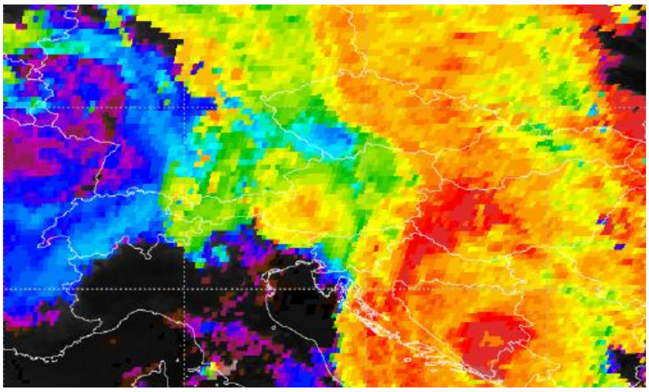
Regional Cooperation for
Limited Area Modeling in Central Europe

LACE
nwp central europe

Data assimilation of all-sky radiance observations from MTG IRS



Author: Suzana Panežić (DHMZ)

Supervisors: Florian Meier, Adhithiyan Neduncheran
(GeoSphere Austria) and Benedikt Strajnar (ARSO)

Place: GeoSphere Austria, Vienna and ARSO, Ljubljana

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GeoSphere Austria DHMZ Czech Hydrometeorological Institute OMSZ IMGW METEO ROMANIA SHMÚ ARSO METEO Slovenia

1 Introduction

The Metop satellites are Europe's first operational meteorological satellites in polar orbit. Each Metop satellite carries the same sophisticated suite of instruments providing fine-scale global data. One such instrument is an Infrared Atmospheric Sounding Interferometer (IASI) that measures infrared energy emitted by the earth-atmosphere system in 8461 individual spectral channels with a spatial resolution of 50 km at nadir.

Infra-red sounder (IRS) should be launched on an MTG geostationary orbiting platform in the summer of 2025 (latest information on the launch date at the time of writing this report), measuring infrared energy emitted in 1960 individual spectral channels. Measurements should be performed over the full Earth disk with a particular focus on Europe, with a spatial resolution of 4 km at the nadir and a temporal resolution of 30 min.

Both instruments are nadir looking Fourier transform spectrometers but with such high spatial and temporal resolution, IRS should provide invaluable data for the operational nowcasting systems. With this in mind, we are using IASI data as a proxy to prepare for the assimilation of the high-resolution IRS data. The assimilation of multilayer cloud-affected infrared radiances using the all-sky assimilation approach by Okamoto [1] is explored and relevant code parts for the ALARO/AROME implementation are highlighted in the next section.

2 Code routines

The code version CY48T3_bf3 is used to fully take advantage of the latest code development and OOPS framework. It is also the latest export version at the time of writing this report. As such, we can explore the assimilation of IASI data using EnVar schemes. Relevant routines were explored to familiarize ourselves with the code, and this section contains their overview regarding the assimilation of IASI data.

Routine: odb/pandor/module/bator_decodbufr_mod.F90

Bator routine for decoding bufr files containing observed IASI radiance data. Data quality check rejects data with zenith angle outside of the [0,75] degrees range, latitudes outside the [-90,90] range, longitudes outside of the [-180,180] range and altitudes lower than 90 km. Brightness temperatures at a given wavenumber ($T_B(\nu)$) is derived using the inverse Planck formula with the formulation below:

$$T_B(\nu) = \frac{C_2\nu}{ln(\frac{C_1\nu^3}{r}+1)} \tag{1}$$

where first Planck constant is $C_1 = 1.1910659e-10 \quad \frac{W}{m^2.ster.m^{-2}}$, the second Planck constant is $C_2 = 1.438833 \quad \frac{K}{cm}$, r is observed radiance and ν is a channel's wavenumber. Derived brightness temperature is then stored in the odb database as the obs value.

The routine also contains protection against dividing with very small numbers around the 0 value (larger than -0.00001 and smaller than 0.00001) when deriving brightness temperatures in order to avoid floating-point exceptions. Such data are rejected. Additionally, unrealistic brightness temperature values are rejected (smaller than 150 K and larger than 350 K).

Routine: arpifs/obs_preproc/read_iasichans.F90

Reads the channel list file (named iasichannels) to determine the IASI channels to be used in upper-air data assimilation. Example of a channel list file:

```
 &CHANNELS2LOAD
   I__number_of_channels= 314,
   I__channels(1)= 16,
   I__channels(2)= 38,
   I__channels(3)= 49,
...
   I__channels(314)= 8007,
 /
 &NACIETEO
 /
 &NAEAEM7
 /
 &NAMCA
 /
 &NAMENKF
 /
 &NAMFPDYF
 /
 &NAMGWD
 /
 &NAMGWWMS
 /
 &NAMPPVI
 /
```

Furthermore, it will read all-sky mask file (named iasichannels_allskymask). This part of the code is coded under the LECMWF logical key so in order to allow all-sky mode in ALARO/AROME, modification is needed. All-sky mask file is needed to assign which channels from the channel list to assimilate in all-sky mode (mask value=1 if channel is to be assimilated in the all-sky mode, mask value=0 if not). Example of the namelist:

```
 &CHANNELS2LOAD
   I__number_of_channels= 314,
   I__channels(1)= 1,
   I__channels(2)= 1,
   I__channels(3)= 1,
...
   I__channels(314)= 0,
 /
 &NACIETEO
 /
 &NAEAEM7
 /
 &NAMCA
```

```
/
&NAMENKF
/
&NAMFPDYF
/
&NAMGWD
/
&NAMGWWMS
/
&NAMPPVI
/
```

Routine: arpifs/op_obs/hretr_rad.F90

Routine is used for the preparation and computation of the model brightness temperatures. It sets up and fills VARBC special predictors (nadir viewing and solar zenith angle) then calculates observation biases which will be removed from the observation values:

```
CALL YLVARBC_EXTRA_PRED%SETUP(YDGP5%NDLEN,(/YLVARBC_EXTRA_PRED%NVANG,
      YLVARBC_EXTRA_PRED%SOLZEANG/))
YLVARBC_EXTRA_PRED%VALUE(:,1)=ZNVANG        %Nadir viewing
YLVARBC_EXTRA_PRED%VALUE(:,2)=ZSOLZENANG    %Solar zenith angle

CALL YDVARBC%PREDICTORS(YDGP5, IDATOB, ITIMOB, ZLAT, ZLON, ZXPRED,
      YLVARBC_EXTRA_PRED, LD_MWAVE=.FALSE.)

CALL YDVARBC%BIAS (IXVARBC, IMXBDY, ICMBDY, YDGP5%NDLEN, ZXPRED,
      ZBIAS_PREVIEW, ZBODYPRED)
```

To separate surface and atmospheric effects for low-level channels, surface emissivity information is needed [2]. This can be provided in the form of a climatological data file (atlas) or can be dynamically calculated for better performance. Surface emissivity values are interpolated from the emissivity atlas to the model grid and missing values are filled with the dummy emissivities (value 2.0 for the sea, 0.98 where there is a mixture of sea and land; in cases where the atlas is not used, only dummy values will be used). To compute the dynamic emissivity and skin temperature, a radiative transfer code is called. At locations where dynamic emissivity is available (stored at ZVAROUT output variable), dummy values will be replaced. Through the LDYN_EMIS and LDYN_TSKIN logical keys, atlas values can be further replaced by the dynamic emissivity and skin temperatures.

