Multichannel Singular Spectrum Analysis of the Atmospheric Angular Momentum

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Abstract: Multichannel singular spectrum analysis (MSSA) is applied to 111 years of gridded atmospheric angular momentum (AAM) data from the 20th Century Reanalysis (ERA-20C) model of the ECMWF (European Centre for Medium-Range Weather Forecasts). Components of zonal atmospheric circulation related to length-of-day (LOD) variations are identified, including possible trends as well as global-scale El Niño Southern Oscillation modes. Moreover, we process equatorial AAM components by means of a Panteleev filter with an emphasis on extracting Chandler band-related atmospheric excitations. Maps of regional AAM contributions to the Chandler wobble are examined.

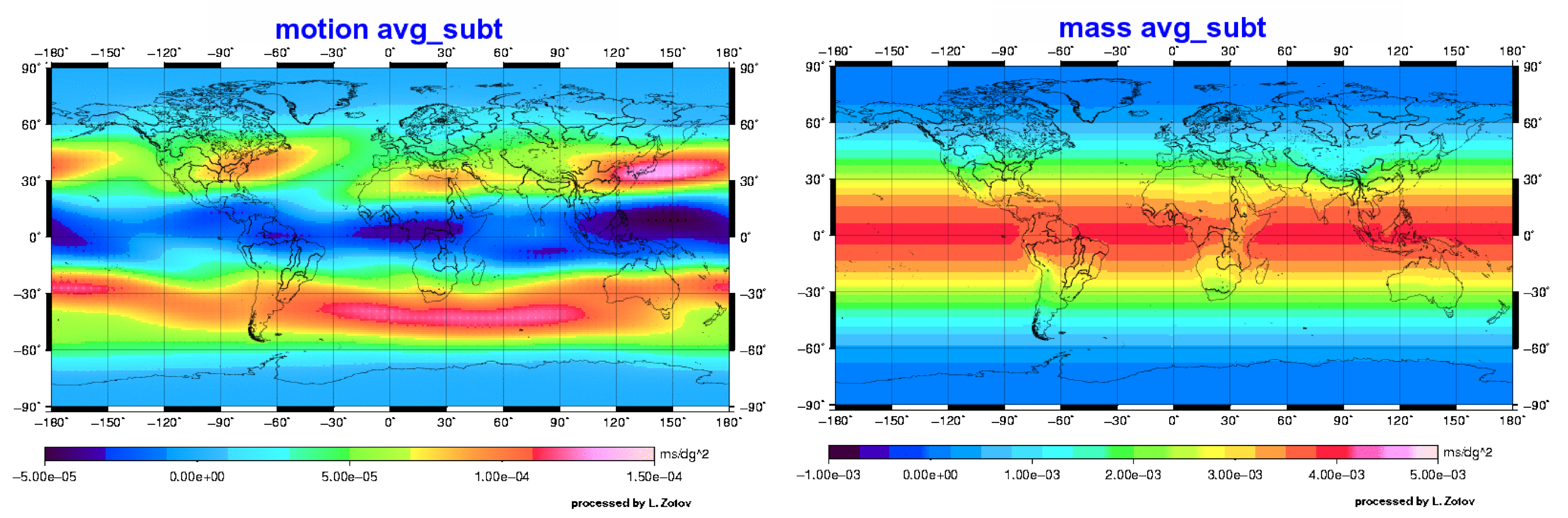

Fig 1. ↑ Mean fields for zonal AAM wind (left) and IB-corrected pressure (right) terms

