The changing seasonality of the Baltic Sea

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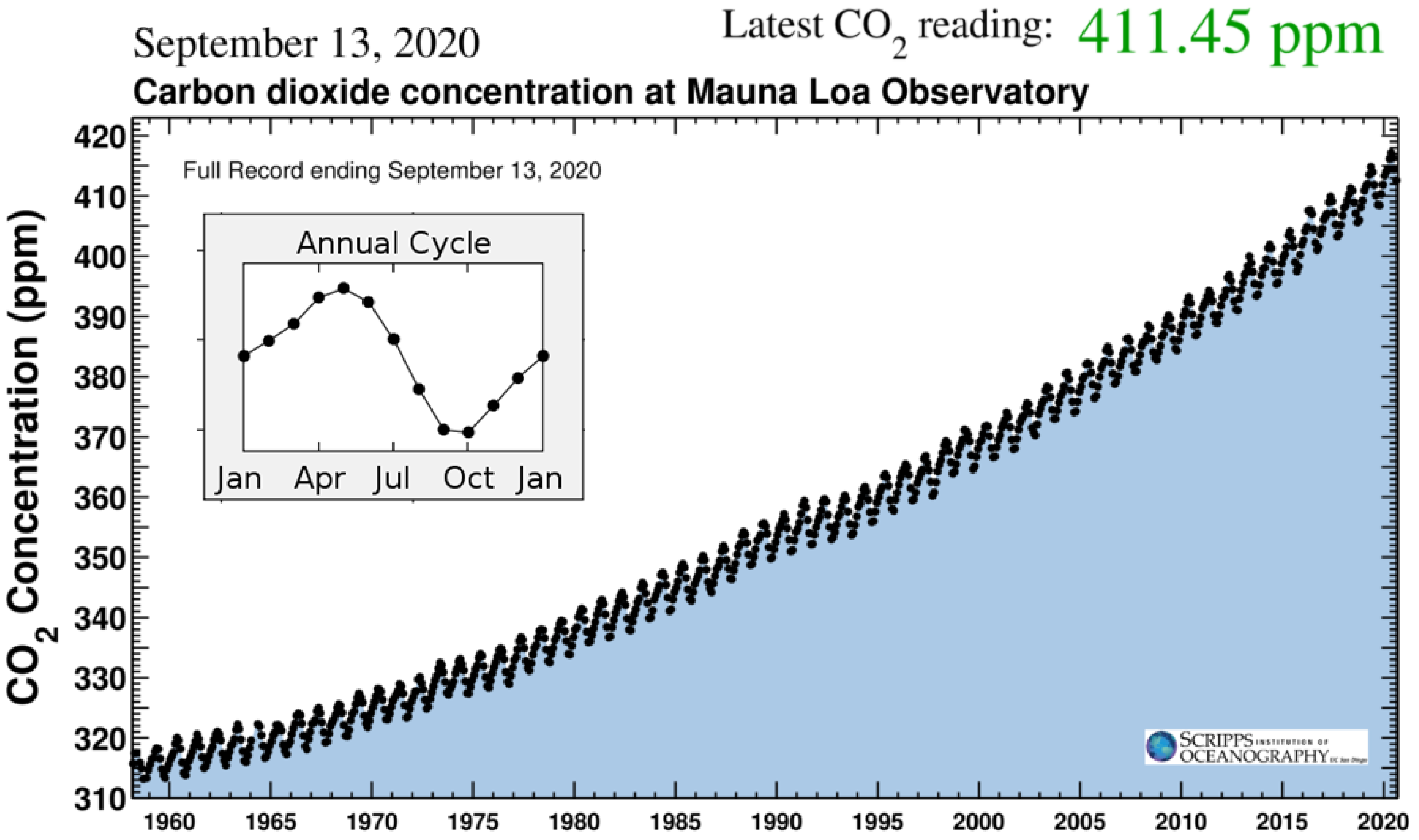
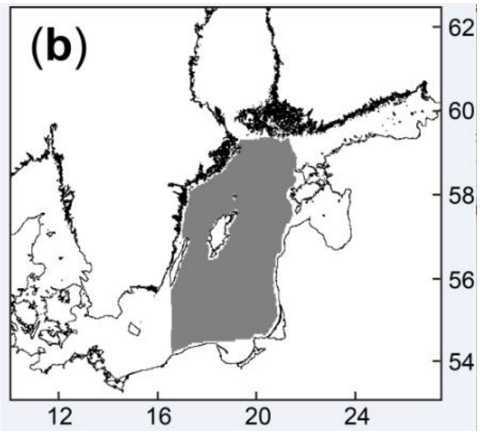
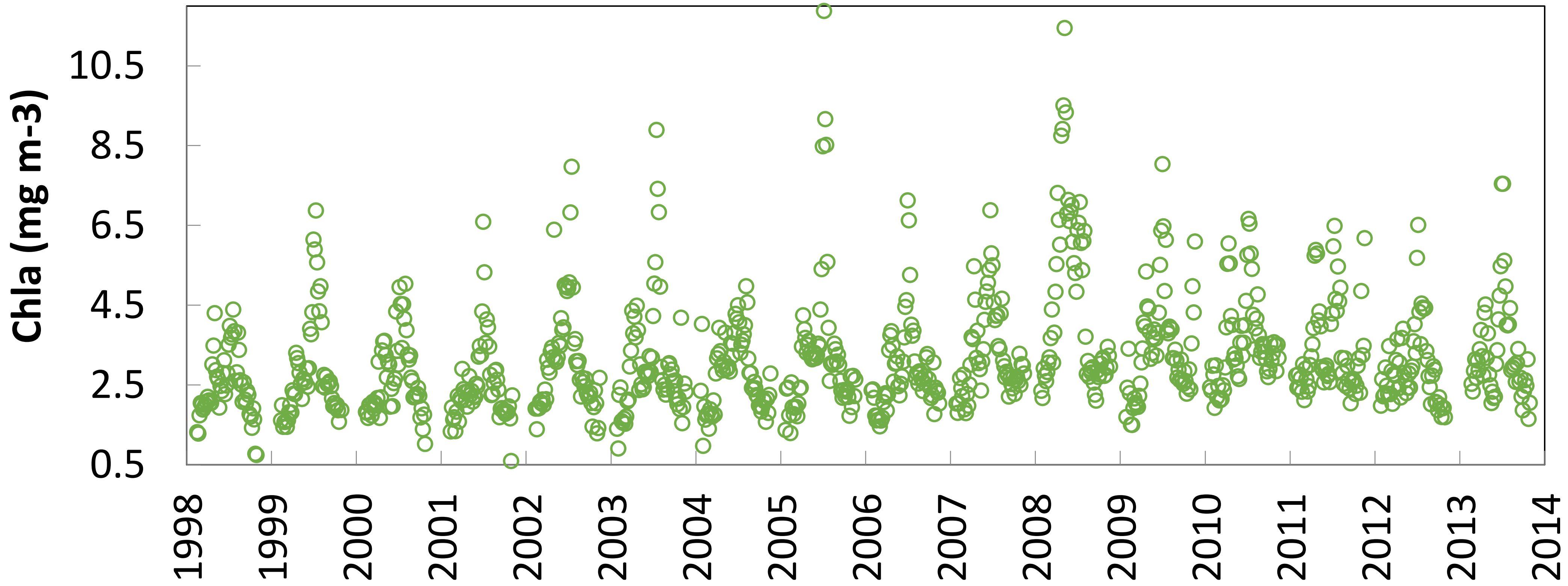
The "Keeling curve" Prof. Charles David Keeling; Prof. Roger Revelle



Chlorophyll-a (Chla) in central Baltic Sea



Time series of the 5-day mean CHL (mg m^{-3}) in the central Baltic Sea derived from the ESA-CCI processing of SeaWiFS, MERIS and Aqua-MODIS satellite data (Sathyendranath et al., 2014, 2015). Trend? Accuracy? What does it measure?



