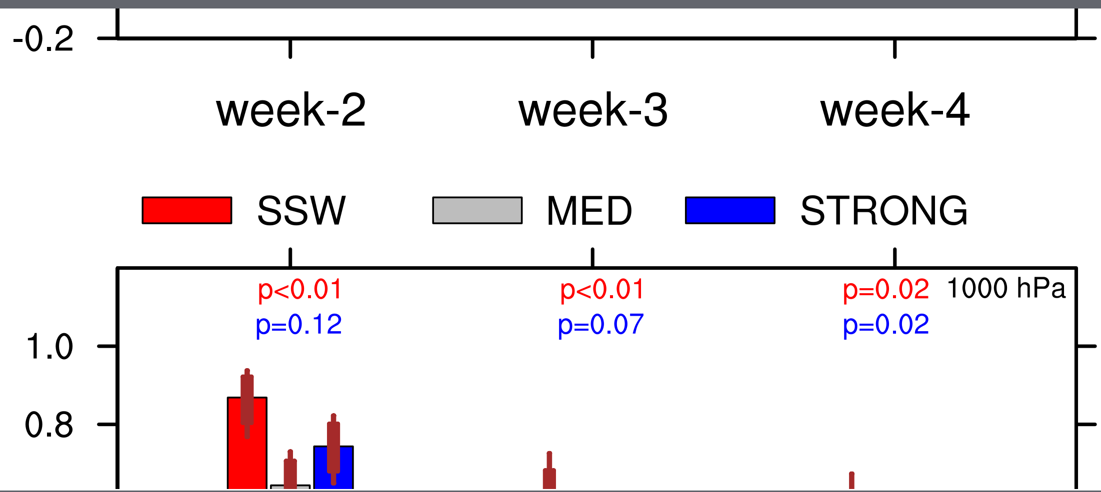
Department of Meteorology

University of Reading

A SIGNAL AND NOISE ANALYSIS OF STRATOSPHERE-TROPOSPHERE COUPLING IN THE S2S MODELS



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KEY QUESTIONS

- Previous work and previous talks in this session have shown that one source of sub-seasonal and seasonal predictability for the extra-tropics is stratosphere-troposphere coupling.
- On seasonal and longer timescales, models have skill but low signal-to-noise ratios (Scaife and Smith, 2018)

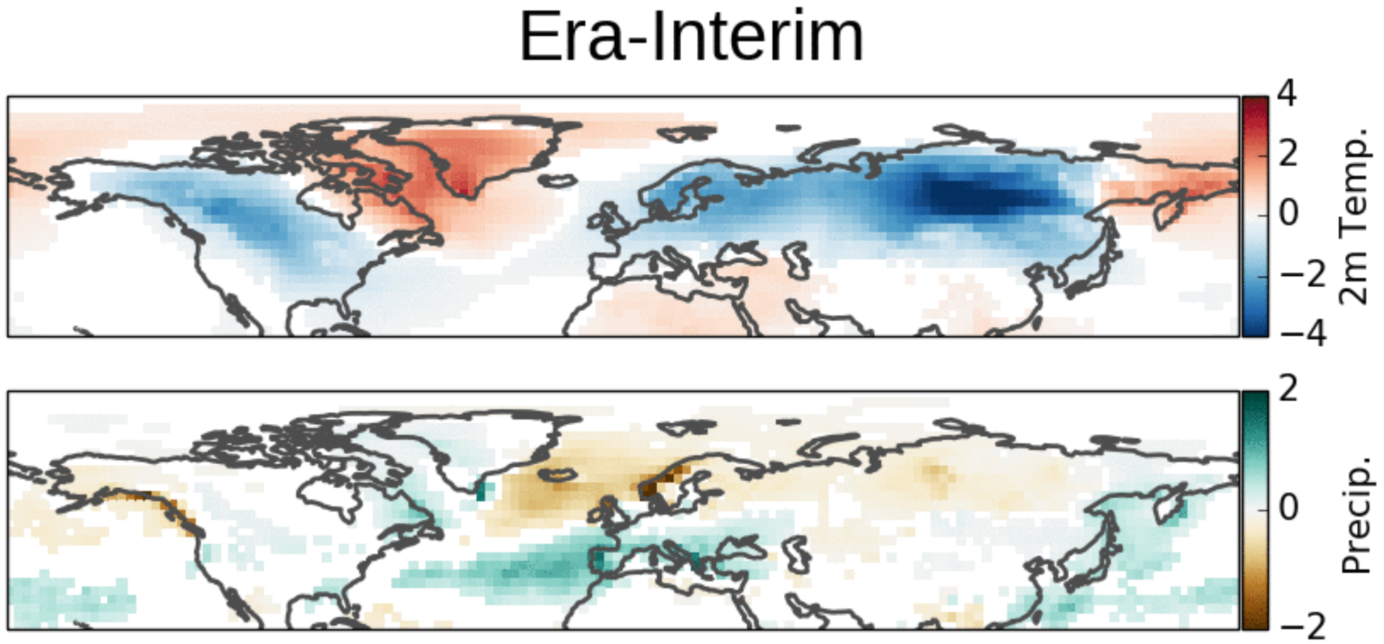
- In this talk:

1. Are models under or over-confident in their predictions of stratosphere-troposphere coupling on sub-seasonal timescales?
2. Do models have a similar degree of stratosphere-troposphere coupling on sub-seasonal timescales?

