SPECIAL PROJECT FINAL REPORT

Project Title:	Homogenization and uncertainty estimation of historic in situ upper air data
Computer Project Account:	spatlh00
Start Year - End Year :	2012 - 2014
Principal Investigator(s)	Leopold Haimberger
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Summary of project objectives

The special project was intended to support the participation of University of Vienna in the EC 7th framework programme project ERA-CLIM. Work package 4 of this project dealt with the assessment of the observation uncertainties of historic in situ data, especially those who have recently been digitized but never have been assimilated. Observation records treated with offline homogenization methods or online with variational bias estimation methods. Main candidates for homogenization back to the early 1940s are radiosonde temperatures and winds. The special project provided timely and convenient access to the reanalysis archives, especially the observations databases. The requested computer time was used mostly for statistical analysis of observation data and background departures.

Summary of problems encountered

Less progress than expected has been made regarding a variational bias adjustment algorithm for wind direction and temperature. Algorithms have been developed but have not reached a state mature enough to be used more widely.

Experience with the Special Project framework

Both application and reporting procedures are quite convenient. User support is excellent.

Summary of results

The users of the special project spatlh00 were active in three fields during the period 2012-2014:

1) Using ERA-20CM and ERA-20C for investigation and uncertainty estimation of upper air data back to the 1920s
2) Implementation of variational bias correction of temperature and wind
3) Though not specifically an aim of the project, energy budget studies with ERA-Interim and the ECMWF ocean reanalysis system ORAS4 have been pursued.

Ad 1)

Good progress has been made in the homogenization of the global radiosonde/PILOT wind data set. Data from ECMWF, NOAA, and the newly digitized data collected in ERA-CLIM have been merged and homogenized. These are available from the PANGAEA data server and have been published (Ramella-Pralungo et al. 2014, Ramella-Pralungo and Haimberger, 2014). Temperature homogenization back to beyond 1958 using the available surface data only reanalyses (ERA-20C and NOAA 20CR) has been found to be unreliable at the current stage. This has changed with the advent of ERA-PreSAT that allowed for more efficient homogenization of early temperature data but a new homogenized temperature data set based on it was not ready until the end of this project.

Good progress has been made in analysing pre-1958 observation data as provided by the CHUAN, the ERA-CLIM newly digitized dataset and and IGRA upper air archives. The bias adjustment method RAOBCORE has been applied to these data and many interesting bias patterns and shifts could be detected. The NOAA 20th century reanalysis has been used as background for wind direction adjustment.
Fig. 1 shows that the homogenization system RAOBCORE, using NOAA-20CR analyses as reference, can remove most of the original shift in wind direction and wind speed at a station. The impact of the adjustments on the global scale is small. Wind data can thus be considered reliable climate variables and they have been used to estimate the presumed amplification of surface trends in the tropics, employing the thermal wind relation. Fig. 2 shows good overall agreement between different upper air tropical temperature trend estimates, either directly from homogenized radiosonde temperature data or indirectly by starting with a reference temperature trend profile in the northern extratropics and then integrating the thermal wind relationship southward, employing radiosonde wind shear data.

