Held and Suarez (1994)再訪

大淵 済 2024/06/06(木) 神戸大・六甲台

今日の発表

とりあえずのShow and Tell（こんなのやりました）

- イントロダクション
    - Held and Suarez 1994の簡単な紹介
    - 私の動機
- 実験結果とHS94の図との比較など
- 遭遇したり，思いついたりした，いくつかの課題
- まとめ

イントロダクション:
「Held and Suarez 1994
の簡単な紹介」と
「私の動機」

Held and Suarez 1994
が目指すところ１

- 「力学コア」に絞った「気候」モデル相互比較のためのテスト（基準/ベンチマーク）の提案（「力学」と「気候 = 気象の統計状態」）
  - AMIP（フルAGCMsの気候モデル相互比較：Gates 1992）はモデルが複雑過ぎる
    - 各モジュールの相互比較も必要
      - ICRCCM（放射コード）：Ellingson et al. 1991; Fouquart et al. 1991
      - 陸面モデル：Henderson-Sellers et al. 1992）
  - Williamson et al. (1992)は2D浅水波の「気象」（その後のWilliamson関連テストなども「気象」（のはず））

Held and Suarez 1994

目指すところ２

- モデルのモジュール化の促進も
  - 取っ替え引っ替え
    - 物理過程についてはKalnay et al. (1989)が議論
- モデルの公開も

問題点

- 正解が分かっていない
- 長期変動がもたらすサンプリング・エラー

何を今さらHS94？

ほかにもいろいろ応用されてきたが，原点に近いところをなぜ？

- In a separate study, we will be looking at this proposed calculation in more depth. In particular, we will study the behavior of these two models as a function of horizontal and vertical **resolution** and discuss their sensitivity to the choice of **dissipation**.
    - 本人たちもやったかもしれないが（というかやったはずだが）出版された形跡がない…
        - おそらく，他の研究者がそれなりにやってしまった（レビュー必要）？
        - スペクトル・モデル同士の比較だと，極めてつまらない？
    - まぁ，それでも，とりあえず，ちょっと何かやってみるかと思った

何を今さらHS94？

e.g. Wan et al. 2008（ECHAM5, T31-159, L16-81）

- Results show that the simulated climate state in the Held–Suarez test is **sensitive to spatial resolution**. Increase of horizontal resolution leads to slight weakening and poleward shift of the westerly jets. Significant warming is detected in high latitudes, especially near the polar tropopause, while the tropical tropopause becomes cooler. The baroclinic wave activity intensifies considerably with increased horizontal resolution. Higher vertical resolution also leads to stronger eddy variances and cooling near the tropical tropopause, but equatorward shift of the westerly jets. The solutions show an indication of **convergence at T85L31** resolution according to all the three statistical tests applied. Differences between integrations with various time steps are judged to be within the noise level induced by the inherent low-frequency variability.

- とりあえず，たぶん，これの後追いに近いことから…

GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L12812, doi:10.1029/2006GL026429, 2006

Explicit global simulation of the mesoscale spectrum of atmospheric motions

Yoshiyuki O. Takahashi,[1] Kevin Hamilton,[2] and Wataru Ohfuchi[3]

these experiments is shown in the upper right panel. We find that to obtain the convergent spectra we need to scale the diffusivity approximately as a power law of the model truncation (the regression fit shown in Figure 3 is $1.2 \times 10^{21}\ n_t^{-3.22}\ \mathrm{m^4 s^{-1}}$, where n_t is the truncation wavenumber).

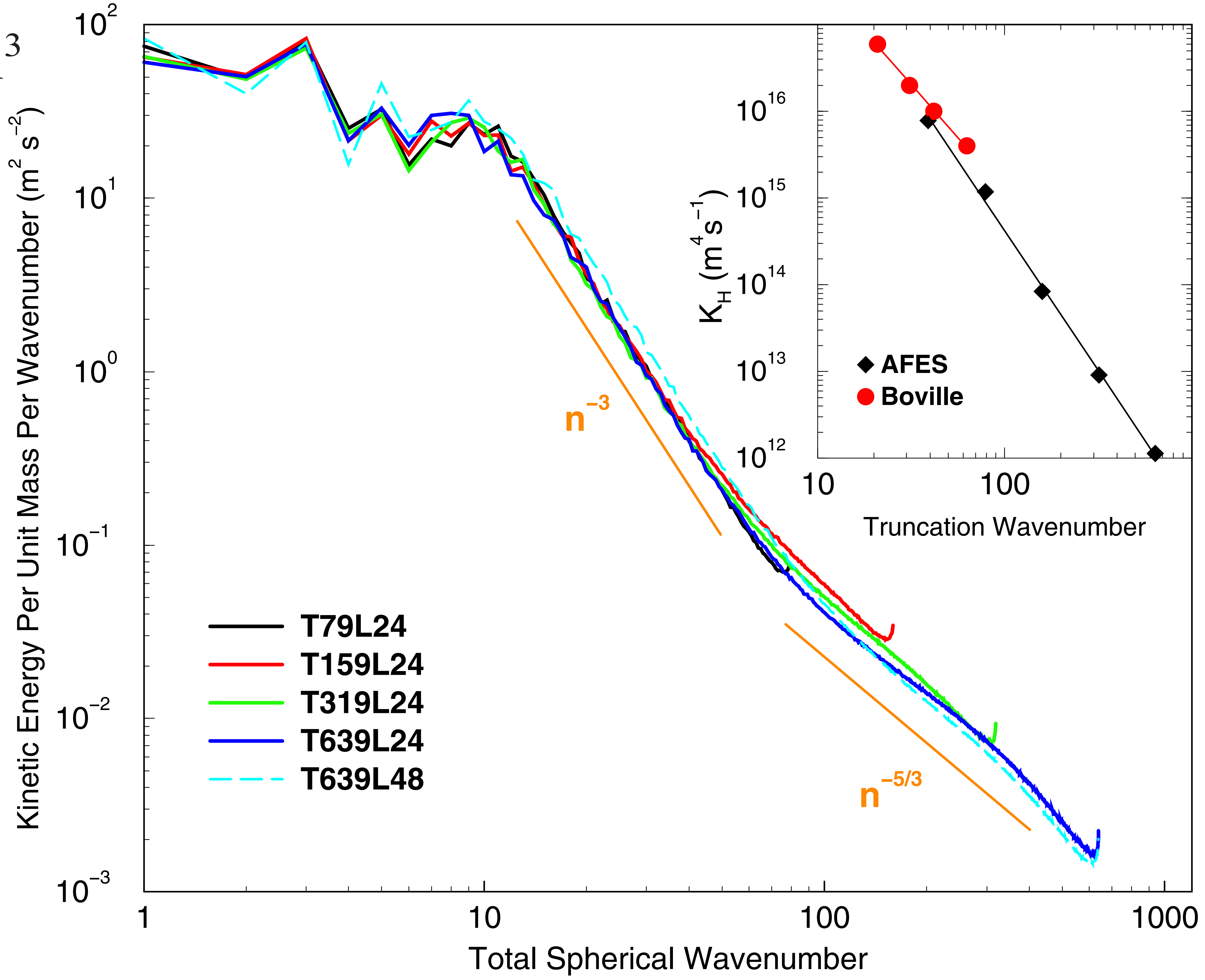


Figure 3. As in Figure 2 but for AFES run with different numerical resolution. Results are shown for the 24 level version truncated at T79, T159, T319 and T639, as well as the T639L48 version. At each horizontal resolution a diffusion coefficient has been determined by trial and error to produce the fairly convergent behavior at the high wavenumber end of the spectrum. The black symbols in the inset show the diffusion coefficient as a function of truncation obtained this way. The red dots show results from a similar analysis of a version of the NCAR atmospheric model obtained by *Boville* [1991]. The lines in the inset are linear regressions.

実験とHS94の図との比較など

実験の強制・設定など

Held and Suarez (1994)

力学コアのみ

乾燥大気，地形なし

地球的パラメータ

DCPAM5-20180304-2

水平粘性

- 8次
- 最高波数のe-folding time: 0.1 [day]

$$\frac{\partial \mathbf{v}}{\partial t} = \cdots - k_v(\sigma)\mathbf{v}$$

$$\frac{\partial T}{\partial t} = \cdots - k_T(\phi, \sigma)\left[T - T_{eq}(\phi, p)\right]$$

$$T_{eq} = \max\left\{200\mathrm{K}, \left[315\mathrm{K} - (\Delta T)_y \sin^2\phi - (\Delta\theta)_z \log\left(\frac{p}{p_0}\right)\cos^2\phi\right]\left(\frac{p}{p_0}\right)^{\kappa}\right\}$$

$$k_T = k_a + (k_s - k_a)\max\left(0, \frac{\sigma - \sigma_b}{1 - \sigma_b}\right)\cos^4\phi$$

$$k_v = k_f \max\left(0, \frac{\sigma - \sigma_b}{1 - \sigma_b}\right)$$

$\sigma_b = 0.7$ $\quad$ $k_f = 1\ \mathrm{day}^{-1}$,

$k_a = {}^{1}/_{40}\ \mathrm{day}^{-1}$ $\quad$ $k_s = {}^{1}/_{4}\ \mathrm{day}^{-1}$

$(\Delta T)_y = 60\mathrm{K}$ $\quad$ $(\Delta\theta)_z = 10\mathrm{K}$

$p_0 = 1000\ \mathrm{mb}$ $\quad$ $\kappa = \frac{R}{c_p} = \frac{2}{7}$ $\quad$ $c_p = 1004\ \mathrm{J\ kg^{-1}\ K^{-1}}$

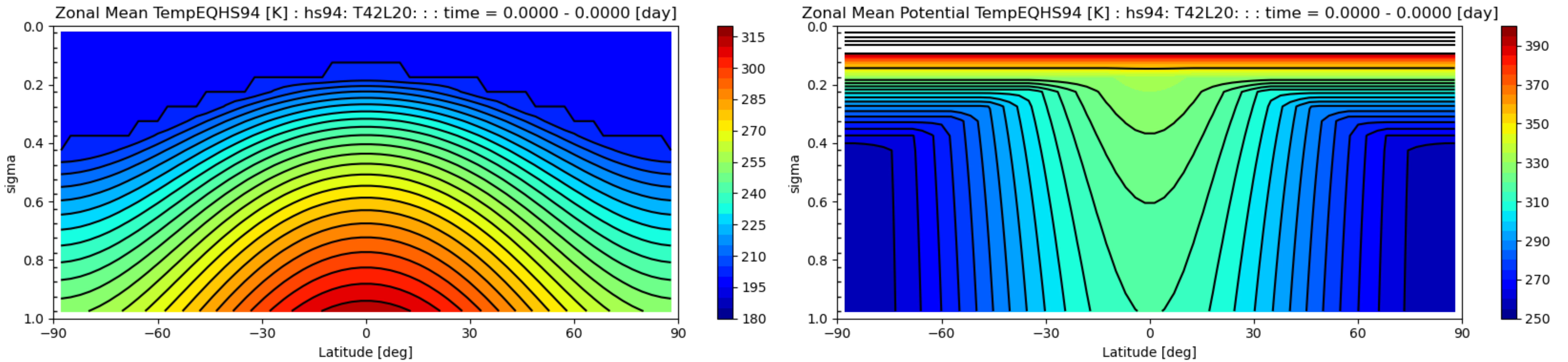
$\Omega = 7.292 \times 10^{-5}\ \mathrm{s}^{-1}$ $\quad$ $g = 9.8\ \mathrm{m\ s^{-2}}$ $\quad$ $a_e = 6.371 \times 10^6\ \mathrm{m}$.

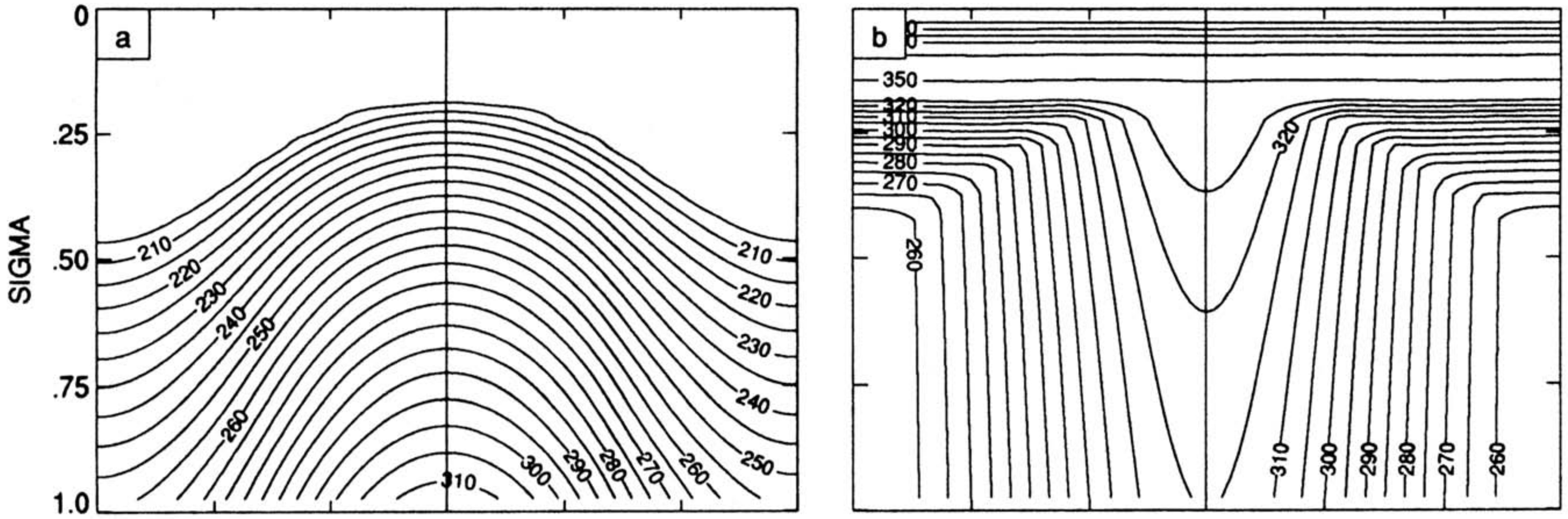
実験の設定

- 解像度（σ等間隔）[Δt (min.)]
  - L20
    - T10 [60]，T21 [60]，T42 [30]，T85 [15]，T170 [6]
  - T42
    - L5 [30]，L10 [30]，L20 [30]，L40 [30]，L80 [20]，L160 [5]，L320 [4]
- 初期条件：等温（250 K + ノイズ）静止
- 6時間ごと出力
- 各1200日積分，解析は最後の1000日

強制温度

Temperature and Potential Temperature: Figure 1 a b

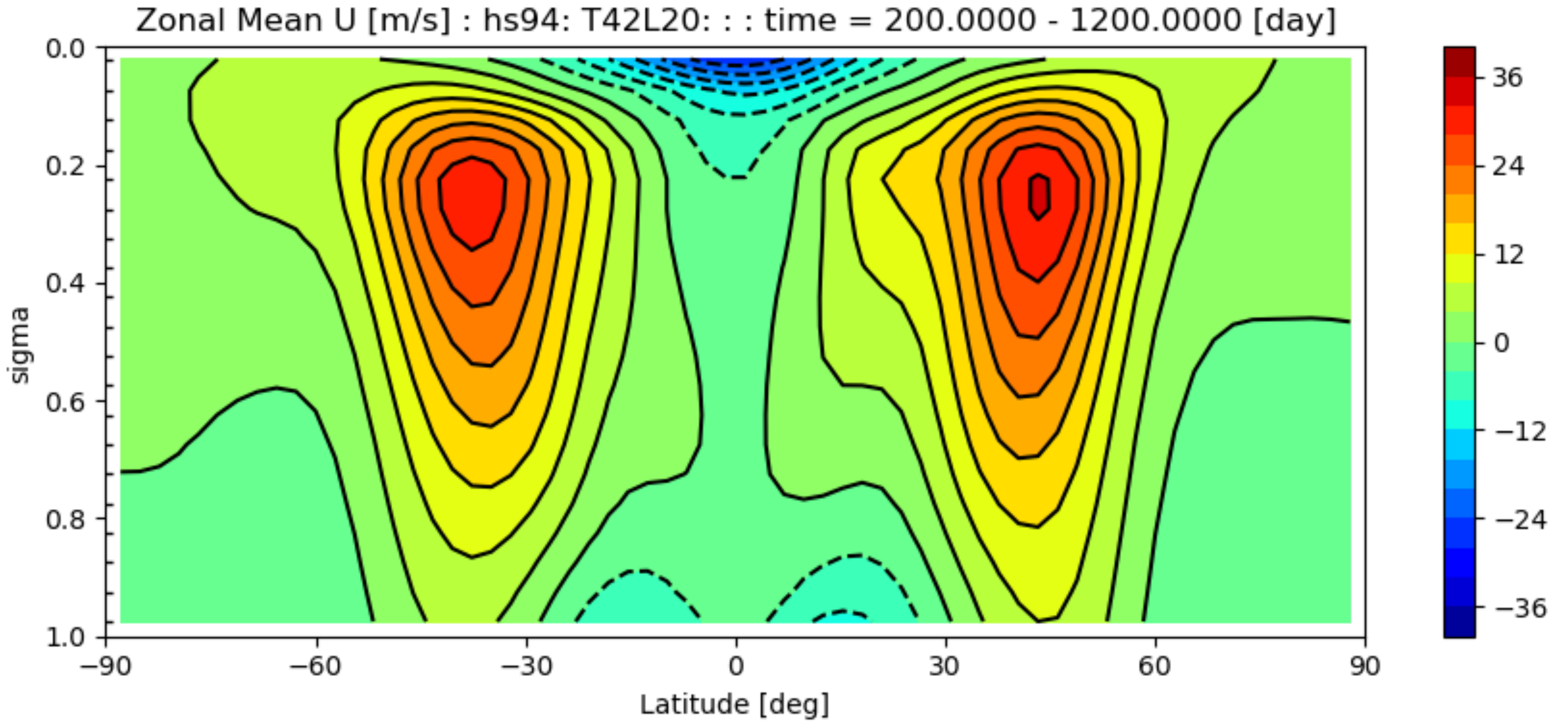




Held and Suarez (1994)

T42L20 vs HS94

U: Figure 2



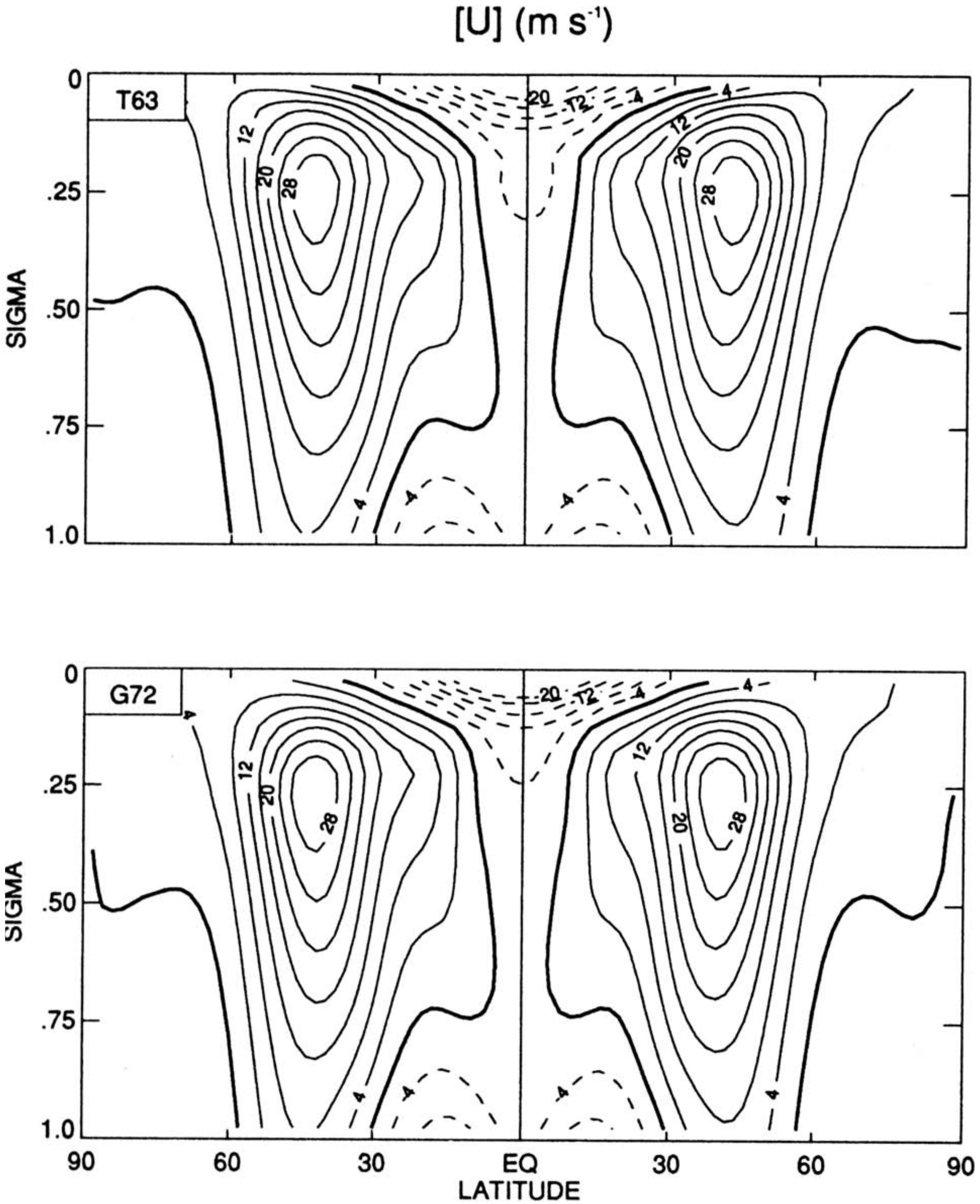
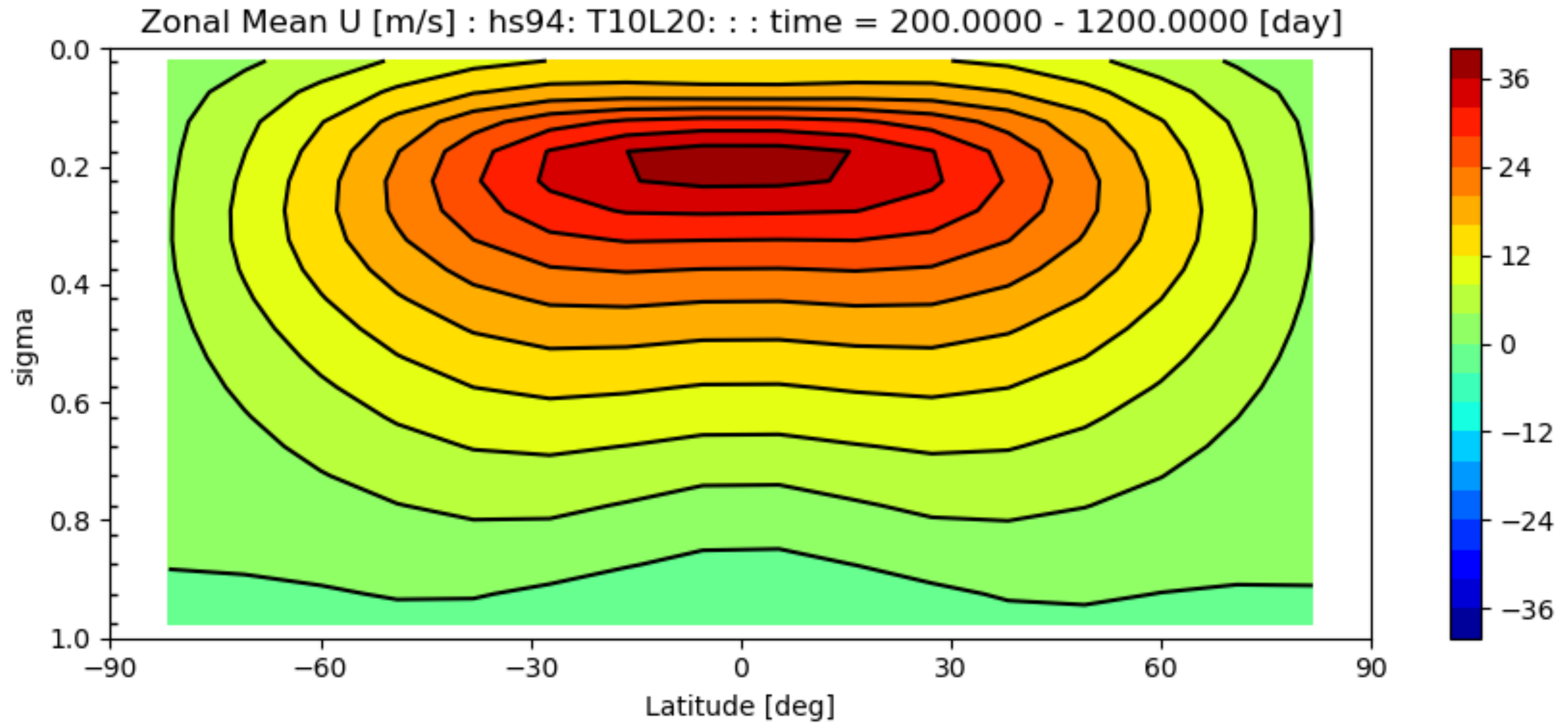


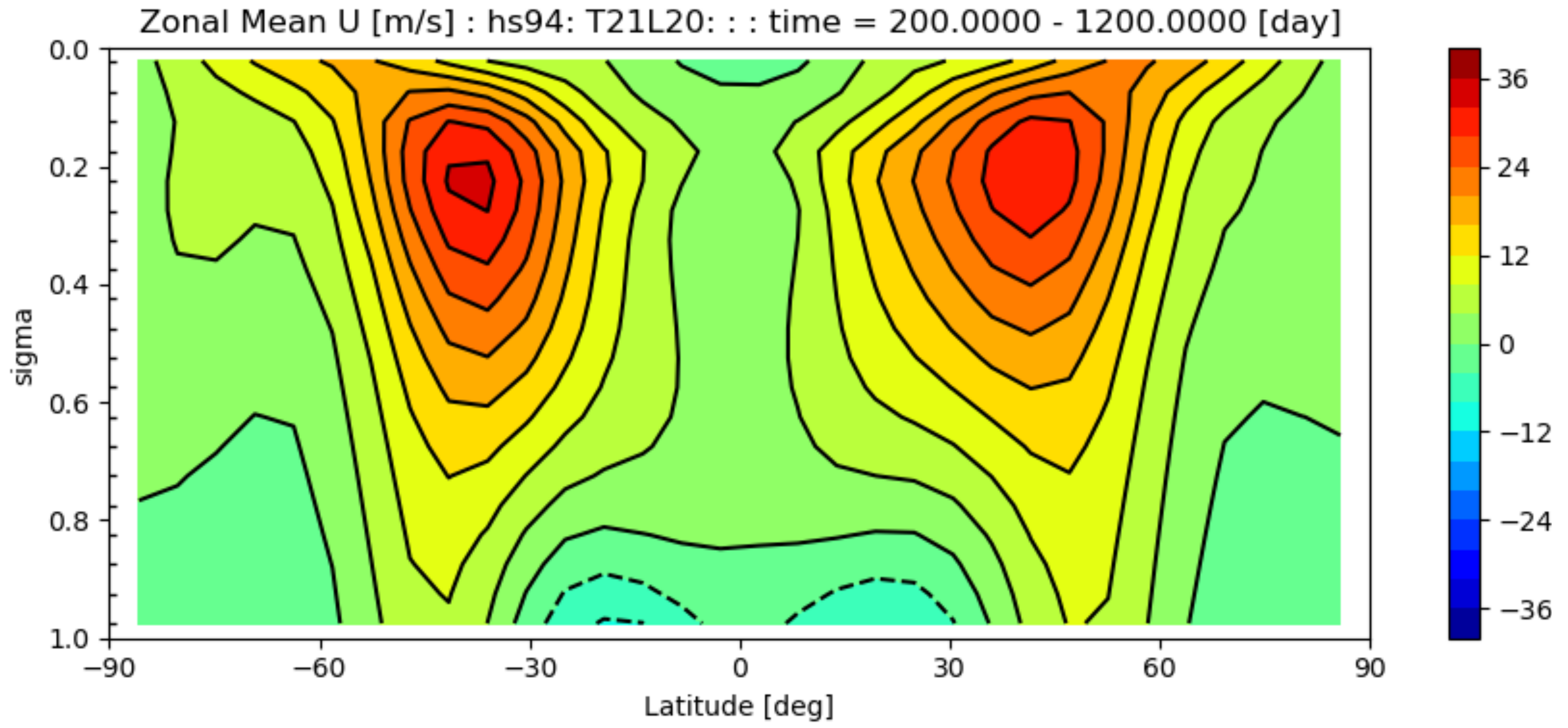
FIG. 2. The zonal-mean zonal wind produced by the T63 spectral model and G72 gridpoint model. Both are 1000-day means. Since the forcing is symmetric about the equator, differences between the hemispheres are indicative of sampling errors.

Held and Suarez (1994)

