Enhancement of Sea Surface Wind Skewness by Filtering

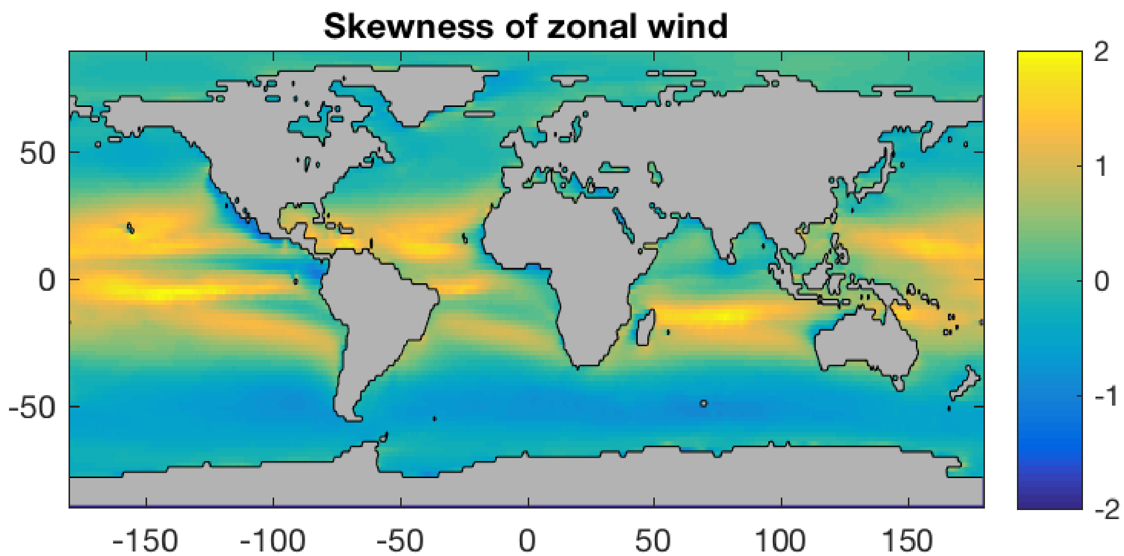
Adam Monahan

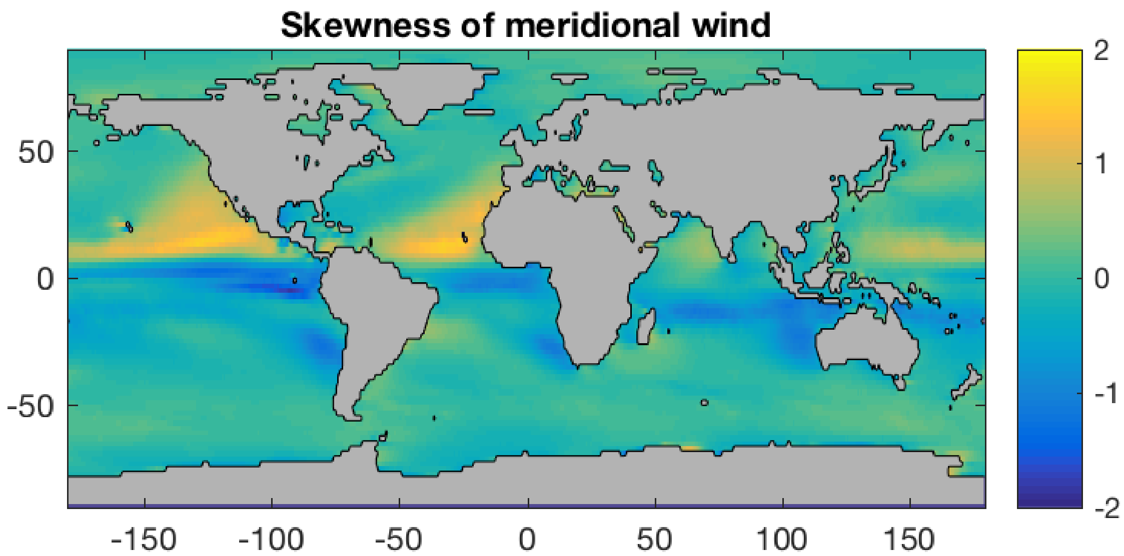
monahana@uvic.ca

School of Earth and Ocean Sciences, University of Victoria
Victoria, BC, Canada

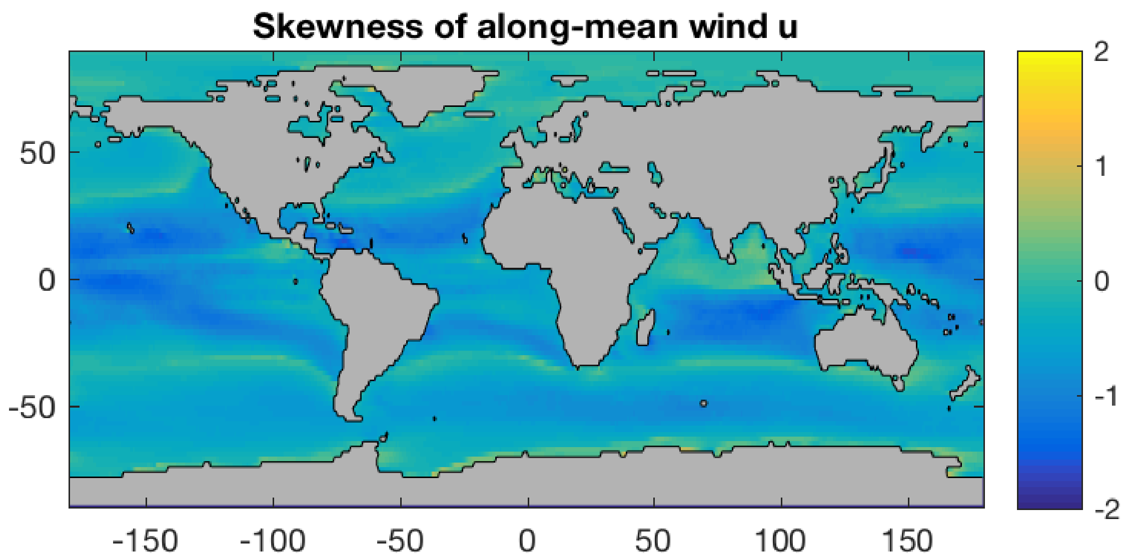
UVic

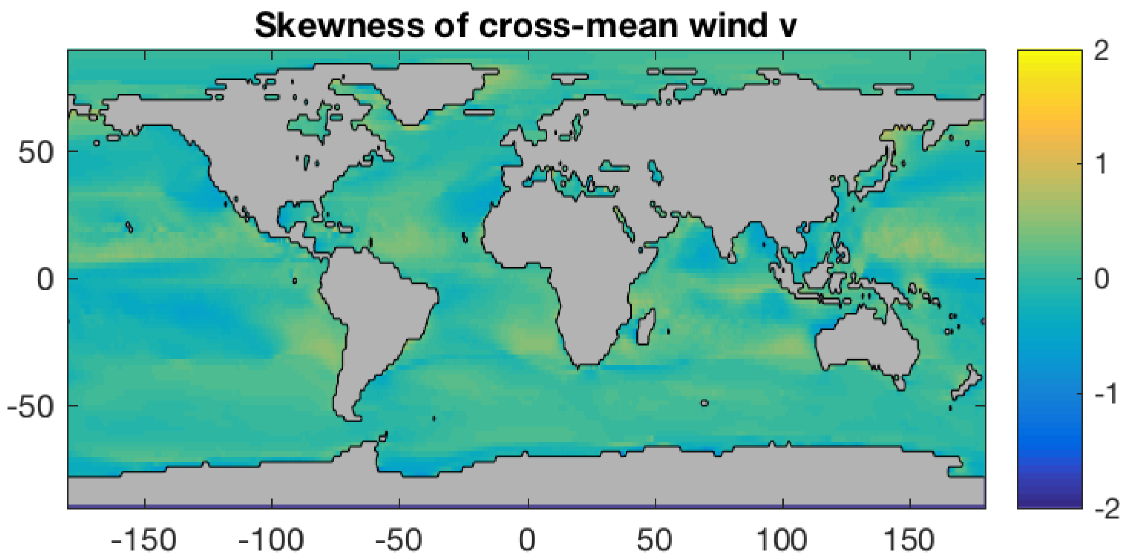
Skewness of sea surface wind components





Skewness of sea surface wind components





Simple model of sea surface wind variability

- Idealized momentum budget of surface layer of depth h:

$$
\begin{aligned}
\frac{d}{dt}u &= \langle \Pi_u \rangle - \frac{c_d}{h}(u^2 + v^2)^{1/2}u + \eta_u \\
\frac{d}{dt}v &= - \frac{c_d}{h}(u^2 + v^2)^{1/2}v + \eta_v
\end{aligned}
$$

UVic

Simple model of sea surface wind variability

- Idealized momentum budget of surface layer of depth h:

$$
\begin{aligned}
\frac{d}{dt}u &= \langle \Pi_u \rangle - \frac{c_d}{h}(u^2+v^2)^{1/2}u + \eta_u \\
\frac{d}{dt}v &= \qquad\quad - \frac{c_d}{h}(u^2+v^2)^{1/2}v + \eta_v
\end{aligned}
$$

- If $(\eta_u, \eta_v) = (\sigma \dot{W}_1, \sigma \dot{W}_2)$ uncorrelated white noise

$$
p_s(u,v) = \mathcal{N} \exp\left(\frac{2}{\sigma^2}\left[\langle \Pi_u \rangle u - \frac{c_d}{3h}(u^2+v^2)^{3/2}\right]\right)
$$

UVic

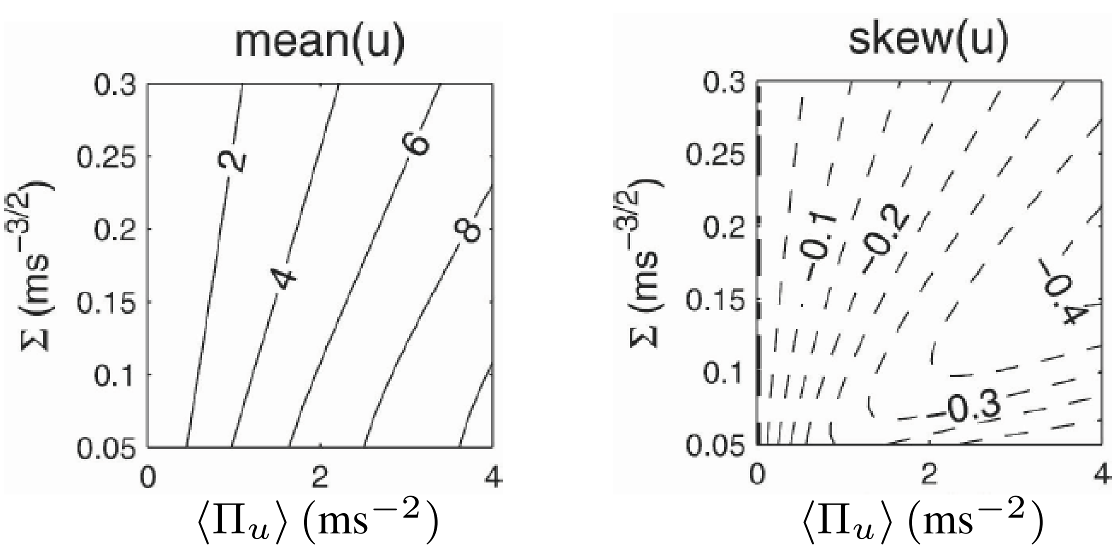
Simple model of sea surface wind variability

