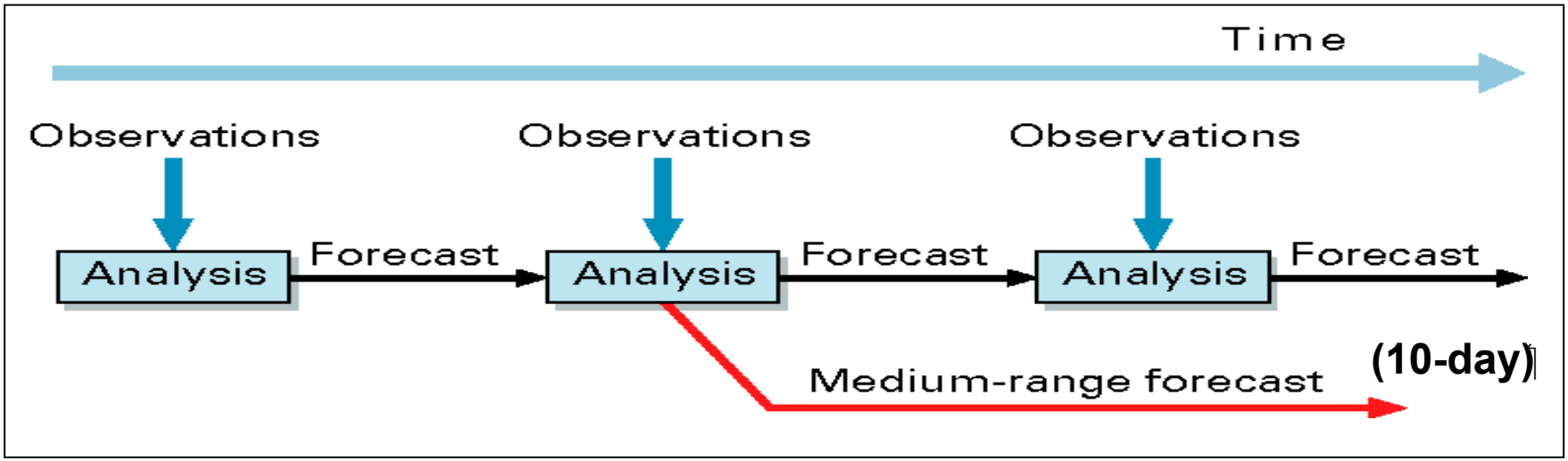
Snow data assimilation for Numerical Weather Prediction at ECMWF

Patricia de Rosnay

Thanks to many colleagues at ECMWF

ECMWF Integrated Forecasting System (IFS)



- **Forecast Model:** GCM including the H-TESSEL land surface model (coupled)
- **Data Assimilation** → **initial conditions of the forecast model prognostic variables**
  - 4D-Var for atmosphere ; 3D-Var for ocean (for ensemble and seasonal)
  - Land Data Assimilation System

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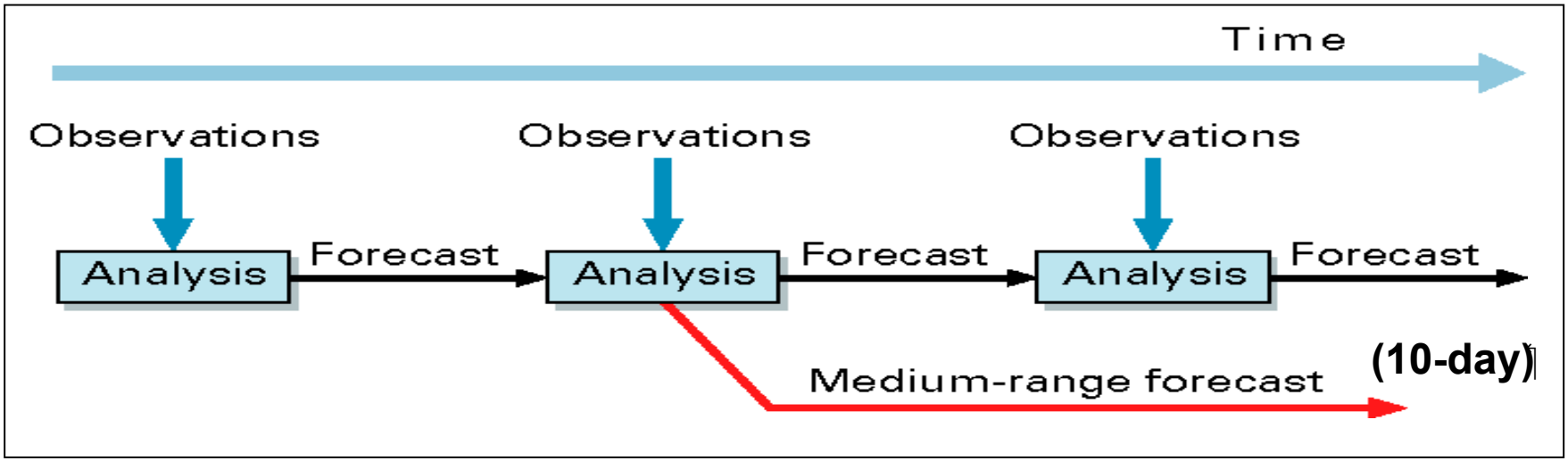

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Different Systems:

NWP (oper):	IFS (with 4D-Var and LDAS), 9km, version 43r1 (2016)
ERA-Interim:	IFS (with 4D-Var and LDAS), 79km, version 31r1 (2006)
ERA5:	IFS (with 4D-Var and LDAS), 32km, version 41r2 (2016)
ERA-Interim-Land:	H-TESSEL LSM simulations (no LDAS), 79km, 37r2 (2011) driven by ERA-I atmospheric cond. corrected by GPCP

