Ecological Indicators from Ocean Colour

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&

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Theme

To establish and assess the value of remotely-sensed imagery for development of ecological indicators in the pelagic zone; and

To illustrate the applications with examples from the North West Atlantic Ocean

Context: Stewardship of the Ocean

Global consensus: Management should have ecosystem basis, integrity of ecosystem should not be compromised.

(Maintain ecosystem attributes such as health, vigour, resilience)

How to Quantify Ecosystem Integrity?

- Concepts such as the health, vigour and resilience of the ecosystem are subjective and difficult to quantify

- Instead, develop suite of Ecological Indicators as an aid to ecosystem-based management

- They are objective metrics for the pelagic ecosystem that can be applied serially, in operational mode, to detect changes that may occur in response to environmental perturbation

Ideal Characteristics of Pelagic Indicators

- Represent a well-understood and widely-accepted ecosystem property
- Quantifiable unambiguously in standard units
- Measurable rapidly at low incremental cost
- Repeat frequency compatible with intrinsic time scale of properties under study
- Measurable at a variety of scales
- Possibility to create long (multi-decadal) time series

Platt and Sathyendranath, 2008

Remote sensing for Operational Metrics

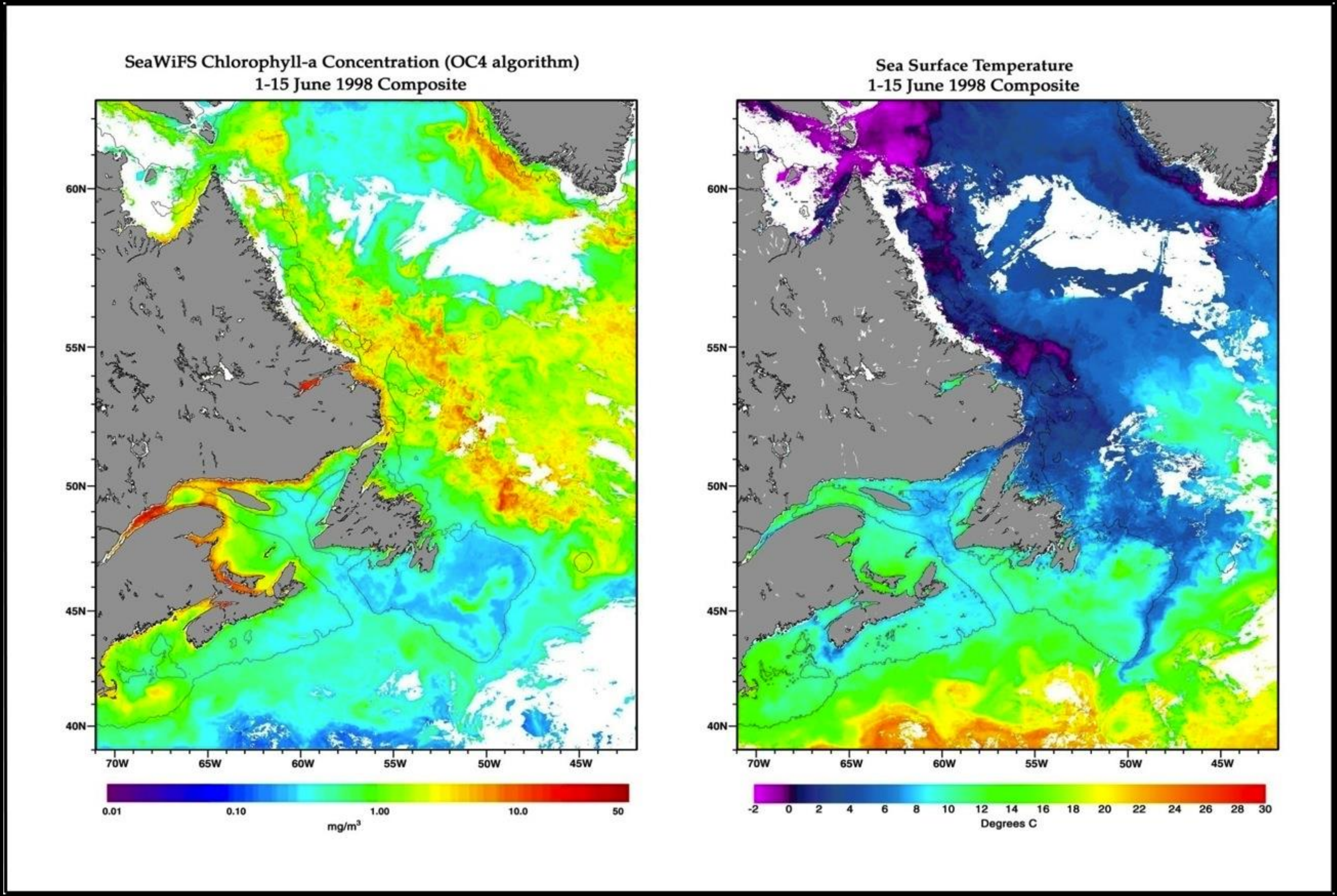
- Meets requirements of speed, resolution, repeat frequency and cost-effectiveness
- Autotrophic biomass important ecosystem property
- Primary production fields can also be generated
- SST and chlorophyll obtainable at same resolution
- Can construct time series: seasonal dynamics can be quantified objectively
- Allows interannual comparisons

Platt and Sathyendranath 2008

Role of Remote Sensing

- Ecosystem-based management should be knowledge-based
- Knowledge base has to be updated continually, because the ocean is dynamic
- Knowledge has to supplied on appropriate scales of time and space
- At same time, ocean is being modified by climate change
- But collecting data by ships alone is prohibitive (cost of fuel, manpower)
- Remote sensing is cost effective
- EBM requires quantitative metrics (ecosystem indicators)
- EO is key for operational approach to marine ecosystem

Chlorophyll and Temperature: Fundamental properties of the ecosystem


SeaWiFS Chlorophyll-a Concentration (OC4 algorithm)
1-15 June 1998 Composite

Sea Surface Temperature
1-15 June 1998 Composite

Remotely-sensed imagery: not just pretty pictures

Added Value

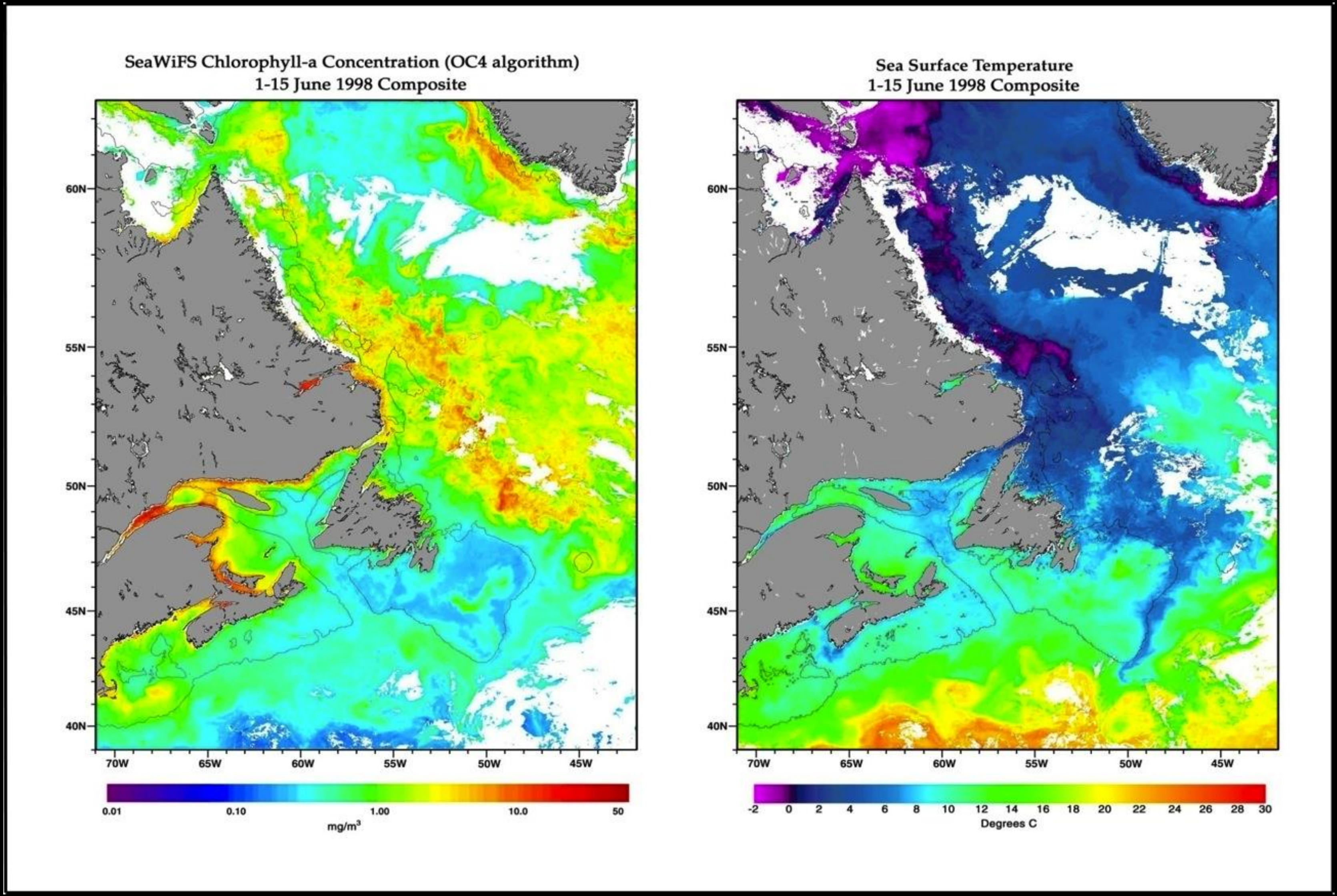
The beauty of the imagery may conceal the reality that they are achieved only through application of rigorous and quantitative optical physics to spectral radiometric data collected by satellites.

