Challenges in data compression for current and future imagers and hyperspectral sounders

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or …

How to store your satellite data without needing too many of these…

Background

- This talk includes material that I presented at the

  ECMWF / EUMETSAT NWP-SAF workshop on efficient representation of hyperspectral infrared satellite observations

  in November 2013

  slides available on the ECMWF web site

- and subsequent short study on options for MTG-IRS

Contents

- Introduction
- Compression of VIIRS
  - example of how the dataset design can be improved
- Compression for IASI
  - to illustrate the various possibilities
- Simulation of MTG-IRS – based on IASI data
- Conclusions

Large level 1 datasets include

- Current sensors:
  - IASI – 16 GB/day (global, BUFR)
  - CrIS – 8 GB/day (global, BUFR)
  - VIIRS – 8 GB *per 12-min overpass* (SDR, day)

    5 GB at night

    ~ 800 GB/day

    not all disseminated, but stored in NOAA/CLASS
- Future sensors:
  - IASI-NG – twice the spectral resolution of IASI
  - METimage
  - MTG-FCI
  - MTG-IRS – 700 GB/day (uncompressed)

    Dissemination required, for NWP

    Also archiving at EUMETSAT

Types of data compression

- Lossless
  - Reconstruct the input exactly – to machine precision
- Near-lossless
  - Can reconstruct the input with a defined maximum error
  - Error typically a defined (small) fraction of instrument noise
  - Example: digitisation error (or quantisation error)
    - Max error = $\delta y / 2$
    - RMS error = $\delta y / \sqrt{12}$
  - Will discuss PC scores plus residuals
- Lossy
  - e.g. jpeg for images
  - e.g. PC scores for hyperspectral sounders

Standard compression tools

- useful for lossless and lossy compression

- File compression tools
  - bzip2, gzip, xz, lzip, compress, etc.
- image compression tools
  - jpeg, jpeg-ls, jpeg2000, szip, etc.
- They work best with files containing *integers*, not *floats*
- BUFR – widely used in operational context
  - Look at all occurrences of an element within a message
  - Express as a minimum, an increment width and a set of increments (in a reduced number of bits) to be added to that minimum.

BUFR effectively accounts for data with a limited range of values, but does not do any entropy (Huffman) encoding

- *Sometimes worthwhile to apply file compression after BUFR encoding*

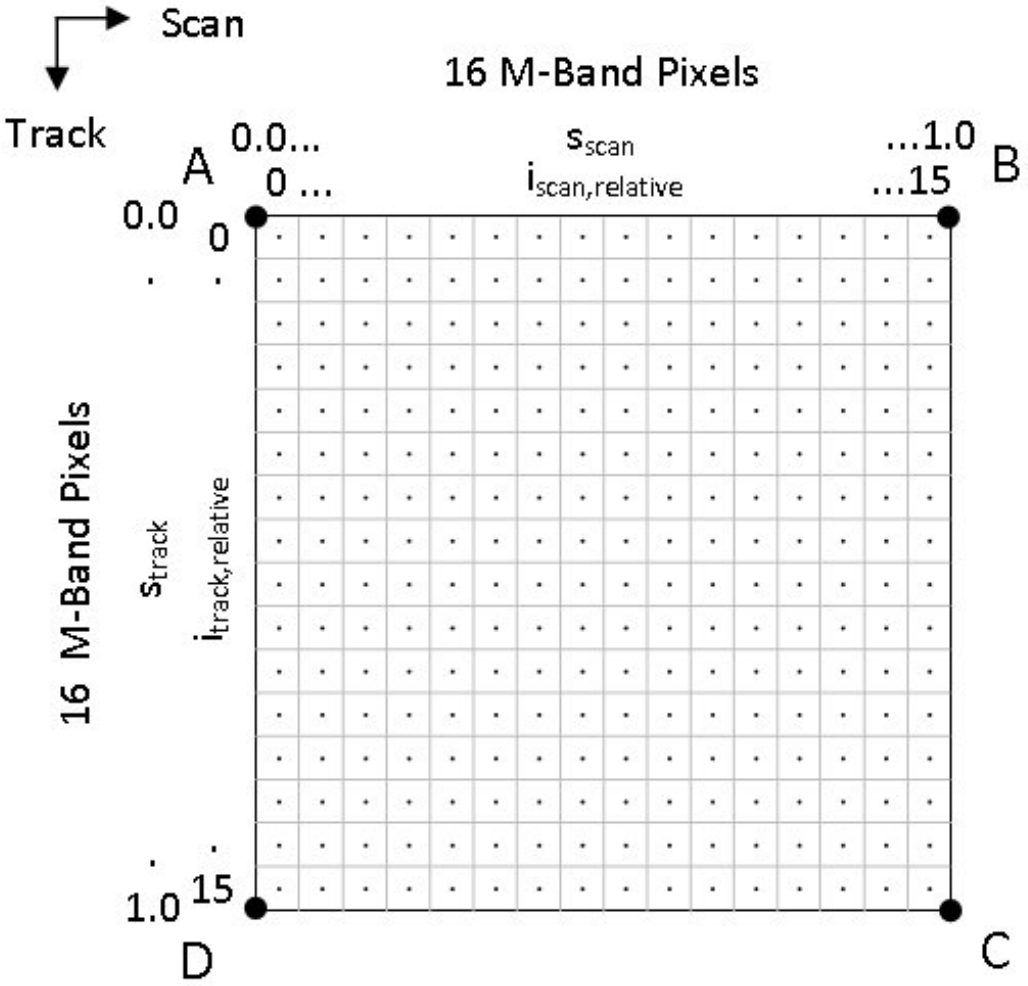
A badly designed format? VIIRS SDR (NOAA)

