Pseudo-analyses of the Gulf of St. Lawrence (GSL) based on prognostic 3D oceanic simulations

19 décembre 2008

(implementation planned for the winter 2009)

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(1) - CMC
(2) - RPN
(3) - National Labs. Halifax
(4) - CMOI

Gulf of St. Lawrence (GSL) pseudo-analysis

Presentation plan

- What is our GSL pseudo-analysis?
- Comparison with the sea surface temperature (SST) analysis from CMC
- Verification with in situ data from ships and fixed stations
- Preliminary verification of non coupled ice forecast (positive effect of including ice growth and decay)
- Improvements made to the current experimental system
- Future work

GSL pseudo-analysis

What is it?

- **A 3D ice-ocean model output that we use as an analysis to initialize oceanic forecast (e.g. to start the coupled forecast)**

- **The output comes from a climate type seasonal simulation driven by the atmosphere with solutions from regional GEM (end to end 006-018 forecast, 00Z + 12Z)**

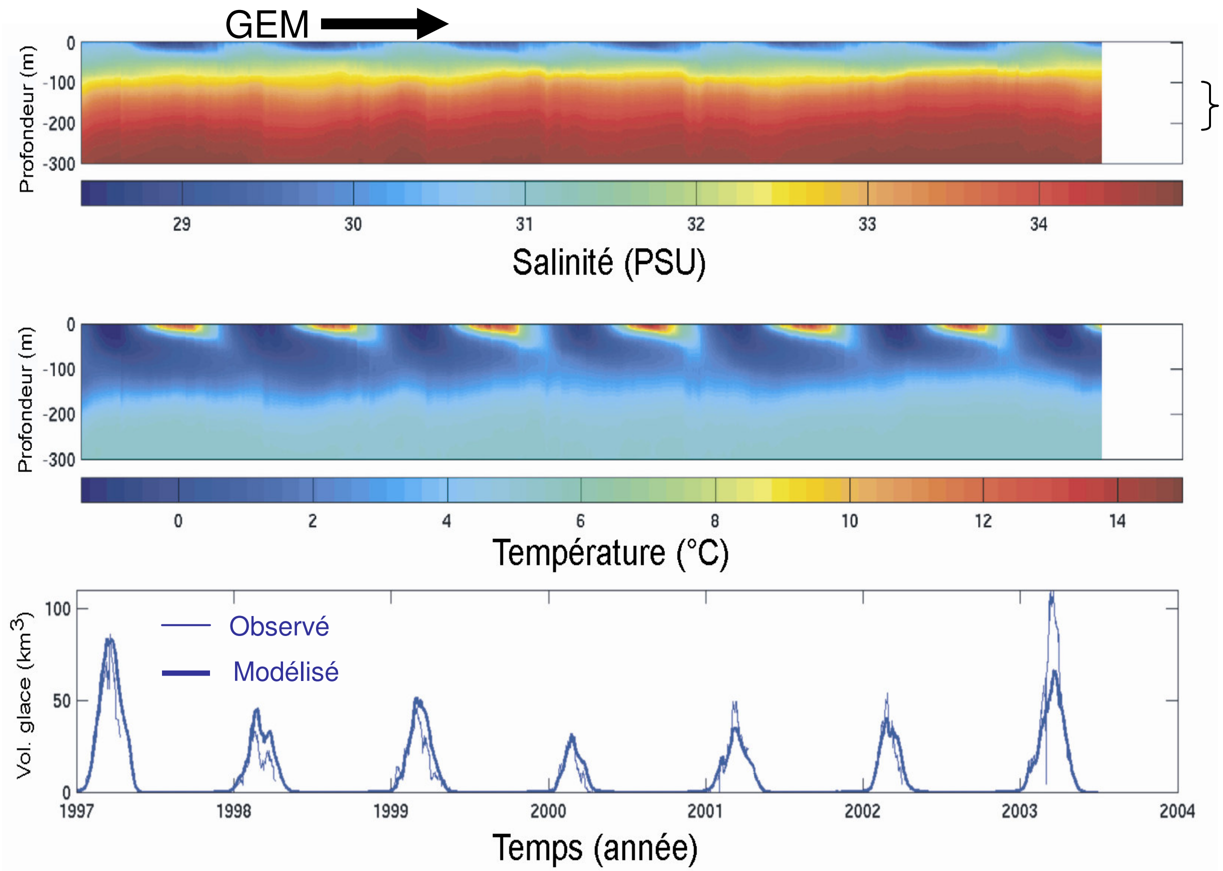
- **The simulation is produced without the use of real-time data (no data assimilation except for ice in winter)**

- **The simulation is produced with neither flux correction nor restoring methods (prognostic)**

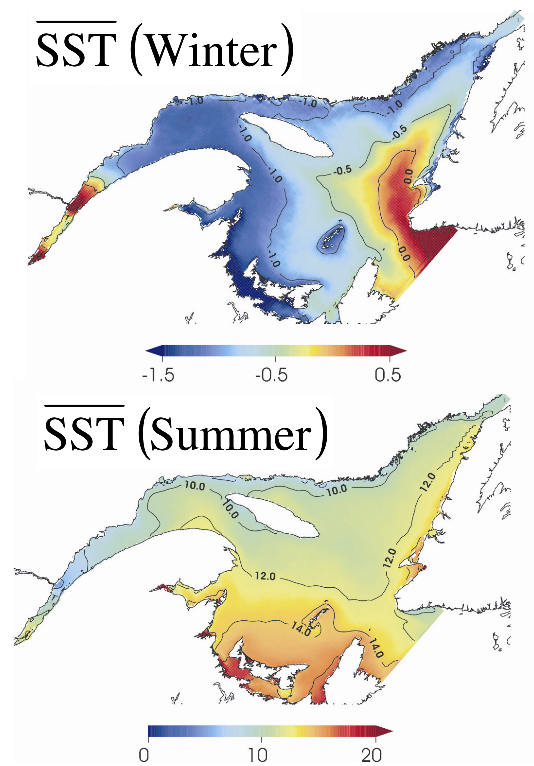
GSL pseudo-analysis: scientific grounds

We benefit from recent developments in ice-ocean modeling

(prognostic 7 year simulation, no data assimilation, reasons to believe we can do similar in real-time)



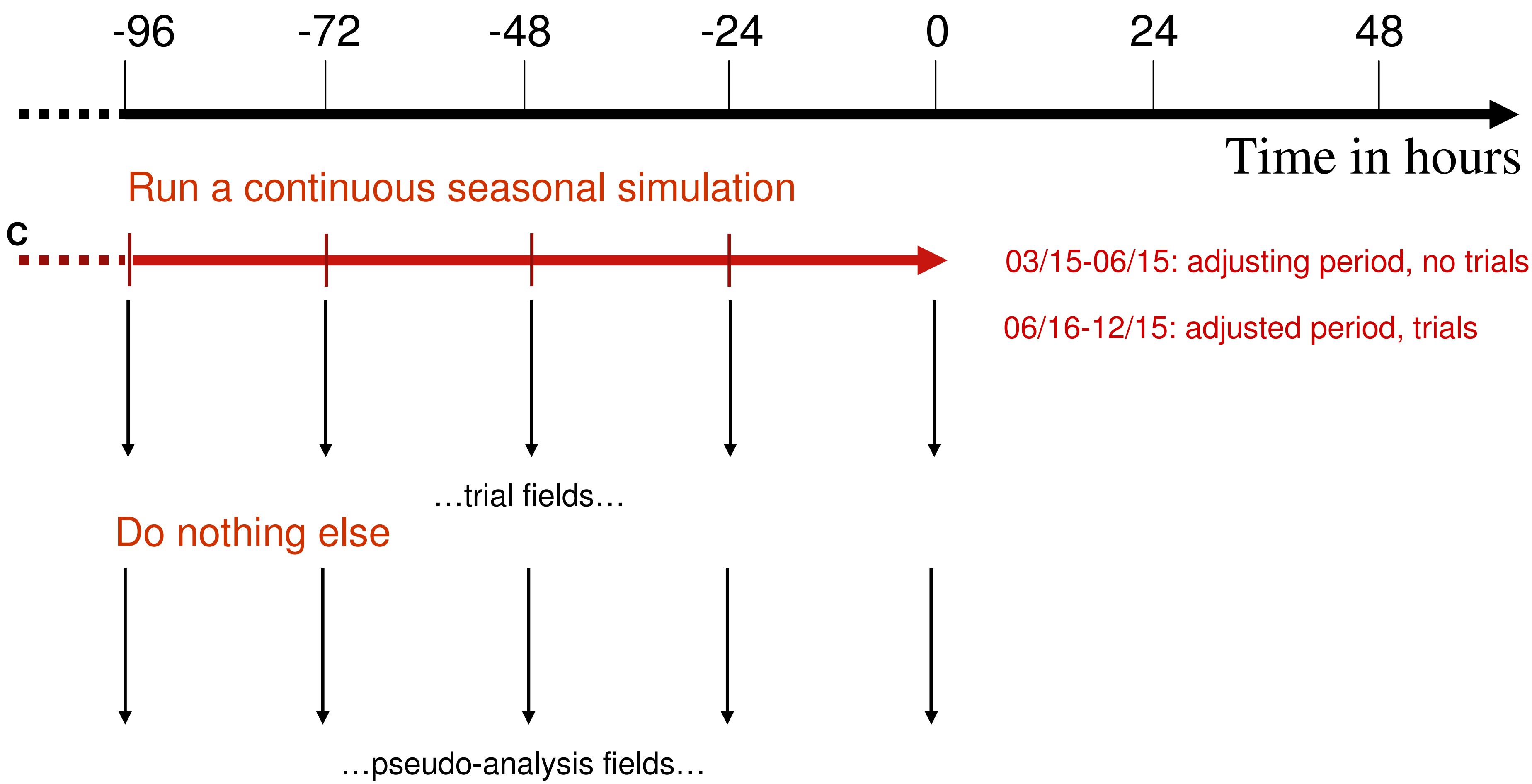
}+0.5 p.s.u. small drift



Saucier, F. J., F. Roy, S. Senneville, G. Smith, D. Lefaivre, B. Zakardjian et J-F. Dumais (2008). Modélisation de la circulation dans l'estuaire et le golfe du Saint-Laurent en réponse aux variations du débit d'eau douce et des vents. *Revue des Sciences de l'Eau,* 21(4) 525-542.

GSL pseudo-analysis: technical description

In summer …

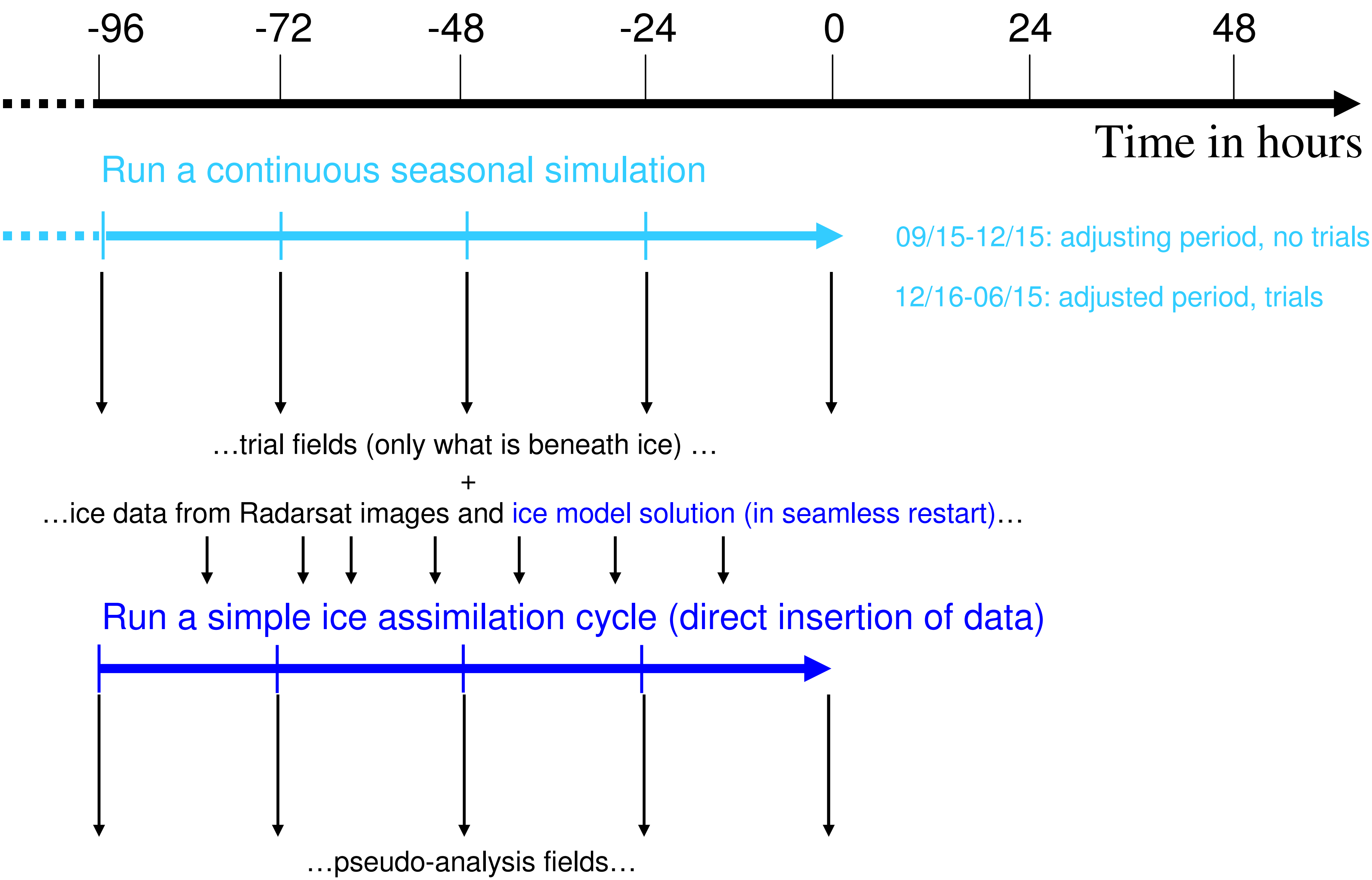


In practice:

cp $CMCGRIDF/trial/gulfStLawrence.thermo0315/2008112500_000
    $CMCGRIDF/anal/gulfStLawrence/2008112500_000

