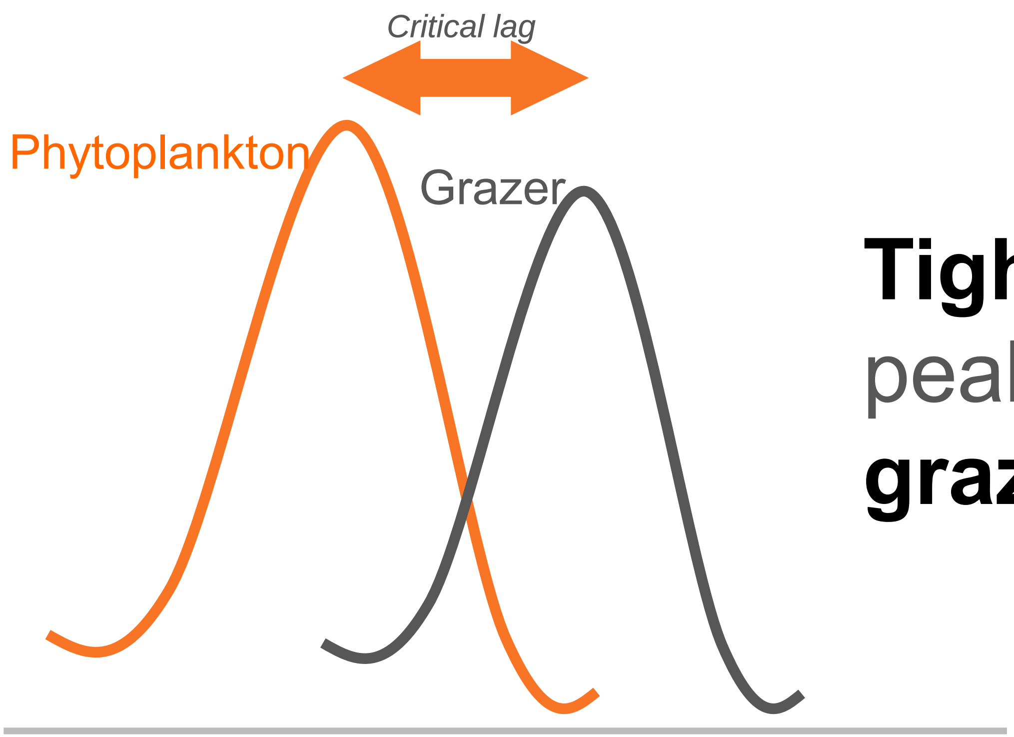
Variability of chlorophyll-*a* bloom timing associated with physical forcing in the East Sea/Sea of Japan (1998-2014)

PICES-2015 Annual Meeting

Soonmi Lee, Sinjae Yoo, Young Baek Son
Jeju International Marine Science Center for Research & Education
Korea Institute of Ocean Science and Technology

Why **phenology** is important?

The study of the timing of periodic biological events



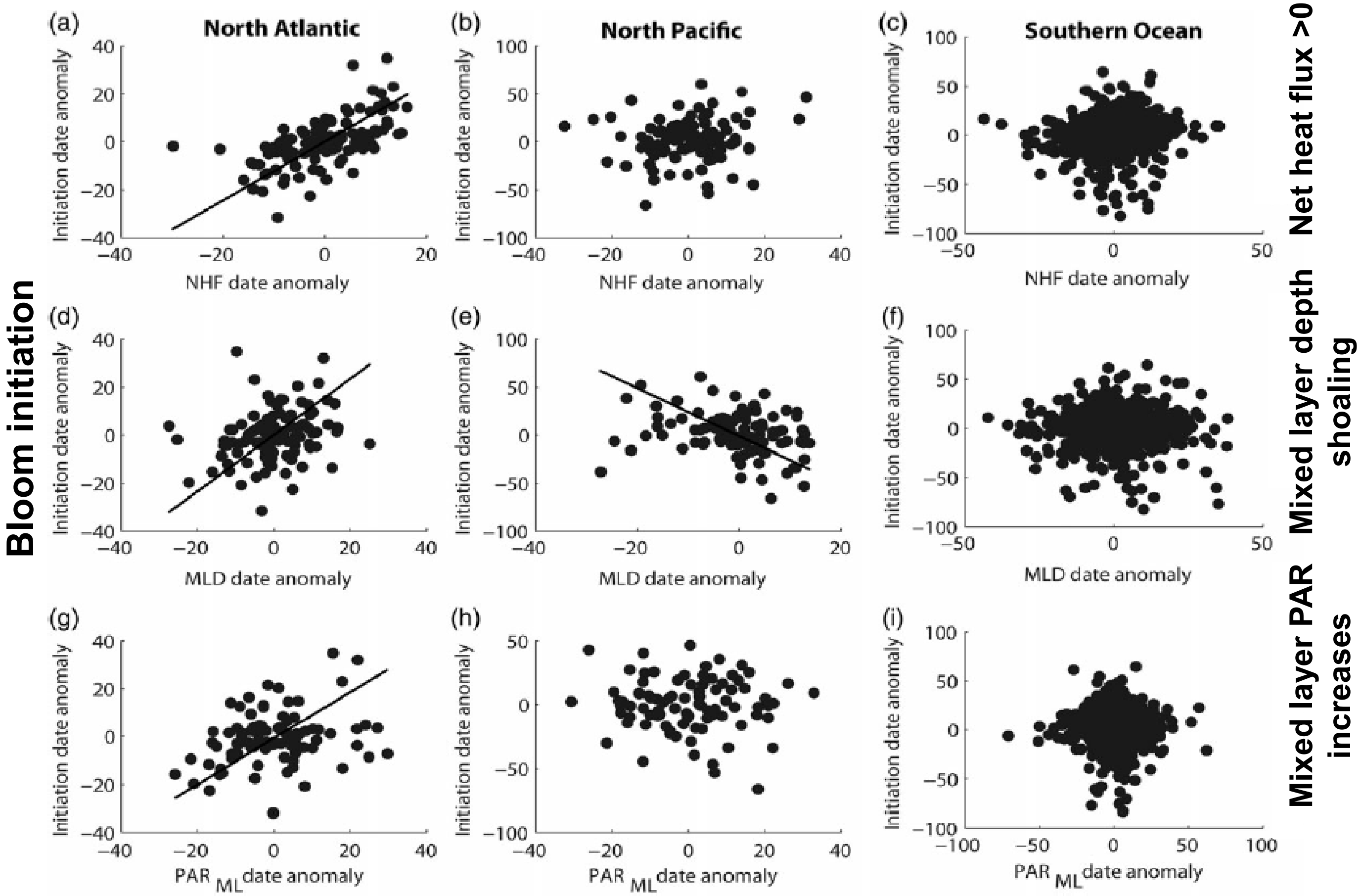
Match-mismatch hypothesis
[Cushing, 1990]

Tight linkage to the peak abundance in **grazers** [Longhurst, 2007]

byelggi@kiost.ac.kr

Introduction

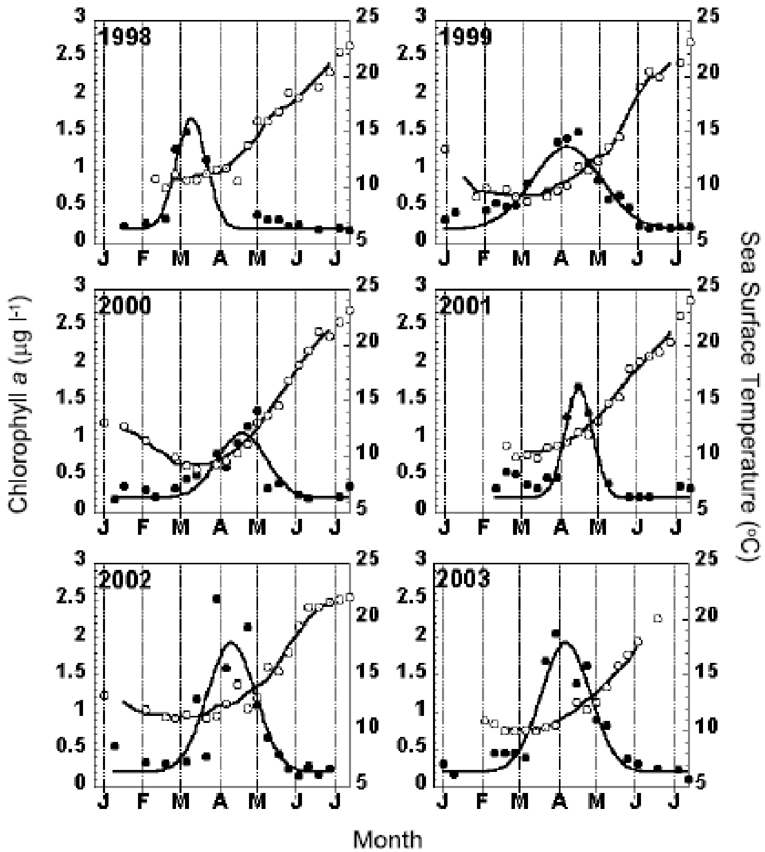
Global ocean (for subpolar regions)



[Cole *et al.*, 2015]

Introduction

The East Sea/Sea of Japan



[Yamada and Ishizaka, 2006]

Period: 1982~2002

1. Using Gaussian curve

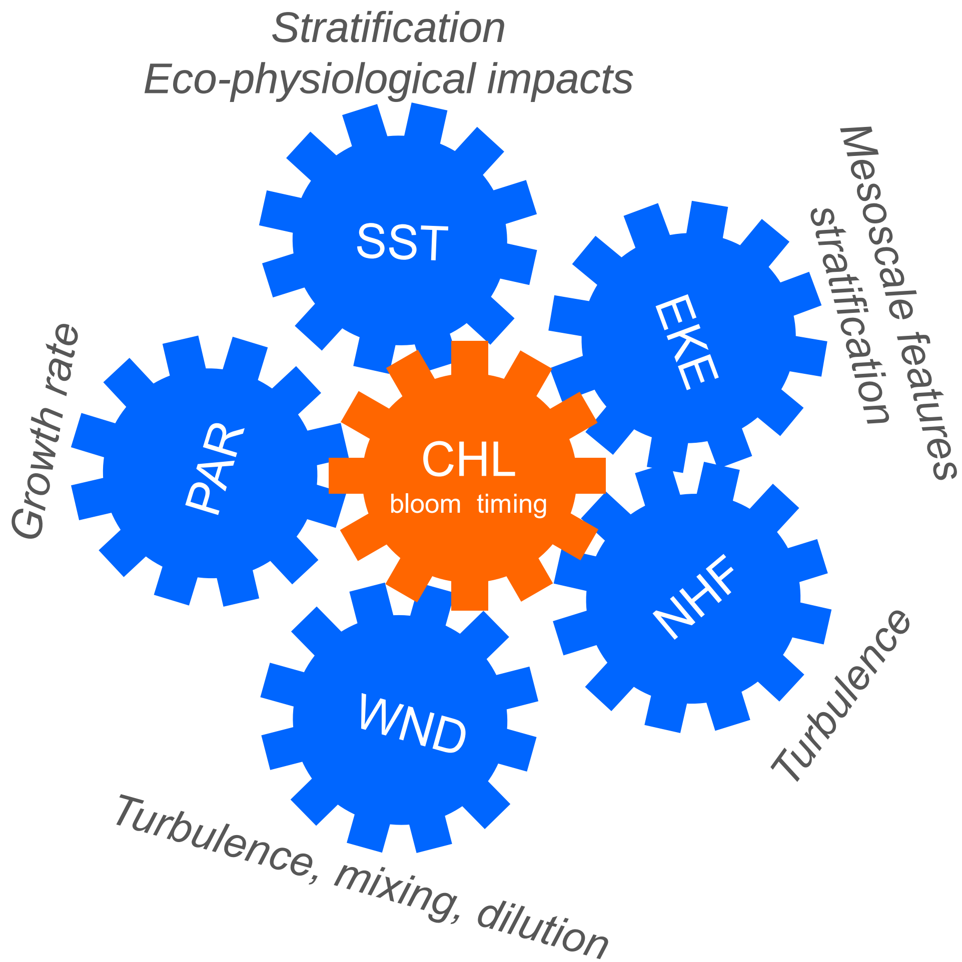
2. Spring bloom initiation
   ∝ average wind speed in February and March

