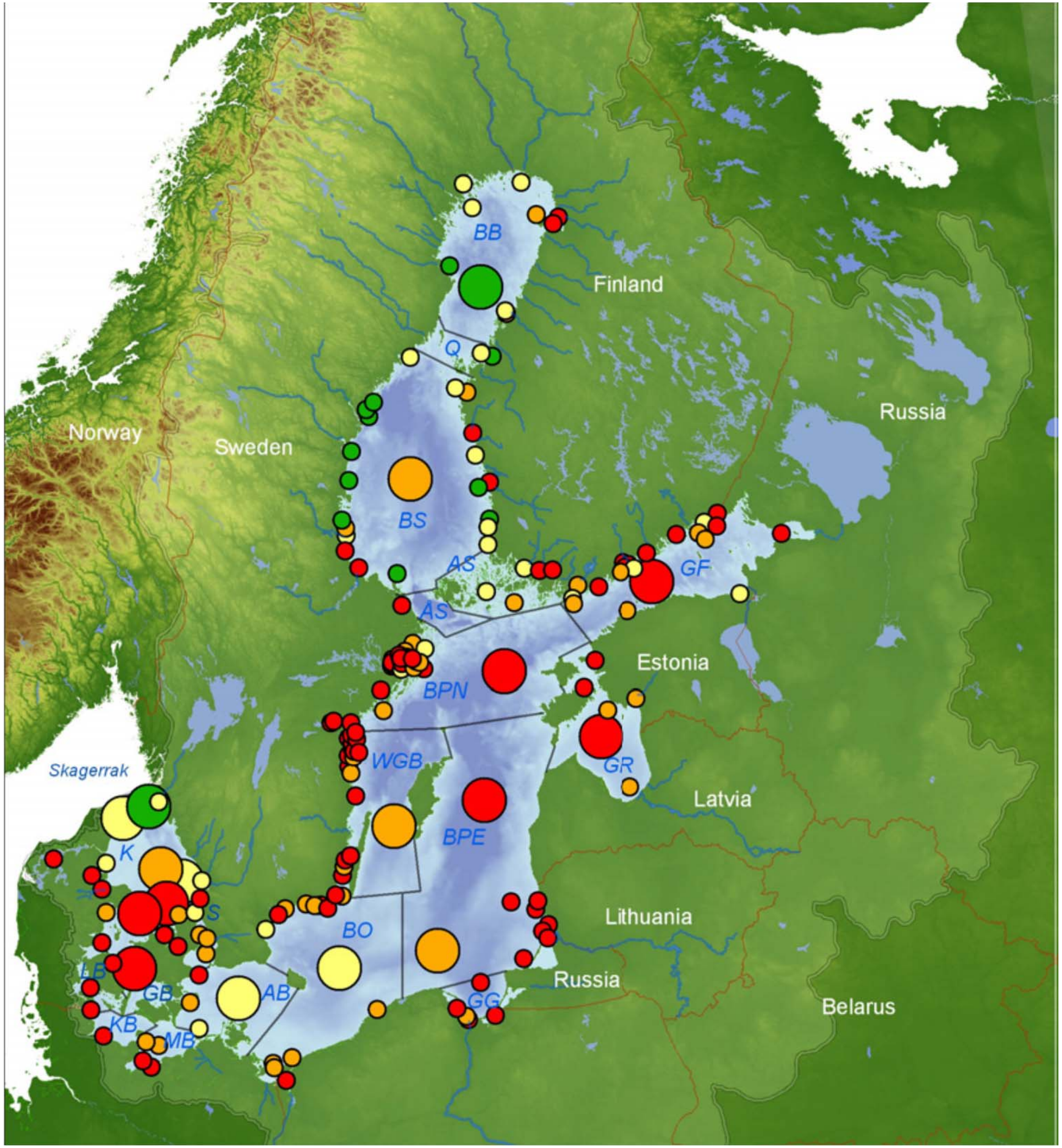
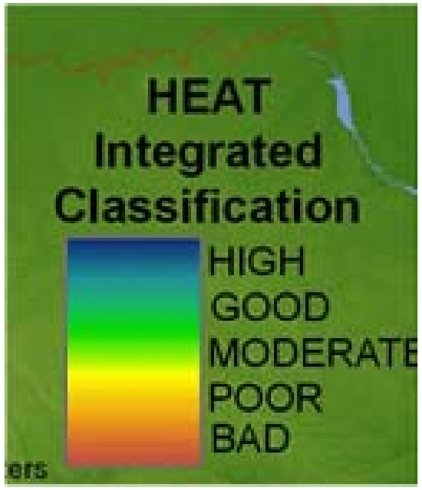
Origin and possible effets of episodic oxidezed nitrogen deposition events over the Baltic Sea

Marke Hongisto
Finnish Meteorological Institute





Current Eutrophication status
189 areas, 6 elements
High =blue: areas not affected
None of the places

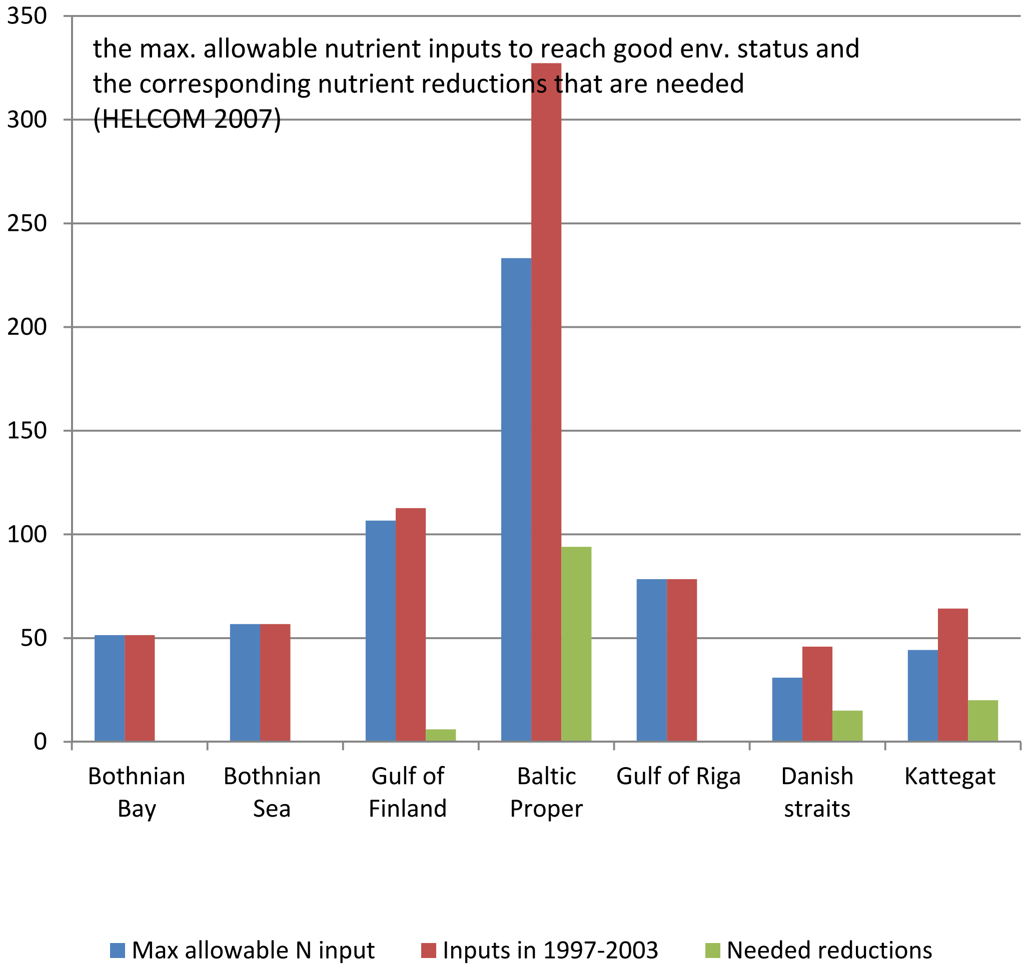
Large circles: open basins,
small circles coastal areas
or stations.HELCOM 2009

HELCOM: eutrophication is the
major problem of the BS
- Extensive algae blooms,
oxygen depletion, death of
benthic organisms, including
fish, decreased secci depth

25-30 % of nitrogen load
airborne

HELCOM Baltic Sea Action plan 2007

the maximum nutrient input to the Baltic Sea that can be allowed and still reach good environmental status with regard to eutrophication is about 21,000 tonnes of P and 600,000 tonnes of N (HELCOM 2007)



country-wise provisional nutrient reduction requirements:

Country	**Phosphorus (tonnes)**	**Nitrogen (tonnes)**
Poland	**8760**	**62400**
Sweden	**290**	**20780**
Denmark	**16**	**17210**
Lithuania	**880**	**11750**
Russia	**2500**	**6970**
Germany	**240**	**5620**
Latvia	**300**	**2560**
Finland	**150**	**1200**
Estonia	**220**	**900**
Transb. Common pool	**1660**	**3780**

Tool: The Hilatar model

numerical solution of the transport equation

$$\frac{\partial}{\partial t} c(\vec{x},t) + [\nabla \bullet \vec{V}(\vec{x},t)c(\vec{x},t)] = \nabla \bullet K(\vec{x},t)c(\vec{x},t) + S(\vec{x},t)$$

A nested dynamic 3D model Hilatar
Covering Europe and the Baltic Sea area

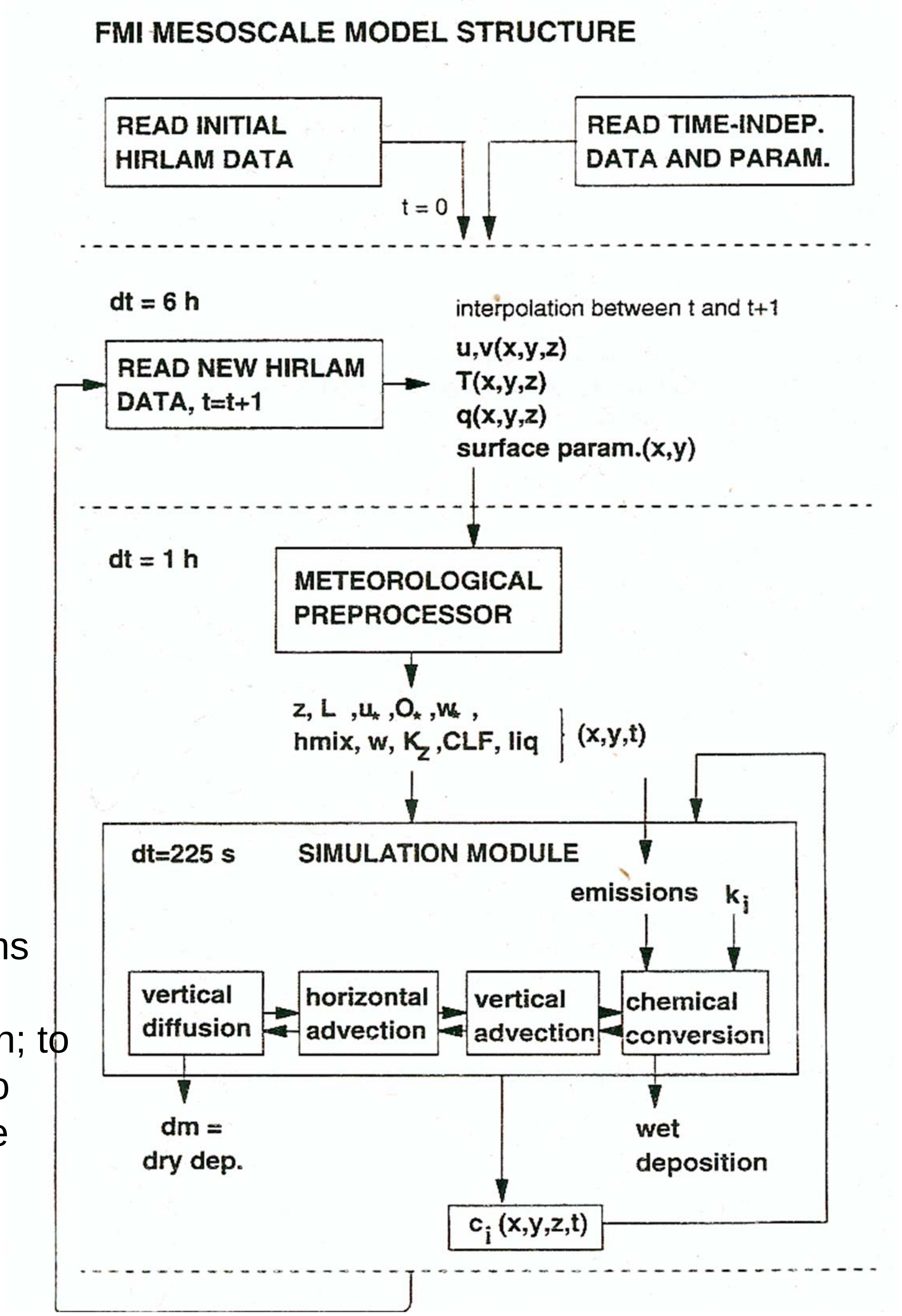
Nitrogen, sulphur and ammonium chemistry
HIRLAM grid (rotated spherical – hydrid)

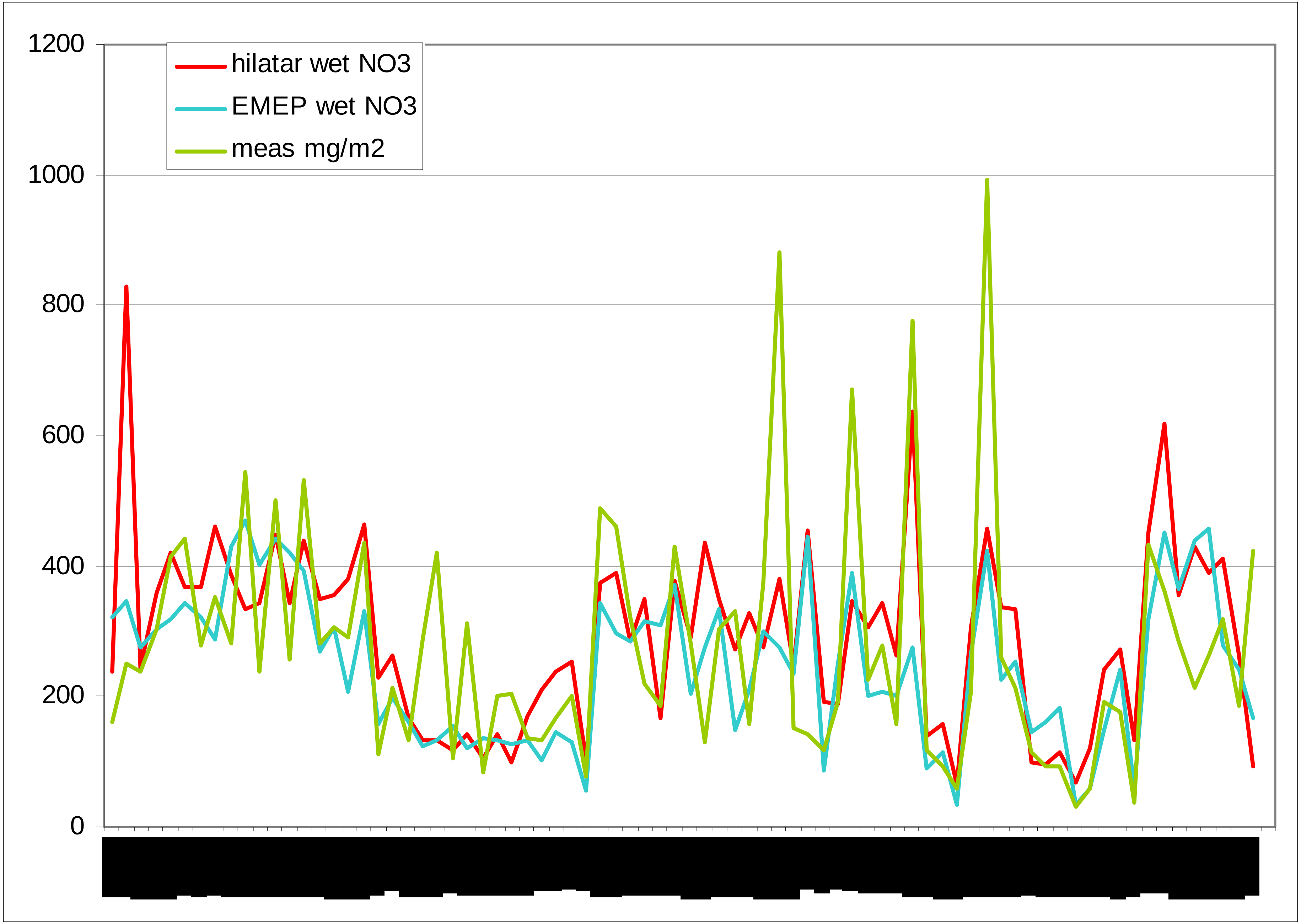
0.5º … 0.068º horizontal grid; top ~10 km;
Up to 17 vertical layers below 2 km

Non backgroud from a global model
Acid compound chemistry,

Has been used for source receptor calculations for the BS traffic; EMEP uses this method for individual coutries; time-consuming appproach; to find the places where its might be important to reduce emissions backward simulations of the biggest deposition event has bees performed

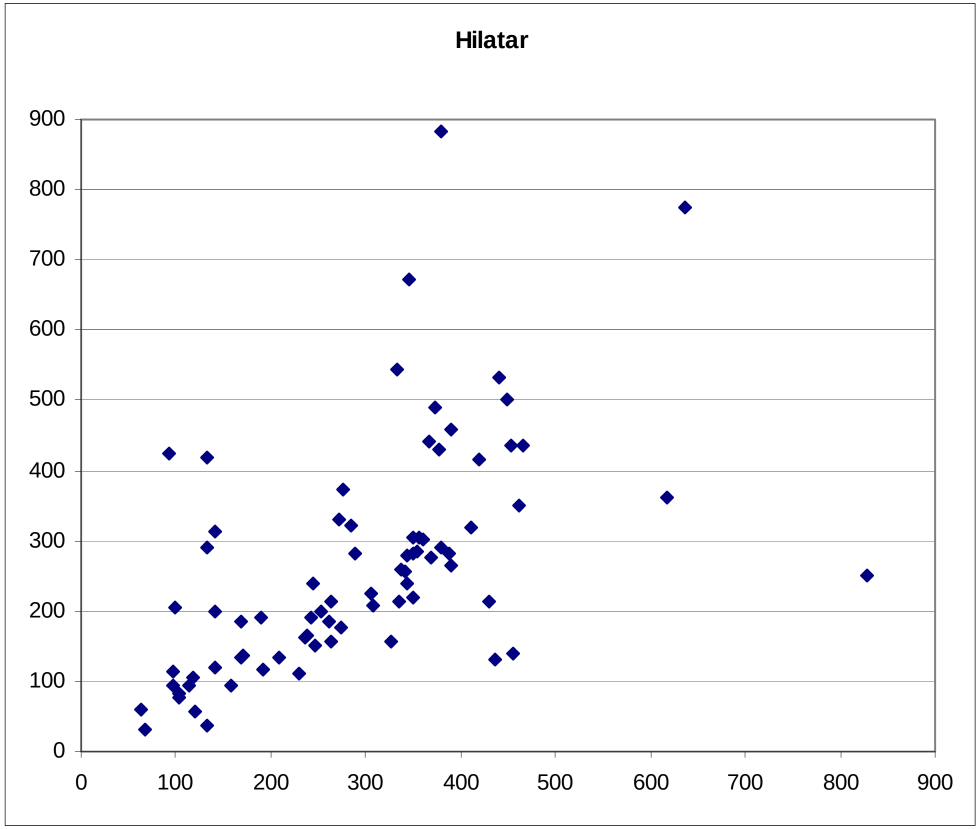
http://lib.hut.fi/Diss/2003/isbn9512264811/index.html

