Suggesting a 1DVAR System for NWP Assimilation Pre-Processing


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• **Scope/Agenda of the presentation**
  – Present a 1DVAR system to pre-process radiances
  – Show the applicability in non-conventional areas (over land, sea ice, etc. and in cloudy/rainy conditions)
  – Promote it as a pre-processor to NWP assimilation models

• **The Microwave Integrated Retrieval System**
  – System Design & Mathematical Basis
  – Assimilation/Retrieval

• **Potential Benefits to NWP Assimilation**
  – QC & Precipitation/Ice Detection
  – Suggested sounding in Precipitating Conditions
  – Emissivity Spectrum & Surface Type Information
  – Expanded coverage
The MIRS System
System Design & Architecture

MIRS Algorithm

Measured Radiances

Simulated Radiances

Comparison: Fit Within Noise Level?

No

Update State Vector

New State Vector

Yes

Solution Reached

Initial State Vector

Could be from:
- Climatology,
- Regression
- NWP

Community Radiative Transfer Model
(validity: in clear, cloudy, precip)
The MIRS System

• **Mathematical Basis:** *Minimization of Cost Function*

\[
J(X) = \left[ \frac{1}{2}(X - X_0)^T \times B^{-1} \times (X - X_0) \right] + \left[ \frac{1}{2}(Y^m - Y(X))^T \times E^{-1} \times (Y^m - Y(X)) \right]
\]

• **State Vector X comprises:**
  - Temperature & Moisture profiles
  - Non-precipitating cloud **profile**
  - **Hydrometeors profiles** (liquid & frozen phases)
  - Skin Temperature
  - Surface Emissivity spectrum

• **EOF Decomposition** *to balance X with information content of radiances Y*

\[
\Theta = L^T \times B \times L
\]

- Diagonal Matrix *(used in reduced space inversion)*
- Transf. Matrix *(computed offline)*
- Covariance matrix *(geophysical space)*

Atmosphere

Surface
Assumptions in the Assimilation with MIRS

(Usual suspects…)

- The PDF of X is assumed Gaussian
- Operator Y able to simulate measurements-like radiances
- Errors of the model and the instrumental noise combined are assumed (1) non-biased and (2) Normally distributed.
- Forward model assumed locally linear at each iteration.

CRTM used in MIRS to provide:
(1) Simulation of Radiances and
(2) Jacobians for all parameters

Rely on CRTM

Valid assumption. Reminder: This is just the RTM FWD model. No cloud model coupled with the RTM

A variable transformation is needed for Q, Hydr

Usually valid
How Does MIRS work in Precipitating Conditions?

1. Turn ON Rain and Ice & Update Tuning

2. 1st Attempt

3. TB

4. Attempt Retrieval

5. Convergence?

6. Yes → Output

7. No → 1st or 2nd Attempt?

8. 1st or 2nd Attempt?

9. Convergence Failed
Example of convergence

First Retrieval: non-convergence in precip conditions

Where non-convergence occurs, second attempts are made

Convergence after second attempt

Convergence Metric:

\[ \varphi^2 = \left[ (Y^m - Y(X))^T \times E^{-1} \times (Y^m - Y(X)) \right] \]
How is Assimilation done in Cloudy/Precipitating Conditions?

- X includes clouds and Hydrometeors Parameters
- Rely on CRTM to provide radiances that account for scattering and absorption due to cloud/rain/ice
- Rely on CRTM to provide Jacobians of Radiances wrt cloud/rain/ice parameters
- Constraints provided in the Covariance Matrix

Cloud and Hydrometeors parameters are treated in a similar way as the traditional temperature and moisture parameters

No cloud resolving model is used in the forward operator
Covariance Matrix Used in MIRS

Obtained by combining ECMWF-based covariance with WRF-based correlations for rain (correlations with Ice, Temperature, Humidity, etc).

This assures that T, Q, CLW, Rain and Ice Retrievals are physically consistent, on average.

No cloud resolving model is used in the forward operator.

Makes the covariance matrix very important.
Results of MIRS (Convergence)

Absorption Only (no rain, no ice) Hydrometeors turned ON

Significant improvement in convergence

ChiSq
Results of MIRS
(Hydrometeors retrieval -GWP)

Absorption Only

Absorption+Scattering

No convergence was reached before
Comparison at MHS Resolution

High spatial correlation MSPPS / MIRS
Coastal transition smooth
Potential Benefits to NWP Assimilation
Detecting Cloud/Precip/Ice

Ice and Rain could be retrieved at the same time or one without the other, depending on the signal in the radiances and the Jacobians from CRTM.
Providing NWP with QC

Convergence Metric:

\[ \varphi^2 = [(Y^m - Y(X))^\top \times E^{-1} \times (Y^m - Y(X))] \]

Non-convergence is a powerful QC tool for NWP assimilation.

It could signal a contamination, a surface mixture that is hard to model or anything that might be inconsistent with the forward operator.
Detecting Surface Type

- Thanks to retrieved Emissivity spectrum:
  - Sea Ice detected over water
  - Snow detected over land
Provide an Estimate of the State Vector, Including in Precip Conditions

Accuracy is hard to assess but estimated to be less than 3~5 Kelvin within convective areas
Expanded (Global) Coverage

Most parameters are retrieved globally (over land/ocean/sea ice/desert/snow/coast/etc)
Conclusions

• No difference between a variational Retrieval and 1DVAR radiance assimilation
• Algorithm estimates sounding, cloud, precipitation and surface parameters in non-traditional areas (could be used as 1st Guess to NWP assimilation models)
• MIRS also offers powerful QC indicators for NWP assimilation
• MIRS could be considered a rapid pre-processing tool that could help the full 3D or 4D VAR NWP assimilation
• MIRS is generic (for all MW sensors), so treatment of sensors data is consistent (used routinely for AMSU, MHS, SSMIS)
• MIRS is freely available to scientific community.