CAM angular momentum conservation on slow rotators

or

trials and tribulations with the Titan CAM

Erik Larson
University of Colorado
Whole Atmospheres Working Group meeting
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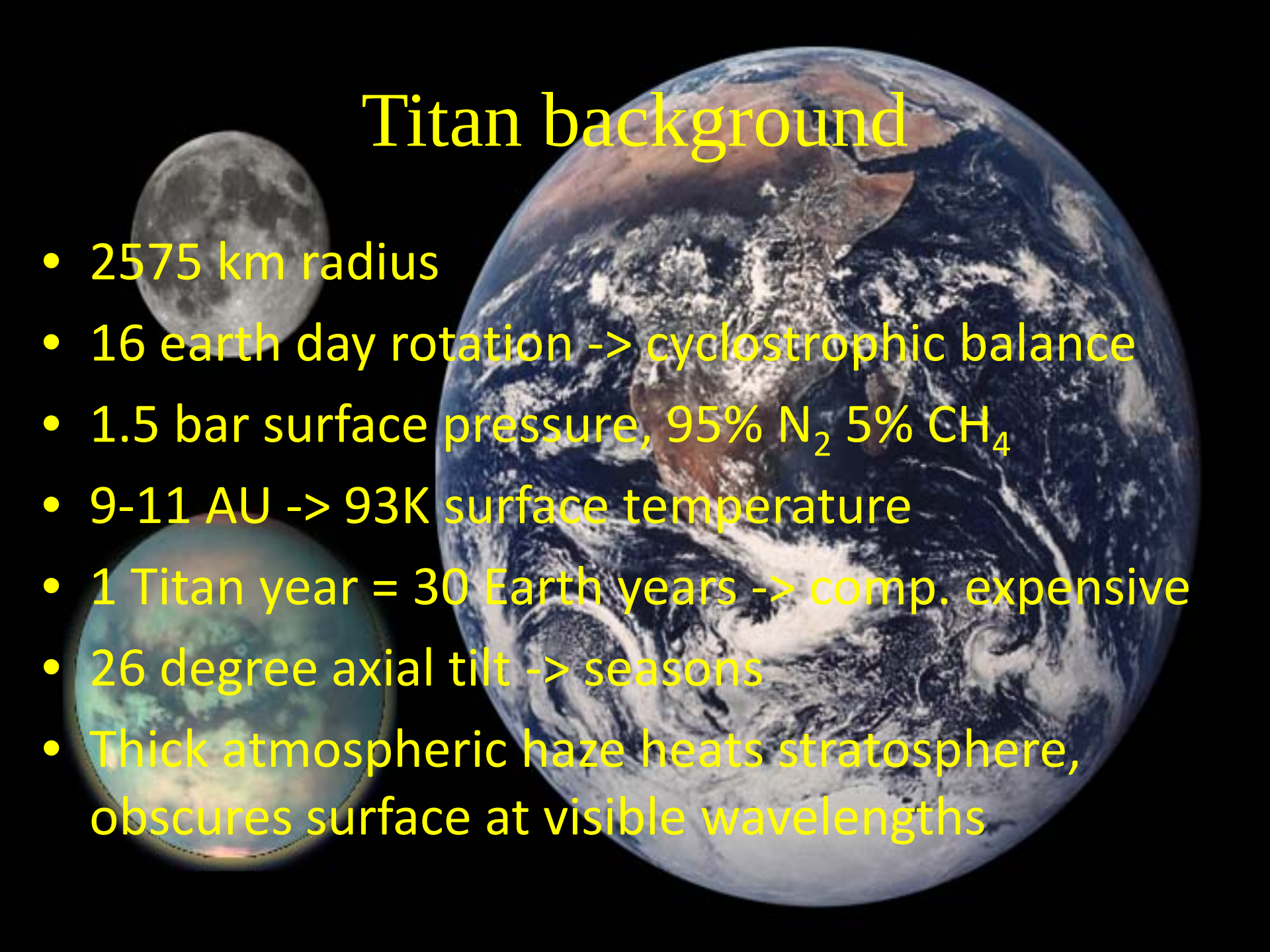
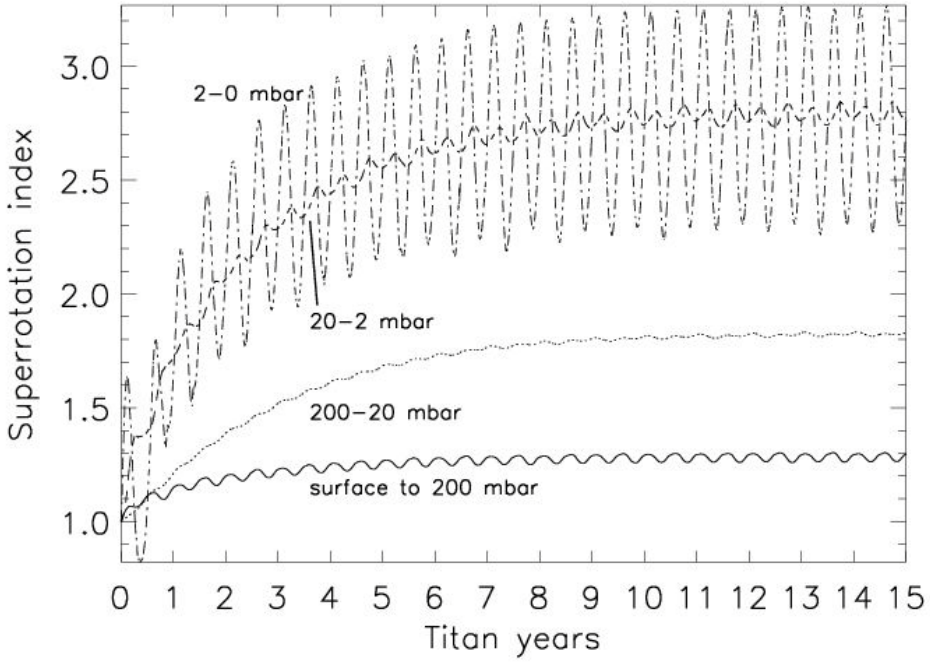
Titan background



