Pixels to Embeddings

AI for Geo Spatial Remote Sensing Data

Moving from processing individual tiles to global-scale "Vector Databases"

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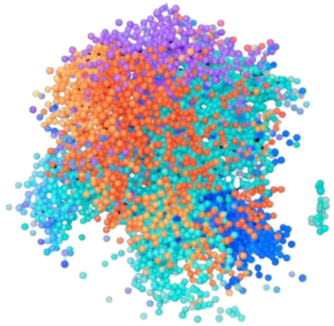
What Are Remote Sensing Embeddings?

Embeddings are not satellite imagery themselves; rather, they are a **numerical representation** or *compression* of the vast data within satellite and Earth observation imagery. They function like AI-powered pixels that make complex geospatial data analysis-ready for machine learning models.

Traditional remote sensing relies on spectral signatures (pixel values), while AI relies on **latent representations**.

Pixels to Embeddings

Aspect	Raw Imagery	Embeddings
Size	Very large	Compact
Interpretability	Low	High (features)
ML readiness	Requires preprocessing	Ready for ML
Cross-sensor Use (Interoperability)	Limited	Highfusion (optical + SAR + LiDAR).
Aspect	Raw Imagery	Embeddings



Ready-to-use, globally pre-computed embedding datasets that summarize complex data into compact numerical vectors, ideal for downstream tasks like classification or clustering.

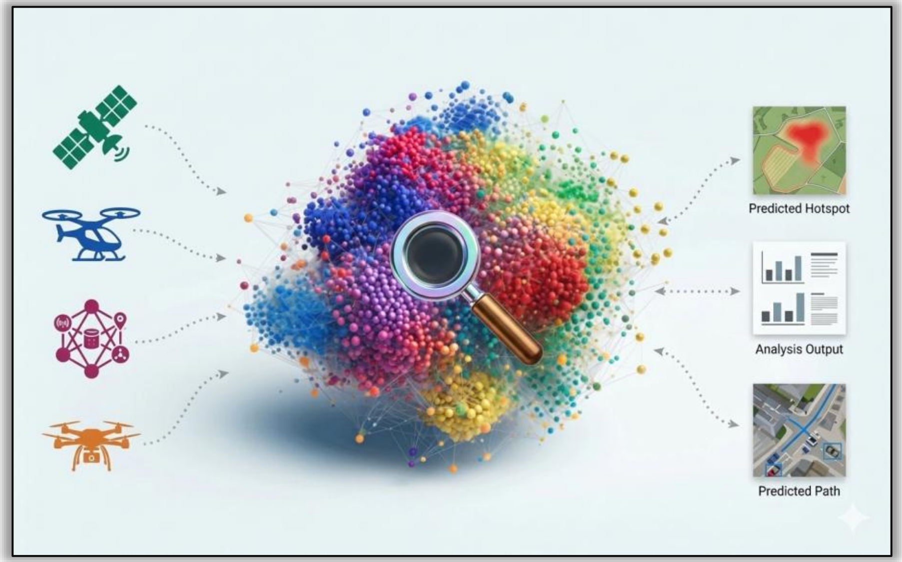
Multi-Source Remote Sensing Data

Embeddings unify the following into a **single numerical representation**

ISRO's multisource remote sensing provides comprehensive Earth observation data that can be harnessed for embedding generation and advanced analytical applications.

Spanning :

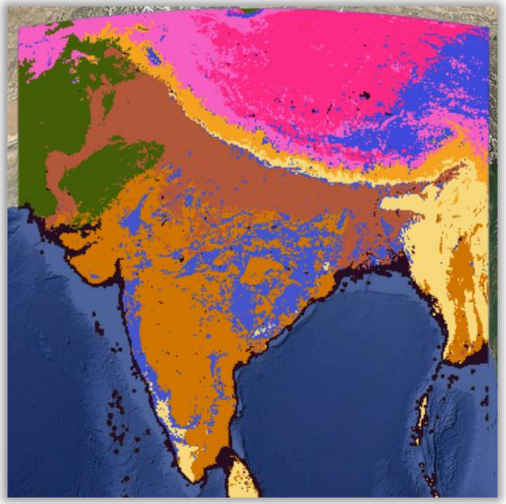
- ✓ *Optical Imagery*
- ✓ *Microwave Imagery*
- ✓ *Hyperspectral Imagery*
- ✓ *LiDAR , UAV and Aerial imagery*
- ✓ *Meteorological Data*



Advantages of Using Embeddings

- ✓ Beyond the Metadata Bottleneck: Semantic Search
- ✓ Zero-Label Intelligence (Self-Supervised Power (Zero/Few shot detection)
- ✓ Native Multi-Sensor interoperability Fusion (Latent Alignment)
- ✓ Reduction in Computational Costs
- ✓ Capture subtle land-cover differences and Support real-time decision-making (disaster response, crop monitoring).