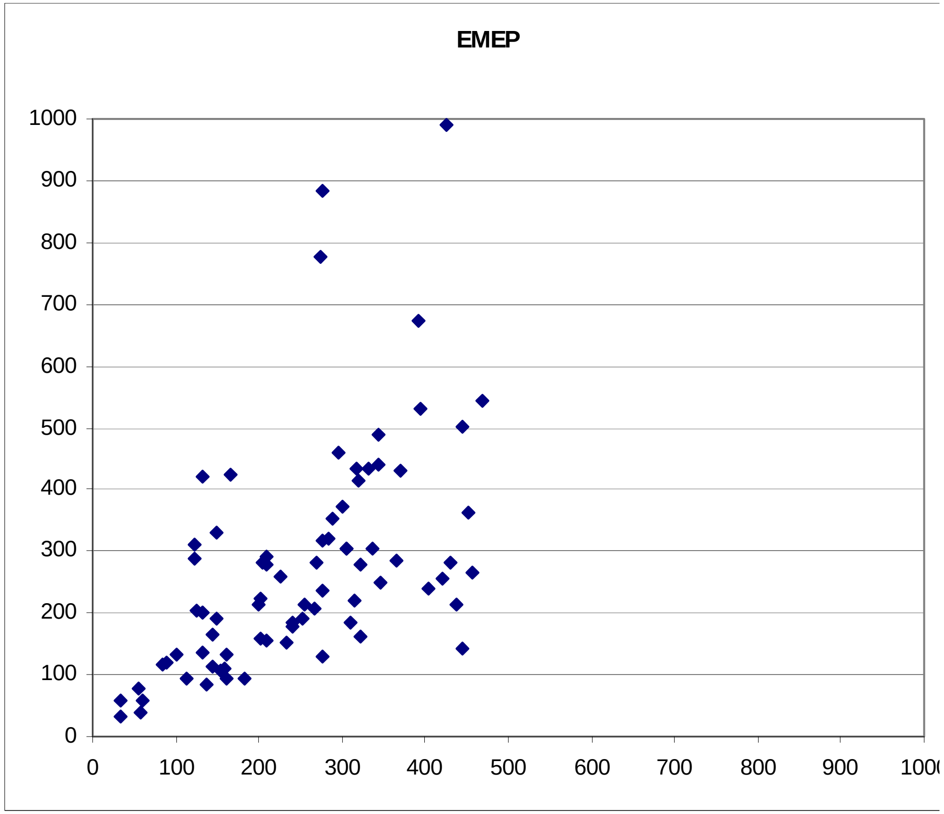


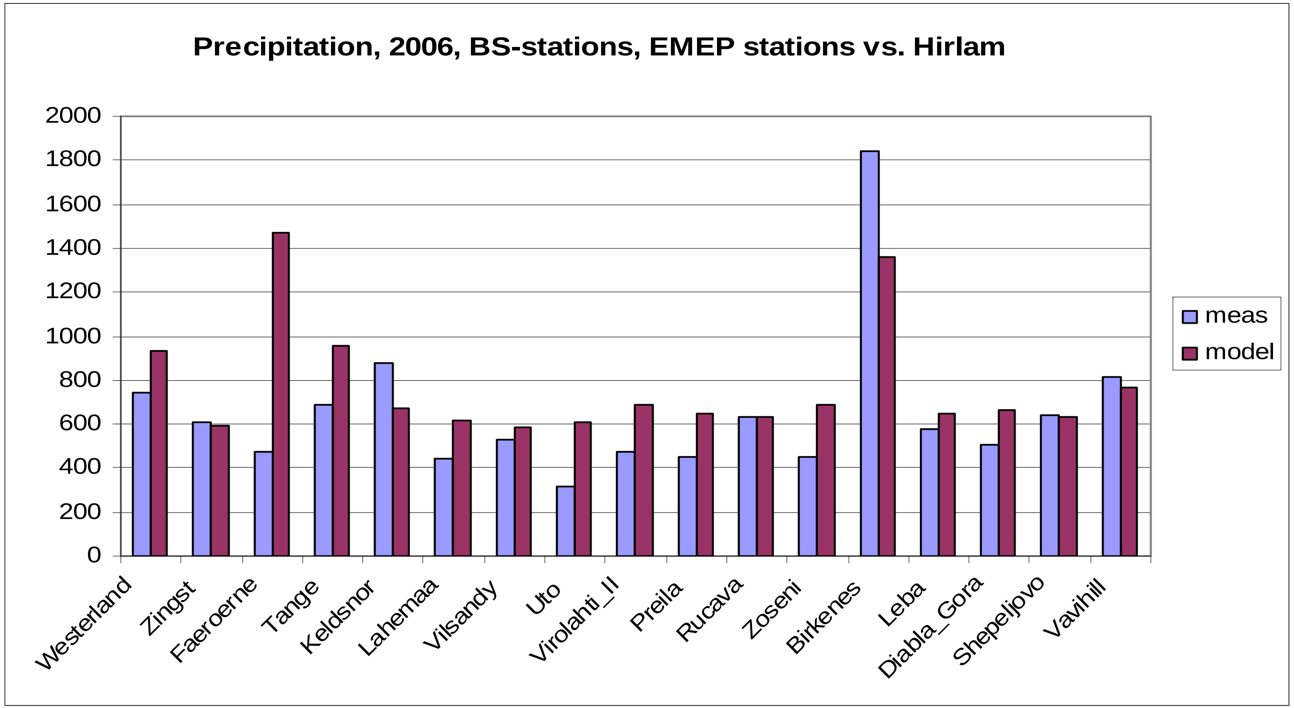

1200
1000
800
600
400
200
0
hilatar wet NO3
EMEP wet NO3
meas mg/m2

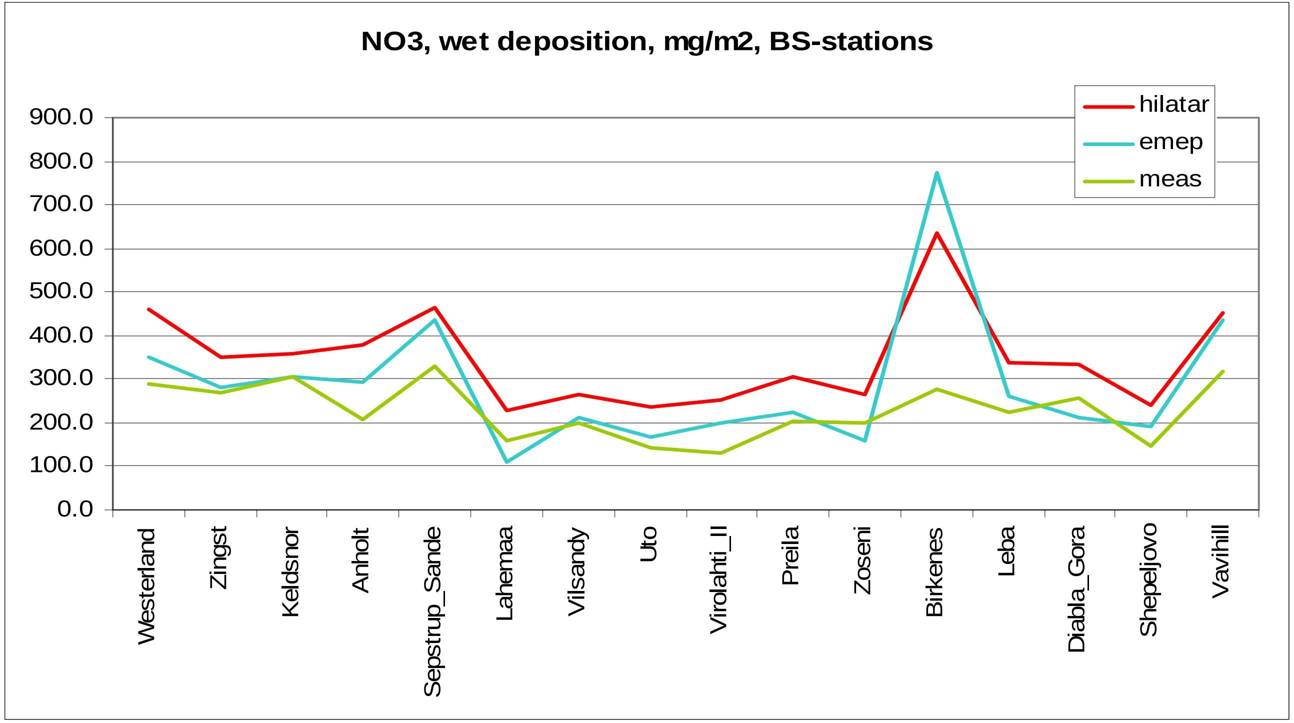
[redacted]

Model-measurement, NO3 wet deposition, 2006, Hilatar and EMEP

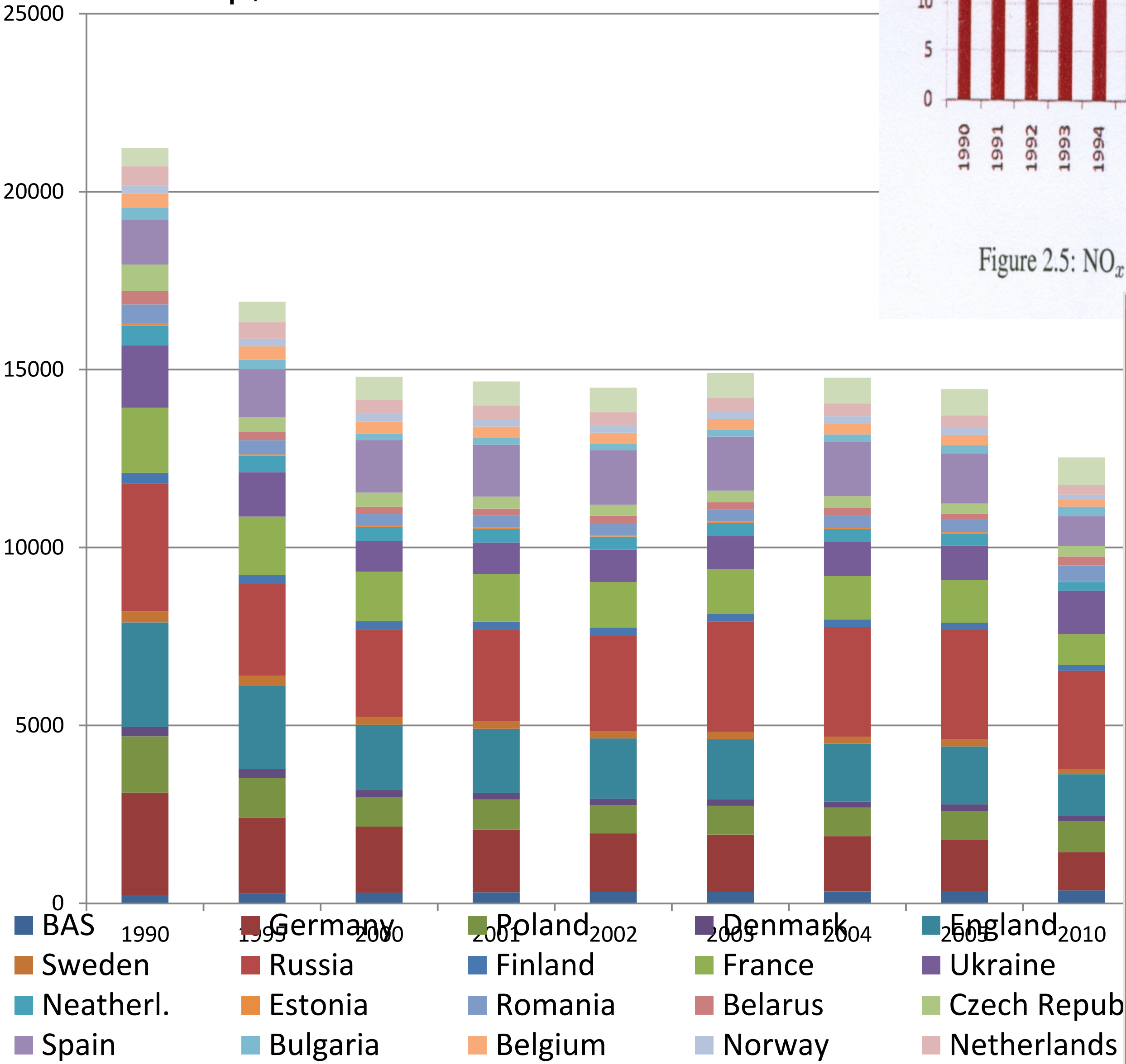





Precipitation, 2006, BS-stations, EMEP stations vs. Hirlam


NO3, wet deposition, mg/m2, BS-stations

Model input: Europe: 50 x 50 km2 EMEP-NOx emissions, trend:
countries contributing to BS dep; 1990-2010,
www.emep,emission-DB



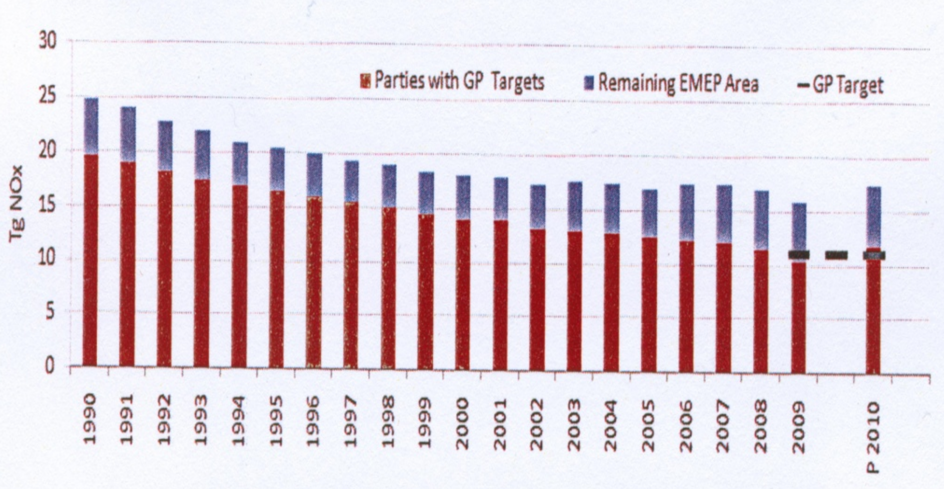
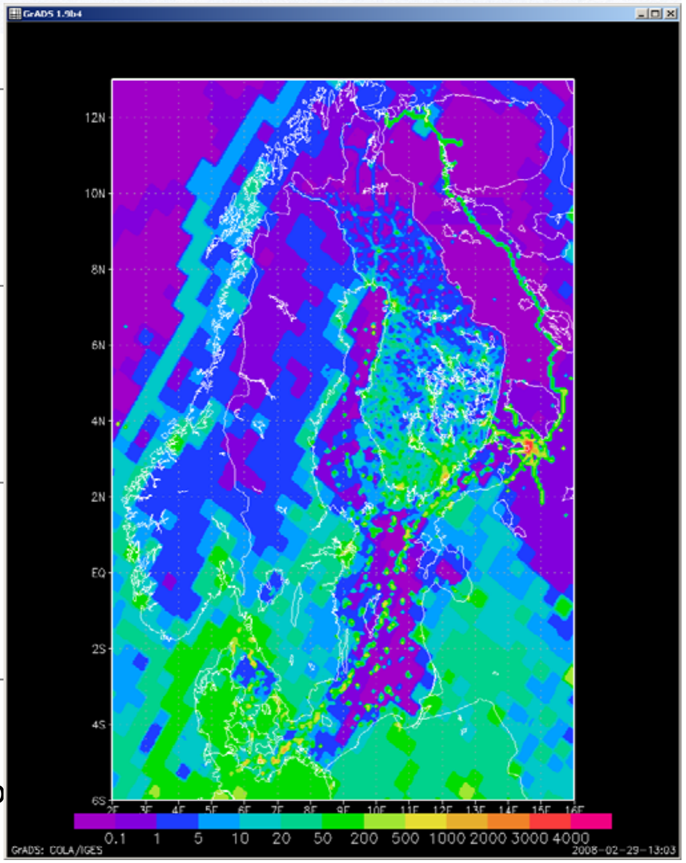
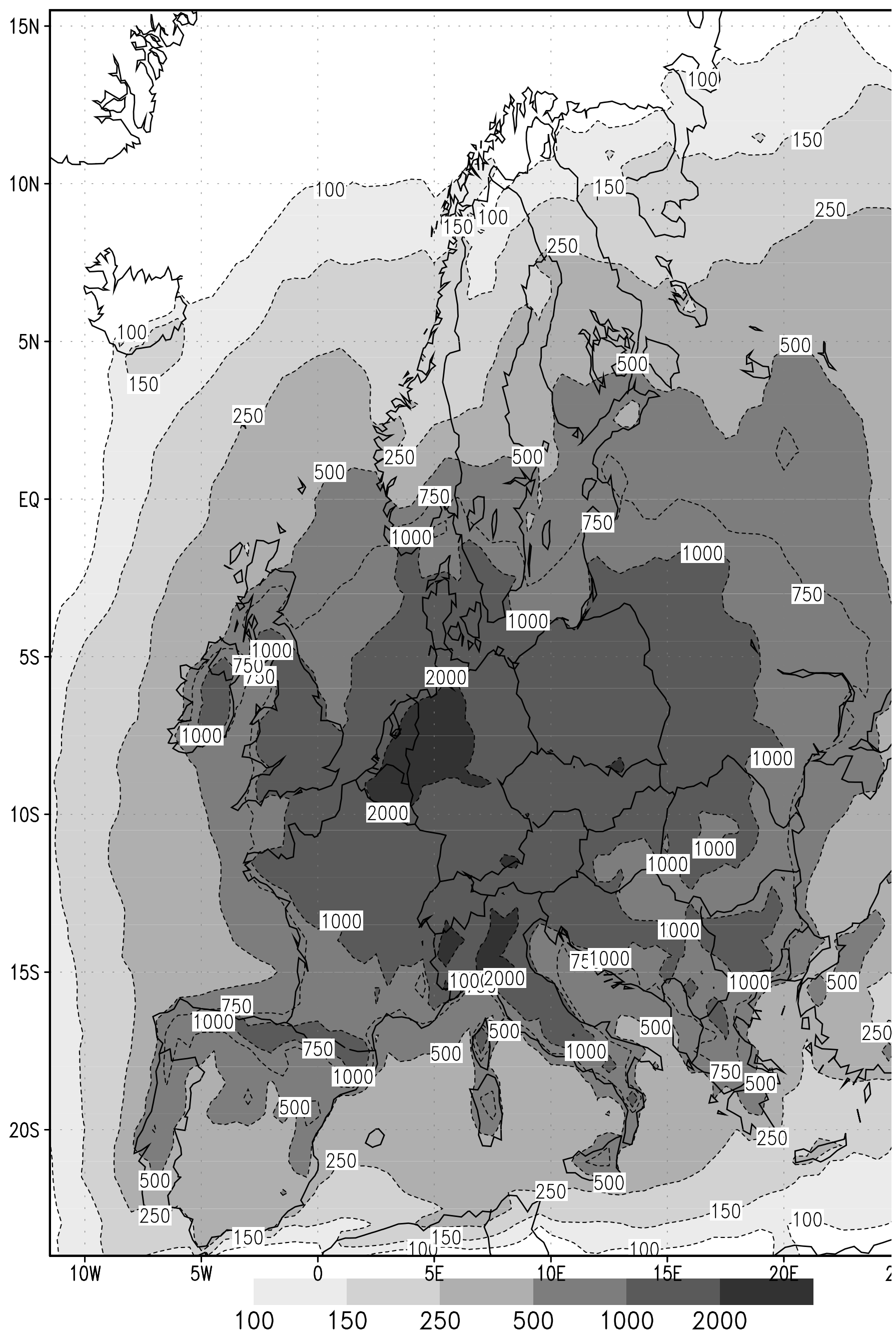
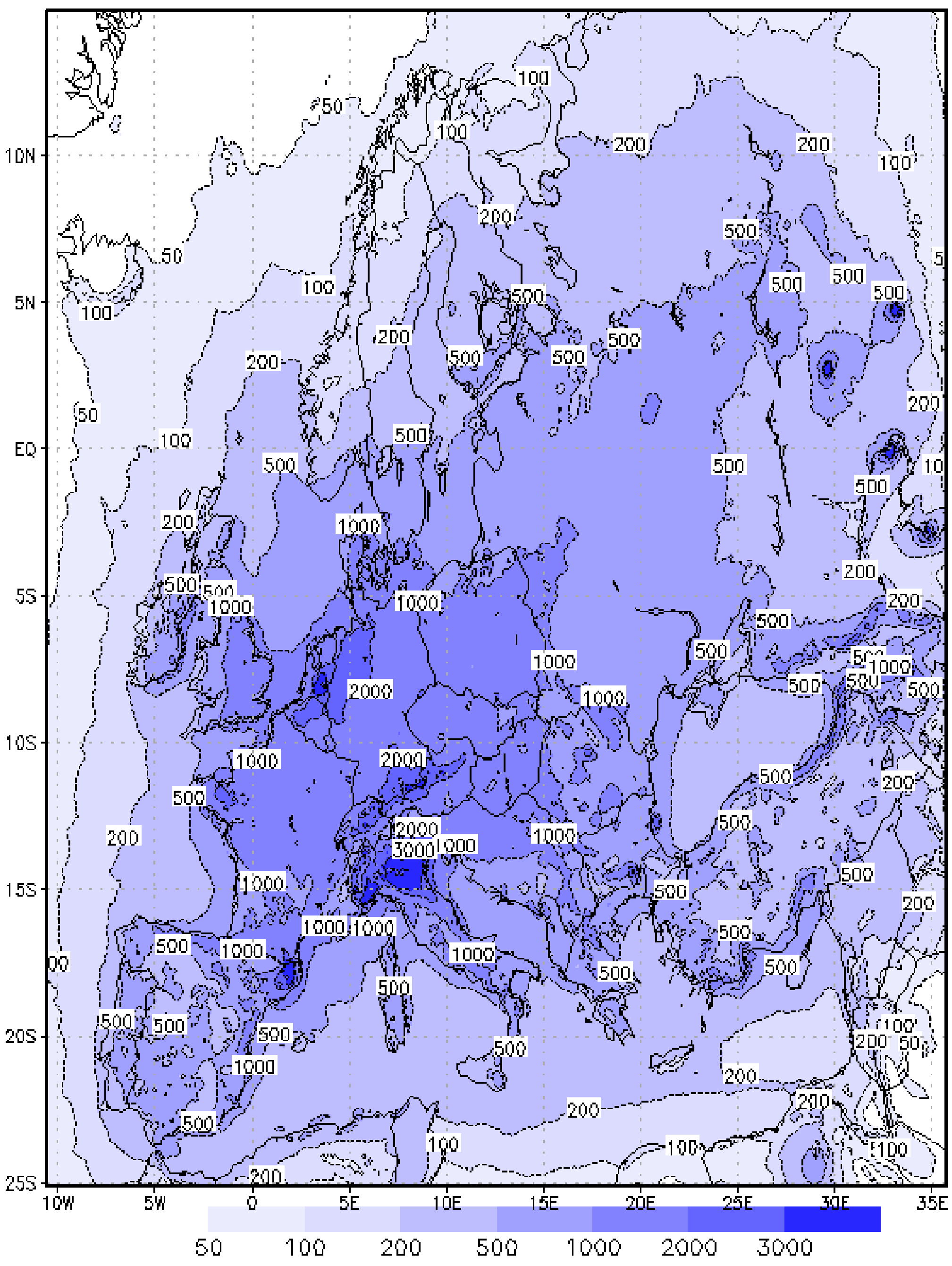


Figure 2.5: NO_x emission trends and distance to GP target in EMEP area.

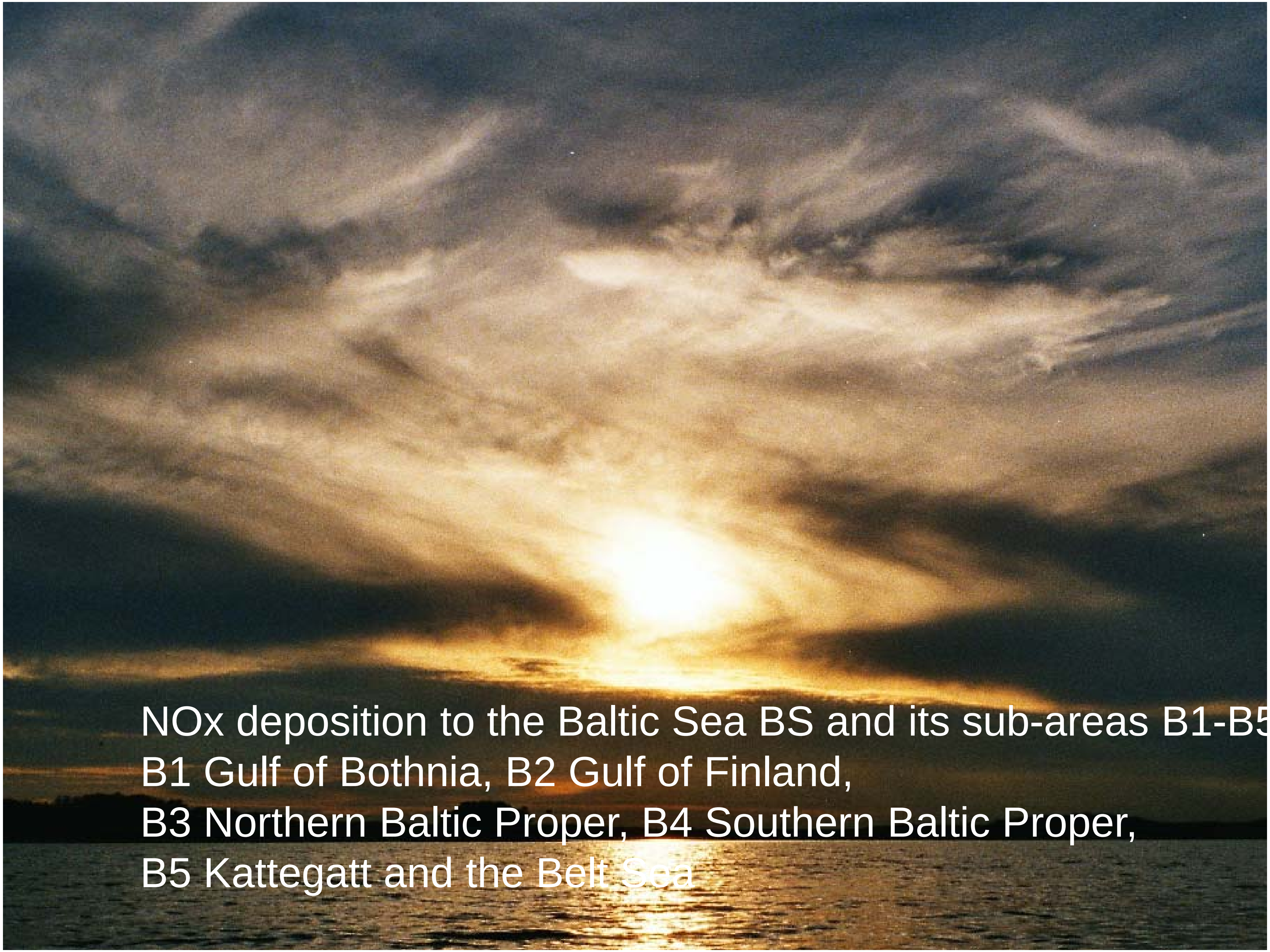




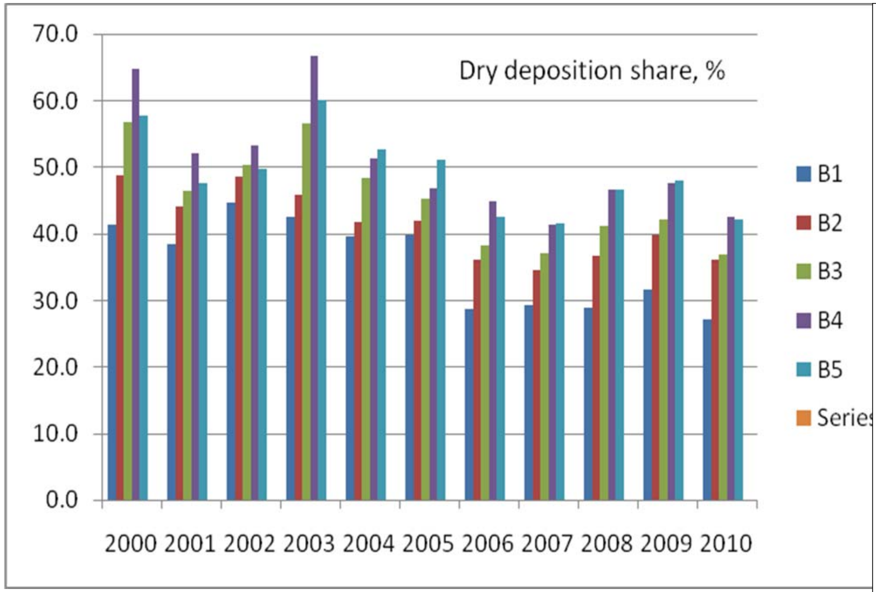
N deposition, mg(N) m-2, 1996-1998 avera