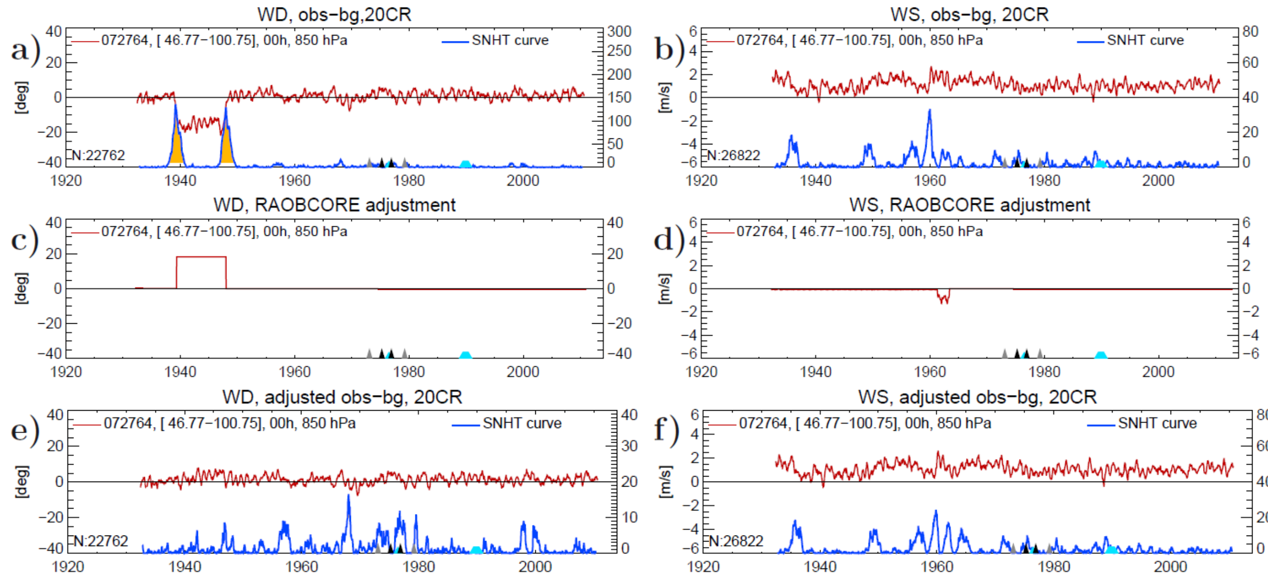

Fig. 1: Municipal Bismarck,North Dakota USA, 072764 Wind Direction (deg North) and Wind Speed analysis departure (Obs-20CR) time series at time 12 GMT for 850hPa, with running mean of 200 days (red curves). The blue curves (right axes) show the SNHT (Standard Normal Homogeneity) time series. Panels a,b): Before adjustment, panels c,d): adjustments (constant wind direction, wind speed adjustment proportional to wind speed), panels e,f): after adjustment with RAOBCORE.

