A discussion on the paper
" Digital repeat photography for phenological research in forest ecosystems"

Oliver Sonnentag *et al.*, 2012

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2017/10/06

Outline

- Introduction
- Methods
- Results and discussion
- Conclusions

Introduction

- Recently, conventional digital cameras taking repeated images of the landscape at high frequencies (several images per day) over several months or even years have obtained increased attention for phenological research (Ahrends et al., 2009; Graham et al., 2010; Ide and Oguma, 2010; Kurc and Benton, 2010; Migliavacca et al.,2011; Richardson et al., 2009a; Sonnentag et al., 2011).

Introduction

Indoor webcam

Outdoor webcam

Introduction

Plant-cam

Game-cam

Introduction

DSLR camera

P-and-S camera

Introduction

- The color channel information of digital images can be extracted as separate RGB digital numbers (DN) for quantitative analysis.

- Red-green-blue brightness levels are influenced by scene illumination,but these influences can be suppressed by a nonlinear transform of RGB DN to rgb chromatic coordinates (Gillespie et al.,1987; Woebbecke et al., 1995), defined as:

Introduction

$$r_{cc} = \frac{R}{(R+G+B)}; \quad g_{cc} = \frac{G}{(R+G+B)}; \quad b_{cc} = \frac{B}{(R+G+B)}$$

- A widely used example to describe canopy greenness is excess green (ExG) defined as: 2G-(R+B)

Methods

Harvard Forest and Howland Forest

One-year archives of digital landscape images

Diurnal, seasonal and weather-related changes

Nine additional one-year archives and one non-vegetated site

Calculate ExG and g_{cc}

Methods

Eleven additional three-month archives

Every 30 min between 04:00 and 21:30 local time

Digital camera and image file format choice

Table 1 PhenoCam forest study sites

Site	Lat.; long. (d.d.)	Elev. (m asl)	Forest type	Dominant tree species	Year	Reference
Arbutus Lake	43.98; −74.23	535	Decid.	Sugar maple (*Acer saccharum*); American beech (*Fagus grandifolia*)	2009	http://www.esf.edu/hss/em/huntington/arbutusCam.html
Bartlett Forest[a]	44.06; −71.29	268	Decid.	Red maple (*Acer rubrum*); American beech	2009	Richardson et al. (2007)
Chibougamou[b]	49.69; −74.34	380	Conif.	Black spruce (*Picea mariana*)	2009	Bergeron et al. (2007)
Dolly Sods Wilderness[c]	39.11; −79.43	1141	Decid.	Sugar maple; red maple; American beech	2009	http://www.fsvisimages.com/
Grand Canyon[d]	36.06; −112.12	2177	–	–	2009	http://www.nature.nps.gov/air/WebCams/
Harvard Forest Environmental Measurement Site (EMS)[a]	42.54; −72.17	340	Decid.	Red oak (*Quercus rubra*); red maple; eastern hemlock (*Tsuga canadensis*)	2009	Urbanski et al. (2007)
Howland Forest[a]	45.20; −68.74	80	Conif.	Red spruce (*Picea rubens*); eastern hemlock; red maple; balsam fir (*Abies balsamea*)	2009	Hollinger et al. (2004)
Morgan Monroe State Forest[a]	39.32; −86.41	275	Decid.	Sugar maple; tulip poplar (*Liriodendron tulipifera*)	2009	Schmid et al. (2000)
Niwot Ridge[b]	40.033; −105.55	3050	Conif.	Subalpine fir (*Abies lasiocarpa*); Engelman spruce (*Picea engelmannii*); lodgepole pine (*Pinus contorta*)	2009	Monson et al. (2002)
Pasayten Wilderness[c]	48.39; −119.90	1250	Conif.	Ponderosa pine (*Pinus ponderosa*)	2009	http://www.fsvisimages.com/
Smoky Purchase-Knob[d]	35.59; −83.08	1550	Decid.	Yellow birch (*Betula alleghaniensis*); American beech; red maple; tulip poplar	2009	http://www.nature.nps.gov/air/WebCams/
Shining Rock Wilderness[c]	35.39; −82.77	1500	Decid.	Yellow birch; American beech; red maple; tulip poplar	2008	http://www.fsvisimages.com/

[a] AmeriFlux.
[b] Canadian Carbon Program.
[c] USDA Forest Service Air Resource Management program.
[d] National Park Service Air Resources program.

Table 2 Digital camera overview

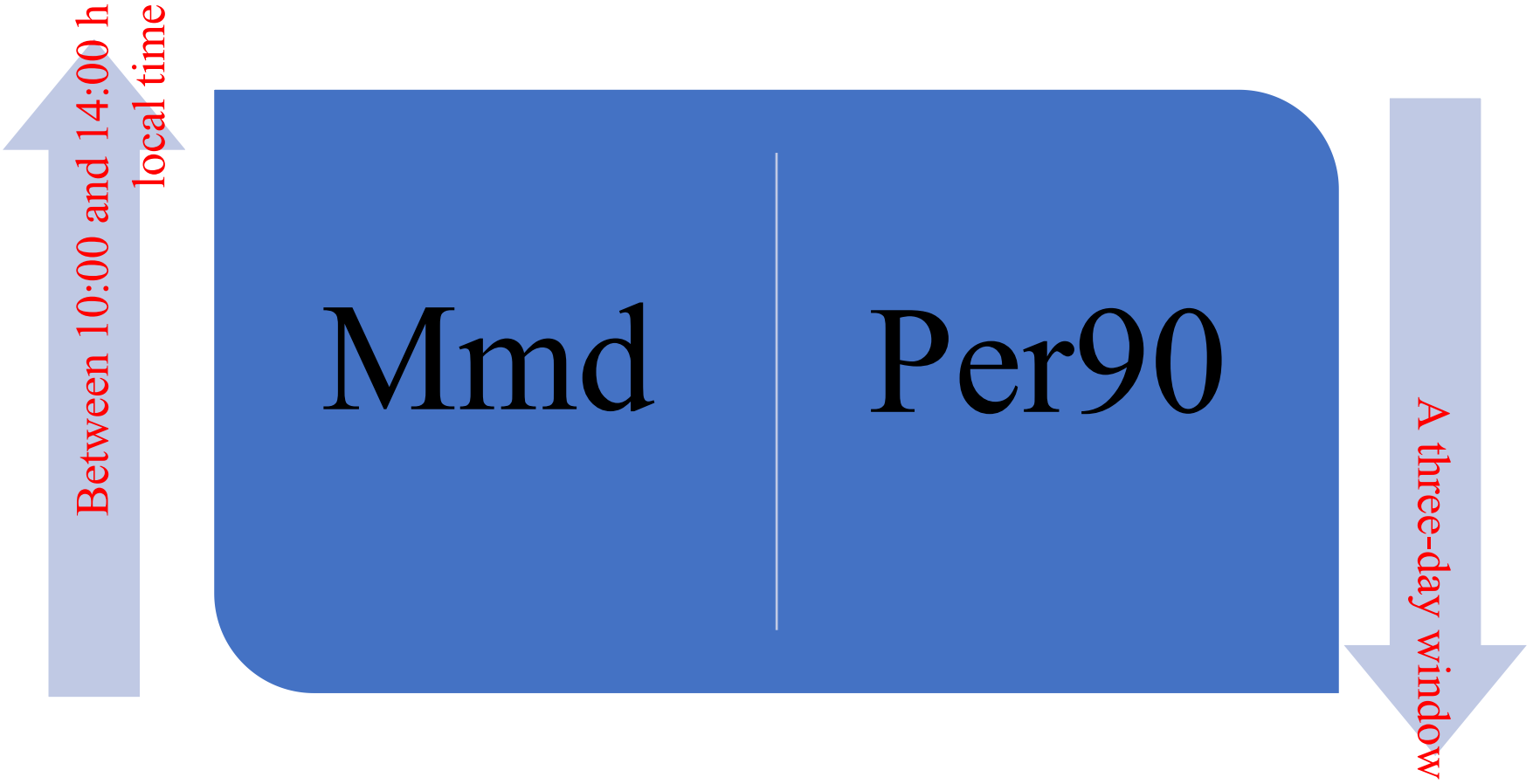
Site	Manufacturer; model	Interval; temporal coverage (h local time)	Imaging sensor	Resolution	Type	View direction; tilt angle from horizontal (0°)	Reference
Arbutus Lake	StarDot; NetCam SC 1.3MP	hh; 04:00–21:30	1/2.5″-type CMOS	1296 × 960	Out. webcam	~N; ~20°	This study
Bartlett Forest	Axis; 211	10-min; 12:00–13:00	1/4″ CCD	640 × 480	Out. webcam	~N; ~20°	Richardson et al. (2009a)
Chibougamou	StarDot; NetCam SC 1.3MP	hh; 04:00–21:30	CMOS (n. s. f.)	1296 × 960	Out. webcam	~NE; ~20°	This study
Dolly Sods Wilderness	Olympus; SP-500	3-h; 09:00–15:00	1/2.5″-type CCD	1599 × 1199	DSLR camera	~S, 0°	This study
Grand Canyon	Olympus; E-420	h; 08:00–20:00	Live MOS (n.s.f.)	640 × 480	DSLR camera	~N, 0°	This study
Harvard Forest Environmental Measurement Site (EMS)	StarDot; NetCam SC 1.3MP	hh; 04:00–21:30	1/2.5″-type CMOS	1296 × 960	Out. webcam	~N; ~20°	This study
Harvard Forest[b]	Axis; 207MW	hh; 05:00–21:30	1/3″-type CMOS	1280 × 720	In. webcam	~N; ~20°	This study
Harvard Forest[b]	Axis; 211	hh; 05:00–18:30	1/4″-type CCD	640 × 480	Out. webcam	~N; ~20°	Richardson et al. (2009a)
Harvard Forest[b]	Axis; 223M	hh; 05:00–21:30	1/2.7″-type CCD	1600 × 1200	Out. webcam	~N; ~20°	This study
Harvard Forest[b]	StarDot; NetCam SC 1.3MP	hh; 05:00–20:30	1/2.5″-type CMOS	1296 × 960	Out. webcam	~N; ~20°	This study
Harvard Forest[b]	StarDot; NetCam XL 3MP	hh; 05:00–19:30	1/2″-type CMOS	2048 × 1536	Out. webcam	~N; ~20°	Richardson et al. (2009a)
Harvard Forest[b]	Vivotek; IP7160	hh; 05:00–20:00	1/3.2″-type CMOS	1600 × 1200	Out. webcam	~N; ~20°	This study
Harvard Forest[b]	D-Link; DCS-920	hh; 05:00–20:30	1/4″-type CMOS	320 × 240	In. webcam	~N; ~20°	Sonnentag et al. (2011)
Harvard Forest[b]	Wingscapes; PlantCam WSCA04	hh; 00:00–24:00	n.s.[c]	2048 × 1536	Plant-cam	~N; 20°	This study
Harvard Forest[b]	Moultrie; Game Spy I-60	h; 00:00–24:00	n.s.[c]	2048 × 1536	Game-cam	~N; 20°	Kurc and Benton (2010)
Harvard Forest[b]	Pentax; K100D[a]	hh; 08:00–19:30	23.5 × 15.7 mm CCD	3040 × 2024	DSLR camera	~N; 0°	Bater et al. (2011)
Harvard Forest[b]	Canon; A560	h; 07:00–20:00	1/2.5″-type CCD	3072 × 2304	P-and-S camera	~N; ~20°	This study
Howland Forest	StarDot; NetCam XL 1MP	hh; 04:00–21:30	1/2″-type CMOS	1024 × 768	Out. webcam	~N; ~20°	Richardson et al. (2009a)
Morgan Monroe State Forest	StarDot; NetCam SC 1.3MP	hh; 04:00–21:30	1/2.5″-type CMOS	1296 × 976	Out. webcam	~N; ~20°	Richardson et al. (2009a)
Niwot Ridge	Canon; VB-C10R	2-h; 06:00–20:00	1/4″-type CCD	640 × 480	In. webcam	~N; ~20°	This study
Pasayten Wilderness	Olympus; C-730	3-h; 09:00–15:00	1/2.7″-type CCD	1600 × 1200	DSLR camera	~SW; 0°	This study
Smoky Purchase-Knob	Olympus; E-420	h; 07:00–19:00	Live MOS (n.s.f.)	640 × 480	DSLR camera	~NE; 0°	This study
Shining Rock Wilderness	Olympus; SP-500	3-h; 09:00–15:00	1/2.5″-type CCD	1536 × 1024	DSLR camera	~NW; 0°	This study

