Effects of transboundary nutrient transport and riverine nutrient loading from a phytoplankton transport model of the North Sea

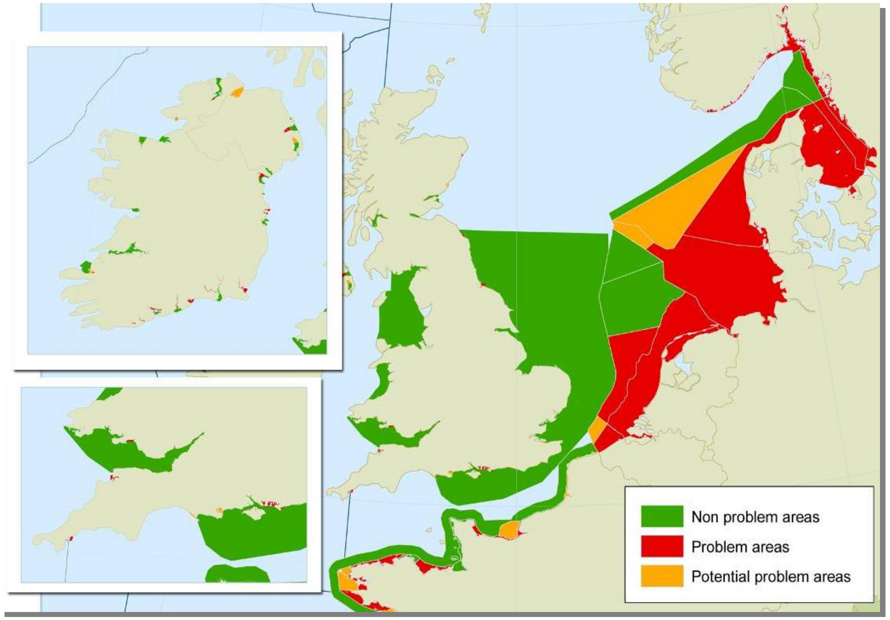
Hans Los*, Xavier Desmit^, Meinte Blaas*, Tineke Troost*, Jan van Beek*

*** Deltares**
^ Mumm

EcoQOs

OSPAR works with Eco Quality Objectives

Eutro EcoQO: starting in 2010 no more ‘problem areas’



‘Comprehensive Procedure’

Combi of quatitative tests (QSRs)

- Winter DIN & DIP concentrations & ratio
- Summer phytoplankton Chl-a concentrations
- HAB-indicator species (*Phaeocystis*)
- DO undersaturation

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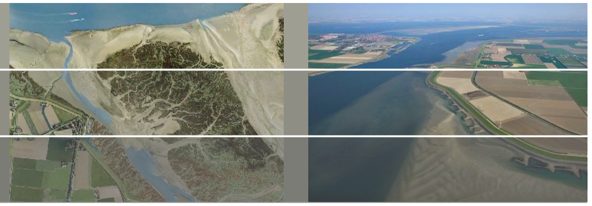
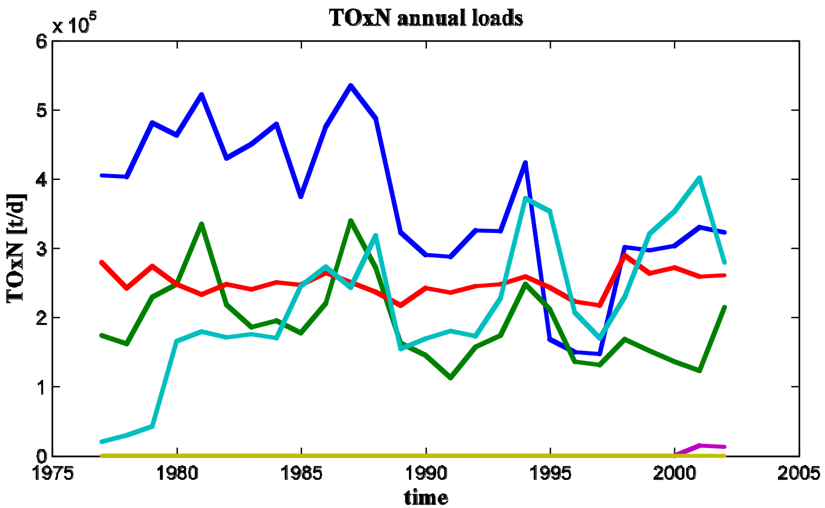
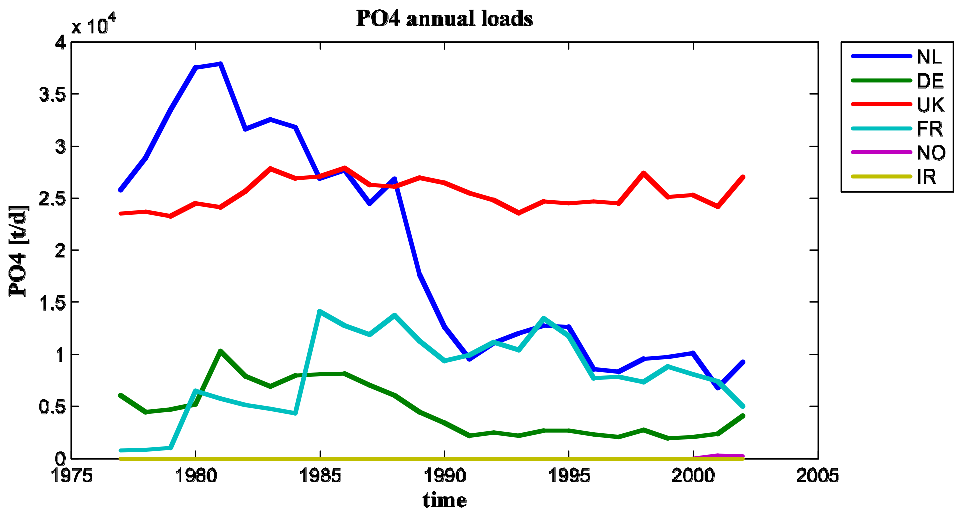
EcoQOs & measures



Measure: get to source, emission reduction N & P

- Sources: agriculture, industry, seawage treatment plants, atmosphere (N)
- 50% reduction since 1985 achieved for P (continent), not for N, not in UK





Effectiveness measures, how to determine? i.e. Max(Chl-a), min (O2)

⇨ Monitoring strategy, support by complex models

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Traditional use of model

- Setup a (deterministic) model
- Demonstrate its applicability (Calibrate / validate)
- Change some forcings
- Rerun (scenarios)
- Look at difference between scenario and base case

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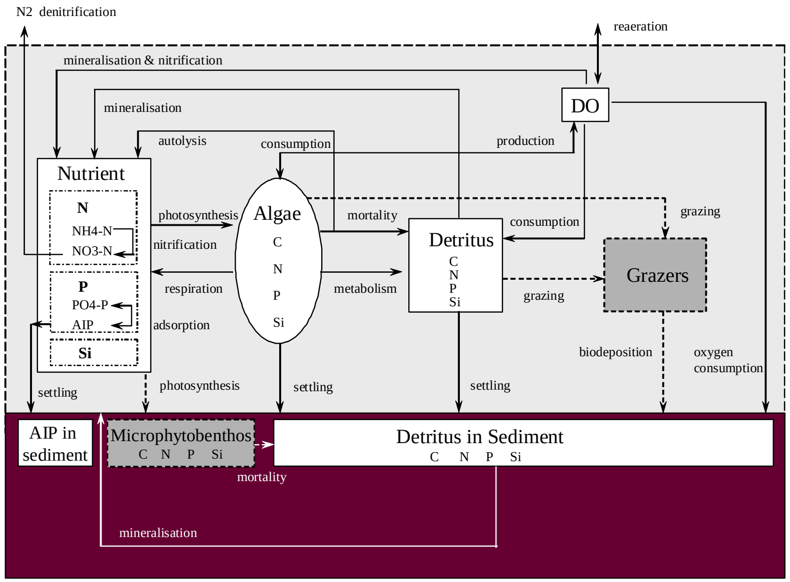
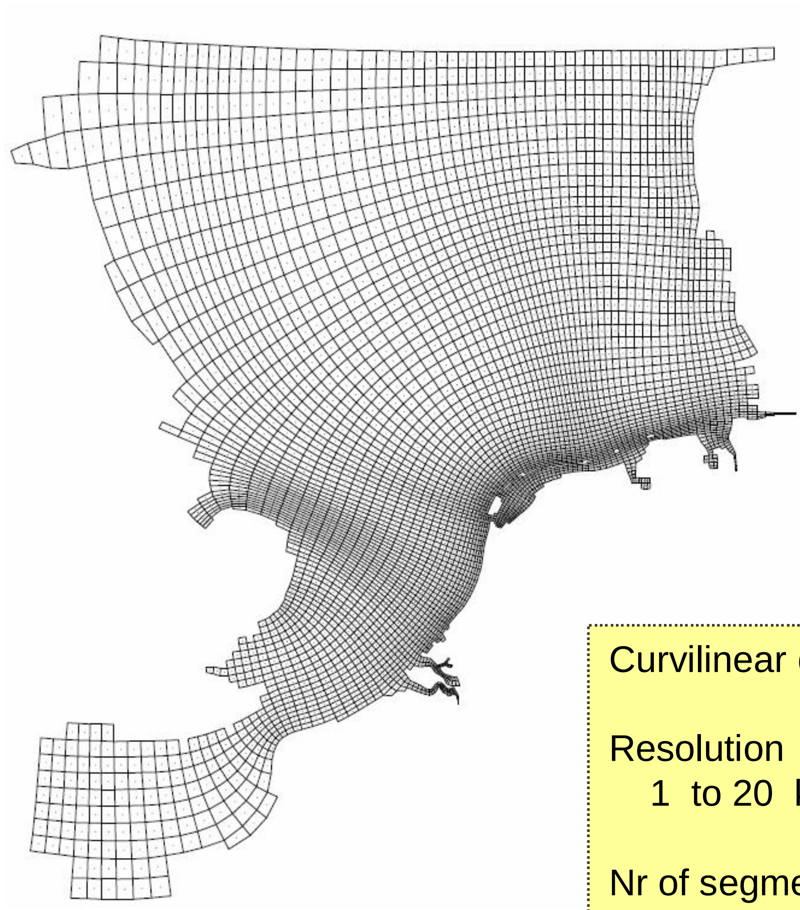
Model Setup GEM - BLOOM