FORECASTS AND PARAMETERS

- Data taken from 10 models in the S2S database
- Hindcasts initialized during NDJF; Only common period (1999-2009) used
- Key diagnostic is Northern Annular Mode index (Polar Cap Geopotential Height anomaly, 60-90N)

Regression of Polar Cap Height Anomaly with surface fields



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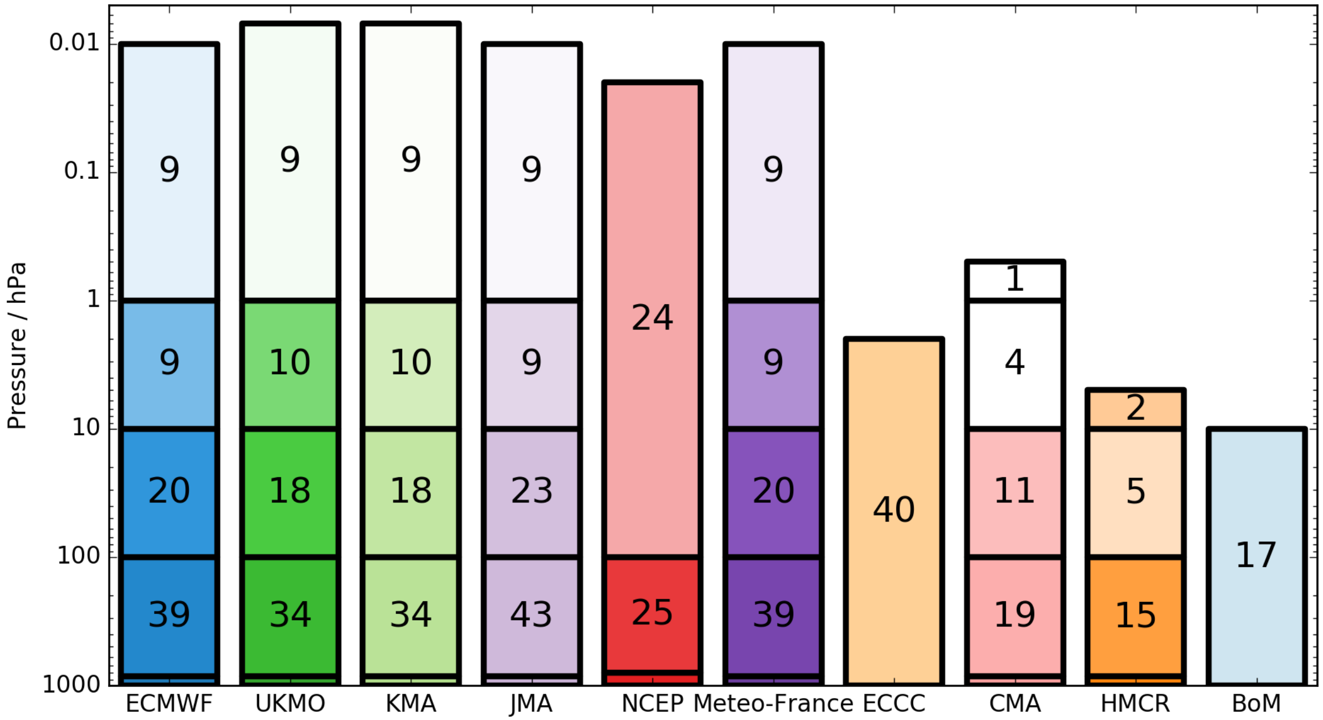
VERTICAL RESOLUTION

- Number of levels in different parts of the atmosphere
- Shading proportional to resolution



- A number of the S2S models have low vertical resolution or are 'low-top'
- Does this restrict their ability to capture stratosphere-troposphere coupling?

SIGNAL/NOISE MODEL

- Based on model of Siegert et al. (2016) applied to seasonal predictions

$$y_t = \mu_y + \beta_y \ s_t + \epsilon \ n_t$$

$$x_{t,r} = \mu_x + \beta_x \ s_t + \eta \ p_{t,r}$$

y – observation

x – forecast member

s_t – predictable signal; N(0,1)

n_t, $p_{t,r}$ – unpredictable noise; N(0,1)

$\beta_{x,y}$ – amplitude of shared predictable signal in observations and model

ε,η – amplitude of uncorrelated noise terms

Fit statistical model to forecast data using Maximum-Likelihood Method with bootstrapping to estimate confidence intervals