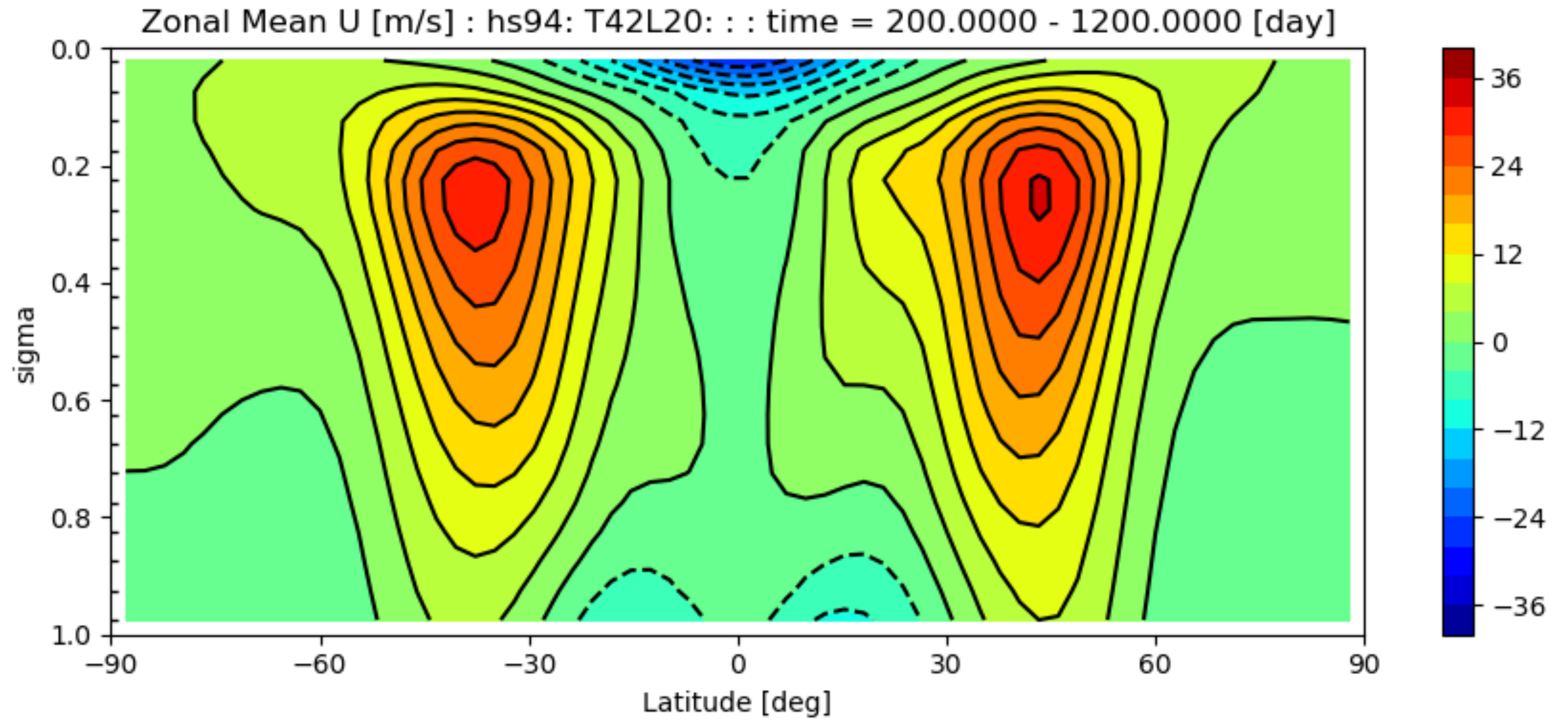
何も考えずに水平解像度を変える: U



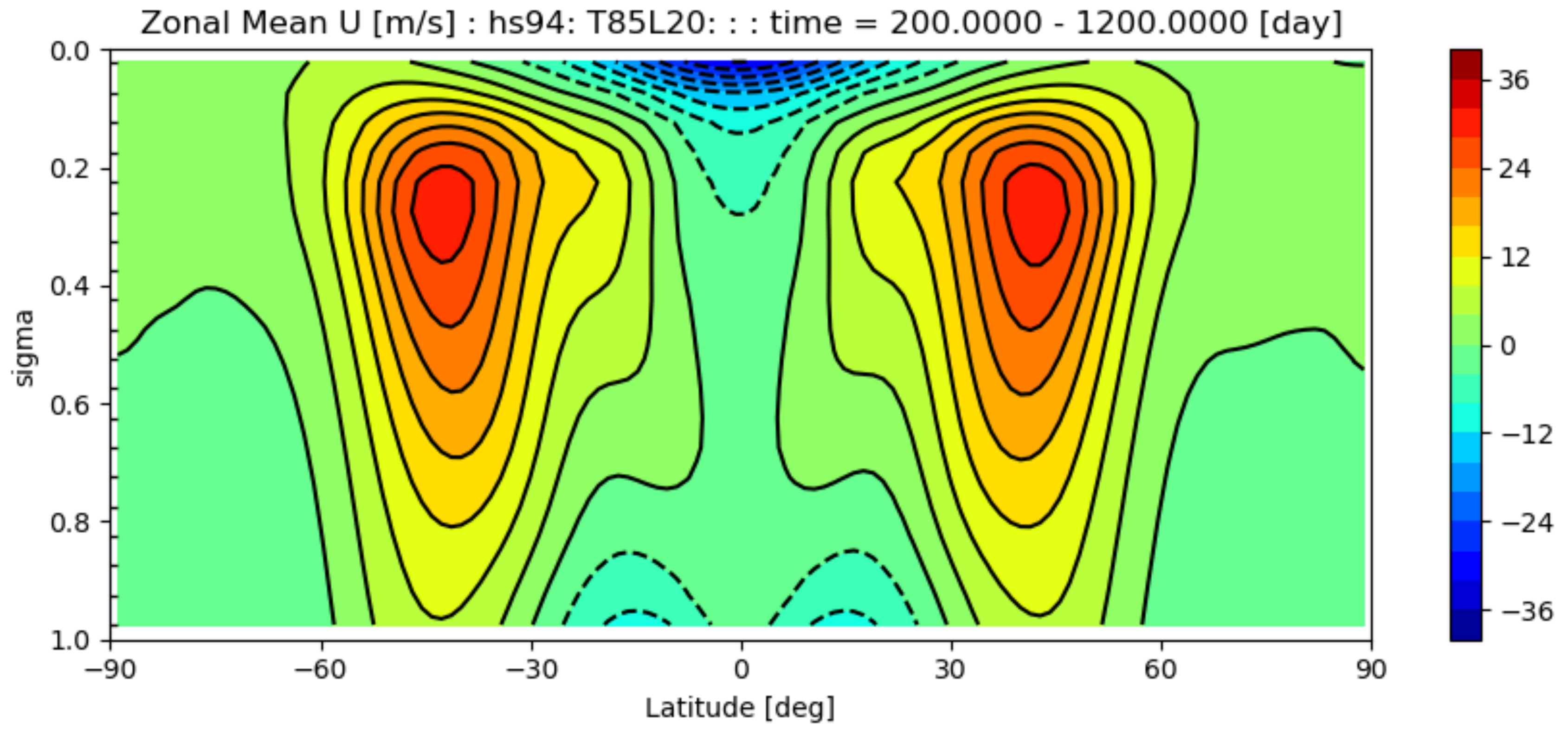
T10L20



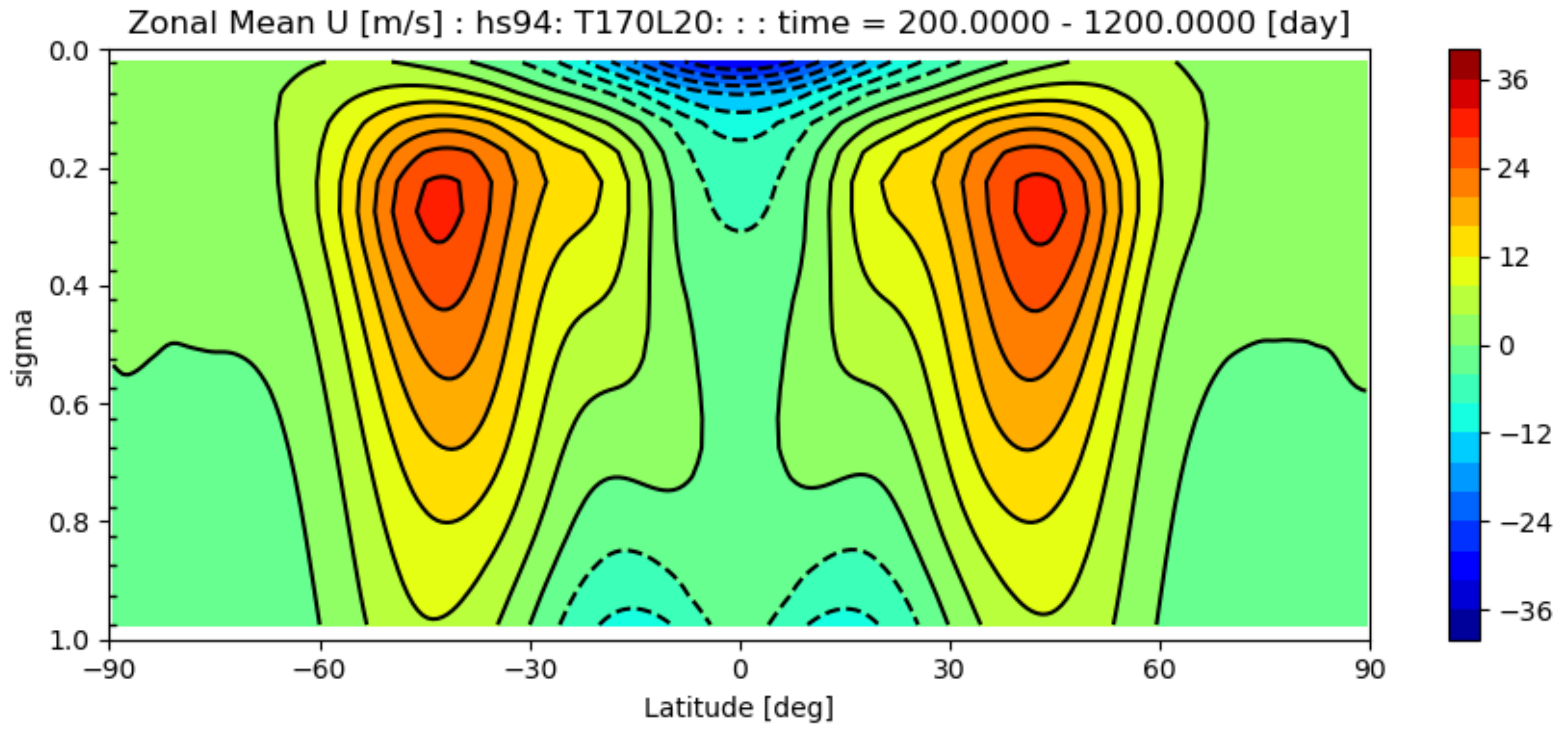
T21L20



T42L20

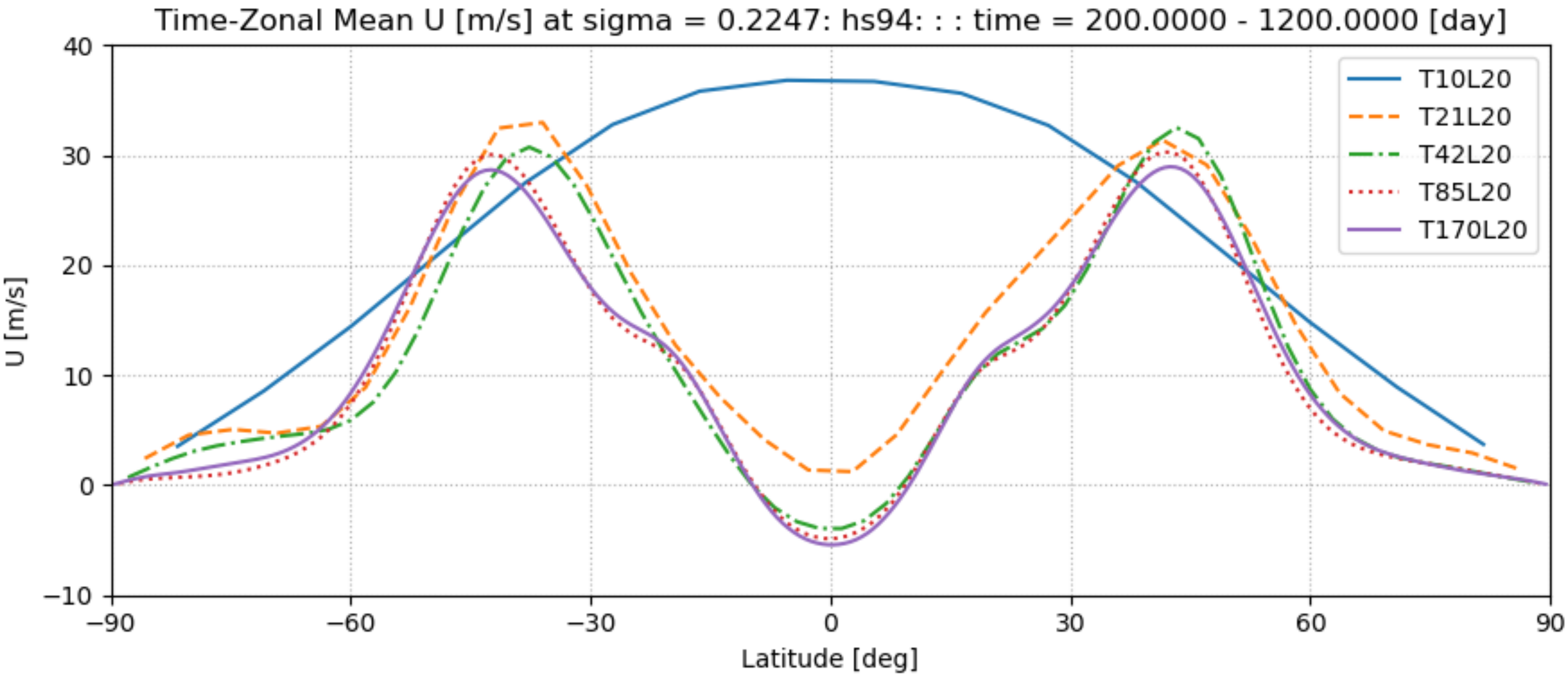


T85L20

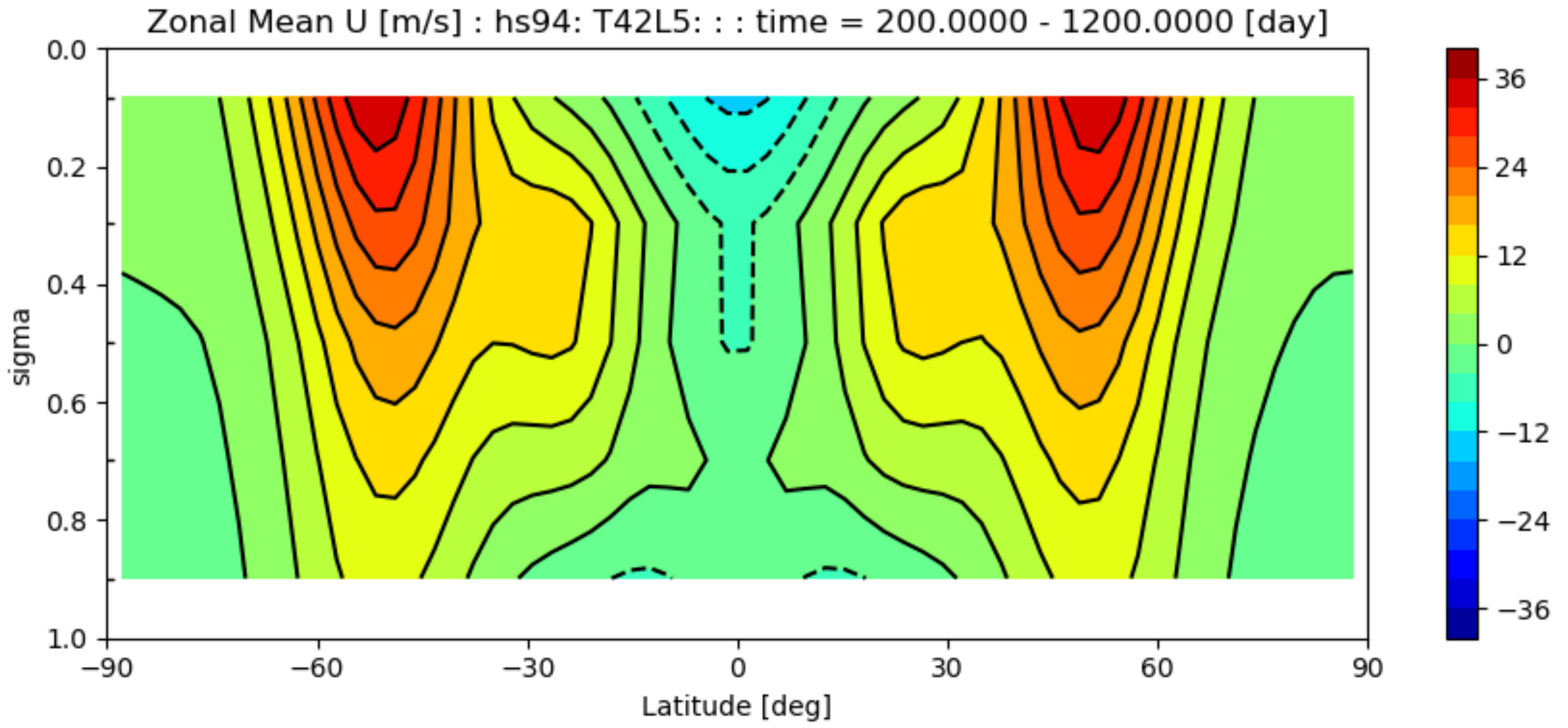


T170L20

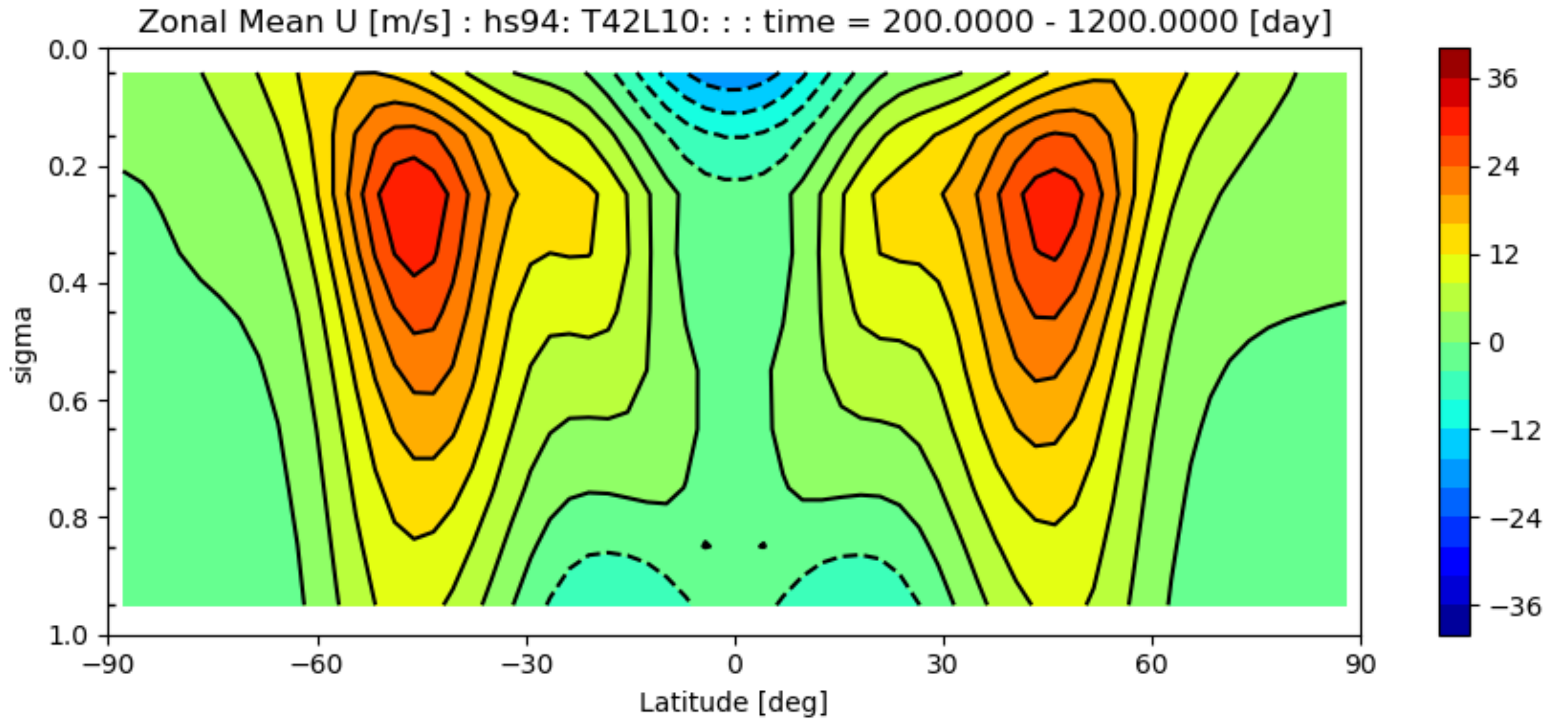
何も考えずに水平解像度を変える: U



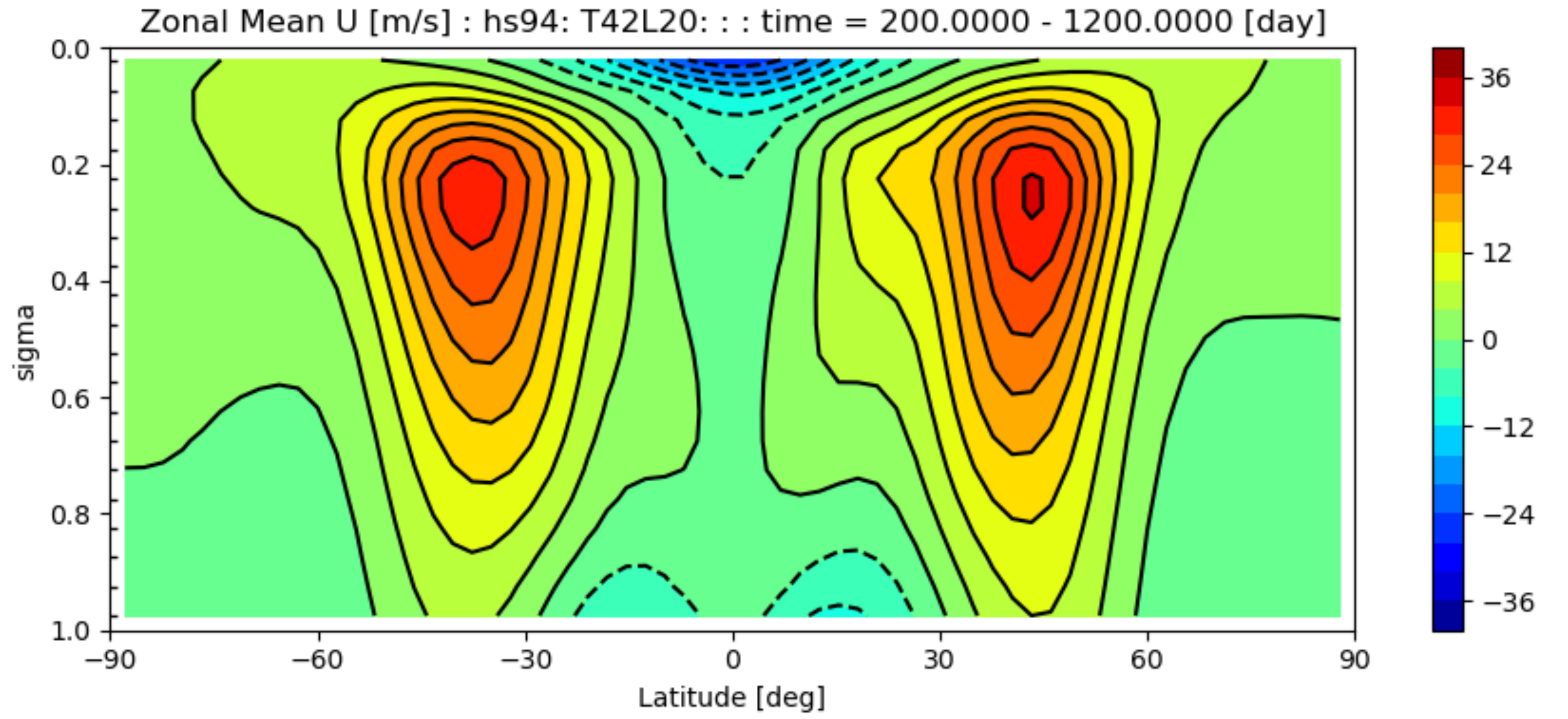
何も考えずに鉛直解像度を変える: U



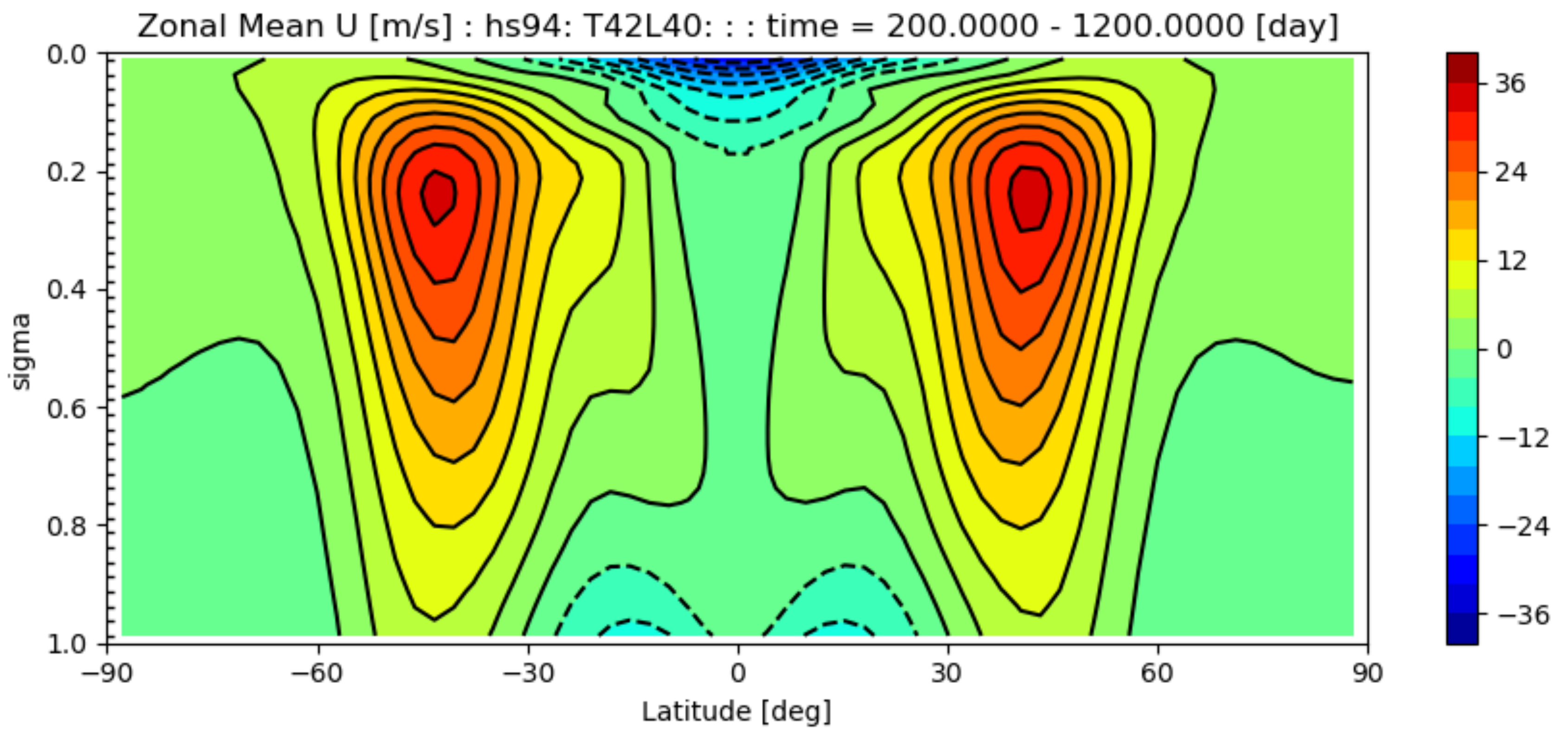
T42L5



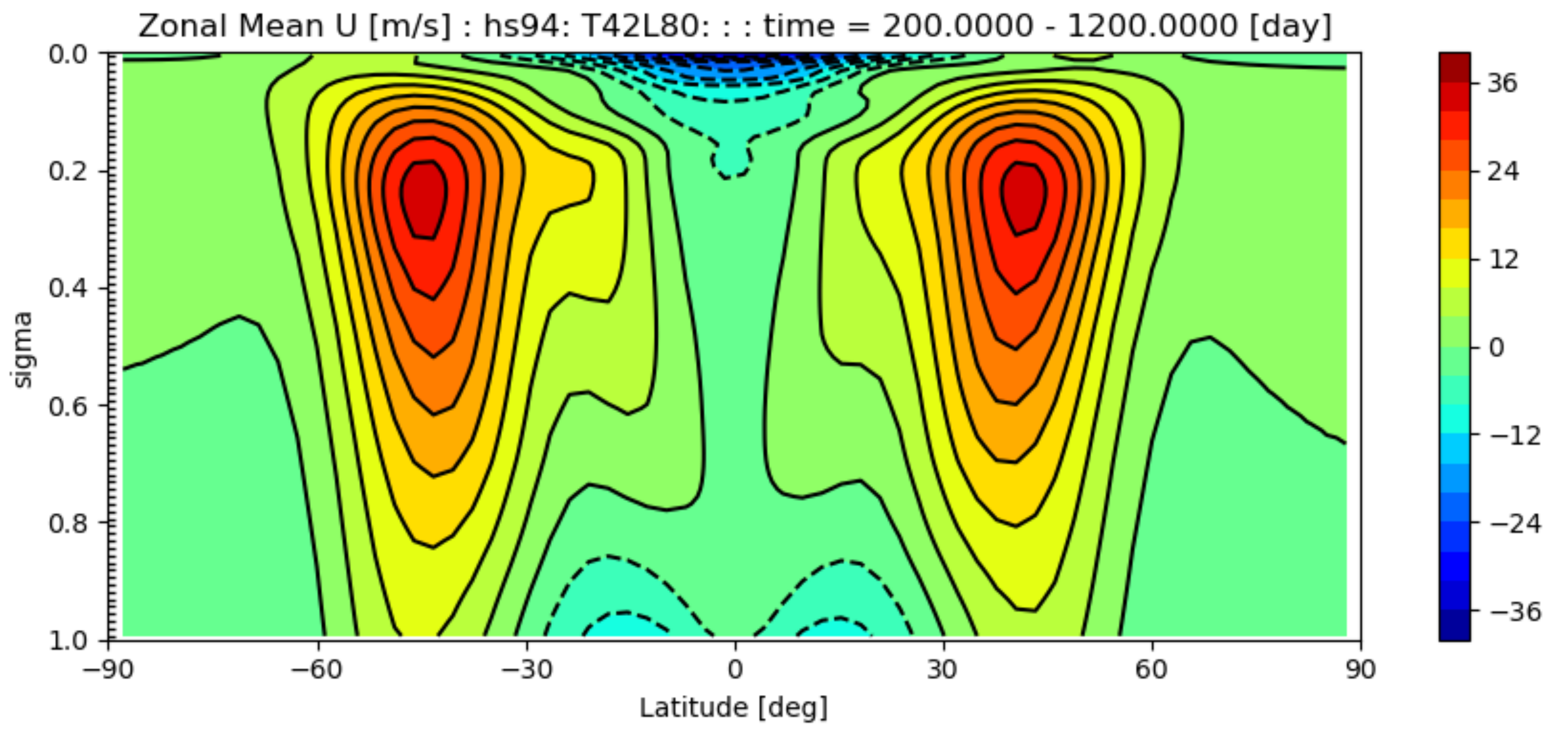
T42L10



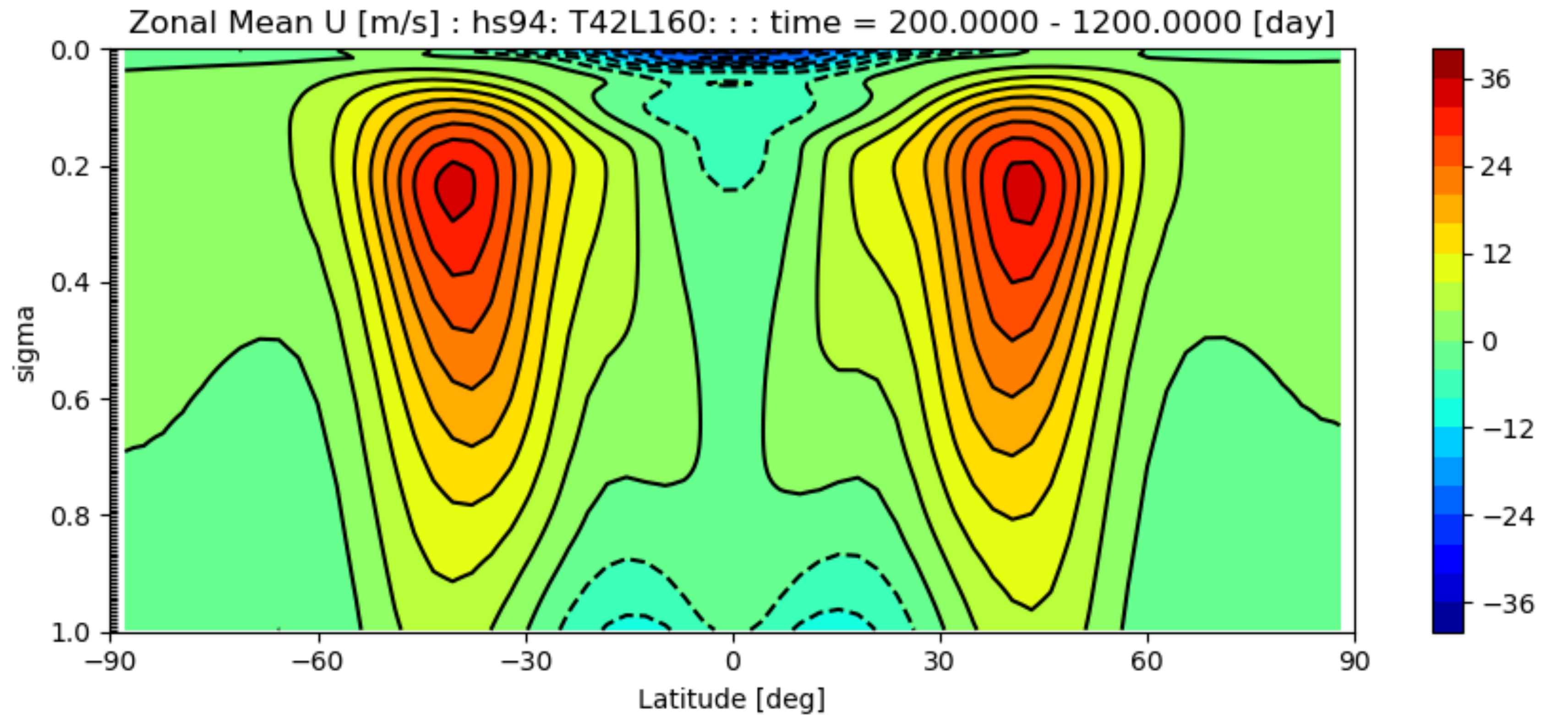
T42L20



T42L40



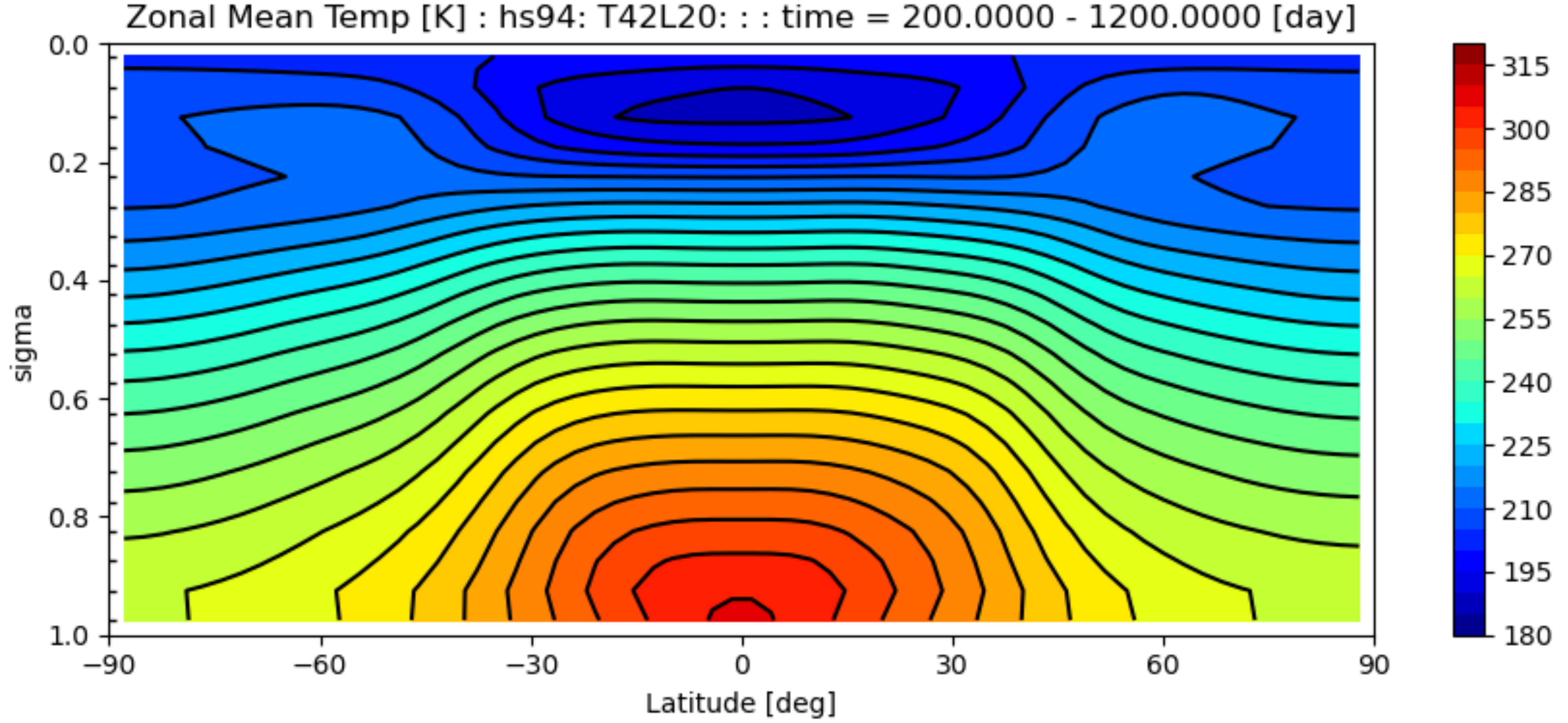
T42L80

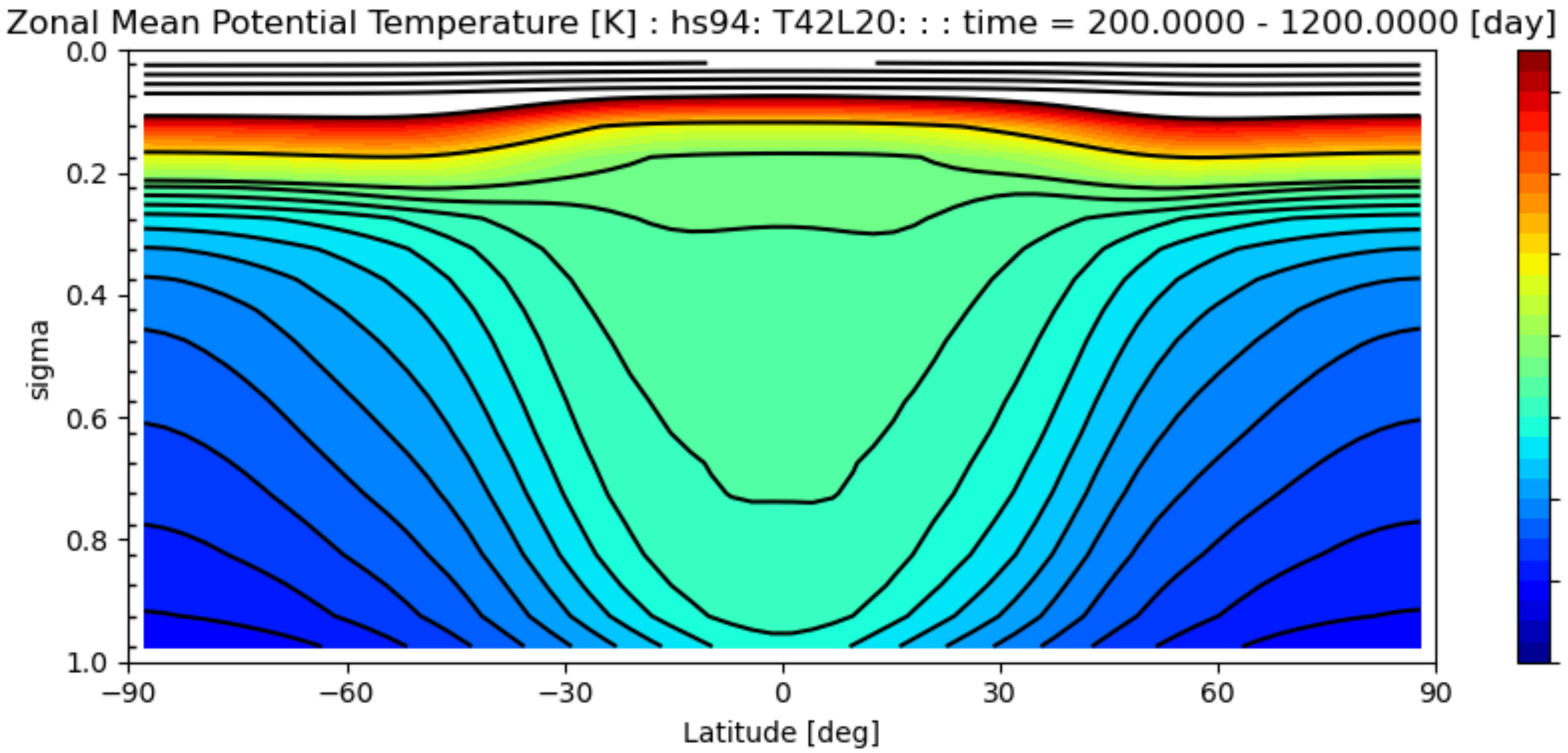


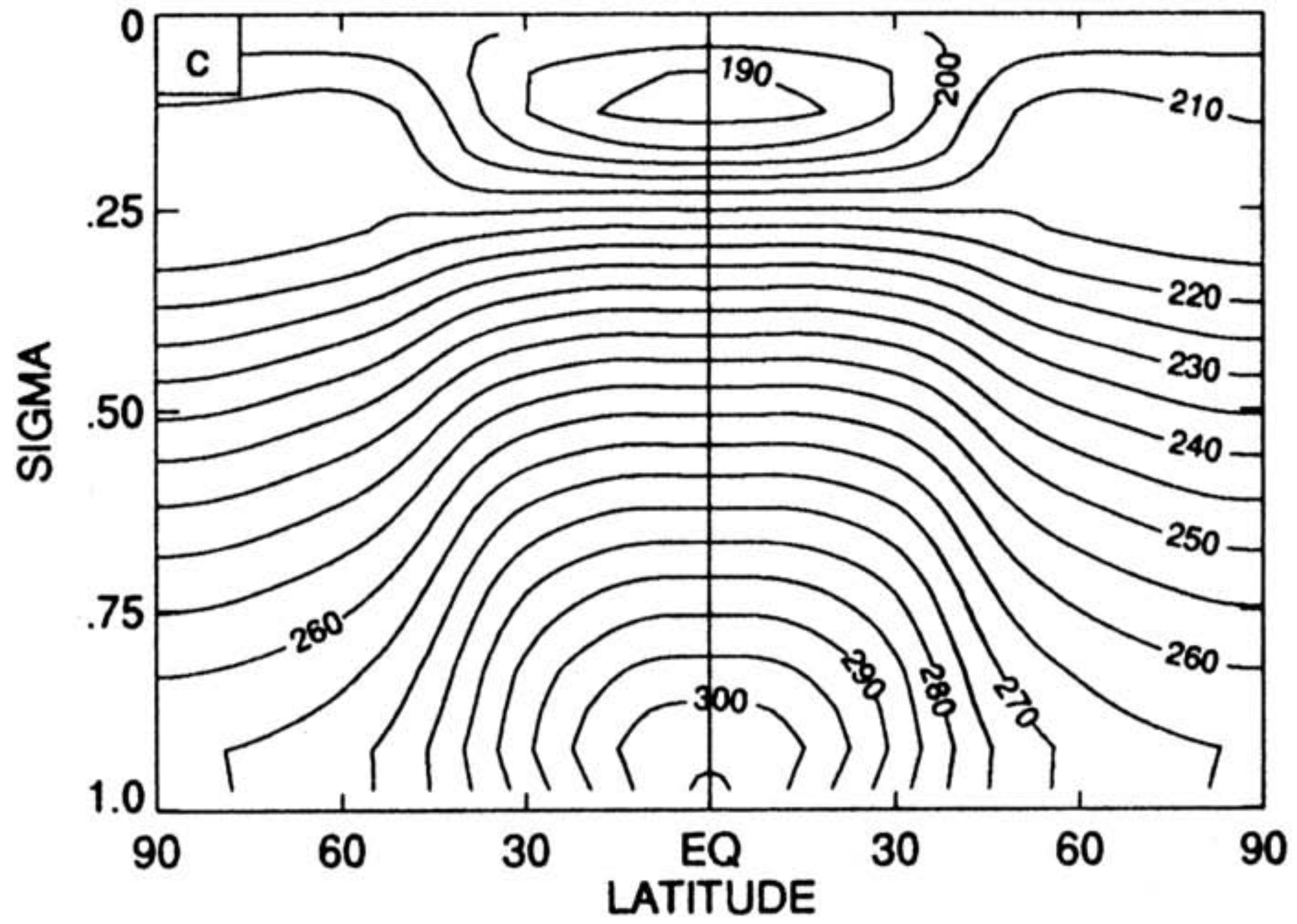
T42L160

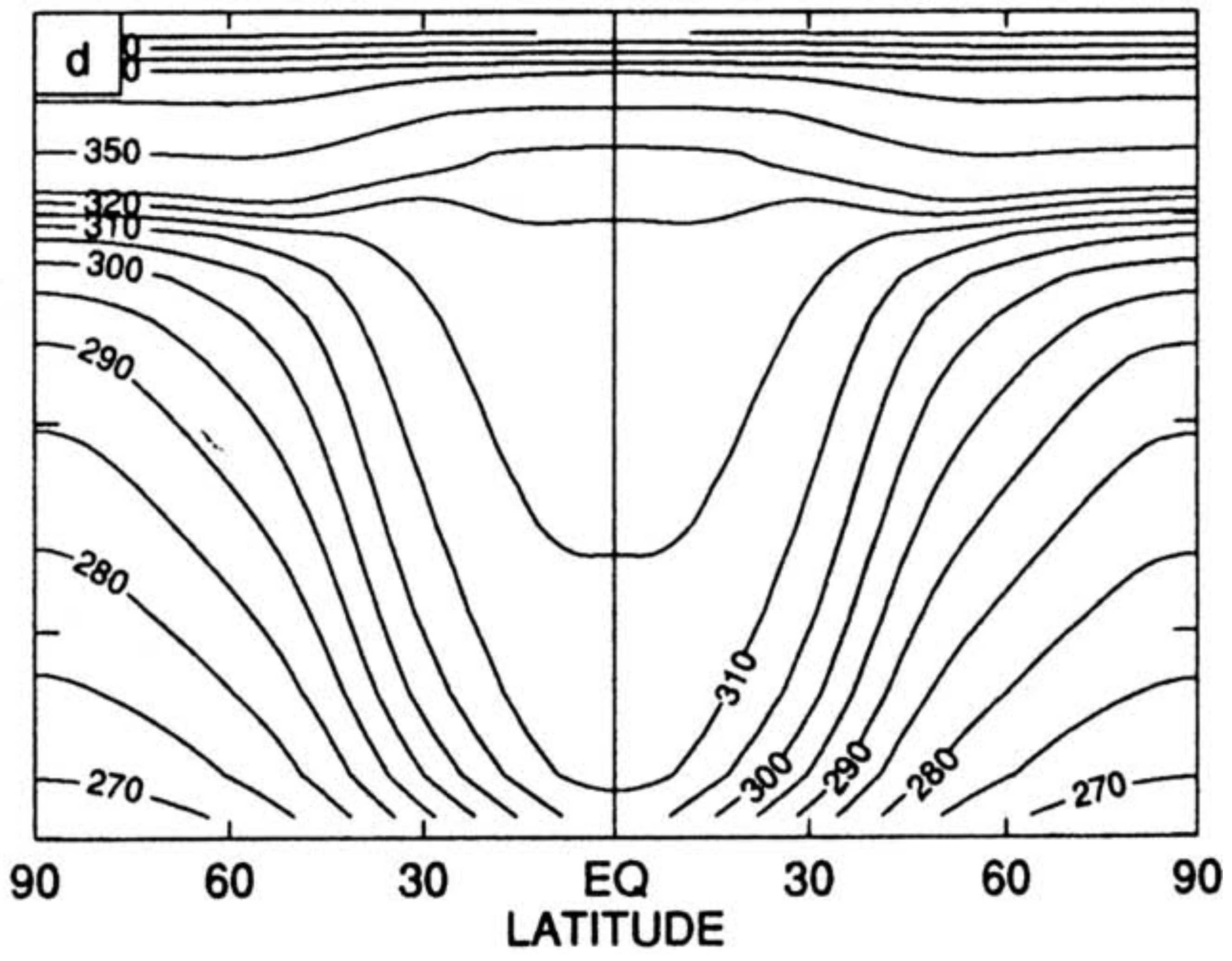
T42L20 vs HS94 (G72)