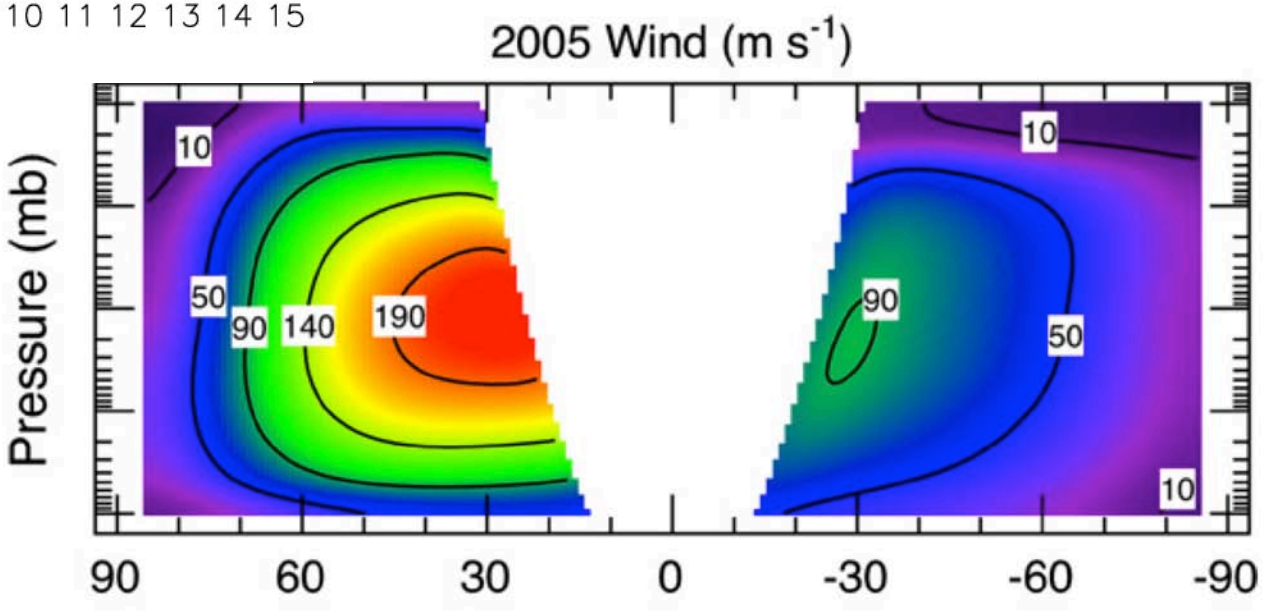
- 2575 km radius
- 16 earth day rotation -> cyclostrophic balance
- 1.5 bar surface pressure, 95% N_2 5% CH_4
- 9-11 AU -> 93K surface temperature
- 1 Titan year = 30 Earth years -> comp. expensive
- 26 degree axial tilt -> seasons
- Thick atmospheric haze heats stratosphere, obscures surface at visible wavelengths

Superrotation with 200m/s jets



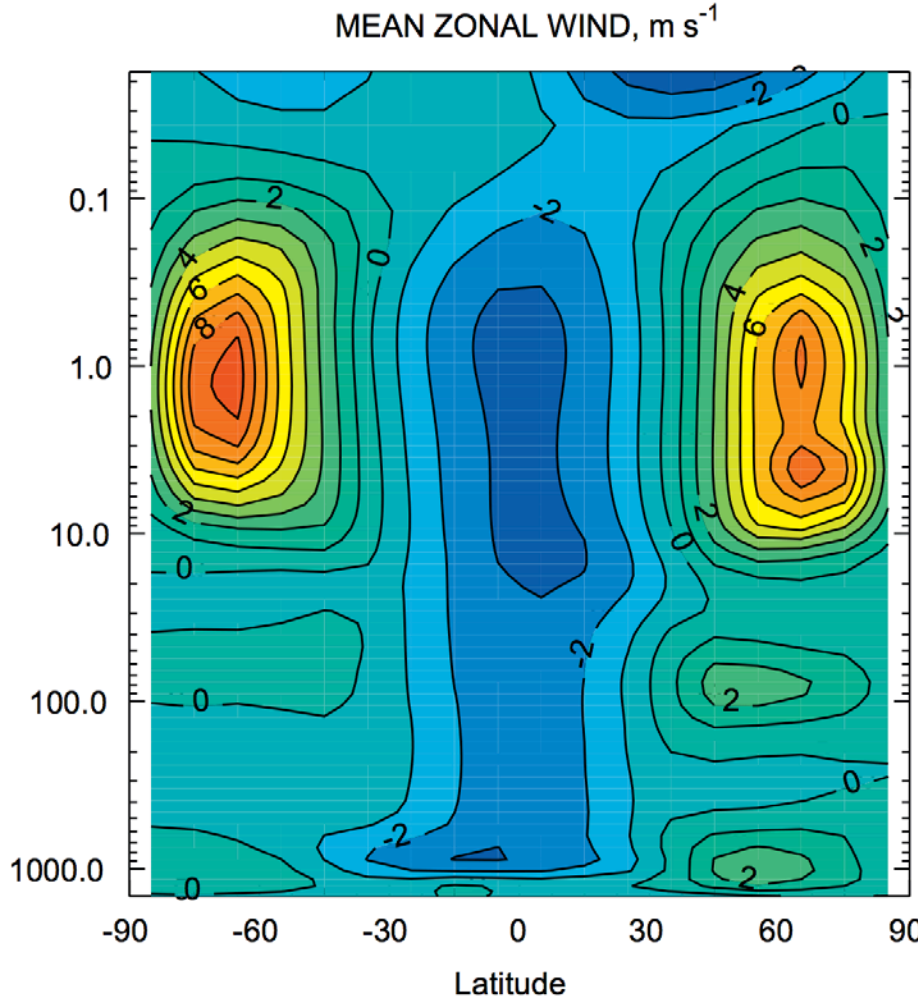
TitanWRF - Newman et al. 2011
Needed to remove all diffusion to achieve superrotation

