電波掩蔽観測の観測システムシミュレーション実験によるコールドカラー再現性

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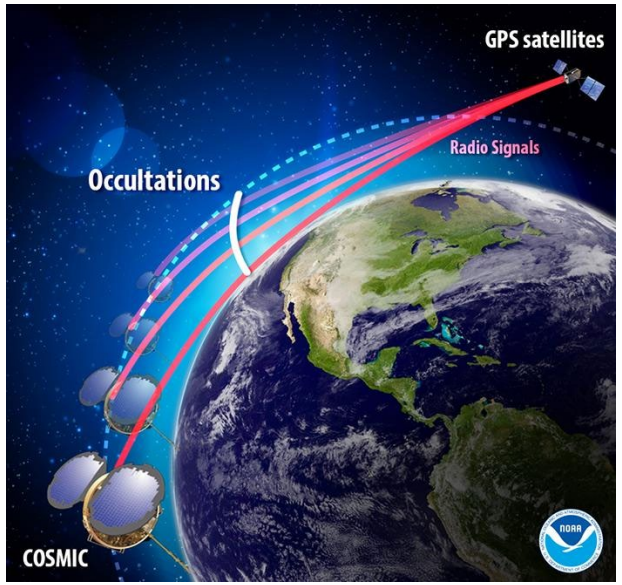
金星大気の観測・シミュレーション・データ同化に関する研究会 (2023/03/28)

Satellite observations of Venus

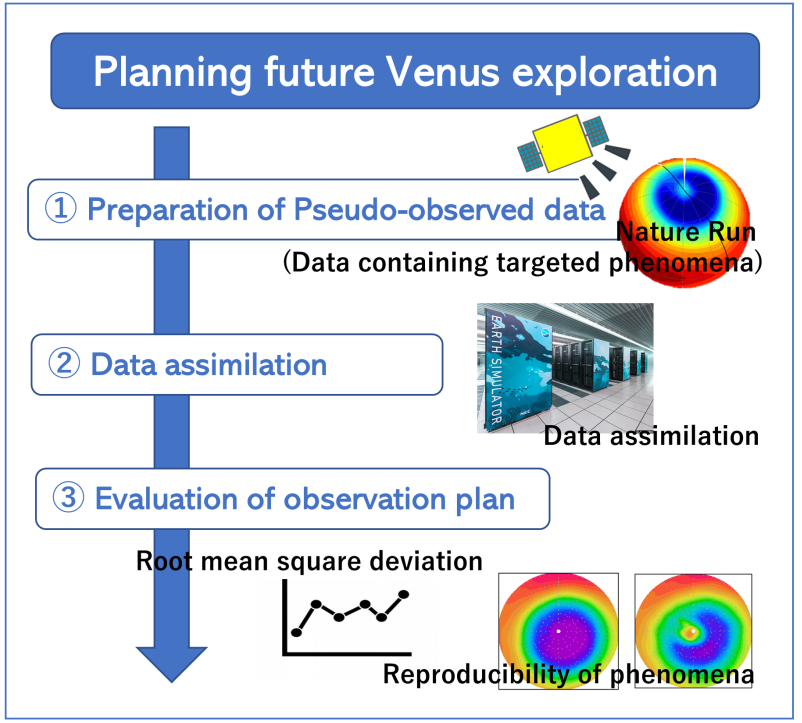
- Radio occultation measurements (RO) among small satellites
  - RO is an effective means of observing the lower cloud layers of Venus.
  - Limit of the communication environment between the orbiter and the Earth.
  - RO between multiple small satellites is possible to obtain a global vertical temperature profile including below the cloud layer at high frequency.
- LIR and UVI observations（Akatsuki）
  - Observation data such as horizontal winds (UVI) and temperature (LIR) are accumulated by Akatsuki.
- Future Venus exploration research group
  - Established in 2022 to study next Venus satellite observation plan in Japan.



RO among small satellites on the Earth (COSMIC@NOAA)

Observing system simulation experiment (OSSE)

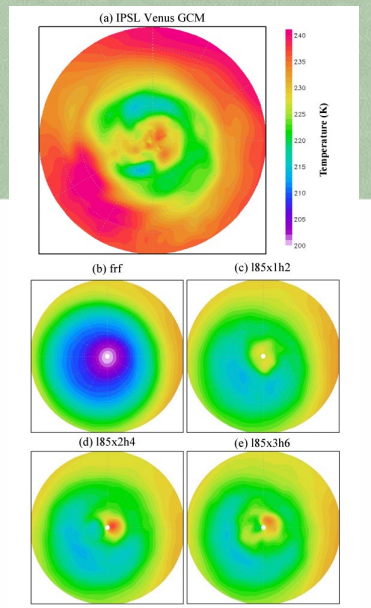
- Observing system simulation experiment (OSSE)
  - Method for testing a virtual observation system using data assimilation
  - Active use on the Earth (Masutani et al., 2010)
  - Use in optimization of observation equipment and observation plans in advance
- Not many examples outside of the Earth
  - Requires data assimilation system, observations and advanced numerical models
  - On Mars, a proposed framework for OSSE (Reale et al., 2021)
- OSSE on Venus is still in its early stages



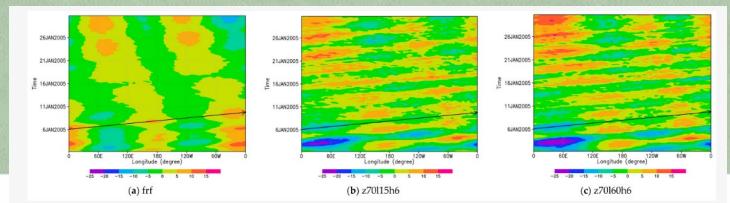
Introduction

OSSE of AFES-Venus

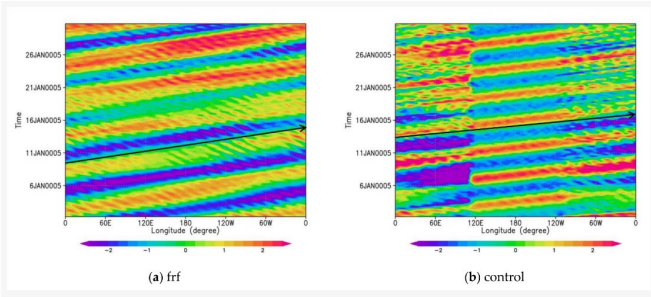
- We have worked so far:
  - RO (temperature)
    - cold collar (Sugimoto 2019c)
    - super-rotation
  - UVI (horizontal wind)
    - 4-day Kelvin wave (Sugimoto 2021a, 2022a)
    - Rossby wave (Mr. Komori is currently analyzing)
  - LIR (temperature)
    - thermal tides (Sugimoto 2022b)



