APPENDIX F

Oregon Health & Sciences University Modeling Results

TOWARDS THE UNDERSTANDING OF CHANNEL DEEPENING IMPACTS

Antonio M. Baptista
Yinglong Zhang
Arun Chawla
Charles Seaton

Center for Coastal and Land-Margin Research,
Department of Environmental Science and Engineering,
OGI School of Science and Engineering
Oregon Health & Science University

1 CONTEXT AND OBJECTIVES

This investigation was conducted in the context of the Columbia River Channel Improvement Reconsultation Project, by the joint request of the U.S. Army Corps of Engineers (contracting agency), National Marine Fisheries Service, U.S. Fish and Wildlife Service, and Port of Portland.

The investigation sought to address, in a limited period of time, the following questions:

> Q1: Is there evidence to reasonably challenge the conclusion of the Waterways Experiment Station that the impact of channel deepening on salinity intrusion is small?
>
> Q2: Is there evidence to anticipate that channel deepening will significantly impact estuarine habitat opportunity?
>
> Q3: Is there evidence to anticipate that water temperature will be increased by channel deepening during Summer months?

The supporting technology consists of best available CORIE ([1], [2]) models and sensors. The use of CORIE technology is done with understanding of all parties that:

- Use is parallel to on-going code and model refinements.
- Use precedes a rigorous one-year “estuary modeling certification” research project for CORIE (now on-going, with separate funding).
- Some sub-optimal modeling choices are required to meet the time constraints of the reconsultation.

The investigation was conducted in coordination with the project managers of the four agencies listed above. Most of the results contained herein were presented and discussed in one of the following forums:

Aug. 15, 2001:	Project managers meeting
Aug. 28, 2001:	Public workshop, organized by the Sustainable Ecosystems Institute as an element of the Columbia River Channel Improvement Reconsultation Project
Sep. 27, 2001:	Project managers meeting

2 FINDINGS

Q1: Is there evidence to reasonably challenge the conclusion of the Waterways Experiment Station that the impact of channel deepening on salinity intrusion is small?

We found no evidence to challenge the conclusion that the impact of channel deepening on salinity intrusion in the estuary will be characterized by generally small numerical values (e.g., Figs. 1-6,8, 9-10). In particular, we found no evidence of significant impact on salinity intrusion upstream of Tongue Point.

Within the framework of generally small numerical differences between base and plan, spatial patterns of impact are identifiable. In particular, the plan appears to increase salinity propagation in the navigation channel, with a decrease of salinity in Grays Bay and some areas of the North Channel (e.g., Figs. 3, 6, 9-10).

Differences between base and plan may, in some small pockets within the navigation channel, reach large values (e.g., Fig. 9-10). This is generally consistent with earlier findings of the Waterways Experiment Station.

Impacts on salinity intrusion depend on prevailing conditions of river discharge. The trends described above seem to apply across the low, moderate and high river discharge conditions considered in the simulations (Fig. 12), and across a range of associated stratification regimes, although specifics of the impact will vary.

Patterns such as those of Figs. 3,6,9-10 may be used to guide management decisions, including evaluation of need and/or design of mitigation or restoration efforts, but only if model uncertainty is further reduced.

Q2: Is there evidence to anticipate that channel deepening will significantly impact estuarine habitat opportunity?

We find modest, but numerically detectable, changes in physical habitat opportunity in the estuary between base and plan. Habitat opportunity is defined as in [3], with extensions described in Figs. 13-15. Changes can have either sign (e.g., Fig. 16-21).

No credible net negative impact larger than a few hours per week was detected for the average habitat opportunity in any of the six regions (Fig. 22) considered in the analysis of [3].

- Spatial patterns of change are easier to detect for the velocity and salinity criteria than for the depth criterion.

- Based on the salinity criterion, the largest negative impacts are in the navigation channel, with the area of Grays Bay often experiencing beneficial impacts.

- Based on the velocity criterion, negative impacts are typically found in the navigation channel, while beneficial impacts are often found in the lateral bays.

The analysis of habitat opportunity was conducted only for the estuary.

Patterns such as those of Figs. 16-21 and 23 may be used to guide management decisions, including evaluation of need and/or design of mitigation or restoration efforts, but only if model uncertainty is further reduced. Fig. 23 illustrates remaining model uncertainties, representative of mid-range and high discharge conditions.

Q3: Is there evidence to anticipate that water temperature will be increased by channel deepening during Summer months?

During the Summer, ocean water is cooler than river water (e.g., Fig. 24). Any increased penetration of ocean water due to channel deepening will therefore tend to reduce rather than increase the temperature of estuarine waters.

Negative impacts of channel deepening on temperature could in theory occur in:

- regions where penetration of ocean water is inhibited in the plan(e.g., where there is a beneficial salinity habitat opportunity impact).

- shallow regions where flushing is inhibited (e.g., where there is a beneficial velocity habitat opportunity impact).

However, simulations for August 1999 do not reveal any significant impact on the maximum temperatures (Fig. 25).

3 PROCESS

The project involved, often through leverage of other on-going CORIE projects, the following inter-related steps:

- Model development and benchmarking (Section 3.1)
- Bathymetry development and analysis (Fig. 26)
- Grid generation (Fig. 27)
- Creation of plan bathymetry (Figs. 28-29)
- Gathering of input/control data from CORIE and external observations

- Computer resources expansion (4 independent 667 MHz DEC Alphas, with a shared on-line storage of 0.5 TB, were used to support this investigation)
- Limited model calibration and validation (Section 3.2)
- Creation of the simulation database (Section 3.2)
- Development of metrics of impact (Figs. 13-15)
- Assessment of model uncertainty (Section 3.2)
- Assessment of impact based on multiple metrics (Section 2)

3.1 Model development and benchmarking

The numerical model used in this project is ELCIRC ([4] and modifications thereof). ELCIRC solves the 3D shallow water equations using a Eulerian-Lagrangian finite volume method inspired on [5].

ELCIRC is a recent model, still undergoing enhancements and benchmarking through funding from the National Marine Fisheries Service, U.S. Fish and Wildlife Service, Office of Naval Research and National Science Foundation. Several significant changes were introduced to ELCIRC during the period of this project, often influenced by the experience acquired by the present model application. A partial list of key modifications includes:

- Version 3.0: (a) Redefinition of the location of definition of several primary variables within the elements. Variables are now defined as follows: horizontal velocities at side centers; vertical velocity, salinity, temperature and water levels at element centers. Benefit: internal consistency, mass conservation. (b) Multiple representations of vertical mixing were added, including [6] and [7]. Benefit: physical realism, conditional to appropriate parameterization.
- Version 3.1: Solution of the transport equation for salinity and temperature was changed from an interpolation Eulerian-Lagrangian method (ELM) to an integration ELM. Benefit: mass conservation (e.g., see discussion in [8]);
- Version 3.6: An ITPAK solver was adopted to solve linear systems of equations. Benefit: robustness, efficiency.
- Version 3.9: (a) Boundary conditions were imposed to the momentum equation prior to substitution in the 3D continuity equation. Benefit: preservation of horizontal fluxes, via minimization of lateral leakage. (b) Incorporation of water-air exchanges in the heat budget, including links to global models. Benefit: improved representation of temperature.

Consistently with the principle of adapting best-available technology at any given time, several different versions of ELCIRC were used to produce simulations. There are enough differences between ELCIRC3.9 and ELCIRC3.1 that the two model versions should have been calibrated separately. However, because of time constraints, only ELCIRC3.1 was systematically calibrated.

3.2 Model application

3.2.1 Simulation database

In addition to a large number of specific-purpose runs, four versions of the simulation database were developed. Each version covered a different sub-set of the target runs, and differed from the others by the ELCIRC version and/or computational choices made for the simulations. A summary follows:

Version	Grid	Coverage	Δt (min)	Heat balance
1	Multiple	May 97, May 01, Jul 01 (all partial)	7.5, 15	no
2	Production/Longview	May 97, May 01, Jul 01 (comprehensive)	7.5	no
3	Production/Longview	May 97, Aug 99 (first week of each month)	2.5	no
4	Production/complete	May 97, Aug 99 (first week of each month)	7.5	Only for Aug 99

3.2.2 Modeling choices

Version 1 of the simulation database was designed to explore sensitivities to various choices of domain, numerical parameters, and physical parameters. Results led to the following modeling choices in subsequent versions of the database, often reflecting concessions to the time constraints of the reconsultation process:

- The *production* grid was chosen over the *fine* grid (Fig. 27) for versions 2-4 of the simulation database. While the level of resolution of the *fine* grid is preferable from a numerical viewpoint, the fine grid was prohibitively expensive for this project.

- Longview, rather than Bonneville and Willamette Falls, was the default upstream boundary of the computational domain (Fig. 27). This choice was initially dictated by a deficiency in the bathymetric database (Fig. 26), but was retained through versions 1-3 of the simulation database, for considerations including: (a) the need to keep computational costs low, (b) lack of time for an appropriate calibration of the levels and flows upstream of Longview, and (c) concerns on lateral flow leakage in narrow, coarsely resolved parts of the domain (resolved in ELCIRC3.9, see latter part of this section).

- We chose a default time step of 7.5 minutes. This choice, coupled with the choice of the production grid, limited our ability to represent strong stratification. In version 3 of the simulation database, we used a smaller time step (2.5 minutes) to enable stratification to develop more realistically.

- Different representations of friction were used downstream of the Astoria-Megler Bridge and upstream of Tongue Point. We typically used drag coefficients of 0.0025 downstream the bridge, and 0.0045 or 0.0065 upstream of Tongue Point, with a linear transition in-between. This approach is consistent with Hamilton (reference), although he used a lower coefficient (0.0011) downstream. Hamilton's rationale for a bi-modal representation is based on known differences in bottom characteristics.

- We chose a simplified parameterization of the vertical mixing, inspired in [7].

A thorough calibration and validation of the model was beyond the time constraints of this project. Limitations of our calibration include (a) lack of differentiation of friction coefficients between channels and shallow or intertidal regions, and (b) simplistic parameterization of local vertical mixing, (c) lack of optimization of the grid based on internal error metrics of the model, and (d) lack of significant recalibration after replacement ELCIRC3.1 by ELCIRC3.9 (in version 4 of the simulation database).

Figs. 31a-h show comparisons between simulations and observations at multiple CORIE stations (Fig. 30), for July 2001 (week 27), one of the low flow conditions. These figures are illustrative of the best matches obtained between simulations and observation data. Fig. 32 illustrates, for a higher river discharge condition (1999, week 31) the type of match that was considered acceptable under more strongly stratified conditions.

Three key factors appear to be necessary for this type of match: correct local fluxes, low vertical noise, and adequate parameterization of friction. The first factor appears to be inherently guaranteed in ELCIRC3.9 (but not in ELCIRC3.1). Taming the vertical noise requires, for the production grid, very small time steps (version 3 of the database) – a better optimized grid is a more effective alternative, but out of the scope of this project. Adequate parameterization of friction is a straightforward process, successfully done for critical simulations in version 2 (including the simulation shown in Figs. 31a-h).

Modeling choices have direct implications on modeling error and uncertainty. Key examples are:

- The grid resolution was insufficient to avoid artificial vertical mixing at the tidal inlet, for the default time step of 7.5 minutes. Stratification was therefore under-represented in most runs, with the exception of version 3 simulations (where the time step was 2.5 minutes) – Figs. 33a-c.

- Setting the upstream boundary conditions at Longview was limiting in two ways. First, we lost strict control of the actual river discharge, because the only condition that could be realistically imposed there were water levels. Second, because the deepening extends to Longview, imposing the same levels for base and plan do not assure the same river discharges. Versions 1 and 3 of the simulation database are substantially affected by this problem. The problem was minimized in version 2 (by forcing the same depth in base and plan in the immediate vicinity of Longview) and solved in version 4 (by using Bonneville dam and Willamette Falls as upstream boundary conditions).

Algorithmic details in the numerical codes also have direct implications on modeling error and uncertainty. A key example is the imposition of land boundary conditions in the momentum equation prior to (rather than after) its substitution into the continuity equation. Prior imposition (as in ELCIRC3.9) leads to excellent mass and flux preservation, while posterior imposition (as in ELCIRC3.1) allows resolution-dependent water leakage through complex lateral boundaries. In the latter case, mass balances are respected, but flux preservation is controlled by spatial and temporal resolution.

It is relevant to note that, although the absolute model results changed with the different modeling choices (boundary conditions, time step, etc.), the resulting negative impacts of the plan remained consistently of small numerical magnitude across modeling choices. In a context of small-magnitude differences, spatial patterns of difference between base and plan are, however, sensitive to the actual modeling choice, in particular when stratification is underestimated (e.g., Fig. 23).

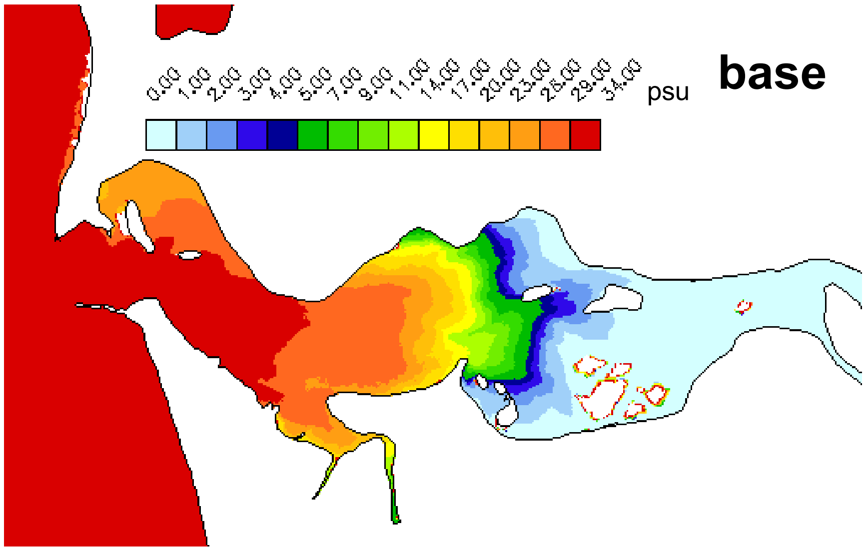
3.2.3 Computational costs

All simulations were conducted in four independent 667 MHz DEC alpha workstations. Using a time step of 7.5 minutes, computational costs per week of simulation were 29h, 33h and 49 h, respectively, for the production grid cut at Longview, the complete production grid, and the fine grid cut at Longview. Costs increased essentially linearly by reducing the time step from 7.5 minutes to 2.5 minutes.

REFERENCES

1. Baptista, A.M., et al., *Coastal and estuarine forecast systems: a multi-purpose infrastructure for the Columbia River*, in *Earth System Monitor*. 1999, Environmental Information Services, National Oceanic and Atmospheric Administration: Washington, D.C. p. 1-2, 4-5, 16.
2. Baptista, A.M., *Modern paradigms for modeling and visualization of environmental systems*, in *Encyclopedia of Physical Science and Technology*, R.A. Meyers, Editor. 2001 (in press), Academic Press.
3. Bottom, D.L., et al., *Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon*. 2001: National Marine Fisheries Service.
4. Myers, E.P.I. and A.M. Baptista. *Baroclinic Modeling of River-Dominated Tidal Inlets and Plumes*. in *XIII International Conference on Computational Methods in Water Resources (Abstract)*. 2000. Calgary, Alberta, Canada.
5. Casulli, V. and P. Zanolli. *A Three-Dimensional Semi-Implicit Algorithm for Environmental Flows on Unstructured Grids*. in *Institute for Computational Fluid Dynamics Conference on Numerical Methods for Fluid Dynamics VI*. 1998.
6. Mellor, G.L. and T. Yamada, *Development of a turbulence closure model for geophysical fluid problems.* Rev. Geophys., 1982. **20**: p. 851-875.
7. Pacanowski, R.C. and S.G.H. Philander, *Parameterization of vertical mixing in numerical models of tropical oceans.* Journal of Physical Oceanography, 1981. **11**: p. 1443-1451.
8. Oliveira, A. and A.M. Baptista, *A comparison of integration and interpolation Eulerian-Lagrangian methods.* Int. J. Num. Meth. in Fluids, 1995. **21**: p. 183-204.

(a)



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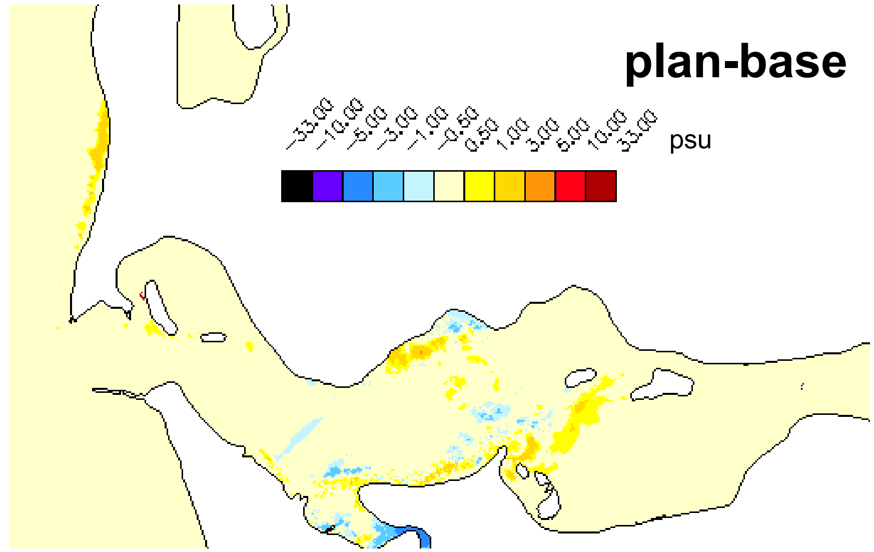

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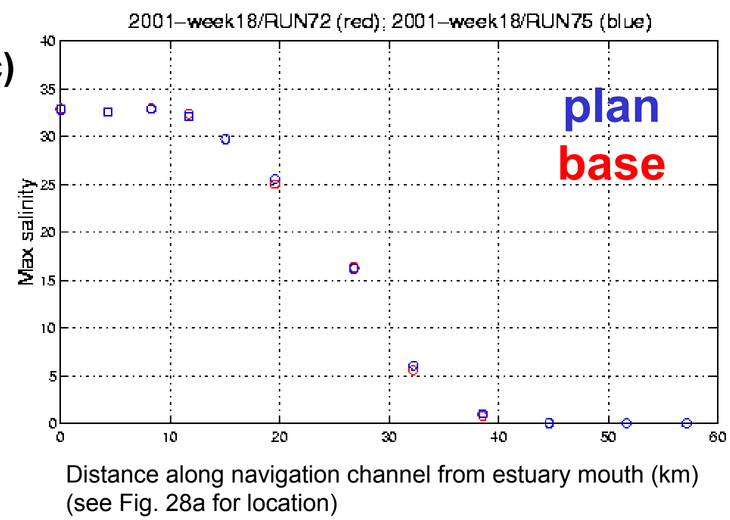
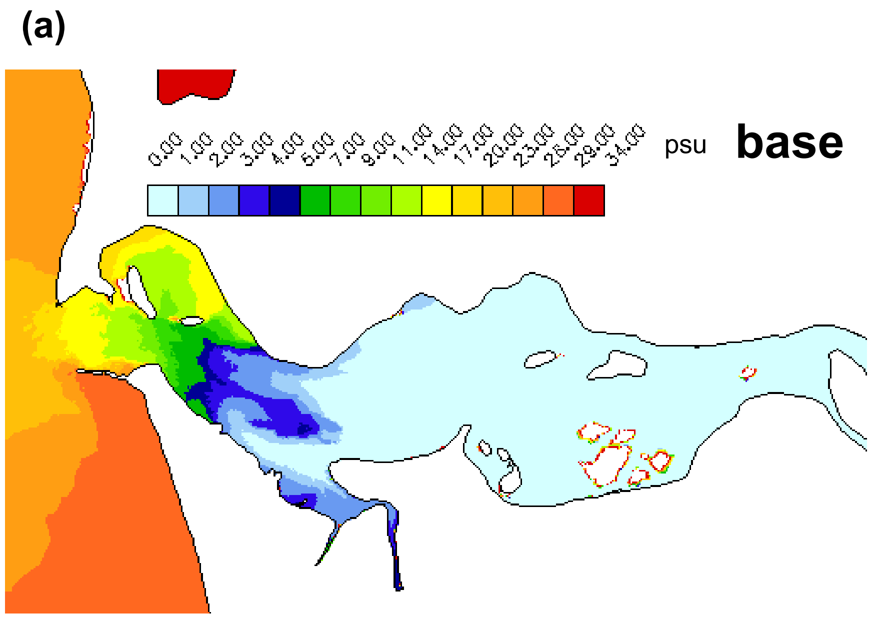


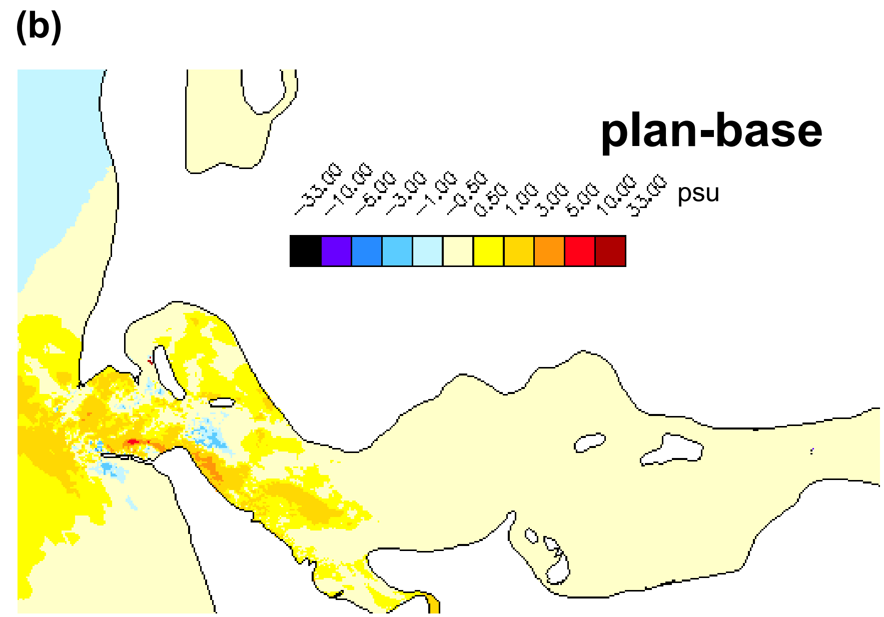
2001 – week 18

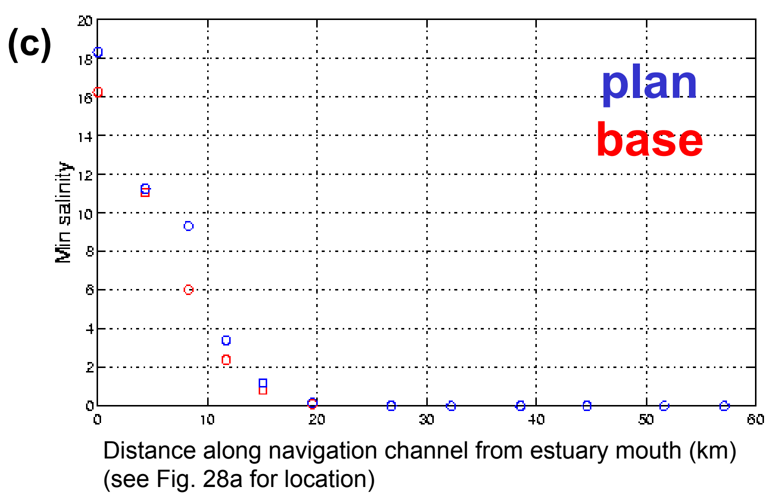
(May)

Version 2 of simulation database

Fig. 1: (a) Maximum salinity (psu) for base conditions. (b) Difference between maximum salinities: plan minus base. (c) Maximum salinities along the navigation channel, for base and plan.





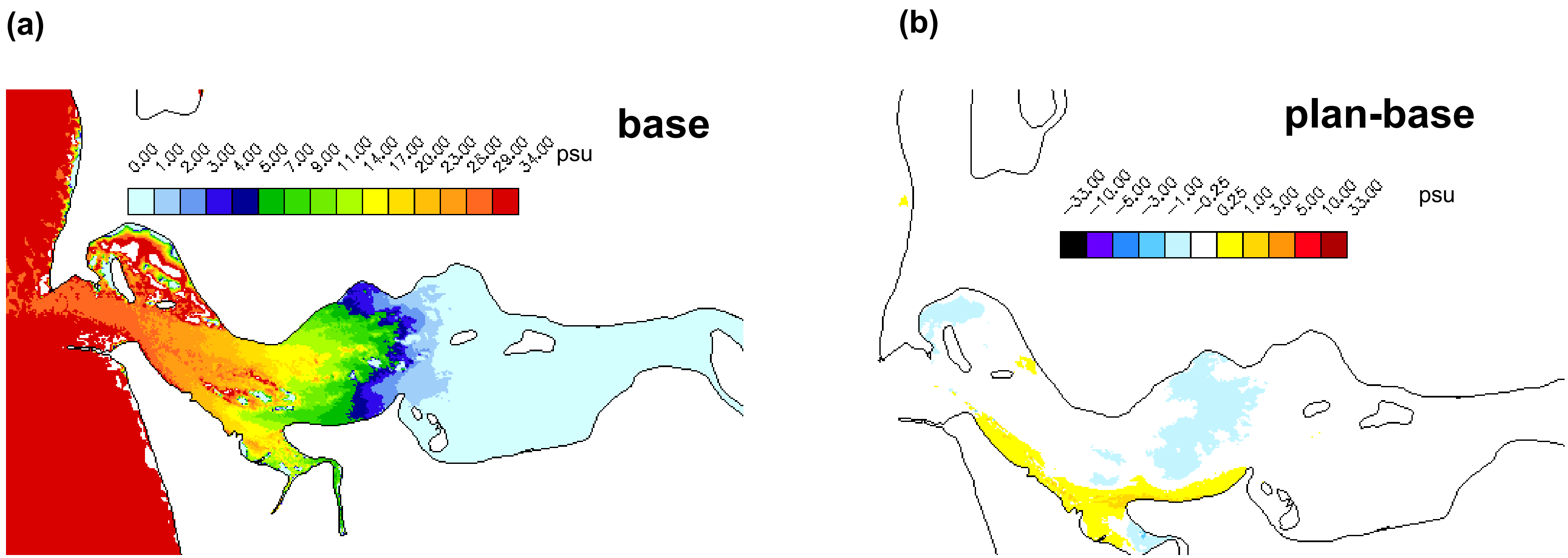


2001 – week 18

(May)

Version 2 of simulation database

Fig. 2: (a) Minimum salinity (psu) for base conditions. (b) Difference between minimum salinities: plan minus base. (c) Minimum salinities along the navigation channel, for base and plan.



$$S_{ac} = \frac{\iint_{D,T} s(t,z)\,dz\,dt}{D_{MSL}T}$$

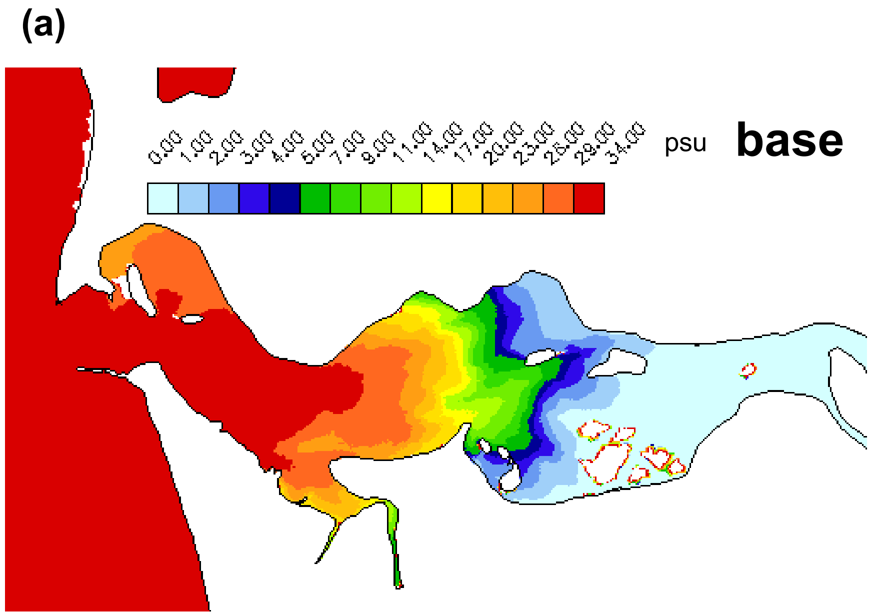
2001 – week 18

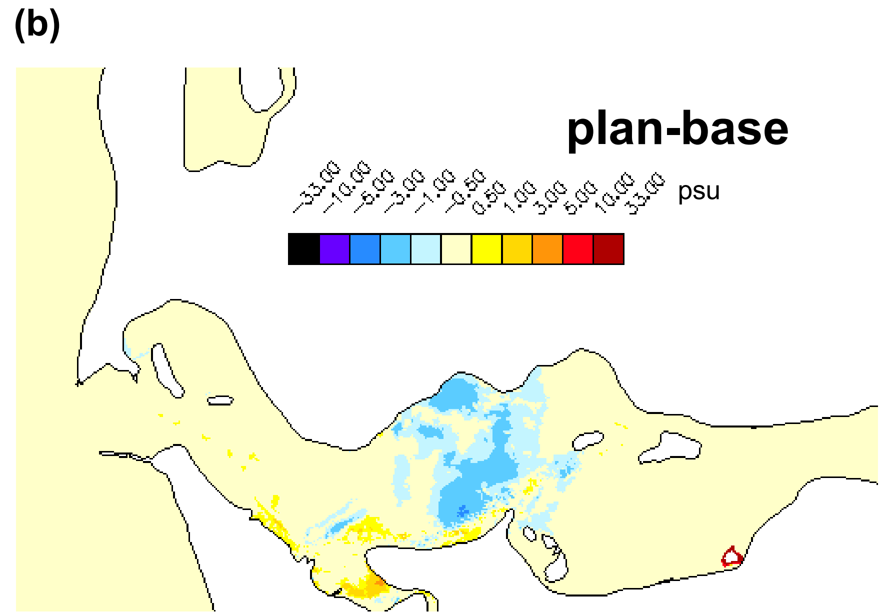
(May)

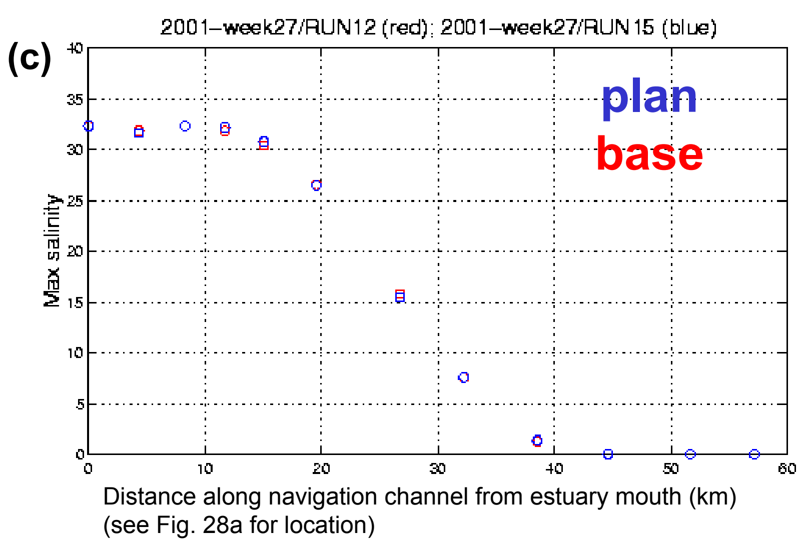
Version 2 of simulation database

Fig. 3: (a) Salinity accumulation, S_{ac} (psu), for base conditions. (b) Difference between salinitiy accumulations: plan minus base. While differences are numerically small, a clear spatial pattern of differences can be observed.