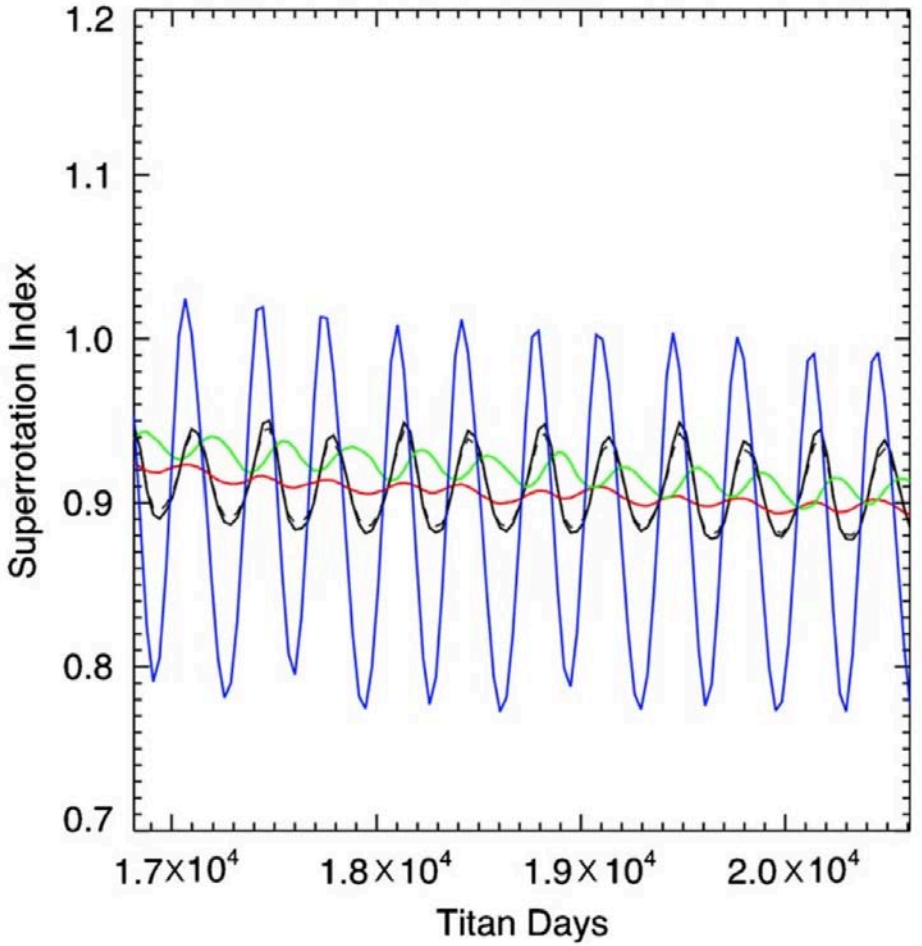
Achterberg et al. 2009



State of the Titan CAM 2009

(Friedson et al. 2009)





What's causing the lack of zonal winds?

Guess

- Improper heating/cooling
- Gravity wave parameterization
- Sponge layer
- Numerical diffusion
- Surface stresses
- Topography
- Dynamical core

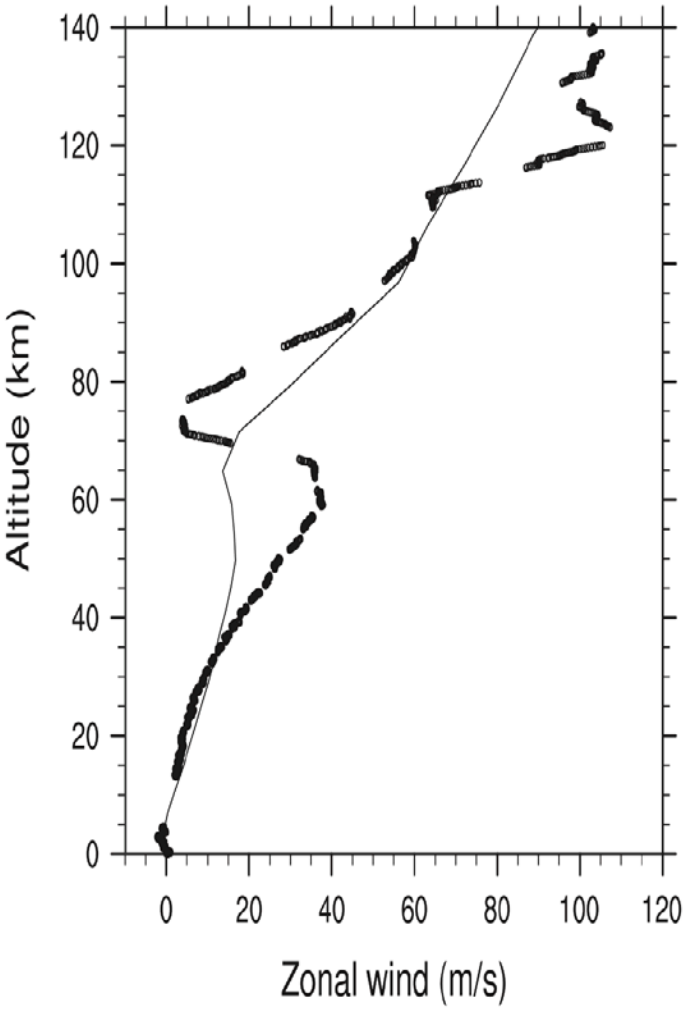
Attempted fix

- Add realistic aerosol heating and cooling - CARMA
- Adjust or remove
- Reduce sponge layer diffusion
- Test higher resolution (4x5)
- Reduce surface drag
- Include realistic Cassini based topography
- Try other cores (unsuccessful)

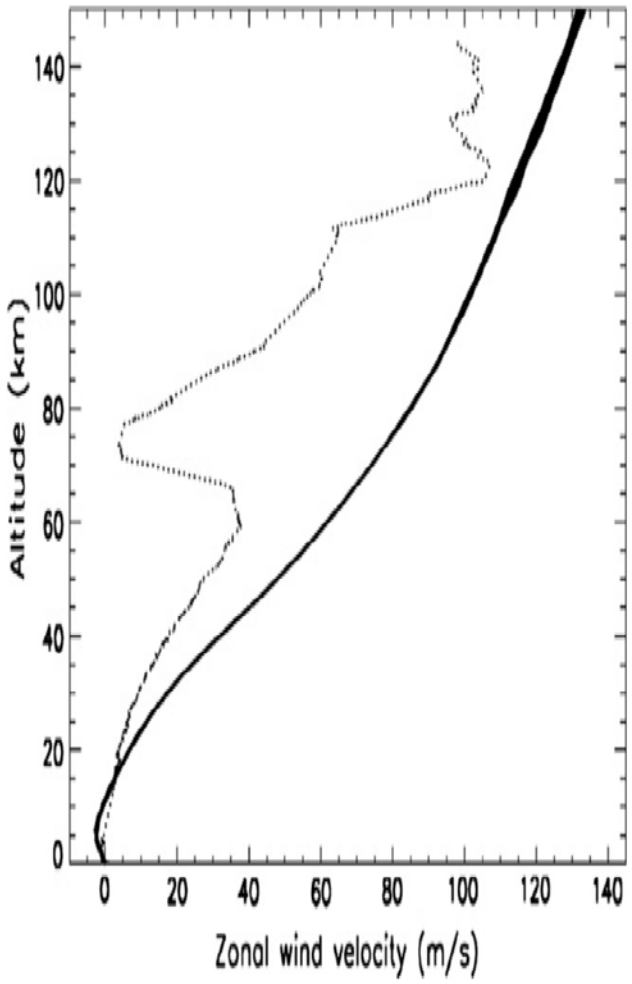
None of these greatly improved the zonal wind speed or superrotation with the possible exception of higher resolution

