ATMOSPHERIC MARTIAN DATA ANALYSIS AND SIMULATIONS

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Exomars Atmospheric Science and Missions Workshop, 26.-30.3.2017, Saariselkä, Finland

UCM Martian Studies

Luis Vázquez, Francisco Valero, Pilar Romero, María Luisa Martín, María Pilar Velasco, Salvador Jiménez, Carlos Aguirre, Raquel Caro-Carretero, Gonzalo Barderas, David Usero, Germán Martínez, Ignacio M. Llorente, José Luis Vázquez-Poletti, Pedro Pascual, Álvaro Vicente-Retortillo, María Ramirez-Nicolás

Sociedad Española de Matemática Aplicada (SEMA) n. 14, January 2017.

PLATAFORMA TECNOLÓGICA AEROESPACIAL ESPAÑOLA

http://www.plataforma-aeroespacial.org/

Outline

- ***The Cloud Computing Environment.***
- ***The Solar Radiation and Atmospheric Dust.***
- ***Fractional Calculus Modelling.***
- ***Data Analysis: Tomographic Approach.***
- ***Sensor Multivariate Analysis.***

Outline

From the known…

Weather Research & Forecasting Model

… to the less known

Dust devil tomography*

Radiation diffusion through fractional calculus**,***

Sensor multivariate statistical analysis*

* Identification of events very localized in space and/or in time (dust devils, electromagnetic fluctuations).

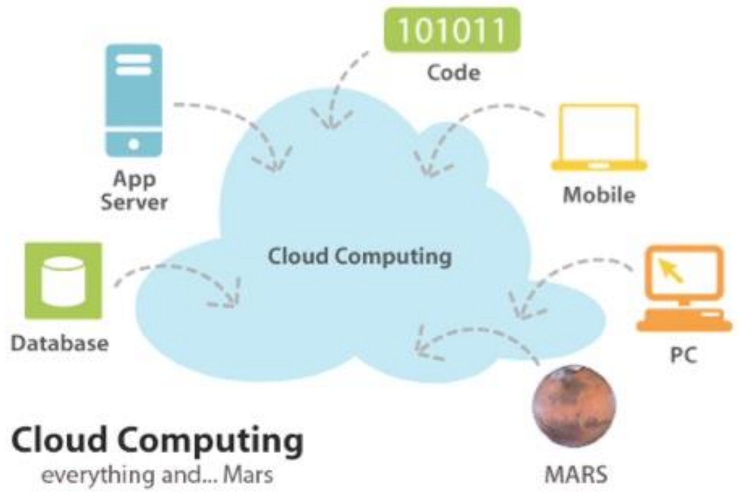
** Propagation of solar radiation in the Martian atmosphere.

*** Dynamics of the atmospheric dust.

Cloud Computing-I

Seamless paradigm that allows **provision of computing resources**

dynamic / elastic / on-demand



Public cloud infrastructures ("pay as you go" basis) represent a valid alternative to in-house solutions in many situations

Main problem is:

How many resources? What type?

Performance? Cost?

Cloud Computing-II

Cloud Computing

- Seamless computing provision paradigm
- Allows application porting to distributed architectures in short time

"The infrastructure adapts to the application, not the application to the infrastructure."

However…

- Public cloud infrastructures provide many offerings (setups, prices)
- A valid strategy per application is needed (profile ➔ model)

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Using Computing Clouds for Martian applications

1. Study the applications (execution profile, requisites)
2. Port application to generic cloud infrastructure
3. Optimize provisioning (small experiments and model)

The Martian Group Studies at UCM started with the participation in the MetNet Project (Russia, Finland and Spain), covering modelling, algorithms and computation.

Harri, A.-M., Pichkadze, K., Zeleny, L., Vazquez, L., Schmidt, W., Alexashkin, S., Korablev, O., Guerrero, H., Heilimo, J., Uspensky, M., Finchenko, V., Linkin, V., Arruego, I., Genzer, M., Lipatov, A., Polkko, J., Paton, M., Savijärvi, H., Haukka, H., Siili, T., Khovanskov, V., Ostesko, B., Poroshin, A., Michelena-Diaz, M., Siikonen, T., Palin, M., Vorontsov, V., Polyakov, A., Valero, F., Kemppinen, O., Leinonen, J., and Romero, P.: *The MetNet vehicle: A lander to deploy environmental stations for local and global investigations of Mars*, **Geosci. Instrum. Method. Data Syst. Discuss.**, 6, 103-124 (2017).

J.L. Vázquez-Poletti, G. Barderas, I.M. Llorente and P. Romero: *A Model for Efficient Onboard Actualization of an Instrumental Cyclogram for the Mars MetNet Mission on a Public Cloud Infrastructure*. **PARA2010: State of the Art in Scientific and Parallel Computing**, Reykjavík (Iceland), June 2010. Proceedings published in Lecture Notes in Computer Science (LNCS). Volume 7133, pp. 33-42, 2012. Springer Verlag.

P. Romero, G. Barderas, J.L. Vázquez-Poletti and I.M. Llorente: *Chronogram to detect Phobos Eclipses on Mars with the MetNet Precursor Lander*. **Planetary and Space Science**, vol. 59, n. 13, 2011, pp. 1542-1550.

G. Barderas, P. Romero, L. Vázquez, J.L. Vázquez-Poletti and I.M. Llorente: *Opportunities to observe solar eclipses by Phobos with the Mars Science Laboratory*. **Monthly Notices of the Royal Astronomical Society**, Volume 426, Number 4, pp. 3195–3200, 2012. Wiley.

A.-M. Harri, W. Schmidt, P. Romero, L. Vázquez, G. Barderas, O. Kemppinen, C. Aguirre, J.L. Vázquez-Poletti, I.M. Llorente and H. Haukka: *Phobos Eclipse Detection on Mars, Theory and Practice*. **Finnish Meteorological Institute Research Report 2012:2**, Finland, 2012.

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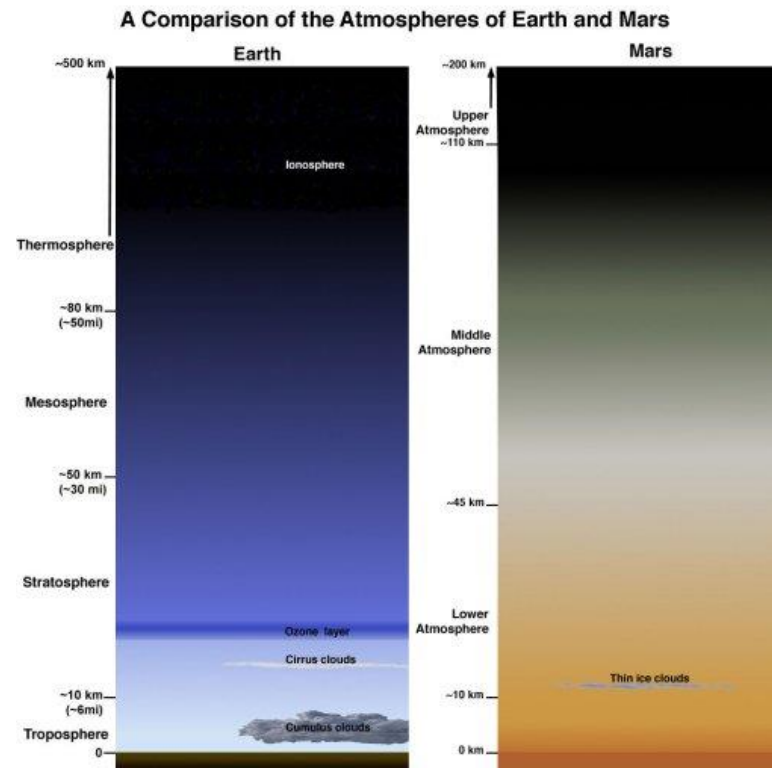
Martian Meteorology

Starting point

- Need of a Martian meteorological model

Computational workplan

- Cost optimization of terrestrial meteorological models
    - Will apply to Martian models later
- Validation of proposed Martian models
    - Huge amount of data process



