Comparison of Hyperspectral and Multispectral Satellites for Discriminating Land Cover in Northern California

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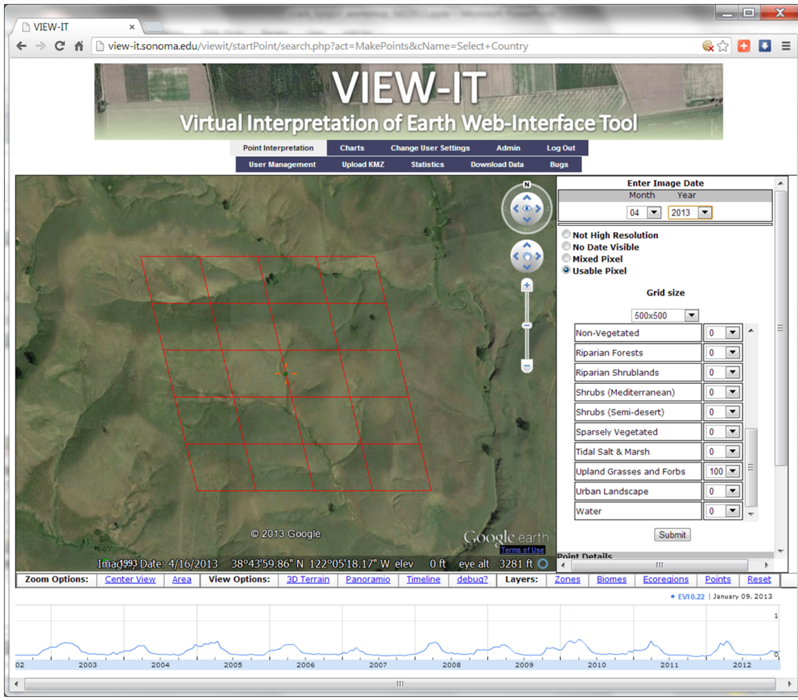
Goals

- Land use/land cover is an important variable to map at local to global scales
- Accuracy of VSWIR HyspIRI-like satellite imagery for mapping land cover at a regional scale
  - <u>Scalable methods</u> – eye on global scale mapping from HyspIRI
  - Machine learning - Random Forests (RF) vs. Multiple-Endmember Spectral Mixture Analysis (MESMA)
  - Summer vs. Multi-temporal (spring, summer, fall)
- Compare accuracy to multispectral satellite sensors
  - Simulated Landsat OLI and Sentinel-2
  - Real Landsat OLI
  - Radiance and reflectance

Reference data

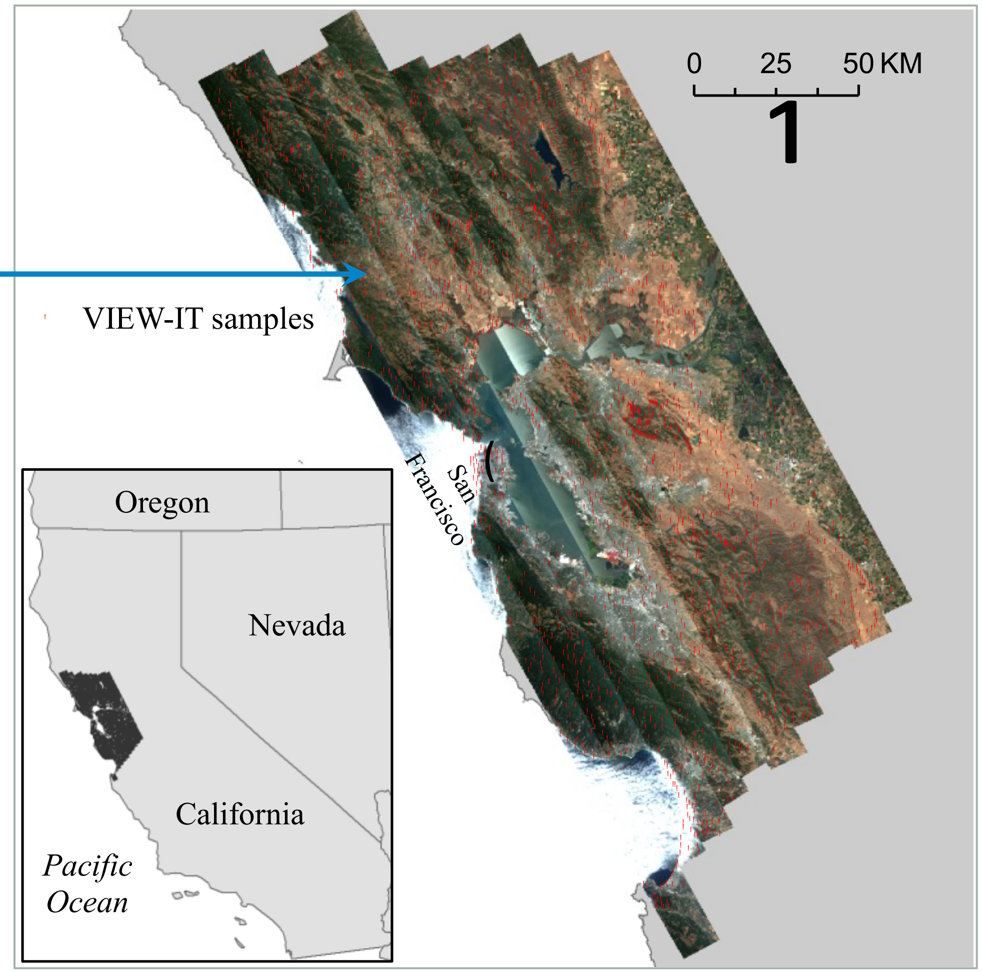


Percent Cover

Impervious Surface
Water
Urban Landscape
Annual Crops
Perennial Crops
Beaches or Dunes
Sparsely Vegetated
Non-Vegetated
Tidal Marsh
Upland Grasses and Forbs
Dune Vegetation
Shrubs
Needleleaf Trees
Evergreen Broadleaf Trees
Deciduous Broadleaf Trees

30,000 km^2
image area
(no overlap)

22,500 km^2
terrestrial area



Land Cover Classification System (LCCS)

Global, universal system - U.N. FAO

- Annual Crops
- Perrenial Crops
- Bare
- Built-up
- Urban Vegetated
- Tidal Marsh
- Dune Vegetation
- Herbaceous
- Open Shrub
- Open Evergreen Needleleaf Trees
- Open Deciduous Broadleaf Trees
- Open Evergreen Broadleaf Trees
- Open Mixed Broadleaf Trees
- Open Mixed Broadleaf/Needleleaf Trees
- Closed Shrub
- Closed Evergreen Needleleaf Trees
- Closed Deciduous Broadleaf Trees
- Closed Evergreen Broadleaf Trees
- Closed Mixed Broadleaf Trees
- Closed Mixed Broadleaf/Needleleaf Trees

20 classes

Closed-Canopy: > 65% cover trees or shrubs
Open-Canopy: 15% - 65% cover trees or shrubs

Dominant Plant Functional Types

- Annual Crops
- Perrenial Crops
- Bare
- Built-up
- Urban Vegetated
- Tidal Marsh
- Dune Vegetation
- Herbaceous
- ~~Open Shrub~~
- ~~Open Evergreen Needleleaf Trees~~
- ~~Open Deciduous Broadleaf Trees~~
- ~~Open Evergreen Broadleaf Trees~~
- ~~Open Mixed Broadleaf Trees~~
- ~~Open Mixed Broadleaf/Needleleaf Trees~~
- Closed Shrub
- Closed Evergreen Needleleaf Trees
- Closed Deciduous Broadleaf Trees
- Closed Evergreen Broadleaf Trees
- ~~Closed Mixed Broadleaf Trees~~
- ~~Closed Mixed Broadleaf/Needleleaf Trees~~

