HyspIRI Scaling Issues For Coastal Ocean Science

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The Aquatic Macrophyte Opportunities:

- **Floating kelp canopy provides a strong reflecting target**
  - **no overlying water column**

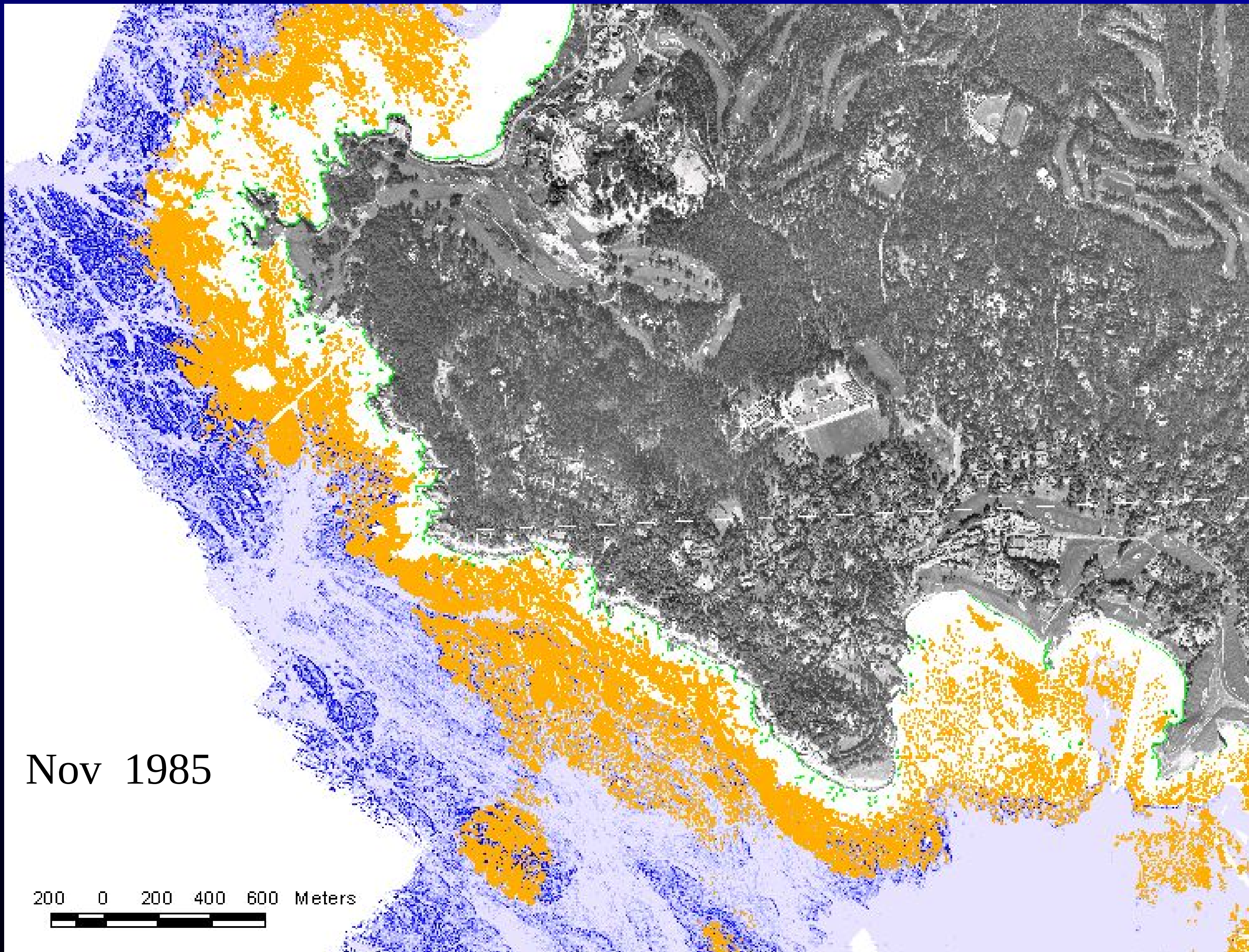
- **Seagrasses grow in optically shallow water – within the visible range of remote sensing**

How can we use imaging spectroscopy to remotely quantify abundance and productivity of giant kelp forests and seagrass meadows?

- **The need**
  - **Better understand and manage the dynamics of macrophyte "engineers" that define ecosystems**
- **The challenge**
  - **Distribution**
    - **Patchy across time and space**
    - **Bounded by land (bright pixels) and deep water (dark pixels)**
  - **Water depths and optical properties are highly variable**
- **The opportunity for repeated coverage**
  - **Temporal dynamics of populations**
  - **Coastal biogeochemistry – C, N, P**

Giant Kelp abundance is dynamic across time and space

- Oceanographic Conditions
  - Storm-dependent mortality
    - Winter on central coast
  - Nutrient limtation
    - Summer in Southern California
  - Urchin-related barren grounds that persist for years



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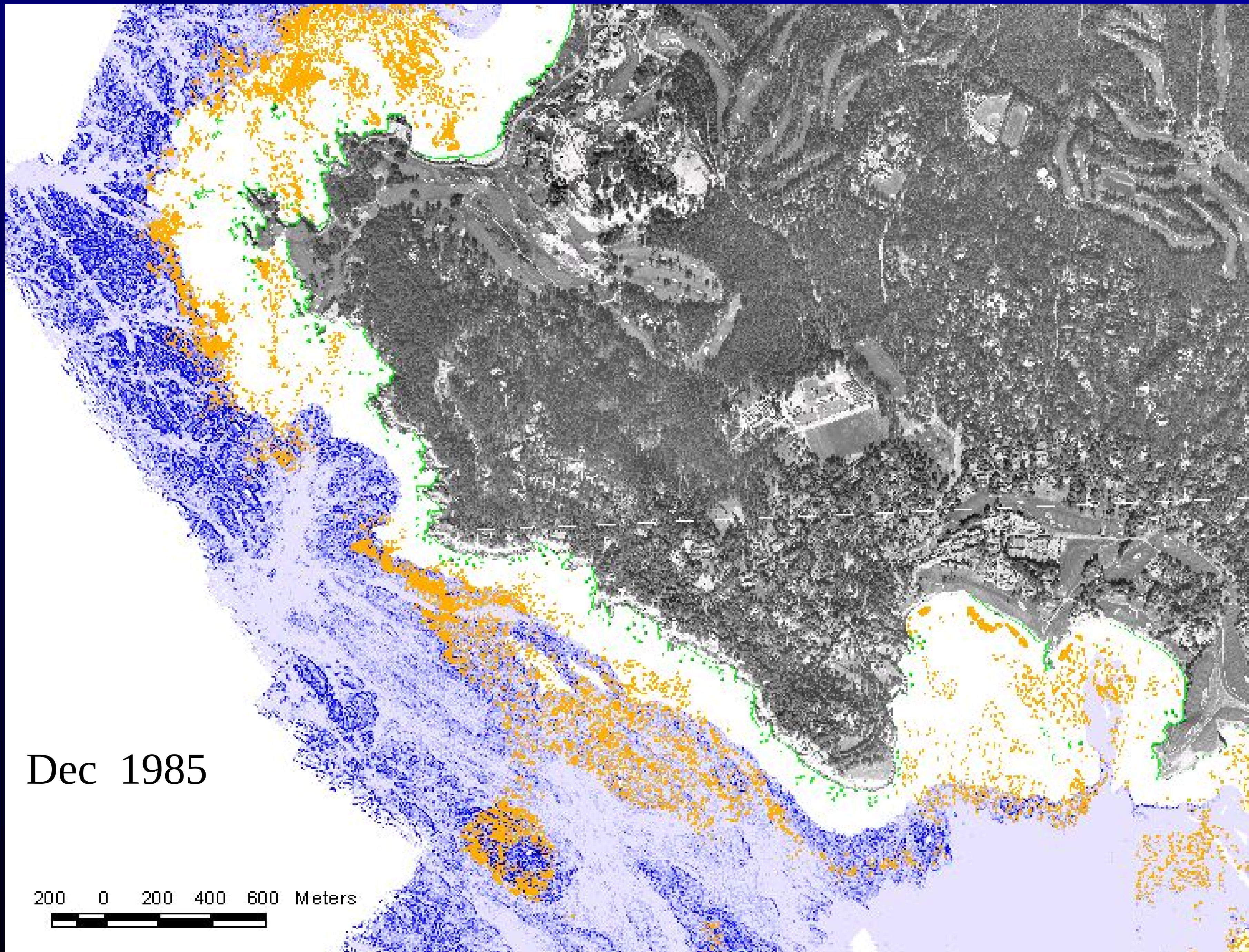

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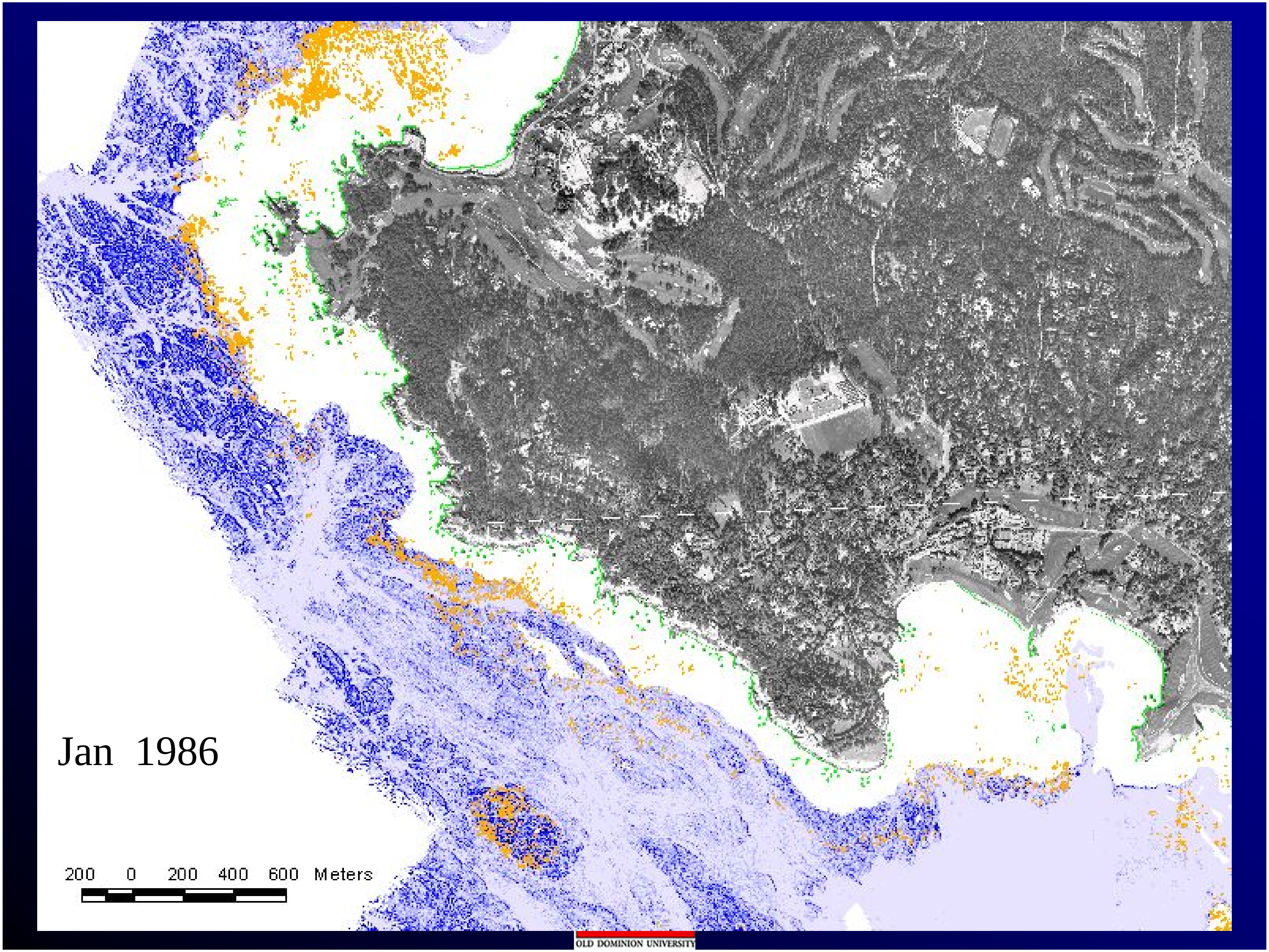
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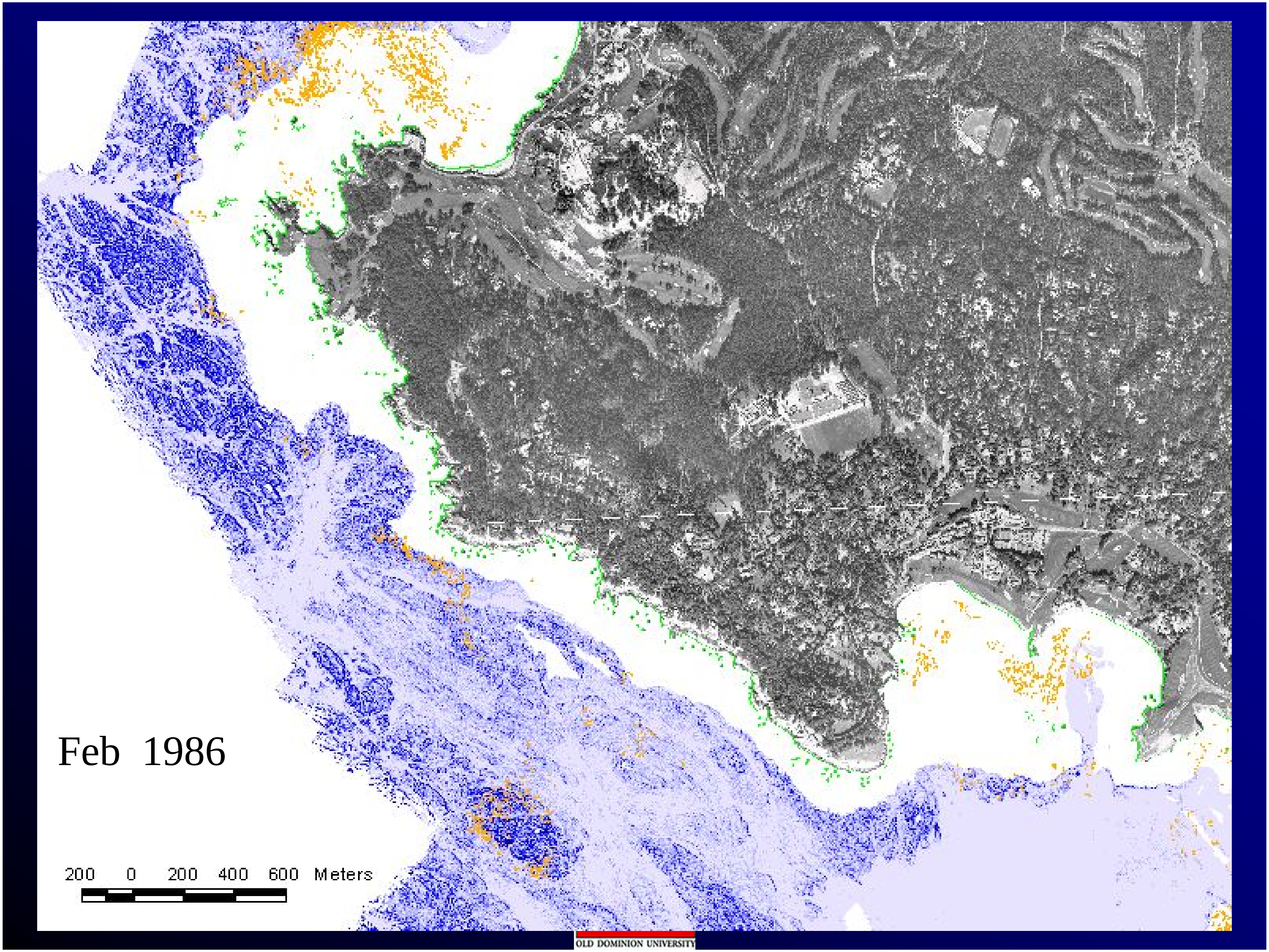
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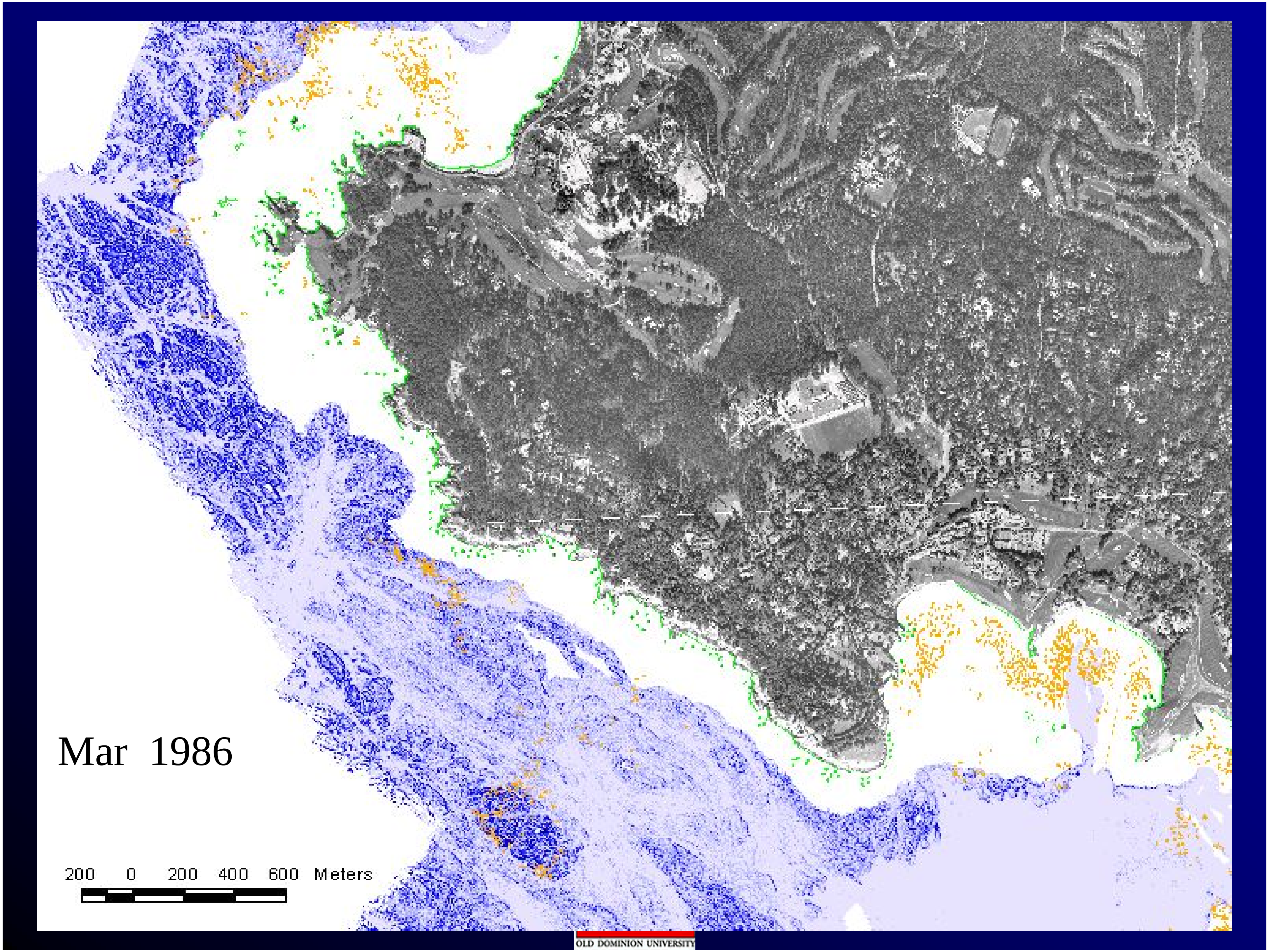
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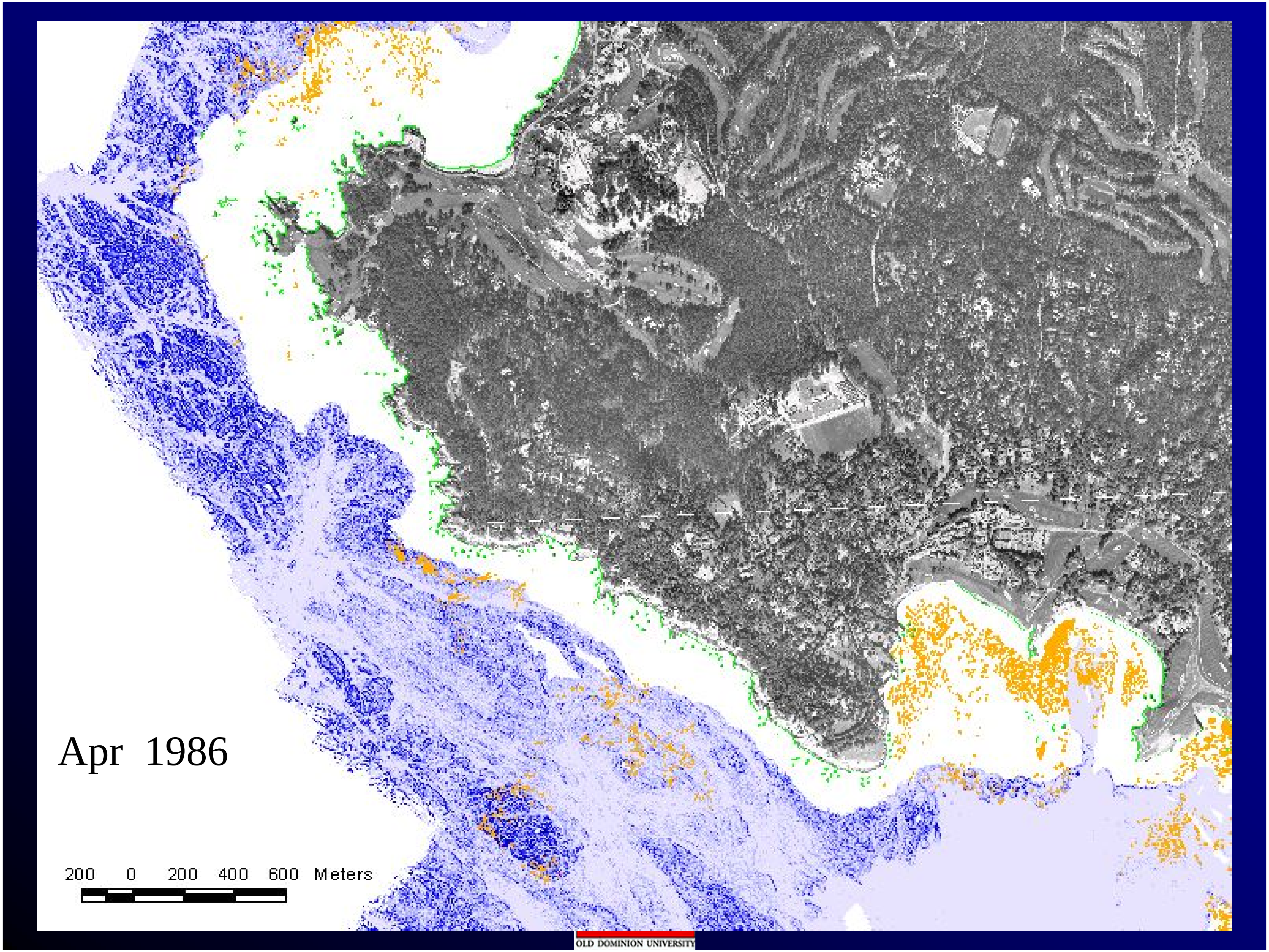
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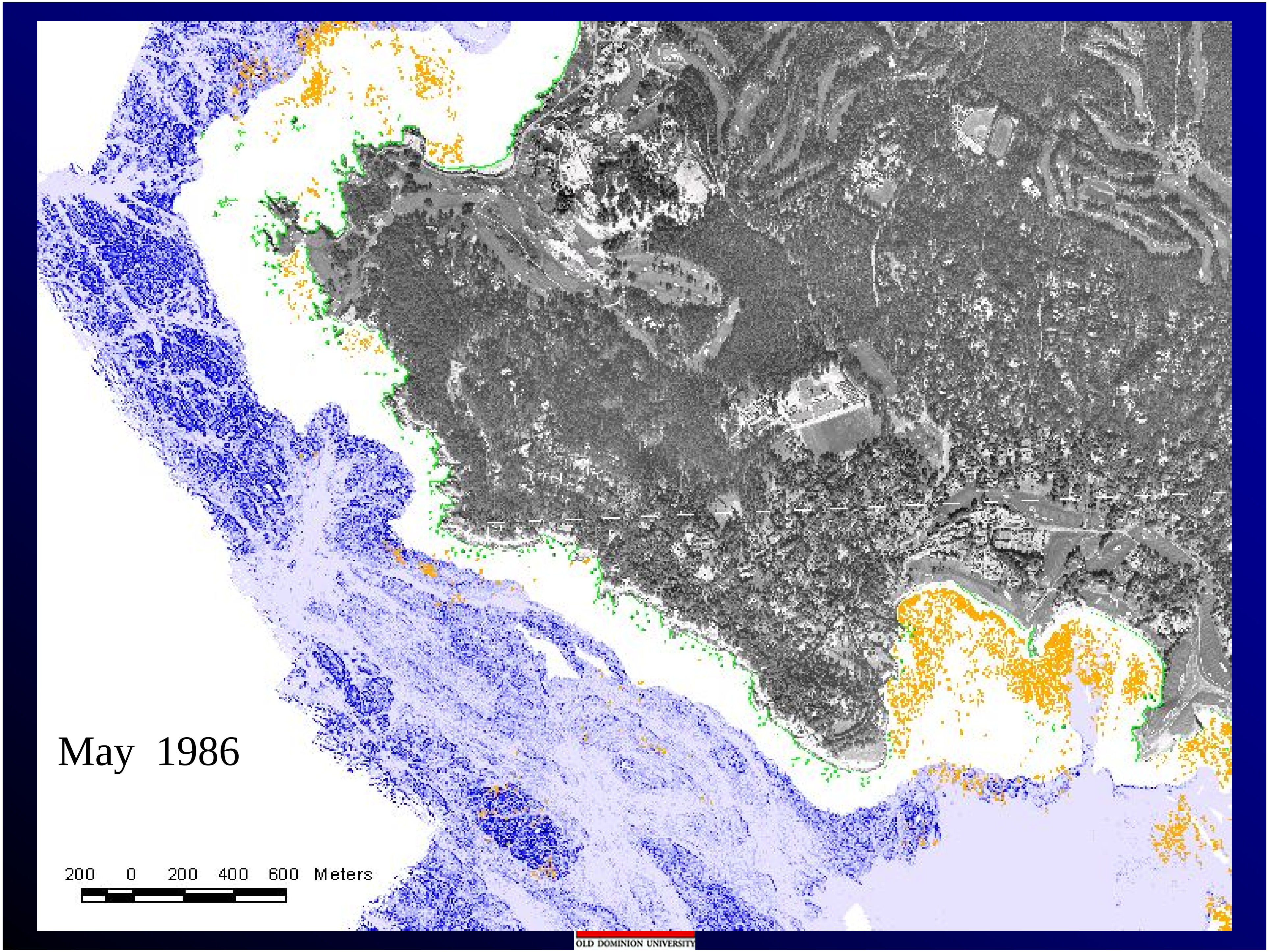
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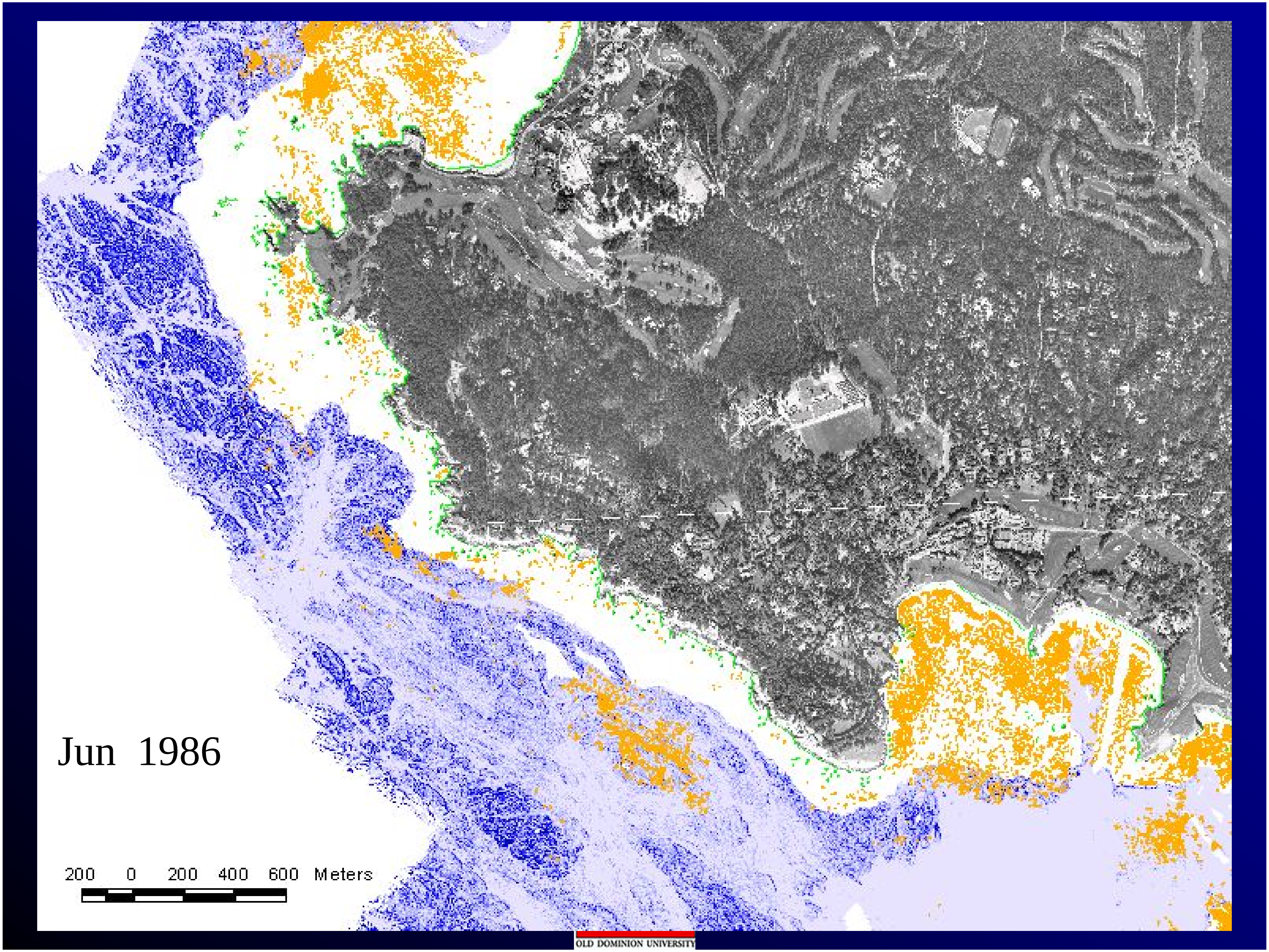
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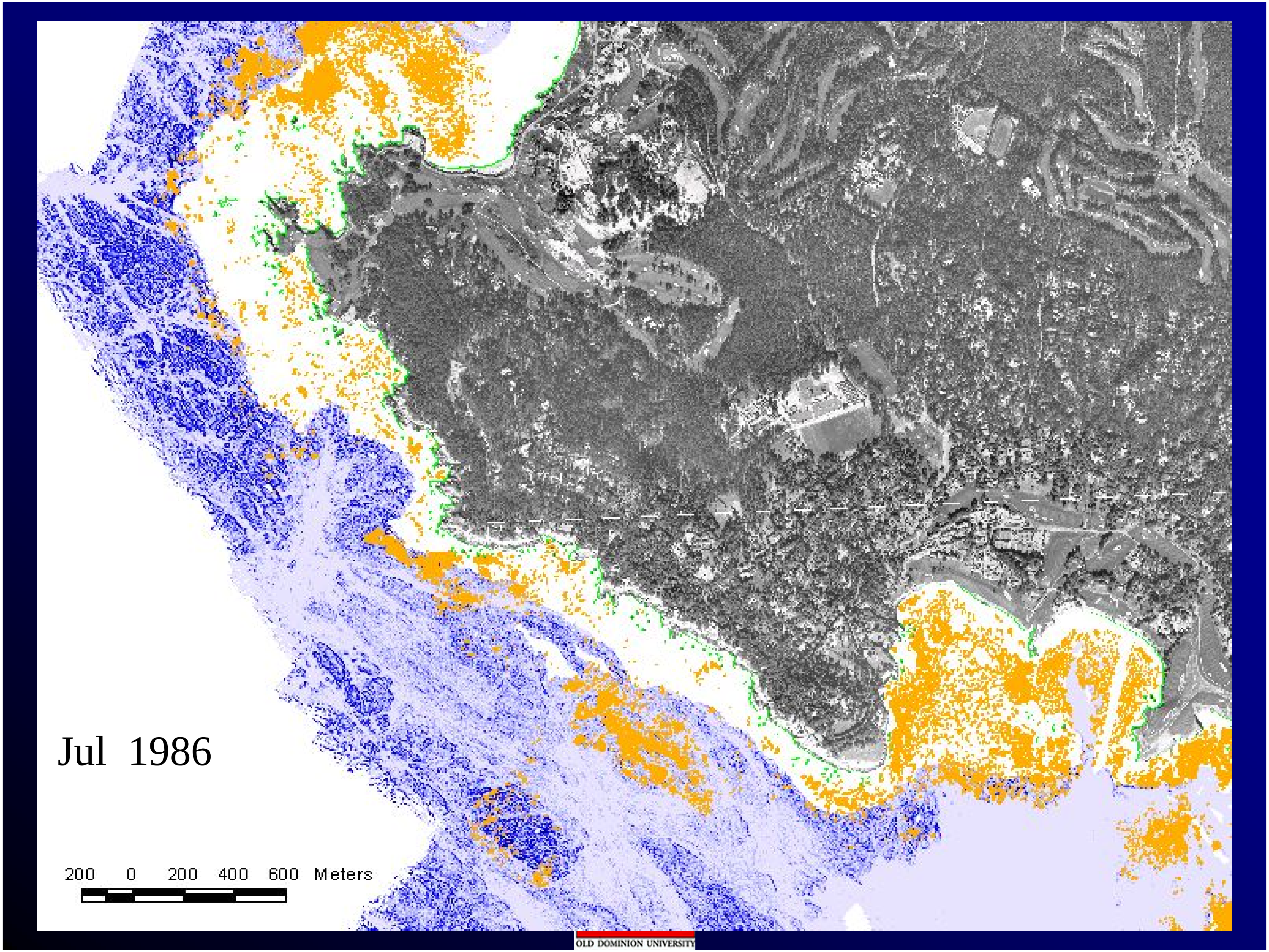