[a] This digital camera is approximately similar to the Olympus DSLR cameras used by the USDA Forest Service Air Resource Management program and National Park Service Air Resources program.

[b] Digital cameras for the intercomparison were mounted on an ancillary instrumentation tower at Harvard Forest located approximately 130 m southwest of the EMS instrumentation tower.

[c] The manufacturer declined to release information on the imaging sensors.

Methods


Between 10:00 and 14:00 h local time
Mmd
Per90
A three-day window

Results and discussion

Table 3 Comparison of root mean square errors

（3.32-4.14）/4.14=-20%
Indicating that per90 is better than mmd

Site	n_{total}	DN threshold	n_{filter}	ExG			g_{cc}		
				mmd	perOpt[a]; per90[a]	% change (perOpt; per90)	mmd (×10³)	perOpt[a] (×10³); per90[a] (×10³)	% change (perOpt; per90)
Arbututs Lake	13,155	20	8846	4.14	2.19 (50); 3.32 (90)	−47; −20	6.27	4.59 (90); 4.59 (90)	−27; −27
Bartlett Forest	2895	40	2479	2.99	2.14 (80); 2.25 (90)	−28; −25	2.61	2.16 (60); 2.44 (90)	−17; −7
Chibougamau	11,613	35	7284	2.64	1.82 (80); 1.90 (90)	−31; −28	3.37	2.27 (80); 2.33 (90)	−33; −31
Dolly Sods Wilderness	4231	20	3805	7.11	3.39 (90); 3.39 (90)	−52; −52	11.15	5.71 (60); 5.86 (90);	−53; −52
Grand Canyon	3991	60	3125	2.47	1.12 (60); 1.91 (90)	−55; −23	2.29	1.10 (70); 1.71 (90)	−52; −26
Harvard Forest	12,171	35	8000	3.91	3.07 (50); 3.21 (90)	−21; −18	5.38	4.45 (50); 4.45 (90)	−17; −17
Howland Forest	11,846	10	8079	2.43	1.41 (60); 1.48 (90)	−42; −39	12.51	6.95 (90); 6.95 (90)	−44; −44
Morgan Monroe State Forest	10,338	45	6186	3.27	2.01 (90); 2.01 (90)	−38; −38	5.13	3.08 (80); 3.08 (90)	−40; −40
Niwot Ridge	2748	80	2117	7.96	5.21 (80); 5.22 (90)	−34; −34	6.64	4.33 (90); 4.34 (90)	−35; −35
Pasayten Wilderness	4745	5	4252	4.53	2.26 (50); 2.62 (90)	−50; −42	7.11	3.22 (80); 3.47 (90)	−55; −51
Smoky Purchase-Knob	4159	10	3831	5.17	3.29 (50); 3.90 (90)	−36; −25	8.51	4.16 (90); 4.16 (90)	−51; −51
Shining Rock Wilderness	957	–	957	8.48	3.71 (50); 4.30 (90)	−56; −49	8.25	5.37 (50); 7.17 (90)	−35; −13

[a] Number in brackets denotes the percentile.