Snow in the ECMWF IFS for NWP

Snow Model: Component of H-TESSEL **(Dutra et al., JHM 2010, Balsamo et al JHM 2009)**

Single layer snowpack

- Snow water equivalent SWE (m)
- Snow Density ρ_s

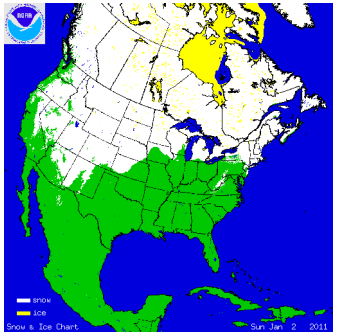
} **Prognostic variables**

Observations: **de Rosnay et al ECMWF Newsletter 2015**

- Conventional snow depth data: SYNOP and National networks
- Snow cover extent: NOAA NESDIS/IMS daily product (4km)

Data Assimilation: **de Rosnay et al SG 2014**

- Optimal Interpolation (OI) is used to optimally combine the model first guess, in situ snow depth and IMS snow cover
- The result of the data assimilation is the analysis of SWE and snow density
- It is used to initialize the NWP system.



Snow cover observations

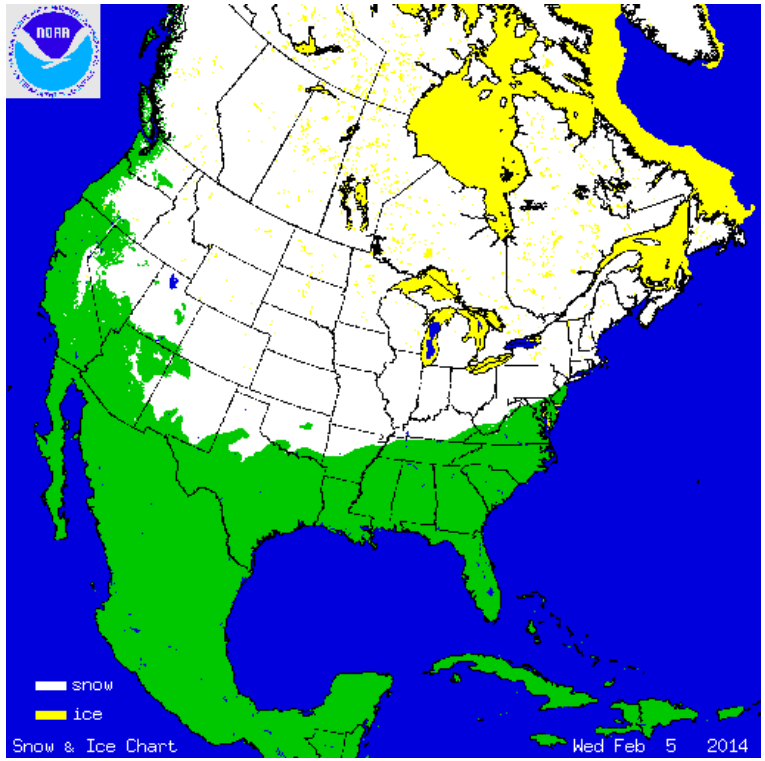
Interactive Multisensor Snow and Ice Mapping System (IMS)

- Time sequenced imagery from geostationary satellites
- AVHRR,
- VIIRS,
- SSM/I, etc….
- Station data

Northern Hemisphere product

- Daily
- Polar stereographic projection

NOAA/NESDIS
IMS Snow extent data



http://nsidc.org/data/g02156.html

Information content: Snow/Snow free

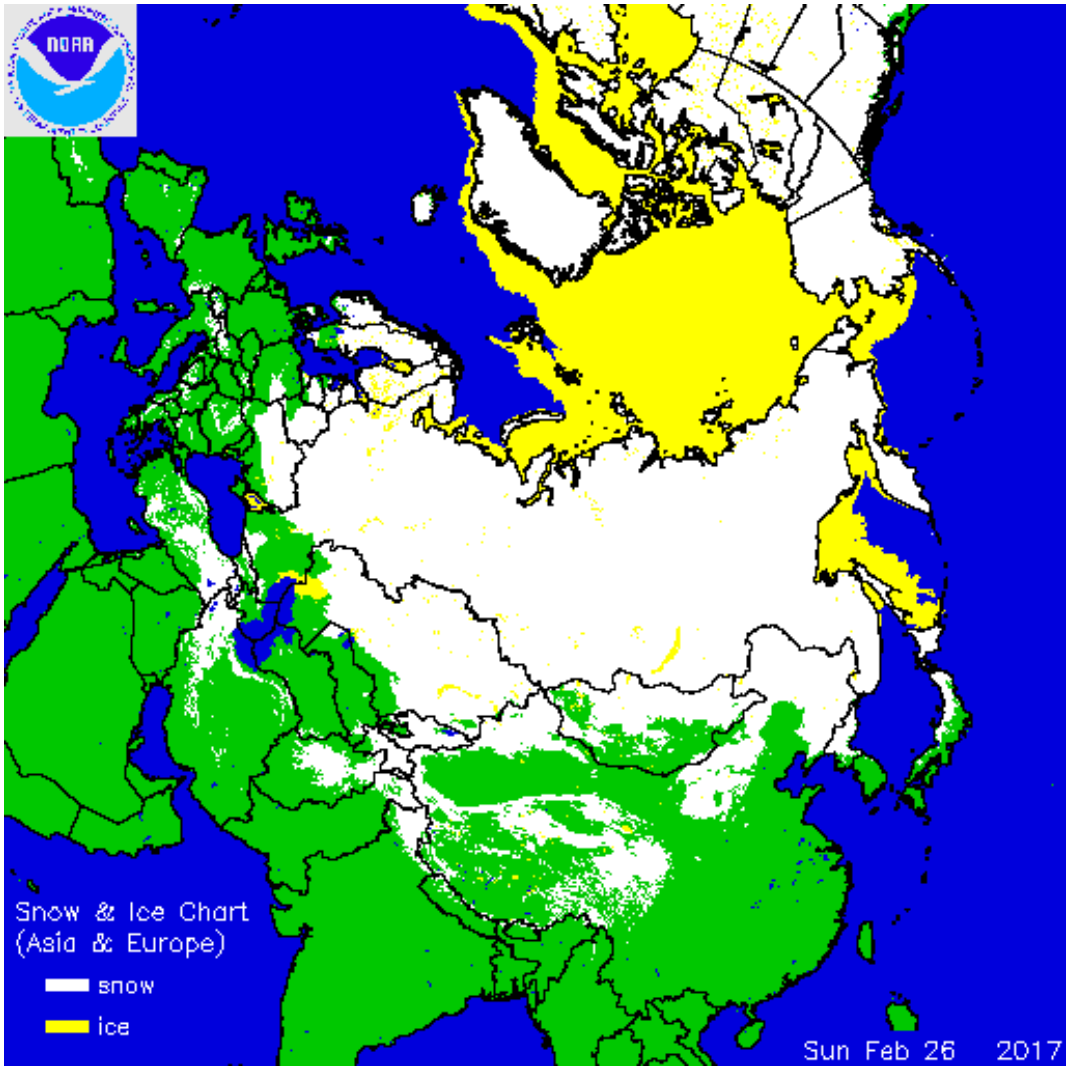
Data used at ECMWF:

- **24km product** (ERA-Interim)
- **4 km product** (NWP, ERA5)

Latency:

Available daily at 23 UTC. Assimilated in the subsequent analysis at 00UTC

Snow cover observations



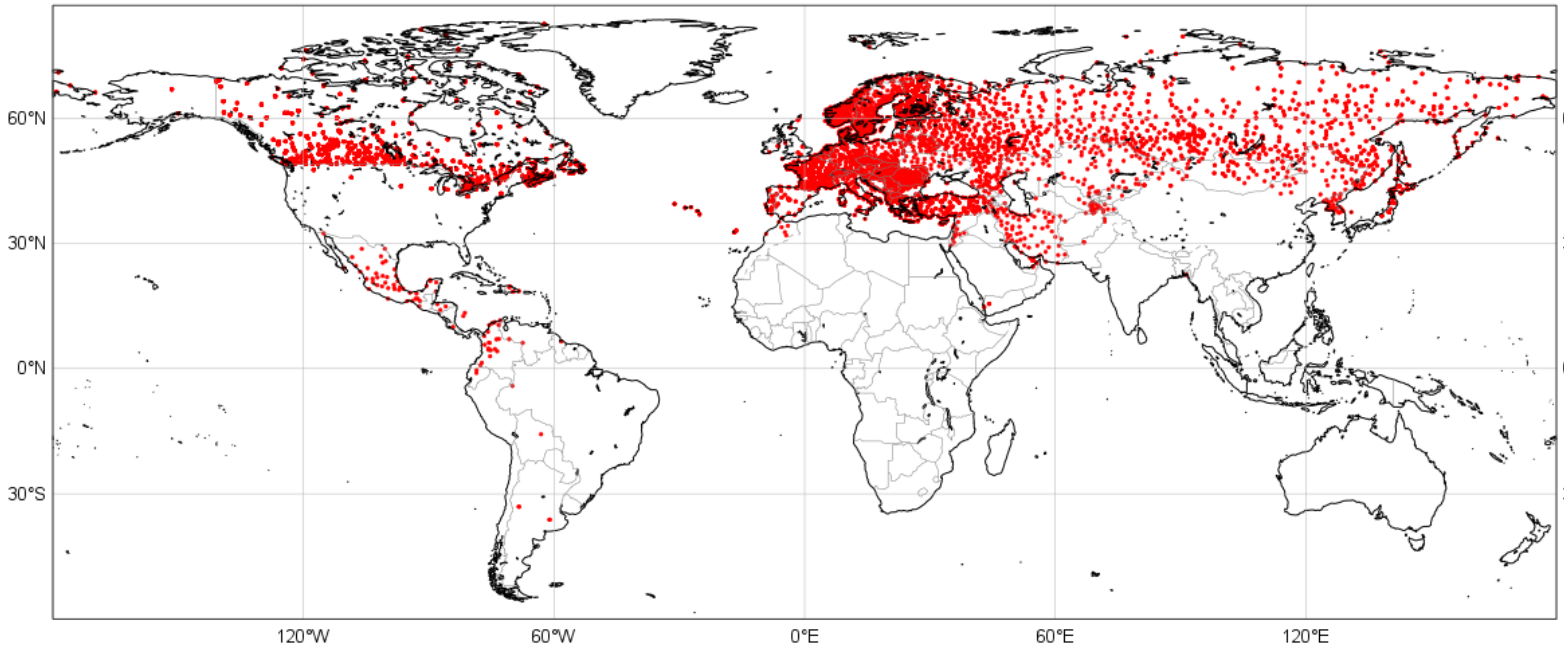
IMS snow cover on 26 February 2017

In situ snow depth observations

GTS Snow depth availability

SYNOP TAC + SYNOP BUFR + national BUFR data

Status on 5 February 2017



- Gap USA: NRT data exist and is available (more than 20000 station in the USA), but it is not on the GTS for NWP applications.
- Improvement in China (since status in de Rosnay et al, ECMWF NL article 143, 2015)

