MAPPING THREATS TO AGRICULTURE IN EAST AFRICA: PERFORMANCE OF MODIS DERIVED LST FOR FROST IDENTIFICATION IN KENYA'S TEA PLANTATIONS

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SERVIR

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INTRODUCTION

- Increased prevalence of weather related hazards in eastern Africa including drought, floods, hail and frost threatening agricultural productivity.
- Kenya is heavily dependent on agriculture for economic growth (FAO 2013)
  - Agriculture contributed 23.5% and 21.5% of GDP in 2009 and 2010 respectively
  - Employment to half a million households of smallholders and 150,000 on large tea estates
- Tea growing in Kenya depends on stability of the weather (Cheserek et al 2015)
  - Weather is unpredictable
  - Frost has contributed 30% of tea leaf losses
  - Drought has contributed 14-30%
  - The losses are experienced between January and march - frost and dry season

"Inadequate knowledge and lack of early warning systems"

…CONT… INTRODUCTION

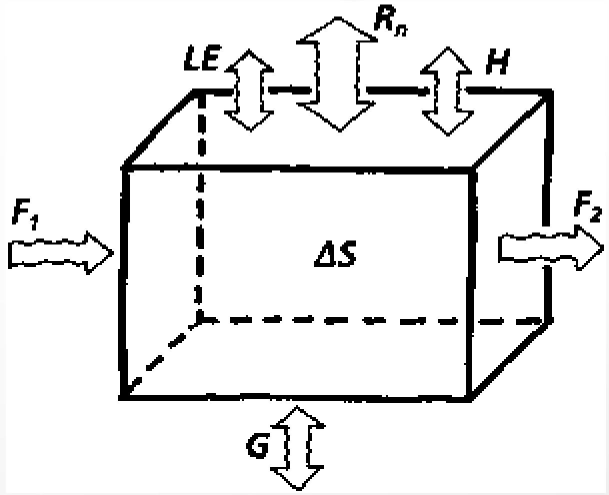
- Frost has widely been defined in relation to the occurrence of temperatures of 273K (0^0C) or below, as measured within an appropriate weather shelter at a height of between 1.25 and 2.0 m from the ground surface (Snyder, R. L. et al 2005)
- Casually used to describe a meteorological condition involving low temperatures when plants are damaged
- Two categories of frost (Richard L. Snyder, 2000)
  - Advective
  - Radiative
- Radiative frost is most common in Kenya

FROST MITIGATION

- During a radiative frost night, falling temperatures result from:
  - Decreasing sensible heat of the air when:
    - The sum of
      - Sensible heat transfer downward from the air,
      - Soil heat flux upward to the soil surface, and
      - Transfer of heat within the vegetation to the plant surface
    - Is insufficient to
  - Replace the sensible heat content losses resulting from net radiation energy losses
- Therefore,
- Goal of any frost damage prevention mechanism is to manipulate energy transfer

  processes of:
  - Conduction through the soil to the surface,
  - Horizontal convection through the air and
  - Downward radiation from the sky to reduce the net energy loss

  "Any factor that affects these processes affects frost occurrence"



net radiation (Rn),
sensible heat flux (H),
latent heat flux (LE),
soil heat flux or conduction (G),
sensible and latent energy advection in (F1) and out (F2),
and energy storage in the crop (DS)

(Snyder, R. L. et al 2005)

FROST ASSESSMENT IN KENYA

- Based on mapping and classifying MODIS LST values into levels to represent light to severe frost risk.
  - Proven useful in indicating areas affected by frost
  - Concern on underestimation of ligher frosts
- Basing on MODIS LST alone, frost tend to occur at higher LST ranging 260K to 288K (-13^{0}C to 15^{0}C).
- While this range may be calibrated to indicate frost occurrences, the occurrence of these temperatures does not always correspond to frost occurrence and crop damage.
- Studies have indicated frost occurrence to be a combination of microclimatic factors including topography, weather conditions and land surface characteristics affecting night minimum LST which is the major determinant (Blennow, K, 1998; Lindkvist, L 2000).

