Application of OSS to hyper-spectral infrared sounders

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OSS Overview

- Extension of *k*-distribution technique, e.g. Goody et al. (2011)
- For present application: model observations as weighted sum of monochromatic radiances

$$\hat{y}_l = \sum_{i=1}^{N_l} w_{li}\tilde{y}(\nu_i)$$

(Eq. 1)

OSS model localized training (Moncet et al., 2008) **:**
- Search method finds optimal $\{\nu_i\}$ (nodes) selection to fit reference radiances (for set of training scenes) in individual channels within *prescribed accuracy*
- Weights w_{li} obtained by linear regression
- Reference model: LBLRTM (v12.1)

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Attributes (summary)

- Selectable accuracy at training
- Selectable number of variable species (at training or at run time)
- Fast (possibility of trade off between speed and accuracy)
- Applicable to **clear/cloudy (scattering) radiances** over o**cean/land** background
- Spectral coverage: **microwave to Vis/UV** (LTE)
- Any viewing geometry
- **Local/global training** (see below)
- **Applicable to PCs, channel radiances**

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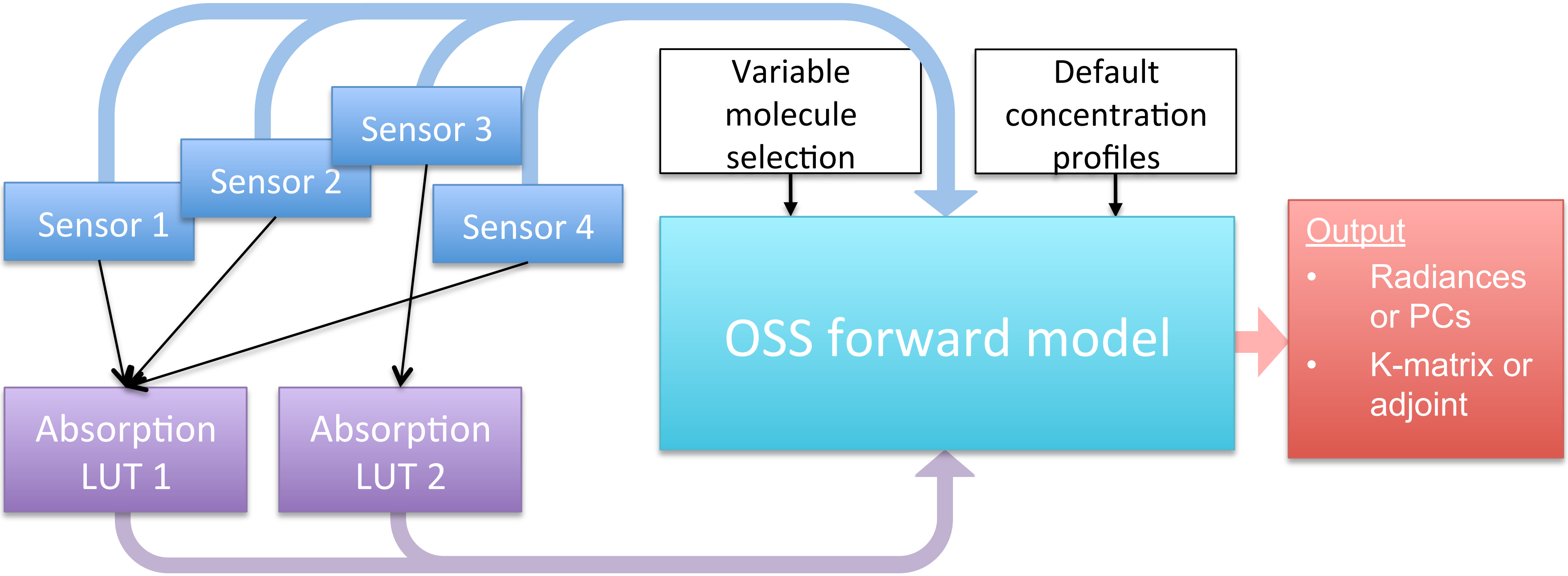
OSS forward model

