

熱潮汐波に着目した
あかつき UVI 観測から得られる
水平風速のデータ同化と
金星客観解析データ作成の試み

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金星大気の観測・シミュレーション・データ同化に関する研
究会

2021/03/15 オンライン

はじめに



はじめに 本研究の目的

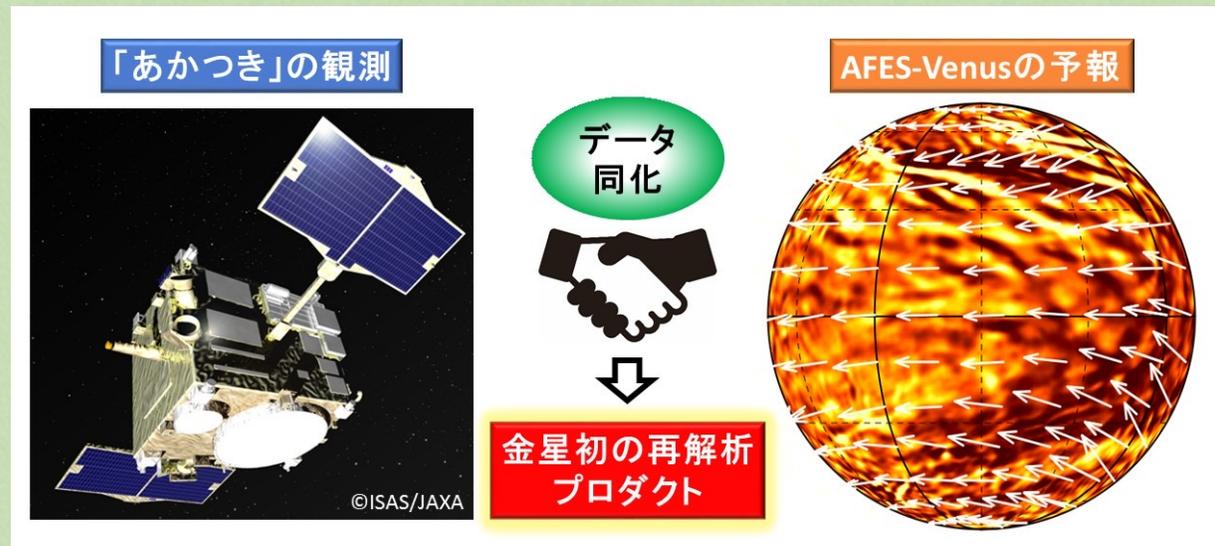
- 目的：あかつきデータから金星の再解析プロダクトを作成・公開
- 地球：
 - JRA（気象庁）
 - ERA（ECMWF）
 - NCEP/NCAR 再解析
- 火星：
 - EMARS（The Ensemble Mars Atmosphere Reanalysis System）
 - MACDA（The Mars Analysis Correction Data Assimilation Dataset）
- 金星：
 - かがみ

火星の再解析プロダクトの公開例
(MACDA)

はじめに 再解析プロダクトの作成に必要なもの

- モデル: 観測とある程度近い挙動を持つモデル
→ AFES-Venus (Sugimoto et al. 2017) (Atmospheric GCM For the Earth Simulator)
- データ同化システム:
→ ALEDAS-V (Sugimoto et al. 2017) (AFES LETKF Data Assimilation System

for Venus)

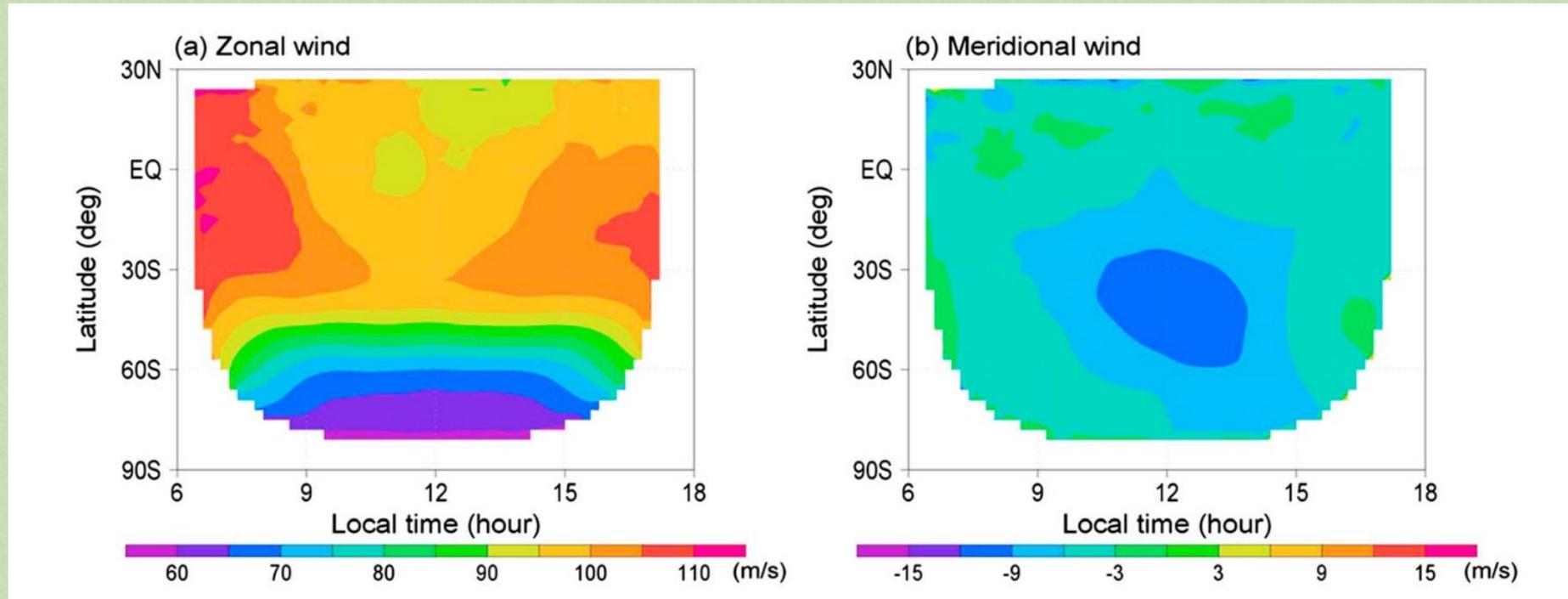


科研費・基盤S「あかつきデータ同化が明らかにする金星大気循環の全貌」



はじめに 熱潮汐波の位相改善 (Sugimoto et al. 2019)

- 同化に用いた観測データ
 - Venus Express 紫外イメージャから得られる水平風速

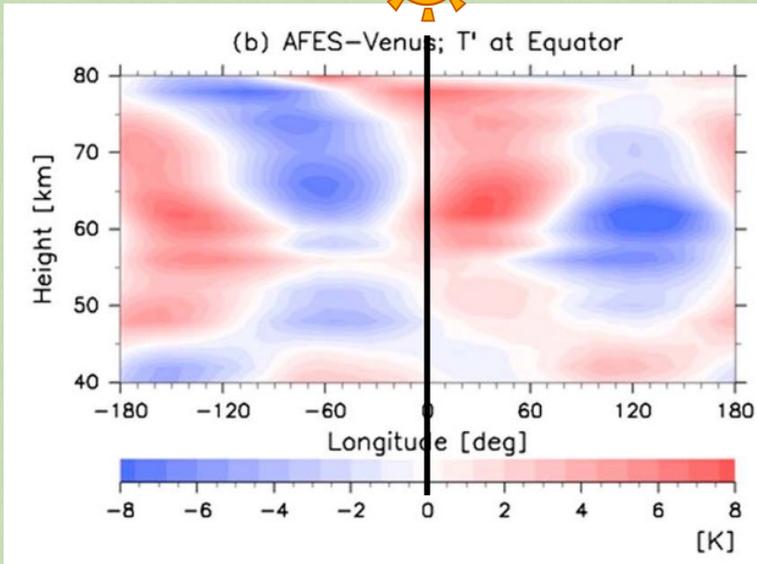


同化に用いた観測データ (東西風・南北風)



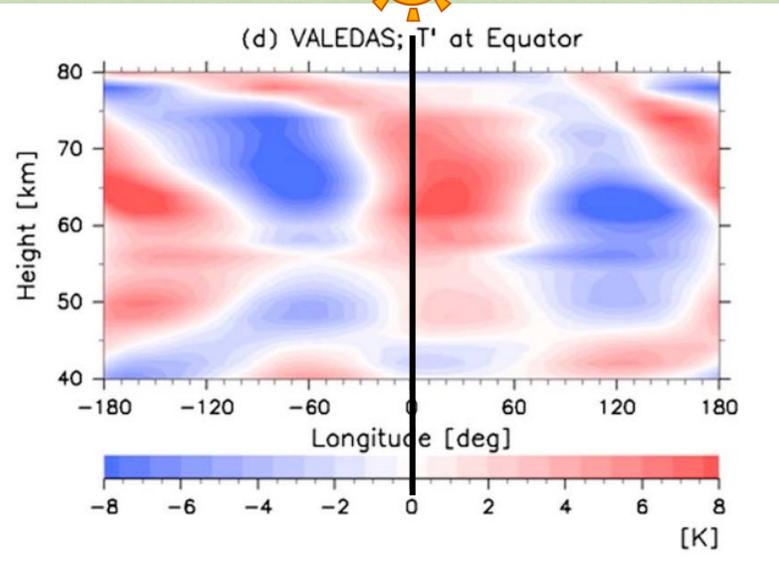
はじめに 熱潮汐波の位相改善 (Sugimoto et al. 2019)

- 温度の緯度高度断面 (赤道上)
 - 東西風速を同化することで、温度の位相が改善

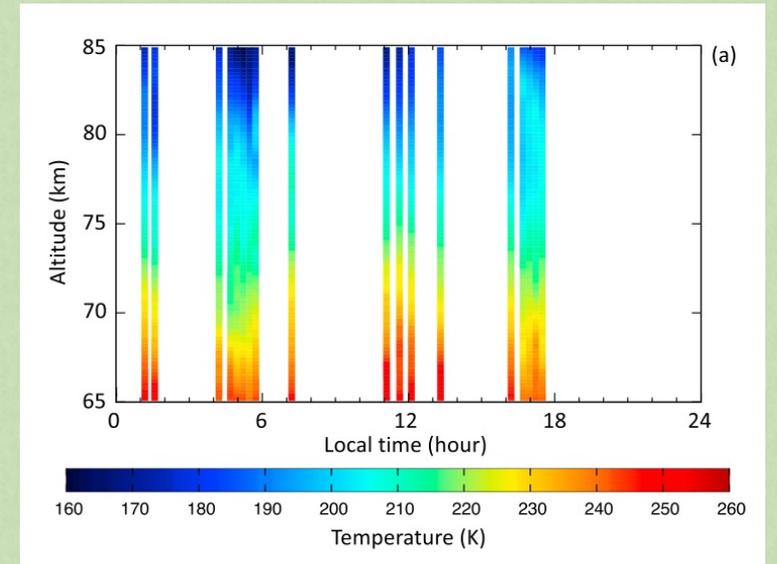


AFES-Venus

太陽直下点を参照点に30地球日のコンポジット平均



ALEDAS-V

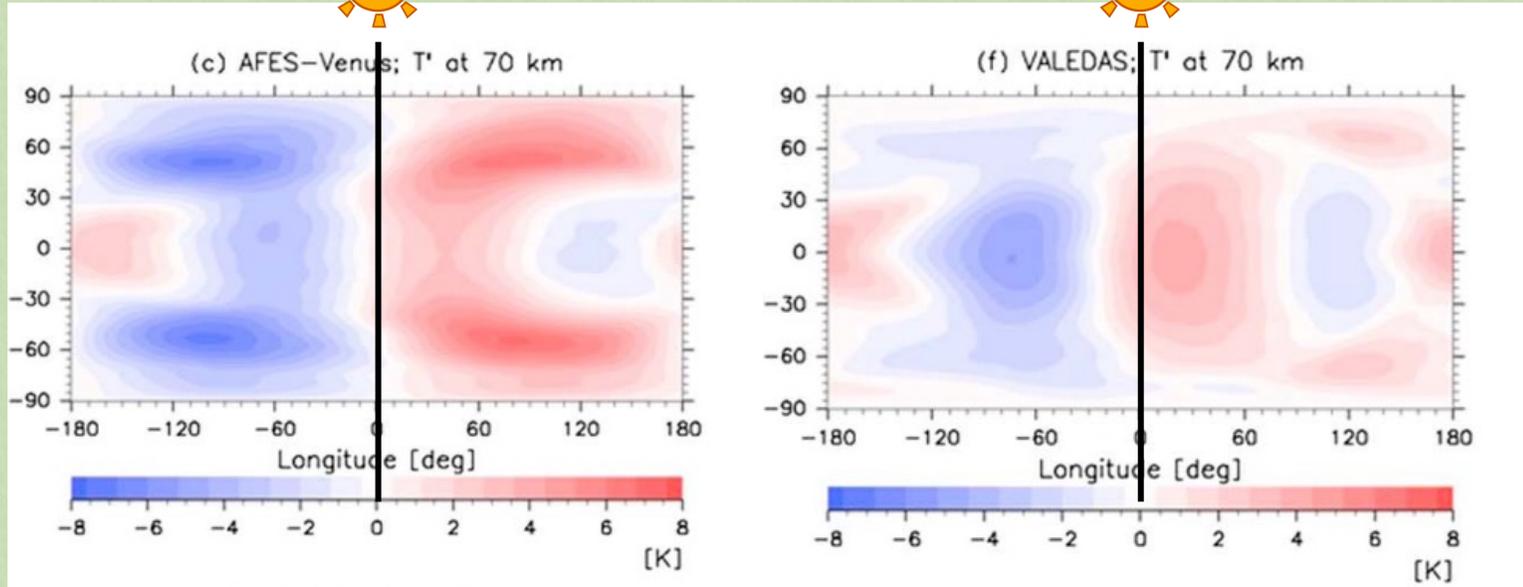


あかつきの電波掩蔽観測
(Ando et al. 2018)



はじめに 熱潮汐波の位相改善 (Sugimoto et al. 2019)

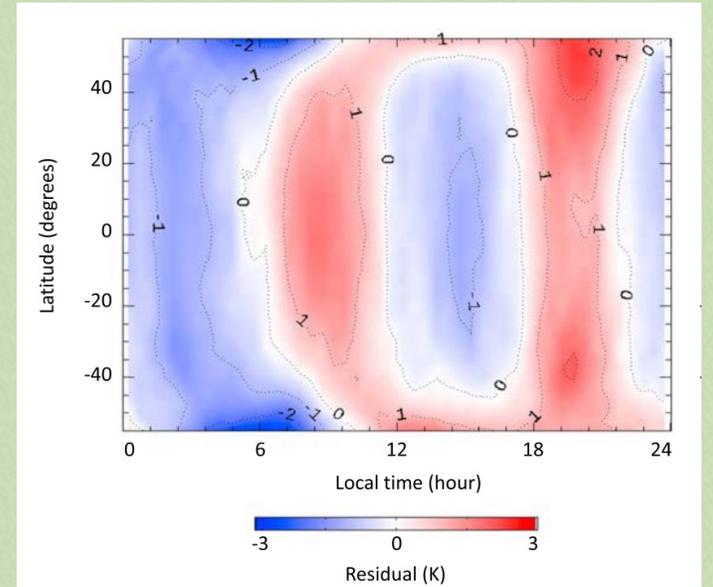
- 温度の緯度経度断面 (高度70km)
 - 東西風速を同化することで、温度の位相が改善



AFES-Venus

ALEDAS-V

太陽直下点を参照点に30地球日のコンポジット平均



あかつきのLIR観測
(Kouyama et al. 2019)



はじめに
本発表では

- あかつき観測により得られる水平風速を同化
- 以下の変化を確認
 - 風速場（スーパーローテーション）
 - 熱潮汐波の位相

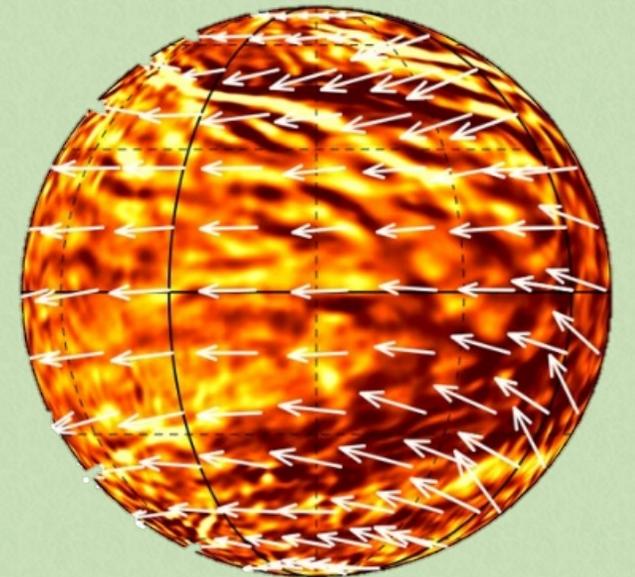
モデル・実験設定・観測データ



モデルと実験設定

AFES-Venus (Venusian atmospheric GCM)

- 3次元球面プリミティブ方程式（静水圧平衡）乾燥大気
- 解像度: T42L60 (128 × 64 × 60)
- 初期値: スーパーローテーションを仮定した東西風（4地球年スピニングアップ）
- 比熱: C_p 一定 (1000 J/kg/K)
- 水平超粘性: 0.1地球日の e-folding time
- 鉛直超粘性: $0.15 \text{ m}^2\text{s}^{-1}$
- 地形や惑星境界層はなし
- 太陽加熱:
 - 日変化成分を含む
 - Tomasko (1980) と Crisp (1989) に基づく
- 赤外放射過程: ニュートン冷却で簡略化
$$dT/dt = -\kappa (T - T_{\text{ref}}(z)) \text{ (Crisp, 1986)}$$





モデルと実験設定

ALEDAS-V (Data Assimilation System)

- アンサンブルメンバー: 31
- データ同化サイクル: 6時間
- 観測ウィンドウ: 1時間
- インフレーション: 10 %
- 局所化パラメータ (水平): 400 km
- 局所化パラメータ (鉛直): $\log P=0.4$ (P: 圧力) ~ 4km
- ランダム誤差 (風速): 4.0 m/s
- 9時間予報をして ($t=0$)、 $t=3$ から $t=9$ を同化に用いる。
- $t=3$ から $t=9$ の観測を入力して同化、 $t=6$ を再解析値とする。 (=4D LETKF)



観測データ

観測データと同化期間

- 使用データ：あかつき紫外イメージャ(365nm)の雲追跡（水平風速）
 - Release : 20190903/CMV_UVI_201512-201812/
 - Filename : concat_365_eps10_pphvlen2.nc
 - Resolution : 120x60
 - Produced by : Takeshi Horinouchi
 - References : Ikegawa and Horinouchi (2016), Horinouchi et al. (2017), Horinouchi et al. (2018)
- 高度70kmに同化。加工は特にしていない。
- 同化期間
 - epoch1: 201612 – 201701
 - epoch2: 201707 – 201709
 - epoch3: 201802 – 201804
 - epoch4: 201809 – 201812（今日の発表）



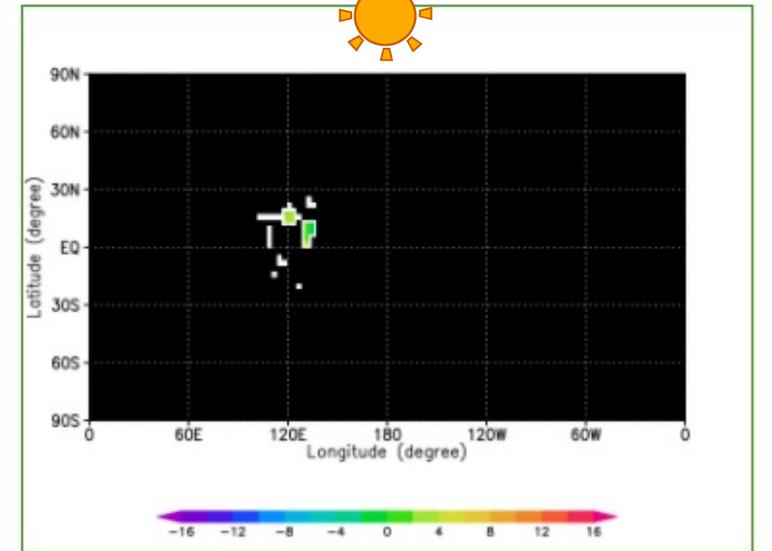
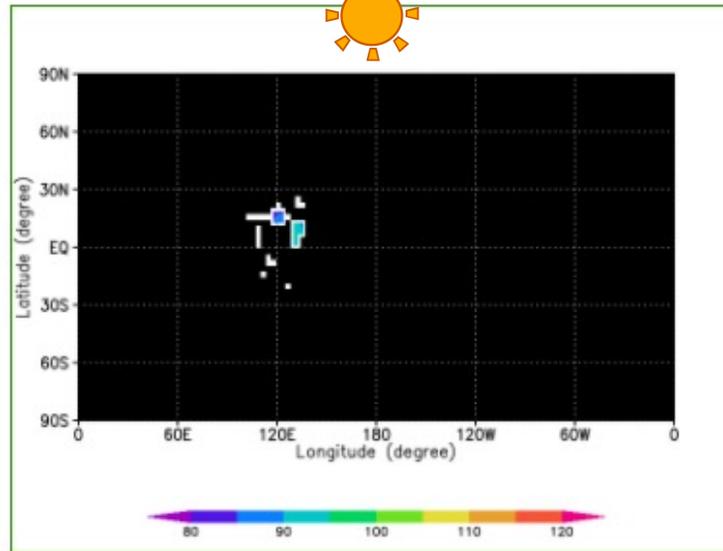
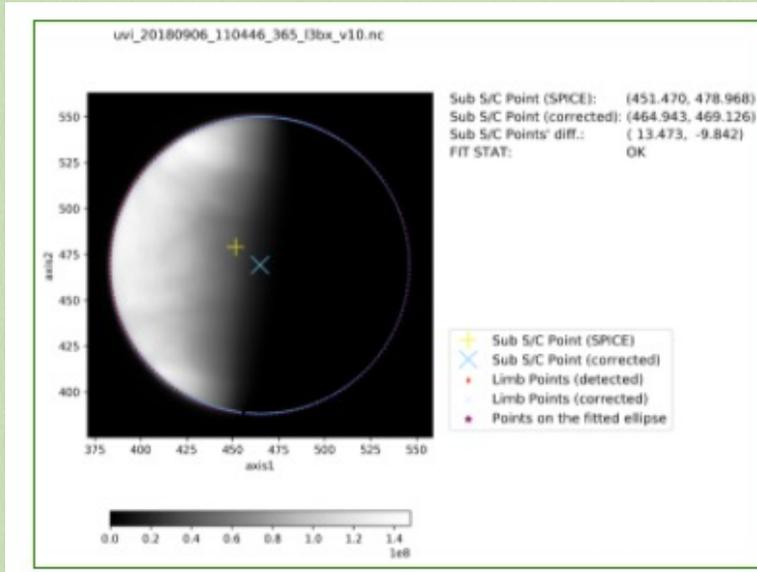
観測データ (201809-201812) スナップショット

- 2018-09-06 11:00

東西風



南北風





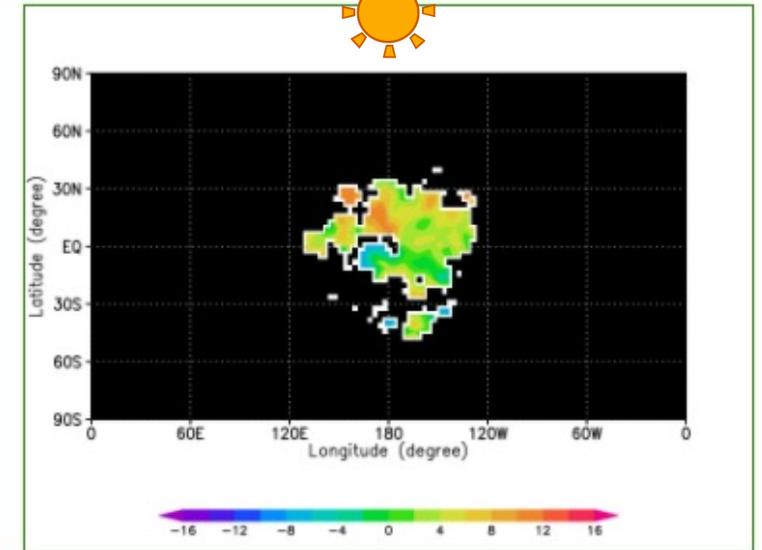
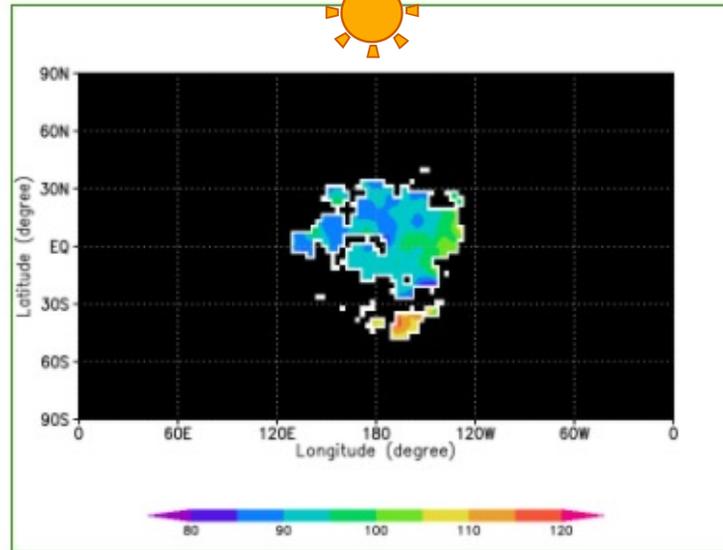
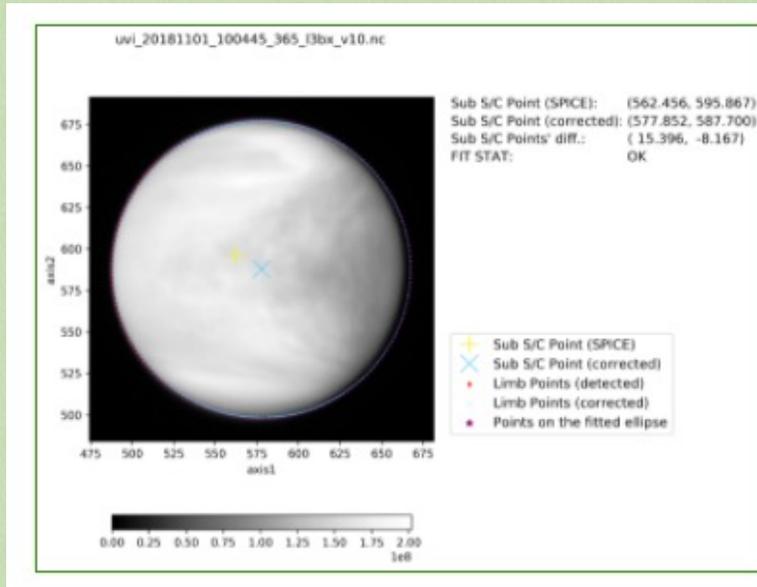
観測データ (201809-201812) スナップショット