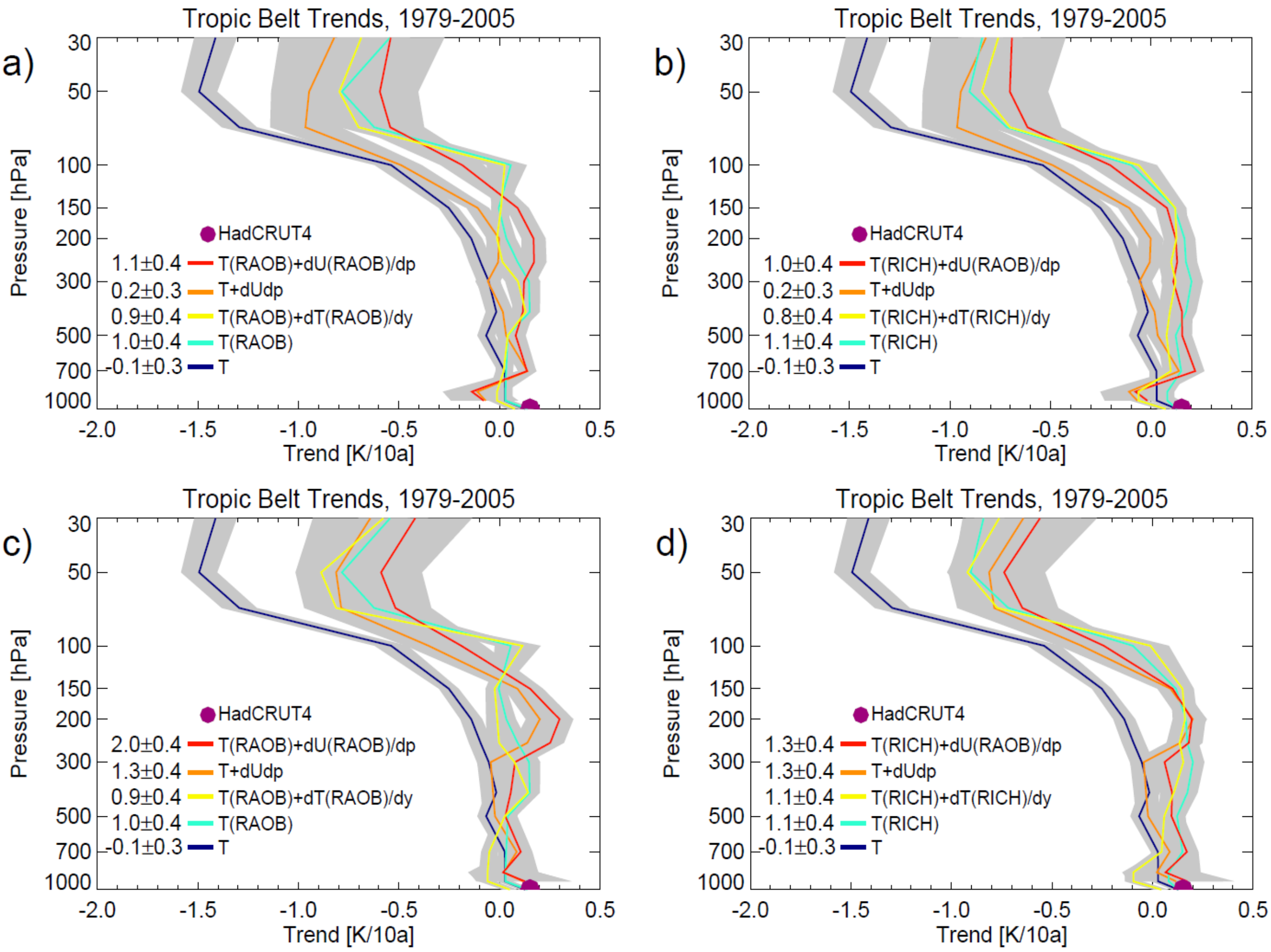

Fig. 2: Global mean temperature trends for the period 1979-2005 in the tropical belt (20N-20S) inferred either from zonal wind vertical wind shear and temperature at 35N (panels a,b) or 45N (panels c,d) or from temperature alone (no dU). The blue trend profile from unadjusted radiosonde temperatures is the same in all four panels. The grey shaded areas are 95%confidence intervals for the profiles. For details see Ramella-Pralungo and Haimberger (2015)

Ad 2):
Dr. Marco Milan implemented an offline radioosonde bias correction scheme, using the ERA-Interim background departures as reference. The scheme consists of a statistical model that fits a function of pressure and solar elevation to the background departure profiles. The fits can be done for individual radiosonde types (the information on radiosonde types comes from S. Schroeder's (TAMU) Vapor library database), or for clusters of sonde types having similar mean departure profiles in the vertical.

While the scheme does not yield as smooth maps of trend profiles than do the RAOBCORE/RICH methods (Haimberger et al. 2012), they yield similar zonal mean trend profiles, suggesting that its implementation within a variational bias correction context would have a similar effect as the use of RAOBCORE v1.5 adjustments. A manuscript submitted to J. Geophys. Res. (Milan and Haimberger, 2015) has been conditionally accepted

The maps of trends at the 100 hPa level in Fig. 3 indicate that the trend heterogeneity is improved only slightly by application of this bias model (panels c,d vs a). RAOBCORE v1.5 (panel b) performs much better in this respect. However, RAOBCORE adjusts the bias level by level whereas the new bias model does some smoothing in the vertical. At least the new bias model could be applied to almost all radiosonde types. Thus the number of stations adjusted is as high as in RAOBCORE if clusters of radiosonde types are used. If the radiosonde types are adjusted individually, there are more often too few data but the number of stations adjusted is still quite high.

The zonal mean trend patterns in Fig. 4 show that all three adjustment methods yield similar results. The spurious cooling maximum in the tropical stratosphere is substantially reduced by all methods. A warming maximum in the tropical upper troposphere is restored.

