Extreme events and statistical structure of sea-level variability: AVISO vs multi-resolution DRAKKAR simulations

DRAKKAR Ocean Modelling Consortium

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QUESTIONS

- How does a **1/4° global model** simulate the **observed** mean, standard deviation, skewness, kurtosis of SSH over 1993-2004 ?
- How do **coarser resolution (IPCC-like) models** do the job ?

ABSTRACT

The DRAKKAR Consortium has performed an ensemble of global, multi-decadal ocean/sea-ice simulations that mostly differ by their horizontal resolution (2°, 1°, 1/2°, 1/4°, 1/12°). These simulations are first collocated at the spatial and temporal resolution of the AVISO altimeter SLA dataset, then quantitatively compared to AVISO and among themselves with respect to the first four statistical moments of SLA (mean, variance, skewness and kurtosis), in three frequency ranges. We precisely quantify in this study how increased model resolution progressively improves the magnitude and geographical patterns of simulated mean flows, mesoscale activities and large-scale interannual variabilities. Based on a statistical mechanics theory, we extend this observation/multi-model global comparison to the distribution and statistical structure of extreme events (skewness and kurtosis of SLA distributions), and to the dynamical relationships between the latter 2 statistical moments. Beyond this multi-moment assessment of our simulations, our results raise open questions about the ocean dynamics, and the contribution of multiplicative noise in numerical simulations.

1 - The first 4 moments of a distribution : what do they mean?

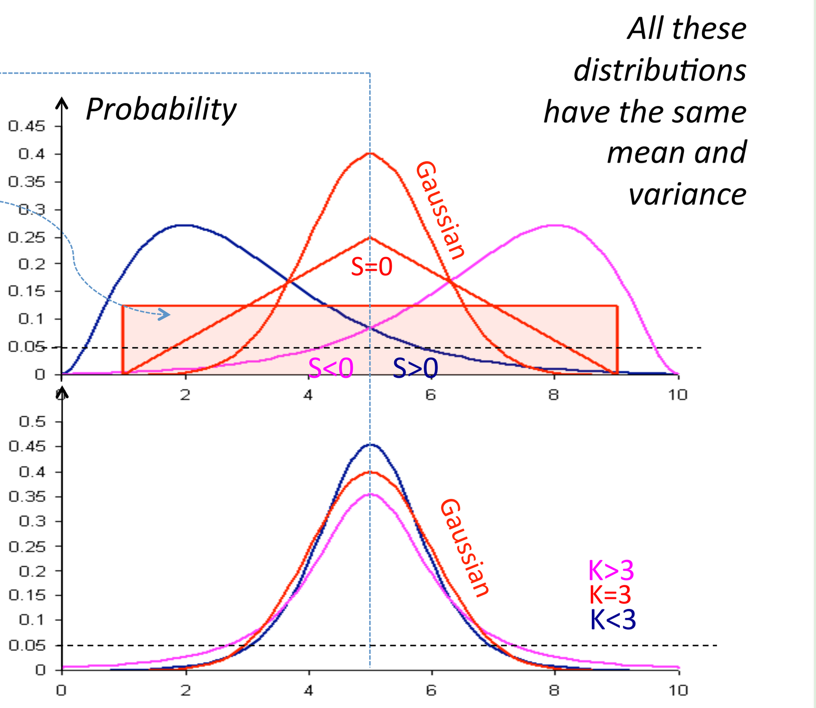
What is the time average? — 1st : Mean

How much variability around the mean? — 2nd: Variance (*area*)

Are there more negative or positive extreme events ? — 3rd: Skewness (*asymmetric*)

Are extreme events more or less likely than normal ? — 4th: Kurtosis (*long-tailed*)