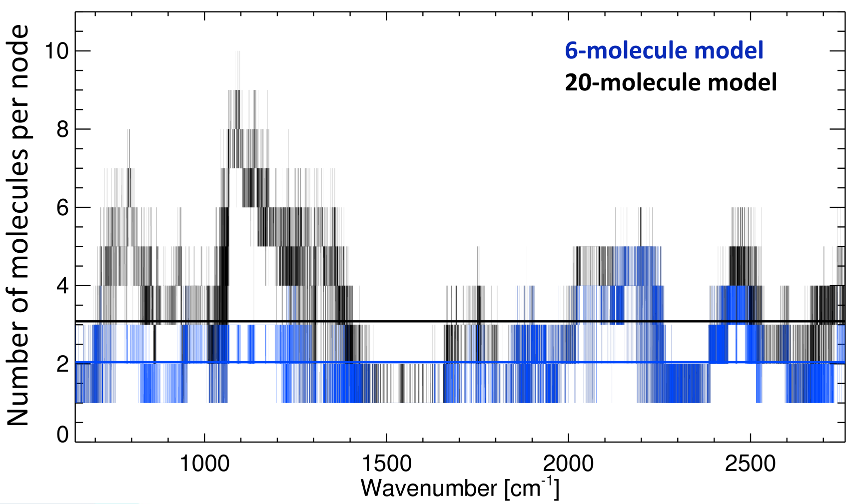
- **Sensor files:** contain node-to-channel (or PC) mapping-index information and OSS weights
- **Absorption look-up table:** mono-λ absorption coefficients (at each node) for individual molecules as a function of temperature and pressure
  - **Accommodate multiple sensors**
  - **Fixed/variable species partitioning selectable at run time**



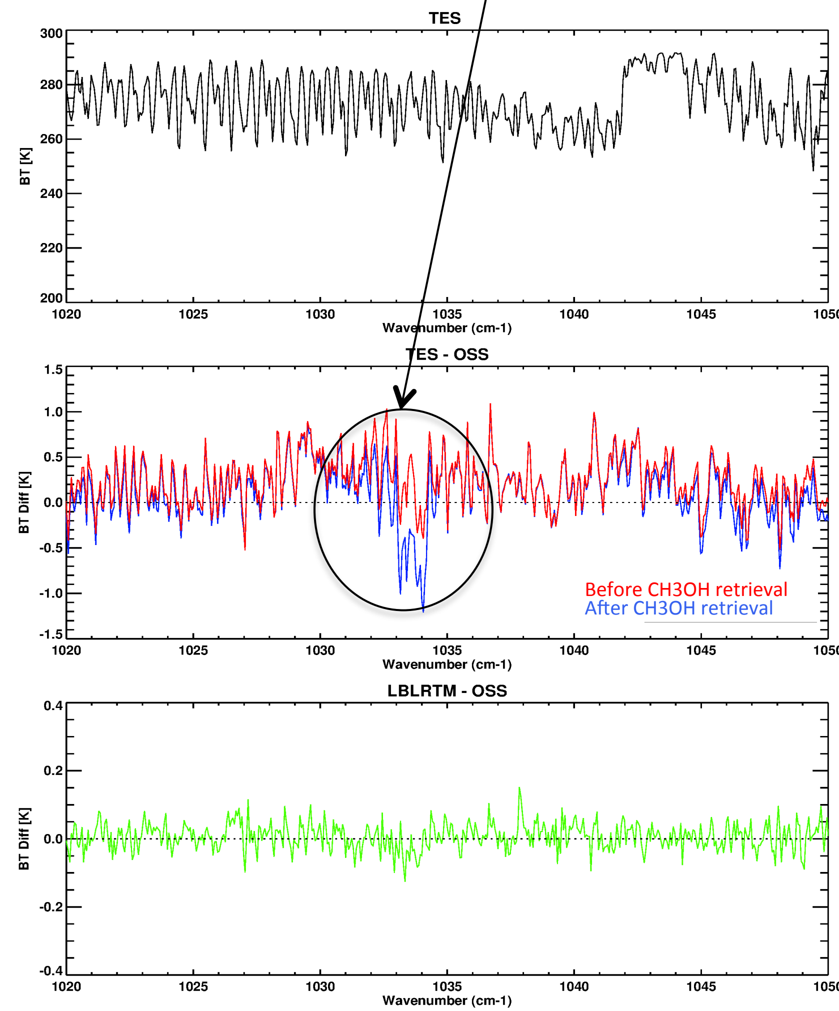
Variable species

- Number of variable species treated by OSS model increased to 20 in the infrared to accommodate TES applications

