DARE WP1.1 A tool for urban flood delineation using Synthetic Aperture Radar.

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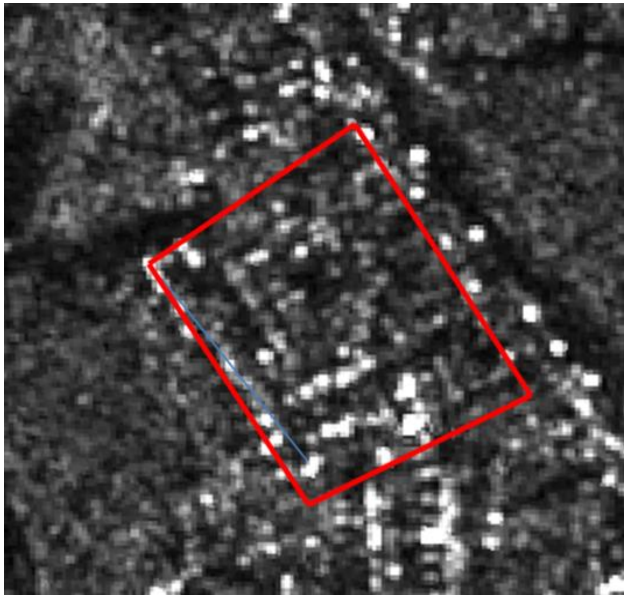
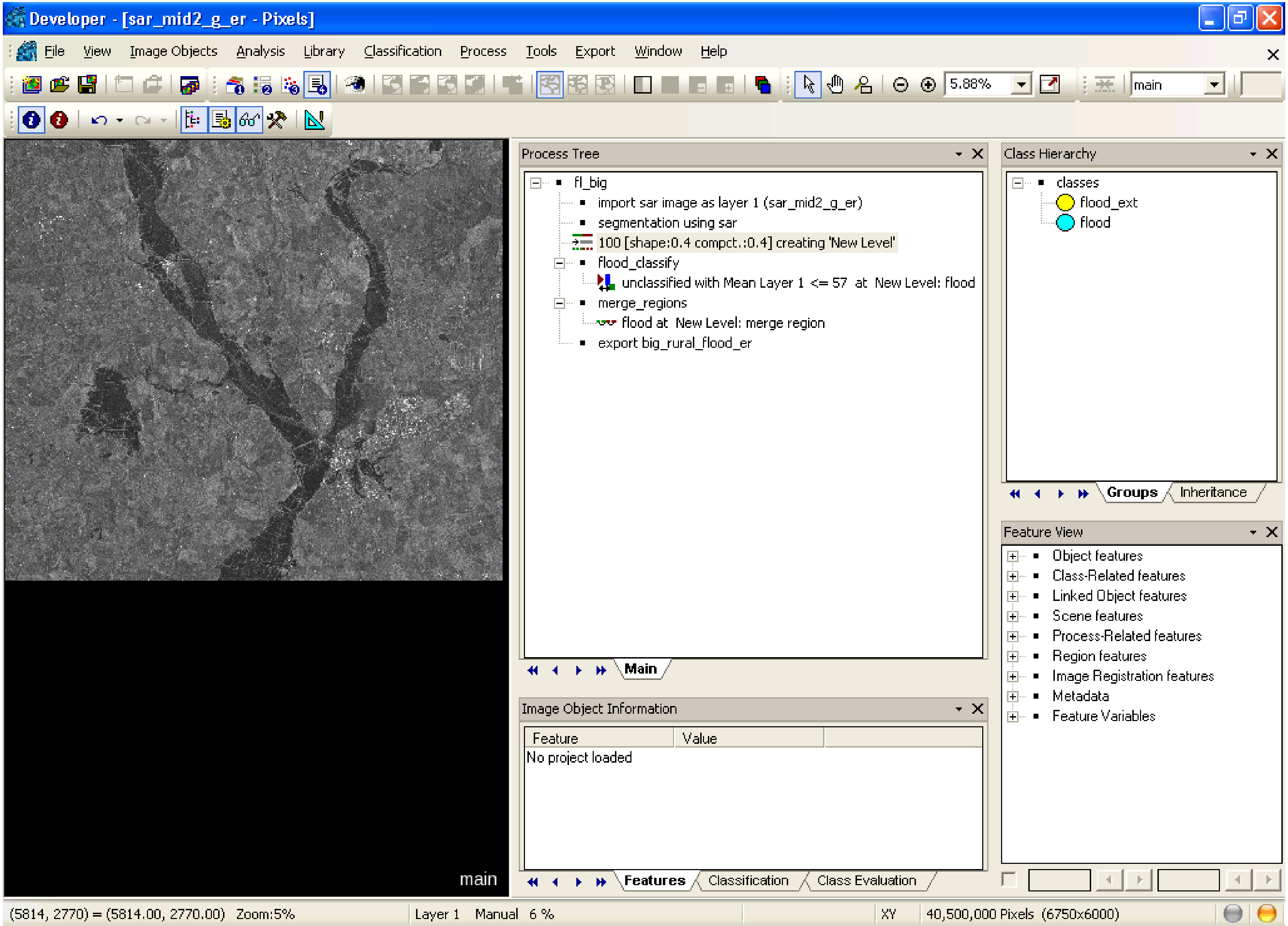
- High resolution SAR sensors now commonly used in natural disasters such as flooding (synoptic, all-weather, day/night)
- Sensors have resolutions as high as 1m
  - TerraSAR-X, RADARSAT-2, COSMO-SkyMed constellation
  - Sentinel-1 constellation
- Flood water generally appears dark in SAR image

