Environment Canada Environnement Canada

Canada

Overview of sea ice data assimilation activities at Environment Canada

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  - An estimate of analysis error
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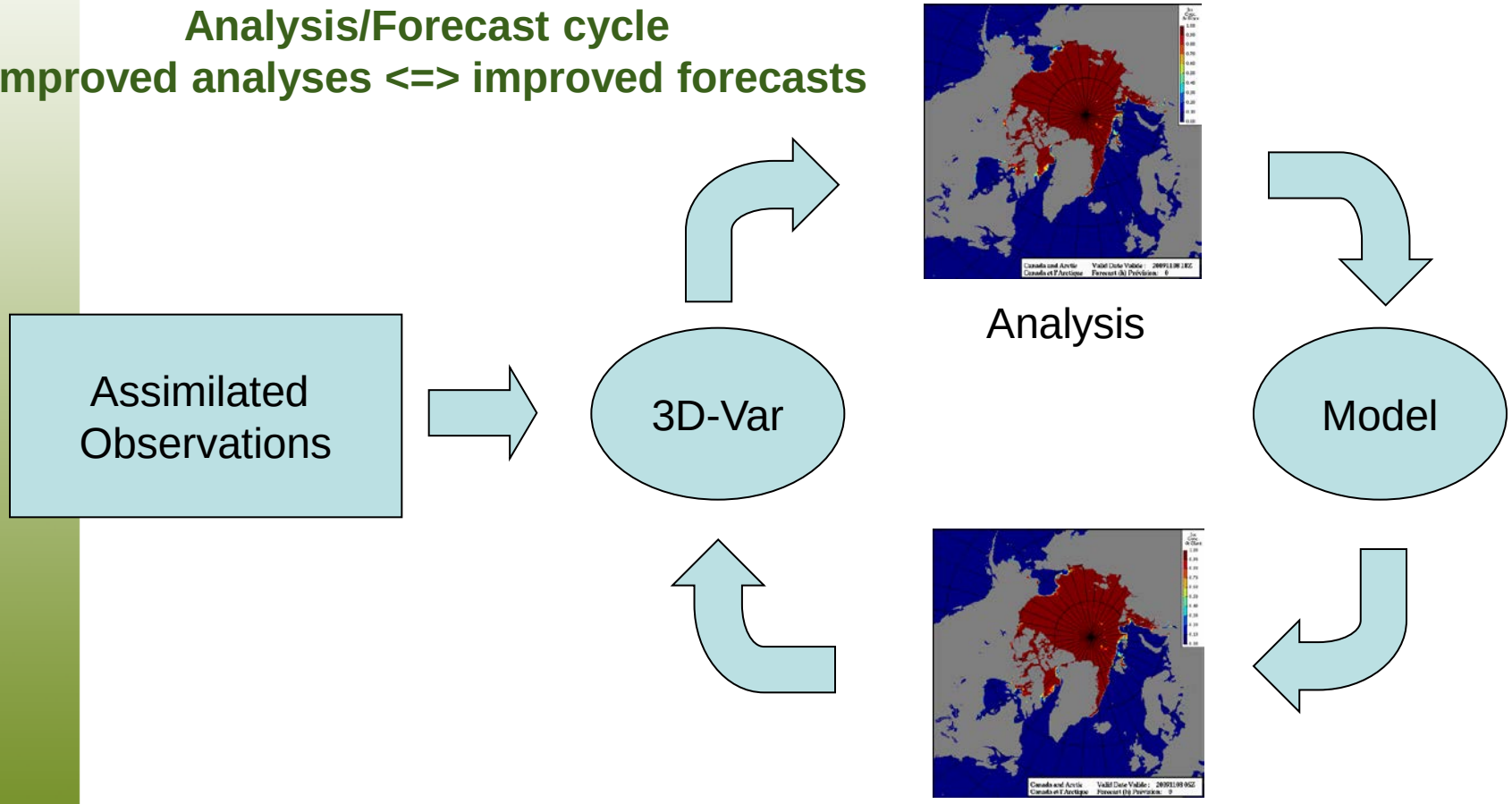
- Future Outlook

Sea Ice Data Assimilation Project

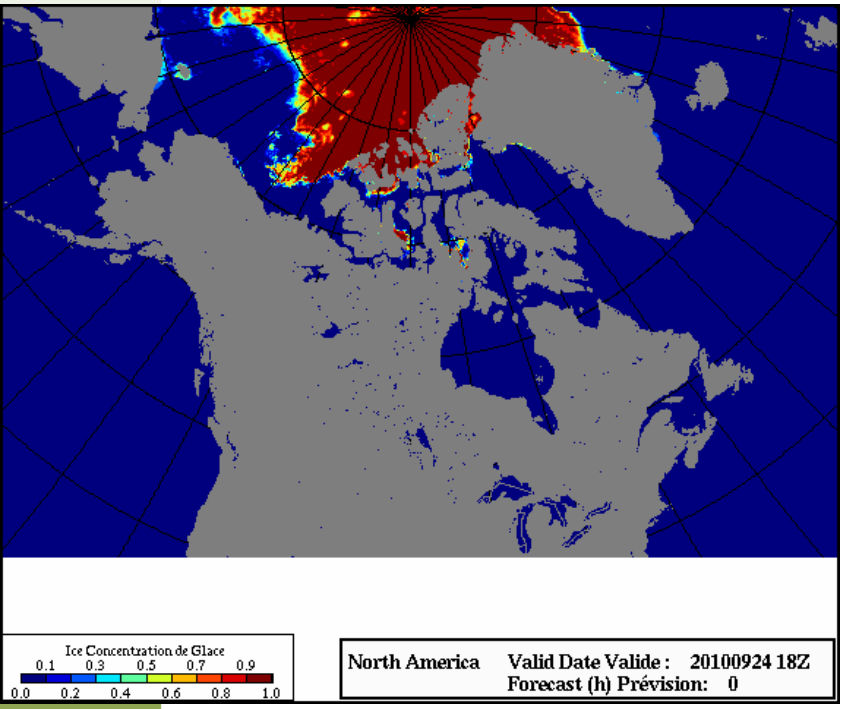
- Collaboration between Meteorological Research and the Canadian Ice Service (CIS)
- Goal is to produce automated analyses of sea-ice conditions for the operational needs of the Meteorological Service of Canada:
  - enhanced ability of CIS to deliver operational sea-ice products for marine navigation over larger area than currently possible (including new arctic METAREAs)
  - improved NWP by supplying new sea-ice analyses for atmospheric models and for initializing coupled ice-ocean-atmosphere forecasts
- Assimilate numerous observation types using 3D-variational data assimilation (3D-Var)
- Single system developed for several current and future applications: regional and global ice analysis systems
- Until now focus is mostly on ice concentration, soon to work on including thickness

Evolution towards an NWP-like Approach to Sea-Ice Analysis/Prediction

Analysis/Forecast cycle
Improved analyses <=> improved forecasts



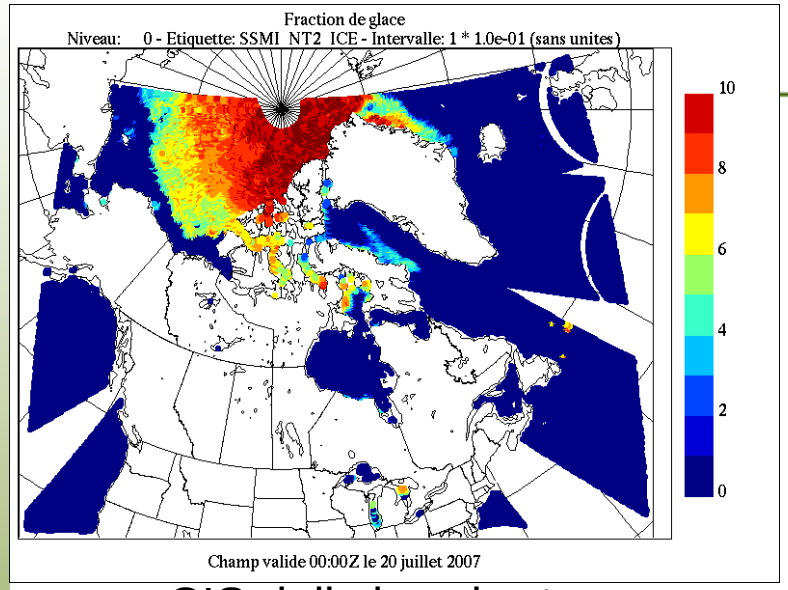
Regional Ice Prediction System: RIPS



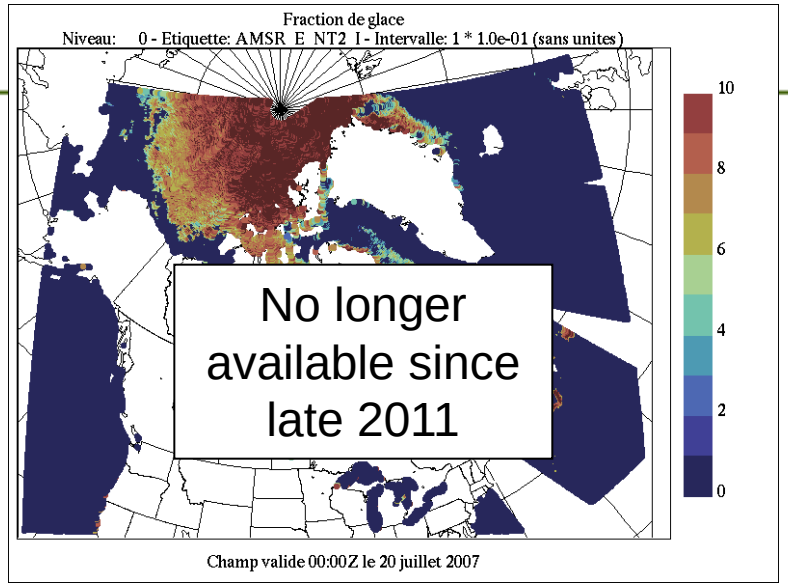
- Main use: provide input for generation of CIS operational products (both manual and automated)
- Four analyses per day of ice concentration at 5 km resolution on rotated lat-lon grid
- Domain chosen to include new METAREAs and meet the needs of North American Ice Service (USA/Canada)
- Background state is previous analysis, persisted in time (no ice model)
- Also compute simple measure of uncertainty at each grid point

Assimilated data: Typical data coverage

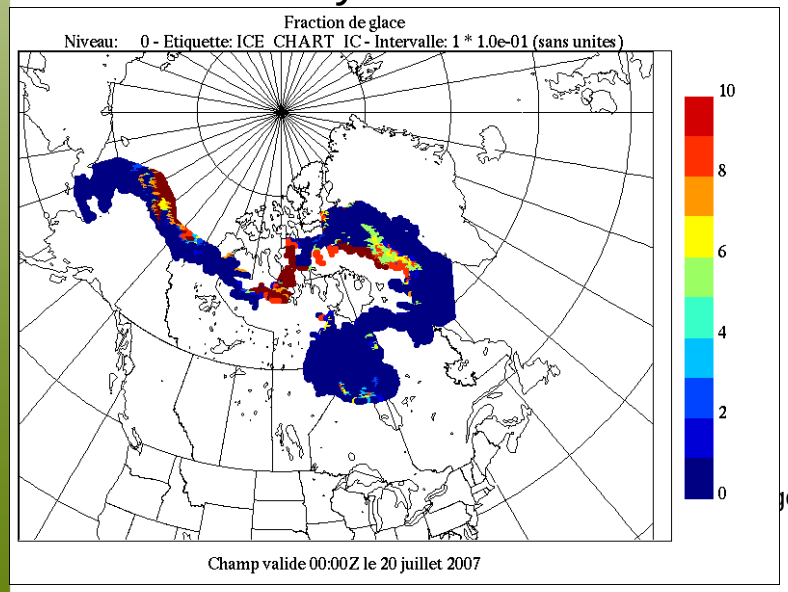
SSM/I ice concentration



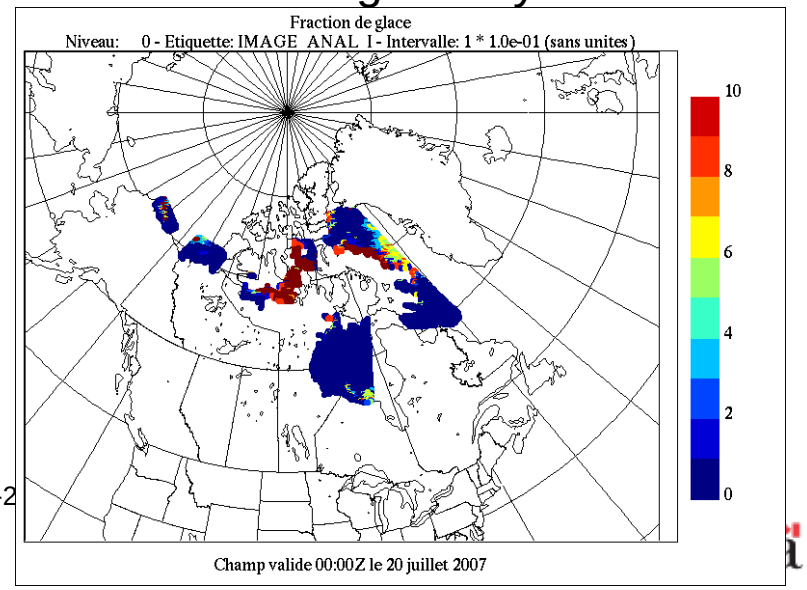
AMSR-E ice concentration



CIS daily ice charts



CIS image analyses



Variational data assimilation approach

- Based on 3D variational data assimilation approach:
  - the code is independent from the NWP variational data assimilation code
  - but follows the same basic structure of NWP code and uses the same Quasi-Newton minimization algorithm (N1QN3)
- Assumes Normally distributed errors, but ice concentration in range [0,1] (reset unphysical values after analysis)
- Like NWP system, uses the preconditioned form of cost function:

$$J(\xi) = \frac{1}{2}\xi^T\xi + \frac{1}{2}(H[\mathbf{x}_b] + \mathbf{H}\mathbf{B}^{1/2}\xi - \mathbf{y})^T\mathbf{R}^{-1}(H[\mathbf{x}_b] + \mathbf{H}\mathbf{B}^{1/2}\xi - \mathbf{y})$$

- For low resolution observations, *H* and **H** perform spatial averaging

  - $\mathbf{x}_b$ is the short-term forecast used as the background state
  - **B** is the background-error covariance matrix
  - **y** is the vector of observations
  - **R** is the observation-error covariance matrix
  - H observation operator: maps model variables into observation space

