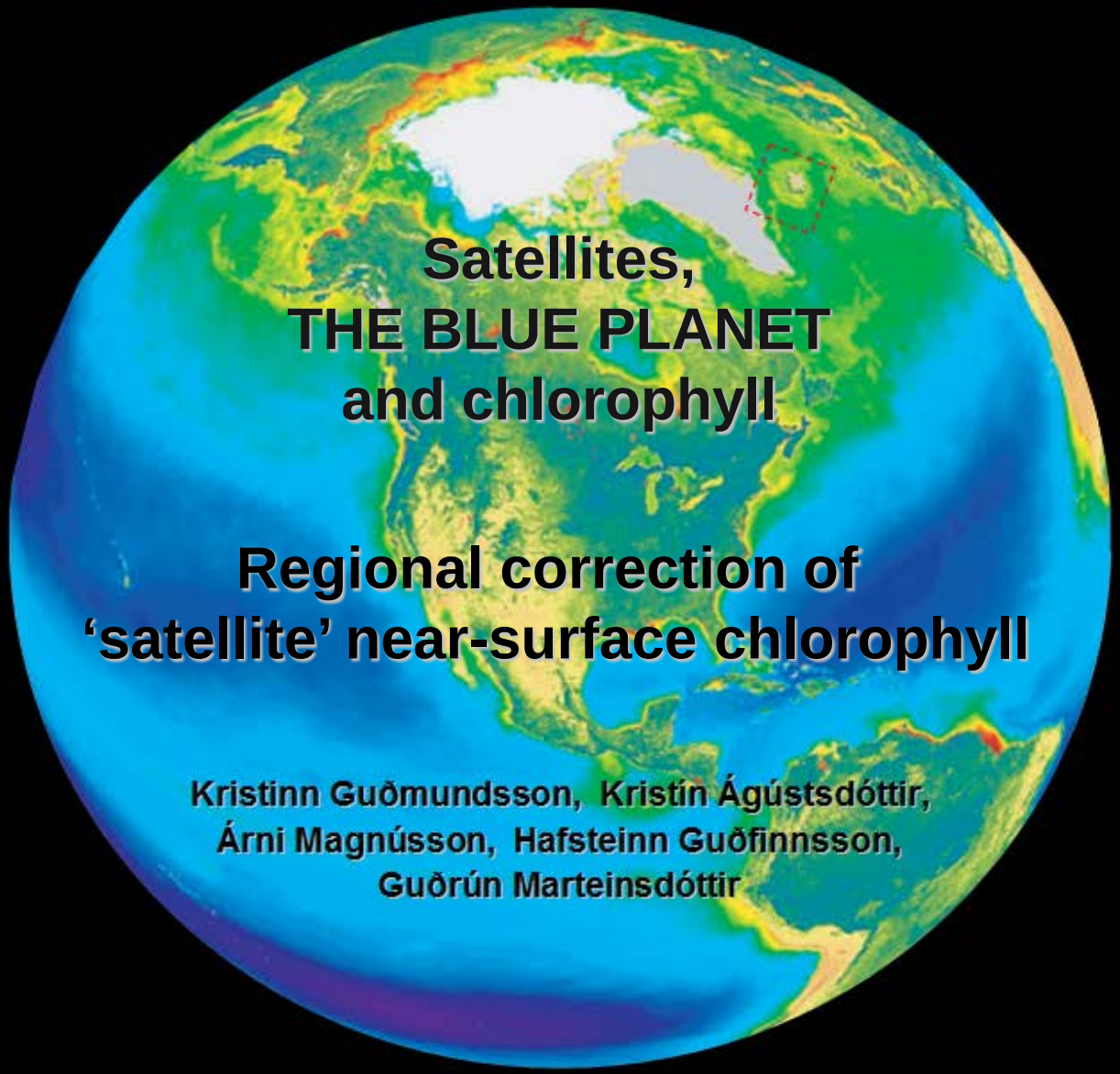


Satellites, THE BLUE PLANET and chlorophyll

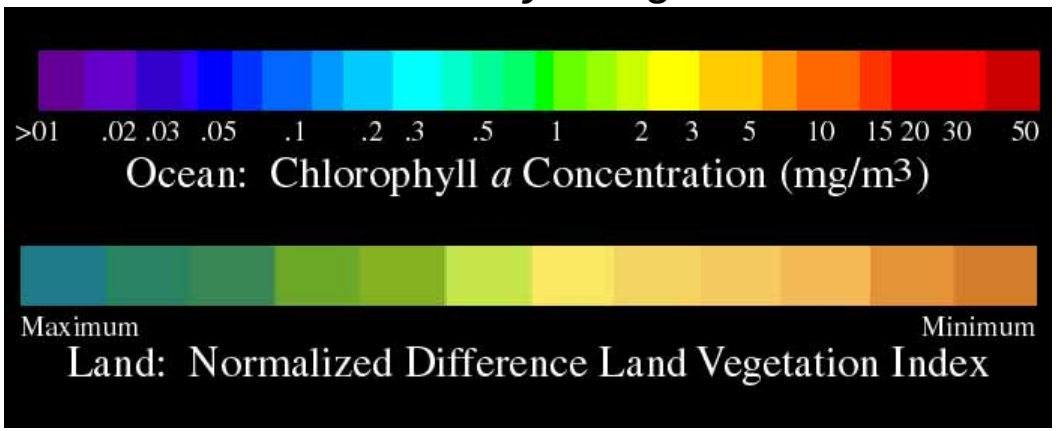
Regional correction of ‘satellite’ near-surface chlorophyll

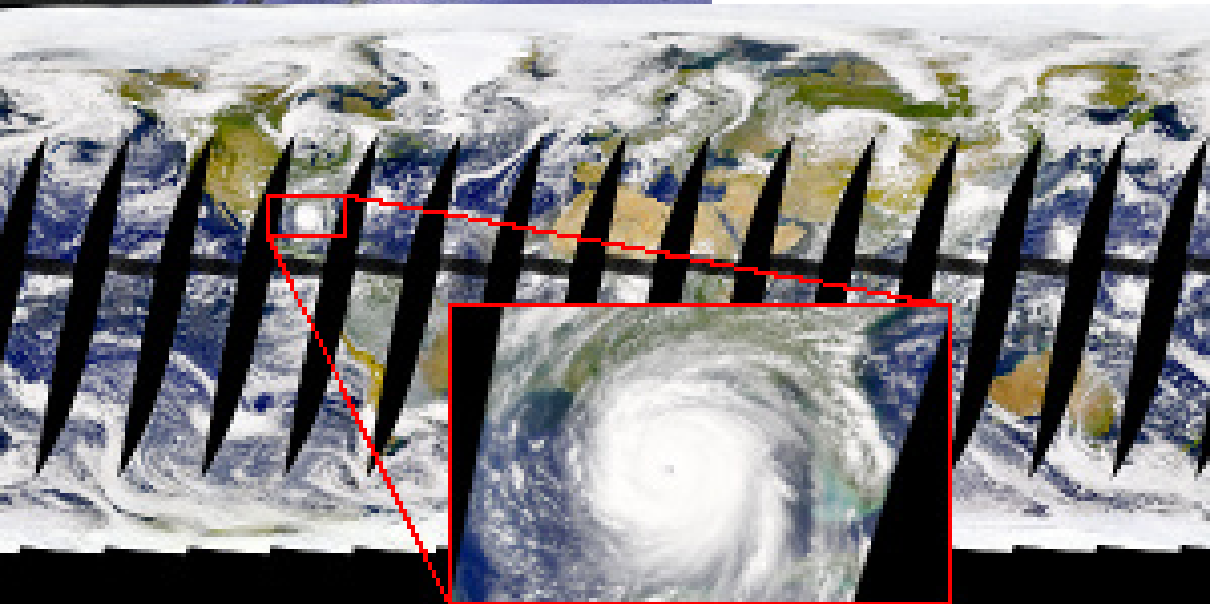
Kristinn Guðmundsson, Kristín Ágústsdóttir,
Árni Magnússon, Hafsteinn Guðfinnsson,
Guðrún Marteinsdóttir

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.