H_2O	CO_2	O_3	N_2O	CO
CH_4	SO_2	NH_3	HNO_3	OCS
HCN	C_2H_2	HCOOH	C_2H_4	CH_3OH
CCl_4	CFC-14	CFC-11	CFC-12	HCFC-22
CFC-113*				



Example of Methanol (CH_3OH) signature in TES observations over the South Pacific (east of Australia) after the "Black Saturday" fires in February of 2009



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Training scenes

- Relatively few scenes needed:
  - 52 atmospheres from diverse ECMWF set (noise added and trace species added at random)
  - x 5 scan angles between 0-60° (higher angles for geostationary sensors)
- For localized instrument function: model trained in clear-sky with spectrally flat emissivity works in cloudy conditions and over ocean and land
  - analogous to treatment of surface and clouds with channel-transmittance parameterizations
- **Non-apodized interferometer functions (*sinc* function):** need to include spectral variations in surface emissivity and cloud properties in training.
  - total number of scenes remains of the order of a few hundreds.

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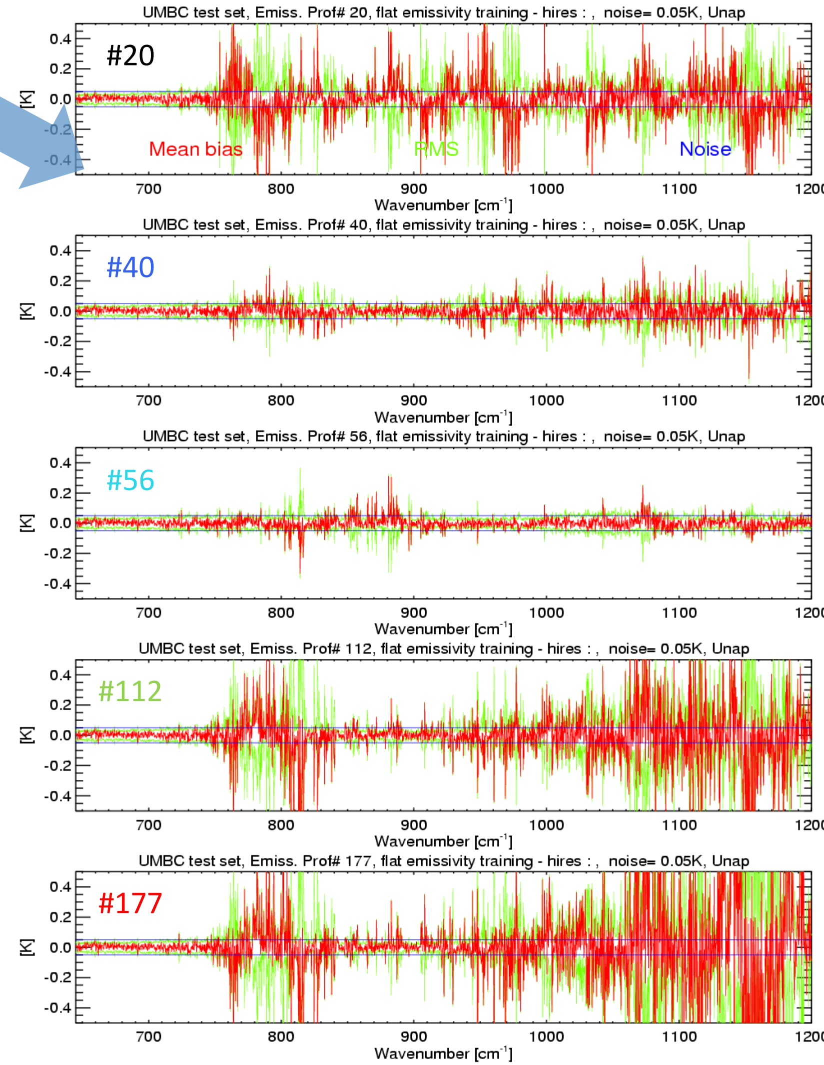
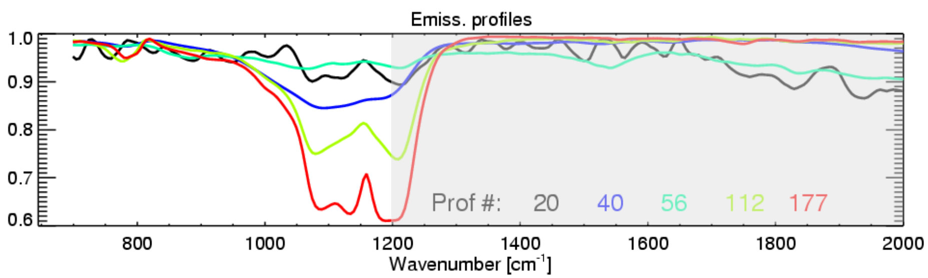
Unapodized (sinc) function – land training