GSL pseudo-analysis: technical description

In winter …



GSL pseudo-analysis

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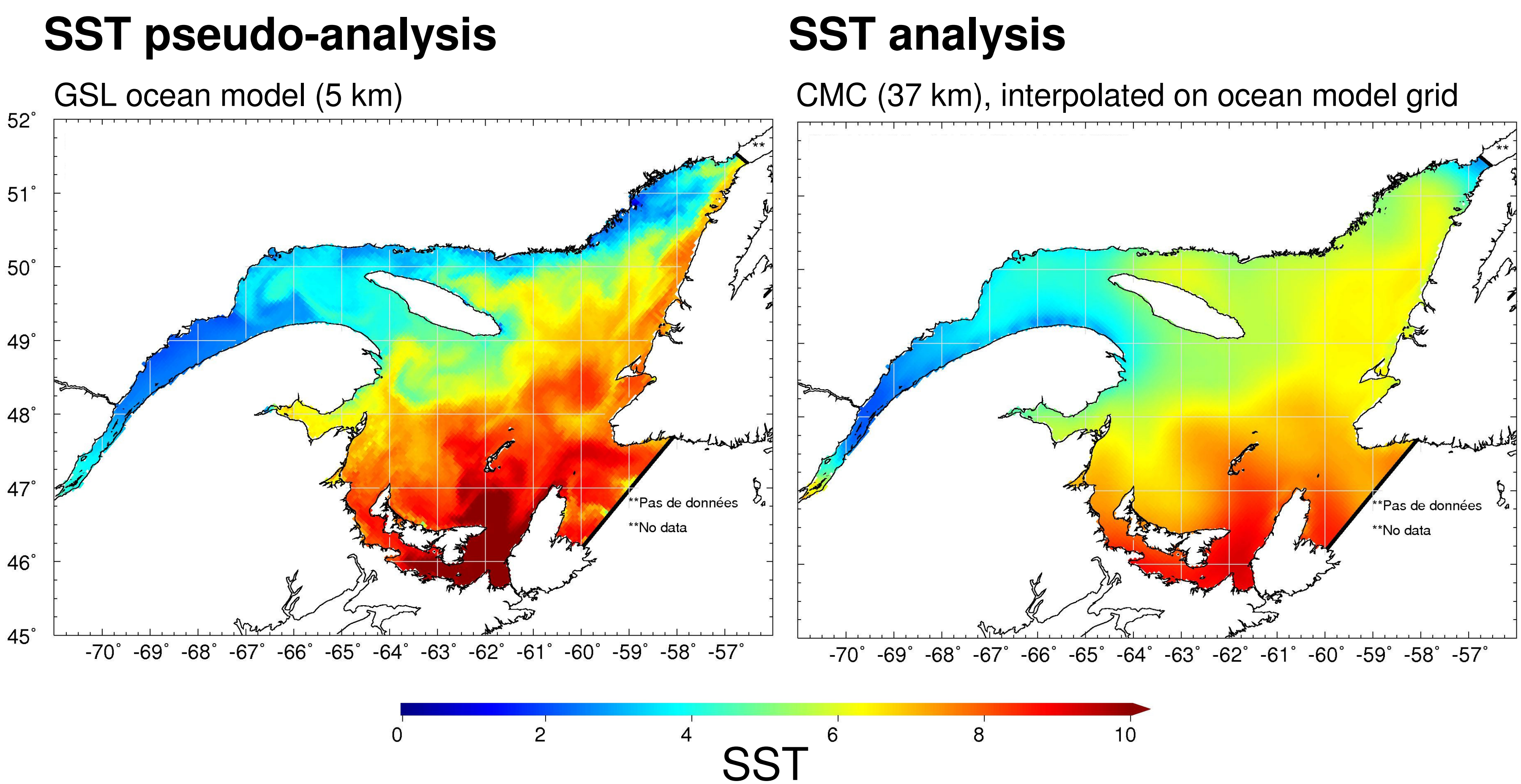
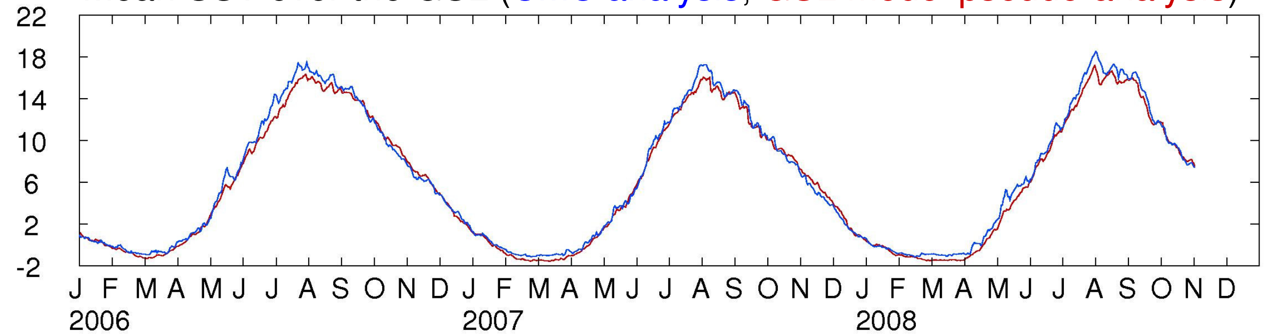
GSL pseudo-analysis: example, November 5, 2008

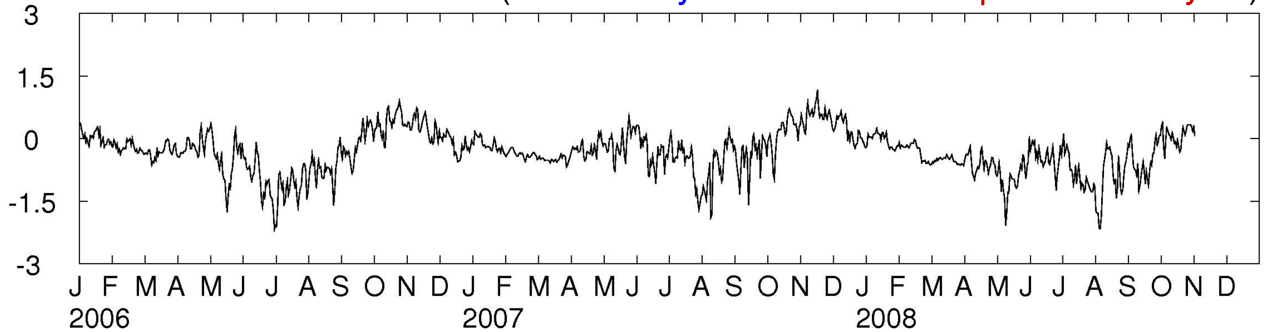


GSL pseudo-analysis: results over 3 years

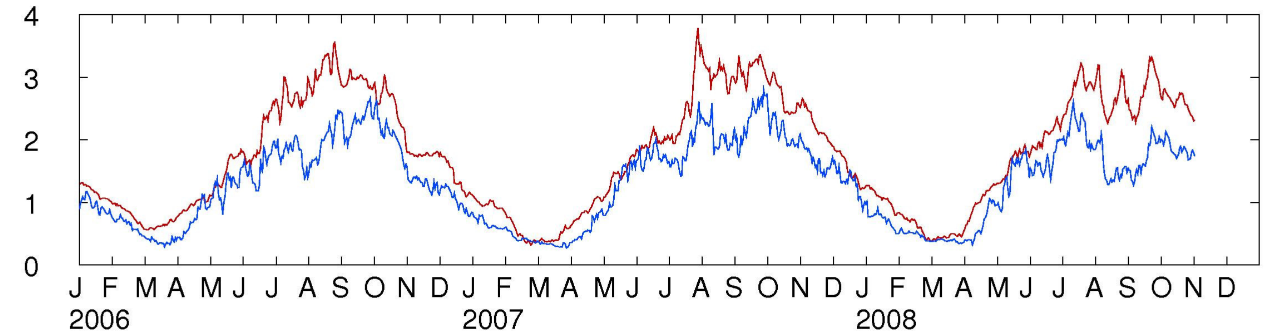
Mean SST over the GSL (CMC analysis, GSL model pseudo-analysis)



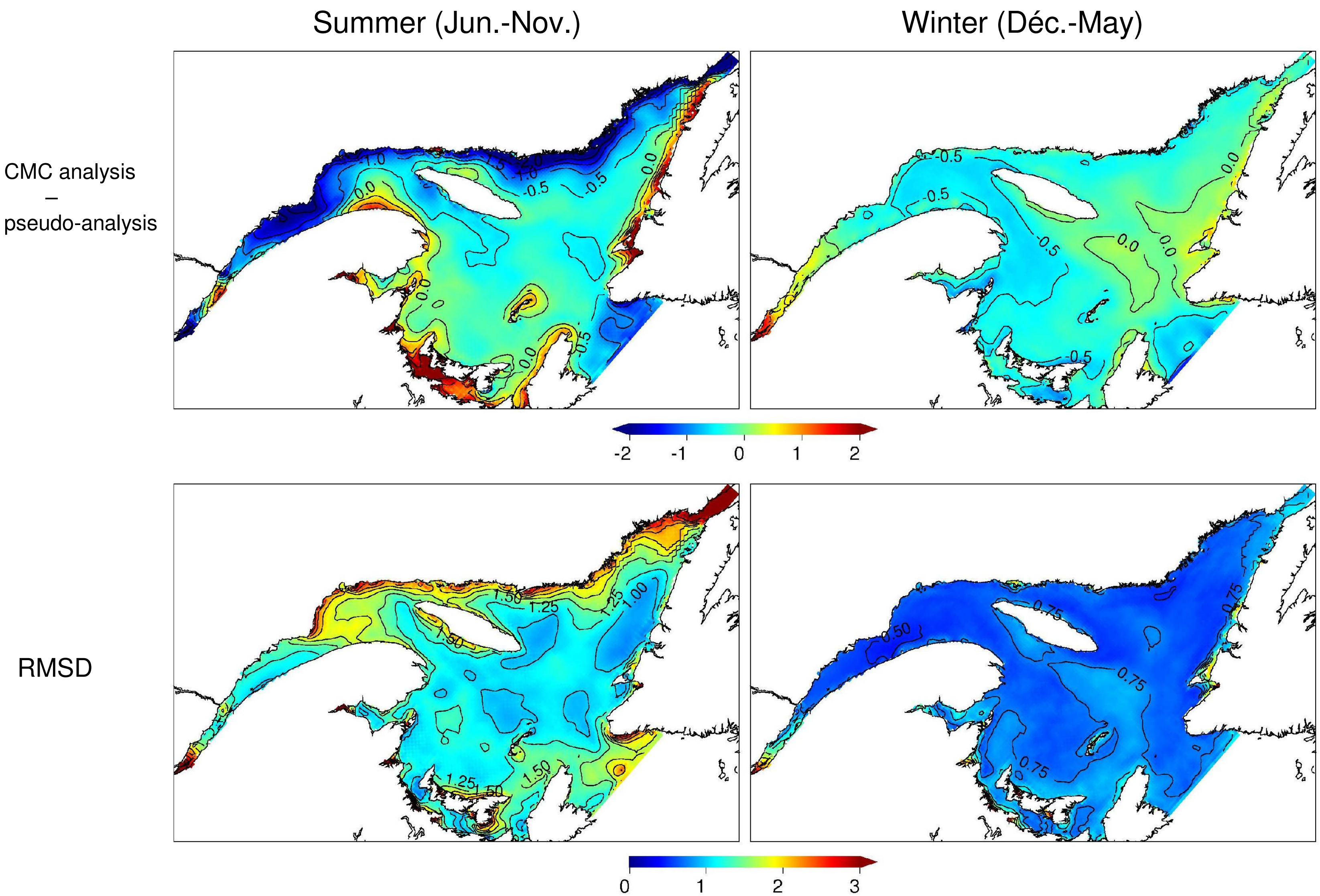
Mean SST over the GSL (CMC analysis – GSL model pseudo-analysis)



Standard deviation over the GSL (CMC analysis, GSL model pseudo-analysis)



GSL pseudo-analysis: differences with CMC analyses



GSL pseudo-analysis

Presentation plan

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Verification with in situ data: definitions

$$A_i \text{ : Analyses or pseudo} - \text{analyses}$$

$$O_i \text{ : Observations}$$

$$E_i = A_i - O_i \text{ : Errors}$$

$$BIAS = \overline{E} = \frac{1}{n}\sum_{i=1}^{n} E_i = \frac{1}{n}\sum_{i=1}^{n} A_i - \frac{1}{n}\sum_{i=1}^{n} O_i = \overline{A} - \overline{O}$$

$$RMSD^2 = \frac{1}{n}\sum_{i=1}^{n}\left(E_i - \overline{E}\right)^2 = \frac{1}{n}\sum_{i=1}^{n}\left[\left(A_i - \overline{A}\right) - \left(O_i - \overline{O}\right)\right]^2$$

$$\Leftrightarrow RMSD^2 = \sigma_A^2 + \sigma_O^2 - 2\sigma_A\sigma_O R$$

$$R = \frac{\mathrm{cov}(A,O)}{\sigma_A\sigma_O}$$

Verification with in situ data: considerations

$$A_{cmc} \ : \mathrm{CMC\,analysis\,(\sim 37\,km, 24\,h)}$$

$$A_{gsl} \ : \mathrm{GSL\,model\,pseudo-analysis\,(5\,km, dt = 225s)}$$

$$RMSD_{cmc}^2 = \sigma_{A_{cmc}}^2 + \sigma_O^2 - 2\sigma_{A_{cmc}}\sigma_O R_{A_{cmc}O}$$

$$RMSD_{gsl}^2 = \sigma_{A_{gsl}}^2 + \sigma_O^2 - 2\sigma_{A_{gsl}}\sigma_O R_{A_{gsl}O}$$