Other GCMs produce fast zonal winds

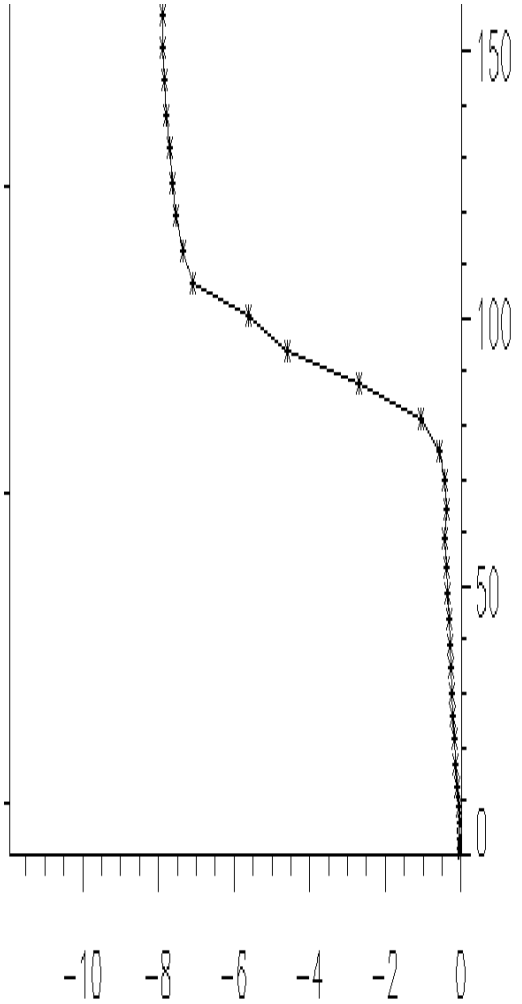
Lebonnois et al. 2012



Newman et al. 2011

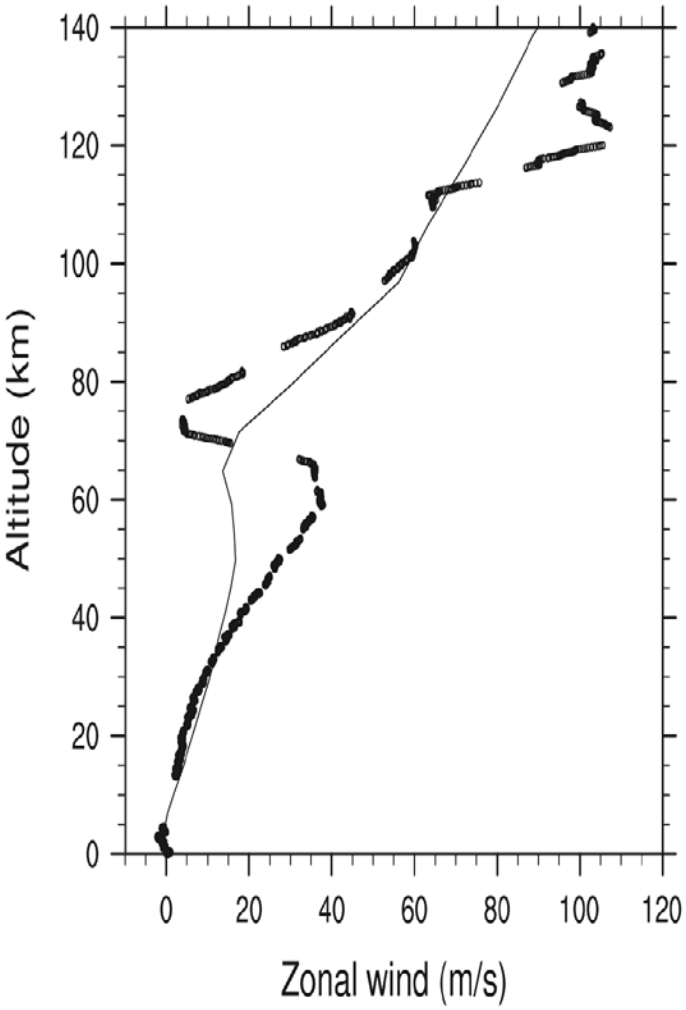


Titan CAM3

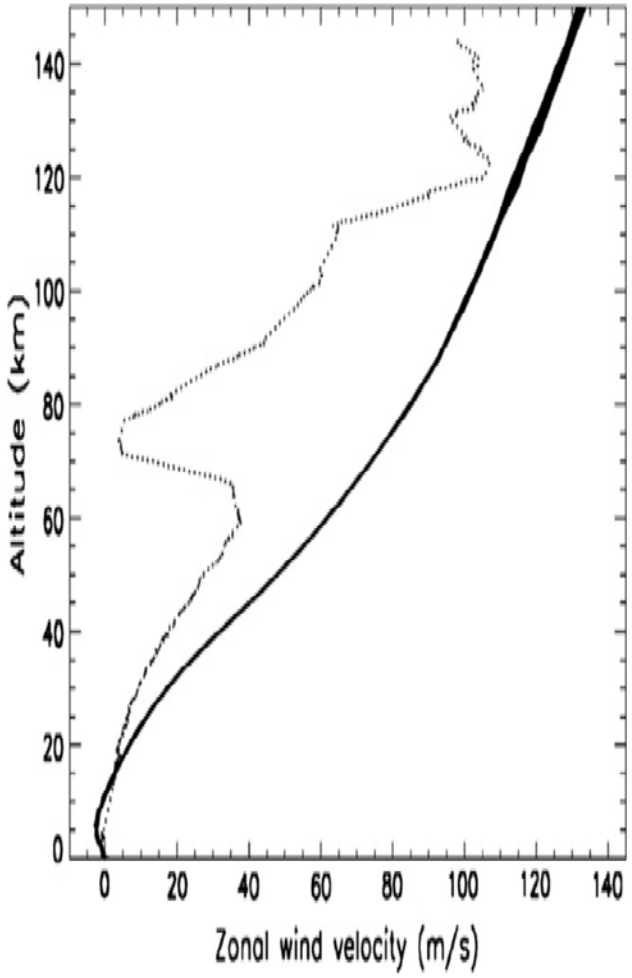


Finally, we just forced the zonal winds

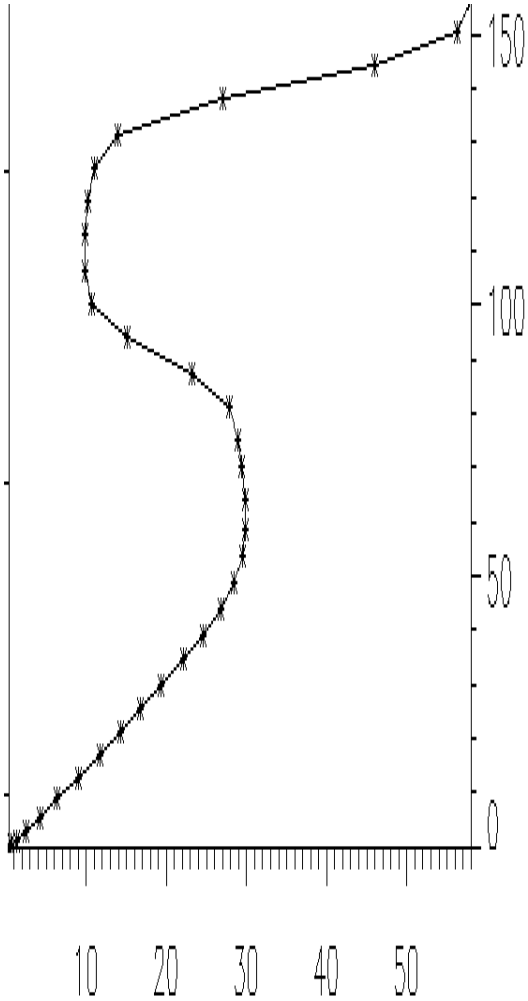
Lebonnois et al. 2012



Newman et al. 2011



Titan CAM3 - forced



Lebonnois et al. 2012 - Angular momentum budget in General Circulation Models of superrotating atmospheres: A critical diagnostic

	$\overline{T^+}$	$\overline{T^-}$	$\overline{F^+}$	$\overline{F^-}$	$\overline{\epsilon^*}$	ξ
LMDIN	0.	0.	10.23	−0.74	−6.79	0.66
LMDIT	28.13	−29.86	4.83	−3.26	1.24	0.04
LMDFN	0.	0.	0.50	−0.94	−0.66	0.70
LMDFT	30.73	−30.09	2.19	−6.24	3.54	0.10
IN2S	0.	0.	0.94	−0.24	−6.54	6.96
IN4S	0.	0.	1.74	−0.	−5.13	2.95
IN4R10	0.	0.	0.26	−0.33	−0.75	2.27
IN4R30	0.	0.	0.13	−0.79	−1.06	1.34
IN42R10	0.	0.	0.24	−0.43	−1.32	3.07
I0N42R10	0.	0.	0.59	−0.12	4.07	6.90
IT2S	273.9	−241.6	0.17	−0.07	−30.92	0.11
IT4S	216.1	−330.6	0.23	−0.06	116.52	0.35
IT4R10	267.5	−267.1	0.23	−0.07	3.18	0.01
IT4R30	274.2	−255.8	0.23	−0.07	−15.08	0.05
