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Variability of mesospheric water vapor above Bern in relation to the 27-day solar rotation cycle

Martin Lainer, Klemens Hocke and Niklaus Kämpfer
Institute of Applied Physics
University of Bern

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Motivation

- Sun rotation triggers Lyman-α (121.56 nm) oscillations with a mean synodical period of 27.28 days
- Linking mechanisms (e.g. photolysis) between variability of mesospheric water and solar radiation are of interest
- Signatures of 27-day solar variability were found in tropical middle atmospheric OH, H_2O (Shapiro et al., 2012, ACP) and zonally averaged CO (Ruzmaikin et al., 2014, ASR)
- Extra-tropical investigations including observations of middle atmospheric water vapor found less attention, motivating our study

Mid-latitudes: 27-day solar variability → Effects on mesospheric water?

MIAWARA: Middle Atmospheric Water Vapor Radiometer

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Located near Bern, Switzerland (46.88°N / 7.46°E)

Operational since 2002

Operating during day and night at all weather conditions except precipitation (rain, snow)

Measures the pressure broadened rotational transition line of H_2O at 22.235 GHz

Vertical H_2O profile retrieval by the Optimal Estimation Method (OEM)

Measurement Principle - Basics 1

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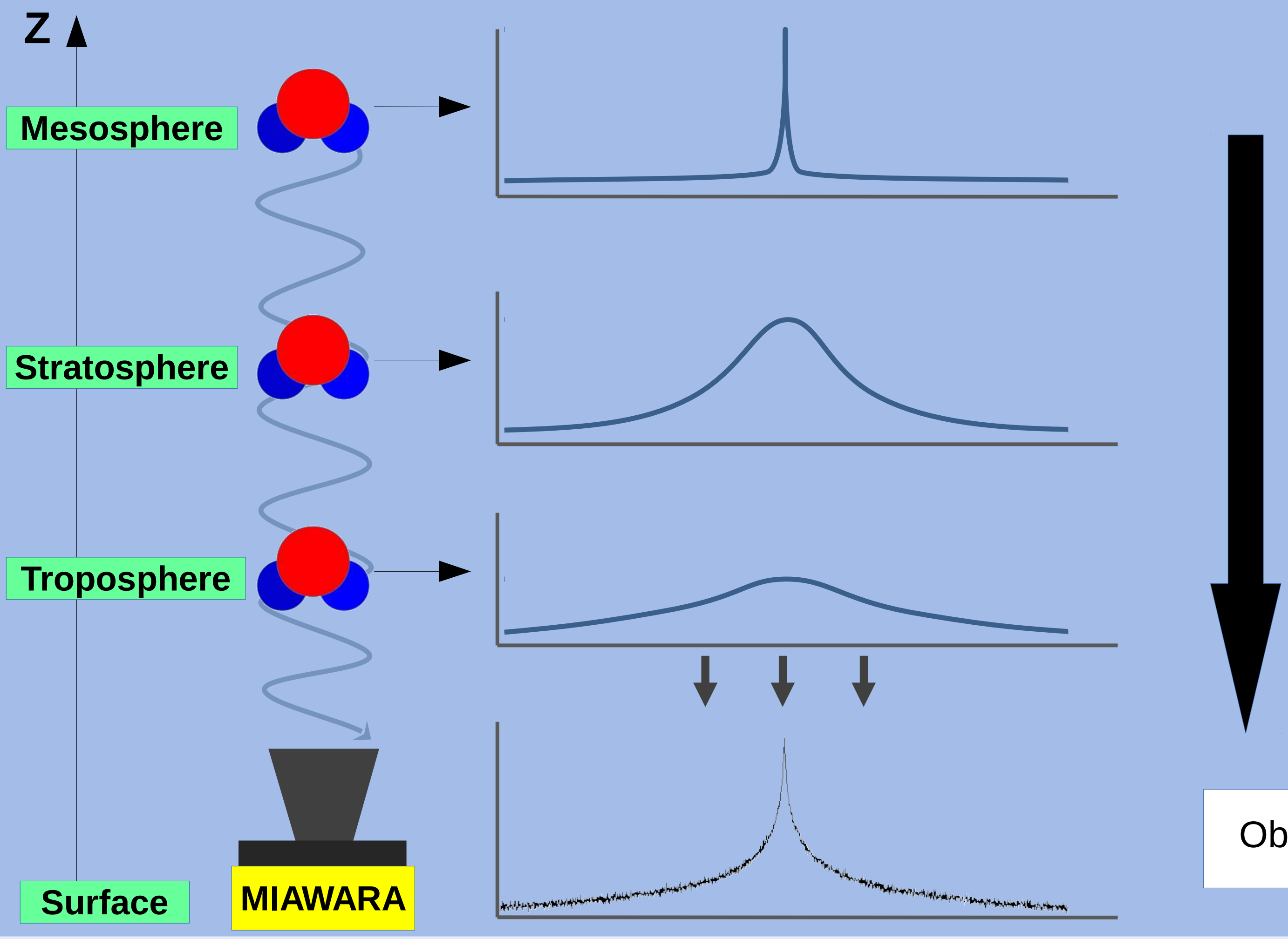


