Estimating surface energy fluxes in Arctic ecosystems using a thermal-based remote sensing model

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Outline

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1. Introduction

- Alaska's landscape, largely dominated by tundra and boreal forest, is witnessing unprecedented changes in response to climate warming ➔ acceleration of the hydrological cycle.
- Quantifying the surface energy balance and its spatio-temporal trends is key to understanding the processes and feedbacks responsible for significant changes in hydrology and vegetation in Alaska's Arctic and sub-Arctic regions.

Credits: Rudi Gens, ASF

Credits: David Wright, USFS

Credits: ADF&G

2. Project aims

NASA EPSCoR grant*: "Estimating Spatio-Temporal Variability in Evapotranspiration in Interior Alaska Using Field Measurements, Modeling and Remote Sensing"*

NASA EPSCoR RID grant: "*Estimating year-round surface energy fluxes in Alaska Arctic and sub-Arctic watersheds through remote sensing and field measurements*"

AIMS:

a) Implement a two source energy balance model for summer and snow conditions based on remote sensing data to map energy fluxes at local and regional scales in winter and snow-melting phase.

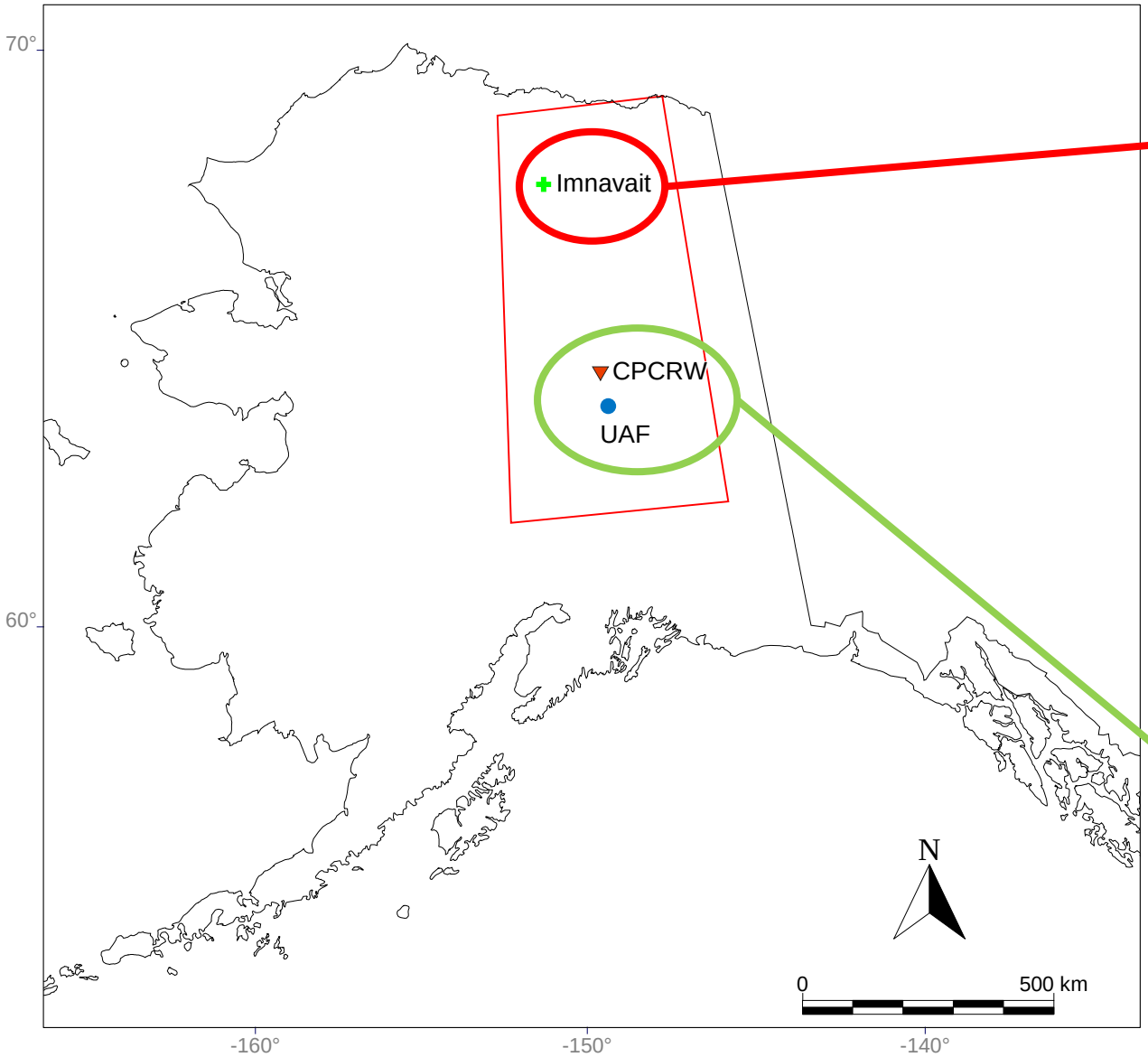
b) Validate modeled energy fluxes with in situ flux tower data.

c) Assess year-round spatio-temporal dynamics of energy fluxes in Arctic and sub-Arctic environments.

Credits: Toolik field station, UAF

Credits: UAF project team

3. Study area: Cal/Val sites in Alaska

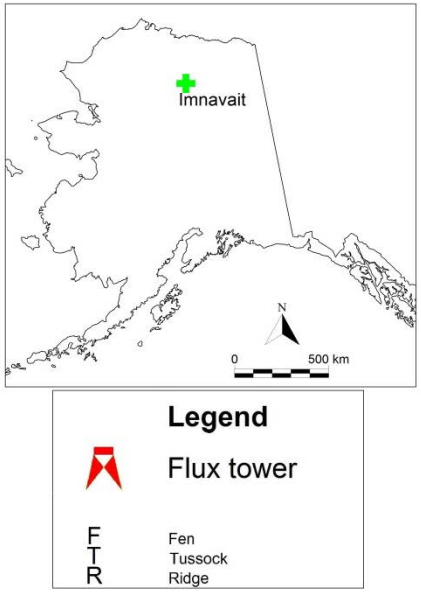


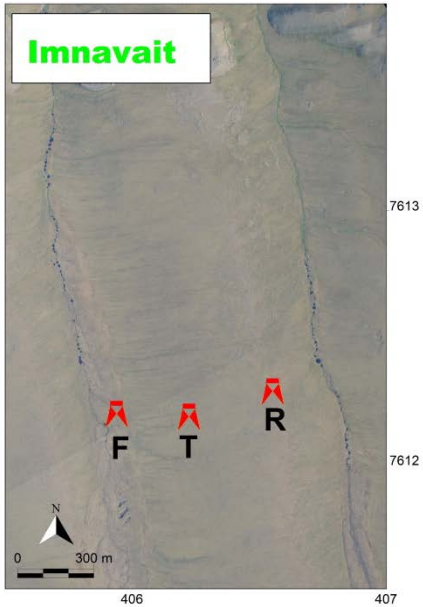
Arctic tundra ➔
AON tundra sites

sub-Arctic boreal forest ➔

UAF (black spruce) and CPCRW (birch)

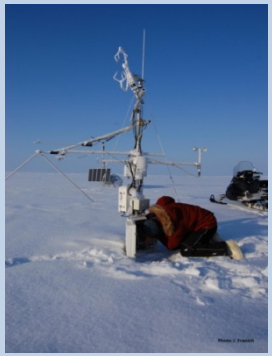
3. Study area: AON Imnavait Creek





Ridge tower (R)

The Ridge tower sits atop a broad dry ridge at the top edge of the watershed boundary in a heath tundra ecosystem dominated by Dryas spp, lichen, and dwarf shrubs.



