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Canada

# Sea ice data assimilation for NWP and operational ice services at Environment and Climate Change Canada

**ECMWF Workshop on observations and analysis of sea-surface temperature and sea ice for NWP and Climate Applications**

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# Contents

- Motivation for sea ice data assimilation at ECCC
- Data assimilation methodology
- Recent addition of new observations
- Current research projects

# The need for coupled Atmosphere-Ice-Ocean prediction

Davidson et al., SCOR, 2013

## ECCC requires ice-ocean forecasts and information services for:

- Sea ice prediction
  - Improved automated analyses and forecasts for the Canadian Ice Service – to complement manual ice chart analyses
  - Identify/predict high pressure areas dangerous for ships
- Improved weather and wave prediction
  - Timescales from days to seasons
  - Sea ice, tropical cyclones, surface interactions
- Emergency response
  - Comprehensive trajectory modelling capacity
  - E.g. dispersion of pollutants

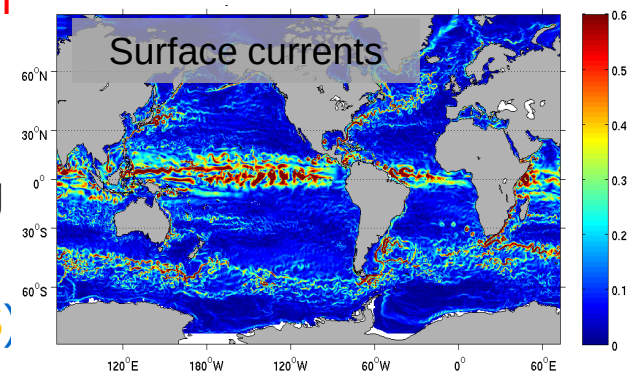
# Ice-ocean modelling with
## Applications and domains

NEMO + CICE

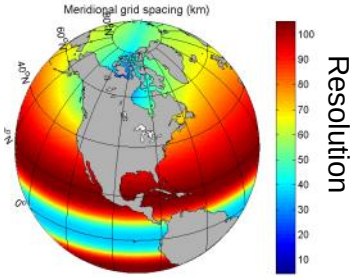
**Operational**
**Experimental**
**In development**

- Global 1° resolution (CanSIPS-GI
  - Seasonal forecasting
- Global 1/4° resolution (GIOPS)
  - Medium-monthly forecasting
  - Fully-coupled for NWP
- N. Atlantic & Arctic 1/12° (RIOPS)
  - Short-to-medium range forecasting
  - Coupled HRDPS-Polar for YOPP
- Great Lakes 2km and Gulf of St. Lawrence 5km
  - Short-term forecasting

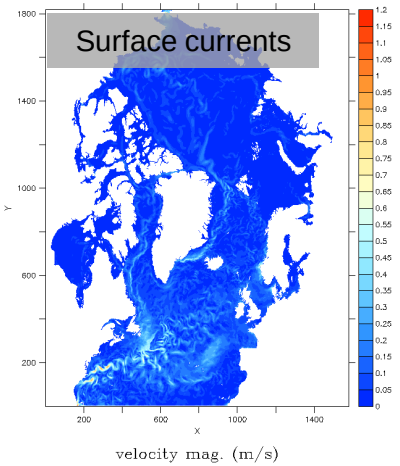
1/4° Global

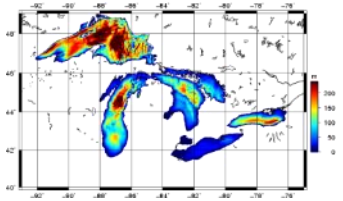



1° Global



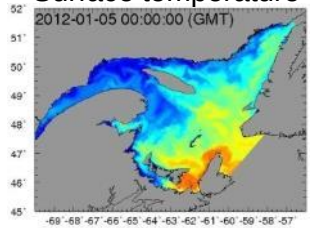

1/12° N. Atlantic and Arctic



Bathymetry

Surface temperature

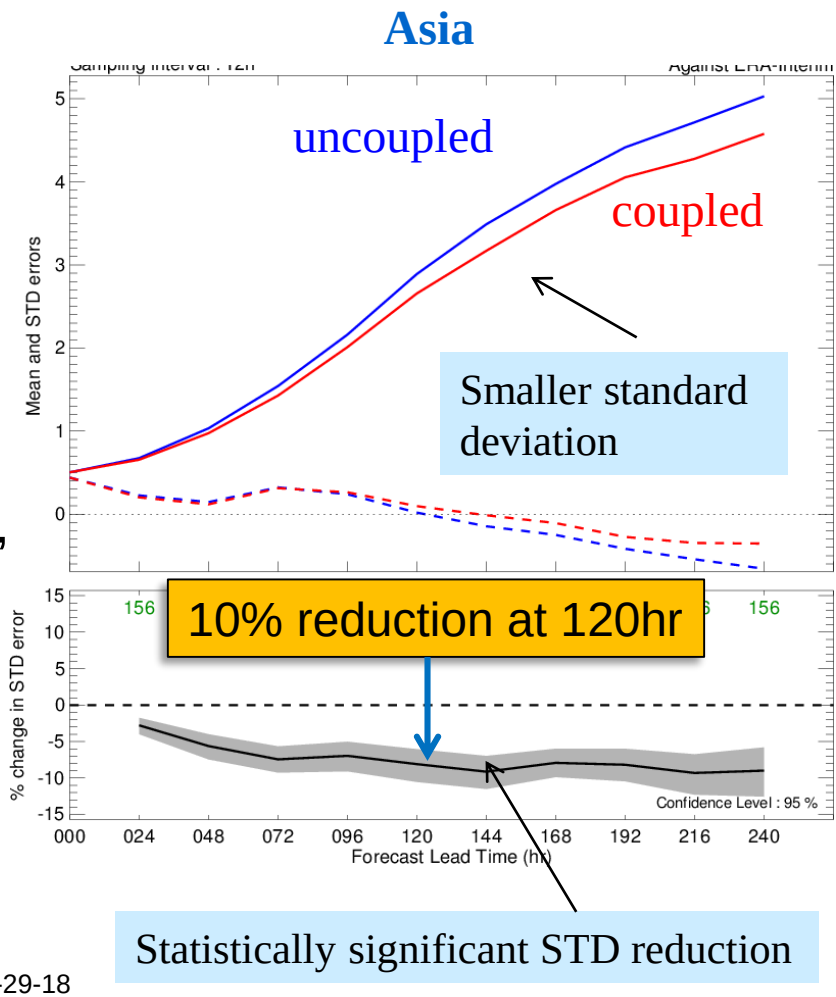


# Coupled Global Forecast

## Recently became operational

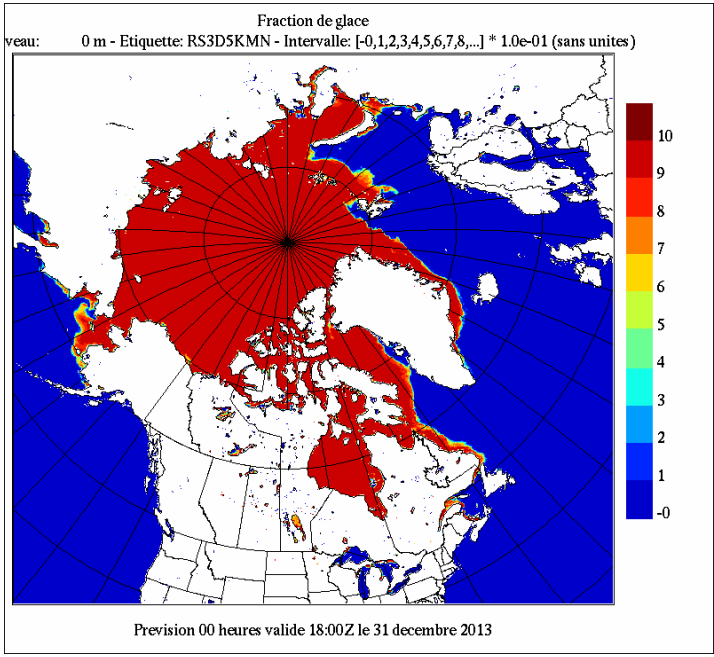
G Smith, J-M Belanger, F Roy, …

- Coupled model:
  - Atm: GEM 25km
  - Ocean: NEMO-ORCA025 (1/4°)
  - Ice: CICE4
  - Uncoupled DA
- Evaluation of summer trials
  - 10 day forecasts 15 Jun–31 Aug, 2014
  - Significant forecast improvements over most areas
  - Shown: 850hPa geopotential height versus ERA-Interim



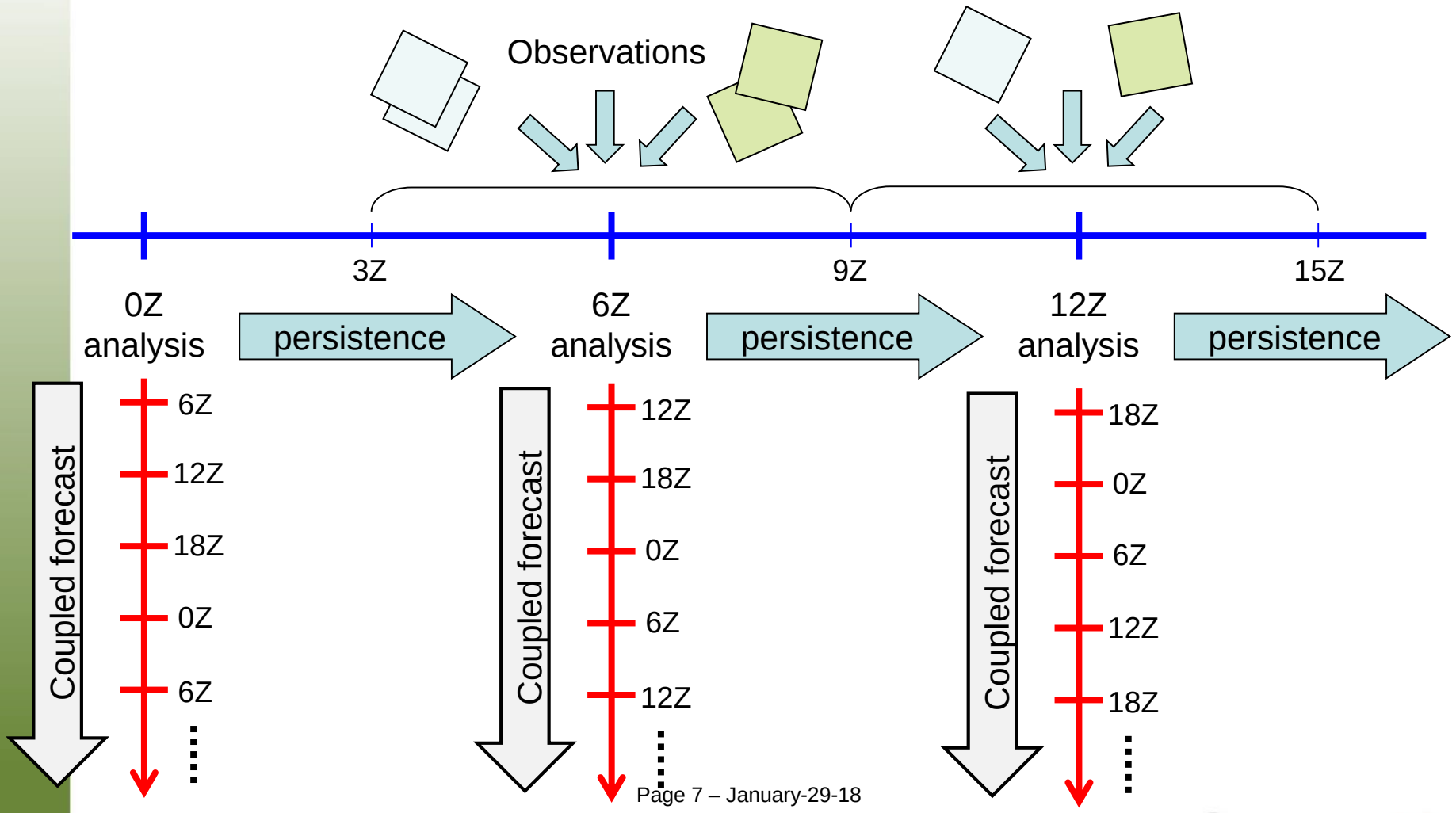
# Regional / global ice concentration analyses (Buehner et al. 2016)