IT42R10	263.9	−269.8	0.23	−0.07	9.23	0.03
I0T42R10	265.0	−264.5	0.22	−0.07	3.19	0.01
TITAN	0.	0.	34.3	−24.9	−6.63	0.19
EIN2S	0.	0.	98.8	−87.8	−11.33	0.12
EIN4S	0.	0.	101.4	−90.3	−11.60	0.11
EIN4R10	0.	0.	102.7	−85.2	−18.17	0.18

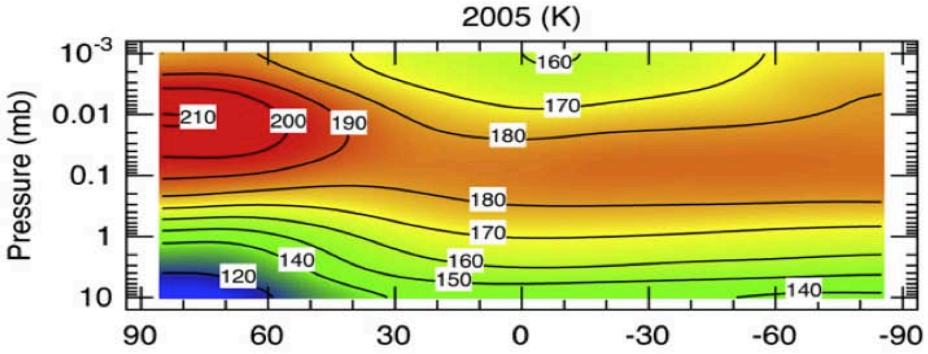
[a]The dimensionless ratio ξ is defined in the text. Units (other than ξ) are 10^{18} kg m^2 s^{-2} for Venus and the Earth, 10^{15} kg m^2 s^{-2} for Titan.

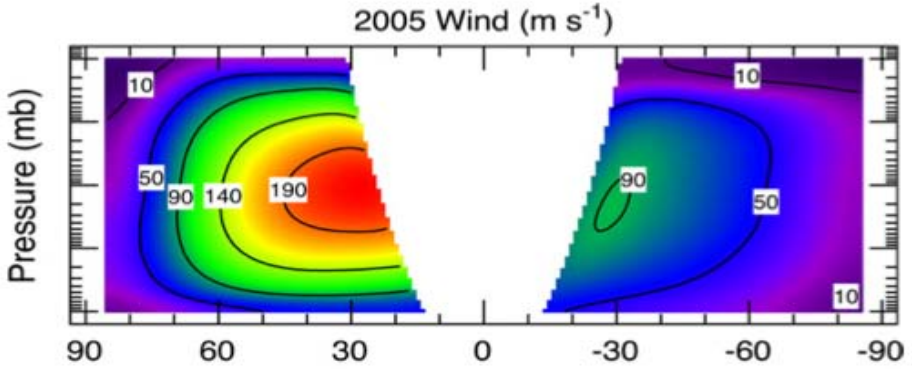
	(sponge layer)
D	Residual torque due to conservation errors in the horizontal dissipation parameterization
Dy	Total variation of AAM in the dycore of the GCM
ϵ	Residual numerical rate of AAM variation due to conservation errors in the dycore
ϵ^*	$=S + D + \epsilon$, should theoretically be zero
Σ	$=F + Dy$, should be equal to dM_z/dt
F^+	Positive (source) part of the friction torque
F^-	Negative (sink) part of the friction torque
T^+	Positive (source) part of the mountain torque
T^-	Negative (sink) part of the mountain torque
ξ	Ratio between $\lvert\overline{\epsilon^*}\rvert$ and Max $(\overline{T^+} + \overline{F^+}, \lvert\overline{T^-} + \overline{F^-}\rvert)$