- 2018-11-01 08:00

東西風



南北風





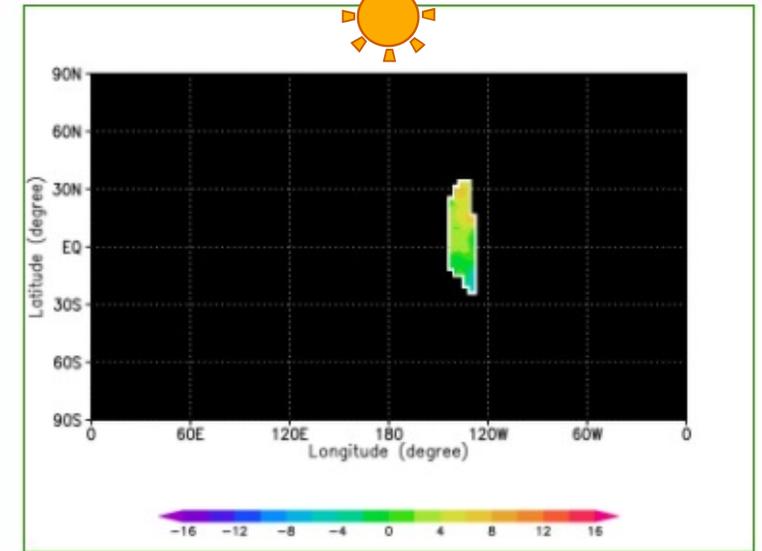
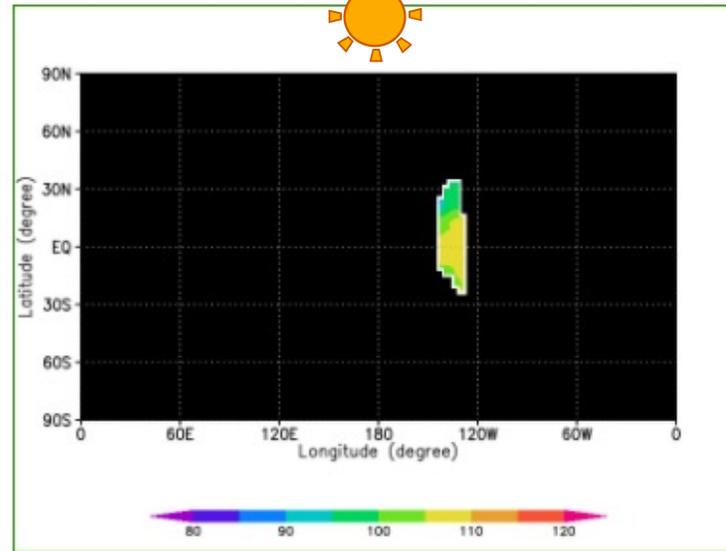
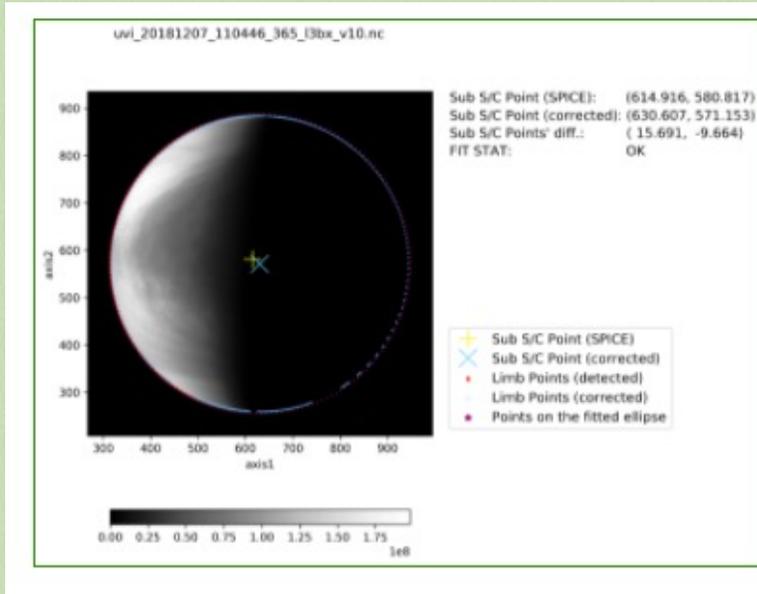
観測データ (201809-201812) スナップショット

- 2018-12-07 11:00

東西風



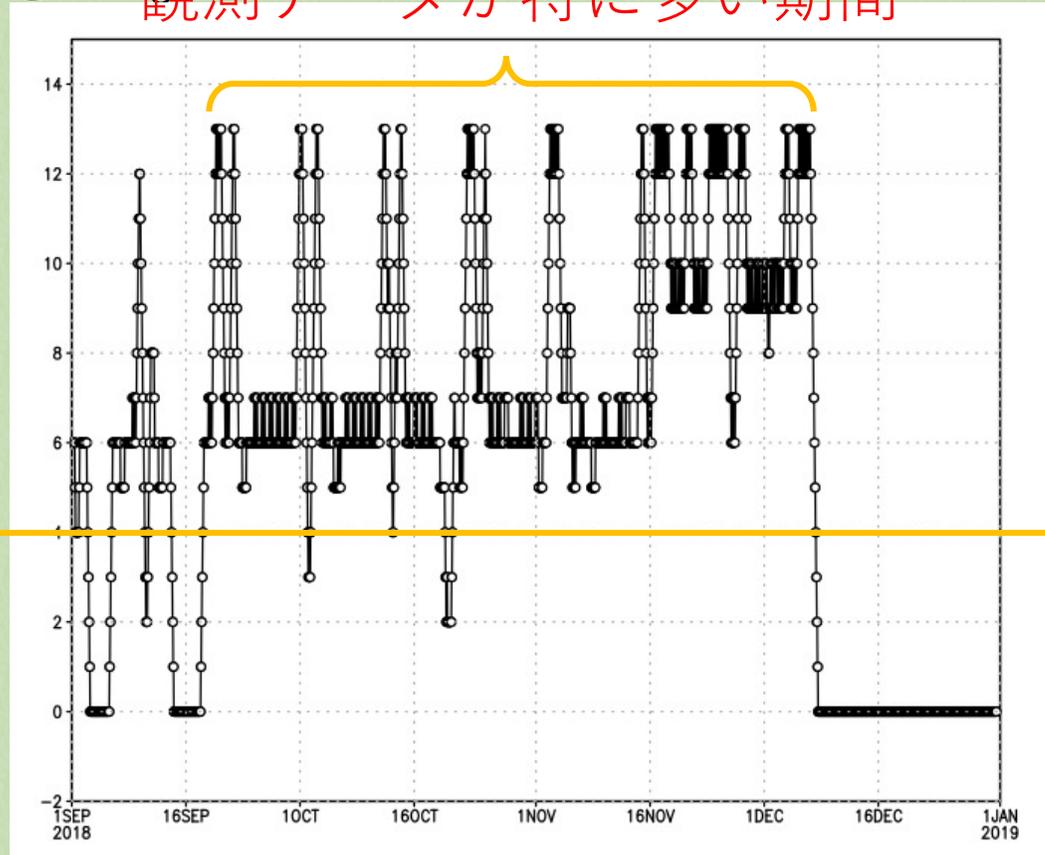
南北風





観測データ (201809-201812) 観測頻度 (1日あたりのデータ数)

- データ同化には、6時間に1回(1日あたり4回)以上のデータ数があることが望ましい。**観測データが特に多い期間**

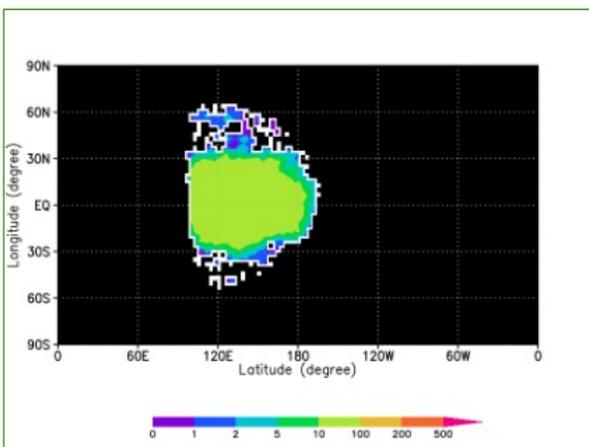




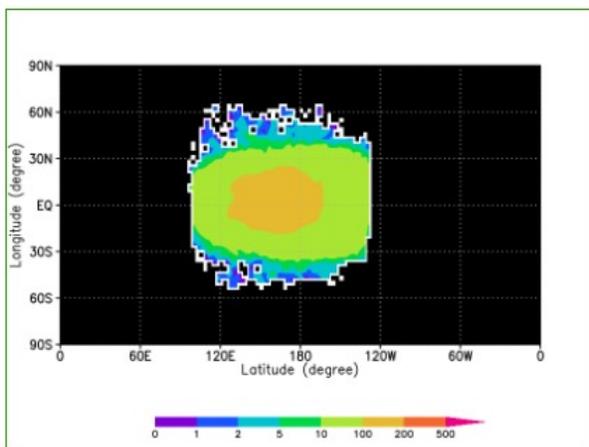
観測データ (201809-201812)

コンポジット平均：データ数 (1か月あたり)

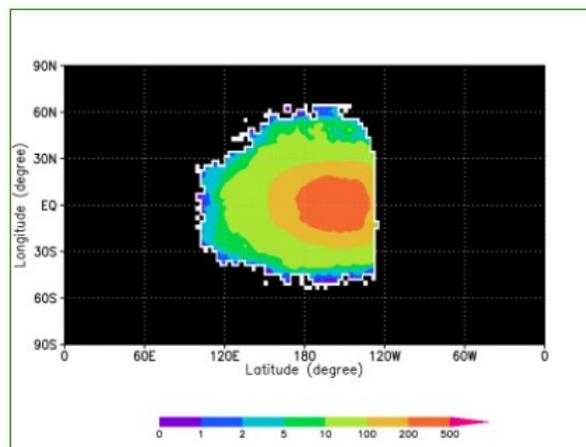
201809



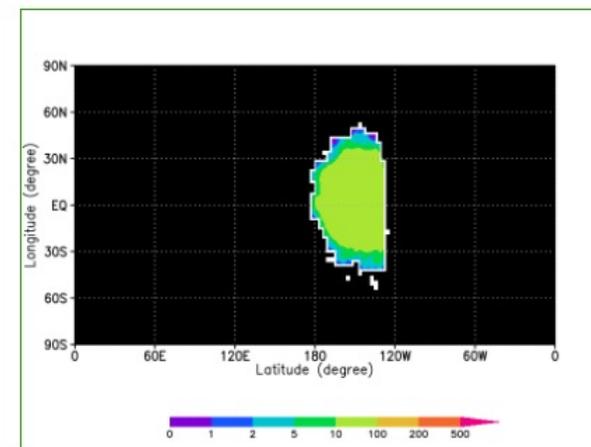
201810



201811



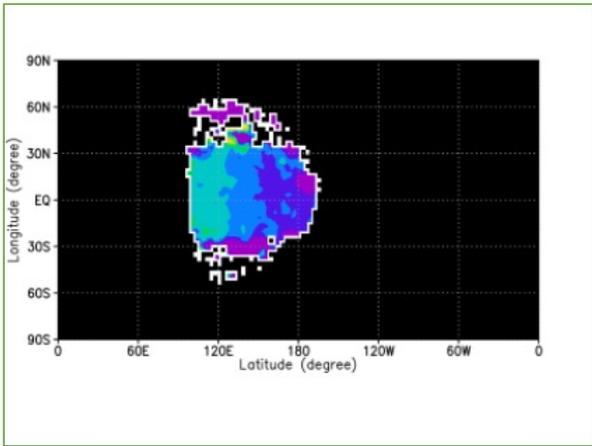
201812



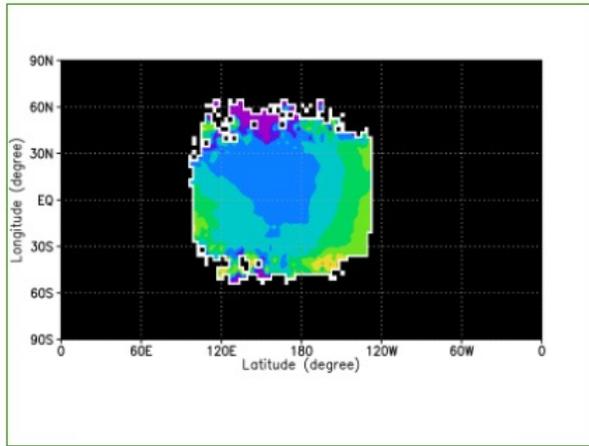


観測データ (201809-201812) コンポジット平均：東西風

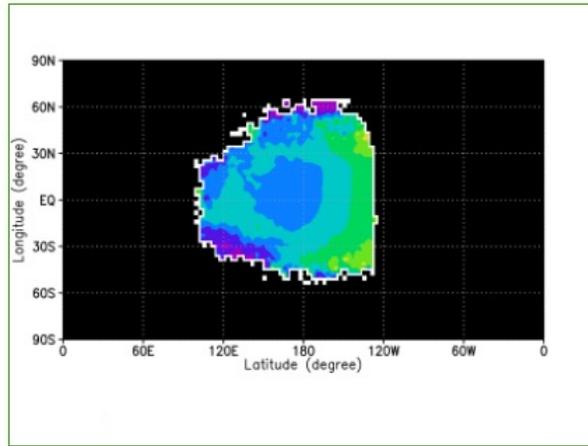
201809



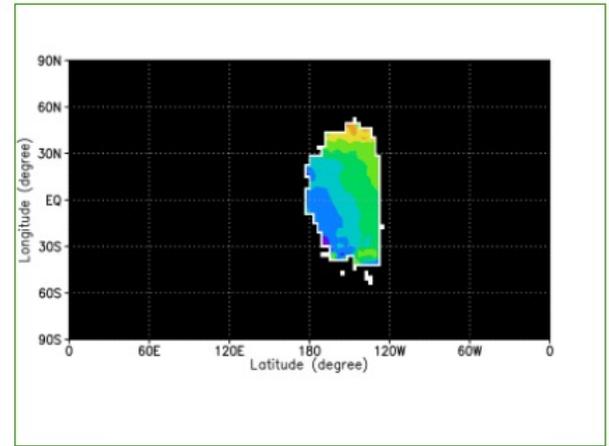
201810



201811



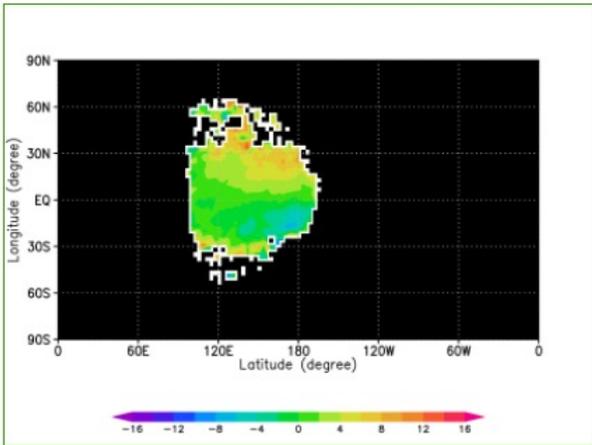
201812



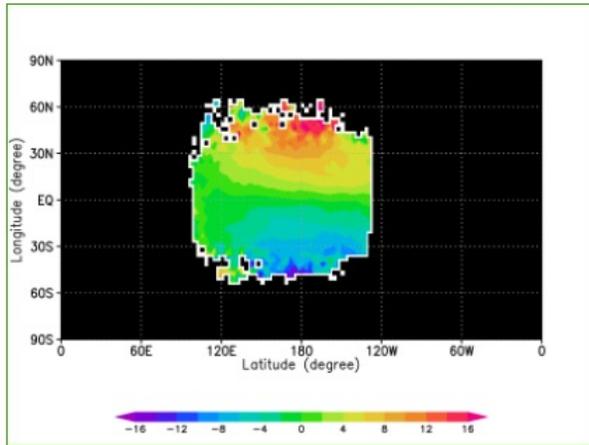


観測データ (201809-201812) コンポジット平均：南北風

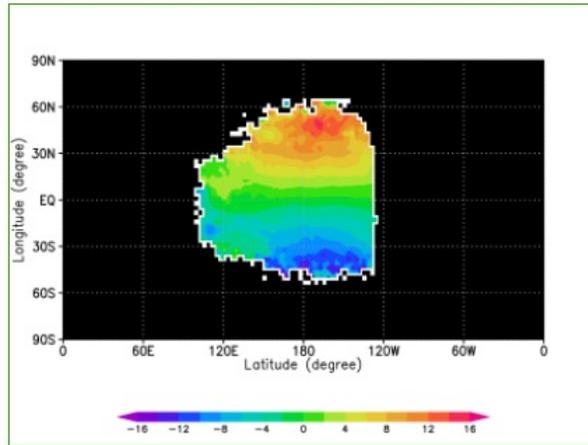
201809



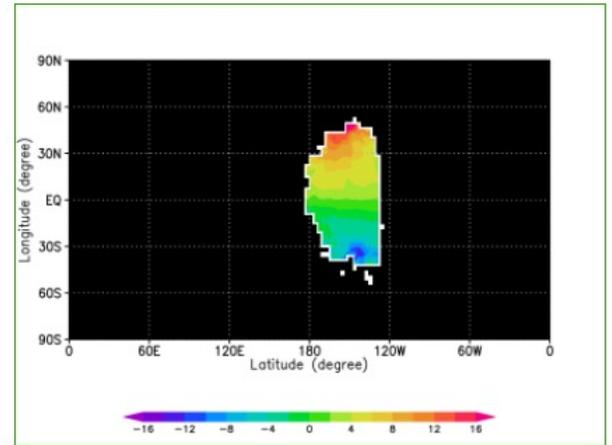
201810



201811



201812



実験結果



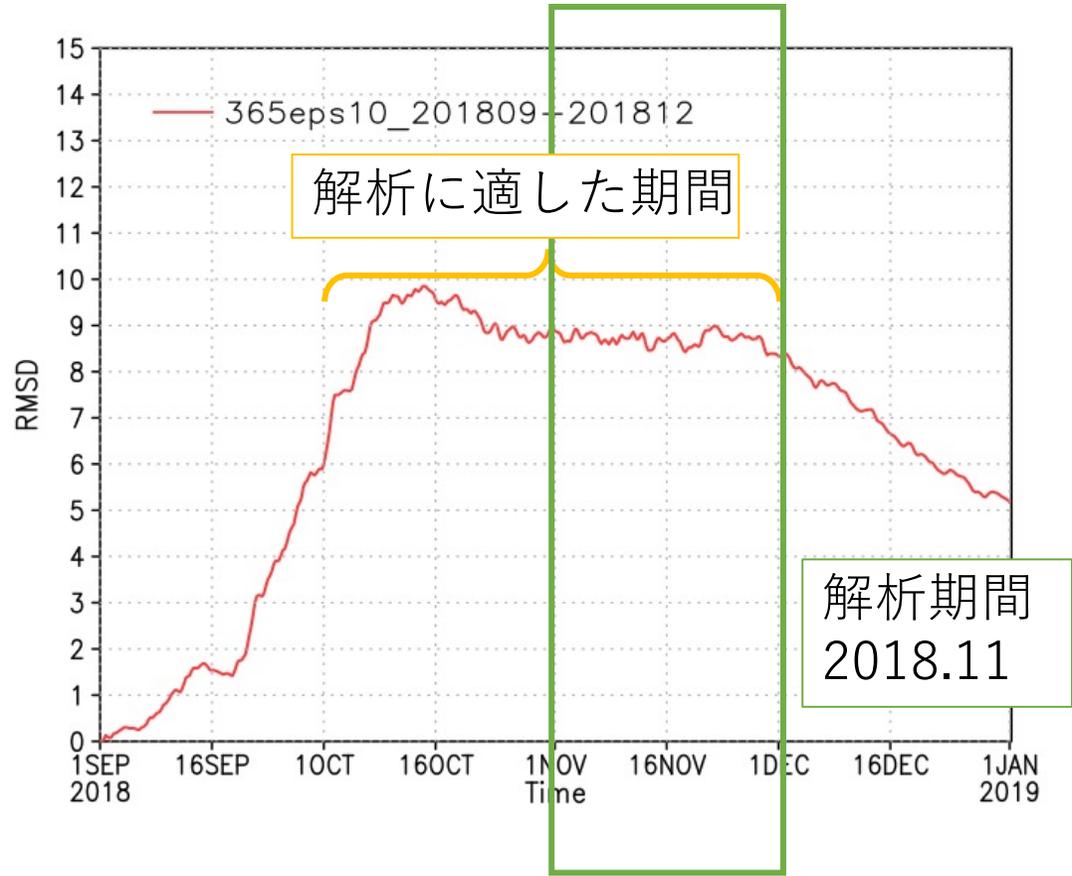
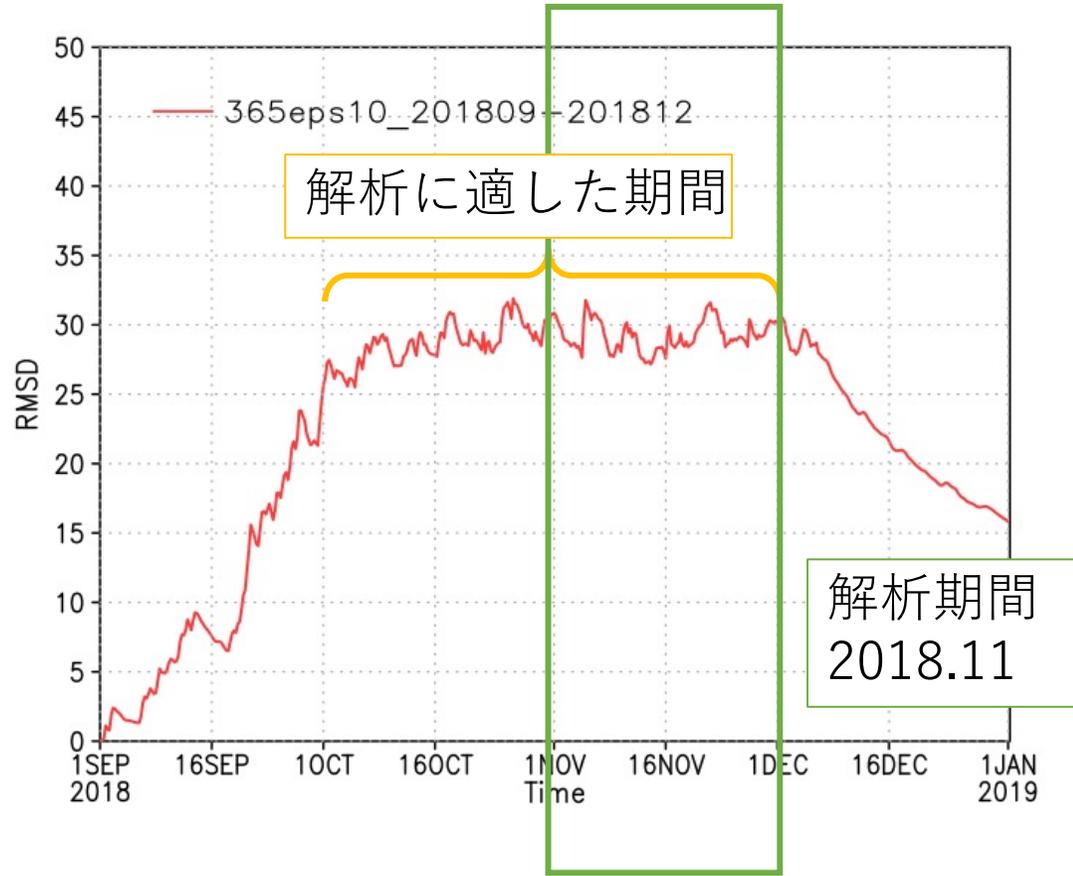
実験結果 RMSD (高度70km)

$$RMSD = \sqrt{\frac{1}{N} \sum_{i=1}^N (X_i - x_i)^2}$$

X_i : frf (without assimilation)
 x_i : 365eps10

東西風

温度

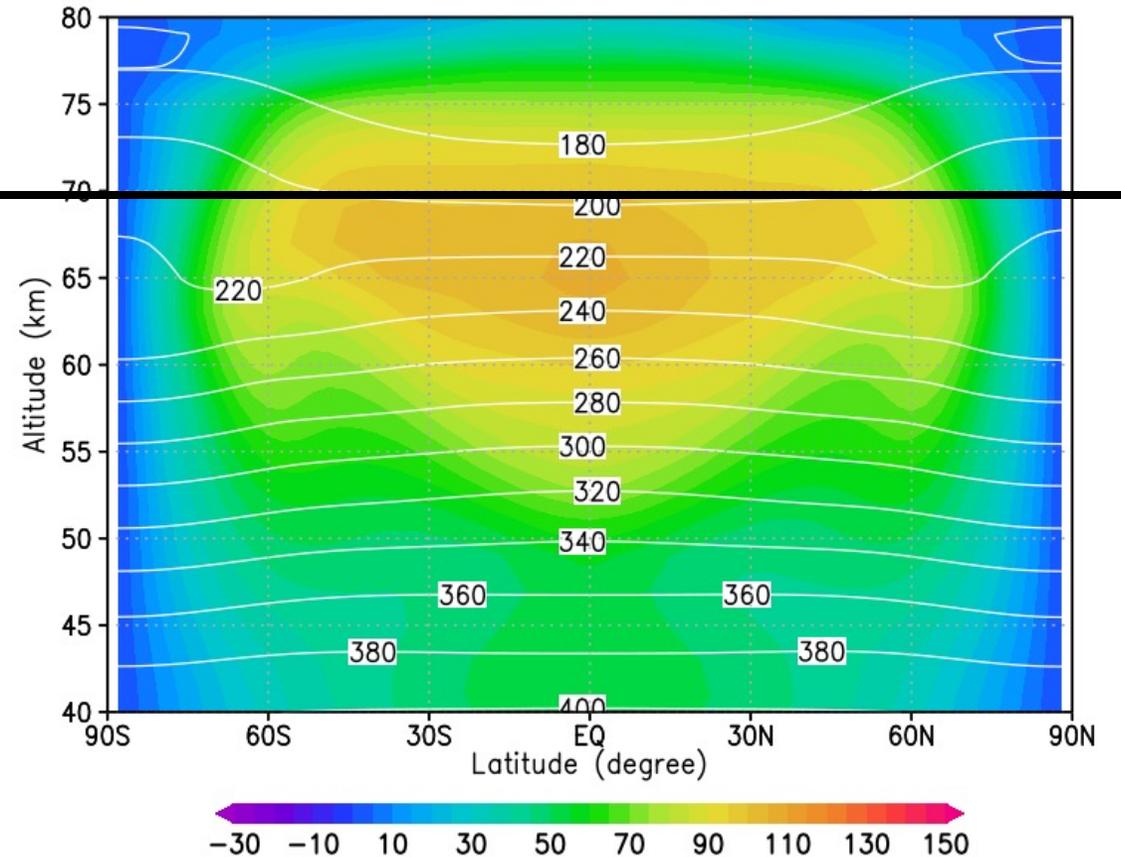
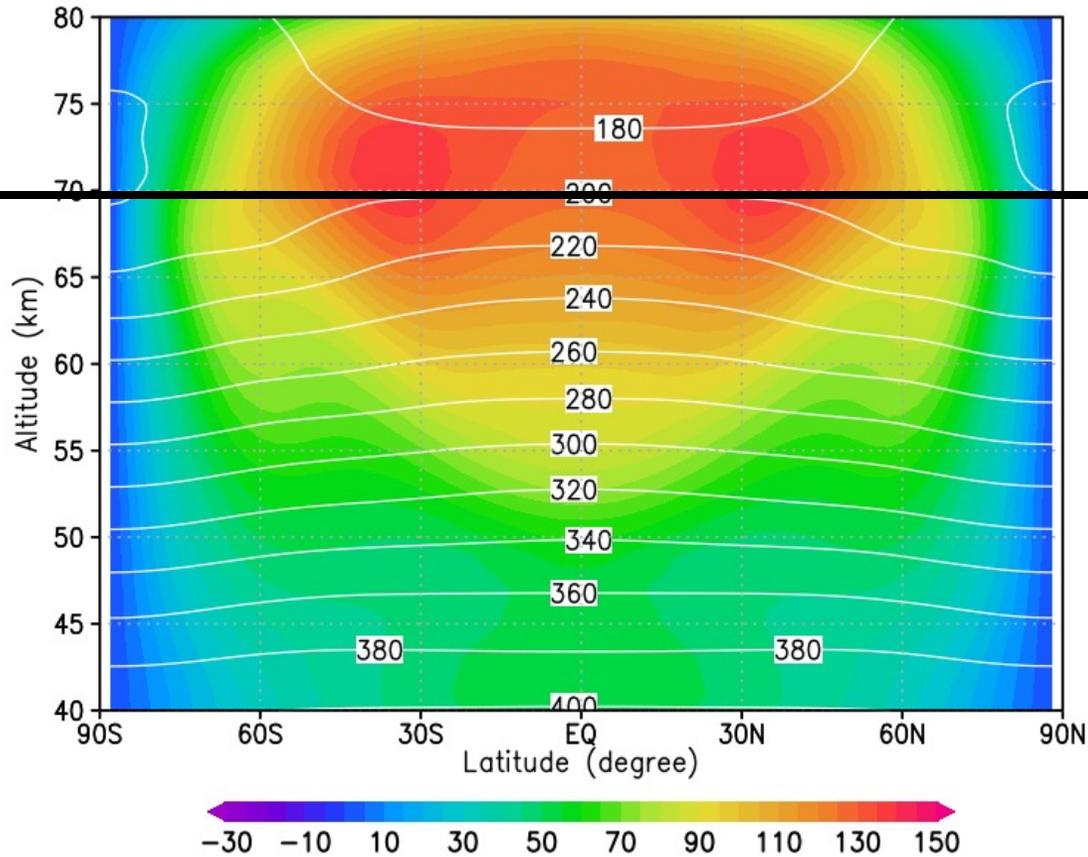




実験結果 東西風 緯度高度断面 (時間東西平均)

frf(without assimilation)