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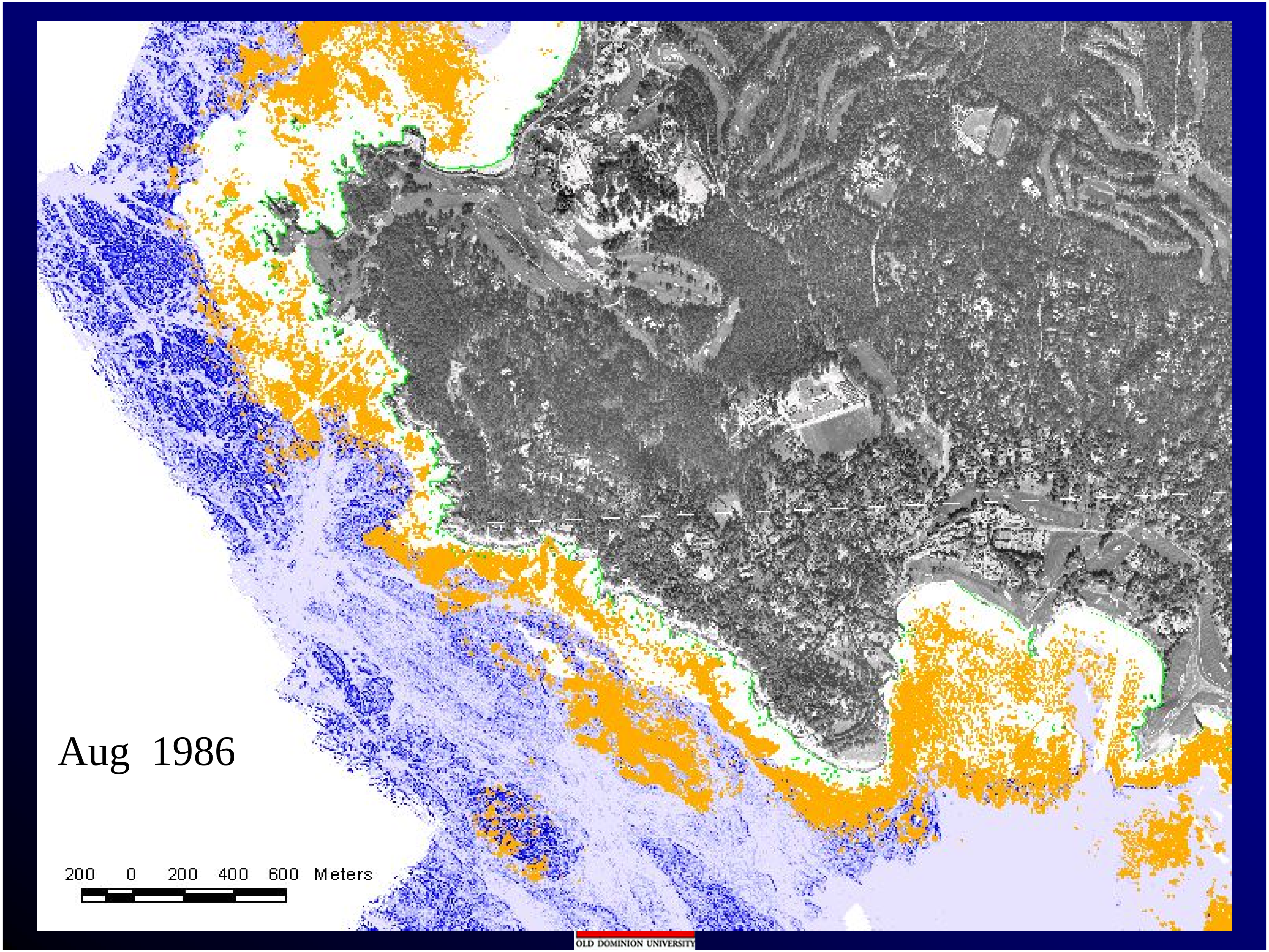

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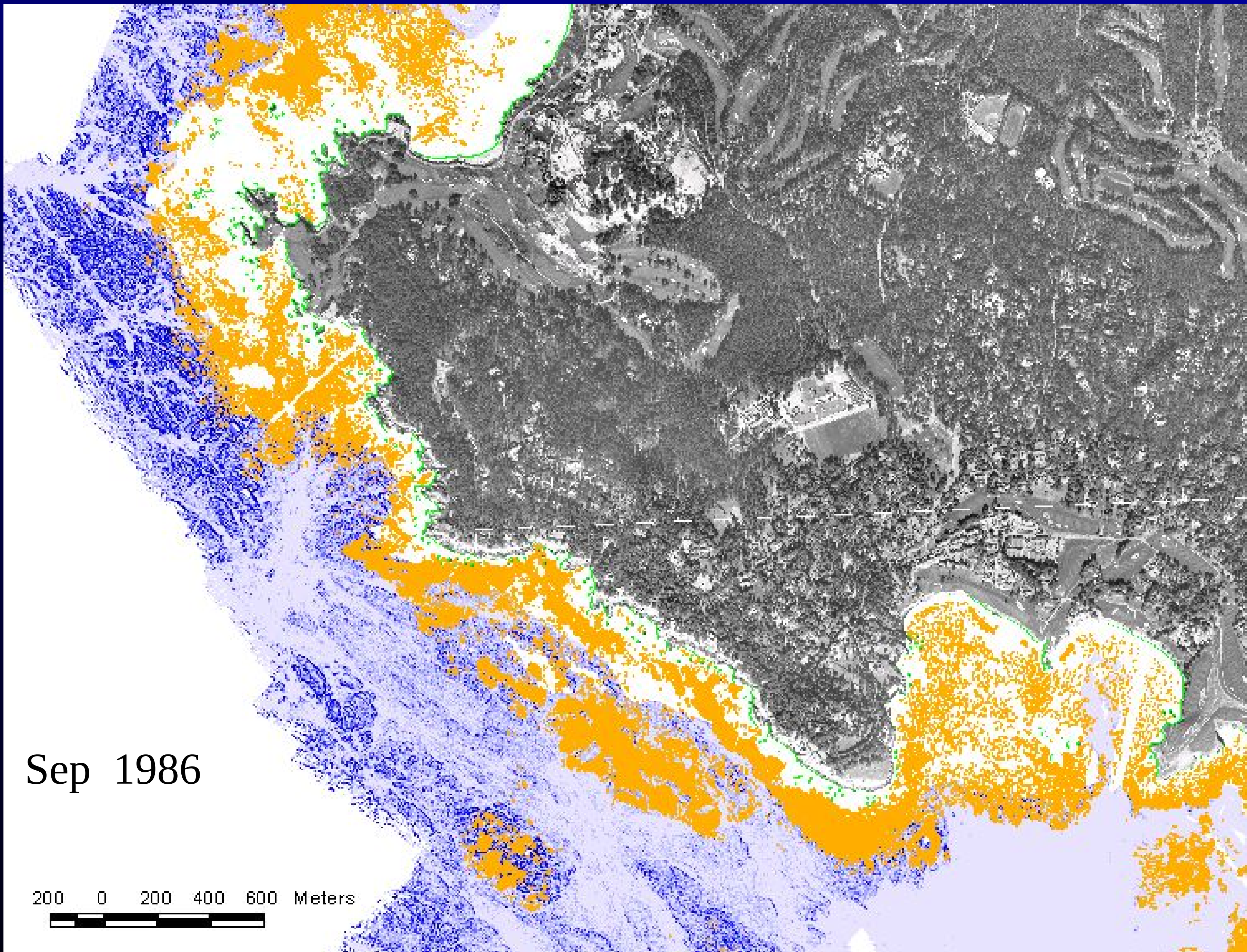

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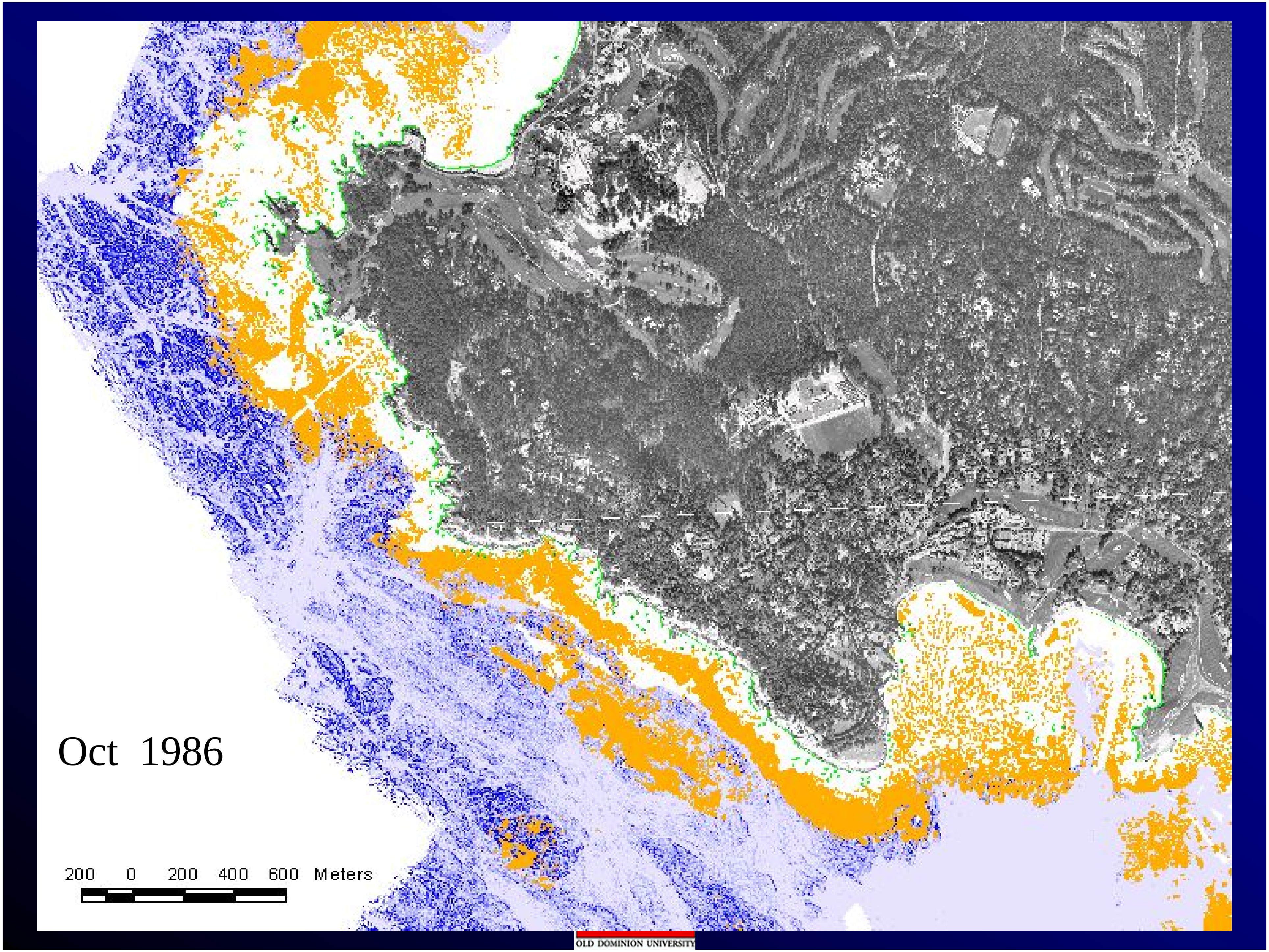

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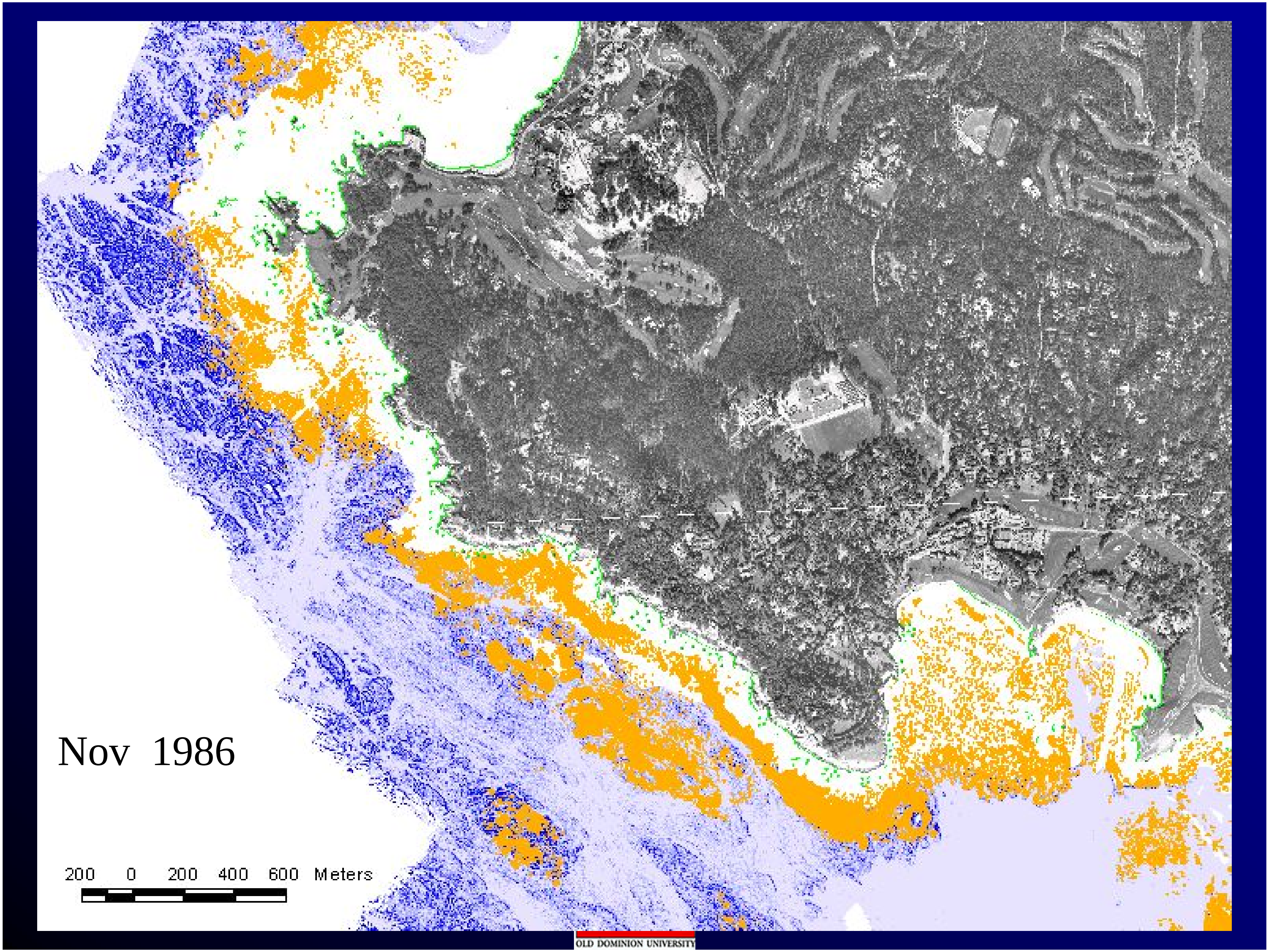
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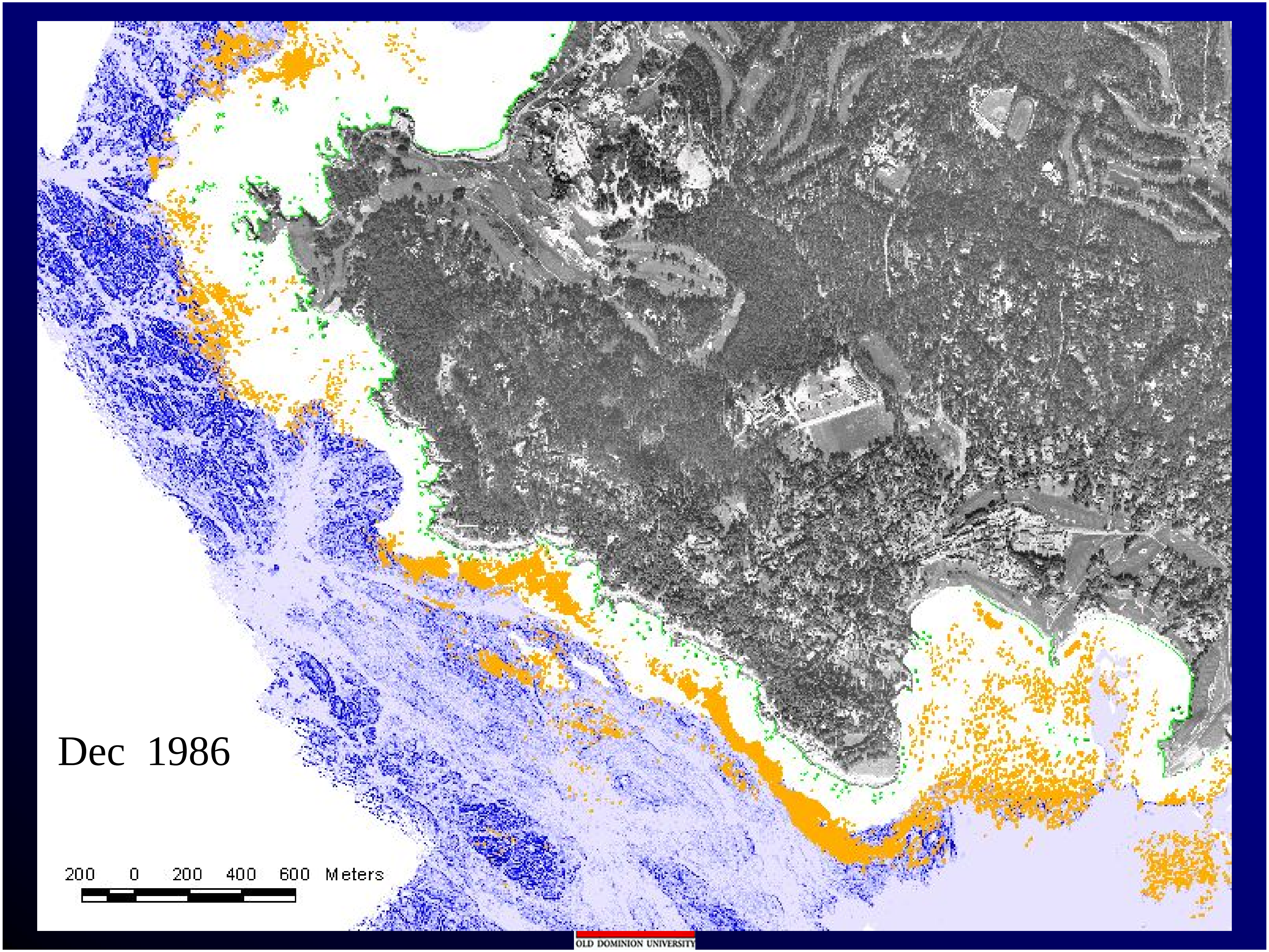
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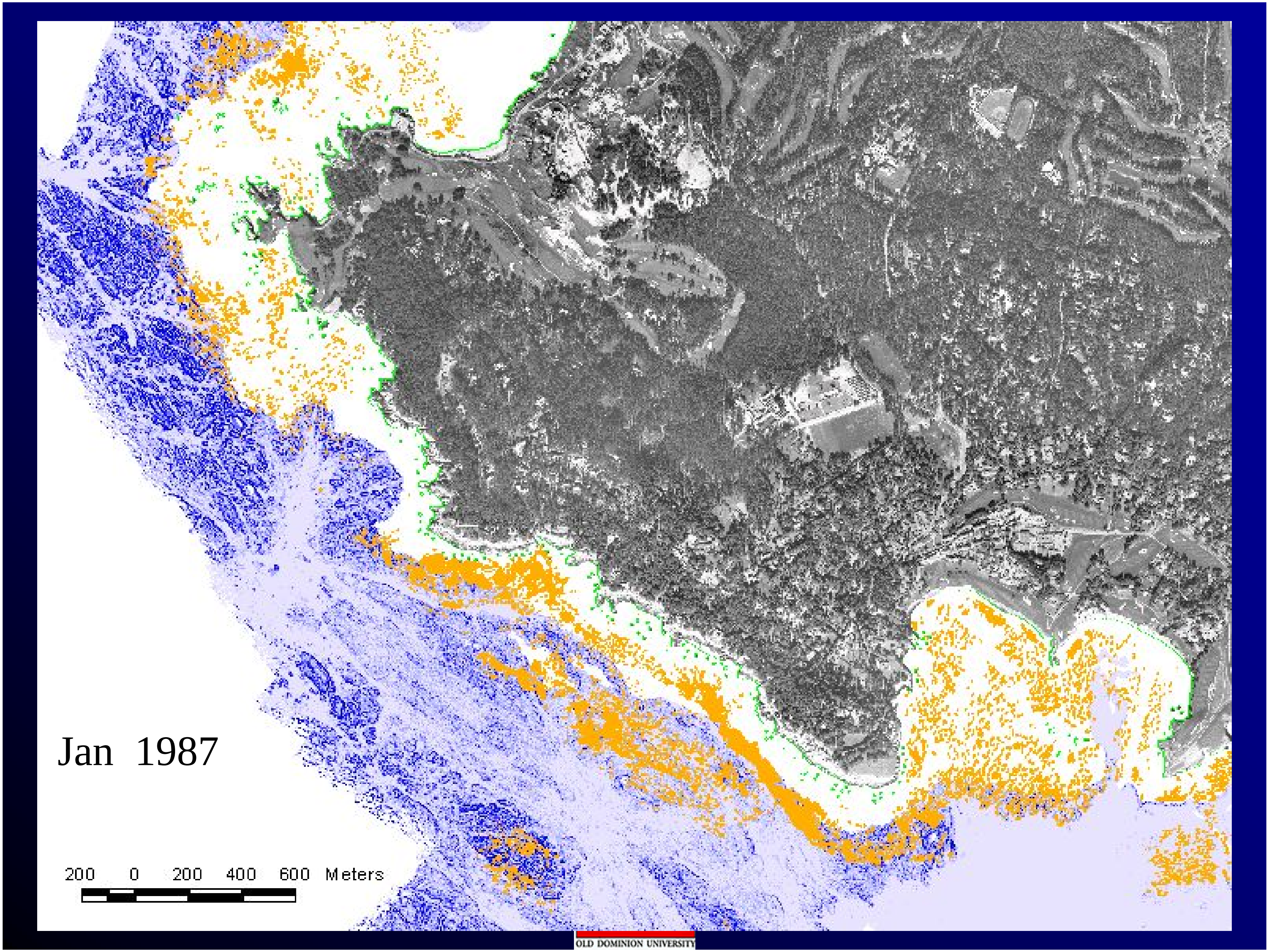
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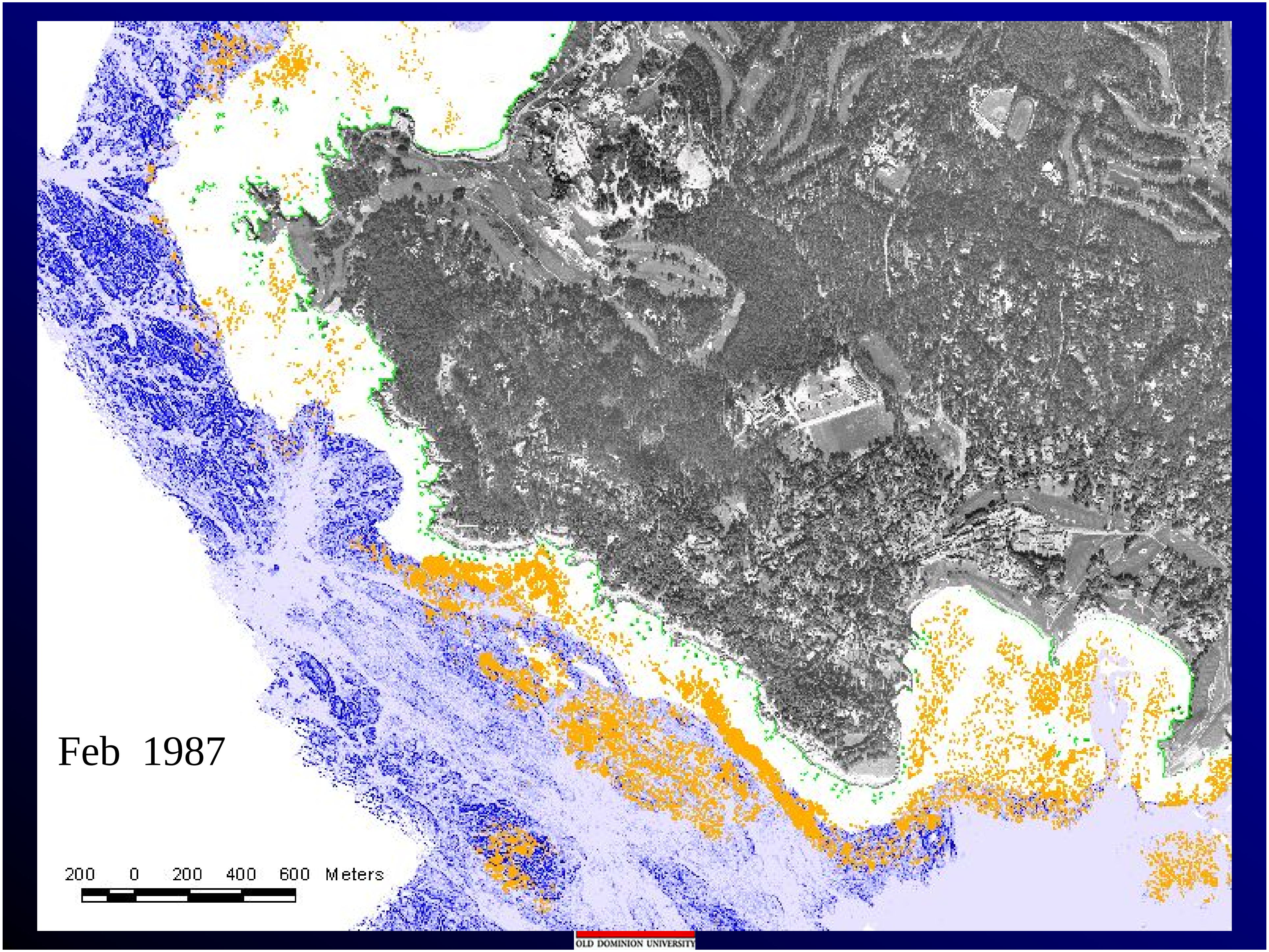
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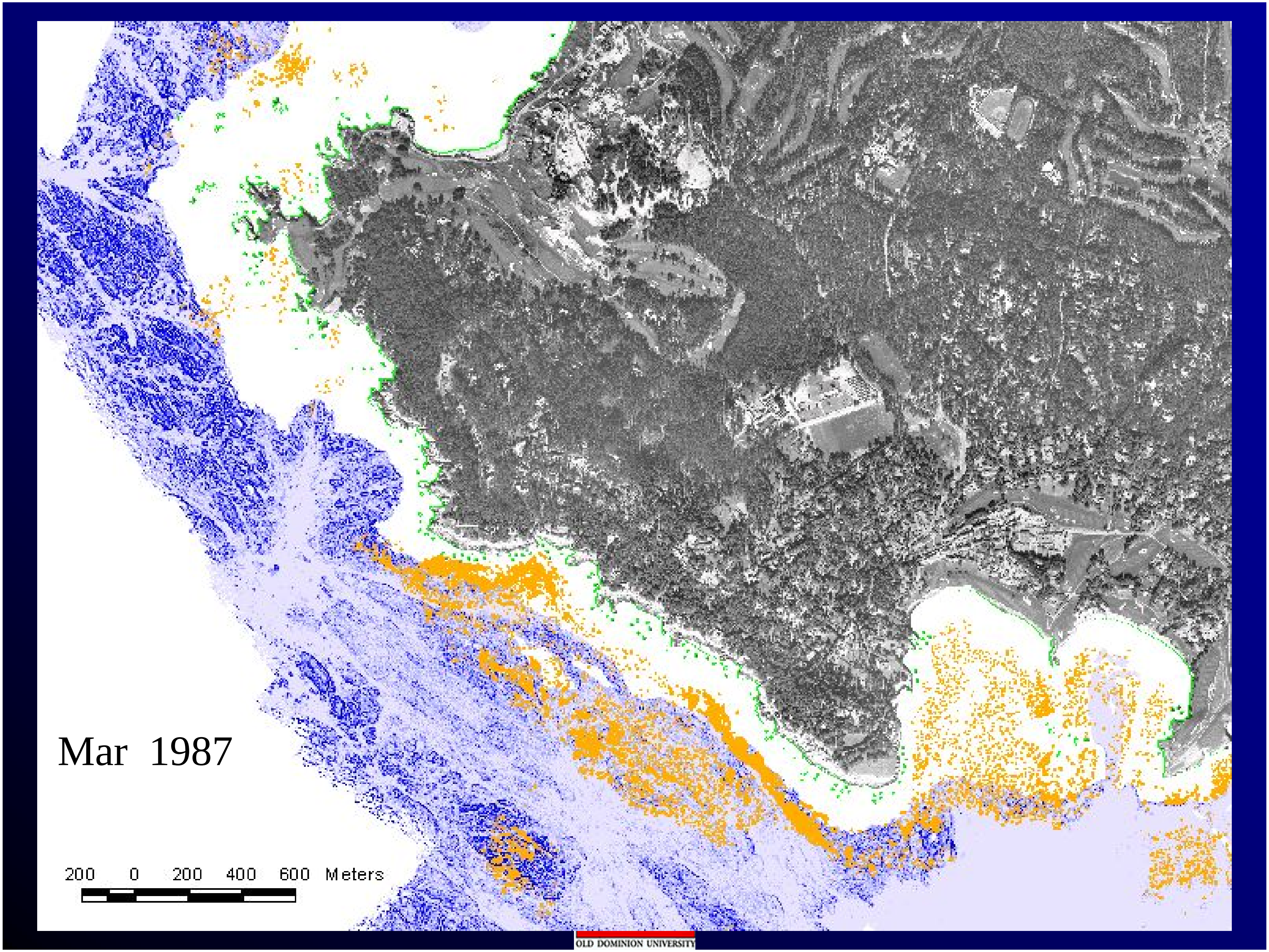
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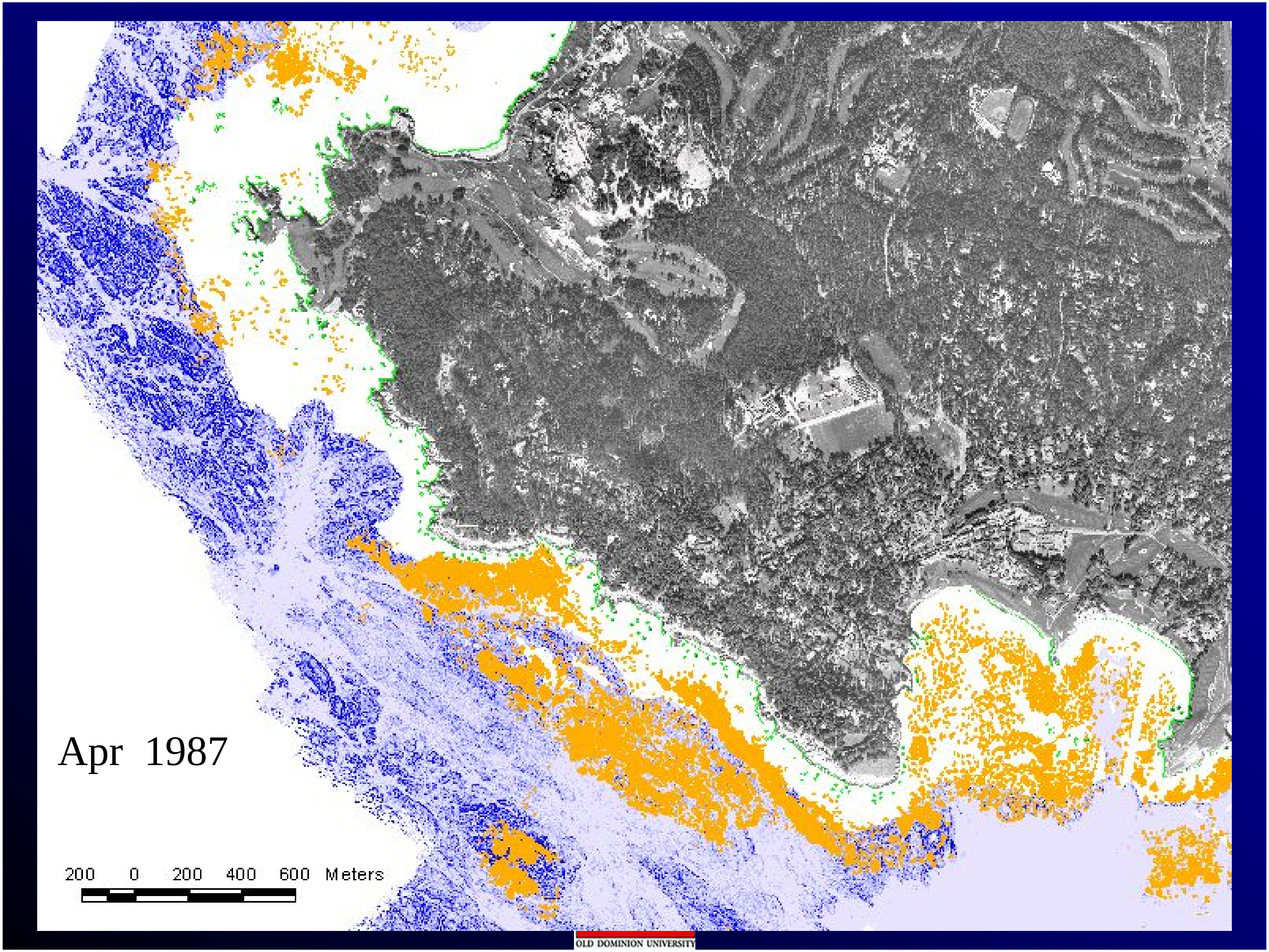