- Idealized momentum budget of surface layer of depth h:

$$\begin{aligned}\frac{d}{dt}u &= \langle \Pi_u \rangle - \frac{c_d}{h}(u^2+v^2)^{1/2}u + \eta_u \\ \frac{d}{dt}v &= \quad\quad - \frac{c_d}{h}(u^2+v^2)^{1/2}v + \eta_v\end{aligned}$$

- If $(\eta_u, \eta_v) = (\sigma \dot{W}_1, \sigma \dot{W}_2)$ uncorrelated white noise

$$p_s(u,v) = \mathcal{N} \exp\left(\frac{2}{\sigma^2} \left[\langle \Pi_u \rangle u - \frac{c_d}{3h}(u^2+v^2)^{3/2} \right] \right)$$



UVic

Correlated Additive-Multiplicative (CAM) noise

- Linear SDE with correlated additive & multiplicative noise terms:

$$\frac{d}{dt}x = \left(Lx - \frac{1}{2}Eg\right) + (Ex + g) \circ \dot{W}_1 + b\dot{W}_2$$

UVic

Correlated Additive-Multiplicative (CAM) noise

- Linear SDE with correlated additive & multiplicative noise terms:

$$\frac{d}{dt}x = \left(Lx - \frac{1}{2}Eg\right) + (Ex + g) \circ \dot{W}_1 + b\dot{W}_2$$

$\Rightarrow$ skewed, kurtotic stationary pdf

$$p_s(x) = \mathcal{N}\left[(Ex+g)^2 + b^2\right]^{-(\nu+1)} \exp\left[\frac{2g\nu}{b}\tan^{-1}\left(\frac{Ex+g}{b}\right)\right]$$

where

$$\nu = -\left[\frac{A}{E^2} + \frac{1}{2}\right]$$

UVic

Correlated Additive-Multiplicative (CAM) noise

- Linear SDE with correlated additive & multiplicative noise terms:

$$\frac{d}{dt}x = \left(Lx - \frac{1}{2}Eg\right) + (Ex + g) \circ \dot{W}_1 + b\dot{W}_2$$

