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Seasonal Variations of the Hadley Cell and Differential Hemispheric Methane Release Could Drive the Seasonal Methane Cycle on Mars

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The in situ detection of methane at Gale crater by the SAM instrument suite on the MSL Curiosity rover has garnered significant attention because of the implications for the potential of indigenous Martian organisms. Background CH_4 levels in Gale exhibit a strong, repeatable seasonal variability with a mean value of 0.4 ppbv (Webster et al. 2018, W18; Figure 1). If ground temperature controls the release of CH4 on seasonal timescales then the CH4 flux should be higher during warmer seasons. Methane clathrates are one example where this mecha- nism could operate, assuming that clathrates could be preserved due to slow dissociation and diffusion rates. Temperature dependent metabolism of methanogens is another example. Our colleagues on the MSL team Christina Smith, John E. Moores et al. show in their LPSC2019 abstract #1289 that seasonal variation in TLS-SAM data can be satisfactorily replicated with a diffusive-adsorptive model if sub-surface seepage is permitted through the regolith. The Mars Regional Atmospheric Modeling System (MRAMS) is used to study what the role of atmospheric transport and mixing may play in the seasonal cycle assuming a CH_4 release similar to Mumma et al. 2009 (M09; Figure 2). This configuration provides a scenario to test how a large CH_4-enriched air mass would be transported, mixed and diffused into the topographically complex Gale region. In order to characterize changes to seasonal transport, simulations were conducted at three key seasons: Ls155, when the high CH_4 values by M09 were reported; Ls270, a wholesale inundation of the crater by external crater air season (Rafkin, Pla-Garcia et al, 2016); Ls90, representative of the rest of the year.

MRAMS Configuration

Methodology

The model is run for 12 sols. Horizontal grid spacing = 240 km. Initialization and boundary condition data are taken from a NASA Ames GCM simulation with column dust opacity driven by zonally-averaged TES retrievals. Vertical dust distribution is given by a Conrath-ν parameter that varies with season and latitude.

Vertical Grid Spacing

14.54m: First atmospheric layer	2500m: Maximum grid spacing
30m: Initial vertical grid spacing	50: Number of vertical grid points
1.12: Geometric stretch factor	51 km: Model top

Subsurface model and physics

11 soil levels with 1mm initial layer depth and 1.5m bottom layer depth	NASA Ames two-stream, correlated-k radiatioon
Initialized from NASA Ames GCM	Topographic shadowing and slope radiation effects
Subgrid-scale level 2.5 TKE parameterization	Monin-Obukhov surface layer
	CO_2 ice statically placed from GCM
	Conductive regolith model

Tracers in the model

Can be placed anywhere, and may be released instantaneously or at a user-specified, time-dependent rate. Tracers are not radiatively active and do not contribute to the tendency of any model prognostic variables.

