Towards a NNORSY
Synergistic GOME-2/IASI
Ozone Profile ECV

Anton Kaifel, Martin Felder, Frank Senke, Roger Huckle*
Center for Solar Energy and Hydrogen Research (ZSW)

* now working @ EUMETSAT

Study partly funded by Eumetsat
Outline

1. NNORSY Overview

2. Co-registration of METOP data and clouds

3. NNORSY-METOP Version 3

4. Learn-O-Matic: NNORSY-METOP Version 4 and channel selection

5. Conclusions
Co-registration and Clouds on GOME-2/IASI

GOME-2 FOV used as base grid for retrieval

→ Collocation GOME-2 & IASI
→ Collocation GOME-2 & AVHRR
→ Collocation IASI & AVHRR

Collocations with ozone profile measurements

~ 90 000 each for
→ ozone sondes
→ ACE-FTS
→ AURA-MLS
Operational Setup for NNORSY-METOP Version 3
Combining Hierarchical Networks and Averaging

same or slightly different config.

IASI
50% clouds

GOME
50% clouds

ECMWF
T-profile

IASI
100% clouds

GOME
100% clouds

hierarch
50% clouds

average output

hierarch
100% clouds

average output

weighted average

“cloud free net”

“global net”

cloud cover

retrieved profile

+ one error
network trained on retrieved profile errors
Improvements of NNORSY V3 compared to V2

NNORSY Methodology

- V2 scheme's RMSE was higher by a factor of 1.2 to 1.5
- Strongest RMSE reductions in the most critical regions (UTLS, troposphere)
Retrieval Error Assignment Examples

→ Multiplying error output by factor ~1.2 yields approximate standard deviation
**Difference between Training and Validation Data Set**

**NNORSY-METOP V3:**

- MLS training data: ~35 Td.
- MLS validation data: 2.9 Million

Latitudinal distribution of MLS validation data
NNORSY-METOP V3: Long Term Performance

Time series with 4 week moving average

Station 99 (Hohenpeissssenberg)
Learn-O-Matic

Machine Learning and Optimization Tool including Deep Learning and Automatic Feature Selection for NNORSY*

- Multi-tier **GPU** based machine learning system with user friendly web-frontend
- ~ 250 time faster compared to high performance **CPU**

*) Sehnke et al. 2012, Learn-O-Matic - Fully automated Machine Learning, ZSW internal Tech. Note
Learn-O-Matic: Implemented Features

- Deep neural networks
- Reduced Boltzmann machines (Hinton et al. 2006)
- Support vector machines
- Gaussian Processes (sparse approximation/regression scheme)
- Policy Gradient with Parameter-based Exploration (PGPE): reinforcement learning scheme for all kind of optimization tasks (Sehnke et al. 2010, 2011)
This normalisation allows for a result driven feature selection.

The automatic feature selection produces a feature set with corresponding colour coded (blue to red) weight strengths shown here.
Learn-O-Matic: IASI Channel Selection

Joined GOME-2 & IASI retrieval


H₂O, N₂O, CH₄, SO₂

CO  N₂O Col.  Temp.  Surf. & Clouds  CH₄
Learn-O-Matic: GOME-2 Channel Selection

Comparison Joined GOME-2 & IASI and GOME-2 only

- O₃ Hartley band
- O₃ Huggins band
- O₃ Chappuis band

GOME-2 only

GOME-2 & IASI
NNORSY-METOP V3/V4 Comparison

Version 3 vs. 4

→ Version 3 hierarchical and averaging

→ Version 4 single deep NN with automatic channel selection
NNORSY Nadir Satellite Instruments Already Processed

Example NNORSY timeseries for Hohenpeissenberg

- **METOP-GOME-2 & IASI (V3/V4)**
- **ENVISAT-SCIAMACHY (V3)**
- **ERS2-GOME (V2)**

**NNORSY-METOP:** two different ozone profile data sets
- GOME-2 spectra only
- Synergistic retrieval using GOME-2 and IASI spectra
Conclusion

1. NNORSY-METOP Version 3 with hierarchical approach
   - First full joined GOME-2/IASI retrieval
   - IASI improves ozone profile retrieval in UTLS and troposphere

2. Learn-O-Matic
   - Fully automated machine learning tool with channel selection for GOME-2 and IASI → NNORSY-METOP Version 4
   - Already further improvements for ozone profile retrieval with only one deep neural network → expecting more improvements with averaging

3. NNORSY ozone profiles using ERS2/GOME, SCIAMACHY and GOME-2/IASI → long term ozone profile ECV (July 1995 – present)
Questions and Comments
Backup Slides
NNORSY-METOP V3: Validation Single Stations

Hohenpeissenberg

(163 profiles)

Syowa

(39 profiles)
Training Data: Seasonal Dependency

NH spring

NH autumn

NH summer

NH winter
Validation Data: AURA-MLS Latitude Bands

10 degree latitude bands: 90N – 20S
Validation Data: AURA-MLS Latitude Bands

10 degree latitude bands: 30S – 90S

On global scale:
- no offset but STD on validation slightly higher
- STD > 40km up to 20% → MLS itself
- SH: STD + 5% higher
- NH: STD – 5% higher

Latitude bands:
- MLS scan pattern visible
- negative bias over Antarctica
SZA Dependency

Relative [%]

$O_3$ relative bias [%]

$O_3$ relative std.dev. [%]
GOME-2 FOV Dependency

Relative [%]

$O_3$ relative bias [%]

$O_3$ relative std.dev. [%]
Cloud Fraction Dependency

Relative [%]

$O_3$ relative bias [%]

$O_3$ relative std.dev. [%]
Validation Data: Single Station

Hohenpeissenberg (mid latitude)

NNORSY-METOP

latitude band 30.0° to 60.0°

altitude [km]

ozone sonde

relative difference [%]

date (start of year)
Validation Data: Single Station

Syowa: Antarctica

Latitute band -90.0° to -60.0°

NNORSY-METOP

Ozone sonde

Relative difference [%]

Date (Start of Year)
Backup