- **Flat emissivity training inadequate when dealing with extended spectral regimes**
- Sample of typical emissivity spectra (w random perturbations added)included in training to remove spectral correlations and bring model accuracy within specs
- Nominal training accuracy: 0.05K





Selected land surface emissivities from merged University of Wisconsin and NASA Langley data sets (Borbas and Zhou)

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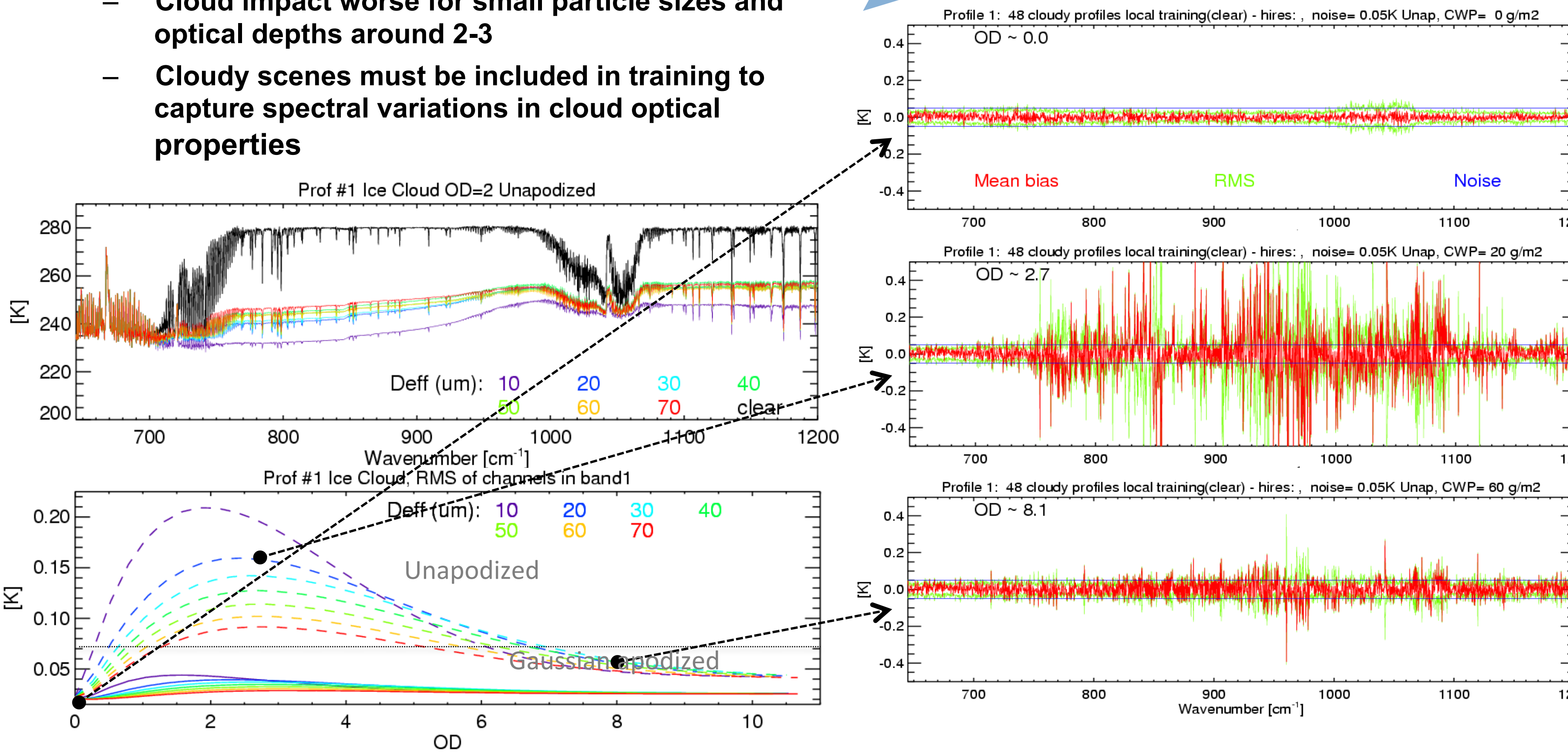
Cloud impact on clear-sky trained sinc model