Regional Ice Prediction System

- RIPS 1.0 (in experimental mode since March 16th, 2011):
  - 0.045° (or approximately 5-km) resolution
  - 4 ice concentration analyses (at 00, 06, 12, and 18UTC) each day
  - 6-hour assimilation windows
  - background = persistence (analysis from 6 hours earlier)
  - observation types assimilated (ice concentration):
    - CIS daily ice charts and image analyses charts
    - CIS lake bulletins
    - AMSR-E (no longer available since October 4th, 2011)
    - SSM/I (DMSP-15)
  - ice concentration obtained from passive microwave data using the "NASA Team 2" algorithm; not assimilated when air temp. > 0°C or when footprint touches land
  - ice in the analysis is removed where CMC SST > 4°C

Regional Ice Prediction System

- RIPS 2.0 (early 2013):
  - Additional assimilated observations:
    - SSM/IS (DMSP16-17-18)
    - ASCAT (1 satellite,… soon 2)
      - measure of anisotropy of 3 look angles related to ice concentration through linear forward model
      - no data rejected based on air temp, instead rejected when wind speed is low
  - A new analysis-error standard deviation field for ice concentration and correction procedure for grid points with high error
  - Sea ice model CICE used to produce short-term forecasts up to 48 hours

Impact of SSM/IS and ASCAT in RIPS:

Verification against IMS ice extent analysis from NOAA

- IMS is the Interactive Multisensor Snow and Ice Mapping System (http://www.natice.noaa.gov/ims/)
- Only ice/no-ice
- Manual production using a wide variety of satellite data
- Resolution ~4 km
- Available daily over entire northern hemisphere analysis domain, including lakes
- 3D-Var analysis is interpolated on the IMS analysis grid and then converted to ice/no-ice using a 40 % threshold
- Not shown: verification against other ice concentration estimates: CIS and NIC manual ice charts

Scores are based on a contingency table

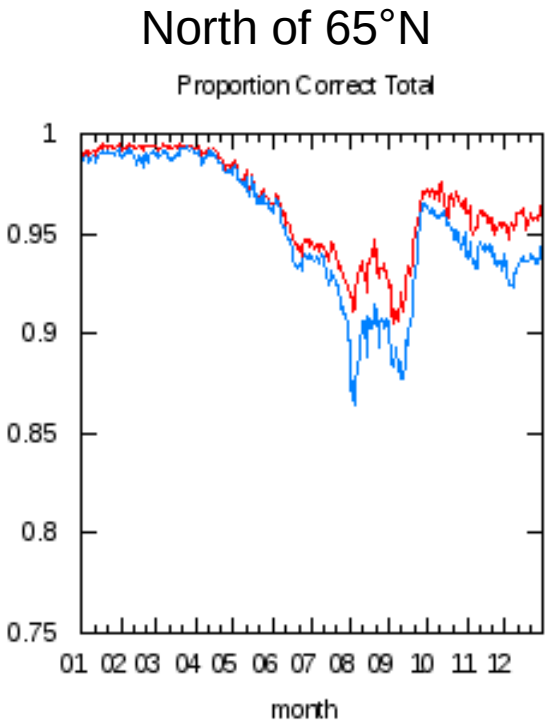
- Scores are ratios of counts and are calculated only when the denominator is greater than 500.

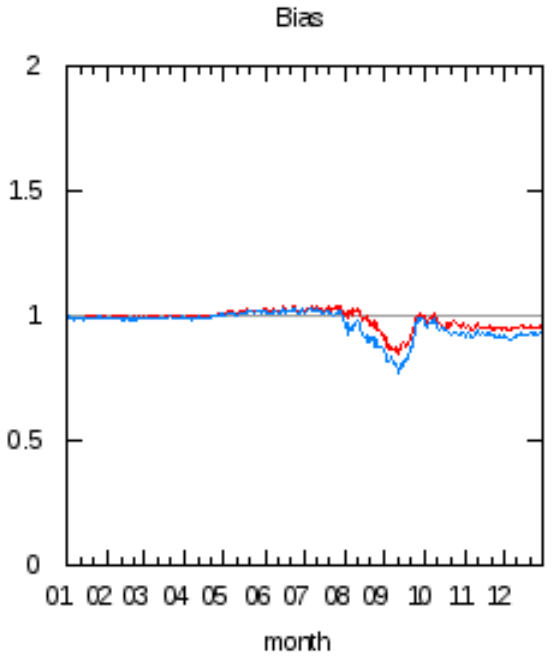
	Observed ice	**Observed no ice**
Analysed ice	Hits (a)	False alarms (b)
Analysed no ice	Misses (c)	Correct no (d)

Name	Definition	Range ; best score
Proportion Correct Total	PCT = (a+d)/(a+b+c+d)	0 - 1 ; 1
Proportion Correct Ice	PCI = a/(a+c)	0 - 1 ; 1
Proportion Correct Water	PCW = d/(b+d)	0 - 1 ; 1
Frequency Bias	BIAS = (a+b)/(a+c)	0 - ∞; 1
Observed Proportion Ice	OPI = (a+c)/n	0 – 1
Obs Count (sample size)	n = a + b + c + d	0 - ∞

Experiments over 2010 Impact of SSM/IS

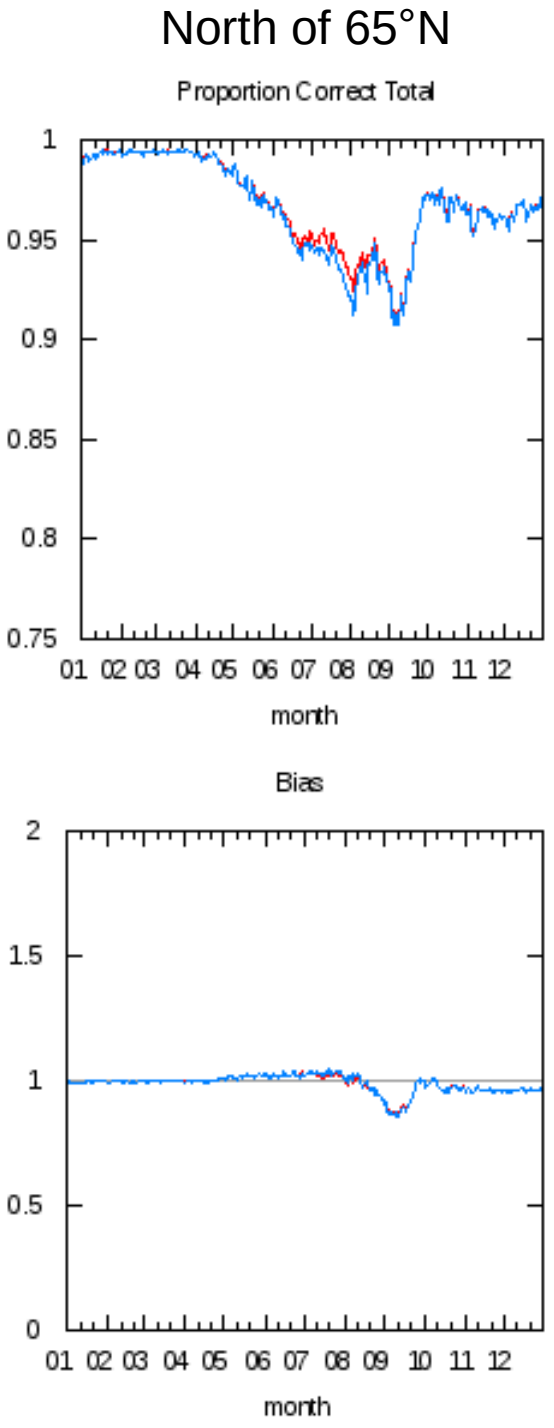
- Experiment 1 (in blue):
  - Observations assimilated:
    - SSM/I
    - CIS daily ice charts
    - CIS image analyses
    - CIS lake ice bulletins
- Experiment 2 (in red):
  - Same as experiment 1, plus…
  - Assimilation of SSM/IS data





Experiments over 2010 Impact of ASCAT

- Experiment 2 (in blue):
  - Observations assimilated:
    - SSM/I
    - CIS daily ice charts
    - CIS image analyses
    - CIS lake ice bulletins
    - SSM/IS
- Experiment 3: (in red)
  - Same as experiment 2, plus…
  - Assimilation of ASCAT data



An estimation of analysis error

- During the ice growth and melt seasons, ice concentration does not change fast enough along the coast line and in narrow passages in the analysis.
- Problem is due to regions being less frequently or never observed by low-resolution (large footprint) satellite observations.
- A measure is required to identify grid points with high uncertainty and to allow the ice concentration at these locations to be “corrected”.
- Problem eventually solved by assimilating high-resolution observations and using a model to evolve the background state.

Error estimation: Simplified Kalman filter

- Used only to estimate the statistics of analysis error, not for the analysis itself (and only error stddev calculated)
- Error variance modified during the analysis step according to:

$$\mathbf{P}^a = \left(\mathbf{I} - \mathbf{KH}\right)\mathbf{B}$$

$$\mathbf{K} = \mathbf{BH}^T\left(\mathbf{HBH}^T + \mathbf{R}\right)^{-1}$$

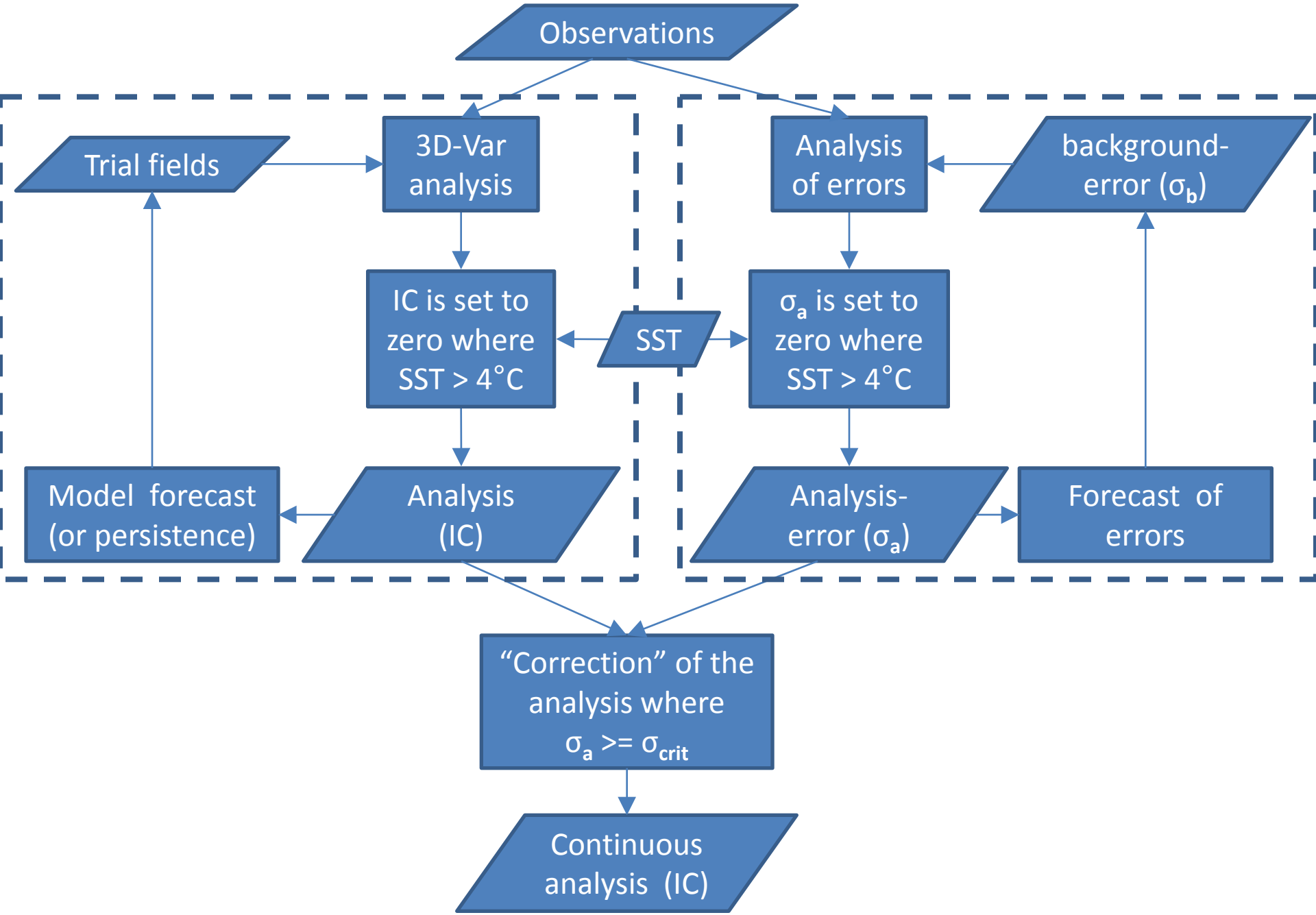
- Analysis-error variance set to zero where SST > 4°C
- During forecast step, use simple model for the linear growth of error stddev, higher growth near ice edge and coast:

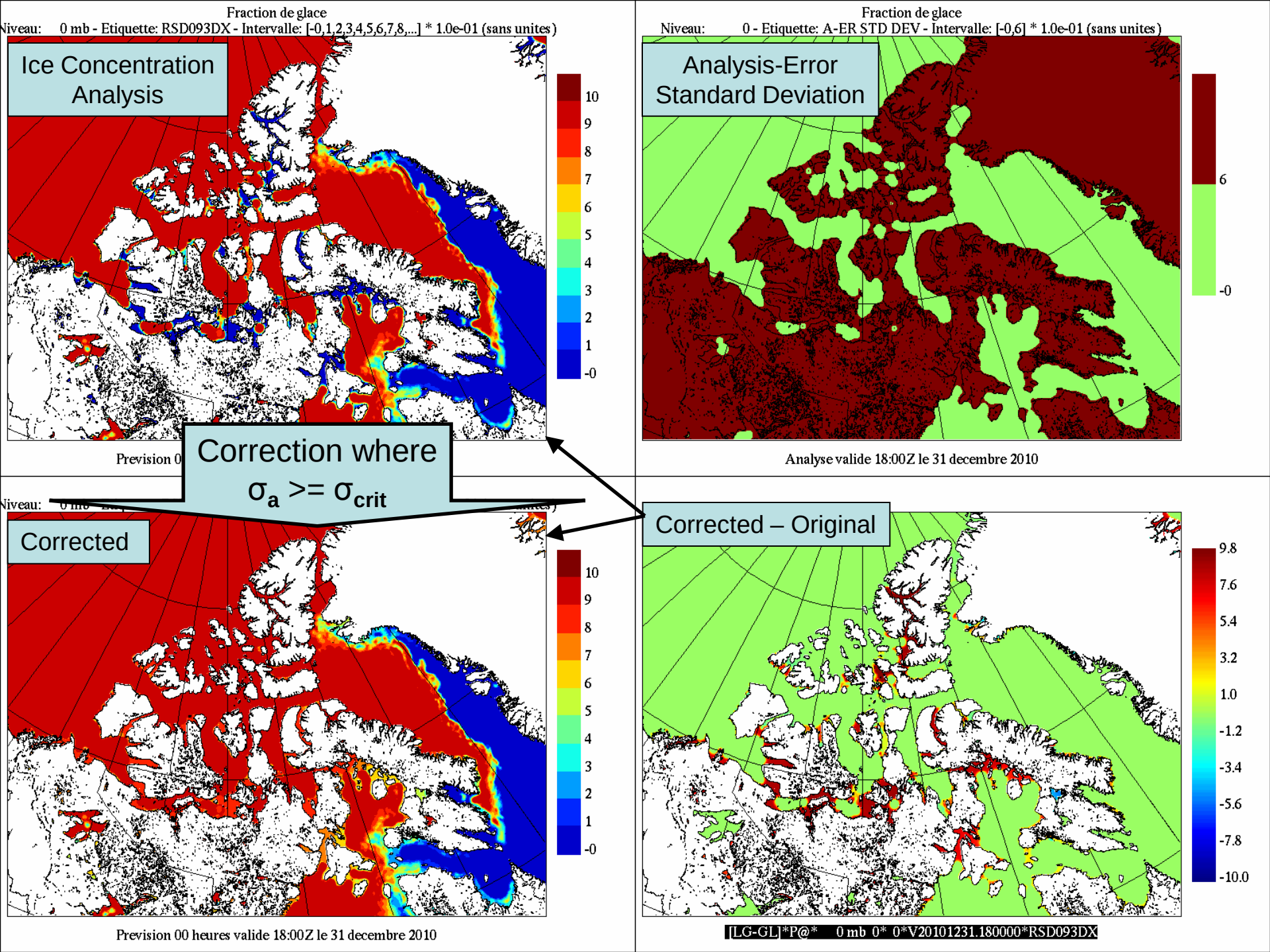
$$\sigma_{b,k+1}(A) = \sqrt{\max\left(\sigma_{a,k}^2(A), \Delta^2(A)\right)} + const$$

$$const = 6\text{ h} / (24\text{ h/day} \times 16\text{ days}) = 0.0156$$

Correction of the analysis

- A correction procedure replaces the ice concentration analysis at grid points where $\sigma_a >= \sigma_{crit}$, all other grid points unchanged.
- Corrected values obtained by solving Laplace's equation using the method of sequential (or Liebman) relaxation, effectively an interpolation/extrapolation procedure.
- Currently, only use the corrected analysis for graphical products and initializing forecast models, but not as background state for next analysis in assimilation cycle

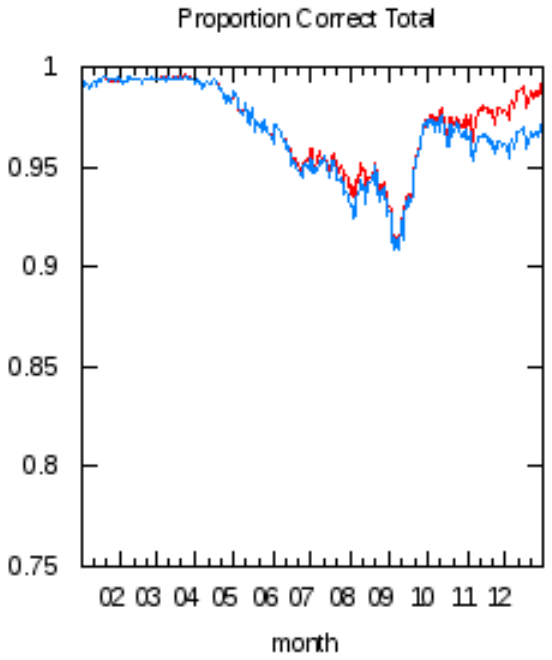

Observations
Trial fields
3D-Var analysis
Analysis of errors
background-error (σ_b)
IC is set to zero where SST > 4°C
SST
σ_a is set to zero where SST > 4°C
Model forecast (or persistence)
Analysis (IC)
Analysis-error (σ_a)
Forecast of errors
"Correction" of the analysis where $\sigma_a >= \sigma_{crit}$
Continuous analysis (IC)

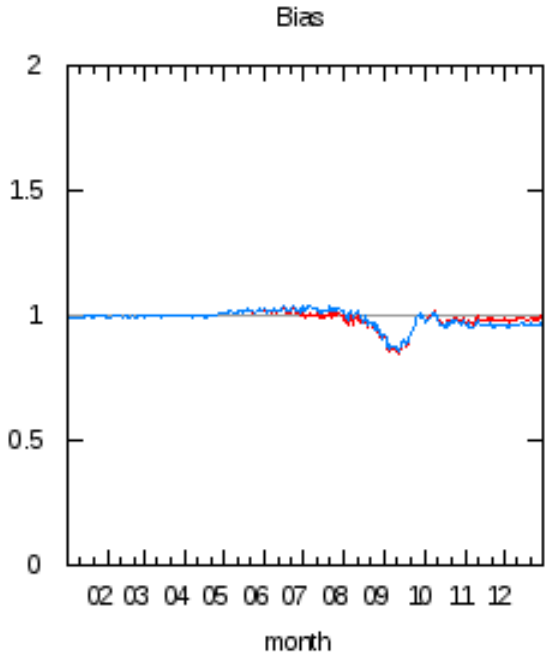

Fraction de glace
Niveau: 0 mb - Etiquette: RSD093DX - Intervalle: [-0,1,2,3,4,5,6,7,8,...] * 1.0e-01 (sans unites)
Ice Concentration Analysis
10
9
8
7
6
5
4
3
2
1
-0
Prevision 0
Fraction de glace
Niveau: 0 - Etiquette: A-ER STD DEV - Intervalle: [-0,6] * 1.0e-01 (sans unites)
Analysis-Error Standard Deviation
6
-0
Analyse valide 18:00Z le 31 decembre 2010
Correction where
$\sigma_a >= \sigma_{crit}$
Niveau:
Corrected
10
9
8
7
6
5
4
3
2
1
-0
Prevision 00 heures valide 18:00Z le 31 decembre 2010
Corrected – Original
9.8
7.6
5.4
3.2
1.0
-1.2
-3.4
-5.6
-7.8
-10.0
[LG-GL]*P@* 0 mb 0* 0*V20101231.180000*RSD093DX

Experiments over 2010 Impact of “corrections”

- Experiment 3 (in blue):
  - Assimilated observations:
    - SSM/I
    - CIS daily ice charts
    - CIS image analyses
    - CIS lake ice bulletins
    - SSM/IS
    - ASCAT
- Experiment 4: (in red)
  - Same as experiment 3, plus…
  - Use analysis-error (threshold = 0.6) as criteria to decide where to “correct” ice concentration

North of 65°N



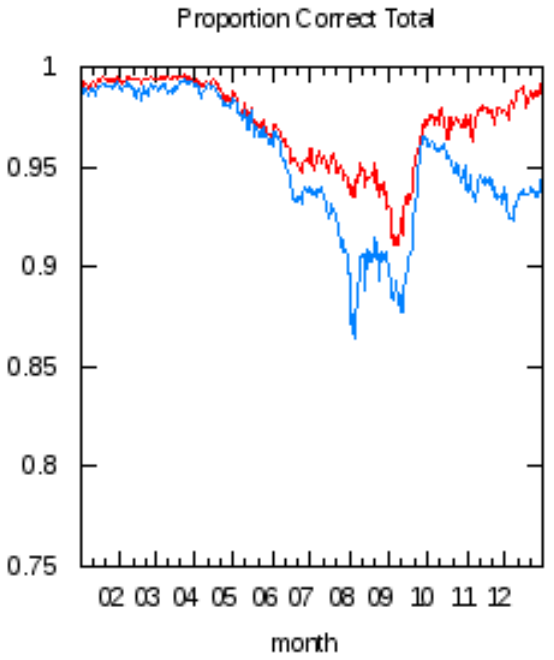


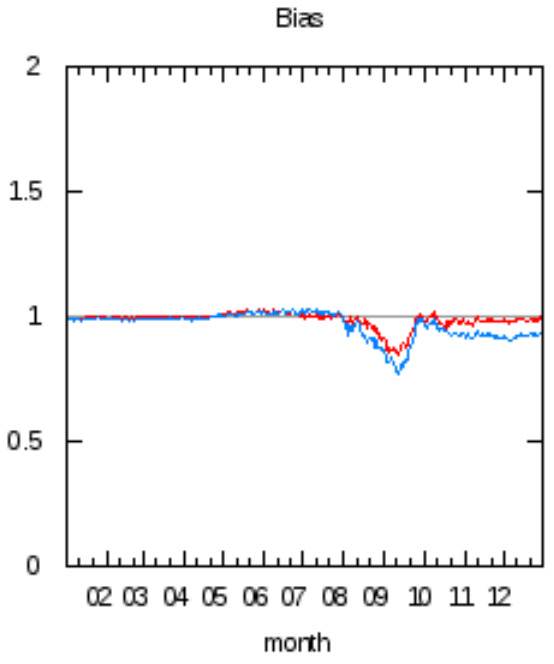
Total impact of all changes over 2010

Additional assimilated observations: SSMIS and ASCAT

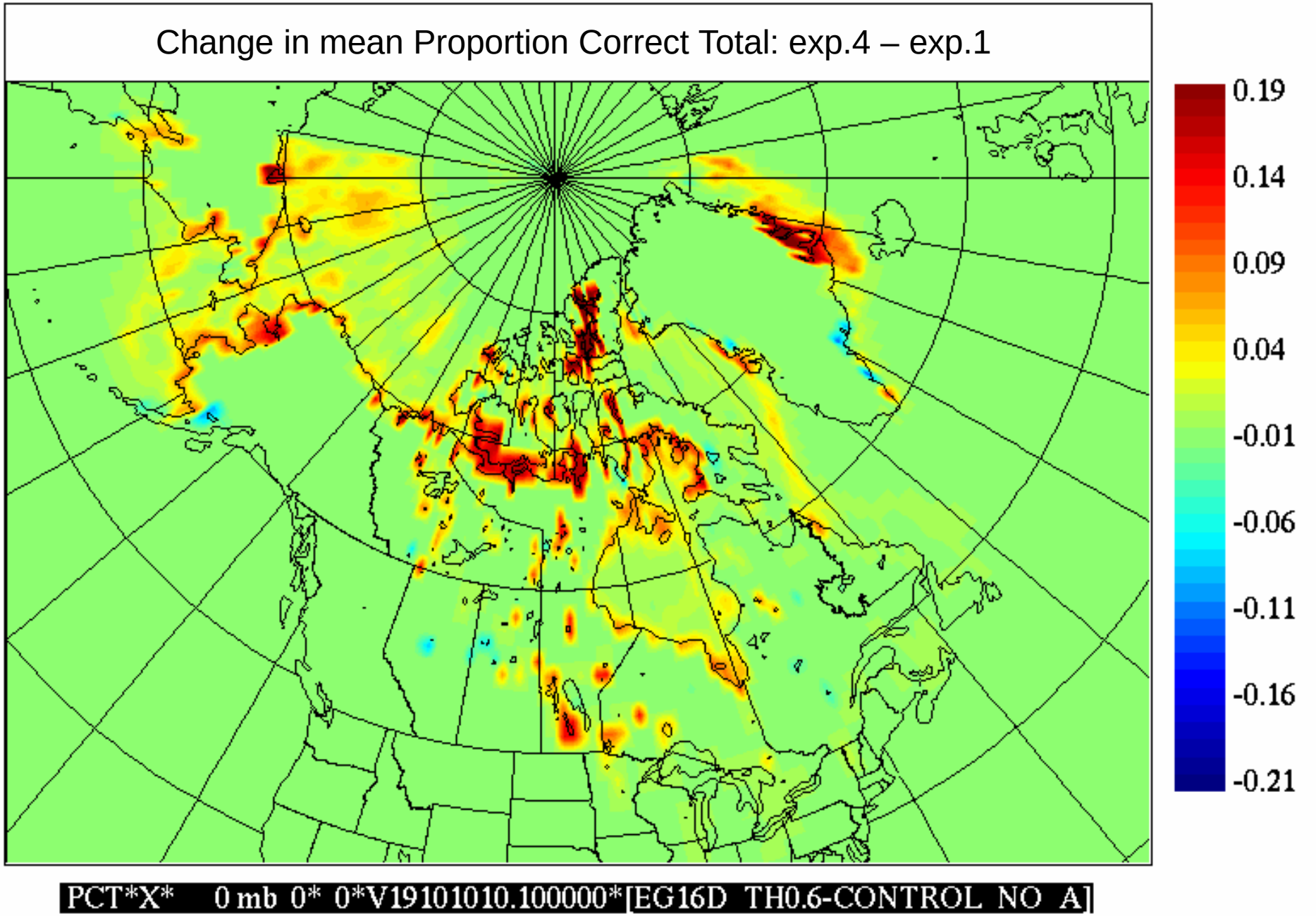
Use of interpolated/extrapolated values to correct analysis where analysis error is high

North of 65°N





Impact of all changes (2010)