Temperature and Potential Temperature: Figure 1 c d



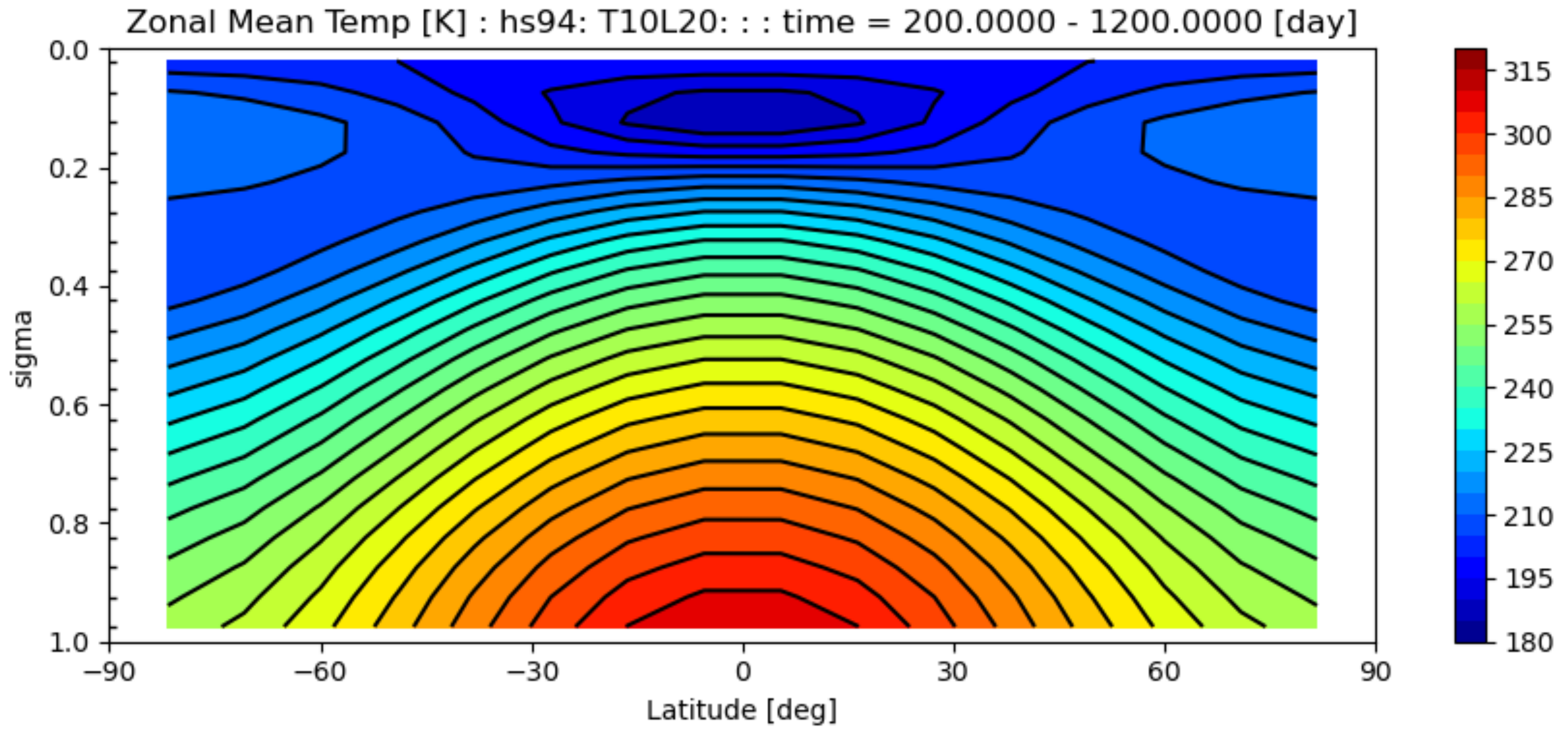




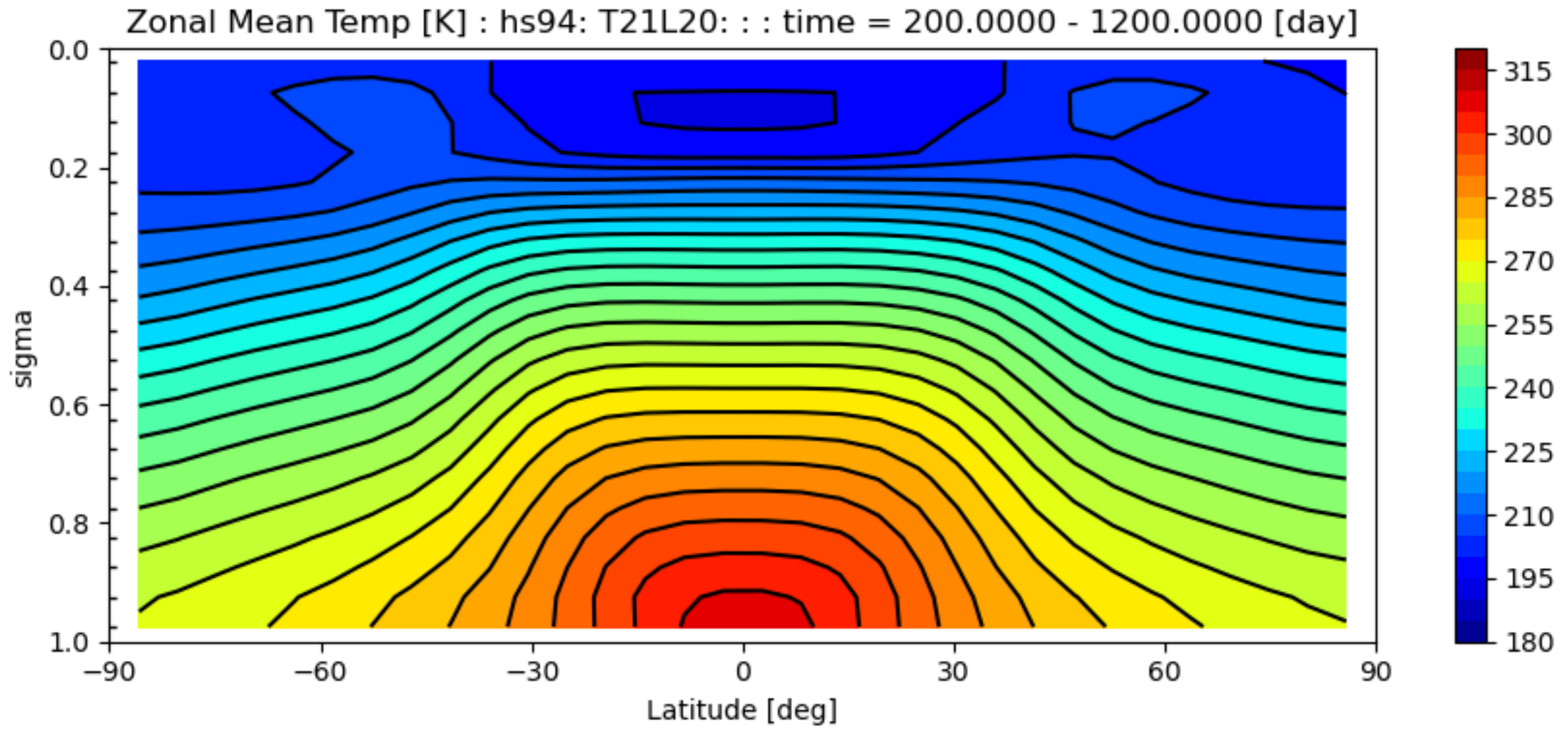


Held and Suarez (1994)