$\Rightarrow$ skewed, kurtotic stationary pdf

$$p_s(x) = \mathcal{N}\left[(Ex + g)^2 + b^2\right]^{-(\nu+1)} \exp\left[\frac{2g\nu}{b}\tan^{-1}\left(\frac{Ex + g}{b}\right)\right]$$

where

$$\nu = -\left[\frac{A}{E^2} + \frac{1}{2}\right]$$

- Has been proposed as a generic model for non-Gaussianity in atmosphere/ocean variables

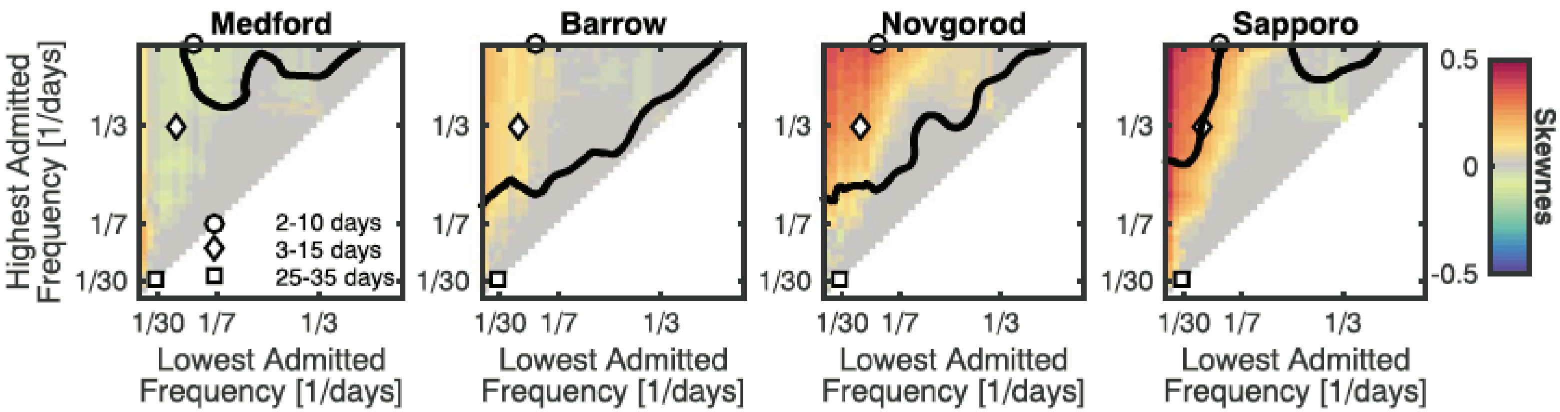
UVic

Skewness of bandpass-filtered temperatures

- Proistosescu et al. (2016) found that skewness of bandpass-filtered daily 850 hPa radiosonde temperatures generally decreases with filter bandwidth

Skewness of bandpass-filtered temperatures

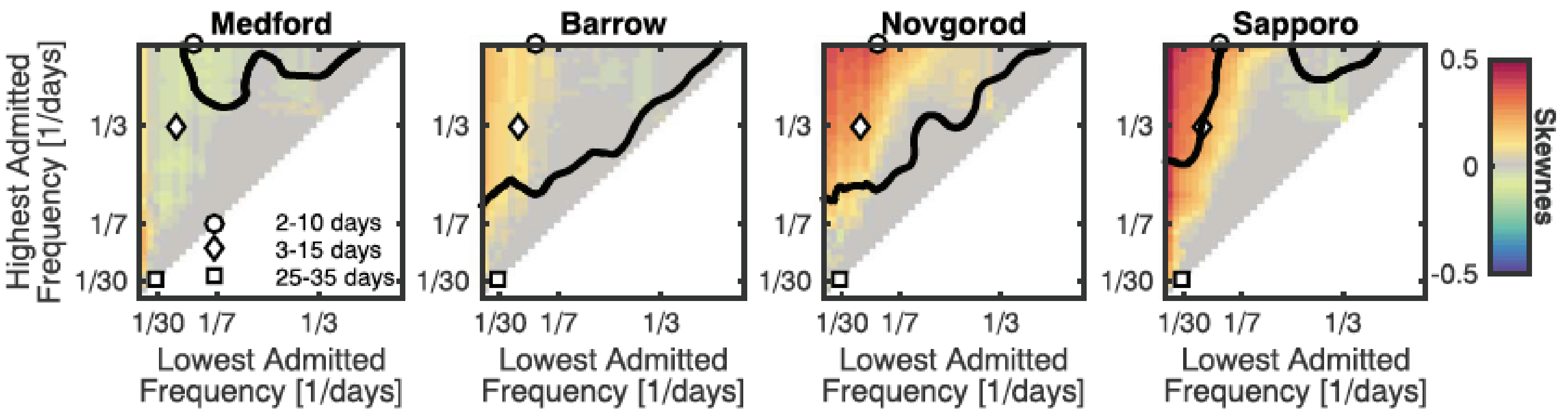
- Proistosescu et al. (2016) found that skewness of bandpass-filtered daily 850 hPa radiosonde temperatures generally decreases with filter bandwidth



Proistosescu et al., GRL, 2016

Skewness of bandpass-filtered temperatures

- Proistosescu et al. (2016) found that skewness of bandpass-filtered daily 850 hPa radiosonde temperatures generally decreases with filter bandwidth



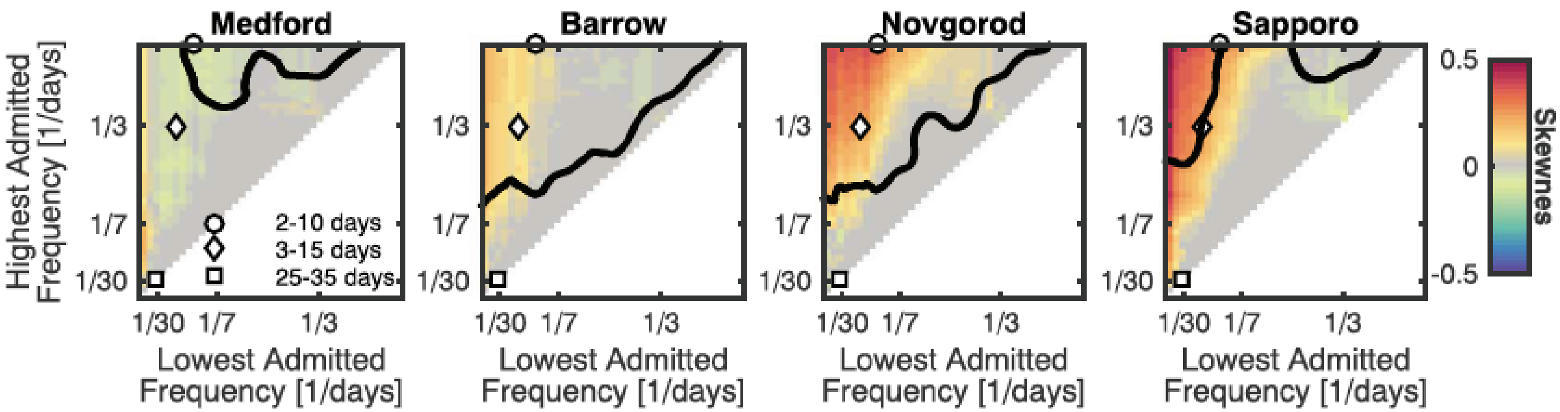
Proistosescu et al., GRL, 2016

- This behaviour was interpreted in terms of the bispectrum of uncorrelated processes; but they also found it in correlated series (including CAM noise)

