Meeting timeliness and throughput constraints in IASI L2 operational processing at EUMETSAT

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EUMETSAT

Contents

Brief overview of IASI processing in the EPS ground segment

Optimisation strategies (code and algorithm)

- **Fast radiative transfer model**
- **Use of reconstructed radiances to keep the number of channels to simulate low**
- **Improved first guess / background to keep the number of iterations low**

Parallelization strategies (past, present and future)

- **In principle easy as IASI L2 algorithm is embarrassingly parallel**

Integration of Forli-CO retrieval code from the EUMETSAT SAF on ozone and atmospheric chemistry monitoring (Daniel Hurtmans, ULB)


EUMETSAT EPS Ground
Segment Network
Version 1d 1/4/2009
Don't worry…
Legend
802.1q VLAN trunk
10/100 BaseT Ethernet
1000 BaseT Ethernet
Serial Line
Router
TELENOR equipment
Remote Entity
NOAA Boundary of Responsibility
Layer 3 Switch
Layer 2 Switch
Svalbard
Frame synchroniser ..159.6
OGKSTR03 Cisco 1721 Fa0 LAN ..159.1/24 LAN HSRP ..159.3/24 Dialer1 ..157.3/24
OGKSTR04 Cisco 1721 Fa0 LAN ..159.2/24 Dialer1 ..157.4/24
ISDN
OGKSTR01 Cisco 1721 Fa0 EUM ..156.1/24 EUM HSRP ..156.3/24 Dialer1 ..157.1/24
OGKSTR02 Cisco 1721 Fa0 EUM ..156.2/24 Dialer1 ..157.4/24
OGKSTC20 3Com Baseline switch
NOAA_EXT
INTERNET
Internet_ISPR01
Internet_ISPR02
SWINT0
SWINT1
OPS Internet
..144.0/24
Sim and test ETT lan
METOP Simulator
OGDSSC20
METOP_SIM
CALVAL ROOM
ATCU-AMIB
SIDAS-MIB
ATCU-DAD
SIDAS-DAN
Static NAT table:
NOEGSC20/ SIDASCAT2
NOEGSR01
NOEGSE LAN
OGL3SC22 Cisco 4948
Workstations
OGL3SC20 Cisco 4948
Servers
OGL3SC21 Cisco 4948
..132.0/24
CAL/VAL Facility (CVF)
Ingate Server
..70.247
..70.244
IN-GATE Facility
External + EUMETCAST
EFTS Server
RMDCN (XGATE)
SVDSSC20
SVMOIC20
SVMCSC20
..10.0/25
SVVT
OGGIFC20 cold spare
OGGIFP01
OGGIFP02
IASI GIF Facility
Windows PC OGOSEP05
Windows PC OGOSEP06
OSE-RT Gateways
OGGIFC20 rack 44 192.168.140.200
IASI TEC/GIF
OUMANS01 Cisco 4503 Supervisor II
OPE Ingestion_Server 10.27.60.3
Backup_Server
OUMANS02 Cisco 4503 Supervisor II
VUMANS01 Cisco 4503 Supervisor II
VAL Ingestion_Server 10.37.60.3
VUMANS02 Cisco 4503 Supervisor II
2X Fiber connection to CSL3SC20
2X Fiber connection to CSL3SC21
UMARF
Toulouse
Astrium EGSE
ISDN
SUITLAND
NOAA Network
OXNOAR01
OXNOAC20
OXNOAS01
OXNOAS04
OXNOAC21
OXNOAS03
OXNOAS02
NOAA Provided
BAIKONUR
Internet LAN
Internet environments; ESA, EUMETSA, ASTRIUM.
ESOC NDIU
ESOC Voice 10.80.0.160
NDIU_R01 PPF ..175.209/24
Astrium EGSE
EGSE_R01 ..175.208/24
Telemetry Workstation ..175.1
B_LNCS1
B_LNCS2
B_LNCR1 Etho ..175.206/24
B_LNCR2 Eth0 ..175.207/24
B_LNCR3 129.168.147.207
STARSEM WAN 2Mb/s
E_LNCR1 ..160.208/24 HSRP ..160.202
E_LNCR2 ..160.208/24
E_LNCS1
E_LNCS2
EUM Voice