Fen tower (F)

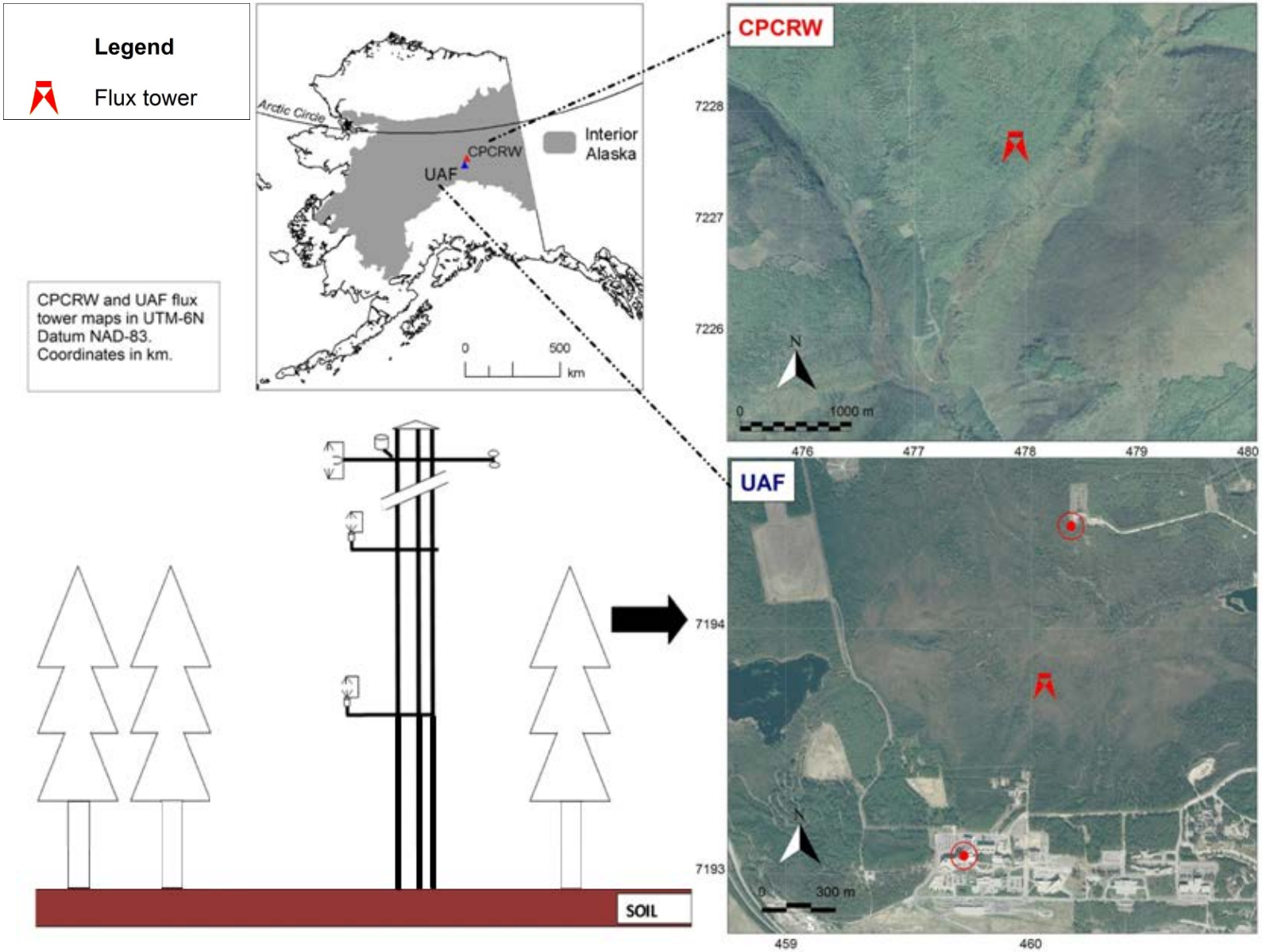
The Fen tower is located in the valley bottom in a wet sedge ecosystem, which includes *Eriophorum angustifolium* and dwarf shrubs such as *Betula nana* and *Salix* spp.

Tussock tower (T)

The Tussock tower is located midslope in a moist acidic tussock tundra ecosystem, dominated by the tussock-forming sedge *Eriophorum vaginatum*, *Sphagnum* spp., and dwarf shrubs such as *Betula nana* and *Salix* spp.

Text and photos from http://aon.iab.uaf.edu/imnavait

3. Study area: black spruce (UAF) and birch (Caribou Poker Creek Research Watersheds)



3. Study area: UAF north campus site

Needleleaf evergreen forest ➔ "flat" area

Overstory:

Black spruce (*Picea mariana*)

➔ cover: ~60%

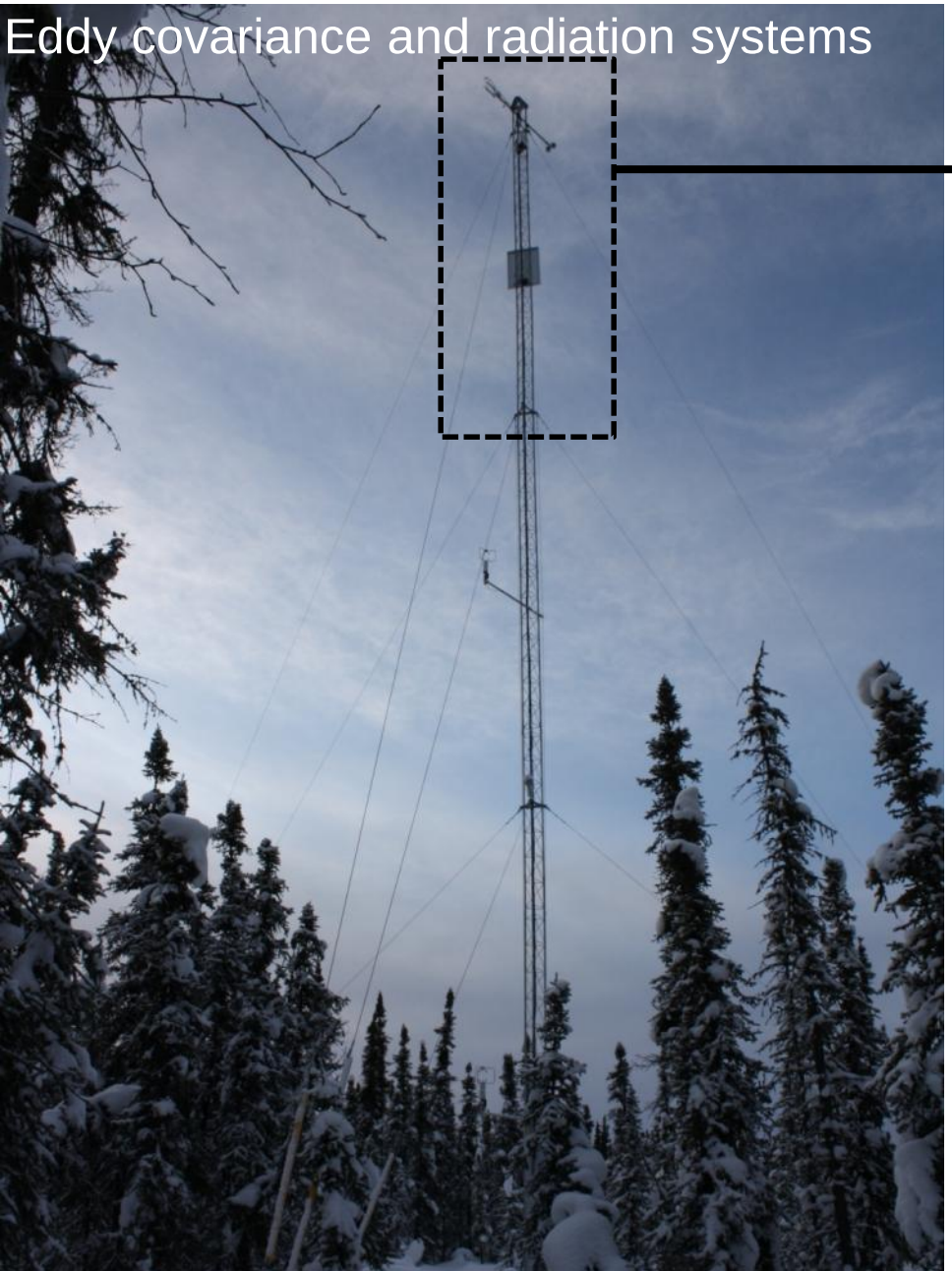
➔ mean tree height: ~5 m

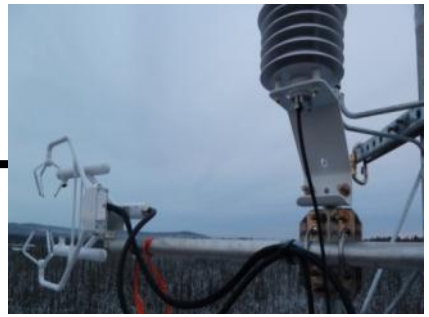
Understory:

➔Small shrubs: *Betula nana*, *Ledum palustre, Vaccinium* sp.

➔Moss layer: *Sphagnum* sp.

3. Study area: UAF north campus site





Canopy Flow Sensors at 24 m: Sonic anemometer and gas analyzer, net radiation and air temperature.