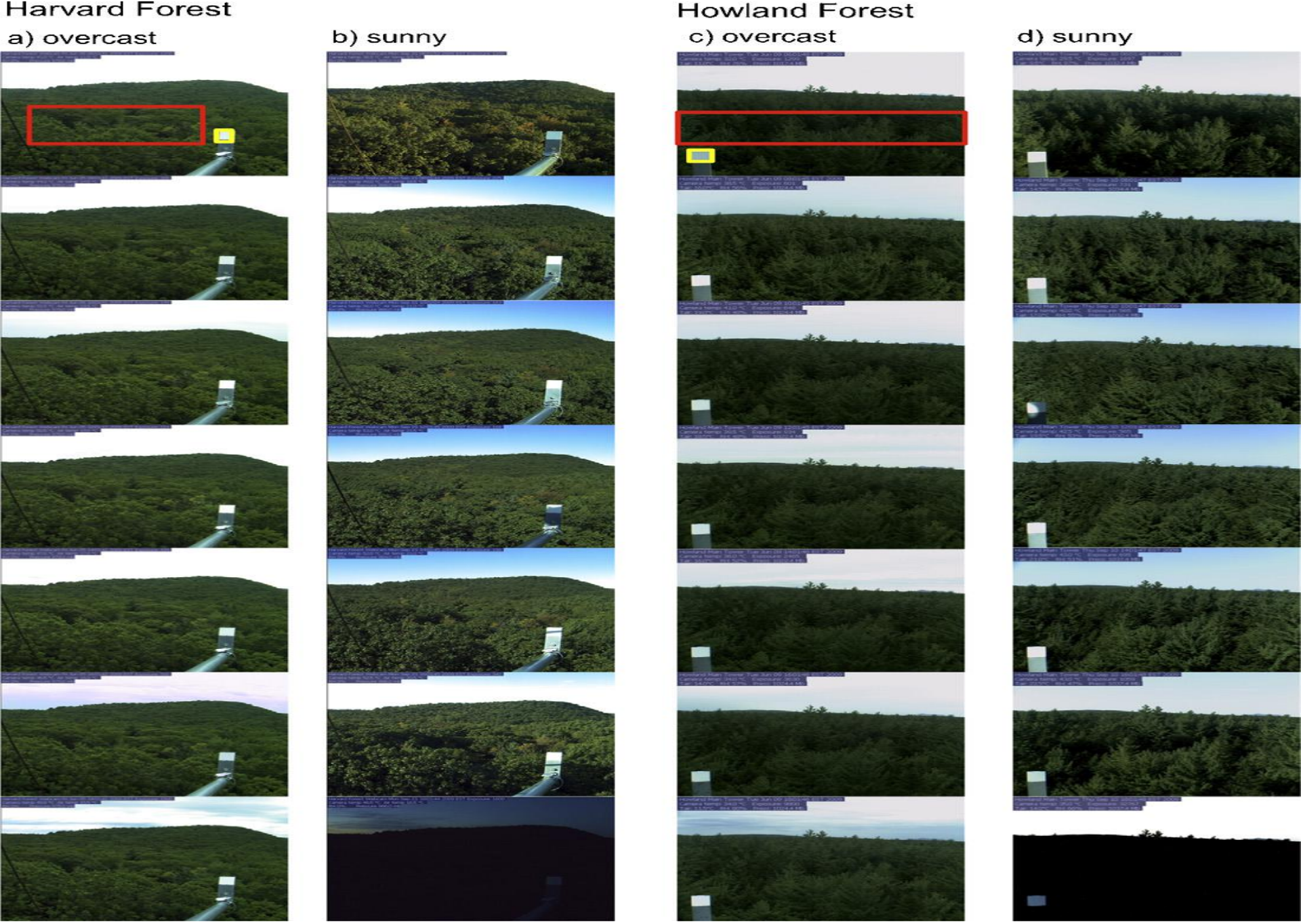


Fig. 1. Example images

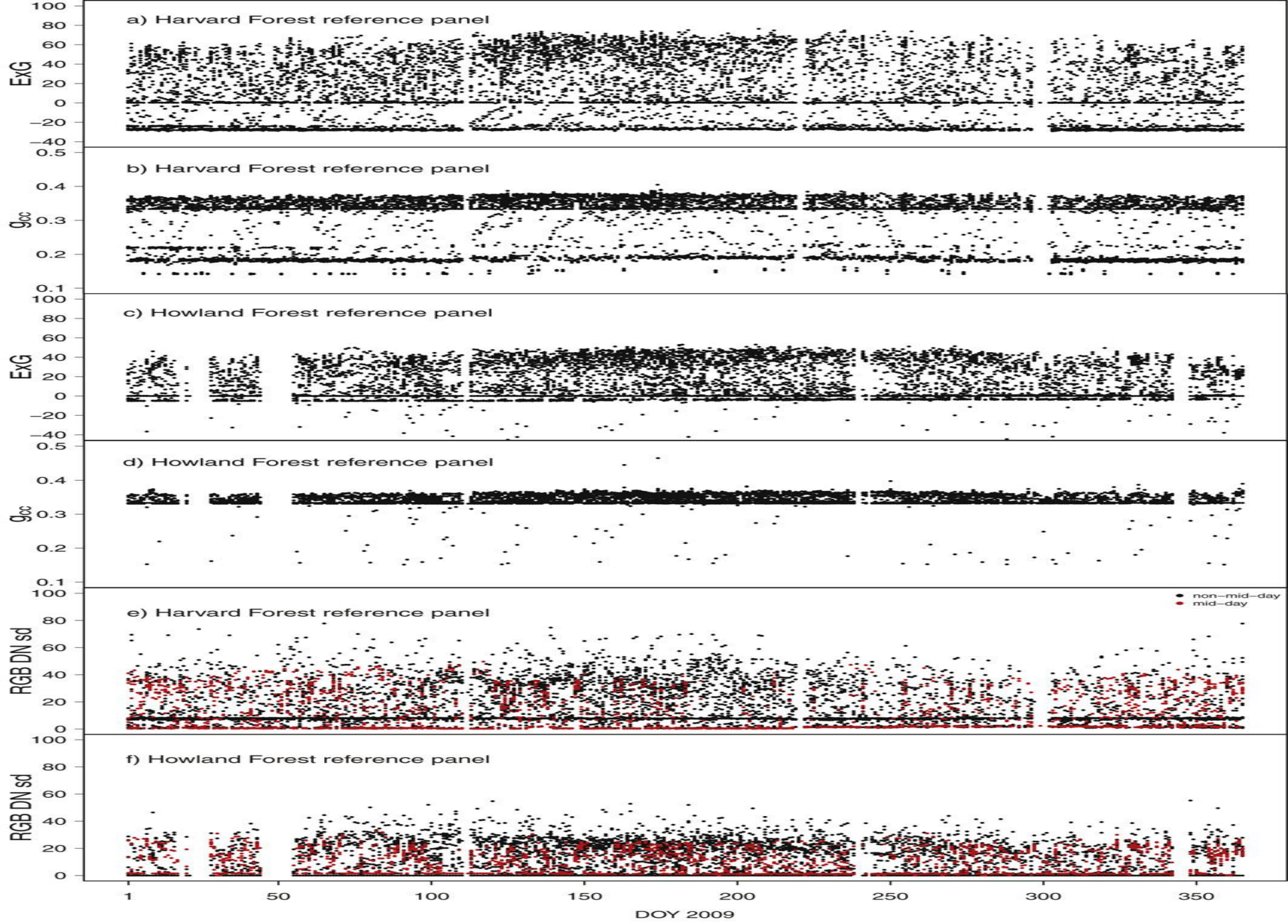


Fig. 2. Reference panel

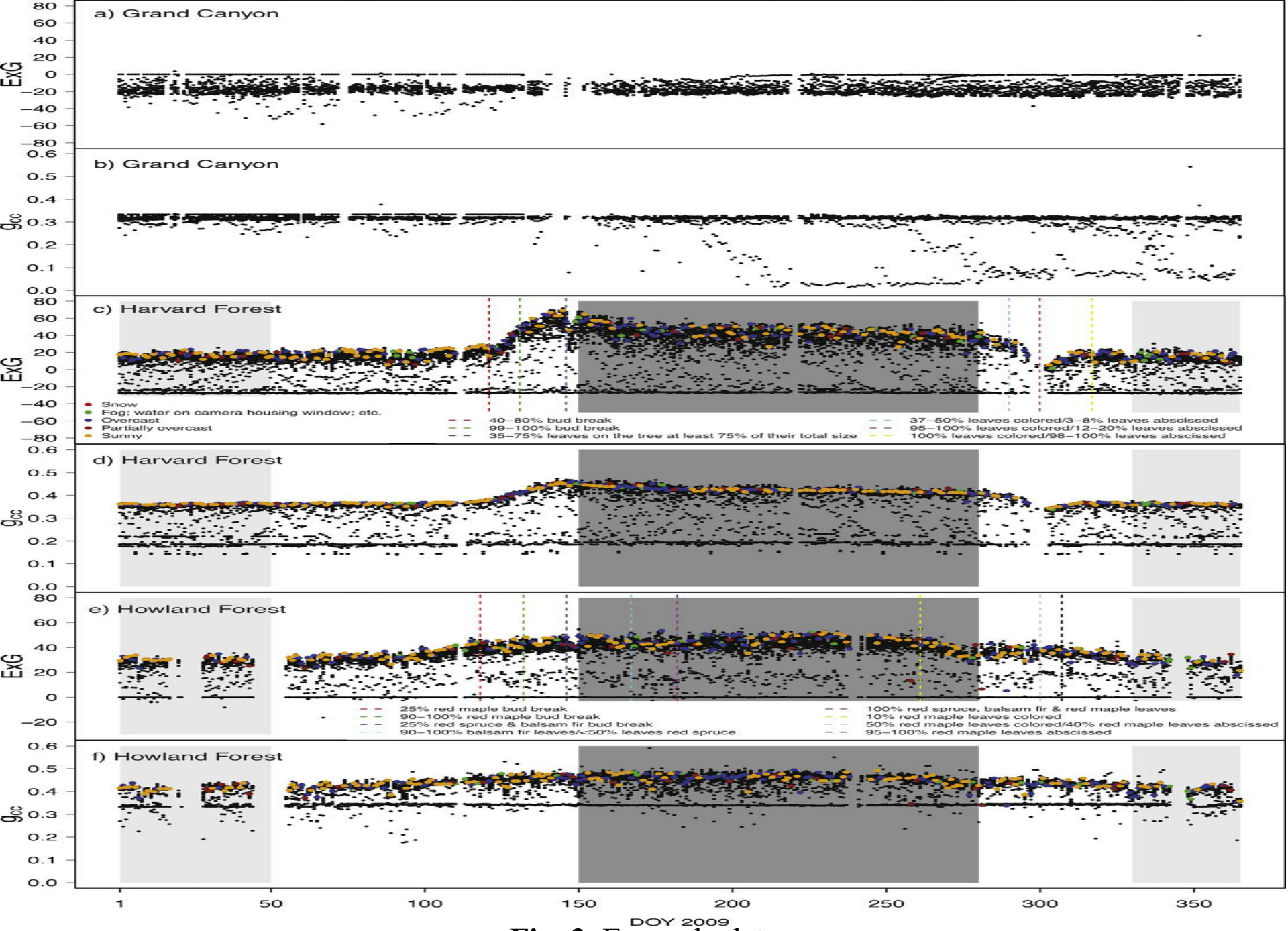