- **Unapodized ILS: clear-sky trained model does not meet requirements in cloudy conditions**
  - **Cloud impact worse for small particle sizes and optical depths around 2-3**
  - **Cloudy scenes must be included in training to capture spectral variations in cloud optical properties**

Conditions: nadir; ice cloud at 300 mb; Deff = 20 μm; 4-stream adding-doubling solution)
Nominal accuracy = 0.05K



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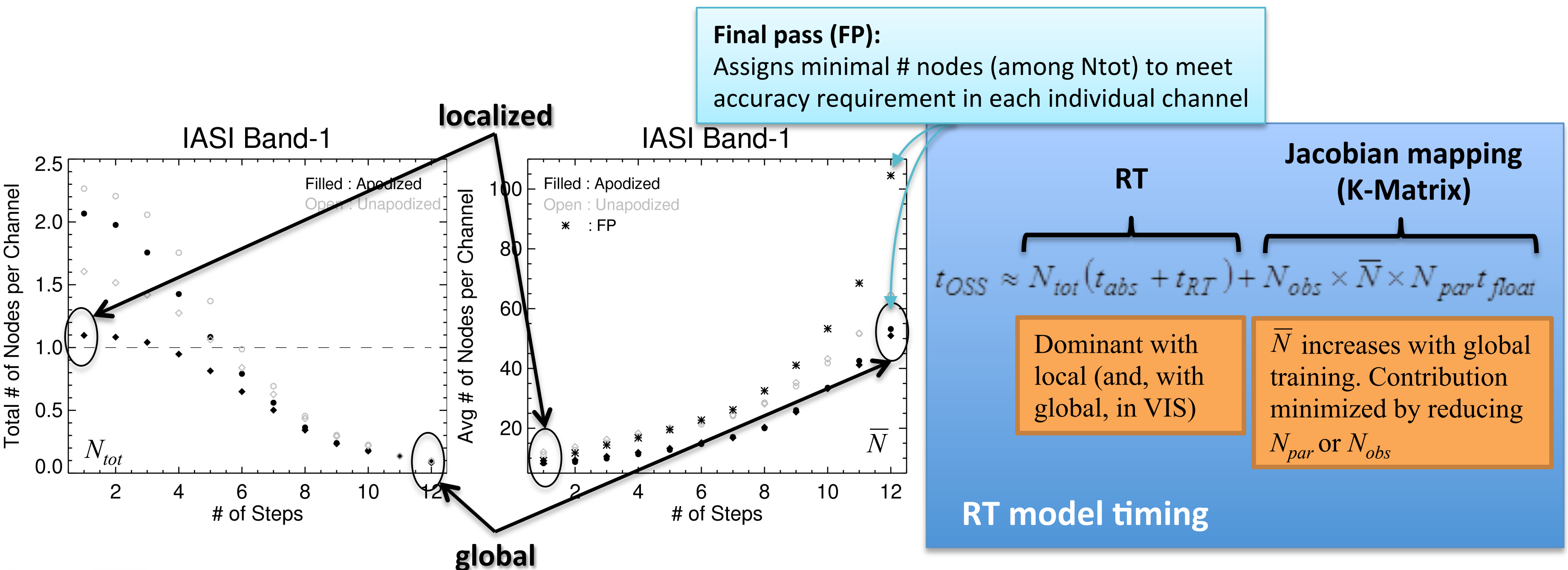
Global OSS solution

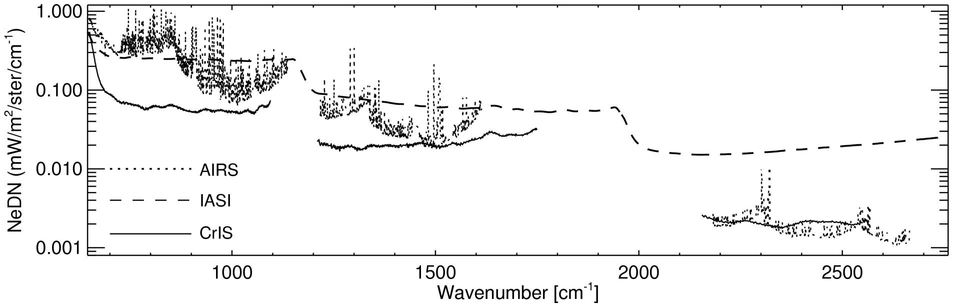
- "Global" OSS node selection applies to all channels at once
  - **Reduces total number of nodes (N_{tot}), i.e., RT execution and LUT size, by an order of magnitude**
- With rigorous method, search time increases with number of possible node combinations
  - Best performance achieved by applying methodology from Moncet et al. (2008) to contiguous pairs of channels and increasing the size of channel groups at each step

