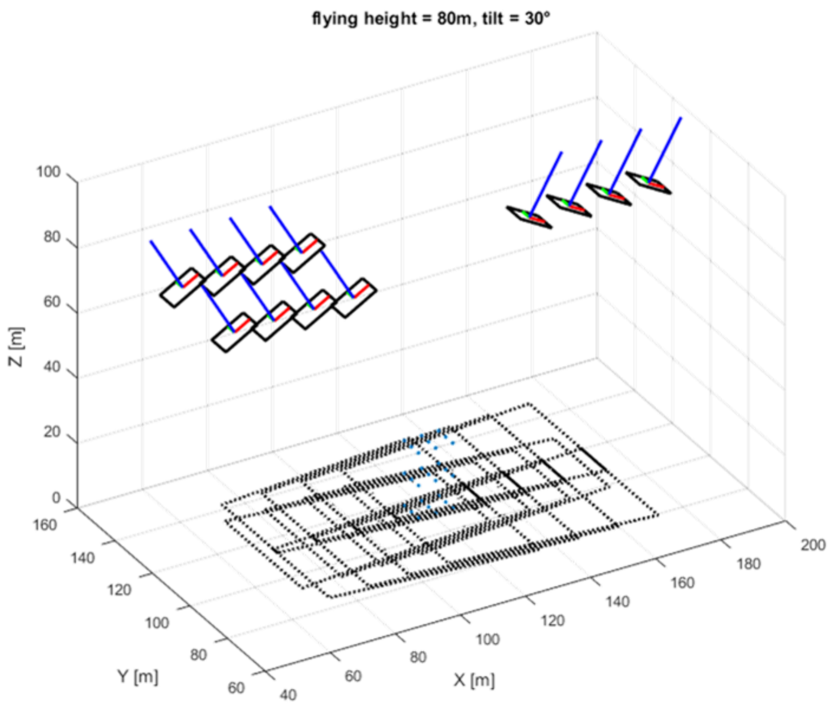
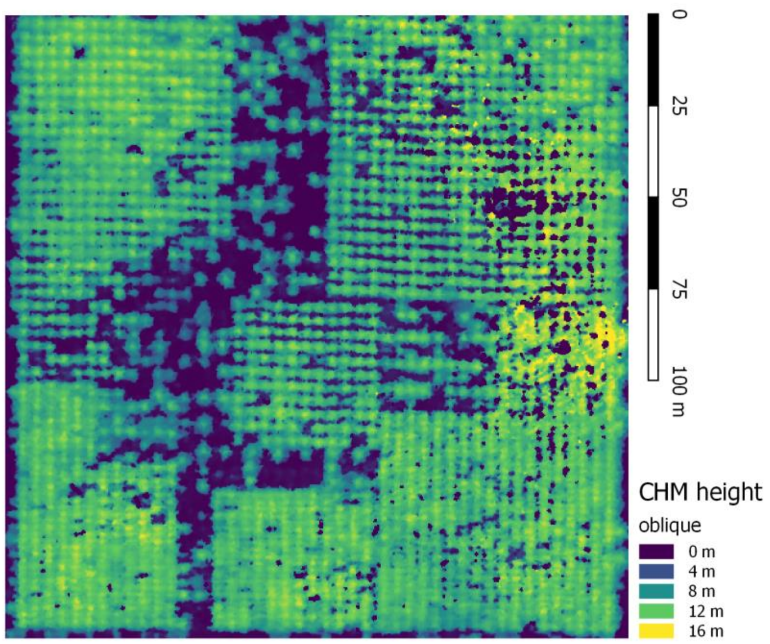




Left: Oblique mission simulation (MATLAB)

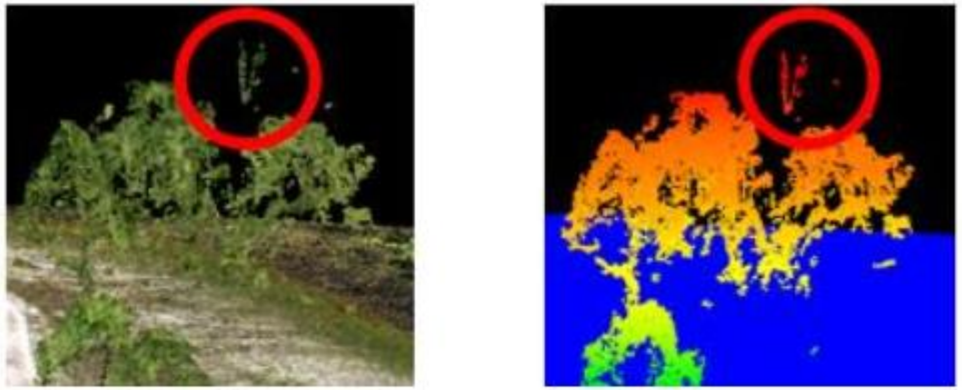
Right: CHM generated from oblique aerial images

Oblique UAS photogrammetry in forested scenes

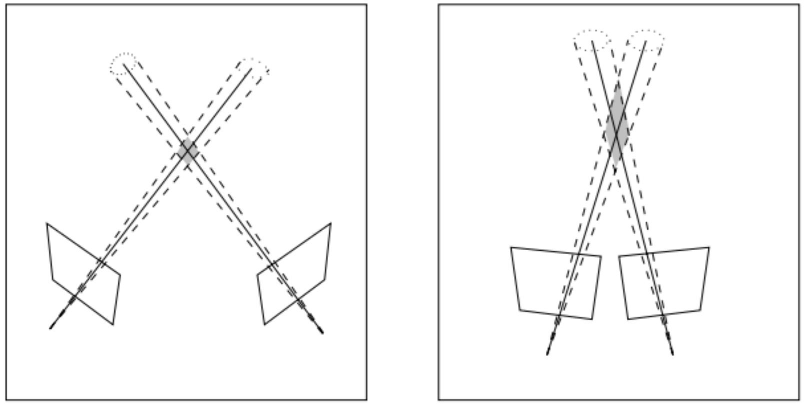
HA Lassiter, LF Ramalho de Oliveira

Objective

- UAS photogrammetry should not be considered as low-altitude aerial photogrammetry, but rather as *dynamic, close-range photogrammetry*
    - Decreased range, increased relief displacement, increased target height:flying height ratio
- Apply close-range photogrammetry considerations to UAS photogrammetry mission planning over forested scene
- Two main concerns in close-range missions—*varying range* of targets and *strong geometry* between exposure stations—can both be achieved through *oblique images*