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Changing seasonality of the Baltic Sea

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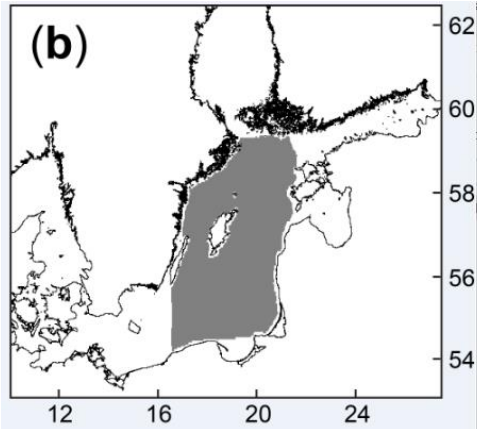
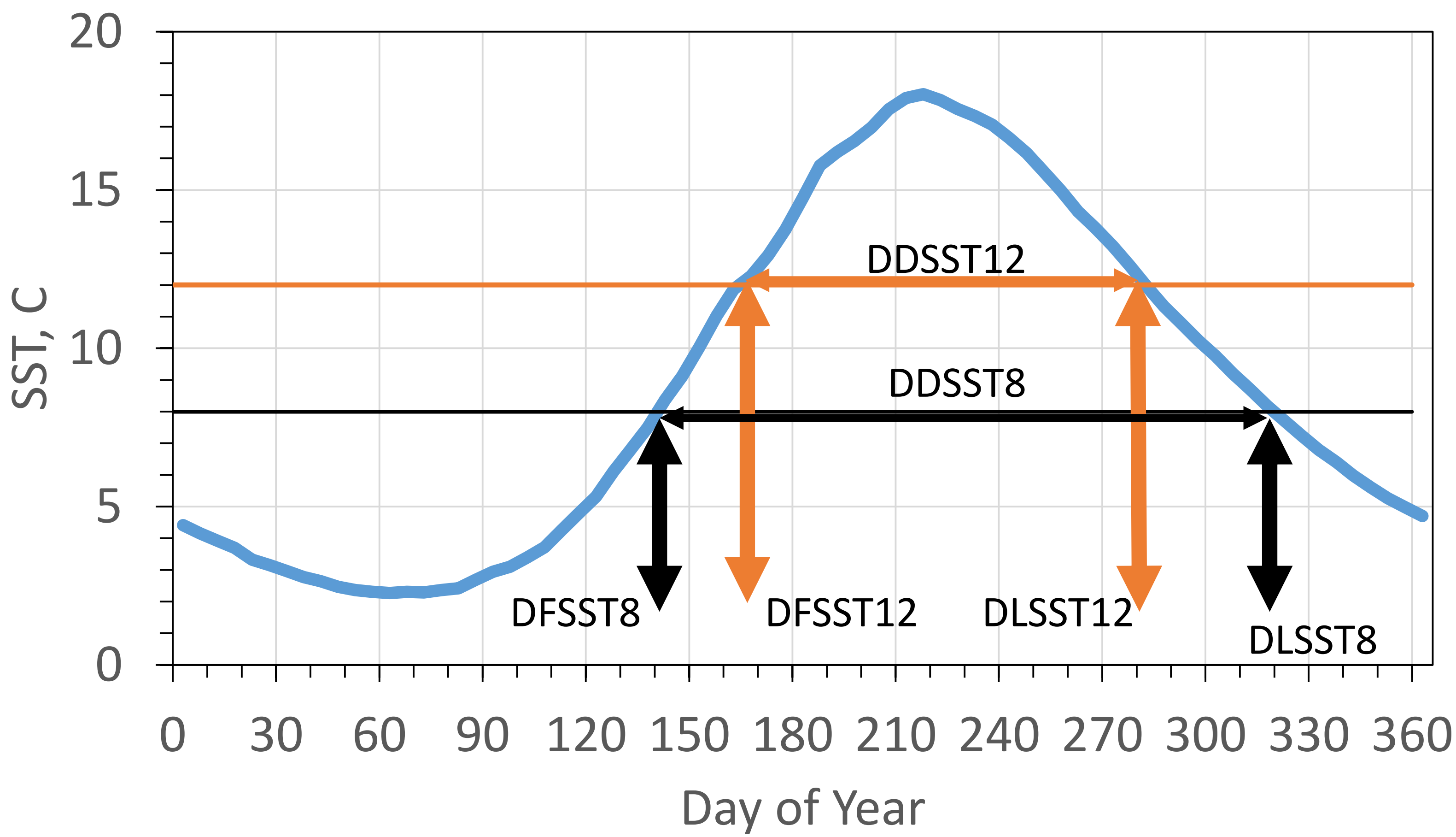
- Using **satellite** data to detect change
    - Satellite data are suitable for this task as they cover multiple (large) **areal scales** (local, basin, global); have consistent **frequency** (in general), are available for **free**; getting longer and more suitable for climate studies
- Trying to **separate** changes caused by **anthropogenic** effects from those due to **natural** climate variability – complicated!

Indices of SST phenology

Mean annual cycle of SST (AVHRROI, 1981-2018) in central Baltic;
Day of the year when 8˚C is first reached, DFSST8 = Day First SST 8, when 8˚C is last reached, DLSST8 = Day Last SST 9, same for 12˚C



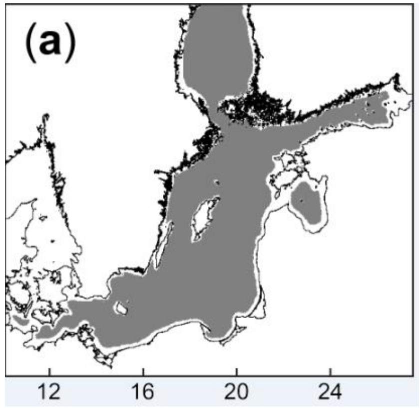


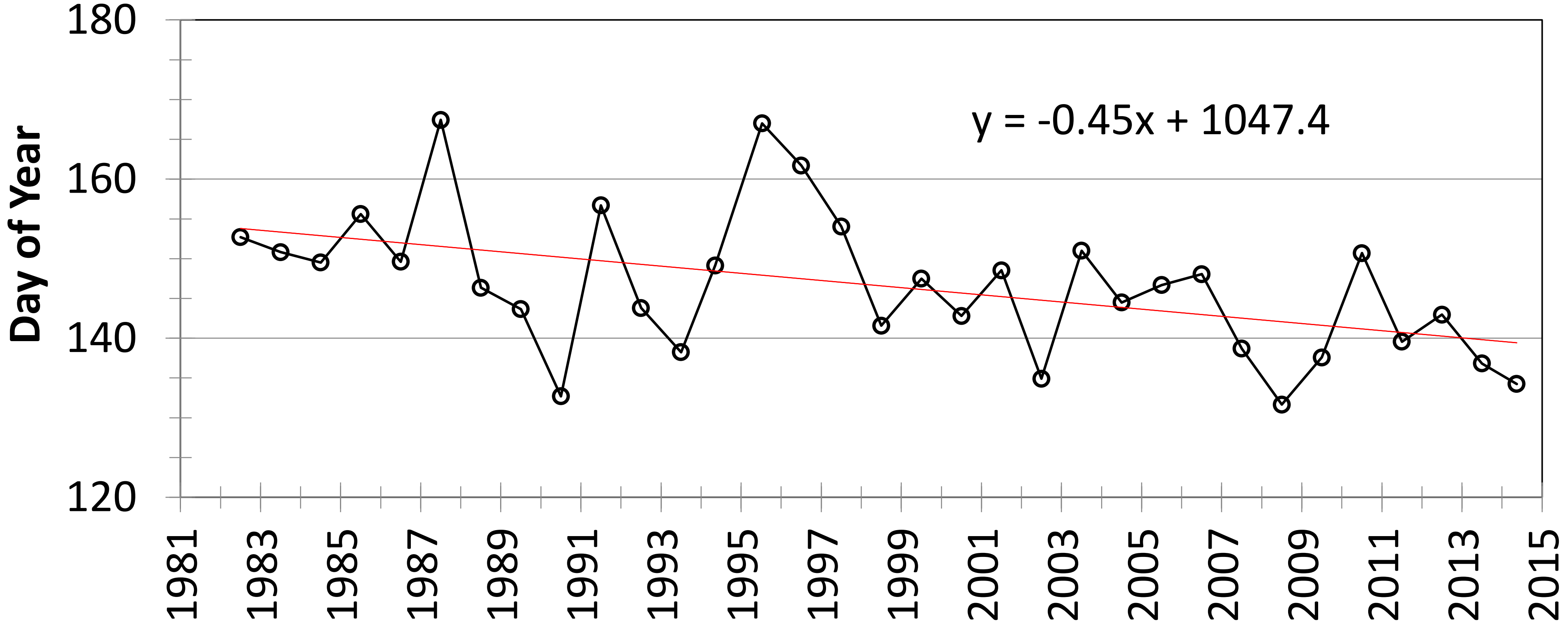
DFSST8 ~140; DLSST8 ~315
DDSST8 = DLSST8 – DFSST8 = 175