- ✓ Temporal Trajectory Analytics
- ✓ Edge-to-Cloud Efficiency



Standardized Embedding Catalog (STAC to STAC-V)

The Data Deluge for smarter Search

- **STAC + Vectors:** To make these AI insights discoverable, we must move beyond the SpatioTemporal Asset Catalog **(STAC) as just a metadata provider**. The next step is **Vector-Enabled (STAC-V)** serves as a **Semantic Index**, transforming static metadata into a searchable, multidimensional "knowledge map" of the Earth's surface.

- While **STAC** tells you where and when an image was taken, **STAC-V** encapsulates what is actually inside the pixels by embedding their features into a unified latent space. This shifts the workflow from manual data discovery to automated machine reasoning.

- **The Technical Edge:** Traditional methods of searching and analysing this data, manual inspection, keyword searches which rely on often incomplete metadata, and cumbersome compute heavy analysis are slow, inefficient, and often miss crucial insights

- **The Interop Win:** A model trained by one organization can output an embedding that an application built by another organization immediately understands, provided they share a common **Foundation Model** (like IBM/NASA's Prithvi or Microsoft's Clay).

Work Flow- Pixels vs Embeddings

Capability	**Pixel-Based Workflow**	**Embedding-Based Workflow (STAC-V)**
Search Basis	Metadata (Keywords)	Semantics (Meaning/Similarity)
Data Handling	Full Raster Processing	Vector-Based Proximity Search
Sensor Fusion	Hard (Requires Calibration)	Native (Latent Space Alignment)
Analysis Speed	Linear (Scan all pixels)	Logarithmic (Vector Indexing)

Connecting Embeddings to AI-Ready Geo Spatial Data

Modern AI systems require **standardized, structured, and machine-interpretable data**.

Raw satellite imagery is **too large, complex, and heterogeneous** for direct AI consumption.

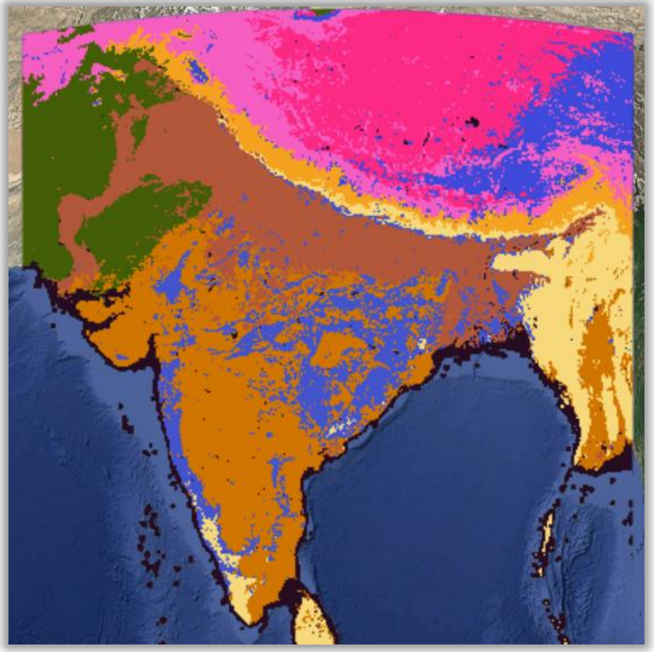
Remote sensing embeddings transform raw imagery into **AI-ready data** by:

- ✓ Converting pixels into compact numerical vectors
- ✓ Encoding spatial, spectral, and temporal patterns
- ✓ Harmonizing data from multiple sensors (optical, SAR, LiDAR, hyperspectral)

This makes embeddings the **foundation layer** for scalable geospatial AI, analytics, and automation.