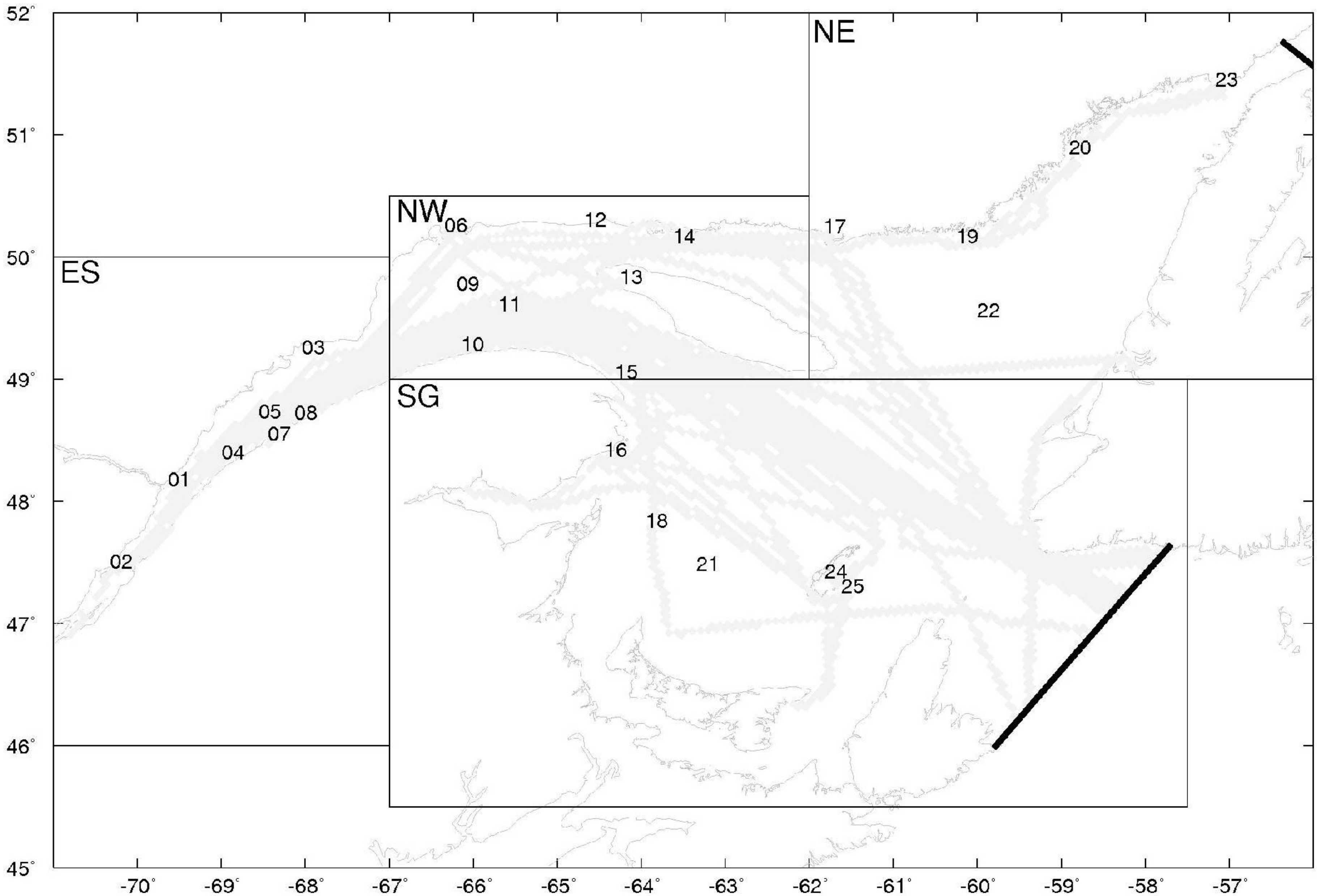
$$If \ \sigma_{A_{cmc}}^2 = \sigma_{A_{gsl}}^2$$

$$RMSD_{cmc}^2 - RMSD_{gsl}^2 = f\,(R_{A_{cmc}O} - R_{A_{gsl}O})$$

$$If \ (R_{A_{cmc}O}, R_{A_{gsl}O}) \rightarrow (0,0)$$

$$RMSD_{cmc}^2 - RMSD_{gsl}^2 \rightarrow \sigma_{A_{cmc}}^2 - \sigma_{A_{gsl}}^2$$