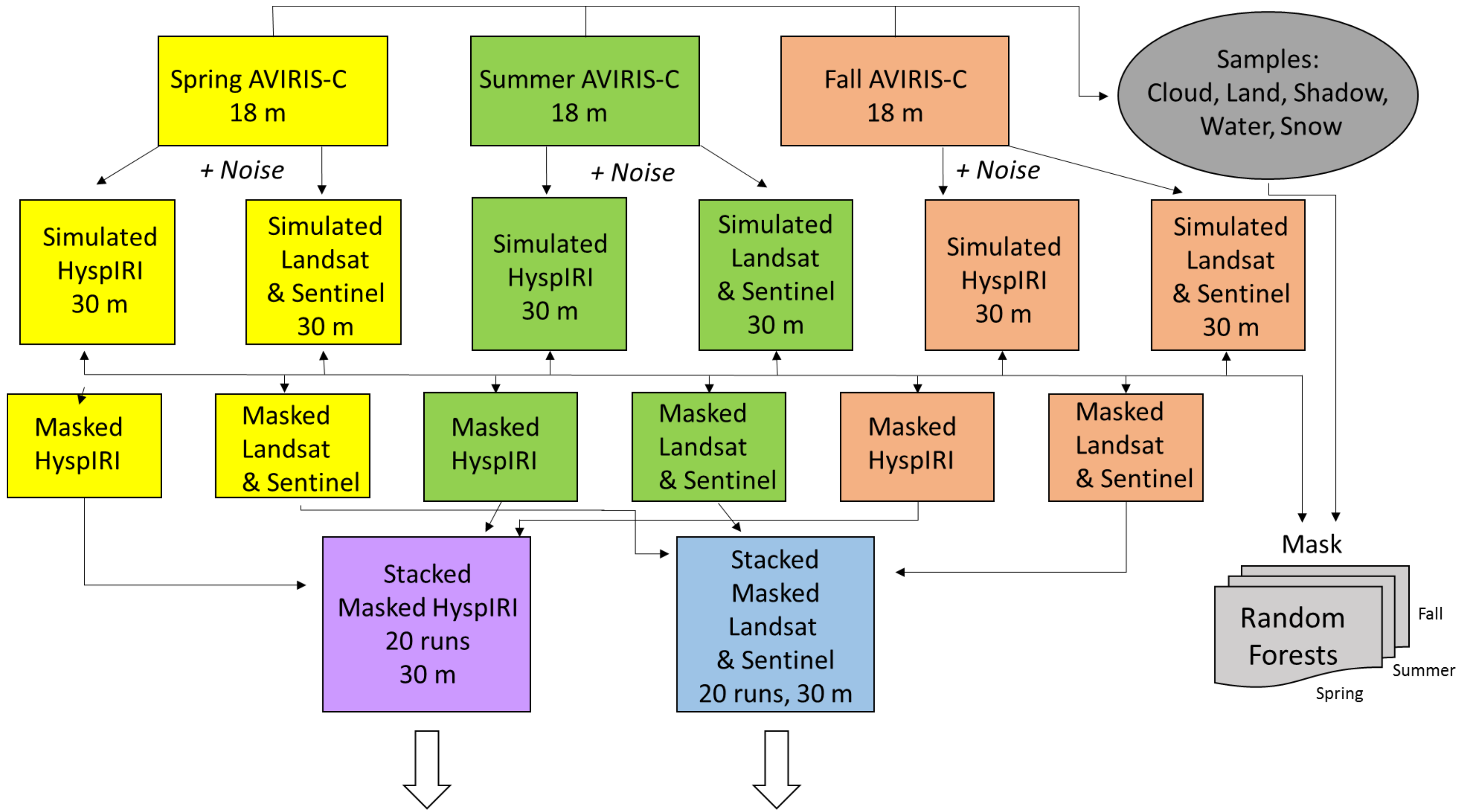
12 classes

Closed-Canopy: > 65% cover trees or shrubs

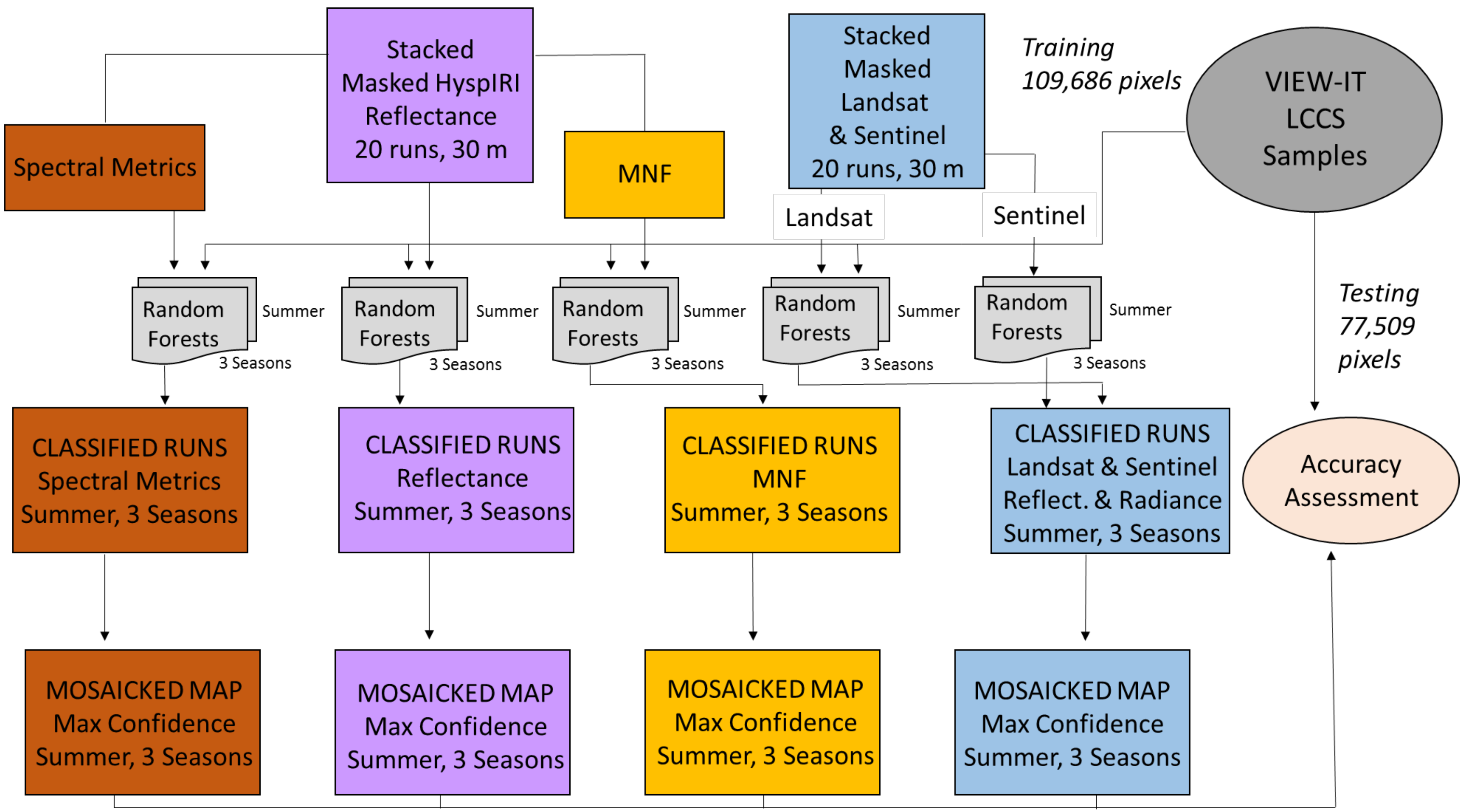
RANDOM FORESTS

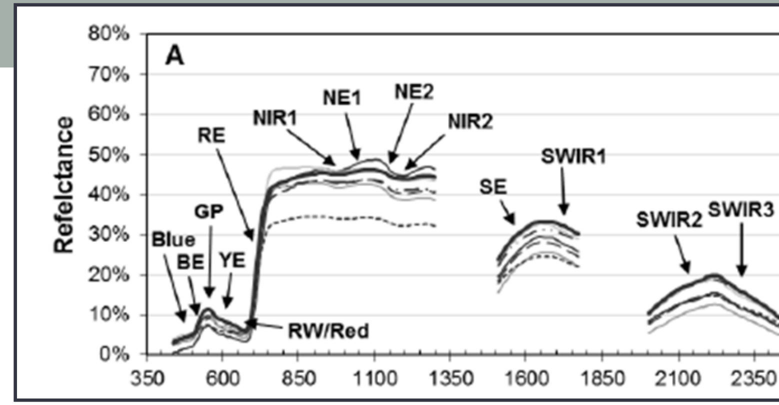
Analysis by Matt Clark

Processing flow



Processing flow (continued)





Spectral metrics

Summary of hyperspectral metrics organized by methods (in bold) and dominant spectral features and region (in italics).