Although satellite images are freely available on the internet, it is the VALUE ADDED to the raw data by informed specialists that optimises their utility.

Remote sensing is still a young science, in the sense that its full potential is yet to be realised. As operational applications grow, new ways of interpreting the data will emerge through research.

In the ideal situation, both operations and research have to go hand in hand.

Chlorophyll and Temperature: Fundamental properties of the ecosystem



SeaWiFS Chlorophyll-a Concentration (OC4 algorithm)
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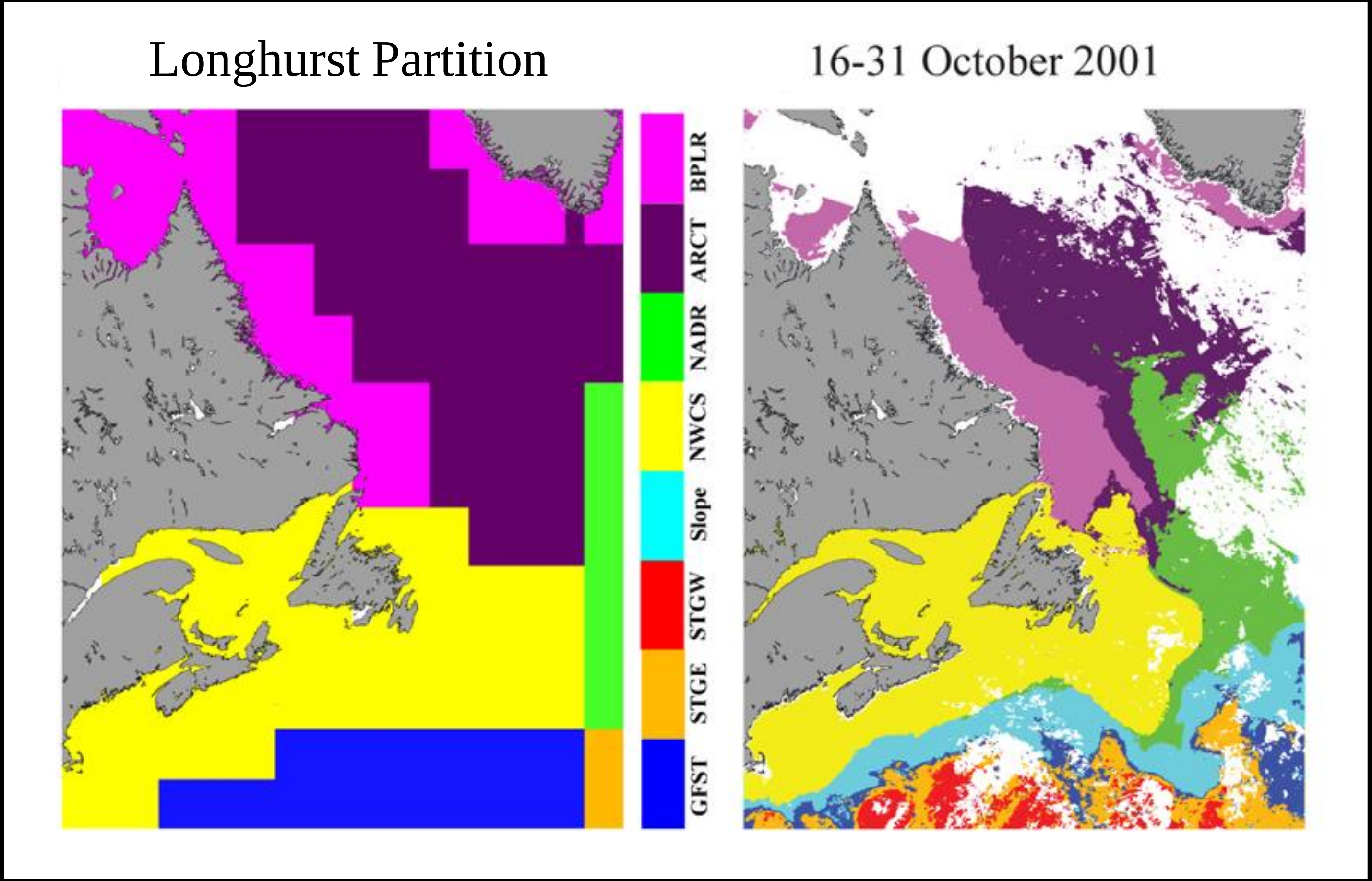
Remotely-sensed imagery: not just pretty pictures

Large-scale Ecological Structure as determined by remote sensing



Longhurst Partition

16-31 October 2001

Boundaries may move seasonally; partition may be developed as time series

Devred et al. 2007

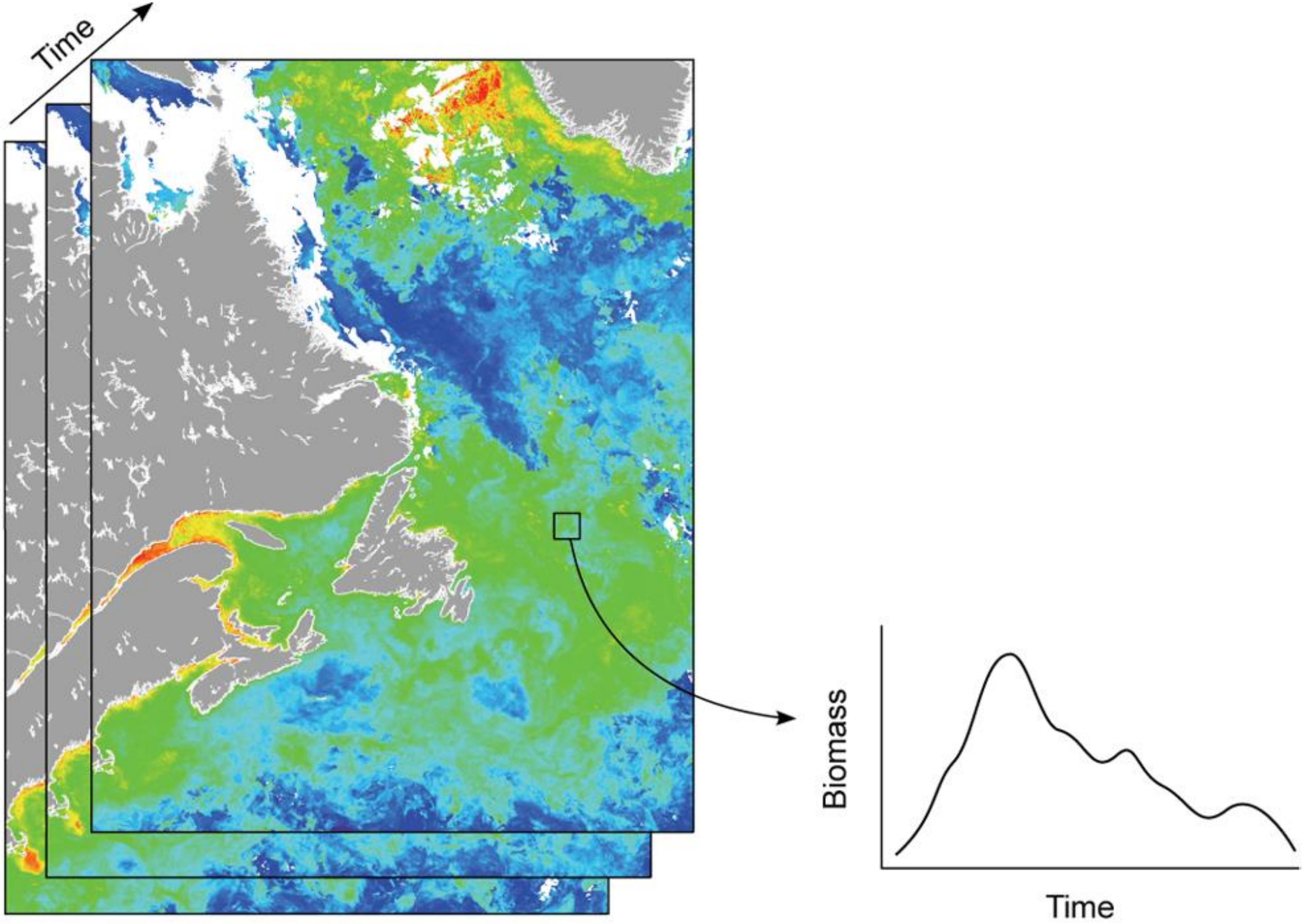
Some Ecological Indicators from Remote Sensing