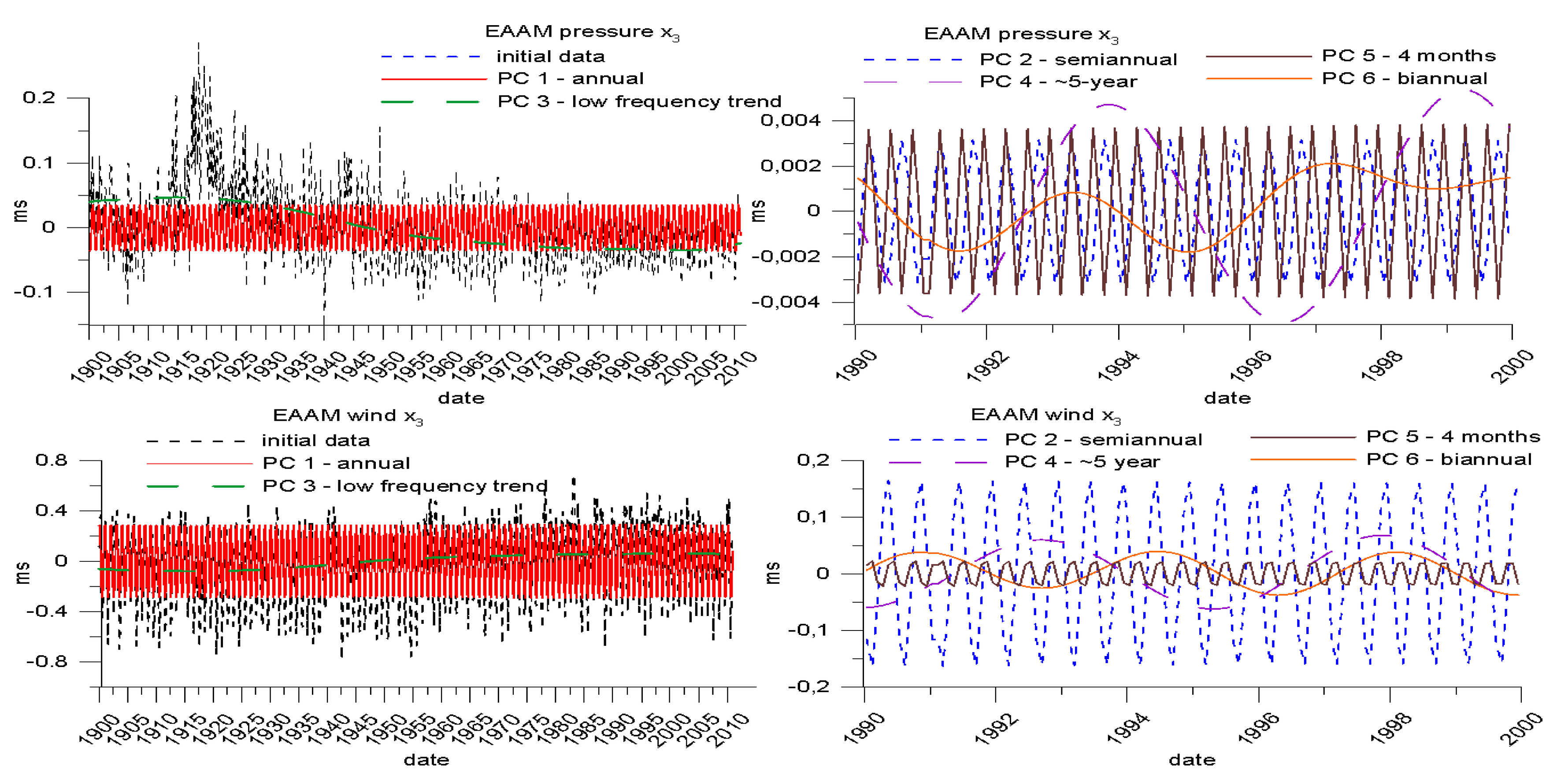

Fig 2. ↑ Integrated components of axial effective AAM after MSSA

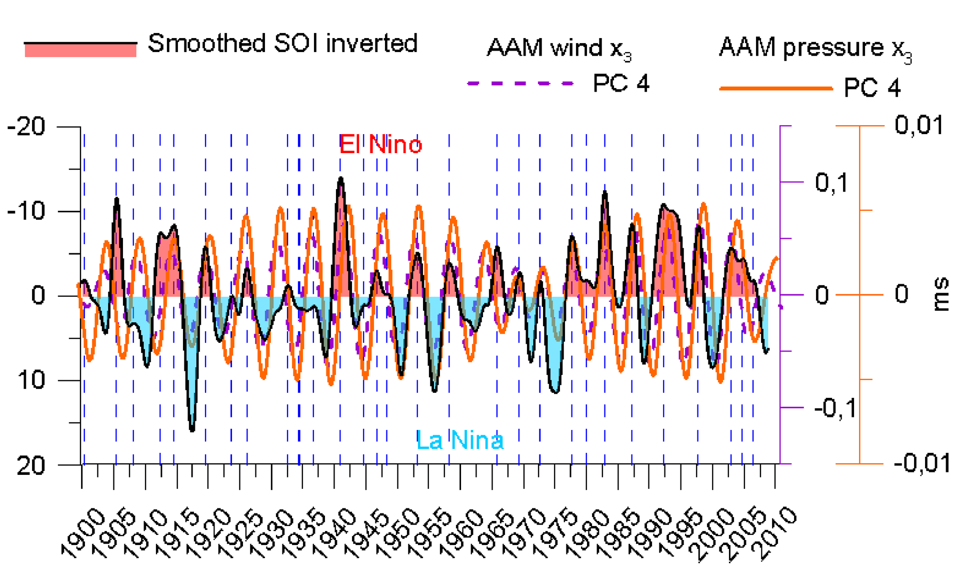

Fig 3. ↑ Smoothed SOI index and El-Niño related PC 4 of wind and pressure axial AAM. El Niño events marked by blue lines

