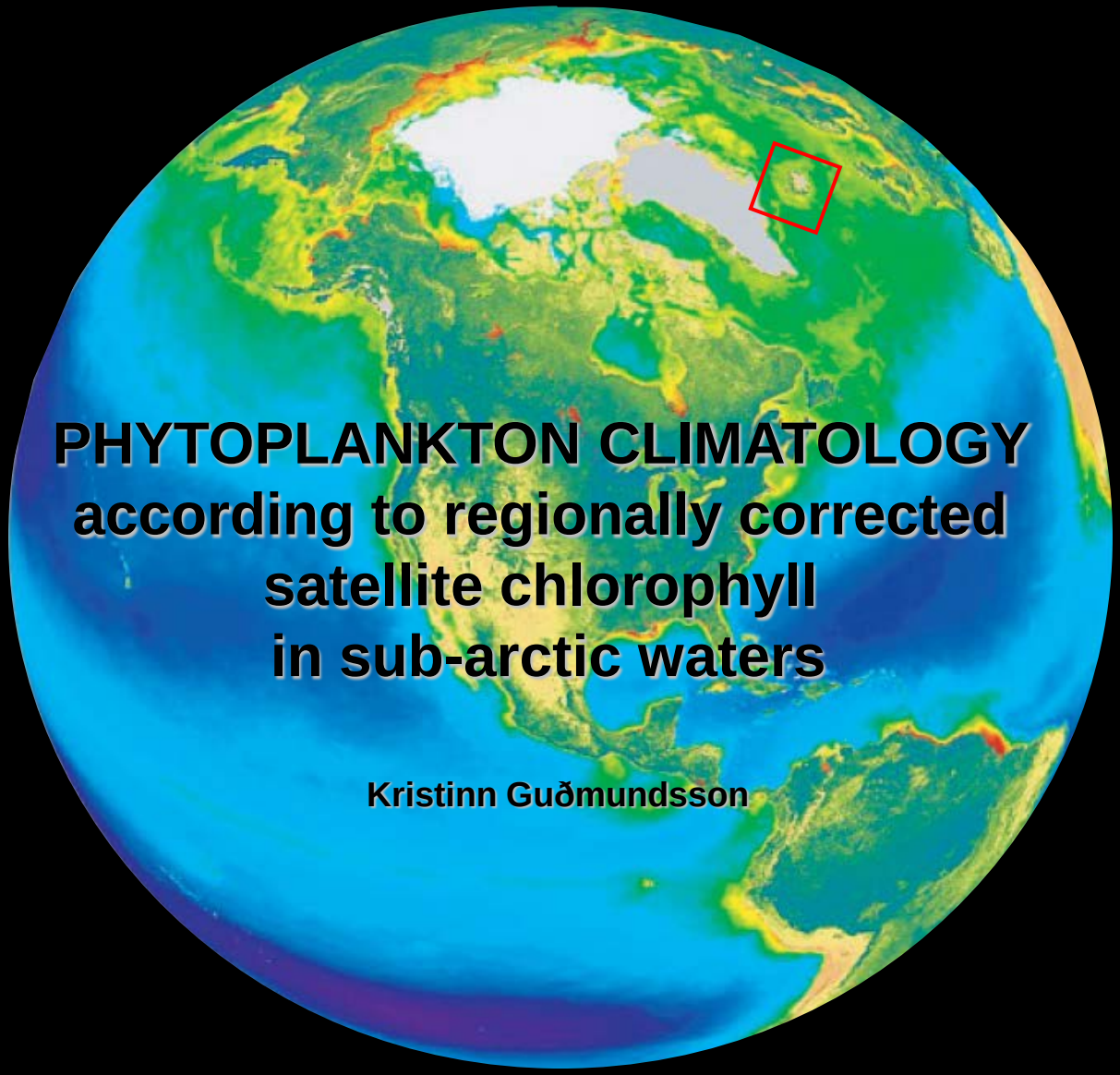
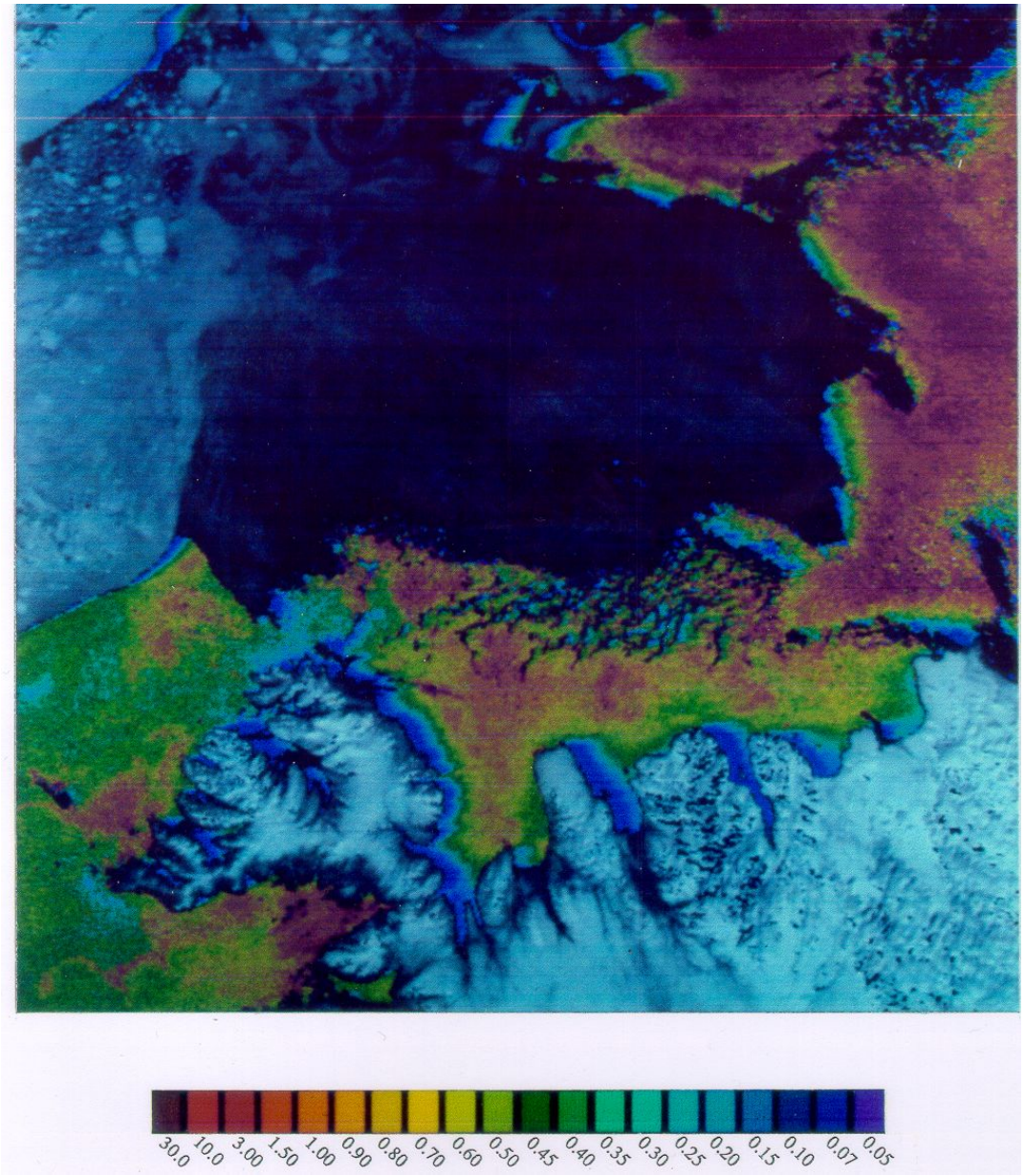


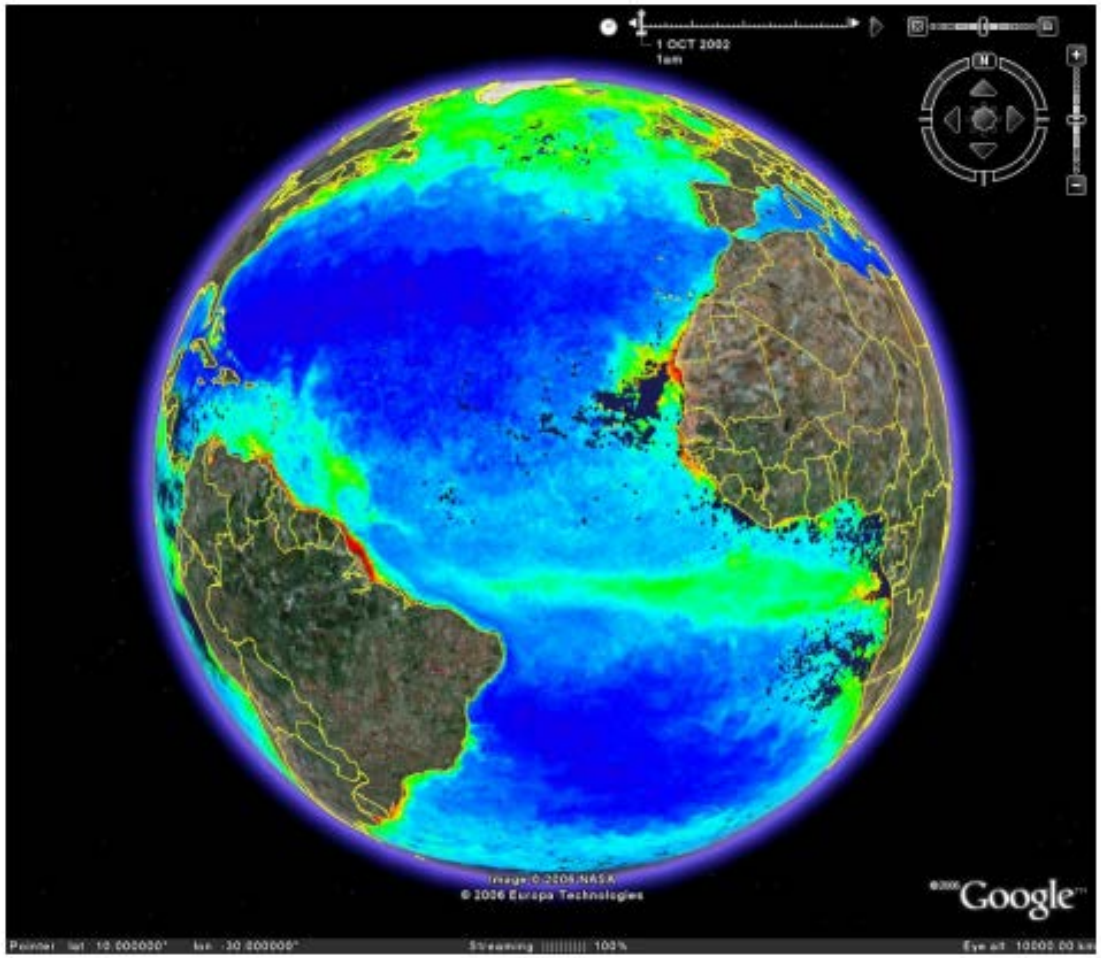
PHYTOPLANKTON CLIMATOLOGY according to regionally corrected satellite chlorophyll in sub-arctic waters

Kristinn Guðmundsson



April 14, 1979
NASA, CZCS orbit 2381
c.f. D.K. Clark and
N. Maynard, 1986

GLOB_animation_CHL1 Chlorophyll-a Concentration - Case 1 Water - AVW Method
20130415 20130422
lon=[-180 - -90] lat=[180 - 90]



Seasonal changes in surface chlorophyll a have be exploered, using standard algorithm for the conversion of satellite records, and made available for the www

c.f. http://www.globcolour.info/gallery/GLOB_animation_2_CHL1_meris_modis_seawifs.avi

Objectives and data:

Near-surface *in situ* and satellite chlorophyll-a data used for **development of a statistical model,** and ANOVA.

A: All relevant measurements of near-surface chlorophyll-*a* (water samples from 0 – 5 meter) is compared with that of satellite records, matched by the day and location (single pixel). Using records from ***GlobColour Project,*** i.e. daily averages on merged chlorophyll records from both NASA and ESA,

i.e. the parameters CHL1_mean and CHL2_mean, for 58° - 72° N and 2° - 40° W in 1998 – 2013, ~ 4.6 km pixel size.

Data used for **analysis of seasonal changes in chlorophyll** (phenology)

Used here is the predicted near-surface chlorophyll-a values, CHL1_mean, from the GlobColour Project, *i.e.* corrected by a regional statistical model.

The downloaded variable 8 day averages on merged chlorophyll records, for 60° - 72° N and 3° - 33° W in 1998 – 2013, ~ 4.6 km pixel size.

Statistical model used for corrections of systematic biases in satellite records on surface chlorophyll-a (CHL1), in accordance with that compared to water sample measurements available for the region

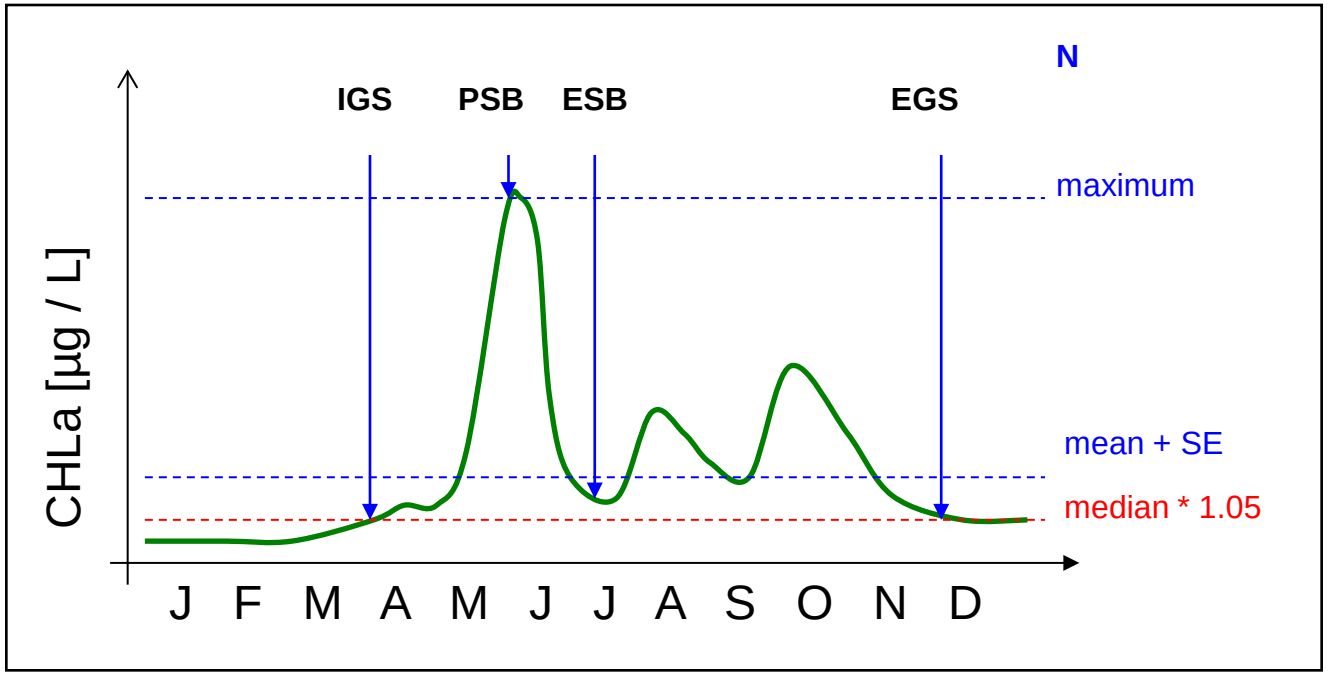
A simple linear regression model, applied for the predictions of regional corrected surface chlorophyll:

lm(log(chl)~log(CHL1_mean)+ dnr + sunH + log(wd2b)

```
Coefficients:
                    Estimate   Std. Error  t value  Pr(>|t|)
(Intercept)         0.547550   0.467123    1.172    0.241741
log(CHL1_mean)      0.732027   0.042140   17.371    < 2e-16    ***
dnr                -0.004877   0.001220   -3.996    7.5e-05    ***
sunH                0.035301   0.009232    3.824    0.000150   ***
log(wd2b)          -0.132454   0.034303   -3.861    0.000129   ***
---
Residual standard error: 0.8531 on 454 degrees of freedom
Multiple R-squared:  0.5151,    Adjusted R-squared:  0.5109
F-statistic: 120.6 on 4 and 454 DF,  p-value: < 2.2e-16
```

AIC = 1163.7

Phenology



1) N: number of observations

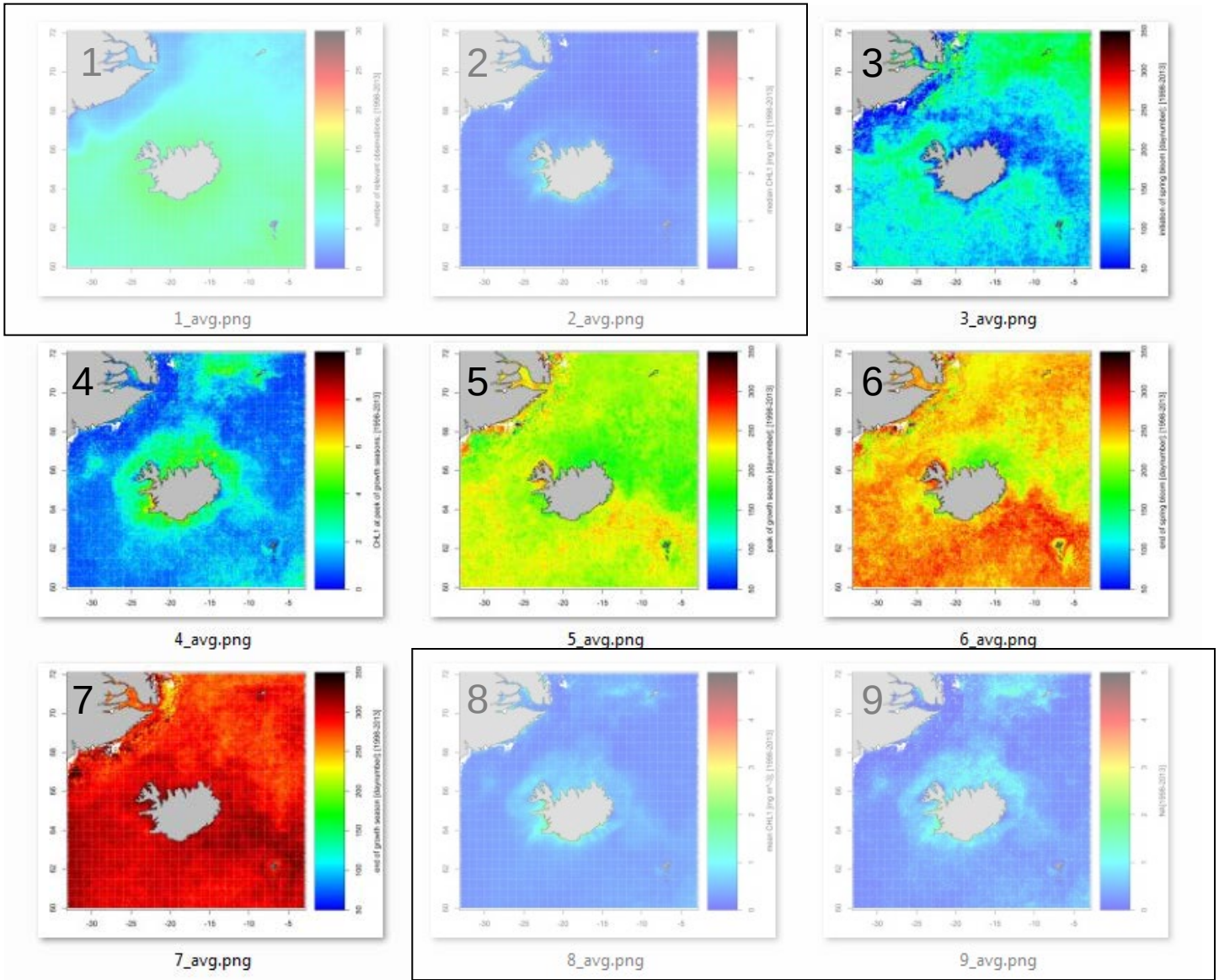
CHARACTERISTICs:

3) IGS: inition of phytoplankton growth season [daynumber]
5) PSB: peak of spring bloom [daynumber]
6) ESB: end of spring bloom [daynumber]
7) EGS: end of phytoplankton growth season [daynumber]

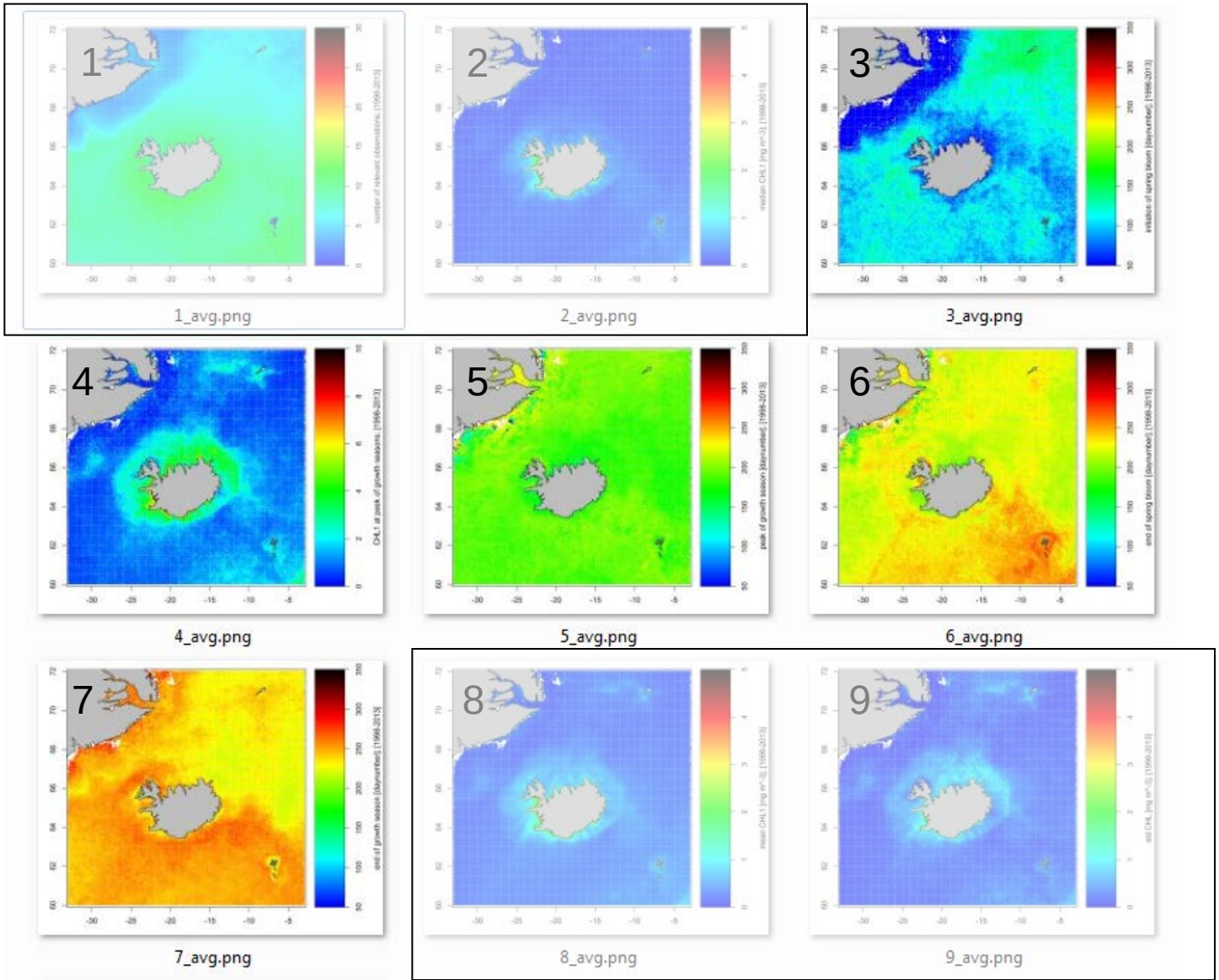
STATISTICs

4) maximum GS: maximum value during growth season [µg CHLa / L]
8) mean GS: calculated mean value for growth season [µg CHLa / L]
2) median GS: calculated median value for growth season [µg CHLa / L] * 1.05
9) SE GS: standard error for a growth season [µg CHLa / L]

Derived parameters: **averages of 1998 – 2013, *i.e.* 1) N; 2) median; 3) IGS; 4) maximum, 5) PSB; 6) ESB; 7) EGS; 8) mean and 9) SE, for the '[raw data](#)' obtained from the 'GlobColour Project'**

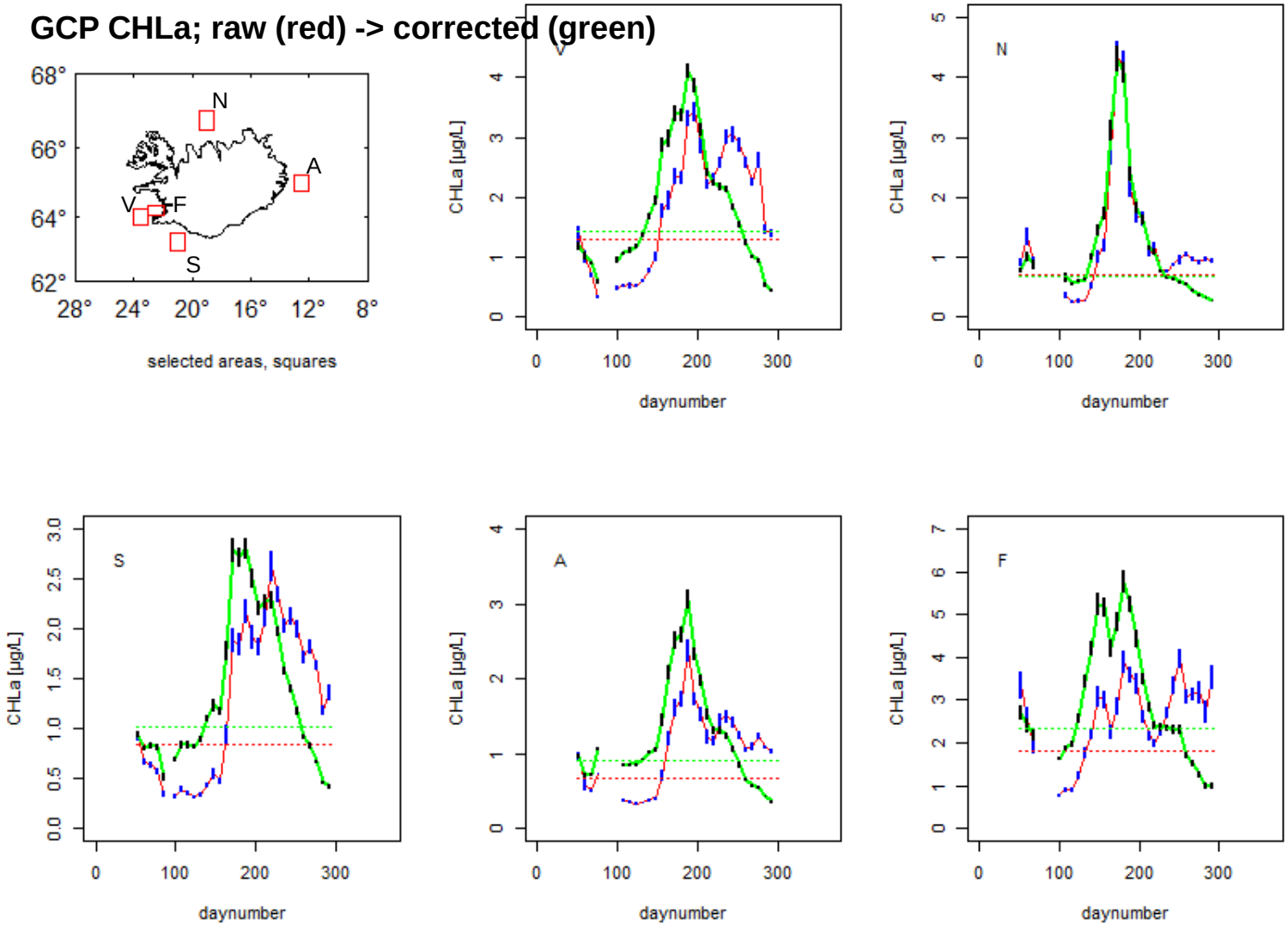


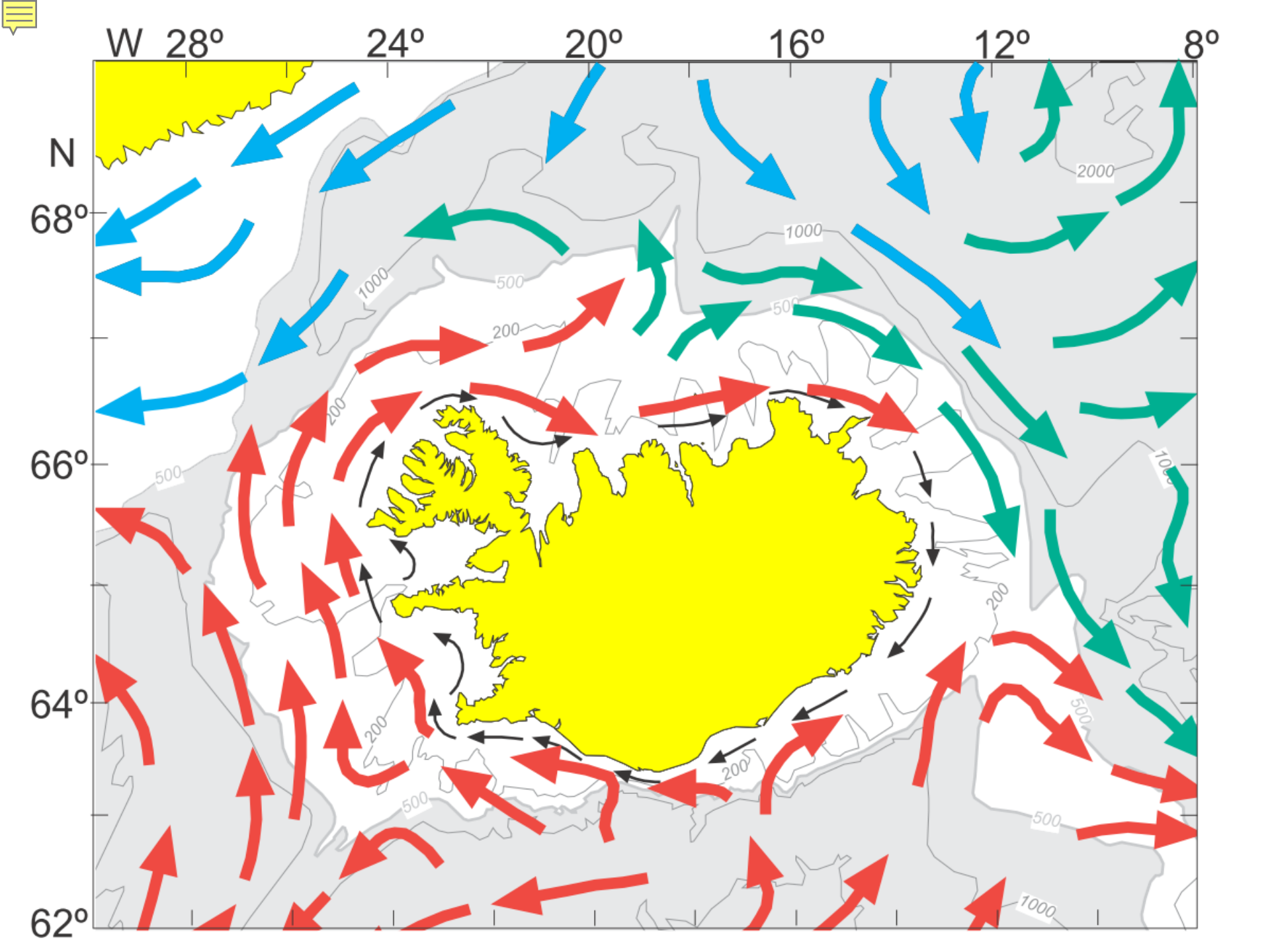
Derived parameters: **averages of 1998 – 2013, *i.e.* 1) N; 2) median; 3) IGS; 4) maximum, 5) PSB; 6) ESB; 7) EGS; 8) mean and 9) SE, for the regionally corrected data**



Comparison of satellite chlorophyll-a (CHL1 ; GCP) before and after local corrections

GCP CHLa; raw (red) -> corrected (green)