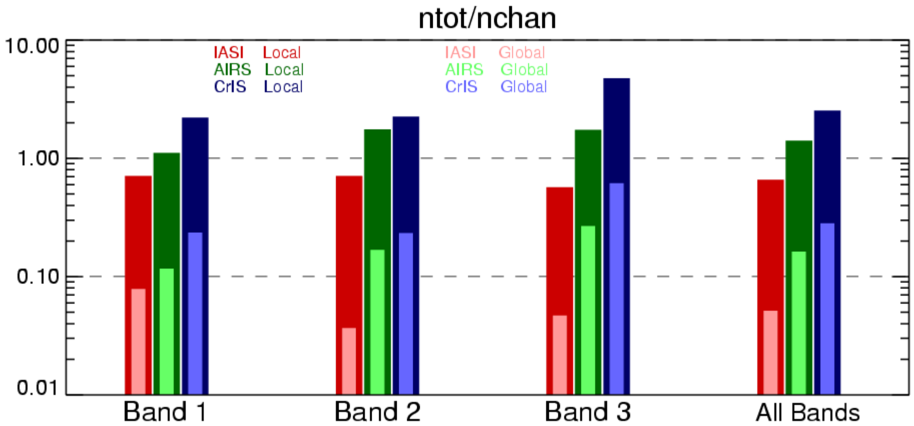


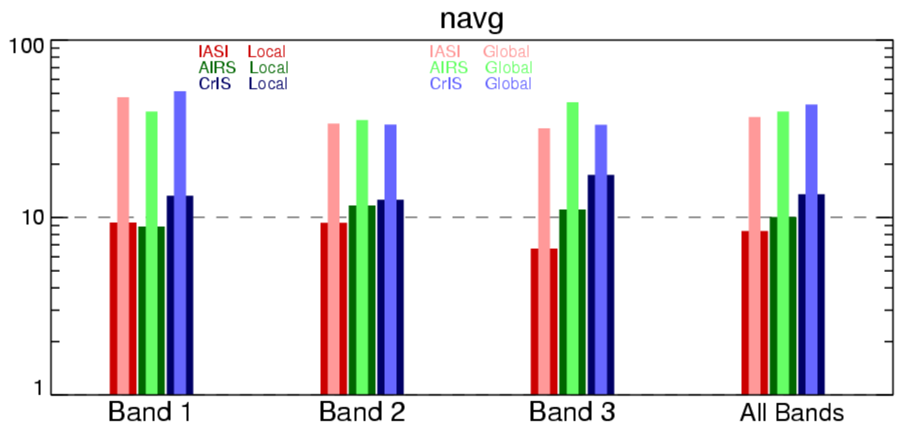
Performance examples

- Total number of nodes (bottom left) and average number per channel (bottom right) with local and global training for IASI, AIRS and CrIS (unapodized)
- Training accuracy = 0.1*NeDN

Sensor	LW		MW		SW	
	Range	Resolution	Range	Resolution	Range	Resolution
AIRS	649 - 1136	0.41-1.04	1265 - 1629	1.05-1.39	2169 - 2674	1.75-2.13
IASI	645-1210	0.5	1210-2000	0.5	2000-2760	0.5
CrIS	650-1095	0.625	1210-1750	1.25	2150-2550	2.5