Note: Unlike maximum and minimum salinities, salinity accumulation filters out numerical noise and episodic events. Hence, S_{ac} may be a more representative metric than maximum or minimum salinity.





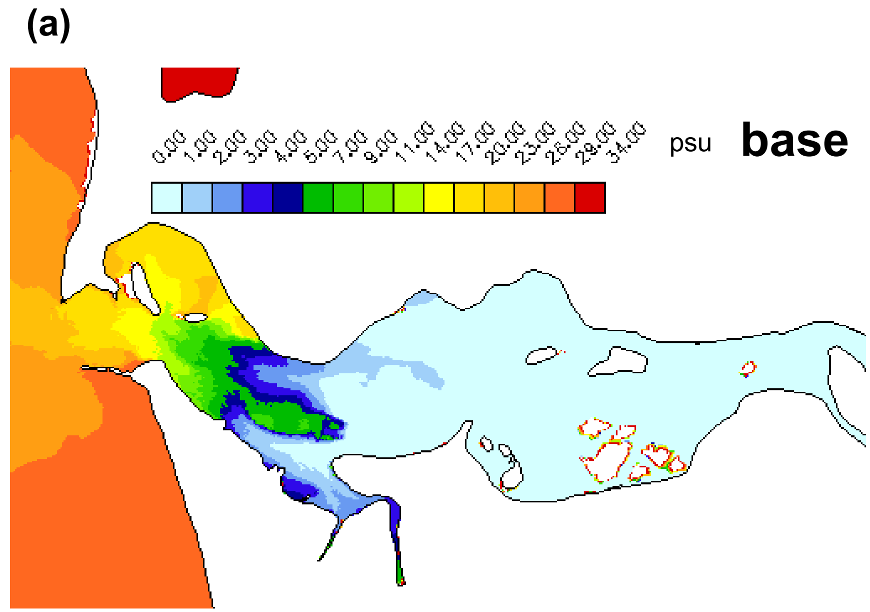


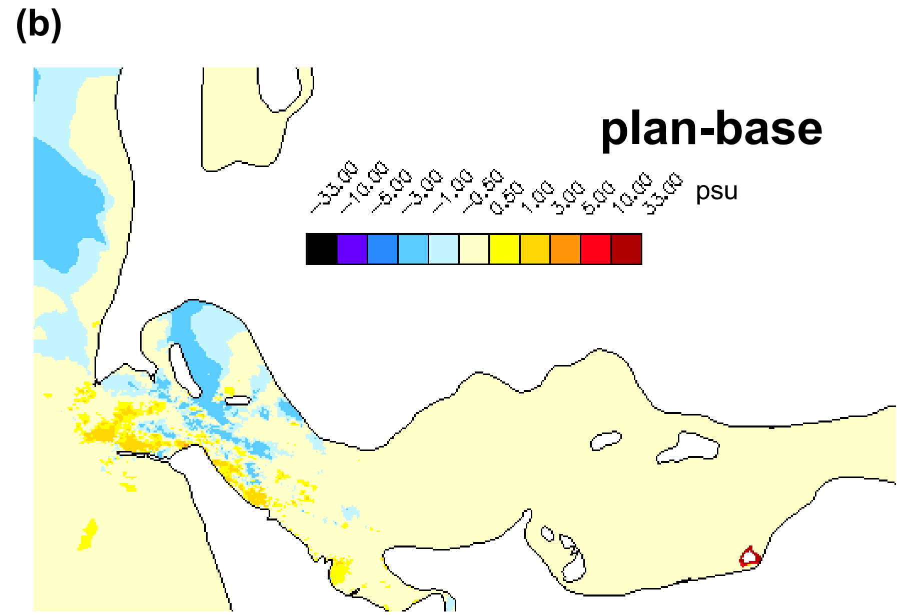
2001 – week 27

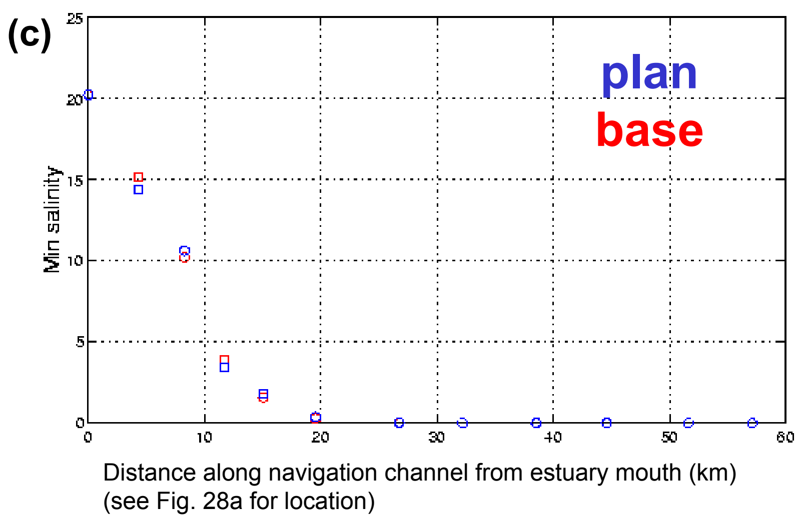
(July)

Version 2 of simulation database

Fig. 4: (a) Maximum salinity (psu) for base conditions. (b) Difference between maximum salinities: plan minus base. (c) Maximum salinities along the navigation channel, for base and plan.







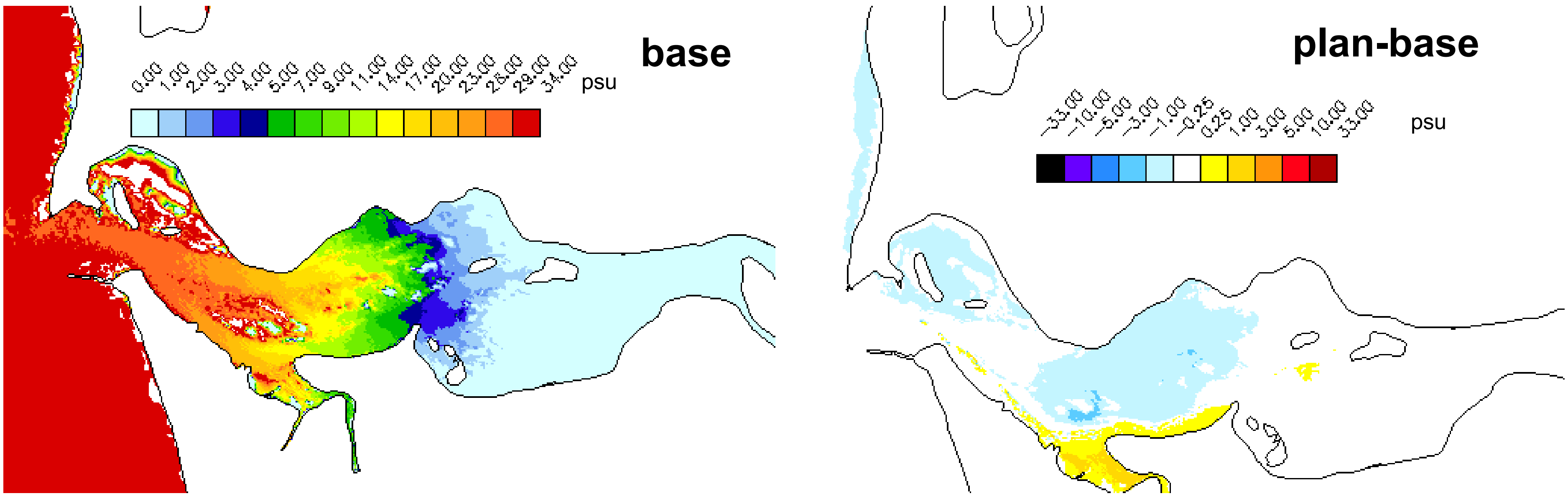
2001 – week 27

(July)

Version 2 of simulation database

Fig. 5: (a) Minimum salinity (psu) for base conditions. (b) Difference between minimum salinities: plan minus base. (c) Minimum salinities along the navigation channel, for base and plan.

(a) (b)



2001 – week 27

(July)

Version 2 of simulation database

$$S_{ac} = \frac{\iint_{D,T} s(t,z)\,dz\,dt}{D_{MSL} T}$$

Fig. 6: (a) Salinity accumulation, S_{ac} (psu), for base conditions. (b) Difference between salinitiy accumulations: plan minus base. While differences are numerically small, a clear spatial pattern of differences can be observed.

Note: Unlike maximum and minimum salinities, salinity accumulation filters out numerical noise and episodic events. Hence, S_{ac} may be a more representative metric than maximum or minimum salinity.

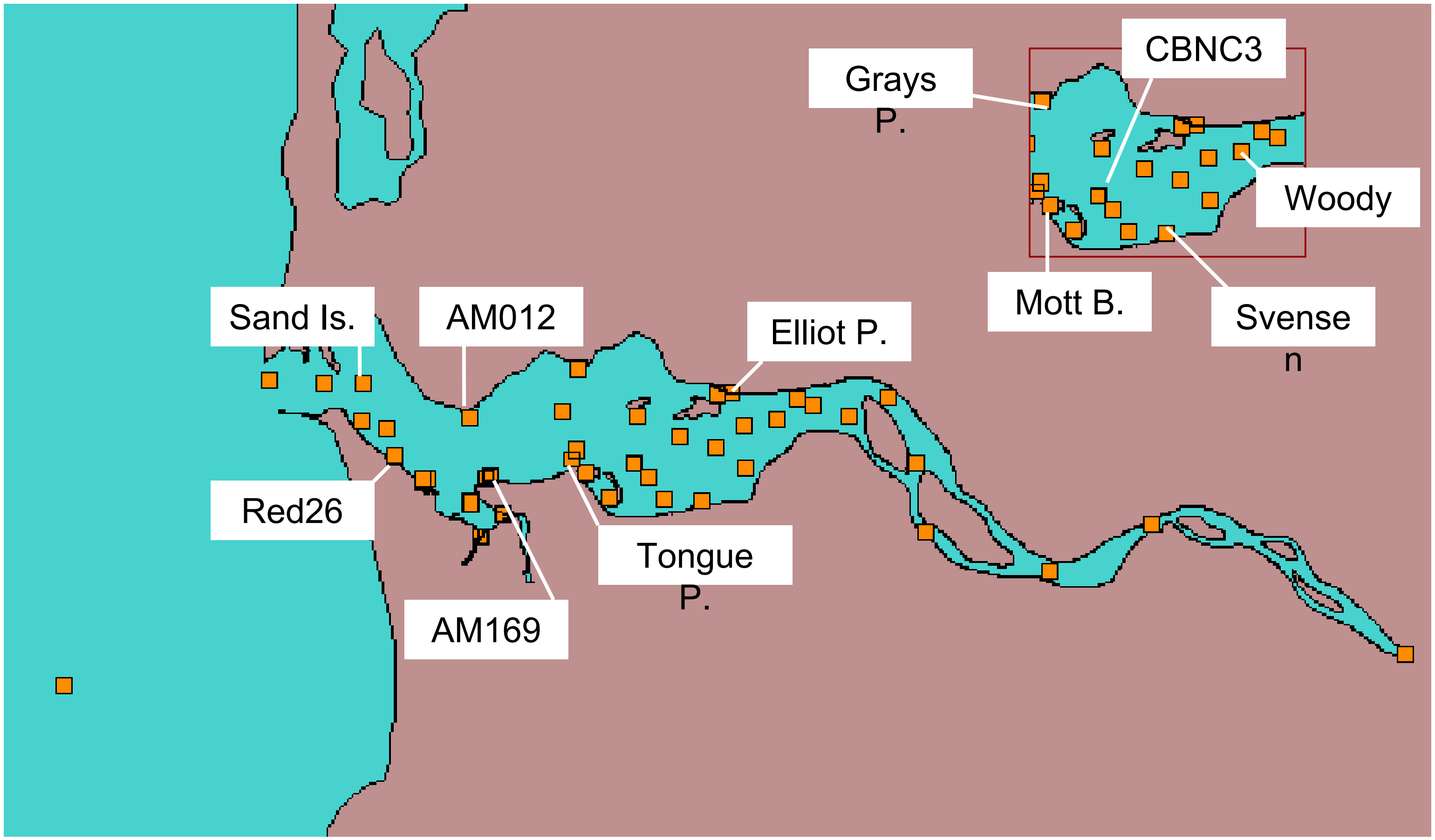


Fig. 7: Time series of water level and of salinity were compared for base and plan at multiple locations in the estuary, shown above as orange squares. Comparisons at representative stations (names shown above) are presented in Figs. 8(a- k), for week 27 of 2001.

Sand Island

2001 – week 27 (July, version 2 of the simulation database)

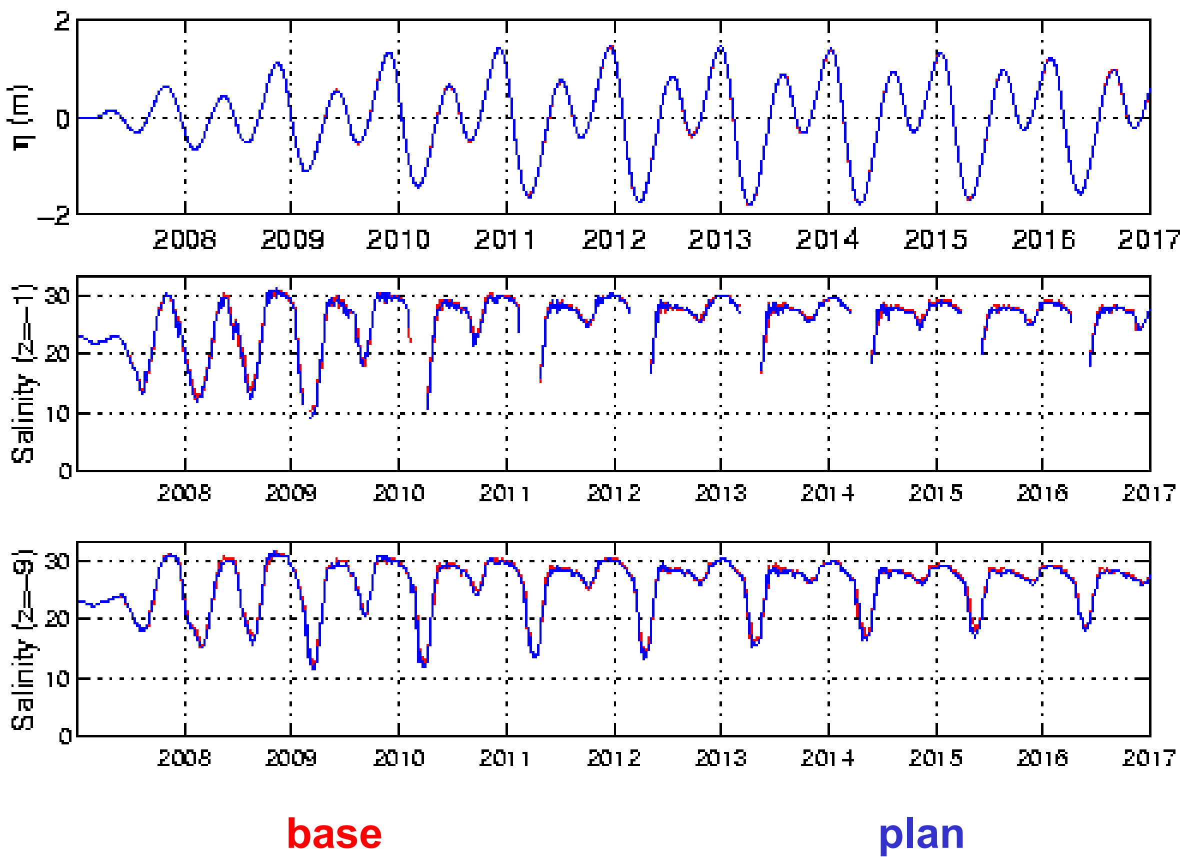


Fig. 8a: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom panel) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

RED26

2001 – week 27 (July, version 2 of the simulation database)

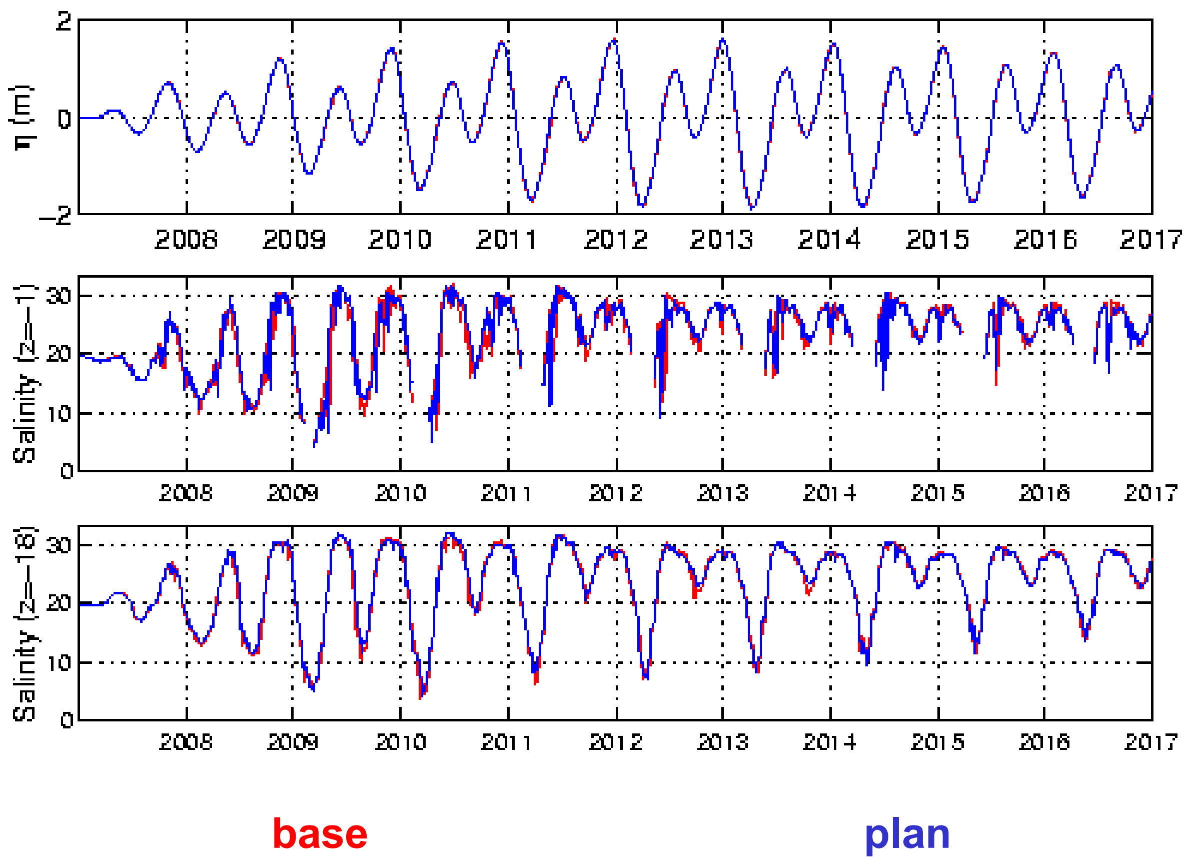


Fig. 8b: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom panel) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

AM012

2001 – week 27 (July , version 2 of the simulation database)

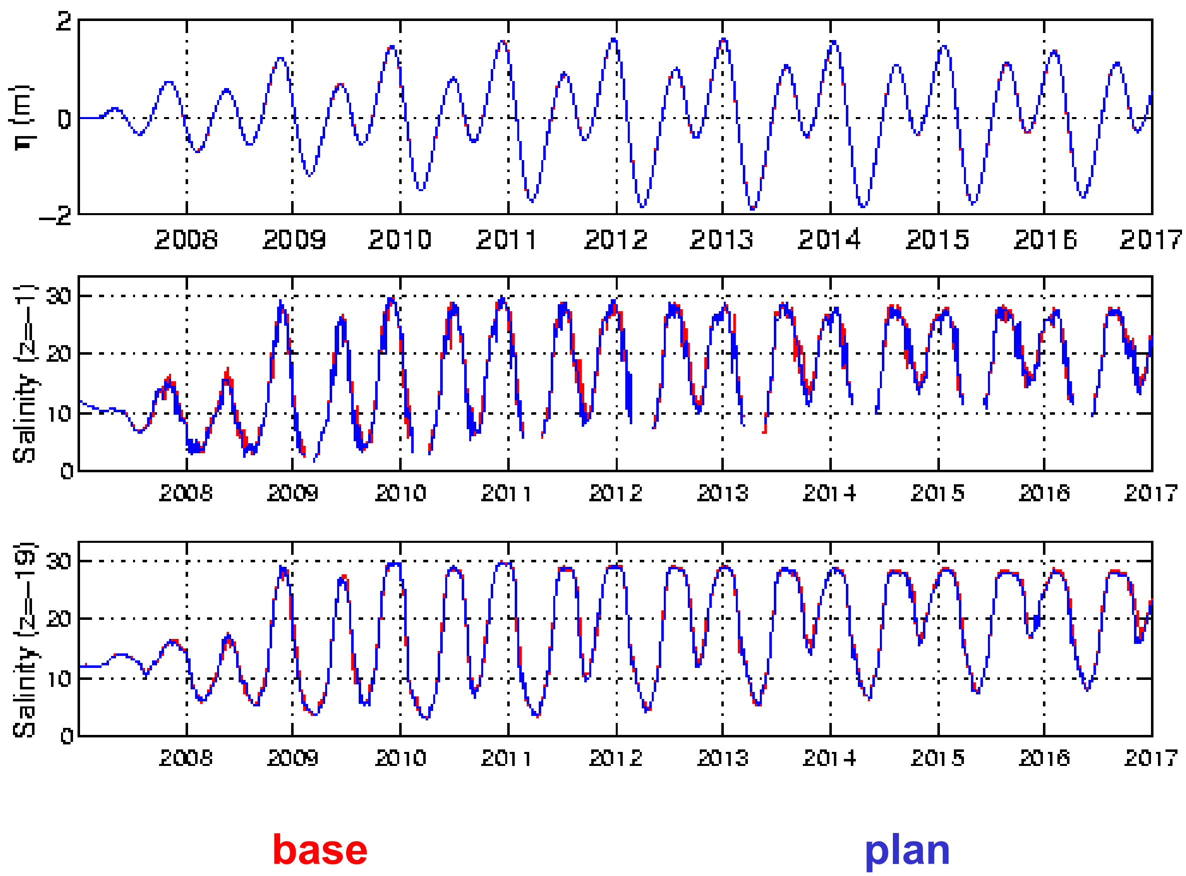


Fig. 8c: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom panel) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

Tongue Point

2001 – week 27 (July, version 2 of the simulation database)

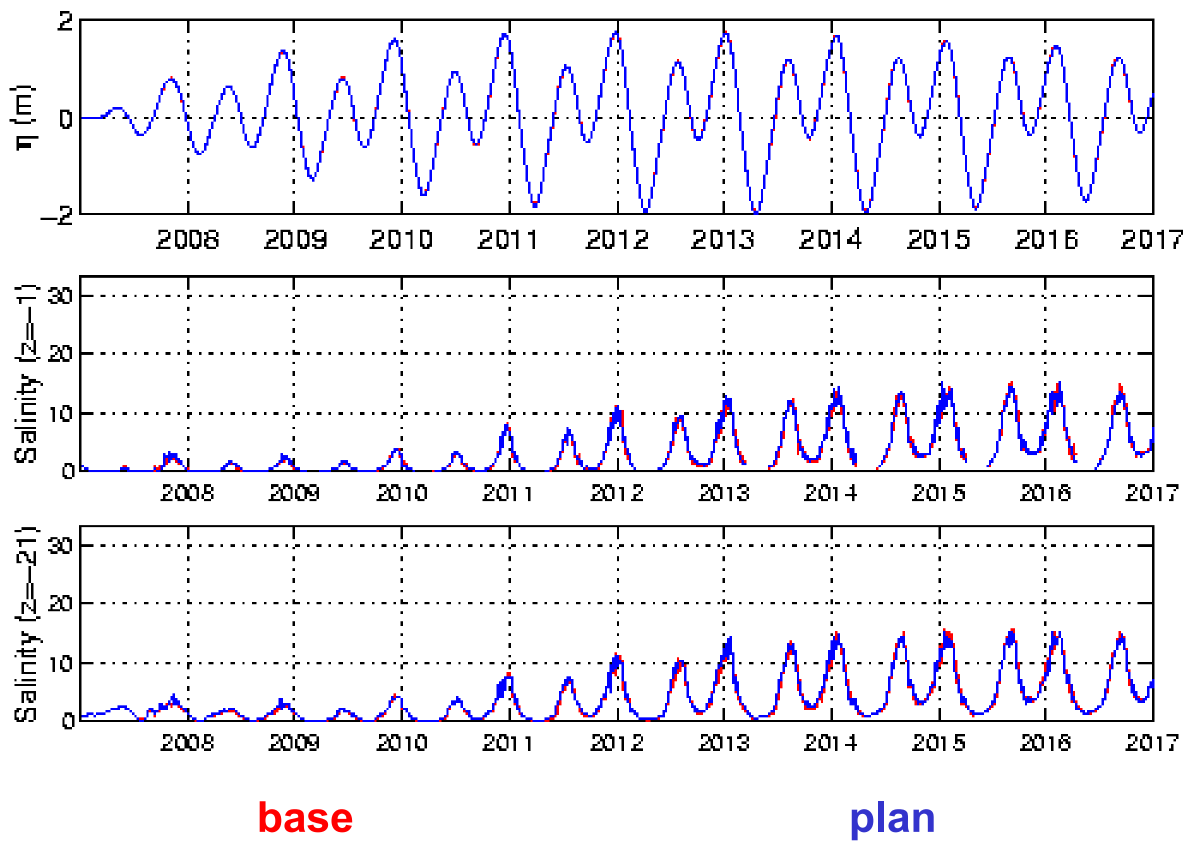


Fig. 8d: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom panel) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

Elliot Point

2001 – week 27 (July, version 2 of the simulation database)

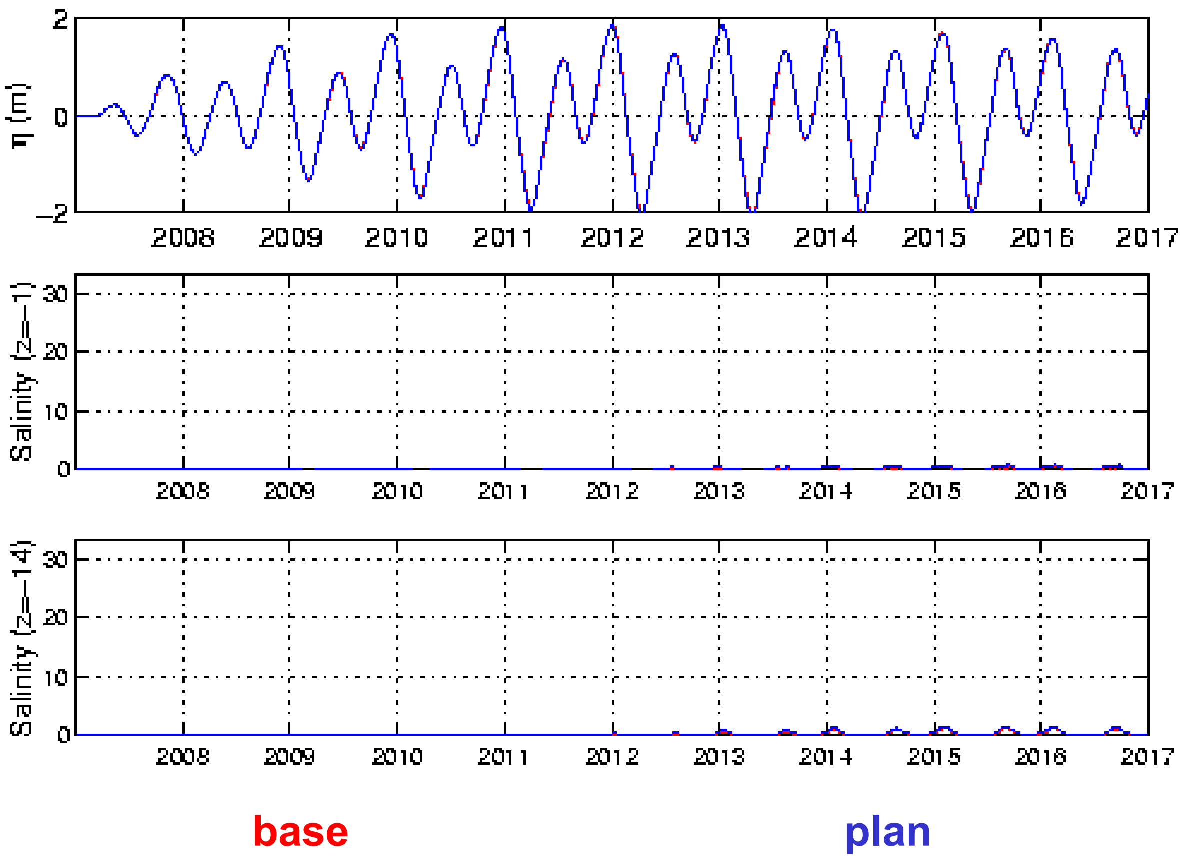


Fig. 8e: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom panel) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