3. Spring peak timing
   ∝ 1/stratification strength

Key Questions

- ***Is there any significant relationship between bloom timing metrics?***

- ***What physical drivers influence the relationship between bloom timing metrics?***



※ bloom timing metrics: bloom initiation, peak timing, duration, termination, peak magnitude

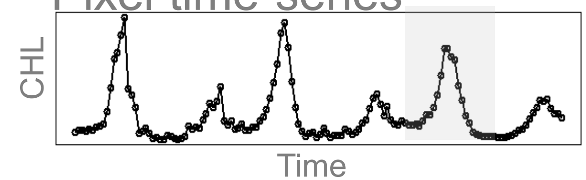
byelggi@kiost.ac.kr

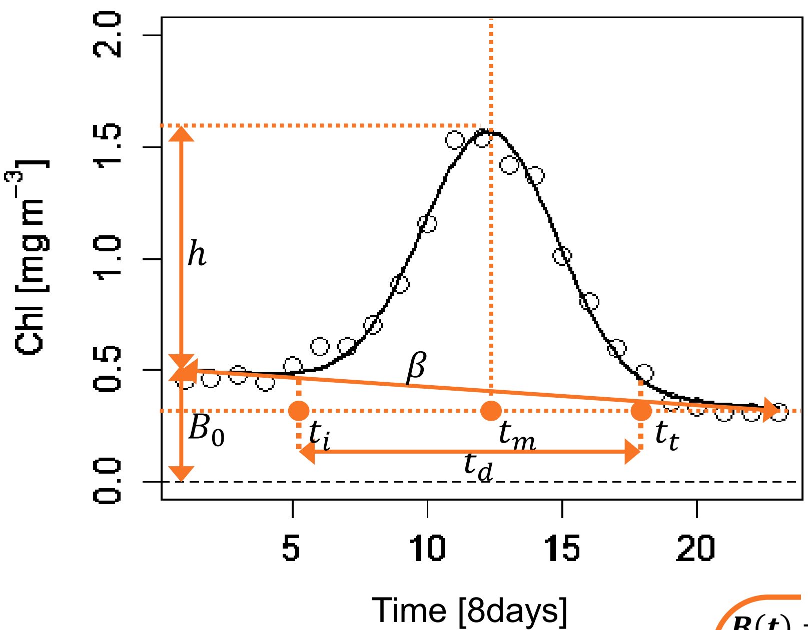
Data & Methods

Definition

Feature extraction using shifted Gaussian Curve

Pixel time-series





$$B(t) = B_0 + \beta \times t + h \times exp^{\frac{-(t-t_m)^2}{2\sigma^2}}$$

$$t_i = t_m - (-2 \times log0.2)^{\frac{1}{2}} \times \sigma$$
$$= t_m - 1.76 \times \sigma$$

$$t_d = 2 \times (t_m - t_i)$$

$$t_t = t_i + t_d$$

$$t_p = B_0 + \beta \cdot t + h$$

[Zhai *et al.*, 2011]

Bloom timing matrics of Gaussian Curve

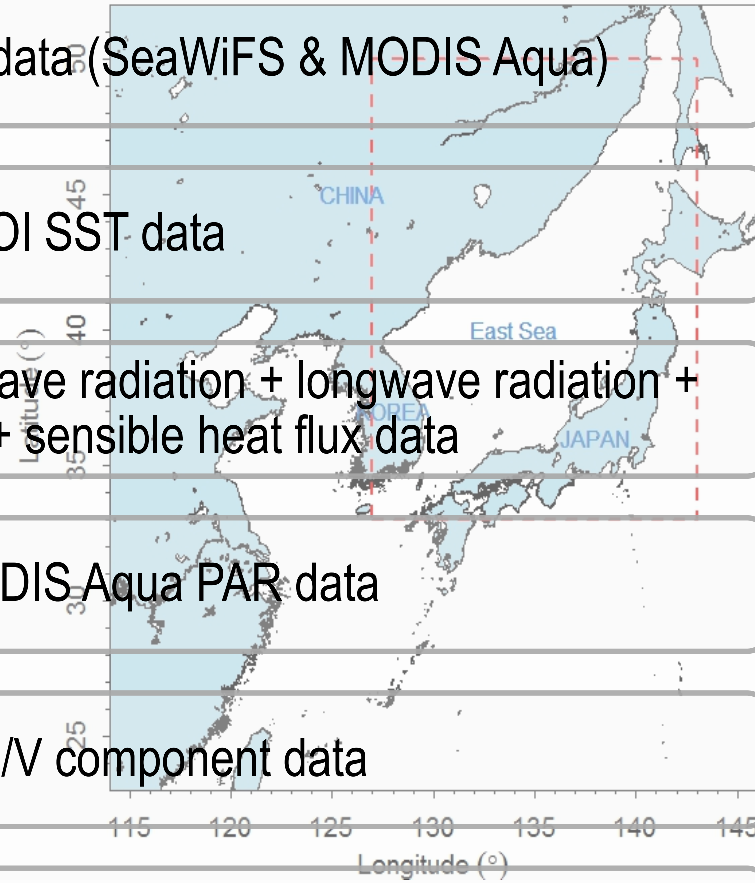
$B(t)$ = *shifted Gaussian function*
B_0 = *backgourd value of chl*
$\beta \times t$ = *additive linear term*
h = *amplitude of bloom*
σ = *width of chl peak*
t = *time*

t_i = *time when chl* $\left(B(t) - (B_0 + \beta \times t)\right)$ *reaches 20% of bloom amplitude*
t_m = *time when bloom peaks*
t_t = *time when chl(") decreases to 20% of bloom amplitude*
t_d = *period from initiation to termination*
t_p = *peak intensity*

KIOST
byelggi@kiost.ac.kr

Data sources

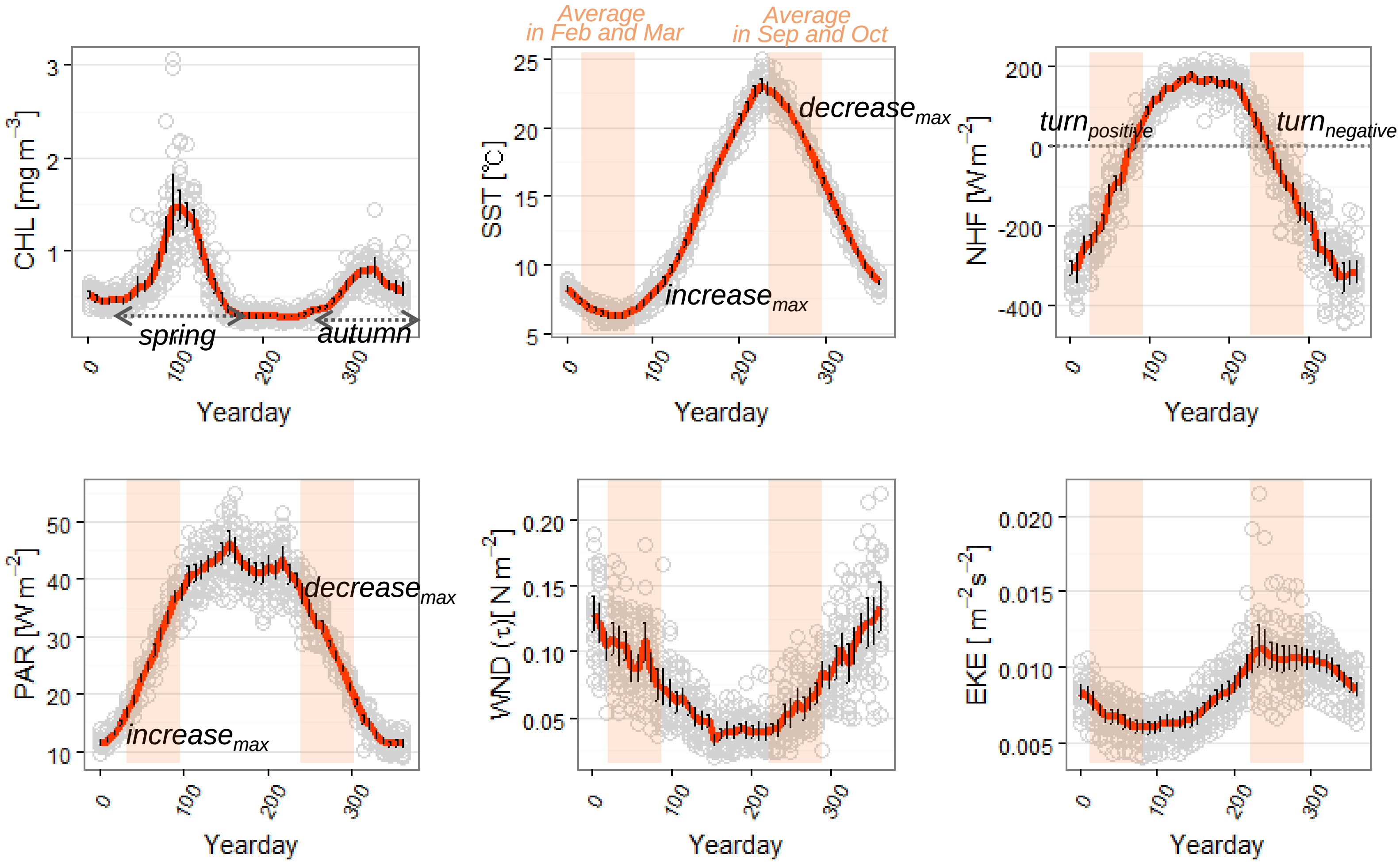
0.25degree, 8days, 1998~2014



Chlorophyll *a* (CHL[mgm^{-3}])	• Oc4v6 merged data (SeaWiFS & MODIS Aqua)
Sea Surface Temperature (SST[°C])	• NOAA AVHRR-OI SST data
Net Heat Flux (NHF [$W\ m^{-2}$])	• ECMWF shortwave radiation + longwave radiation + latent heat flux + sensible heat flux data
Photosynthetically Available Radiation (PAR[$W\ m^{-2}$])	• SeaWiFS & MODIS Aqua PAR data
Wind Stress (WND τ[Nm^{-2}])	• ECMWF wind U/V component data
Eddy Kinetic Energy (EKE[m^2s^{-2}])	• AVISO U/V component data