GEM

- grid ZUNO-3D
- Delft3D Flow hydrodynamics
- processes Delft3D BLOOM





Curvilinear grid

Resolution
1 to 20 km

Nr of segments
10 x 4350

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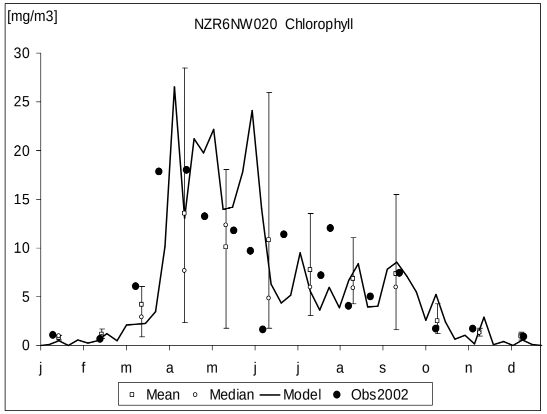
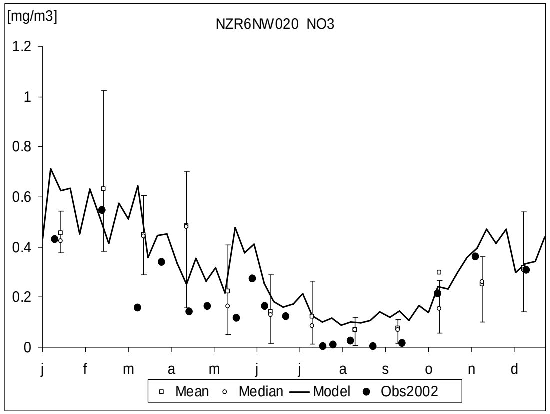
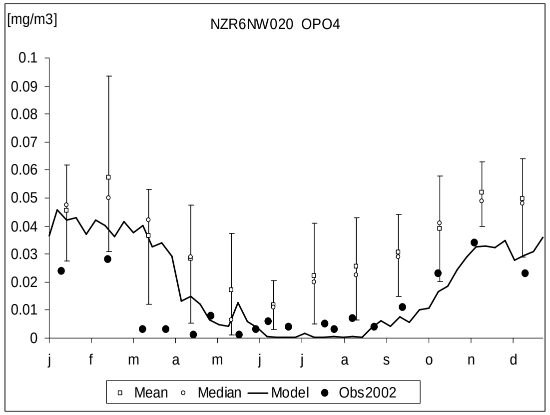
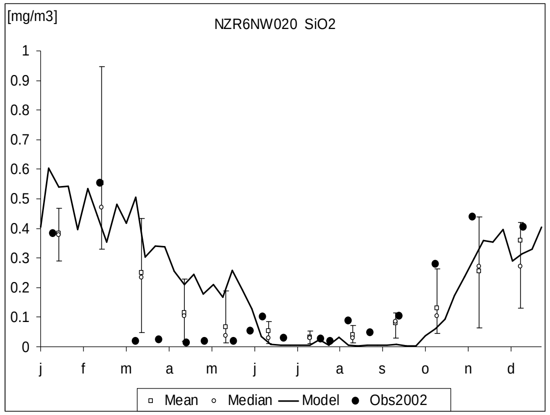
Noordwijk 20km 2002 Validation









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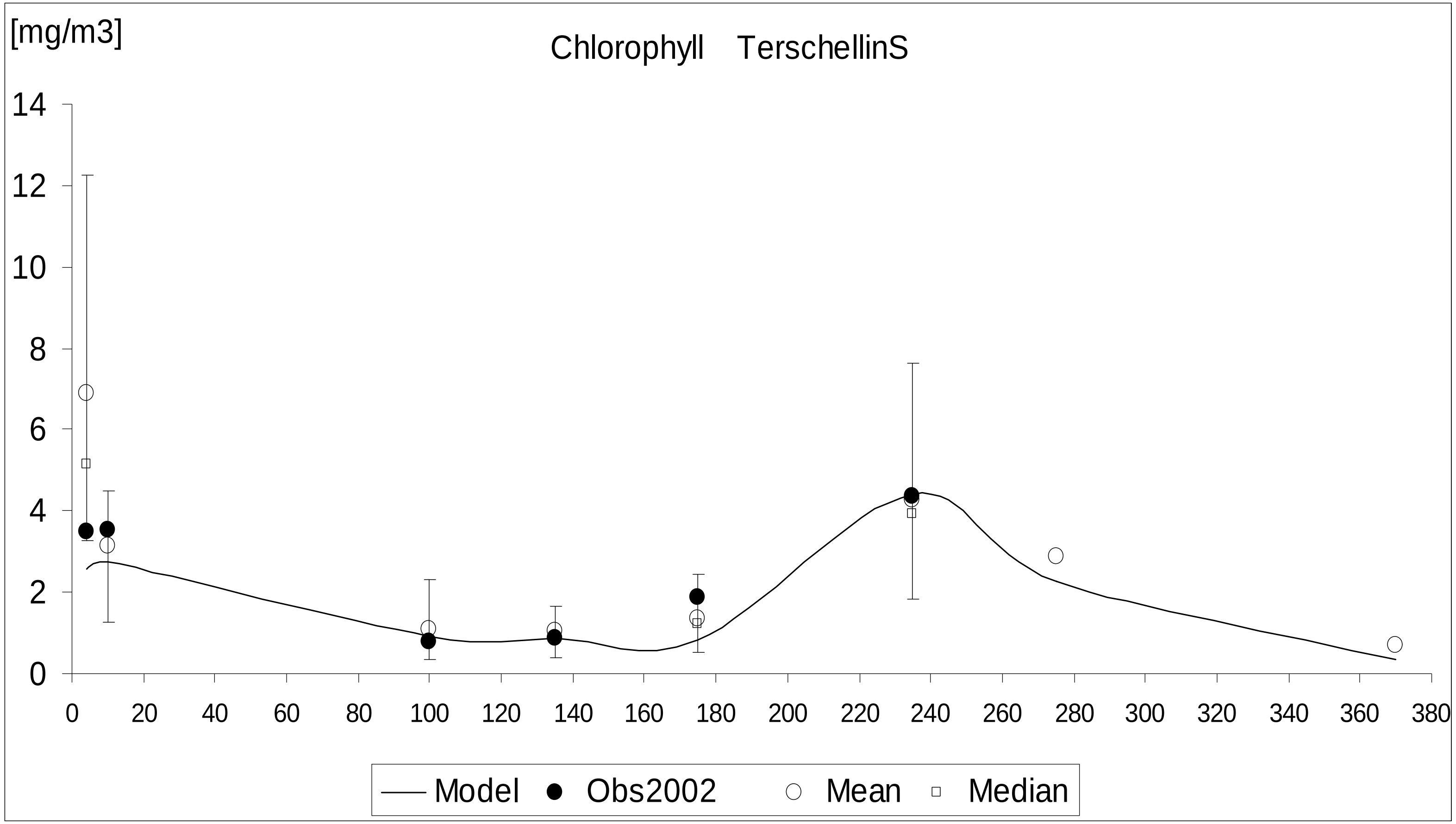
Terschelling transect 2002 March chlorophyll



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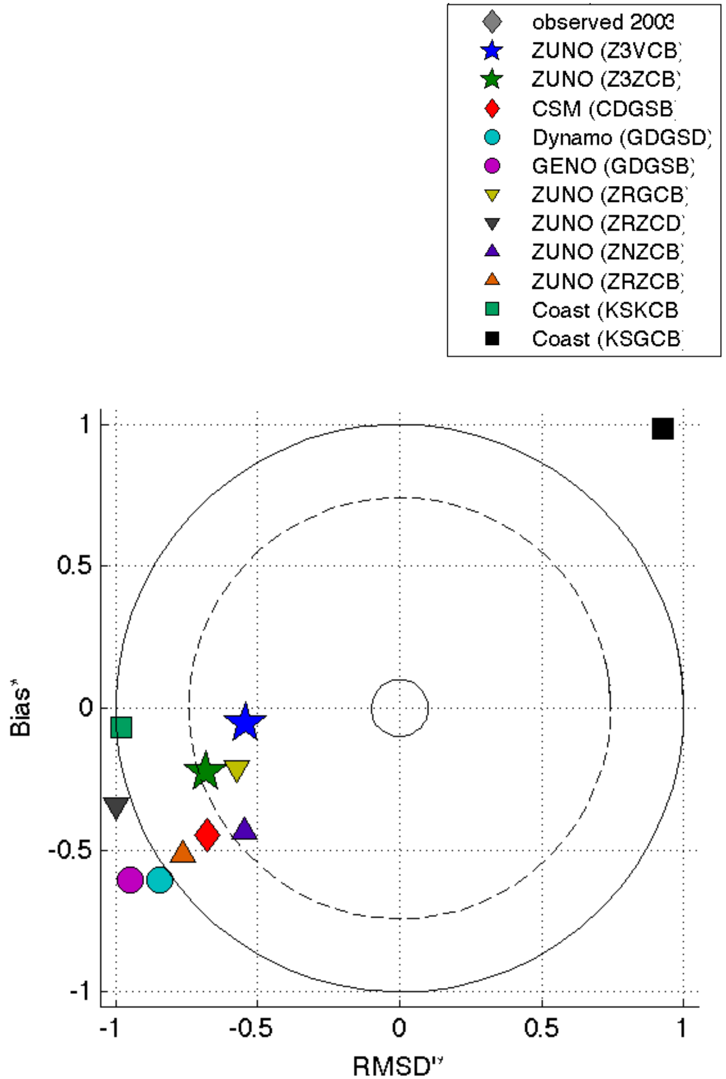
Formal GOF criterion: Target Diagram

- Time series plot: many differences
- Target Diagram: single point with information on nature of skill
- Classification of results based on statistics
  - > outside outer circle 'poor'
  - > between 2 circles 'reasonable'
  - > within inner circle 'good'

  (radius: top 15% of R^2 scores Chla, $R^2 \geq 0.45$)
- See: Los & Blaas (2010)