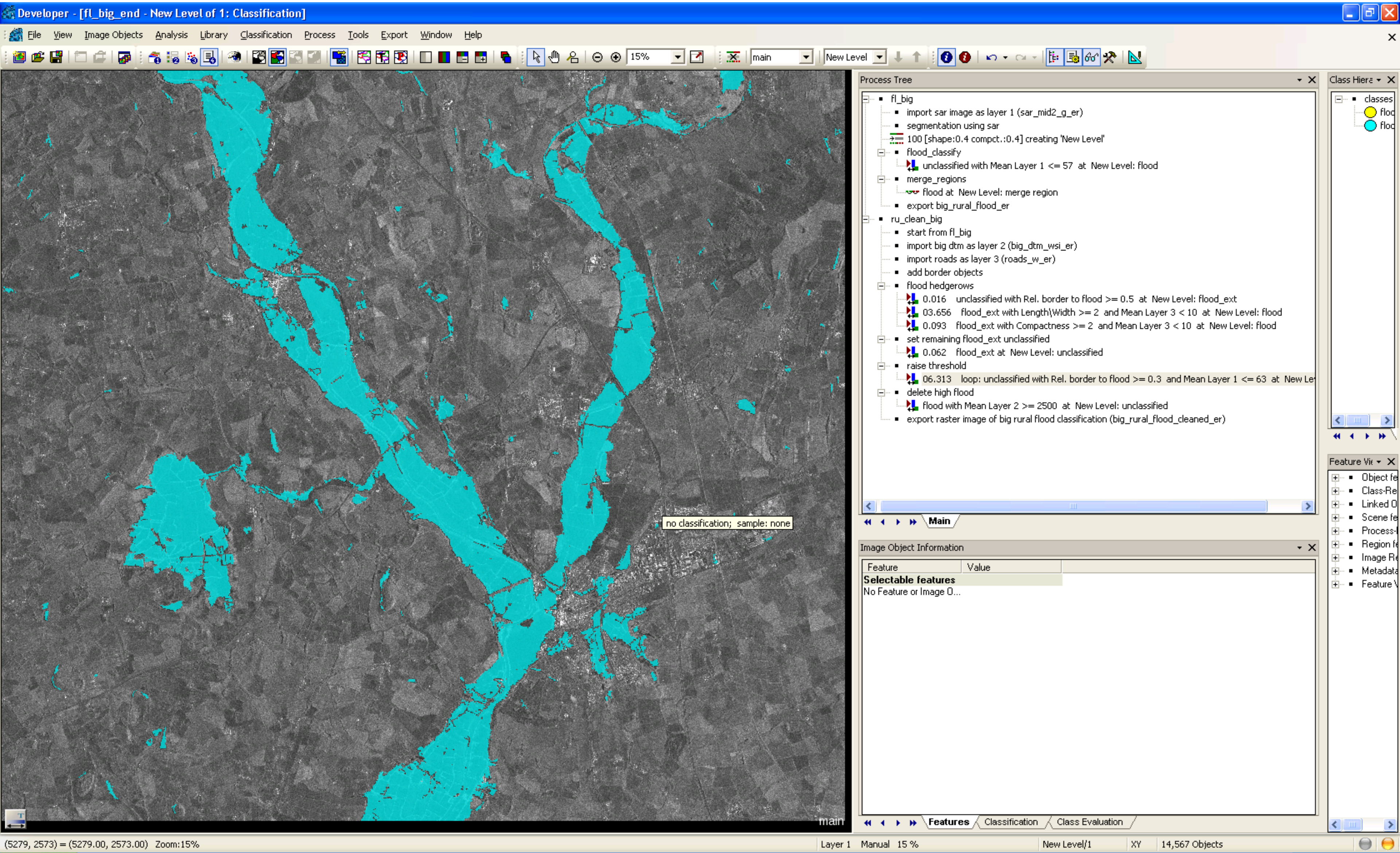


Uses of flood extents derived from near real-time SAR images.

