Geospatial Analysis of Terrain Dynamics Using Lidar Technologies and Open Source GIS

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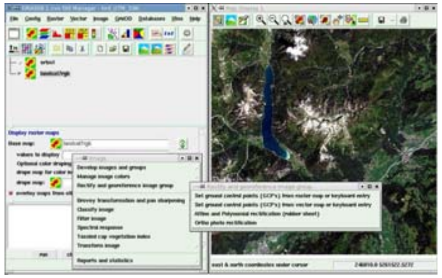
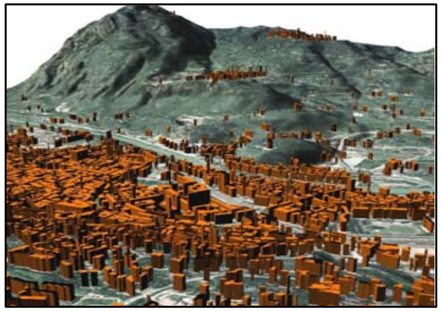
GRASS GIS

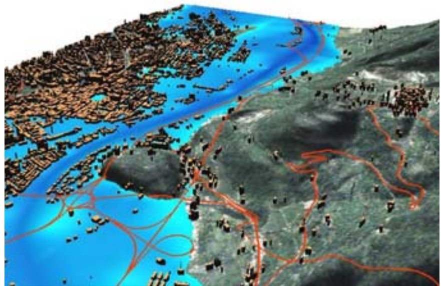
OSGeo.org
The Open Source Geospatial Foundation

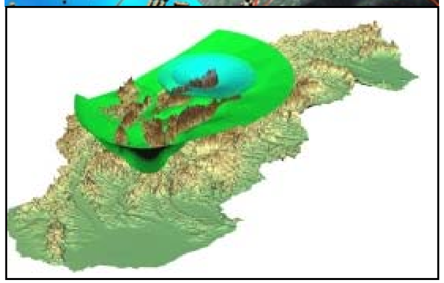
GRASS6.3

http://grass.osgeo.org









GPL since 1999, current development coordinated from Trento, Italy

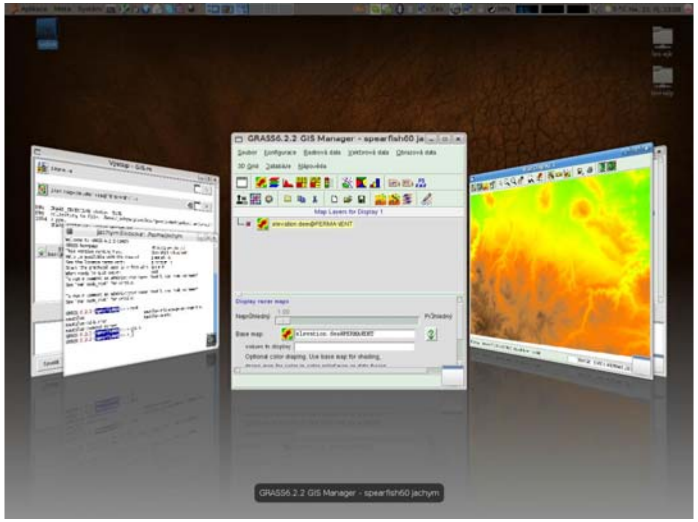
General purpose FOSS GIS :
2D/3D raster and (new) vector data management, analysis, modeling, visualization

Fully integrated 350+ modules and add-ons for geospatial data processing, with DBMS attribute management, SQL support, and WebGIS coupling WMS, WPS

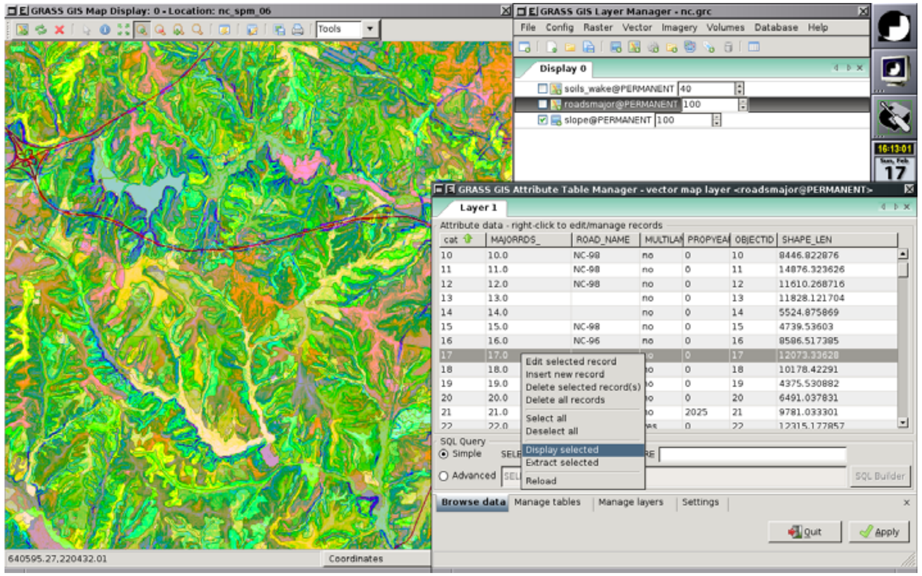
Many modules provide powerful tools for lidar data analysis: e.g., the per cell statistics module computes 6m resolution raster maps from 1.5 billion points in 1-6 hours on a PC depending on the type of statistics (D. Newcomb, FWS).

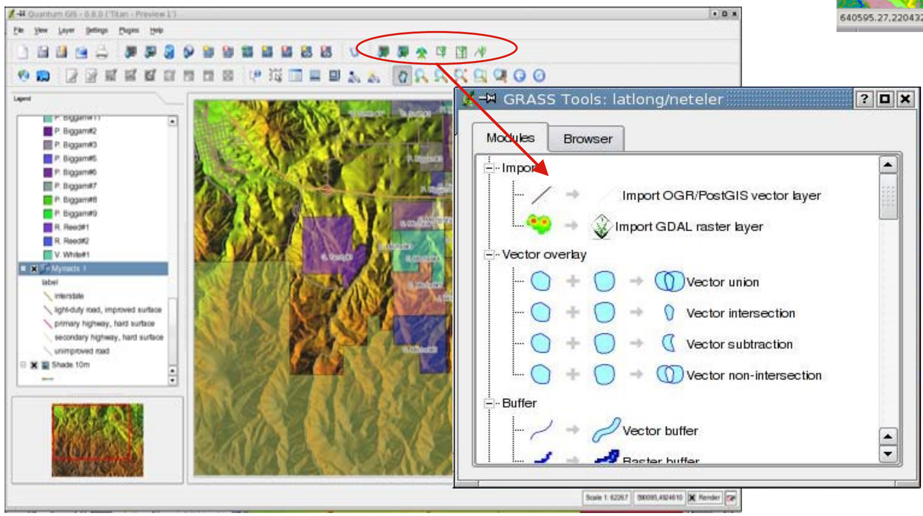
GRASS GUIs

gis.m: stable TclTk GUI



wxgrass: new wxPython GUI

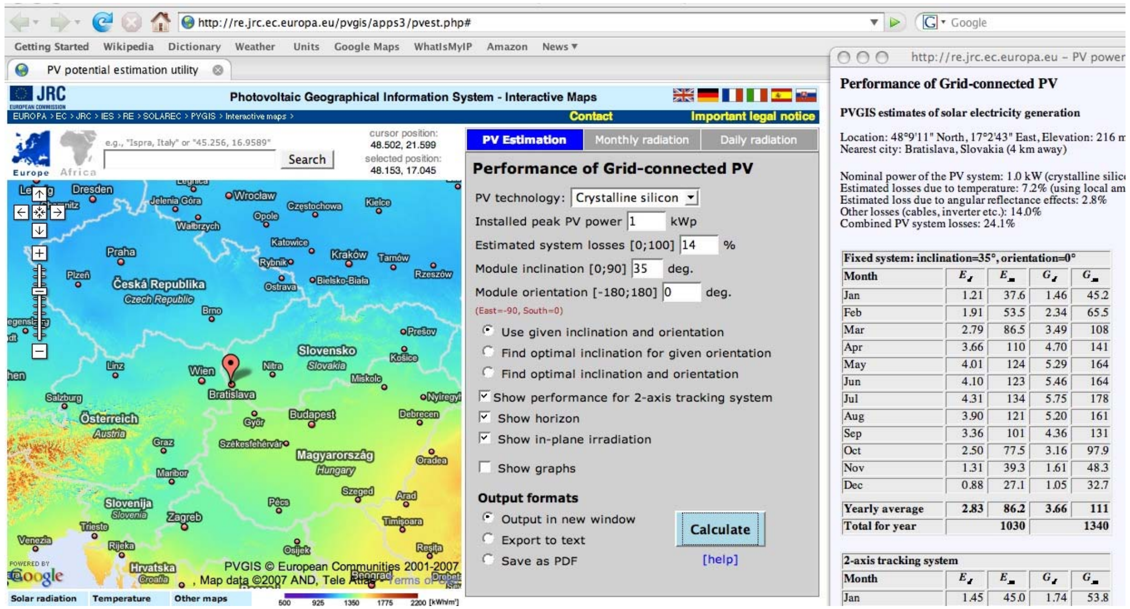


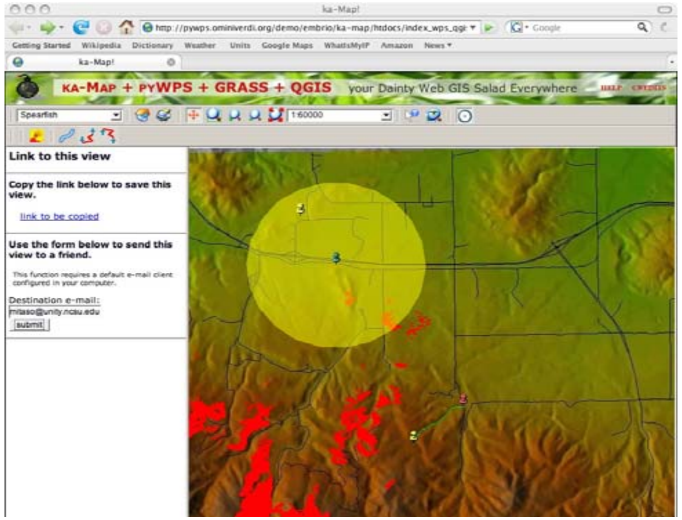


Quantum GIS: easy to use GIS viewer with GRASS plugin

Many power users prefer command line interface

Web applications





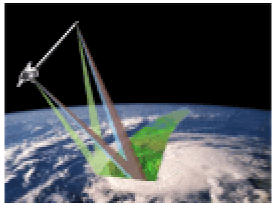
Combining GRASS and Google Maps in Photovoltaic GIS

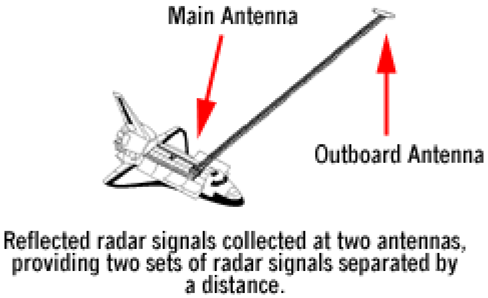
PVGIS © European Communities, 2001-2007 Developed at ISPRA

Run GRASS on the web:

interactively compute viewshed, buffers, easiest natural path, street path

Rapid Terrain Mapping

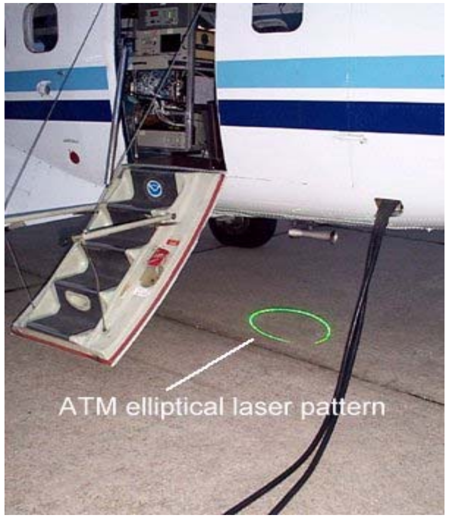




Shuttle Radar Topography Mission

Earth elevation mapped in 9 days at 30m resolution

processing still takes months and years!!!



Lidar: coast, states

1996-2000: ATM II
2001: NC Flood mapping
2003: EAARL (Isabel)
2004: Topo-bathy, USACE
2005: post Ofelia

RTK-GPS: local

Real-time kinematic GPS: beach mapping, precision agriculture
(*D.Bernstein, Geodynamics llt*)

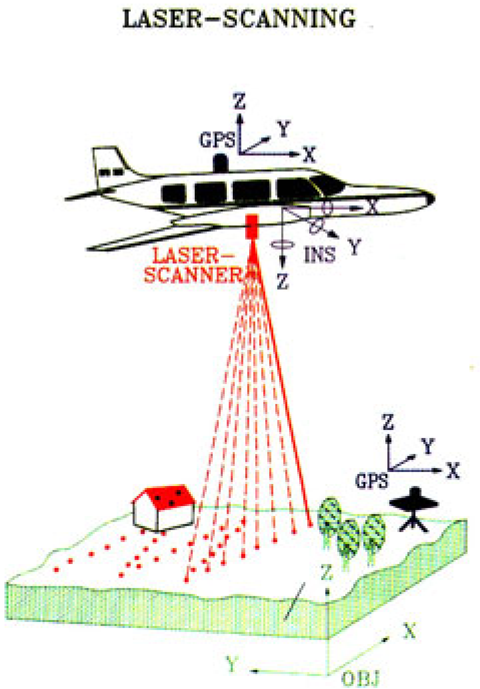
Challenges :

massive data sets: 1 mil pts/hr (ARO grant NCSU/Duke U. project)
noise, complex surfaces, heterogeneous distribution of points

Nearshore bathymetry and beach topography

Single-beam sonar
Real Time
Kinematic GPS

Airborne laser scanning with LIDAR



LIght Detection And Ranging

The laser/scanning assembly:
- typical operation at 700 - 2500m
- Inertial Measurement Unit (gyros, etc)
- GPS airborne and ground

Overall accuracy:
15-30cm vertical
30-200 cm horizonal
1 point per 0.35 – 3m density

Multiple returns: height of vegetation

Various modifications:
bathymetry, atmospheric properties

Working with lidar data in GRASS

- **using general point and raster processing tools, such as**
  - **r.in.xyz**: import and analysis of massive x,y,z point clouds using per-cell statistics (number of points, mean, range, min, max, sttdev, …)
  - **v.surf.rst**: simultaneous interpolation, smoothing, computation of topographic parameters (slope, aspect, curvatures, part. derivatives)
  - **r.mapcalc** and other raster and vector processing tools
- **specialized modules**
  - **v.lidar.edgedetection, v.lidar.growing, v.lidar.correction**

Related development

- open source **libLAS** library
- GRASS TIN support update (funded by **Google SoC**)
- **TerraSTREAM** (Duke and BRICS, Aarhus, Denmark) complete workflow for massive data sets (library and extensions for GRASS and ArcGIS: points - raster or TIN DEM - weighted flowaccumullation - stream extraction - watershed hierarchy - erosion factor

Lidar and terrain change

Lidar mapping at high spatial and temporal resolutions allows us to study terrain as a dynamic phenomenon.

