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Potential advantages of an OSS node-based radiance compression approach in assimilation of hyperspectral sounding data

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OSS Background

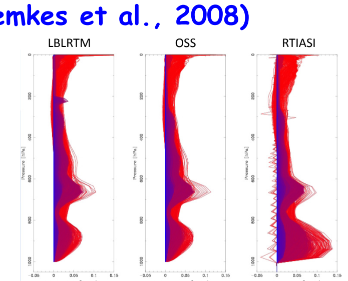
- Single channel training (e.g. Moncet et al. 2001, 2003, 2008):

$$y_i \cong \sum_{j=1}^{N} A_{ij}\tilde{y}(\nu_j); \qquad \nu_j \in \Delta\nu_i$$

  - Wavenumbers ν_i (nodes) and weights w_i are optimally selected to fit calculations from a reference line-by-line model for a globally representative set of profiles (training set)
- OSS models trained with single channel (localized) approach (described in details in Moncet et al. 2008) have shown significant advantages over OPTRAN or RTTOV for hyper spectral sounders
  - Increase forward model speed by ~ an order of magnitude
    - Computational time proportional to total number of nodes
    - Efficient Jacobian calculation
  - Provide greater numerical accuracy
  - Provide greater flexibility:
    - Selectable accuracy
    - Highly flexible and computationally efficient treatment of minor species

Testing with IASI (Tjemkes et al., 2008)

- OSS adopted by EUMETSAT for MTG-IRS Level 2 concept development
- OSS and RTIASI provide similar retrieval accuracies when applied to real observations (limited by uncertainties in spectroscopy and "truth" profiles, and instrument noise)
- Significant OSS timing advantage



Temperature Jacobians for each IASI channel with RTIASI and OSS compared to LBLRTM Jacobians (single profile)

Note: negative spikes in RTIASI Jacobians fixed

Computational speed in inversion /assimilation (non-scattering media) limited by algebra, no longer by forward model speed. Need to reduce size of observation vector for further gain.

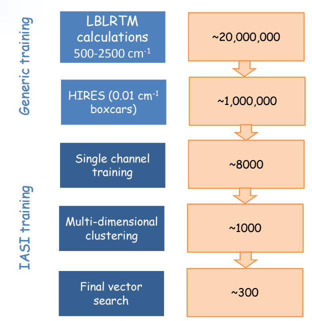
Average computational time (in sec/profile) for inversion of full IASI spectrum using RTIASI and OSS with non-linear iterative retrieval algorithm used in the development of operational Meteosat Third Generation-IRS Level 2 concept. Timings for forward models alone are provided in column 3

Forward model	Retrieval	Direct + Jacobians
RTIASI	502	246.3
OSS	269	10.0

Courtesy of EUMETSAT (Tjemkes et al., 2008)

Global (vector) OSS training

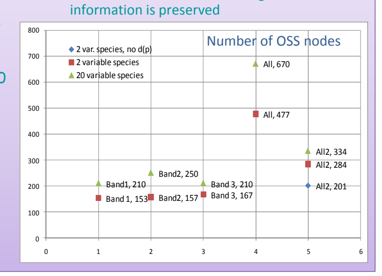
- Global training applies to a vector of individual channels (instead of individual channels)
  - Could be individual bands, optimal channel subset or whole spectrum (or PCs)
- Training becomes prohibitive and problem is to find ways of speeding up the training w/o compromising the optimality of the solution
- Global training still monitors accuracy in each individual channel!



- Total number of nodes depends on multiple factors - application dependent (difficult to provide a single number for given instruments)
- These include:
  - Model accuracy (0.05K – current training does not take instrumental noise into account)
  - Number of variable species (from 2 to 20 in current RT model)
  - Difficulty of training set (random perturbations δ(p) added to profiles to remove vertical correlation, secular trends for e.g. CO_2 added)
  - Number of bands
  - Handling of variations in viewing geometry (currently applies from 0 to ~70° to include geostationary sensors – scan angle binning could reduce # nodes)

Example of OSS performance (IASI)

- Model accuracy: 0.05K for all channels
- Numbers not expected to change significantly when applied to PCs or PC-reconstructed radiances so long as most information is preserved



Handling node radiances in variational systems

- Jacobian mapping from node to channel space (forward model level) may be very expensive if number of channels is large
  - Reduced with PC
  - Suppressed with node based representation
- Reduction in algebraic manipulation by 1-2 orders of magnitude with node (or PC) based representation
- Overall gain in 1DVAR: ~20

Node radiance estimated from full observations vector:

$$y^{obs} \rightarrow \hat{\tilde{y}}^{obs} = By^{obs}$$

where $B = \left(A^T S_\varepsilon^{-1} A\right)^{-1} A^T S_\varepsilon^{-1}$

and $\tilde{S}_\varepsilon = \left(A^T S_\varepsilon^{-1} A\right)^{-1}$

$$x_{n+1} = x_0 + \left(K_n^T S_\varepsilon^{-1} K_n + S_x^{-1}\right)^{-1} K_n^T S_\varepsilon^{-1}\left[\left(y^{obs} - y_n\right) + K_n\left(x_n - x_0\right)\right]$$

$$x_{n+1} = x_0 + \left(\tilde{K}_n^T \tilde{S}_\varepsilon^{-1} \tilde{K}_n + S_x^{-1}\right)^{-1} \tilde{K}_n^T \tilde{S}_\varepsilon^{-1}\left[\left(\hat{\tilde{y}}^{obs} - \tilde{y}_n\right) + \tilde{K}_n\left(x_n - x_0\right)\right]$$