All these distributions have the same mean and variance



2 – DRAKKAR ocean/sea-ice simulations

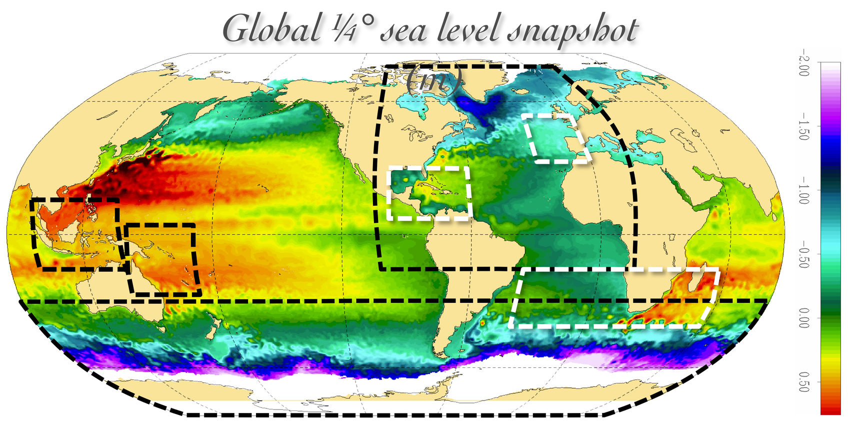
- Four resolutions : 1/4°, 1/2°, 1°, 2°
- SGS adapted to each resolution
- No data assimilation
- See *Penduff et al, 2010*

- Same atmospheric forcing : (see *Brodeau et al, 2010*)
  - ***47 years : 1958-2007***
  - *6-hour ERA40 atmosph. variables*
  - *Satellite SW/LW radiations*
  - *Xie and Arkin precipitations*
  - *Moderate SSS restoring*
  - *No SST restoring*

Models' SSH(x,y,t) are collocated in time and space onto AVISO (7 day*1/3°*1/3°)

http://www.ifremer.fr/lpo/drakkar/

Global ¼° sea level snapshot

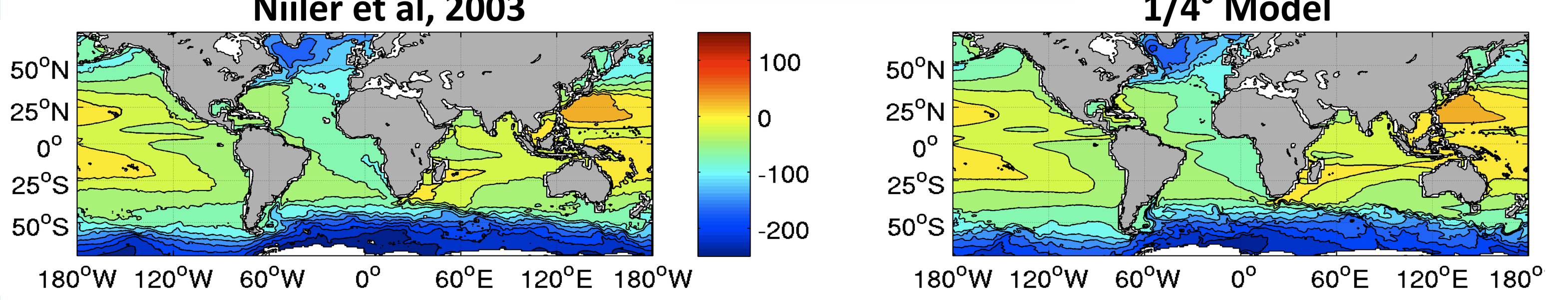


- NEMO ocean/sea-ice/^{14}C/CFC_{11} z-level code
- Global 2°, Global 1°, Global ½°, Global ¼°, Global 1/12°
- Stand-alone configurations
- Nested configurations
- Regional & global studies over 1958-present
- 160+ users collaborating on scientific studies

3 – Moments 1 and 2

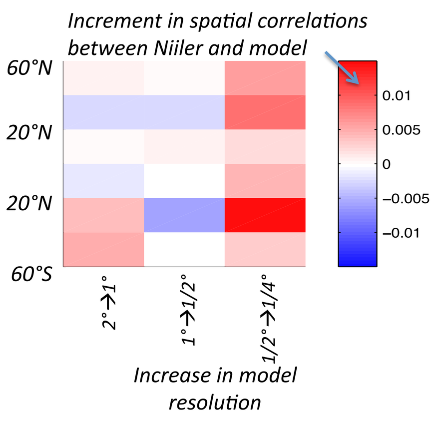
(See *Penduff et al, 2010*)