Challenges: massive data sets and rapidly evolving technology: increasing point densities

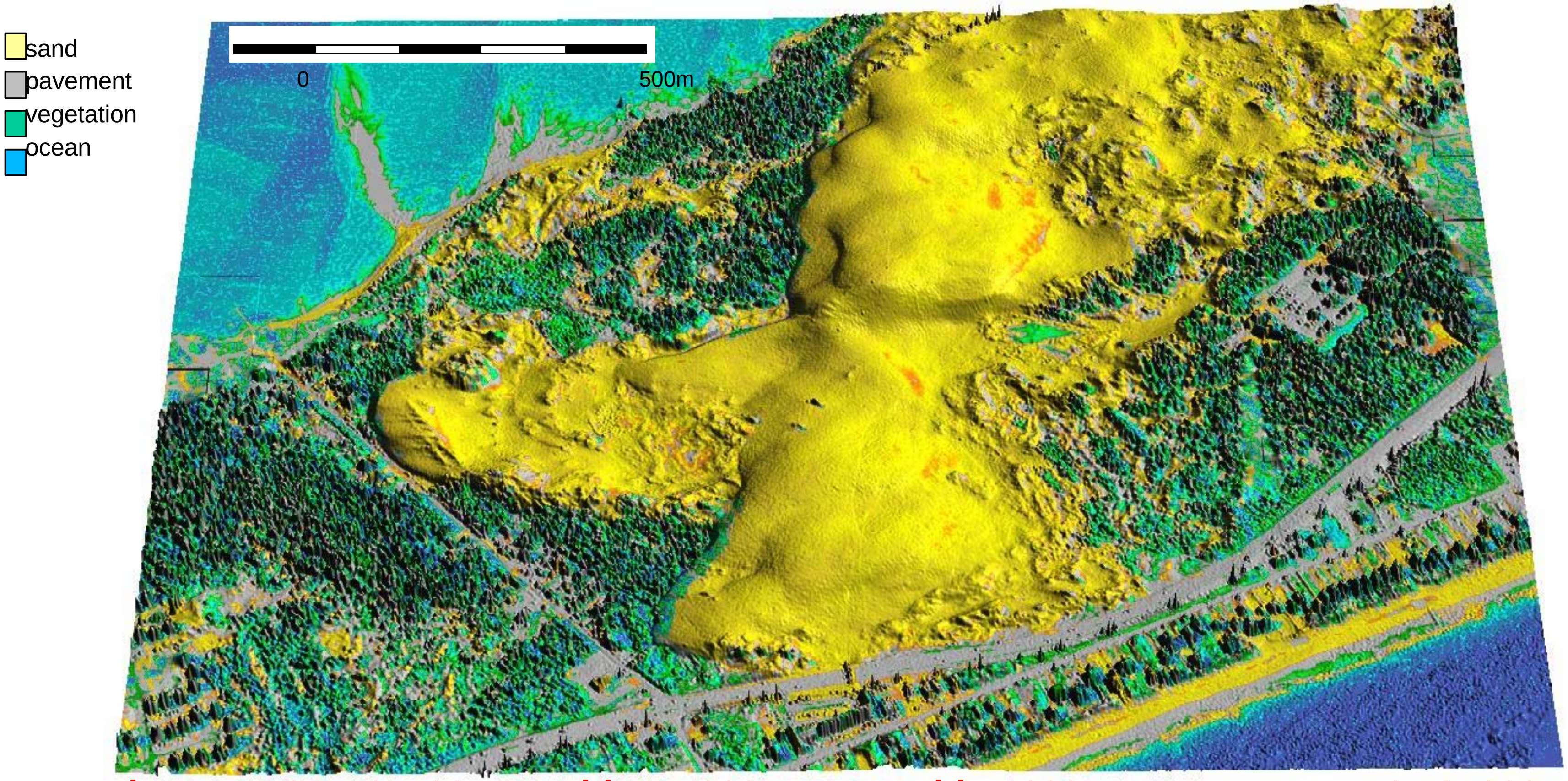
Workflow: topographic change

- **Data integration:** coordinate system transformation **cs2cs, ogr2ogr**
- **Point density and noise analysis:** selection of common resolution and gridding method using per cell statistics **r.in.xyz**
- **Detection of systematic error** and its elimination for all DEMs
- **Simultaneous spatial approximation** (gridding), smoothing of random noise and computation of topographic surface parameters **v.surf.rst**
- **Definition of topographic change measures** - dependent on application and geomorphology
- **Extraction of features** to measure the change (shoreline, ridges, streams, peaks): **r.mapcalc, r.watershed, r.terraflow, r.param.scale**
- **Quantification of change**, generation of topographic change maps

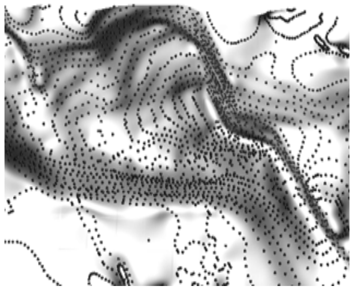
Dunes in NC and Japan

Sand dune migration analysis

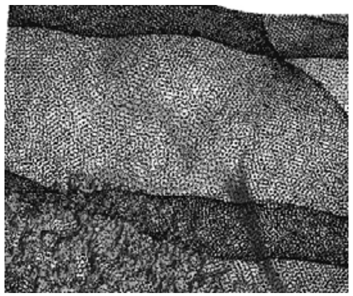
Jockey's Ridge 1999



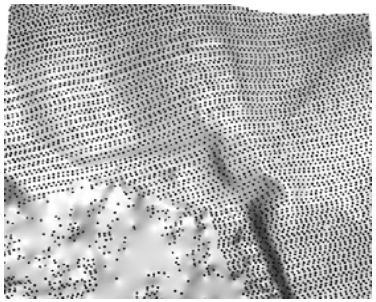
Photogr. 1974, 95, 98



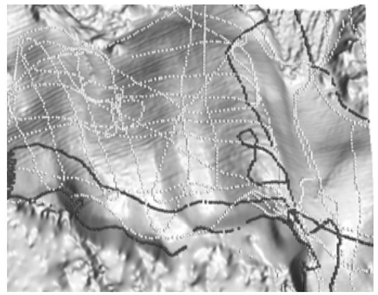
Lidar 1999



Lidar 2001

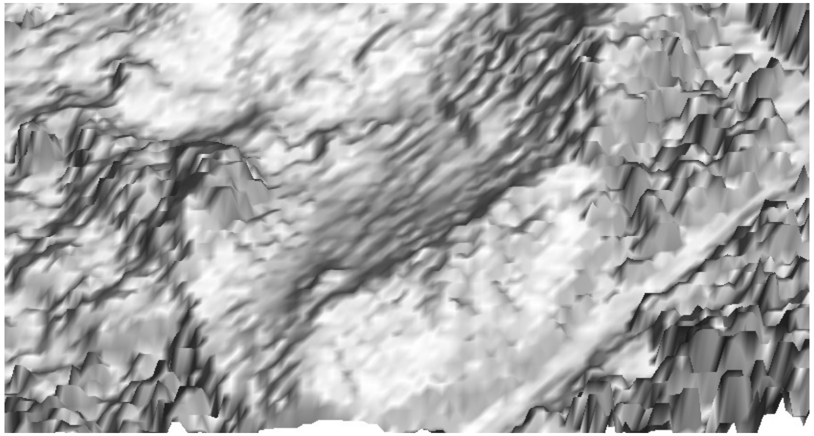


RTK-GPS 2004

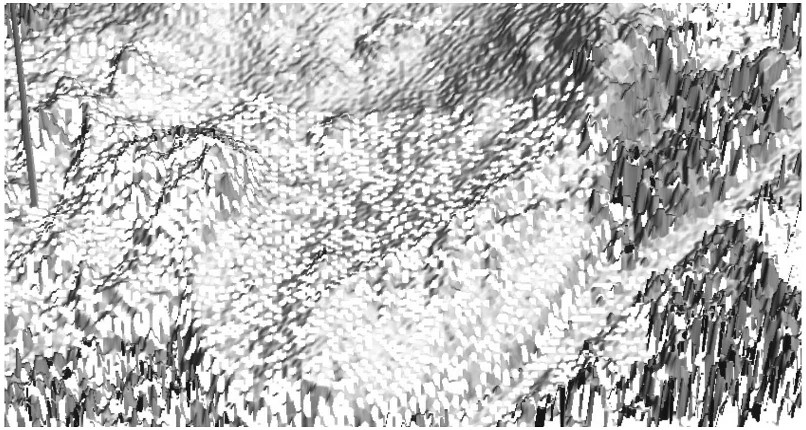


Spatial approximation

Binning: points' mean z assigned directly to grid cells



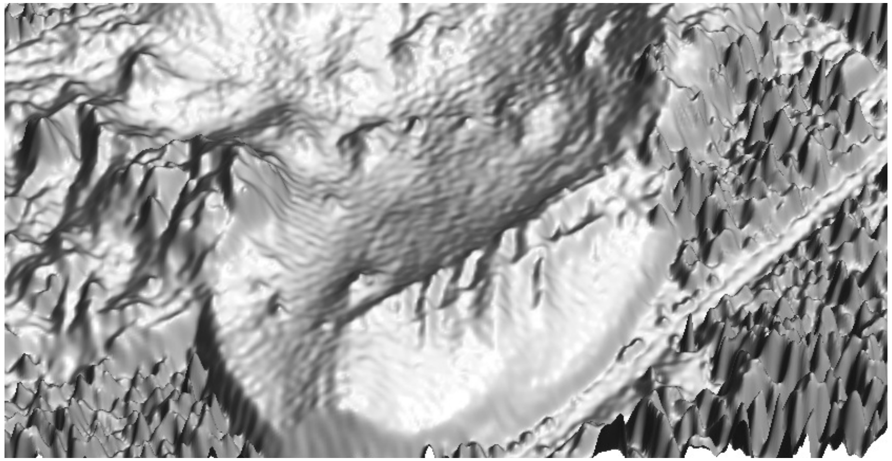
3m grid cell: lost breaklines



1m grid cell: gaps in surface

Spatial approximation with simultaneous topo analysis:
Regularized Spline with Tension

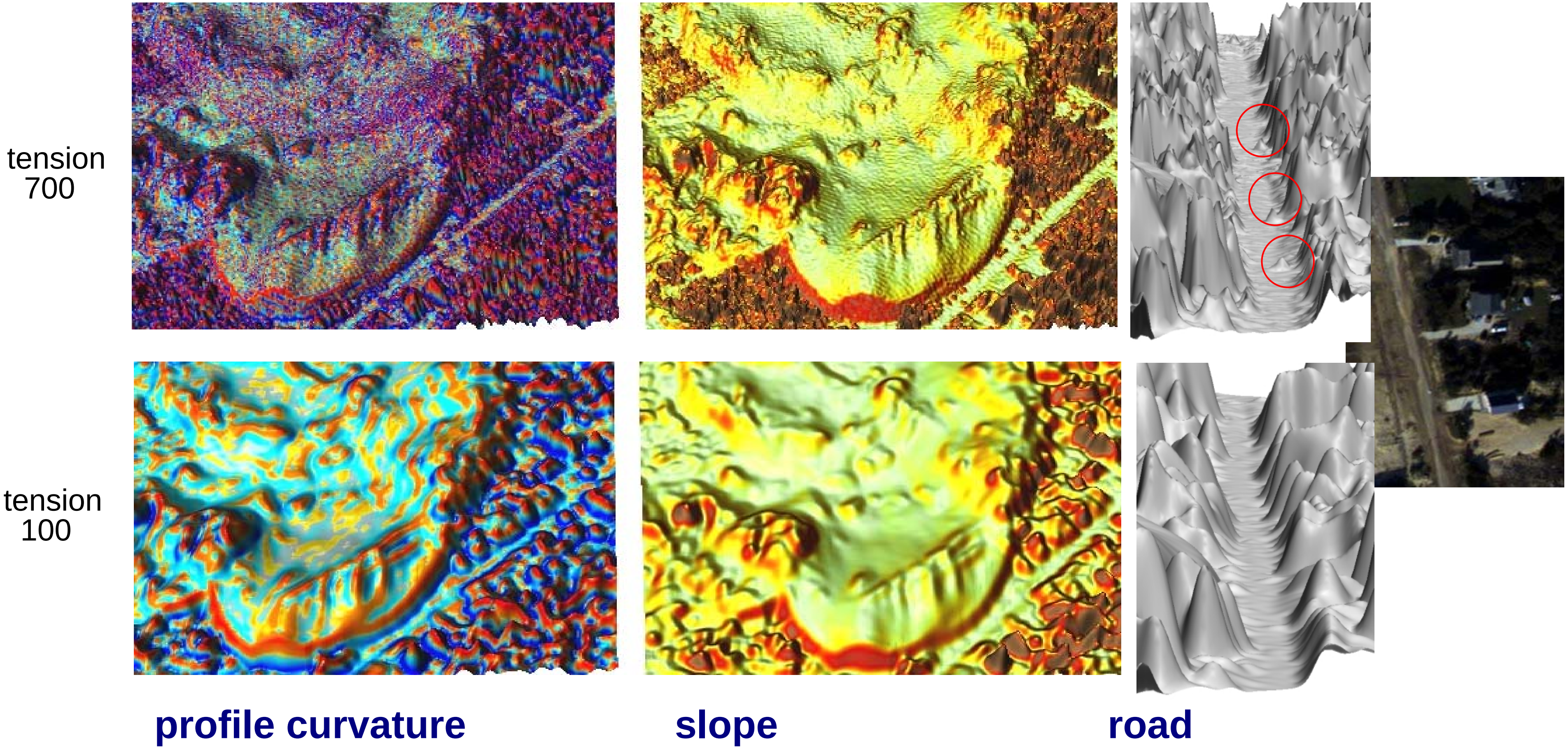
1m resolution grid :
manual definition of breaklines is not necessary (fences burried in sand)



1m grid cell, continuous surface

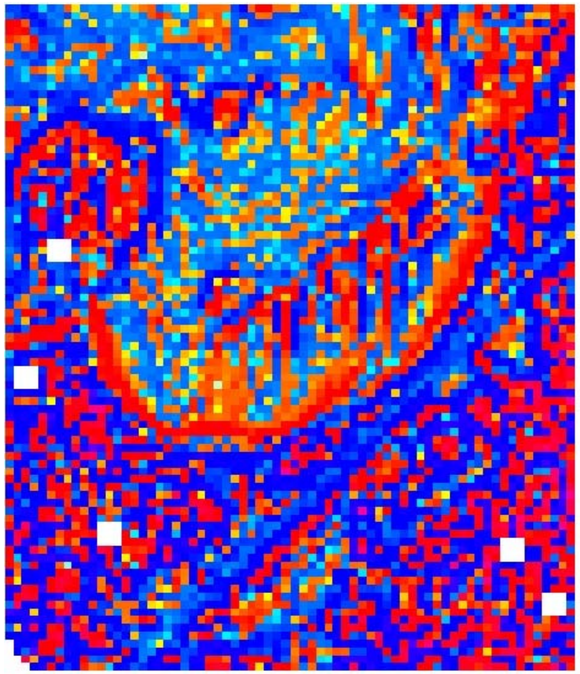
Smoothing and geometry analysis

Surface geometry (gradients, curvatures) is computed simultaneously with approximation.
Tension and smoothing is used to create a surface at a desired level of detail and smooth-out the noise.



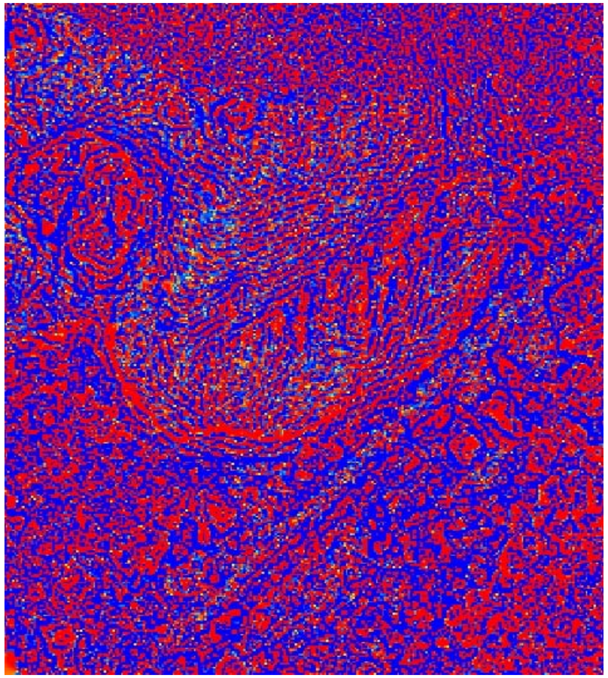
Profile curvature

resolution lower and resolution higher than point density



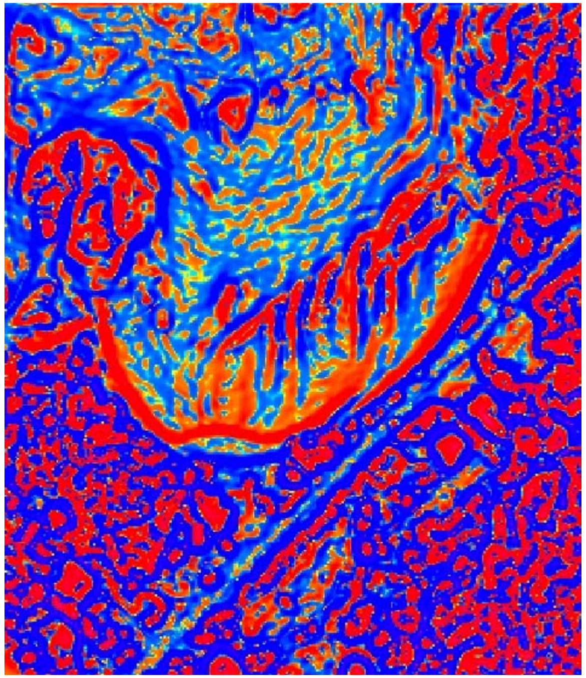
4m binned mean

- captures slip-faces, road, some empty cells
- **fast processing**



1m default RST

level of detail too high, noise



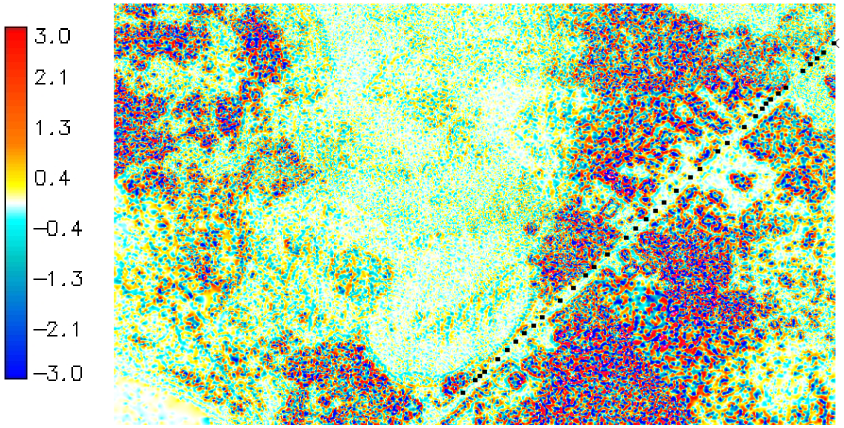
1m adjusted RST

captures slip-faces, fences and convex shape of road

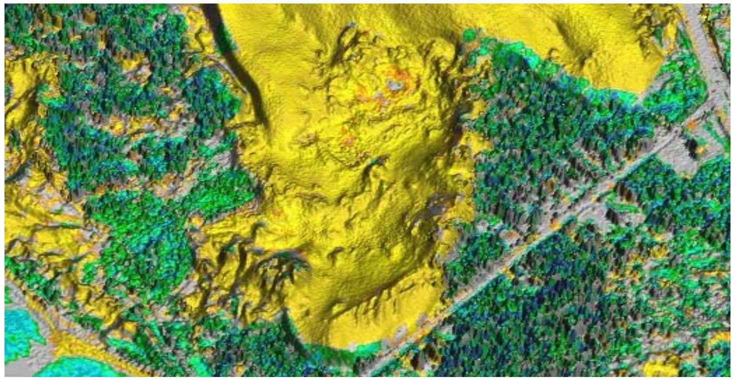
Accuracy of approximated DEMs

RMSE of interpolated DEMs, based on 50pts measured on pavements using RTK-GPS: 0.25m (1995) and 0.03m (lidar 1999, 2001)