Equivalent to:

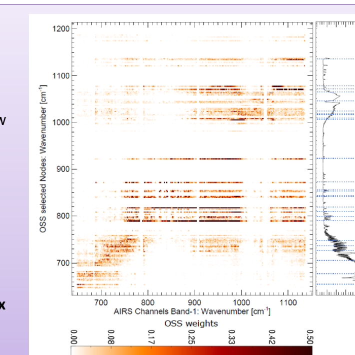
$$x_{n+1} = x_0 + \left(K_n^T S_\varepsilon^{-1} K_n + S_x^{-1}\right)^{-1} K_n^T S_\varepsilon^{-1}\left[\left(ABy^{obs} - y_n\right) + K_n\left(x_n - x_0\right)\right]$$

Node vs. PC representation

- PCA inherits the correlations from the set of profiles used for training. Solution constrained to lie in the space defined by the retained eigenvectors
- PCA tend to filter out small signals due to minor constituents
- PCA blends information relative to the different constituents complicating their use in the inversion and assimilation
- PCA blends the vertical signal making it difficult to perform dynamic selection in assimilation to retain for instance only the information relative to the clear atmosphere above cloud top. Same with land surface.

- Node based representation cannot achieve same compression factor as PC (basis vectors not orthogonal)
- Less reliant on training set (more robust)
  - OSS is more physical
  - Nodes selected to represent variability in each channel
- Jacobians are localized

When applying OSS to PC modeling, all selected nodes contribute to each individual PC, which makes it impossible to isolate a posteriori specific parts of the spectrum for the inversion. One key advantage of remaining in channel space (whether it is raw or reconstructed radiances) is that it allows performing a single channel search on the final node selection to allocate nodes to the different channels. This last operation minimizes the "blending" of the spectral information which complicates the utilization of PCs in some applications.

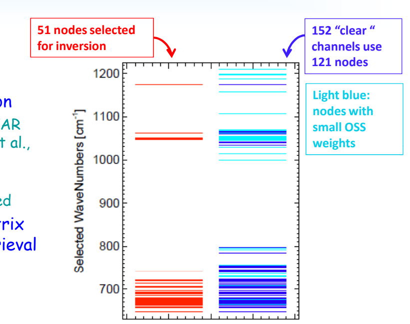


AIRS channel-to-OSS-node mapping matrix in the long wave

Application to clear retrieval down to cloud top (IASI Band 1; black cloud at 500 mb)

Approach:

- **Project full cloudy radiance spectrum onto nodes**
- Perform dynamic node selection
  - Using e.g. Jacobians and 1DVAR cloud top retrieval (Pavelin et al., 2008) or other technique
  - In this experiment, perfect knowledge of cloud top is used
- Trim obs error covariance matrix (node space) and perform retrieval with reduced set of nodes



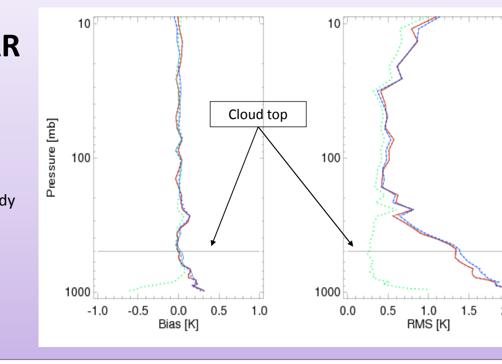
Example of 1D-VAR retrieval results

(Climatology background)

Red: Node space
Clear (dashed)/cloudy (solid) temperature retrieval errors with cloudy node selection

Blue: Channel space
Retrieval with 500mb clear channel selection

Green: Channel space
Full Band 1 channel set clear-sky retrieval (for reference only)



Node representation vs. Reconstructed Radiances

- **In current applications, advantages of using RR are:**
  - Noise reduced through PC filtering (no significant additional noise reduction expected due to using whole spectrum)
  - All information, in theory, contained in reduced set of channels
  - Optimal channel selection can in principle be applied to reduce number of components in the observation vector w/o additional loss of information
  - Suffers from the same limitations as PC (see above)
- **Node based representation:**
  - All spectral information (within limits of model accuracy) contained in selected nodes: no significant gain expected with additional PC filtering
  - Node selection remains the same whether it is used to model the full spectrum or a subset of channels, **provided that the channel selection is truly optimal**
  - From an information content point-of-view, there is little to be gained by using channel selection applied to RR as opposed to the full raw radiance spectrum to estimate node radiances.
  - In this context, one should be able to avoid channel selection (and combined PC noise filtering step) altogether
- **Need to compare both approaches in assimilation (or inversion) to quantify impact of methodology differences**

Summary

- OSS method is fast, numerically accurate and very flexible
  - Can easily be configured to apply to channel radiance modeling, PC, reconstructed radiances…etc (no change to the forward model required – just the weights)
- A simple thought is to use node-based representation for compress hyper-spectral observations in inversion or assimilation
  - Unlike PC this representation is sub-optimal
  - But it has potential to alleviate some of the issues relating to use of PC (e.g. non-localized behavior)
- This work is very preliminary
- May be worth exploring further???