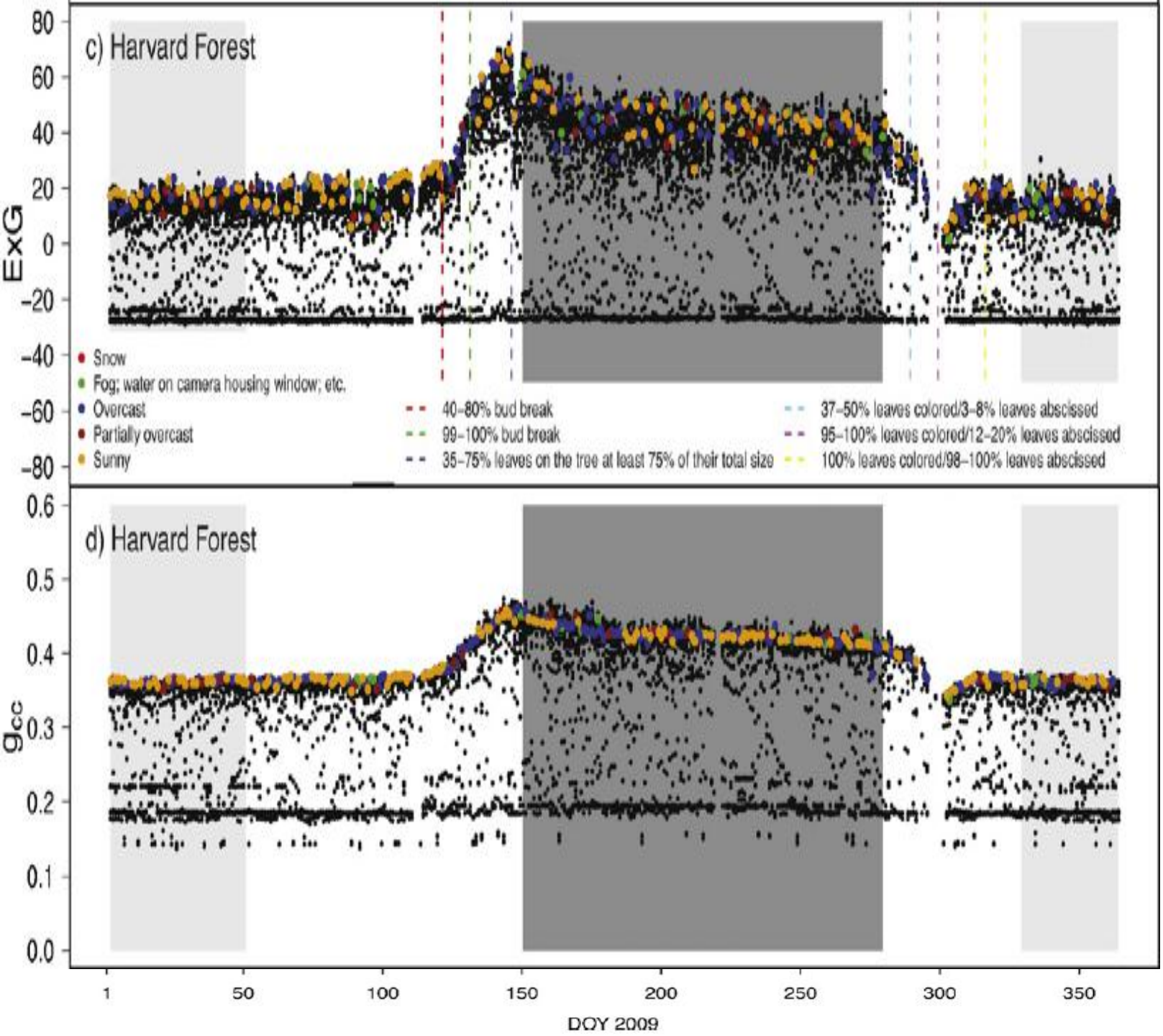


Fig. 3. Example data



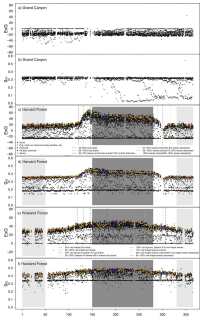
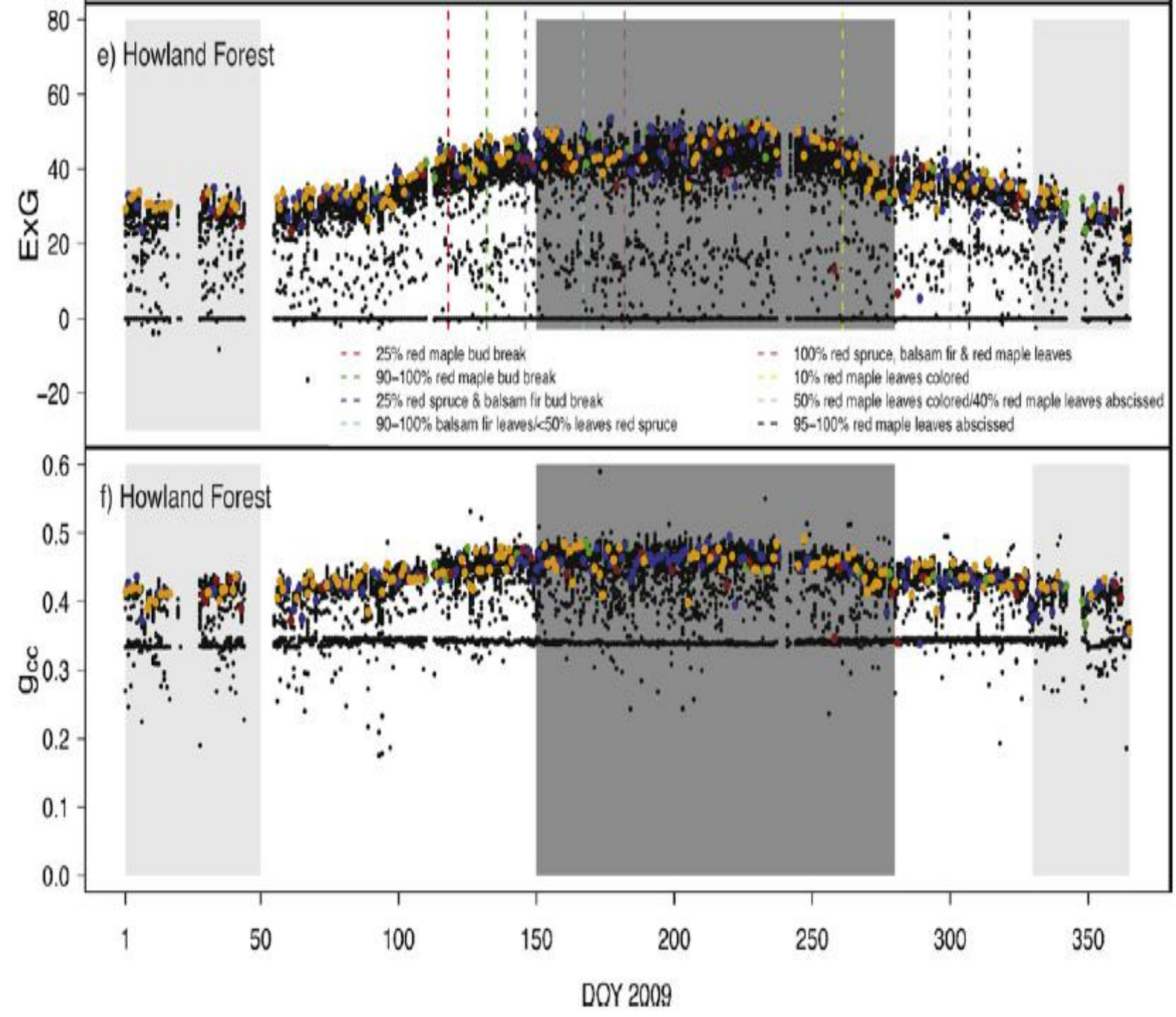


