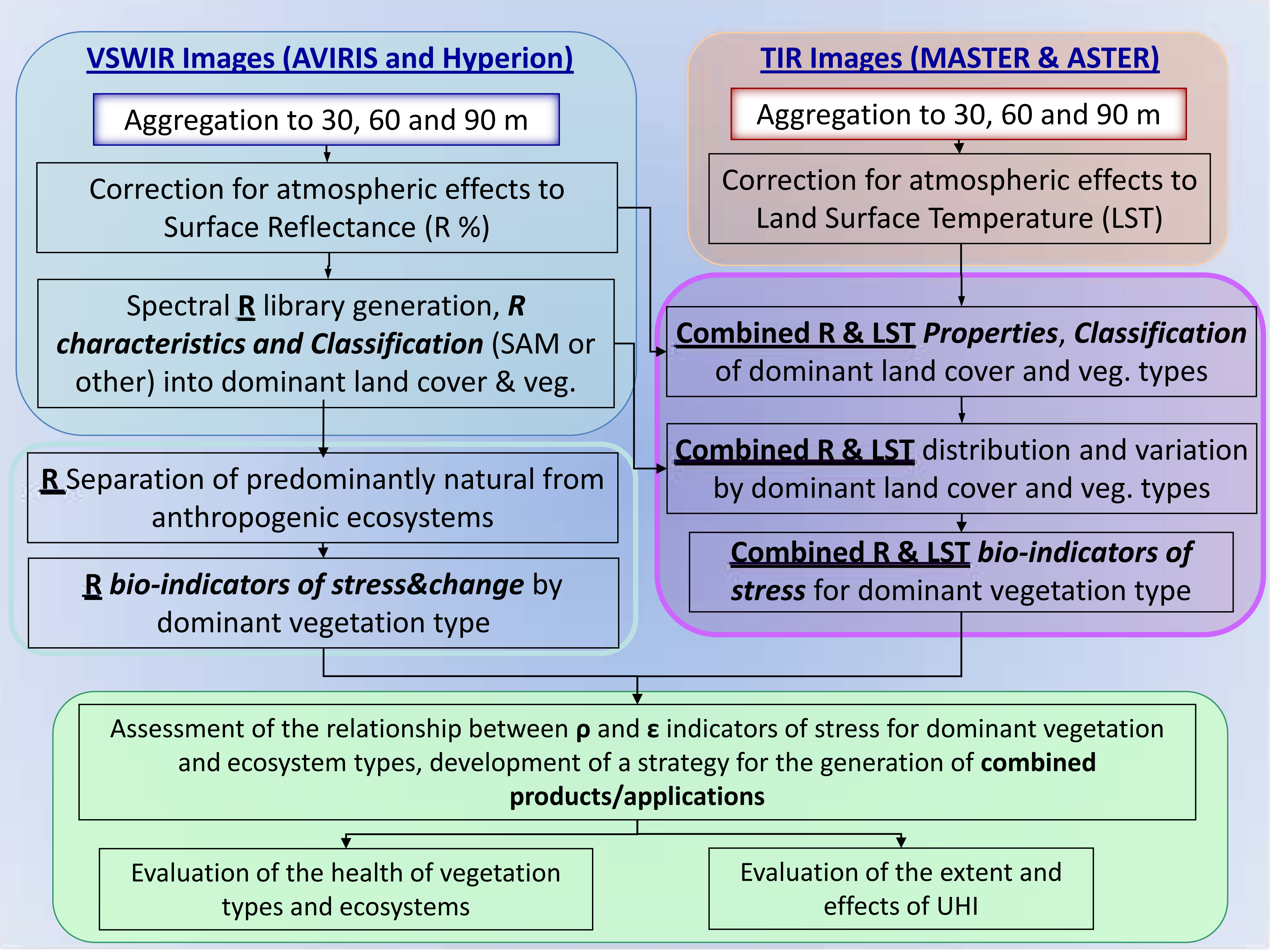
Data

Parameters	HyspIRI VSWIR	AVIRIS	EO-1 Hyperion
Spectral range	*0.38 - 2.5 µm*	0.4 - 2.5 µm	0.4 - 2.5 µm
Band width	*10 nm*	10 nm	10 nm
number of bands	*~ 220*	224	220 (196 calibrated)
Spectral Coverage	*contiguous*	contiguous	contiguous
Spatial resolution	*60 m*	20 m	30 m
Swath width	*145 km*	11 km	7 km

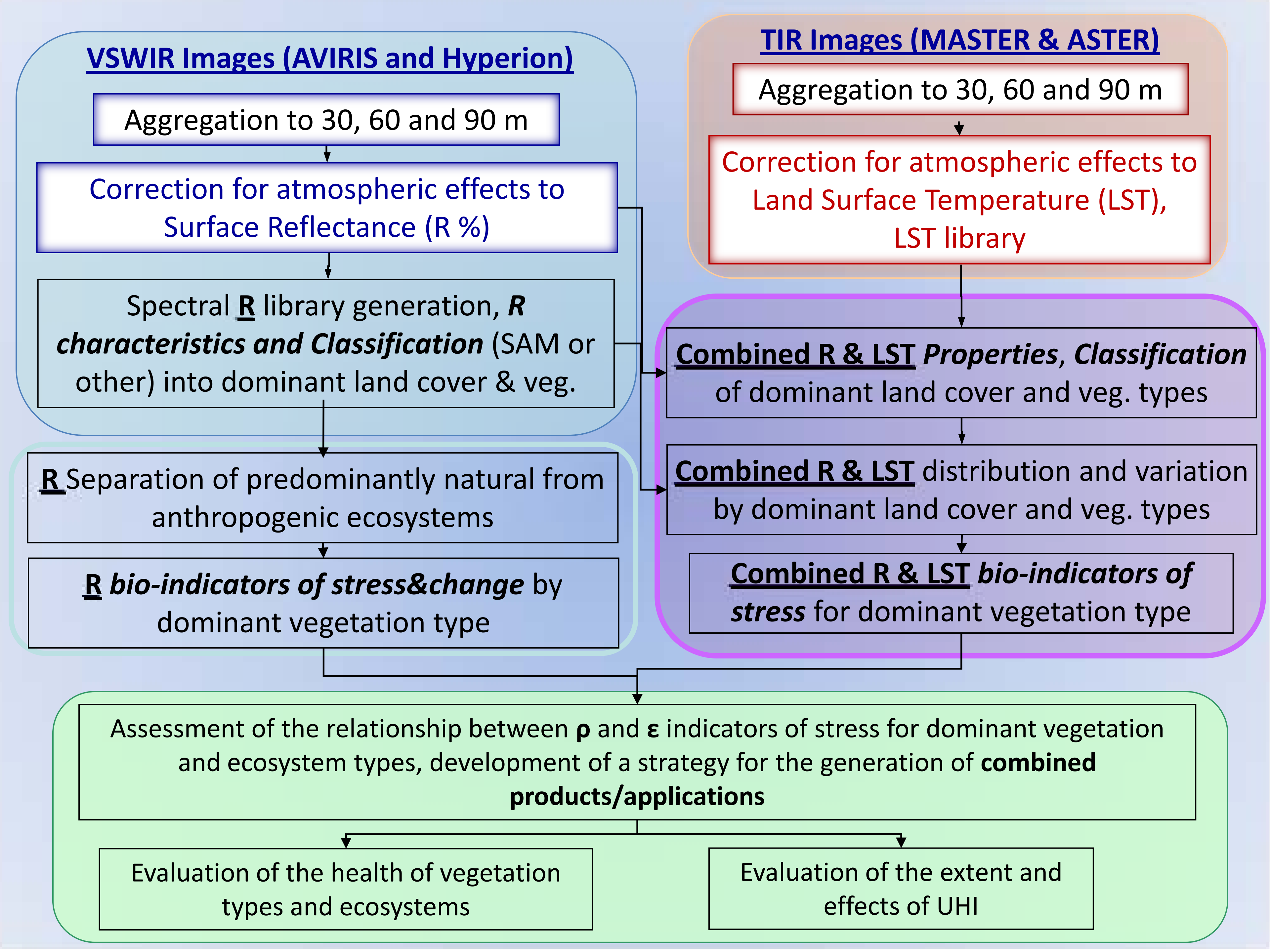
Thermal infrared emission instruments and data characteristics (summary/overview)

HyspIRI TIR	Number of bands	Spectral bands (discrete)	Spatial resolution
TIR channel centers	*8*	*3.98, 7.35, 8.28, 8.63, 9.07, 10.53, 11.33, 12.05 µm*	*60 m*
Swath width	*600 km*		

MASTER	Number of bands	Spectral bands (discrete)	Spatial resolution
Spectral range 0.4 - 13 µm	50		5-25 m (B200) 10-30 m (DC-8) 50 m (ER-2)
0.45-2.39 µm	25	0.05 µm a part	
3.15-5.27 µm	15	0.15 µm a part	
7.75-12.87 µm	10	0.40-0.80 µm a part	
Total field of view	85.92º		