Verification with in situ data: coverage



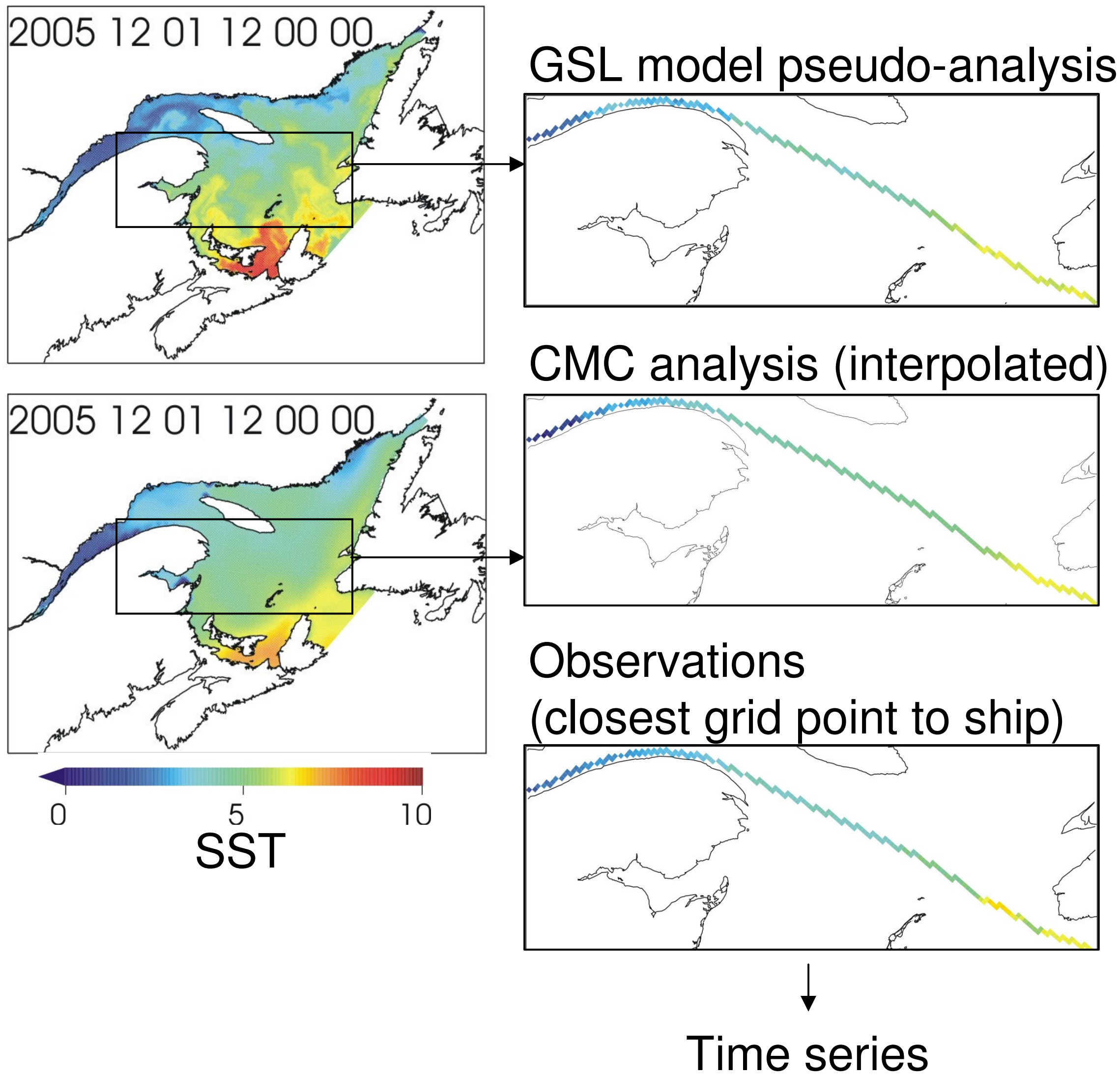
In situ data from commercial ships

Cicero/Cabot

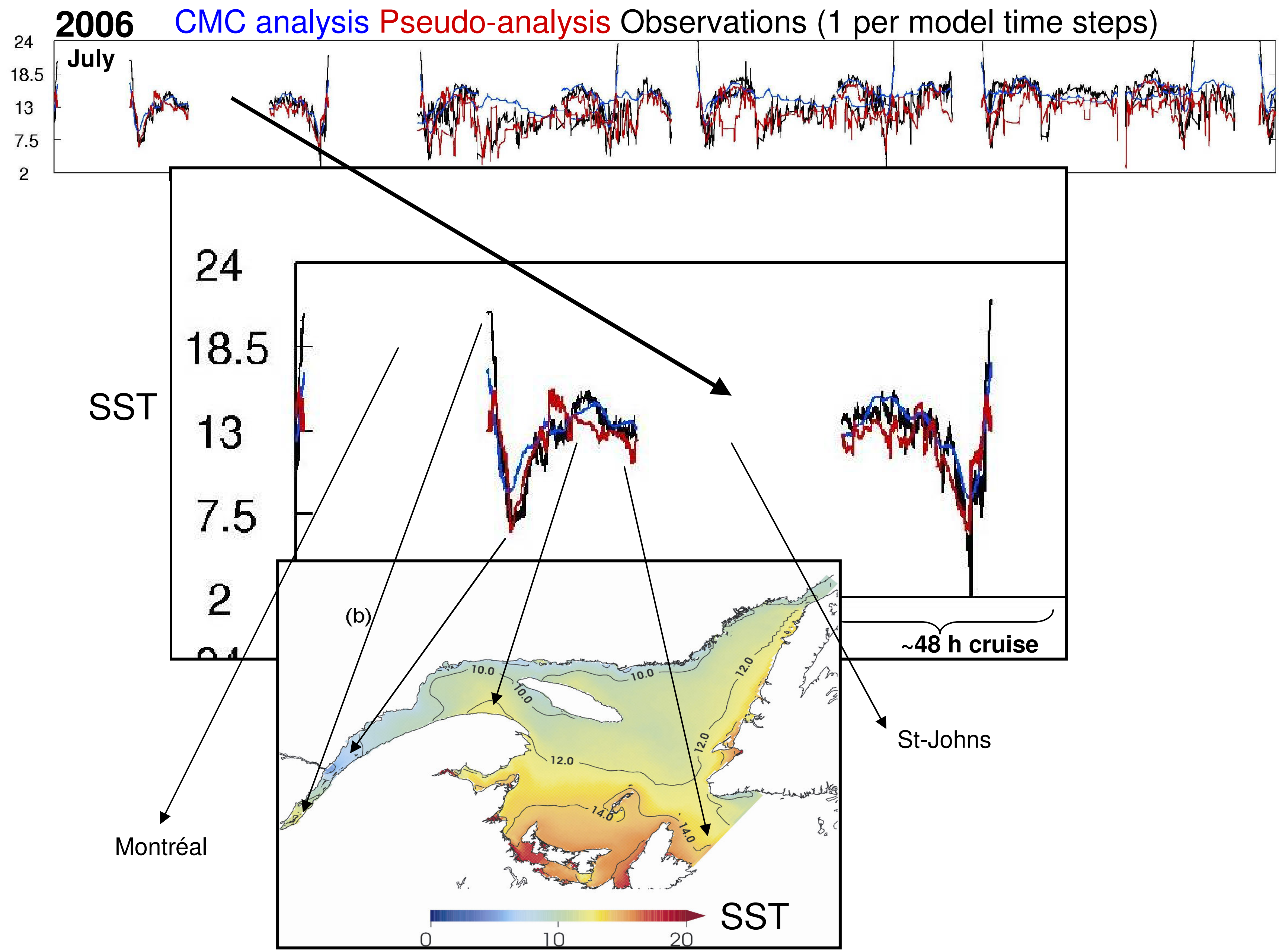
Nordik Express

C.T.M.A. Voyageur

Data extraction method

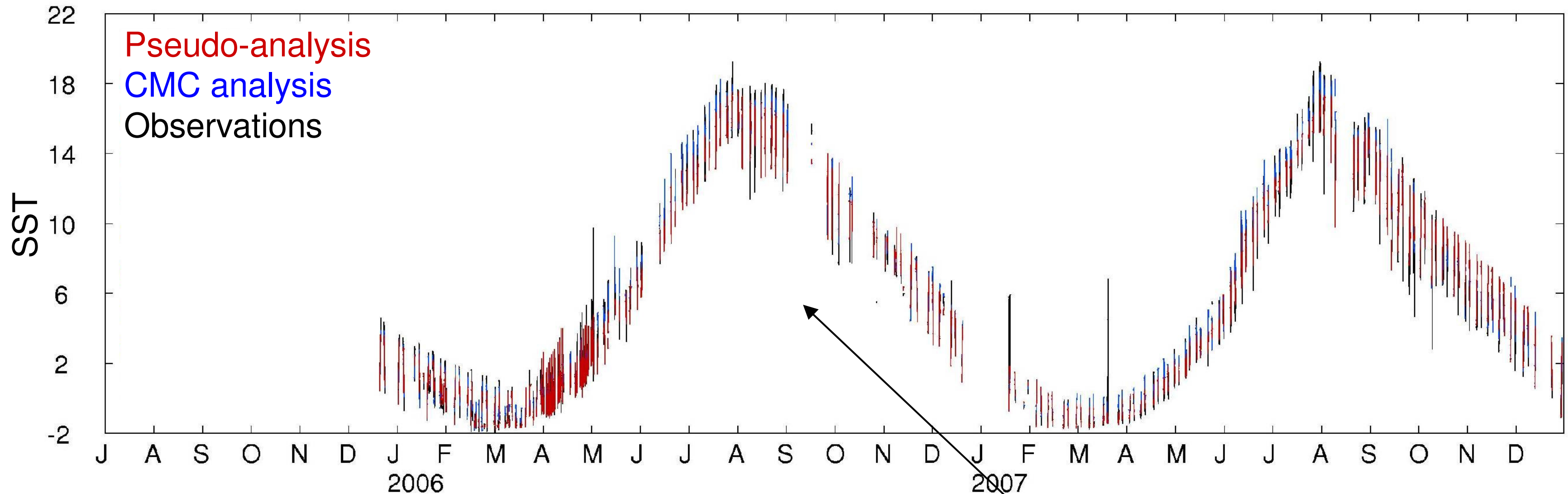


In situ data from commercial ships: example

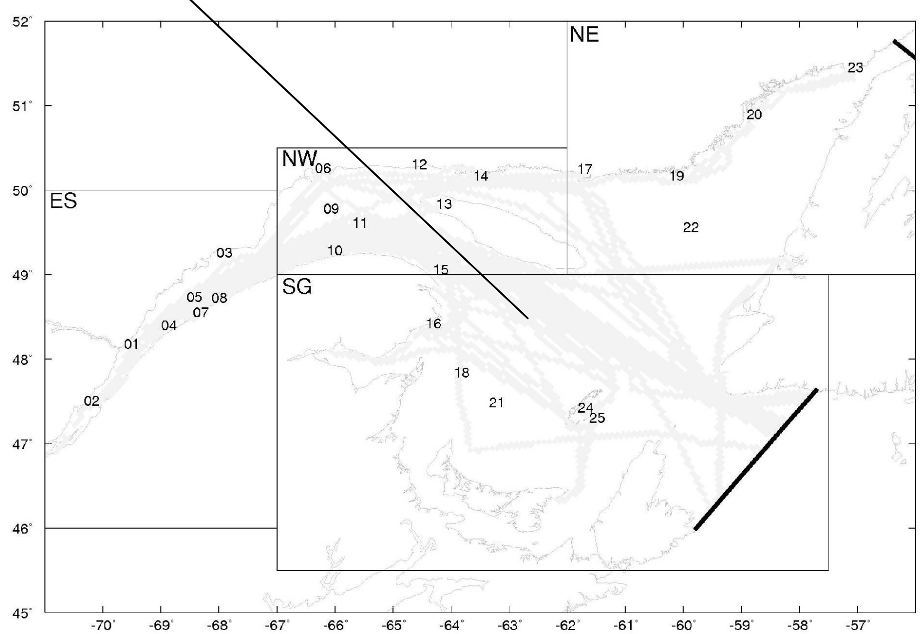


In situ data from commercial ships: statistics (SST)

Seasonal scale: compute metrics over long time series



REGIONS	SG	NW	ES	NE
BIAS	**-0.12**	**-0.14**	**-0.11**	**-0.94**
BIAS	**0.25**	**0.69**	**0.49**	**0.88**
RMSD	1.1	1.7	1.9	1.9
RMSD	0.84	1.7	1.7	1.7
STD (standard deviation)	5.7	6.1	4.4	4.9
STD	6.0	6.5	5.2	5.7
STD	6.0	6.1	5.0	5.6
R	**0.98**	**0.96**	**0.92**	**0.94**
R	**0.99**	**0.97**	**0.94**	**0.96**
COVERAGE (DAYS)	108	77	77	**24**

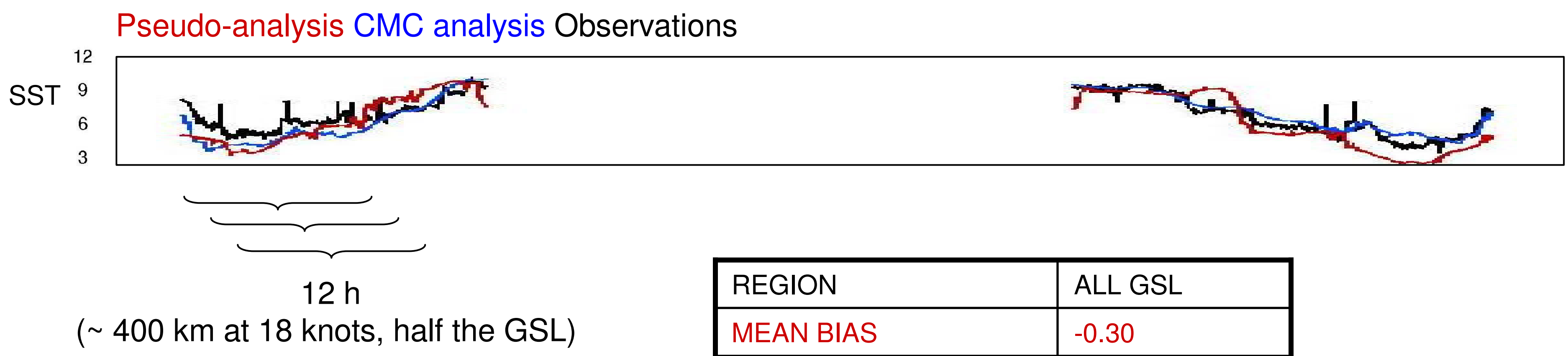


In situ data from commercial ships: statistics (SST)

Synoptic scale:

- compute metrics over available successive 12 h period

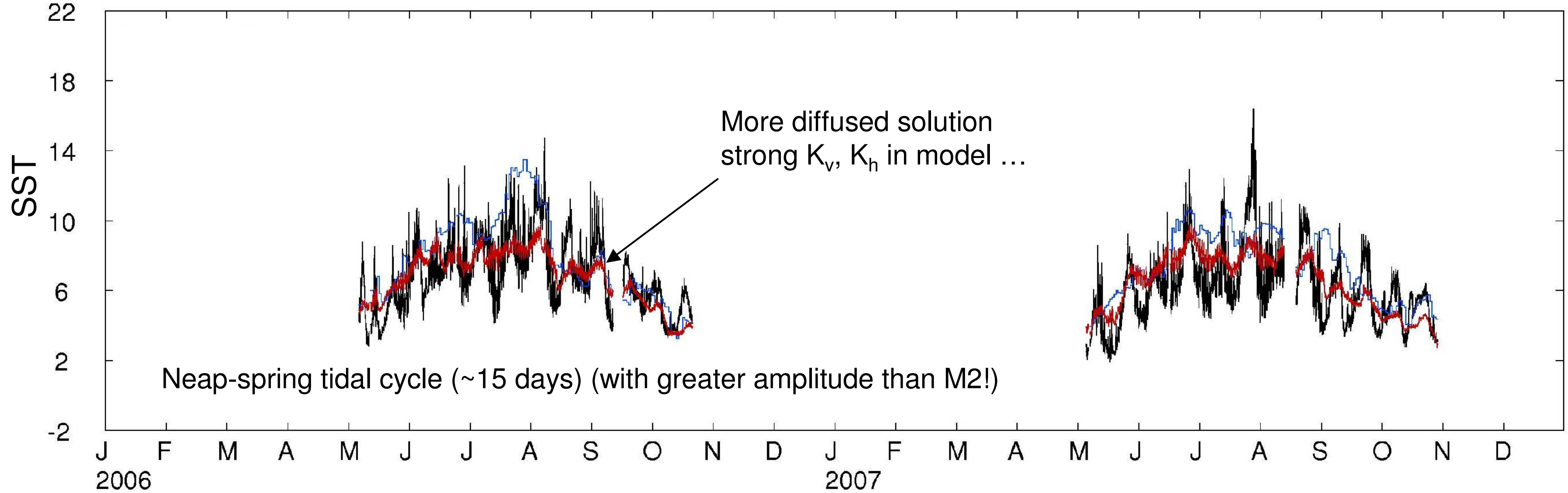
- filter model data over 37 km to reduce local variance (not working)

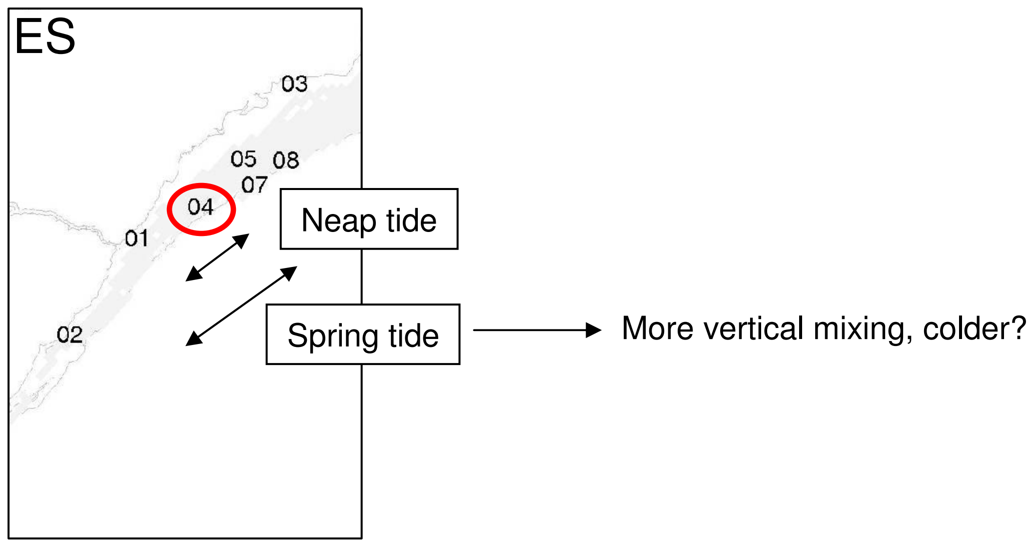


REGION	ALL GSL
MEAN BIAS	-0.30
MEAN BIAS	0.64
MEAN RMSD	0.97
MEAN RMSD	0.77
MEAN STD	**0.83**
MEAN STD	**0.51**
MEAN STD	**0.93**
MEAN R	**0.40**
MEAN R	**0.48**
N. OF PERIODS	31499 (82 days)

In situ data from thermographs: example (SST)

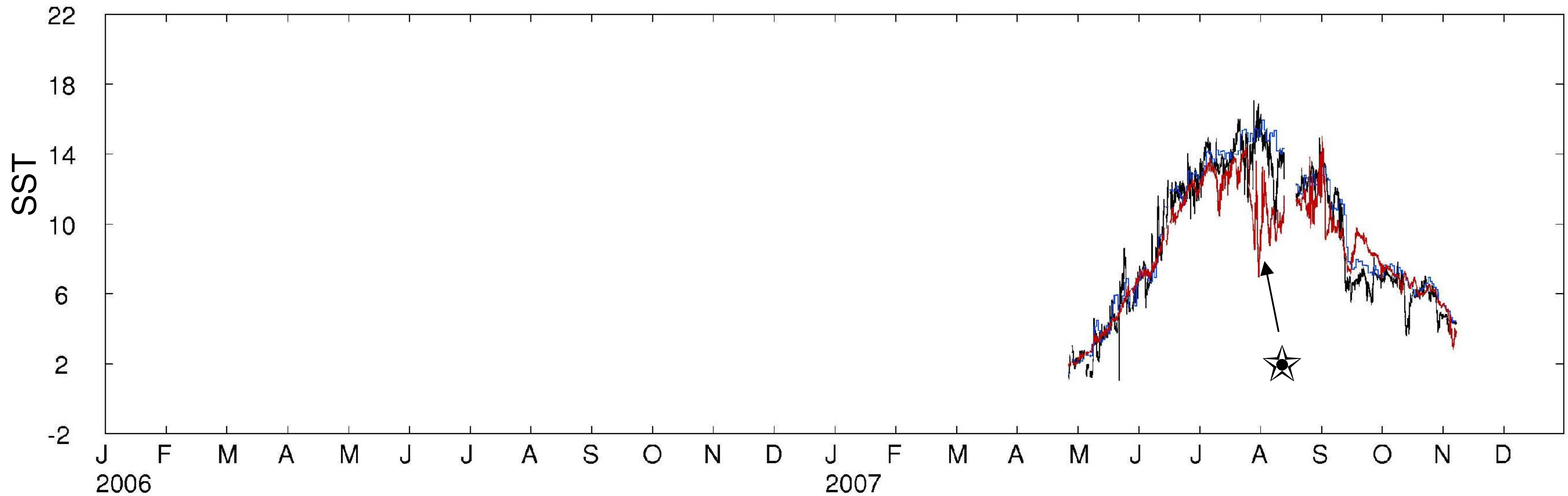
CMC analysis Pseudo-analysis Observations (1 per 15 minutes)