#1 : Mean

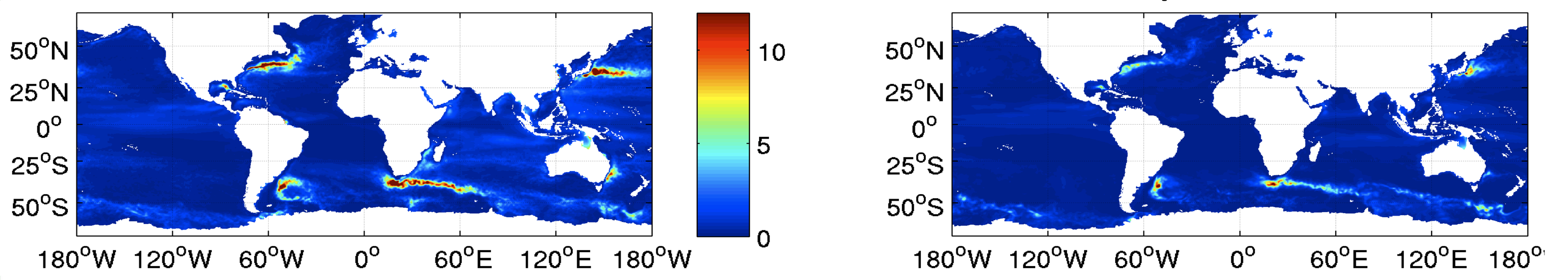


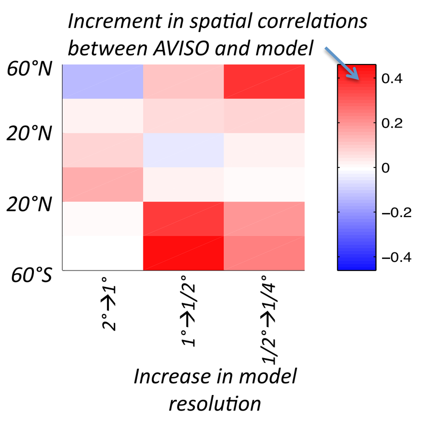
- Mean SSH well distributed at 1/4°. A few fronts are mislocated, though. (*Barnier et al, 2006*)
- Halving resolution does not systematically deteriorate mean SSH maps, except 1/4° → 1/2°

- ***Colors*** *= change in model-obs spatial correlation for each increase in resolution*
- ***Red*** *= More realistic*
- ***Blue*** *= Less realistic*



#2 : Standard deviation





- σ well distributed at 1/4°. A few fronts are mislocated, though.
- Halving resolution systematically deteriorates σ maps, and reduces variability, especially 1/4° → 1/2° and 1/2° → 1°
- This is true (and more noteworthy) at large time and spatial scales : **The large-scale interannual variability is strongly deteriorated by coarser resolution, both in magnitude and distribution.**

4 – Multiplicative noise → Non gaussian dynamics → (S,K) inequality

Sardeshmukh & Sura, JC 2009 ; Sura & Gille, 2010

State vector : $X = (u, v, T, \eta ..)$

$$\frac{dX_i}{dt} = \underbrace{L_{ij}X_j}_{linear} + \underbrace{N_{ijk}X_jX_k}_{nonlinear} + \underbrace{F_i}_{forcing},$$

Decompose **X** :

$$X = \underbrace{x}_{mean} + \underbrace{x}_{slow} + \underbrace{\eta}_{fast\ (mesoscale = stochastic\ noise)}$$

Slow evolution :

$$\frac{dx_i}{dt} = A_{ij}x_j + \underbrace{(E_{ijm}x_j + G_{im})\eta_m}_{multiplicative\ noise} - \frac{1}{2}E_{ijm}G_{im} + (f_{ext})_i$$

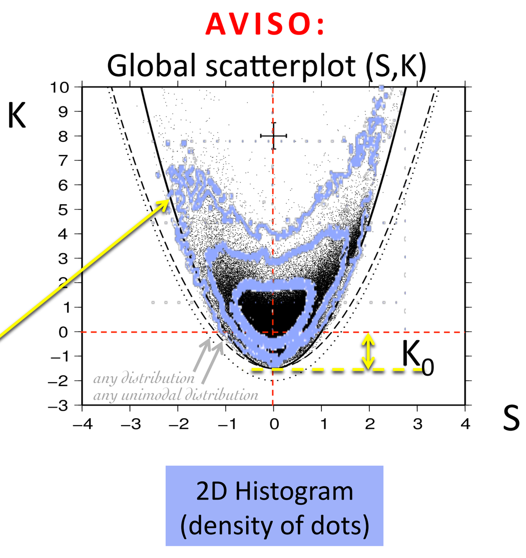
neglect: ☺ Red spectra ☹ Gaussian PDF (*Hasselmann 76*)

keep: ☺ **Red spectra** ☺**Non gaussian PDF** (as observed in AVISO)