Initiatives relevant to address snow observations availability on the Global Telecommunication System (GTS)

GCW Snow Watch Activity

Snow Watch reporting Handout 2015 (ECMWF/UKMO)

http://globalcryospherewatch.org/reference/documents/

COST action on Snow: HarmoSnow

"A European network for a harmonised monitoring of snow for the benefit of climate change scenarios, hydrology and numerical weather prediction".

http://www.cost.eu/COST_Actions/essem/Actions/ES1404

http://costsnow.fmi.fi/

NAEDEX (North America Europe data exchange)

Discussions NOAA/NCEP to improve availability of snow depth on the GTS

OSCAR

Observing Systems Capability Analysis and Review Tool

- New section for in situ surface data
- Relevant to use it to monitor snow depth data availability

Snow Data assimilation method

Snow depth increments: $\Delta S_j^a = \sum_{i=1}^{N} w_i \times \Delta S_i$

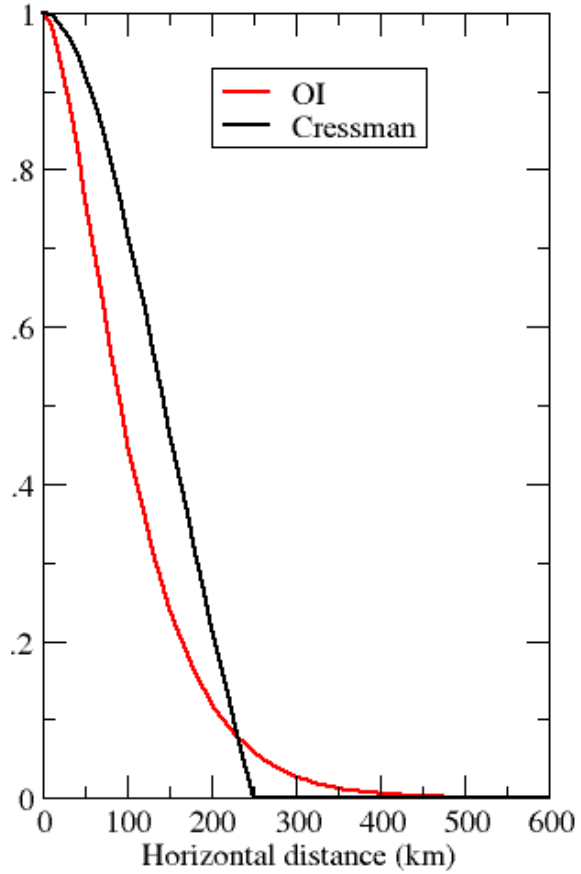
Cressman: ERA-Interim and NWP until 2010

Weights are function of horizontal and vertical distances. Do not account for observations and background errors.

Optimal Interpolation (OI): NWP since 2010

The correlation coefficients follow a second-order autoregressive horizontal structure and a Gaussian for the vertical elevation differences.

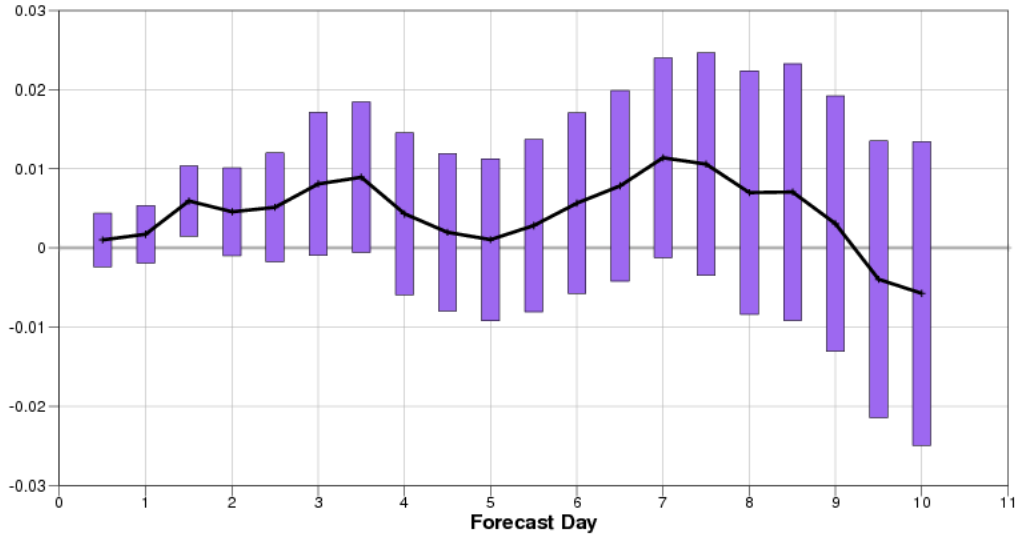
OI has longer tails than Cressman and considers more observations. Model/observation information optimally weighted using error statistics.