KEY PARAMETERS OF MODEL

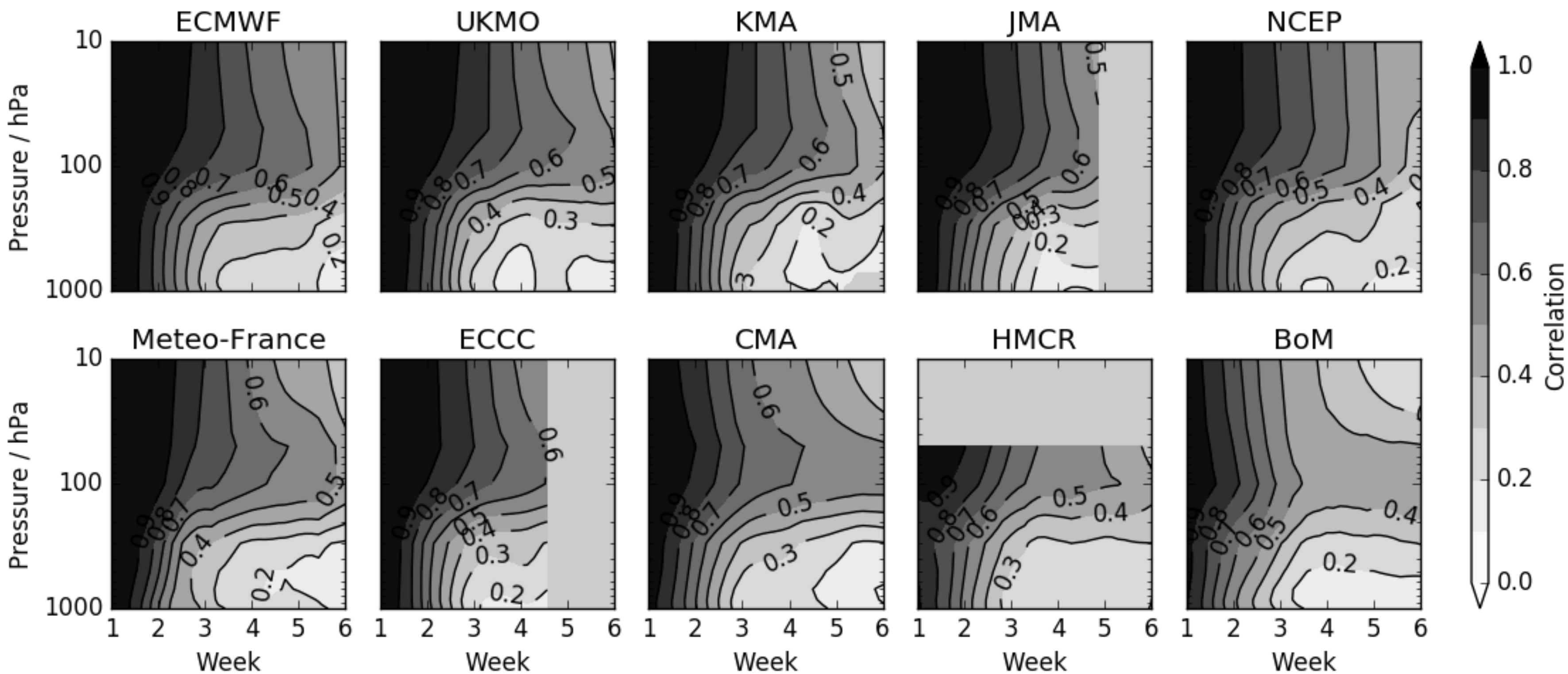
$$SNR_{\text{obs}} = \frac{\beta_y}{\epsilon}$$

$$SNR_{\text{mod}} = \frac{\beta_x}{\eta}$$

$$\rho = \sqrt{\frac{\text{SNR}_{\text{obs}}}{1 + \text{SNR}_{\text{obs}}}}\sqrt{\frac{\text{R SNR}_{\text{mod}}}{1 + \text{R SNR}_{\text{mod}}}}$$

- Signal-to-noise ratio can be calculated for both the model and the observations.
- The observational estimate depends on the model system
- The correlation is a complex function of the signal-to-noise ratio (SNR)

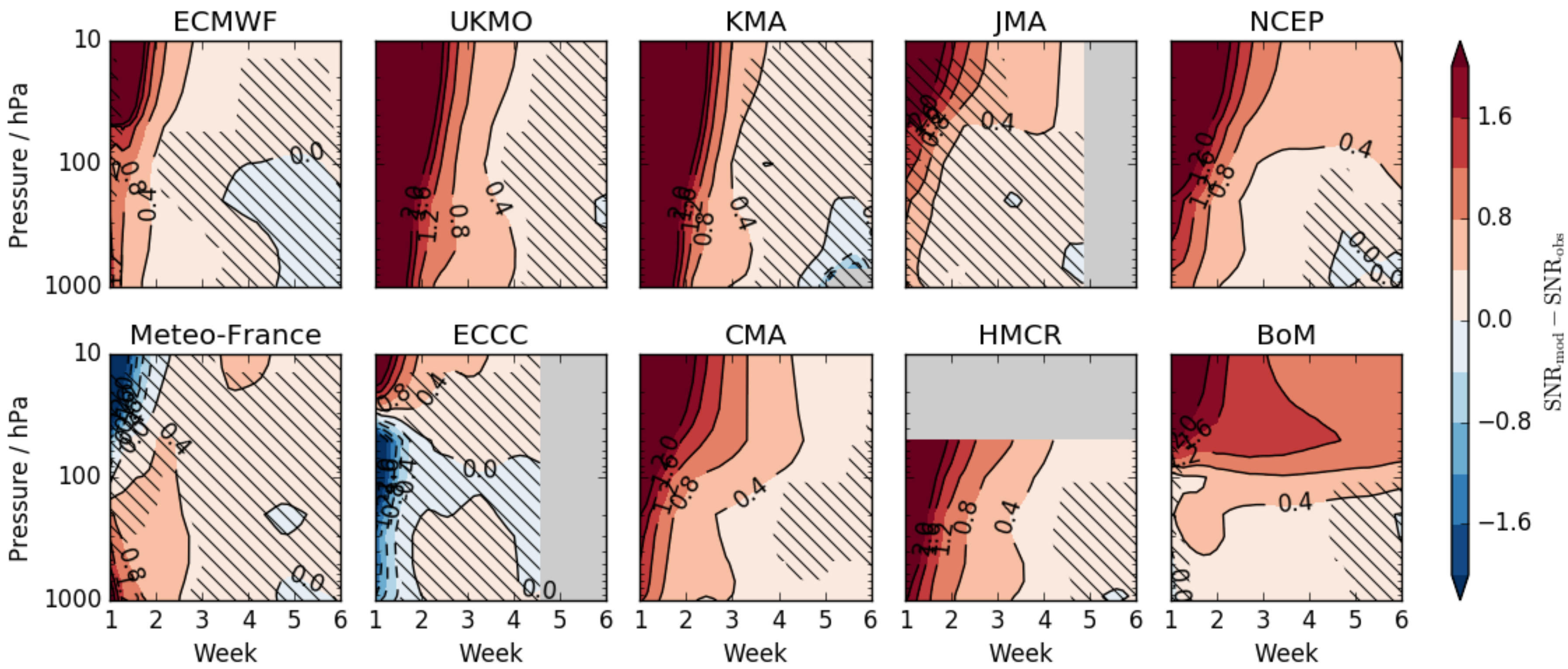
CORRELATION



- Lower Stratospheric skill to week 4 or 5 in many cases
- Low-top models (BoM, HMCR) reduced skill