Initiation of spring bloom
Timing of spring maximum
Total production in spring bloom
Initial slope, light-saturation curve
Particulate organic carbon
Carbon-to-chlorophyll ratio
Generalised phytoplankton loss rate
Spatial variance in biomass field
Phytoplankton functional types

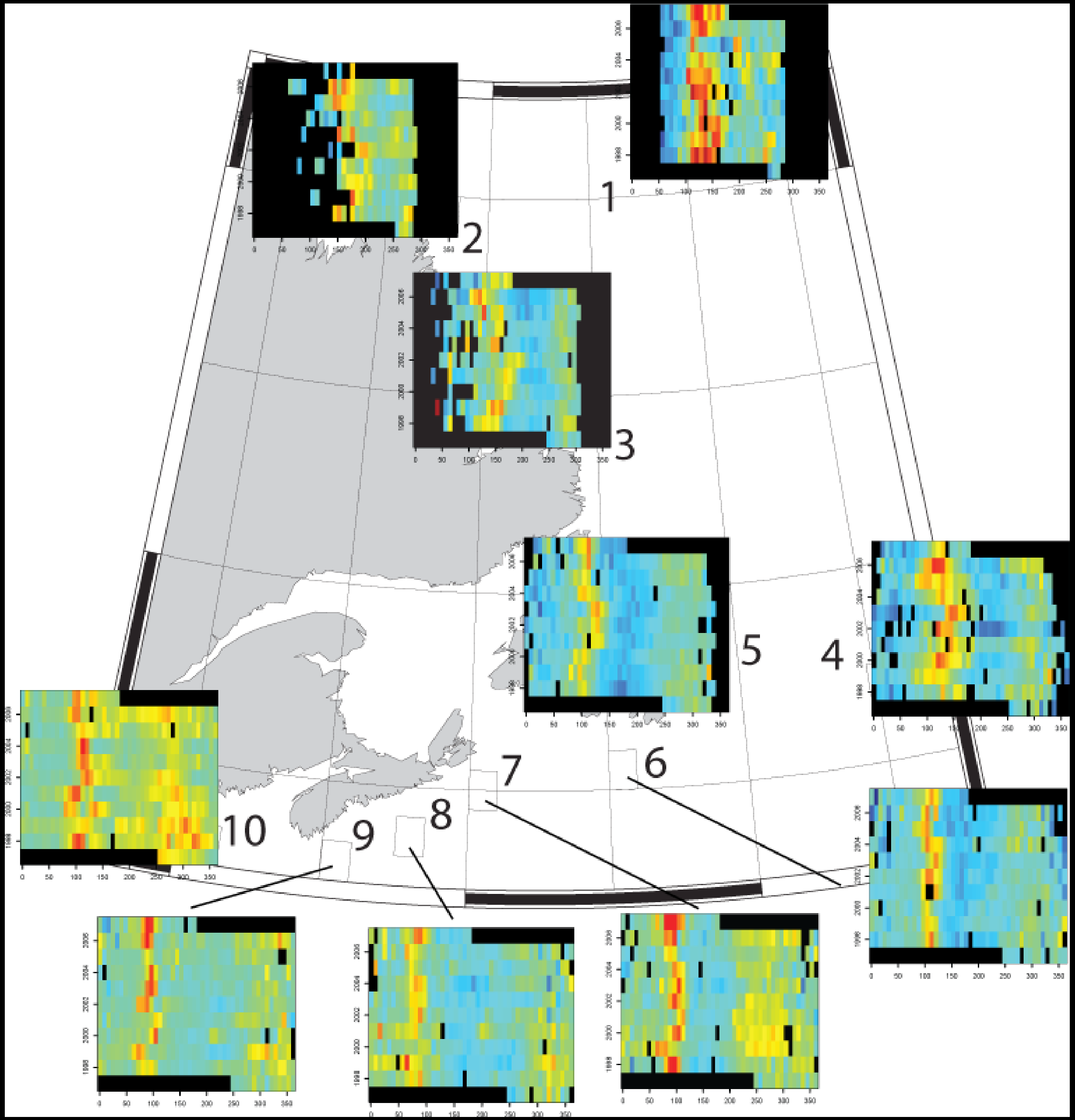
Amplitude of spring bloom
Duration of spring bloom
Annual phytoplankton production
Assimilation number
Phytoplankton carbon
Phytoplankton growth rate
Integrated phytoplankton loss
Spatial variance in production field
Biogeochemical provinces

