プログラム－３


衛星リモートセンシングによる植物フェノロジーのモニタリング
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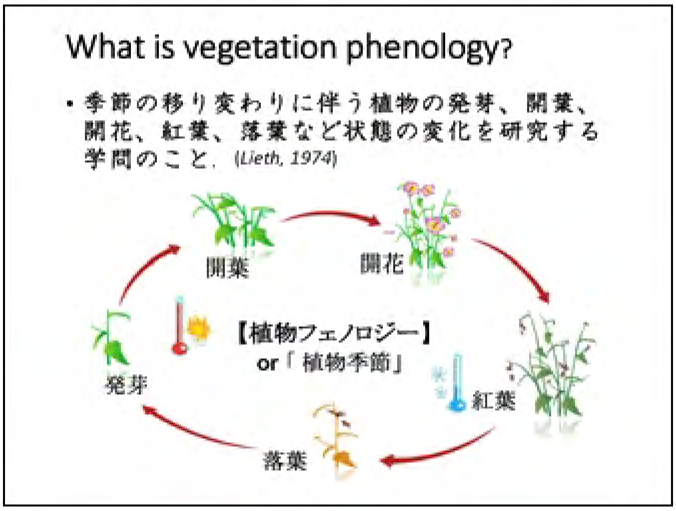
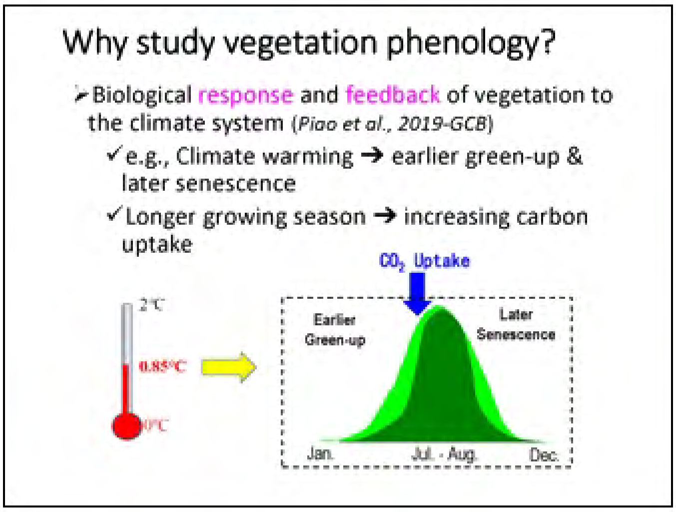
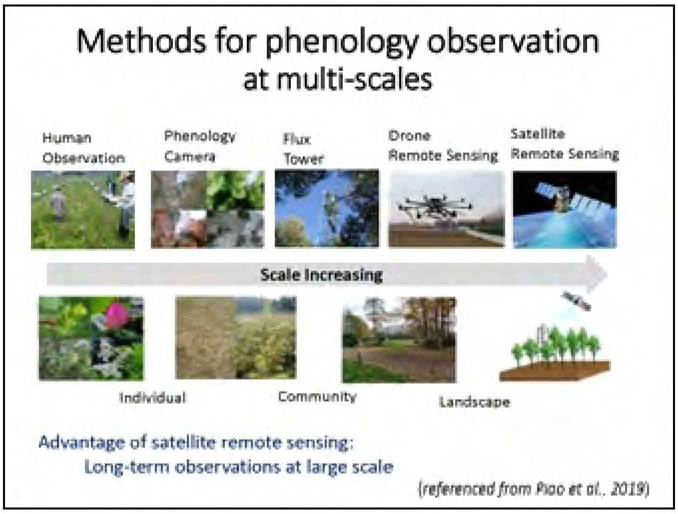
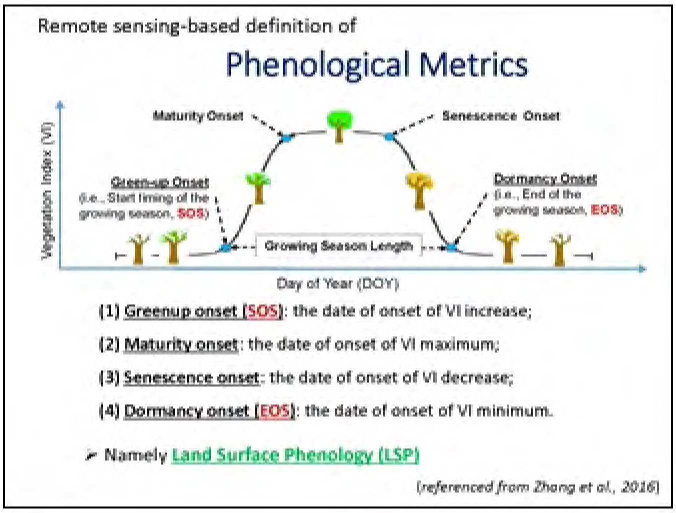
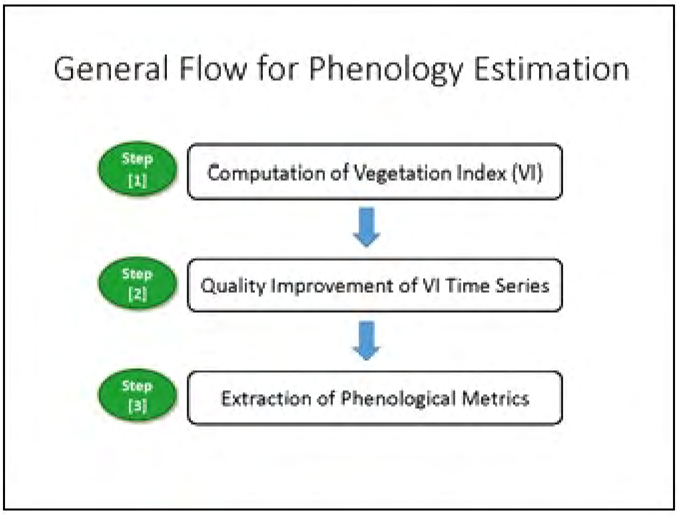
CHIBA UNIVERSITY