Motivation

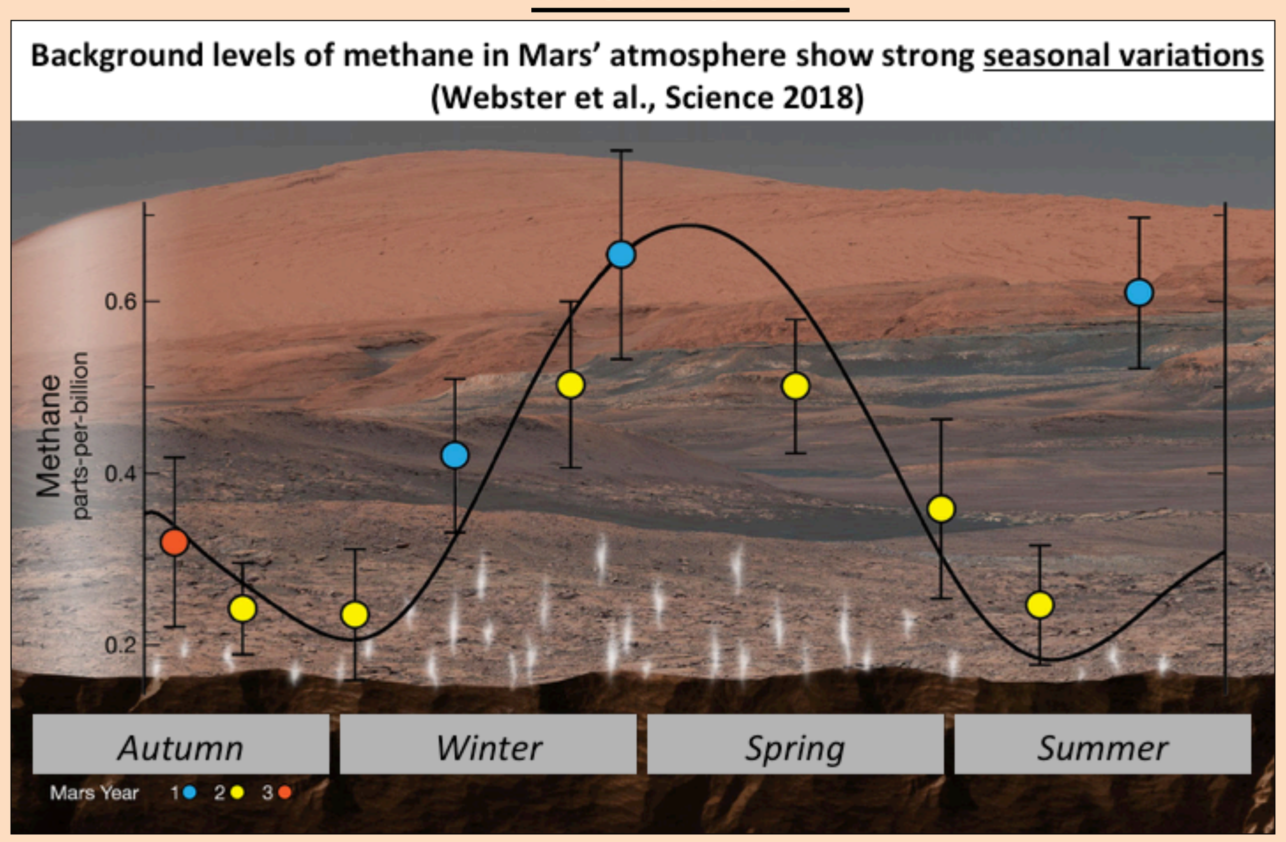

Figure 1. MSL-SAM detected seasonal changes in atmospheric CH_4 in Gale crater. The CH_4 signal has been observed for nearly three Martian years (nearly six Earth years), peaking each southern winter.