Indices	**Absorption-Based**	**Derivative**
Photosynthetic pigments, LAI, structure, physiology, stress (VIS-NIR)		
SR, NDVI, EVI, SAVI, ARVI ARI1, ARI2, mARI, CRI1, CRI2 PRI, RVSI mSR705, NDVI705, MCARI VOG1, VOG2, VOG3 VIgreen, VARIgreen, CIrededge PSRI, NDII	Blue-D,W,A,As Red-D,W,A,As	BE-Wvl,Mag,DArea GP-Wvl,Refl YE-Wvl,Mag,DArea RW-Wvl,Refl RE-Wvl,Mag,DArea
Water and structure (NIR)		
WBI NDWI MSI	EWT NIR1-D,W,A,As NIR2-D,W,A,As	NE1-Wvl,Mag NE2-Wvl,Mag
Lignin, cellulose, nitrogen (SWIR)		
CAI NDLI NDNI	SWIR1-D,W,A,As SWIR2-D,W,A,As SWIR3-D,W,A,As	SE-Wvl,Mag

Wvl = wavelength, Mag = derivative magnitude, Refl = percent reflectance, D = depth, W = width, A = area (width x depth), As = Asymmetry.

86 metrics per season

Spring, Summer, & Fall

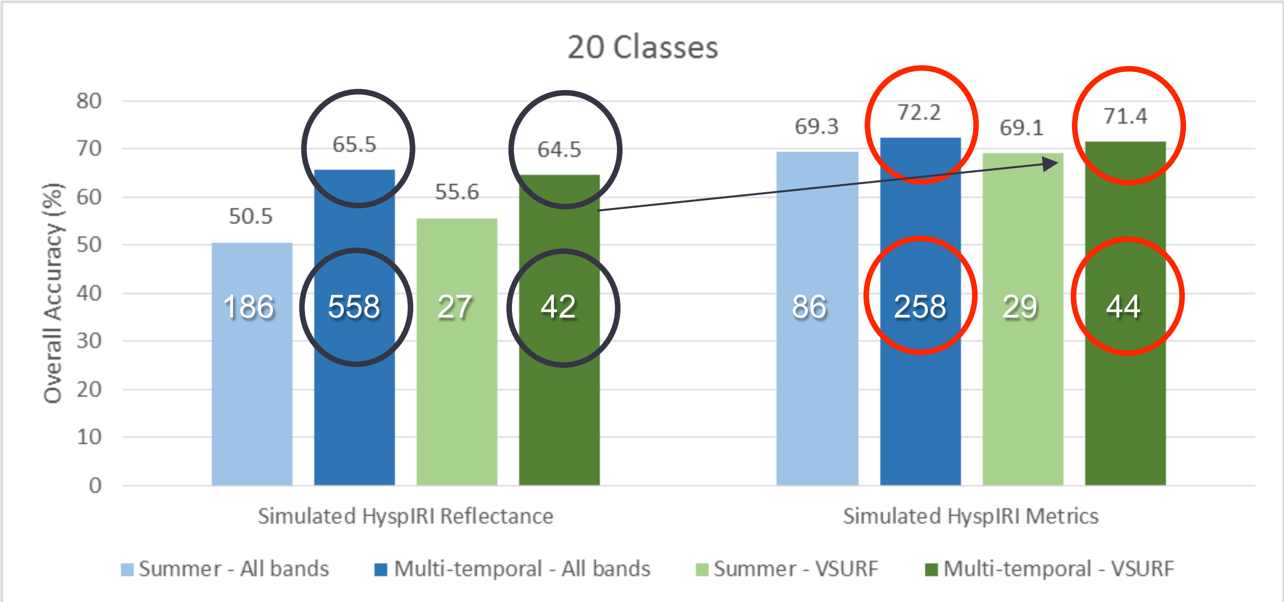
Results

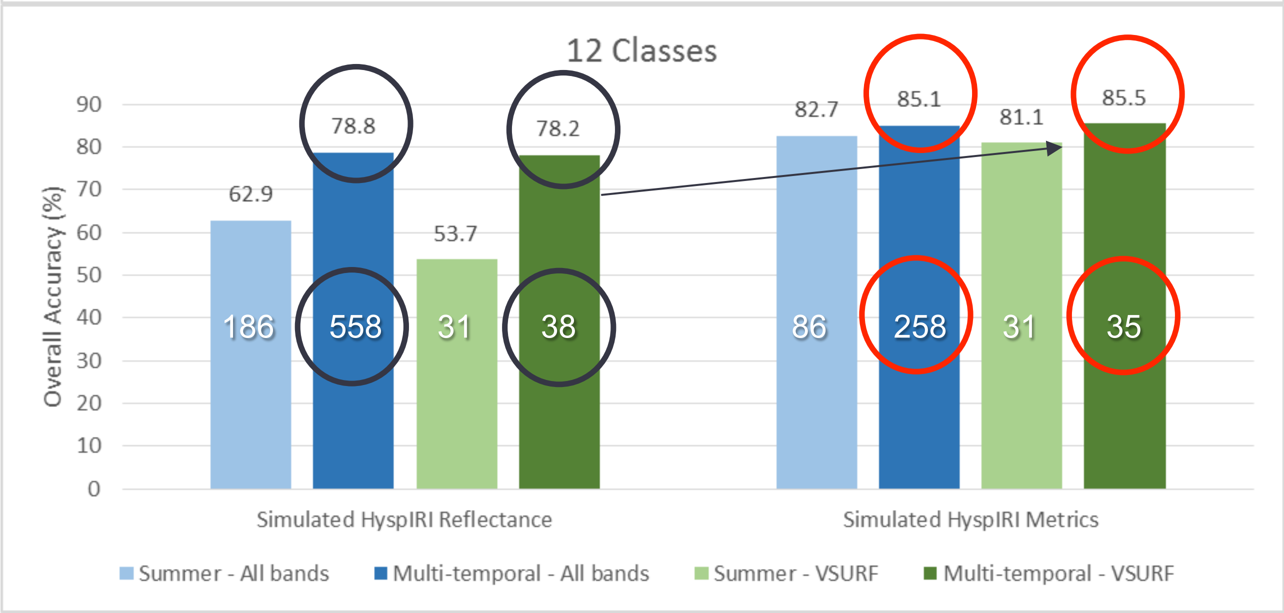
	MNF		Reflectance		Hyperspectral Metrics	
Classes	Summer	Multi-temp	Summer	Multi-temp	Summer	Multi-temp
20	41.2	55.8	50.5	65.5	69.3	72.2
12	52.0	68.5	62.9	78.8	82.7	85.1

<u>All variables in Random Forests, no optimization</u>

- MNF = 100 summer, 100 three seasons
- Reflectance = 186 summer, 558 three seasons
- Metrics = 86 summer, 258 three seasons