- ✓ Multiplicative noise may come from $\underline{u}'.\nabla\overline{T}$, stochastic momentum advection, etc
- ✓ It can be shown from this stochastic model that multiplicative noise yields

$K > (3/2).S^2 - K_0$

- ✓ It is suggested that large K_0 is due to large correlations between data points

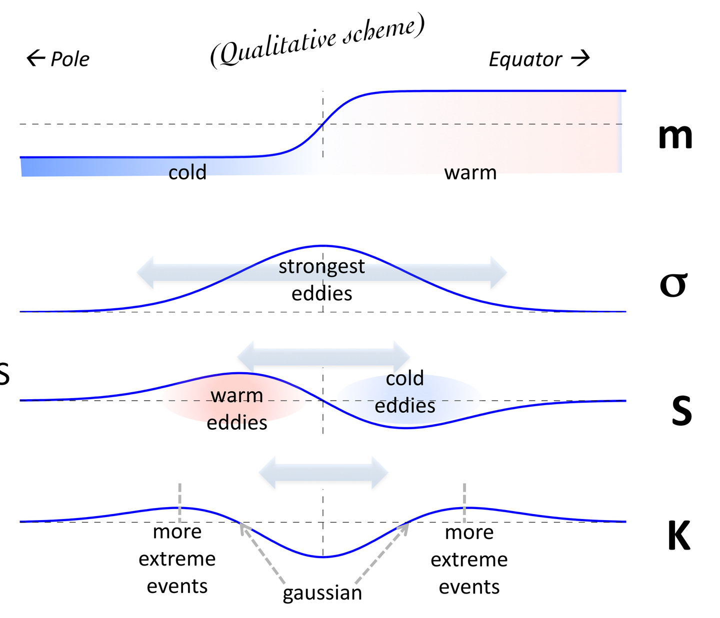


→ Can the 1/4° model simulate this inequality ?
→ How does resolution affect this feature ?

Hughes et al, OM 2010

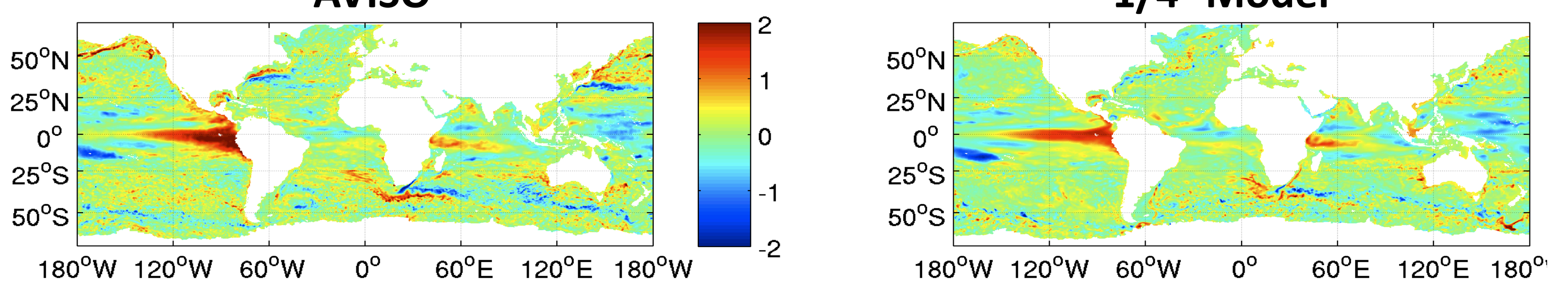
- ✓ Core of jet : max(σ), S=0, min(K)
- ✓ S is asymmetric, K is symmetric
- ✓ K has shorter meridional scales than S