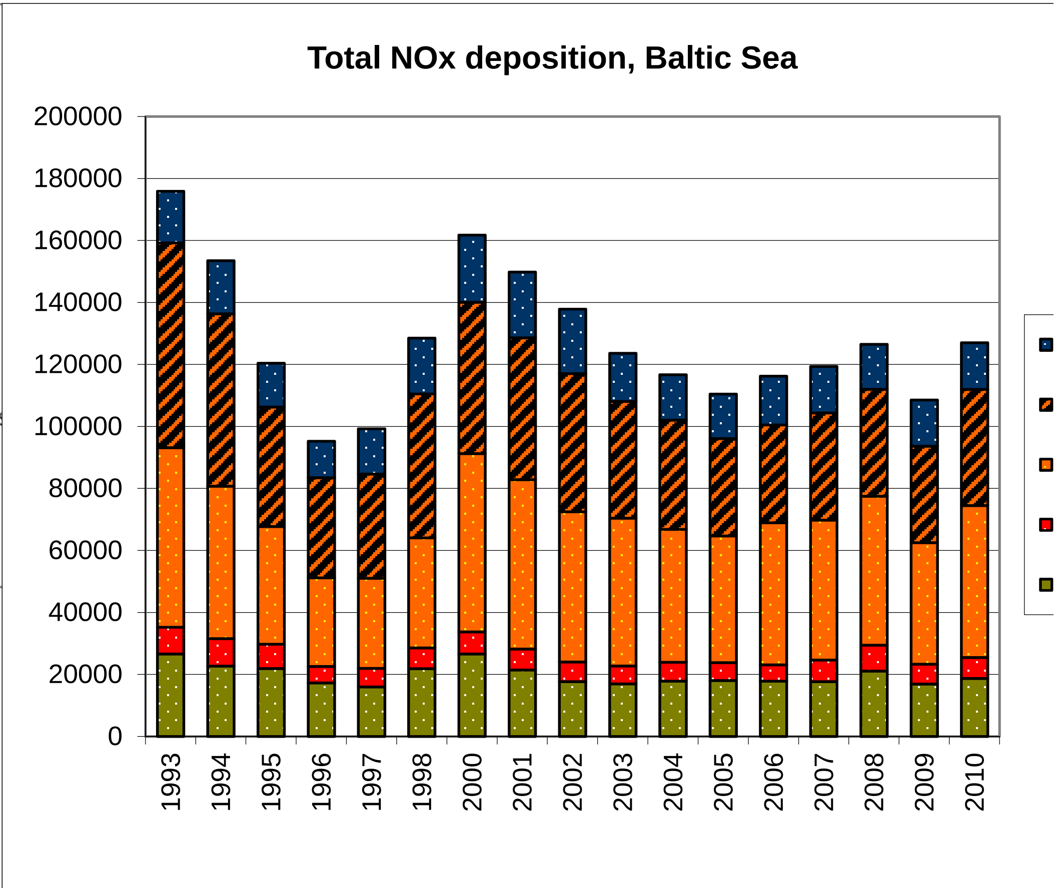


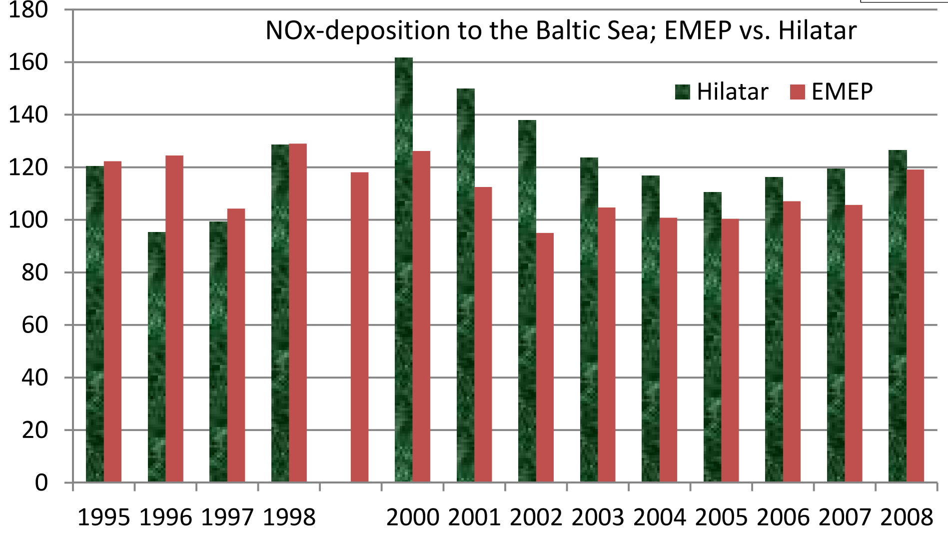
Total N deposition, mg(N) m-2, 2010



NOx deposition to the Baltic Sea BS and its sub-areas B1-B5
B1 Gulf of Bothnia, B2 Gulf of Finland,
B3 Northern Baltic Proper, B4 Southern Baltic Proper,
B5 Kattegatt and the Belt Sea



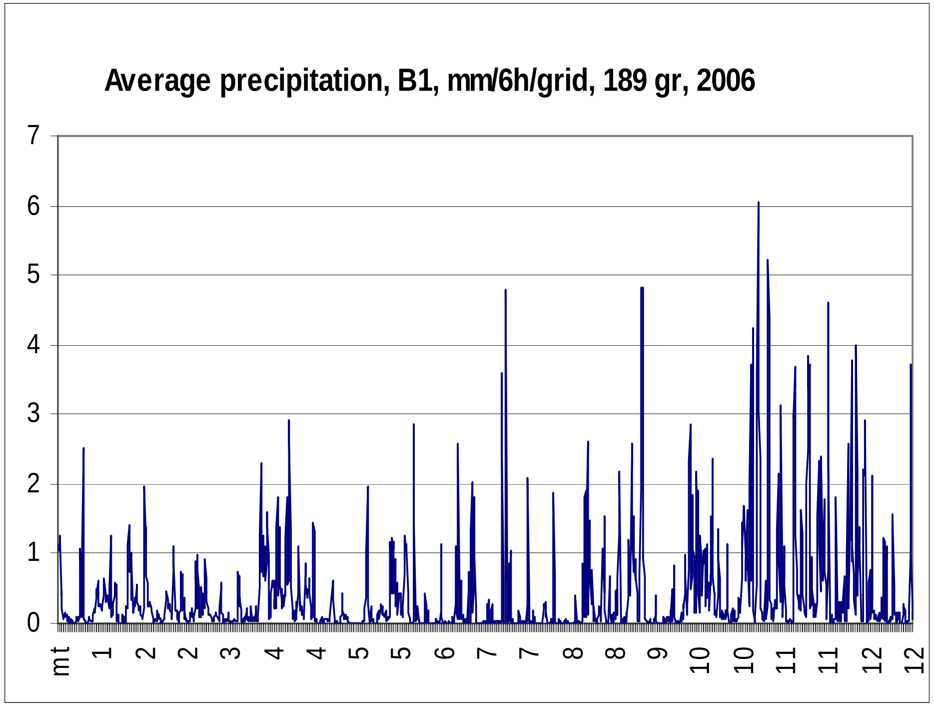




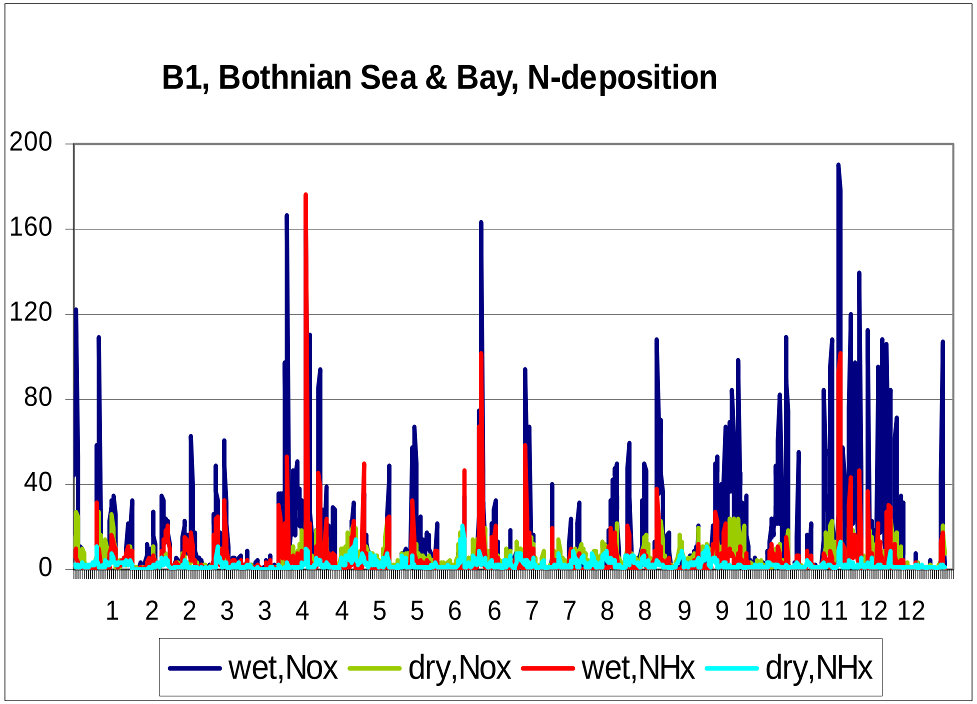
EMEP-values:
Bartnicki J., 2010. Nitrogen deposition to the Baltic Sea area. HELCOM Indicator Fact Sheets 2010 http://www.helcom.fi/environment2/ifs/en_GB/cover/.

HILATAR deposition to the BS is 6-12 % higher in 2005-2008;
EMEP-model underpredicts nitrate in precipitation by 14-15 %

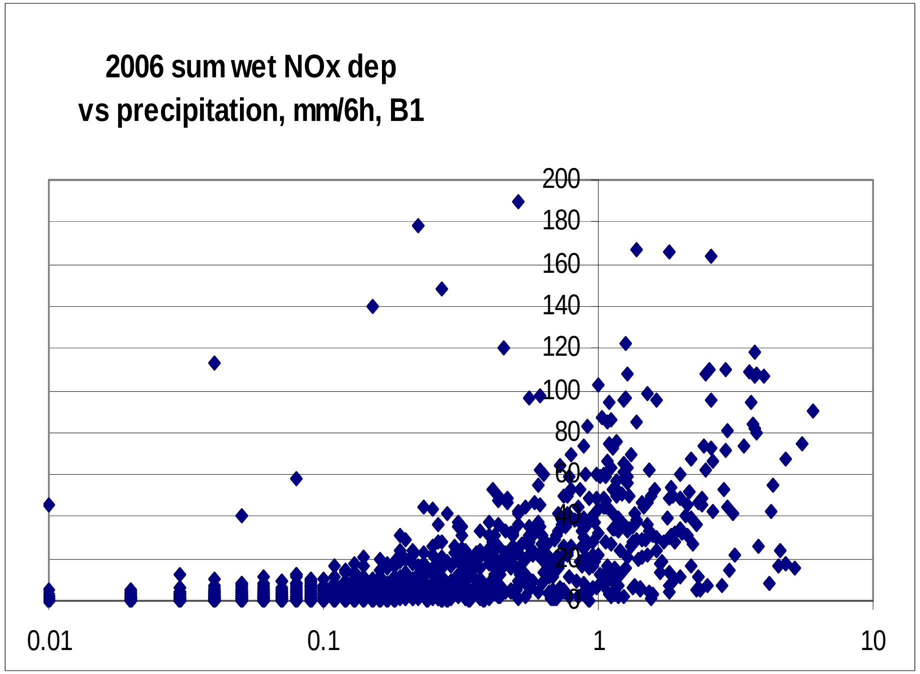
Grid structure, dry deposition velocities numerical methods etc. have an effect



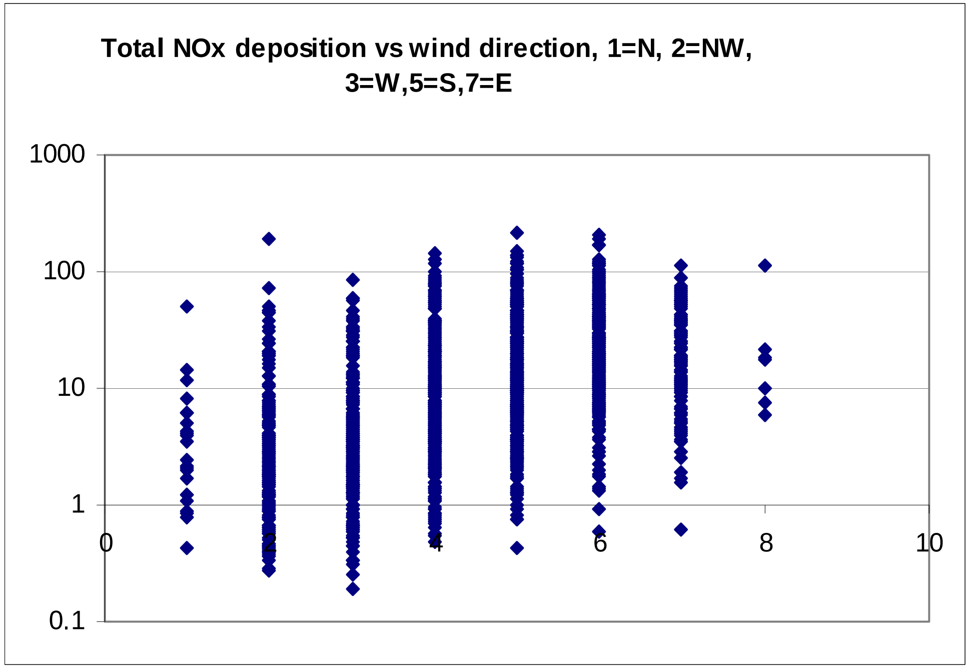
Average precipitation, B1, mm/6h/grid, 189 gr, 2006



B1, Bothnian Sea & Bay, N-deposition



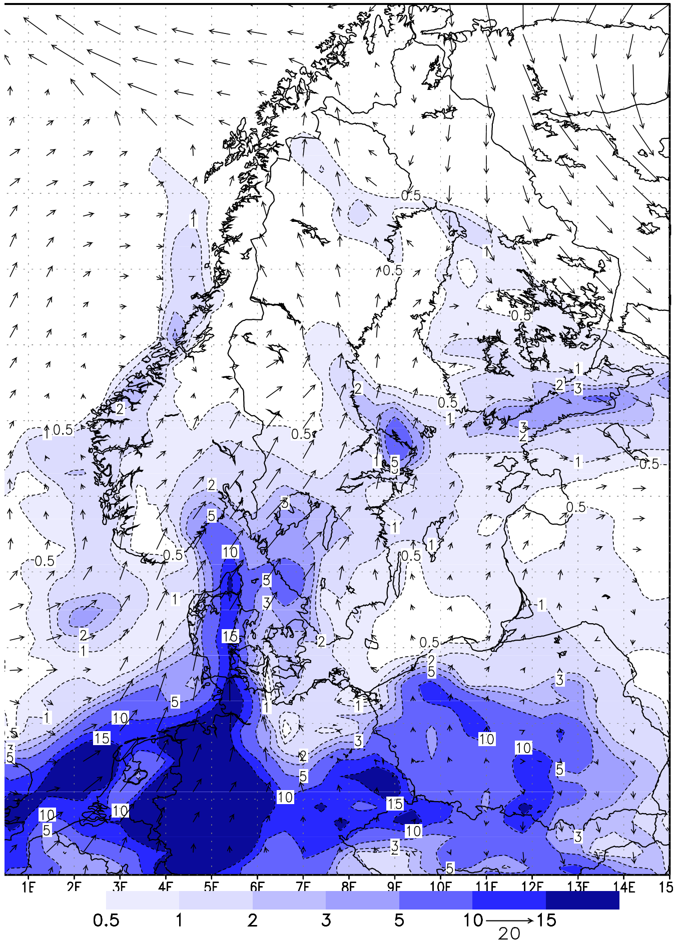
2006 sum wet NOx dep
vs precipitation, mm/6h, B1



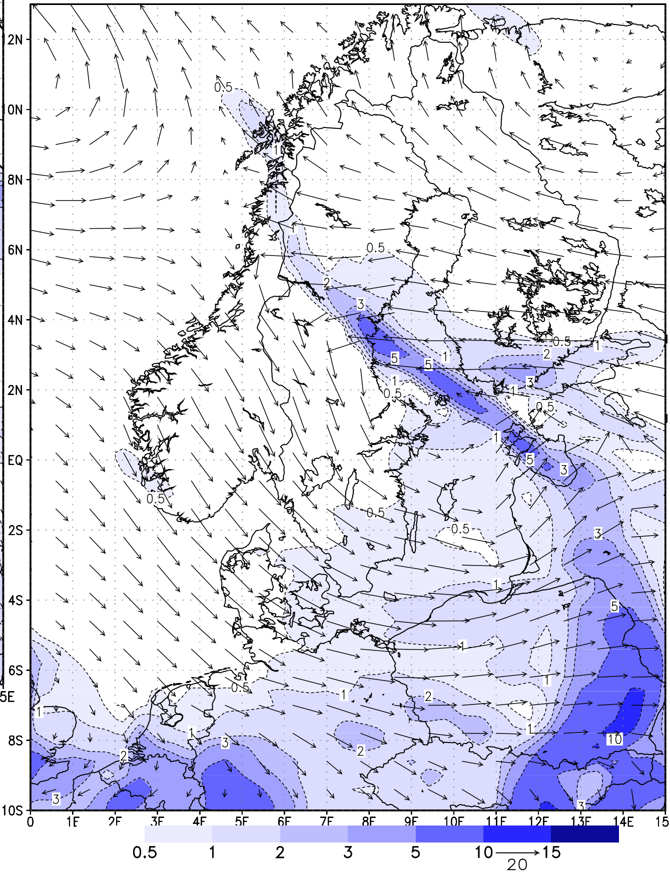
Total NOx deposition vs wind direction, 1=N, 2=NW, 3=W,5=S,7=E