What is vegetation phenology?
• 季節の移り変わりに伴う植物の発芽、開葉、開花、紅葉、落葉など状態の変化を研究する学問のこと。(Lieth, 1974)
開葉
開花
【植物フェノロジー】
or「植物季節」
発芽
紅葉
落葉


Why study vegetation phenology?
➢Biological response and feedback of vegetation to the climate system (Piao et al., 2019-GCB)
✓e.g., Climate warming ➔ earlier green-up & later senescence
✓Longer growing season ➔ increasing carbon uptake
CO2 Uptake
2℃
0.85℃
0℃
Earlier Green-up
Later Senescence
Jan.
Jul. - Aug.
Dec.


Methods for phenology observation at multi-scales
Human Observation
Phenology Camera
Flux Tower
Drone Remote Sensing
Satellite Remote Sensing
Scale Increasing
Individual
Community
Landscape
Advantage of satellite remote sensing:
Long-term observations at large scale
(referenced from Piao et al., 2019)


Remote sensing-based definition of
Phenological Metrics
Maturity Onset
Senescence Onset
Green-up Onset
(i.e., Start timing of the growing season, SOS)
Dormancy Onset
(i.e., End of the growing season, EOS)
Growing Season Length
Vegetation Index (VI)
Day of Year (DOY)
(1) Greenup onset (SOS): the date of onset of VI increase;
(2) Maturity onset: the date of onset of VI maximum;
(3) Senescence onset: the date of onset of VI decrease;
(4) Dormancy onset (EOS): the date of onset of VI minimum.
➢ Namely Land Surface Phenology (LSP)
(referenced from Zhang et al., 2016)