3. Study area: Caribou Poker Creek Research Watershed

Deciduous forest ➔
"hilly" area

Overstory:

Mainly paper birch (*Betula neoalaskana*)

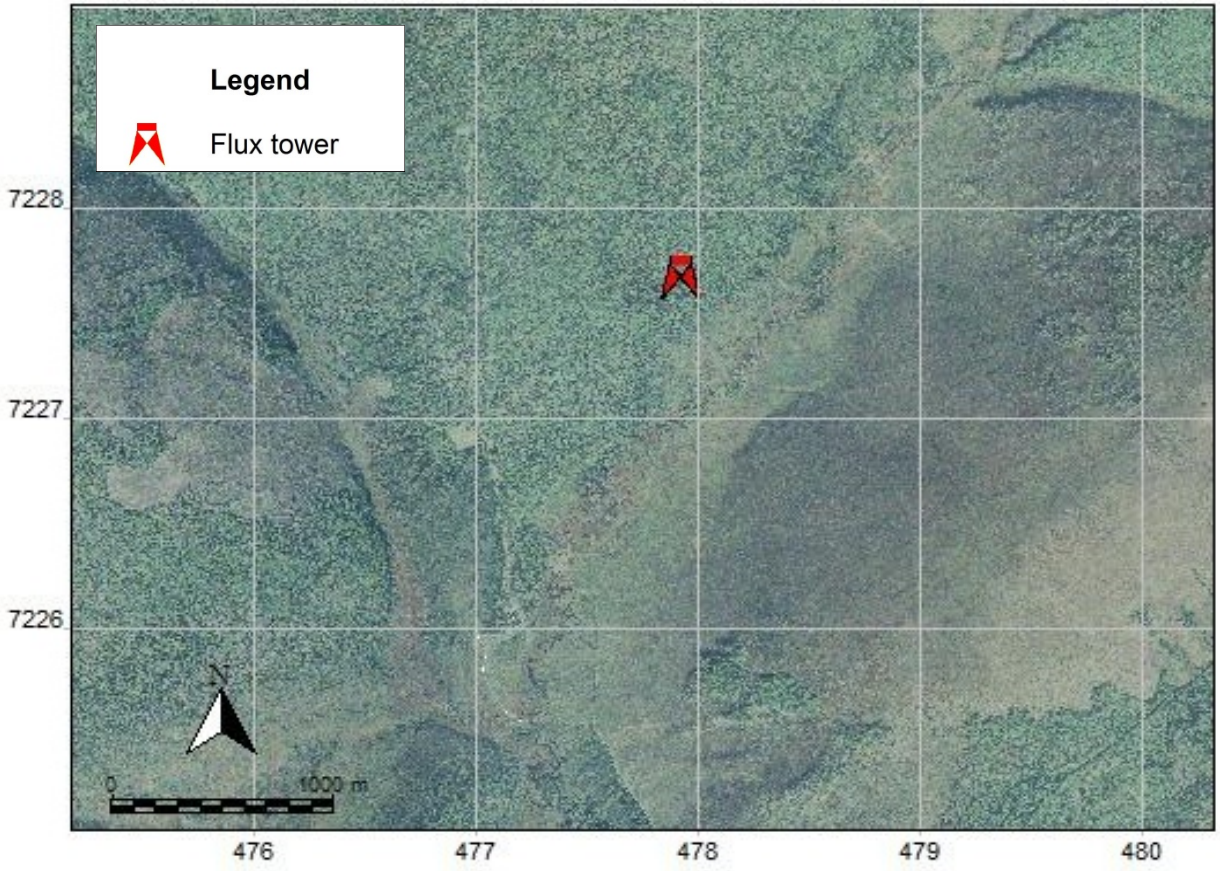
➔ cover: ~85%

➔ mean tree height:~18m

Understory:

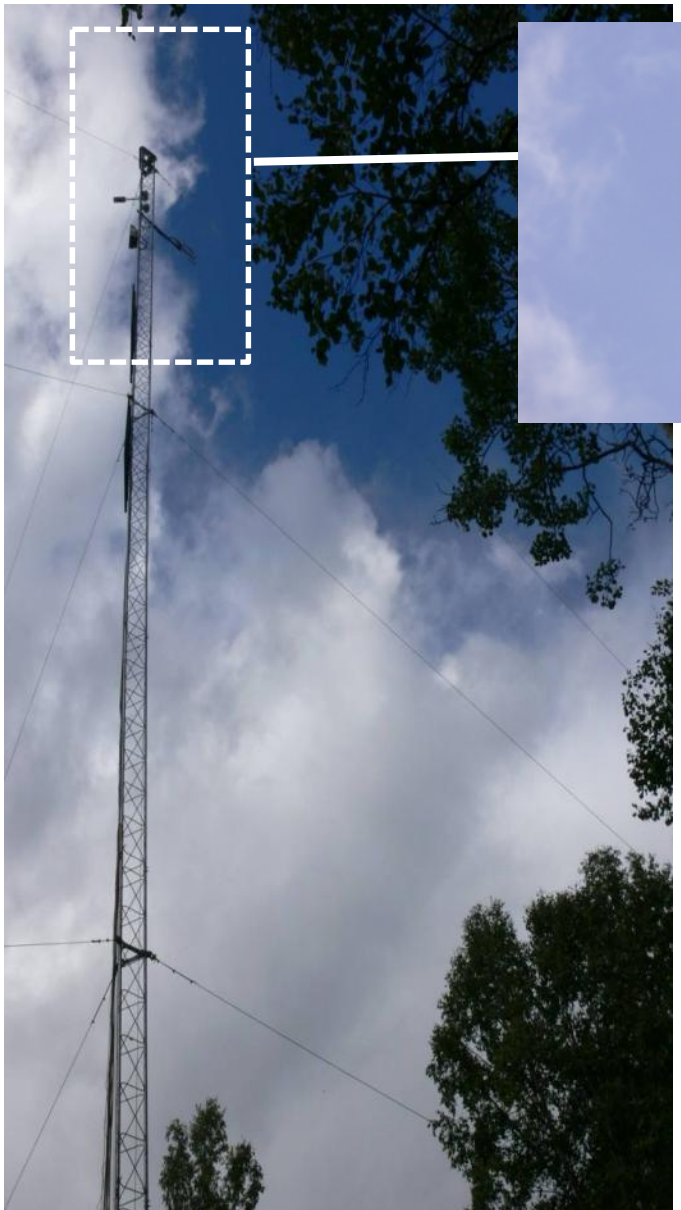
➔Small shrubs: *Ledum palustre*, *Vaccinium* sp.

➔Moss layer: *Sphagnum* sp.



3. Study area: Caribou Poker Creek Research Watershed

Eddy covariance and radiation systems

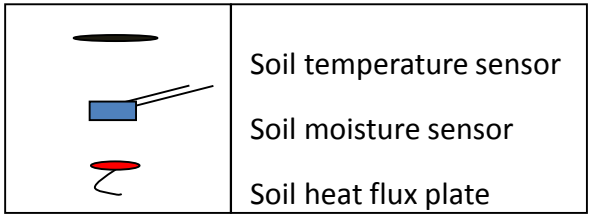


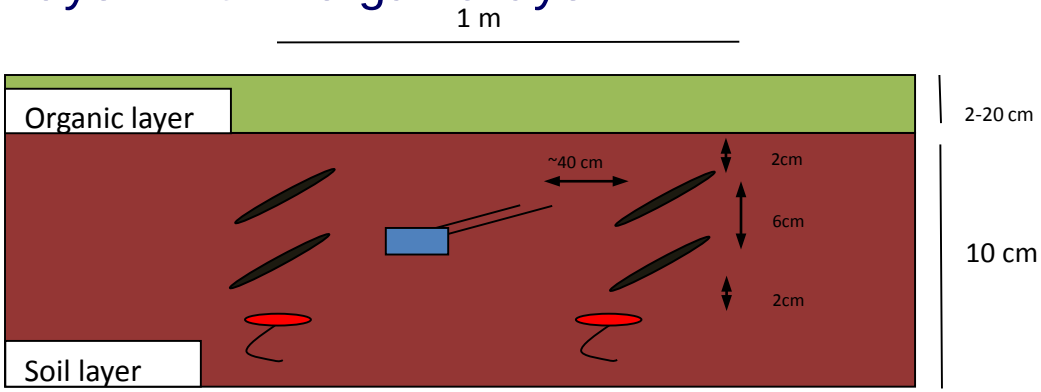
Canopy Flow Sensors at 23 m: Sonic anemometer and gas analyzer, net radiation, air temperature and relative humidity.

3. Study area: UAF and CPCRW

Soil heat flux system (G)

➔ Designed to account only for soil layer ➔ thin organic layer
➔ two G system samples





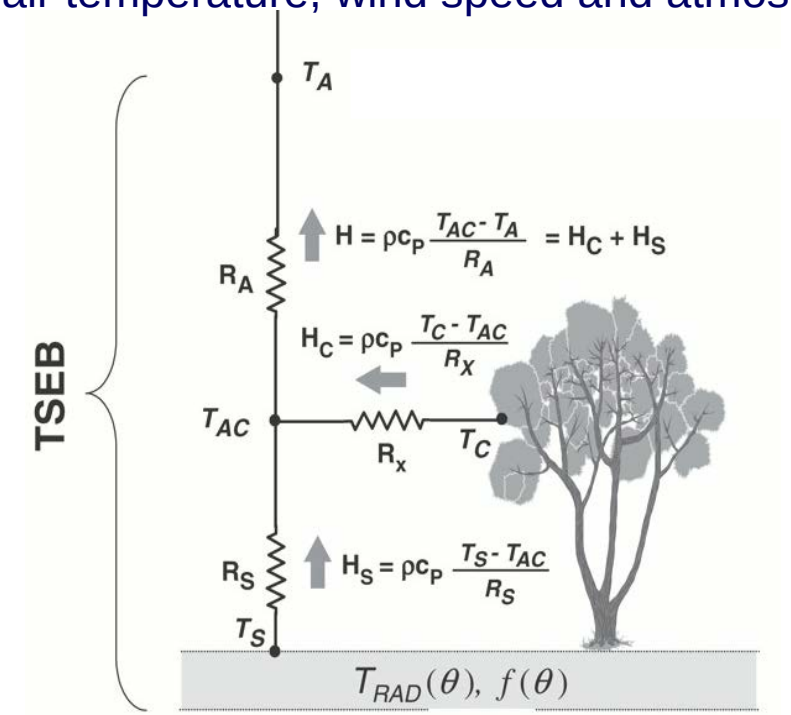
4. TSEB and DTD model application in the Arctic and sub-Arctic (1/4)

TSEB *(*Kustas and Norman, 2000) and **TSEBS** (Kongoli *et al.,* 2013)➔ thermal-based two sources energy balance models ➔ model surface energy fluxes ➔ local implementation

Dual-Temperature-Difference (DTD, Norman et al. 2000) ➔ Regional implementation of TSEB and TSEBS

Main inputs:

- Remote sensing data➔ LAI and LST (TERRA/AQUA MODIS), LST (Landsat-5 TM), snow cover fraction, NDVI/EVI for f_G
- Meteorological data➔ Solar radiation, air temperature, wind speed and atmospheric pressure, actual vapor pressure.