False positives detected in dense matching point cloud over forested scene



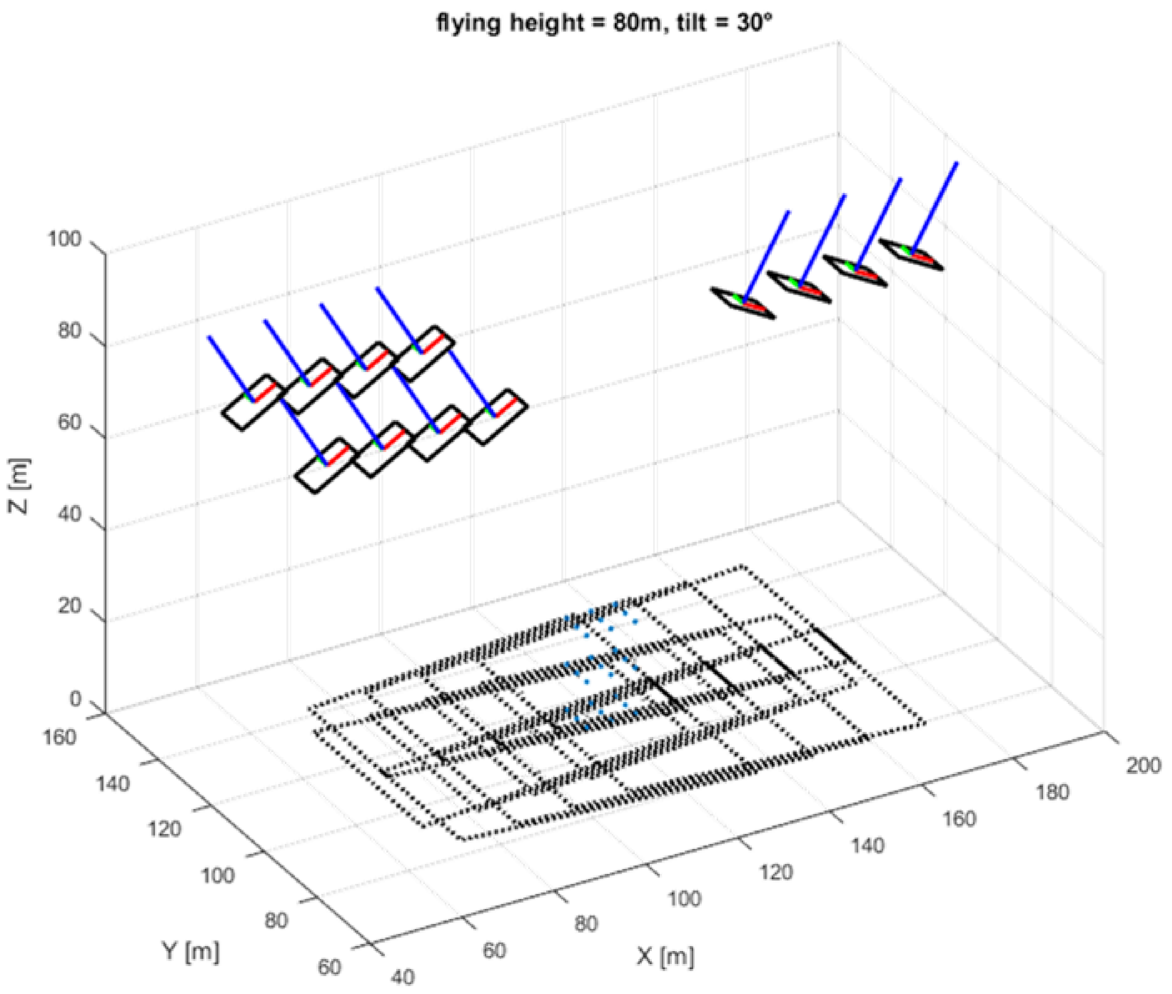
Uncertainty of reconstruction (Hartley & Zisserman)

Methods

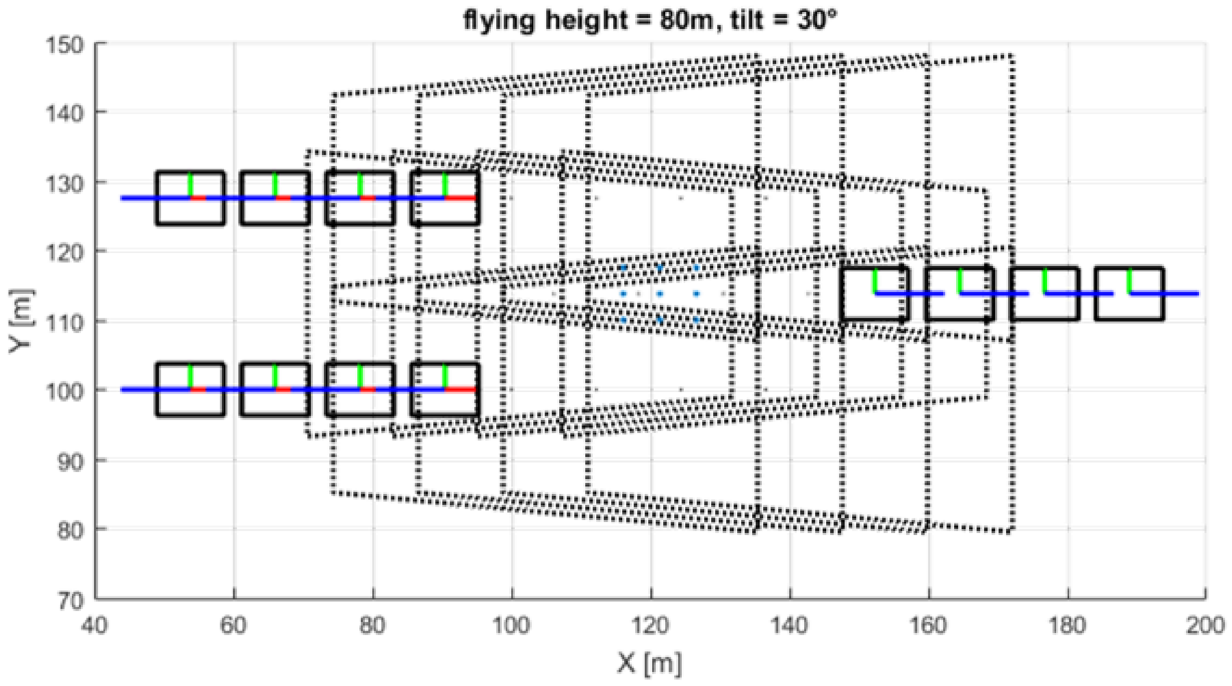
1. Write a program (MATLAB) that will simulate a small UAS photogrammetry mission
2. Perform bundle adjustments on the outputs of this program at varying tilts, focal lengths, and flying heights
   - Compare the statistics from each bundle adjustment to determine how much tilt (if any) can improve the accuracy of the bundle adjustment while allowing for an efficient mission
3. Create mission planning guidelines that best balance camera orientation, exposure settings, and flight time
4. Collect data for quantitative (checkpoint errors), qualitative (CHMs: oblique vs. lidar; nadir vs lidar), application (canopy ITD) analyses