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WRF

Weather Research & Forecasting Model

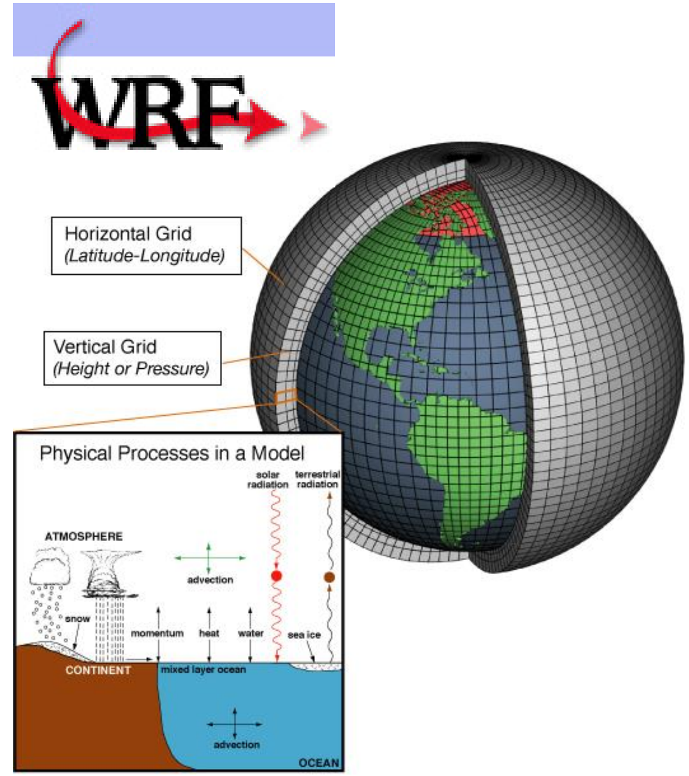
- portable, flexible, and state-of-the-art code, especially efficient when executed in a massively parallel computing environment
- various physics options and can be used in a broad spectrum of applications across scales, ranging from meters to thousands of kilometers
- currently used in many worldwide meteorological agencies and adopted by a huge community of users (over 20,000 in over 130 countries)

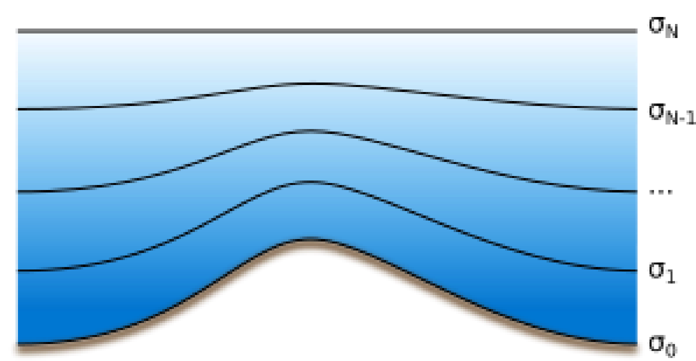
Numeric mesoscale:

- uses mathematical models to predict the weather on current conditions
- divides the atmosphere vertically

Chosen compiling options:

- Distributed Memory
- Message Passing Interface (MPI)





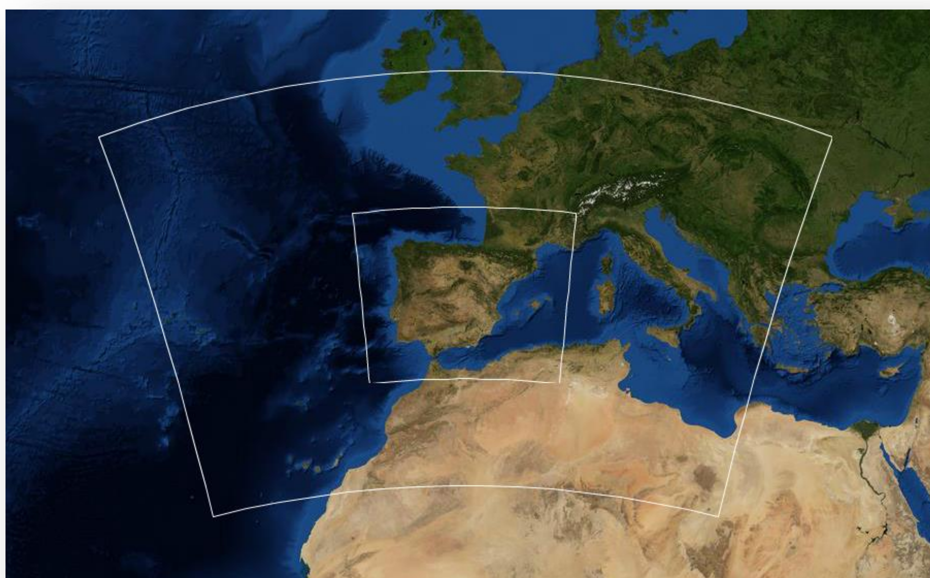
WRF

Target area for study:

- Iberian Peninsula
- resolution: 5x5 km (horizontal) and 28 levels (vertical)
- 301x250 grid mesh
- 48-hour forecast horizon

Data models:

- **GFS**-NCEP**:** free data, sometimes imprecise, 2 level computation
- IFS-**ECMWF:** restricted access data, 1 level computation
    - **$207,002.19/year** (for target area)



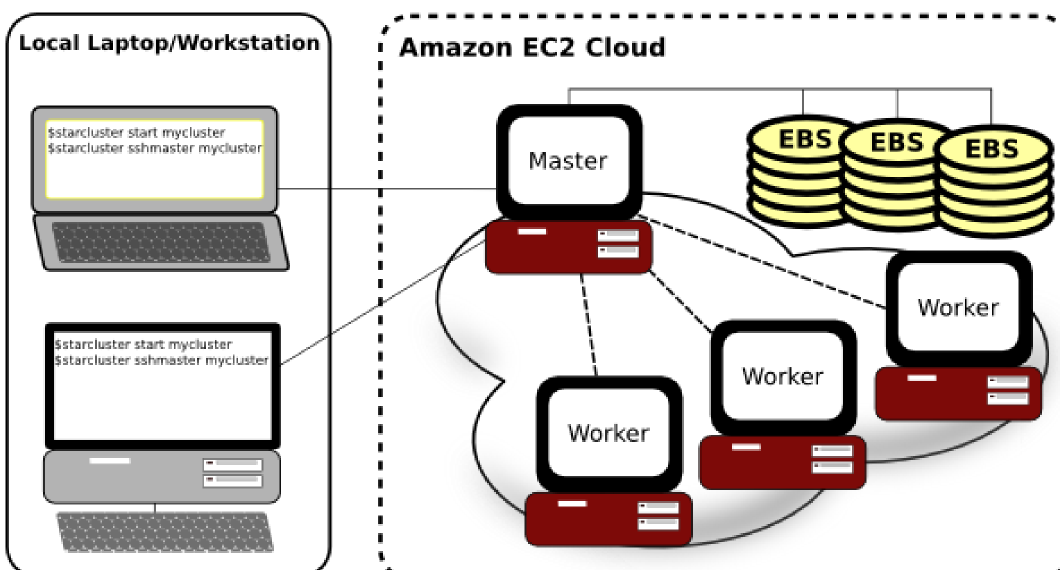
WRF on Cloud

Execution of WRF is a typical HPC problem

- Different technologies have been used (multi-core to GPU)
- (Public) cloud computing infrastructures have not been studied before