General Flow for Phenology Estimation
Step [1]
Computation of Vegetation Index (VI)
Step [2]
Quality Improvement of VI Time Series
Step [3]
Extraction of Phenological Metrics

Step [1] Computation of Vegetation Index (VI)

Step [2] Quality Improvement of VI Time Series

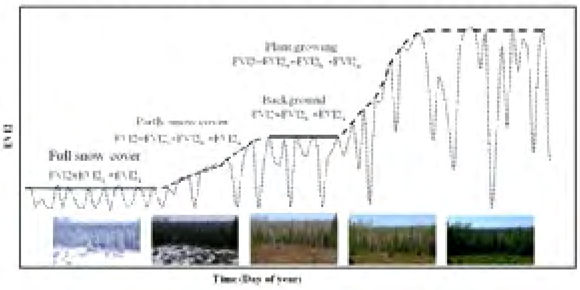
Step [3] Extraction of Phenological Metrics

Conventional Vegetation Indices (VIs)

- NDVI (normalized difference vegetation index)
- EVI (enhanced vegetation index)
- EVI2 (two-band enhanced vegetation index)
- ……

➢ However, these indexes are sensitive to the influence of snow effect on phenology estimation.

春先の雪解けの影響

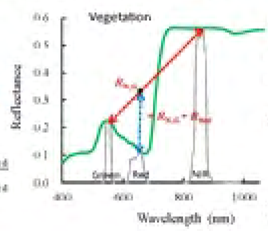


- EVI2 is increased by snowmelt in early spring
- Estimation of SOS will be advanced (Zhang et al., 2015)

Step [1] A novel snow-free vegetation index:

Normalized Difference Greenness Index [NDGI]

$$NDGI = \frac{DVI^*}{R_{N.G} + R_{Red}} = \frac{R_{N.G} - R_{Red}}{R_{N.G} + R_{Red}} = \frac{\varepsilon \times R_{Green} + (1-\varepsilon) \times R_{NIR} - R_{Red}}{\varepsilon \times R_{Green} + (1-\varepsilon) \times R_{NIR} + R_{Red}}$$



波　長：
- ✓ 緑、
- ✓ 赤、
- ✓ 近赤外

➢ 緑と近赤外バンドの間に直線

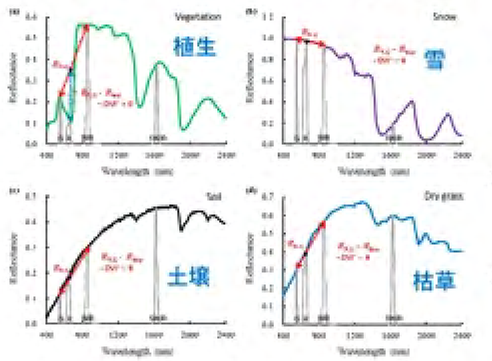
➢ この線と赤バンドの距離

$$NDGI_{MODIS} = \frac{0.65 \times R_{Green} + 0.35 \times R_{NIR} - R_{Red}}{0.65 \times R_{Green} + 0.35 \times R_{NIR} + R_{Red}}$$

➢ NDGI is designed to remove the snow effect on phenology estimation.

(Yang et al., 2019, Remote Sens. Environ.)

Mechanism of NDGI for being snow-free



波　長：
- ✓ 緑
- ✓ 赤
- ✓ 近赤外

➢ 緑と近赤外バンドの間に直線

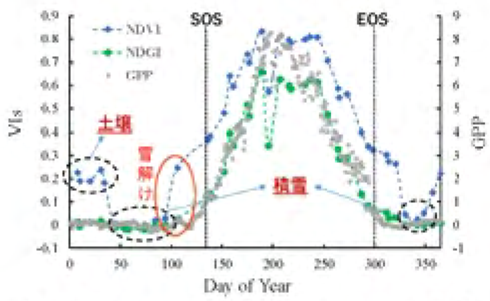
➢ この線と赤バンドの距離

➢ NDGI is almost 'zero' except for green vegetation.