Change in H_2O line shape due to pressure broadening

Observed H_2O line shape

Measurement Principle - Basics 2

OEM (Optimal Estimation Method)

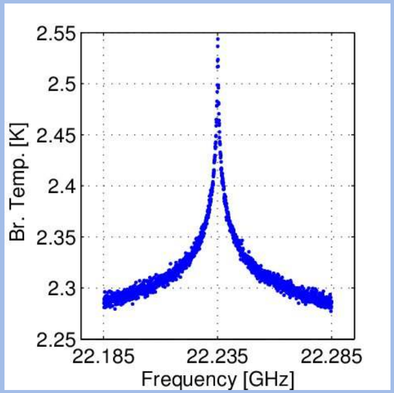
Minimize the cost function c based on measurements $\boldsymbol{y}$, apriori knowledge $\boldsymbol{x_a}$ and a radiative transfer model $F()$ to obtain the optimally estimated solution $\hat{\boldsymbol{x}}$:

$$c = [\boldsymbol{y} - F(\hat{\boldsymbol{x}})]^T \boldsymbol{S_y^{-1}} [\boldsymbol{y} - F(\hat{\boldsymbol{x}})] + [\hat{\boldsymbol{x}} - \boldsymbol{x_a}]^T \boldsymbol{S_a^{-1}} [\hat{\boldsymbol{x}} - \boldsymbol{x_a}]$$