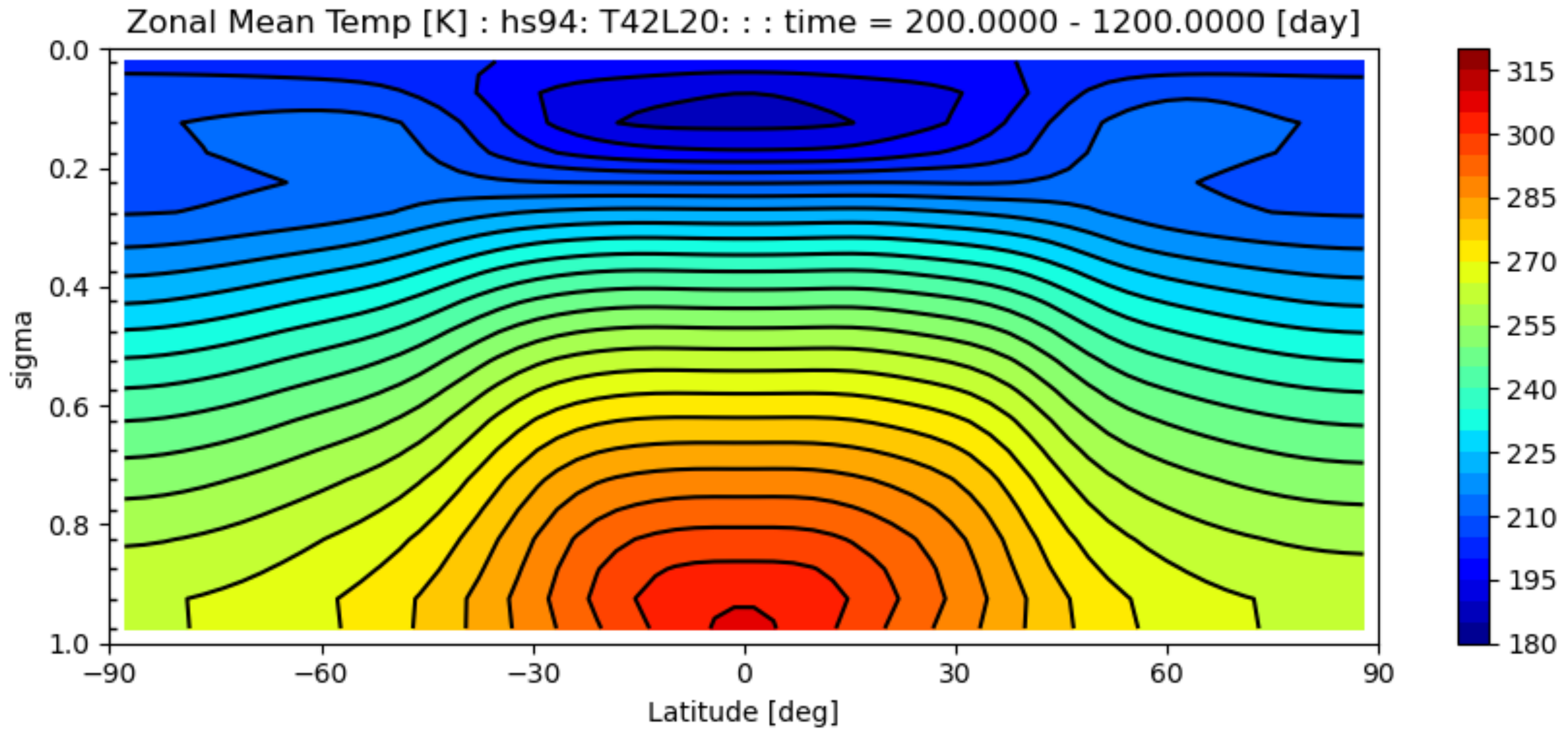
何も考えずに水平解像度を変える: T



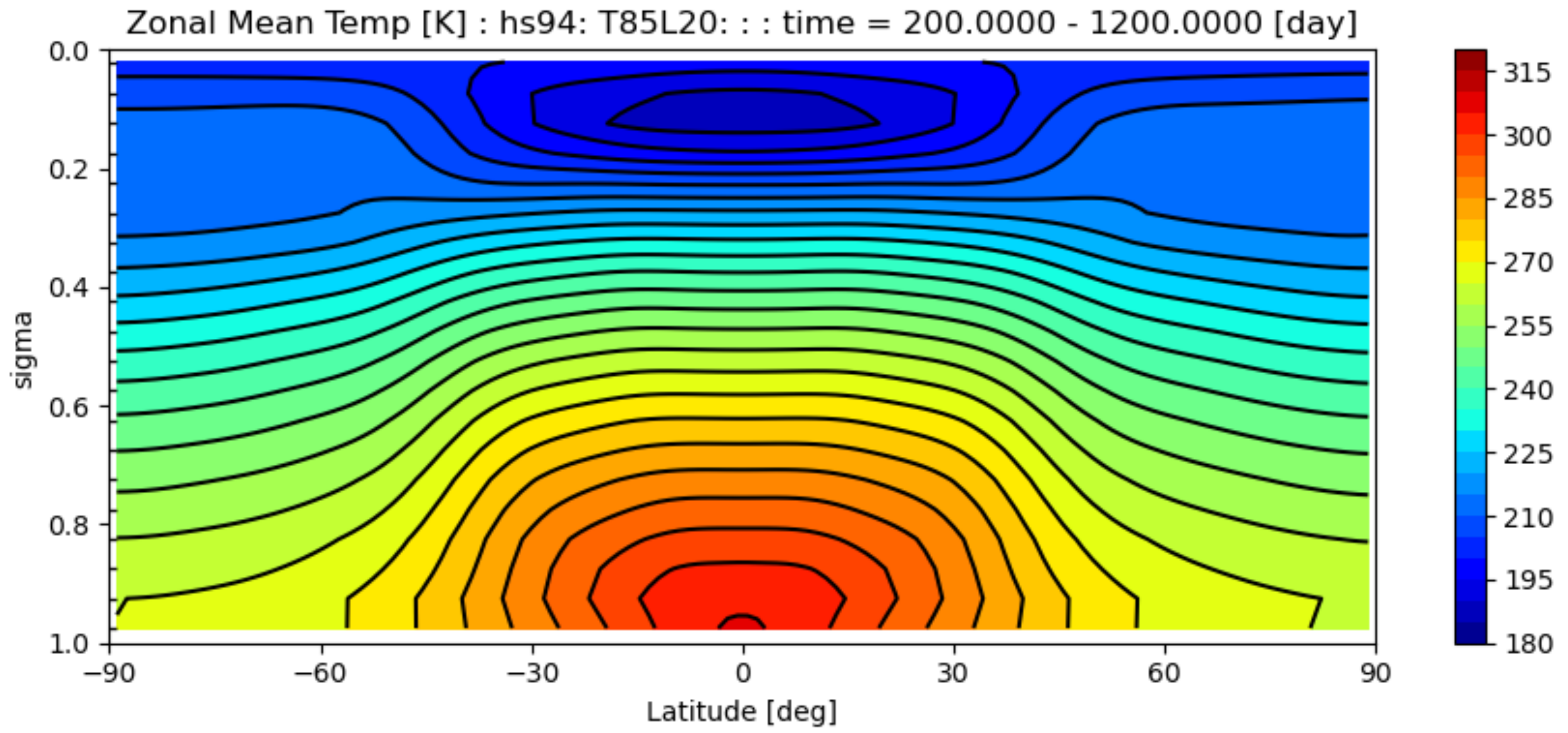
T10L20



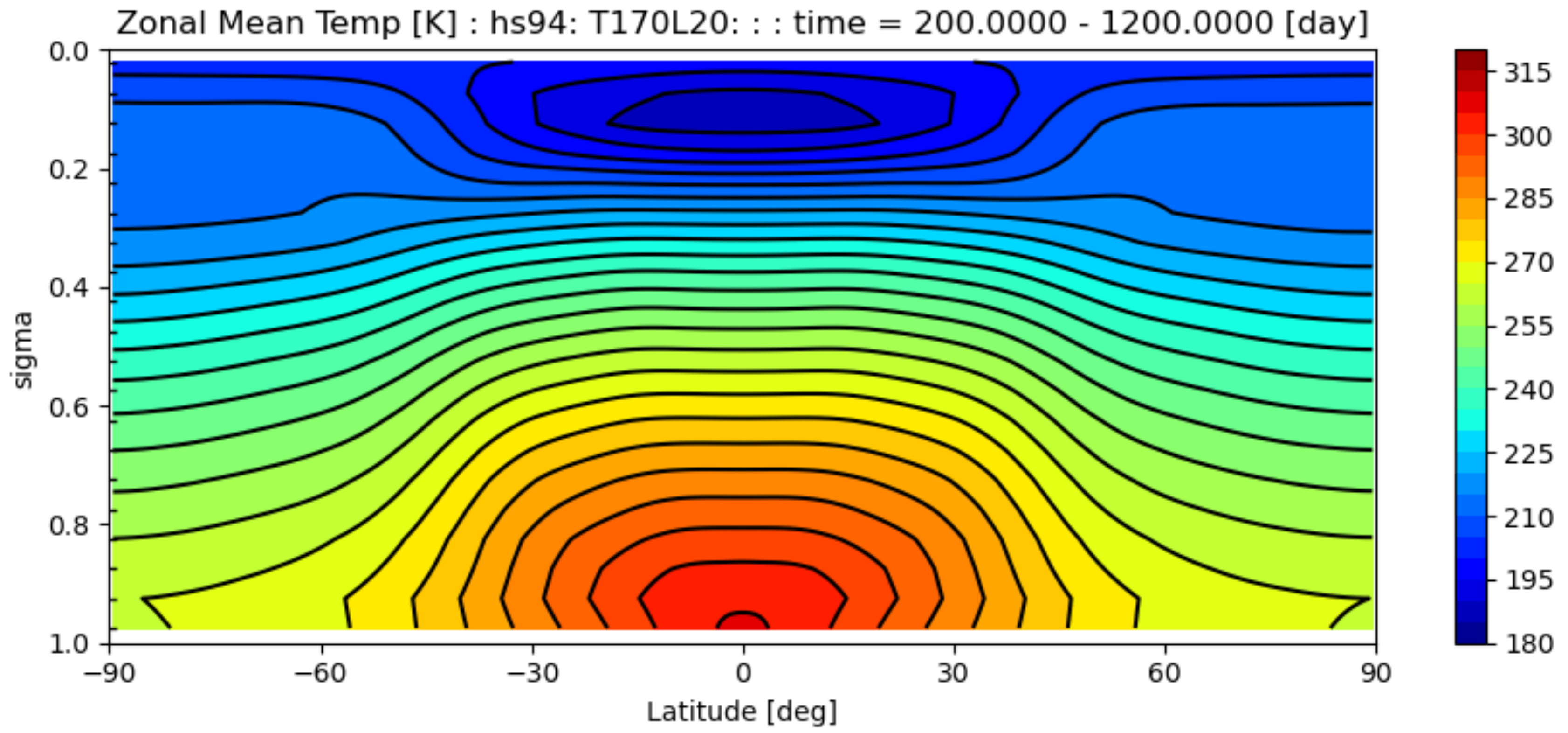
T21L20



T42L20

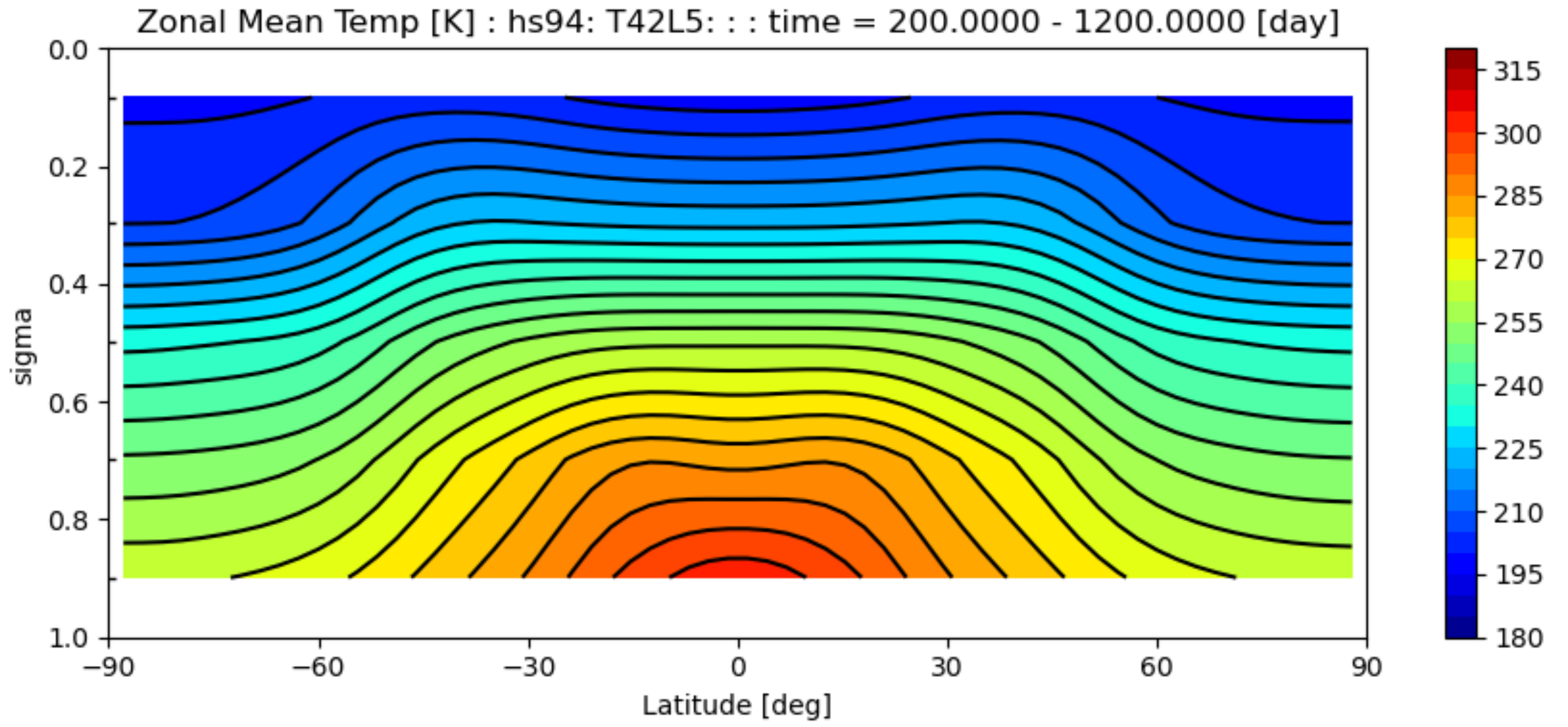


T85L20

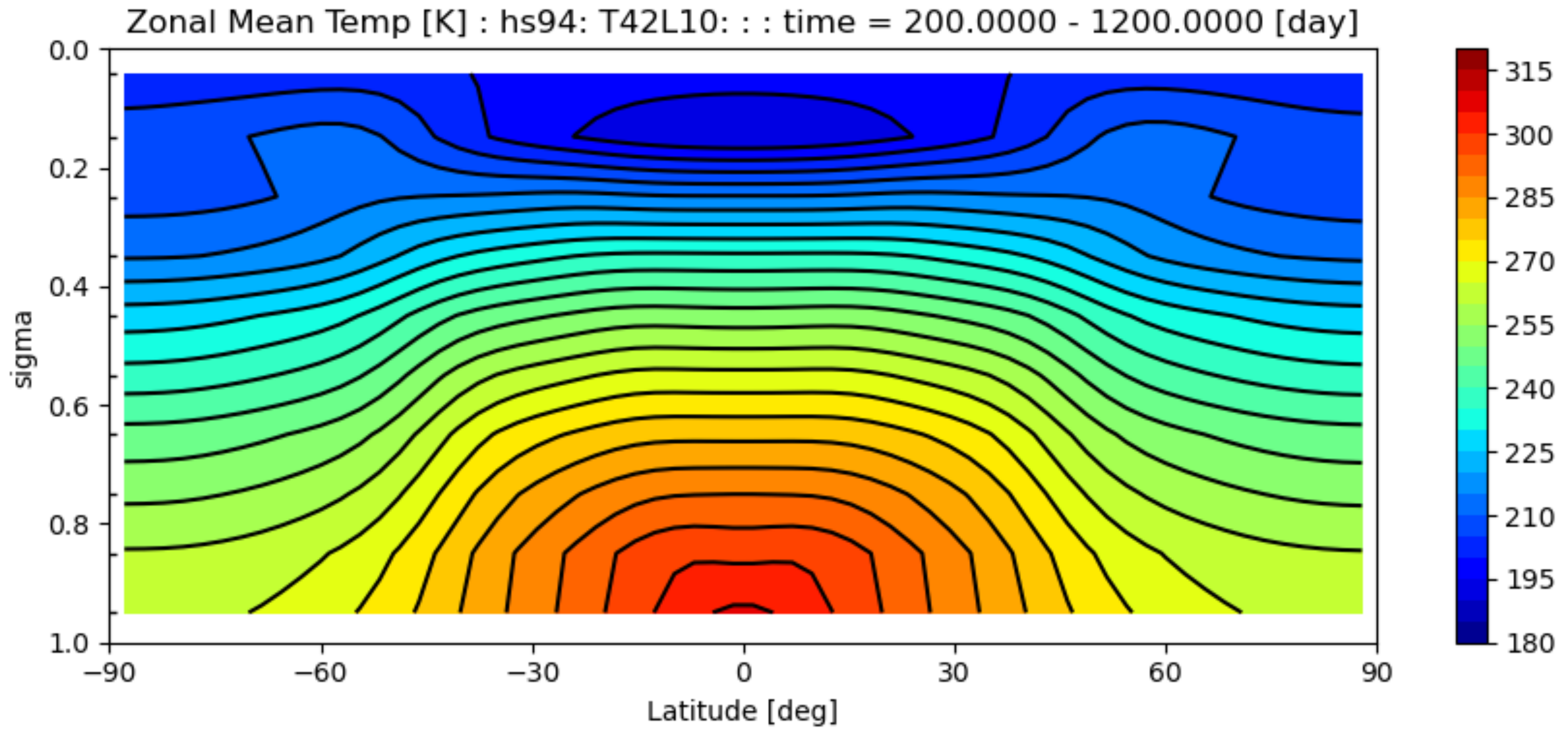


T170L20

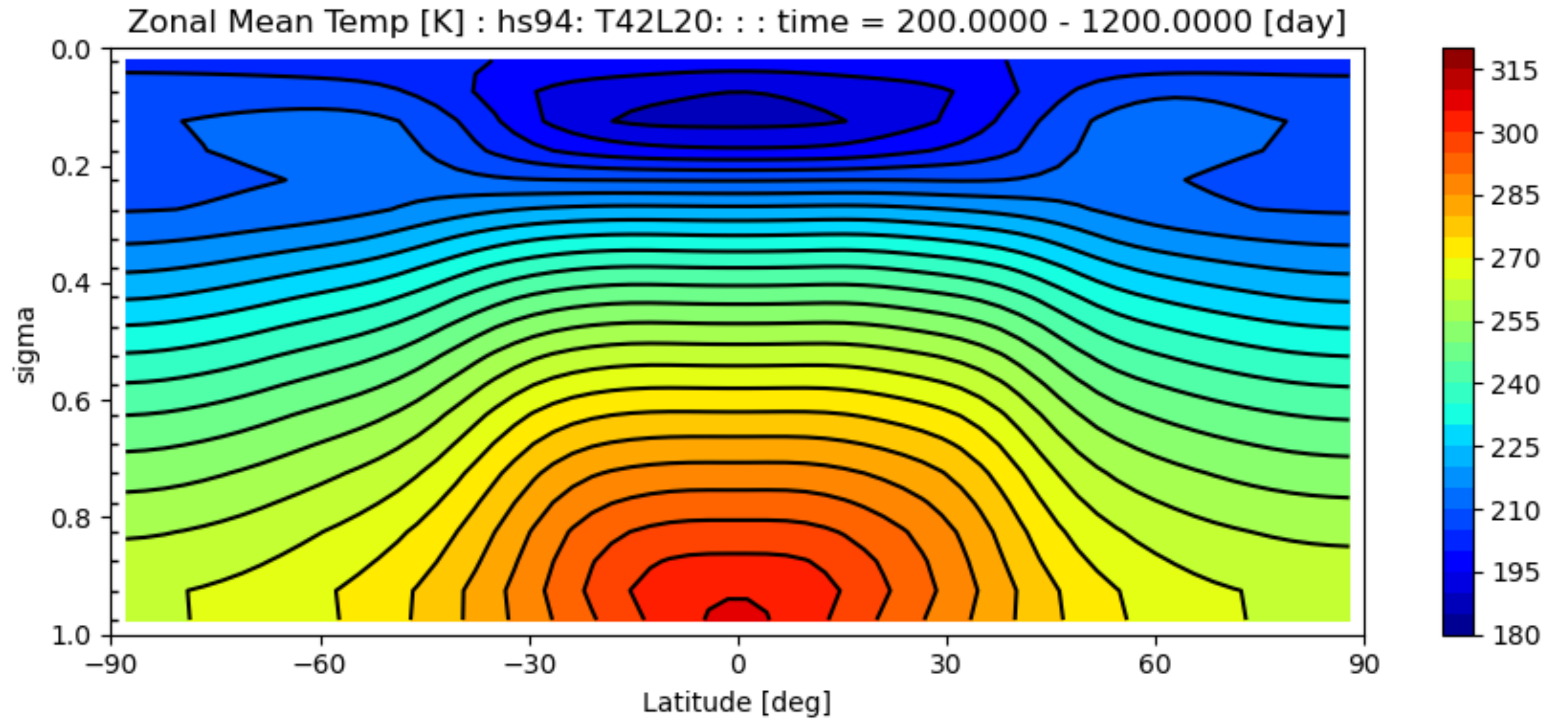
何も考えずに鉛直解像度を変える: T



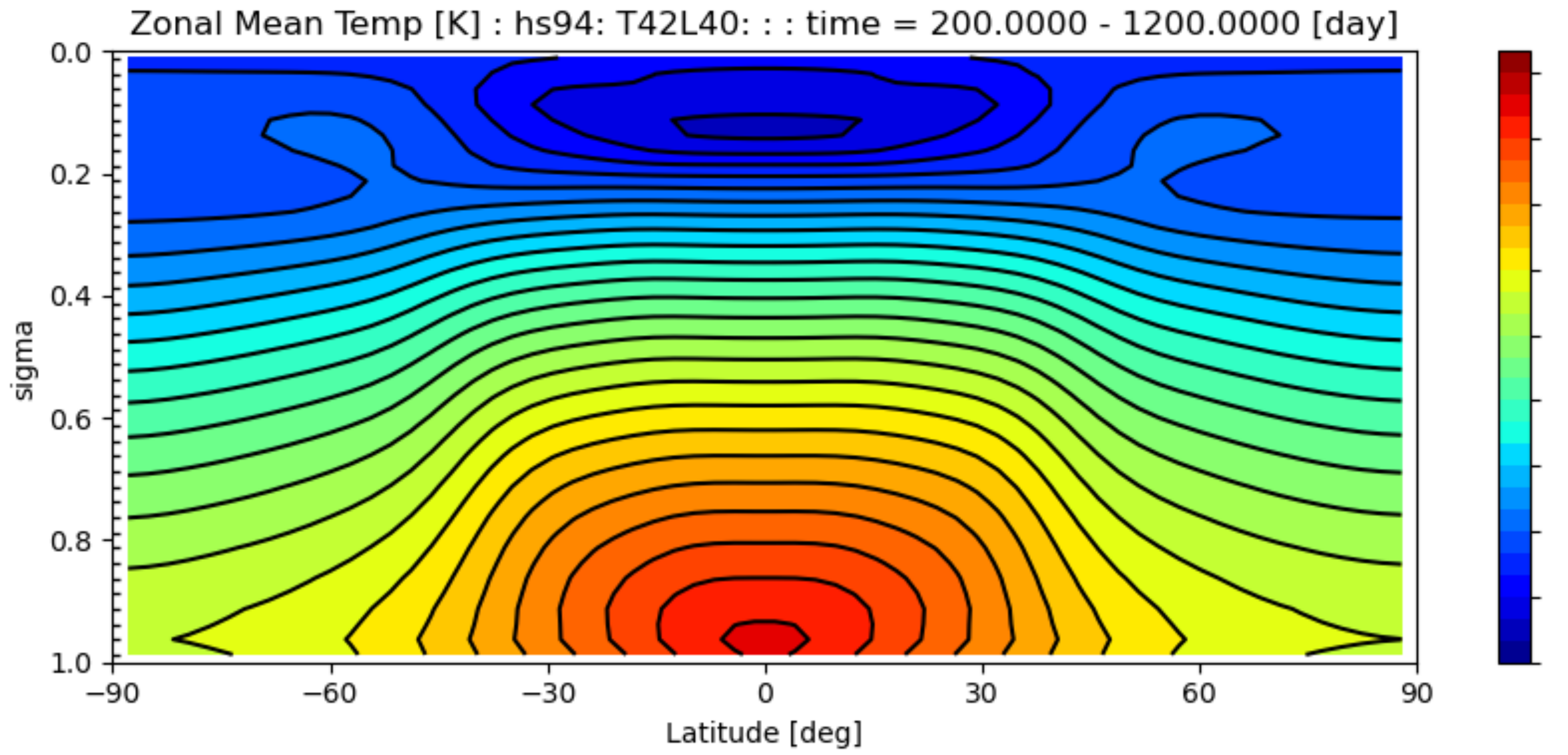
T42L5



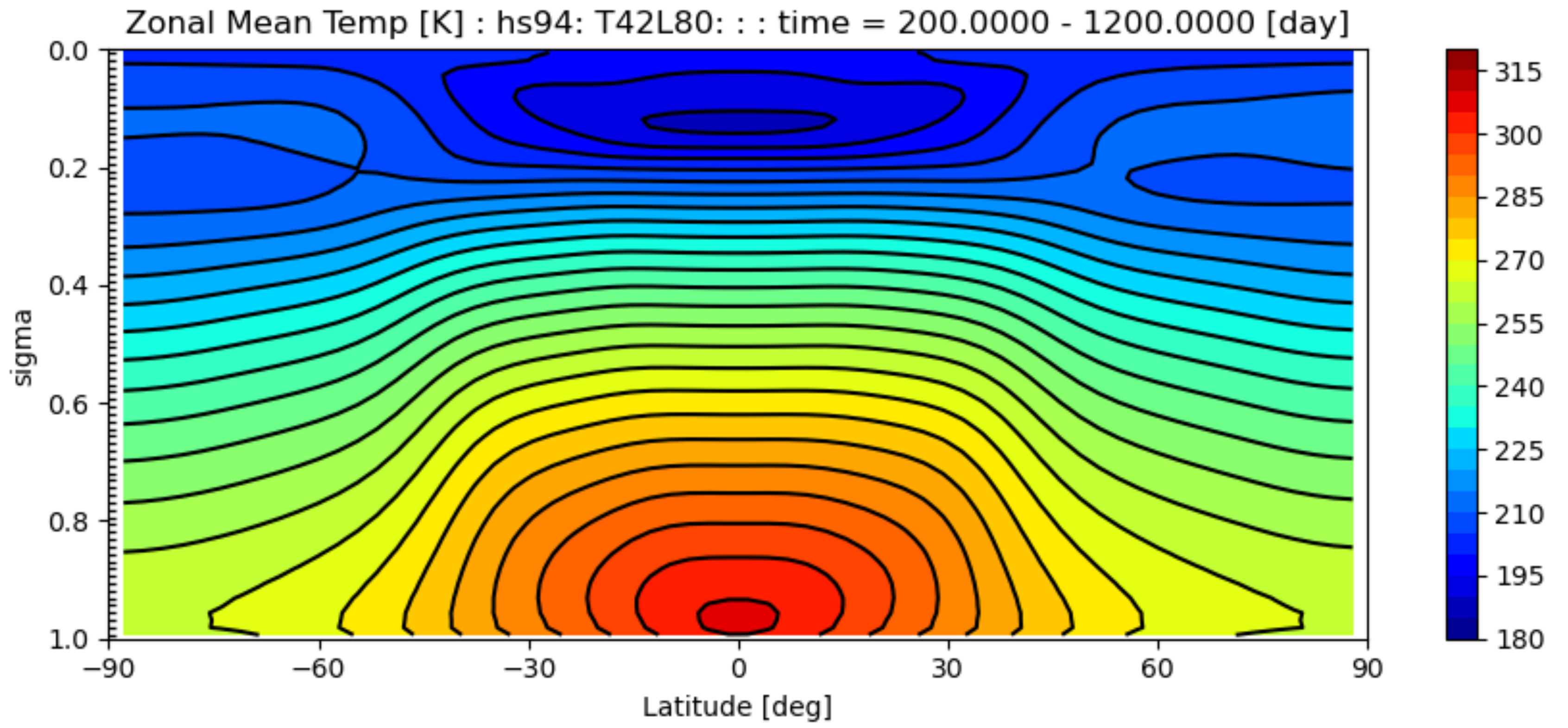
T42L10



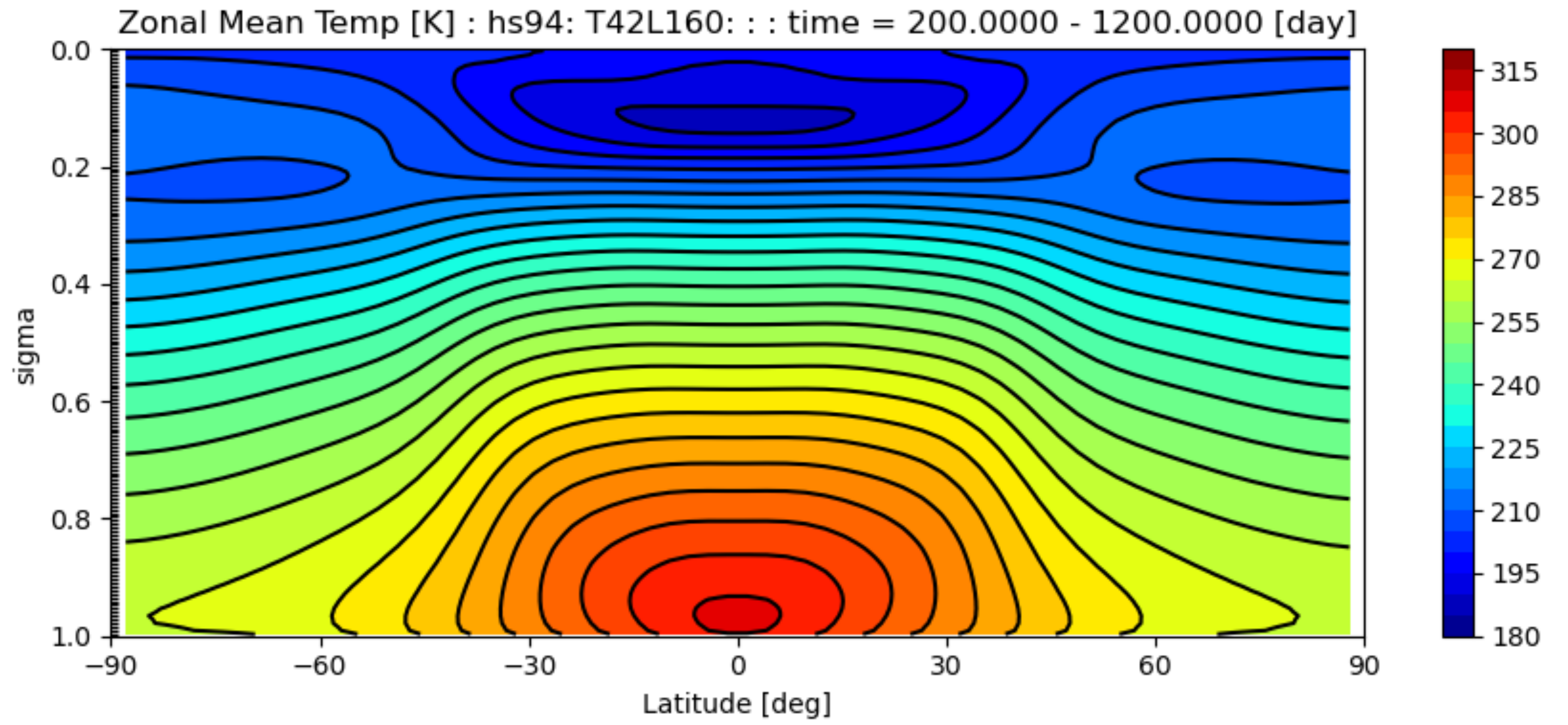
T42L20



T42L40



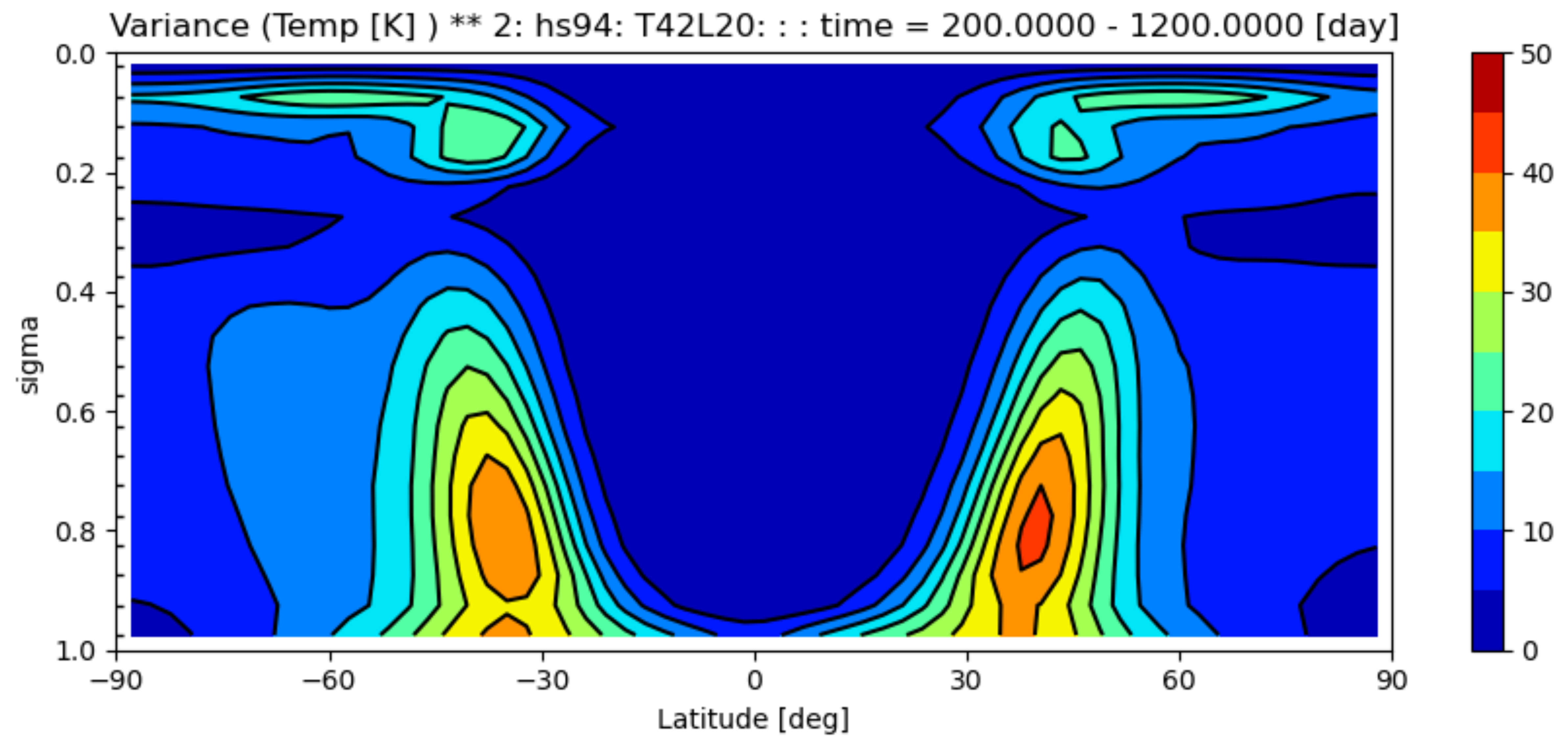
T42L80

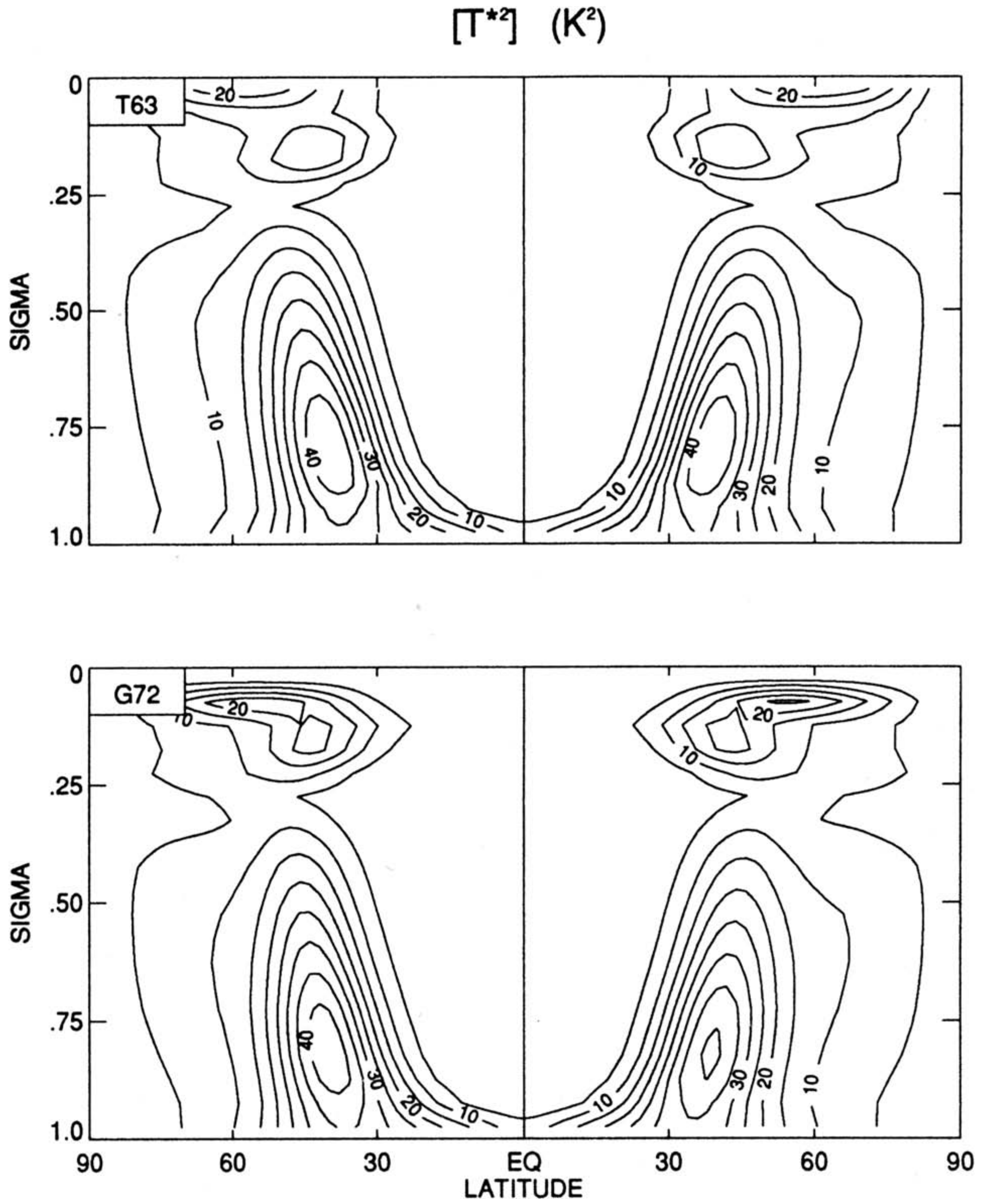


T42L160

T42L20 vs HS94

T* Variance: Figure 3

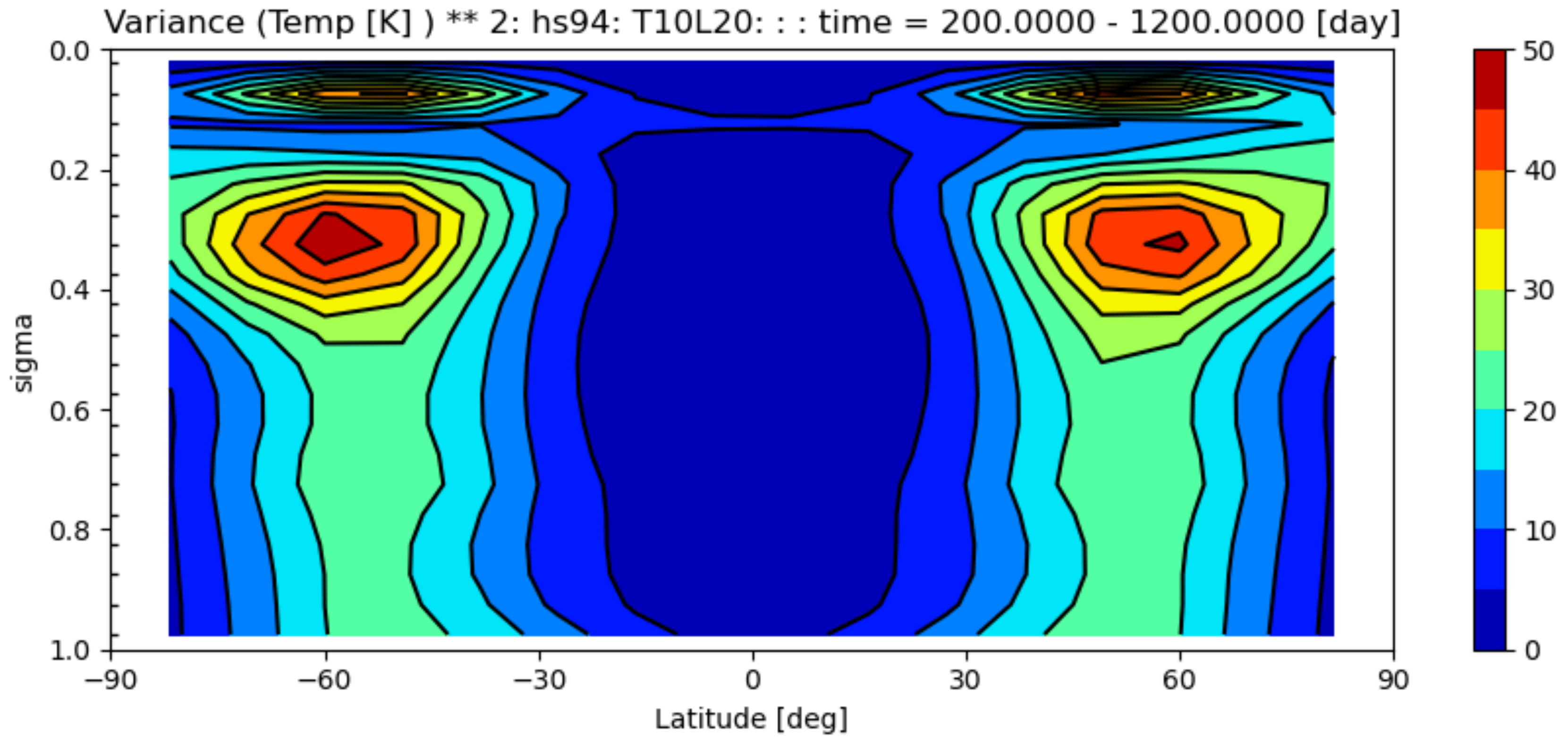




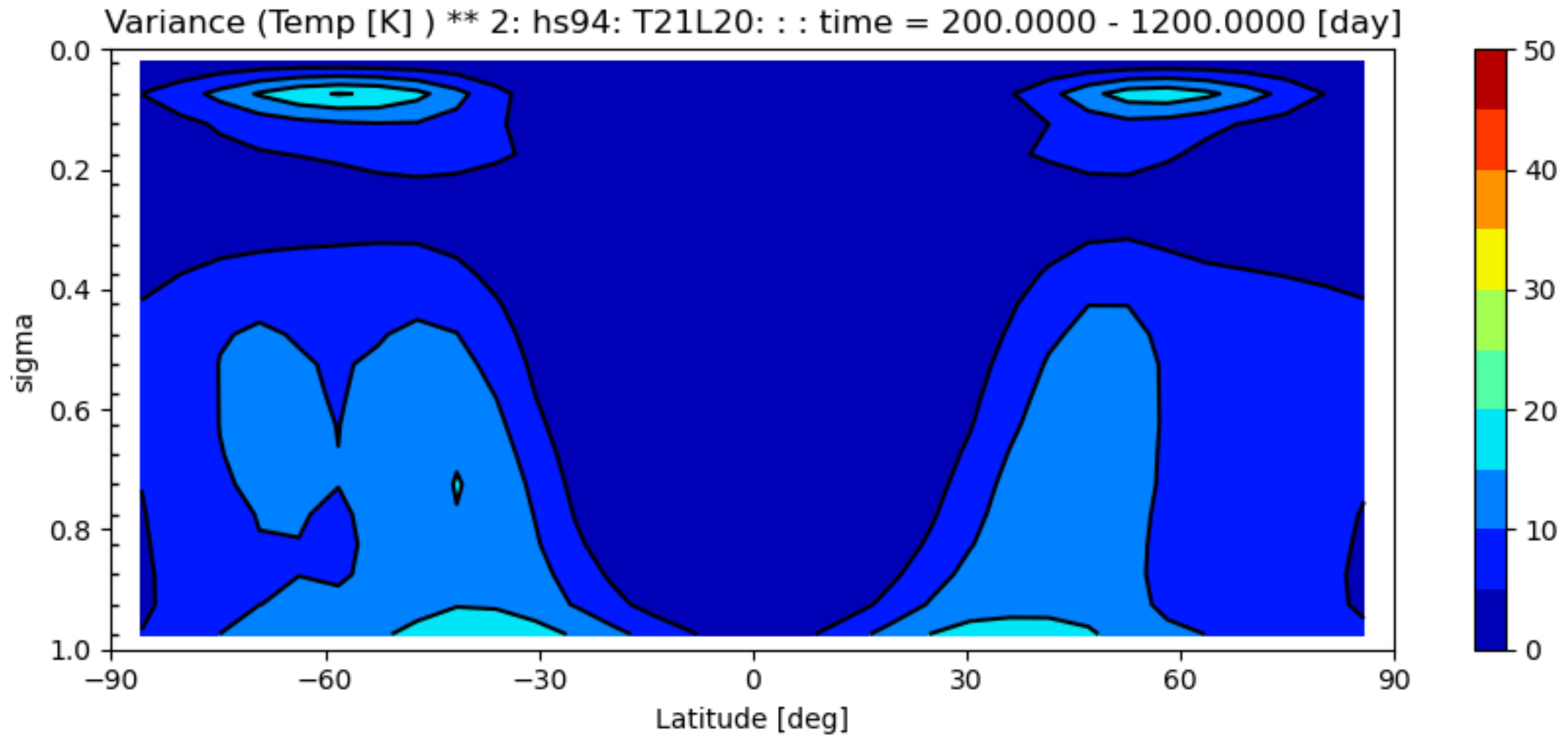
Held and Suarez (1994)

FIG. 3. As in Fig. 2 but for the eddy variance of the temperature.