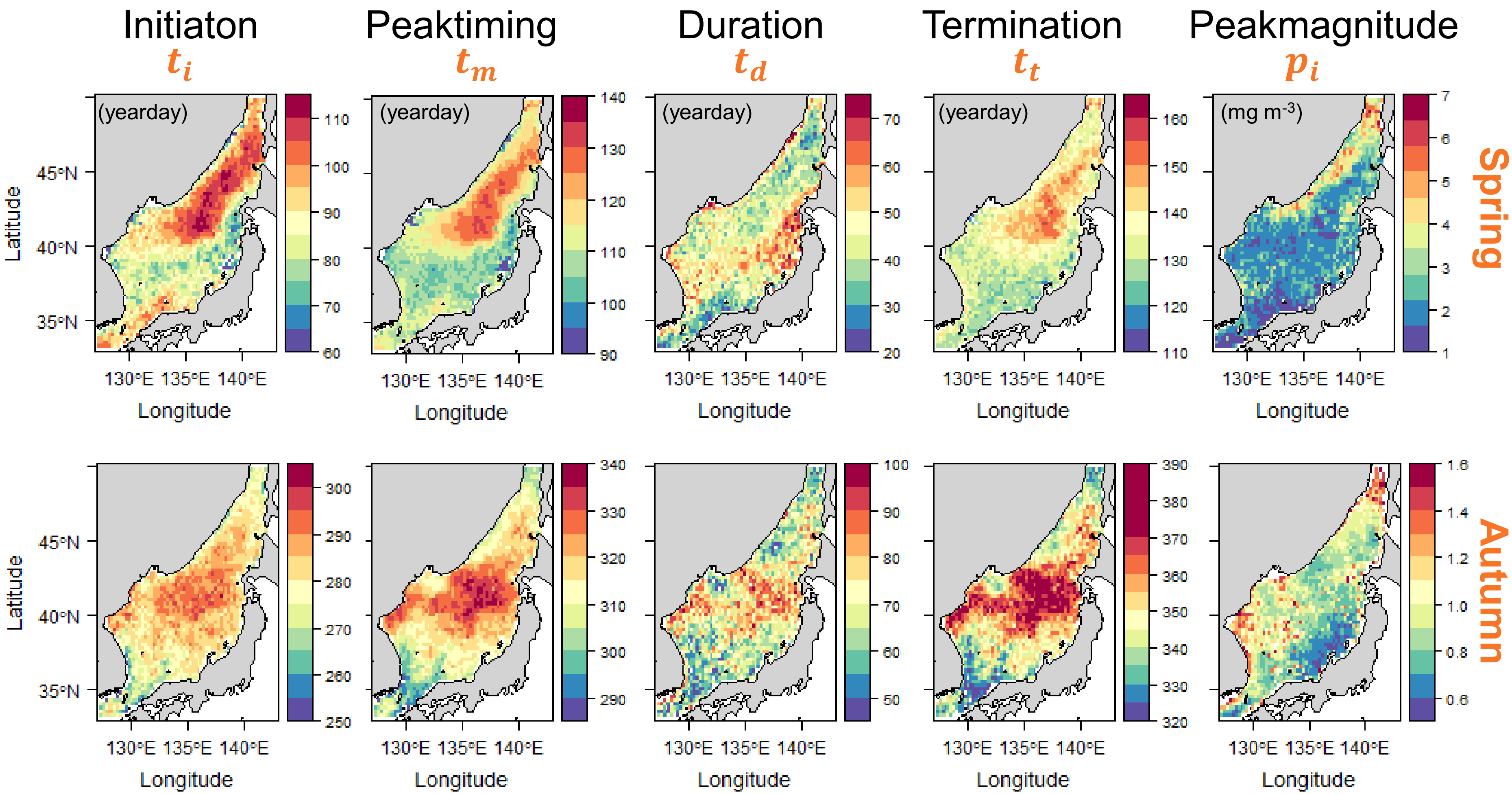
byelggi@kiost.ac.kr

Annual mean


Average
in Feb and Mar
Average
in Sep and Oct
CHL [mg m^-3]
spring
autumn
SST [℃]
decrease_max
increase_max
NHF [W m^-2]
turn_positive
turn_negative
PAR [W m^-2]
decrease_max
increase_max
WND (τ)[N m^-2]
EKE [m^-2 s^-2]
Yearday

Result & Discussion

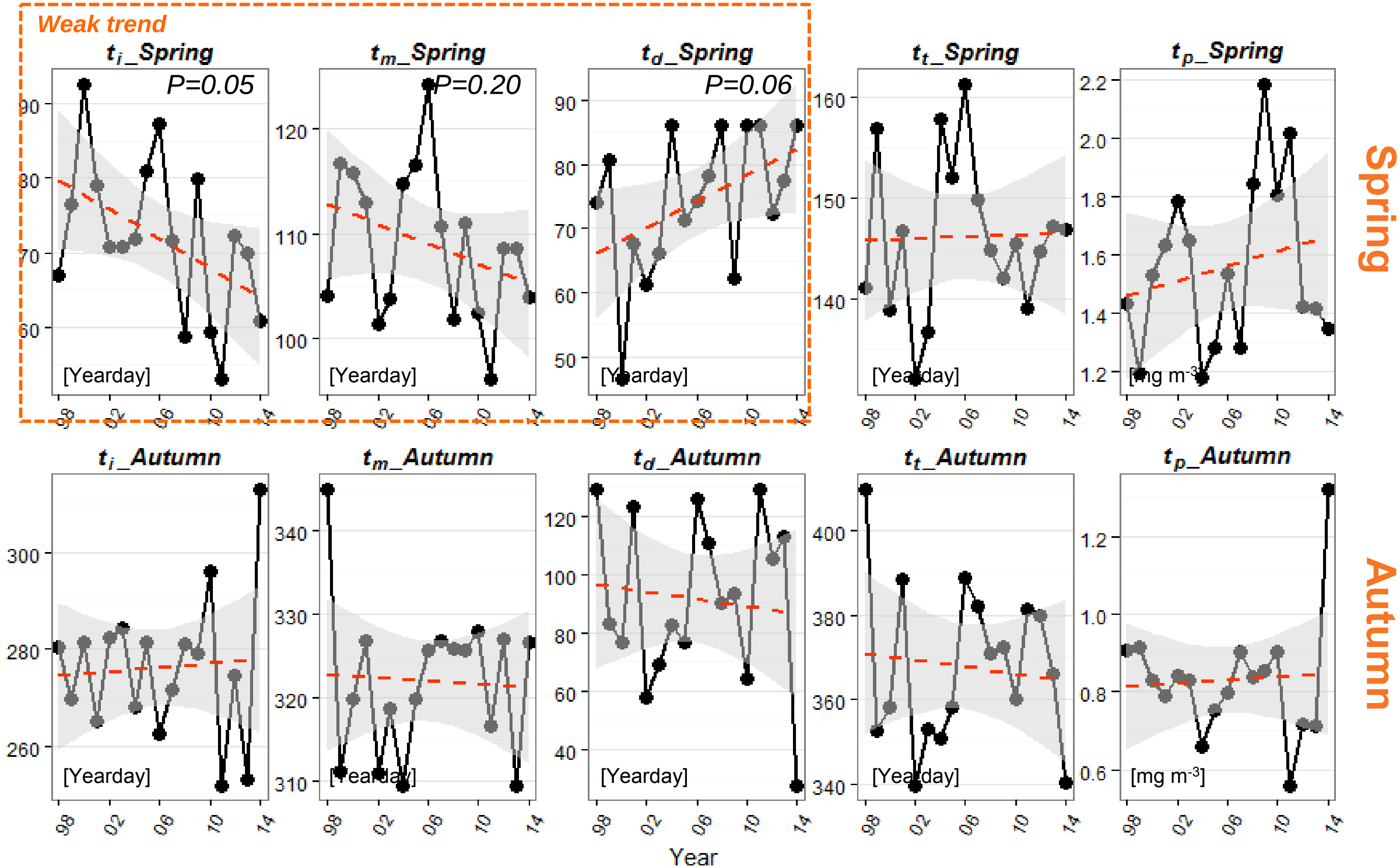
Spatial distribution: climatological mean