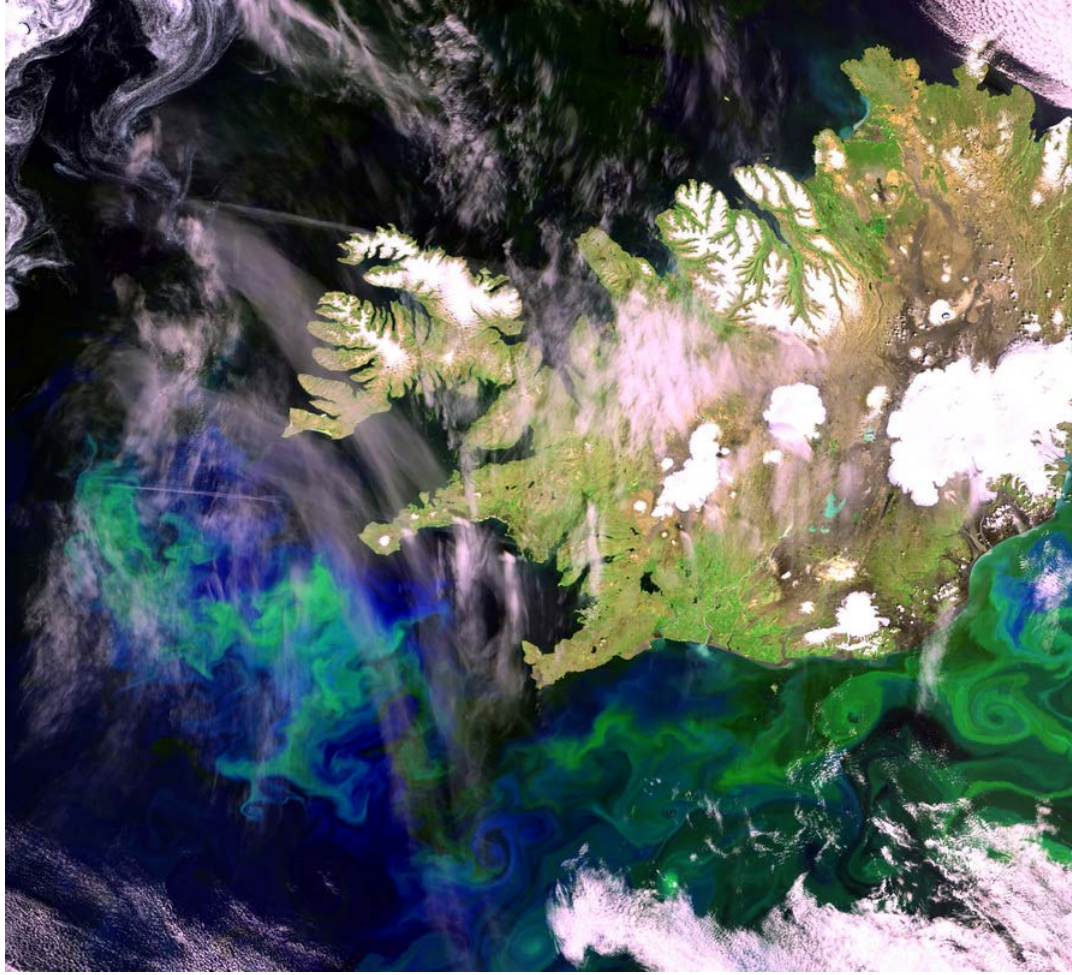
The sensitivity is logarithmic

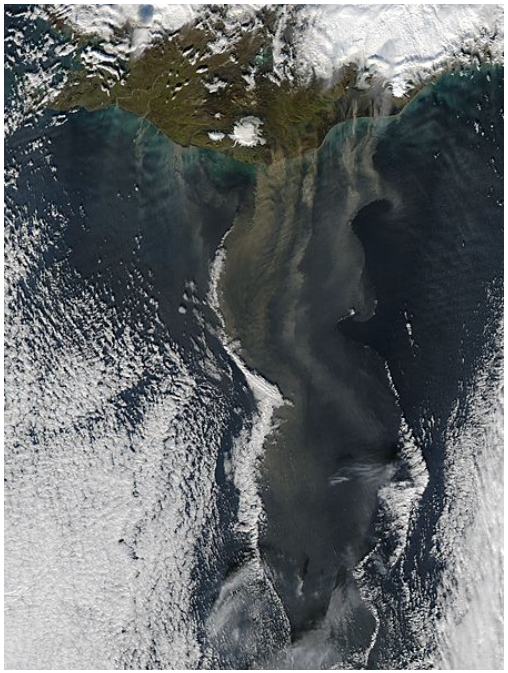




Different optical properties of water has been categorized as either simple (**case 1**) or complex (**case 2**) with respect to correlation of *in situ vs*. satellite surface chlorophyll. ***The latter calls for regional analysis!***

Not just fascinating images,





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

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 – 2012, ~ 4.6 km pixel size.

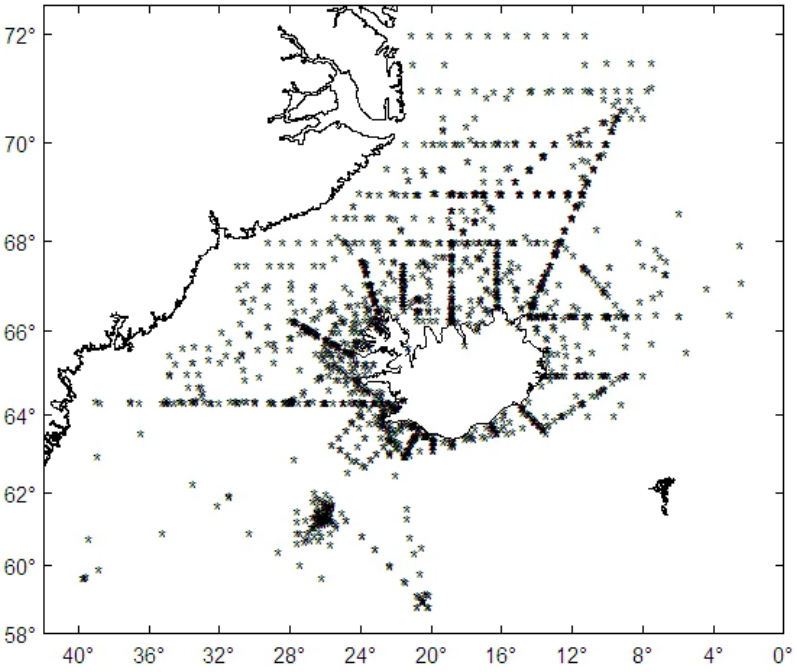
Data used for **analysis of seasonal changes in chlorophyll** (phenology)

B: Predicted near-surface chlorophyll-a values, *i.e.* CHL1_mean from the GlobColour Project corrected by the regional statistical model, above.

The downloaded variable 8 day averages on merged chlorophyll records, for 60° - 72° N and 3° - 33° W in 1998 – 2012, ~ 4.6 km pixel size.

MRI's chlorophyll-*a* records, collated for near-surface measurements 1998 – 2012 (and addition of 2013 data)

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					101								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					38	18	14	10					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.

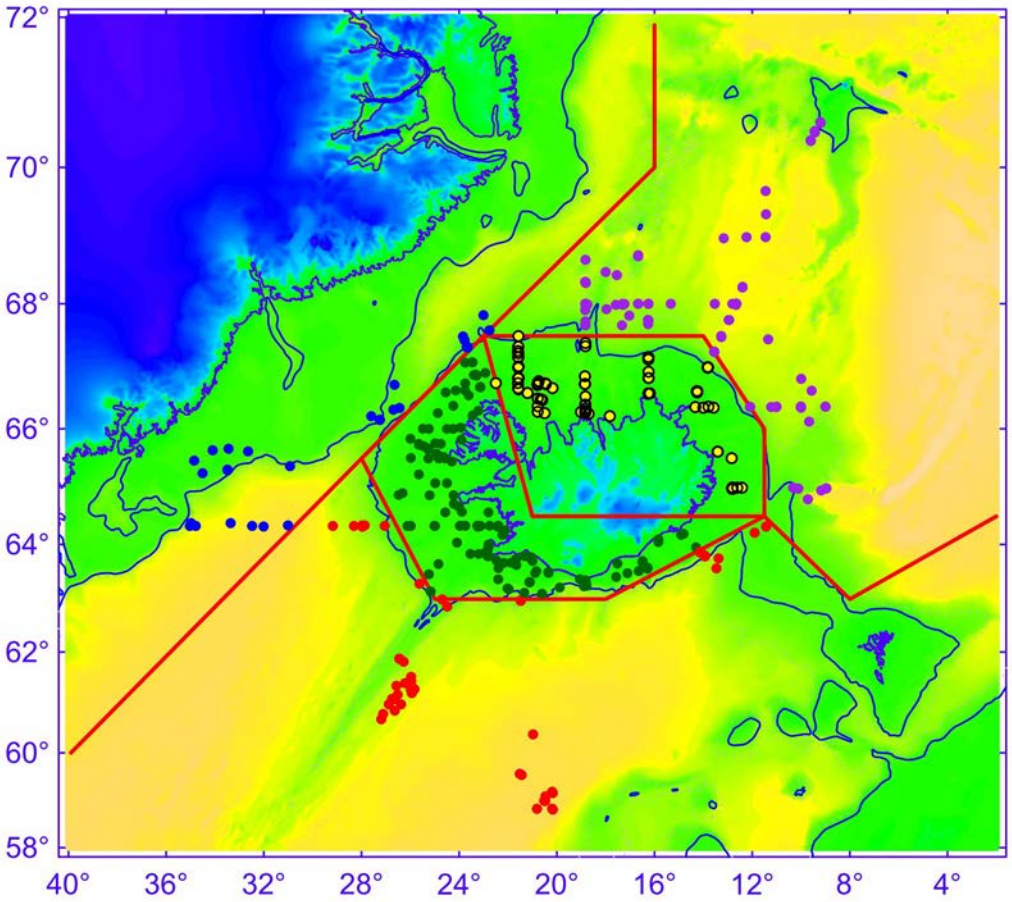
Near-surface *in situ* chlorophyll-*a* 1998 – 2013 matched with that of GlobColour records, and a proposed first deviation of the research area.

A total of 2503 (+181) near-surface water sample measurements on chlorophyll-a were considered and 436 (+23) was mached with GlobColour Project 'CHL1_mean' records, by the day and location (pixel).

Of the above some 131 matched both with 'CHL1_mean' and the 'CHL2_mean' (values of CHL2_mean are only calculated for the 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

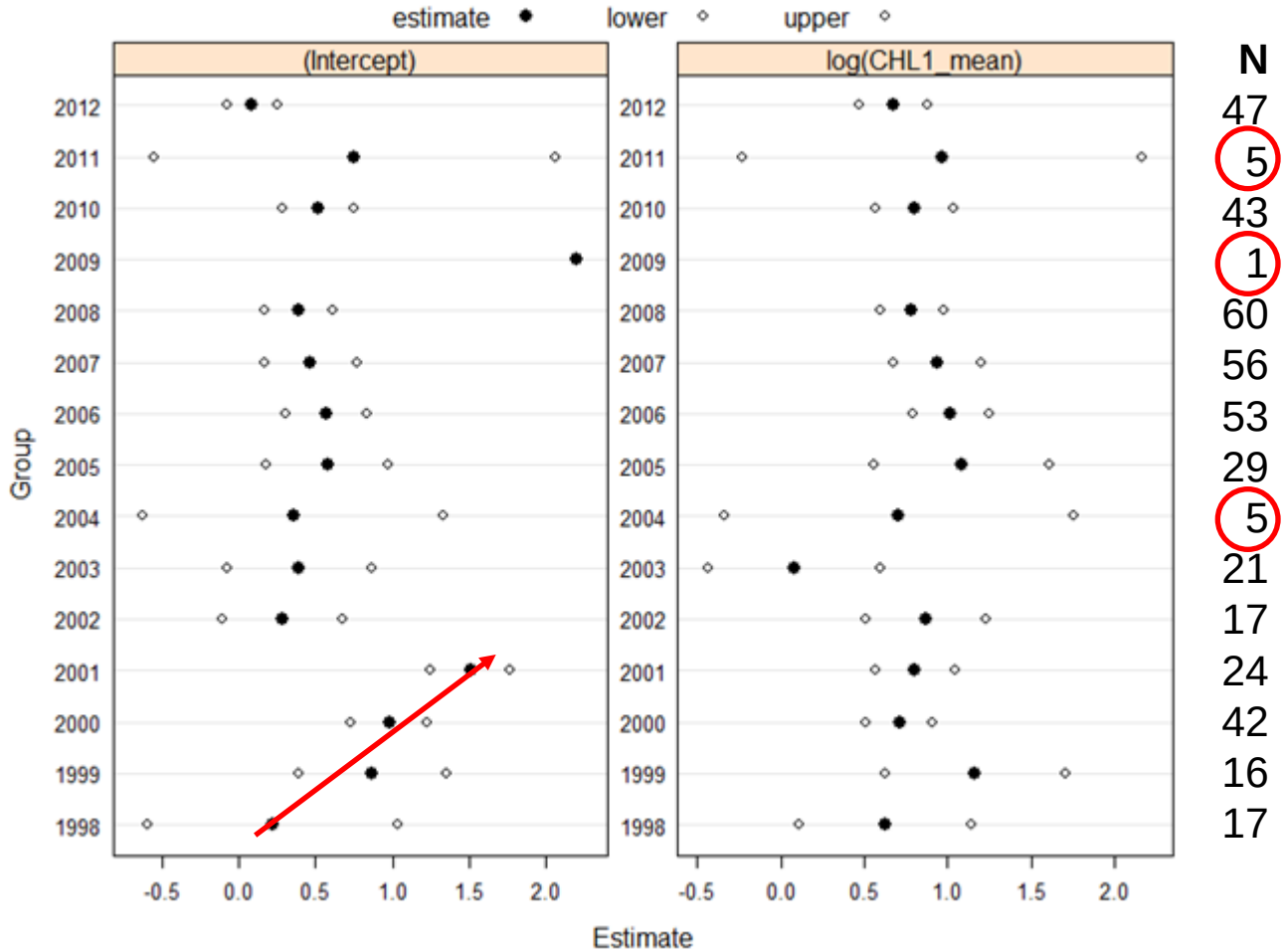
CHL1 (assuming case 1 water**)** and **CHL2** (assuming case 2 water**)** was compared, using a set on 131 common data pairs matched with results of measured chlorophyll in near-surface water samples **(CHLa).** Linear regression analysis show that the correlation is significatn for both these lines (**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, mainly 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.

