Data Assimilation Changes Low-Level Jets in Mars GCMs

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Image: Global Aerospace Corporation

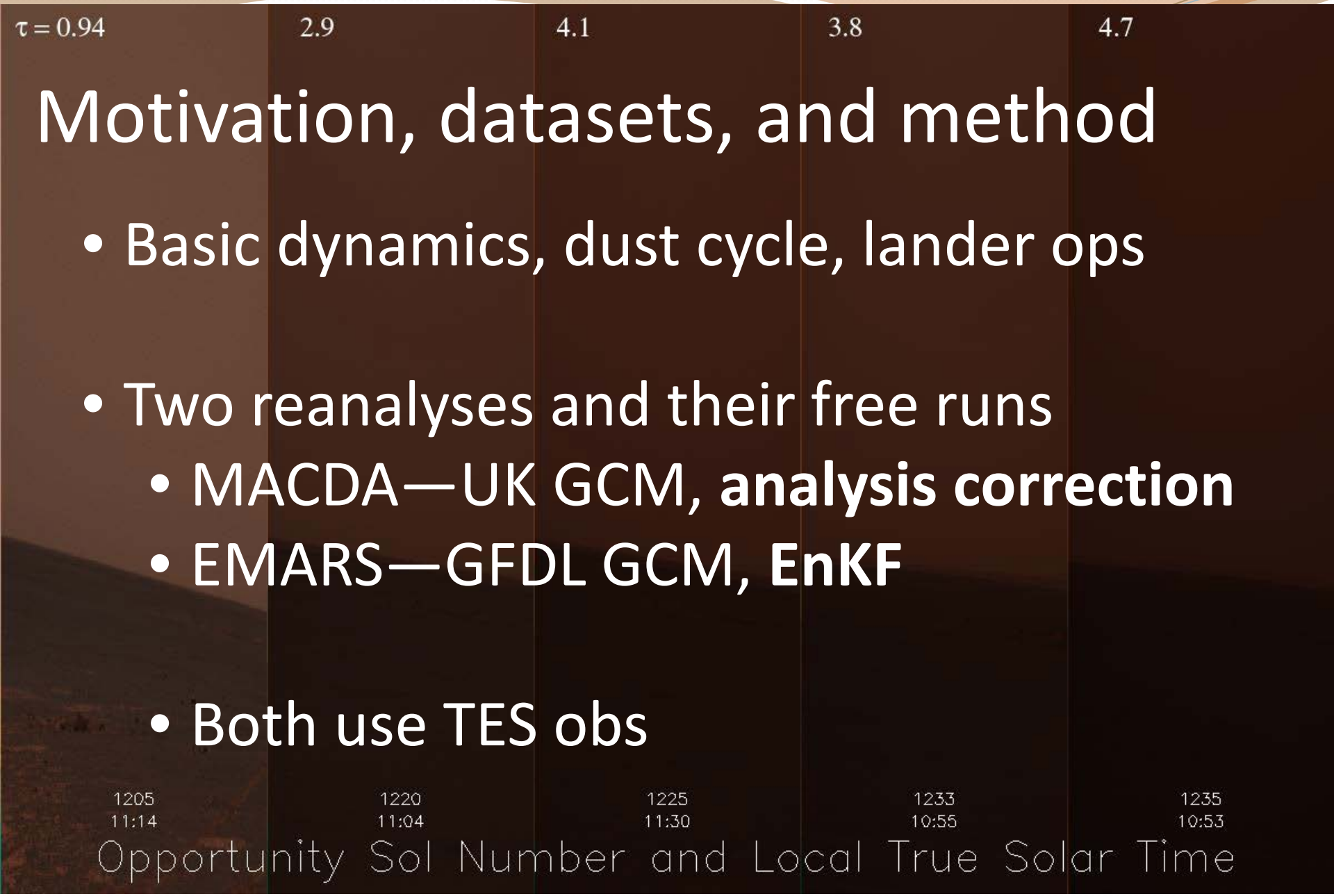
(How much) should we believe GCMs?

- They work … as far as we can see
- Limited non-temperature dynamics obs
  - Can reanalysis be a substitute?
- **Today: How good are low level flows?**
  - **Diagnostic work, then theory**

Motivation, datasets, and method

- Basic dynamics, dust cycle, lander ops

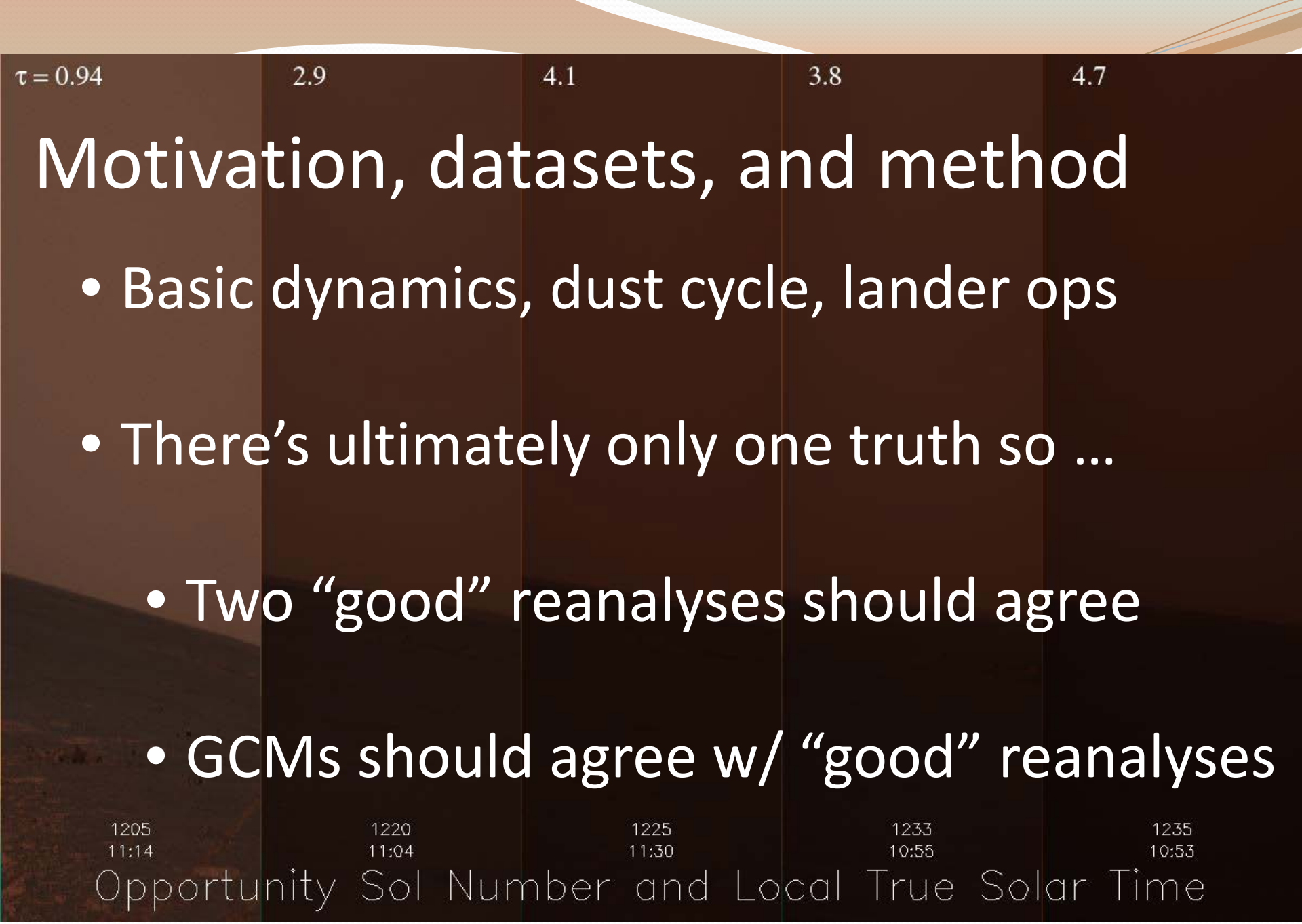
Image: NASA/APOD



Motivation, datasets, and method

- Basic dynamics, dust cycle, lander ops
- Two reanalyses and their free runs
  - MACDA—UK GCM, **analysis correction**
  - EMARS—GFDL GCM, **EnKF**
  - Both use TES obs

Image: NASA/APOD

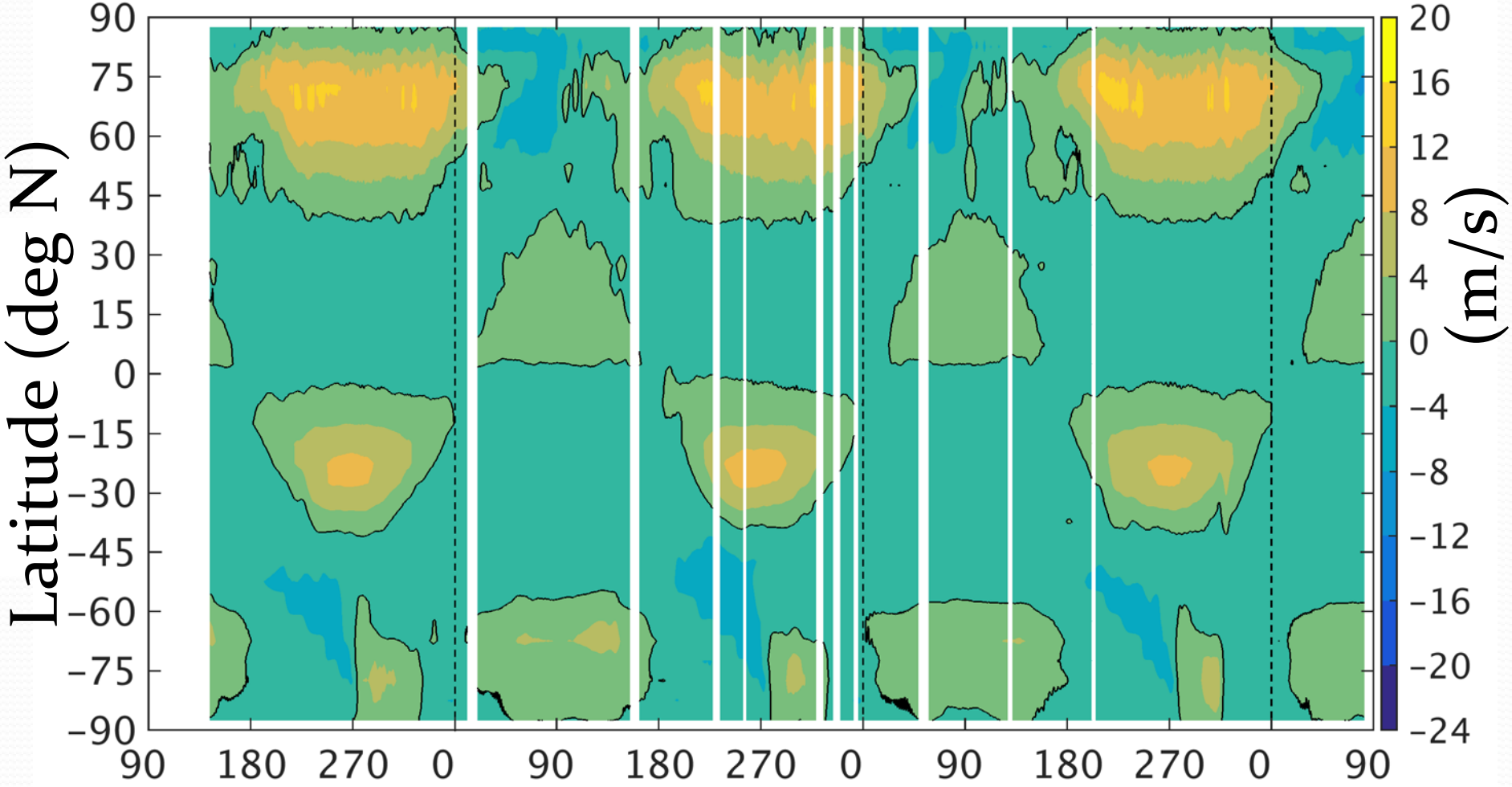


Motivation, datasets, and method

- Basic dynamics, dust cycle, lander ops
- There's ultimately only one truth so …
  - Two "good" reanalyses should agree
  - GCMs should agree w/ "good" reanalyses