Cloud Infrastructure

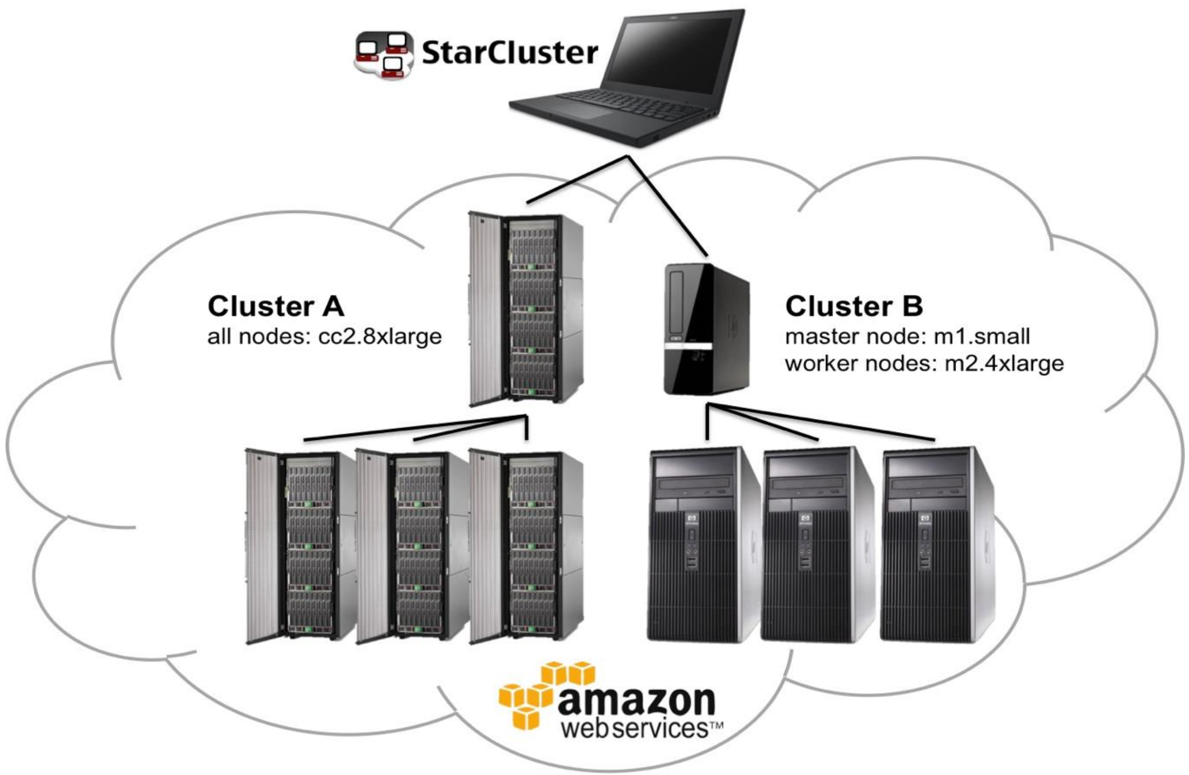
- **IaaS:** Amazon EC2
  - great instance type offering
- **PaaS:** StarCluster
  - allows the automation and simplification of the building, configuration and management of computing clusters deployed on Amazon EC2



WRF on Cloud

Amazon EC2 Machines:

Type	Family	vCPU	ECU	Memory (GB)	Storage (GB)	Network Performance	Cost ($)
m1.small	General	1	1	1.7	1 x 160	Low	0.60
cc2.8xlarge	Compute Optimized	32	88	60.5	4 x 840	10 Gigabit	2.40
m2.4xlarge	Memory Optimized	8	26	68.4	2 x 840	High	3.50



WRF on Cloud

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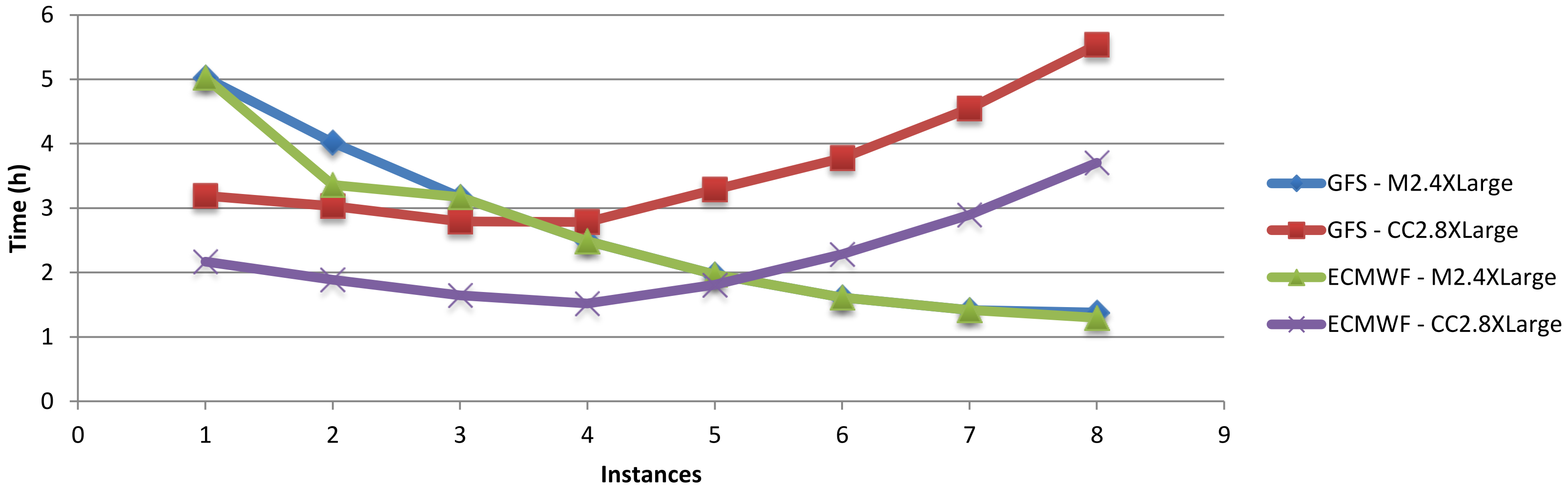
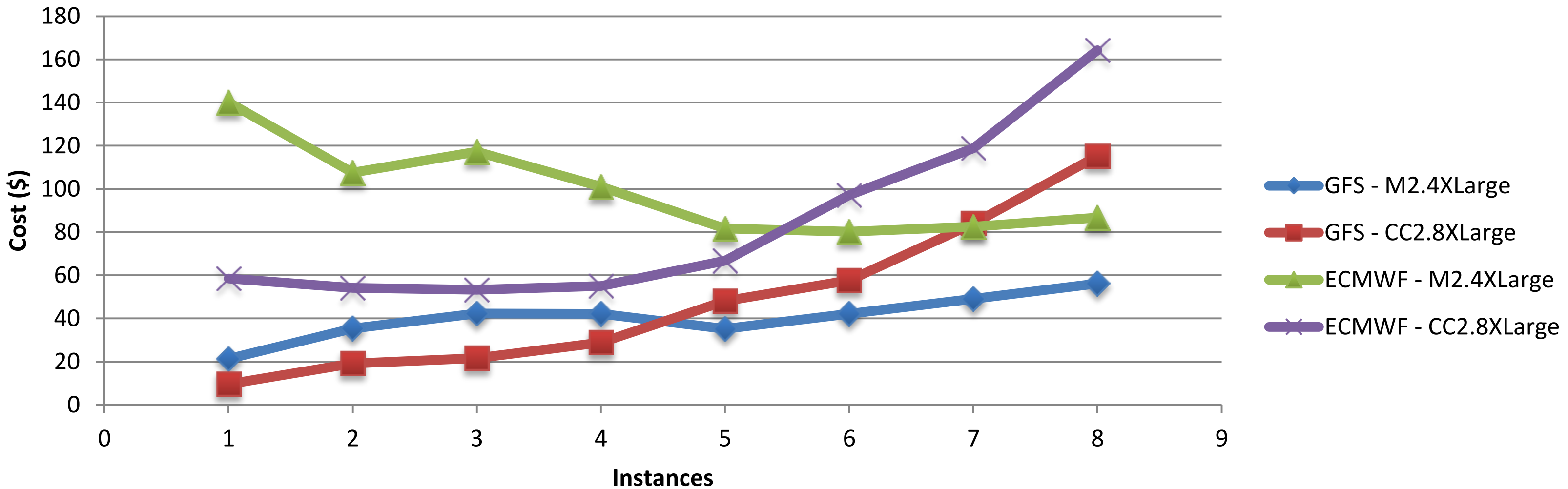
Experimental results