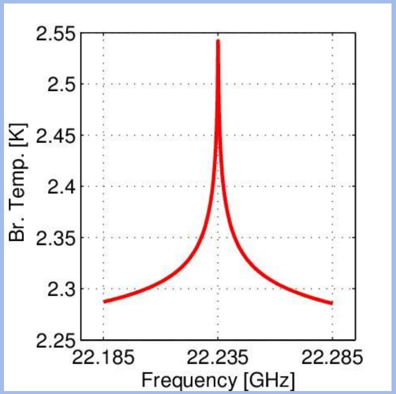
S_y: Measurement covariance matrix

S_a: Apriori covariance matrix

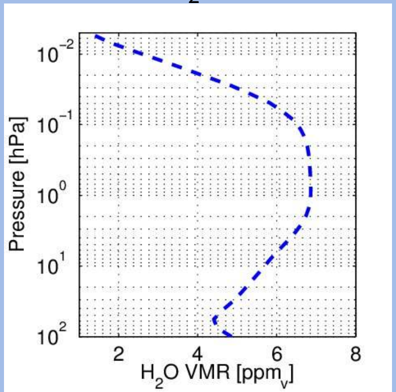
Measurements



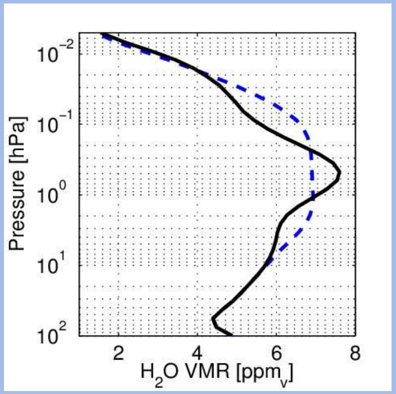
RT model



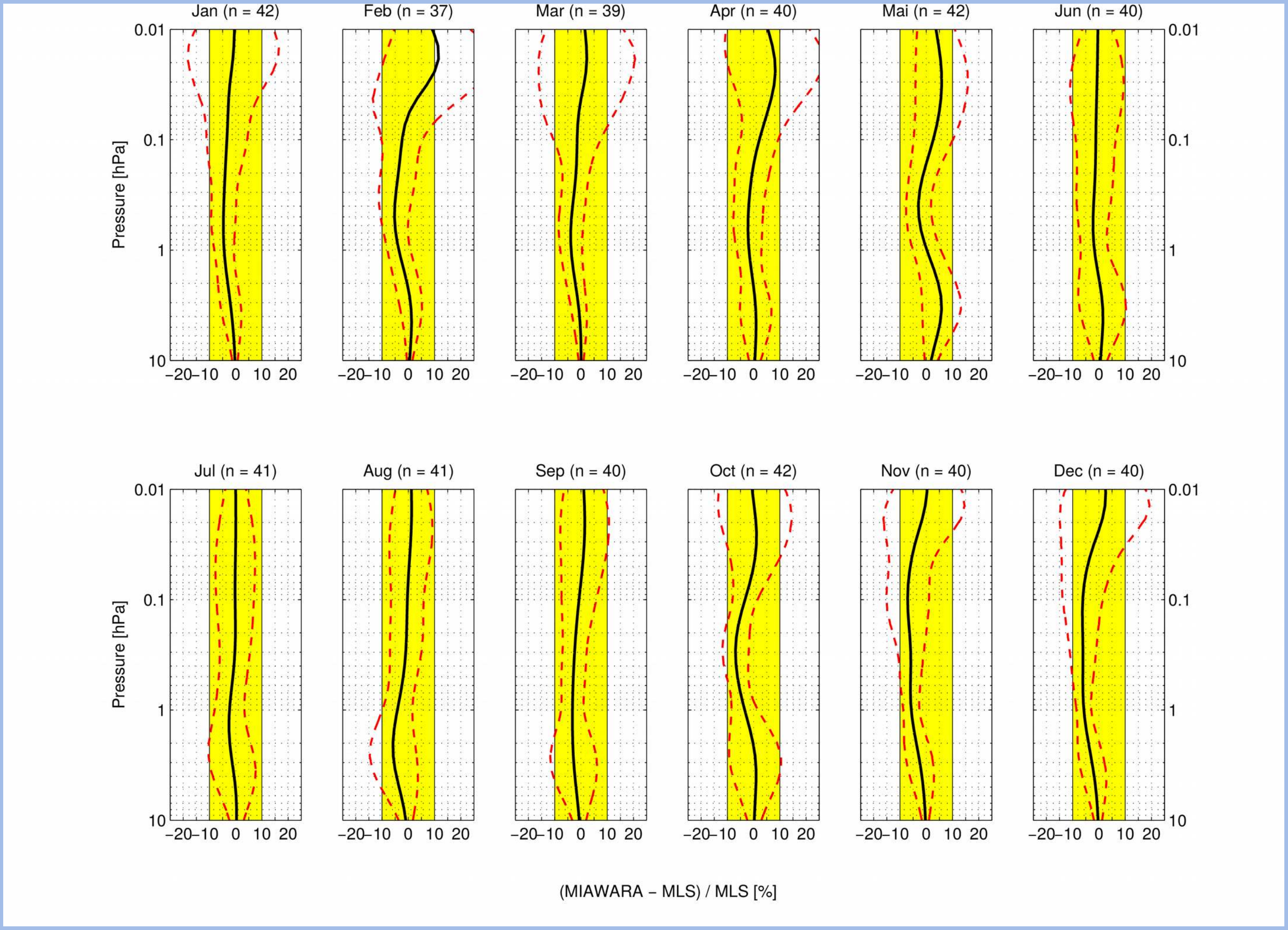
Apriori H_2O profile



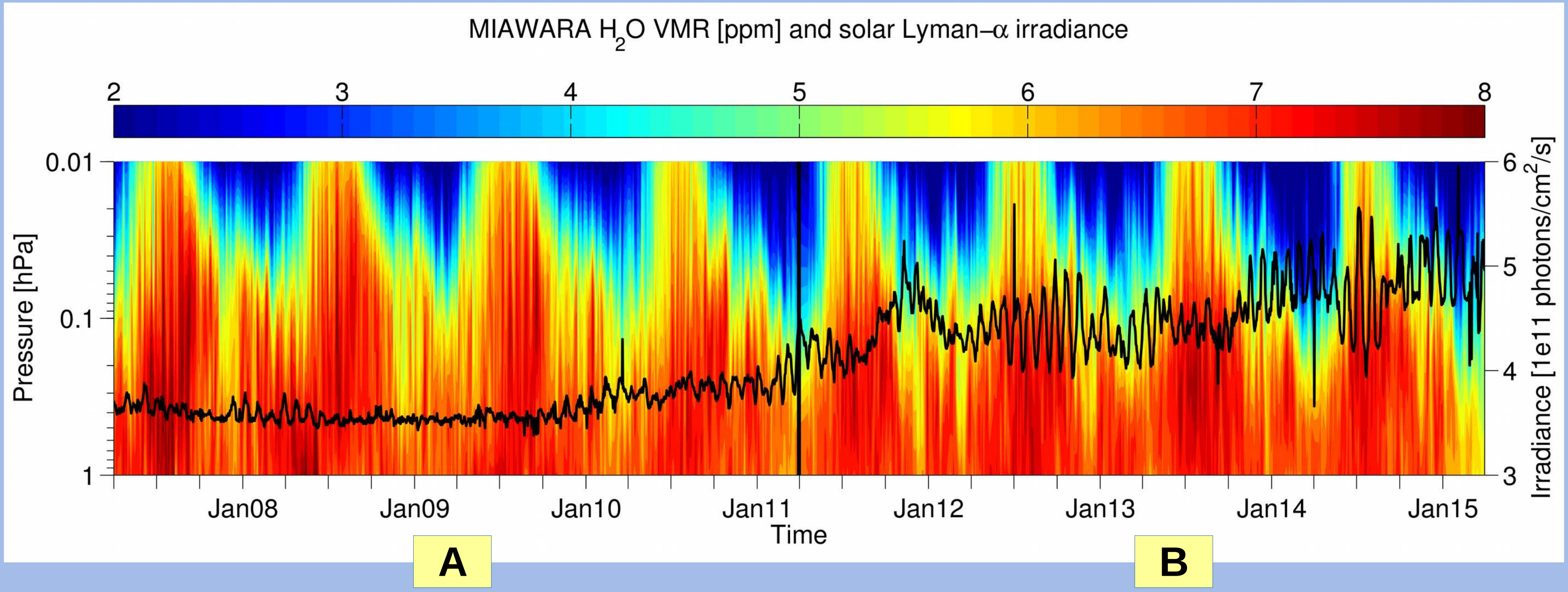
OEM solution $\hat{\boldsymbol{x}}$



Comparison between MIAWARA & Aura/MLS (Monthly mean statistics 2007 – 2011 of H_2O profiles)

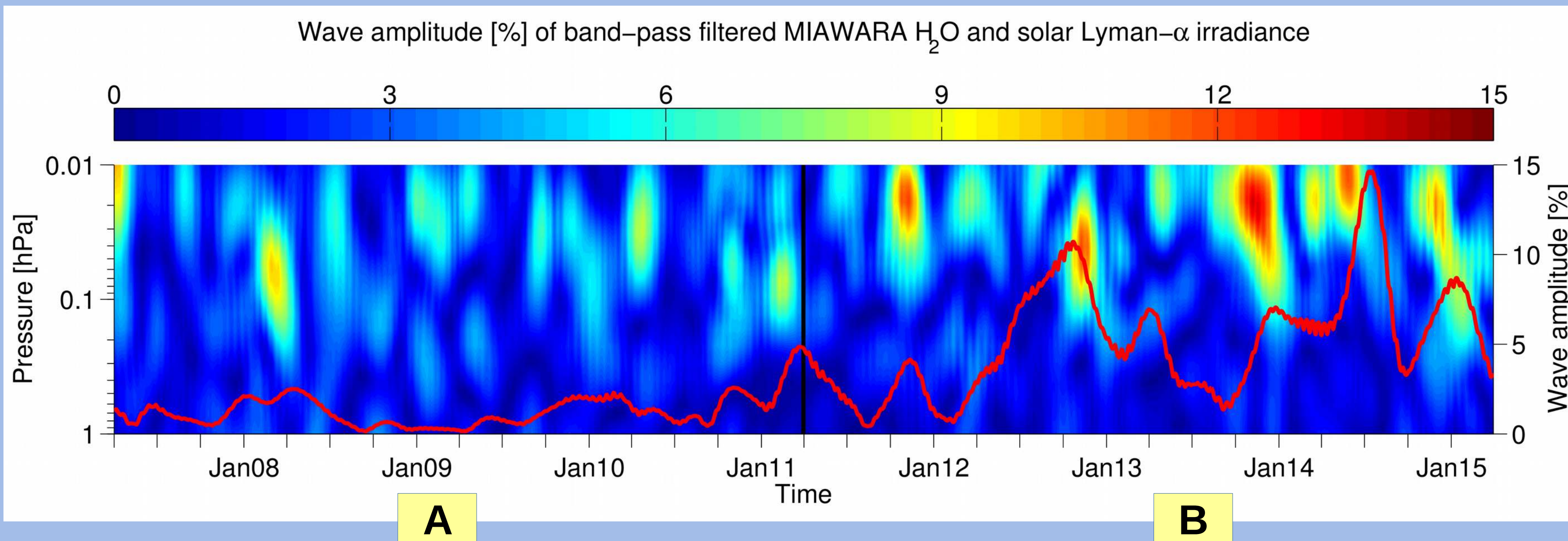


MIAWARA H_2O time series & solar Lyman-α composite



- MIAWARA H_2O time series (April 2007 until March 2015) between 50 and 80 km
- Composite Lyman-α time series from LISIRD (LASP Interactive Solar Irradiance Data Center)

27-day relative wave amplitudes



- Non-recursive FIR band-pass filter with Hamming window
- Central frequency $f_p = 1/27$ d; Cut-off frequency $f_c = f_p \pm 0.1 * f_p$
- Oscillations higher or shorter than f_c are suppressed
- Filter runs forward and backward along the data time series (zero phase lag)