byelggi@kiost.ac.kr

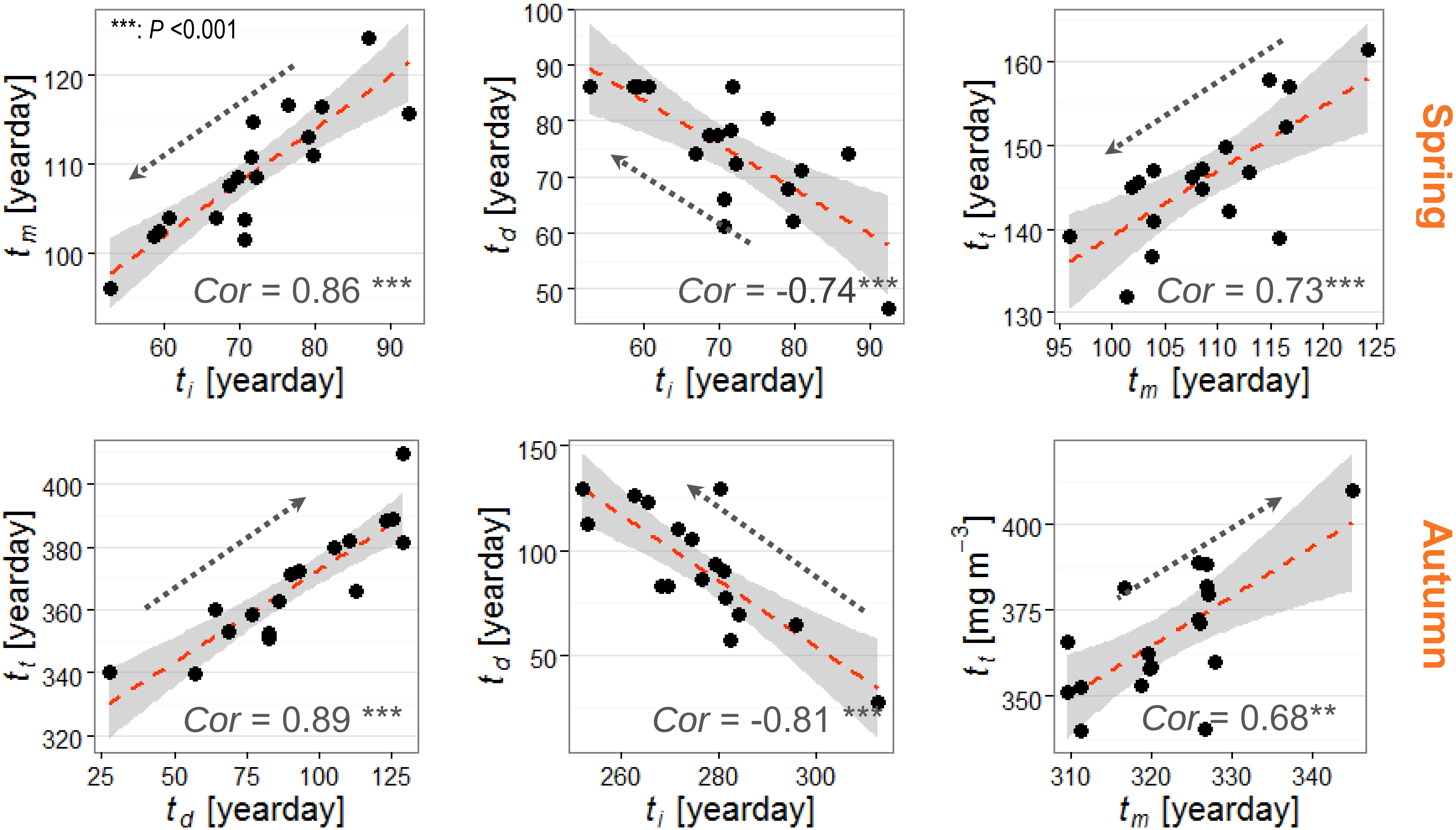
Result & Discussion

Interannual variability



Result & Discussion

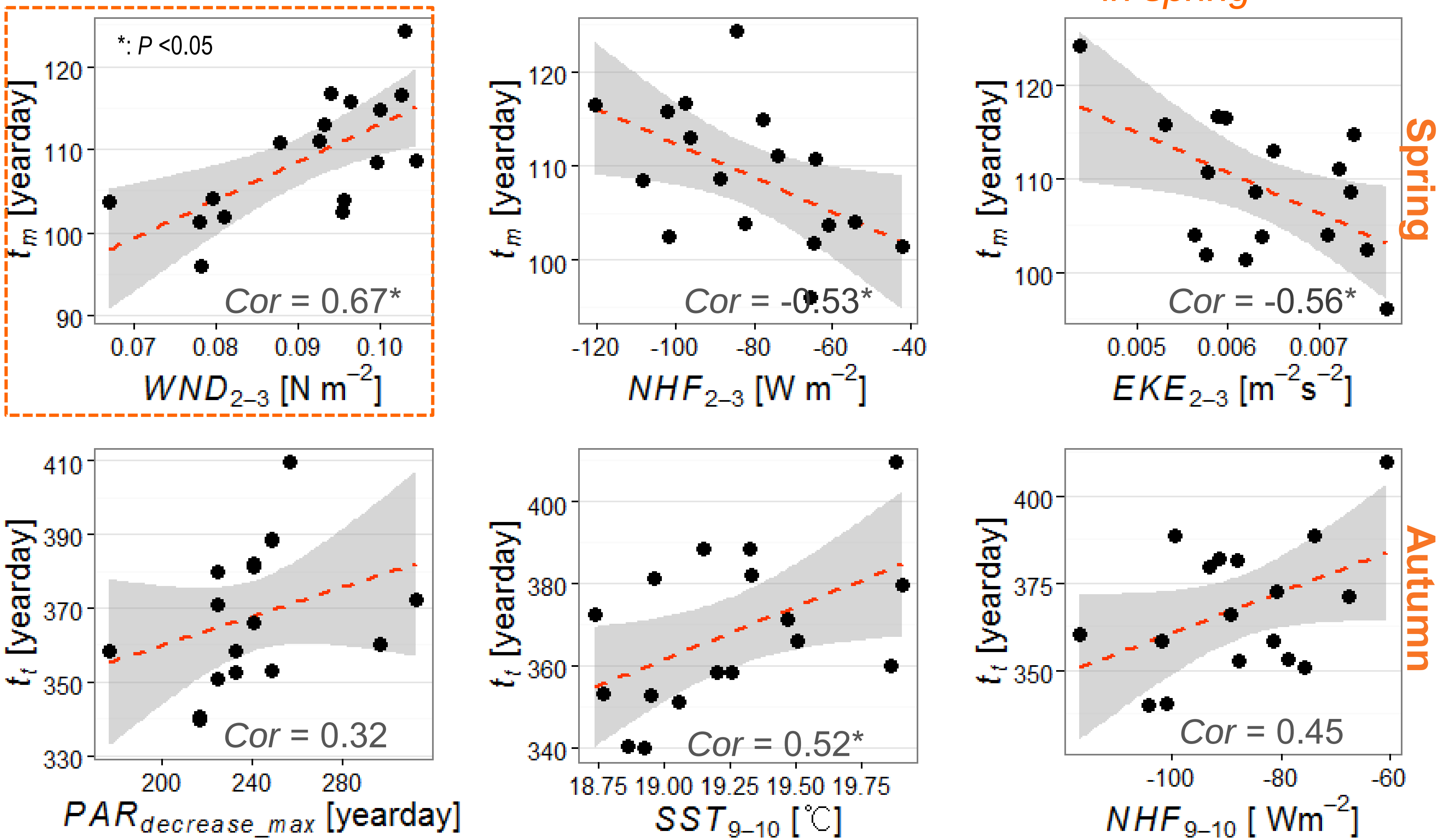
Relationship between bloom timing metrics



Result & Discussion

The effect of physical factors

Strong correlation in spring



byelggi@kiost.ac.kr

Summary

◂◂ advanced ◂—▸ longer
▸▸ delayed ▸—◂ shorter

	Spring	Autumn
	In the East Sea (1998~2014)	
Temporal Trend	Weak trend t_i ◂◂ t_t ◂◂ t_d ◂—▸	No remarkable trend
Q1. Relationship between bloom timing metrics	$t_i \propto \frac{1}{t_d}$ $t_i \propto t_m$	$t_t \propto t_d$ $t_t \propto t_m$
Q2. Influence of physical forcing	$t_i, t_m \propto WND_{2-3}$ faster and strong stratification: earlier blooms?	*weak correlation* The biotic impact is more important?

byelggi@kiost.ac.kr

Further thought

✓ Why does the earlier bloom tend to be longer lasting?

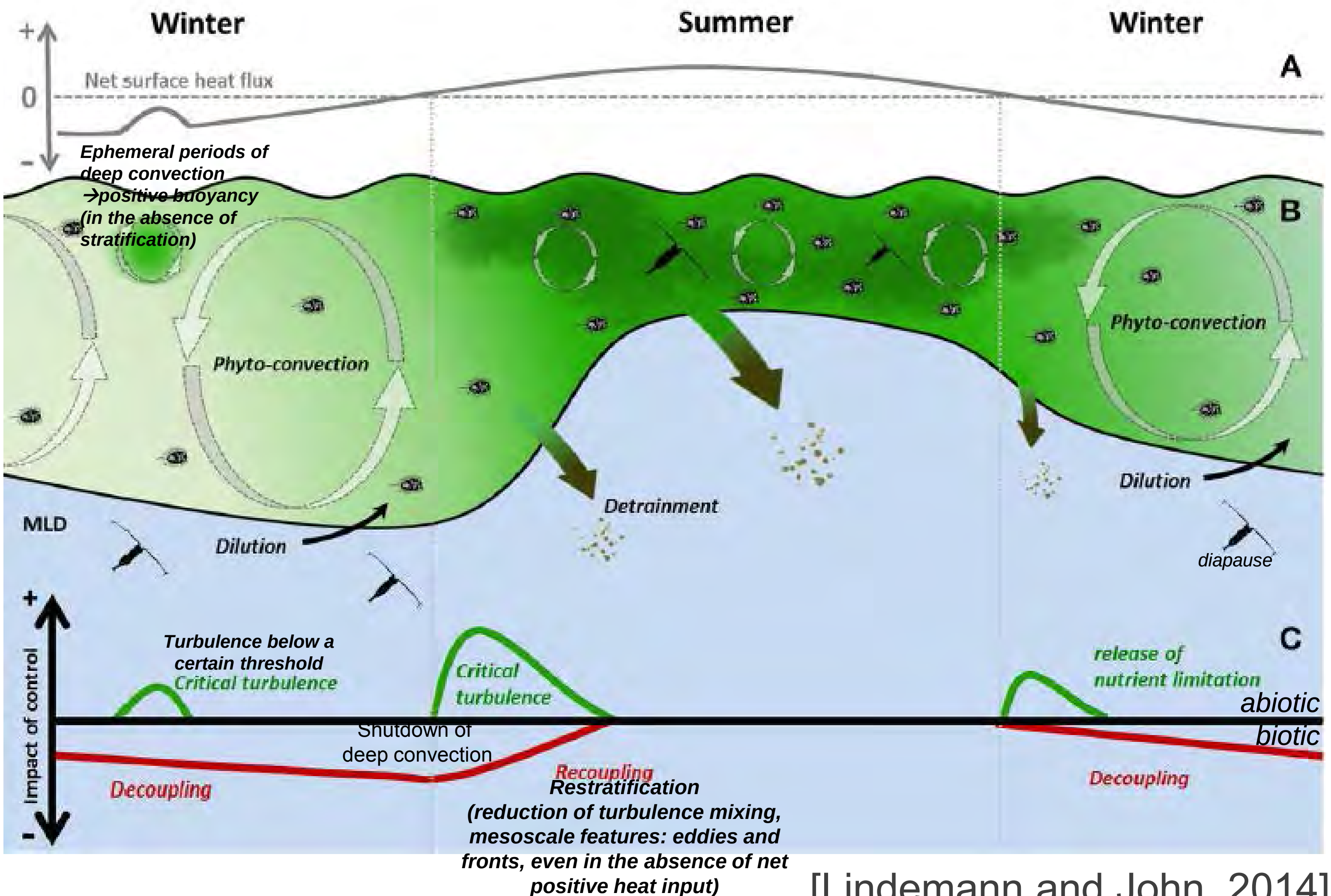
✓ We expected that if the bloom initiation is advanced, the peak magnitude is lower. But, why is there no relationship between them?

✓ Is the wind stress in Feb and Mar really going to decrease? If not, how can we explain the trend of bloom initiation in the East Sea?

byelggi@kiost.ac.kr

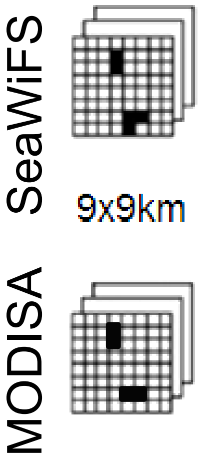
Thank You!!

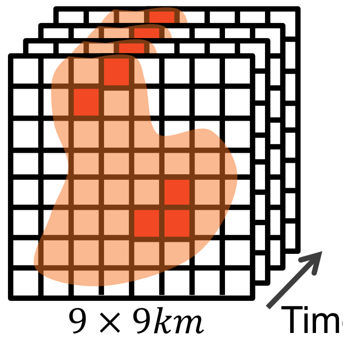
Introduction



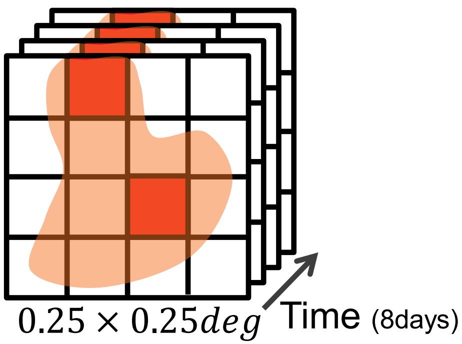
[Lindemann and John, 2014]

Analysis flow

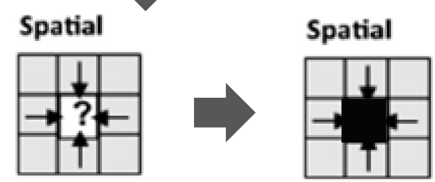




Creating merged data (oc4v6)

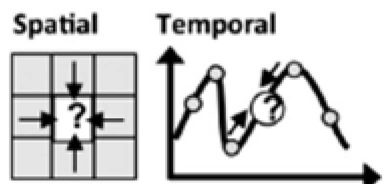


Spatial binning



(chl<50, mean-1.96•sd≤x≤mean-1.96•sd, n≥3)
95% of all observations

Spatial filtering



(spatial: interval value using mean
(horizontally, vertically, diagonally), n ≥ 4)

Gab Filling

Parameters

t_i, t_m, t_d, t_t, t_p

using shifted Gaussian Curve

- t_i *bloom initiation*
- t_m *peak timing*
- t_d *bloom duration*
- t_t *bloom termination*
- t_p *peak magnitude*

[Racault *et al.*, 2014]