Effect of Variable Selection

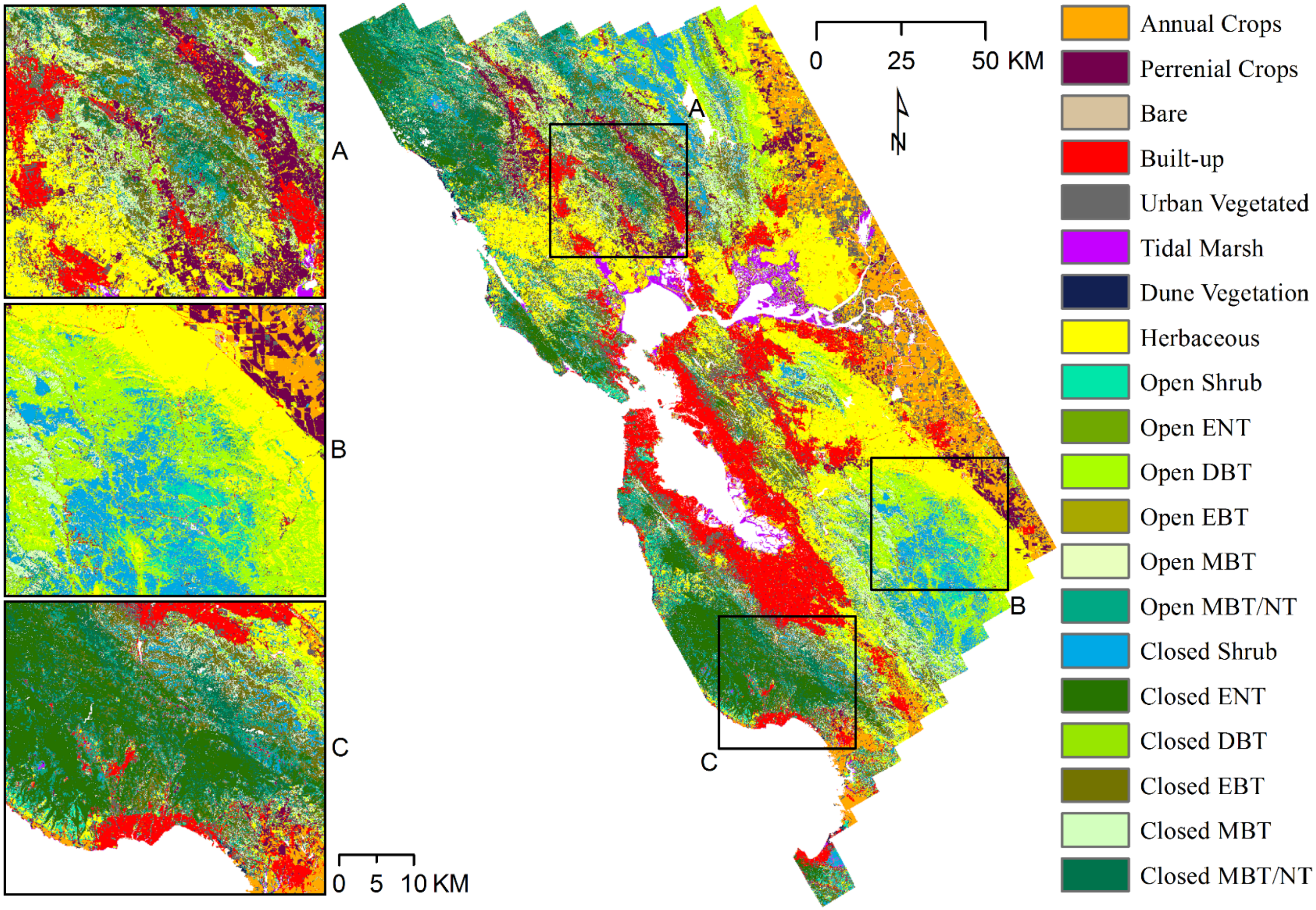




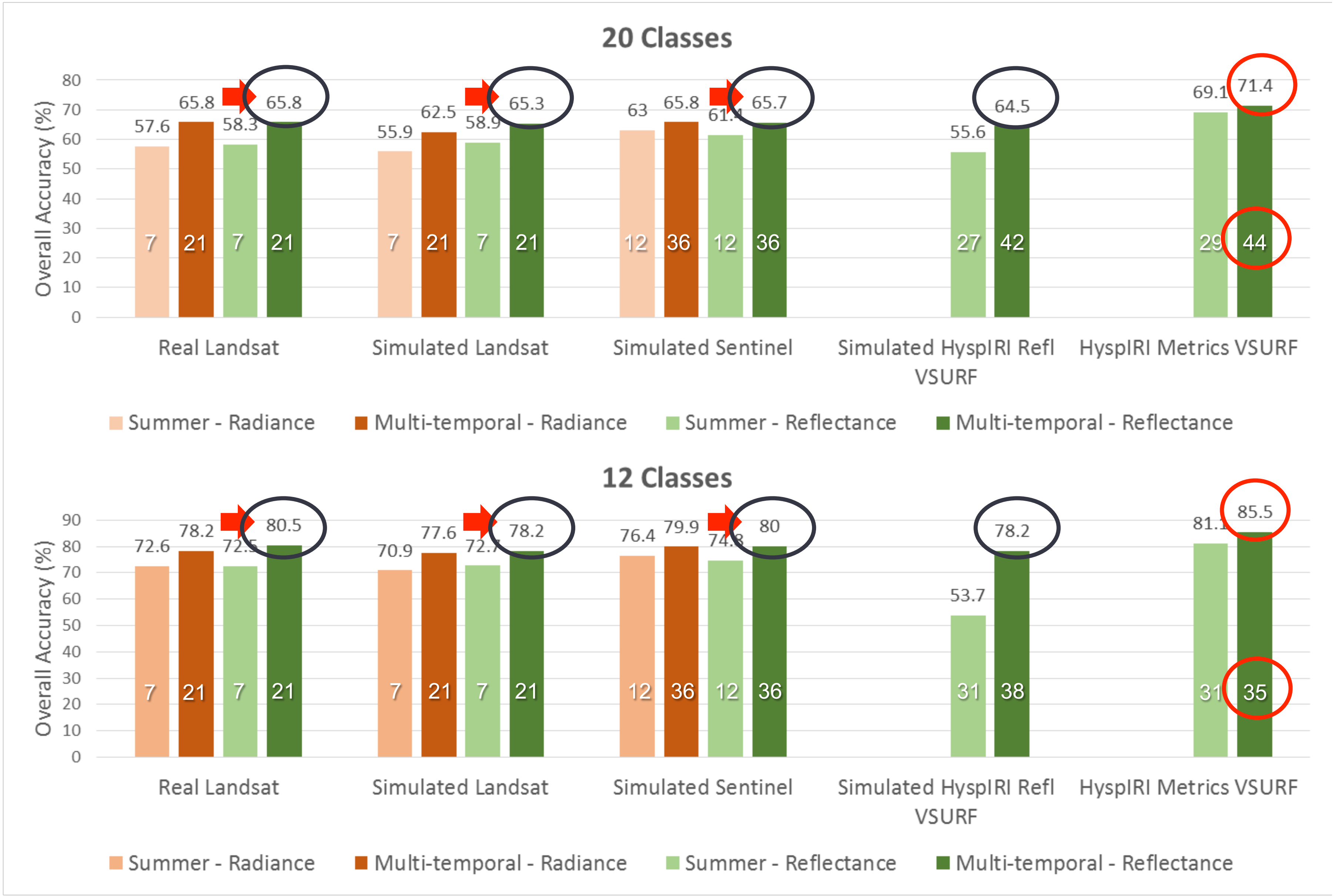
# of variables in RF

R package VSURF = Variable Selection Using Random Forests, Genuer et al., 2015

20 classes – Multi-temp, HyspIRI metrics



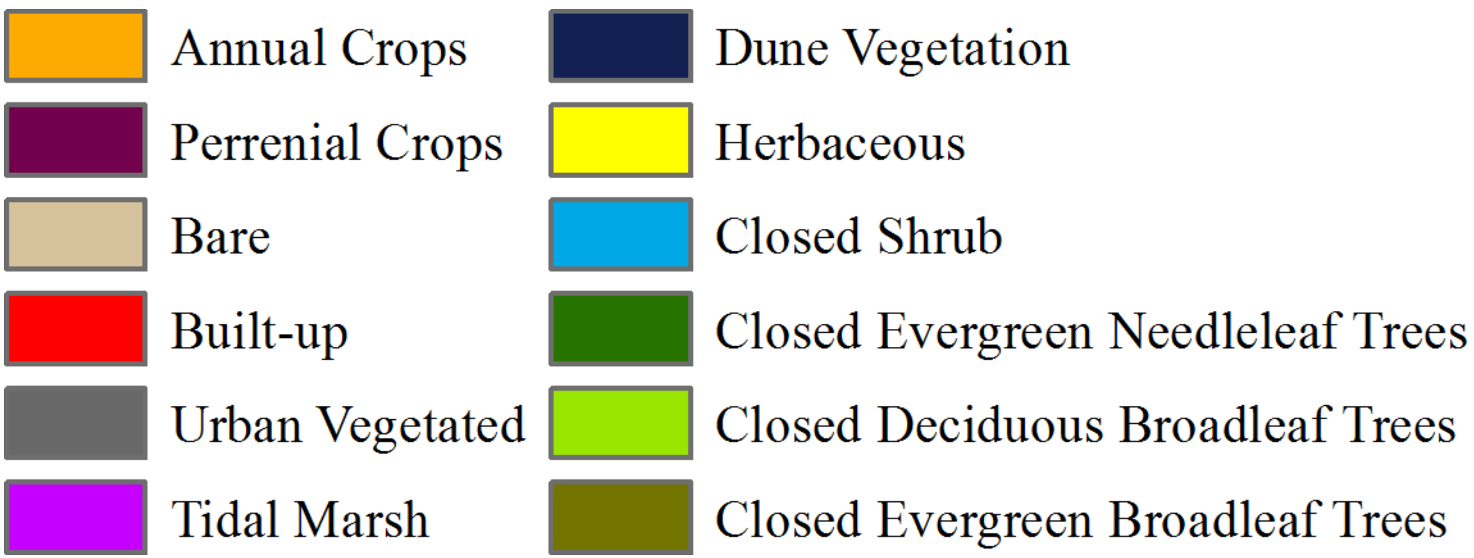
HyspIRI compared to Landsat and Sentinel