- Some channels represented by 32-bit floats

```
GROUP "VIIRS-M13-SDR_All" {
  DATASET "BrightnessTemperature" {
    DATATYPE  H5T_IEEE_F32LE
    DATASPACE  SIMPLE { ( 768, 3200 ) / ( H5S_UNLIMITED, H5S_UNLIMITED ) }        }
```

- Latitude and longitude given as 32-bit floats *for every image spot*
  - so you need a large geolocation file even if only interested in 1 channel
  - A limitation when downloading data from NOAA/CLASS
- Both radiance and BT/reflectance are given (unnecessary)
- Typical 10-minute pass:
  - 2.4GB uncompressed – *M-band channels only* (740m spatial)
  - 1.3GB with gzip
- Too large to put this on EUMETCast!

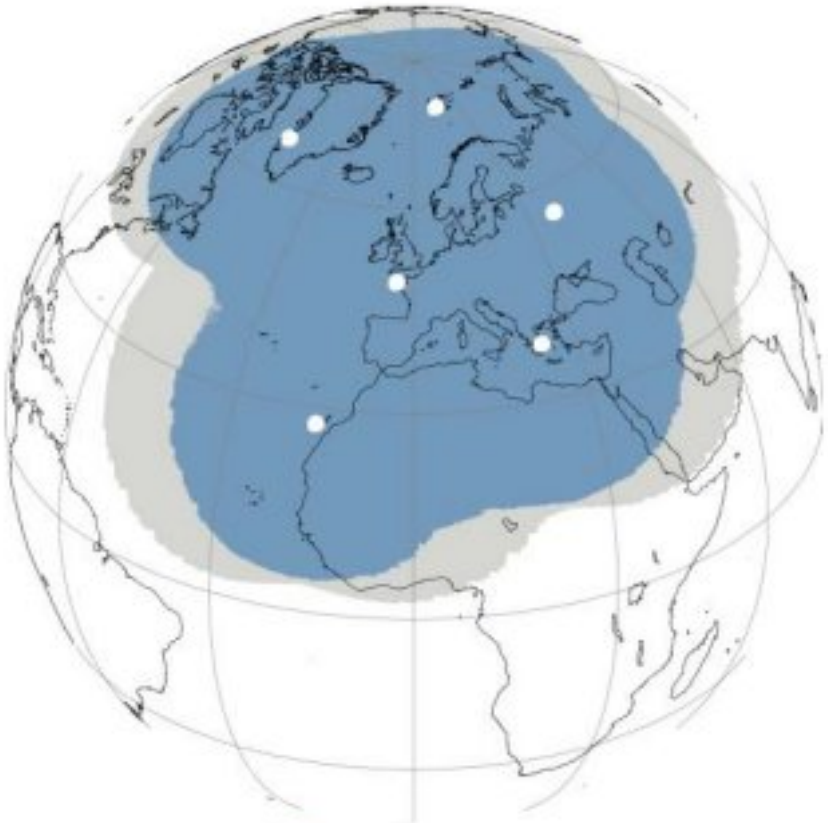
EUMETSAT's compressed VIIRS format



- Tie points for geolocation
- 16-bit integers for all radiances
- Remove duplication (no BTs)
- 0.93 GB uncompressed
- 0.43 GB with gzip
- 0.38 GB with bzip2
  - 6-fold reduction compared with input file
- Can be accommodated on EUMETCast
- EUMETSAT have provided conversion software (java) – works well