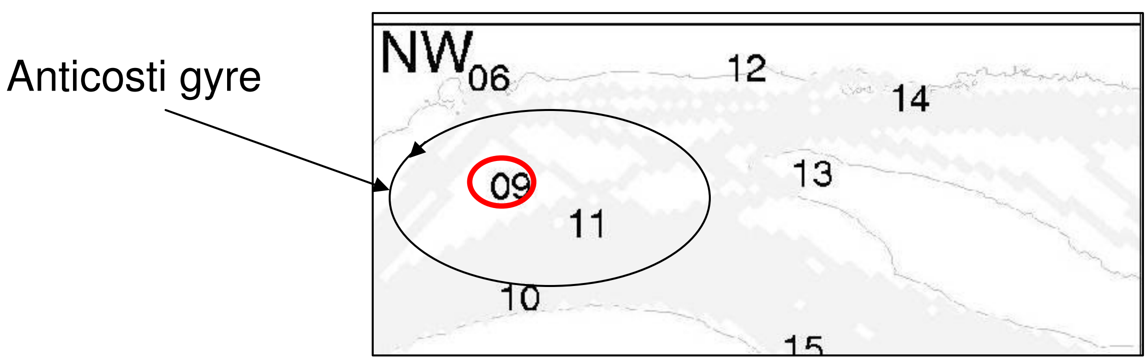




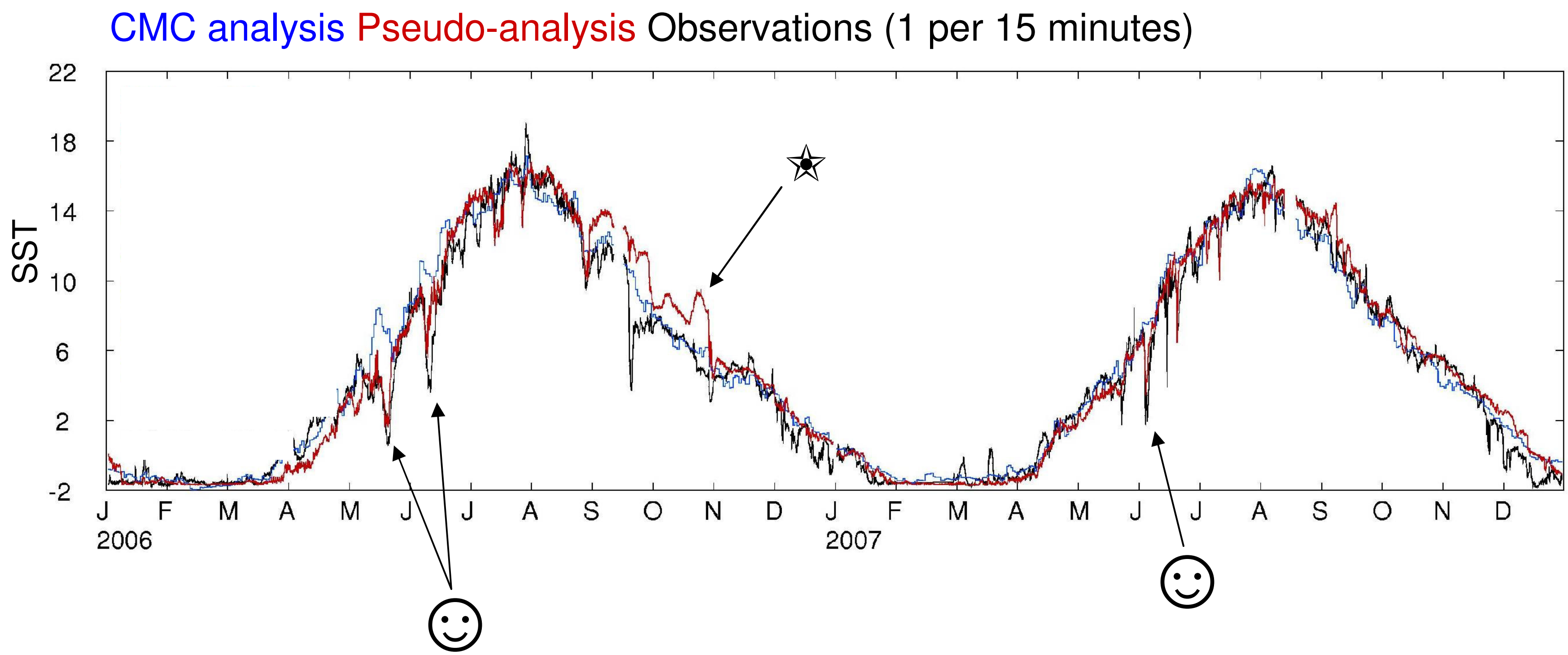
In situ data from thermographs: example (SST)

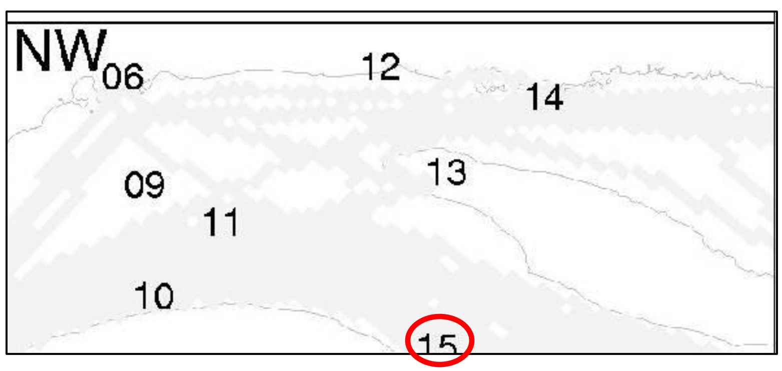
CMC analysis Pseudo-analysis Observations (1 per 15 minutes)





In situ data from thermographs: example (SST)





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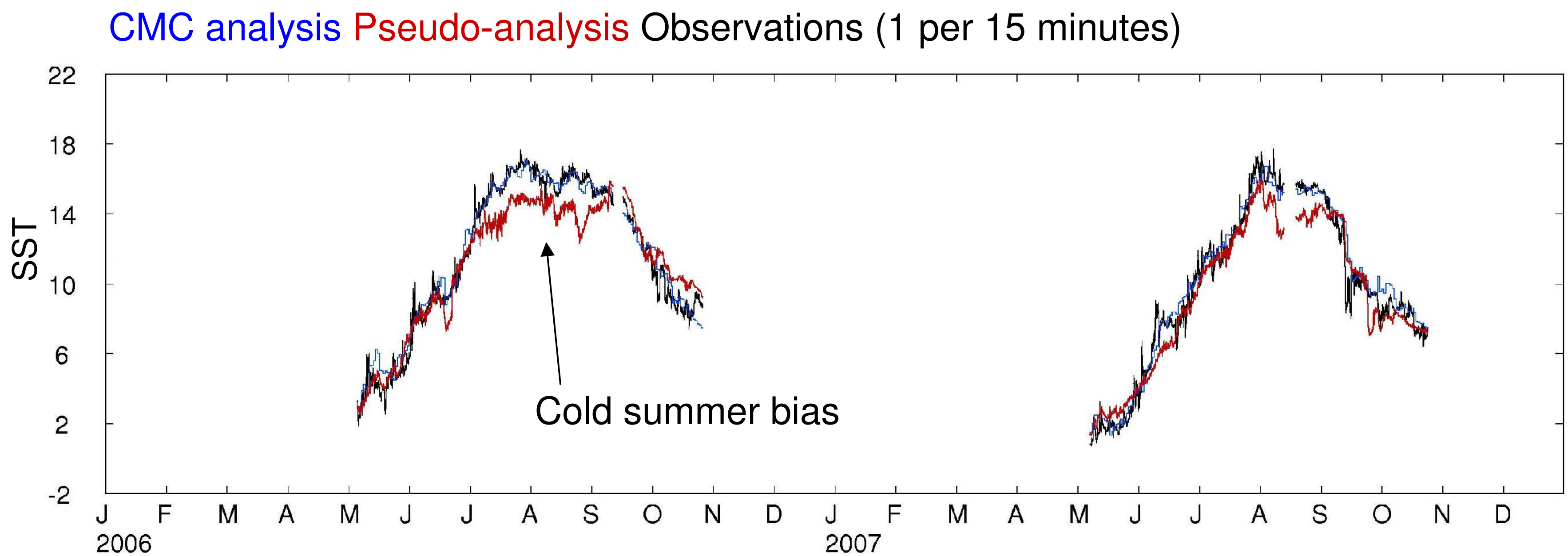
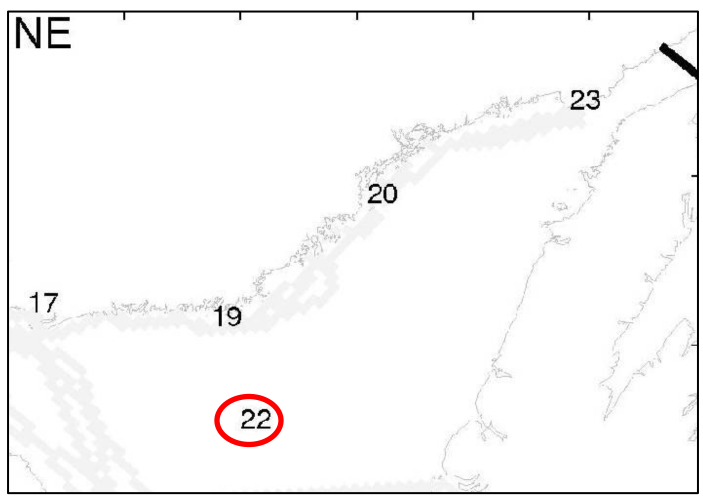
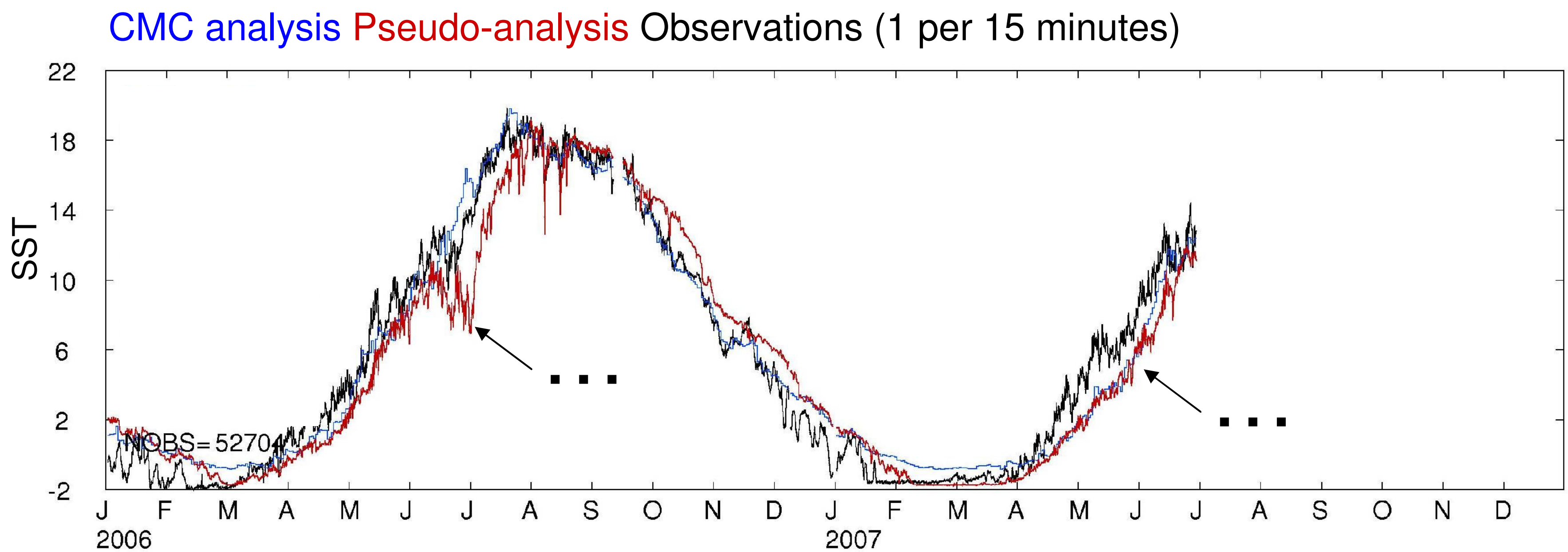
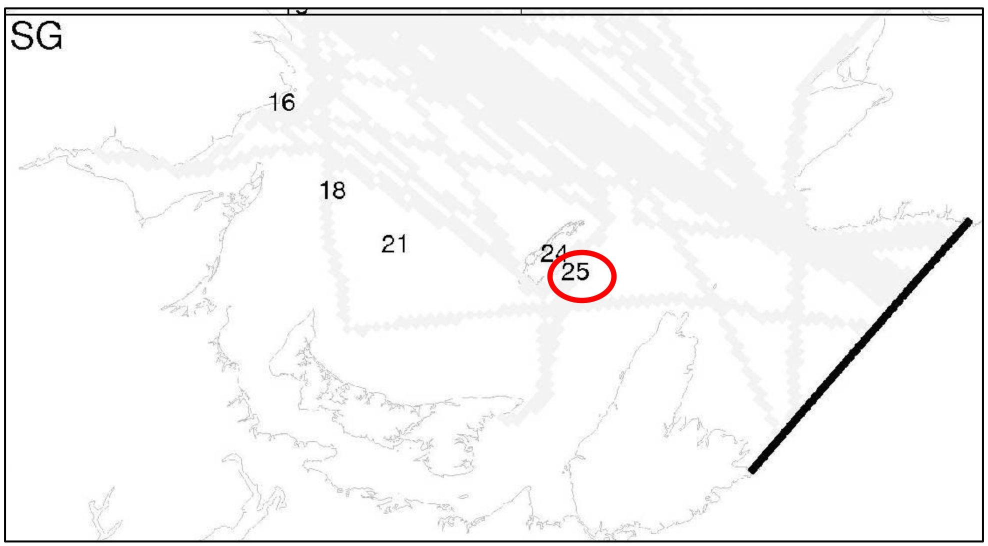




In situ data from thermographs: example (SST)