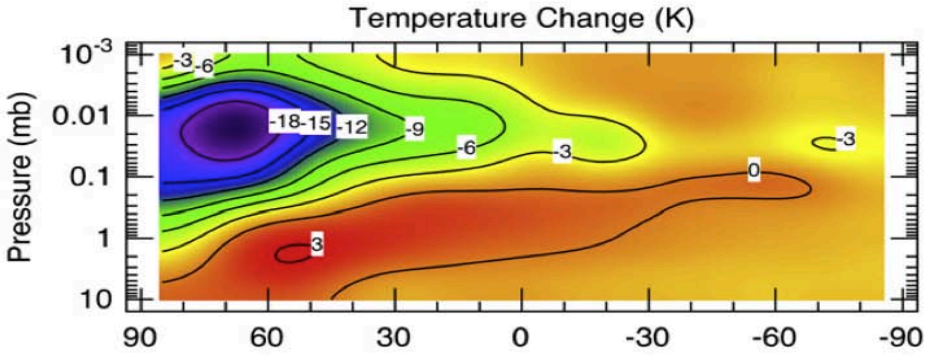
[a]The overbar indicates a time average over the whole simulation.

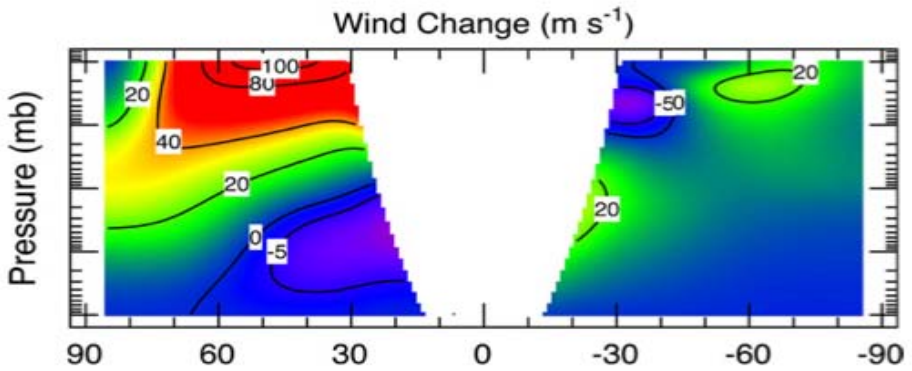
How well does CAM conserve angular momentum?

