DATA ASSIMILATION INSIGHTS ON SELECTING THE MOST VALUABLE ATMOSPHERIC MEASUREMENTS. S. J. Greybush[1], T. H. McConnochie[1], L. Montabone[2,3], R. J. Wilson[4], M. J. Hoffman[5], R. Hoffman[6], F. Forget[2], S. R. Lewis[7], T. Miyoshi[1], K. Ide[1], E. Kalnay[1]
[1]University of Maryland, College Park, MD [2]LMD, Paris, France [3]University of Oxford, Oxford, UK, [4]GFDL, Princeton, NJ [5]RIT, Rochester, NY [6]AER, Lexington, MA. [7]Open University, Milton Keynes, UK.

Introduction: We discuss how objective guidance on selecting the most valuable atmospheric measurements on future Mars spacecraft missions can be provided through already developed Martian atmospheric data assimilation systems (e. g. [1], [2], [3], [4]), and in particular through Observing System Simulation Experiments (OSSEs) which are widely used to design instruments for the Earth's atmosphere.

Data Assimilation: The study of the Martian atmosphere, including the general circulation, the carbon dioxide cycle, and the impact of dust storms and other aerosol processes are critical not only to advance scientific understanding of planetary atmospheres, but to provide estimates of atmospheric density, winds, opacity, and their uncertainties necessary to support spacecraft aerobraking; entry, descent, and landing (EDL); and surface mission planning and operations. Atmospheric reanalyses, e.g. [1], [3], which use data assimilation to combine sparse spacecraft observations with atmospheric dynamics and physics embodied in general circulation models, provide dynamically consistent four dimensional fields of temperatures, densities, winds, and dust. Mars atmosphere reanalyses can, for example, estimate the temperatures and densites along an EDL trajectory with greater accuracy than a "free run" (i.e. absent assimilated data) general circulation model [5]. Assimilation systems also enable the generation of near real time forecast fields through numerical weather prediction (NWP).

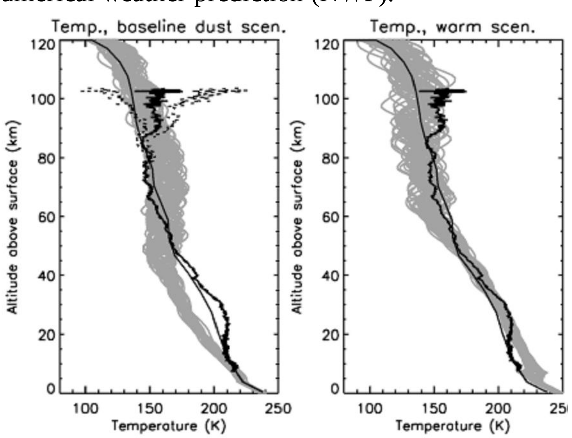

Figure 1: Temperature profiles retrieved from Spirit's accerometer (thick dark line), UK assimilation (thin dark line), and the Mars Climate Database (gray lines). Adapated from [5].

OSSEs: Future spacecraft missions have great potential to advance atmospheric science and improve atmospheric models and reanalyses, and hence guidance for spacecraft operations. However, with limited missions to Mars, with limited manifests, choices must be made. Data assimilation provides an objective technique to assess the impact of proposed observation systems on forecast quality and/or the ability to constrain critical parameters such as dust lifting theshholds and the sources and sinks of atmospheric constituents. Observing system simulation experiments (OSSEs, e.g. [7], [8], [9]) have been used for decades in terrestrial applications to help select new earth observing instruments, and should also have great value for the Mars community. Such capabilities are already available for Mars [2].

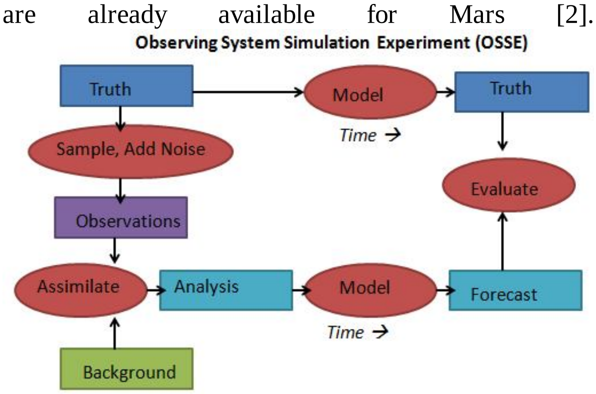

Figure 2: Schematic of an OSSE.

In OSSE experiments, a model simulation is used to represent the true atmospheric state and observations are created from this model run. These synthetic observations are then assimilated to estimate the true state. Within the OSSE framework, the expected output from prospective observing platforms or instruments can be simulated and, because the truth is known, detailed diagnostics of the system performance can be computed to evaluate the impact of the new observations on the atmospheric state estimate. These can be used, for example, to compare the impact of a set observations for constraining modeled climatology or improving the forecast quality of operationally important quanitites such as winds, densities, and opacities. The set of observations in question could be, to name some examples, surface pressure measured by one or more landers, orbital soundings of temperature and dust profiles, or remotely sensed winds.

Working hypotheses regarding highest impact atmospheric measurements: Although we have not yet undertaken any formal OSSEs that address possible future measurements, our extensive experience with Mars data assimilation provides some insight into the general types of measurement that will have the highest impact on advancing science. The most critical unsolved problem in Martian meteorology is the initiation and evolution of dust storms, and predictability is diminished by rapidly evolving dust activity [9]. Aerosol fields also have a large impact on atmospheric temperature and heating in the upper atmosphere. A second important measurement is atmospheric winds, particularly in the tropics (where they are not well constrained by temperatures), and near the surface where wind stress result in dust lifting. Finally, surface pressure observations provide information on the entire vertical column, revealing the passage of the semidiurnal tide, which relates to globally integrated thermal forcing, as well as traveling weather systems that are linked to dust storm initiation, and provide constraints for the seasonal CO2 cycle. The spatial coverage and long time series of temperature and aerosol opacity data from spacecraft (TES [10] and MCS [11] instruments, among others) have enabled great advances in our understanding of Martian weather and climate and form the backbone of Mars NWP. Our modeling experience suggests that these data may be well complemented by new measurement types, and our capability for OSSEs can help quantify their impact.

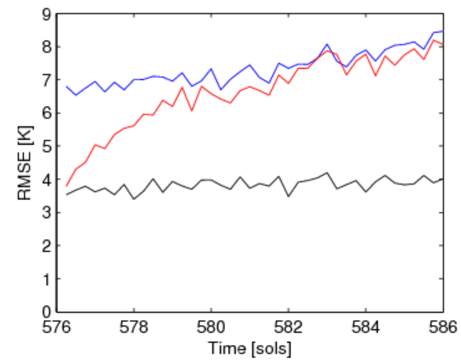

Figure 3: Global mean RMSE [K] to TES observations from a freely running model (blue), atmospheric reanalysis (black), and forecast initialized from a reanalysis (red) using an ensemble data assimilation system [3], demonstrating the capability for Mars numerical weather prediction.

References:

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