MAIN GOAL AND RESEARCH QUESTIONS

- **The main purpose of this research is to establish how well MODIS derived LST data, specifically the MYD11A1 product, performs in discriminating between frost and no frost locations.**

The research questions are:

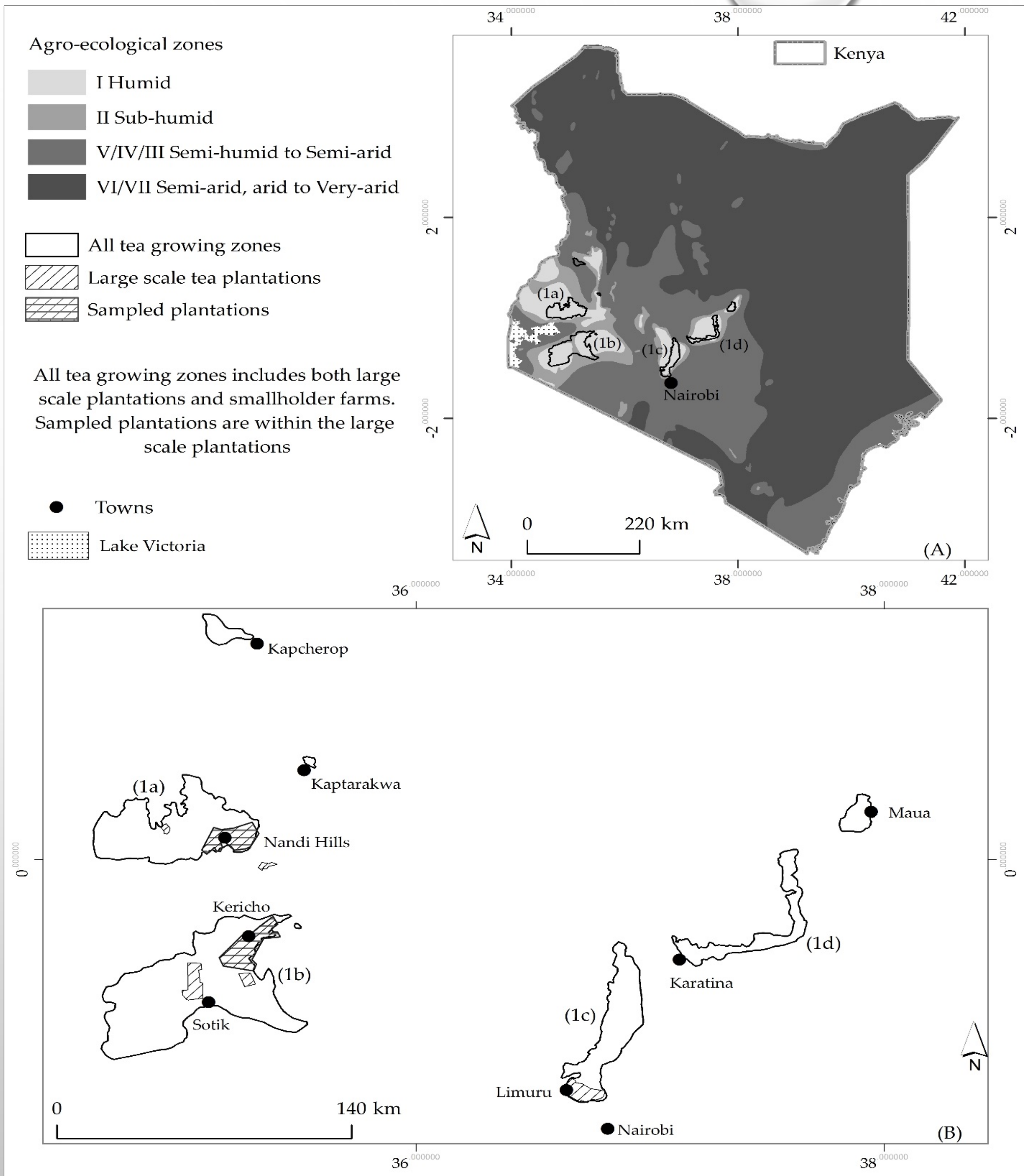
1. What is the accuracy of the currently operational frost identification model and the LST thresholds in defining frost occurrence LST in the Kenyan tea zone?
2. What is the overall performance of MODIS derived LST product in discriminating between frost and no frost zones within the Kenyan tea zone?
3. What is the role of remotely sensed data in facilitating agricultural monitoring in regions with sparse network of ground observation stations?