GFS: free data, sometimes imprecise, 2 level computation

ECMWF: restricted access data ($23.61/h), 1 level computation





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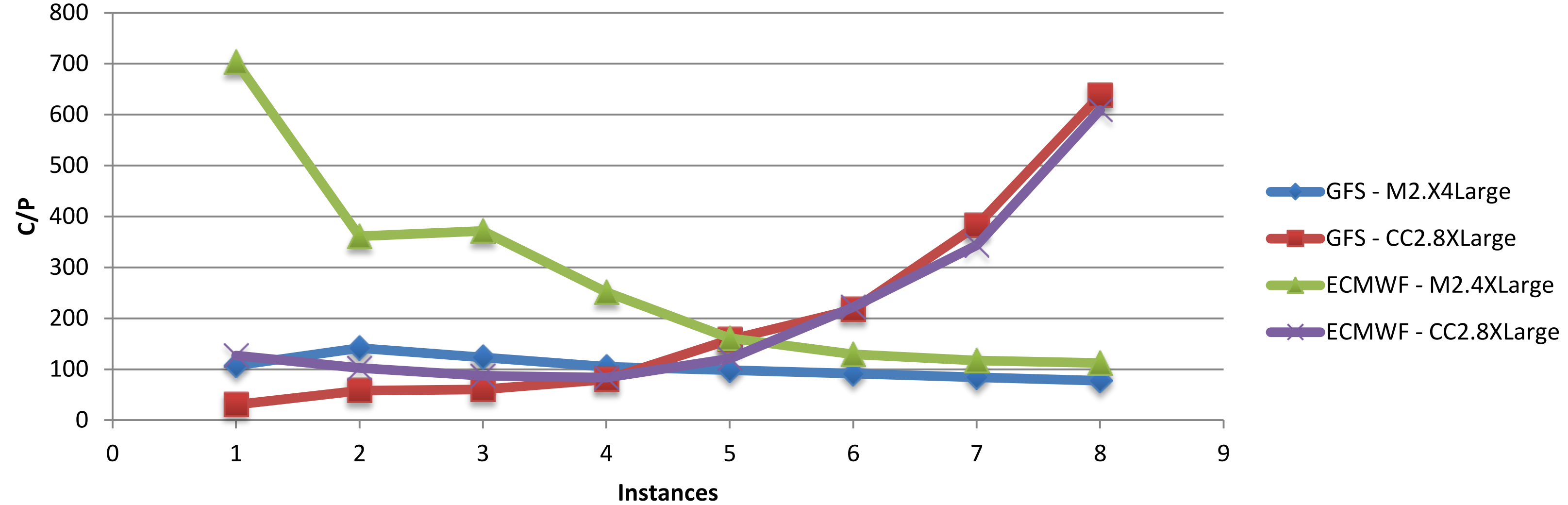
WRF on Cloud

GFS: free data, sometimes imprecise, 2 level computation

ECMWF: restricted access data ($23.61/h), 1 level computation

C/P Metric



Strategy:

GFS

•cc2.8xlarge (1 to 4 nodes)

•m2.4xlarge (5 to 8 nodes)

ECMWF

•m2.4xlarge (no less than 6 nodes)

•Example: 2 hours (around 60 €) → 10 hours (AEMET)

J.L. Vazquez-Poletti, S. Santos-Muñoz, I.M. Llorente and F. Valero: *A Cloud for Clouds: Weather Research and Forecasting on a Public Cloud Infrastructure*. **Cloud Computing and Services Sciences**, Volume 512, pp. 3-11, 2015. Springer.

Dust devil tomography

- **n:Tomographic analysis consists on using as projecting basis the eigenvectors of linear combinations of operators (time-frequency, time-resolution, time-conformal).**

Adapted Tomography identifies signals by using an operator with the shape of a given event

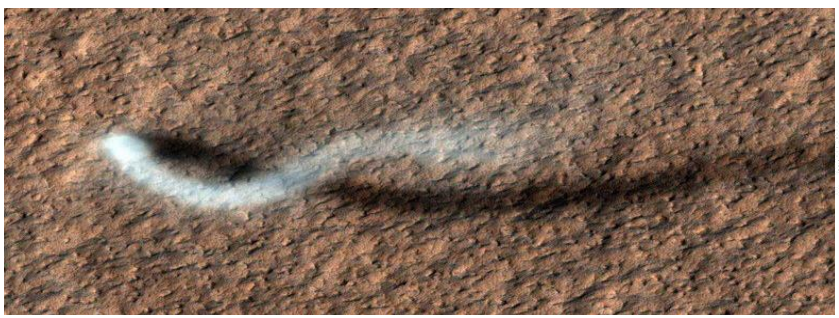
$$B(\mu,\nu) = \mu t + \nu\omega = \mu t + \nu i \frac{\partial}{\partial x}$$

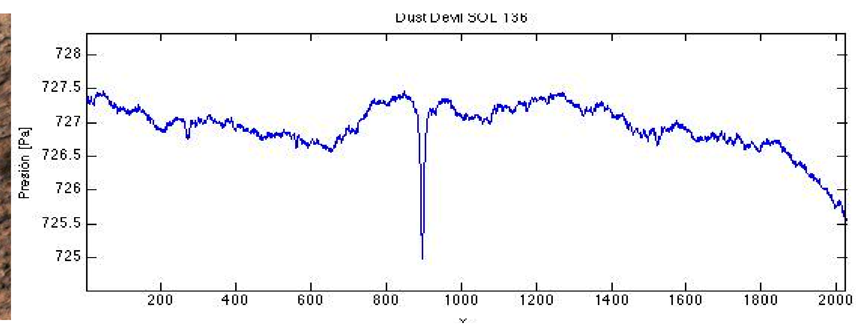
Time-frequency tomogram

projecting a given signal ***f(t)*** over the eigenvector set of a linear operator ***B(α)***.

linear operator

$$B(\mu,\nu) = \mu t + \nu O = \nu \begin{pmatrix} 1\Delta t & & & & \\ & 2\Delta t & & & \\ & & 3\Delta t & & \\ & & & \ddots & \\ & & & & N\Delta t \end{pmatrix} + \nu \sum_{i=1}^{k} \alpha_i \Phi_i \Phi_i^t$$





Input data: pressure

C. Aguirre and R. Vilela Mendes, *Signal recognition and adapted filtering by non-commutative tomography*. **IET Signal Processing**. Volume 8, pp. 67-75, 2014. IET.

Á. Giménez-Bravo, C. Aguirre, L. Vázquez, *Tomographic Signal Analysis for the detection of dust-devils in Mars atmosphere*. **Fifth Moscow Solar System Symposium**. 2014.

Signal-adapted tomography as a tool for dust devil detection

C. Aguirre [1](a), G. Franzese (b,c), F. Esposito(b), Luis Vázquez(d), Rui Vilela-Mendes(e), Raquel Caro(f), María Ramírez-Nicolás (d), F. Cozzolino(b), C.I. Popa(b)

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ABSTRACT

Dust devils are important phenomena to take into account in order to understand the global dust circulation of a planet. On Earth their contribution to the injection of dust into the atmosphere seems to be secondary. Otherwise, there are many indications that dust devils role on other planets, in particular on Mars, could be fundamental and impact the global climate. The capability to identify and study these vortices from the acquired meteorological measurements assumes a great importance for planetary science.
Here we present a new methodology to identify dust devils from the pressure time series measured in 2013 in the Tafilalt region (Morocco) in the North-Western Sahara. While dust devils are usually studied in the time domain, we move to a time-signal adapted domain using a bilinear transformation called a tomogram. The tomography technique has already been successfully applied in other fields like, for example, plasma reflectometry or the neuronal signatures. Here we show its effectiveness also in this new field. In order to test our results, we have also used a time domain analysis to identify candidate dust devils. We show the level of agreement between the two methodologies and the advantages and disadvantages of the tomographic approach.

1. INTRODUCTION

Dust devils are dust loaded convective vortices, with diameter usually of the order of ten meters and height of hundred meters. Their formation is favoured in conditions of strong insolation, a low humidity environment, lack of vegetation and buildings or other high obstacles and a gently sloping topography [Balme and Greeley 2006]. For these reasons, they are often observed in terrestrial deserts and are also very common on the surface of Mars.
Martian and Terrestrial dust devils have a common formation mechanism and similar dynamics [Ringrose et all 2007], but the Martian dust devils can be an order of magnitude larger than the terrestrial ones.