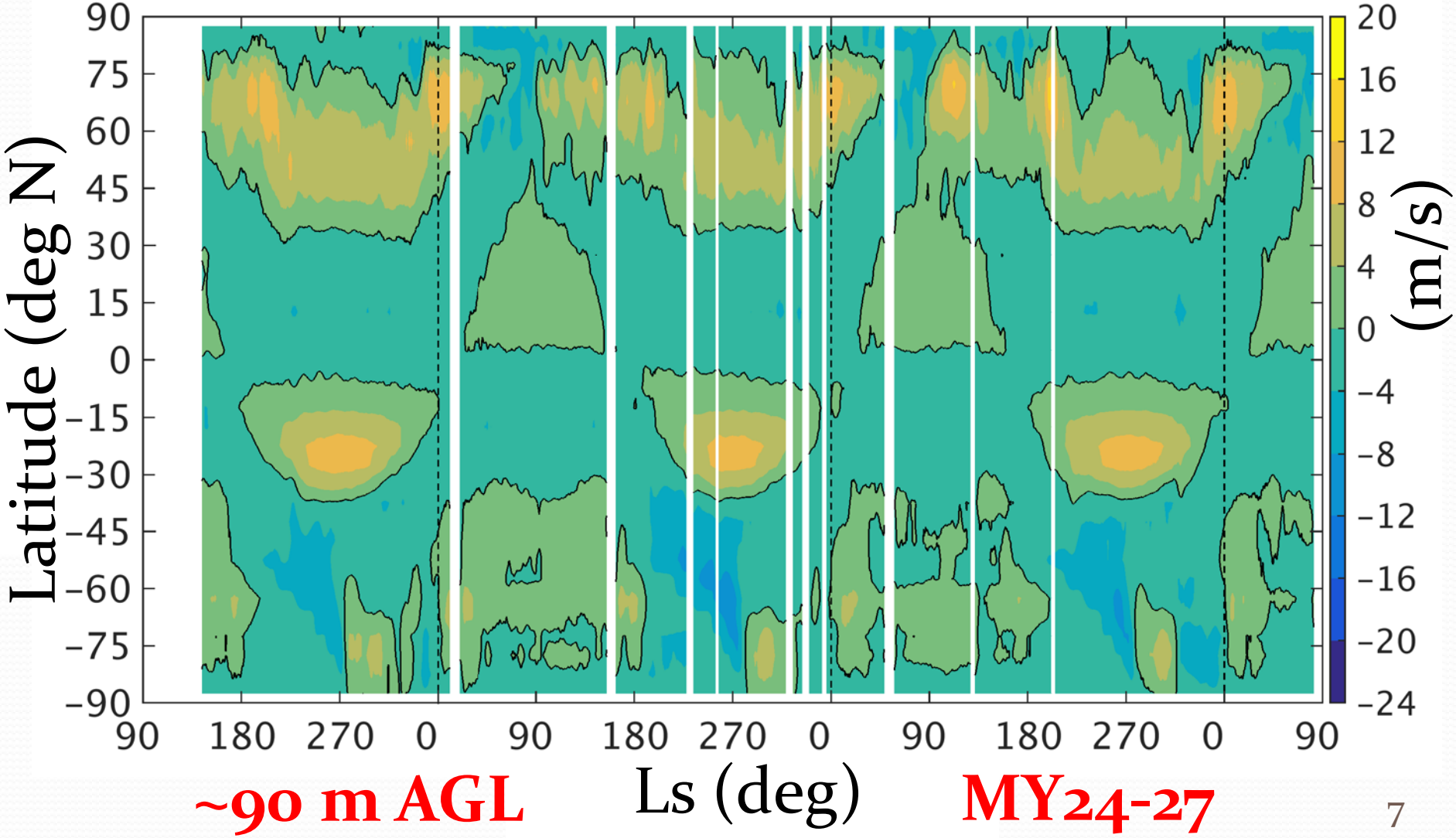
Image: NASA/APOD

Strong NH winter jets (MACDActrl)