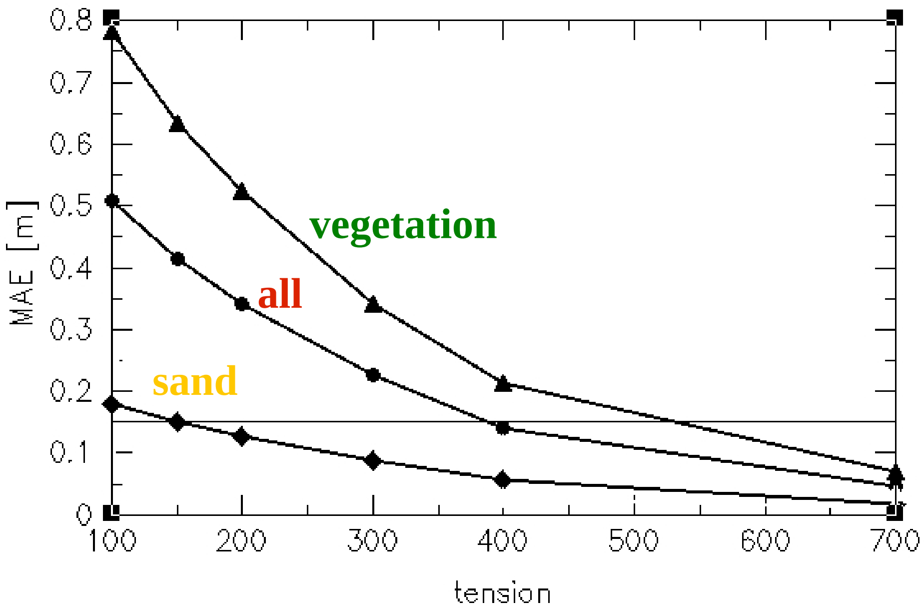
Lidar 1999, first return data: spatial distribution of deviations from RST surface



spatial distribution of vegetation



Surface deviation (smoothing) from the given points as function of tension



v.surf.rst - each point can have different smoothing parameter: allows to pass exactly through selected points

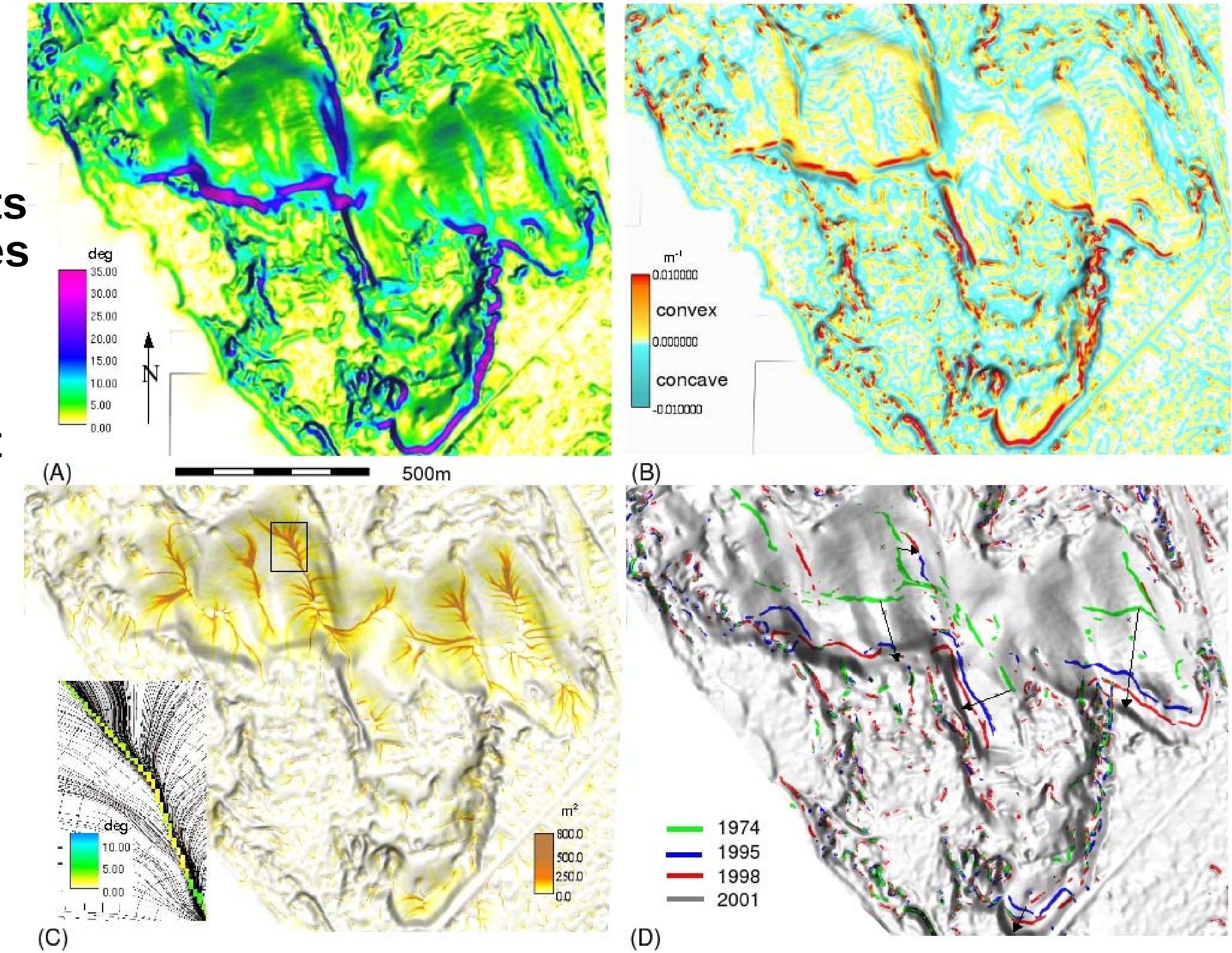
Feature extraction, change analysis

Extracting:

A: Slip faces
B: Dune crests
C: Dune ridges

Measuring:

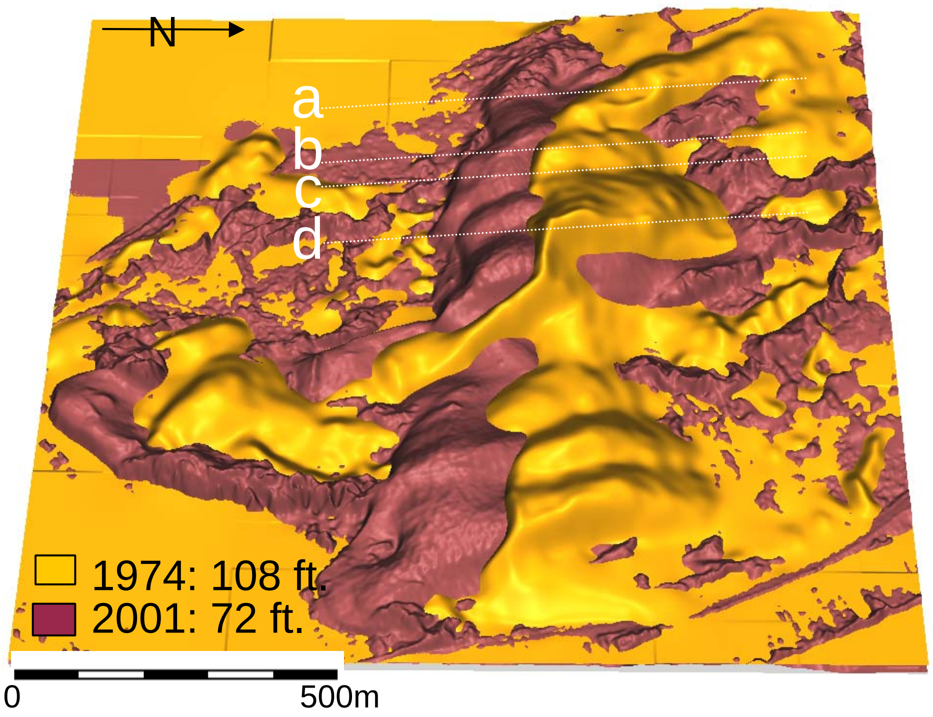
D: Dune crest migration

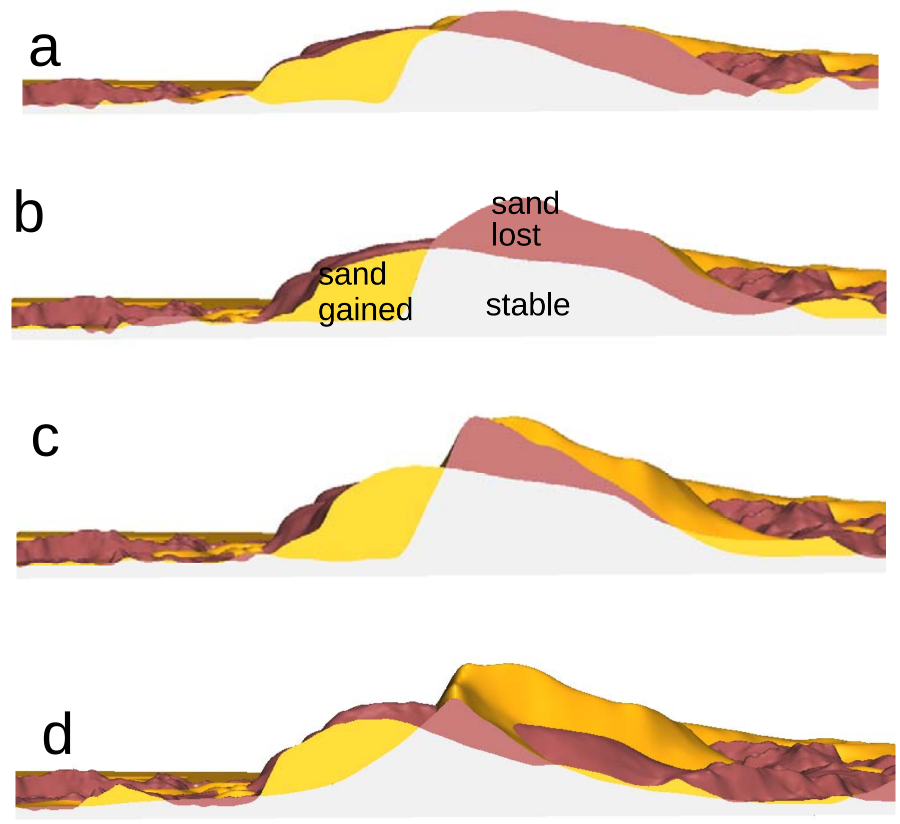


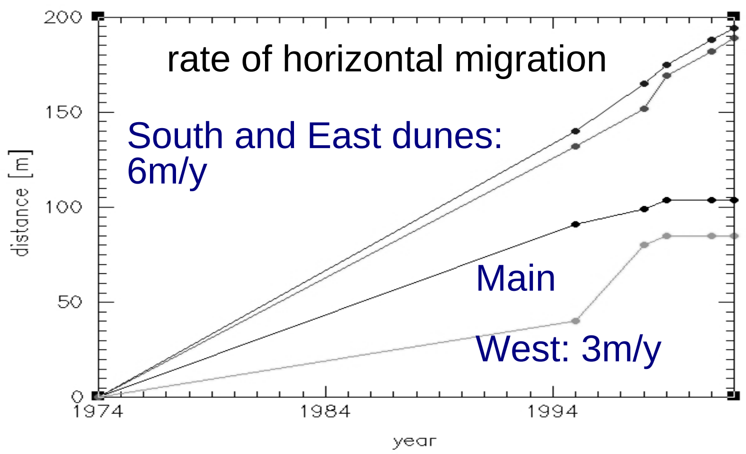
Mitasova, Overton, and Harmon, 2005, Geomorphology 72

Mitasova, Mitas, and Harmon, 2005, IEEE GRSL 2(4)

Dune Migration



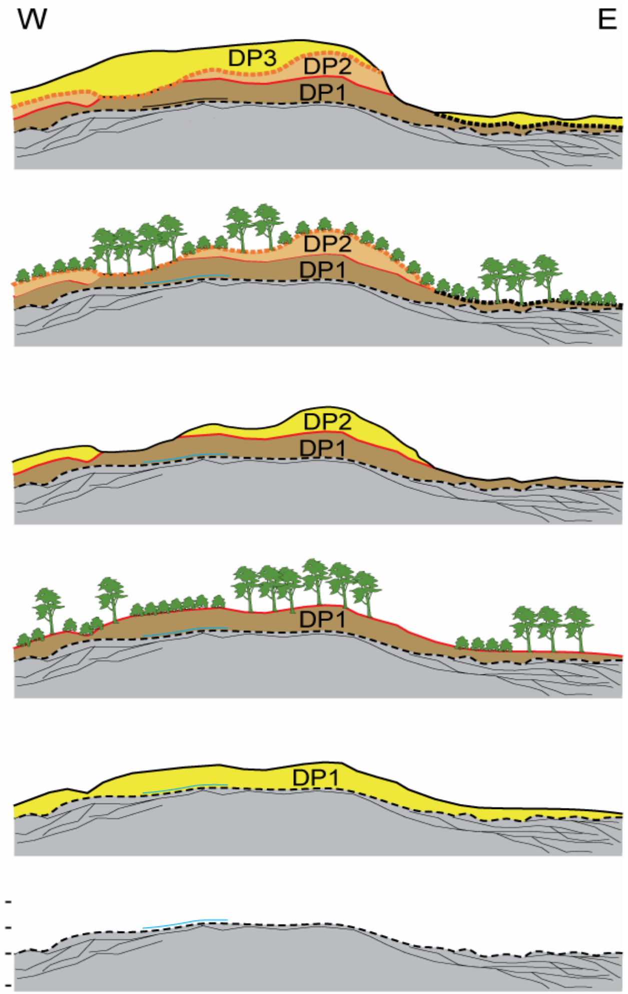


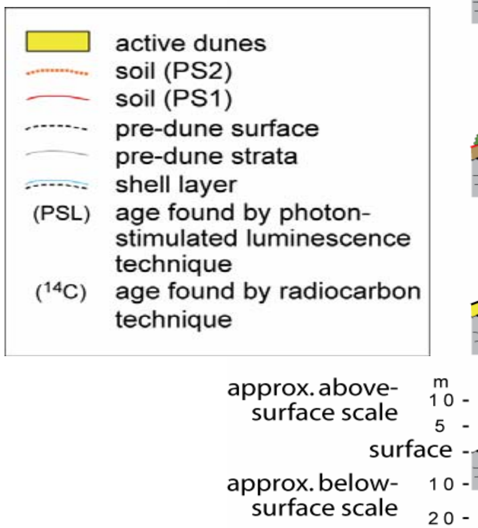


The main dune rotates clockwise while its peak moves southeast.
Volume and area are relatively stable

The most important discovery came from old maps - the dune was a short term phenomenon and is going back to its ridge form

Jockeys Ridge has buried soils that indicate that there have been times in the past when these dunes have been stabilized and covered with soil and vegetation. These times of stability have alternated with times when the dunes were active.