All diagnostics for right justified weekly mean values (e.g. 14 = week 3)

SNR DIFFERENCE



- At the start of the forecast models mostly have too large SNR
- Little evidence of under-confidence on sub-seasonal range

Hatching - difference not significant at p-level 0.05

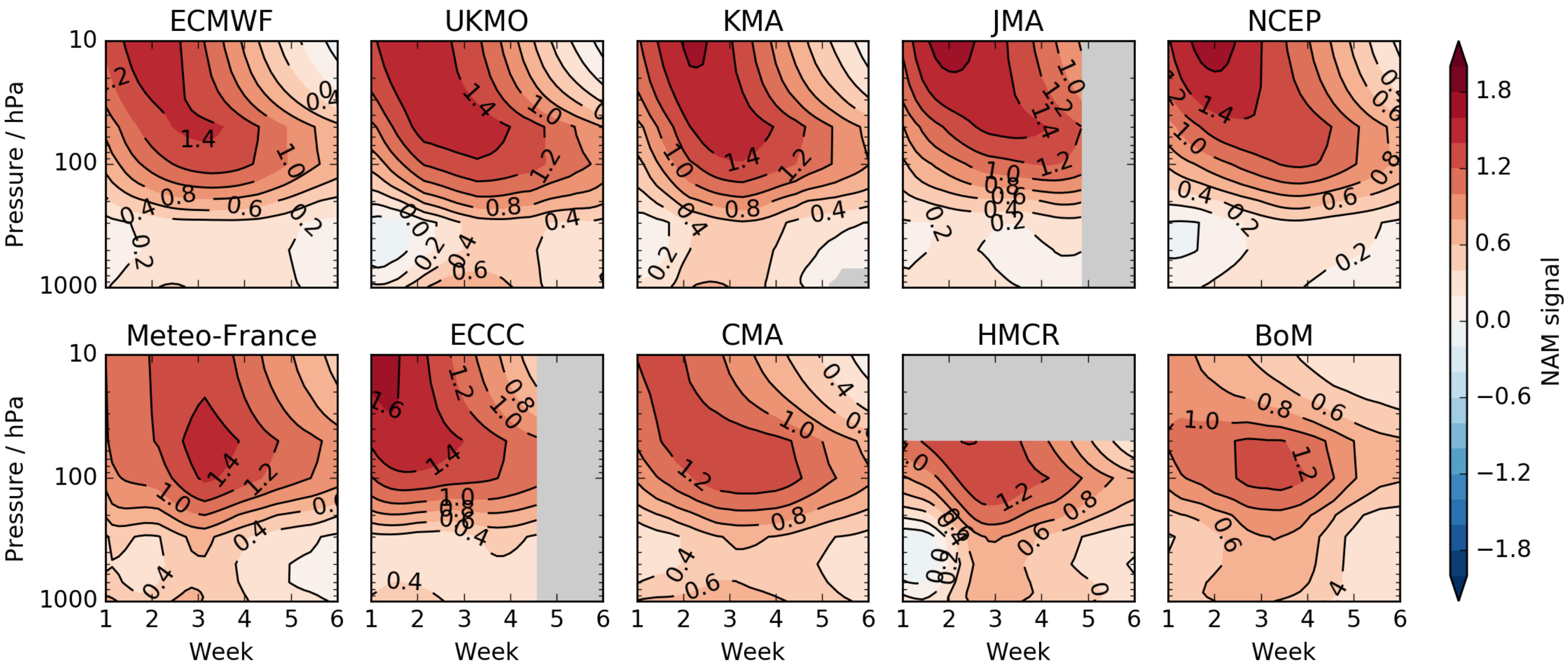
STRAT-TROP COUPLING

- Use the same statistical model to examine the development of the predictable signal, $\beta_x s_t$, in the stratosphere and troposphere
- Composites of forecasts in which there is a large predictable signal in the lower stratosphere (100hPa) on sub-seasonal timescales (week 4)