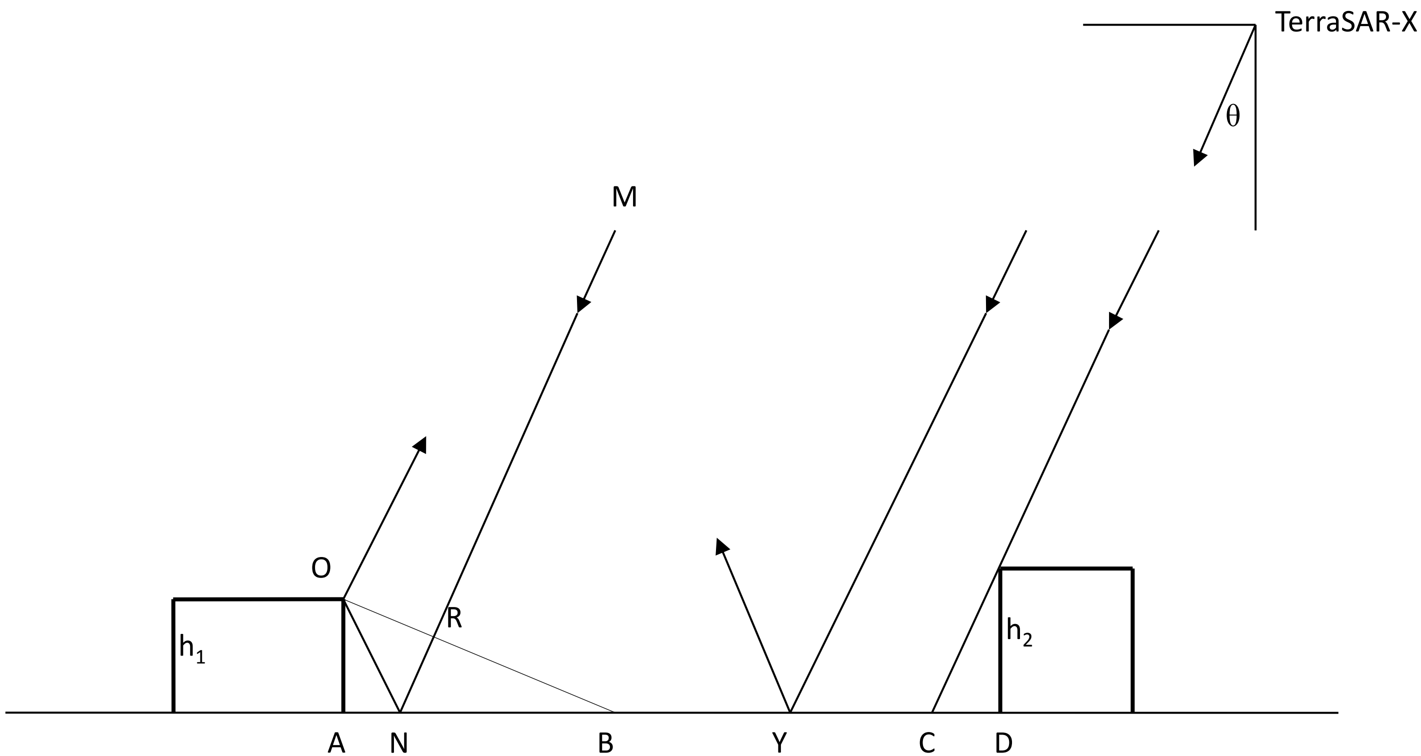
- Sentinel-1 provides processed multi-look geo-registered images 1 hour after reception.
- Uses of near real-time flood extents –
  - Flood relief management
    - Pitt report
    - EA use of SAR images.
  - Improved flood forecasting using data assimilation
    - Water level observations
    - Probabilistic flood inundation maps (Giustarini et al., 2017).
- Several systems to extract the flood extent from a SAR image developed
  - tend to work well in rural areas and poorly in urban areas.

Flood extent delineation algorithm.