Dune evolution

DP3: Modern dunes active by 1810 A.D. (PSL)

PS2: Stabilization, soil developed by 1700 A.D. (^{14}C)

DP2: Dunes of phase 2, active by 1260 A.D. (PSL)

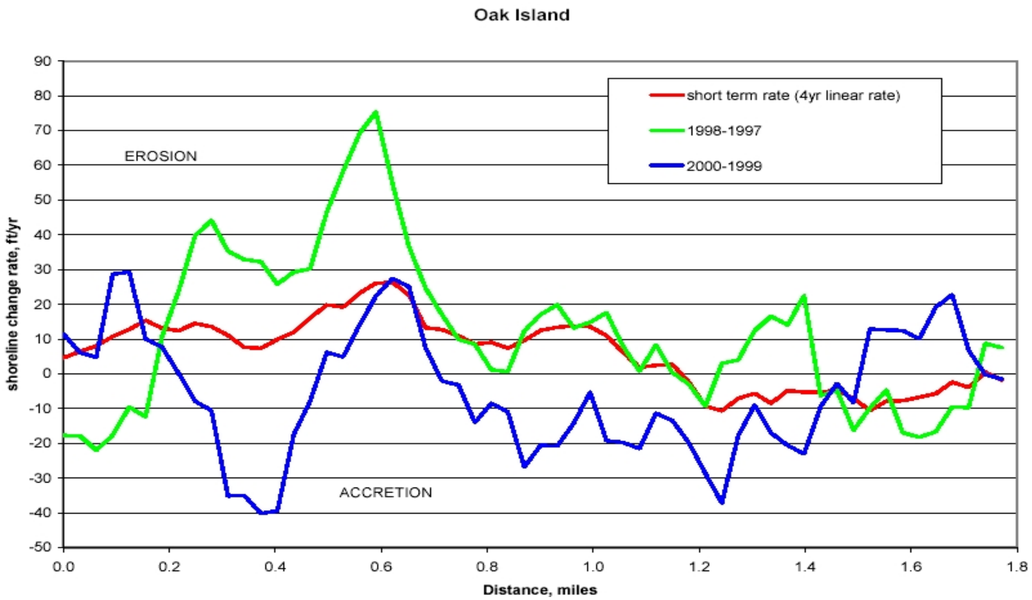
PS1: Stabilization, soil developed by 1000 A.D. (^{14}C)

DP1: Dunes of phase 1, active by 765 A.D. (PSL)

Pre-dune barrier island

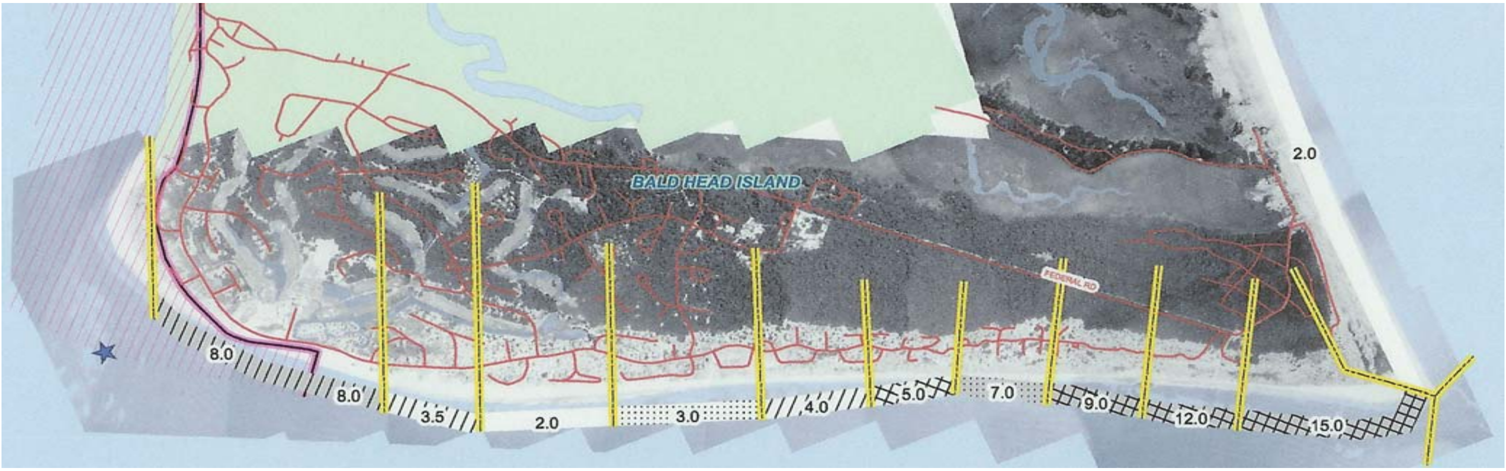
Havholm, K.G., Ames, D.V., Whittecar, G.R., Wenell, B.A., Riggs, S.R., Jol, H.M., Berger, G.W., Holmes, M.A., 2004. Stratigraphy of back-barrier coastal dunes, northern North Carolina and southern Virginia. Journal of Coastal Research 20(4), 980-999.

Beach and foredune evolution



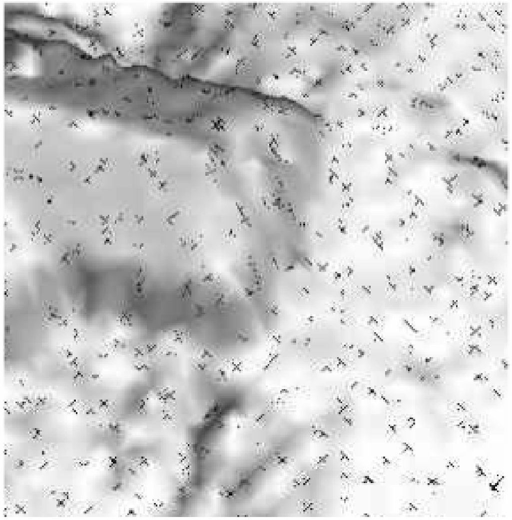
Challenge:
over 10 lidar surveys

Standard approach:
spatially averaged volume or shoreline change graphs



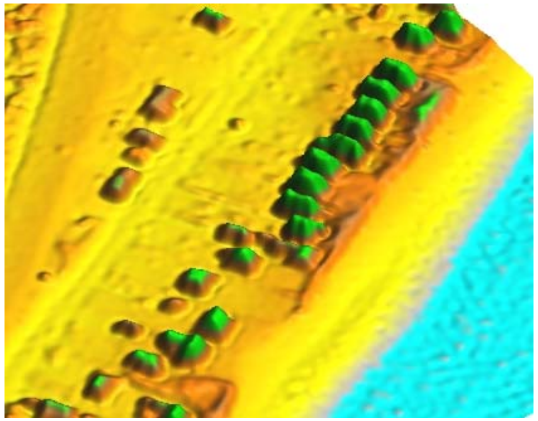
Increasing LIDAR point density

1998

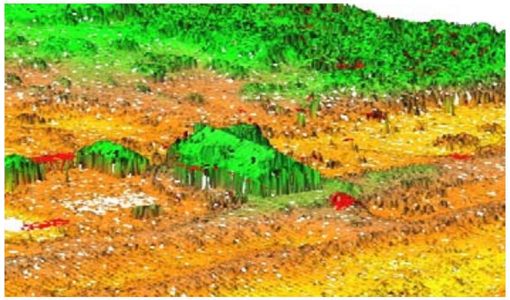


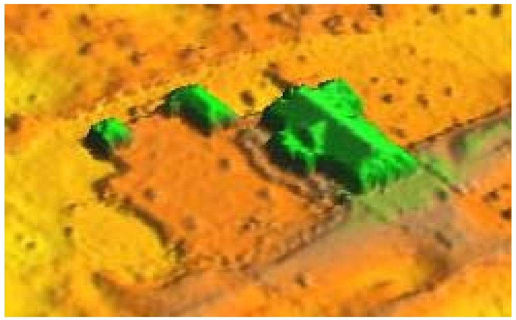
2004

no. of points/2m grid cell
1996 **0.2**
1997 **0.9**
1998 **0.4**
1999 **1.4**
2001 **0.2** NCflood
2003 **2.0**
2004 **15.0**
2005 **6.0**



1m res. DEM, computed
by RST, 1998 lidar data



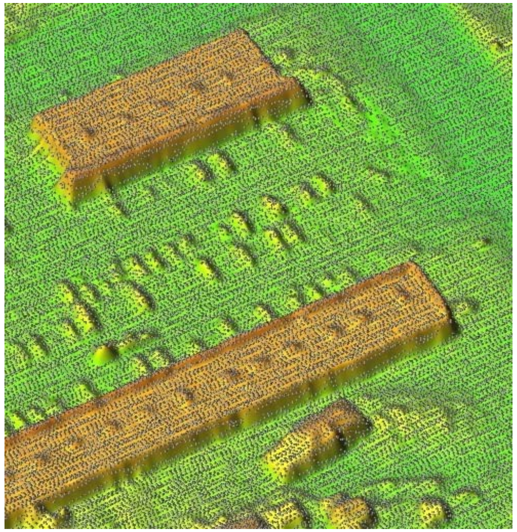


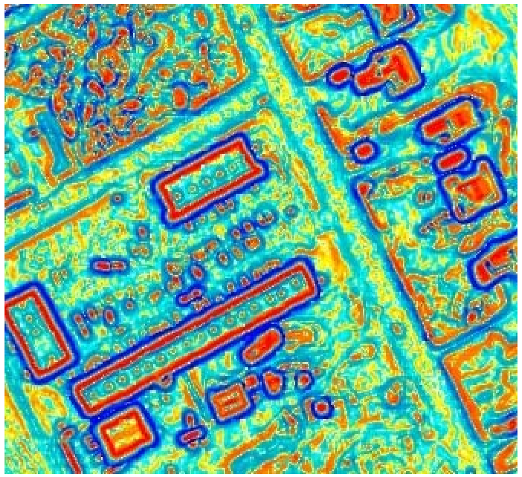
substantially improved representation of structures but much larger data sets

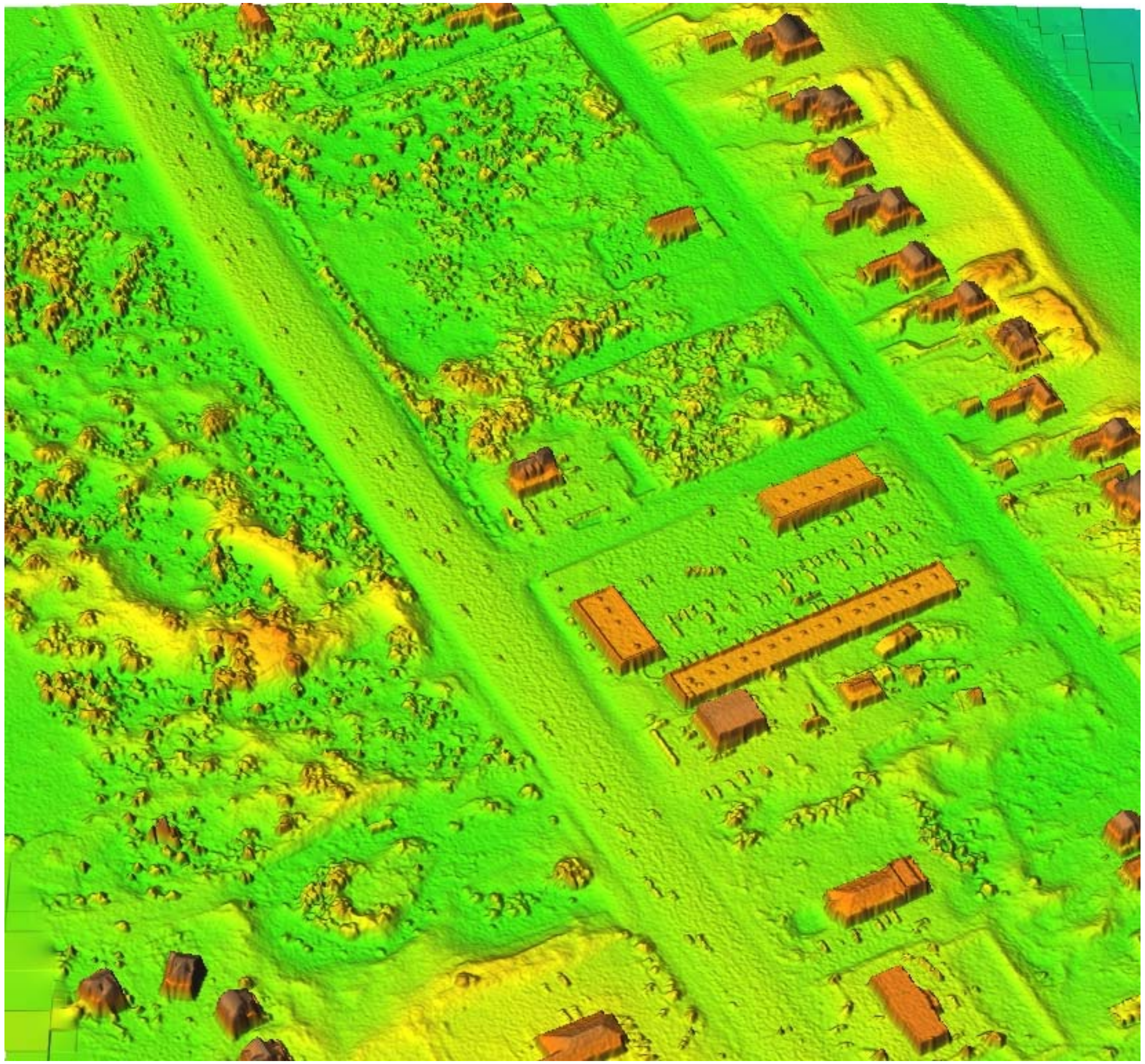
2004 lidar, 0.5m resolution DEM binned and computed by RST (smoothes out the noise and fills in the gaps

USACE SHOALS LIDAR topo mapping

2004 DEM 1ft res



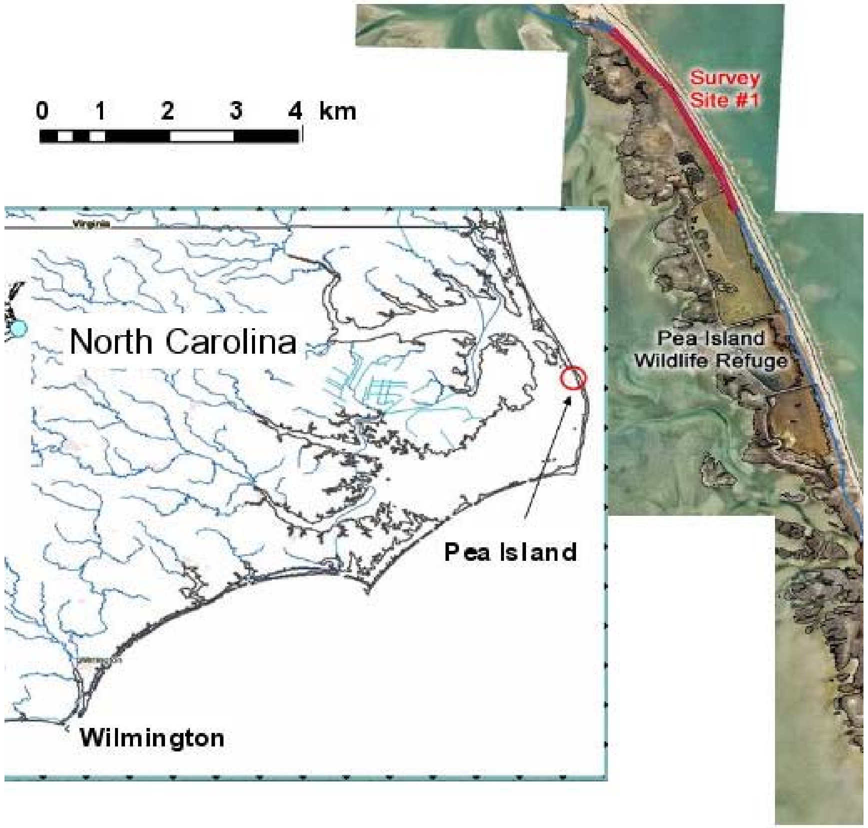




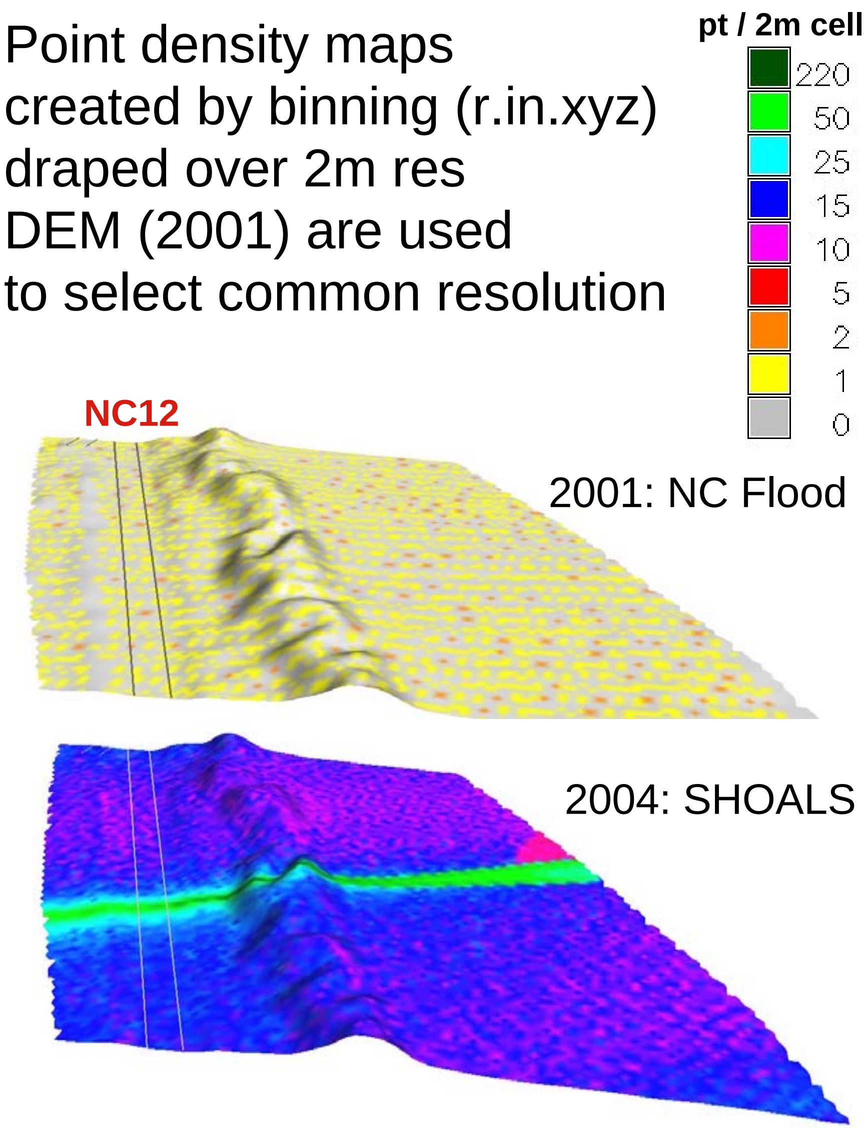
Mapping LIDAR point density

Study area: NC barrier island

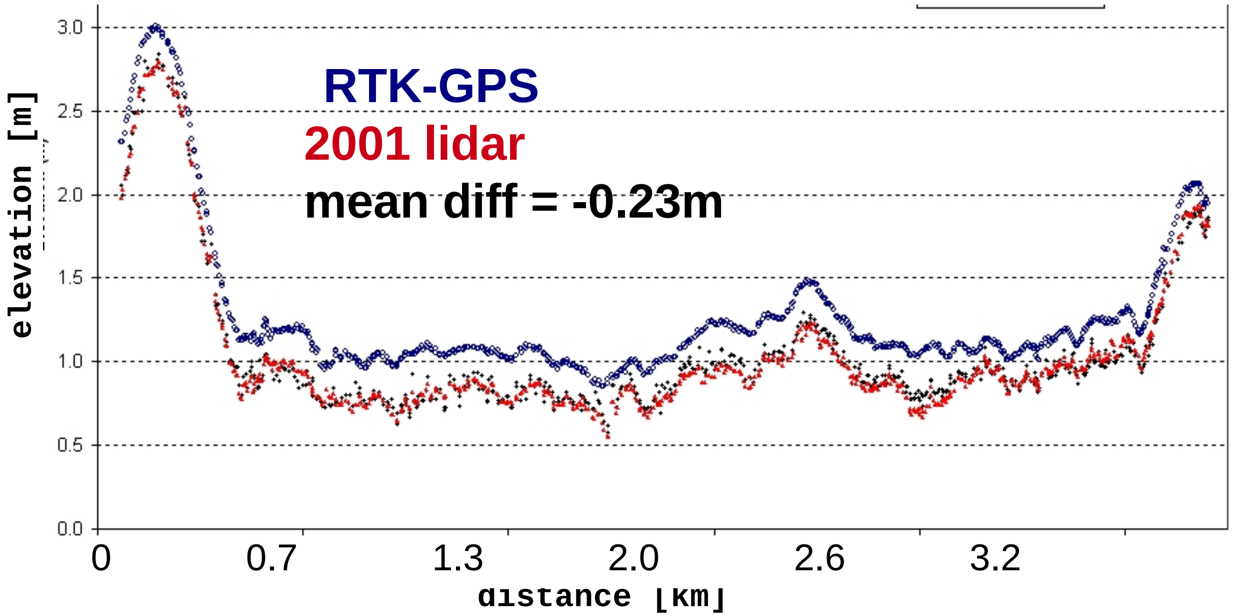
RTKGPS survey and NCDOT benchmarks along NC12 used for lidar data assessment