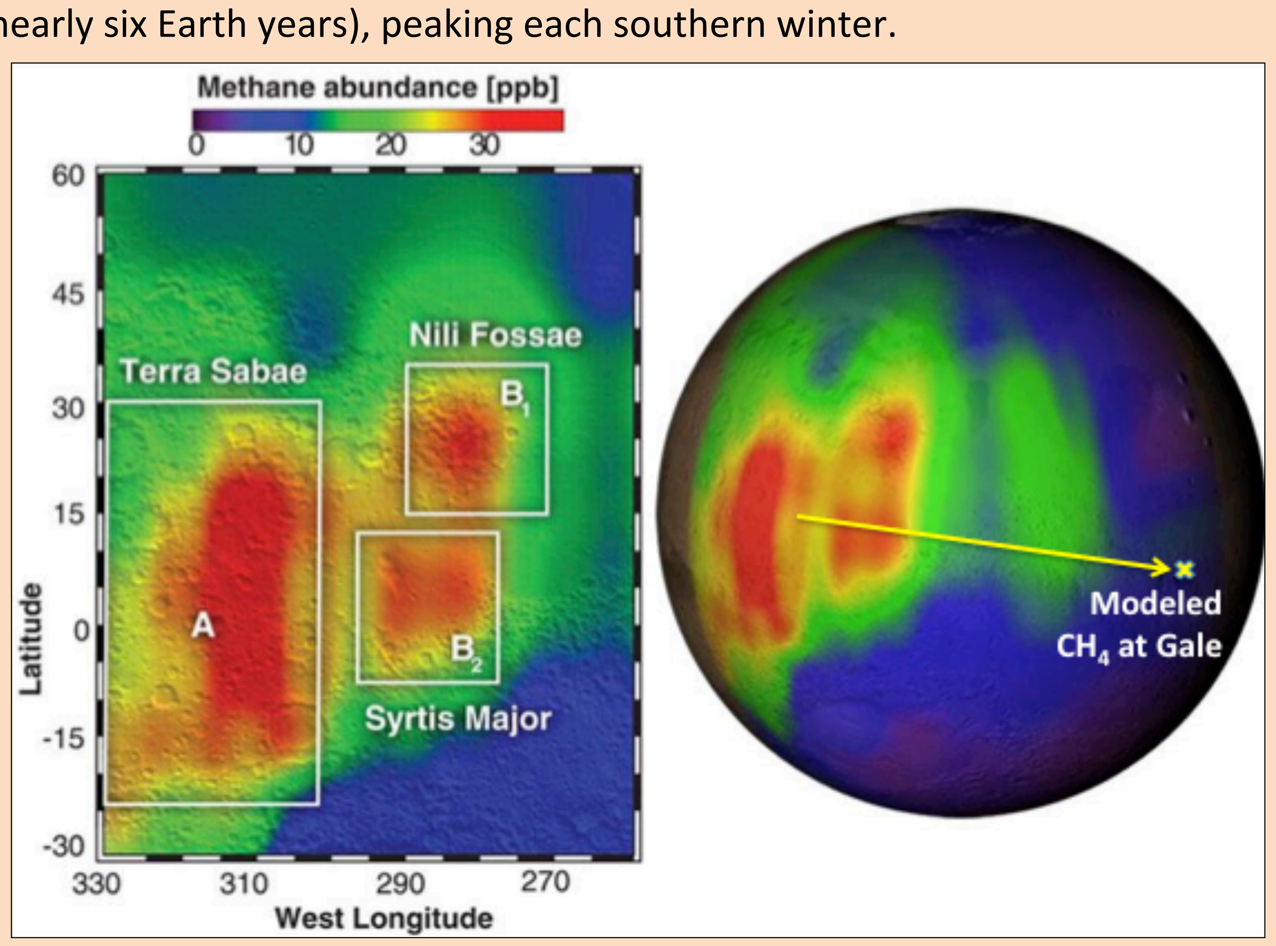

Figure 2. MRAMS large area (~900,000 km2) steady methane release emission based on theoretical estimates from clathrate [Gloesener et al. 2017]. ($1.8x10^{-6}$ kg m^{-2} s^{-1}) at M09 area for **Ls 155**. Adapted from M09.