365eps10_201811

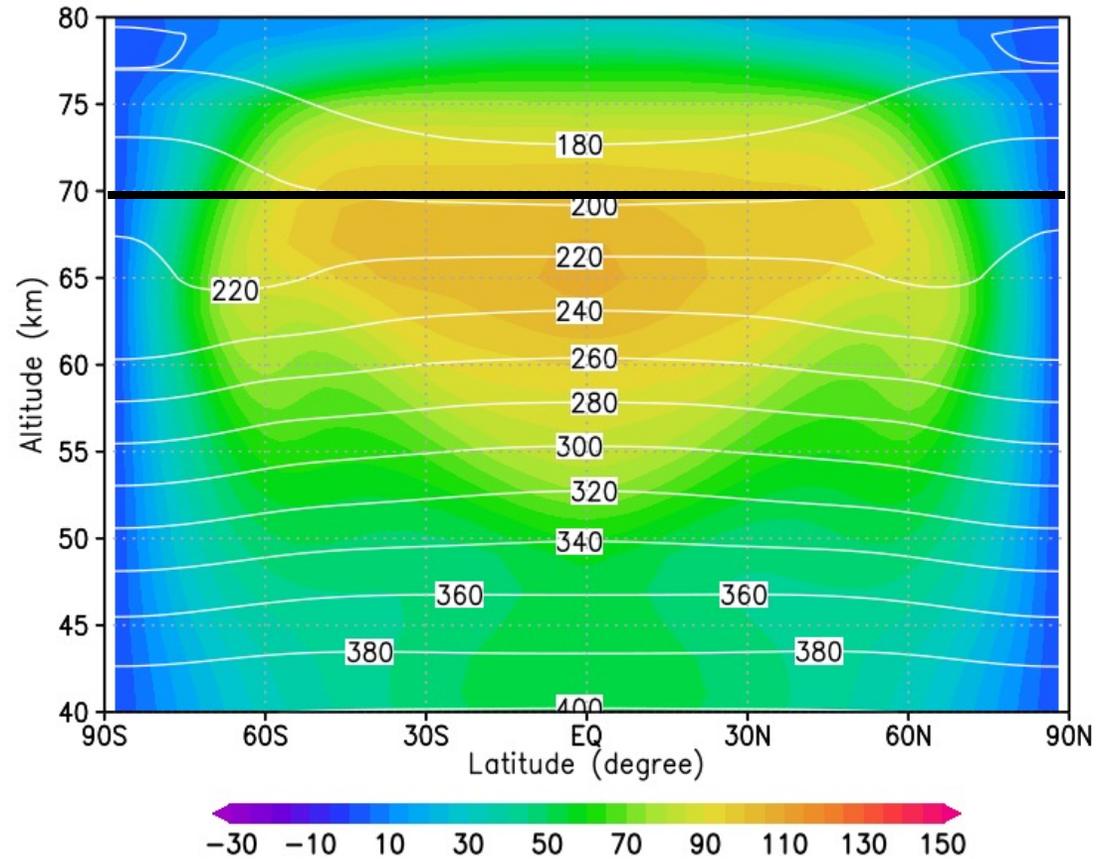
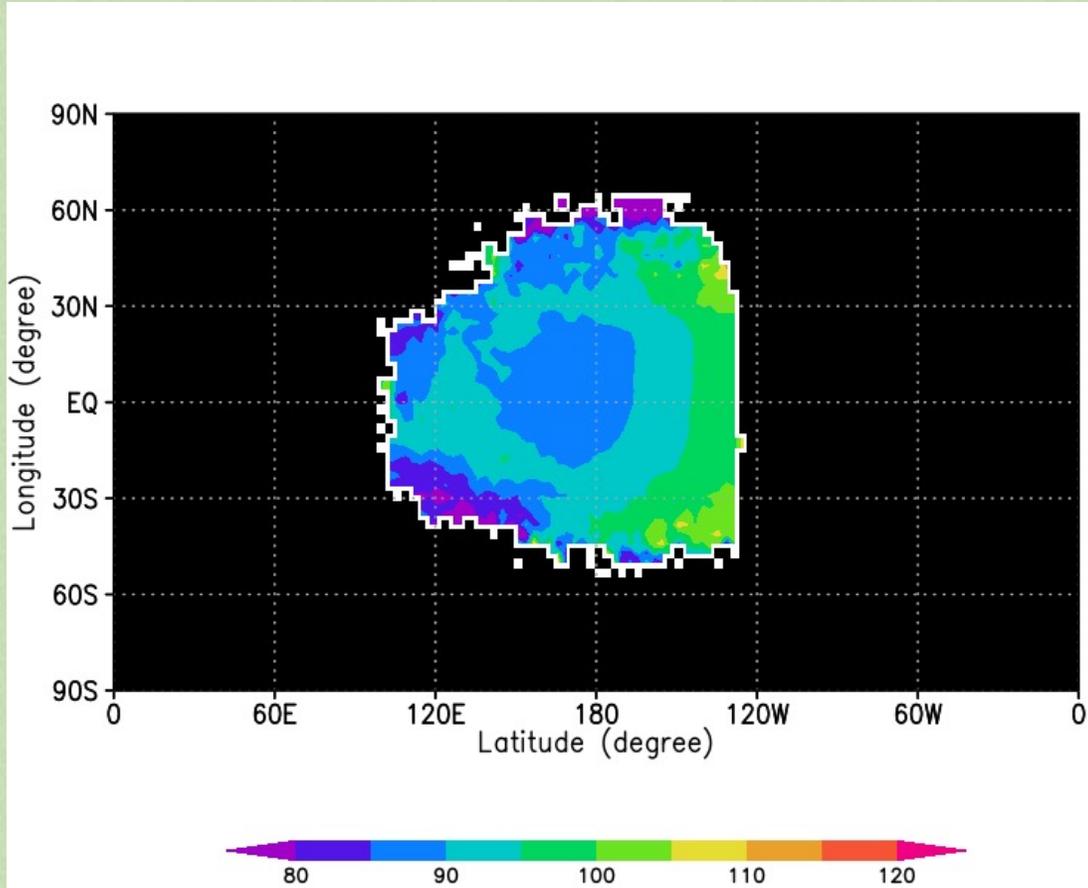




実験結果 東西風 高度時間断面 (時間東西平均)

観測 (2018.11)

365eps10_201811



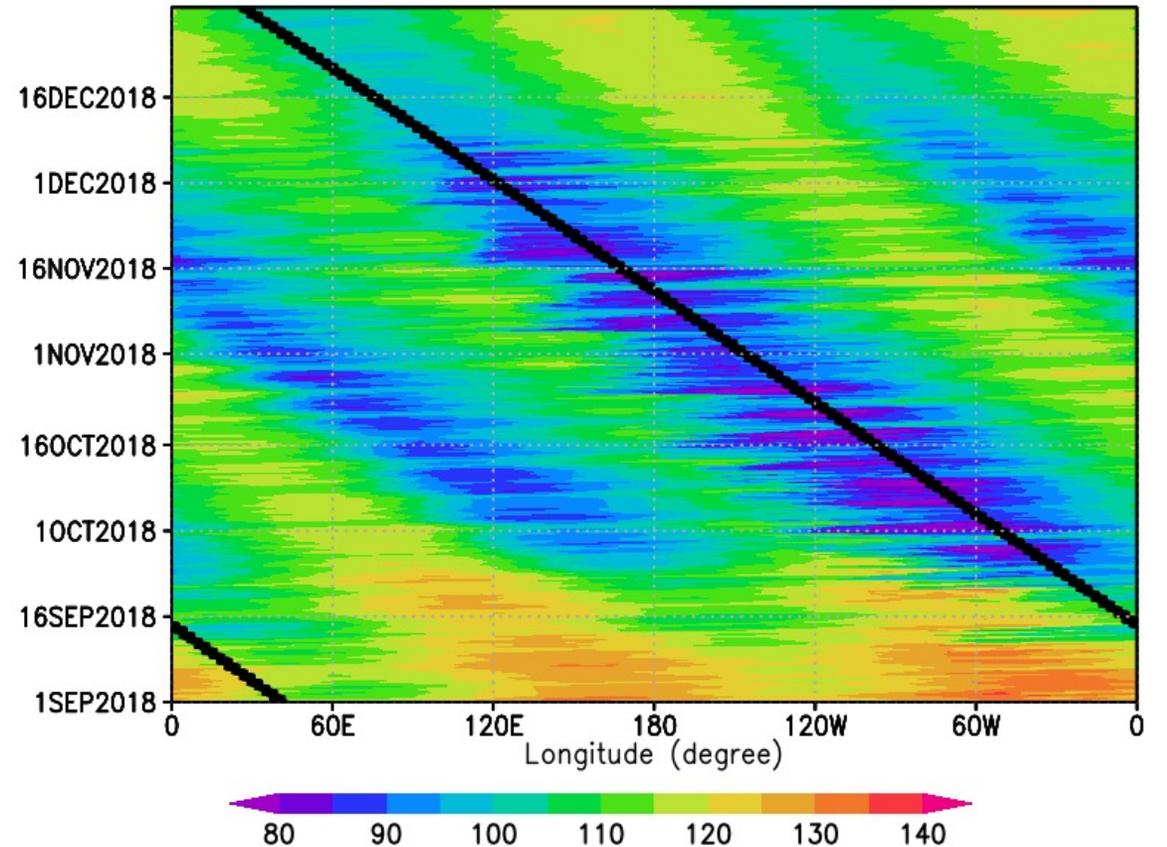
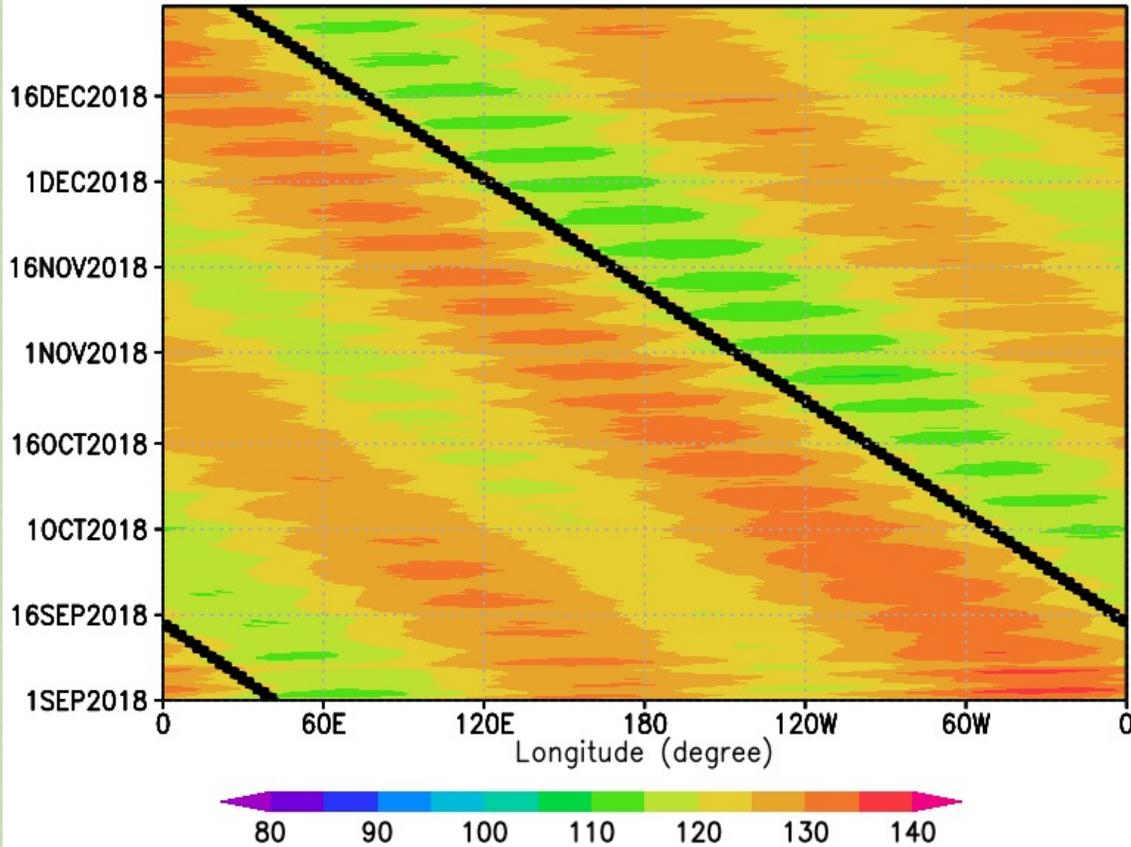


実験結果

東西風 赤道上経度時間断面 (高度70km)

frf(without assimilation)

365eps10_201811





実験結果

水平風 コンポジット平均

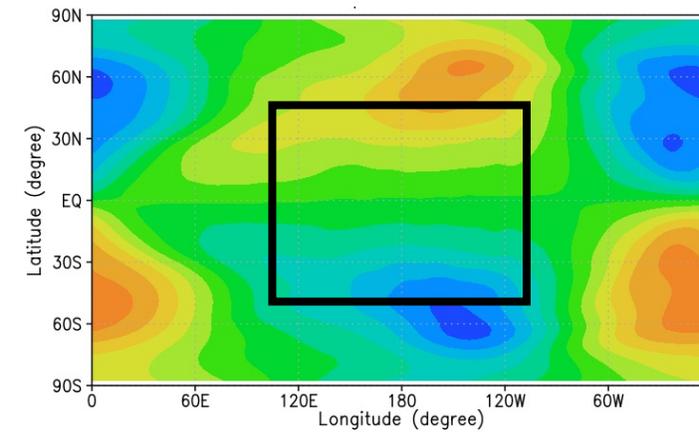
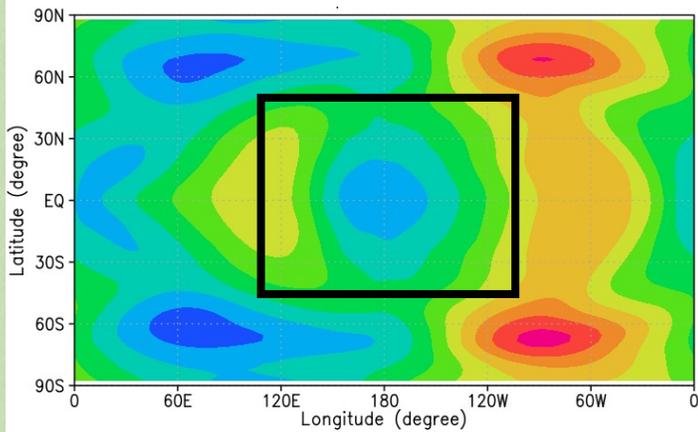
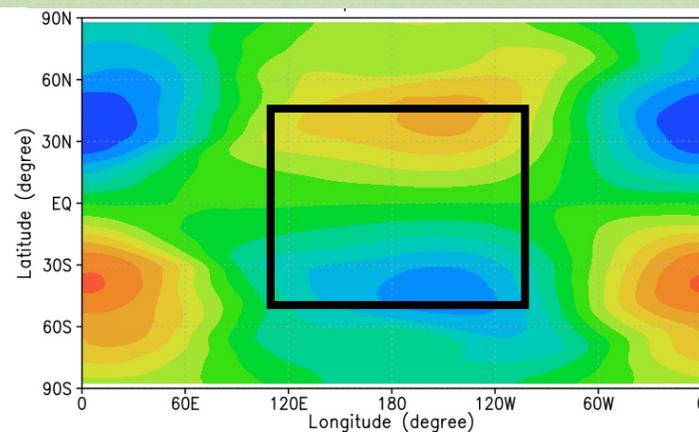
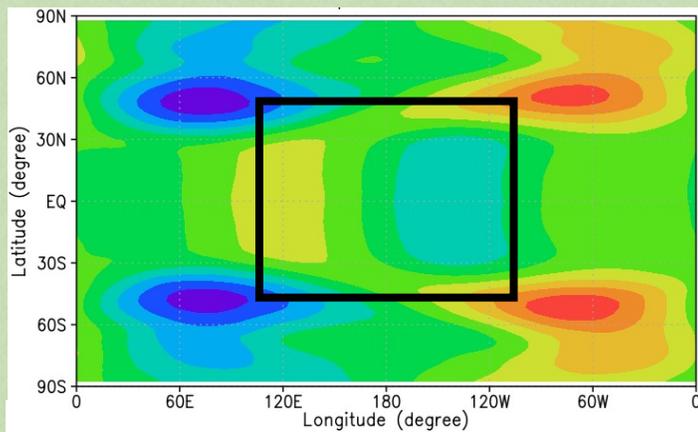
緯度経度図 (高度 70km)

東西風

南北風

frf

同化結果





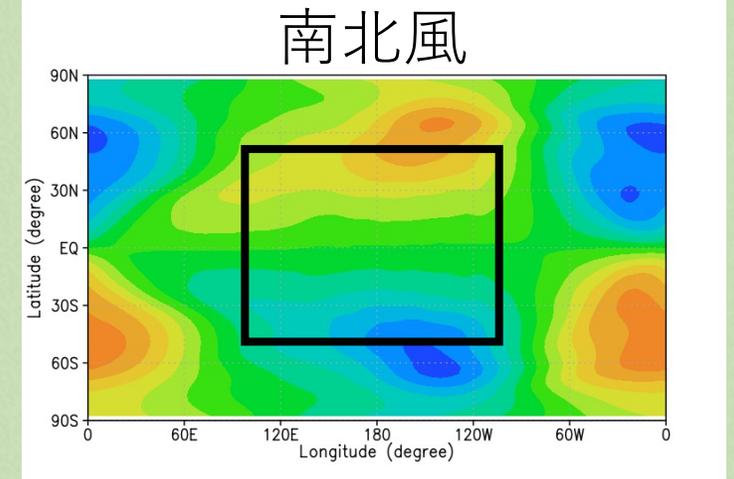
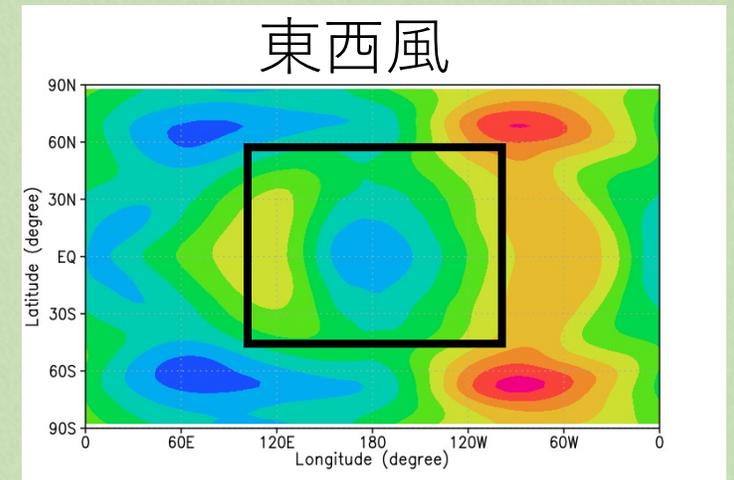
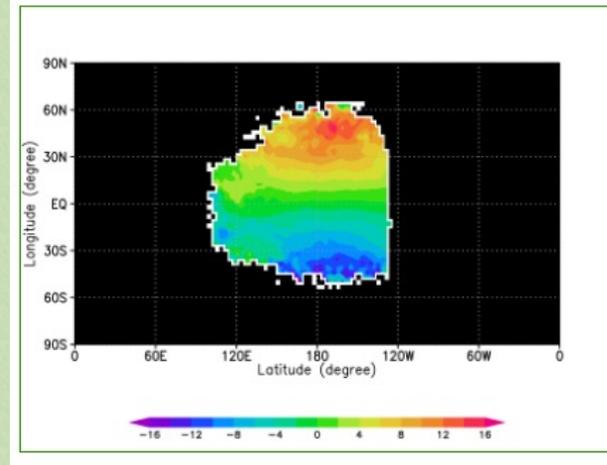
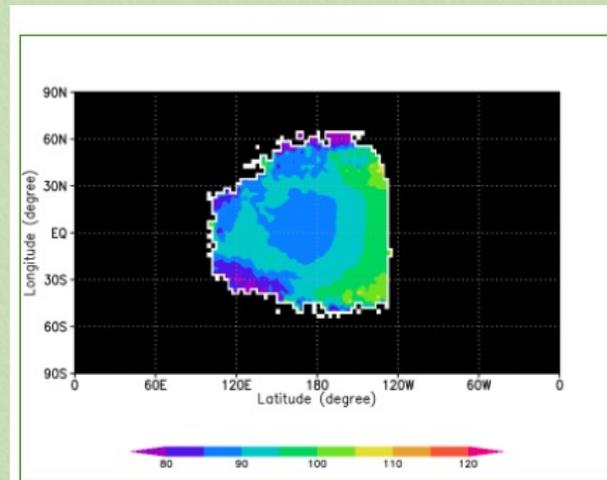
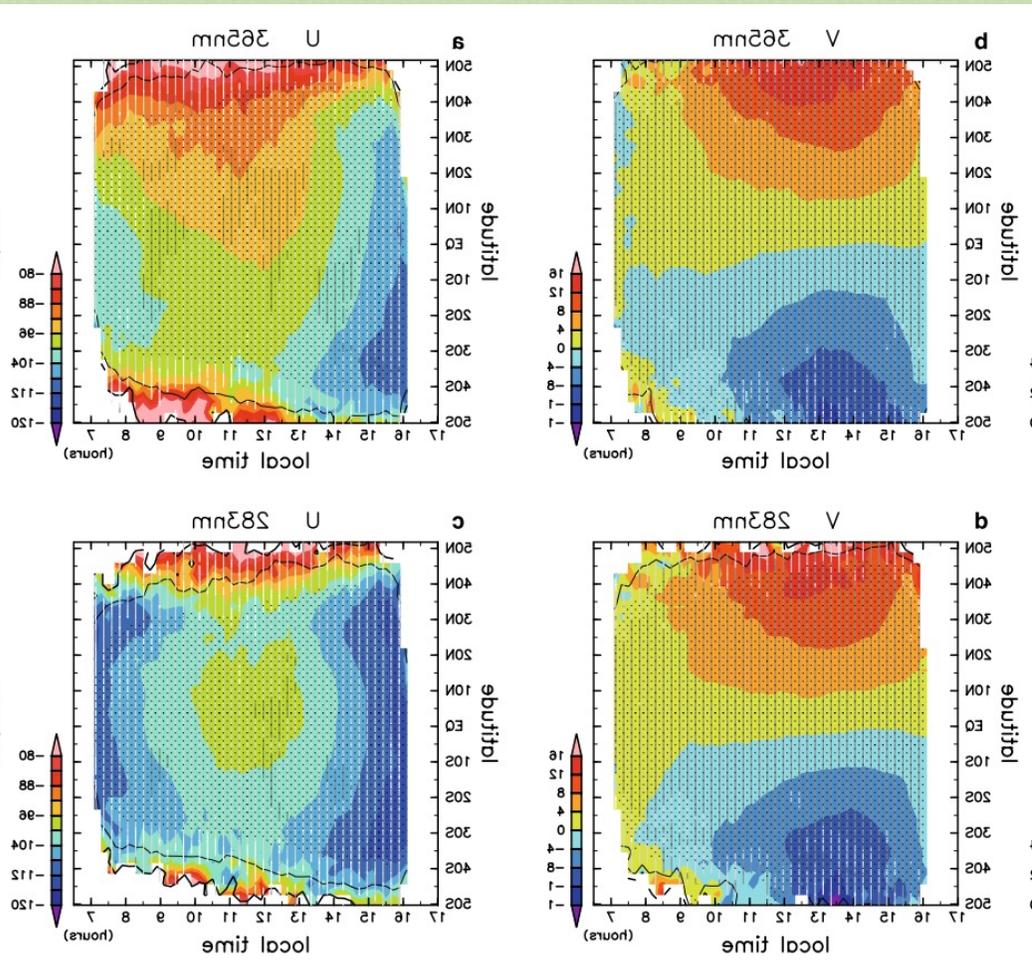
実験結果

水平風 コンポジット平均 観測との比較

Horinouchi et al. (2018)

観測 365nm (2018.11)

同化結果

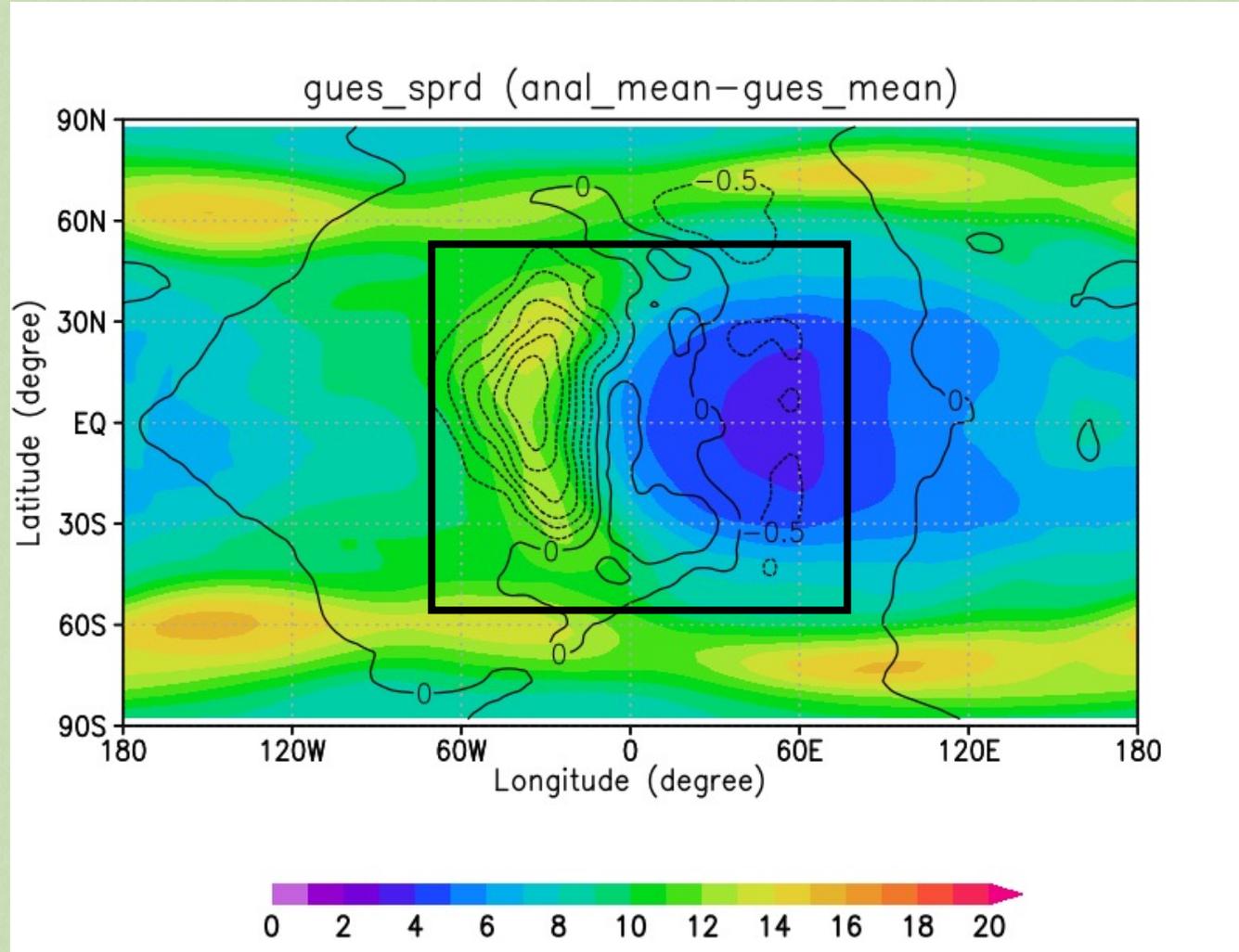




実験結果

東西風 背景誤差

緯度経度図 (高度70km)



