Towards assimilation of ExoMars TGO ACS observations into the LMD Mars GCM

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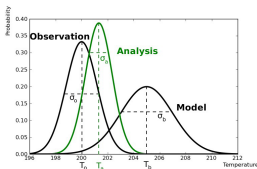
[*] and Earth, Planetary and Space Sciences, UCLA

From Mars Express to ExoMars, ESAC, 28 February 2018

LMD data assimilation scheme for Mars

Data assimilation in principle:
An optimal blend of observations and model

$$\frac{1}{\sigma_a^2} = \frac{1}{\sigma_b^2} + \frac{1}{\sigma_o^2}$$

$$T_a = T_b + \frac{\sigma_b^2}{\sigma_b^2 + \sigma_o^2}(T_o - T_b)$$

LMD scheme in practice:

Local: Using observations local to each grid point avoids projecting spurious correlations to large distances, and makes computation practical.
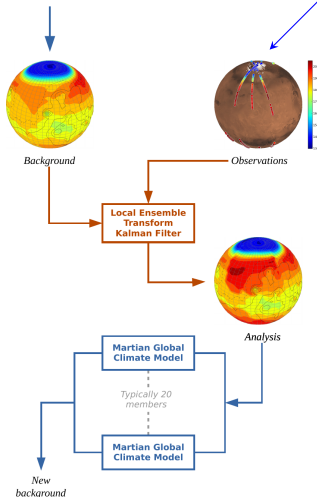**E**nsemble: Analysis, background, and their uncertainties are represented by mean and spread of values in an ensemble of model runs.
Transform: Model error covariance projected onto ensemble members.
Kalman: Optimal linear combination of observations and background, assuming Gaussian uncertainties.
Filter: Uses information from past to infer state at present.

[Navarro, 2016, +2017]

LMD Global Climate Model for Mars

Background

Observations

Local Ensemble Transform Kalman Filter

Analysis

Martian Global Climate Model

Typically 20 members

Martian Global Climate Model

New background

Scheme has used **Mars Climate Sounder** temperature, dust, water ice profiles up to now.
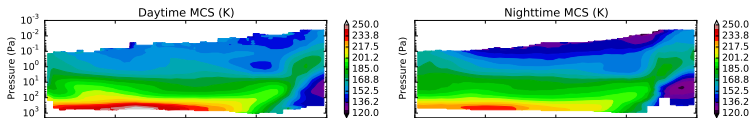
Always: $T \rightarrow T$
$T \rightarrow p_s, u, v$

Optional:
$T, q_{\text{dust}} \rightarrow q_{\text{dust}}$
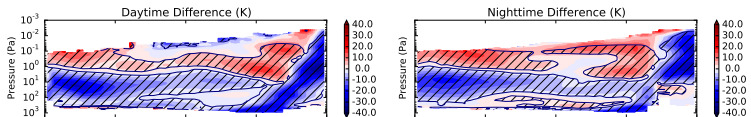$q_{\text{ice}} \rightarrow q_{\text{ice}}, q_{\text{vap}}$

Optimal (current):
$T \rightarrow T, q_{\text{dust}}$
No $q_{\text{ice}}, q_{\text{vap}}$
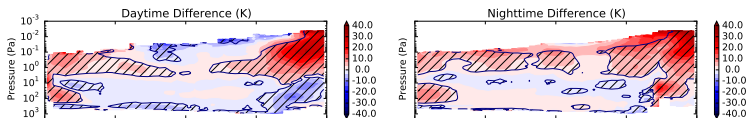
Temperature analyses vs. MCS, MY29 $L_s = 310 - 315$
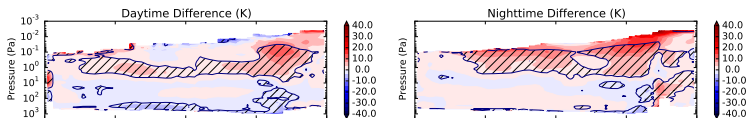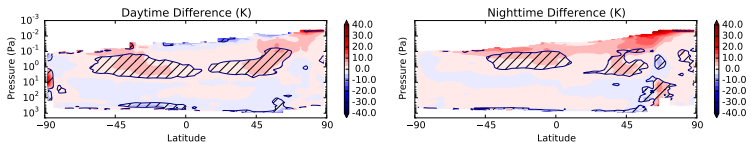
MCS 5-L_s binned observations