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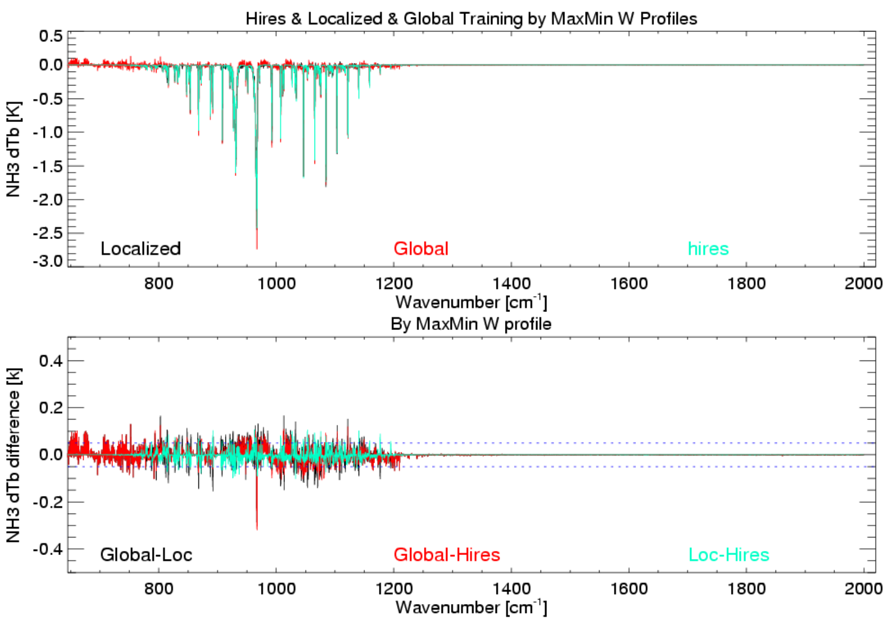
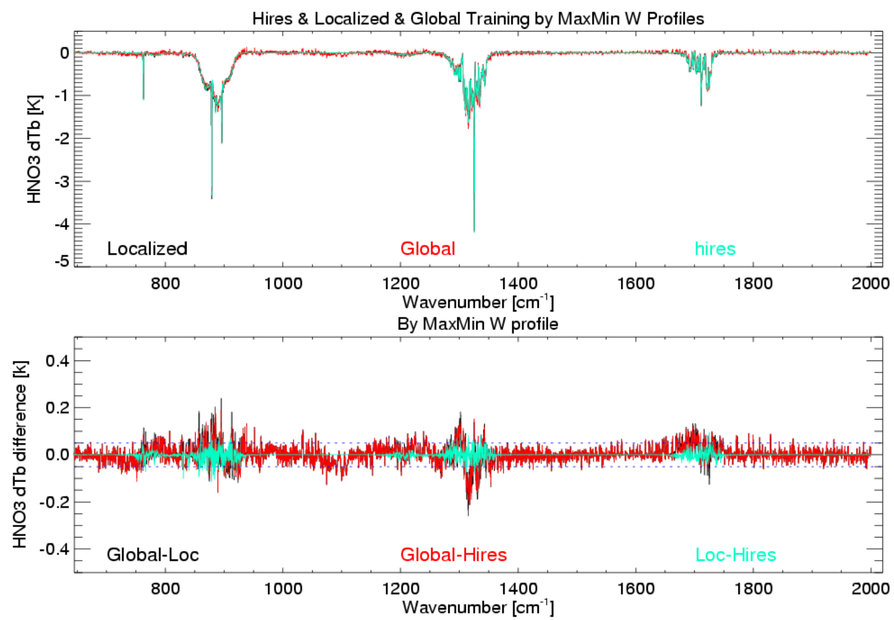
Spectral Mixing

- IASI (Band 1+ 2) global training:
  <300 nodes represent 5420 IASI channels
- No significant spectral mixing

NH3 Jacobians



HNO3 Jacobians



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PC compression

- **Use of PC to compress spectral information has been thoroughly investigated in past studies**
  - EOFs must be carefully chosen so signal due to trace species not “wiped out”
  - “Spectral mixing” prevents one from excluding undesired features e.g., cloud top, surface

key limitation for satellite data assimilation

- **EOFs treated in OSS as any other instrument function**
  - Same OSS (local/global) training method applies
- **Main speed gain (N_{tot}) in radiance domain comes from global training: no further gain expected by dealing with PCs instead of radiances**
  - For a same N_{tot}, radiance and PC-model performances are equivalent (so long as information content is preserved through PC filtering)

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Model transformation

- **Radiance-trained model can be transformed into a PC model by simply re-computing the weights:**

$$y = W\tilde{y} \quad \text{(same as Eq.1 - vector form)}$$

$$PC = U^T y = \left(U^T W\right)\tilde{y}$$

or vice versa (equation not shown)
  - When all nodes are used to reconstruct each channel, transformed weights are optimal (accuracy of transformed model same as directly trained PC-model)