Embeddings by AEF

2023



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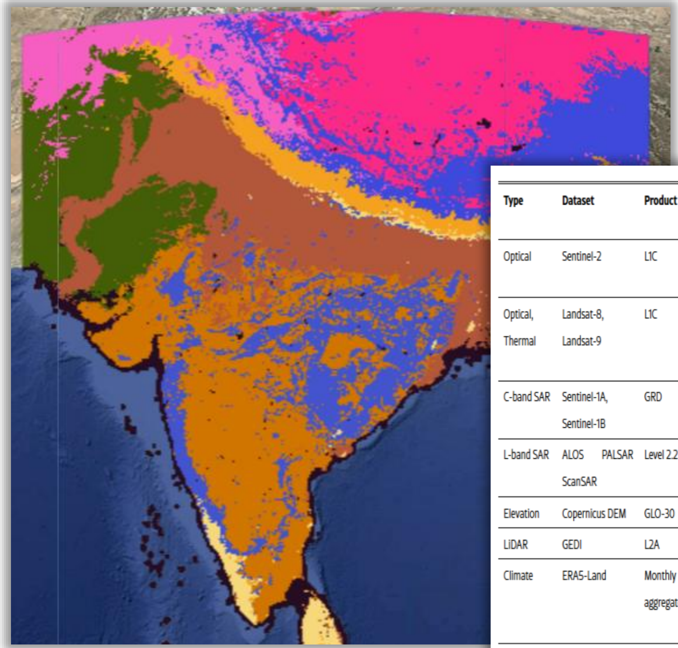


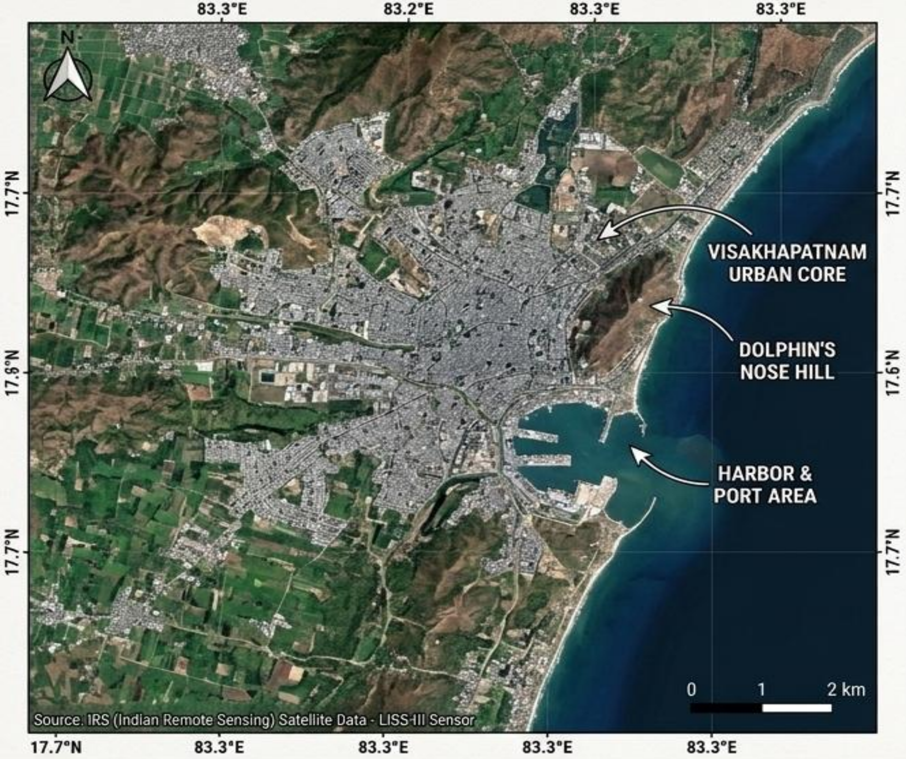
Type	Dataset	Product	Bands	Resolution (m)	Usage
Optical	Sentinel-2	L1C	B2 (Blue), B3 (Green), B4 (Red), B8 (NIR), B11 (SWIR)	10, 20, 60	input, target
Optical, Thermal	Landsat-8, Landsat-9	L1C	B2 (Blue), B3 (Green), B4 (Red), B5 (NIR), B6 (SWIR), B8 (Panchromatic), B10 (Thermal)	15, 30, 100	input, target
C-band SAR	Sentinel-1A, Sentinel-1B	GRD	VV, VH, HH, HV, angle	10	input, target
L-band SAR	ALOS PALSAR ScanSAR	Level 2.2	HH, HV, lin	25	target
Elevation	Copernicus DEM	GLO-30	DEM (elevation)	30	target
LiDAR	GEDI	L2A	Relative height metrics (rh*)	25	target
Climate	ERA5-Land	Monthly aggregates	total precipitation (sum, min, max), air temperature 2m (and min, max), dewpoint temperature 2m (and min, max), surface pressure (and min, max)	11132	target
Gravity fields	GRACE	Monthly mass grids	equivalent liquid water thickness	11132	target (@50%)
Land cover	National Land Cover Database	NLCD 2019, 2021	landcover	30	target (@50%)