AM169

2001 – week 27 (July, version 2 of the simulation database)

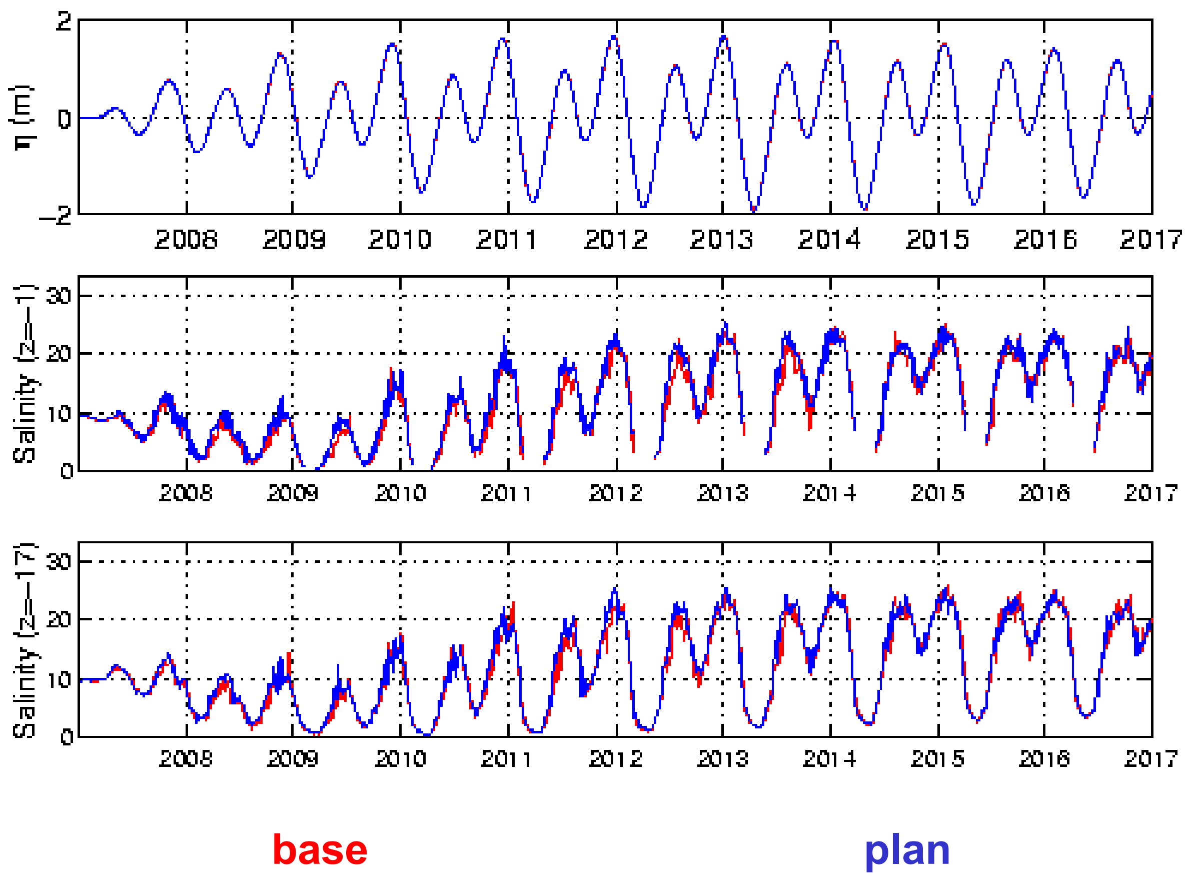


Fig. 8f: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom panel) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

Grays Point

2001 – week 27 (July, version 2 of the simulation database)

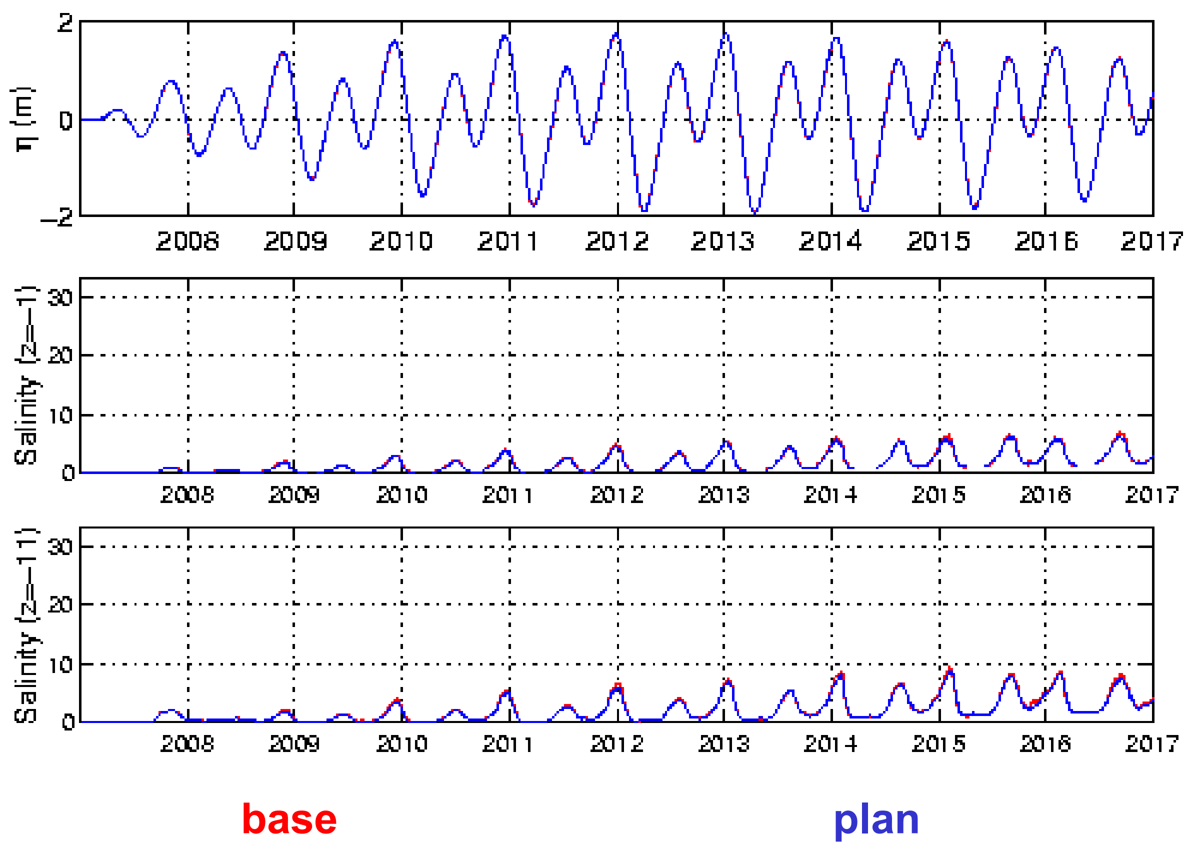


Fig. 8g: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom panel) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

Mott Basin

2001 – week 27 (July, version 2 of the simulation database)

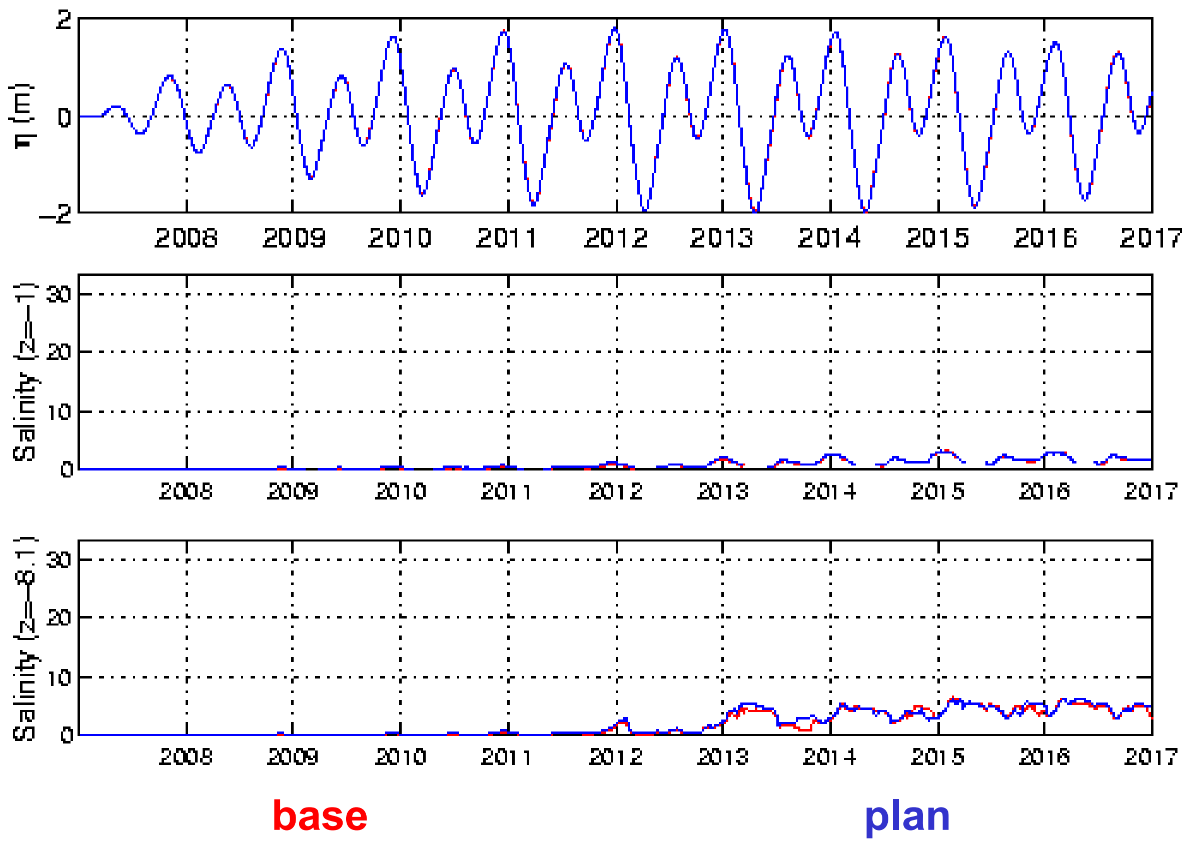


Fig. 8h: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom panel) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

CBNC3

2001 – week 27 (July, version 2 of the simulation database)

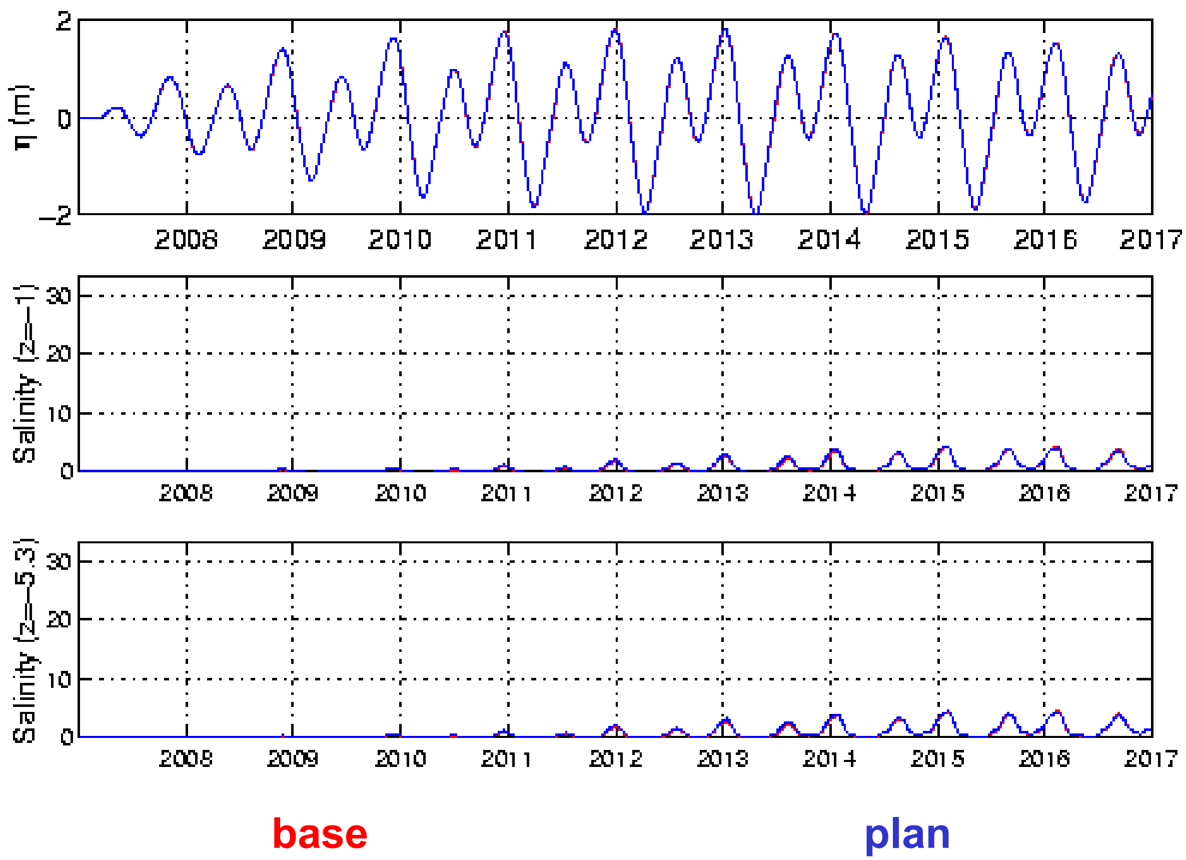


Fig. 8i: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom panel) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

Woody Island

2001 – week 27 (July, version 2 of the simulation database)

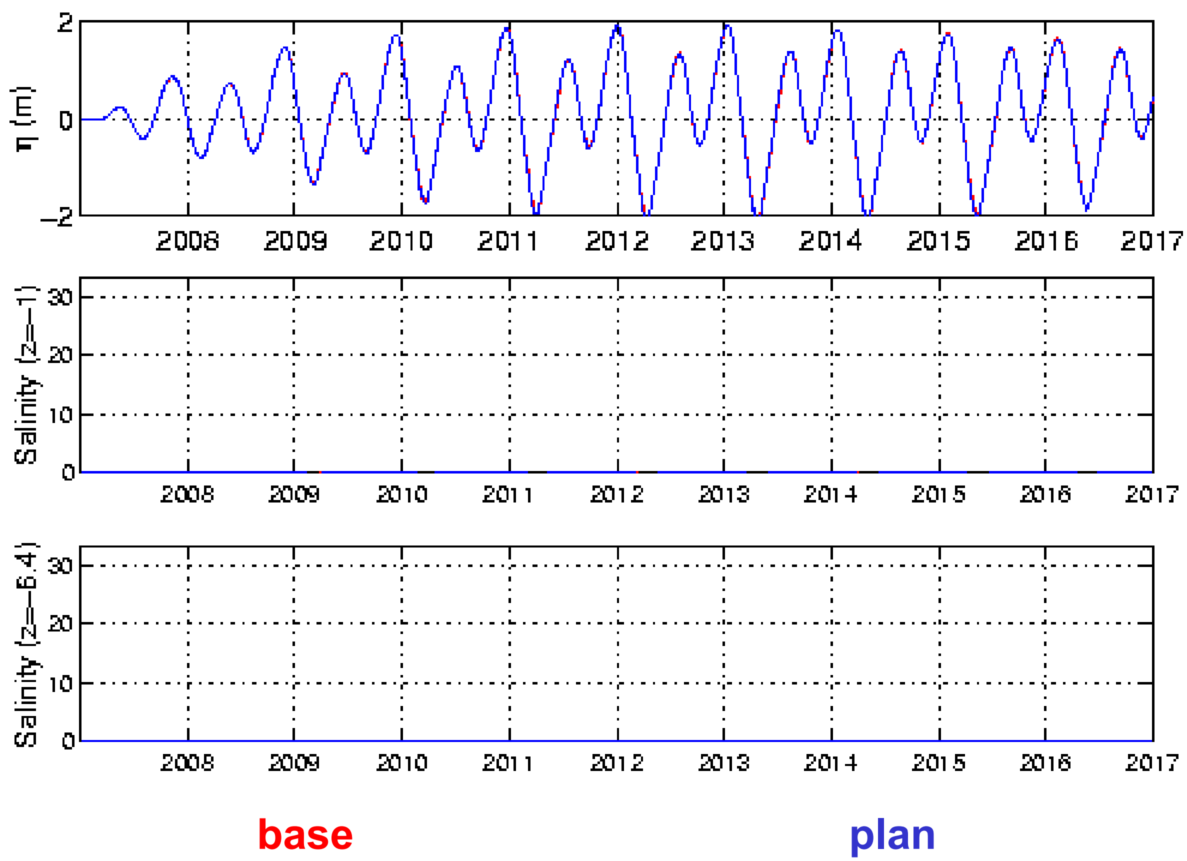


Fig. 8j: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom panel) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

Svensen Island

2001 – week 27 (July, version 2 of the simulation database)

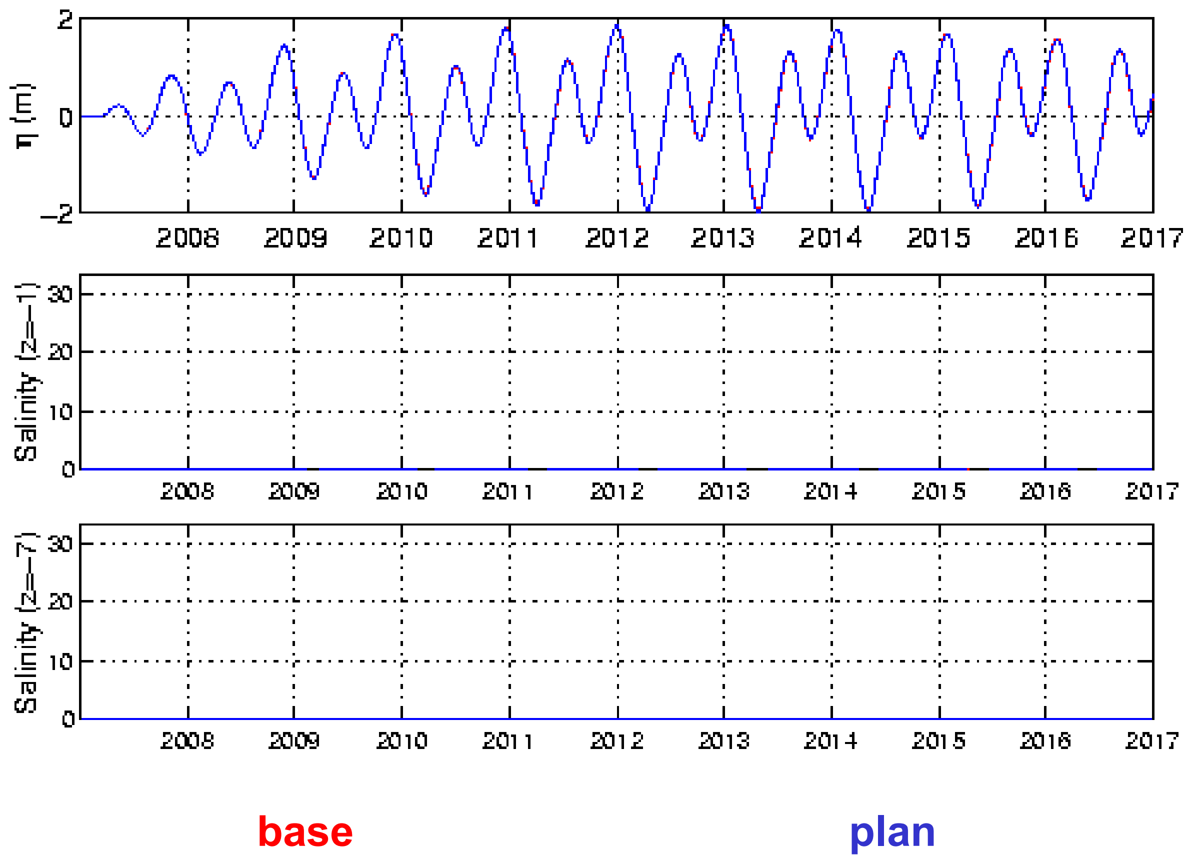
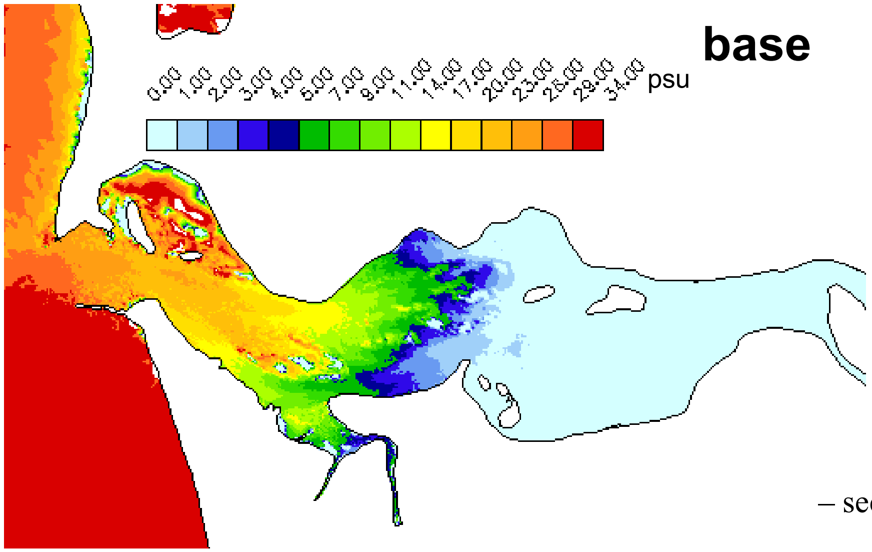
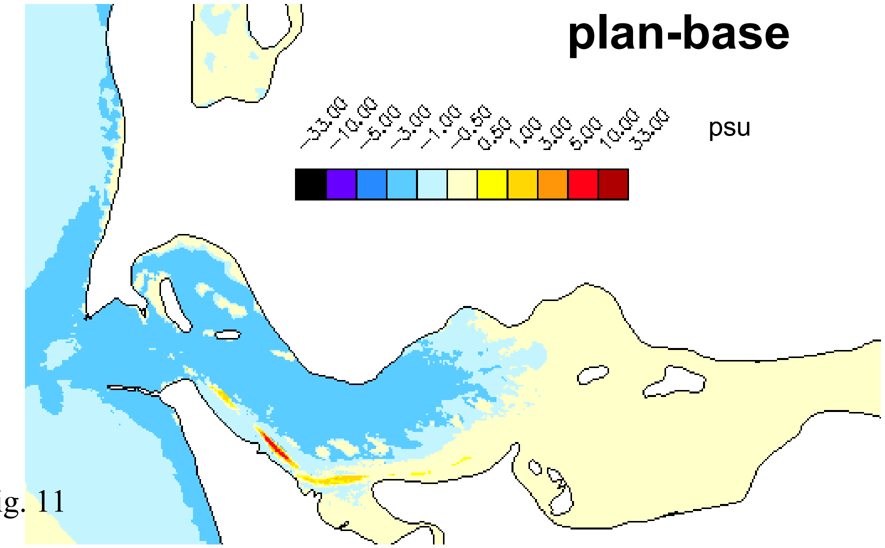


Fig. 8k: Time series of water level (η, top panel) and of salinity near the water surface (middle panel) and near the bottom (bottom) for base and plan, respectively. See Fig. 7 for station location. Time is in *CORIE days* (origin: January 1, 1996). The first three days represent a warm-up phase.

(a)



(b)



– see Fig. 11

1997 – week 18

(May)

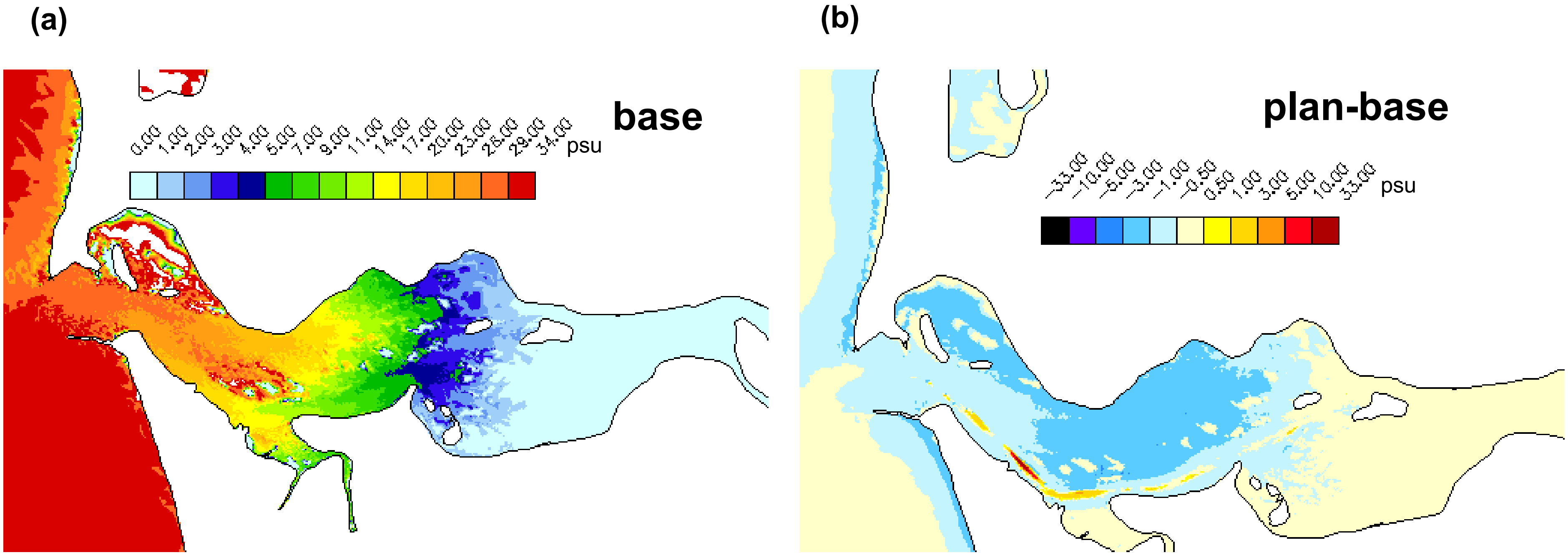
Version 3 of simulation database

$$S^{*}_{ac} = \frac{\iint\limits_{D,T} s(t,z)\,dz\,dt}{D^{\text{base}}_{MSL}\,T}$$

Note: definition of S^{*}_{ac} is, for plan, slightly different than in Figs 3 and 6 (scaling is based on the pre-deepening depth of the channel, arguably a better measure of impact – see Fig. 11)

Fig. 9: (a) Salinity accumulation, S^{*}_{ac} (psu), for base conditions. (b) Difference between salinitiy accumulations: plan minus base. While differences are numerically small, a clear spatial pattern of differences can be observed.

Note: Differences between base and plan may be underestimated, because of difficulty in controlling upstream discharges in version 3 of the simulation database.



1999 – week 31

(August)

Version 3 of simulation database

$$S^*_{ac} = \frac{\iint\limits_{D,T} s(t,z)\,dz\,dt}{D^{\text{base}}_{MSL}\,T}$$

Note: definition of S^*_{ac} is, for plan, slightly different than in Figs 3 and 6 (scaling is based on the pre-deepening depth of the channel, arguably a better measure of impact – see Fig. 11)

Fig. 10: (a) Salinity accumulation, S^*_{ac} (psu), for base conditions. (b) Difference between salinitiy accumulations: plan minus base. While differences are numerically small, a clear spatial pattern of differences can be observed.

Note: Differences between base and plan may be underestimated, because of difficulty in controlling upstream discharges in version 3 of the simulation database.