Launcher Module
ESOC
ESOC_R1
OPSNET EIT subnet 195.74.163.36/28 EPOS subnet 195.74.161.0/24 VOIP 10.80.0.89 NM subnet 195.74.162.0/27
ESOC_R2
ESOC - OXLEOR01 EUM ..160.210/24 EUM HSRP ..160.203/24
ESOC - OXLEOR02 EUM ..160.211/24
OXLEOW01 ESATEST Workstation
Madrid
ESOC_BUCC_POP1
GRAS_GSN, LEOP & TT&C PROVIDER (ESOC)
Backup Control Centre
Internet
Metop Sim
M&C_VLAN
BUL2SC25 ..92.91 Cisco 2950T-24
BUL2SC26 ..92.92 Cisco 2950T-24
BUPIXC20 ..92.46 Cisco PIX 515E
BUL2SC24 ..92.36 Cisco 2950T-24
BUL2SC20 ..31.59 Cisco 2950T-24
BUPIXC21 ..92.45 Cisco PIX 515E
BUL2SC21 ..31.60 Cisco 2950T-24
BUL2SC23 ..92.37 Cisco 2950T-24
BURTRR01 Loop 0 ..82.10 Cisco 3745
BURTRR02 Loop 0 ..82.20 Cisco 3745
BUCC INT
BUCC EXT
BUCC DMZ
ISDN TO ECM
Slide: 3
Internet VPN CS-BUCC following HSRP add of R01
ISDN TO BUCC
External Communications Module
CSL2SC20 Cisco 2950T-24 ..90.36/28
CSL2SC21 Cisco 2950T-24 ..90.37/28
CSPIXC21 Cisco PIX 515E
CS_INT
CS_EXT
CS_DMZ
NOAA DEW
CSDEWS01
CSGFTS01
OGSEP01
CSFTPS01
NOEGSEP01/ DEL2
DE-DAR-EUM1 Cisco 3745
DE-DAR-EUM2 Cisco 3745
CSRTRR04 Cisco 3845
CSRTRR05 Cisco 3845
Link to Telenor For management
CSSDHM81
CSSDHM82
Redundant connection point for NOAA TAT/DEW. Needs manual intervention to restore the connection
1344kb/s Fract E1 ?
New York
Intelsat 10-02 spot 1 TRSP72
45Mb/s duplex
5Mb/s-256kb/s CDA link
320kb/s duplex BUCC link
Svalbard
Fibre Patch in svalsat comproom Rack E1
PSSDHM81
PSSDHM80
PSRTRR05 Cisco 3845
PSRTRR04 Cisco 3845
NO-SVAL-EUM1 Cisco 3745
NO-SVAL-EUM2 Cisco 3745
PSL2SC22 Cisco 2950T-24
PSL2SC23 Cisco 2950T-24
PSRTRR01 Cisco 3745
PSRTRR02 Cisco 3745
PSL2SC20 Cisco 2950T-24
PSL2SC21 Cisco 2950T-24
MER1
MER2
CDA1 .20.1-63
CDA2 .20.64-127
AER1
AER2
CDA1 LAN
CDA2 LAN
NOAA Suitland
US-NOAA-EUM1 Cisco 2600 Chassis type: 2610XM
US-NOAA-EUM2 Cisco 2600 Chassis type: 2610XM
NOL2SC20
NOL2SC21
NOL2SC22 .93.10
NOL2SC23 .93.11
NORTRR01 Cisco 3745
NORTRR02 Cisco 3745
NOAA LAN 172.20.16.0/24
NOAA_INT_LAN
NOAA_DEW_LAN
NODEWS00 .93.1
NODEWS01 .93.2
NODEWS02 .93.3
Central Site Communications Module
DEV_WSs
CSL2SC22 Cisco 2950T-24
CSL3SC20 Cisco 3750
CSL3SC21Cisco 3750
UMARF V 3
CSDIFP01
CSDIFP02
CSSADW02
CSSADW01
Vlan 33
Vlan 51
CSL2SC28
OXREFS01
OXREFS02
CSRTRR03 Cisco 3745
Key Centre
PC 1
PC2
Ground Segment 1
G1L3SC20 Cisco 4506 Lp0 ..80.100/32
G1L3SC21 Cisco 4506 Lp0 ..80.105/32
Ground Segment 2
G3L3SC20 Cisco 4506 Lp0 ..80.110/32
G3L3SC21 Cisco 4506Lp0 .80.115/32
Ground Segment 3
G3L3SC20 Cisco 4506 Lp0 .80.120/32
G3L3SC21 Cisco 4506 Lp0 .80.125/32
Portchan 2
M&C_VLAN
DIF_VLAN for multicast traffic
PGF_VLAN
PPF
DIF & PFG S01
DIF & PFG S02
Exgate Test TM propagator
OGOSEP12
OGOSEP10
OGOSEP11
Thin Client
For management only
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Product Processing Facilities (PPFs)