- Regional: ~ 5.0 km resolution; Global: ~10 km resolution
- 4 analyses per day
- background = analysis 6 hours earlier
- total ice concentration (3DVar) and analysis-error stddev estimate (KF)
- observations assimilated:
  - CIS image analyses and daily and regional ice charts, lake bulletins
  - SSM/I, SSM/IS, AMSR2
  - ASCAT
  - AVHRR (ice/water)
- ice is removed where SST > 4°C
- ice field is “corrected” where analysis-error stddev is high




1768 × 1618 grid points

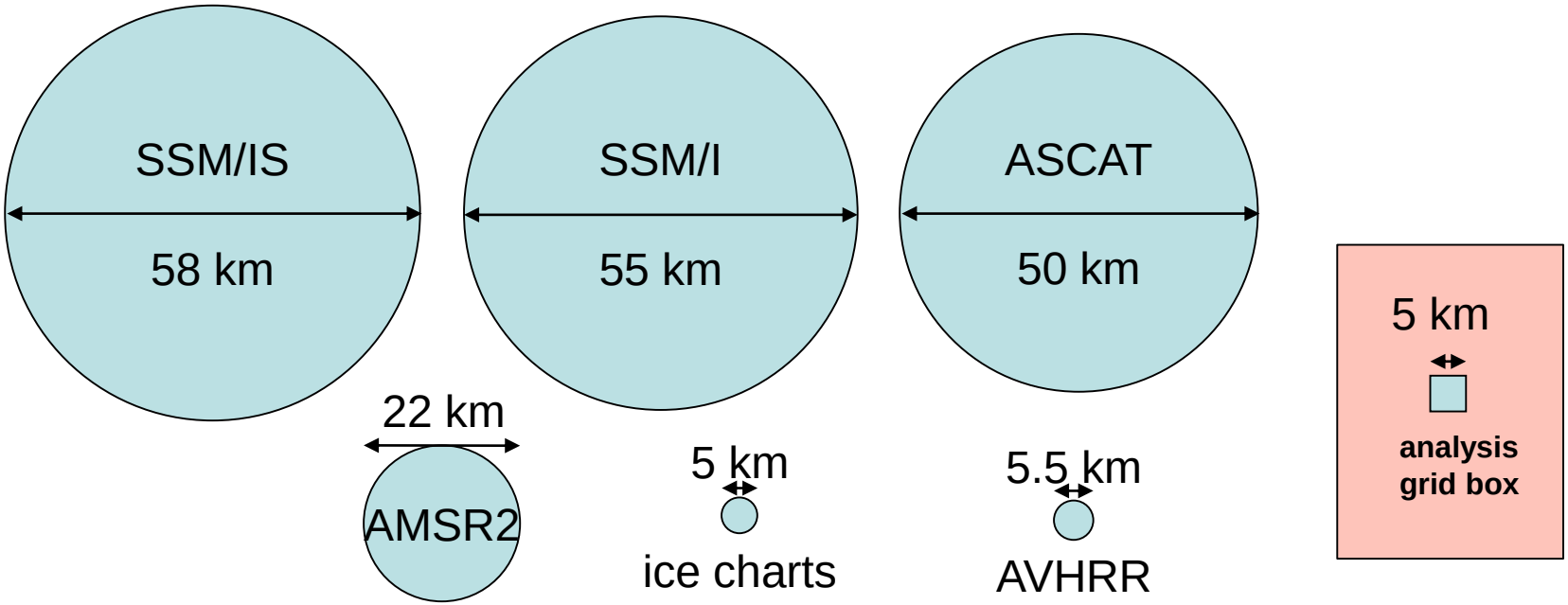
# Sea ice data assimilation cycle



# Passive microwave data
## SSMI, SSMIS, AMSR2

- Assimilation:
  - Total ice concentration estimated from NASA Team 2 (NT2) retrieval algorithm
  - Use "footprint" observation operator that aggregates gridded ice concentration over footprint of instrument
- Quality control - reject data when:
  - Surface Air Temperature (SAT) > 0°C (melt ponds)
  - Retrieved ice concentration is not zero AND
    - Sea Surface Temperature (SST) is above 4°C OR
    - Historical Frequency of Occurrence of ice is 0 OR
    - Wind speed > 25 knots (Wind filter)
- Background check:
  - Reject entire observation swath with bad/corrupted data (based on average RMS difference with background state)

# Observation footprints

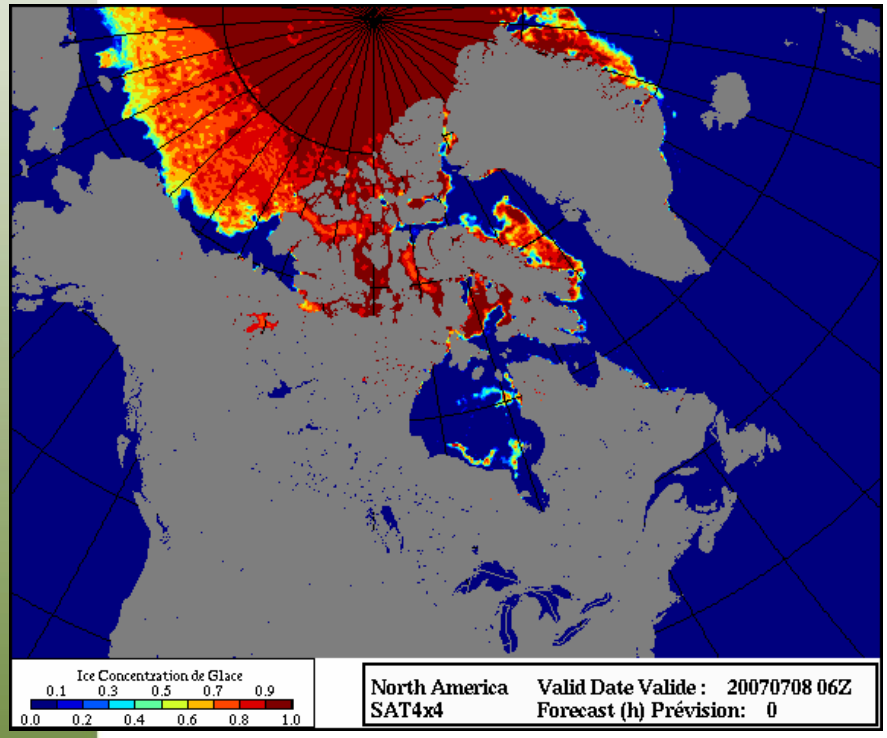



- Footprint observation operator important for combining information from sensors with such different resolution
- Observation rejected if footprint touches land, removing most low resolution obs near coast and in narrow channels