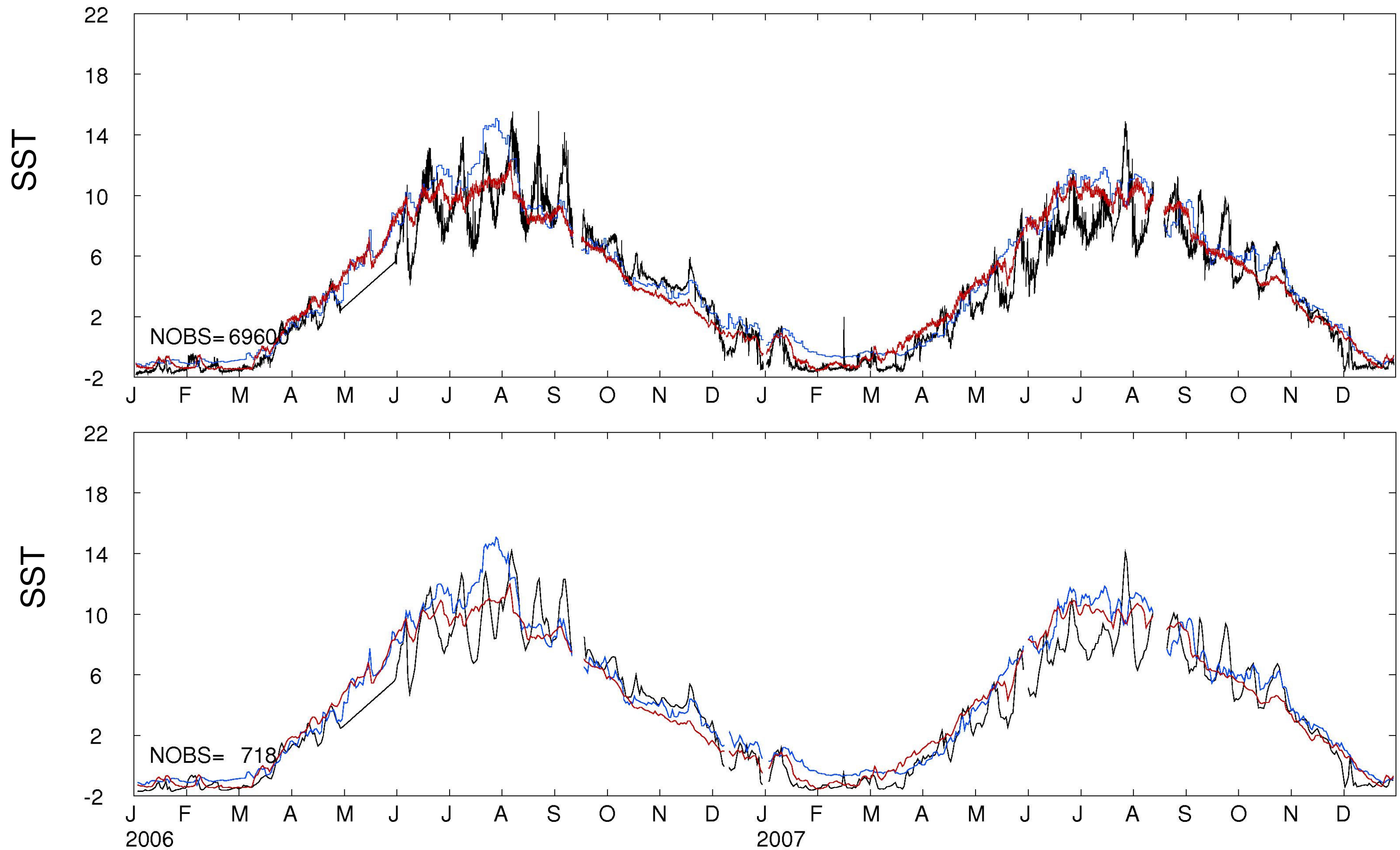




In situ data from thermographs: statistics (SST)

Seasonal and daily scale:

- compute 24 h averages to reduce local variance in ocean model and obs.



- compute metrics over long time series (seasonal scale) and over successive 10 day periods (daily scale)

In situ data from thermographs: statistics

Seasonal scale

STATION	1	2	3	4	5	7	8
BIAS	**-1.7**	**1.1**	**-1.4**	**0.07**	**-0.91**	**0.35**	**-0.45**
BIAS	**0.69**	**1.3**	**0.54**	**1.1**	**0.53**	**0.73**	**0.58**
RMSD	**1.4**	**1.6**	**1.2**	**1.3**	**1.3**	**1.3**	**1.5**
RMSD	**1.5**	**1.7**	**1.6**	**1.8**	**1.3**	**1.5**	**1.5**
STD	1.5	5.3	2.4	1.6	2.5	4.1	2.3
STD	2.6	5.7	3.4	2.2	2.8	4.4	2.5
STD	2.2	4.3	2.9	2.0	3.2	4.2	2.6
R	0.80	0.97	0.92	0.76	0.93	0.95	0.83
R	0.82	0.98	0.88	0.62	0.91	0.94	0.82
COVERAGE (DAYS)	175	718	357	320	177	718	160

4/7 better

Daily scale

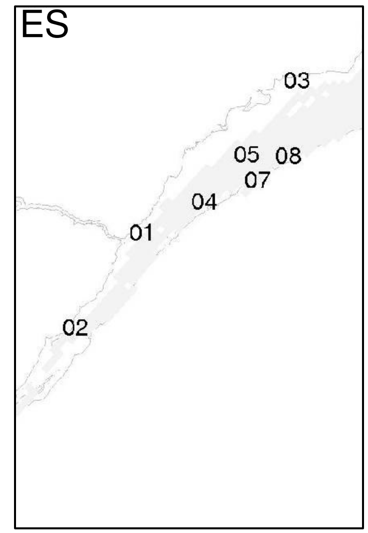
STATION	1	2	3	4	5	7	8
MEAN BIAS	-2.0	1.2	-1.5	0.08	-1.1	0.35	-0.55
MEAN BIAS	0.71	1.3	0.56	1.1	0.63	0.75	0.57
MEAN RMSD	**0.98**	**0.29**	**0.81**	**1.0**	**0.74**	**0.71**	**0.99**
MEAN RMSD	**1.1**	**0.34**	**1.0**	**1.3**	**0.93**	**0.75**	**1.1**
MEAN STD	**0.34**	**0.28**	**0.53**	**0.40**	**0.39**	**0.33**	**0.36**
MEAN STD	**0.41**	**0.34**	**0.59**	**0.55**	**0.52**	**0.42**	**0.50**
MEAN STD	1.0	0.35	1.0	1.2	0.86	0.75	1.1
MEAN R	**0.25**	**0.55**	**0.49**	**0.58**	**0.48**	**0.34**	**0.35**
MEAN R	**0.06**	**0.38**	**0.25**	**0.01**	**0.14**	**0.25**	**0.24**
N. OF PERIODS	106	655	312	262	135	655	124

4/7 better

Increased K_h,K_v

7/7 better (neap-spring tidal cycle)

Pseudo-analysis
CMC analysis
Observations



Freshwater input
Tides
Vertical and horizontal mixing

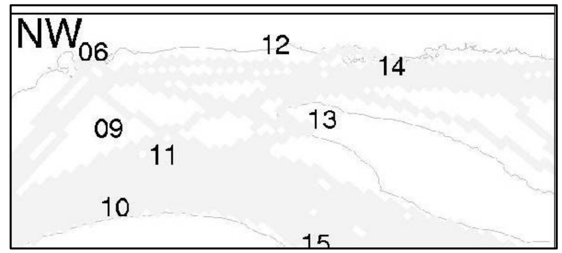
In situ data from thermographs: statistics

Seasonal scale

STATION	6	**9**	**10**	**11**	12	13	14	**15**
BIAS	**-0.43**	**-0.46**	**1.4**	**0.73**	**-0.16**	**1.4**	**0.41**	**0.34**
BIAS	**0.54**	**0.39**	**0.64**	**0.41**	**1.9**	**1.3**	**1.5**	**0.32**
RMSD	**1.6**	**1.6**	**1.5**	**2.0**	**2.4**	**1.8**	**2.1**	**1.2**
RMSD	**1.9**	**0.87**	**1.3**	**1.0**	**2.2**	**2.2**	**2.0**	**1.1**
STD	4.9	3.1	3.7	4.1	2.8	3.6	3.0	6.0
STD	5.5	3.9	3.4	3.9	3.6	3.7	3.6	5.7
STD	4.5	3.9	3.3	4.0	3.3	4.0	3.2	5.7
R	0.94	0.92	0.91	0.88	0.71	0.90	0.77	0.98
R	0.95	0.97	0.93	0.97	0.81	0.84	0.83	0.98
COVERAGE (DAYS)	718	174	135	333	294	323	303	718

Pseudo-analysis
CMC analysis
Observations

4/8 better, almost 5



Daily scale

STATION	6	9	10	11	12	13	14	**15**
MEAN BIAS	-0.44	-0.41	1.3	0.74	-0.40	1.3	0.32	0.28
MEAN BIAS	0.53	0.45	0.64	0.36	2.1	1.3	1.5	0.29
MEAN RMSD	0.67	0.83	0.96	0.87	1.4	1.2	1.1	0.54
MEAN RMSD	0.69	0.71	0.93	0.73	1.4	1.5	1.2	0.54
MEAN STD	**0.51**	**0.69**	**0.80**	**0.79**	**1.2**	**0.93**	**1.1**	**0.47**
MEAN STD	**0.39**	**0.55**	**0.47**	**0.58**	**0.59**	**0.69**	**0.69**	**0.43**
MEAN STD	0.72	0.78	0.90	0.78	1.3	1.6	1.1	0.58
MEAN R	**0.40**	**0.40**	**0.34**	**0.45**	**0.47**	**0.56**	**0.49**	**0.38**
MEAN R	**0.35**	**0.38**	**0.25**	**0.39**	**0.18**	**0.30**	**0.21**	**0.42**
N. OF PERIODS	655	133	117	240	210	229	231	655

Residual circulation
(baroclinic + barotropic + Coriolis +
winds)
Gaspe current
Anticosti gyre
Coastal upwellings

Captures more variability

7/8 better, almost 8

In situ data from thermographs: statistics

Seasonal scale

STATION	16a	16b	18	**21**	**24**	25
BIAS	**0.25**	**0.00**	**0.12**	**-0.36**	**1.7**	**-0.29**
BIAS	**0.09**	**-0.1**	**0.25**	**-0.03**	**0.13**	**-0.08**
RMSD	1.5	1.1	1.4	1.5	1.6	1.7
RMSD	1.3	1.0	1.0	0.75	1.7	1.2
STD	4.1	4.1	4.6	4.7	6.6	6.3
STD	4.0	3.9	4.2	4.8	5.0	6.4
STD	3.9	4.0	4.1	4.9	5.7	6.7
R	0.93	0.96	0.96	0.95	0.98	0.97
R	0.94	0.97	0.97	0.99	0.96	0.98
COVERAGE (DAYS)	171	169	164	371	205	544

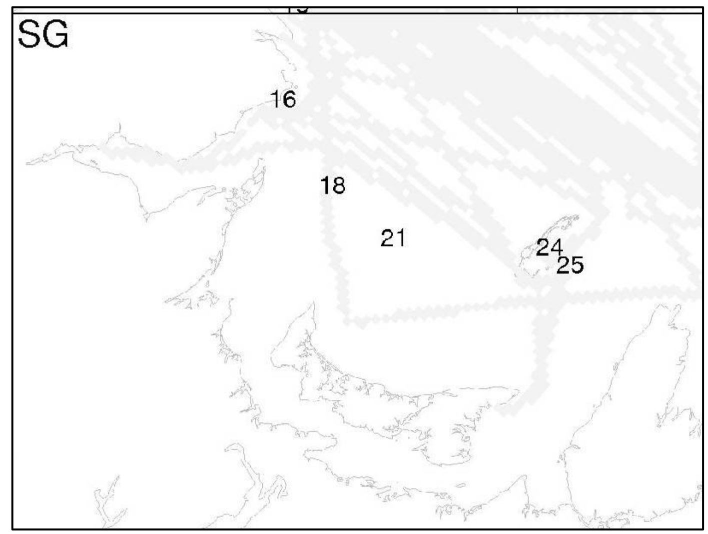
0/5 better,
3 relatively close
(16, 18, 25)

Pseudo-analysis
CMC analysis
Observations

Daily scale

STATION	16a	16b	18	21	24	25
MEAN BIAS	0.54	0.07	0.24	-0.46	1.7	-0.45
MEAN BIAS	0.07	-0.08	0.17	-0.11	0.20	0.00
MEAN RMSD	0.80	0.65	0.67	0.48	0.55	0.51
MEAN RMSD	0.91	0.81	0.71	0.54	0.68	0.50
MEAN STD	0.55	0.53	0.68	0.49	0.55	0.44
MEAN STD	0.53	0.56	0.62	0.59	0.58	0.41
MEAN STD	0.90	0.83	0.71	0.62	0.78	0.56
MEAN R	**0.51**	**0.47**	**0.46**	**0.61**	**0.65**	**0.50**
MEAN R	**0.22**	**0.34**	**0.38**	**0.54**	**0.54**	**0.41**
N. OF PERIODS	114	128	122	248	187	499

4/4 better



Shallow stations
SW+LW budget, T_A, Winds
Freshwater influence but less pronounced

