Overview of HIRLAM data assimilation activities
On algorithmic developments and Use of Observations

Collected by Jelena Bojarova

The 34th EWGLAM and 19th SRNWP Meeting, FMI, Helsinki, 8-11Oct. 2012
HARMONIE- HIRLAM-B programme

developments for convection-permitting scales

Powerful and flexible research tool
designed for synoptic scale systems

HIRLAM (HIgh Resolution Limited Area Model)  ECMWF IFS (Integrated Forecasting System)

ALADIN (Aire Limitée Adaptation Dynamique Développement InterNational)

The goal: move operational activities here but is still under development

HARMONIE (Hirlam Aladin Regional/Meso-scale Operational NWP In Europe)
(Pre-)Operational HARMONIE at KNMI

by Jan Barkmeijer and Siebren de Haan, KNMI

Data usage: ModeS from 2012041906
Improved use of the existing observational network

TAC data format → TDCF data format

Higher resolution,
Better accuracy,
More Metadata

SMHI data

Direct from GTS

(by Eoin Whelan, The Irish Meteorological Service)
Short-term framework
for meso-scale DA

*Implementation of the RUC setup* ((pre-)operational at KNMI);
— 3h update frequency (1h dynamical “spin-up” problem)

*High resolution high frequency observations*
— conventional data: temp, synop, ships+
— ModeS (pre-operational at KNMI) + AMDAR (Bias Correction!)+
— RADAR, GPS, ASCAT (in progress) +
— screen level observations for UA DA (first priority) +
— “moist” observations (cloud initialisation + cloudy radiances) (research)

*A configuration of the observation network plays an important role for the efficiency of the RUC scheme, in particular reducing the “spin-up” problem: both upper air and lower tropospheric observations should be present*
Assimilation of radar reflectivity data in HARMONIE (1)

Method from Météo-France: 1D Bayesian + 3DVAR [2, 3, 1]

- **Reflectivity** is not a model control parameter
- Generate pseudo-observations from the model background (first guess): Profiles of relative humidity

Illustration: Olivier Caumont

- Several neighboring columns of simulated reflectivity \( H_Z(x_i) \) are used to generate one single pseudo-obs. column of relative humidity (RH, \( x_i^U \)).

(by Martin Sigurd Grønsleth and Roger Randriamampianina, met.no report)
Assimilation of radar reflectivity data in HARMONIE (2)

Case Study in a non-optimal setup
(small domain + 6h update frequency)
Positive impact on surface pressure, 12h accumulated precipitation and temperature scores for short forecast length

Figure 3.16: Analysis increments for BAR5_EXP_RADAR. We can see that assimilation of radar reflectivity is increasing/decreasing relative humidity at appropriate places. Note that the pseudo-CAPFI plot does not reflect the full volume of observed reflectivity (which is used in the assimilation).

(by Martin Sigurd Grønsleth and Roger Randriamampianina, met.no report)
Quality control of radar data is the core issue for the successful radar data assimilation. (KNMI, DMI, SMHI, AEMET, met.no)

→ Poster “Quality control of polar weather radar data using the baltrad toolbox" by Daniel Michelson et al.

“Three bullets“

* the BALTRAD toolbox is an Open Source software framework for processing and improving the quality of weather radar data

* the toolbox and its tools have been trialed at the European level using data from ~115 radars. HIRLAM community is investigating pros and cons of the BALTRAD Toolbox as a COMMON radar data QC tool

* the toolbox will be deployed by OPERA's Odyssey in support of NWP's needs.
Extended radar data impact studies
7-24 Aug 2010 (extended Danish domain)

are initiated by HIRLAM community in order to speed up the progress in implementing high-resolution high-frequency observations

3DVAR AROME HARMONIE RUC 3h
(conventional + radar data + ZTD GNSS + ASCAT winds + IASI (water vapour sensitive) + AMSU-a, AMSU-b)

Some information on the pre-processing of ZTD GNSS → “AEMET National poster” (by Jana Sanchez Arriola)
Assimilation of radiances in HARMONIE

Water vapour sensitive IASI channels

The moisture increments from water vapour sensitive IASI channels do not affect the total precipitation amount but impact the positioning of individual cells and bands.

Case 19 aug 21 utc

<table>
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Research topic:
What is the optimal set of predictors assimilating radiances on meso-scale model?