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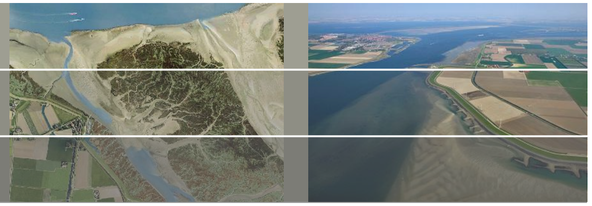
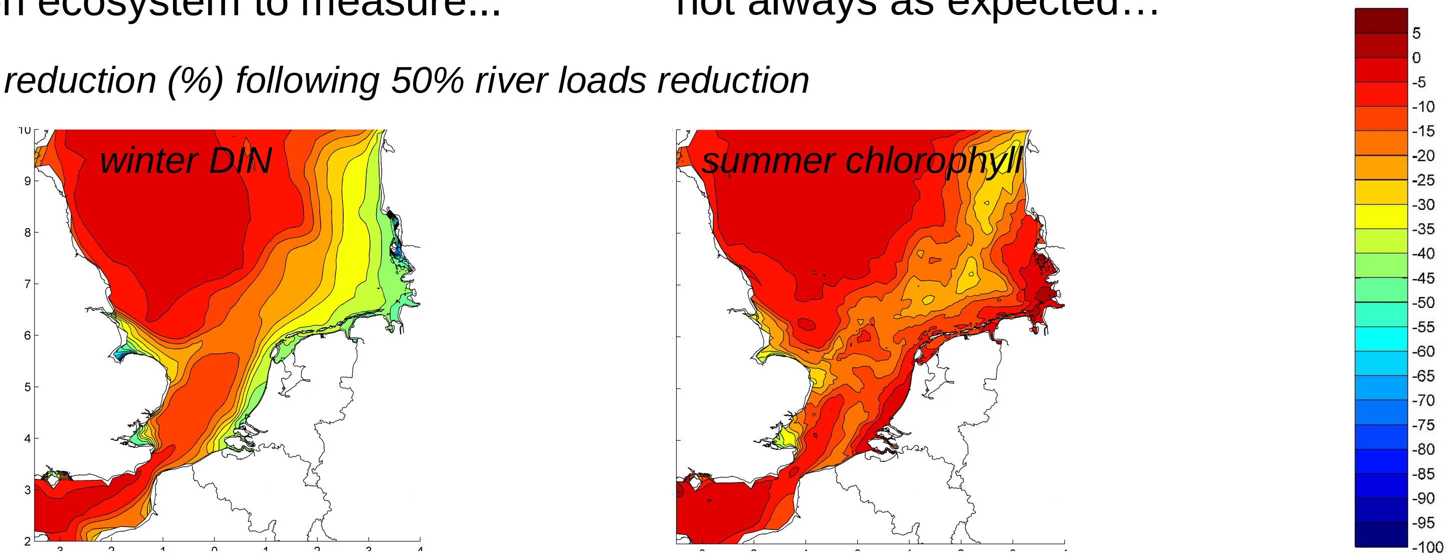
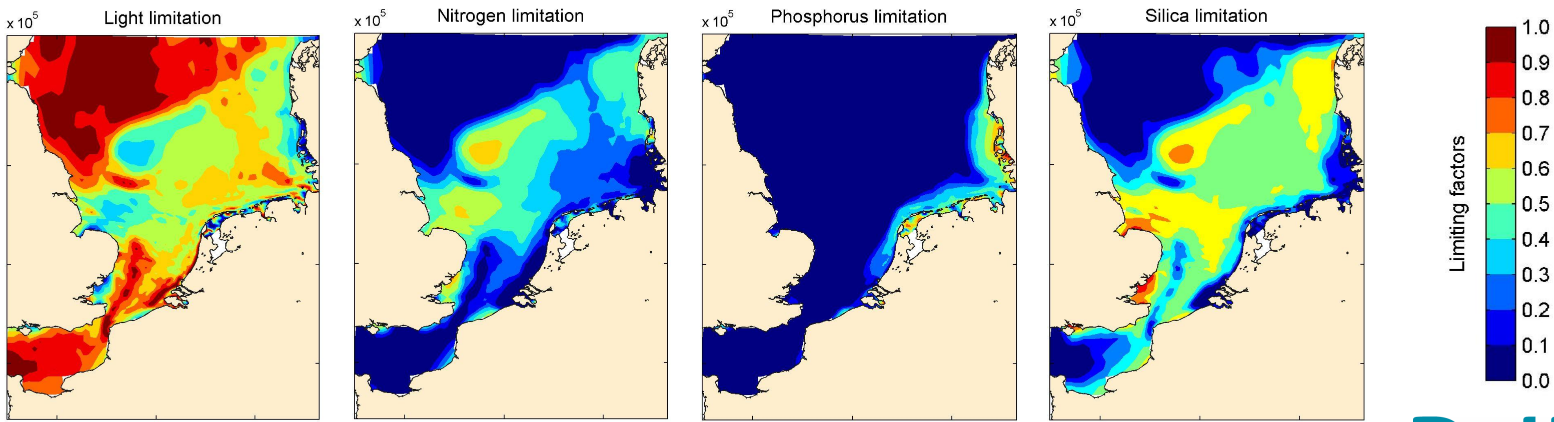
ICG-EMO Scenarios



Reaction ecosystem to measure... not always as expected…

Relative reduction (%) following 50% river loads reduction





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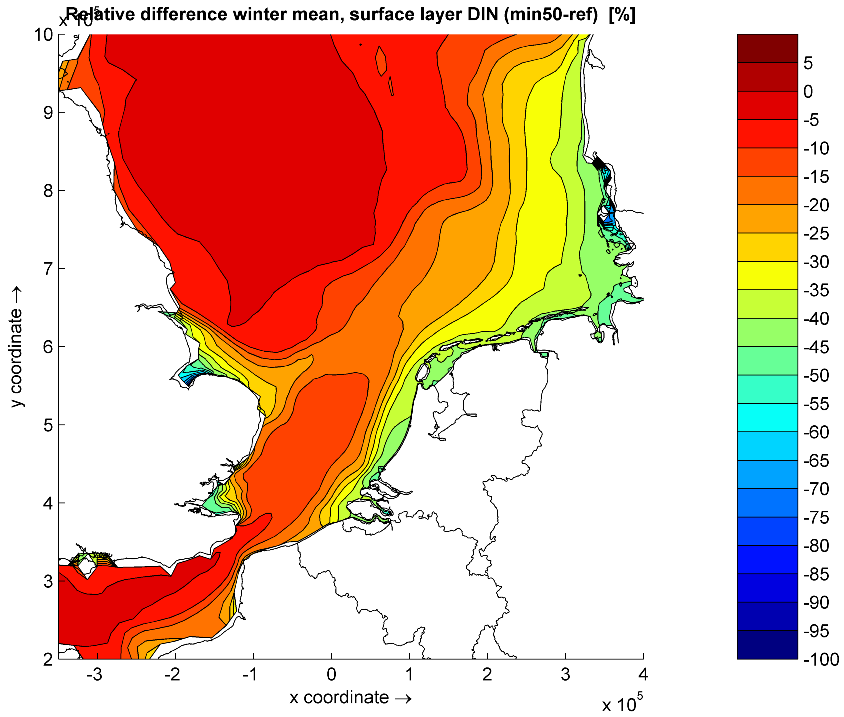
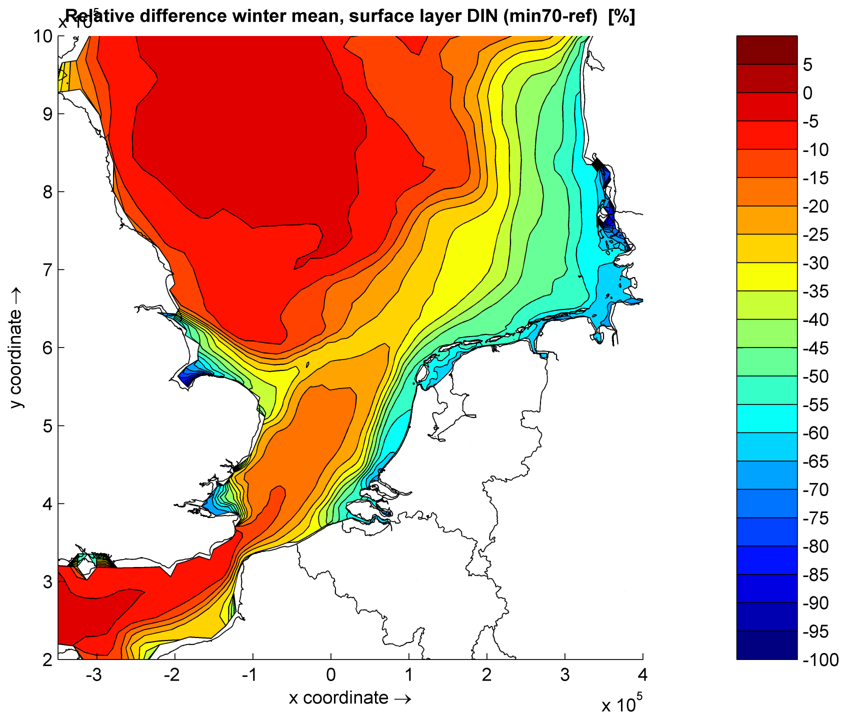
Relative Difference:
DIN: winter mean, surface layer