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N
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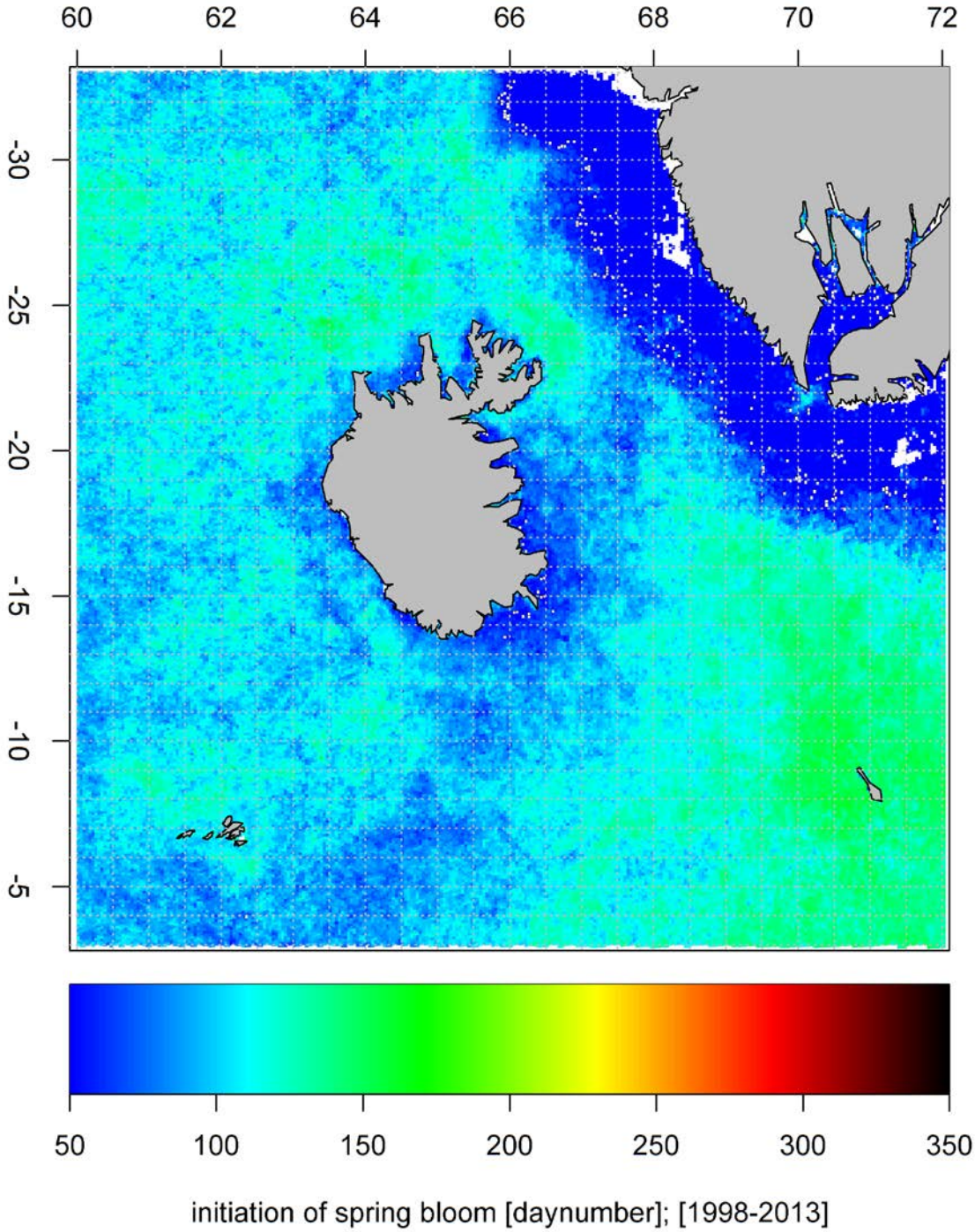
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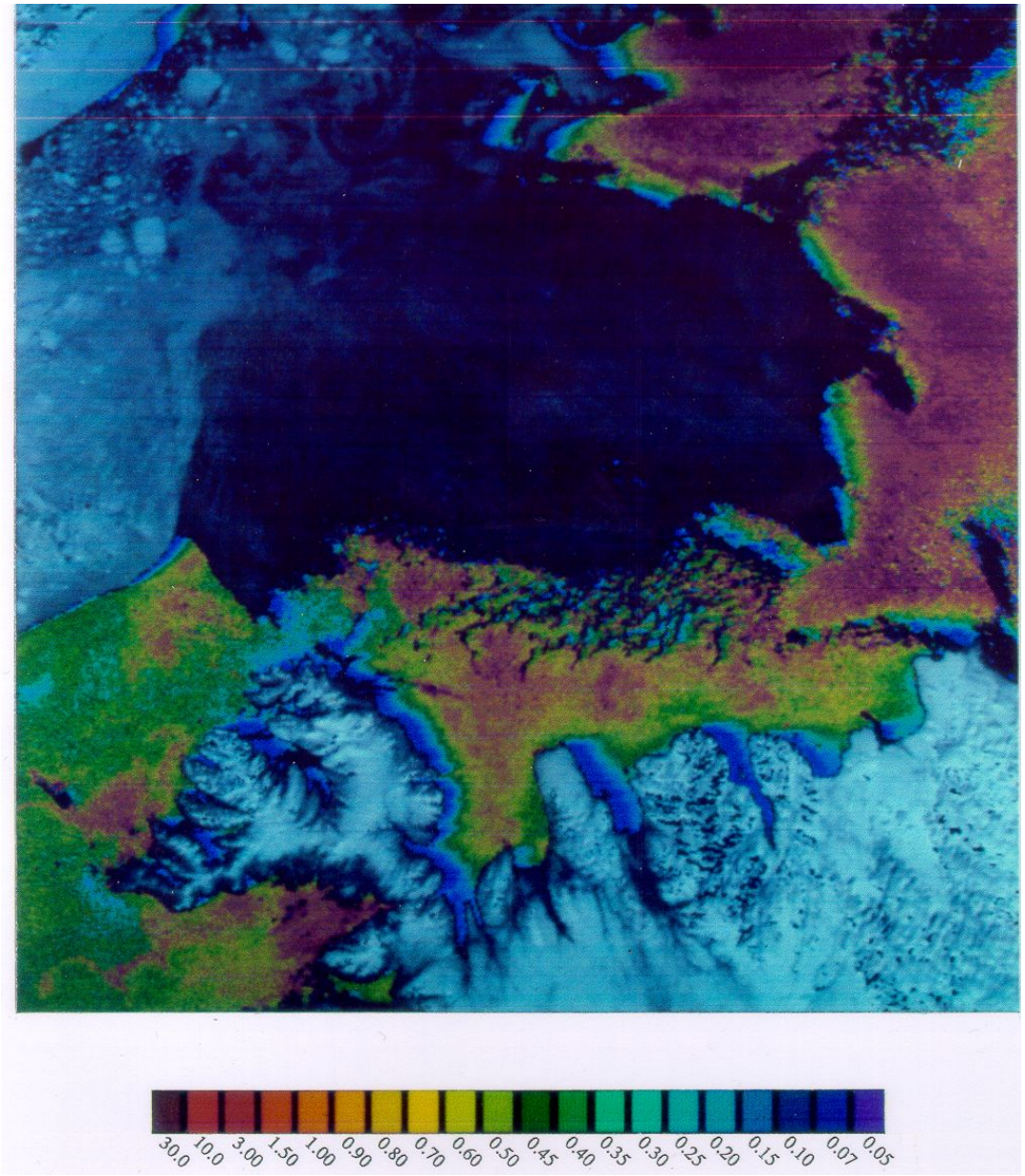
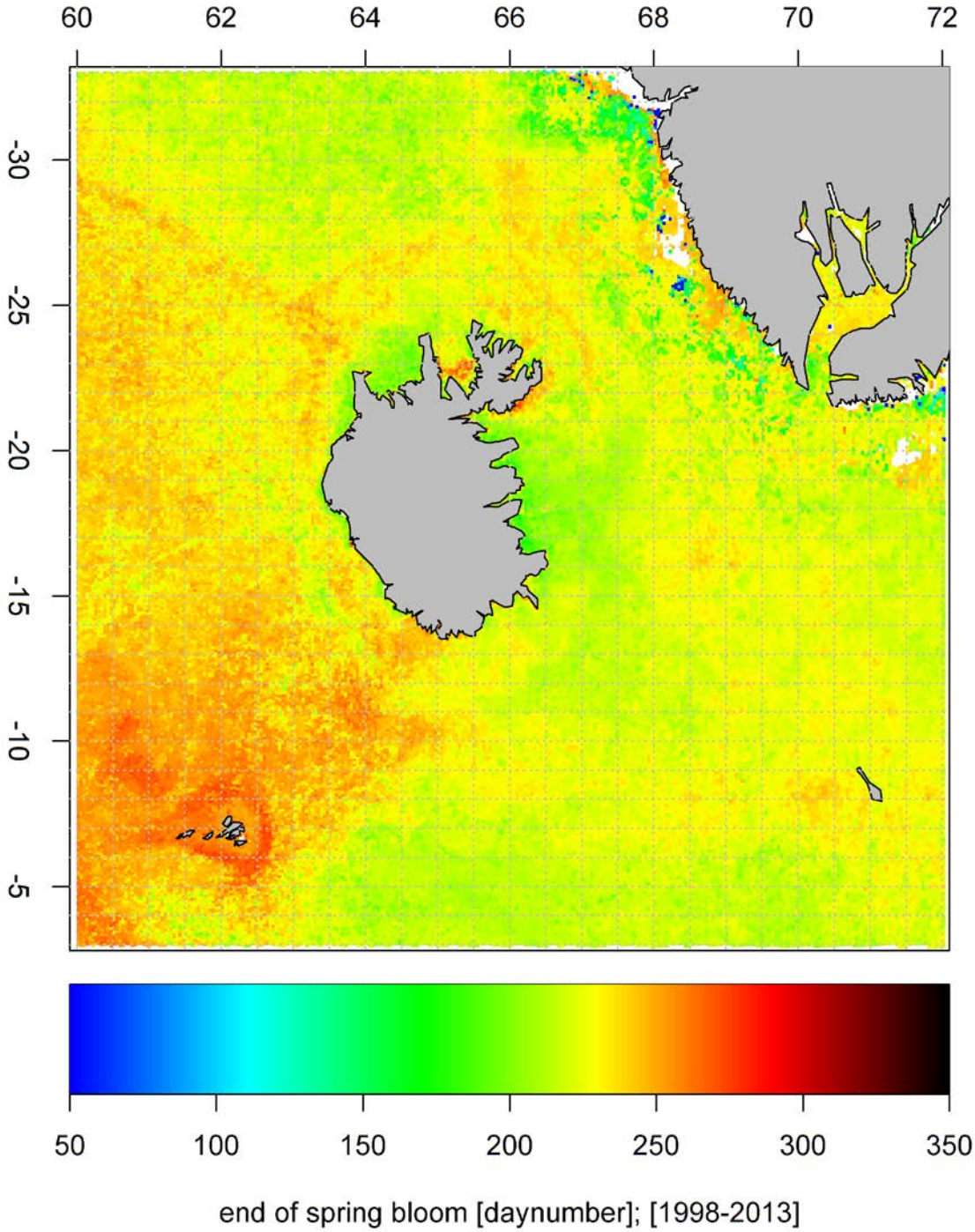
initiation of spring bloom [daynumber]; [1998-2013]



April 14, 1979
NASA, CZCS orbit 2381
c.f. D.K. Clark and
N. Maynard, 1986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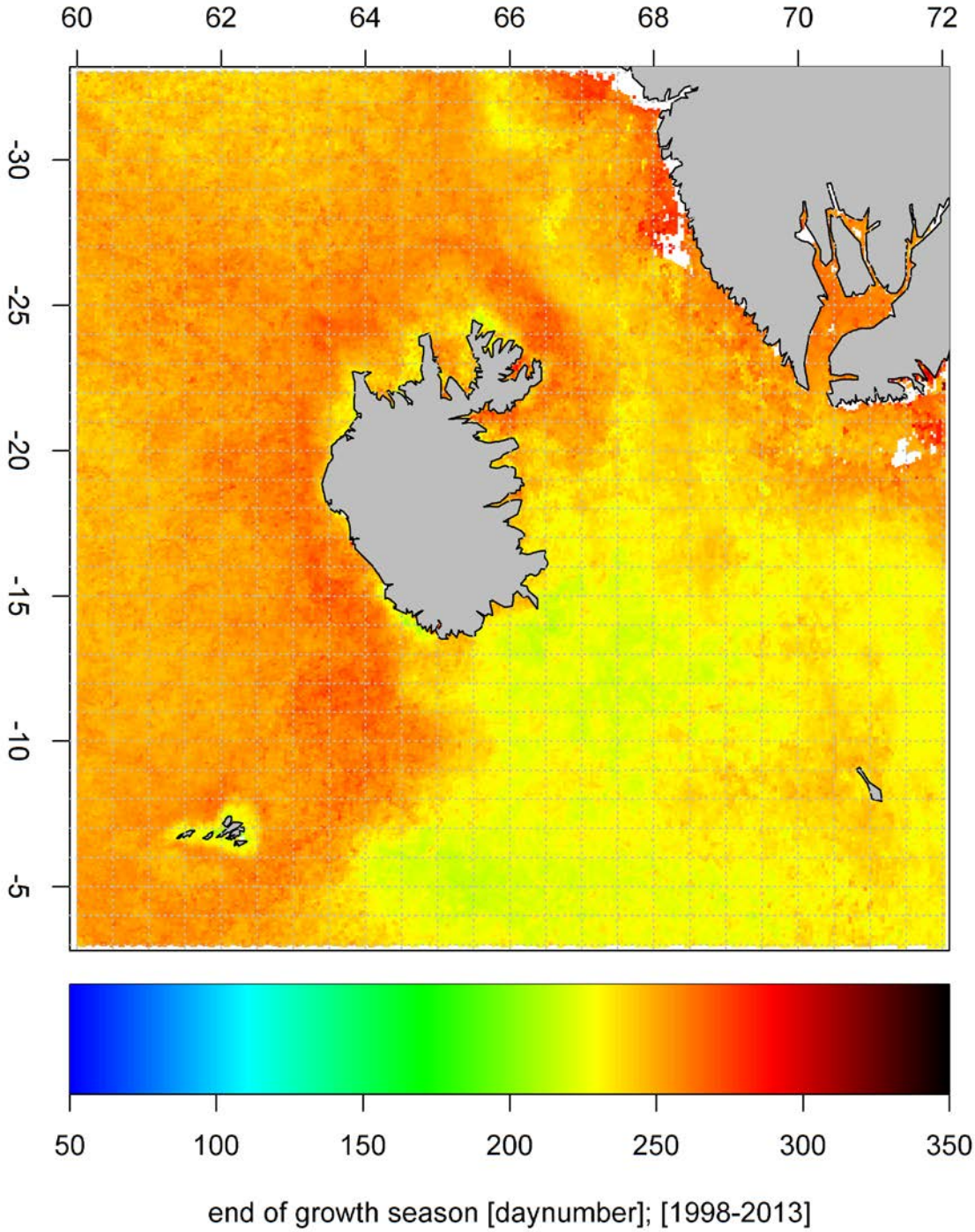
end of spring bloom [daynumber]; [1998-2013]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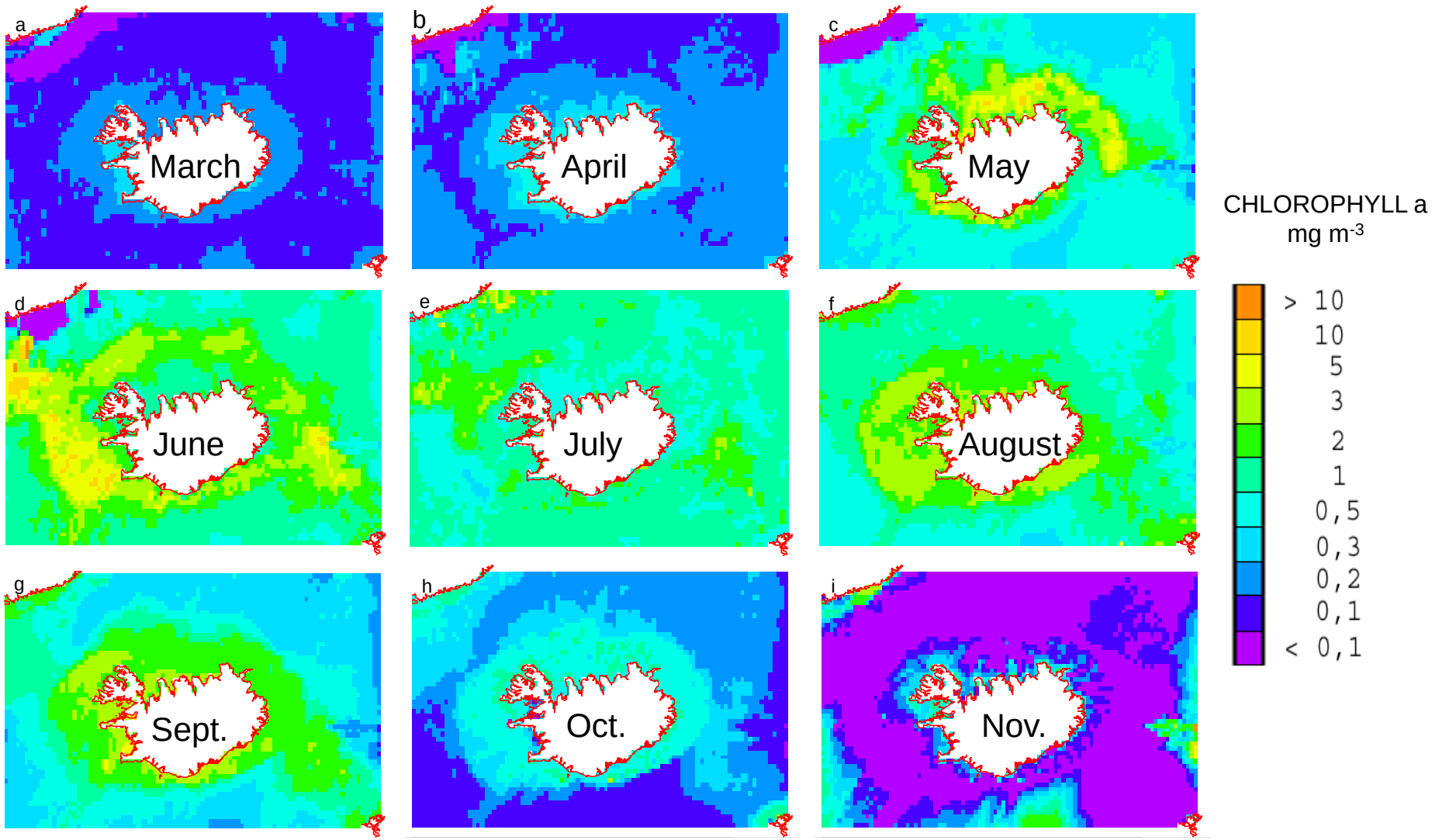
200
250
300
350
end of growth season [daynumber]; [1998-2013]

So far we have been looking at average values, for multiple years

And that help us to make comparisons with results from earlier studies. Some of the earlier studies illustrate variations that are to be expected in the area, *as* apparent from the three following slides, *i.e.* the first revealing model prediction of average monthly concentrations of surface chlorophyll in the area (K. Guðmundsson, M.R. Heath, E.D. Clarke 2009), the next detailing the results of a study on phytoplankton growth SV of Iceland (T. Thórdardóttir 1986), and finally a unpublished figure illustrating effects due to different water regimes prevelance over the Northern shelf of Iceland (N-Atlantic vs. polar water influence).

However, what is the most exciting with satellite chlorophyll data is the fact that information may be extracted with respect to much more spatial and temporal resolution than one could ever obtain from 'ship samples'. The aim is to create tools to extract annual indexes on changes in surface chlorophyll (phytoplankton biomass), e.g. for application in diverse ecological studies. More on that later..