STUDY AREA

- Focus on the tea growing regions of Kenya.
- Sampling frame - all major tea plantations

- As of the year 2010;
- Total tea growing area 171,916 hectares
  - Large plantation farms 56,893 hectares
  - Smallholder farms 115,023 hectares

- The sampled farms are about;
  - 30 % of all the tea growing area
  - 60% of the sampling frame.

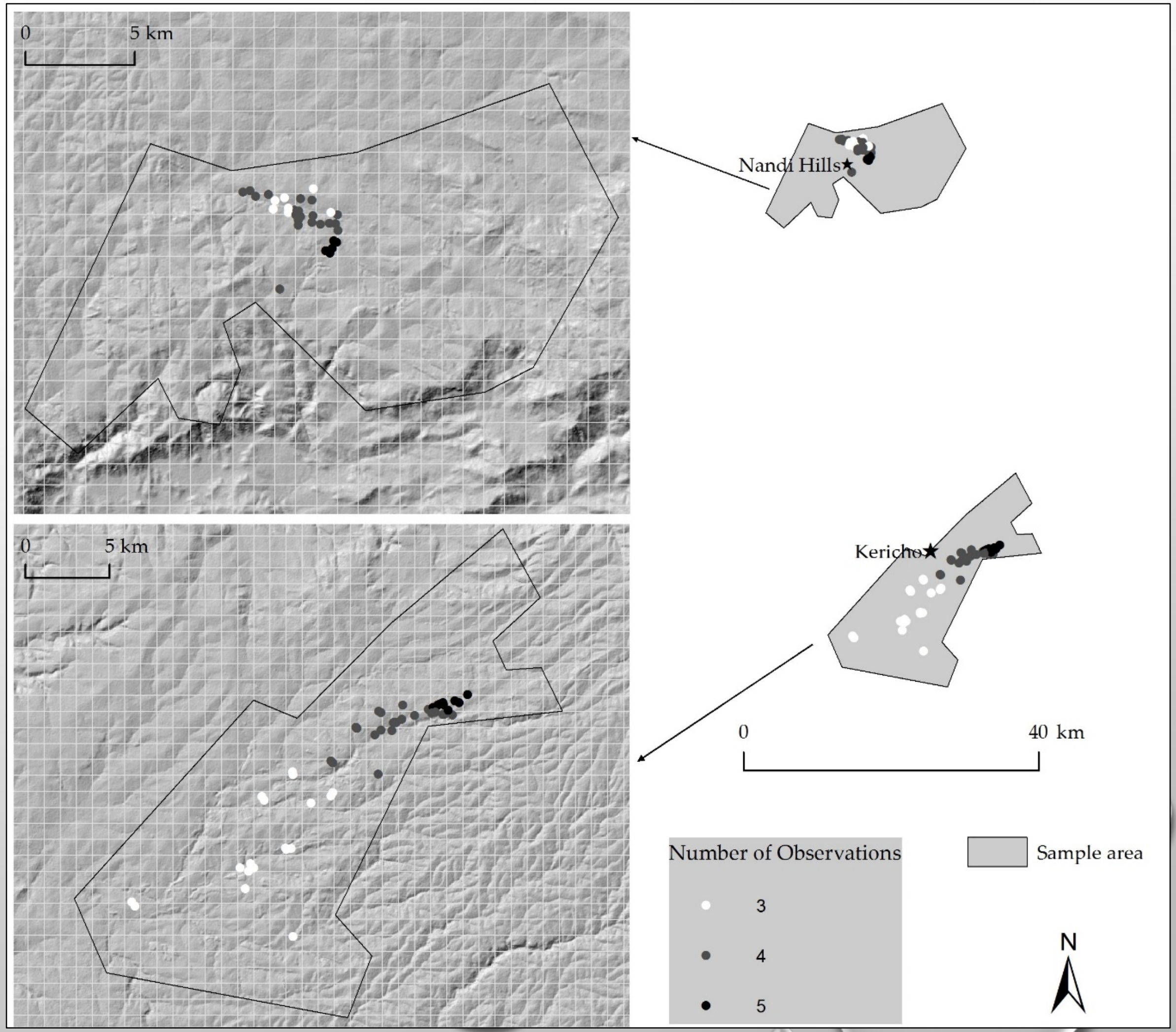


DATA

1. Frost and No frost observations

Not all collected points were used

	Total Observations	Used Observations
Frost	215	190
No frost	121	92
	336	282



2. MODIS derived LST

- Aqua satellite
- Daily night product MYD11A1 LST
- 1km spatial resolution
- 1:30 am equatorial overpass time

METHODS

- Frost likelihood categories were reclassified into two groups:
  - Frost
  - No frost.
- 6 different cutoff thresholds were tested.
- Depending on the cutoff threshold, frost locations were coded as 1 and no frost was coded 0.

<table>
<tr><td colspan="2"></td><td colspan="6">Reclassified thresholds</td></tr>
<tr><td>MODIS LST</td><td>Frost Likelihood</td><td>Baseline</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>>288K</td><td>No Frost</td><td>No Frost</td><td rowspan="2">No Frost</td><td rowspan="3">No Frost</td><td rowspan="4">No Frost</td><td rowspan="5"><=273K=Frost
>273K=No Frost</td><td rowspan="5"><=278.5K=Frost