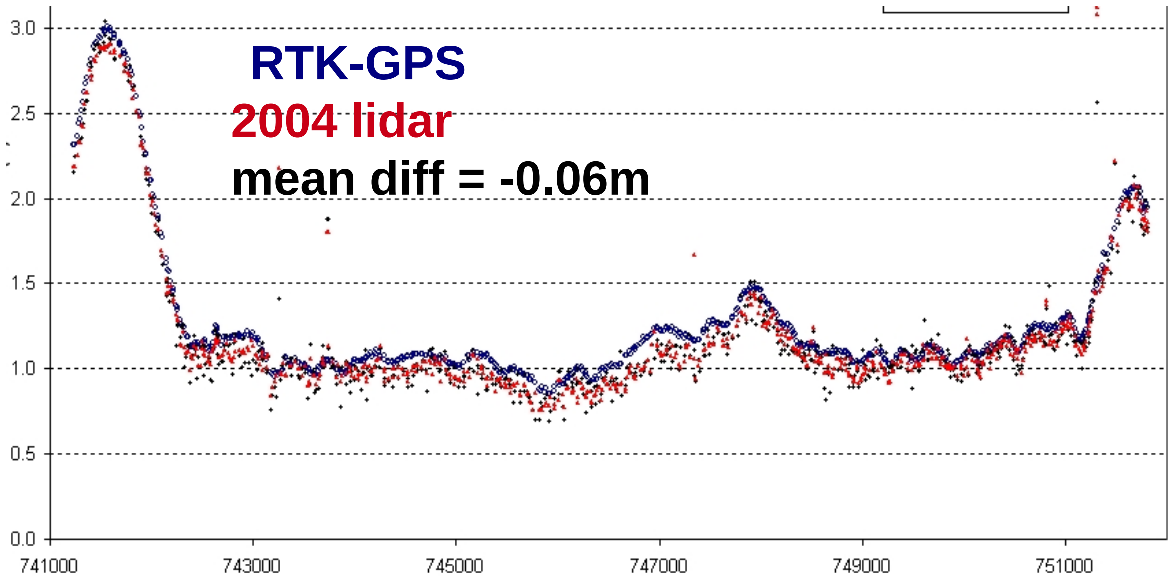


Point density maps created by binning (r.in.xyz) draped over 2m res DEM (2001) are used to select common resolution



Analysis of systematic error



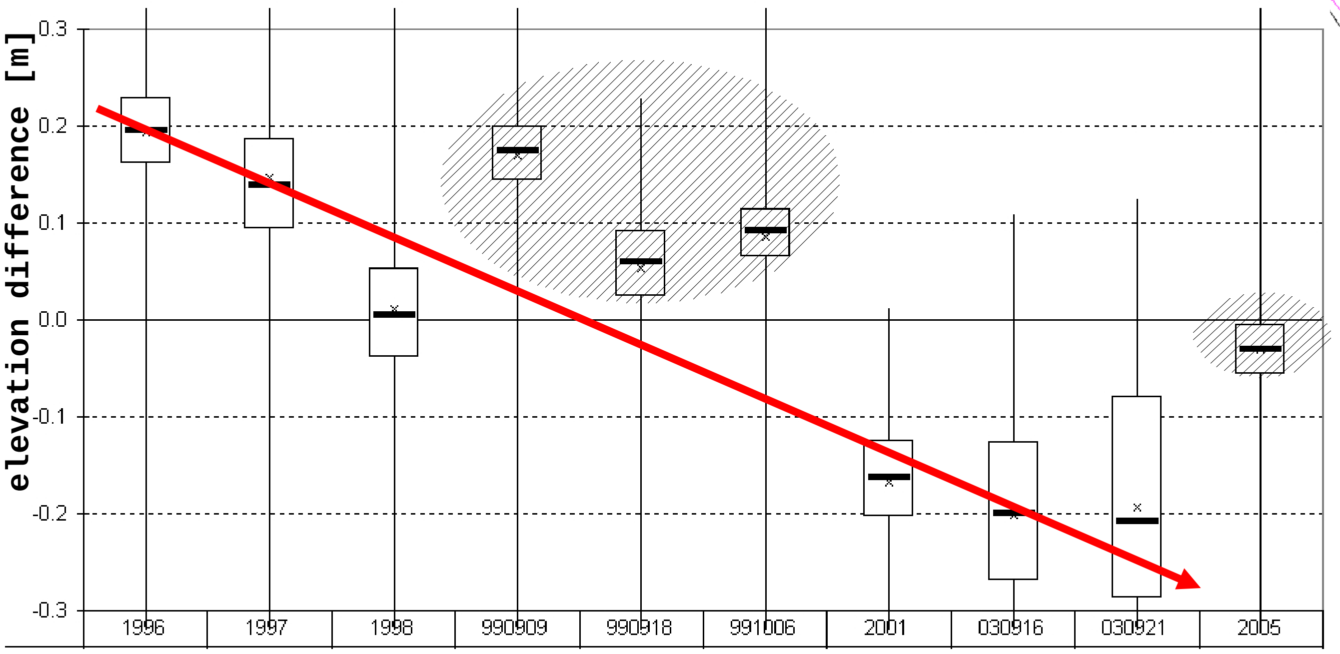


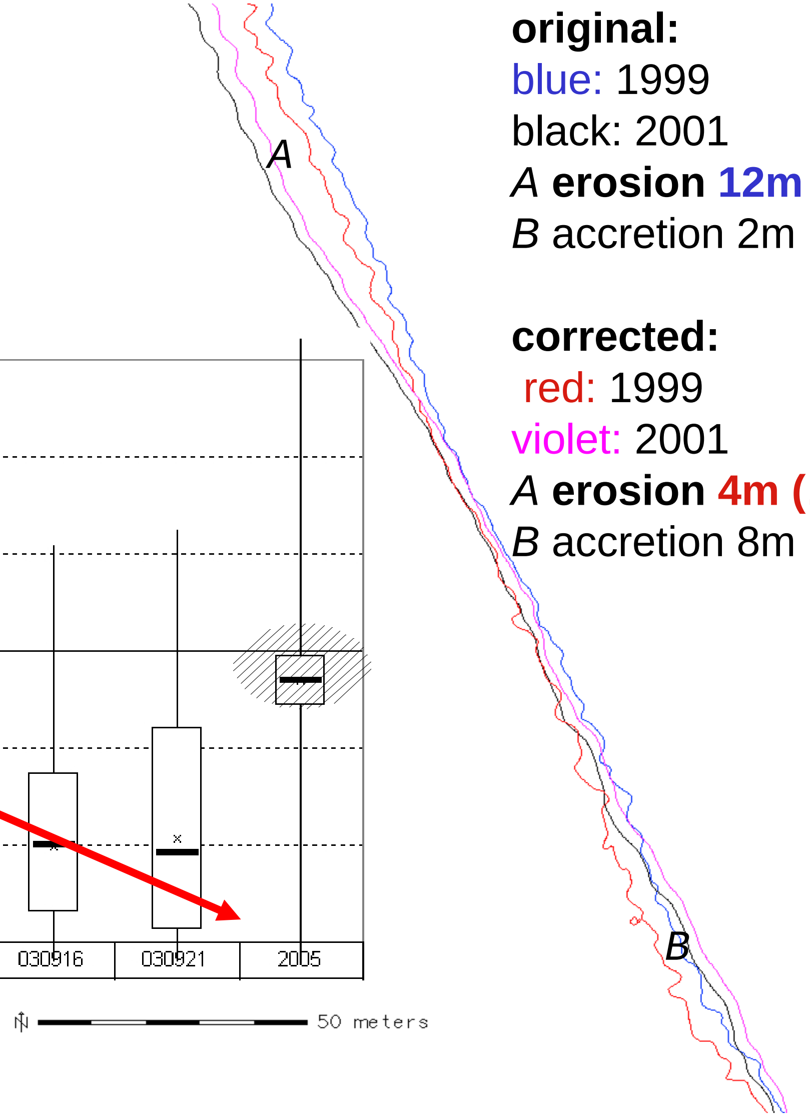
Elevation difference between RTK-GPS survey (0.03m RMSE) and lidar data along centerline of a stable road (NC12).

Impact of shifts in Lidar data

Do we have high erosion rate?

Is the road sinking?

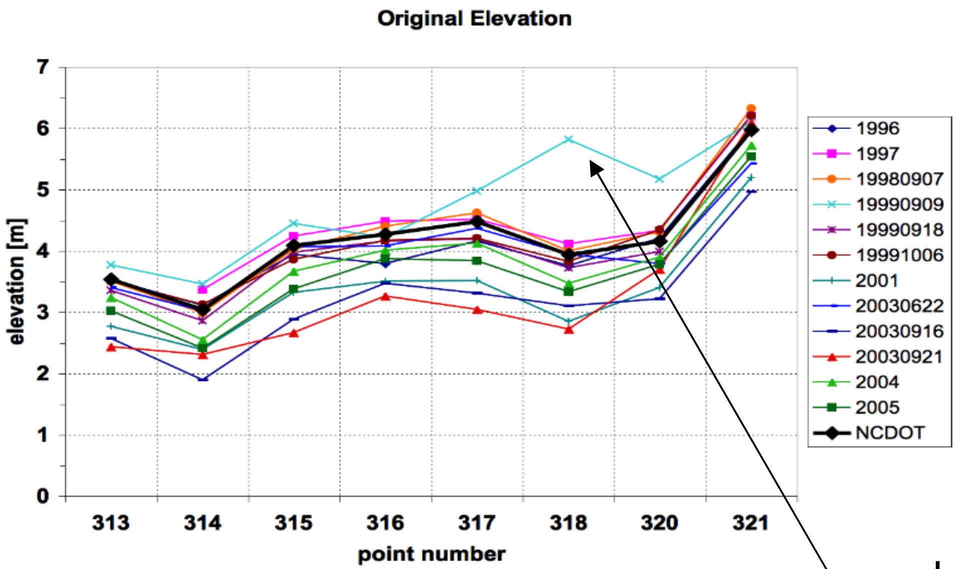




original:
blue: 1999
black: 2001
A **erosion 12m**
B accretion 2m

corrected:
red: 1999
violet: 2001
A **erosion 4m (!)**
B accretion 8m

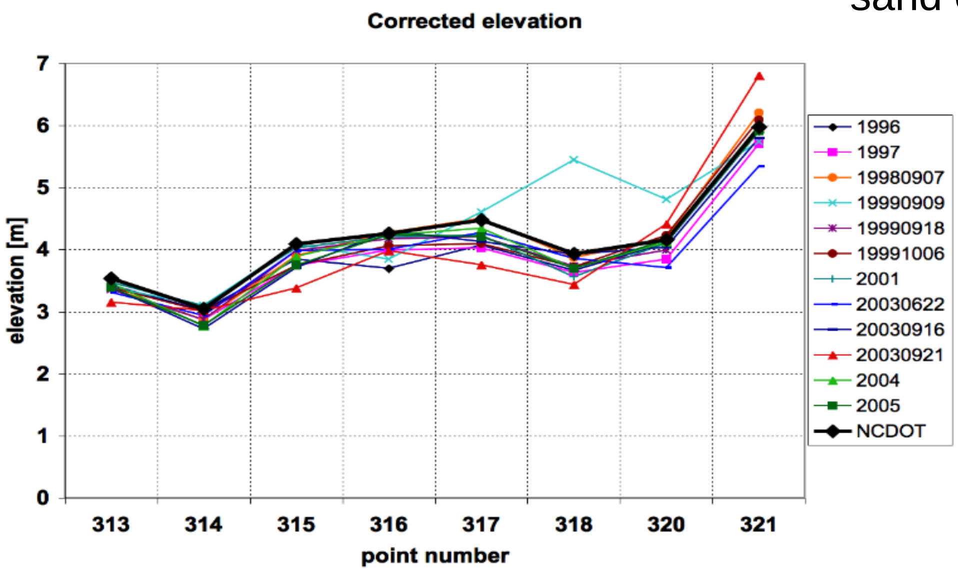
Reducing systematic error

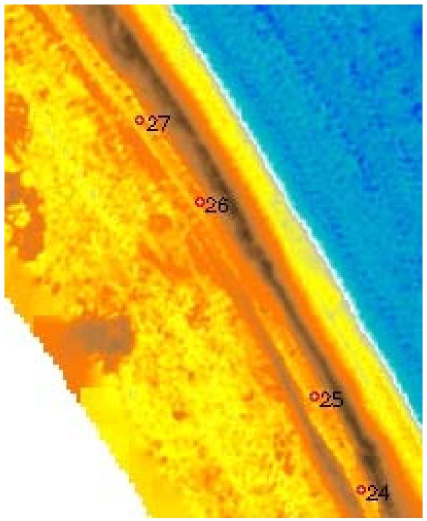


Improved data consistency:

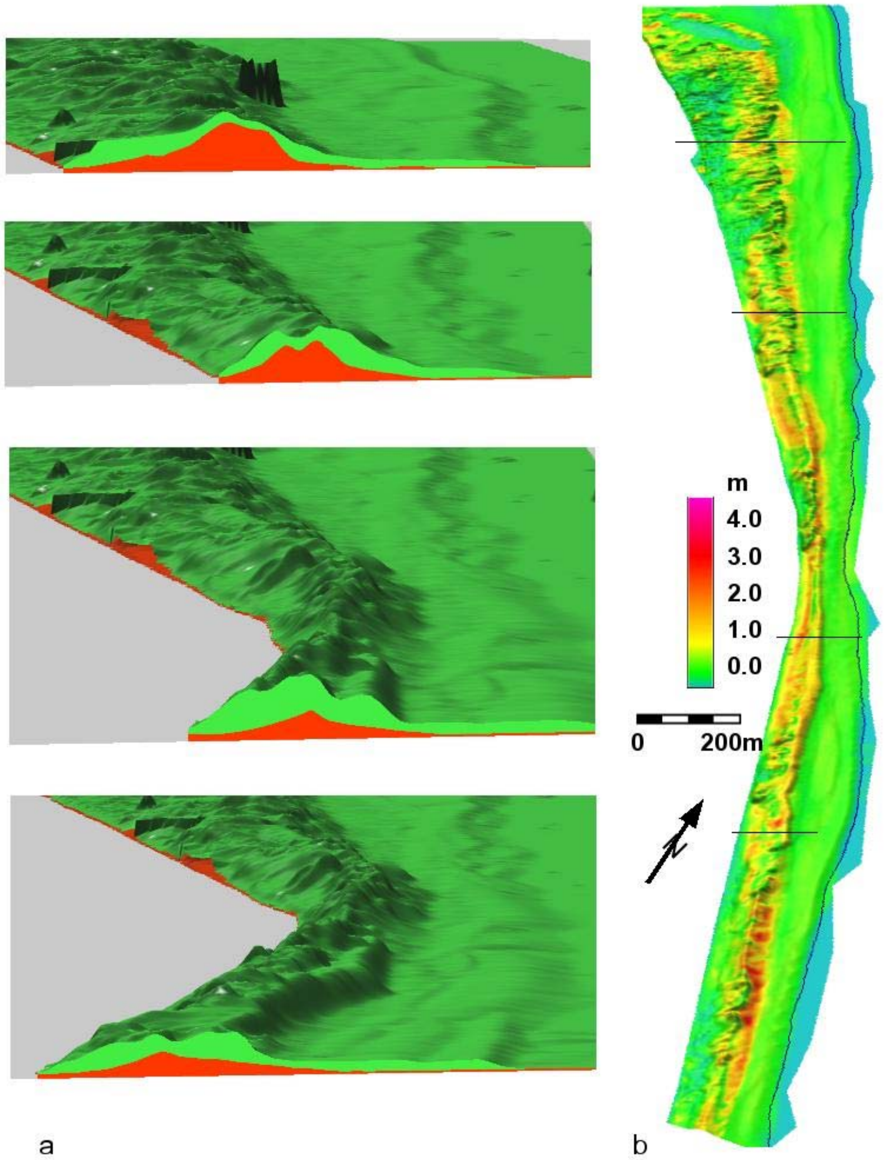
elevation at NCDOT benchmarks derived from original and corrected DEMs