UVic

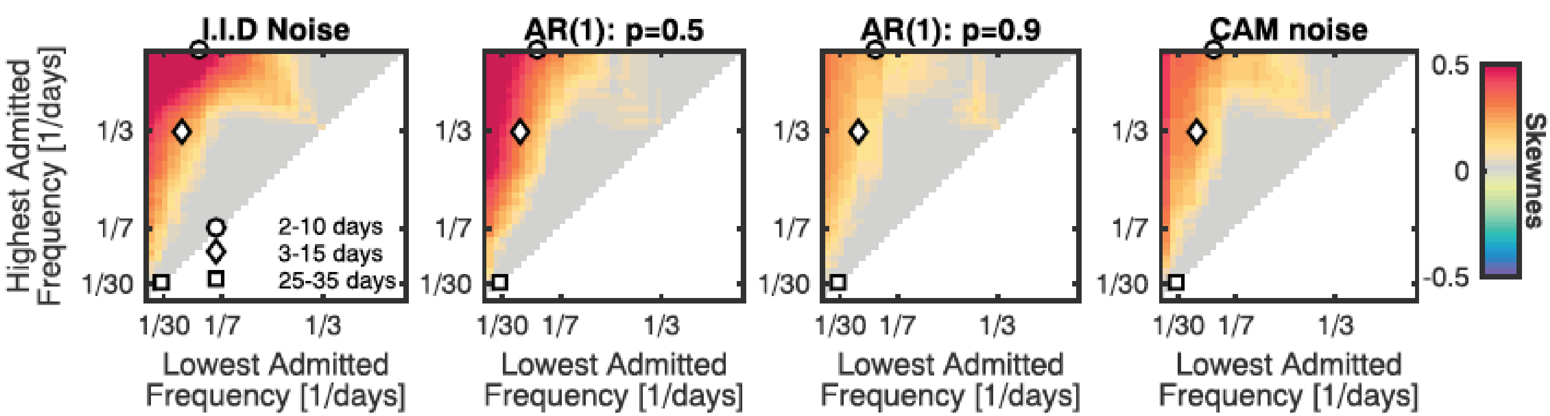
Skewness of bandpass-filtered temperatures

- Proistosescu et al. (2016) found that skewness of bandpass-filtered daily 850 hPa radiosonde temperatures generally decreases with filter bandwidth



Proistosescu et al., GRL, 2016

- This behaviour was interpreted in terms of the bispectrum of uncorrelated processes; but they also found it in correlated series (including CAM noise)



Proistosescu et al., GRL, 2016

Sea surface wind data

- Use 10m wind data from MERRA-2 reanalysis

Sea surface wind data

- Use 10m wind data from MERRA-2 reanalysis
- Hourly resolution from 01/01/79-31/12/16

Sea surface wind data

- Use 10m wind data from MERRA-2 reanalysis
- Hourly resolution from 01/01/79-31/12/16
- 60°S to 60°N

UVic

Sea surface wind data

- Use 10m wind data from MERRA-2 reanalysis
- Hourly resolution from 01/01/79-31/12/16
- 60°S to 60°N
- At each gridpoint, convert to local along-wind (u) and across-wind (v) components

Sea surface wind data

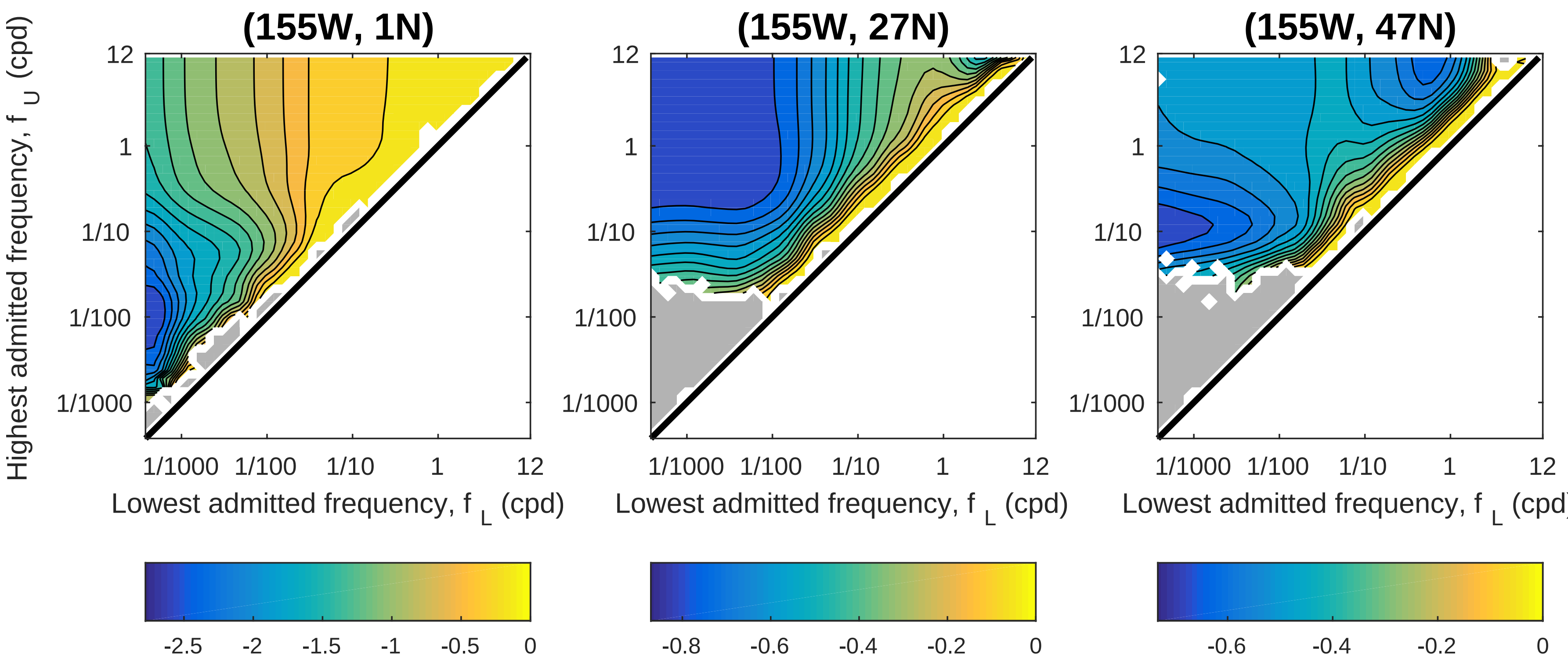
- Use 10m wind data from MERRA-2 reanalysis
- Hourly resolution from 01/01/79-31/12/16
- 60°S to 60°N
- At each gridpoint, convert to local along-wind (u) and across-wind (v) components
- Subtract harmonic fit seasonal cycle of mean; divide by harmonic fit to season

