Evaluation of new IASI channel selections to improve the assimilation of cloud-affected radiances by the retrieval of cloud microphysical variables

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Context of the study

- Experimental campaign **HyMeX [1]**: better understanding of the hydrological cycle in the Mediterranean Sea.
- Convective scale model AROME W MED: 2.5 km grid size (Fourrié et al, 2012)
- 80 % of satellite data are covered by clouds.

New developments to improve the assimilation of cloud-affected radiances from the hyperspectral infrared sounder IASI in the convective scale model AROME.
State of the art for the treatment of cloud-affected radiances

Operational assimilation

• Use two cloud parameters: cloud top pressure ($CTOP$) and effective cloud fraction ($Ne$) to constrain the assimilation (Guidard, Fourrié et al, 2011)

  + Use of cloud-affected channels
  - Problems for the detection of low level clouds and thin cirrus clouds, simplified modelling of clouds (single layers of opaque clouds)
State of the art for the treatment of cloud-affected radiances

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New developments

- Use of microphysical variables for the assimilation: liquid water content (lwc) and ice water content (iwc).
  
  + Better modelling of clouds (multi layer, mixed phase).
  - Linearity

Encouraging results have been found by Martinet et al (2012)\(^1\) with only 77 channels.

Are these channels suitable for cloudy retrievals? Can we improve the retrieval of microphysical variables with new channels sensitive to cloud variables?

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\(^1\): Martinet et al 2012: Towards the use of microphysical variables for the assimilation of cloud-affected infrared radiances, QJRMS, DOI: 10.1002/qj.2046.
Methodology

- Evaluation of the selection of the 366 IASI channels used operationally at the European Centre for Medium-Range Weather Forecast (ECMWF). This selection was performed with the Degrees of Freedom of the signal (DFS) as the figure of merit on clear atmospheric profiles (Collard and McNally 2009).

- Addition of 134 channels sensitive to cloud variables. 366+134=500 channels: limit of the GTS to provide IASI observations to operational centres.

- Selection on 15 cloudy profiles from AROME: 5 semi-transparent ice clouds, 5 ice opaque clouds, 5 low liquid clouds.
Comparison of two channel selections

Selection based on the spectral sensitivity to the perturbation of \( lwc/iwc \)

\[ \Delta BT = BT(x+\delta x) - BT(x) \]

• BT response to the perturbation of each atmospheric constituent: \( lwc, iwc, T,q, Tskin, O_3, CH_4, CO \).

• Selection of channels with the highest sensitivity to \( lwc/iwc \) variables, the lowest sensitivity to interfering species (\( T,q \)…) and the lowest instrumental noise.

Semi-Transparent cloud: \( \Delta BT \) after perturbation

<table>
<thead>
<tr>
<th>( lwc/iwc ) perturbation: +10%</th>
<th>Ozone perturbation: +10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q perturbation: +10%</td>
<td>T perturbation: +1 K</td>
</tr>
<tr>
<td>Tskin perturbation: +1 K</td>
<td></td>
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</tbody>
</table>

Selection based on the DFS

\[ DFS = \text{tr}(I-AB^{-1}) \]

A: analysis error covariance matrix.
B: background error covariance matrix.
(cloudy matrix computed from a 6 member AROME ensemble on convective cases).

• Based on linear estimation theory
• Selection of the channels that most improve the DFS.
• Update of the B matrix with the A matrix computed after \( i \) channels have been chosen to take into account redundant information.

Ackn: C. Clerbaux and J. Hadji-Lazaro for CO profile
Comparison of two channel selections

Selection based on the spectral sensitivity to the perturbation of lwc/iwc

- Only 24 channels shared by the two methods of selection

- Selection in the 3 window regions: 800-1000 cm\(^{-1}\), 1090-1200 cm\(^{-1}\), 1800-2150 cm\(^{-1}\)

- Selection of water vapour channels by the DFS (contribution to cloud variables and cross-correlations between lwc/iwc and q in the \(B\) matrix).

- For both selections, most of the selected channels are located in the band \(1800-2150\) cm\(^{-1}\) (higher wave numbers have been discarded to avoid noisy channels).
Evaluation by mean of 1D-Var retrieval applications in the context of OSSE.