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Results

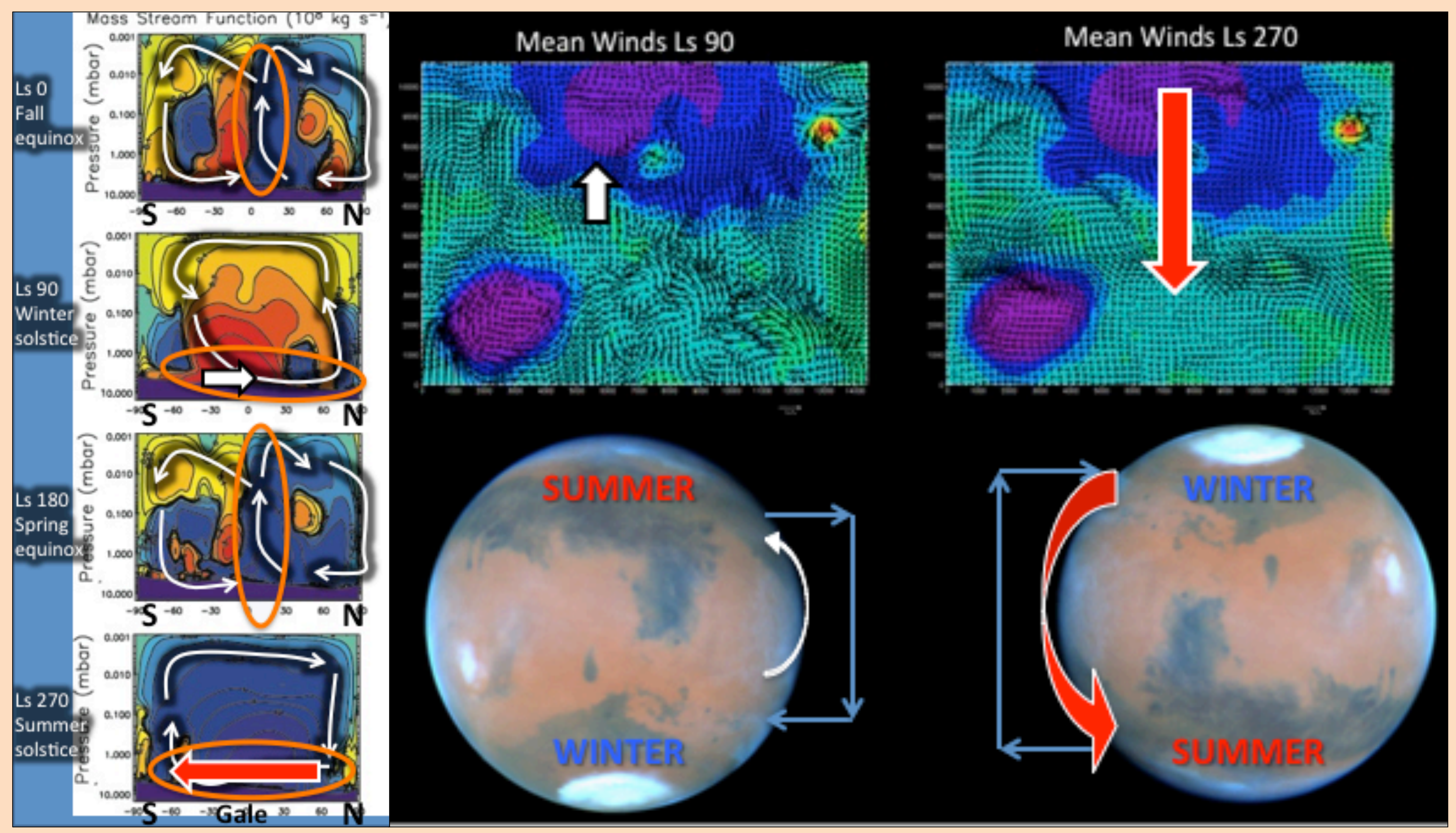


Figure 3. The seasonal wind regime allows for strong and deep transport of air from the northern high latitudes around Ls 270. At other seasons, the transport is more localized. Adapted from Rafkin, Pla-Garcia et al. 2016.