(Yang et al., 2019, Remote Sens. Environ.)

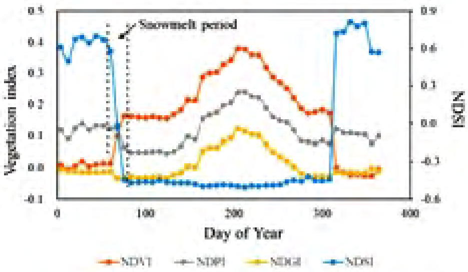
検証結果：時系列の比較

- FLUXNETサイトのCH-Hab（2006年）



➢ 積雪と土壌のNDGI値が同様で、植生の成長プロセスは捉えること

Validation @Grassland of Inner Mongolia (from third party)



- NDGI-based SOS estimations are more reliable than NDVI and NDPI-based SOS (Cao et al., 2020)

Step [1] Computation of Vegetation Index (VI)

Step [2] **Quality Improvement of VI Time Series**

Step [3] Extraction of Phenological Metrics

Limitation of existing filtering methods

- Savitaky-Golay (SG) filter
- Fourier transform
- Wavelet transform
- Whittaker filter
- … …

➢Limitation: cannot deal with continuous gaps (caused by snow, cloud or shadow) within the VI time-series

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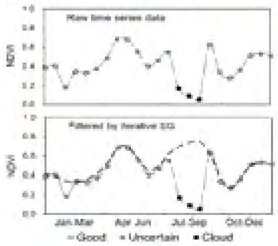
Step [2] A new filtering algorithm:

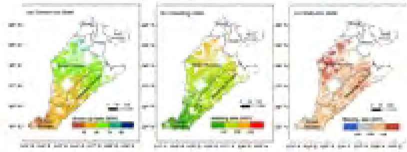
Spatial-Temporal Savitzky-Golay (STSG) filter

➢ Integrates spatiotemporal information with the Savitzky-Golay method

➢ Can address continuous missing data in the VI time series

(Cao, …, Yang, 2018, Remote Sens. Environ.)





- Applied to estimate winter wheat phenology in North China plain (Wu, Yang*, et al., 2019, Remote Sens.)

Step [1] Computation of Vegetation Index (VI)

Step [2] Quality Improvement of VI Time Series

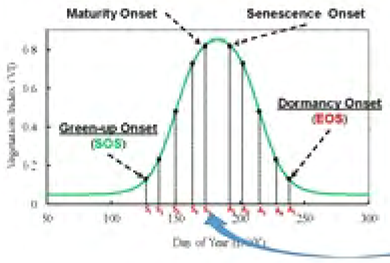
Step [3] **Extraction of Phenological Metrics**

Step [3] A widely-used phenology extraction method:

Double Logistic Function-based method

➢ Double Logistic Function (**DLF**):

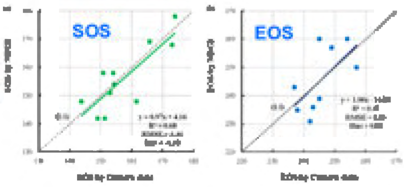
$$NDGI(DOY) = NDGI_w + (NDGI_{MAX} - NDGI_w) \times \left(\frac{1}{1+e^{m1\cdot(DOY-n1)}} + \frac{1}{1+e^{m2\cdot(DOY-n2)}} - 1 \right)$$



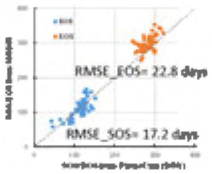
➢ Extracted Phenological Metrics

Phenology based on NDGI + DLF

- Time-lapse camera
（ツンドラ，6 サイト）



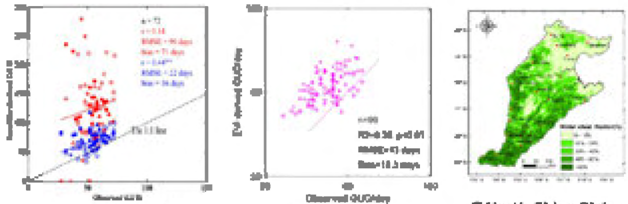
- PhenoCam sites
（森林，9 サイト）



➢ Satisfactory accuracies have been obtained.