>278.5K=No Frost</td></tr>
<tr><td>284-288K</td><td>Minor Frost Pockets</td><td rowspan="4">Frost</td></tr>
<tr><td>281-284K</td><td>Moderate Frost</td><td rowspan="3">Frost</td></tr>
<tr><td>277-281K</td><td>Severe Frost</td><td rowspan="2">Frost</td></tr>
<tr><td><277K</td><td>Very Severe Frost</td><td>Frost</td></tr>
</table>

ACCURACY ASSESSMENT

Overall accuracy of each threshold

- "OVERALL ACCURACY $= (TP + TN)/(TP + TN + FP + F) = (TP + TN)/N$

Overall accuracy of MODIS LST

- RECEIVERS OPERATING CHARACTERISTICS (ROC) CURVE
  - Allows the threshold to vary and measures the changes in true and false positive fractions .
  - A roc curve is used as an estimate of overall performance of the predictor (MODIS derived LST) to discriminate between occurrence and non-occurrence and is described by the true positive rate (TPR) and the false positive rates (FPR)

  - $\mathbf{True\ Positive\ Rate\ (Sensitivity) = TP/TP + FN}$
  - $\mathbf{Specificity = TN\ /FP + TN}$
  - $\mathbf{False\ Positive\ Rate\ (1 - Specificity) = FP/FP + TN}$

RESULTS

Overall Accuracy of each Threshold

Threshold	Cutoff point (K)	True Positives	False Positives	True Negatives	False Negatives	Overall Accuracy
Baseline	288	190	92	0	0	67.38%
1	284	190	92	0	0	67.38%
2	281	190	98	4	0	68.79%
3	277	108	30	62	82	60.28%
4	273	84	26	66	106	53.19%
5	278.5	156	45	47	34	71.99%