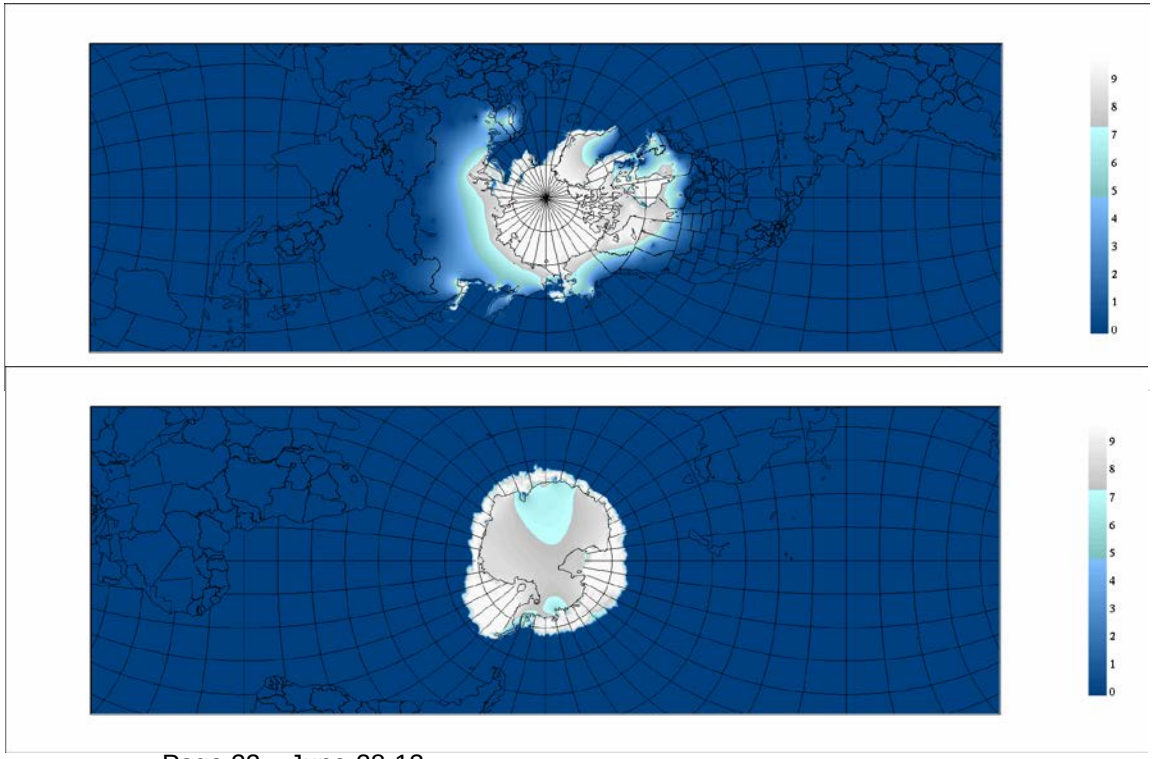


New Global Ice Analysis: Numerical Grid

- Ice concentration analysis produced on 2 separate overlapping rotated latitude-longitude grids (Yin-Yang approach)

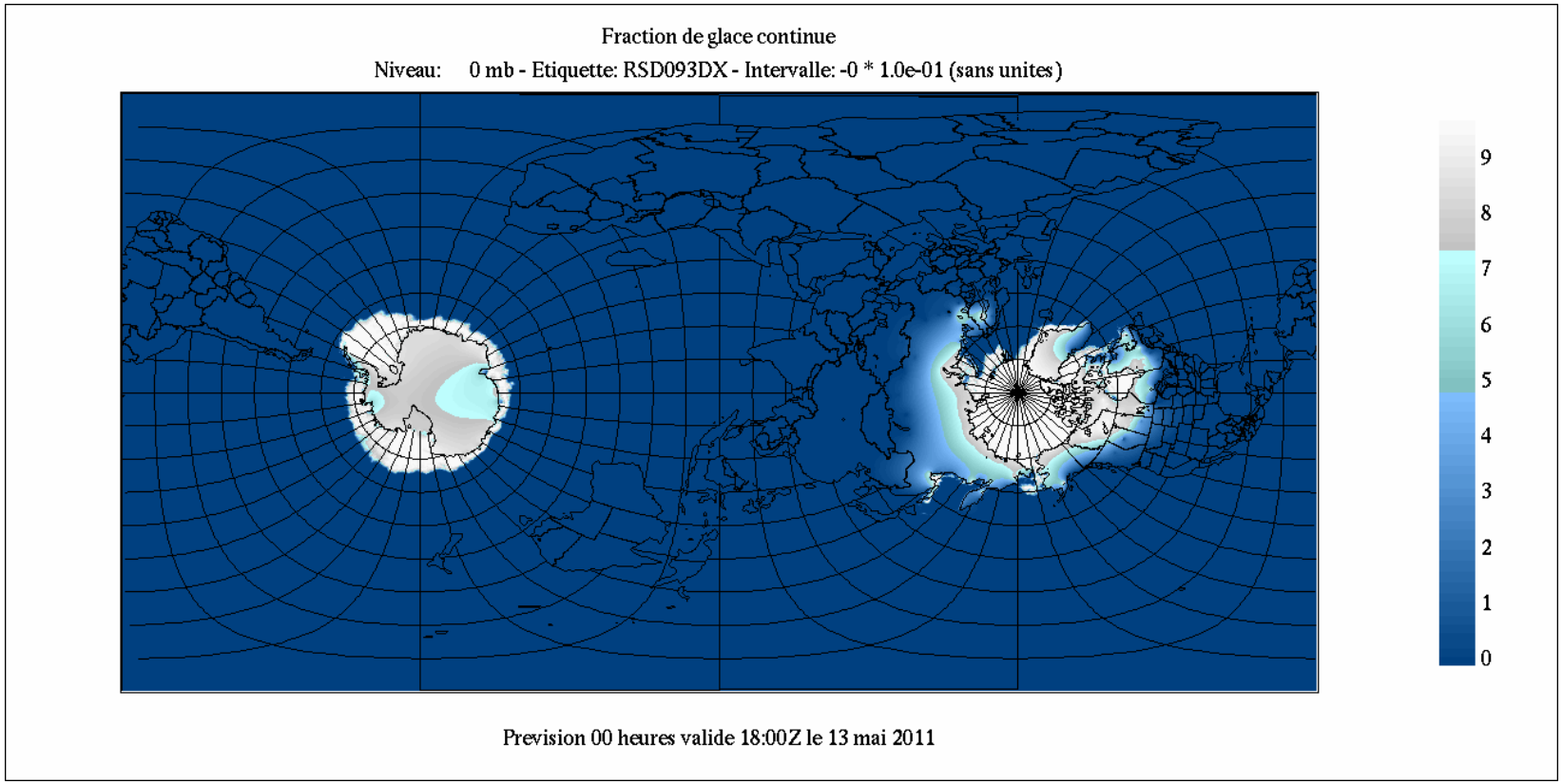
"Yin" grid = Arctic + North America + Asia

"Yang" grid = Antarctic + Africa



New Global Ice Analysis: Numerical Grid

Global grid at 10km resolution produced by interpolating Yang grid (Antarctic) onto global version of Yin grid (Arctic) and combining both

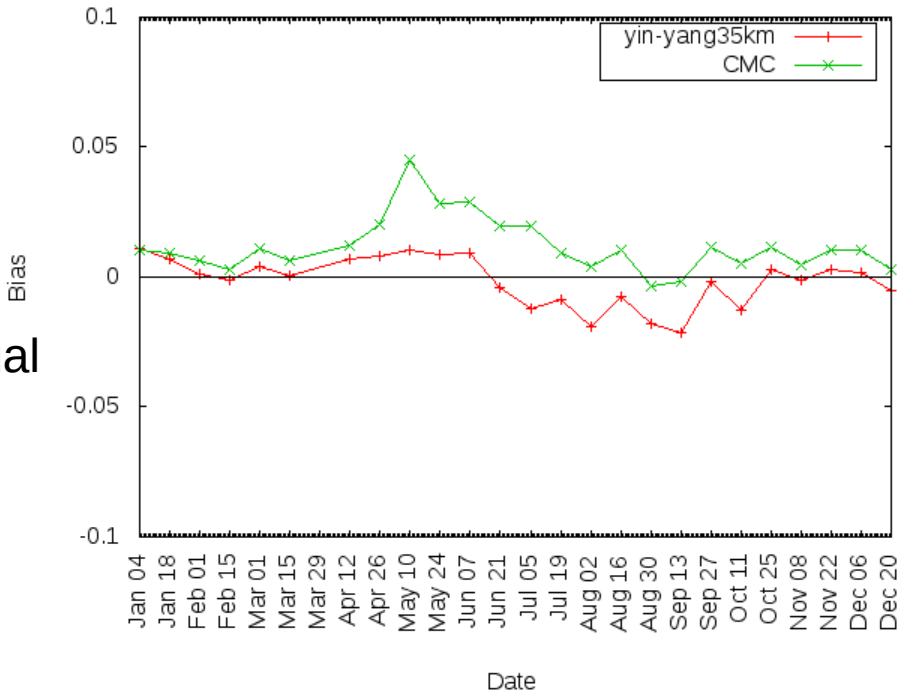


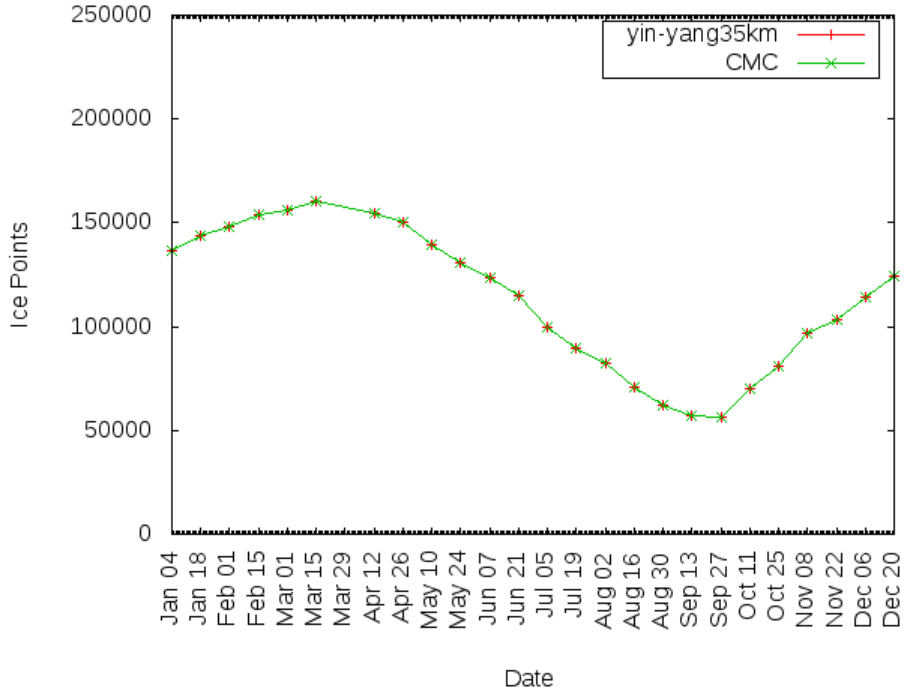
System Comparison

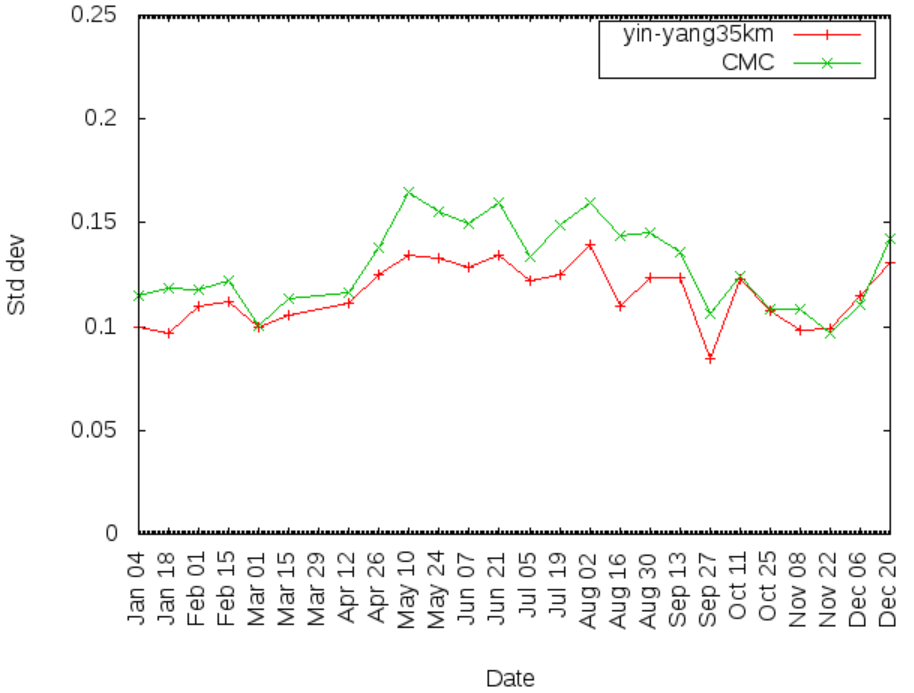
	Operational global ice analysis (CMC)	New global ice analysis (EXP)
Resolution	GL ~ 100km LG ~ 35km	GL and LG ~ 10km
Assimilation method	Averaging with more weight to CIS data	3D-var
Return to climatology	Over oceans and lakes	Over lakes
Frequency	Once a day at 00 UTC	00, 06, 12, 18 UTC
Retrieval algorithm	AES-York	NASA Team 2 (NT2)
Assimilated Observations	CIS – daily ice charts CIS – lakes ice bulletins SSMI – DMSP15	CIS – daily ice chart CIS – lakes ice bulletins CIS - RADARSAT analyses SSMI – DMSP15 SSMIS – DMSP16-17-18 (No ASCAT yet)