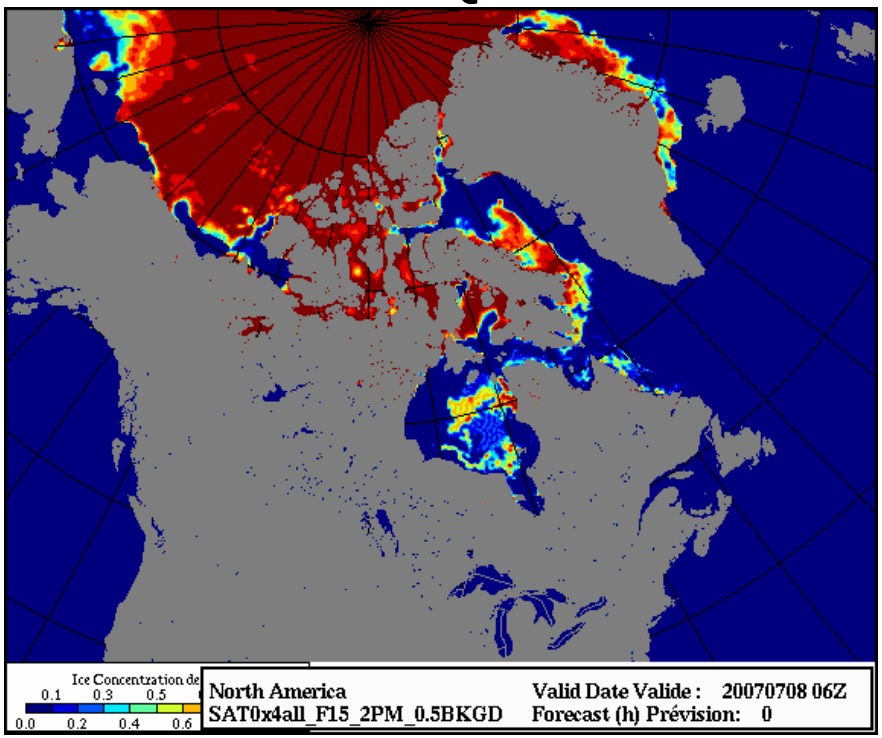
# Impact of observation quality control

## Example: July 8, 2007

**Without QC**

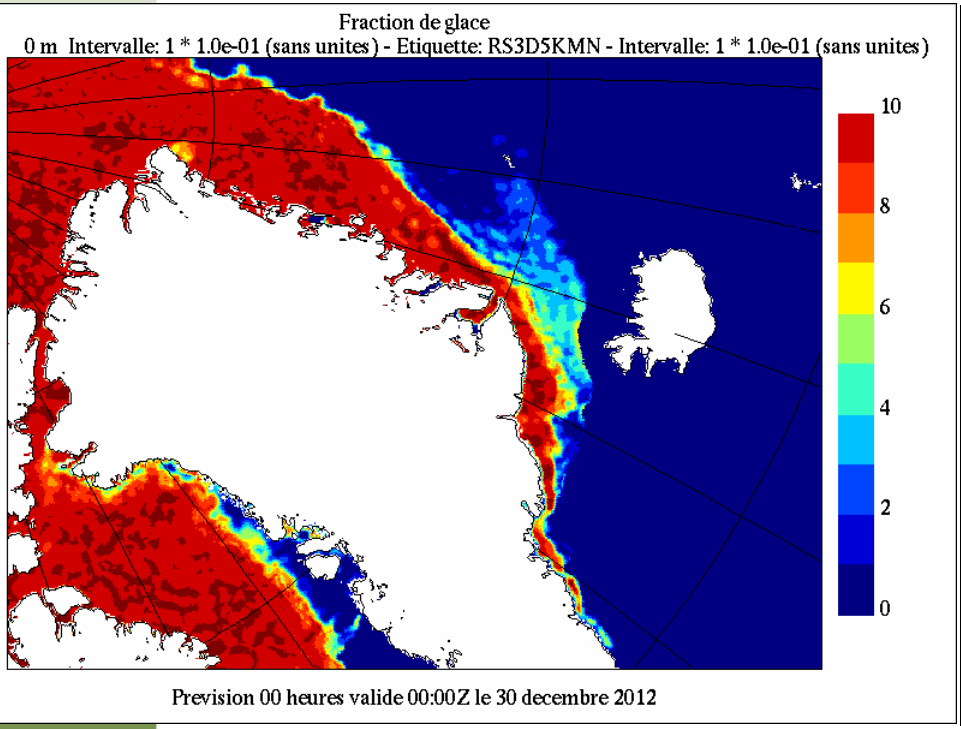



**With QC**

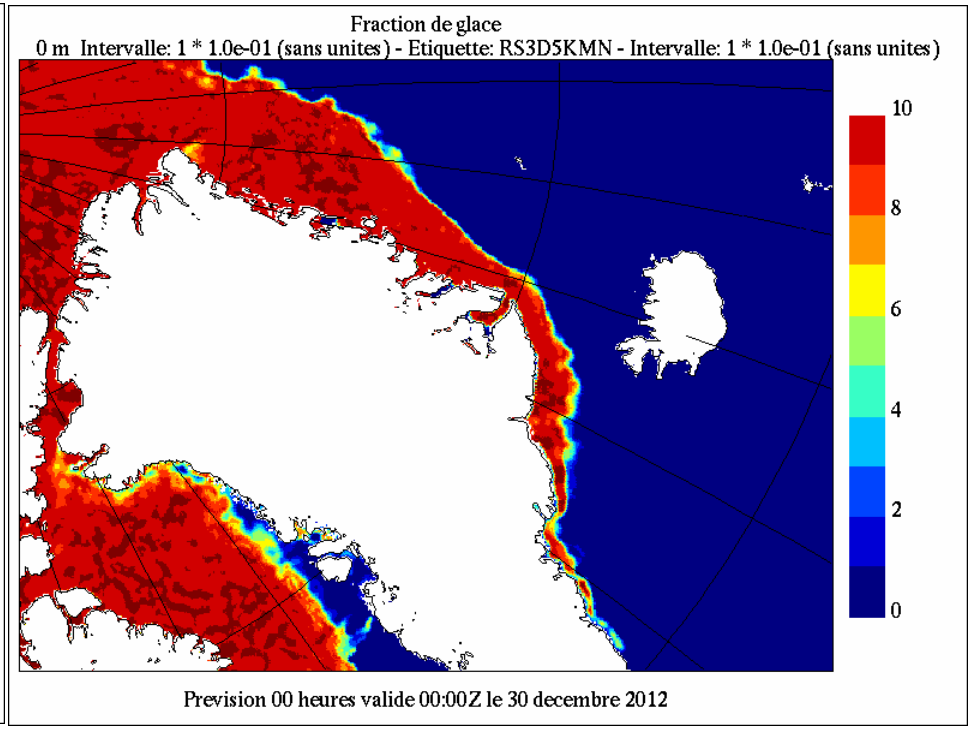


# Effect of wind filter

## Without wind filter

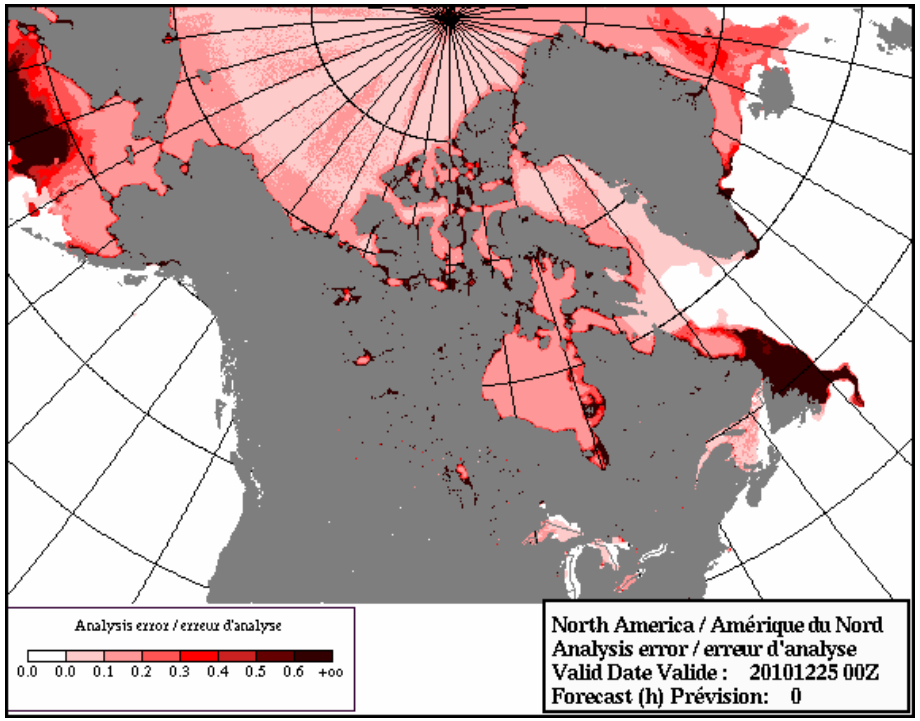


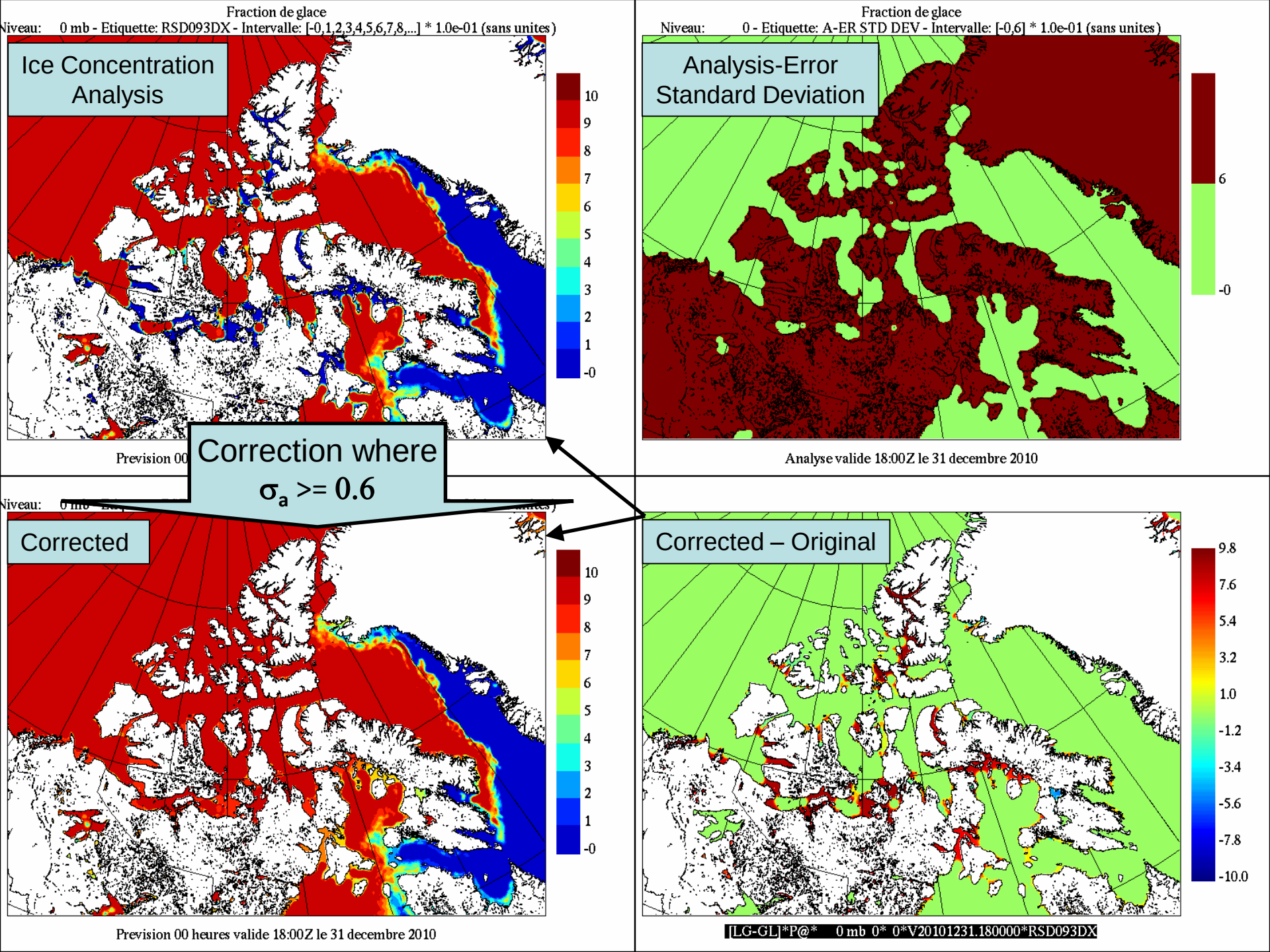

## With wind filter



# Analysis error stddev

- Due to QC procedures, may not assimilate data in a particular region for an extended period
- Therefore, also estimate analysis error stddev with simplified KF and simple error growth model
- Where ice is removed due to SST > 4°C, stddev set to zero
- Used when initializing forecasts: only replace model value at grid points with low uncertainty
- Used for forecast verification: only consider grid points with low uncertainty