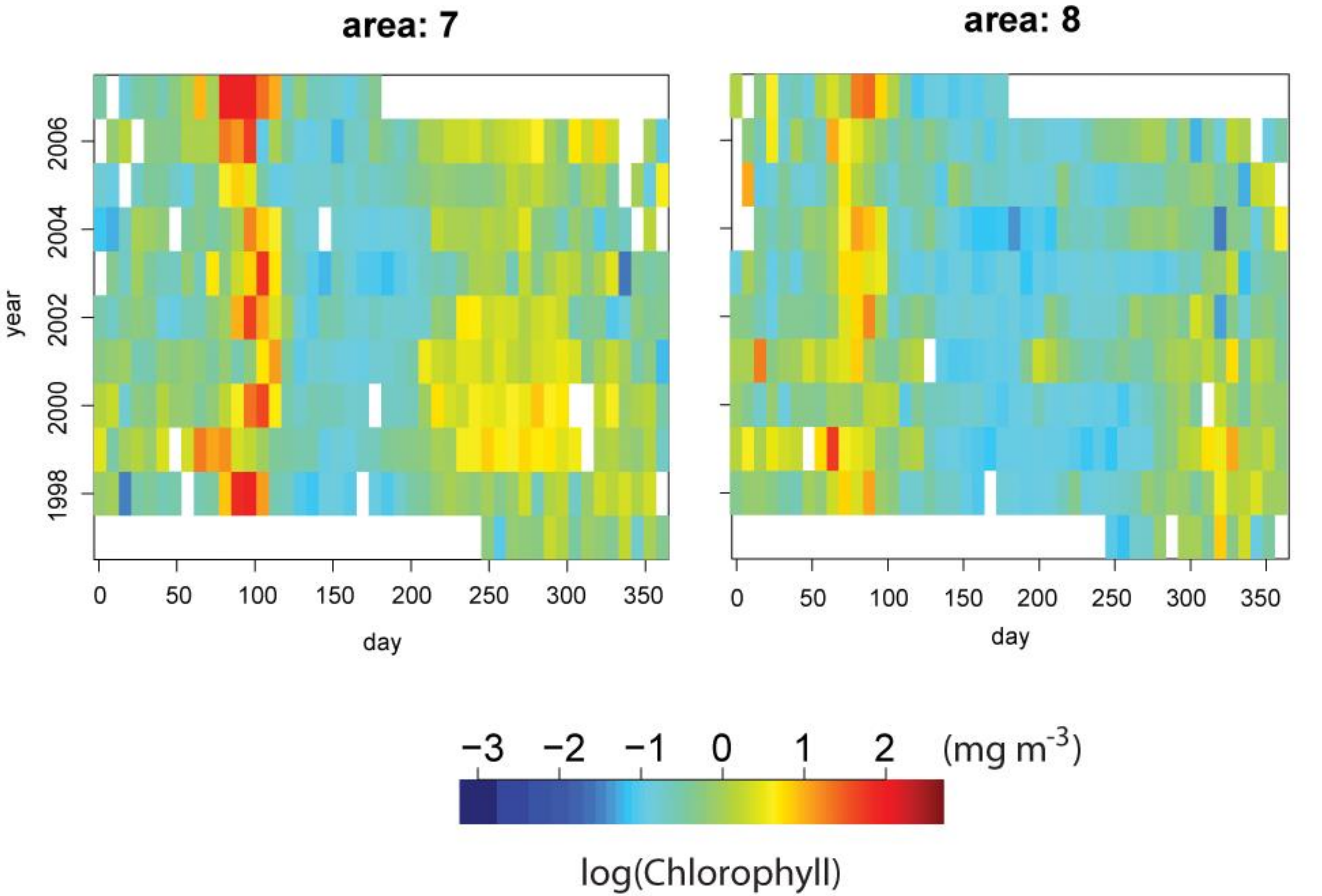
Platt and Sathyendranath, 2008

Construction of time series possible at any chosen scale of spatial averaging



The Time Series




area: 7
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year
2006
2004
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day
−3
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−1
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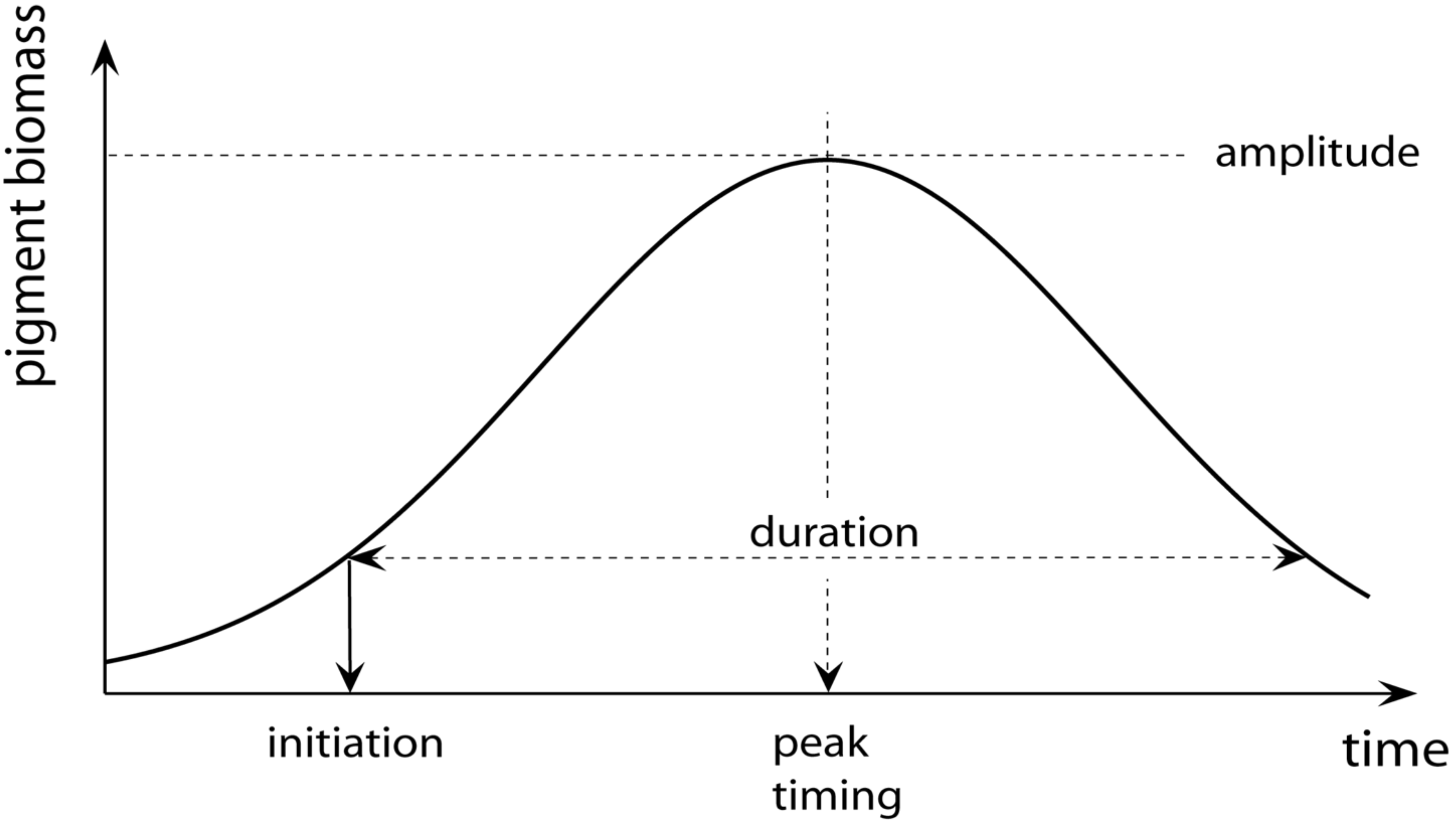
1
2
(mg m-3)
log(Chlorophyll)

Seasonality

Seasonal signal is key feature of the time series: Spring bloom is dominant event in seasonal cycle

How to analyse it?