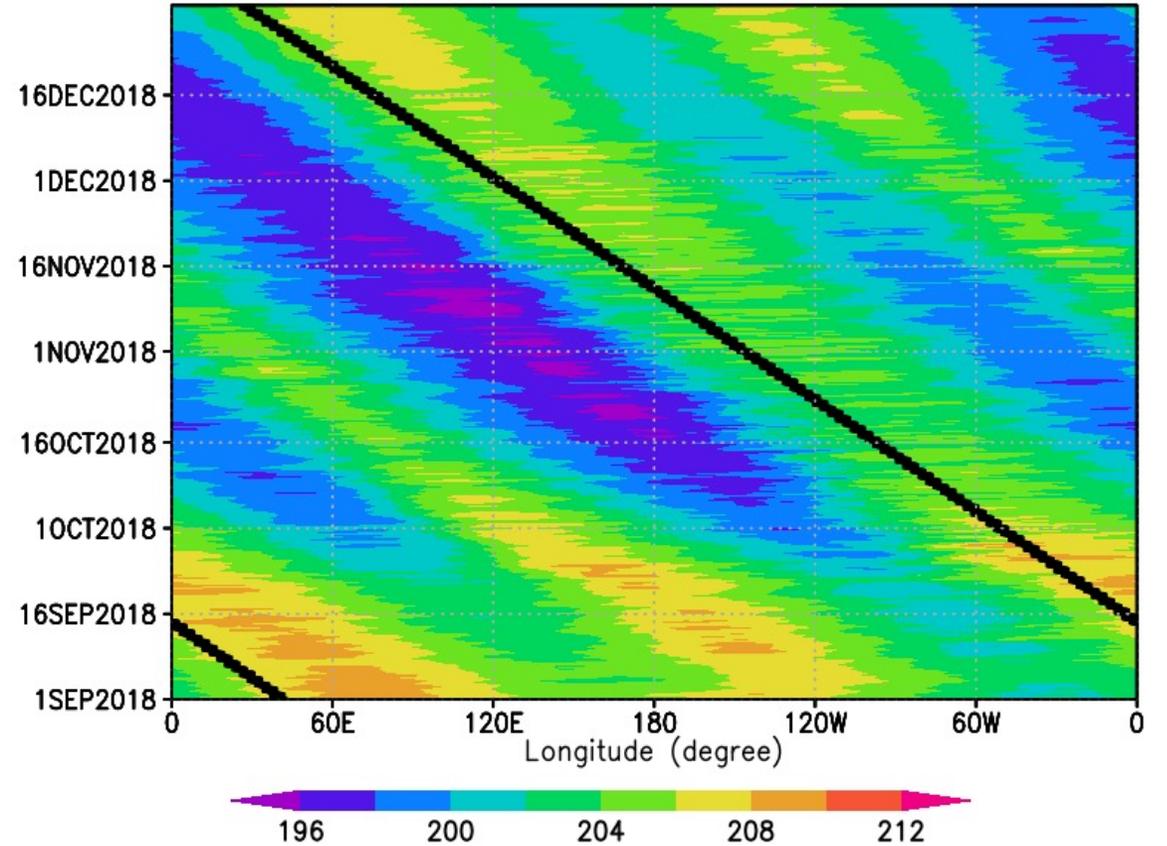
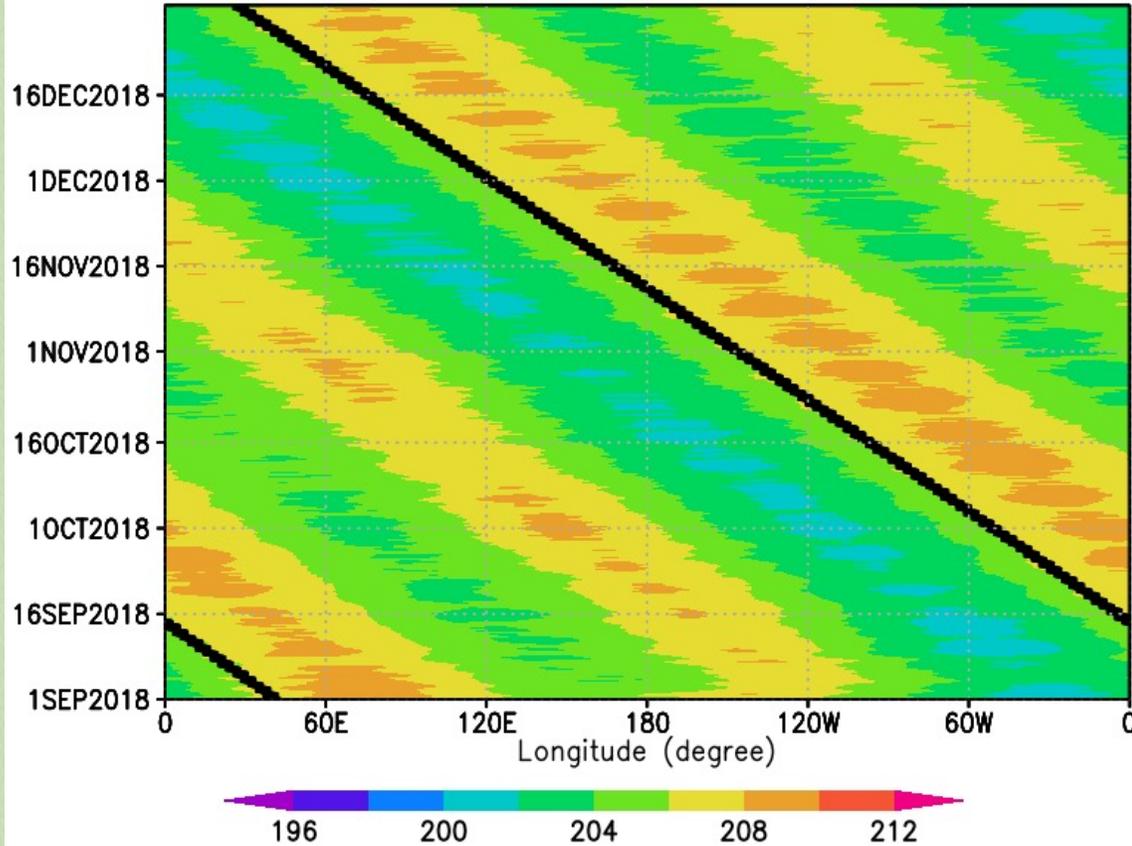


実験結果

温度 赤道上経度時間断面 (高度70km)

frf(without assimilation)

365eps10_201811





実験結果

温度 コンポジット平均

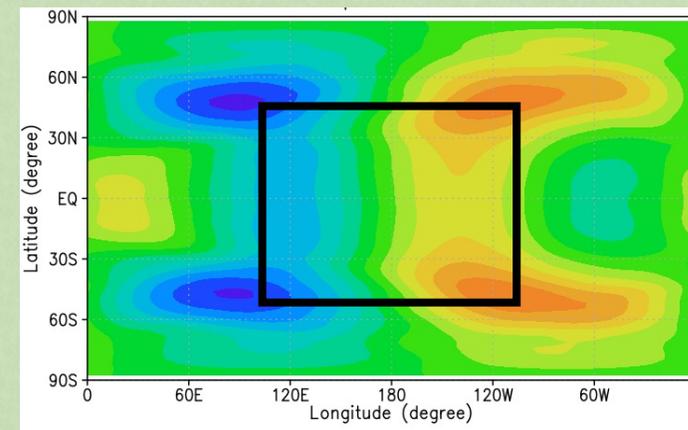
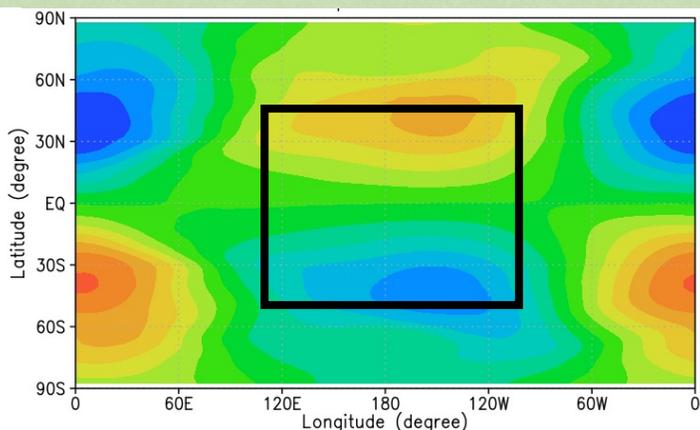
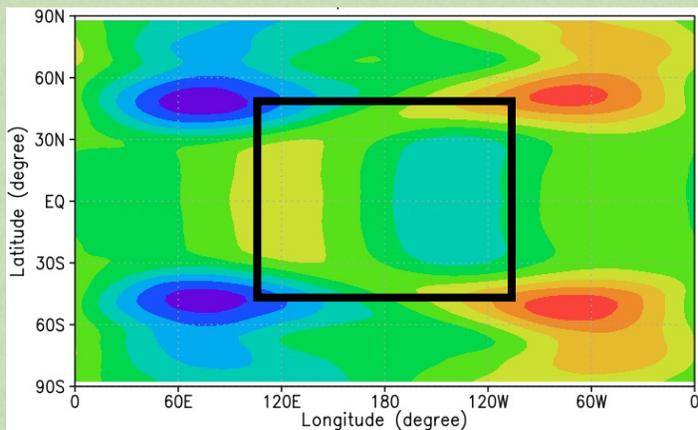
緯度経度図 (高度 70km)

東西風

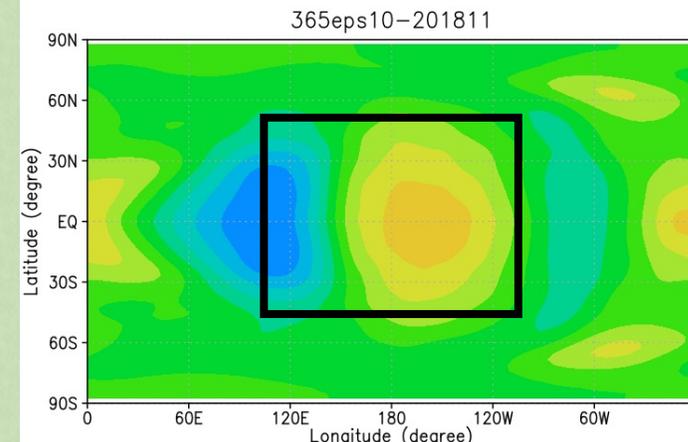
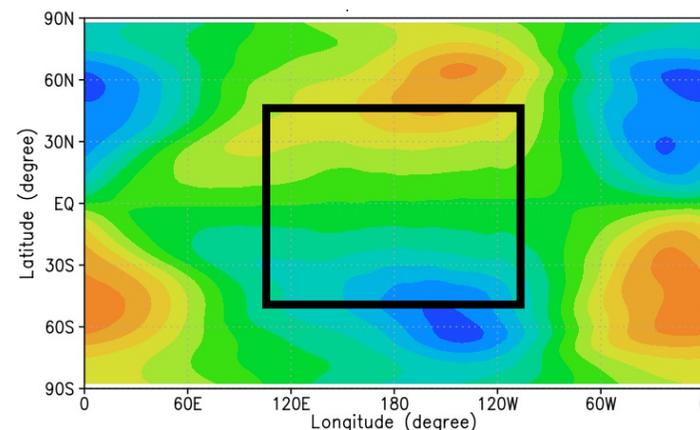
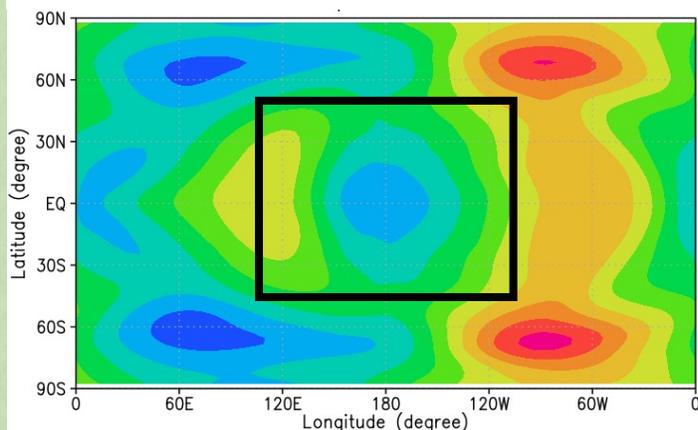
南北風

温度

frf



同化結果





実験結果 温度の高度平均の加重関数

Kouyama et al. (2019)

Taguchi et al. (2007)

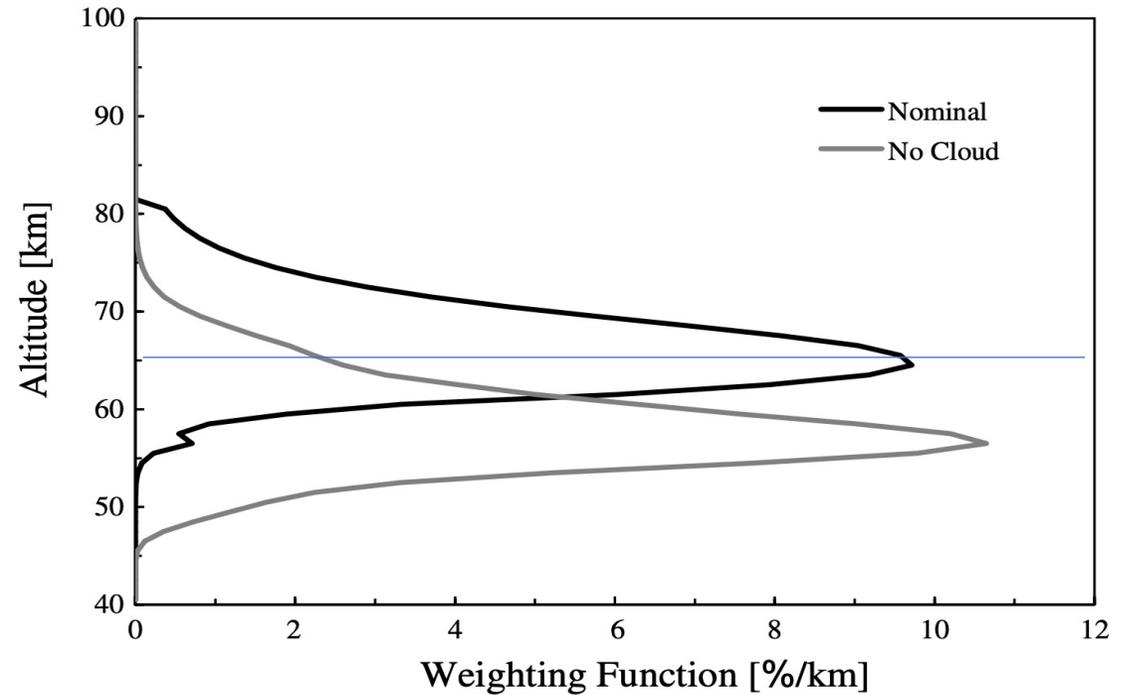
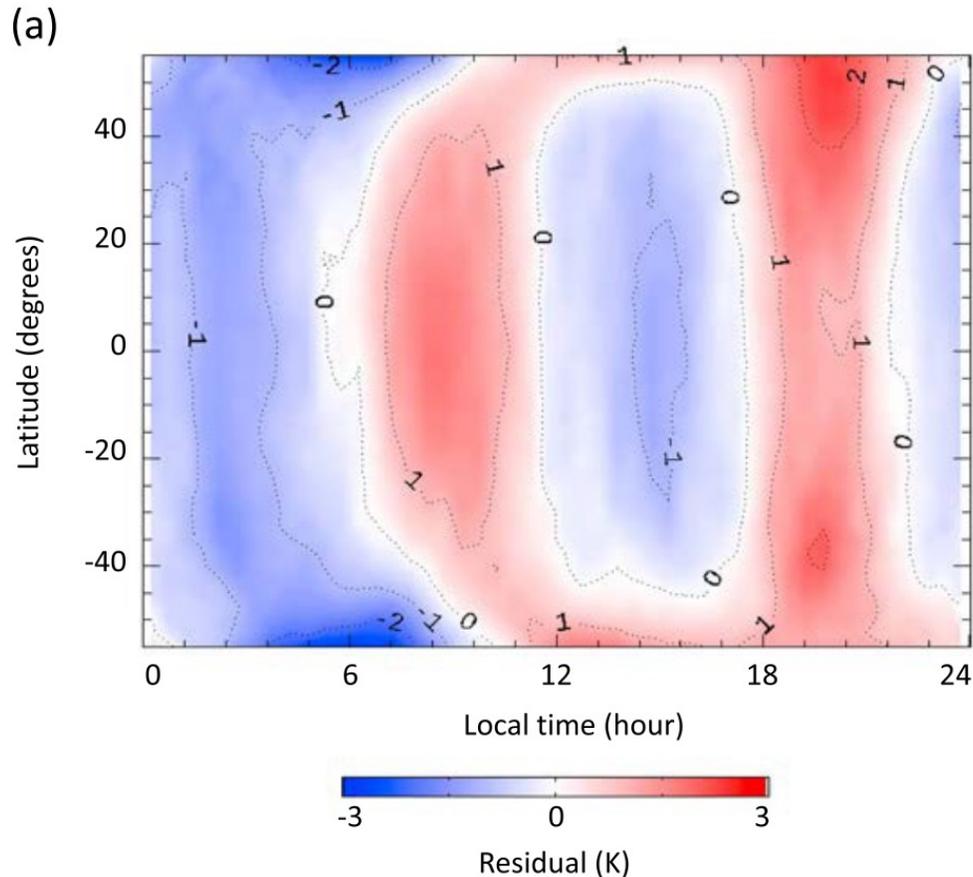


Fig. 6. Weighting functions of LIR for nominal and no cloud cases.

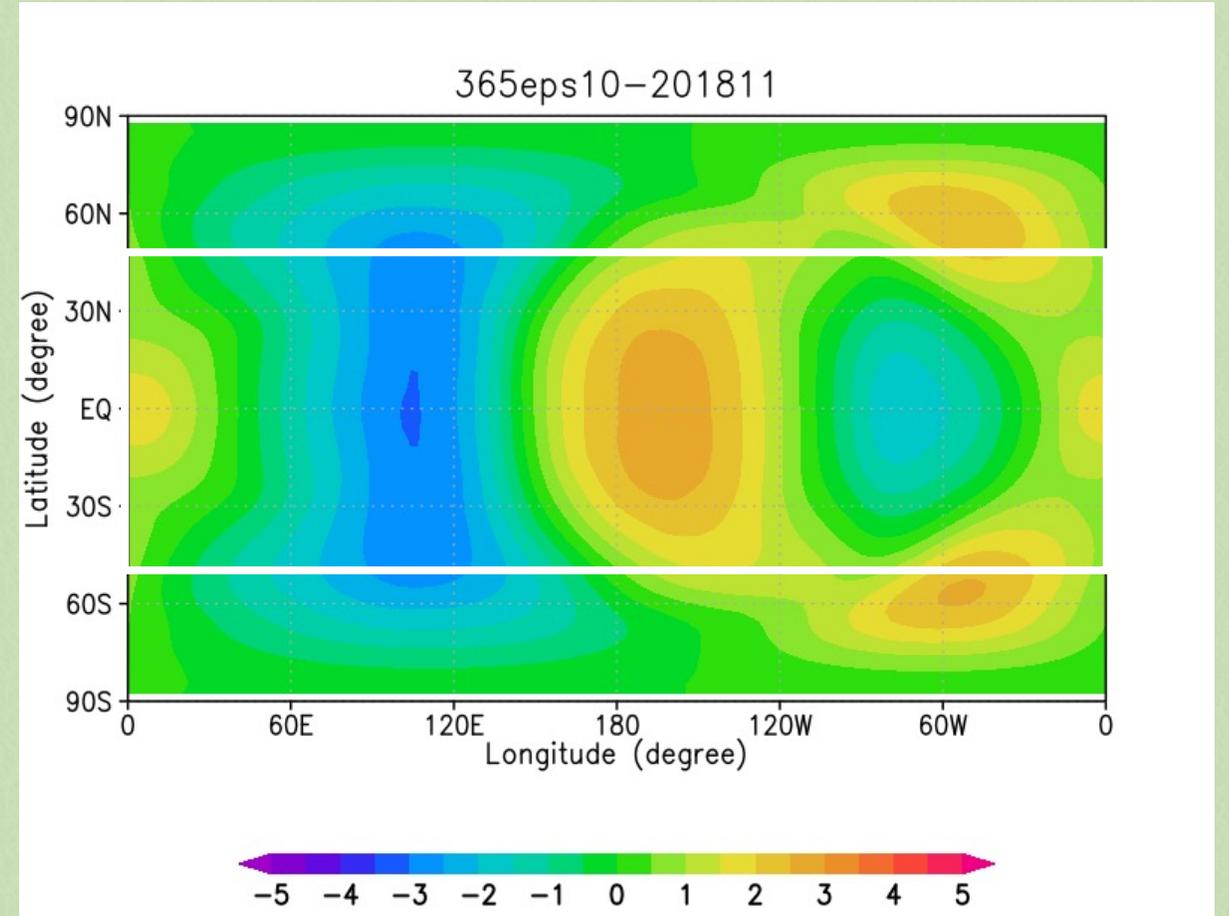
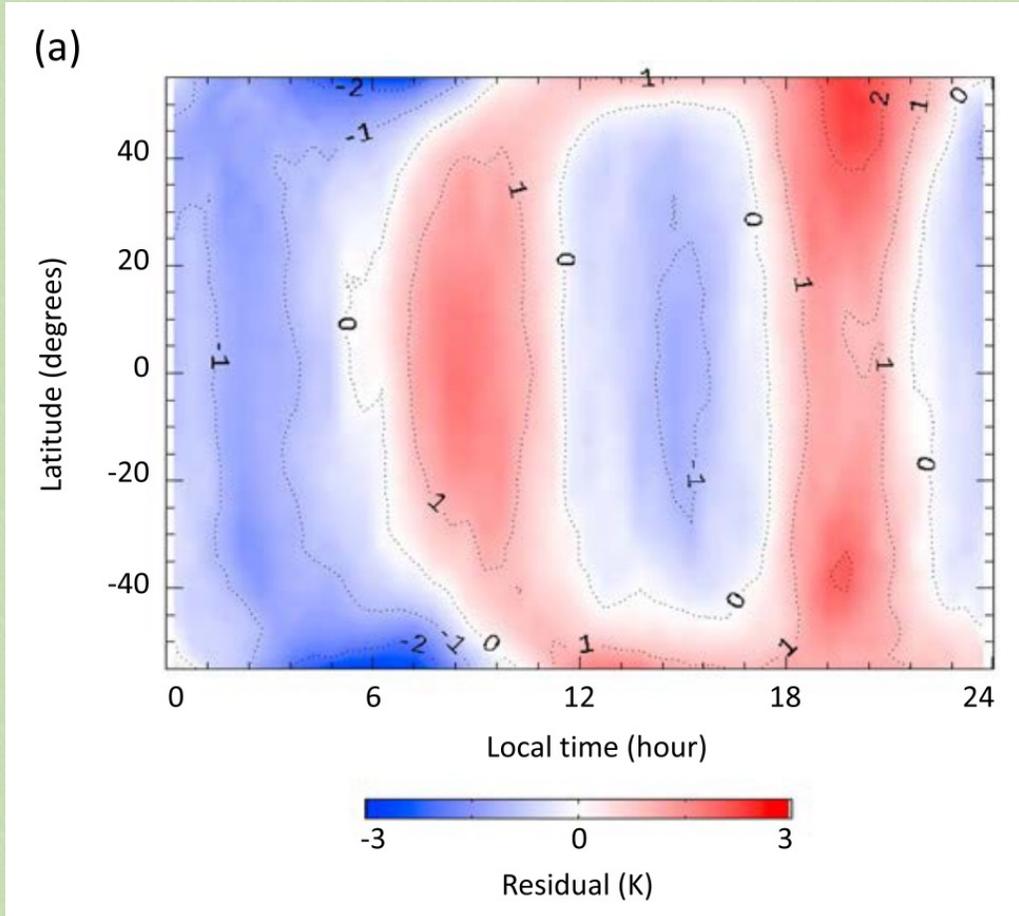


実験結果

温度 赤道上経度時間断面 観測との比較

Kouyama et al. (2019)

同化結果 (2018.11)





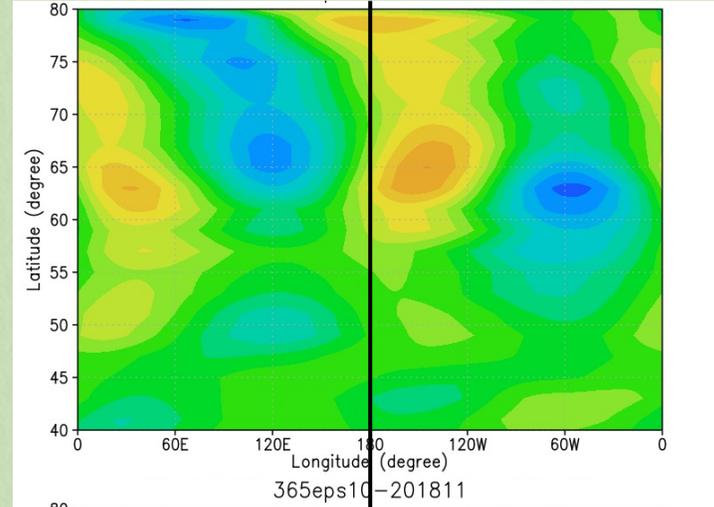
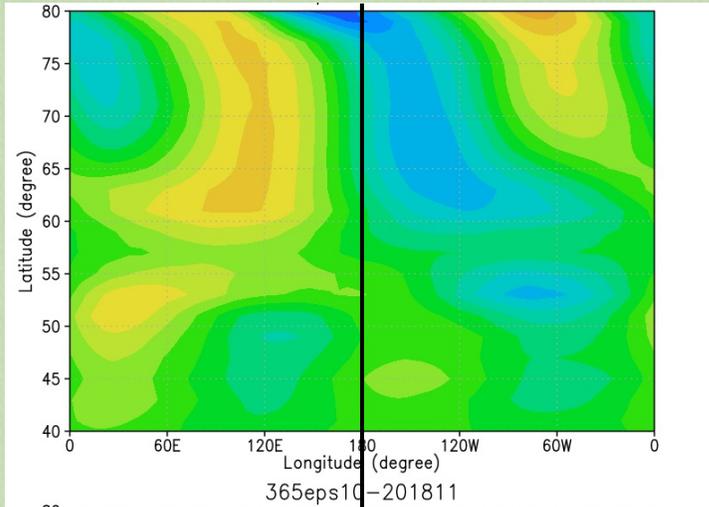
実験結果

東西風・温度 コンポジット平均 経度高度図

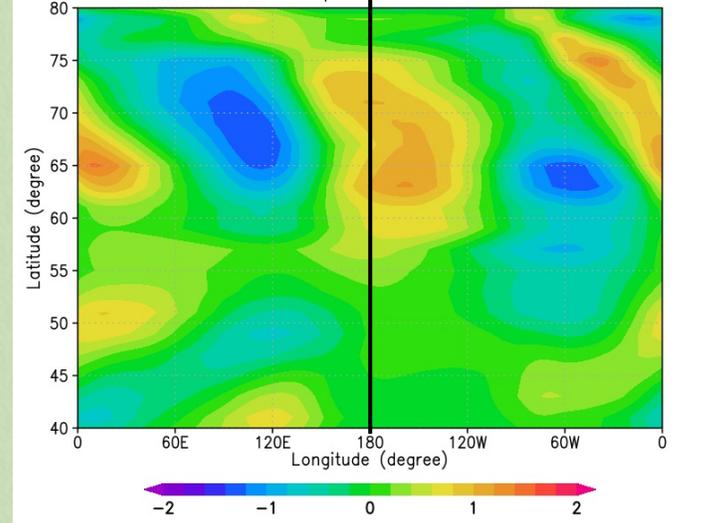
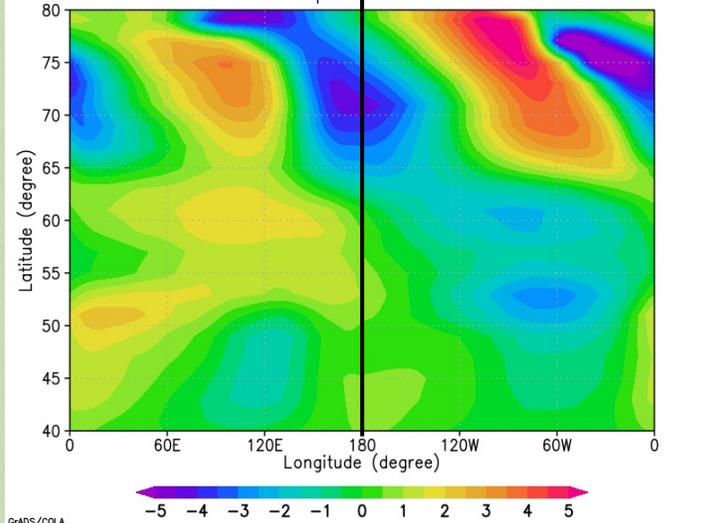
東西風($\sqrt{\rho u}$)