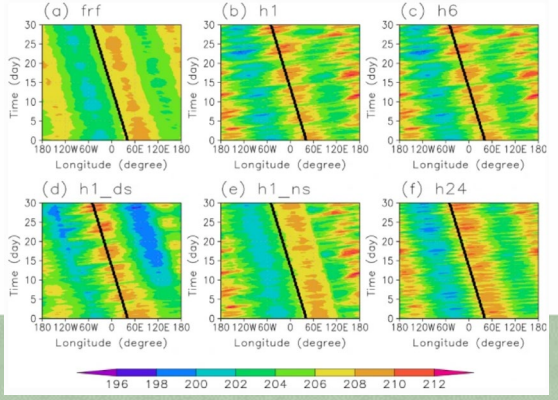
Sugimoto (2019c)



Sugimoto (2021a)



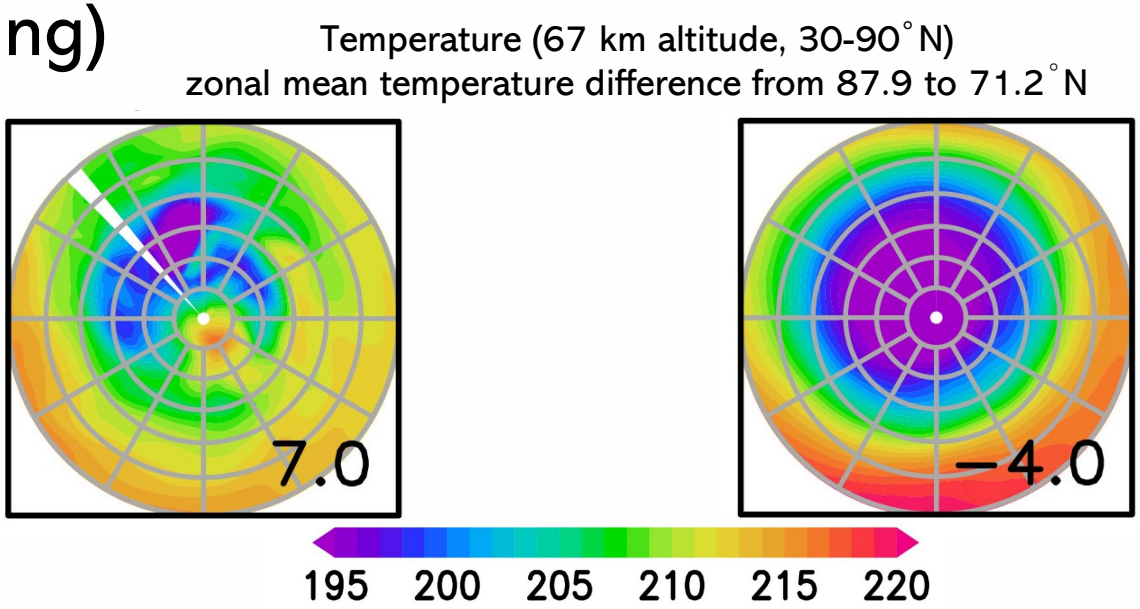
Sugimoto (2022a)



Sugimoto (2022b)

In this presentation

- OSSEs focusing on the reproducibility of cold collar
  - Thermal structure in the polar region at 60-70 km altitude where the temperature is higher than that of the surrounding area
  - Difficult to express it properly in GCM
  - Pseudo-observation data: IPSL Venus GCM (cold collar reproduction by radiative forcing)



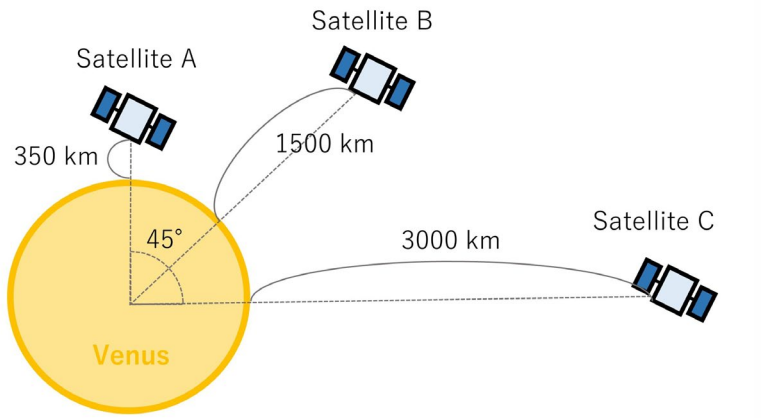
IPSL Venus GCM (Nature Run; NR)　　AFES-Venus（Free Run; FR）

Model & Settings

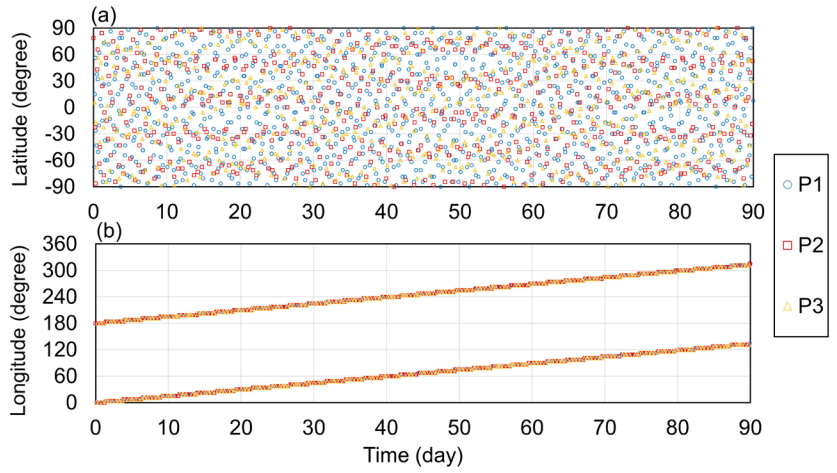
Observation conditions

- RO (Radio occultation measurements)
  - Three polar orbiting satellites (by Chi Ao), observation altitude: 40-90km
  - Number of observations north of latitude 75°N: 2.1 obs./day
- LIR (Longwave Infrared Camera)
  - 65 km altitude, Daytime (8-16LT), 0-90 °N, 2.0 obs./day (Reference: Akatsuki)