VSWIR Images (AVIRIS and Hyperion)
Aggregation to 30, 60 and 90 m
Correction for atmospheric effects to Surface Reflectance (R %)
Spectral R library generation, R characteristics and Classification (SAM or other) into dominant land cover & veg.
R Separation of predominantly natural from anthropogenic ecosystems
R bio-indicators of stress&change by dominant vegetation type
TIR Images (MASTER & ASTER)
Aggregation to 30, 60 and 90 m
Correction for atmospheric effects to Land Surface Temperature (LST)
Combined R & LST Properties, Classification of dominant land cover and veg. types
Combined R & LST distribution and variation by dominant land cover and veg. types
Combined R & LST bio-indicators of stress for dominant vegetation type
Assessment of the relationship between ρ and ε indicators of stress for dominant vegetation and ecosystem types, development of a strategy for the generation of combined products/applications
Evaluation of the health of vegetation types and ecosystems
Evaluation of the extent and effects of UHI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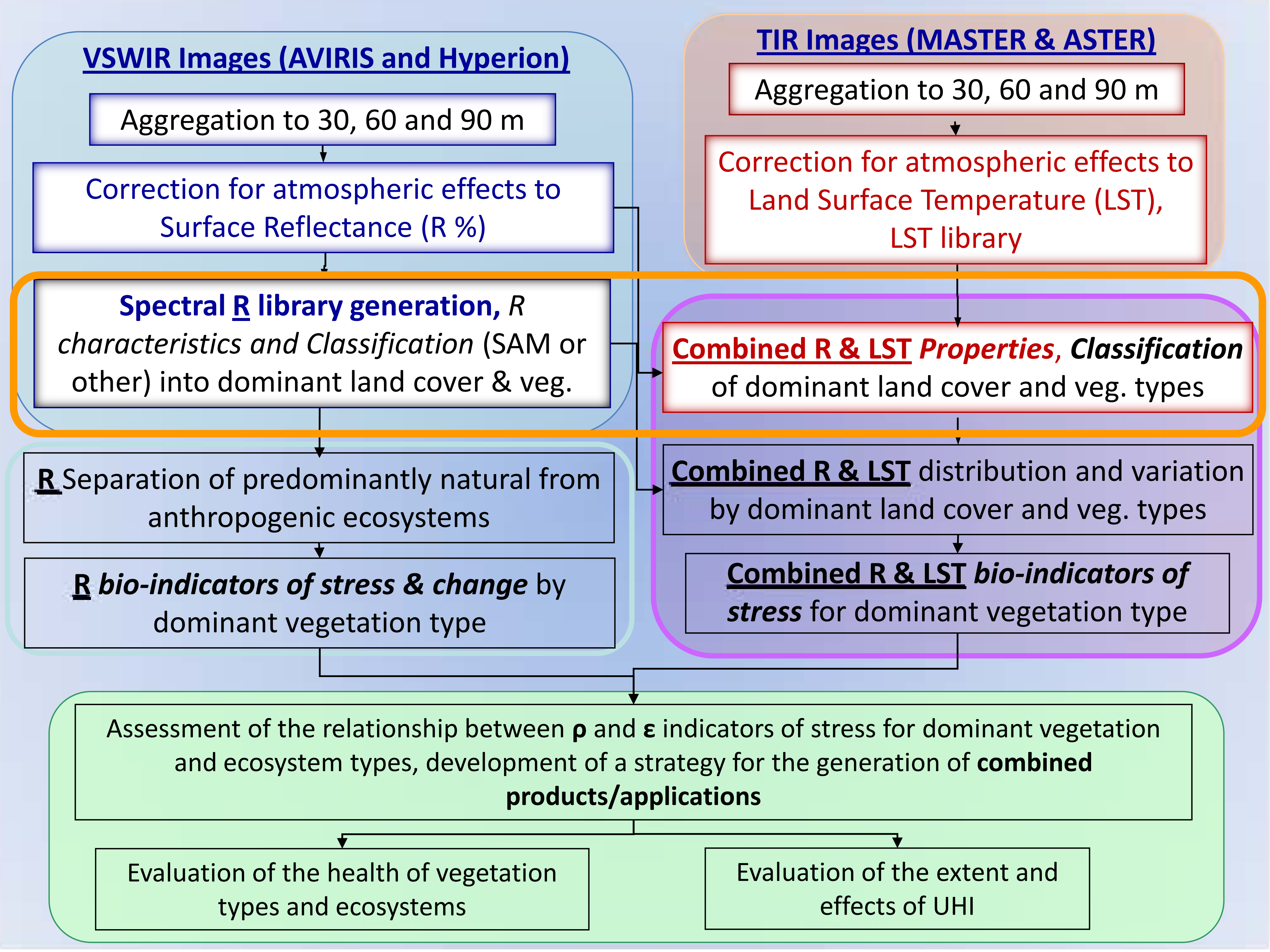
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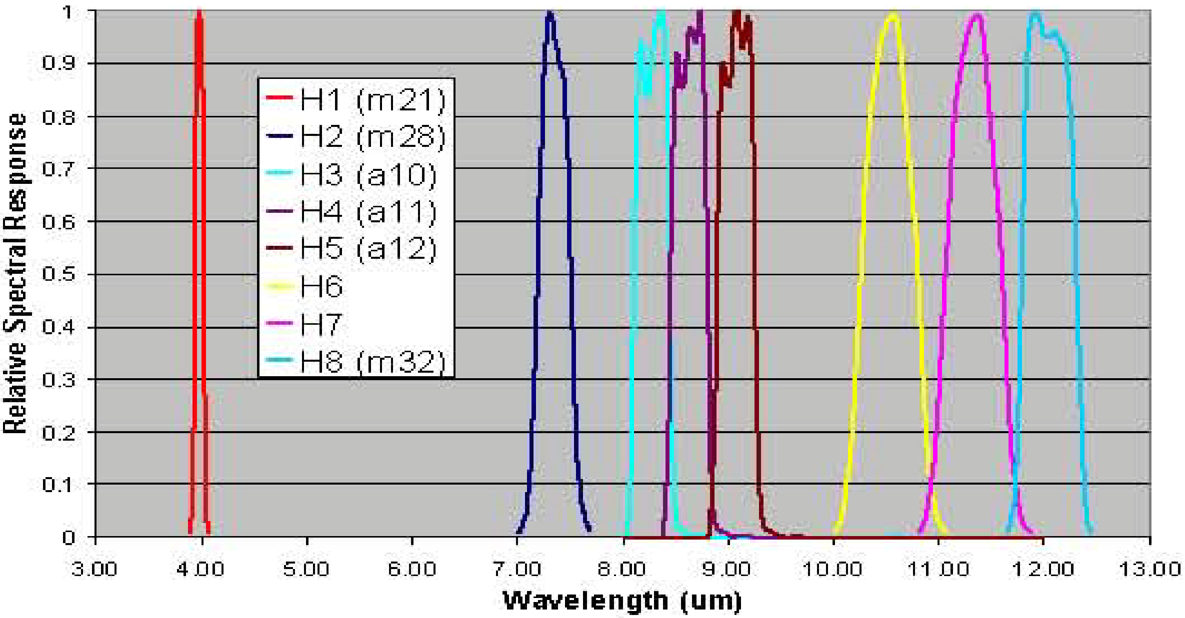
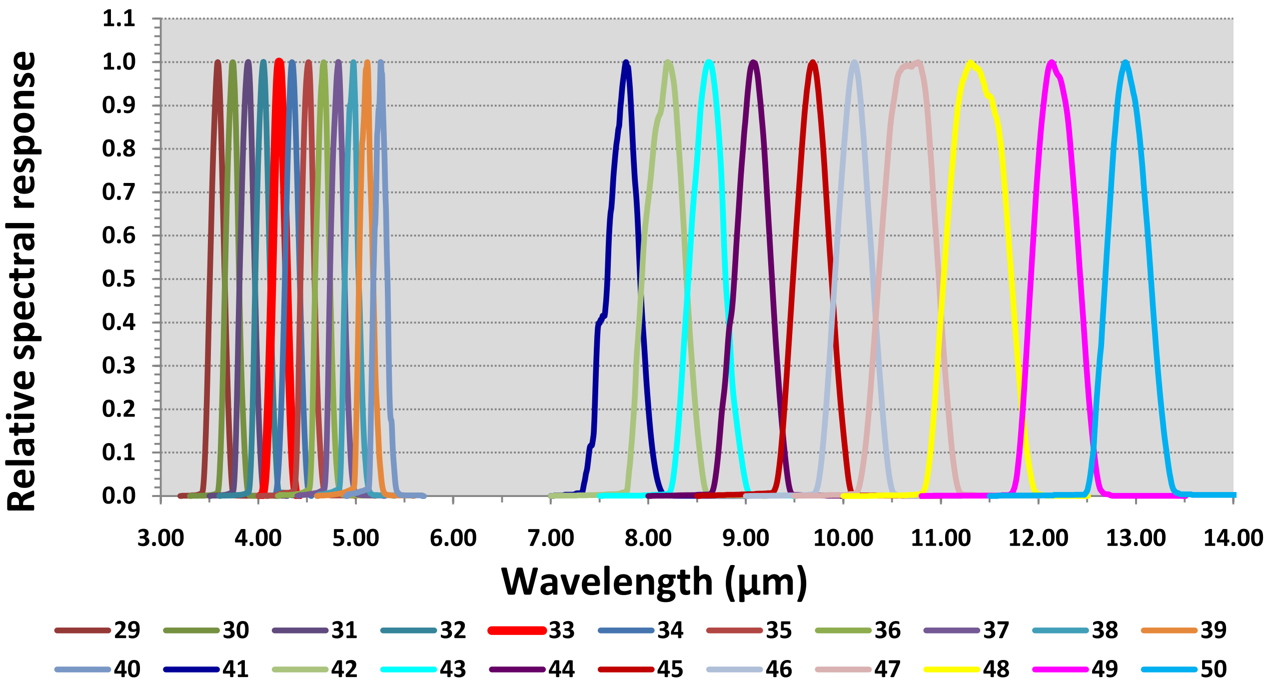
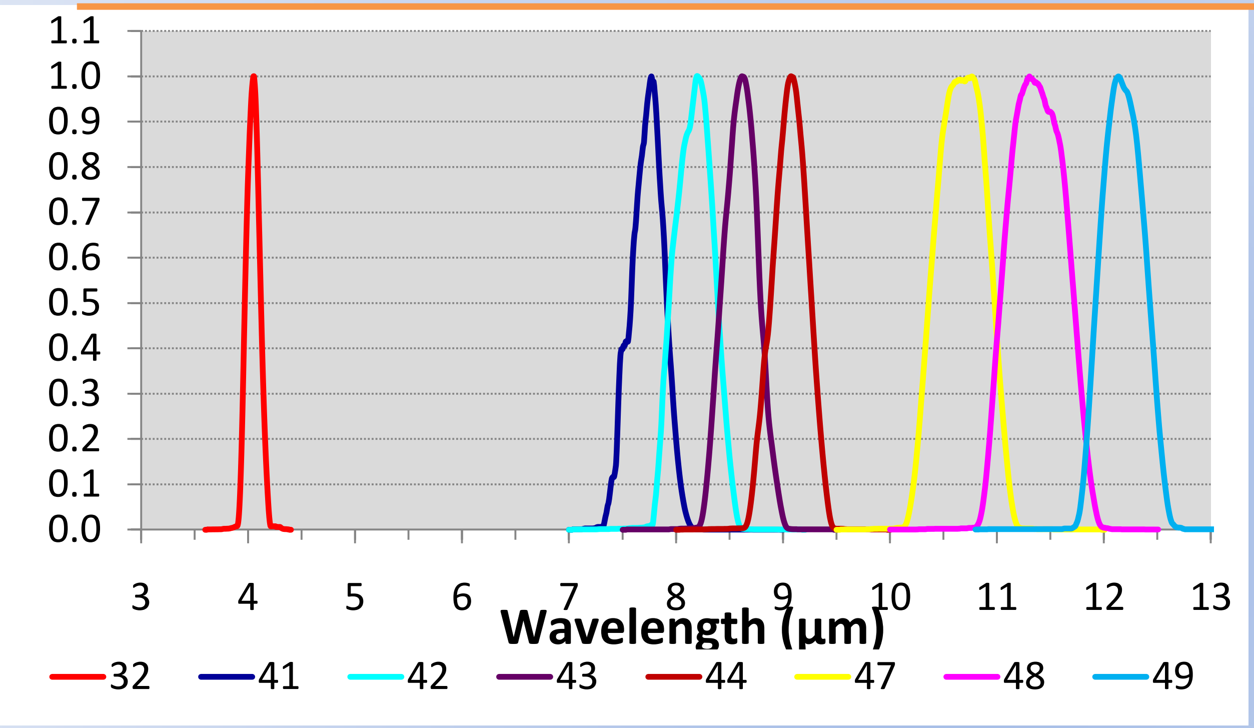
HyspIRI Thermal Bands

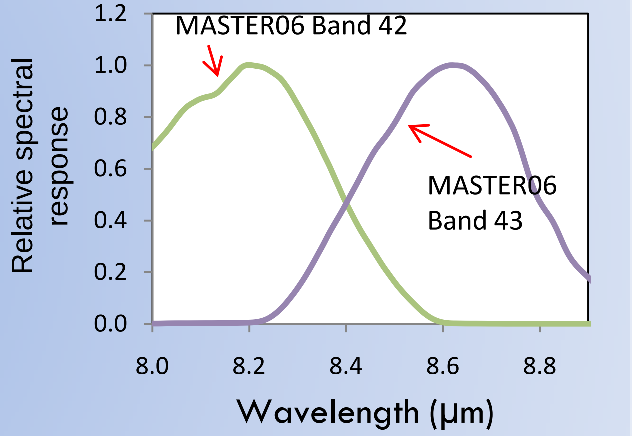


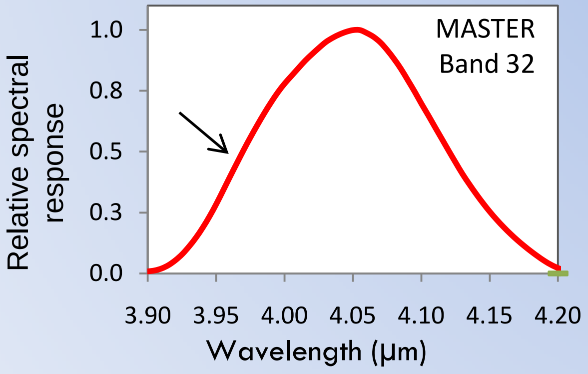
MASTER Thermal Bands

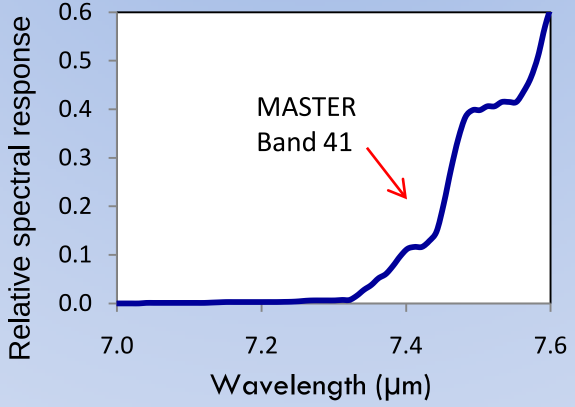


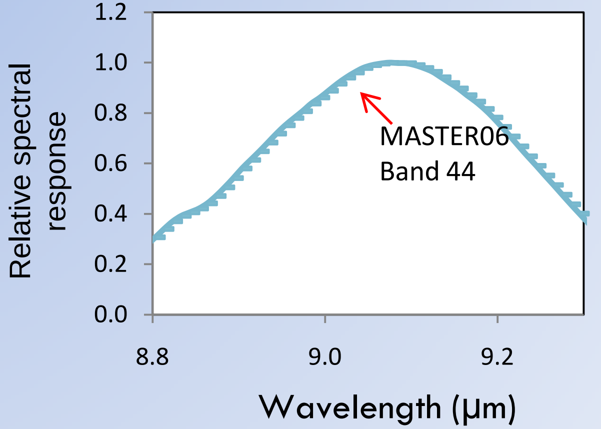
MASTER Thermal Bands Relative to HyspIRI











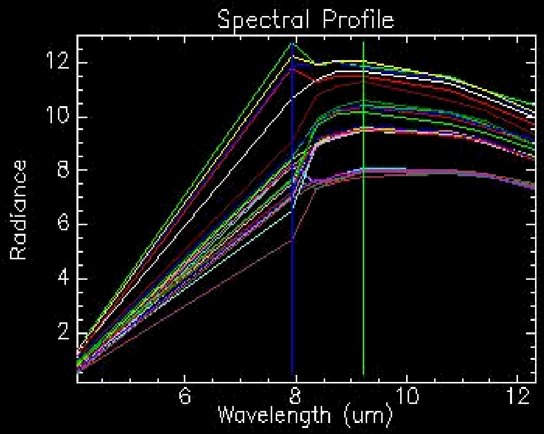
Spatial Aggregation of HyspIRI-like Thermal Bands

Original image pixel size varies (49.1 m, bands 32, 41, 42, 43, 44, 47, 48 and 49)

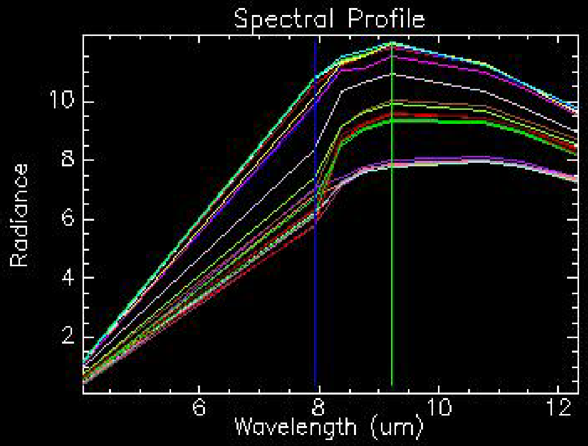
Aggregation to 60 m (MASTER, band 44)

Aggregation to 90 m (MASTER, band 44)

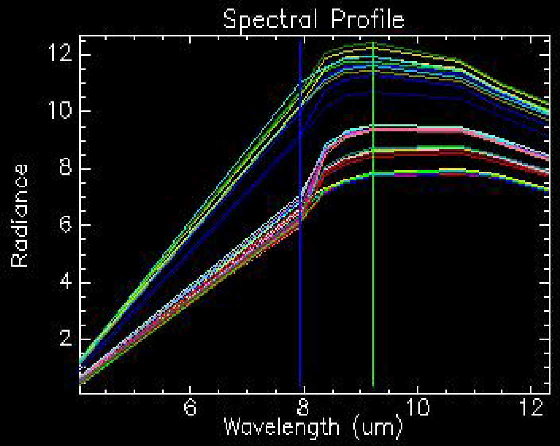
Atmospheric Correction of Thermal Data



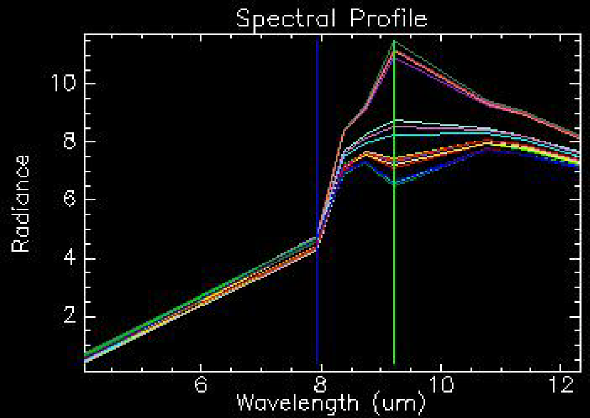
Max hit-normalized regression, 49.1 m resolution



