Changing Jet-Stream Waviness Assessed Using Self-Organizing Maps (SOMs)

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Abstract

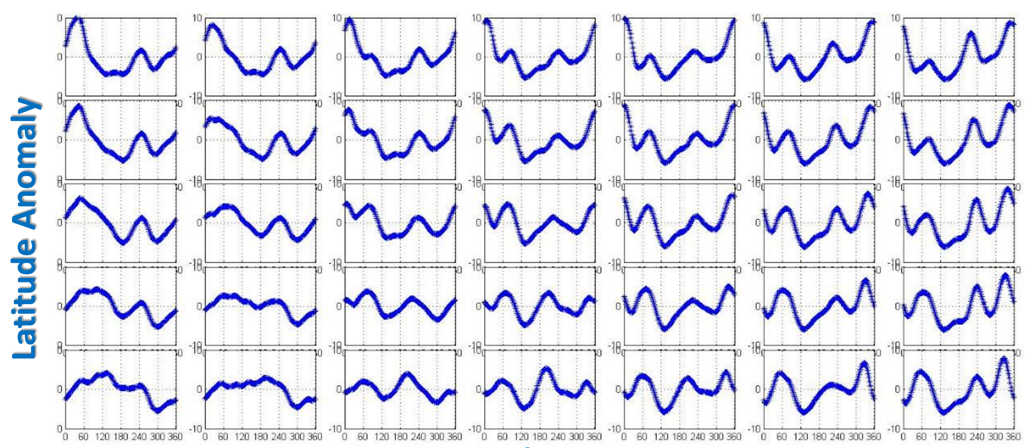
A Self Organizing Maps (SOMs) approach is used to diagnose changing meridional (north/south) wave amplitude in the 500-hPa geopotential height field of the northern hemisphere during the "Arctic amplification (AA) era" of 1995-2012 relative to 1948-1990. The total change in wave amplitude is separated into contributions from (1) changing frequency of occurrence (FOC) of patterns identified by the SOM algorithm, (2) changing cluster-mean amplitudes for each SOM pattern, and (3) a combination of the two. We find an overall increase in amplitude that results primarily from an increase in cluster-mean wave amplitude, augmented by an increased frequency of high-amplitude patterns. These results support the hypothesis by Francis & Vavrus (2012) and the new analysis by Francis & Vavrus (2015).

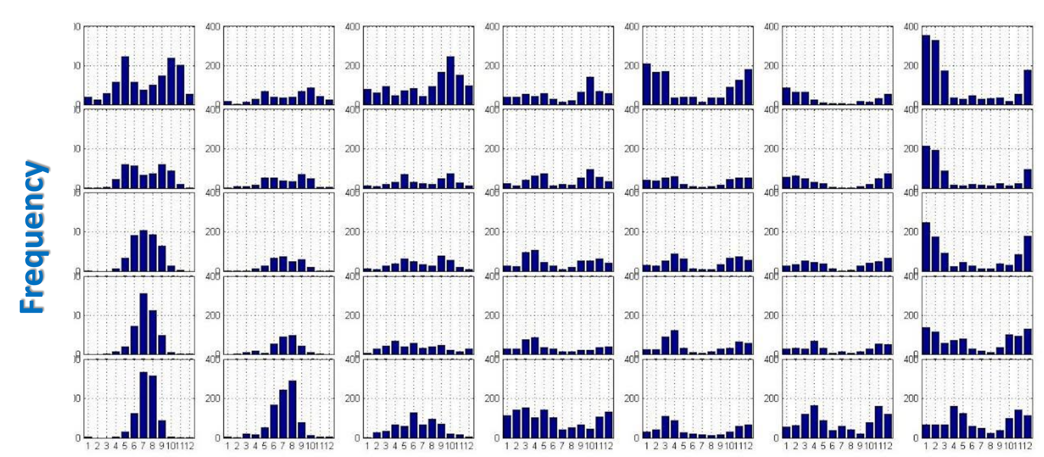
What are Self-Organizing Maps (SOMs)?