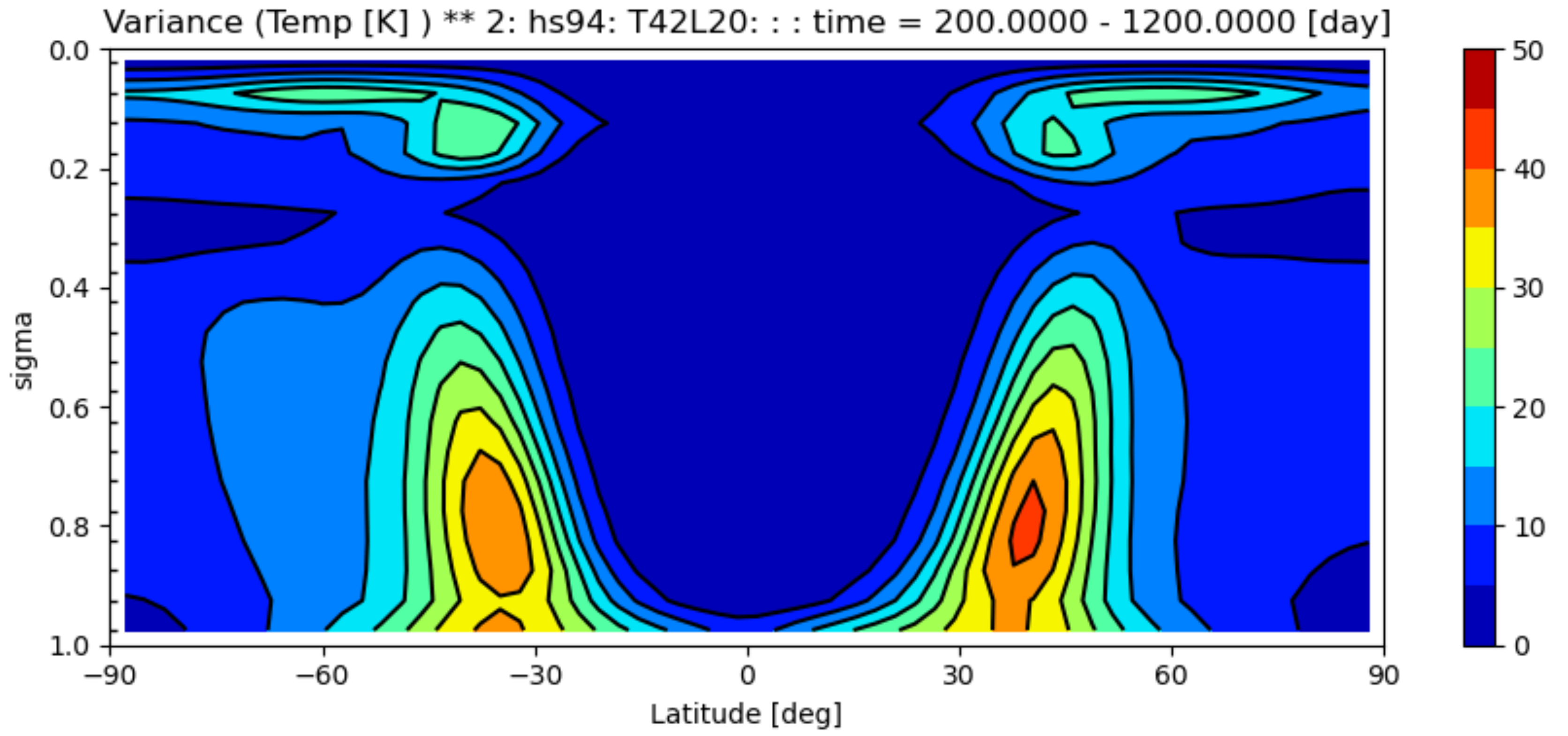
何も考えずに水平解像度を変える:
T* Variance



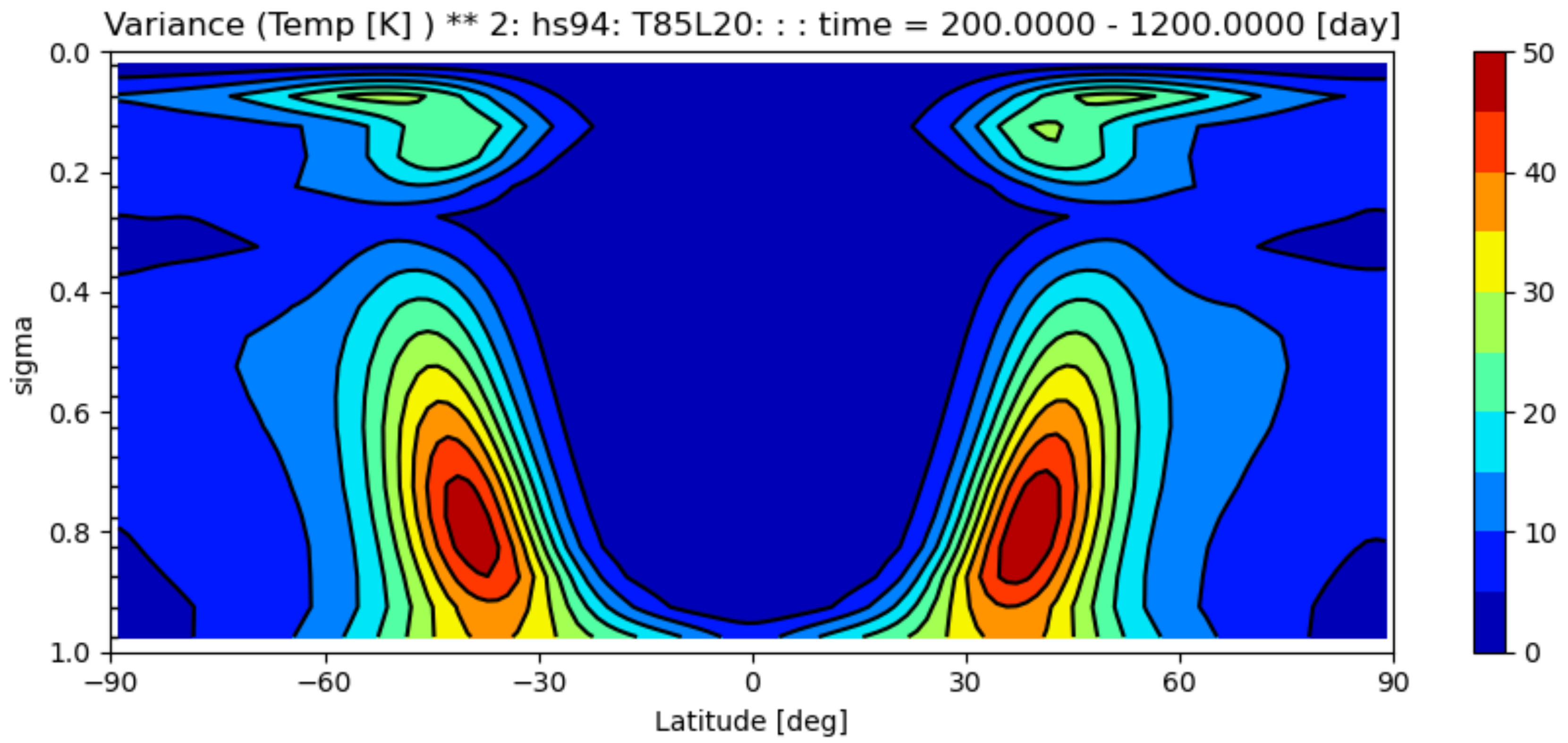
T10L20



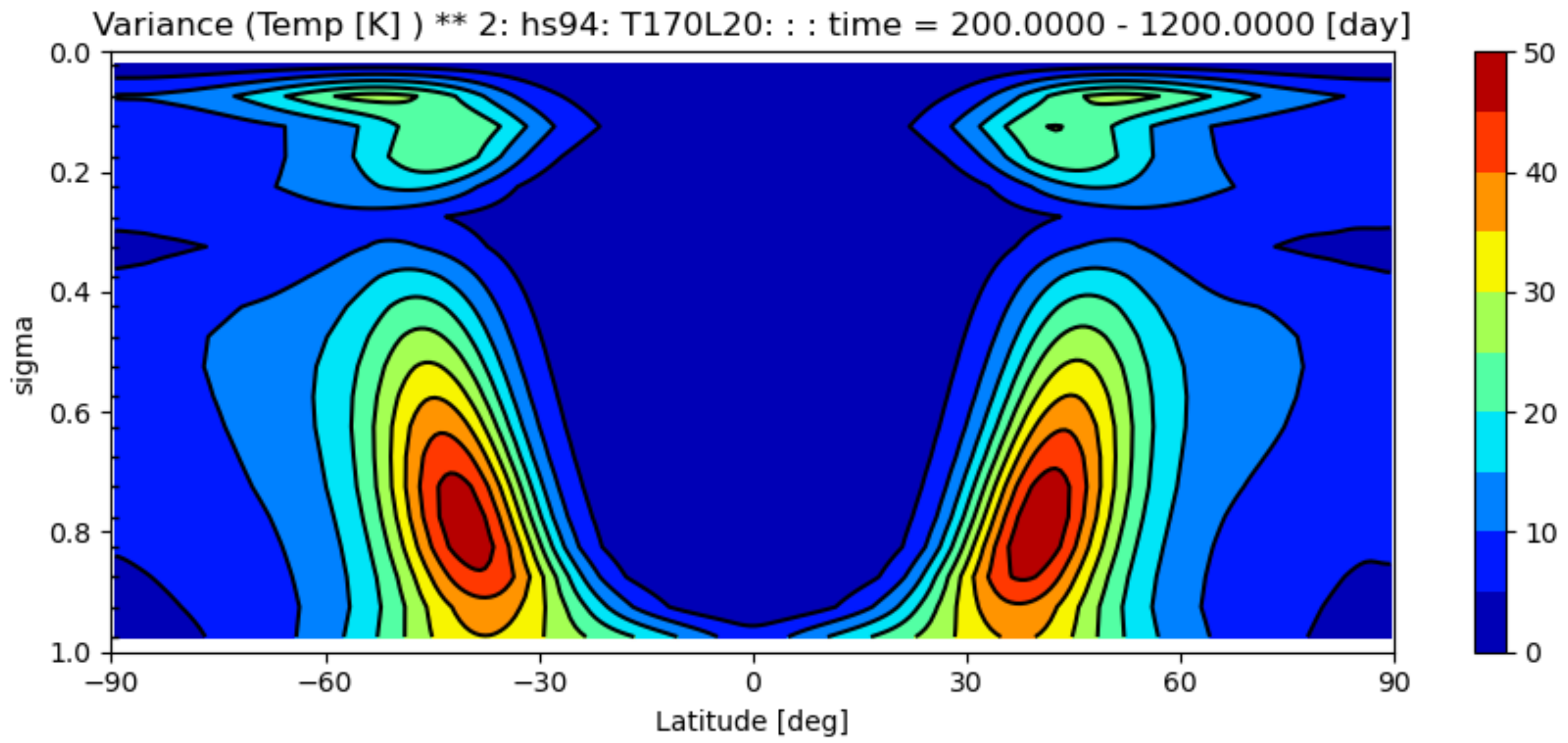
T21L20



T42L20

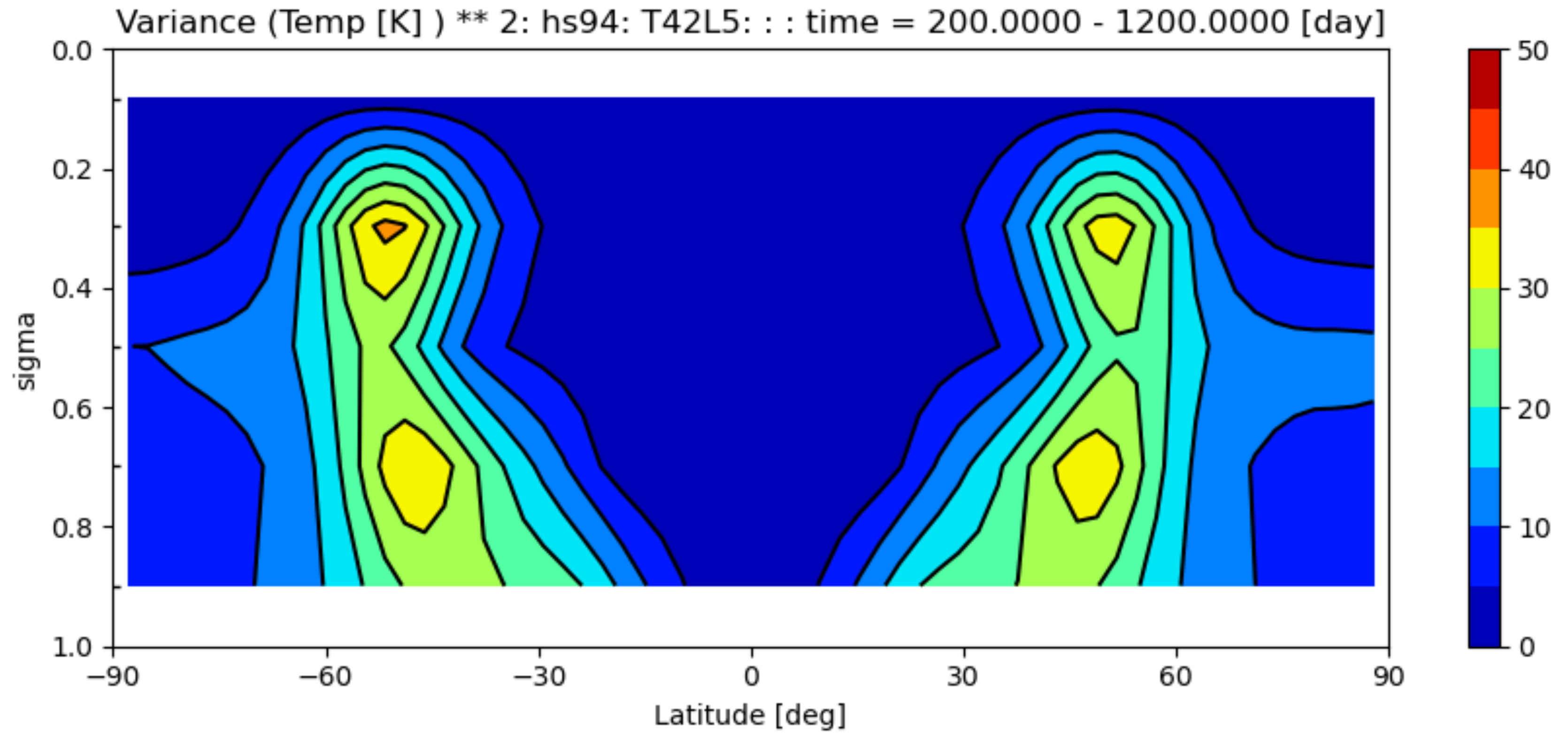


T85L20

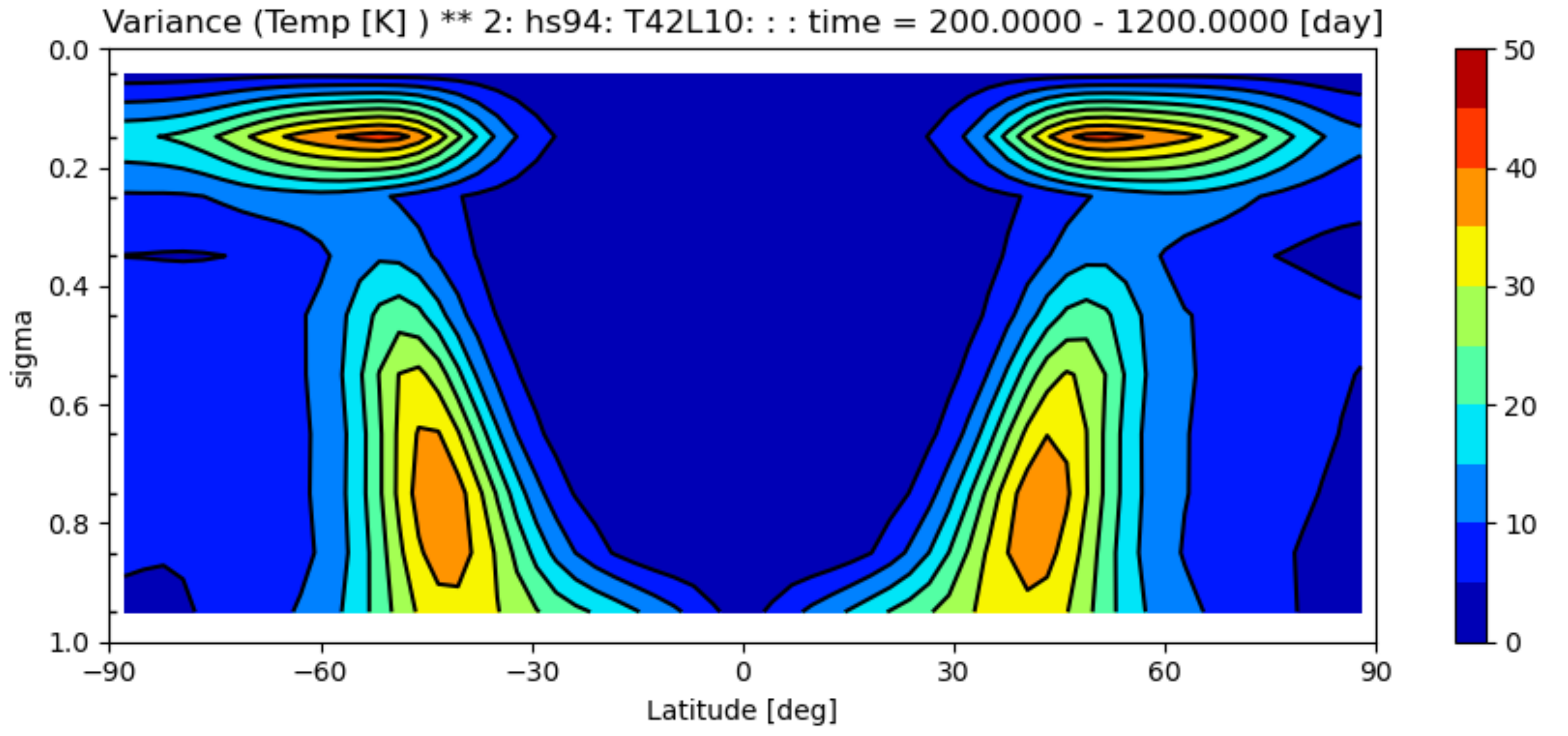


T170L20

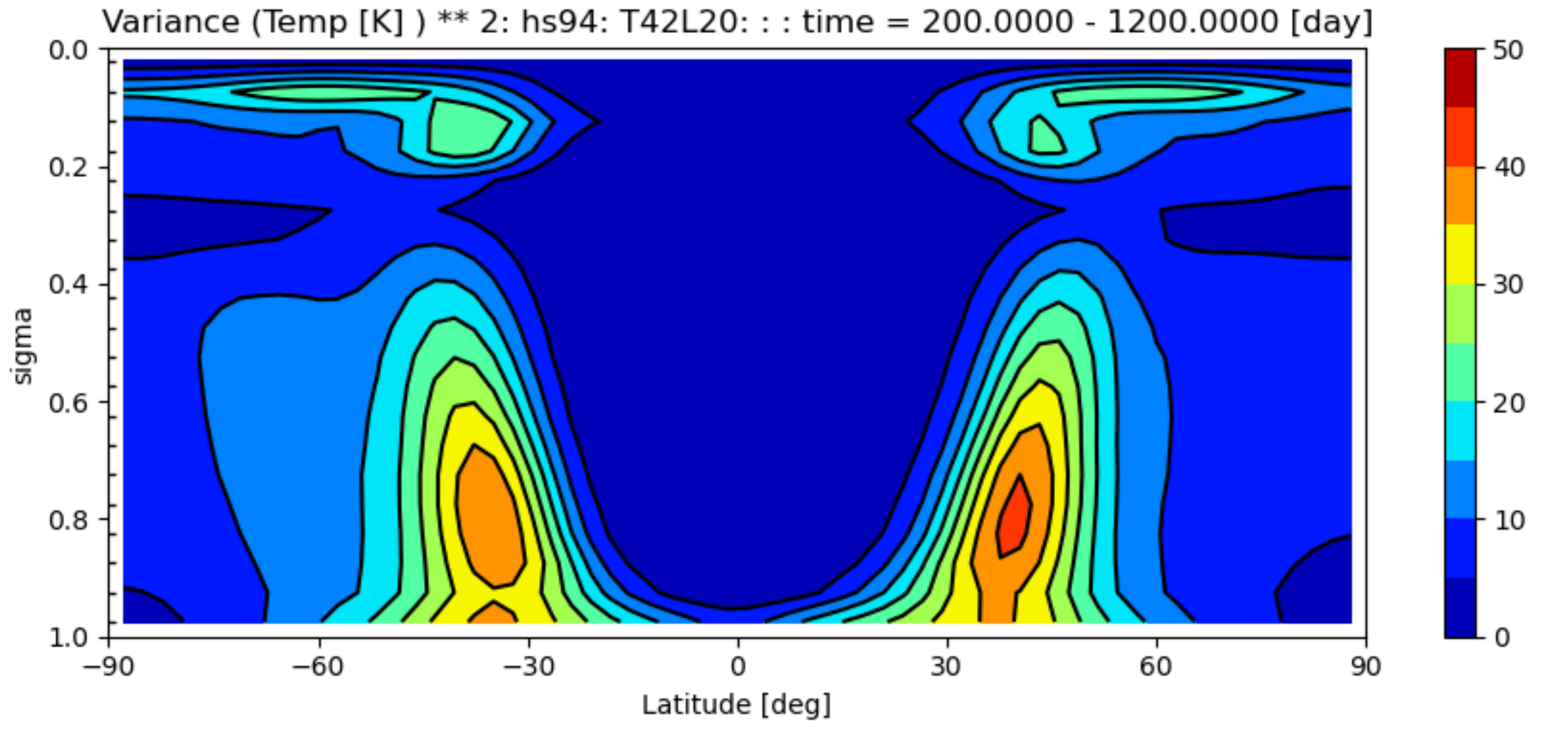
何も考えずに鉛直解像度を変える: T* Variance



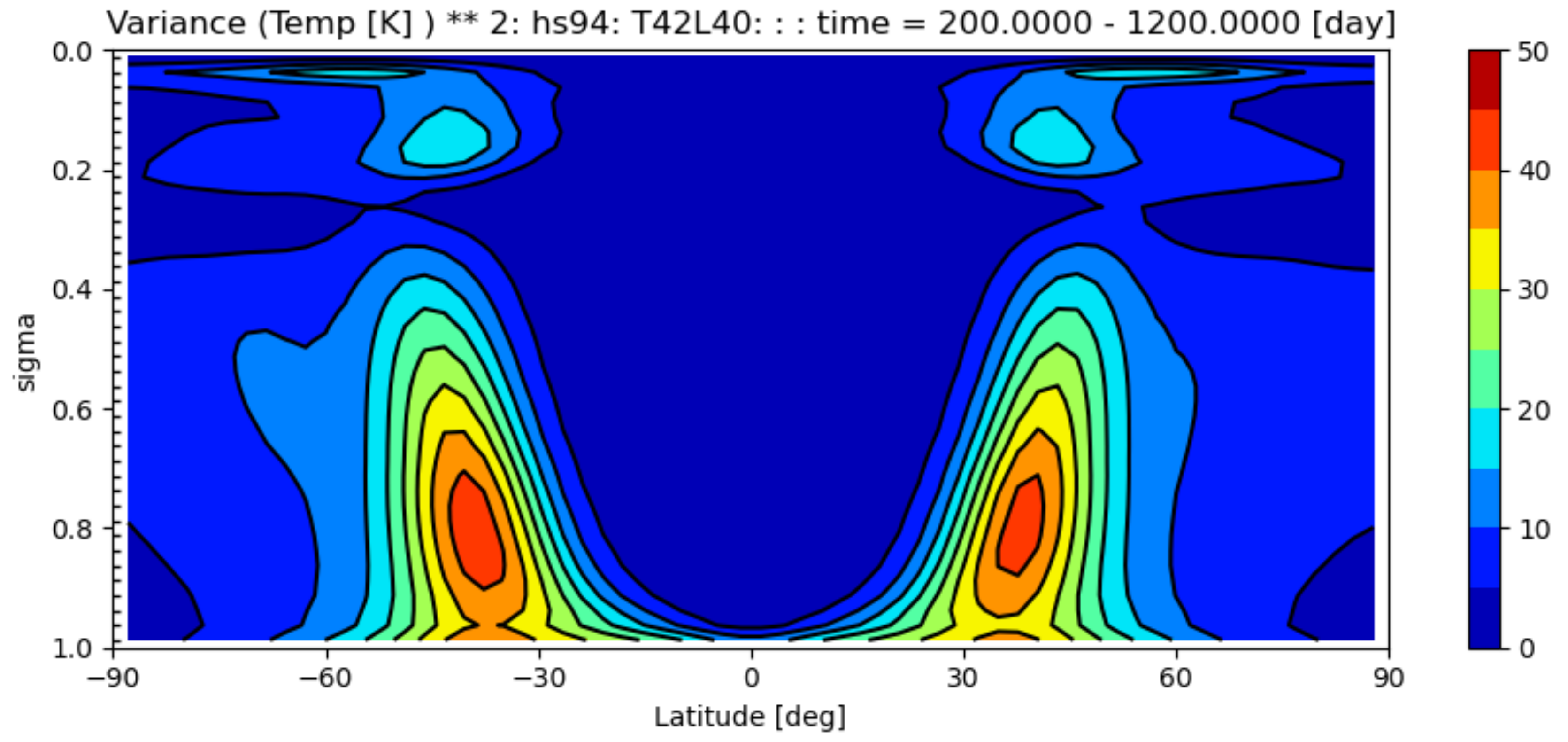
T42L5



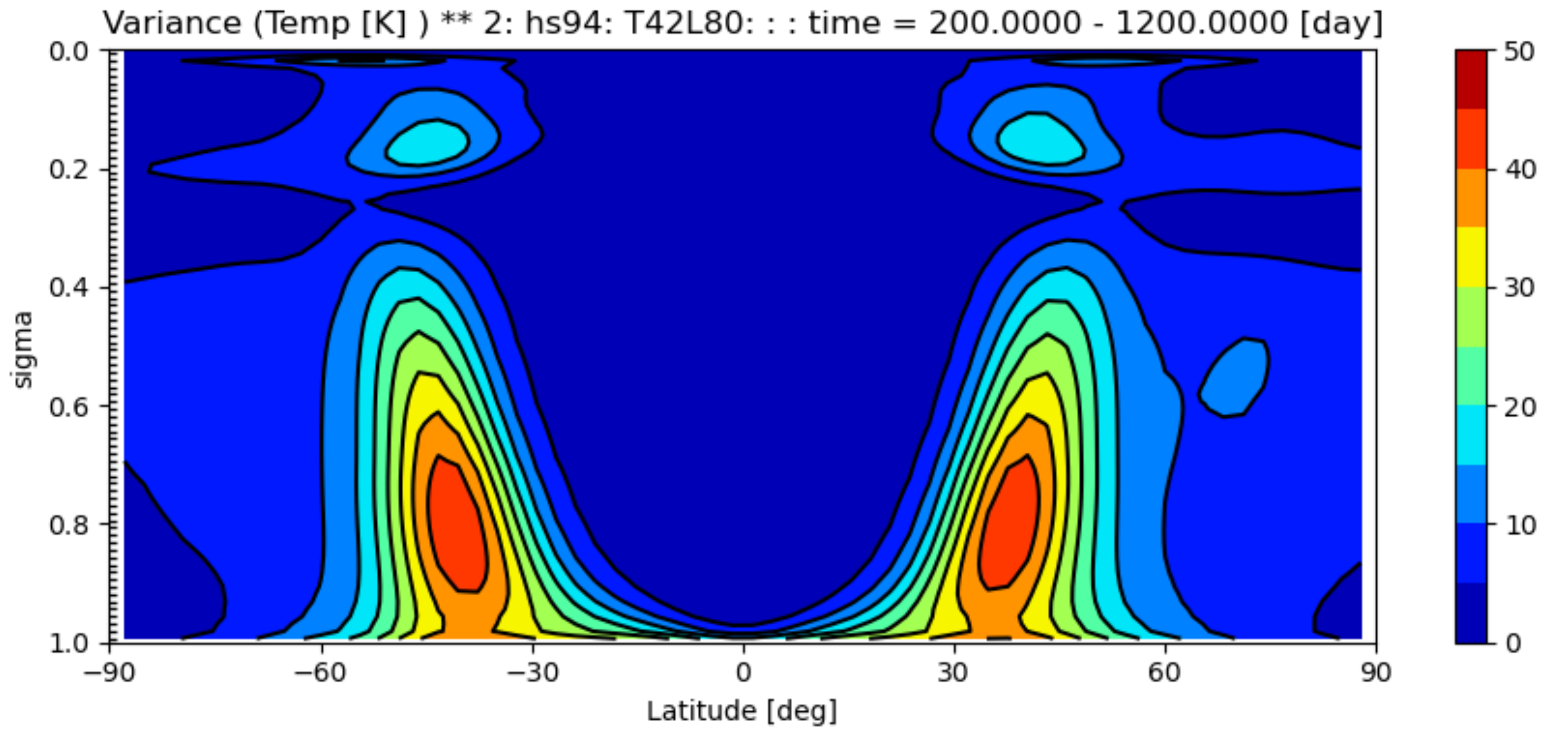
T42L10



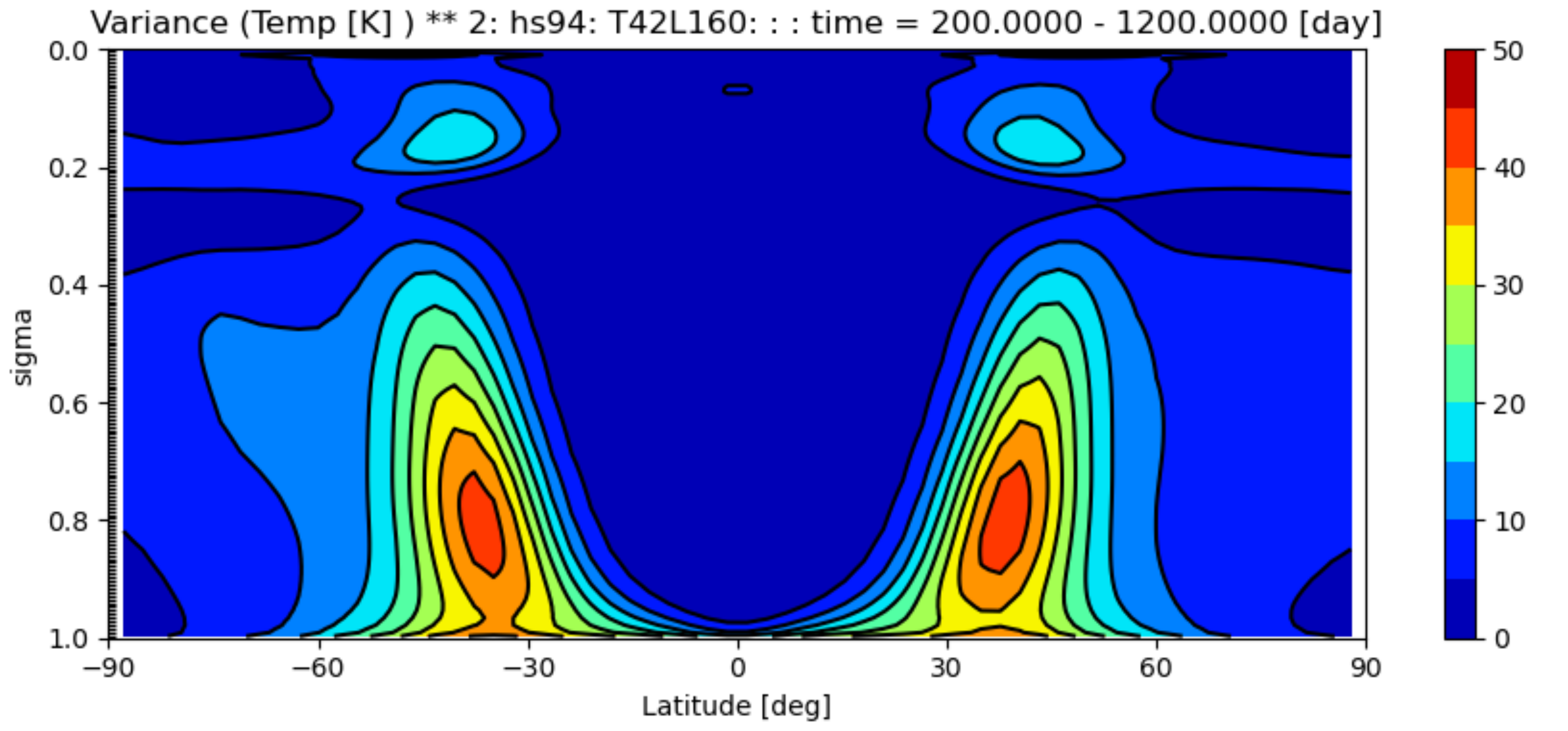
T42L20



T42L40



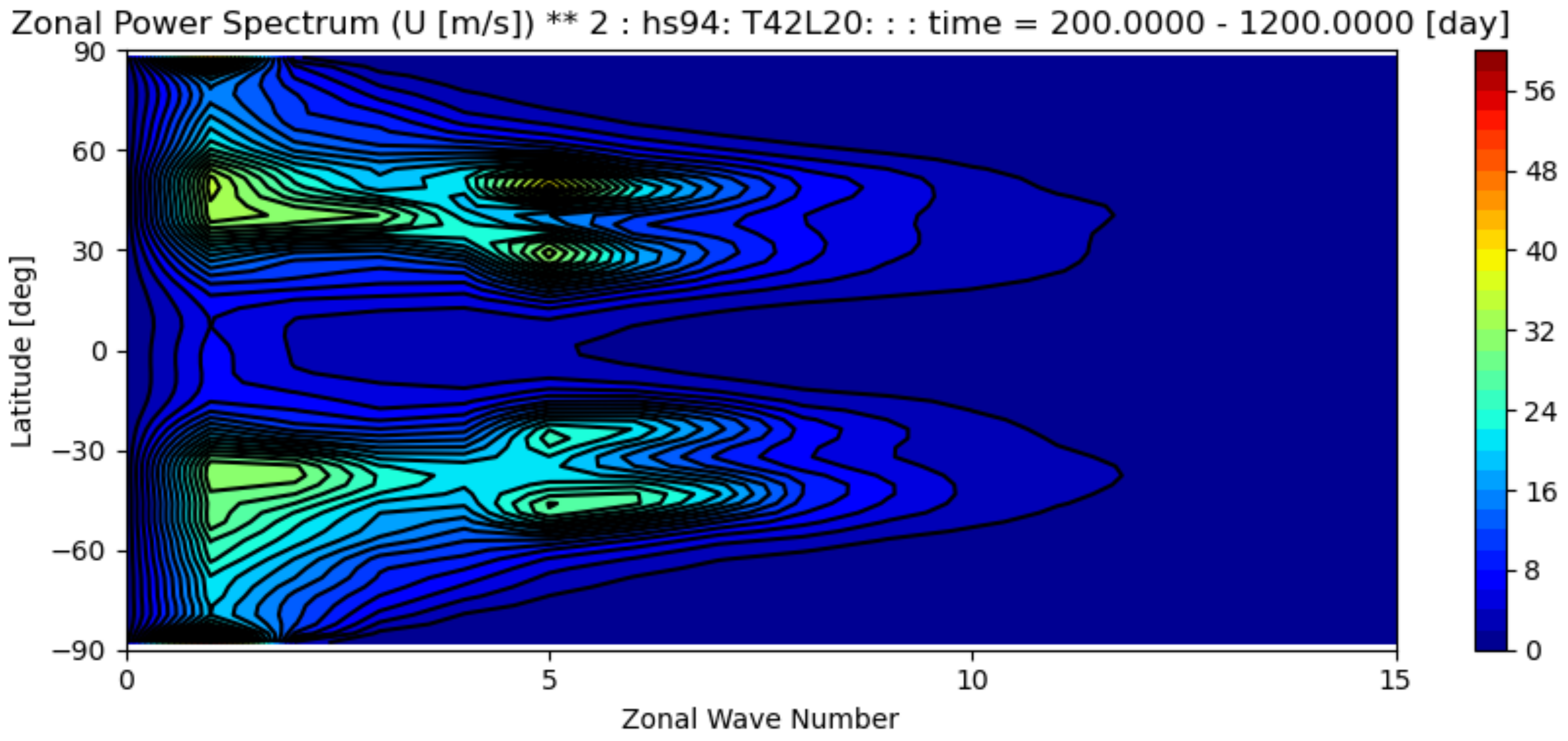
T42L80



T42L160

T42L20 vs HS94

U*^2 Spectra: Figure 4



HS94と比較して値が1.5~2倍くらい？
フーリエ係数の定義等要チェック

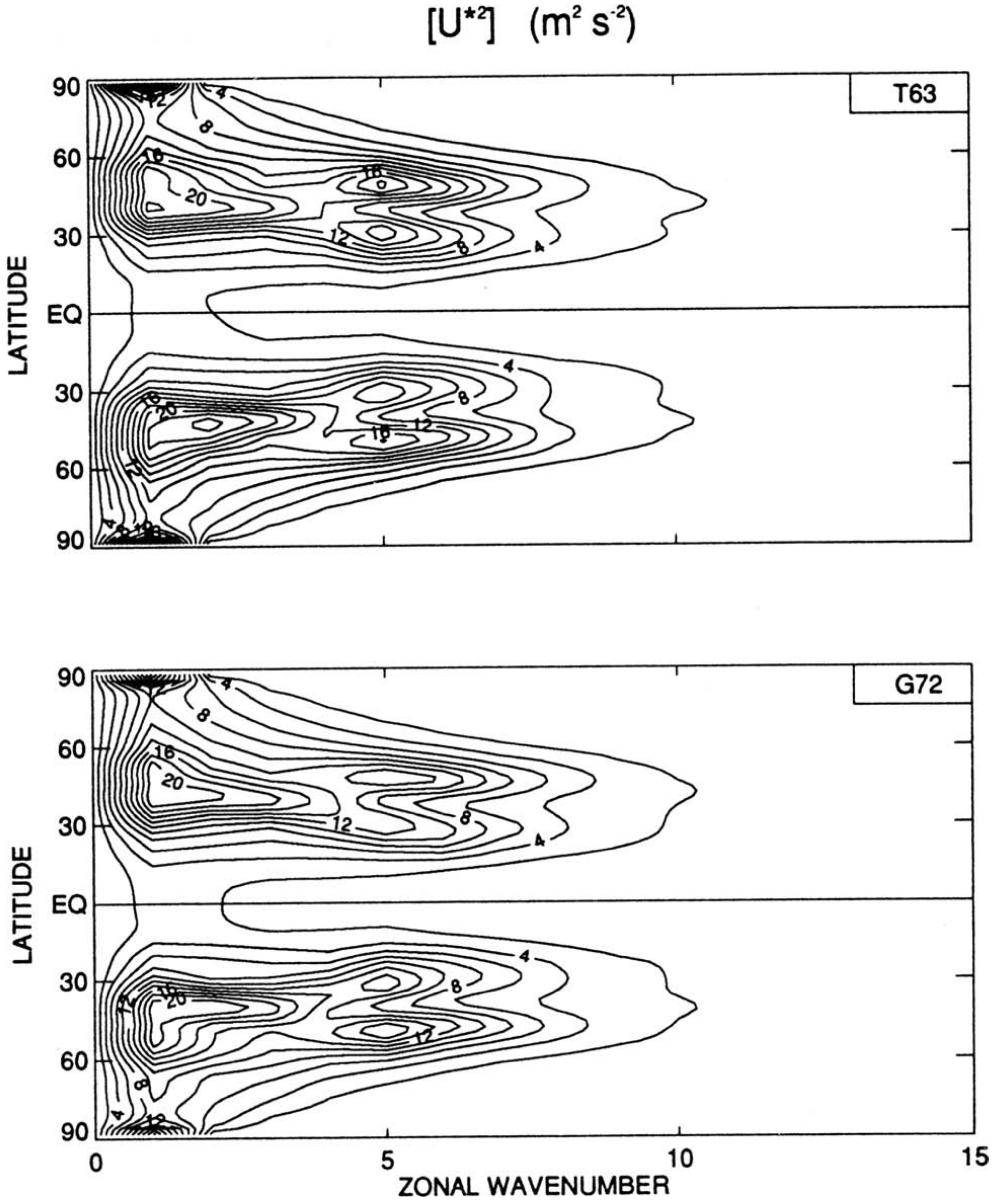
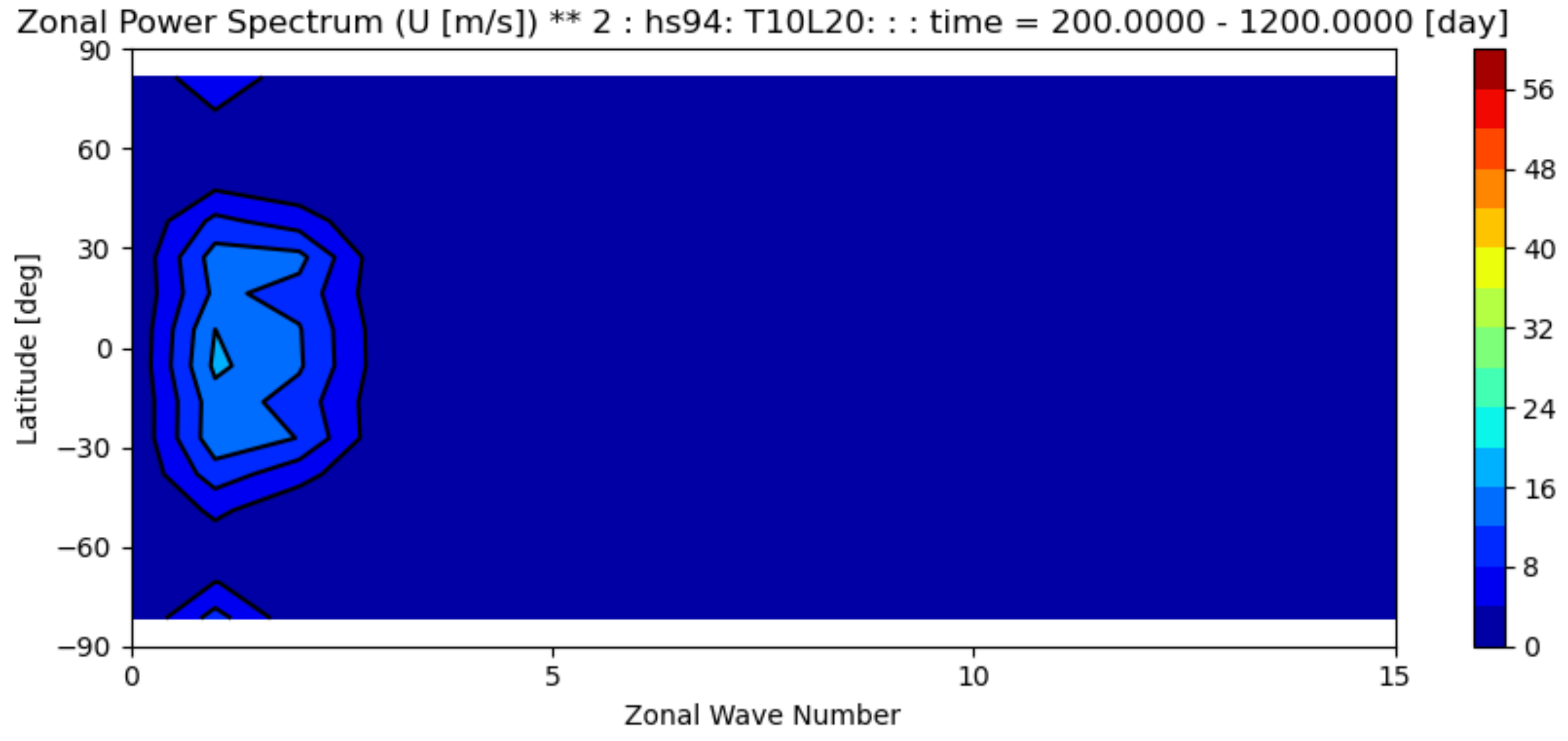


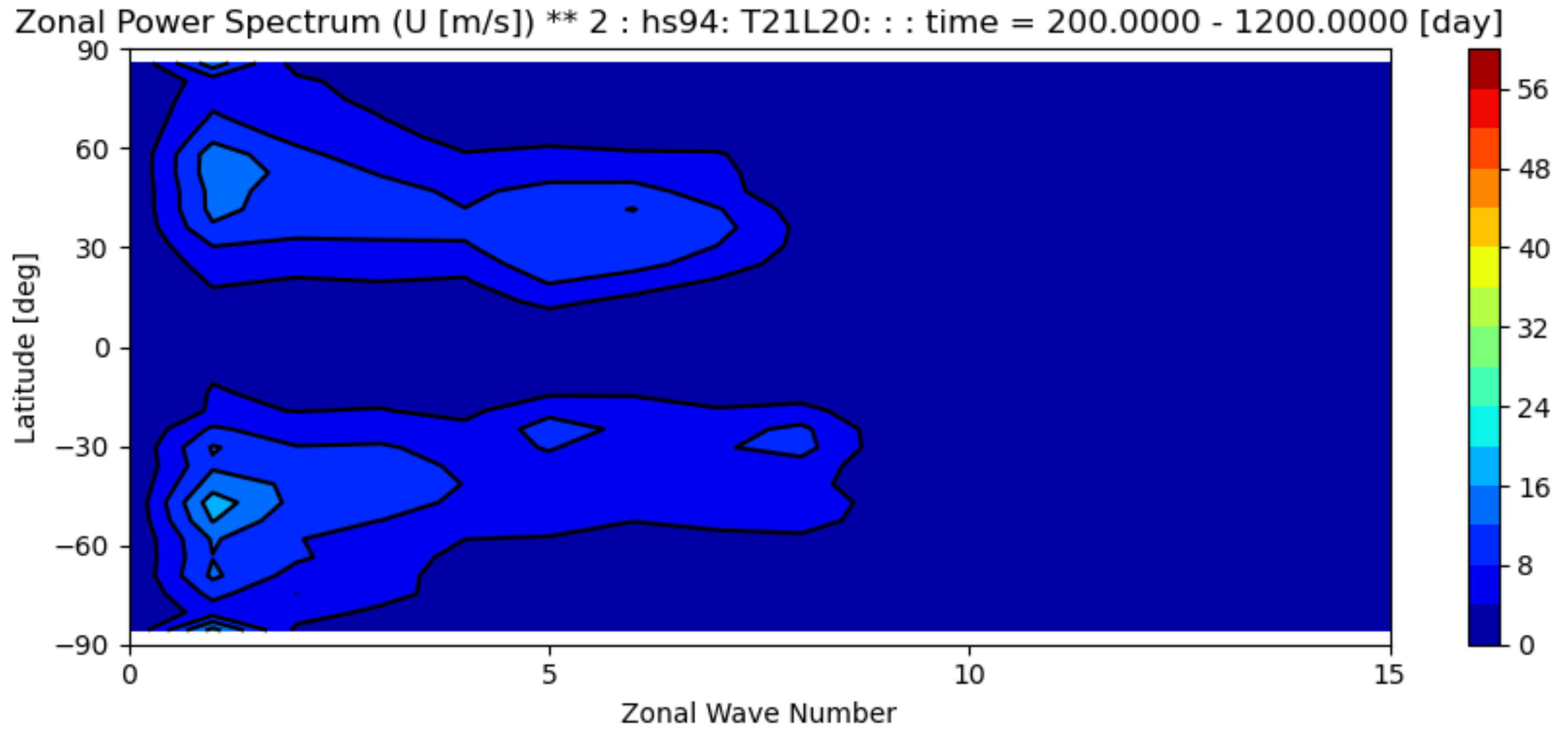
FIG. 4. As in Fig. 2 but for the vertically averaged zonal spectra of the eddy variance of zonal wind.

Held and Suarez (1994)