Routine has several methods which can be used for computation in cloudy conditions. Under the logical key LCO2_DIAG_IASI exists the CO2 slicing method, which combines infrared longwave-window channel data with CO2 absorption channel data to specify the cloud height. In this case, the radiative transfer code will run with the additional option LDCO2SLICING= .TRUE. and will estimate the cloud-top pressure and effective cloud fraction. It is then possible to use these estimated cloud parameters as set constraints to assimilate cloud-affected infrared radiances (controlled by logical keys LCLDSINK and LTOVSCV in the routine). This method is used by Météo-France for the assimilation of AIRS data [3].

To allow the computation of cloudy model brightness temperatures within the radiative transfer code, logical key LRTCALC_HRETR=.TRUE. needs to be used. At this point, the radiative transfer code is called and calculates total/cloudy (ZTBTOT) and clear brightness temperatures (ZTBCLR), using emissivity data (ZEM5) as input. More precisely, ZTBCLR is a pseudo-cloud-free model brightness temperature first-guess that is provided by RTTOV in addition to the regular brightness temperature first-guess (ZTBTOT). For the computation of the model pseudo-cloud-free brightness temperature, the cloud scattering is switched off and clouds do not impact the radiative transfer [4]. For the computation of cloudy brightness temperatures, additional model first-guess profiles are to be provided as input to the radiative transfer code: cloud liquid water (CLWF), cloud ice water (CIWF), and cloud cover (CCF). Currently, these values are set to zero for clear-sky calculations in ALARO/AROME so this part requires modification.

```
IF ((.NOT.LECMWF) .AND. (.NOT. LBAY_RADIF)) THEN
   YDGP5%CCF(:,:,IH)  = 0.0_JPRB
   YDGP5%CLWF(:,:,IH) = 0.0_JPRB
   YDGP5%CIWF(:,:,IH) = 0.0_JPRB
 ENDIF

 CALL RADTR_ML(ICOEF,ISENSOR,YDGP5%NDLEN,IMXBDY,ICOUNT,&
   & SATGRP_TABLE(YDSET%GROUP)%NTOPLEVELS,ZVPOBS,&
   & SATGRP_TABLE(YDSET%GROUP)%CLD_RTCALC_SCREEN,&
   & ZZEANG,ZAZIANG,ZSOLZENANG,ZSOLAZIANG,ZLAT,ZLON,&
   & YDGP5,ZO3F_UPDATED,&
   & ZPS5,ZTS5_UPDATED(:),ZT2M_TOVS5,ZQ2M_TOVS5,&
   & ZCTOP_TOVS5,ZCAMT_TOVS5,ZEM5,&
   & ZTBCLR, ZTBTOT, ZTAU, ZRADCLDLEV,YDJOT,&
   & PCLDLEV=ZCLDLEV, PTAUSFC=ZTAUSFC)
```

Collocated AVHRR data provide information on surface properties and the presence of clouds in the IASI field of view (FOV) and are used for cloud detection in IFS [3]. For ALARO/AROME different cloud detection method is used. Brightness temperatures in clear-sky conditions (ZTBCLR) and debiased observation data (ZOBSC) are used as input for the cloud detection algorithm. Observations that are affected by clouds are flaged with ICLDFLAG=1. For IFS, there is an additional detection of trace gas and aerosols which are then used to flag aerosol-affected observations with ICLDFLAG=-1.

```
CALL CLOUD_DETECT(ISENSOR, IMXBDY,&
  & NINT(ZVPOBS(JOBS,:)),&
  & ZTBCLR(JOBS,:),ZOBSC(JOBS,:),&
  & ZCLDLEV(JOBS,:),ICLDFLG(JOBS,:),IMINLEV(1), IMAXLEV(1),&
  & IMAGER_CLOUD_FLAG(JOBS) )
```

If differences between ZTBCLR and ZOBSC are too small, cloudy data might be filtered out as instrument noise and not be flagged as cloudy by the cloud detection algorithm. Therefore, an additional check is needed to ensure a similar amount of cloudy data as in observations. It is performed by comparing the values of the total/cloudy (ZTBTOT) and clear brightness temperatures (ZTBCLR). In case the ZTBCLR - ZTBTOT difference (marked as LLMCLD) is greater than 0.08 K for humidity channels then the observation is flaged as cloudy by a model cloud flag. Afterward, if the observation is flagged as cloud or aerosol-affected, the observation error is inflated to the value of 5.0.

```
  IF ( ICLDFLG(JOBS,ICOUNT(JOBS)) == 1 .OR. ICLDFLG(JOBS,ICOUNT(JOBS)) == -1
    .OR. LLMCLD ) THEN

    ROBODY%ERRSTAT%OBS_ERROR(IBODY) = 5.0_JPRB ! Obs error (see RAD1COBE)
    ROBODY%ERRSTAT%FINAL_OBS_ERROR(IBODY) = 5.0_JPRB ! Final error
```

Atmospheric transmissivity (TAUSFC) calculated by the radiative transfer code is stored to the odb database as:

```
SATBODY%RADIANCE_BODY%TAUSFC(IBODY)=ZTAUSFC(JOBS,ICOUNT(JOBS))
```

Routine: arpifs/op_obs/cloud_detect.F90

Cloud detection algorithm uses brightness temperatures in clear-sky conditions (ZTBCLR) and debiased observation data (ZOBSC) in order to calculate the corresponding departure vector. Channels are then ranked depending on their sensitivity to clouds (larger departures = larger sensitivity to clouds) and split into several departure vectors (one for each spectral band). In order to remove instrument noise, the moving average is applied to the departure vectors. Within each vector, maximum departure is found. In sounding locations where no departure values exceed a predefined threshold, observation is marked as a clear-sky observation (K__CLOUD_FLAG=0). The rest of them are marked as cloudy.

For cloudy data, an additional search for cloud top is performed. In each band, starting from the channel ranked most sensitive to the cloud, the channel index is incremented upwards (i.e. decreasing cloud sensitivity in the ranked space). When the gradient and the absolute value of the filtered departure vector fall below their respective predefined thresholds, the channel in question is considered to correspond to the cloud top. In the search algorithm, the signs of the thresholds are set according to the sign of the filtered departure for the lowest channel to be equally able to deal with a cold cloud over a warm surface or warm cloud over a cold surface [5].