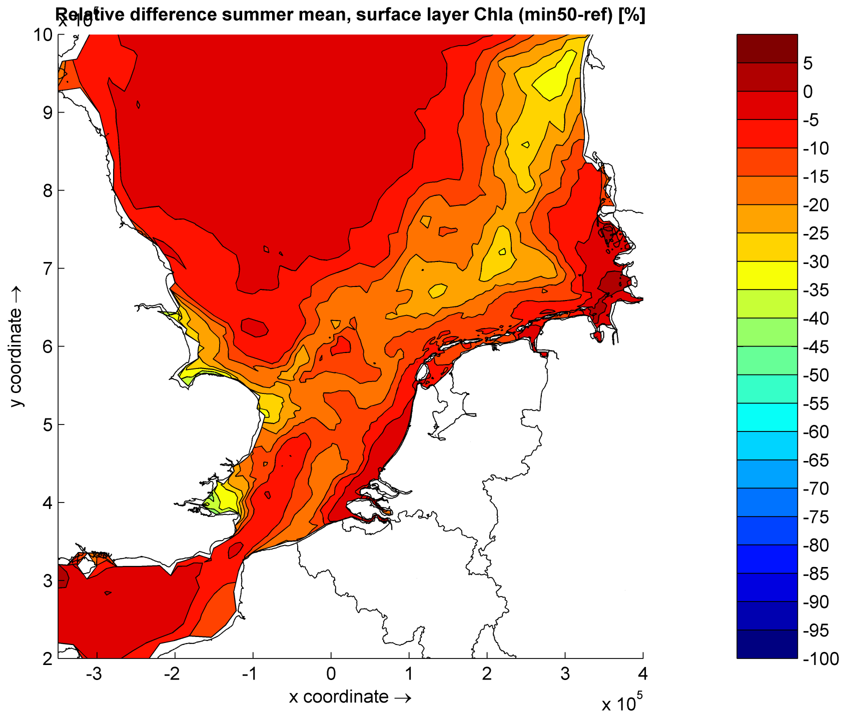


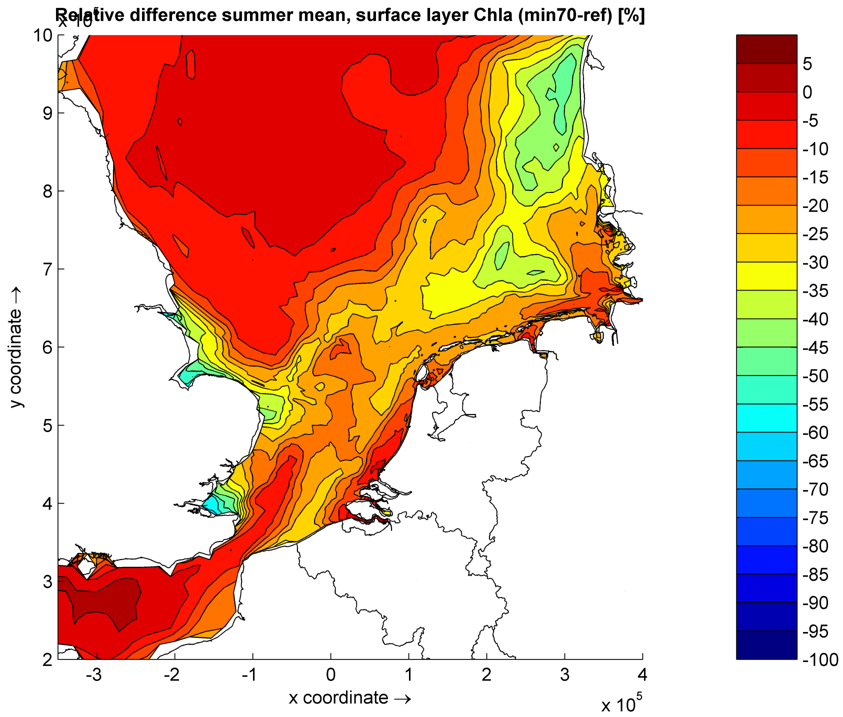


50 % reduction

70 % reduction

Relative Difference:
Chlorophyll: summer mean, surface layer





50 % reduction

70 % reduction

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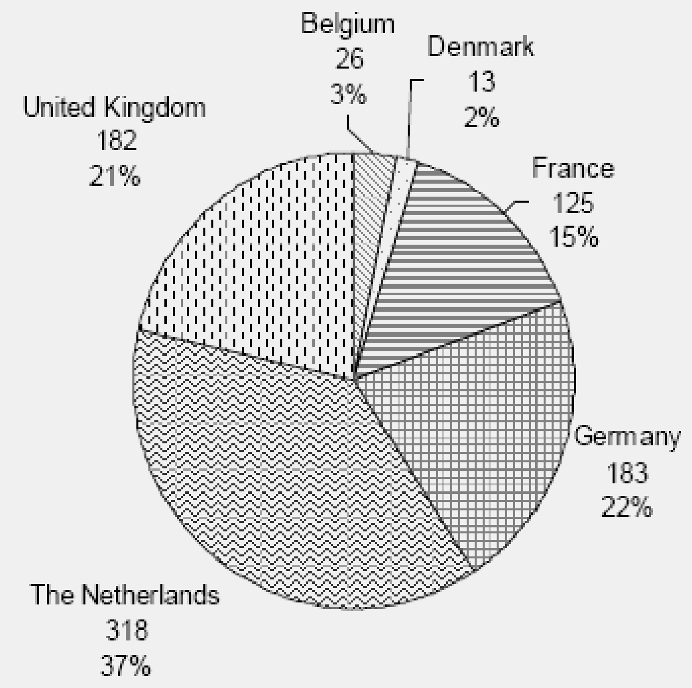
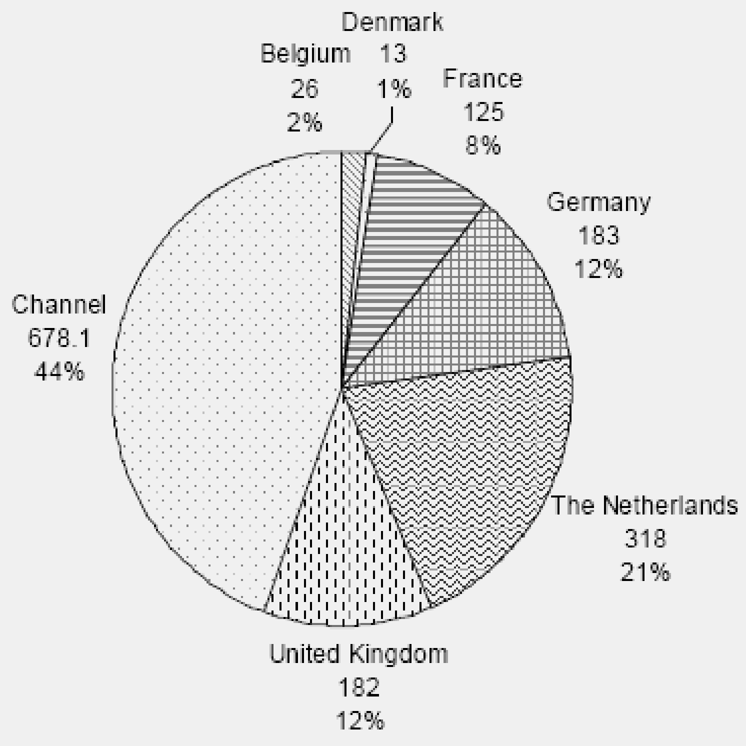
Cumulative N loads per country of discharge

Only fresh water

Including marine boundaries





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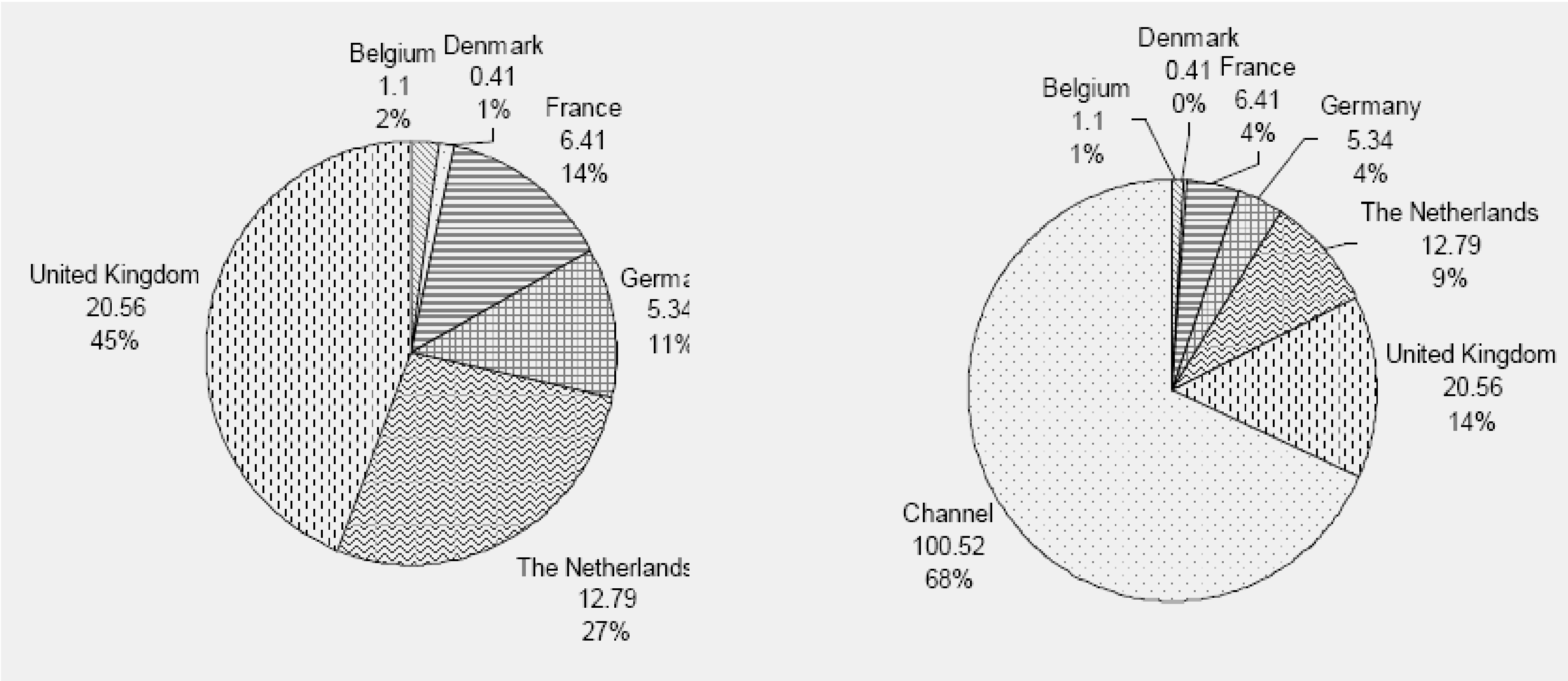
Cumulative P loads per country of discharge

Only fresh water

Including marine boundaries



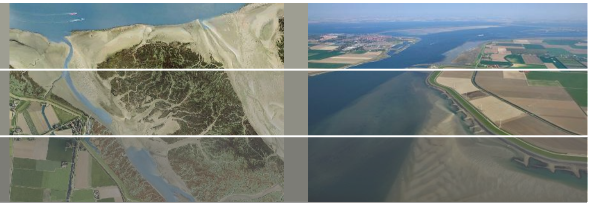
Intermediate conclusions

- Non linear behaviour (DIN reacts more strongly than Chl)
- Spatial patterns resembles freshwater discharges, but not in a simple way.
- We have info on individual sources (see fig) but we don't know their importance at various locations / areas / time periods due to non-linearities
- We need info relating individual target areas to individual sources

Conclusions

- Non linear behaviour (DIN reacts more strongly than Chl)
- Spatial patterns resembles freshwater discharges, but not in a simple way.
- We have info on individual sources (see fig) but we don't know their importance at various locations / areas / time periods due to non-linearities
- We cannot answer questions such as: ‘Is it more effective to achieve a specific target in a certain area to implement state of the art seawage treatment in the UK or to reduce agricultural sources in the Rhine basin?’

Selection of methodology



We compared three methods to relate nutrients in system to sources:

Method 1 (derivative/impulse)

- accuracy uncertain due to linearization assumption
- large number of simulations required
- will work for any model

Method 2 (look at behaviour semi-conservative substances TotalN, TotalP)

- only gives estimates on contribution of sources to Total N & P, *not* in terms of specific ecological effects (PP, Chla, …)

Method 3 (labeling)

- theoretically superior
- requires tracking fluxes through all processes
- major increase number of state variables hence simulation time

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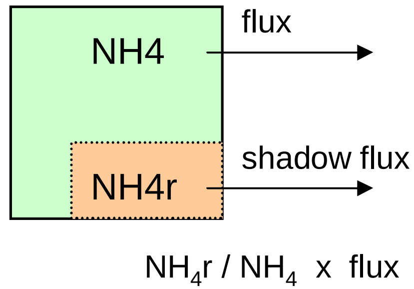
Tagging Technique (Method 3)

Principle of Tagging Method (N & P)



1) New state variables are added

NH4-r	
NO3-r	PO4-r
all organic N species -r	all organic P species –r

2) Tagged variables are inputed in specific sources (e.g. RNL1)

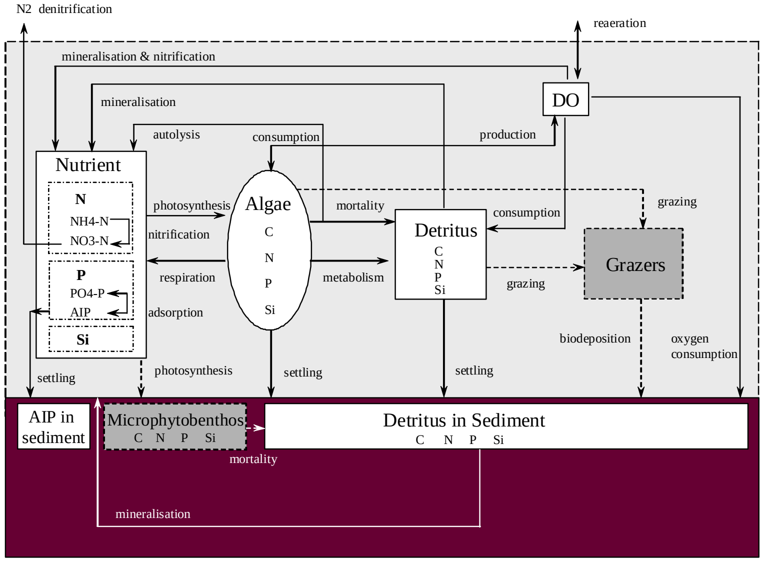
3) Shadow fluxes are computed on the basis of

- Real fluxes for corresponding untagged state variables
- Proportion of tagged to untagged variable (e.g. NH4-r/NH4)