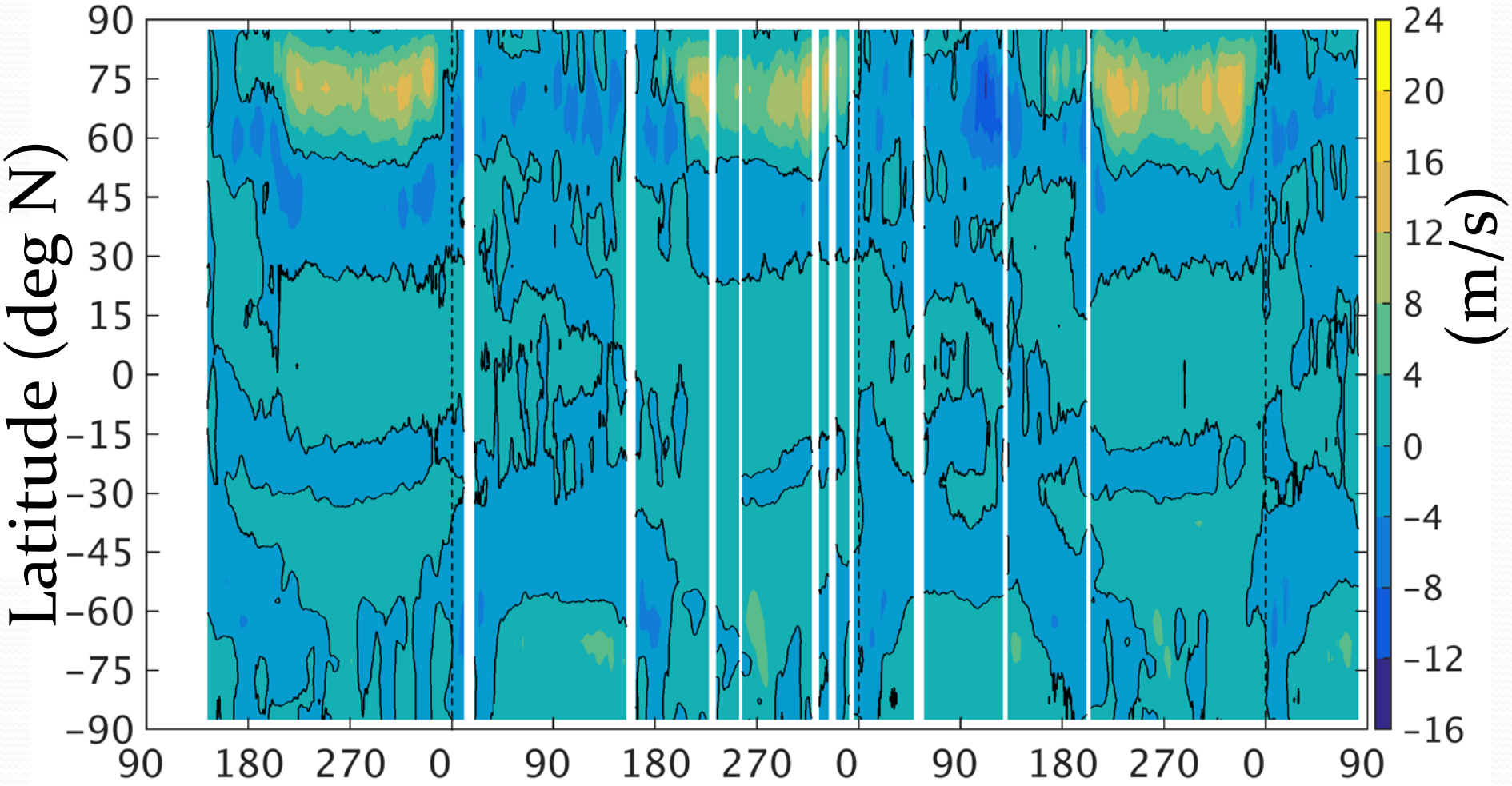
~90 m AGL **MY24-27**

MACDA jets weaker, farther south



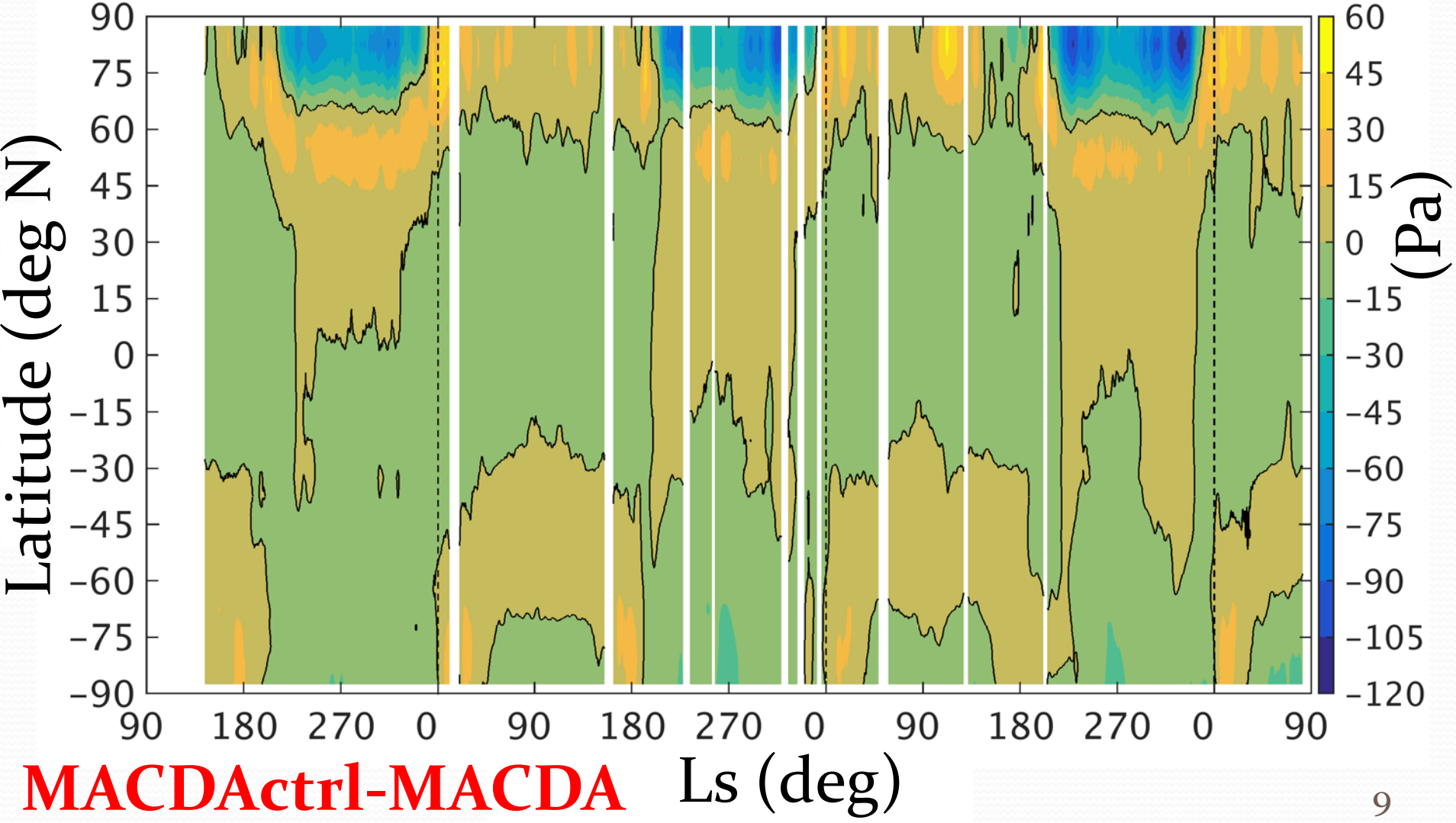
~90 m AGL **MY24-27**

DA effect is interannually repeatable



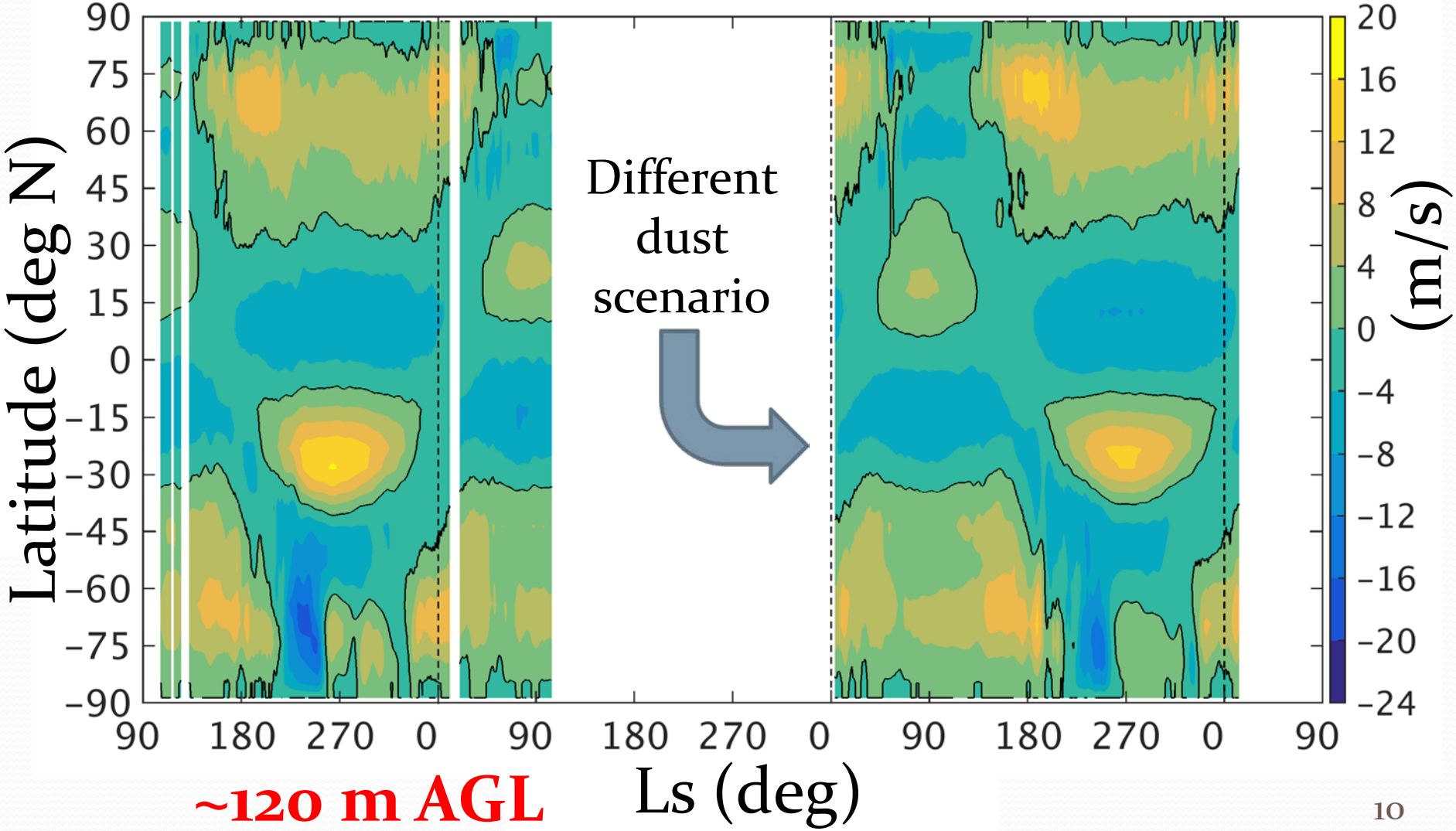
MACDActrl-MACDA

DA (relatively) raises polar p_{surf}



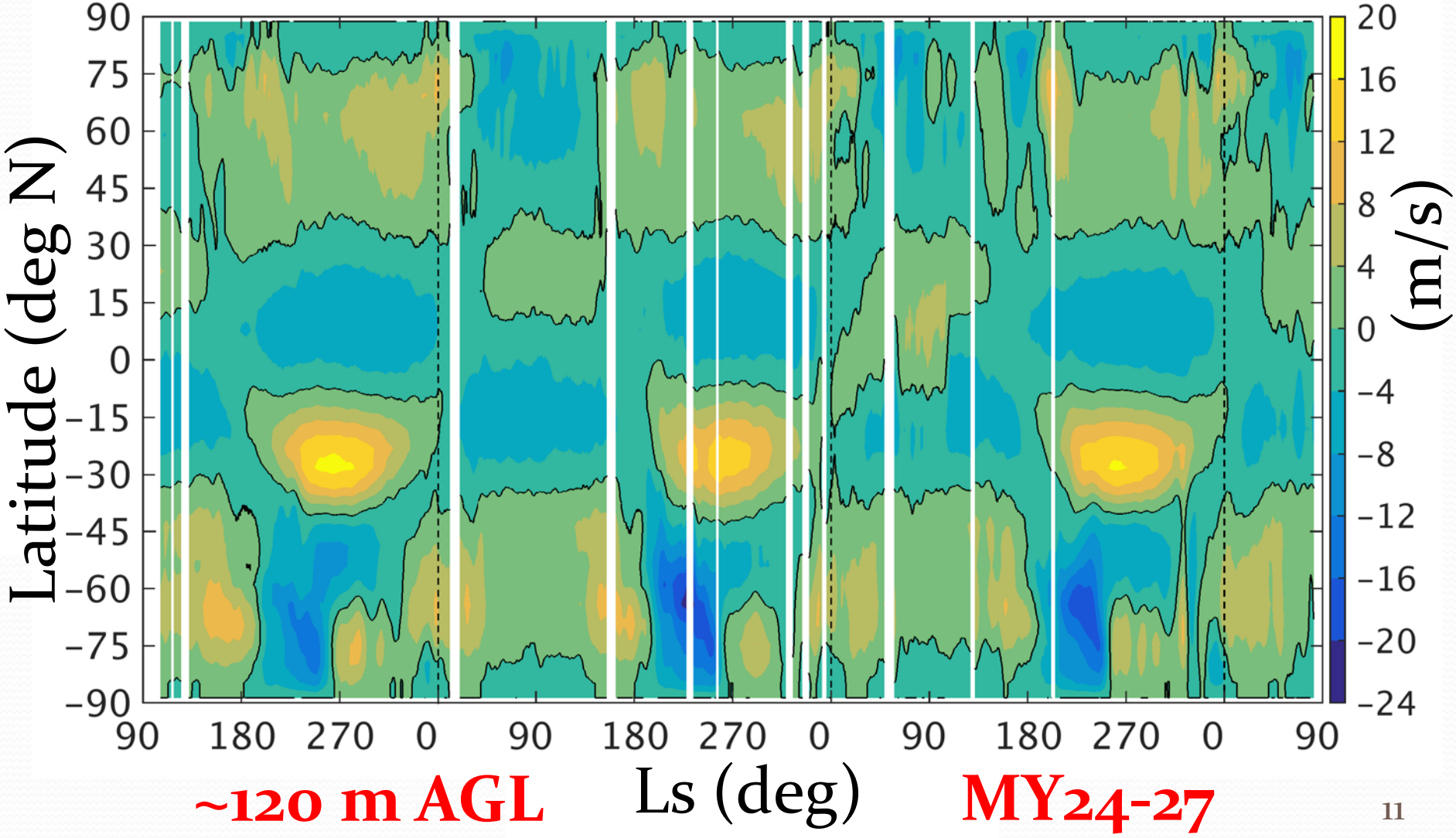
MACDActrl-MACDA

Similar seasonal cycle in EMARSctrl



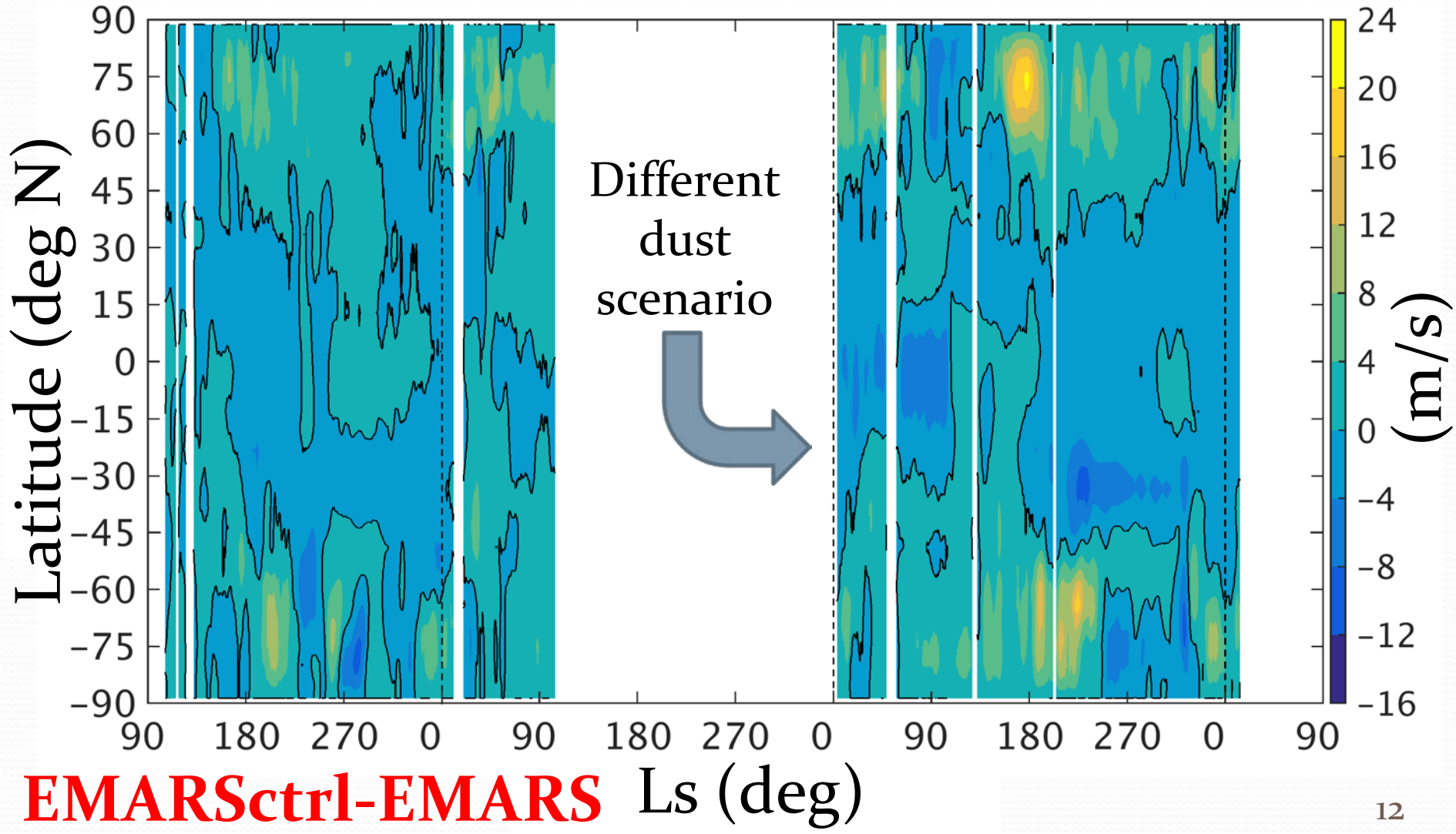
~120 m AGL

DA weakens the EMARS jet



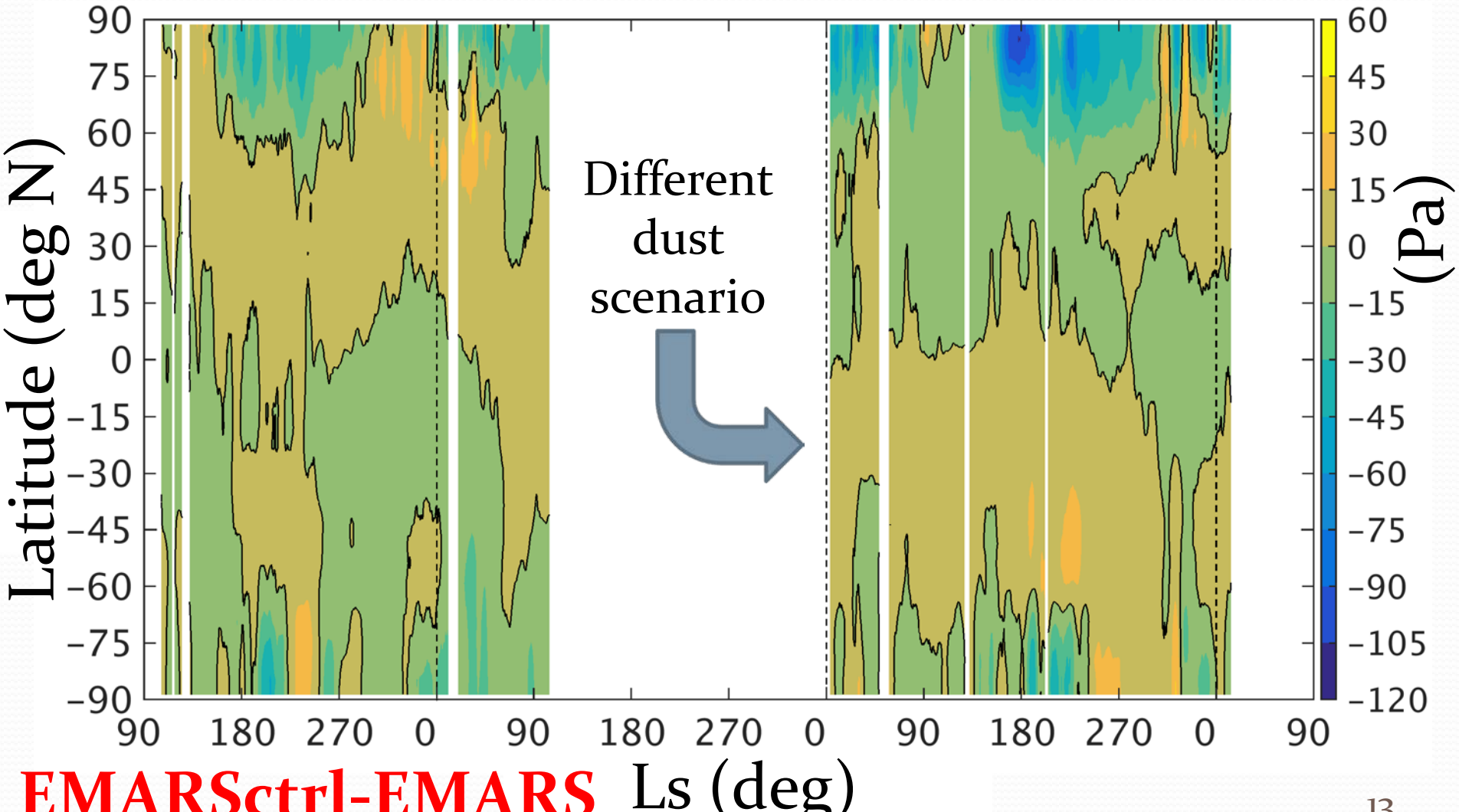
~120 m AGL **MY24-27**

DA response less than in MACDA



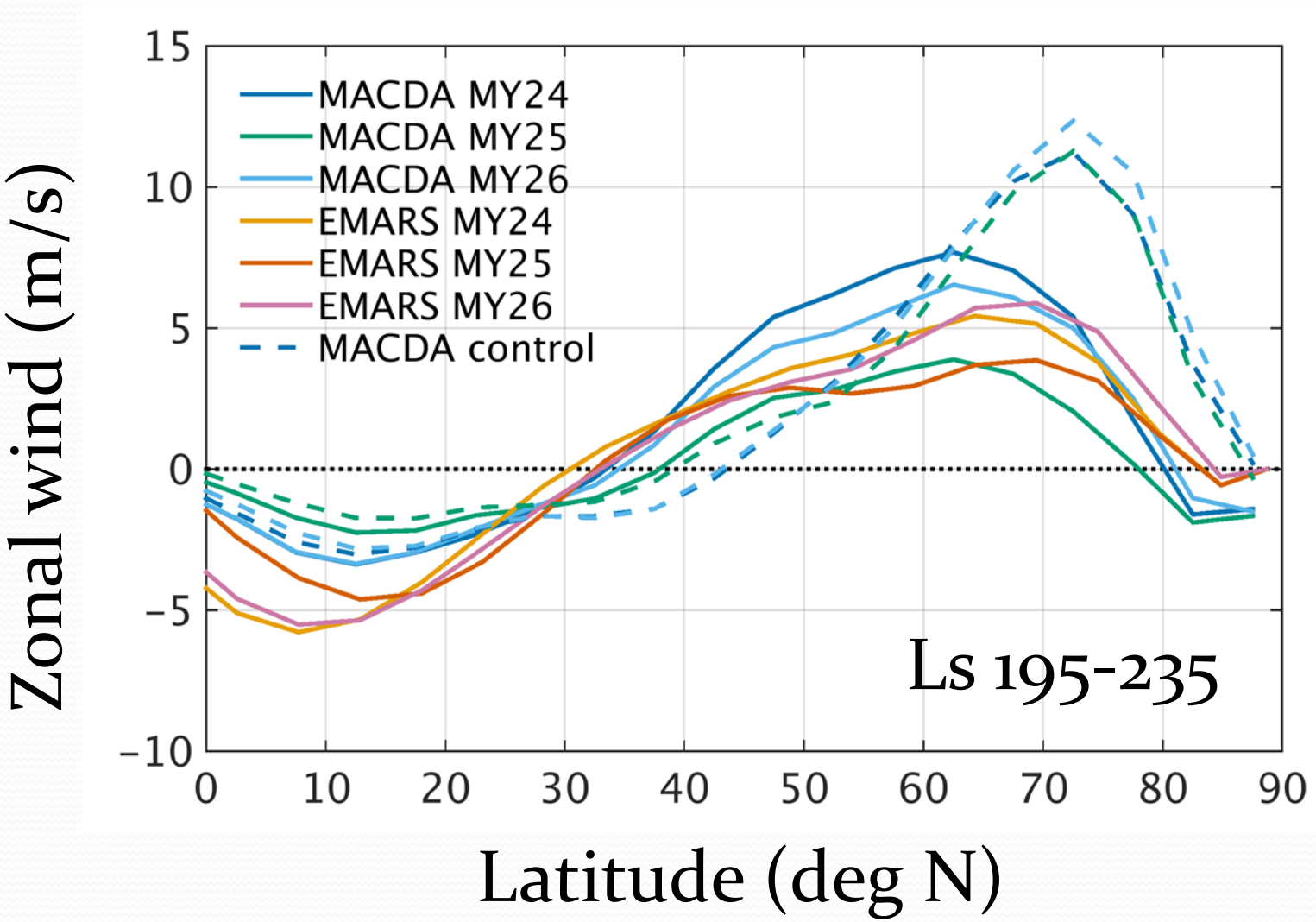
EMARSctrl-EMARS

DA effect on p_{surf} phased differently

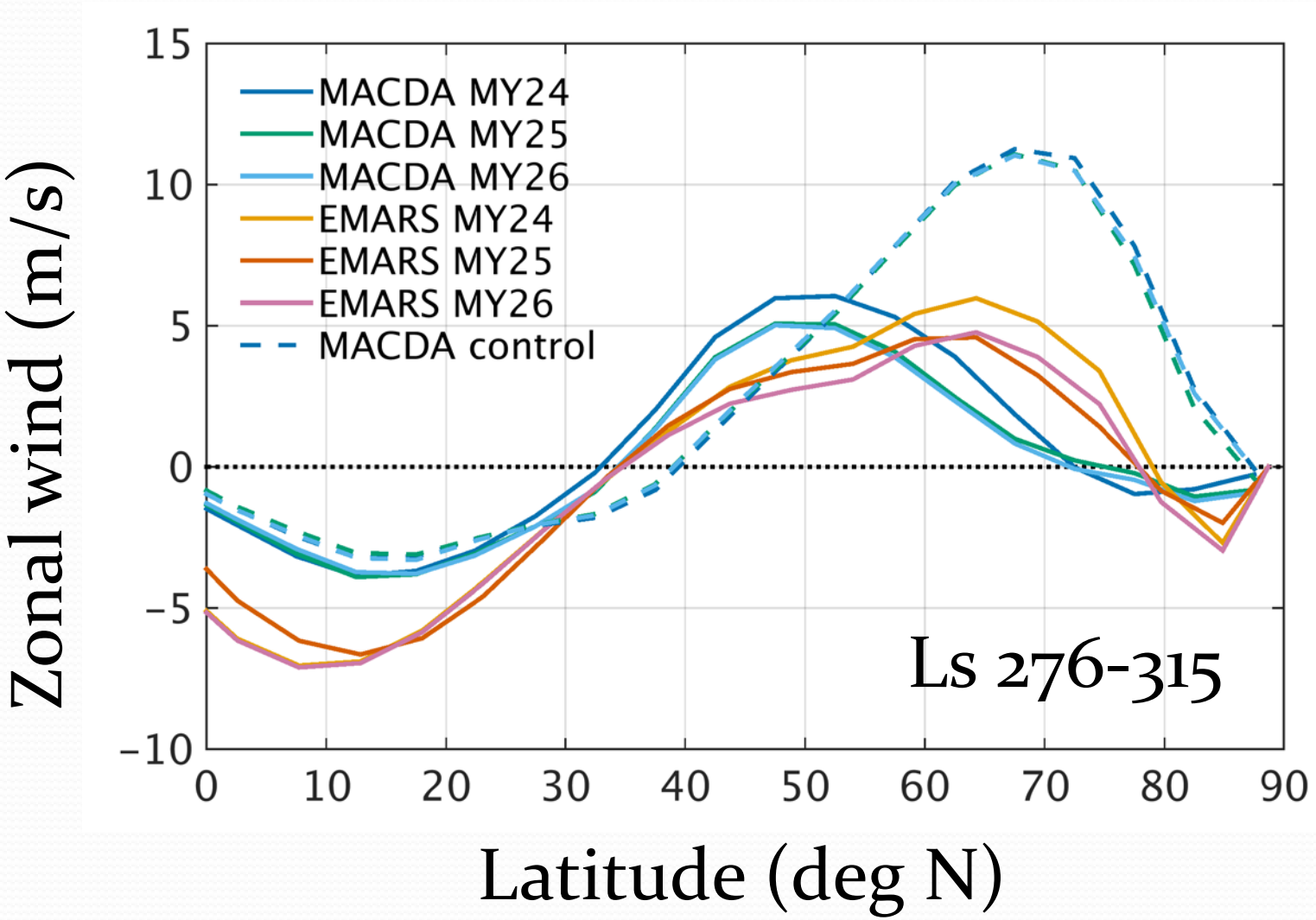


EMARSctrl-EMARS

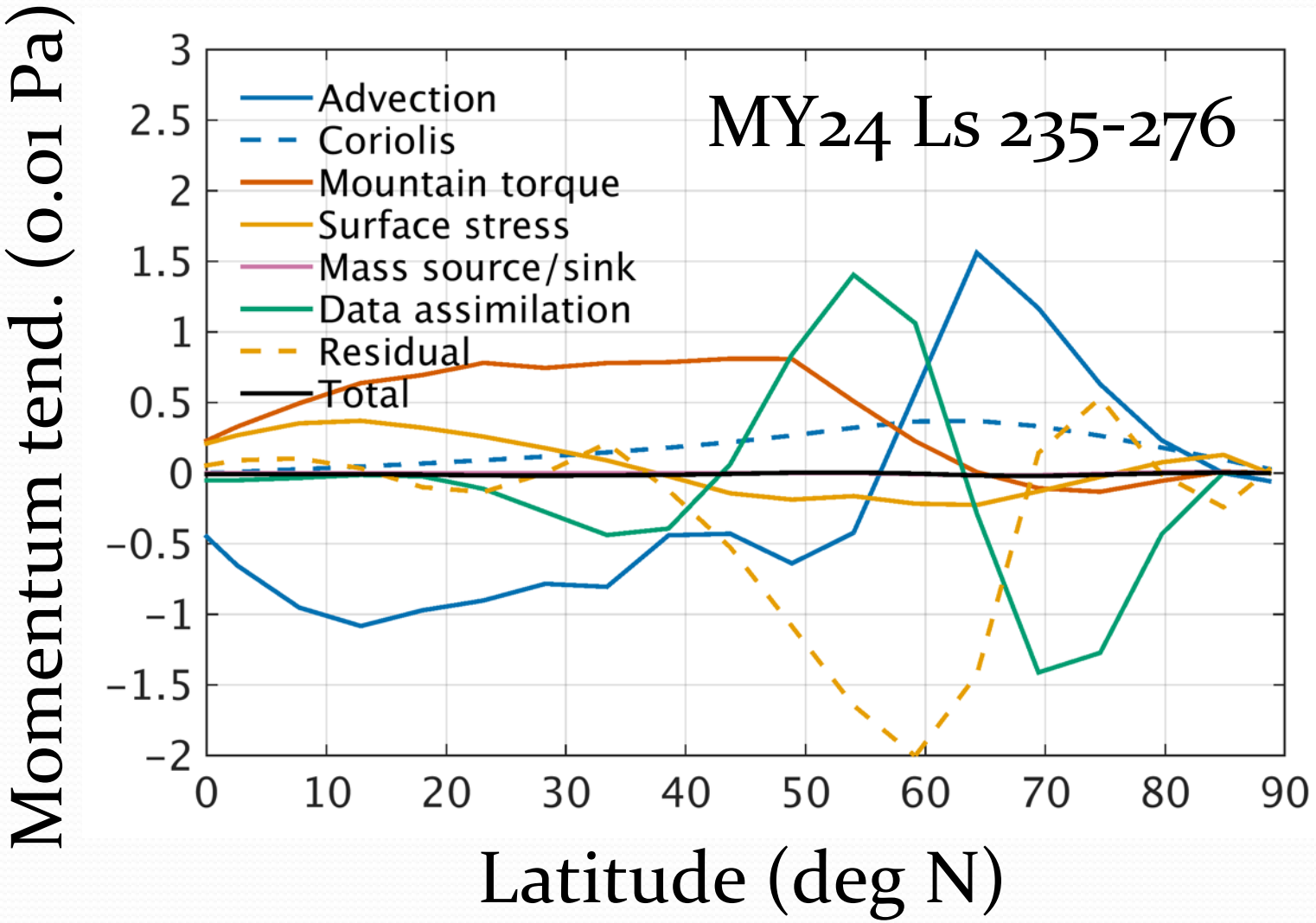
DA adds variability to MACDA



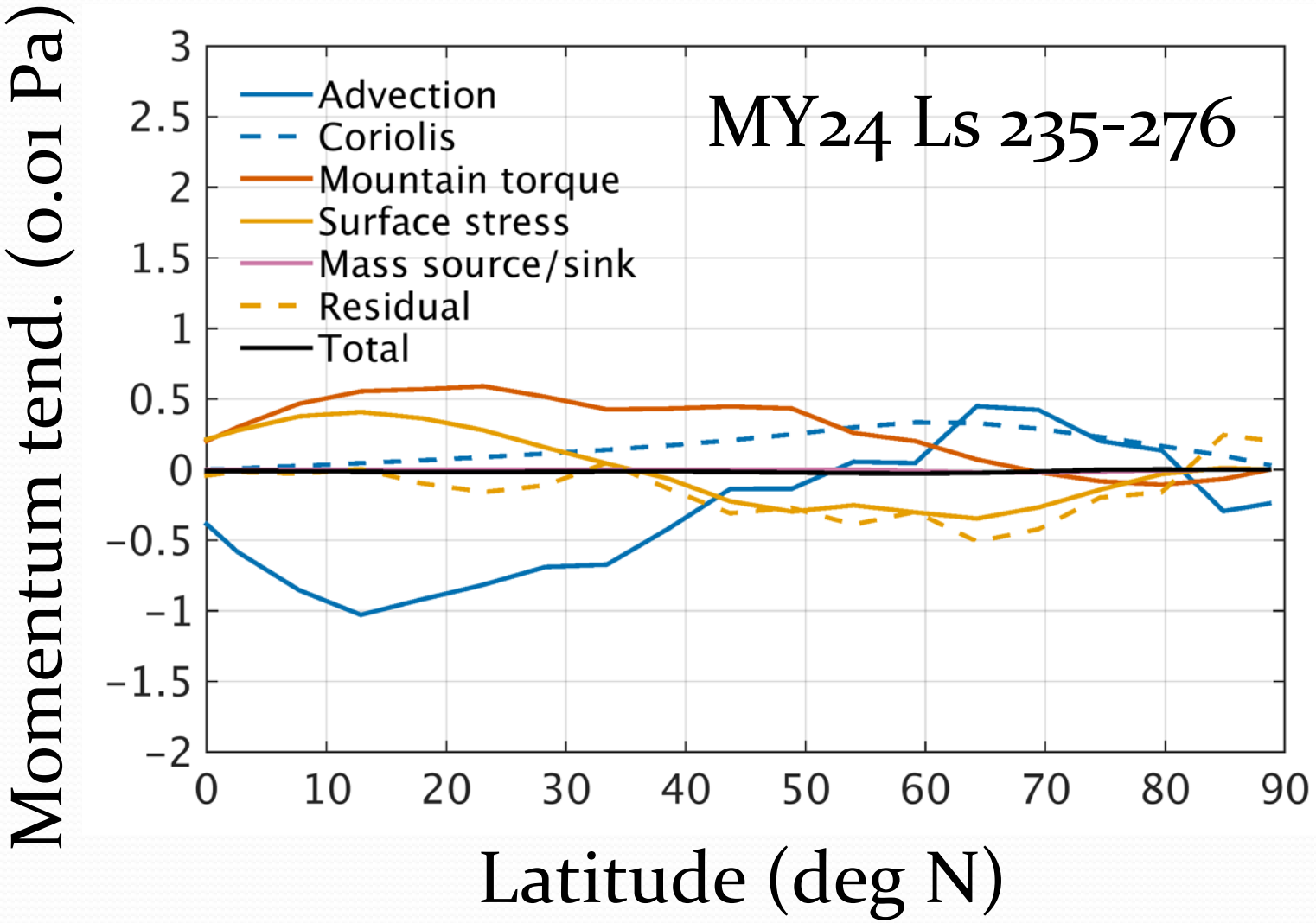
Jet positions can disagree



DA tendencies directly shift jet



Warning: budget closure issue



Summary of diagnostic work

- T assimilation
  - Weakens NH jet
  - Shifts it equatorward, esp. in MACDA
  - Effect smaller in EMARS than MACDA

- Surface jet position—a **common GCM bias**?

- **But** reanalyses still clearly disagree

Theoretical aside

- In a toy problem (Boussinesq QG theory), perfect 4D temperature data does **NOT** uniquely determine flow

- Also need heating/friction info … physics

Broader conclusions/speculations

- What other GCM errors can't we see?
- Need good models for data assimilation
  - Budget closure as evaluation metric?
- Better near-surface obs might help
  - Aeolus or RO constellation?

Some theory

- What can we learn from temperature alone?
- Toy problem: Boussinesq QG theory
- **Will show:**
  - Must know heating & friction to deduce surface flow

Some theory

- What can we learn from temperature alone?