$$y_t = \mu_y + \beta_y \; s_t + \epsilon \; n_t$$

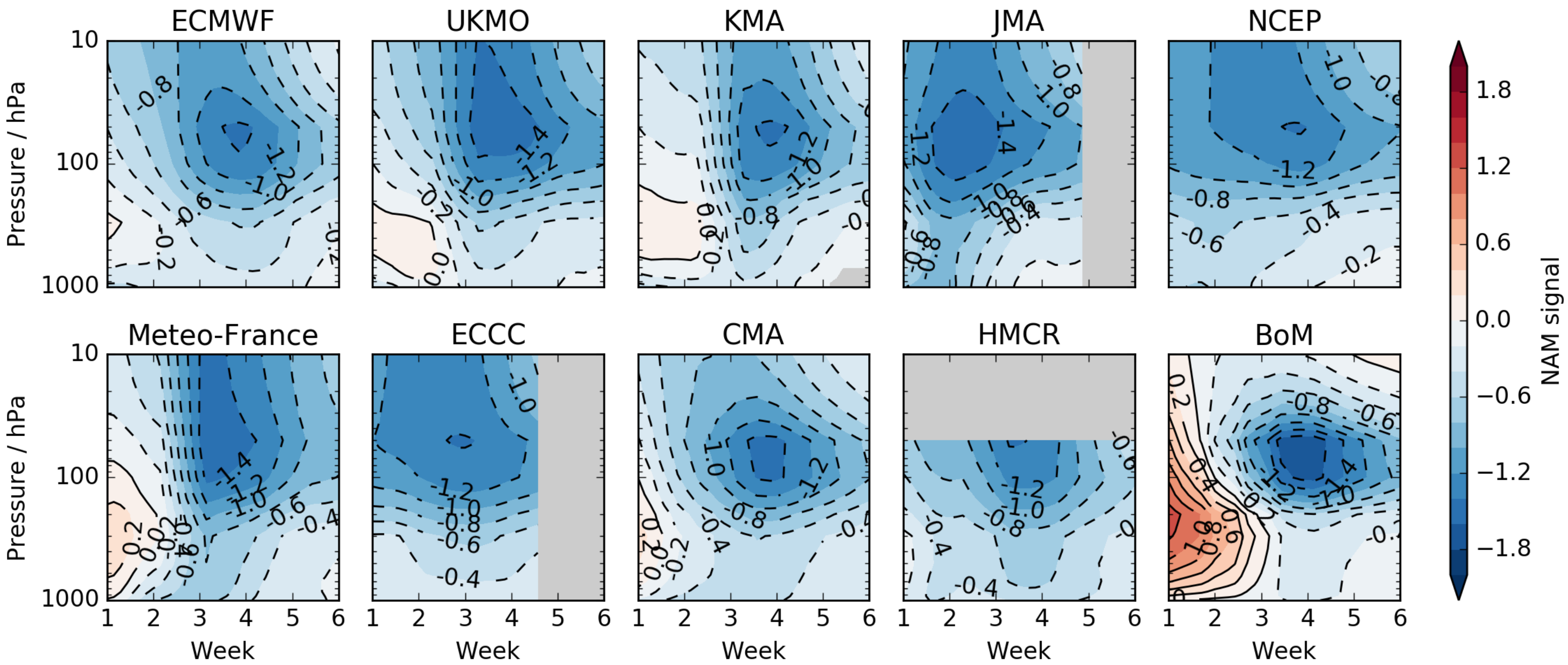
$$x_{t,r} = \mu_x + \beta_x \; s_t + \eta \; p_{t,r}$$

WEAK VORTEX COMPOSITE



- Strong evidence of downward propagation through the stratosphere, a predictable signal at 100hPa results from a predictable signal in the middle stratosphere.
- Coupling to the surface is variable – strong in some low-top models

STRONG VORTEX COMPOSITE



- Less evidence of downward propagation through the stratosphere for strong vortex cases, but links to the surface can be very strong in some models

CONCLUSIONS

- The simple statistical model of Siegert et. al (2016) is a useful tool to apply to sub-seasonal forecasts – in this case to examine coupling between the Stratosphere and Troposphere
- There is little evidence of model under confidence on the sub-seasonal timescale when examining the Northern Annular Mode.
- During the first 2-3 weeks, the signal-to-noise ratio of model forecasts is larger than suggested by the observations, linked to a lack of noise in the Stratosphere
- Predictable signals on the sub-seasonal timescale propagate from the upper to lower stratosphere in all models, particularly for weak vortex events.
- Links between the lower stratosphere and surface have greater differences between the models.

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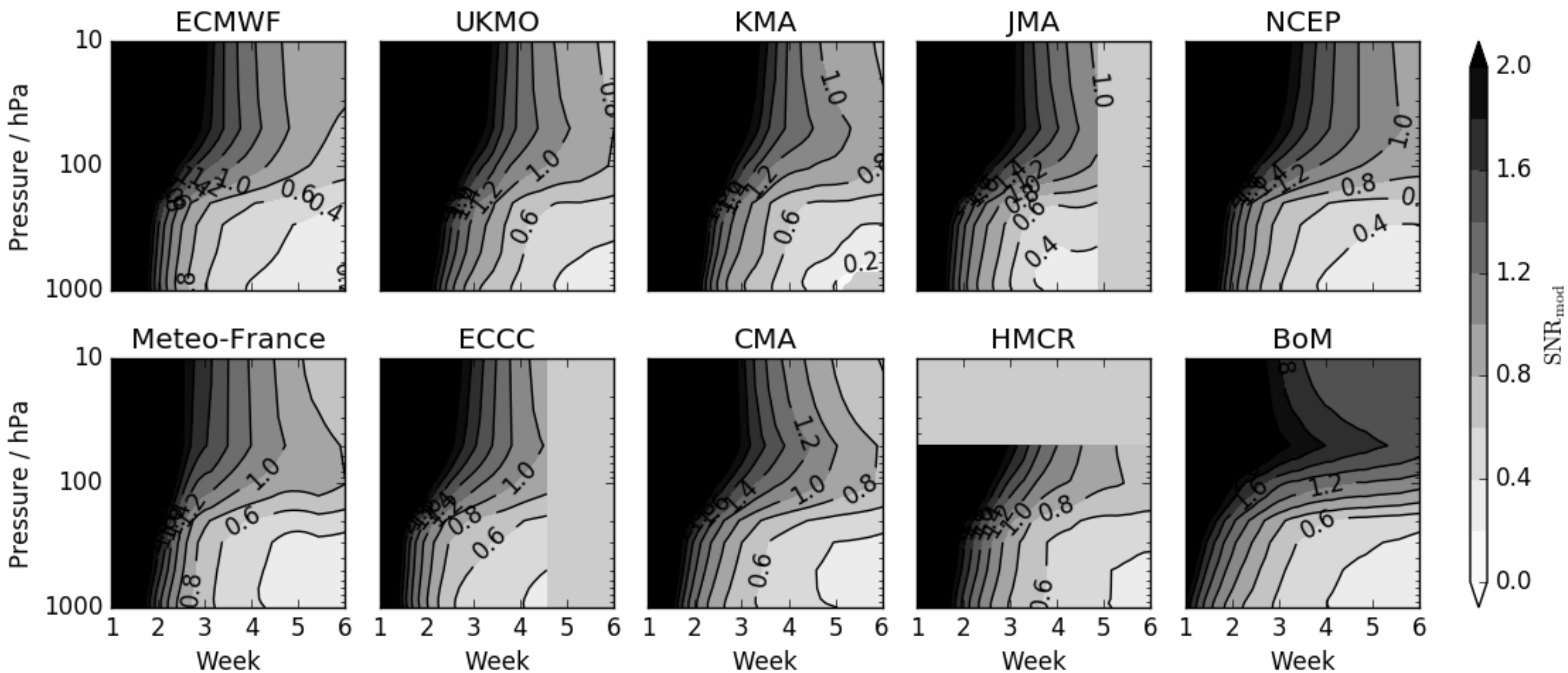
SPARE SLIDES