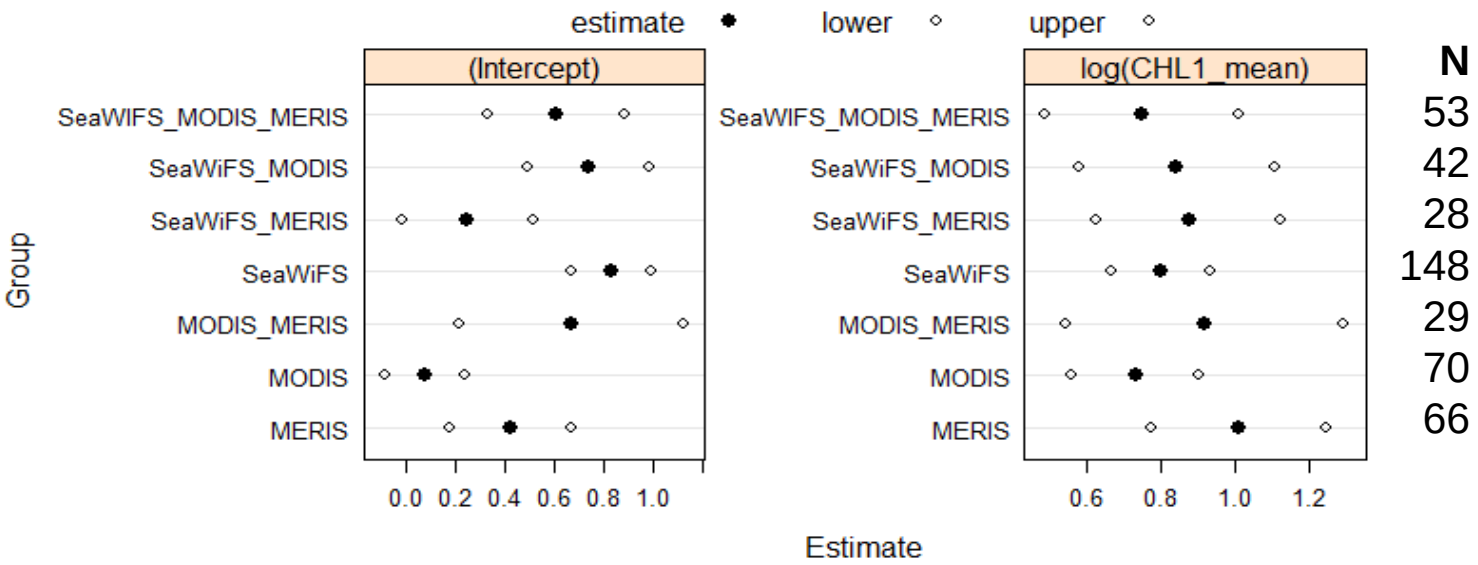
The number (N) in all following statistical analysis on CHLa vs. CHL1 is 436, for the complete data set, if not particularily stated otherwise.

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.*

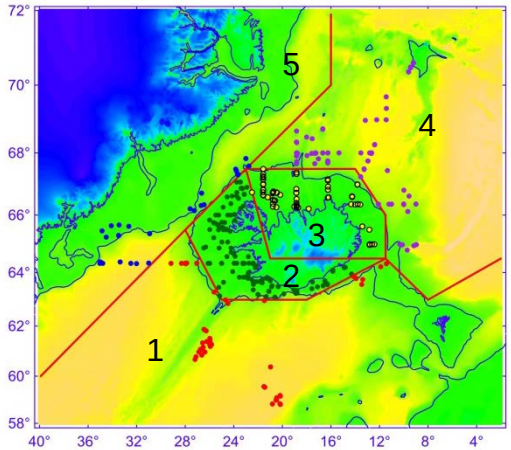
Comparison of intercepts and slopes of data subsets on *in-situ* vs. remotely sensed surface chlorophyll-*a*, Remote sensors (and merged data records)



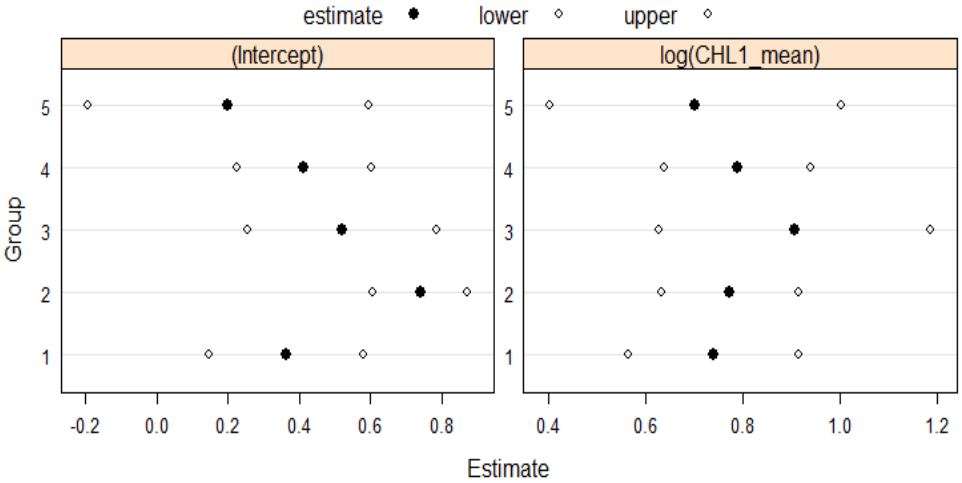
Check on data uniformity with respect to different combination of remote sensors used in merged data records.

Apparently GCP has 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. Oceanic stations (bottomdepth > 500 m) SV (1) and NE (3) and above the shelf SV (2) and NE (4) of Iceland, and in the domain of the East Greenland Current (Polar water) (5)

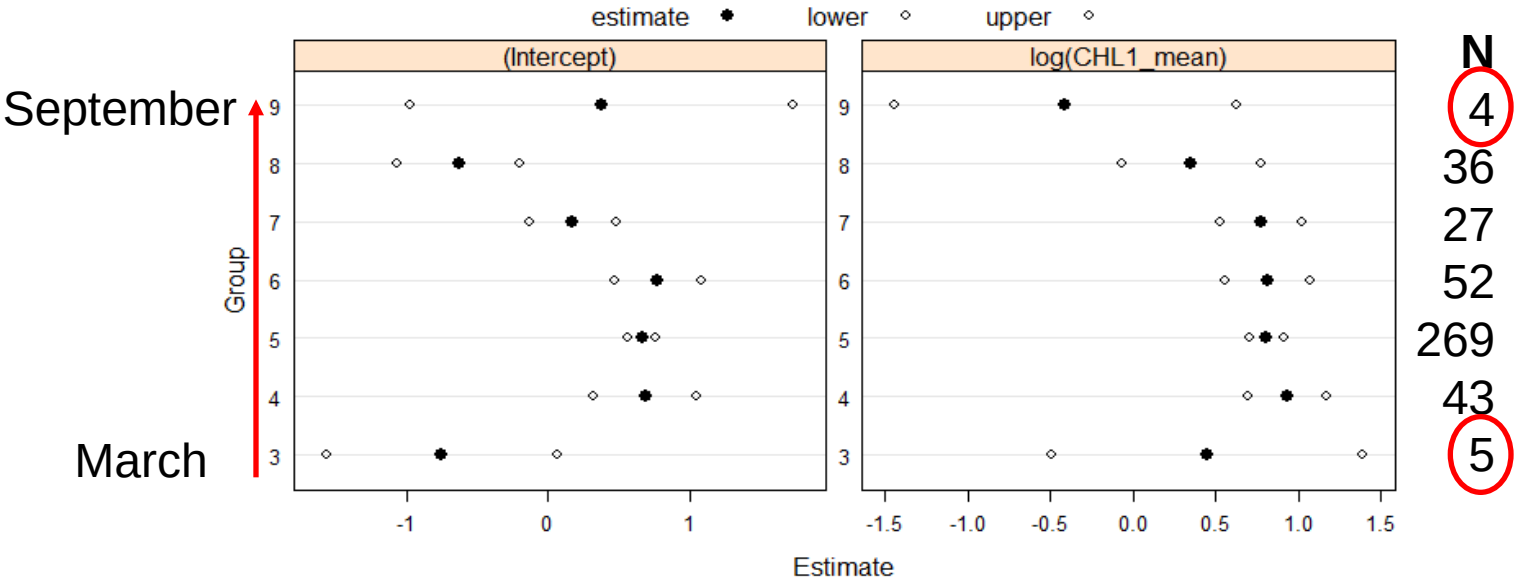


N
32
95
81
168
60

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

Not considered 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 there is a systematic bias in satellite CHL1 is a function of the time of the year, that calls for further consideration.