Harald Schyberg et al (met.no) in collaboration with Roger Randriamampianina
MSG cloud mask initialisation in HARMONIE (1)

(using cloud mask nowcasting SAF, MSC cloud top temperature and SYNOP cloud base height)

Relation between cloud amount and specific humidity:

\[ q_m = q_s \cdot (1 - C) \cdot \sqrt{N + C} \]

\[ q_m = \min(q_m, C \cdot q_s) \]

\[ C = r h_{max} - (r h_{max} - r h_{min}) \cdot \sin(\pi \frac{p}{p_s}) \]

N: 3-D cloud cover

Preserve buoyancy when changing humidity (keep virtual T constant)

especially important in Harmonie!

\[ T_v = T \left(1 + 0.61 q_m - q_l - q_i - q_r - q_s - q_g\right) \]

Correction: \[ T = T_v / \left(1 + 0.61 q_m - q_l - q_i - q_r - q_s - q_g\right) \]

(by Sibbo van der Veen, KNMI)
Convection in HARMONIE
Severe thunderstorm 10 July 2010

(by Sibbo van der Veen, KNMI)
Fog in HARMONIE

(by Sibbo van der Veen, KNMI)
Cloud mask initialisation in HARMONIE (2)

**HIRLAM model**
— improved forecast of cloud cover, precipitation, upper air temperatures and surface pressure
— worse bias of 2m temperature

**HARMONIE model**
— increased thunderstorm precipitation considerably
— was able to remove erroneous fog fields up to +24 forecast length
— “buoyancy correction” is very important

**Research topic:**
— How to integrate the methodology into variational data assimilation
Near-real time (15 minutes delay) CPP

2-D physical cloud properties:
- Integrated cloud water [kg m\(^{-2}\)];
- Average effective cloud drop size, \( r_e \) [\( \mu \text{m} \)];
- Cloud top temperature [K];
- Cloud bottom temperature [K].

Meteosat Second Generation (MSG)

\[
\begin{align*}
\mathcal{R}(x, y; \lambda, \theta_0, \theta, \phi; \rho(\theta_0, \theta, \phi), CW_P, r_e) \\
\mathcal{R}(x, y; \lambda = 810\text{nm}) + \mathcal{R}(x, y; \lambda = 1640\text{nm}) = {} & \Rightarrow \\
CW_P(x, y) + r_e(x, y) 
\end{align*}
\]

Nakajima & King (1990); Roebeling et al. (2006).

Comparing HARMONIE with 2D cloud MSG cloud water path

Beta version

For Northwestern Europe:
https://hirlam.org/portal/oprint/Webgraf/OBSCPP/OBS/?choice_ind=NORDIC

(Kristian Pagh Nielsen, DMI)
Surface DA : improved spatialisation tool

(MESCAN, EURO4M in collaboration with MF)

Introduction of more realistic correlation function in CANARI:

**Old:**

\[ Corr_{CAN}(r) = e^{-0.5 \frac{r}{d_1}} \]

**New:**

\[ Corr_{MES}(r, d_p, d_z) = 0.5 \left( e^{-\frac{r}{d_2}} + \left(1 + \frac{2r}{d_2}\right) e^{-2\frac{r}{d_2}} \right) F_p(d_p)F_z(d_z) \]


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The new anisotropic correlation function creates more realistic analysis increments (right Figure) by accounting for height difference and land-sea mask.

(by Tomas Landelius, SMHI)
Surface DA in Nordic Conditions
(snow data assimilation)

50 % snow probability map
(met.no product)

HARMONIE control

snow/no snow (SWE< 25kg/m²)

Local precipitation stations

(by Mariken Homleid and Mari-Anne Killie, met.no)
Large-scale error constraint in LAM
in collaboration with MetCoOp project

Adjust model state to host model and observations

Extra term in cost-function

\[ J(x) = J_b + J_o + (x - x_{ls})^T V^{-1} (x - x_{ls}) \]

Truncate Jk information at K=20

AROME 2.5 km;
Host model
ECMWF

by Per Dahlgren, SMHI
Correction of non-additive errors (1)

research with H IRLAM model

Handling – two step method

Estimate the phase error (displacement field) and warp the first guess.

$\hat{x}_b(s+T)$

Minimize the additive error using standard VAR-method.

by Tomas Landelius & Magnus Lindskog, SMHI
Correction of non-additive errors (2)

Example: SEVIRI data (WV 073)

by Tomas Landelius & Magnus Lindskog, SMHI
Correction of non-additive errors (3)

**Balances**

- The warped field is introduced as pseudo-observations and used to modify the original background field in a full-scale data assimilation with HIRLAM variational data assimilation and its balance constraint.
- The resulting field is then used as background field in the following standard 3D-Var, when a full set of observations are assimilated.