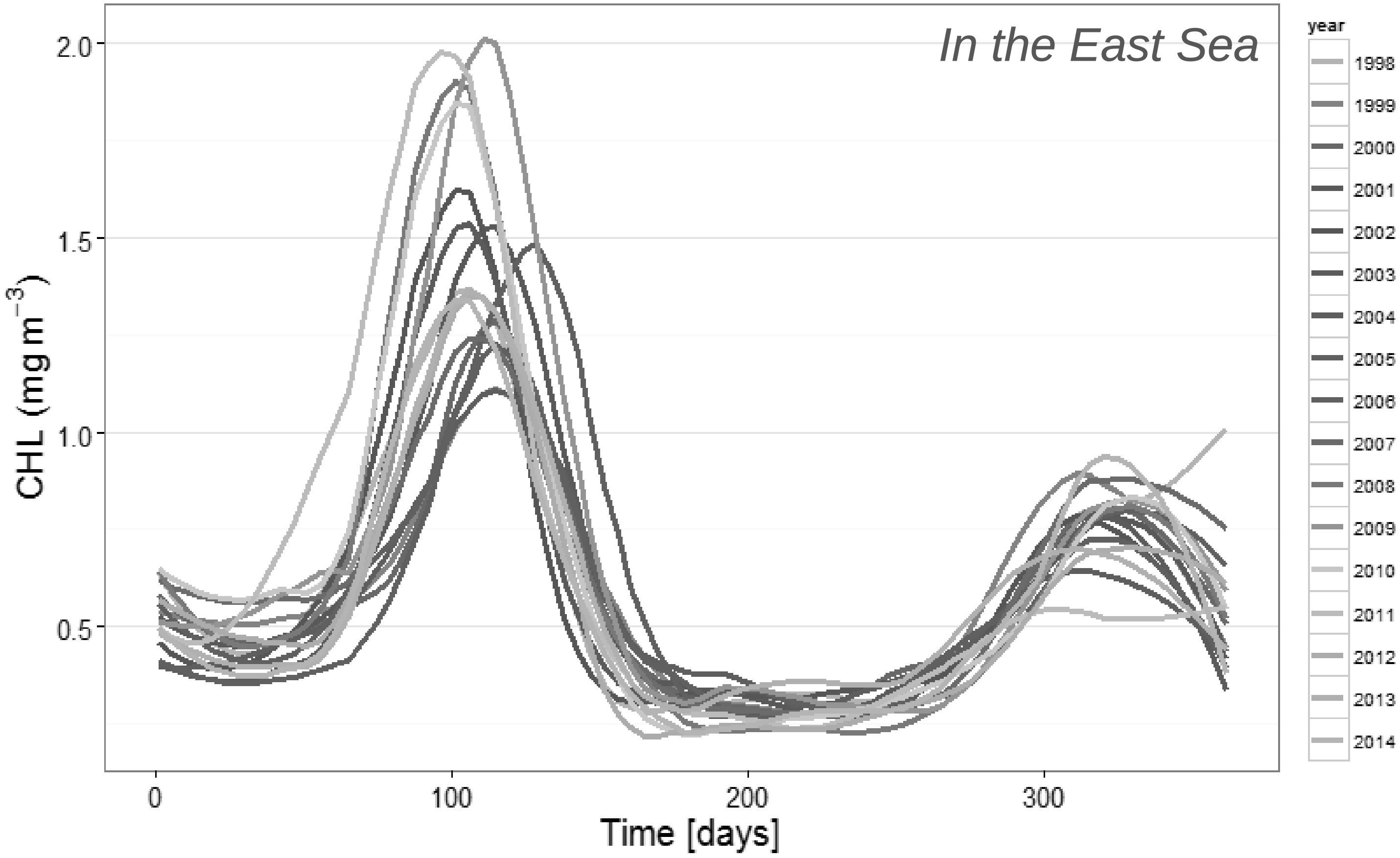
Description of physical metrics

Physical driver	Metric name	Definition
SST	$SST_{2\text{-}3}$	The SST average in Feb and Mar
	$SST_{inacrease\_max}$	The date of largest increase rate in SST between the beginning of the annual cycle and the maximum SST
	$SST_{9\text{-}10}$	The SST average in Sep and Oct
	$SST_{deacrease\_max}$	The date of largest decrease rate in SST between the maximum SST and the end of the annual cycle
NHF	$NHF_{2\text{-}3}$	The NHF average in Feb and Mar
	NHF_{turnp}	The first date when NHF turns from zero into positive value
	$NHF_{9\text{-}10}$	The NHF average in Sep and Oct
	NHF_{turnn}	The first date when NHF turns from zero into negative value
PAR	$PAR_{2\text{-}3}$	The PAR average in Feb and Mar
	$PAR_{inacrease\_max}$	The date of largest increase rate in PAR between the beginning of the annual cycle and the maximum PAR
	$PAR_{9\text{-}10}$	The PAR average in Sep and Oct
	$PAR_{deacrease\_max}$	The date of largest decrease rate in PAR between the maximum PAR and the end of the annual cycle
WND	$WND_{2\text{-}3}$	The WND average in Feb and Mar
	$WND_{9\text{-}10}$	The WND average in Sep and Oct
EKE	$EKE_{2\text{-}3}$	The EKE average in Feb and Mar
	$EKE_{9\text{-}10}$	The EKE average in Sep and Oct

byelggi@kiost.ac.kr

Result & Discussion

Interannual variability

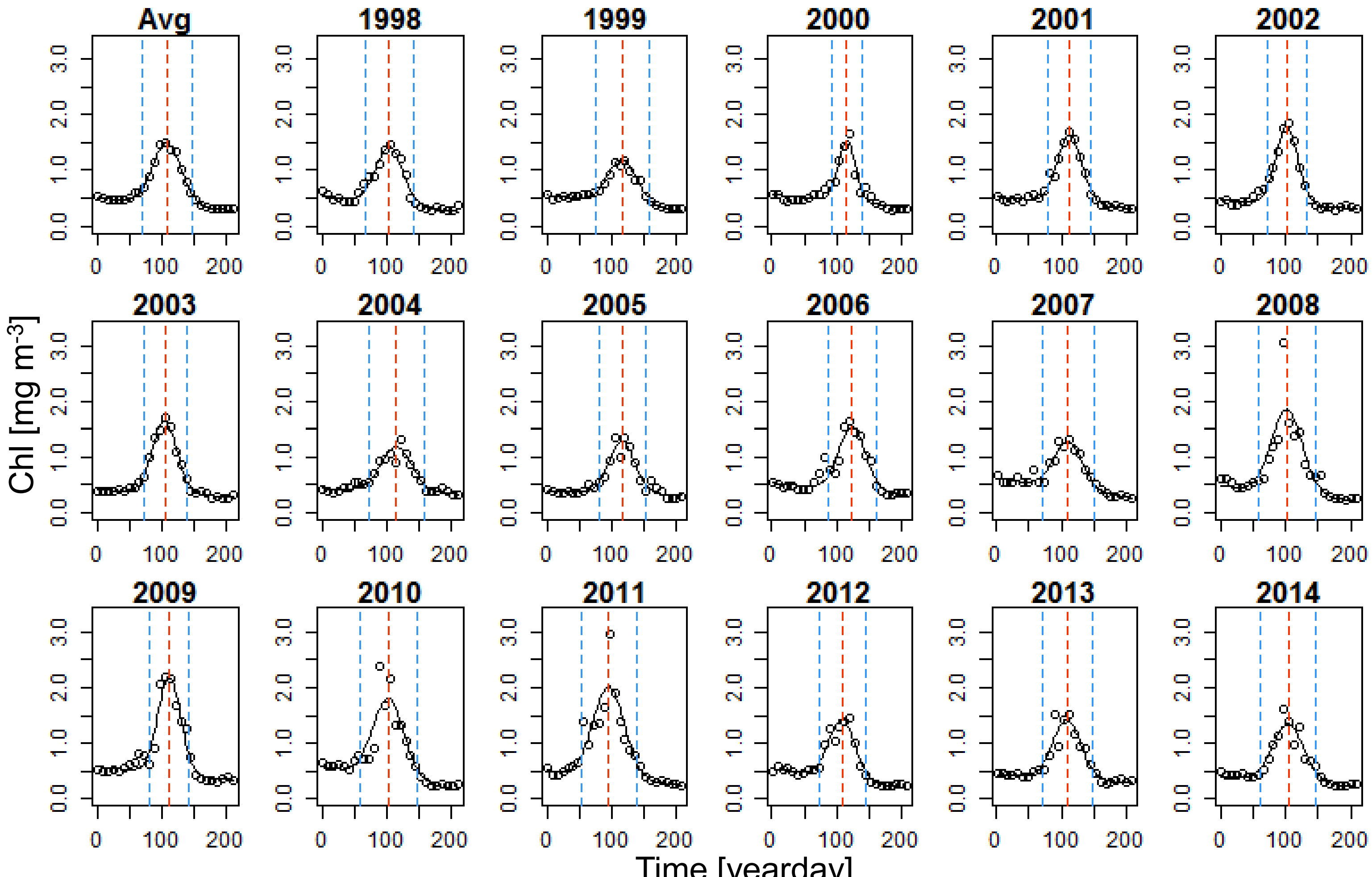


byelggi@kiost.ac.kr

Result & Discussion

Interannual variability: Spring

(h>0.8 mg m^{-3})