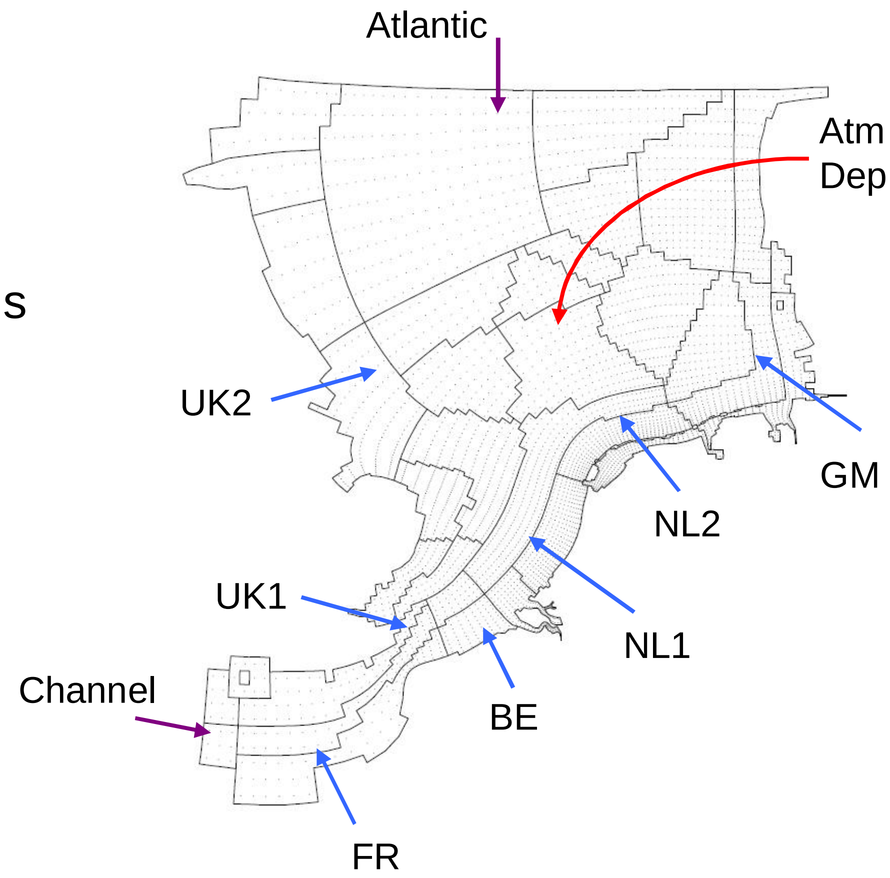
Transbounday nutrient transport

- *Tagging*: DNA profile of nutrients

- Distinction of sources
- Distinction of destination (specific locations or zones)



- *Flow* of substances through entire system can be traced in space and time



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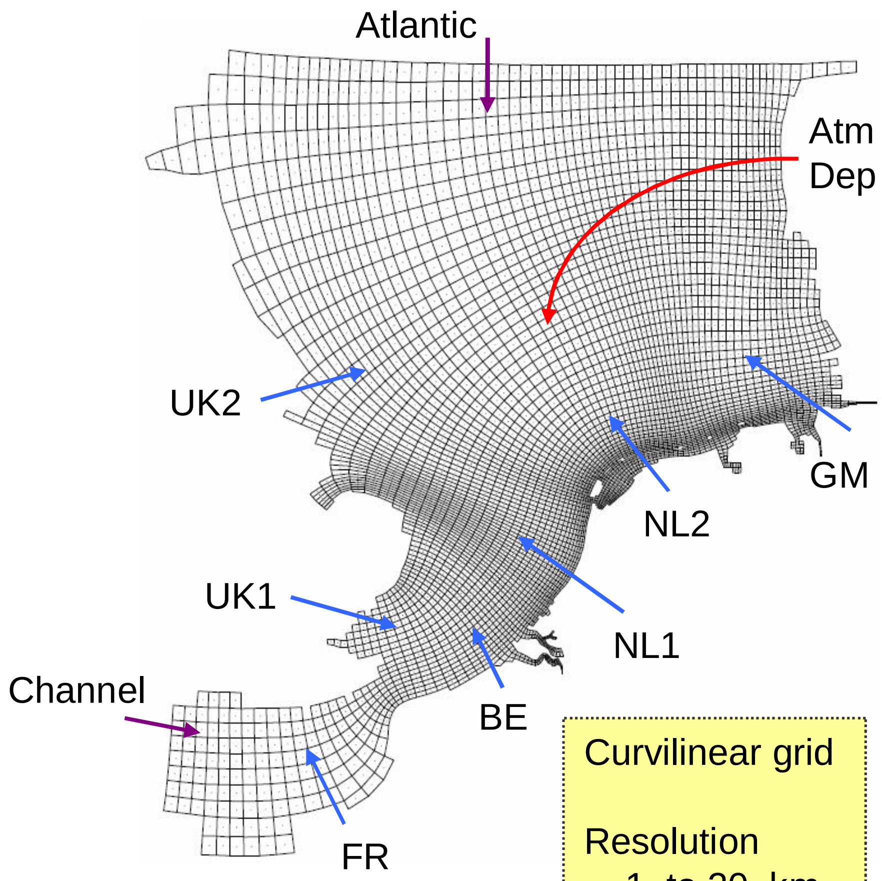
Model Setup

- GEM grid (ZUNO-3D), 3D hydrodynamic
- Boundaries from measurements
- River loads from measurements
- GEM validation in :

  Los, Villars and Van der Tol (2008)

  Los and Blaas (2009 in press)

- TBNT using tagging technique



Curvilinear grid

Resolution
1 to 20 km

Nr of segments
10 x 4350

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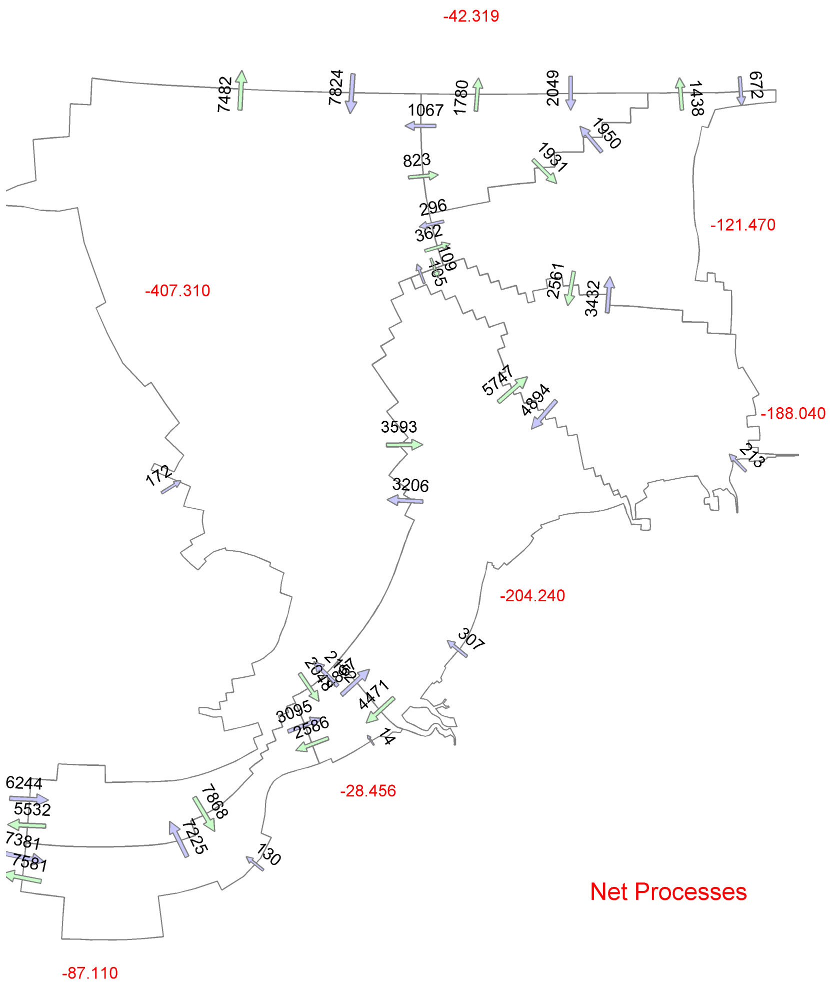
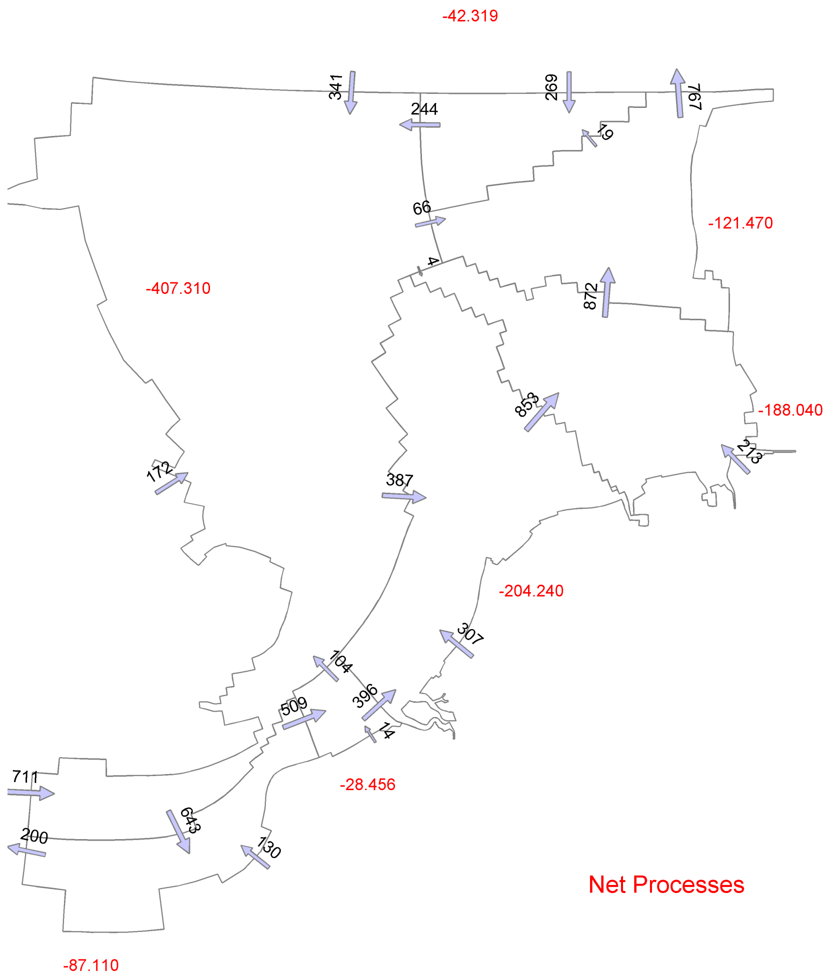
Annual transboundary fluxes of TotN (all sources)



All TotN - Gross fluxes (kTon N/yr)



All TotN - Net fluxes (kTon N/yr)