温度($\sqrt{\rho T}$)

frf



同化
結果



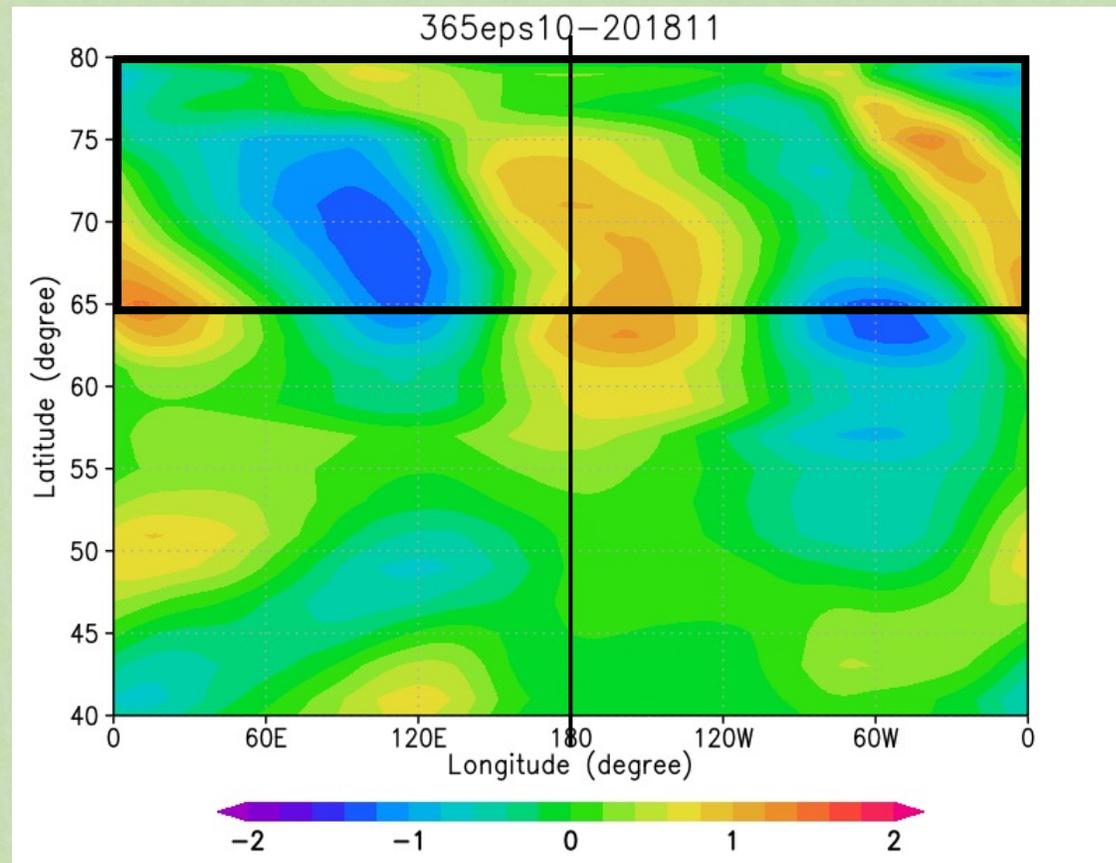
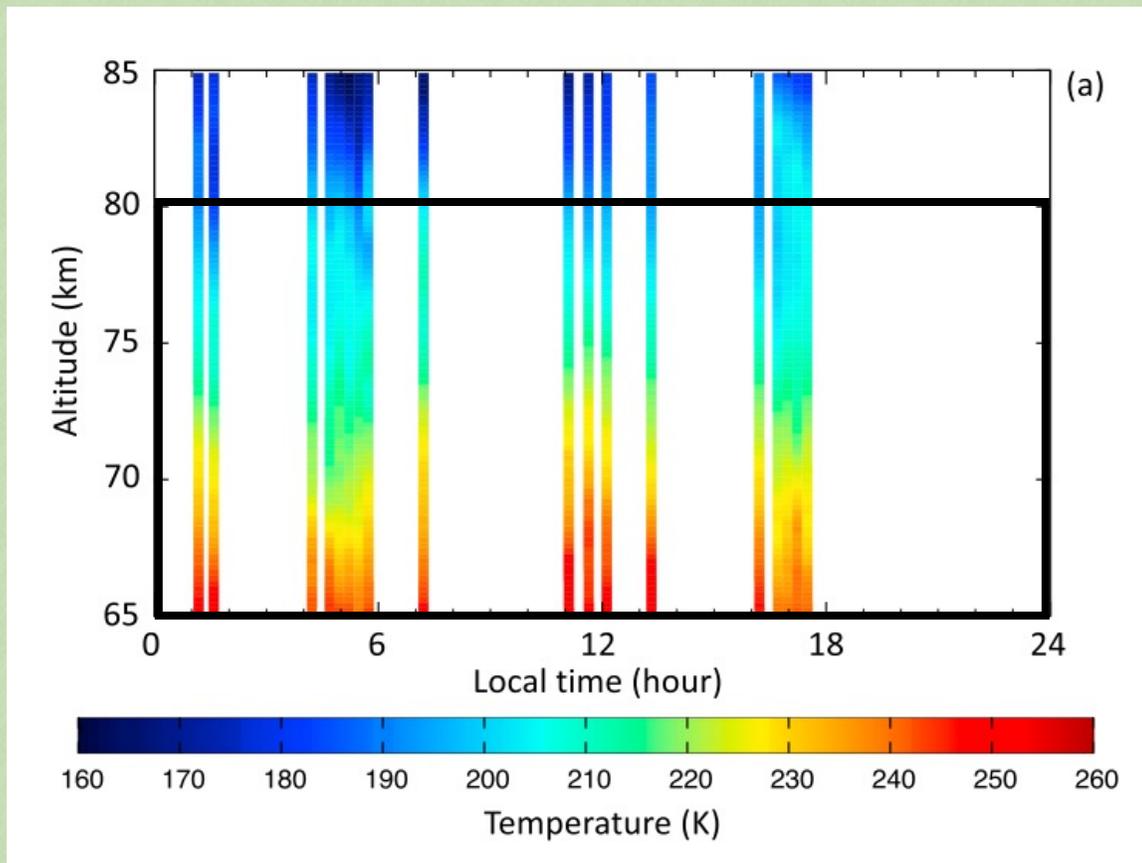


実験結果

温度 コンポジット平均 経度高度図 観測との比較

Ando et al. 2018

同化結果(2018.11)



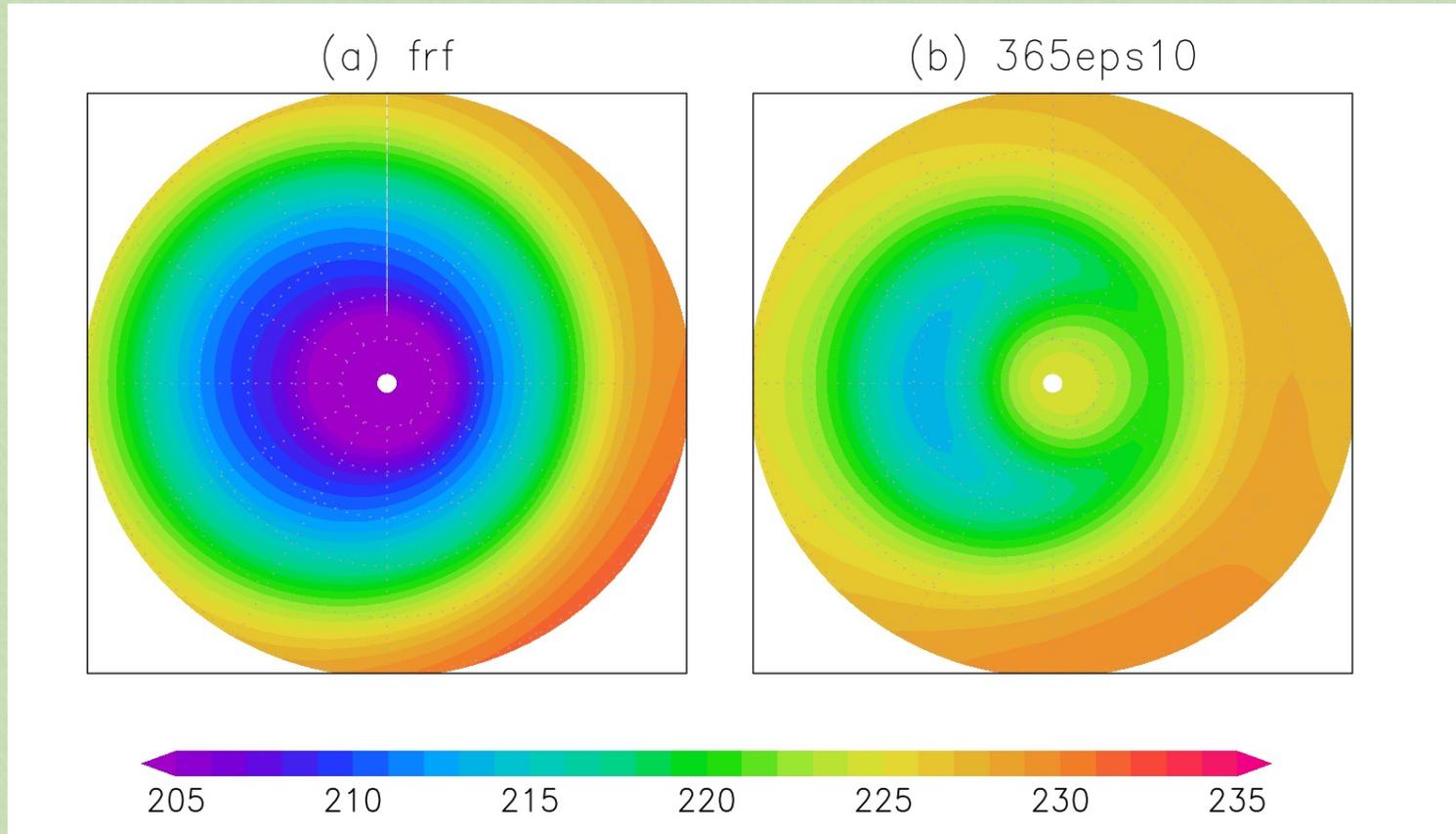


実験結果

温度 高度65km 30-90° N (コールドカラー)

frf(without assimilation)

同化結果(2018.11)



まとめ



まとめ

熱潮汐波に着目した分析

- あかつき観測により得られる水平風速を同化
 - 風速場（スーパーローテーション）の改善
 - 熱潮汐波の位相の改善
 - コールドカラーの再現



まとめ

再解析プロダクトの公開

- 今回の同化結果をファーストアナリシスとしてweb公開
 - データ形式：NetCDF
 - 同化期間：
 - epoch1: 201612 – 201701
 - epoch2: 201707 – 201709
 - epoch3: 201802 – 201804
 - epoch4: 201809 – 201812
- Ver2の作成
 - データ同化上の改善点の取り込み
 - UVI(283nm) ・ LIRの同化
 - 同化期間を検討（短周期擾乱の解析に適した期間等）

資料

LIR加重関数

LIR 加重関数

Taguchi et al. (2007) Fig.6

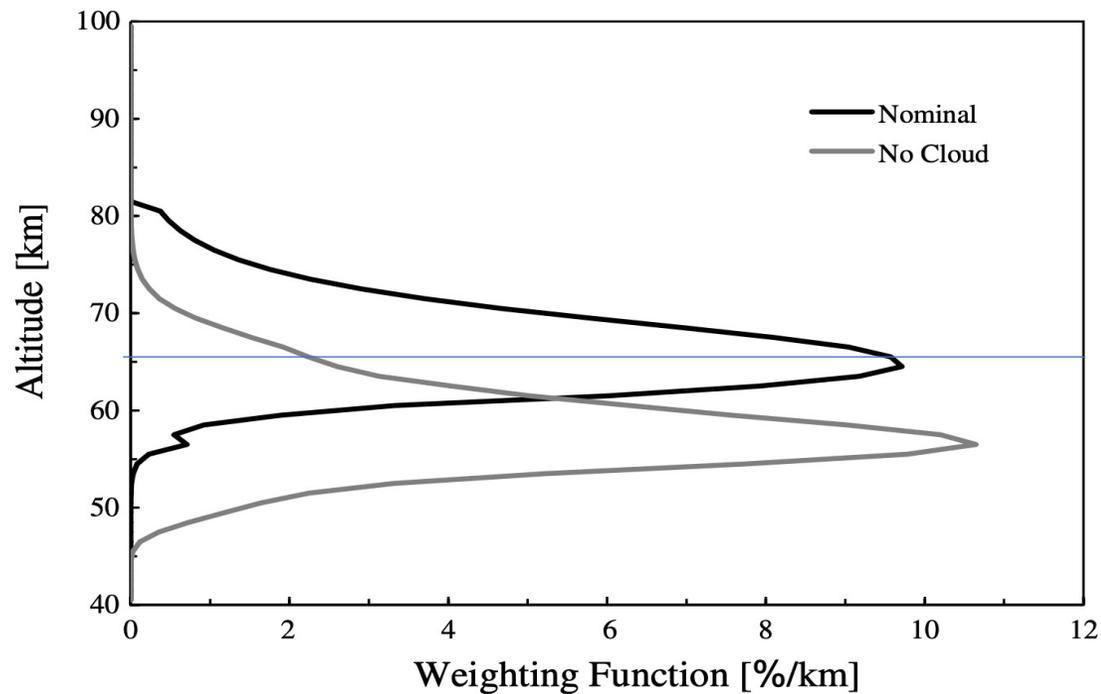
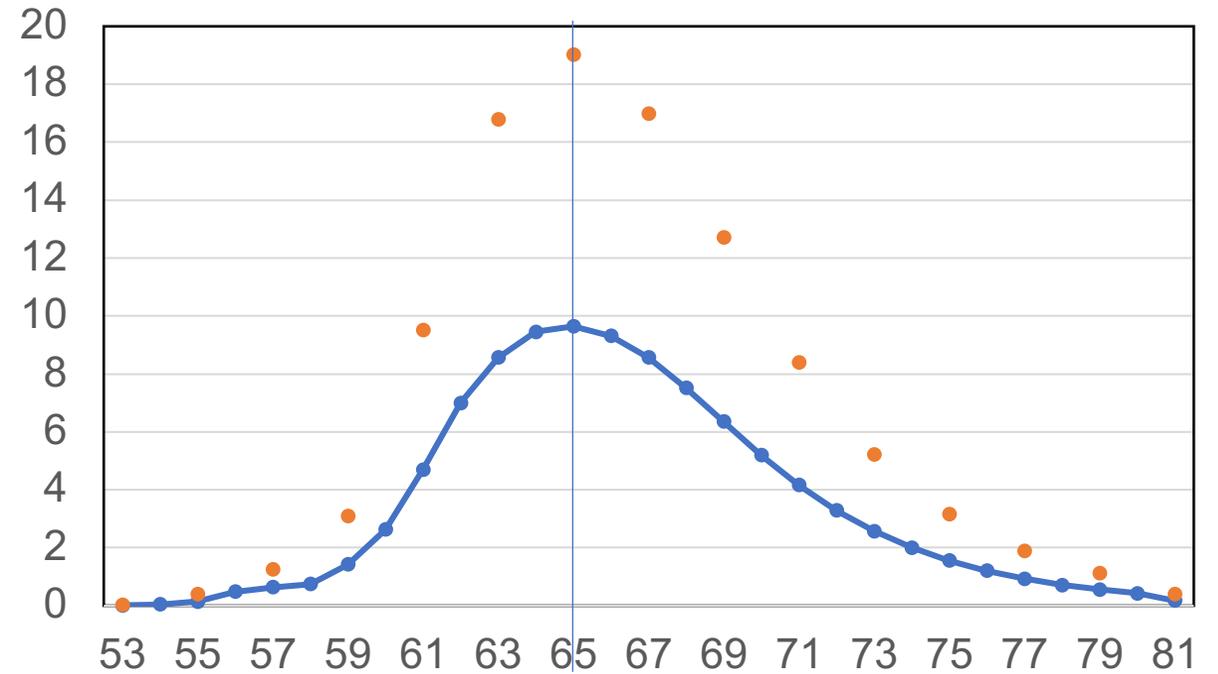


Fig. 6. Weighting functions of LIR for nominal and no cloud cases.

今回使用したLIR 加重関数 (オレンジ点)



● 高木さん作成 (1kmおき) ● データ同化用(2kmおき)

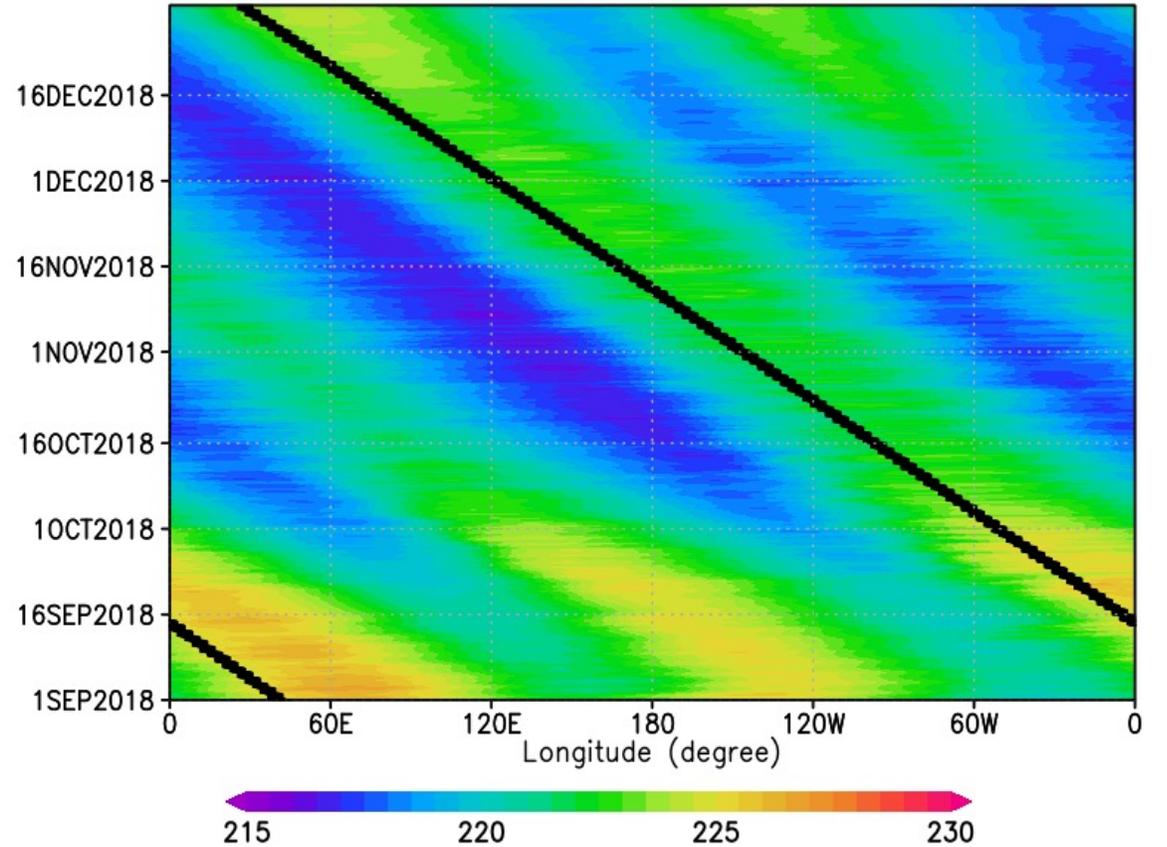
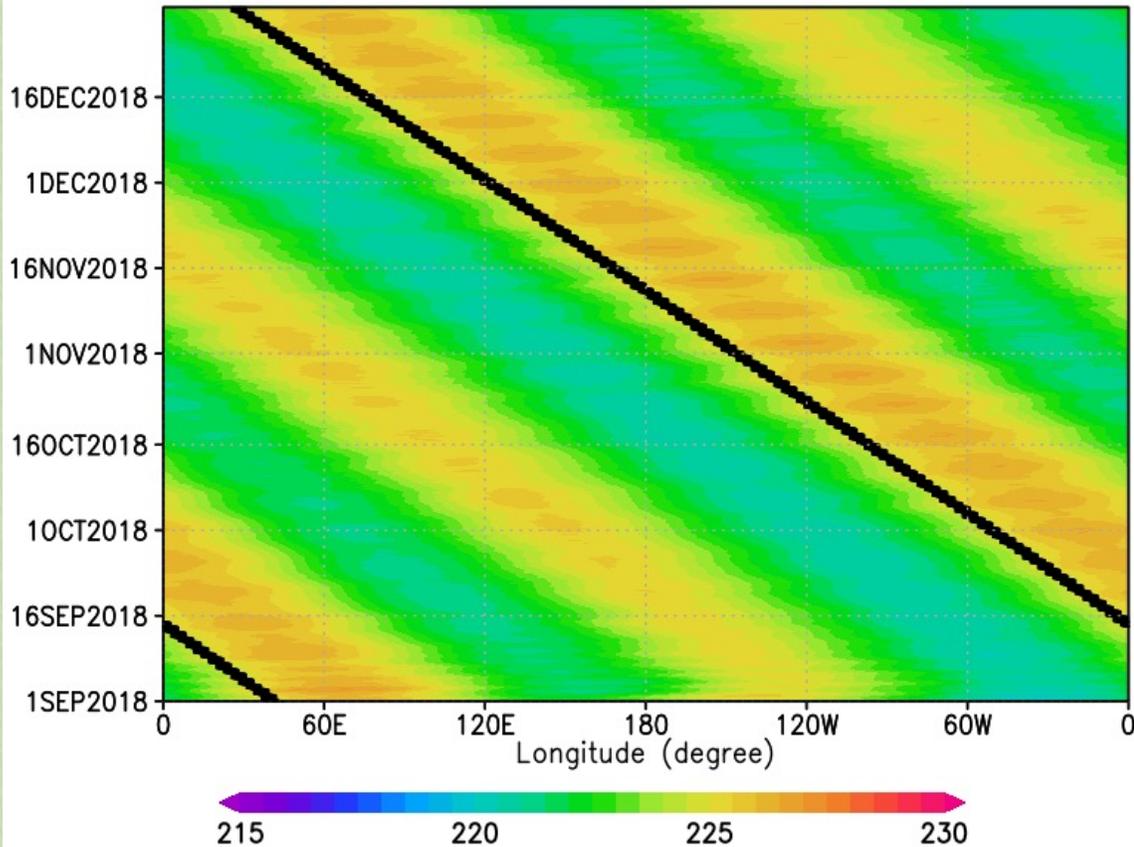


実験結果

温度 赤道上経度時間断面 (高度加重平均)

frf(without assimilation)

365eps10_201811





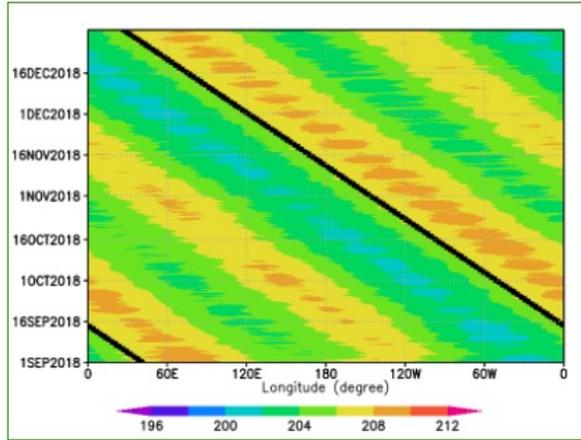
実験結果

温度 赤道上経度時間断面 (高度加重平均)

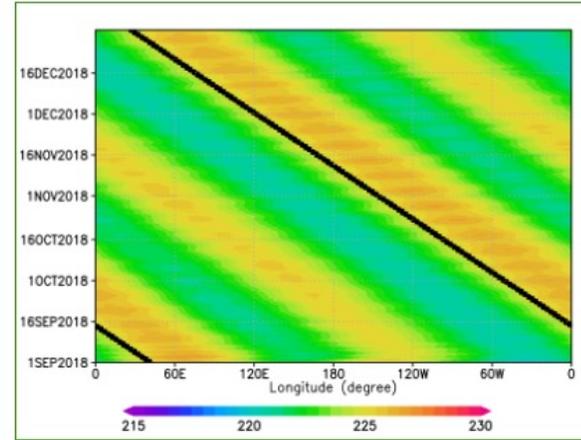
高度70km

高度加重関数

frf

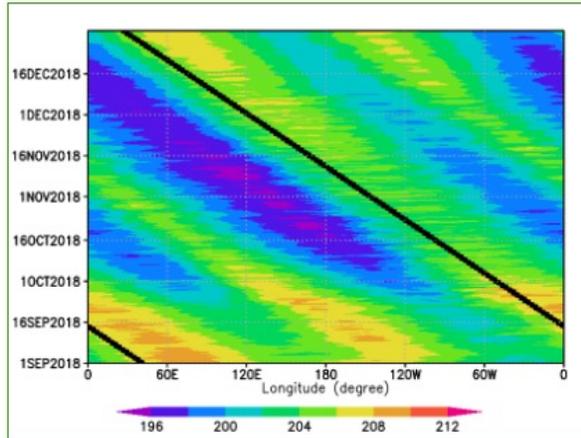


frf_201809-201812-xt_t_z35

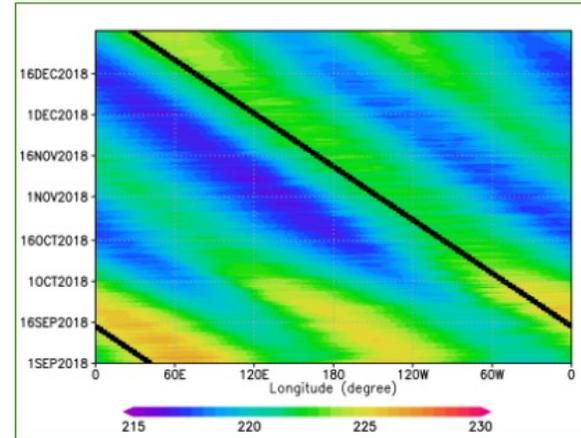


frf_201809-201812-xt_t_zlir

同化
結果



365eps10_201809-201812-xt_t_z35



365eps10_201809-201812-xt_t_zlir



実験結果

温度 コンポジット平均 平均)

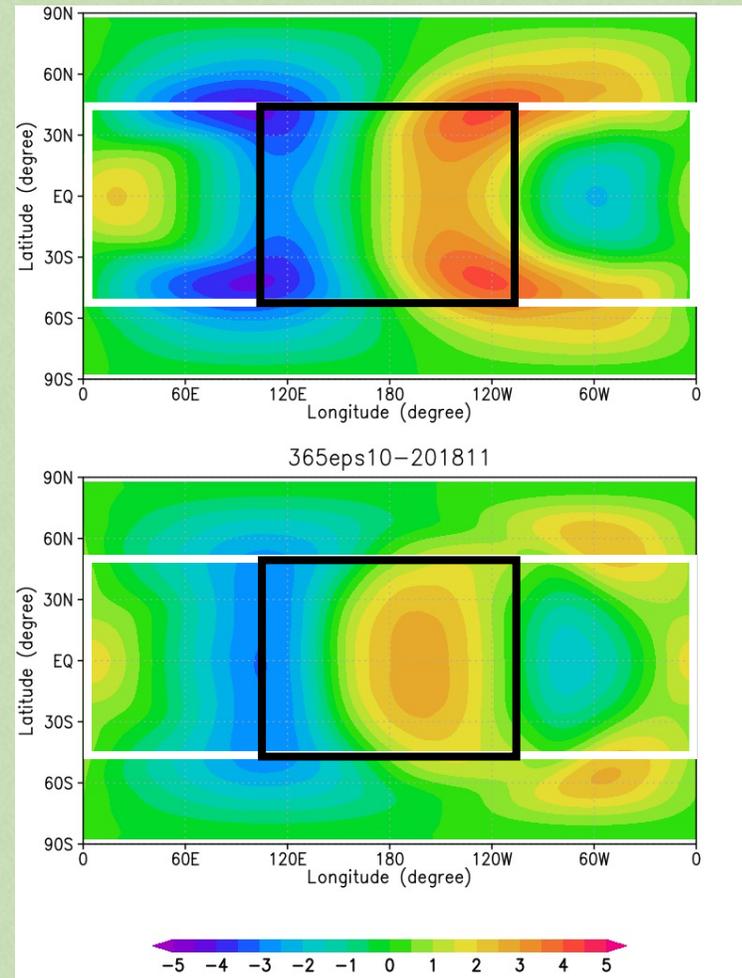
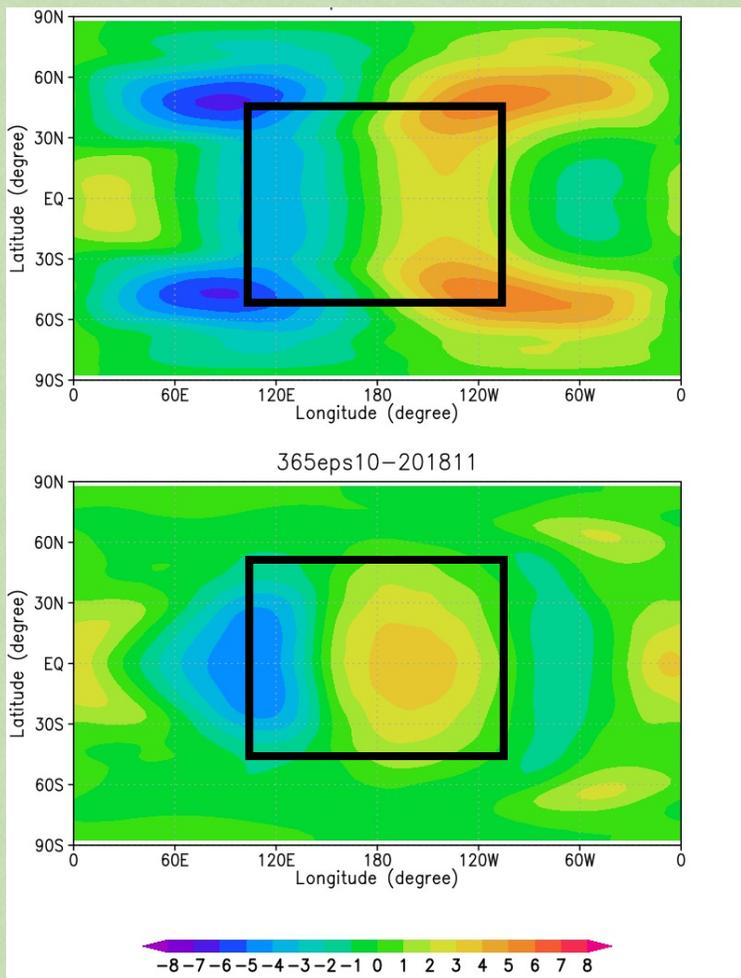
緯度経度図 (高度加重

温度 (高度70km)