EARS-VIIRS service

- Regional VIIRS
- Lannion now
- Other stations in early 2014



EUMETSAT

Compression options for IASI

1. Full spectra (only BUFR compression)
   - nominally lossless (but apodisation has introduced losses compared with original self-apodised spectra)
     - Operational on EUMETCast
   - could reduce volume via noise-normalisation + quantisation
2. Channel subset
   - Operational on EUMETCast and GTS (366 channels = 4%)
3. PC scores only
   - lossy (but most of the “loss” is noise)
     - Operational on EUMETCast (not many users?)
     - 4% of BUFR volume
4. PC scores plus quantised residuals
   - near-lossless
   - not used operationally (no need at present, because full spectra are available)
     - 44% of BUFR volume (see later slide)

PC scores and quantised residuals

(proposed by Tony Lee and Steve Bedford, 2004)

1. Noise-normalised radiance: $\mathbf{y} = \frac{\mathbf{r}}{\mathbf{n}} - \mathbf{y_0}$

radiance spectrum → $\mathbf{r}$; *mean* → $\mathbf{y_0}$; *noise* → $\mathbf{n}$

Eigenvectors (truncated) → $\mathbf{E}^{\mathrm{T}}$

2. PC Score (integer): $\mathbf{s} = NINT\left(\frac{\mathbf{E}^{\mathrm{T}}\mathbf{y}}{f_s}\right)$ Typically f_s = 0.5

3. Residual (integer): $\Delta y = NINT\left(\frac{\mathbf{y} - f_s\mathbf{E}\,\mathbf{s}}{f_r}\right)$ Typically f_r = 0.5
gives 1% noise increase

4. Huffman encode and disseminate

Eigenvectors, E are computed off-line

Experiments with IASI data (1)

As an example, I used a direct-readout pass received at Exeter,

IASI_xxx_1C_M02_20130422084559Z_20130422085406Z_V_T_20130422085721Z

size: 166.695 MB, number of scans: 61 (= 488 sec), number of spectra: 7320

First, look at the standard formats. Reference is AAPP l1c format which uses 16 bit integers for the spectra. Size = 135.4 MB (spectra comprise 91.5% of this)

Format	**Volume w.r.t. AAPP l1c**
Native PFS	1.23 *Larger than AAPP due to IIS etc.*
PFS + gzip	0.91 (11 sec)
PFS + xz	0.73 (85 sec)
PFS + bz2	0.72 (25 sec)
BUFR	0.68
AAPP l1c + bz2	0.63 *Smaller than BUFR*

Experiments with IASI data (2)

Comparison of l1b (self apodised) and l1c (gaussian apodised)

	Format (all with bz2, except BUFR)	**Volume w.r.t. AAPP (1b)**	**Volume w.r.t. AAPP (1c)**
Non-PC	BUFR		0.68
Non-PC	AAPP l1b/l1c	0.67	0.63
Non-PC	Quantised at 0.5xNEΔT	0.36	0.37
Non-PC	Quantised at 0.5xNEΔT + diff from mean	0.35	0.28
PC	PCs + 16-bit residuals	0.55	0.47
PC	PCs + residuals quantised at 0.5xNEΔT	0.30	0.20
PC	PCs + residuals quantised at 0.125xNEΔT		0.31
PC	300 PC scores only	0.018	0.029

1b contains more information than 1c?

A large part of the benefit comes from quantisation

Implications for IASI-NG

- IASI-NG will have doubled spectral resolution compared with IASI, and lower noise
- Design of 1c format needs care, to avoid loss of information (e.g. apodisation should be reversible)
- Likely that compressed data volume will be more than double that of IASI

A look at MTG-IRS

	IASI	MTG-IRS
Spectral sampling	0.25 cm^{-1}	0.625 cm^{-1}
Samples per spectrum	8461	1808 (2 bands)
Spatial sampling at nadir	25 km	4 km
Spectra per hour	54000	8.0×10^6 (full disk every hour)
Samples per hour	4.6×10^8	1.4×10^{10}
Data volume for radiances assuming 16-bit words	0.92 GB/h	28 GB/h
Operational BUFR (2 IASI instruments)	1.3 GB/h	