Poor performances for croplands

➢ E.g., for winter wheat phenology estimation

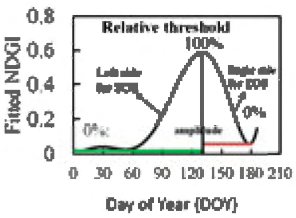


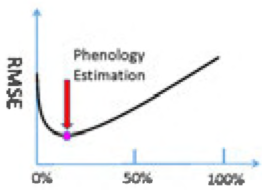
Guo et al. (2019)　Wang et al. (2017)　@North China Plain

- Large discrepancies between field measurements and satellite estimations (by logistic function) of winter wheat SOS

Relative Threshold method

recalibrated for winter wheat

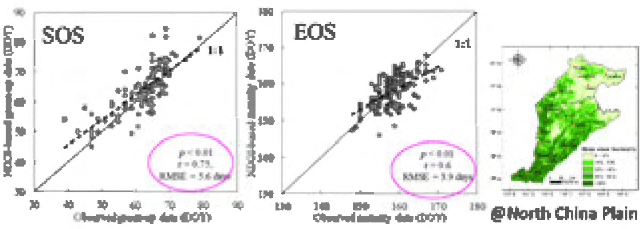




- A data-driven empirical method may not be globally applicable

(Wu, Yang*, et al., 2019, Remote Sens.)

Improved performances for winter wheat

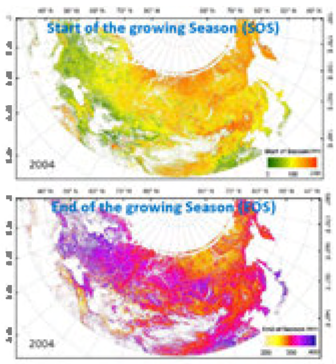


- Good agreements between field measurements and satellite estimation of winter wheat SOS and EOS

(Wu, Yang*, et al., 2019, Remote Sens.)

LSP衛星プロダクトの試　作

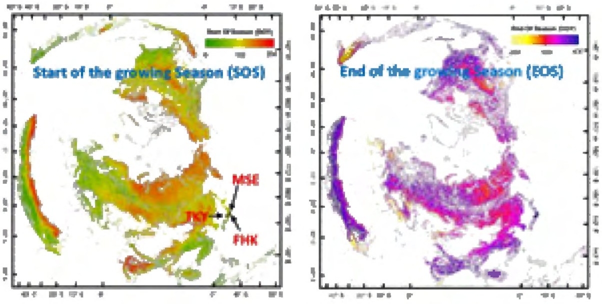
MODIS data-based Estimation



➢ Input data: MOD09A1 (8-day, 500-m reflectance)
➢ Period: 2001-2018
➢ Areas: >30°N, Asia &Europe

✓ Reasonable spatial and temporal patterns were observed for SOS and EOS.