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

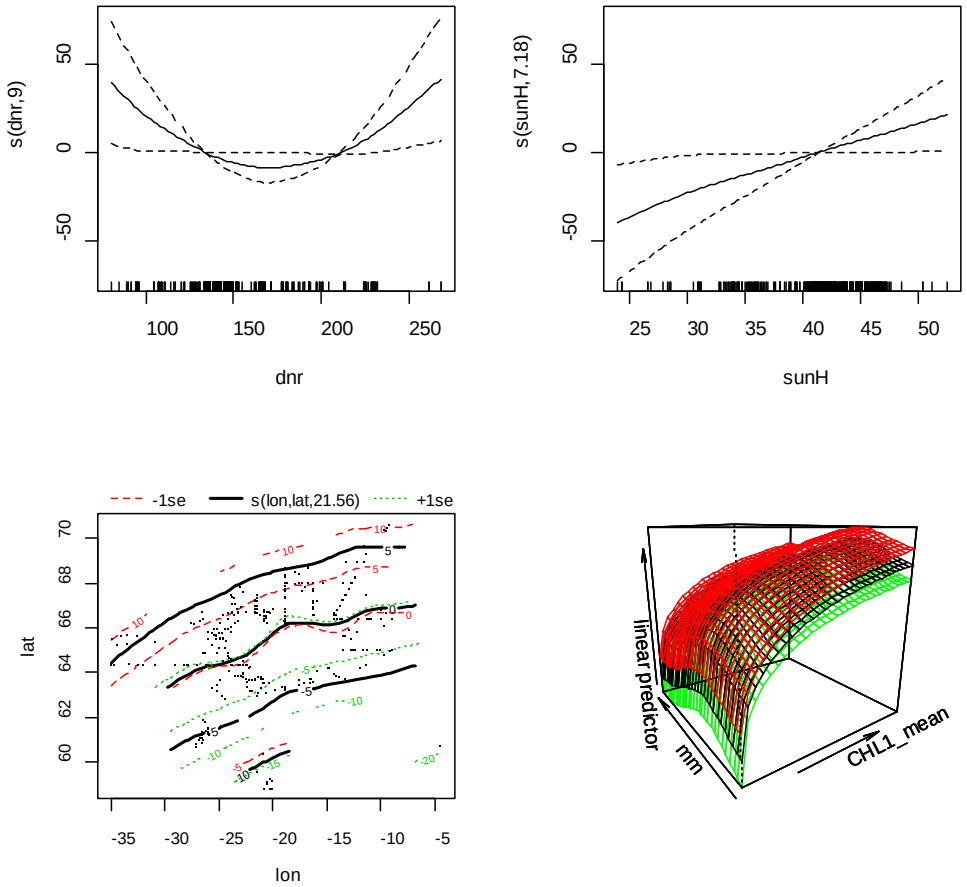
The correlation of simple linear regression on log(chl) ~ log(CHL1_mean): R^2: 0.47

gam(log(chl)~log(CHL1_mean)+ s(dnr) + s(sunH) + factor(year) + s(lon,lat))

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

```
Parametric coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)      0.21893    0.21866   1.001  0.31731
log(CHL1_mean)   0.71158    0.03985  17.858  < 2e-16 ***
factor(year)1999  0.39959    0.31001   1.289  0.19815
factor(year)2000  0.71283    0.24649   2.892  0.00404 **
factor(year)2001  1.11205    0.25806   4.309 2.06e-05 ***
factor(year)2002 -0.05857    0.28292  -0.207  0.83609
factor(year)2003  0.34269    0.29275   1.171  0.24244
factor(year)2004  0.10030    0.40099   0.250  0.80262
factor(year)2005  0.01739    0.25858   0.067  0.94641
factor(year)2006  0.27444    0.25330   1.083  0.27924
factor(year)2007  0.20511    0.27116   0.756  0.44983
factor(year)2008  0.66366    0.29682   2.236  0.02590 *
factor(year)2009  1.91347    0.76293   2.508  0.01253 *
factor(year)2010  0.09835    0.25076   0.392  0.69511
factor(year)2011  0.33059    0.39864   0.829  0.40742
factor(year)2012 -0.09818    0.27407  -0.358  0.72037
factor(year)2013 -0.35149    0.26739  -1.315  0.18941
---
Approximate significance of smooth terms:
              edf Ref.df     F  p-value
s(dnr)      9.000  9.000 5.358 5.87e-07 ***
s(sunH)     7.183  8.224 3.008   0.0025 **
s(lon,lat) 21.559 25.865 3.106 8.82e-07 ***
---
R-sq.(adj) =  0.655   Deviance explained = 69.5%
GCV score = 0.58341  Scale est. = 0.51383   n = 459
```

AIC = 1050.2



red/green are +/- 2 s.e.

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

gam(log(chl)~log(CHL1_mean)+ s(dnr) + s(sunH) + s(lon,lat))

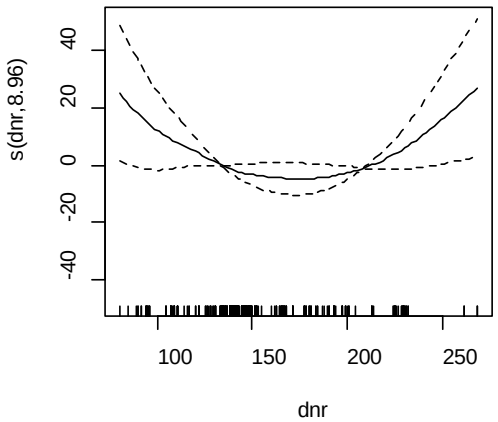
Parametric coefficients:

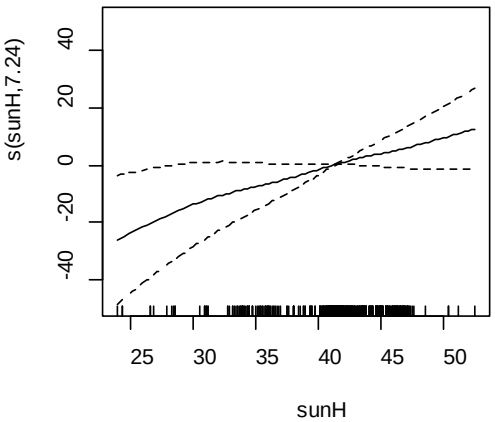
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.50696	0.03848	13.17	<2e-16	***
log(CHL1_mean)	0.71767	0.04068	17.64	<2e-16	***

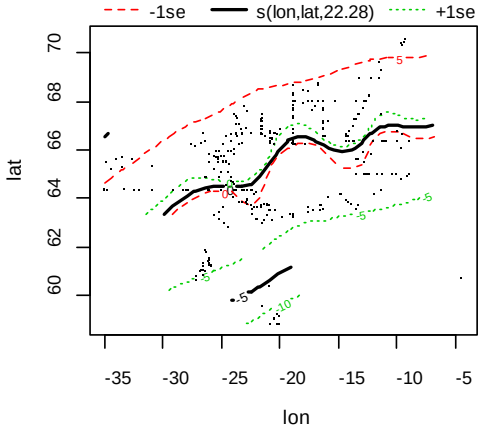
Approximate significance of smooth terms:

	edf	Ref.df	F	p-value	
s(dnr)	8.956	8.993	5.889	8.92e-08	***
s(sunH)	7.242	8.278	3.652	0.000342	***
s(lon,lat)	22.281	26.340	3.171	4.18e-07	***

R-sq.(adj) = 0.612 Deviance explained = 64.6%
GCV score = 0.63255 Scale est. = 0.57677 n = 459



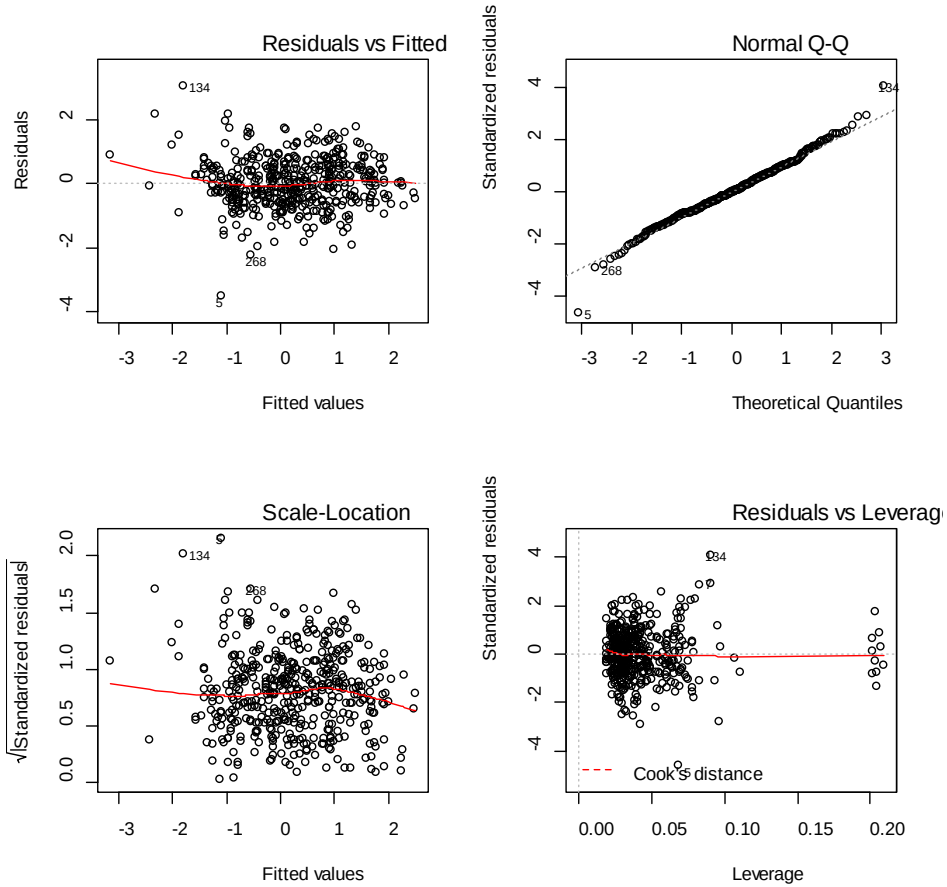




AIC: 1090.6

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

lm(log(chl)~log(CHL1_mean)+ factor(year)+dnr+sunH+ log(wd2b)+abs(sin(bear/15*pi/12))



Coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.219960	0.550867	0.399	0.689869	
log(CHL1_mean)	0.747530	0.040190	18.600	< 2e-16	***
factor(year)1999	0.348267	0.295836	1.177	0.239744	
factor(year)2000	0.579549	0.229773	2.522	0.012013	*
factor(year)2001	0.918349	0.255067	3.600	0.000354	***
factor(year)2002	-0.240206	0.277613	-0.865	0.387373	
factor(year)2003	0.359003	0.268496	1.337	0.181888	
factor(year)2004	0.013407	0.407213	0.033	0.973751	
factor(year)2005	-0.004134	0.251217	-0.016	0.986879	
factor(year)2006	0.091592	0.228554	0.401	0.688801	
factor(year)2007	0.050591	0.233671	0.217	0.828696	
factor(year)2008	0.181165	0.237794	0.762	0.446555	
factor(year)2009	2.471451	0.811024	3.047	0.002449	**
factor(year)2010	0.077975	0.237345	0.329	0.742667	
factor(year)2011	0.295756	0.403876	0.732	0.464381	
factor(year)2012	-0.313548	0.233050	-1.345	0.179188	
factor(year)2013	-0.102223	0.256035	-0.399	0.689900	
dnr	-0.005251	0.001228	-4.277	2.33e-05	***
sunH	0.021030	0.009952	2.113	0.035151	*
log(wd2b)	-0.059310	0.038841	-1.527	0.127483	
abs(sin(bear/15 * pi/12))	0.655425	0.134425	4.876	1.52e-06	***