Model prediction of chlorophyll distribution, from March to November



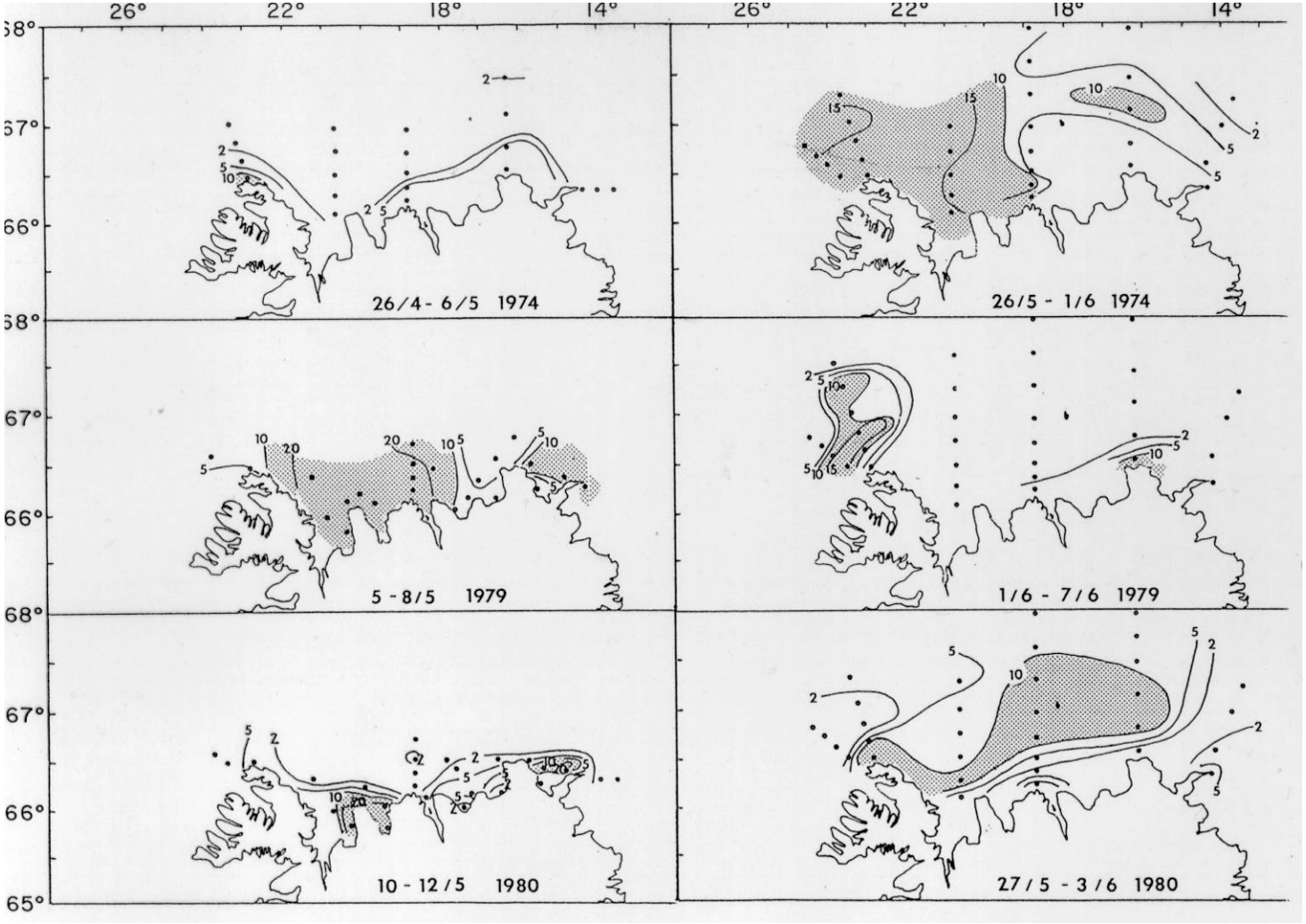
Guðmundsson et al. 2009

Northern banks

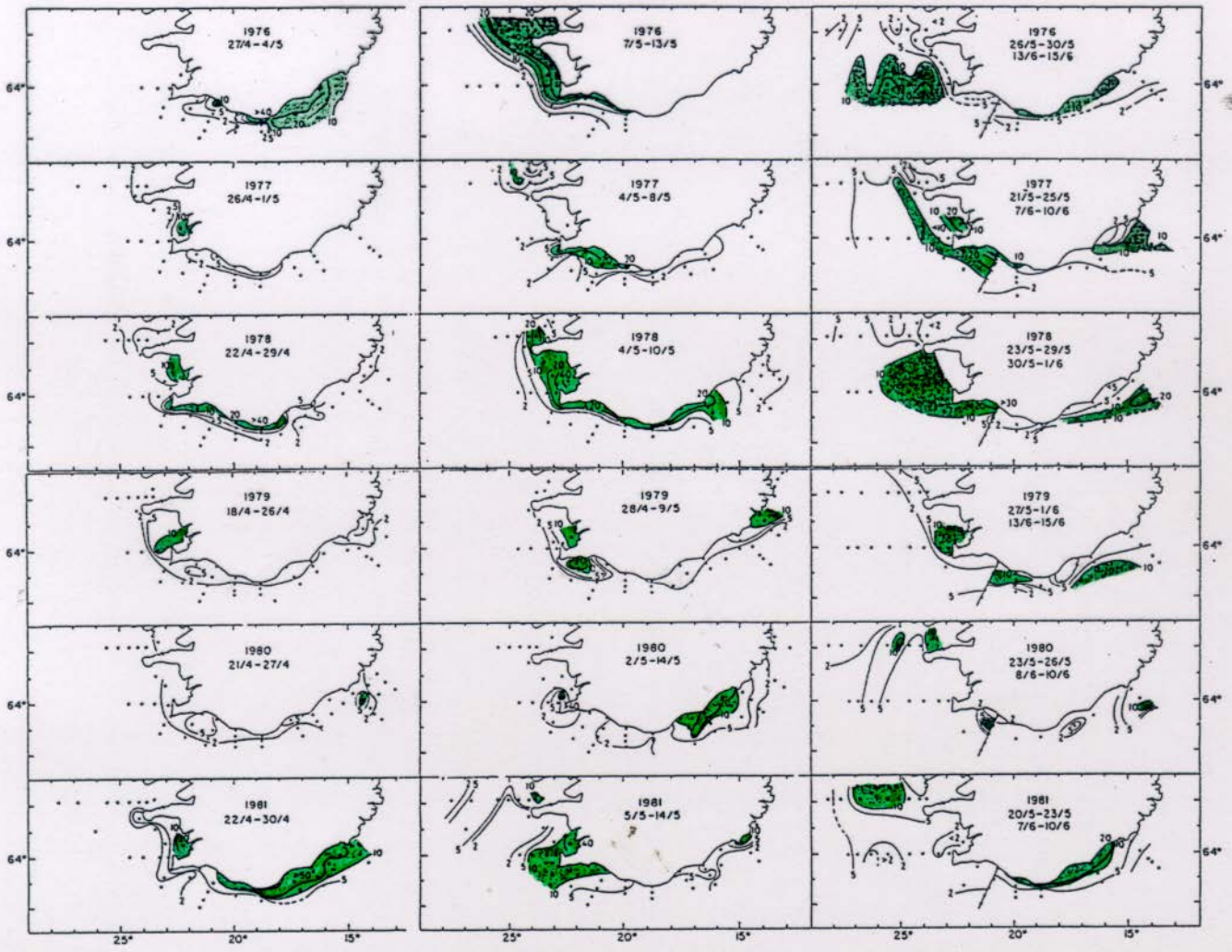
The mean
mg C m^{-2} y^{-1} for
Siglunes 1- 4

1974: 120
“warm year”

1979: 60
“cold year”



April / May May May / June



1976

1977

1978

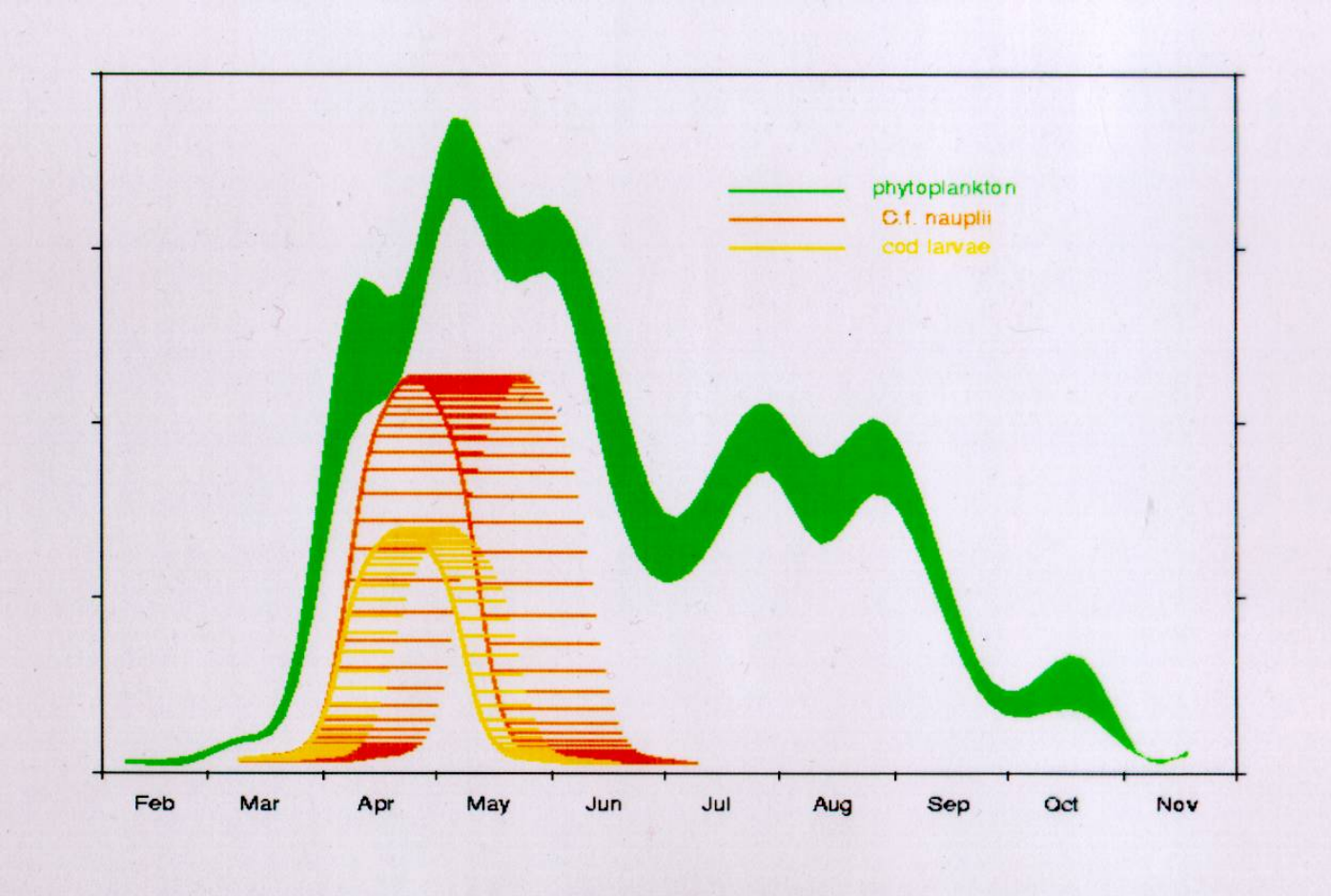
1979

1980

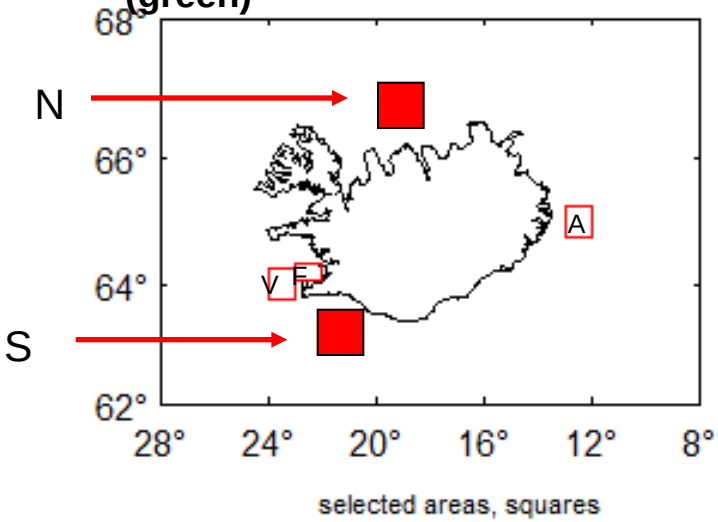
1981

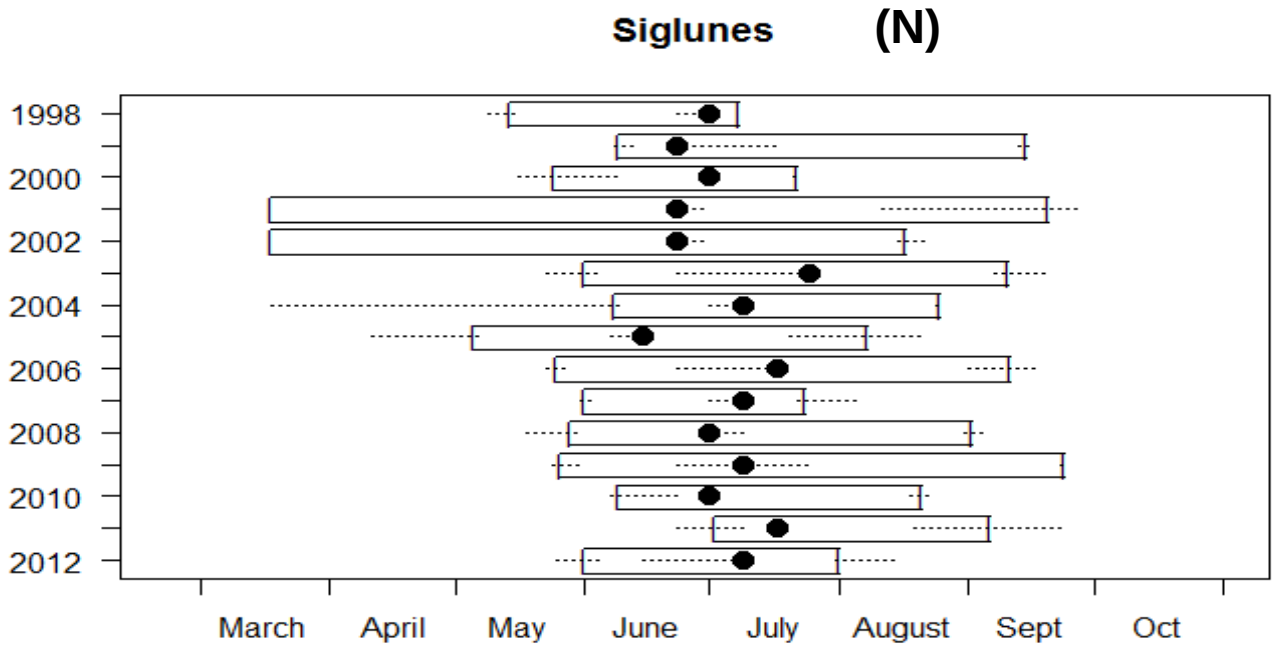
Fig. 4. Primary production (mg C m^{-3} h^{-1}) at 10 m from April to early June in the years 1976-1981.

Match-mismatch: comparison of the mean of measured chorophyll at SW coastal area, hatching and duration of *Calanus* larval stages and yolk sack cod larva

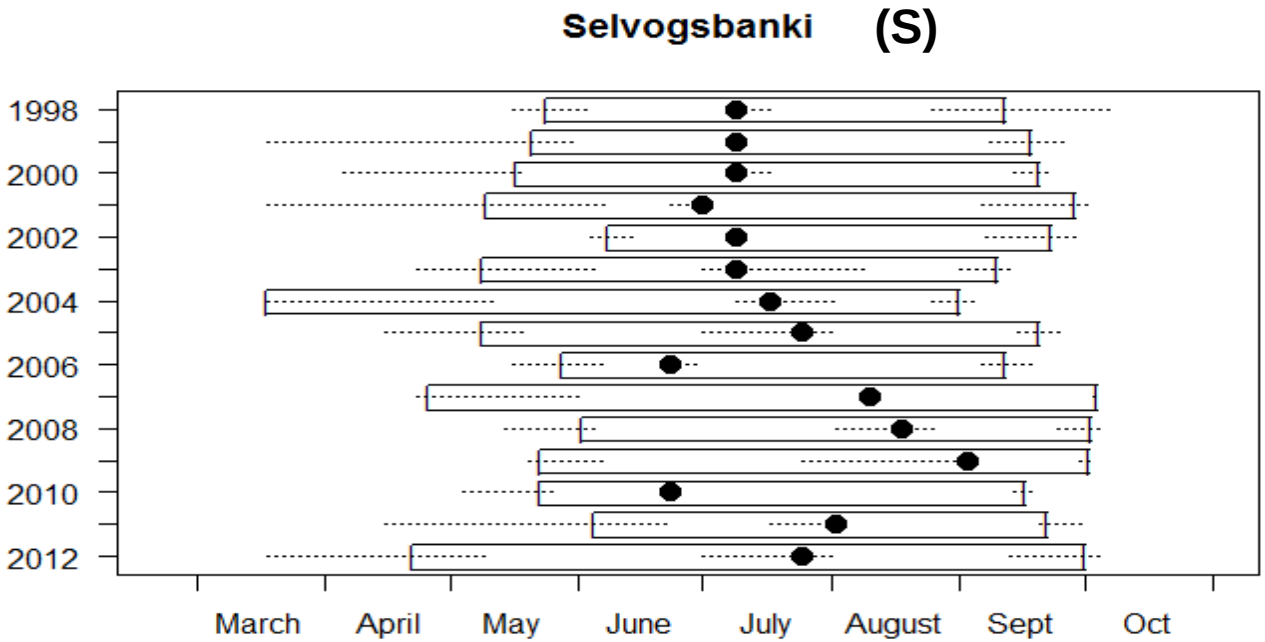


GCP CHLa; raw (red) -> corrected (green)



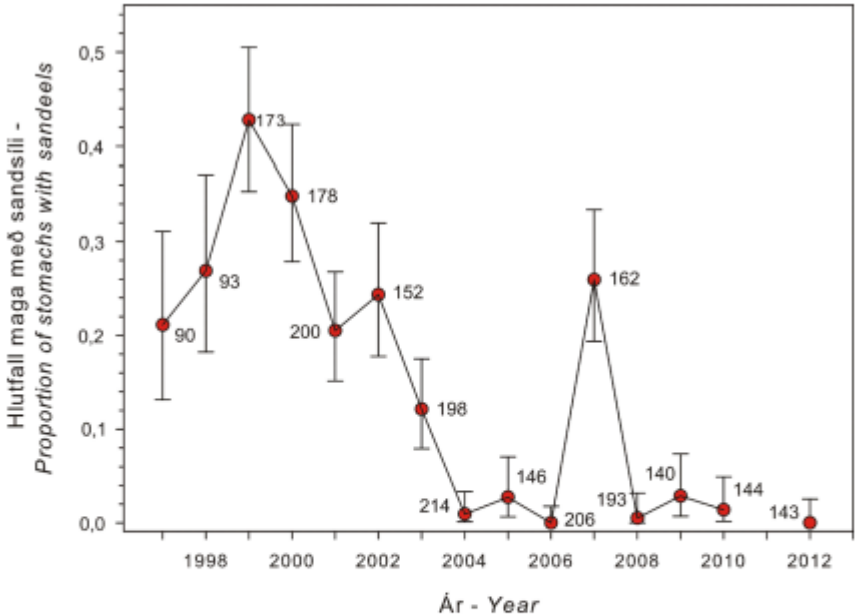


Uppfæra myndina og hafa með niðurstöður frá 2013 !!! – Sést á síðustu glæru!



Kristján Lilliendahl, Erpur S. Hansen, Valur Bogason, Marinó Sigursteinsson, Margrét L. Magnúsdóttir, Páll M. Jónsson, Hálfdán H. Helgason, Gísli J. Óskarsson, Pálmi F. Óskarsson og Óskar J. Sigurðsson

Náttúrufræðingurinn 83 (1–2), bls. 65–79, 2013

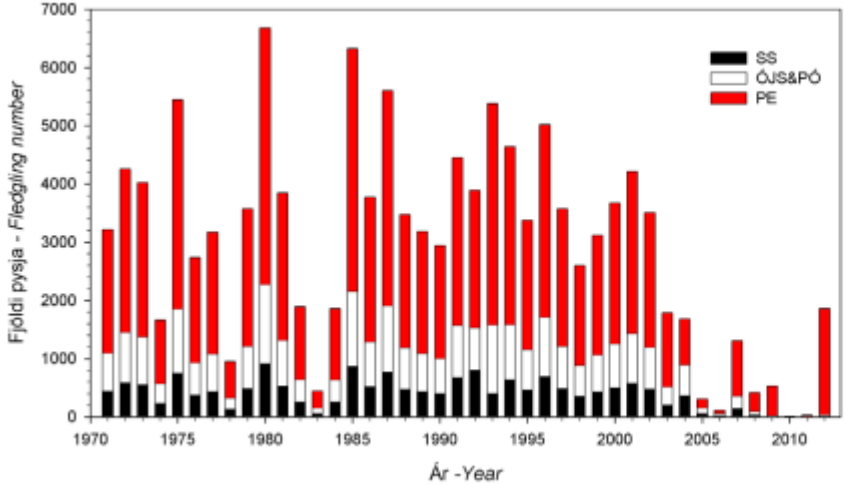


15. mynd. Hlutfall ýsumaga sem innihéldu sandsíli í rannsóknaleiðöngrum Hafrannsóknastofnunar á árunum 1998–2012. Gögn frá þeim fjórum svæðum þar sem sandsíli hefur verið rannsakað eru sameinuð og heildarfjöldi maga hvert ár gefinn. Sýnd eru 95% öryggismörk hlutfalla. – The proportion (with 95% CI) of haddock Melanogrammus aeglefinus *stomachs containing sandeel during autumn surveys in 1998–2012 of the Marine Research Institute. Data from four sandeel research areas are combined, with sample size (total no. of stomachs) shown at respective data points.*

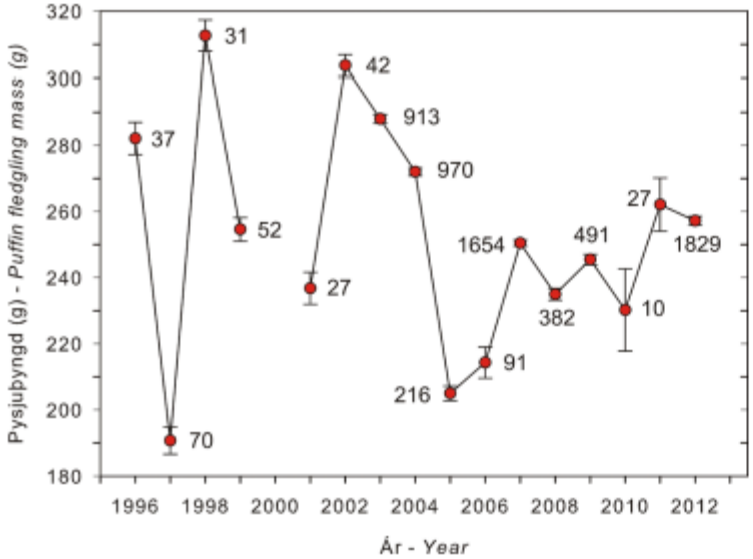
NB! Phytoplankton index was apparently close to “normal” in 2006, the year before?