- With transformed models, $N_{av} = N_{tot}$ which slows down Jacobian mapping in K-matrix.
  - OK when transforming radiance trained model into PC (few PCs to model)
  - Speed loss important when transforming PC-trained model into channel radiances (many channels)
  - Best to train directly in radiance domain for processing channel radiances and in PC domain for processing PCs

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Performance Examples

IASI Band 1 +2 clear-sky timing comparison
(forward model only: radiance + Jacobians – no inversion)

Computational gain
(local training = reference)

Representation	Training Mode	Retrieved profiles in geophysical space		Retrieved profiles in EOF space	
Channel Radiance	Localized	0.140	**1.00**	0.179	**1.00**
	Global	0.033	4.28	0.011	16.53
	PC-trans	0.212	0.66	0.040	4.50
PC	Localized	0.028	5.09	0.030	6.02
	Global	0.012	11.28	0.008	21.95
	Chan-trans	0.015	9.48	0.008	22.46
Node	Global	0.004	32.12	0.006	28.34

Timings in seconds

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Node based inversion

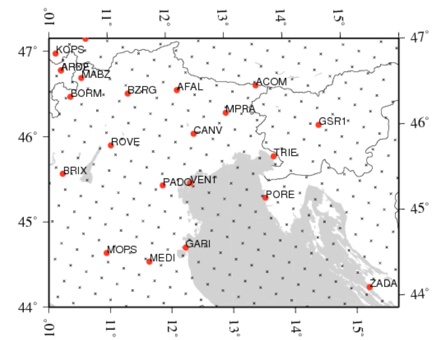
- Predict node radiances from real observations
- Perform inversion in node-space (no Jacobian mapping)
- Unlike PC: no spectral mixing problem
- In assimilation: same approach as with channels
  - Bias correction
  - Node selection

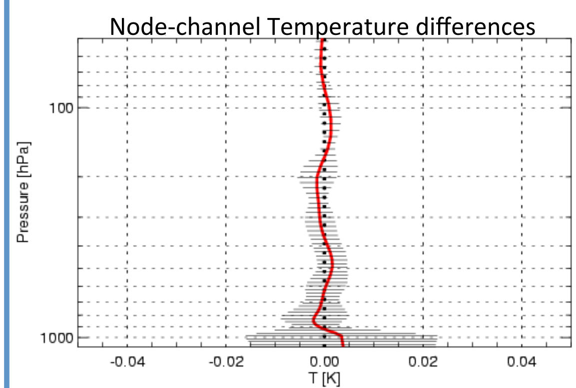
IASI retrieval inter- comparison (EUMETSAT – several international participants)

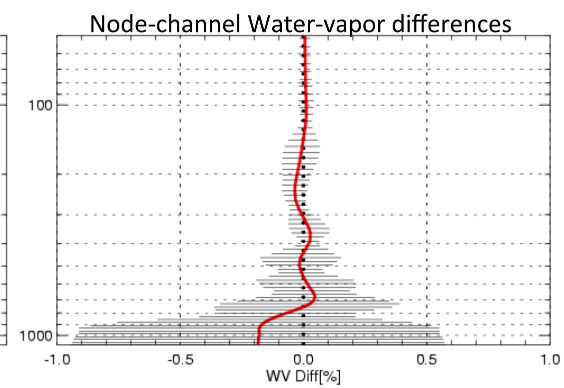
Differences between node-space and channel space results within retrieval uncertainties
(and well within range of solutions obtained with different algorithms)

Node vs. channel T (left) and q (right) retrieval differences

Selected IASI FOV from Udine (Italy): July- November, 2009







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Summary

- **OSS technology now mature**
  - Choice of options(local/global training; channel radiance/EOF. node-based inversion)
    - Localized radiance training: fast and robust (used for e.g., trace species retrieval)
    - Global training with node-based inversion: ~20 times faster (need more validation with e.g., TES and comparisons with to PC-inversion)
  - Used in JPSS/CrIS (not recently updated), in DoD future operational cloud analysis and for TES retrievals
  - JCSDA/CRTM-OSS
  - Independently tested at U. Wisconsin (UWPHYSRET package)
  - Acquisition on by EUMETSAT for production of MTG/IRS Level 2 product
- **On going work:**
  - Validation in precipitating environment (microwave)
  - Visible training: actually less demanding
  - Handling of Doppler shift/Zeeman splitting
  - Scattering calculations acceleration

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