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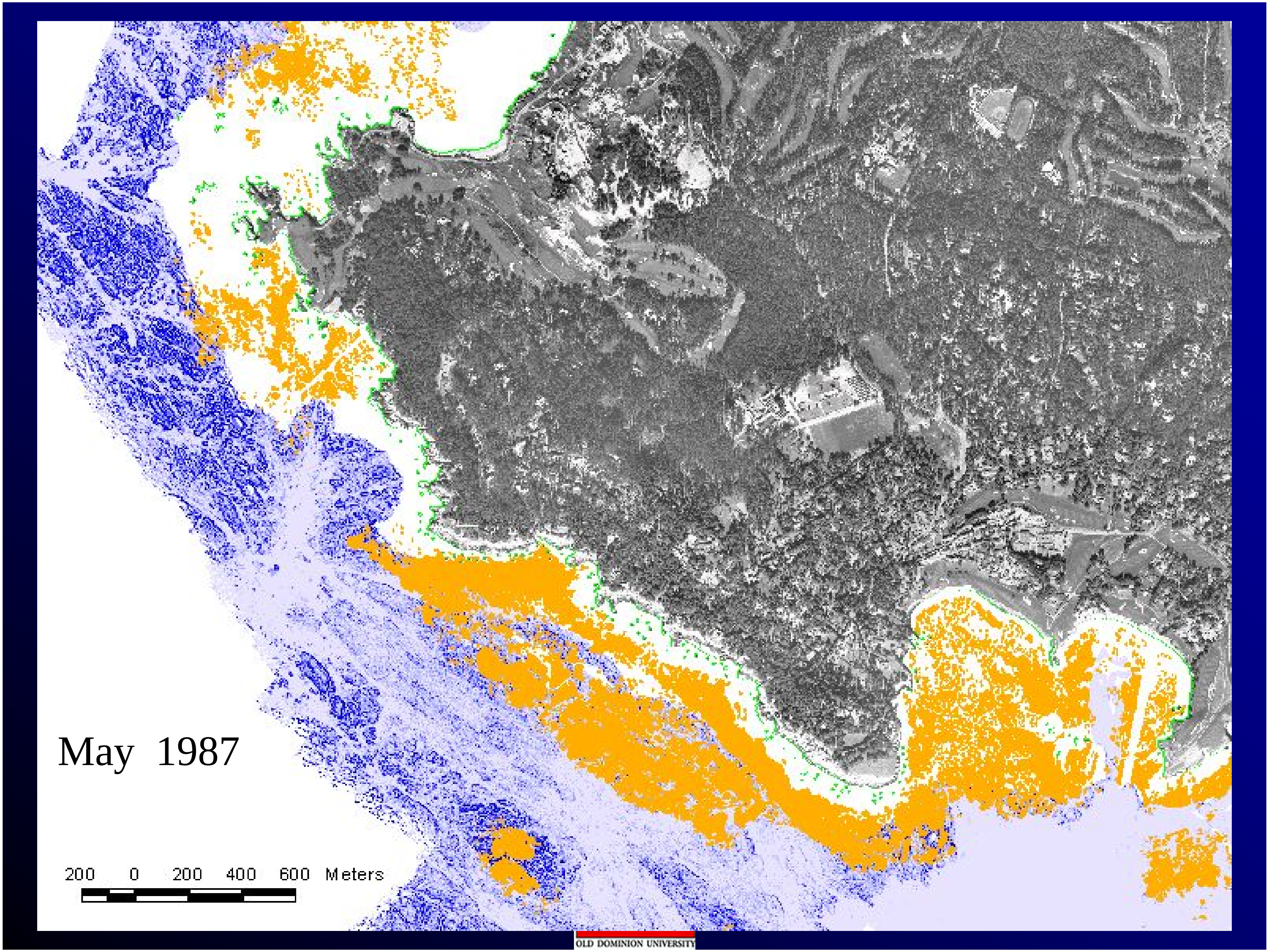
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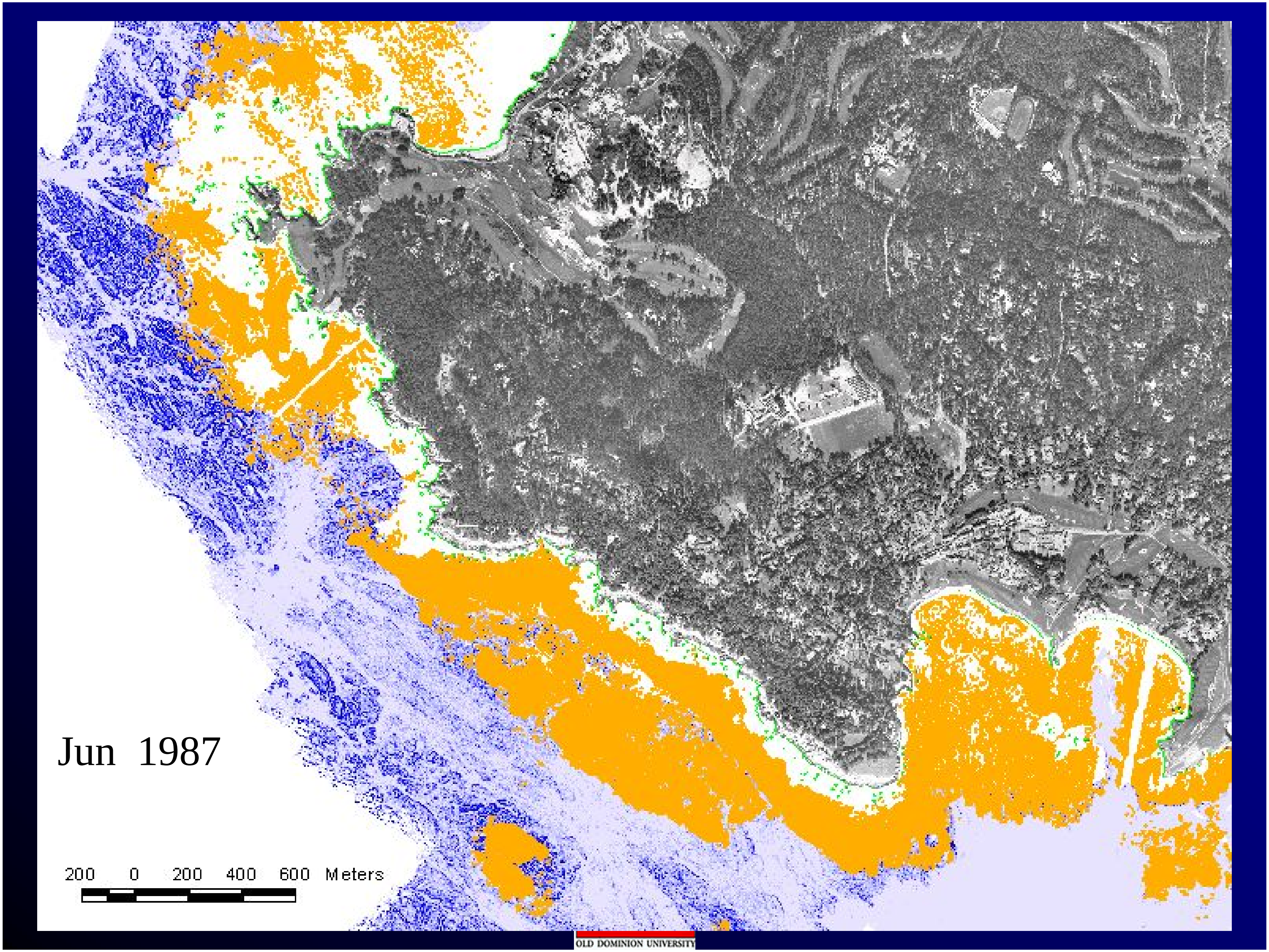
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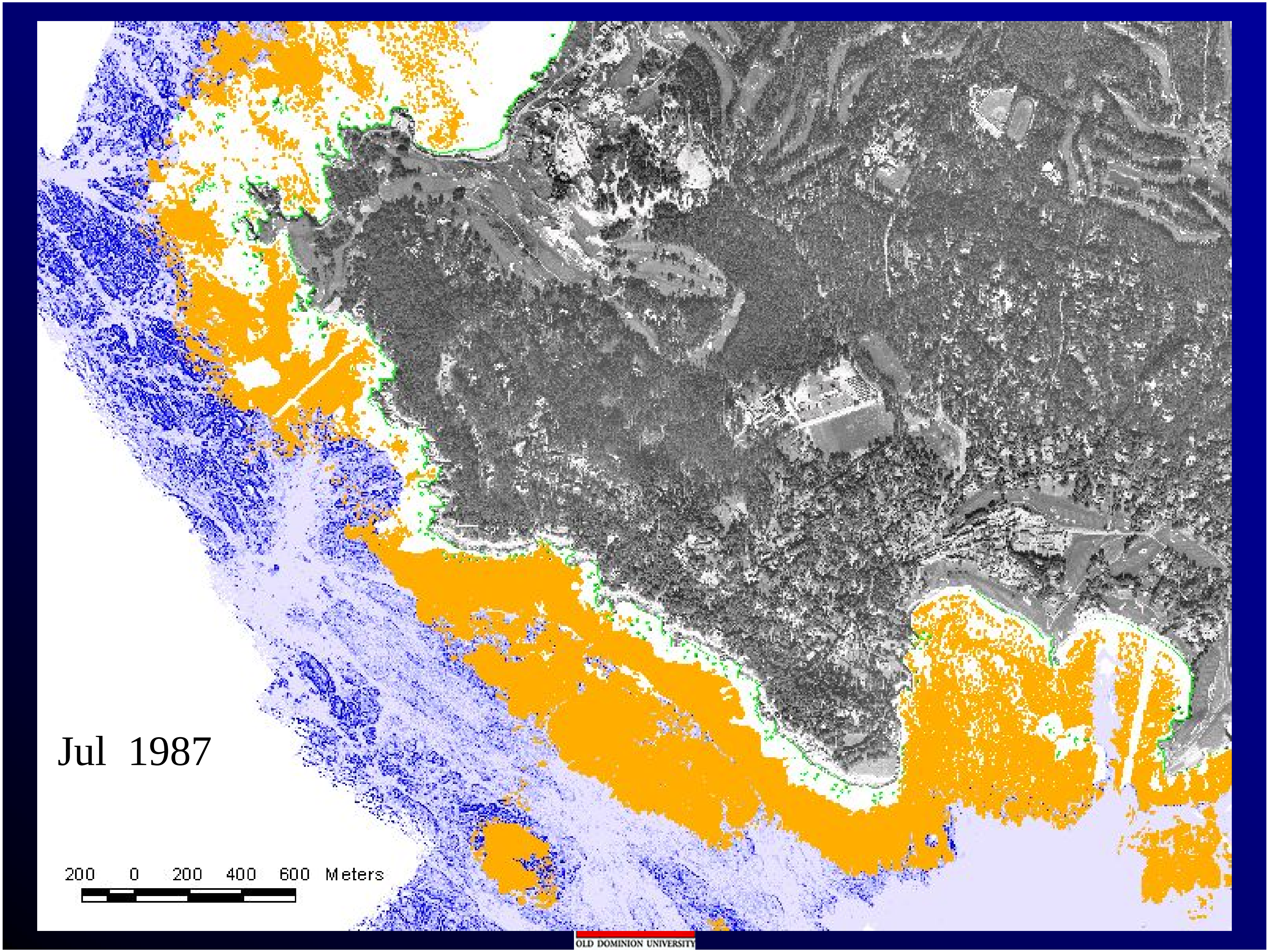
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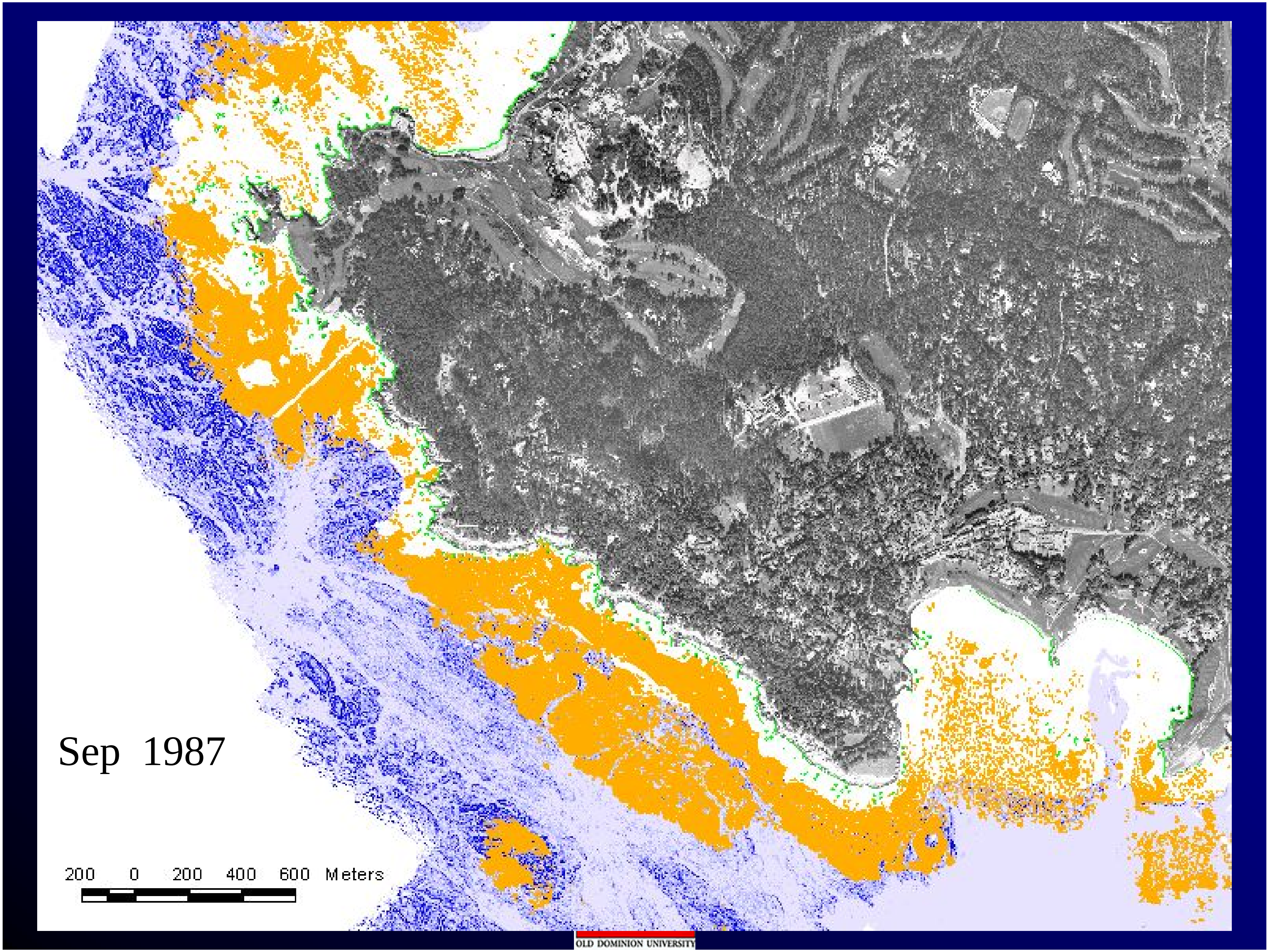
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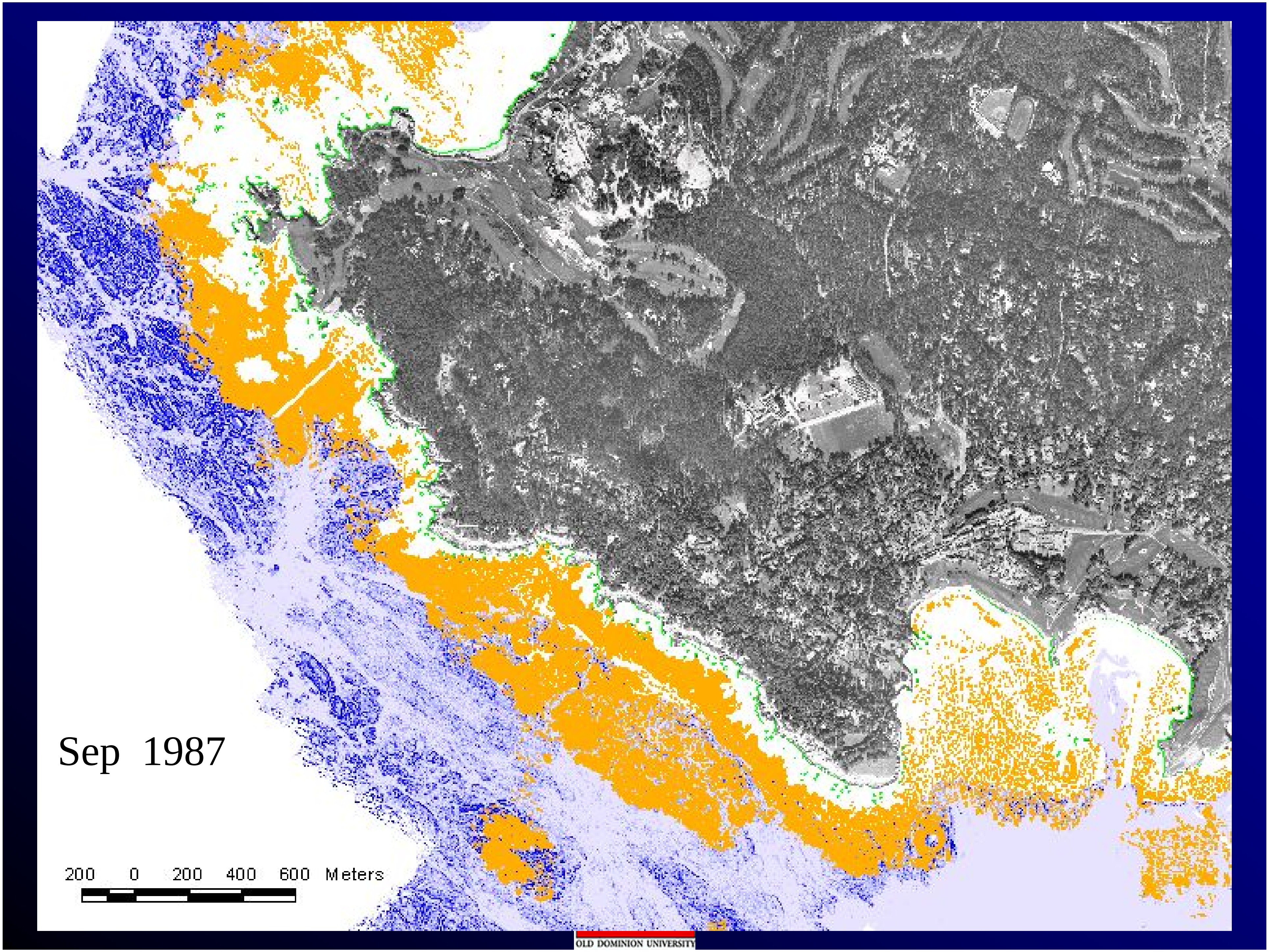
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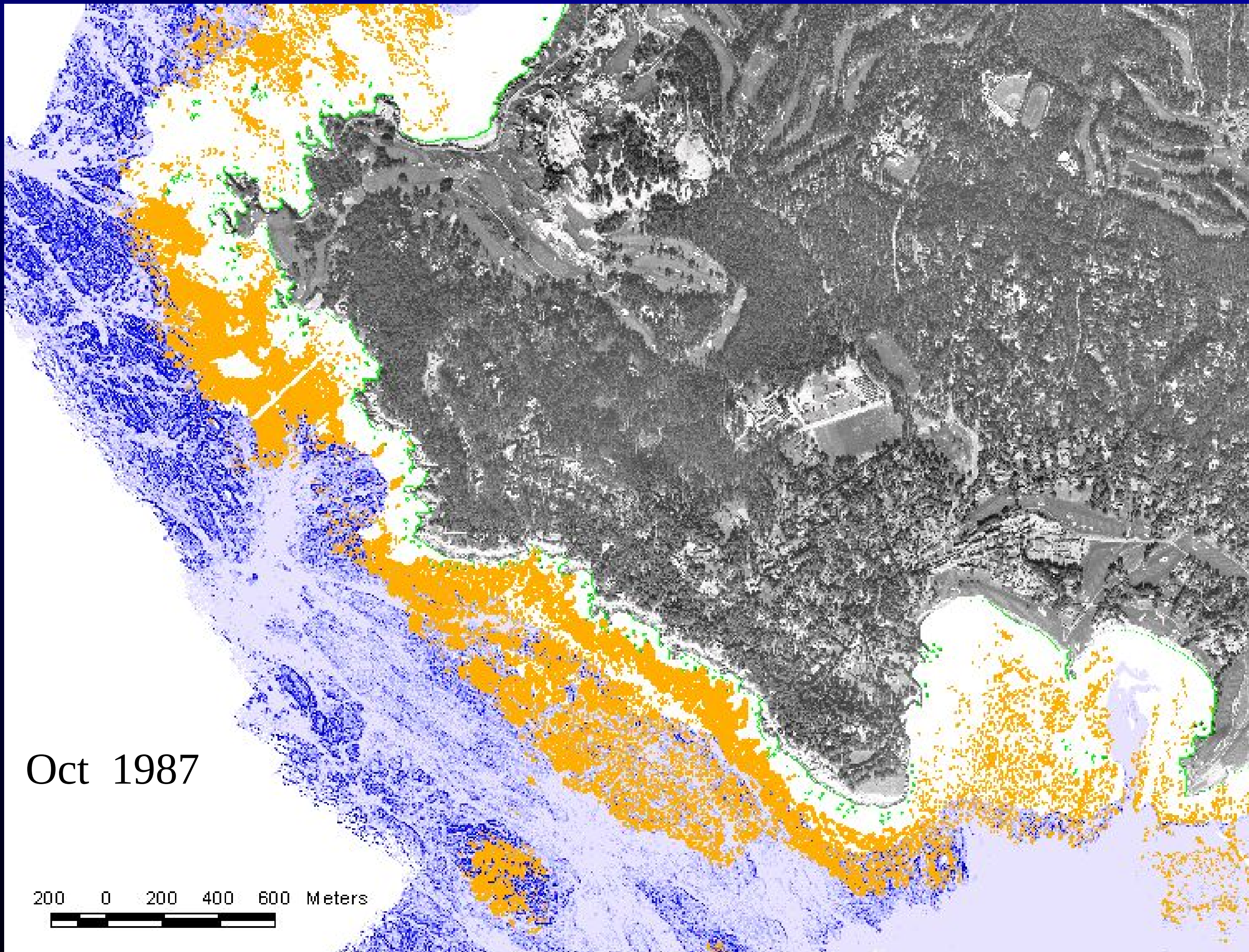