Sea surface wind data

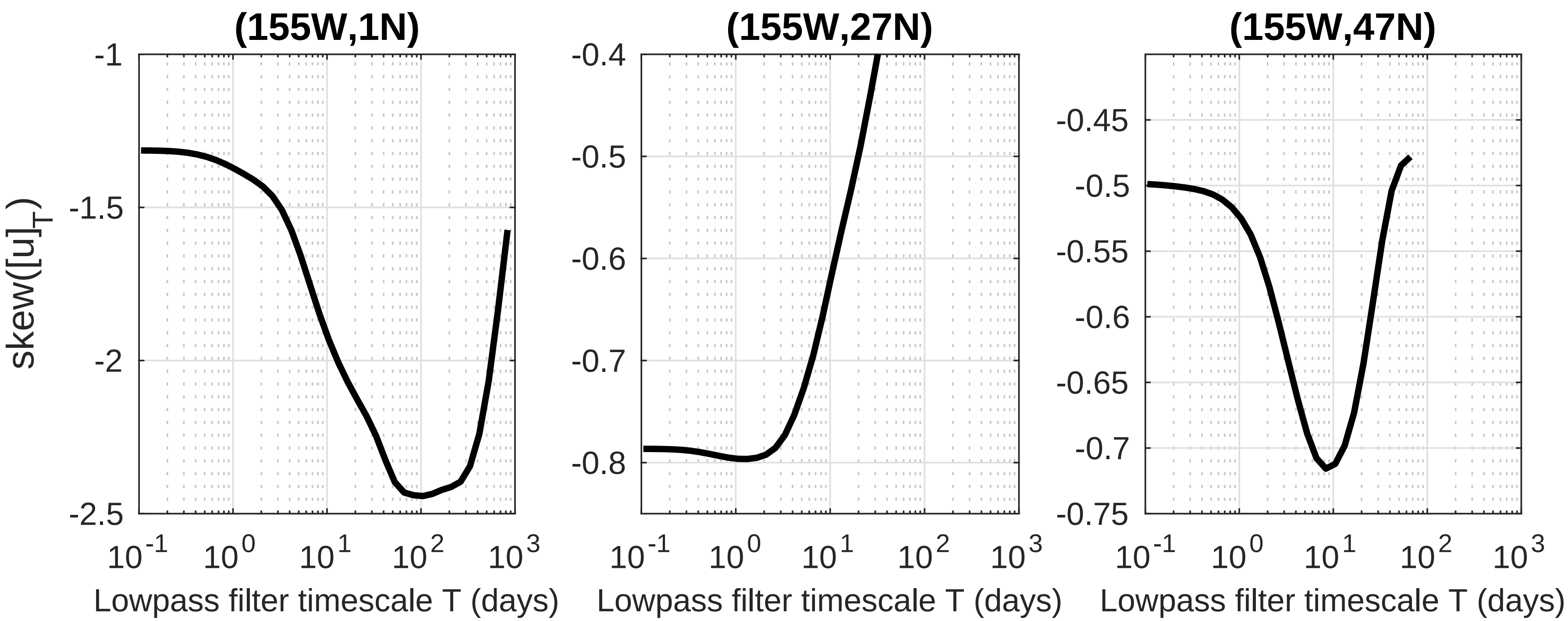
- Use 10m wind data from MERRA-2 reanalysis
- Hourly resolution from 01/01/79-31/12/16
- 60°S to 60°N
- At each gridpoint, convert to local along-wind (u) and across-wind (v) components
- Subtract harmonic fit seasonal cycle of mean; divide by harmonic fit to season
- Bandpass filter using forward-backward Butterworth filter

UVic

Bandpass-filtered skew(u)

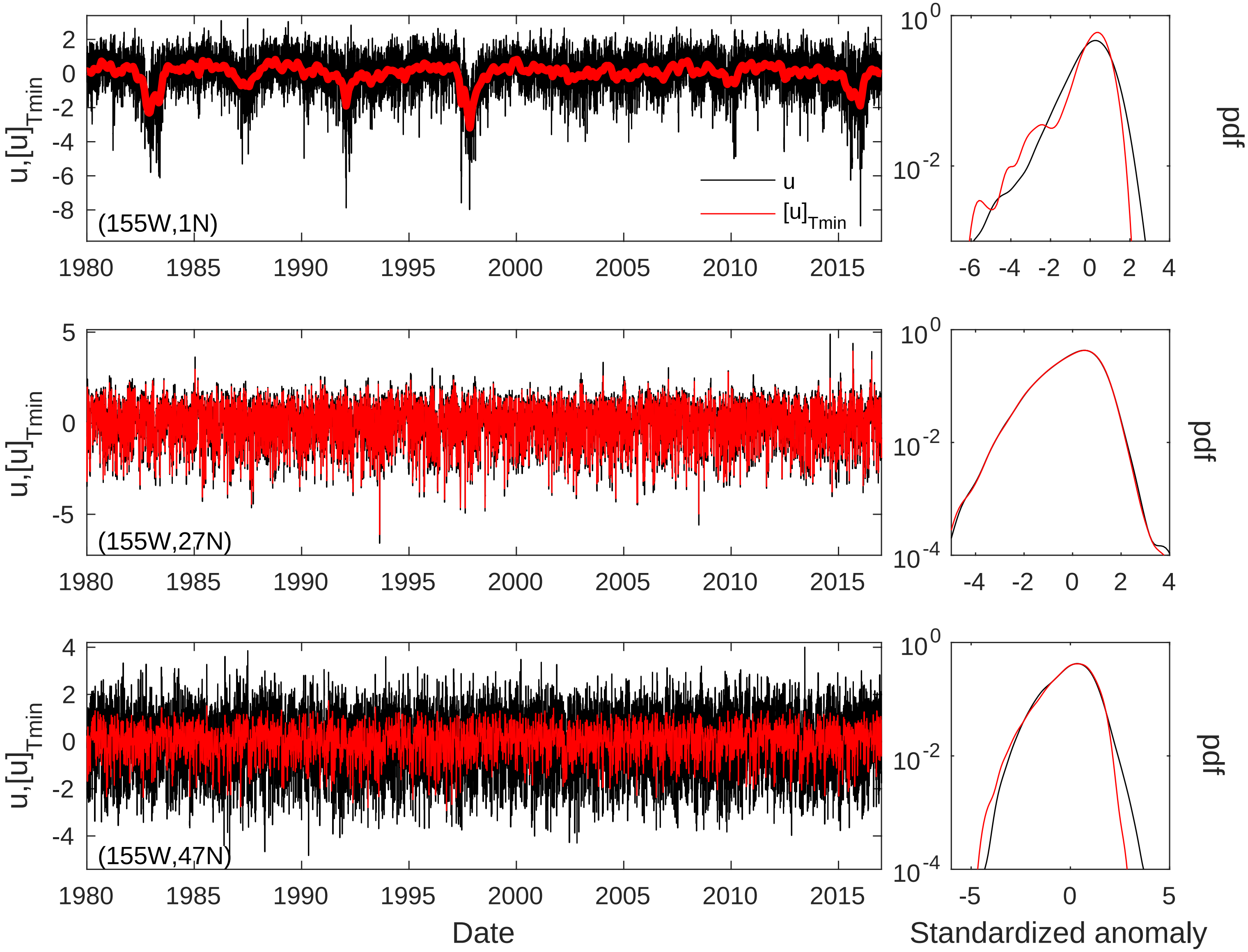


Lowpass-filtered skew(u)