RESULTS

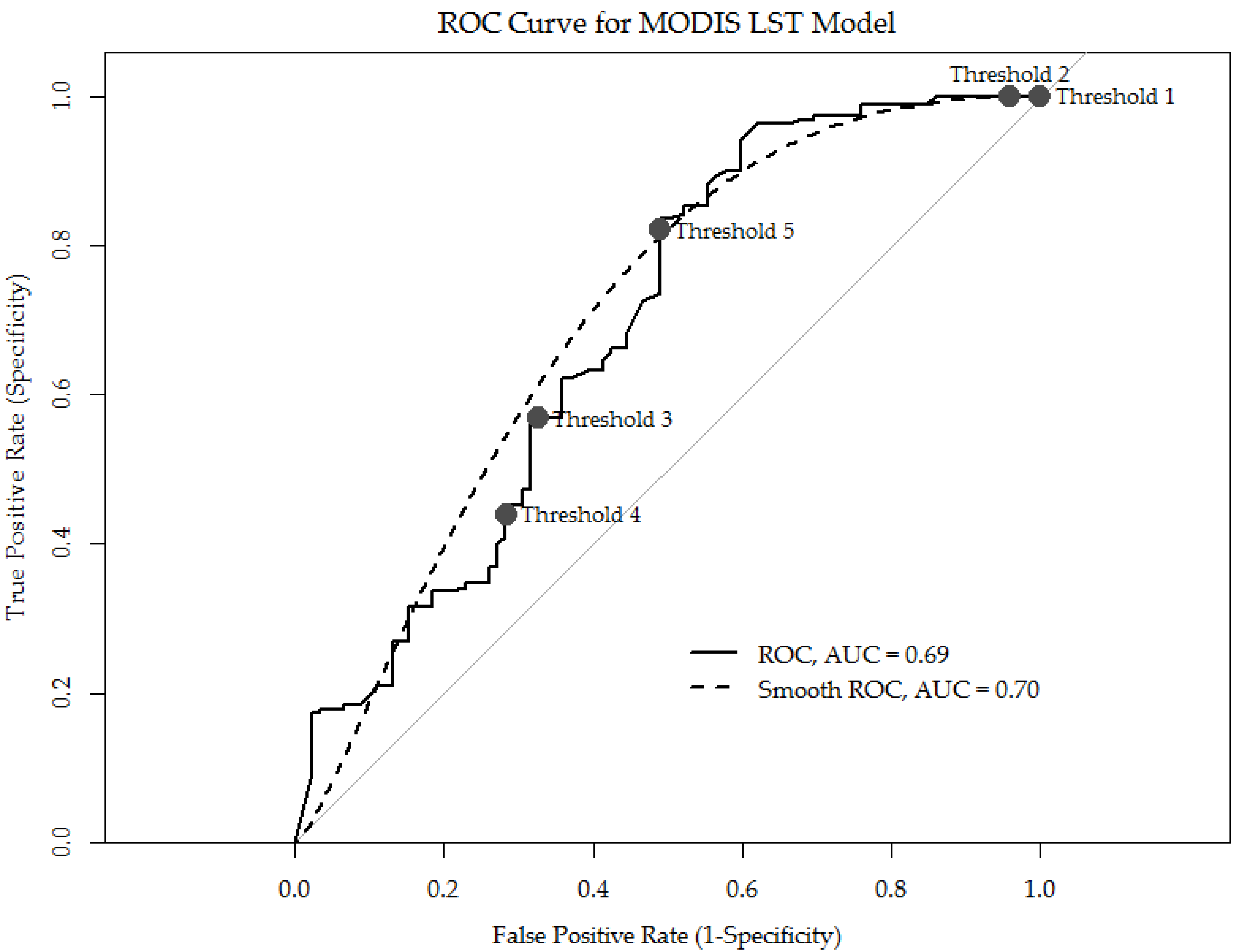
Overall Accuracy of MODIS derived LST

Threshold	Cutoff point (K)	Predicted Frost events (Count)	Predicted No Frost events (Count)	Sensitivity (True Positive Rate)	Specificity	1-Specificity (False Positive Rate)
Baseline	288	282	0	1	0	1
1	284	282	0	1	0	1
2	281	278	4	1	0.04	0.96
3	277	138	144	0.568	0.674	0.326
4	273	110	172	0.44	0.717	0.283
5	278.5	201	81	0.821	0.511	0.489