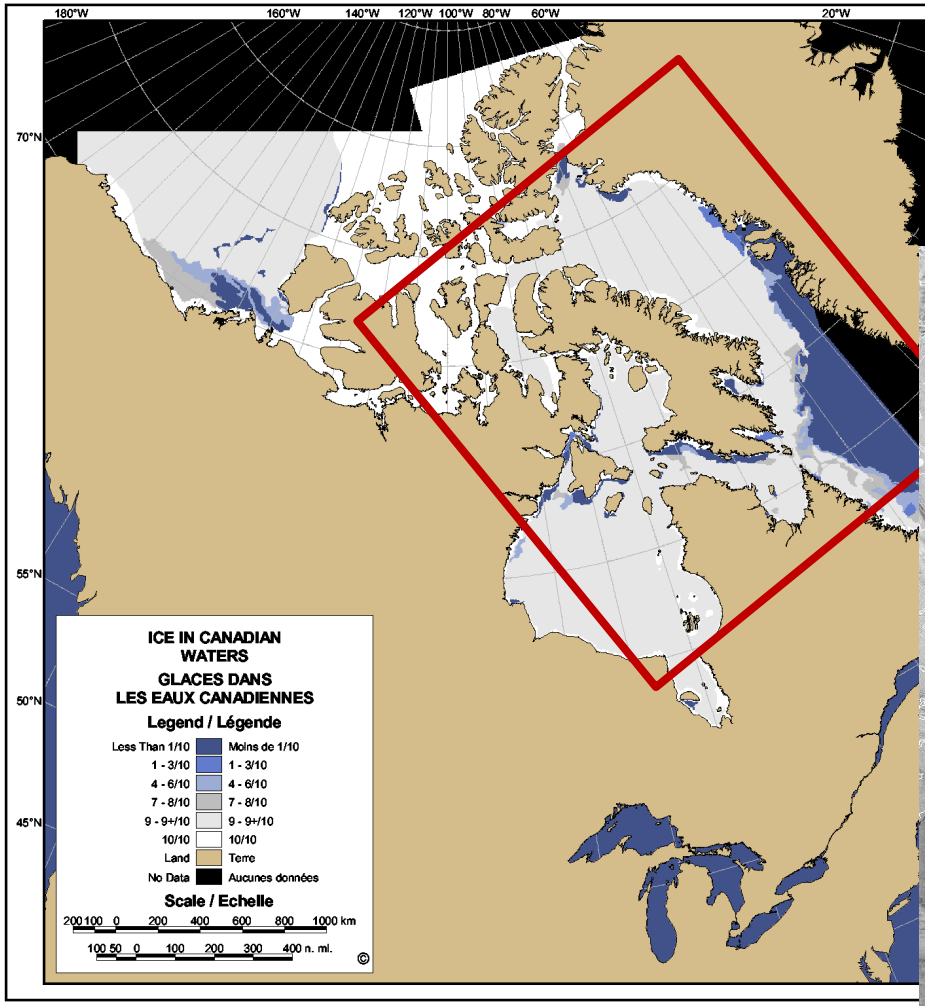


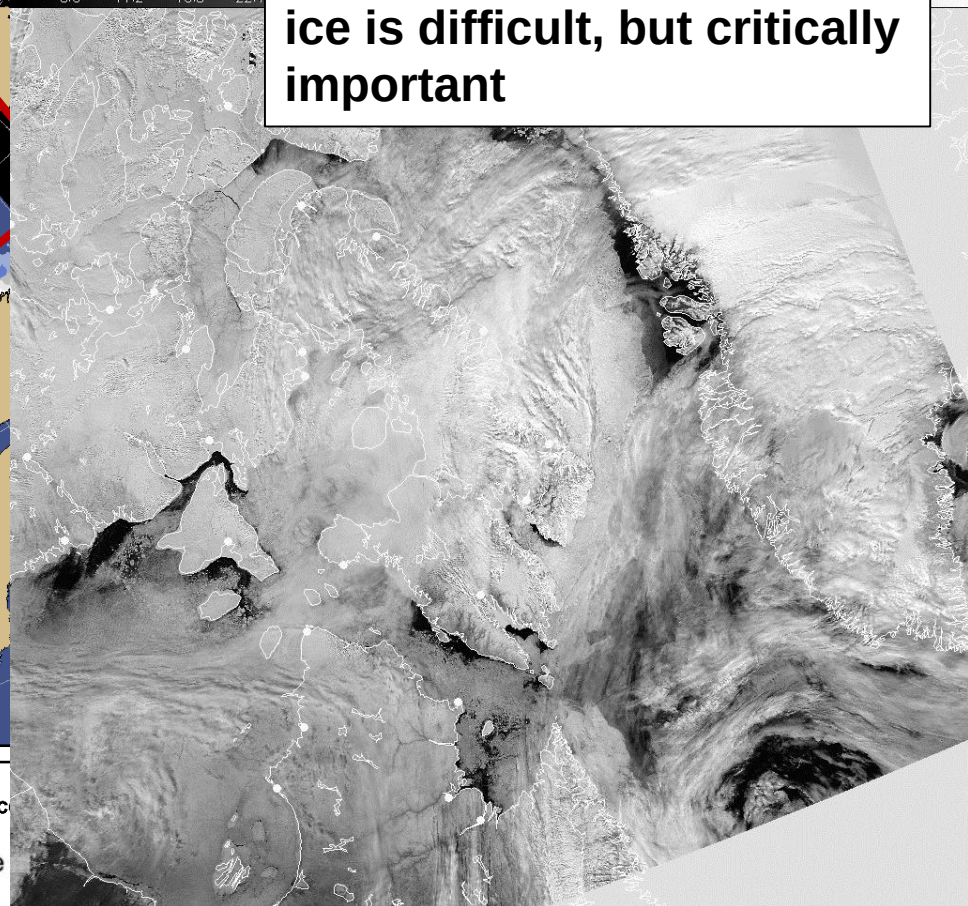

Fraction de glace
Niveau: 0 mb - Etiquette: RSD093DX - Intervalle: [-0,1,2,3,4,5,6,7,8,...] * 1.0e-01 (sans unites)
Ice Concentration Analysis
10
9
8
7
6
5
4
3
2
1
-0
Prevision 00
Fraction de glace
Niveau: 0 - Etiquette: A-ER STD DEV - Intervalle: [-0,6] * 1.0e-01 (sans unites)
Analysis-Error Standard Deviation
6
-0
Analyse valide 18:00Z le 31 decembre 2010
Correction where
$\sigma_a$ >= 0.6
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

# Ice / water classification from AVHRR (visible and infrared)

**We developed a simple classification procedure (ice / water / ambiguous / cloud)**

**Distinguishing cloud from ice is difficult, but critically important**



SOURCE: CIS DAILY AND REGIONAL ICE CHARTS / SOURCE: CARTES QUOTIDIENNES ET RÉGIONALES DES GLACES DU SC

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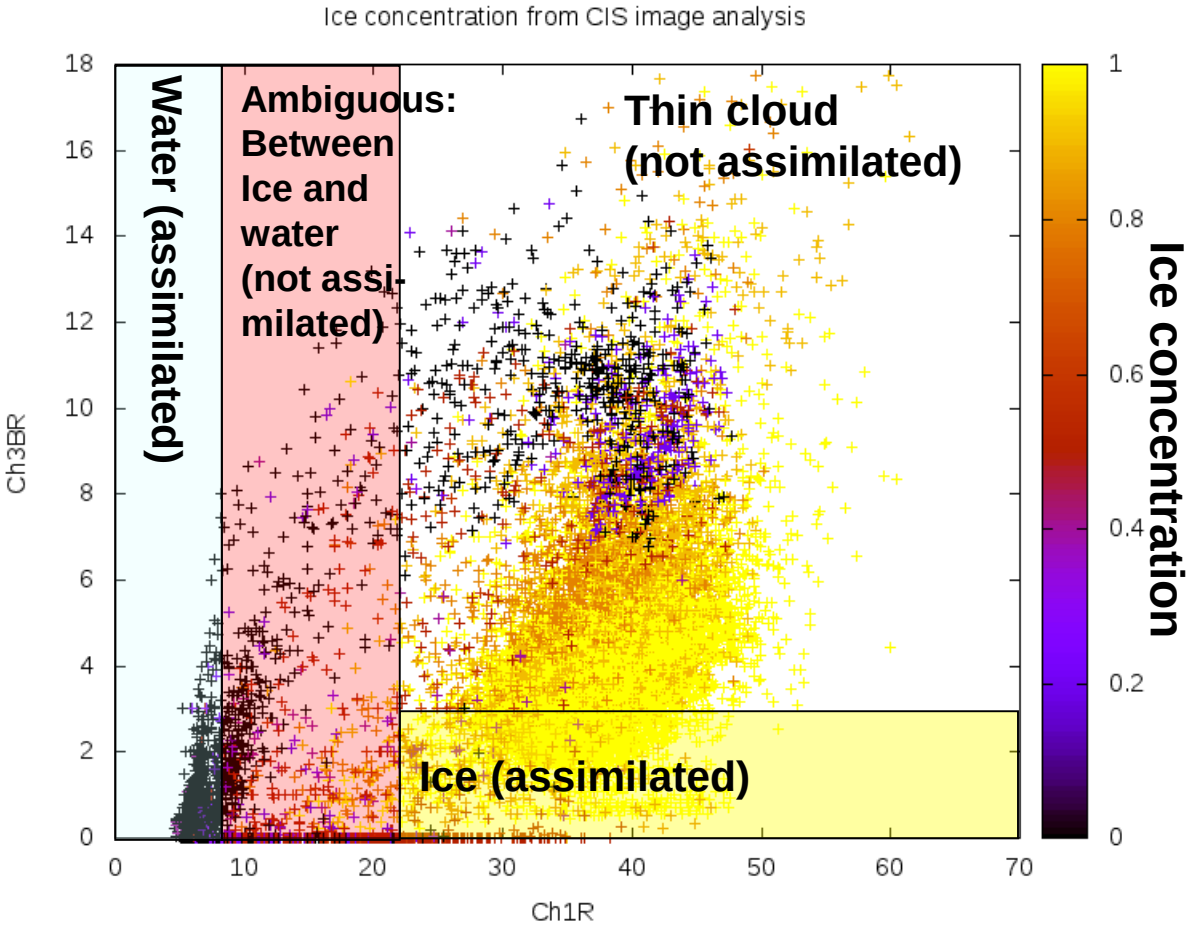
# Example: 2011-08-05 16Z Western Arctic