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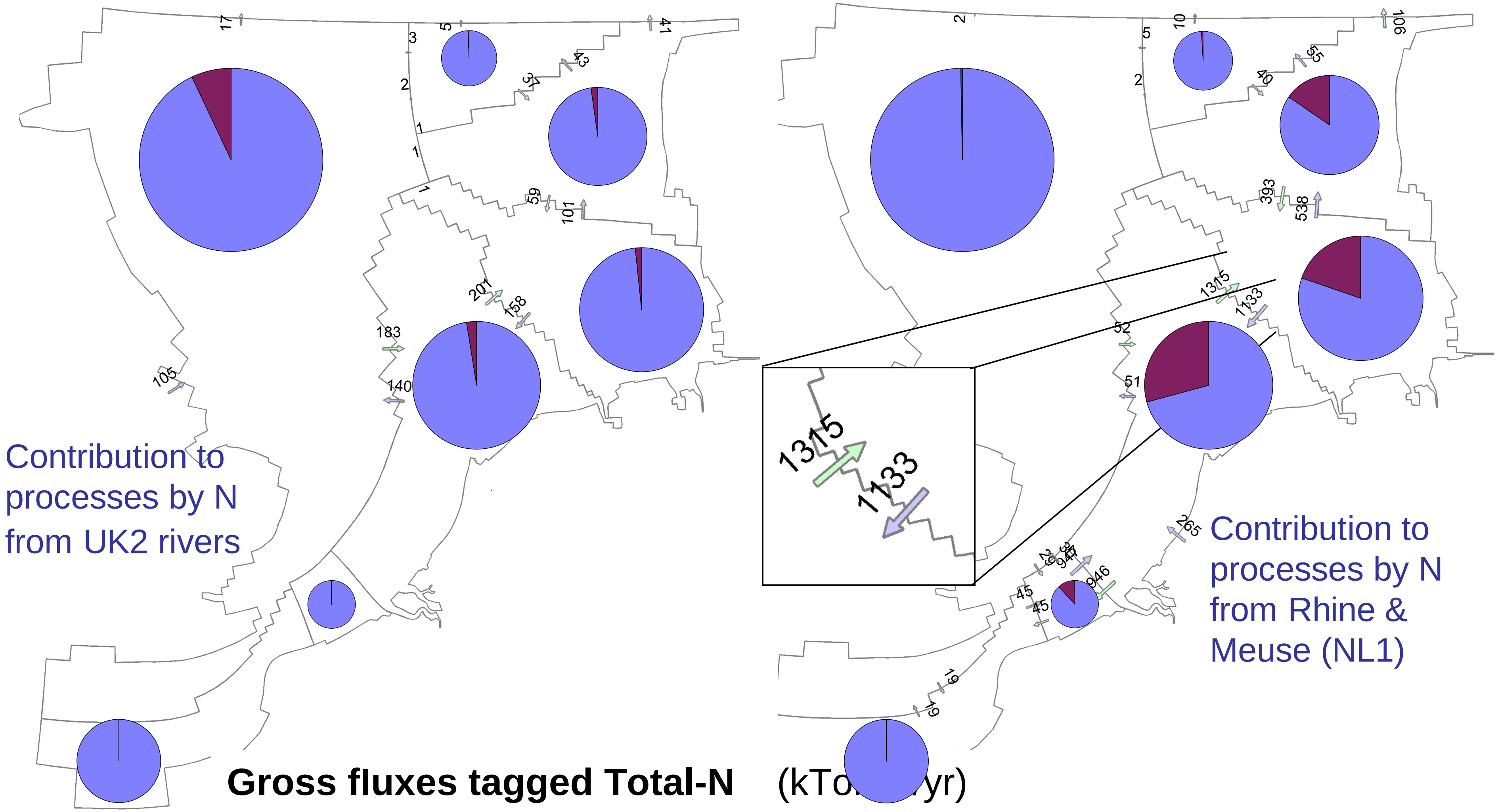
TotN from UK2 & NL1 rivers



Contribution to processes by N from UK2 rivers

Contribution to processes by N from Rhine & Meuse (NL1)

Gross fluxes tagged Total-N (kTo /yr)
Size of circle ~ total process rate (kTon N/yr)

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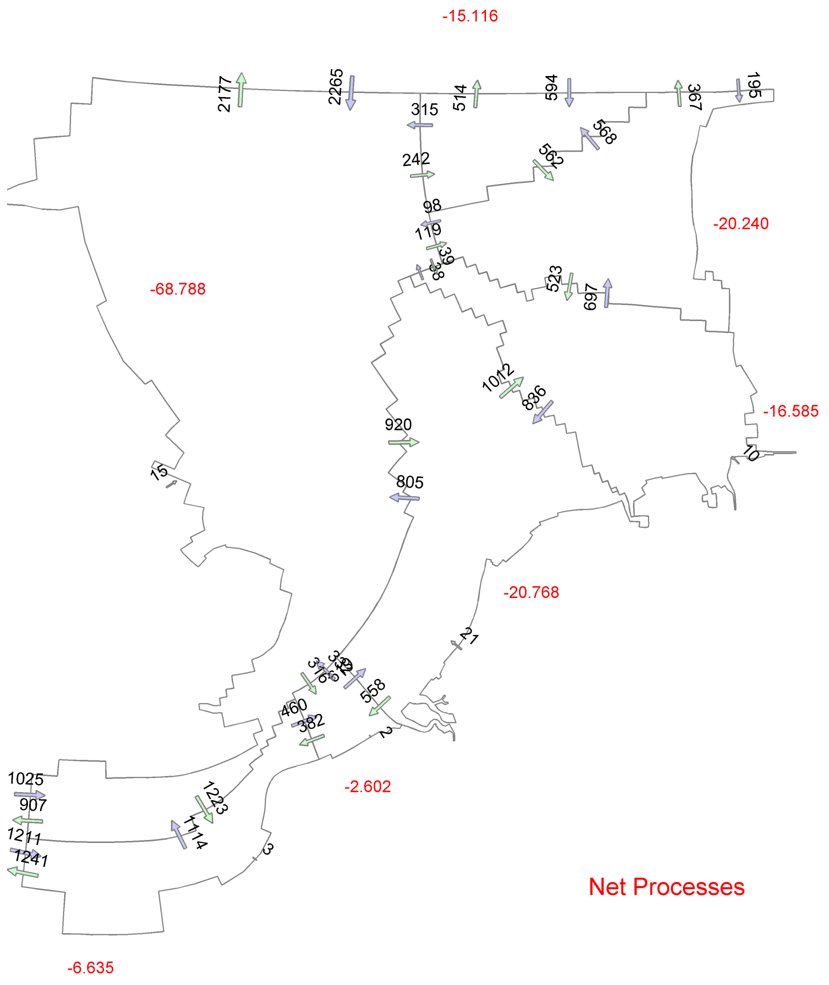
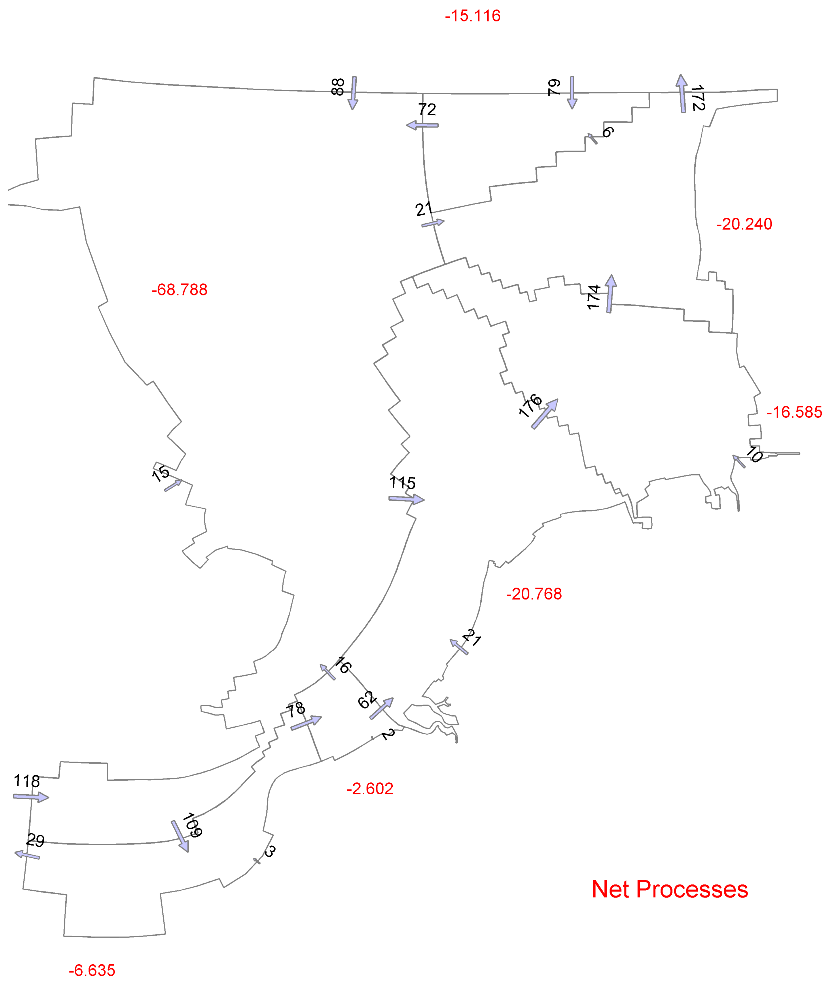
3.3 Annual transboundary fluxes of TotP (all sources)