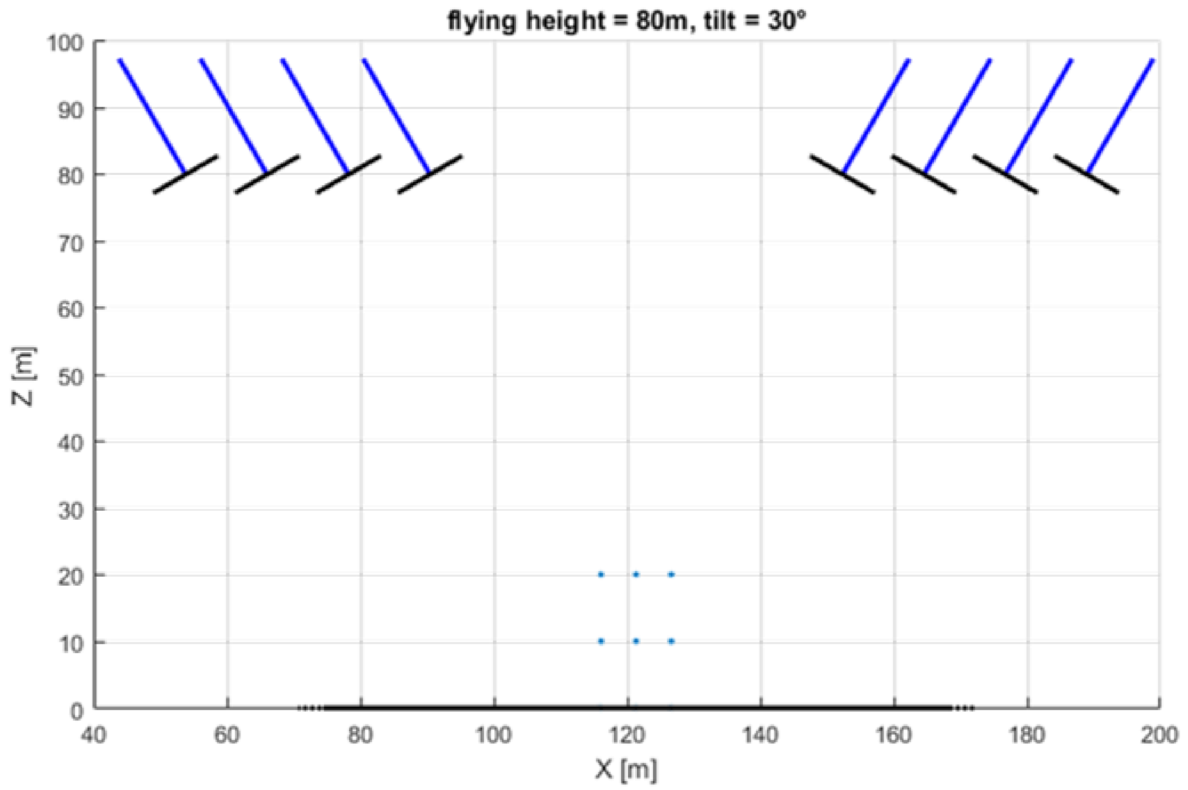
Mission simulation

- Input: endlap, sidelap, flying height, tilt
- Camera parameters of Canon EOS Rebel SL1 (f=25 mm and 40 mm)
- Three strips of four photos each over a 3x3x3 array of points
  - Photos = back-projections of array of 3D points + 0.5 pixel noise
- Goal: virtual images from all 12 exposure stations; used as input for BA

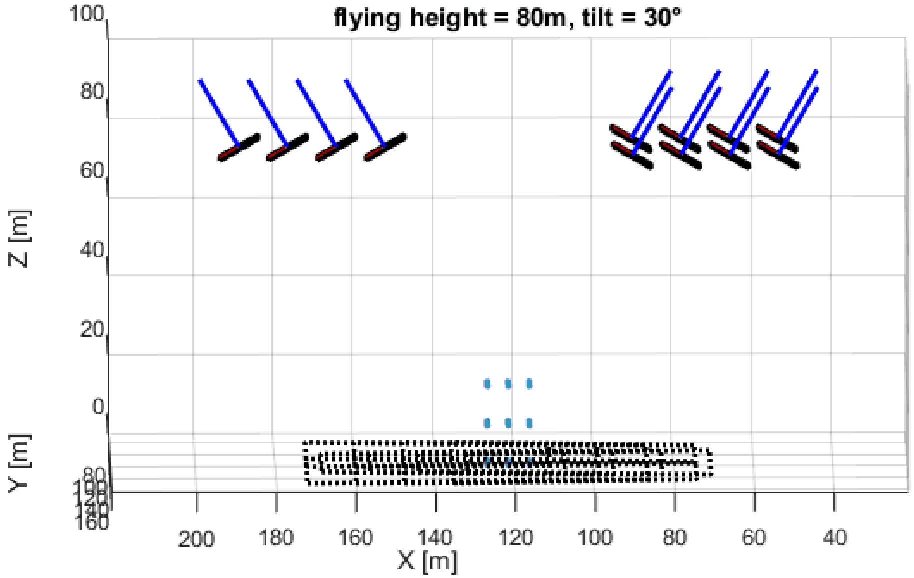


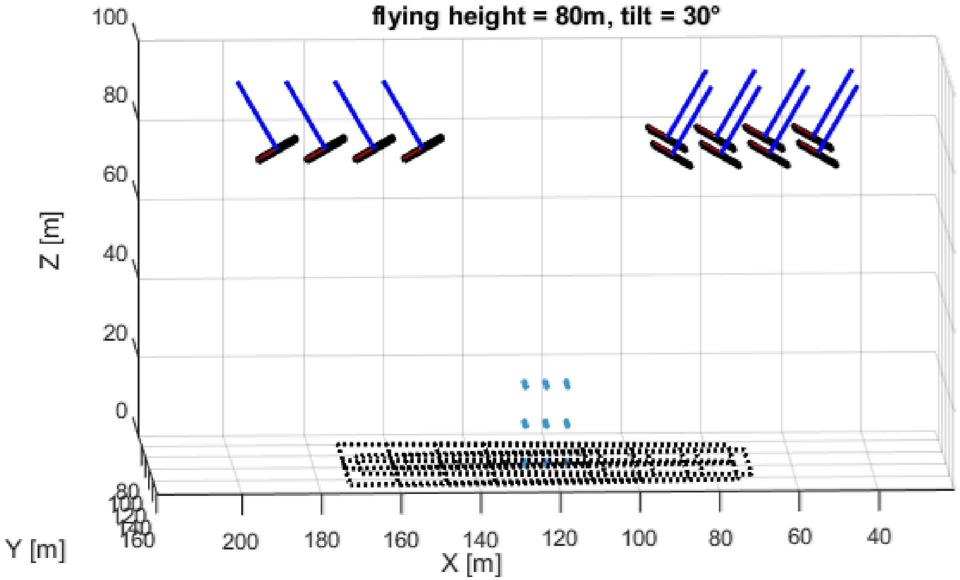
Mission simulation





Mission simulation





0/4.99 s

Mission simulation[3]

- Air base for *low* oblique images:

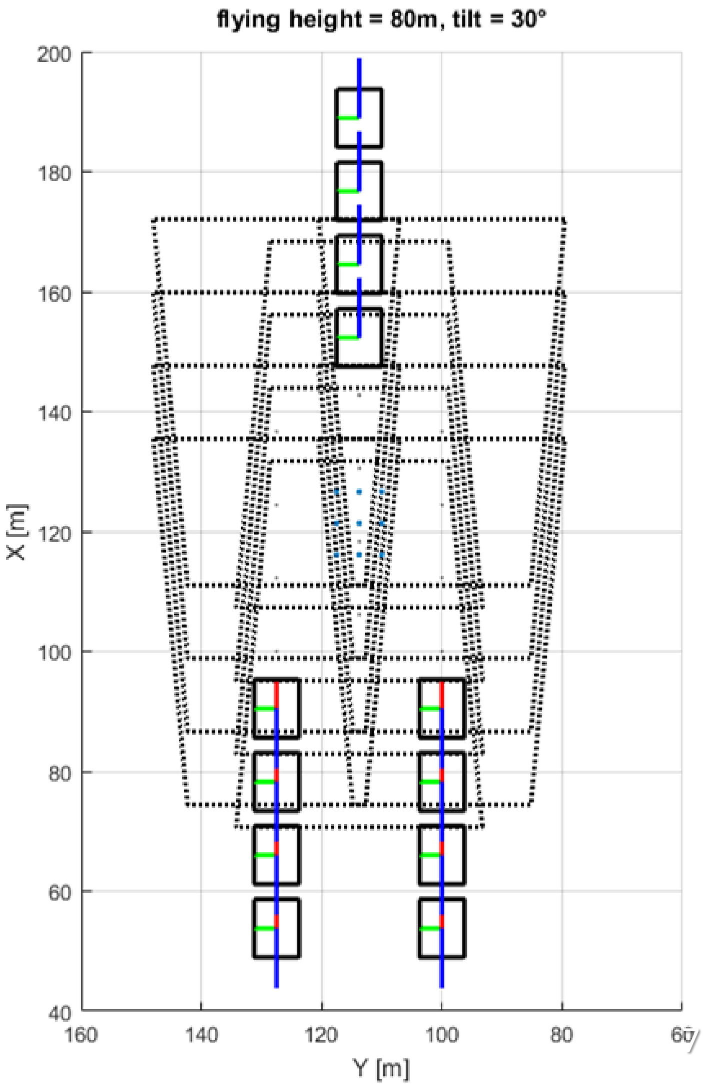
$$B = H'\left[\tan\left(t + \frac{\phi}{2}\right) - \tan\left(t - \frac{\phi}{2}\right)\right](1 - E)$$

This formula is weak because the domain of tangent is not continuous.

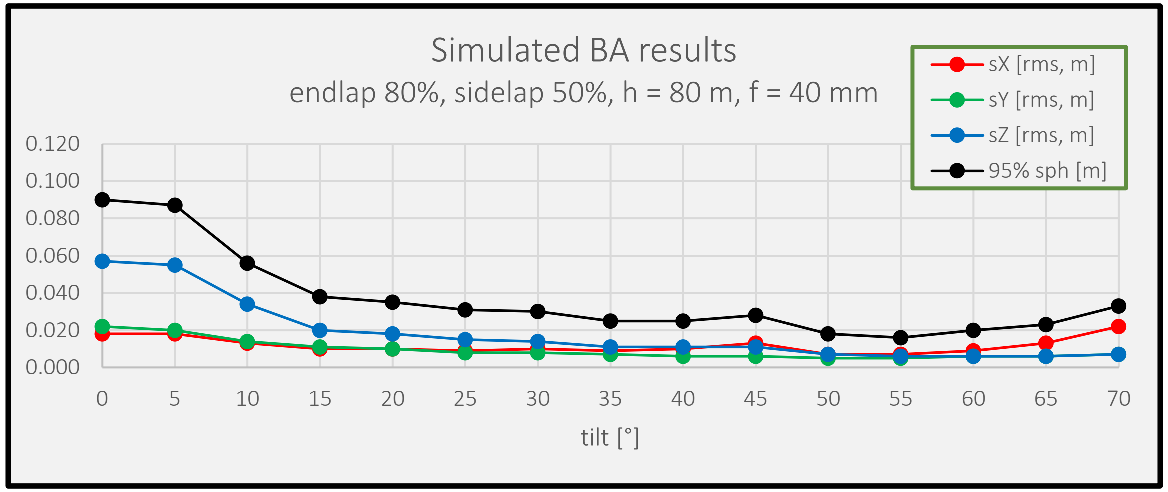
- Air width:

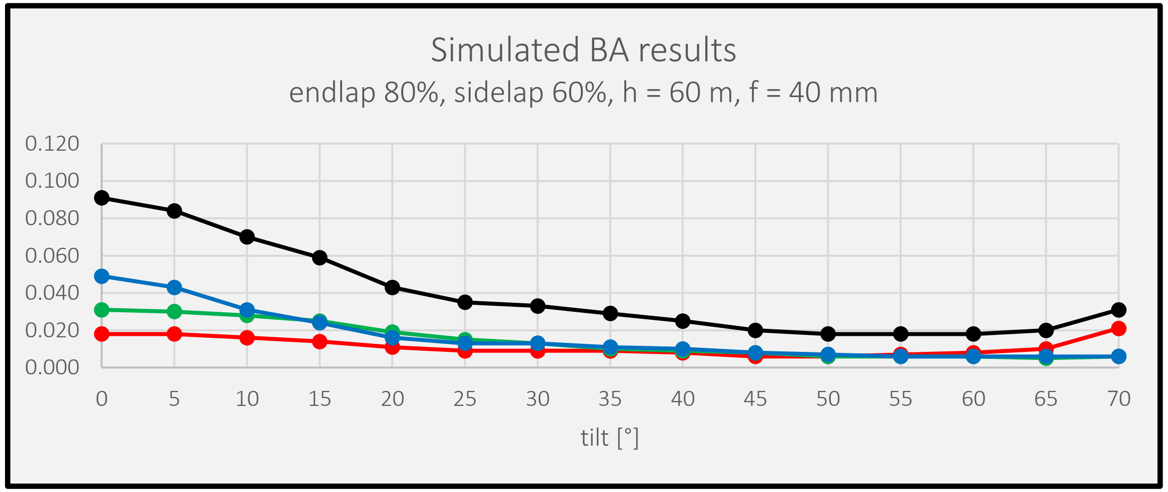
$$W = H'\frac{w}{f\cos t}(1 - S)$$

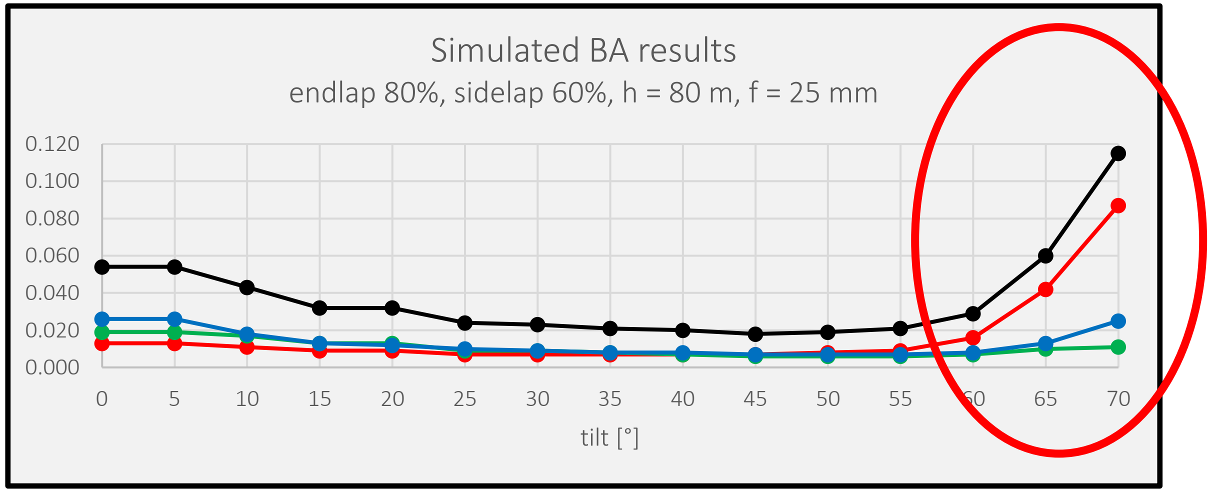
t = tilt, ϕ = FOV, w = format width, f = focal length
E = endlap percentage, S = sidelap percentage estimate*

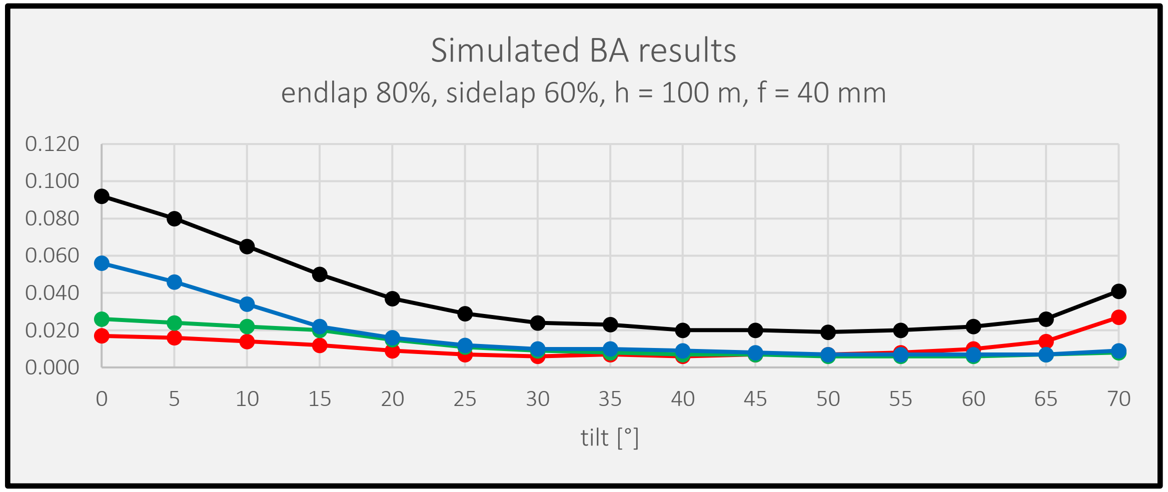


Simulated BA results[4]



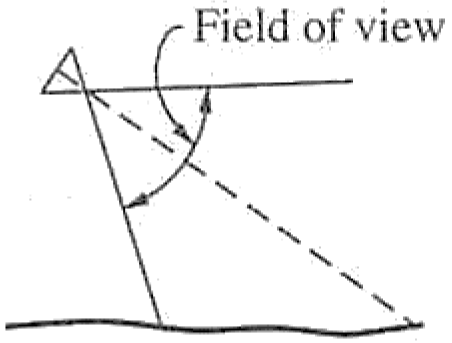




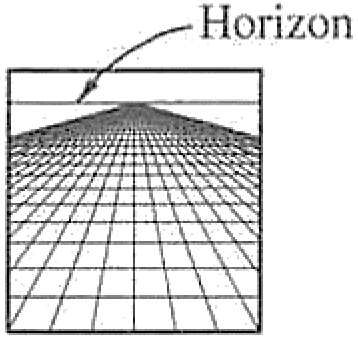


Simulated BA results

- The RMS of the standard deviations in X, Y, and Z, as well as the 95% spherical error, decreases as tilt increases (up to a point)
- RMS of stdev of Z decreases most rapidly as tilt increases, confirming the stronger geometry
- RMS of stdev of X (i.e., direction of travel) begins to increase sharply as tilt (and subsequently airbase) gets too long
- High oblique images (circled in red, previous slide) cause RMS of s_X and subsequently 95% spherical error to rise sharply



High oblique



High oblique

GSD considerations

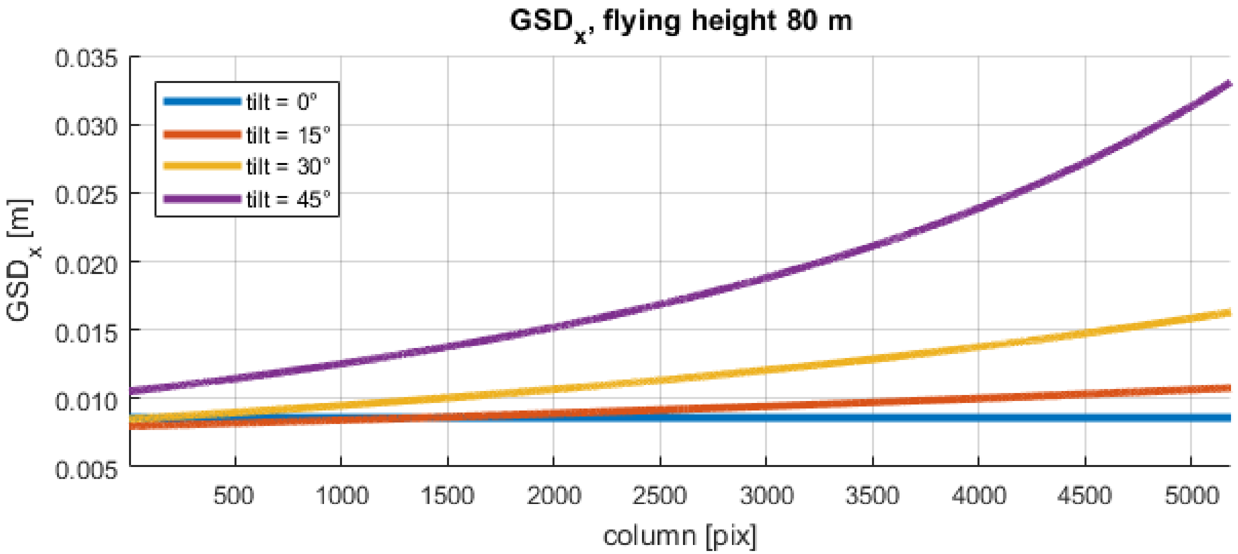
- With oblique photos, GSD is a function of tilt as well as pixel size and focal length[5]:

$$\mathrm{GSD}_{x,p} = H'\left[\tan\left(t + \mu_{p+1}\right) - \tan\left(t + \mu_p\right)\right]$$

$$\mu_p = \operatorname{atan}\left(\frac{p - m/2}{f}\right)$$

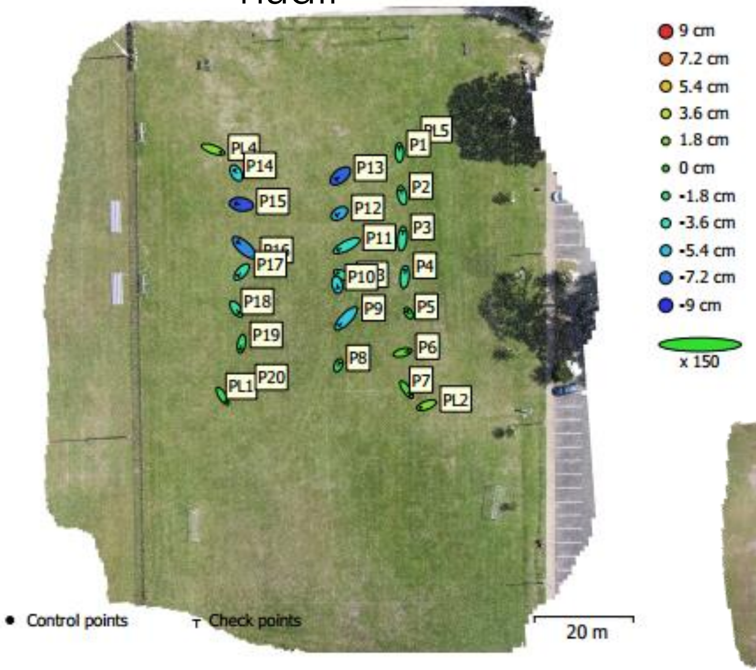
p = column $\quad m$ = no. of columns

f = focal length [pix]