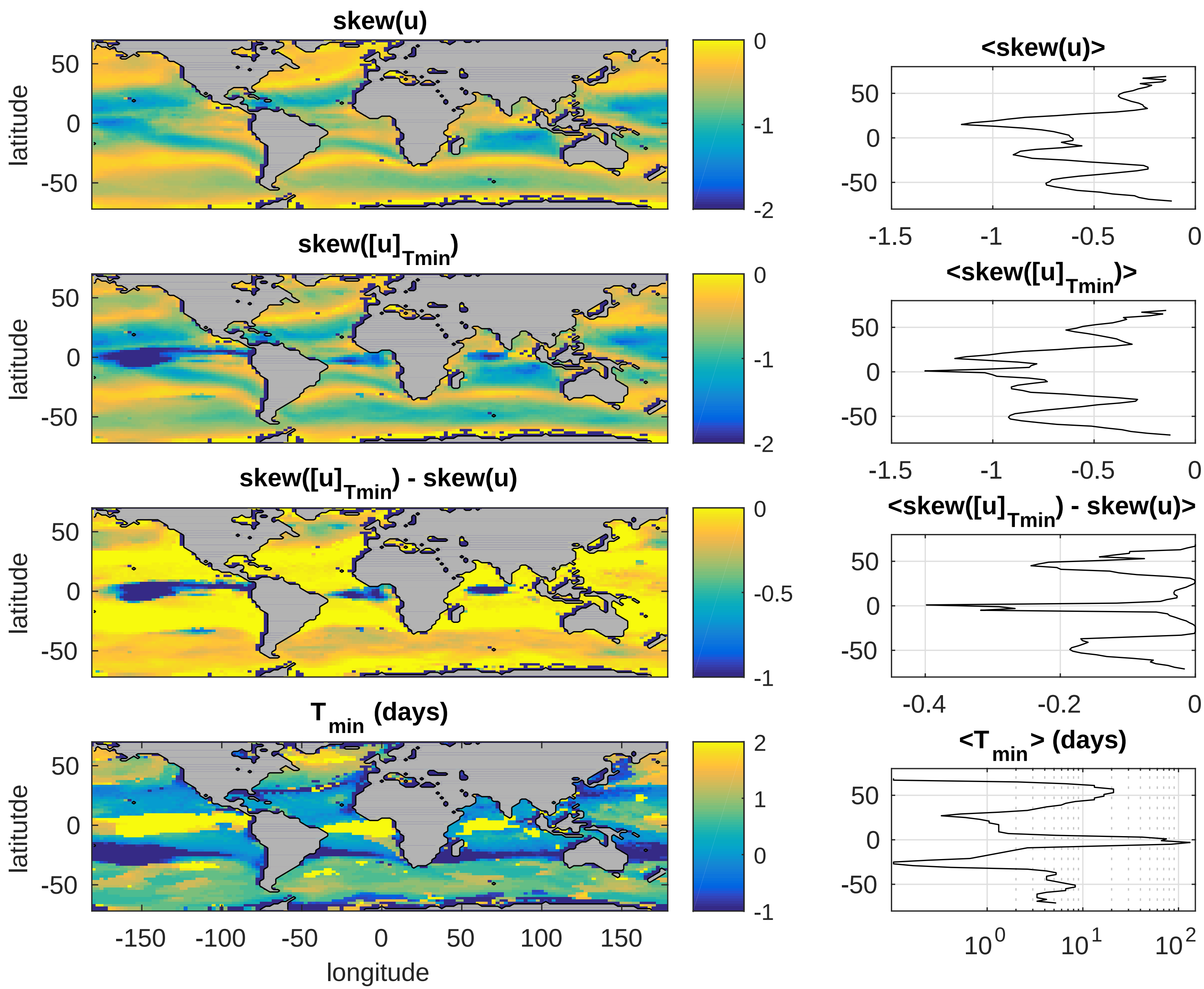


$$T = f_c^{-1}$$

Raw and lowpass-filtered time series



Spatial distribution



Timescales of idealized model

- Idealized near-surface momentum budget:

$$\begin{aligned}\frac{d}{dt}u &= \langle \Pi_u \rangle - \frac{c_d}{h}(u^2+v^2)^{1/2}u + \eta_u \\ \frac{d}{dt}v &= \quad\quad\;\, - \frac{c_d}{h}(u^2+v^2)^{1/2}v + \eta_v\end{aligned}$$

UVic

Timescales of idealized model

- Idealized near-surface momentum budget:

$$\begin{aligned}\frac{d}{dt}u &= \langle \Pi_u \rangle - \frac{c_d}{h}(u^2+v^2)^{1/2}u + \eta_u \\ \frac{d}{dt}v &= -\frac{c_d}{h}(u^2+v^2)^{1/2}v + \eta_v\end{aligned}$$

- Model (η_u, η_v) as red-noise process

$$\begin{aligned}\frac{d}{dt}\eta_u &= -\frac{1}{\tau}\eta_u + \frac{\sigma}{\tau}\dot{W}_1 \\ \frac{d}{dt}\eta_v &= -\frac{1}{\tau}\eta_v + \frac{\sigma}{\tau}\dot{W}_2\end{aligned}$$

UVic

Timescales of idealized model

- Nondimensionalize using dynamical speed and time scales

$$
\begin{aligned}
U &= \left(\frac{\langle \Pi_u \rangle \, h}{c_d} \right)^{1/2} \\
\theta &= \left(\frac{h}{\langle \Pi_u \rangle \, c_d} \right)^{1/2}
\end{aligned}
$$