AM169: 1997 – week 18 (version 3 of the simulation database)

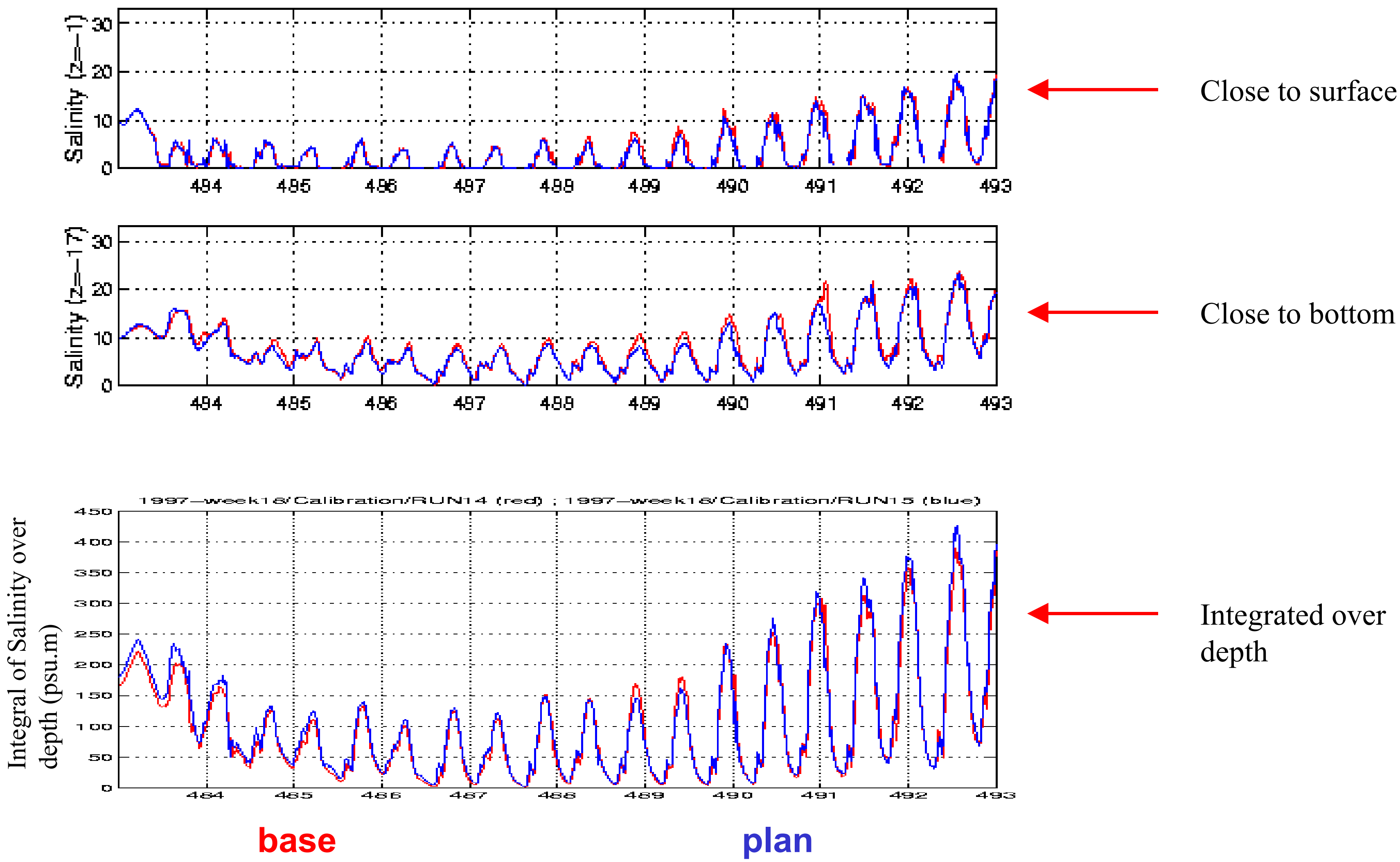


Fig. 11: Because channel is deeper for plan than for base, integration of salt over depth may show larger amount of salt for plan even when salinities are lower at a given depth. This suggests that S^*_{ac} may be preferable to S_{ac} as a metric of impact. Note also that spring-neap transition modulates base-plan differences, an effect best seen when (as in version 3 of the simulation database) stratification is realistically represented.

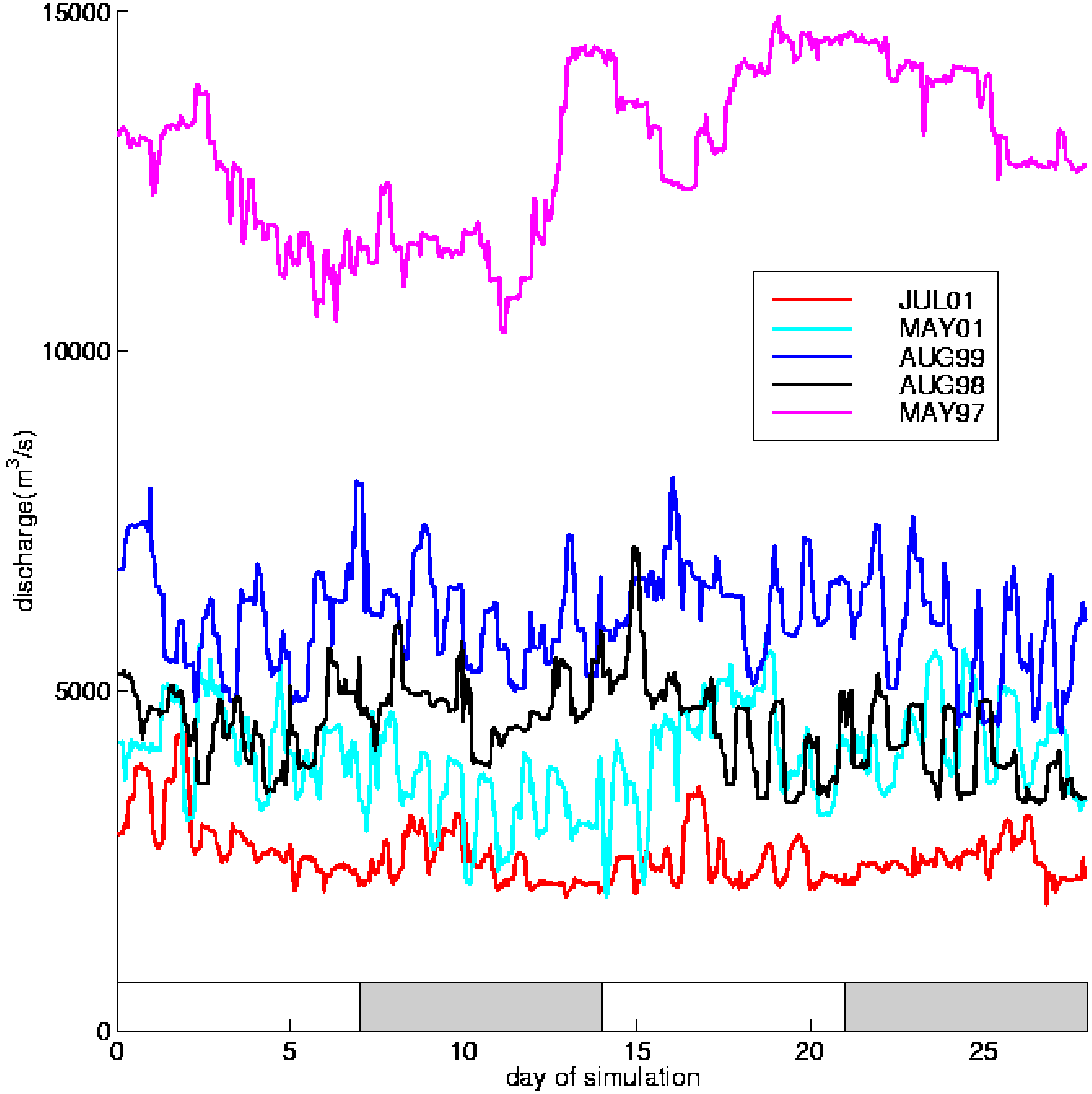


Fig. 12: River discharges at Bonneville, for the various periods considered in this project.

Note:

Month	Refers to …
‘May’	Weeks 18-21 of the year (week 18 includes days in late April)
‘July’	Weeks 27-30 (week 27 includes days in late June)
‘Aug’	Weeks 31-34 (week 31 includes days in late July)

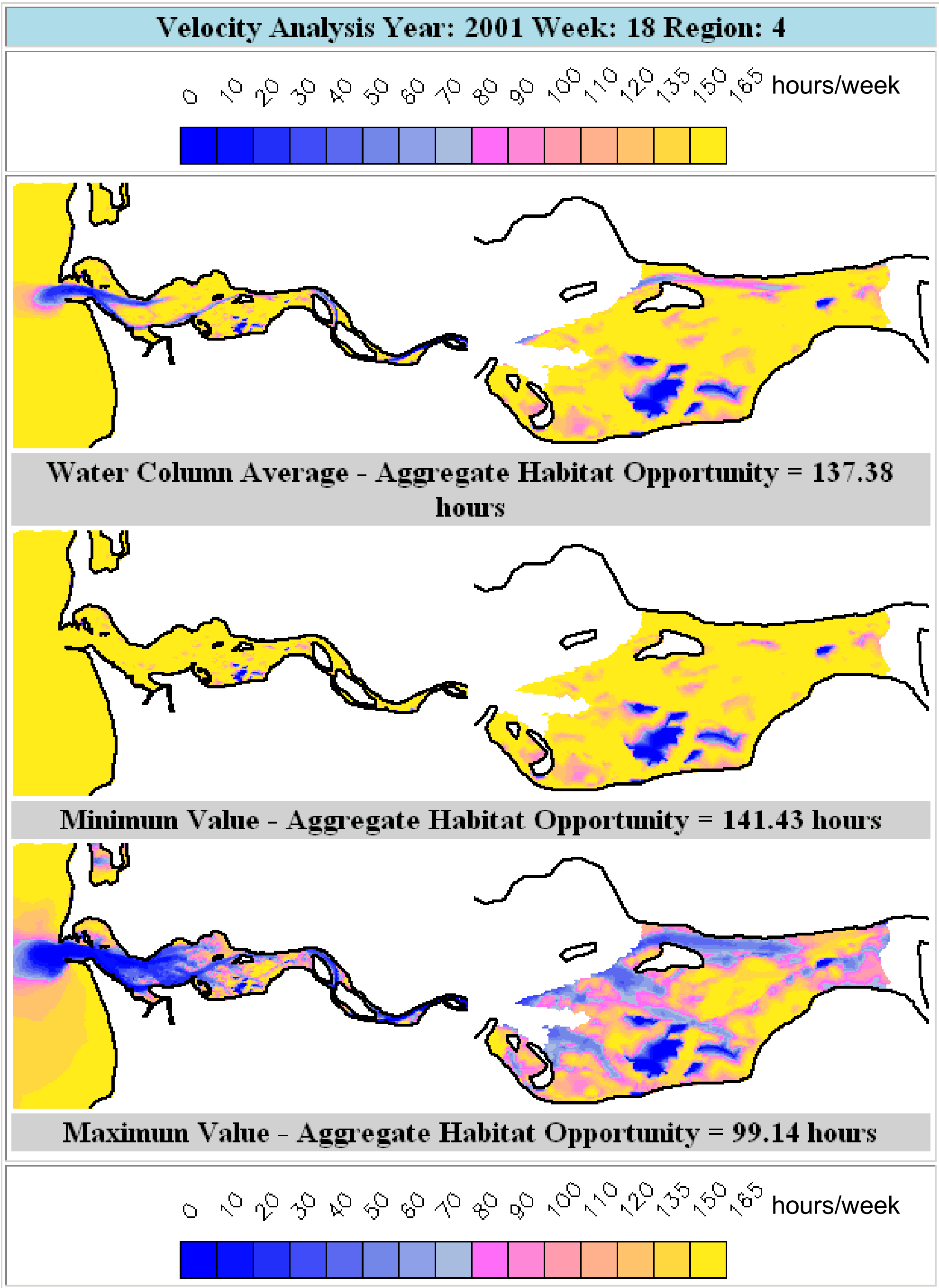


Fig. 13: Definition of the habitat opportunity criterion based on water velocity represents an extension of Bottom et al. 2001, to account for the availability of a 3D description of the velocity field. Three forms of the criterion are considered, differing on what velocity is chosen.

Criterion is met … if the depth-averaged velocity does not exceed 30cm/s

… if there is at least one point in the water column where velocity does not exceed 30cm/s

… if in no point of the water column does velocity exceed 30cm/s

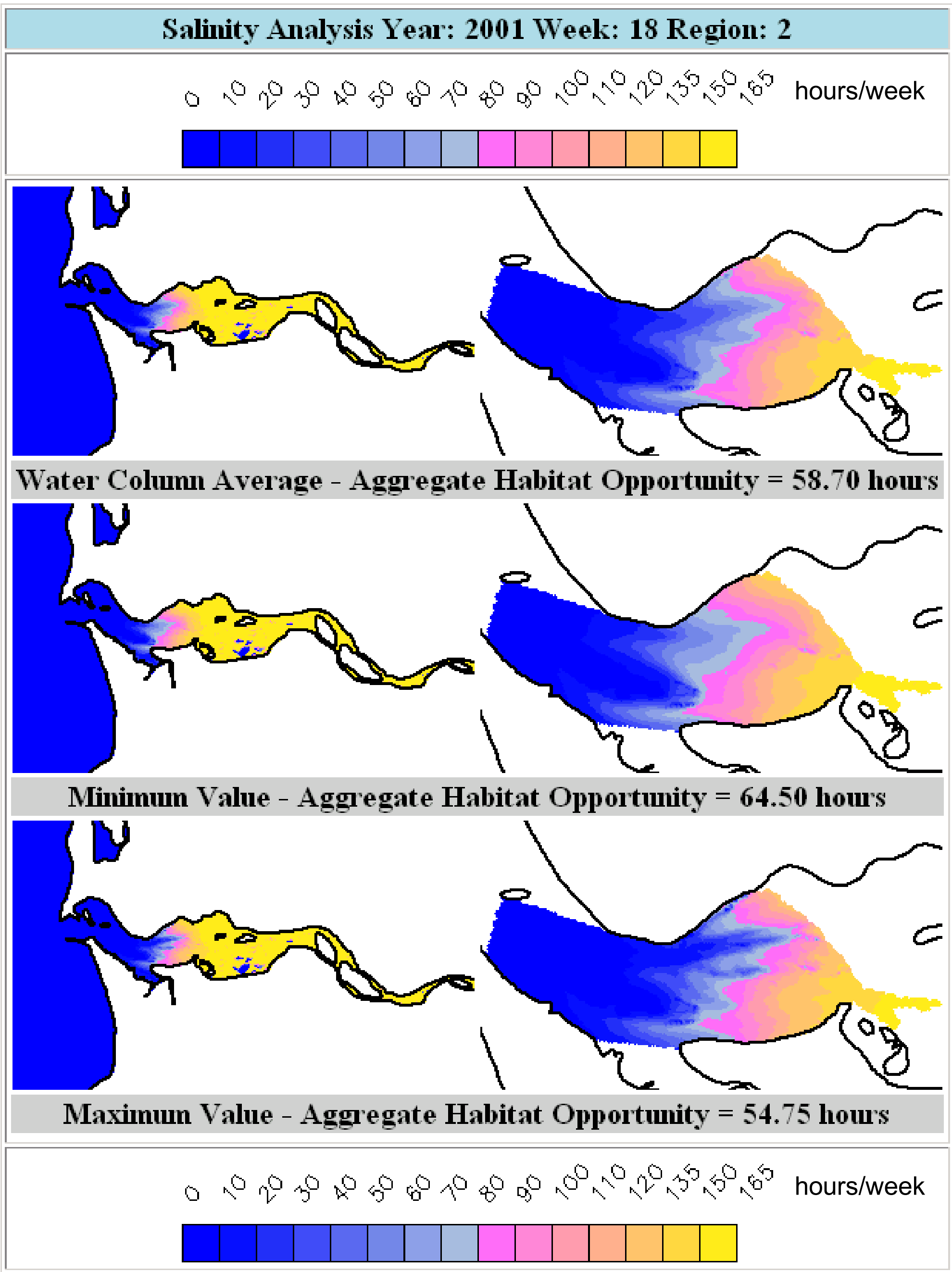


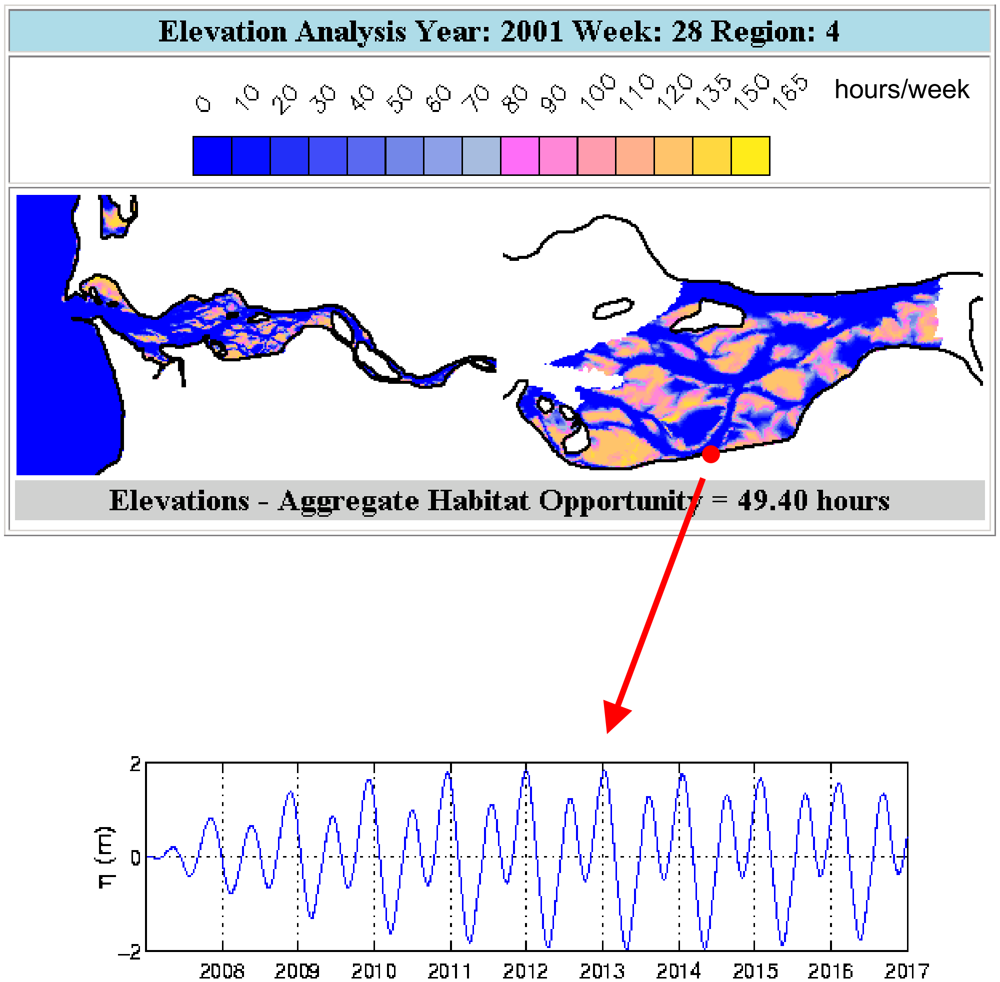
Fig. 14: Definition of the habitat opportunity criterion based on salinity represents an extension of Bottom et al. 2001, to account for the availability of a 3D description of the salinity field.. Three forms of the criterion are considered, differing on what salinity is chosen.

Criterion is met … if the depth-averaged salinity does not exceed 5 psu

… if there is at least one point in the water column where salinity does not exceed 5 psu

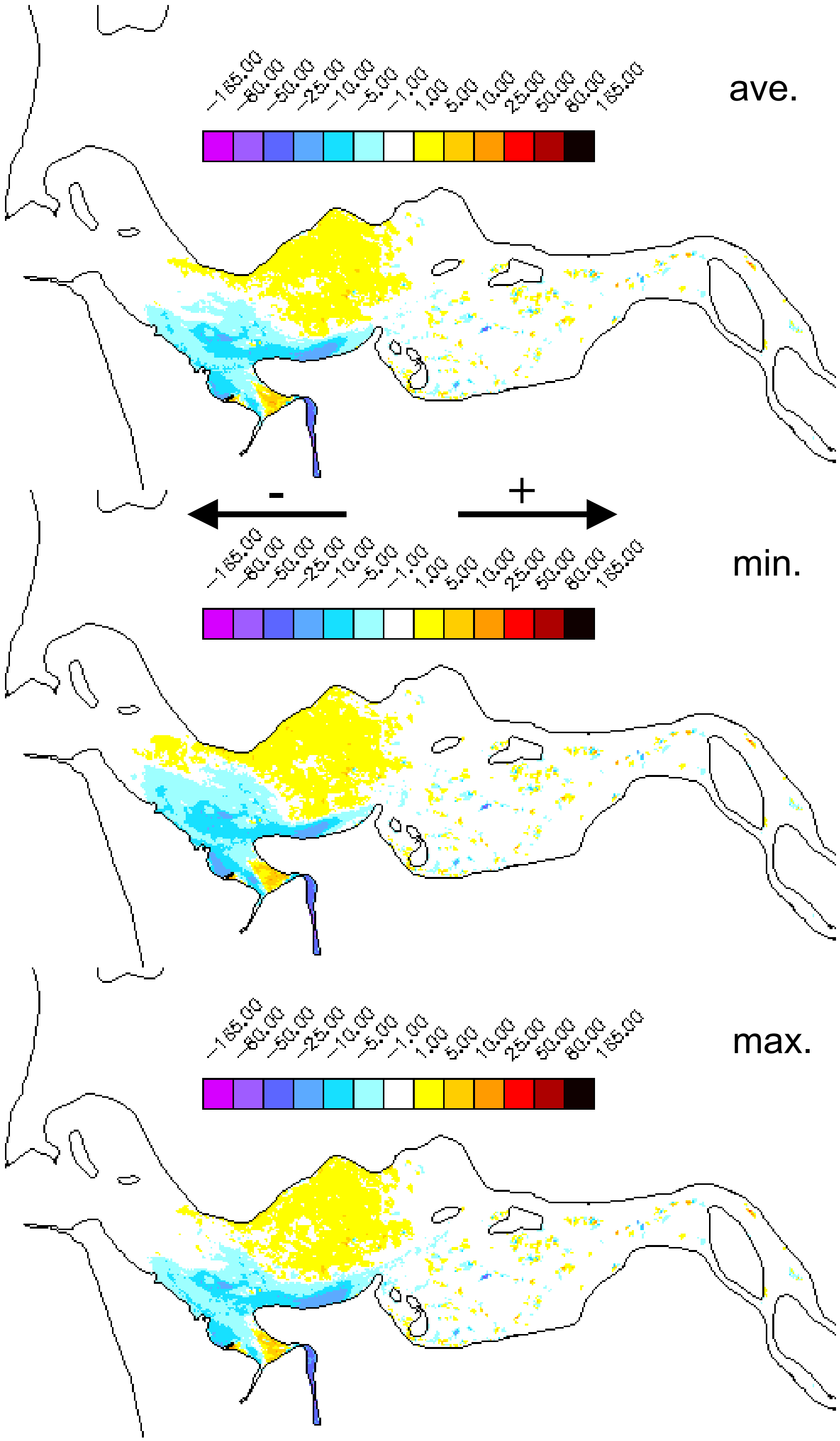
… if in no point of the water column does salinity exceed 5 psu

Fig. 15: Definition of the habitat opportunity criterion based on water depth is the same as in Bottom et al. 2001.



Criterion is met if the water depth is between 10cm and 2m

Note: Tidal fluctuation controls much of the opportunity in regions like Cathlamet Bay

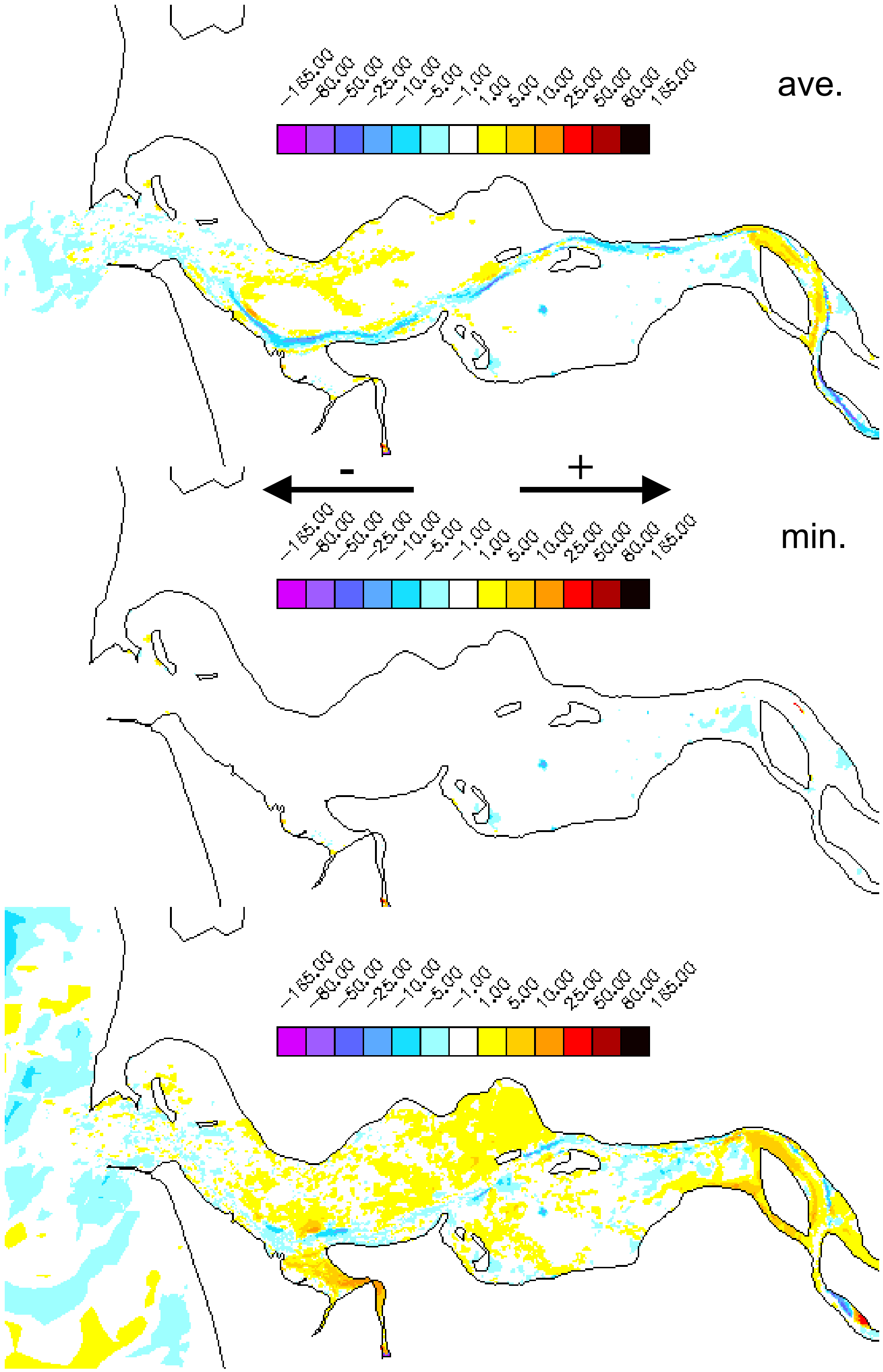


Salinity criteria
2001 – week 18
(May)
Version 2 of simulation database

Fig. 16: Impact of the plan on habitat opportunity, in hours/week, based on: (top panel) depth-averaged salinity; (middle panel) minimum salinity over depth; and (bottom panel) maximum salinity over depth.

Note:

- ❑ Positive values indicate higher habitat opportunity for plan (thus a beneficial impact)
- ❑ Negative values indicate higher habitat opportunity for base (thus a negative impact)



Velocity criteria 2001 – week 18

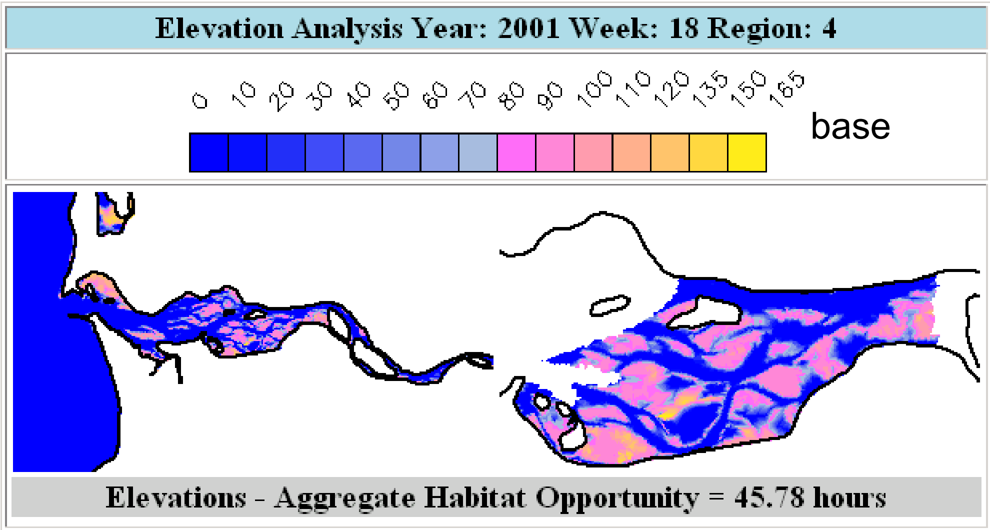
(May)

Version 2 of simulation database

Fig. 17: Impact of the plan on habitat opportunity, in hours/week, based on: (top panel) depth-averaged velocity; (middle panel) minimum velocity over depth; and (bottom panel) maximum velocity over depth.

Note:

- ❑ Positive values indicate higher habitat opportunity for plan (thus a beneficial impact)
- ❑ Negative values indicate higher habitat opportunity for base (thus a negative impact)



Depth criterion
2001 – week 18
(May)
Version 2 of simulation database

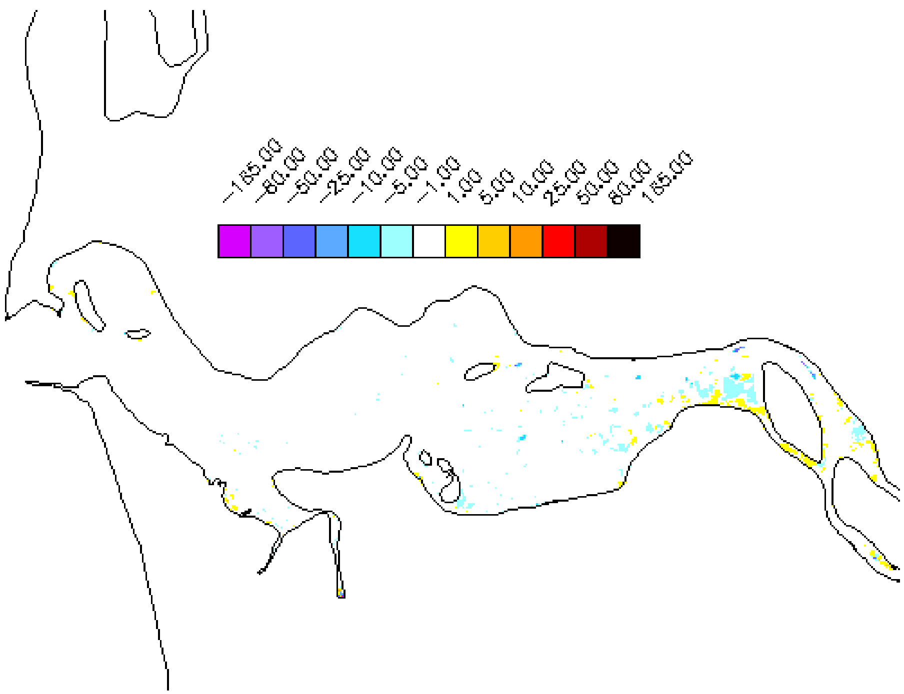


Fig. 18: (top panel) Habitat opportunity, for base conditions; (bottom panel) impact of the plan on habitat opportunity, based on depth. Units are in hours/week.