Kristján Lilliendahl, Erpur S. Hansen, Valur Bogason, Marinó Sigursteinsson, Margrét L. Magnúsdóttir, Páll M. Jónsson, Hálfdán H. Helgason, Gísli J. Óskarsson, Pálmi F. Óskarsson og Óskar J. Sigurðsson

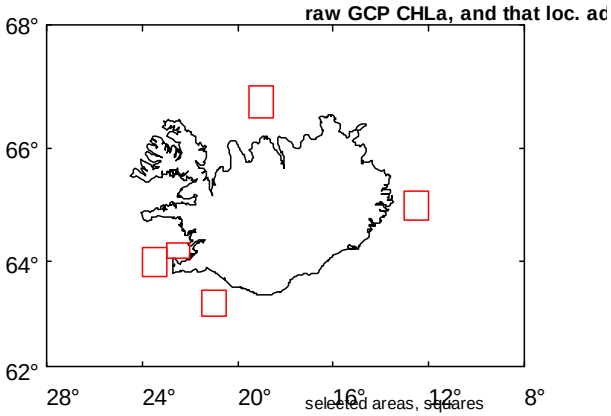
Náttúrufræðingurinn 83 (1–2), bls. 65–79, 2013



6. mynd. Gróflega áætlaður fjöldi pysja sem hafa fundist á Heimaey frá árinu 1971 sem sýnir mun á milli tímabilanna fyrir og eftir 2005. Myndin er byggð á gögnum frá Sigurgeiri Sigurðssyni (1971–1993), Óskari J. Sigurðssyni og Pálma Óskarssyni (ÓJS&PÓ; 1991–2009) og Pysjueftirlitinu (PE; 2003–2012). Áætlunin byggist á bak- og framreikningum á gögnunum (sjá: aðferðir vegna útreikninga). – A rough estimate of puffin fledgling numbers found on the Heimaey island from 1971. The different colouring in the columns reflects different sources of data. The result is based on both forward and backward estimations from three data series from the periods of 1971–1993, 1991–2009 and 2003–2012.



8. mynd. Meðalþyngd pysja sem fundist hafa á Heimaey á tímabilinu 1996–2012 ásamt staðalskekkju. Fjöldi mælinga er sýndur við hvern punkt (gögn Gísla Óskarssonar frá árunum 1996 til 2002 og frá 2003 eru gögnin úr Pysjueftirlitinu). – Mean mass of puffin fledglings found on the Heimaey island in the period 1996 – 2012 (± S.E.), with sample size shown at each data point.


raw GCP CHLa, and that loc. ac
68°
66°
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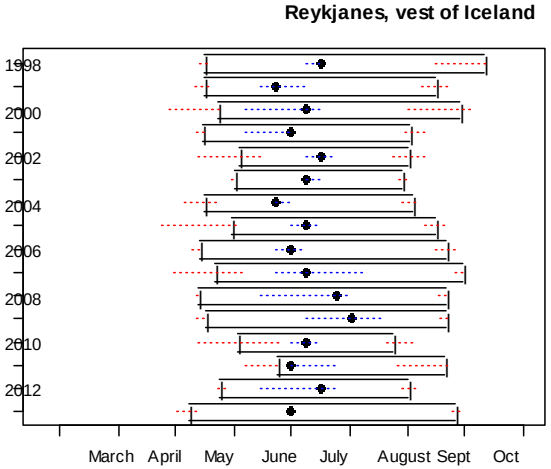
62°
28°
24°
20°
16°
12°
8°
selected areas, squares


Reykjanes, vest of Iceland
1998
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March
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July
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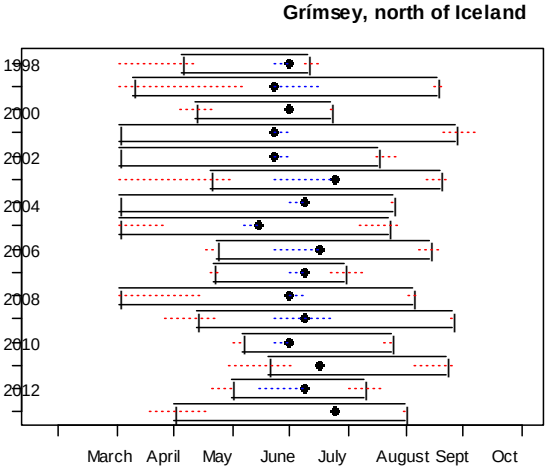
Grímsey, north of Iceland
1998
2000
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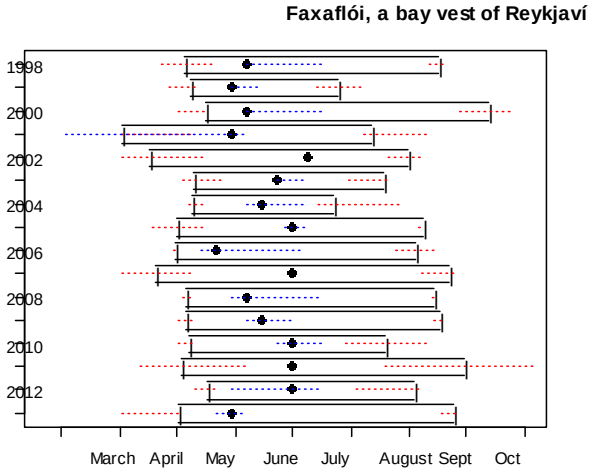
Faxaflói, a bay vest of Reykjaví
1998
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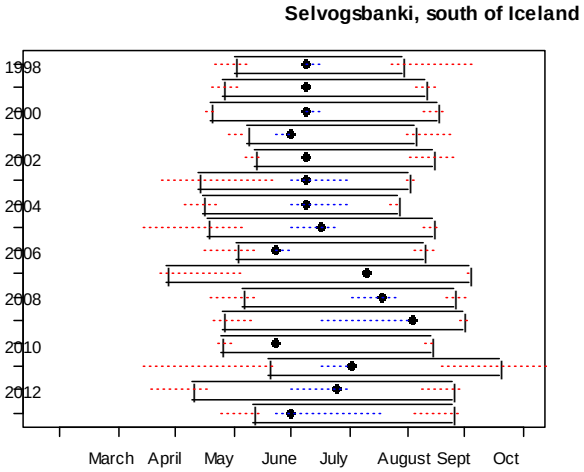
Selvogsbanki, south of Iceland
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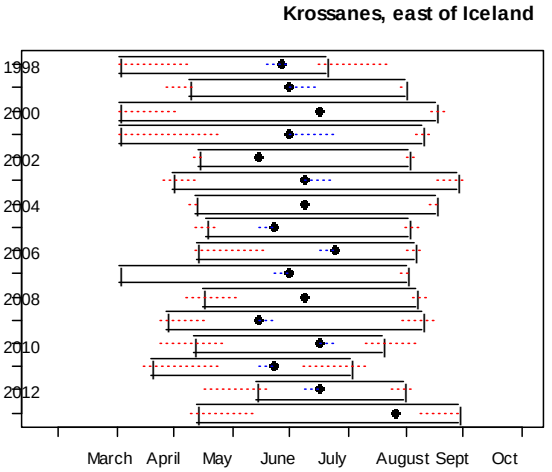
Krossanes, east of Iceland
1998
2000
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March
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July
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Sept
Oct

Thanks are due to the GlobColour Project, for making the merged satellite data from NASA and MERIS available.

Also, I sincerely thank my colleagues for diverse help during the work on processing data, and time to discuss the results.

and THANK YOU for your attention

Man, I'm out, but "they are coming to take you away"!

kristinn@hafro.is

LUNDARANNSÓKNIR 2013

VÖKTUN VIÐKOMU, FÆÐU, LÍFTALA & KÖNNUN VETRARSTÖÐVA

© Erpur Snær Hansen & Arnþór Garðarsson

Óheimilt er að vitna í niðurstöður án heimildar höfunda.

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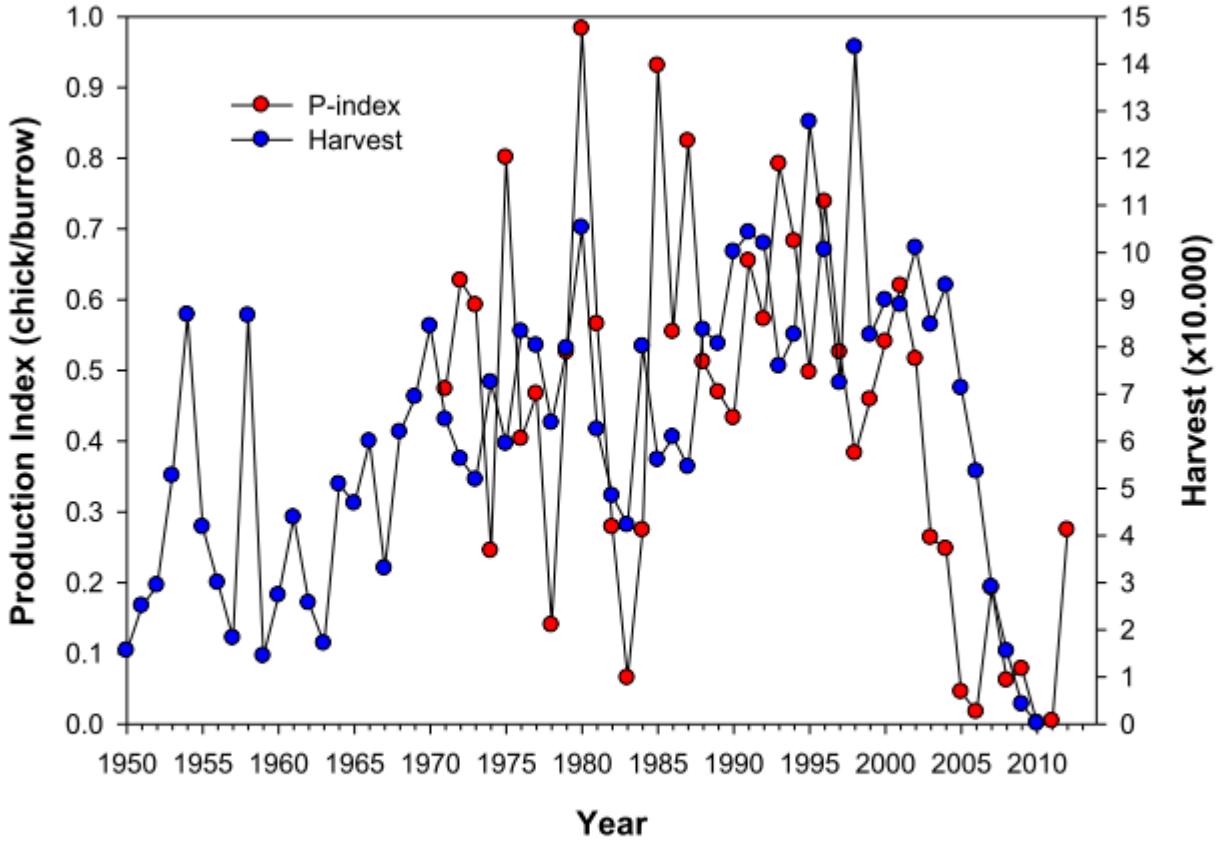
SKÝRSLA TIL VEIÐIKORTASJÓÐS – UMHVERFIS- & AUÐLINDARÁÐUNEYTI

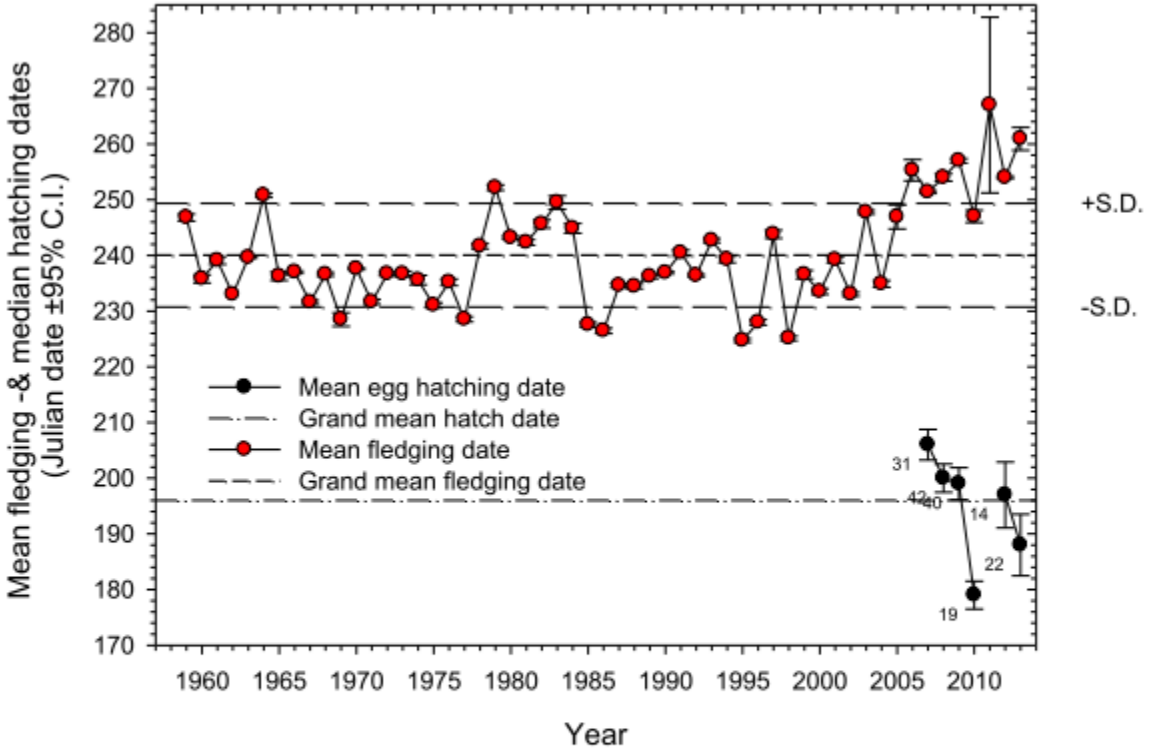
Náttúrustofa Suðurlands

DESEMBER 2013

Athuga með leyfi til að nota þær tvær myndir sem fylgja hér á eftir.



28. Mynd. *Viðkomuvísitala - P-index (fleygar pysjur / varpholu) samanborið við lundaveiði í háf.*

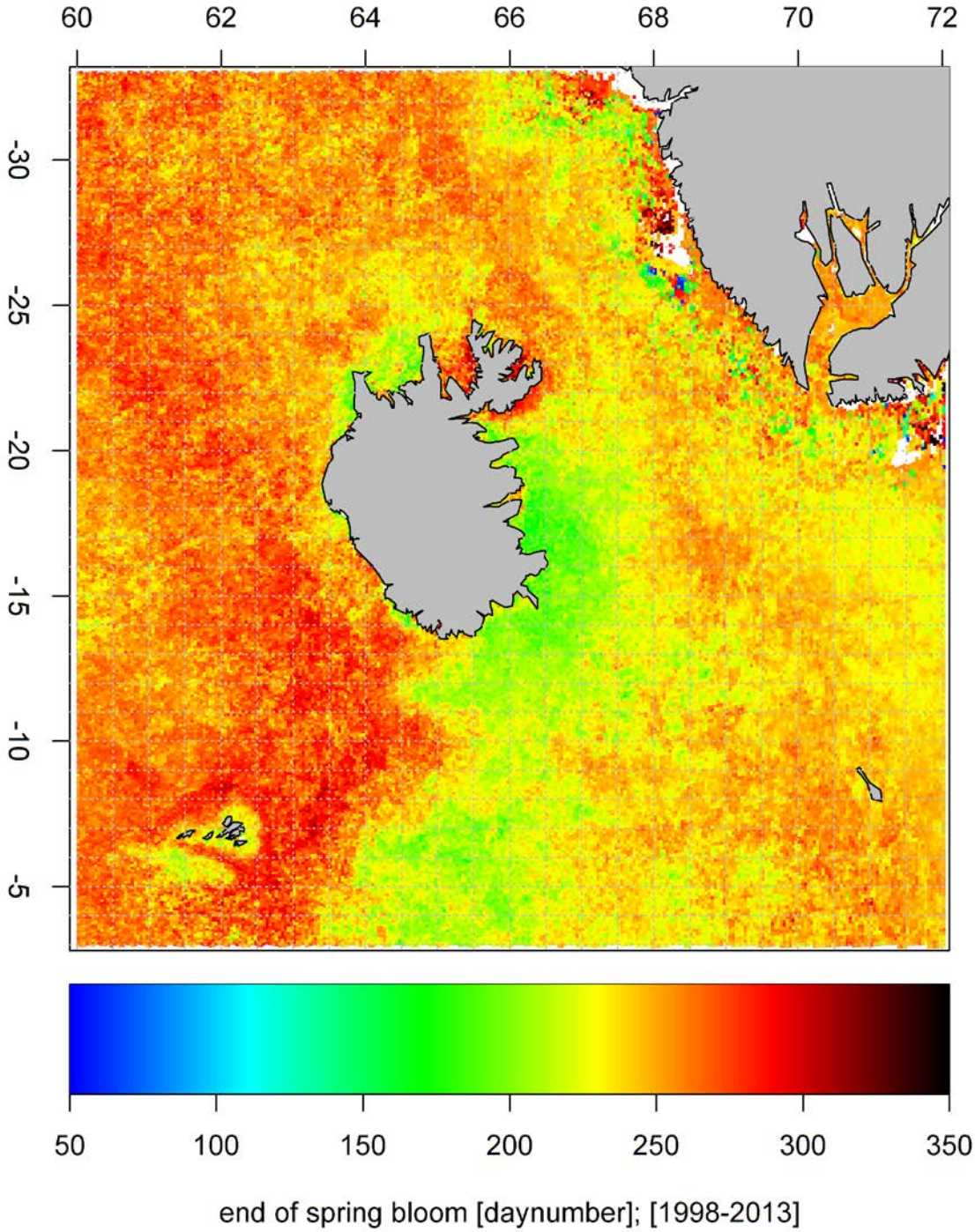


***29. mynd**. Meðalbrottfarartími bæjarpysja í Vestmannaeyjum (± 95% öryggismörk). Heildarmeðaltal (dagur 240 = 28. ágúst,) er sýnt með stuttri brotalínu og staðalfrávik þess með löngum brotalínum. Einnig er sýndur meðalklaktími 2007-2013 (15. júlí) með punktstrikalínu. Um 80% eggja voru afrækt árið 2010, öll egg árið 2011, og um 90% eggja voru afrækt 2013.*

FINE

A colony of Northern Gannet (*Morus bassanus*) on Eldey, SW of Reykjanes, in 2008 / kg