RO

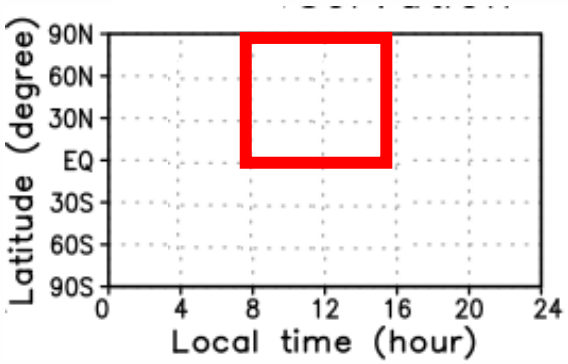


Satellite position (initial value)



Observation point longitude/latitude – experiment period cross sections

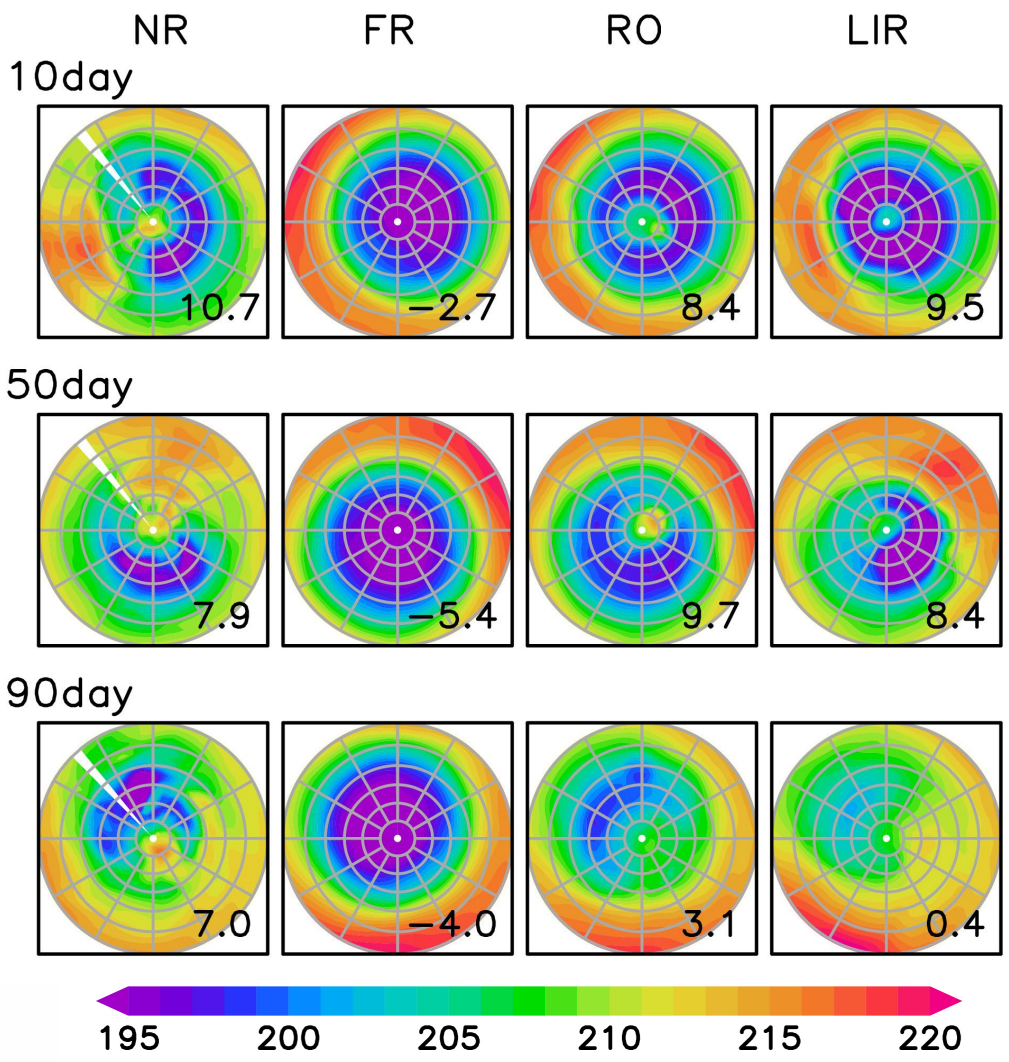
LIR



Observation region latitude–local time cross section

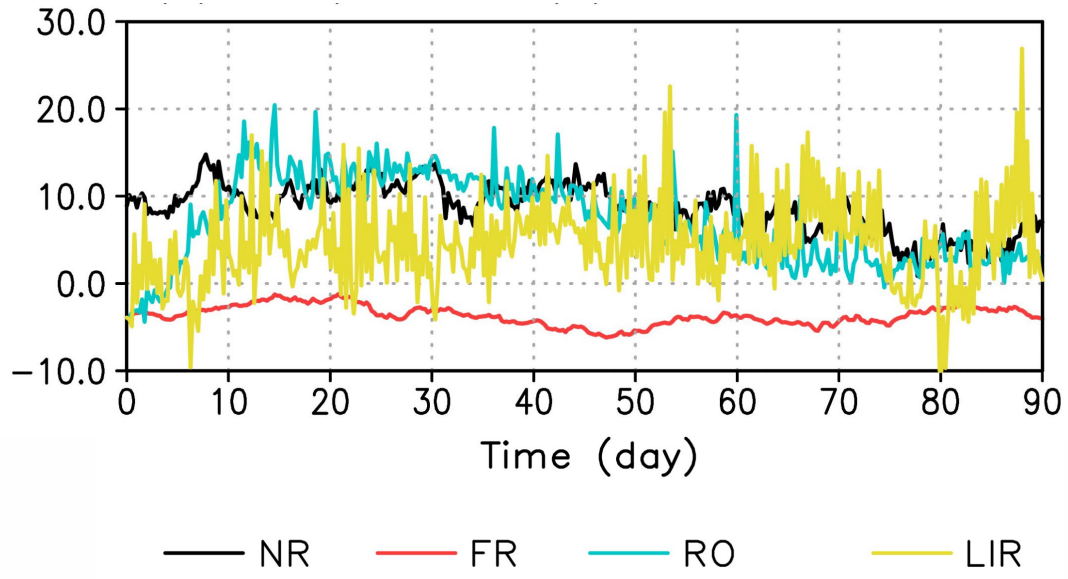
Result

Temperature at 67km altitude



Temperature (67 km altitude, 30-90˚N)
zonal mean temperature difference from 87.9 to 71.2˚N