Mean H_2O amplitude spectra (Bern)

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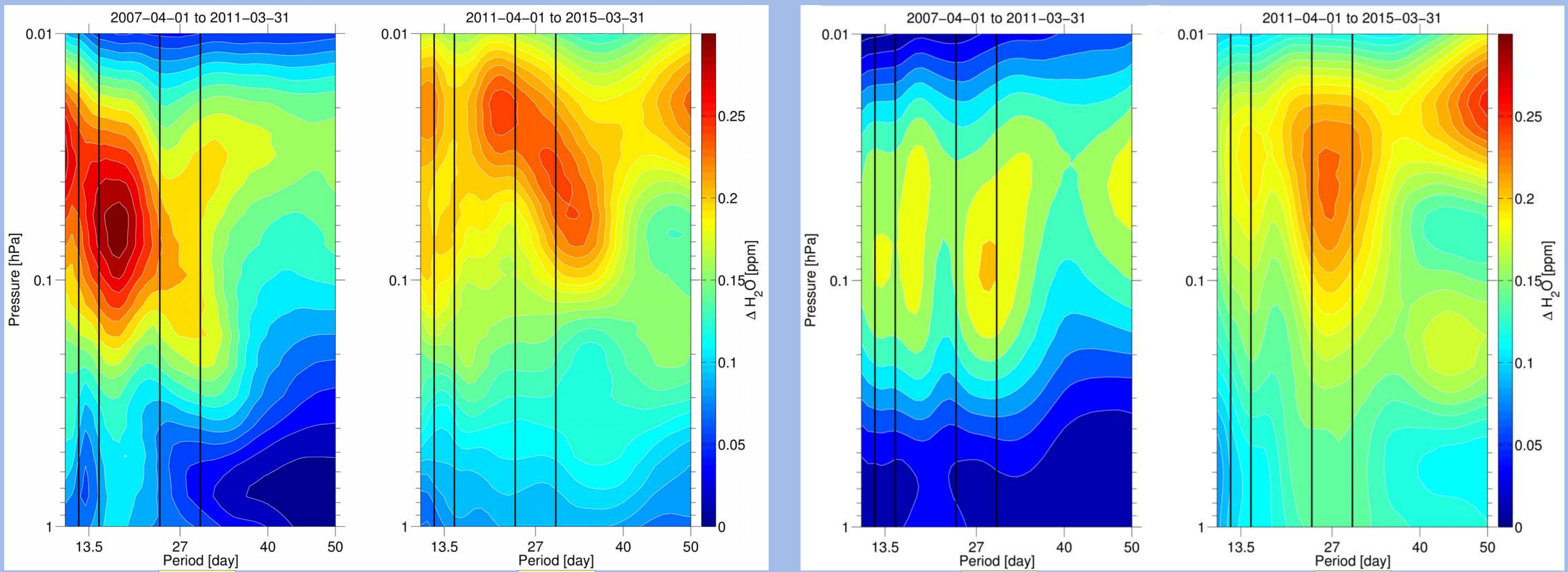
MIAWARA

Aura MLS (v4.2)



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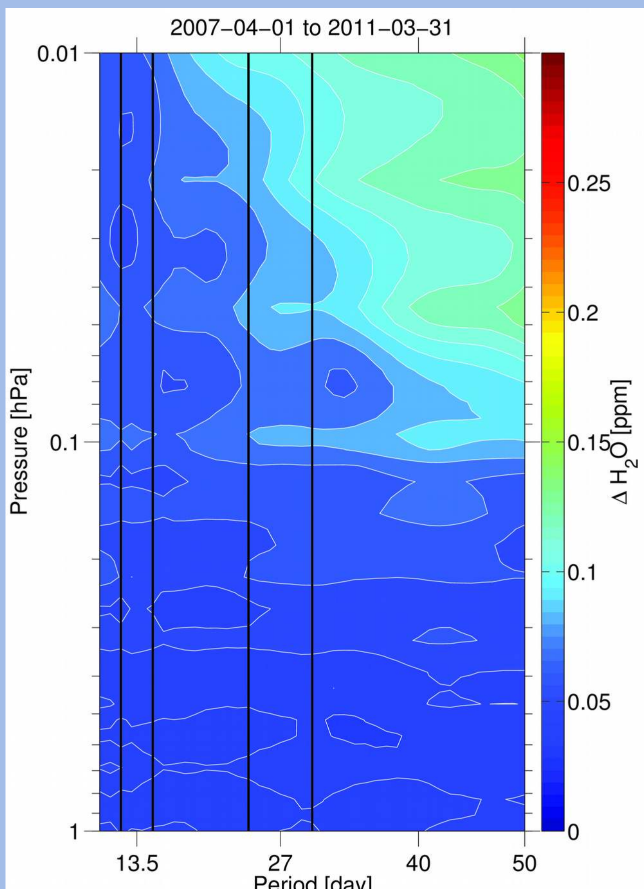
- Derived from band-pass filtering at frequencies between 1/10 d and 1/50 d
- Differences presumable due to horizontal inhomogeneity (limb vs. line of sight observation)