DFSST12 ~170; DLSST12 ~280
DDSST12 = DLSST12 – DFSST12 = 110

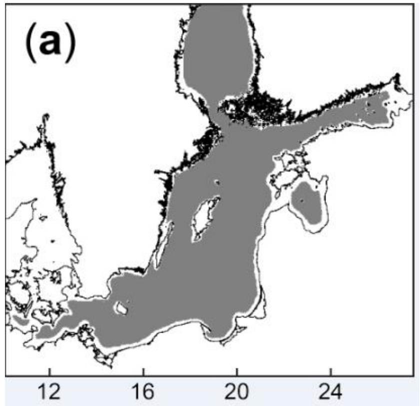
Trends in SST phenology: DFSST8

Day of the year when 8 ˚C is reached in spring (DFSST8 = Day First SST 8C). Slope = -0.45, i.e. in 10 years 8 ˚C is reached 4.5 days earlier; in 40 years -> 18 days earlier





Phenology indices



Explanation	Type	Example variable groups
First day of reaching a threshold	DF	DFSST, DFCHL, DFKED
Last day of reaching a threshold	DL	DLSST, DLCHL, DLKED
Duration of the period between DF and DL	DD	DDSST, DDCHL, DDKED
Count of days over the threshold	DC	DCSST, DCCHL, DCKED
Day of reaching the annual maximum	DM	DMSST, DMCHL, DMKED
First day of reaching a cumulative threshold	DFCUM	DFCUMSIS, DFCUMSST

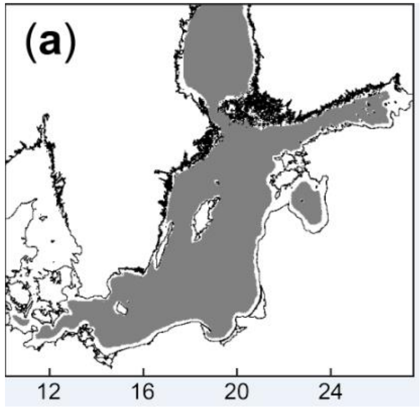
↔ Coral bleaching (DC)

↔ Radiative heating (DFCUM)

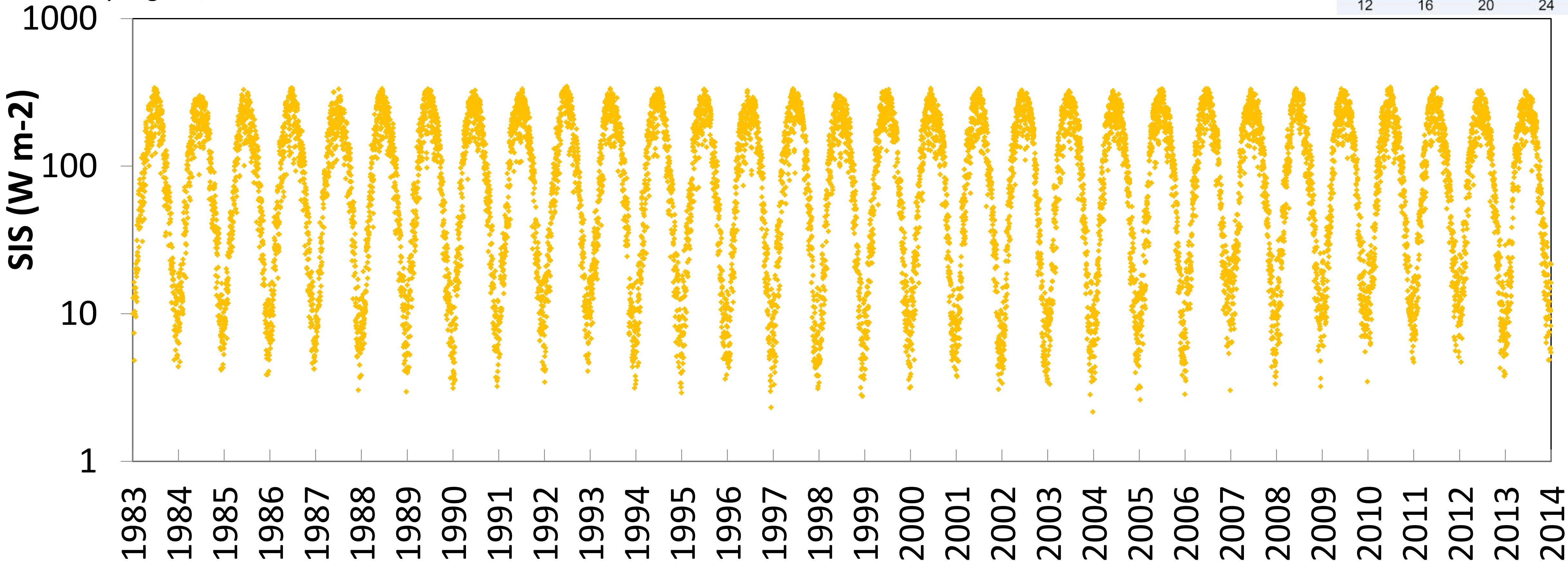
Surface Incoming Shortwave irradiance (SIS, W m^{-2}) from geostationary Meteosat sensors

(Mueller et al., 2009, Müller et al., 2015).