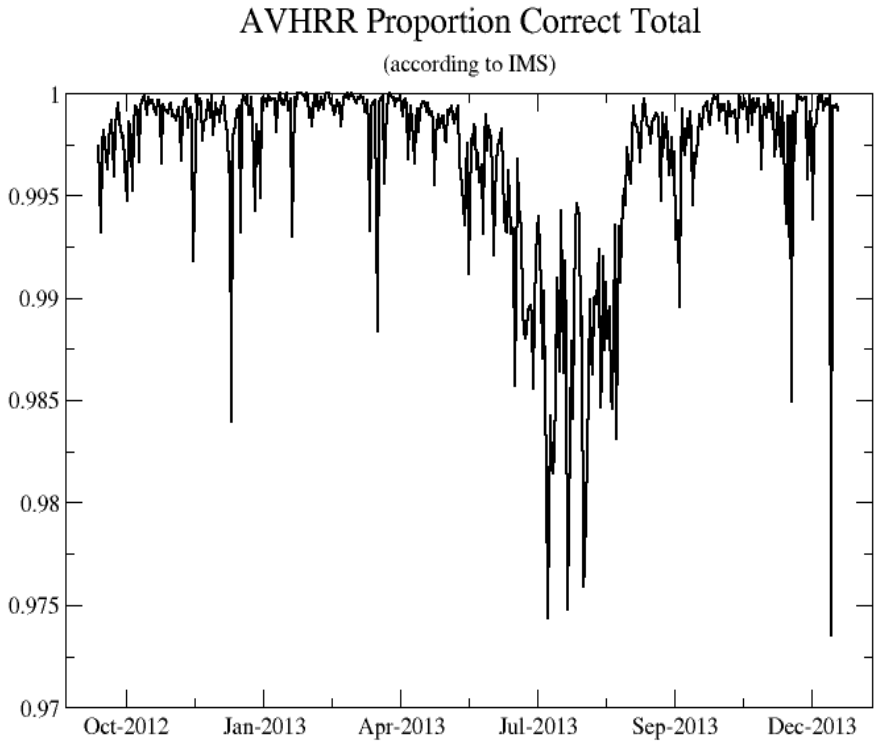
(after thick cloud removed)

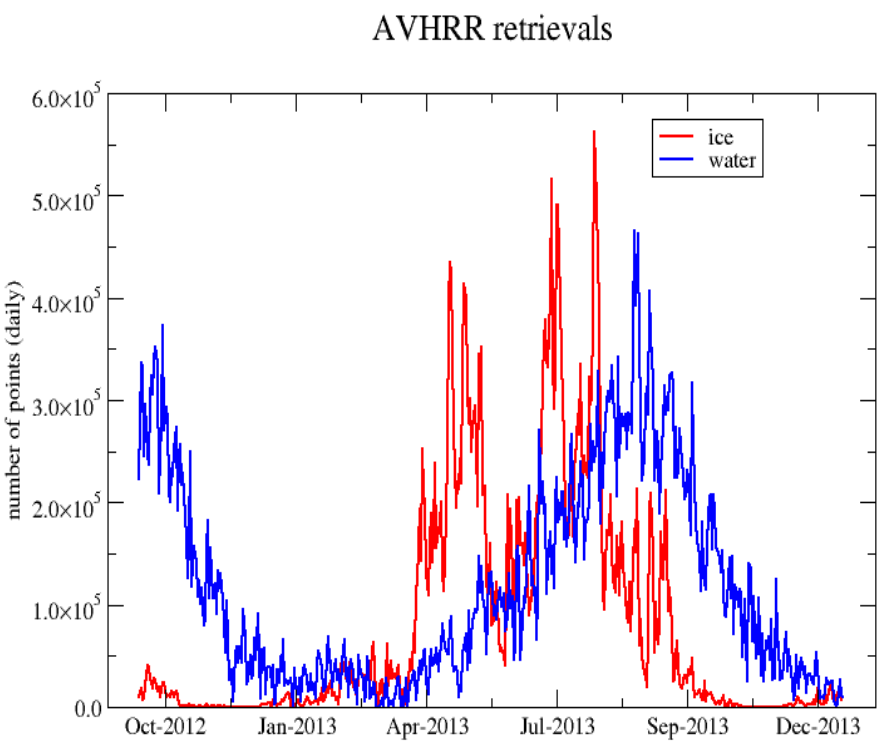



## Assimilation strategy:

- Water observations assimilated as 0%, Ice assimilated as:
  - 85% when background concentration < 85%
  - otherwise, rejected (background already consistent with obs)

# Comparison of Ice / Water from AVHRR and IMS (NOAA manual ice/water product)

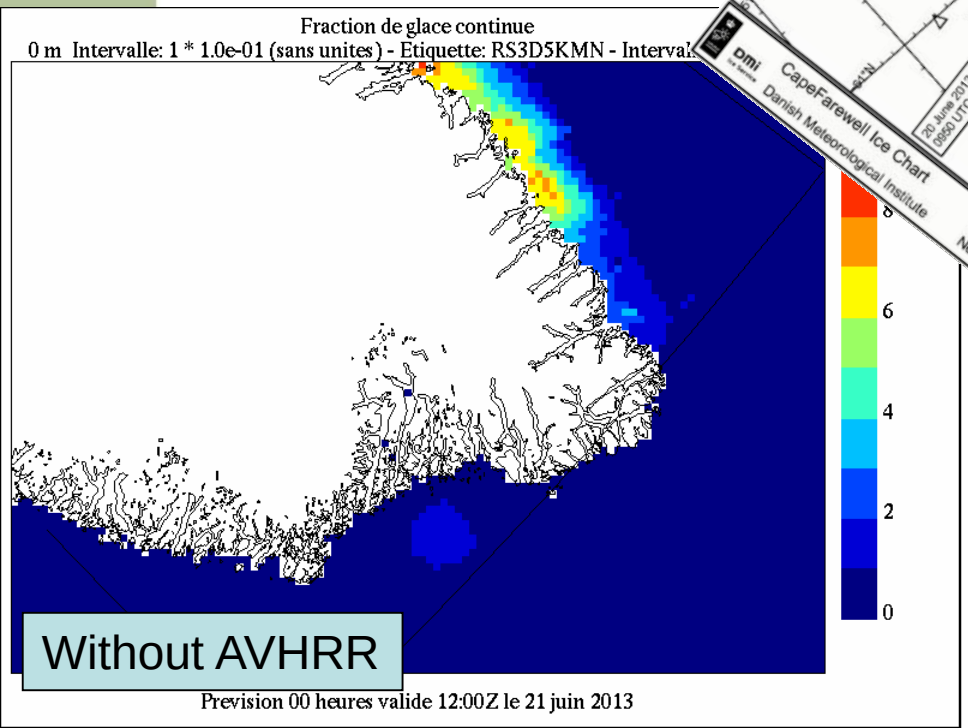


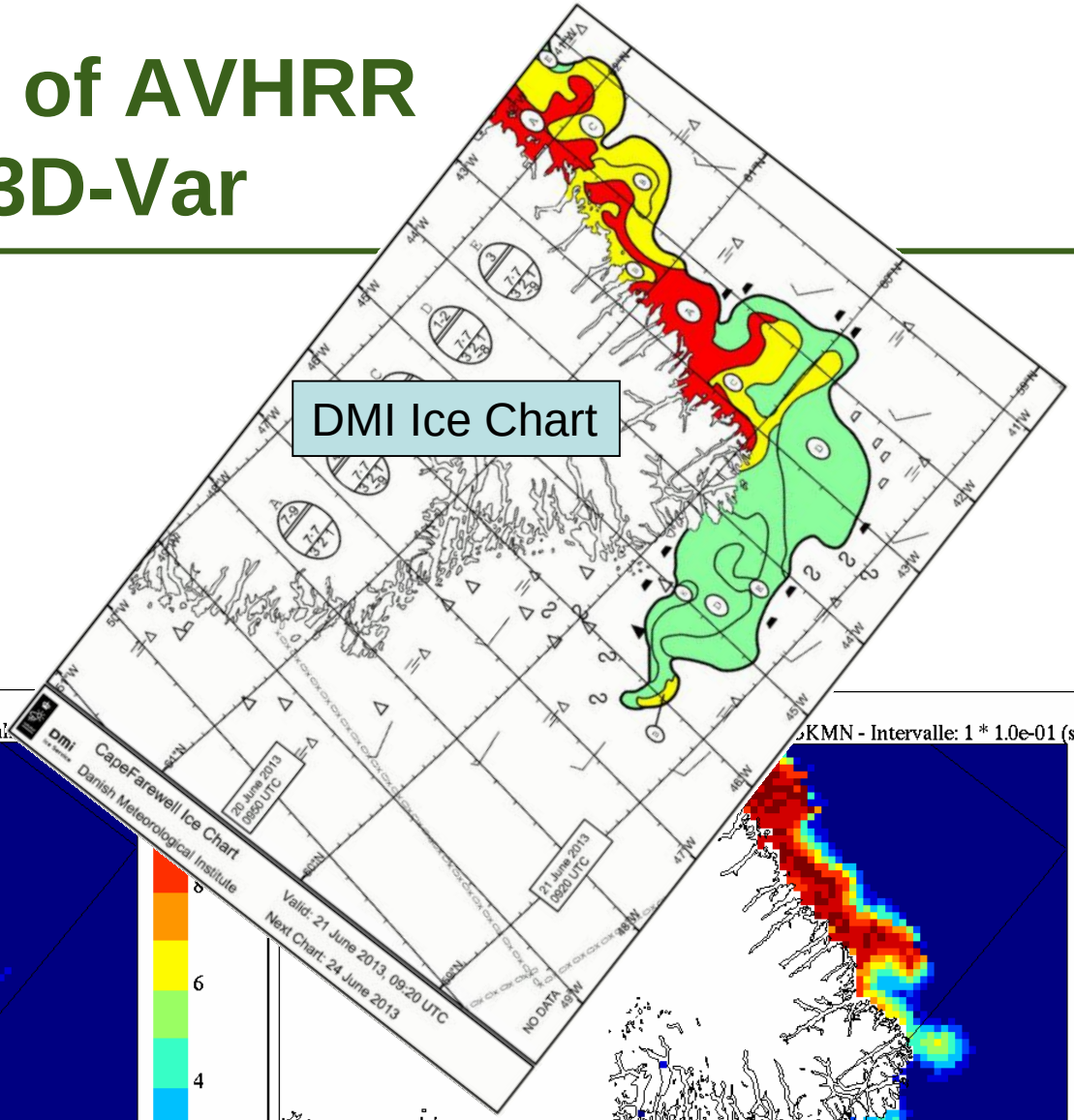




- Few observations in winter (insufficient solar illumination)
- Generally high accuracy (> 99%), but lower in summer