All Metop products are generated by PPFs, processing 3 minutes chunks of data - so-called PDUs

Most PPF executables are invoked and exits again for each PDU

- **Only exception is the IASI L1 PPF (invoked once per orbit)**

Three ground segment instances (GS3=>GS2=>GS1)

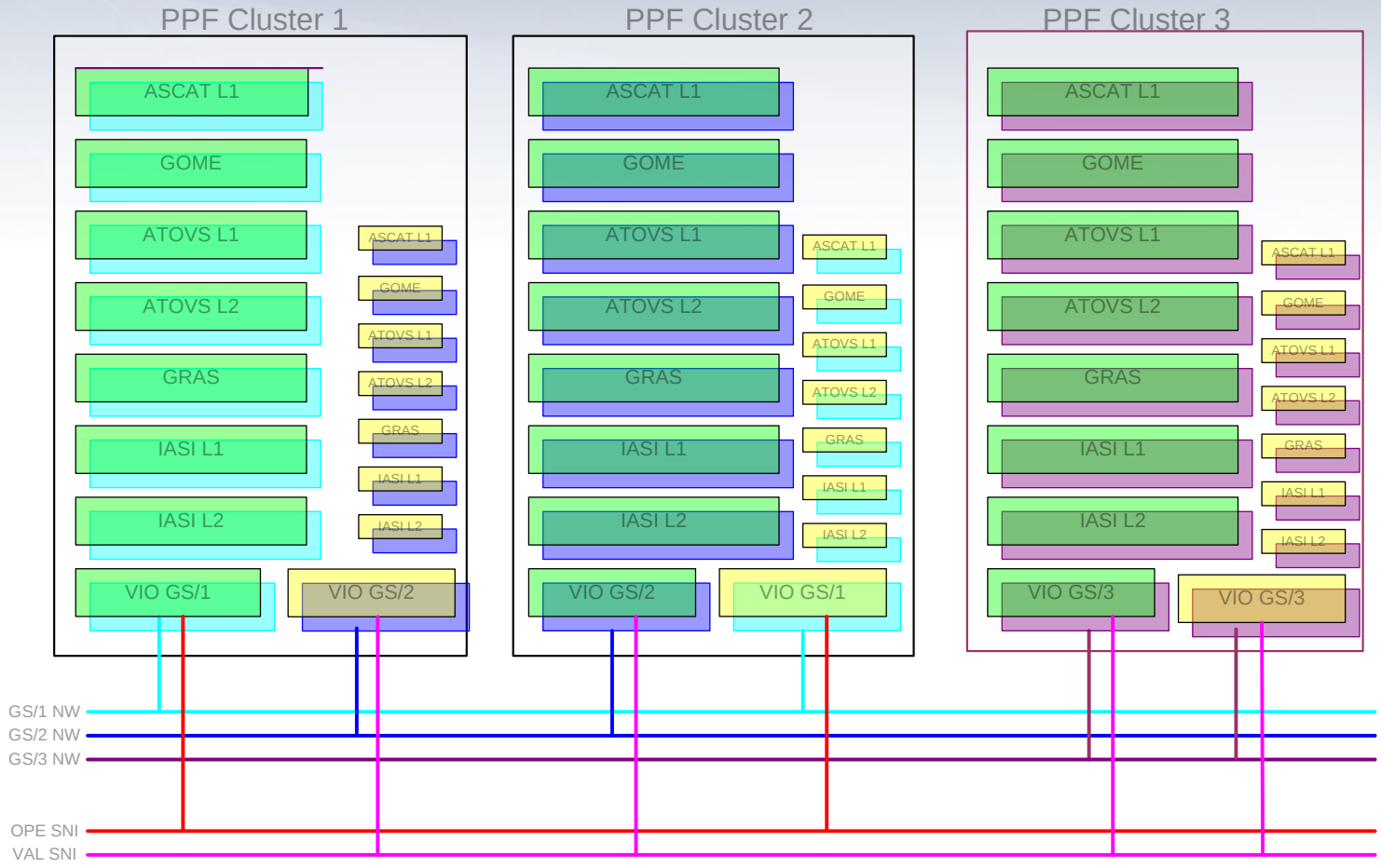
GS1 Operational processing

GS2 Validation

GS3 Testing

PPFs are installed on nodes (virtual machines) on three IBM p575 HPC clusters with 32 4.7 GHz POWER6 processor cores each.

(Operating system is AIX 6.1, 64 bit)


PPF Cluster 1
ASCAT L1
GOME
ATOVS L1
ATOVS L2
GRAS
IASI L1
IASI L2
VIO GS/1
VIO GS/2
ASCAT L1
GOME
ATOVS L1
ATOVS L2
GRAS
IASI L1
IASI L2
PPF Cluster 2
ASCAT L1
GOME
ATOVS L1
ATOVS L2
GRAS
IASI L1
IASI L2
VIO GS/2
VIO GS/1
ASCAT L1
GOME
ATOVS L1
ATOVS L2
GRAS
IASI L1
IASI L2
PPF Cluster 3
ASCAT L1
GOME
ATOVS L1
ATOVS L2
GRAS
IASI L1
IASI L2
VIO GS/3
VIO GS/3
GS/1 NW
GS/2 NW
GS/3 NW
OPE SNI
VAL SNI

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Product Processing Facilities (PPFs)

- **IASI L1 PPF** **One node (4 virtual CPUs, 2Mb Memory)**
- **IASI PCC PPF** **One node (2 virtual CPUs, 2Mb Memory)**
- **IASI L2 PPF** **Three nodes (4 virtual CPUs, 2Mb Memory)**

Per satellite (Metop-A/Metop-B)

per ground segment (GS1/GS2/GS3)

(Nominal/Spare)

Some scope for increasing the number of (virtual) CPUs on the nodes, but not the number of nodes themselves.

- **Integrate PCC PPF into L2 PPF (**PCC processing fast and repeated for noise filtering in the L2 PPF anyway. Get 4 nodes available for IASI L2)
- **IASI L2 on node parallelization (**currently workorders are split in 2 by the start-up script)