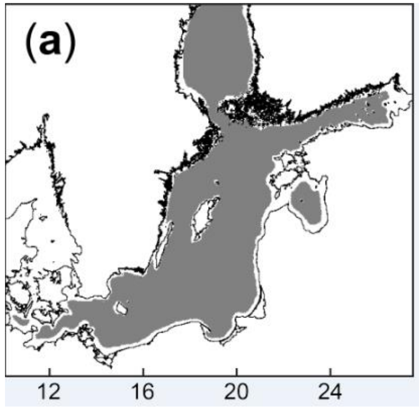
EUMETSAT CM SAF CLIMATE MONITORING



Extremely regular, no trends detectable in absolute values



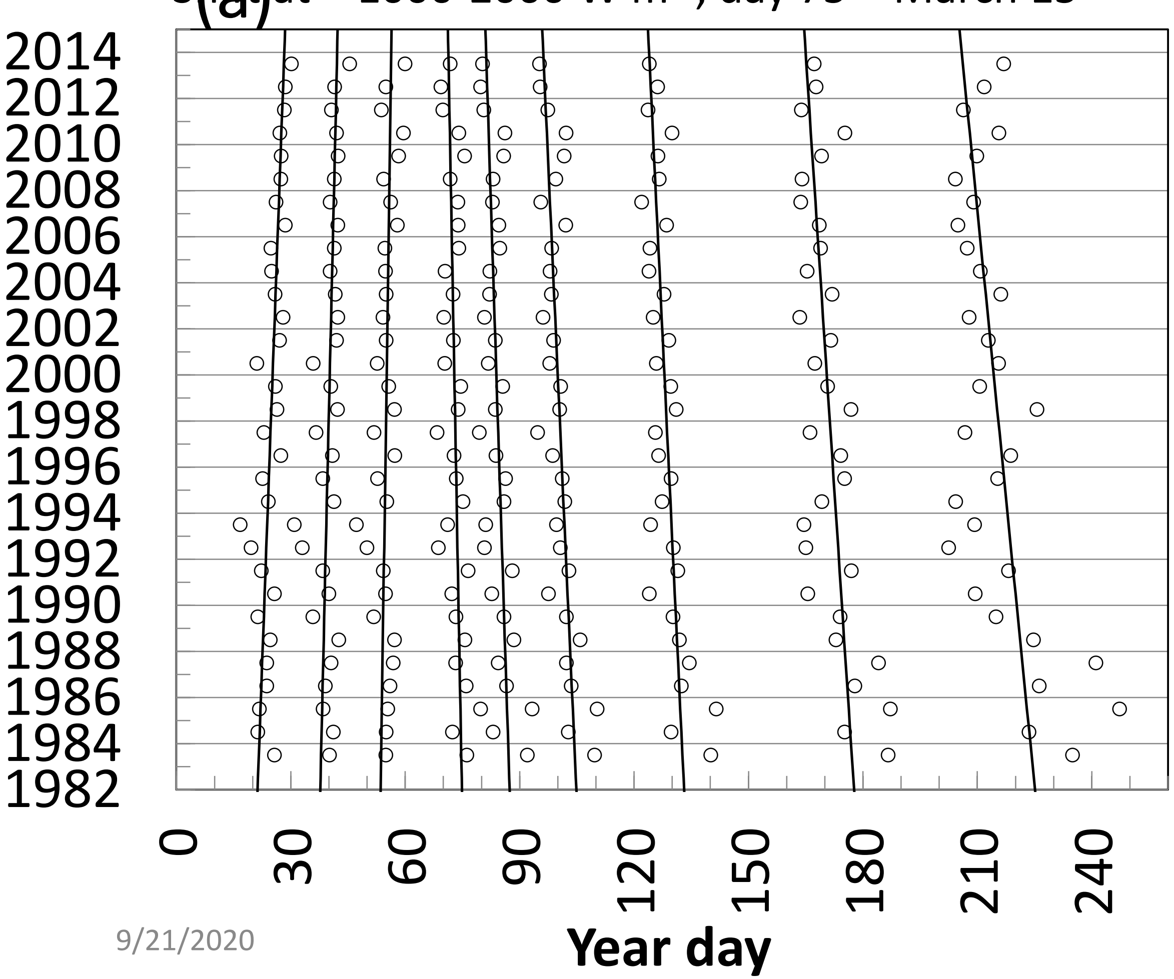
Trends in SIS (Surface Incoming Shortwave irradiance, W m^{-2})

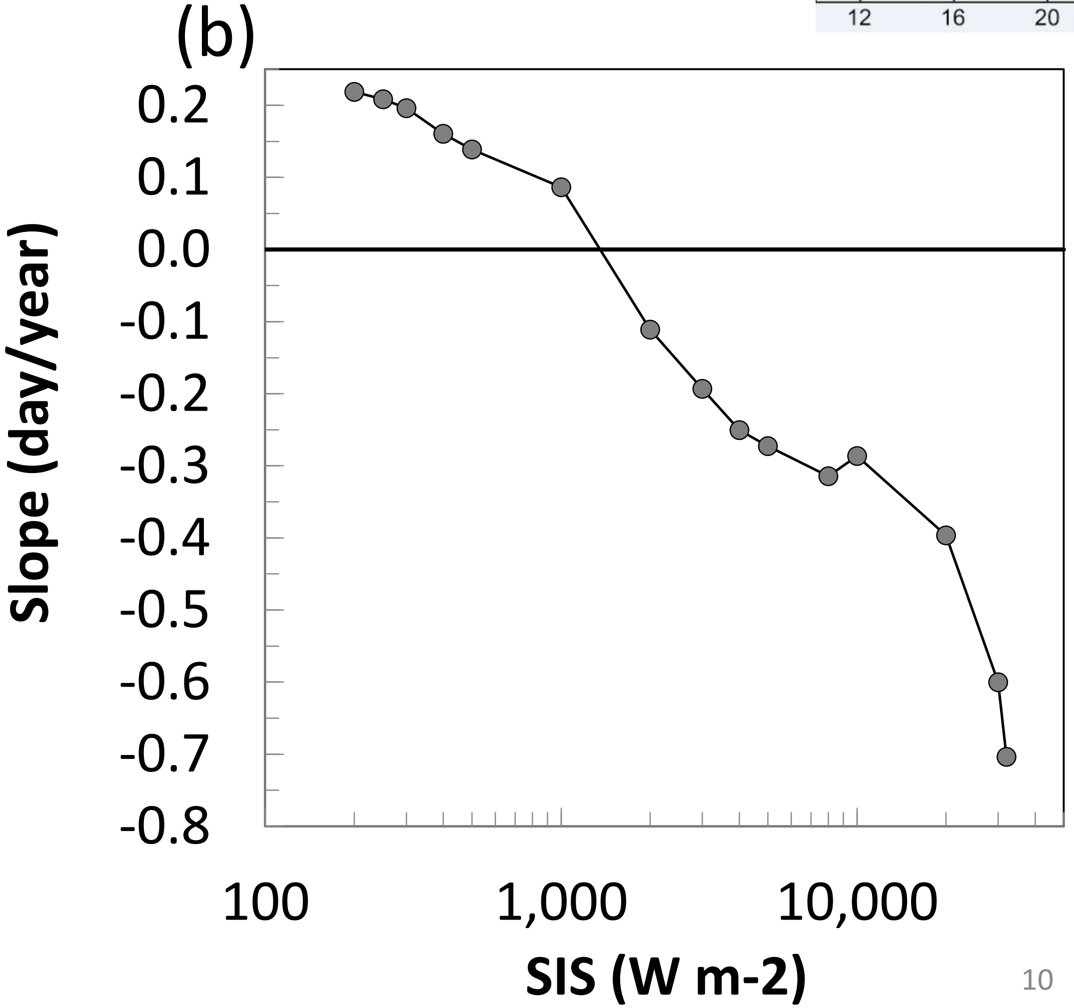


(a) DFCUMSIS, i.e. day of year when the annual sum of daily SIS reaches the following thresholds: 200, 500, 1000, 2000, 3000, 5000, 10000, 20000 and 30000 W m^{-2}. For each threshold the circles show the day of the year and the line shows the respective linear regression; (b) Slope of the linear regression.

DFCUMSIS 30K Wm^{-2} was reached ~day 237 in 1983 but on day 214 in 2014, i.e., 23 days earlier.