UVic

Timescales of idealized model

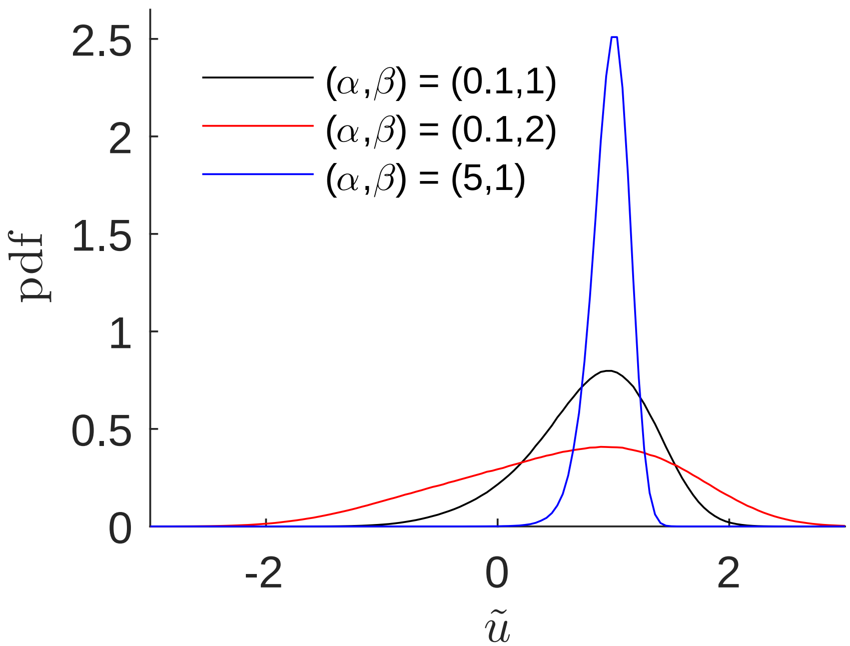
- Nondimensionalize using dynamical speed and time scales

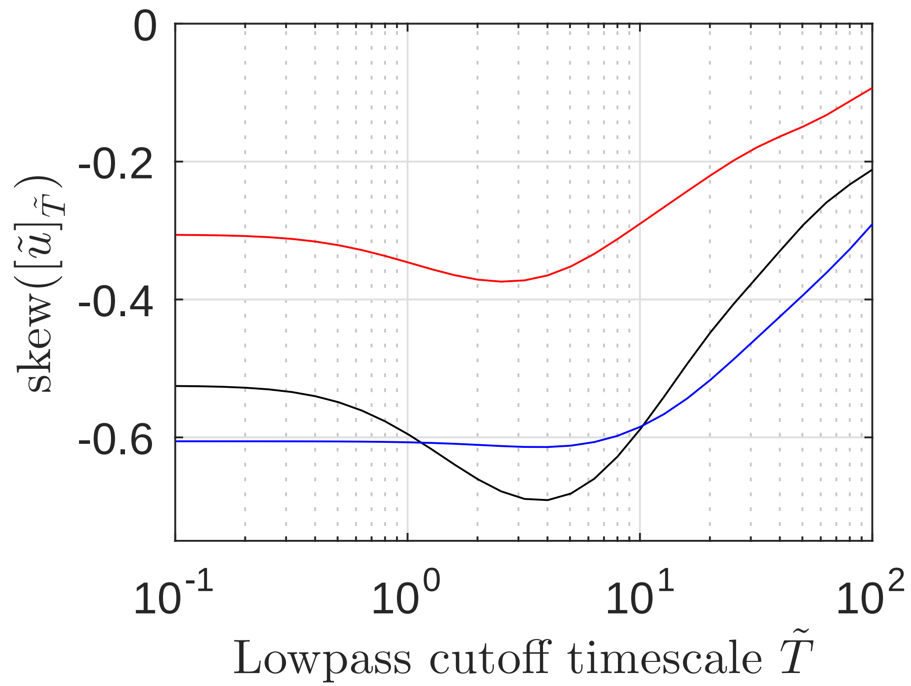
$$
\begin{aligned}
U &= \left(\frac{\langle \Pi_u \rangle h}{c_d}\right)^{1/2} \\
\theta &= \left(\frac{h}{\langle \Pi_u \rangle c_d}\right)^{1/2}
\end{aligned}
$$

$\Rightarrow$ System characterized by two non-dimensional parameters:

$$
\begin{aligned}
\alpha &= \frac{\tau}{\theta} \\
\beta &= \left(\frac{\sigma^4 c_d}{h \langle \Pi_u \rangle^3}\right)^{1/4}
\end{aligned}
$$

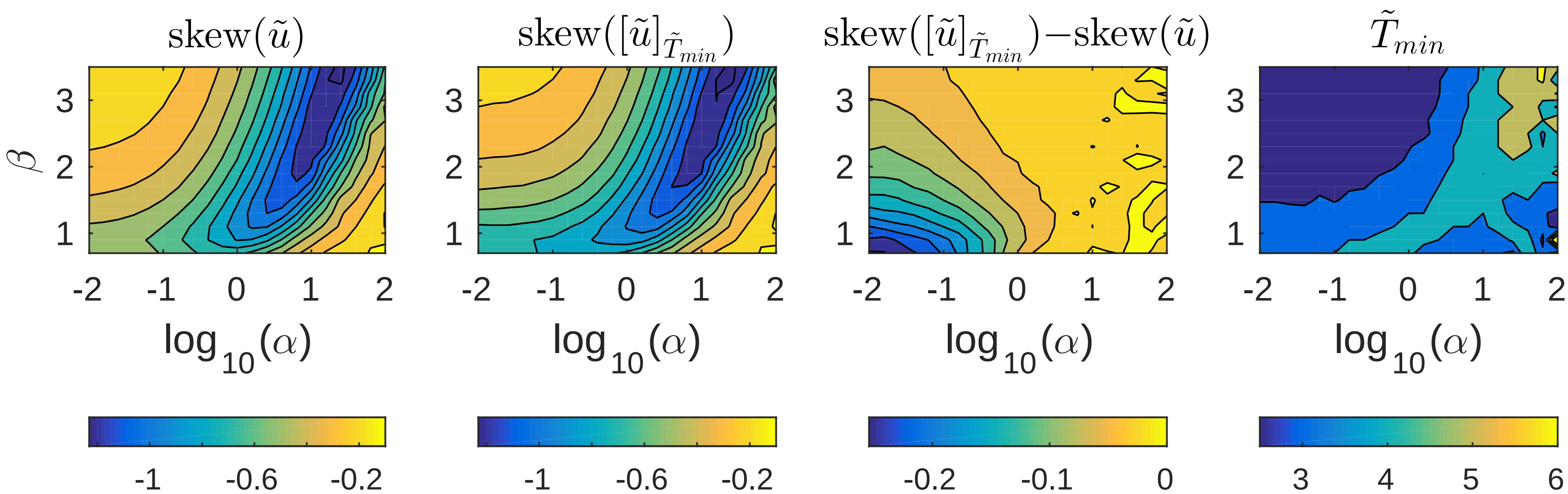
Lowpass-filtered model skew$(\tilde{u})$





$$\alpha = \frac{\tau}{\theta} \qquad \beta = \left(\frac{\sigma^4 c_d}{h \left\langle \Pi_u \right\rangle^3} \right)^{1/4}$$