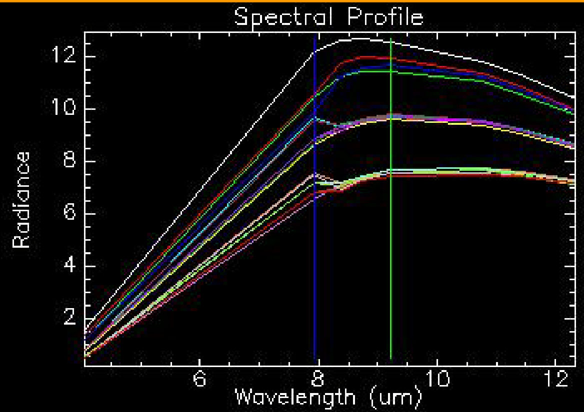
Max hit-top of bins, 60 m resolution



All-top of bins, 90 m aggregated image



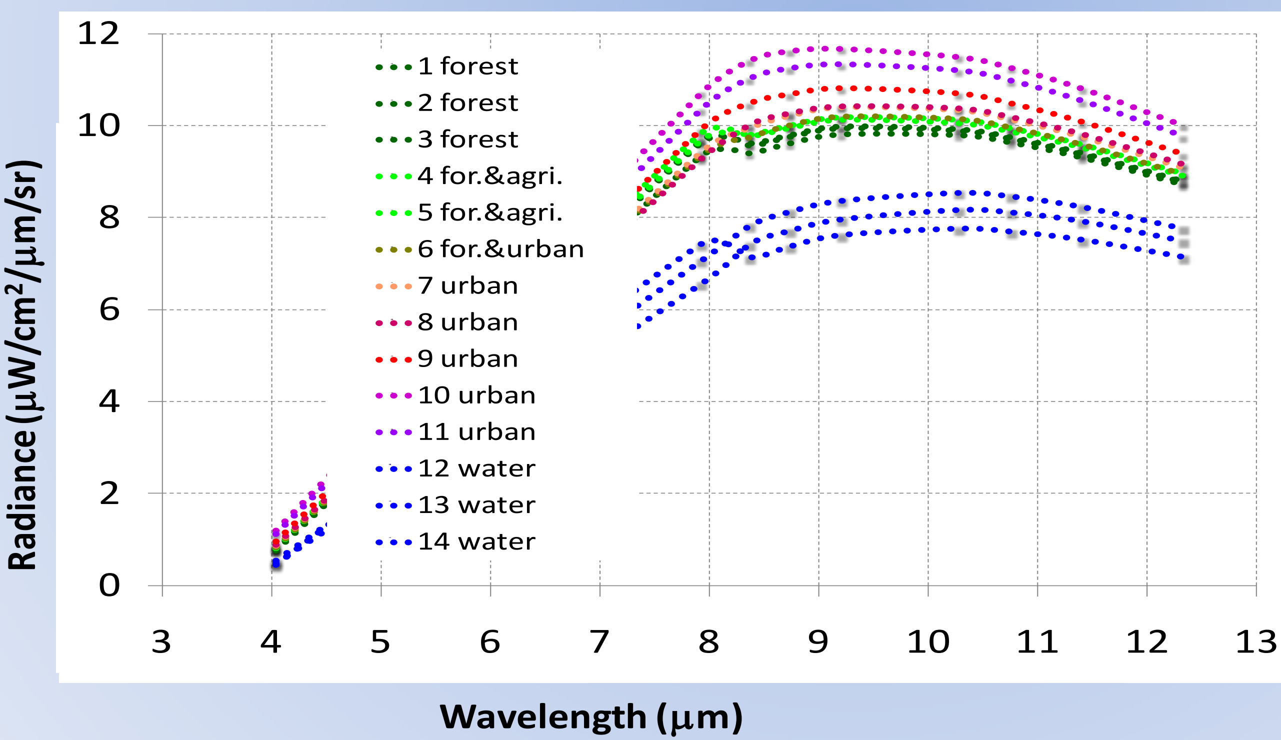
<u>Ineffective</u> atmospheric correction – images lacking contrasting cover types (e.g. large barren, or ocean cover, 60m)



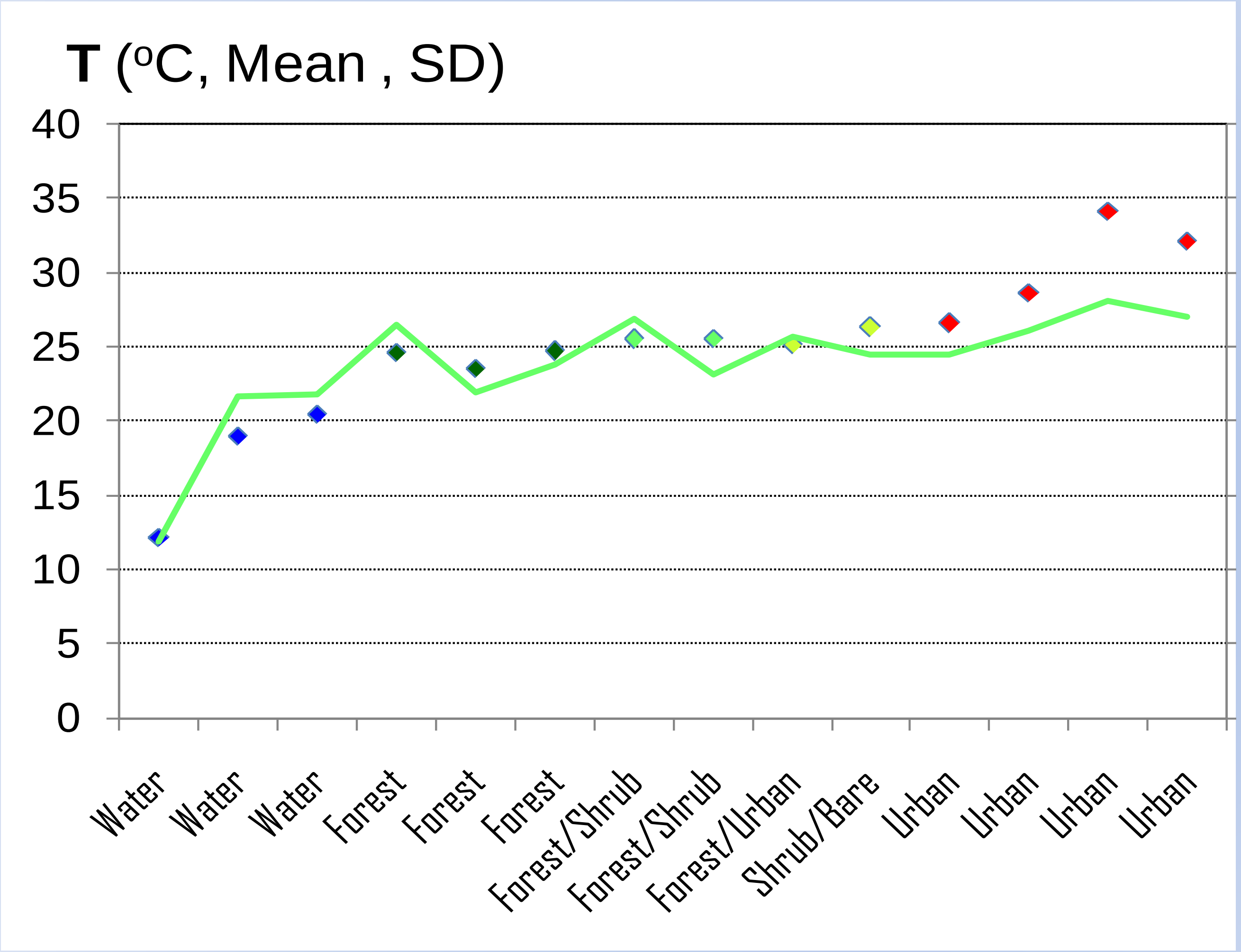
<u>Effective</u> atmospheric correction (60 m resolution, max hit-normalized regression)

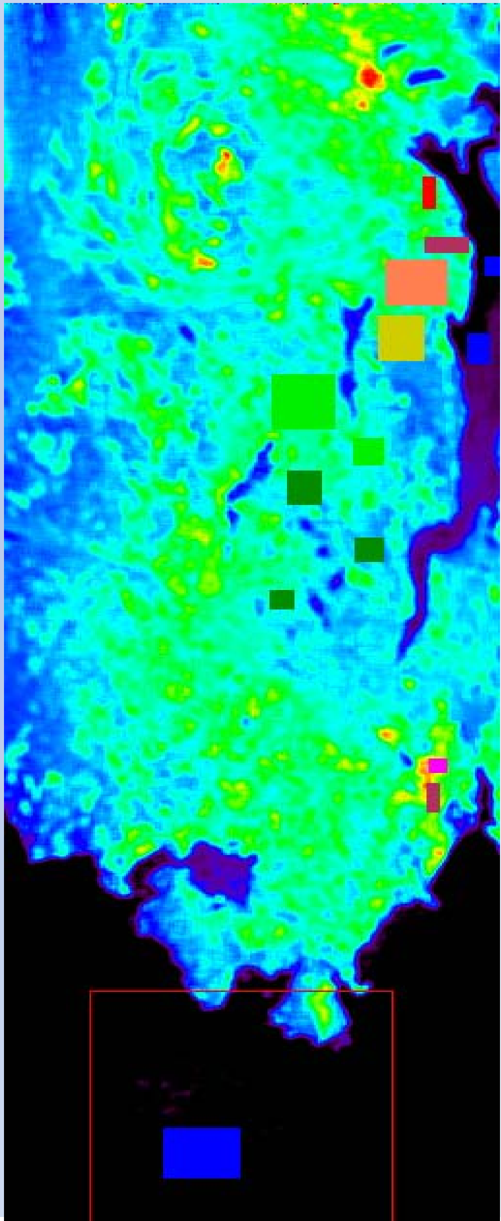
Thermal Radiance of Rural Urban and Environments

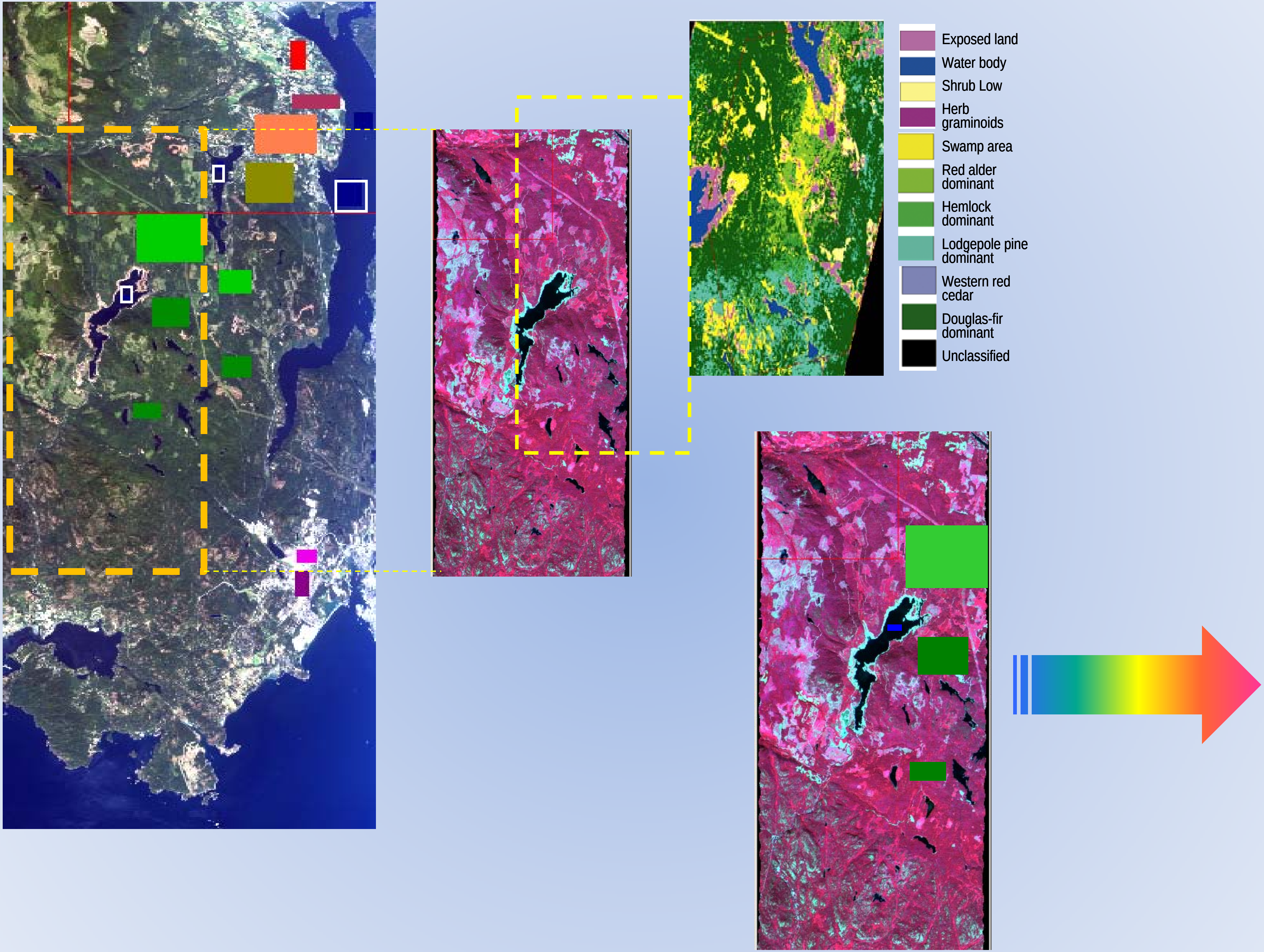
- Assess the Variations in Thermal Radiance for ecosystems ranging from natural to urban
- Convert Radiance to Emissivity and Temperature to quantify the temperature and emissivity differences in ecosystems