- Toy problem: Boussinesq QG theory

Momentum $$\frac{D\vec{u}}{Dt} + f\hat{z} \times \vec{u} = -\frac{\nabla p}{\rho_{00}} + \vec{F}$$

Mass conservation $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

Thermo $$\frac{D\rho}{Dt} = -S$$

Hydrostatic balance $$\frac{\partial p}{\partial z} = -g\rho$$

Boussinesq QG equations

QGPV equation $$\frac{D_g q}{Dt} = \nabla \times \vec{F} + \frac{g f_0}{\rho_{00}} \frac{\partial}{\partial z}\left[\frac{S}{N^2}\right]$$

QGPV definition $$q = \beta y + \left[\nabla^2 + \frac{\partial}{\partial z}\frac{{f_0}^2}{N^2}\frac{\partial}{\partial z}\right]\varphi$$

Winds $(u, v) = \left(-\frac{\partial \varphi}{\partial y}, \frac{\partial \varphi}{\partial x}\right)$ "Temperature" $\frac{\partial \varphi}{\partial z}$

Boundary conditions @ z = o & H $$\frac{D}{Dt}\frac{\partial \varphi}{\partial z} = \frac{gS}{f_0 \rho_{00}}$$

The big idea

Assume solution $\varphi(x, y, z, t), \vec{F}, S$

Then $\varphi(x, y, z, t) + \Delta\varphi(x, y, t), \vec{F} + \Delta\vec{F}, S + \Delta S$

has different sfc flow but same "temperatures"

Subtract solutions, w/ $\Delta\varphi \neq 0$ can find $\Delta\vec{F}$ & ΔS

E.g. $$\left[-\frac{\partial\Delta\varphi}{\partial y}\frac{\partial}{\partial x} + \frac{\partial\Delta\varphi}{\partial x}\frac{\partial}{\partial y}\right]\frac{\partial\varphi}{\partial z} = \frac{g\Delta S}{f_0\rho_{00}}$$

at boundaries

The big idea

Assume solution $\varphi(x, y, z, t), \vec{F}, S$

Then $\varphi(x, y, z, t) + \Delta\varphi(x, y, t), \vec{F} + \Delta\vec{F}, S + \Delta S$

has different sfc flow but same "temperatures"

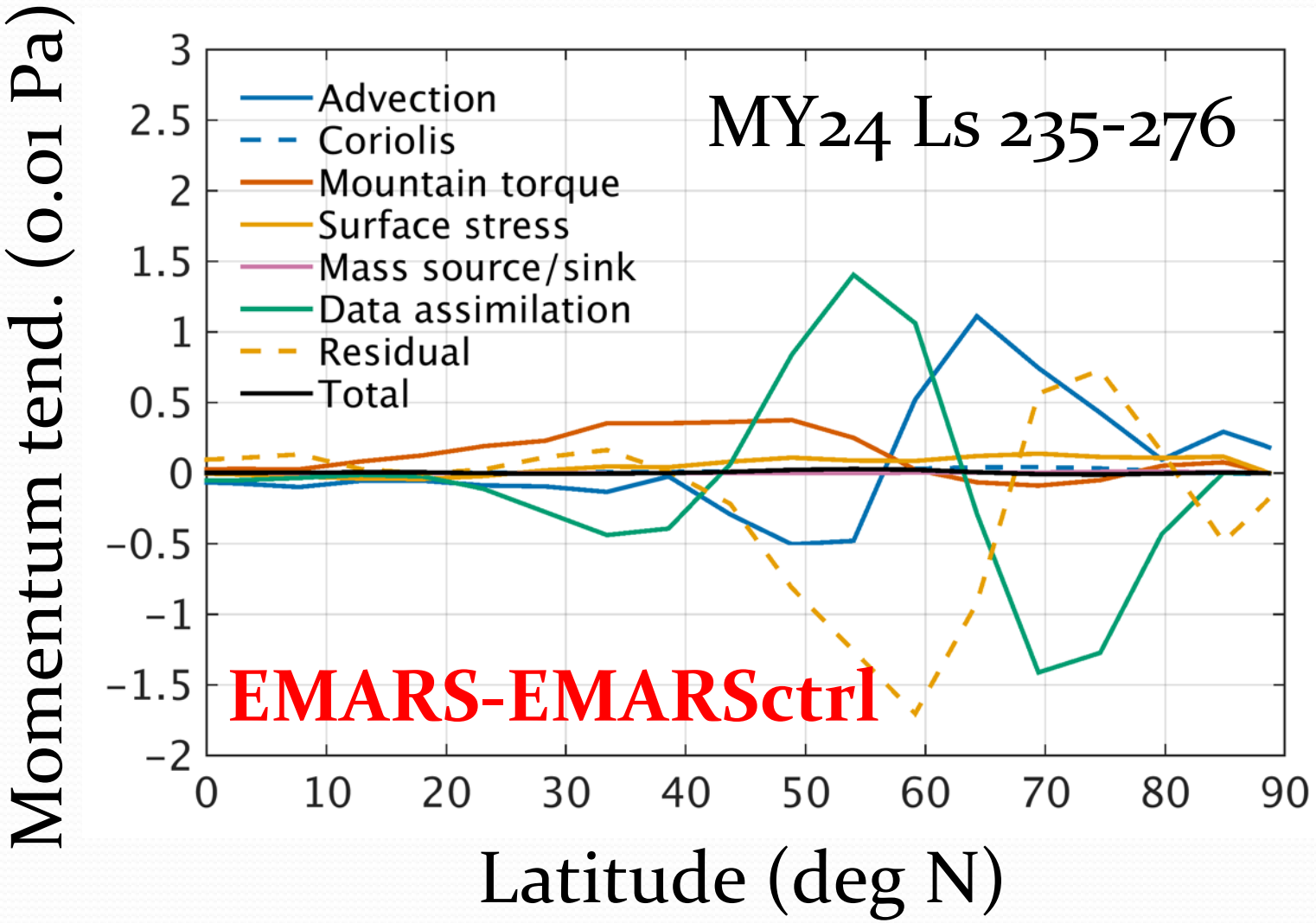
Subtract solutions, w/ $\Delta\varphi \neq 0$ can find $\Delta\vec{F}$ & ΔS

Must know $\vec{F}$ and S to get barotropic φ

Caveats and implications

- Heating/friction not totally unconstrained
- Perturbed physics for ensemble DA = good?
- Problem for parameter estimation?

Momentum budget difference



Are GCM & reanalysis results robust?

- Aside: should DA work near surface?

	MACDA	EMARS
T data	TES	TES
Dust data	TES	TES
Control	Yes	Yes
GCM	UK spectral	GFDL lat-lon FV
DA method	Analysis correction	Ensemble Kalman filter

Mars low-level circulation

- Almost all Mars atmospheric dynamics data is infrared temps from orbiters

- What about wind, etc.?
  - Use temps to constrain Mars GCM
  - Model + observations = reanalysis

- How well does this work at low altitudes?

The big idea

Assume solution $\varphi(x, y, z, t), \vec{F}, S$

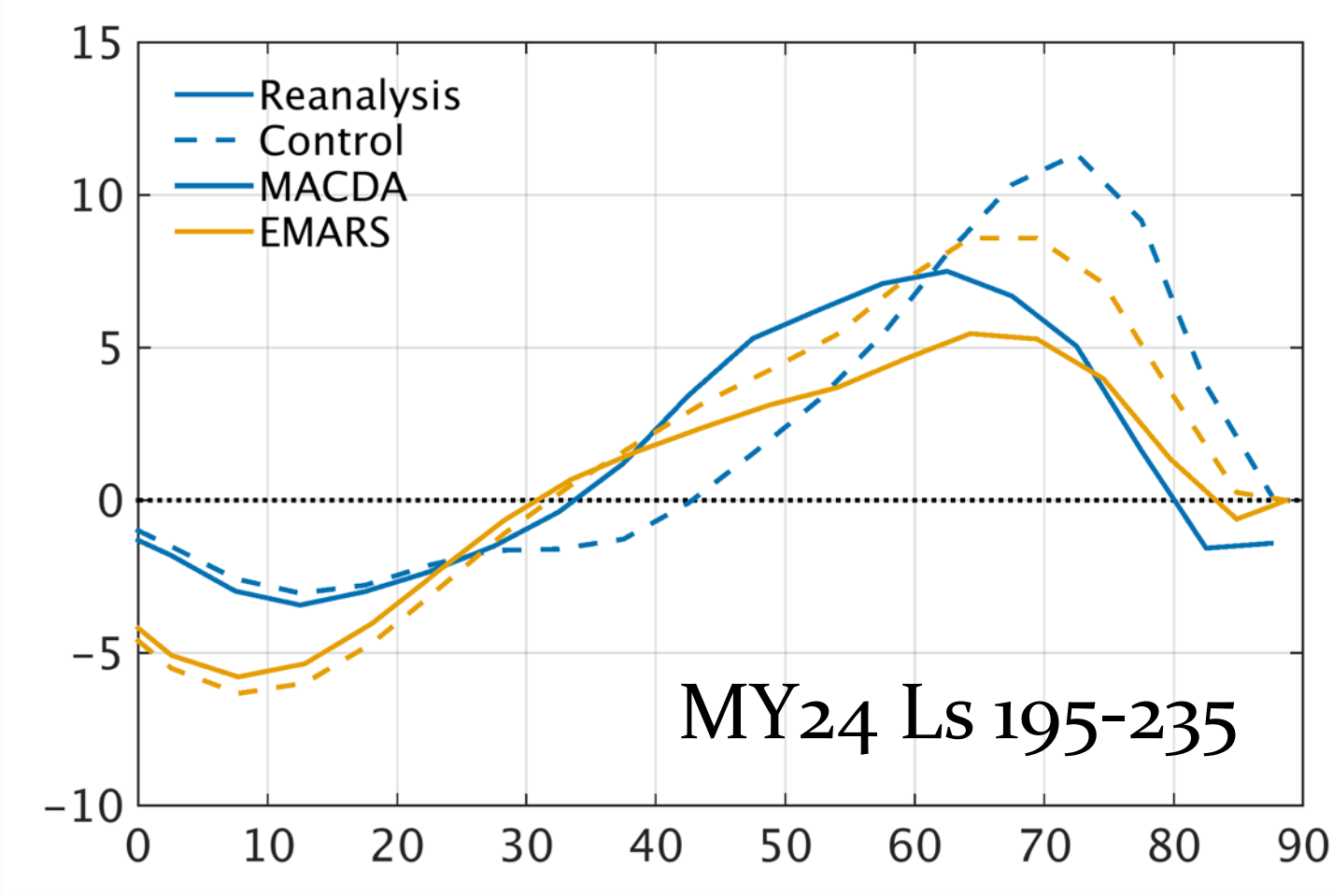
Then $\varphi(x, y, z, t) + \Delta\varphi(x, y, t), \vec{F} + \Delta\vec{F}, S + \Delta S$

has different sfc flow but same "temperatures"

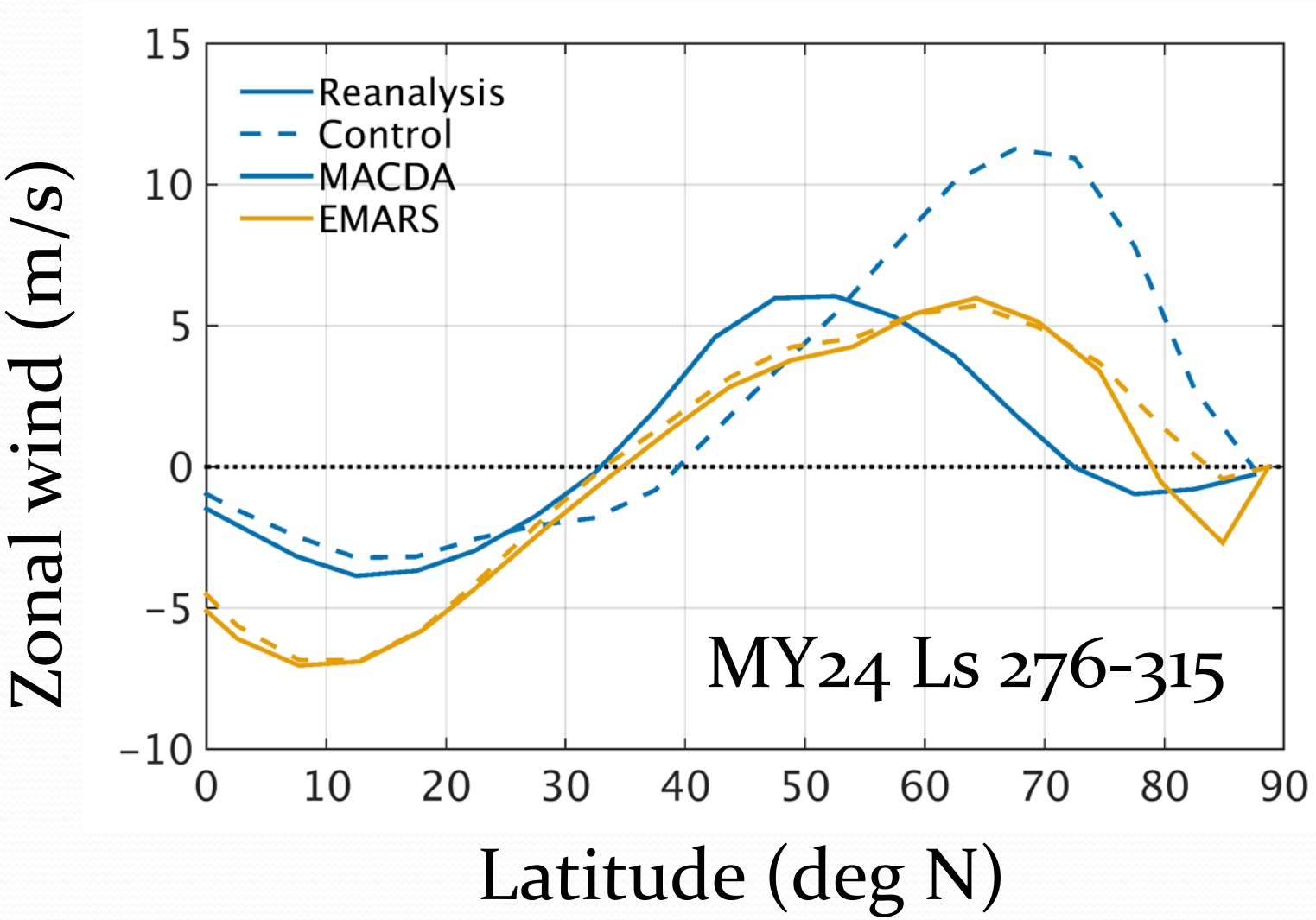
Given $\Delta\varphi \neq 0$ can find $\Delta\vec{F}$ & ΔS