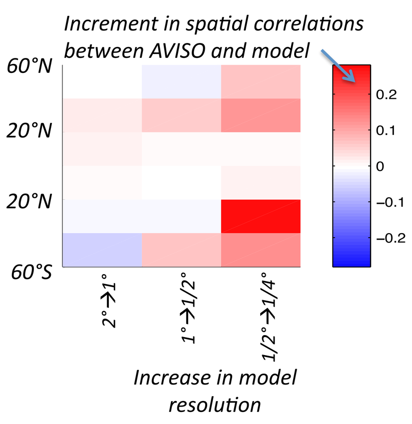
(K could also be a proxy for lagrangian mixing)



5 – Moments 3 and 4

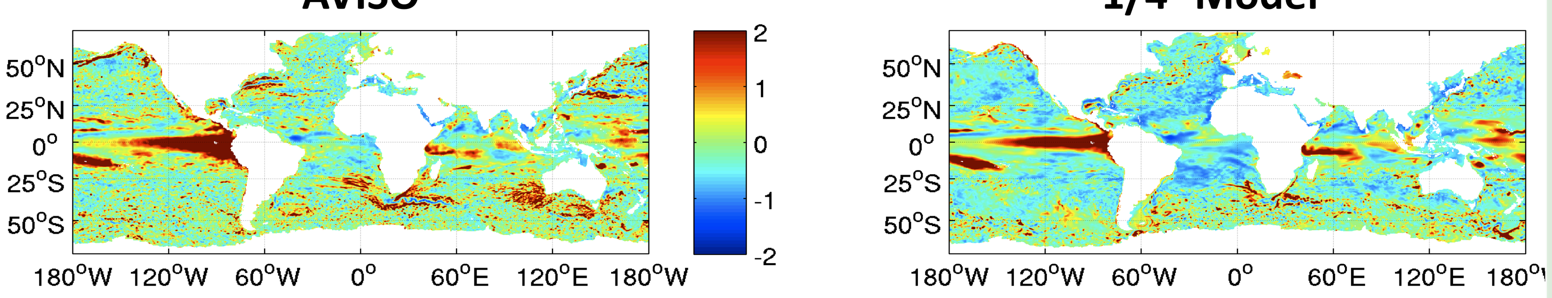
#3 : Skewness

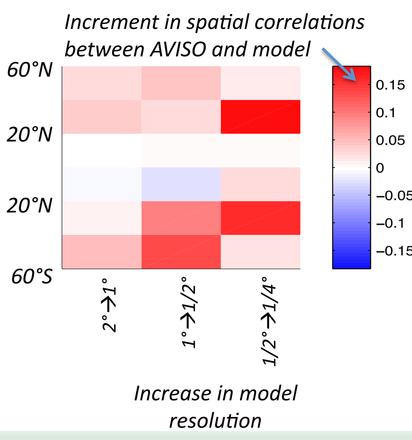




- **S** correctly distributed at 1/4°. This is true at large scale, with realistic dipoles along fronts.
- Halving resolution most often deteriorates **S** maps at all latitudes, especially 1/4° → 1/2°