T_A: Air temperature

T_{AC}: Air temperature in the canopy

H: Sensible heat flux integration ➔ H from the canopy (H_c) and H from the soil (H_s).

R_A: Aerodynamic resistance

R_x: bulk leaf boundary layer resistance

R_s: soil surface boundary layer resistance

T_{RAD}: surface temperature

f(0): Vegetation and/or snow cover fraction

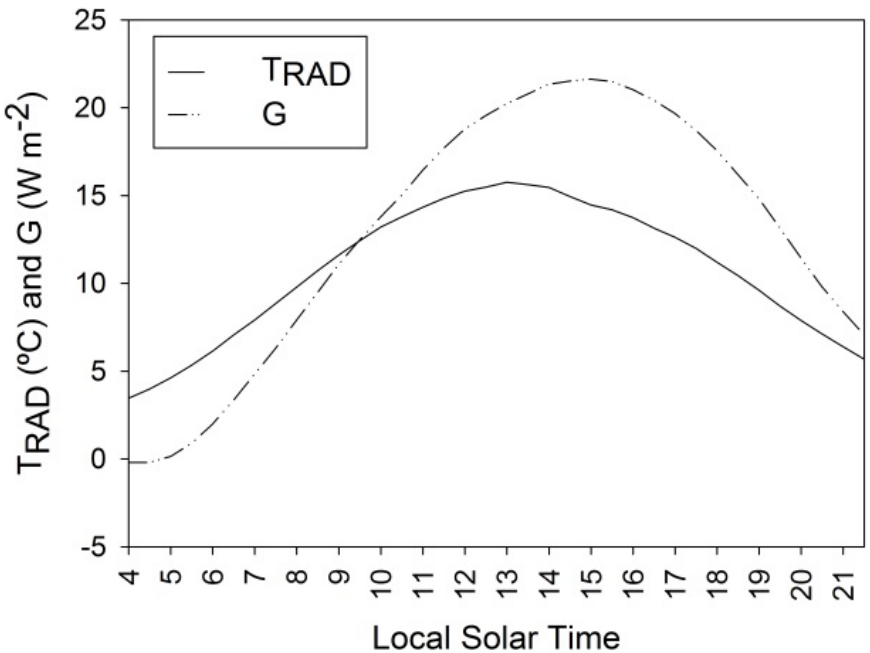
4. TSEB and DTD model application in the Arctic and sub-Arctic: new G parameterization (2/4)

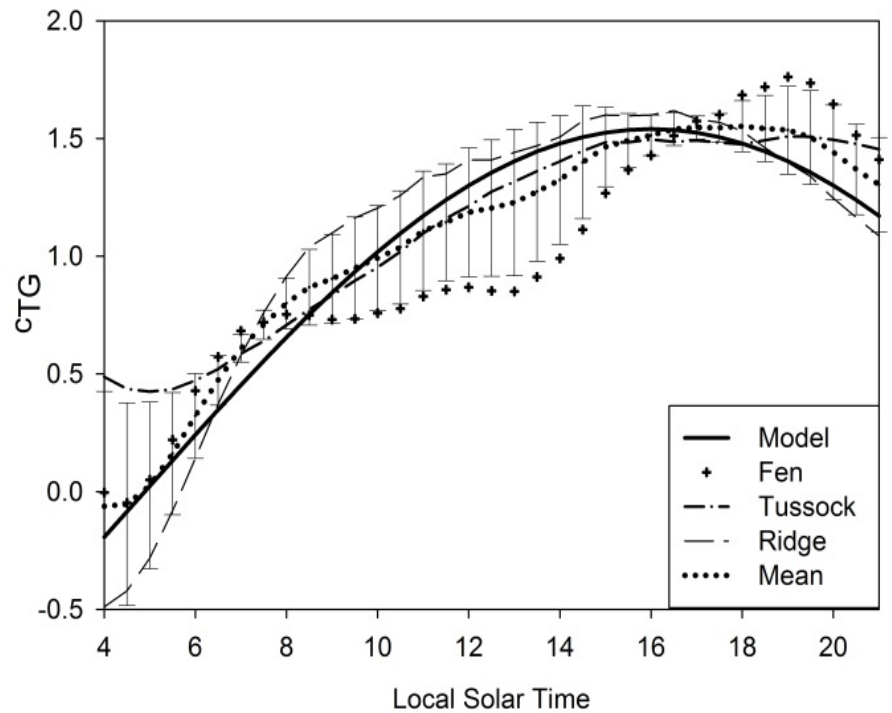
G usually estimated as a fraction of Rn ➔ Tundra ~10% ➔ $G = c_G R_N$