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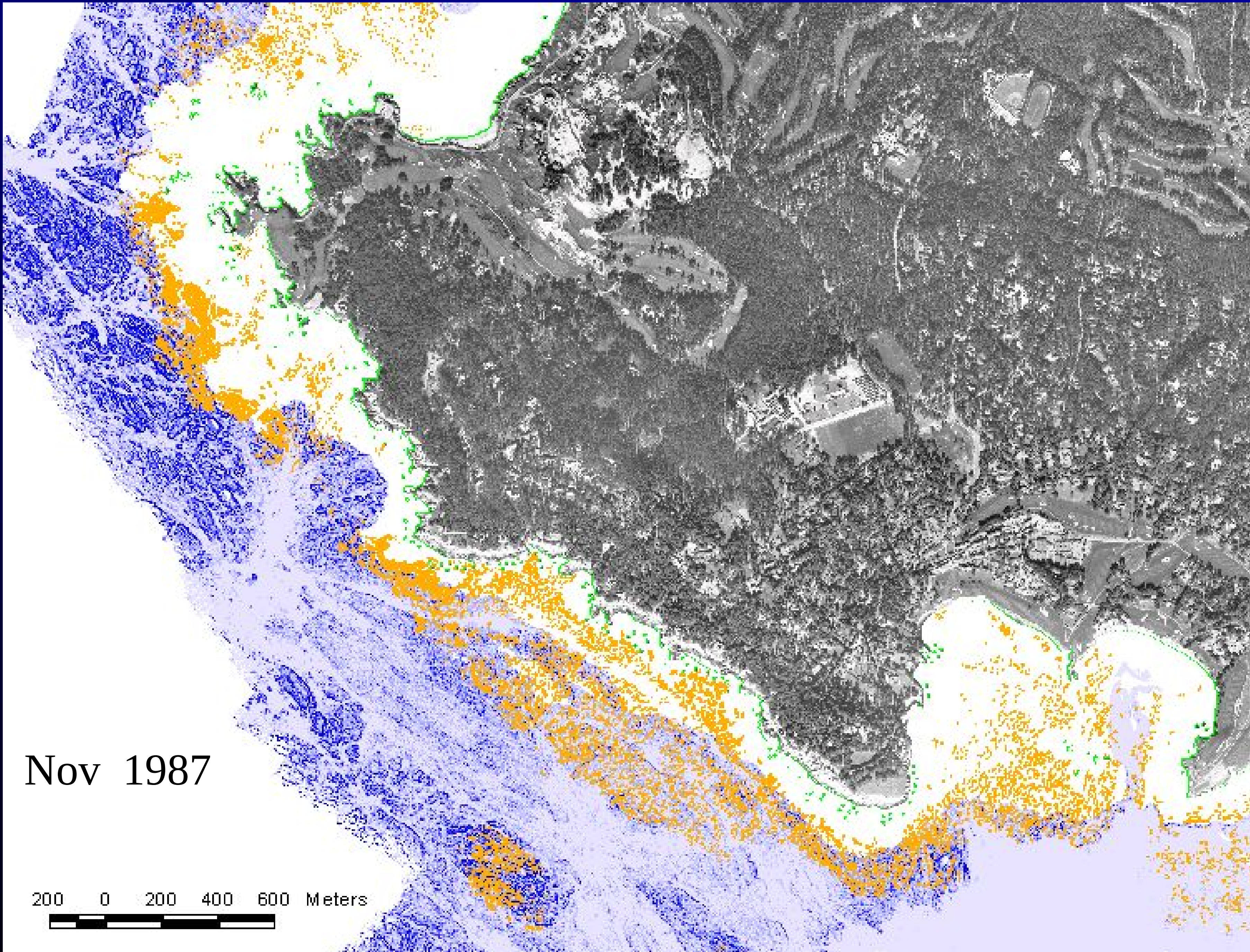
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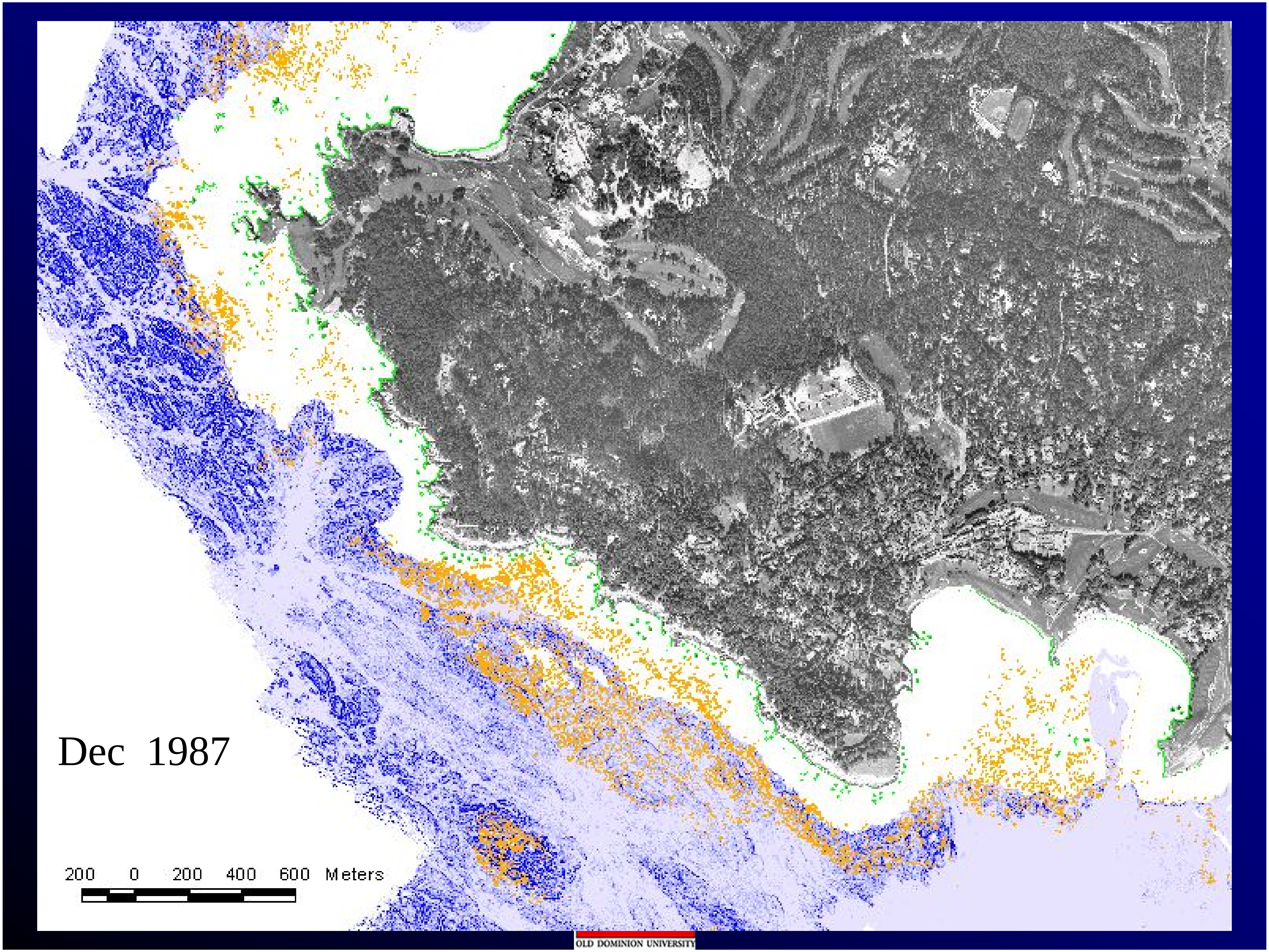
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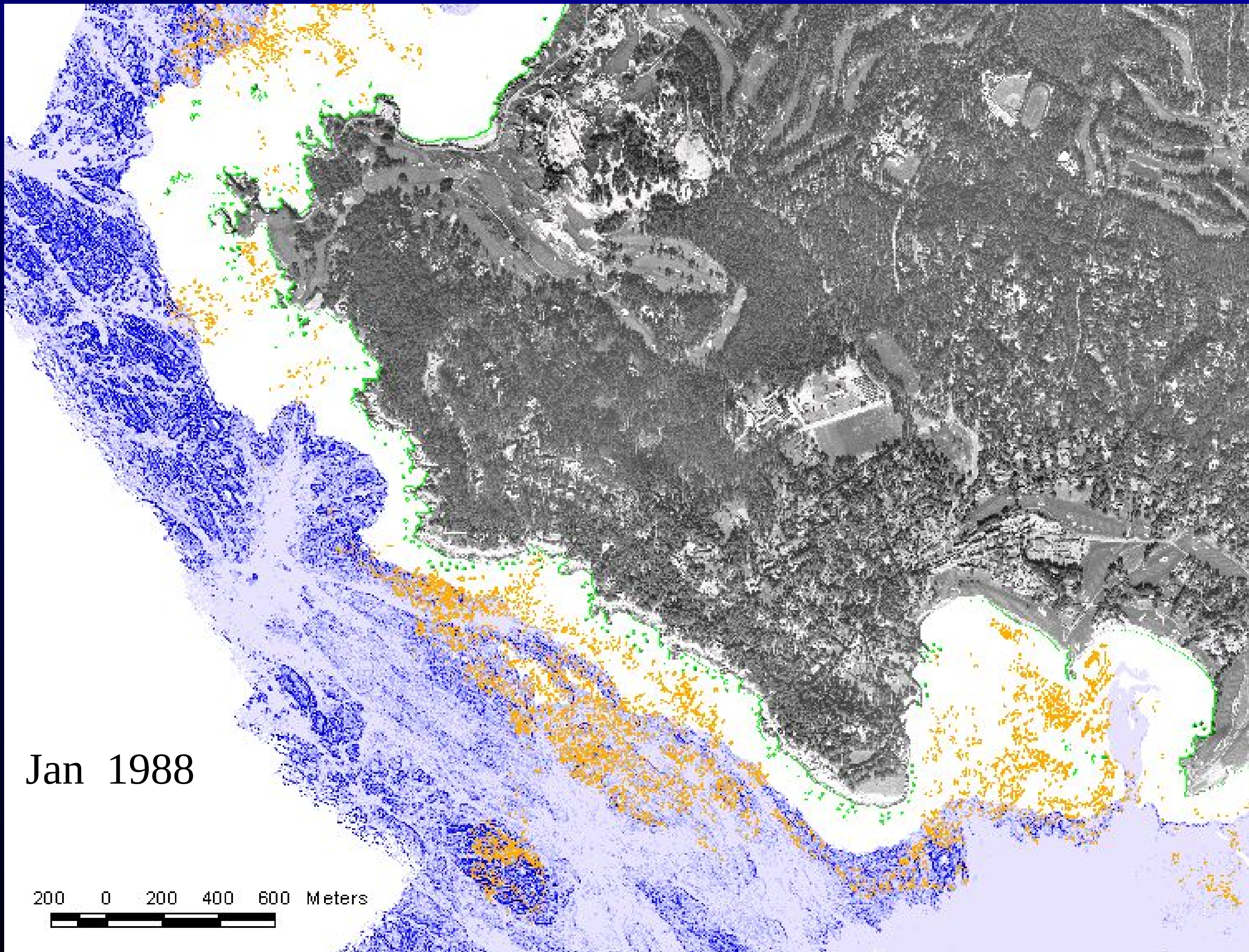
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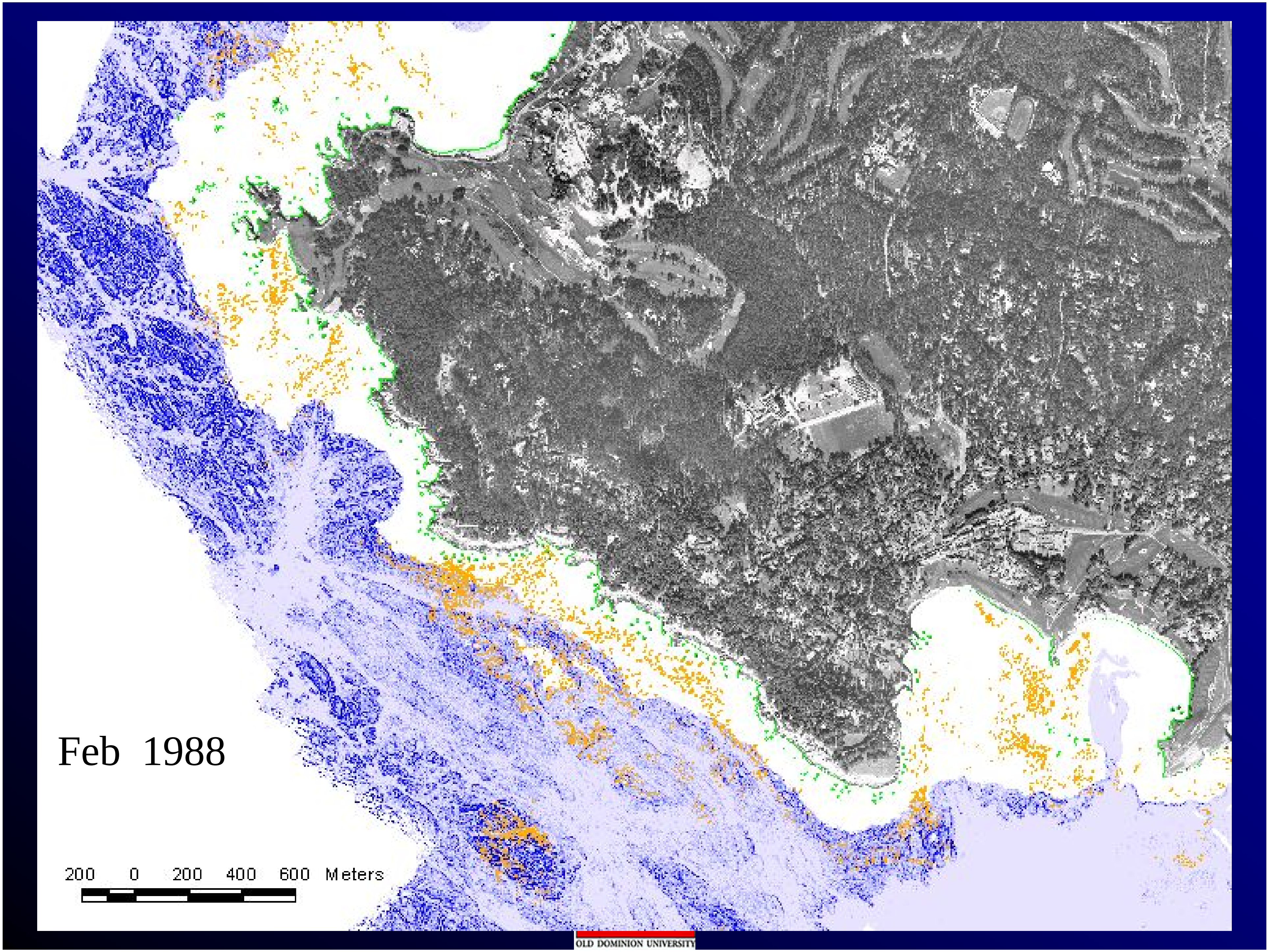

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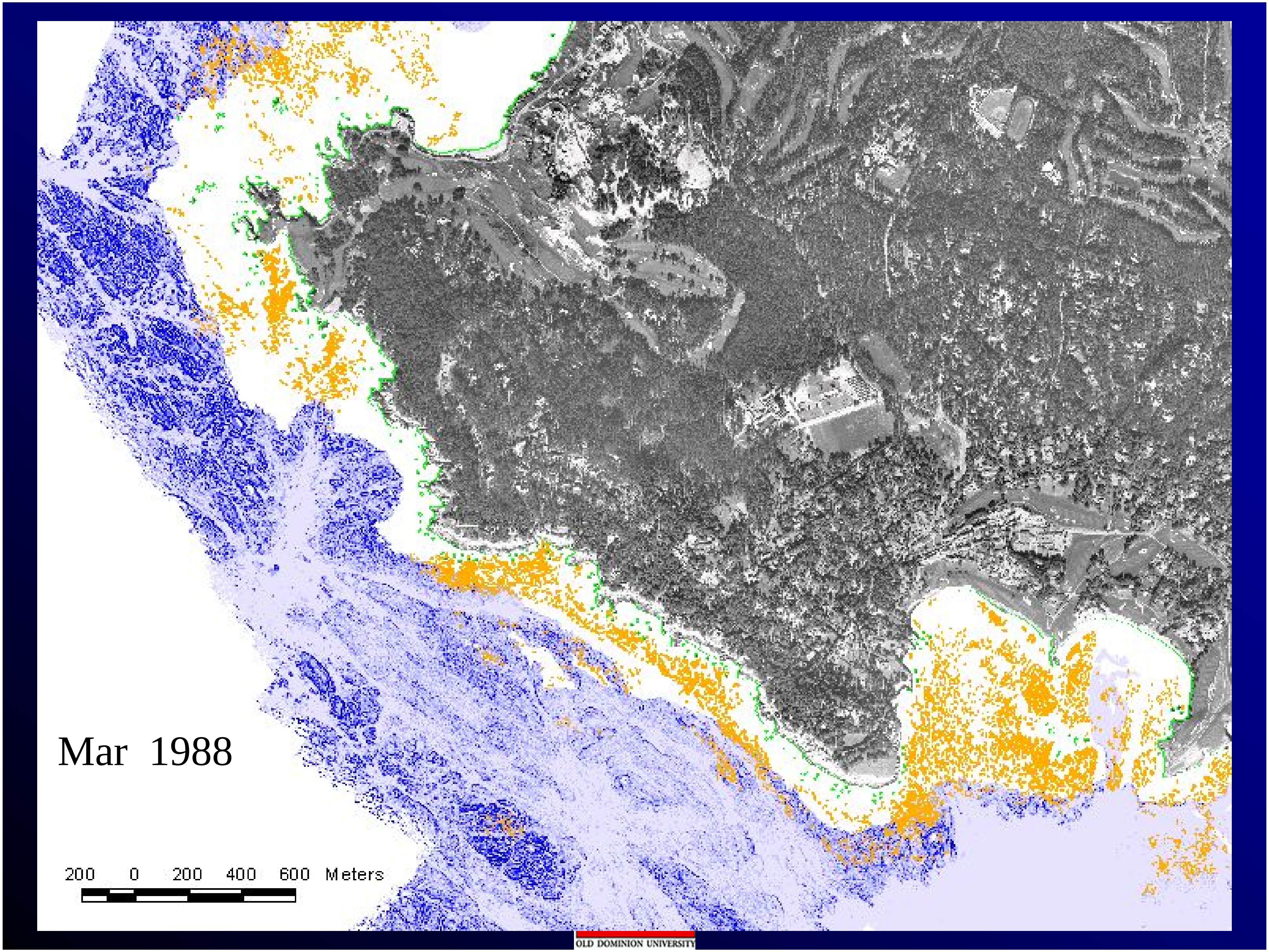

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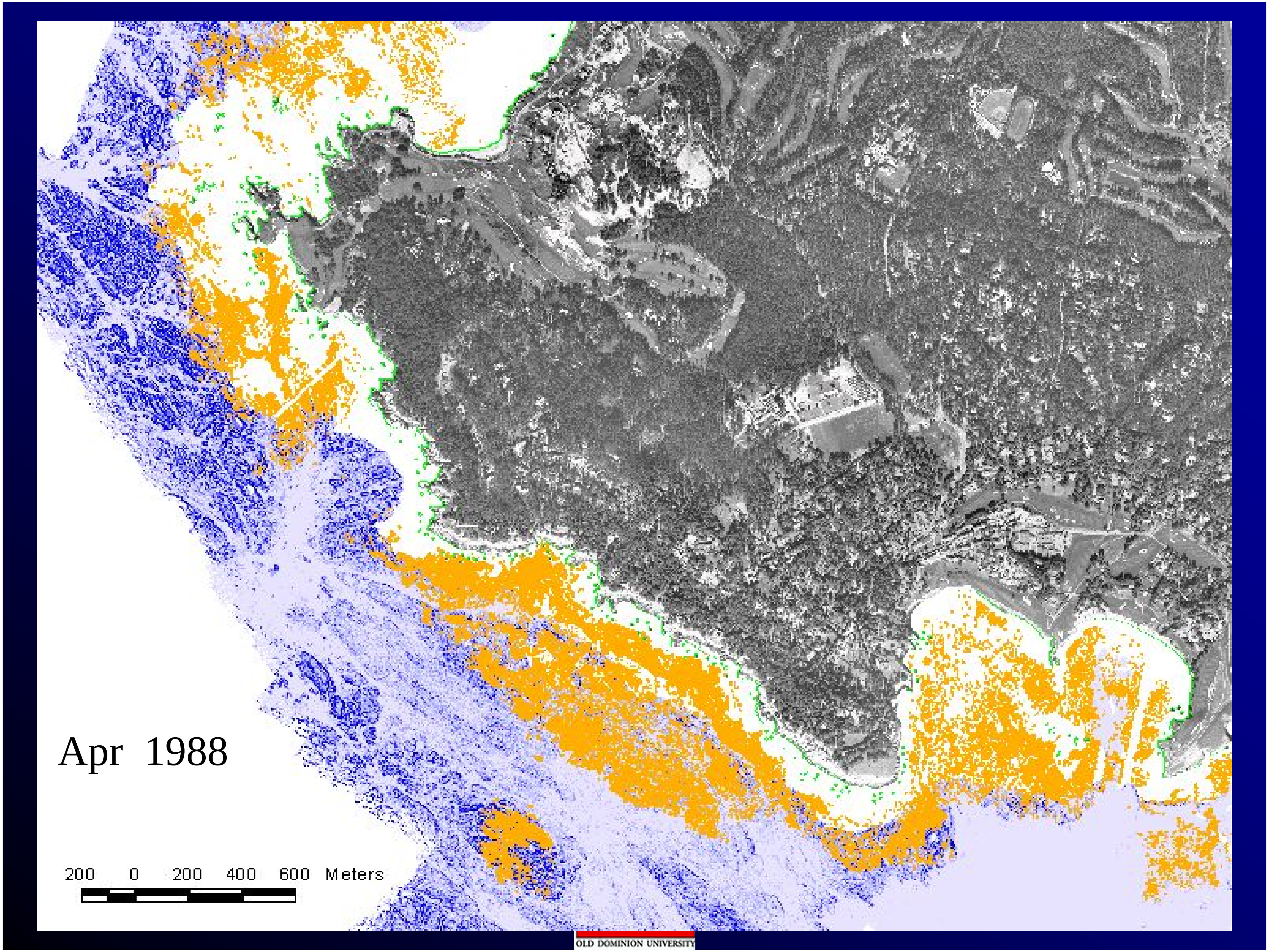
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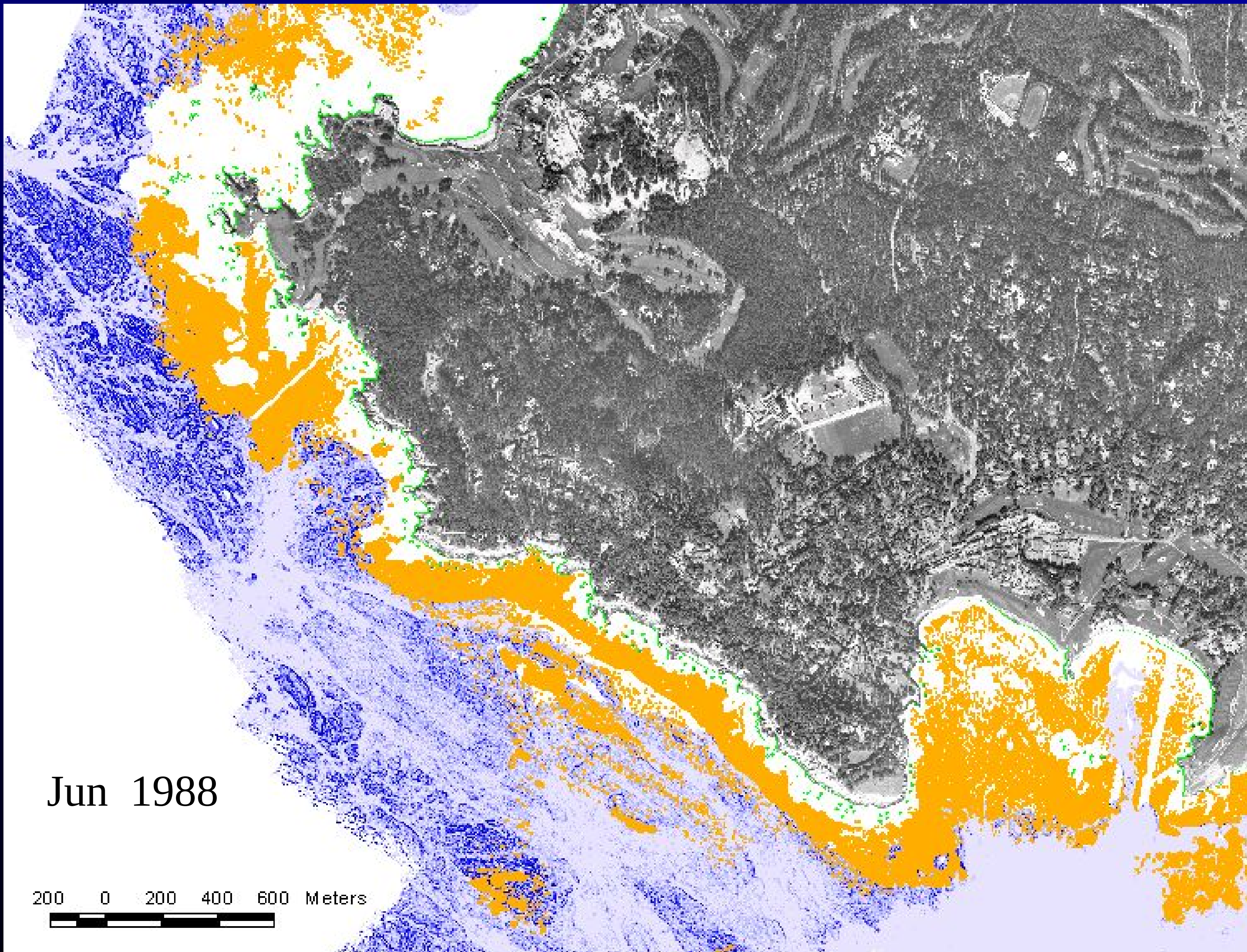

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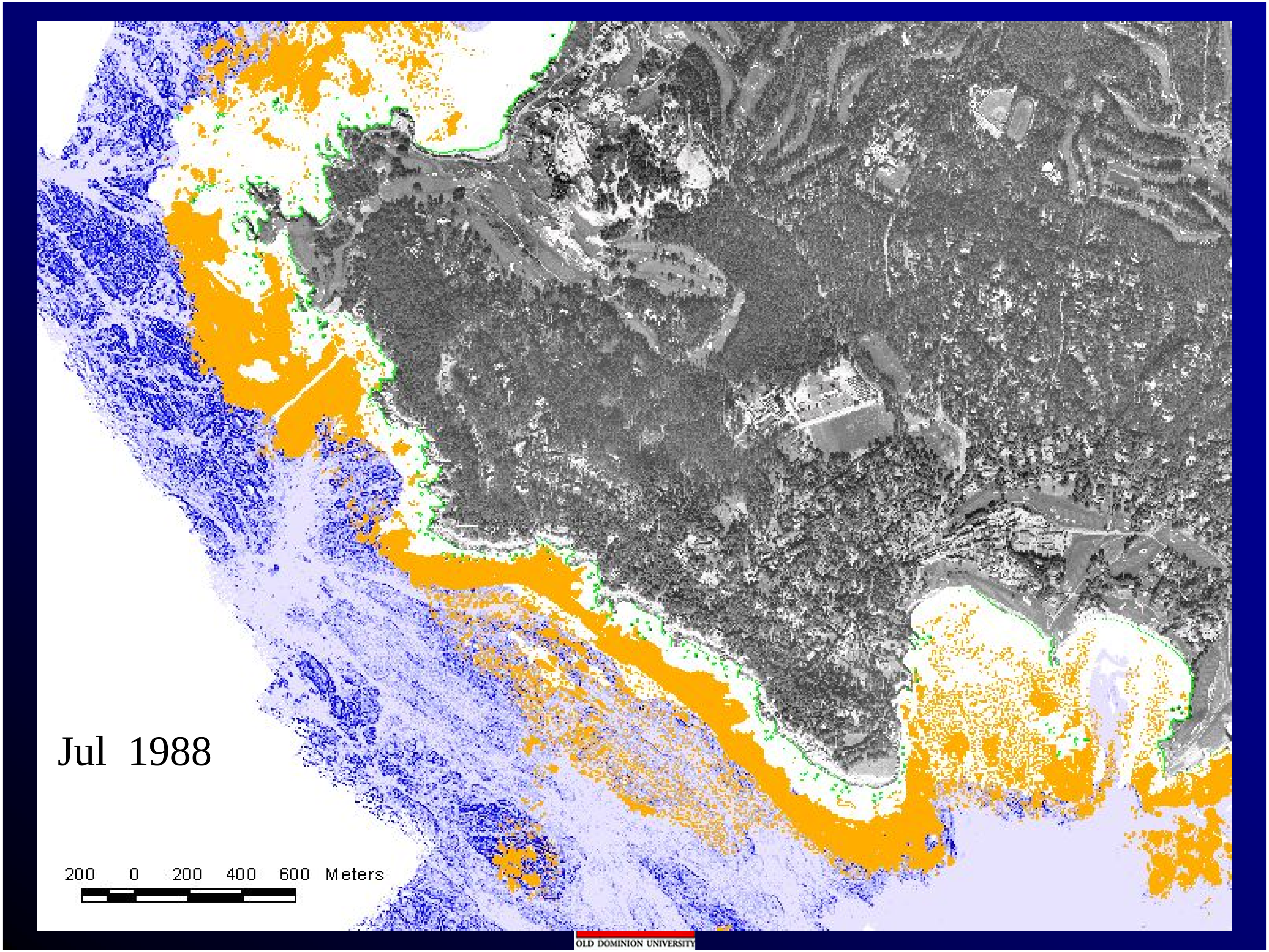
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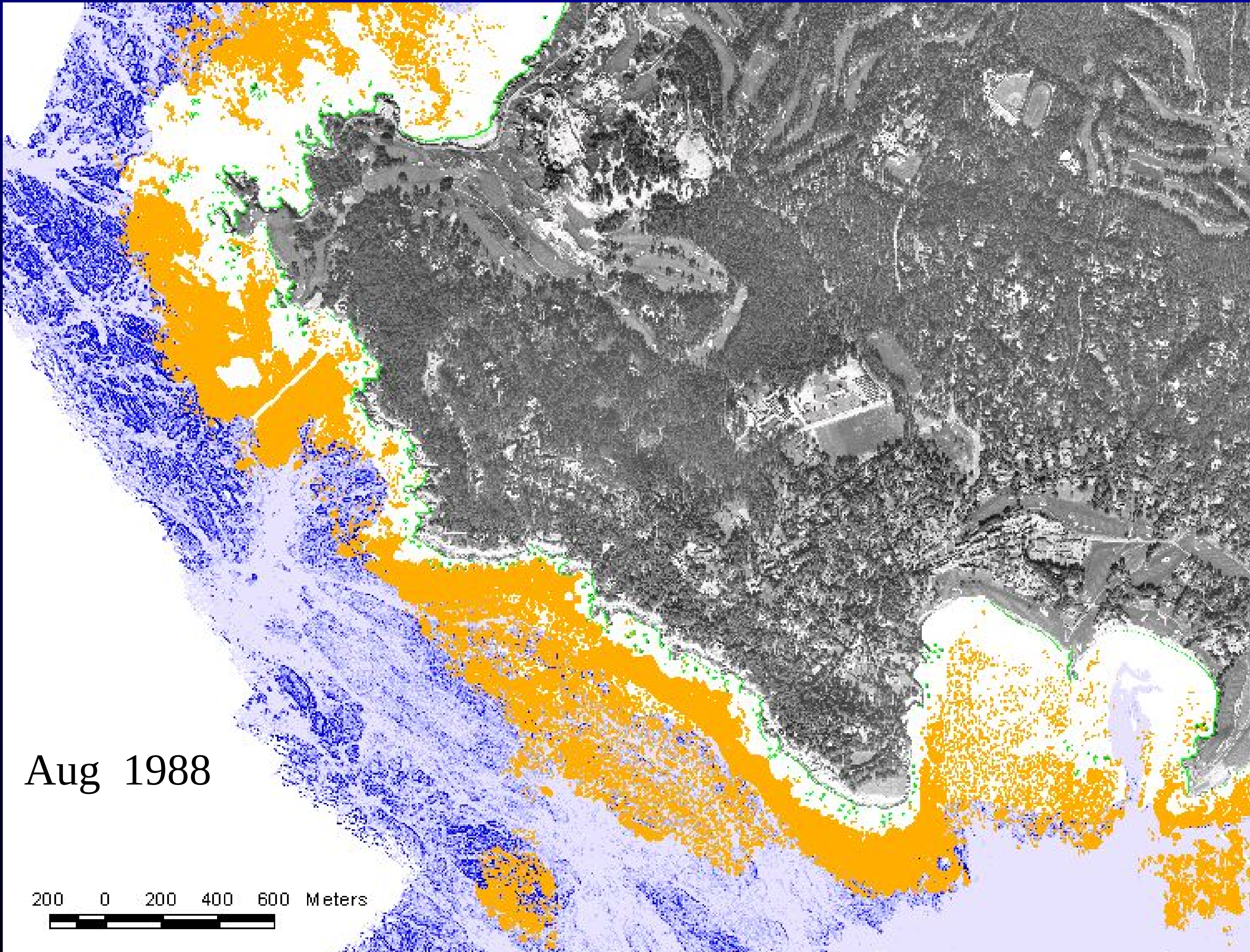