Must know $\vec{F}$ and S to get barotropic φ

No shift in EMARS



Almost no DA effect in EMARS



~1 km zonal wind in MACDA reanalysis

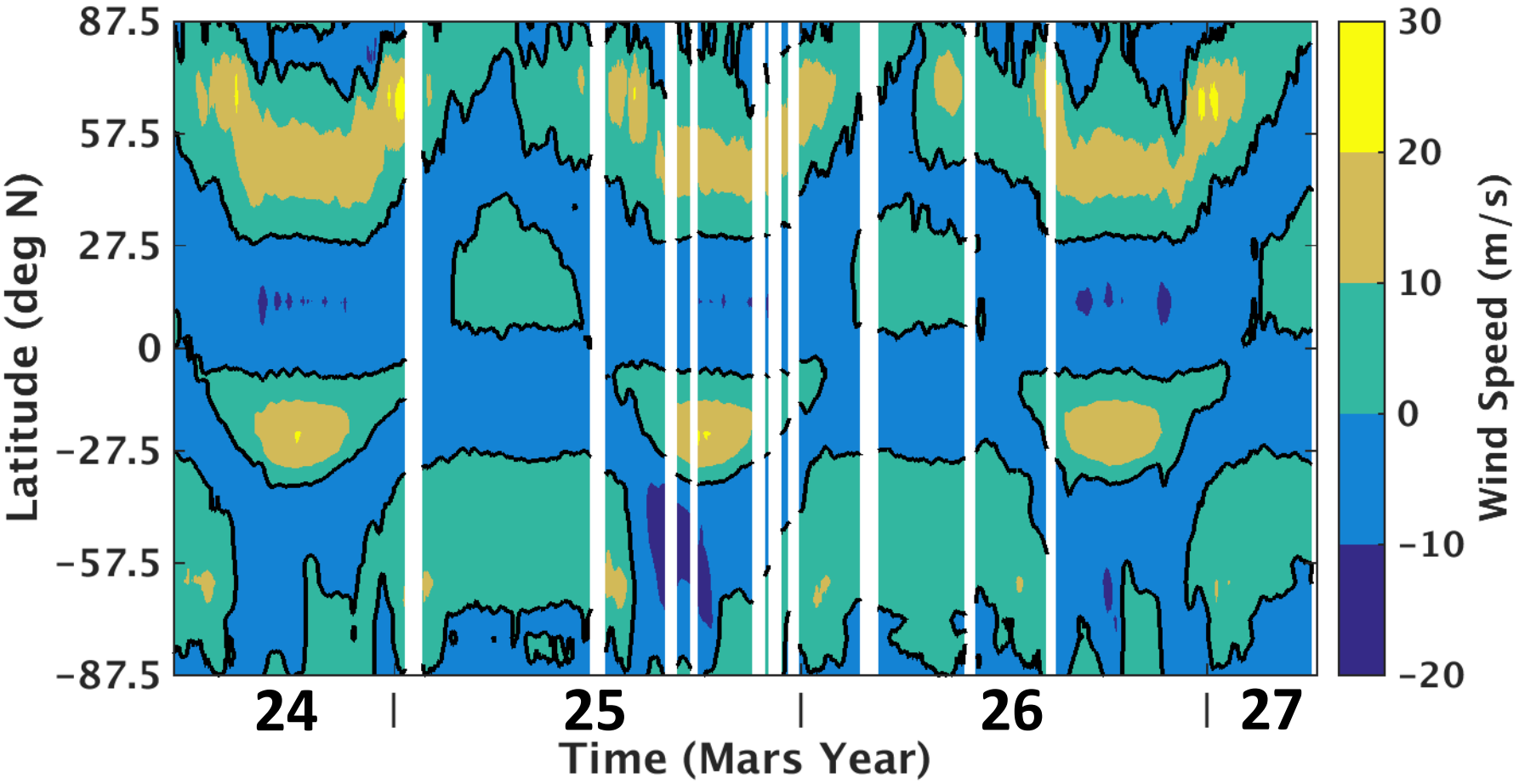


Figure: G. Davis

~1 km zonal wind in control run

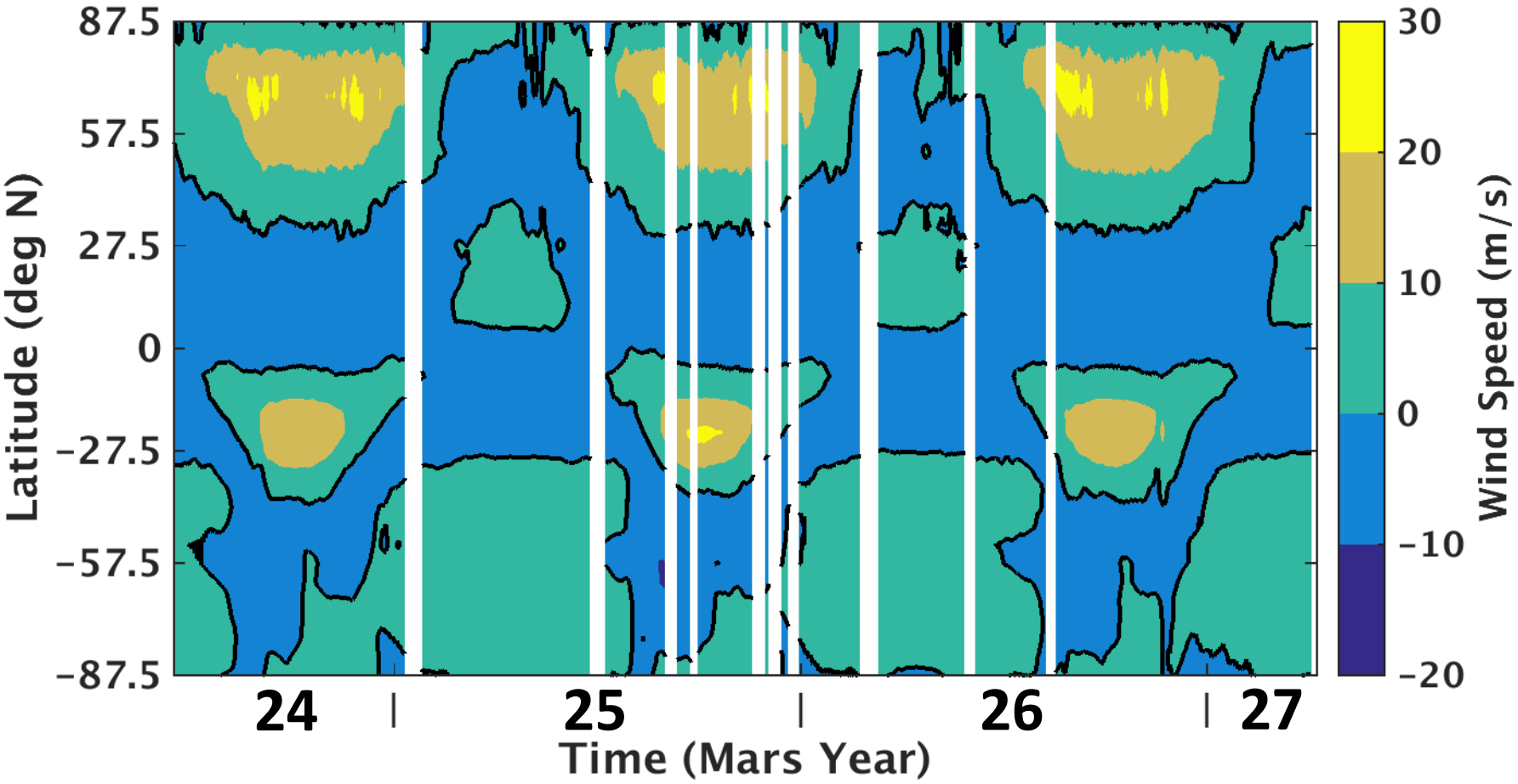


Figure: G. Davis

Difference (control – reanalysis)