IASI L2 operational processing

IASI provides 1.296.000 hyperspectral infrared measurements per day

15 spectra, of 8461 spectral channels each, per second

IASI L2 Product Processing Facility (PPF) turns spectra into atmospheric profiles of temperature, water vapour and ozone, by iteratively applying a fast radiative forward model (FRTM) until the measurement is matched

Processing time is dominated by the FRTM and is roughly linear in the number of iterations, the number of channels used and the number of fields of view

The timeliness requirement for IASI L2 products on EUMETCast is 3 hours (maximum difference between sensing and reception time)

Processing and dissemination is based on PDUs (chunks of data corresponding to about 3 minutes of sensing time)

IASI L2 PDUs can be processed in parallel on N (currently 3) different processing nodes.

Throughput constraint: average processing time per PDU < N * 3 minutes

Timeliness constraint: maximum processing time per PDU < 25 minutes

➔ Need for parallelization within each individual PDU

Optimization of RTTOV (the FRTM used for IASI L2)

-lmass library (for fast exponential function)

Optimizations performed at EUMETSAT on RTIASI (later merged with RTTOV) and fed back to ECMWF (speed up factor 5 – 10)

- **loop reordering for improved data locality**
- **taking constant expressions out of the loops**

Further RTTOV developments to benefit from

- **new RTTOV coefficients with pre-computed contribution from fixed trace gases**
- **new RTTOV coefficients on 51 levels (instead of 101)**