温度 (温度加重平均)

frf

同化
結果



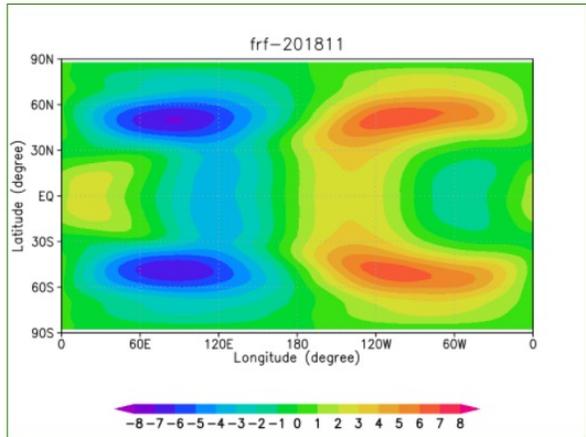
緯度経度断面 (z35, 加重関数なし)

T

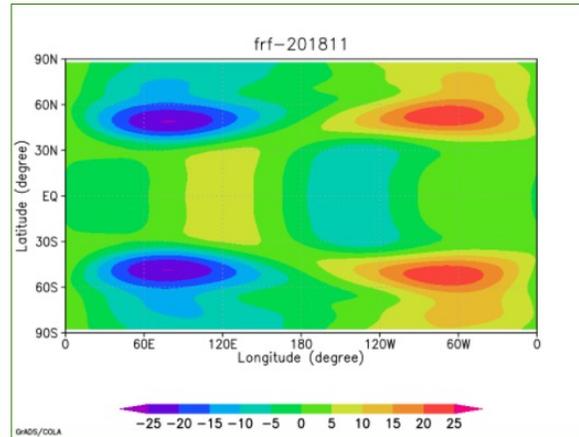
U

V

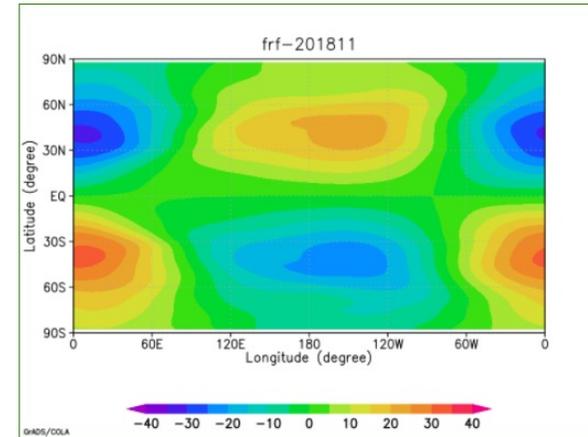
frf



frf-xy_t_z35_t201811_compst

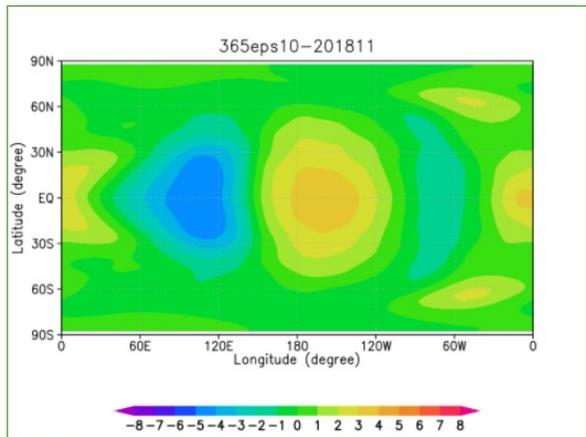


frf-xy_u_z35_t201811_compst

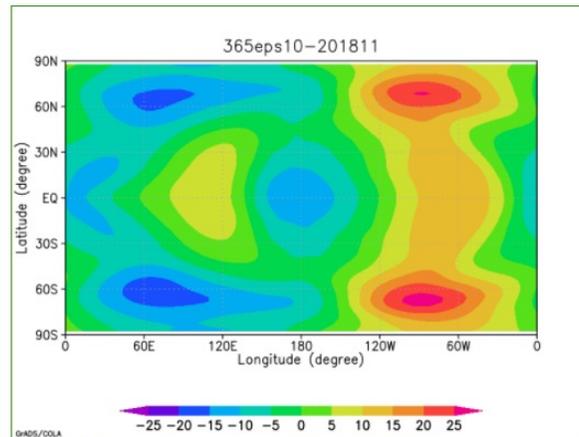


frf-xy_v_z35_t201811_compst

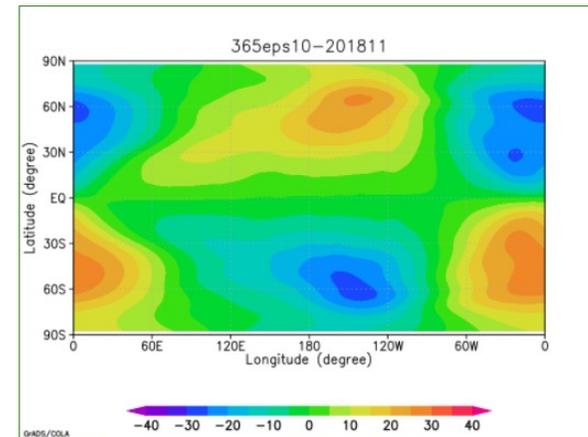
365eps10



365eps10-xy_t_z35_t201811_compst



365eps10-xy_u_z35_t201811_compst



365eps10-xy_v_z35_t201811_compst

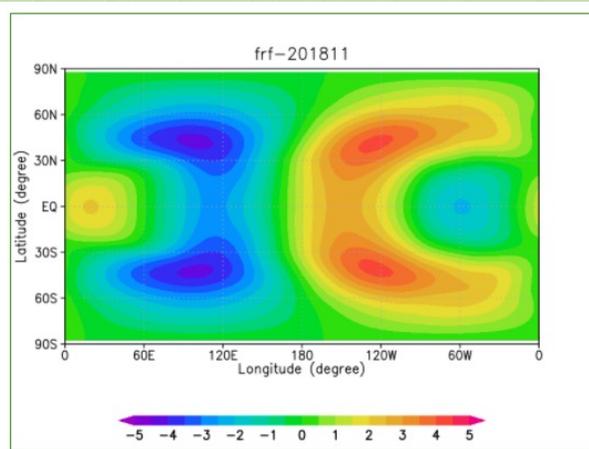
緯度經度断面 (加重関数)

T

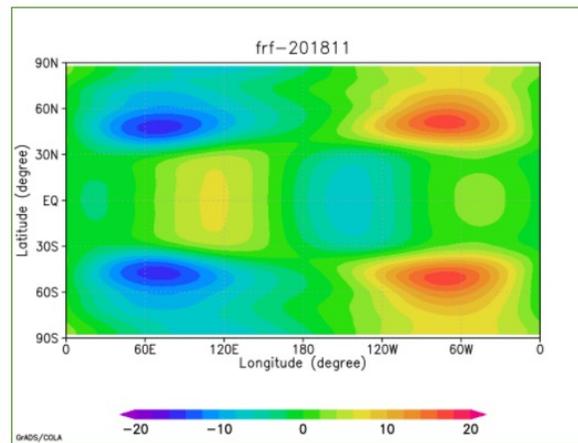
U

V

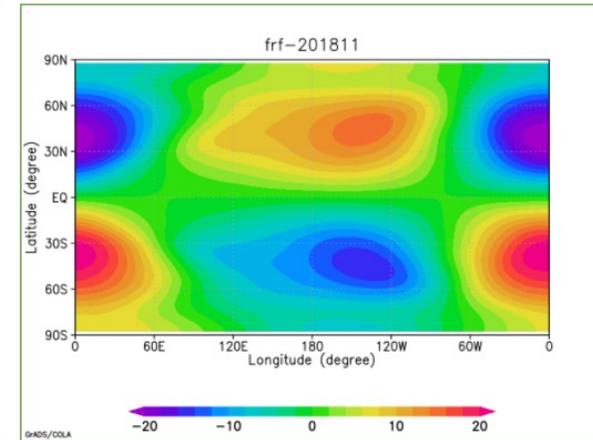
frf



frf-xy_t_zlir_t201811_compst

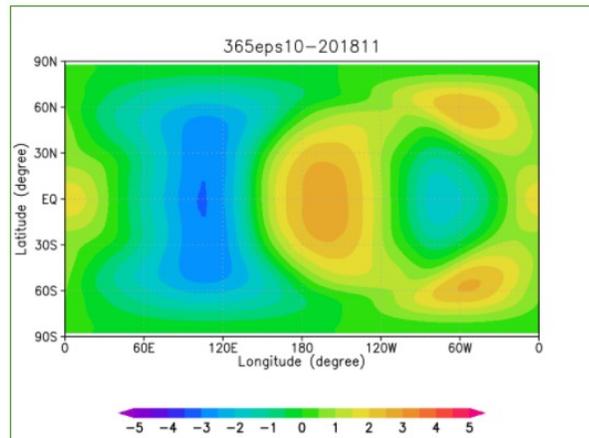


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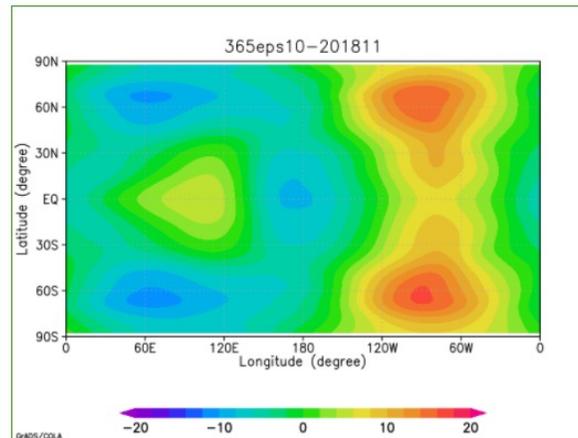


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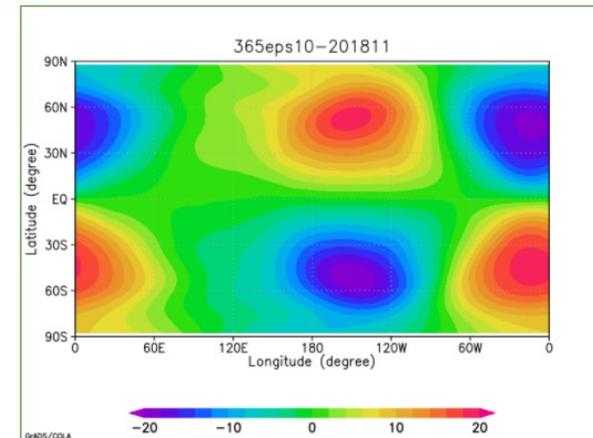
365eps10



365eps10-xy_t_zlir_t201811_compst



365eps10-xy_u_zlir_t201811_compst



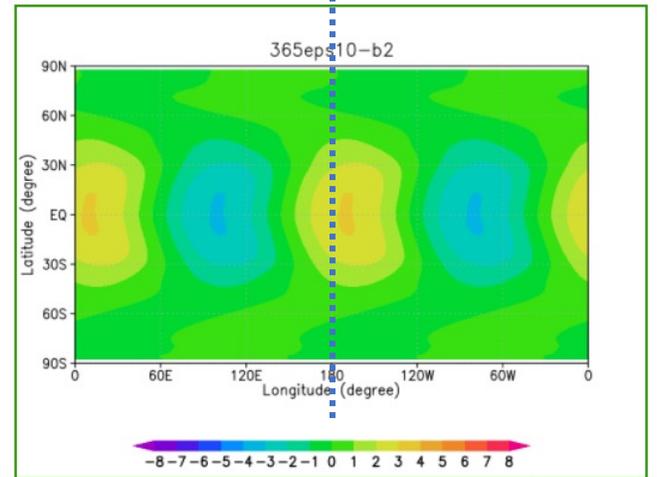
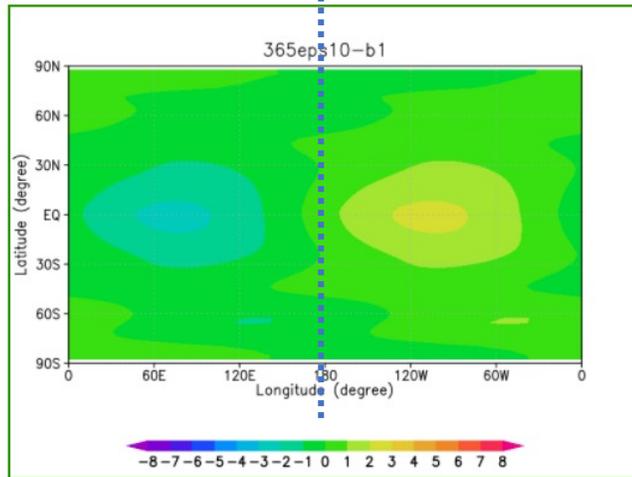
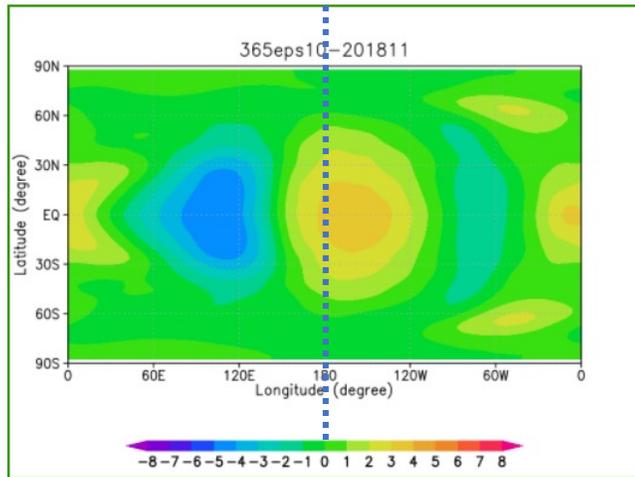
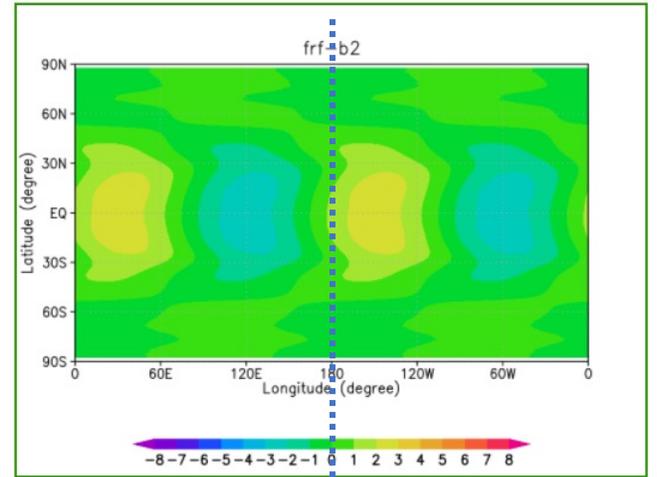
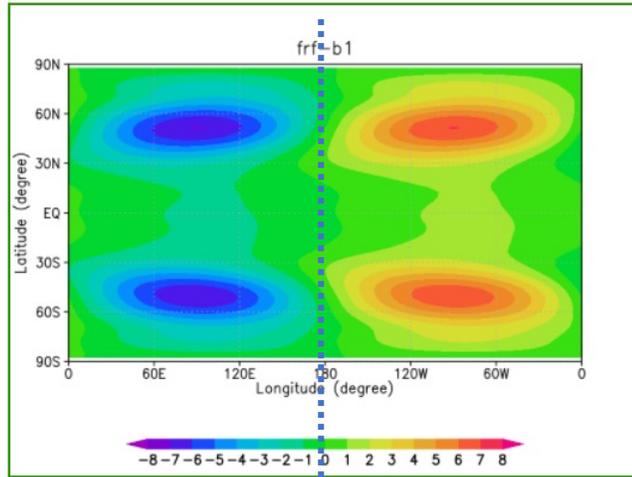
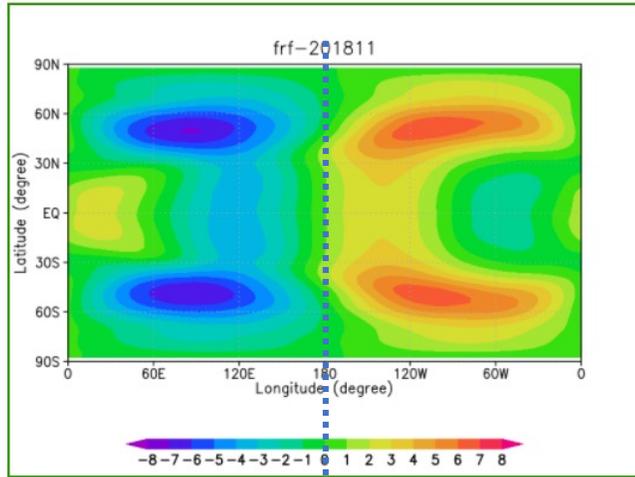
365eps10-xy_v_zlir_t201811_compst

波数分解(高度70km)



コンポジット図 (高度70km) 温度

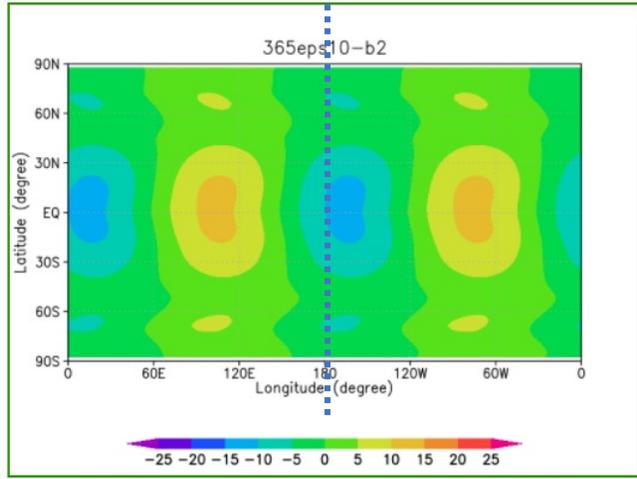
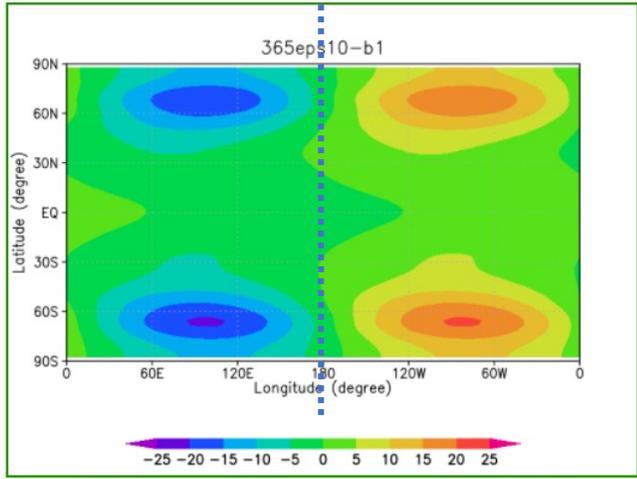
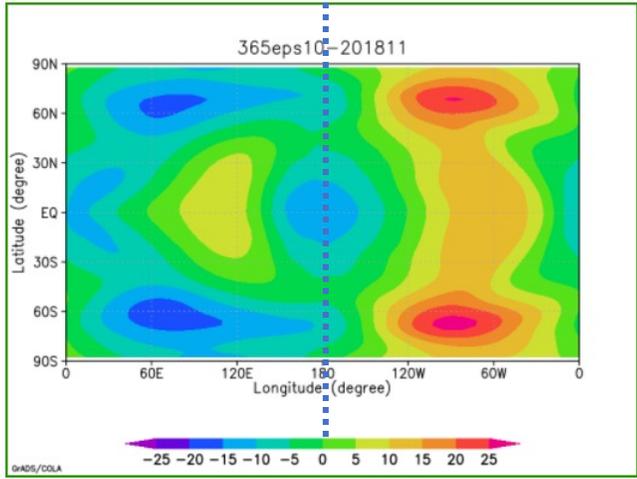
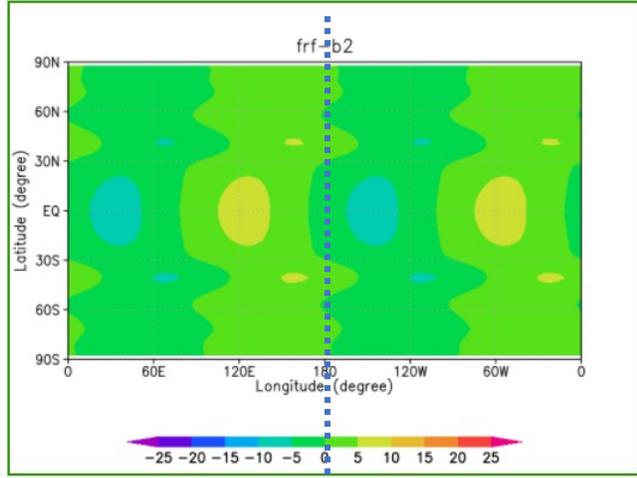
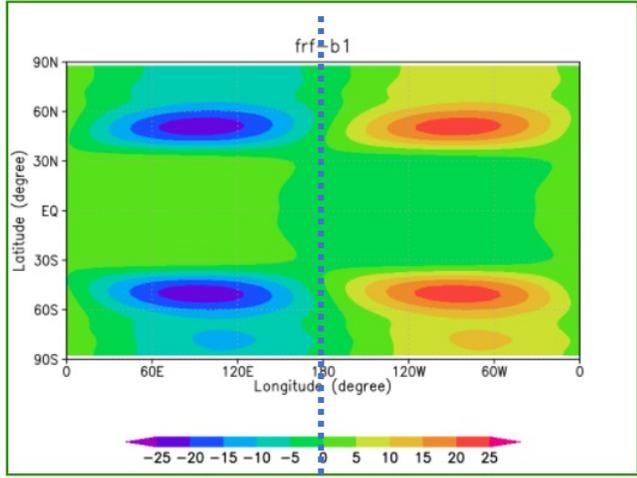
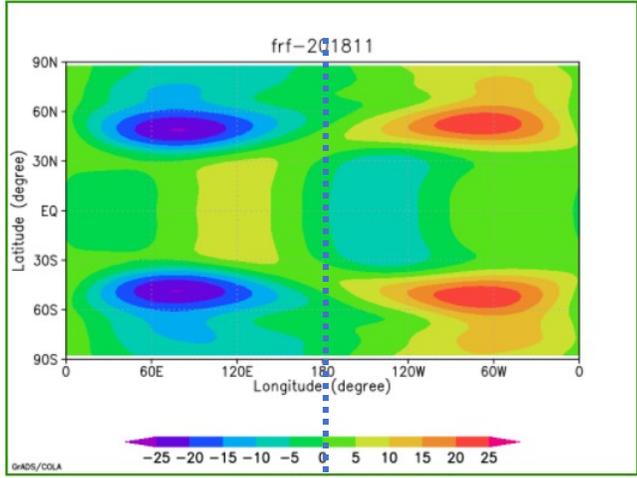
frf



365eps10
201811

コンポジット図 (高度70km) 東西風

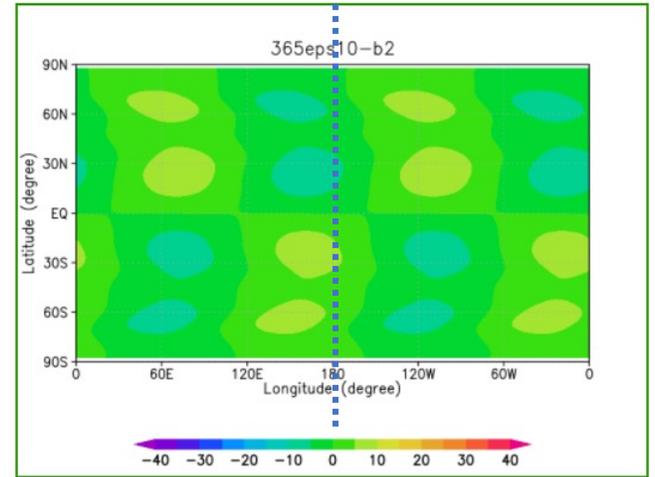
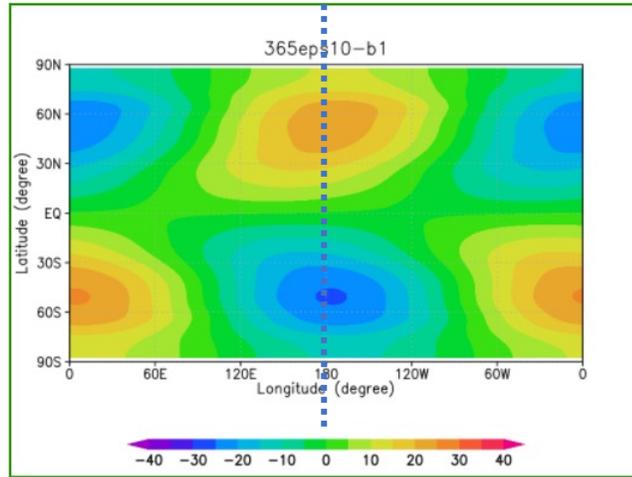
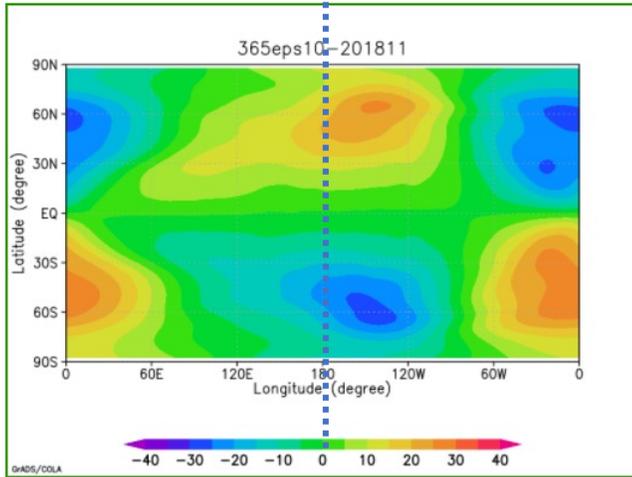
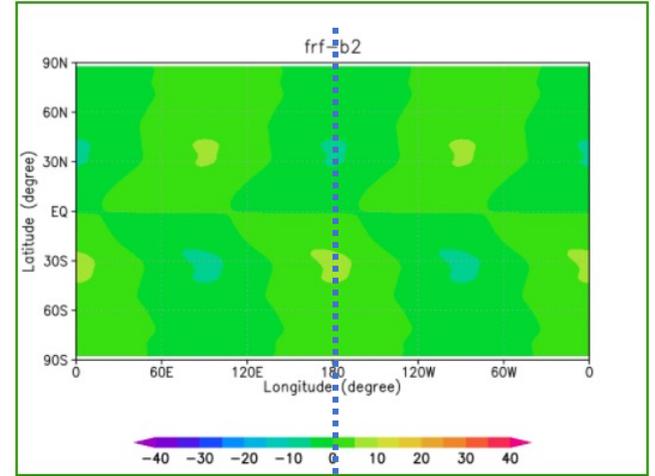
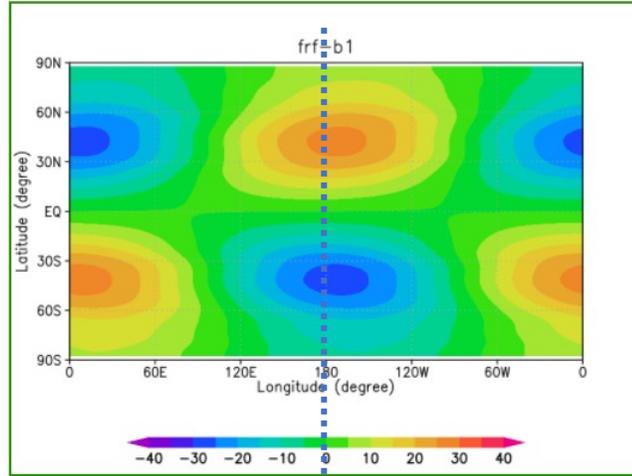
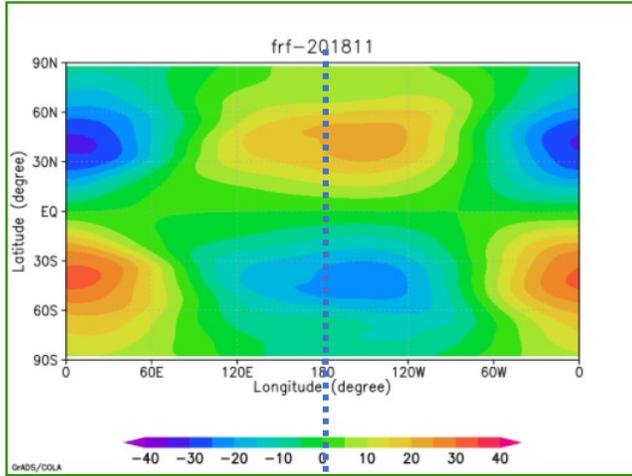
frf



365eps10
201811

コンポジット図 (高度70km) 南北風

frf



365eps10
201811

波数分解(赤道上高度経度図)