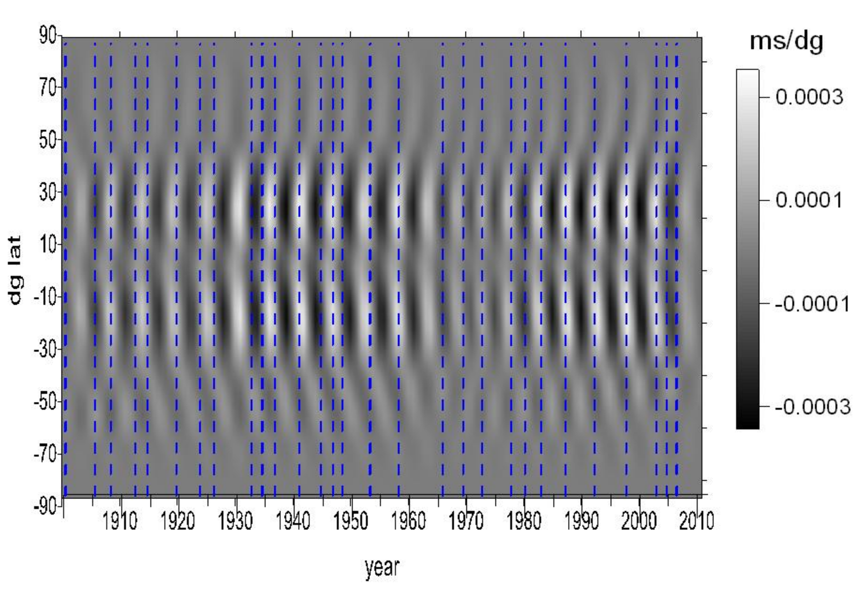

Fig 4. ↑ Hovmöller plot of zonal winds propagation for PC 4

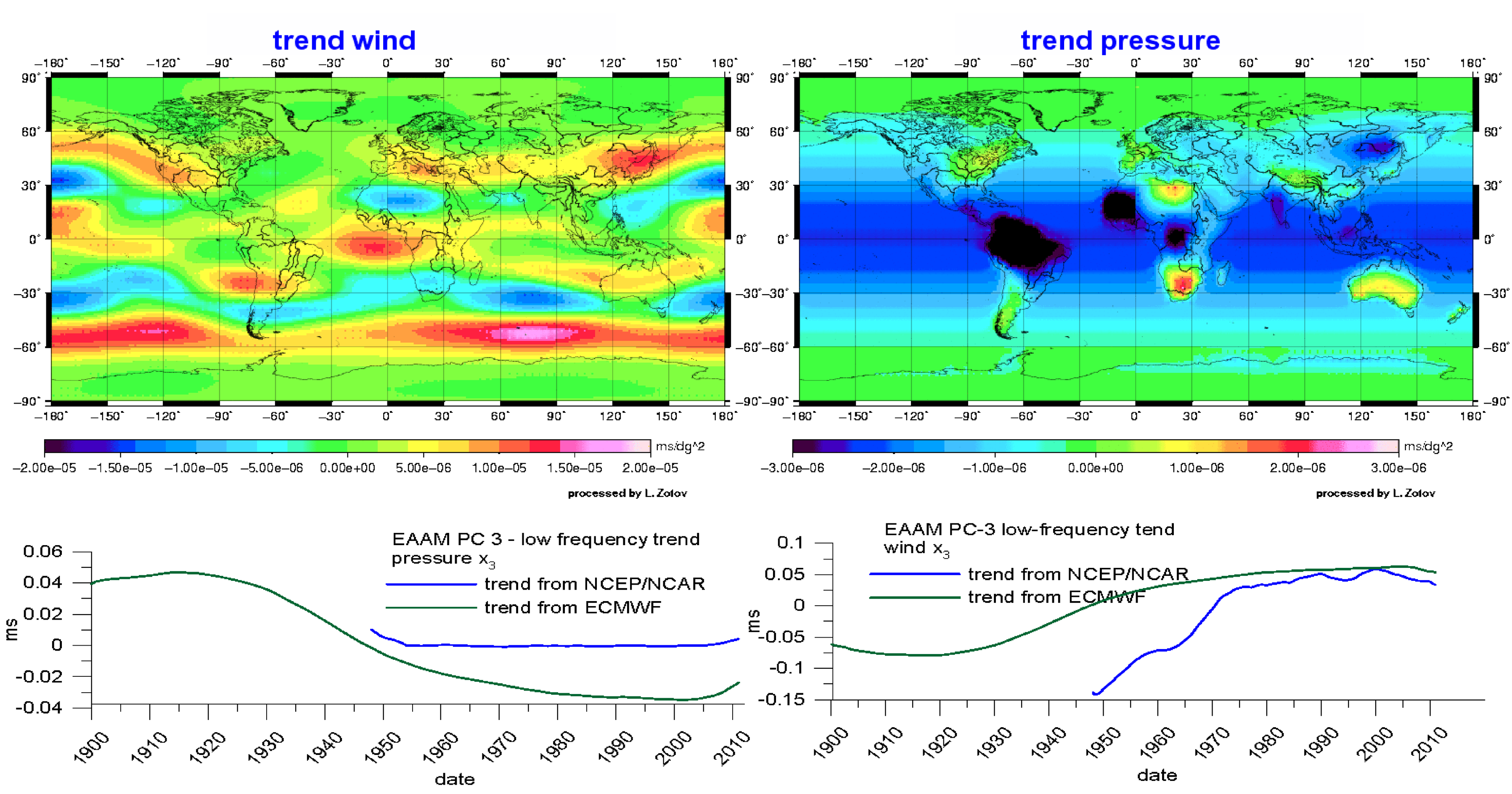

Fig 5. ↑ Maps of the ECMWF AAM wind and pressure trends (PC 1) for 110 years

References:

1. Bizouard C. (2016), Elliptic polarisation of the polar motion excitation. *Journal of Geodesy*, 90:179–188, doi:10.1515/jiip-2013-0085.

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MSSA Method: Multichannel Singular Spectrum Analysis (MSSA), also called Extended EOF, is a generalization of Singular Spectrum Analysis (SSA) for multidimensional (multichannel) time series. SSA, in turn, is a Principal Component Analysis (PCA), generalized for time series in such way, that instead of the simple correlation matrix, the trajectory matrix is analyzed through embedding the time series into the *L*-dimensional space. The parameter *L* is called lag or "caterpillar" length, and when *L=1*, SSA reduces to the PCA. For every point *ij* on the map we have a time series $A_{ij}(t_k)$ of length *N*. The associated trajectory matrix $X_{A_{ij}}$ must be built and incorporated into a large block matrix *X* as follows:

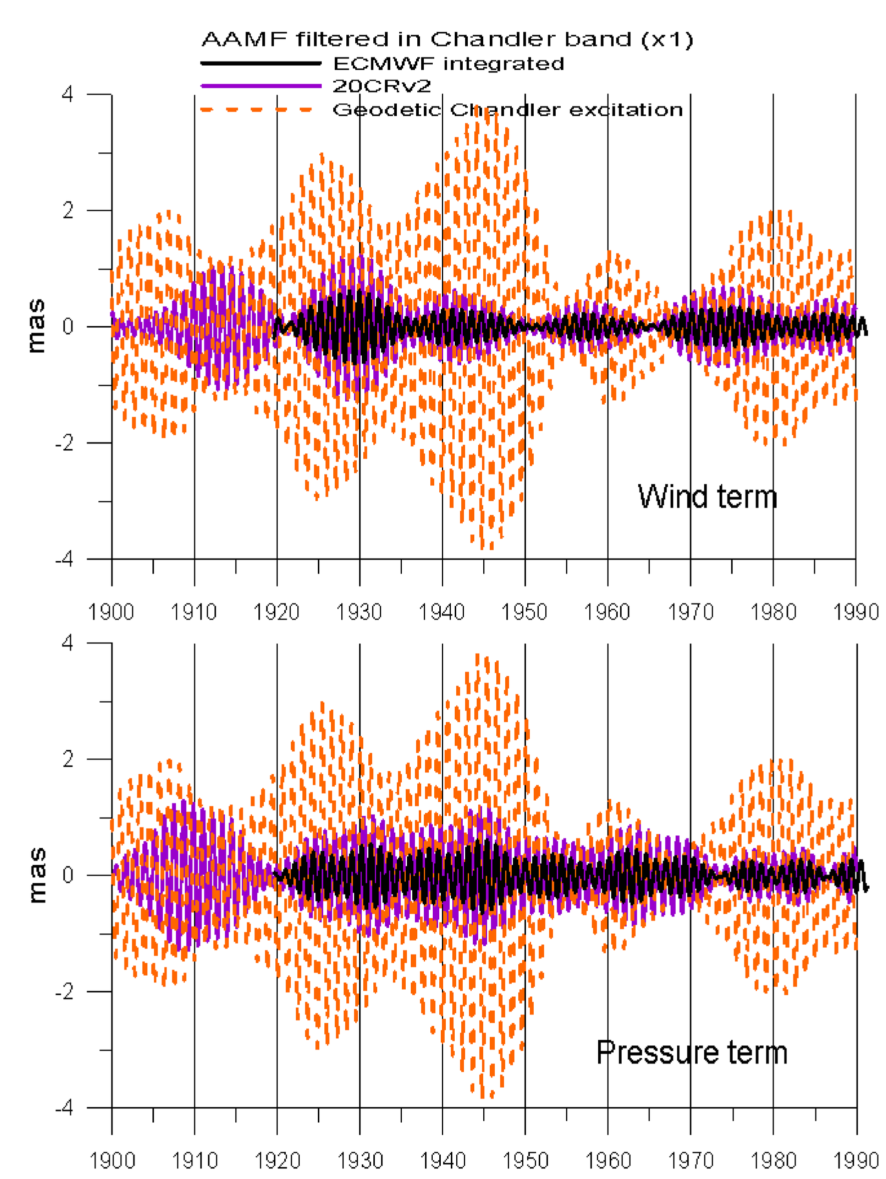
$$X_{A_{ij}} = \begin{pmatrix} A_{ij}(t_0) & A_{ij}(t_1) & \ldots & A_{ij}(t_{K-1}) \\ A_{ij}(t_1) & A_{ij}(t_2) & \ldots & A_{ij}(t_K) \\ \ldots & \ldots & \ldots & \ldots \\ A_{ij}(t_{L-1}) & A_{ij}(t_L) & \ldots & A_{ij}(t_{N-1}) \end{pmatrix}$$

$$X = [X_{A_{1,1}}, X_{A_{2,1}}, X_{A_{1,2}} ..., X_{A_{ij}}, ..., X_{A_{P-1,Q}}, X_{A_{P,Q}}]^T$$

$K = N - L + 1$ SVD: $X = USV^T$ PC-i matrix: $X^i = s_i u_i v_i^T$

Application of Singular Value Decomposition (SVD) on *X* produces (i) a sequence of singular numbers (SNs) s_i along the diagonal of matrix *S* in order of decreasing values and (ii) the corresponding eigenvectors u_i, v_i. The Principal Components (PCs) can be reconstructed from them, knowing the structure of the matrix X^i. Some of the computed SNs may be related to one and the same PC, representing similar time series behavior. In that case, SN components should be grouped together and reconstructed as one PC. The final result is a set of PCs with decreasing amplitudes that are indicative of different modes of time series variability.