Arctic ice concentration

Verification against the U.S. NIC manual ice charts produced every 2 weeks



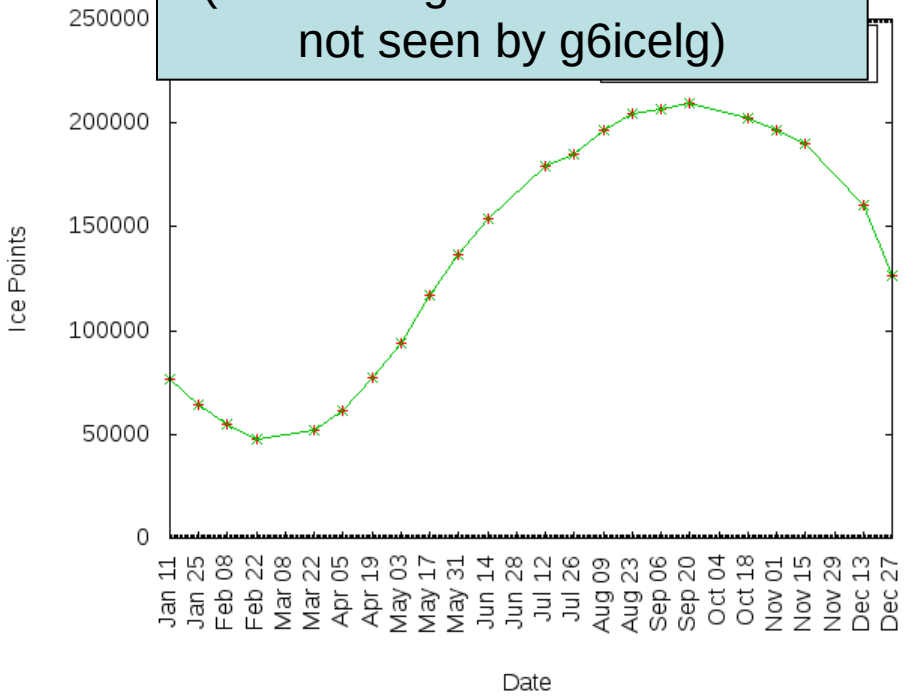


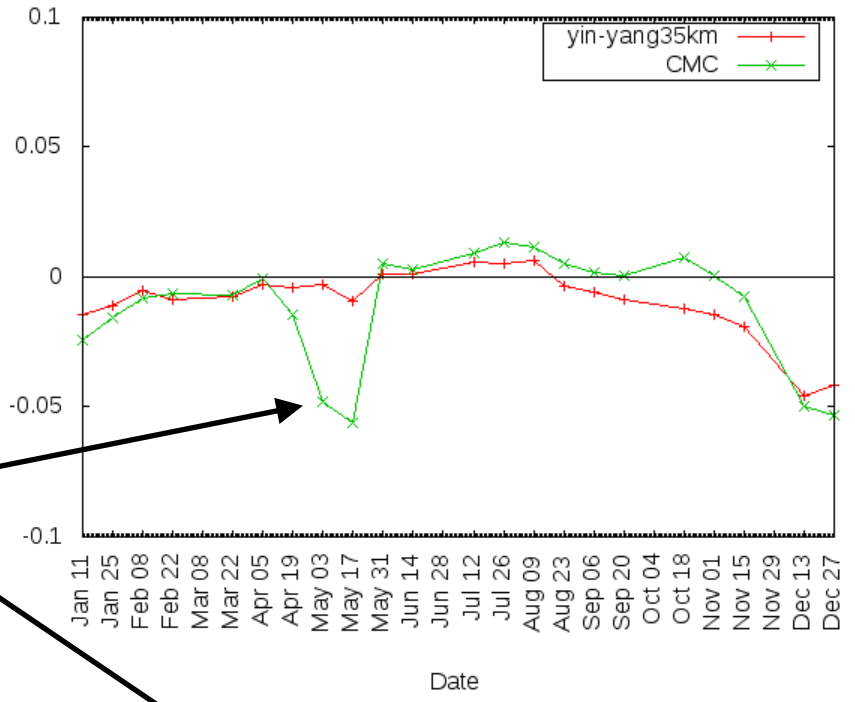


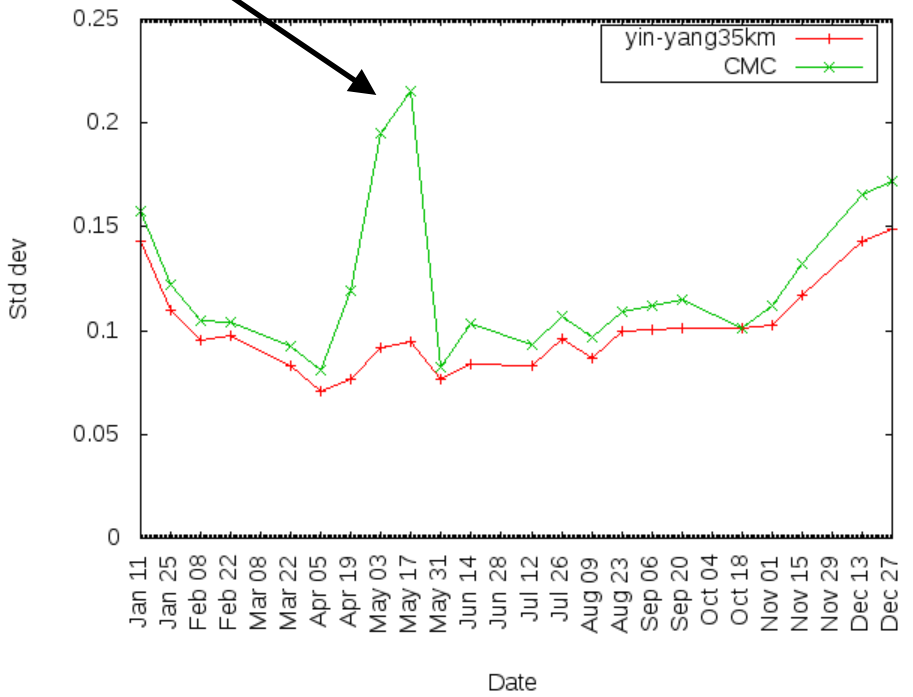
Antarctic ice concentration

Verification against the U.S. NIC manual ice charts produced every 2 weeks

No SSM/I data between April 17 and May 26 2010 in the CMC sea ice analysis ! (LINUX migration => new TM not seen by g6icelg)





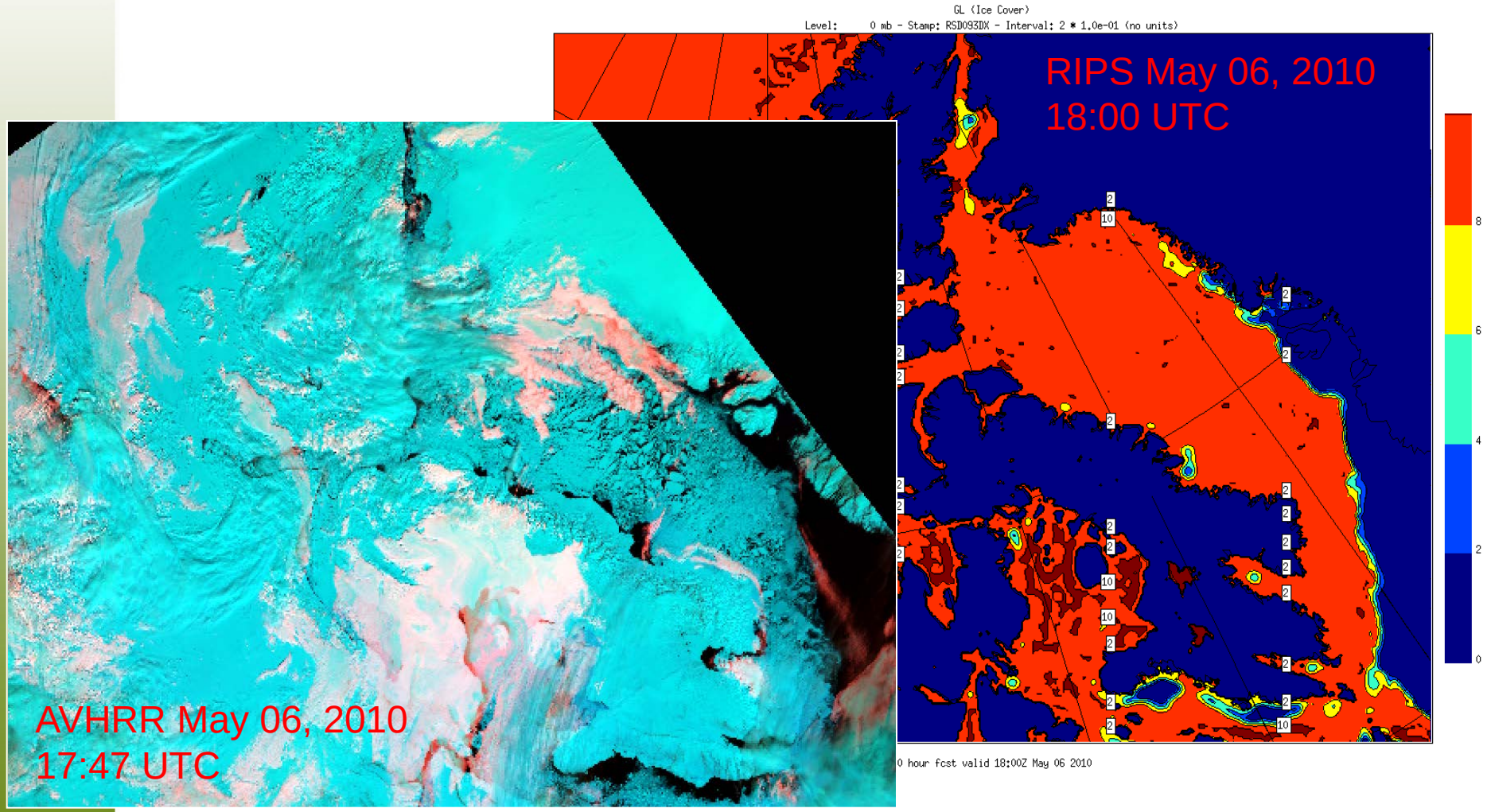


Summary:

Global Ice Analysis System

- Based on 3 different types of objective verifications (only 1 shown here), the new global ice analysis is improved relative to operational system
- To be used as part of next upgrade to global and regional NWP systems (early 2014)

RIPS 2.0 analysis vs. AVHRR observations
A potential for higher resolution



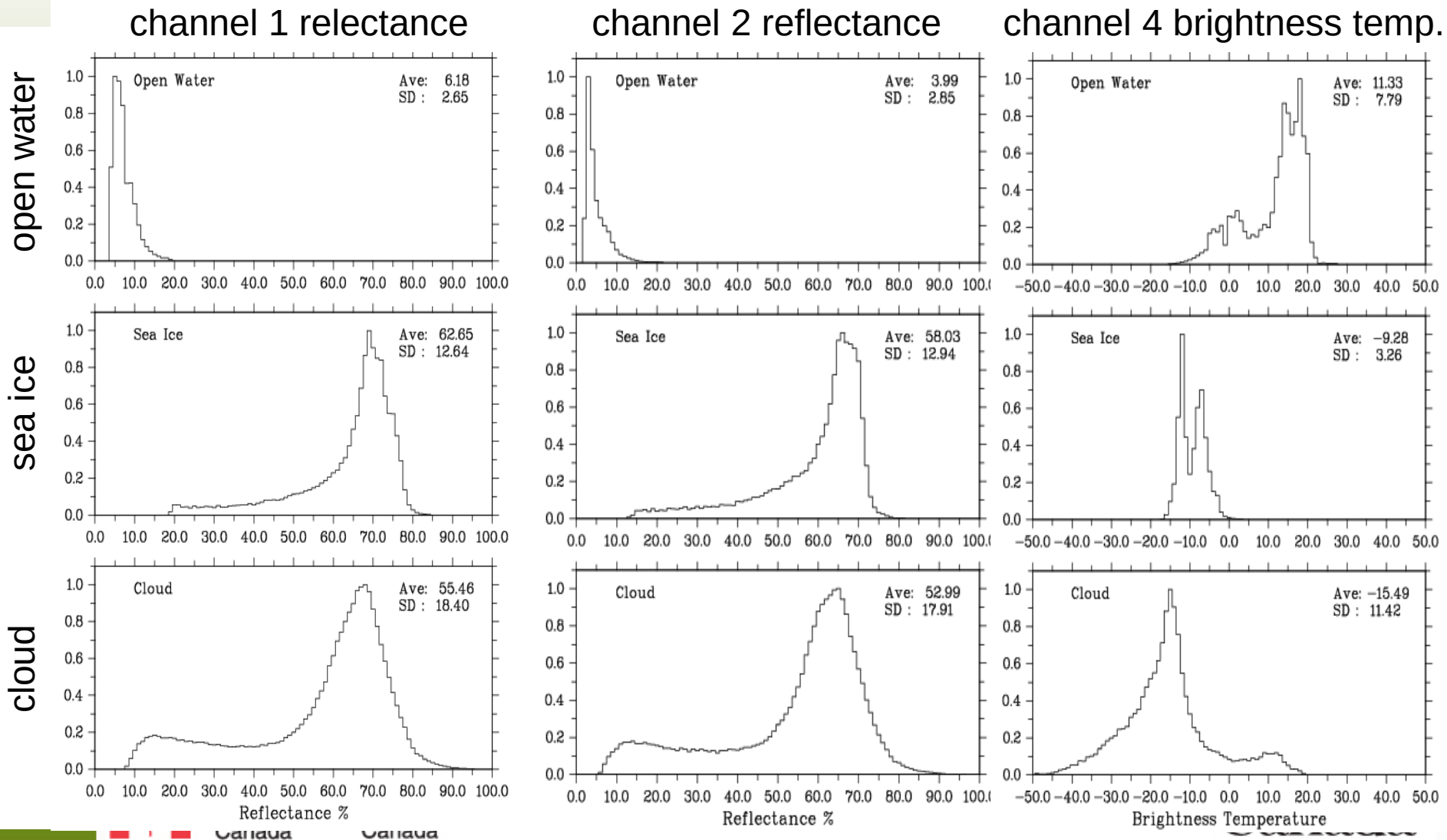
Advantages of using AVHRR

- AVHRR/VIIRS will be operationally available for the foreseeable future
- AVHRR imagery has good spatial and temporal coverage at relatively high resolution: 1km (VIIRS even better)
  - observing ice openings and conditions in narrow passages important for marine navigation
  - also observing conditions along the coast and in small lakes important for NWP
- AVHRR has multiple bands including visible, NIR, thermal IR that can be used to distinguish ice, water and cloud
- Mature algorithms have been developed for AVHRR data pre-processing