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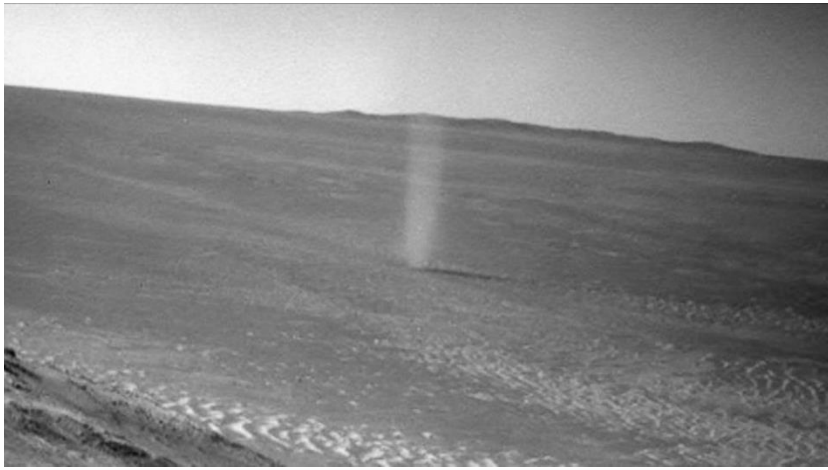
[1] Corresponding author

Dust devil tomography on Cloud



Application

C Code

Libraries: BLAS and LAPACK

Use case

DREAMS data set

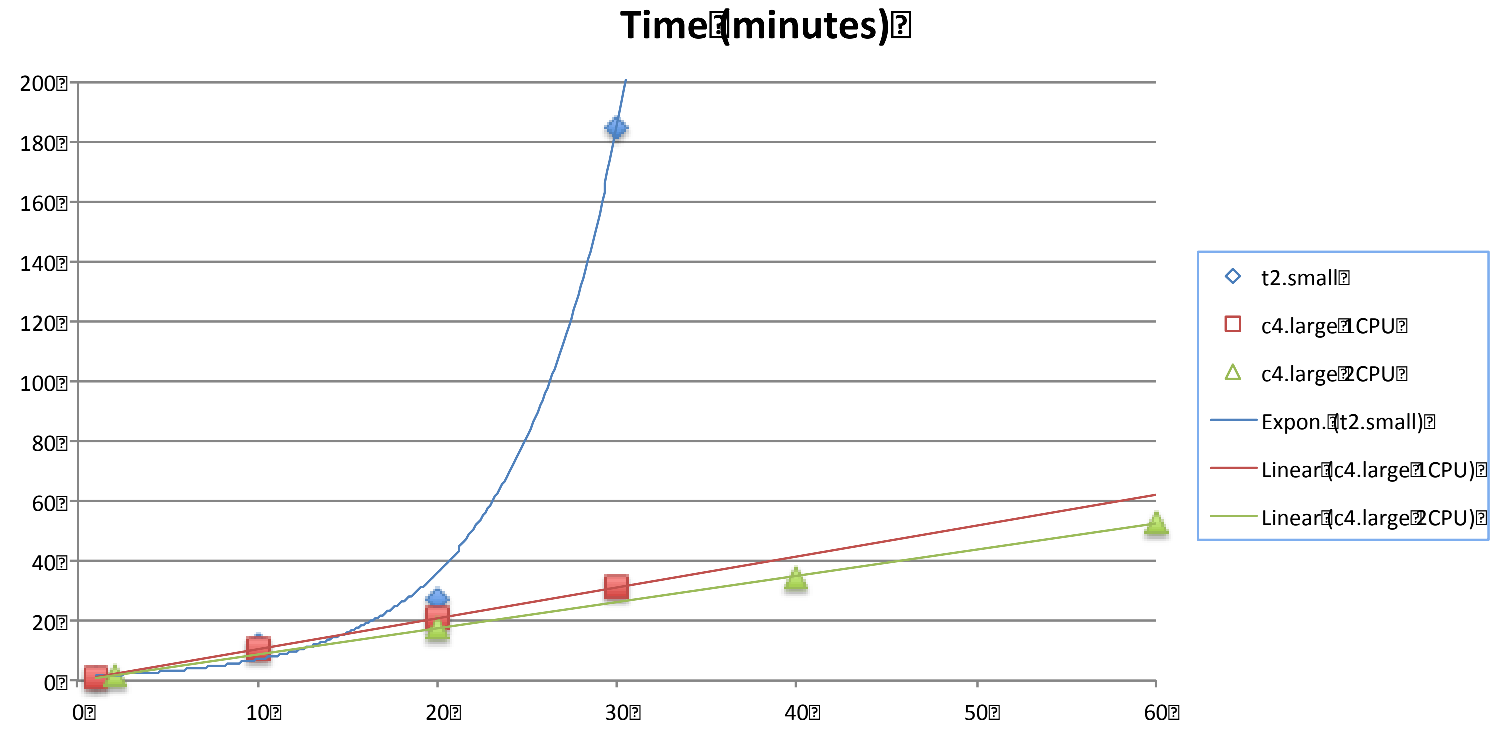
Experiment unit: 1,000 seconds – 1 sample/second

Considered machine setup (Amazon EC2):

- t2.small: 1 CPU, 2GB, $0.026/h
  - 1 task/machine
- c4.large: 2 CPU, 3.75GB, $0.105/h
  - 1 task/machine
  - 2 tasks/machine

Dust devil tomography on Cloud

Execution



t2.small $y = 1.3972e^{0.1626x}$

c4.large 1CPU $y = 1.0313x + 0.1646$

c4.large 2CPU $y = 0.8743x - 0.0209$

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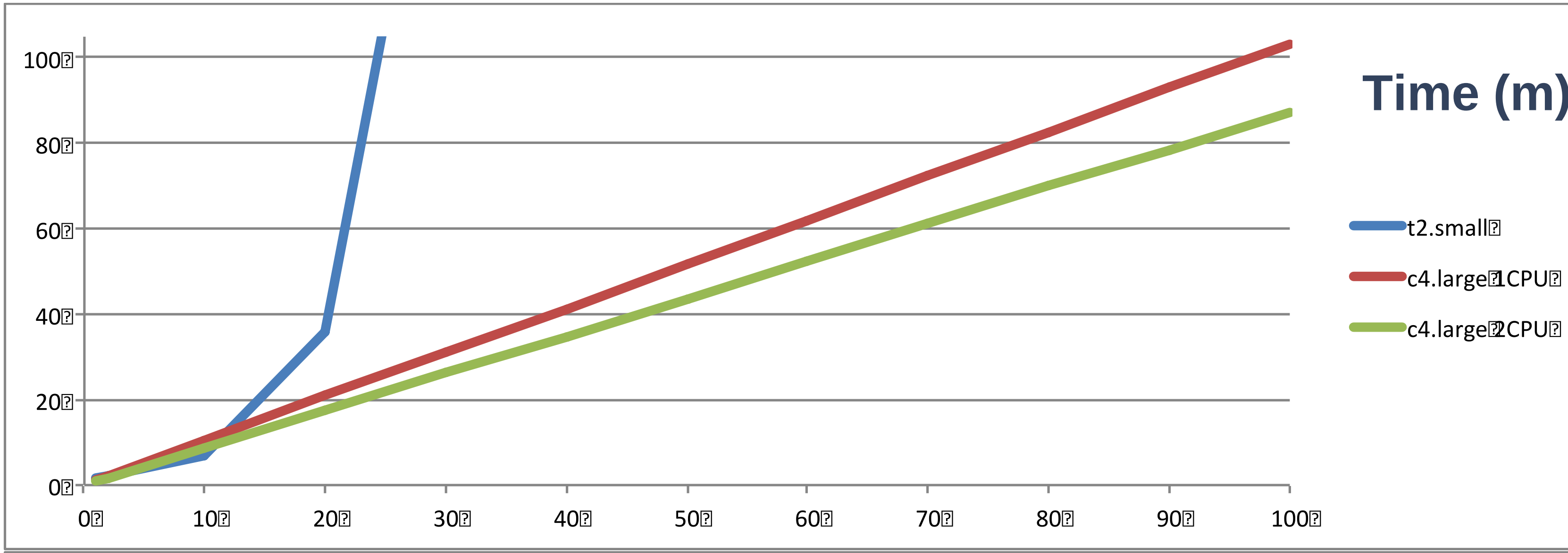
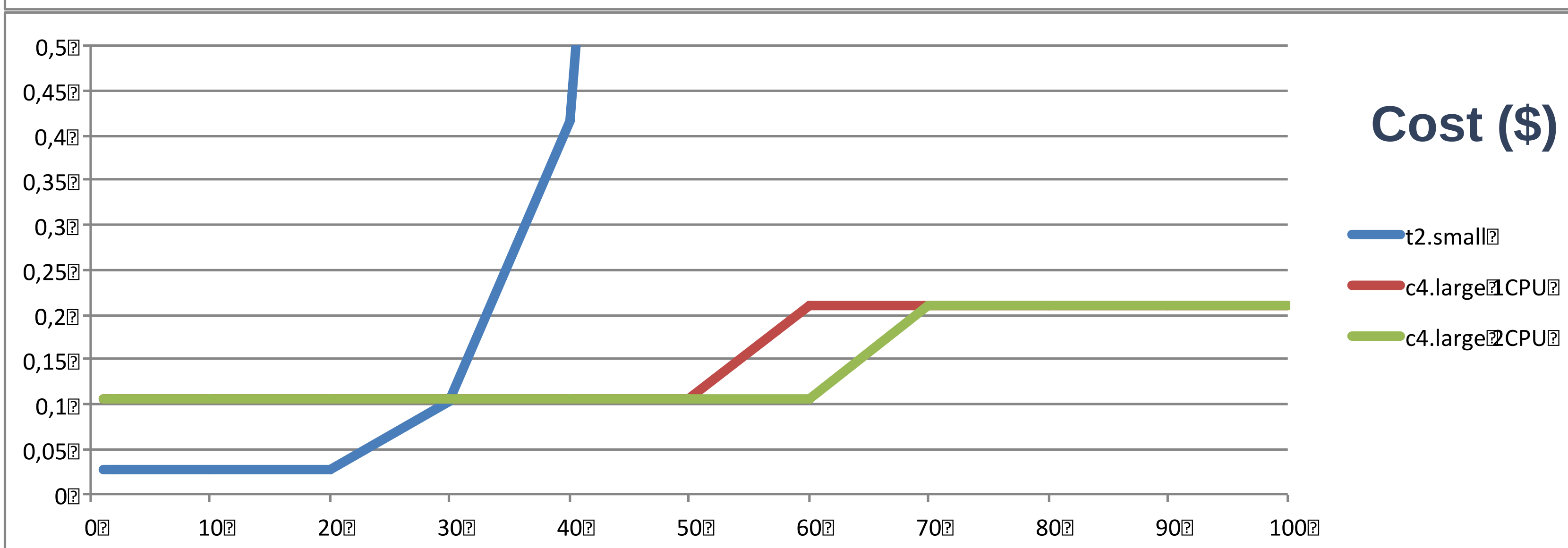
Dust devil tomography on Cloud