TAKK!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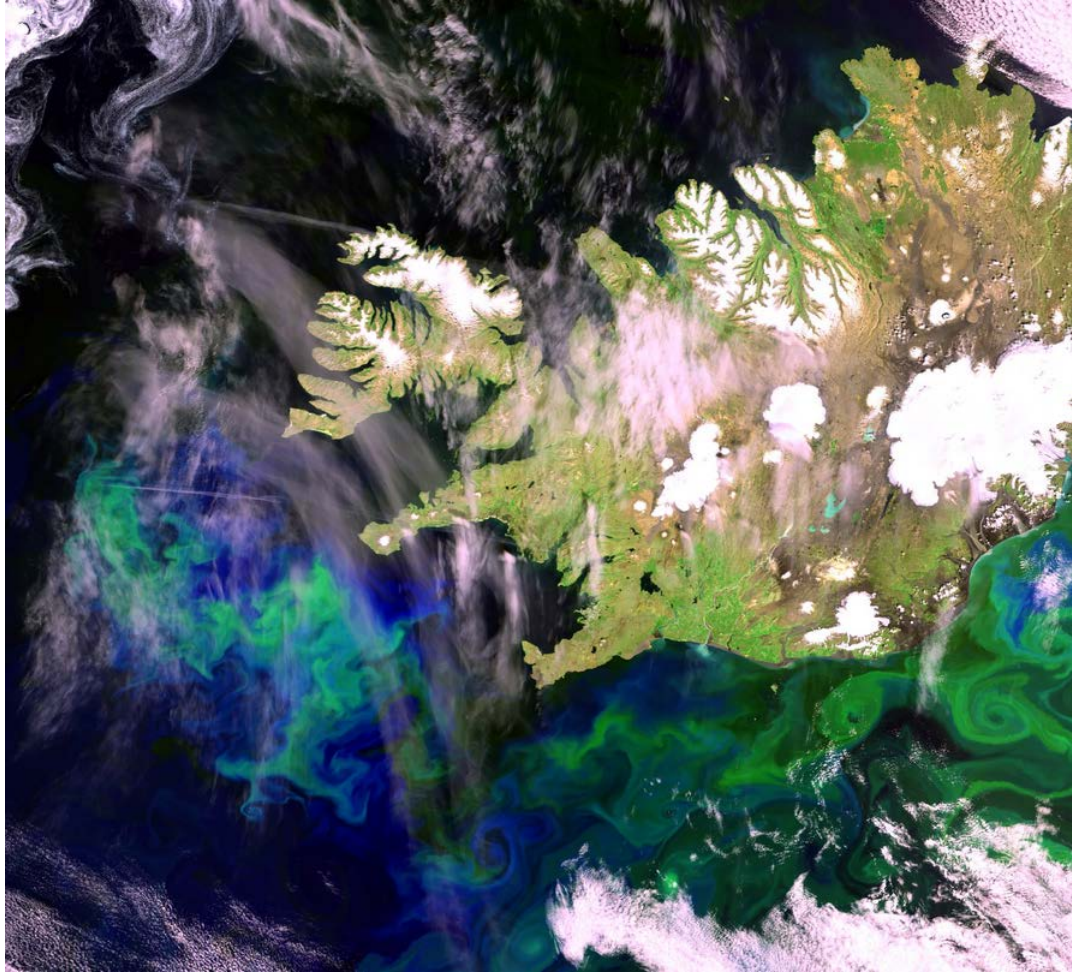
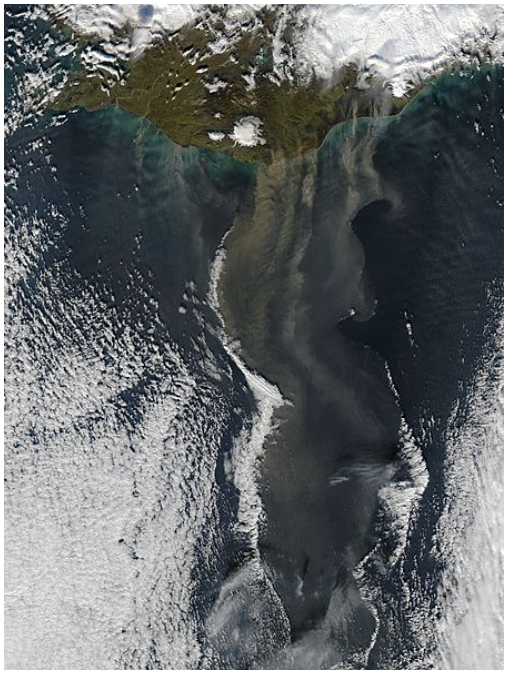
end of spring bloom [daynumber]; [1998-2013]

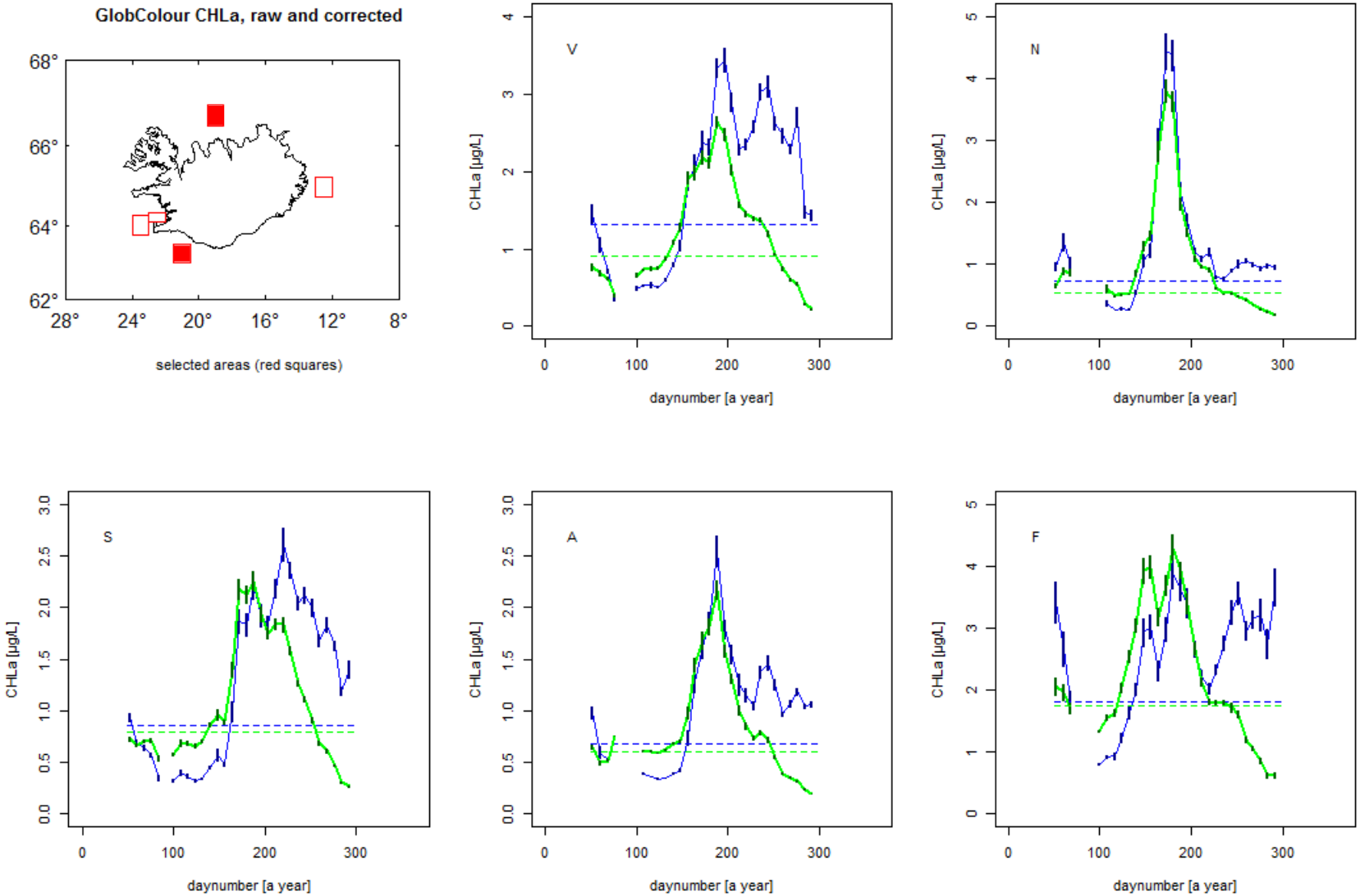
Not just fascinating images,





local conditions may disturb monitoring of near-surface chlorophyll-a / or mask the view for long periods.

Phenology, according to the ‘raw’ GlobColour CHL1_mean data, and that regionally corrected

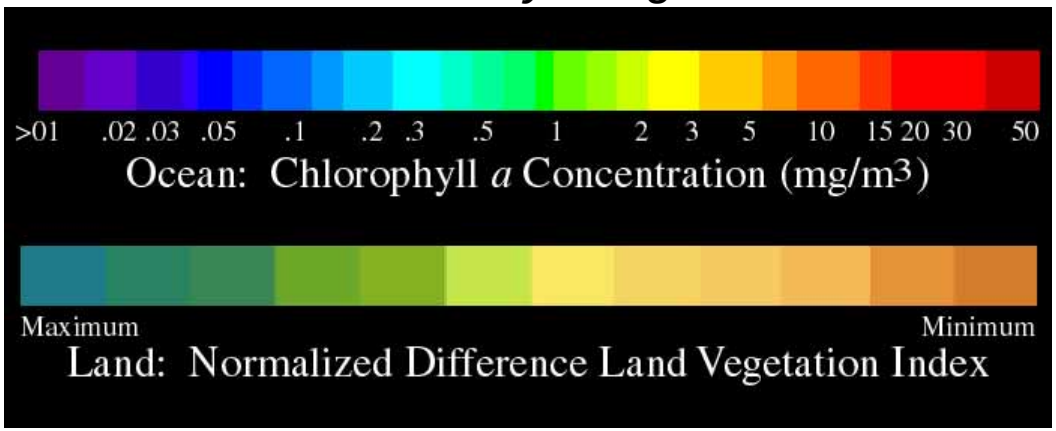


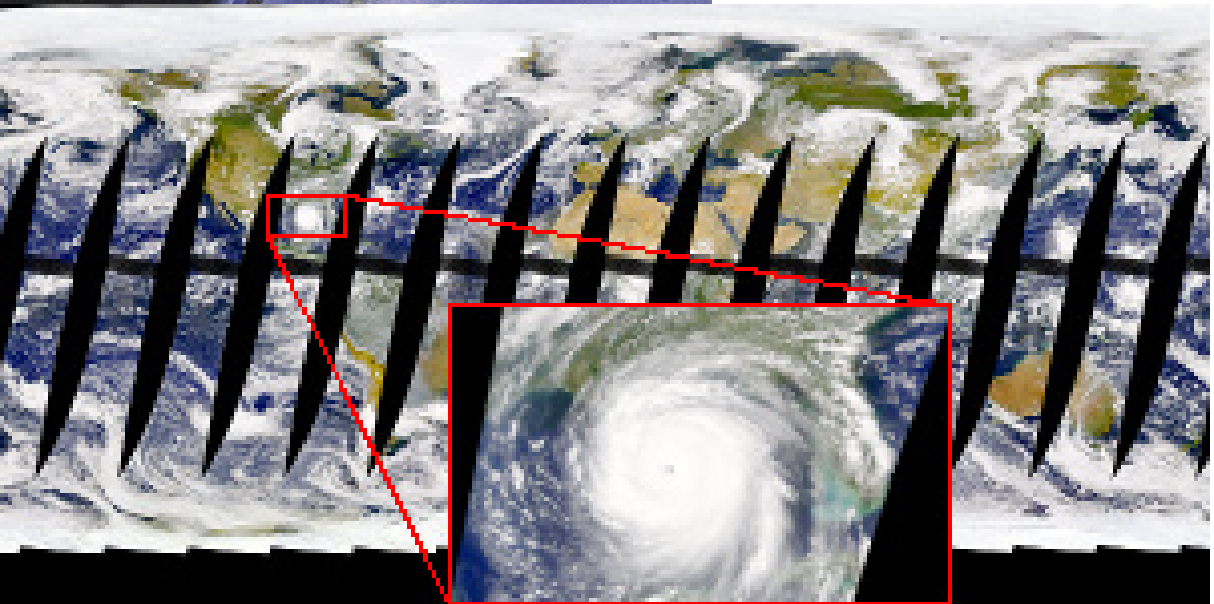
Seasonal changes for five selected areas, i.e. W, N, S and E of Iceland, and one inside the Faxaflói

Satellites and near-surface **chlorophyll a**

Ratio of blue and green colours in reflected light from the ocean surface shift in accordance with near-surface chlorophyll *a* concentrations.

The sensitivity is logarithmic

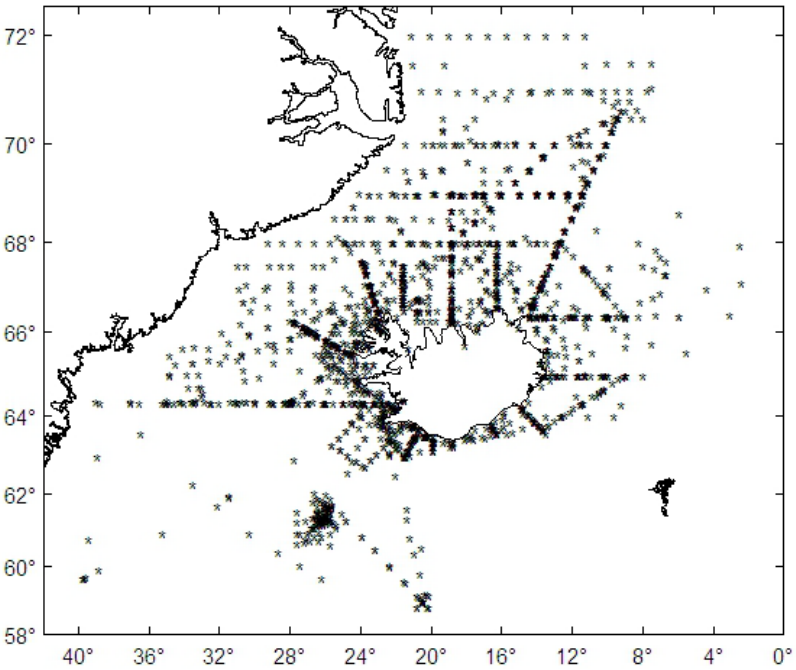




Optical properties of water has been categorized as either simple (**case 1**) or complex (**case 2**) with respect to correlation of *in situ vs*. satellite surface chlorophyll. ***The latter calls for regional analysis!***

MRI's chlorophyll-*a* records, collated for near-surface measurements 1998 – 2012

Spatial and temporal distributions



No distinction is required because of the different groups of water samples!

GlobColour													Samræmdar skráðar færslur frá NASA og ESA
***In situ* chlorophyll *a* measurements from the upper most 5 meter, since 1997**													
months	1	2	3	4	5	6	7	8	9	10	11	12	Total
Chlorophyll a measurements from water samples collected at CTD stations													
1997													0
1998													0
1999													0
2000					95								95
2001					19								19
2002					12								12
2003					17	12							29
2004					19								19
2005					18								18
2006		6			77	38		7			2		130
2007				30	18		12	96					**156**
2008				6	109	18		140	5				**278**
2009					19								**19**
2010					94								**94**
2011					86	12							**98**
2012					106								**106**
2013													**0**
													1073
For calibration of fluorescence, recorded in a flow-through system on board r/v Bjarni Sæm													
1997					39	15							**54**
1998				23	21	74	18		11				**147**
1999					65	30							**95**
2000					54	40							**94**
2001					42	22							**64**
2002					36								**36**
2003					38								**38**
2004					41								**41**
2005					30								**30**
2006					62		140	14					**216**
2007				50	35		12	122					**219**
2008				23	28	32							**83**
2009					32								**32**
2010				10	33								**43**
2011					7								**7**
2012					52								**52**
2013													**0**
													1251
Sampling on board the ferry Herjolfur, at two fixed stations, for calibration of fluorescence records													
1999			4	8	4		12	6	6				**40**
2000	2	2	8	6	10	4	8	4	6				**50**
2001					10	7	6	4					**27**
2002	2	2	4	8	10	8	7	8	4	10	2	2	**67**
2003	2	4	4	6	6	8	10	8	8		2	2	**60**
													244
months	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
Total	**6**	**14**	**20**	**170**	**1344**	**320**	**225**	**409**	**40**	**10**	**6**	**4**	**2568**

CTD water sampler

Flow-through syst.

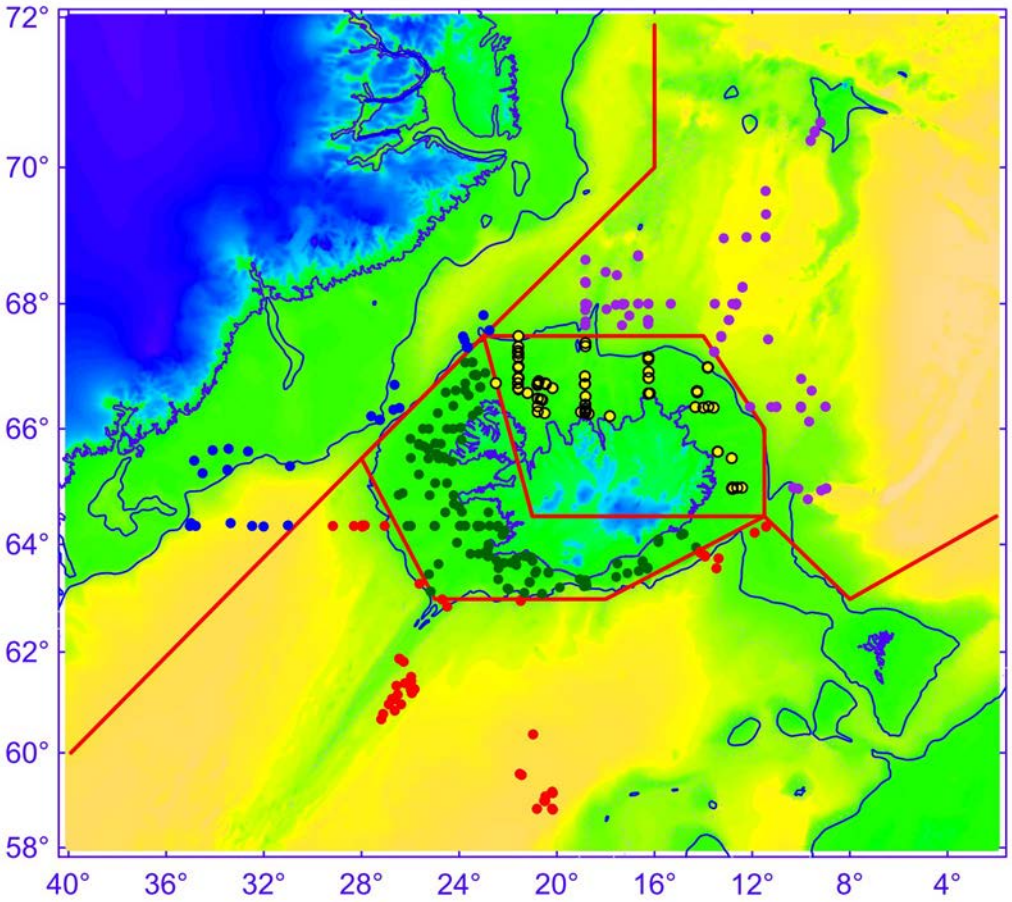
Near-surface *in situ* chlorophyll-*a* 1998 – 2013 matched with that of GlobColour records, and a proposed first deviation of the research area.