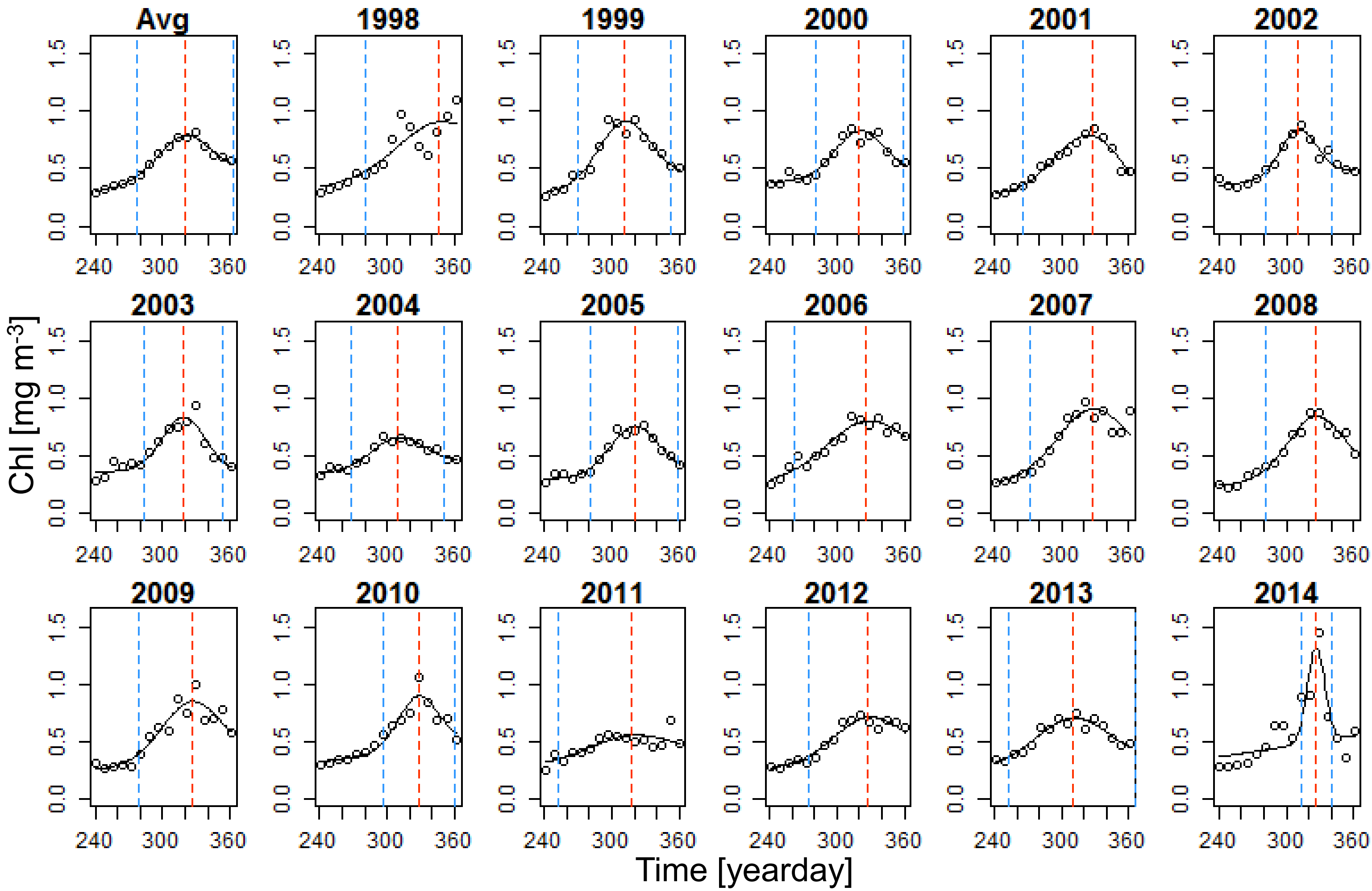


byelggi@kiost.ac.kr

Result & Discussion

Interannual variability: Autumn

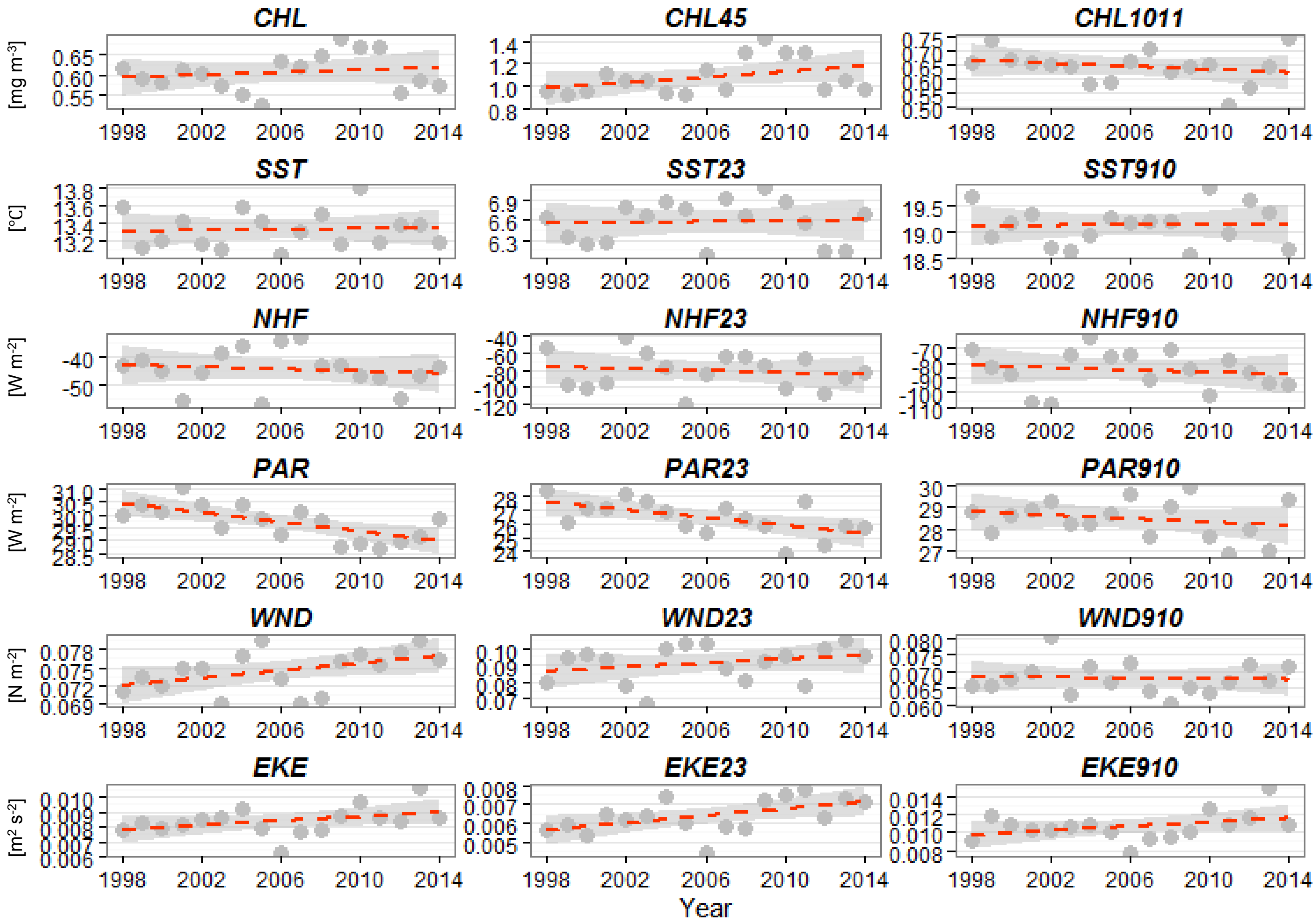
(h>0.2 mg m^{-3})