Developer - [fl_big_end - New Level of 1: Classification]
File View Image Objects Analysis Library Classification Process Tools Export Window Help
15%
main
New Level
Process Tree
fl_big
import sar image as layer 1 (sar_mid2_g_er)
segmentation using sar
100 [shape:0.4 compct.:0.4] creating 'New Level'
flood_classify
unclassified with Mean Layer 1 <= 57 at New Level: flood
merge_regions
flood at New Level: merge region
export big_rural_flood_er
ru_clean_big
start from fl_big
import big dtm as layer 2 (big_dtm_wsi_er)
import roads as layer 3 (roads_w_er)
add border objects
flood hedgerows
0.016 unclassified with Rel. border to flood >= 0.5 at New Level: flood_ext
03.656 flood_ext with Length\Width >= 2 and Mean Layer 3 < 10 at New Level: flood
0.093 flood_ext with Compactness >= 2 and Mean Layer 3 < 10 at New Level: flood
set remaining flood_ext unclassified
0.062 flood_ext at New Level: unclassified
raise threshold
06.313 loop: unclassified with Rel. border to flood >= 0.3 and Mean Layer 1 <= 63 at New Le
delete high flood
flood with Mean Layer 2 >= 2500 at New Level: unclassified
export raster image of big rural flood classification (big_rural_flood_cleaned_er)
Main
Class Hiera
classes
floo
floo
Feature Vie
Object fe
Class-Re
Linked O
Scene fe
Process-
Region fe
Image R
Metadata
Feature V
no classification; sample: none
main
Image Object Information
Feature
Value
Selectable features
No Feature or Image O...
Features
Classification
Class Evaluation
(5279, 2573) = (5279.00, 2573.00) Zoom:15%
Layer 1 Manual 15 %
New Level/1
XY
14,567 Objects

TerraSAR-X image of Tewkesbury flooding on 25^{th} July 2007 showing urban areas (3m resolution, dark areas are water).



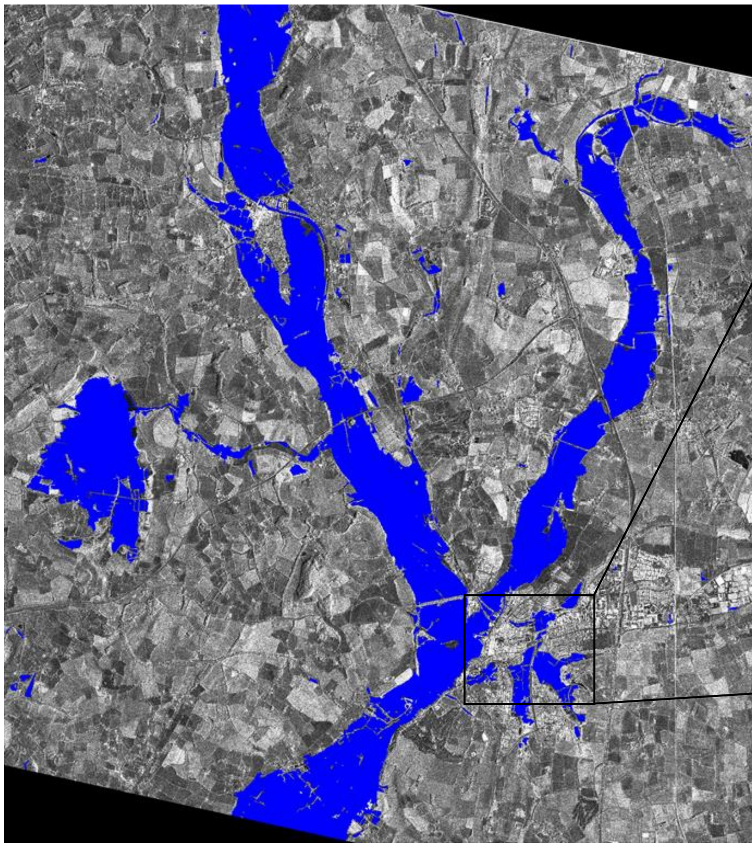
Layover (AB) and shadow (CD) in a flooded street between adjacent buildings.

Regions unseen by TerraSAR-X in LiDAR DSM due to combined shadow and layover (satellite looking West).