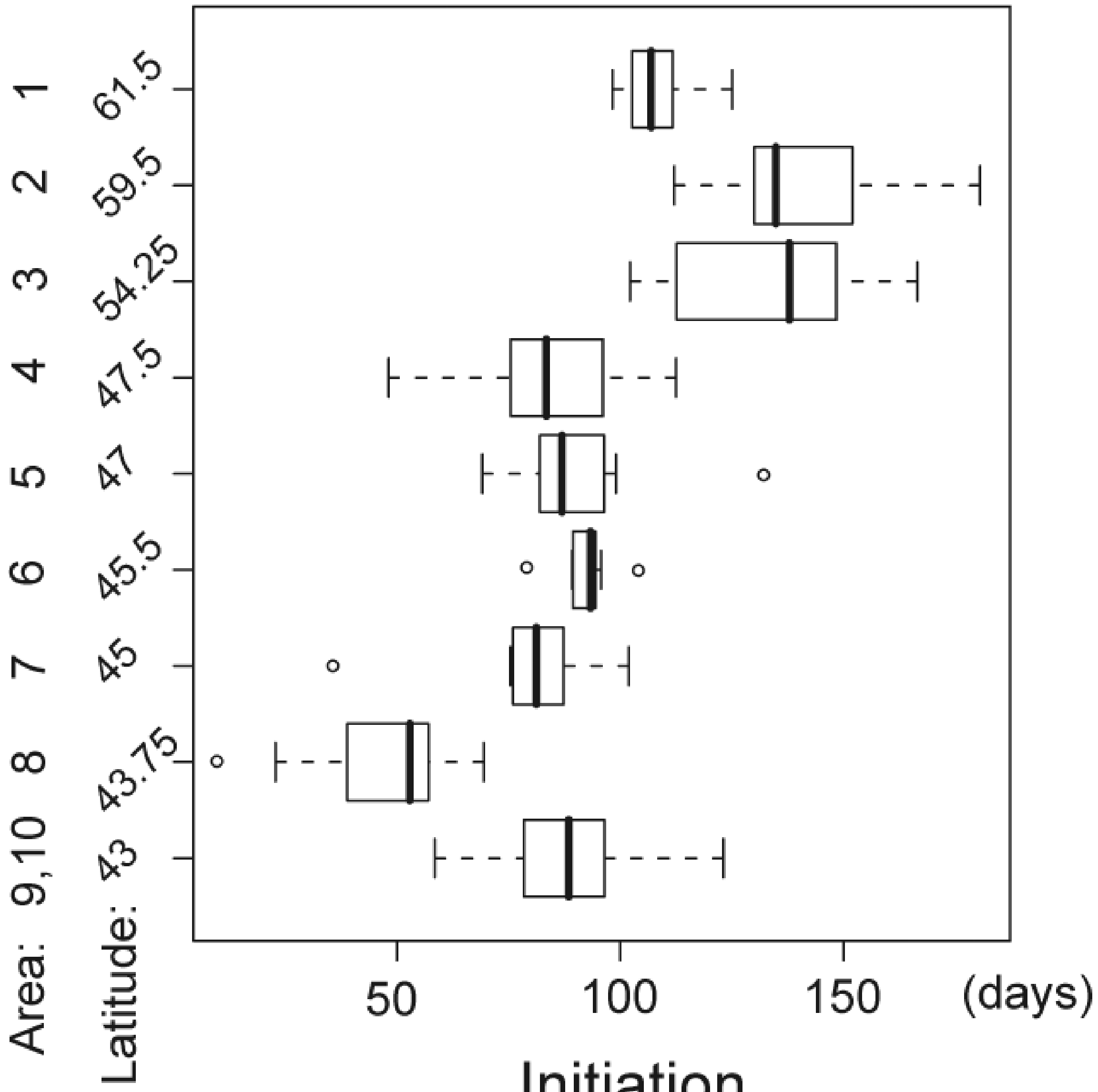
Quantifying the Seasonality

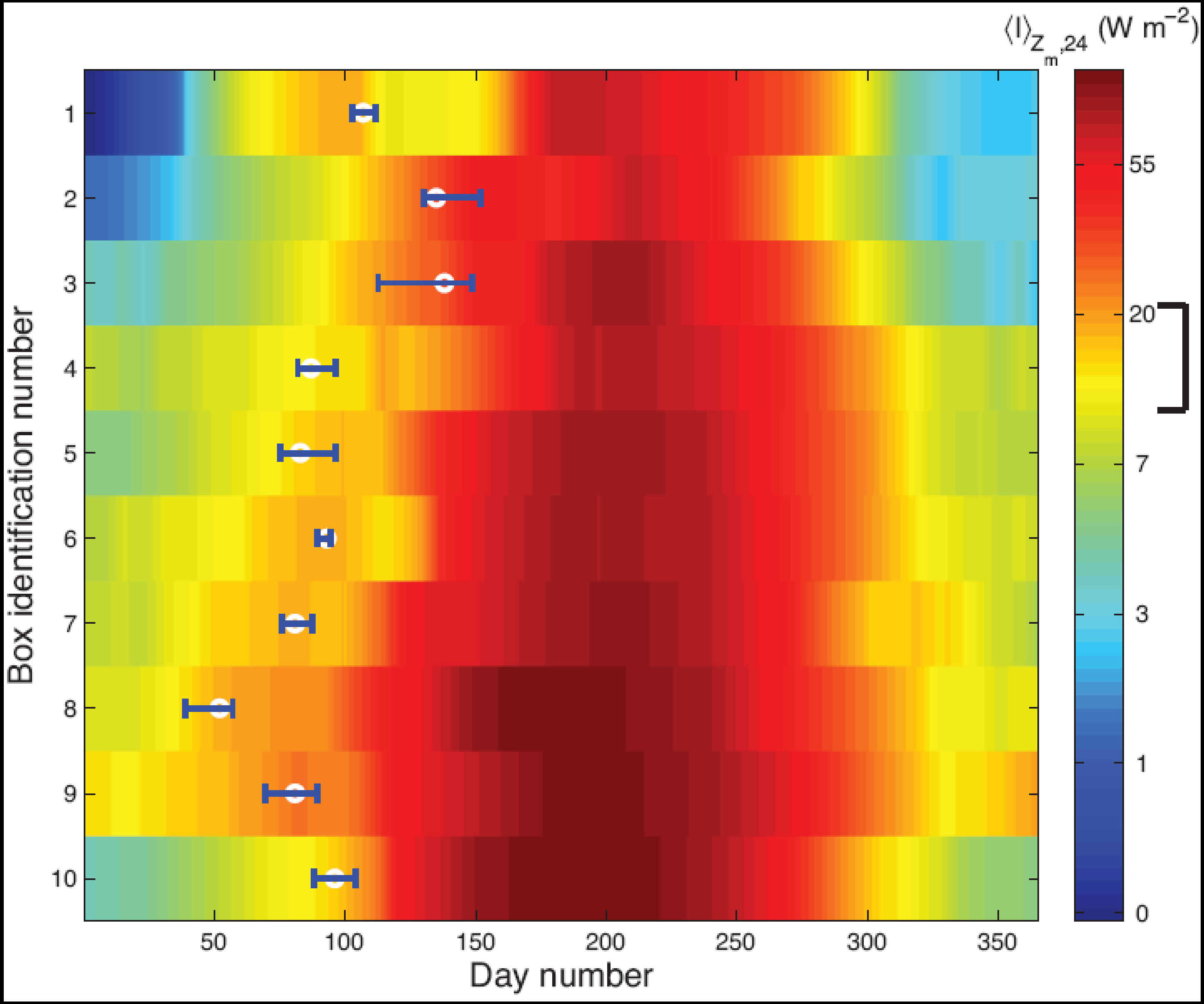


Any or all of these indices may vary between years
(at any or all of the pixels in the region of interest)

Platt, Sathyendranath & Fuentes-Yaco, 2007

Results for Bloom Initiation




$\langle I \rangle_{Z_m,24}$ (W m^{-2})
Box identification number
1
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Day number
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55

Demonstration

Application of Seasonality Results

Significance of interannual variability in timing of the spring phytoplankton bloom

Cushing’s Match-Mismatch Hypothesis

- Interannual fluctuations in dynamics of spring bloom account for significant fraction of interannual variance in survival of larval fish (autotrophic dependence)

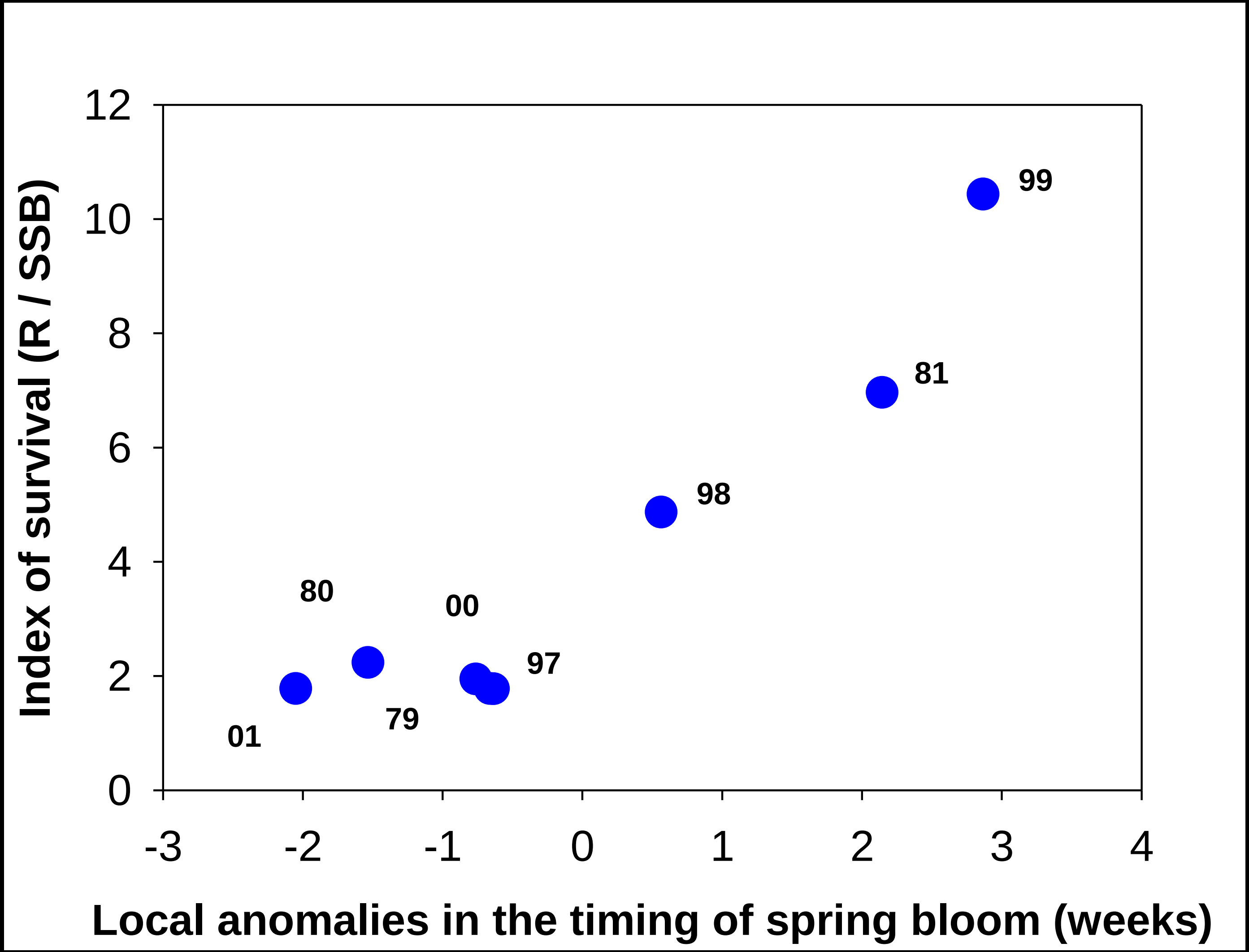
Operational Test of Hypothesis

- Characterise spring bloom in each year by objective, quantitative criteria, preserving all spatial structure