Note: In bottom panel,

- Positive values indicate higher habitat opportunity for plan (thus a beneficial impact)
- Negative values indicate higher habitat opportunity for base (thus a negative impact)

Salinity criteria
2001 – week 27
(July)
Version 2 of simulation database

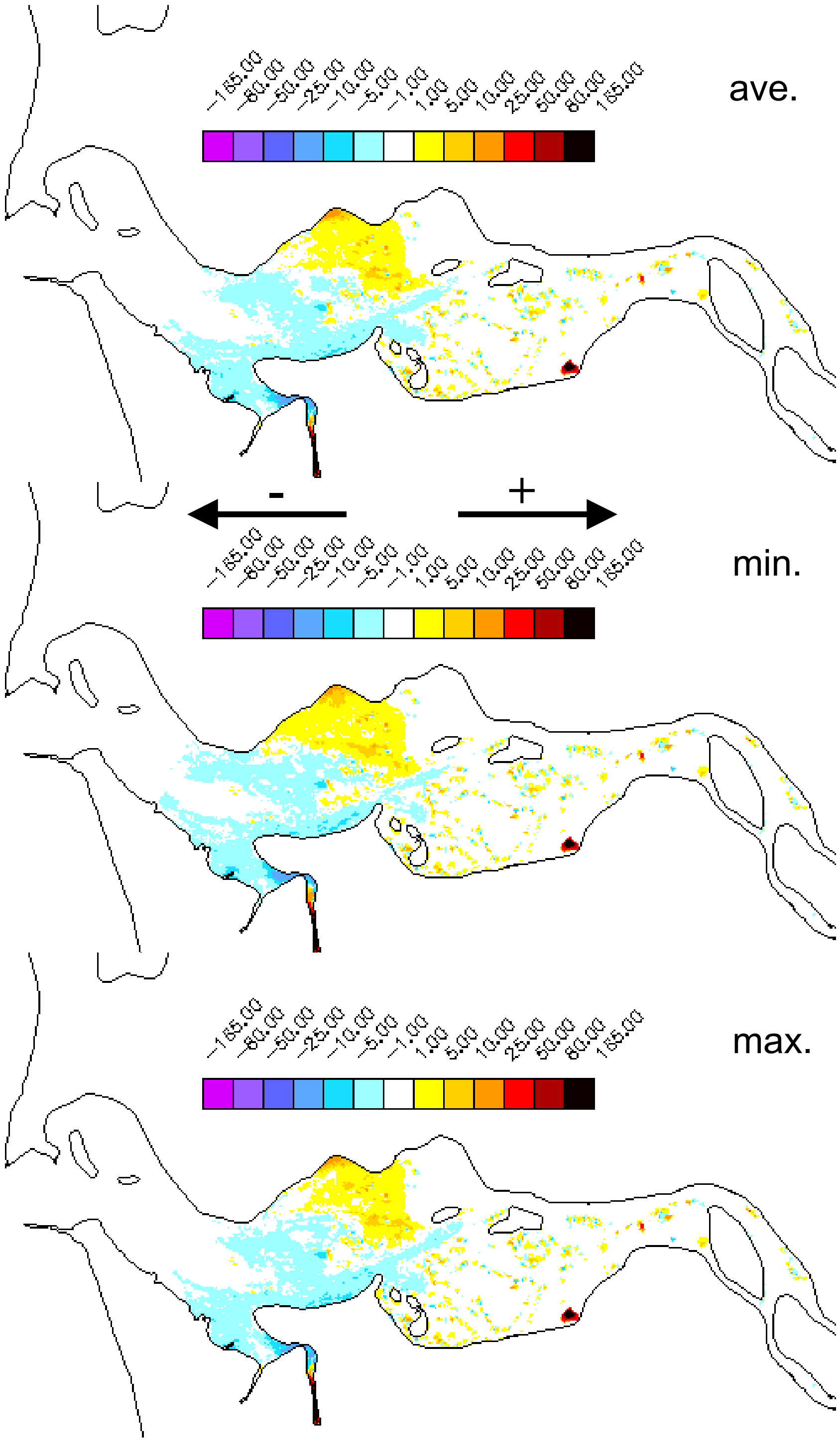


Fig. 19: Impact of the plan on habitat opportunity, in hours/week, based on: (top panel) depth-averaged salinity; (middle panel) minimum salinity over depth; and (bottom panel) maximum salinity over depth.

Note:

- ❑ Positive values indicate higher habitat opportunity for plan (thus a beneficial impact)
- ❑ Negative values indicate higher habitat opportunity for base (thus a negative impact)

Velocity criteria
2001 – week 27
(July)
Version 2 of simulation database

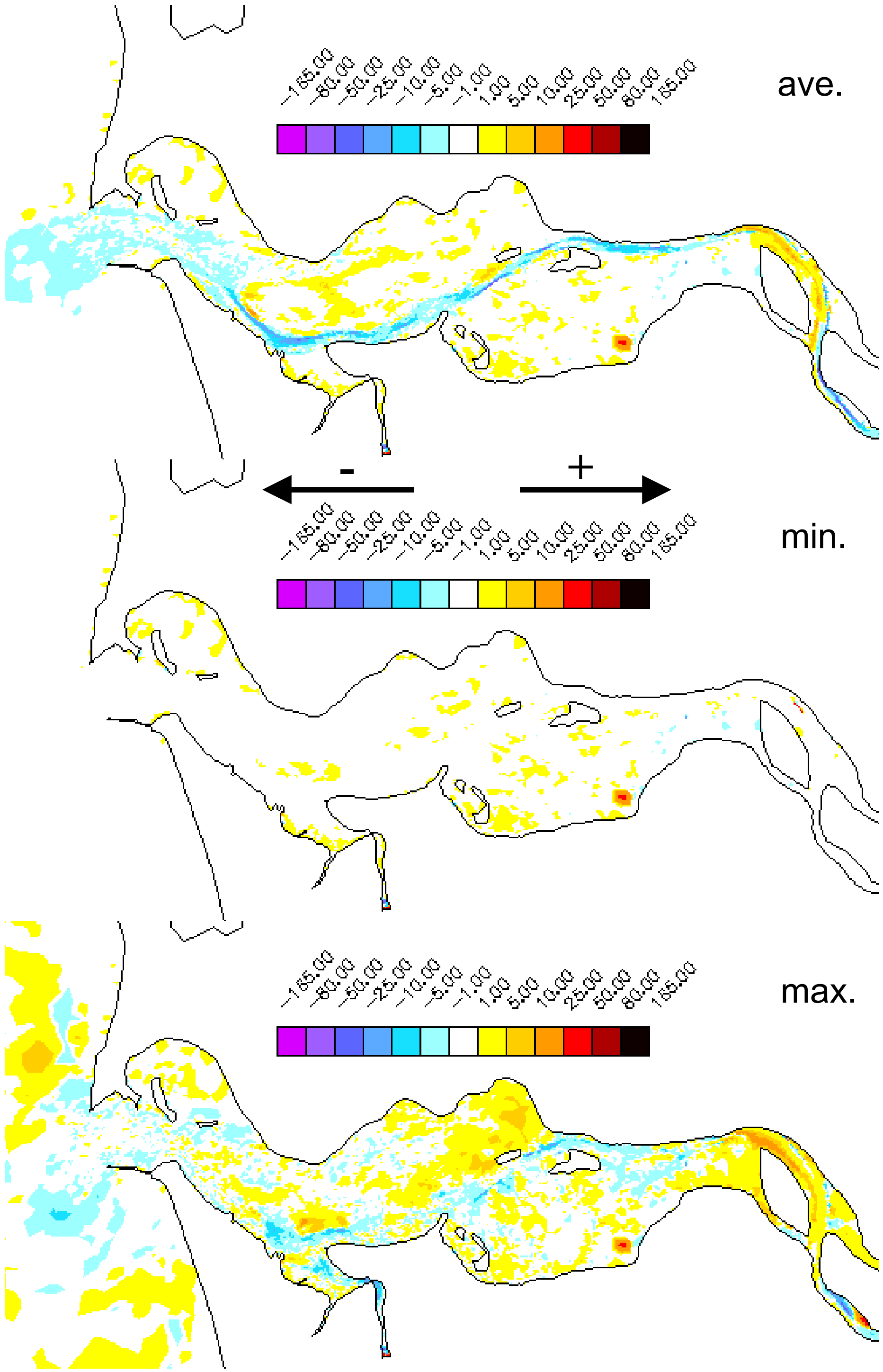
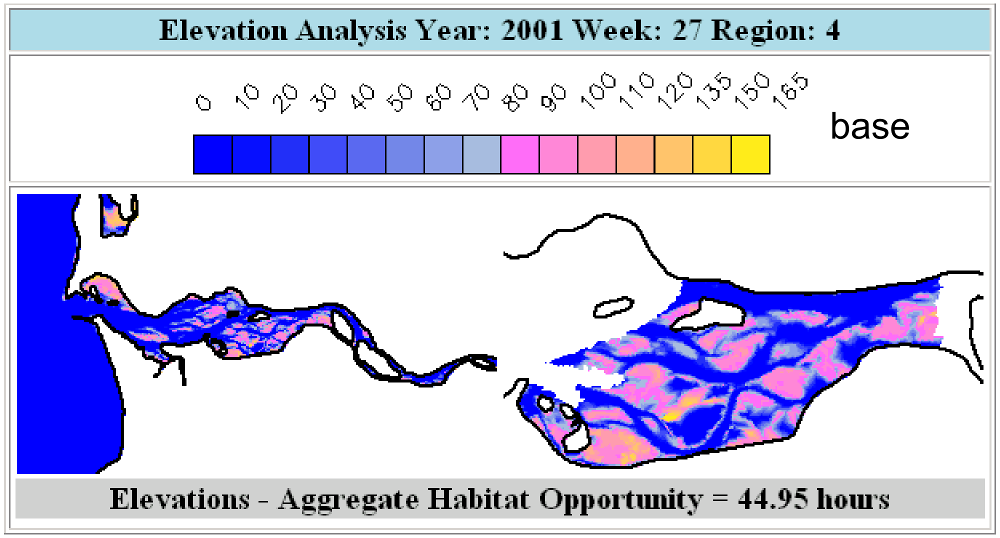


Fig. 20: Impact of the plan on habitat opportunity, in hours/week, based on: (top panel) depth-averaged velocity; (middle panel) minimum velocity over depth; and (bottom panel) maximum velocity over depth.

Note:

- Positive values indicate higher habitat opportunity for plan (thus a beneficial impact)
- Negative values indicate higher habitat opportunity for base (thus a negative impact)



Depth criterion
2001 – week 27
(July)
Version 2 of simulation database

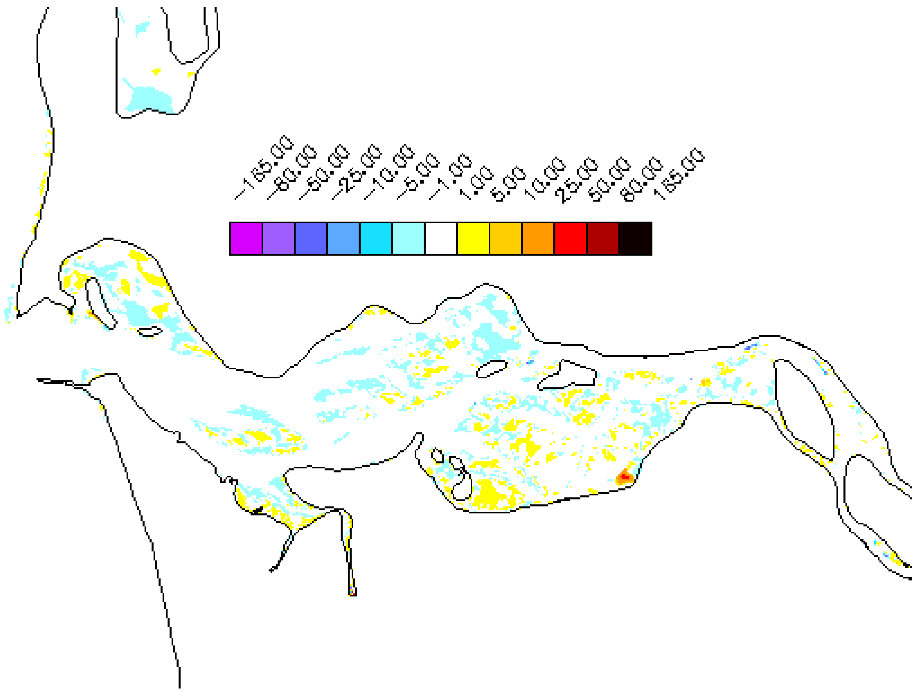


Fig. 21: (top panel) Habitat opportunity, for base conditions; (bottom panel) impact of the plan on habitat opportunity, based on depth. Units are in hours/week.

Note: In bottom panel,

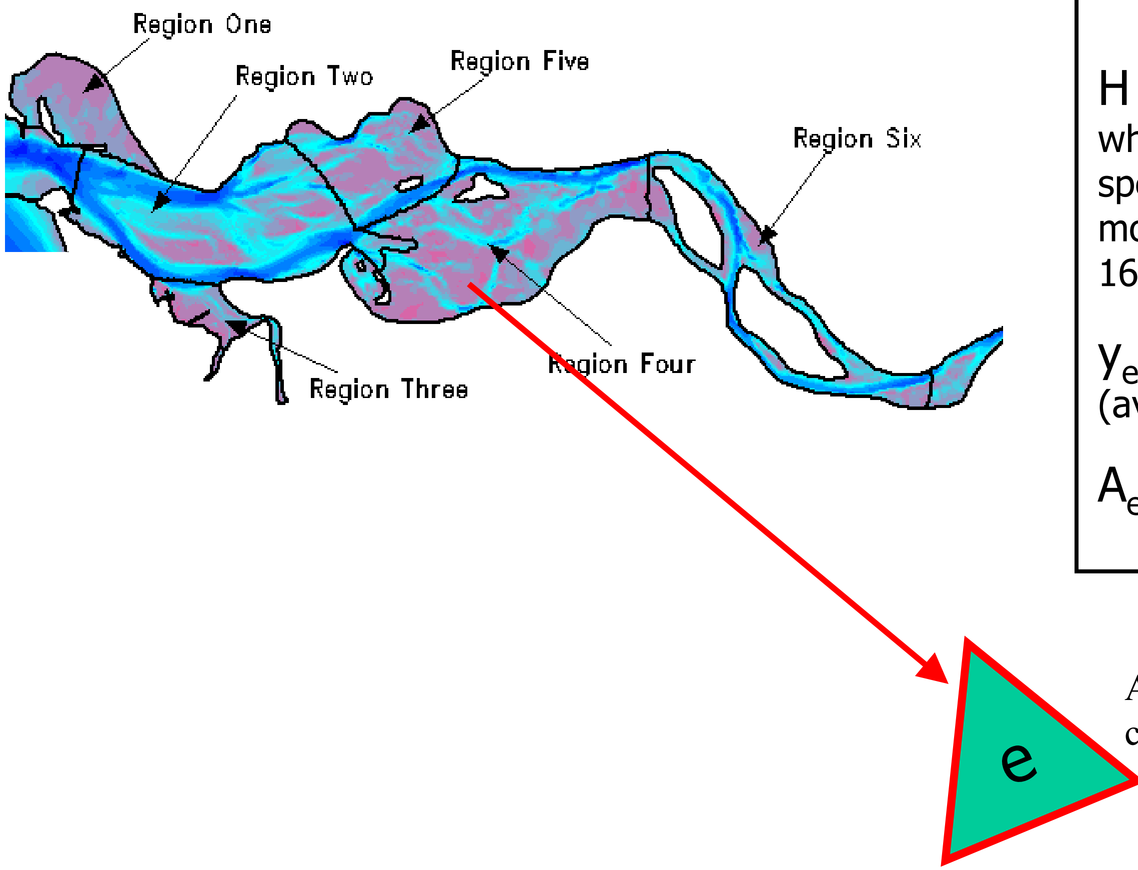
- Positive values indicate higher habitat opportunity for plan (thus a beneficial impact)
- Negative values indicate higher habitat opportunity for base (thus a negative impact)

$$H = \sum_{\text{elements}} y_e . A_e \, / \sum A_e$$

H – weighted average hours in which criterion is met over a specific period of time (a 720h month in Bottom et al. 2001; a 165h week in this study)

y_e – hours in which criterion is met (average over element)

A_e – area of element



An element in the computational grid

Fig. 22: The analysis of habitat opportunity in Bottom et al. 2001 concentrated in the domain and regions represented above. For each region, an average habitat opportunity can be computed as shown in the panel. In this report we typically emphasized the analysis of the domain over individual regions.

Salinity criteria: 1999 – week 31 (August, versions 3 [left] and 4 [right] of the database)

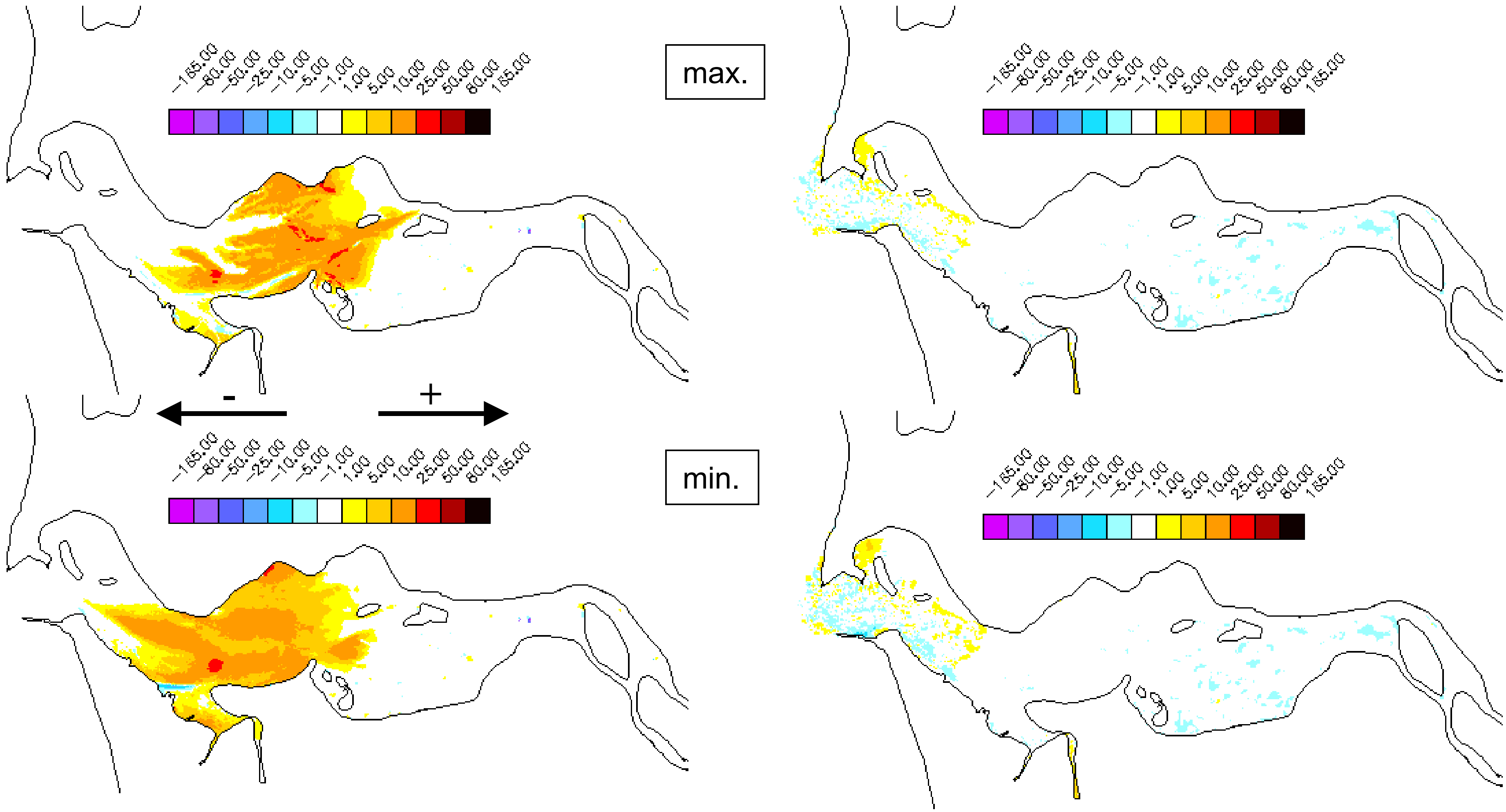


Fig. 23: Impact of the plan on habitat opportunity for: (top panels) maximum salinity; (bottom panels) minimum salinity.

Note: The differences between left and right panels illustrate the effect of remaining model uncertainties on predicted impacts. Left panels are computed from version 3 of the database, where stratification is realistic but *plan* discharges are slightly exaggerated relative to *base*; we observe significant differences between top and bottom panels, and consider impacts of the plan under-estimated but with reasonable spatial patterns (qualitatively consistent with Figs. 16 and 19). Right panels are computed from version 4 of the database, where stratification is under-estimated but *plan* and *base* discharges are consistent; we do not observe significant differences between top and bottom panels, and impacts are much more neutral (reflecting both consistency of discharges and underestimation of salinity penetration in both *base* and *plan*).

Note: Positive values indicate higher habitat opportunity for plan (thus a beneficial impact). Negative values indicate higher habitat opportunity for base (thus a negative impact).

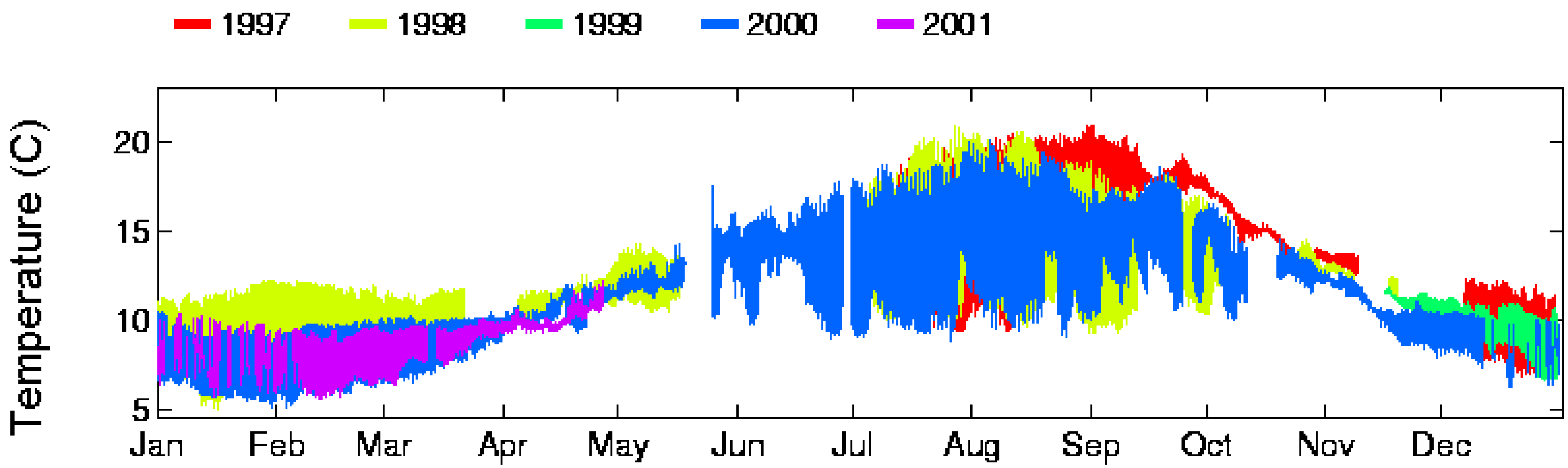


Fig. 24: Annual variation of temperature at Sand Island (raw data, from sensor installed low in the water column), for 1997-2001. River (ocean) water roughly represents the upper (lower) envelope of the temperature curve at Sand Island during the Summer, and the upper (lower) envelope during the Winter.

(a)

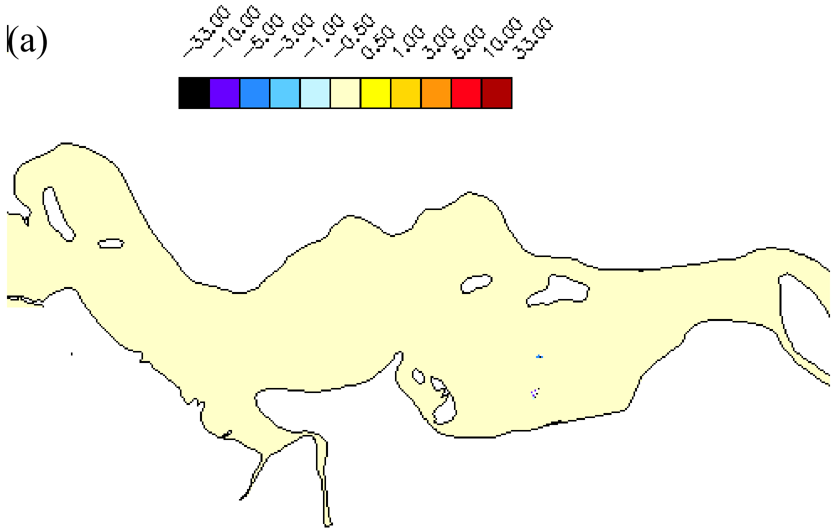
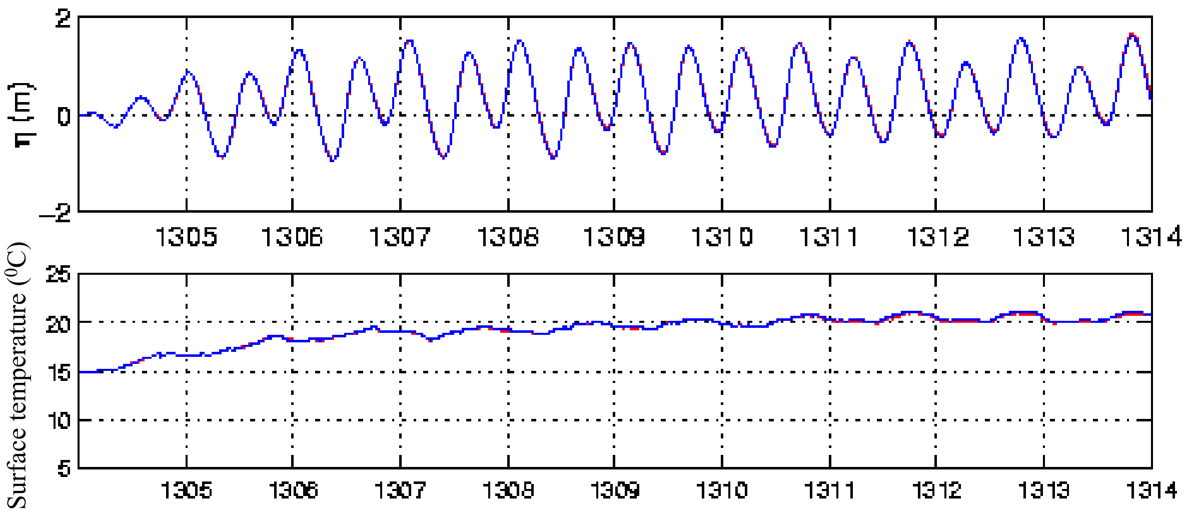


Fig. 25: (a) Differences in maximum temperature between base and plan. (b) Time series of water elevation and temperature at Svensen Island (see Fig. 7 for location). The red line corresponds to base and the blue line to plan.

Note: Time is in *CORIE days* (origin: January 1, 1996). The model is allowed to freely adjust to air-water heat exchanges (adjustment can be seen in the form a significant warm-up during the first 3-4 days).