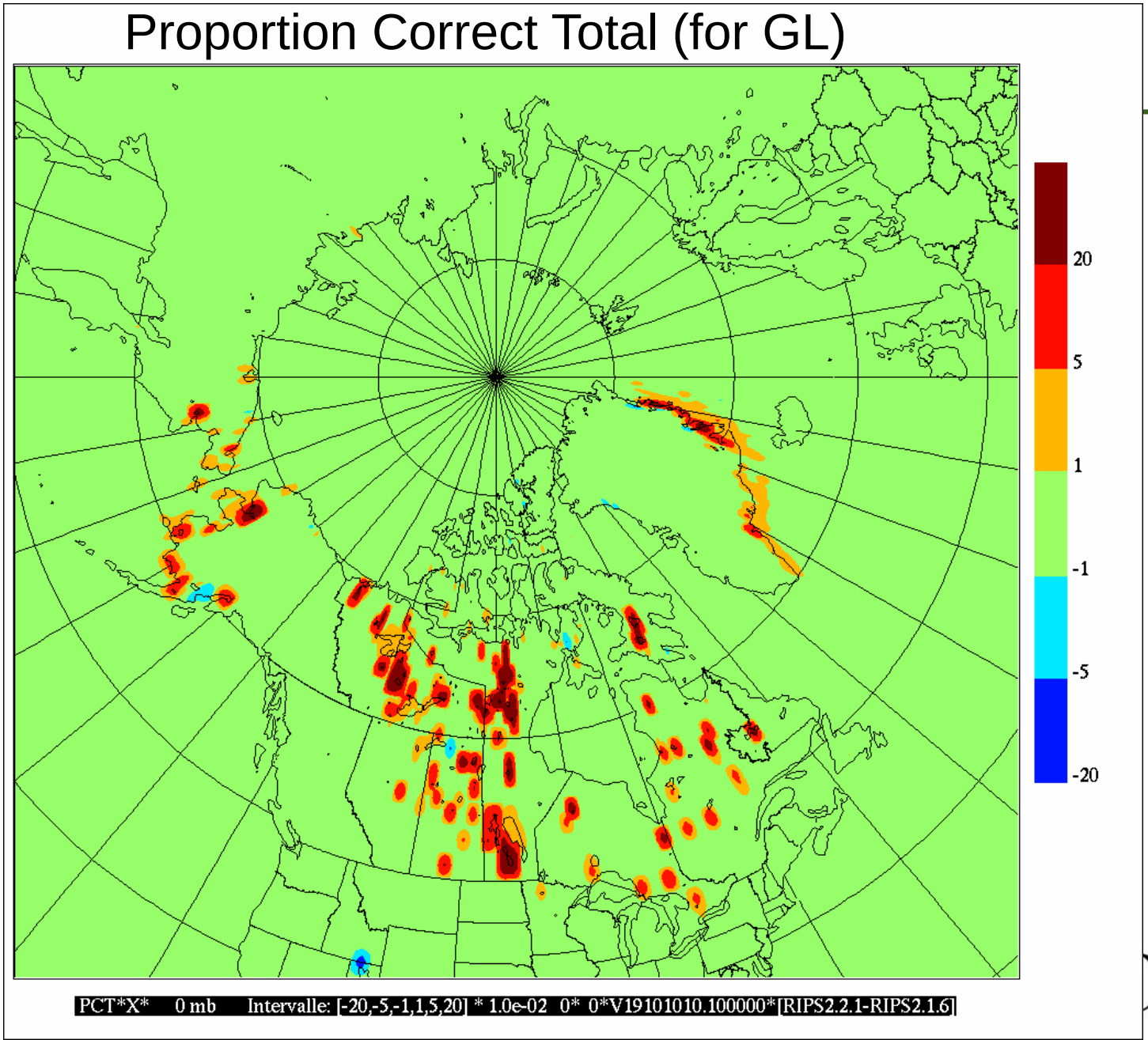
# Assimilation of AVHRR ice/water in 3D-Var

- Cape Farewell
- 21 June 2013



# Impact of AVHRR (vs IMS) (2012/09/01 – 2013/12/31)



# Ice / water retrieval from RADARSAT-2

## Komarov and Buehner, TGRS, 2017

- Assimilation of SAR data could improve ice analyses, particularly in narrow channels – very high resolution, not limited by cloud or solar illumination
- Challenge: Backscatter signal from ice and open water often overlap
- Most conventional automated methods for ice/water classification do not provide sufficiently high level of confidence required for data assimilation

**Goal:** Develop a technique for automated classification of RADARSAT-2 data (**ice / water / ambiguous**) based on estimation of probability of ice/water

# Key variables related to presence of ice

After some exploratory work, chose the following variables:

1. Difference between wind speed from SAR (HH-HV) [Komarov et al., TGRS, 2014] and from NWP
2. HH-HV spatial correlation
3. Spatial standard deviation of SAR-derived wind speed

Each is computed over a 2km x 2km window (41x41 50m pixels)

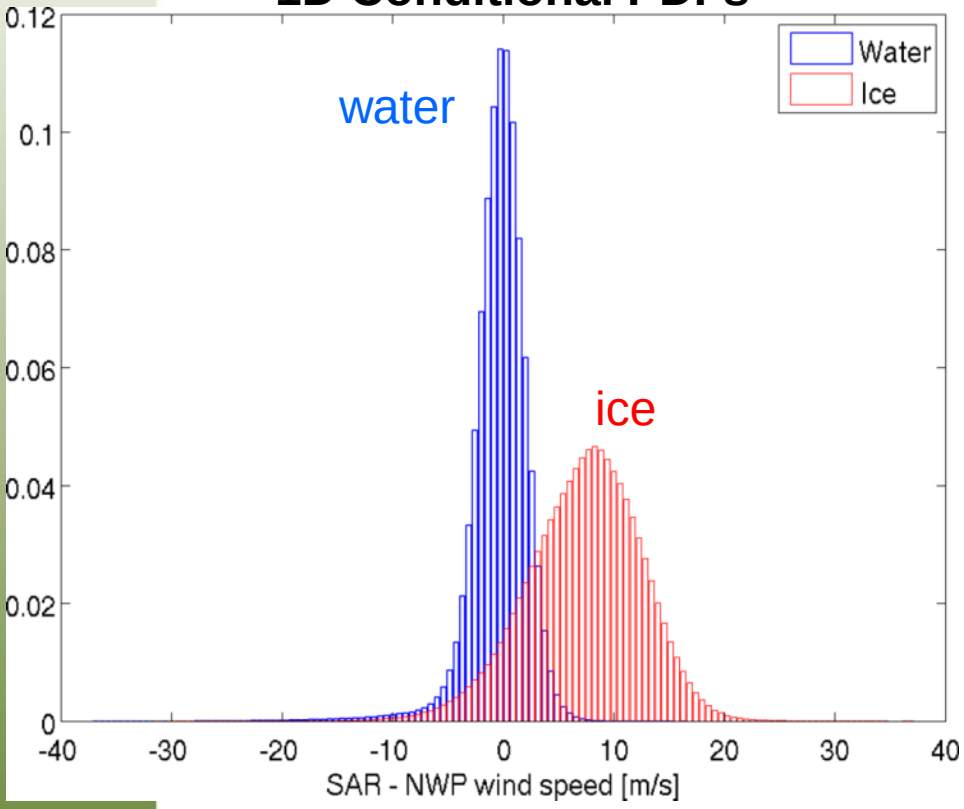
## Benefits:

- Independent of instrument parameters (incidence angle, noise floor)
- Indirect use of HH and HV backscatter signals
- Good potential to transfer to other SAR instruments (e.g. RCM: RADARSAT Constellation Mission)

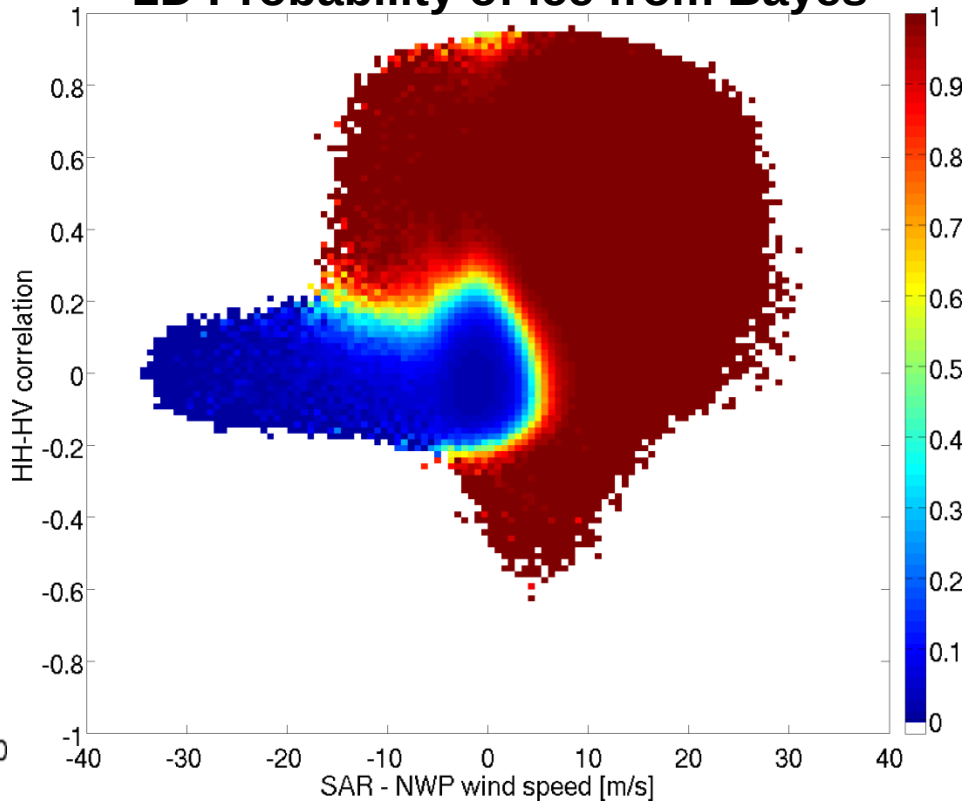
# Key variables related to presence of ice