LRT-Case: Effect of storms on deposition, August 2001

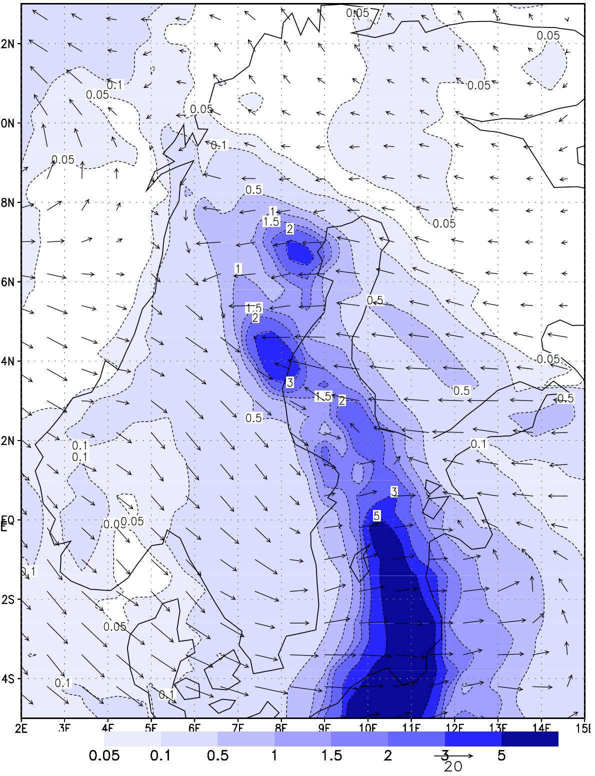
NOx+HNO3+NO3+PAN, ug/m3 26 00

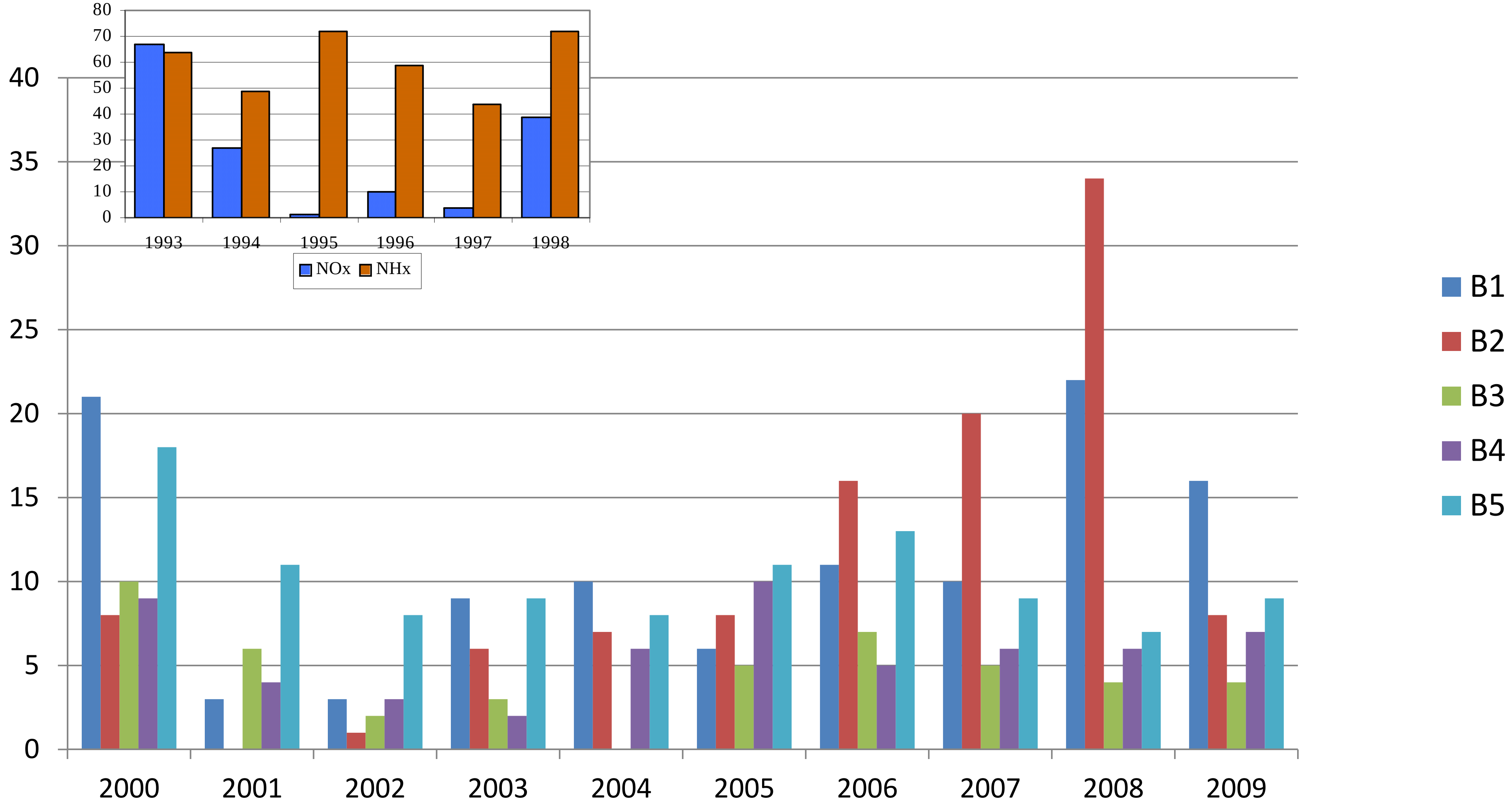


NOx+HNO3+NO3+PAN, ug/m3 28 00

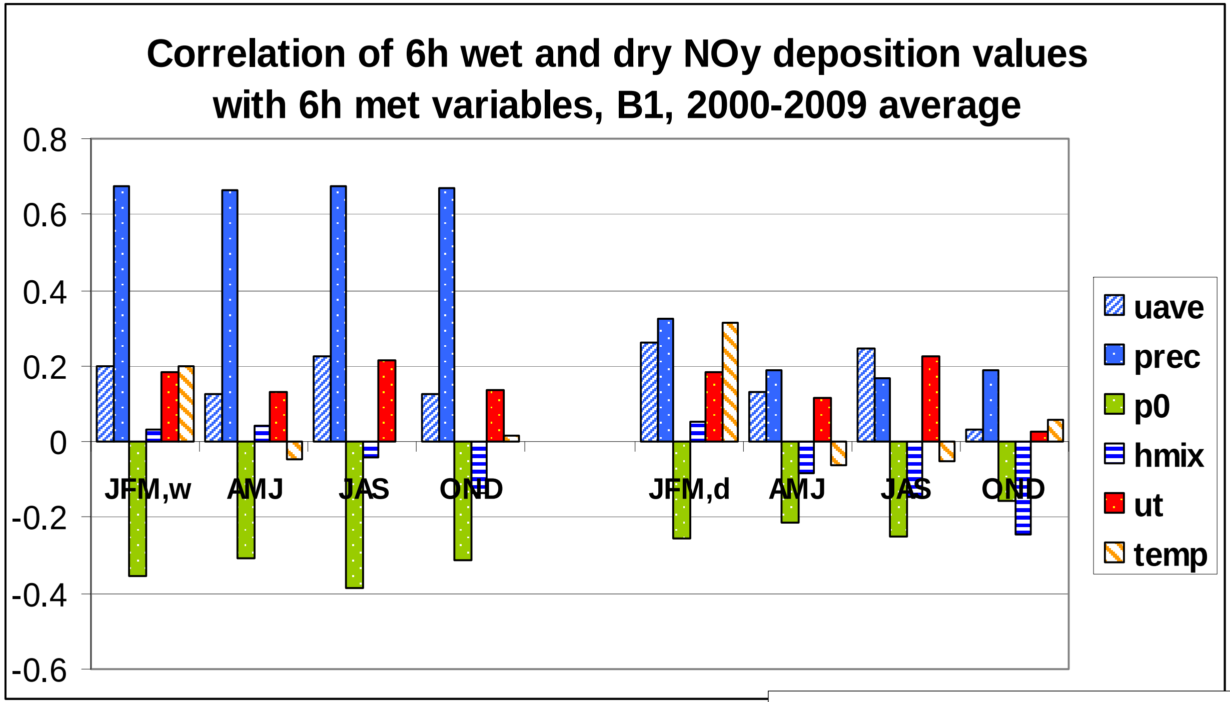


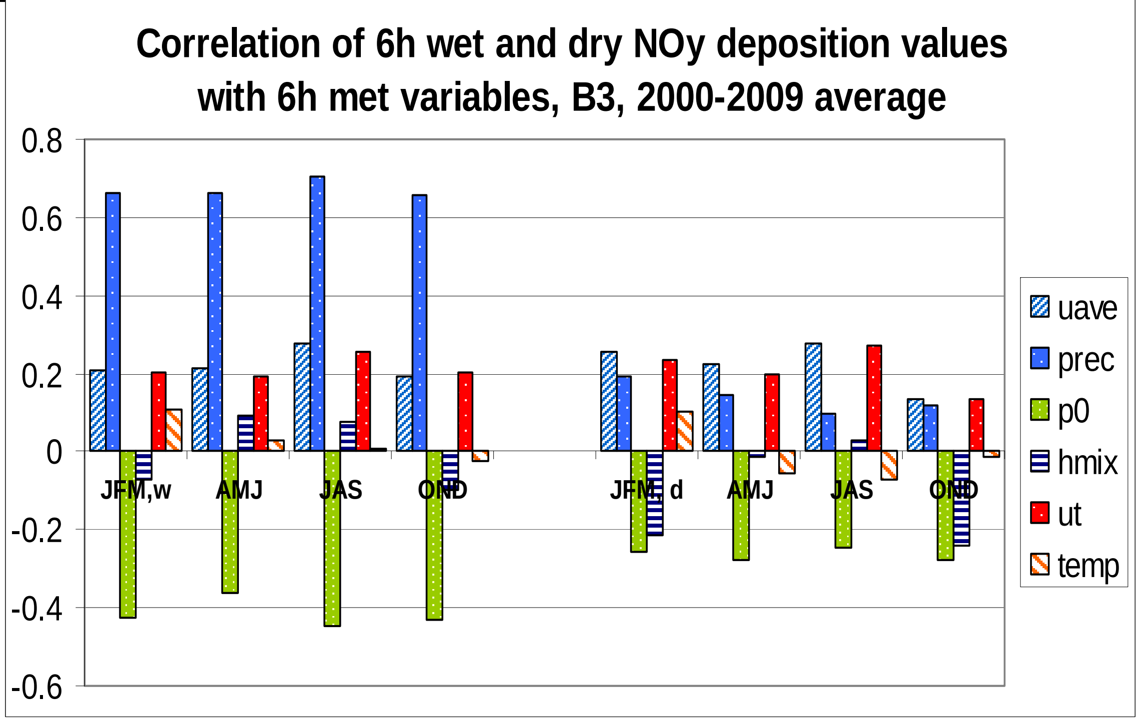
NOx deposition, mg/m2 in 6 hours 27 18

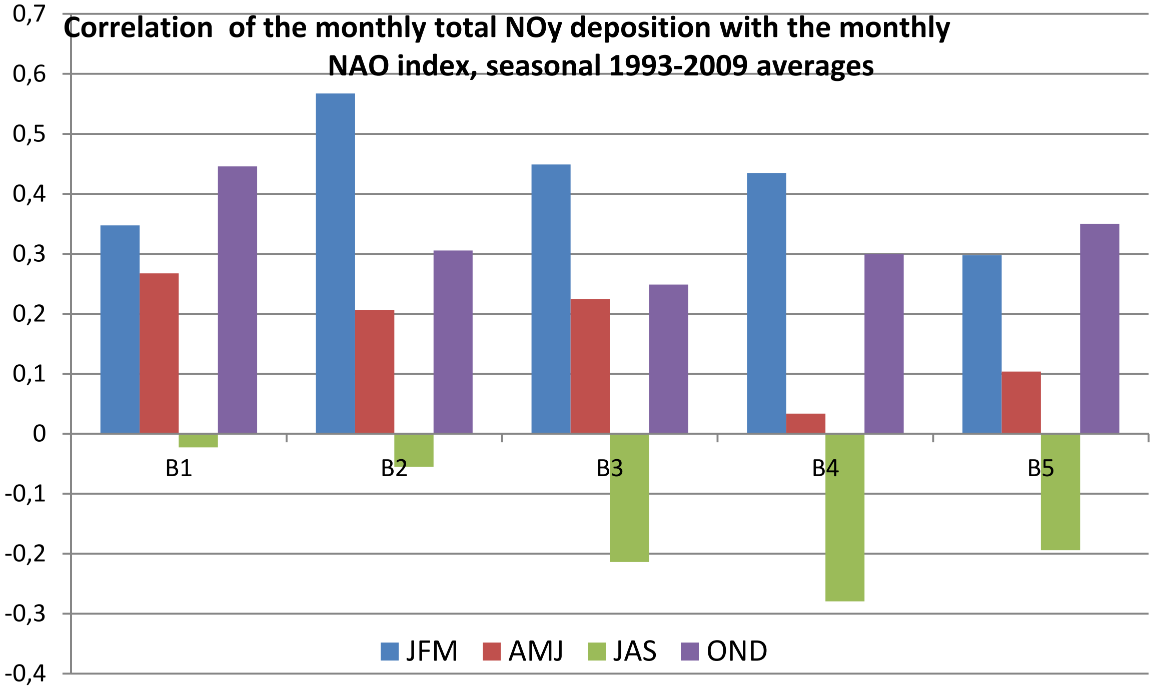


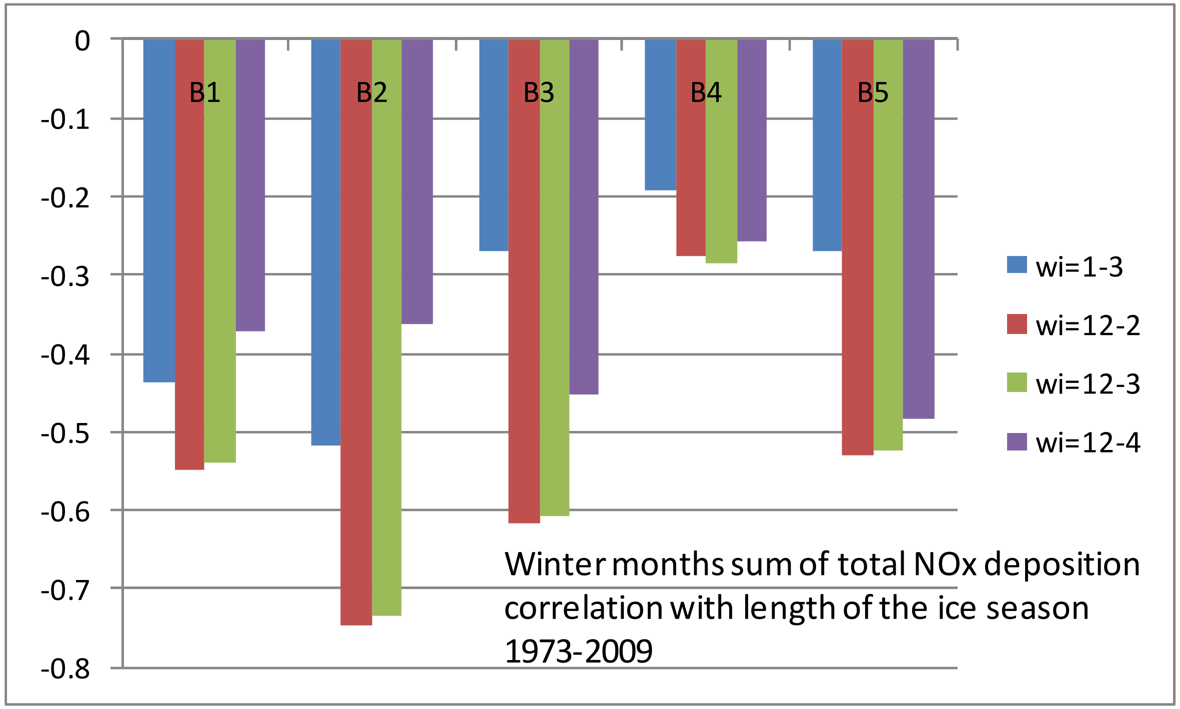


Number of wet episodes (6h deposition of sub-basin Bi exceeding the respective 10-year average monthly value by 10-fold) 2000-2009/ Number of high deposition episodes exceeding 400 kg (6h)-1 for NOx and 100 kg (6h)-1 for NHx 1993-1998


Correlation of 6h wet and dry NOy deposition values
with 6h met variables, B1, 2000-2009 average
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
JFM,w
AMJ
JAS
OND
JFM,d
AMJ
JAS
OND
uave
prec
p0
hmix
ut
temp


Correlation of 6h wet and dry NOy deposition values
with 6h met variables, B3, 2000-2009 average
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
JFM,w
AMJ
JAS
OND
JFM, d
AMJ
JAS
OND
uave
prec
p0
hmix
ut
temp

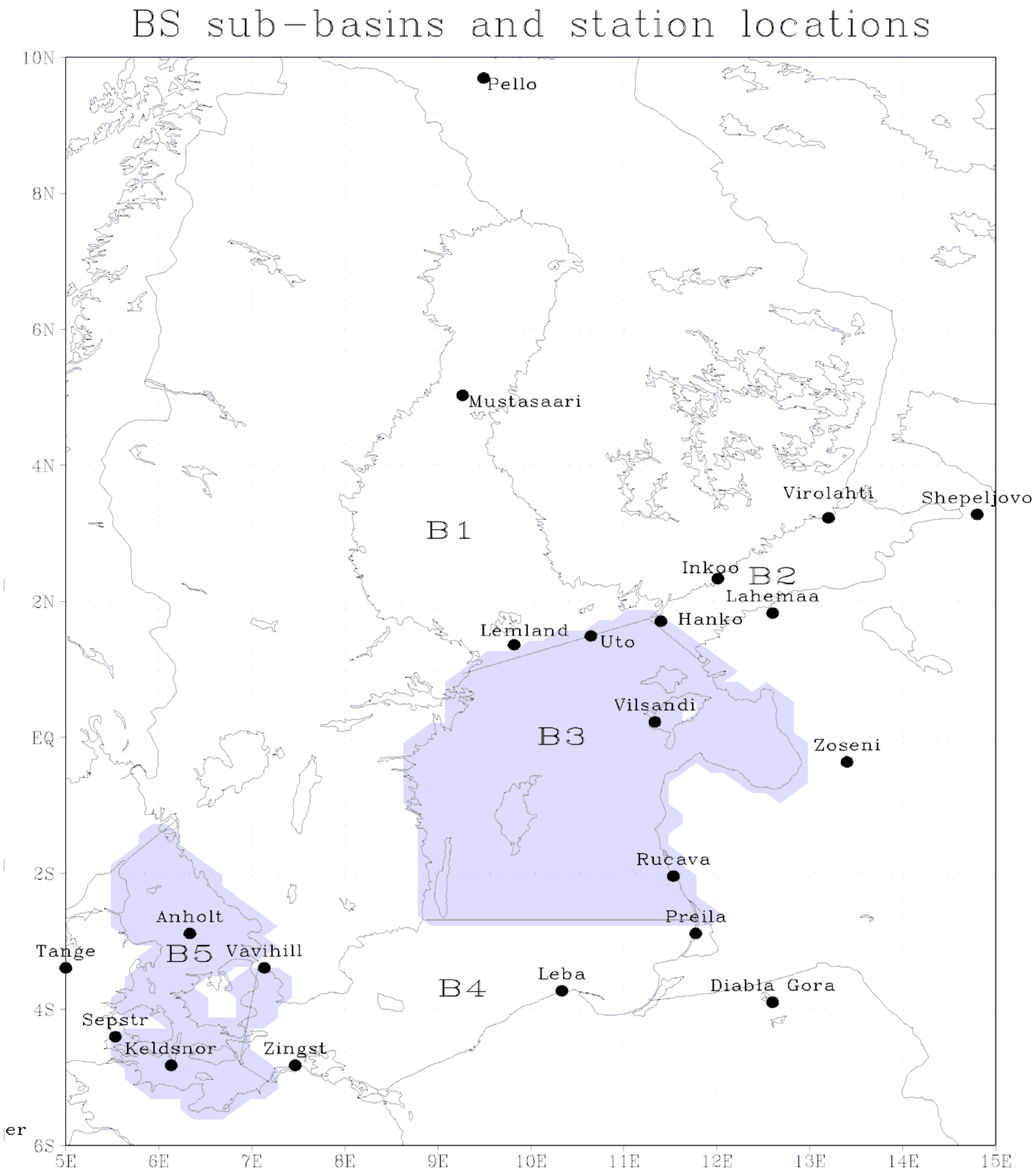

Correlation of the monthly total NOy deposition with the monthly NAO index, seasonal 1993-2009 averages


Winter months sum of total NOx deposition correlation with length of the ice season 1973-2009

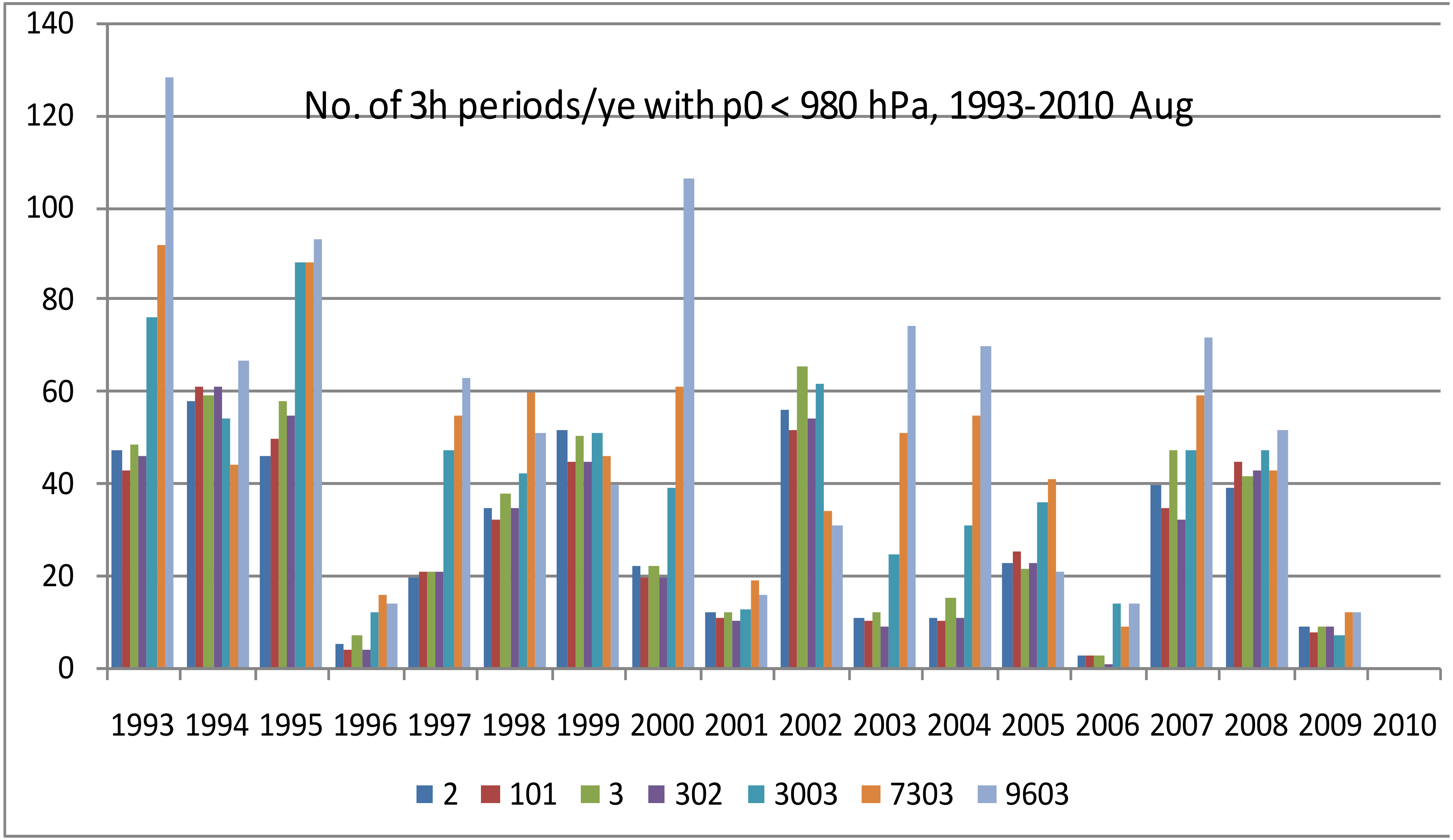
Episodes are connected to extreme weather events

Storm variability From measurements

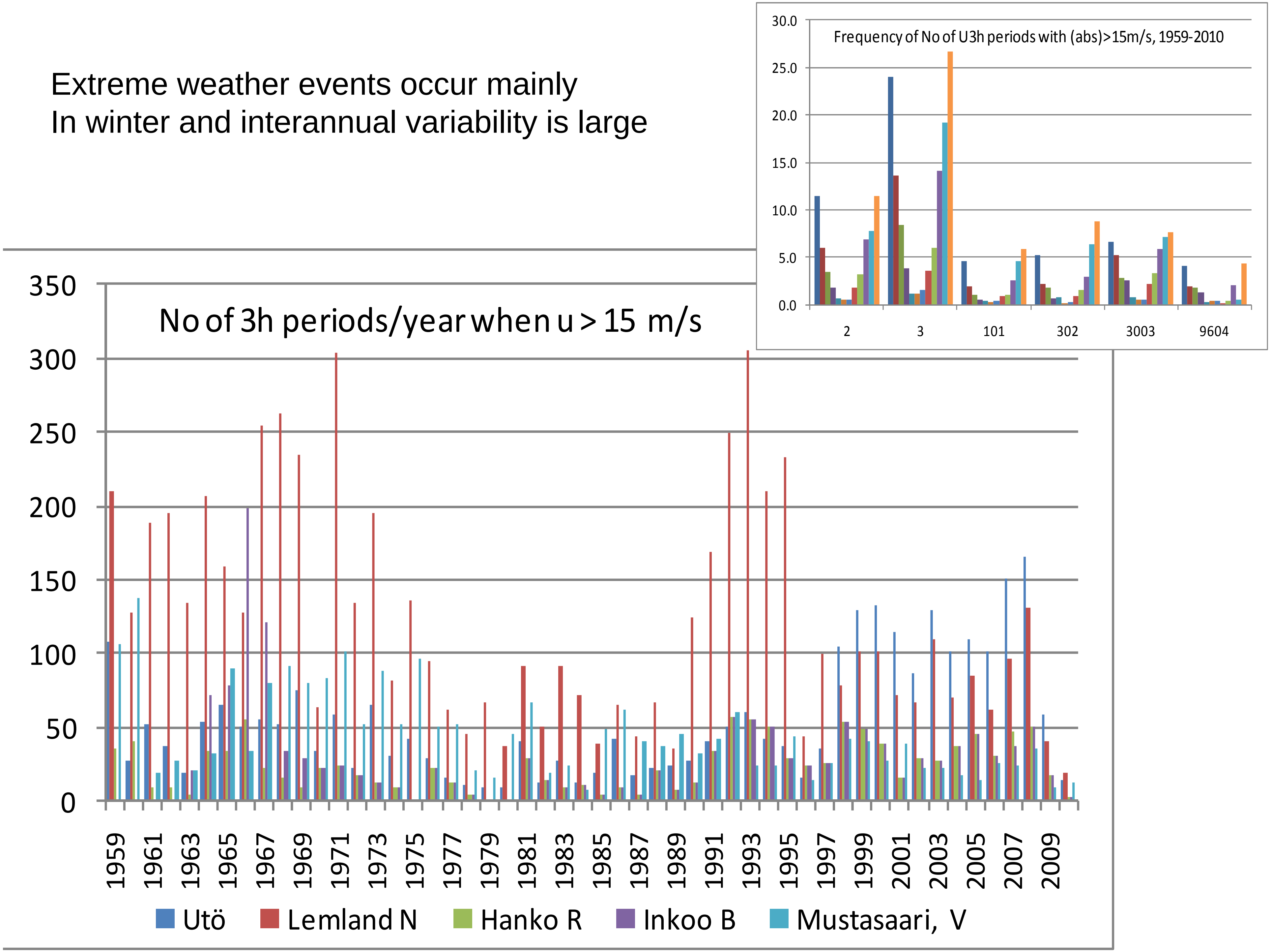
Utö
Lemland
Hanko
Inkoo
Mustasaari



Number of 3h periods with p0 < 980 hPa,
1993-2010, at 6 FMI stations
and at Utö in1959-2010 August.