3 Code modifications

All-sky code modification made by Adhithiyan Neduncheran [6] was used as the basis to build on and assimilate IASI data. On ECMWF ATOS machine a clean main pack for CY48T3_bf3 was installed on:

```
/perm/hr1g/pack/CY48t3_bf.03.OMPIIFC2104.x
```

All code modifications used for testing can be found on a user pack:

```
/perm/hr1g/pack/CY48t3_iasi_04.01.OMPIIFC2104.x
```

Routine: arpifs/obs_preproc/sugoms.F90

As all-sky assimilation of infrared radiances affects cloud liquid water content (GID%L), cloud ice content (GID%I), and cloud fraction (GID%A), they need to be added to the part of the code that deals with radiative transfer calculations in cloudy conditions. In this case, we have switched hydrometeors from diagnostic moist physics (GID%PHYS) that are relevant for MW all-sky DA (communication with Adhithiyan Neduncheran) with three relevant ones.

```
IF (.NOT.LCANARI) THEN
  IF( ANY(SATGRP_TABLE(:)%CLD_RTCALC_ASSIM) .OR. ANY(SATGRP_TABLE(:)%CLD_RTCALC_SCREEN)
    )THEN
    CALL GOM_SET_INTERPOLATED( YDGOM, KID=GID%L, KOBTYPE=NSATEM,LDINTERP=.NOT.LDOBSTL)
    CALL GOM_SET_INTERPOLATED( YDGOM, KID=GID%I, KOBTYPE=NSATEM,LDINTERP=.NOT.LDOBSTL)
    CALL GOM_SET_INTERPOLATED( YDGOM, KID=GID%A, KOBTYPE=NSATEM,LDINTERP=.NOT.LDOBSTL)
    !CALL GOM_SET_INTERPOLATED( YDGOM, KID=GID%PHYS, KOBTYPE=NSATEM, LDINTERP=.TRUE.)
  ENDIF
ENDIF
```

Routine: arpifs/module/gom_plus.F90

As the modification in the prior routine affects hidrometeors, we want them to not have a negative value. Therefore, we are extending this part of the routine so that it involves ALARO/AROME by removing the LECMWF logical key.

```
!if (lecmwf) then
  where ( gp%clwf(:,1:gp%nflevg,jhoriz) < 0.0_jprb)
    gp%clwf(:,1:gp%nflevg,jhoriz) = 0.0_jprb
  where ( gp%ciwf(:,1:gp%nflevg,jhoriz) < 0.0_jprb)
    gp%ciwf(:,1:gp%nflevg,jhoriz) = 0.0_jprb
  where ( gp%ccf(:,1:gp%nflevg,jhoriz) < 0.0_jprb)
    gp%ccf(:,1:gp%nflevg,jhoriz) = 0.0_jprb
!endif
```

Routine: arpifs/obs_preproc/read_iasichans.F90

As mask file in all-sky assimilation of IASI data is only read for IFS, we are removing the LECMWF logical key here as well. This means the mask file will be mandatory for now, until a better condition is found.

```
! Open channel mask file
!     IF(LECMWF) THEN
       INIU1=NULUSR4
       WRITE(NULOUT,*)’READING iasichans_allskymask namelist file:’
       OPEN(INIU1,STATUS=’OLD’,FORM=’FORMATTED’,FILE=’iasichannels_allskymask’,
       IOSTAT=IOS)
...
!     ENDIF
```

Routine: arpifs/op_obs/hretr_rad.F90

As mentioned in previous section, for the calculation of total brightness temperature (ZTBTOT) in all-sky conditions, additional first-guess profiles (cloud liquid water, cloud ice water and cloud cover) are required. Therefore, condition where three variables are not initialized to zero value is extended with logical keys CLD_RTCALC_ASSIM and CLD_RTCALC_SCREEN related to cloud radiative transfer calculations.

By default, cloudy observations are assigned a fixed observation error and final observation error (5.0). In Okamoto (2023), a predictor that quantifies the cloud amount in both the first-guess and the observations is defined. This is the averaged cloud effect (C_A; in code defined as a new variable ZCLDA):

$$C_A = \frac{|B - B_{CLR}| + |O - B_{CLR}|}{2} \tag{2}$$

where B is a total brightness temperature (ZTBTOT), B_{CLR} is a clear brightness temperature (ZTBCLR) and O is observed brightness temperature value (ZOBS). In order to not introduce systematic errors, both the observation and the model first-guess cloud effect are considered. In the article, the observation error linearly increases with the averaged cloud effect. For a starting test, we have defined the inflation of observation error as a sum of a default clear-sky observation for each channel (ROBODY%ERRSTAT%OBS_ERROR(IBODY)) and an averaged cloud effect (ZCLDA)(similar behaviour as in article). This should later be replaced by a diagnosed linear fit from a longer assimilation cycle. Following the work of Okamoto (2023), quality control was added where the observation was rejected if averaged cloud effect exceeded 5 K.

```
REAL(KIND=JPRB)   :: ZCLDA
...
!IF ((.NOT.LECMWF) .AND. (.NOT. LBAY_RADIF)) THEN
IF (((.NOT.LECMWF) .AND. (.NOT. LBAY_RADIF)) .AND. &
    & (.NOT. SATGRP_TABLE(YDSET%GROUP)%CLD_RTCALC_ASSIM) &
    & .OR. (.NOT. SATGRP_TABLE(YDSET%GROUP)%CLD_RTCALC_SCREEN)) THEN
    YDGP5%CCF(:,:,IH)  = 0.0_JPRB
    YDGP5%CLWF(:,:,IH) = 0.0_JPRB
    YDGP5%CIWF(:,:,IH) = 0.0_JPRB
ENDIF
...
IF ( ICLDFLG(JOBS,ICOUNT(JOBS)) == 1 .OR. ICLDFLG(JOBS,ICOUNT(JOBS)) == -1 &
    & .OR. LLMCLD ) THEN
    ZCLDA=(ABS(ZTBTOT(JOBS,ICOUNT(JOBS))-ZTBCLR(JOBS,ICOUNT(JOBS))) &
    & +ABS(ZOBS(JOBS,ICOUNT(JOBS))-ZTBCLR(JOBS,ICOUNT(JOBS))))/2.0_JPRB

    !Obs error
    ROBODY%ERRSTAT%OBS_ERROR(IBODY) =ROBODY%ERRSTAT%OBS_ERROR(IBODY)+ZCLDA
    !ROBODY%ERRSTAT%OBS_ERROR(IBODY) = 5.0_JPRB
    !Final obs error
    ROBODY%ERRSTAT%FINAL_OBS_ERROR(IBODY) = ROBODY%ERRSTAT%FINAL_OBS_ERROR(IBODY)+ZCLDA
    !ROBODY%ERRSTAT%FINAL_OBS_ERROR(IBODY) = 5.0_JPRB
```

```
    IF (ZCLDA > 5.0_JPRB) THEN
        ROBODY%BODY%DATUM_STATUS(IBODY) = ZCHSTAT_REJECT(ROBODY%BODY%DATUM_STATUS(IBODY)
    ENDIF
ENDIF
```

4 Setting up a C-LAEF 1k IASI data assimilation experiment

C-LAEF (Convection-permitting Limited-Area Ensemble Forecasting) has been developed at the Austrian national weather service Geosphere and has been running operationally at the European Centre for Medium Range Weather Forecasts (ECMWF) supercomputer since November 2019. Since 2023, there has been strong effort on upgrading C-LAEF to 1km resolution (C-LAEF 1k). Cooperation with Slovenia and Croatia has been established with common development and maintenance in mind. With 16 3D-Var ensemble members and one additional EnVar member, it makes a good base for testing and development of all-sky IASI data assimilation.