(b)



1999 – week 31

(August)

Version 4 of simulation database

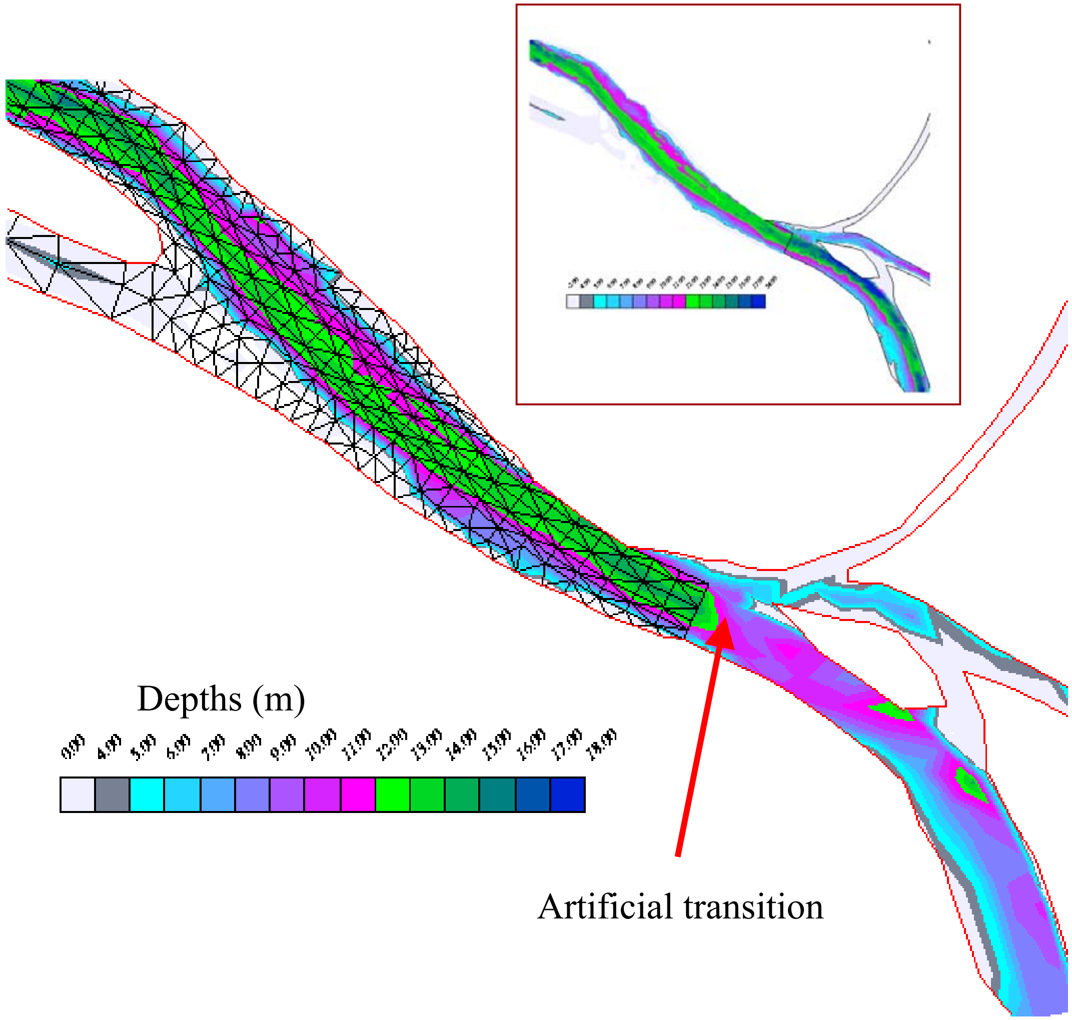
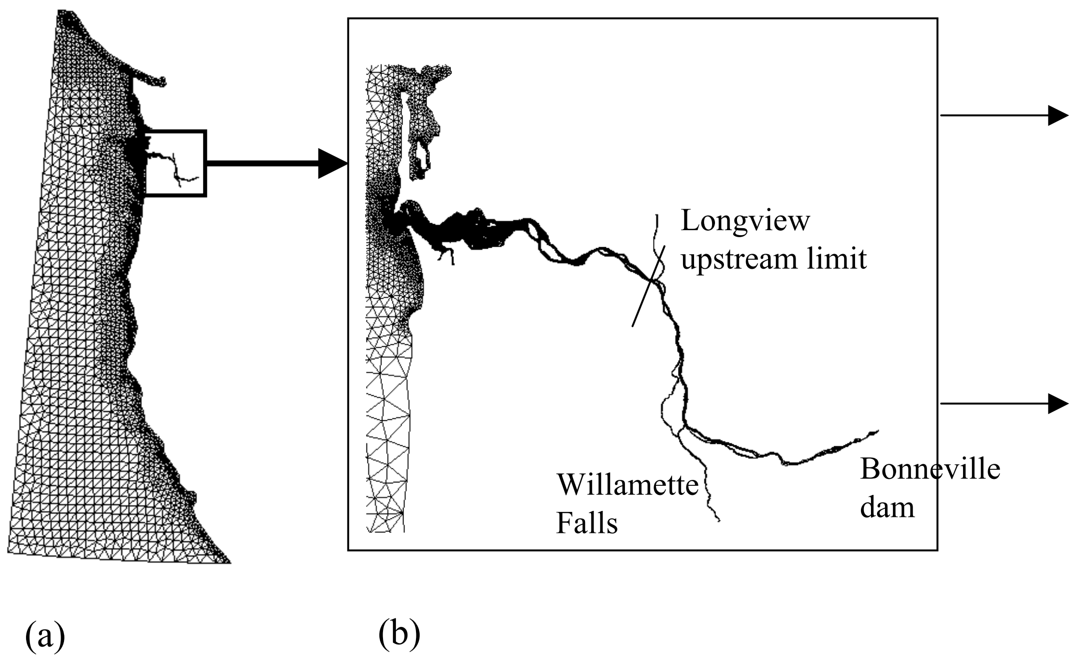
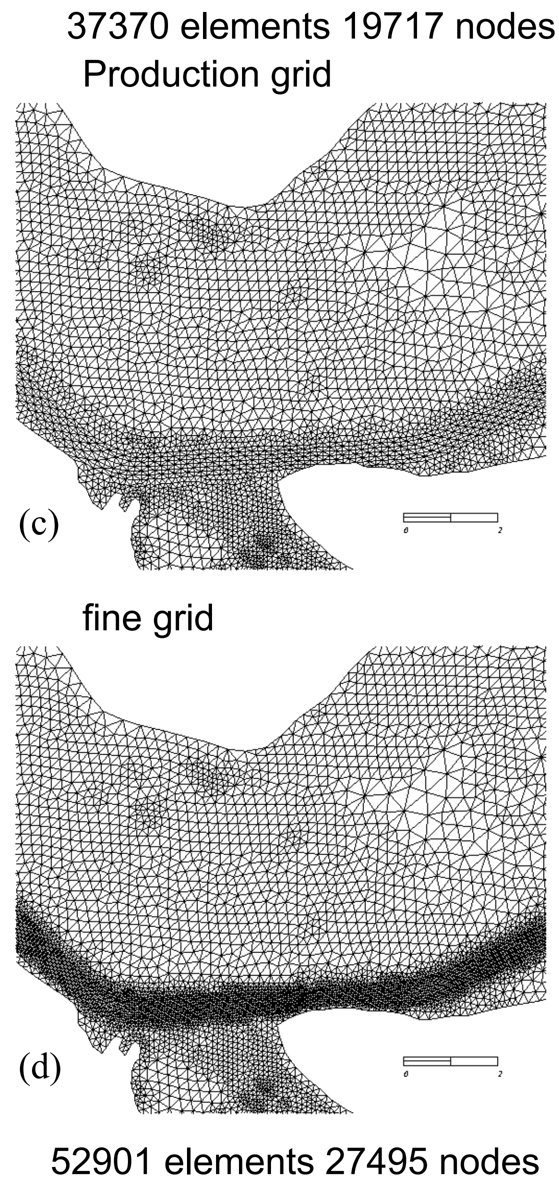


Fig. 26: A detailed analysis of the bathymetry available to us at the beginning of the project revealed an artificial, brusque transition of channel depths downstream and upstream of Longview (main figure). The problem was solved (inset) with bathymetry provided by the Corps of Engineers, but influenced early choice of grid domain (Fig. 27)

Fig. 27: Several grids were considered in this project. (a) All grids extended oceanward beyond the continental slope, north to British Columbia and south to California. (b) Most simulations were conducted with grids extending upstream only to Longview. Version 4 and selected version 1 simulations were conducted with *complete* grids, extending upstream to Bonneville dam and to Willamette Falls. (c) Most simulations were conducted with *production* grids, characterized by moderate spatial resolution. (d) Selected version 1 simulations were conducted with a *fine* grid, with twice the spatial resolution. Both fine and production grids became coarser upstream of Longview.





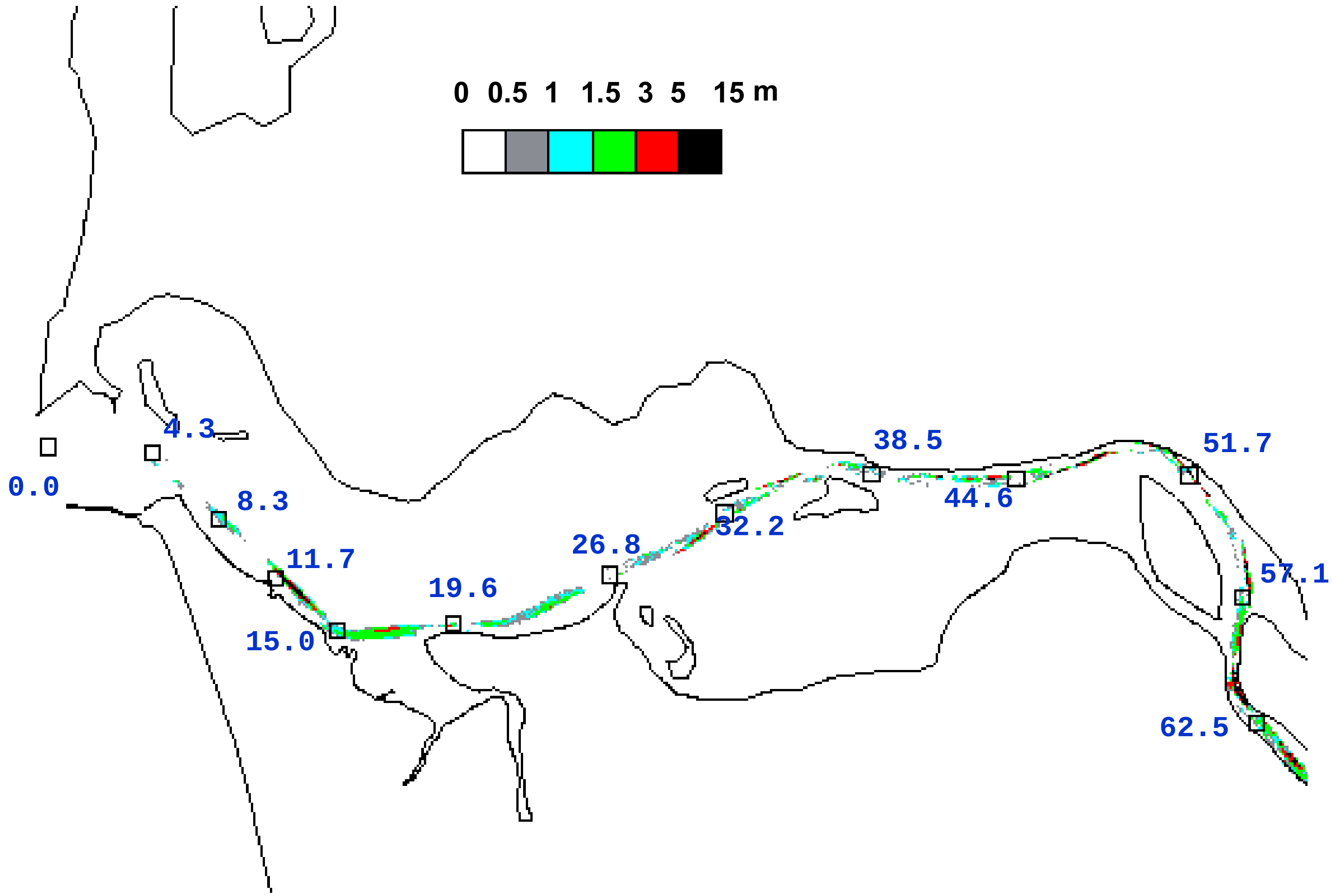


Fig. 28a: Depth differences between base and plan (general view). Numerical values represent kilometers of distance to the entrance of the estuary, measured along the navigation channel.

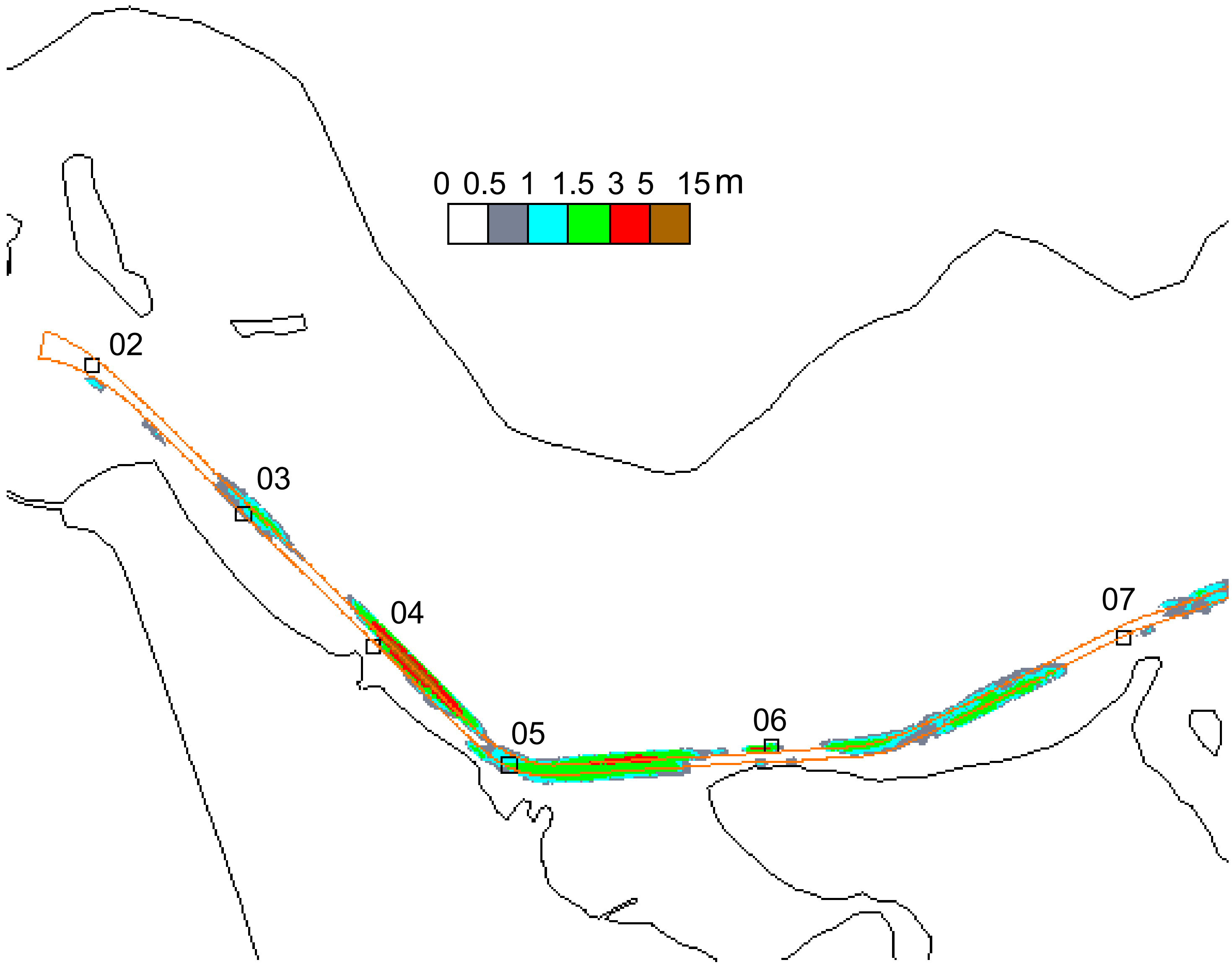


Fig. 28b: Depth differences between base and plan (detail). Numbers refer to the cross sections shown for illustrative purposes in Fig. 29.

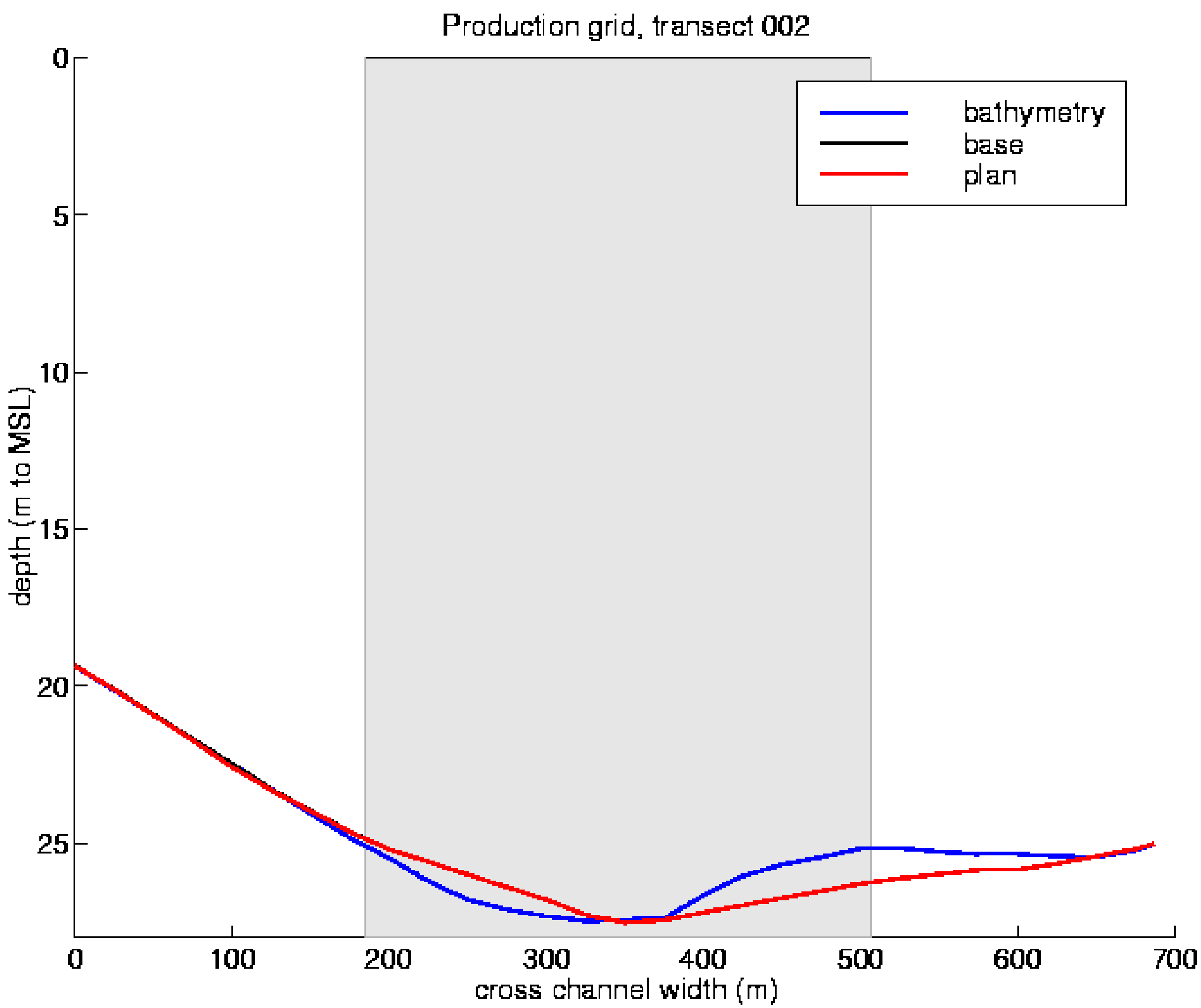


Fig. 29a: Depth at cross-section 02 (see Fig. 28b for location). Different curves represent the cross-section as 'viewed' by either: the detailed grid representing bathymetric data (*bathymetry*), the production grid with base bathymetry (*base*), or the production grid with bathymetry modified to account for channel deepening (*plan*). Shaded area represents the core channel.

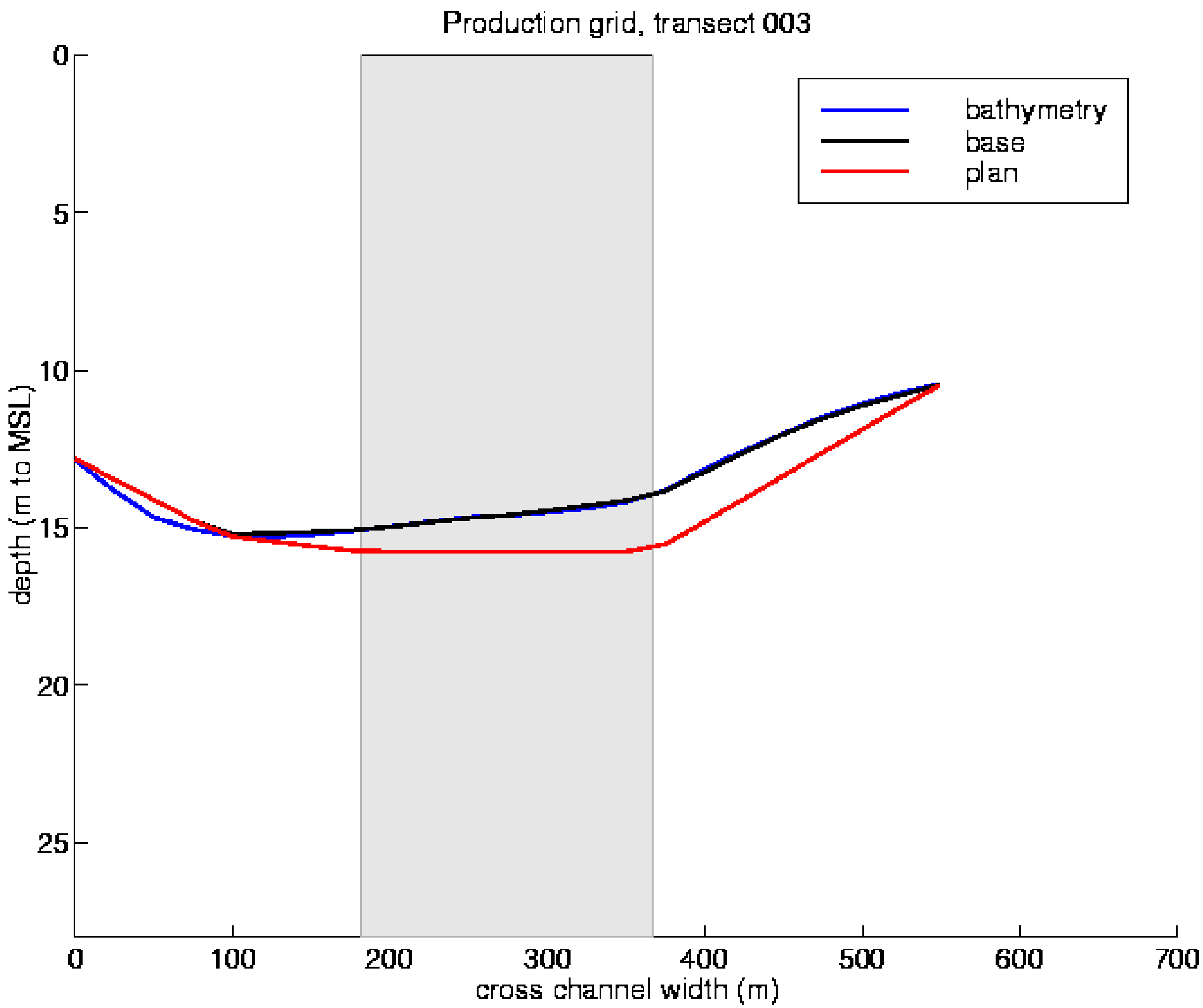


Fig. 29b: Depth at cross-section 03 (see Fig. 28b for location). Different curves represent the cross-section as 'viewed' by either: the detailed grid representing bathymetric data (*bathymetry*), the production grid with base bathymetry (*base*), or the production grid with bathymetry modified to account for channel deepening (*plan*). Shaded area represents the core channel.

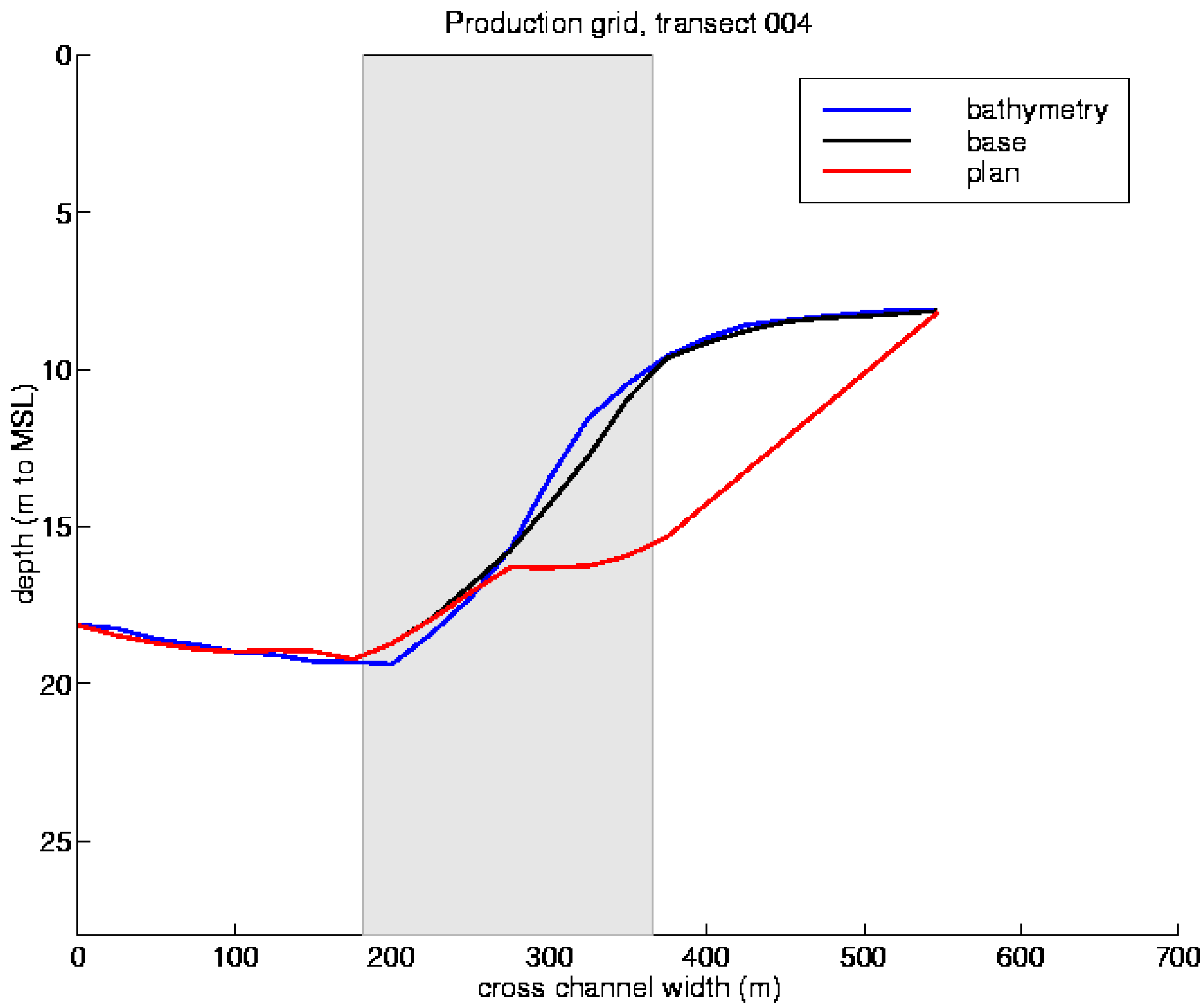


Fig. 29c: Depth at cross-section 04 (see Fig. 28b for location). Different curves represent the cross-section as 'viewed' by either: the detailed grid representing bathymetric data (*bathymetry*), the production grid with base bathymetry (*base*), or the production grid with bathymetry modified to account for channel deepening (*plan*). Shaded area represents the core channel.

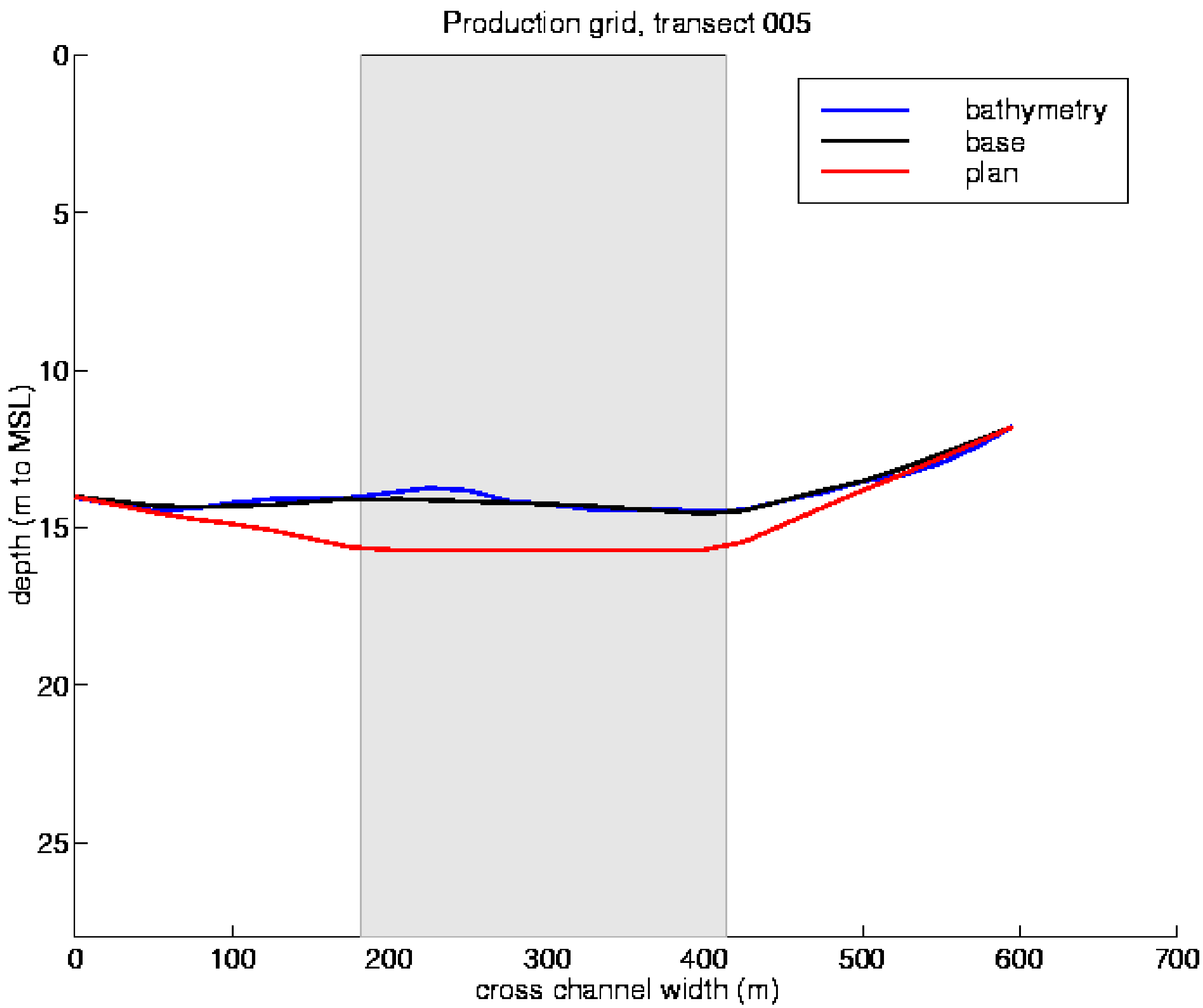


Fig. 29d: Depth at cross-section 05 (see Fig. 28b for location). Different curves represent the cross-section as 'viewed' by either: the detailed grid representing bathymetric data (*bathymetry*), the production grid with base bathymetry (*base*), or the production grid with bathymetry modified to account for channel deepening (*plan*). Shaded area represents the core channel.