Extreme weather events occur mainly
In winter and interannual variability is large



Origin of the episodes: Backward simulations;
10 highest episodes in 2009: mainly wet deposition events in winter

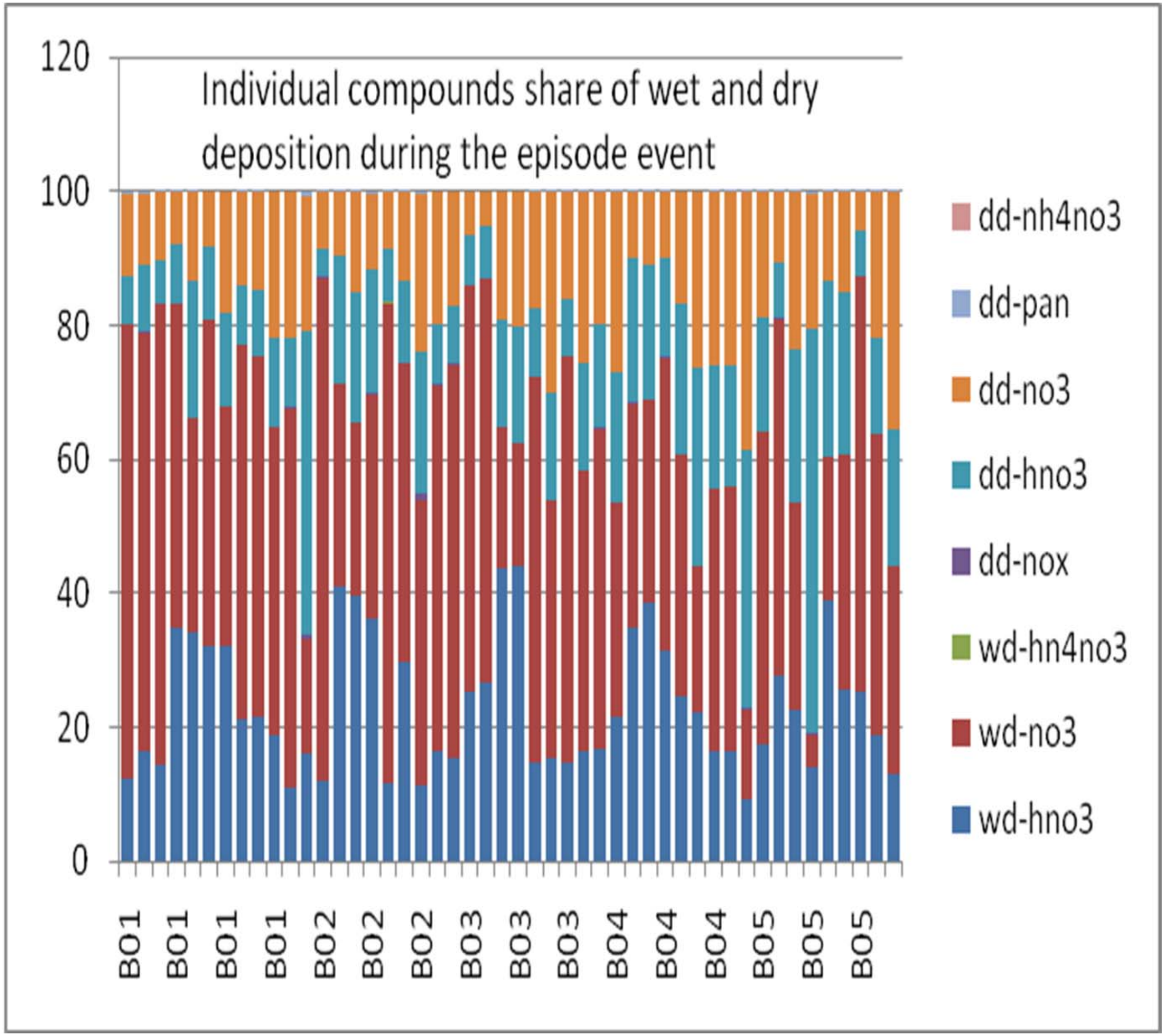
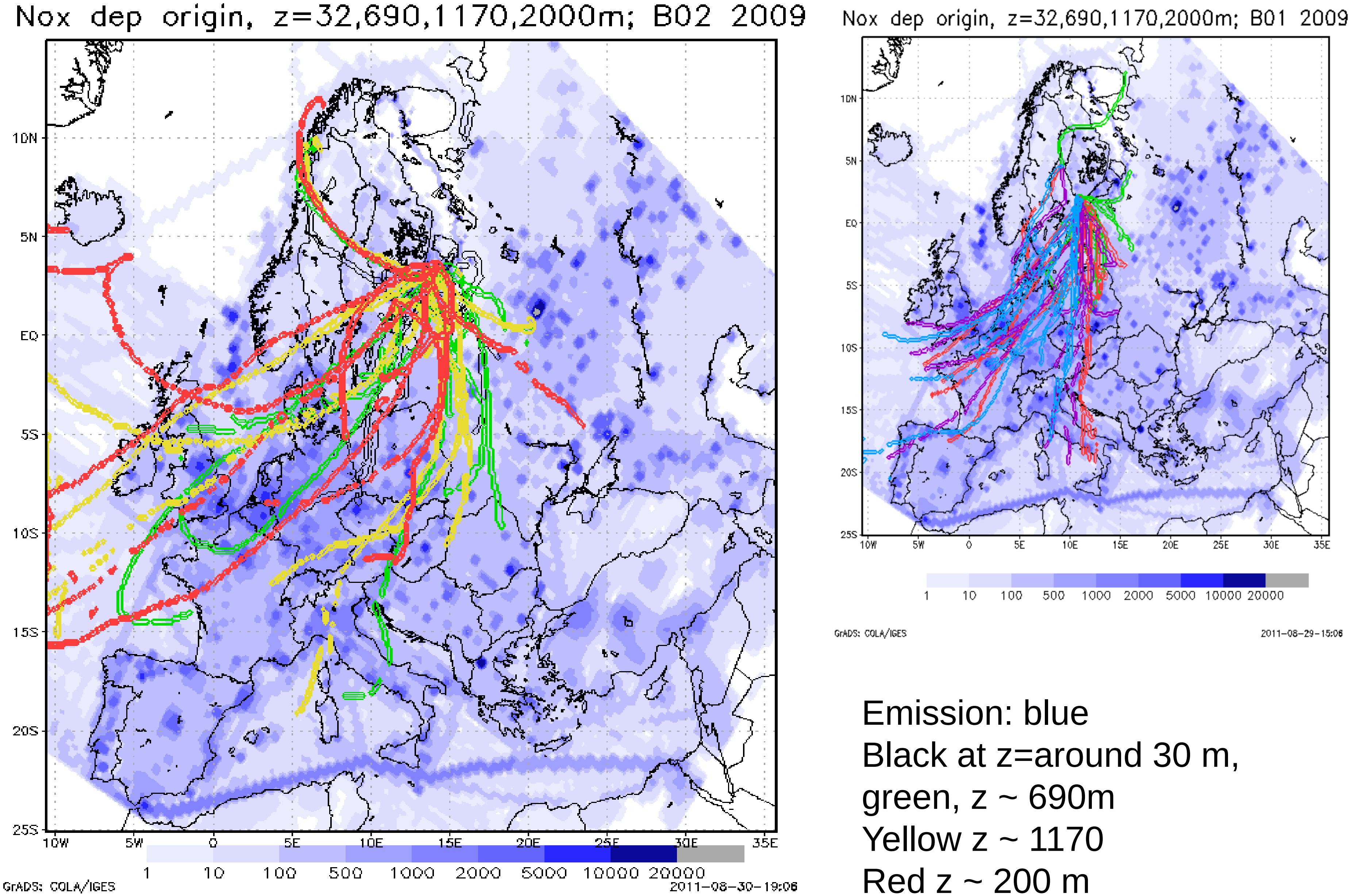
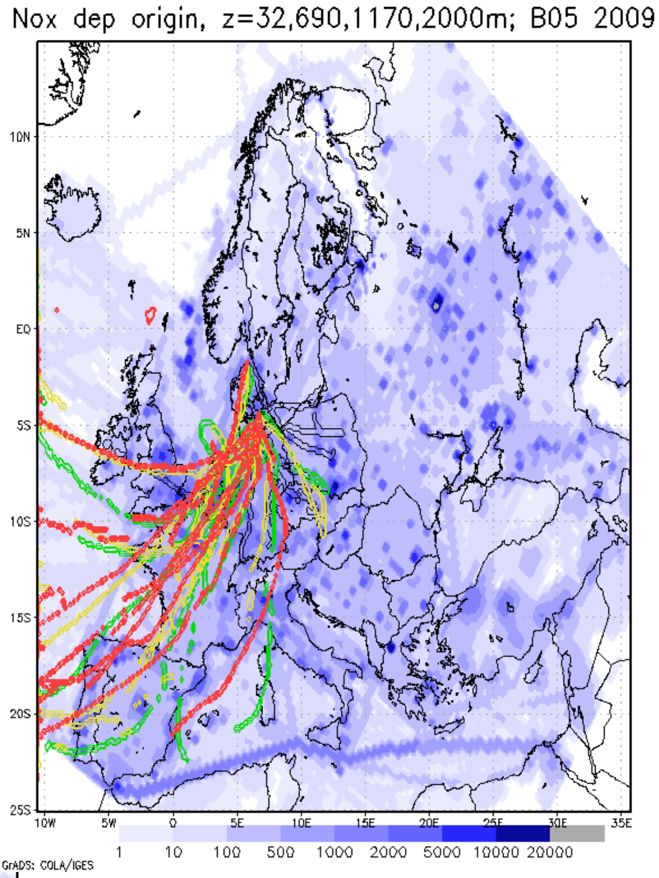


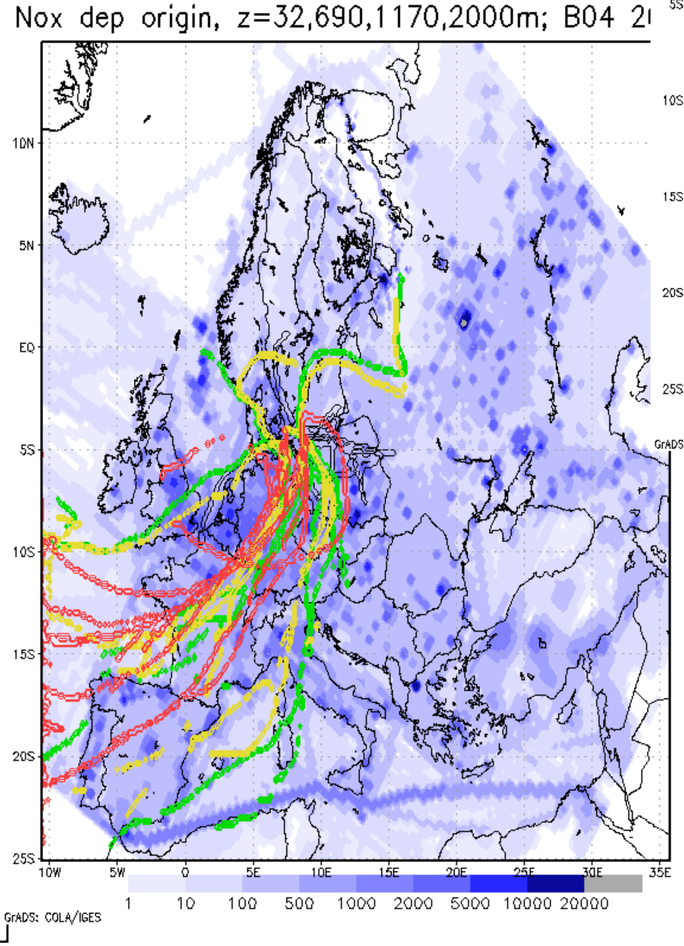
Figure 1. Backward trajectories from the 10 highest deposition episode locations.

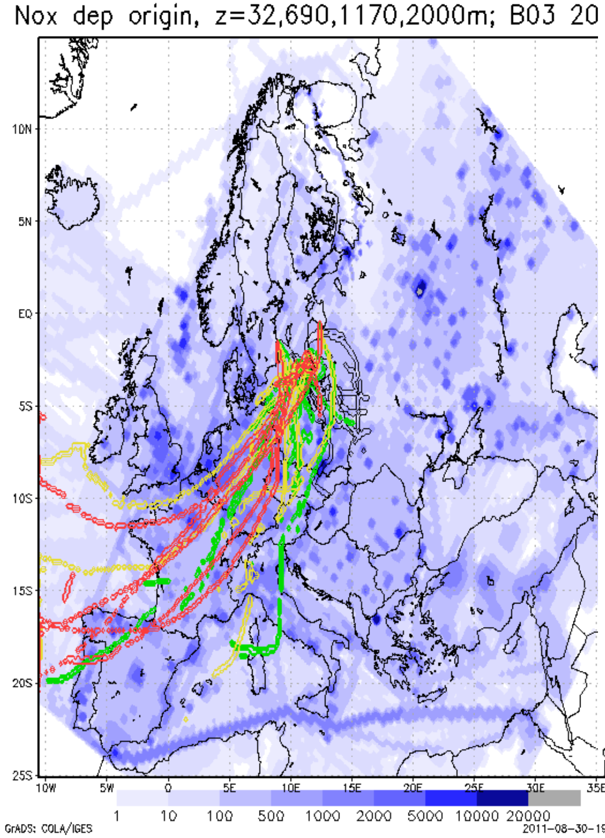


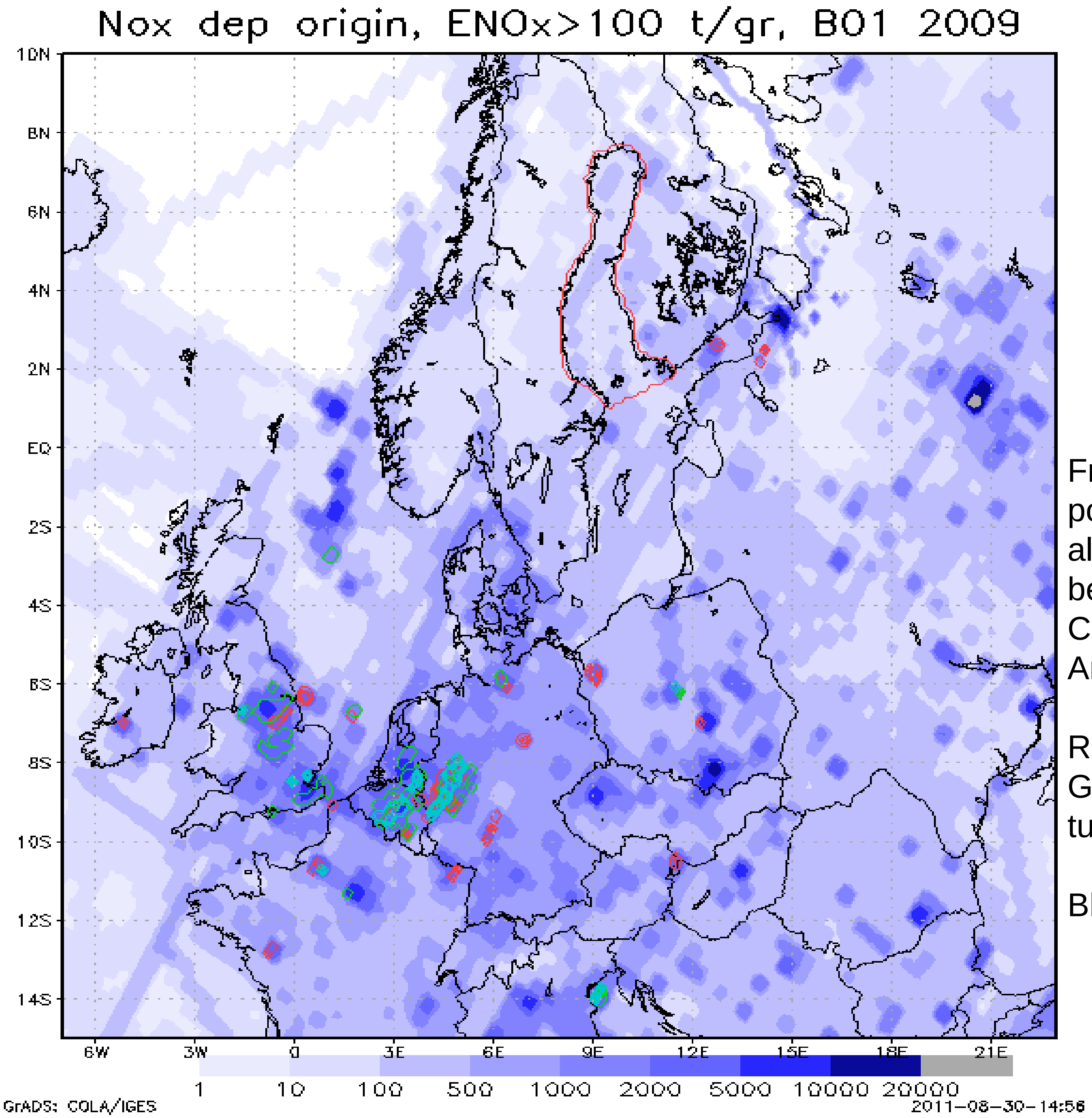
Emission: blue
Black at z=around 30 m,
green, z ~ 690m
Yellow z ~ 1170
Red z ~ 200 m

All parameters along each 21 vertical trajectories needed for source area identification are collected; Emission, p0, RR, hmix, u_{abs}, T, K_z


Nox dep origin, z=32,690,1170,2000m; B05 2009


Nox dep origin, z=32,690,1170,2000m; B04 2

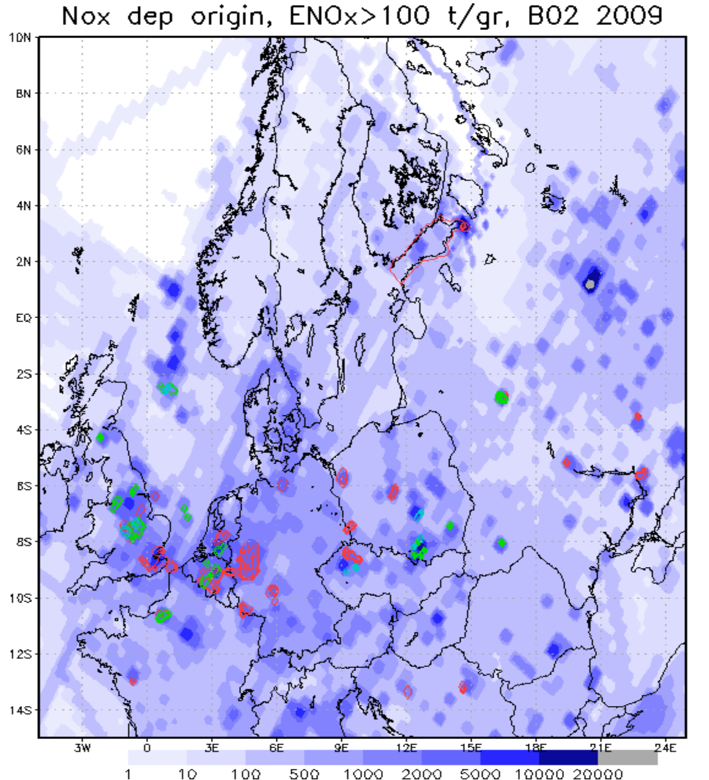

Nox dep origin, z=32,690,1170,2000m; B03 20

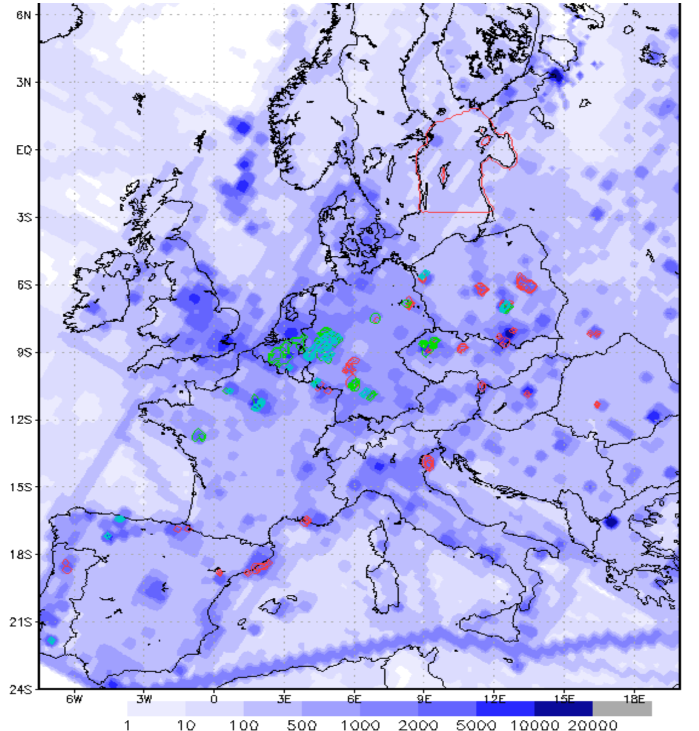


From the data collected possible emission areas along the trajectory can be estimated by varying Criteria; here just Emis And hmix are used

Red z<650
Green z ~ 700-1200m
turquoise 1300-1400 m

Blue: NOx emission
intensity



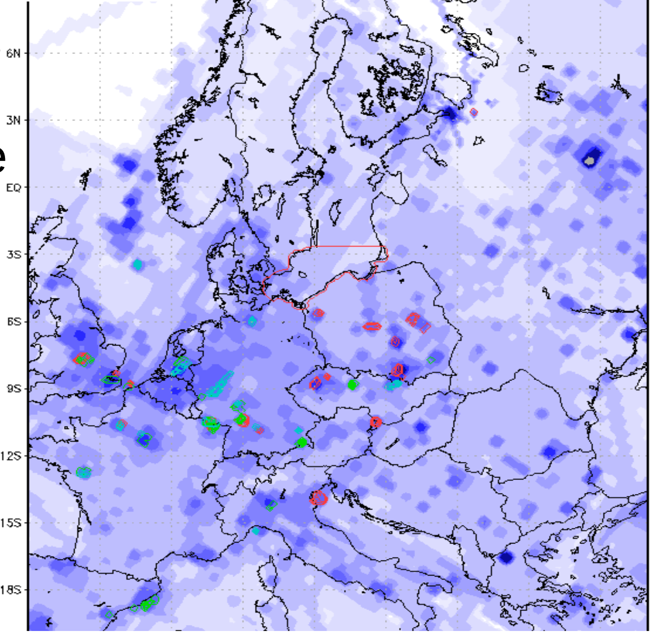


Possible emission areas
Along the trajectory
2009 10 highest episode

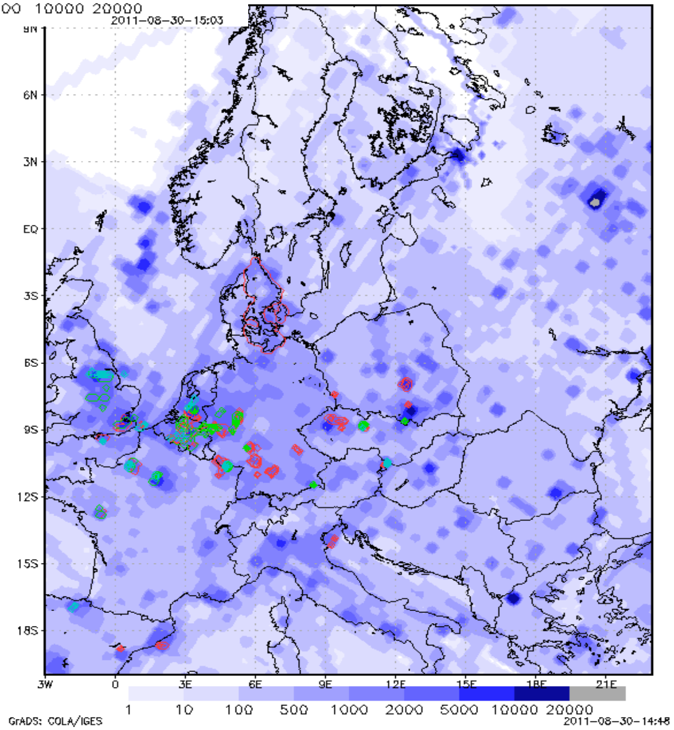
Red z<650
Green z ~ 700-1200m
turquoise 1300-1400 m