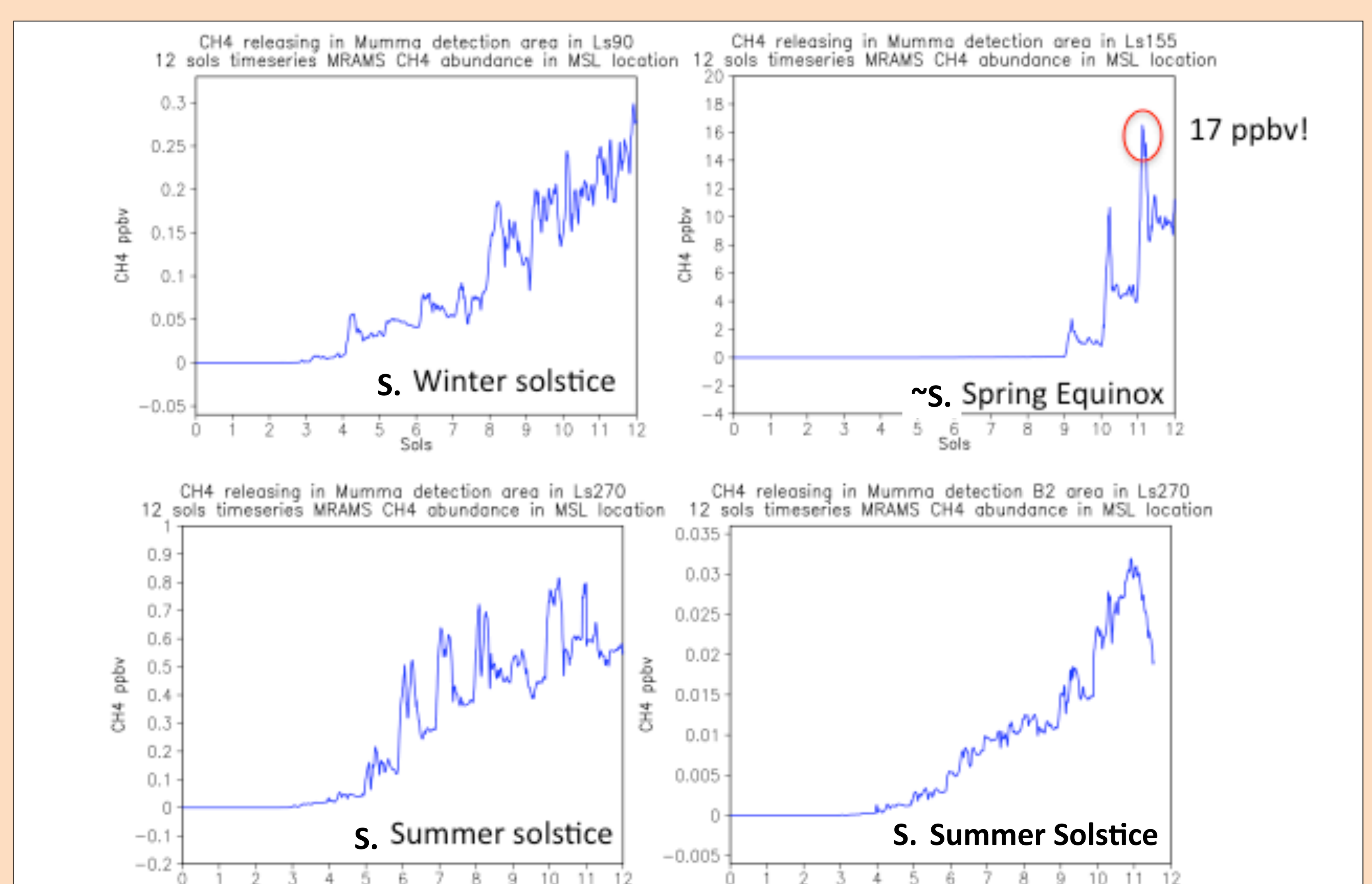
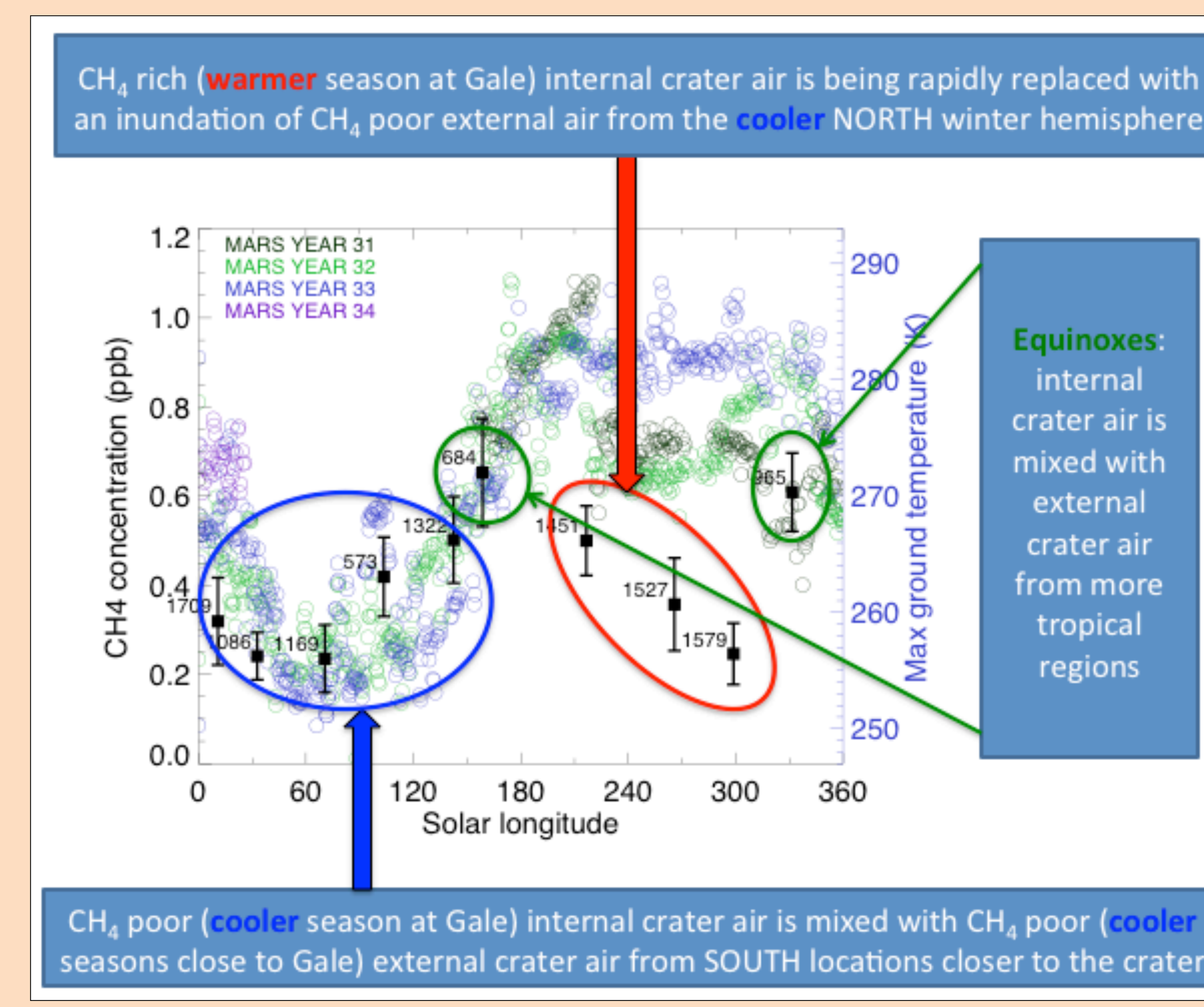