MESMA

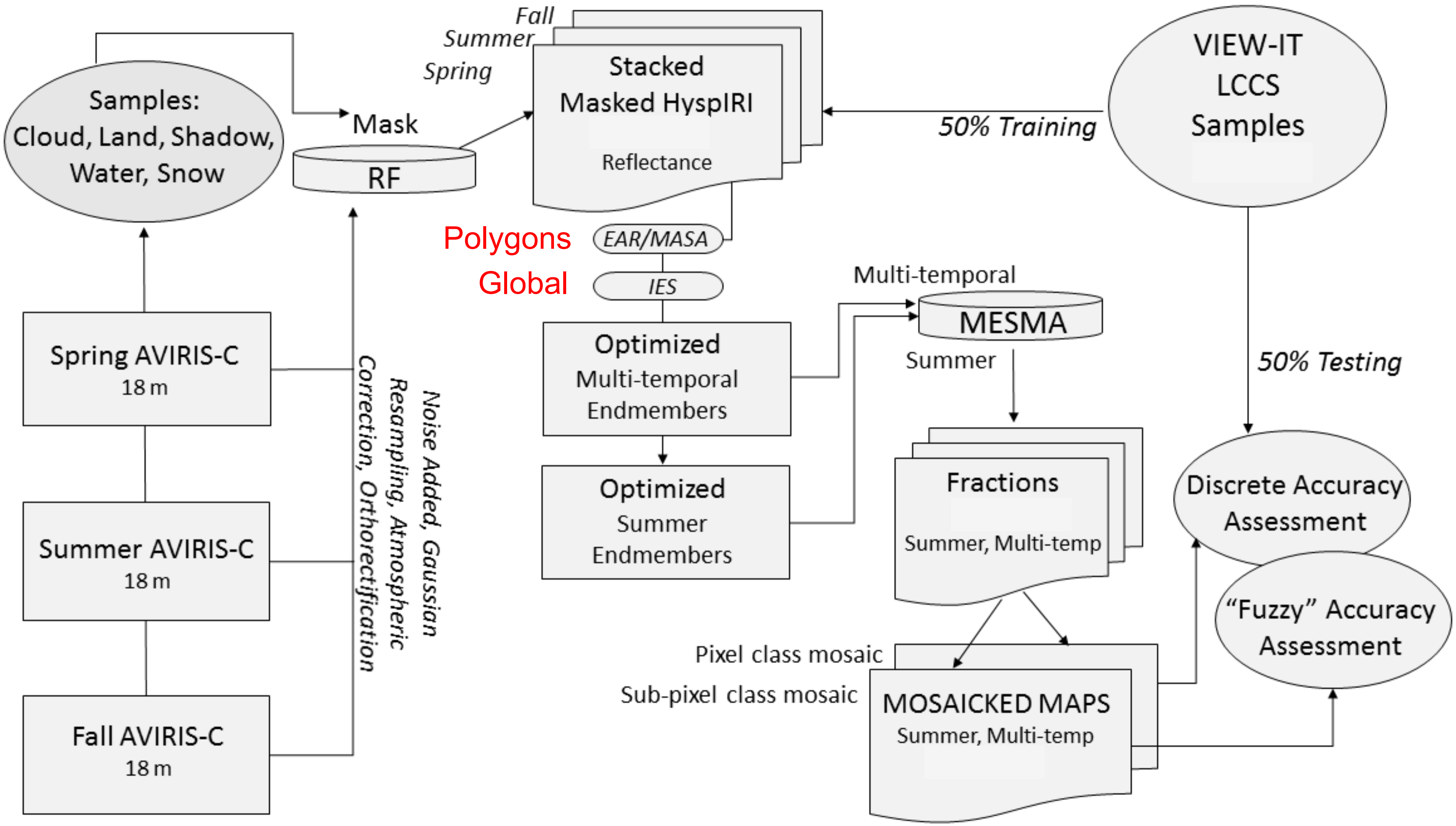
Analysis by Nina Kilham

Endmembers



VIEW-IT training samples with ≥ 90% cover of one type selected

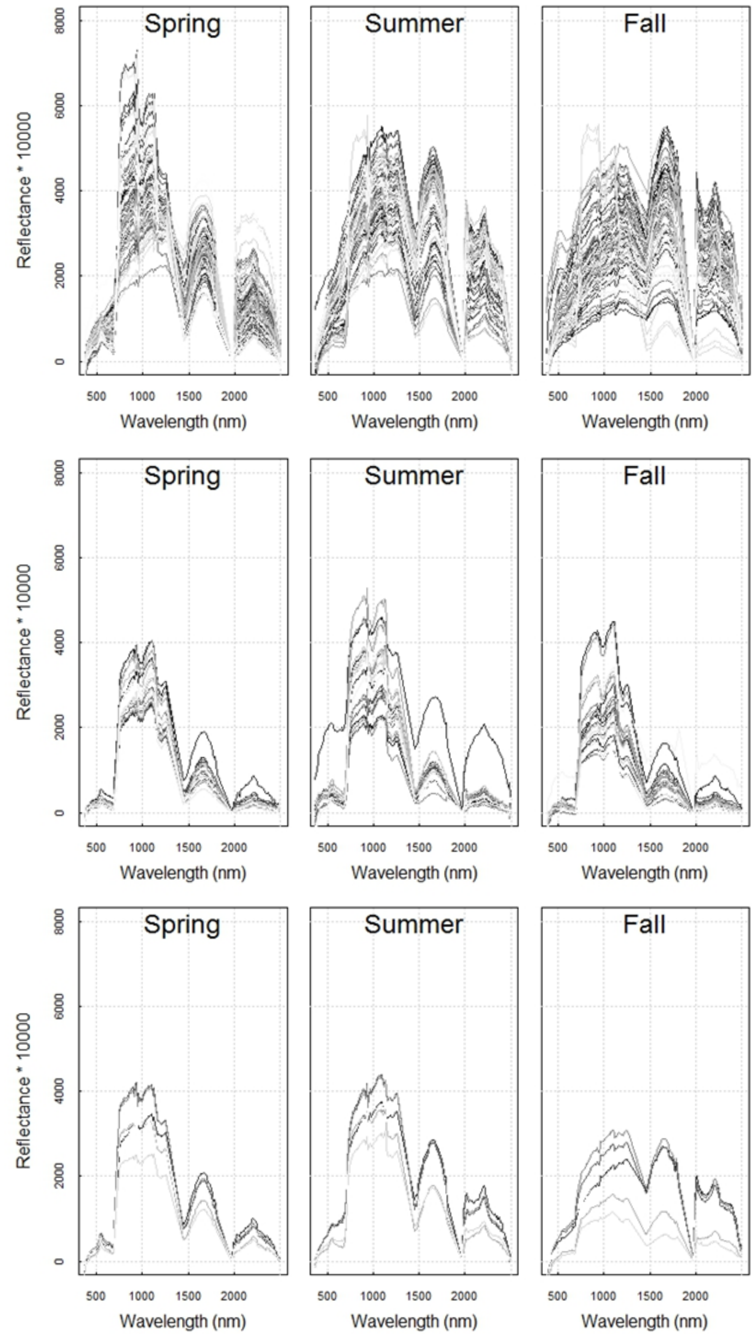
MESMA



ViperTools 2.0 with 2- to 3-EM models – shade & 1-2 other EMs

Image endmembers optimized using EAR/MASA and Iterative Endmember Selection (IES)