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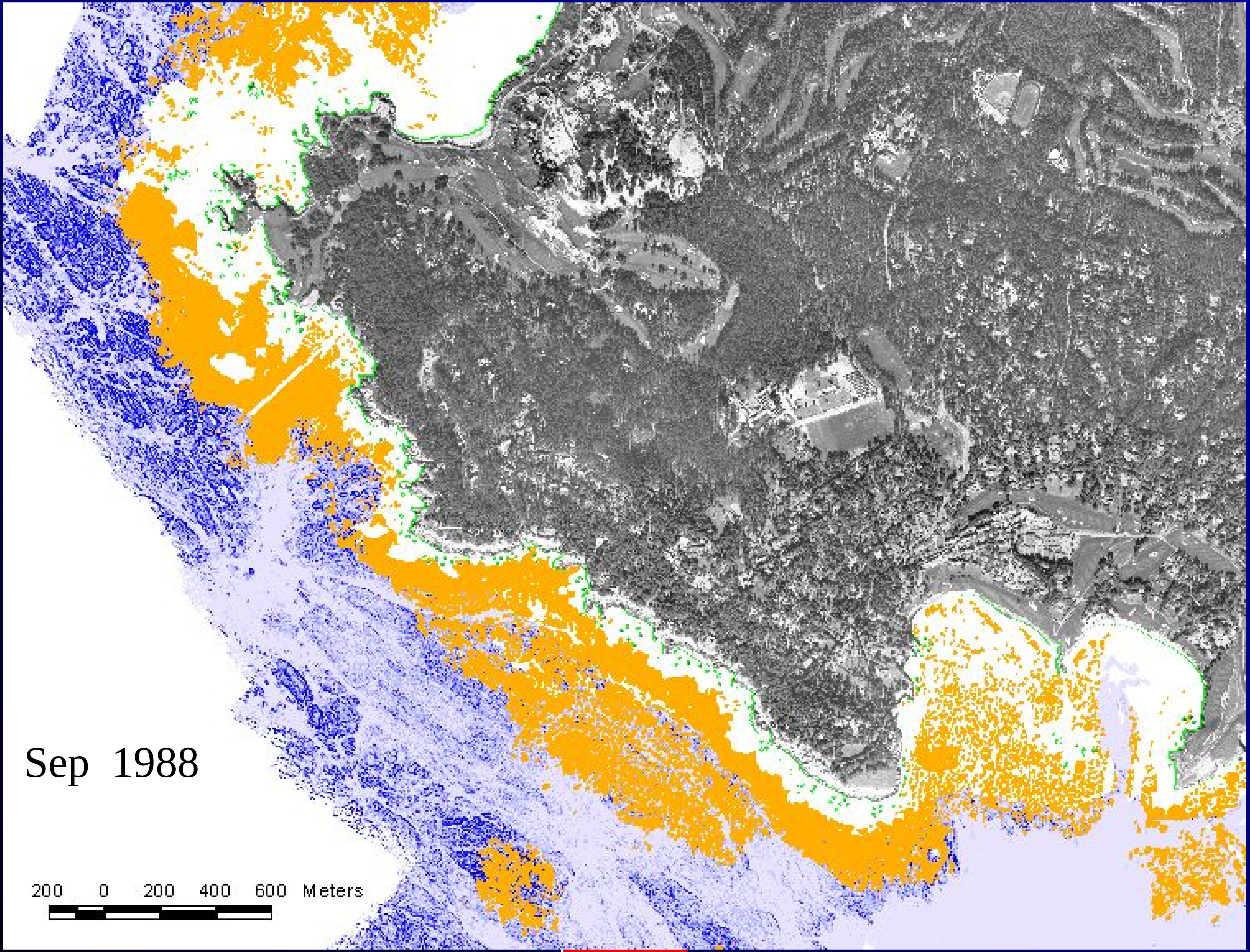

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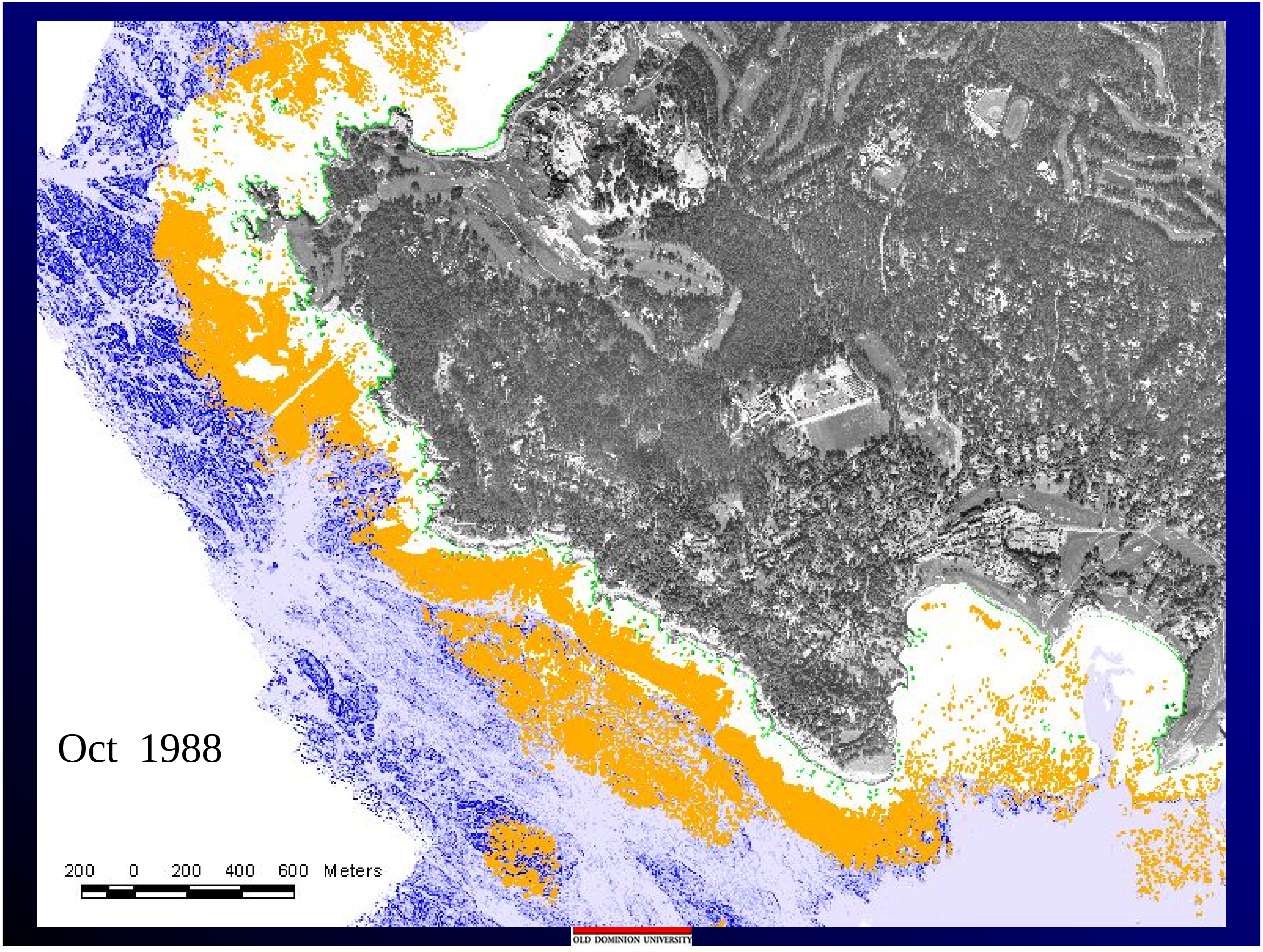
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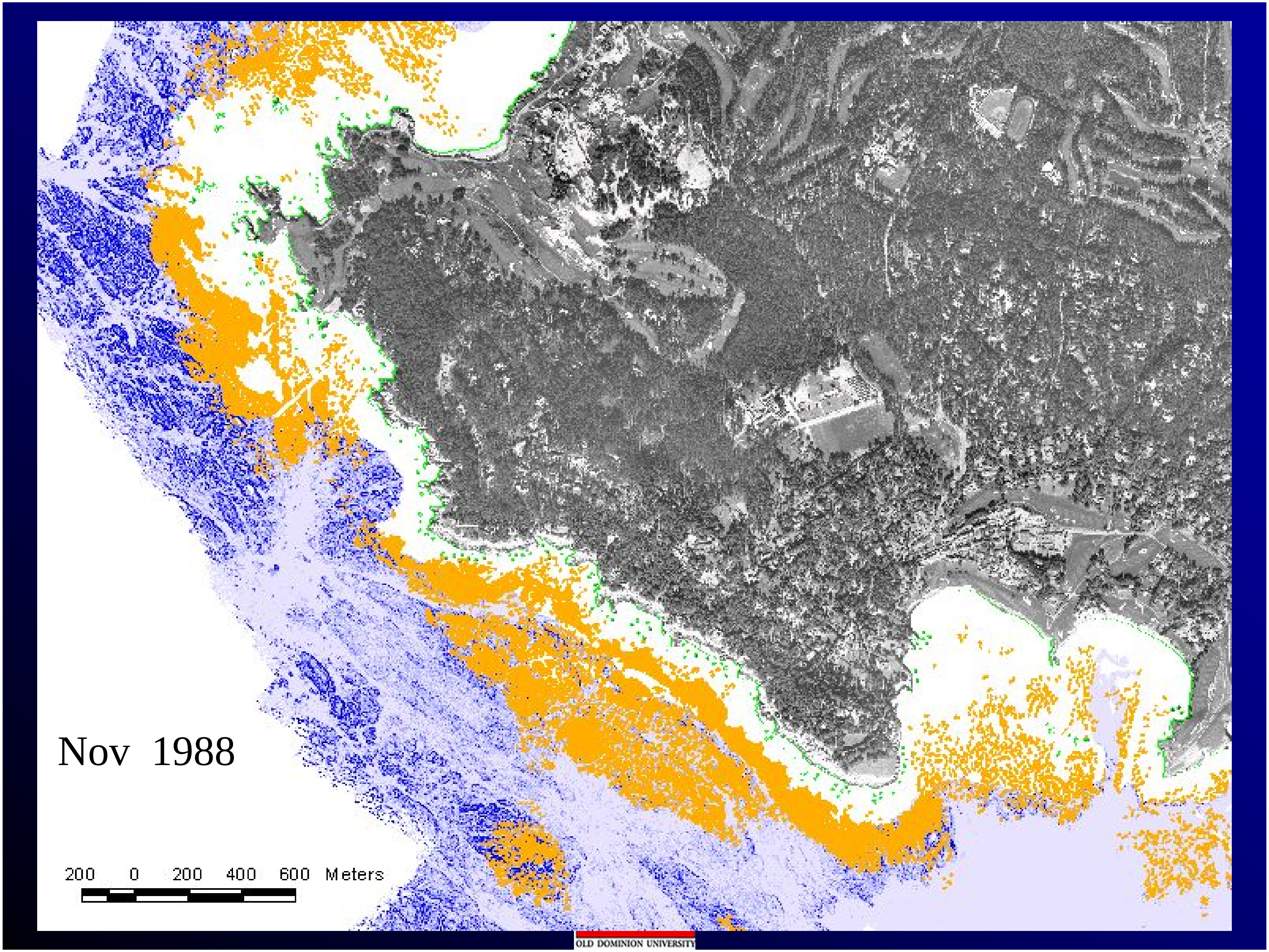
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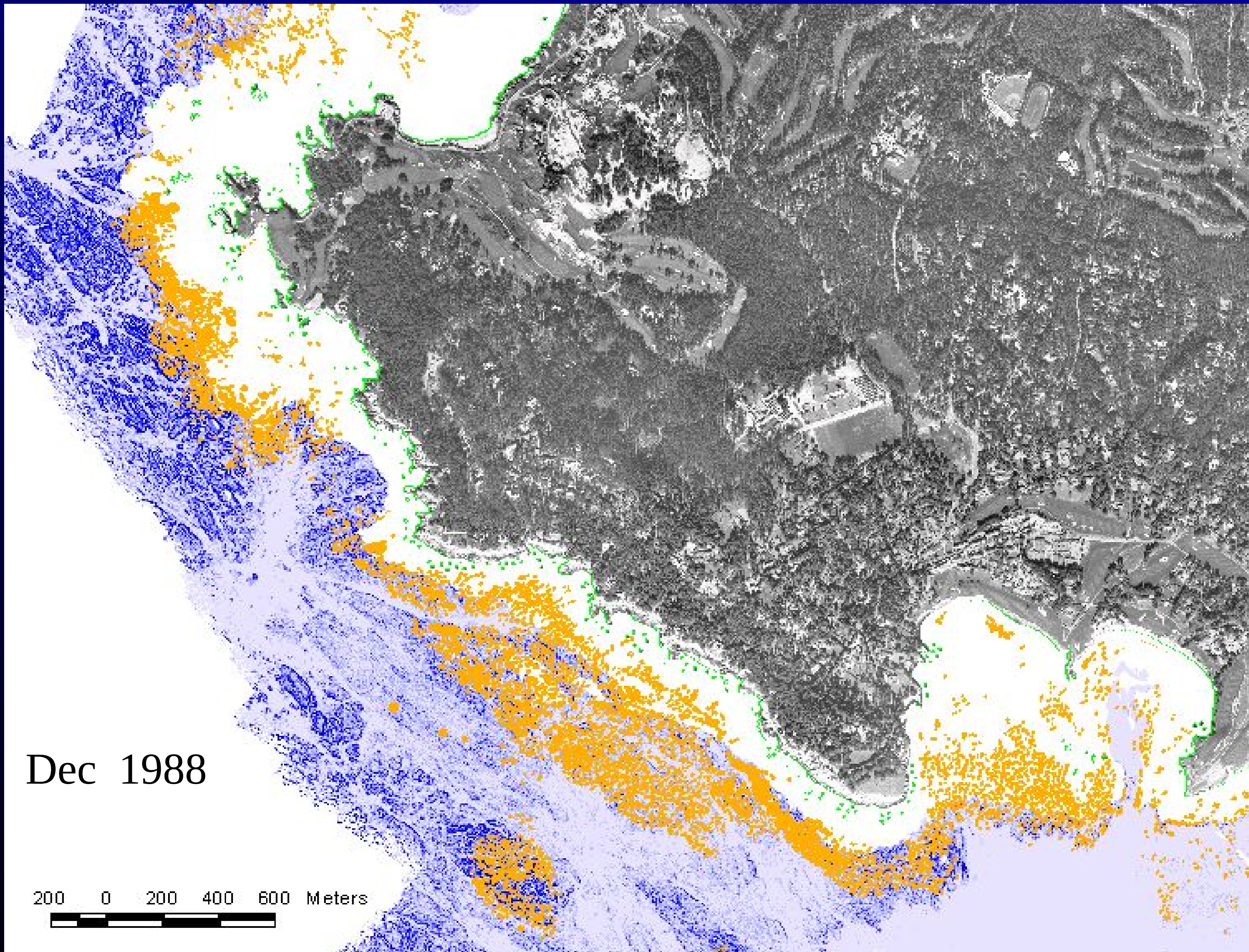

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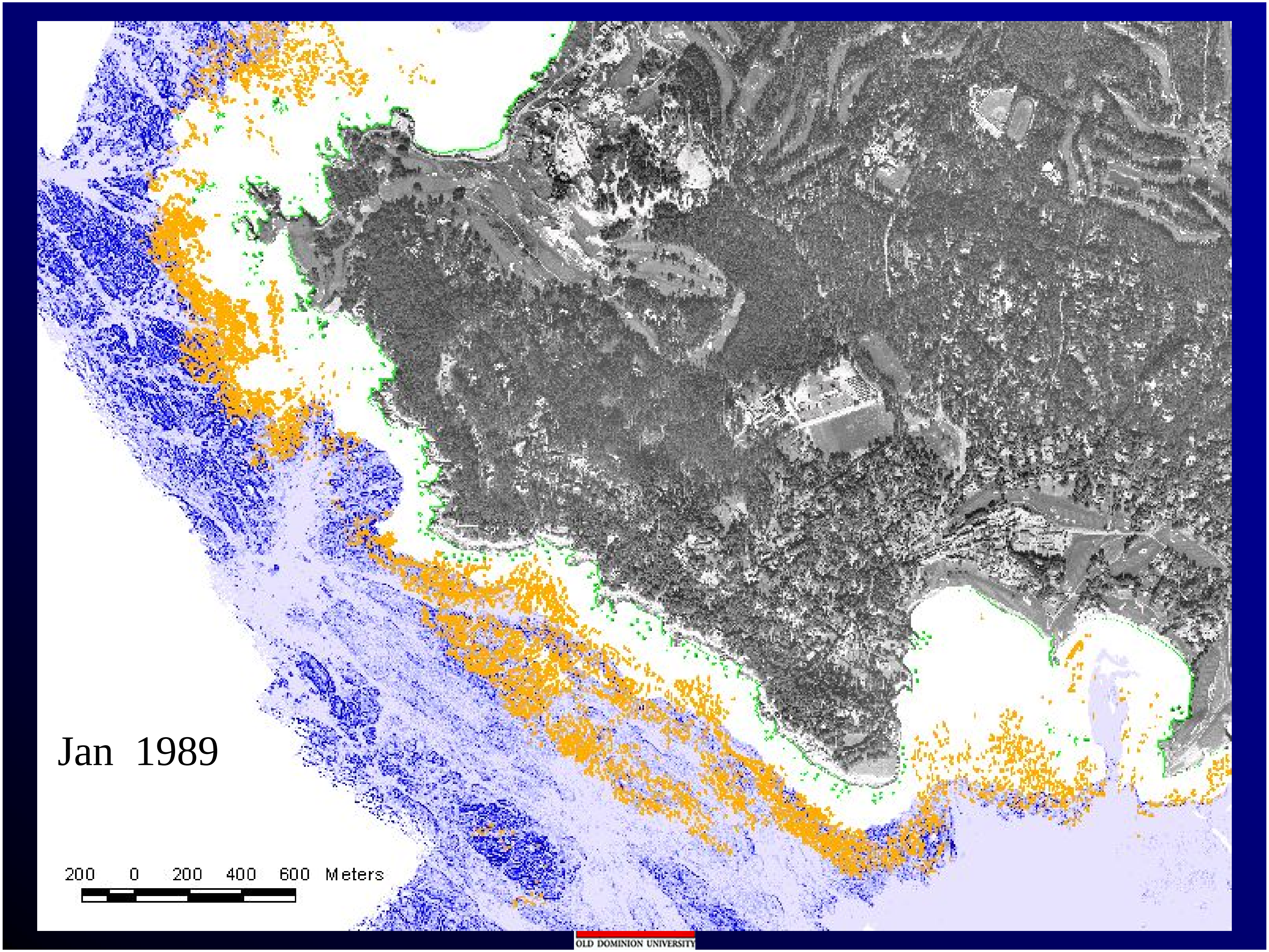
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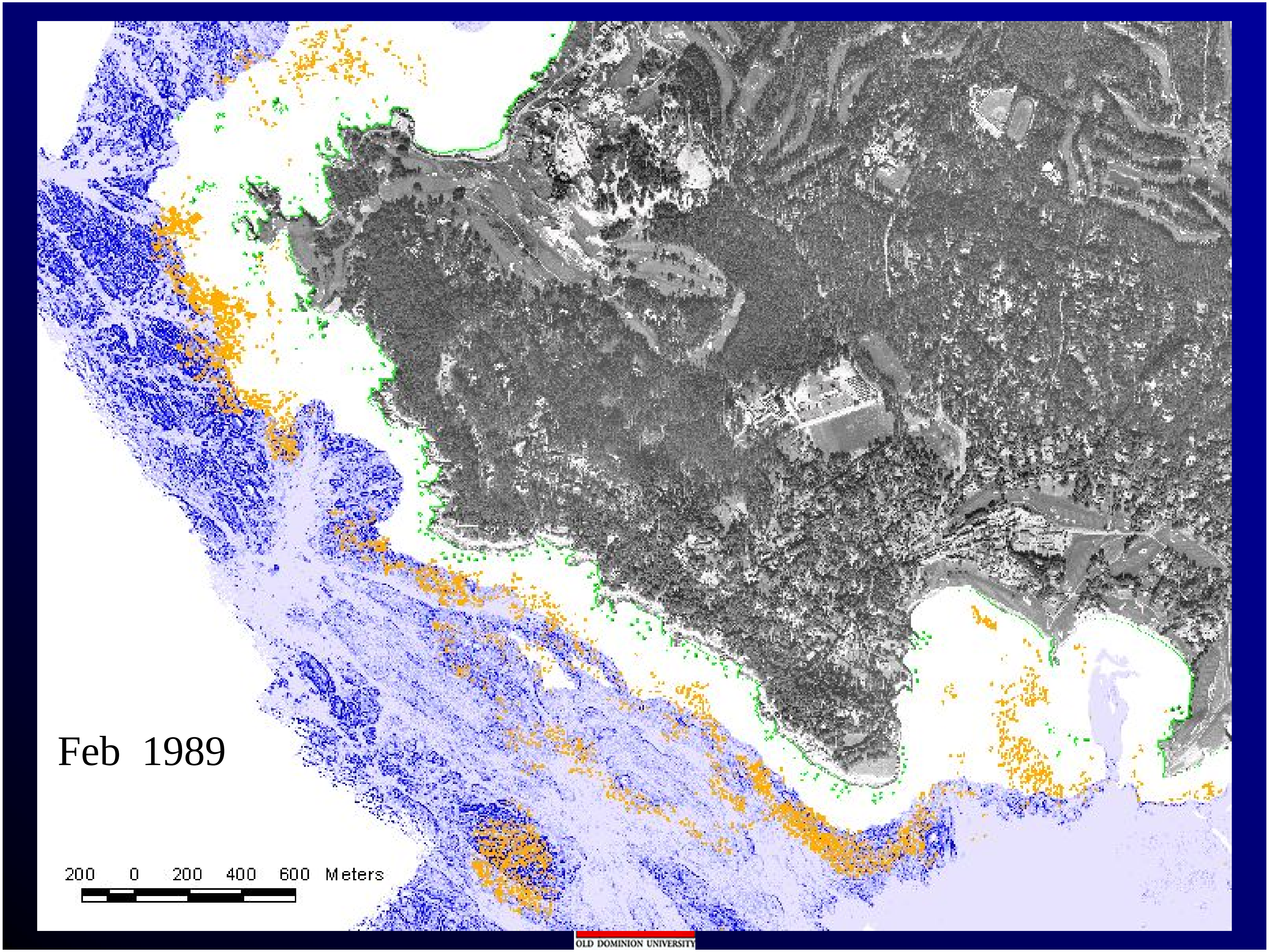
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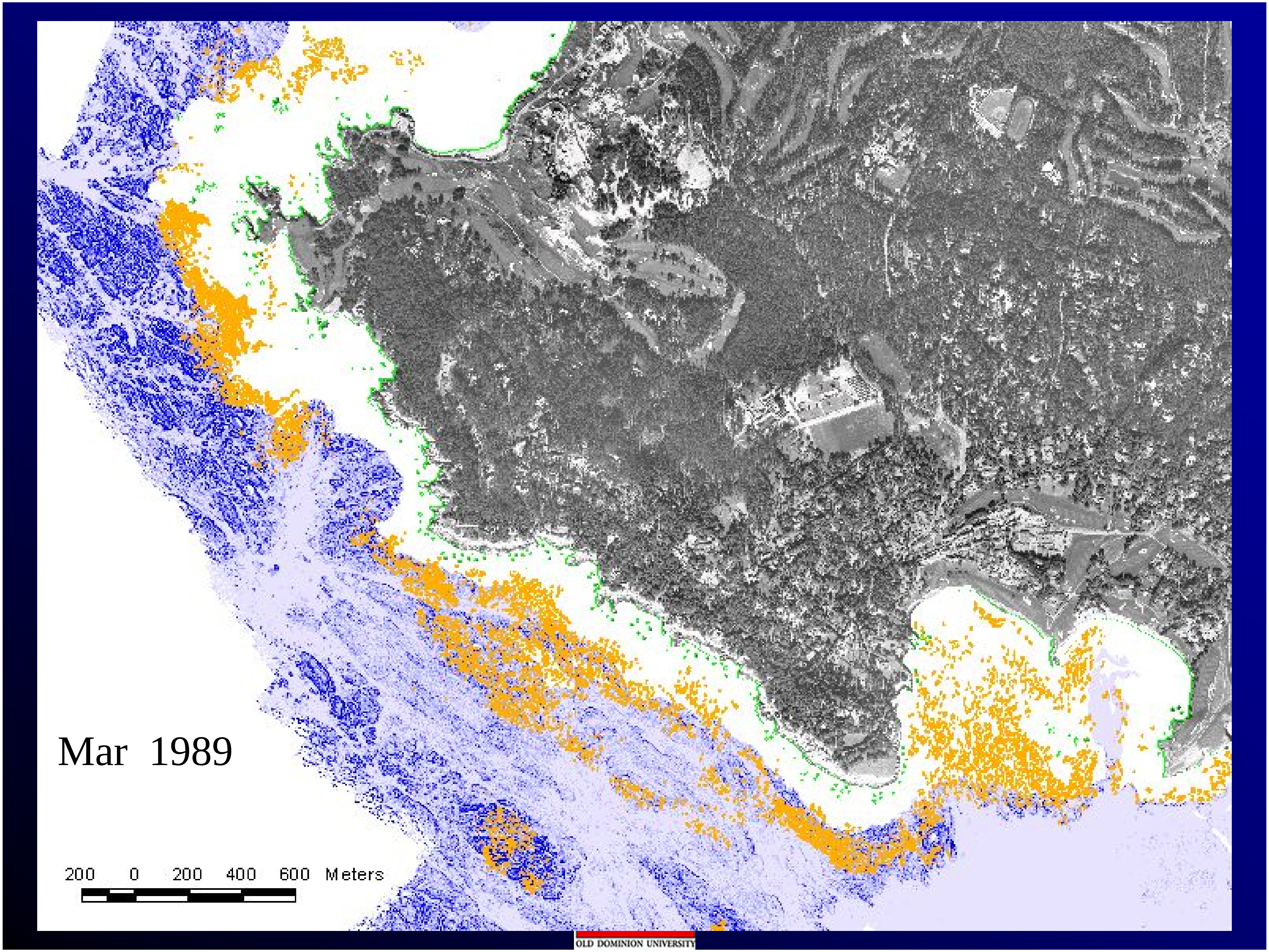
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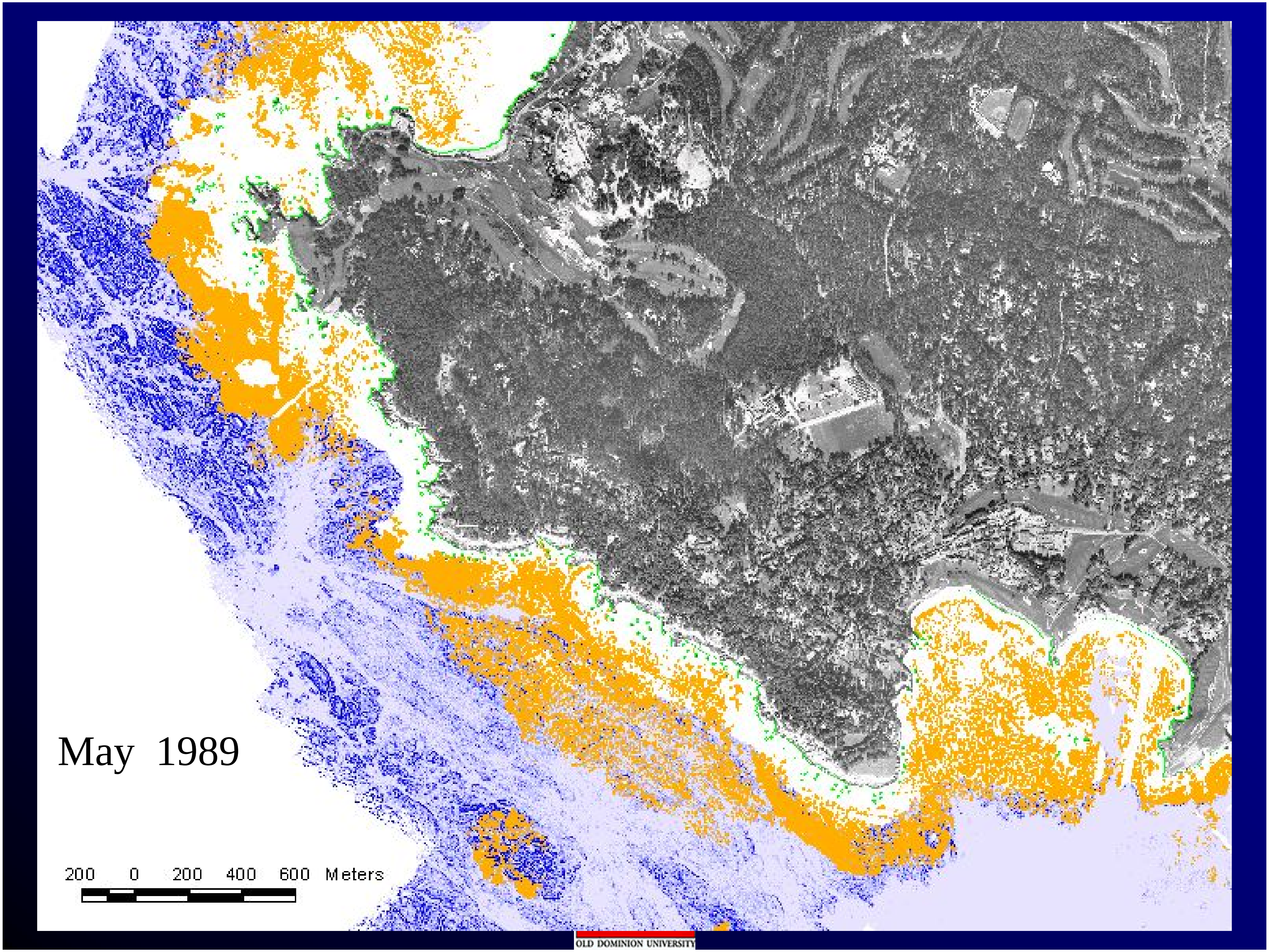
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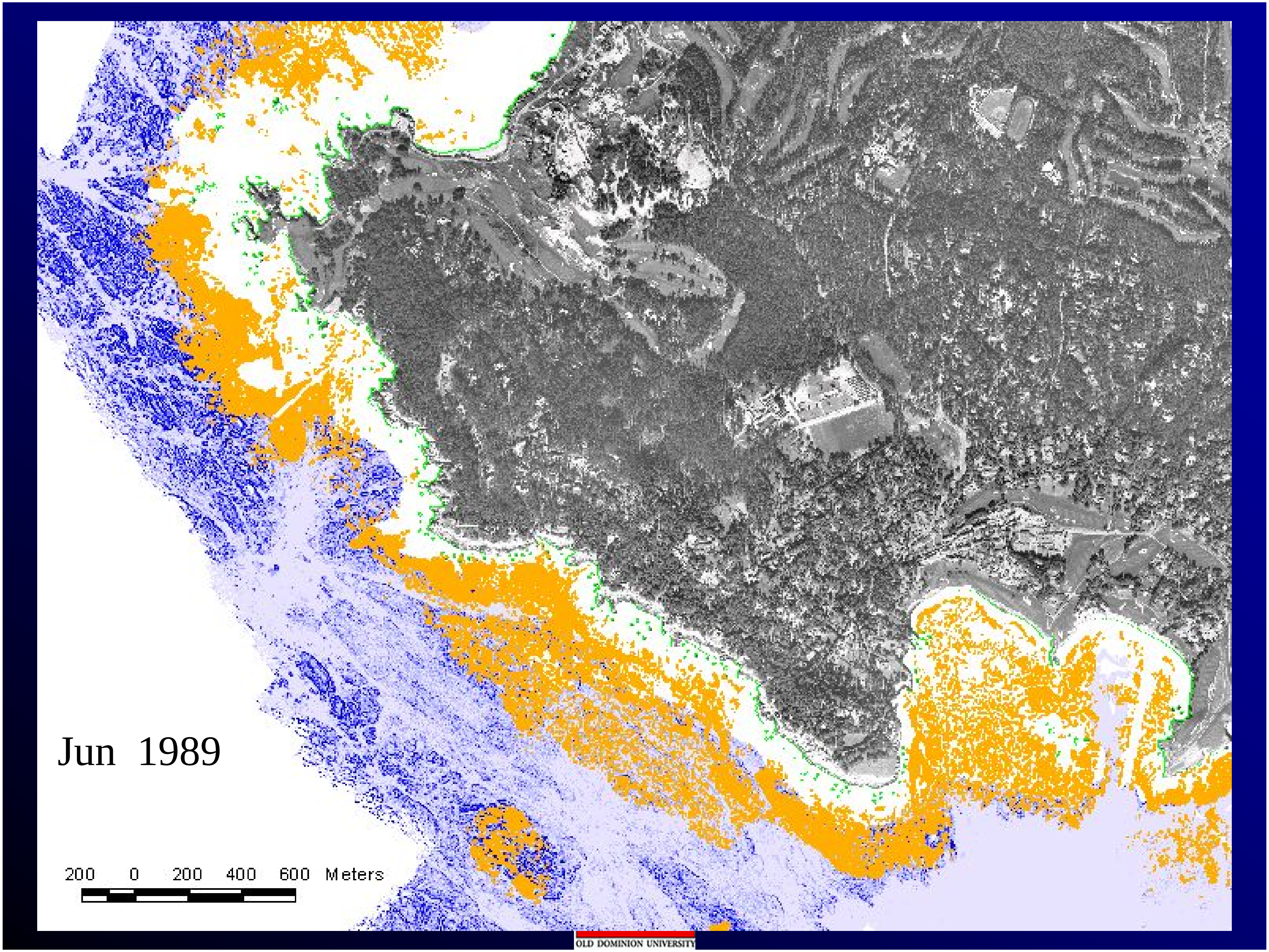
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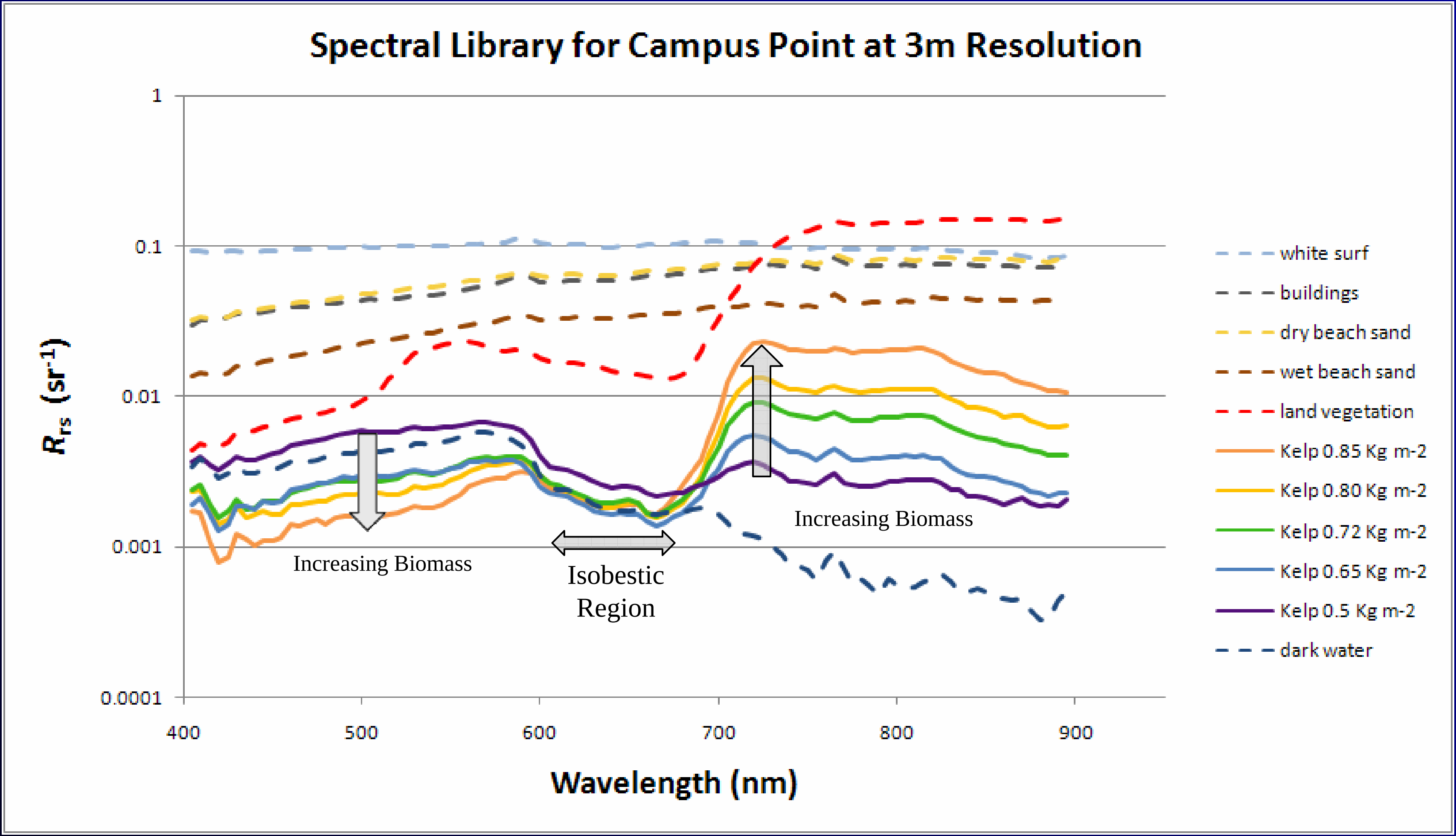
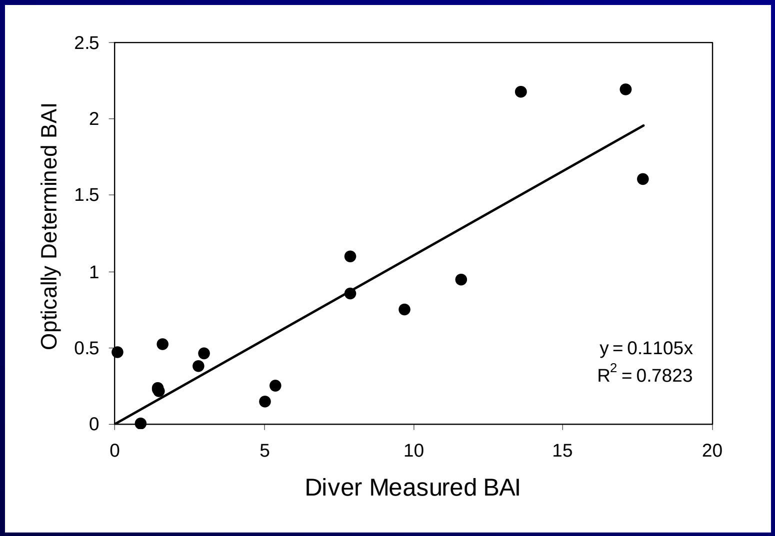
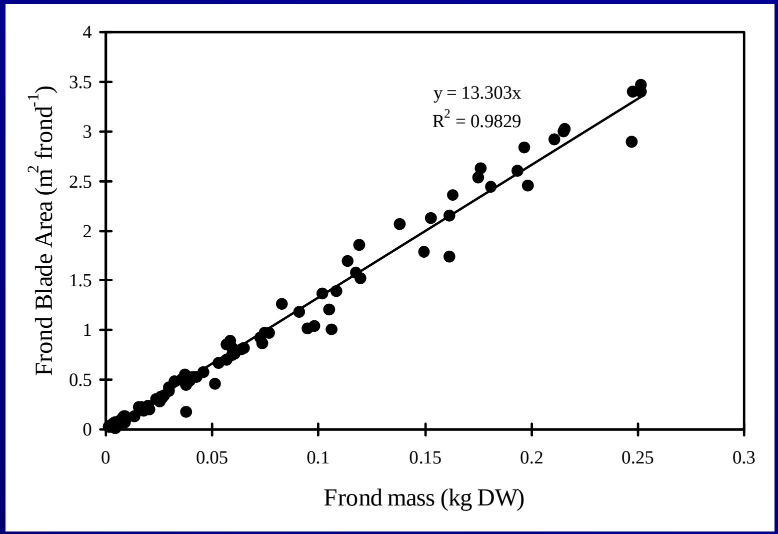
Floating kelp optical signatures are distinct from land and water