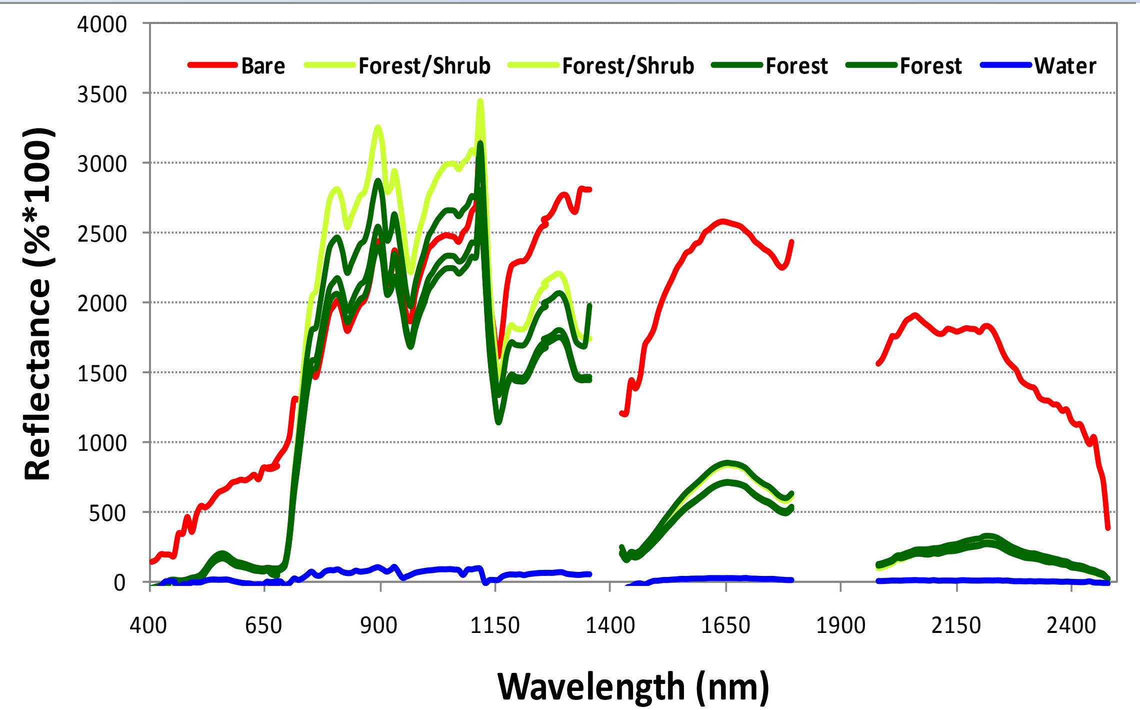


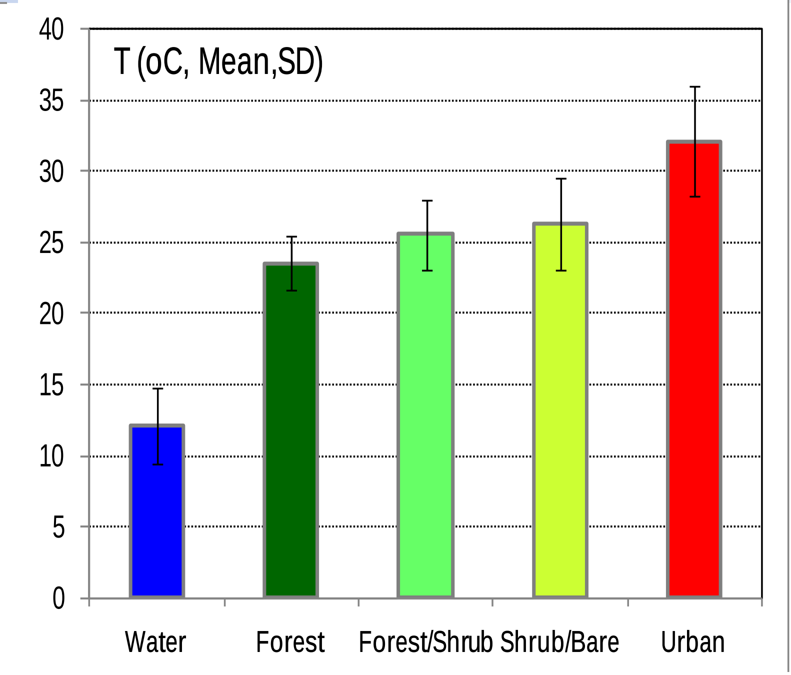
Temperature Gradient of Rural Urban and Environments

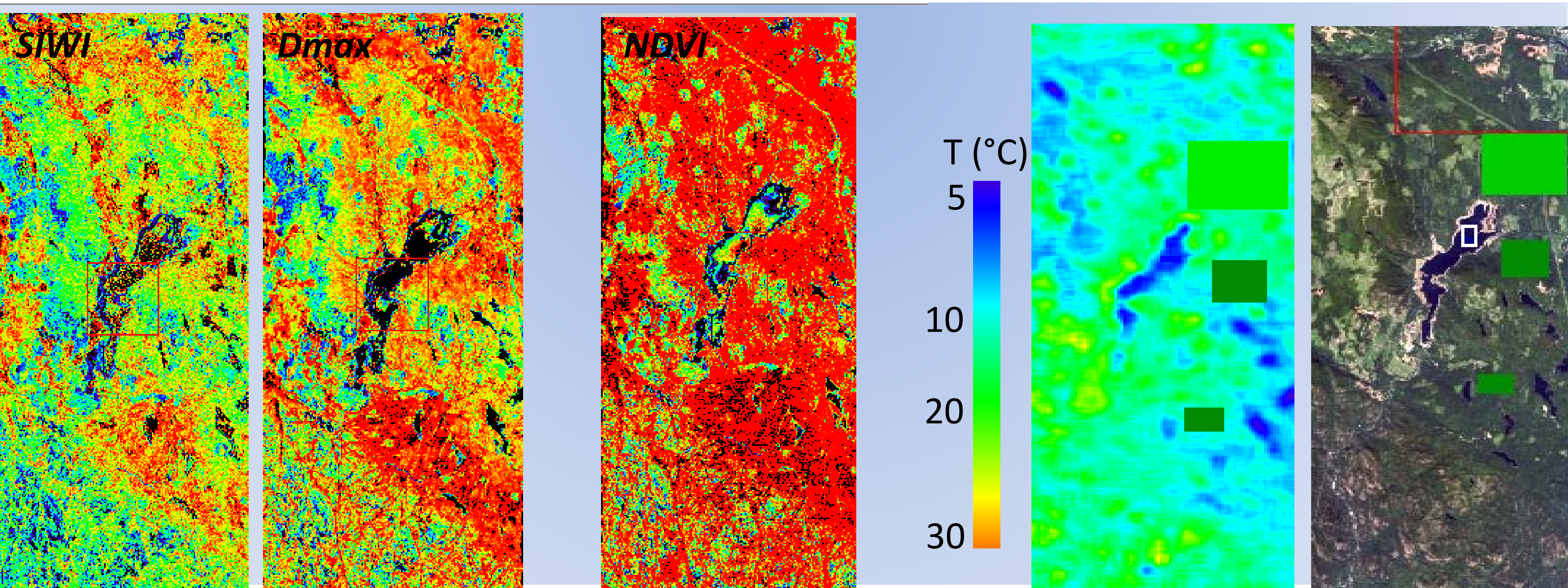


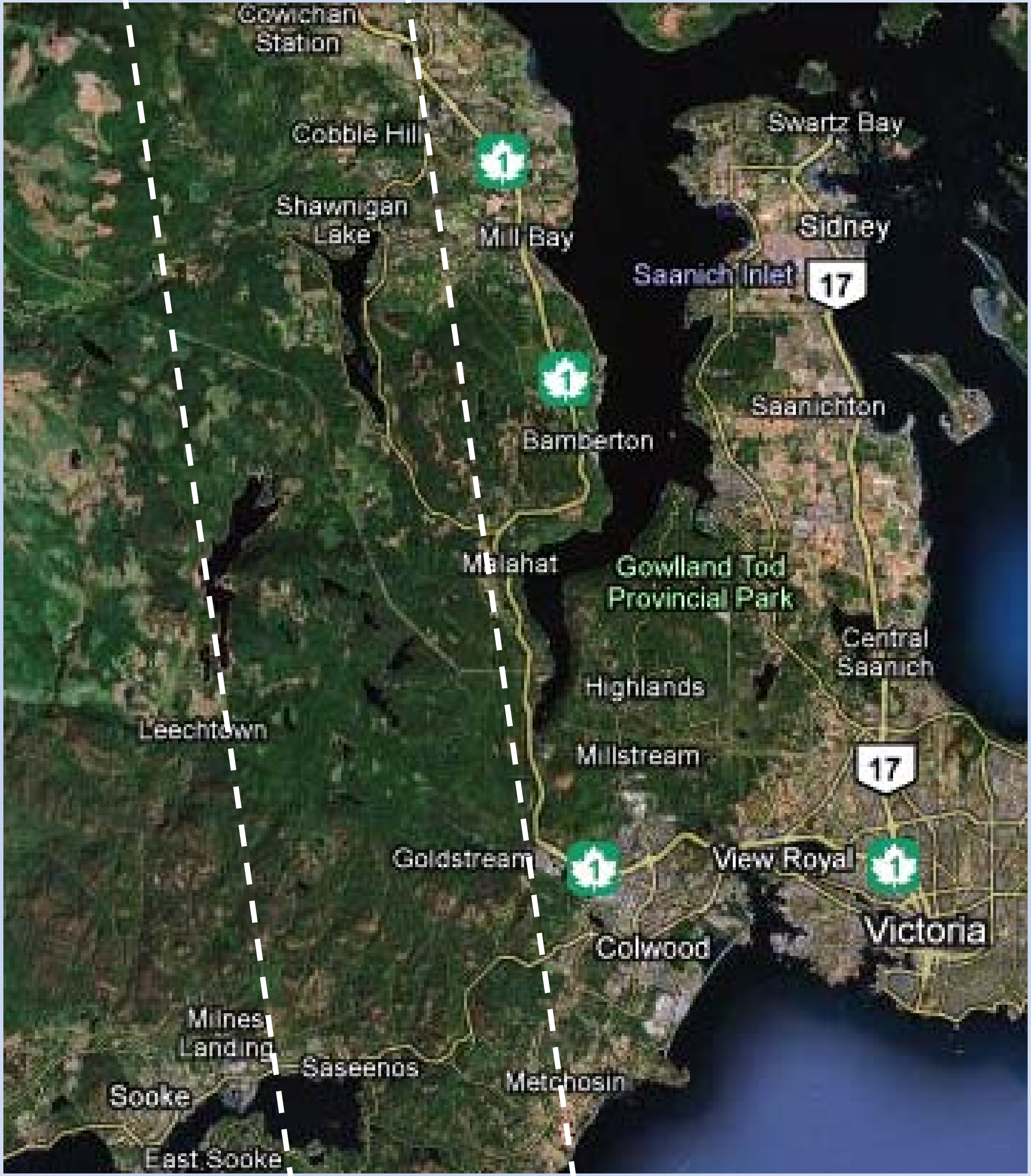



Exposed land
Water body
Shrub Low
Herb graminoids
Swamp area
Red alder dominant
Hemlock dominant
Lodgepole pine dominant
Western red cedar
Douglas-fir dominant
Unclassified

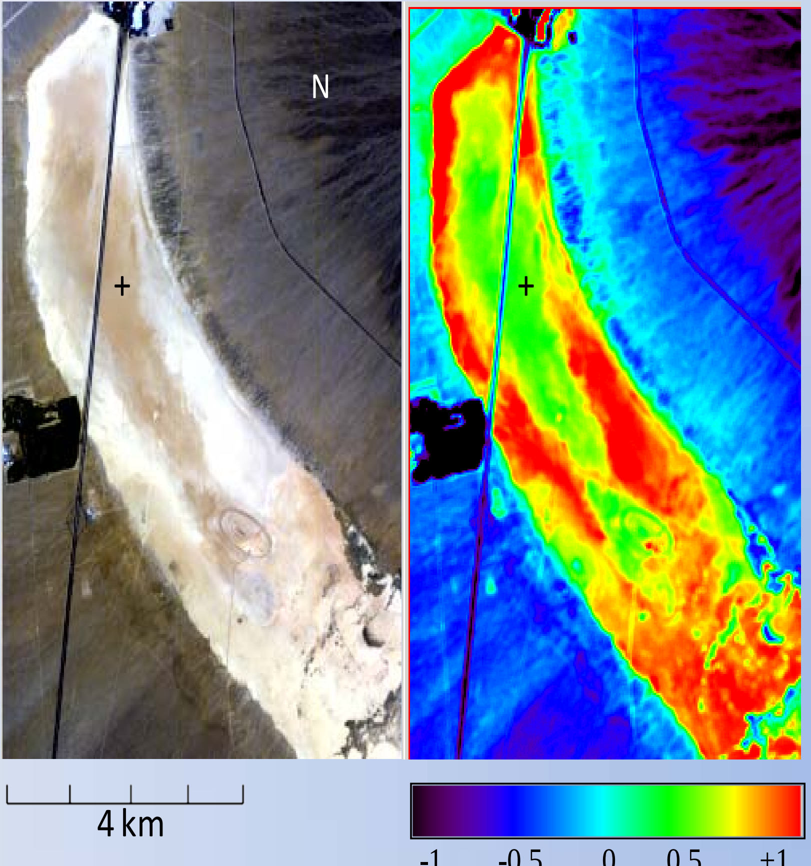

Bare
Forest/Shrub
Forest/Shrub
Forest
Forest
Water
Reflectance (%*100)
0
500
1000
1500
2000
2500
3000
3500
4000
400
650
900
1150
1400
1650
1900
2150
2400
Wavelength (nm)


T (oC, Mean,SD)
0
5
10
15
20
25
30
35
40
Water
Forest
Forest/Shrub
Shrub/Bare
Urban


SIWI
Dmax
NDVI
T (°C)
5
10
20
30


Cowichan Station
Cobble Hill
Shawnigan Lake
Mill Bay
Swartz Bay
Sidney
Saanich Inlet
17
1
Saanichton
Bamberton
Malahat
Gowlland Tod Provincial Park
Central Saanich
Highlands
Leechtown
Millstream
17
Goldstream
View Royal
Victoria
Colwood
Milnes Landing
Saseenos
Metchosin
Sooke
East Sooke