Compared to EOF, MSSA is more flexible in extracting trends and modulated oscillations of different periods, and in de-noising multidimensional time series. Different channels "help" each other to capture spatio-temporal correlation patterns. We applied MSSA jointly to AAM mass and motion term grids with 4º x 4º spatial and monthly temporal resolution. The lag parameter was selected to be *L=240* (20 years).



↑ **Fig 6.** Integrated AAM functions filtered in the Chandler frequency band, compared with the geodetic excitation of the Chandler wobble (*x*-component). Two models of AAM were used (ECMWF, 20CRv2)

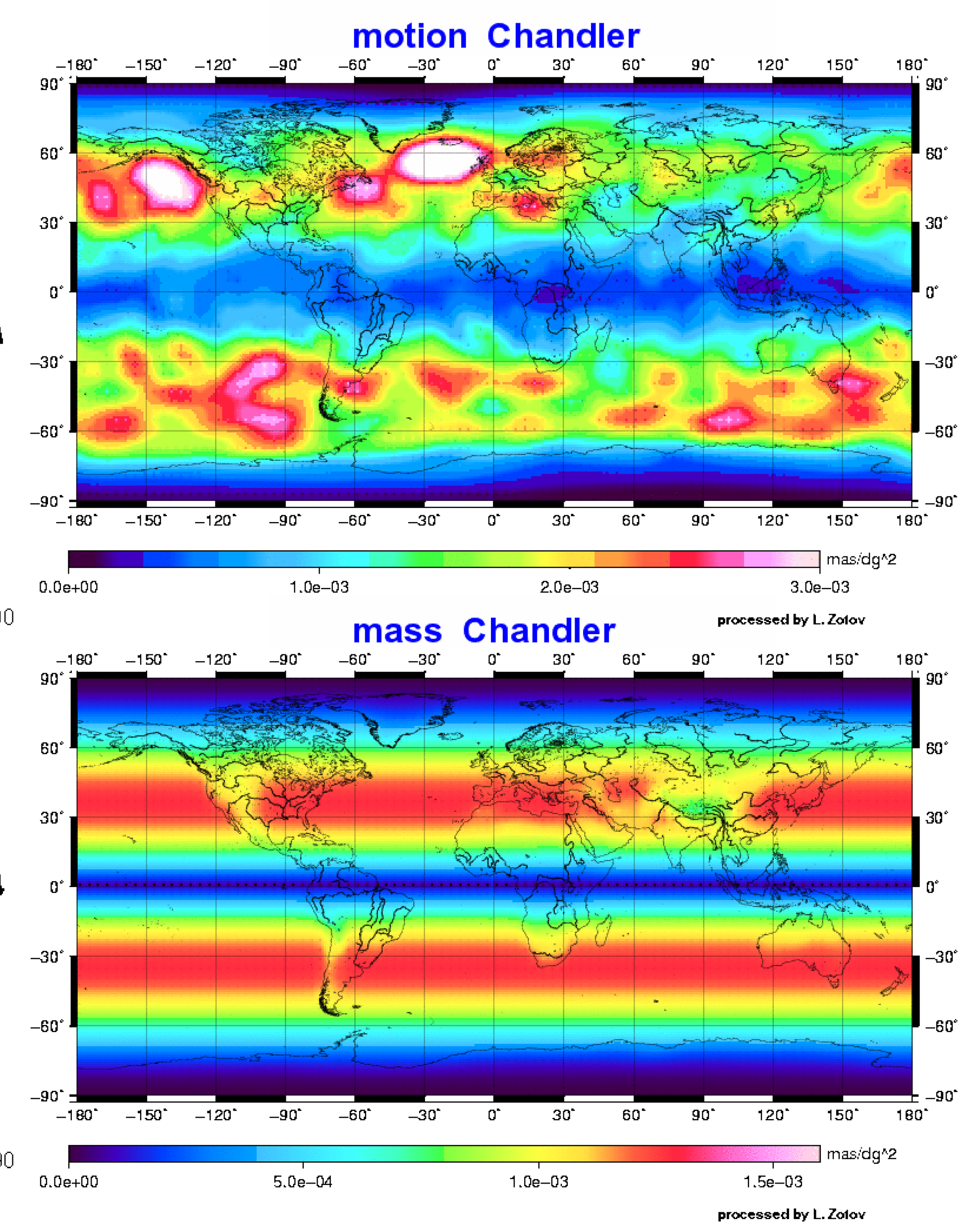
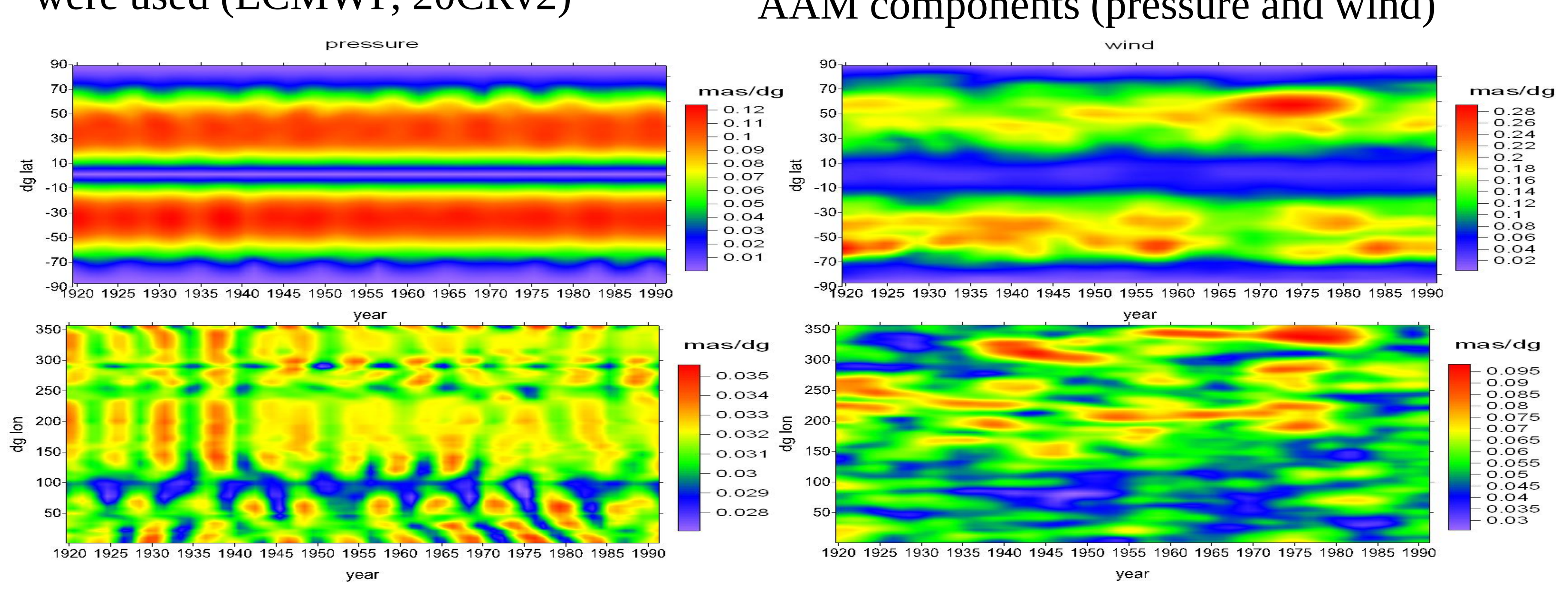


Fig 7. ↑ Maps of the mean absolute AAM field for wind (top) and pressure (bottom) in the Chandler frequency band

Fig 8. ↓ Hovmöller plots for these Chandler AAM components (pressure and wind)



Discussion: We have examined gridded ECMWF atmospheric angular momentum data that extend back to 1900. Pressure (IB) and wind terms of axial AAM were analyzed through MSSA. Mean (**Fig 1**), secular (**Fig 5**), El-Nino related (**Fig 3**), annual and other components (**Fig 2**) were separated. Some of the obtained low-frequency signals are spurious and merely reflect observing system changes (e.g., during WWI). Equatorial components of AAM were filtered in the Chandler frequency band and compared with geodetic excitation (**Fig 6**), revealing amplitude modulations with quasi-decadal periods. Regions contributing to the Chandler AAM excitation are depicted in **Fig 7**, complemented by Hovmöller plots for AAM in the Chandler frequency band (**Fig 8**).