Shift at ~ 1000-2000 W m^{-2}, day 75 ~ March 15

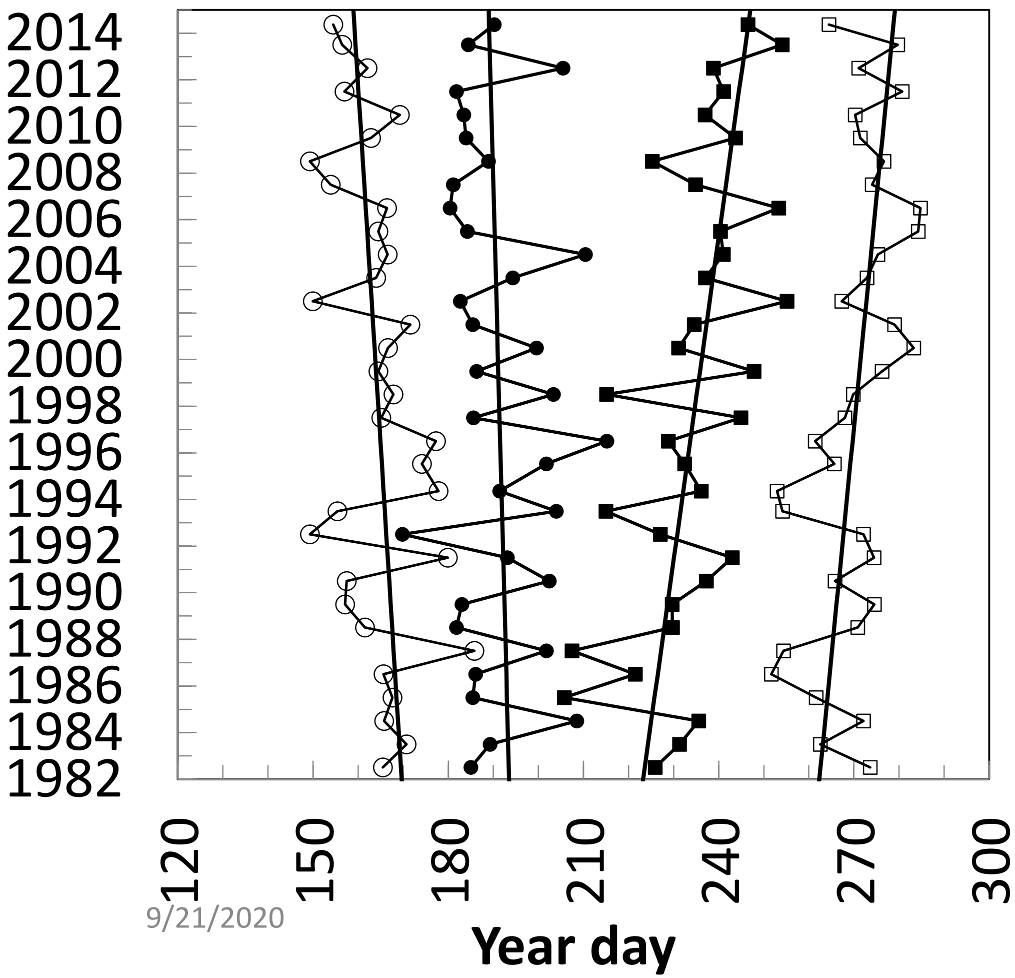


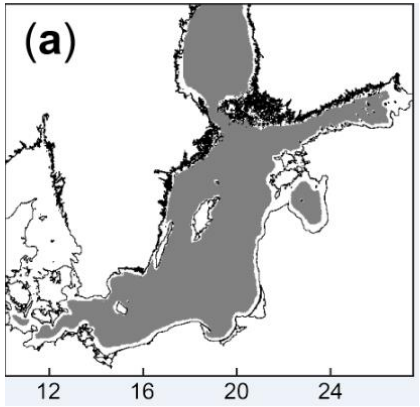


Trends in SST phenology

(a) The symbols and regression lines from left to right: first day when 12 ˚C is reached (DFSST12, open circles), first day when 17 ˚C is reached (DFSST17, filled circles), last day when 17 ˚C is reached (DLSST17, filled squares), last day when 12 ˚C is reached (DLSST12, open squares).

(a)



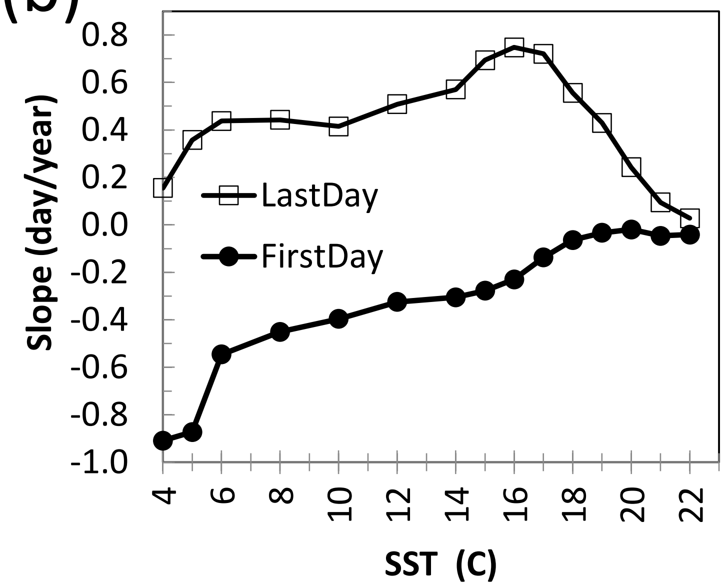


(b) Rate of change (day/year) in the day of year when a SST level is first reached (DFSST, filled circles) and when a SST level is last reached (DLSST, open squares) for the Baltic Sea.

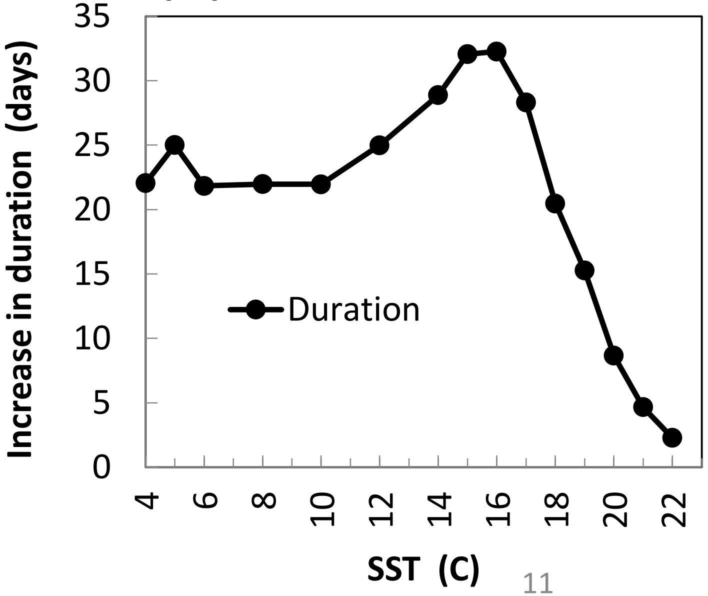
(c) Increase in the duration of a period with SST above a certain level (DDSST) from 1982 to 2014 (32 years). DSST17 increased > 1 month!

-> What does it mean for a fish or crab?