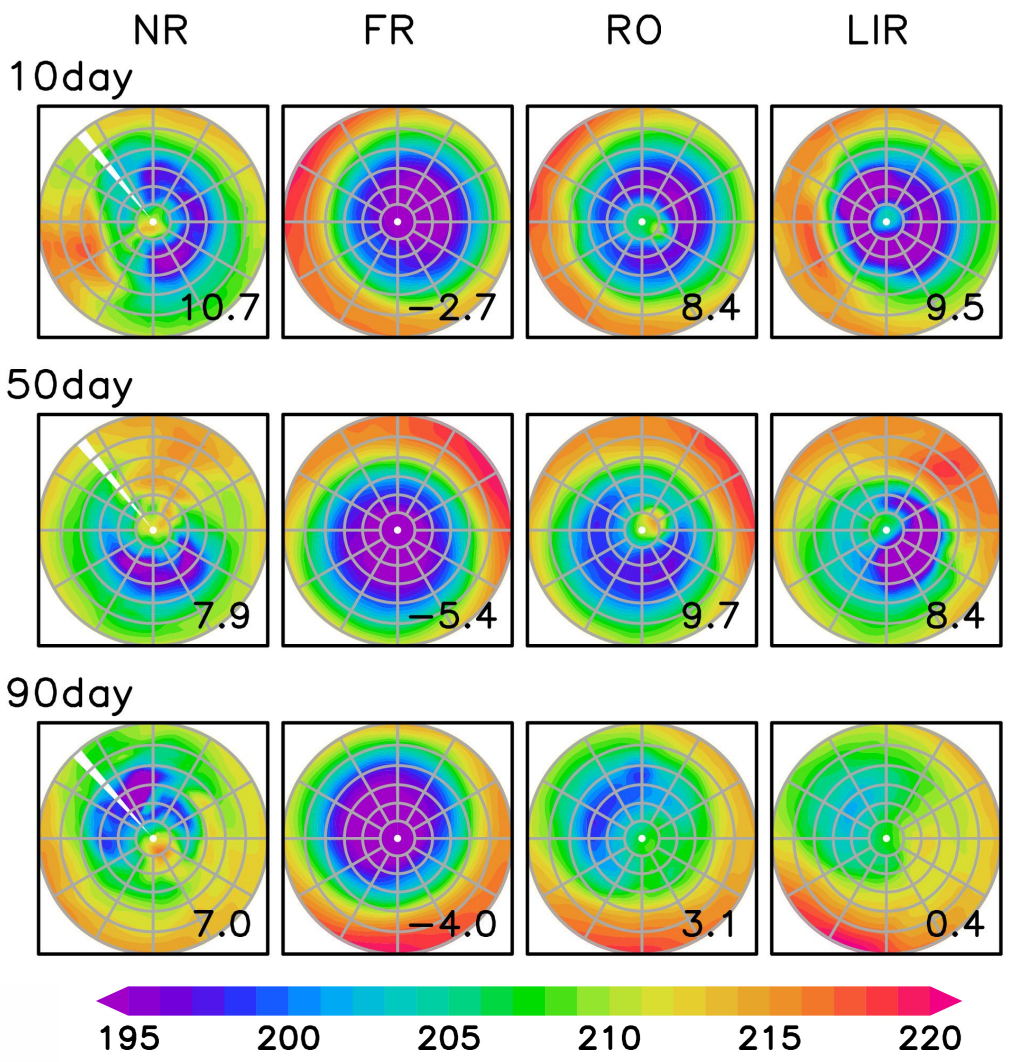
Time series of zonal mean temperature difference from 87.9 to 71.2˚N



- Assimilation warmed the temperature near the pole (RO, LIR)
- Temperature fluctuates unnaturally in a short period (LIR)

Result

Temperature at 67km altitude, RMSD



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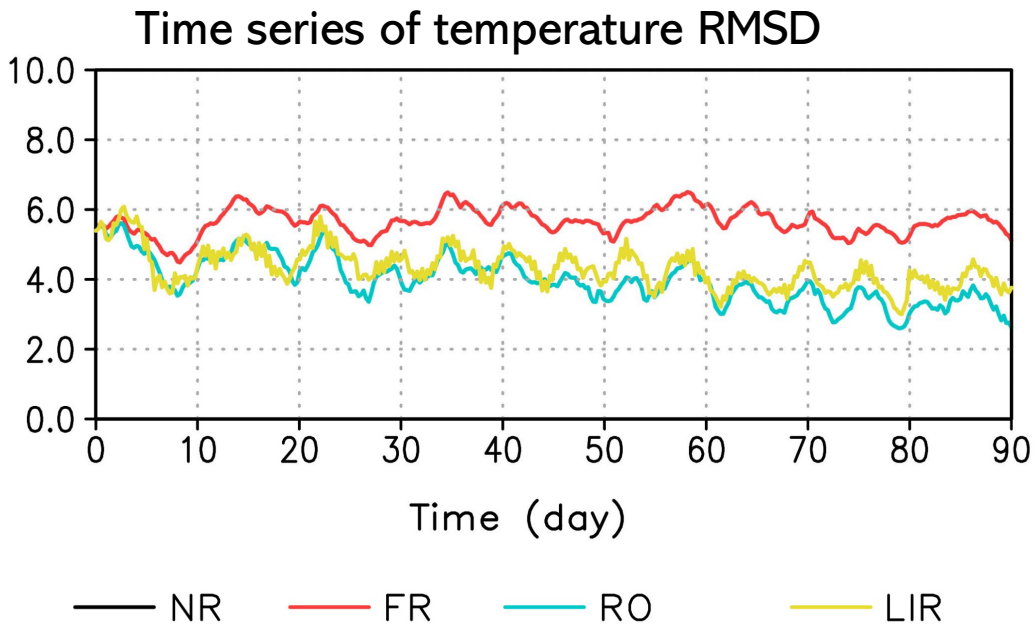