Mean zonal mean H_2O amplitude spectra

Weak Lyman-α variability

Strong Lyman-α variability



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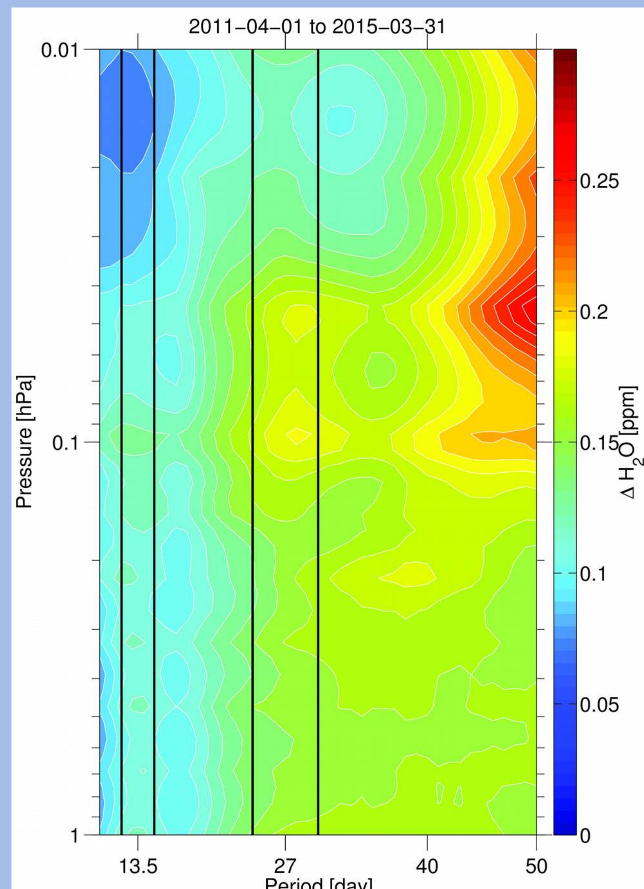

B

Aura/MLS (v4.2) measurements within the latitude belt 44°-50°N are processed

Enhanced amplitudes in the 27-day and 13.5-day period band in time period B (in comparison to period A)

Time lagged cross-correlation between 1 and 0.01 hPa

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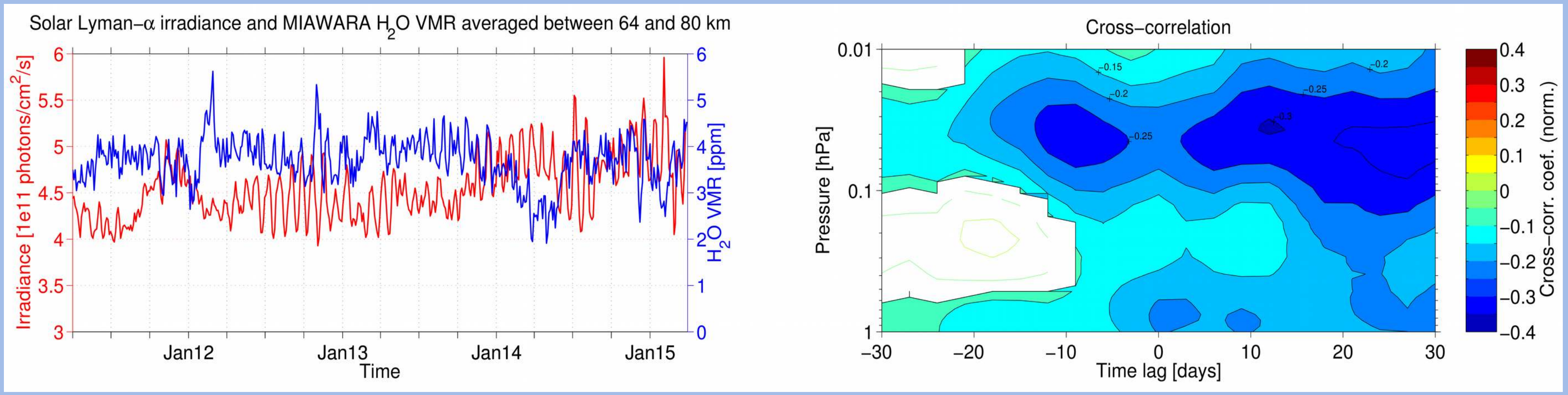

Negative cross-correlations
up to -0.3 (upper mesosphere)
Confidence ≥ 99 % (filled contours)