- Compare these ecosystem indices with larval survival in corresponding years

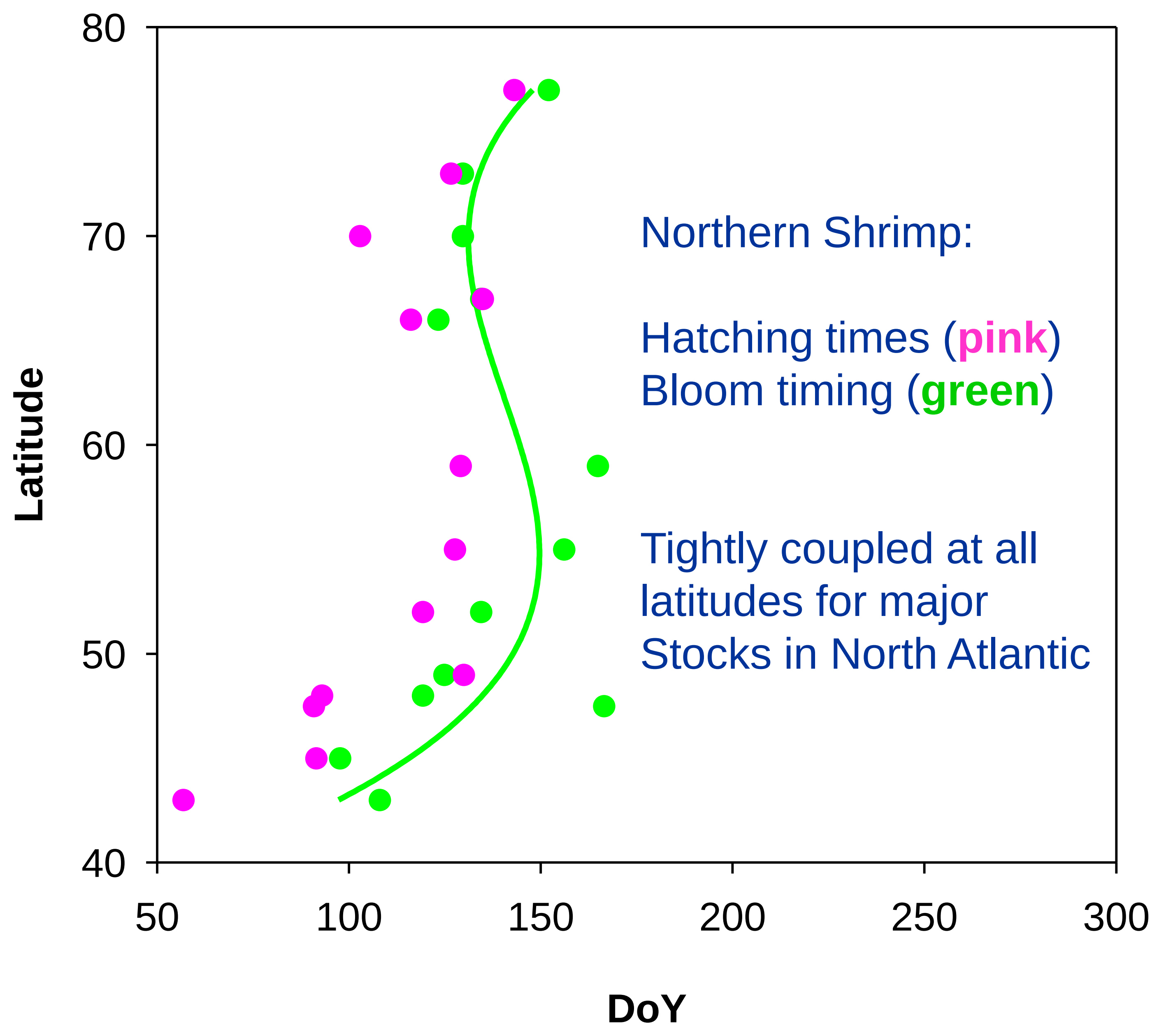
- Test whether significant proportion of variance in larval abundance (survival) can be accounted for by variations in ecosystem indices

Normalised Survival as Function of Timing of Spring Bloom



Platt et al. 2003

Basin-scale coherence of North Atlantic shrimp stocks



Northern Shrimp:

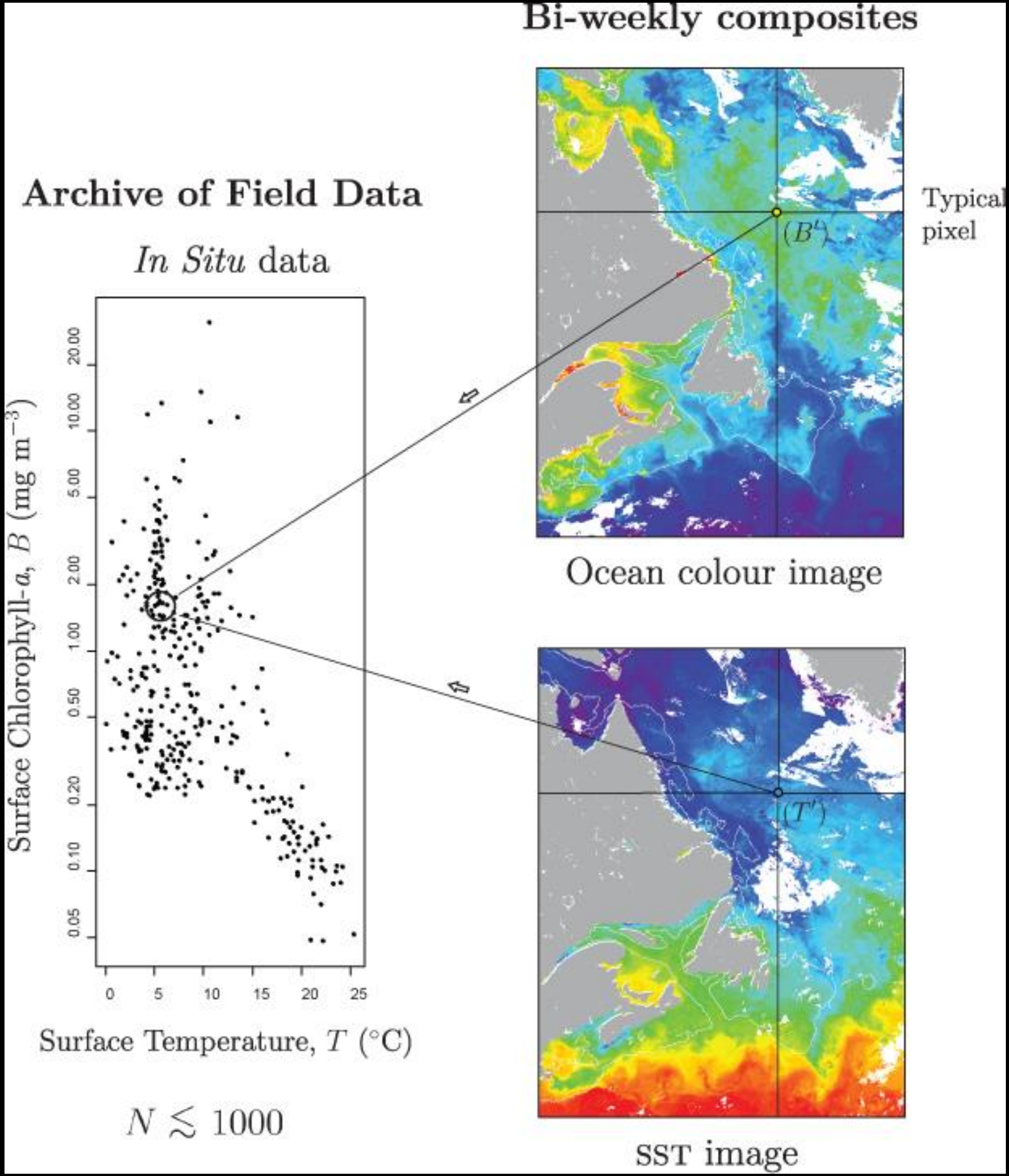
Hatching times (**pink**)
Bloom timing (**green**)

Tightly coupled at all latitudes for major Stocks in North Atlantic

Koeller, Fuentes-Yaco, Platt, Sathyendranath and others

Computation of
Primary Production

Assignment of Parameters for Computation of Primary Production



The model is robust, but needs a protocol for assignment of parameters relating to