In situ data from thermographs: statistics

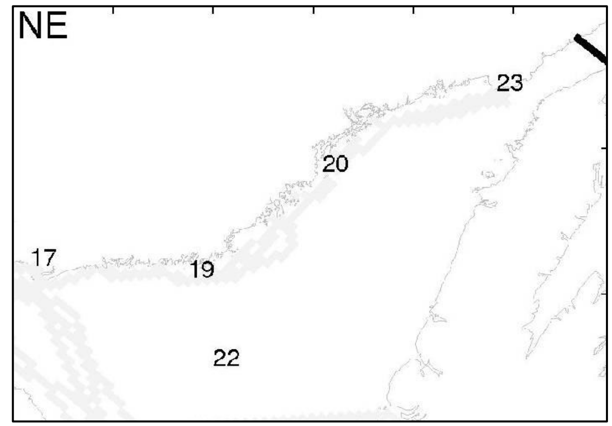
Seasonal scale

STATION	17	19	20	**22**	23
BIAS	**-0.35**	**-0.60**	**-0.76**	**-0.45**	**-0.23**
BIAS	**-0.16**	**1.3**	**1.1**	**0.20**	**2.2**
RMSD	**2.3**	**1.2**	**1.8**	**1.1**	**2.8**
RMSD	**2.7**	**1.5**	**1.7**	**0.69**	**1.6**
STD	3.6	3.2	3.0	3.9	3.1
STD	3.7	3.7	3.2	4.3	3.8
STD	3.8	3.4	3.3	4.4	3.8
R	0.81	0.93	**0.84**	0.97	**0.68**
R	0.75	0.91	**0.87**	0.99	**0.91**
COVERAGE (DAYS)	297	296	289	327	286

4/5 better

boundary

Pseudo-analysis
CMC analysis
Observations



Atm. forcing
Coastal upwellings
Input from Belle-Isle strait
Practically no freshwater

Daily scale

STATION	17	19	20	22	23
MEAN BIAS	-0.35	-0.71	-0.80	-0.48	-0.33
MEAN BIAS	0.14	1.5	1.1	0.23	2.2
MEAN RMSD	1.6	0.85	0.83	0.47	1.6
MEAN RMSD	1.8	0.89	1.0	0.53	1.1
MEAN STD	**0.74**	**0.94**	**0.89**	**0.53**	**1.5**
MEAN STD	**0.55**	**0.52**	**0.48**	**0.57**	**0.58**
MEAN STD	1.8	0.97	1.0	0.61	1.1
MEAN R	**0.28**	**0.53**	**0.63**	**0.62**	**0.31**
MEAN R	**0.13**	**0.36**	**0.30**	**0.47**	**0.27**
N. OF PERIODS	219	218	205	291	232

Captures more variability, upwellings

5/5 better

SST verification: conclusion

The SST pseudo-analysis produced with our GSL ice-ocean model is as realistic as the CMC analysis:

SST bias in the interval of ±1°
RMSD of the order of 1-1.5°

What distinguishes our SST pseudo-analysis:

More variability: tides, winds, upwellings, vertical mixing
➔ greater correlation with obs. over 10 periods most of the time

Prognostic solution with strong correlations over the seasonal scale ➔ potential for SST forecast far beyond 48 h (rely mainly on atmospheric predictability)

The solution at hour 0 is suitable for coupled model initialization, good grounds for data assimilation in the GSL

Future work

Complete the exhaustive verification over a 3 year period

Support for 3D VAR ice assimilation in same GSL modeling framework (Mark Buehner, Alain Caya, CIS)

Support and guidance for upcoming NEMO regional implementation in GSL

Include real time St. Lawrence freshwater runoff?
(impact on SST: direct through stratification, indirect through circulation)

Mechanical redistribution of ice in GSL forecast?

Short-term snow accumulation in the ice model?

GSL pseudo-analysis

Presentation plan

-What is our GSL pseudo-analysis?

-Comparison with the sea surface temperature (SST) analysis from CMC

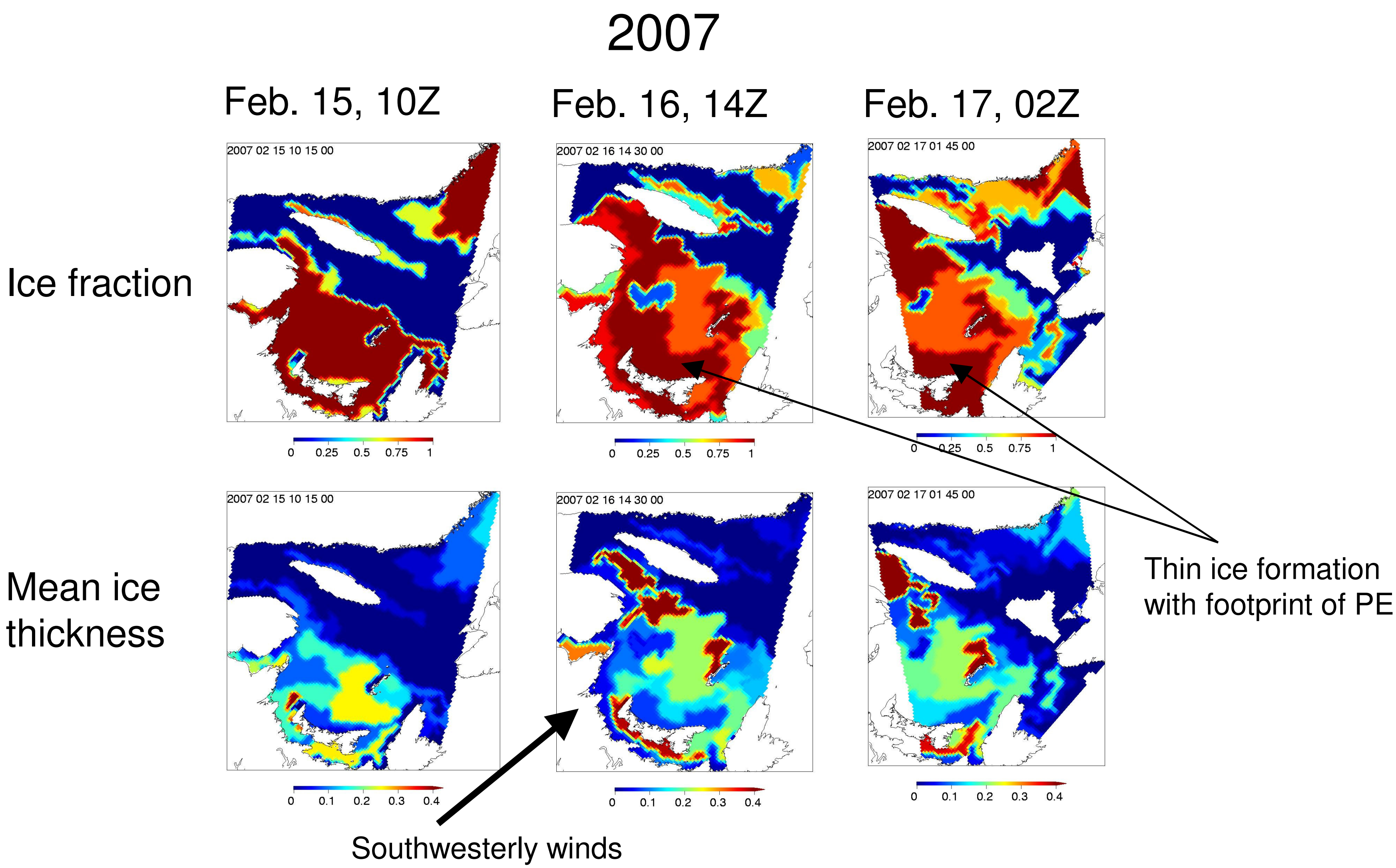
-Verification with in situ data from ships and fixed stations

-**Preliminary verification of non coupled ice forecast (positive effect of including ice growth and decay)**

-Improvements made to the current experimental system

-Future work

Sequence of Radarsat images (CIS interpretation)

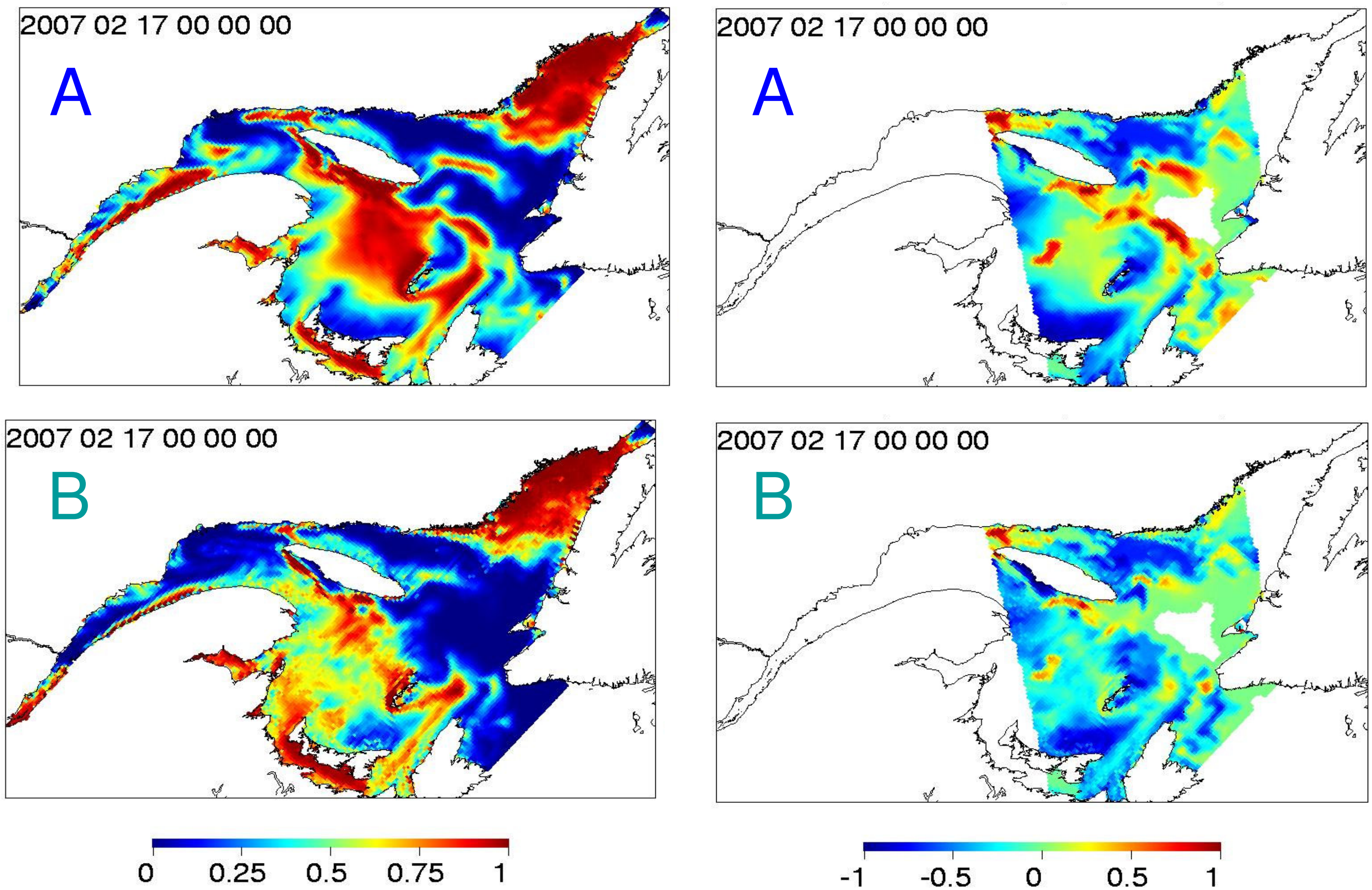


Corresponding 48 h forecast (GSL model)

With (B) and without (A) ice growth and decay

Ice fraction

Error (based on Radarsat image)



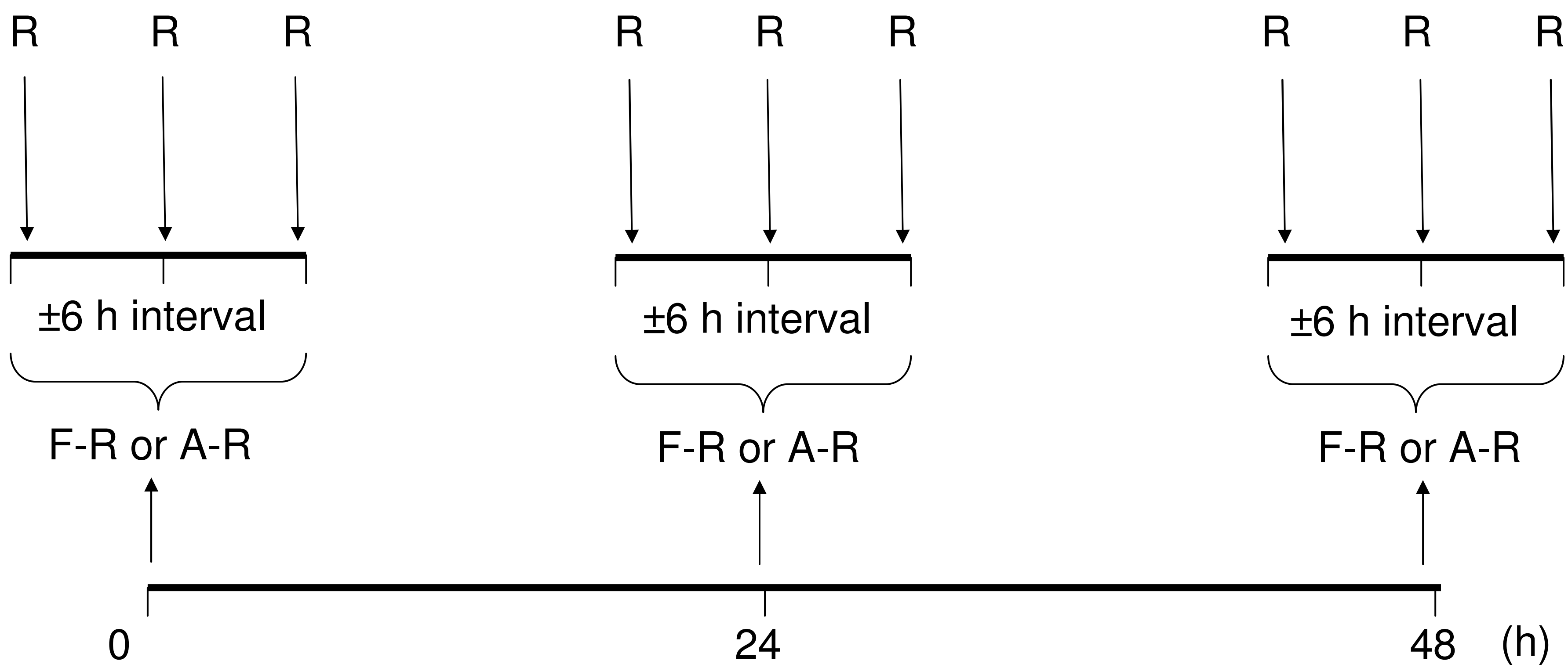
Preliminary verification with Radarsat data