#4 : Kurtosis

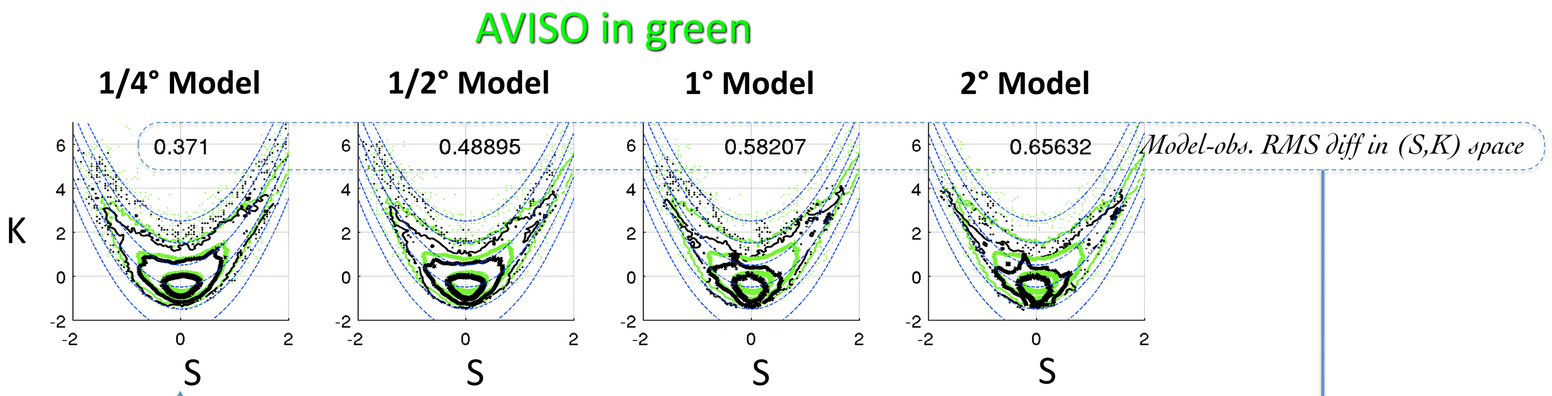




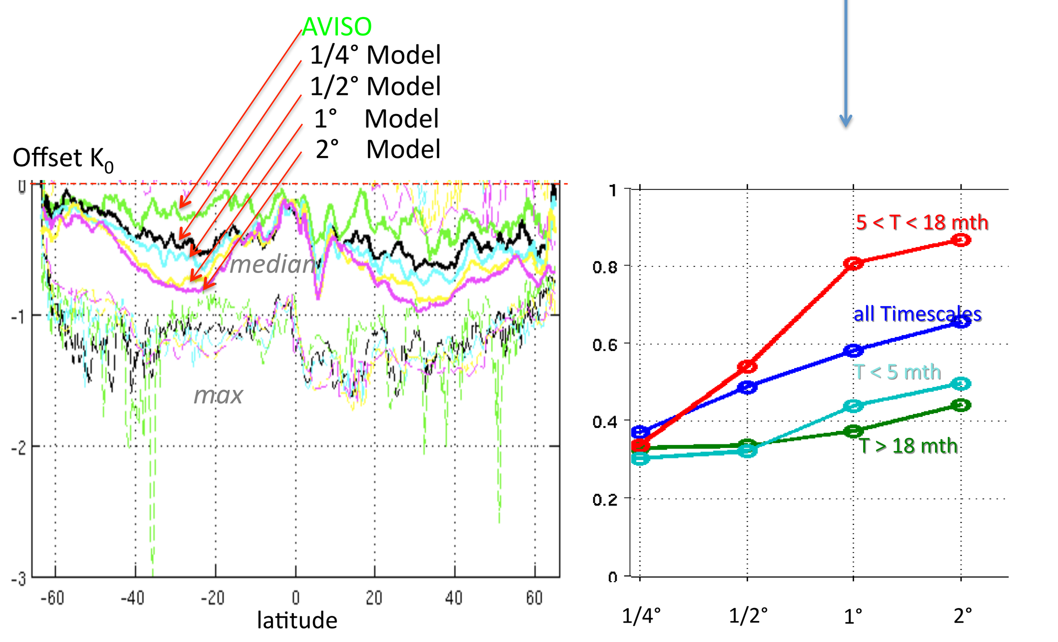
- **K** correctly distributed at 1/4° at large scale, with realistic tripoles along fronts.
- Halving resolution most often deteriorates **K** maps at all latitudes.
- **K** has smaller spatial scales than **S** and σ : resolution yields smaller changes; 1/12° might be necessary for a substantial improvement.

6 – Relationship between Skewness and Kurtosis : global scatterplots

AVISO in green



- The observed/predicted **(S,K)** relationship is well simulated at 1/4° → dynamical consistency despite a few mislocated fronts
- Halving resolution deteriorates the **(S,K)** relationship at all timescales, especially 1/4° → 1/2°
- Halving resolution increases offset K_0 → probably more spatial autocorrelations.



7 – Conclusions

- The DRAKKAR 1/4° global model **correctly simulates the patterns and magnitudes of observed mean, standard deviation, skewness, and kurtosis of SSH** over 1993-2004. Nonlinearities (multiplicative noise) at work at 1/4° yield the **observed relationship between skewness and kurtosis**, which is also predicted by statistical theories.
- Coarsening resolution (back to present IPCC standards) does not affect large-scale mean SSH much, but **deteriorates the patterns/magnitude of the large-scale interannual variability, the S and K patterns and their mutual relationship.**
- Higher resolution yield better physical consistency and realism in SSH, even at large scales.

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