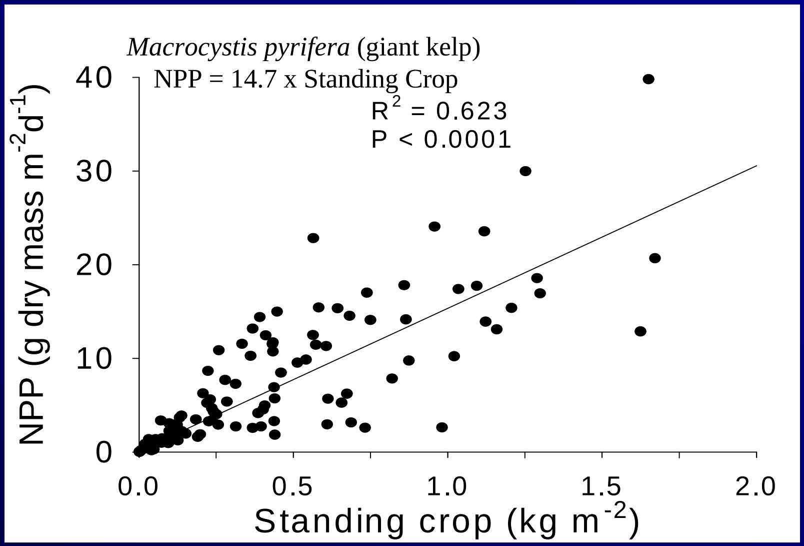


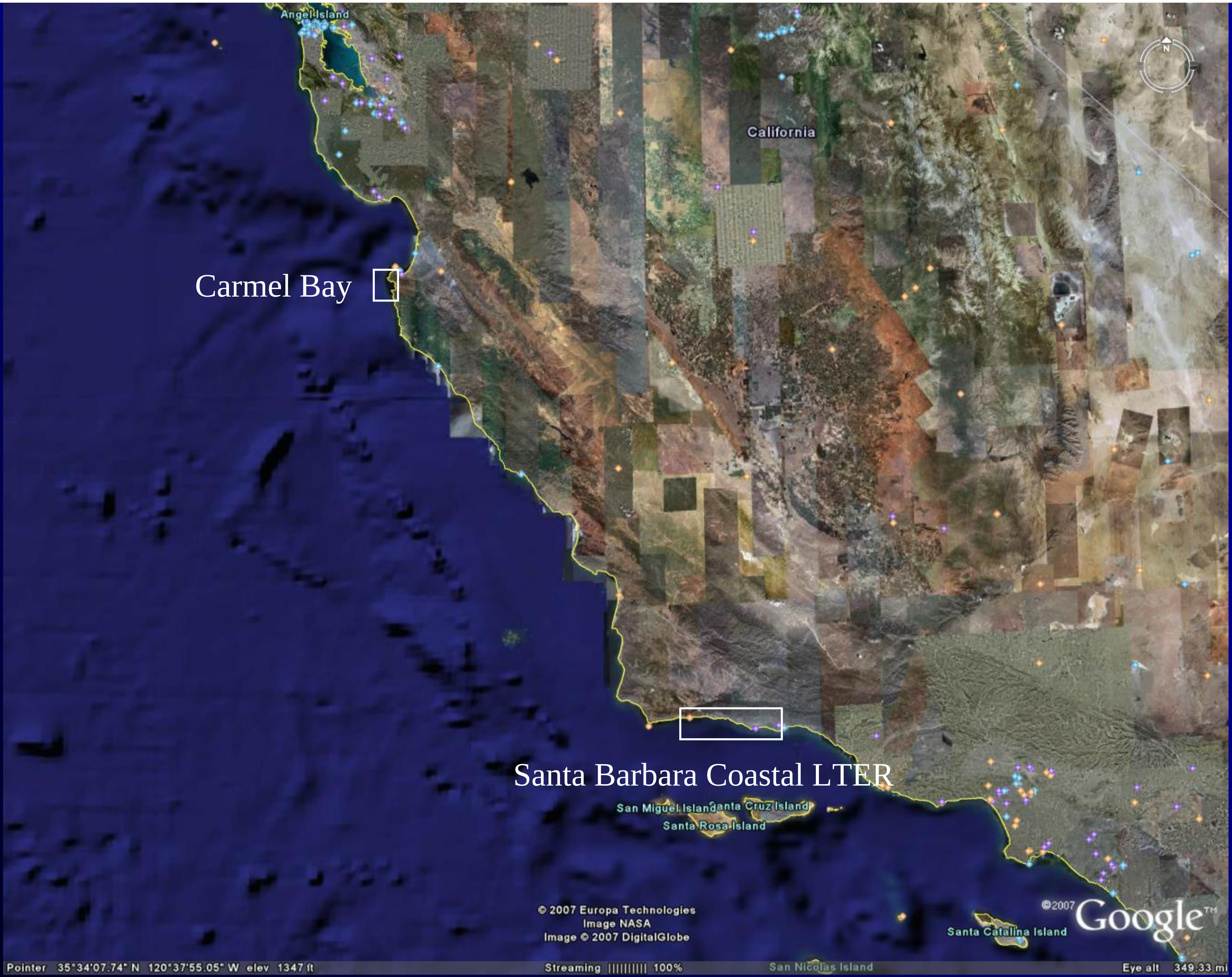
- **Converting NDVI into absolute kelp abundance and productivity:**





- **Optical BAI = NDVI/0.71**
- **True BAI = Optical BAI * 9.04**
- **Biomass = True BAI/13.3**
- **Productivity = Biomass * 14.7**




Carmel Bay
Santa Barbara Coastal LTER
Angel Island
California
San Miguel Island
Santa Cruz Island
Santa Rosa Island
Santa Catalina Island
San Nicolas Island
© 2007 Europa Technologies
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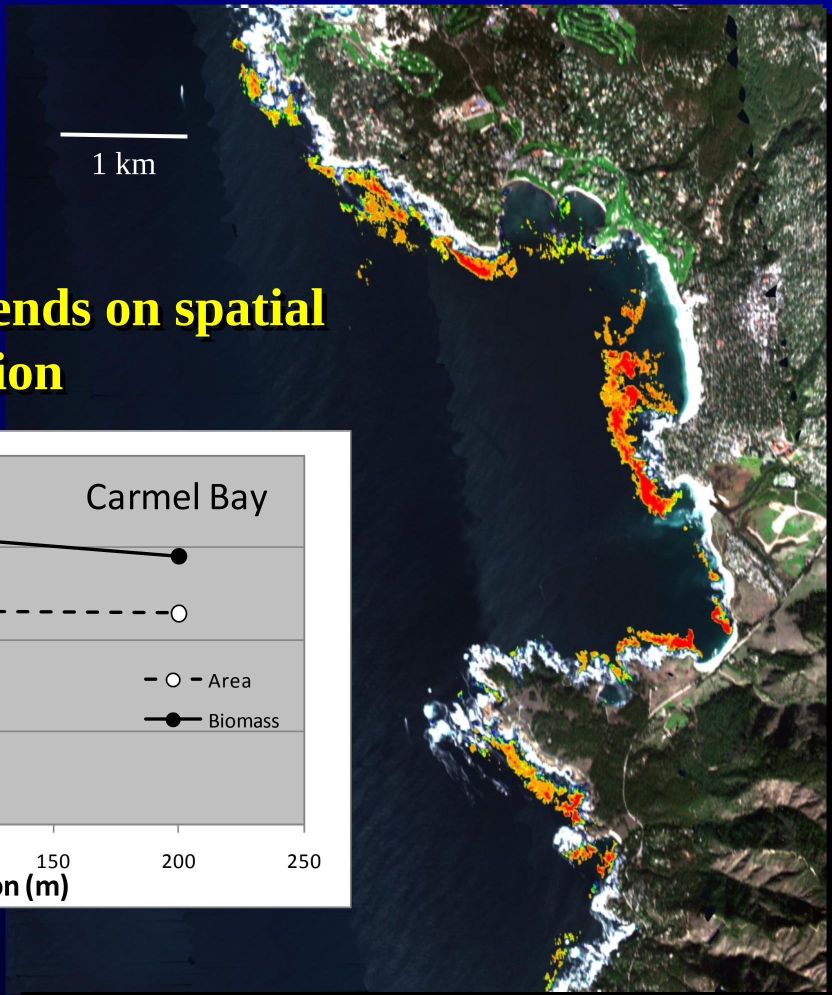
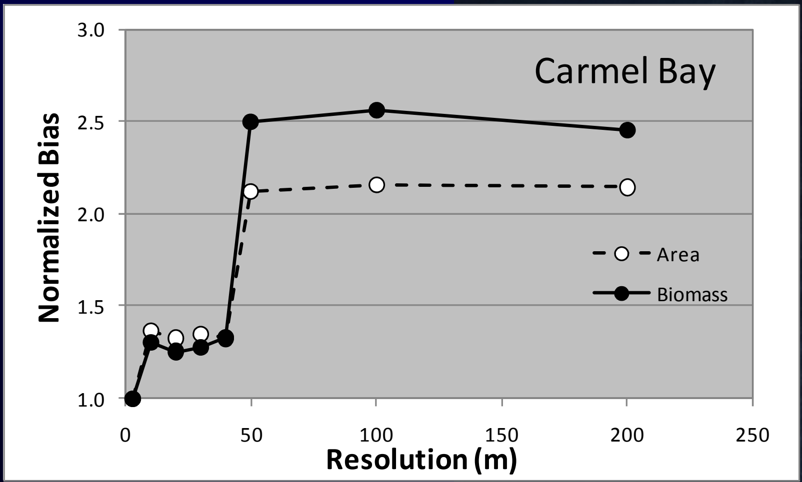
Pointer 35°34'07.74" N 120°37'55.05" W elev 1347 ft
Streaming ||||||||| 100%
Eye alt 349.33 mi

NDVI Derived Density and Productivity of Giant Kelp: Carmel Bay November 2004



Kelp retrieval depends on spatial resolution

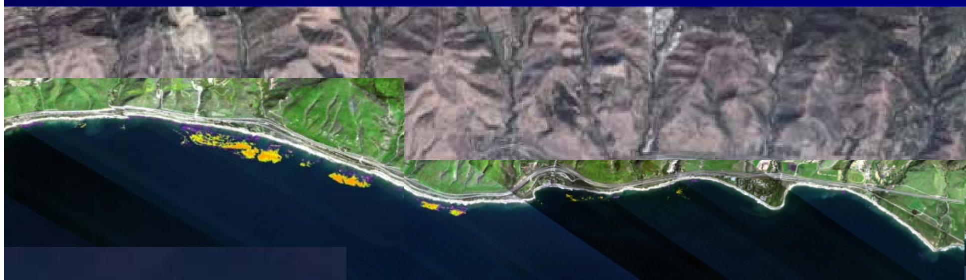


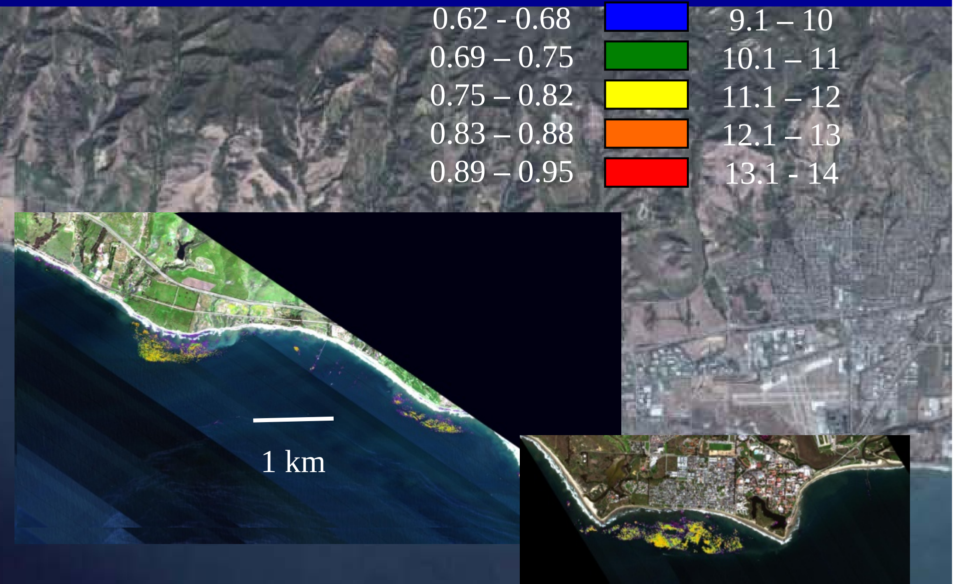
- **15 Km of irregular coastline**
- **1.7 Km^2 of kelp canopy**
- **Biomass: 1400 metric tons dry kelp biomass**
- **NPP: 19 metric tons dry biomass d^{-1}**

Kelp Density ($Kg\ DW\ m^{-2}$)		Kelp Productivity ($g\ DW\ m^{-2}\ d^{-1}$)
0.54 – 0.61		8 – 9
0.62 - 0.68		9.1 – 10
0.69 – 0.75		10.1 – 11
0.75 – 0.82		11.1 – 12
0.83 – 0.88		12.1 – 13
0.89 – 0.95		13.1 - 14

NDVI Derived Density and Productivity of Giant Kelp: Santa Barbara Coastal LTER Region March 2006

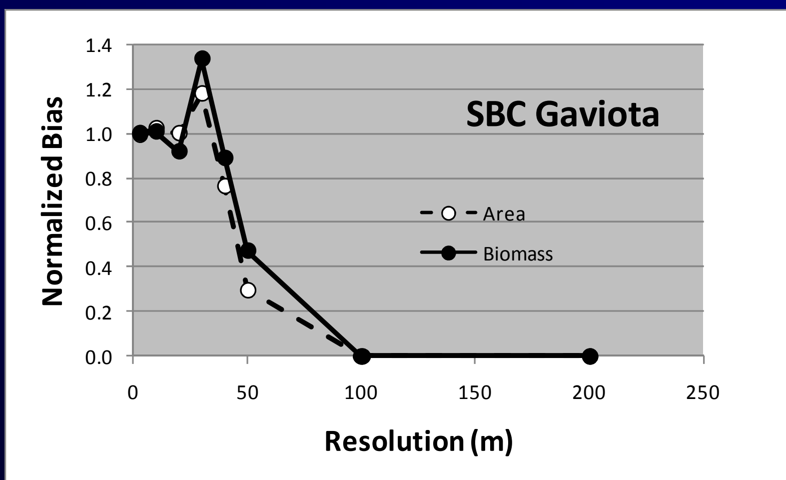
Kelp Density (Kg DW m^{-2})		Kelp Productivity (g DW m^{-2} d^{-1})
0.54 – 0.61	purple	8 – 9
0.62 - 0.68	blue	9.1 – 10
0.69 – 0.75	green	10.1 – 11
0.75 – 0.82	yellow	11.1 – 12
0.83 – 0.88	orange	12.1 – 13
0.89 – 0.95	red	13.1 - 14





- 35 Km mostly linear coastline
- 1.9 Km² kelp canopy
- Biomass: 1100 metric tons
- NPP: 17 metric tons per day

Kelp retrieval depends on spatial resolution



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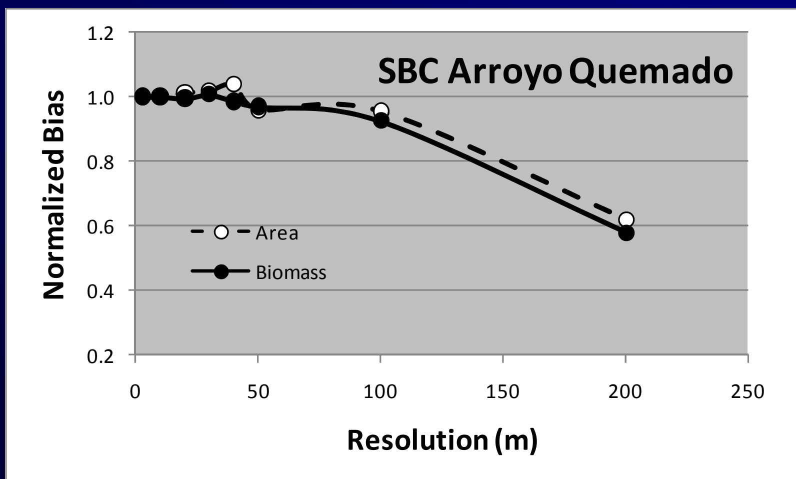

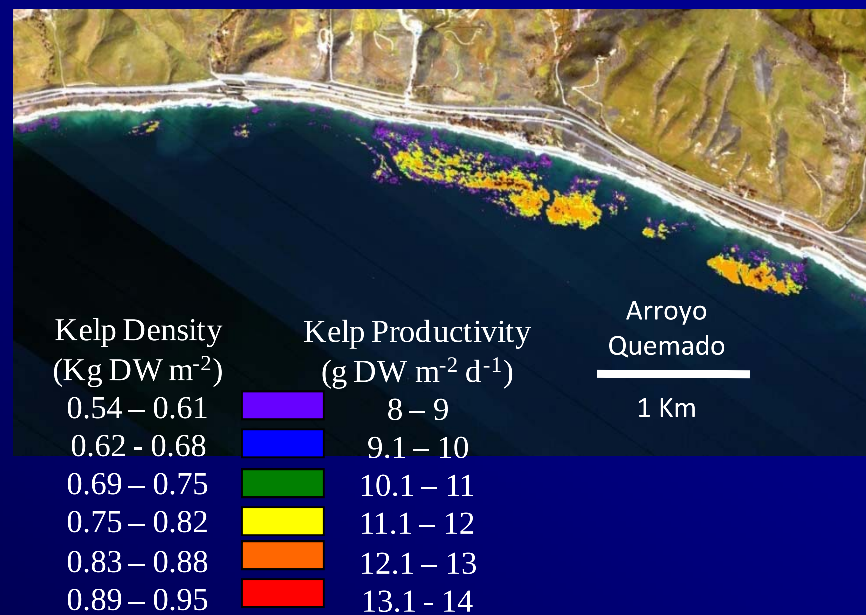

Kelp retrieval depends on spatial resolution

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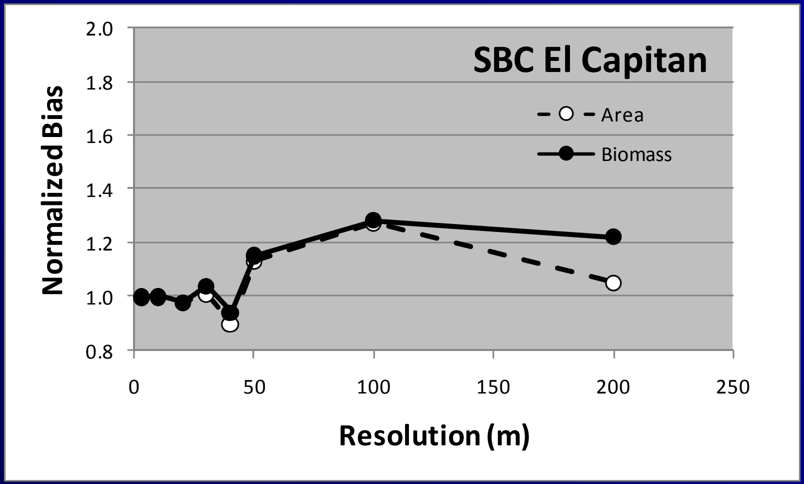