Snow Data assimilation method

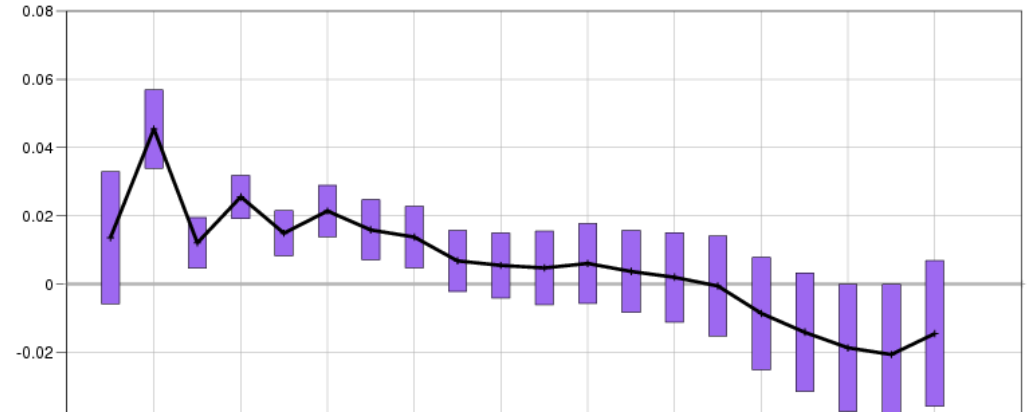
Impact on the Atmospheric Forecasts

RMS 1000hPa Geopotential height
Northern Hemisphere
DJF 2009-2010



Cressman –OI impact
(both use IMS 24km)

Positive : OI improves



Overall impact
(Old-New)

New: OI+IMS 4km
Old: Cressman+ IMS 24km

Positive: new improves

→ Main impact of snow data assimilation on atmospheric forecasts due to the IMS 4km and revised QC

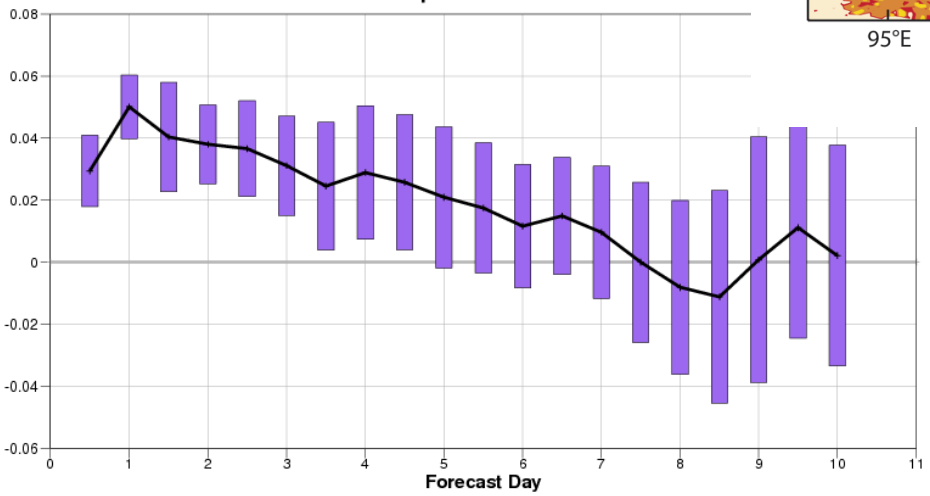
Snow Data assimilation

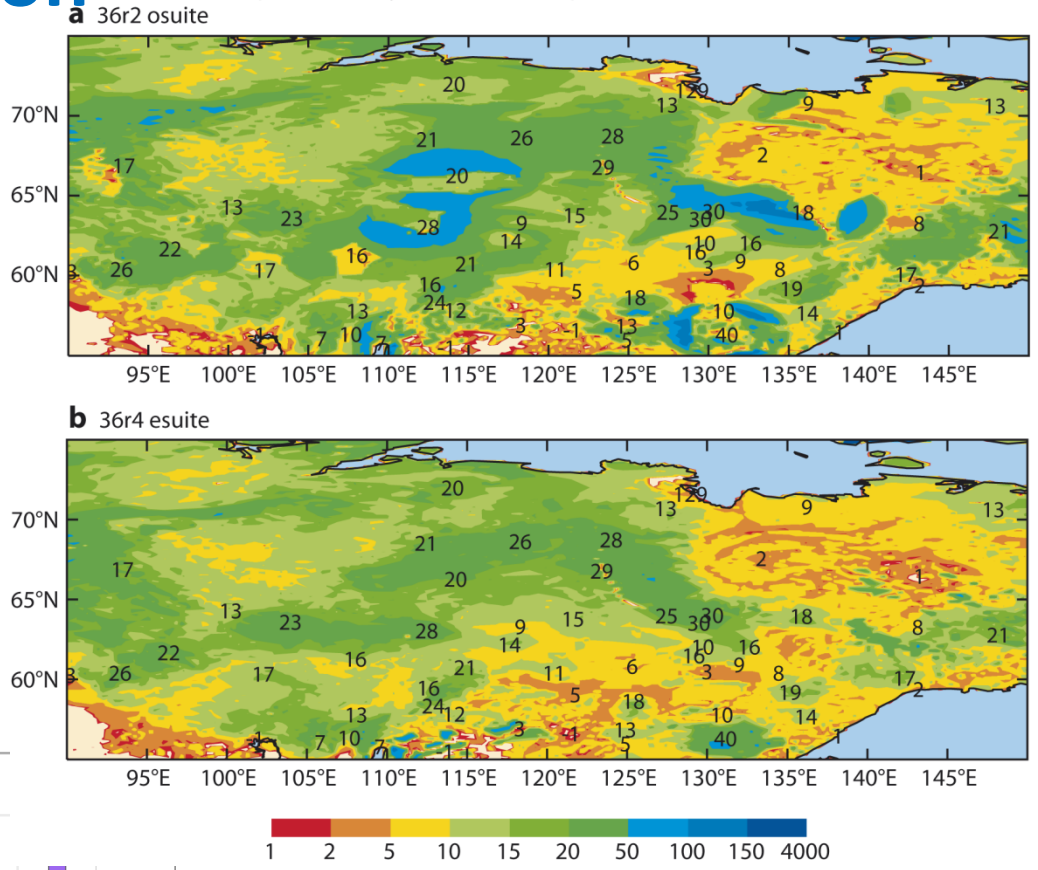
Old:
Cressman+ IMS 24km

New:
OI+ IMS 4km

FC impact (East Asia)