Model:





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Radiation Diffusion modeled by Fractional Calculus (FC)

Introduction

- Study of radiation attenuation when traversing the Martian atmosphere
- Application of the aerosol optical thickness (Angstrom) equation used by Lambert-Beer-Bouguer law
- Interesting case of 3D fractional calculus application
- **See poster by S. Jiménez et al.**

Application

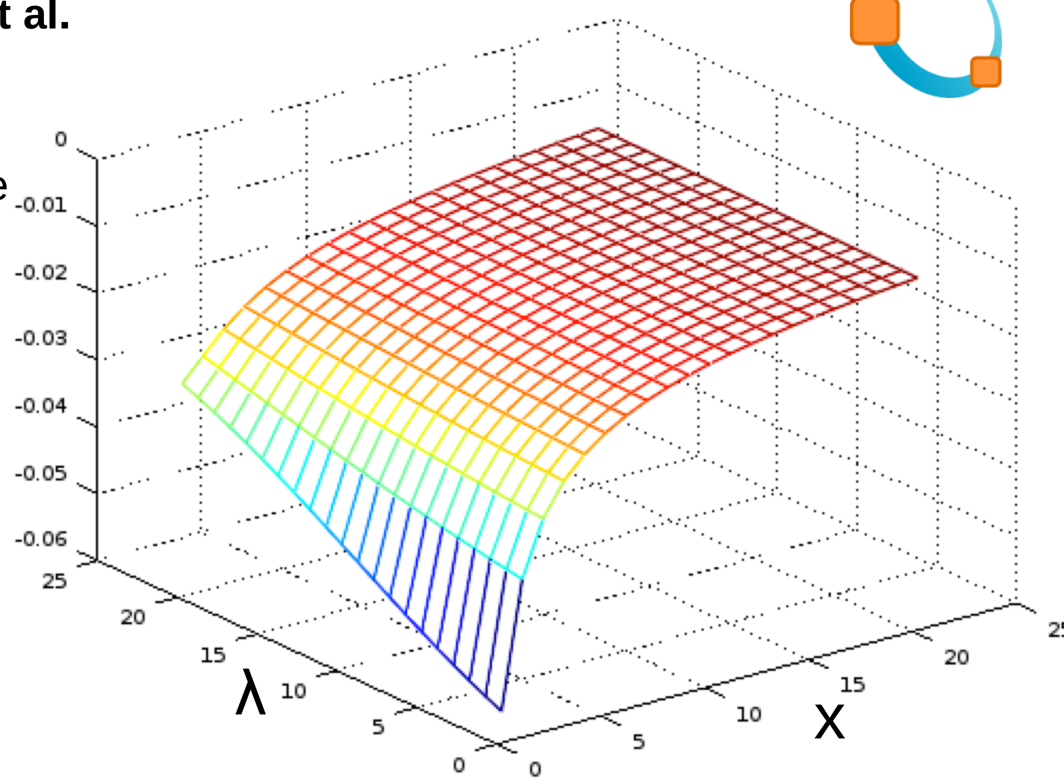
- Matlab code ported to Octave
- 1D case
- Variables (x, λ)

$$\tau_a = \frac{\beta}{\lambda^\alpha} \quad \text{Angstrom aerosol optical thickness}$$

$$\xrightarrow{\text{variable change}} \mu = \frac{1}{\beta}\lambda^\alpha$$

2-order moment of a classical fractional diffusion equation where the time derivative is replaced by the wavelength derivative:

$$\frac{\partial^\alpha \varphi}{\partial \lambda^\alpha} = \frac{1}{2\beta}\frac{\partial^2 \varphi}{\partial x^2}$$



M.P. Velasco, D. Usero, S. Jiménez, C. Aguirre, L. Vázquez, *Mathematics and Mars Exploration*, **Pure and Applied Geophysics** 172, 33-47, 2015, Springer.

Mathematics and Mars Exploration

M. P. Velasco, D. Usero, S. Jiménez, C. Aguirre & L. Vázquez

Pure and Applied Geophysics
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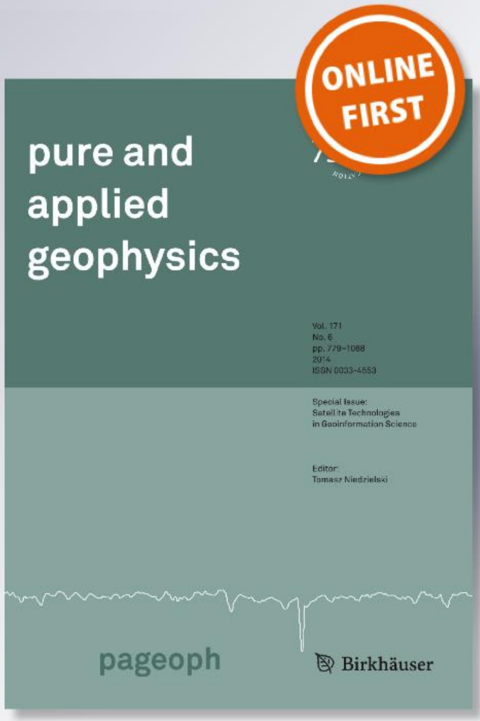
ISSN 0033-4553

Pure Appl. Geophys.
DOI 10.1007/s00024-014-0870-3



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Cent. Eur. J. Phys. • 11(10) • 2013 • 1163-1163
DOI: 10.2478/s11534-013-0291-4

VERSITA

Central European Journal of Physics

Fractional calculus: theory and numerical methods*

Editorial

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Received 27 July 2013; accepted 29 July 2013

This issue represents a contribution to a panoramic view of the Fractional Calculus through a large spectrum of possible applications in different experimental scenarios. The included papers show the modelling potentiality of the Fractional Calculus as well as a vision of the associated many open fractional questions which deserve deeper studies and developments. A complete development of the Fractional Calculus similar to the Classical Calculus is still not achieved. They are many open questions and we could say that, at this moment, the limits exist in the imagination.