A total of 2503 near-surface water sample measurements on chlorophyll-a were considered and 436 mached with GlobColour Project ‘CHL1_mean’ records, by the day and location (pixel).

Of the above 131 mathed also with ‘CHL2_mean’, as values of CHL2_mean are only calculated for MERIS records.

The min- and maximum values:

µg chl L-1	satellite	*in-situ*
CHL1	0,0–7,5	0,0-24,2
CHL2	0,1–7,7	0,1-16,4



Analysis of chlorophyll measured in water samples and correlations with that of satellite measurements

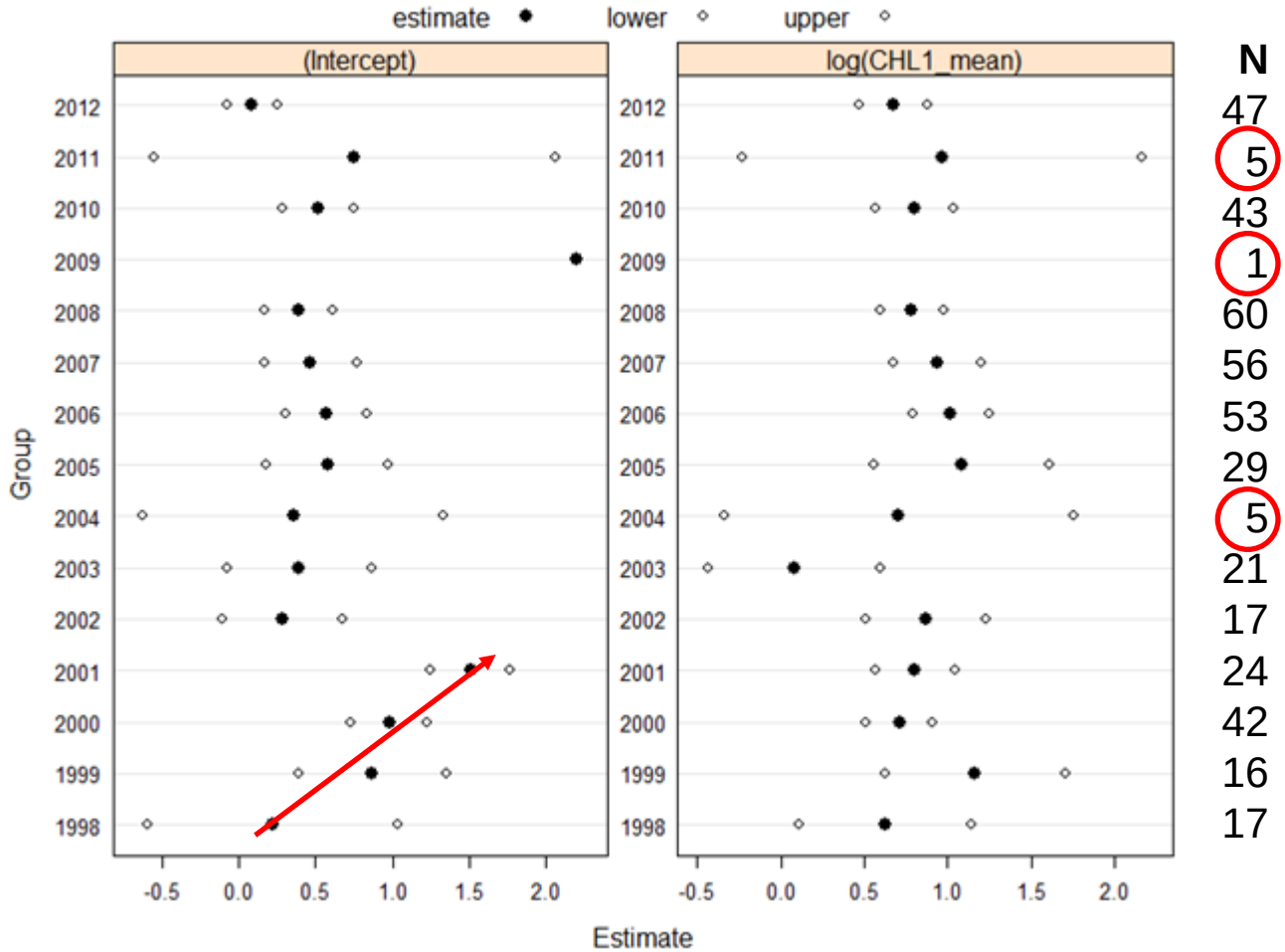
CHL1 (assuming case 1 water**)** and **CHL2** (assuming case 2 water**)** was compared, using a set on 131 common data pairs matched with results of measured chlorophyll in near-surface water samples **(CHLa).** Linear regression analysis show that the correlation is significatn for both these lines (**R^2= 0,44 og 0,49,** respectively). The slopes are similar (**0,83** and **0,88,** respectly, revealing ~15% overestimate), but intercepts differ (**0,51** and **0,12,** in same order; p<0,05) and indicate some baseline issues. The high intercept, in case of CHL1, means that satellite surface chlorophyll according to CHL1 is overestimated in the region, especially when the chlorophyll concentration is at the lowest. *Nevertheless, we use CHL1 for the further analysis, because of the better data coverage:*

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
CHL1	17	16	42	24	17	21	5	29	53	56	60	1	43	5	47
CHL2					6	6	2	11	25	31	22	2	28	4	

All the following statistical analysis are performed on logarithmical-transformed chlorophyll values, due to general left skewed distribution.

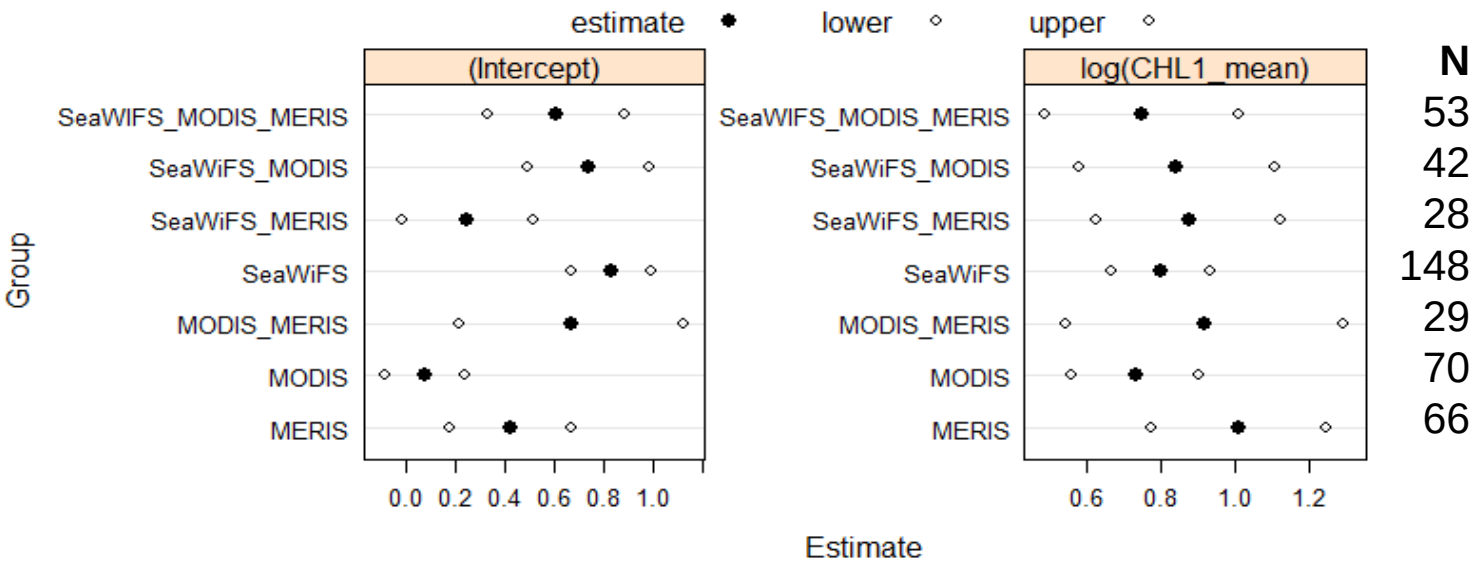
The number (N) in all following statistical analysis on CHLa vs. CHL1 is 436, for the complete data set.

Comparison of intercepts and slopes of data subsets on *in-situ* vs. remotely sensed surface chlorophyll-*a*, Years; records collected



Considerable changes in intercepts (SeaWiFS 1998 – 2001), while differences in slopes are insignificant. NB! The low number of data points in 2004, 2009 and 2011.

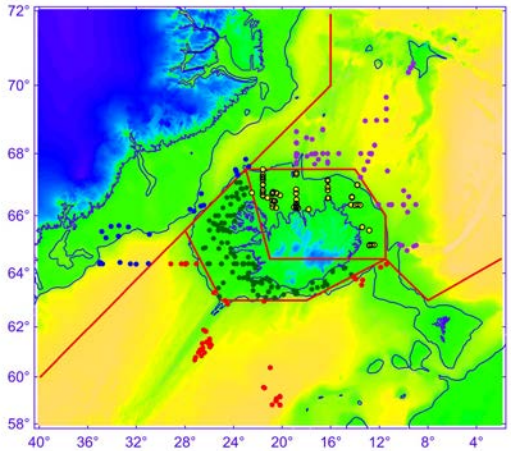
Comparison of intercepts and slopes of data subsets on *in-situ* vs. remotely sensed surface chlorophyll-*a*, Remote sensors (and merged data records)



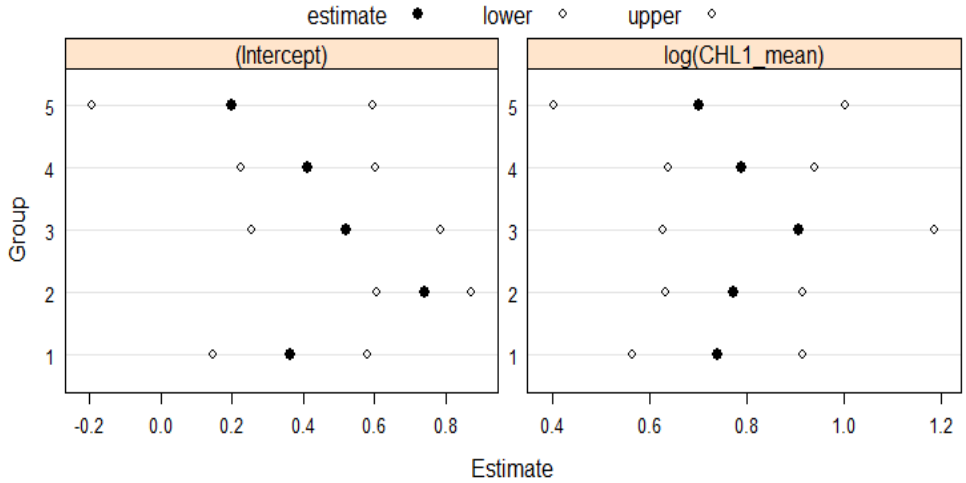
Check on data uniformity with respect to different combination of remote sensors used in merged data records.

GCP has apparently done a good job on merging the data series

Comparison of intercepts and slopes of data subsets on *in-situ* vs. remotely sensed surface chlorophyll-*a*, Sub regions – different domains



For checking possible differences in correlations between *in-situ* and remotely sensed chlorophyll-a, due to different geographical domains we split the data collection accordingly. Stations: SV of Iceland (1) oceanic (bottomdepth > 500 m) and (2) shelf, NE of Iceland (3) shelf and (4) oceanic and (5) East Greenland Current (Polar water)

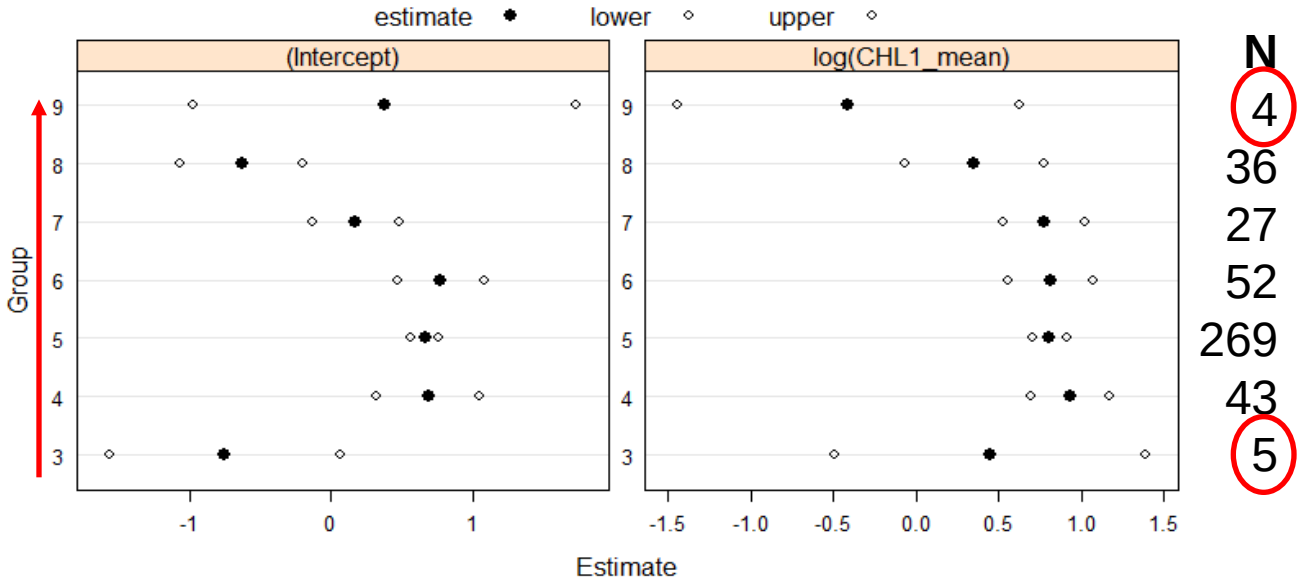


N
32
95
81
168
60

Check on data uniformity with respect to suggestion of different geographical sub-regions reveal no significant differences.

Not a reason for splitting the data set

Comparison of intercepts and slopes of data subsets on *in-situ* vs. remotely sensed surface chlorophyll-*a*, Seasonal changes



Check on seasonal trends in our data set, analyzed on monthly basis, reveal seasonal trends in both the slopes and intercepts.

Apparently a systematic bias in satellite CHL1 is a function of the time of the year, but that is not a reason for splitting the data set.

Analysis of systematic trends in variance when comparing satellite records on surface chlorophyll-a (CHL1) with that of water sample measurements [GAM]

GM2 <- gam(log(chl)~s(log(CHL1_mean),bs="cr",k=3)+s(mm,bs="cc",k=4) + s(lon,lat,k=16),data=sat)

par(mfrow=c(2,2)) ; ***plot.gam****(GM2);*
vis.gam*(GM2,se=2,theta=-35)*

summary(GM2)
Parametric coefficients:

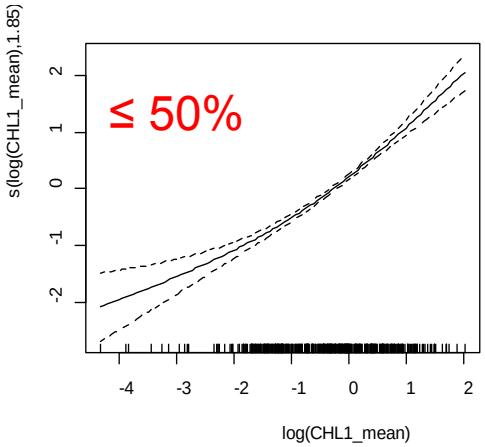
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.24872	0.03832	6.49	2.43e-10	***

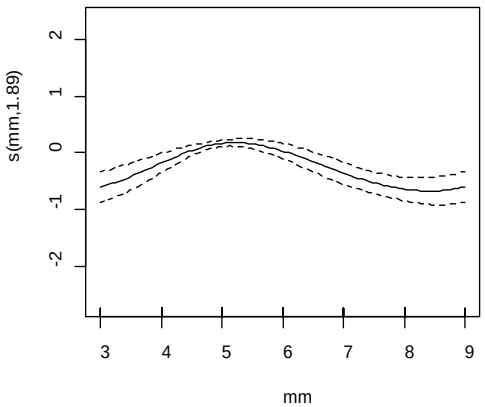
Approximate significance of smooth terms:

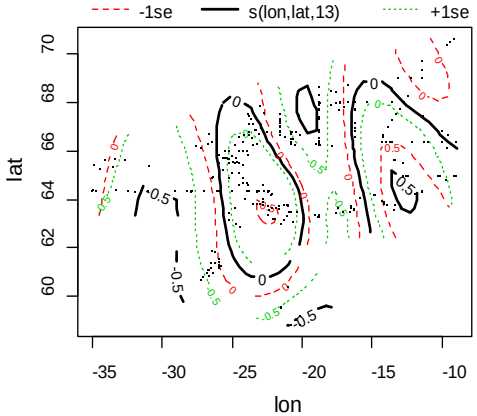
	Edf	Ref.df	F	p-value	
s(log(CHL1_mean))	1.852	1.978	149.54	< 2e-16	***
s(mm)	1.890	2.000	19.70	1.68e-09	***
s(lon,lat)	13.000	14.499	4.19	4.58e-07	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
R-sq.(adj) = 0.582 Deviance explained = 59.8%
GCV score = 0.6674 Scale est. = 0.64024 n = 436

AIC = 1062.3







Analysis of systematic trends in variance when comparing satellite records on surface chlorophyll-a (CHL1) with that of water sample measurements [GAM]

GM3 <- gam(log(chl)~s(log(CHL1_mean),bs="cr",k=3)+factor(year)+s(mm,bs="cc",k=4) + s(log(wd2b),k=3), data=sat)