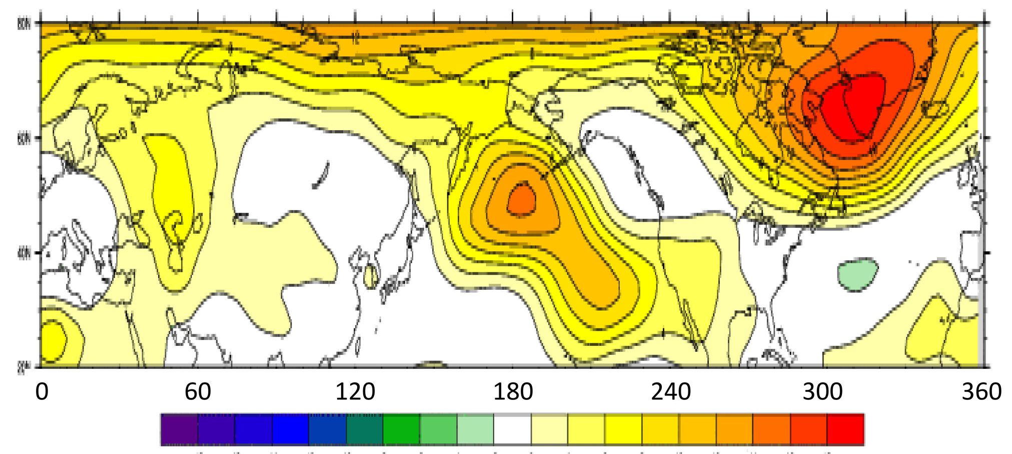
The Self Organizing Maps (SOM) algorithm employs an artificial neural network through an unsupervised training process to:

- Determine representative patterns in the input data, typically daily maps of a well-behaved variable
- Organize similar data records into clusters or nodes that form a 2D matrix of representative patterns
- Our SOM training uses 66 years of daily 5600-m contours of the 500 hPa height field in the northern hemisphere obtained from the NCEP/NCAR Reanalysis.
- Other variables (e.g., meridional wave amplitude) can then be mapped onto the Master SOM for further analysis