sand overwash after hurricane Dennis





Spatial coastal change indicators



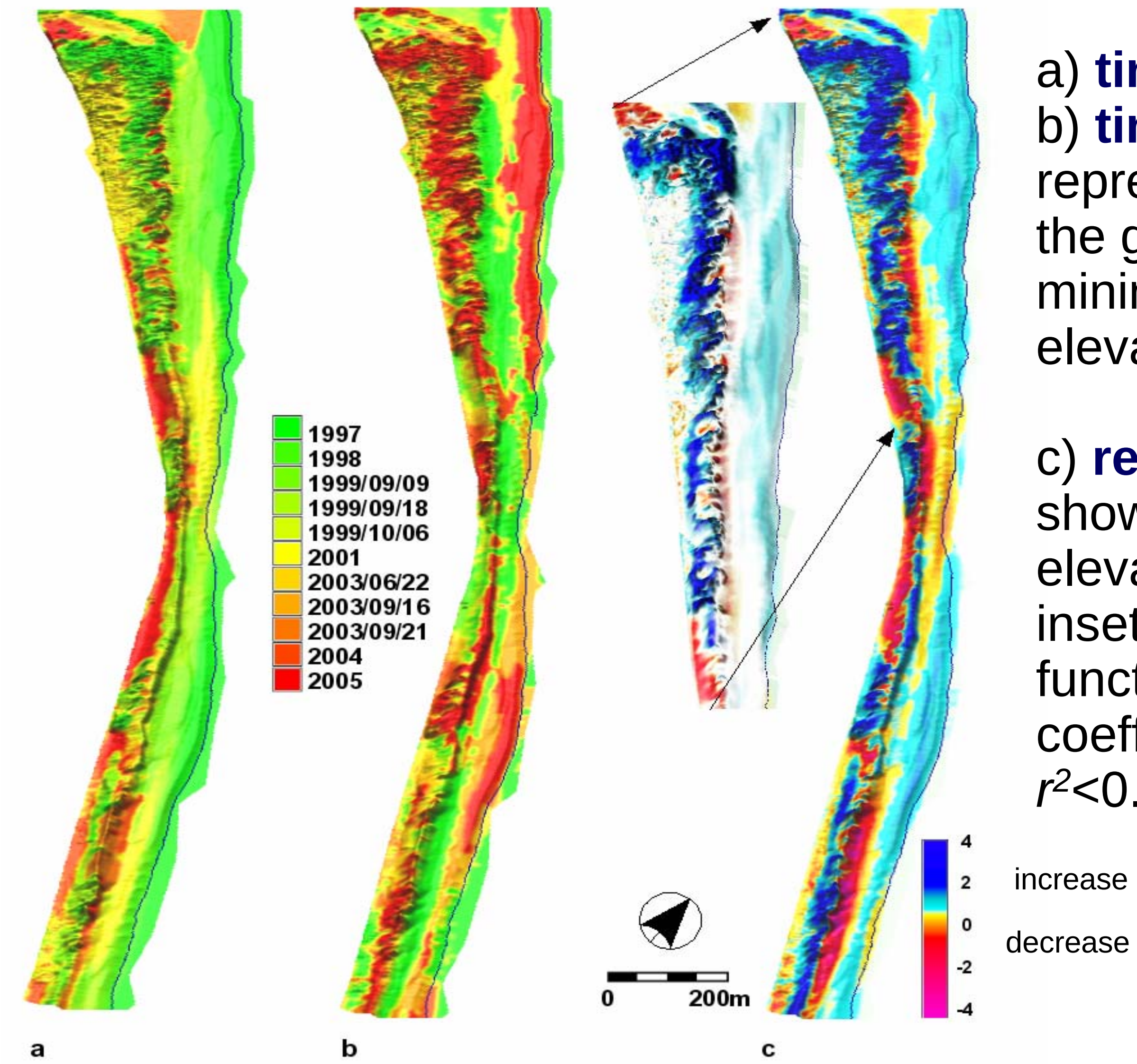
New, spatial indicators representing coastal terrain evolution based on per grid cell statistics using **r.series**:

a) core surface below which elevation never decreased and terrain dynamics **outer envelope** above which elevation never increased (core is 67% the envelope volume)

b) standard deviation map shows areas with most elevation change in red

Mitasova, Overton, Recalde, Bernstein, and Freeman, to appear in JCR
Wegmann and Clements, 2004, GRASS Newsletter

Spatial and temporal indicators

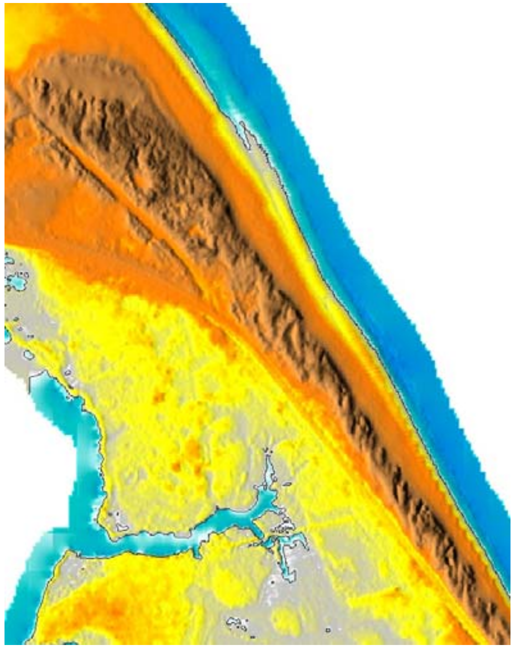


a) **time at minimum** and
b) **time at maximum** maps represent time[year] when the grid cell was at its minimum and its maximum elevation

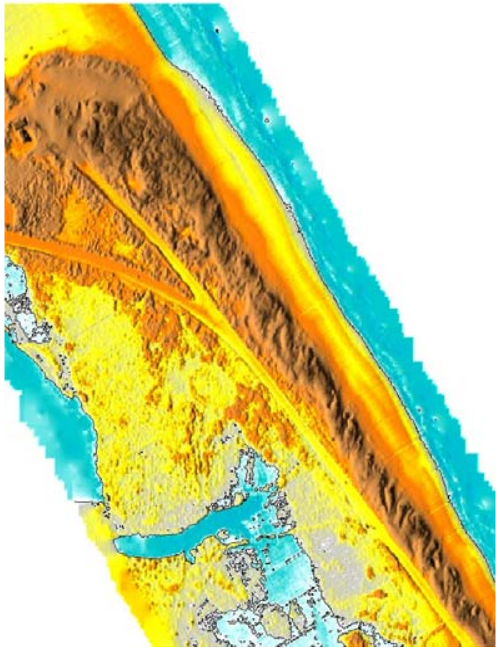
c) **regression slope** maps show spatial pattern of elevation trends,
inset: transparency added as function of correlation coefficient, white areas have r^2<0.3

Elevation surface evolution

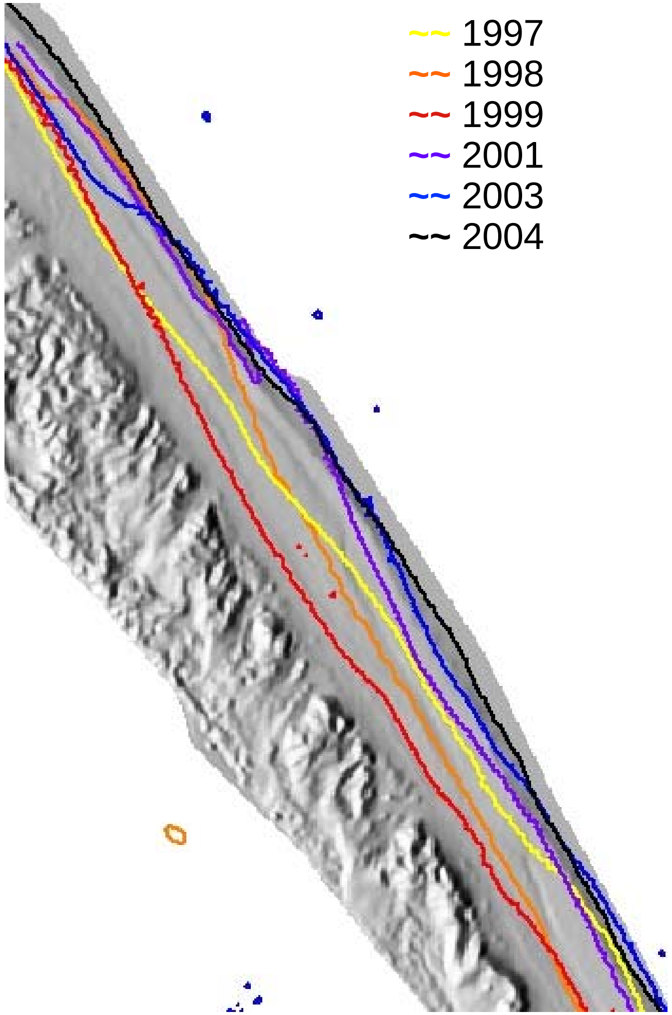
Standard representation:
series of DEMs and hard to interpret set of shorelines



DEM Feb. 2001



June 2003



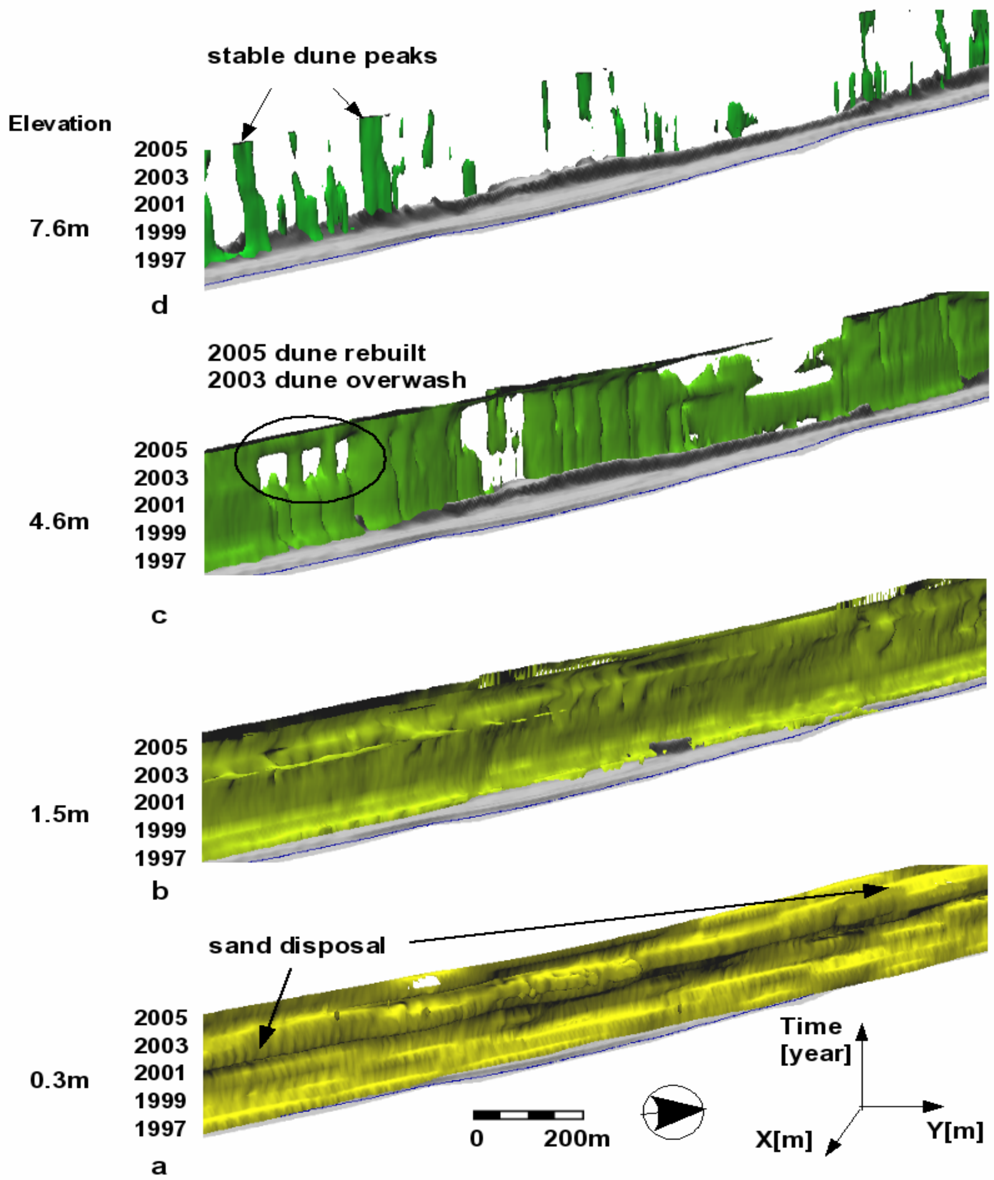
Surface evolution as volume

New approach:

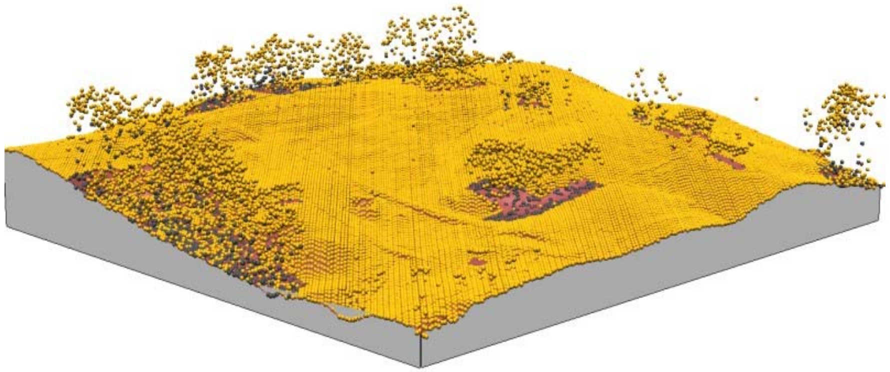
Evolution of terrain surface is represented as a **volume** with time used for 3rd dimension.

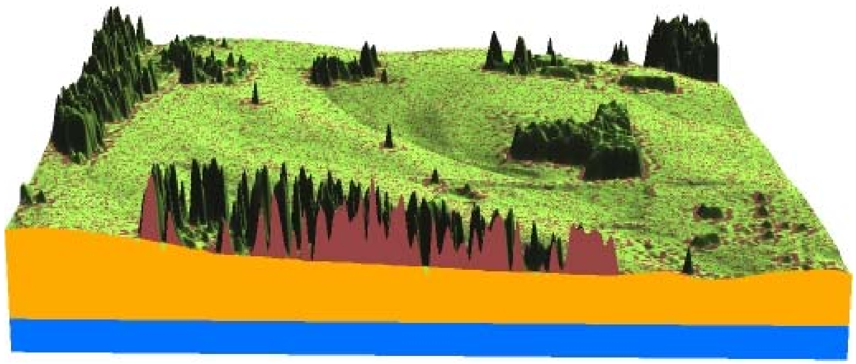
Evolution of a contour is then represented as an **isosurface**.

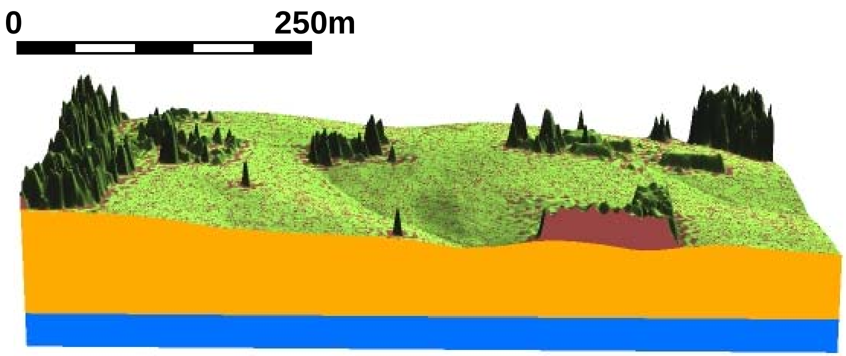
The approach reveals often neglected high dynamics of foredunes (z> 4m)
and stability of backshore beach (z=1.5m)