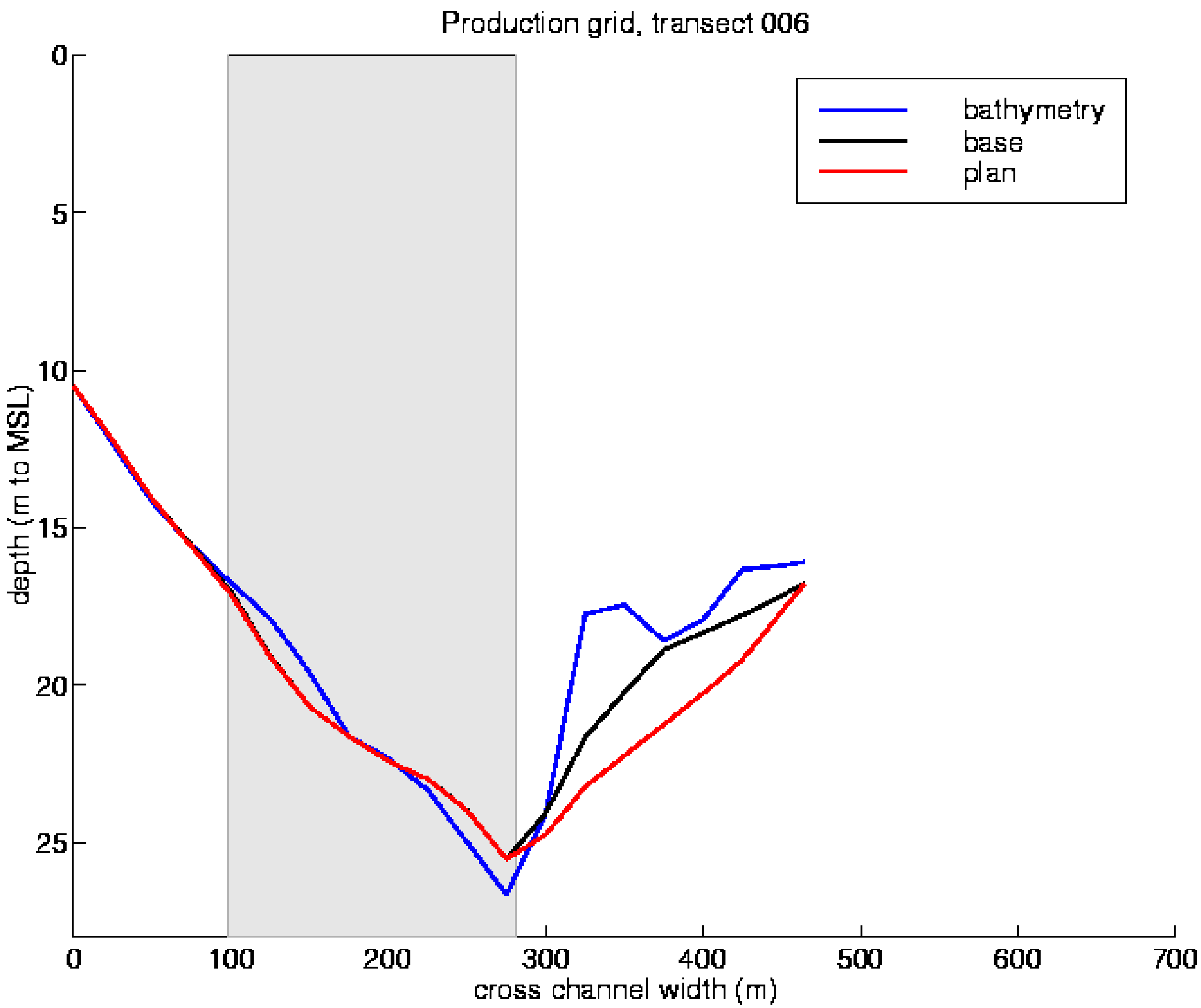


Fig. 29e: Depth at cross-section 06 (see Fig. 28b for location). Different curves represent the cross-section as 'viewed' by either: the detailed grid representing bathymetric data (*bathymetry*), the production grid with base bathymetry (*base*), or the production grid with bathymetry modified to account for channel deepening (*plan*). Shaded area represents the core channel.

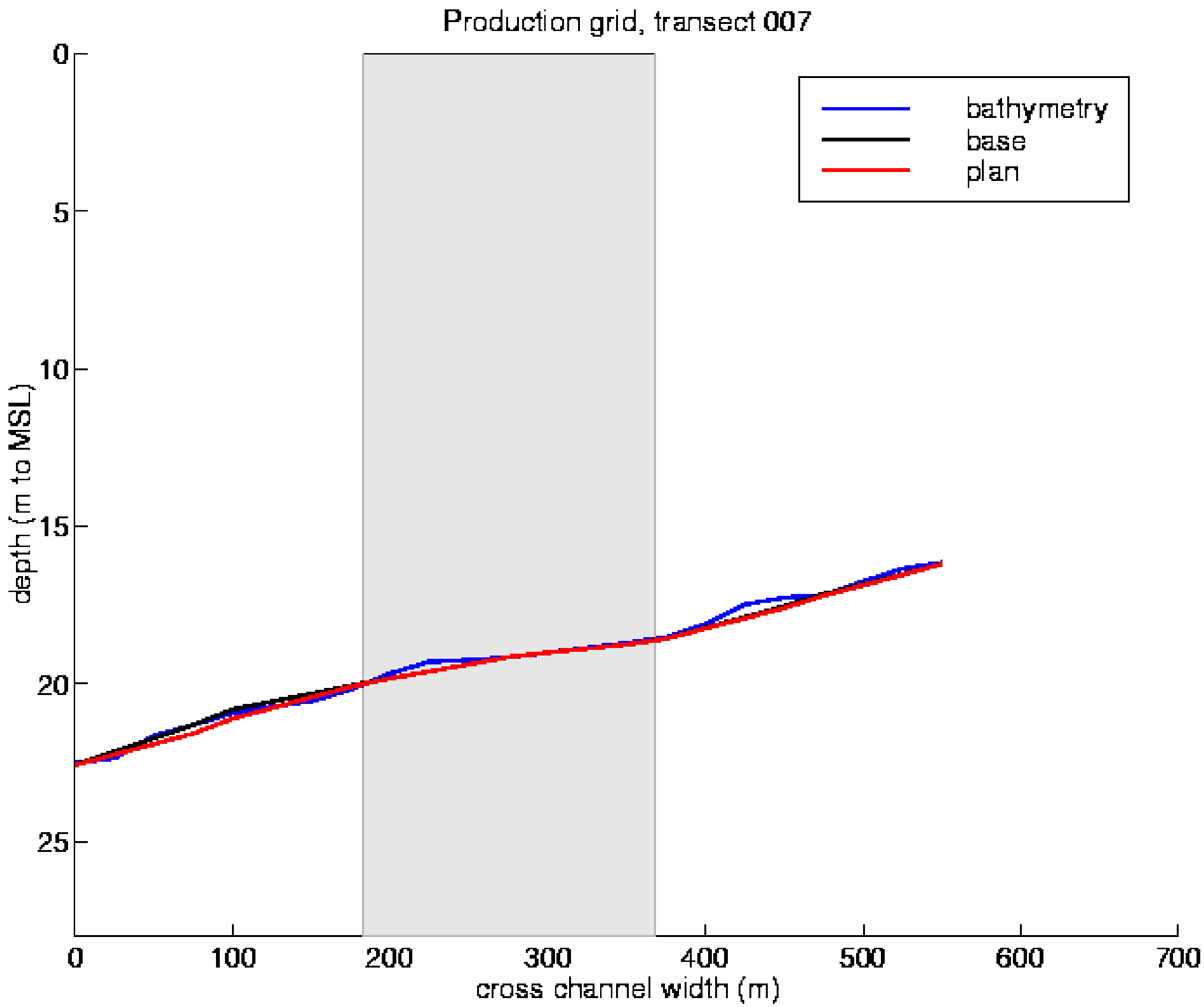


Fig. 29f: Depth at cross-section 07 (see Fig. 28b for location). Different curves represent the cross-section as 'viewed' by either: the detailed grid representing bathymetric data (*bathymetry*), the production grid with base bathymetry (*base*), or the production grid with bathymetry modified to account for channel deepening (*plan*). Shaded area represents the core channel.

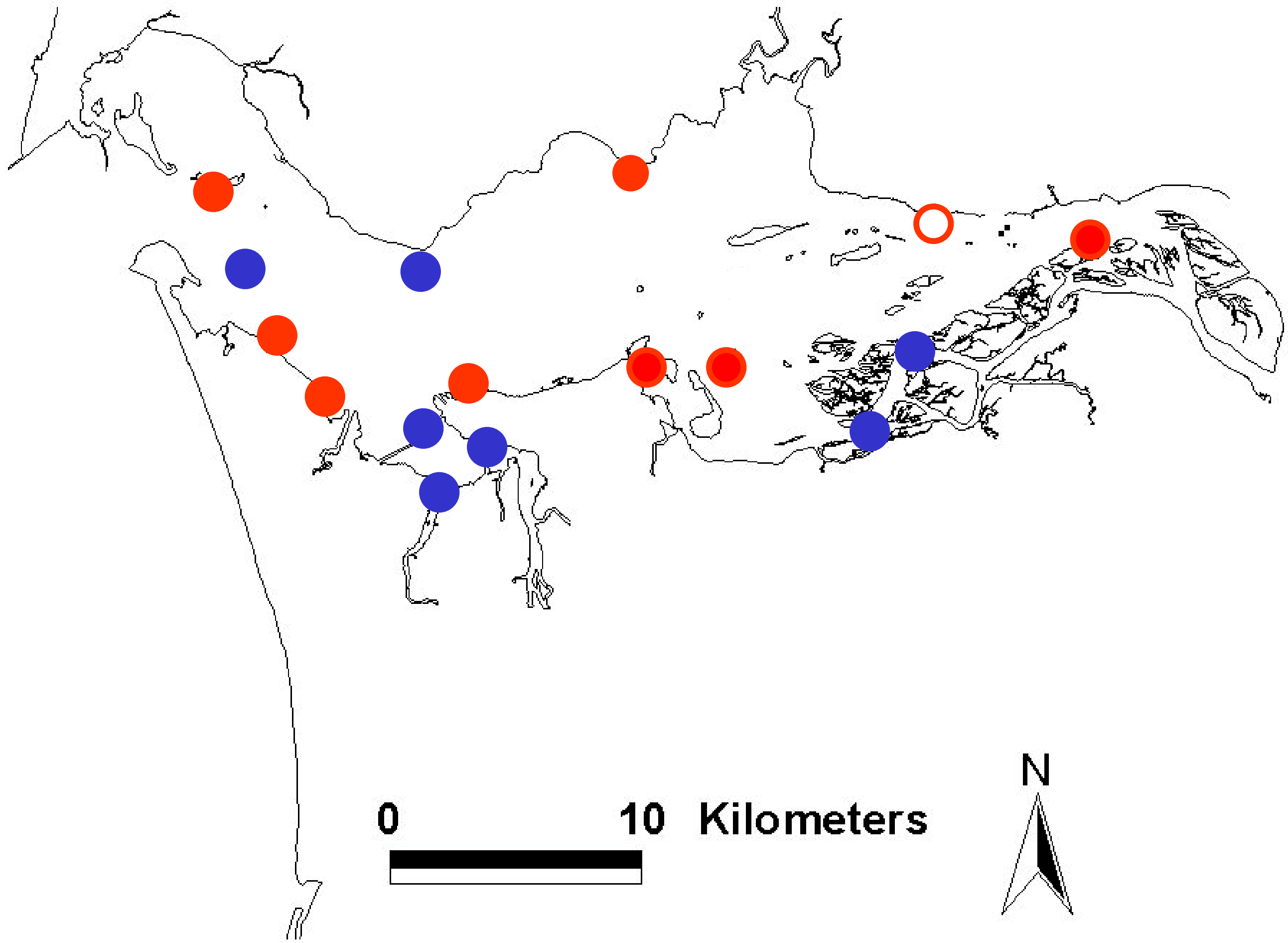
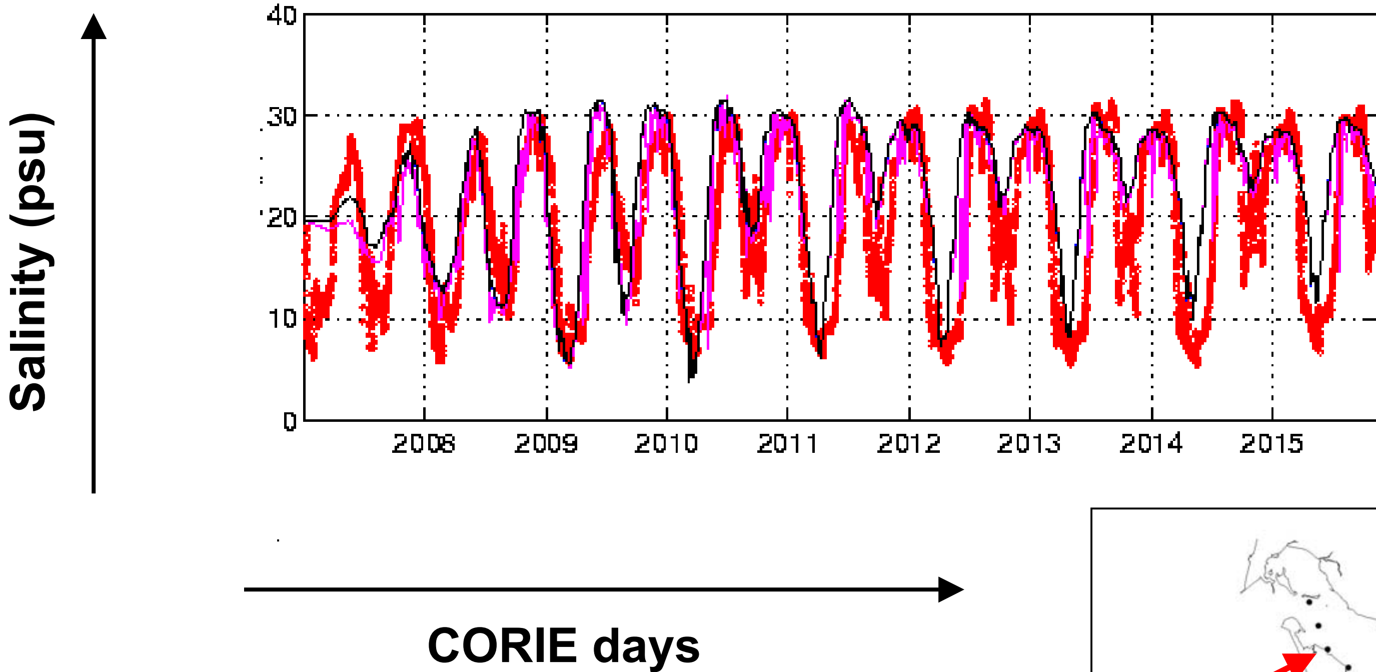


Fig. 30: Red circles represent the CORIE stations with salinity data available for model comparison in week 27 of 2001 (July). Model-data comparisons are shown in Fig. 31a-h. Blue circles represent CORIE stations for which data are not available for the period.

2001 – week 27

(July)

Version 2 of simulation database



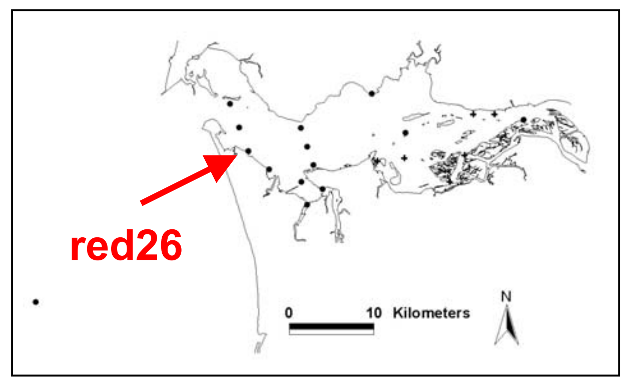


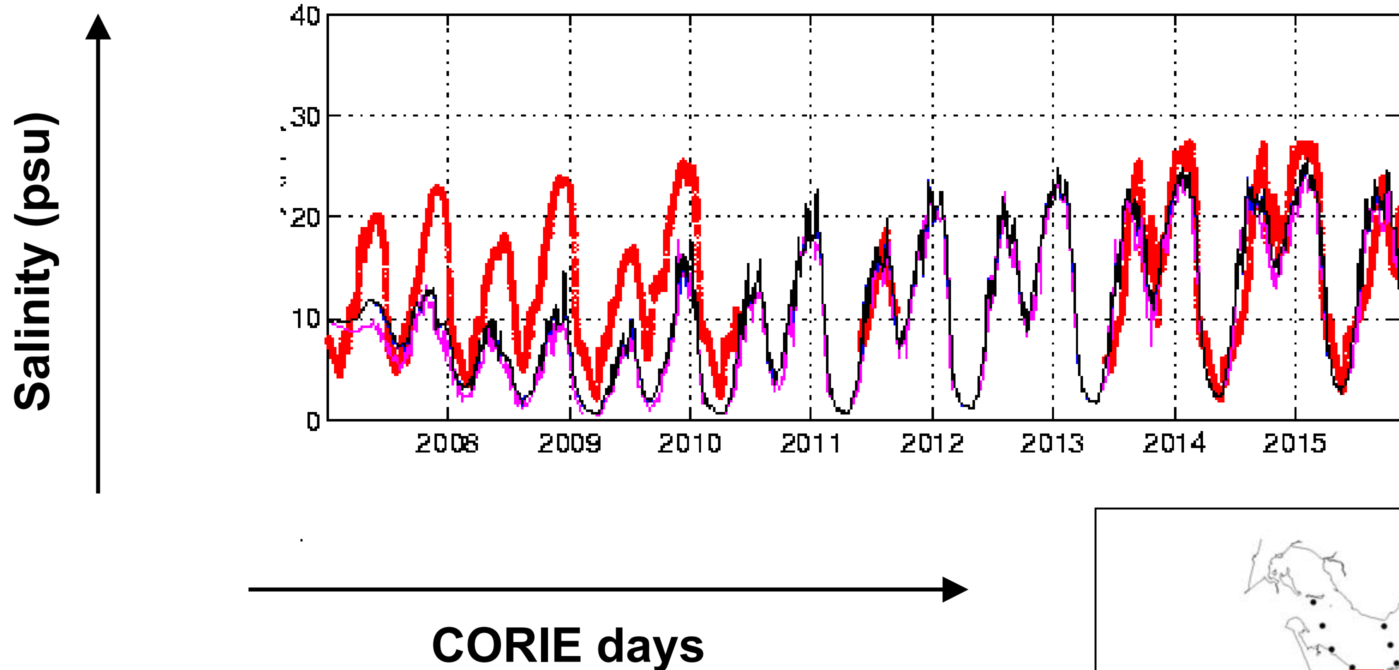
Fig. 31a: Model-data comparisons for the period and CORIE station shown. Data is in red, model at comparable depth is in purple. Model at other depths in black and blue.

Note: The first three days correspond to a warm-up period.

2001 – week 27

(July)

Version 2 of simulation database



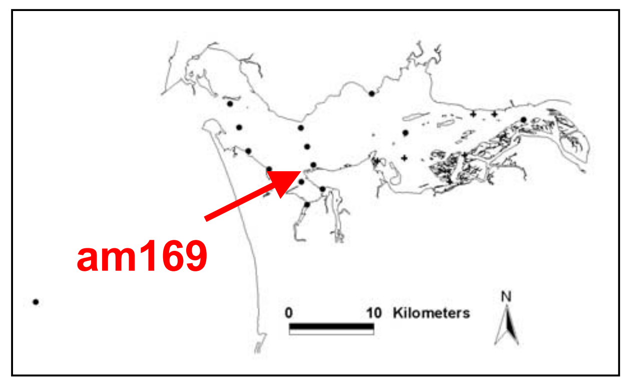


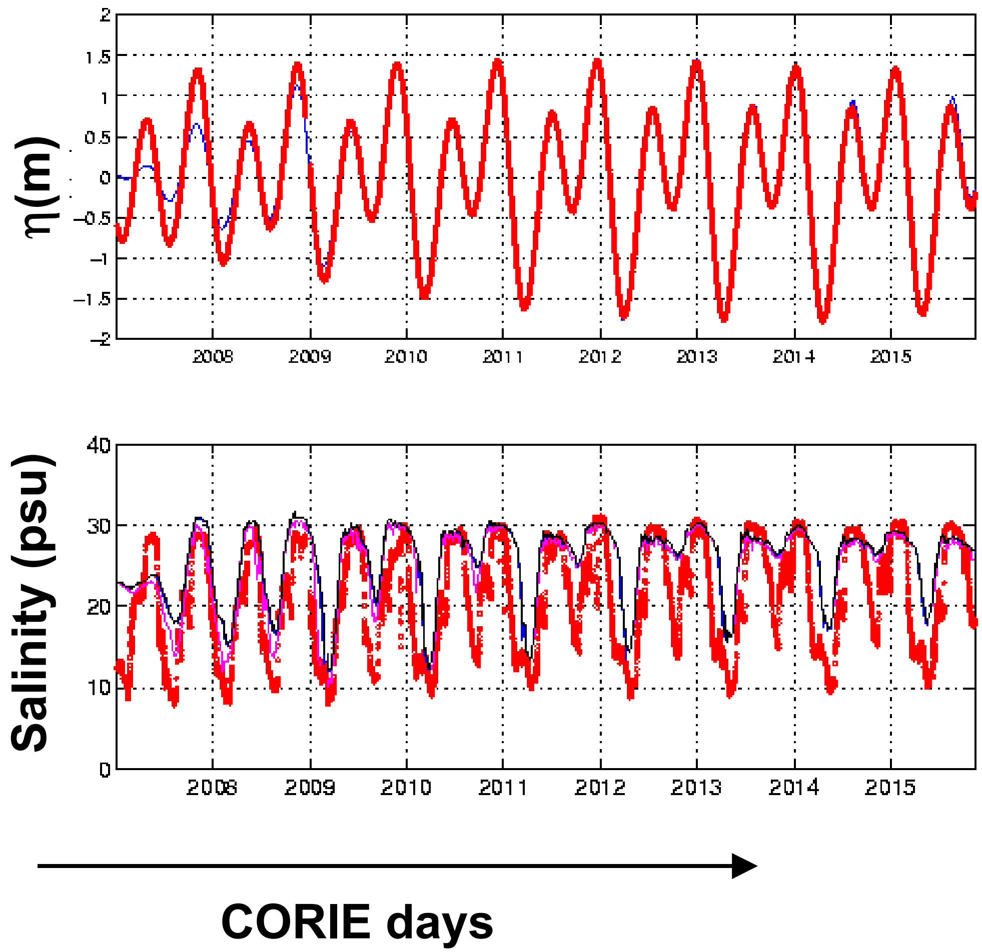
Fig. 31b: Model-data comparisons for the period and CORIE station shown. Data is in red, model at comparable depth is in purple. Model at other depths in black and blue.

Note: The first three days correspond to a warm-up period.

2001 – week 27

(July)

Version 2 of simulation database



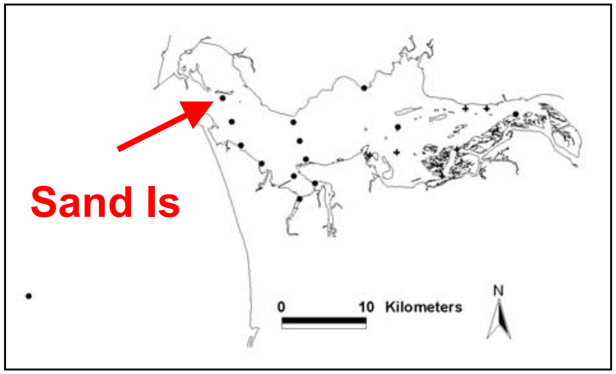


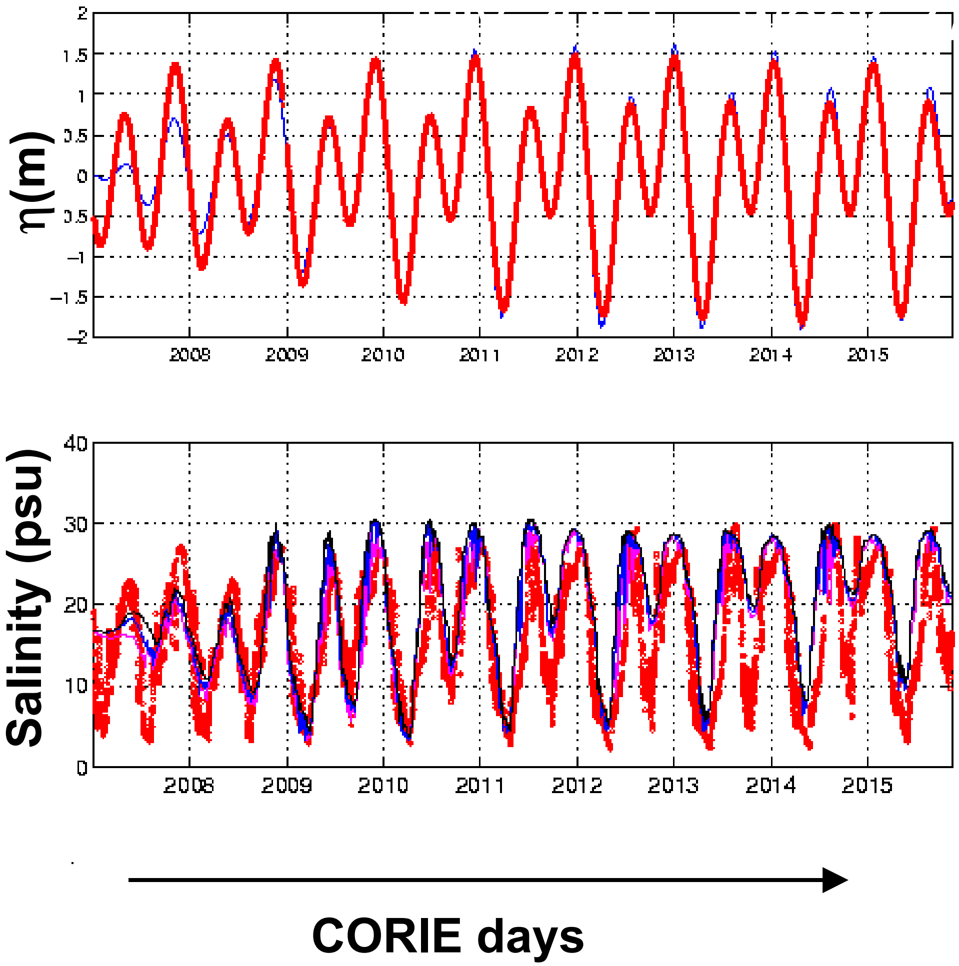
Fig. 31c: Model-data comparisons for the period and CORIE station shown. <u>Water elevation</u>: data in red, model in blue. <u>Salinity</u>: data in red, model at comparable depth in purple; model at other depths in black and blue.

Note: The first three days correspond to a warm-up period.

2001 – week 27

(July)

Version 2 of simulation database



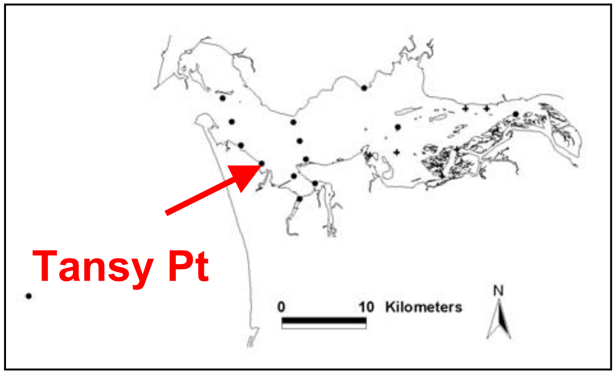


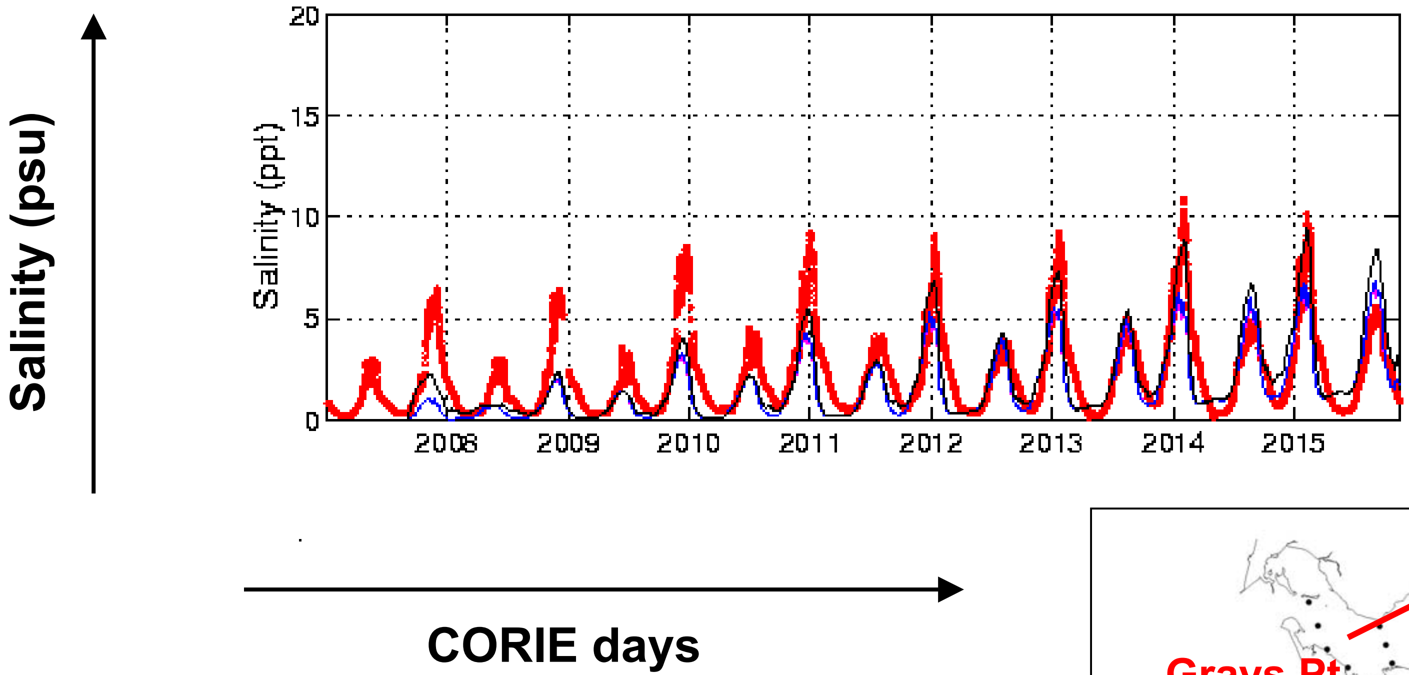
Fig. 31d: Model-data comparisons for the period and CORIE station shown. Water elevation: data in red, model in blue. Salinity: data in red, model at comparable depth in purple; model at other depths in black and blue.