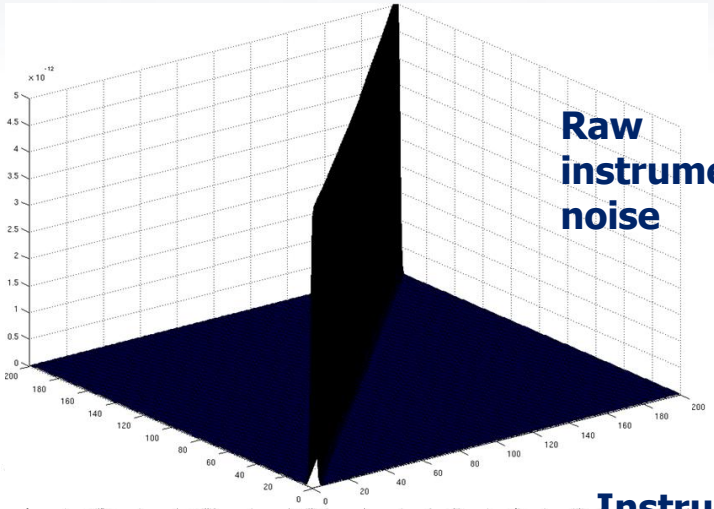
➔(wanted) faster implementation of variable trace gases (CO2, CH4, N20 and CO) avoiding multiplications with zeros ("sparse" implementation)

Reconstructed radiances

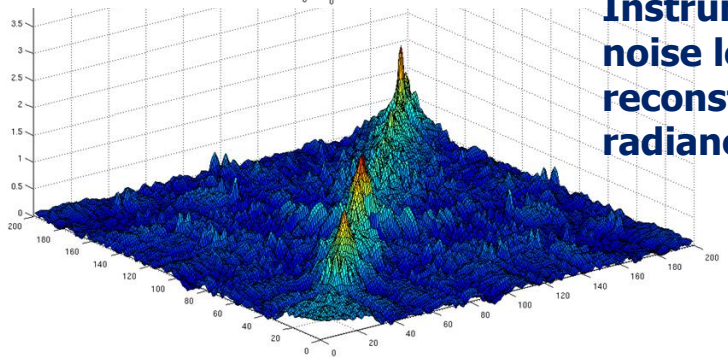
Virtually all information in the IASI spectra can be captured by a limited number of PC scores – or equivalently a limited number of reconstructed channels ➔

Use a small subset of channels (200-300 of 8461) while keeping information from the full spectra

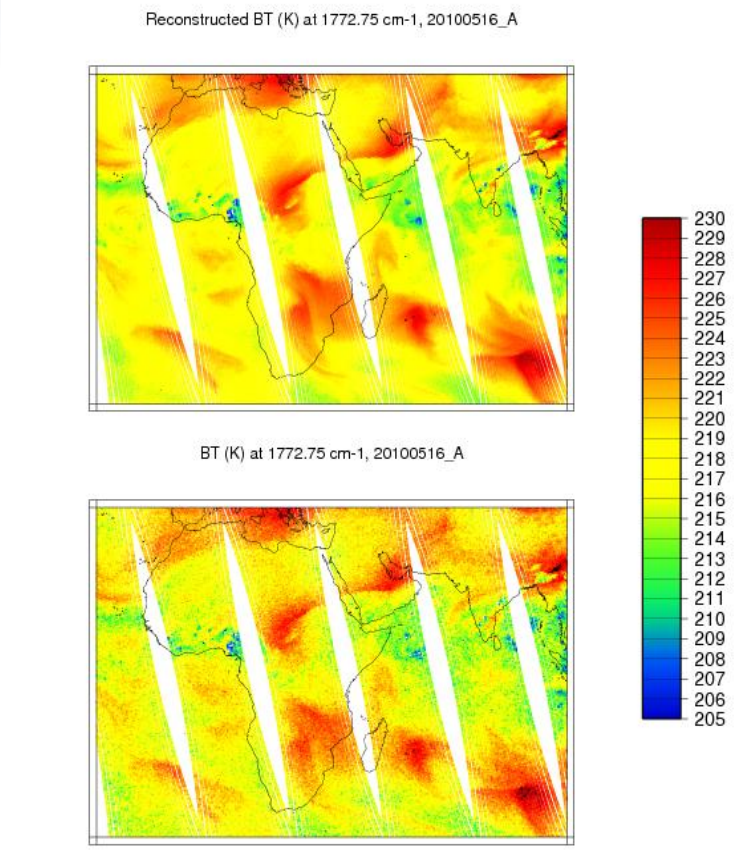
No need for PC based forward model (does not harm if not too slow)