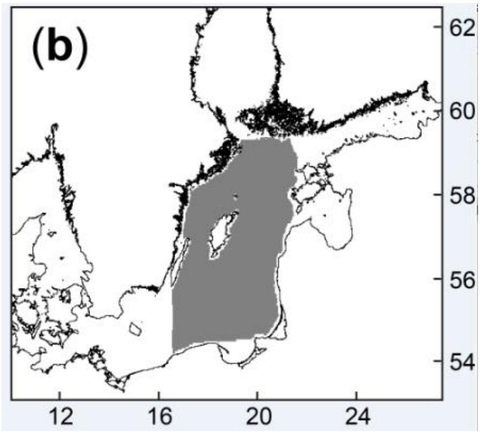
(b)



(c)

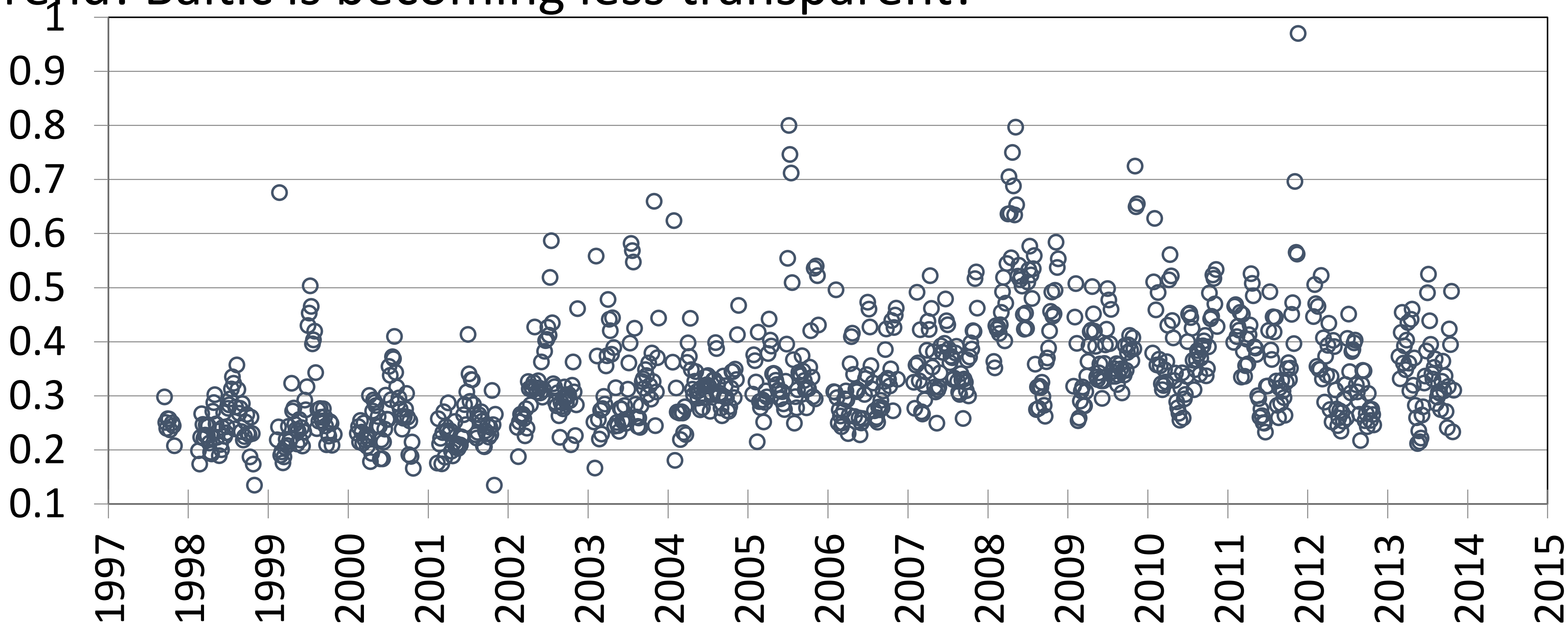


Coefficient of light attenuation (Ked490) in central Baltic Sea



Time series of the 5-day mean KED490 (m^{-1}) in the central Baltic Sea derived from the ESA-CCI processing of SeaWiFS, MERIS and Aqua-MODIS satellite data using the Lee algorithm.

Trend! Baltic is becoming less transparent!