The Master SOM





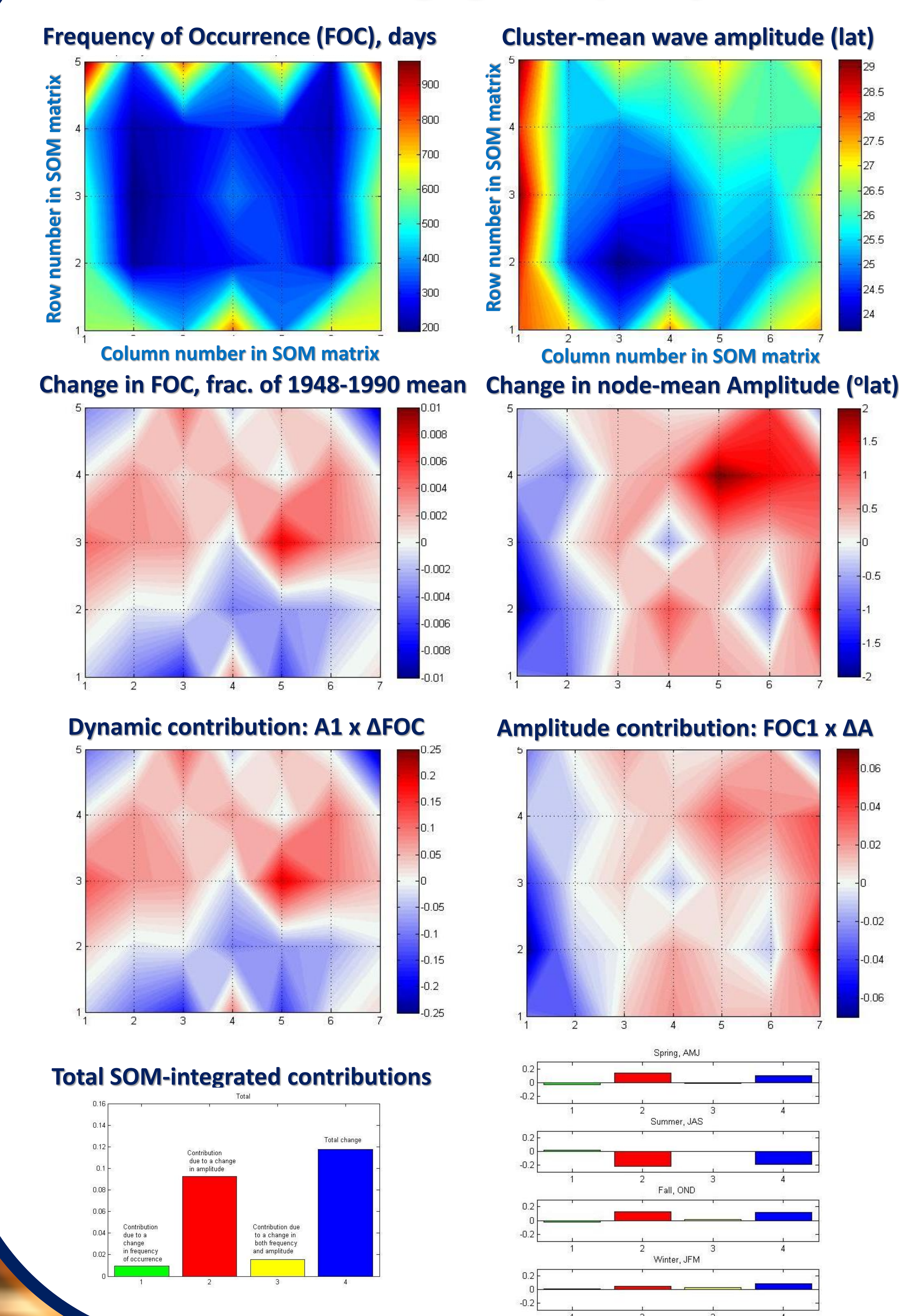


Annual-mean 500 hPa height anomalies for 1995-2013 relative to 1981-2010. Data from NCEP/NOAA Reanalysis, Image provided by the NOAA-ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/

Upper left: Matrix of characteristic patterns in the 5600-m contour of daily 500 hPa heights during 1948-2012. Daily mean contour latitude is subtracted first to obtain latitude anomalies. Longitudes of ridge/trough patterns can be referenced to map underneath, which shows annual-mean 500-hPa height anomalies in the northern hemisphere for the AA era (1995-2012).

Upper right: Because we know which days belong in each node or cluster of the SOM, the monthly frequency distribution for each node can be diagnosed. **Winter-only** patterns tend to reside in the upper-right of the matrix, **summer-only** patterns in the lower left, and **transition-season** patterns in the upper left/center and lower right. Note that patterns in the matrix center occur relatively infrequently.

Mean and Changing: Frequency of Occurrence (FOC) and Amplitudes



Upper left: Number of days that belong in each node or cluster in the SOM matrix. Patterns around the matrix edges are most common and have largest amplitudes.

Upper right: Mean amplitude (°lat) of contours. **Amplitude = max latitude minus min latitude** for each daily contour. Nodes with highest mean amplitudes also have high standard deviations (not shown).

Middle left: Fractional change in FOC of days in each node during AA era relative to reference period 1948-1990. Largest increases in FOC tend to occur for less frequent patterns that have large cluster-mean amplitudes and feature a broad ridge over Asia, a trough in the W. Pacific, and ridge in N. Atlantic.

Middle right: Change in cluster-mean amplitudes. Most patterns except summer-only nodes exhibit increasing amplitudes.

Contribution Analysis (after Cassano et al, 2007) Changes can be separated into contributions from changing FOC (dynamic factor), changing amplitudes (amplitude factor), or a combination of both.