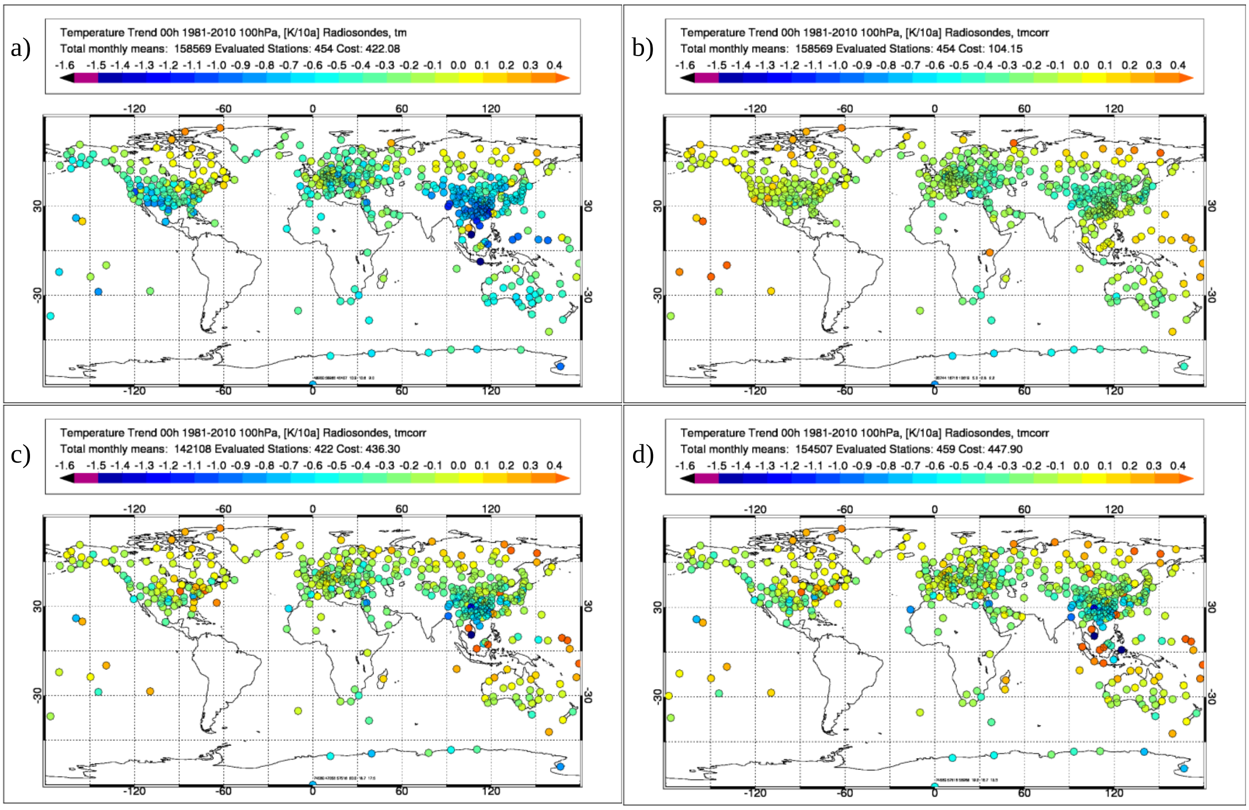

Fig. 3: Maps of temperature trends 1981-2010 from radiosondes at the 100 hPa level a) from unadjusted time series, b) from RAOBCORE adjusted series, c) from series with sonde-type based adjustments, d) from series with sondetype cluster based adjustments.