Site Spatial Uniformity / Spectral Variability

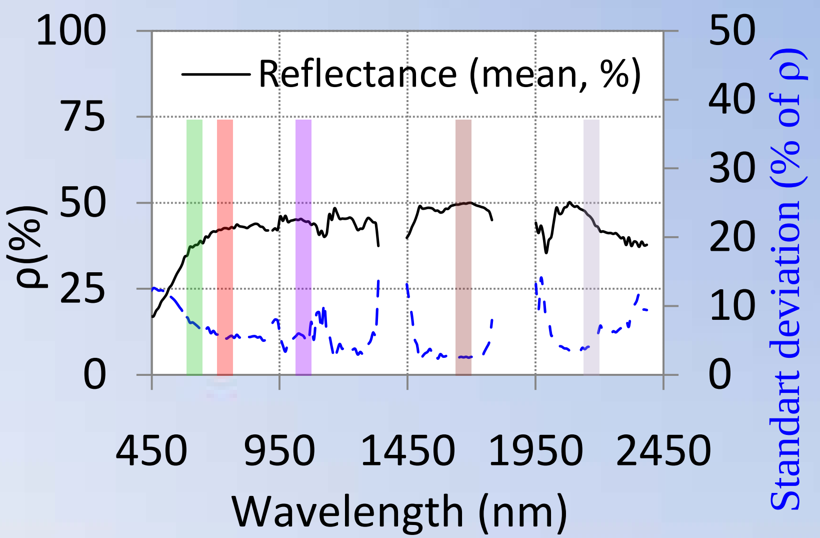


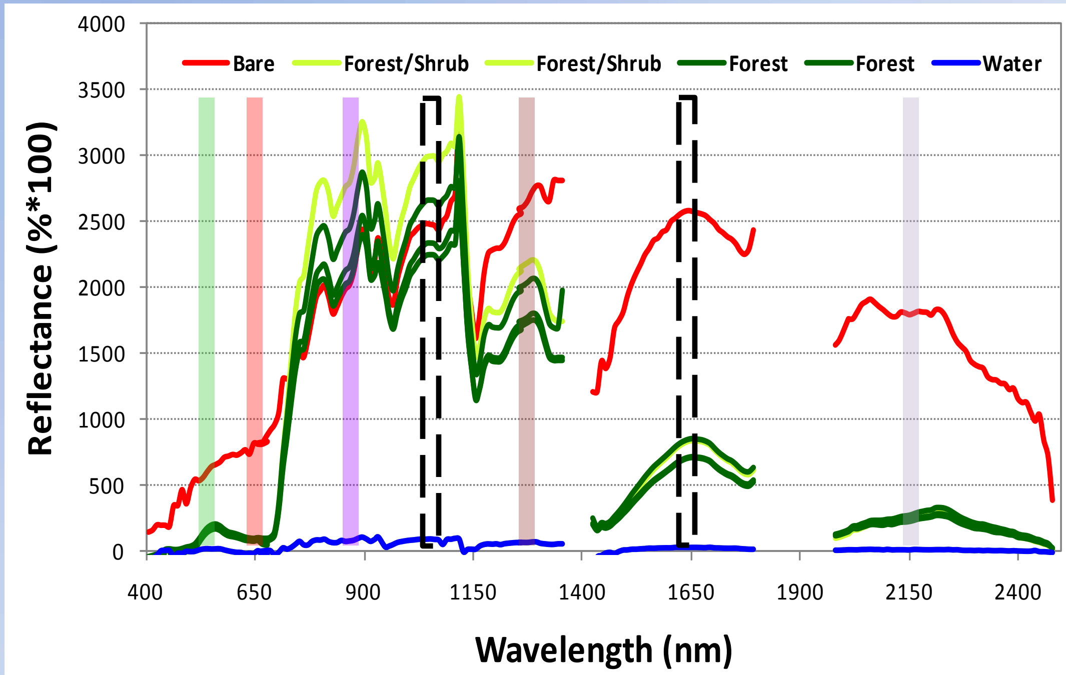
<u>Example from Ivanpah Playa, Hyperion</u>

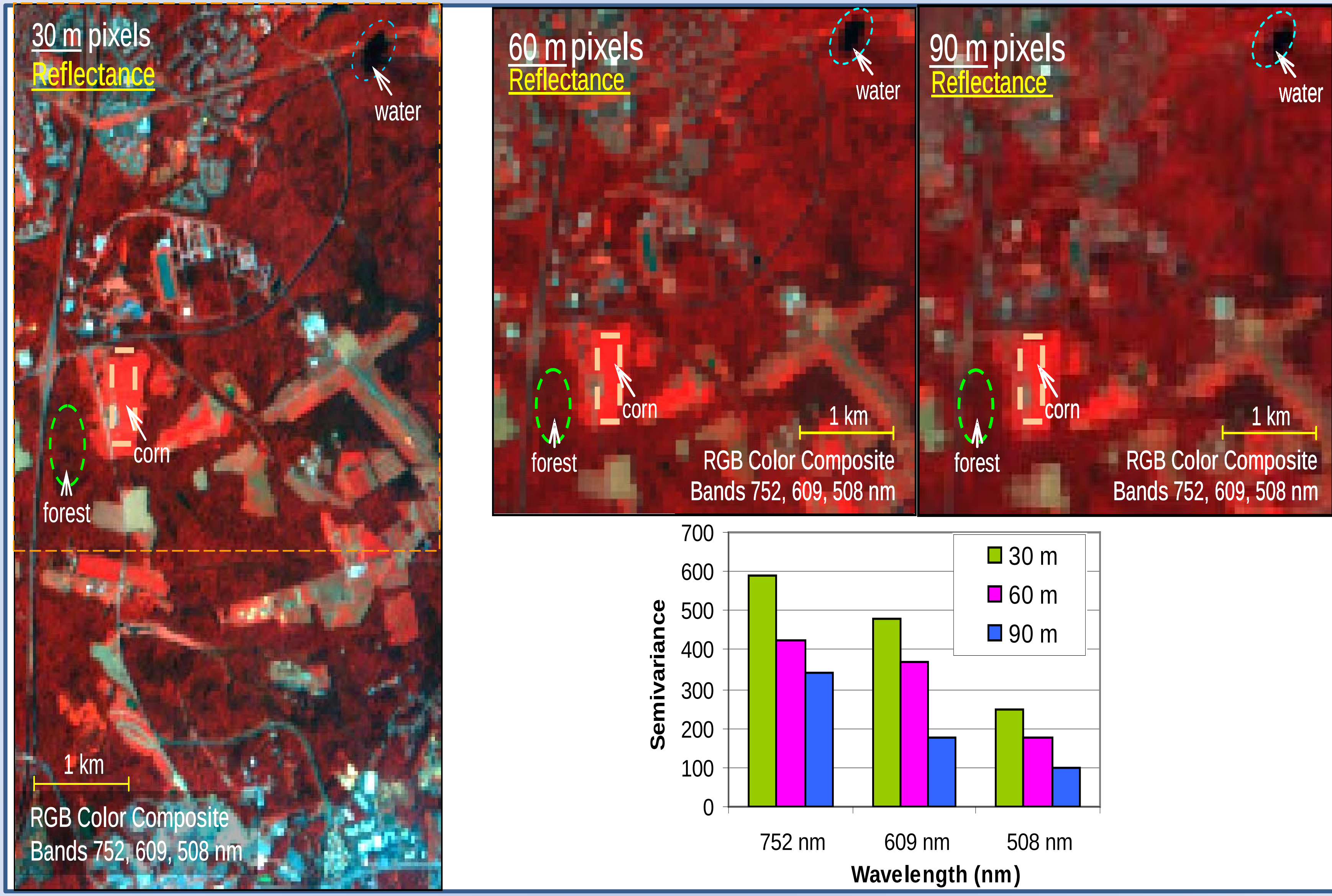
A. Natural color composite (RGB: 651, 549, 447)

B. B. Getis Gi* statistics (band 549) calculated for 197 Jul day image

The Gi statistics calculated for G, R, NIR, SWIR bands produced similar results.







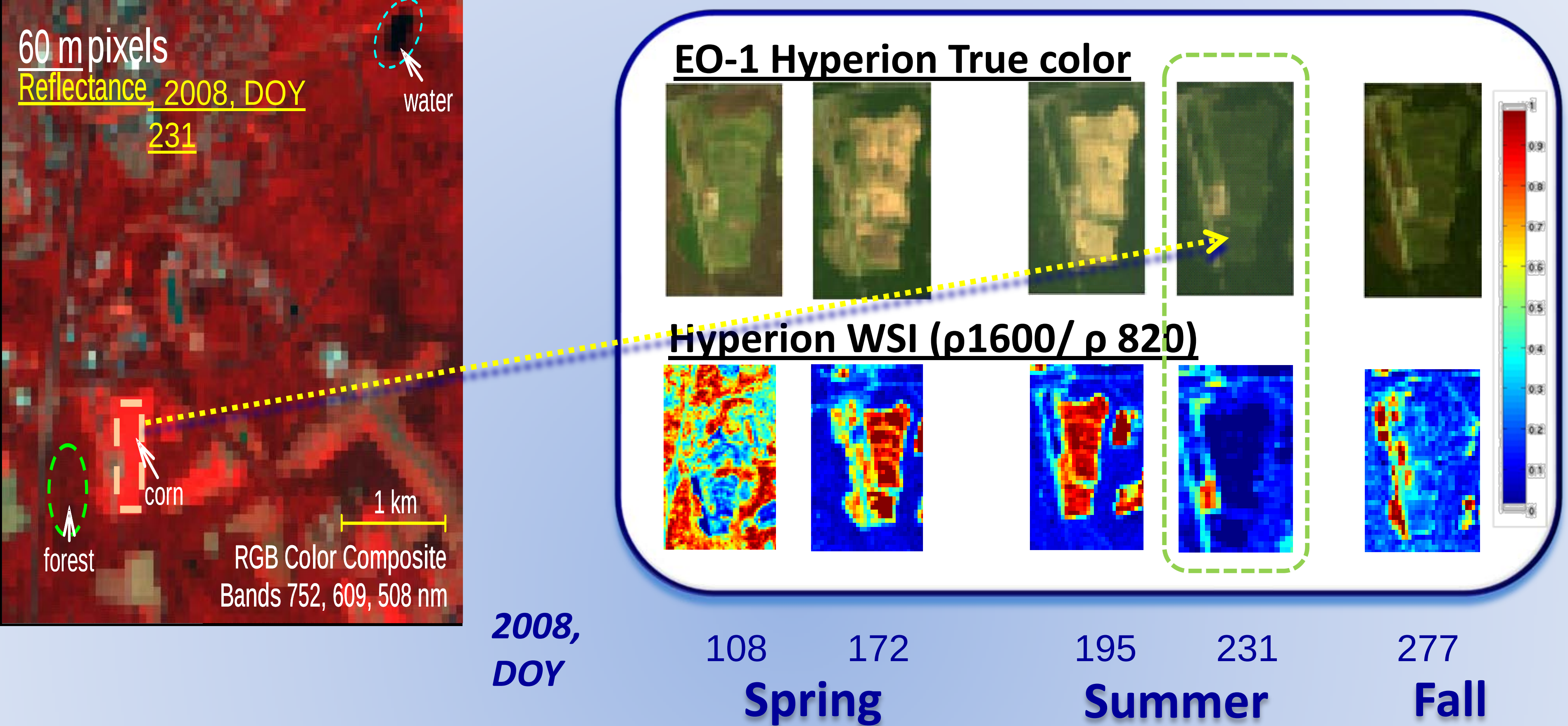
Examples of Hyperion reflectance image (30 m pixels) and the re-sampled to 60 and 90 m subset, demonstrate the spatial differences between HyspIRI-like data (60 m) and 30 and 90 m data.

30 m pixels

60 m pixels

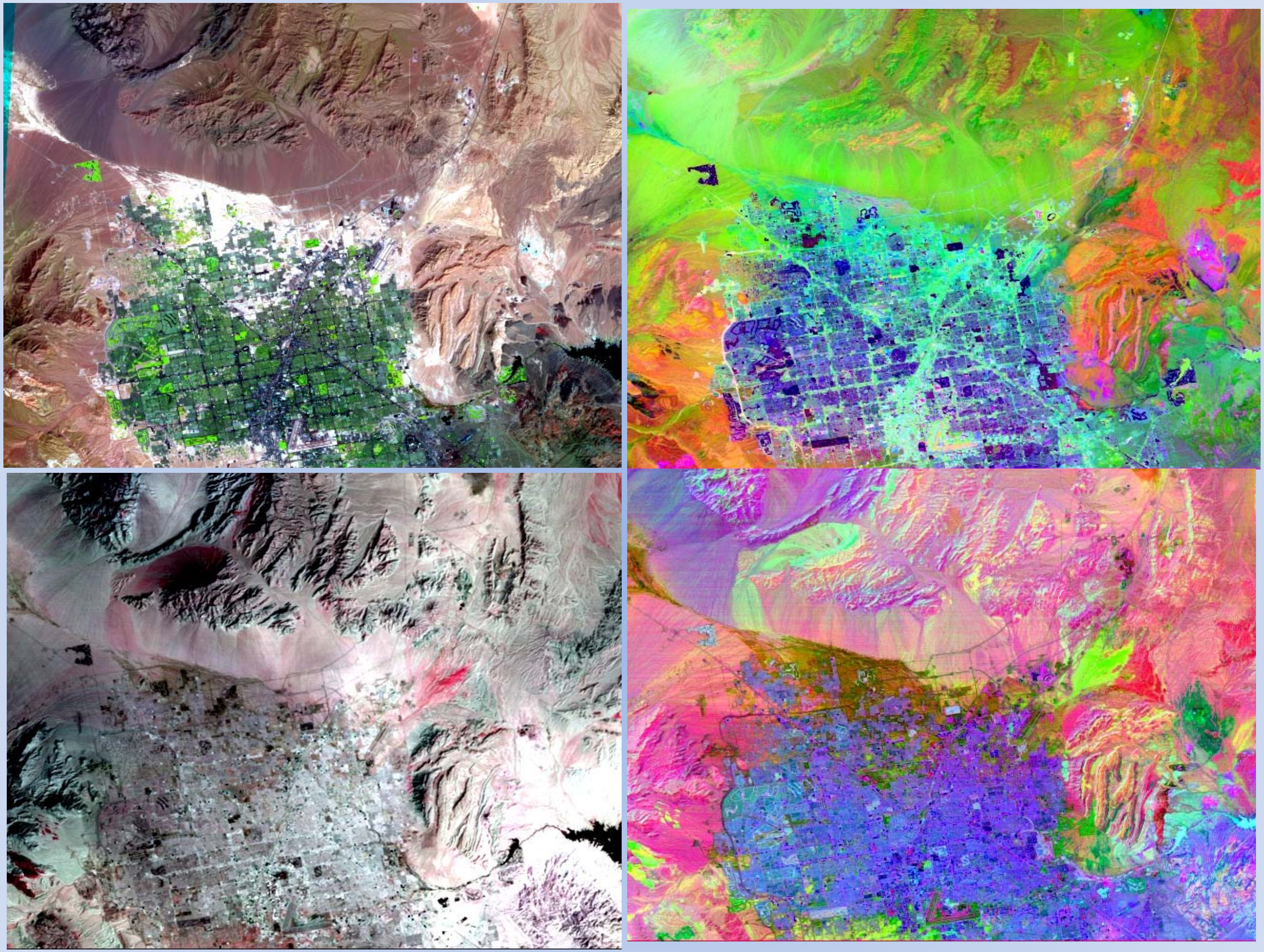
Pixel	Vegetation Indices:						Albedo		
size	V1	PRI	REIP	Dmax	NDWI	NDVI	water	corn	forest
30 m	1.81	-0.14	721	0.749	0.14	0.81	0.03	0.20	0.14
60 m	1.88	-0.15	721	0.748	0.15	0.82	0.04	0.20	0.13

While there were significant differences in the spatial variability between the original 30 m and the aggregated to 60 and 90 m data, the spectral properties of the major land cover types did not significantly differ.