Raw instrument noise



Instrument noise left in reconstructed radiances

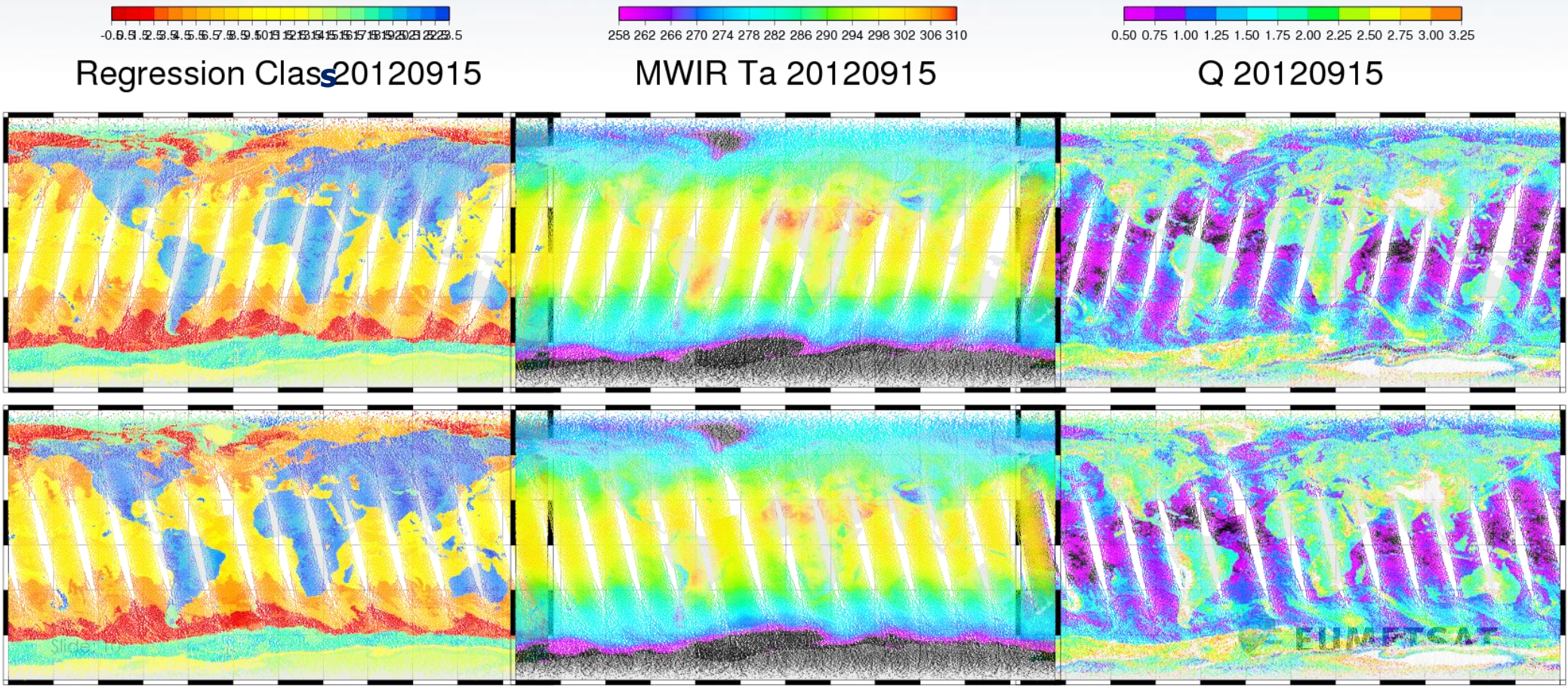


Improvement of first guess / background

Training data based on co-located ECMWF forecasts - 393735 cases from 5 days (in different months).

The retrieval statistics are improved considerably by dividing the data into 24 regression classes for which individual regression coefficients are retrieved. The class is determined solely by the AMSU radiance in channel 2 and 4 and the first two PC scores in IASI band 2.