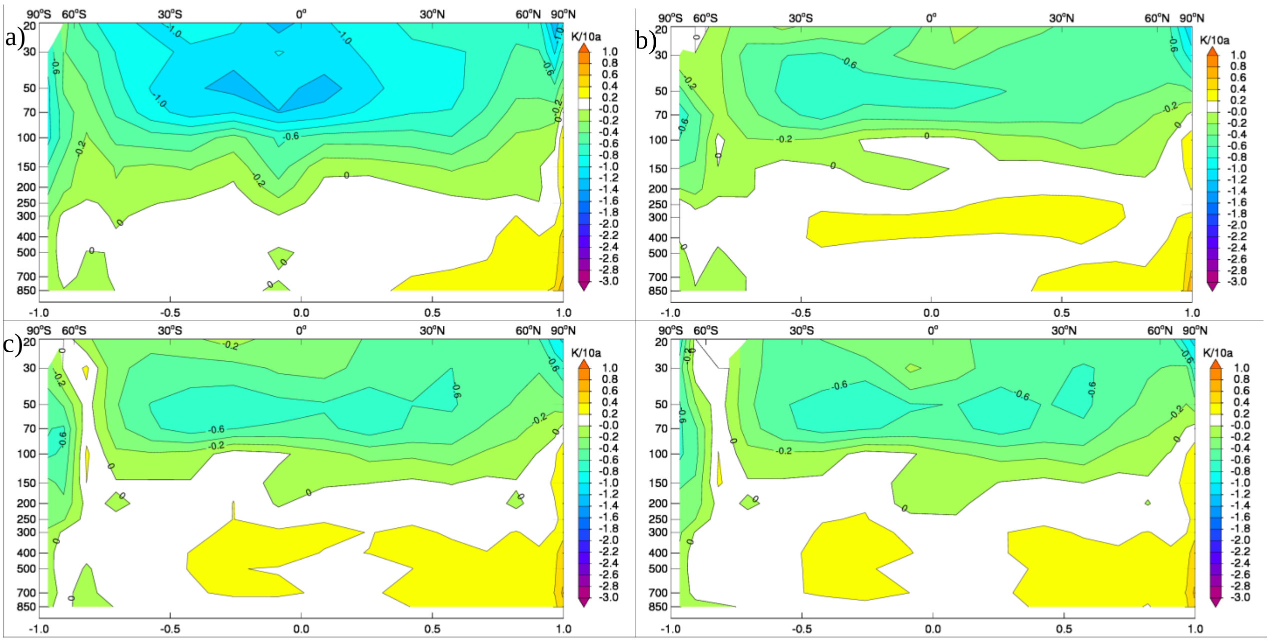

Fig.4: Zonal mean temperature trends for period 1981-2010 with panels corresponding to panels in Fig.1

Ad 3):

A coupled diagnostic budget methodology with adjustment of mass flux imbalances has been refined and the question of inhomogeneities affecting budget evaluations has been addressed (Mayer et al. 2013).