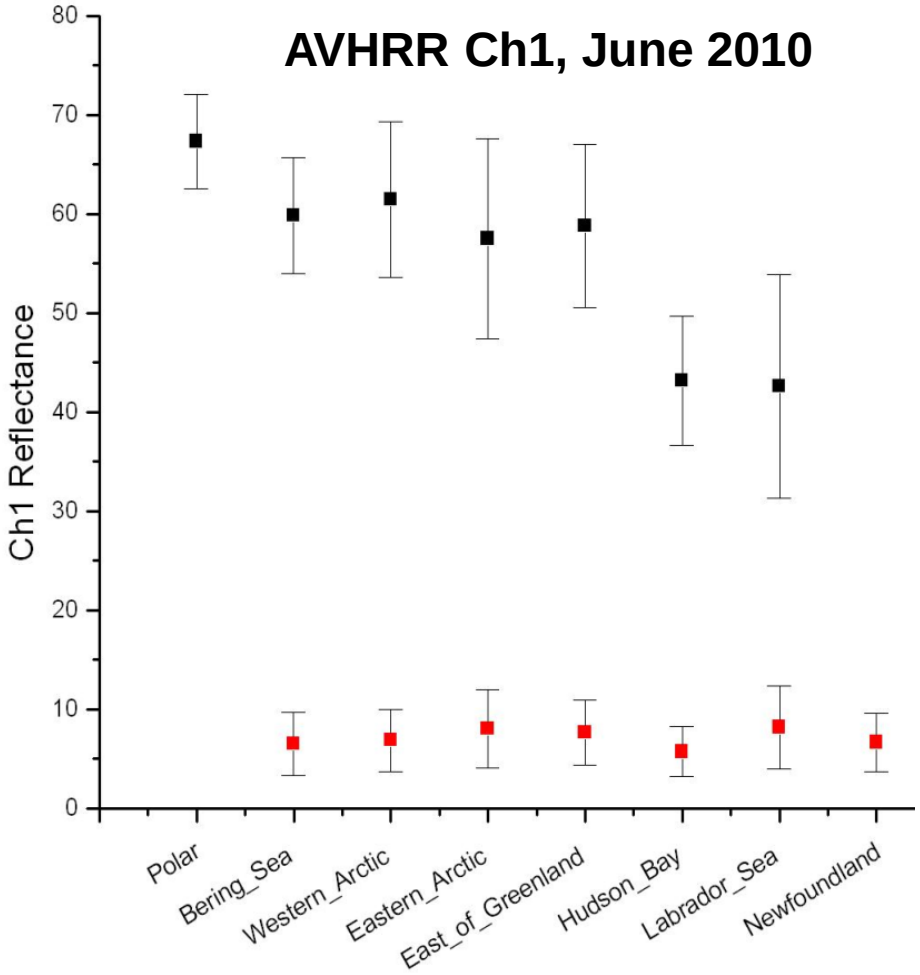
Challenges of using AVHRR data

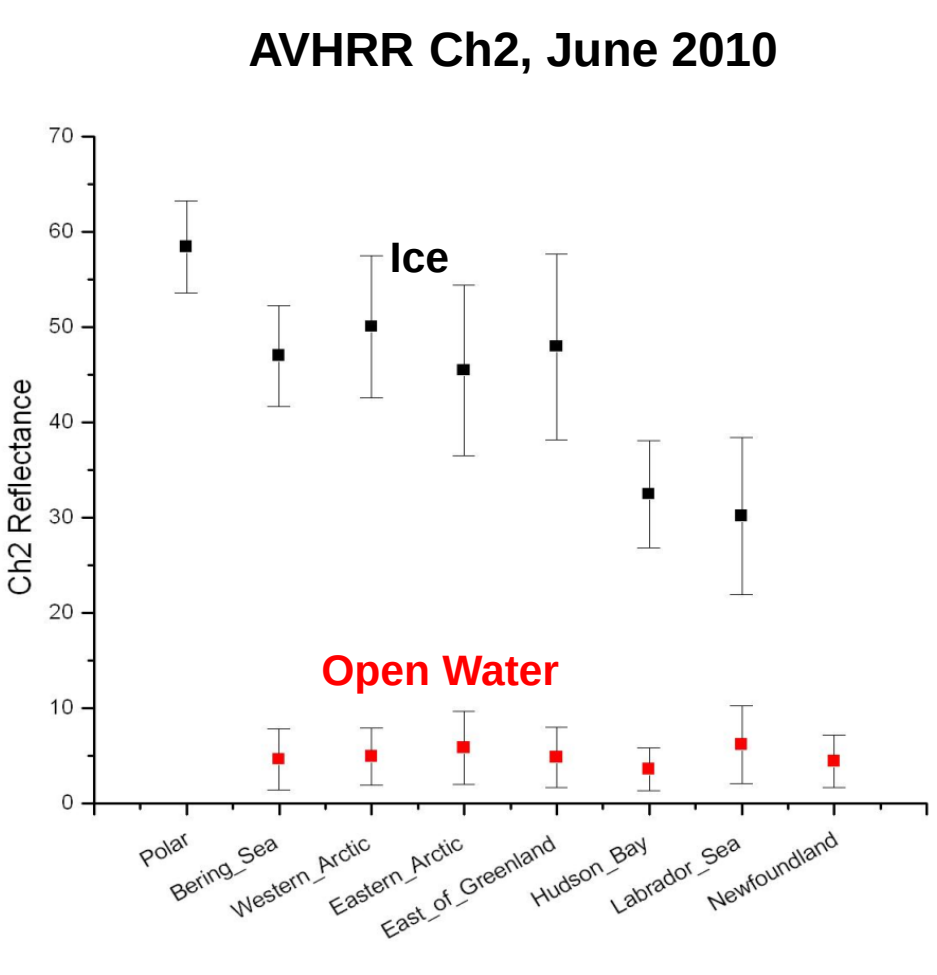
- Cloud contamination (including shadowing effect)
- Image geolocation errors
- Reflectance depends on sun-satellite-target geometry
- Ice signal is also region and season dependent
  - developed a system for on-line estimation of “characteristic values” based on region/time/solar_angle/etc.

Observed Distributions of R1, R2, BT4



Characteristic Values (CV) of sea ice and open water for various regions

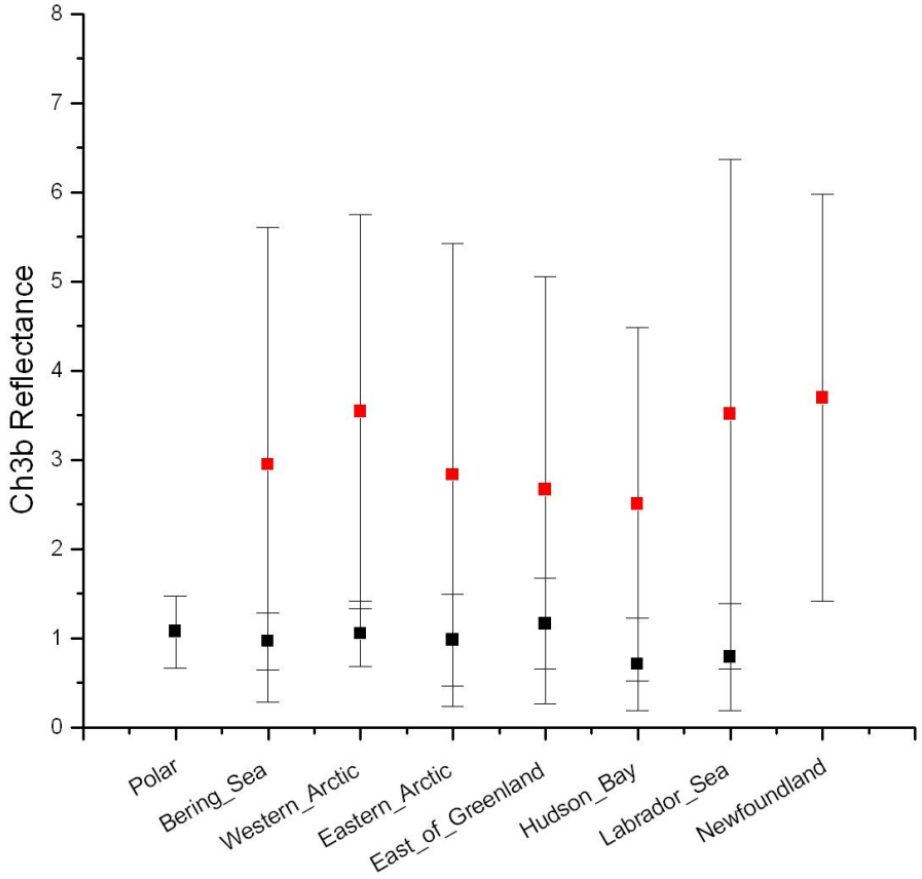




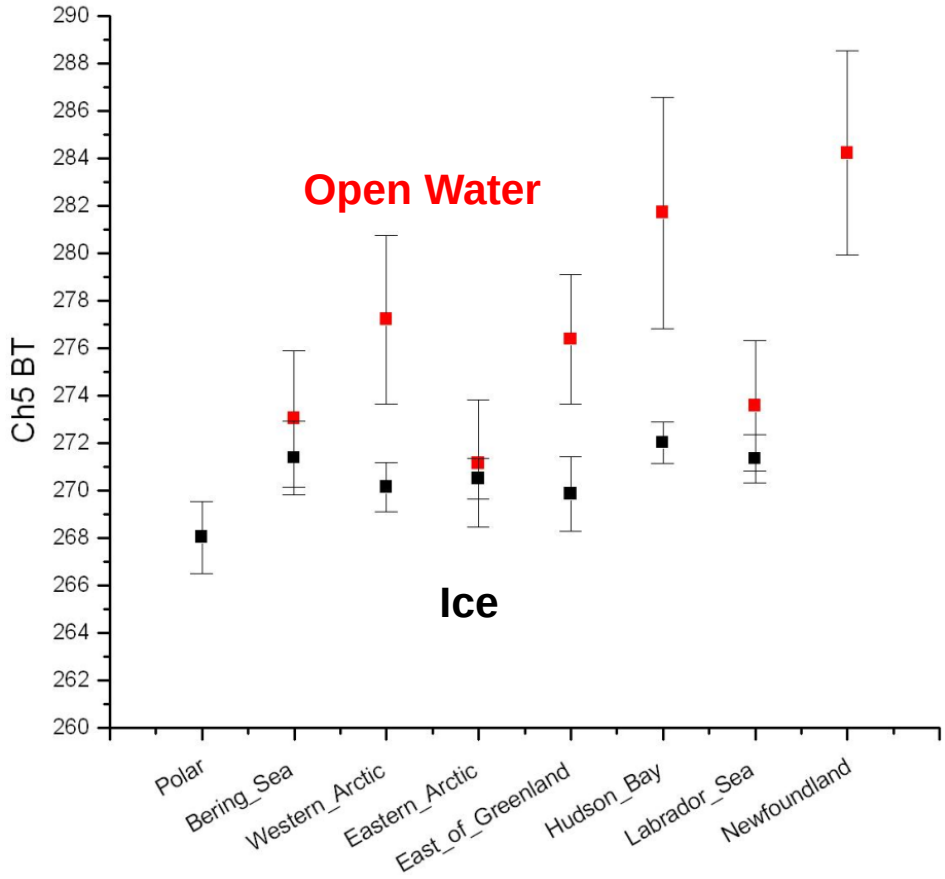
Ch1 and Ch2 reflectance are well separated for ice and open water.

Characteristic Values (CV) of sea ice and open water for various regions

AVHRR Ch3b, June 2010



AVHRR BT5, June 2010



Ch3b has significant overlap; Ch5 BT has overlap that varies with region

0D-Var experiments

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T+\mathbf{R})^{-1}(\mathbf{y}-H(\mathbf{x}_b))$$

Where

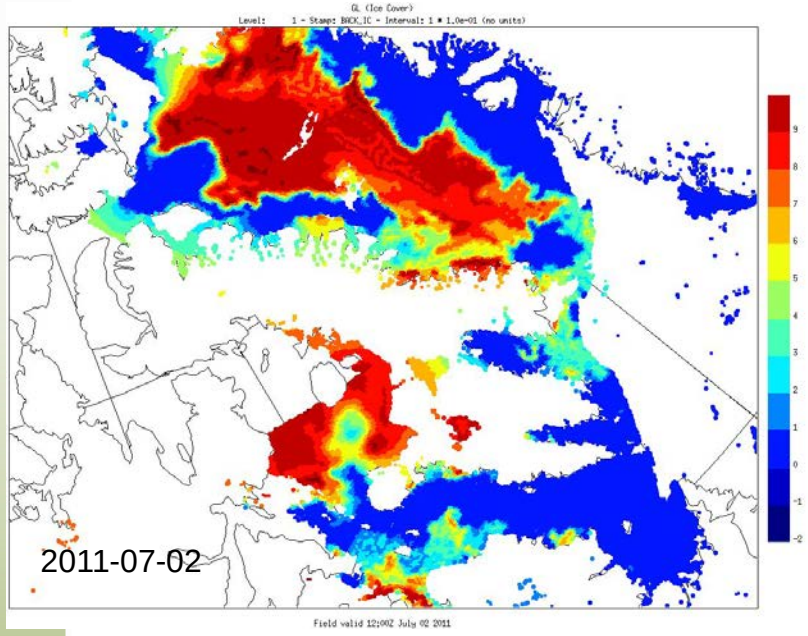
- $\mathbf{x}_a$ and $\mathbf{x}_b$ are analysis and background ice concentrations
- **y** are the observations
- **B** is the background error covariance matrix (~0.1^2)
- **R** is the observation error covariance matrix approximated by the average CV distribution variance: $\alpha(\sigma^2_{ice} + \sigma^2_{water})$
- *H* is the observation operator

$$H(x) = (1 - x)*CV_{water} + x*CV_{ice}$$

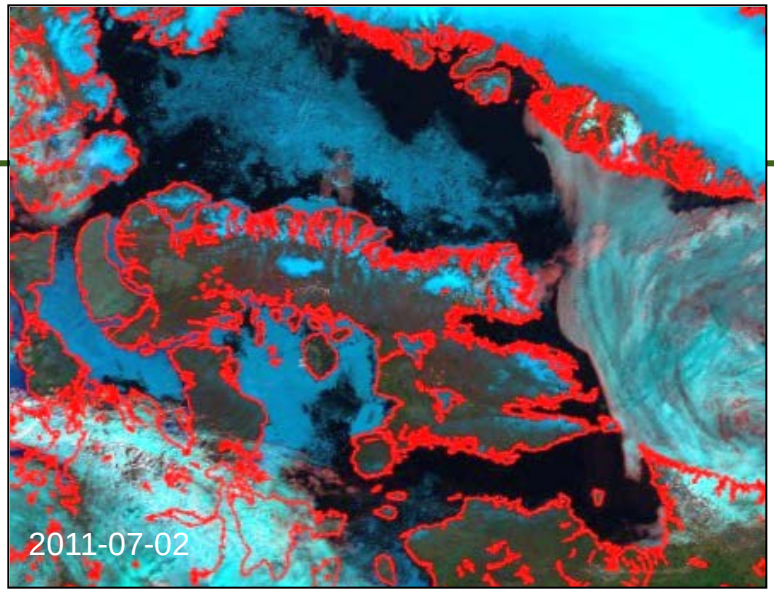
CV_{ice} – typical observed value of 100% ice concentration
CV_{water} – typical observed value of open water

- **H** is the jacobian of *H* (i.e. $dH/dx = CV_{ice} - CV_{water}$)
- Applied to observations after cloud masking