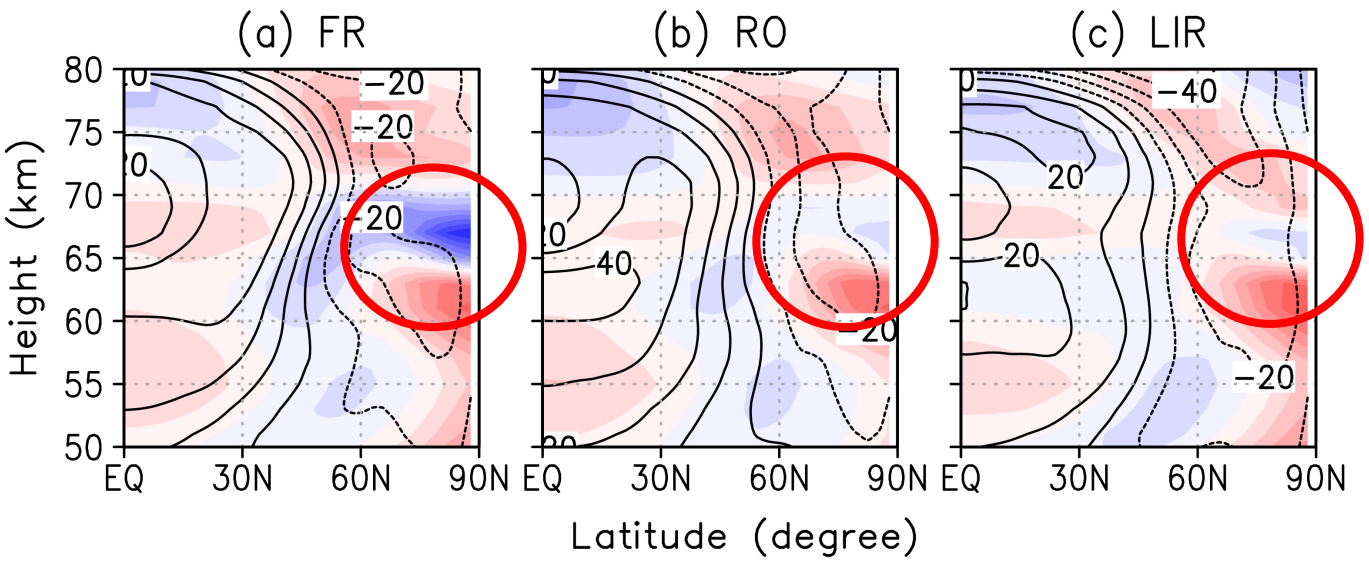
$$RMSD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - x_i)^2}$$

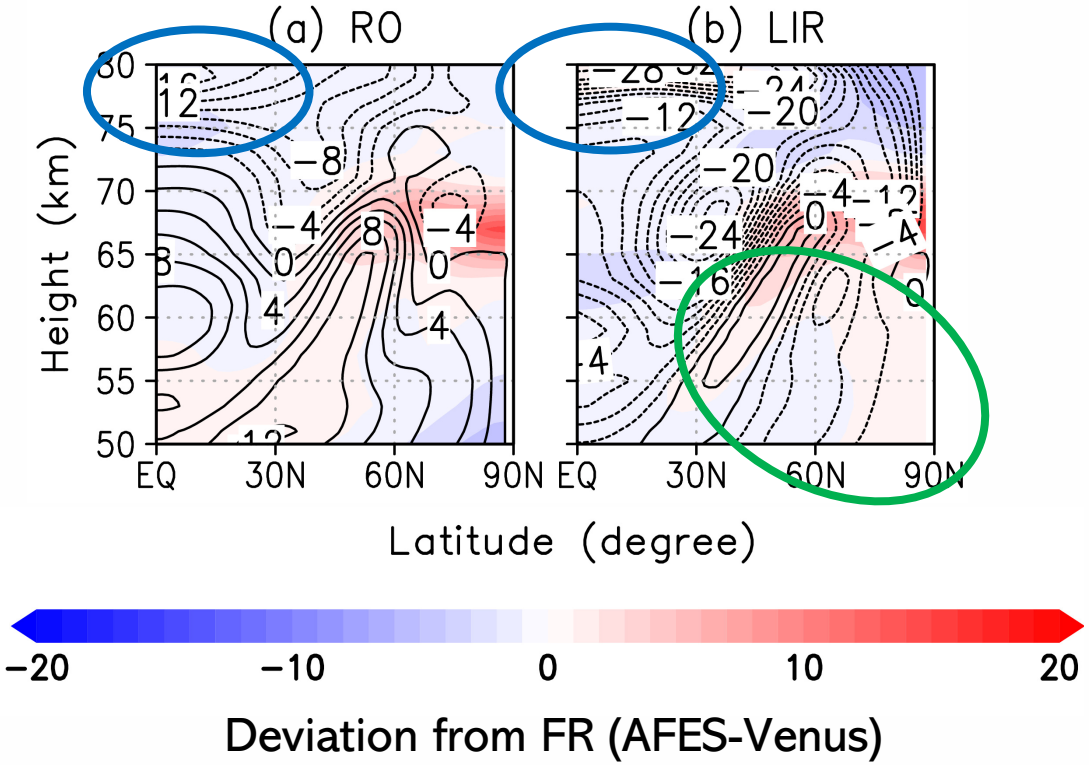
X_i : IPSL
x_i : FR, RO, LIR
N : Number of grid points

- RMSD is slightly better for RO than LIR

Result

Zonal mean Temperature and zonal wind





mean for the last 30 Earth days (Color: temperature, contour: zonal wind)

- Zonal wind (super-rotation) is decelerated by temperature assimilation (blue circles)
- Multiple local circulations appear in LIR ? (grean circles)