RMSE 500 hPa Geopot H

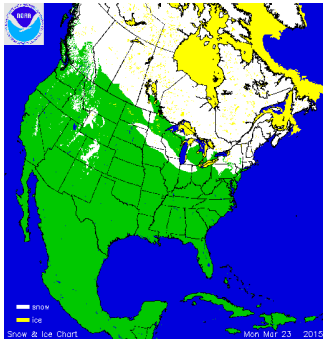




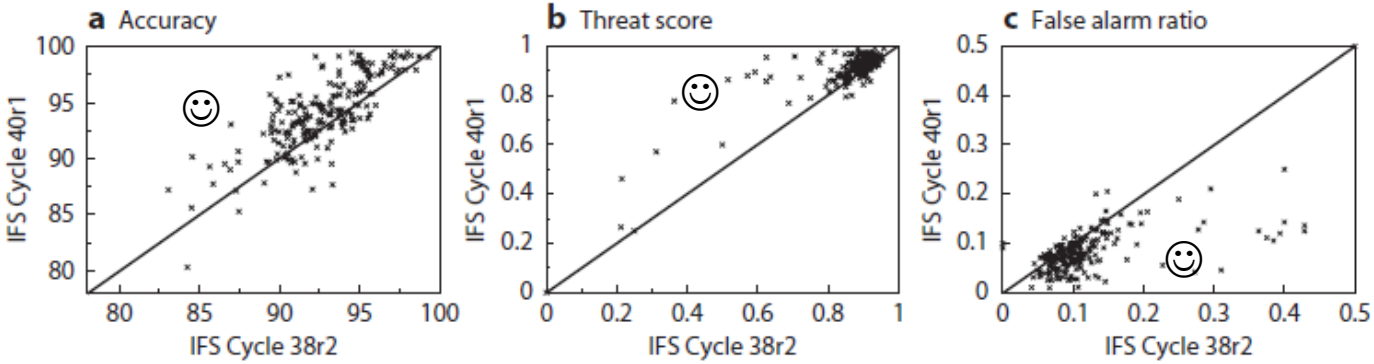
New snow analysis improves both the snow depth patterns (OI impact) and the atmospheric forecasts (IMS 4km+QC impact)

Snow analysis: Forecast impact

Revised IMS snow cover data assimilation (2013)



Impact on snow October 2012 to April 2013
(using 251 independent in situ observations)



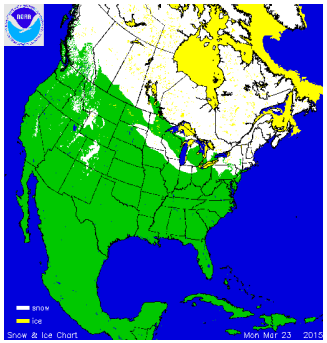
	Snow observed	No snow observed
Snow in analysis	a Hits	b False alarm
No snow in analysis	c Misses	d Correct no snow

The following scores are used for the evaluation:

- Accuracy = a+d / (a+b+c+d)
- False alarm ratio = b / (a+b)
- Threat score = a / (a+b+c)

Snow analysis: Forecast impact

Revised IMS snow cover data assimilation (2013)



Impact on snow October 2012 to April 2013
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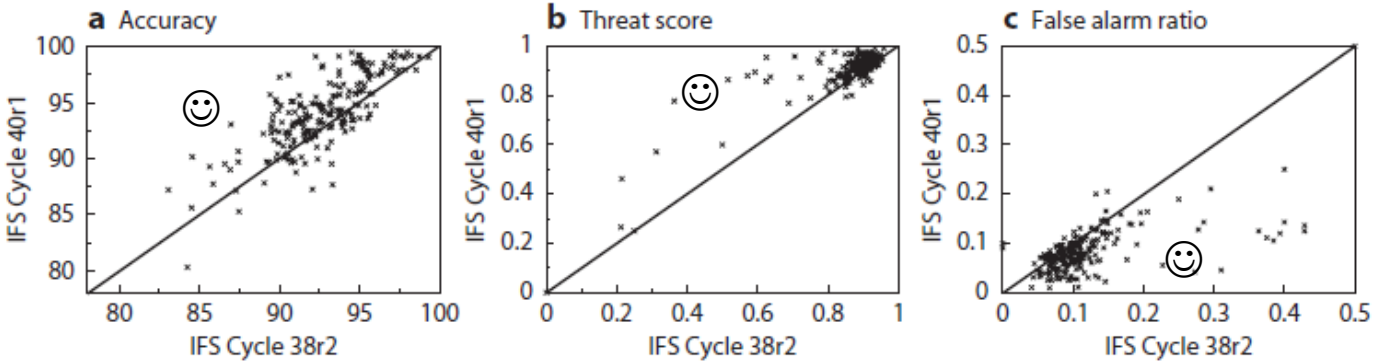


Impact on atmospheric forecasts

October 2012 to April 2013 (RMSE new-old)