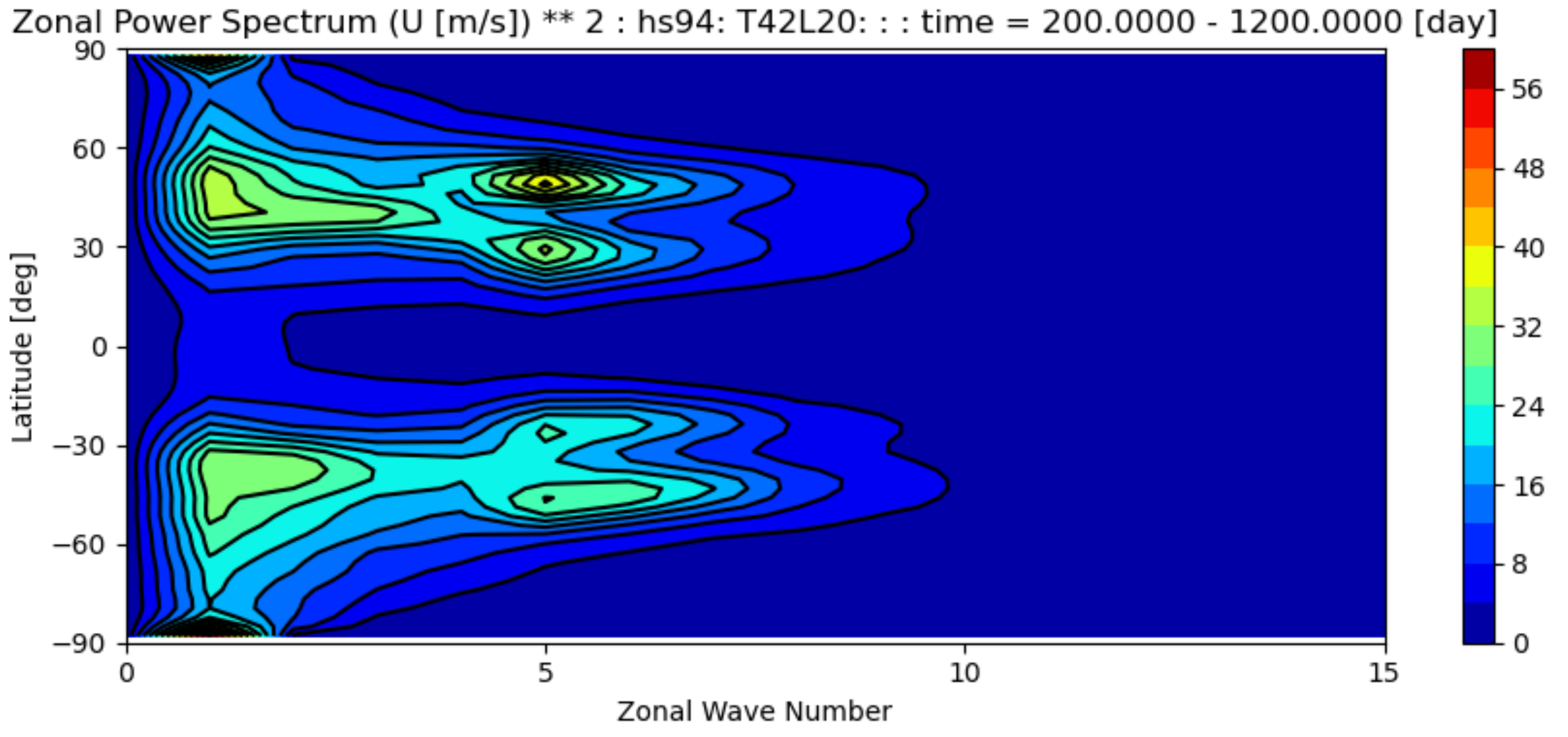
何も考えずに水平解像度を変える:
U*^2 Spectra



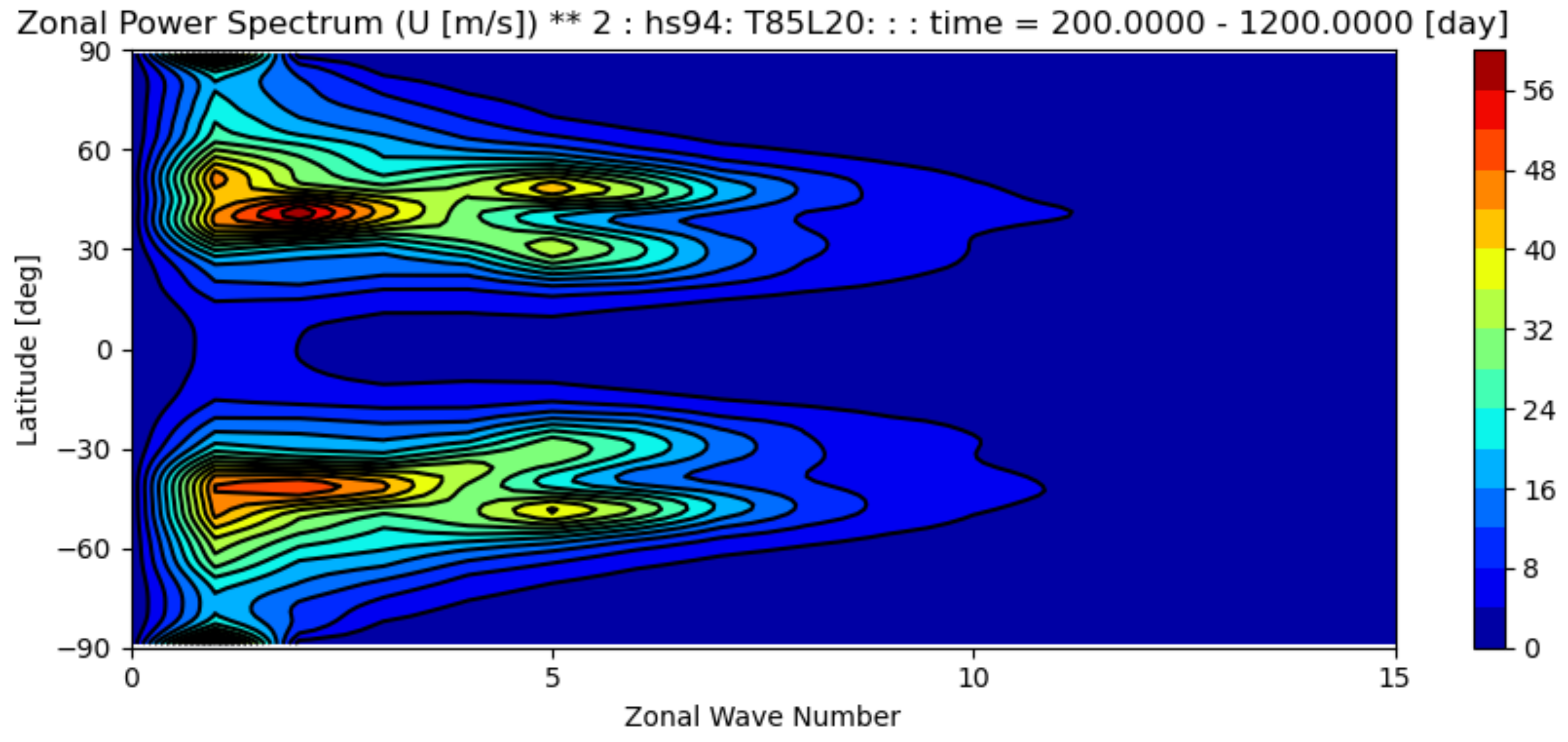
T10L20



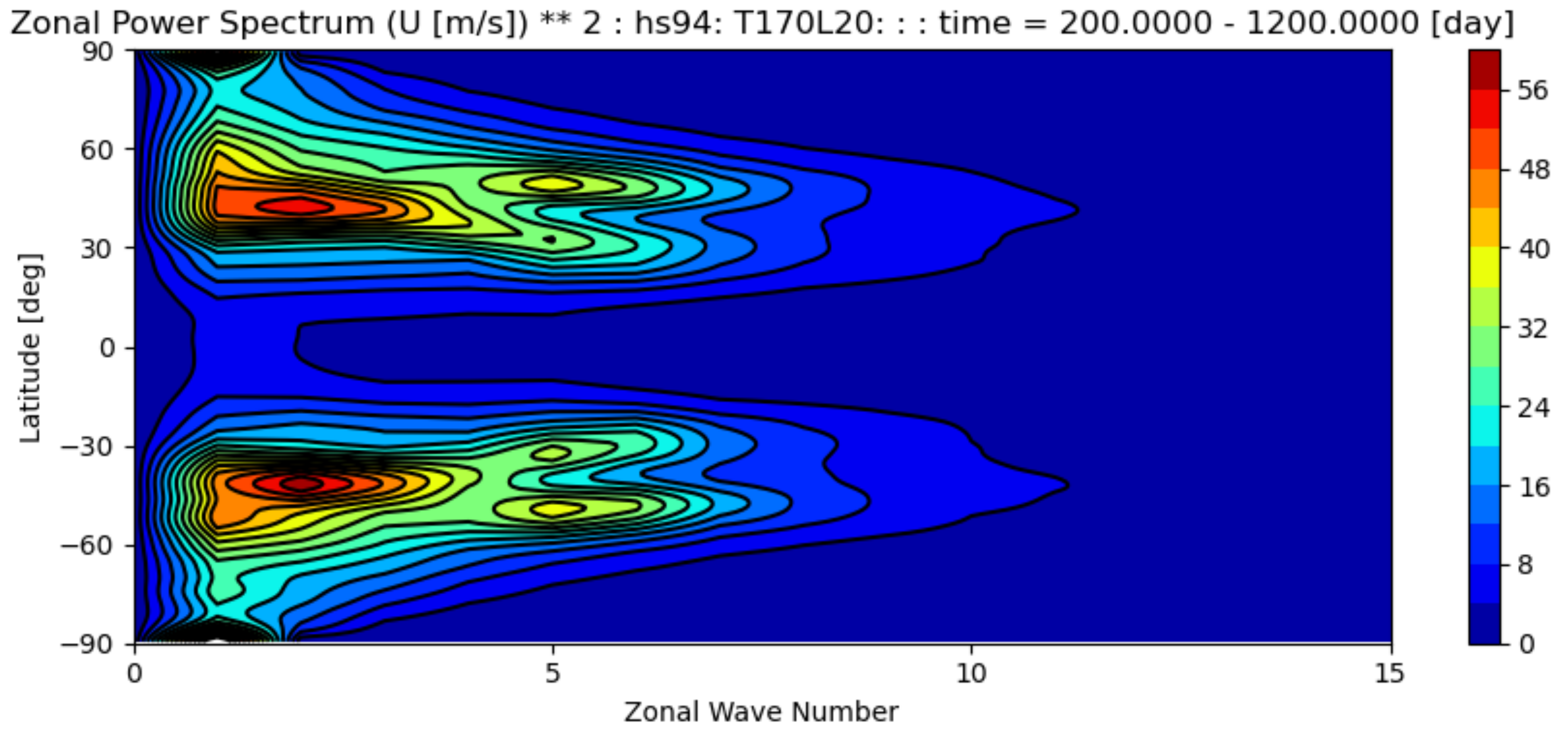
T21L20



T42L20

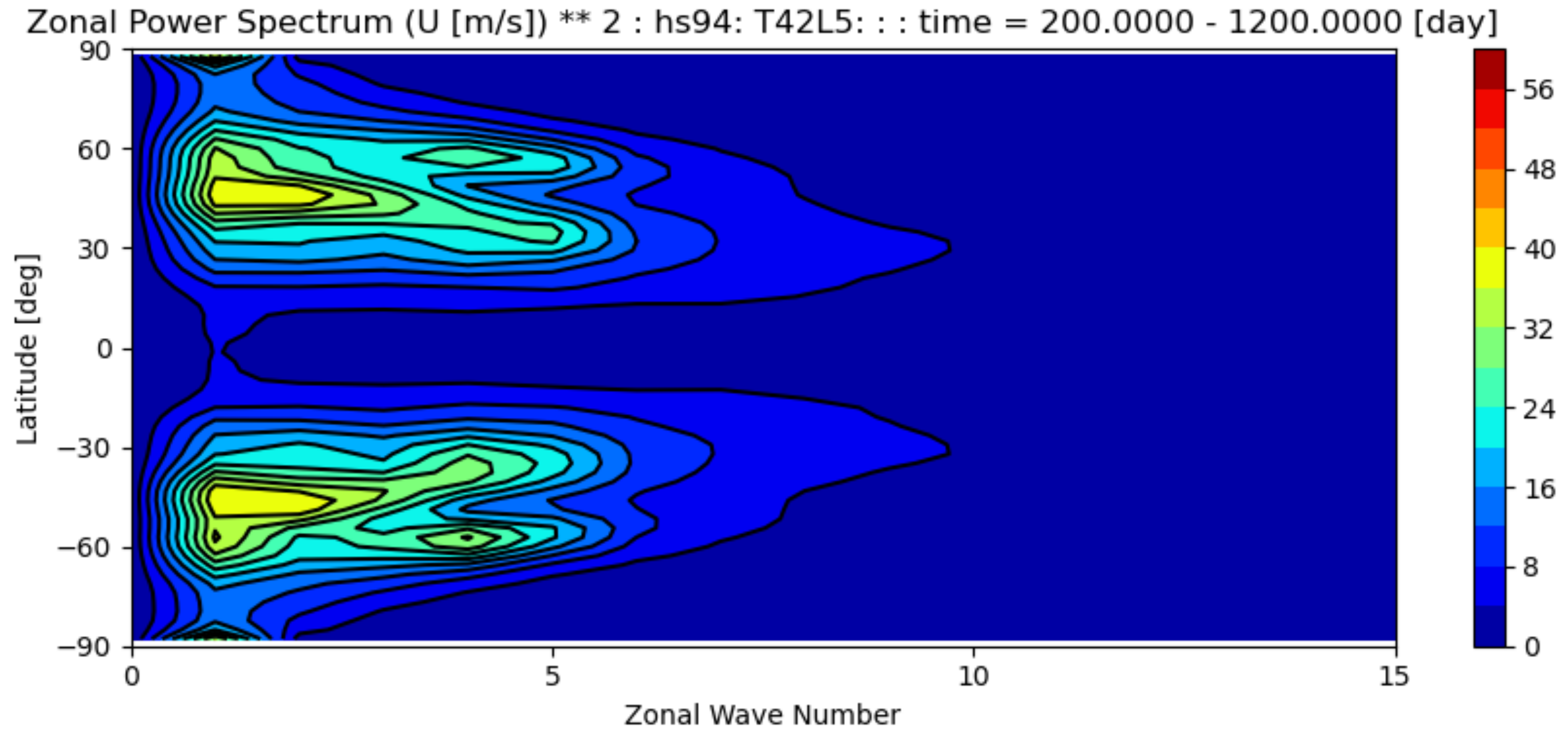


T85L20

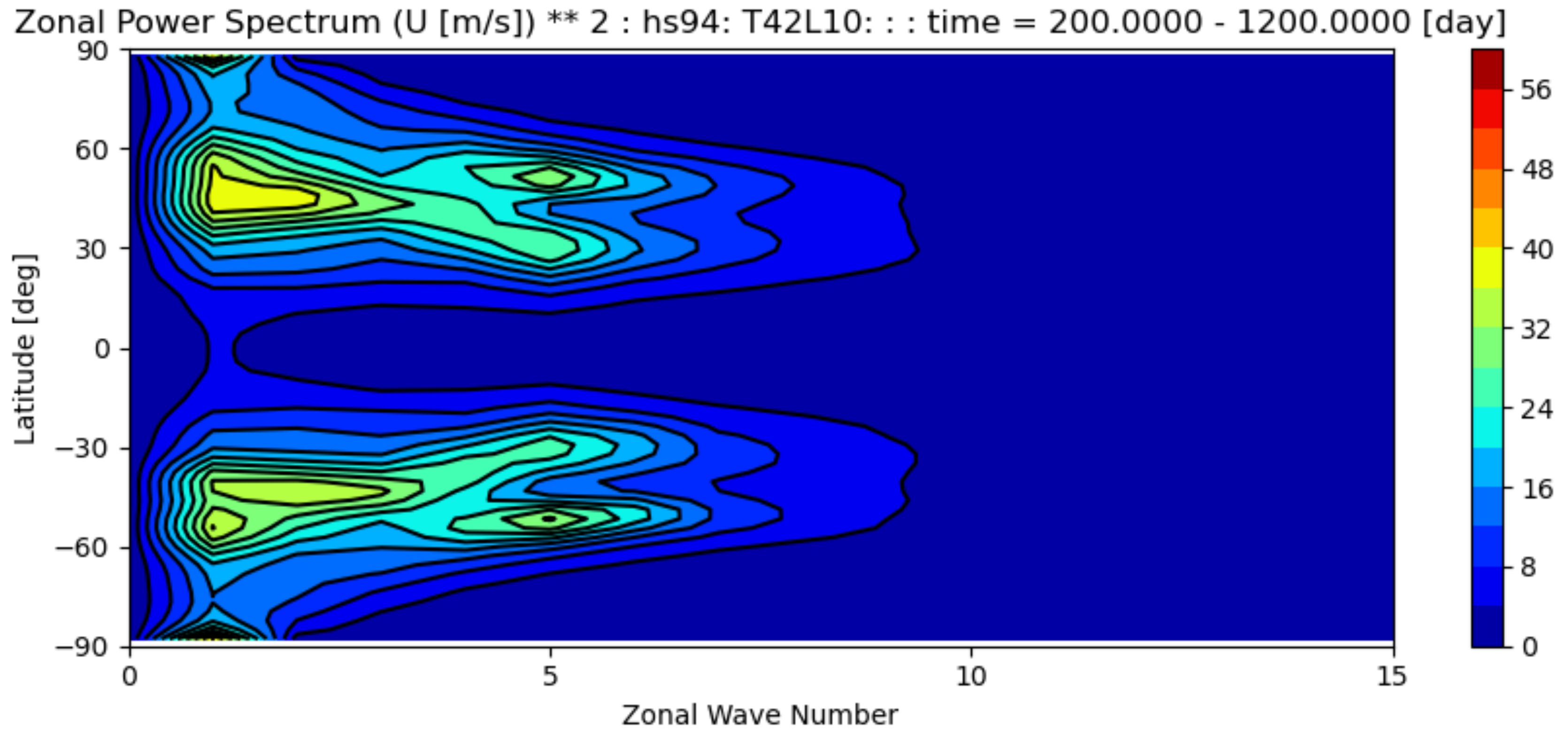


T170L20

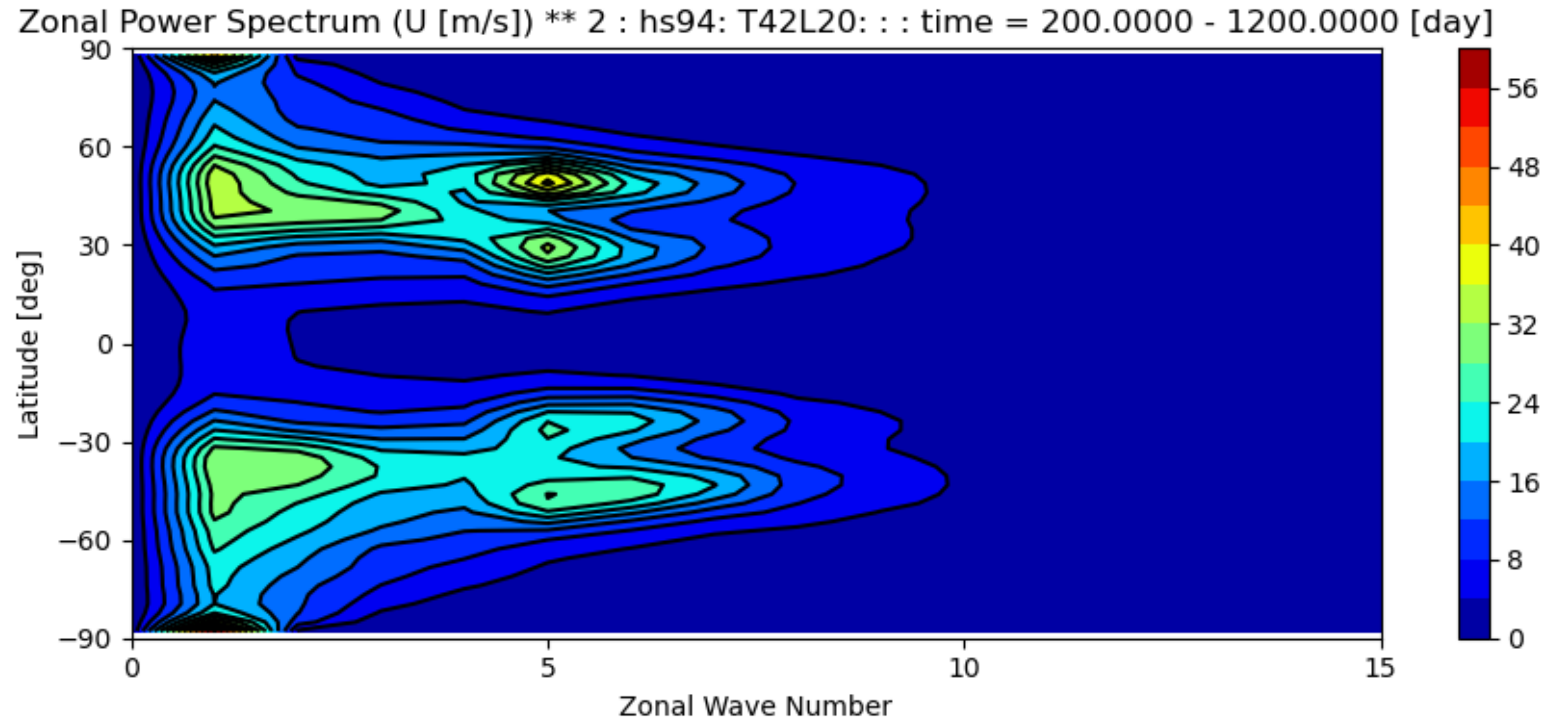
何も考えずに鉛直解像度を変える:
U*^2 Spectra



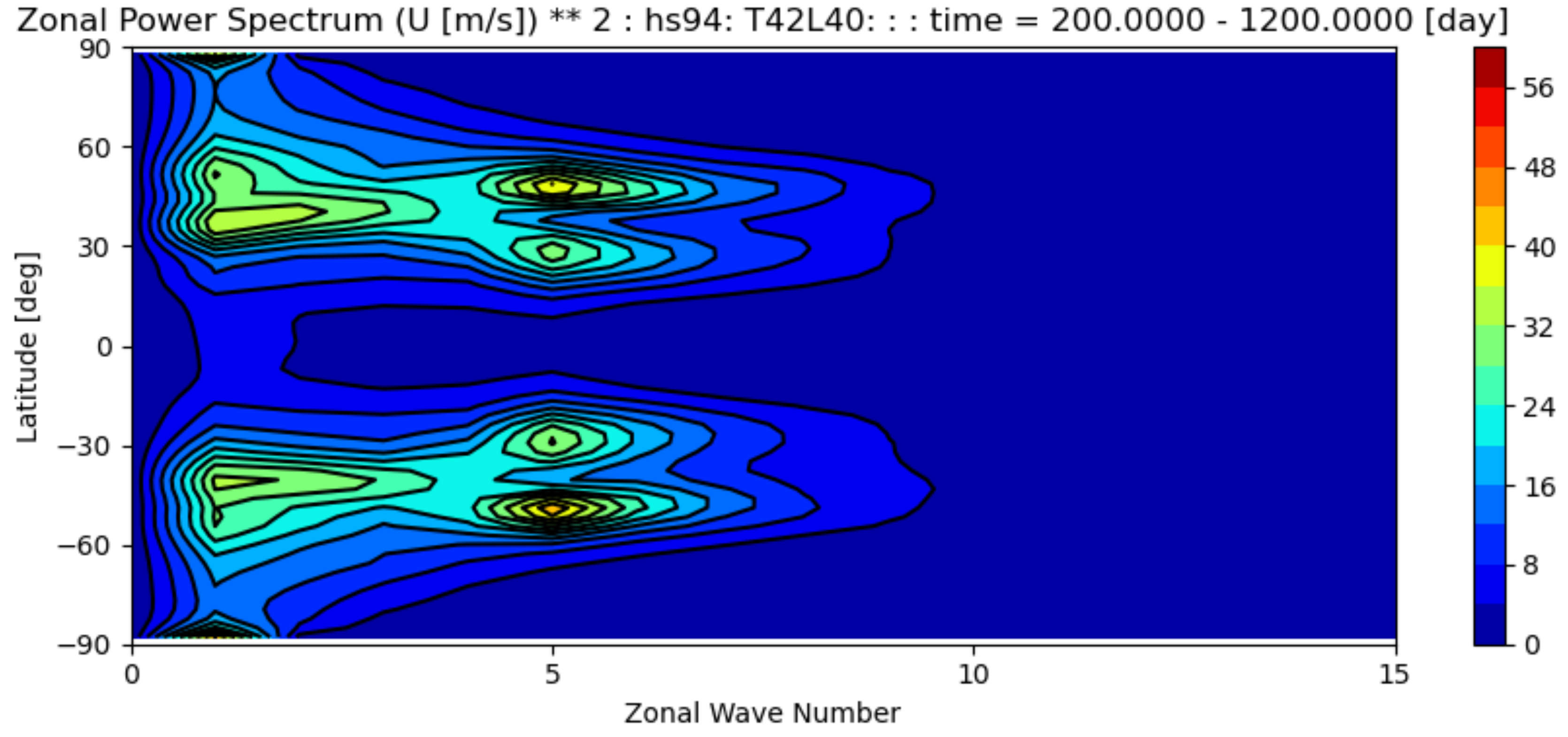
T42L5



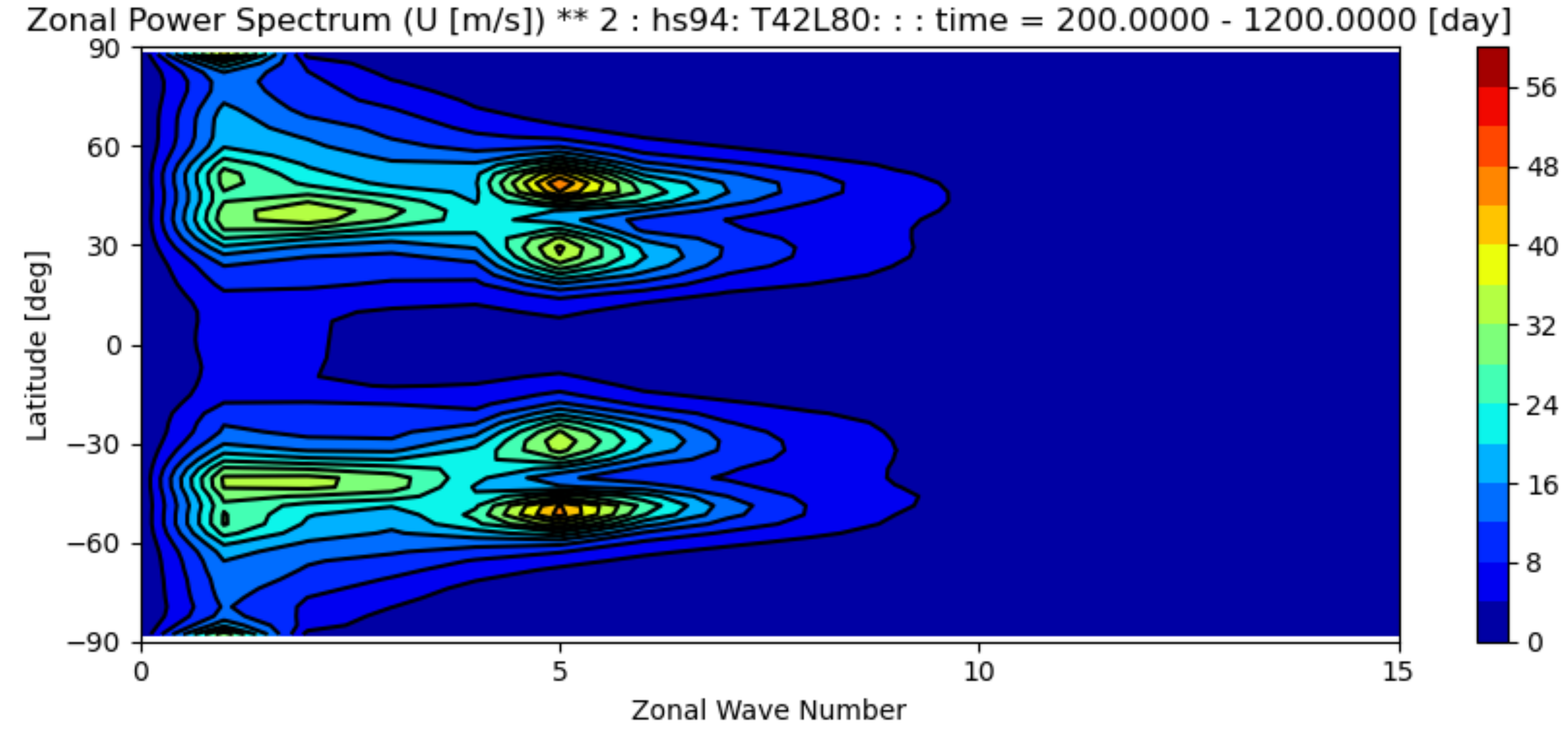
T42L10



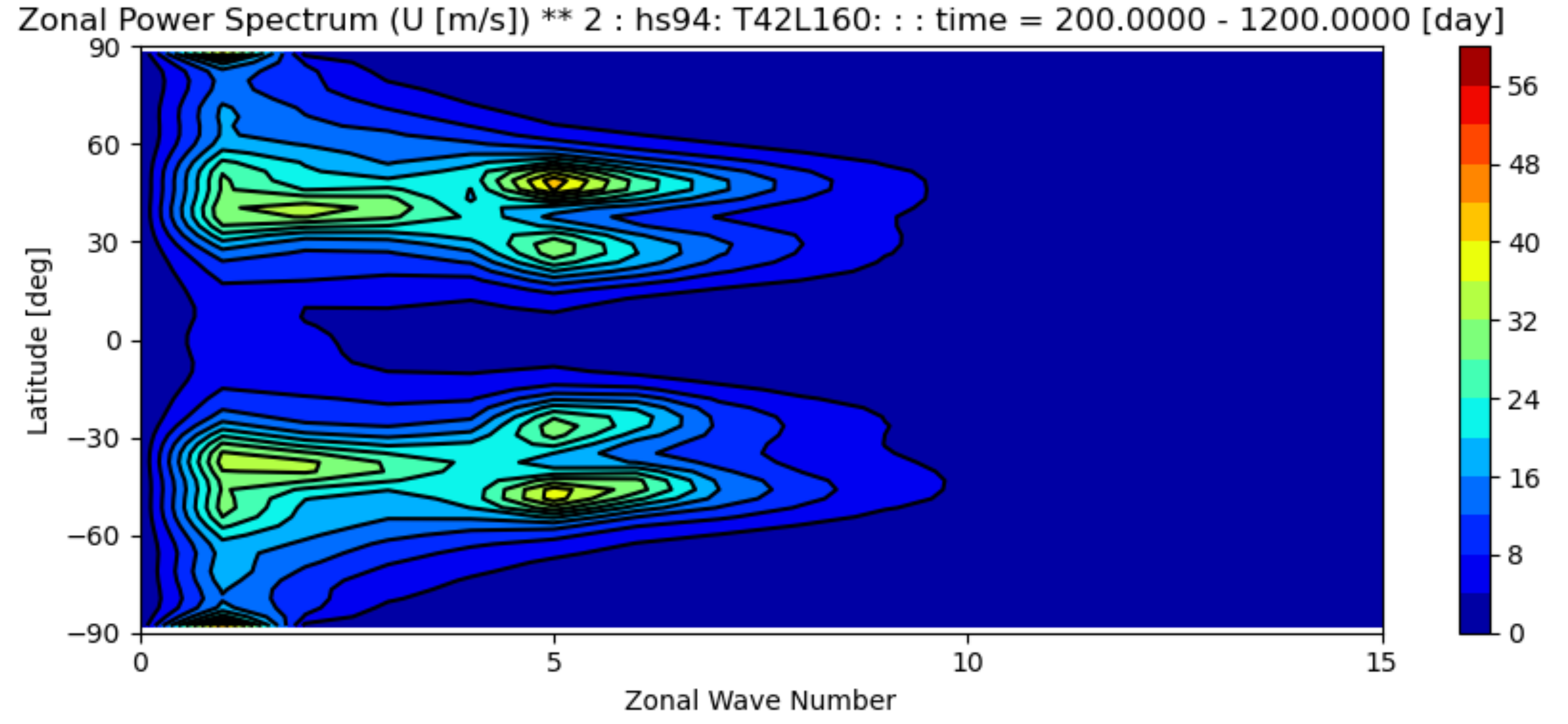
T42L20



T42L40

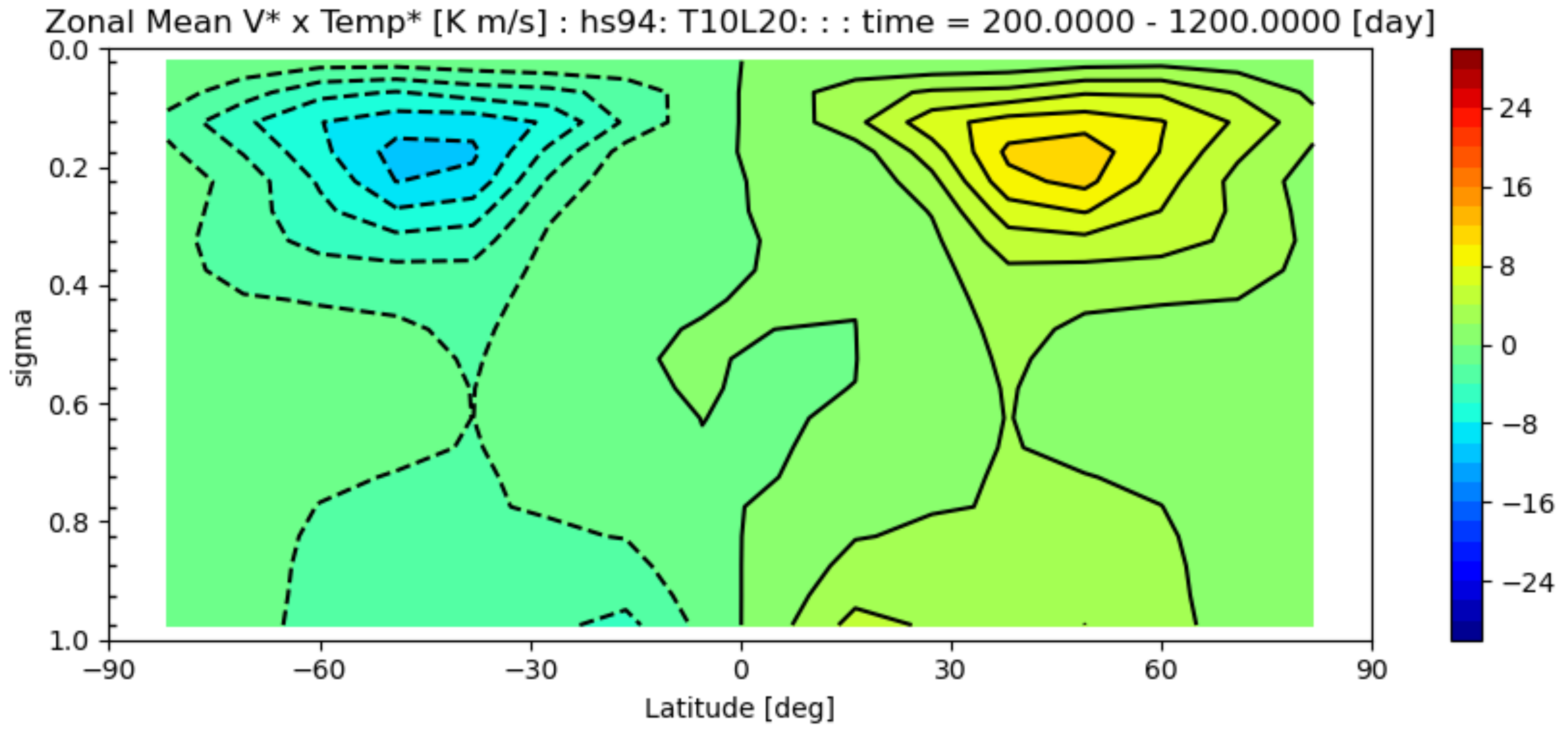


T42L80

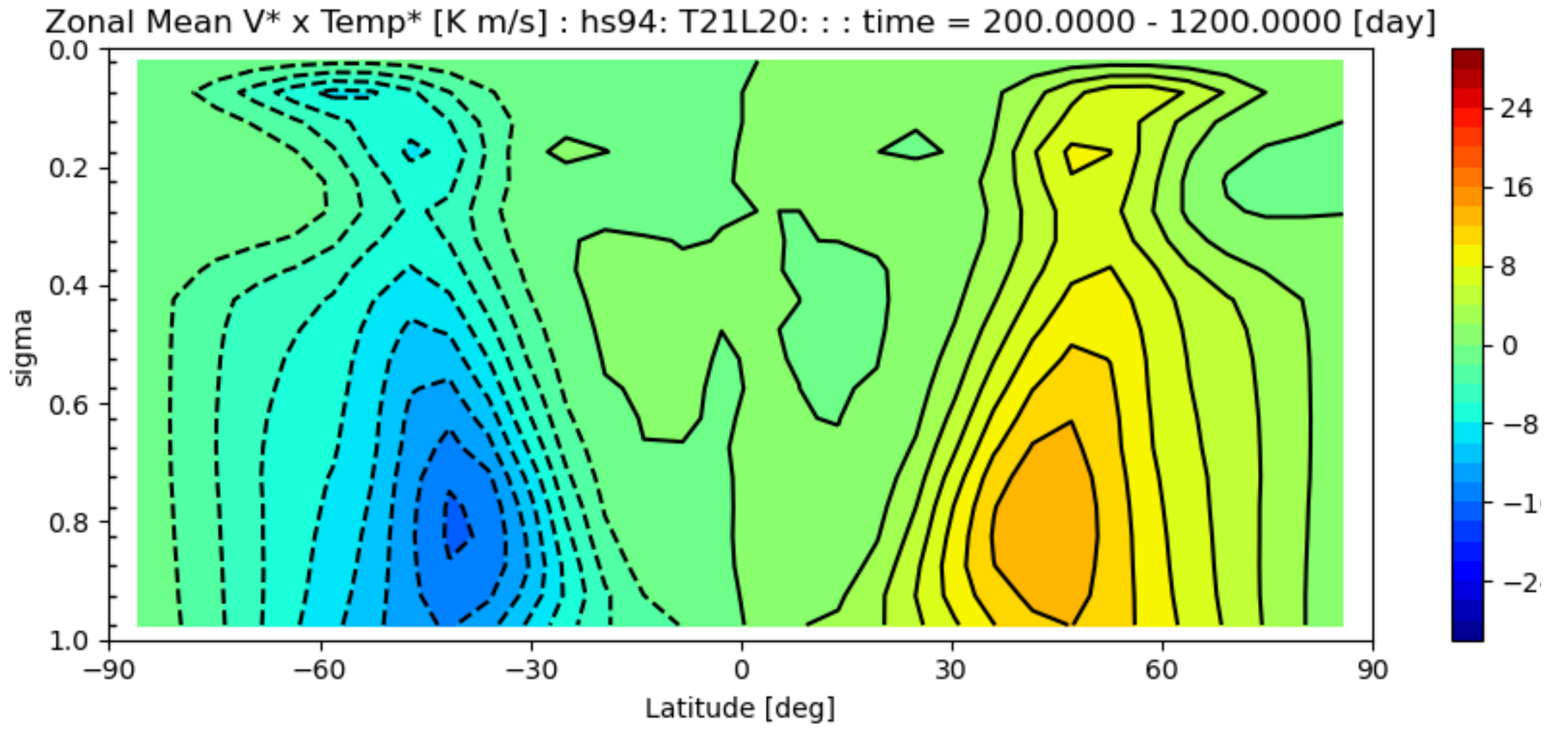


T42L160

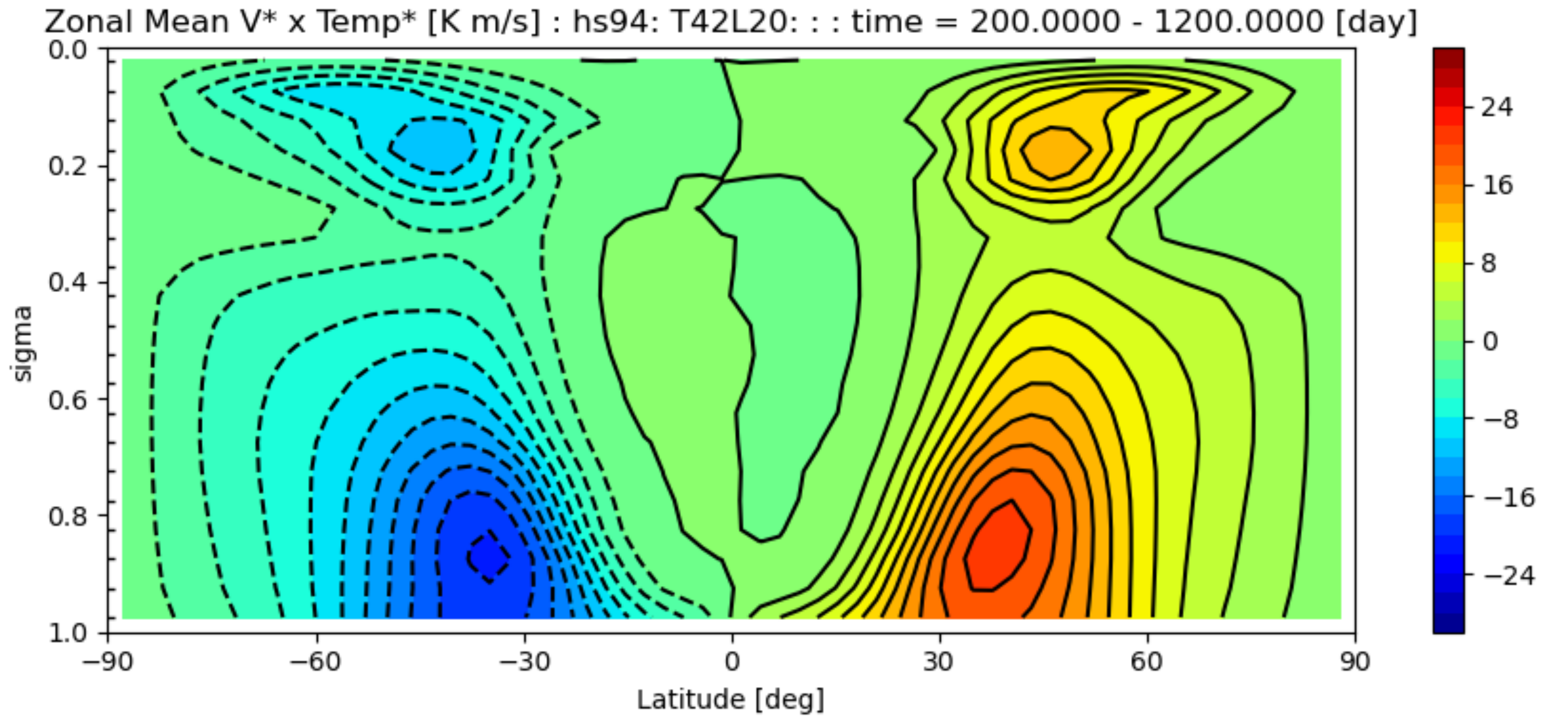
何も考えずに）水平解像度を変える: V*Temp*



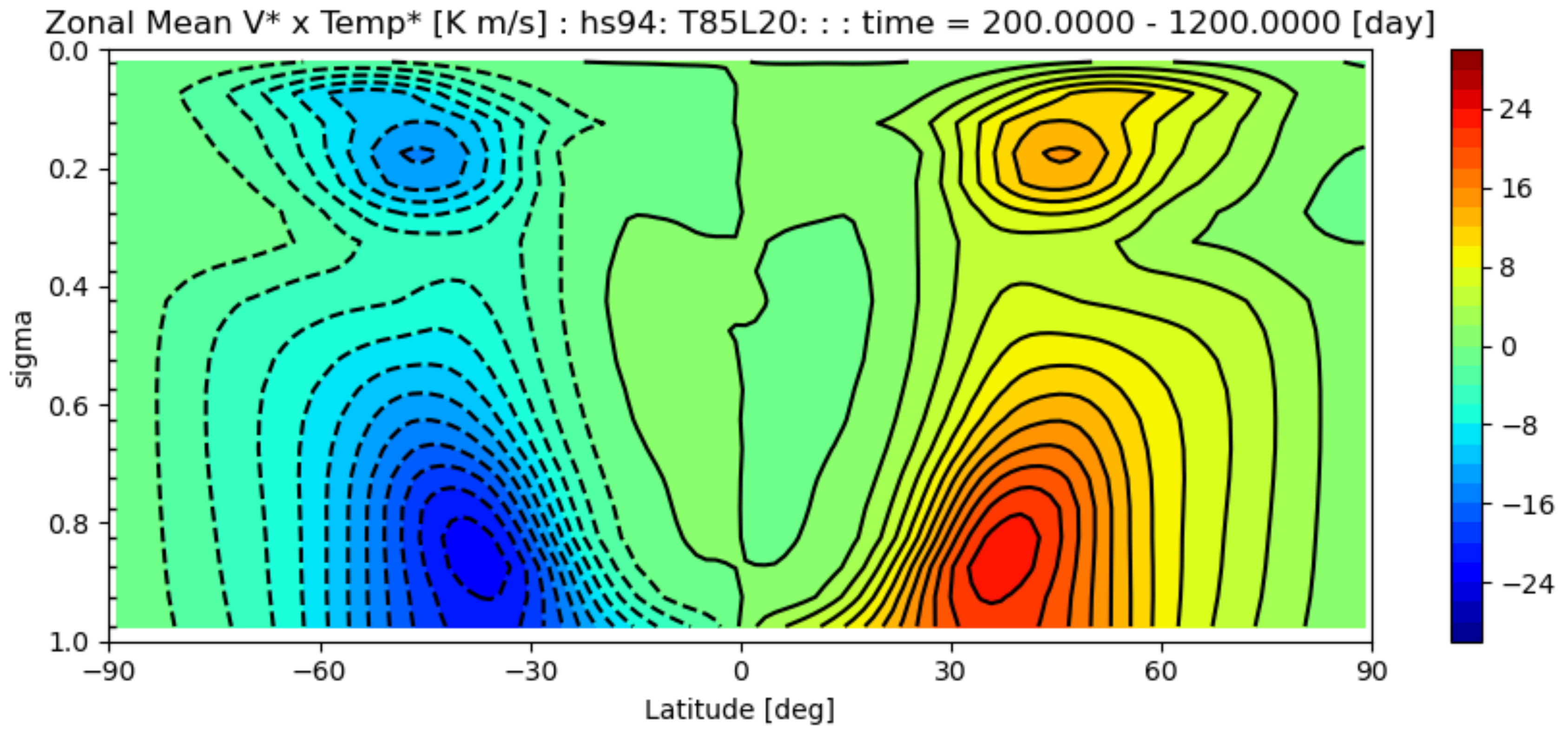
T10L20



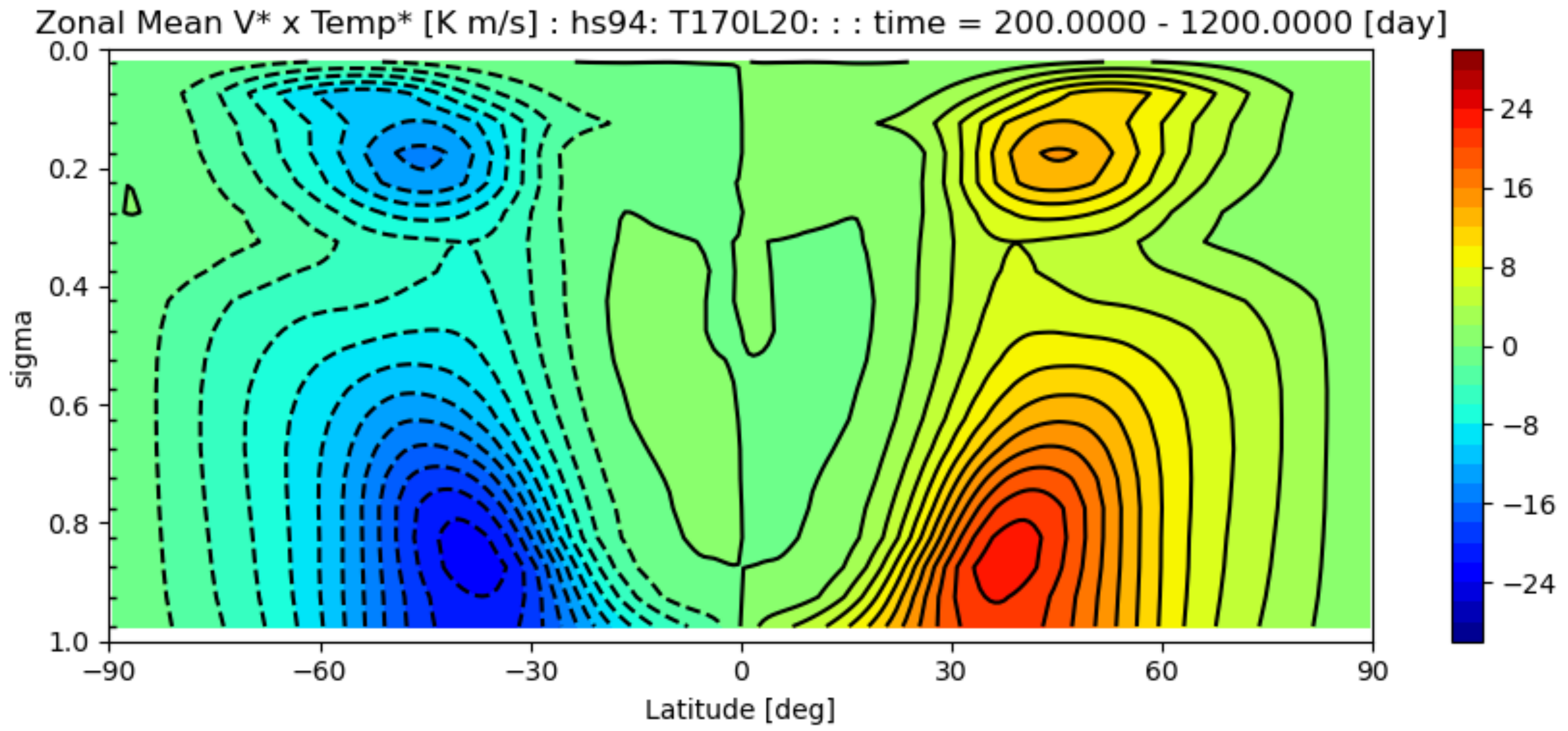
T21L20



T42L20

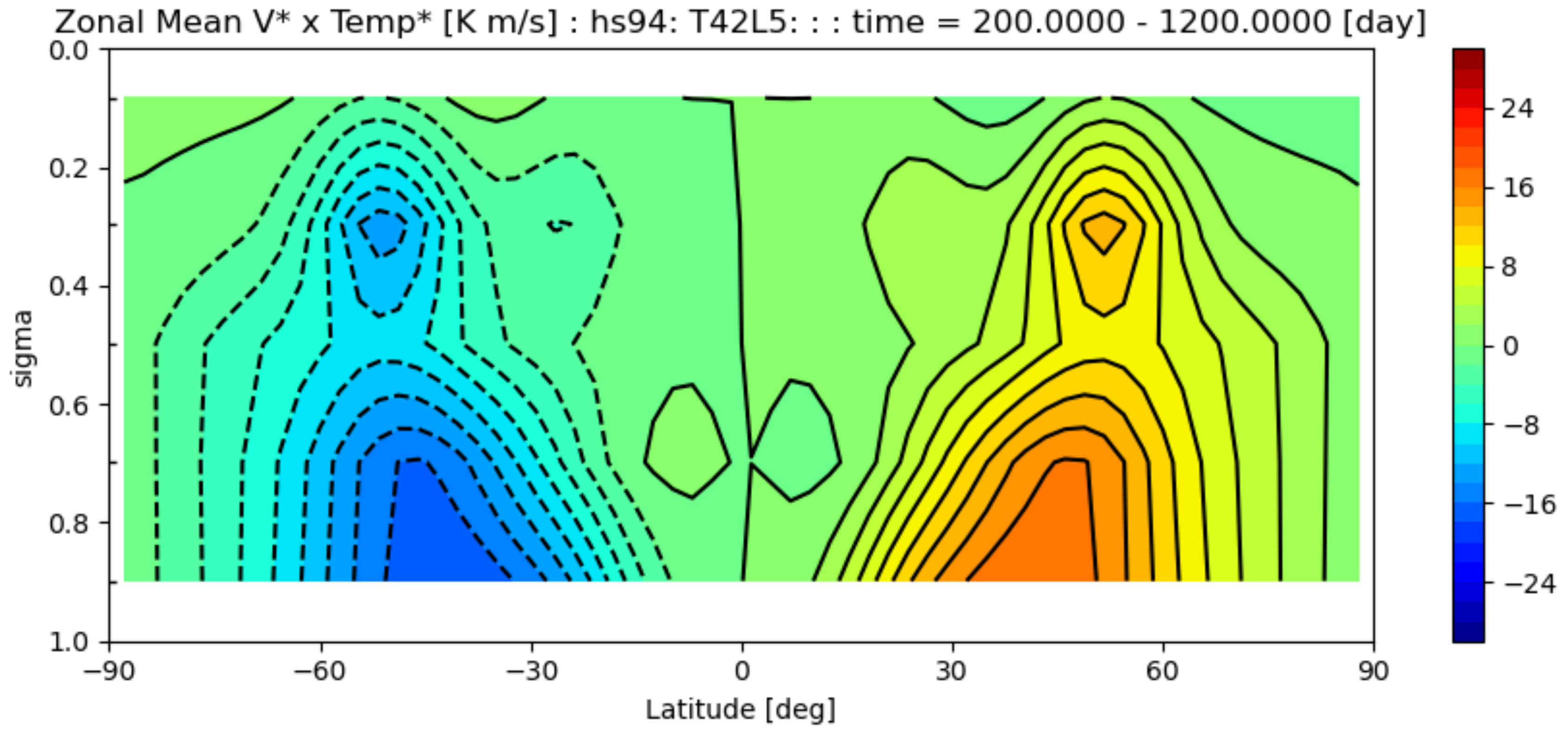


T85L20

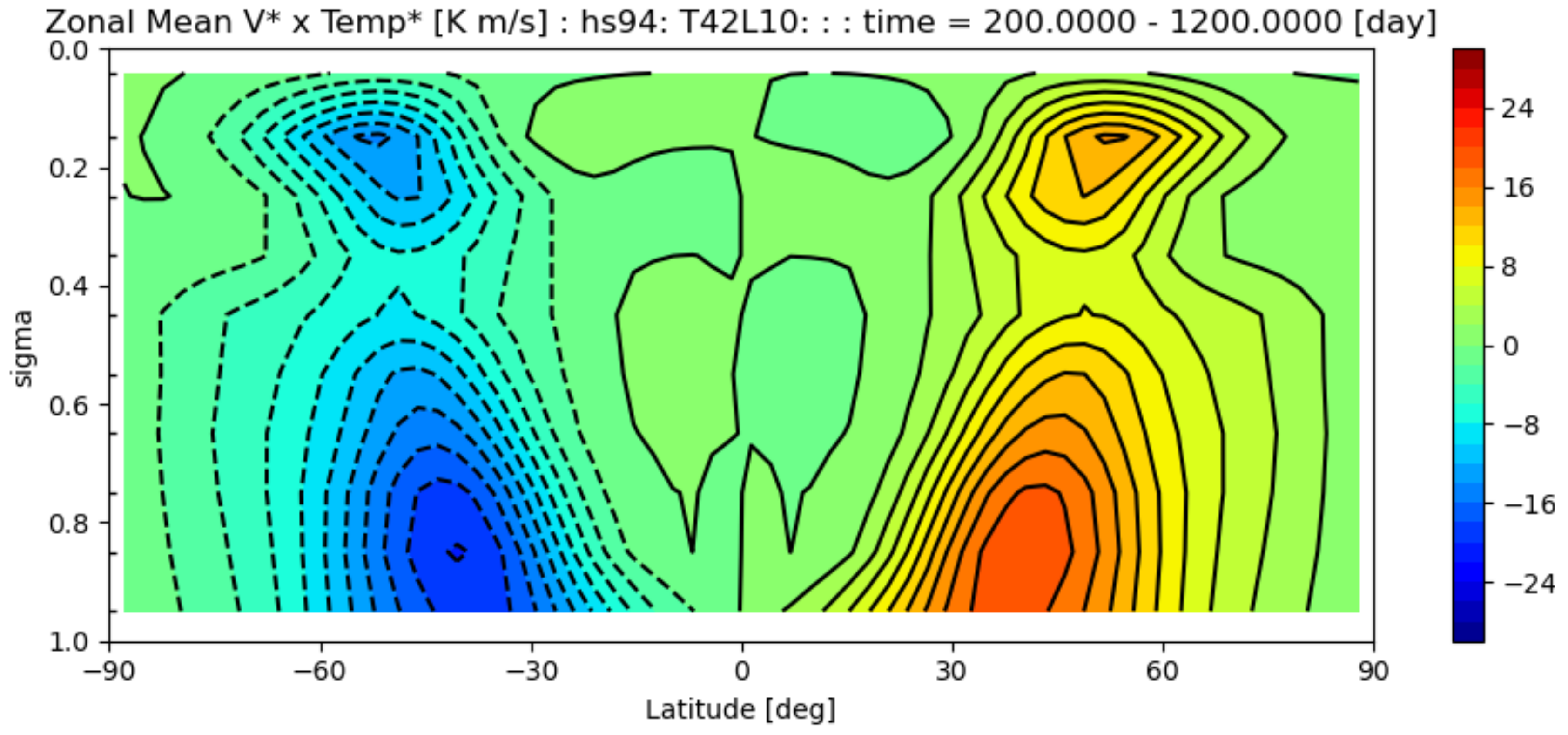


T170L20

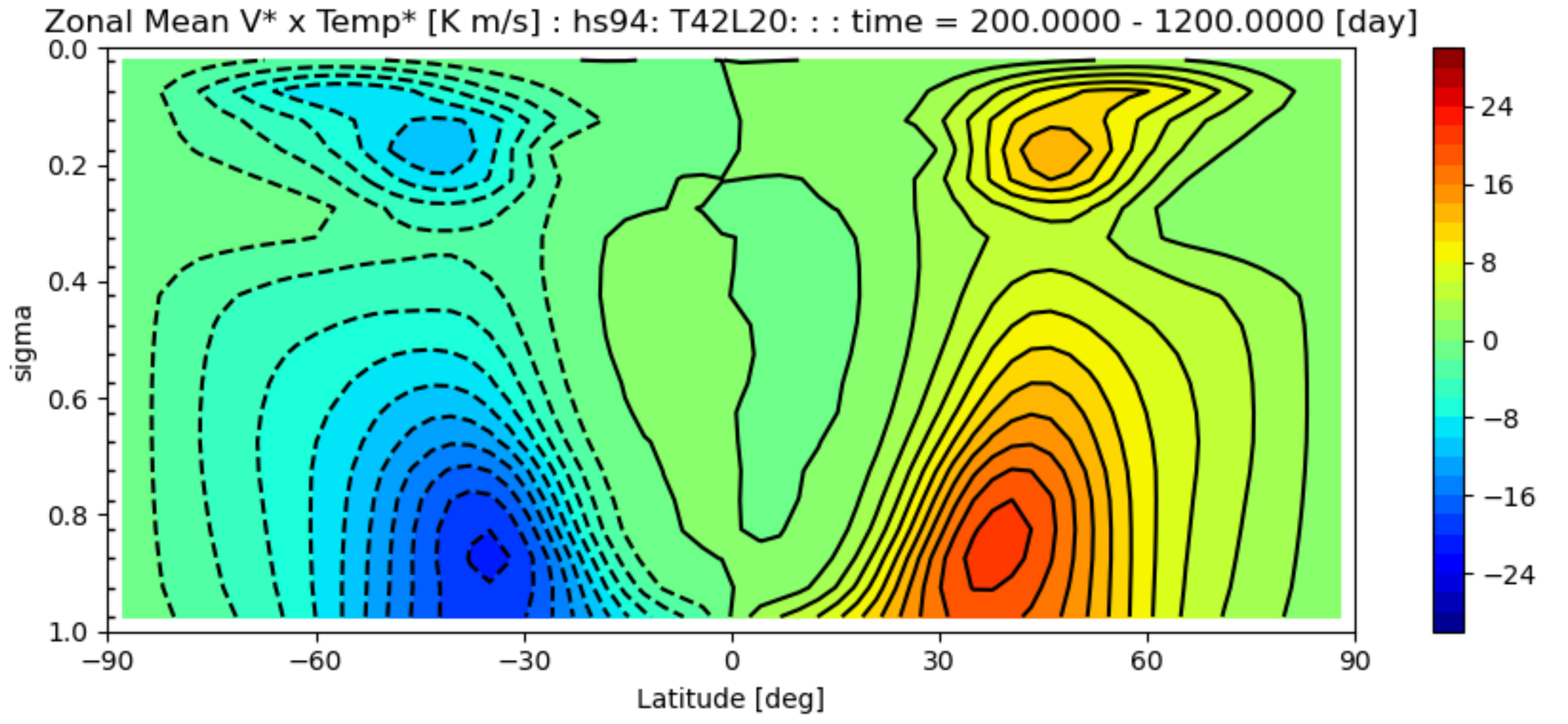
何も考えずに鉛直解像度を変える: V*Temp*



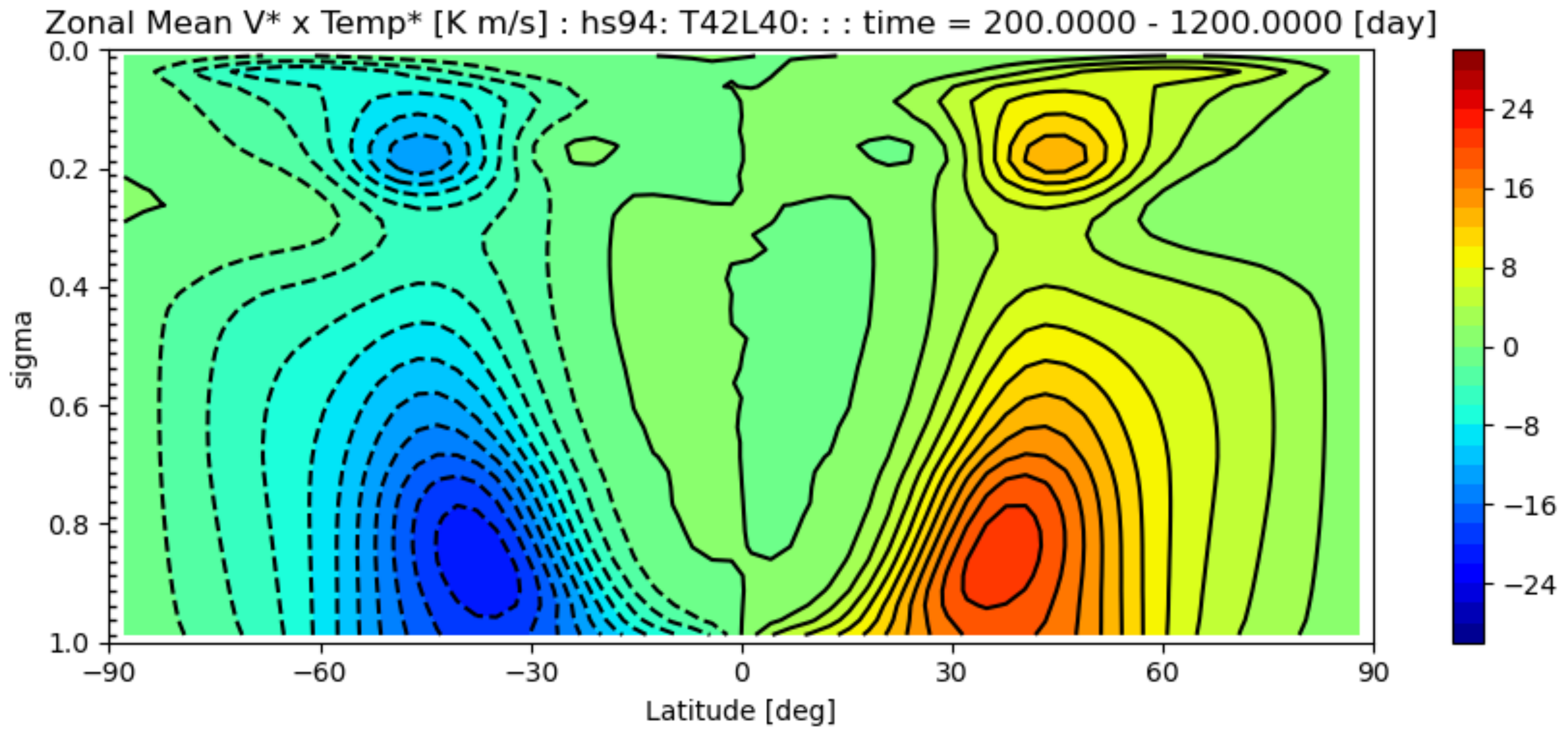
T42L5



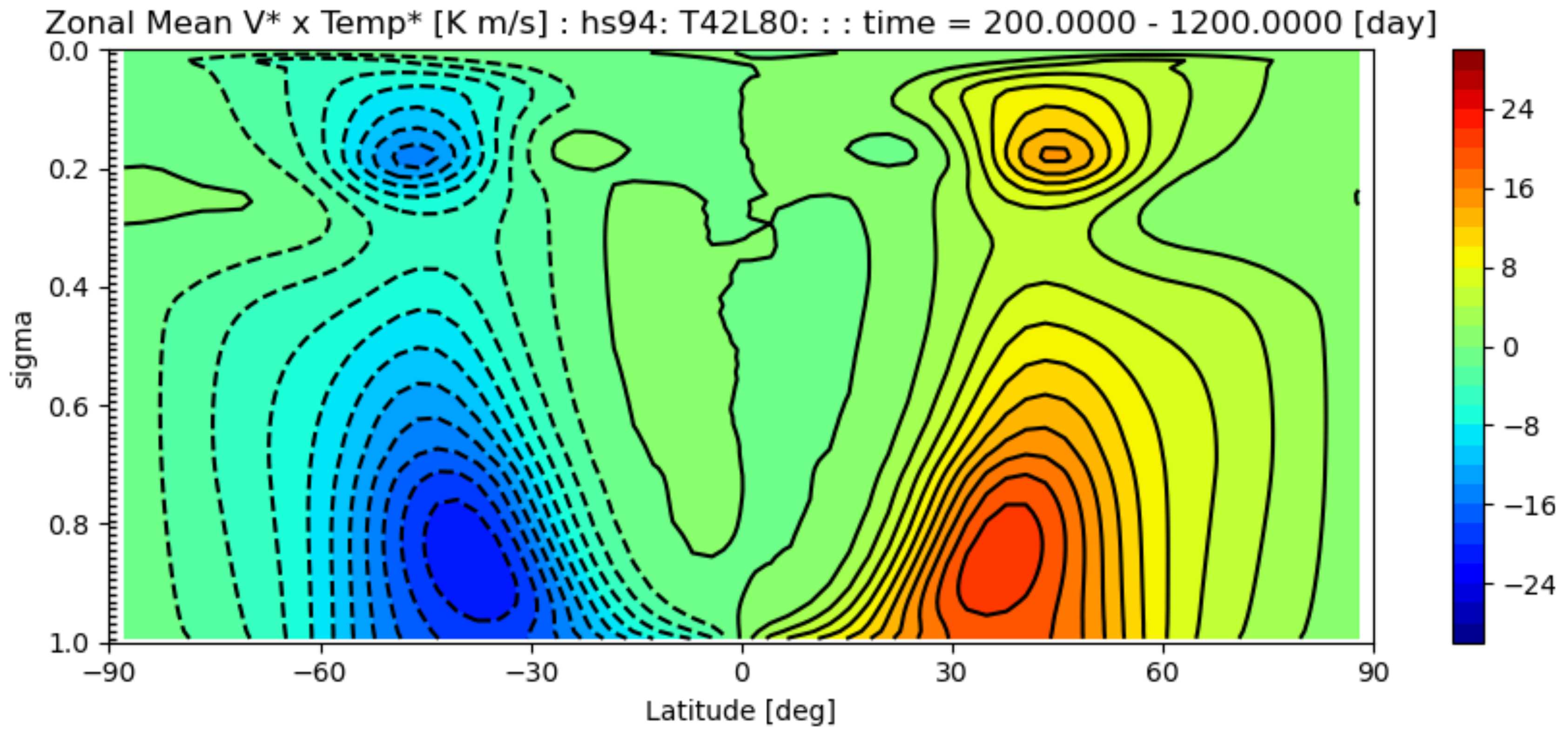
T42L10



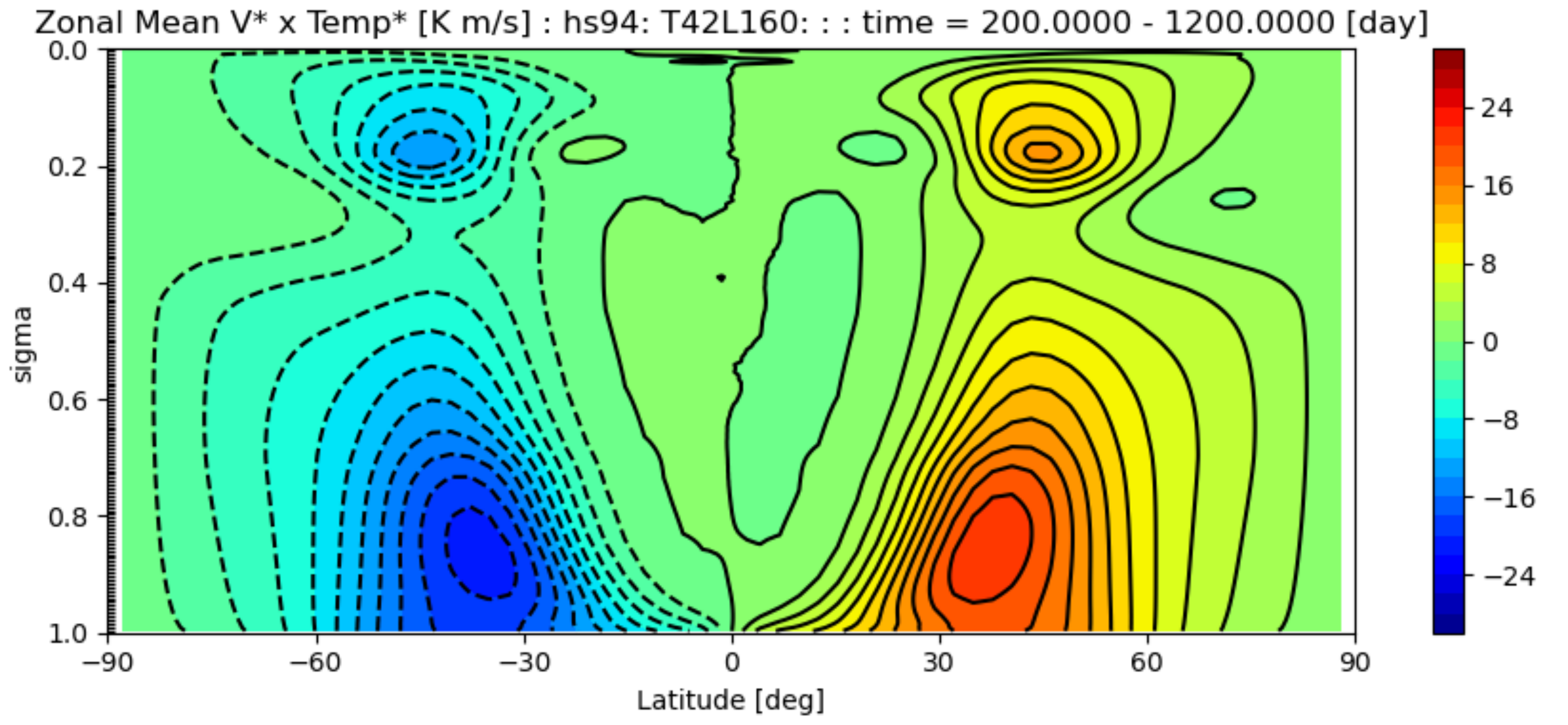
T42L20



T42L40

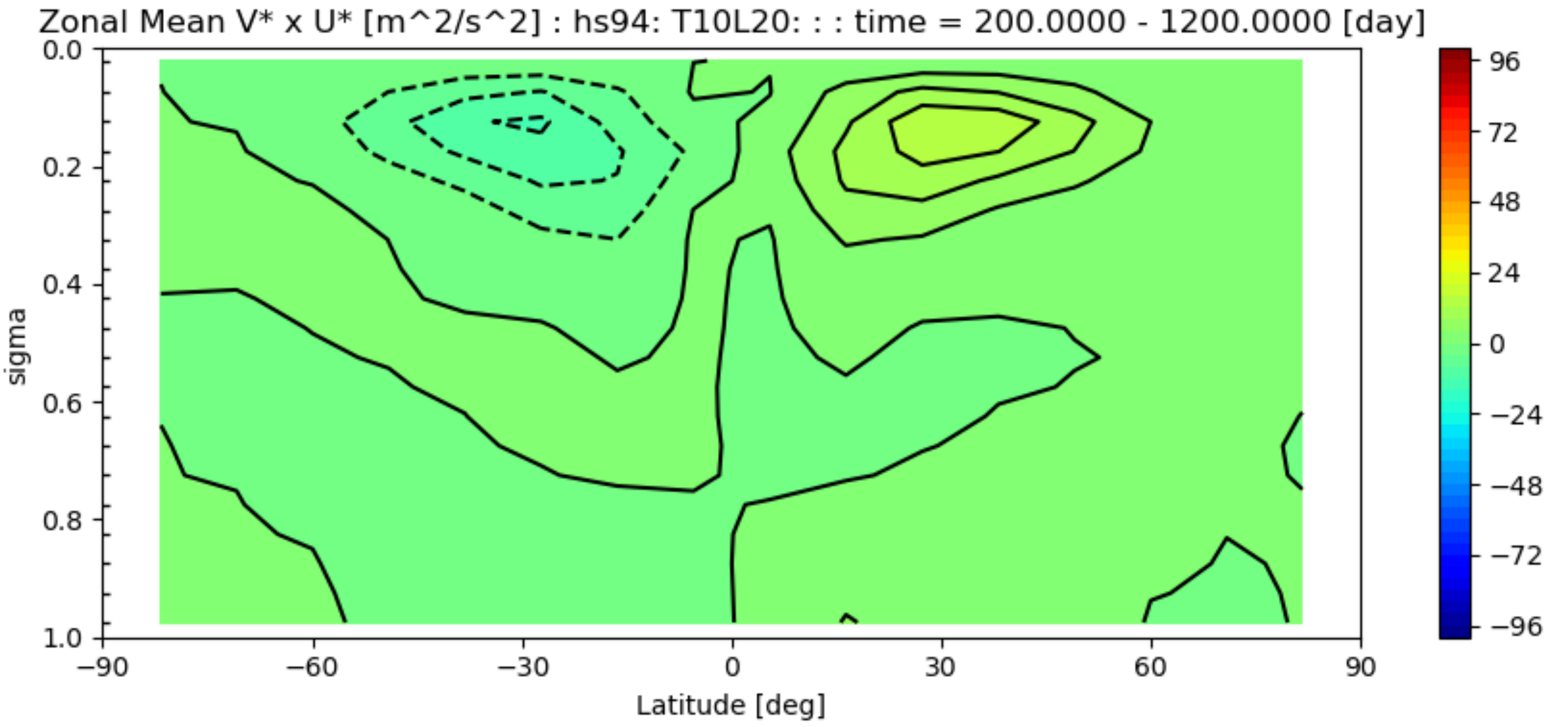


T42L80

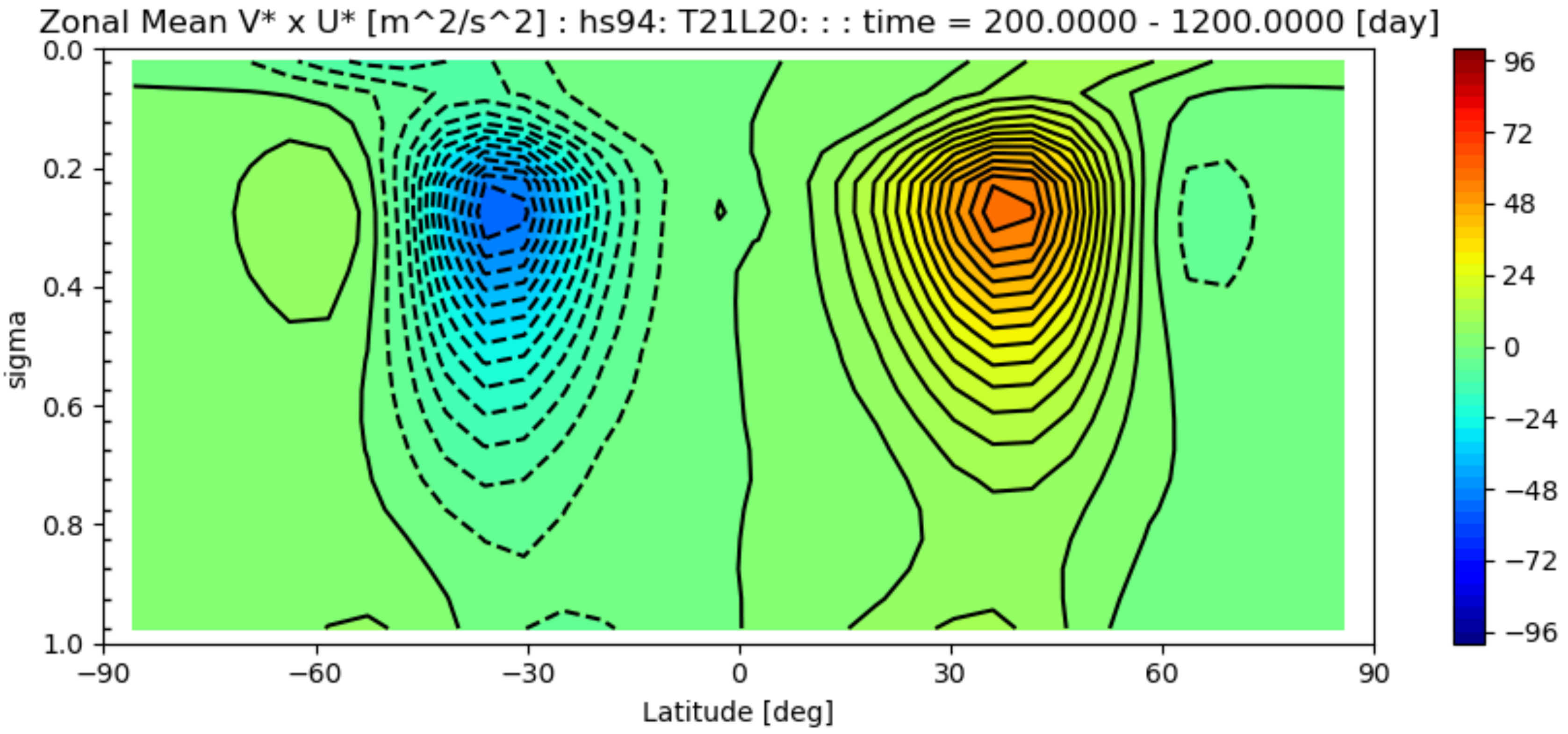


T42L160

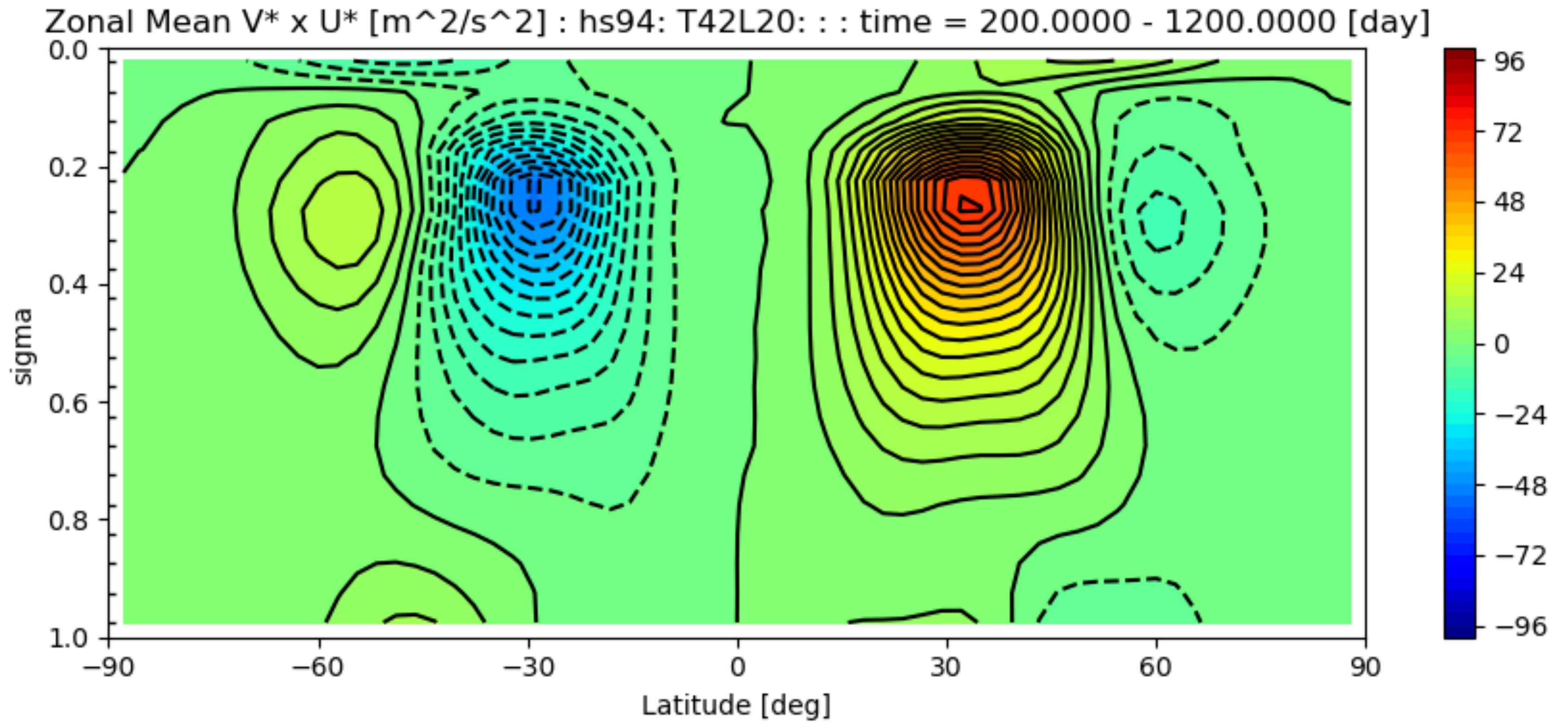
何も考えずに）水平解像度を変える: V*U*



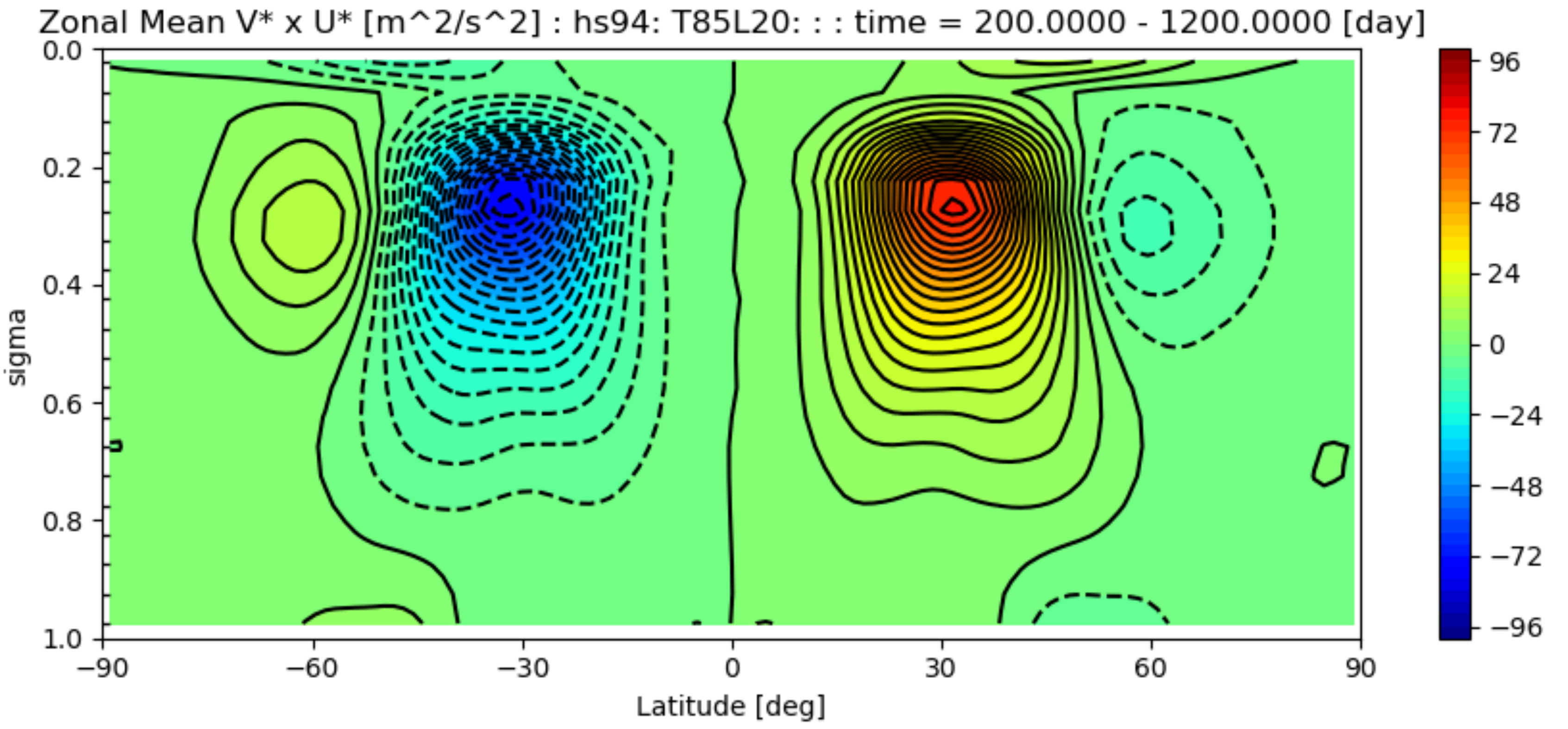
T10L20



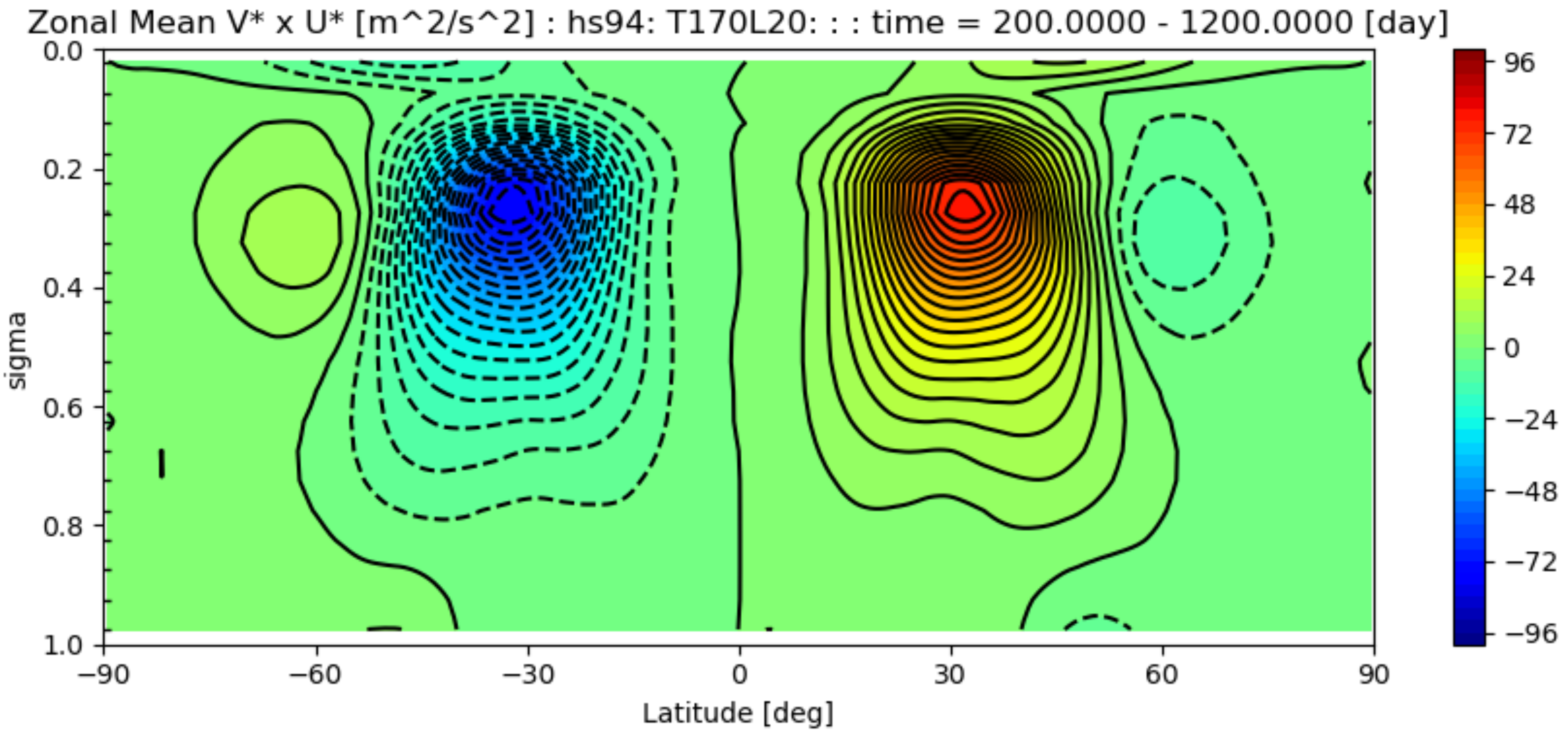
T21L20