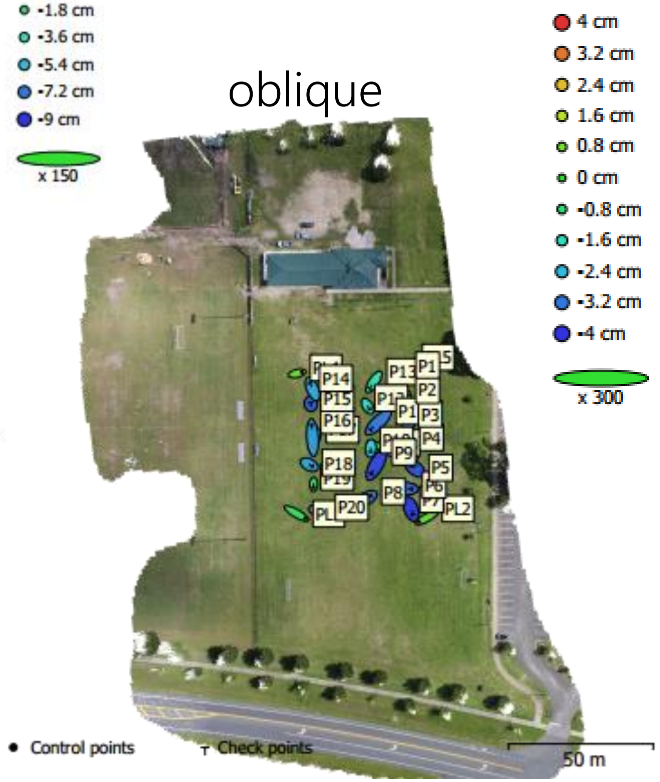


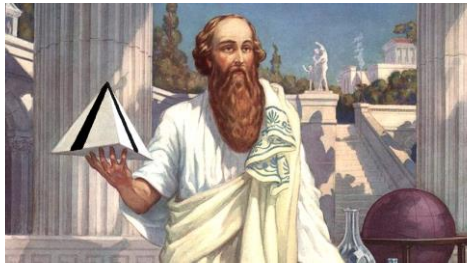
Quantitative study: Jonesville

nadir



oblique





Shapiro-Wilk

- $p_n = 0.17;\ p_o = 0.68$
- do not reject H_0 of normal distribution of errors

F-test for variance

- $F > F_{crit}\ (p = 0.0004)$
- Reject H_0: $s_n^2 = s_o^2$

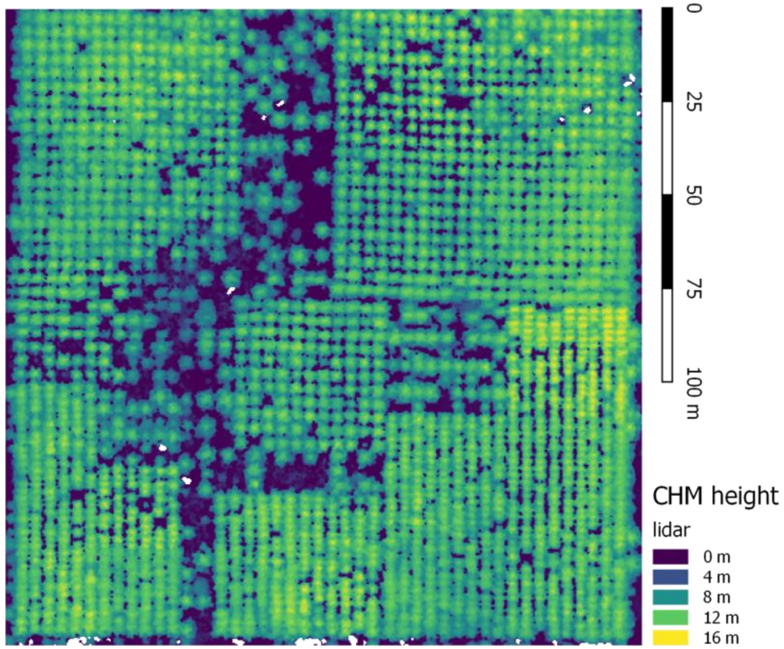
One-tailed, unequal variance t-test

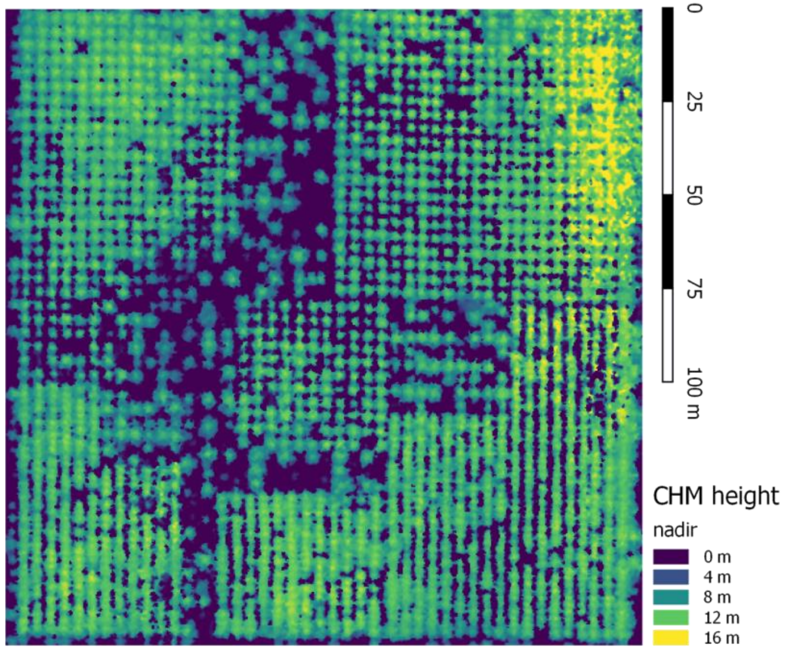
- $t > t_{crit}\ (p = 0.0360)$
- Accept H_A: $\bar{x}_n > \bar{x}_o$

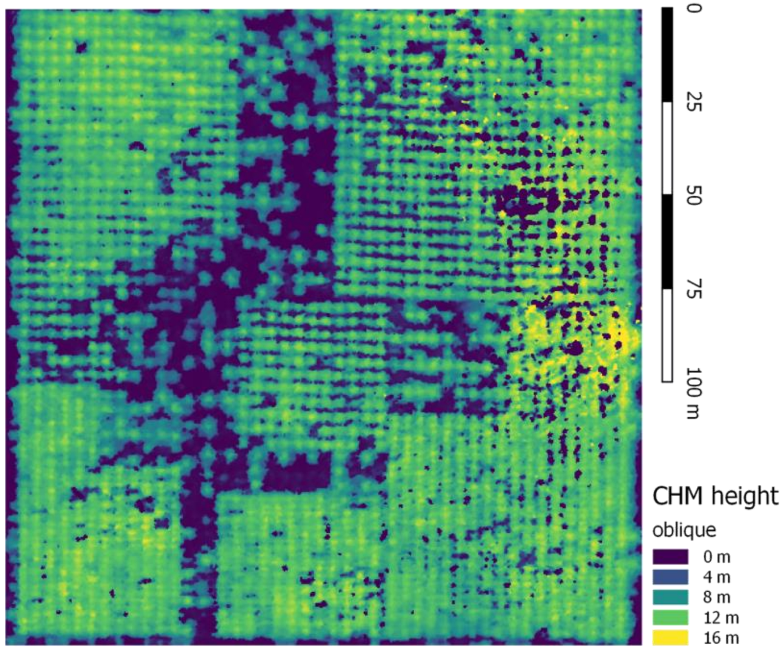
Total error [cm]		
Chkpt	Nadir	Oblique
P1	2.5	1.7
P2	3.0	1.5
P3	3.6	3.0
P4	3.3	2.9
P5	1.0	3.8
P6	1.9	3.7
P7	1.9	4.1
P8	1.9	3.5
P9	5.8	4.4
P10	4.8	2.3
P11	4.7	4.0
P12	5.9	1.9
P13	7.9	2.4
P14	4.9	3.1
P15	8.3	3.5
P16	7.2	4.1
P17	3.7	2.5
P18	3.2	2.8
P19	2.1	0.9
P20	1.3	3.0
Mean	**3.95**	**2.95**
Variance	**4.76**	**0.92**

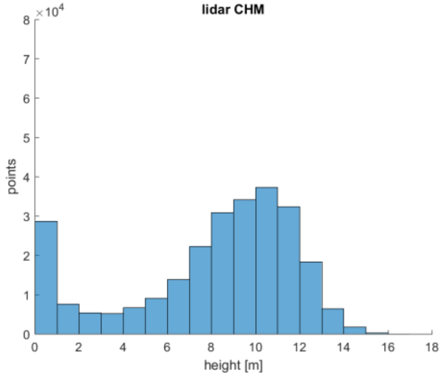
Qualitative study: Millhopper

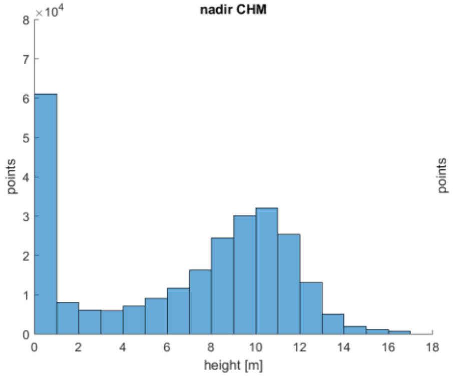
	CHM cell height [m]				
	lidar	nadir	oblique	nad-lidar	obl-lidar
mean	8.00	6.76	7.96	-1.24	-0.04
stdev	3.85	4.61	4.27	3.02	2.74