*Differences in color indicate **changes in land structure or use**.*

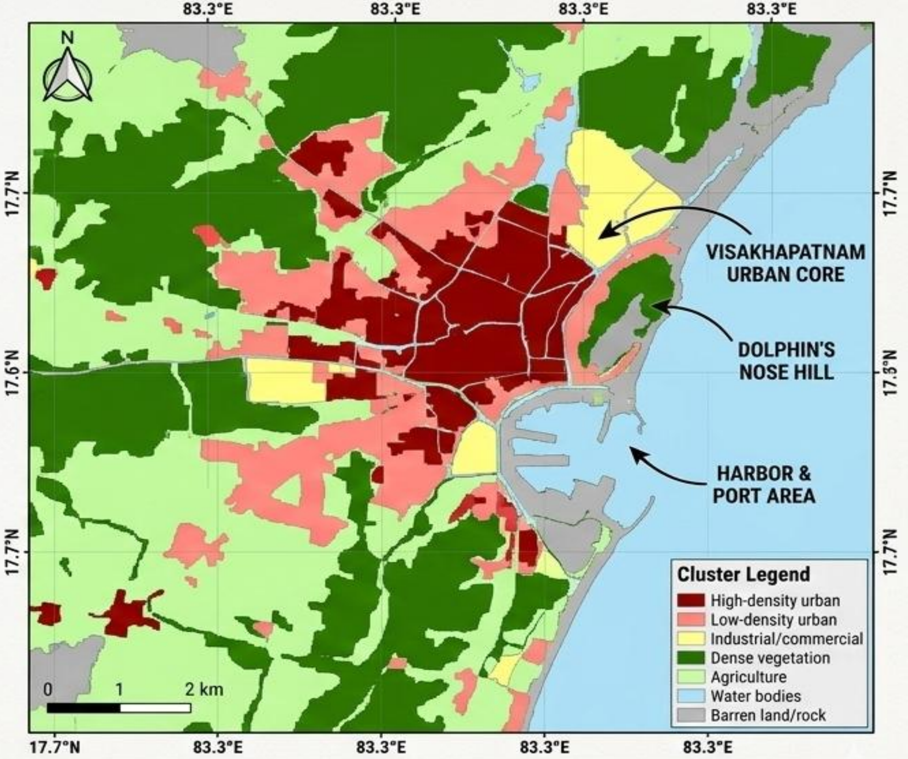
*The embedding representations were clustered into **10 clusters** to identify latent groupings in the data.*

SATELLITE IMAGE ANALYSIS: RAW LISS-III RGB vs. LAND-USE CLUSTER MAP (ANDHRA PRADESH REGION)

LEFT: RAW LISS-III RGB SATELLITE IMAGE (TRUE COLOR)