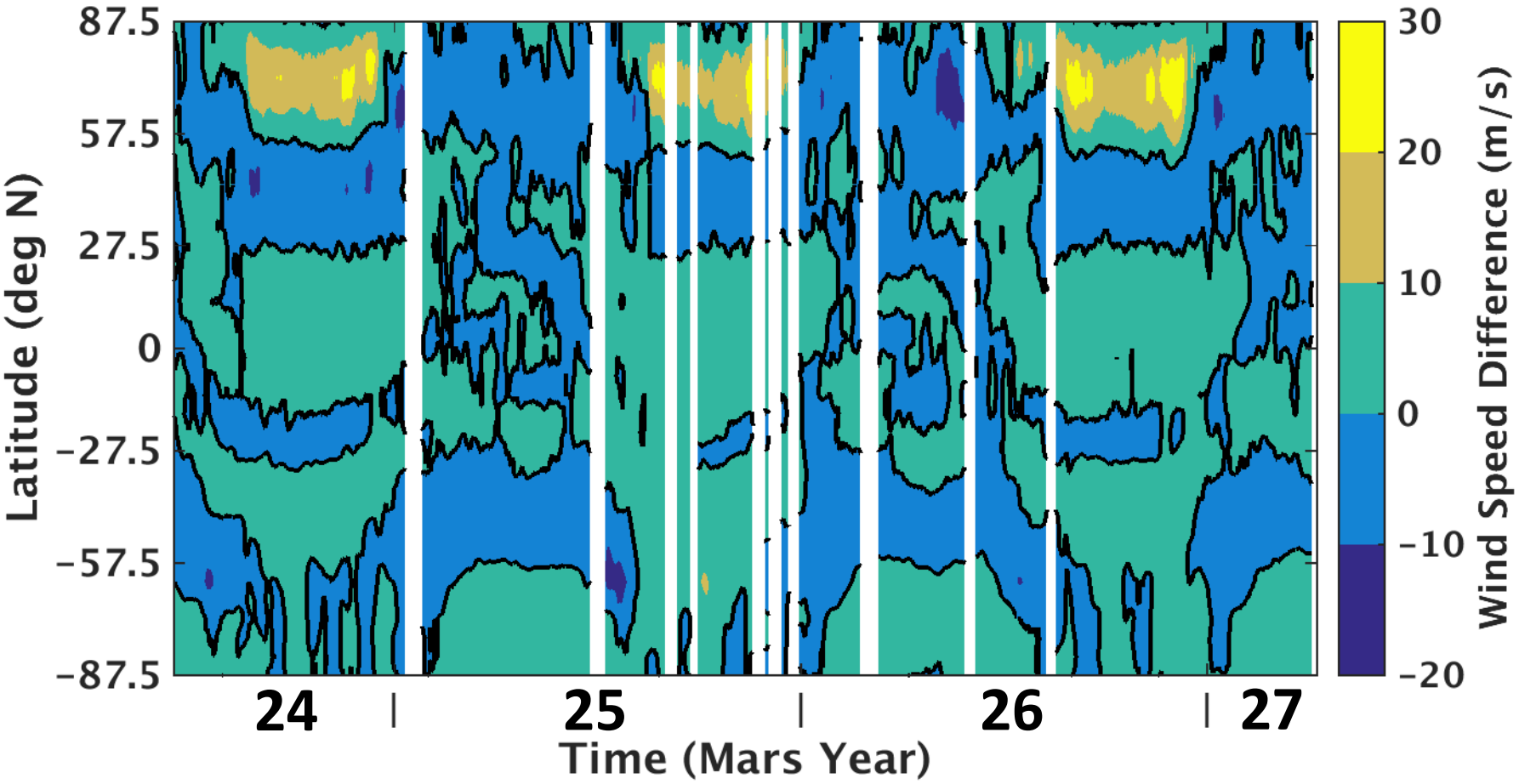


Figure: G. Davis

P_{surf} & zonal jet differences are linked

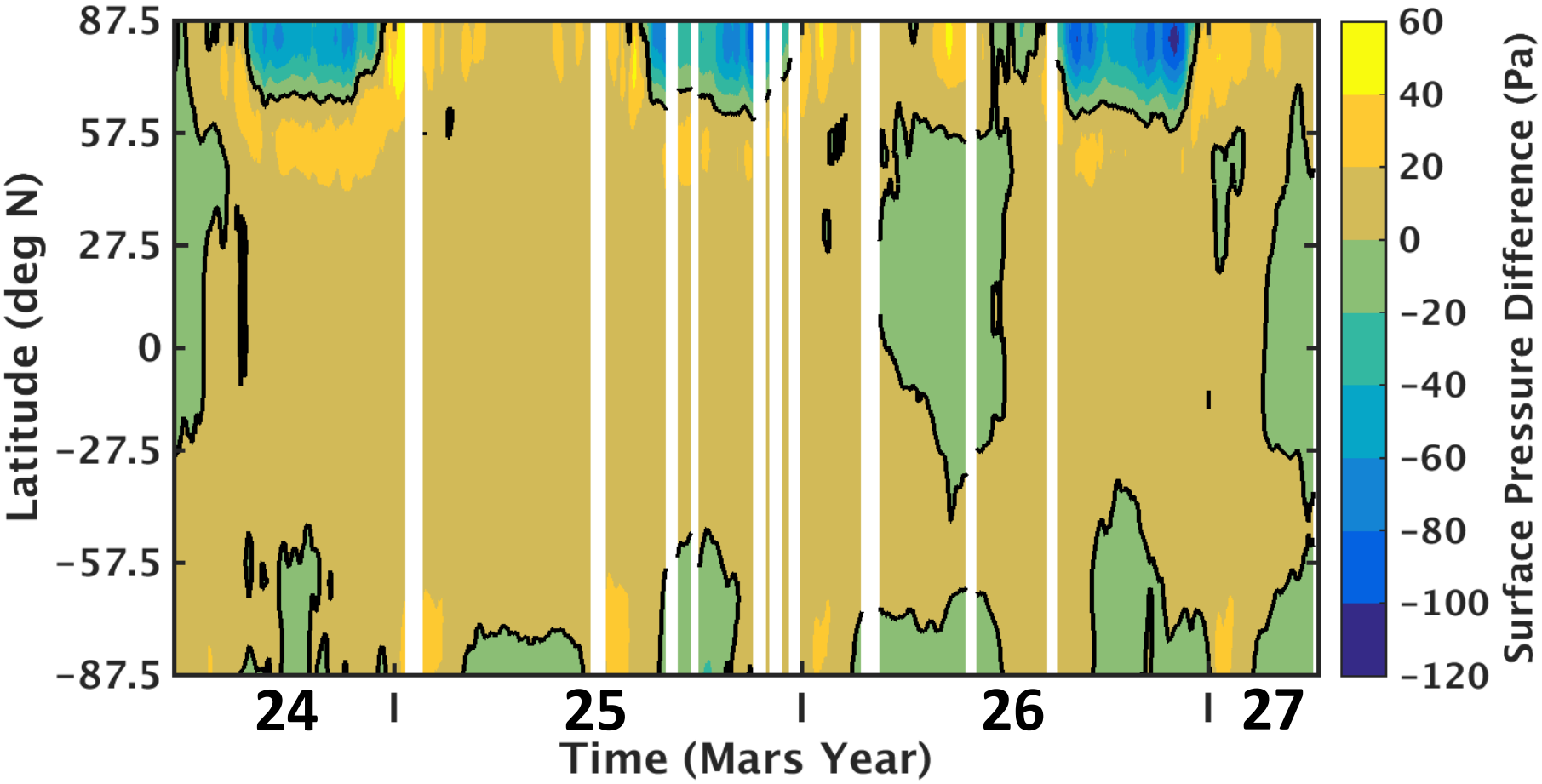
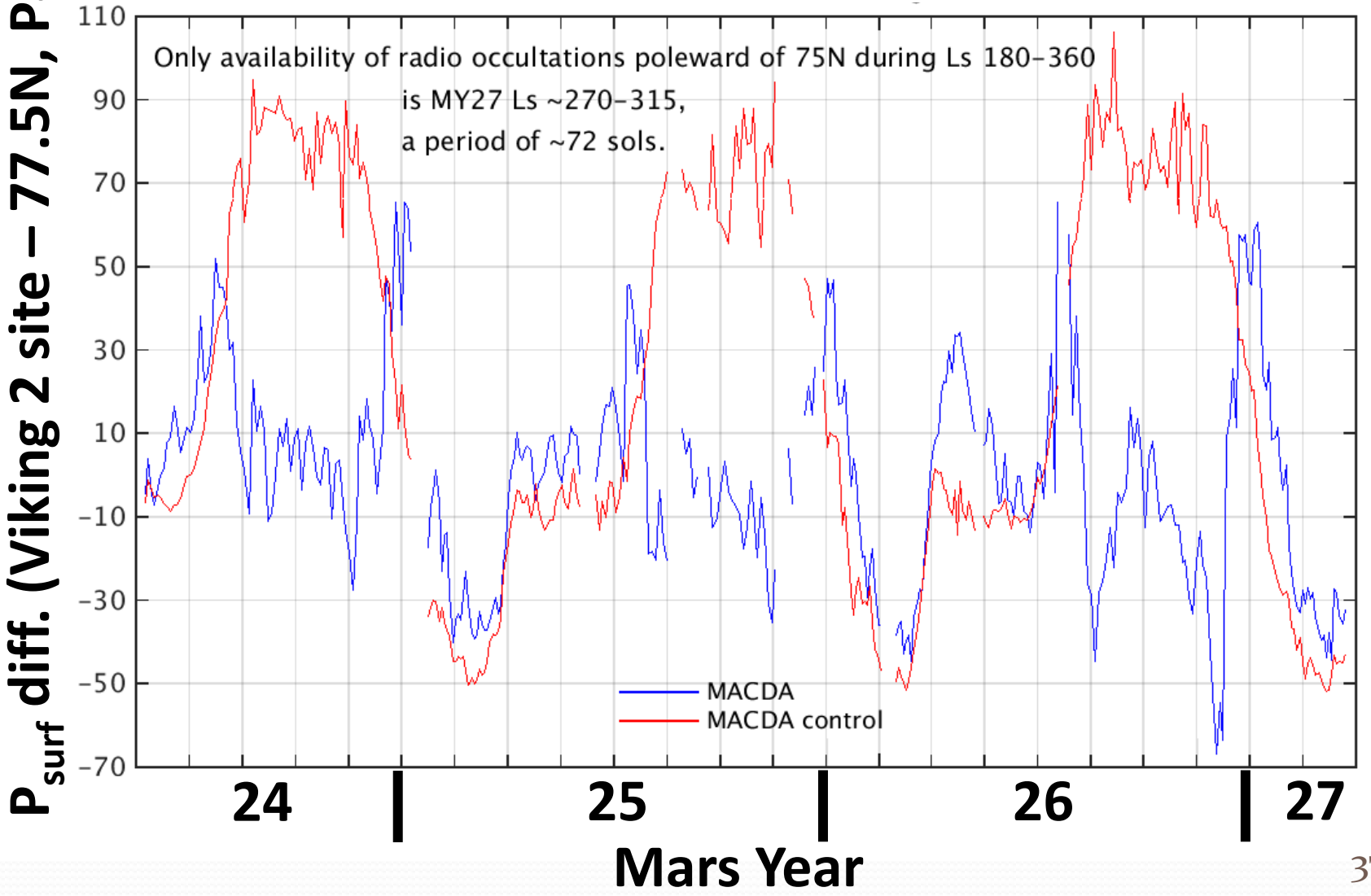


Figure: G. Davis

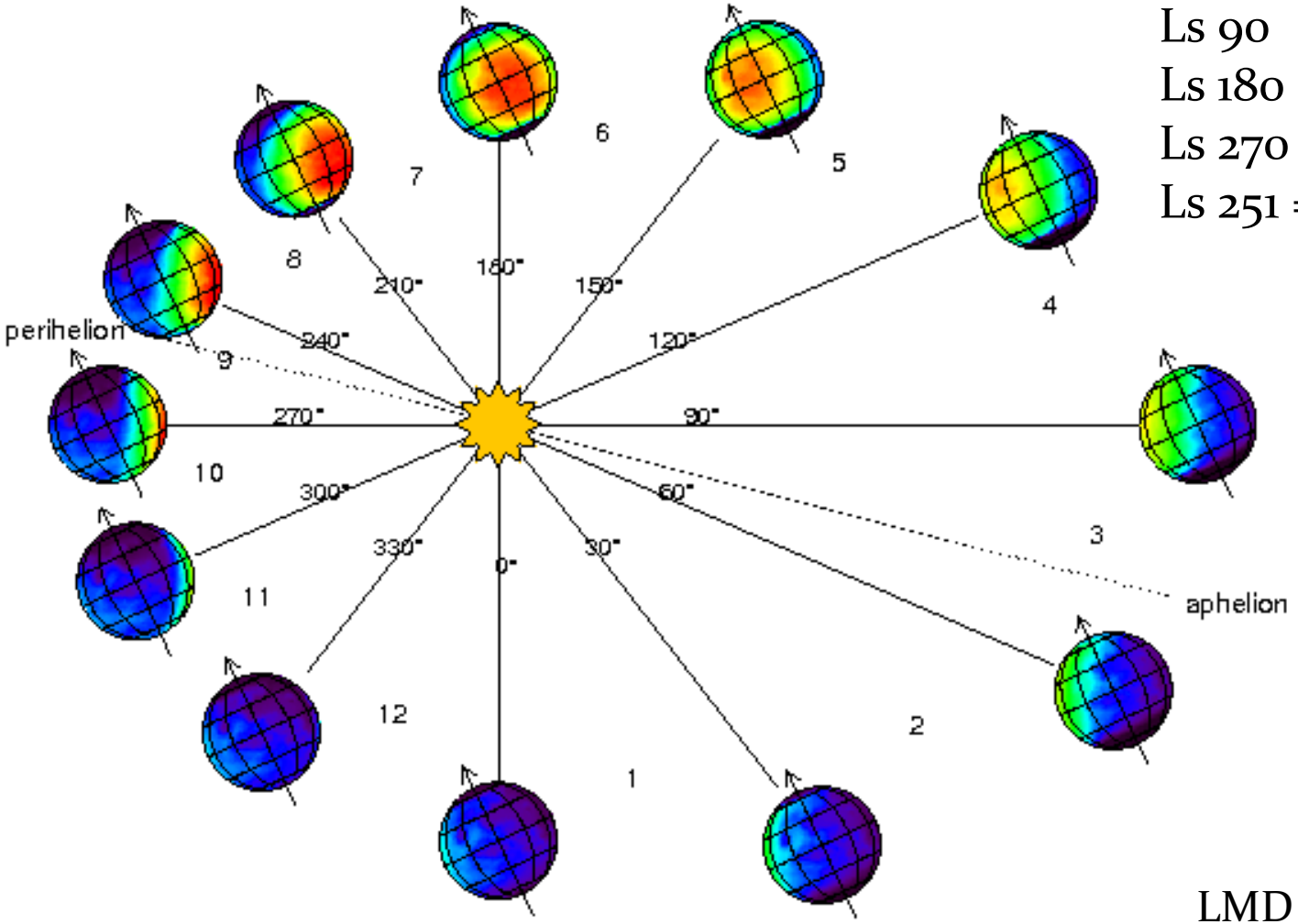
P_{surf} difference may be observable



(Mars) conclusions and caveats

- Conclusions
  - Data assimilation notably alters low-level circulation
  - “Truth” not obvious, but could likely learn more about it without new Mars mission
- Caveats
  - Differences less stark in more modern reanalysis (EMARS)

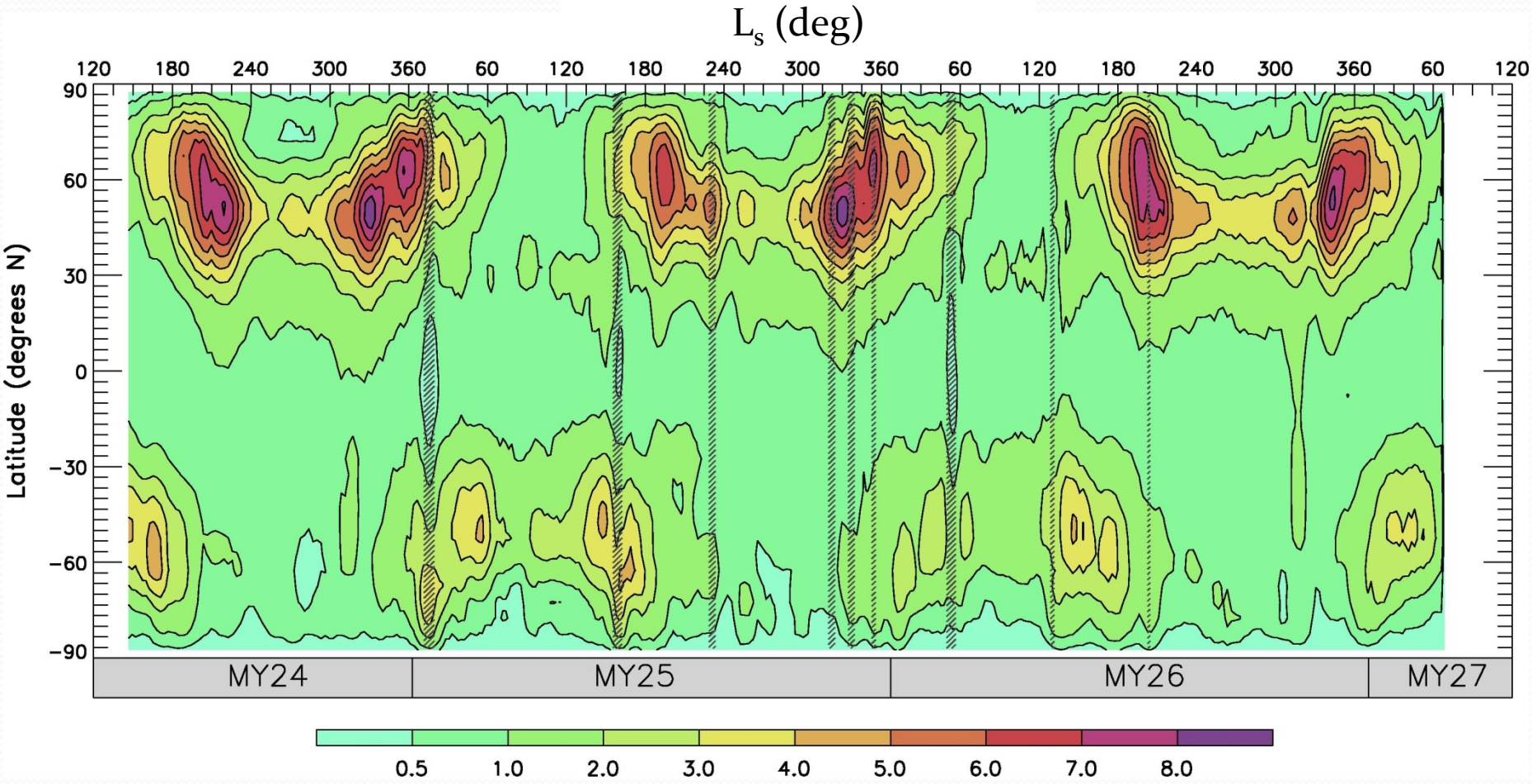
Mars calendar



Ls 0 = NH spring
Ls 90 = NH summer
Ls 180 = NH autumn
Ls 270 = NH winter
Ls 251 = Perihelion

LMD Mars Climate Database n.d.