- Model: AROME CY46T1 (16 members) + AROME CY48T3 (1 member)
- Domain: C-LAEF 1k; Δx = 1 km; 1500x1080 GP; 90 vertical levels,
- Coupling: 3h space consistent coupling from IFS
- Upper air analysis: 3D-Var (16 members) or EnVar scheme (1 member) using OOPS framework; 3h Assimilation cycle; REDNMC=0.5, Ensemble data assimilation B matrix;

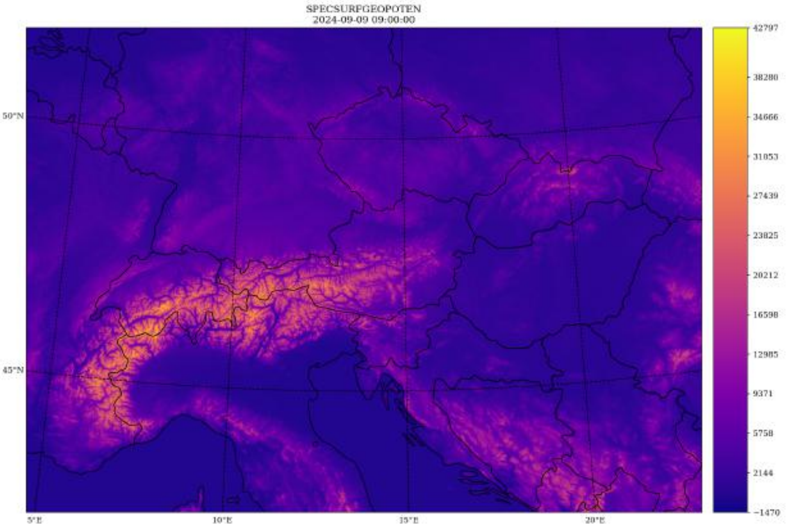


Figure 1: C-LAEF 1k domain

C-LAEF 1k code was pulled from the github:

`https://github.com/C-LAEF/claef_1k`

C-LAEF 1k suite was set up on ECMWF machine under ecFlow workflow package on:

`/home/hr1g/claef_1k`

Since no satellite data is currently assimilated within operational C-LAEF 1k suite, additional files, script and namelist modifications were needed to allow the assimilation of the IASI data.

In order to assimilate IASI data in C-LAEF 1k, the RTTOV v12 land surface infrared emissivity atlases were downloaded from:

`https://nwp-saf.eumetsat.int/site/software/rttov/download/`

As older RTTOV v11 visible/IR cloud/aerosol coefficients could not be processed by v12 RTTOV, a selection of v12 coefficients was downloaded from the MF Belenos machine (rtcoef_metop_2/3_iasi.H5 and sccldcoef_metop_2/3_iasi.H5 containing cloud related coefficients for all-sky DA). The coefficient files that were downloaded contained information for 314 channels and were in '.H5' format. Bator namelist was adapted to process these 314 channels. IASI channel list files were set up as in section 2 examples. Following the work of Alan Geer [7] and Kozo Okamoto [8], four IASI water vapor channels were chosen for the assimilation in all-sky mode (from both articles channel list + that are not blacklisted in mf_blacklist.b): **2951, 2958, 3049** and **3105**. The rest of the channels are assimilated in clear-sky mode. VARBC file was taken from the AT operational archive. To explore the impact of the current version of implemented IASI data all-sky assimilation, **2 km thinning distance** was used.

For running assimilation of IASI data in all-sky mode with the modified user pack from section 3, additional logical switches in "naml_observations" and screening/minimization namelists are needed (for cloud radiative transfer calculations):

```
&NAMSATS
    LCLD_RTCALC_SCREEN(16)=.TRUE.,
    LCLD_RTCALC_ASSIM(16)=.TRUE.,
    LRTCALC_HRETR(16)=.TRUE.
```

As Metop satellites are polar orbiting satellites, IASI data are available only twice per day above Europe (around 09 UTC and 21 UTC). To have a meaningful case for an all-sky case study with the IASI data, good data coverage above a mesoscale convective system was needed. As such, two cases were selected: 22.07.2024. at 09 UTC and 09.09.2024. at 09 UTC [Figure 2].

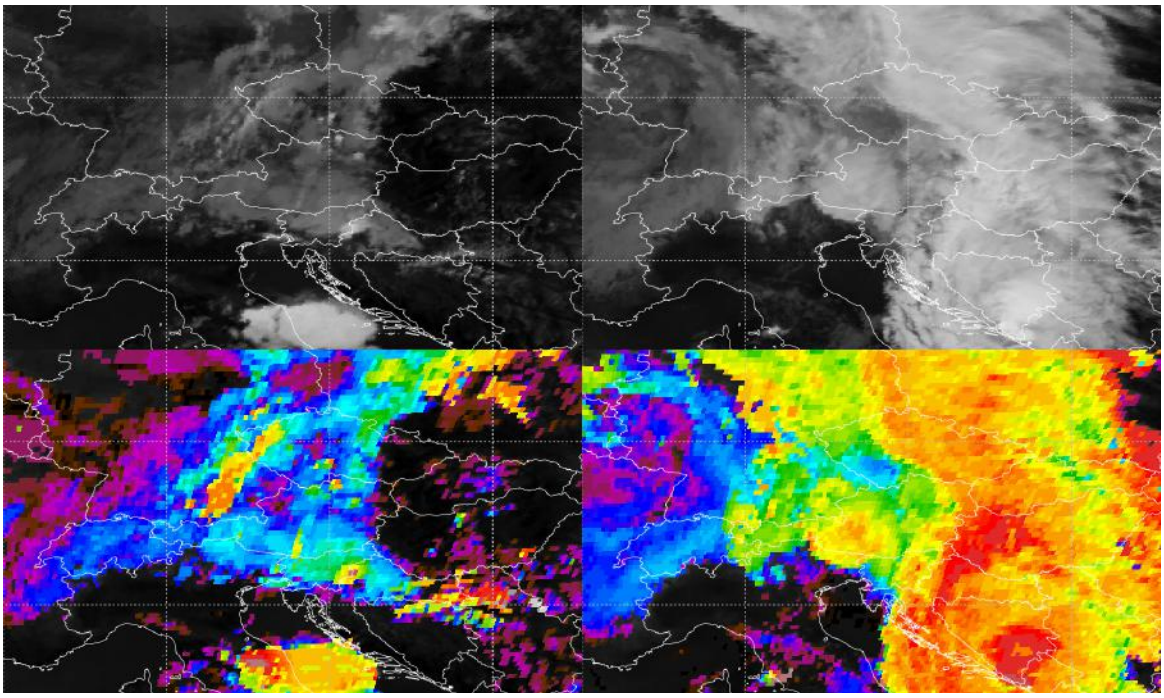


Figure 2: Eumetview: High Rate SEVIRI IR10.8 μm Image (upper picture) and Cloud top product (lower picture); Cases 22.07.2024. at 09 UTC (left) and 09.09.2024. at 09 UTC (right)

5 Case studies

Odb databases are evaluated as to see if variate observation errors are applied correctly and what data are kept or rejected by the quality control.