Free run No assimilation

T assimilation $<60°$ lat only 6 hour cycle

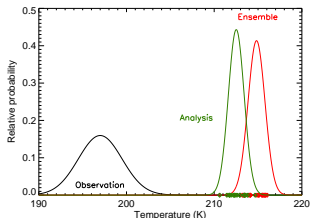T assimilation all latitudes 6 hour cycle

T assimilation all latitudes 3 hour cycle

Challenges for Mars ensemble-based data assimilation

Ensemble, observations diverge as ensemble converges (unlike Earth)

## Dust / water ice hard to assimilate with temperature: all are inter-dependent

→ Observed q_{dust}, q_{ice} can easily fall outside ensemble when obs or whole ensemble = 0.
→ Ensemble aerosol uncertainty distributions are non-Gaussian.
→ Observed dust structures may not be reproducible by model, so forecast step removes them.

→ Water ice needs model-consistent dust concentration as condensation nuclei, otherwise forecast step will adjust one or the other.
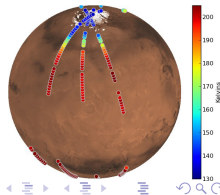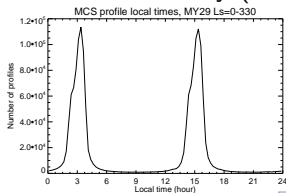→ Direction of causality connecting changes in water ice and temperature is ambiguous.
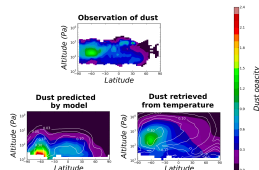
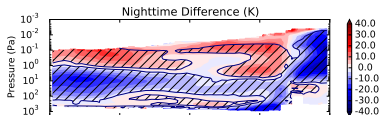## Ensemble, observations diverge quickly once assimilation stops
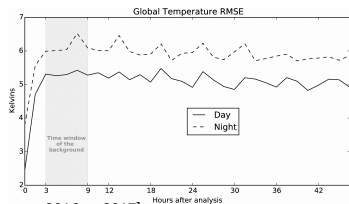
Observations always at same local time of day (until TGO): 3h, 15h
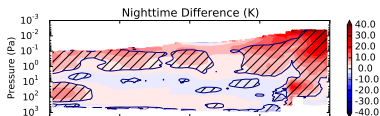

[Navarro, 2016, +2017]

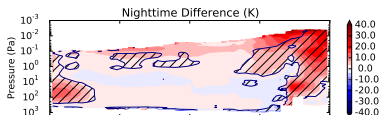# Effect of assimilation cycle length on temperature
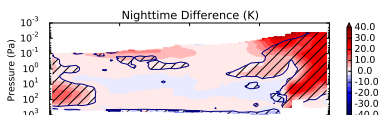
Free run
No assimilation

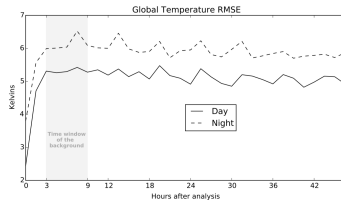6 hour cycle

3 hour cycle

2 hour cycle
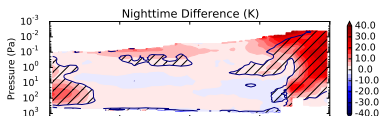
1 hour cycle

(NB: all $<60^{\circ}$ lat only)

Nighttime Difference (K)

Forecast error after 2 sols

[Navarro et al., 2017]

Zhao et al. (2015): Cycle
<6 hours removes spurious
forcing of semidiurnal tide

Error statistics stay closer
to linear growth and so
may remain Gaussian

Towards assimilation of ACS data

Thermal infrared channel (TIRVIM). Retrievals at LMD by Sandrine Guerlet.
Initially: Atmospheric temperature profiles
Potentially: Surface temperatures, column dust opacity, column ice opacity

Coverage vs MCS:

MCS 1-sol coverage

MCS 7-sol coverage

ACS 1-sol coverage

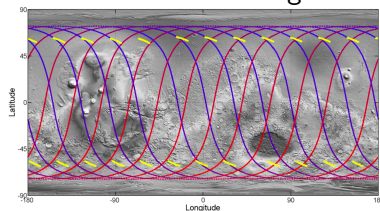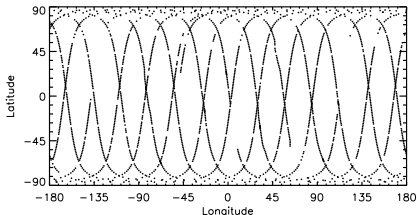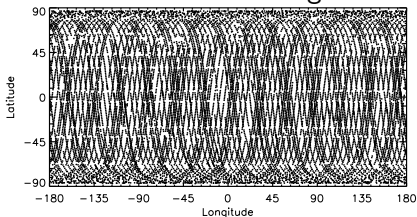ACS 7-sol coverage

[Korablev et al., 2018]

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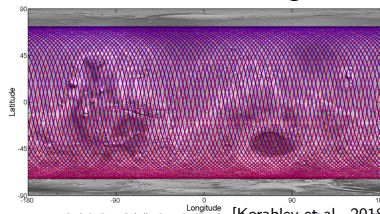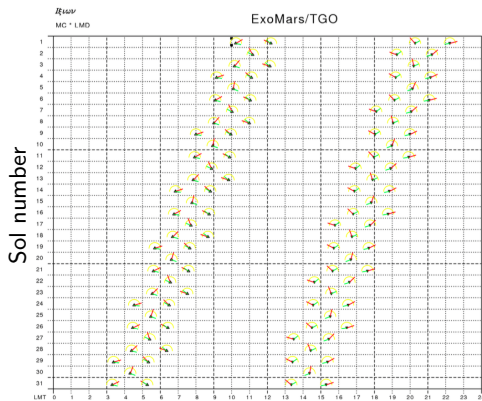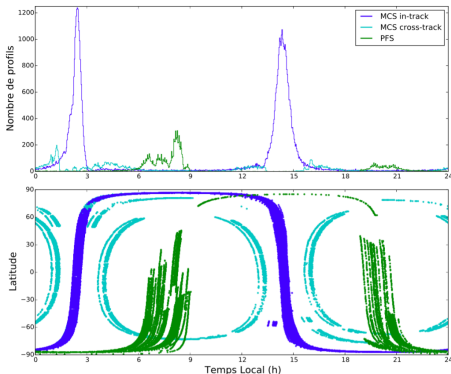Potentially: Surface temperatures, column dust opacity, column ice opacity
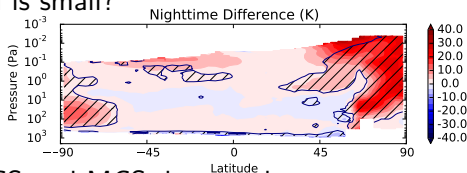
Local times vs MCS:

MCS/PFS local times   ACS local times at 45°N / 0°E

Local time   [Navarro, 2016]

Steps towards and beyond ACS assimilation

- Integrate ACS temperature retrievals into current scheme
- Test pipeline using synthetic observations and/or observations taken during aerobraking
- How can we make the assimilation trust observations over model when ensemble spread is small?
- Add surface temperature to assimilated quantities — should not have problems we have with dust/water ice

Nighttime Difference (K)

- Joint assimilation of both ACS and MCS data at the same time (needs protocol for removing inconsistent data)
- Incorporate ACS dust and ice retrievals
- Extend to other datasets (anything, in principle)

One intriguing question whose answer I would like to know:

> What will we learn about Mars' atmosphere by assimilating the full range of local times?

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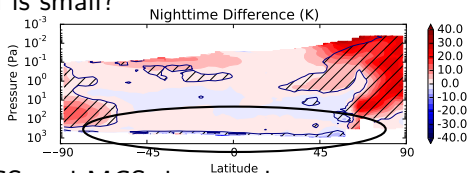- Extend to other datasets (anything, in principle)

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