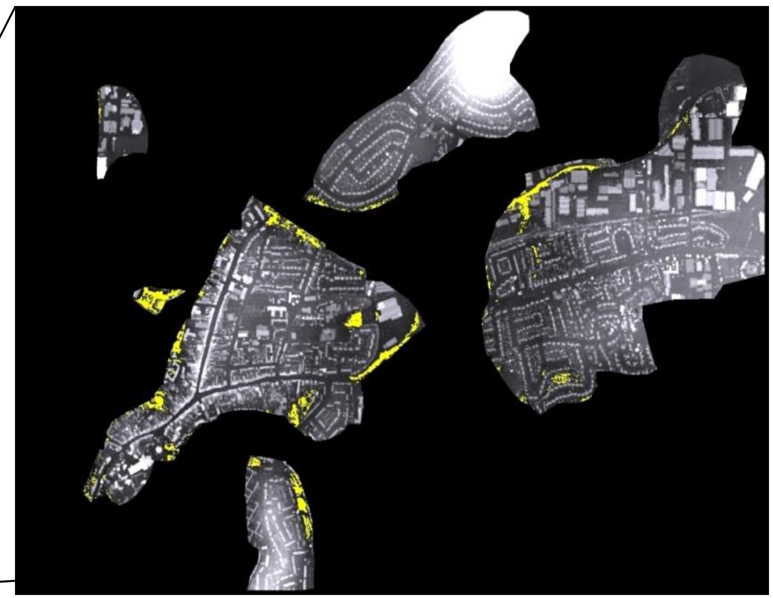
Urban flood detection

- Guided by rural flood detection
  - use local waterline heights in the rural areas
  - flooding in urban areas should not be at a substantially higher level than in nearby rural areas.
  - group low backscatter/low height pixels using region-growing
  - regions of shadow and layover masked out.

Flood extent detected automatically in near real-time



(a) Rural



(b) Urban

Urban flood detection methods.

- Current project = short project developing existing method
  - Advantage is only needs single SAR image
  - Backscatter from flooded street low, but also low from tarmac areas
  - Can be adapted to work in change detection situation.

- Flood detection accuracy using just SAR backscatter may be improved in future
  - E.g. Pulvirenti et al. (2016) show it helps to use SAR coherence as well as backscatter
  - Need image pair
  - Un-flooded urban area = high coherence, flooded = low coherence.

- Alternative method (Tanguy et al., 2017) does urban flood mapping using SAR and flood return period data
  - Finds flood level in rural area using SAR, then uses flood return period data to calculate where urban flood should be.
  - Doesn't need shadow/layover calculation
  - But flood return period data must be accurate, rainfall pattern same.

Thames flooding west of London in February 2014

- Substantial urban areas flooded, especially around Wraysbury, Staines.
- Peak flow 404 m^3/s on 11/02/2104
- CSK images acquired under CORSAIR project –
  - 12/02/2014 (gets Wraysbury not Staines)
  - 13/02/2014 (flow only 5% less than peak, gets Staines)
  - 14 – 18/02/2014.

Aerial photo of flooding in Blackett Close, Staines (13/02/2104) (150 x 150 m).

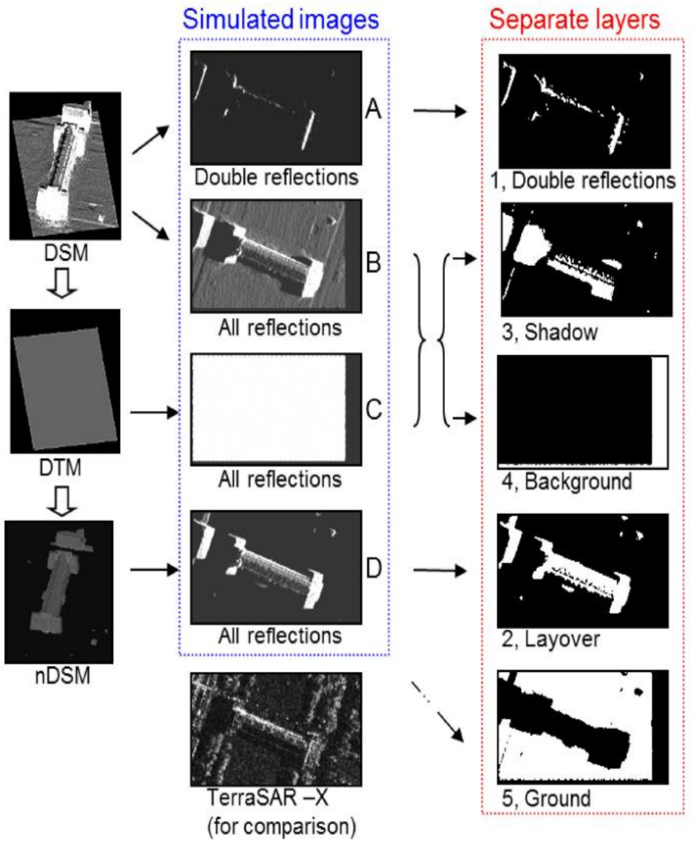
CSK sub-image (1 x1 km) of Thames flood in West London (Staines) 13/02/2014 (dark areas are water). (Aerial photo coverage in red).