Case studies were performed for dates: 22.07.2024. at 09 UTC and 09.09.2024. at 09 UTC. As the main interest lies with the CY48T3 EnVar member (MEM_17) of the C-LAEF 1k system, three experiments with said member were set up:

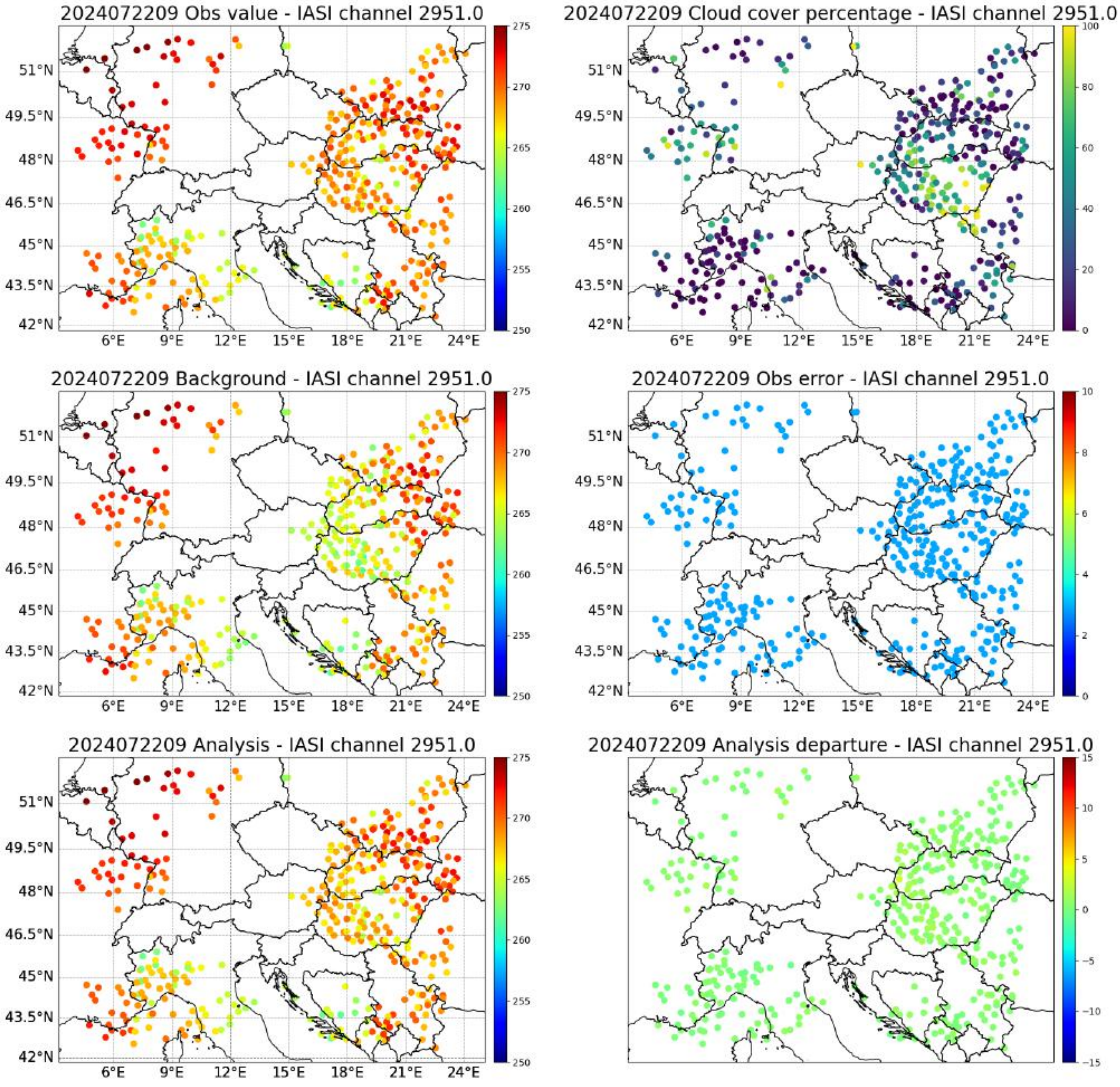
- REF_CLRSKY - assimilation of only clear-sky observations; observations with cloud flag are rejected
- ALLSKY_NQC - assimilation of all-sky observations for 4 WV channels; other channels are assimilated in clear-sky mode; observation error of cloudy observations varies with averaged cloud effect;
- ALLSKY_QC - assimilation of all-sky observations for 4 WV channels; other channels are assimilated in clear-sky mode; observation error of cloudy observations varies with averaged cloud effect; additional quality control (data where $C_A > 5.0$ rejected)

Odb data samples have been depicted on a map for both cases, featuring observed, simulated, and analyzed brightness temperatures, as well as cloud cover percentage, observation error, and analysis departure (Figures 3-7). Comparing them with Figure 2, it can be seen that the high values of observation errors are assigned to the high and thick clouds with very low brightness temperatures. Such observations will have large first-guess departures and will be rejected by the additional quality control (($C_A > 5.0$). This can be seen on both histograms as well (Figures 8 and 9). Quality control shows similar behavior as in Okamoto (2023) with histograms' cold tail cut-off value positioned at 10 K. With only two cases that were selected especially for their large cloud coverage, it would be wrong to make conclusions about the Gaussianity of the first guess departure statistics, so this will be left for later exploration. The number of assimilated observations in all-sky mode is significantly larger than in clear-sky mode (around 3x more).

Looking at the mapped analysis departures it can be seen that the observations with a large observation errors have very small impact on the analysis, which is the wanted behavior. At the same time, cloudy observations have a significant cooling effect where needed and don't impede the atmospheres warming by warm observations.

6 Conclusion

Initial results showed no unwanted behaviour by the above explained setup of IASI all-sky data assimilation in C-LAEF 1k system, so it can be used as a basis for the future development. Next steps would be to implement the averaged cloud effect variable as an additional VARBC predictor, explore additional QC as described in Okamoto (2023), better modeling of observation error and perform impact studies.



2024072209 Obs value - IASI channel 2951.0

2024072209 Cloud cover percentage - IASI channel 2951.0

2024072209 Background - IASI channel 2951.0

2024072209 Obs error - IASI channel 2951.0

2024072209 Analysis - IASI channel 2951.0

2024072209 Analysis departure - IASI channel 2951.0

Figure 3: IASI DA MEM_17 - 22.07.2024. at 09 UTC; REF_CLRSKY experiment; IASI channel 2951