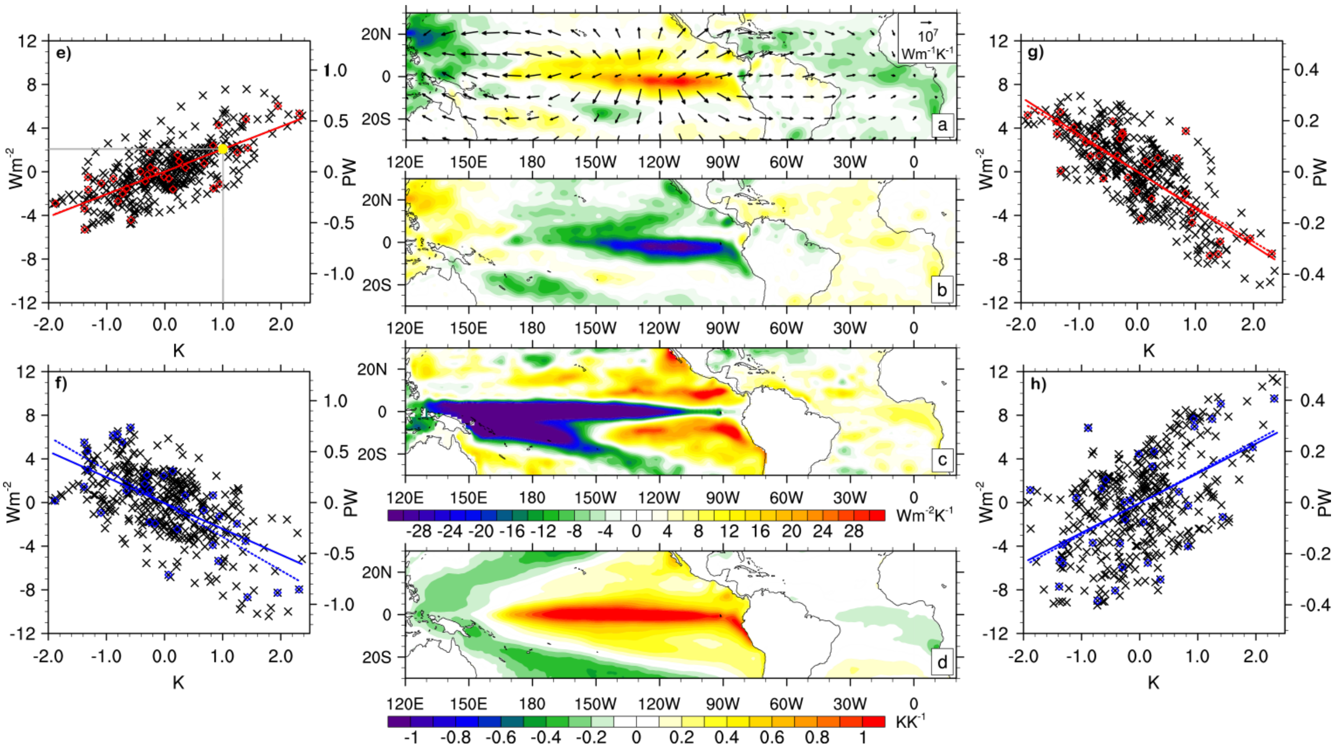

Fig. 5: Regression of energy budget fields onto the Nino 3.4 (N34) index:
Regression of (a) ERA-I vertically integrated atmospheric energy flux divergence and divergent energy transport, (b) indirectly estimated F_S, (c) ORAS4 OHCT and (d) SST with N34 at zero lag. Scatter plots of area-averaged tropical (e) Pacific and (g) Atlantic (30S-30N) DIVFA (ERA-I) anomalies with N34 (red squares represent all Decembers – ENSO events usually peak in December). Scatter plots of area-averaged tropical (f) Pacific and (h) Atlantic (30S-30N) OHCT (ORAS4) anomalies with N34 (blue squares represent all Decembers). Continuous red/blue regres-sion lines in e-h are computed from the full 1979-2012 sample, dashed regression lines from the 34 Decem-ber sample. Yellow dot in (e) denotes the regression coefficient of tropical Pacific DIVFA in $Wm^{-2}K^{-1}$. 1 PW corresponds to 2 Wm^{-2} globally. For details see Mayer et al. (2014)

In the course of evaluations it was found that a remarkably high fraction of the excess heat emitted from the Tropical Pacific during ENSO events causes a strong anomalous atmospheric energy flux that eventually goes into the tropical Atlantic and Indian Oceans, respectively (Fig. 5, for details see Mayer et al. 2014). This is contrary to the often stated paradigm that most of the excess heat released in the Pacific is radiated to space. The anomalous transport of energy into neighbouring tropical ocean basins could be qualitatively but not quantitatively be reproduced by CMIP5 climate model runs. It is likely related to unrealistically weak vertical redistribution of heat anomalies in models, and it could also hint to problems with modelled heat storage in the deep ocean in association with climate change. A comparison paper between CMIP3 and CMIP5 coupled model runs and reanalyses has been submitted to Climate Dynamics (Mayer et al. 2015). The coupled diagnostic budget methodology is currently also used to investigate the air-sea coupling over the Arctic ocean and surrounding areas. A research proposal for detailed budget evaluation of this region has been submitted to the Austrian Science Funds.

List of publications/reports from the project with complete references

- Mayer, M., Trenberth, K. E., Haimberger, L, Fasullo, J. T., 2013: The Response of Tropical Atmospheric Energy Budgets to ENSO. J. Climate, **26**, 4710-4724.
- Mayer, M., Haimberger, L., and Balmaseda, M. A., 2014: On the energy exchange between tropical ocean basins related to ENSO. Journal of Climate **27**, 6393–6403.
- Mayer, M., J T. Fasullo, K. E. Trenberth and L. Haimberger, 2015: ENSO-Driven Energy Budget Perturbations in observations and CMIP models. Submitted to Clim. Dyn.
- Milan, M. and Haimberger, L.: Predictors and grouping for variational bias correction of radiosondes. J. Geophys. Res., conditionally accepted
- Ramella-Pralungo, L., Haimberger, L., Stickler, A., Brönnimann, S., 2014: A global radiosonde and tracked balloon archive on 16 pressure levels (GRASP) back to 1905 - Part 1: Merging and interpolation to 00:00 and 12:00 GMT. Earth System Science Data, **6**, 185-200.
- Ramella Pralungo, L. and Haimberger, L., 2014: A Global Radiosonde and tracked-balloon Archive on Sixteen Pressure levels (GRASP) going back to 1905 – Part 2: homogeneity adjustments for pilot balloon and radiosonde wind data. ESSD **6**, 2, S. 297-316
- Ramella Pralungo, L., Haimberger, L. 2015: New estimates of tropical mean temperature trend profiles from zonal mean historical radiosonde and pilot balloon wind shear observations. JGR D, in press

Future plans

This project is succeeded by special project “SPATLH00 - Homogeneous upper air data and coupled energy budgets” that started in 2015. This project was instrumental for the success of research projects P18120-N22 and P25260-N29 of the Austrian science funds (FWF) and of the University of Vienna contribution to EU-project ERA-CLIM.