Seasonal cycle of low-level eddies

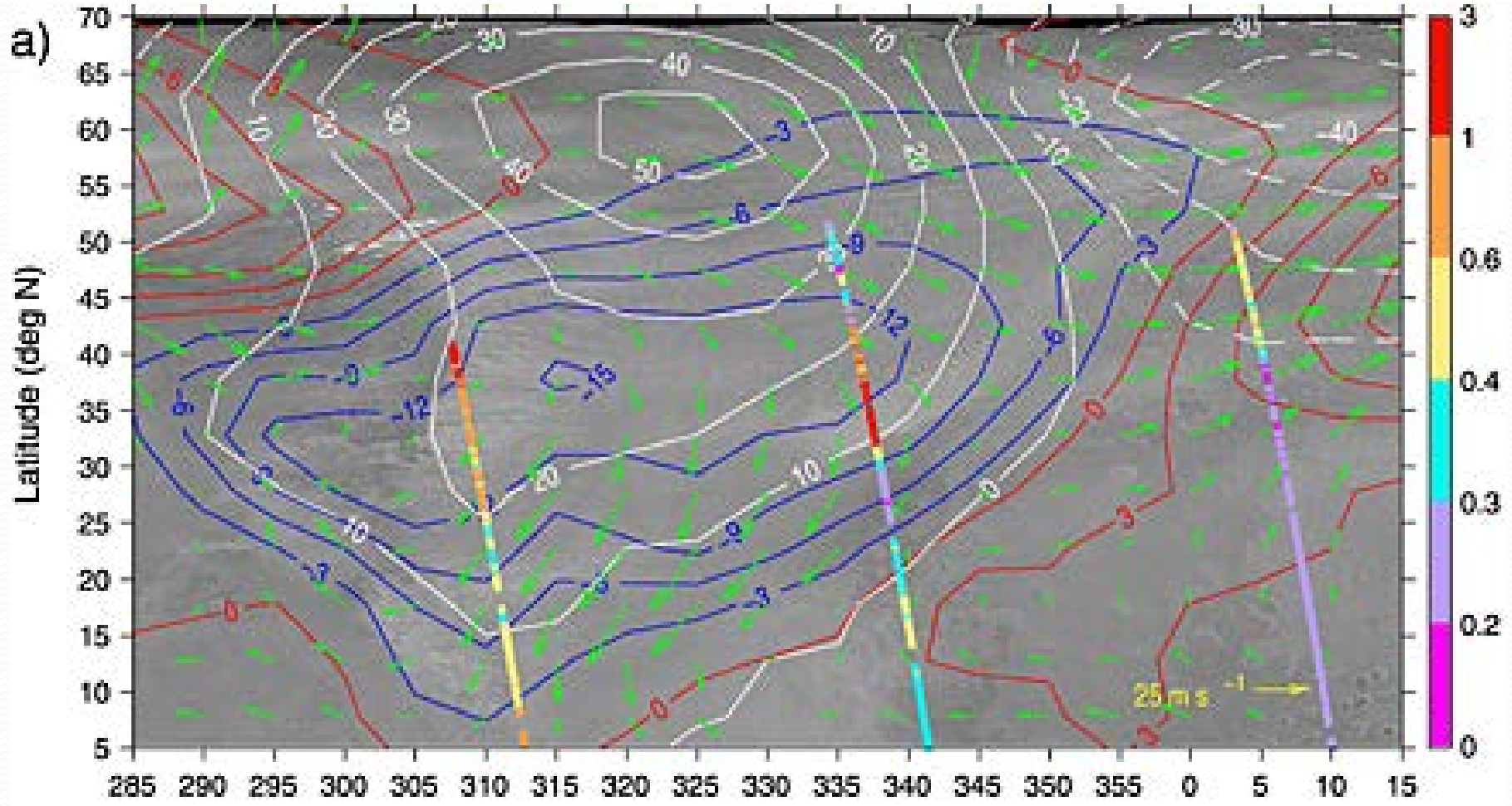


RMS T' (K), 2.5 km altitude

Lewis et al. 2016

Flushing dust storm in Acidalia/Chryse

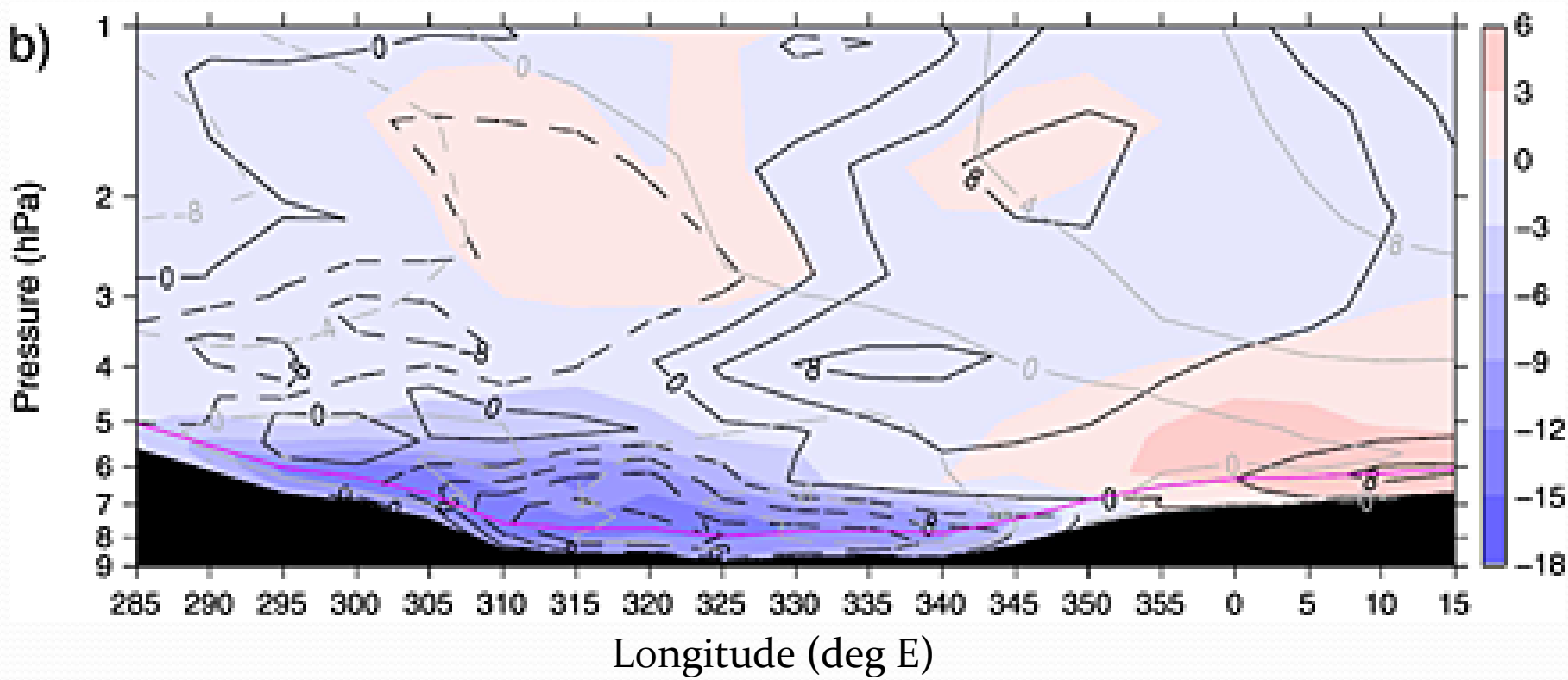
Green: Total wind (Ã= 0.9, m/s) Red/blue: T' (Ã= 0.9, K) White: p_s' (Pa) MY24 L_s 224



Mooring & Wilson 2015

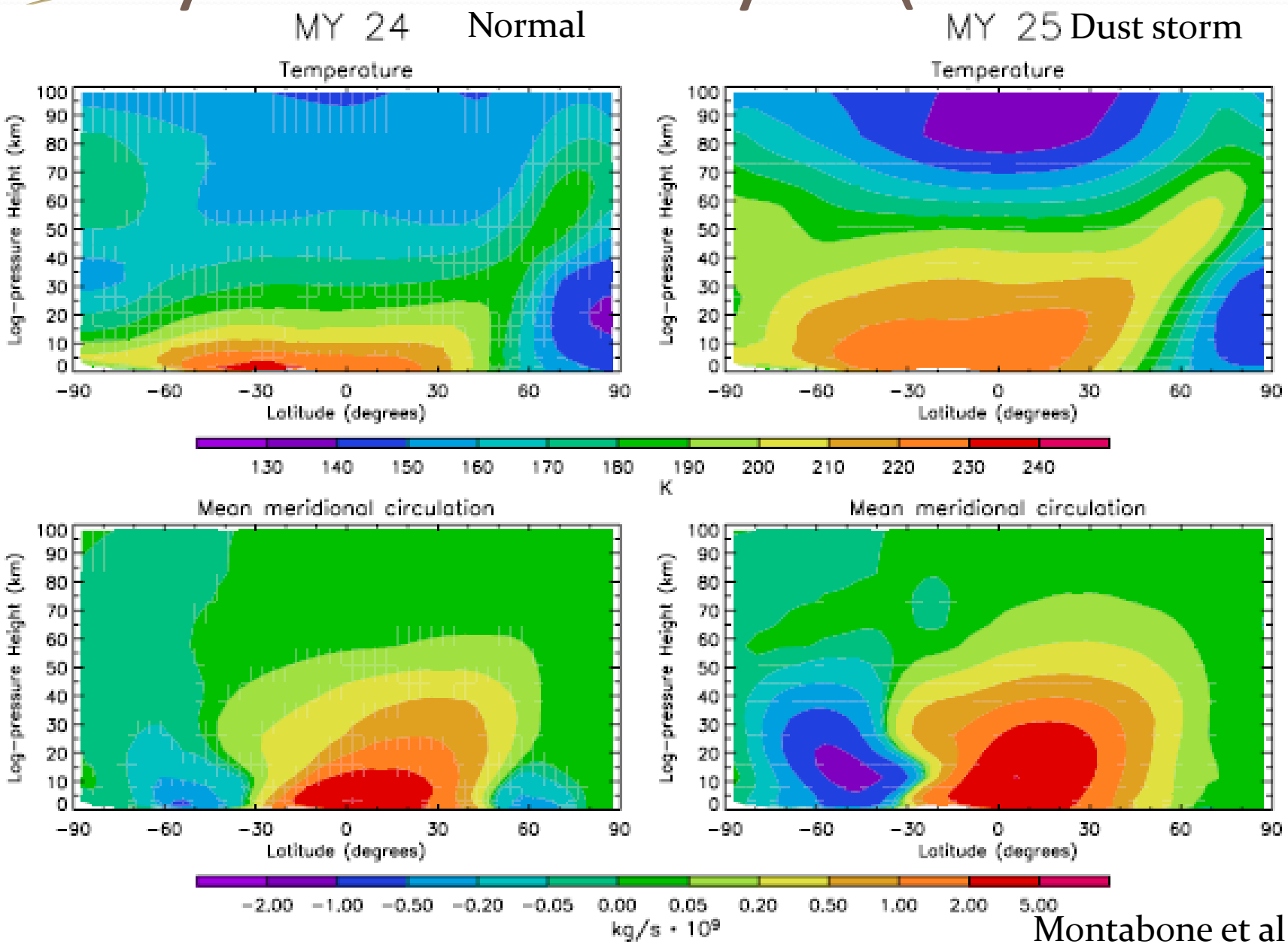
Flushing dust storm in Acidalia/Chryse

Black: v' (m/s) Red/blue: T' (K) Gray: quasistationary v (m/s) MY24 L_s 224, 32.5N



Mooring & Wilson 2015

Hadley cell in reanalysis (Ls 195-225)



Montabone et al. 2005

Mars topographic map

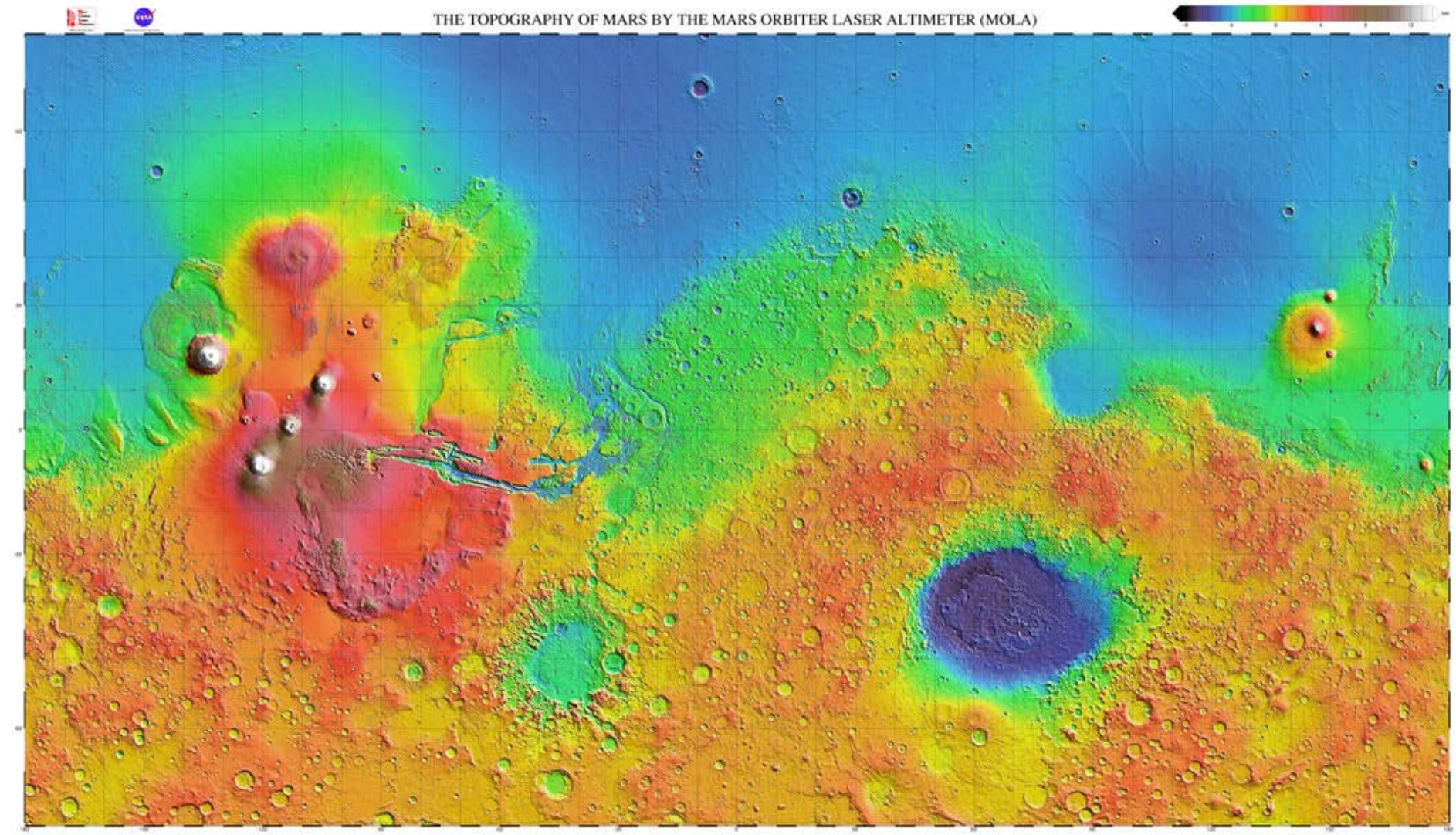


Image: MOLA Science Team