TITAN'S ANNULAR MODES OF CLIMATE VARIABILITY COMPARED TO EARTH AND MARS. J. M. Battalio[1] and J. M. Lora[1], [1]Department of Earth and Planetary Sciences, Yale University, 210 Whitney Ave., New Haven, CT 06511, joseph.battalio@yale.edu

Introduction: Annular modes are zonally symmetric patterns of climatic variability that explain large percentages of the variance in zonal-mean wind, eddy activity, and precipitation on Earth [1,2]. Indications of annular modes have been shown on Mars too [3], which is expected given the similarity in their extratropical dynamics. Titan inhabits a distinct dynamical regime, where the extratropics are confined close to the poles; thus, it is not obvious that Titan should have similar annular variability. Here, we compare annular modes in the atmospheres of Earth, Mars, and Titan.

Methods: Empirical Orthogonal Function (EOF) analysis [4] defines the annular mode of the anomalous (non-seasonal) zonal-mean zonal wind ($[u]$) and eddy kinetic energy ($[EKE] = [u^{*2}+v^{*2}]/2$). Regressions of the modes onto the eddy heat flux $[v^*T^*]$ and eddy momentum flux $[u^*v^*]$ are also considered. Reanalyses are used for Mars (MACDA [5] and EMARS [6]). For Titan, a 20-Titan year simulation of the Titan Atmospheric Model (TAM) [7] is used that is re-initialized from simulations [8] using a surface hydraulic conductivity of $k=5\times10^{-5}$ m/s.

Results: Titan and Mars do indeed have annular modes of variability, just as Earth does [9]. The modes broadly share the same types of spatial structures as Earth's modes; however, the exact patterns and details elucidate differences in each world's climate.

Zonal-mean zonal wind. The annular mode in the $[u]$ for Earth is barotropic, in that the mode connects with momentum fluxes and has a vertically stacked structure. The leading (first) pattern of spatial variability is a dipole with centers of action at 70N/S and 45 N/S [1,2]. This represents the movement of the jet stream north and south. For Mars, this is also generally the case. For Titan, the annular mode in $[u]$ is also a dipole, but the centers of action are aligned vertically instead of horizontally, that is at roughly the same latitude but at 400 and 1000 hPa. This behavior reflects movement of the jet vertically, which is seen in previous simulations of Titan's climate [8]. Additionally, the amount of variance in $[u]$ explained is ~68%, compared to only 20–30% for Earth and Mars. Titan's mode associates with eddy momentum fluxes, just as on Mars and Earth, but also regresses strongly onto eddy heat fluxes, which may indicate that the jet on Titan relies on barotropic and baroclinic processes.

Zonal-mean eddy kinetic energy. The annular mode in the $[EKE]$ for Earth is baroclinic in that it links to heat fluxes but not momentum fluxes. It explains about 40% of the $[EKE]$ variance and is mono-polar, representing the intensification of the storm track [2]. Mars's $[EKE]$ mode resembles Earth's, but it does link to eddy momentum fluxes, revealing the interconnected nature of the baroclinic wave lifecycle on Mars [10]. Titan's annular $[EKE]$ mode connects to eddy and momentum fluxes and, like Mars, explains a larger percentage of $[EKE]$ variance (~40–60%). Despite the wide extent of the Hadley circulation on Titan, the $[EKE]$ mode regresses most strongly onto the EKE at the same latitudes as that of Mars and Earth (Fig. 1). However, the order of magnitude of the regression is (10^3 J/m^2)—two orders smaller than Earth's mode.

The ubiquity of annular modes demonstrates the similarities between the climates of Earth, Mars, and Titan and will inform efforts to understand the variability of dust activity on Mars and methane precipitation on Titan, among other phenomena.

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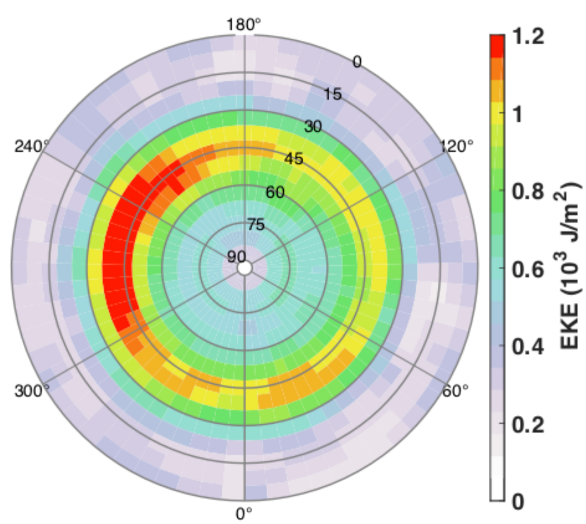

Fig 1. Annular mode in [EKE] for Titan.