Summer and three seasons analyzed separately, no band selection

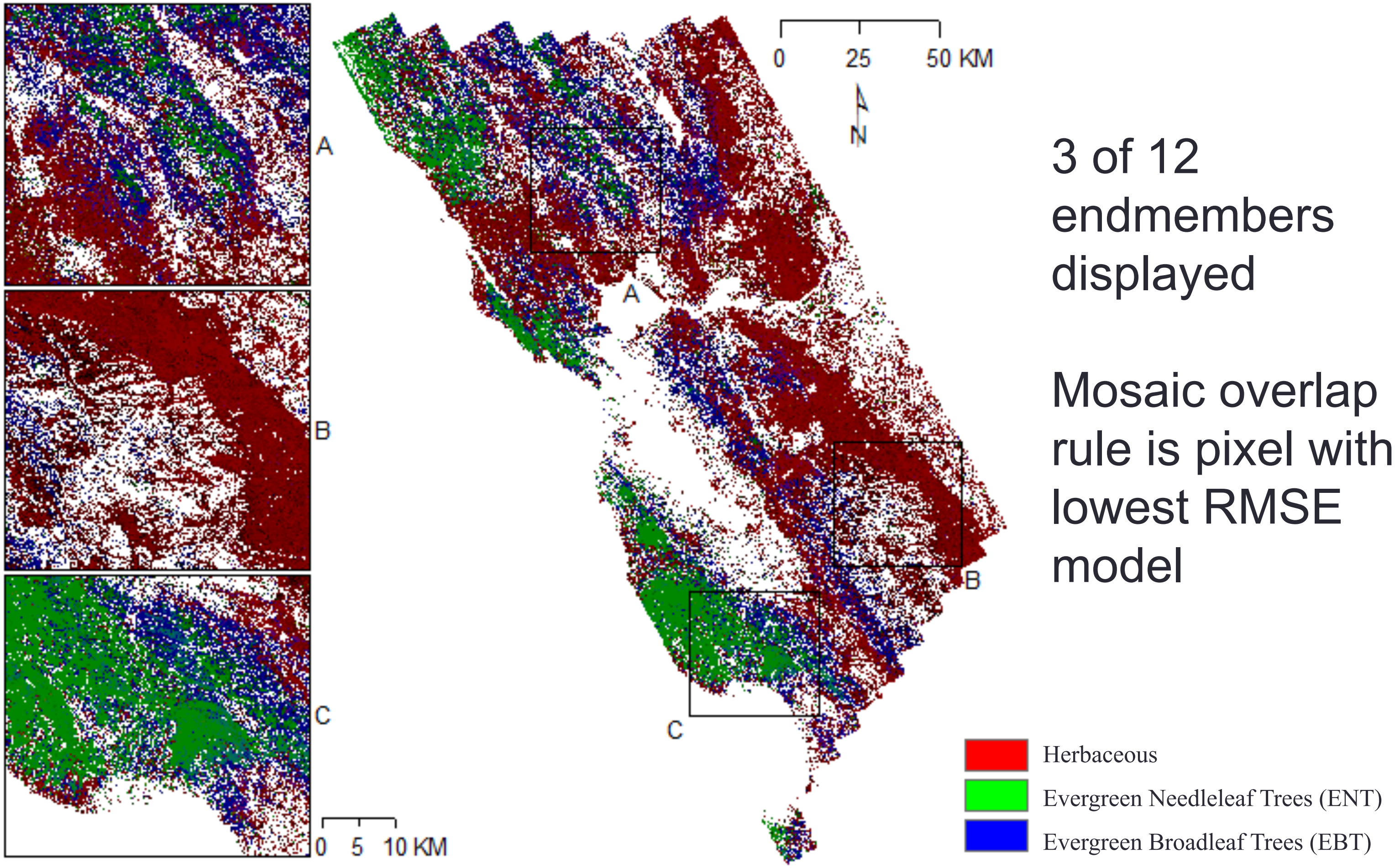


Herbaceous

Evergreen Needleleaf Trees

Deciduous Broadleaf Trees

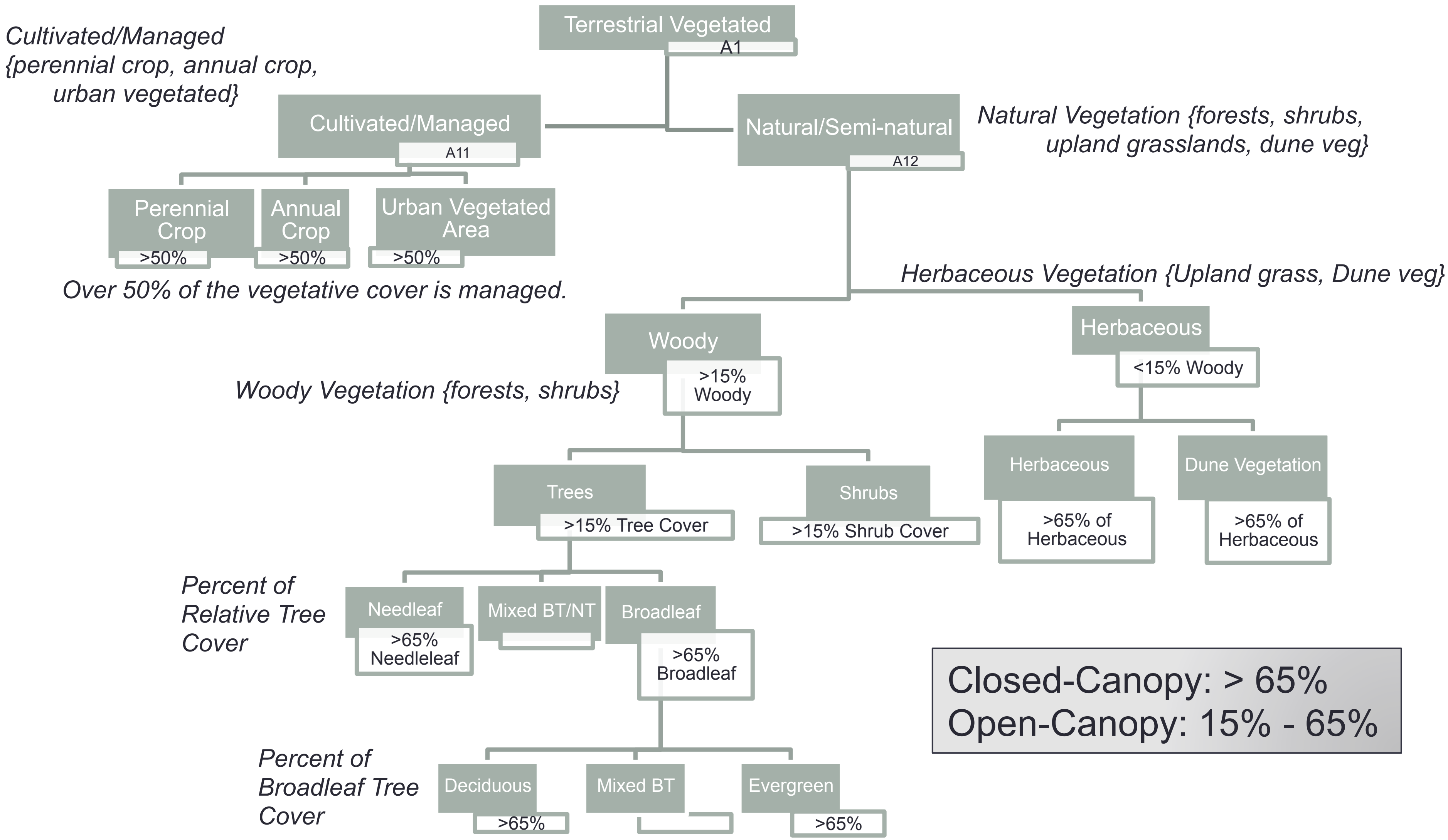
MESMA fraction images



3 of 12 endmembers displayed

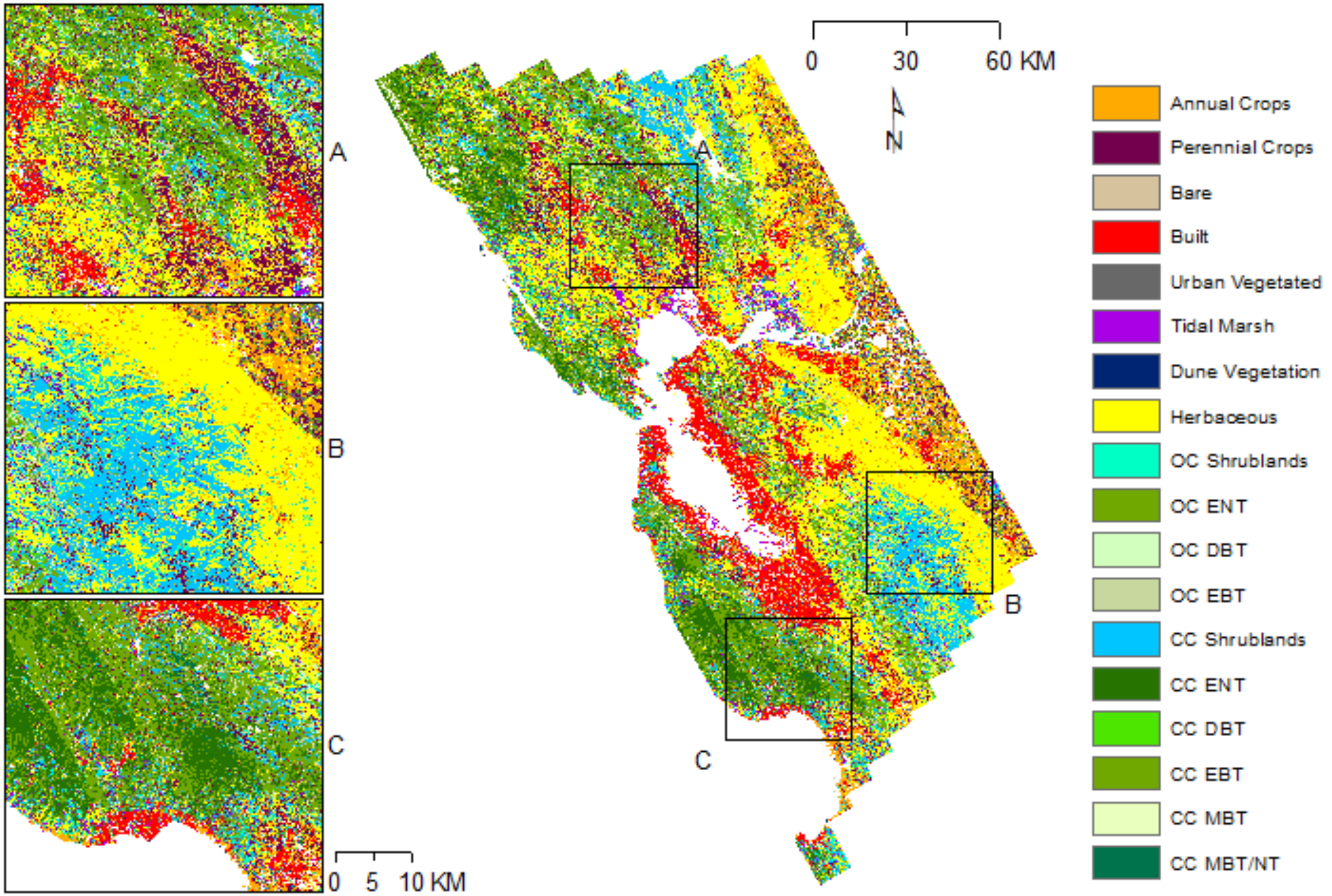
Mosaic overlap rule is pixel with lowest RMSE model

Fractional abundance to LCCS classes



MESMA Classification

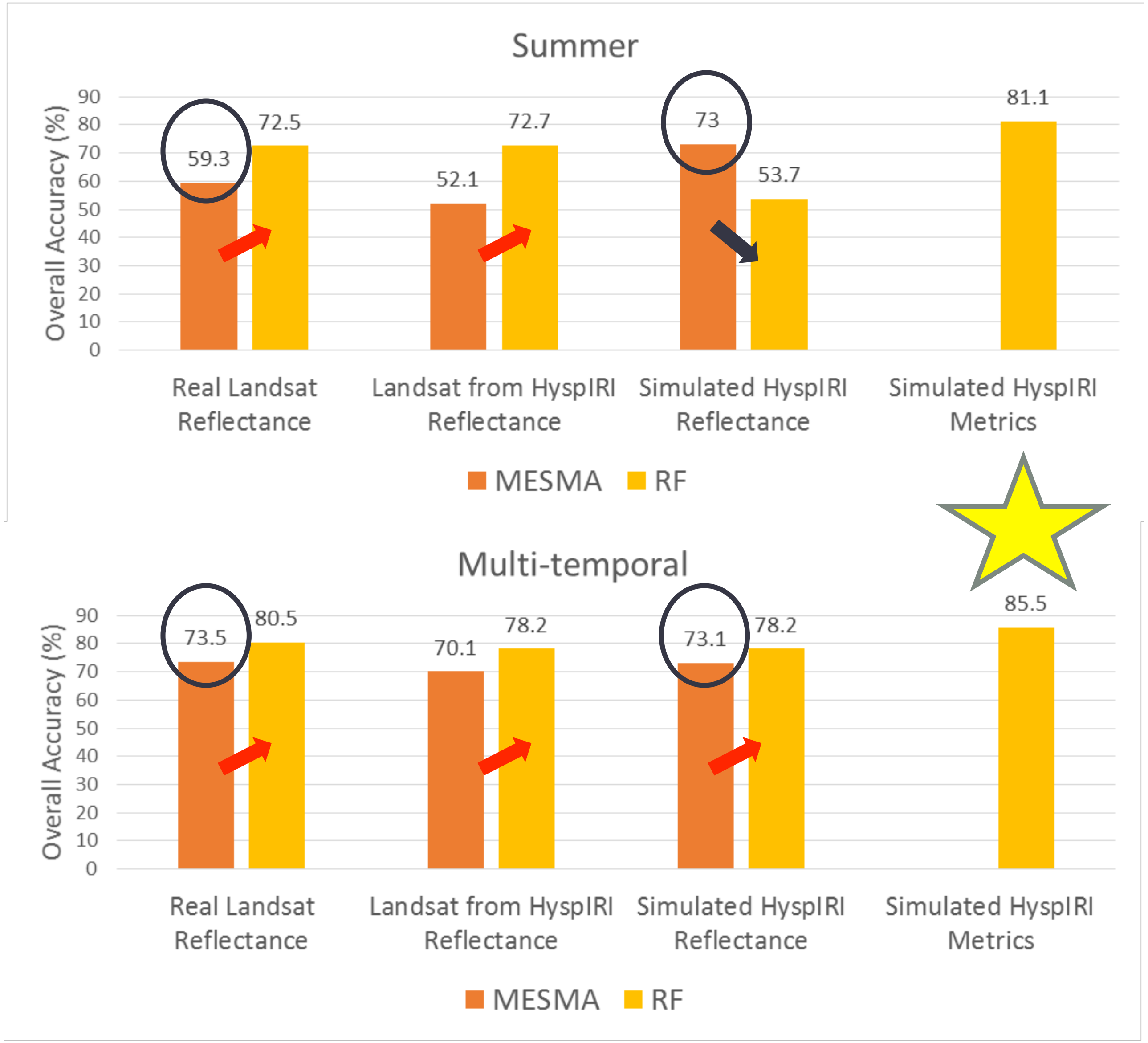
Lowest RMSE model in scene overlap



12 Classes

Dominant Plant Functional Types

No Open-canopy or Mixed Forests



VSURF optimization for HyspIRI Random Forests

Simulated HyspIRI Summary

- Random Forests
  - Multi-temporal, metrics produced best results
    - 72.2% (20 class)
    - 85.5% (12 class)
  - Metrics significantly better than reflectance or MNF bands
  - FAST - <1 day (although computing metrics & VSURF slow)
- MESMA – 12 classes
  - No benefit for multi-temporal data with MESMA (as implemented)
  - MESMA maps more heterogeneous (pixelated)
  - RF multi-temporal metrics had 12.4% higher accuracy
  - SLOW - days, even with multi-threaded processing