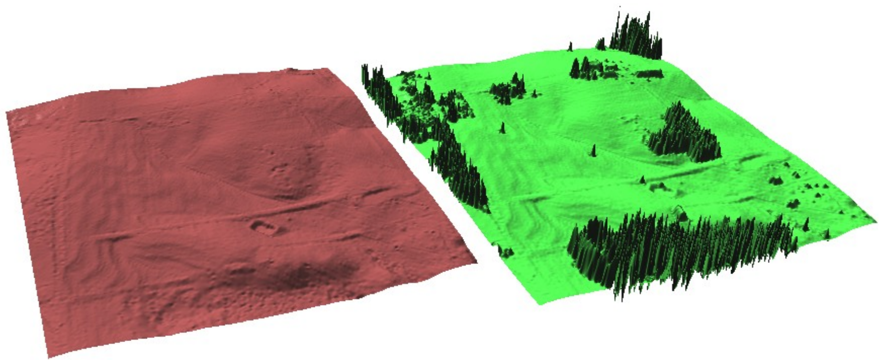
Multiple return data visualization



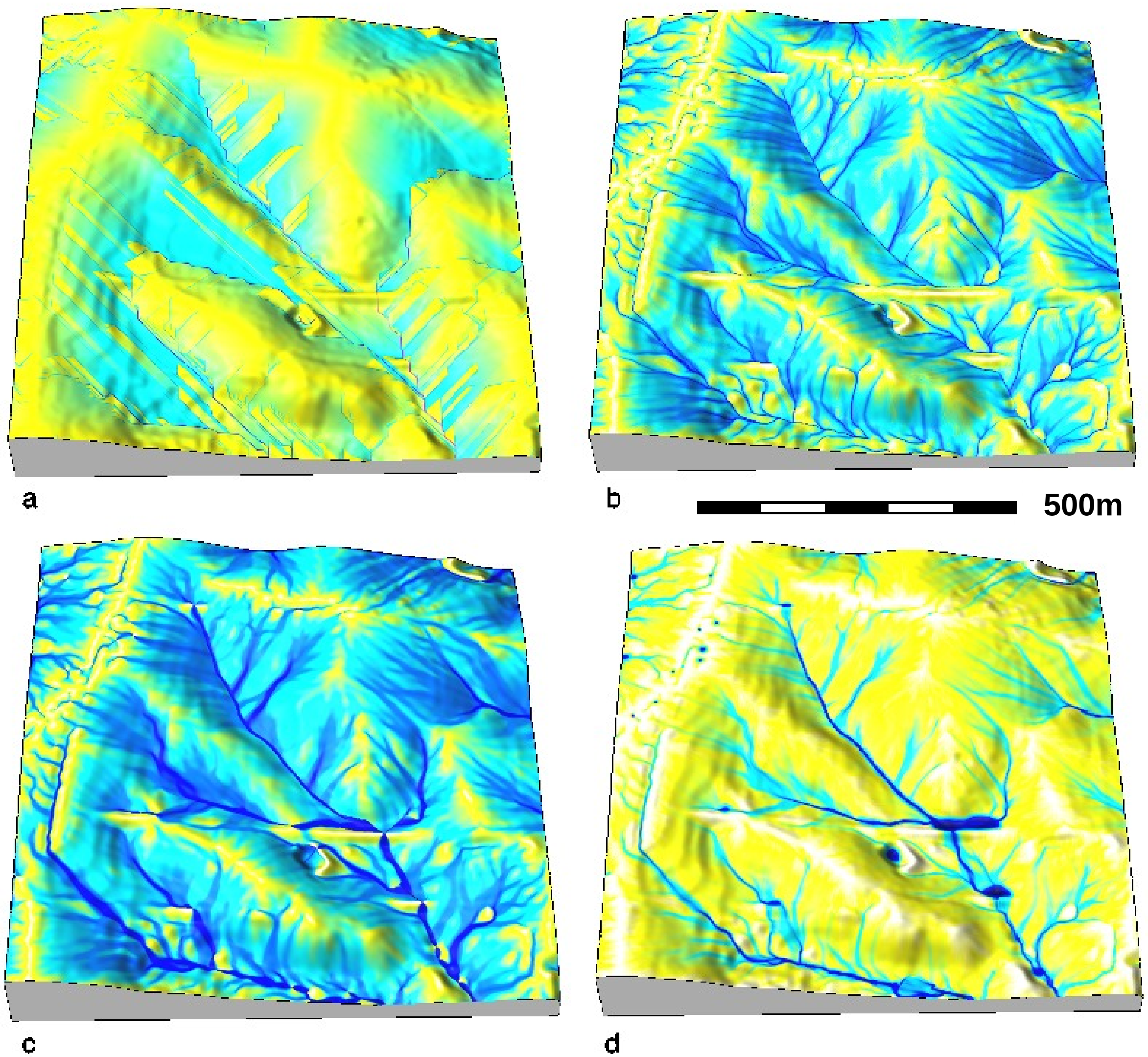




NC Floodplain Mapping Program provides both bare earth and multiple return data that can be visually analyzed using GRASS nviz module with support for multiple surfaces, interactive cutting planes and 3D vector points



Flow analysis



Flowtracing and watershed analysis:

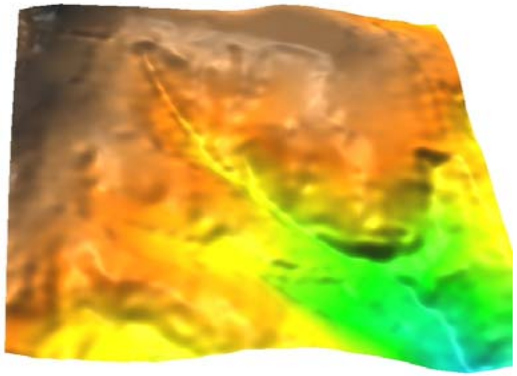
a) **r.watershed, r.water.outlet**: D8, Single flow direction (SFD), least cost path (no sink filling)
b) **r.flow**: Dinf, SFD, hillslopes
c) **r.terraflow**: D8, MFD, massive DEMs

Process-based modeling:
d) **r.sim.water**: overland water flow
r.topmodel
r.hydro.casc2d

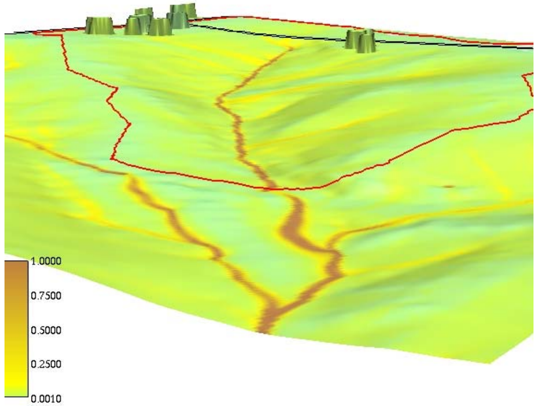
PDE solvers library and 2D/3D groundwater modeling
JGRASS, HydroFOSS

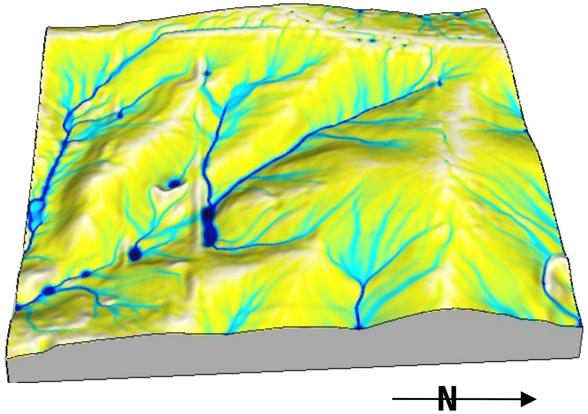
Anthropogenic terrain change

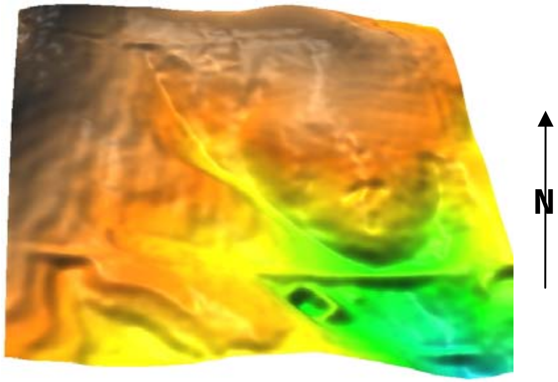
Road flooding and sediment are already a problem
Create land management alternatives and evaluate their impacts
Topography is crucial - requires creating alternatives in 3D space - can be tedious using 2D screen



1993 photogrammetric DEM







2001 lidar-based DEM

Sediment pollution

Flooding

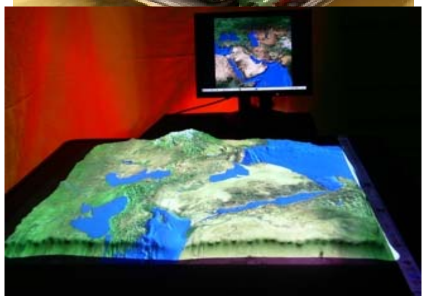
GIS and physical 3D models

New technologies combine easy to interpret 3d physical models of landscape with geospatial data to facilitate communication and collaboration

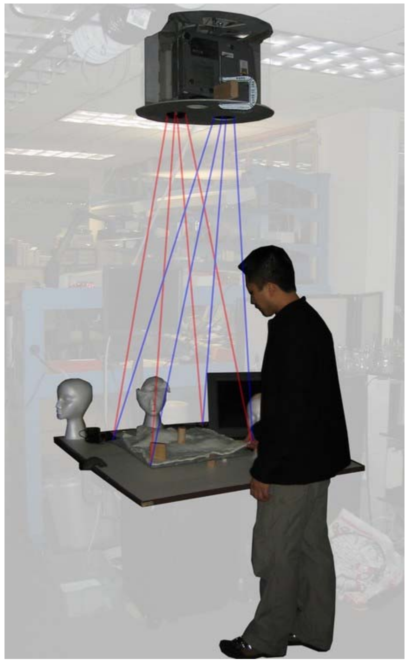
Illuminated Clay - Tangible GIS
developed by MIT Media Lab and SENSEable City lab

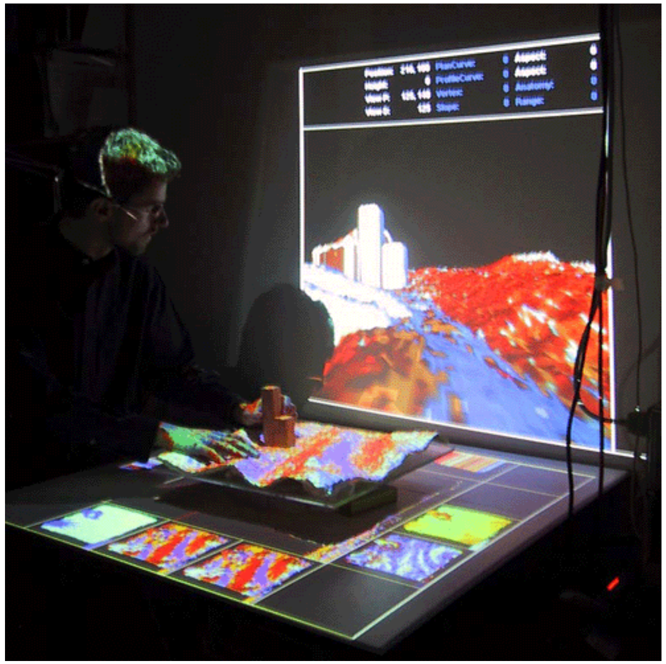
Mitasova, Mitas, Ratti, Ishii, Alonso, Harmon, 2006,
IEEE Computer Graphics & Applications, Special Issue - GeoVisualization, 26(4)

Viewer: GISon3D

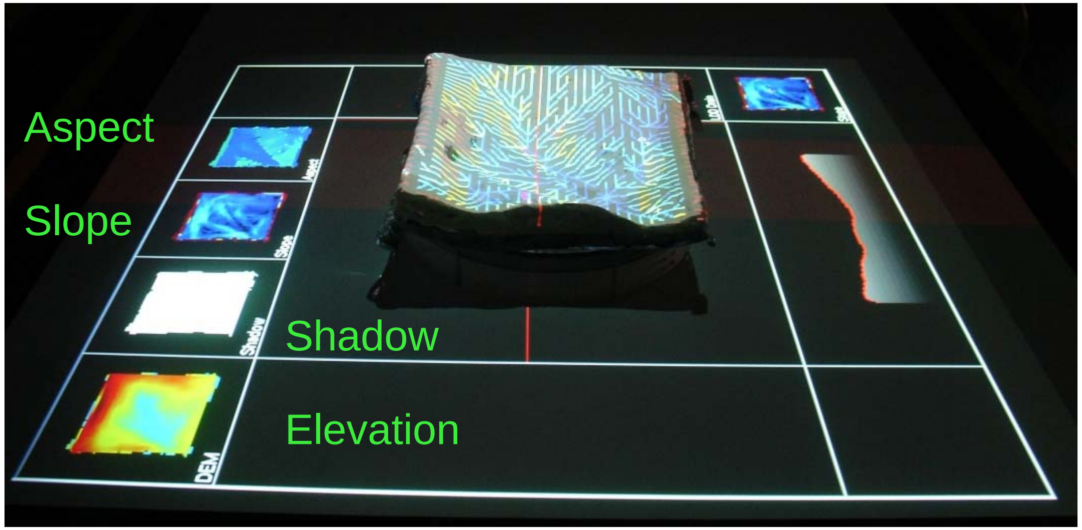


Xenovision Dynamic
Matrix Display
NG Terrain Table

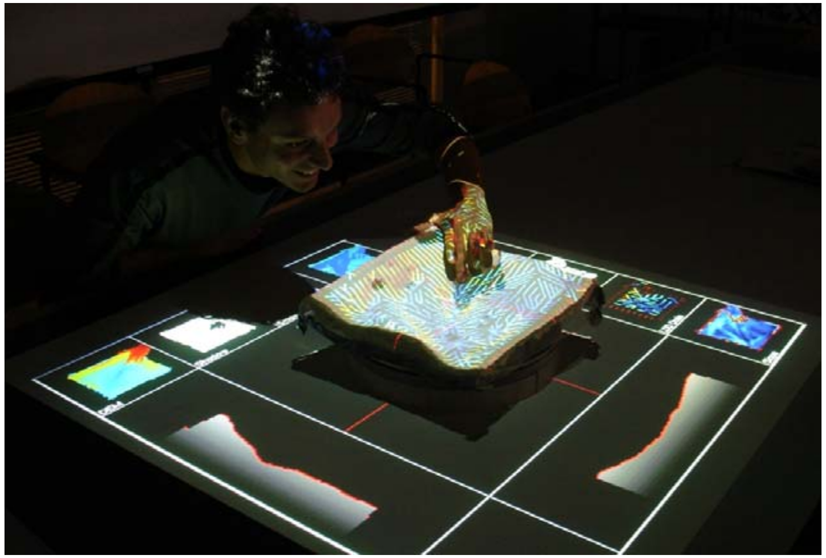




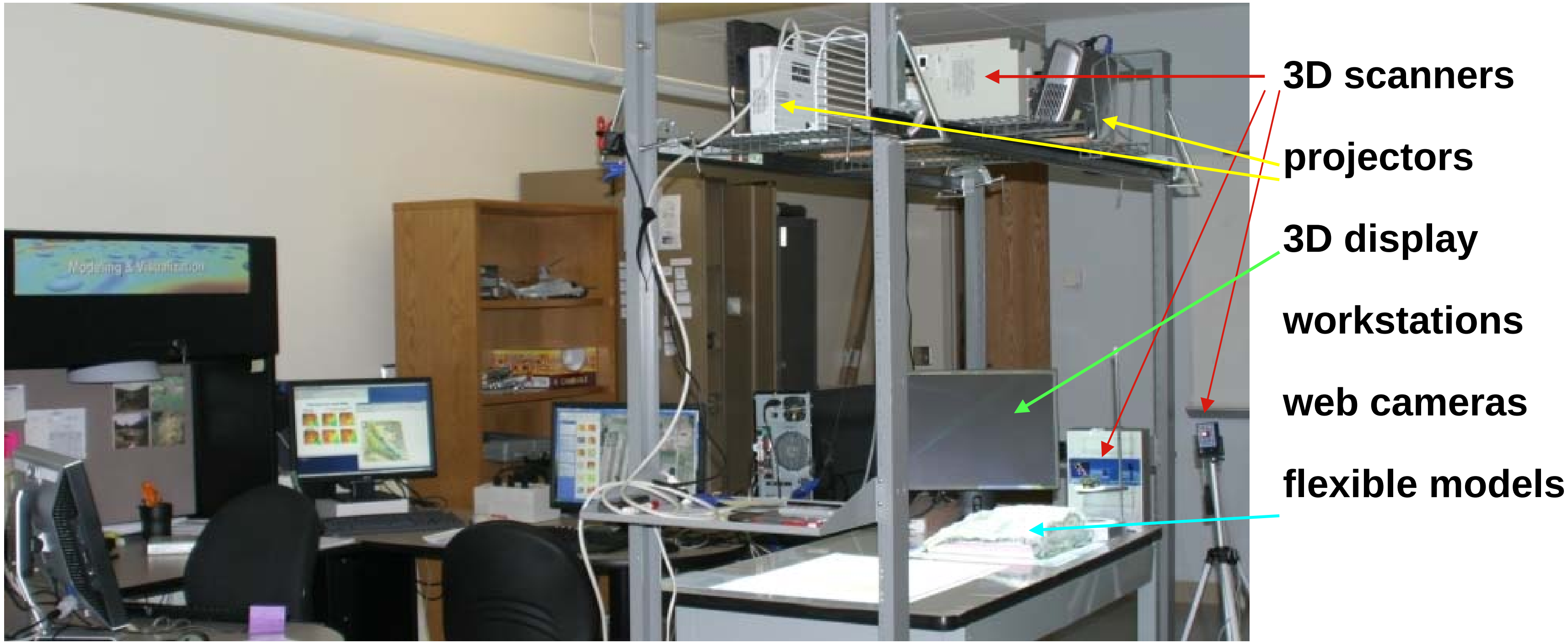
Analysis using a physical model

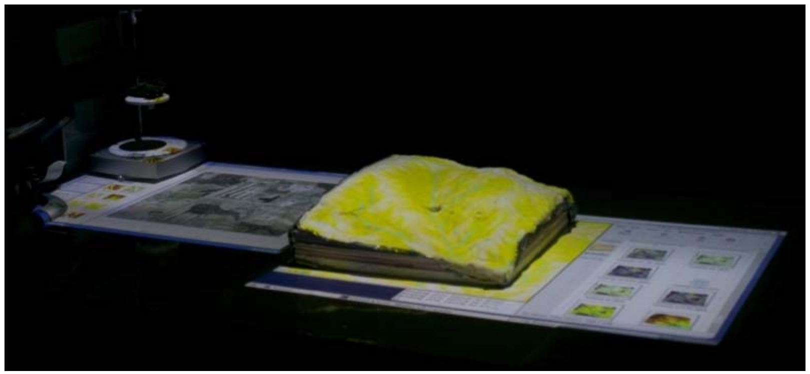


Model is continuously scanned while flow direction, slope, elevation change, profiles are computed in real time and projected over the model or workspace.
System not linked to GIS