$G = c_{TG} T_{RAD}$ ➔ phase shift ~3h

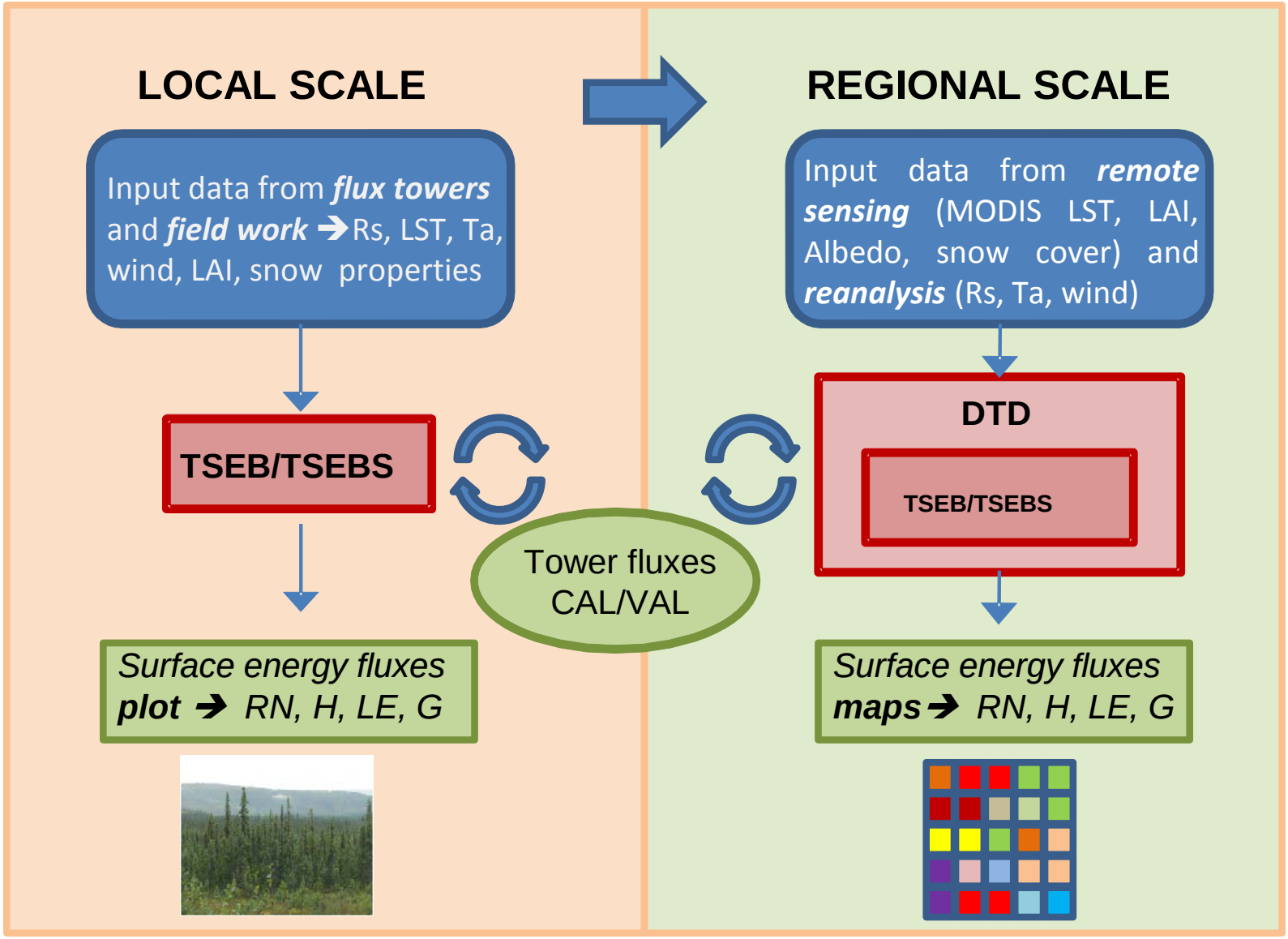
$c_{TG} = A\, cos[2\pi(t + S)/B]$

Based on Santanello and Friedl, 2003

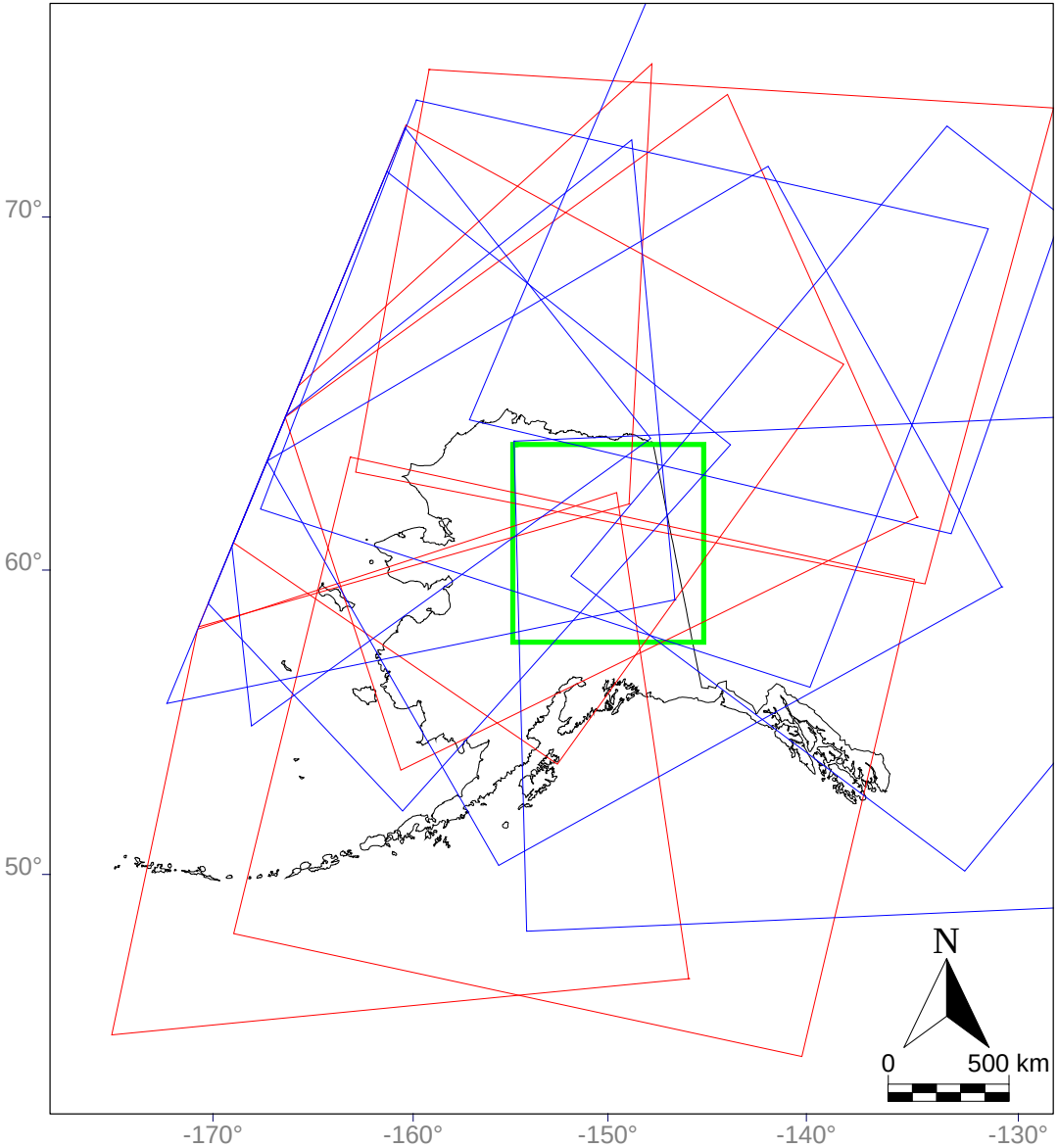




4. TSEB and DTD model application in the Arctic and sub-Arctic (3/4)



4. TSEB and DTD model application in the Arctic and sub-Arctic (3/4)



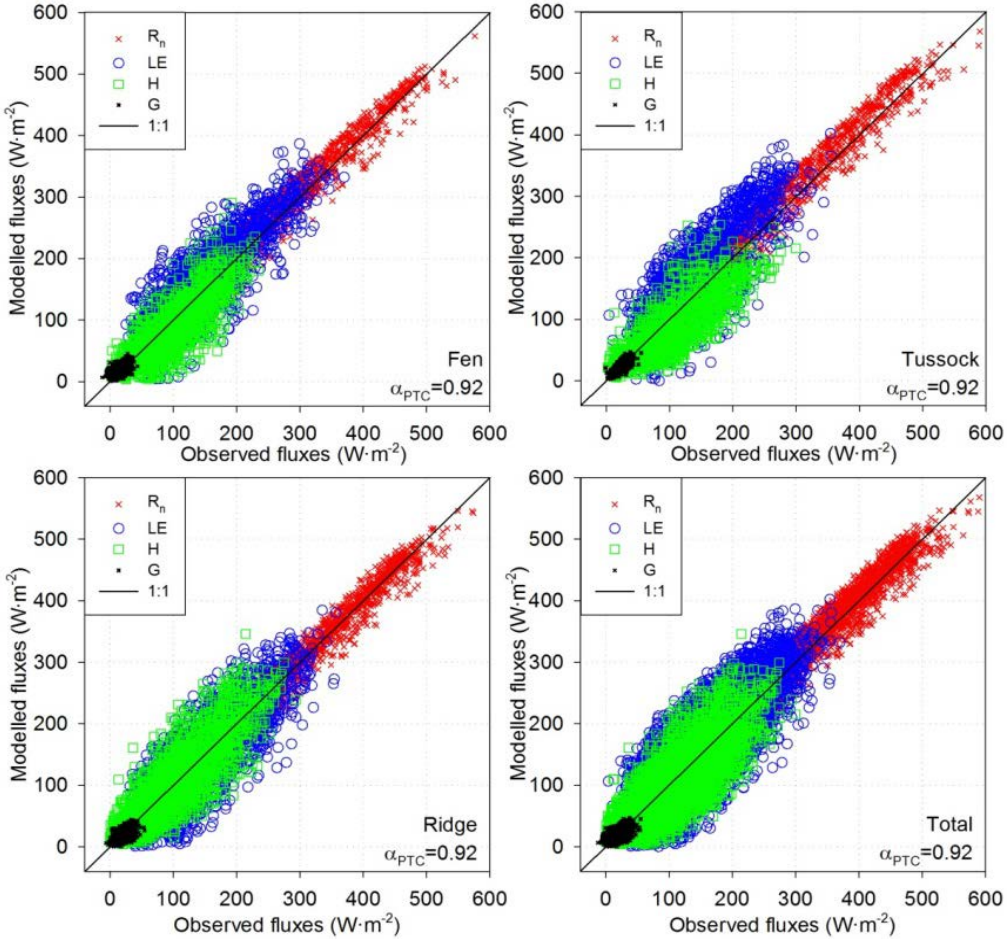
14 potential Terra/Aqua MODIS images per day in Alaska

Terra (blue polygons) and Aqua (red polygons) LST product (MOD011/ MYD011) passes over the study area (green polygon) for DOY 197 of 2010

AVHRR ➔ More than 40 potential images per day!!!!!

5. Multi-temporal TSEB and DTD results in Arctic tundra using remote sensing and local meteorological data (1/7)

Flux station name	Fen	Tussock	Ridge
Period (Year|Day of Year)	2008|194-252 2010|142-262 2011|217-262 2012|153-264	2009|194-253 2010|142-262 2012|156-226	2008|194-252 2009|159-253 2010|143-262 2011|147-262 2012|156-226



Model validated under daylight and all sky conditions (6:00 to 18:00 AKST).

LST derived from the flux tower.