Note: The first three days correspond to a warm-up period.

2001 – week 27

(July)

Version 2 of simulation database



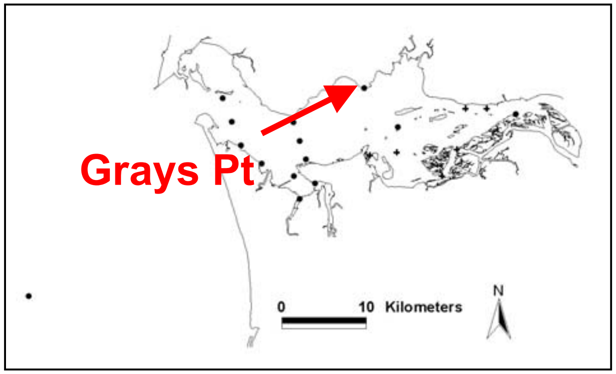


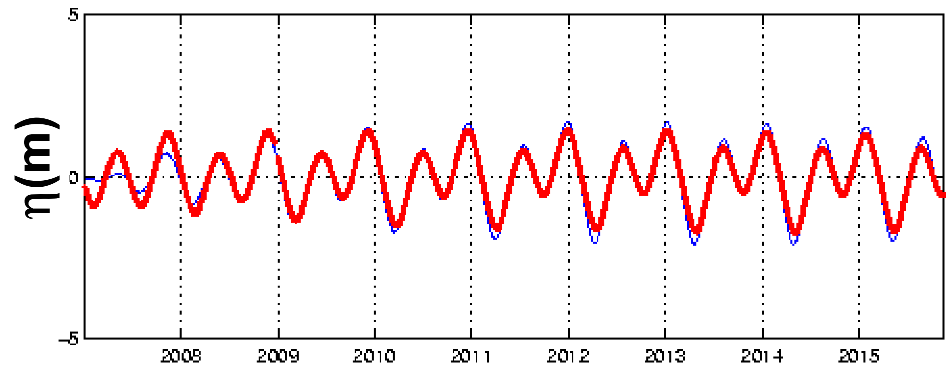
Fig. 31e: Model-data comparisons for the period and CORIE station shown. Data is in red, model at comparable depth is in purple. Model at other depths in black and blue.

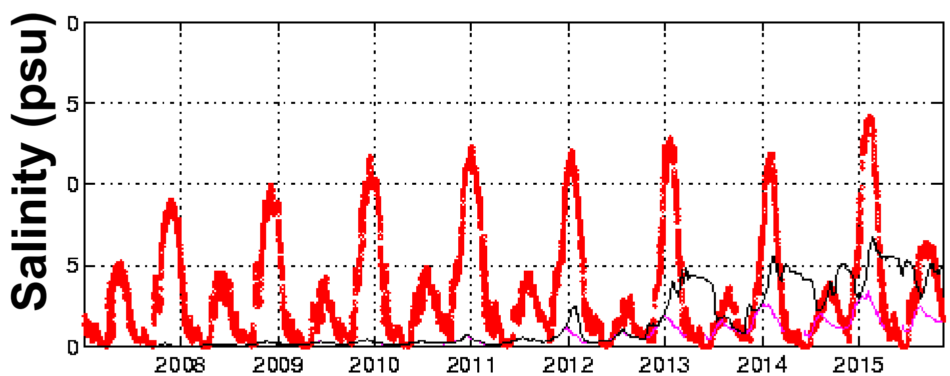
Note: The first three days correspond to a warm-up period.

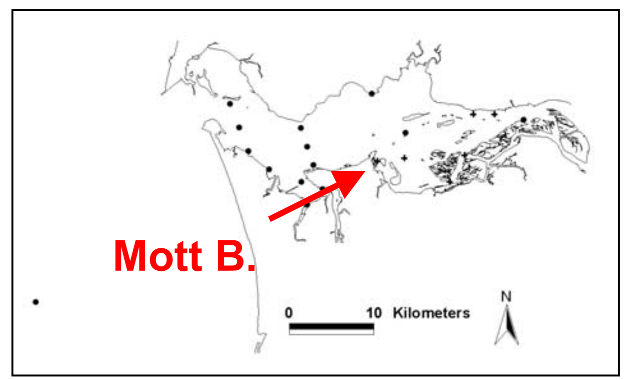
2001 – week 27

(July)

Version 2 of simulation database







CORIE days

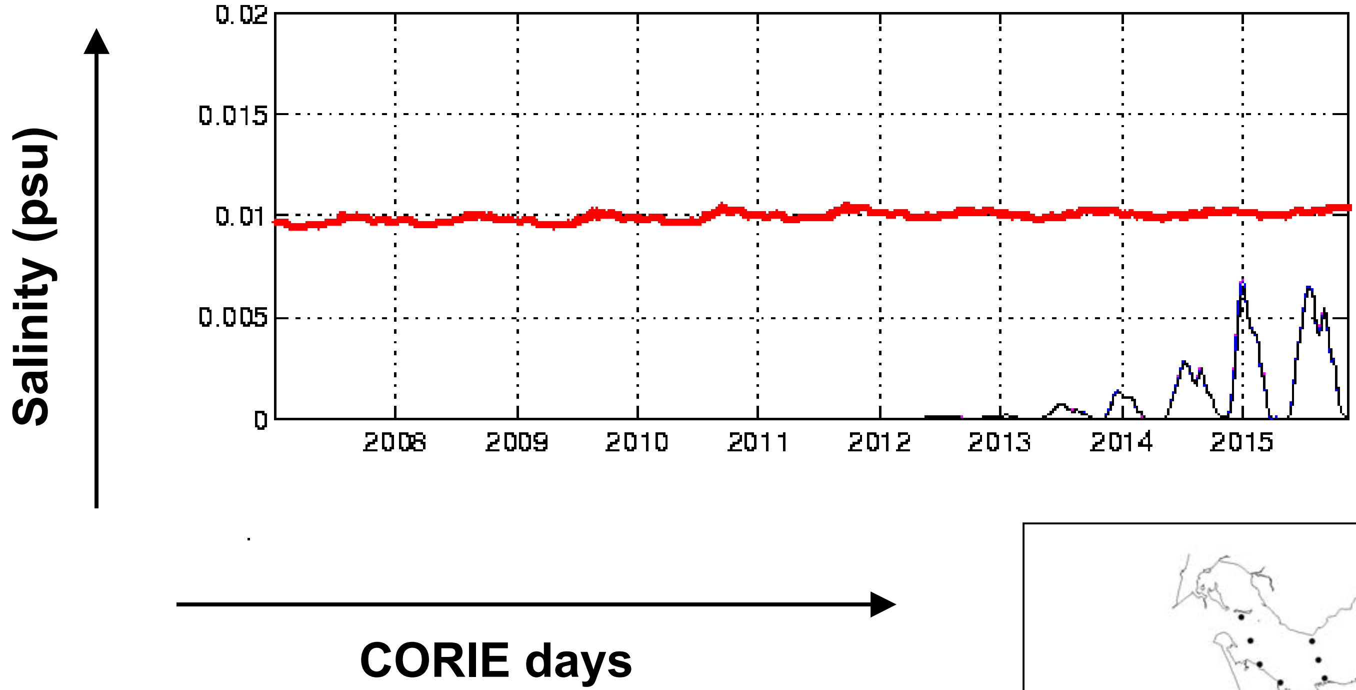
Fig. 31f: Model-data comparisons for the period and CORIE station shown. Water elevation: data in red, model in blue. Salinity: data in red, model at comparable depth in purple; model at other depths in black and blue.

Note: The first three days correspond to a warm-up period.

2001 – week 27

(July)

Version 2 of simulation database



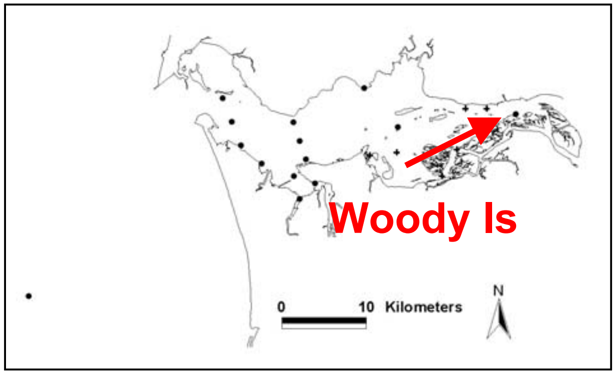


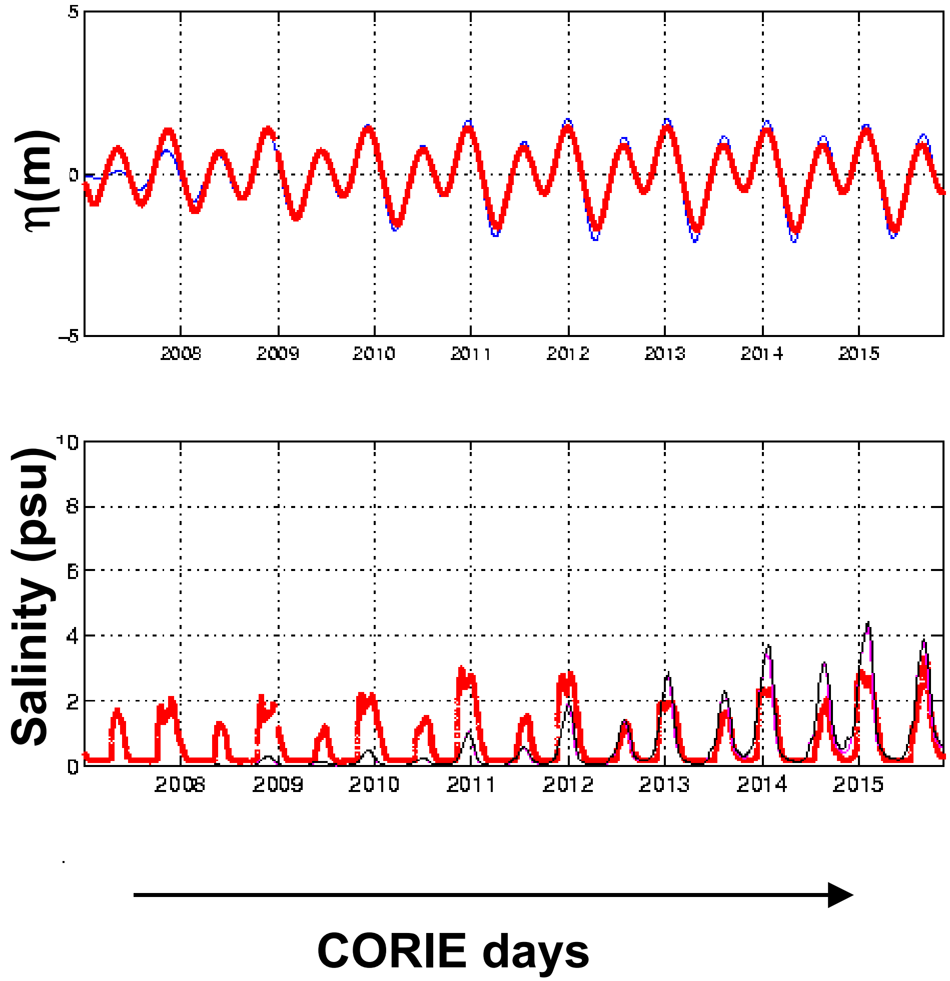
Fig. 31g: Model-data comparisons for the period and CORIE station shown. Data is in red, model at comparable depth is in purple. Model at other depths in black and blue.

Note: The first three days correspond to a warm-up period.

2001 – week 27

(July)

Version 2 of simulation database



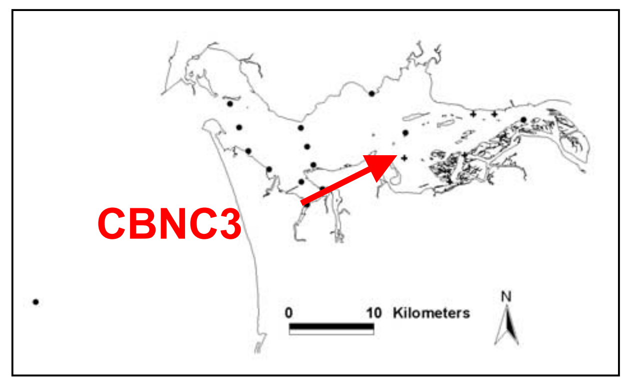


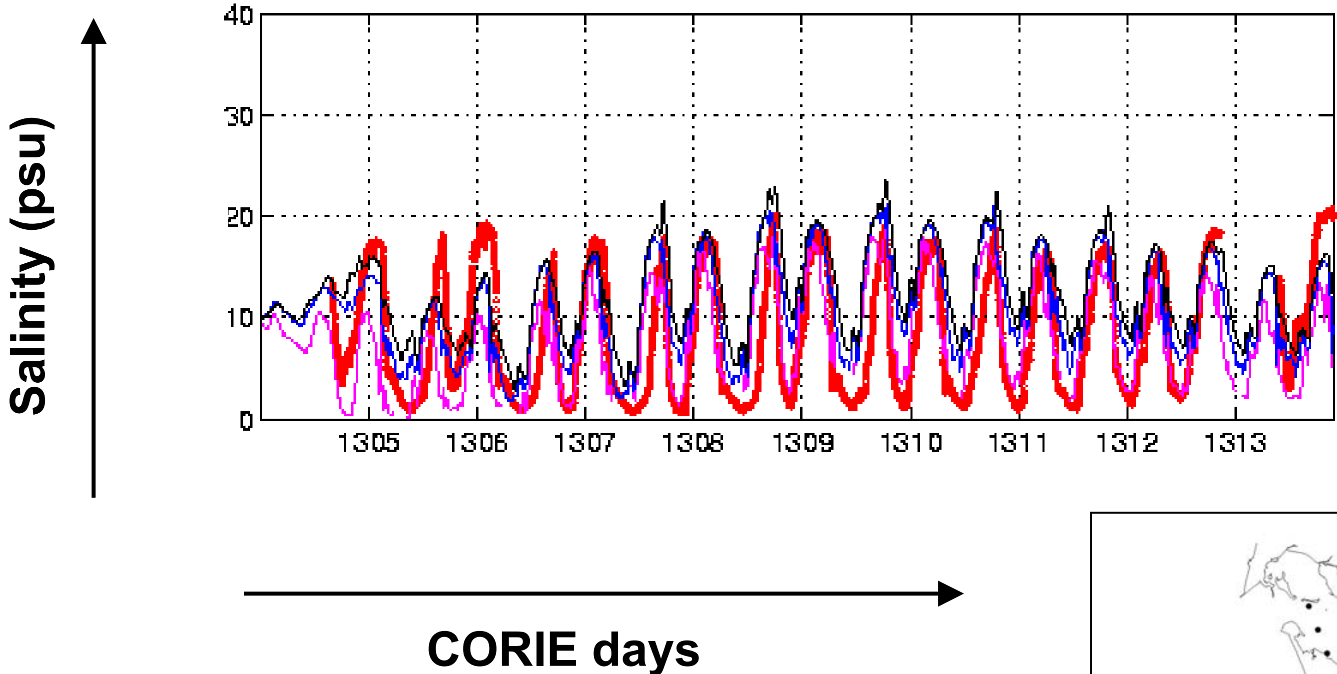
Fig. 31h: Model-data comparisons for the period and CORIE station shown. Water elevation: data in red, model in blue. Salinity: data in red, model at comparable depth in purple; model at other depths in black and blue.

Note: The first three days correspond to a warm-up period.

1999 – week 31

(August)

Version 3 of simulation database



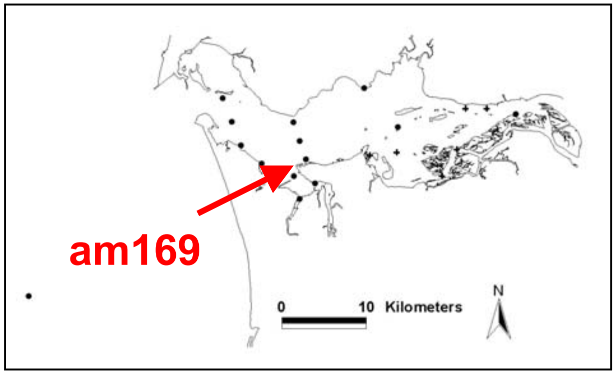


Fig. 32: Model-data comparisons for mid-range river discharges, with stratification represented by the model. Data is in red, model at comparable depth is in purple. Model at other depths (closer to bottom) in black and blue.

Note: The first three days correspond to a warm-up period.

1997 – week 18

(May)

Sand Island

Version 2
Version 3

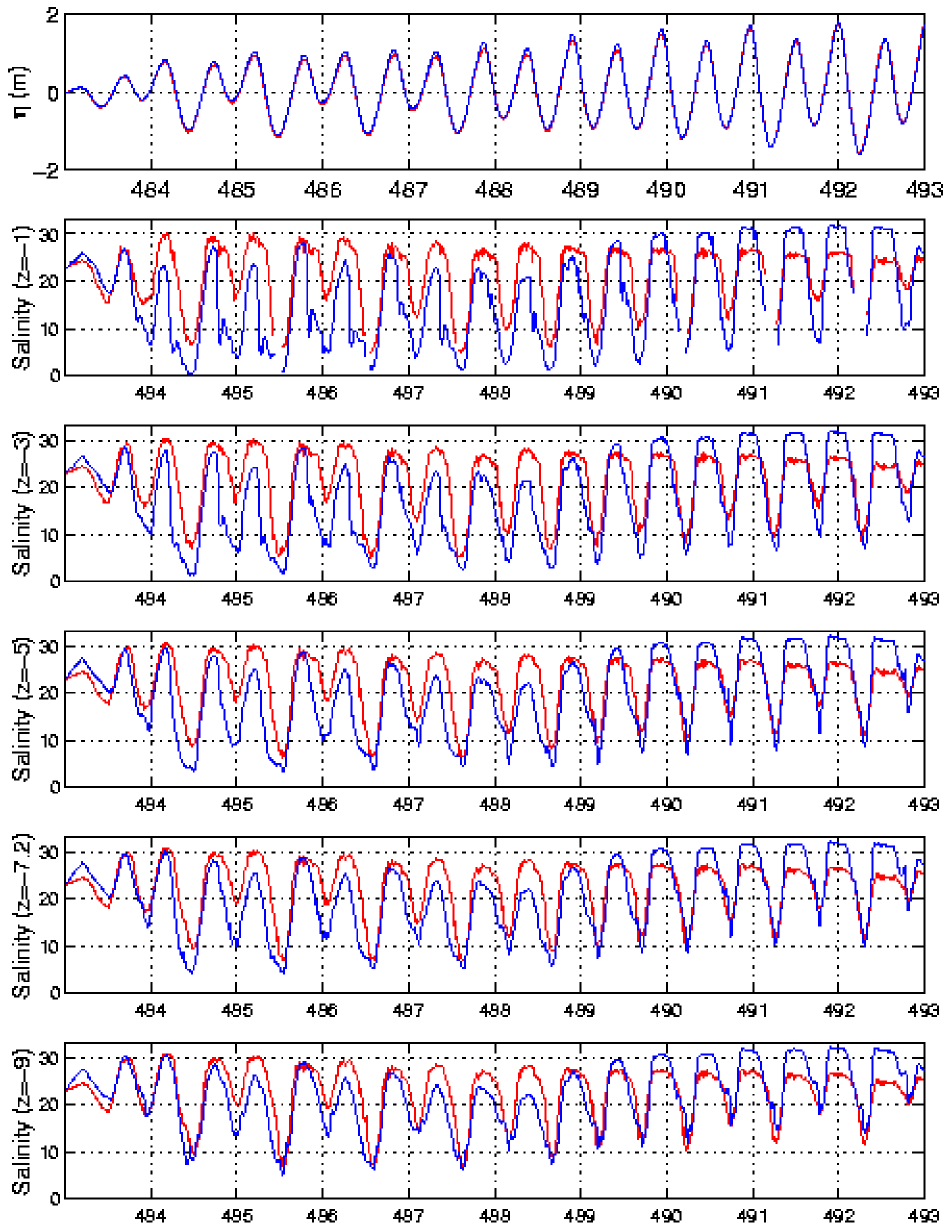
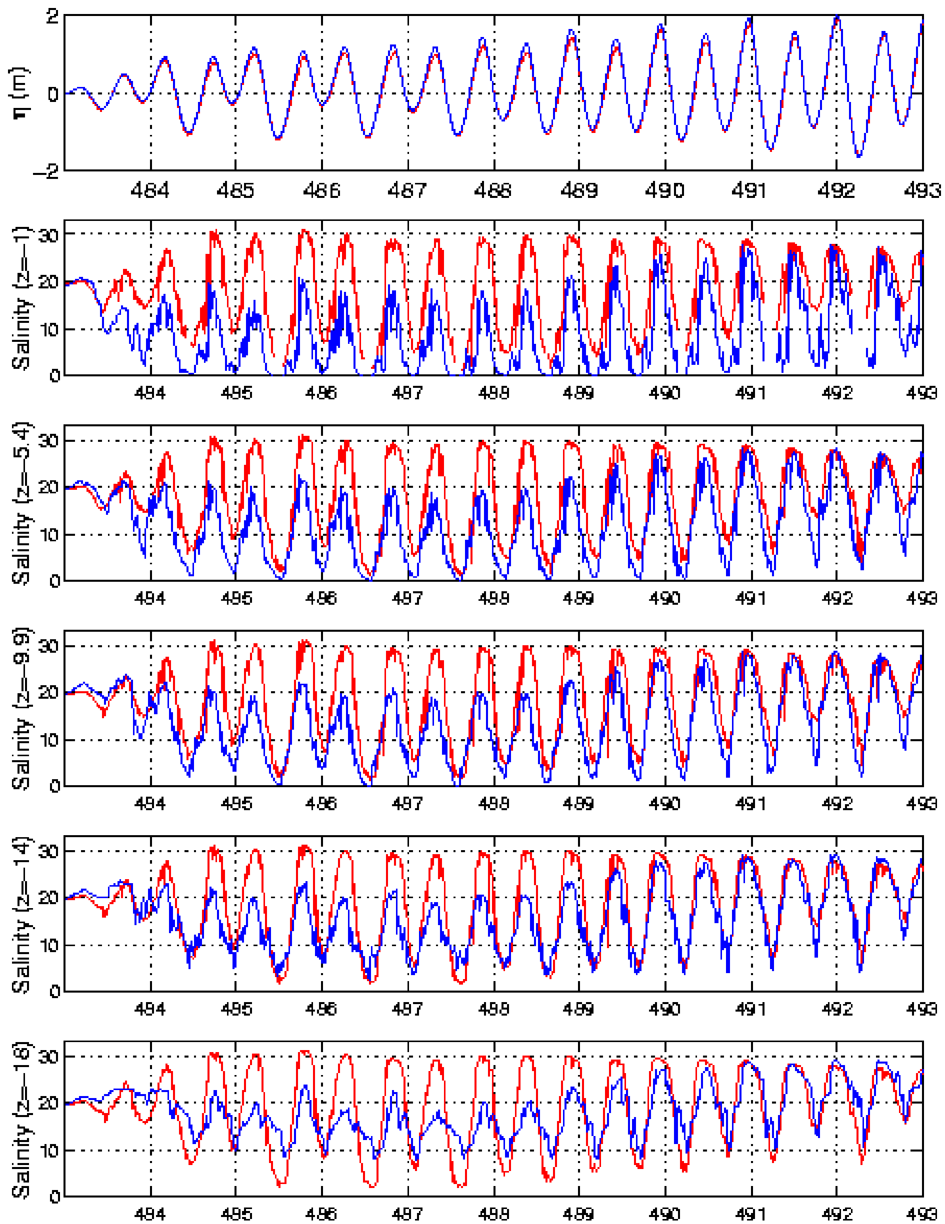


Fig. 33a: Model-model comparisons for high river discharges, with stratification underestimated (version 2) and more realistically represented (version 3). Version 2 and 3 differ on the time step used (7.5 versus 2.5 minutes).

Note: The first three days correspond to a warm-up period.



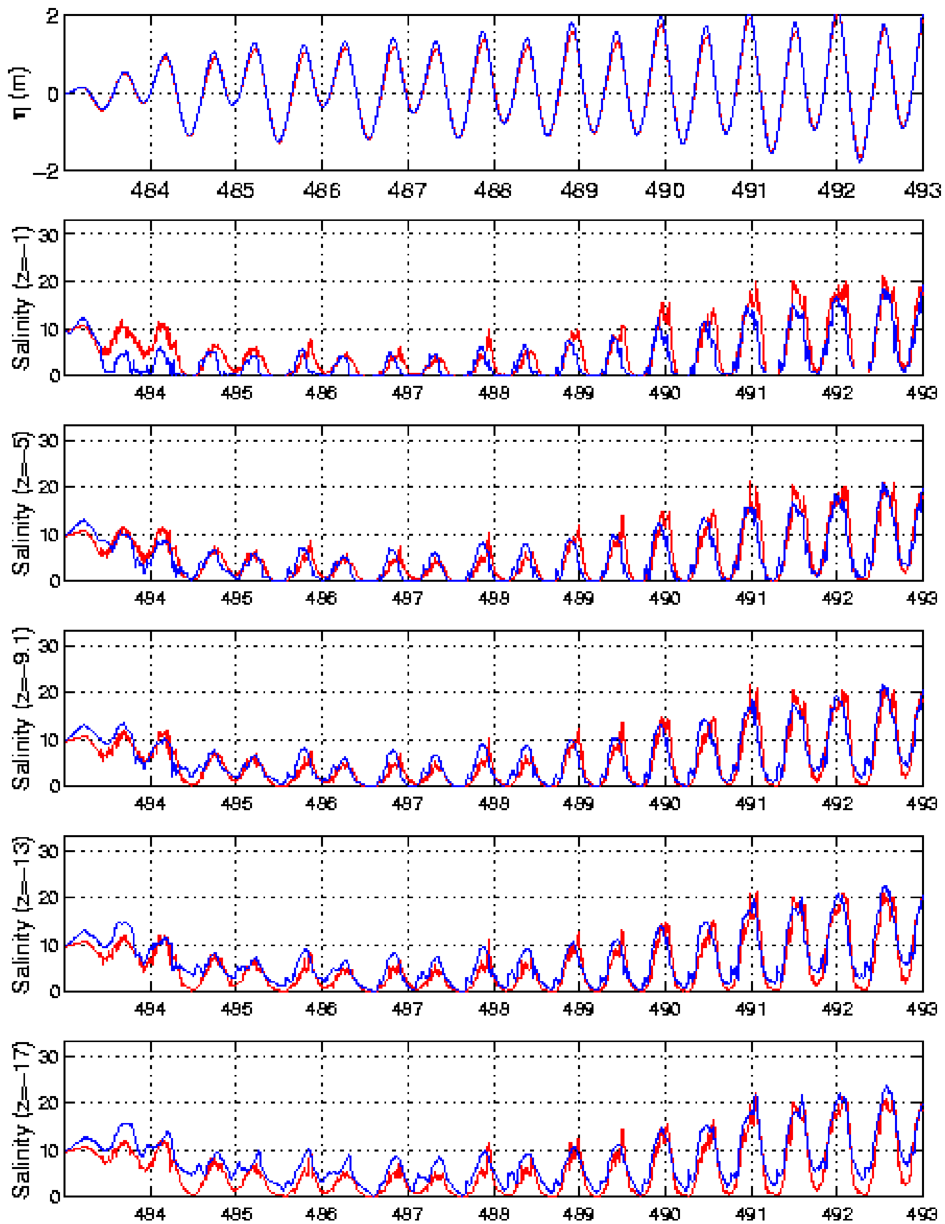
1997 – week 18
(May)

Red26

Version 2
Version 3

Fig. 33b: Model-model comparisons for high river discharges, with stratification underestimated (version 2) and more realistically represented (version 3). Version 2 and 3 differ on the time step used (7.5 versus 2.5 minutes).

Note: The first three days correspond to a warm-up period.



1997 – week 18

(May)

AM169

Version 2
Version 3

Fig. 33c: Model-model comparisons for high river discharges, with stratification underestimated (version 2) and more realistically represented (version 3). Version 2 and 3 differ on the time step used (7.5 versus 2.5 minutes).

Note: The first three days correspond to a warm-up period.