Residual standard error: 0.7861 on 438 degrees of freedom

Multiple R-squared: 0.6028, **Adjusted R-squared: 0.5846**

F-statistic: 33.23 on 20 and 438 DF, p-value: < 2.2e-16

AIC = 1104.2

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

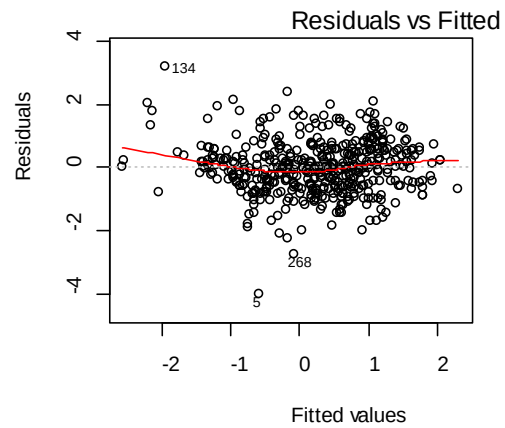
Selecting a simple model:
lm(log(chl)~log(CHL1_mean)+ dnr + sunH + log(wd2b)

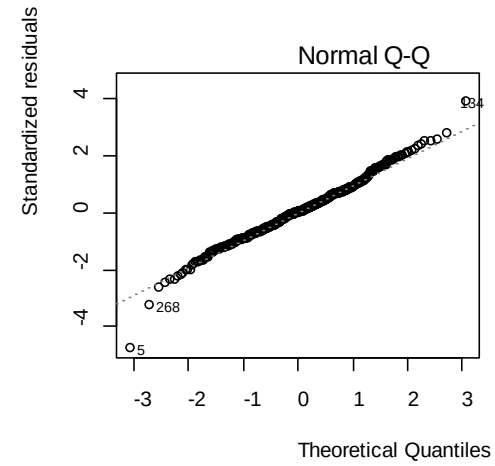
Coefficients:

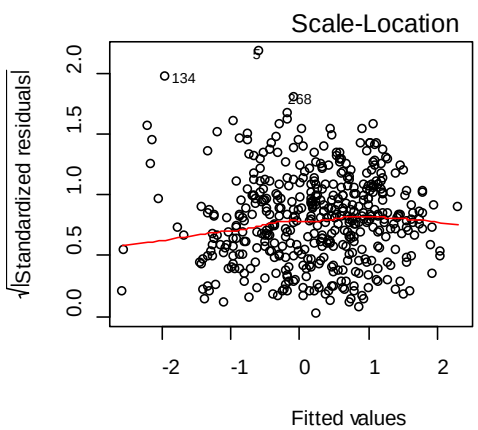
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.547550	0.467123	1.172	0.241741	
log(CHL1_mean)	0.732027	0.042140	17.371	< 2e-16	***
dnr	-0.004877	0.001220	-3.996	7.5e-05	***
sunH	0.035301	0.009232	3.824	0.000150	***
log(wd2b)	-0.132454	0.034303	-3.861	0.000129	***

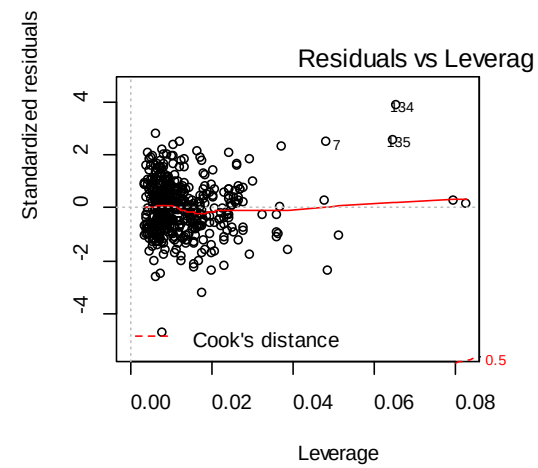
Residual standard error: 0.8531 on 454 degrees of freedom
Multiple R-squared: 0.5151, **Adjusted R-squared: 0.5109**
F-statistic: 120.6 on 4 and 454 DF, p-value: < 2.2e-16

AIC = 1163.7









In context with published results:

Basic model: BM (GAM and LM)

log(chl) vs. log(CHL1_mean);

R^2 ~ 0.47, revealed for both LM and GAM analysis

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

Full models with regard to year of sampling: (GAM 1 & 2 and LM 1 & 2)

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

R^2 ~ 0.60, revealed for both LM (0.58) and GAM (0.69) models
(cf. 0.60 for SeaWiFS data in general for case 1 waters, Gregg&Casey 2004, RSE93)

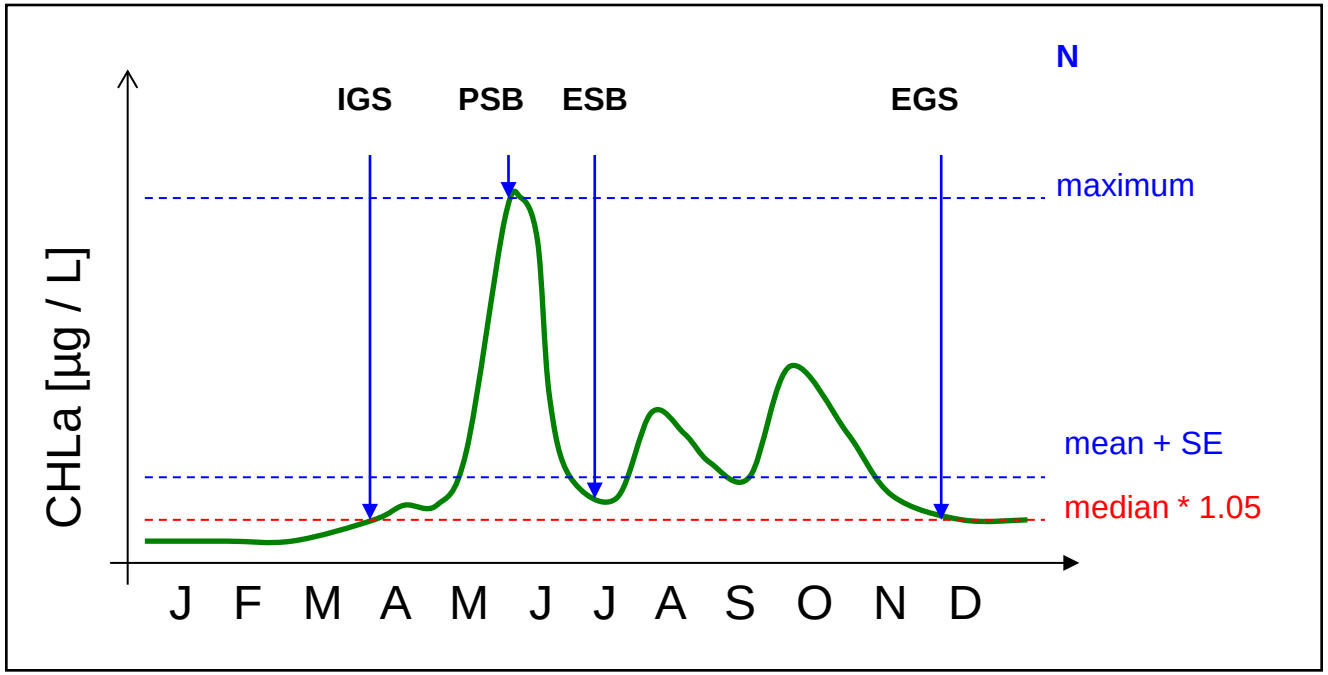
Residuals:

One possible reason for unexplained residuals may be 'patchiness in chlorophyll concentrations' on smaller scale than the size of pixels (~25 km^2) in our satellite data

Leaving out 'year of sampling' as factor from our full model (and thus obtaining a timeless model) lower the performance, approaching the basic model level.

However, apparent information extracted from regionally corrected data is convincing (c.f. next slides). The performed corrections are explainable and: Furthermore, correlations might improve considerably if the sampling intensity in March - April and August - September is improved.

Indexes on phenology, etc.



1) N: number of observations

CHARACTERISTICs:

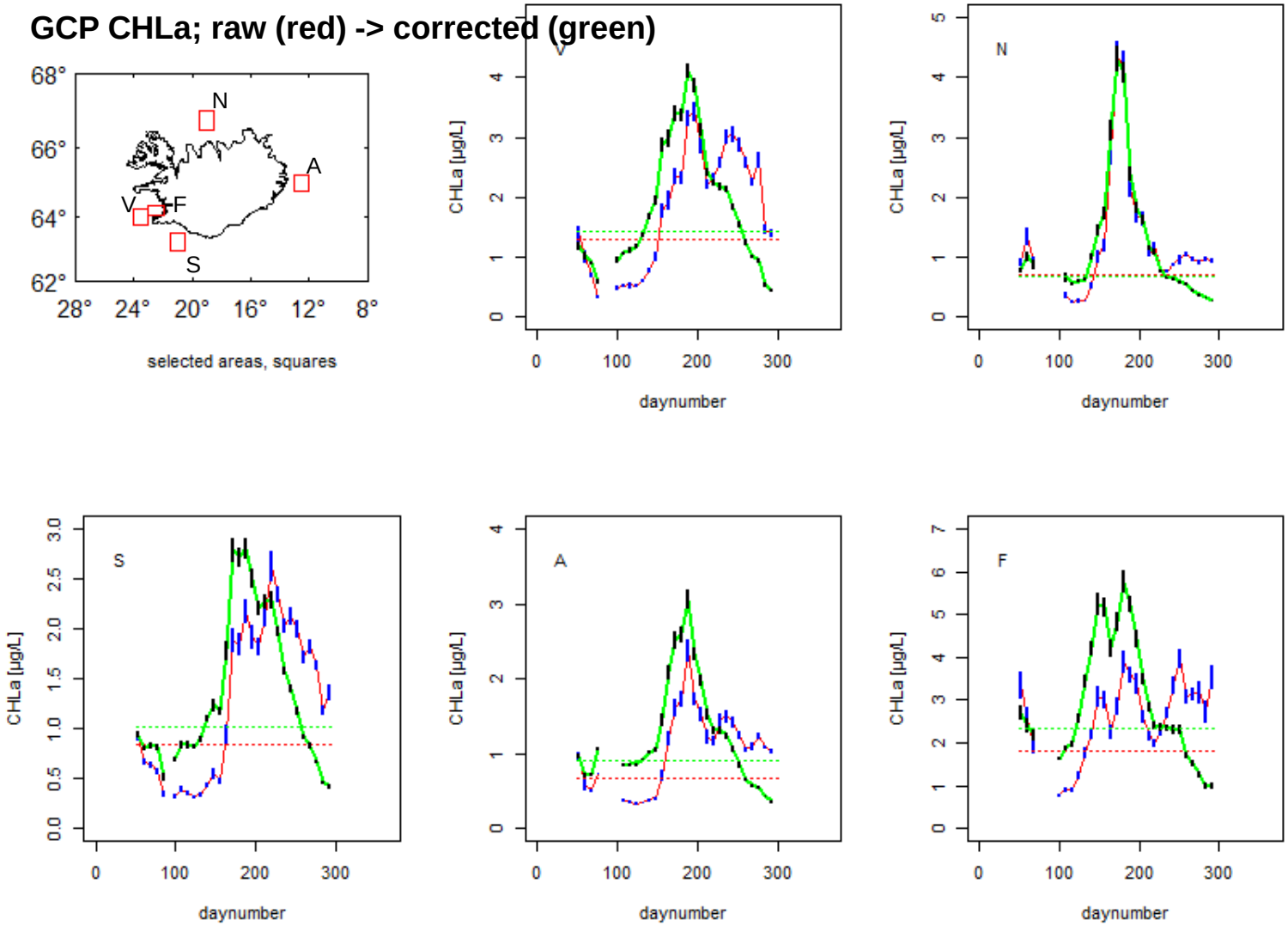
2) IGS: inition of phytoplankton growth season [daynumber]
3) PSB: peak of spring bloom [daynumber]
4) ESB: end of spring bloom [daynumber]
5) EGS: end of phytoplankton growth season [daynumber]