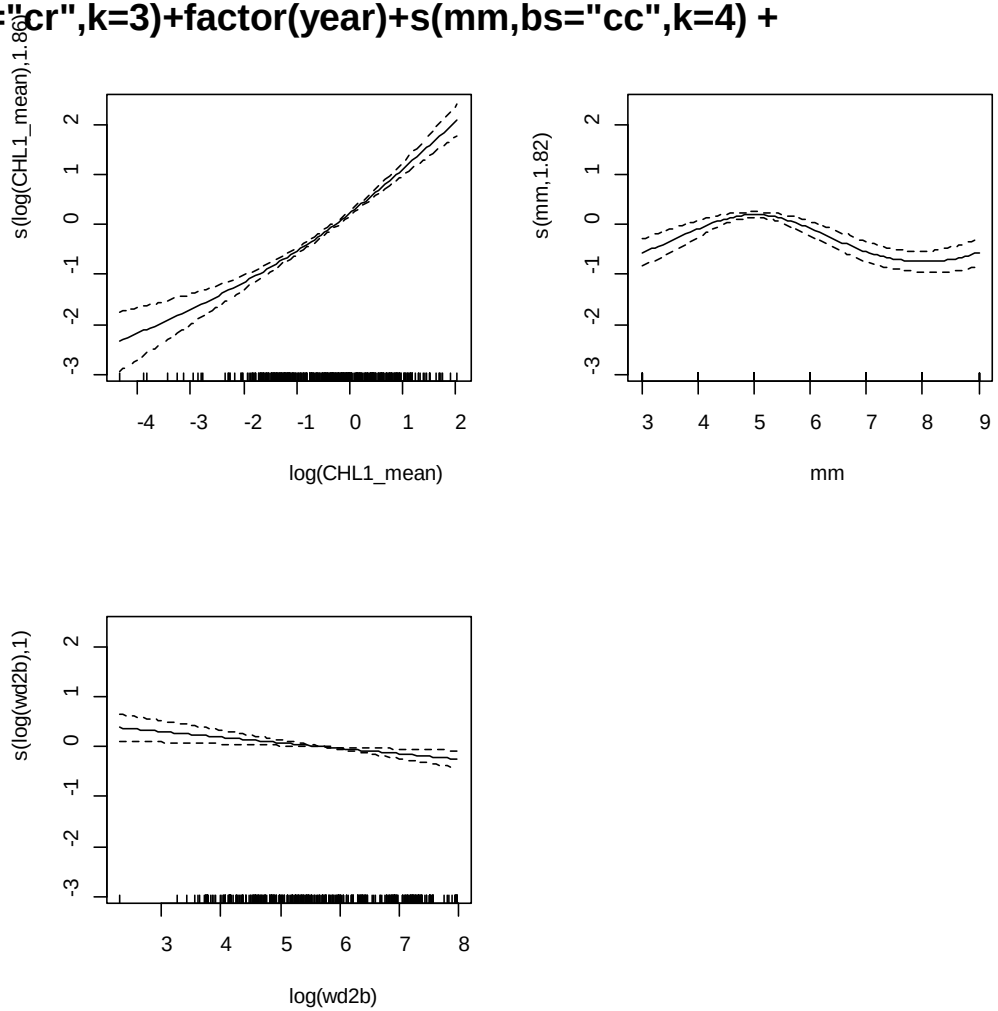
par(mfrow=c(2,2)) ; ***plot.gam****(GM3);*

vis.gam*(GM3,se=2, theta=-35)*

summary(GM2)

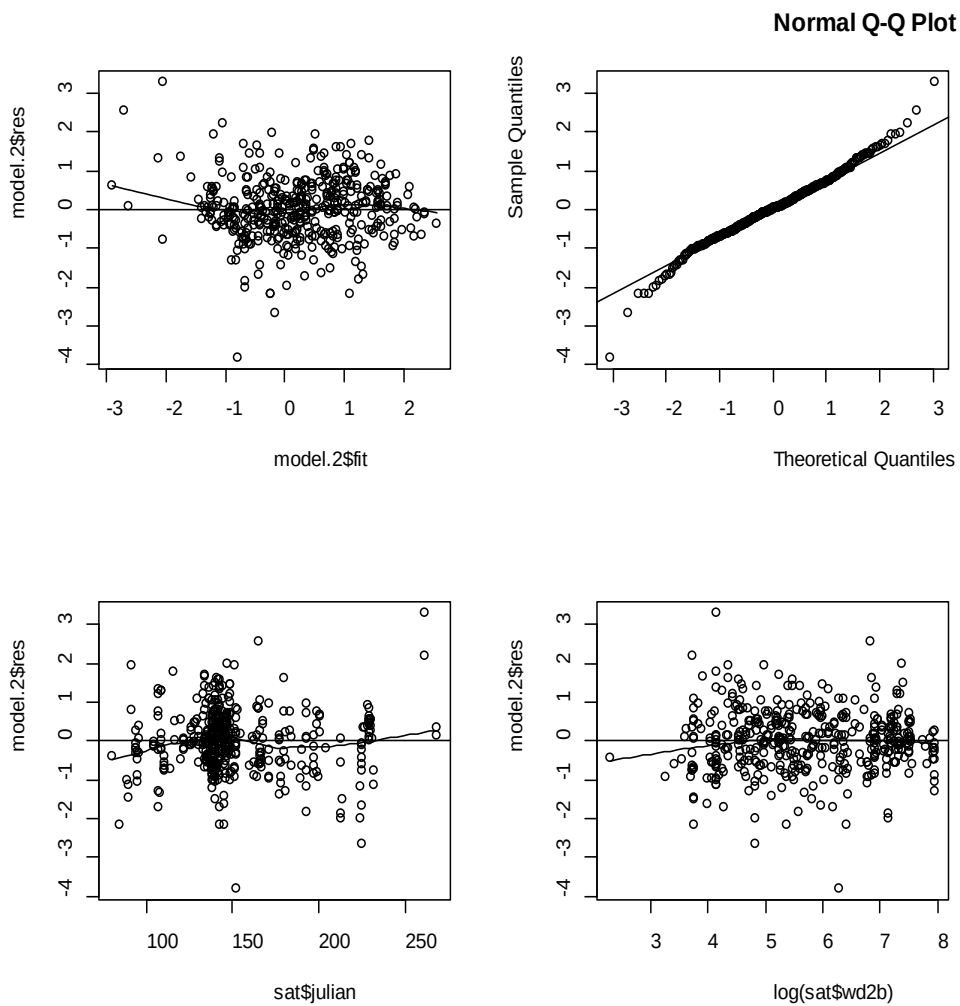
```
Parametric coefficients:    Estimate Std. Error t value Pr(>|t|)
(Intercept)                  0.15021    0.20578   0.730 0.465818
factor(year)1999             0.37402    0.30053   1.245 0.213994
factor(year)2000             0.41604    0.23387   1.779 0.075981 .
factor(year)2001             0.93376    0.25133   3.715 0.000231 ***
factor(year)2002            -0.27521    0.27753  -0.992 0.321942
factor(year)2003             0.21400    0.27278   0.785 0.433184
factor(year)2004            -0.08055    0.41031  -0.196 0.844453
factor(year)2005            -0.05932    0.25760  -0.230 0.817978
factor(year)2006             0.16633    0.22607   0.736 0.462284
factor(year)2007             0.10743    0.24159   0.445 0.656791
factor(year)2008             0.15914    0.24158   0.659 0.510422
factor(year)2009             2.46207    0.80564   3.056 0.002387 **
factor(year)2010            -0.12965    0.24479  -0.530 0.596649
factor(year)2011             0.10280    0.40360   0.255 0.799083
factor(year)2012            -0.47647    0.24149  -1.973 0.049154 *
---
Approx. significance of smooth terms:
                              edf     Ref.df      F       p-value
s(log(CHL1_mean))           1.861  1.981 177.213  < 2e-16 ***
s(mm)                       1.819  2.000   27.647 4.27e-13 ***
s(log(wd2b))                1.000  1.000    8.188  0.00442 **
---
R-sq.(adj) =  0.605   Deviance explained = 62.2%
GCV score = 0.6336  Scale est. = 0.605     n = 436
```

AIC = 1085.5



Analysis of systematic trends in variance when comparing satellite records on surface chlorophyll-a (CHL1) with that of water sample measurements [LM]

LM1 <- lm(log(chl)~log(CHL1_mean)+factor(year)+julian+I(julian^2)+log(wd2b), data=sat)




```
Residuals:
    Min      1Q  Median      3Q     Max
-3.8178 -0.4883  0.0159  0.4822  3.2949

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)       -8.030e-01  9.226e-01  -0.870  0.38462
log(CHL1_mean)     7.646e-01  4.243e-02  18.021  < 2e-16 ***
factor(year)1999   4.526e-01  3.069e-01   1.475  0.14104
factor(year)2000   6.148e-01  2.374e-01   2.590  0.00995 **
factor(year)2001   1.066e+00  2.605e-01   4.091 5.15e-05 ***
factor(year)2002  -1.338e-01  2.859e-01  -0.468  0.64006
factor(year)2003   4.727e-01  2.841e-01   1.664  0.09683 .
factor(year)2004   1.017e-01  4.204e-01   0.242  0.80907
factor(year)2005   1.641e-01  2.565e-01   0.640  0.52259
factor(year)2006   2.151e-01  2.323e-01   0.926  0.35495
factor(year)2007   2.058e-01  2.400e-01   0.858  0.39156
factor(year)2008   2.886e-01  2.521e-01   1.145  0.25283
factor(year)2009   2.683e+00  8.381e-01   3.201  0.00147 **
factor(year)2010   1.108e-01  2.440e-01   0.454  0.65008
factor(year)2011   3.214e-01  4.171e-01   0.771  0.44144
factor(year)2012  -2.652e-01  2.398e-01  -1.106  0.26928
julian             2.472e-02  1.040e-02   2.378  0.01787 *
I(julian^2)       -8.884e-05  3.055e-05  -2.908  0.00383 **
log(wd2b)         -9.130e-02  4.077e-02  -2.240  0.02564 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

Residual standard error: 0.8135 on 417 degrees of freedom
Multiple R-squared:  0.5855,    Adjusted R-squared:  0.5676
F-statistic: 32.72 on 18 and 417 DF,  p-value: < 2.2e-16
```

AIC = 1077.9

Analysis of systematic trends in variance when comparing satellite records on surface chlorophyll-a (CHL1) with that of water sample measurements [LM]

LM2 <- lm(log(chl)~log(CHL1_mean)+julian+sundec+log(wd2b), data=sat)

```
> summary(lm(log(chl)~log(CHL1_mean)+dnr+I(dnr^2)+log(wd2b), data=sat))

Call:
lm(formula = log(chl) ~ log(CHL1_mean) + dnr + I(dnr^2) + log(wd2b),
    data = sat)

Residuals:
    Min      1Q  Median      3Q     Max
-4.0561 -0.5627  0.0107  0.5330  3.3270

Coefficients:
                 Estimate Std. Error t value Pr(>|t|)
(Intercept)    -4.006e-01  7.646e-01  -0.524 0.600588
log(CHL1_mean)  7.501e-01  4.348e-02  17.254  < 2e-16 ***
dnr             2.540e-02  9.010e-03   2.819 0.005047 **
I(dnr^2)       -8.850e-05  2.641e-05  -3.351 0.000877 ***
log(wd2b)      -1.384e-01  3.524e-02  -3.927 0.000100 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.8629 on 431 degrees of freedom
Multiple R-squared:  0.5179,    Adjusted R-squared:  0.5135
F-statistic: 115.8 on 4 and 431 DF,  p-value: < 2.2e-16
```

AIC = 1115.7

In context with publicated results:

Basic model: BM (GAM and LM)

log(chl) vs. log(CHL1_mean);

R^2 ~ 0.48, revealed for both LM and GAM analysis

(*cf. 0.44 for SeaWiFS data in N-Atlantic waters, Gregg&Casey 2004, RSE93*)

Full model: (GAM 1 & 2 and LM 2 & 1)

log(chl) vs. log(CHL1_mean) + year of sampling + season + bottom depth;

R^2 ~ 0.60, revealed for both LM and GAM models
(cf. 0.60 for SeaWiFS data in general for case 1 waters, Gregg&Casey 2004, RSE93)

Residuals:

One possible reason for unexplained residuals may be 'patchiness in chlorophyll concentrations' on smaller scale than the size of pixels in our satellite data

Leaving year of sampling as factor from our full model (LM2), and thus obtaining a timeless model (LM1), lower the performance to a level with the basic model (but might improve considerably by increased sampling in March)

Thanks are due to Kristín J. Valsdóttir, for measuring, calculating and keeping records of most of the water samples on chlorophyll used for the given analysis.

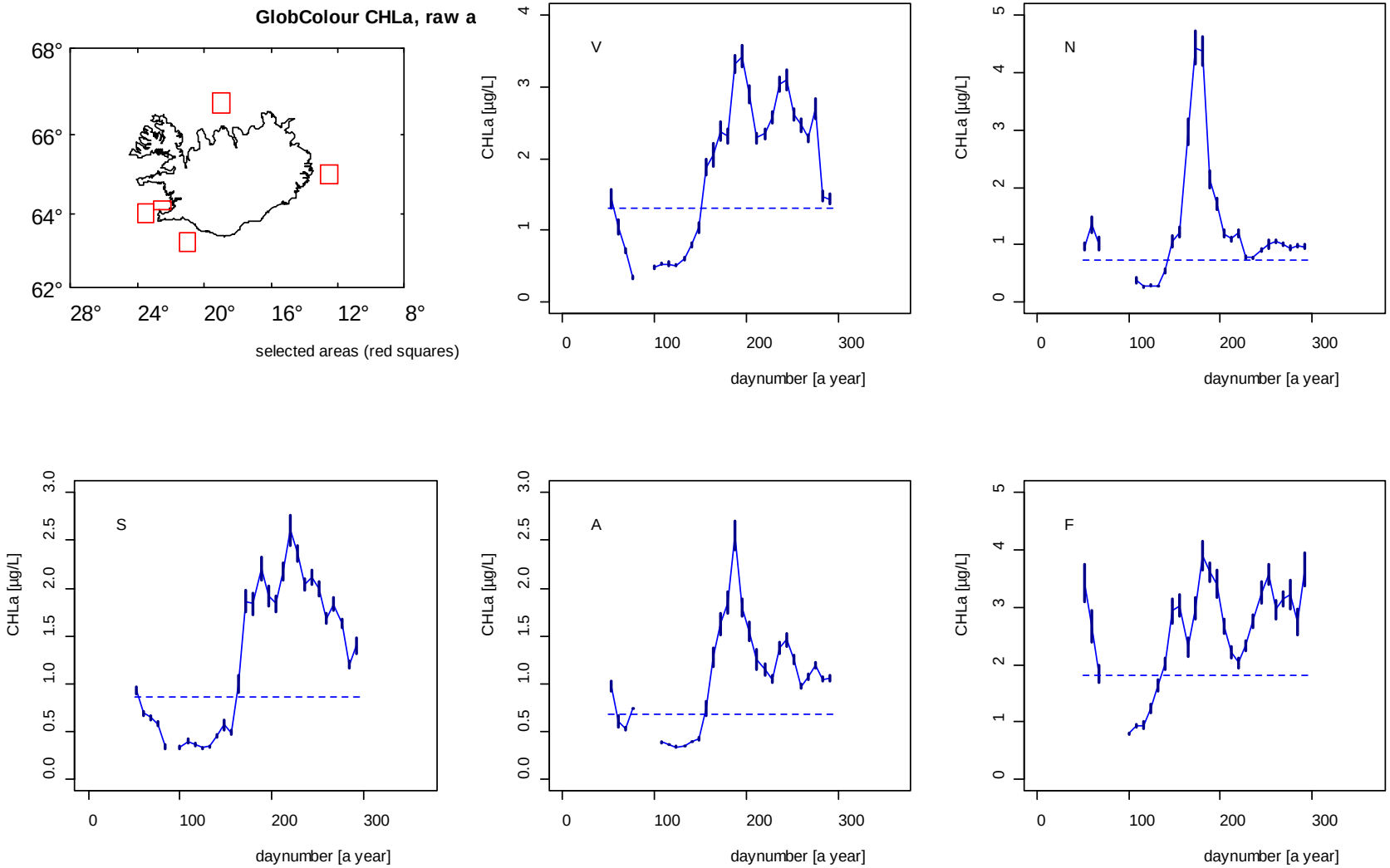
We also sincerely thank other colleagues, both the crew of our research vessels and fellow scientists that have assisted us on board and/or in the lab, but it is beyond the scope to list all the individuals.

THANK YOU FOR YOUR ATTENTION

Please …… come out now!

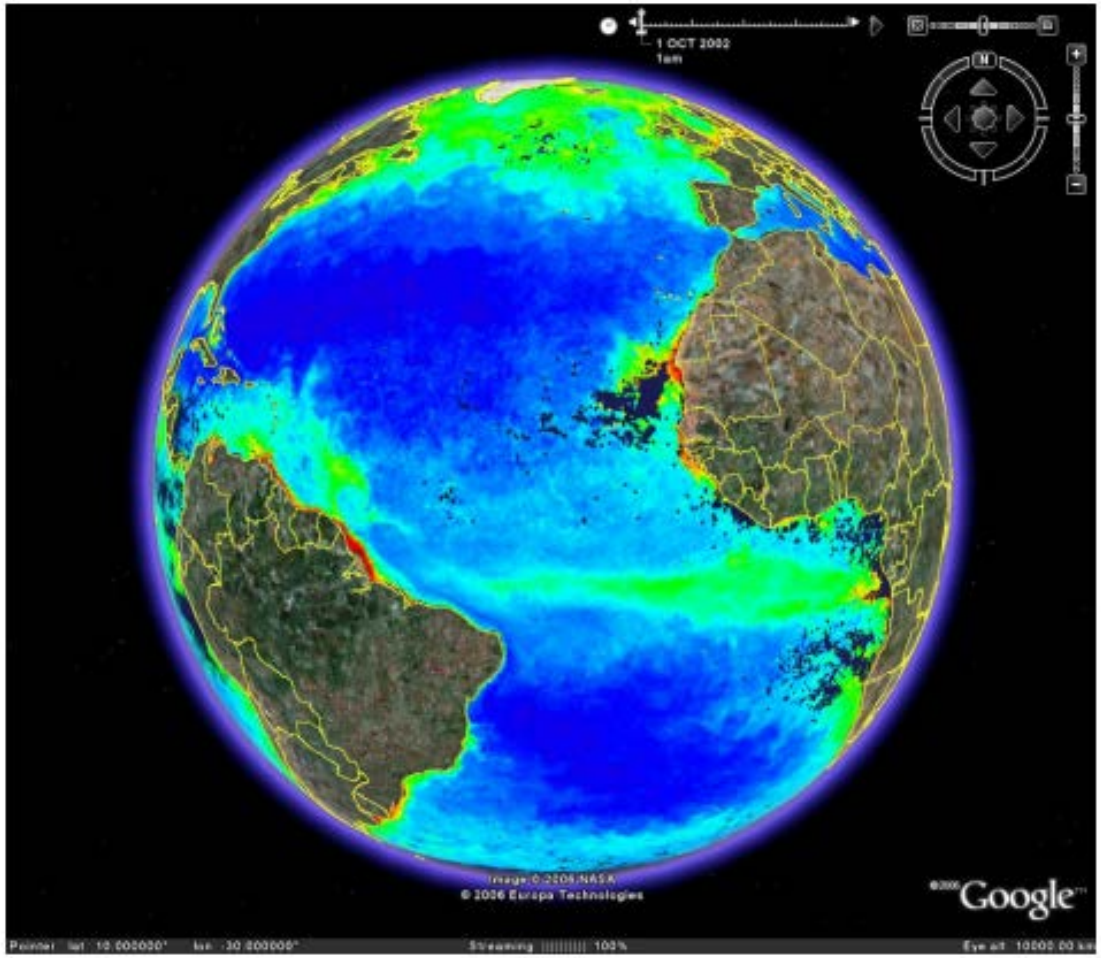
kristinn@hafro.is

Phenology, according to the ‘raw’ GlobColour CHL1_mean data



GLOB_animation_CHL1

Chlorophyll-a Concentration - Case 1 Water - AVW Method
20130415 20130422
lon=[-180 - -90] lat=[180 - 90]



Seasonal changes in surface chlorophyll a have be exploered, using standard algorithm for the conversion of satellite records

c.f. http://www.globcolour.info/gallery/GLOB_animation_2_CHL1_meris_modis_seawifs.avi

Phytoplankton climatology according to regionally corrected satellite chlorophyll in sub-arctic waters