Cover Type	Hyperion, 2008	V1	PRI	REIP	Dmax	WBI	Albedo
Corn	13-Jun	1.03	-0.04	712	0.36	0.96	0.461
	18-Aug	1.81	-0.06	722	0.75	1.09	0.197
	3-Oct	1.15	0.04	721	0.51	0.98	0.155
Forest	13-Jun	1.12	-0.06	712	0.89	1.00	0.257
	18-Aug	1.56	-0.03	722	0.51	1.01	0.140
	3-Oct	1.61	-0.10	712	0.42	0.94	0.127
Water	13-Jun	0.15	0.01	712	0.16	1.23	0.058
	18-Aug	0.52	0.02	712	0.10	1.46	0.031
	3-Oct	0.62	-0.07	712	0.08	0.93	0.036

Bio-physical parameter	Spectral bio-indicators *(examples)*	References
<u>TIR indicators</u>		
Water stress (100% vegetative cover)	CWSI = (ΔTcanopy – ΔTnws)/(ΔTmax – ΔTnws), where Tmax for non-transpiring and Tnws is "non-water-stressed" baseline temperature. 0 = no stress, 1 = maximal stress, Δ = (Tsurface - Tair)	Idso et al. 1981, Jackson, 1981
Irrigated vs. non-irrigated (100% veg.)	IG = (Tmax – Tcanopy)/(Tcanopy – Tnws),	Jones 1999
Increase in sensible heat due to UHI	Rn = G + LE + H, Rn + A = G + LE + H; where Rn is net radiation, G ground heat, LE latent heat, H sensible heat, A anthropogenic heat	Kato and Yamaguchi, 2005
<u>Combined VSWIR & TIR indicators</u>		
Relative water status (Veg. cover < 100%)	WDI trapezoid, defined by the fractional vegetation cover and Δ = (surface - air temperature); 0.0 well-watered (latent heat flux is limited only by atmospheric demand), 1.0 no available water	Moran et al. 1994
Water supply	WSVI=NDVI/Ts, where Ts is the brightness temperature at ~11 µm, the smaller this index is, the more severe the drought is	Hatfield et al. 2008
Temperature–vegetation dryness index	TVDI = (*T*s – *T*s_min)/(*a* + *b*NDVI – *T*s_min), where *T*s_min is the minimum temperature in the triangle; and *a* and *b* are the interception and slope of the dry edge, respectively	Wand et al. 2004
After WSVI and TDVI	Like WSVI and TVDI, but using VSWIR parameters sensitive to water stress, such as NDWI or SIWI.	New, to test



ASTER imagery, Las Vegas area: VSWIR aggregated to 90 m (upper left, vegetation in green) and TIR bands (lower left), principle components of reflective bands (upper right) and all VSWIR and TIR (lower right).

Deliverables and Milestones

- Best estimates of atmospheric properties needed to atmospherically correct the two HyspIRI-like data sets;
- Algorithm to spatially convolve the airborne or spaceborne imager data sets to 30, 60, and 90 m spatial resolution;
- Development of HyspIRI-like datasets;
- Development of HyspIRI-like spectral bio-indicators of ecosystem health;
- Classifications of HyspIRI-like data for a broad range of natural and anthropogenic ecosystems and vegetation functional types;
- Presentations at HyspIRI meetings, and final report.

Expected Results

- Through the combined use of reflective and emissive data, the proposed work will **evaluate the suitability of HyspIRI for delineating ecosystem functional types and tracking the conversion of land from rural to urban**.
- The research will produce two HyspIRI-like data sets combining reflectance and thermal data, which will be used to assess the **potential of HyspIRI data for delineating land cover and vegetation types**, discriminating natural versus urban ecosystems, and **assessing ecosystems diversity and health**.
- In addition, the work will produce methods and tools for work with the HyspIRI data.

Preliminary Findings

- MASTER's spectral bands 32 and 41 may not provide ideal simulation for HyspIRI
- Atmospheric correction of thermal images at 60m worked as well and better, than at the original resolution
- Thermal atmospheric correction was effective when playa, vegetation and water regions are present and well-delimited
- The 60m resolution can estimate differences in emissivity for urban and rural regions, and demonstrated higher temperatures in urban areas

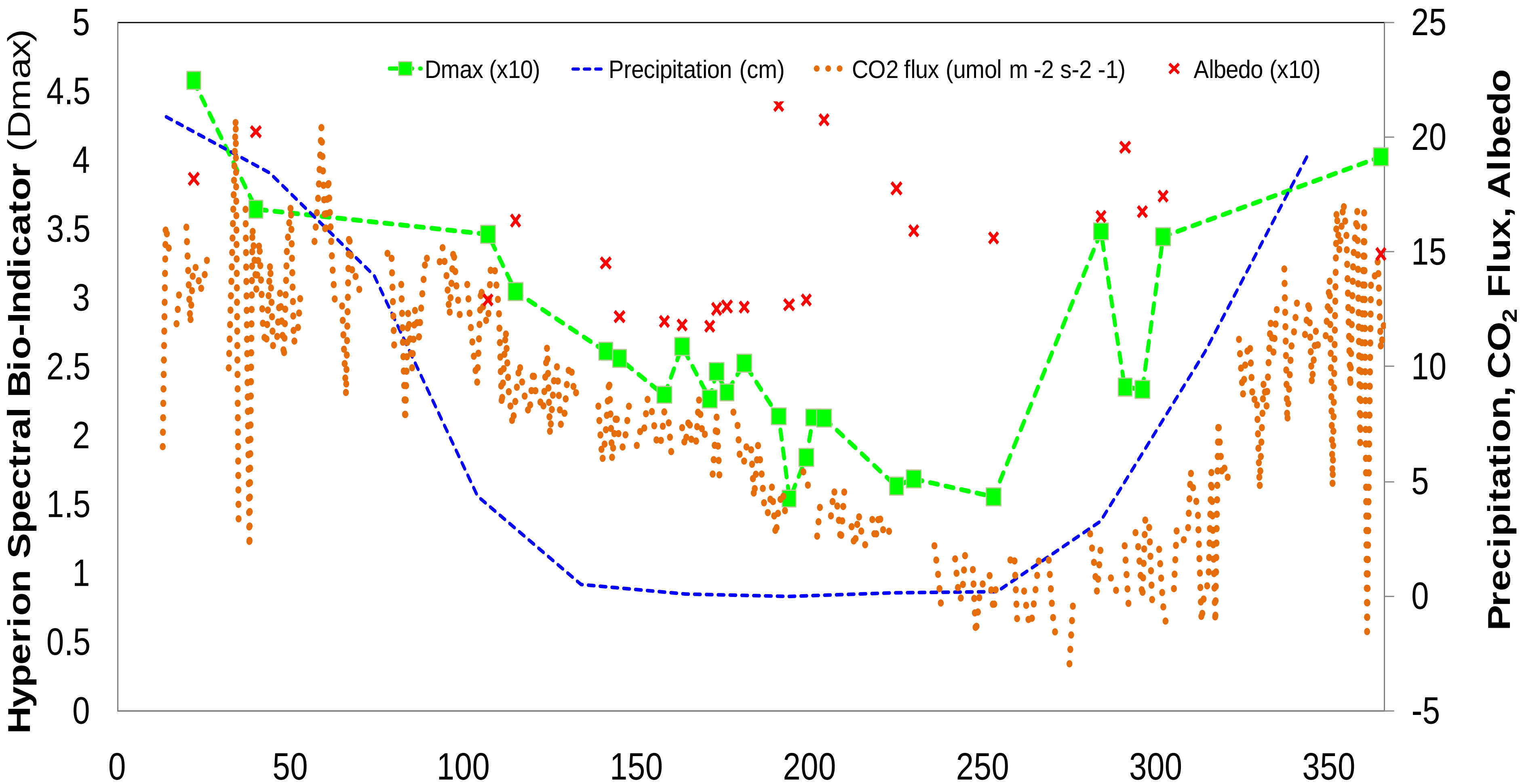
Project Collaborators

- *Prof. David Goodenough (CFS Victoria, BC)*
- *Dr. Nicholas Coops (UBC, Vancouver, CA)*
- *Dr. Nona R. Chiariello (Stanford University, CA)*
- *Dr. Tony Trofymow (CFB Esquimalt, BC)*
- *Dr. Elizabeth Middleton (NASA/GSFC)*

Acknowledgments

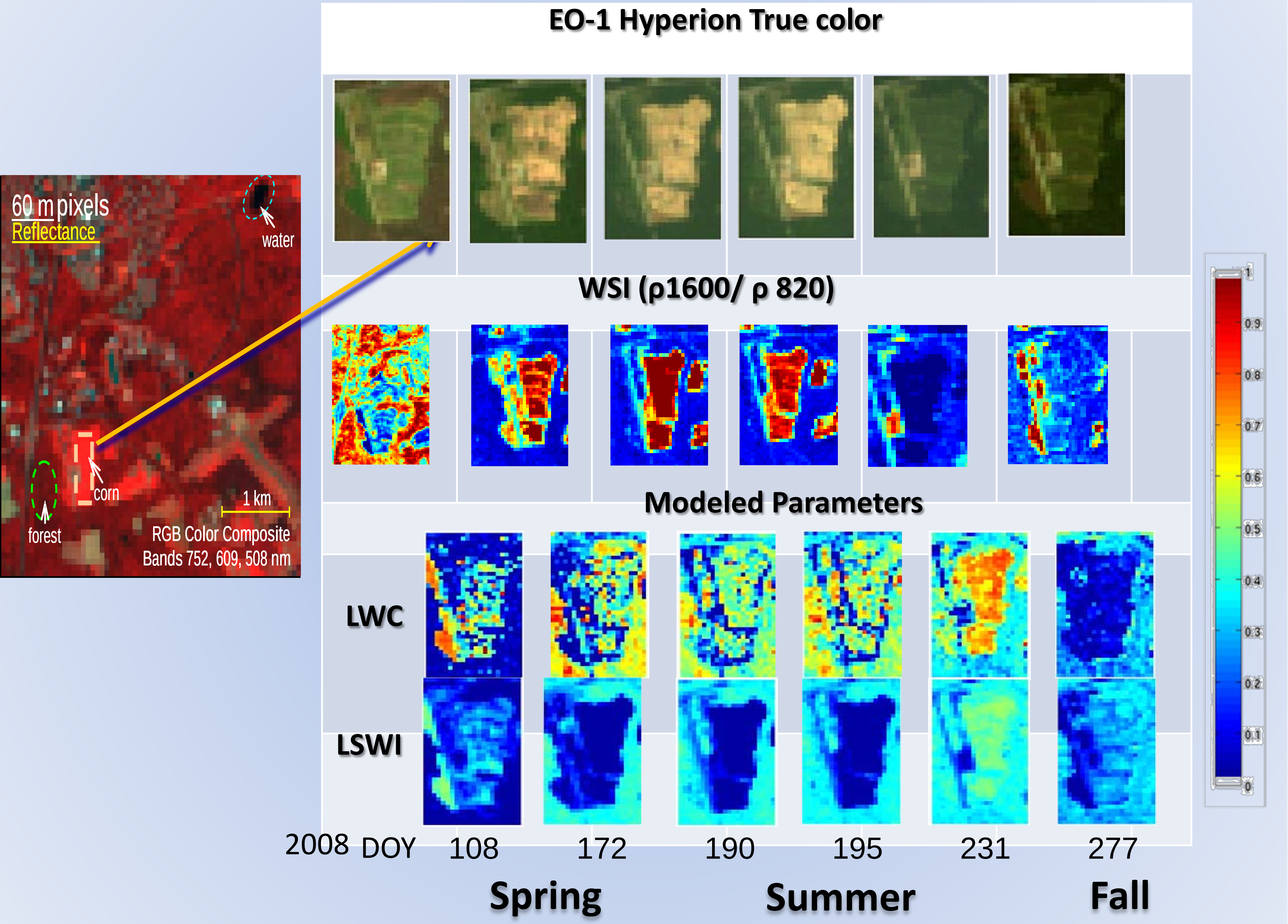
The project provides research experience for graduate and undergraduate students, which participate through established programs, assisting with data processing, analysis and preparation of reports.