STATISTICs

6) maximum GS: maximum value during growth season [µg CHLa / L]
7) mean GS: calculated mean value for growth season [µg CHLa / L]
8) 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]

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

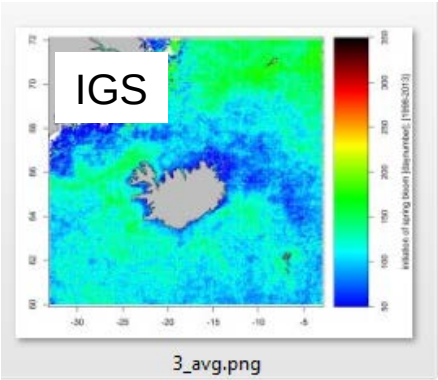
GCP CHLa; raw (red) -> corrected (green)

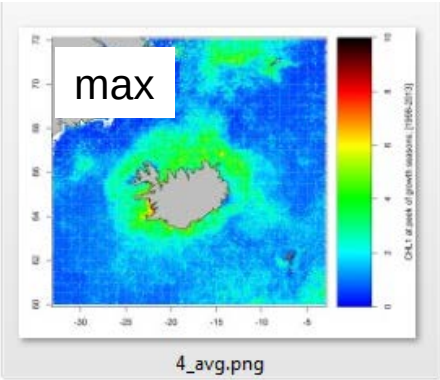


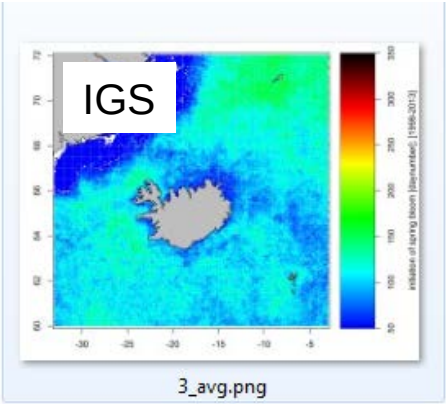
Comparison of satellite chlorophyll-a (CHL1 ; GCP) before and after local corrections

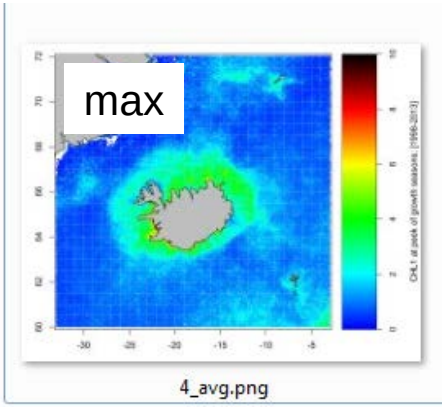
‘RAW GCP’

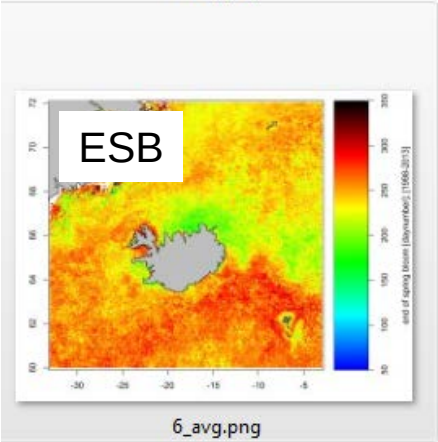
PREDICED

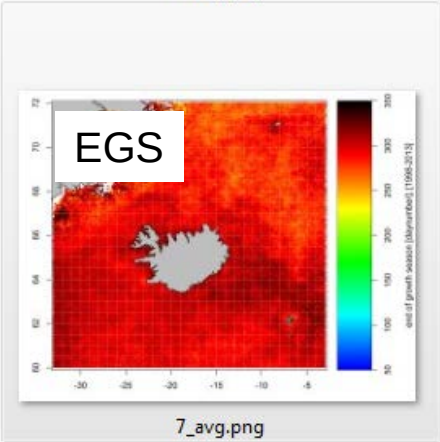


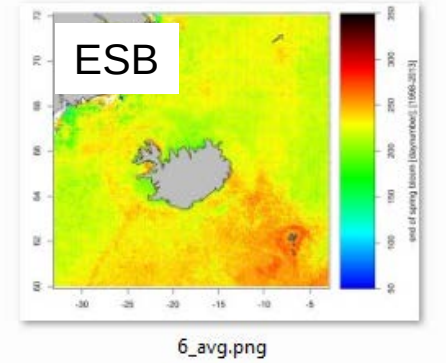


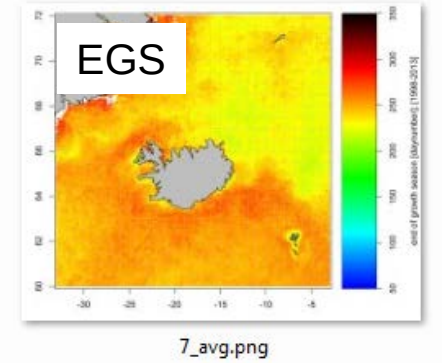












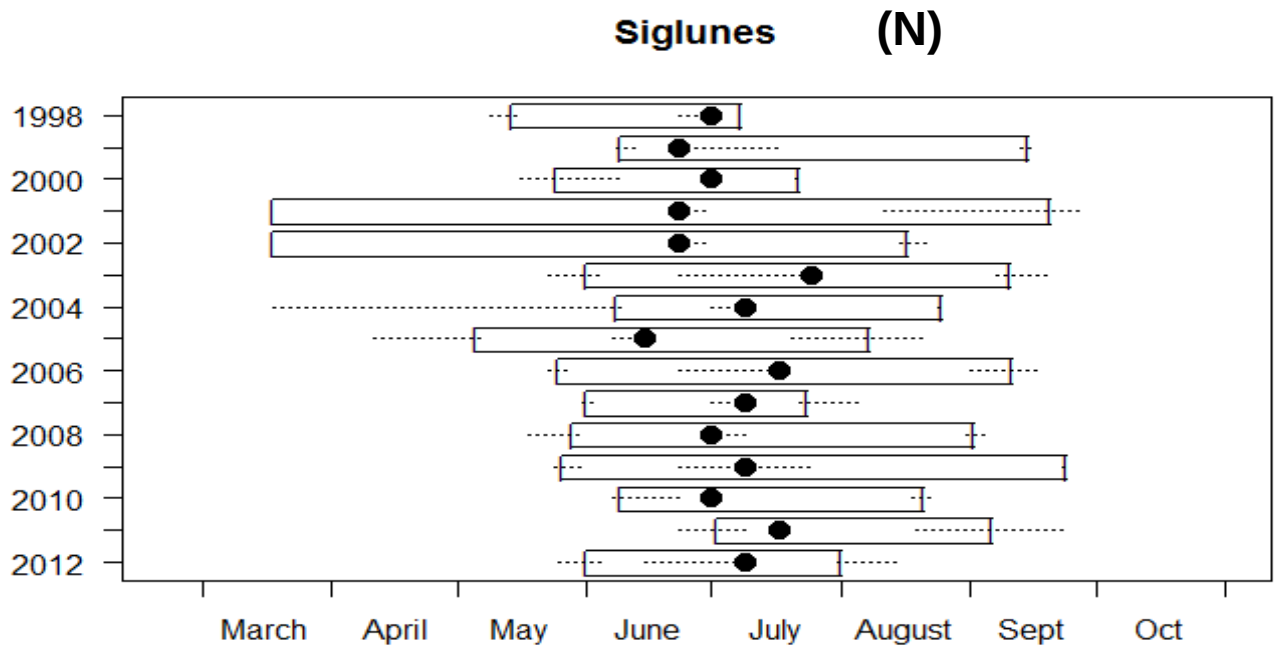
Thanks are due to Kristín J. Valsdóttir, for measuring, calculating and keeping records of most of the chlorophyll water samples used for the presented analysis.

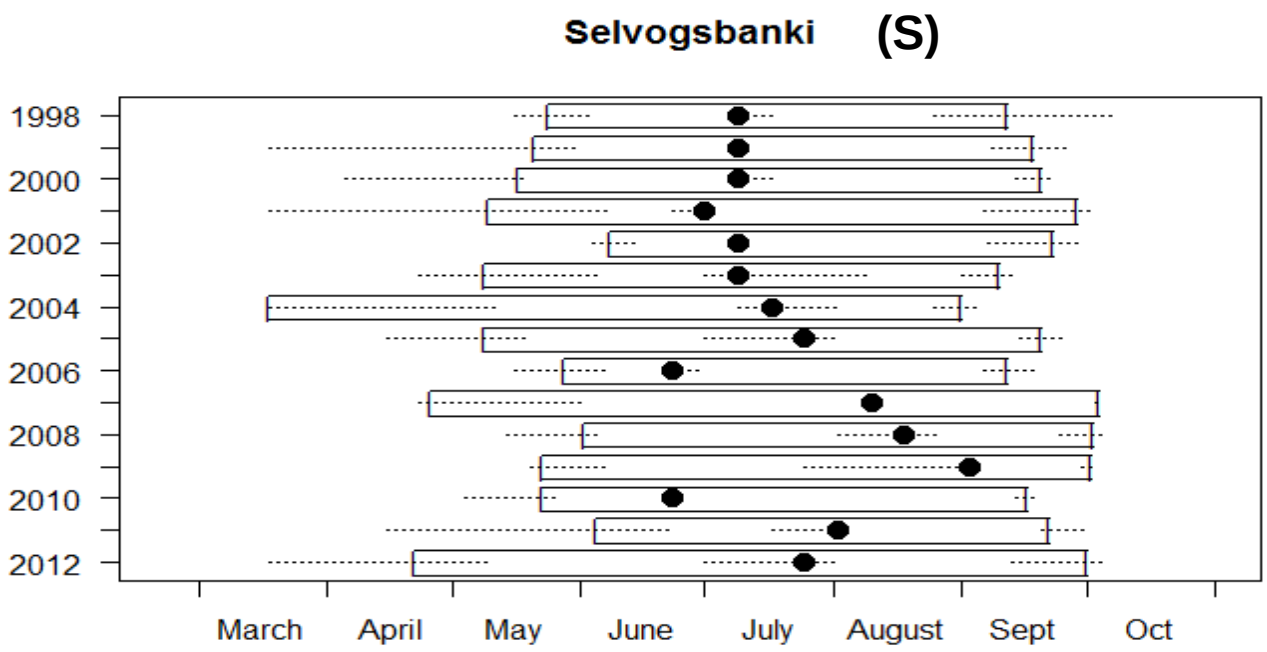
We also sincerely thank other colleagues, both the crew of our research vessels and fellow scientists that have assisted us on board and/or in the lab, but it is best not to list all the individuals.