Comparison to Multispectral Sensors

- Random Forests (HyspIRI, Landsat, Sentinel)
  - Multispectral accuracy also benefited from multi-temporal data
  - With 12 or 20 classes,
    - HyspIRI reflectance roughly equivalent to broadband, multispectral sensors (real & simulated)
    - However, ~5% boost in accuracy with HyspIRI metrics
- MESMA (HyspIRI, Landsat)
  - Large (+13-20%) increase in accuracy with multi-temporal data for Landsat, but not HyspIRI
  - Multi-temporal real Landsat and HyspIRI had the same accuracy
  - MESMA had 5-8% lower accuracy than equivalent Random Forests tests

Take home messages

- Multi-temporal data from satellites - phenology
- Machine learning with key hyperspectral metrics that target vegetation biochemistry, structure, and phenology outperforms Landsat and Sentinel by <u>5% or better</u>
- Metrics are possible due to many narrow, contiguous bands in hyperspectral data
- Machine learning finds optimal variables (importance ranks are interesting as well!)
- Spectral Mixture Analysis may not be best approach for broad-scale land-cover mapping
- Compare results to multispectral satellites over large areas (<u>Land-cover community wants more Landsats!)</u>

EXTRA SLIDES

Indices

Region	*Metric*	*Spring*	*Summer*	*Fall*
VNIR	SR			
VNIR	mSR705			
VNIR	NDVI			
VNIR	mNDVI705			
VNIR	NDVI705			
VNIR	SAVI			
VNIR	PRI			
VNIR	EVI			
VNIR	ARVI			
VNIR	RVSI			
VNIR	NDII			
VNIR	VOG1			
VNIR	VOG2			
VNIR	PSRI			
VNIR	CRI1			
VNIR	CRI2			
VNIR	ARI1			
VNIR	ARI2			
VNIR	mARI			
VNIR	VIgreen			
VNIR	VARIgreen			
VNIR	CIrededge			
VNIR	MCARI			
NIR	WBI			
NIR	NDWI			
NIR	MSI			
SWIR	NDNI			
SWIR	NDLI			
SWIR	CAI			

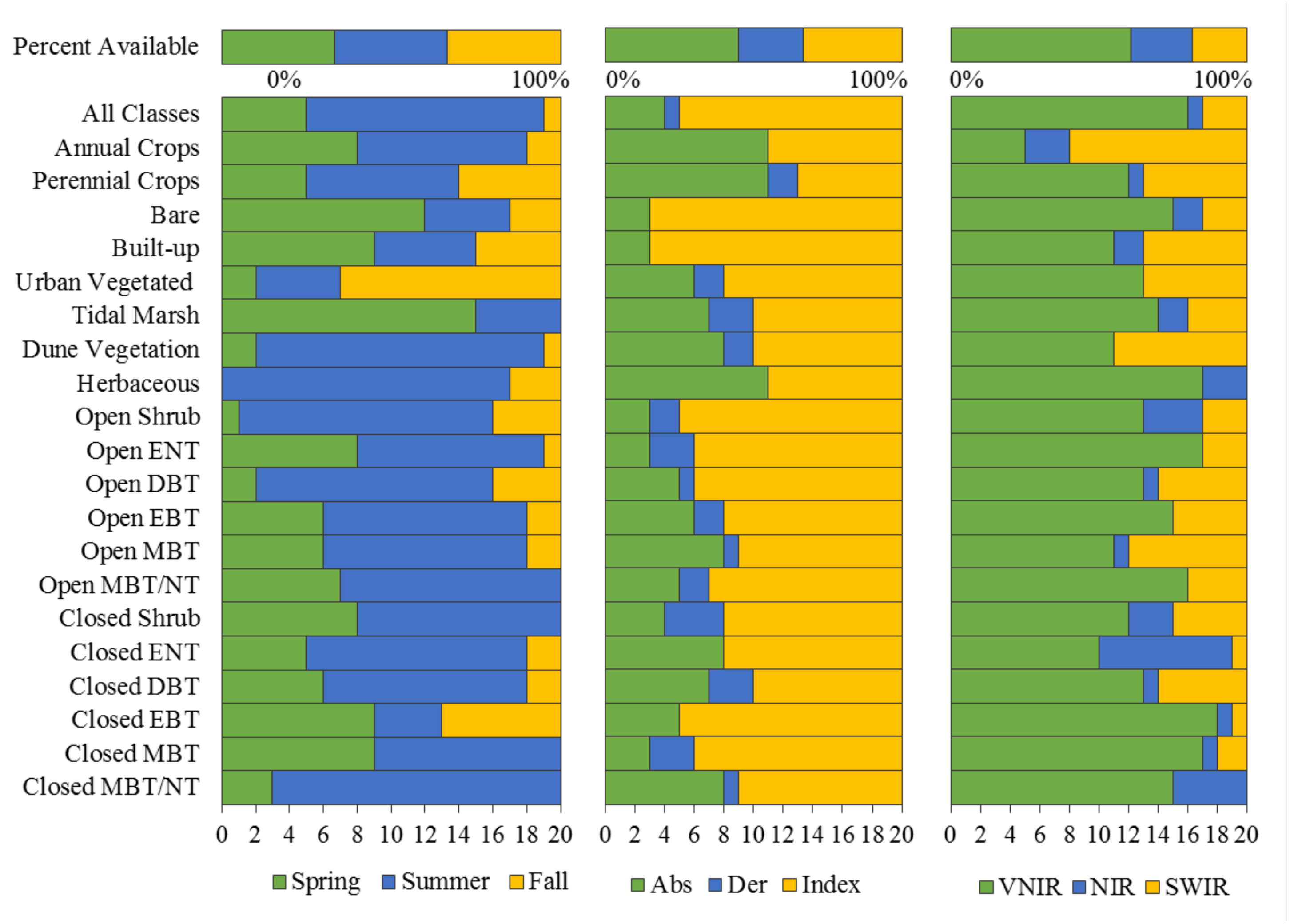
Absorption-based

Region	*Metric*	*Spring*	*Summer*	*Fall*
VNIR	Blue-Wvl			
VNIR	Blue-D			
VNIR	Blue-W			
VNIR	Blue-A1			
VNIR	Blue-A2			
VNIR	Blue-As			
VNIR	Red-Wvl			
VNIR	Red-D			
VNIR	Red-W			
VNIR	Red-A1			
VNIR	Red-A2			
VNIR	Red-As			
NIR	EWT			
NIR	NIR1-Wvl			
NIR	NIR1-D			
NIR	NIR1-W			
NIR	NIR1-A1			
NIR	NIR1-A2			
NIR	NIR1-As			
NIR	NIR2-Wvl			
NIR	NIR2-D			
NIR	NIR2-W			
NIR	NIR2-A1			
NIR	NIR2-As			
NIR	NIR2-A2			
SWIR	SWIR2-Wvl			
SWIR	SWIR2-D			
SWIR	SWIR2-W			
SWIR	SWIR2-A1			
SWIR	SWIR2-A2			
SWIR	SWIR2-As			
SWIR	SWIR3-Wvl			
SWIR	SWIR3-D			
SWIR	SWIR3-W			
SWIR	SWIR3-A1			
SWIR	SWIR3-A2			
SWIR	SWIR3-As			

Derivative

Region	*Metric*	*Spring*	*Summer*	*Fall*
VNIR	BE-Wvl			
VNIR	GP-Wvl			
VNIR	YE-Wvl			
VNIR	RW-Wvl			
VNIR	RE-Wvl			
VNIR	NE1-Wvl			
VNIR	NE2-Wvl			
VNIR	SE-Wvl			
VNIR	BE-Mag			
VNIR	GP-Rfl			
VNIR	YE-Mag			
VNIR	RW-Refl			
VNIR	RE-Mag			
VNIR	RE-DArea			
VNIR	DZ1DGVI			
VNIR	DZ2DGVI			
VNIR	BE-DArea			
VNIR	YE-DArea			
NIR	NE1-Mag			
NIR	NE2-Mag			
SWIR	SE-Mag			

Important metrics



Abs = absorption-fitting Der = derivative Index = narrowband indices

RF User and Producer Accuracy