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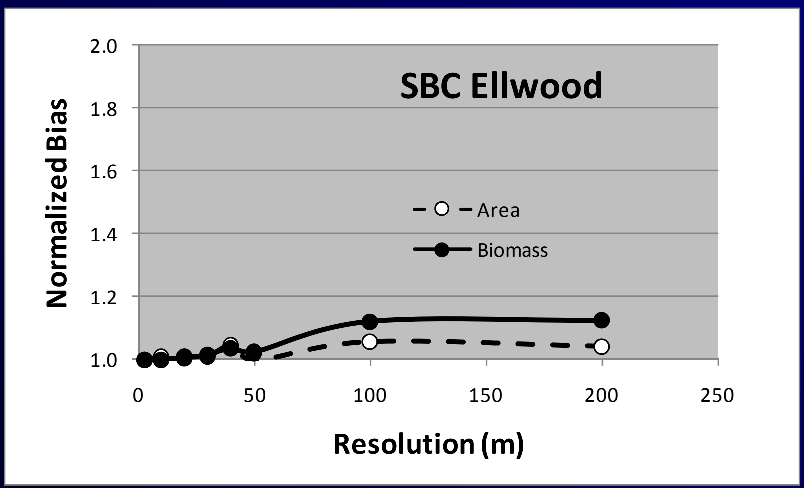
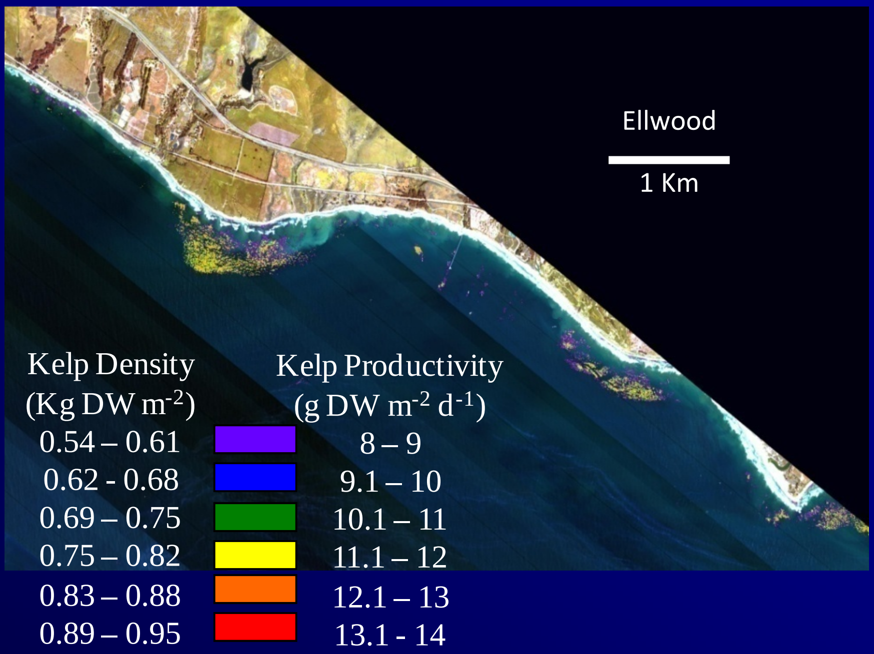
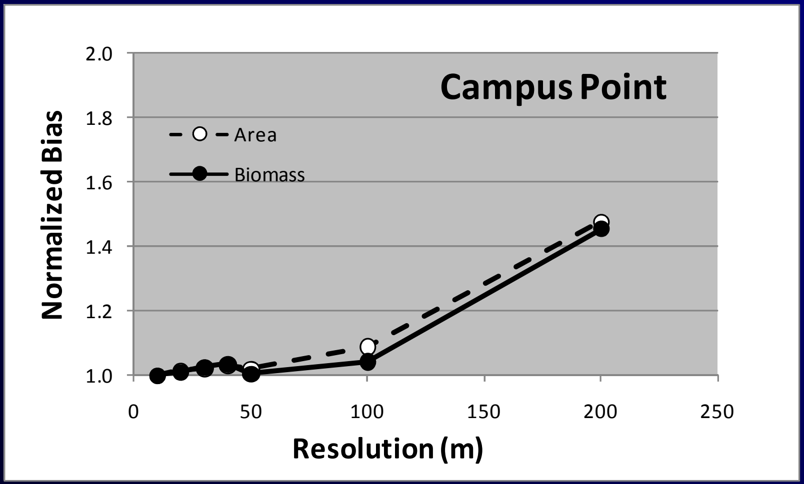




Kelp retrieval depends on spatial resolution



Kelp Density (Kg DW m^{-2})		Kelp Productivity (g DW m^{-2} d^{-1})
0.54 – 0.61		8 – 9
0.62 - 0.68		9.1 – 10
0.69 – 0.75		10.1 – 11
0.75 – 0.82		11.1 – 12
0.83 – 0.88		12.1 – 13
0.89 – 0.95		13.1 - 14

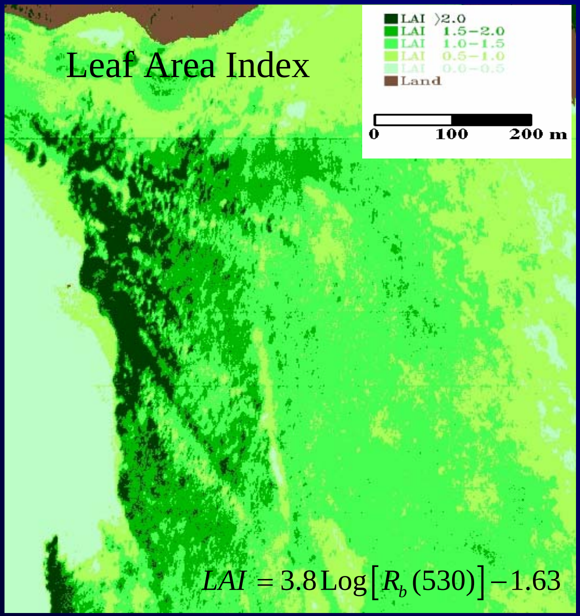
To date, resolution-dependent biases are scene-dependent:

- Large, dense canopies (e.g. Carmel Bay) produce large positive bias
- Small, sparse canopies disappear (e.g. Gaviota)
- Canopies of intermediate size and density are "just right", at least to 60 m resolution

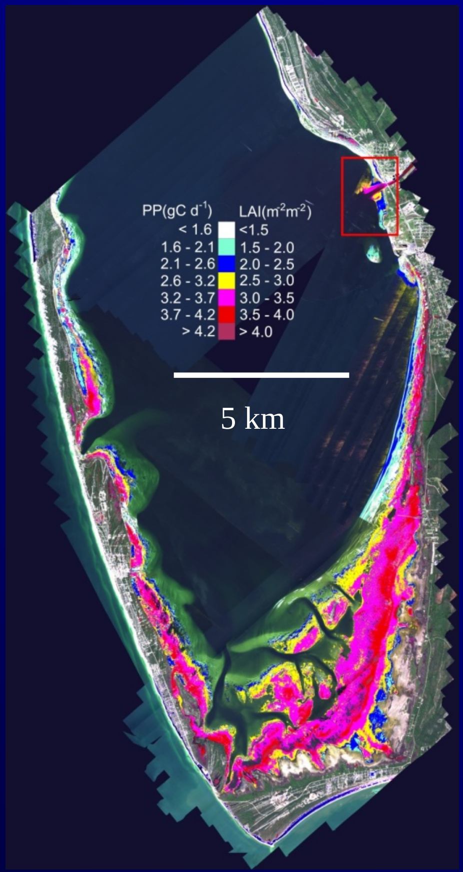
What controls the "Goldilocks" phenomenon?

- Patch dimension – shape and continuity are fractal properties
  - What can they tell us about emergent ecological properties?
    - Connectivity, productivity and ecological stability?
- Density and proximity
  - averaging bright and dark pixels across the water-kelp-land continuum

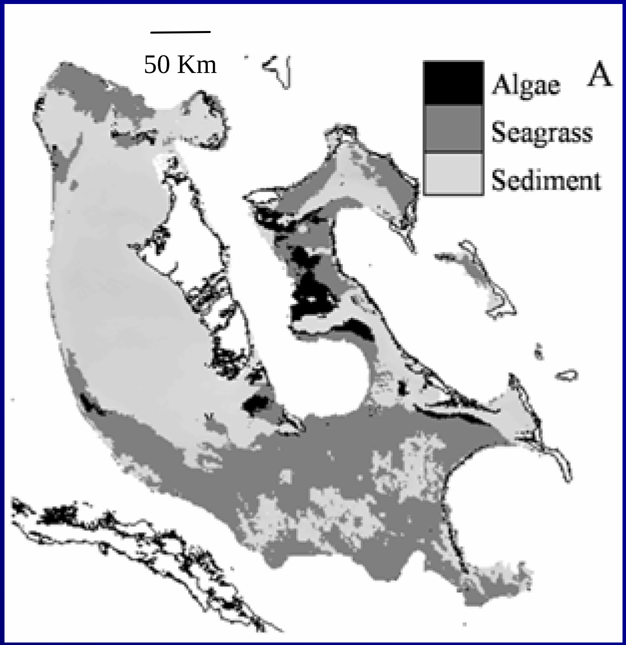
Seagrasses also exhibit a remarkable degree of spatial variability at scales ranging from meters to km



Lee Stocking Island, Bahamas
Dierssen et al. 2003

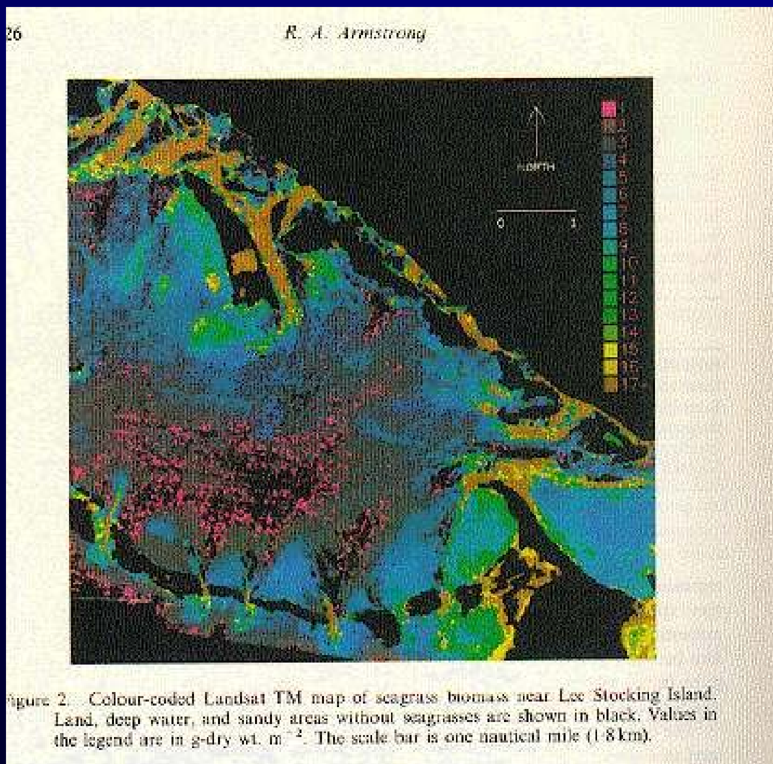


St. Joseph's Bay, FL
Hill et al. in prep



Great Bahama Bank
Dierssen et al. in review

….that can be remarkably stable across time

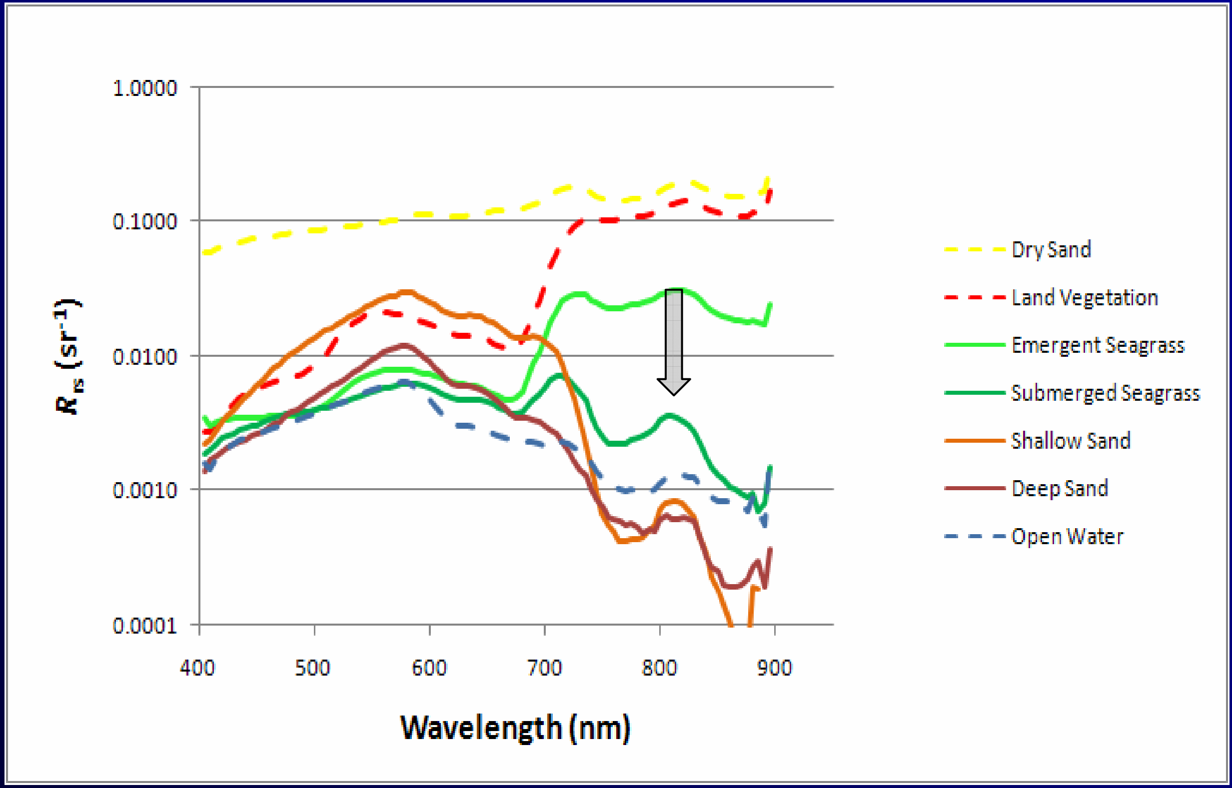


igure 2. Colour-coded Landsat TM map of seagrass biomass near Lee Stocking Island. Land, deep water, and sandy areas without seagrasses are shown in black. Values in the legend are in g-dry wt. m^{-2}. The scale bar is one nautical mile (1·8 km).

1978 TM image of Exumas, Bahamas
Armstrong 1993

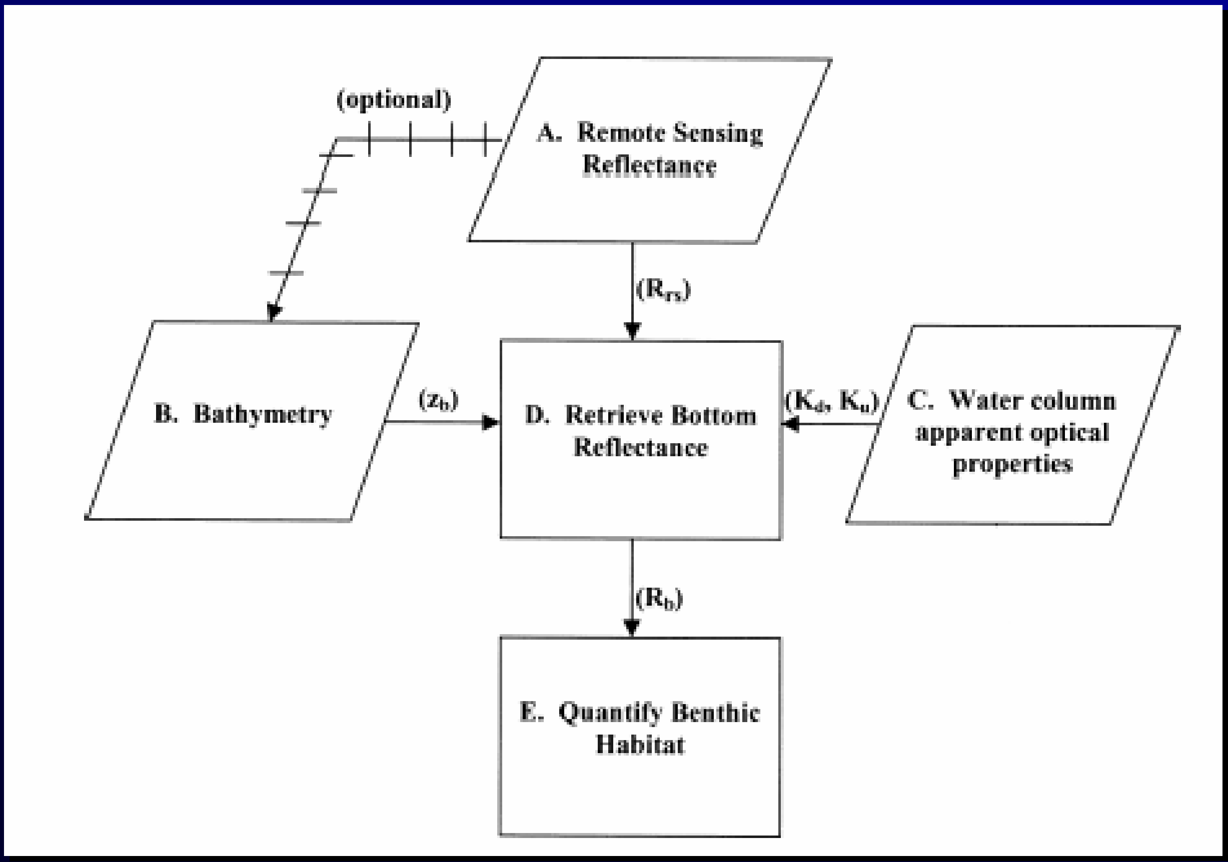
2009 RGB image of Euxmas Bahamas
From Google Earth

SAV has less impact on R_{rs} than floating kelp canopies……

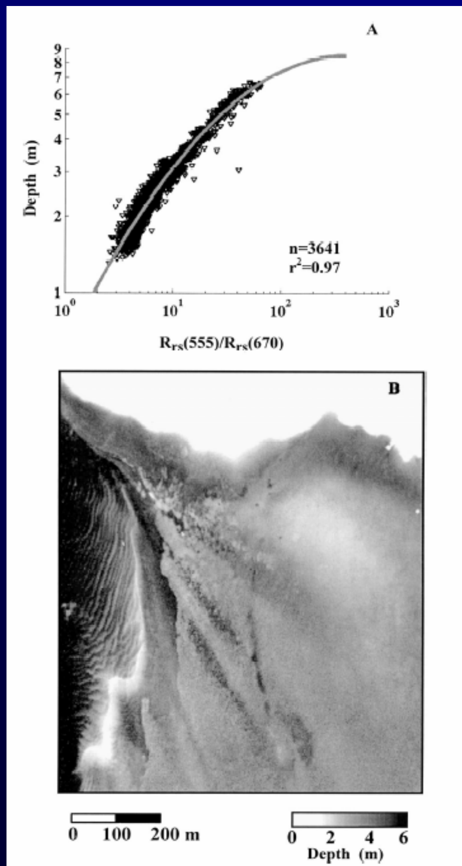


…and decreases as the water column deepens

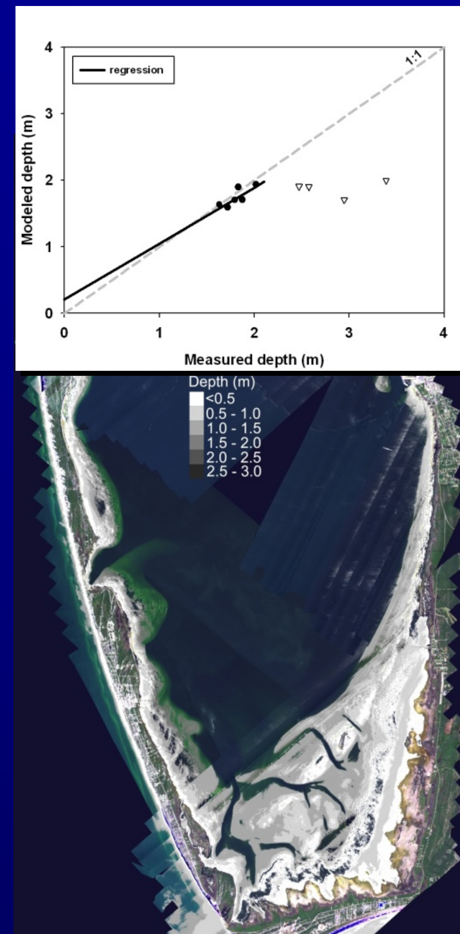
We can remove water column effects if we know their optical properties *and* bathmetry



We can obtain bathymetry from R_{rs}

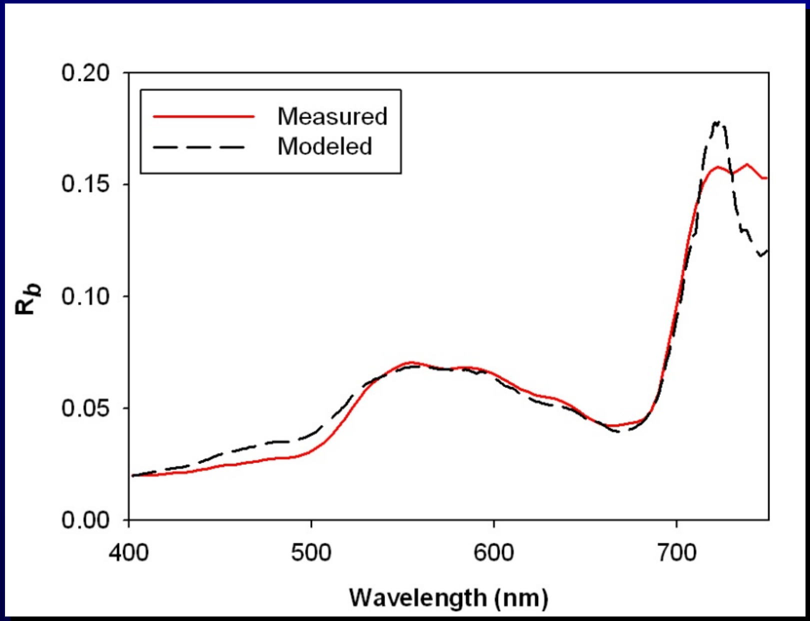


to 7 m in clear Bahamian water using R_{555}:R_{670} band ratios
Dierssen et al. 2003



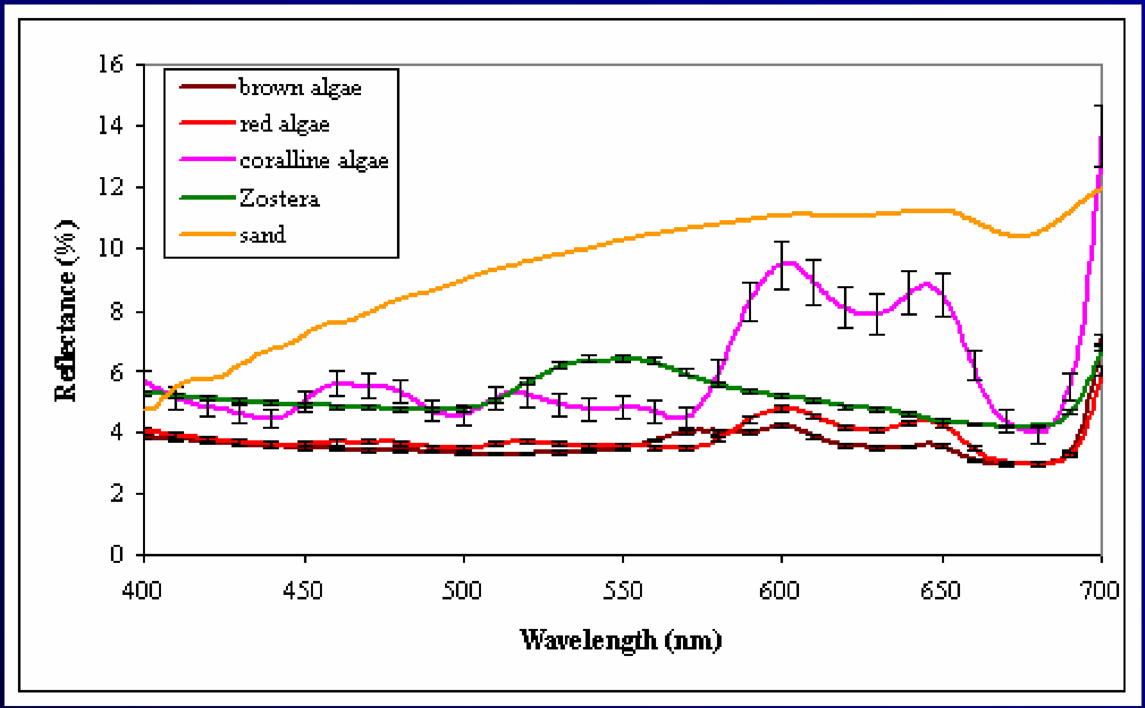
and to 2 m in turbid coastal waters based on logarithmic intensity of R_{810}
Bachmann et al. 2008, Hill et al. in prep

And in combination with knowledge of water column optical properties, retrieve R_b



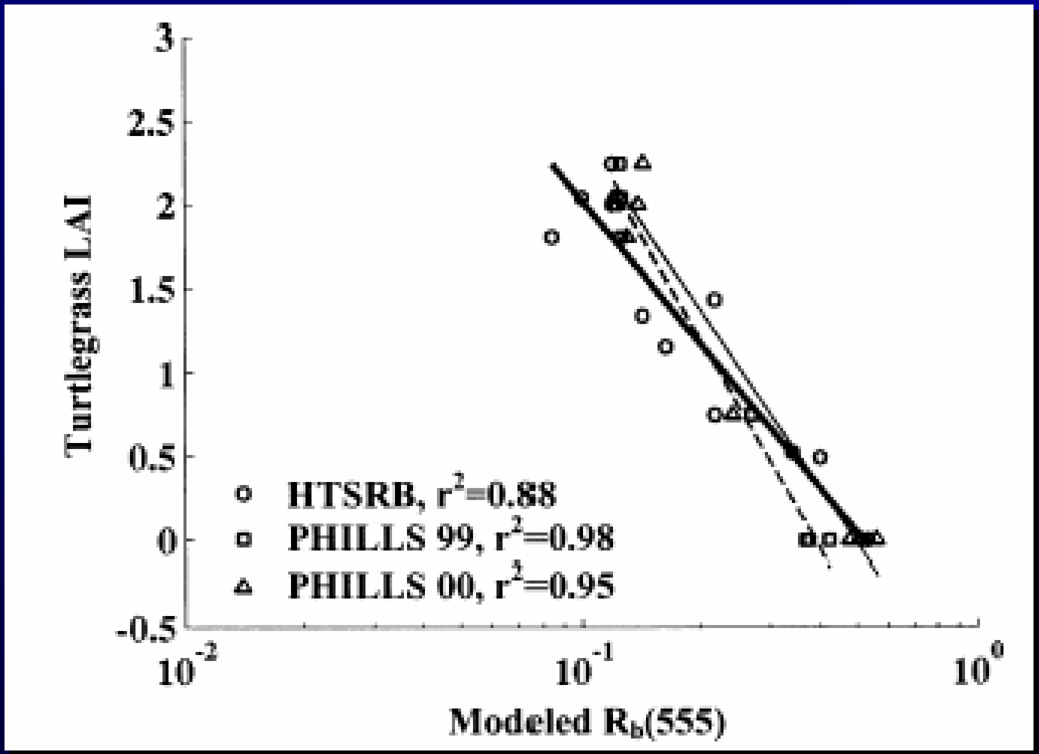
from Hill et al. in prep

Retrieval of R_b of submerged macrophytes are most different between 550 and 700 nm…..