Building TanGIS at the VISSTA lab





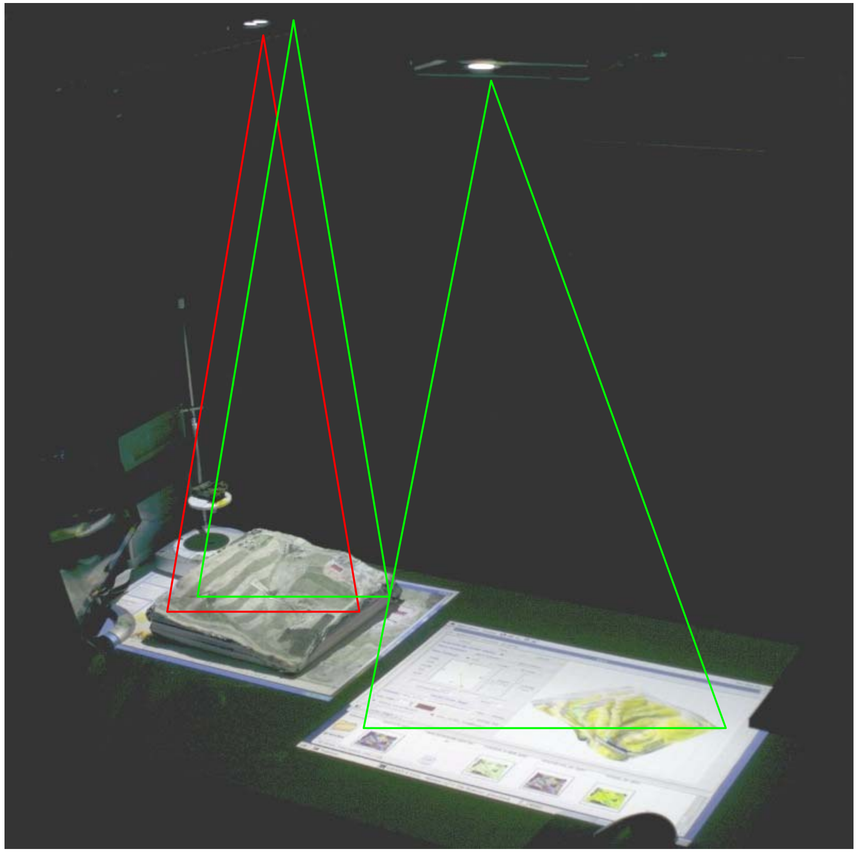
Multipurpose facility at VISSTA Lab at ECE NCSU: Prof. Hamid Krim

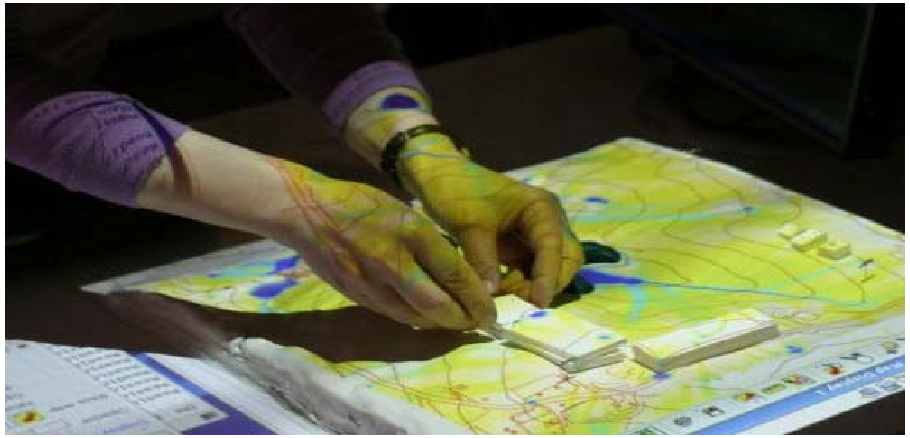
System is linked to GIS (GRASS, ArcGIS)

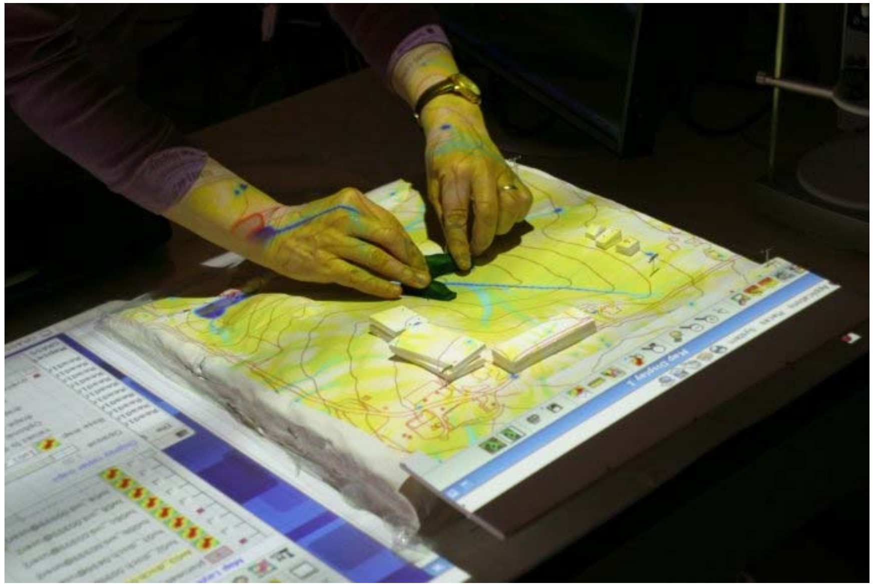
GIS data and results of simulations based on the scanned data are projected over the solid model.

3D land use design

Scanning the model,
projecting data and simulation results

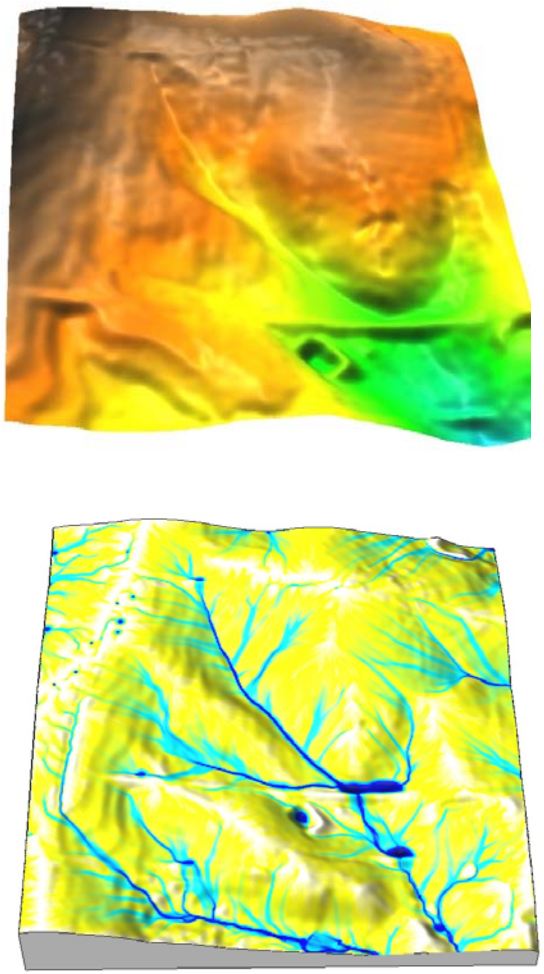




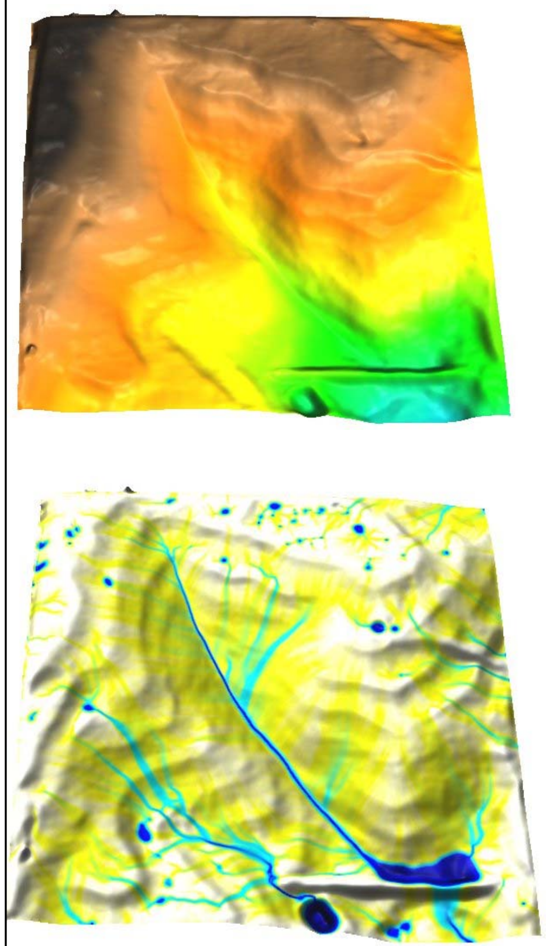


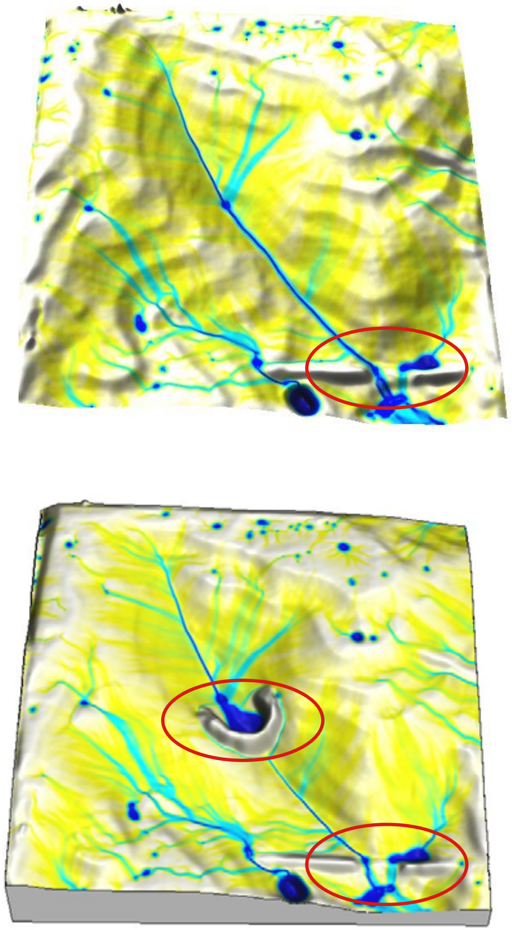
Real-world and model DEMs

lidar-based 2m DEM 2001



**scanned model-based 1mm (2m) DEMs
with modifications and their impact on runoff**





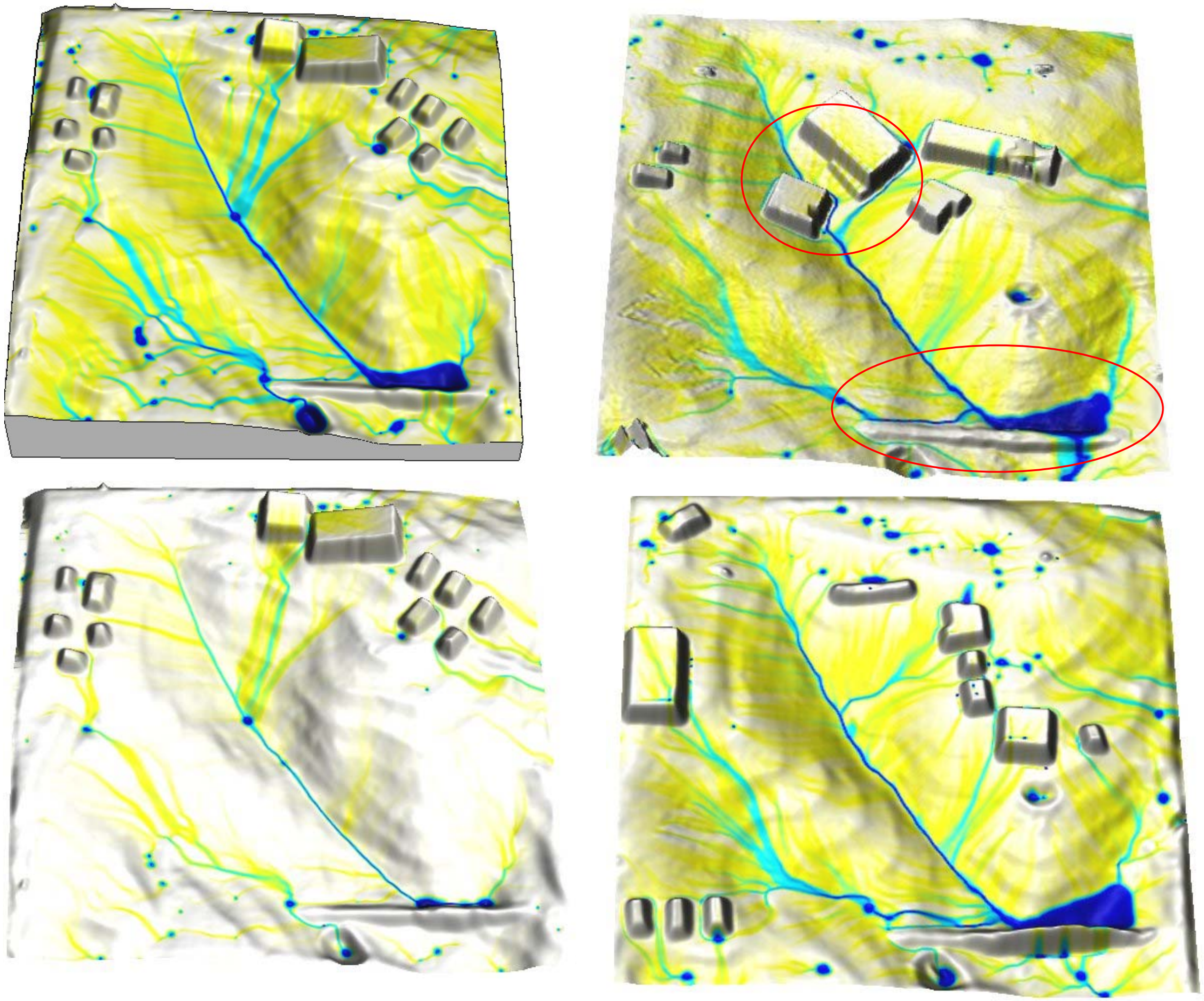
Exploring runoff with TanGIS

Simulating flow over modified surface: **exploring impacts**

Different configurations of buildings and compacted surface

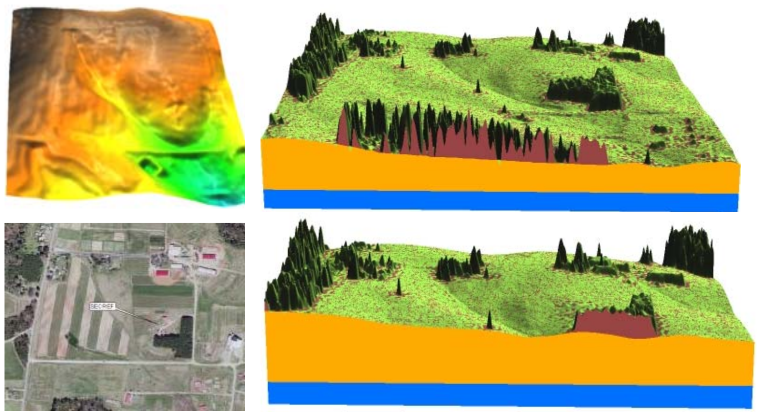
Buildings and high infiltration surface (e.g. forest) >

Buildings and elevated road >>



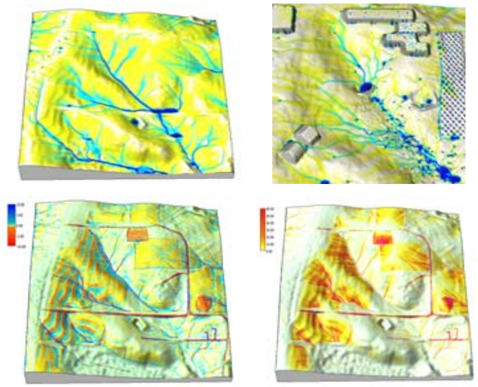
Real-time data from terrestrial sensors:
ISCO samplers, Econet weather station
StarDot webcams,
Leica laser scanner + imagery

Multitemporal geospatial data:
multiple return airborne lidar, high resolution orthophoto, multispectral imagery



GIS:
OSGEO software stack
integration
analysis
modeling

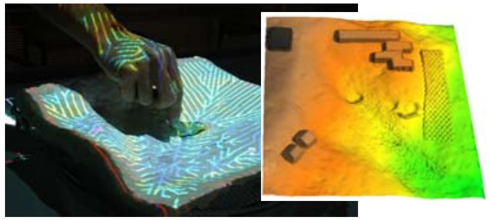
Integrated dynamic virtual model



Tangible GIS

Overlay and analyze:
- real-time data and simulation results over the physical model

Create:
- new development scenarios
- new BMP configurations



Conclusion

Open Source GRASS GIS provides comprehensive set of tools for terrain modeling, analysis and visualization including massive, multitemporal lidar data sets.

New approach was developed for analysis of spatial and temporal variability in coastal terrain evolution using time series of lidar data.

Laboratory 3D laser scanning is used to develop Tangible GIS: an experimental environment for analysis of landscape change impacts and design

Learn more about GRASS at grass.osgeo.org

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NC WRRI and North Carolina Sediment Control Commission
is gratefully acknowledged**