SIGNAL-TO-NOISE RATIO



- Signal-to-noise ratio of models reflects the correlation structure in the previous slide
- Some low-top models have high SNR (because of little stratospheric noise) in the lower stratosphere

SIGNAL DIFFERENCE

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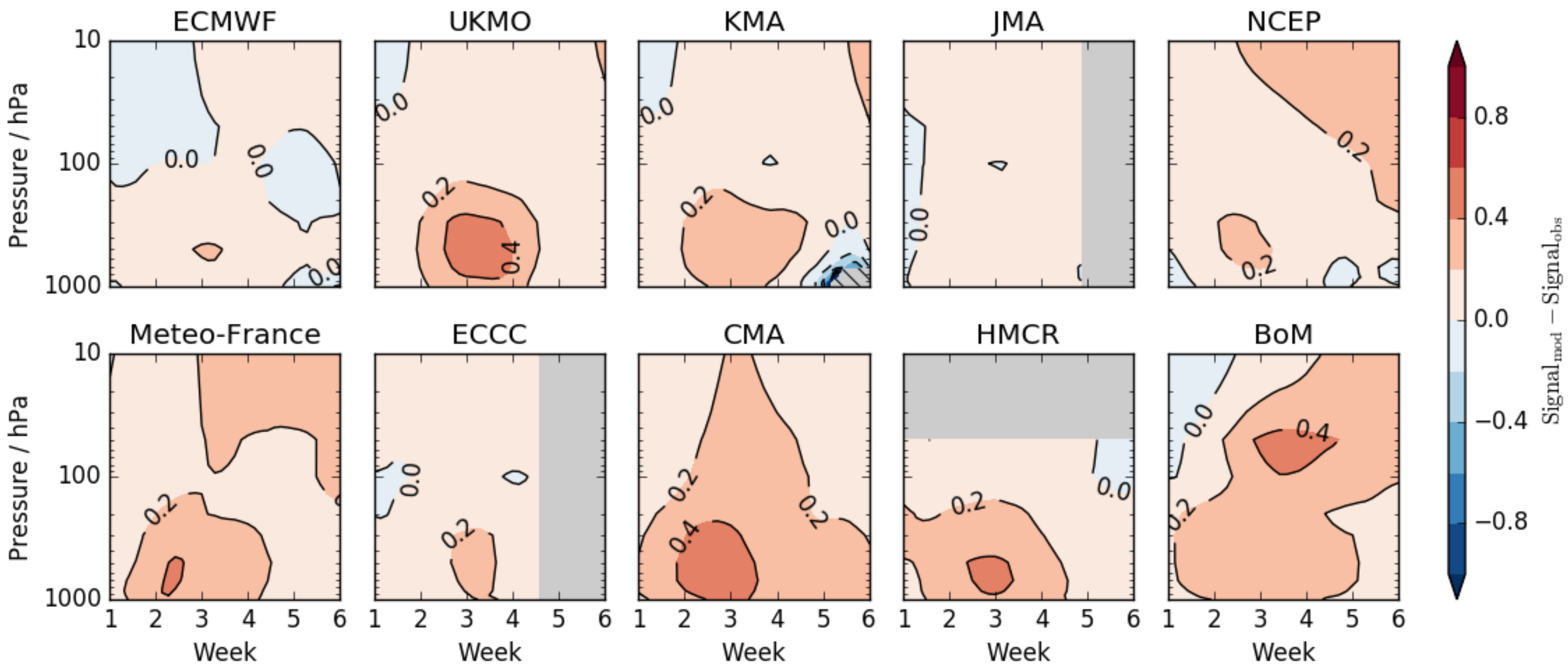
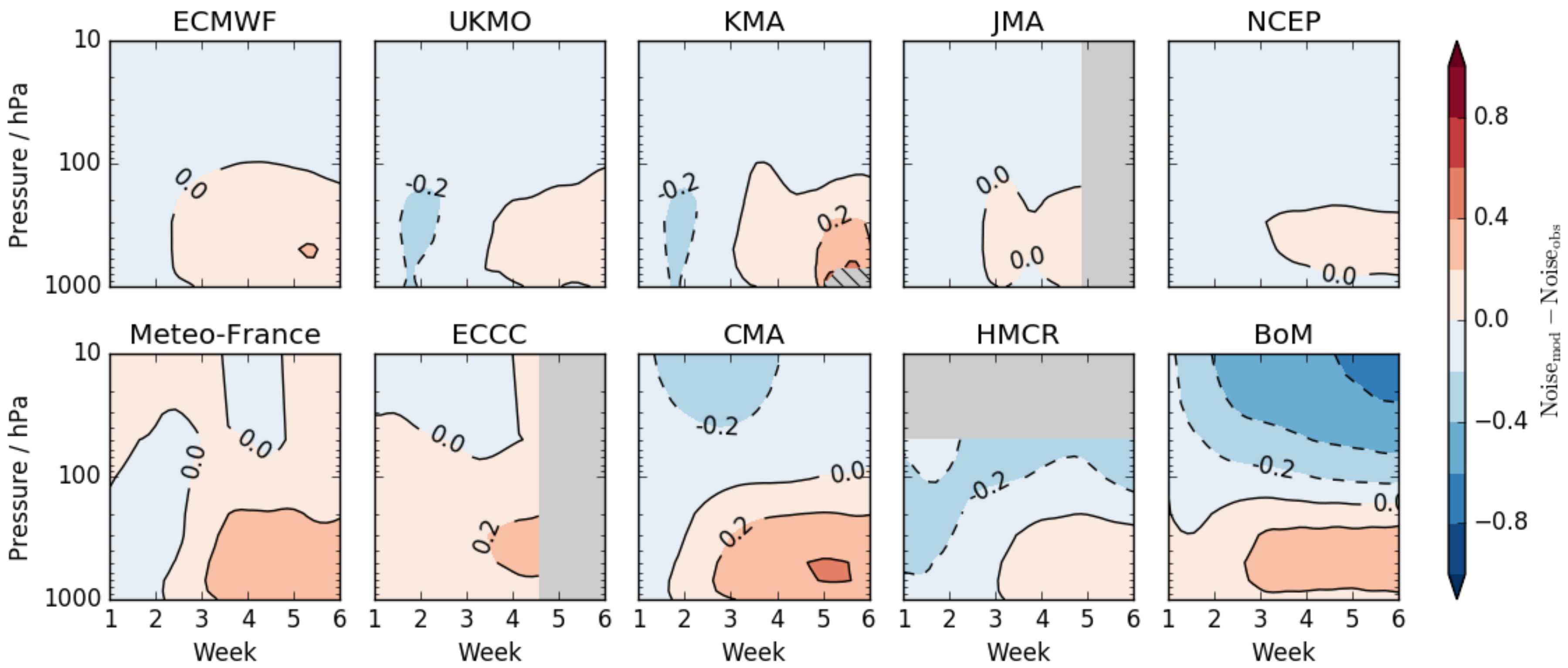