Fig. 3. Example data



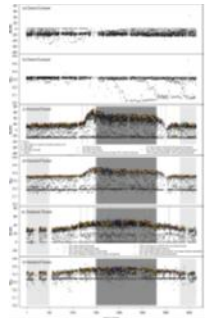


Fig. 3. Example data

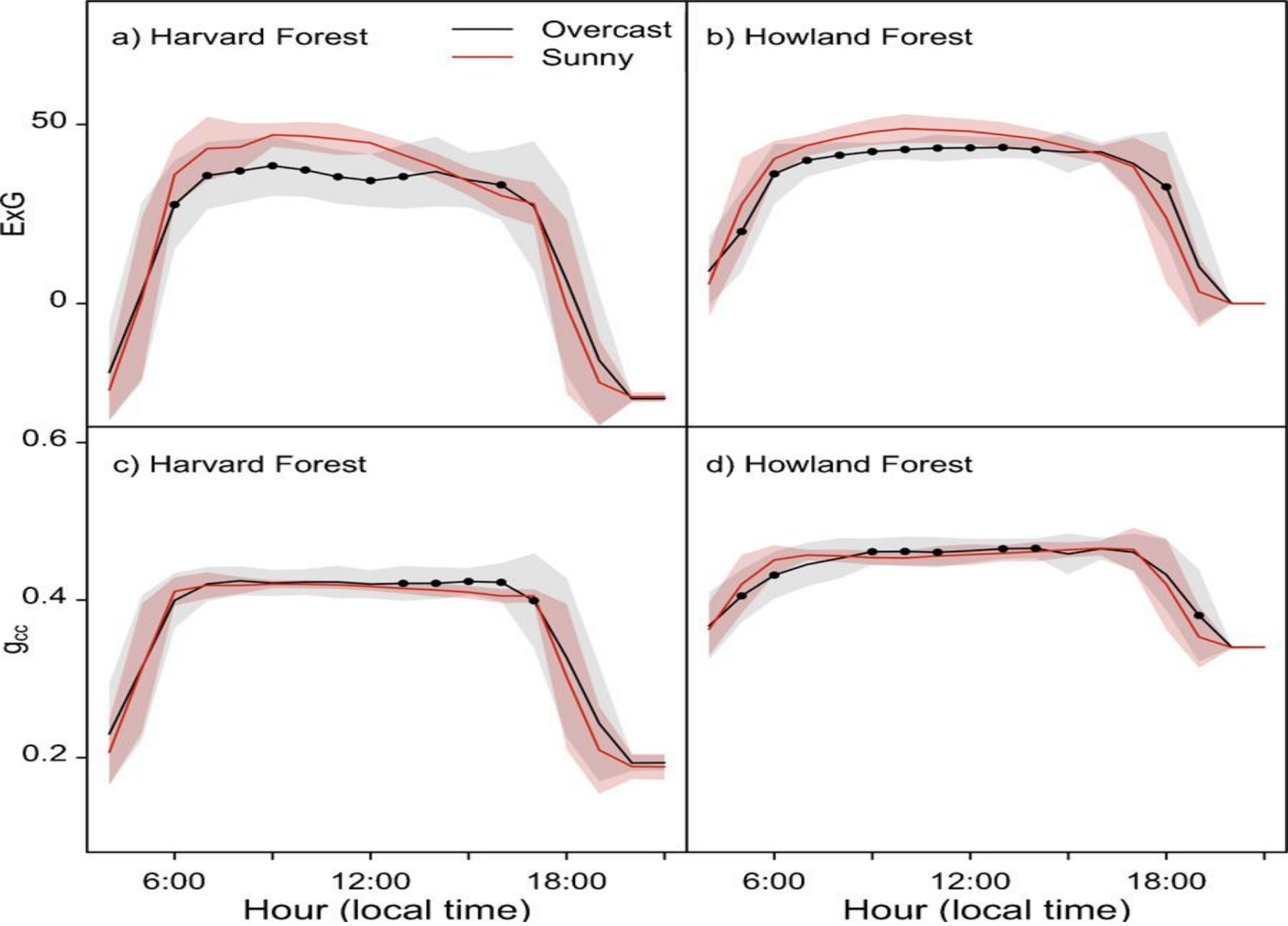


Fig. 4. Mean diurnal patterns

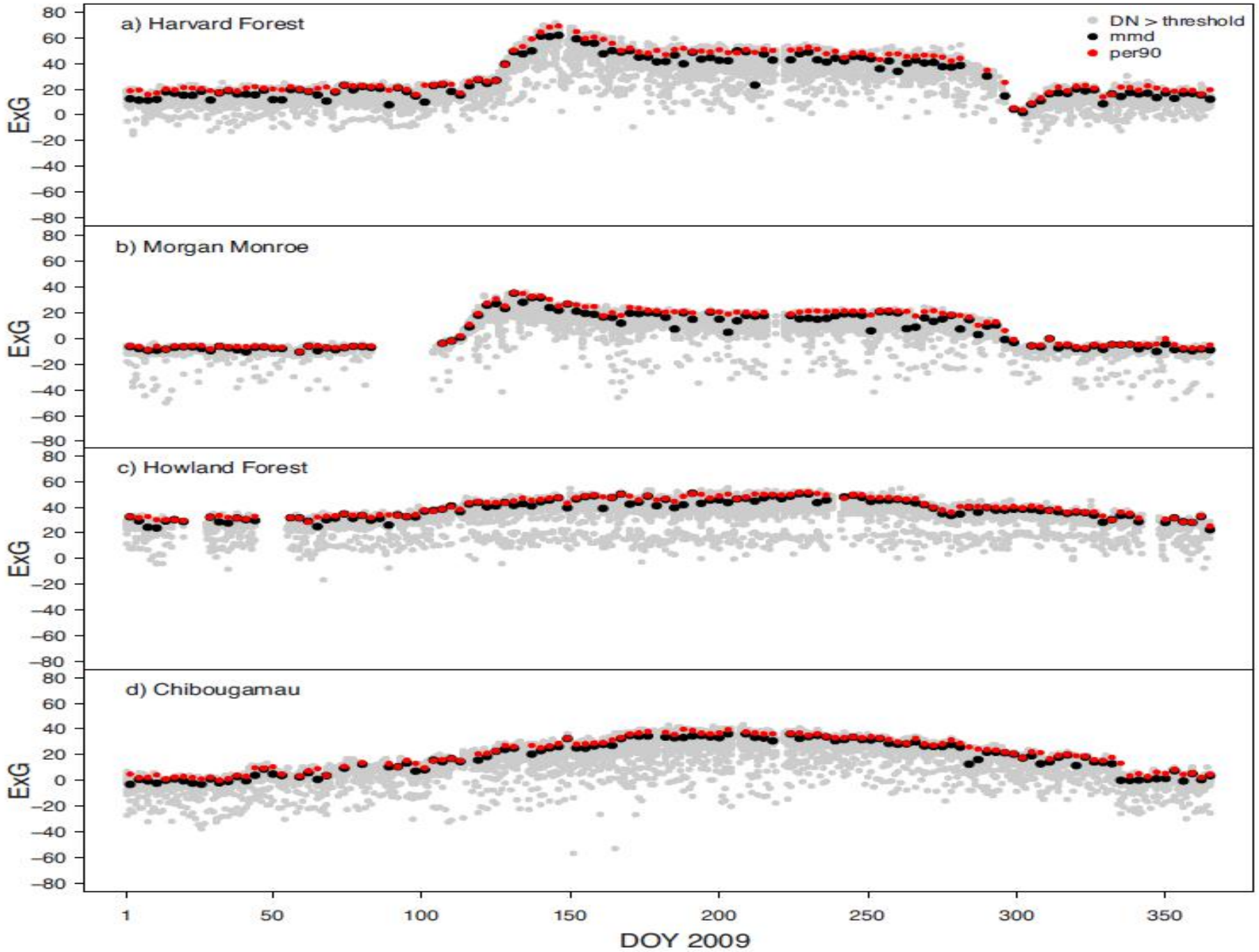