RESULTS

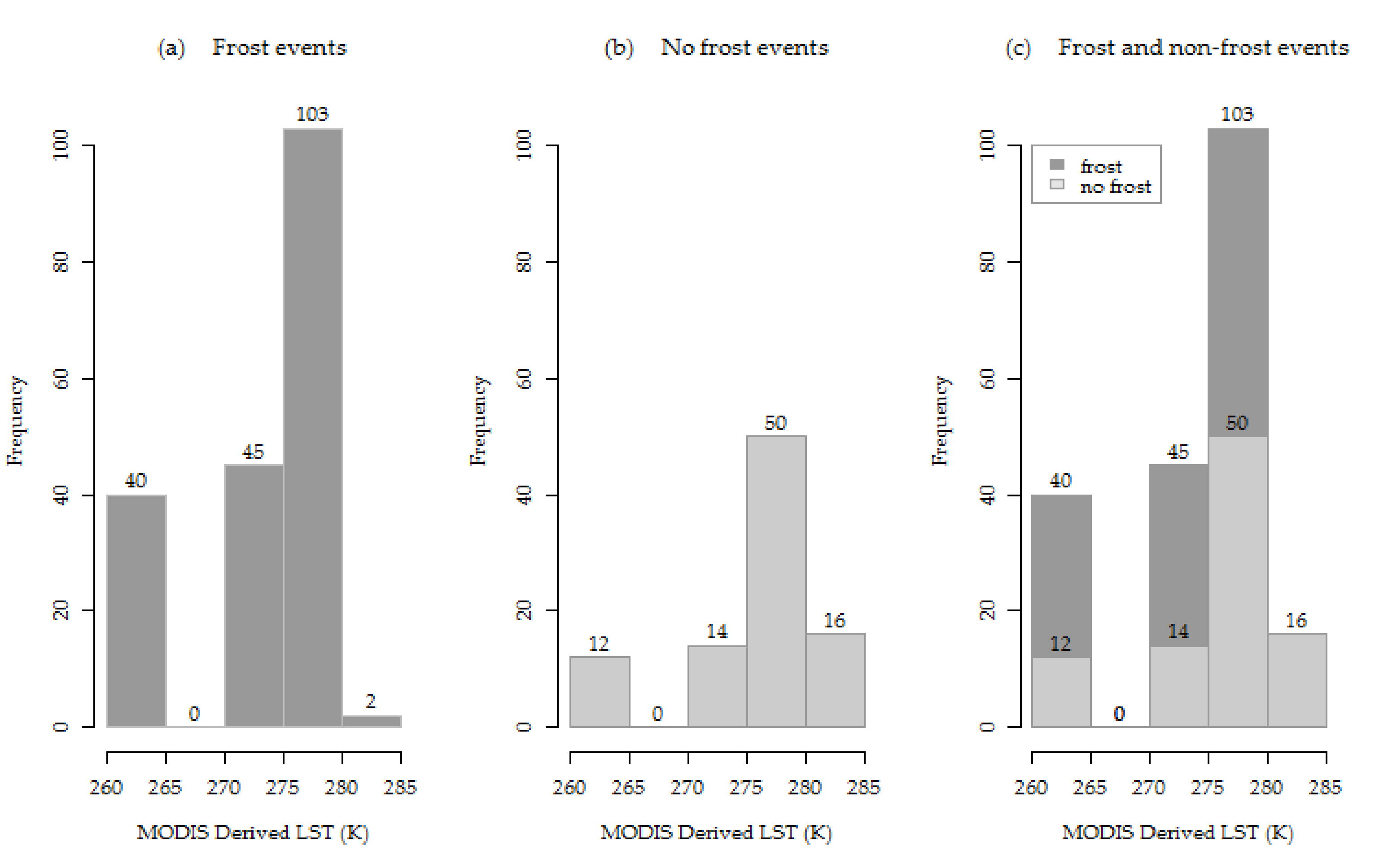
Overall Accuracy of MODIS LST

- Performance of 0.69 on a scale of 0.5 to 1
- A poor Performance
  - 1 - perfect performance
  - 0.5 - worst performance
- At 95% confidence level, an
  - AUC confidence interval of 0.63-0.77



SUMMARY OF FINDINGS

- Frost can occur at LST values higher than 273K
- MODIS LST may be useful in indicating frost zones
- MODIS LST cannot discriminate between frost and no frost with high accuracy



IMPLICATIONS

- MODIS derived LST may be used in conjunction with other variables to guide low cost farmers' decisions on:
  - Pruning tea bushes to avert further crop damage
  - Picking ready tea leaves to cut down on losses
- The findings inform further research on frost and tea
- Use of remote sensing based data in agricultural monitoring is illustrated.

POSSIBLE SOURCES OF UNCERTAINTIES

- Other factors affecting frost occurrence
- Possible sample and sampling errors
- Spatial variation of LST in mountainous areas
- Frost and no frost observations within single MODIS pixel
- Minimum LST and MODIS overpass times
- MODIS LST representation of on the ground LST

CONCLUSIONS

- MODIS LST alone is not a good predictor of frost occurrence
- Further research on characterization of frost occurrence in this region is strongly recommended in order to improve the accuracy of frost prediction.

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REFERENCES