Temporal profile of Hyperion's Spectral Bio-indicators at CEOS/LPV Sites



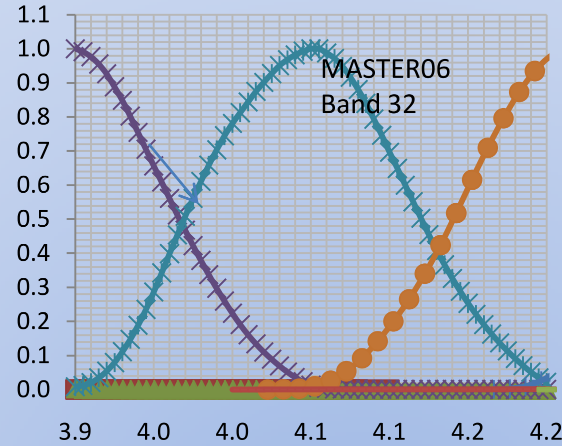
The temporal profile in the derivative spectral bio-indicator Dmax captures the dynamics in vegetation phenology at Mongu, Zambia

Thank You



EO-1 Hyperion True color
60 m pixels
Reflectance
water
corn
forest
1 km
RGB Color Composite
Bands 752, 609, 508 nm
WSI (ρ1600/ ρ 820)
Modeled Parameters
LWC
LSWI
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2008 DOY 108 172 190 195 231 277
Spring
Summer
Fall

Issues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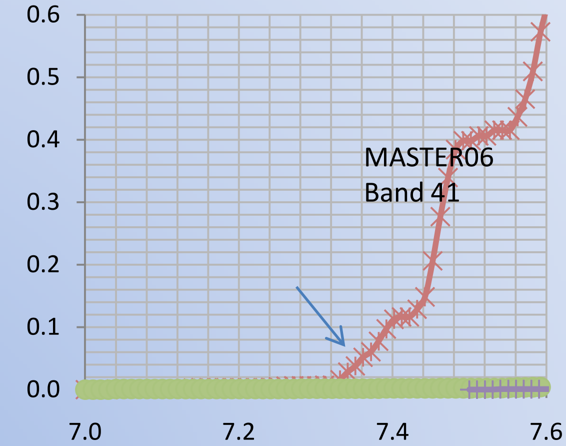
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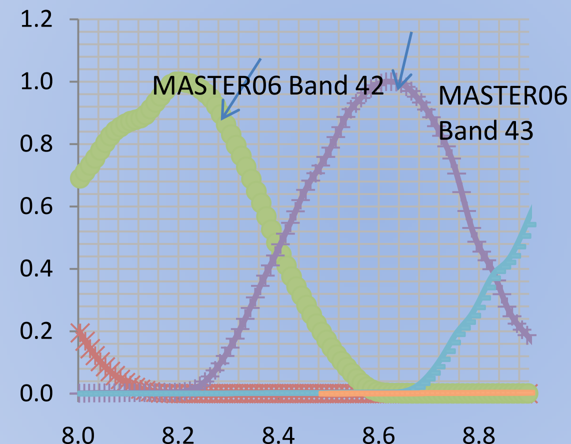
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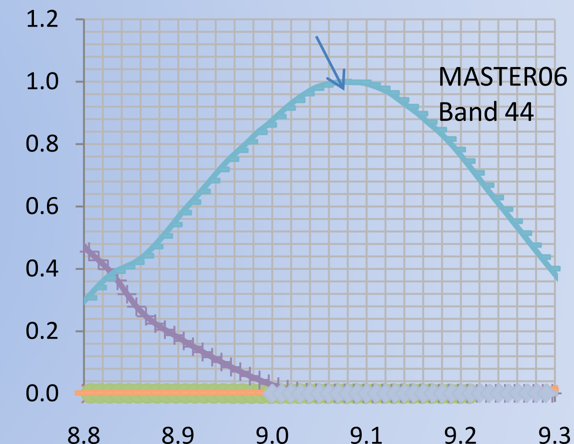
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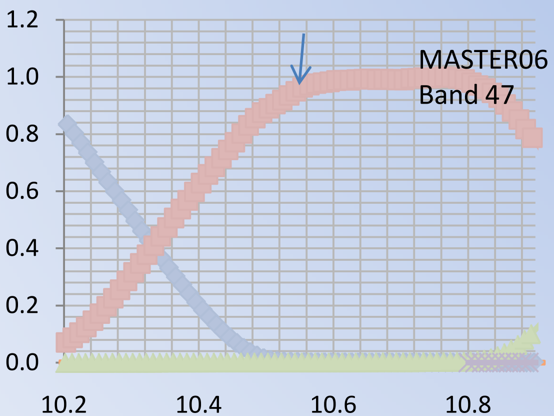
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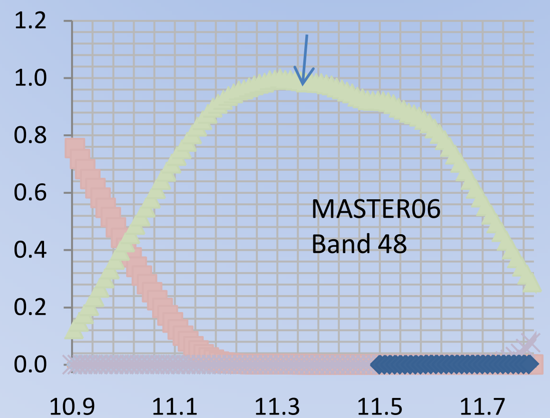
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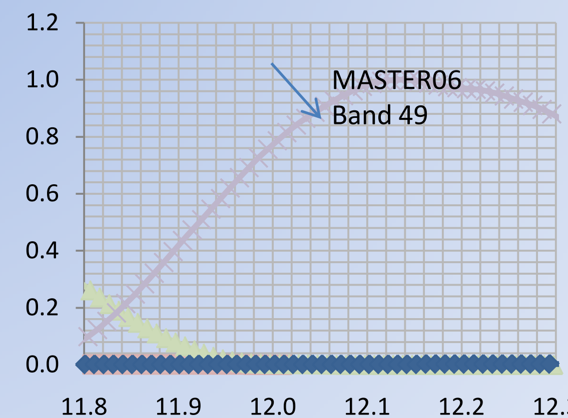
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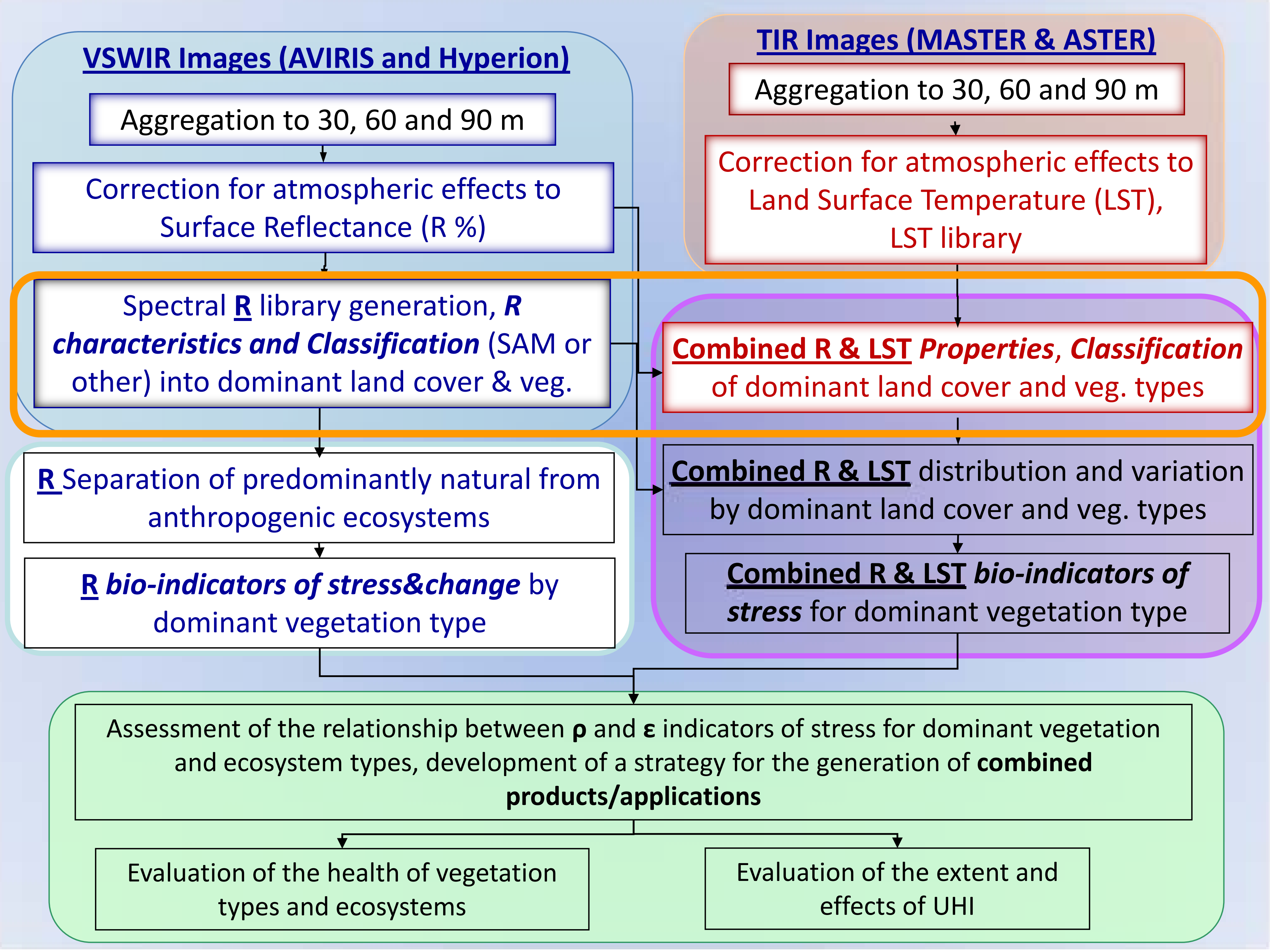
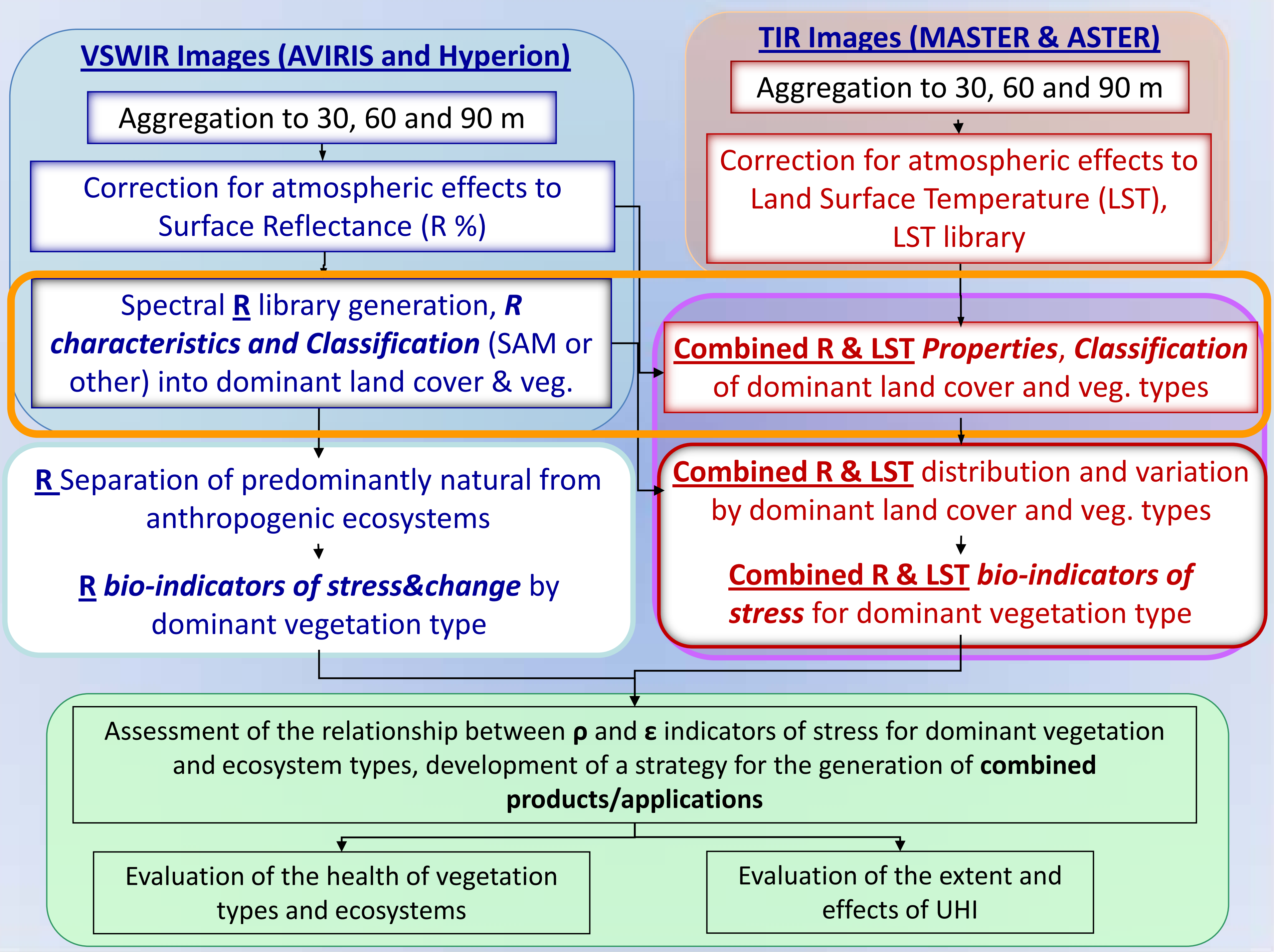