LAI from Terra/Aqua MODIS

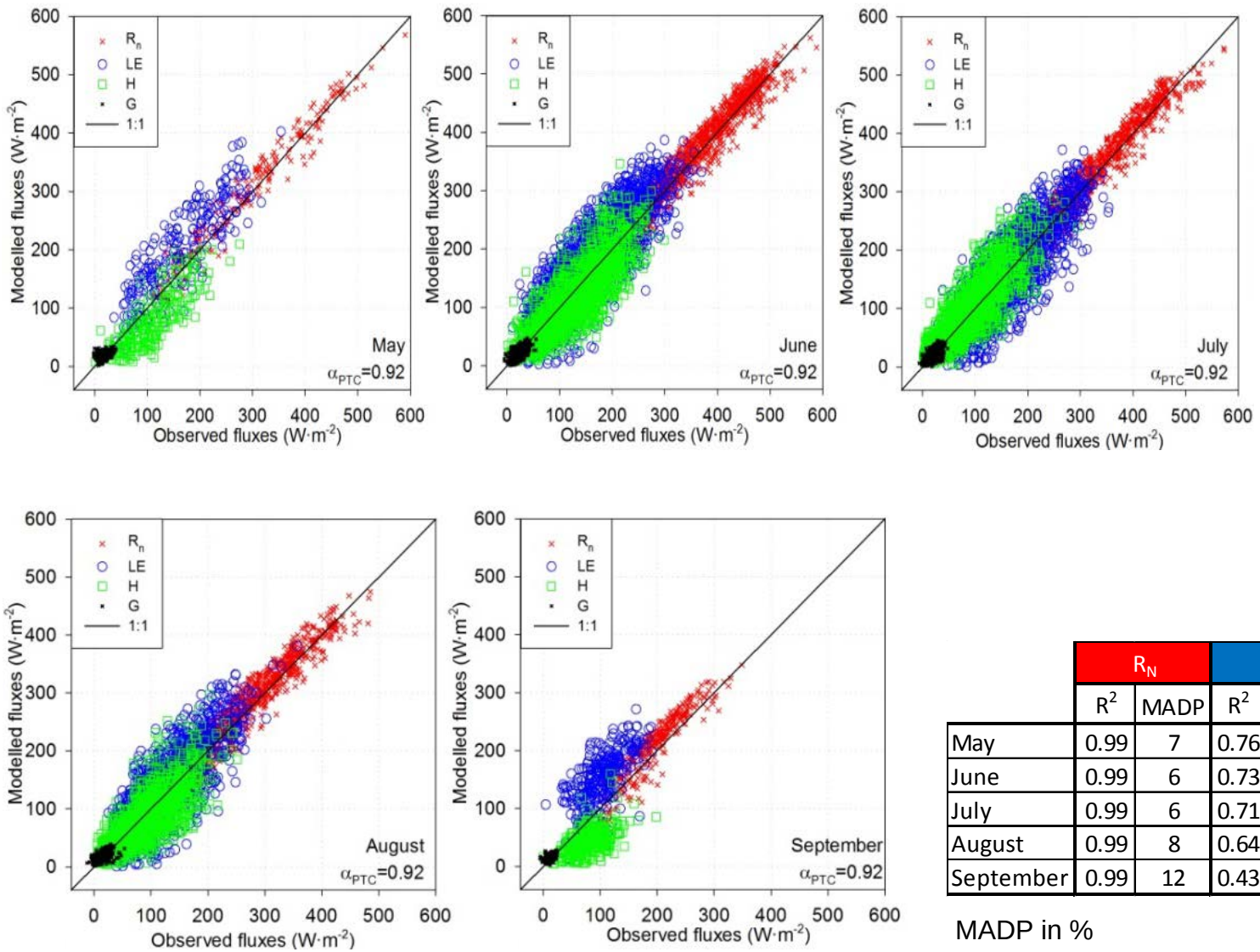
Number of 30 min samples selected: 5178

	R_N	LE	H	G
R^2	0.99	0.68	0.67	0.40
RMSE	23	40	32	8
MADP	7	30	25	29

RMSE in $W \cdot m^{-2}$ and MADP in %

J. Cristóbal; Prakash, A.; Anderson, M. A.; Kustas, W. P.; Euskirchen, E.; Kane D. L. Estimation of surface energy fluxes in the Arctic tundra using the thermal-based two-source energy balance model. Hydrology and Earth System Sciences (Submitted)

5. Multi-temporal TSEB and DTD results in Arctic tundra using remote sensing and local meteorological data (2/7)



	R_N		LE		H		G	
	R^2	MADP	R^2	MADP	R^2	MADP	R^2	MADP
May	0.99	7	0.76	39	0.68	31	0.12	48
June	0.99	6	0.73	33	0.70	23	0.45	26
July	0.99	6	0.71	27	0.72	28	0.49	23
August	0.99	8	0.64	37	0.60	28	0.40	34
September	0.99	12	0.43	69	0.30	46	0.27	40

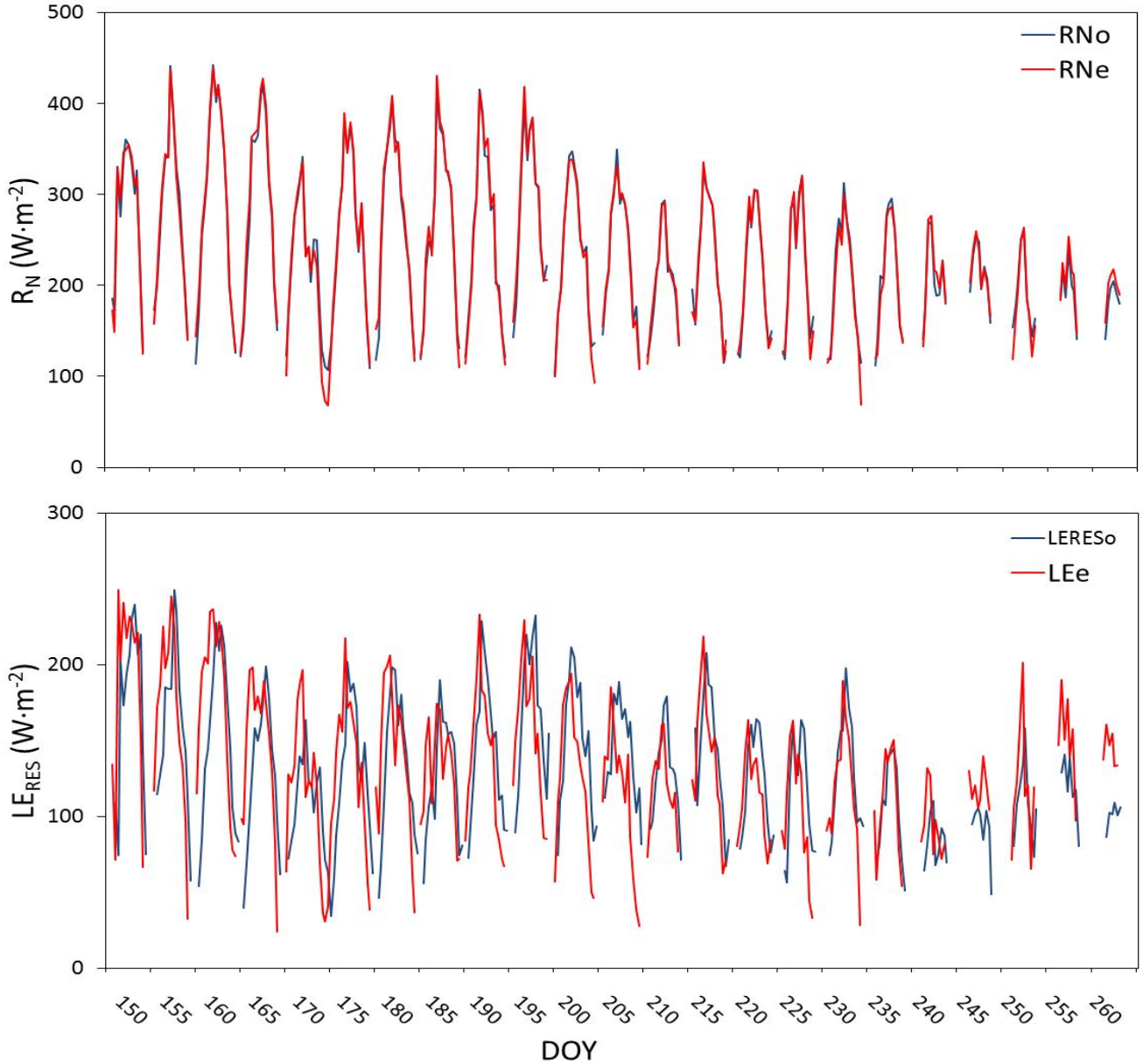
MADP in %

J. Cristóbal; Prakash, A.; Anderson, M. A.; Kustas, W. P.; Euskirchen, E.; Kane D. L. Estimation of surface energy fluxes in the Arctic tundra using the thermal-based two-source energy balance model. Hydrology and Earth System Sciences (In review)

5. Multi-temporal TSEB and DTD results in Arctic tundra using remote sensing and local meteorological data (3/7)

Comparison of hourly flux tower RN and LE observations (from 6 to 21 hours local solar time) at the Heath flux tower.