• Use of AROME profiles within homogeneous overcast observations perturbed with a Gaussian noise proportional to the $B$ matrix:

\[ x = x_{\text{true}} + \varepsilon_b B^{1/2} \]

• Simulation of IASI radiances with RTTOV CLD. Perturbation with the IASI instrument noise provided by CNES and radiative transfer model errors.

\[ y = H(x_{\text{true}}) + \varepsilon_o R^{1/2} \]

• Use of a background error $B$ matrix computed from a 6 member AROME ensemble on convective cases (Thibaut Montmerle [1]).

• Comparison of RMSE of the background and the analysis with respect to the « true » profile. 346 channels monitored at ECMWF + new selection of 134 channels (480 channels total).

1. Michel et al. 2011: Heterogeneous Convective-Scale Background Error Covariances with the inclusion of hydrometeor Variables. Monthly Weather Review, 139, 2994-3015.
Evaluation by mean of 1D-Var retrieval applications in the context of OSSE.

- Good quality of the 366 IASI channels for cloudy retrievals.
- BUT Improvement of the RMSE by 7% with the new selections.

- RMSE equivalent with 366 and 500 channels in the case of semi-transparent clouds (not shown)
- Equivalence of the two selections in terms of RMSE.
Temperature and humidity Jacobians

Liquid cloud

Semi-Transparent cloud

Opaque cloud

Humidity Jacobians: K/ppmv

DFS

Physical

Temperature Jacobians: K/K
Sensitivity to the ice optical parametrizations in RTTOV-CLD. (Example of the physical selection)

- In RTTOV-CLD, the user must choose what assumption to use to parameterize the effective diameter. 4 parametrizations available: Boudala, McFarquhar, Ou and Liou, Wyser.

- 60% of the selected channels are shared by both parametrizations.

- Small differences are observed.

- No impact on 1D-Var retrievals.

Robustness of the physical selection to the ice optical properties.
Sensitivity to the weather regime.

- Atmospheric profiles from the last ECMWF database are used to perform the physical selection.

- Each cloud type (semi-transparent, opaque, liquid) is composed of four air-mass types: Mid-Latitude South, Mid Latitude North, polar and tropical.

Significant differences in bands 800-1000 cm\(^{-1}\) 1090-1200 cm\(^{-1}\) but most of the channels are selected in band 1800-2150 cm\(^{-1}\) for both selections.
Sensitivity to the weather regime: 1D-Var performance.

- No significant difference is observed in terms of 1D-Var retrievals
- The physical selection is quite independent of the air-mass type.

Impact of the analysis of cloud variables on NWP forecast.

- The profiles analysed with 480 channels are used in a 1D-version of the AROME model.
- Evolution of the profiles during 3 hours to evaluate if the information brought by the observation is well conserved by the model.

- Three cases are tested: evolution of the **background**, the analysis of T,q,LWC,IWC and the analysis of only T and q keeping LWC and IWC to the background values.
Conclusion and prospects

Past

• A set of 134 channels selected with a physical approach are proposed to improve the analysis of cloud variables

• Its robustness on the ice optical parametrization and the weather regime was demonstrated.

• Encouraging results have been found on a simplified version of AROME: the analyses of cloud variables are able to modify the forecast of cloud variables during the 3 hours of the assimilation window.

Future

• Modification of the cloud fraction during the assimilation (according to the lwc/iwc modifications).

• Global validation of the new channel selection in a quasi-operational context (if the lwc/iwc variables can be included in the 3D version of the model).
Thanks for your attention.
First studied case: Low Cloud (Observation minus background departures)

Decrease of the model cloudiness to fit the observation.
First studied case: Low Cloud

- Decrease of the liquid water content.
- A small amount of ice water content appears because of the cross-correlations between $q$ and IWC.
Second studied case: Semi-Transparent Cloud

Increase of the model cloudiness to fit the observation.
Second studied case: Semi-Transparent Cloud

- Increase of the ice water content.
- A small amount of liquid water content appears because of the cross-correlations between q and LWC.