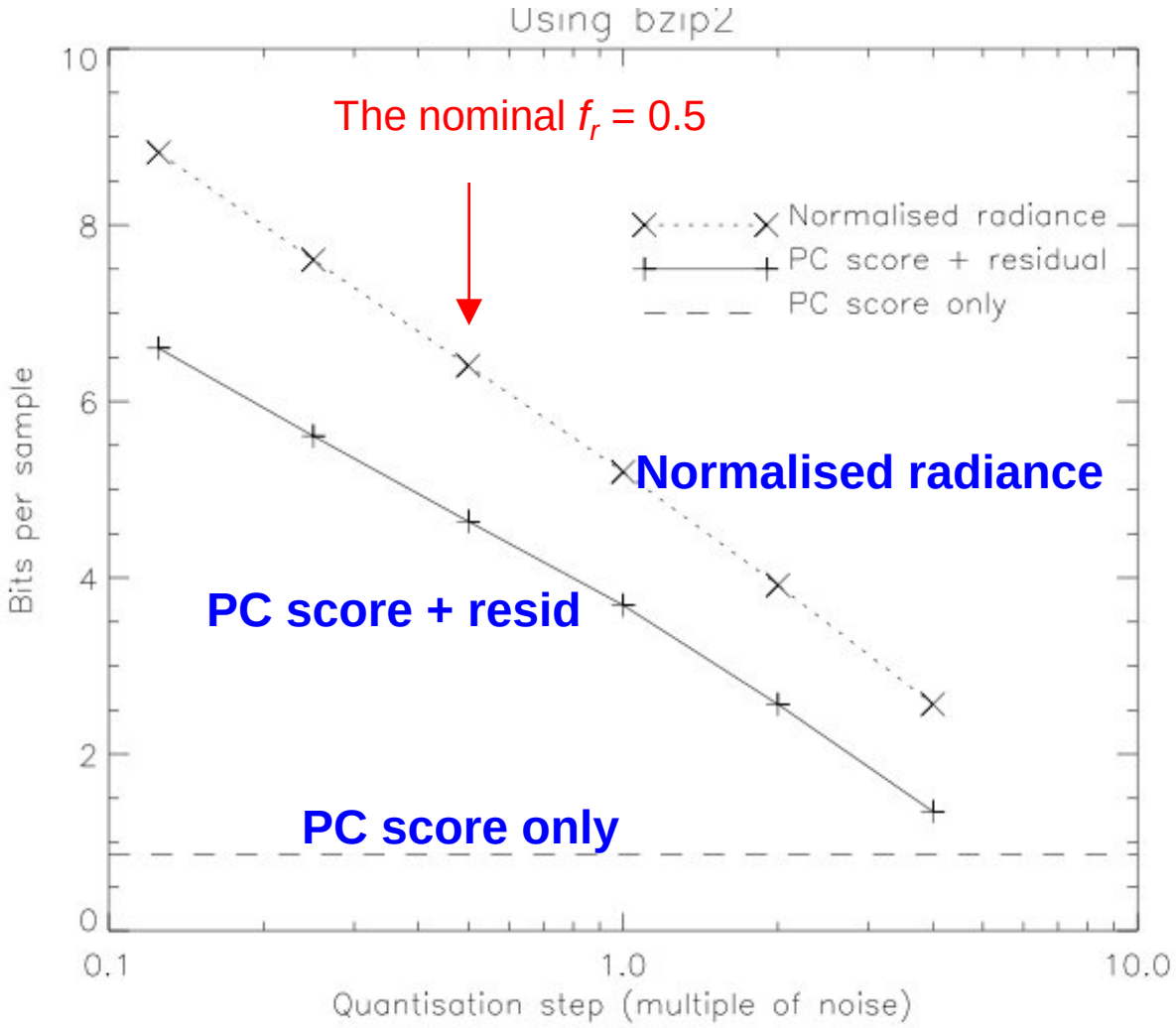
Factor 30 higher than IASI

- Lossy compression is essential for NRT dissemination of MTG-IRS (baseline is PC scores)
- Some users still want access to the full spectrum - don't trust the PCs!
- Requirement to archive the full spectrum centrally