And THANK YOU for your attention!

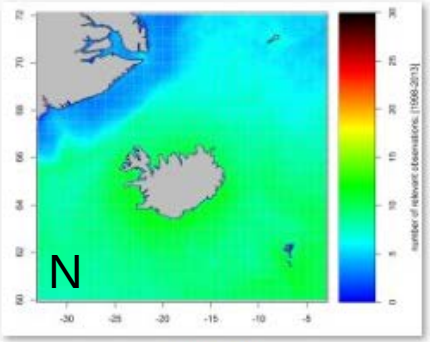
Please quit and come out now!

kristinn@hafro.is

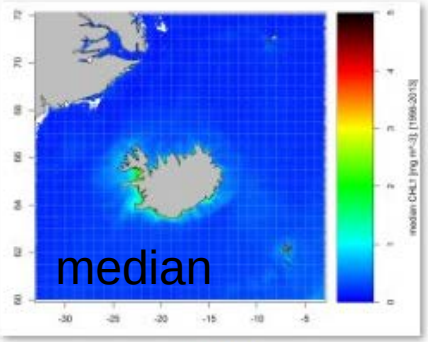

Siglunes
(N)
1998
2000
2002
2004
2006
2008
2010
2012
March
April
May
June
July
August
Sept
Oct


Selvogsbanki
(S)
1998
2000
2002
2004
2006
2008
2010
2012
March
April
May
June
July
August
Sept
Oct

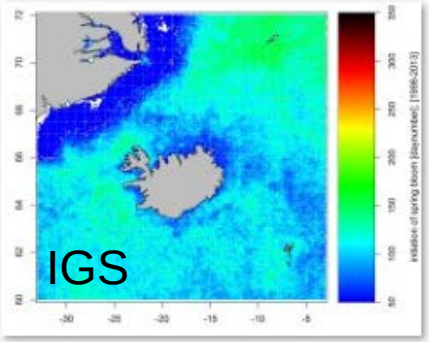
Comparison of satellite chlorophyll-a (CHL1 ; GCP) before and after local corrections