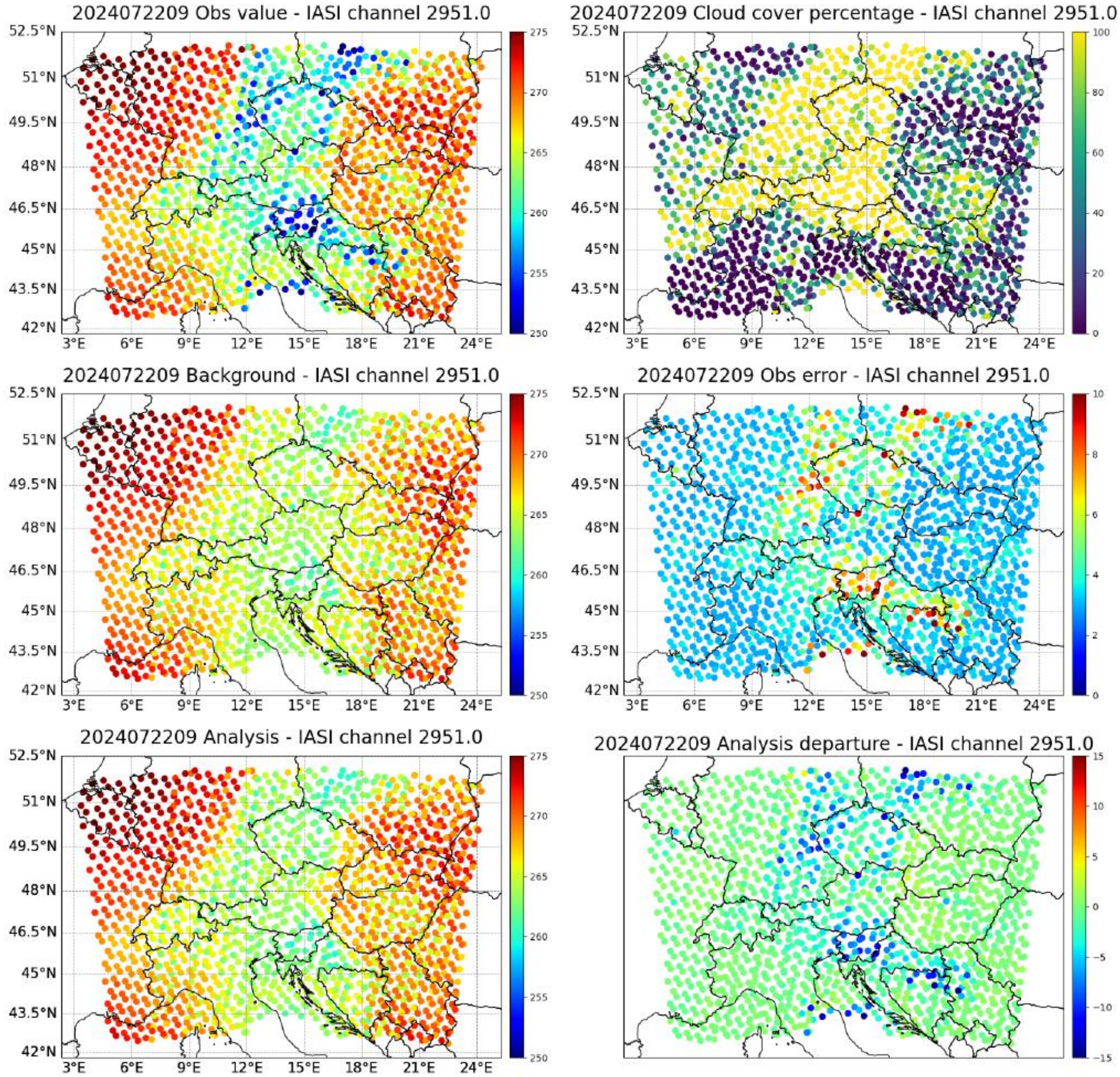


Figure 4: IASI DA MEM_17 - 22.07.2024. at 09 UTC; ALLSKY_NQC experiment; IASI channel 2951

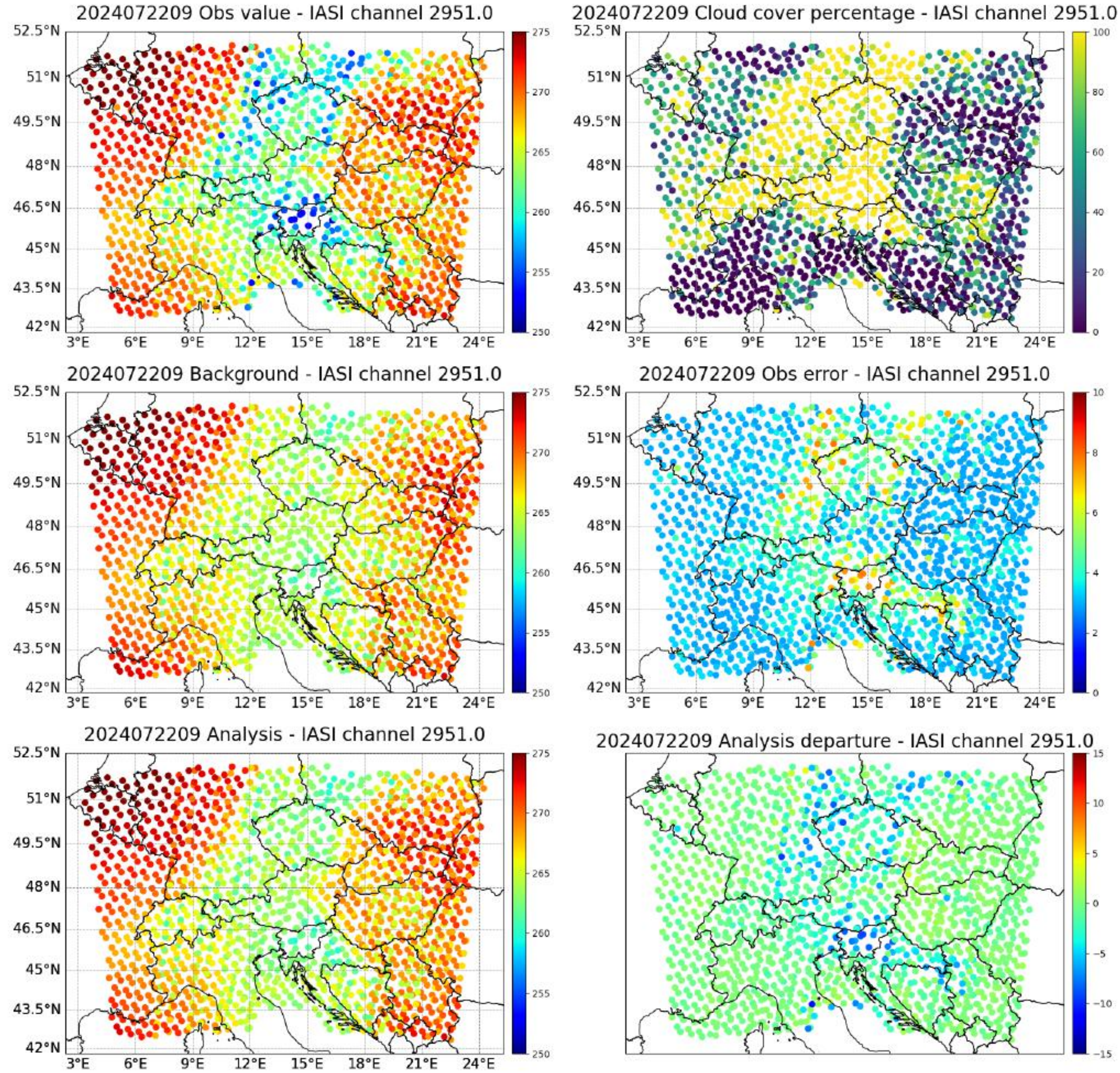
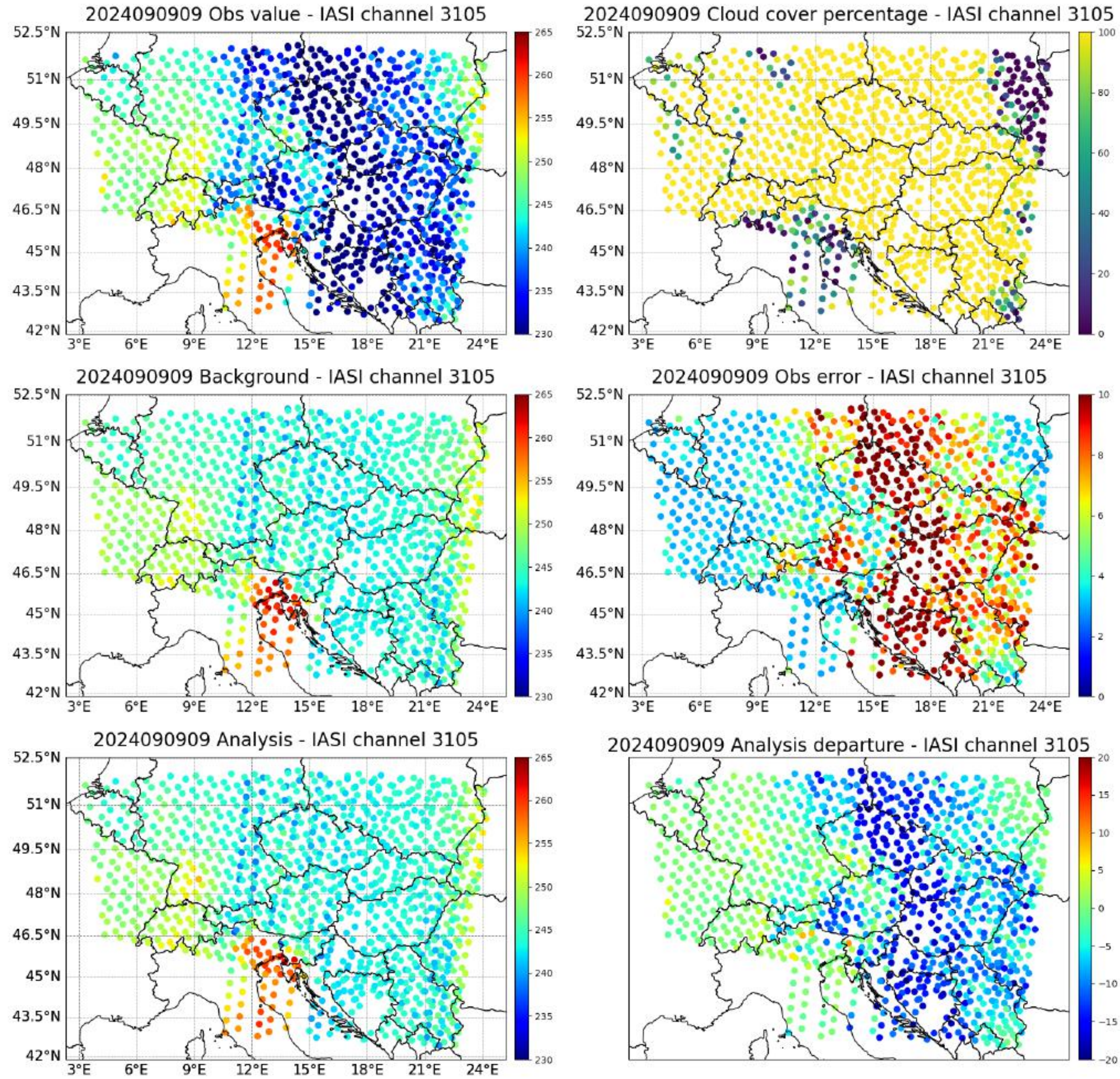