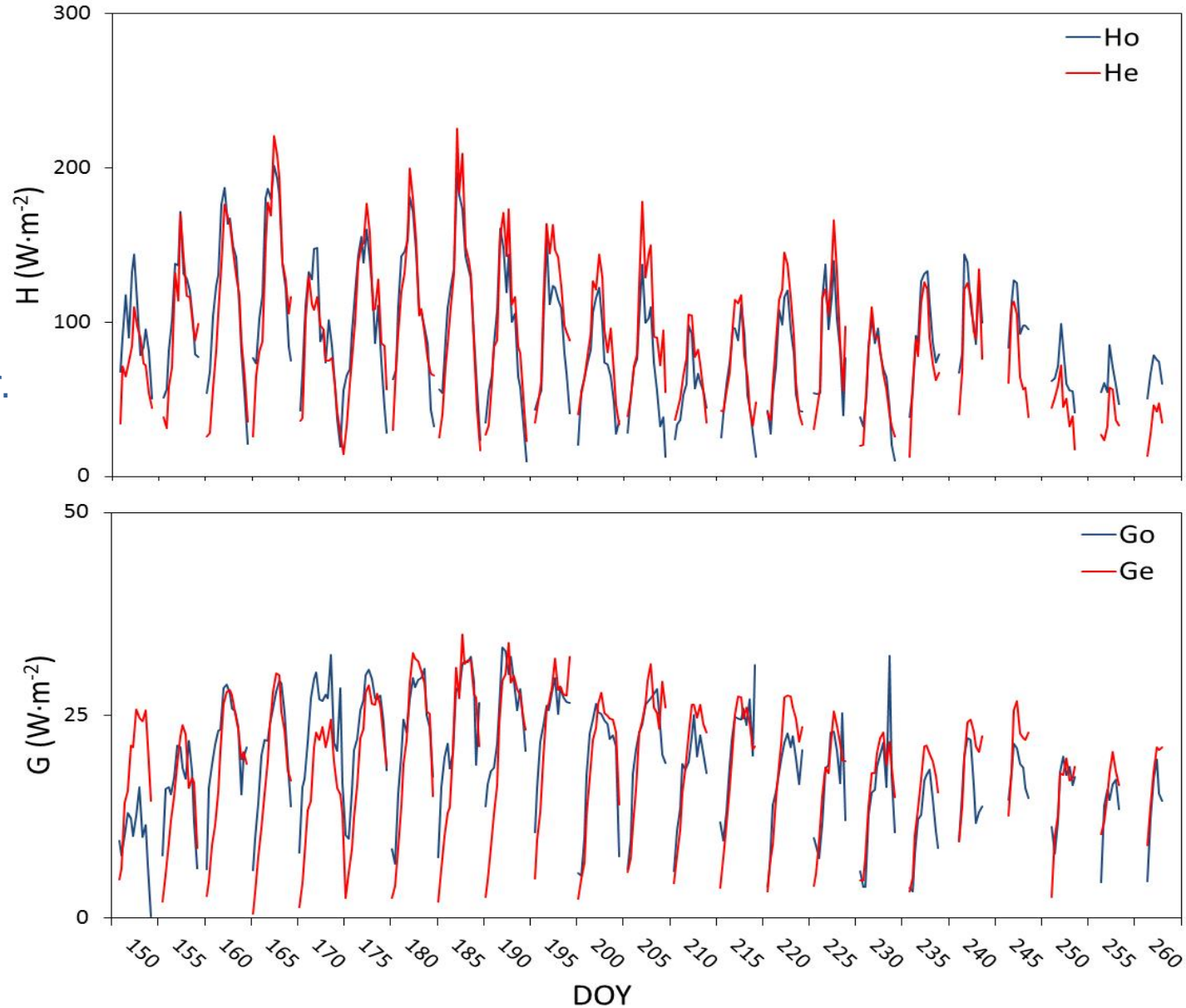
Each diurnal segment represents flux data averaged by hour over 5-day intervals from 2008 to 2012.



5. Multi-temporal TSEB and DTD results in Arctic tundra using remote sensing and local meteorological data (4/7)

Comparison of hourly flux tower H and G observations (from 6 to 21 hours local solar time) at the Heath flux tower.

Each diurnal segment represents flux data averaged by hour over 5-day intervals from 2008 to 2012.



5. Multi-temporal TSEB and DTD results in Arctic tundra using remote sensing and local meteorological data (5/7)

1- DTD remote sensing data

Period	Satellite	n	Date	Product
2008	TERRA/ AQUA MODIS	11	13/07/2008 24/07/2008 13/08/2008 16/08/2008 20/08/2008 24/08/2008 01/09/2008 02/09/2008 03/09/2008 06/09/2008 07/09/2008	•LAI (MOD15/MYD15) •LST (MOD11/MYD11) •NDVI/EVI (MOD09)

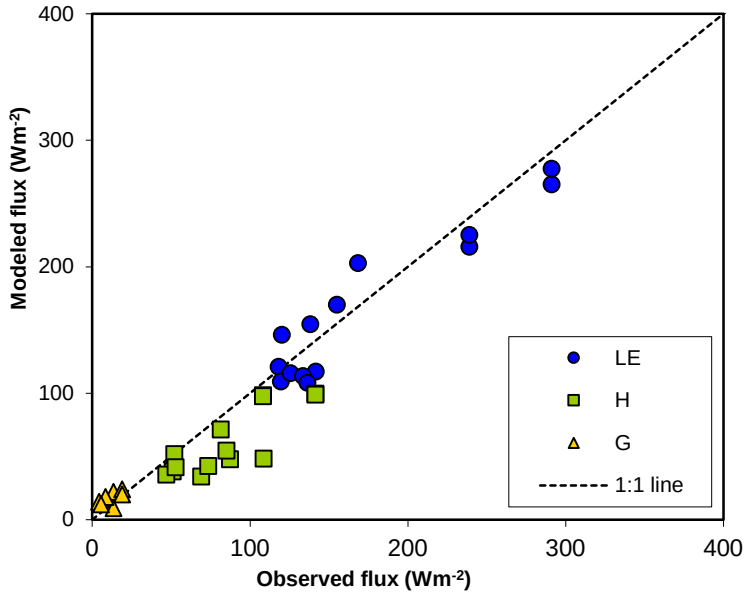
2- TSEB remote sensing data

Period	Satellite	n	Date	Product
2009	Landsat-5 TM	3	05/07/2009 21/07/2009 06/08/2009	•Level-1T
	TERRA MODIS			•LAI (MOD15A2) •Water vapor (MOD05)