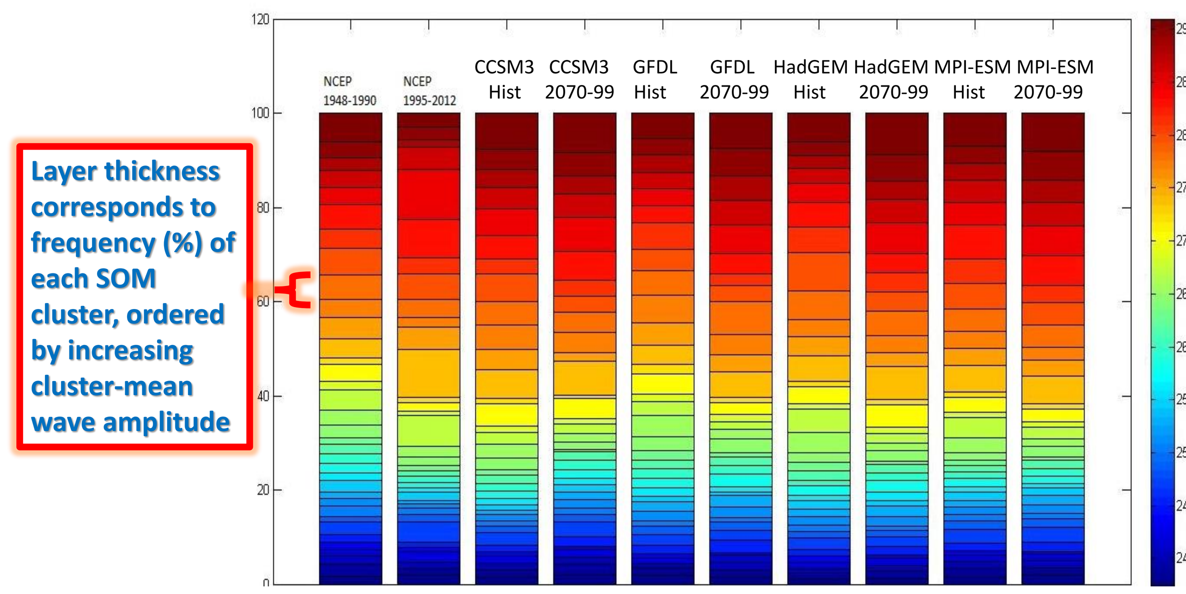
Lower left: Dynamic factor is calculated as change in FOC x mean amplitude during early period.

Lower right: Amplitude factor is calculated as change in amplitude x FOC during early period. Note difference in scale.

Bottom line: Integrated analysis (bottom left) suggests that the increase in total amplitude (**blue**) is caused primarily by increasing cluster-mean amplitudes (**red**) along with small contributions from the frequency term (**green**) and the combined term (**ΔFOC x Δamp, yellow**). There is an *overall amplitude increase in all seasons except summer.*

Increased amplitude of waves in the upper-level flow supports the hypothesis proposed by Francis & Vavrus (2012) and reinforces new evidence presented in Francis & Vavrus (2015).

What about the future?



Daily 500 hPa contours from simulations by CMIP5 models can also be mapped to the SOM to investigate future changes in flow waviness. Historical runs (1970-2005) can be compared to amplitudes from NCEP Reanalysis data (1948-1990) to assess models' realism. Each layer in the bar represents one SOM cluster: its height corresponds to its FOC (%) and color indicates cluster-mean amplitude. Models have fairly realistic distributions: GFDL is most similar to NCEP. In the future (2070-2099, RCP 8.5), all 4 models project increased FOC of nodes with largest amplitudes, with an overall shift toward a wavier flow.

References: Cassano et al (2007), Predicted changes in synoptic forcing of net precipitation in large Arctic river basins during the 21st century, *J. Geoph. Res Biogeosciences, 112*. Francis & Vavrus (2012), Evidence linking Arctic amplification to extreme weather in mid-latitudes. *Geophys. Res. Lett., 39*. Francis & Vavrus (2015), Evidence for a wavier jet stream in response to rapid Arctic warming. Enriron. Res. Lett., in press.

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