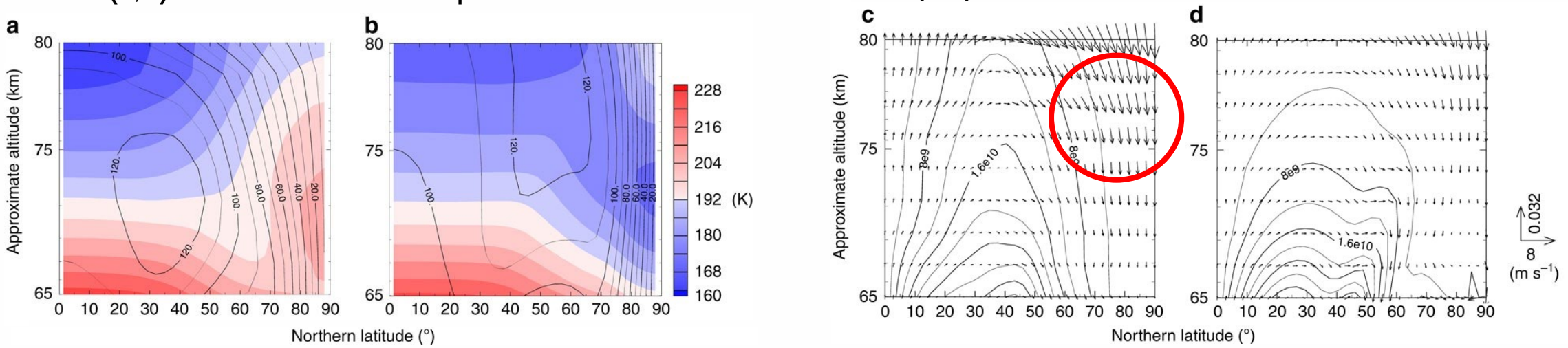
Reference

RMMC (residual mean meridional circulation)

Cold collar reproduction experiment by GCM（Ando et al., 2016）

(a,b) zonal wind and temperature

(c,d) RMMC and mass stream function

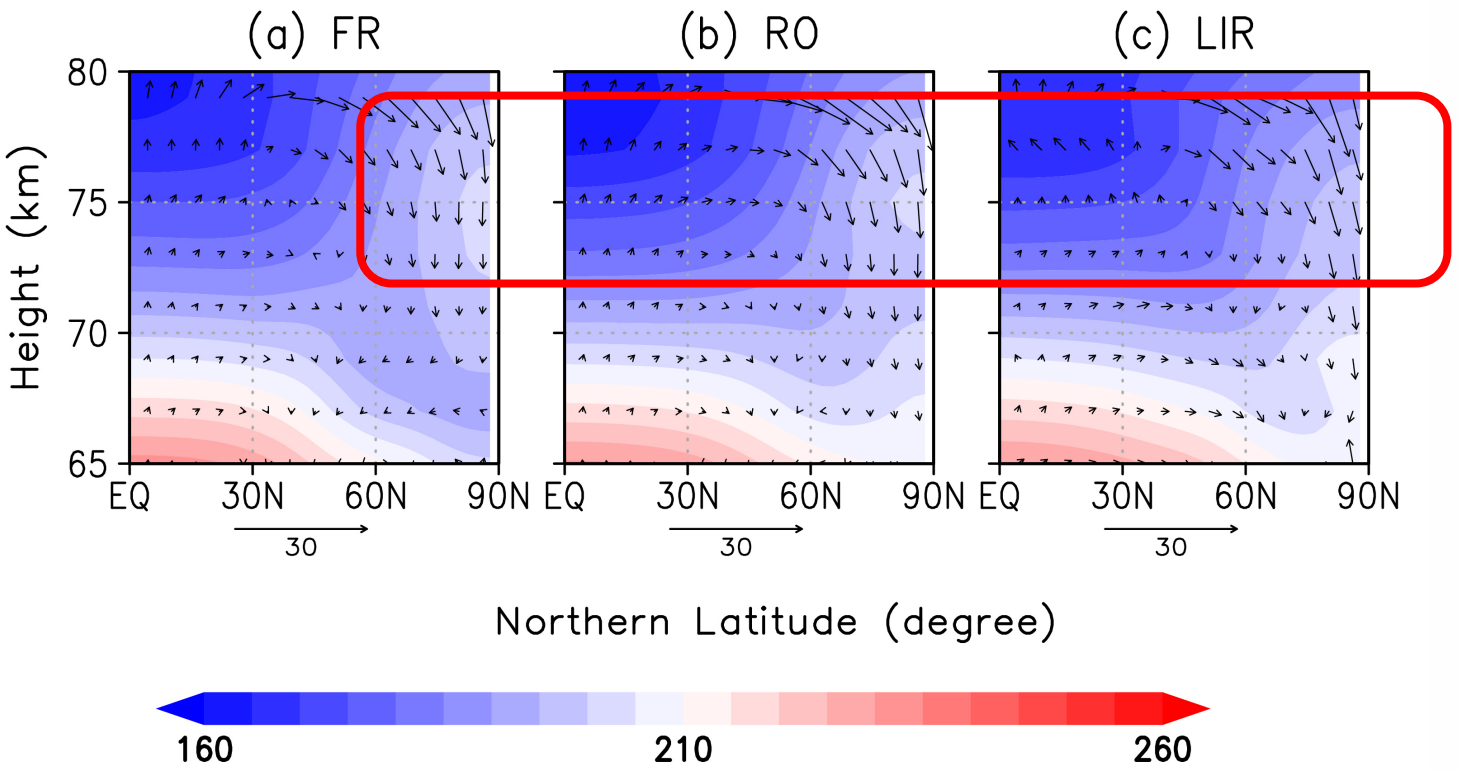


(a,c) Case that reproduces cold collar (diurnal solar heating)
(b,d) Case that does not reproduce cold collar (constant solar heating)

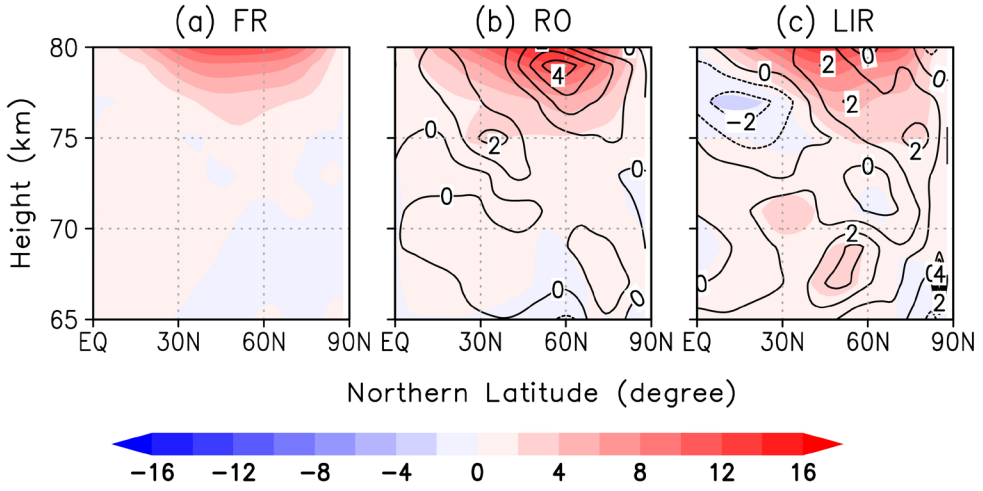
- In diurnal cases, the downward flow of the RMMC was enhanced in the polar regions
- Atmosphere is warmed by adiabatic heating, forming warm polar regions.