Simulation of MTG-IRS

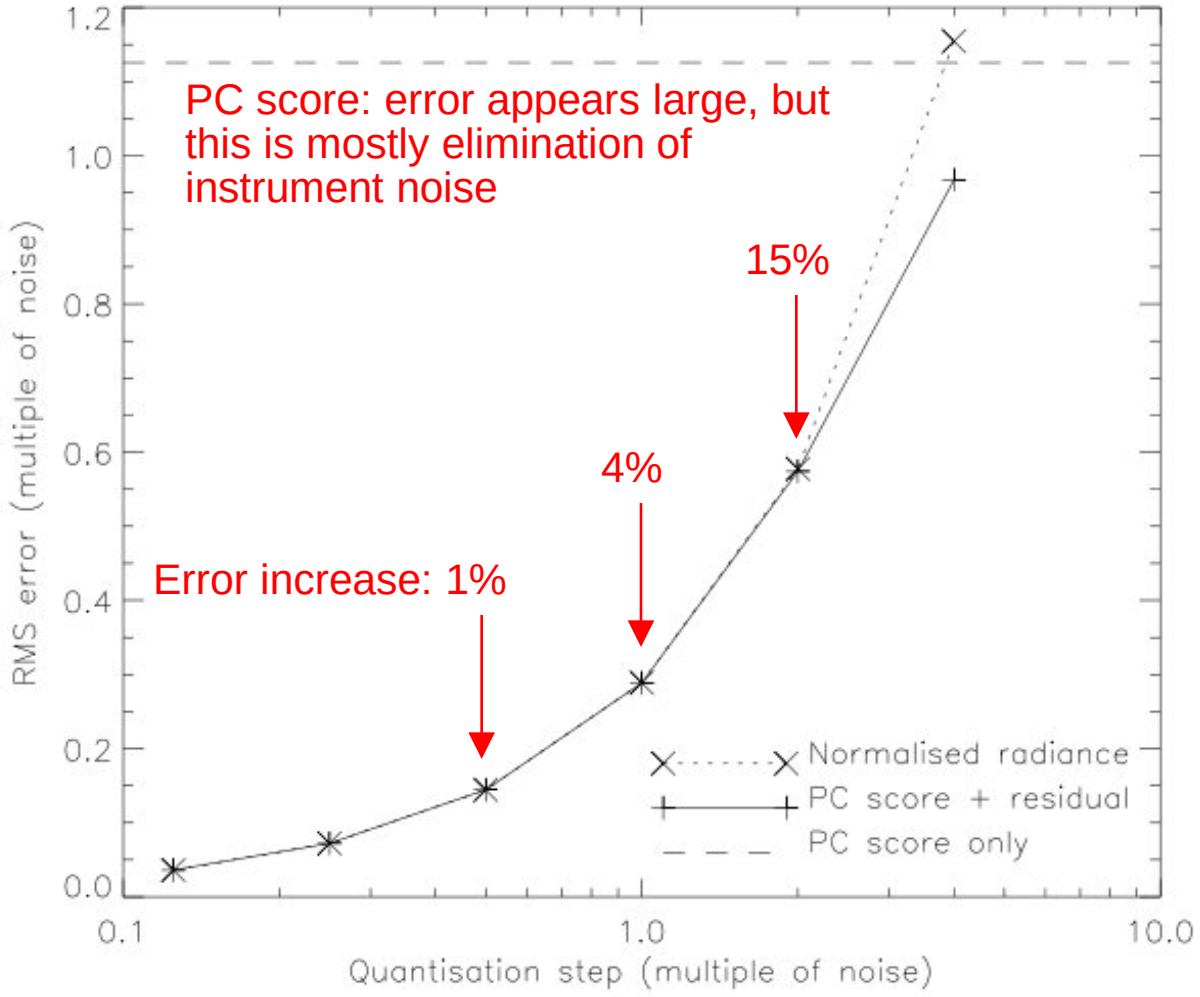
- Used EUMETSAT's IASI covariance matrix
- Transformed to IRS spectral resolution, unapodised
- Computed eigenvalues and eigenvectors for each band
- Applied them to transformed IASI spectra
- Looked at near-lossless compression options

IRS data volumes



- Tradeoff between accuracy and data volume

Reconstruction error



Conclusions

- For MTG-IRS
  - Baseline dissemination is PC scores only
    - 1.6GB/h (factor 18 lower than uncompressed)
    - just over two IASIs
  - Possibility of tradeoff with PC scores + residuals
    - 3 to 6-fold increase compared with PC scores only
    - quantised residuals could be made available off-line
- Design your datasets with compression in mind from the start – not as an afterthought
- Some key decisions are being made now for next-generation instruments

Thank you for listening!

Questions?