(参考) 赤道上経度高度断面 温度

元の図

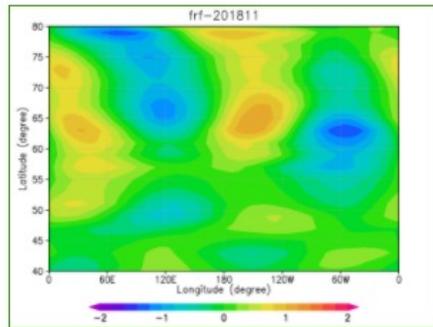
波数 1

波数 2

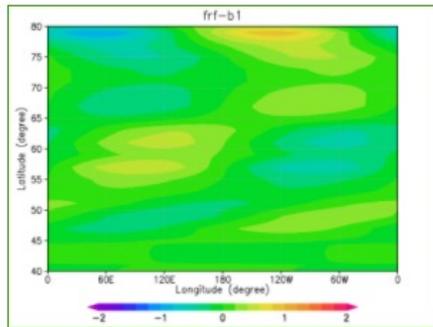
波数 3

波数 4

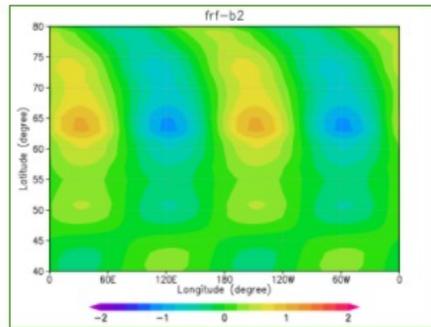
frf



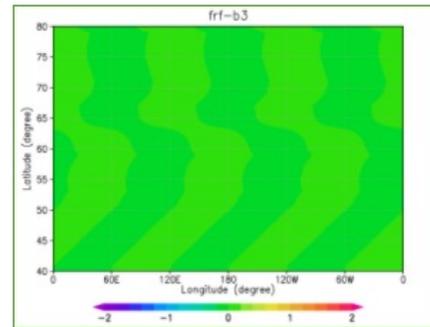
frf-xz_t_y0_t201811_compst



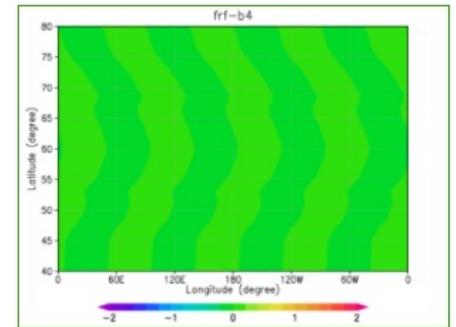
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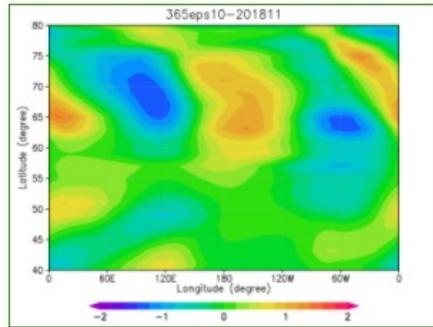


frf-xz_t_y0_b3

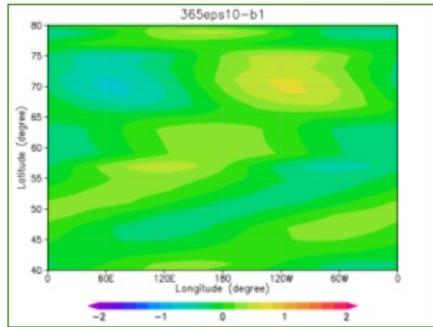


frf-xz_t_y0_b4

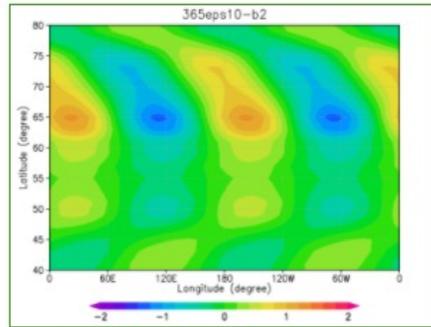
365
eps10



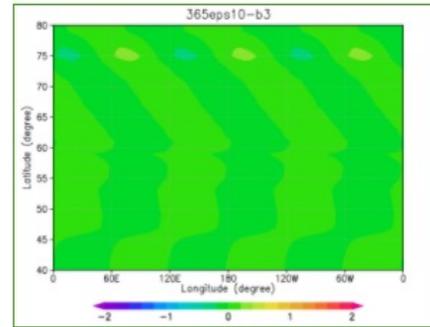
365eps10-
xz_t_y0_t201811_compst



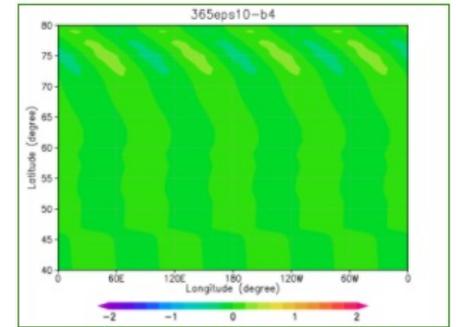
365eps10-xz_t_y0_b1



365eps10-xz_t_y0_b2



365eps10-xz_t_y0_b3



365eps10-xz_t_y0_b4

(参考) 赤道上経度高度断面 東西風

元の図

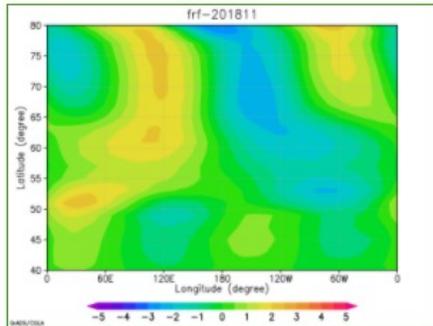
波数 1

波数 2

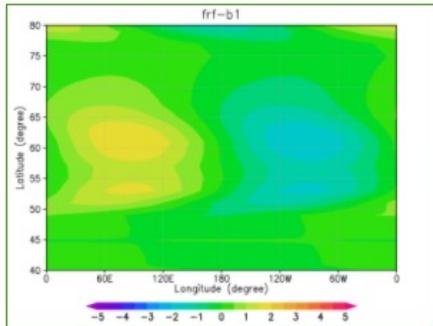
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波数 4

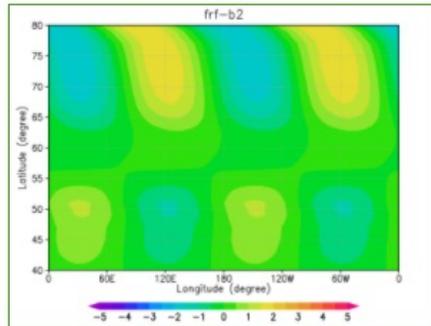
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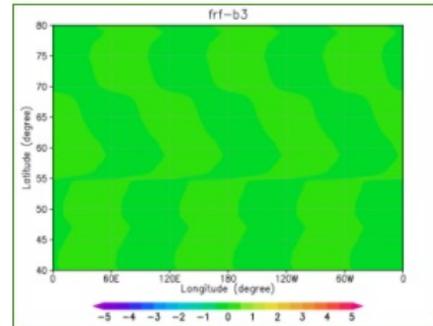
frf-xz_u_y0_t201811_compst



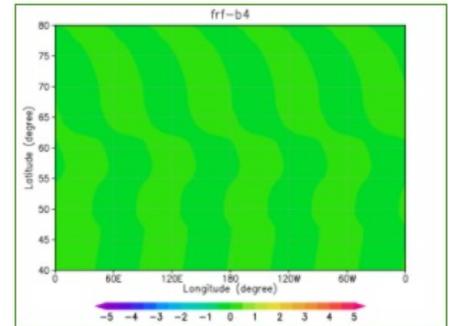
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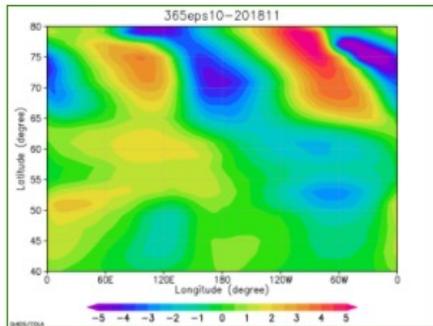


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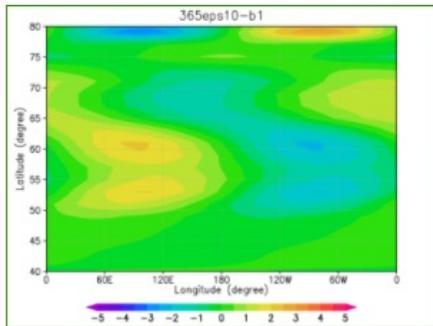


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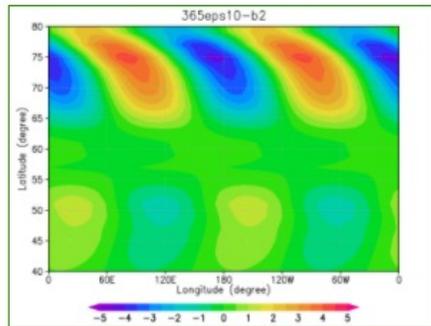
365
eps10



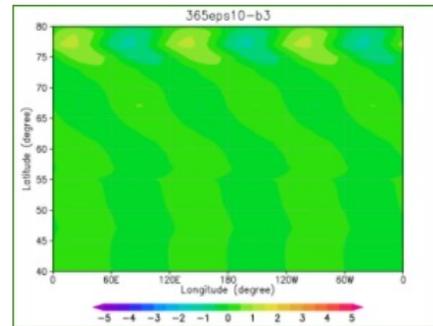
365eps10-
xz_u_y0_t201811_compst



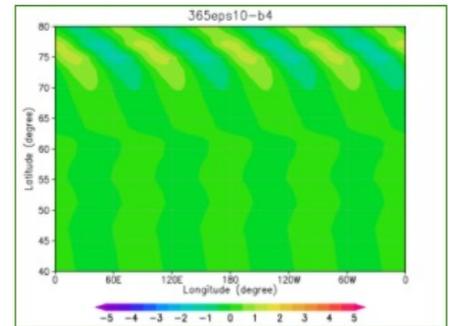
365eps10-xz_u_y0_b1



365eps10-xz_u_y0_b2



365eps10-xz_u_y0_b3



365eps10-xz_u_y0_b4

波数分解(高度加重平均)

緯度経度断面 (加重関数)温度

元の図

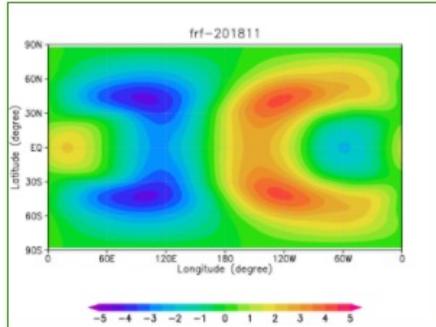
波数 1

波数 2

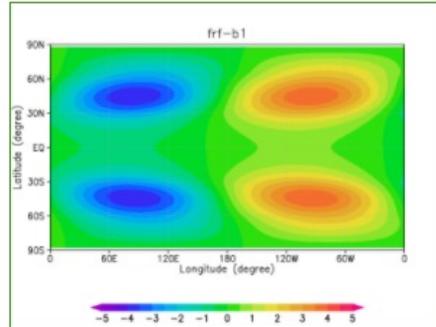
波数 3

波数 4

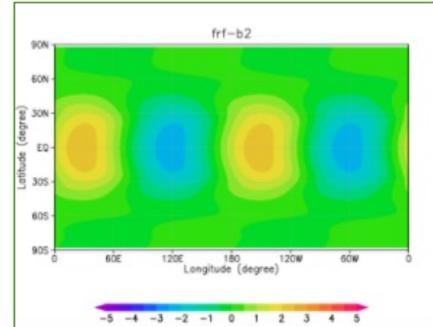
frf



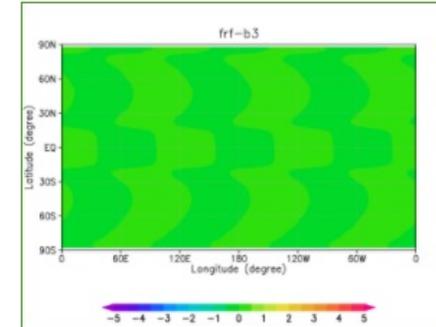
frf-xy_t_zlir_t201811_compst



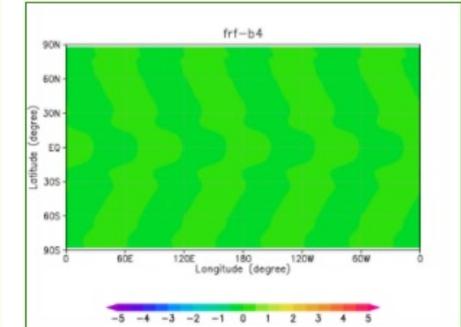
frf-xy_t_zlir_b1



frf-xy_t_zlir_b2

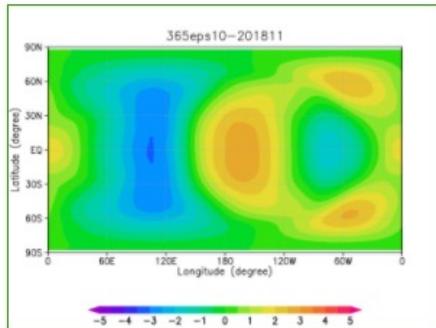


frf-xy_t_zlir_b3

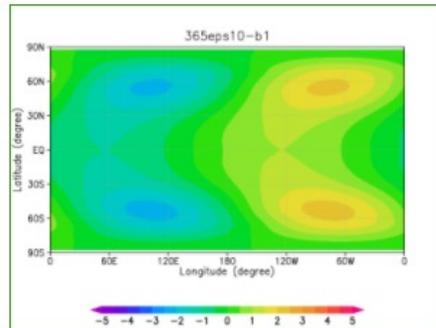


frf-xy_t_zlir_b4

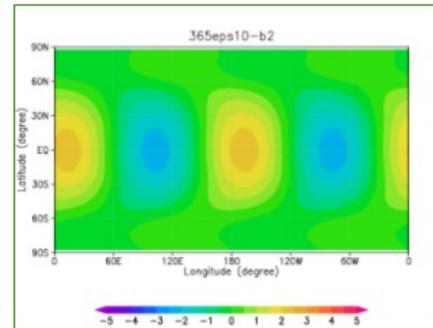
365
eps10



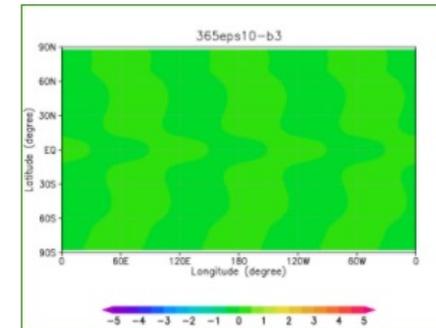
365eps10-



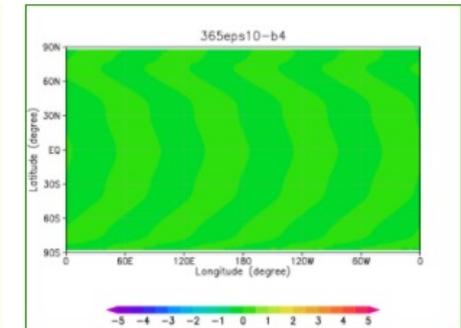
365eps10-xy_t_zlir_b1



365eps10-xy_t_zlir_b2



365eps10-xy_t_zlir_b3



365eps10-xy_t_zlir_b4

緯度経度断面 (加重関数)東西風

元の図

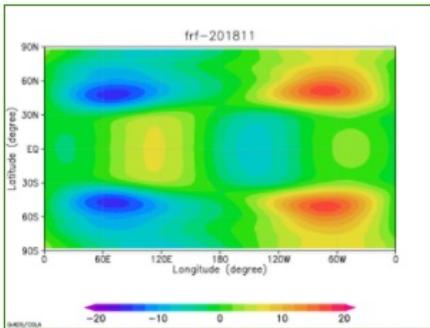
波数 1

波数 2

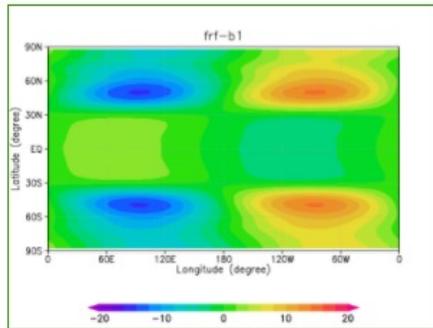
波数 3

波数 4

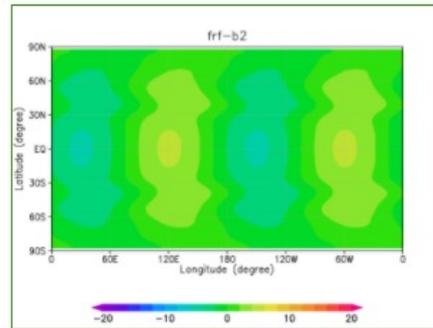
frf



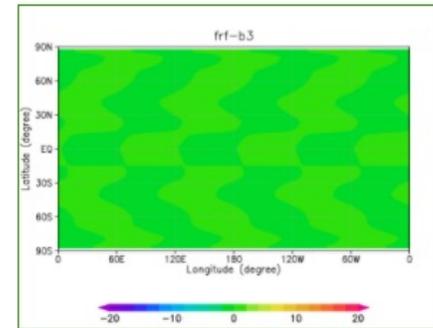
frf-xy_u_zlir_t201811_compst



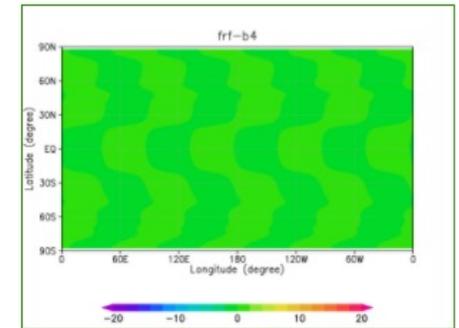
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frf-xy_u_zlir_b2

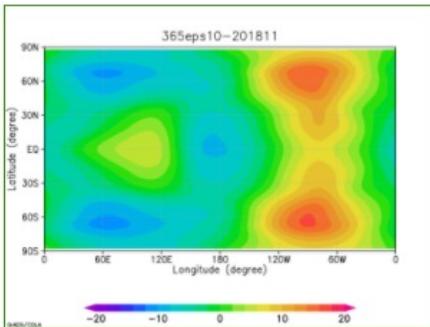


frf-xy_u_zlir_b3

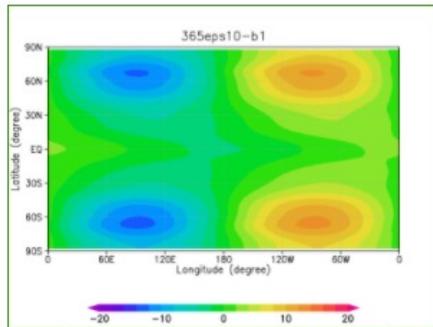


frf-xy_u_zlir_b4

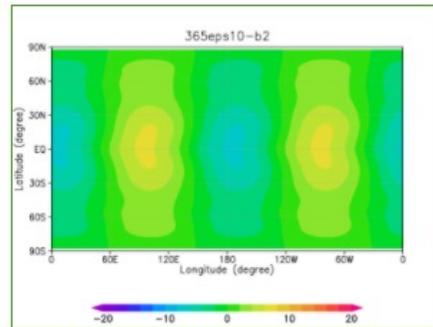
365
eps10



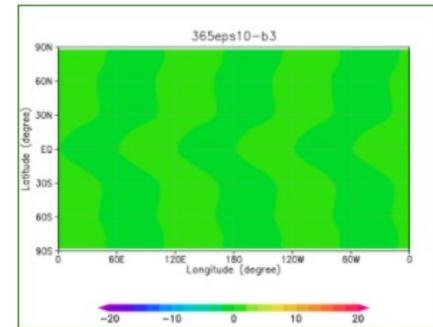
365eps10-xy_u_zlir_t201811_compst



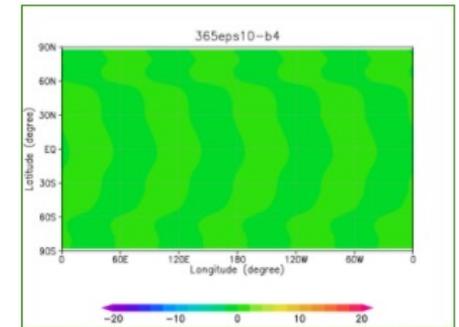
365eps10-xy_u_zlir_b1



365eps10-xy_u_zlir_b2



365eps10-xy_u_zlir_b3



365eps10-xy_u_zlir_b4

緯度経度断面 (加重関数)南北風

元の図

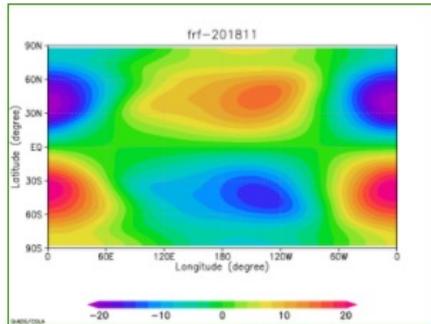
波数 1

波数 2

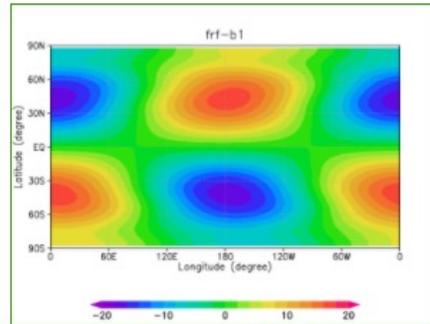
波数 3

波数 4

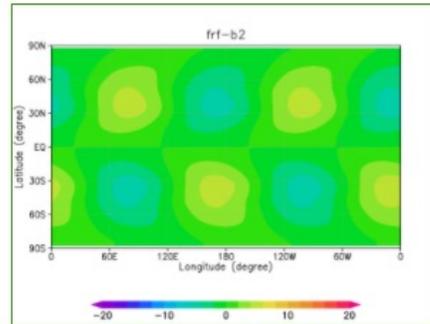
frf



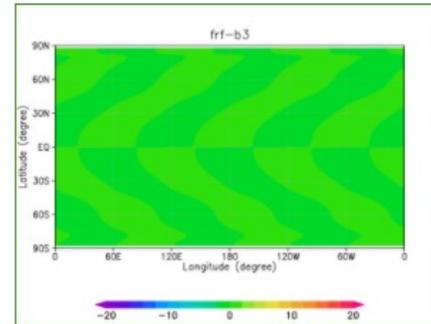
frf-xy_v_zlir_t201811_compst



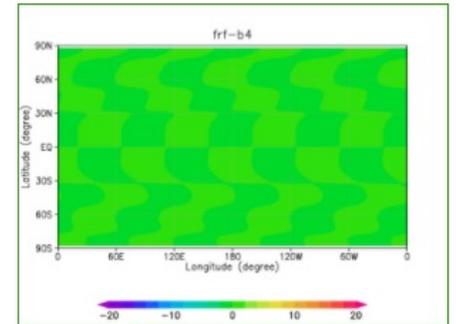
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frf-xy_v_zlir_b2

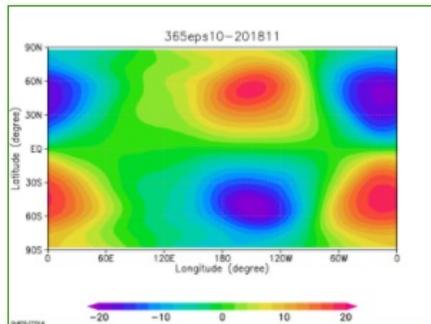


frf-xy_v_zlir_b3

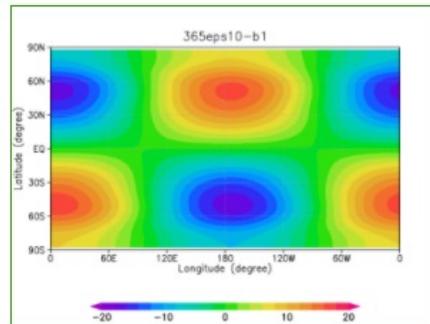


frf-xy_v_zlir_b4

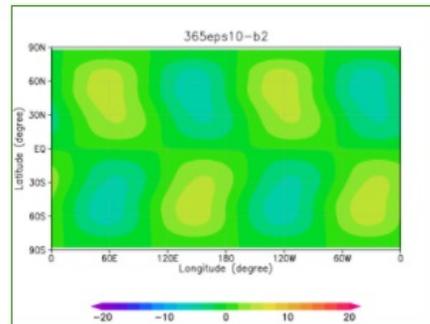
365
eps10



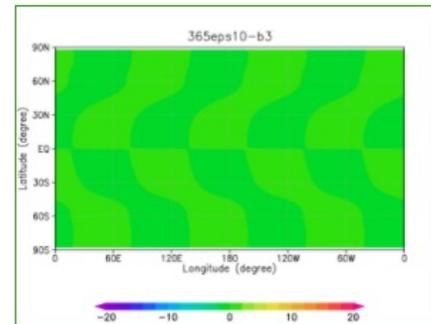
365eps10-xy_v_zlir_t201811_compst



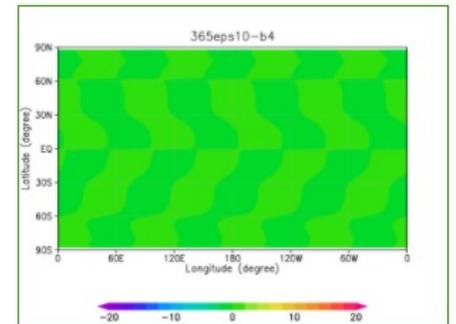
365eps10-xy_v_zlir_b1



365eps10-xy_v_zlir_b2



365eps10-xy_v_zlir_b3

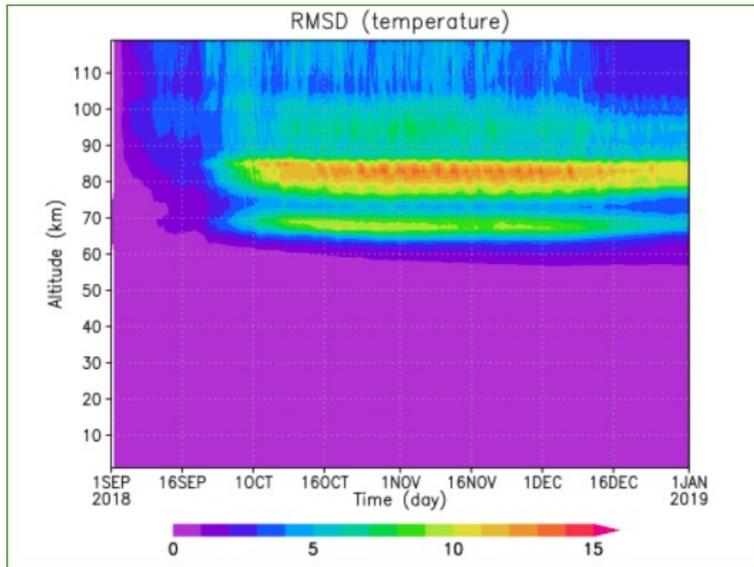


365eps10-xy_v_zlir_b4

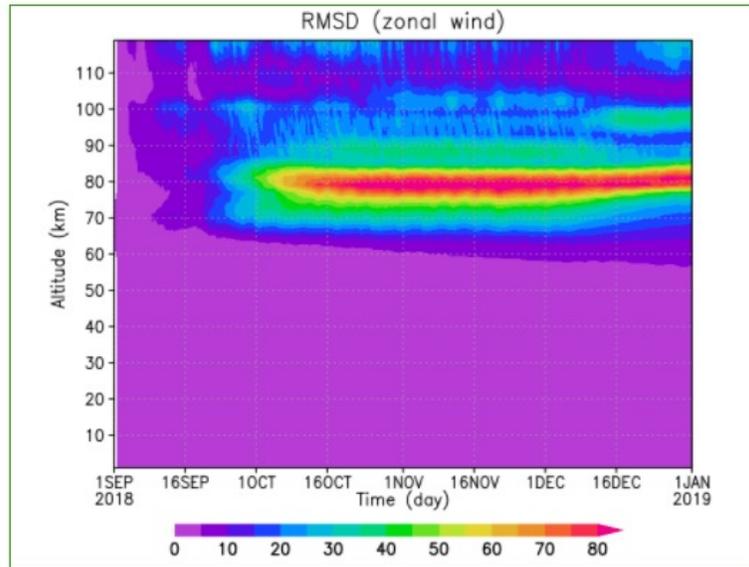
RMSD



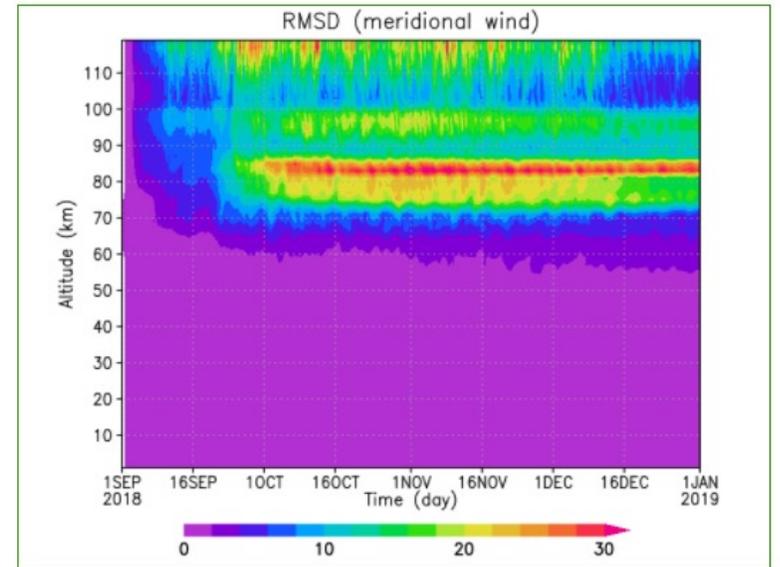
実験結果 RMSD 高度時間断面



365eps10-rmsd_t_201809-201812



365eps10-rmsd_u_201809-201812



365eps10-rmsd_v_201809-201812

運動量フラックス・熱フラックス



実験結果

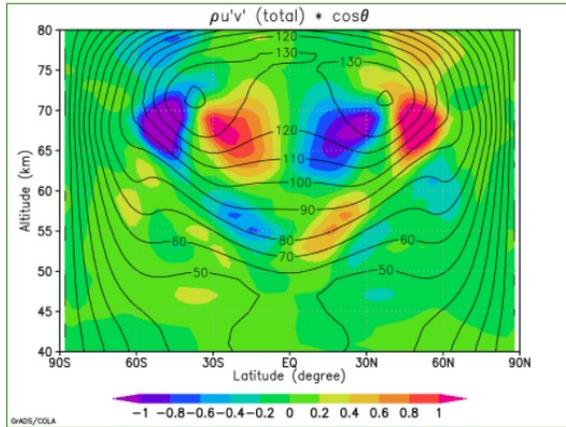
運動量輸送 $\rho \langle u'v' \rangle \cos \theta$