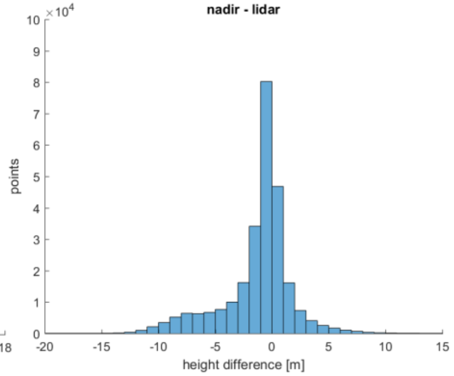


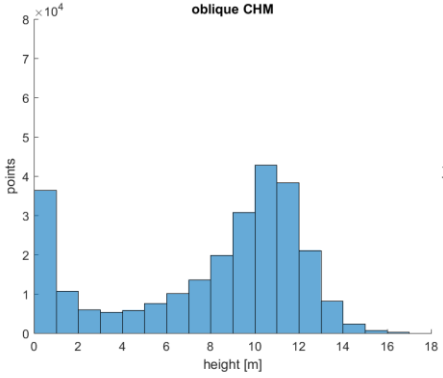


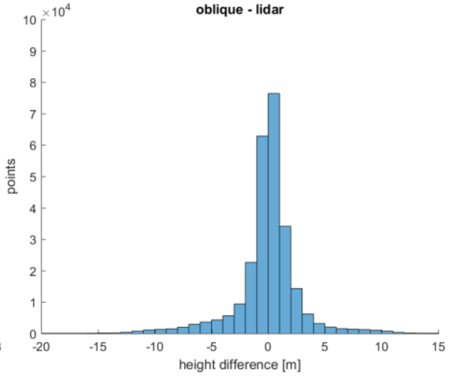












Application study: Millhopper

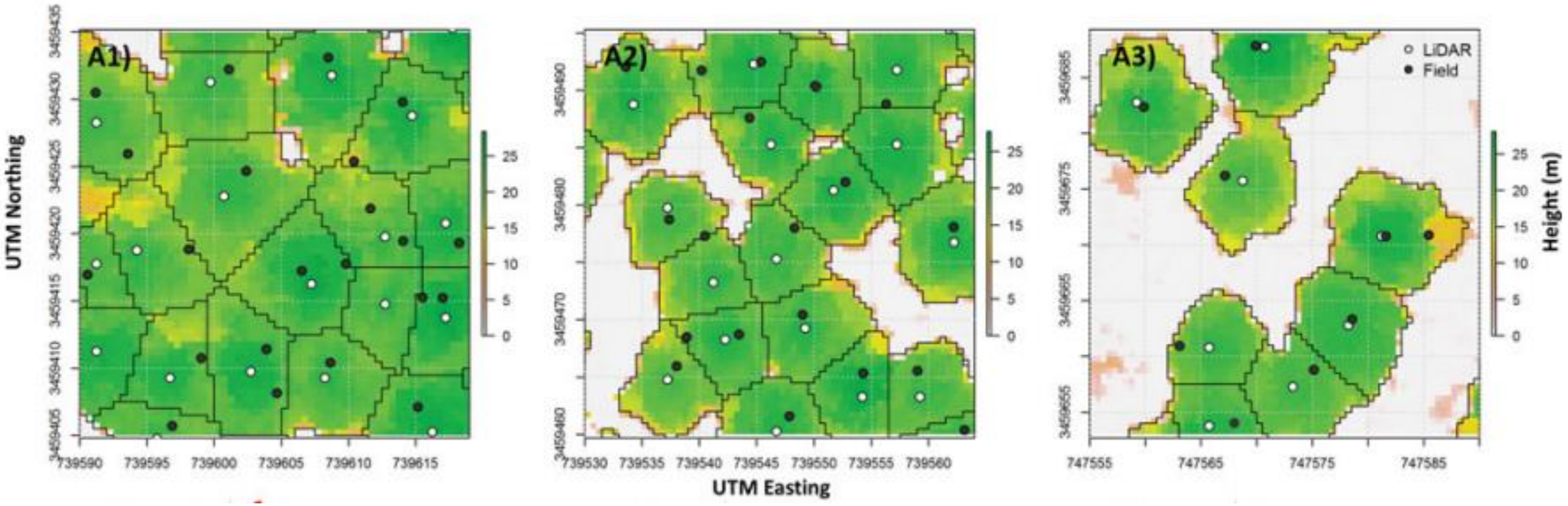
CHM	Inventory	Detected	FP	FN	TP	r	p	F
lidar	2199	2143	20	76	2123	0.96	0.99	0.98
nadir	2199	2086	52	165	2034	0.93	0.97	0.95
oblique	2199	2147	119	171	2028	0.92	0.94	0.93

$$r = \frac{TP}{TP + FN}$$

$$p = \frac{TP}{TP + FP}$$

$$F = 2\left(\frac{r \times p}{r + p}\right)$$

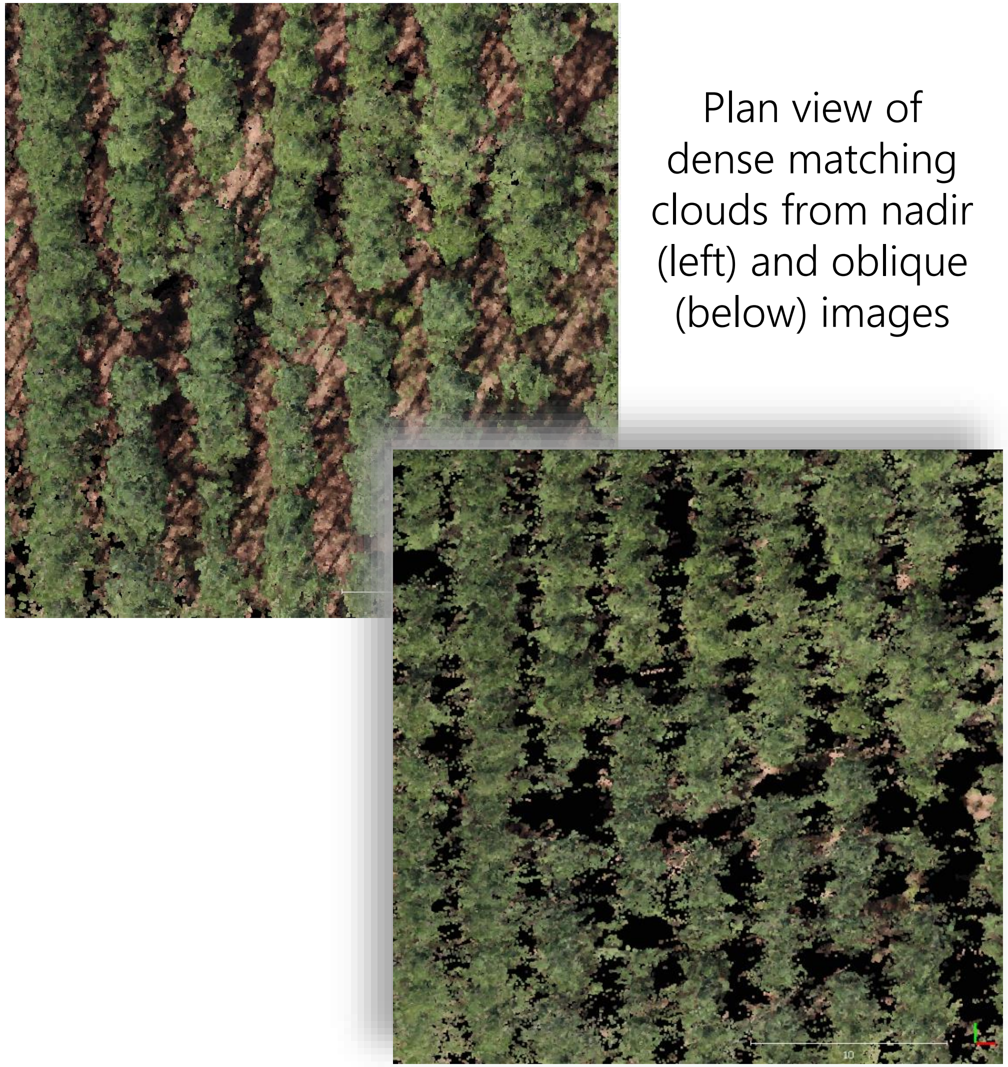
Mohan *et al.*, 2017



Canopy-based ITD (local maxima method) (Silva *et al.*, 2016; Silva *et al.*, 2017)

Discussion

- Likely two types of errors happening simultaneously:
    - Nadir data underestimates at edge of canopy
    - Oblique data showing “false positive” effect in direction of optical axes, inclined in direction of flights
- Beneficial for height estimation at CHM level, deleterious effect for ITD



Plan view of dense matching clouds from nadir (left) and oblique (below) images