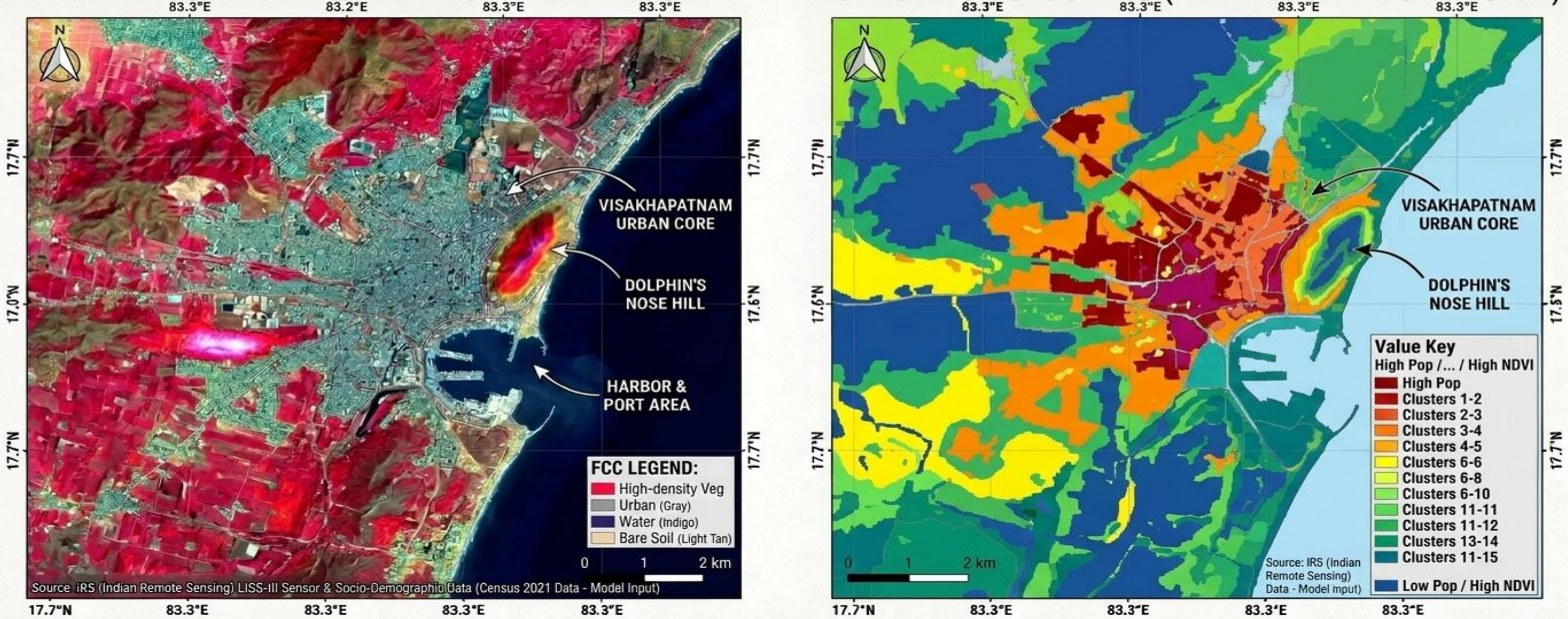
RIGHT: CLUSTER MAP (LAND-USE CLASSIFICATION)



The left panel displays the raw **LISS-III** true-color image of the coastal area. The right panel shows the automated cluster analysis, clearly segmenting distinct land-use types types like **dense urban areas** (reds) and natural landforms (greens), highlighting the **data's utility for urban planning in Andhra Pradesh**. Data provided by **ISRO**.

EMBEDDING ANALYSIS OF SATELLITE & SOCIO-DEMOGRAPHIC DATA

LEFT: FCC - MULTI-CHANNEL SATELLITE INPUT **15 DISTINCT CLUSTERS** (ANDHRA PRADESH REGION)