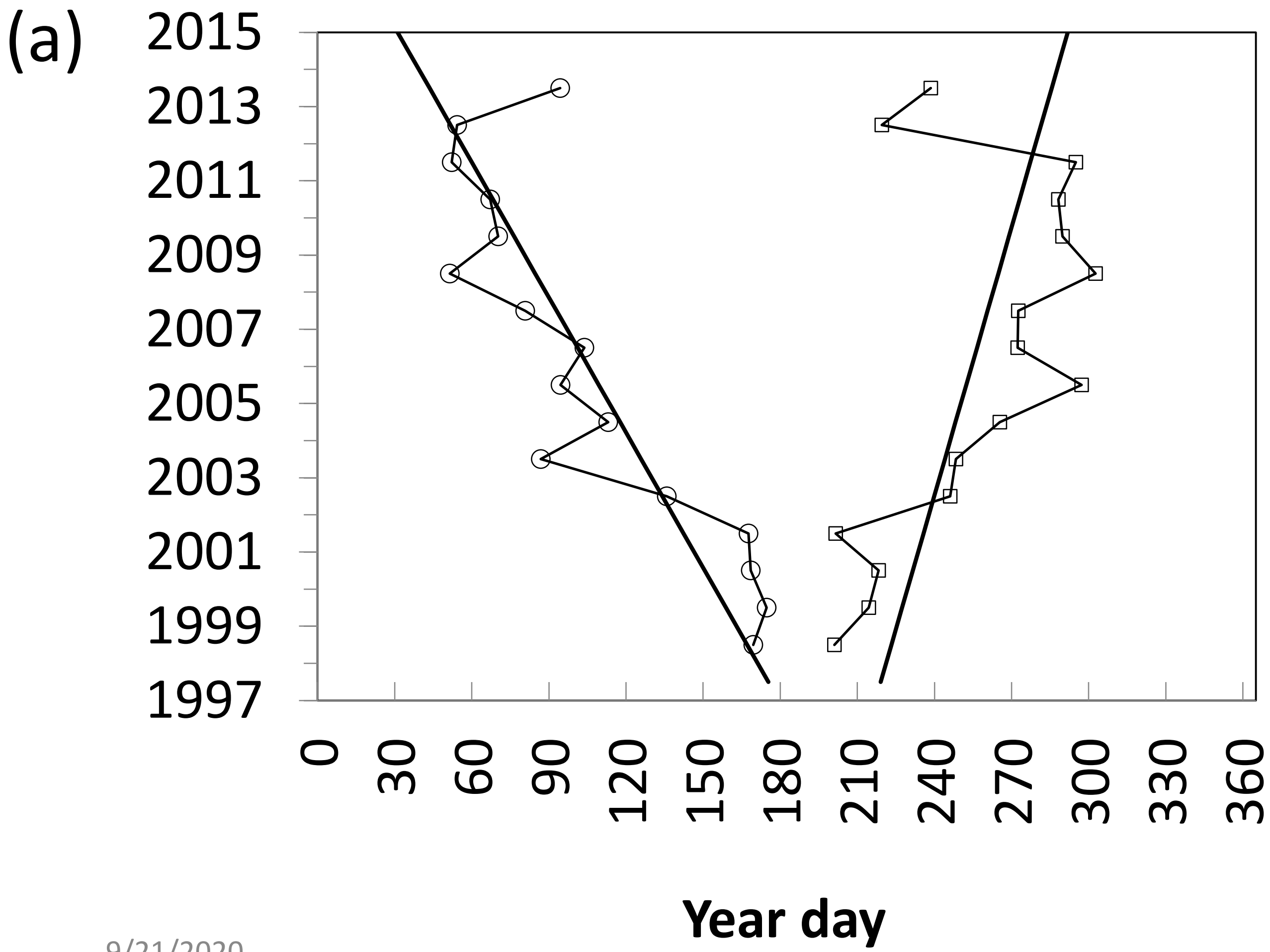


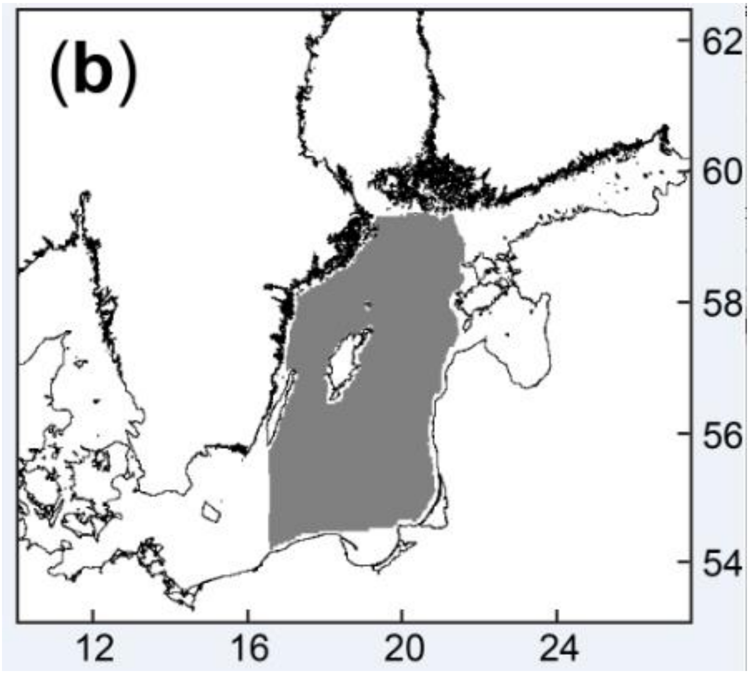
Trends in Ked490 phenology

Temporal changes in the start and end of Ked490 = 0.4 m^{-1} for the central Baltic Sea (area indicated in Figure 1b). The circles show the first day of the year (DFKED) and the squares show the last day of the year (DLKED) with the respective value of Ked490.

Turbid period has increased from <60 days to 240 days, 4x!

What does it mean for a fish?