byelggi@kiost.ac.kr

Result & Discussion

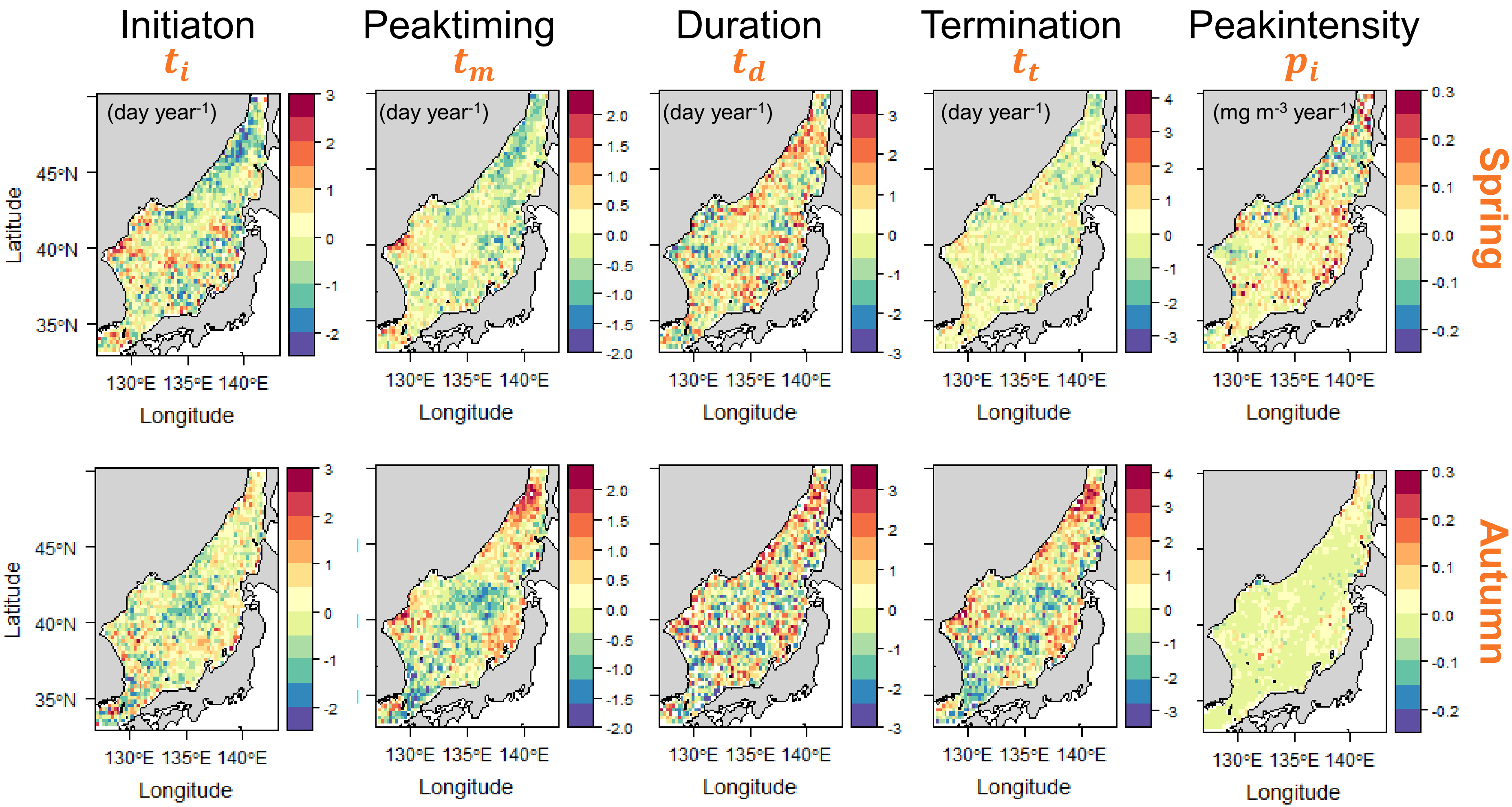
Interannual variability of annual mean



byelggi@kiost.ac.kr

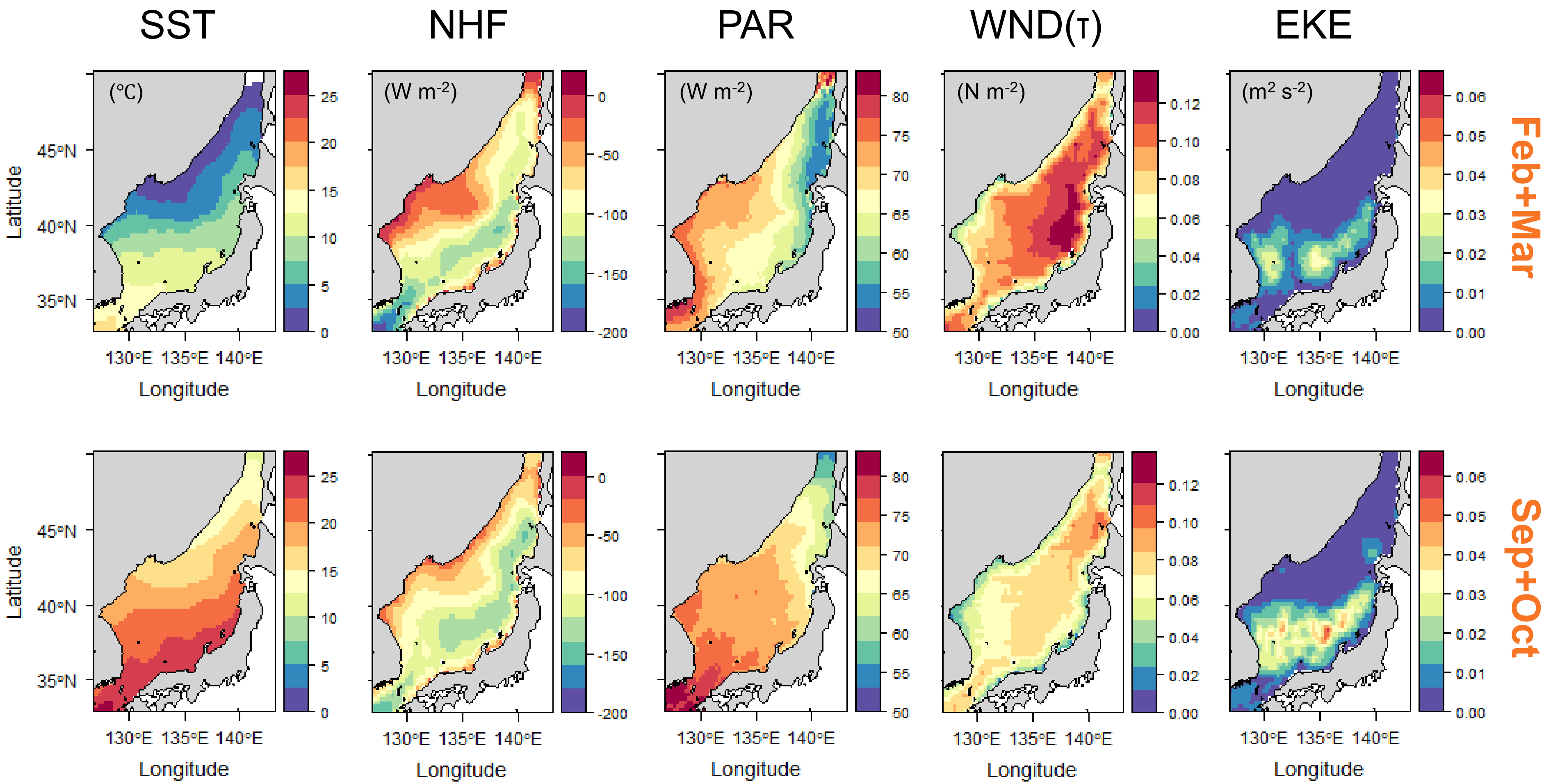
Result & Discussion

Spatial distribution: linear trend



byelggi@kiost.ac.kr

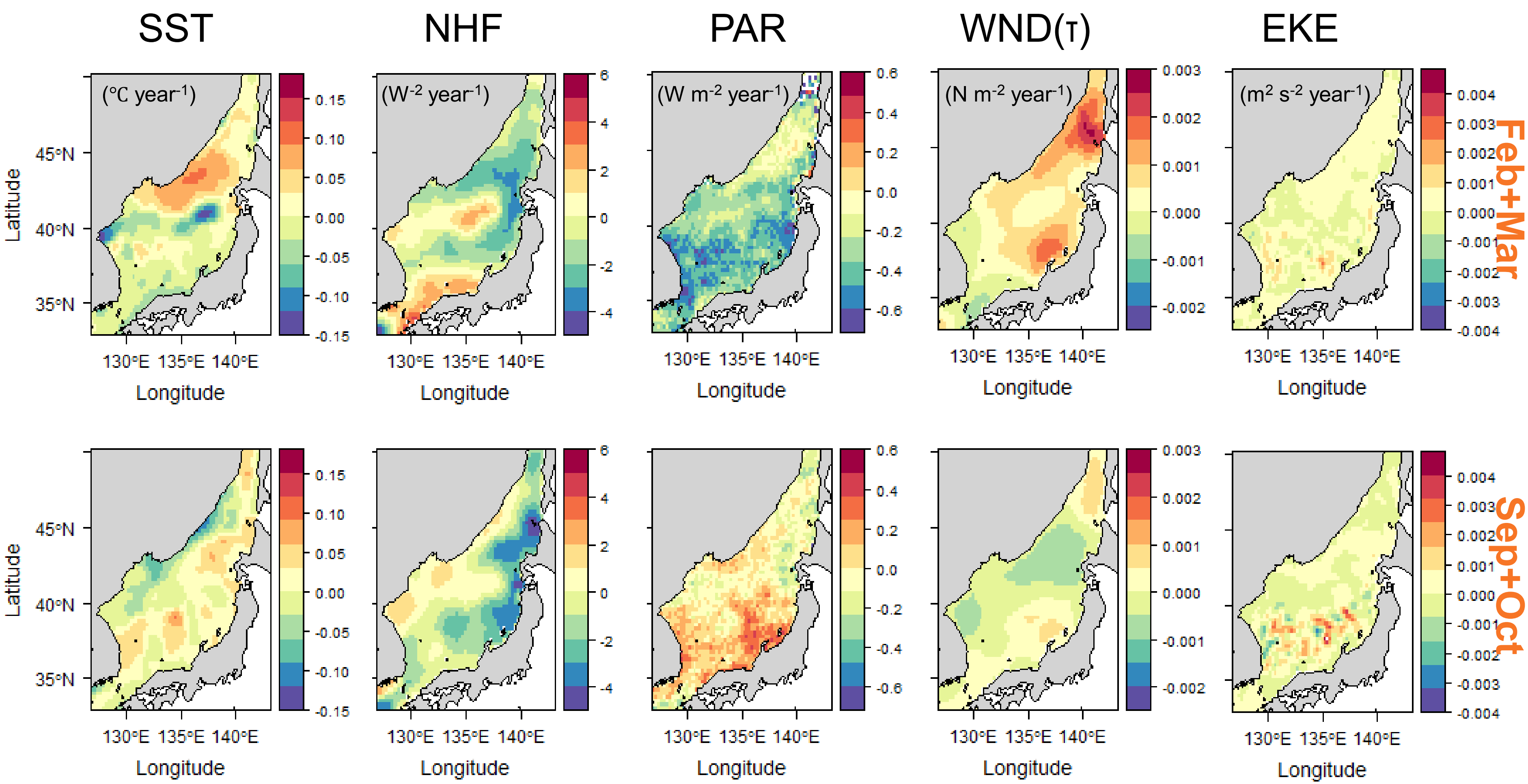
Spatial distribution: climatological mean