SAR simulator: RaySAR

- To date used SETES SAR simulator, not publicly available
- Number of SAR simulators are open-source
- A first step in WP1.1 has been investigation of simulators
- Should not be too computer-intensive
- Selected RaySAR, based on POV-Ray
- POV-Ray is ray-tracer developed for use with incoherent visible light
- RaySAR extends POV-Ray to cope with coherent SAR ray-tracing
- RaySAR can model layover and shadow
- Processing time ~ minutes/scene

Detection of layover and shadow

- Tao (2014) developed GeoRaySAR, uses LiDAR DSMs as input, provides geocoded simulated images.
- Get LiDAR DSM, DTM of study area.
- Create normalised DSM (nDSM) by subtracting DTM from DSM.
- Create simulated ground-range-projected SAR images for DSM, DTM and nDSM.
- Layover is where backscatter > 0 in nDSM SAR image.
- Shadow is where backscatter = 0 in DSM SAR image and backscatter > 0 in DTM SAR image.



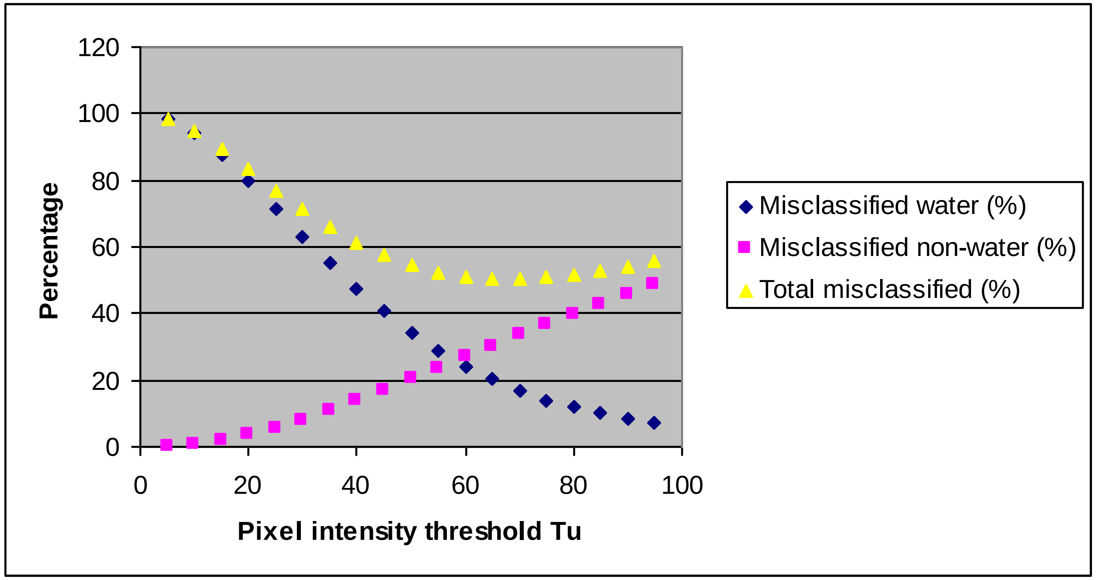
DEMs, simulated images (looking West), and separate layers (after Tao, 2014).

RaySAR processing

- For ray tracing in POVRAY, DEMS converted to Delaunay triangulations.
- RaySAR developed for analysing scenes where incidence angle assumed constant.
- So signal source emitting parallel rays represents transmitter, orthographic camera receiving parallel rays represents receiver.
- Scene/rendering parameters to be defined –
  - position of scene centre
  - position of signal source
  - position of receiver
  - size of simulated image.

Processing of each DEM.

- For processing nDSM, RaySAR produces Delaunay triangulation, triangles of low height suppressed.
- Parameters for ray tracing and SAR image creation calculated
  - for CSK image of 13/02/2014, angle of inclination= 98°, look angle = 31.6°
- RaySAR used to simulate the SAR reflectivity map.
- 2D histogram of scatterers created, contains map of the number of scattering surfaces contributing at each pixel. Layover is where number contributing > 0.
- After image generation , the method uses the geoinformation in the nDSM as well as the orbit and projection parameters of the real SAR image to geo-register the simulated image - enables a direct comparison with the real SAR image.
- Similar processing sequence applied to the DSM and DTM images. When all three DEMs have been processed, the layover and shadow maps can be calculated.



Variation of misclassified water and non-water pixels with SAR backscatter threshold.

Local waterline height threshold

- Local waterline height threshold map calculated using rural flood map.
- Water in urban areas should not be at substantially higher level than in surrounding rural areas.
- But unless height threshold imposed, could be substantial false positives at higher urban levels.
- Detect waterline heights in regions of low DTM slope.
- Mean waterline height calculated for each $1km^2$ area, interpolated over adjacent areas.
- Tries to ensure only waterlines from external boundary of the flood are used.