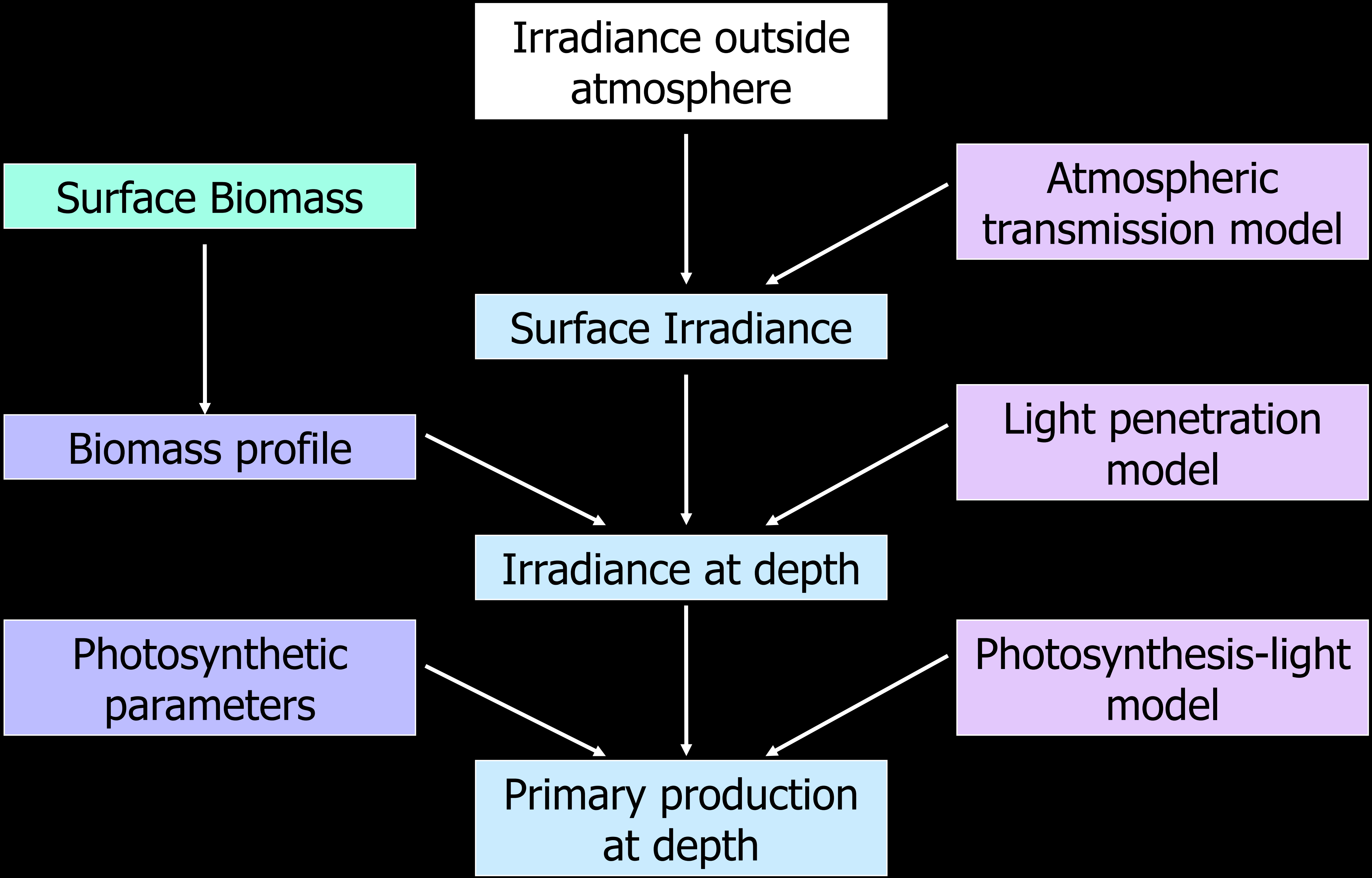
(1) photosynthetic response; and

(2) vertical structure.

Our protocol uses remotely-sensed data as input

Platt et al. (2008)

Computation of primary production field



Irradiance outside atmosphere

Surface Biomass

Atmospheric transmission model

Surface Irradiance

Biomass profile

Light penetration model

Irradiance at depth

Photosynthetic parameters

Photosynthesis-light model

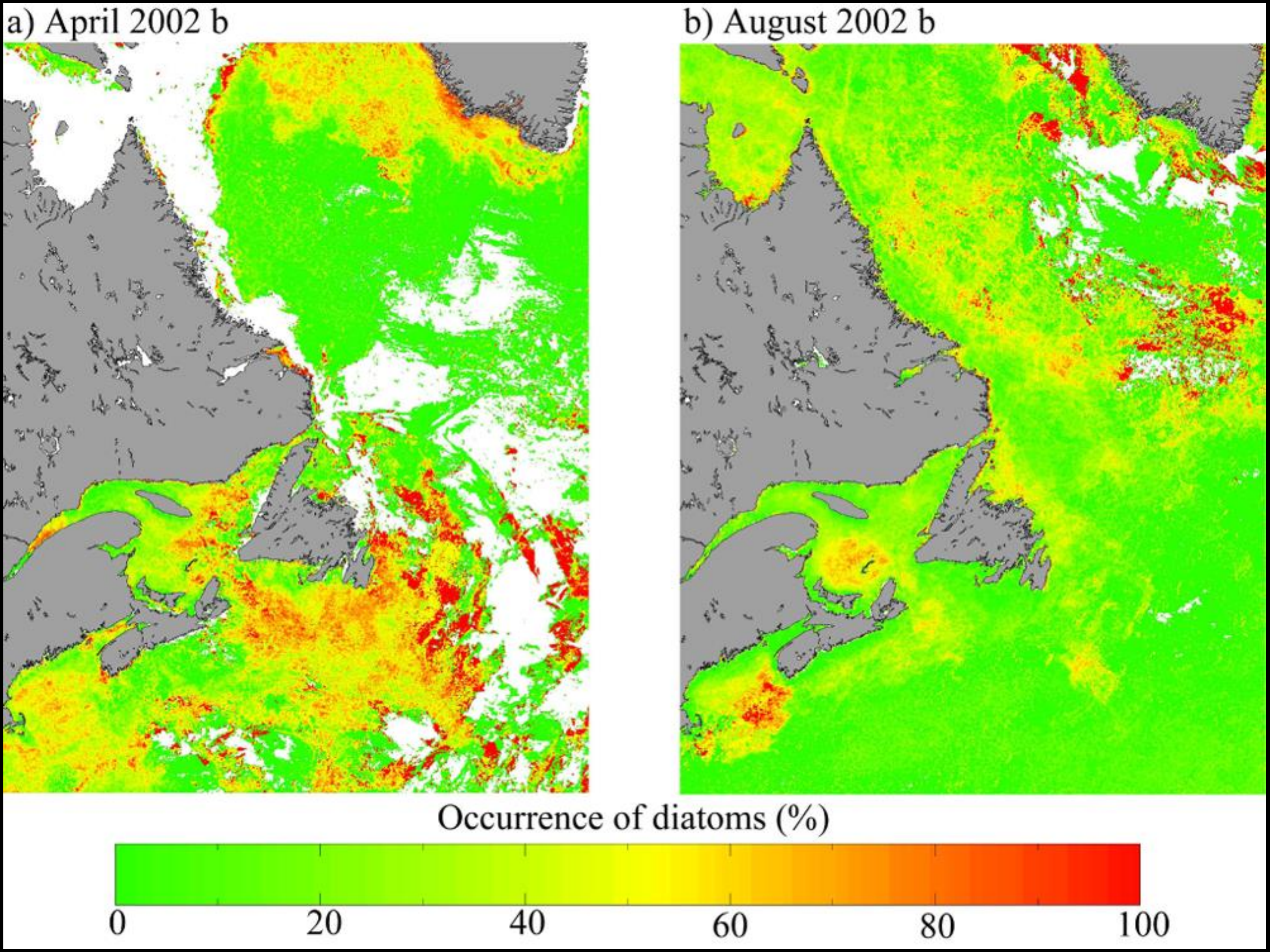
Primary production at depth

Platt and Sathyendranath (2001)