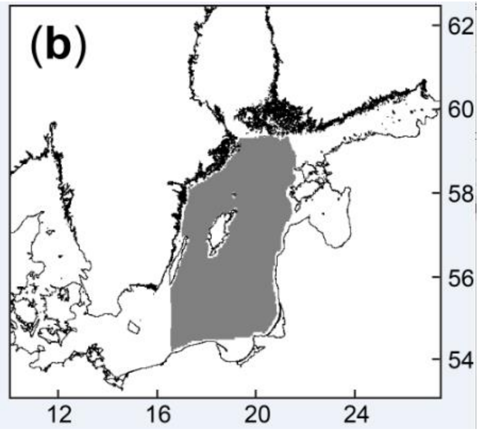


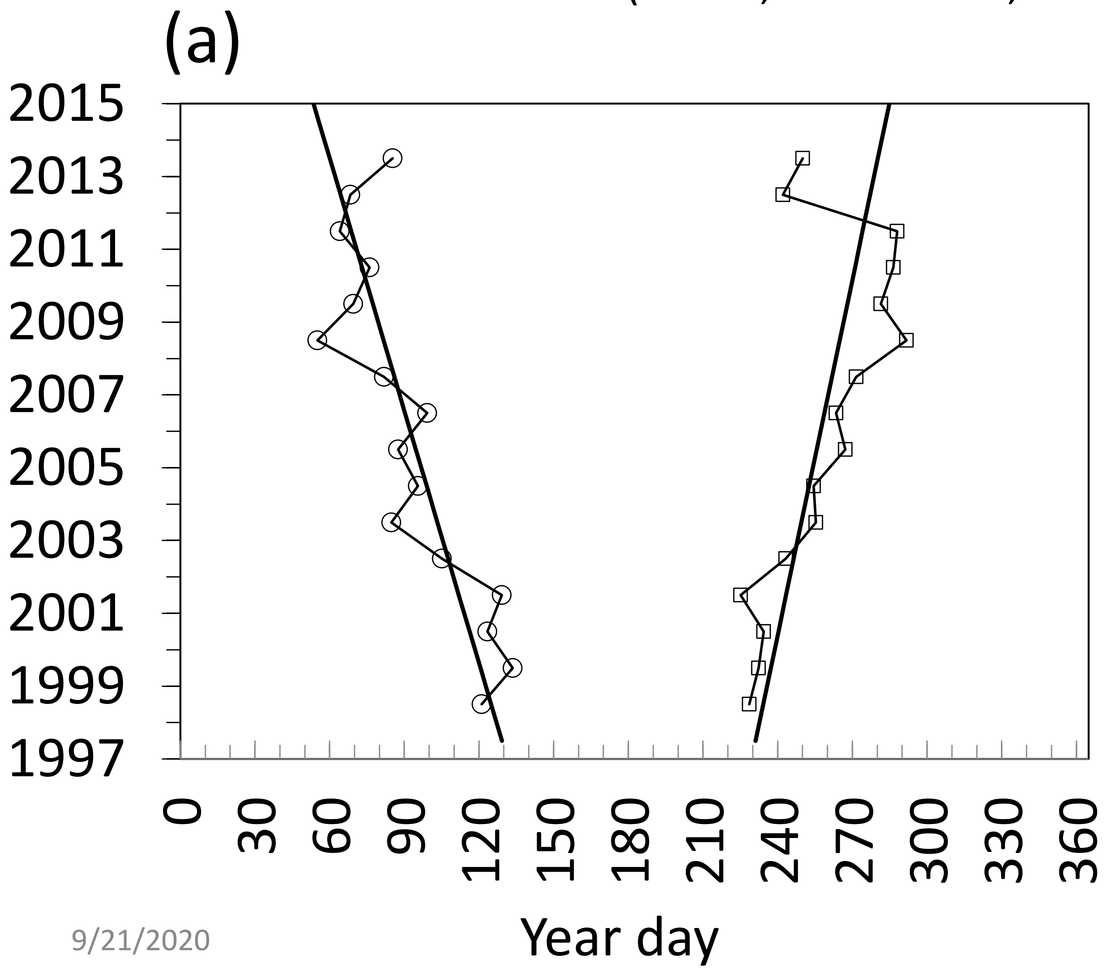


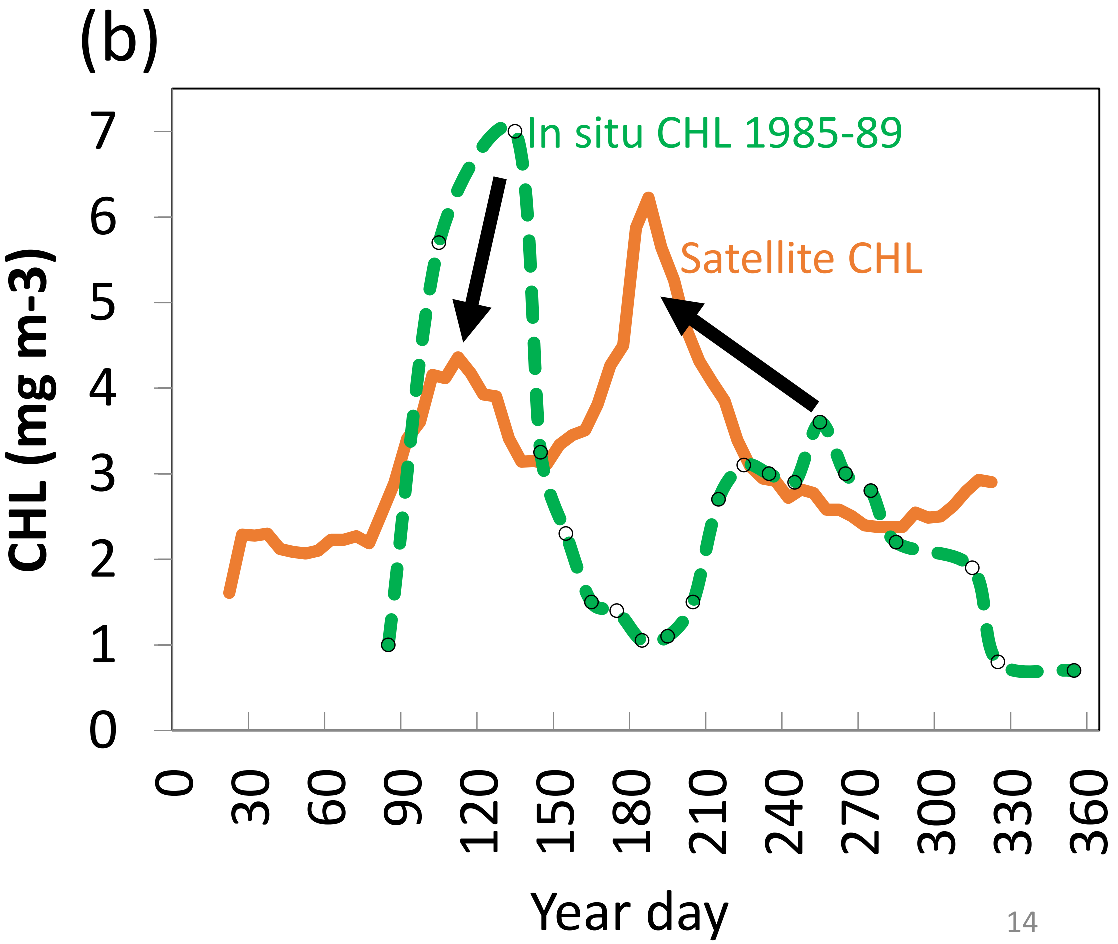
Trends in CHL phenology

(a) Temporal changes in the start and end of the "high chlorophyll season" (CHL >= 3 mg m^{-3}) in the Baltic Sea: day when CHL = 3.0 mg m^{-3} is reached first (DFCHL3, circles) and last (DLCHL3, squares) during the season.

(b) Mean annual cycle of CHL in central Baltic Sea for 1997-2013 (solid line) compared with CHL measured in situ in 1985-1989 (circles, dashed line, from Kahru et al., 1991). Max in May → July

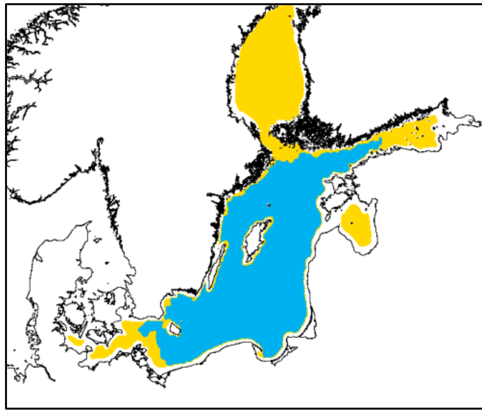


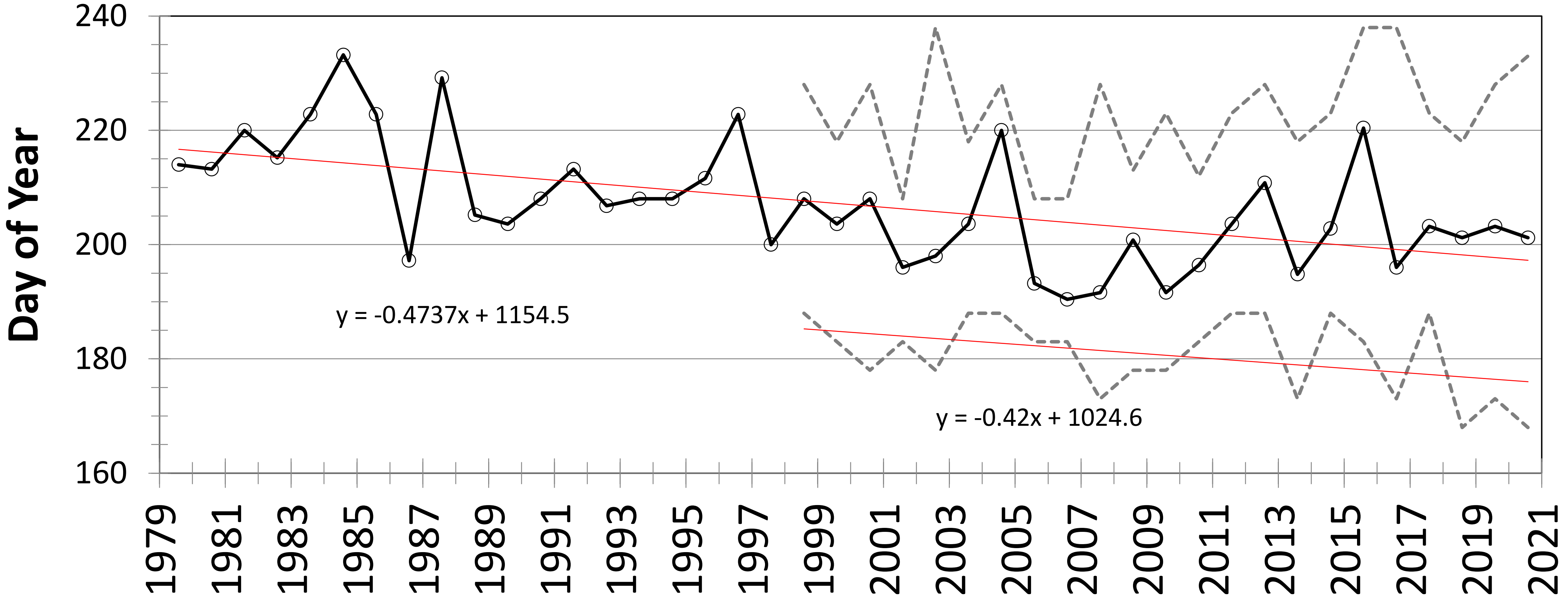




Timing of cyanobacteria accumulations

- Center of timing becoming earlier (1979->2020) but not since ~2006
- Duration becoming longer: starting earlier and lasting longer
- Shown: center of toming, start (first 10% percentile), end (last 90% percentile)
- Duration expanded (from ~day 160 = 06/08 or 06/09 to ~day 240 = 08/27 or 08/28)





Summary

- Phenological indicators are sensitive and can detect changes even when changes in absolute values are hardly detectable
- Some of the indicators, e.g. the duration of the growth season, have direct ecological significance. Timing also important for Match/mismatch between trophic interactions.
- The Baltic Sea has experienced drastic changes in the seasonality during the last decades in a many variables from physical to biological.
- For several ecologically important variables (Ked490, CHL) the length of the annual period of high values has increased by a factor of >2.
- The set of phenological indices can be applied to all kinds of variables but they are particularly suitable for satellite data that have consistent time interval and can be averaged over a spatial domain.

Some Conclusions

- The cumulative sum of 30K W m^{-2} of surface incoming shortwave irradiance (SIS) was reached **23 days earlier** in 2014 compared to 1983.
- The period with **SST ≥17 C has ~doubled** from 29 days in 1982 to 56 days in 2014. It's like the Baltic Sea has moved from Finland to Germany ☺
- The period of **low water transparency** (Ked490 over 0.4 m^{-1}) has increased from <60 days in 1998 to ~240 days in 2013, i.e. **4X**!
- The period of high satellite-detected **CHL (>3 mgm^{-3}) has doubled** from ~ 110 days in 1998 to 220 days in 2013.
- Both the phytoplankton **spring and summer blooms have become earlier**, and the annual CHL maximum may have switched from the spring bloom in the 1980s (in May) to the summer cyanobacteria bloom (in July).

THANK YOU!

Bothnian Sea 2020!

Niemi 1979: no cyano bloom due to N:P ratio