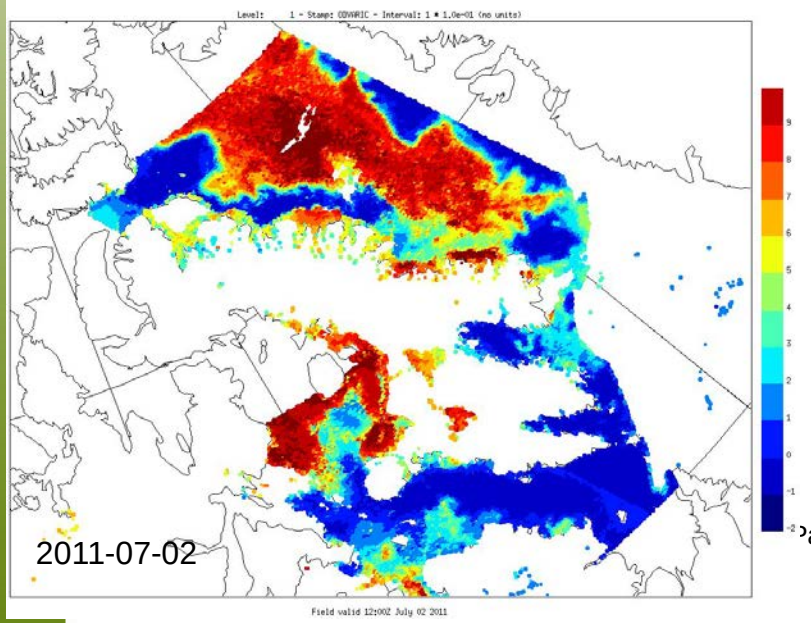
Background IC



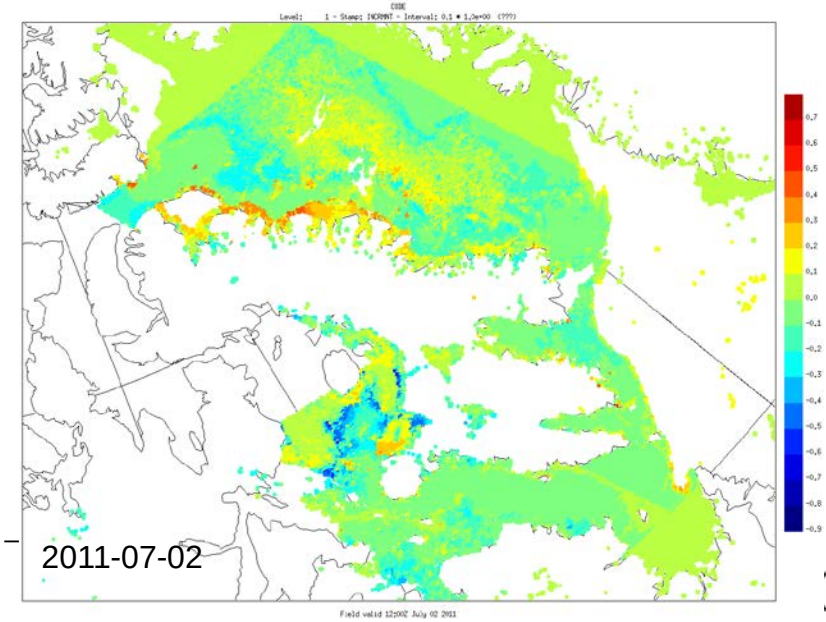
AVHRR Imagery



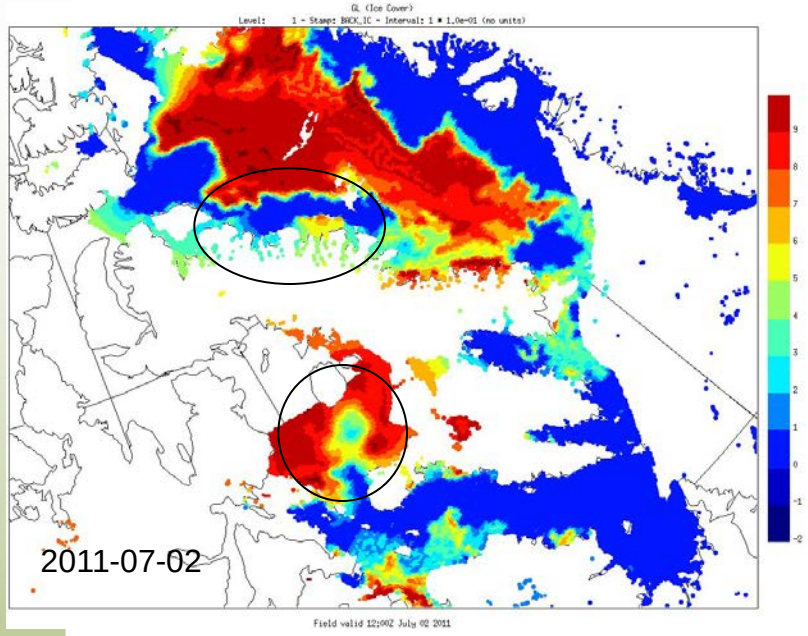
0D-Var IC Retrieval



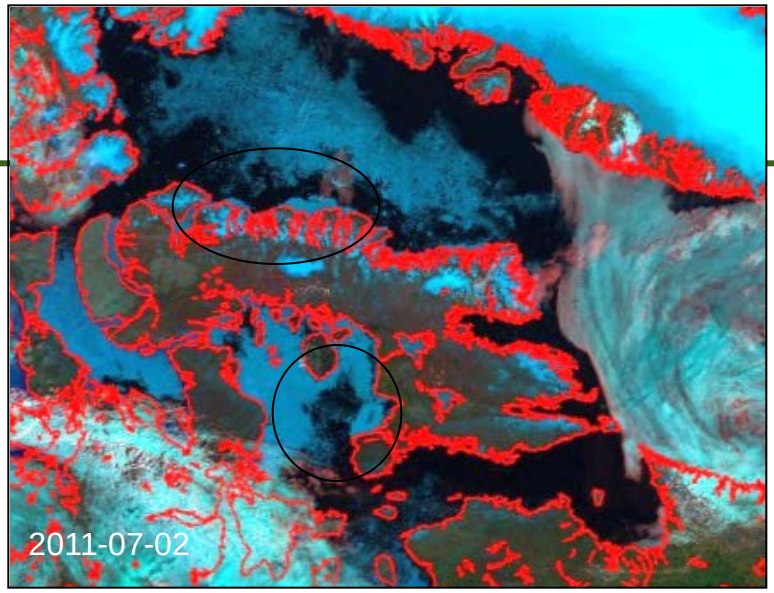
Analysis increment



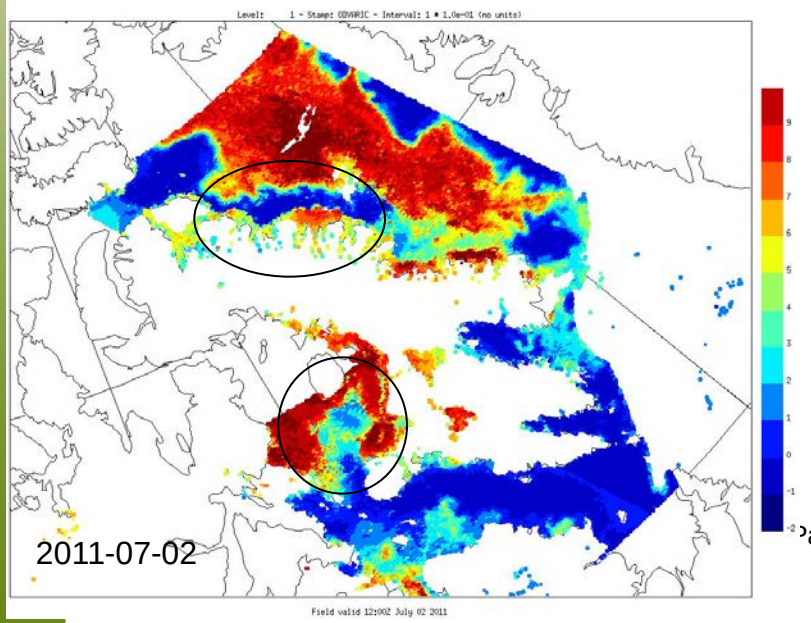
Background IC



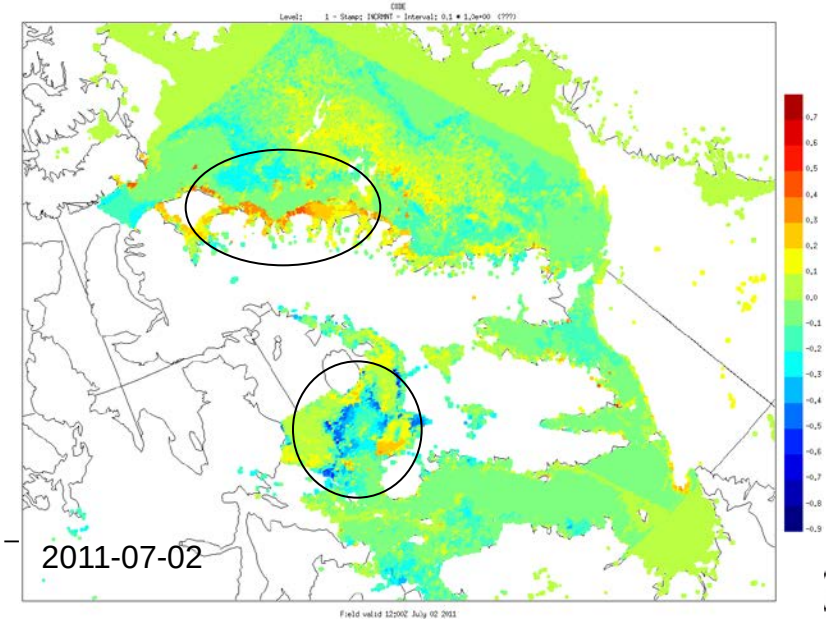
AVHRR Imagery



0D-Var IC Retrieval



Analysis increment

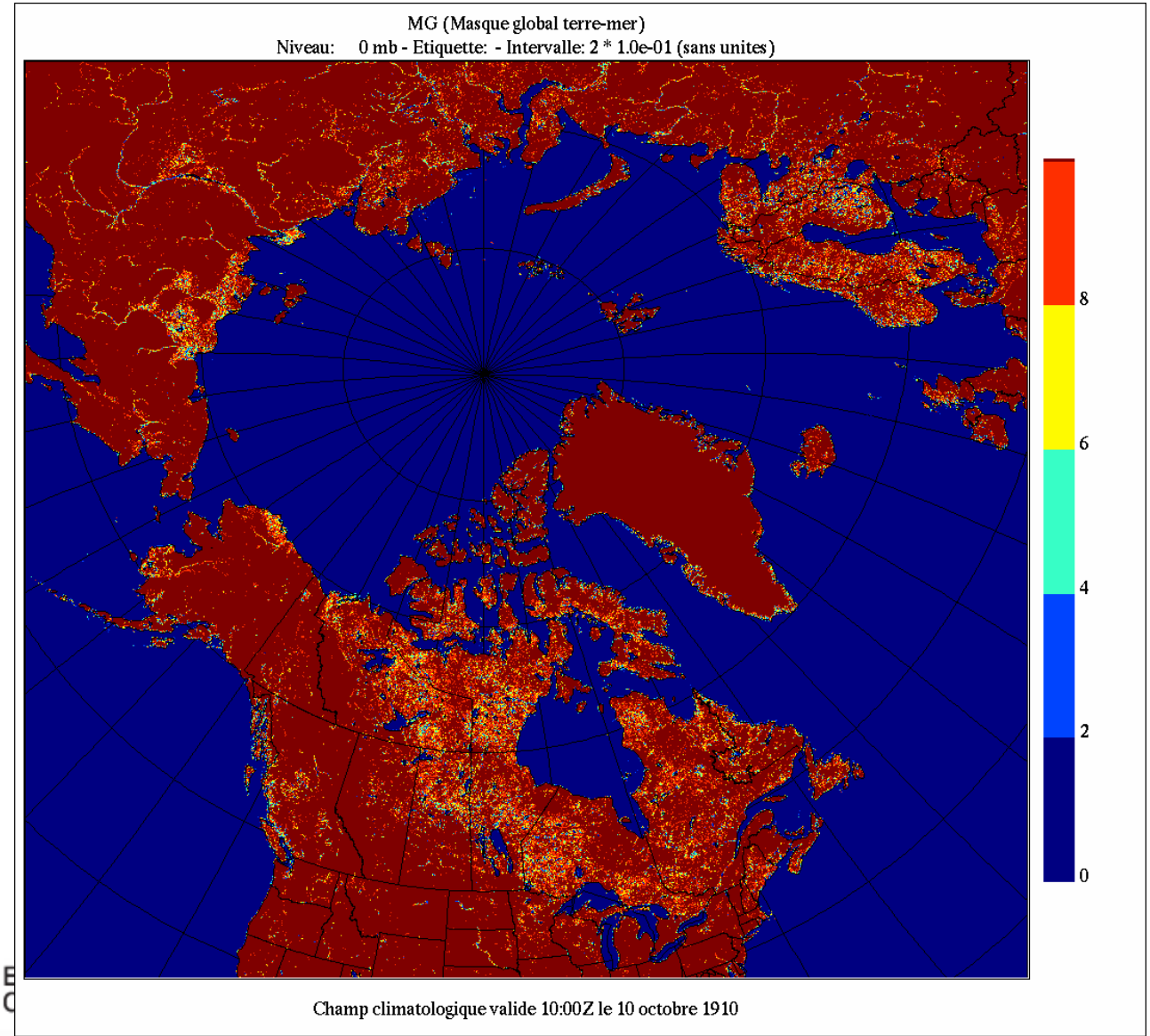


Future Outlook

- Work towards improving Regional Ice Prediction System and Global Ice Analysis System:
  - assimilate AMSR-2 retrieved ice concentration when available
  - assimilate higher-resolution remote sensing data (AVHRR, VIIRS and eventually SAR)
  - assimilate data related to ice thickness: starting with passive microwave (AMSR-2 and SMOS) and nighttime thermal infrared (AVHRR and VIIRS)
- Use of numerical sea-ice model within data-assimilation cycle on an expanded domain covering entire Arctic ocean
- Expand 3D-Var to ensemble of 4D-EnVar assimilation cycles to capture complex spatial and multi-variate background error covariances: conc., thickness, SST, etc.