Blue: NOx emission
intensity

igin, ENOx>100 t/gr, B04 2009



ı, ENOx>100 t/gr, B05 2009



country-wise provisional nutrient reduction requirements:

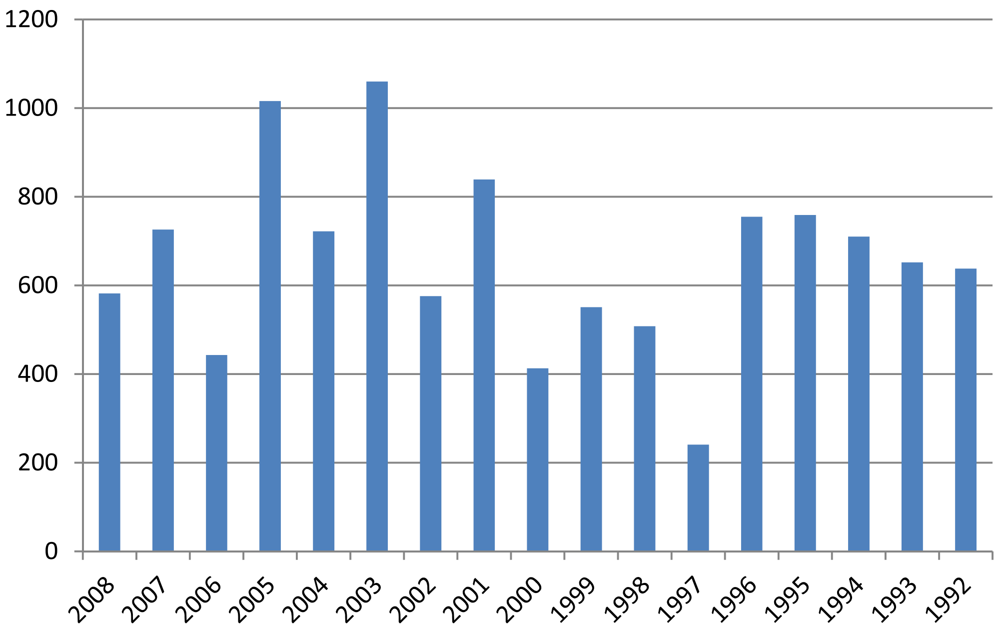
Country	**Phosphorus (tonnes)**	**Nitrogen (tonnes)**
Poland	**8760**	**62400**
Sweden	**290**	**20780**
Denmark	**16**	**17210**
Lithuania	**880**	**11750**
Russia	**2500**	**6970**
Germany	**240**	**5620**
Latvia	**300**	**2560**
Finland	**150**	**1200**
Estonia	**220**	**900**
Transb. Common pool	**1660**	**3780**

Biggest contributors to NOx, NHx and total nitrogen deposition to the Baltic Sea basin averaged over the period 1997–2006. GgN per year.

/Bartnicki et al., 2011/

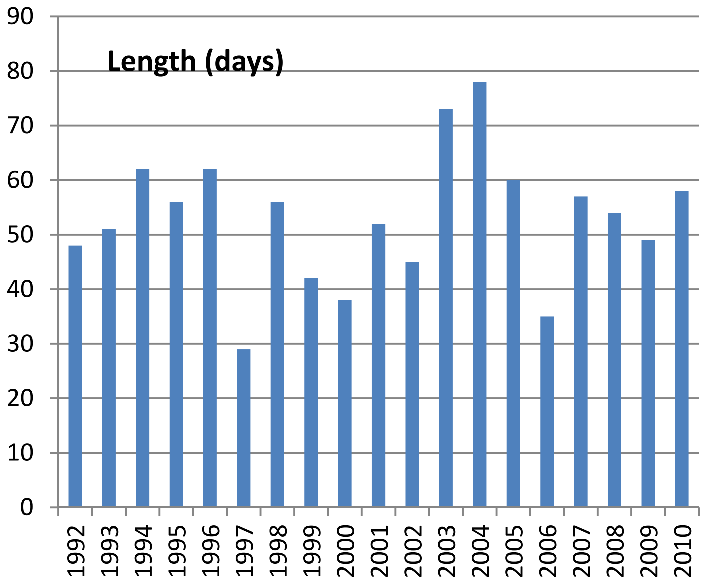
NOx		NHx		Total		
DE	17.38	DE	23.31	**DE**	40.69	**Germany**
GB	11.91	DK	16.36	**PL**	24.7	**Poland**
PL	11.24	PL	13.46	**DK**	20.18	**Denmark**
BAS	10.95	SE	8.38	**GB**	14.48	**United Kingdom**
NOS	7.11	FR	3.85	**SE**	12.82	**Sweden**
RU	5.49	FI	3.15	**BAS**	9.42	**BS intern. Traffic**
FR	5.29	NL	3.13	**FR**	9.15	**France**
SE	4.44	UA	3.04	**RU**	8.02	**Russia**
DK	3.83	GB	2.57	**NOS**	6.82	**North Sea int traffic**
FI	3.65	RU	2.53	**FI**	6.8	**Finland**

Western Gulf of Finland, spring bloom intensity index

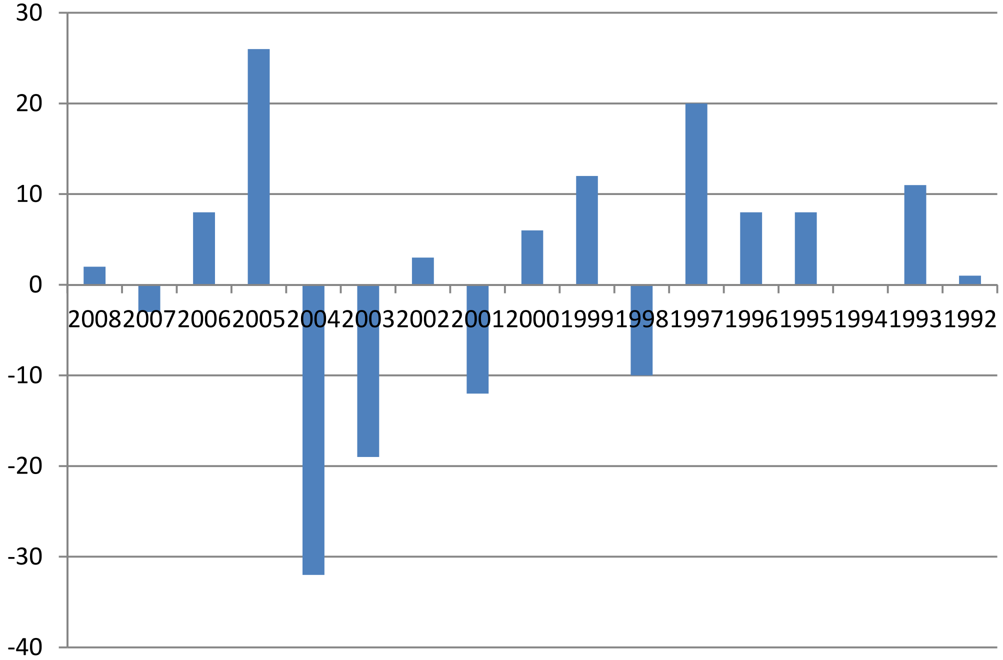


Do the deposition episodes have an effect To the spring bloom intensity and start time ?

Algaline data:
Fleming-Lehtinen V. and Kaitala S., 2008.
Phytoplacton spring bloom biomass in 2008.
HELCOM Indicator Fact Sheet 2008, online



Western GoF, spring bloom start date relative to 31.3



WHY SPRING BLOOM IS STUDIED: Nutrient budget of the Baltic Proper

annual PP	20-30 Mt C yr-1	100 g C m-2 yr-1	
N-needed	3500- 5000	kt N yr^{-1}	
N fixation from air	130-390	kt N yr^{-1}	Larssen et al., 1999
	130		Håkanson 2008
	370		Wasmund et.al 2001
	434		Wasmund et.al 2005
	56-125		Degerholm et al 2008
	941		Schneider et al., 2003
riverine load	200	kt N yr^{-1}	HELCOM, 1996
airborne load	180 kt (155-200)	kt N yr^{-1}	MH&Joffre, 2003, Schulz et al.,99
total external load	485-790	kt N yr^{-1}	
sediment removal	316	kt N yr^{-1}	BASYS*)
	855		Vosset et al., 2005
Advektive transport	+964		
	-729		Wulff&Stiengebrandt,1989
Land uplift	400-600	kt N yr^{-1}	Håkanson 2008
Organic nitrogen			
denitrification			

*) N liberated from Gotland deep, when it changed inoxic in 1994/1995

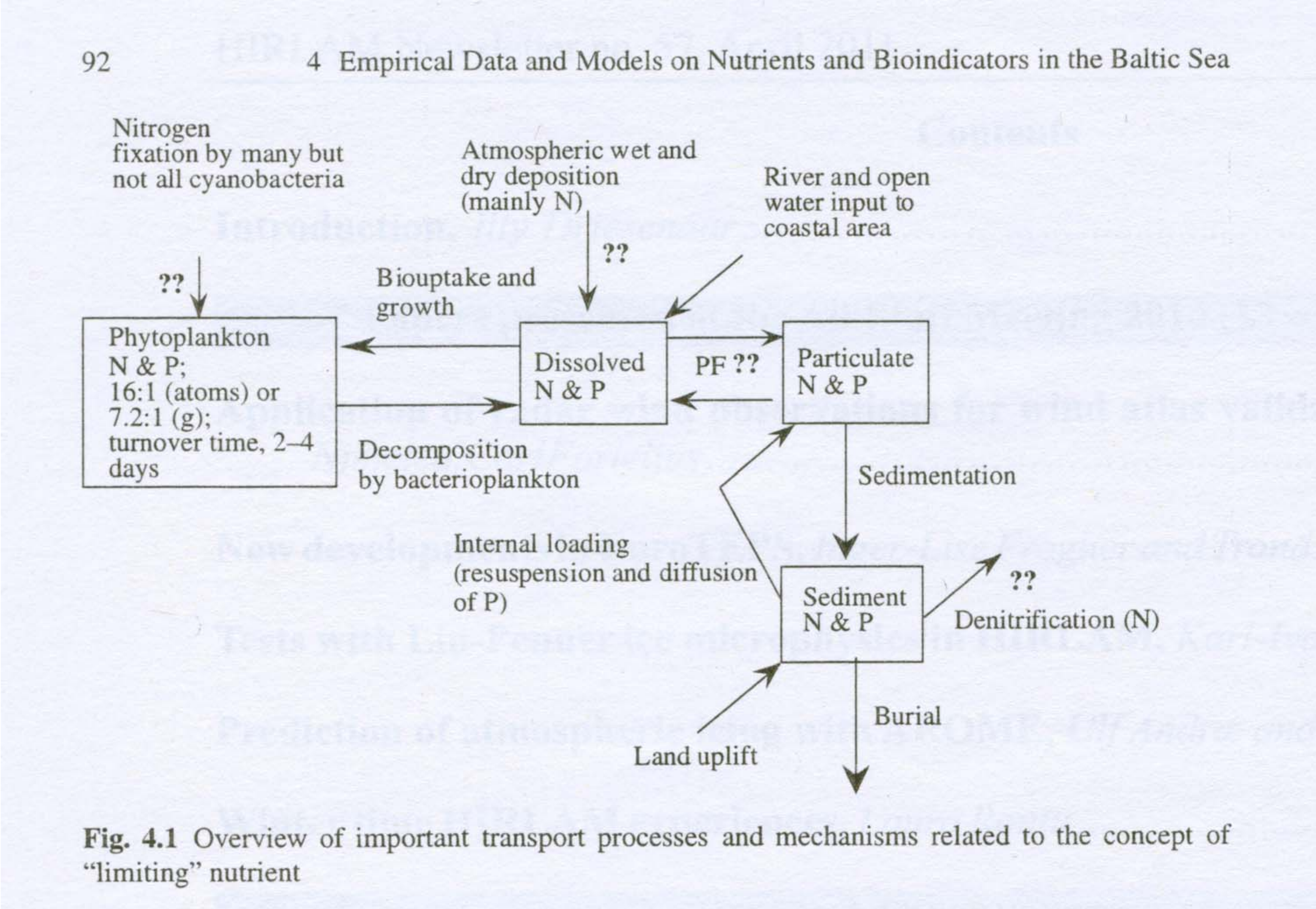
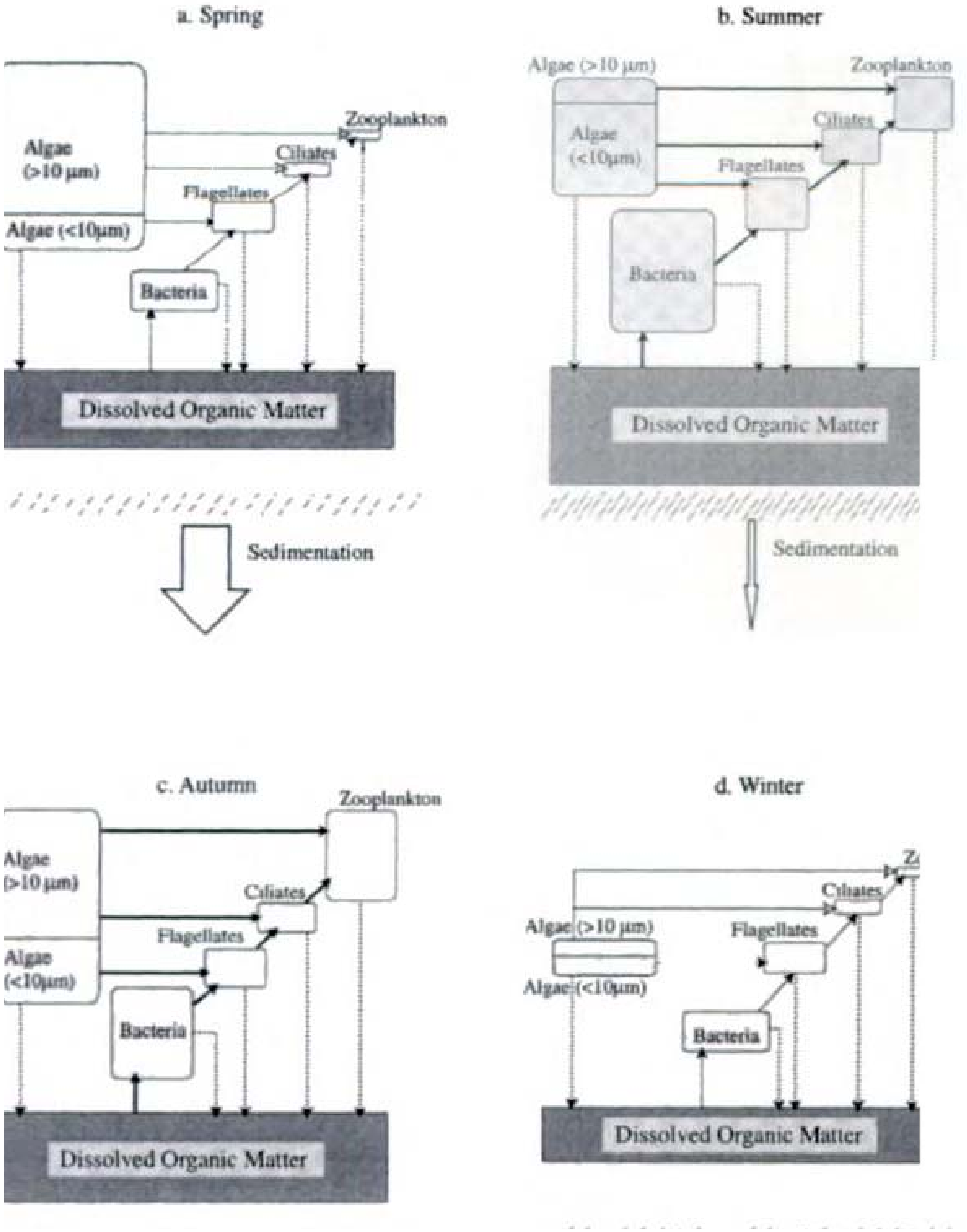


Fig. 4.1 Overview of important transport processes and mechanisms related to the concept of "limiting" nutrient

Håkanson 2008



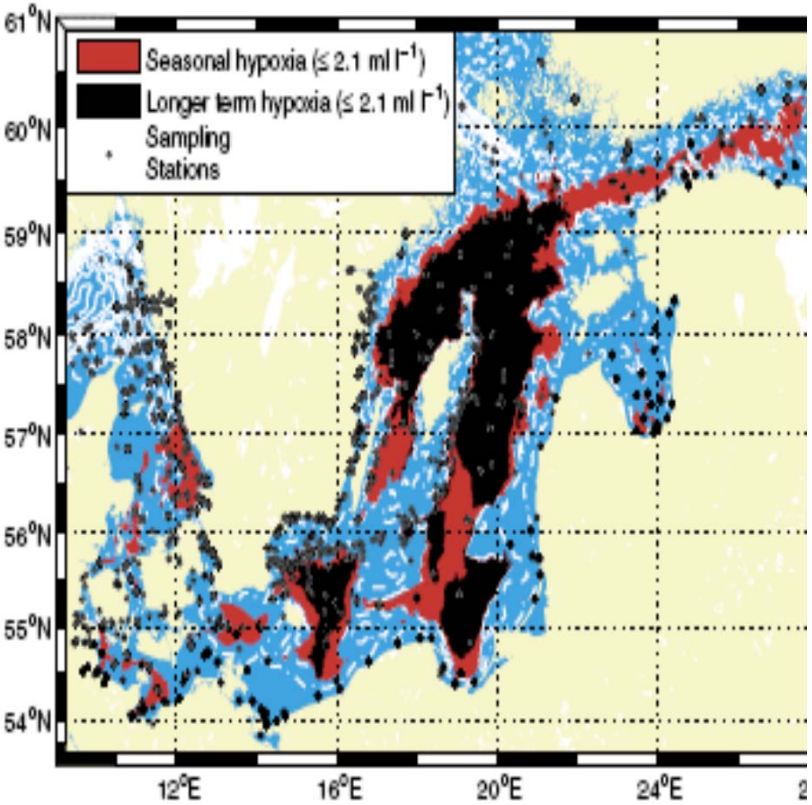
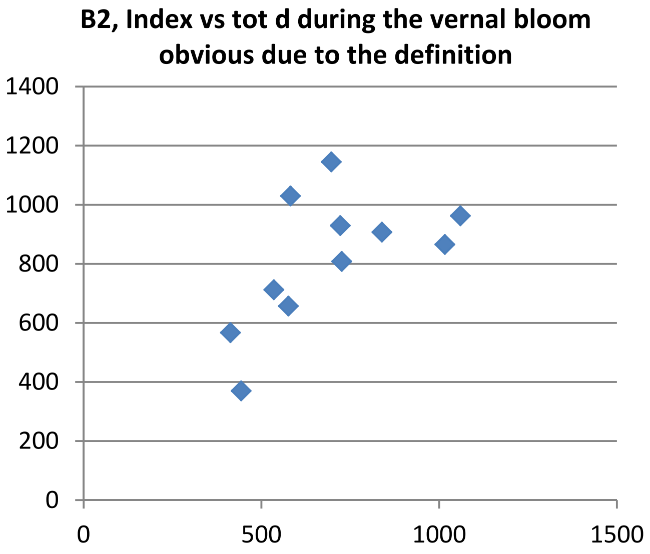
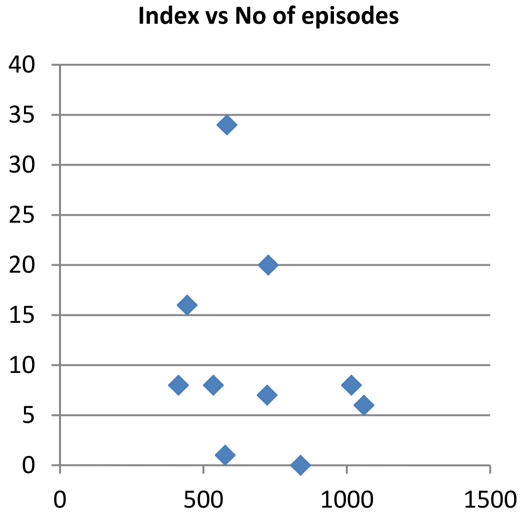
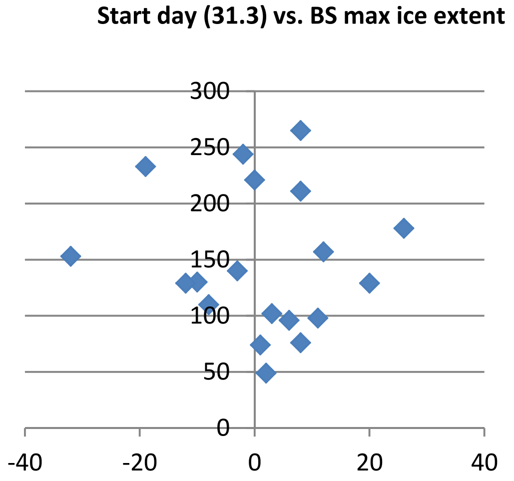
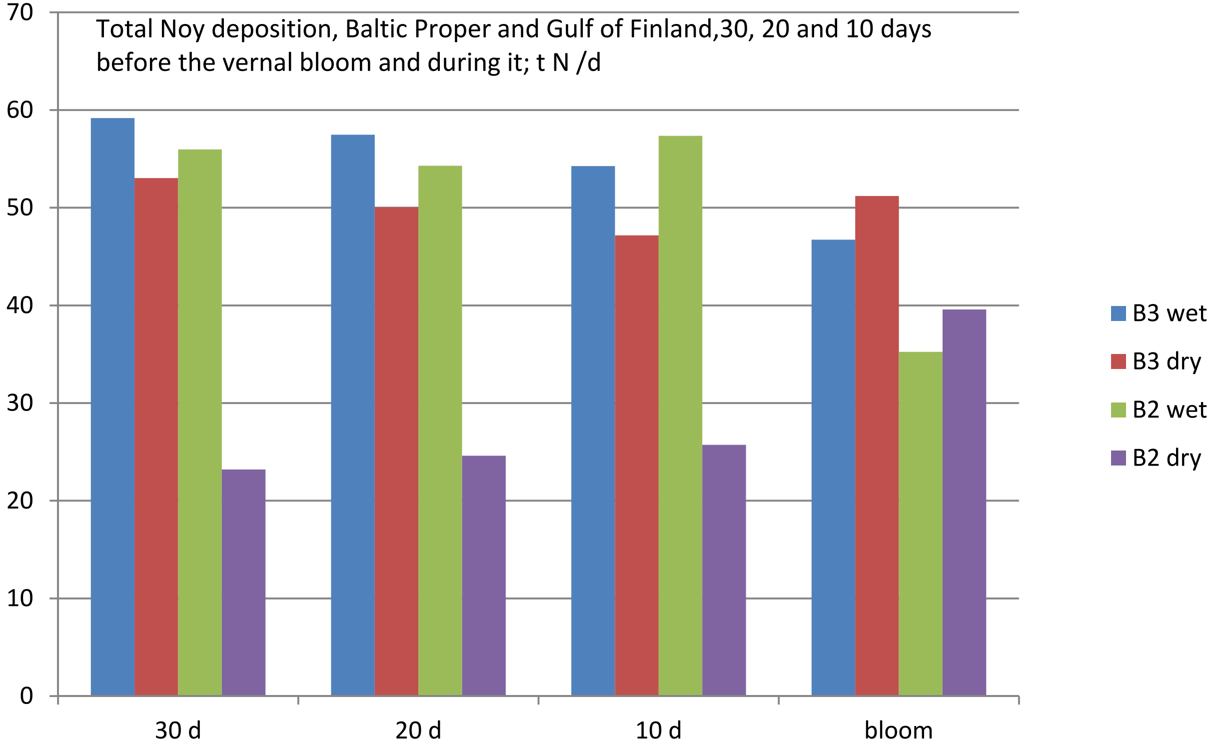


Figure 2.27 Extent of seasonal hypoxia (red) and longer-term hypoxia (black) during 2001–2
hypoxia occurs throughout the year.