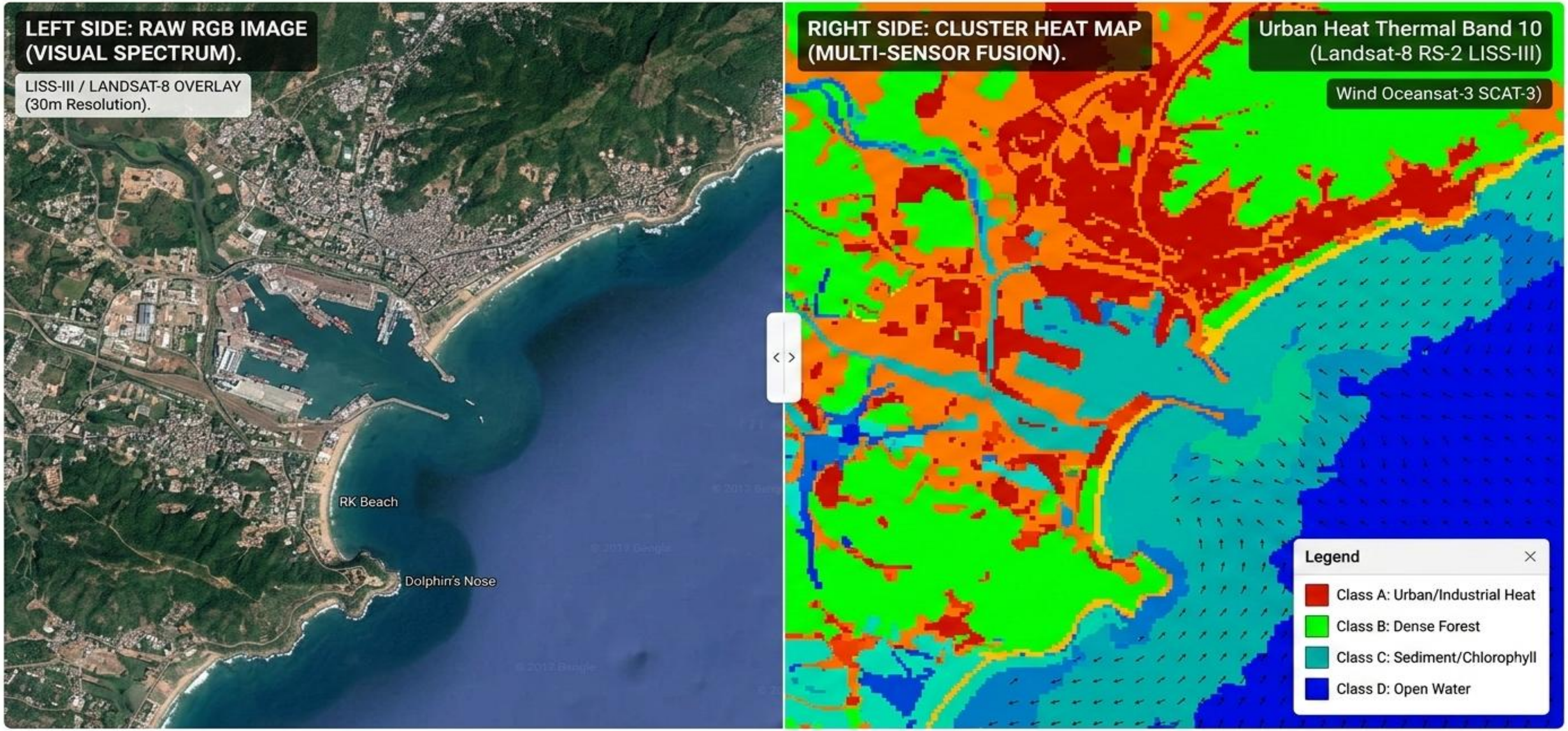


The left panel displays the region with FCC and a superimposed NDVI layer, highlighting vegetation vigor. The **right panel** shows an integrated 'data embedding' map, where multiple variables (NDVI, LST, and Population Density) are segmented into complex combined classes, providing a deeper analysis for resource and urban heat planning in Andhra Pradesh. Data provided by ISRO and secondary sources.

Legend Classification(Prev Slide)

Cluster Range	Type	Characteristics
1 - 4 (Deep Red/Orange)	**High Urban Stress**	High population density, high surface heat (LST), and nearly zero vegetation. (e.g., Visakhapatnam Core).
5 - 6 (Yellow/Light Orange)	**Suburban / Transition**	Moderate population, moderate heat, fragmented vegetation.
7 - 9 (Bright Green)	**Active Agriculture**	Low population, low heat, and very high NDVI (healthy crops/forests).
10 - 12 (Dark Green)	**Dense Natural Forest**	Deep forest cover, lowest surface temperatures, uninhabited. (e.g., Dolphin's Nose slopes).
13 - 14 (Gray/Tan)	**Barren / Industrial**	Low population, high heat, zero vegetation (e.g., port areas or rock outcrops).
15 (Deep Blue)	**Hydrological**	Water bodies (Harbor, Bay of Bengal).

VISAKHAPATNAM MULTI-SENSOR EMBEDDING MODEL V.1.0



Future Trend….

- ✓ Foundation models for Earth observation : A model trained by one organization can output an embedding that an application built by another organization immediately understands, provided they share a common **Foundation Model** (like IBM/NASA’s Prithvi or Microsoft’s Clay).
- ✓ Integration with **digital twins** of Earth.
- ✓ **Self-supervised learning** on global satellite archives having huge peta bytes of data.
- ✓ **Smarter Search** of GeoSpatial Data driven by AI
- ✓ Real-time embedding generation on edge devices.

*Remote sensing embeddings provide a **powerful, scalable, and intelligent way to represent Earth's surface**, enabling next-generation geospatial analytics.*

Thank You

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