DTD results: MODIS

	LE	H	G
R^2	0.92	0.78	0.70
RMSE*	22	23	14
MBE*	-13	-18	12
MAE*	20	18	10

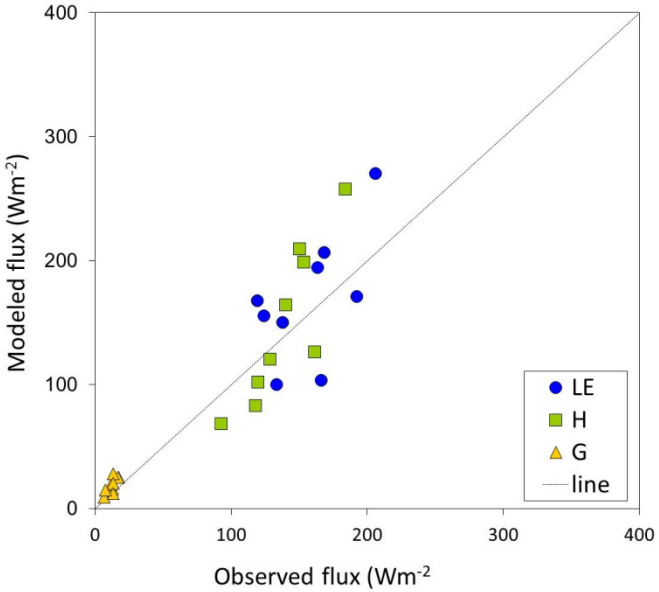
* in $W \cdot m^{-2}$

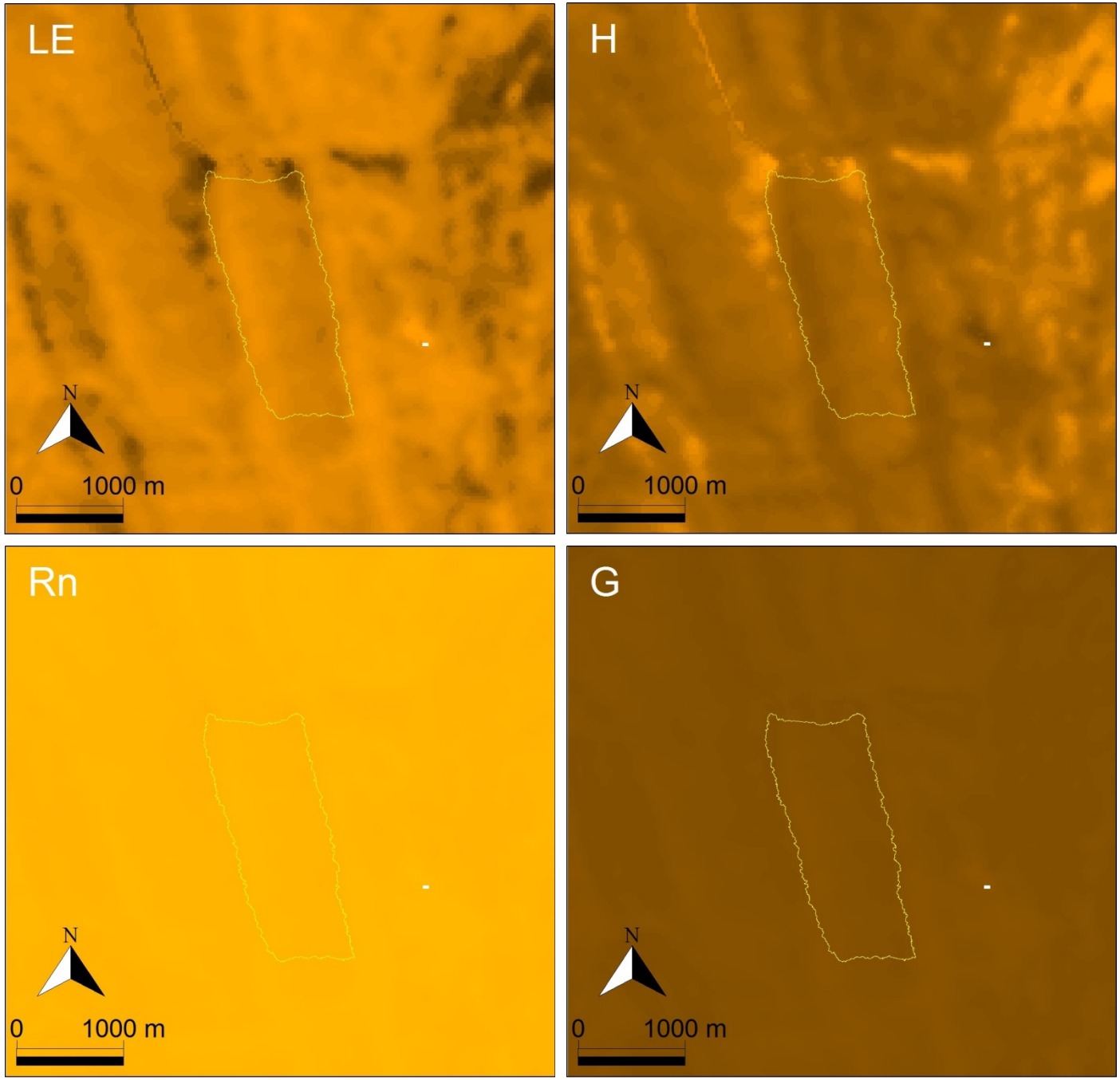


TSEB results: Landsat

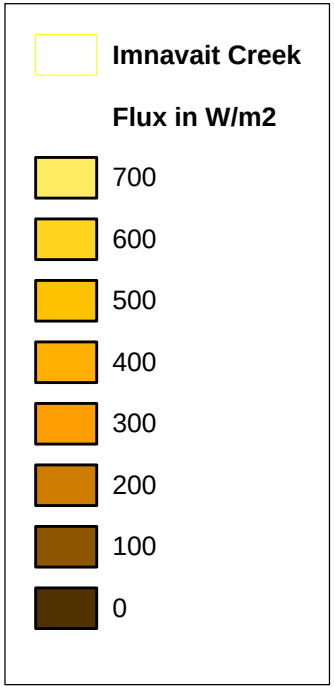
	LE	H	G
R^2	0.5	0.76	0.50
RMSE*	41	41	15
MBE*	12	9	10
MAE*	38	36	11

* in $W \cdot m^{-2}$

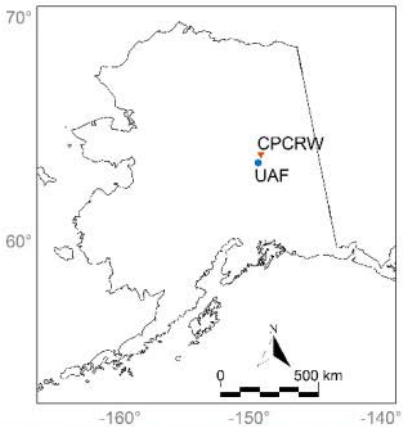


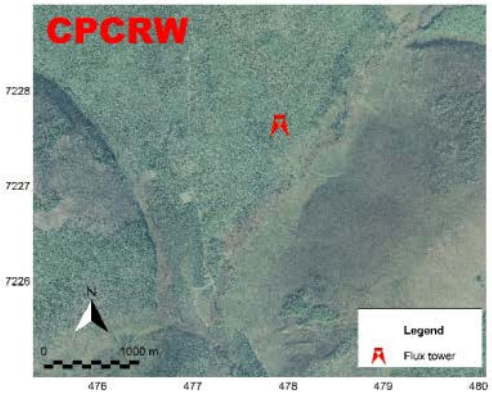


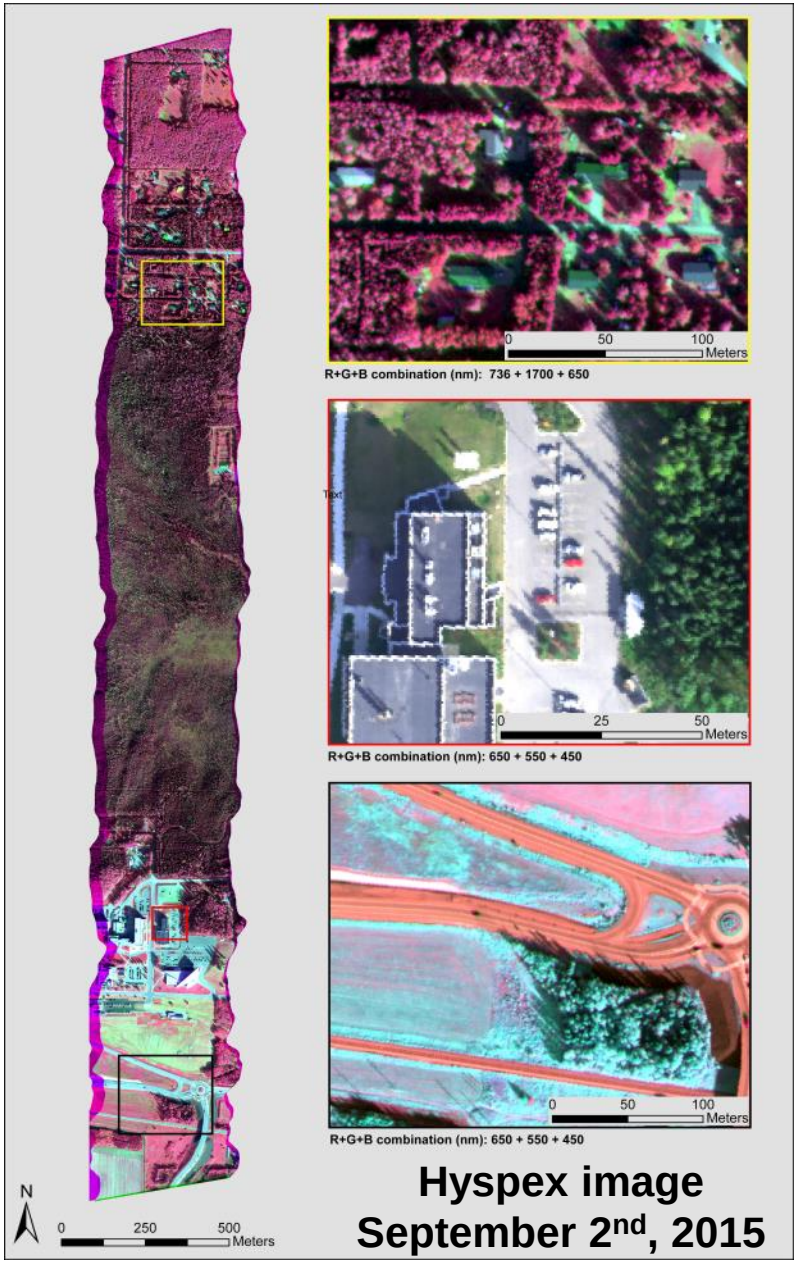
TSEB results in the Imnavait Creek in 05/07/2009 using Landsat-5 TM imagery



6. Airborne Hyperspectral/Thermal surface energy fluxes mapping







6. Conclusions and future research

1) Multitemporal results of TSEB and DTD models using remote sensing and meteorological data in the Arctic tundra show good agreement with flux tower data.

2) TSEB model under DTD model framework showed better performance using two LST images ➔ Arctic implementation

3) Future energy balance implementation under snow cover ➔ TSEBS

4) Estimation of LAI and snow cover/properties using hyperpsectral data ➔ Hyspex (http://hyperspectral.alaska.edu/news_updates.html)

7. Acknowledgements

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Thanks for your attention