The Fractional Calculus is a suitable instrument to model non local phenomena either in space and/or in time. In many contexts the underground dynamics of the system depends either on its history and/or the environment. On the other hand, the Fractional Calculus provides a suitable instrument to analyse possible interpolating dynamics between the properties and dynamics characteristics of the integer derivatives. A relevant reference case is the possible interpolations between the classical diffusion and wave equations through the fractional derivative in time. As we know the definition of fractional derivative is not unique, a basic constraint is to reproduce the established results for the integer case. It makes the Fractional Calculus a very powerful tool because it can be implemented to model a wide set of phenomena.

This issue includes papers dealing with basic questions as the fractional chain-rule to different contexts of applications modelled by ordinary and partial differential equations. Also numerical studies are included. We hope that this topical issue would be very stimulating and helpful for young researchers and Ph.D. students who are the basic vectors for the future developments of the Fractional Calculus.

Finally, we thank to Dr. Krzysztof Malarz, Managing Editor, for the opportunity to prepare this topical issue.

*"Fractional calculus is the calculus of the future, with it, we can solve problems we couldn't have solved before.", Om P. Agrawal

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Radiation Diffusion Modeled by Fractional Calculus

UCM MARTIAN STUDIES

S. Jiménez, M.P. Velasco and L. Vázquez.. “3D Fractional models and numerical methods for atmospheric dust dynamics”. Poster.

Abstract:

We extend our previous 1 dimensional model for the diffusion of solar radiation by dust in the atmosphere of Mars to full 3 space dimensions either in the general or the radial symmetry cases. We also present numerical methods to simulate our models.

Radiation Diffusion modeled by FC on Cloud

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Considered machine setup (Amazon EC2):

•t2.small: 1 CPU, 2GB, \$0.026/h

- 1 task/machine

•c4.large: 2 CPU, 3.75GB, \$0.105/h

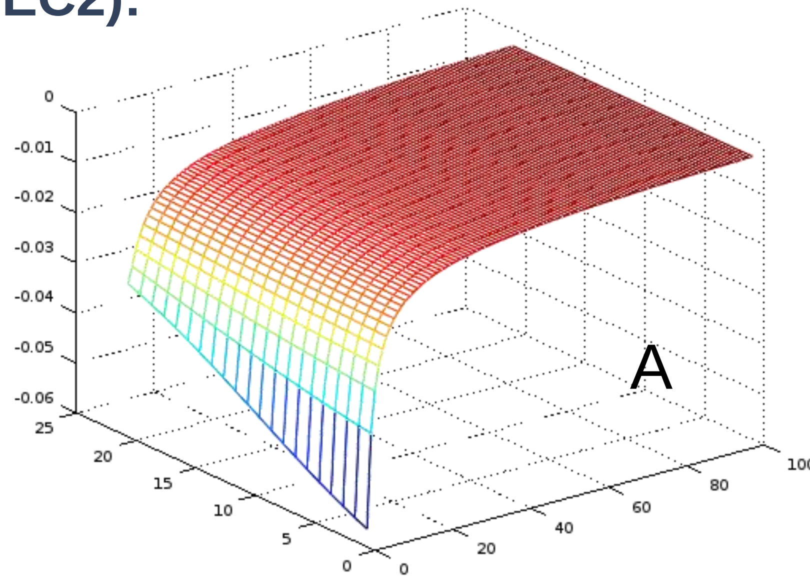
- 1 task/machine
- 2 tasks/machine

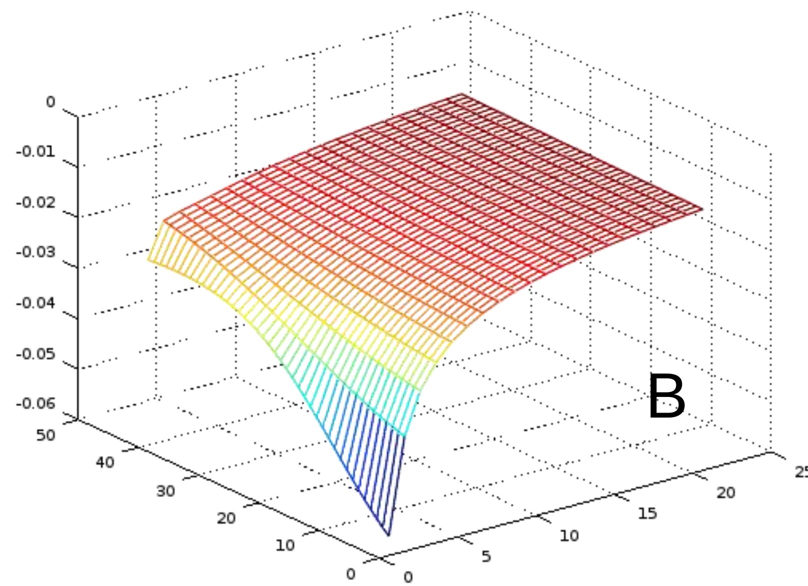
Experiment unit: interval

Sets of experiments:

A. λ=1:1:2, x=0:0.1:*n*

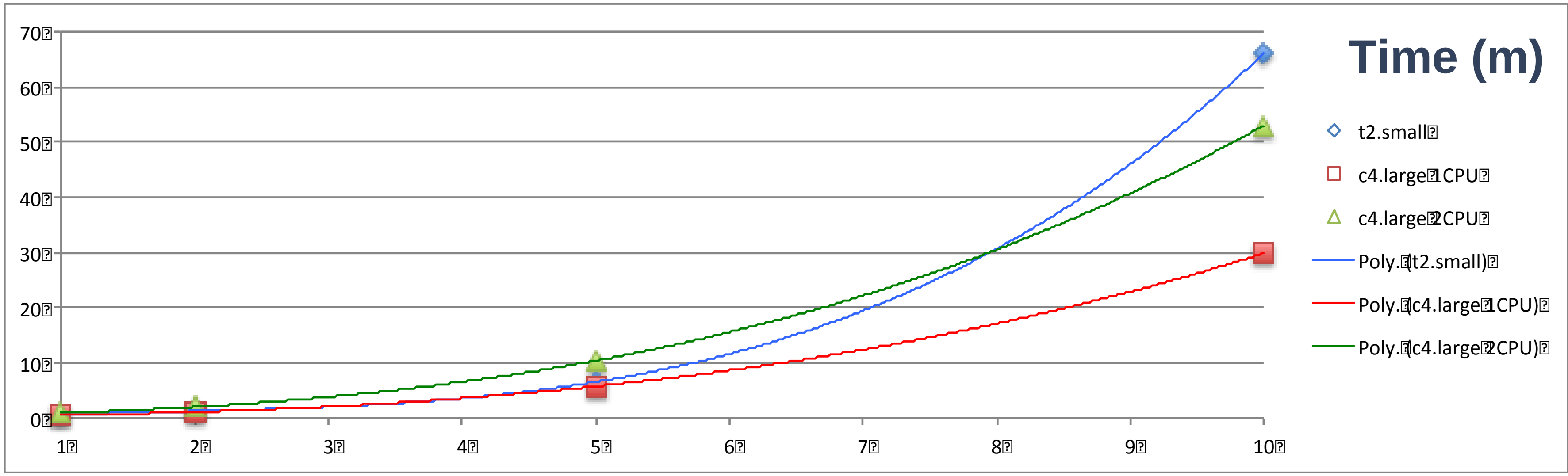
B. x=0:0.1:1, λ=1:1:*n*





Radiation Diffusion modeled by FC on Cloud

A: λ=1:1:2, x=0:0.1:*n* (experiments):