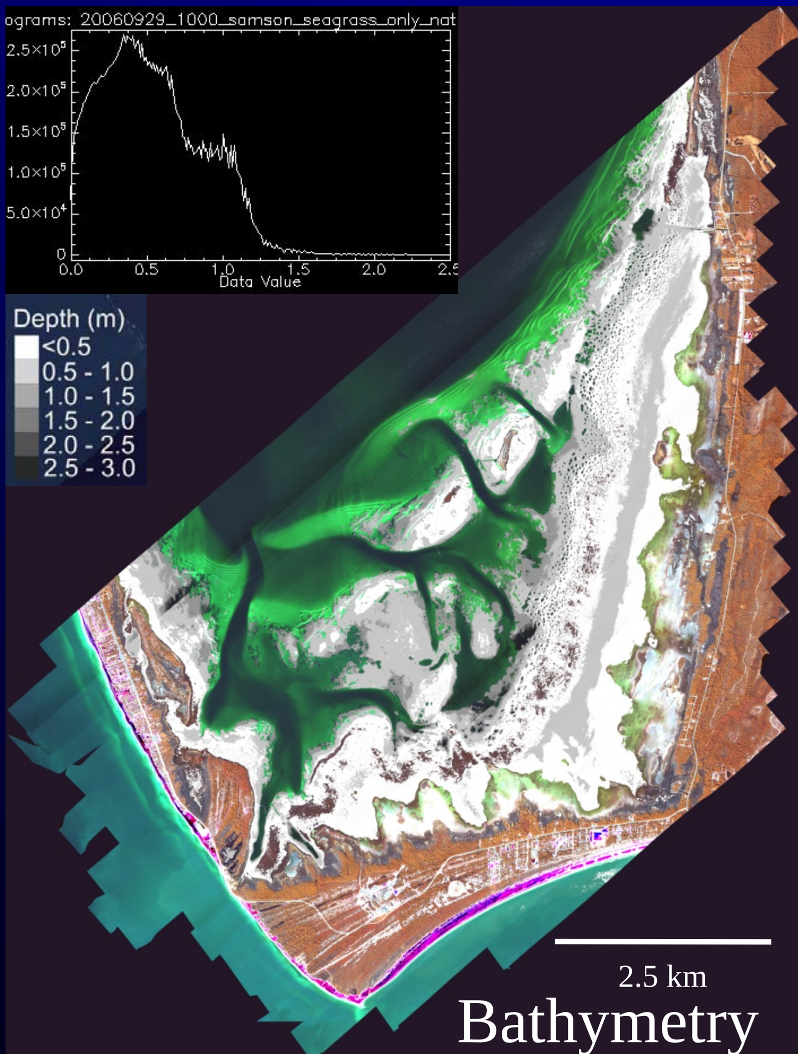
…..where water depth becomes increasingly important

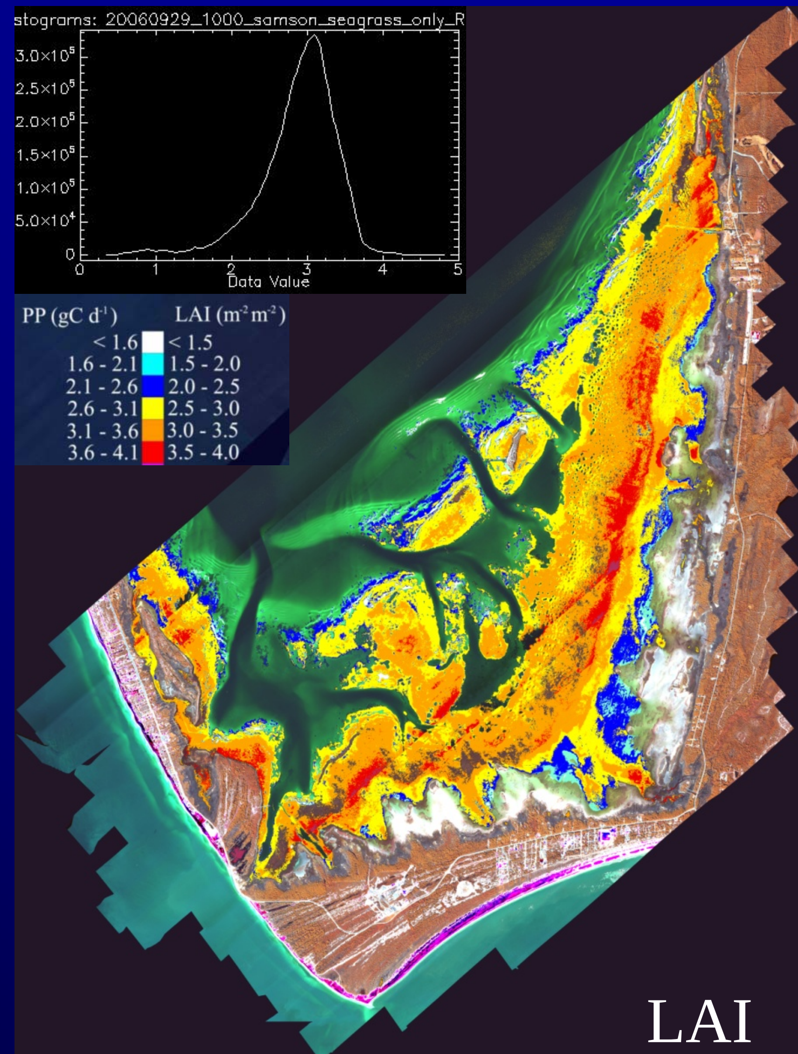
Knowledge of R_b provides a way to identify taxa (e.g. seagrasses) and retrieve biomass (e.g., LAI)……..



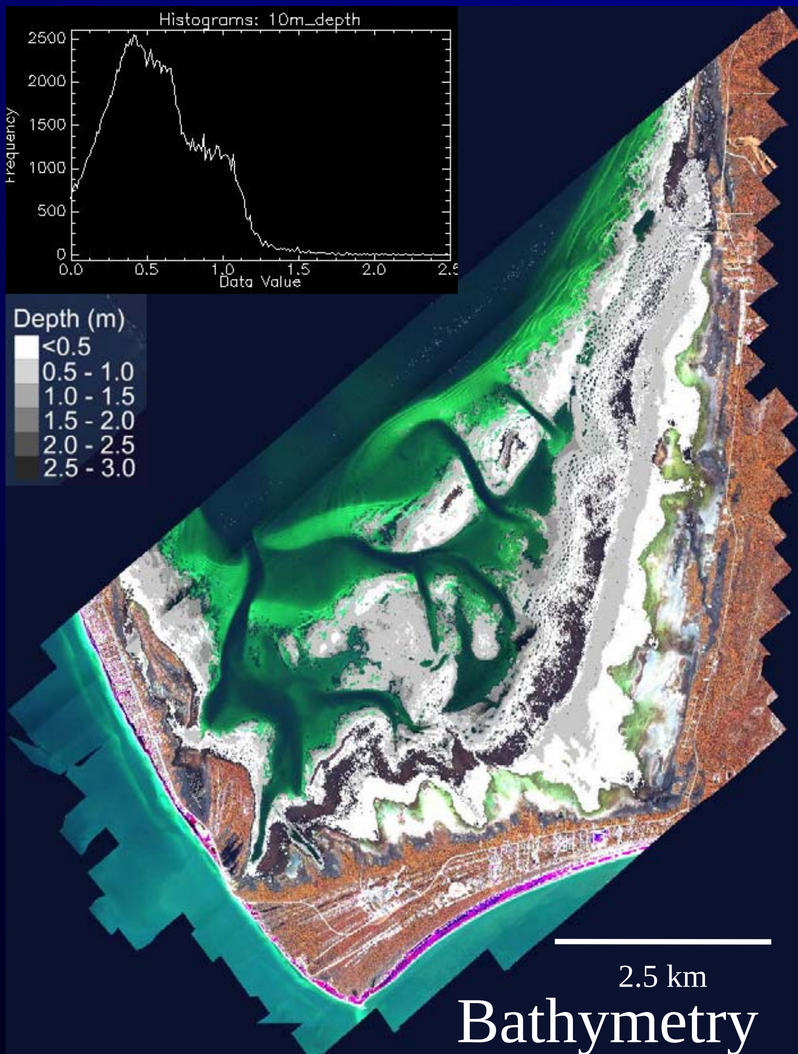
from Dierssen et al. 2003

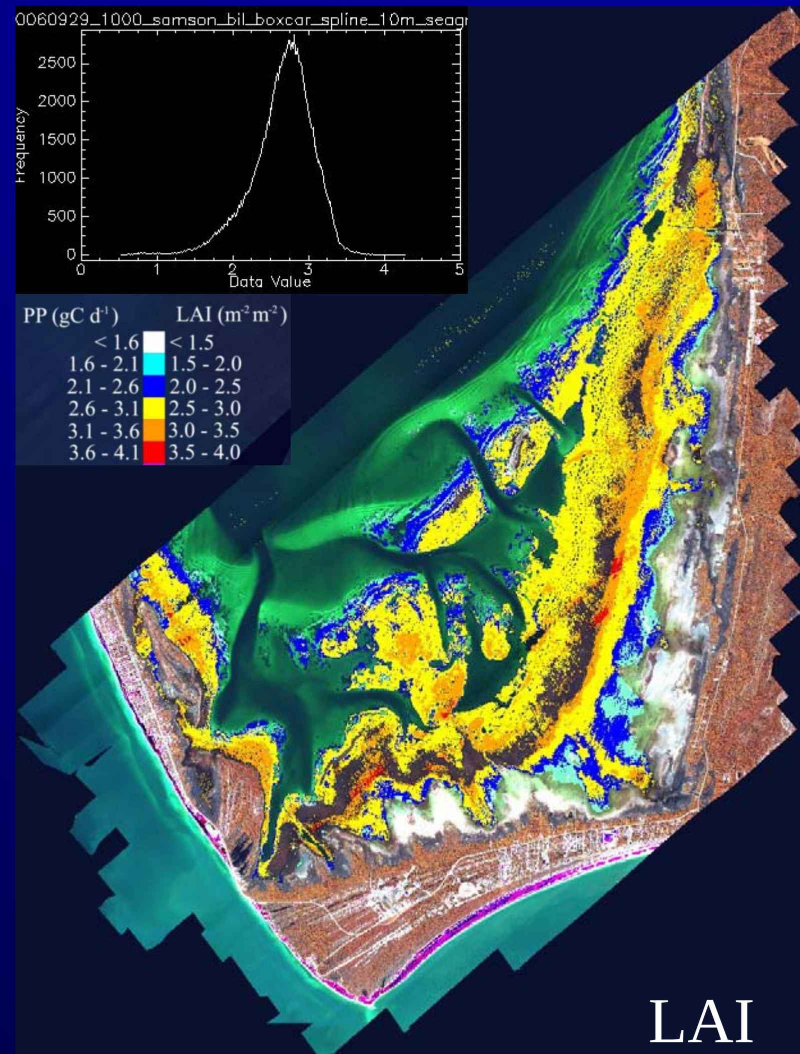
St. Joseph's Bay, FL 1 Meter Resolution



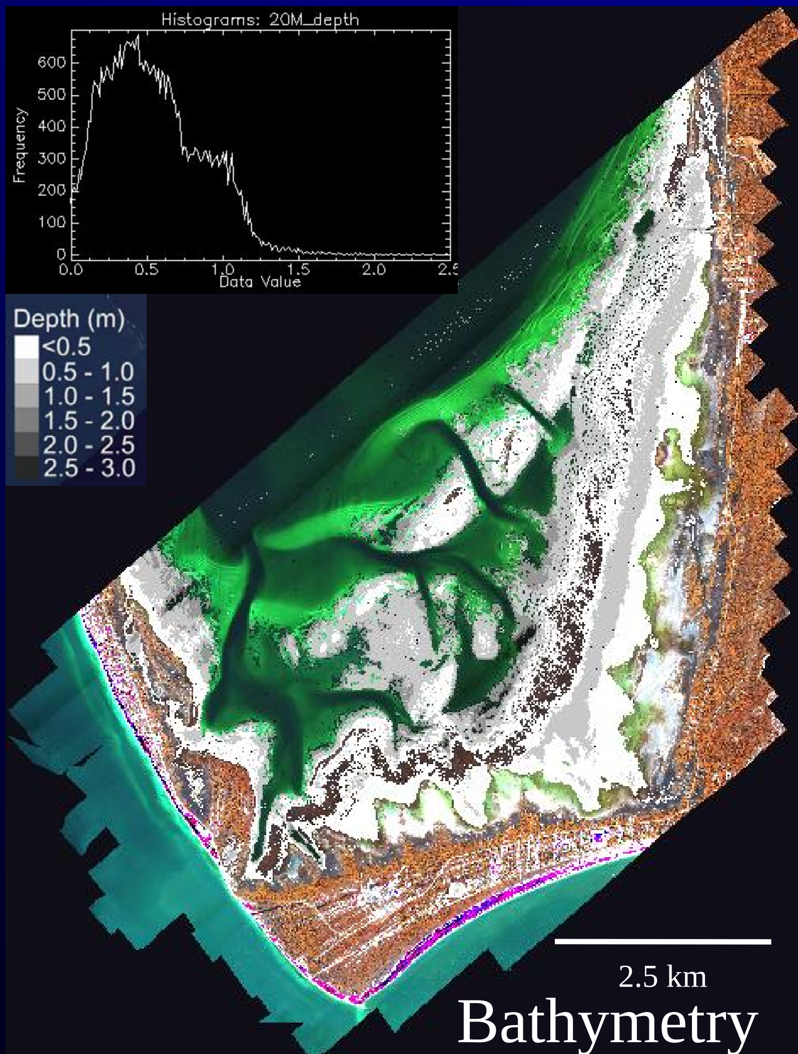


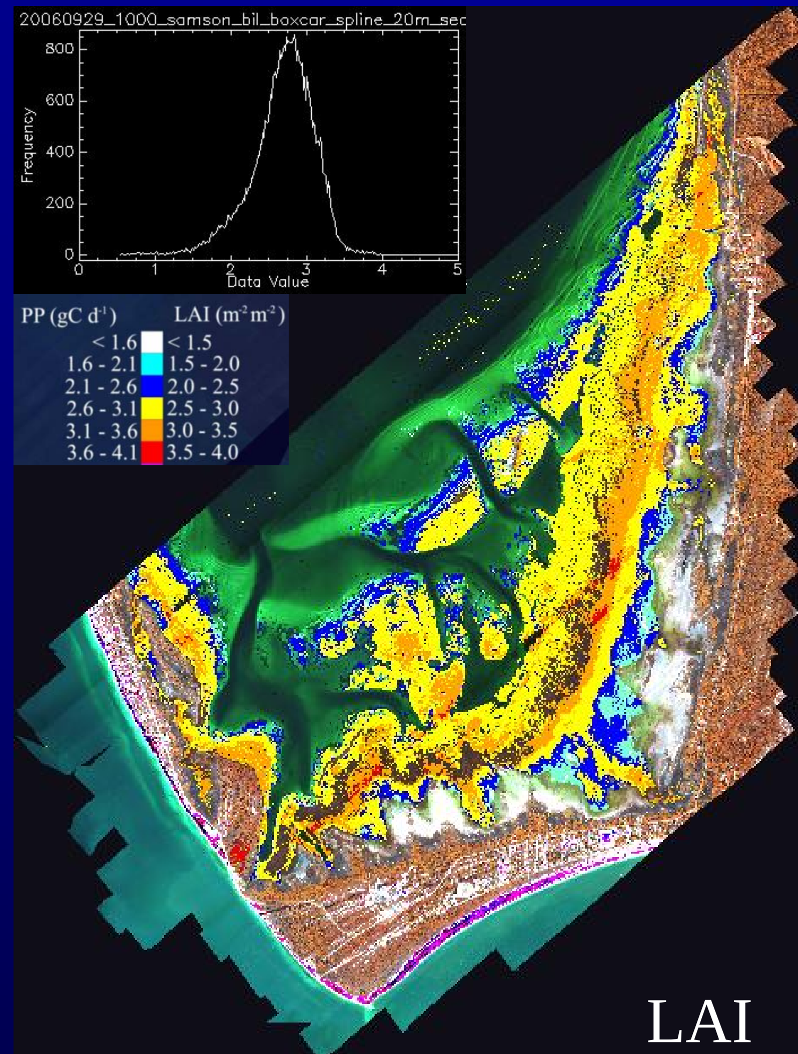
St. Joseph's Bay, FL 10 Meter Resolution



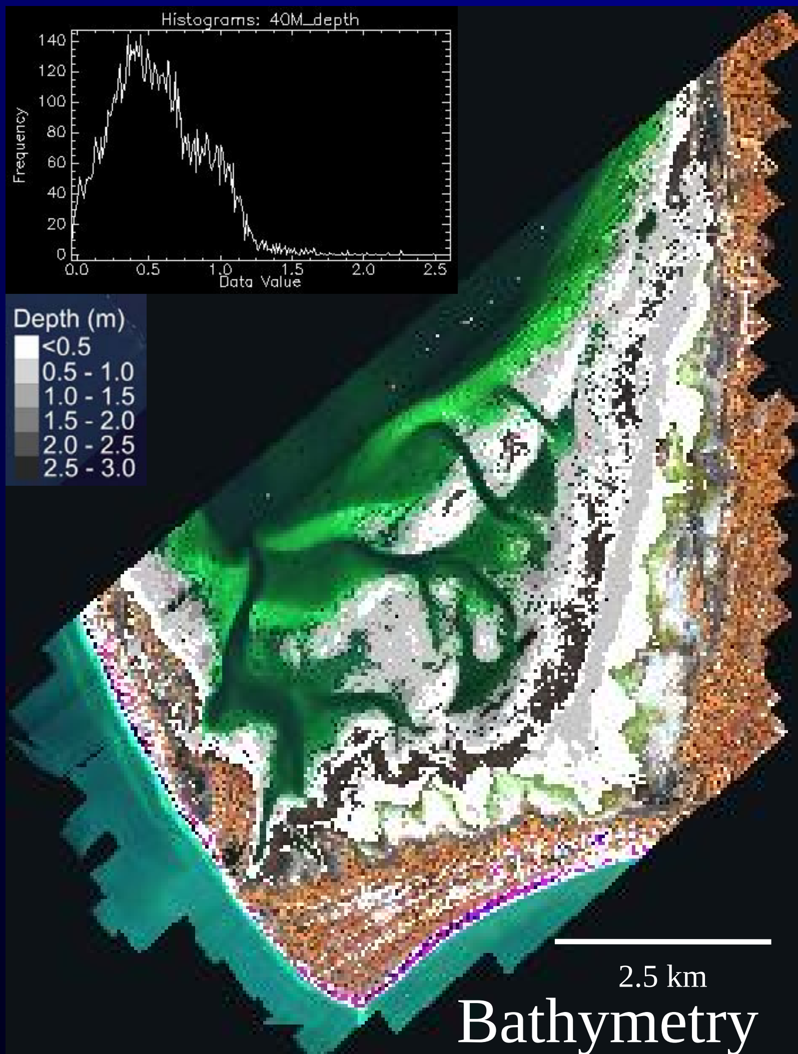


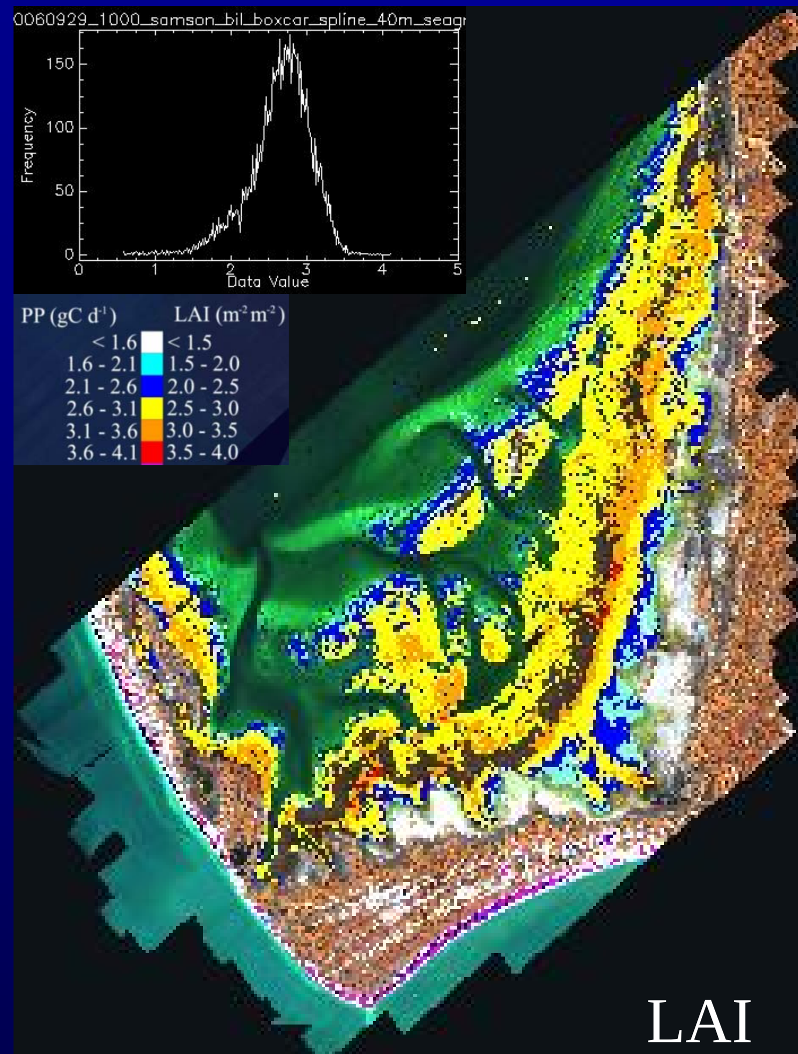
St. Joseph's Bay, FL 20 Meter Resolution



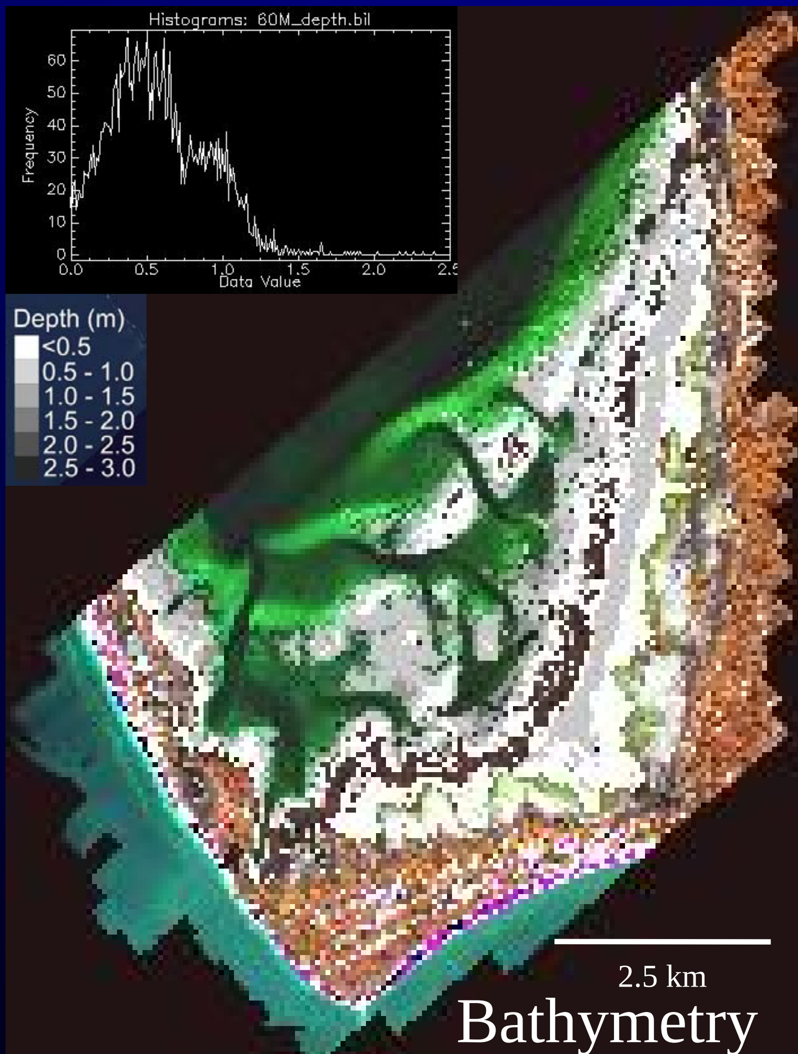


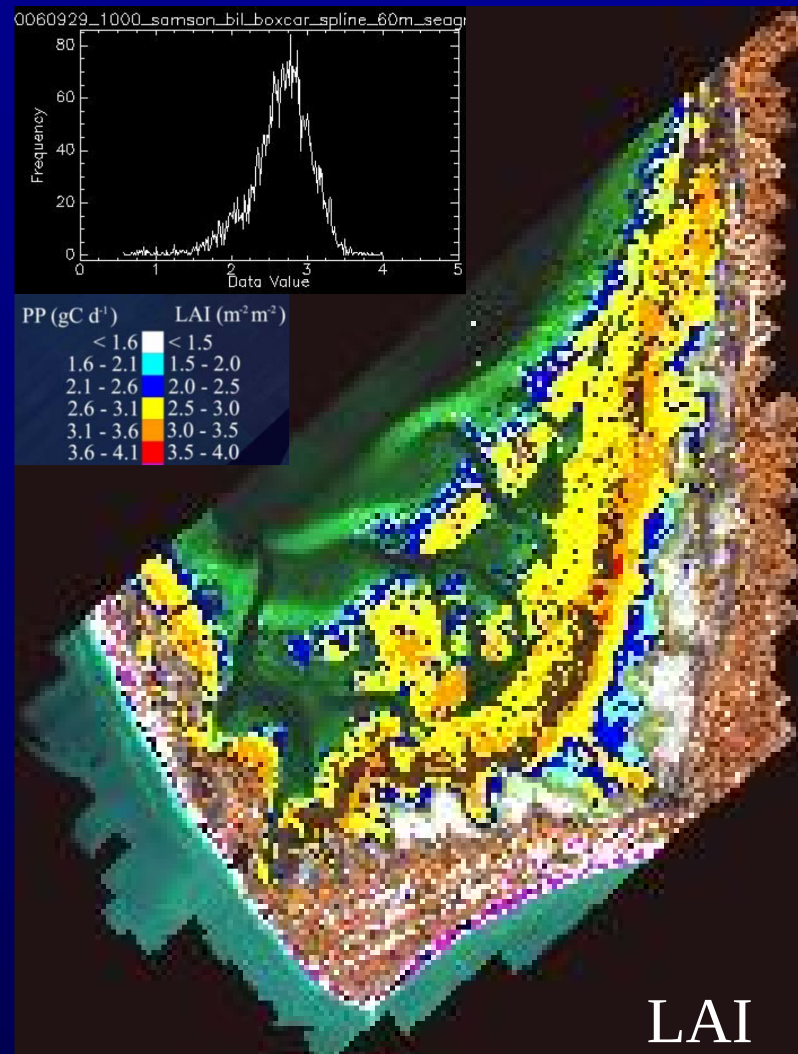
St. Joseph's Bay, FL 40 Meter Resolution

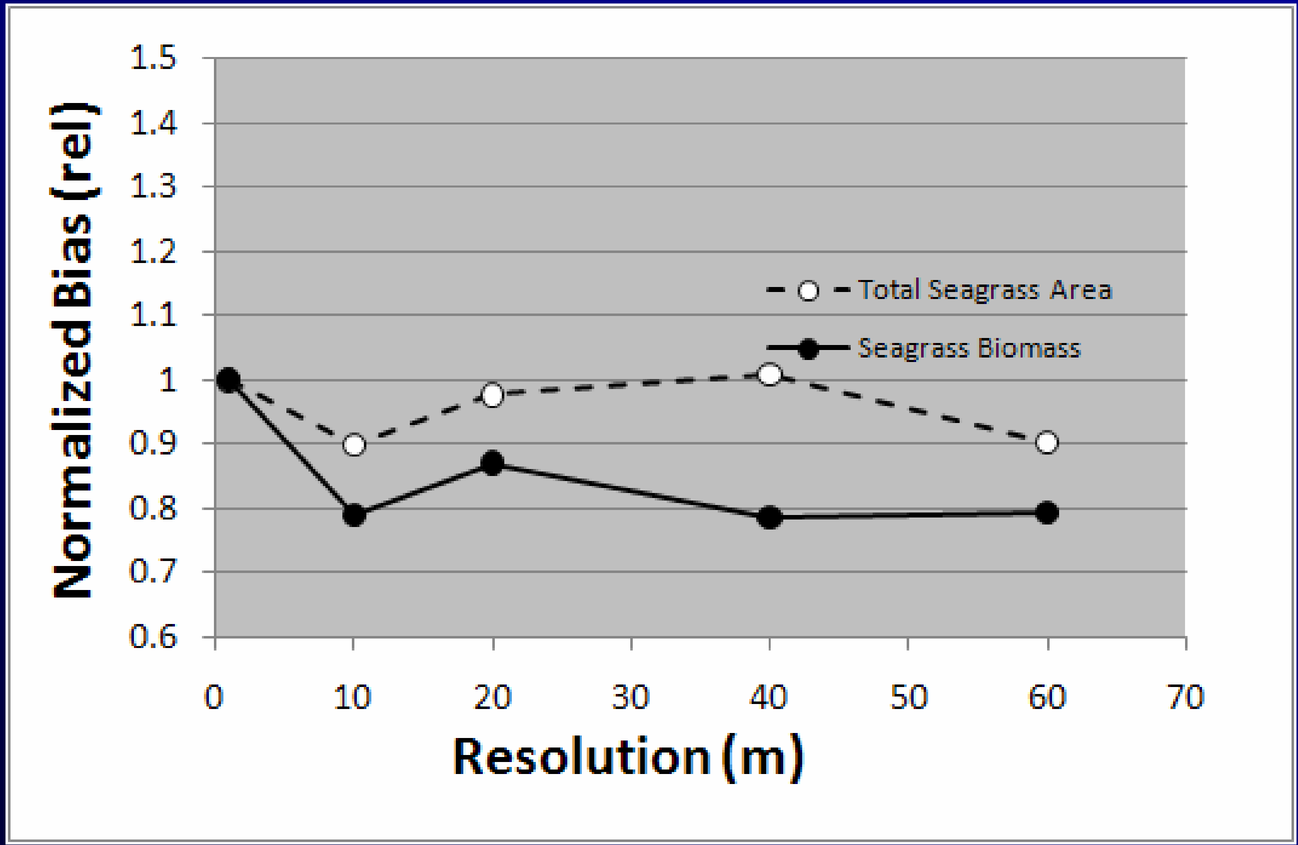




St. Joseph's Bay, FL 60 Meter Resolution






Normalized Bias (rel)
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0
10
20
30
40
50
60
70
Resolution (m)
Total Seagrass Area
Seagrass Biomass

Other Considerations for Routine Use of High Resolution Imaging Spectroscopy

- **Tides will affect locally observed bathymetry:**
  - **Depth of water overlying SAV**
  - **Surface expression of giant kelp canopies**

- **Water column OPs are likely to vary across time and space**
  - **Needed to retrieve R_b**
  - **Knowledge of bathymetry and stable bottom R_b (e.g. sand) may permit retrieval of water column OPs**
  - **Develop local algorithms to obtain OPs from routinely monitored WQ parameters**
    - **Gallegos C (2001) Estuaries 24:381-397**

Conclusions

- Remotely sensed imaging spectroscopy:
  - Can quantify spatial and temporal patterns of macrophyte biomass and system productivity at resolutions up to 60 m
  - May be the only way to provide accurate data at the ecosystem scale needed for research and management
  - Time series observations represented an unprecedented opportunity to understand dynamics of these systems across time and space
- Effect of image resolution on retrieval needs to be investigated
  - Bathymetry, esp in shallow and high relief habitats, e.g. reefs, marsh fringes etc.
  - Averaging Rrs spectra across optically deep, optically shallow and land pixels
  - What causes the retrieval bias and the goldilocks effect?