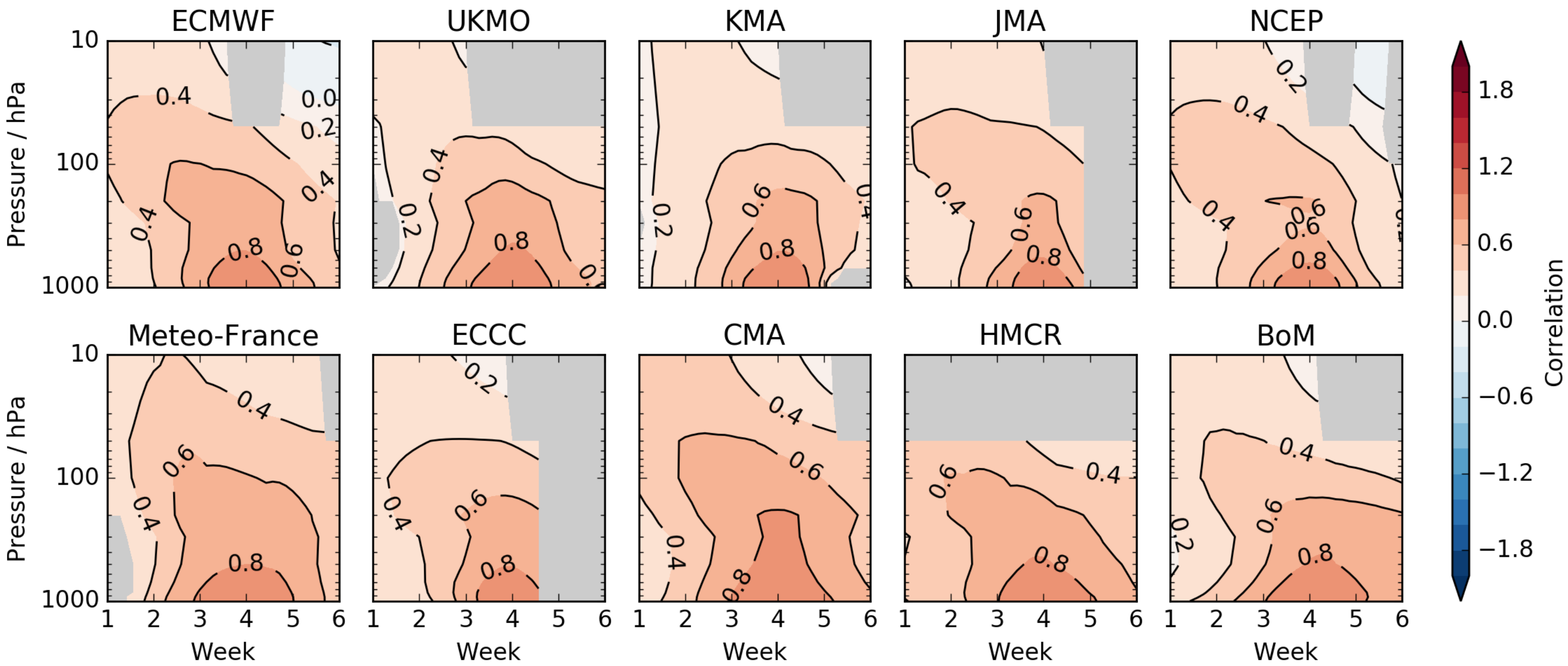
- For weeks 3 and 4 for some models, significantly larger signal in the tropospheric NAM