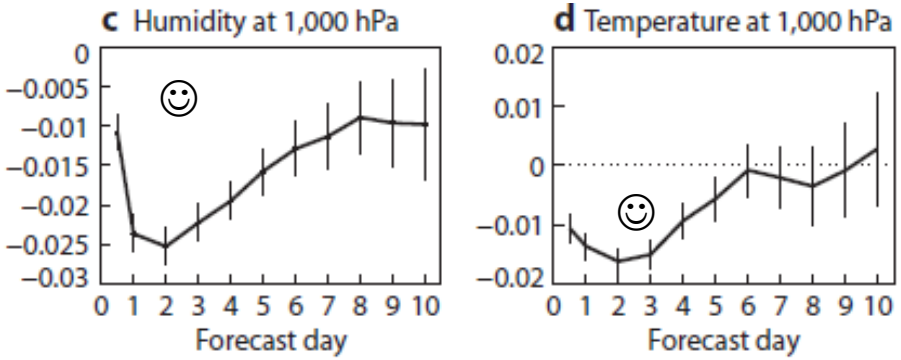
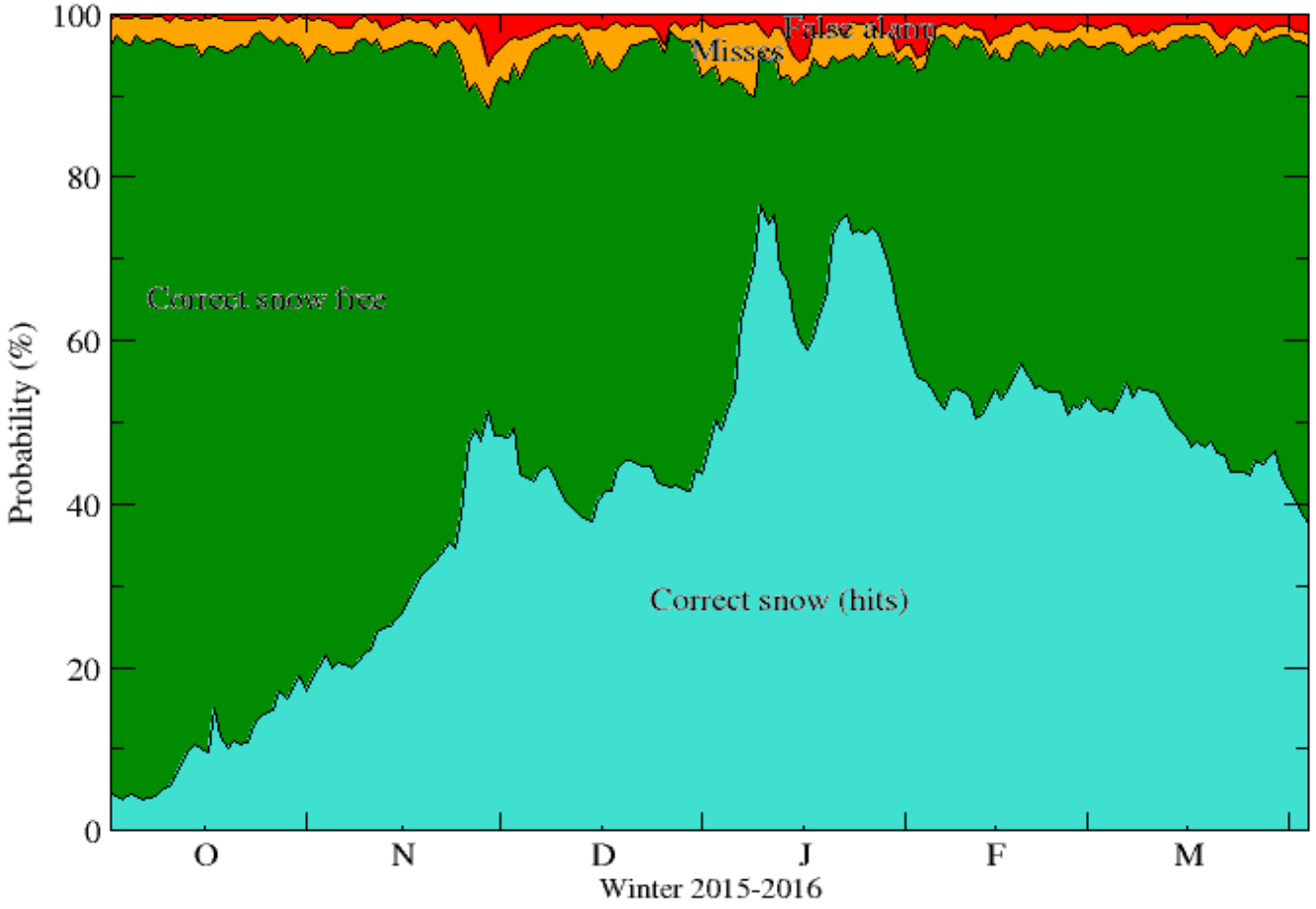


Figure 4 Impact of the revised snow analysis on the normalised root mean square error difference between IFS Cycles 40r1 and 38r2 (40r1 minus 38r2) for (a) humidity forecasts at 850 hPa;

de Rosnay et al., ECMWF NL 143, Spring 2015

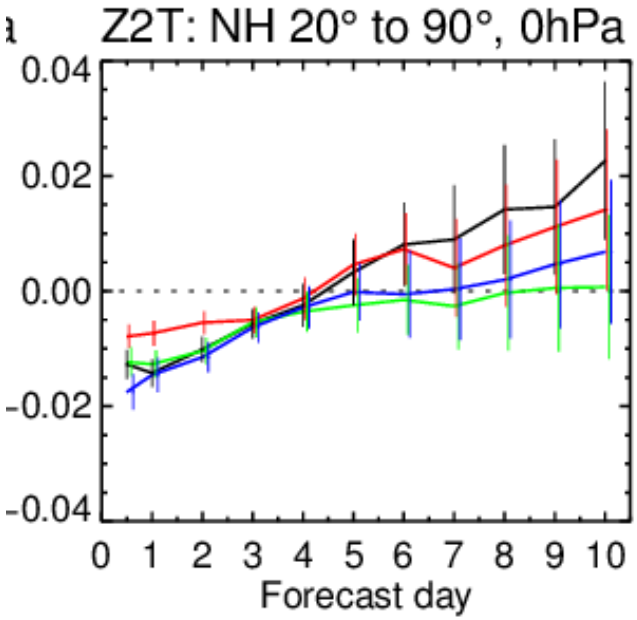
Operational snow analysis evaluation against in situ stations
North Hemisphere - winter 2015-2016