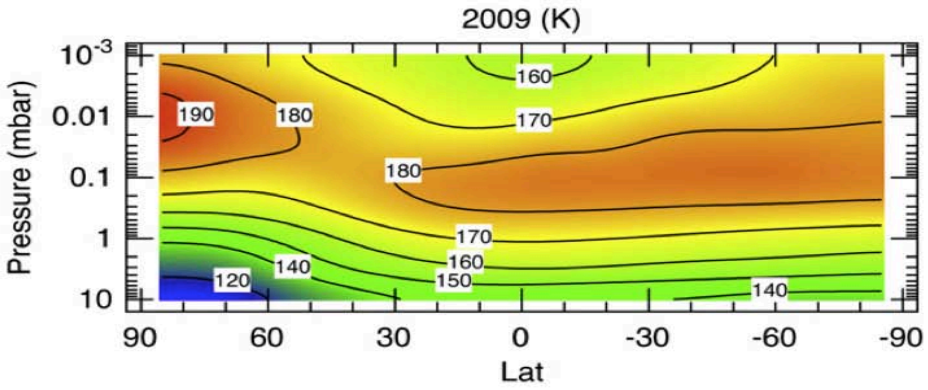
Temperature gradients and winds

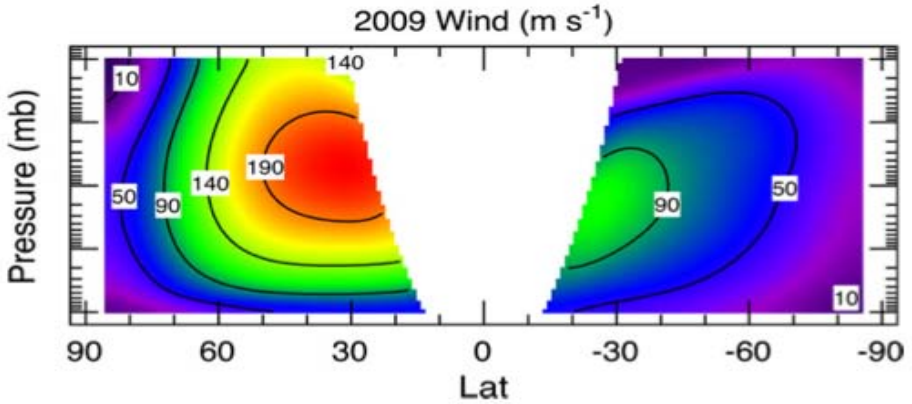






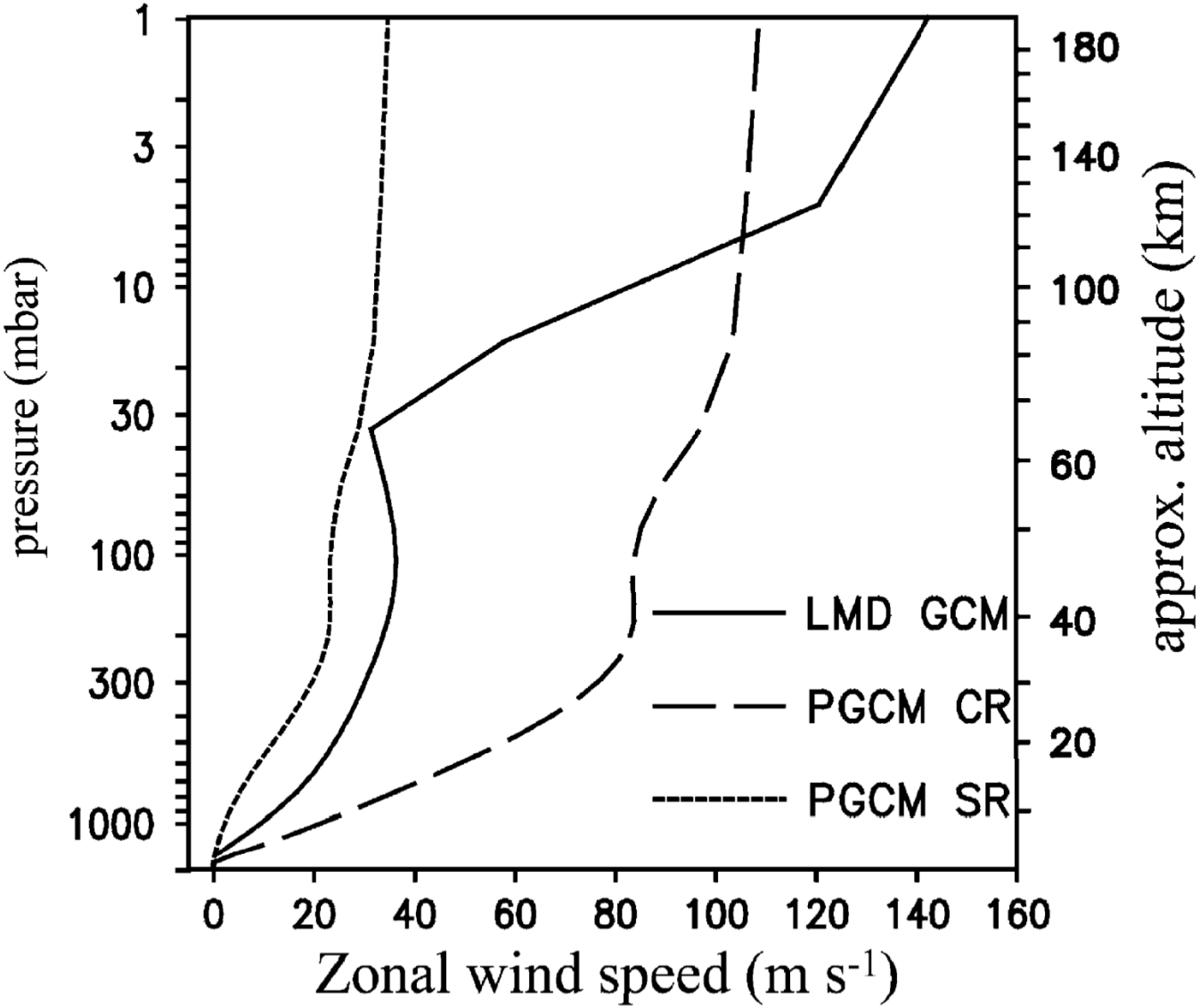




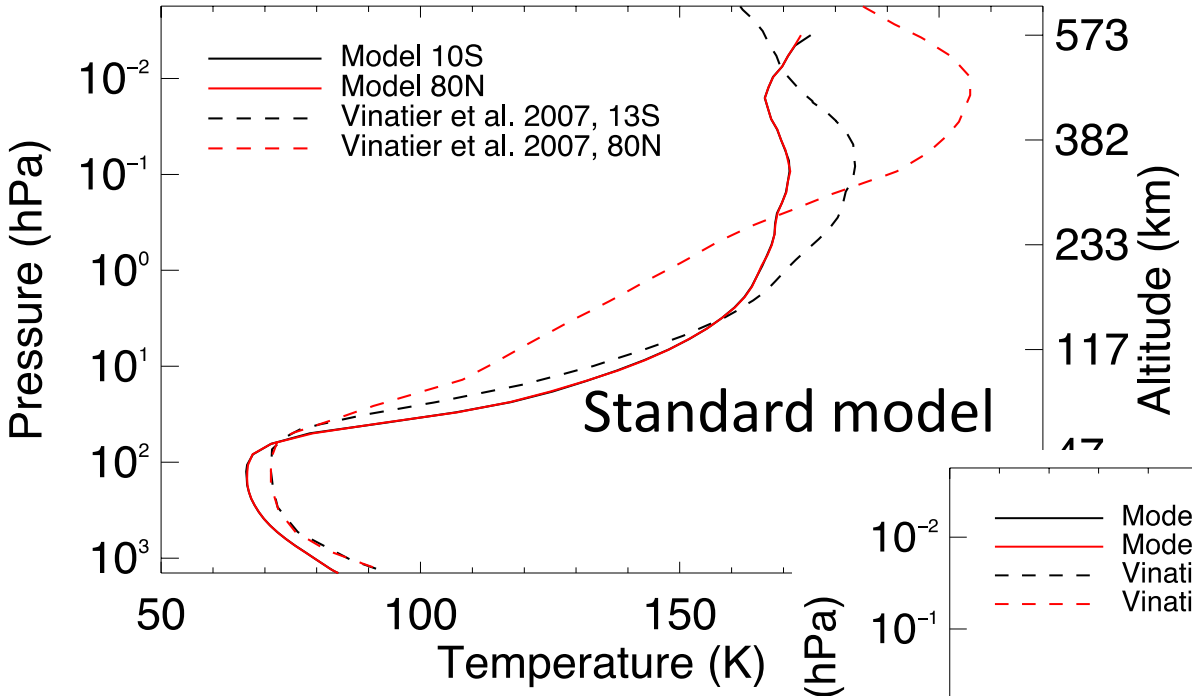


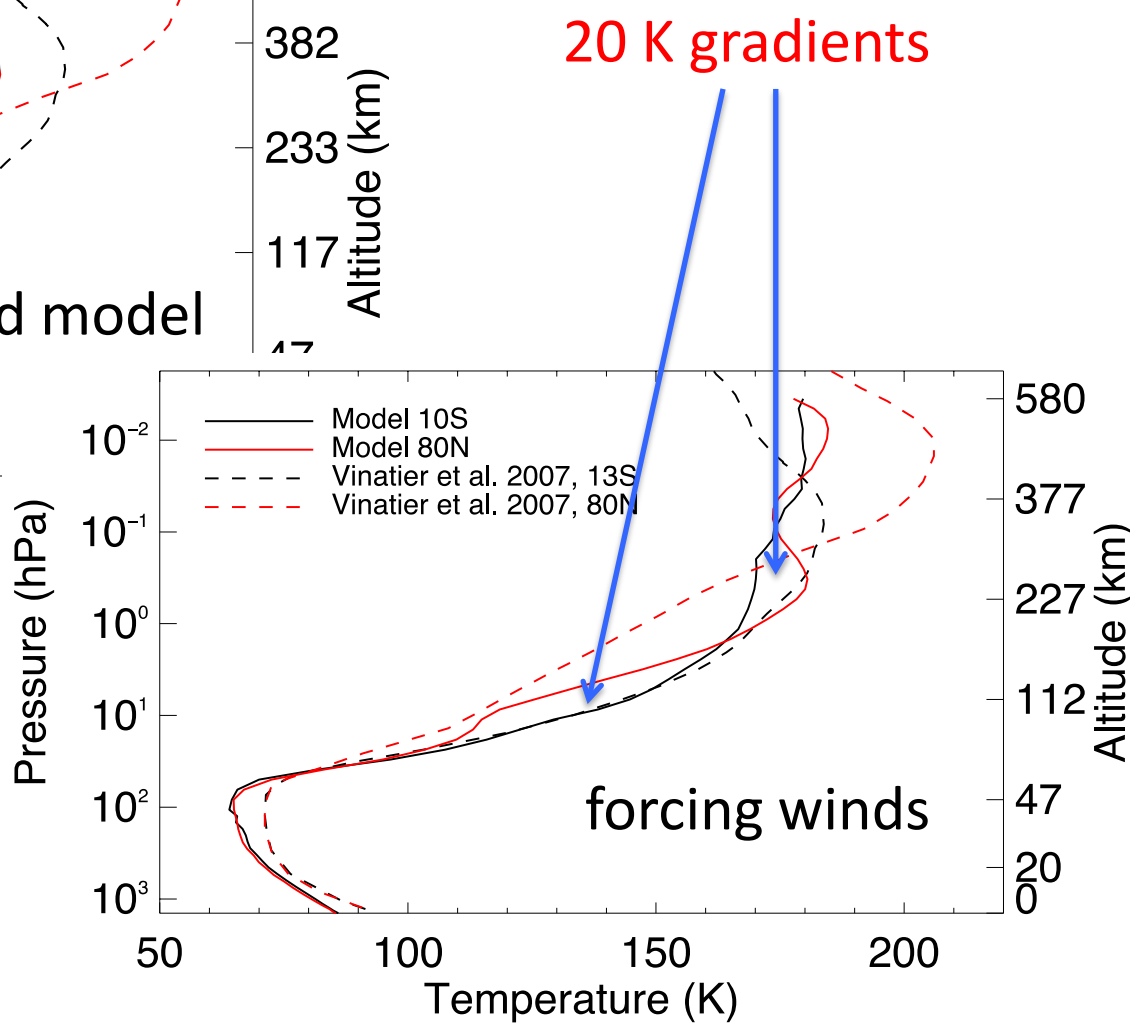
Forcing temperature induces superrotation

Liu et al. 2008
CAM2



Conversely:
Forcing the wind induces a temperature gradient





Future attempts to produce superrotation with the Titan CAM

- Limit meridional wind at top of model?
- Move to CAM5 with other dyn cores?
- Very high resolution (1x1)?

Other ideas?

Titan – slow rotator

Lack of superrotation (Friedson et al. 2008)

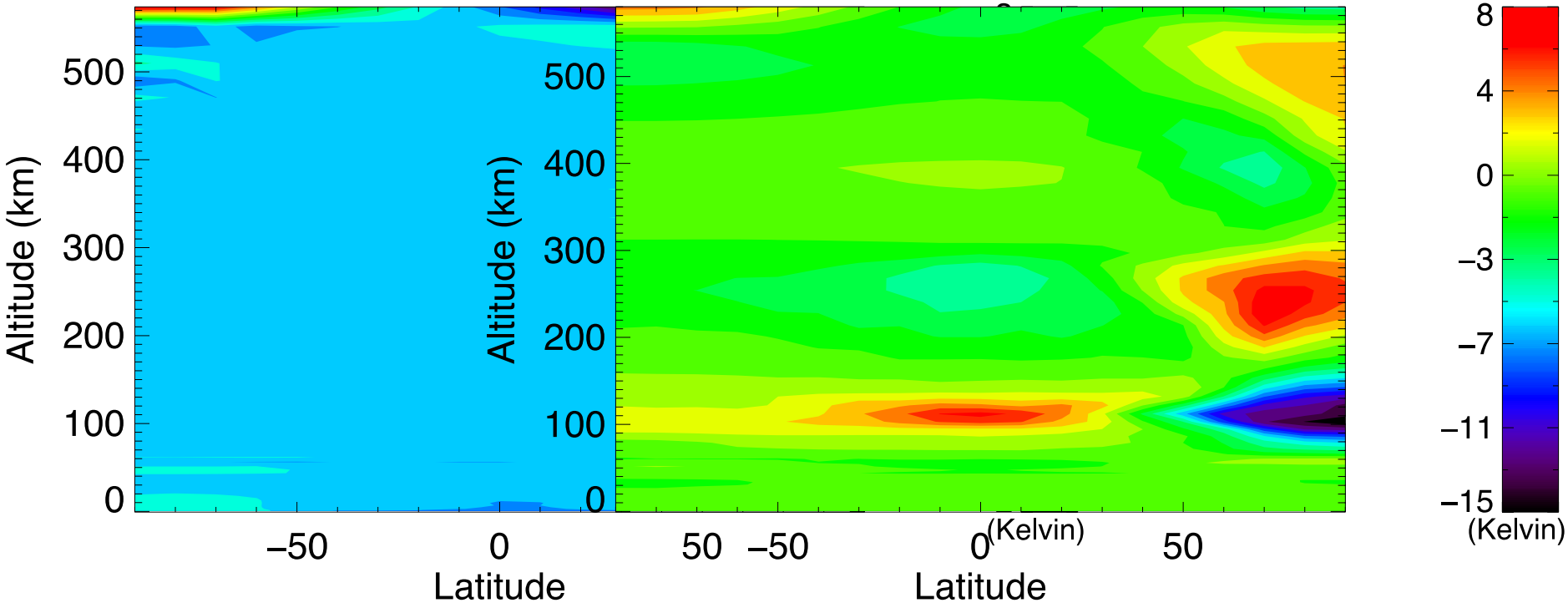
Things tried:
- aerosol forcing
- gravity wave parameterization
- surface friction
- sponge layer at the top of the model
- topography
- **artificial forcing** – allows temperature gradients to form

2 other models are able to reproduce the superrotation
- LMD
- Planet-WRF

Why not CAM3? Lebonnois et al. 2012 – CAM does not conserve angular momentum

CAM5?

Venus and Earth?


Altitude (km)
500
400
300
200
100
0
−50
0
50
Latitude
Altitude (km)
500
400
300
200
100
0
−50
0
50
Latitude
8
4
0
−3
−7
−11
−15
(Kelvin)
(Kelvin)

- By forcing the winds, we are creating a momentum barrier to the strong meridional winds at the top of our model that redistribute heat and destroy temperature gradients