Results

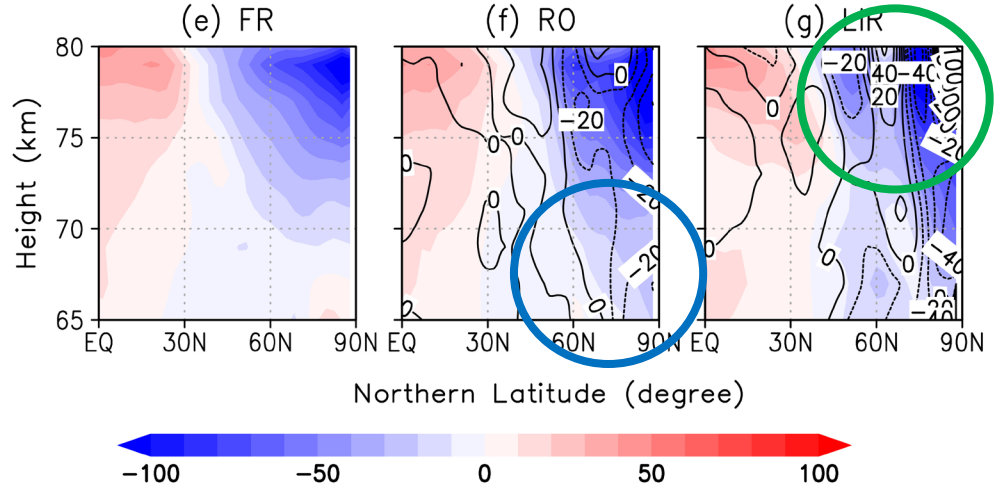
RMMC (residual mean meridional circulation)



Color: temperature, Vector: RMMC (mean for the last 30 Earth days)



Color: meridional component of RMMC, Contour: deviation of FR



Color: vertical component of RMMC, Contour: deviation of FR

- RMMC enhancing, vertical component reaching lower layers, similar to Ando et al. (2016) (RO, LIR) (blue circle)
- Multiple local circulations appear in LIR ? (grean circle)

Summary

- OSSE focusing on cold collar
  - OSSE in both RO and LIR reproduce cold collar in this orbit.
  - Wind as well as assimilated temperature is improved.
  - Atmospheric circulation (RMMC) associated with cold collar is reproduced.
  - OSSE in LIR is unnatural due to large assimilation shocks ??
- RO among small satellites
  - Relatively inexpensive compared to satellites equipped with cameras.
  - There are plans to implement it on Venus and Mars ??（If you know the specific plans, please let me know.）
- OSSE for Venus
  - It is possible to investigate which observations are effective for each atmospheric phenomenon. It is also useful for planetary exploration.

あかつき解析プロダクトの公開準備について

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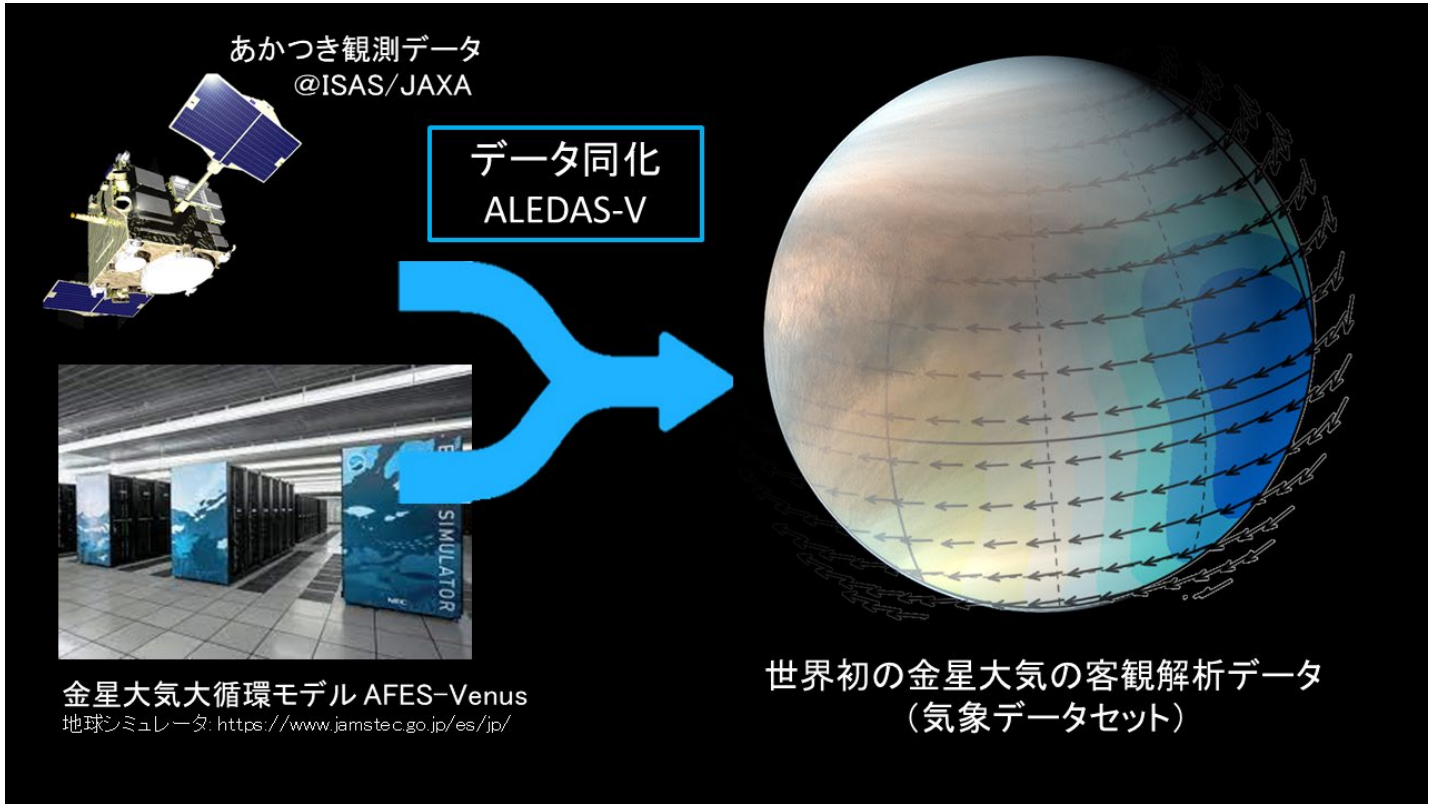
Shin-ya Murakami、Norihiko Sugimoto、Masahiro Takagi、Takeshi Imamura、Takeshi Horinouchi、George L. Hashimoto、Masaki Ishiwatari、