Regression coefficients to predict the sum of the absolute values of retrieval errors of Ta, Wa and Ts are computed, which allows for an estimation of the quality of each individual retrieval.

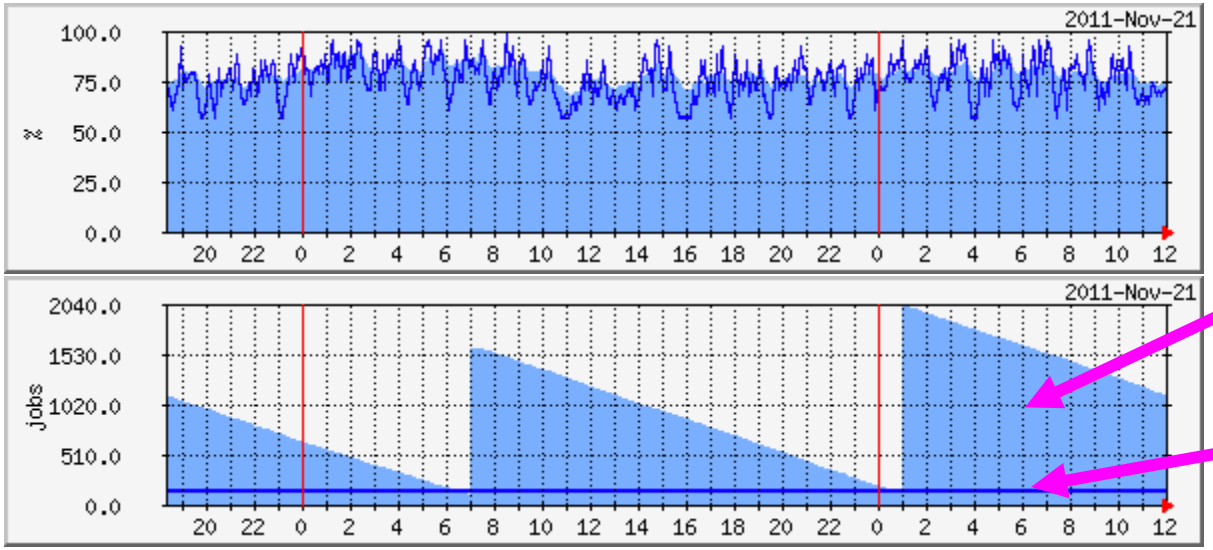


Forli-CO (Processing capacities in Brussels)

232 CPU's dedicated to optimal estimation retrievals of CO, HNO3 and O3

26 Nodes running OpenSuse 12.x

- 21xx: 10 Pentium D @ 3.00GHz (1x Dual core)
- 82xx: 7 Xeon E5420 @ 2.50GHz (2x Quad core)
- 83xx: 7 Xeon E5520 @ 2.27GHz (2x Quad core HT)
- 84xx: 2 Xeon E5620 @ 2.40GHz (2x Quad core HT)