byelggi@kiost.ac.kr

Result & Discussion

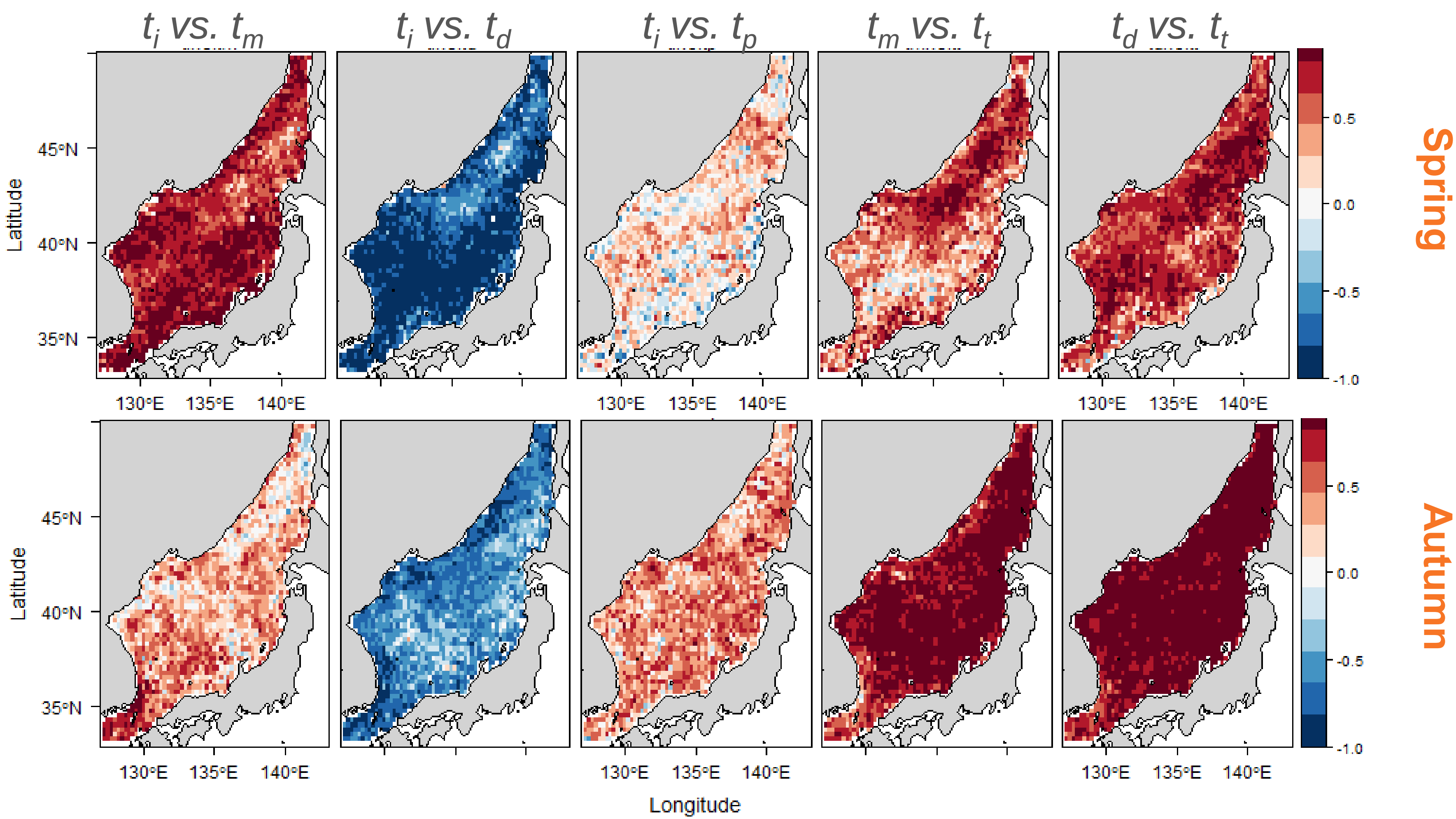
Spatial distribution: linear trend



byelggi@kiost.ac.kr

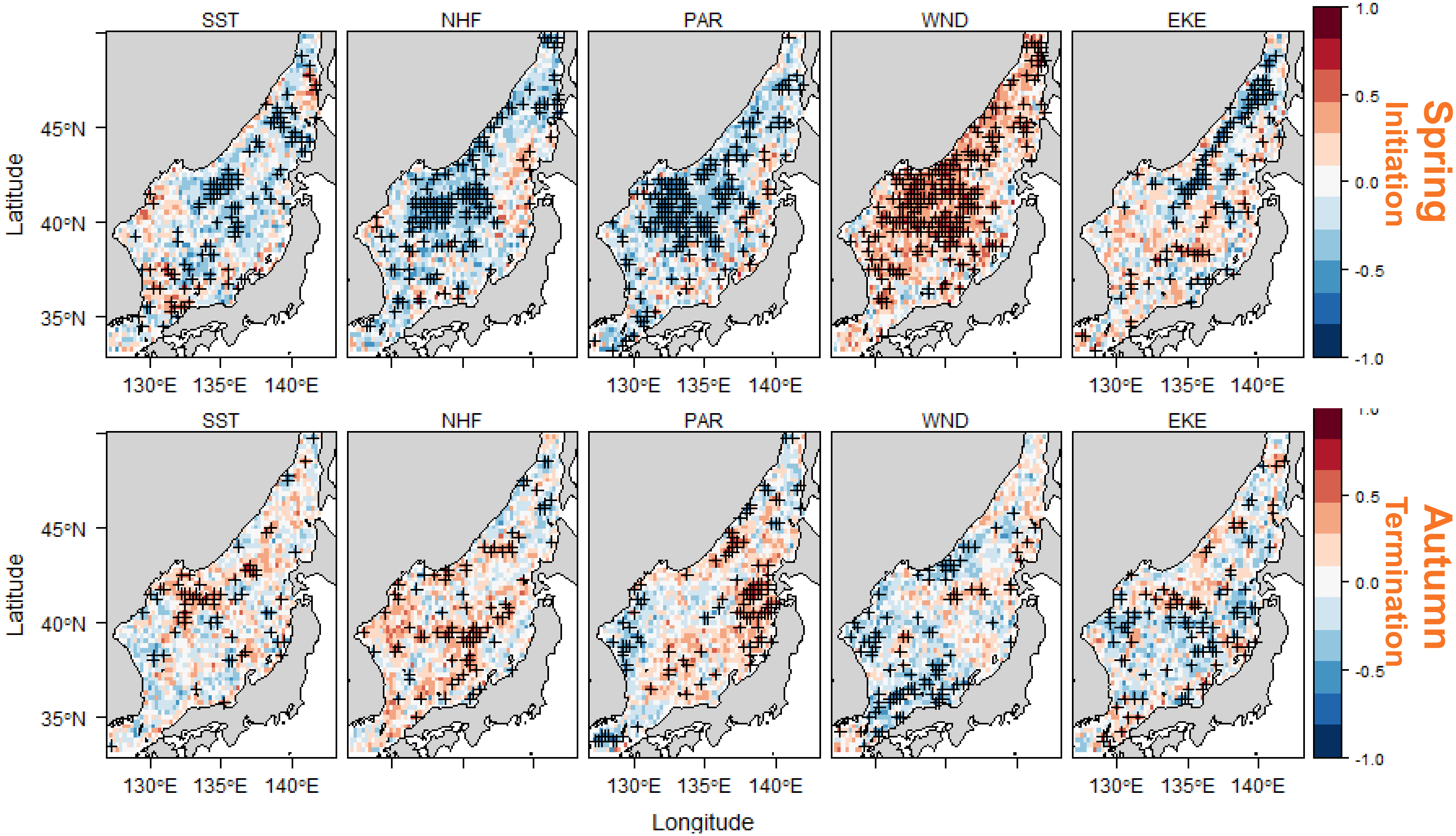
Result & Discussion

Spatial distribution: trend relationship



Result & Discussion

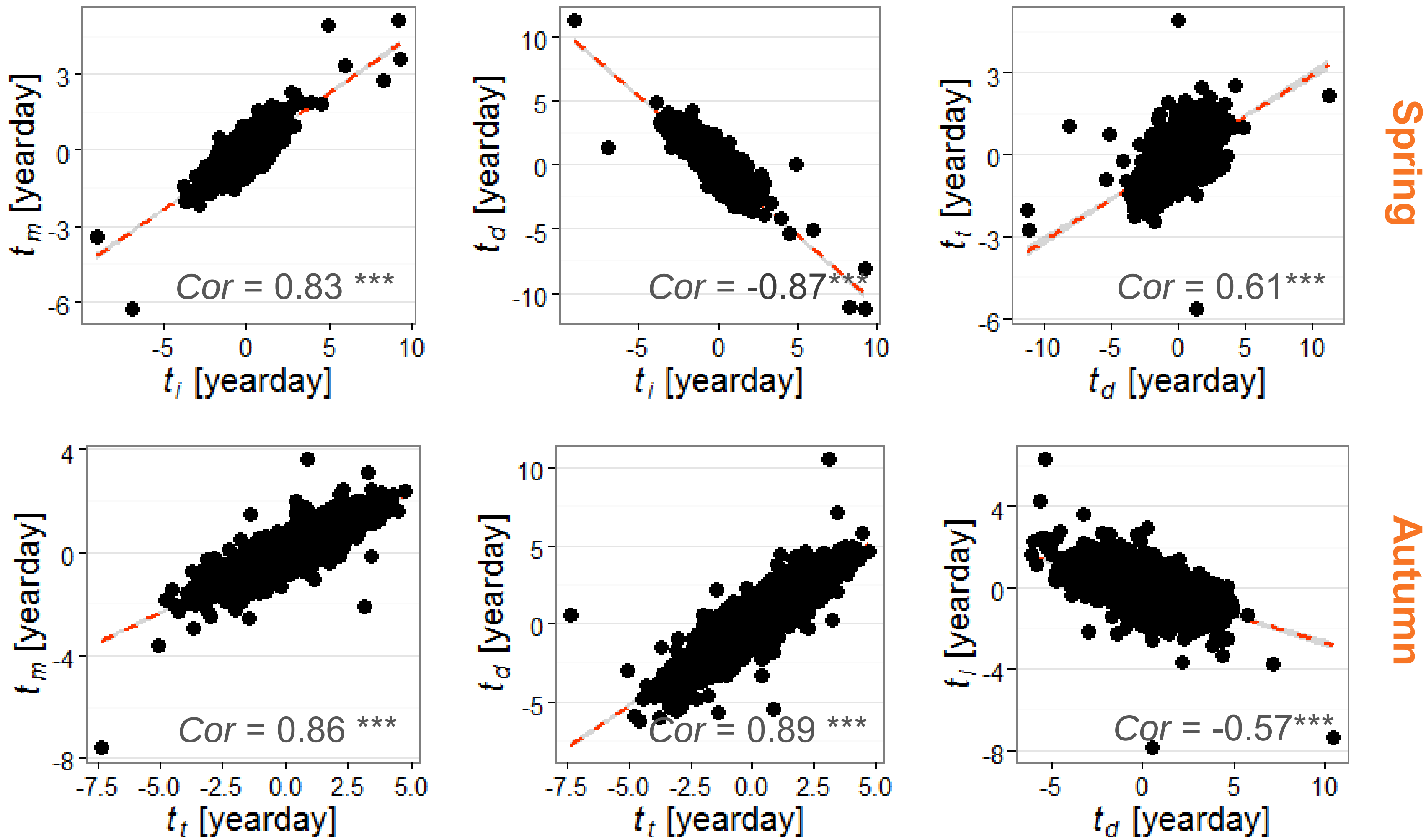
Correlation



Result & Discussion

Spatial distribution: trend relationship

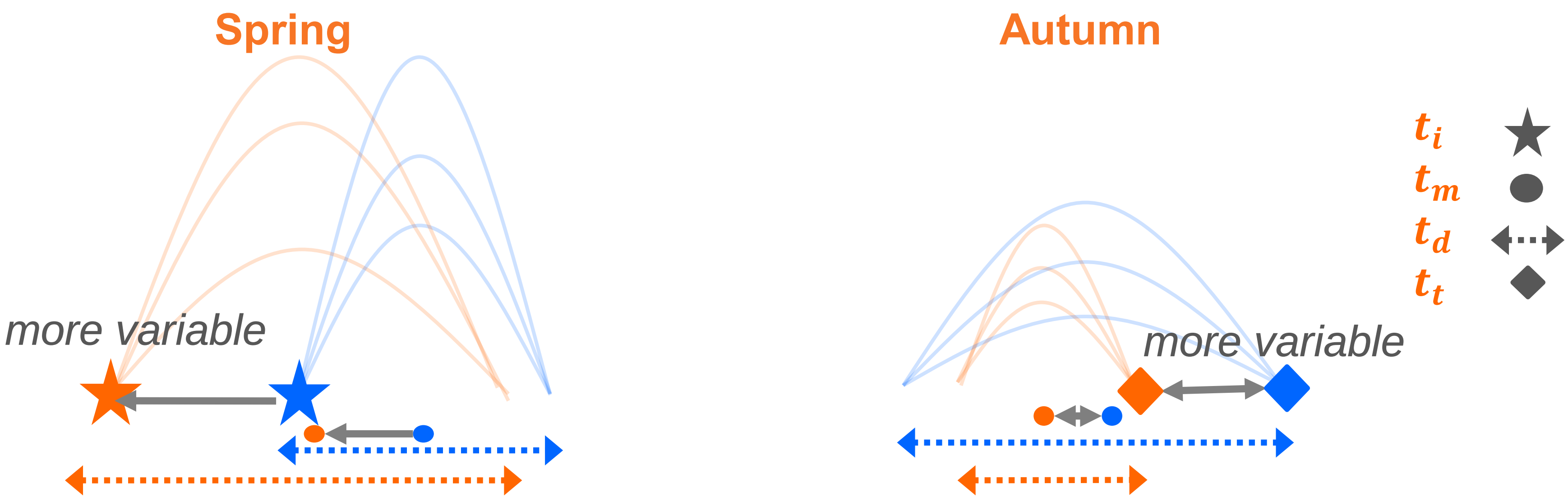
***: *P*<0.001



byelggi@kiost.ac.kr

Result & Discussion

Relationship between bloom timing metrics

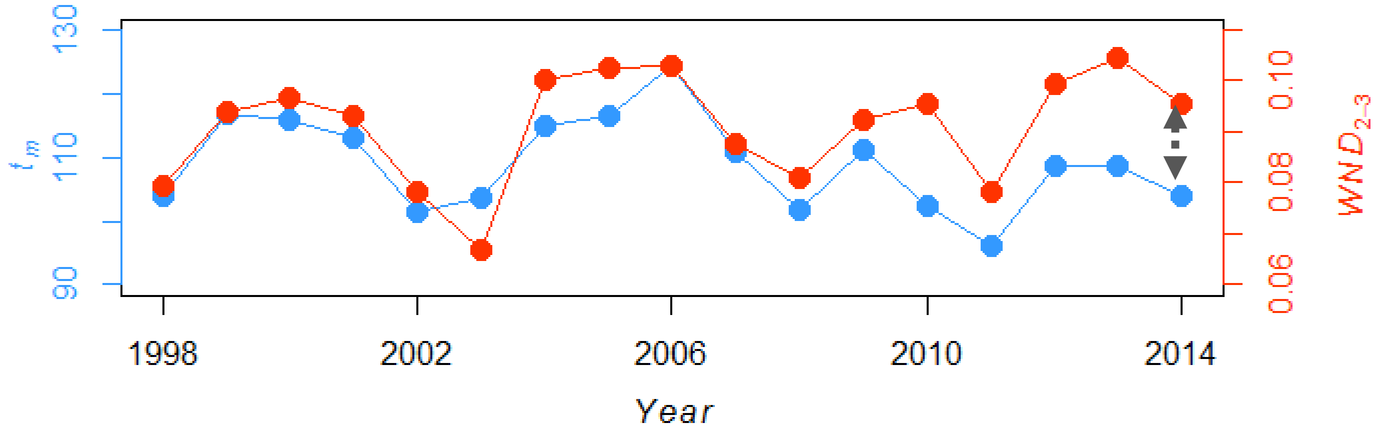


- If the bloom initiation (t_i) advanced, the peak timing (t_m) tends to be advaned.
- If the bloom initiation (t_i) advanced, the bloom tends to last longer (t_d).

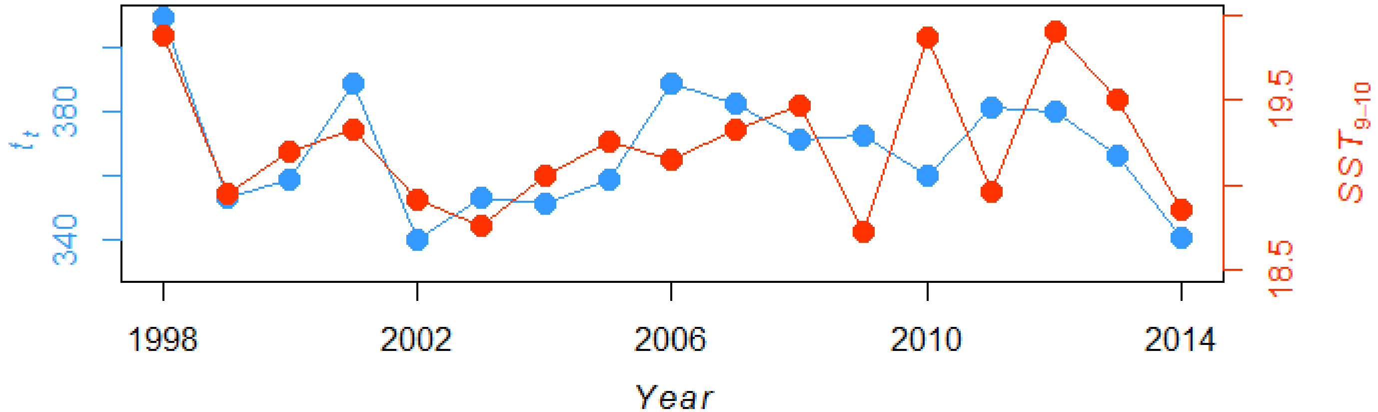
- If the bloom termination (t_t) advanced, the peak timing (t_m) tends to be advanced.
- If the bloom termination (t_t) advanced, the bloom tend to last shorter (t_d).

Result & Discussion

Correlation



Spring

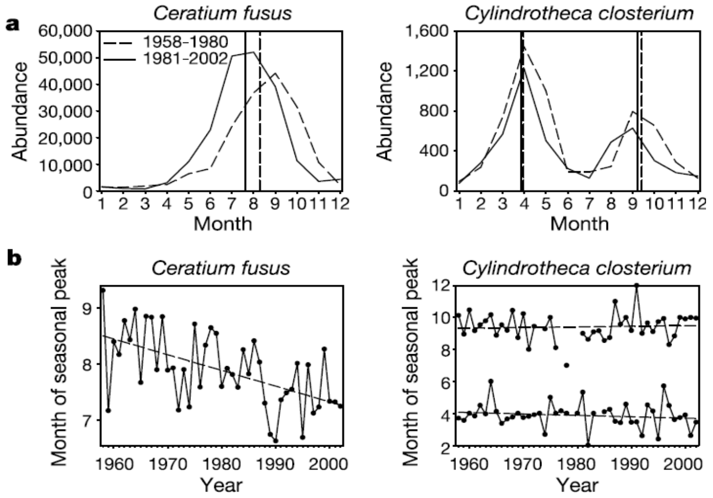


Autumn

Further study

Why does the earlier bloom tends to be longer lasting?

Phytoplankton community respond differently to physical forcing!
→Deriving phytoplankton groups using bio-optical models and HPLC pigments
→Analysis of relationship between phytoplankton bloom feature and physical forcing



[Edwards & Richardson, 2004]

How about the spatial distribution?

Description of spatial differences in phytoplankton phenology patterns
→ using K-means clustering