## Probability distributions based on > 10,000 images

### 1D Conditional PDFs



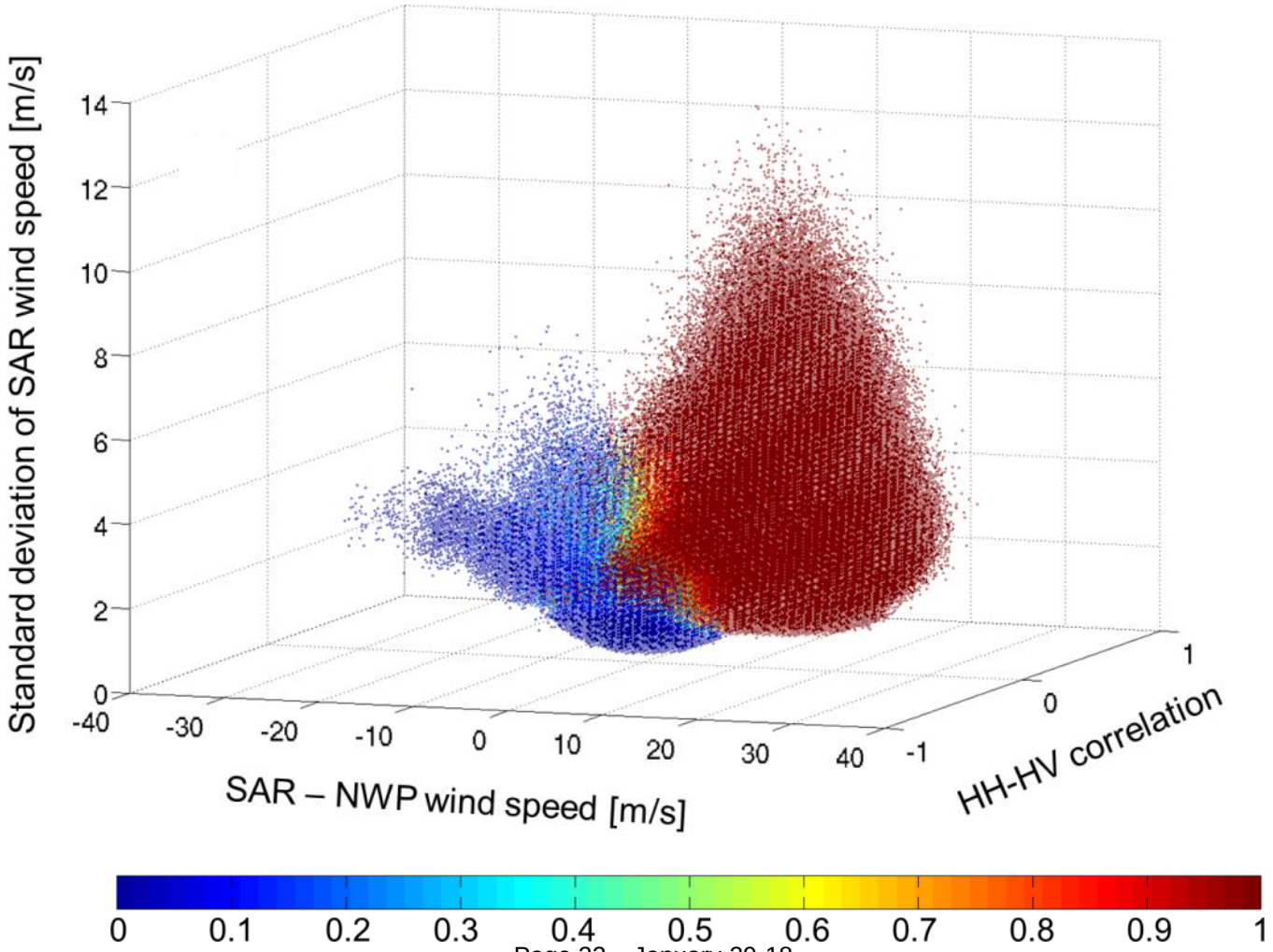

### 2D Probability of ice from Bayes




**Presence of ice/water is obtained from CIS manual image analyses**

# Key variables related to presence of ice

## Probability of ice as function of 3 variables



# 3D Ice Probability Model (IPM)

$$P(\vec{x}) = \frac{1}{1 + e^{f(\vec{x})}}$$

**Probability of ice** computed from 3 predictors using Bayes and logistic regression fit to 5 years of training data (*f* is 3rd order polynomial of 3 predictors)

Probability of ice computed from IPM at each location and classified as follows:

| | |
|---|---|
| P(x) > 0.95 | **ice** |
| P(x) < 0.05 | **water** |
| Else | **ambiguous** |

Also used an adaptive probability threshold to slightly improve accuracy

# IPM Testing Results

## Using CIS image analyses for verification

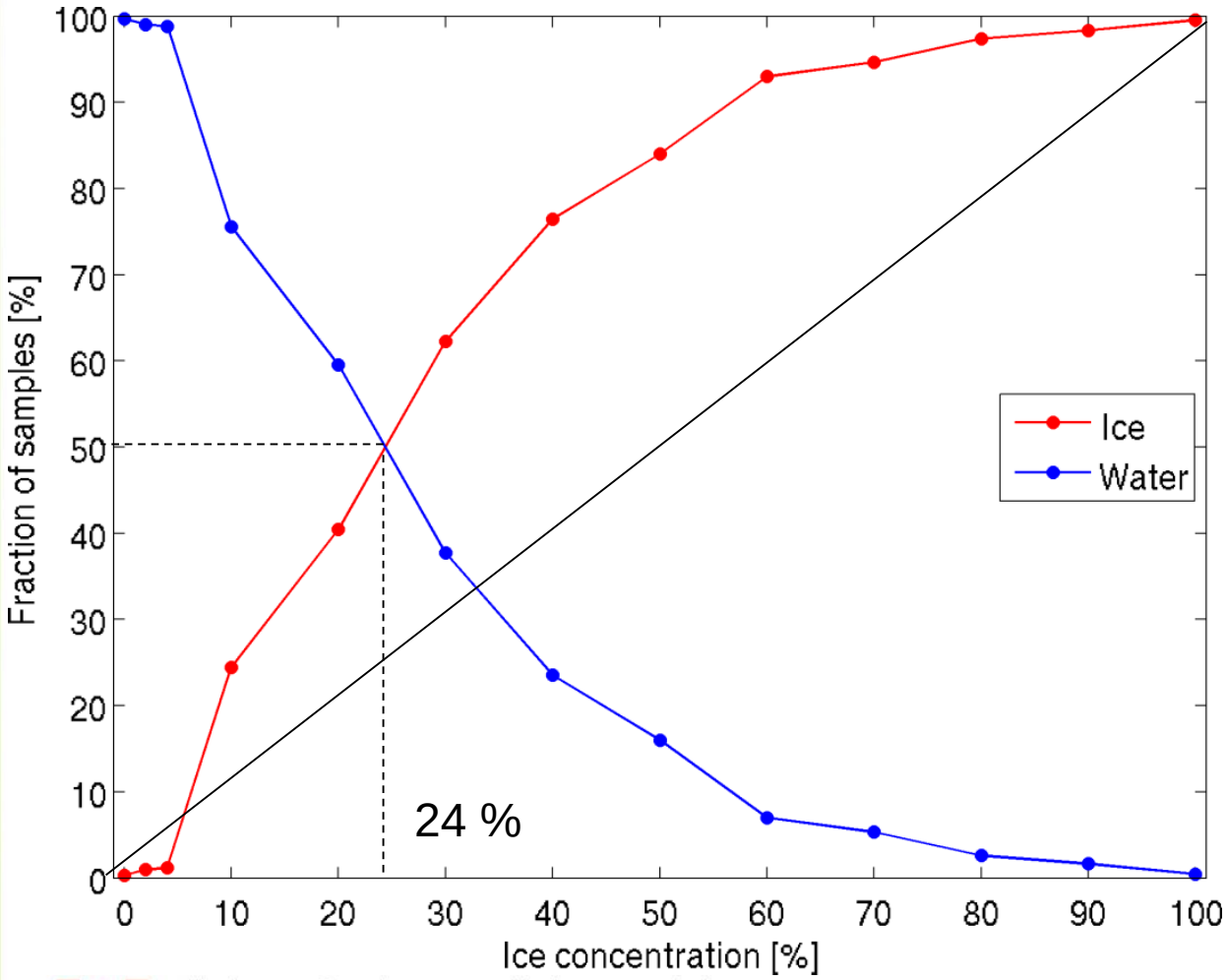
Independent testing subset (Year 2013) **considering only 0 and 100% concentrations**

$P_{threshold}$ – adaptive thresholding

| | # samples | Classified [%] | Misclassified [%] | Unknown [%] | Accuracy [%] Nc / ( Nc + Nm ) |
|---|---|---|---|---|---|
| Pure ice | 990,638 | 83.78 | 0.24 | 15.98 | 99.71 |
| Pure water | 1,490,240 | 54.02 | 0.13 | 45.86 | 99.76 |
| Pure ice & water | 2,480,878 | **65.90** | 0.18 | 33.92 | **99.73** |

# Results with all ice concentration values

## Fraction of SAR ice/water retrievals as a function of CIS manual image analysis concentration



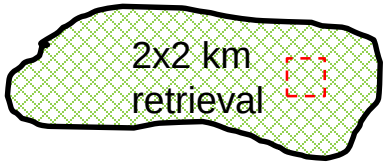

Fraction of ice/water samples

$F_i = N_i / ( N_i + N_w )$

$F_w = 1 - F_i$

Different scales of IPM model and Image Analysis polygon:

Image Analysis polygon



# Verification against IMS

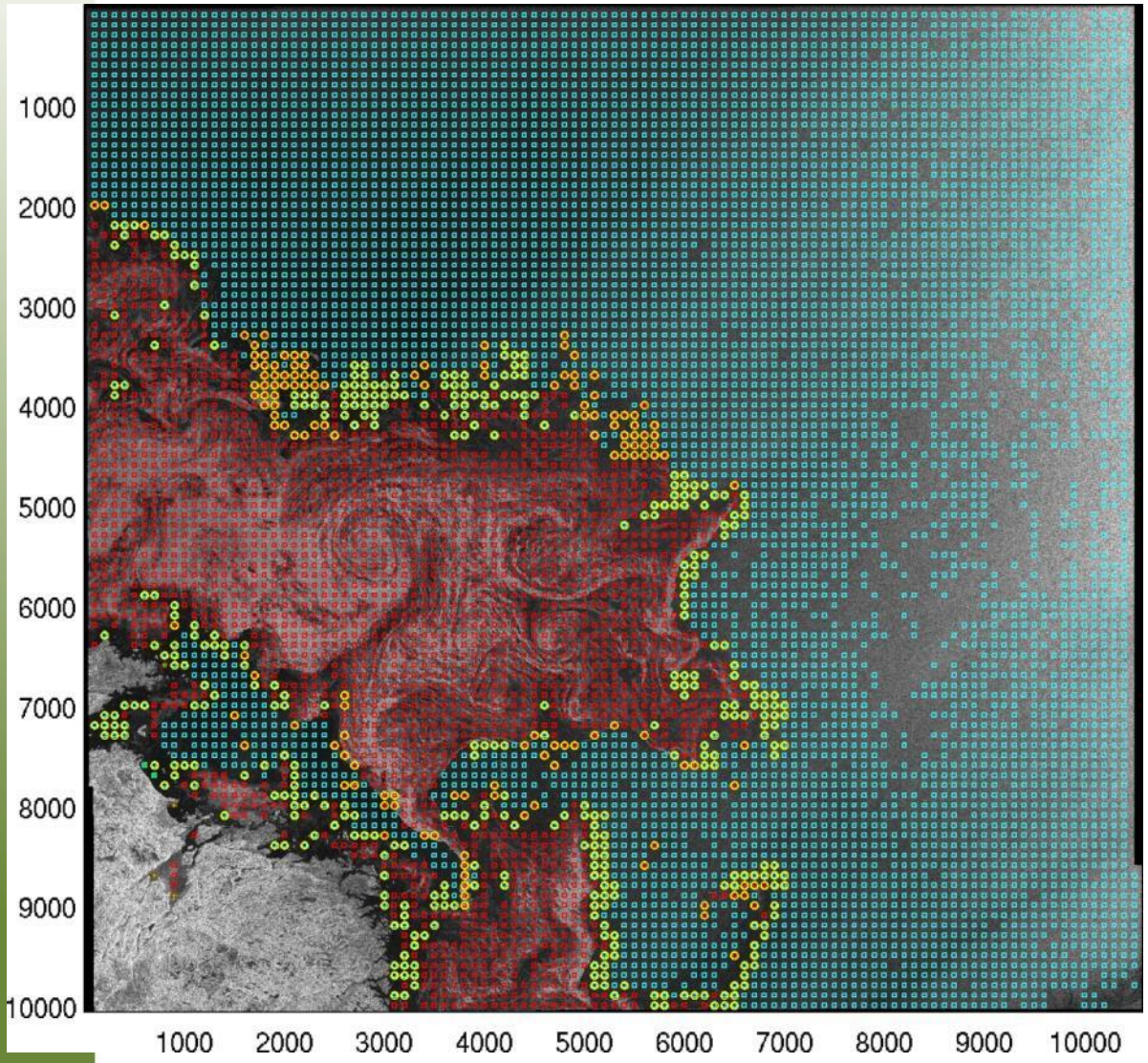
Independent IMS product is available daily, consistent coverage over entire domain of RADARSAT-2 images.

IPM model was applied to all available 7411 RADARSAT-2 images in 2013.

| | # samples | Classified [%] | Misclassified [%] | Unknown [%] | Accuracy [%] Nc / ( Nc + Nm ) |
|---|---|---|---|---|---|
| Ice | 24,719,977 | 75.81 | 2.58 | 21.61 | 96.71 |
| Water | 12,813,635 | 55.53 | 2.90 | 41.57 | 95.04 |
| Ice & Water | 37,533,612 | **68.89** | 2.69 | 28.43 | **96.24** |

# Example comparison with IMS

## Ice edge dynamics – one of the worst cases




Labrador Sea, May 3, 2013

Ice/water retrievals at 5 km spacing

- Ice agrees with IMS
- Water agrees with IMS
- Ice disagrees with IMS
- Water disagrees with IMS

Ice is highly dynamic

Many disagreements likely due to low temporal resolution of IMS and difficulty identifying edge

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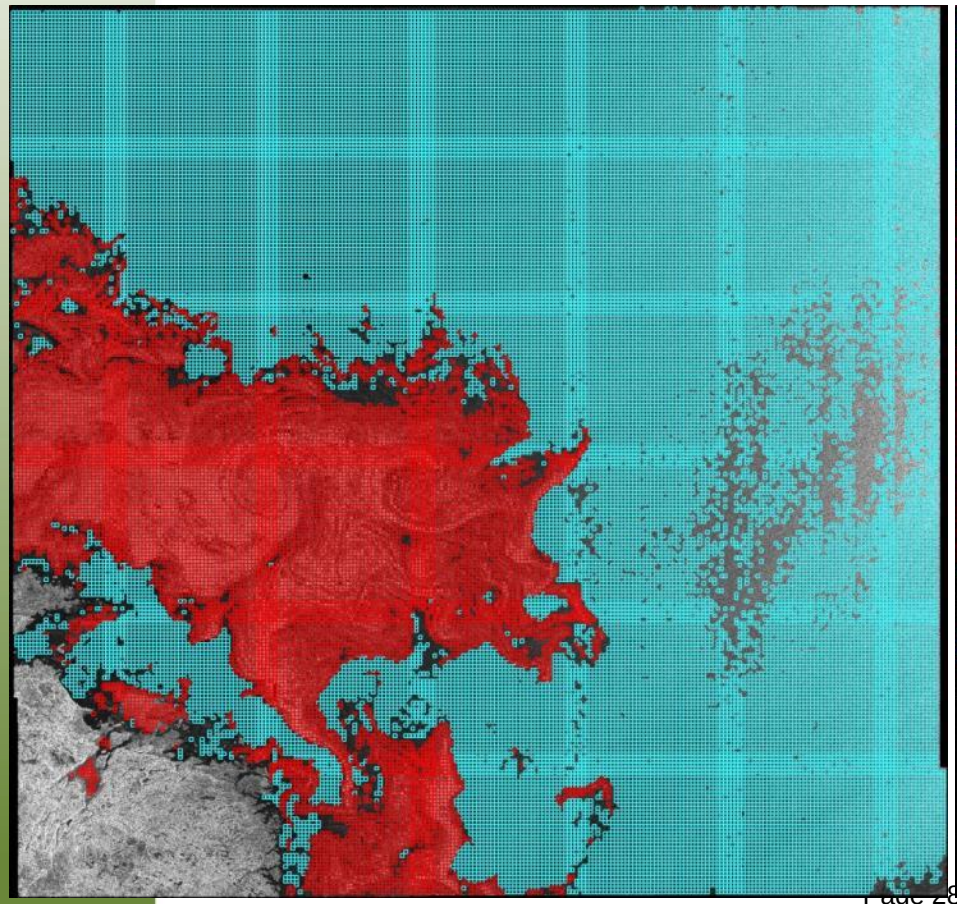
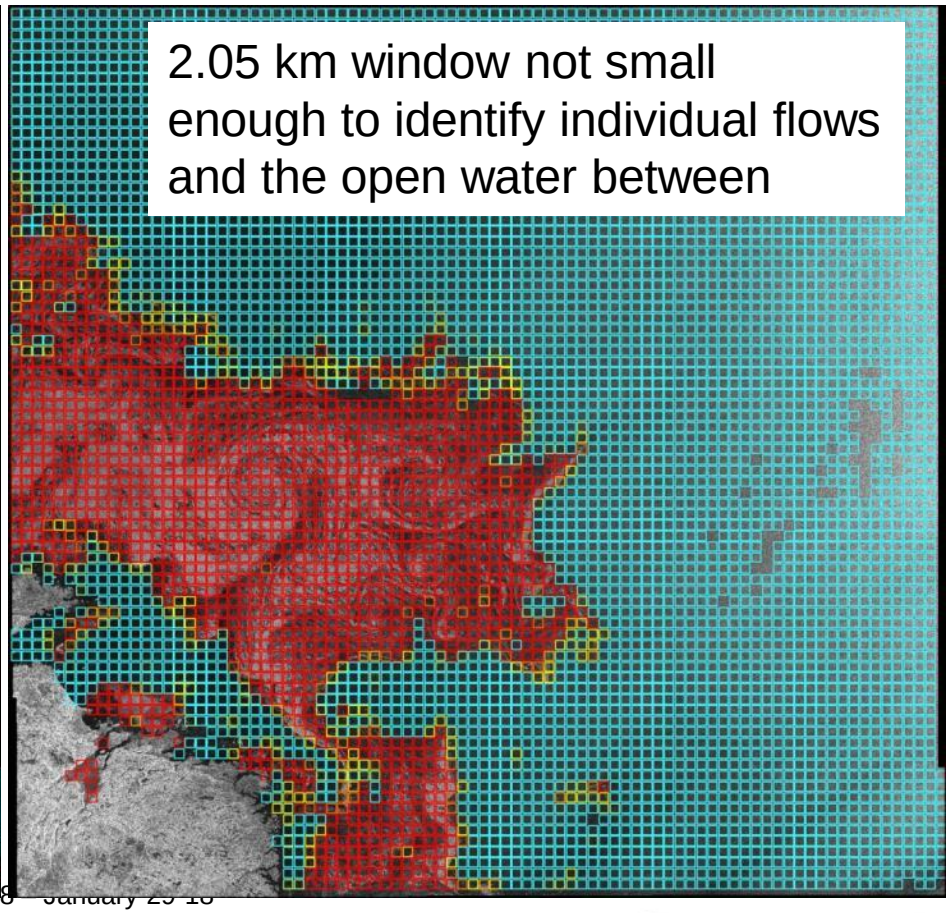
# Ice concentration from ice/water retrievals

## Obtained by counting fraction of ice retrievals

**Ice/water** retrievals at 2.05 km spacing

Ice concentration based on 3x3 ice/water retrievals





2.05 km window not small enough to identify individual flows and the open water between



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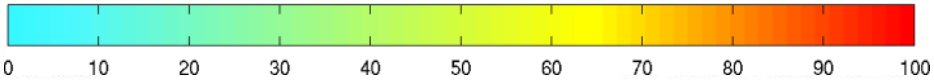

# Sea ice data assimilation

## Other ongoing and future work

- Apply approach used for AVHRR also to VIIRS data (similar channels, higher resolution, larger swath width)
- Based on high accuracy of ice/water RADARSAT-2 retrieval, evaluate impact of assimilating in 3DVar for estimating ice concentration
- Currently developing ice thickness analysis (3DVar) based on SMOS+CryoSat-2, together with estimated analysis error stddev (KF)
- Improve passive microwave retrievals by using RTM to account for atmospheric effects and using dynamic tie-points
- Started migrating **sea ice** and **SST** analyses into the modular software framework used for atmospheric 4D-EnVar → facilitate strongly coupled DA of **atmosphere–ice–upper-ocean** (through **H** and **B**)