Fig. 5. Three-day green excess

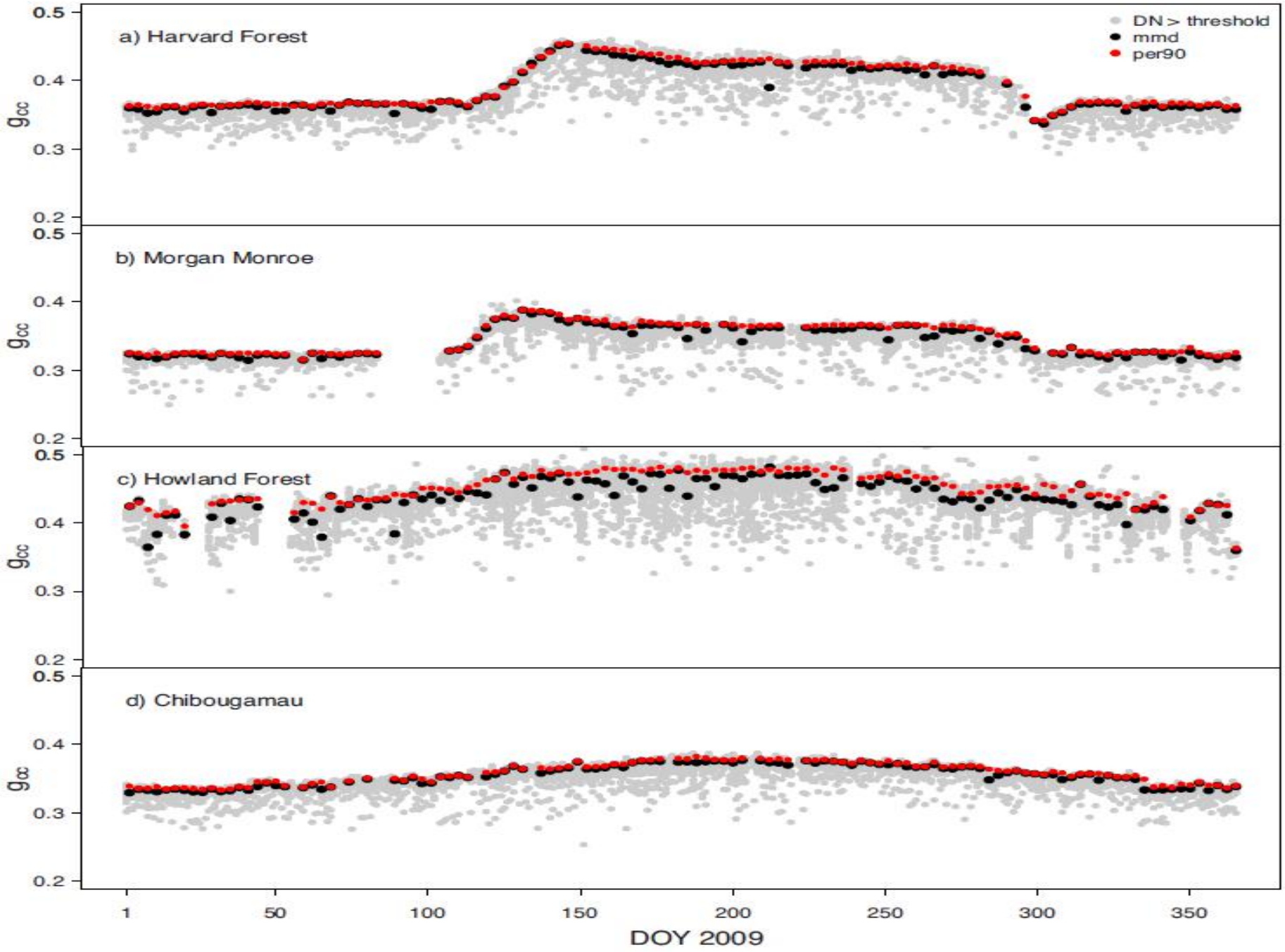


Fig. 6. Three-day green chromatic coordinate

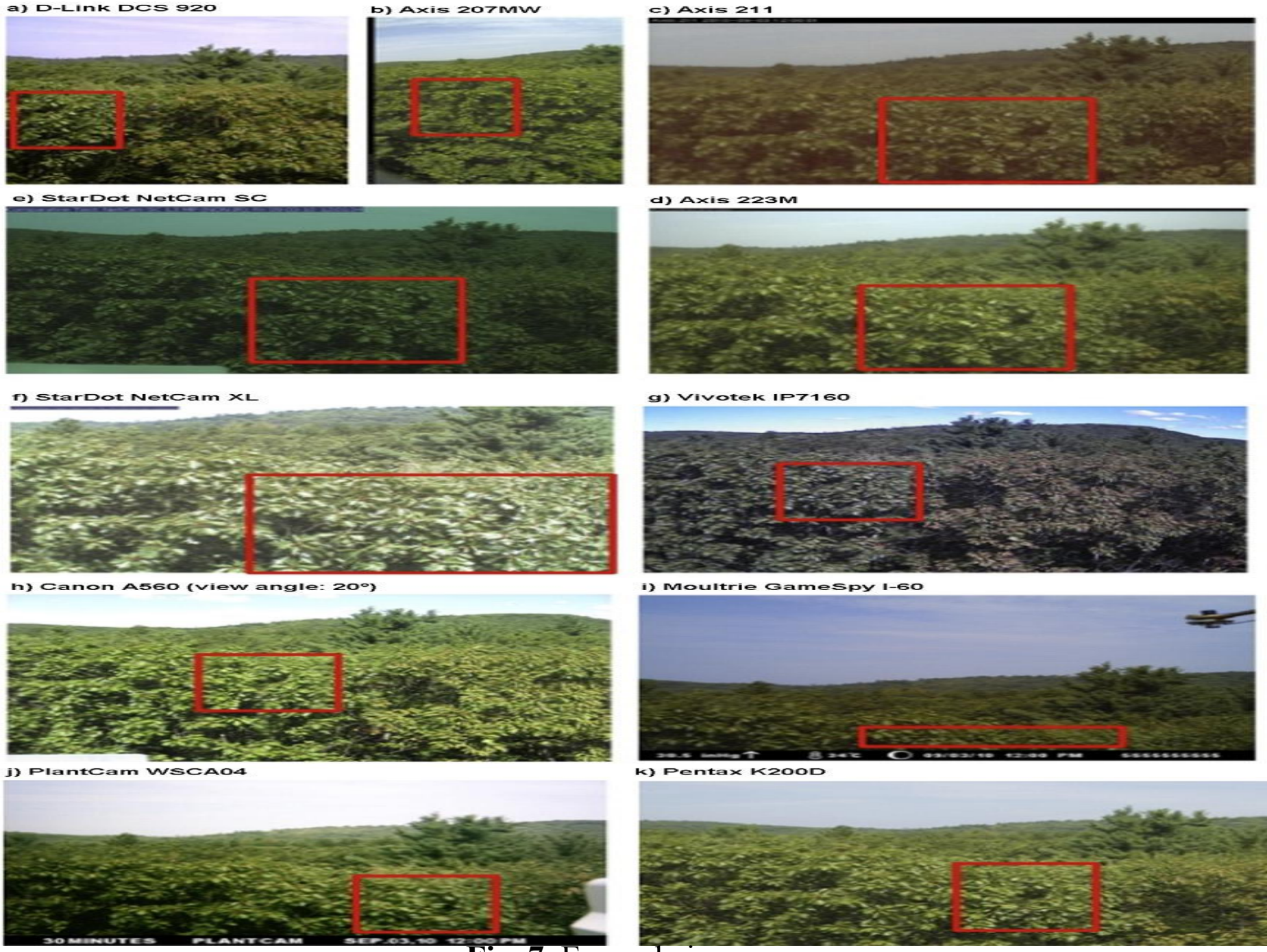
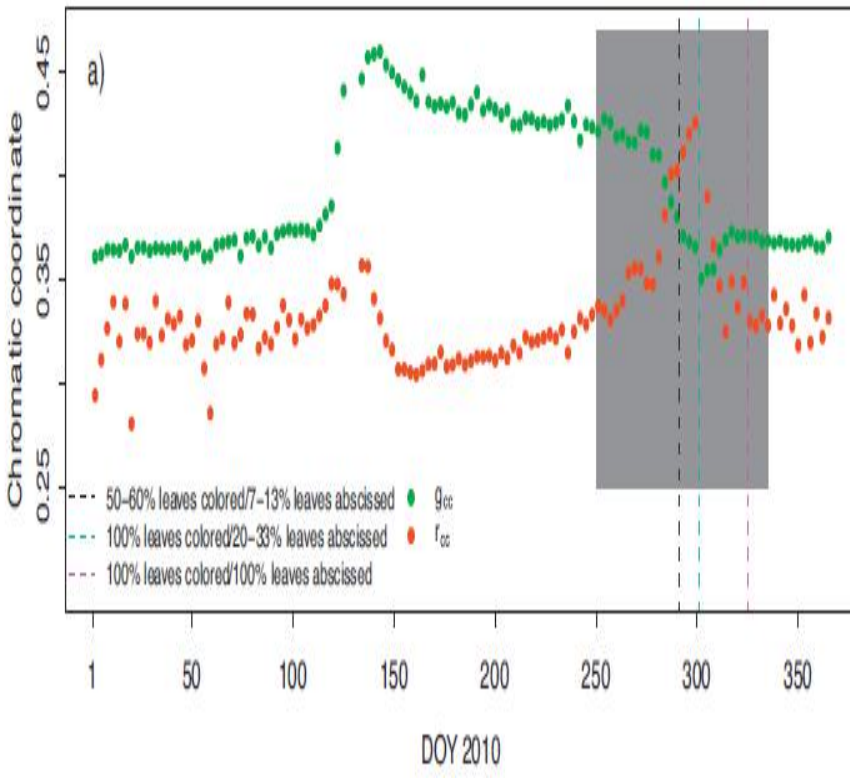