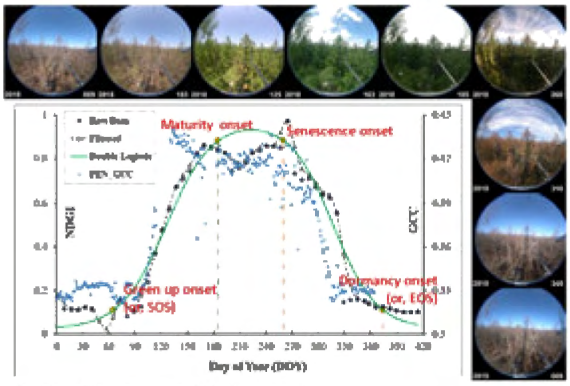
GCOM-C data-based Estimation



- Input data: GCOM-C G4C (8-day, 250-m BRF)
- Period: 2018
- Areas: parts of the North-Hemisphere

Validation by PEN data: FHK site (富士北麓)

(Deciduous Needleleaf Forest)

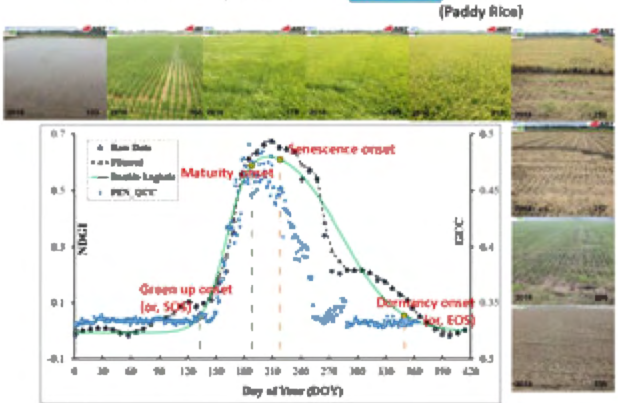


- SOS= 069 (GCOM-C) vs. SOS= 094 (PEN by GCC)
- EOS= 374 (GCOM-C) vs. EOS= 358 (PEN by GCC)

✓ Spring is better than Autumn

Validation by PEN data: MSE site (真瀬水田)

(Paddy Rice)

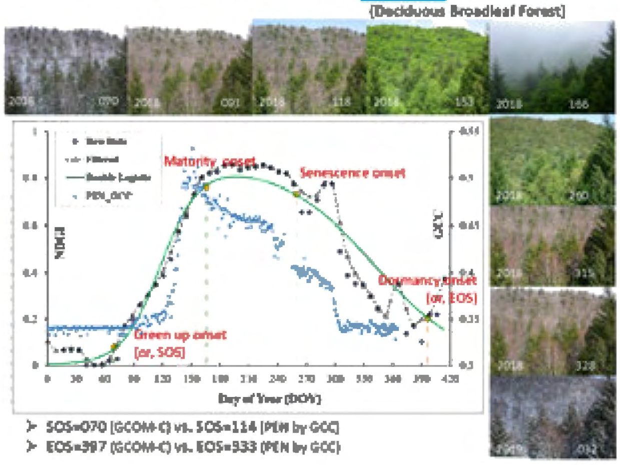


- SOS= 133 (GCOM-C) vs. SOS= 143 (PEN by GCC)
- EOS= 350 (GCOM-C) vs. EOS= 270 (PEN by GCC)

✓ Spring is better than Autumn

Validation by PEN data: TKY site (高山広葉樹林)

(Deciduous Broadleaf Forest)



- SOS=070 (GCOM-C) vs. SOS=114 (PEN by GCC)
- EOS=397 (GCOM-C) vs. EOS=333 (PEN by GCC)

LSP衛星プロダクトの開発の現状

- Developed a new vegetation index (NDGI) and a new filtering method (STSG) for LSP estimation
- Collected phenology field observation datasets (PhenoCam and PEN)
- Generated preliminary LSP products based on MODIS and GCOM-C data

今後の取り組み

- Development of global phenology extraction method (combined ones for different ecosystems?)
- Generation of LSP products based on different satellite data (e.g., Sentinel-2 @10m, GCOM-C @250m, MODIS @500m, Himawari-8/9 @1000m)
- Integration with Earth System Models (e.g., JAMSTEC teams)
- Application to Biodiversity studies as one of the Essential Biodiversity Variables (EBVs)

➢共同研究は大歓迎！

Thank you for your attention