Urban flood detection

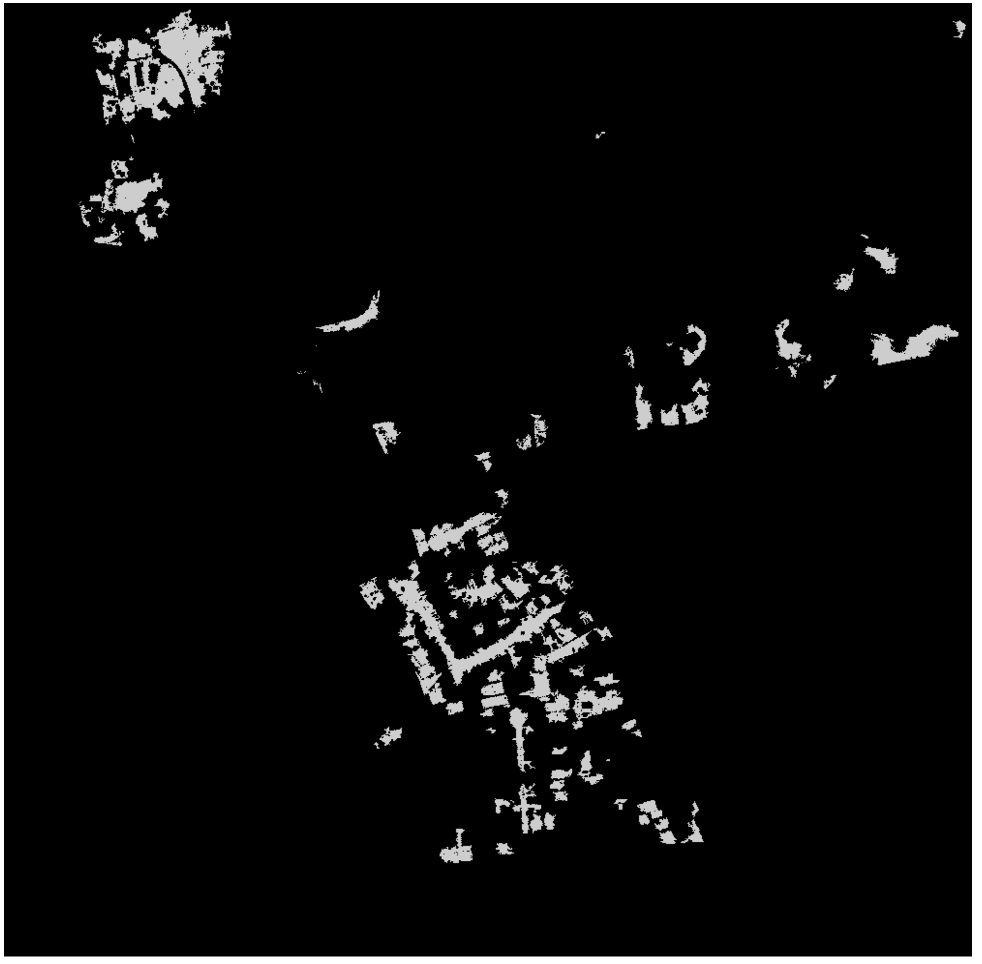
- Guided by rural flood detection
  - PDF of pixels in flooded streets outside shadow/layover has tail towards higher backscatter values

- Urban pixels classed as water seeds if
  - SAR backscatter < backscatter threshold
  - Heights < waterline height threshold
  - Not in shadow/layover