**A Case study with simulated observations, 20090113 12 UTC**

- Better balance in initial state and better quality of short range forecast when the phase error correction through warping is introduced in the form of pseudo observations.

**Future plans**

- Application of pseudo observation approach to real data in the form of SEVIRI radiances and in that context investigate optimal superob averaging sacels.
- Investigate how ensemble approaches can be utilised to handle phase errors.
- Transfer of developments from HIRLAM to HARMONIE framework.

*by Tomas Landelius & Magnus Lindskog, SMHI*
Field alignment technique assimilating radar data reflectivities in HARMONIE is implemented.
→ “National AEMET poster” (by Carlos Geijo)

**Research topic:** the real challenge is how to extend the methodology to the multivariate framework
Weather regime dependency
diagnosis of structure functions (rain/dryness)

**Horizontal spectra**
Dominance in meso-scale for rain cases

**Vertical correlation**
Vorticity: wider for rain than for dryness
Humidity: nearly neutral

**Standard deviation**
Vorticity/Divergence/Humidity: larger for rain than for dryness

**Statistic sampling data collecting**
Rain/Dryness cases are separated from 201006-201008 Harmonie ensemble 6h forecast data set according to corresponding precipitation measurements (by Shiuy Zhuang, DMI)
Ensembles for HIRLAM Hybrid variational ensemble data assimilation

Considerations:
* We need a rich ensemble to describe flow-dependent assimilation increments!
* Can we afford an ensemble size of \(~100\)?
* With a smaller ensemble size, can we improve for the Hybrid by adding lagged members?
* Lagged initial time and/or lagged valid time (to describe timing errors)?
* We also need LBC perturbations!

Experiments for a short winter period 17 – 28 January 2008
- 3D-Var, 3D-Var Hybrid (50% static – 50% EPS-ETKF 12 members)
- 4D-Var, 4D-Var Hybrid (50%-50%)
- 4D-Var Hybrid (75%, 25%, inflated EPS spread)
- 4D-Var Hybrid (50%, 50%), add lagged ensemble (+9h in addition to +3h, correct valid time)
- 4D-Var Hybrid (50%, 50%), add ensemble with lagged valid time (+2h) for possibly correction for timing errors
- 4D-Var Hybrid (50%, 50%), increased number of members to 20
Example of forecast verification scores for a first winter case

(by Gustafsson&Bojarova Family Corporation)
Experiments for 17 - 28 January 2008 (too short period) - Subjective summary of forecast verification scores

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<th>3dvar -&gt; 4dvar</th>
<th>4dvar -&gt; 4dvar hybrid</th>
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Working Week on flow-dependent methods for meso-scale DA
24-28 Sept. 2012, Copenhagen, DMI

Short term
1) RUC 3DVAR 3h cycle.
   1h cycle in research.
   36h
2) FGAT VarBG MesCAN/EXF
3) Correl. errors/thinning/superobsing.

Algorithmic developments:
1) RUC 3h cycle / research 1h cycle
2) 4DVAR AROME
3) 3DVAR Hybrid/3DFGAT / "B"-slicing
4) 4DENSVAR
5) LETKF Kalman filter like/ERFF
6) Gaussian quadrature 4DVAR.
Long term algorithmic developments:

1) critical mass of “team” work is needed to assure the progress;

2) 4D-Ens-VAR framework is proposed as a long perspective “algorithmic investment”
   * 4DVAR (ECMWF non-linear and diabatic simplified physics) and Hybrid ensemble variational data assimilation should be seen a “realisations” of 4D-Ens-VAR

3) Long term core data assimilation developments should consistently fit into OOPS/IFS paradigm
Solution in long term perspective

Transversary issue: interaction of initialisation/dynamics/physics/model error
Problem: too slow progress implementing “new” types of observations in the HARMONIE system

Working Week on the flow-dependent methods for meso-scale DA
Copenhagen, DMI, the 24th - 28th of September

The factors which should speed up progress in Use of Observations
1) “Global” and “stable” pre-processing solutions (COPE on the long perspective)
2) More strict “phasing” procedure with the DA&UO experts involved
3) Two sided “phasing”: HARMONIE developments are phased into cycles evolution
4) Common/joint pre-processing software for as large number of observations as possible
5) Higher level of ambitions in the operational collaboration

The Project Leader on DA&UO should became more experienced and create high level of communication between staff members in HIRLAM consortium
Solution for long term perspective (2)

The theoretical basis of the variational data assimilation is violated in presence of the systematic bias and the flow-dependent representativity error

This is the common situation assimilation remote sensing observations

Assimilate structures instead of point observations