Towards Diagnosis of Phytoplankton Community Structure: Diatoms

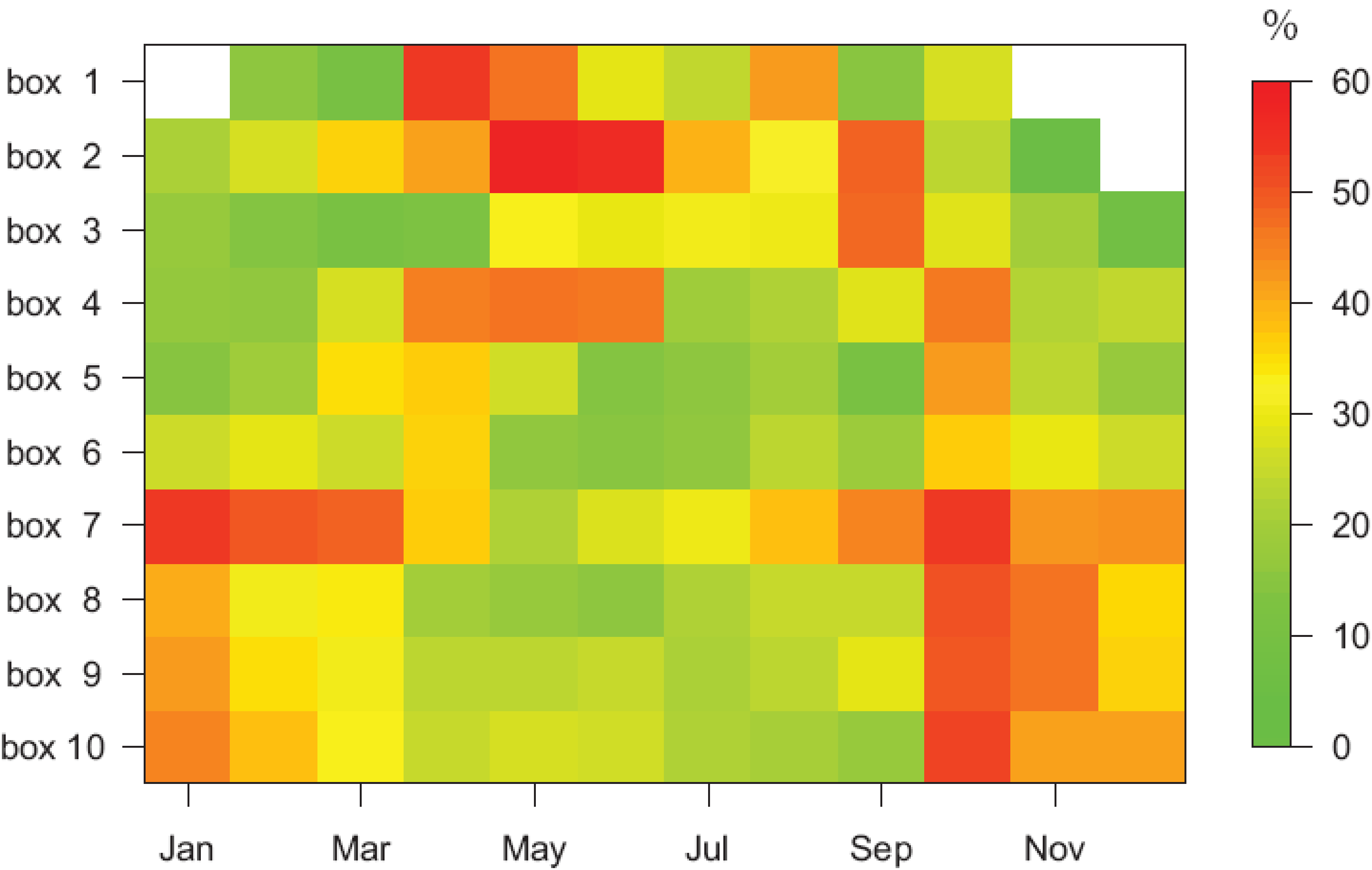
Algorithm to diagnose whether community structure at a given pixel is dominated by diatoms has been developed (Sathyendranath et al. 2004)

Towards Diagnosis of Phytoplankton Community Structure: Diatoms



Can be developed as Time Series

Seasonality of diatom occurrence



Compact description of pelagic ecosystem

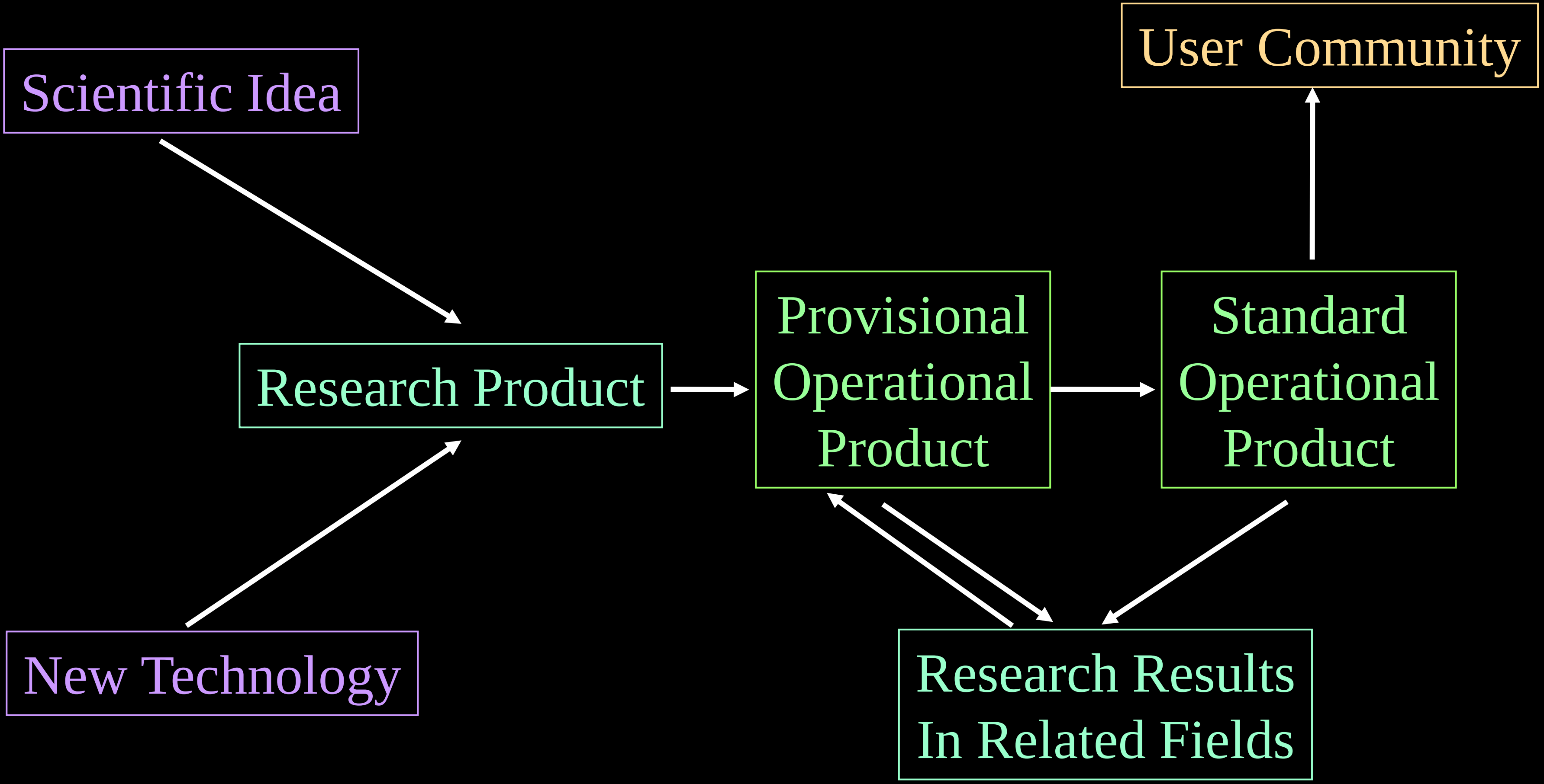
- Pelagic ecosystem can be represented as a time-dependent vector whose elements are chosen from list of ecological indicators

- Choice of elements depends on the particular applications envisaged

Some Ecological Indicators from Remote Sensing

Indicator	**Label**	**Dimensions**
Initiation of spring bloom	b_i	[T]
Amplitude of spring bloom	b_a	[ML^{-3}]
Timing of spring maximum	b_t	[T]
Duration of spring bloom	b_d	[T]
Total production in spring bloom	b_p	[ML^{-2}]
Annual phytoplankton production	P_Y	[ML^{-2}]
Initial slope of light-saturation curve	α^{B}	[L^2]
Assimilation number	$P^B{}_{\mathrm{m}}$	[T^{-1}]
Particulate organic carbon	C_T	[ML^{-3}]
Phytoplankton carbon	C_p	[ML^{-3}]
Carbon-to-chlorophyll ratio	χ	dimensionless
Phytoplankton growth rate	μ	[T^{-1}]
Generalised phytoplankton loss rate	L	[ML^{-3}T^{-1}]
Integrated phytoplankton loss	L_T	[ML^{-3}]
Spatial variance in biomass field	$\sigma_B{}^2$	[M^{2}L^{-6}]
Spatial variance in production field	$\sigma_P{}^2$	[M^{2}L^{-4}]
Phytoplankton functional types	NA	NA
Delineation of biogeochemical provinces	NA	NA

Requirement for Research Component



Scientific Idea

New Technology

Research Product

Provisional Operational Product

Standard Operational Product

User Community

Research Results In Related Fields

Some Results

- Remotely-sensed time series provide cost-effective basis for development of ecological indicators, averaged at appropriate time and space scales.

- Even with only two remotely-sensed variables (chlorophyll and temperature), a rich set of ecological indicators can be derived.

- Interrogate models for magnitudes of ecosystem indicators that can be constructed by remote sensing.

- The time series of indicators provides an economical description of the ecosystem that can be used to detect and quantify change

- Autumn bloom of phytoplankton emerges as a phenomenon no less interesting than the Spring bloom, but is less well understood.

Examples of Potential Applications

- EBM (Healthy and Productive Ecosystems)
- Carrying Capacity for Habitat
- Marine Protected Areas
- Submarine Visibility (DND)
- CWS, Parks Canada, WWF
- Ecosystem Response to Climate Change
- Vulnerable Marine Ecosystems
- High Seas Governance (IGS, GEO-BON)