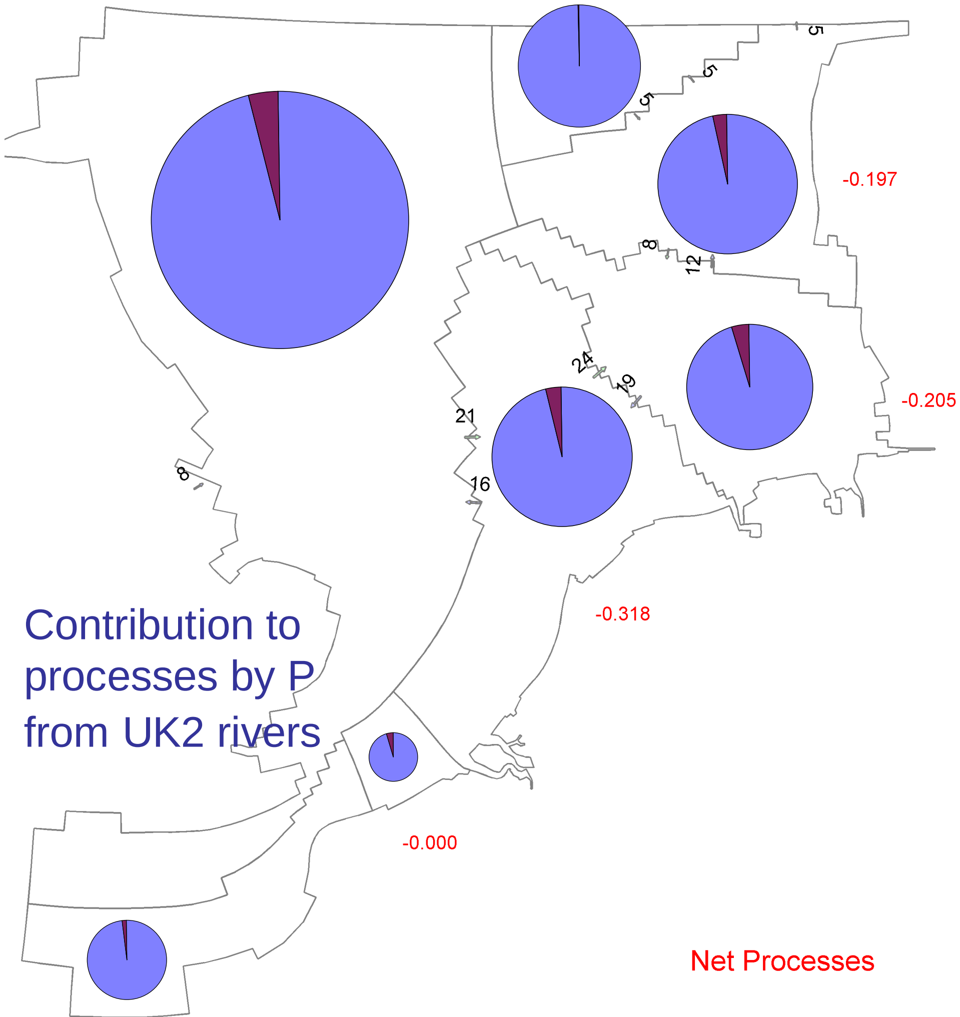


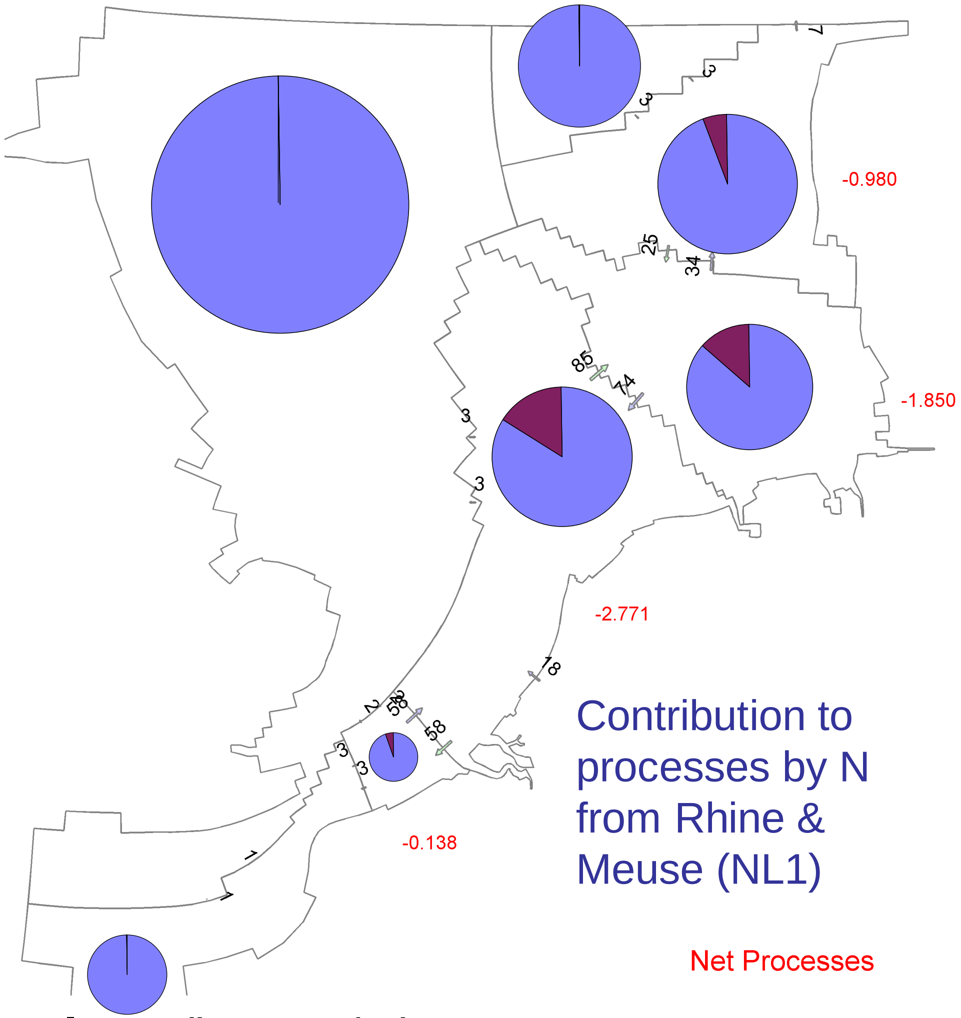
All TotP - Gross fluxes (kTon P/yr)



All TotP - Net fluxes (kTon P/yr)

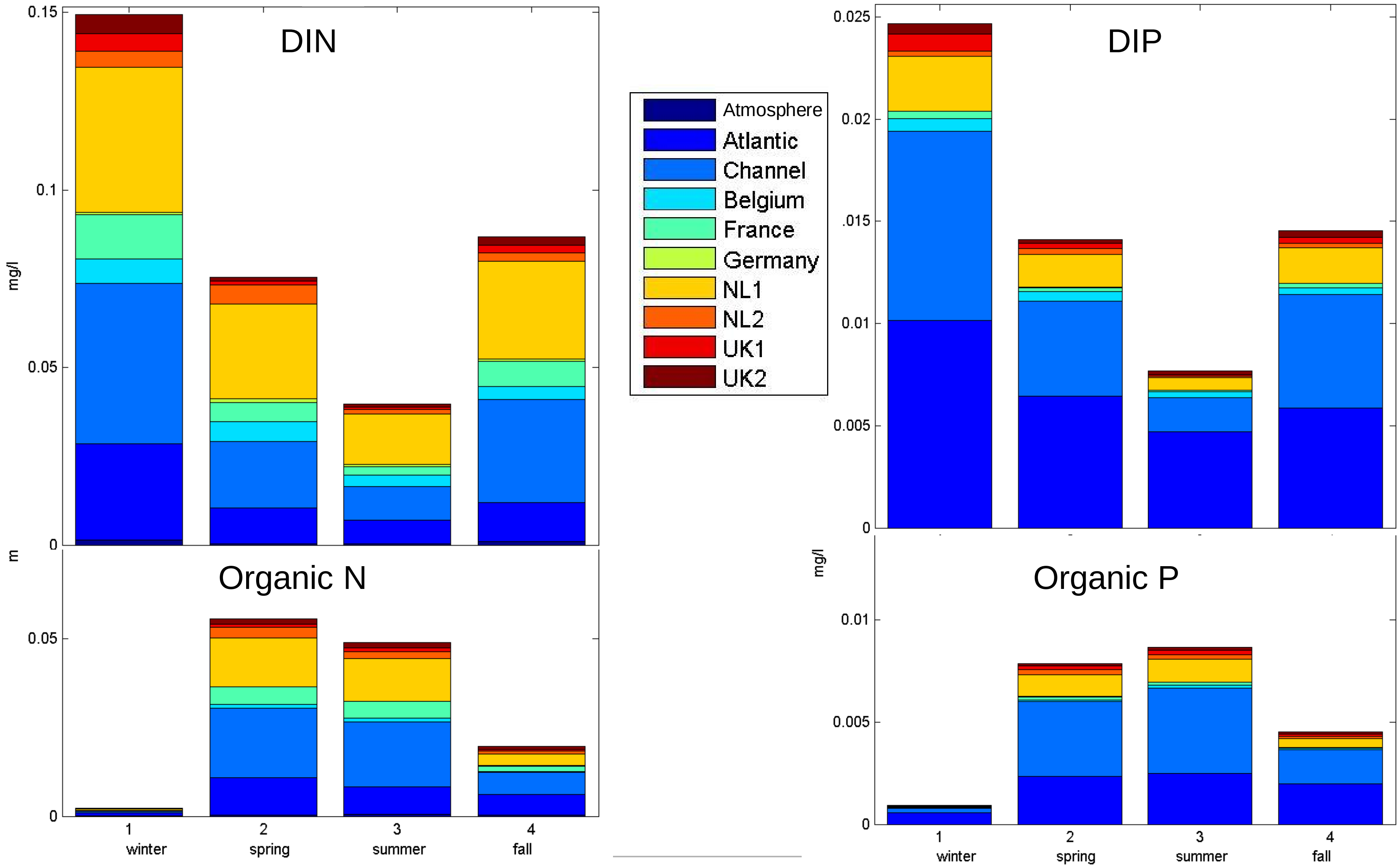
3.4 TotP tagged from UK2 & NL1 rivers





Gross fluxes tagged Total-P (kTon P/yr)
Size of circle ~ total process rate (kTon P/yr)

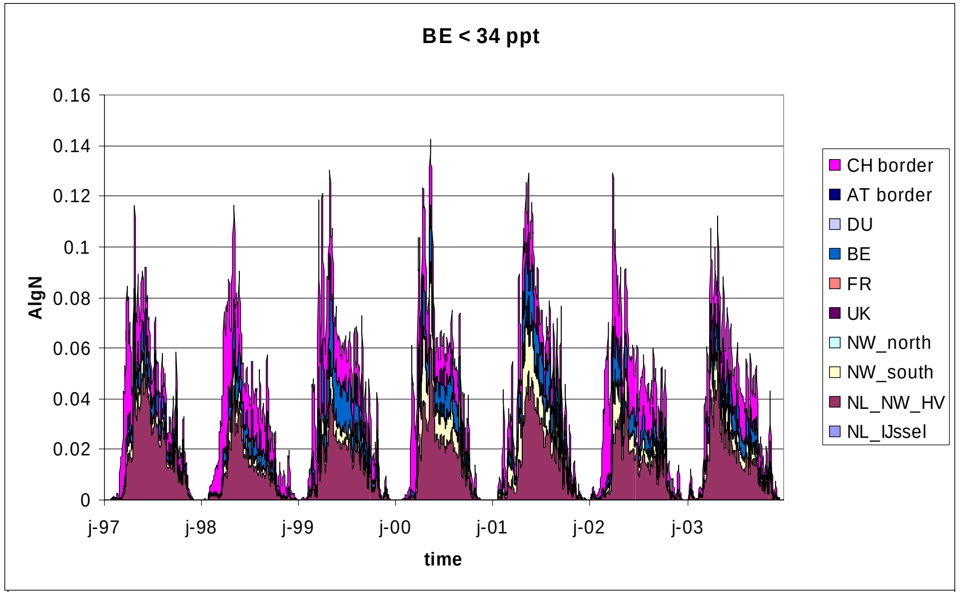
Seasonality at Dutch Continental Shelf zone