Expanded domain for cycling with model

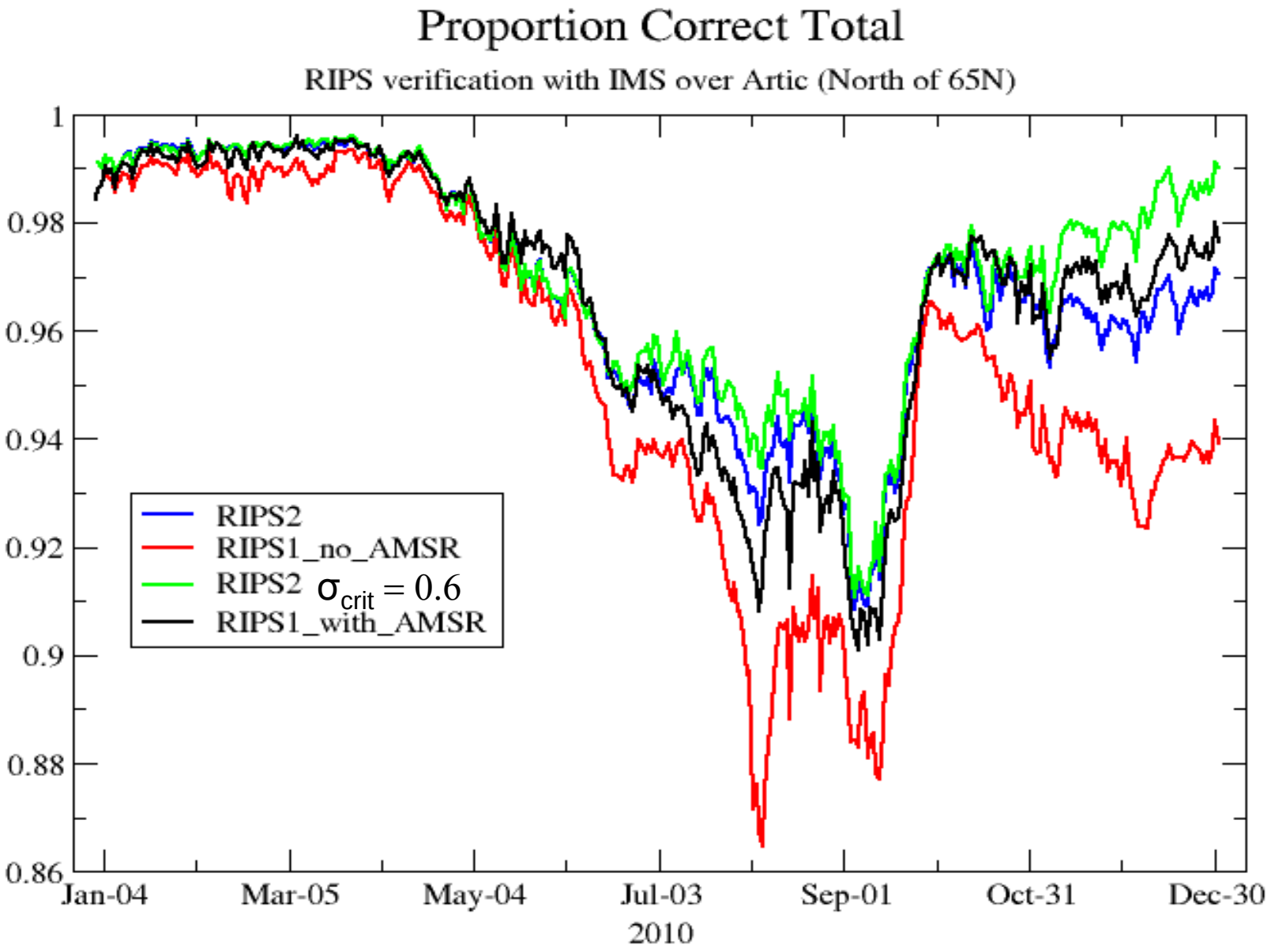
Incremental approach with analysis increment on 5km rotated lat-lon grid (shown), CICE4 on subsection of ORCA12 tri-polar grid



Canada

Extra slides follow

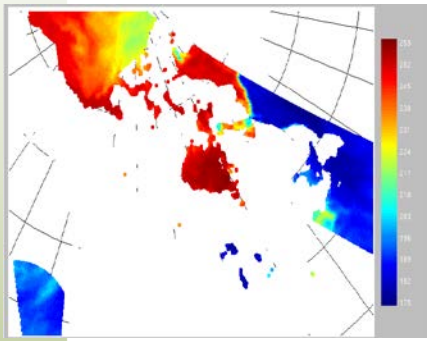
Impact of the loss of AMSR-E



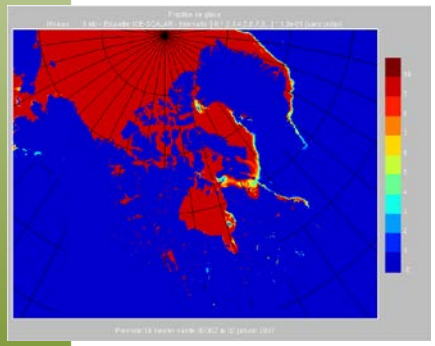
Automatic Calculation of CVs: Motivation

- Onerous to determine a set of CVs manually
  - No guarantee of a standard approach being used
  - Facilitates addition of new instruments, new versions of instruments
- The appropriate set of CVs may vary in time and space
  - Region
  - Season
  - Instrument drift
  - Solar position
  - Atmospheric conditions
  - Direction instrument is looking
- Automatic CV calculation also supplies CV distribution
  - Histogram or simply variance
  - Useful for researching methods to retrieve IC from or assimilate SAR & AVHRR observations

Generating Characteristic Values



Observations



Background

Filter: Land, QC, IC Gradient, etc.

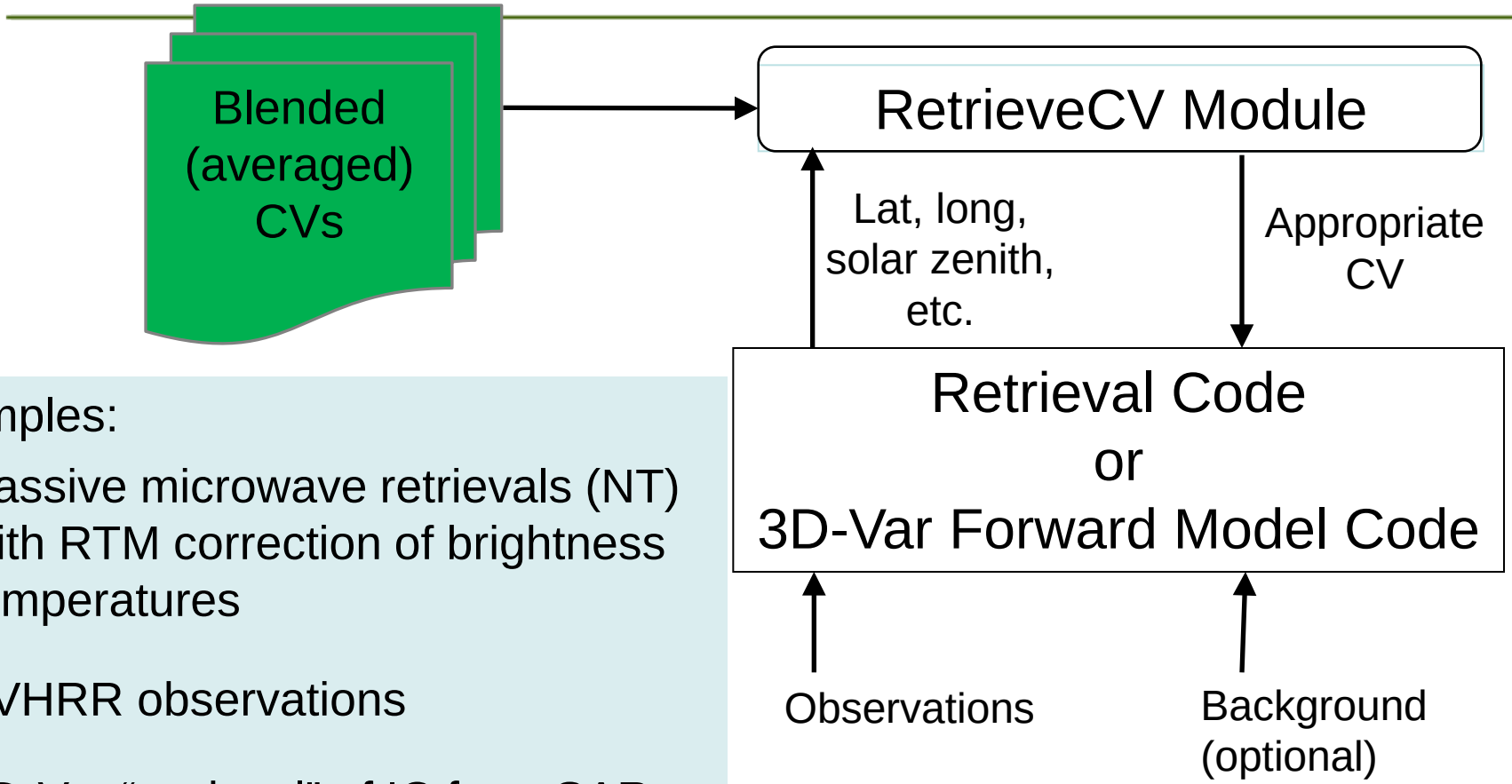
Pick 100% FYI, MYI, and OW Points

Classify by region, incidence angle, etc.

"Average" over all points

Table of CVs

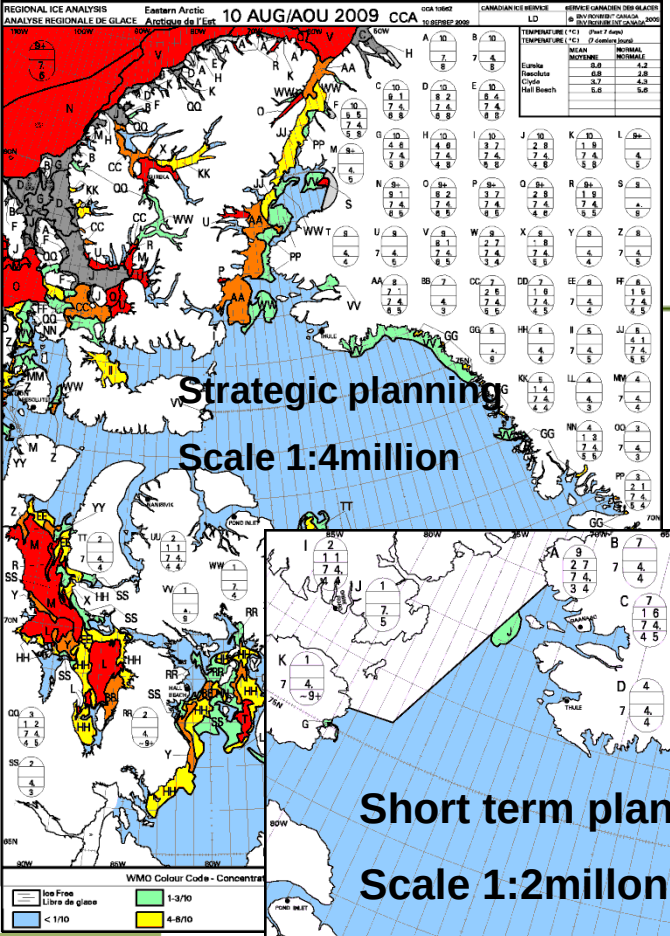
Use of Characteristic Values



Examples:

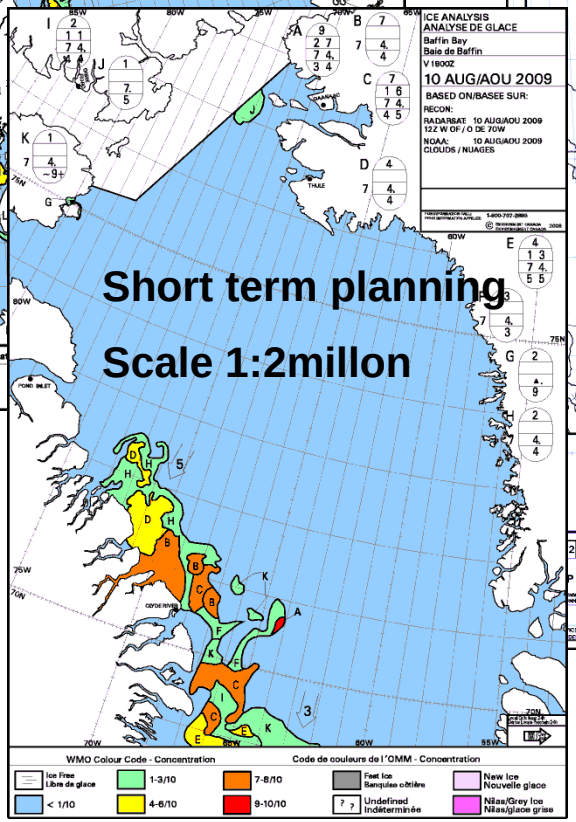
- Passive microwave retrievals (NT) with RTM correction of brightness temperatures
- AVHRR observations
- 0D-Var “retrieval” of IC from SAR image features

Seasonal Outlook for the North American Arctic Waters



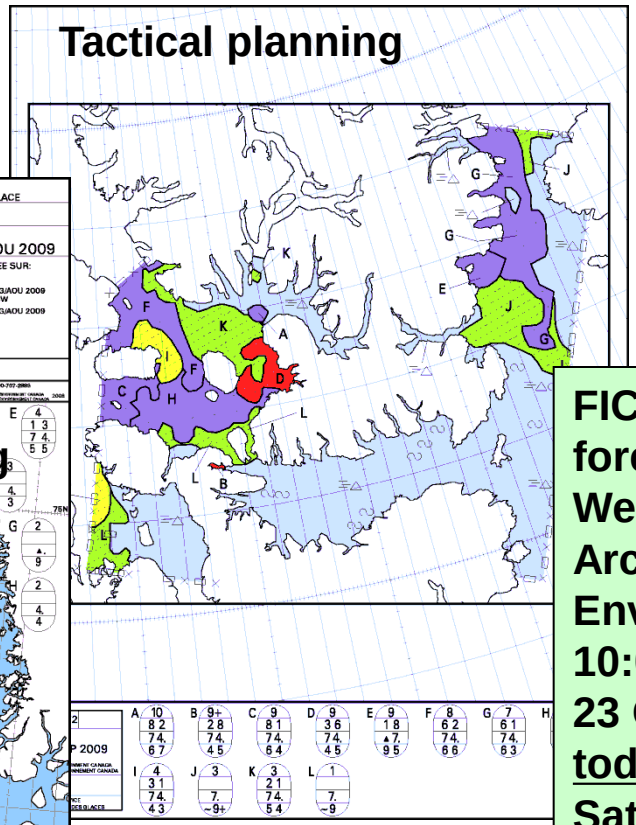
Strategic planning

Scale 1:4million



Short term planning

Scale 1:2millon



Tactical planning

FECN16 CWIS 041800 THIRTY DAY ICE FORECASTS FOR THE EASTERN AND NORTHERN ARCTIC FOR NOVEMBER ISSUED BY ENVIRONMENT CANADA ON 04 NOVEMBER 2009. THIS IS THE LAST 30 DAY ICE FORECAST FOR THE SEASON.

FICN14 CWIS 231400 Ice forecasts for the Western and Central Arctic issued by Environment Canada at 10:00 a.m. EDT Friday 23 October 2009 for today tonight and Saturday. The next scheduled forecasts will be issued at 10:00 a.m. Saturday.