Comparison method

F: GSL model ice analysis and forecast at 00, 24 and 48 h

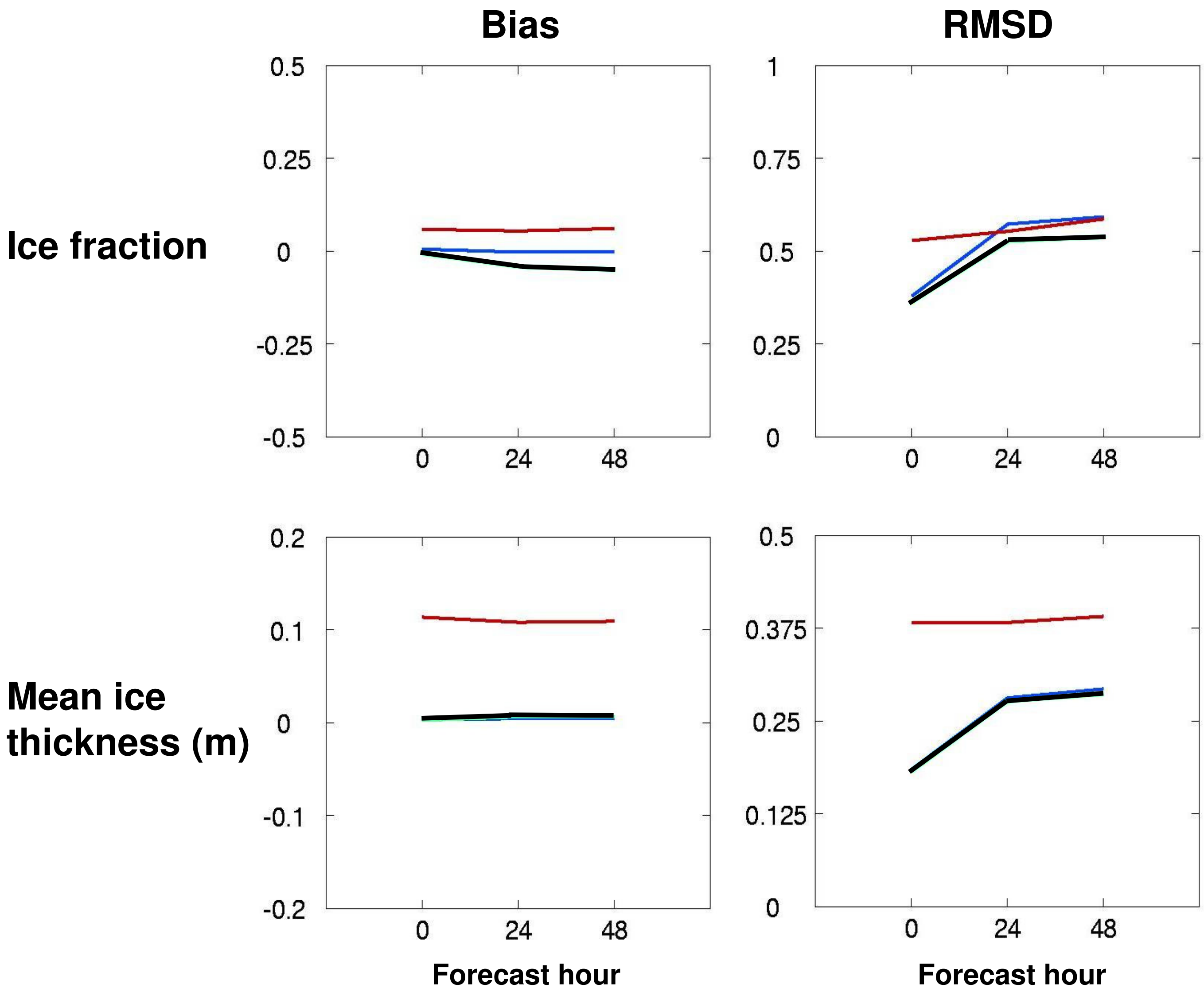
A: CMC ice analysis considered persistent

R: Radarsat images



Preliminary verification with Radarsat: winter 2007

GSL model WITH and WITHOUT ice growth and decay, CMC ANALYSIS (persistence)



GSL pseudo-analysis

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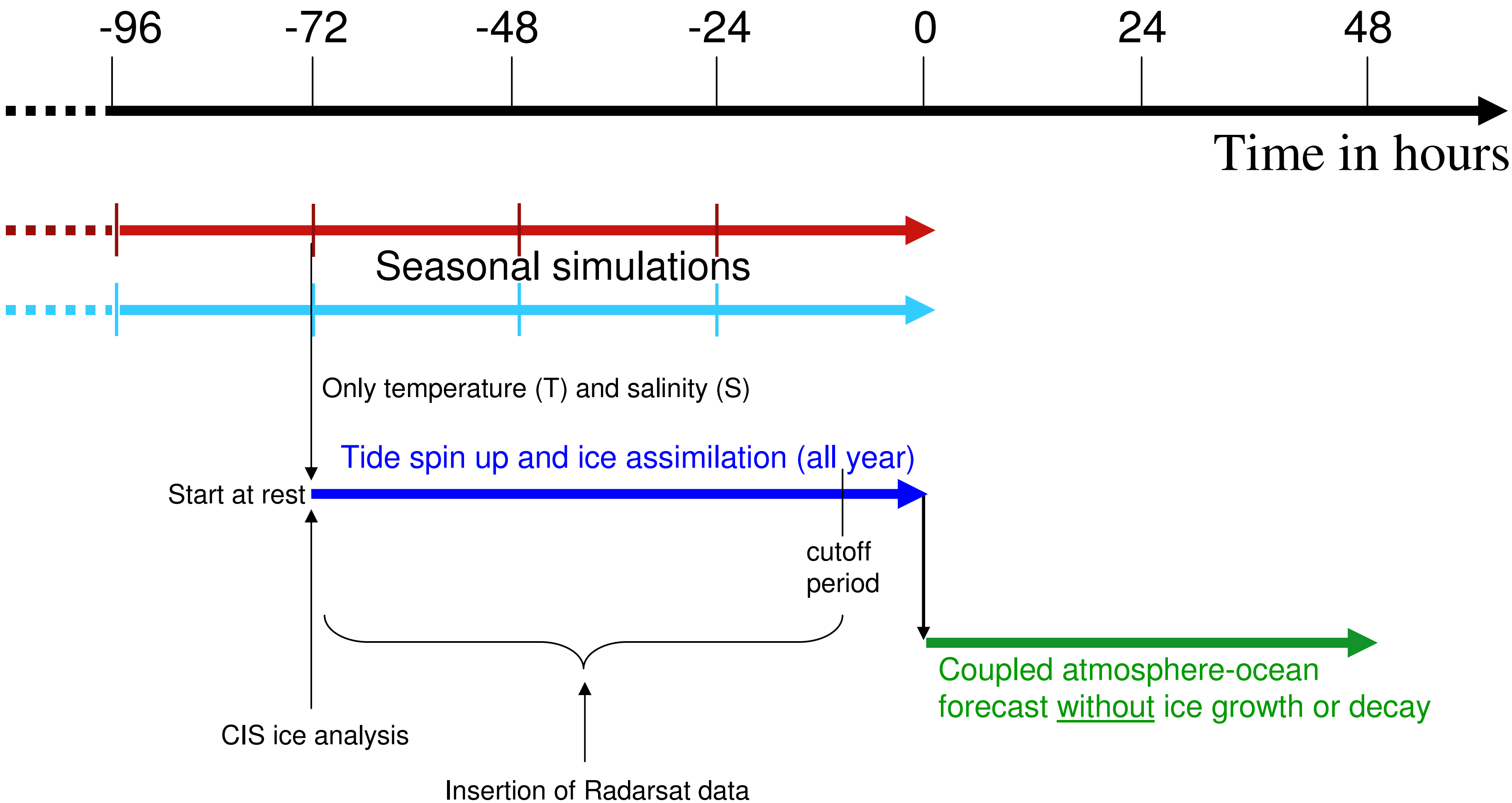
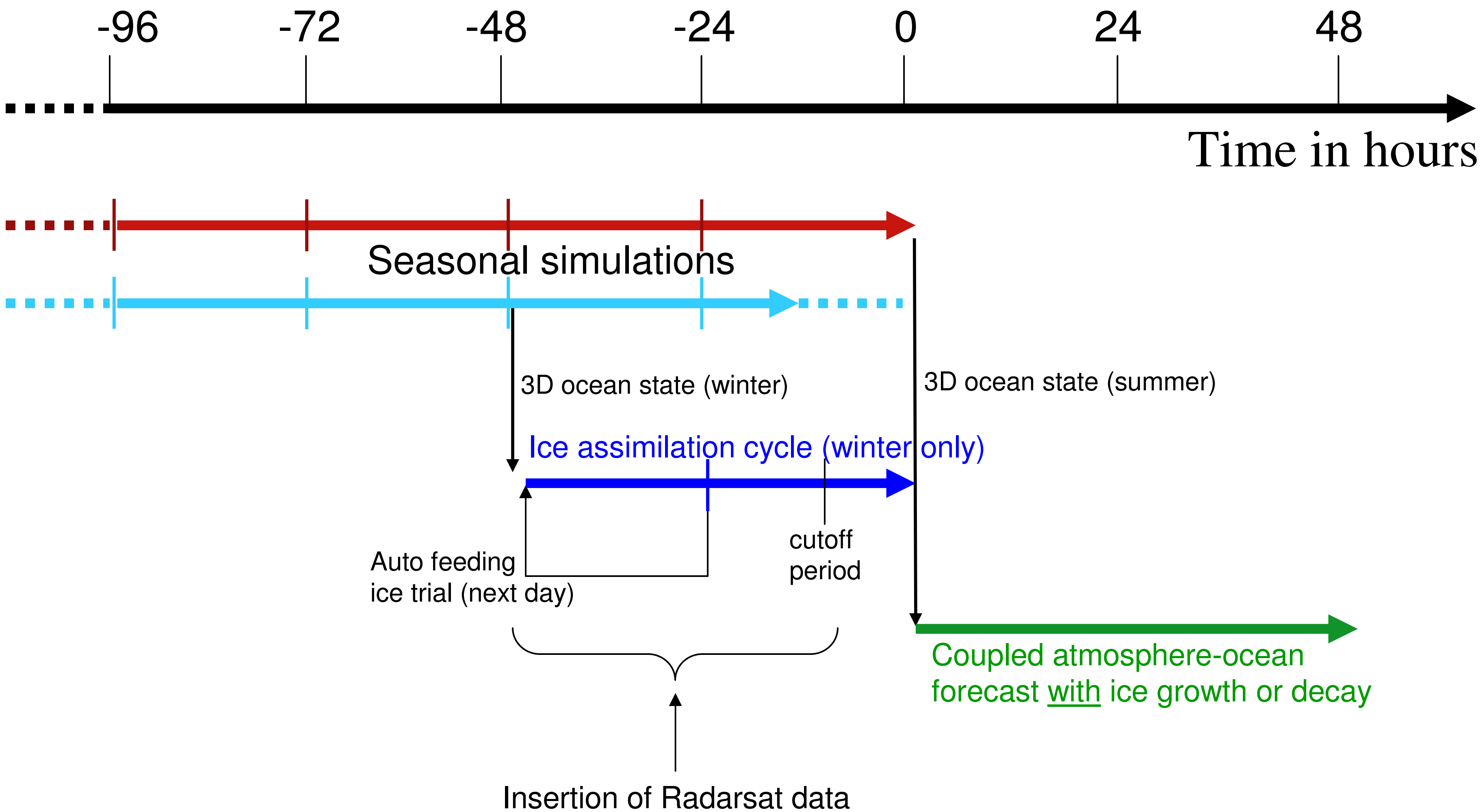
GSL pseudo-analysis: current experimental system

(with relics from the original system developed at IML (DFO))



GSL pseudo-analysis: new system design



GSL pseudo-analysis: new system design

Summary of improvements:

Continuous ice-ocean cycle with seamless restart procedure: initialization of the coupled system with 3D pseudo-analysis including all state variables in dynamic and physical balance (instead of only T and S at rest)

Continuous ice assimilation cycle keeping past observations in memory

Ice thermodynamic growth and decay throughout the ice assimilation cycle and coupled forecast

Model optimization and simplified coding in the context of the scripts unification effort (unified time interpolation for atmospheric forcing and coupling)

Improvement of ice decoder (now decode brash ice, “sarrasin”)

Computational cost

(2 CPUS on maia)

	Winter
Summer pseudo-analysis (24 h)	16 min.
Winter pseudo-analysis (24 h)	16 min.
Ice assimilation cycle (48 h)	32 min.
Total wall clock time (summer)	16-32 min.
Total wall clock time (winter)	48-64 min.