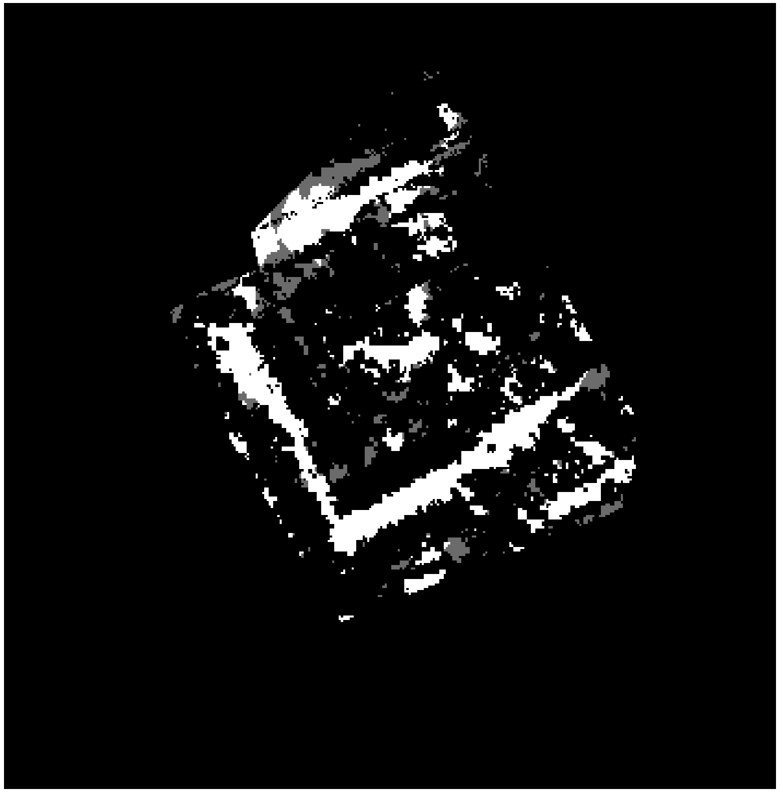
- Flooded region should have high density clusters of water seeds, unflooded region should have low density
  - Developed convolution approach to make seeds survive if they are close to other seeds

Urban flood detection (continued)

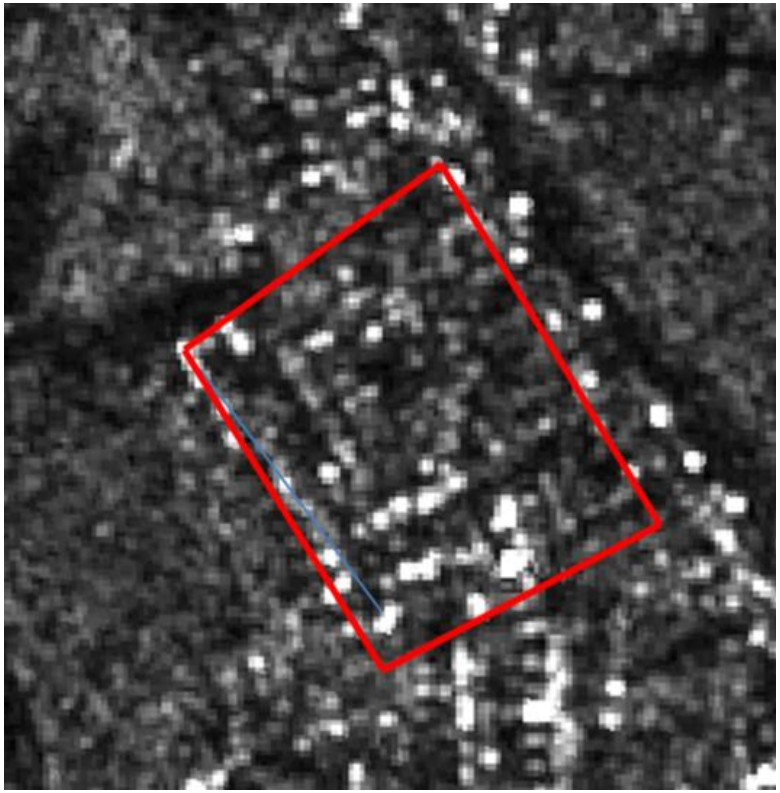
- Weighted distance transform used to grow surviving seeds into flood regions
  - In normal distance transform, each unflooded pixel’s distance value is Euclidean distance to nearest flooded pixel, with distance at flooded pixels = zero
  - In weighted distance transform, distance increment between unflooded pixel (x,y) and its neighbour weighted by SAR backscatter at (x,y)
  - Grows flood regions preferentially along roads with low SAR backscatter
  - Grows also into shadow/layover areas
  - Tries to compensate for limitation of urban flood detection using SAR that SAR can’t see into shadow/layover
  - Pixels with weighted distance < threshold classed as ‘urban flood’
  - Flood edge rather imprecise.



Predicted flood in urban area (white).



Predicted flood extent in Blackett Close validation area (light grey = flooded in SAR and aerial photo, dark grey = flooded in aerial photo only).



Extract from SAR image.

Classification accuracies.

Detection rate scenario	Accuracy (%)
Percentage of urban flood extent visible to SAR and detected by it	77
Percentage of urban flood extent visible in aerial photo, and detected	71
False positive rate in unflooded high area	25
False positive rate including shadow/layover area	19
If shadow/layover map switched off -	
Percentage detection of urban flood extent	76
False positive rate in unflooded high area	37

Next steps

- Test method on further sub-scenes of
  - West London flood
  - Tewkesbury 2007 flood
- Experiment further with method of urban flood detection.