1. Herrero, M.; Ringler, C.; Van De Steeg, J.; Koo, J.; Notenbaert, A.; Thornton, P.; Zhu, T.; Bryan, E.; Omolo, A. *Climate variability and climate change and their impacts on Kenya's agricultural sector*; International Livestock Research Institute. Nairobi, Kenya, 2010.
2. Huho, J. M.; Mugalavai, E. M. The Effects of Droughts on Food Security in Kenya. *Int. J. Clim. Chang. Impacts Responses* **2010**, *2* (2), 61–72.
3. Ochieng, J.; Kirimi, L.; Mathenge, M. Effects of climate variability and change on agricultural production: The case of small scale farmers in Kenya. *NJAS - Wageningen J. Life Sci.* **2016**, *77*, 71–78.
4. Cheserek, B. C.; Elbehri, A.; Bore, J. Analysis of links between climate variables and tea production in the recent past in Kenya. *Donnish J. Res. Environ. Stud.* **2015**, *2* (2), 5–17.
5. Snyder, R. L.; de Melo-Abreu, J. P. *Frost protection: fundamentals, practice, and economics*; Food and Agriculture Organization of the United Nations: Italy, Rome, 2005; Vol. 1.
6. Richard L. Snyder. *Principles of Frost Protection*; University of California, Davis, 2000. Available online:http://biomet.ucdavis.edu/frostprotection/Principles%20of%20Frost%20Protection/FP005.html (accessed on 10 11 2016).
7. Lindkvist, L.; Gustavsson, T.; Bogren, J. A frost assessment method for mountainous areas. *Agric. For. Meteorol.* **2000**, *102*, 51–67.
8. Yu, W.; Ma, M.; Wang, X.; Geng, L.; Tan, J.; Shi, J. Evaluation of MODIS LST products using longwave radiation ground measurements in the northern arid region of China*Remote Sens.* **2014**, *6* (11), 11494–11517.

THANK YOU