NOISE DIFFERENCE



- Most models have significantly greater noise variance in the troposphere from week 3 onwards
- Low top models have very little stratospheric noise

CORRELATION



- Some differences between models for correlation with surface predictable signal

CONTRASTS

- Transform the ensemble (X) using K-1 orthogonal and normalized contrasts (w)

$$m(n) = \frac{1}{K}\sum_{k=1}^{K} X_k(n)$$

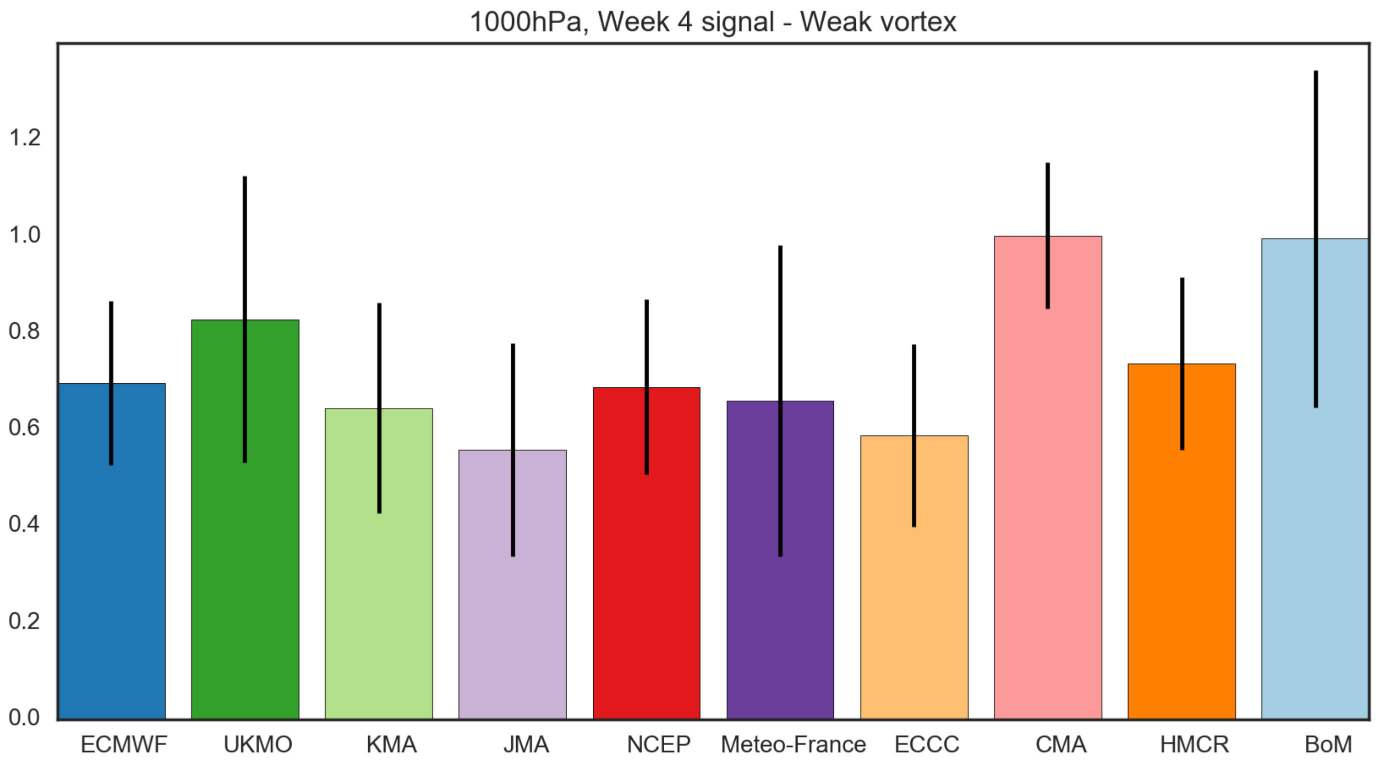
$$\xi_t(n) = \langle\ w, X\rangle \quad \text{for l} = 1, ..., \text{K} - 1$$

- Define a matrix V,

$$V_{k,l} = \left(\frac{k}{K+1} - \frac{1}{2}\right)^l$$

- QR decomposition of V using a Gram-Schmidt procedure leaves a Q matrix with orthogonal columns. Ignoring the first column gives the contrasts
- From m and ξ, all parameters of the statistical model can be calculated

SURFACE SIGNAL - WEAK



SURFACE SIGNAL - STRONG