Takeshi Enomoto、Takemasa Miyoshi、Hiroki Kashimura、Yoshi-Yuki Hayashi

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 (2023/03/28)

金星における解析プロダクト

あかつき観測データにデータ同化手法を用いて得られた金星大気循環場の解析プロダクトを公開する



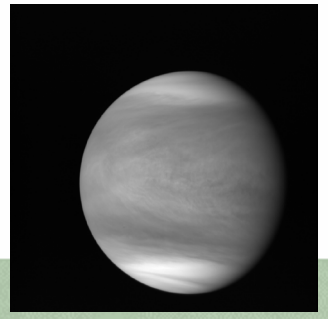
科研費基盤S「あかつきデータ同化が明らかにする金星大気循環の全貌」

あかつき紫外イメージャのデータ処理レベル

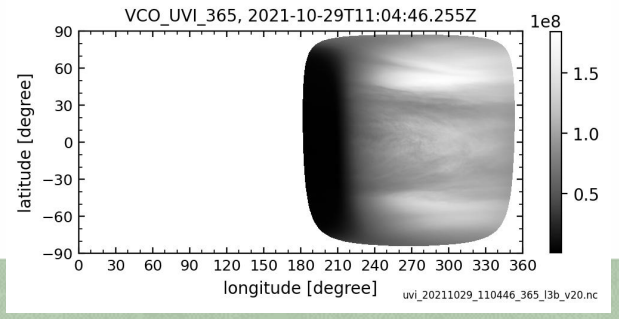
：データ形式

- データは処理レベルに応じて階層的に生成される
  - Level 0: パケット　CCSDSパケット(宇宙データ通信の規格)
  - PDS3
    - Level 1: 生データ（CCD等の検出器の単位）　FITS形式（天文学で使用される規格）
    - Level 2: 較正し輝度や温度の物理量に変換したデータ　FITS形式
  - Level 3：地図投影したデータ　NetCDF形式（気象海洋で使用される規格）
  - “Level 4”: 雲追跡風データ　NetCDF形式
  - “Level 5”: 解析プロダクト　NetCDF形式

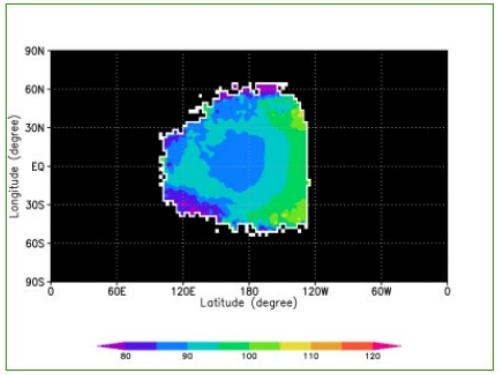
Level2



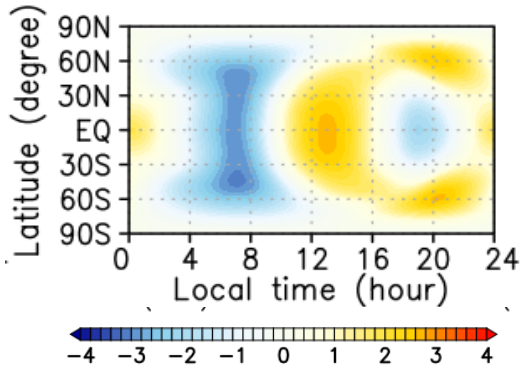
Level3



雲追跡風



解析プロダクト



あかつき観測データの公開方法

- 低次（生）データは PDS3 (Planetary Data System) に準拠
- Level3, 雲追跡風は PDS3 に準拠していない
  - NetCDF形式でCF規約に準拠したメタデータを付与
  - 気象分野の研究者の利便性への配慮
- DARTS (Data ARchives and Transmission System; JAXA) で公開
  - データのまとまりごとにDOIを付与
    - 現在22のDOIが付与されている

火星における解析プロダクト

- 1990年代からデータ同化が試行
- 現在3つの解析プロダクト
  - MACDA (Mars Analysis Correction Sata Assimilation)
    - Montabone et al. (2014)
  - EMARS (Ensemble Mars Atmosphere Reanalysis System)
    - Greybush et al. (2018)
  - OpenMARS (Open access to Mars Assimilated Remote Soundings)
    - Holmes et al. (2020)

火星における解析プロダクトの公開方法

- データ解説論文：同化手法、同化期間、変数、データ形式等
  - MACDA, EMARS: Geoscience Data Journal (RMetS)
  - OpenMARS: Planetary and Space Science
- 自国のデータ公開サイトの利用
  - EMARS (Pennsylvania State University), OpenMARS (Open University)
  - MACDA (Centre for Environmental Data Analysis (CEDA) Archive)
- DOI の付与
- データ形式: netCDF
- Web上のプロッタ（MACDA, EMARS?）

金星解析プロダクト活用の方針

- 基本的に火星の解析プロダクト公開に倣う予定
  - データ解説論文
  - データ公開サイト
    - 神戸大学 惑星科学研究センター CPS
  - データ形式: netCDF