VSWIR Images (AVIRIS and Hyperion)
Aggregation to 30, 60 and 90 m
Correction for atmospheric effects to Surface Reflectance (R %)
Spectral R library generation, R characteristics and Classification (SAM or other) into dominant land cover & veg.
R Separation of predominantly natural from anthropogenic ecosystems
R bio-indicators of stress&change by dominant vegetation type
TIR Images (MASTER & ASTER)
Aggregation to 30, 60 and 90 m
Correction for atmospheric effects to Land Surface Temperature (LST), LST library
Combined R & LST Properties, Classification of dominant land cover and veg. types
Combined R & LST distribution and variation by dominant land cover and veg. types
Combined R & LST bio-indicators of stress for dominant vegetation type
Assessment of the relationship between ρ and ε indicators of stress for dominant vegetation and ecosystem types, development of a strategy for the generation of combined products/applications
Evaluation of the health of vegetation types and ecosystems
Evaluation of the extent and effects of UHI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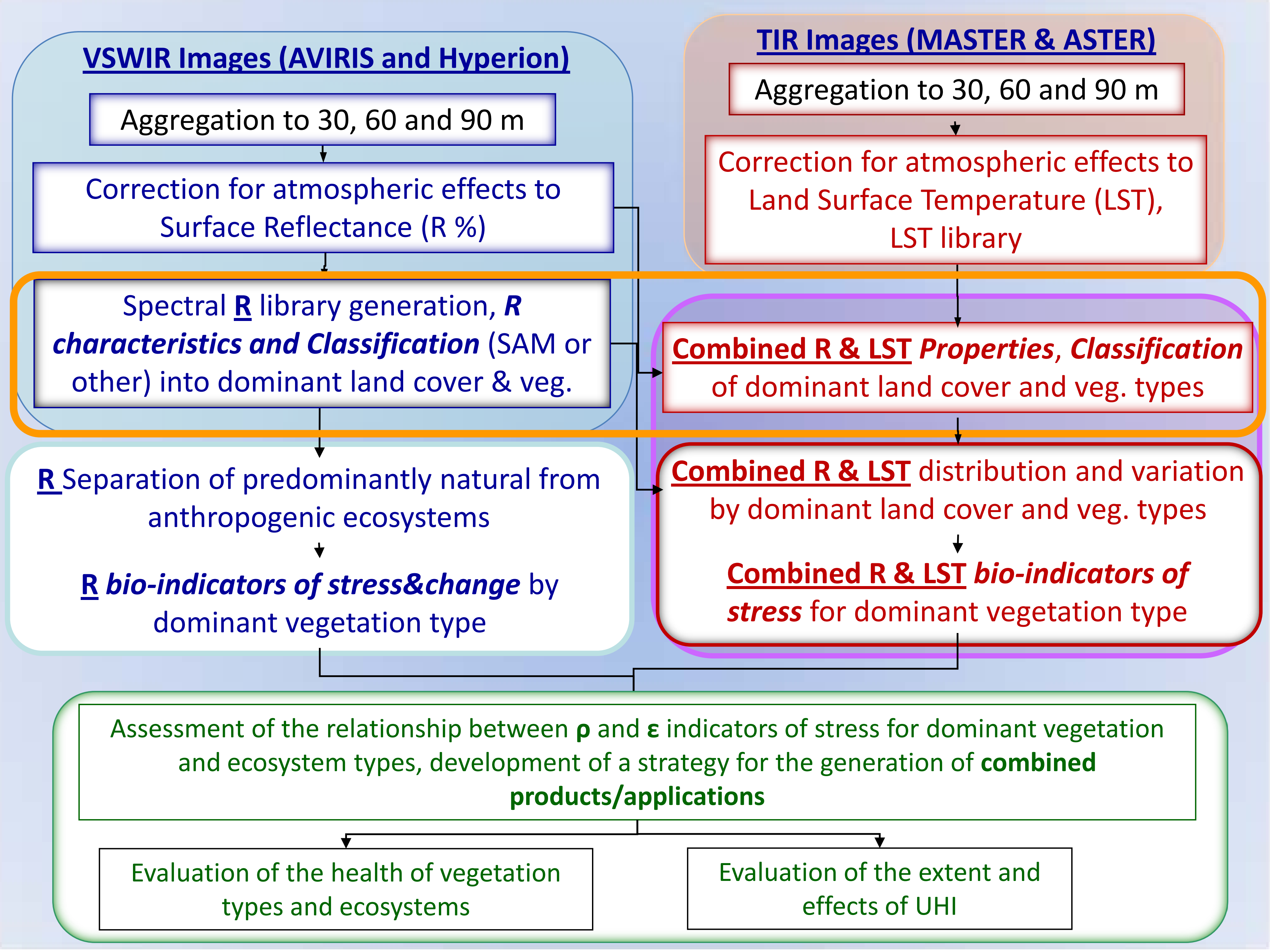
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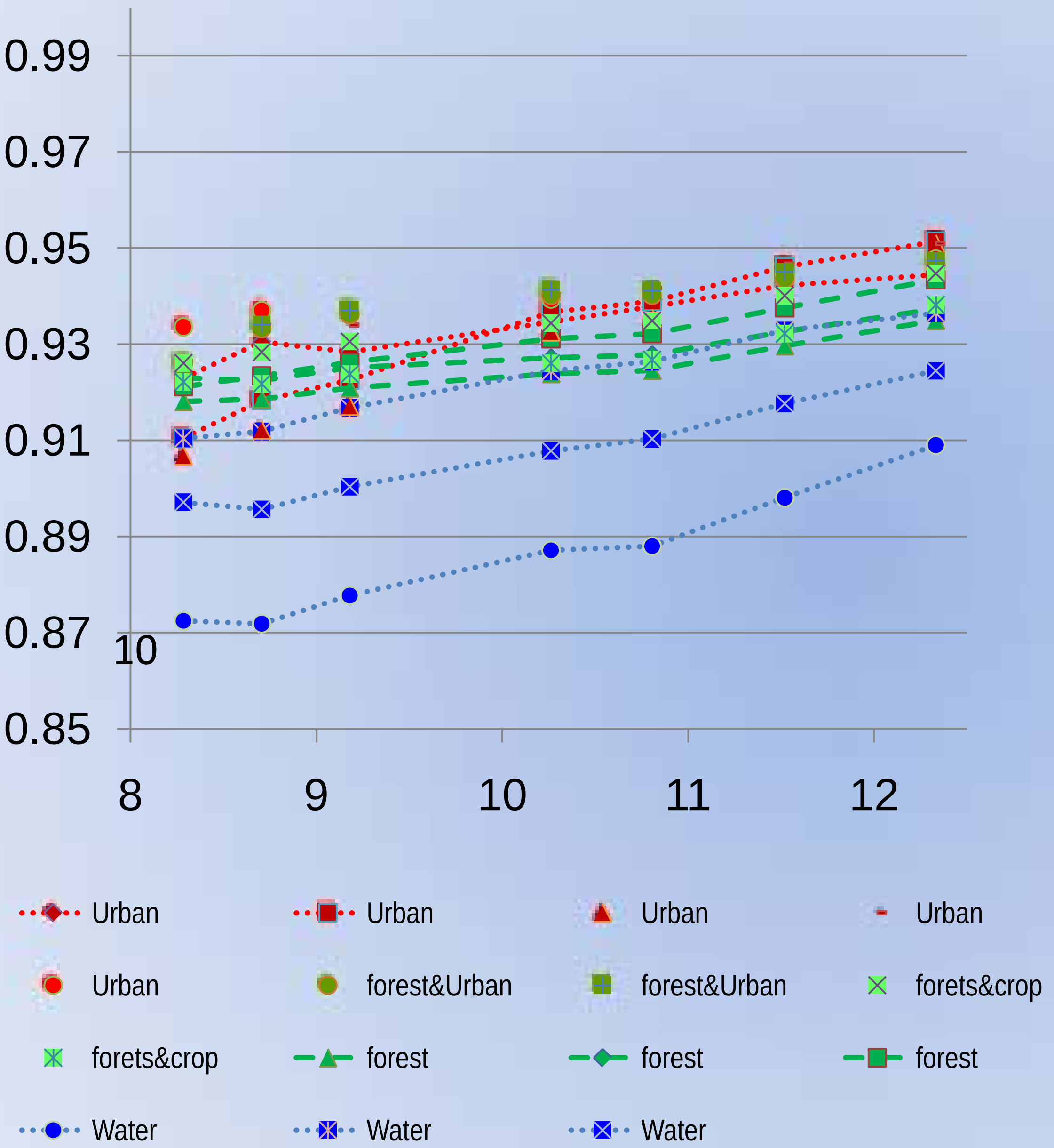

0.99
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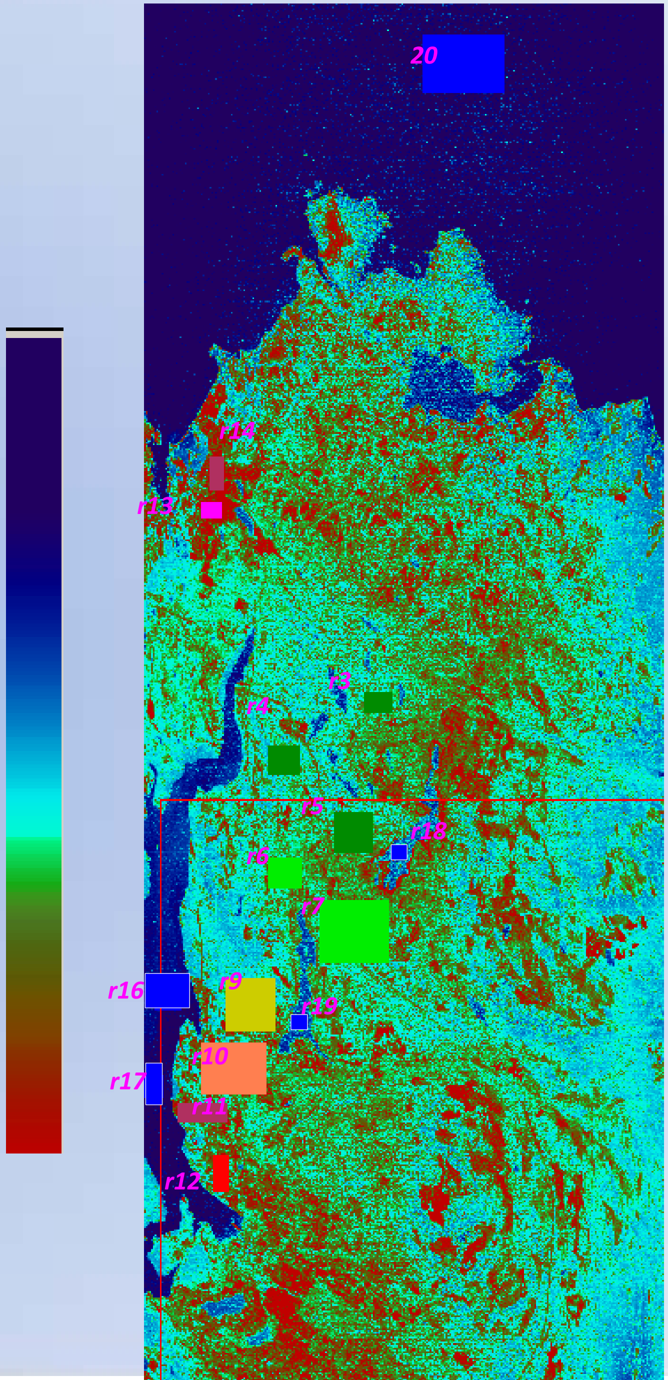
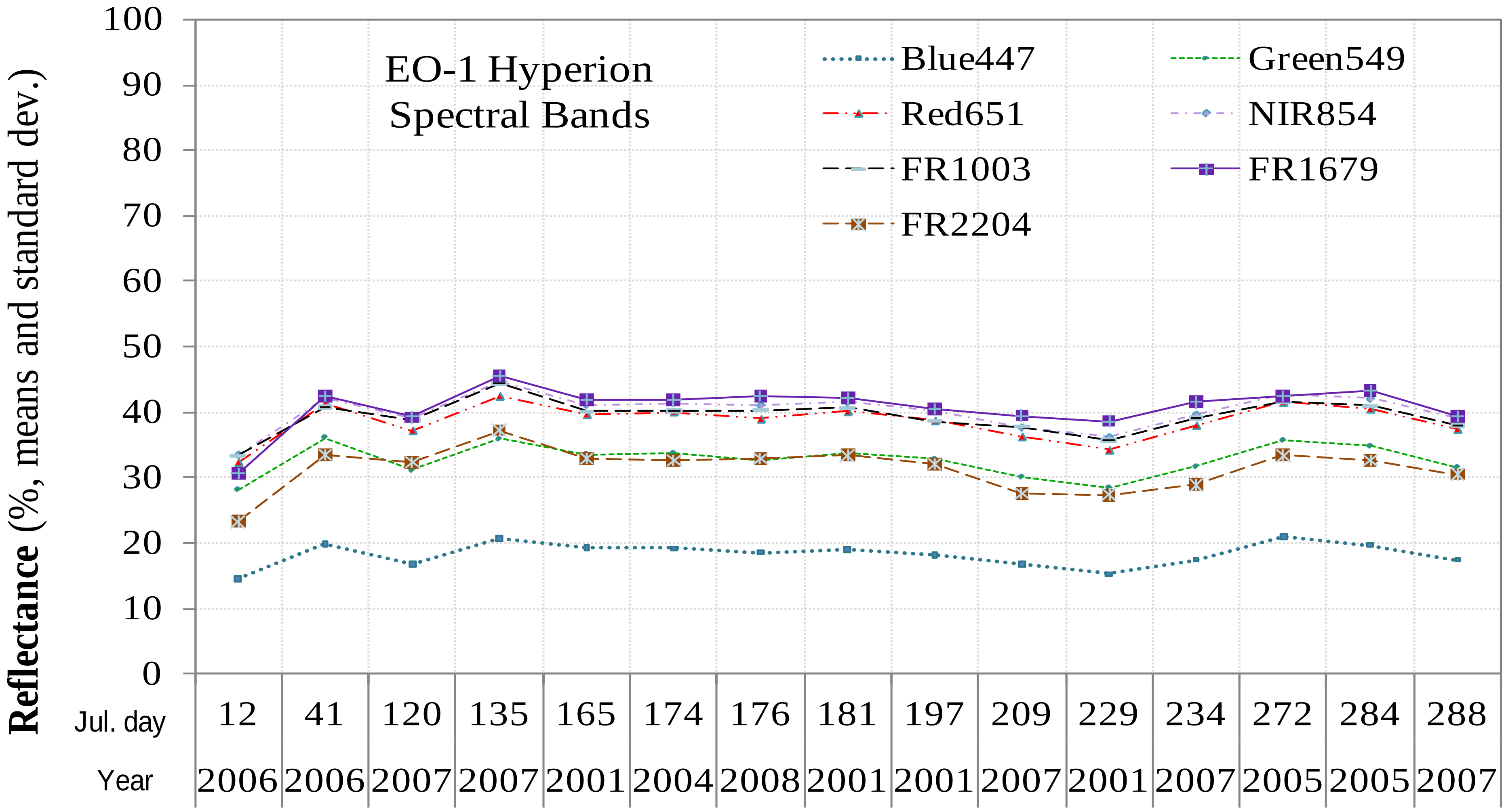
Water



20
r14
r13
r3
r4
r5
r18
r6
r7
r16
r9
r19
r10
r17
r11
r12

Temporal profile of Hyperion at the CEOS Calibration site at Railroad Valley, NV



Linear temporal profile of the spectra demonstrates the relative stability of the spectral characteristics, as indicated for selected bands

Bio-physical parameter	Spectral bio-indicators *(examples)*	References
VSWIR indicators		
Chlorophyll in crops	$(R_{NIR}/ R^{-1}_{720\text{-}730}) - 1$	Gitelson et al., 2005
Canopy greenness	$EVI = G * \frac{R_{NIR} - R_{red}}{R_{NIR} + C_1 R_{red} - C_2 R_{blue} + L}$	Huete et al. 2002
Chlorophyll concentration estimation	$TCARI / OSAVI = \frac{3*[(R_{700} - R_{670}) - 0.2*(R_{700} - R_{550})*(R_{700} / R_{670})]}{(1+0.16)*(R_{800} - R_{700})/(R_{800} + R_{670} + 0.16)}$	Haboudane et al. 2002, Zarco-Tejada et al. 2004
Efficiency of photosynthesis	PRI=(R570-R531)/(R570+R531)	Gamon et al., 1992, Suarez et al. 2008
Canopy foliar water content	$NDWI = \frac{R_{NIR} - R_{1240}}{R_{NIR} + R_{1240}}$	Gao, 1996
Canopy foliar water content	$SIWI = \frac{R_{NIR} - R_{1640}}{R_{NIR} + R_{1640}}$	Fensholt and Sandholt, 2003
Vegetation stress	Average (R675…. R705)	Vogelman, 1993
Veg. structure and foliar biomass	NDVI = (R800-R670)/(R800+R670)	Deering, 1978
Stress/Chlorophyll	D714/D705, where D is product of first derivative transformation of R	Entcheva, 2004
Stress/ Chlorophyll	Dmax/D705, where Dmax is the maximum of D in the 670-730nm region	Entcheva, 2004