Phase lag: ~10 days
Solar forcing leads
the H_2O response

Cross-Wavelet Transform (XWT)

MIAWARA H_2O time series averaged between 64 and 80 km

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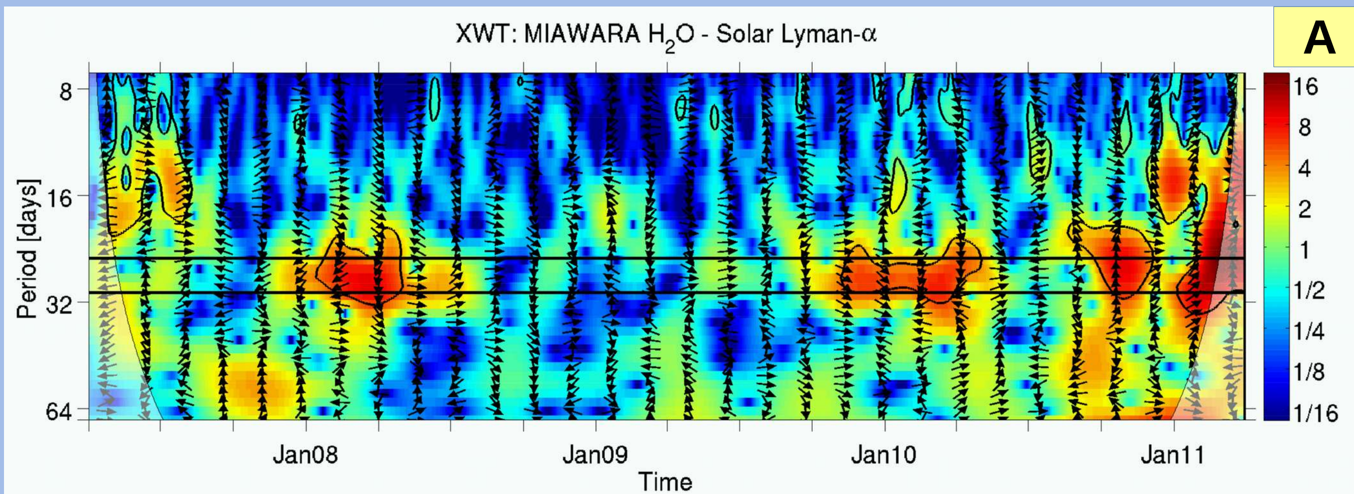
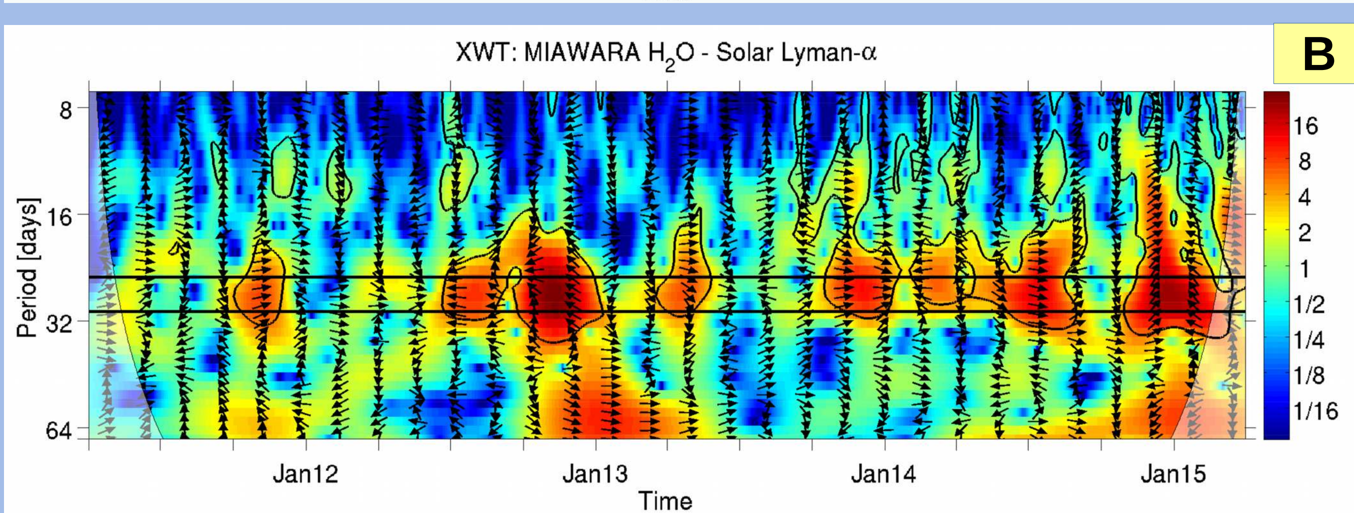