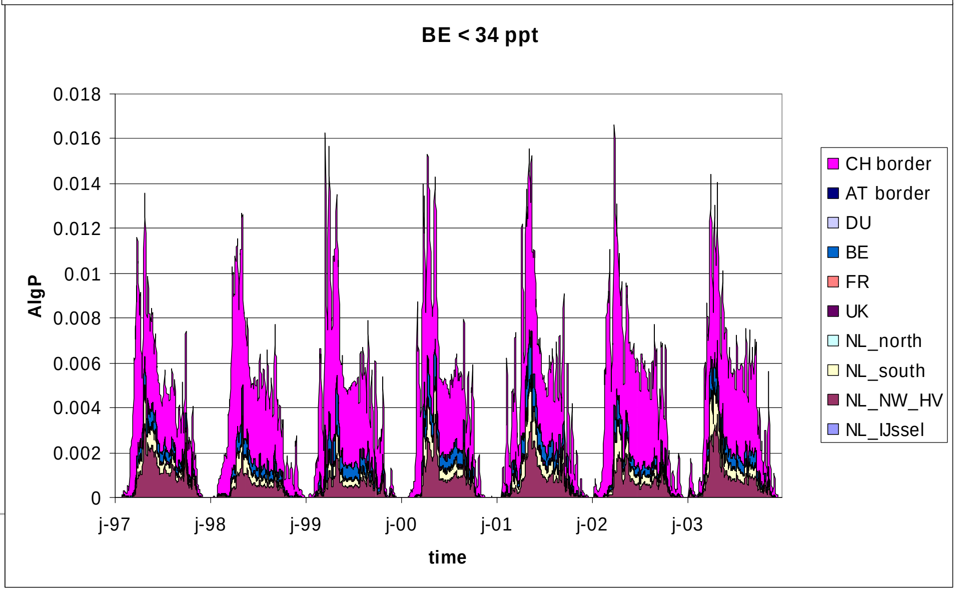


N and P in phytoplankton (high temporal resolution)

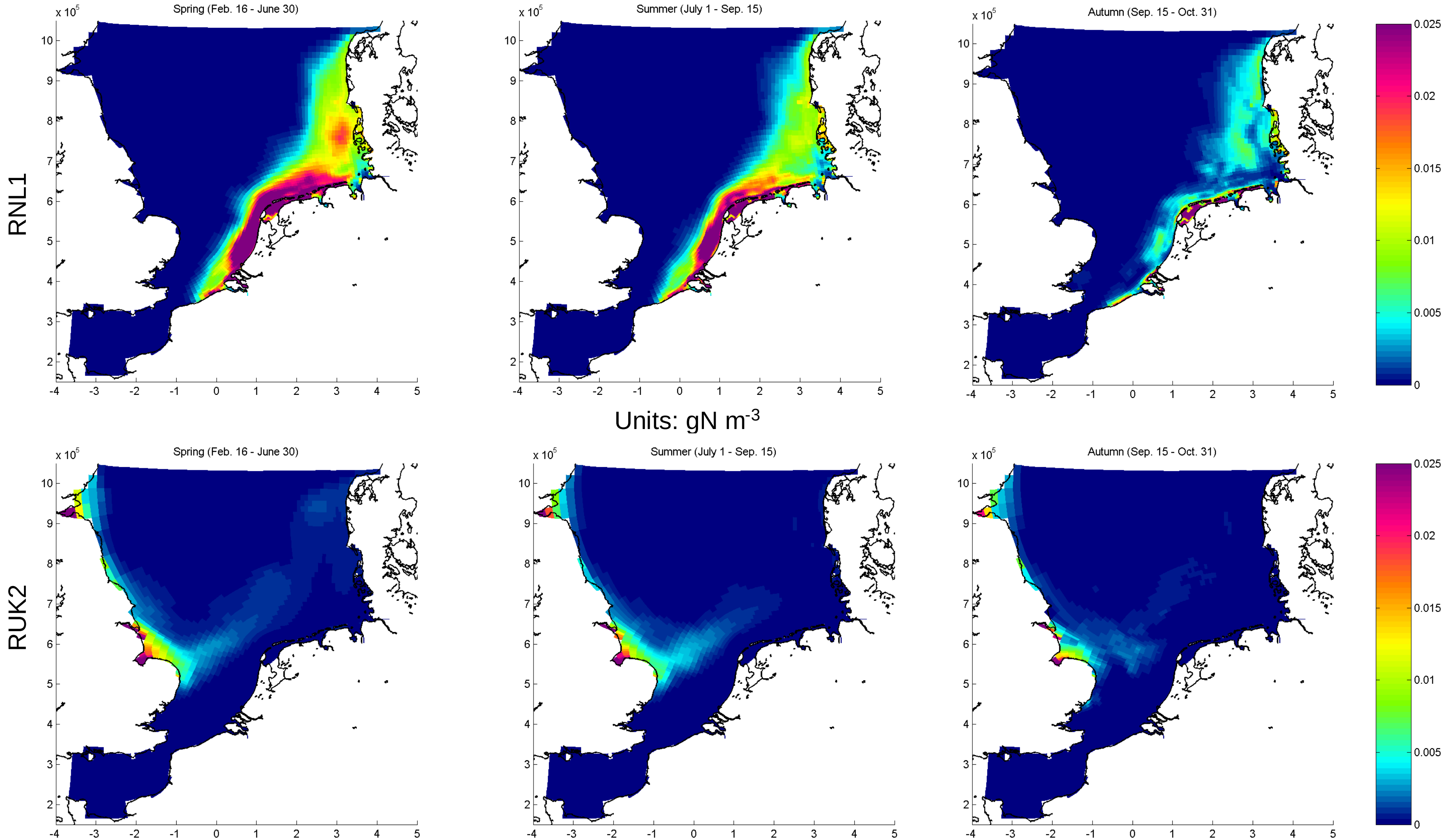
Coastal waters of Belgium

- Annual variations
- Seasonal variations
- Different sources dominant for N than for P

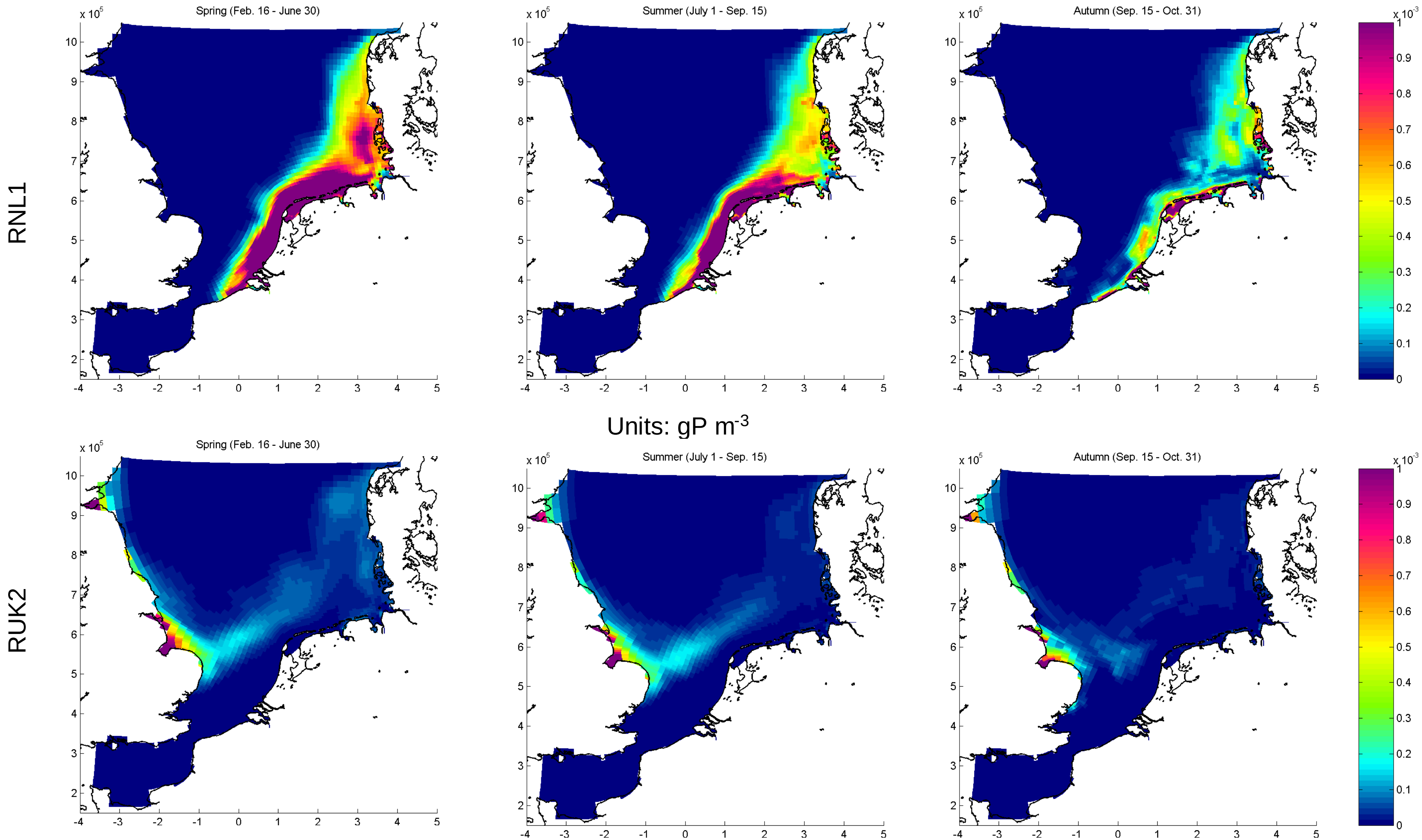




N-tagged phytoplankton (high spatial resolution)



P-tagged phytoplankton (high spatial resolution)



Conclusions (1)

➢ **Fluxes**

- Channel boundary annual mean net source for both N and P
- Channel largest individual source for both nutrients overall
- Annual import & export across N. Atlantic boundary same order of magnitude.

➢ **Processes**

- Overall North Sea: net sink for both N & P in 2002
  - riverine sources + boundary inflow + atmospheric deposition > boundary outflow
  - difference stored in sediment (N and P) or removed to atmosphere (N only)
- All national areas, except NL:
  biochemical nutrient removal > national riverine loading into areas.
- NL region: riverine loads N ~50% higher than total amount N locally processed
- For P: amount removed in the NL region ≈ riverine input
  - difference due to high N / P ratio of NL rivers

Conclusions (2)


➢ **Tagging results: contribution to processes**

- ~30% of the riverine N -input from NL rivers processed within NL region
- Significant amounts processed in GE & DK areas
  (NL river contribution locally 20 to 30% of all sources).
- Contribution NL rivers to BE region is substantial (*e.g.* TotN: 15%).
- At continental side: nutrient removal/km^2 large compared to UK area:
  - along continent, higher sources (both from rivers & Channel)
  - locally (i.e. in GE) longer residence times
  - smaller depth (enhanced reaction rates)

➢ **Temporal and spatial details**

- Many areas large & inhomogeneous
  - transboundary transports locally larger than suggested by spatial averages
  - e.g., NL Oystergrounds: UK rivers largest riverine source
- In most areas contributions of different sources vary seasonally.

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Conclusions Thanks to model support

- **Enhanced knowledge**
  - For each region and time we know contribution of each source on each parameter
  - Easier interpretation statistics for EcoQOs

- **More effective management**
  - Prognoses & scenarios
  - Focus on specific sources and substances
  - Optimalization monitoring (areas; periods)

- **Tagging technique also applicable to**
  - Other substances (silicate, contaminates, fish larvae)
  - Other regions

- **Ongoing applications**
  - KnowSeas (EU project on sustainable management)
  - OSPAR

Thanks to many (ex-) collegues!

Further reading:

- Los & Wijsman (2007)
- Los, Villars & Van der Tol (2008)
- Los & Blaas (2010)
- Lenhart et al. (2010)