Fig. 7. Example images



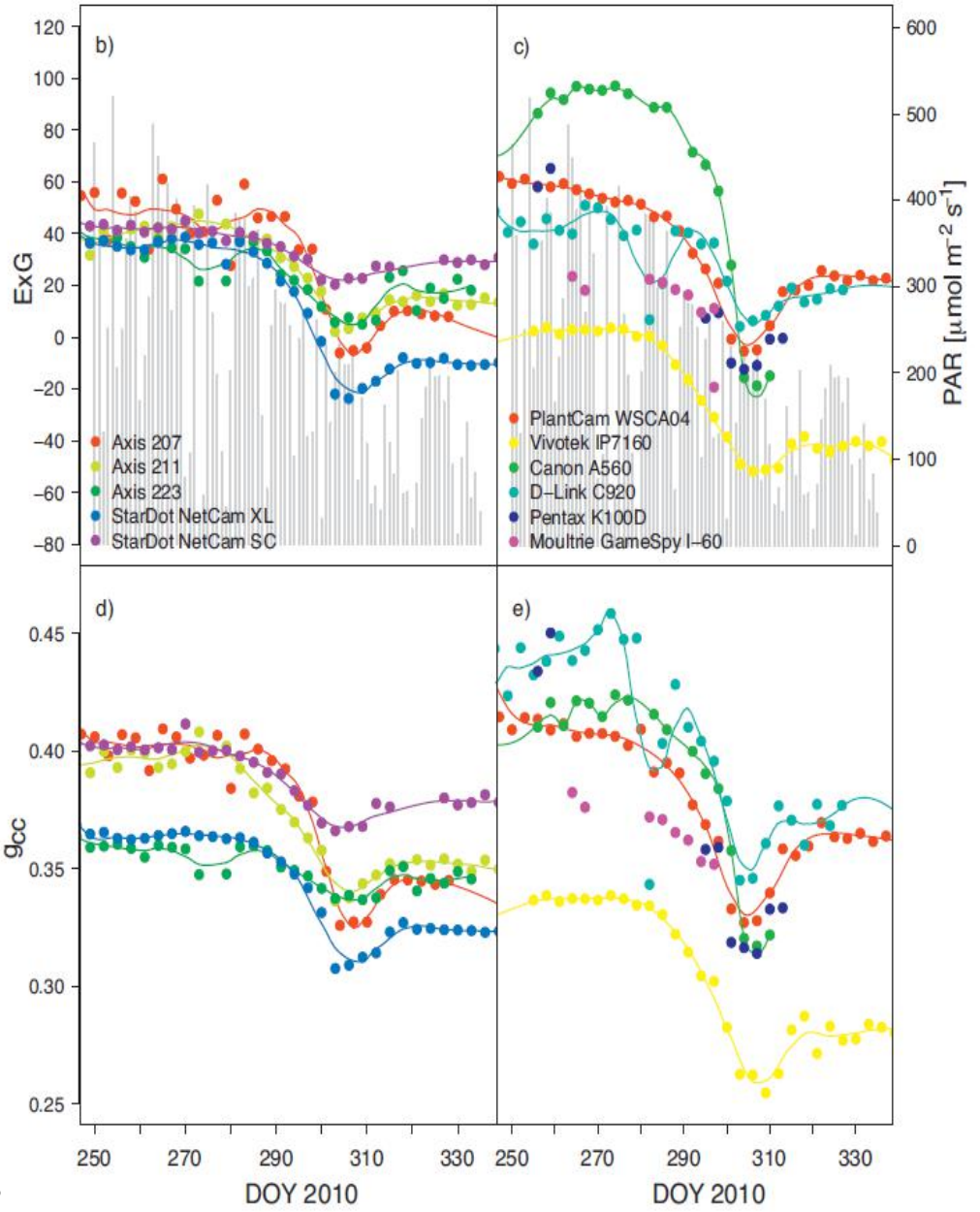


Fig. 8. Three-day (a) green (g_{cc}) and red (r_{cc}) chromatic coordinates at the deciduous-dominated Harvard Forest in 2010 three-day (b) and (c) excess green (ExG) and mean daily incoming photosynthetically active radiation (PAR) as grey-bar backdrop, and (d) and (e) g_{cc} calculated from RGB brightness levels