Figure 5: IASI DA MEM_17 - 22.07.2024. at 09 UTC; ALLSKY_QC experiment; IASI channel 2951


2024090909 Obs value - IASI channel 3105

2024090909 Cloud cover percentage - IASI channel 3105

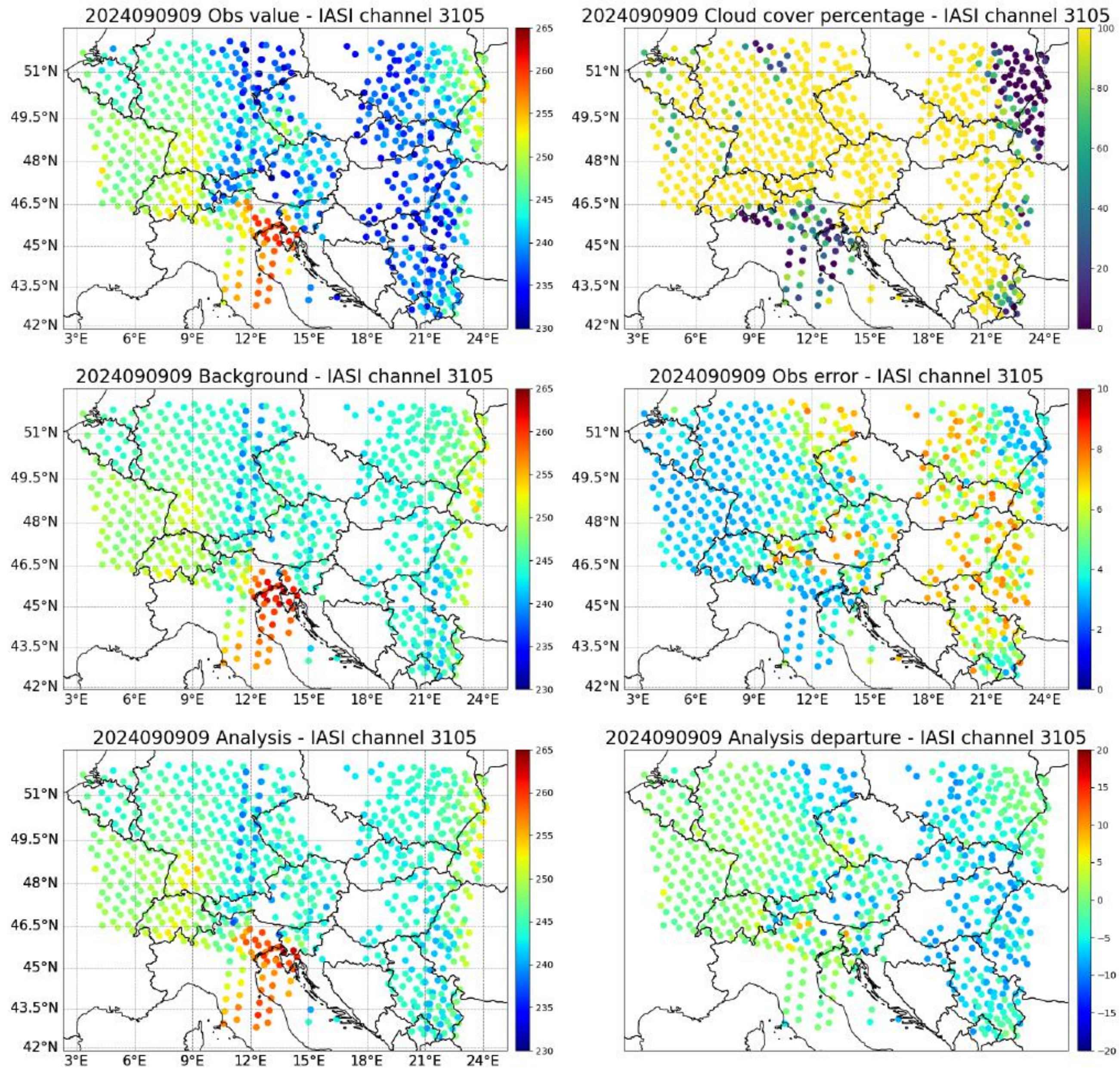
2024090909 Background - IASI channel 3105

2024090909 Obs error - IASI channel 3105

2024090909 Analysis - IASI channel 3105

2024090909 Analysis departure - IASI channel 3105

Figure 6: IASI DA MEM_17 - 09.09.2024. at 09 UTC; ALLSKY_NQC experiment; IASI channel 3105


2024090909 Obs value - IASI channel 3105

2024090909 Cloud cover percentage - IASI channel 3105

2024090909 Background - IASI channel 3105

2024090909 Obs error - IASI channel 3105

2024090909 Analysis - IASI channel 3105

2024090909 Analysis departure - IASI channel 3105

Figure 7: IASI DA MEM_17 - 09.09.2024. at 09 UTC; ALLSKY_QC experiment; IASI channel 3105