Backprocessing PDU's waiting in the queue

~180 PDU's running

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Data flux in Brussels

BUFR
- L1c
- L2

1 CPU = 1 PDU

1 CPU = 1 PDU

1 CPU = 1 PDU

1 CPU = 1 PDU

1 CPU = 1 PDU

1 CPU = 1 PDU

1 CPU = 1 PDU

1 CPU = 1 PDU

PBS
queuing

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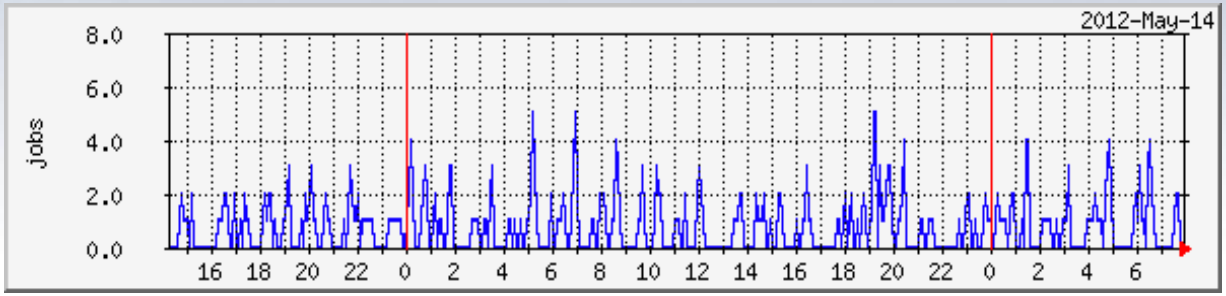
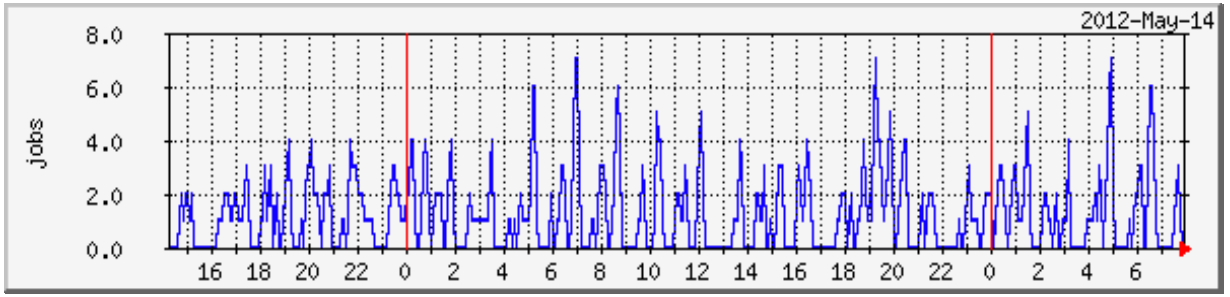
Forli CPU usage after optimisation at ULB

CO



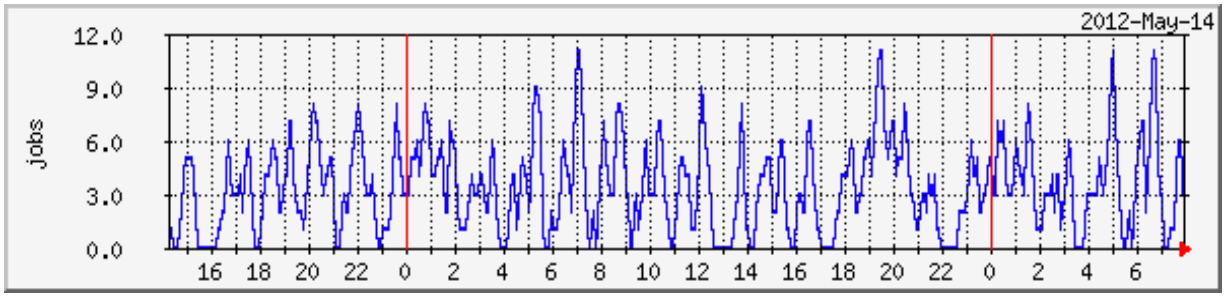
~3 min

HNO_3



~10 min

O_3



~15 min

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Forli-CO rewritten to use thread safe API

File based interface ➔ API (called per each scan-line – about 22 per PDU)

Multithreaded implementation (using pthreads library)

Preliminary execution times (4 threads) on IBM hardware at EUMETSAT:

- **Average time per CPU: 87.5 seconds**
- **Maximum time per CPU: 288 seconds**

More than 5 times slower than reported on Intel Core i7

- **fftw**
- **gsl (➔ essl ?)**

Realistic to squeeze in on current hardware, but not with O3 and HNO3 (which are to be added later) ➔ more CPUs need to be allocated for IASI L2

Multithreaded 1DVAR implementation based on RTTOV

Desirable as current on node parallelization scheme is inefficient and does not scale well

"Update to RTTOV v10.2 - 10th April 2012 - to ensure code is thread-safe in all parallel implementations"

This work not started yet. Potential complications:

- **memory consumption (separate copies of data structures)**
- **does not fit well with current wrapper to C++ (a Fortran Module on top of RTTOV)**

Conclusion:

IASI processing requirements are increasing (more trace gases, more (cloudy) fields of view,....)

➔Faster algorithms, software and hardware are always needed

... and then we'll get MTG-IRS providing about 2560 hyperspectral IR spectra per second