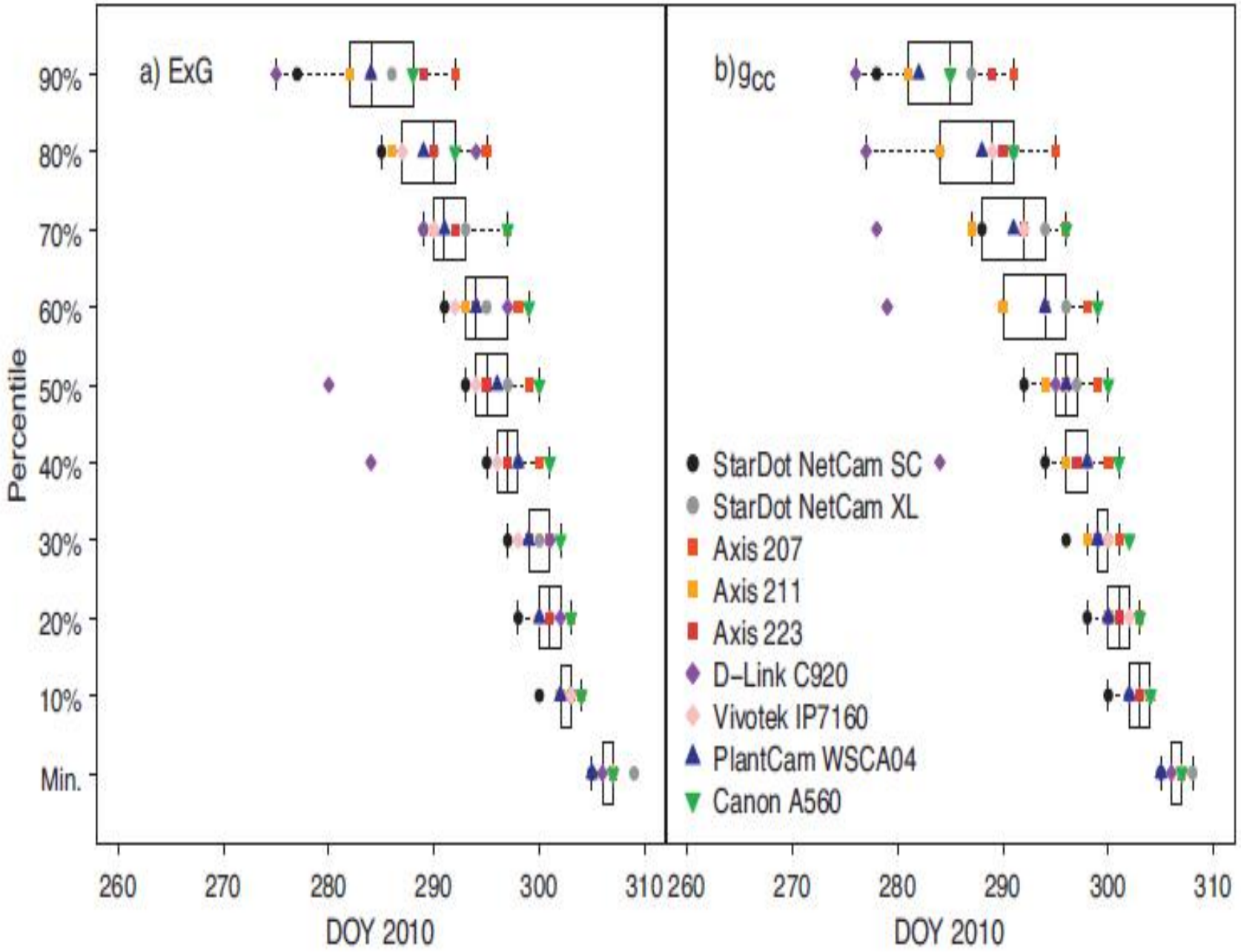


Fig. 9. Comparison of between-digital camera variation

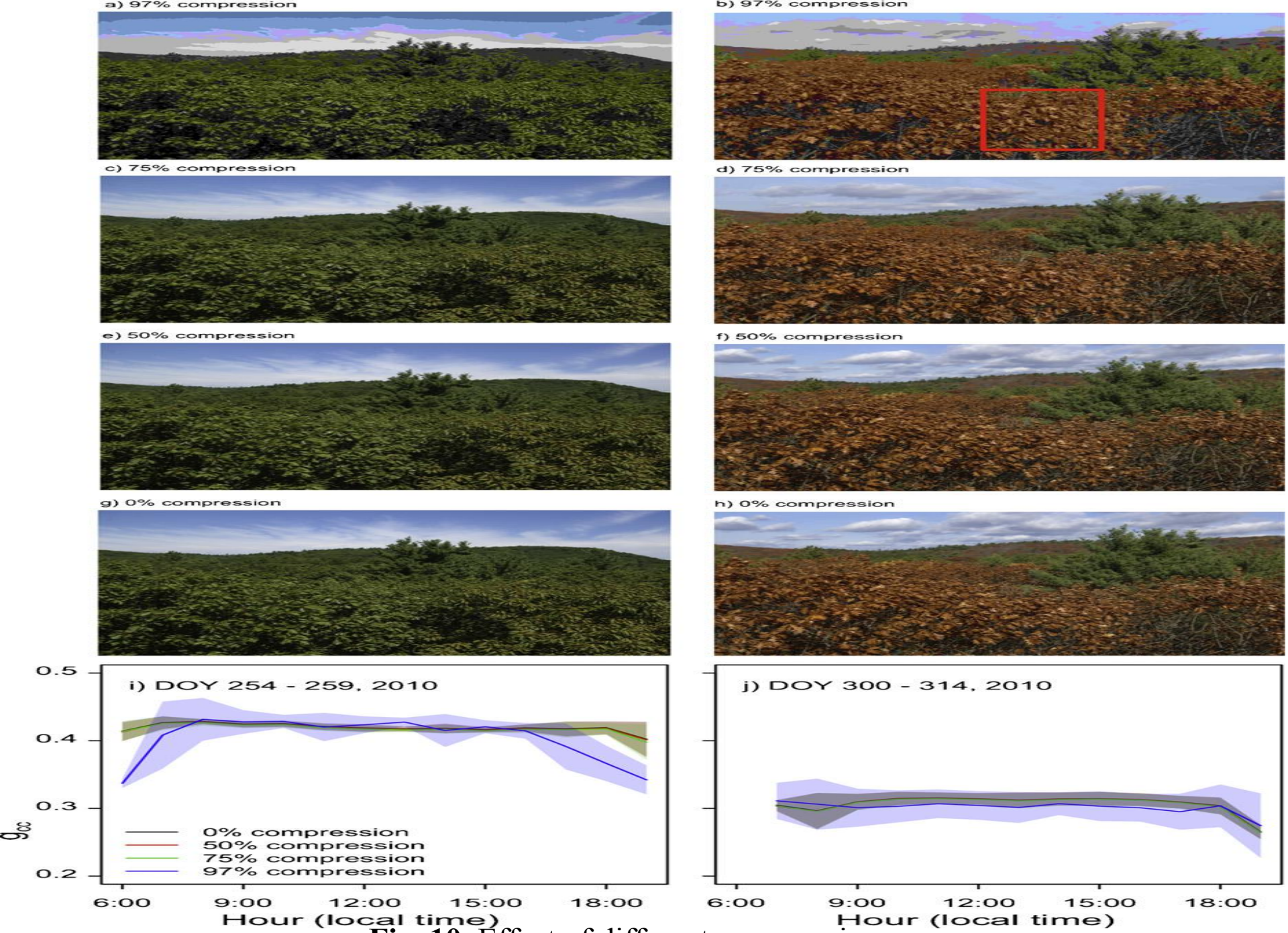


Fig. 10. Effect of different compression

Conclusions

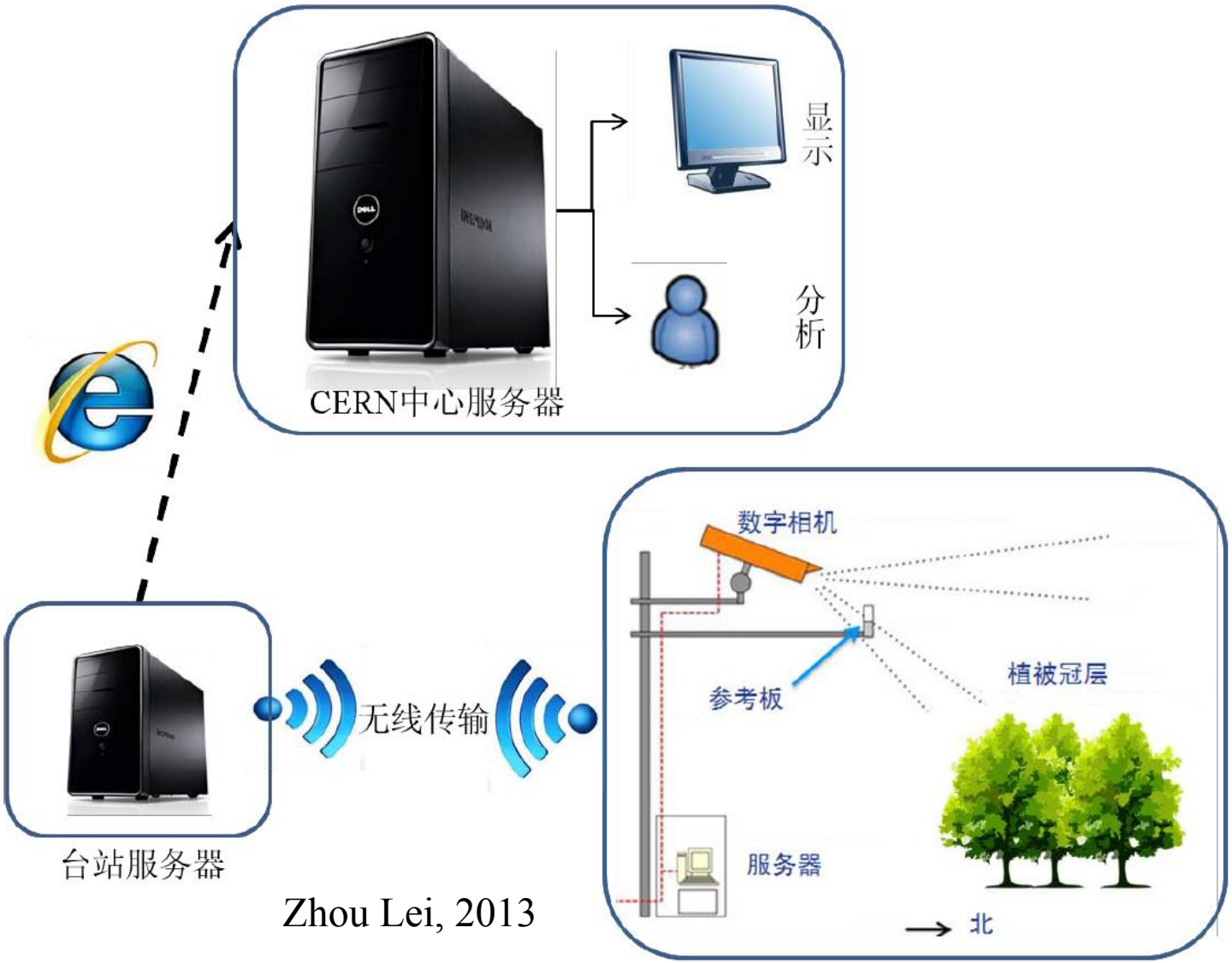
(i) The use of g_{cc} in combination with per90 as a means to characterize the temporal development of forest canopies based on high-frequency digital landscape image archives (e.g., images taken at 30-min intervals during daytime).

(ii) The use of outdoor webcams (e.g., StarDot, Axis or Vivotek) for monitoring of vegetation status with g_{cc} given the appropriate infrastructure (pre-requisites: minimal to medium-level photographic understanding).

(iii) The use of simple "black boxes" such as plant-cams for monitoring of vegetation status with g_{cc} at remote locations lacking appropriate infrastructure (no pre-requisites regarding photographic understanding).

(iv) The installation of reference panels with different levels of grey and/or single-color targets in the digital cameras' FOV (ideally within the forest canopy) to provide a first-order means to assess the continuity and stability of g_{cc} over time.

My idea



Zhou Lei, 2013

My idea

Camera choice:

Colder tones: StarDot NetCam SC 1.3MP, Vivotek IP7160

Warmer tones: Axis 211

Inexpensive webcams: D-Link DCS-920 and Axis 207MW

Bad choice: D−Link C920

Moultrie Game Spy I-60 and the Canon A560 can be operated on external DC power.

Reference: Grasshopper GRAS-14S5C and Grasshopper GRAS-14S5M

Image file format choice: JPEG

Our results do not suggest that any valuable phenological information is lost in the RAW to JPEG conversion.

Problem: The research environment has changed.

Thank you !