Figure 4: Twelve-sol timeseries of MRAMS methane abundances sampled at the MSL Curiosity rover location for a steady-state methane emission scenario corresponding to the M09 detection (Fig. 2) at Ls 90 (top left), Ls 270 (bottom left), Ls270 over a M09 limited area (B2) (bottom right) and Ls 155 (top right). M09 emission area is > 3,000 km away from Gale. Ls155 has the highest CH_4 values compared to other MRAMS scenarios because is approaching to the spring equinoctial global wind period.

¡Around the equinoxes, the rising branch quickly crosses from one hemisphere into the other with individual Hadley cells in each hemisphere and surface winds at the tropical location of Gale that could converge (Fig. 3, left), containing and circulating CH_4-rich air from M09 release area (Fig. 2) in the intertropical zone increasing the background CH_4 levels, as reported in W18 (Fig. 4).

In contrast to equinoxes, the mean meridional winds are northerly at Ls270 and southerly at Ls90 with no large-scale convergence of air in the tropics (Fig. 3, left and right). Furthermore, the source of the air at Gale at Ls270 is found to be from deep within the cold northern high latitudes. The source air at Ls90 emanates from more modest latitudes of the SH with properties similar to those in Gale.

Conclusions



The seasonal change in the global circulation combined with seasonal changes in the hemispheric release of CH_4 could produce a seasonal CH_4 signal at Gale.

If there is a correlation between CH_4 release and ground temperature, then one would expect a strong correlation between the local atmospheric CH_4 value and the ground temperature in the absence of any transport.

This is what was noted by W18, except during **Ls216-298**, when very high latitude northerly air penetrates into Gale. Thus, **the air in Gale during this season would be more representative of a source air mass deep in the NH where it is cold and depleted in CH_4.** In contrast, the source air in Gale at other seasons is more tropical in nature, because the general circulation does not transport air from deep in the southern high latitudes.