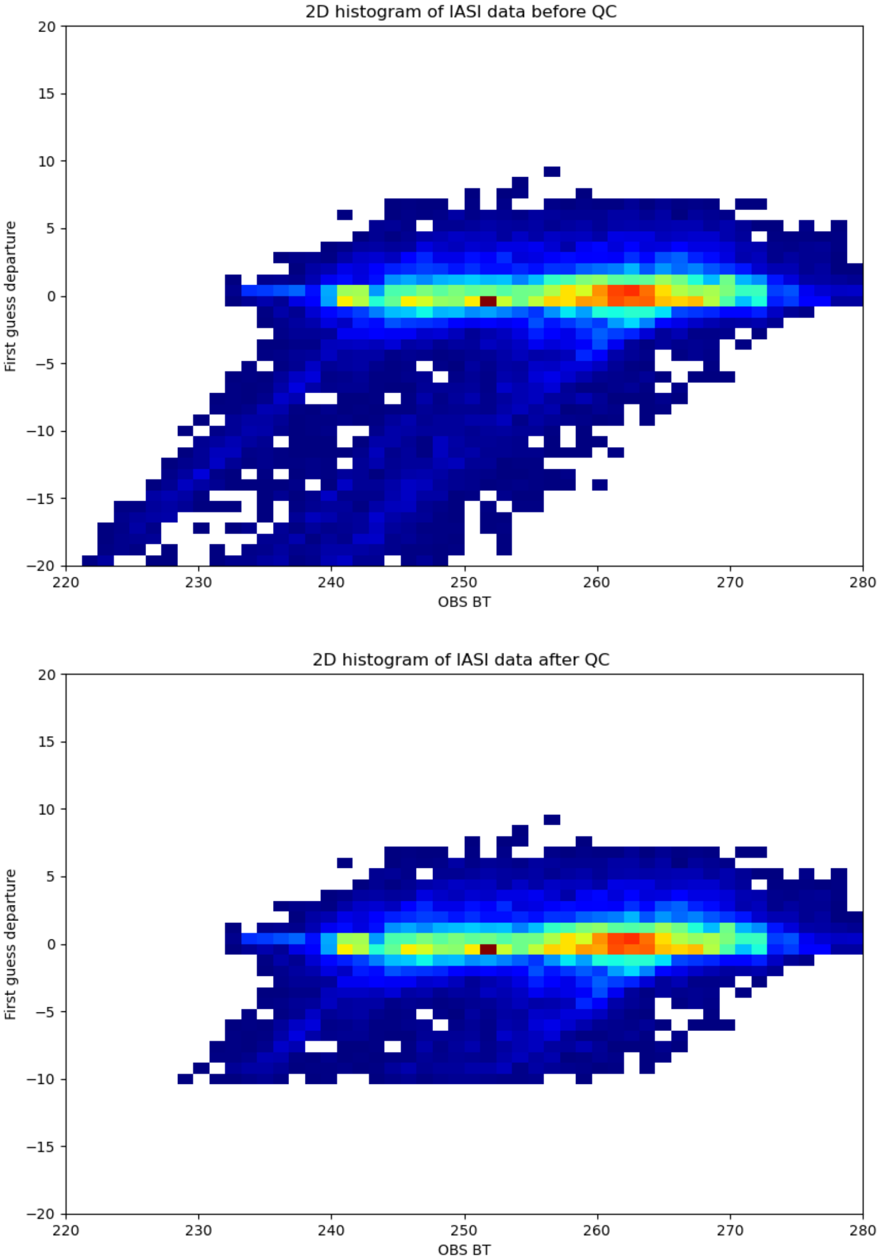


Figure 8: Number of samples as a function of first guess departures and observed brightness temperatures (OBS BT) using odb data from both cases; ALLSKY_NQC (upper picture), ALLSKY_QC (lower picture)

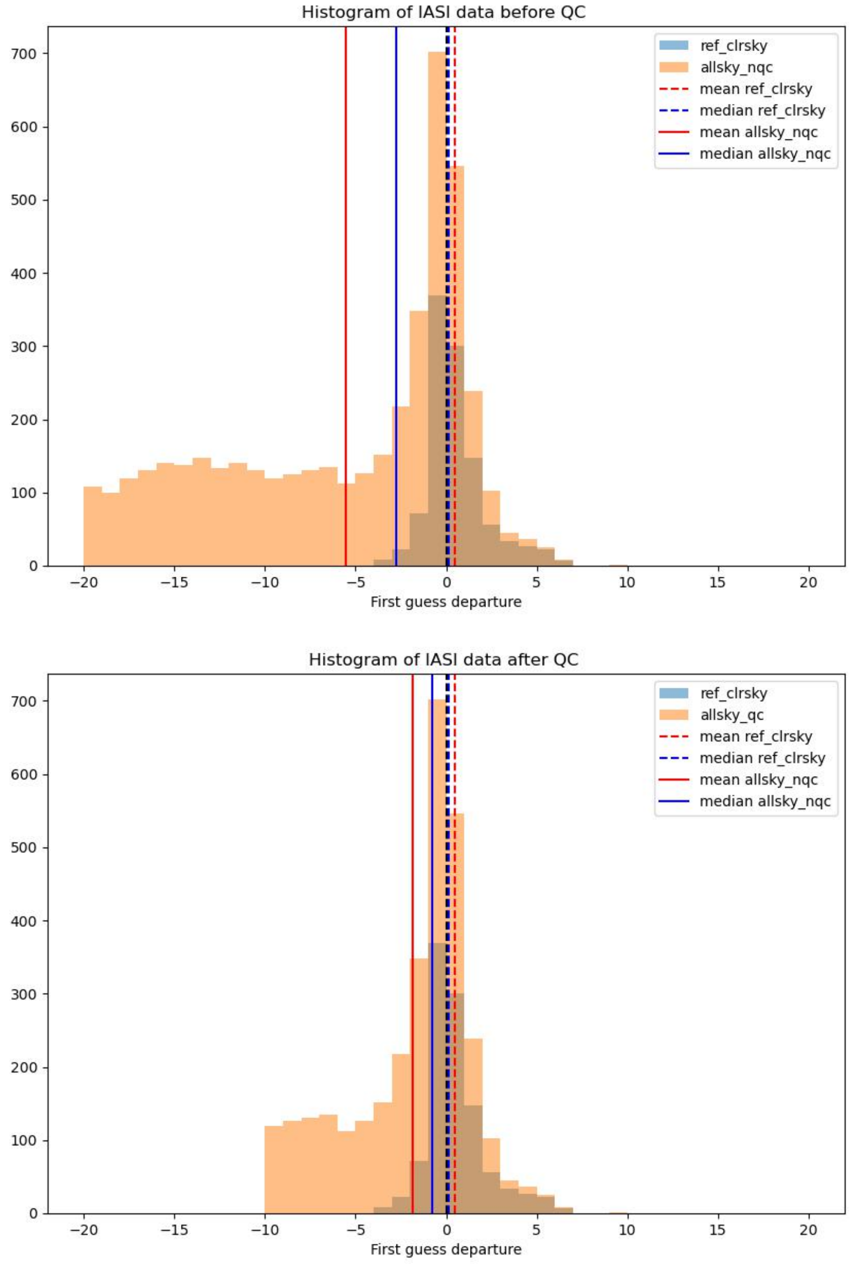


Figure 9: Number of samples as a function of first guess departures using odb data from both cases; REF_CLRSKY (blue, both pictures), ALLSKY_NQC (orange, upper picture), ALLSKY_QC (orange, lower picture) with mean (red line) and median (blue line) values

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