B2, Index vs tot d during the vernal bloom obvious due to the definition


Index vs No of episodes


Start day (31.3) vs. BS max ice extent


Total Noy deposition, Baltic Proper and Gulf of Finland,30, 20 and 10 days before the vernal bloom and during it; t N /d

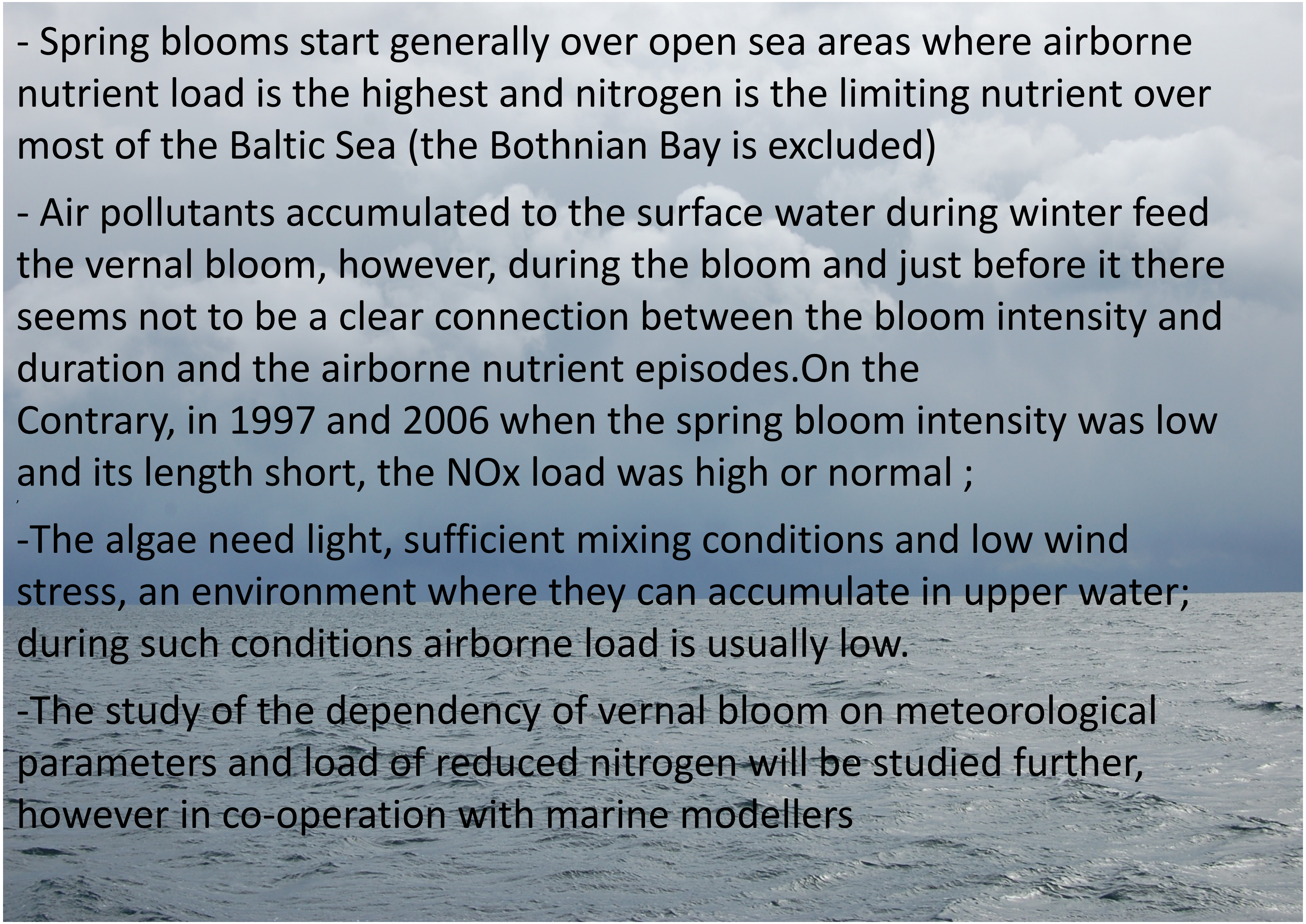
Conclusions

- Between 2000-2009 over the GoB 10 % of the wet load accumulated during 66 hours (11 highest episode events), in 2009 over all sub-basins 48-58 % of the wet load was received in 150 h. Max load does not have to occur during extreme weather events although it is connected to them;

Between 1993-2010 the frequency of episodes had a minima in 1995-1997 and 2001-2005, and 2009-2010

- The possible emission areas should be confirmed by a parallel chemistry, turbulence and deposition analysis along the trajectory
- The confirmed emission areas should be further studied by forward source-receptor re-simulations before the areas, where emissions should be reduced, can be named

- To minimize airborne nutrient load it is not enough to concentrate to reduction of emissions on the BS drainage basin; also emissions of the further away located European source areas should be considered



- Spring blooms start generally over open sea areas where airborne nutrient load is the highest and nitrogen is the limiting nutrient over most of the Baltic Sea (the Bothnian Bay is excluded)

- Air pollutants accumulated to the surface water during winter feed the vernal bloom, however, during the bloom and just before it there seems not to be a clear connection between the bloom intensity and duration and the airborne nutrient episodes.On the Contrary, in 1997 and 2006 when the spring bloom intensity was low and its length short, the NOx load was high or normal ;

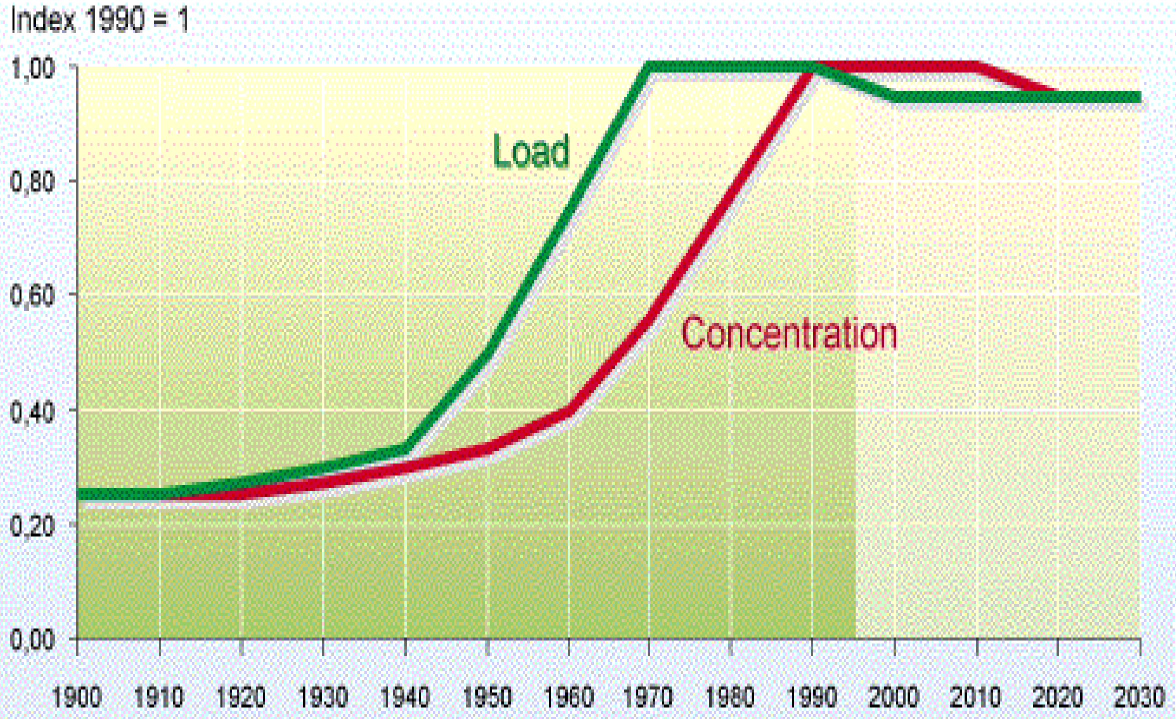
-The algae need light, sufficient mixing conditions and low wind stress, an environment where they can accumulate in upper water; during such conditions airborne load is usually low.

-The study of the dependency of vernal bloom on meteorological parameters and load of reduced nitrogen will be studied further, however in co-operation with marine modellers

Thank you for your attention

Trends in Nitrogen Loads and Concentrations, Baltic Sea, 1900-2030

Scientific estimates based upon current knowledge and likely development trends



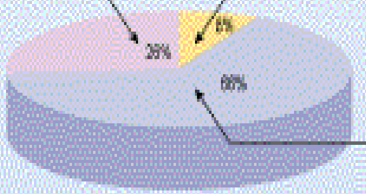
Nordic Council

UNEP GRID Arendal

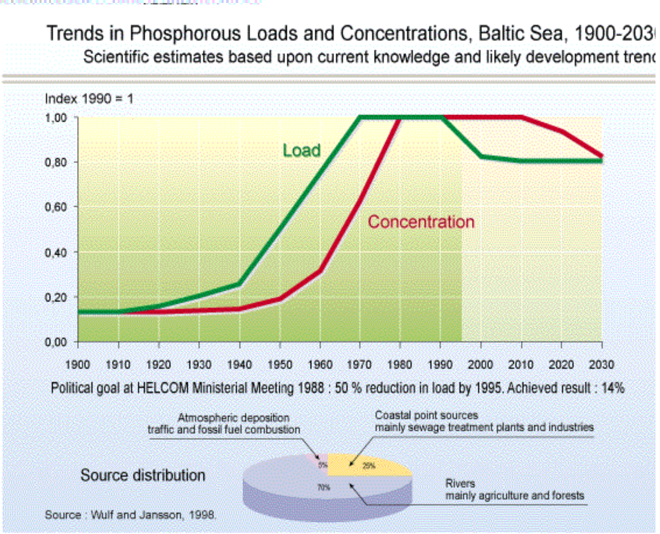
EUROPEAN ENVIRONMENT

Political goal at HELCOM Ministerial Meeting 1988 : 50 % reduction in load by 1995. Achieved result : 3%

Source distribution



Source : Wulf and Jansson, 1998.



Trends in Phosphorous Loads and Concentrations, Baltic Sea, 1900-203

Scientific estimates based upon current knowledge and likely development tren

Political goal at HELCOM Ministerial Meeting 1988 : 50 % reduction in load by 1995. Achieved result : 14%

Source distribution

Source : Wulf and Jansson, 1998.

Increased loads -> Nutrient enrichment: P, N *1); N/P

-> Primary symptoms

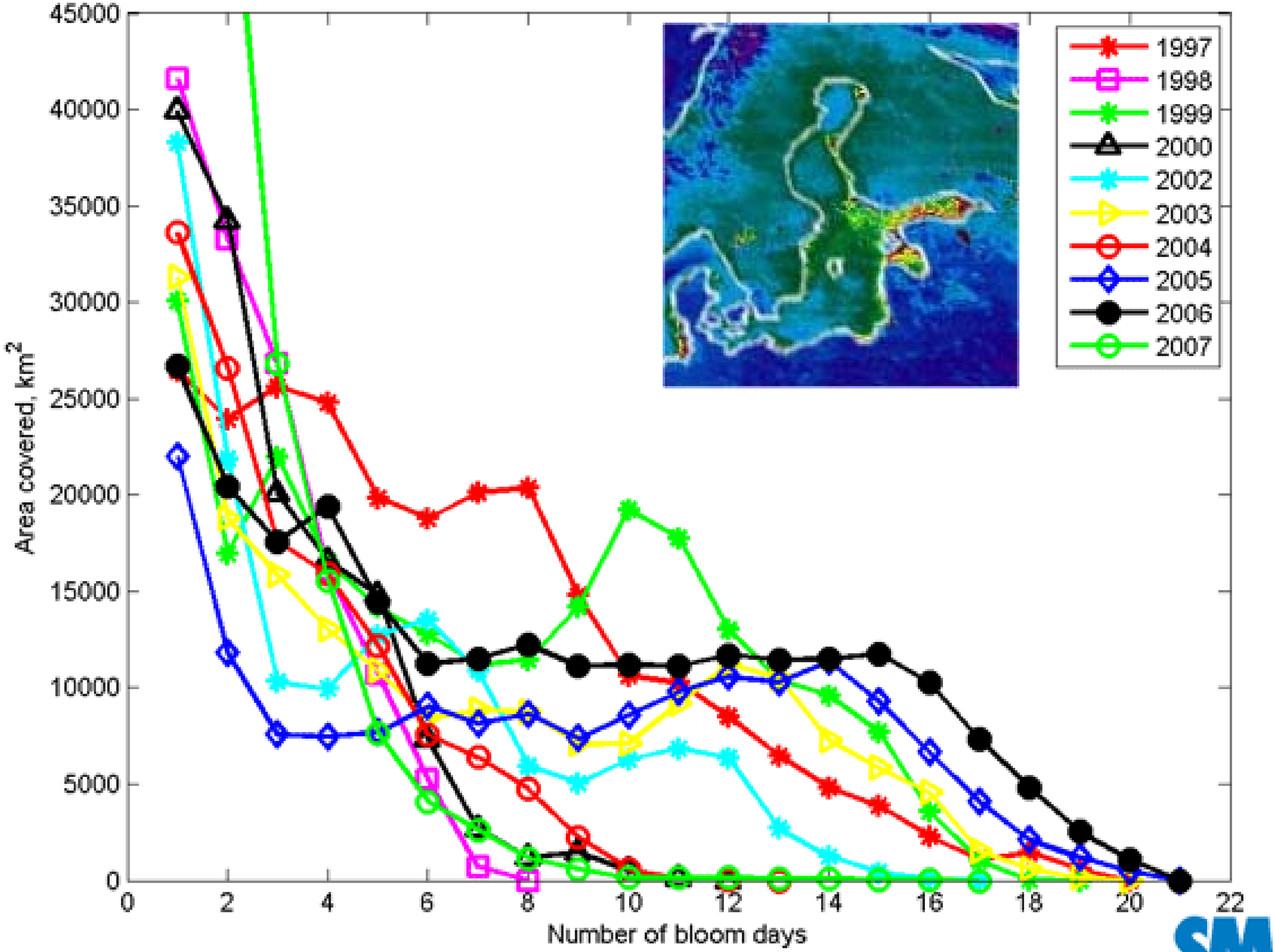
- Increased phytoplankton*2) PP, biomass, bloom frequency
- Changed phytoplancton community structure
- Harmful algae blooms
- Increased growth of short lived nuisance macroalgae
- Increased sedimentation of organic matter

-> Secondary symptoms

- Reduced water transparency*3) and light
- Altered distribution of long-lived submerged vegetation*4)
- Altered benthic invertebrate communities*6)
- Reduced bottom water oxygen concentrations *5)
- Kill of bottom-dwelling fish and invertebrates

*) HELCOM Integrated Thematic assessment of Eutrophication in the BS quality elements to assess their status by Ecological Quality Ratios (EQR)
(acceptable / inacceptable deviation from reference conditions)

2002 Net Primary productivity
www.balticuniv.uu.se



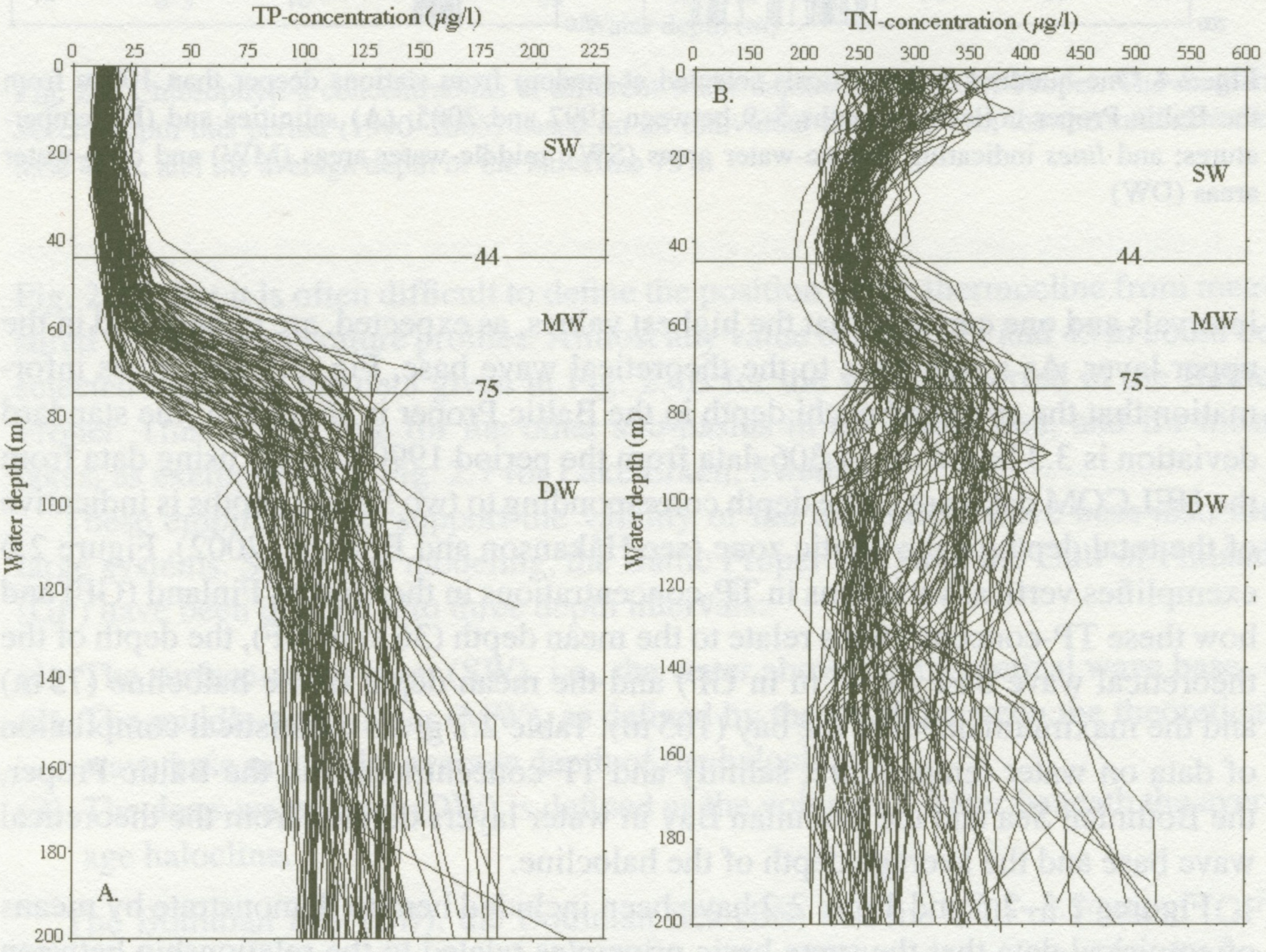


Fig. 2.3 One hundred daily verticals selected at random from stations deeper than 100 m from the Baltic Proper collected months 5–9 between 1997 and 2005: (**A**) TP-concentrations and (**B**) TN-concentrations; and *lines* indicating surface-water areas (SW), middle-water areas (MW) and deep-water areas (DW)

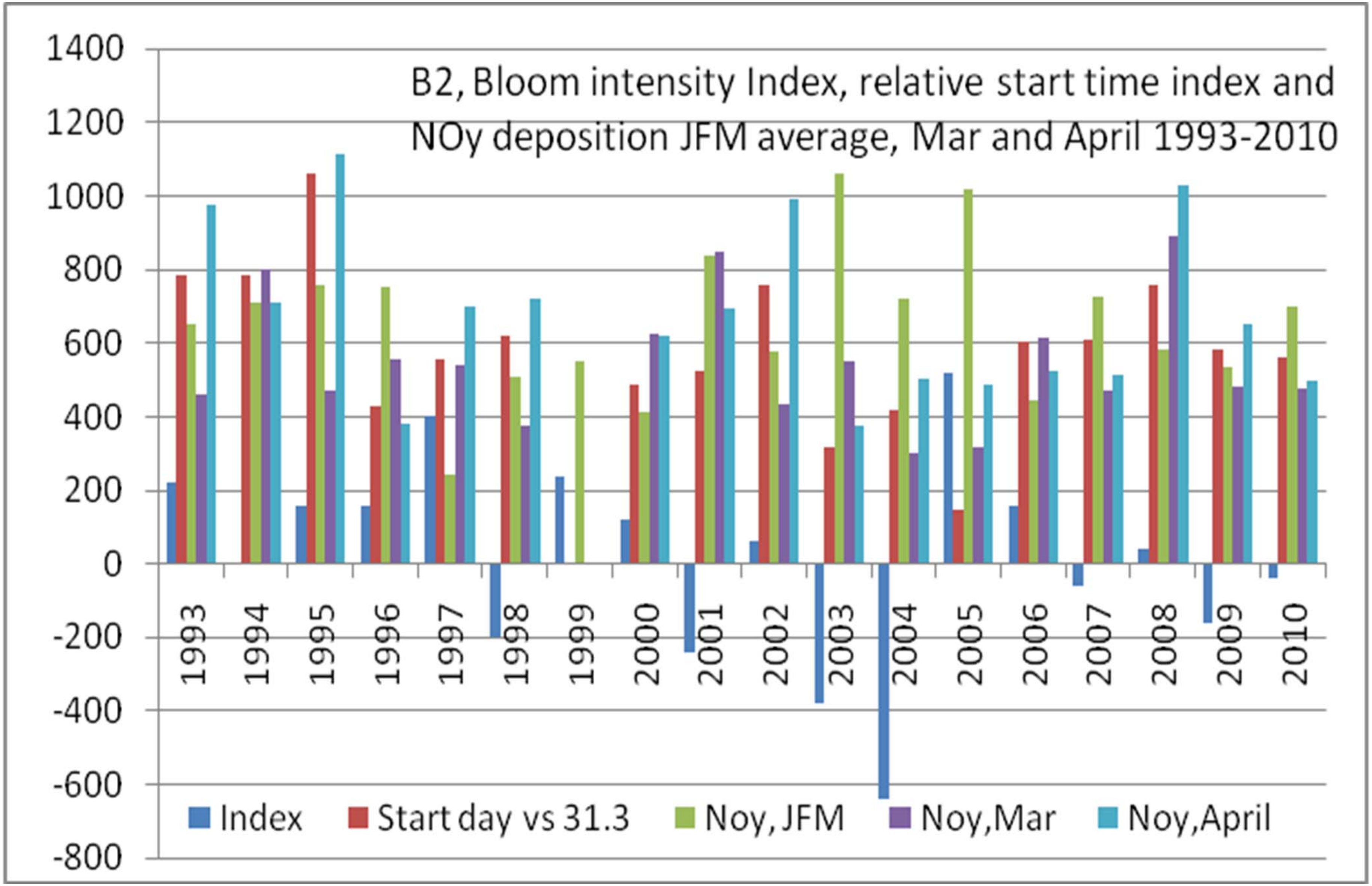
EPISODICITY: Dependency on meteorological parameters:

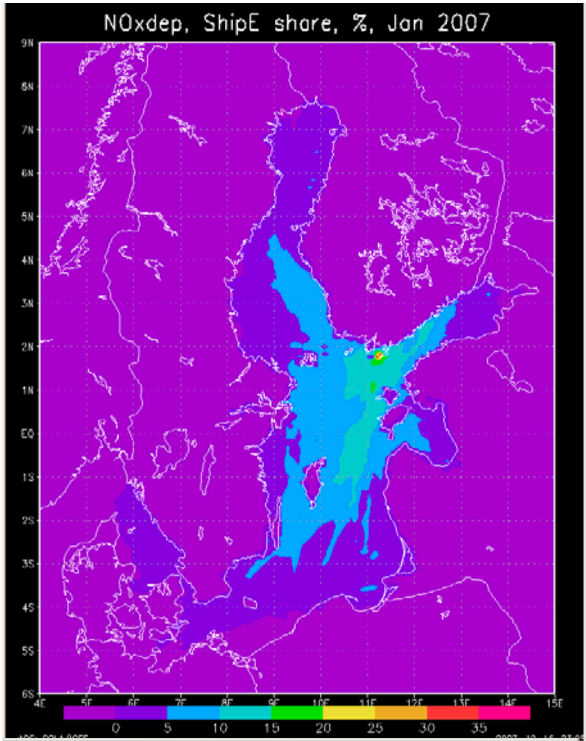
compound stay in the air several days

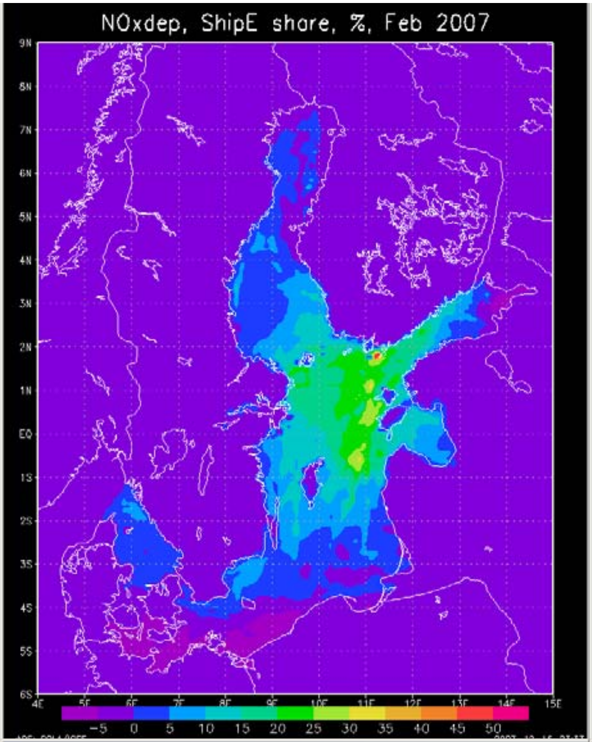
Hmix and turbulence parameters (initial mixing of emissions and vertivcal dispersion along the transport path); u*, 1/L (dry deposition); precipitation (along the transport path) Uabs (transport time), surface state and characteristics, T and moisture (rate of chemical conversion) etc

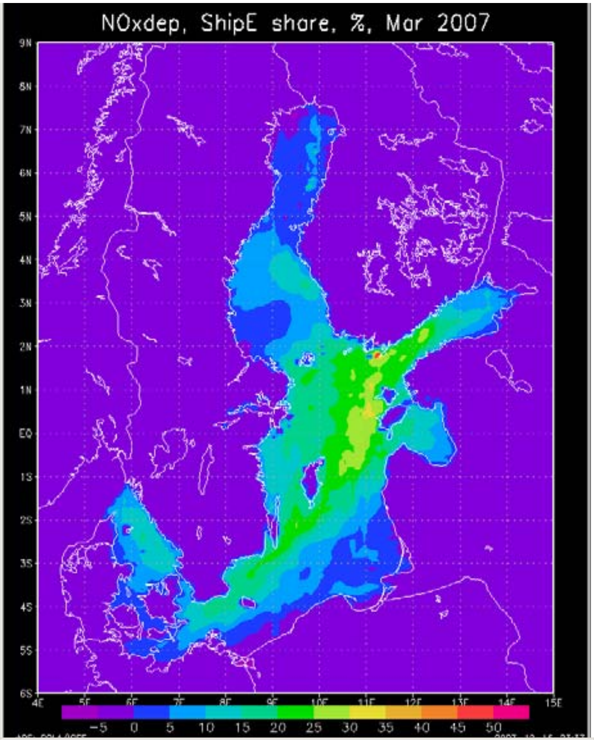
HELCOM Baltic Sea Action plan 2007

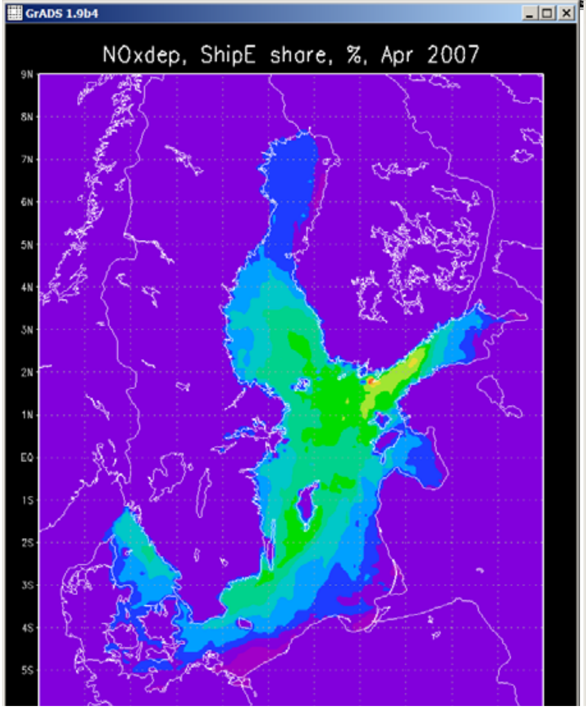
- The overall goal of HELCOM is to have a Baltic Sea unaffected by eutrophication.
- Eutrophication is a major problem in the Baltic Sea. Since the 1900s, the Baltic Sea has changed from an oligotrophic clear-water sea into a eutrophic marine environment. Eutrophication is a condition in an aquatic ecosystem where high nutrient concentrations stimulate the growth of algae which leads to imbalanced functioning of the system, such as:
- intense algal growth: excess of filamentous algae and phytoplankton blooms;
- production of excess organic matter;
- increase in oxygen consumption;
- oxygen depletion with recurrent internal loading of nutrients; and
- death of benthic organisms, including fish.
- Excessive nitrogen and phosphorus loads are the main cause of the eutrophication
- About 75% of the nitrogen load and at least 95% of the phosphorus load enter the Baltic Sea via rivers or as direct waterborne discharges.
- About 25% of the nitrogen load comes as atmospheric deposition.

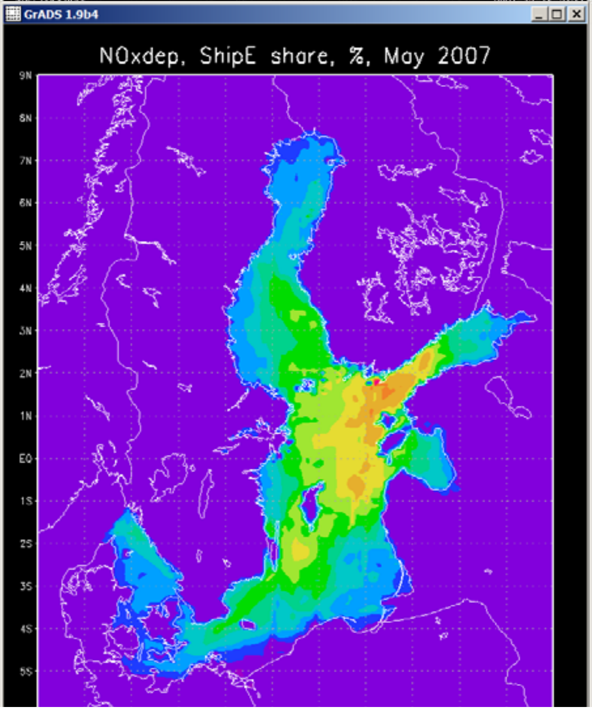

B2, Bloom intensity Index, relative start time index and NOy deposition JFM average, Mar and April 1993-2010
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Index
Start day vs 31.3
Noy, JFM
Noy,Mar
Noy,April

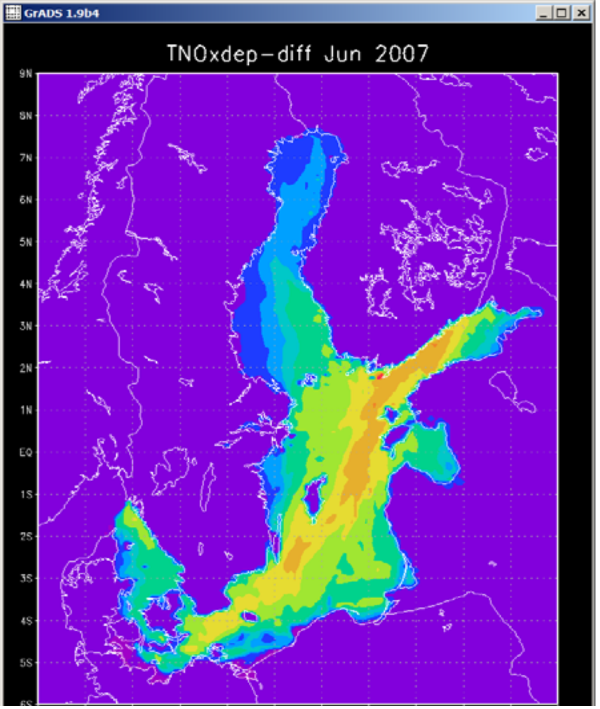

NOxdep, ShipE share, %, Jan 2007
9N 8N 7N 6N 5N 4N 3N 2N 1N EQ 1S 2S 3S 4S 5S 6S
4E 5E 6E 7E 8E 9E 10E 11E 12E 13E 14E 15E
0 5 10 15 20 25 30 35

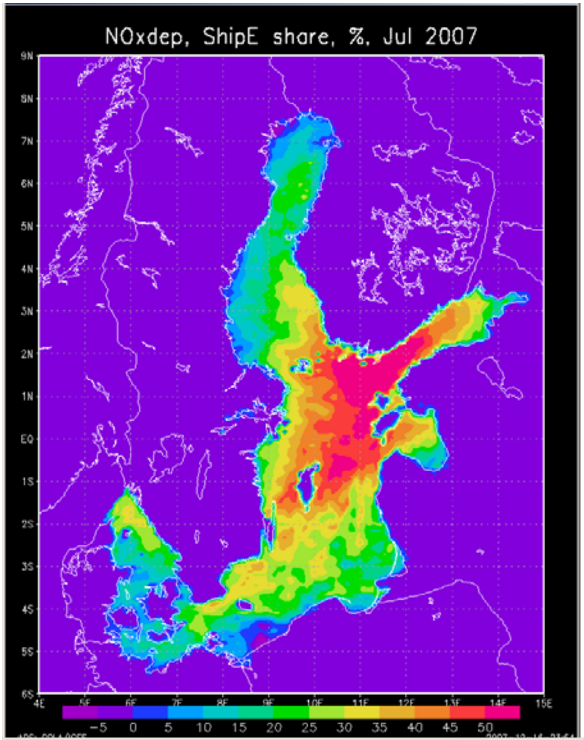

NOxdep, ShipE share, %, Feb 2007
9N 8N 7N 6N 5N 4N 3N 2N 1N EQ 1S 2S 3S 4S 5S 6S
4E 5E 6E 7E 8E 9E 10E 11E 12E 13E 14E 15E
-5 0 5 10 15 20 25 30 35 40 45 50

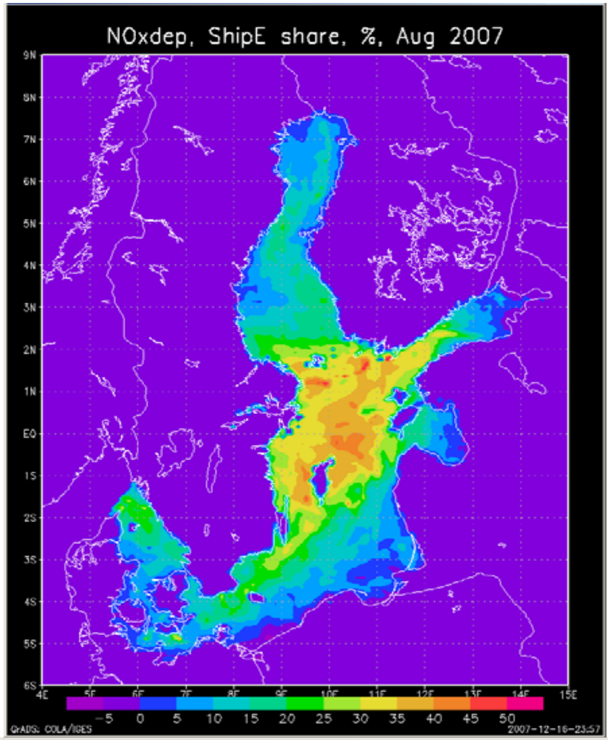

NOxdep, ShipE share, %, Mar 2007
9N 8N 7N 6N 5N 4N 3N 2N 1N EQ 1S 2S 3S 4S 5S 6S
4E 5E 6E 7E 8E 9E 10E 11E 12E 13E 14E 15E
-5 0 5 10 15 20 25 30 35 40 45 50

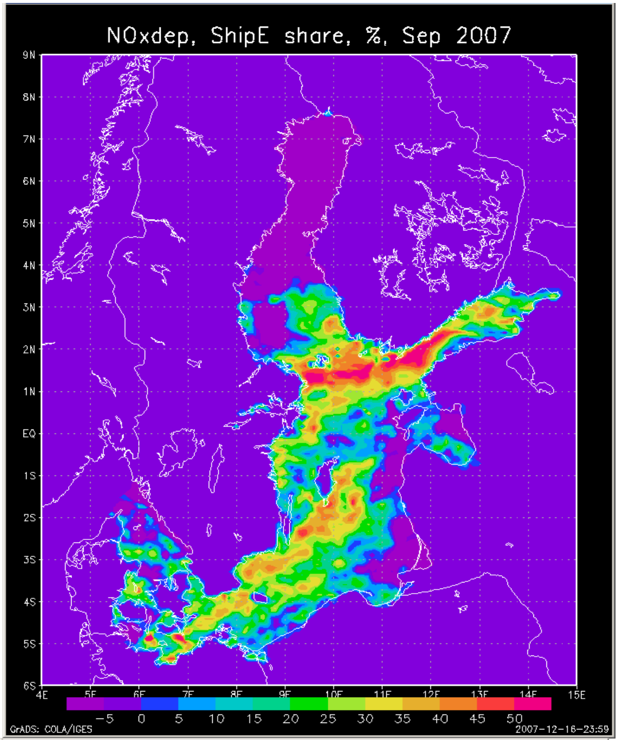

GrADS 1.9b4
NOxdep, ShipE share, %, Apr 2007
9N 8N 7N 6N 5N 4N 3N 2N 1N EQ 1S 2S 3S 4S 5S

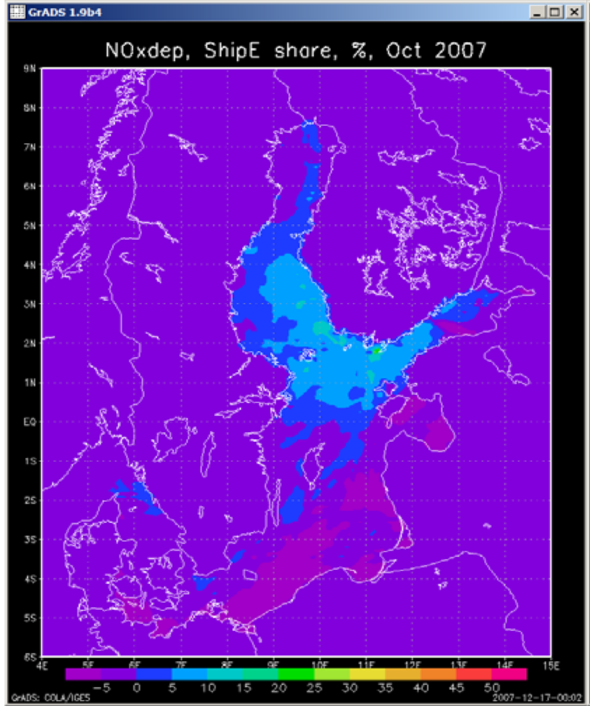

GrADS 1.9b4
NOxdep, ShipE share, %, May 2007
9N 8N 7N 6N 5N 4N 3N 2N 1N EQ 1S 2S 3S 4S 5S

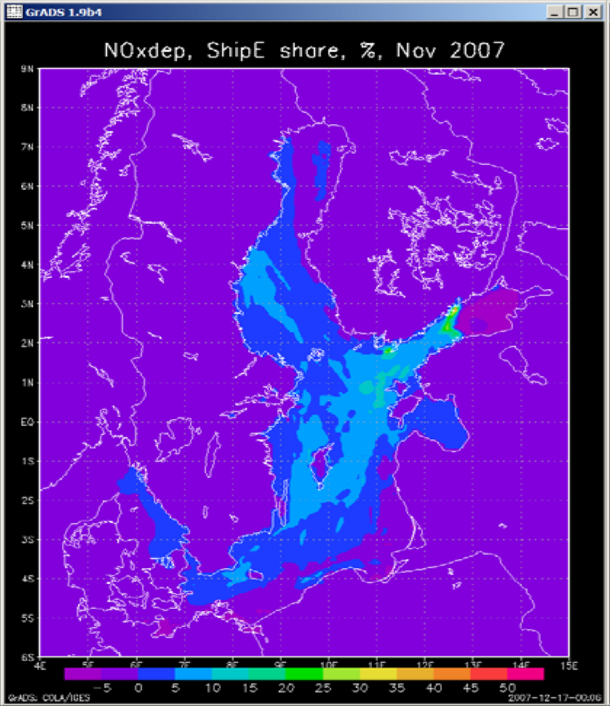

GrADS 1.9b4
TNOxdep-diff Jun 2007
9N 8N 7N 6N 5N 4N 3N 2N 1N EQ 1S 2S 3S 4S 5S 6S

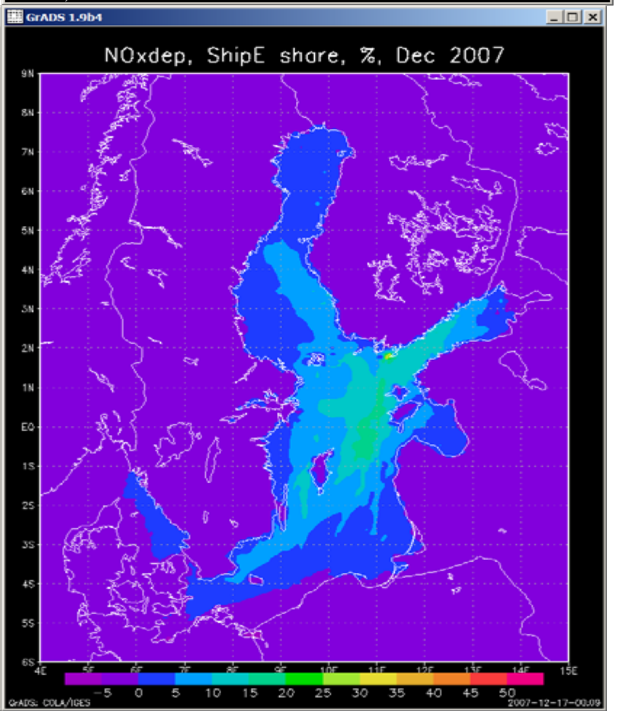

NOxdep, ShipE share, %, Jul 2007
9N
8N
7N
6N
5N
4N
3N
2N
1N
EQ
1S
2S
3S
4S
5S
6S
4E
5E
6E
7E
8E
9E
10E
11E
12E
13E
14E
15E
-5
0
5
10
15
20
25
30
35
40
45
50
GrADS: COLA/IGES

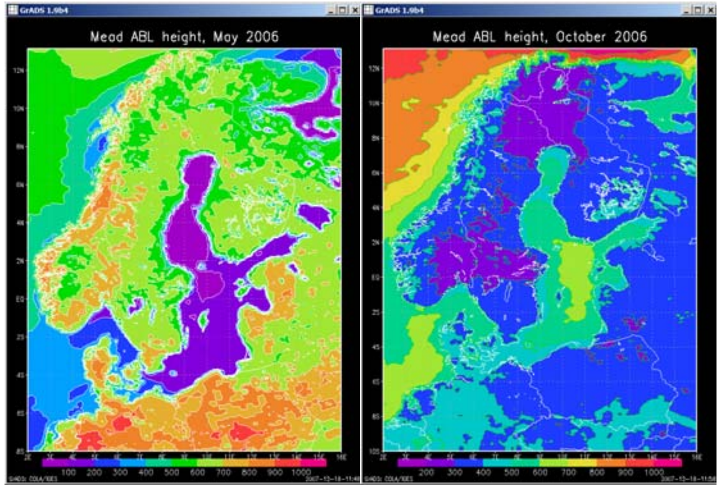

NOxdep, ShipE share, %, Aug 2007
9N
8N
7N
6N
5N
4N
3N
2N
1N
EQ
1S
2S
3S
4S
5S
6S
4E
5E
6E
7E
8E
9E
10E
11E
12E
13E
14E
15E
-5
0
5
10
15
20
25
30
35
40
45
50
GrADS: COLA/IGES
2007-12-16-23:57


NOxdep, ShipE share, %, Sep 2007
9N
8N
7N
6N
5N
4N
3N
2N
1N
EQ
1S
2S
3S
4S
5S
6S
4E
5E
6E
7E
8E
9E
10E
11E
12E
13E
14E
15E
-5
0
5
10
15
20
25
30
35
40
45
50
GrADS: COLA/IGES
2007-12-16-23:59


GrADS 1.9b4
NOxdep, ShipE share, %, Oct 2007
9N
8N
7N
6N
5N
4N
3N
2N
1N
EQ
1S
2S
3S
4S
5S
6S
4E
5E
6E
7E
8E
9E
10E
11E
12E
13E
14E
15E
-5
0
5
10
15
20
25
30
35
40
45
50
GrADS: COLA/IGES
2007-12-17-00:02


GrADS 1.9b4
NOxdep, ShipE share, %, Nov 2007
9N
8N
7N
6N
5N
4N
3N
2N
1N
EQ
1S
2S
3S
4S
5S
6S
4E
5E
6E
7E
8E
9E
10E
11E
12E
13E
14E
15E
-5
0
5
10
15
20
25
30
35
40
45
50
GrADS: COLA/IGES
2007-12-17-00:06


GrADS 1.9b4
NOxdep, ShipE share, %, Dec 2007
9N
8N
7N
6N
5N
4N
3N
2N
1N
EQ
1S
2S
3S
4S
5S
6S
4E
5E
6E
7E
8E
9E
10E
11E
12E
13E
14E
15E
-5
0
5
10
15
20
25
30
35
40
45
50
GrADS: COLA/IGES
2007-12-17-00:09



Mean ABL height (left) and Precipitation(right) May-October 2006