T42L20

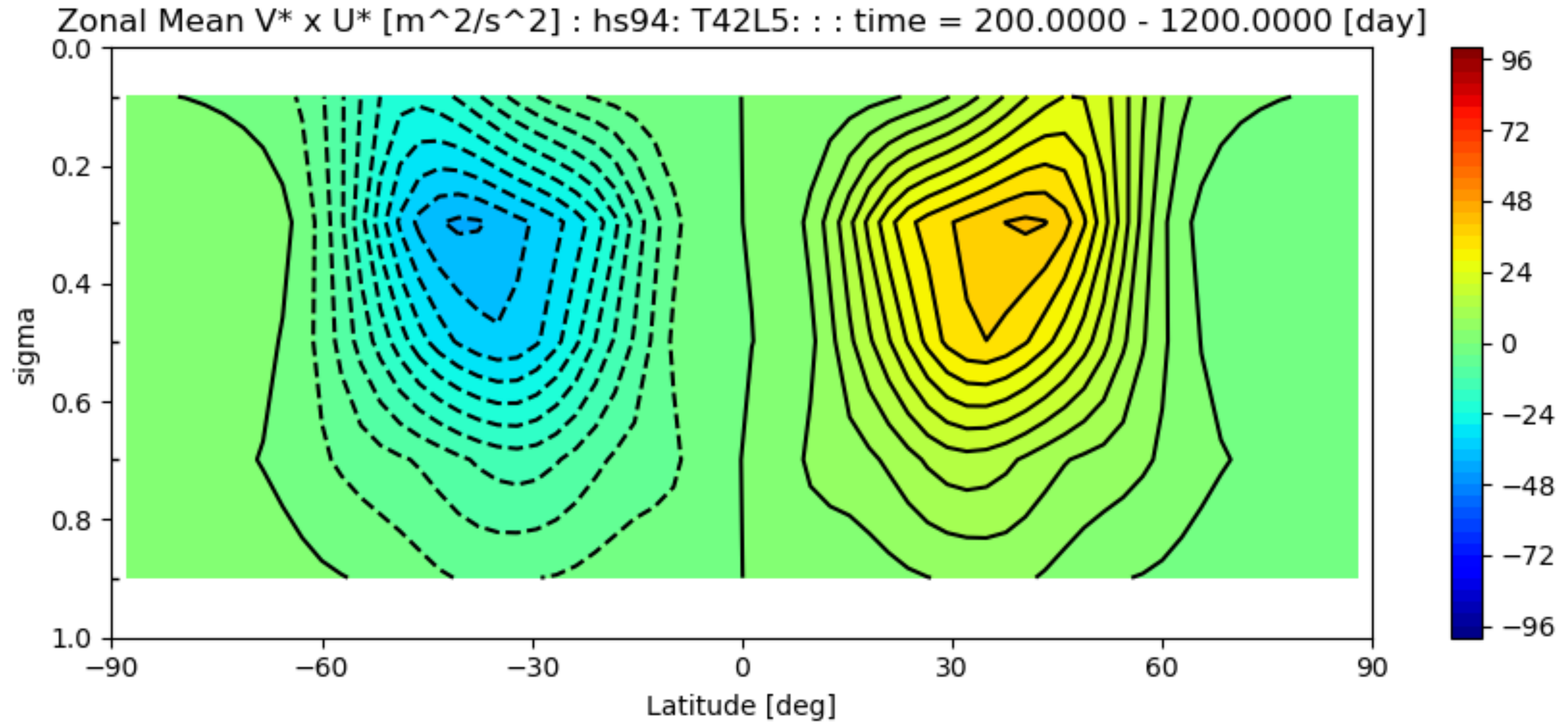


T85L20

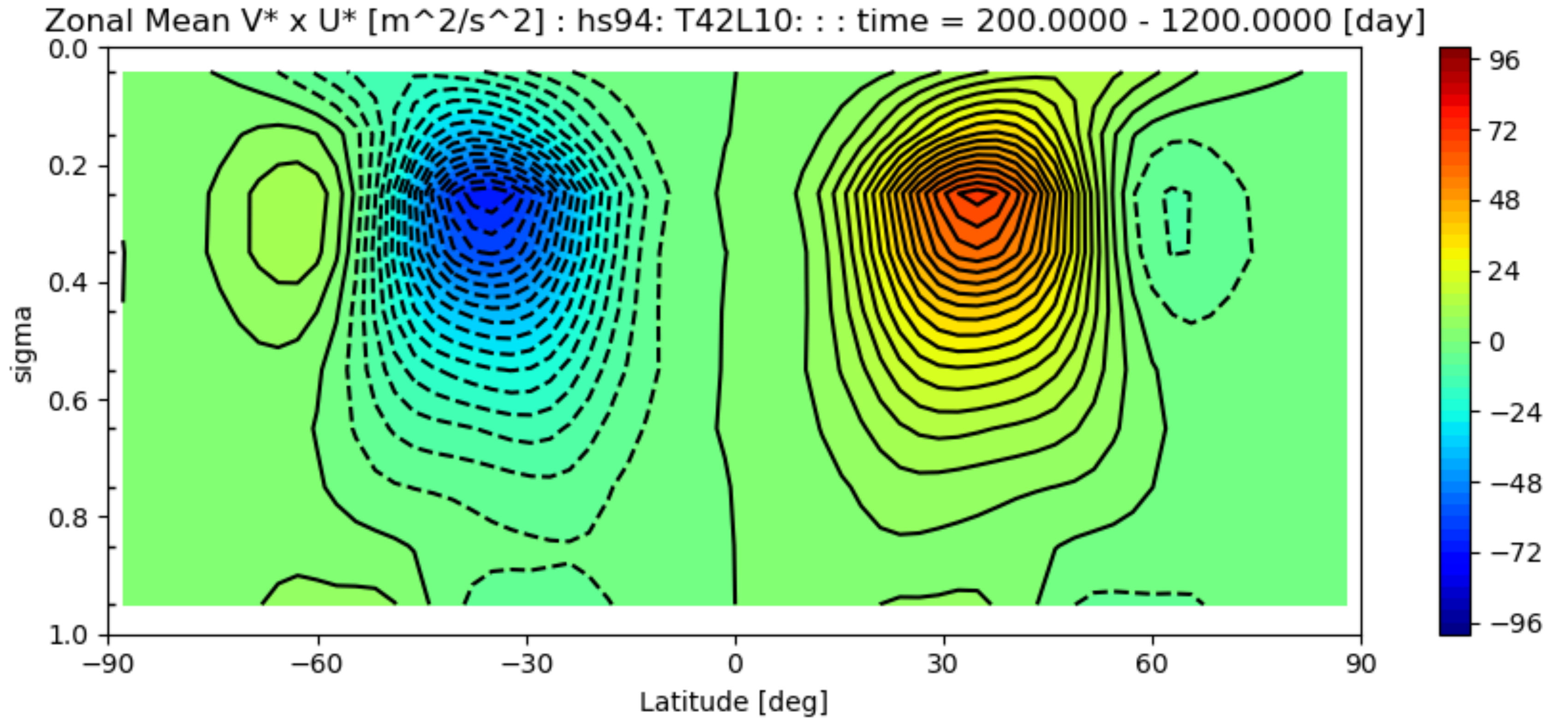


T170L20

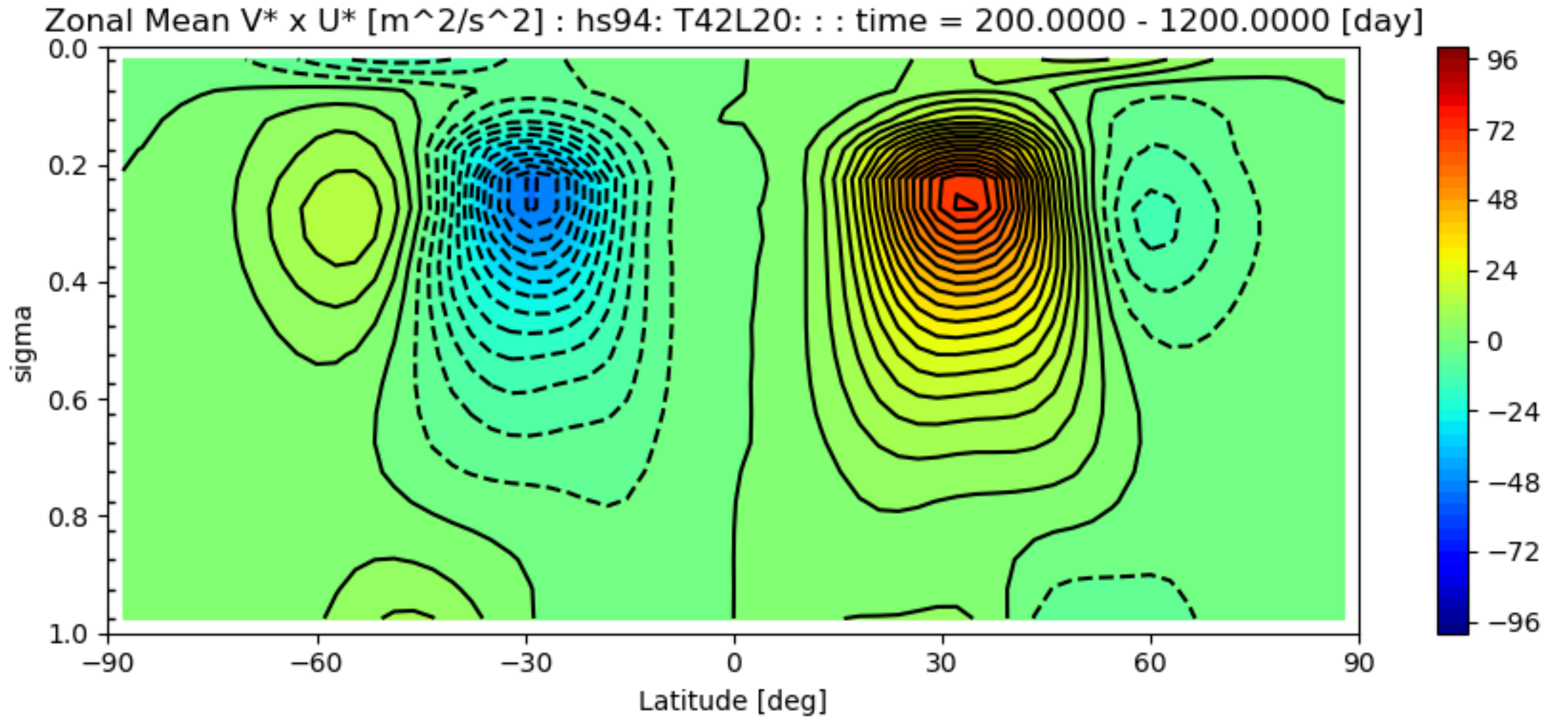
何も考えずに鉛直解像度を変える: V*U*



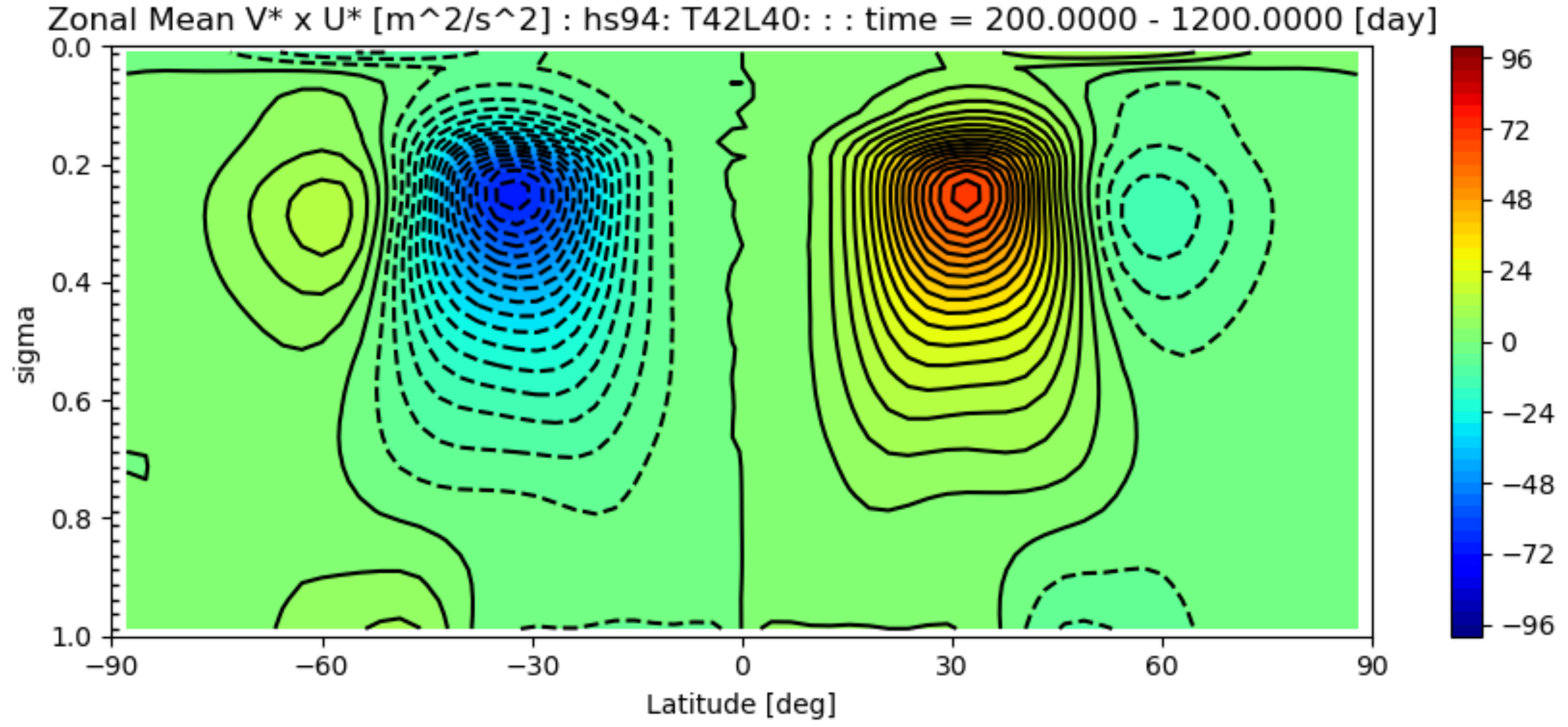
T42L5



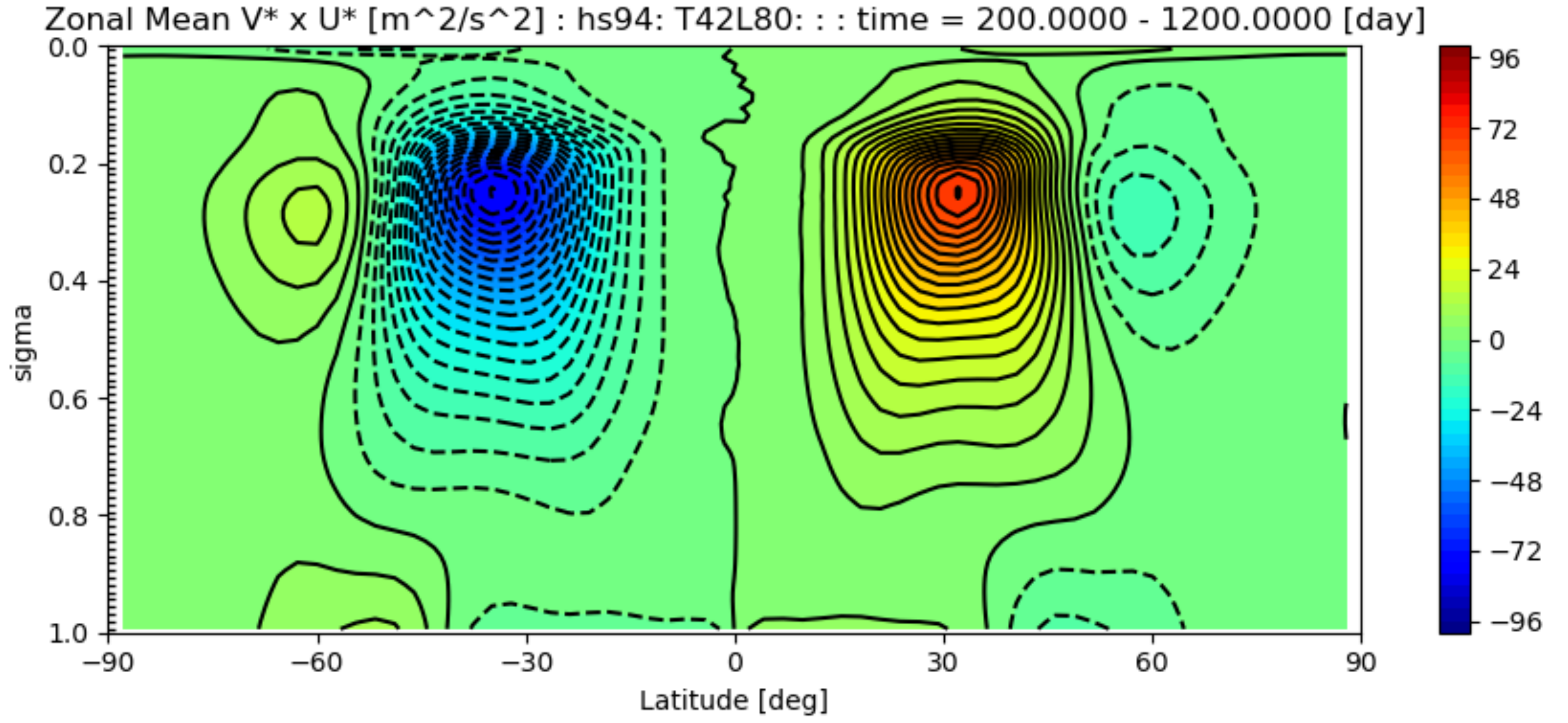
T42L10



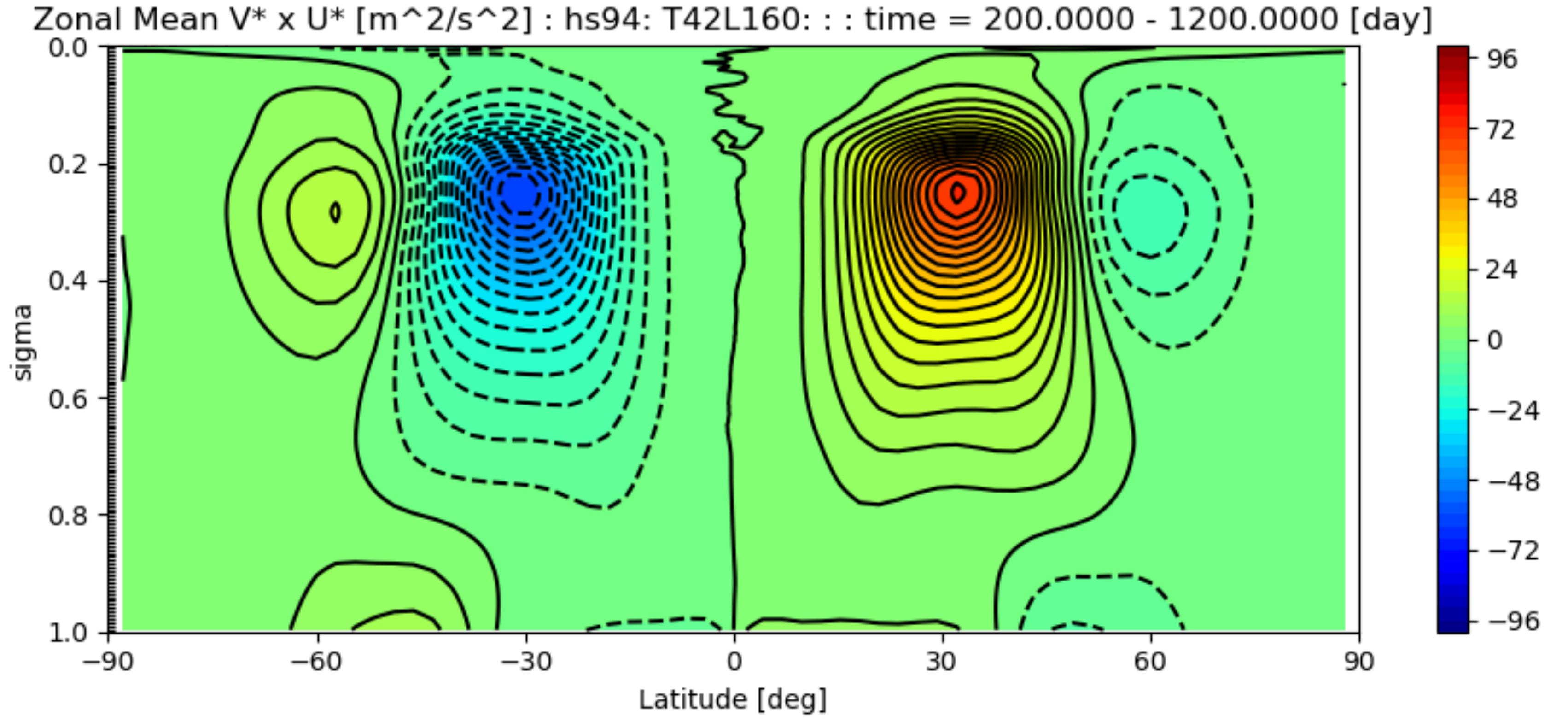
T42L20



T42L40



T42L80



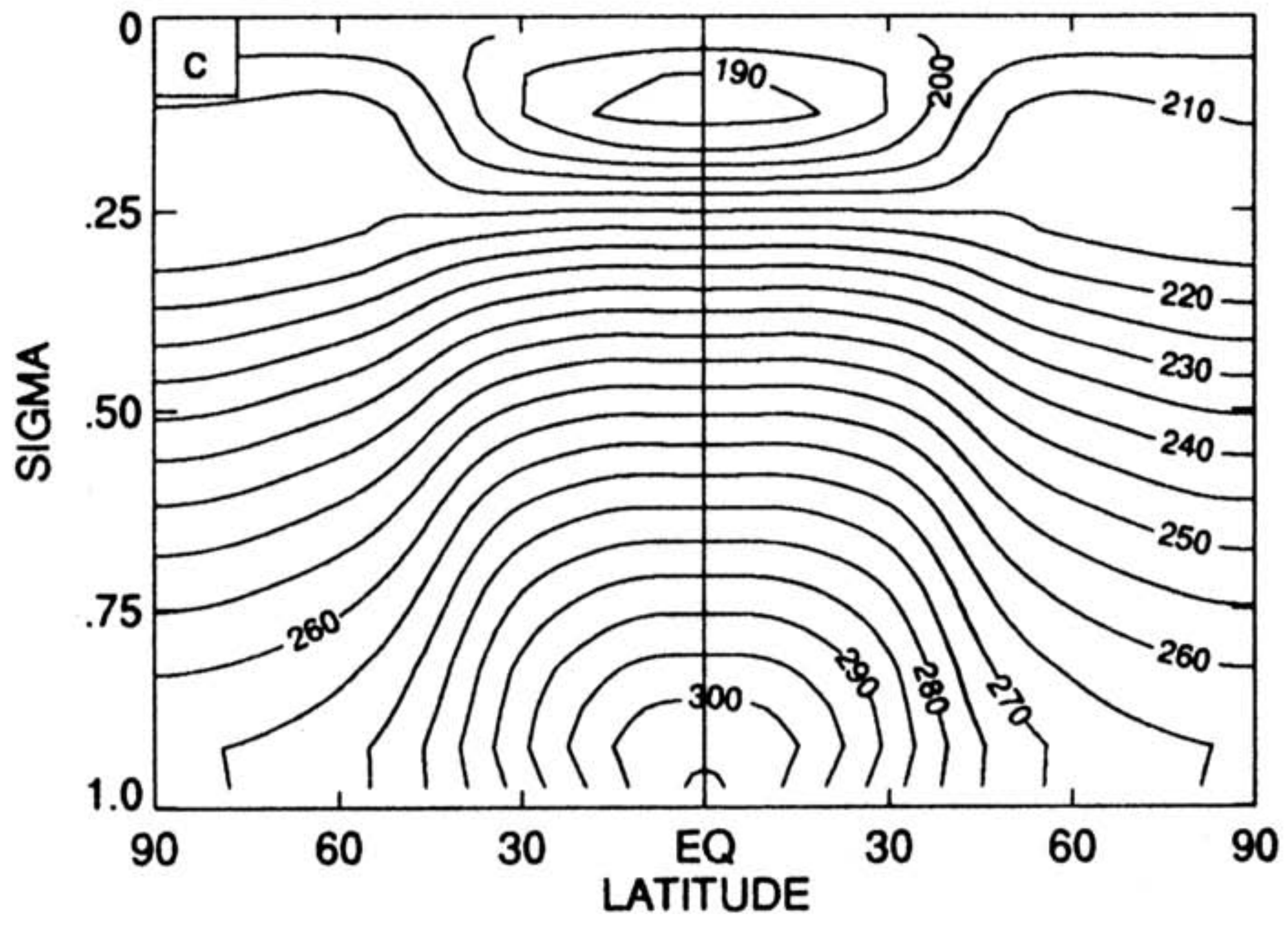
T42L160

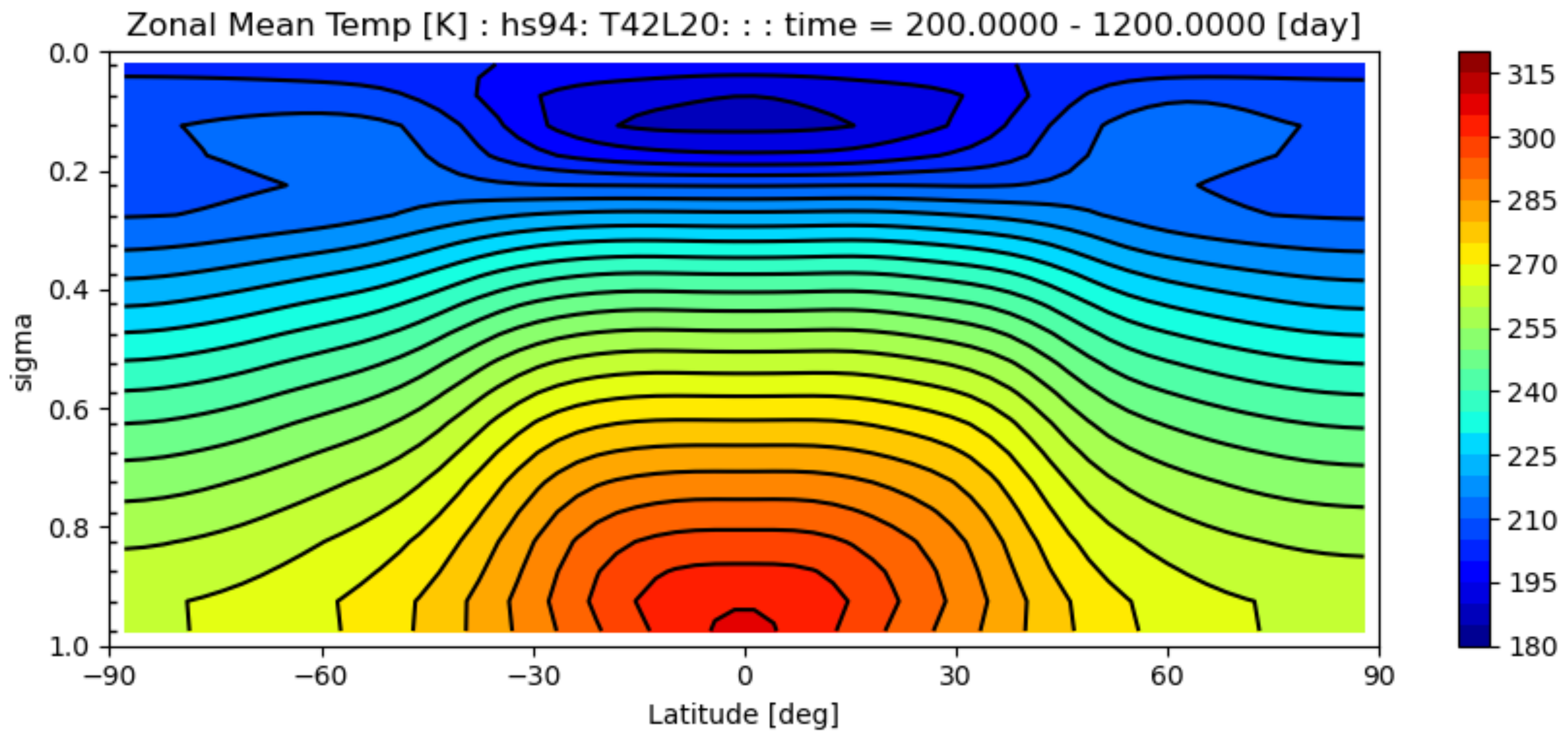
遭遇したり，思いついたりした，
いくつかの課題

いくつかの課題

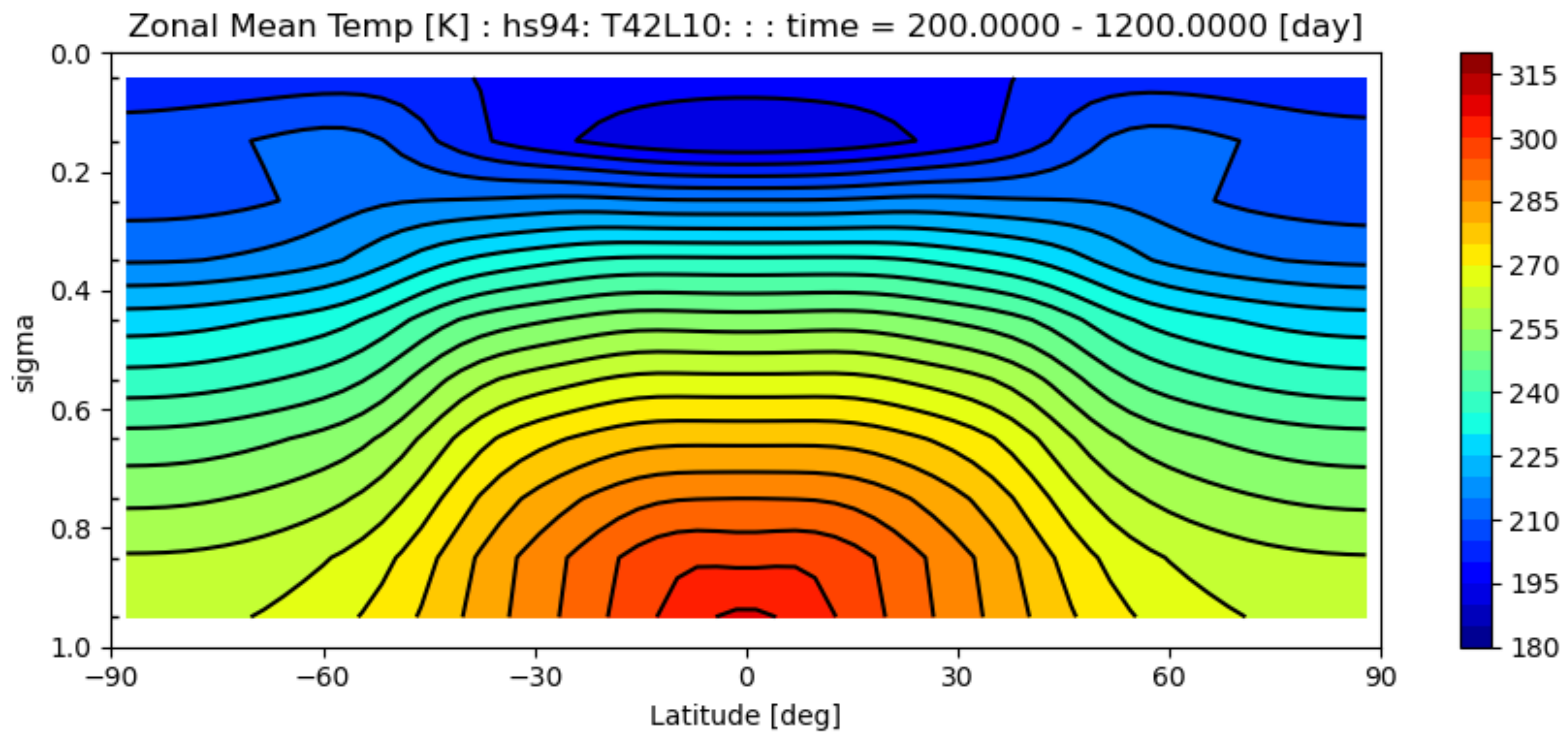
- 地表面付近の温度構造問題
  - 地表面付近が冷えすぎる
  - ガタガタ問題
- 長期変動
- 水平粘性 / エネルギー・スペクトル（再訪）

何故地表面付近に逆転層？

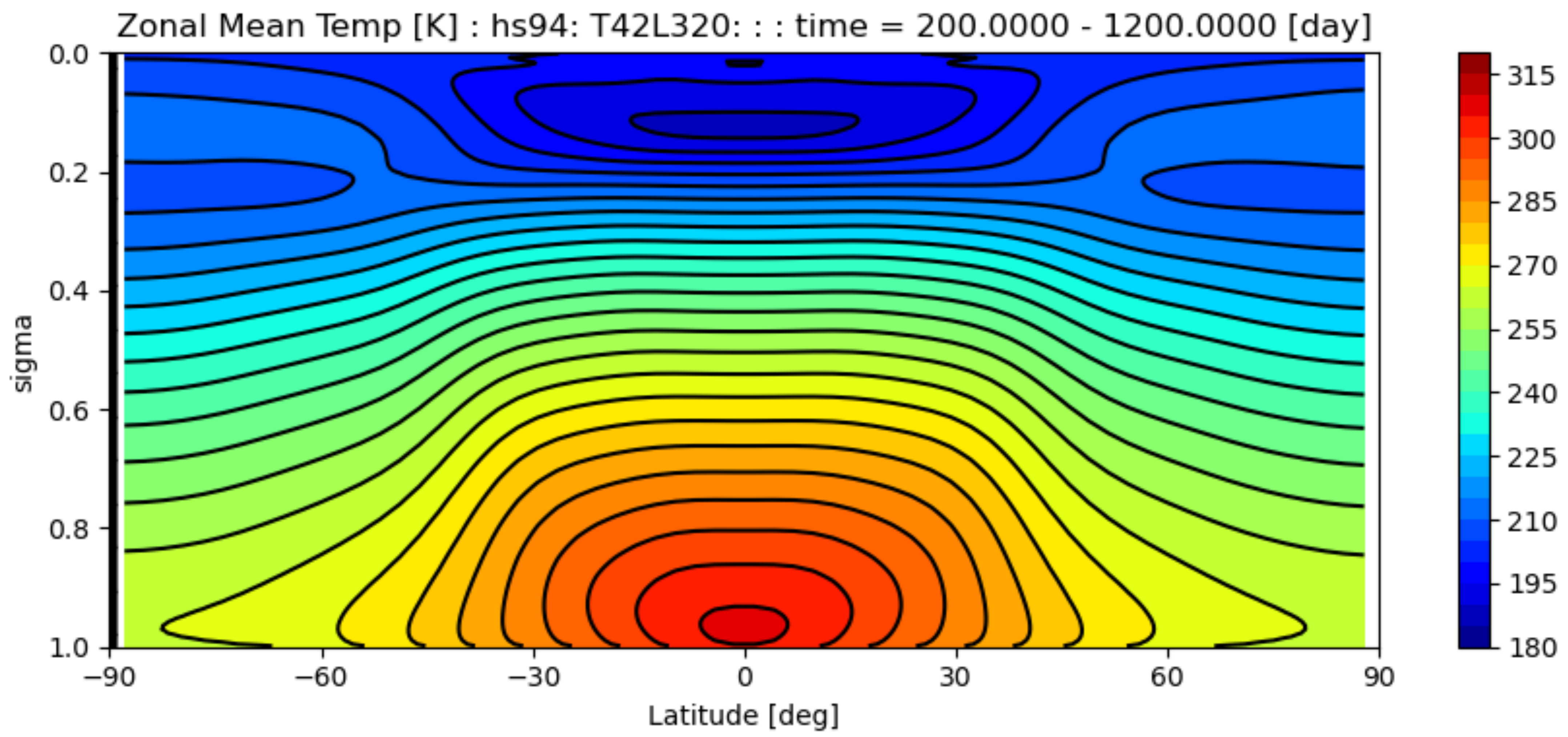




T42L20



T42L10



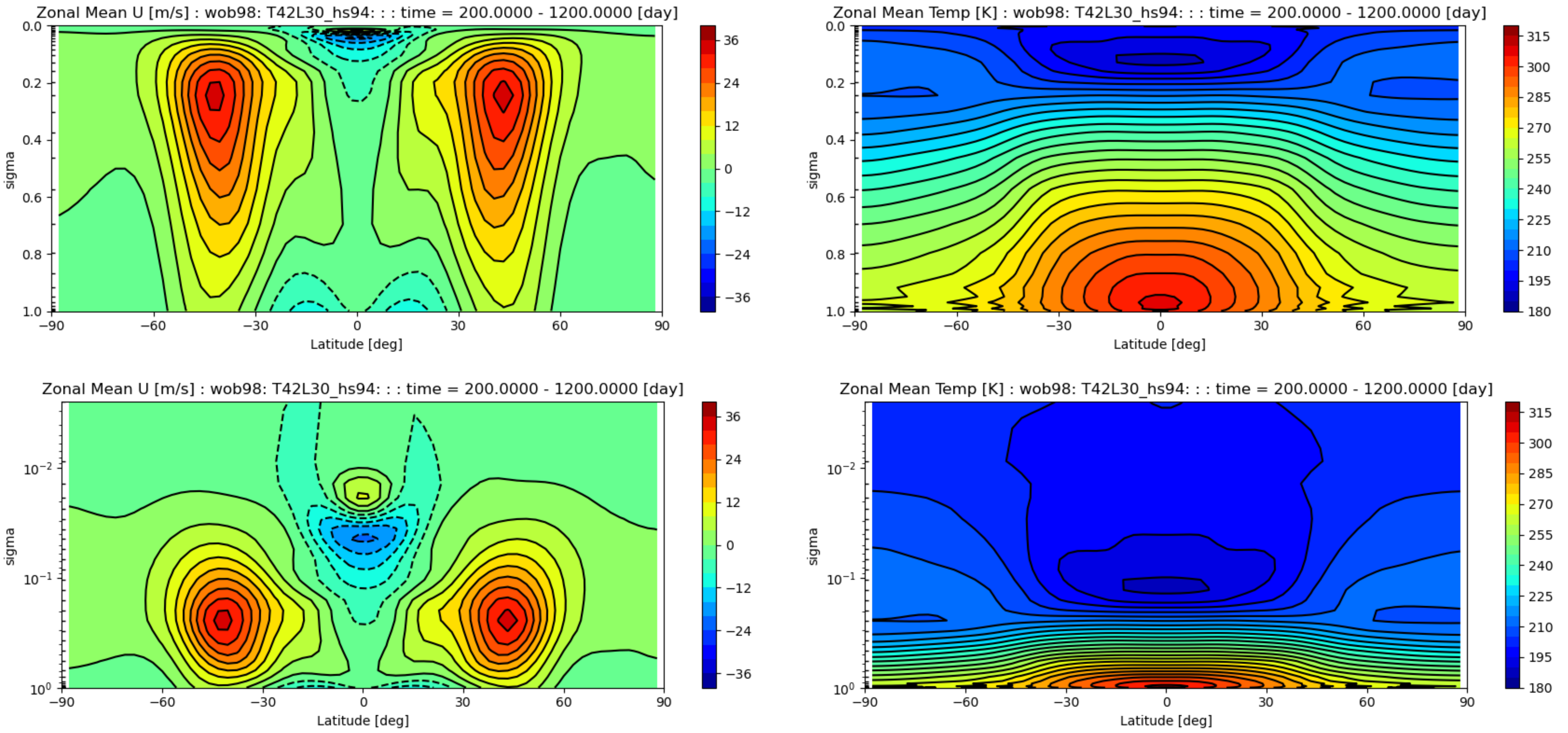
T42L320

下層付近ガタガタ問題

T42L30_hs94（現実的シミュレーション的な鉛直層配置）

σ

$\log \sigma$

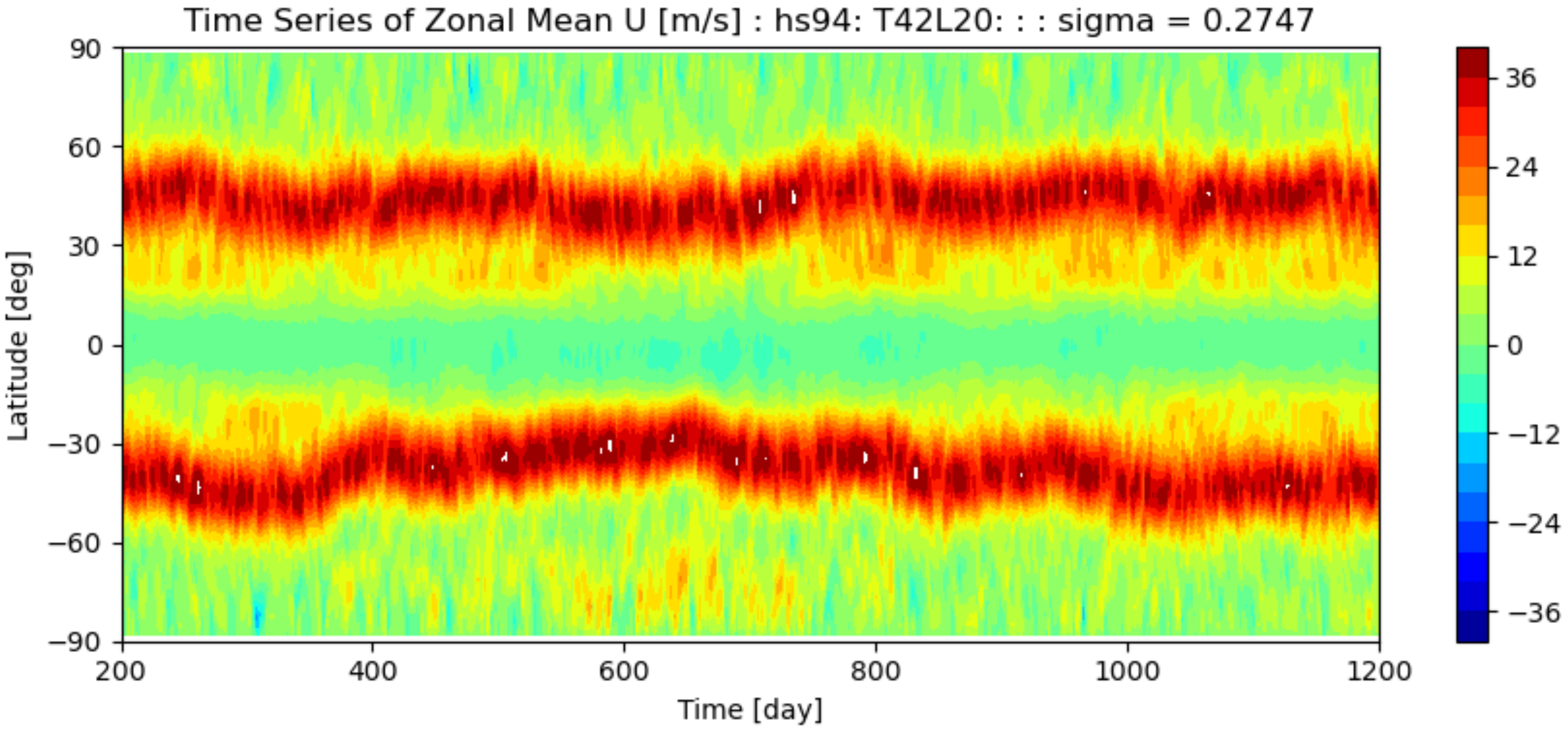


U

T

長期変動

経度平均Uの時間変動



Q. J. R. Meteorol. Soc. (1992), **118**, pp. 1211–1233 551.513.1

Spatial structure of ultra-low-frequency variability of the flow in a simple atmospheric circulation model

By I. N. JAMES and P. M. JAMES

Department of Meteorology, University of Reading, Reading RG6 2AU

(Received 27 March 1991; revised 9 June 1992)

SUMMARY

The internally generated variability of the global circulation on time-scales in excess of one year is investigated using a multilevel baroclinic primitive-equation model with moderate resolution of dynamical processes. The model