Lowpass-filtered model skew$(\tilde{u})$



$$\alpha = \frac{\tau}{\theta} \qquad \beta = \left(\frac{\sigma^4 c_d}{h \left\langle \Pi_u \right\rangle^3} \right)^{1/4}$$

Lowpass-filtered model skew$(\tilde{u})$

- Model shows skewness enhancement with (nondimensional) $\tilde{T}_{min} \sim 3 - 5$

UVic

Lowpass-filtered model skew$(\tilde{u})$

- Model shows skewness enhancement with (nondimensional) $\tilde{T}_{min} \sim 3 - 5$

$\Rightarrow$ timescale set by dynamical timescale θ

UVic

Lowpass-filtered model skew$(\tilde{u})$

- Model shows skewness enhancement with (nondimensional) $\tilde{T}_{min} \sim 3 - 5$

$\Rightarrow$ timescale set by dynamical timescale θ

- $U \sim 5$ ms^{-1}, $h \sim 1000$ m, $c_d \sim 1.3 \times 10^{-3}$ $\Rightarrow$ $\theta \sim 1.8$ days

UVic

Lowpass-filtered model skew$(\tilde{u})$

- Model shows skewness enhancement with (nondimensional) $\tilde{T}_{min} \sim 3 - 5$

$\Rightarrow$ timescale set by dynamical timescale θ

- $U \sim 5$ ms^{-1}, $h \sim 1000$ m, $c_d \sim 1.3 \times 10^{-3}$ $\Rightarrow$ $\theta \sim 1.8$ days

$\Rightarrow$ results consistent with observed $T_{min} \sim$ days

UVic

Lowpass-filtered model skew$(\tilde{u})$

- Model shows skewness enhancement with (nondimensional) $\tilde{T}_{min} \sim 3 - 5$

$\Rightarrow$ timescale set by dynamical timescale θ

- $U \sim 5$ ms^{-1}, $h \sim 1000$ m, $c_d \sim 1.3 \times 10^{-3} \;\; \Rightarrow \;\; \theta \sim 1.8$ days

$\Rightarrow$ results consistent with observed $T_{min} \sim$ days

- Skewness enhancement greatest when $\alpha < 1$, so noise "faster" than dynamics

UVic

Lowpass-filtered model skew$(\tilde{u})$

- Model shows skewness enhancement with (nondimensional) $\tilde{T}_{min} \sim 3 - 5$

$\Rightarrow$ timescale set by dynamical timescale θ

- $U \sim 5$ ms^{-1}, $h \sim 1000$ m, $c_d \sim 1.3 \times 10^{-3} \Rightarrow \theta \sim 1.8$ days

$\Rightarrow$ results consistent with observed $T_{min} \sim$ days

- Skewness enhancement greatest when $\alpha < 1$, so noise "faster" than dynamics

$\Rightarrow$ fast noise partially "buries" dynamically generated skewness, which is brought out by filtering

UVic

Lowpass-filtered model skew$(\tilde{u})$

- Model shows skewness enhancement with (nondimensional) $\tilde{T}_{min} \sim 3 - 5$

$\Rightarrow$ timescale set by dynamical timescale θ

- $U \sim 5$ ms^{-1}, $h \sim 1000$ m, $c_d \sim 1.3 \times 10^{-3} \;\; \Rightarrow \;\; \theta \sim 1.8$ days

$\Rightarrow$ results consistent with observed $T_{min} \sim$ days

- Skewness enhancement greatest when $\alpha < 1$, so noise "faster" than dynamics

$\Rightarrow$ fast noise partially "buries" dynamically generated skewness, which is brought out by filtering

- $O(100$ day$)$ skewness max. in equatorial band suggestive of relatively large θ, or skewed noise (e.g. in ENSO region)

UVic

Lowpass-filtered model skew$(\tilde{u})$

- Model shows skewness enhancement with (nondimensional) $\tilde{T}_{min} \sim 3 - 5$

$\Rightarrow$ timescale set by dynamical timescale θ

- $U \sim 5$ ms^{-1}, $h \sim 1000$ m, $c_d \sim 1.3 \times 10^{-3} \Rightarrow \theta \sim 1.8$ days

$\Rightarrow$ results consistent with observed $T_{min} \sim$ days

- Skewness enhancement greatest when $\alpha < 1$, so noise "faster" than dynamics

$\Rightarrow$ fast noise partially "buries" dynamically generated skewness, which is brought out by filtering

- $O(100$ day$)$ skewness max. in equatorial band suggestive of relatively large θ, or skewed noise (e.g. in ENSO region)
- Not clear why subtropical $\theta \sim 1$ day; need direct estimates of model parameters.

UVic

Conclusions

- Along-mean wind components show systematic enhancement of skewness with lowpass filtering in midlatitudes and equatorial belt

UVic

Conclusions

- Along-mean wind components show systematic enhancement of skewness with lowpass filtering in midlatitudes and equatorial belt
- Timescale of skewness extremum synoptic in midlatitudes, subseasonal-seasonal in equatorial band

UVic

Conclusions

- Along-mean wind components show systematic enhancement of skewness with lowpass filtering in midlatitudes and equatorial belt
- Timescale of skewness extremum synoptic in midlatitudes, subseasonal-seasonal in equatorial band
- Idealized model of surface momentum budget captures many features of observed skewness enhancement; predicts key parameters are dynamical and noise timescales (but unresolved questions remain)

UVic

Conclusions

- Along-mean wind components show systematic enhancement of skewness with lowpass filtering in midlatitudes and equatorial belt
- Timescale of skewness extremum synoptic in midlatitudes, subseasonal-seasonal in equatorial band
- Idealized model of surface momentum budget captures many features of observed skewness enhancement; predicts key parameters are dynamical and noise timescales (but unresolved questions remain)
- Enhancement of skewness by filtering not consistent with CAM process

UVic

Conclusions

- Along-mean wind components show systematic enhancement of skewness with lowpass filtering in midlatitudes and equatorial belt
- Timescale of skewness extremum synoptic in midlatitudes, subseasonal-seasonal in equatorial band
- Idealized model of surface momentum budget captures many features of observed skewness enhancement; predicts key parameters are dynamical and noise timescales (but unresolved questions remain)
- Enhancement of skewness by filtering not consistent with CAM process
- Reduction of skewness by bandpass filtering not a general result

UVic

Conclusions

- Along-mean wind components show systematic enhancement of skewness with lowpass filtering in midlatitudes and equatorial belt
- Timescale of skewness extremum synoptic in midlatitudes, subseasonal-seasonal in equatorial band
- Idealized model of surface momentum budget captures many features of observed skewness enhancement; predicts key parameters are dynamical and noise timescales (but unresolved questions remain)
- Enhancement of skewness by filtering not consistent with CAM process
- Reduction of skewness by bandpass filtering not a general result
- Analyses such as these may provide a tool to assess if non-Gaussian features result from nonlinear dynamics or multiplicative noise

UVic