Observing System Experiments

Winter 2014-2015 (December to April) - Assess the impact of the snow observing system

Expts	SYNOP	National Data	IMS snow cover
0- OL (no snow data assimilation)			
1- Snow DA: SYNOP+IMS	✓		✓
2- Snow DA: SYNOP+Nat (all in situ)	✓	✓	
3- Snow DA SYNOP+Nat+IMS (all)	✓	✓	✓

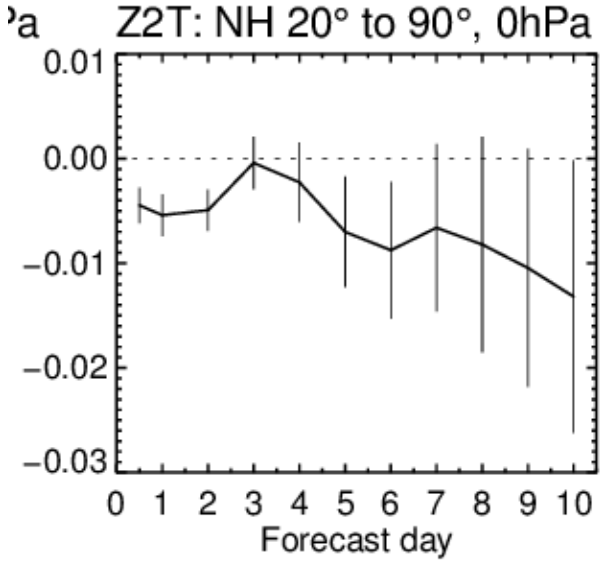


Impact on T2m Forecasts:
Normalized RMSE for T2m FC difference compared to the reference (OL)

SYNOP+IMS (1-0)
SYNOP+Nat (2-0)
SYNOP+Nat+IMS (3-0) -> oper

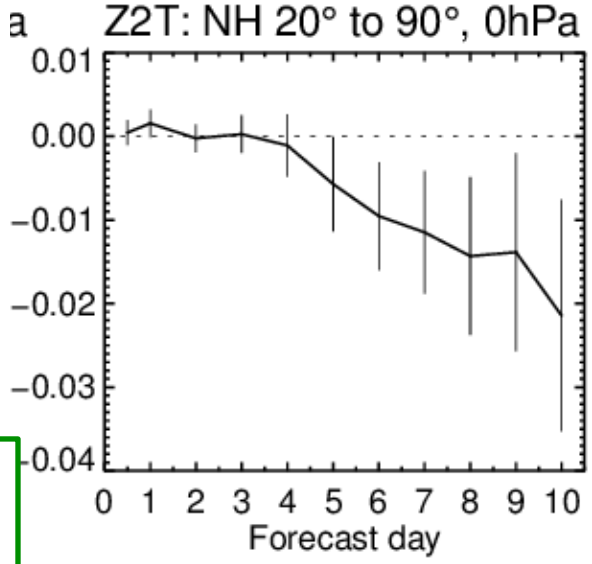
Best T2m Forecast when all observations, combining in situ and IMS, are assimilated.

Impact of IMS snow cover (case 3-2)



All data assimilated (Synop+Nat+IMS)
compared to all in situ data assimilated (SYNOP+Nat)
-> Further T2m forecasts error reduction,
significant at short range

Impact additional network
(case 3-1)



Impact of National data (case 3-1)

All data assimilated (SYNOP+Nat+IMS)
compared to SYNOP+IMS assimilation
-> Further T2m forecasts error reduction at medium range

Contribution& complementarities of each observation types to improve T2m forecasts at short and medium ranges

Summary

- Major developments in the ECMWF data assimilation (DA) in the past few years; large impact on NWP
- OSEs shows that combined DA of in situ snow depth and IMS snow cover significantly improve T2m forecasts
- Gaps in in situ SD reporting, but additional National data contribute to improve near surface weather forecasts
- Nat. Met services encouraged to report snow depth on the GTS
- Contributions from Snow Watch(WMO BUFR), HarmoSnow COST action (Questionnaire, inventory), NAEDEX (US issue), OSCAR (great potential for monitoring SD report availability), …
- Challenges in retrieving snow mass from satellite measurements
  → Novel mission concepts required for SWE for NWP
  → Future Chinese water cycle mission WCOM (Shi et al) of great interest

Thank you for your Attention!

Useful links:

ECMWF LDAS: https://software.ecmwf.int/wiki/display/LDAS/LDAS+Home
Snow Watch: http://globalcryospherewatch.org/reference/documents/

HarmoSnow COST Action: http://www.cost.eu/COST_Actions/essem/Actions/ES1404
http://costsnow.fmi.fi/

ECMWF Land Surface Observation monitoring:
https://software.ecmwf.int/wiki/display/LDAS/Land+Surface+Observations+monitoring