includes idealized heating and friction. Maximum variability is found on time-scales of around a decade. Empirical orthogonal-function analysis reveals that the principal component of this variability is an alternate splitting and coalescence of the subtropical and mid-latitude jets. Associated changes in the strength and distribution of eddy activity are found. The character of the ultra-low-frequency variability is completely changed for very low resolutions, but seems relatively insensitive to details of model formulation at higher resolution. The possibilities of deriving a low-order model which includes ultra-low-frequency variability are considered.

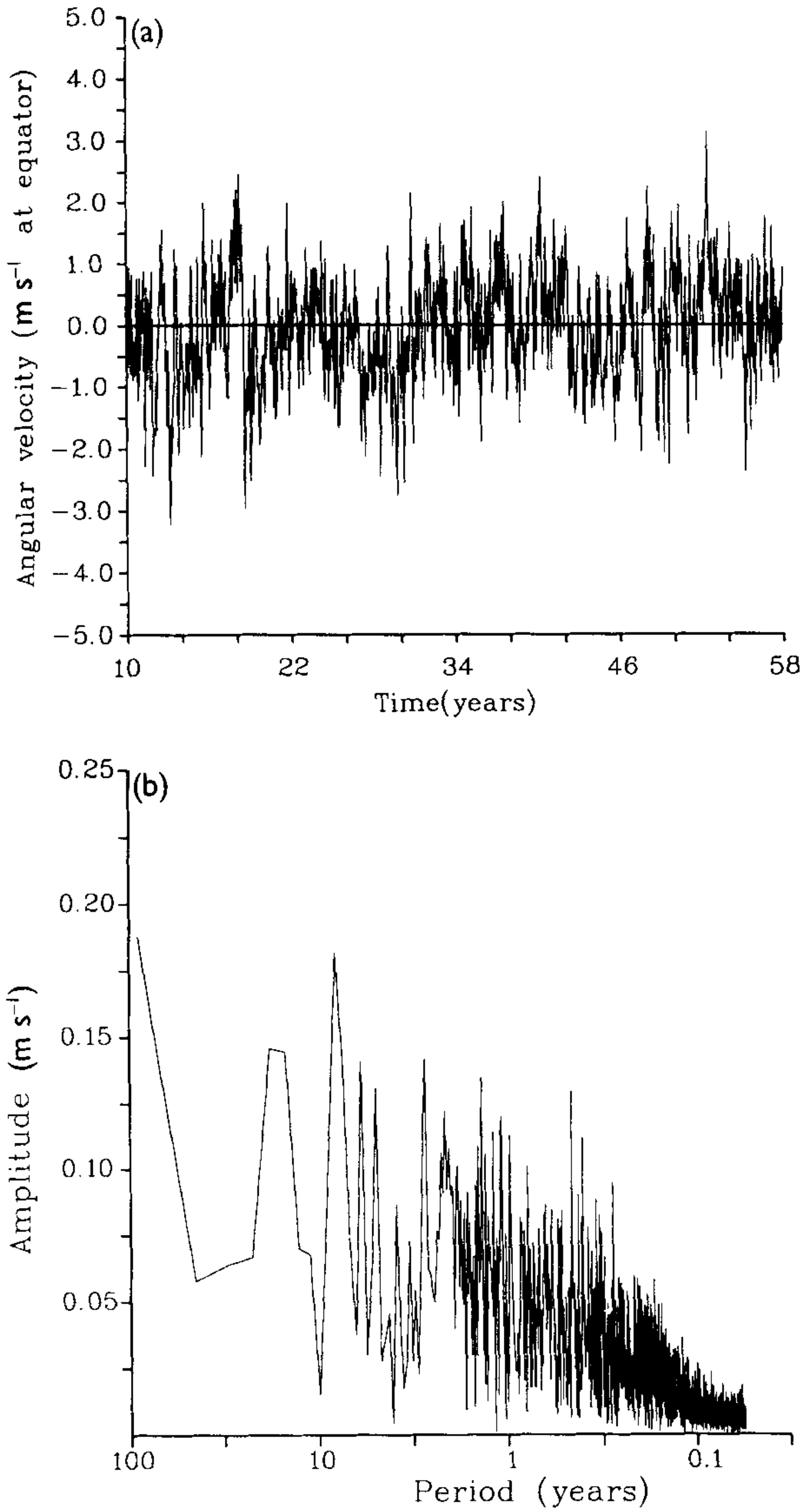


Figure 3. Ultra-low-frequency variability of the atmospheric angular velocity in Run 1. (a) Time series of the angular velocity from year 10 to year 58 of the run. (b) Amplitudes of the Fourier coefficients for the time series from year 4 to year 100.

散逸（水平粘性など）とエネルギースペクトル

- 解像度を変えたとき，粘性係数をどう変えれば良いのか？
- 超粘性の次数への依存性

Held and Suarez (1994)再訪：まとめ

- とりあえずDCPAMを走らせることができた（京大数理研 竹広さんに感謝）
- テスト計算でHS94実験を解像度を変えて行った（網羅的ではない）
- 統計量は解像度に依存し，解像度を上げると収束しているように見えなくもないが，散逸の調整をきちんと考えていないので，更なる検討が必要である
- そのほか，今後の課題として，地表面付近の温度構造，長期変動，エネルギースペクトル + 水平粘性などの問題が挙げられる
- Pythonで解析と描画ができるように整備中 [特に，内挿（σ→p座標変換を含む），スペクトル解析（松嶋さんのISPACKのPythonインタフェースを活用），TEM解析]
- Williamson et al. (1998)の拡張（WOB98）は行った（他人に見せられる状態ではないが）