(2018.10-11)

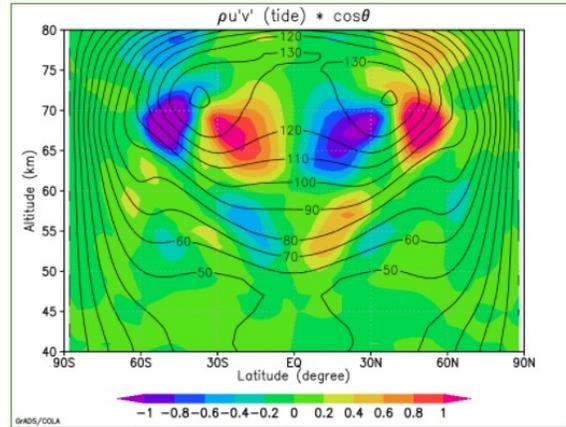
total

熱潮汐波

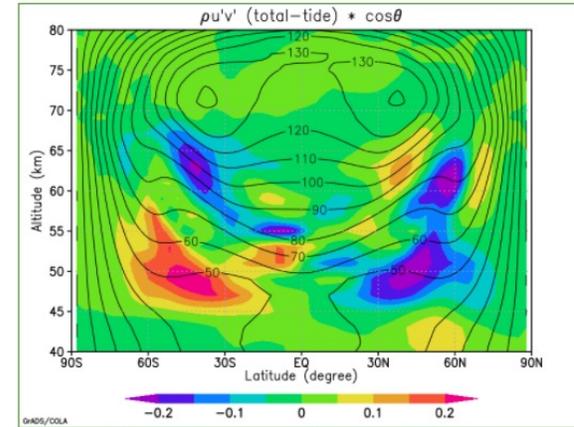
短周期擾乱



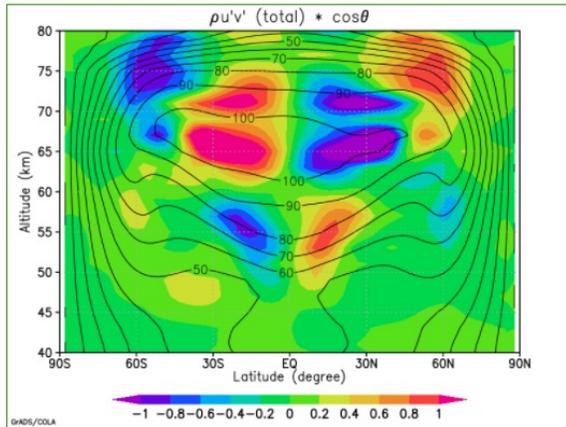
frf_UVrho_total_20181011



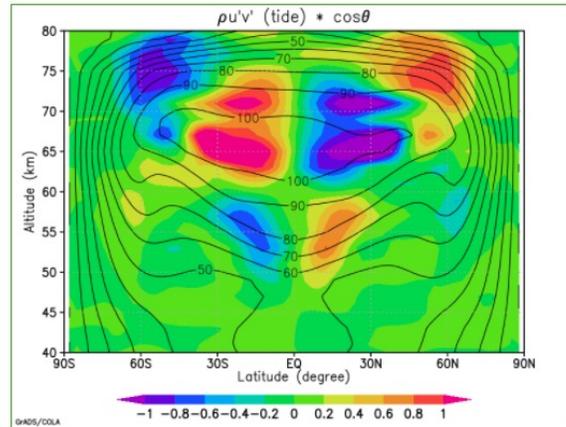
frf_UVrho_tide_20181011



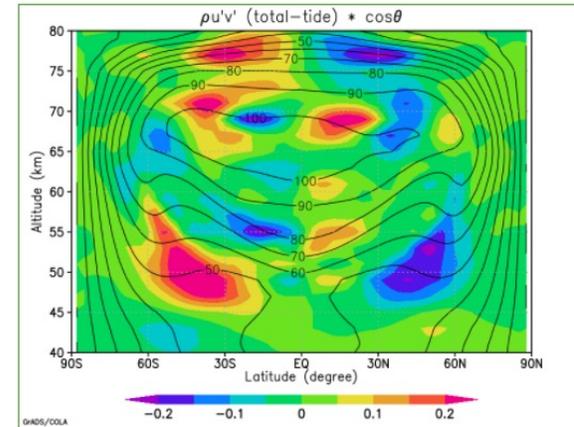
frf_UVrho_another_20181011



365eps10_UVrho_total_20181011



365eps10_UVrho_tide_20181011



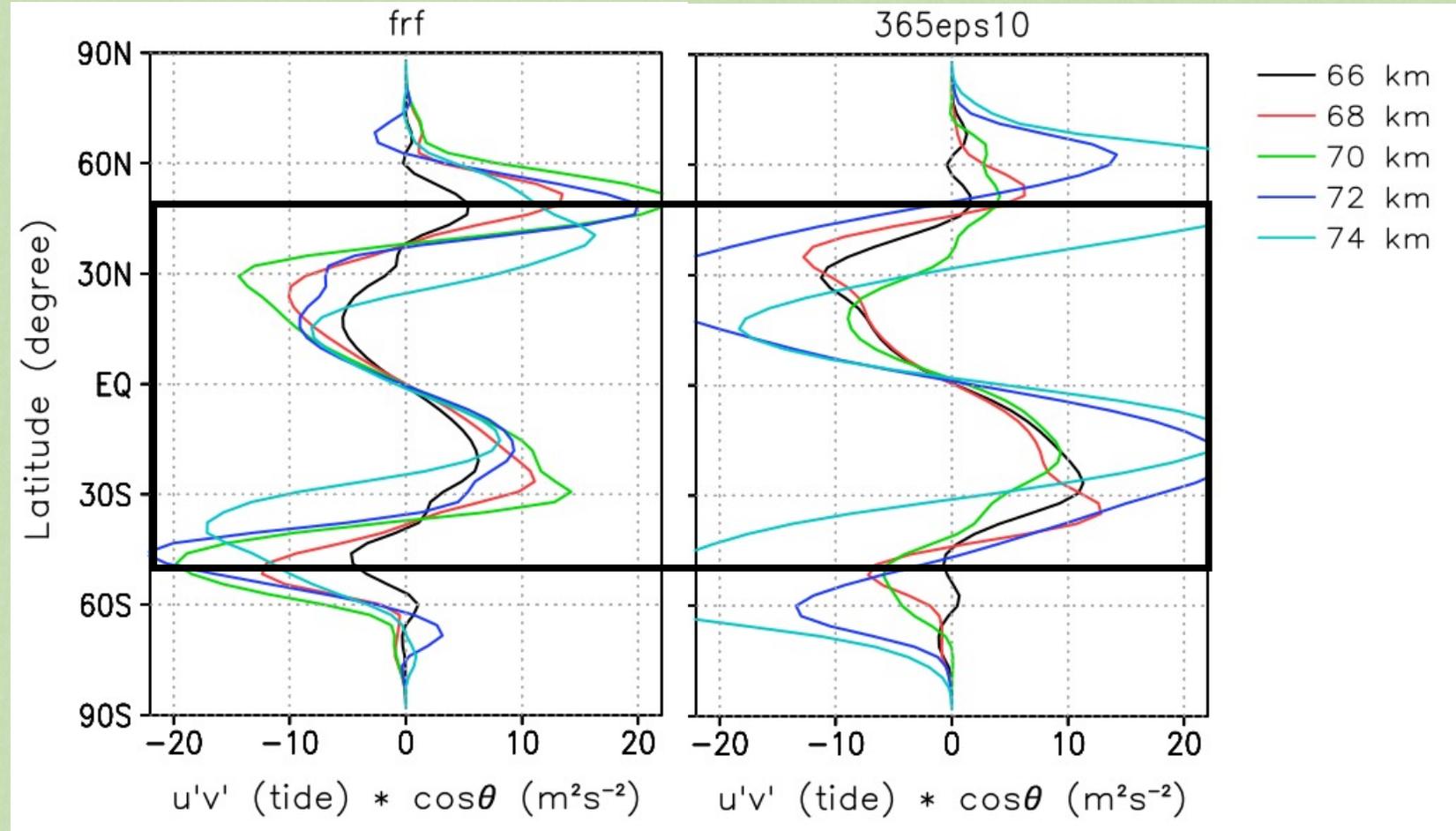
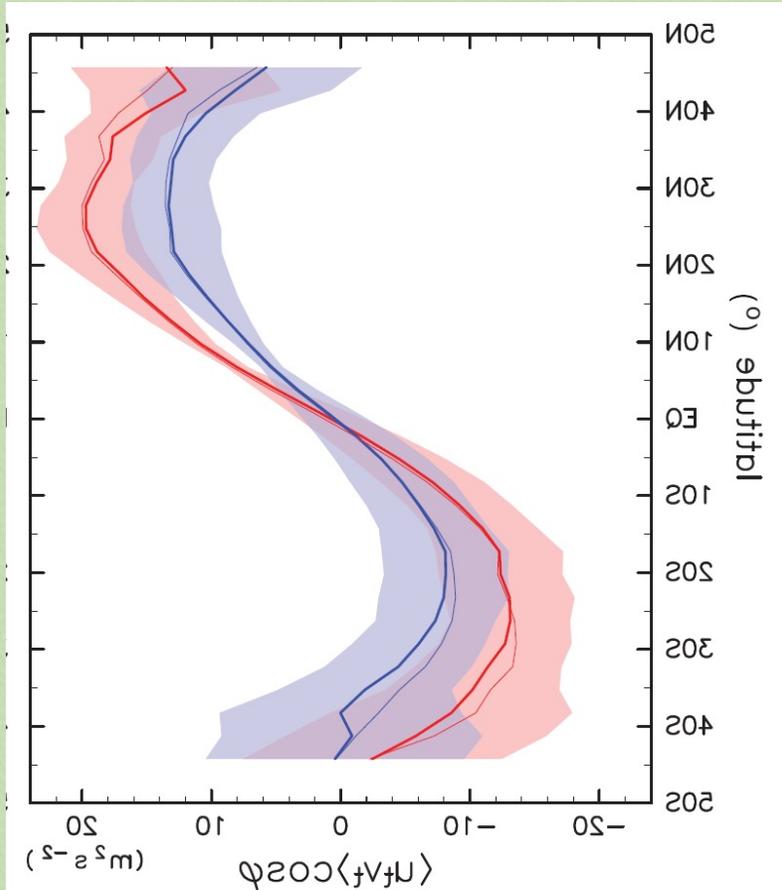
365eps10_UVrho_another_20181011

実験結果 運動量輸送 $\langle u'v' \rangle \cos \theta$ 観測との比較

Horinouch et al. 2020

frf

同化結果(2018.10-11)





実験結果

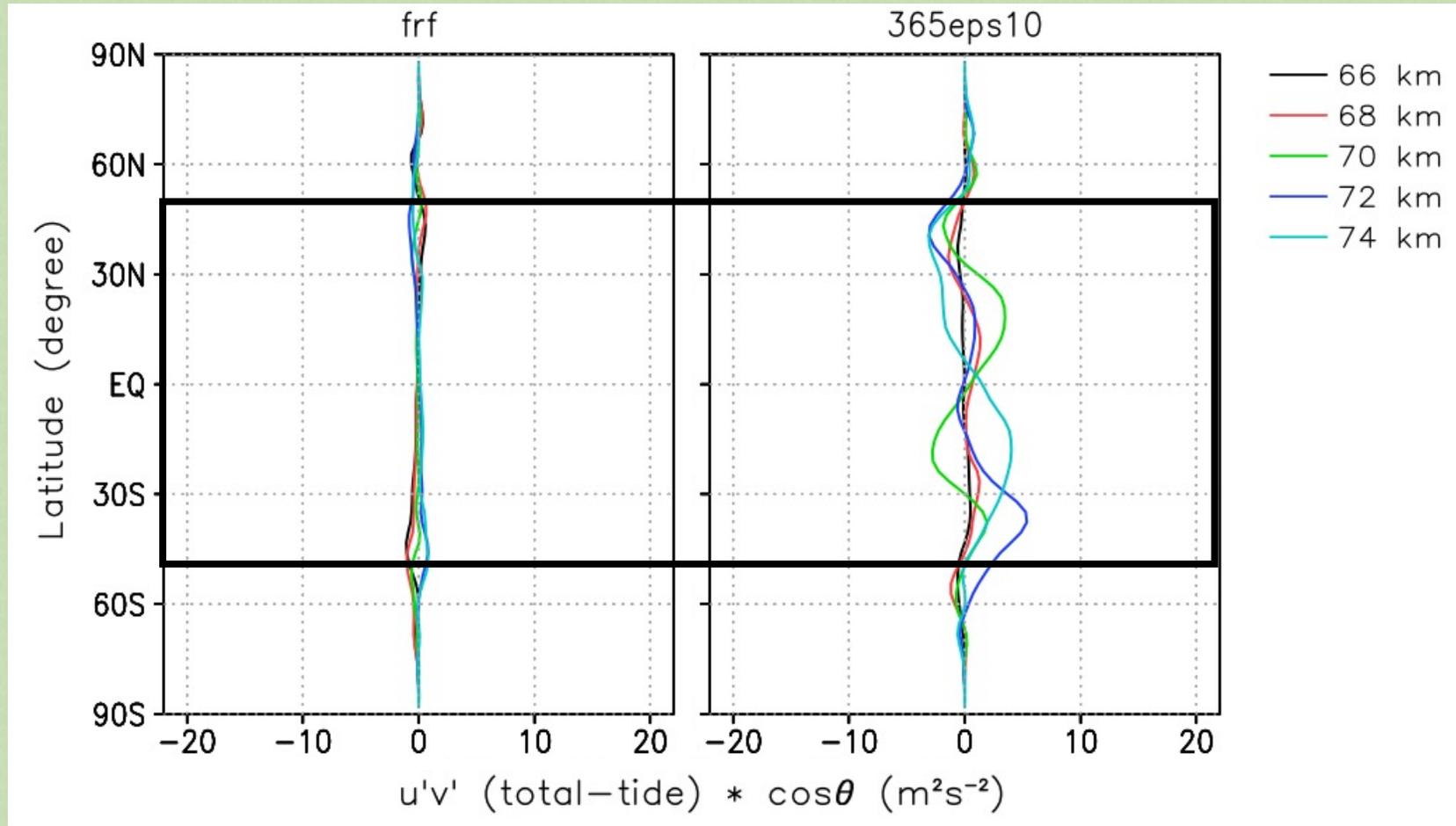
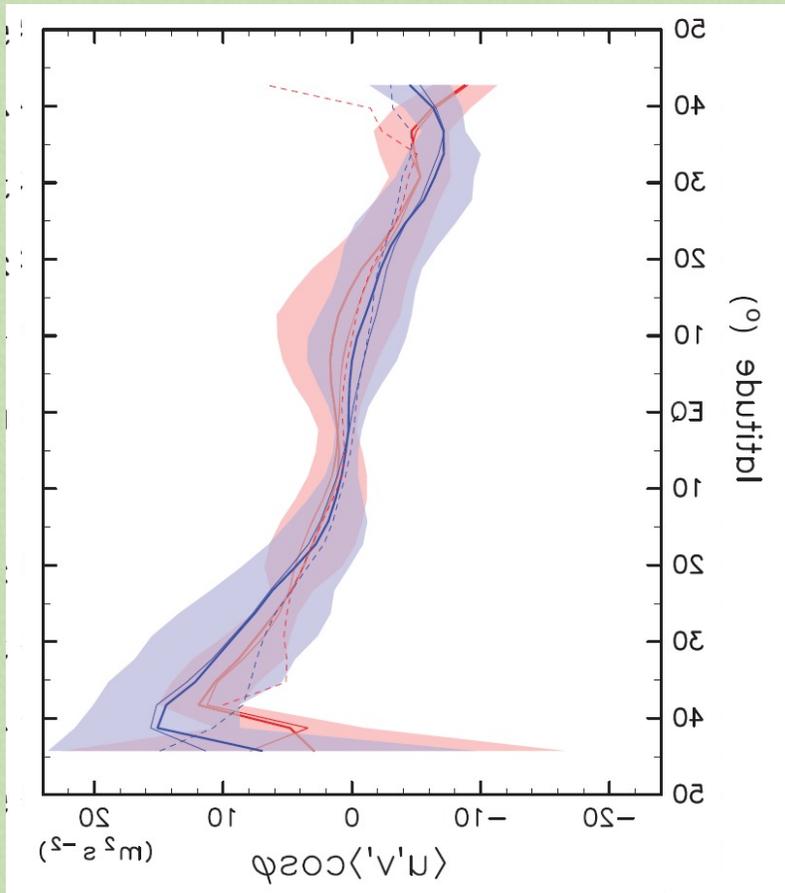
運動量輸送 $\langle u'v' \rangle \cos \theta$ 観測との比較

短周期擾乱

Horinouch et al. 2020

frf

同化結果(2018.10-11)



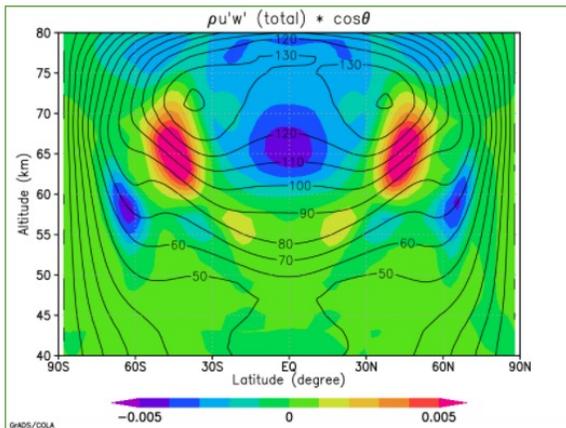
実験結果

運動量輸送 $\rho \langle u'w' \rangle \cos \theta$ (2018.10-11)

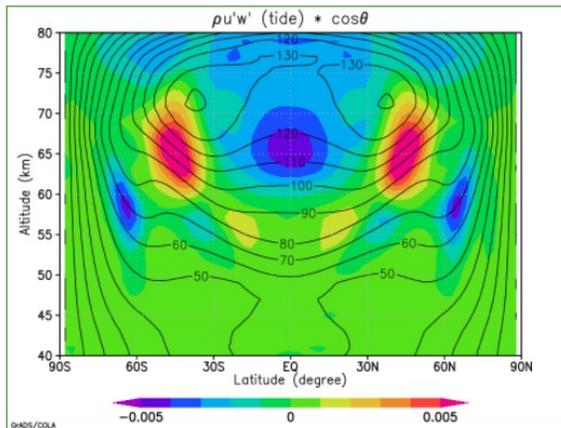
total

熱潮汐波

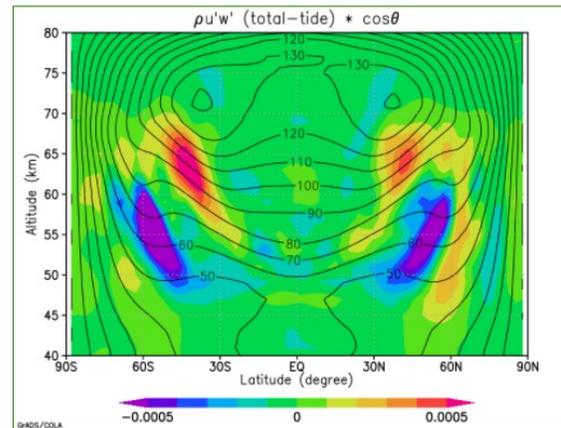
短周期擾乱



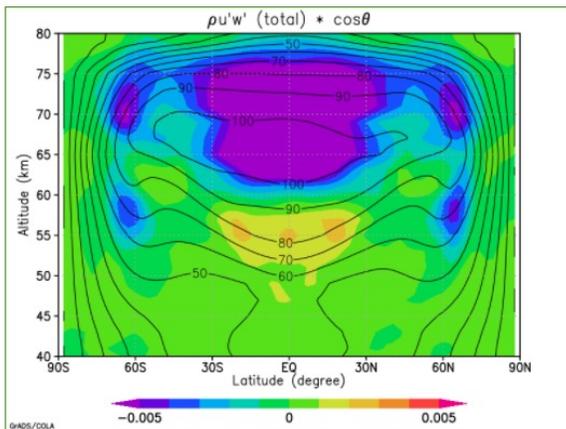
frf_UWrho_total_20181011



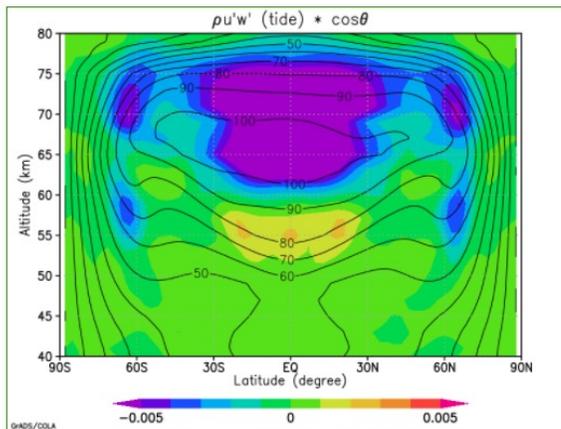
frf_UWrho_tide_20181011



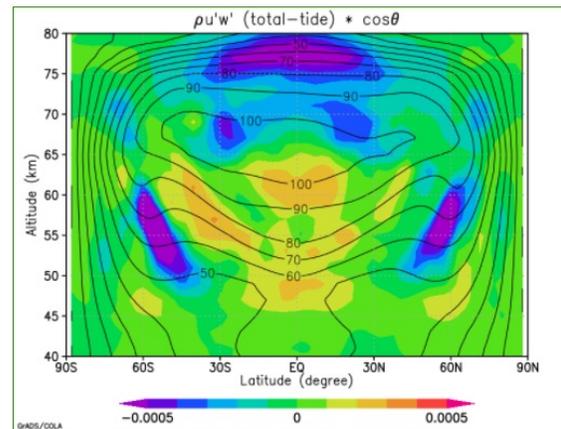
frf_UWrho_another_20181011



365eps10_UWrho_total_20181011



365eps10_UWrho_tide_20181011



365eps10_UWrho_another_20181011

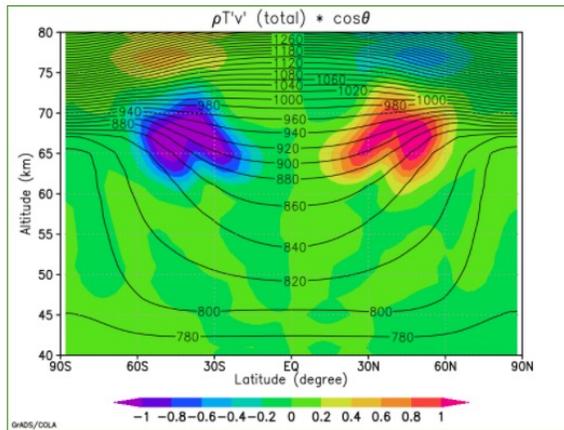
実験結果

熱輸送 $\rho \langle T'v' \rangle \cos \theta$ (2018.10-11)

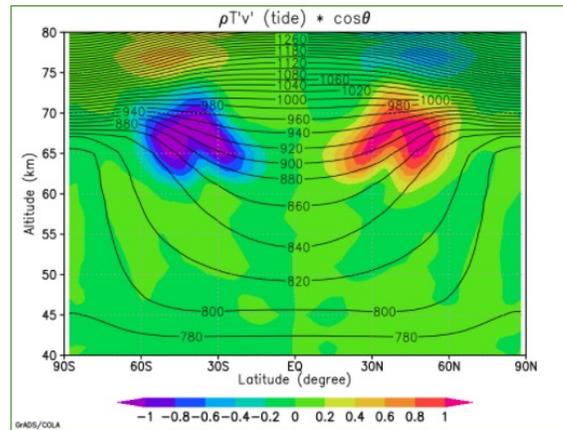
total

熱潮汐波

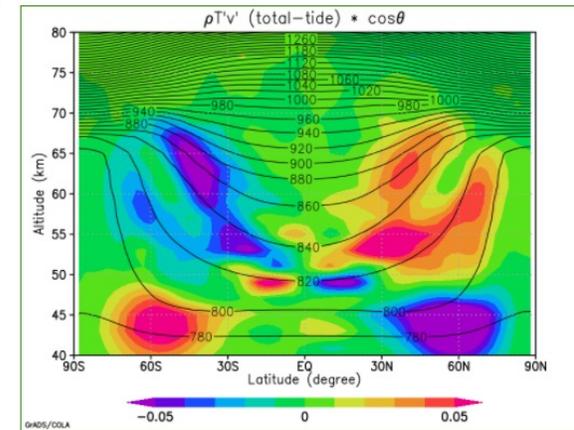
短周期擾乱



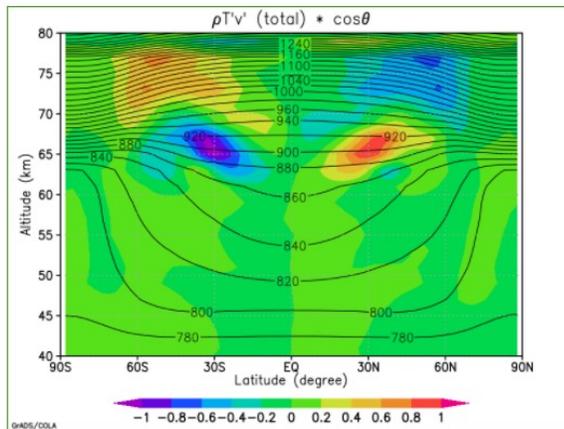
frf_TVrho_total_20181011



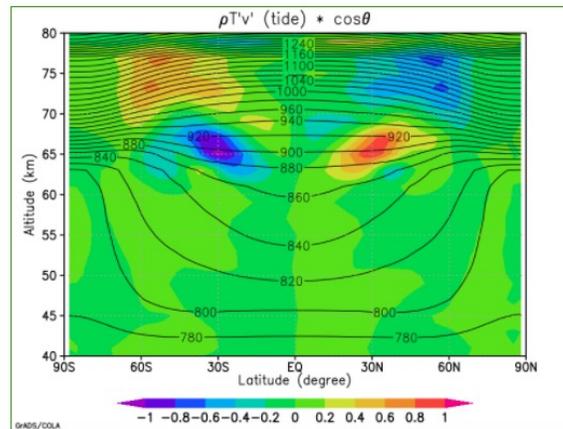
frf_TVrho_tide_20181011



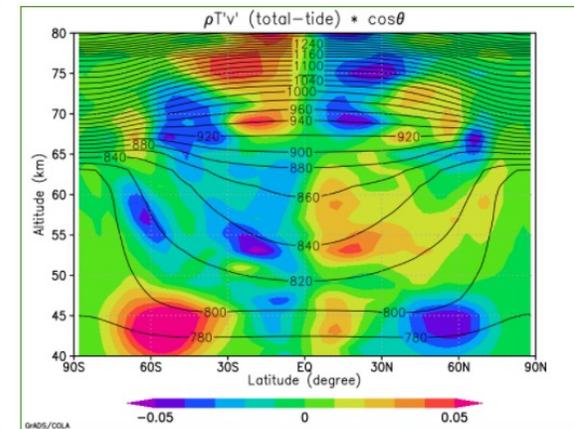
frf_TVrho_another_20181011



365eps10_TVrho_total_20181011



365eps10_TVrho_tide_20181011



365eps10_TVrho_another_20181011