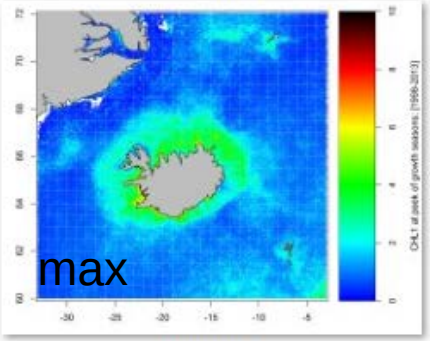
1_avg.png



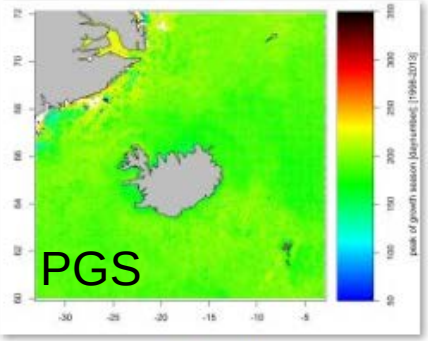
2_avg.png



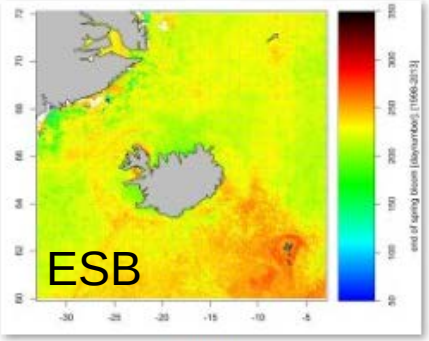
3_avg.png



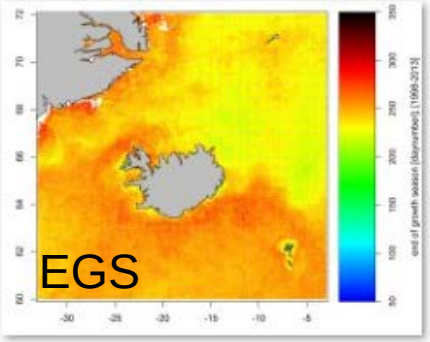
4_avg.png



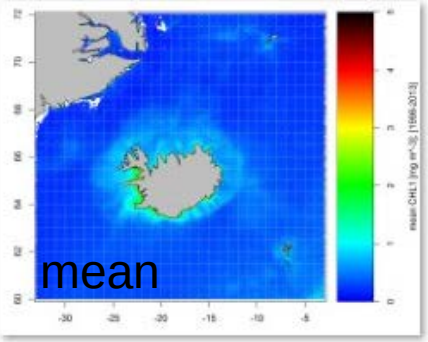
5_avg.png



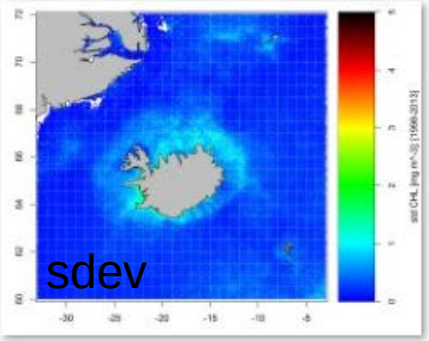
6_avg.png



7_avg.png

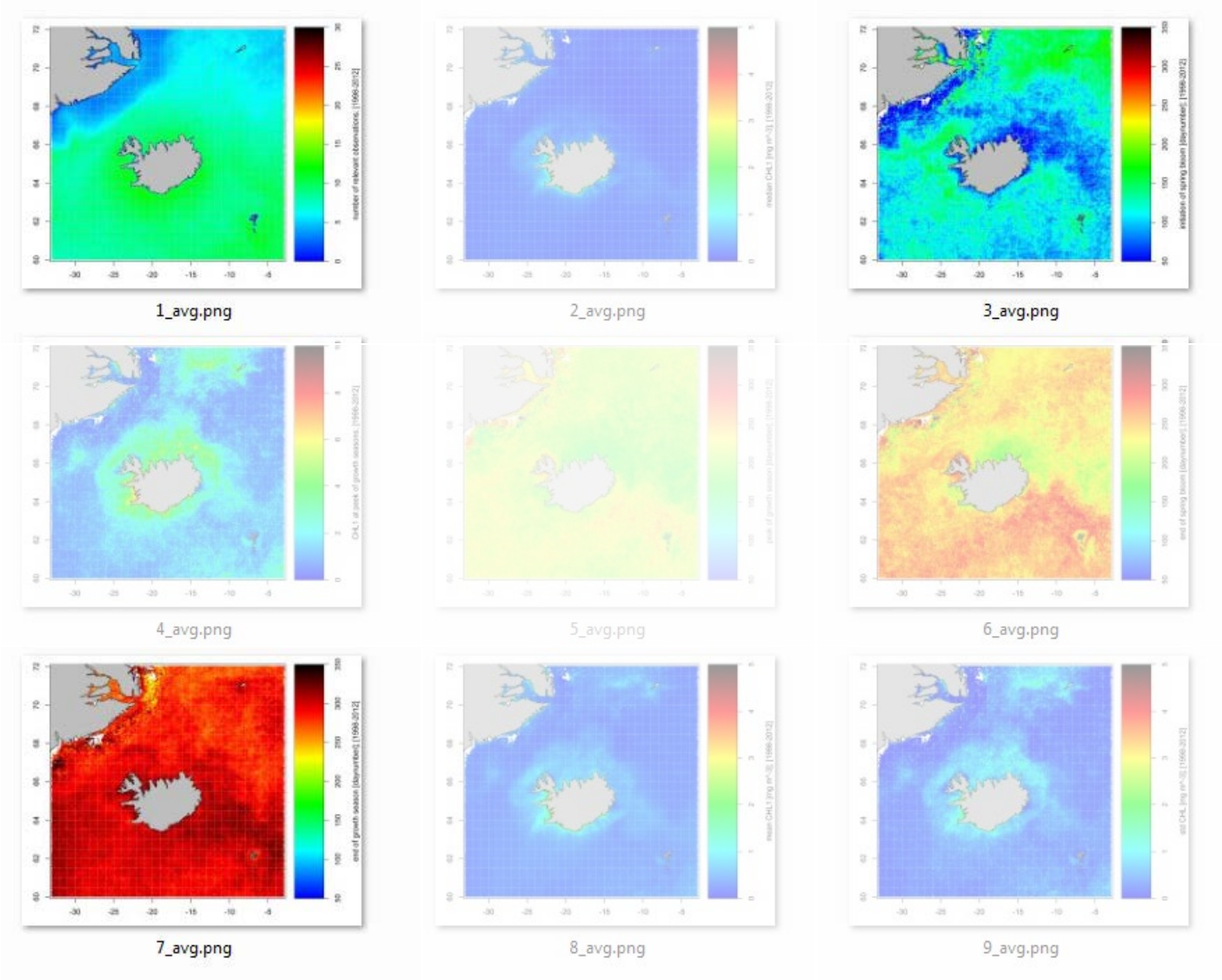


8_avg.png

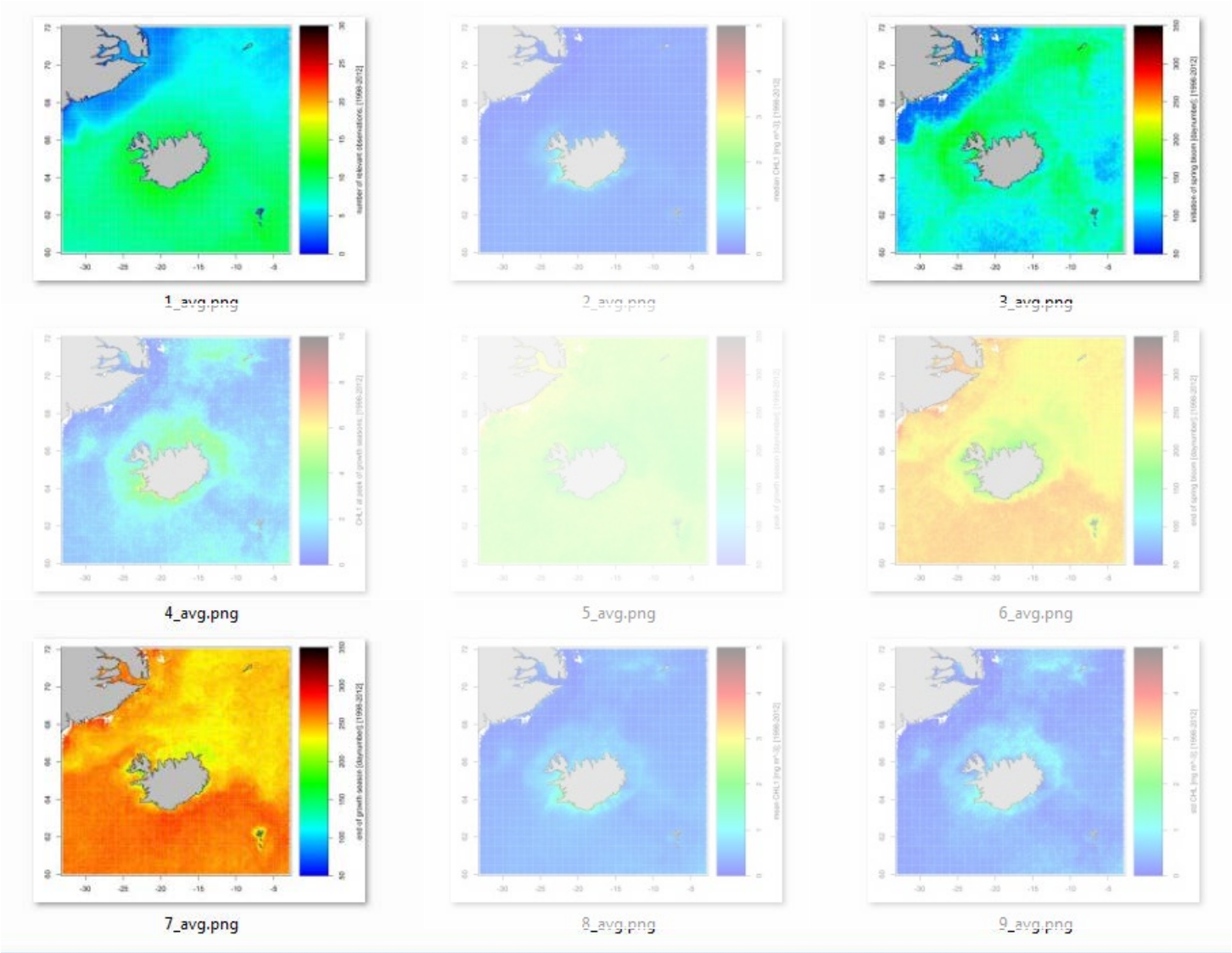


9_avg.png

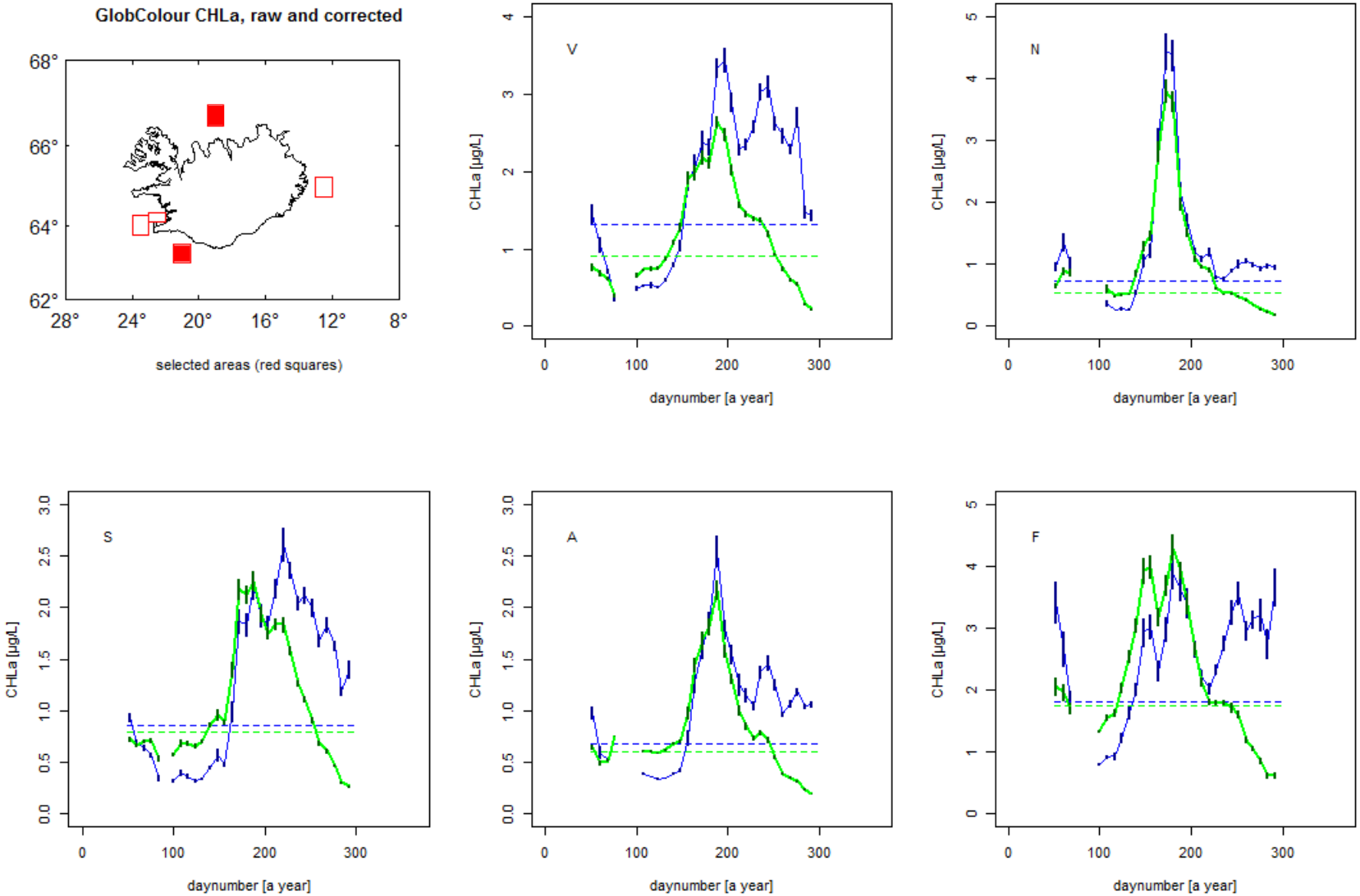
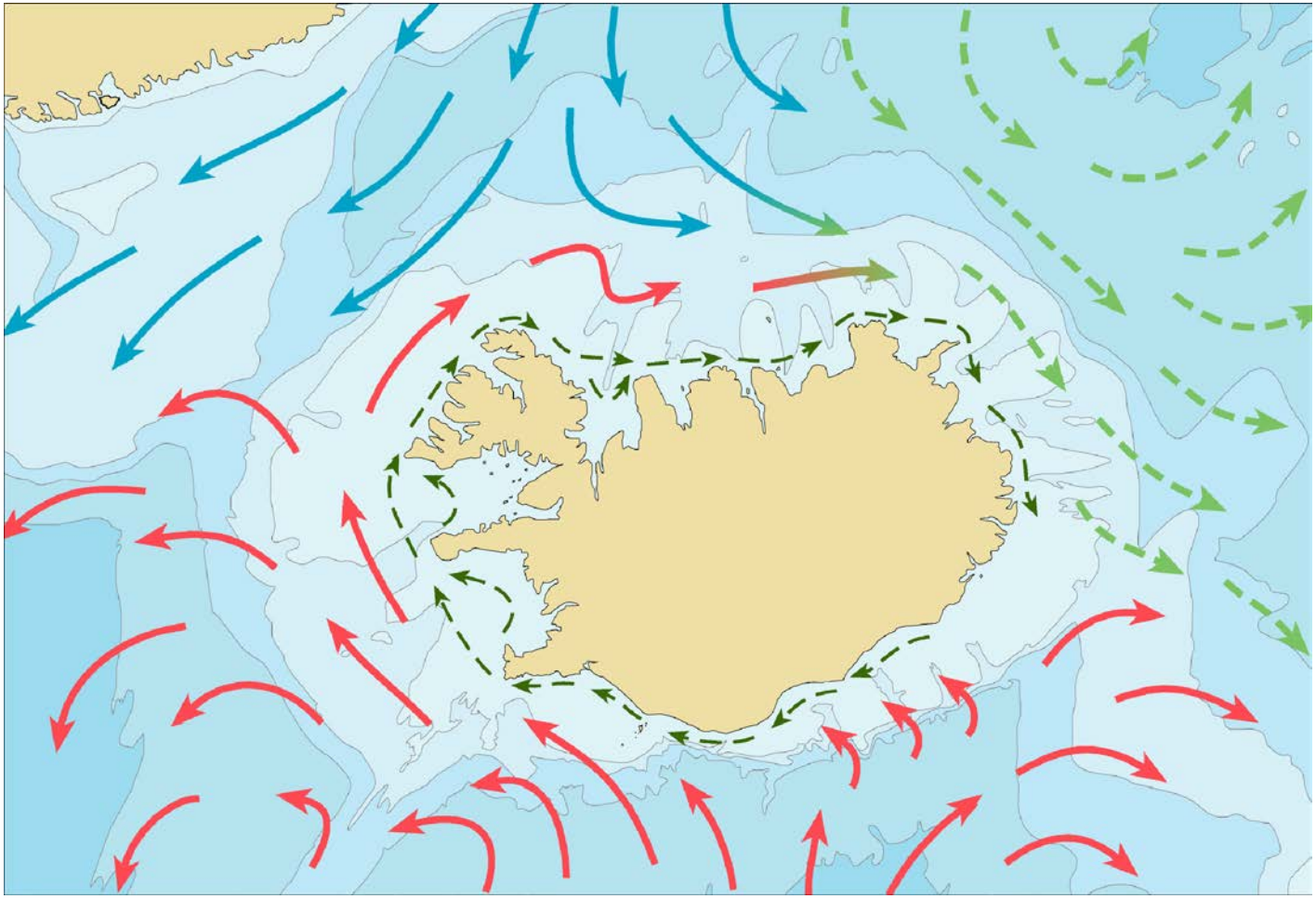
Derived parameters: **averages of 1998 – 2012, *i.e.* 1) N; 2) median; 3) IGS; 4) maximum, 5) PSB; 6) ESB; 7) EGS; 8) mean and 9) SE, for the '[raw data](#)' obtained from the 'GlobColour Project'**



Derived parameters: **averages of 1998 – 2012, *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**



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