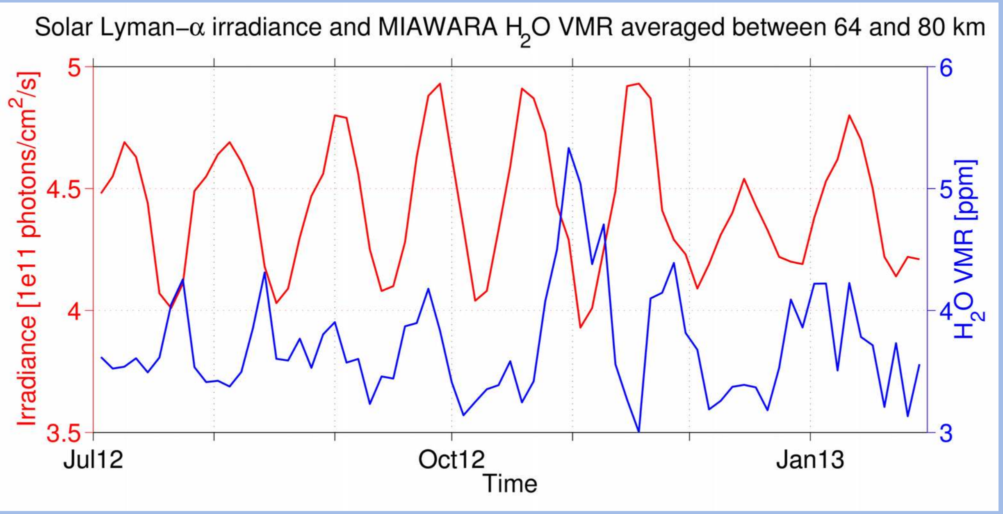
Significant (two sigma level) high common wavelet power in the 27-day band when Lyman-α oscillations intensify



Variable phase relationship

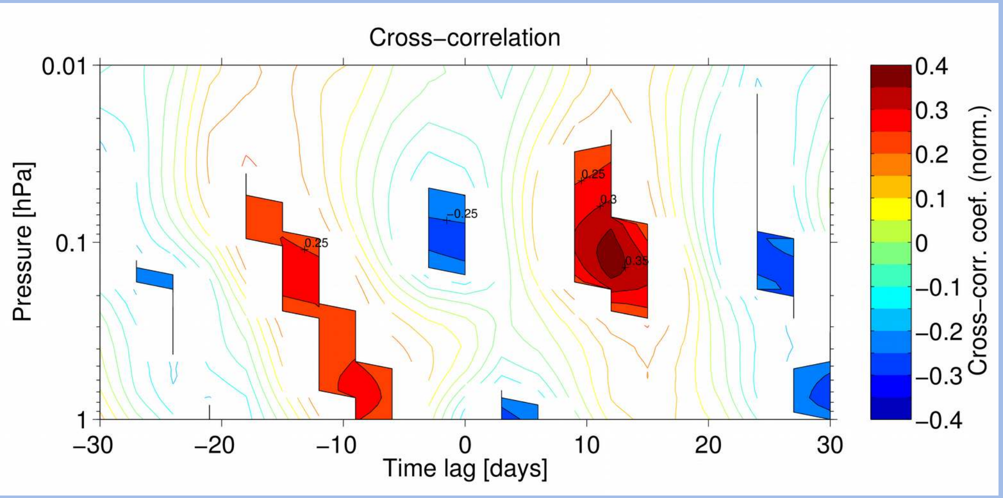
Solar superstorm 2012

Cross-correlation between MIAWARA H_2O and solar Lyman-α



Time series of Lyman-α and MIAWARA H_2O (deseasonalized, averaged between 64 and 80 km

Anti-correlation



Time lagged cross-correlation between Lyman-α and MIAWARA H_2O for pressure levels between 1 and 0.01 hPa

Confidence ≥ 95 % (filled contours)

Conclusions

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- Enhanced H_2O wave activity above 0.1hPa in the 27-day band is present during the more active time of solar cycle 24 (period B from 2011-04-01 to 2015-03-31), not only locally for Bern but also at other places in the 44°-50°N latitude belt
- Cross-correlation coef. of about -0.3 between solar Lyman-α and MIAWARA H_2O (phase lag of around 10 days)
- Cross-Wavelet analysis: Significant (two sigma level) high common wavelet power in the 27-day band with variable phase lock behavior
- The competition between advective transport and photo-dissociation loss of mesospheric H_2O may explain the sometimes variable phase relationship between mesospheric H_2O and solar Lyman-α oscillations

Solar variability on the 27-day periodicity scale causes observable photochemical and dynamical processes in the mid-latitude mesosphere

The End

Thank you for your attention!