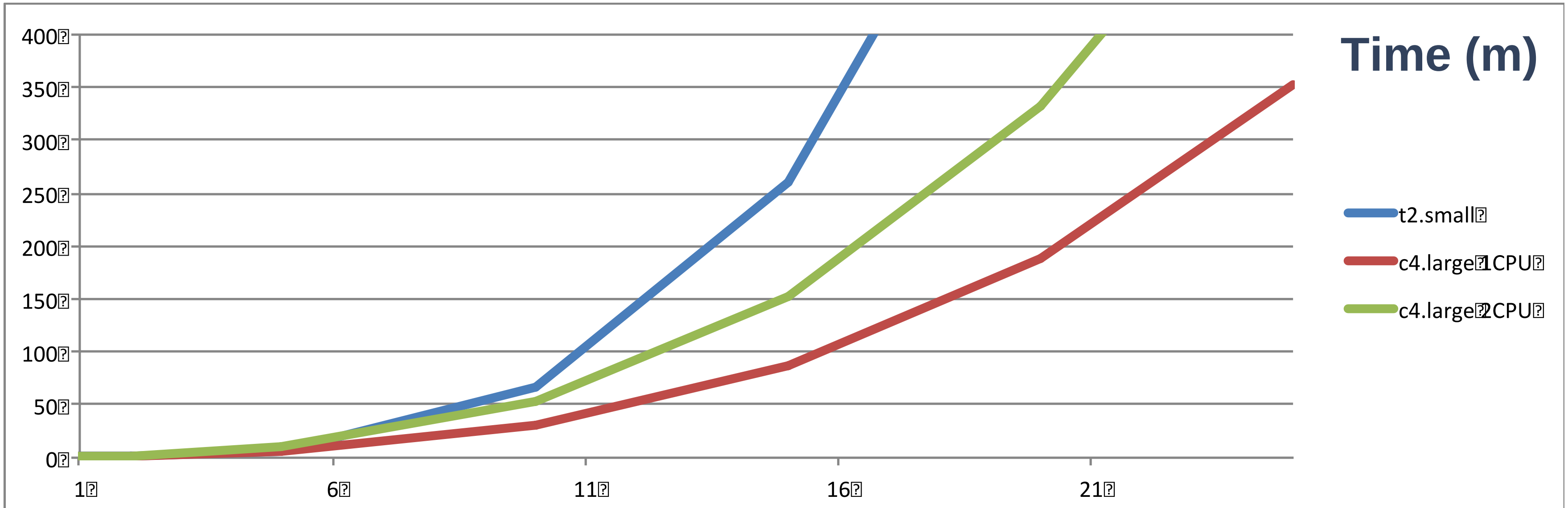
t2.small $y = 0.1108n^3 - 0.6193n^2 + 1.7873n - 0.7275$

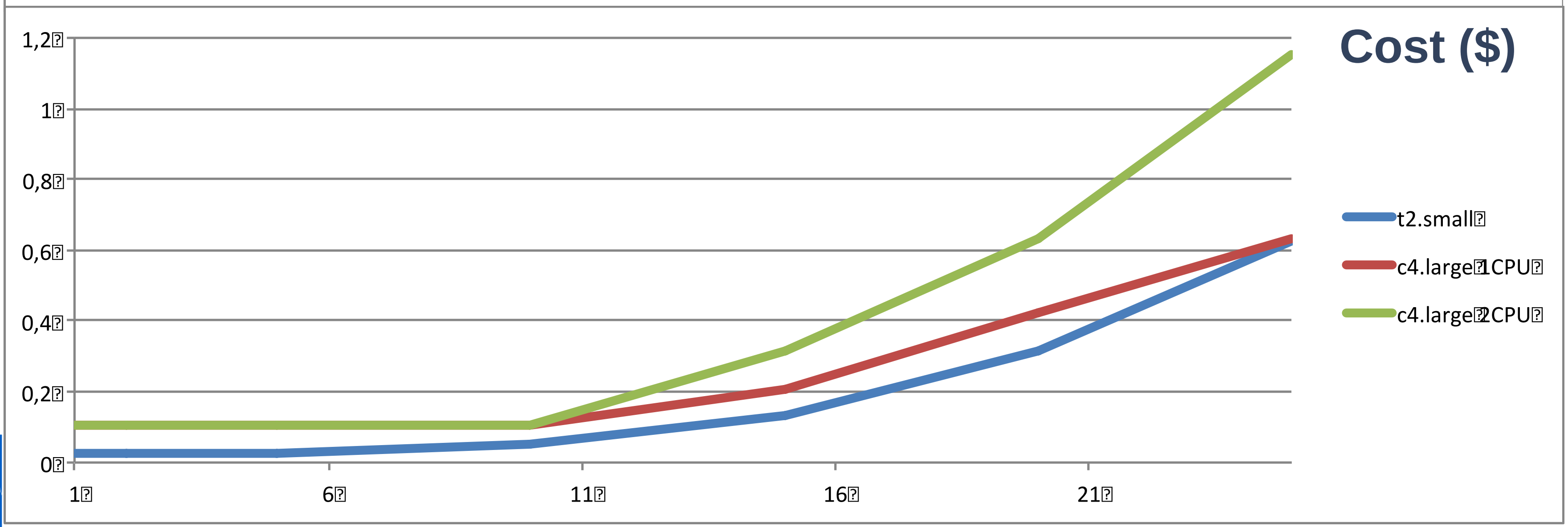
c4.large 1CPU $y = 0.0185n^3 + 0.0926n^2 + 0.1924n + 0.1704$

c4.large 2CPU $y = 0.0322n^3 + 0.1649n^2 + 0.3969n + 0.3063$

Radiation Diffusion modeled by FC on Cloud

A: λ=1:1:2, x=0:0.1:*n* (model):





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Radiation Diffusion modeled by FC on Cloud

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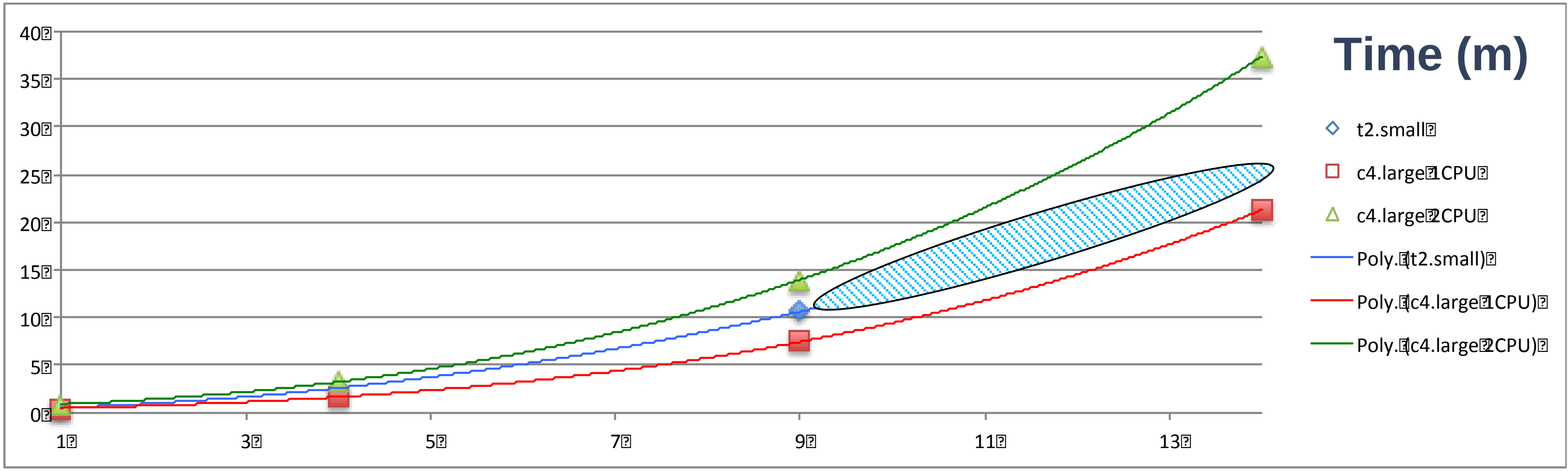
B: x=0:0.1:1, λ=1:1:*n* (experiments):



t2.small $y = 0.1142n^2 + 0.1188n + 0.3183$

c4.large 1CPU $y = 0.0052n^3 + 0.0214n^2 + 0.1909n + 0.2565$ $x \le 9$

c4.large 2CPU $y = 0.0066n^3 + 0.077n^2 + 0.2686n + 0.5416$

Radiation Diffusion modeled by FC on Cloud

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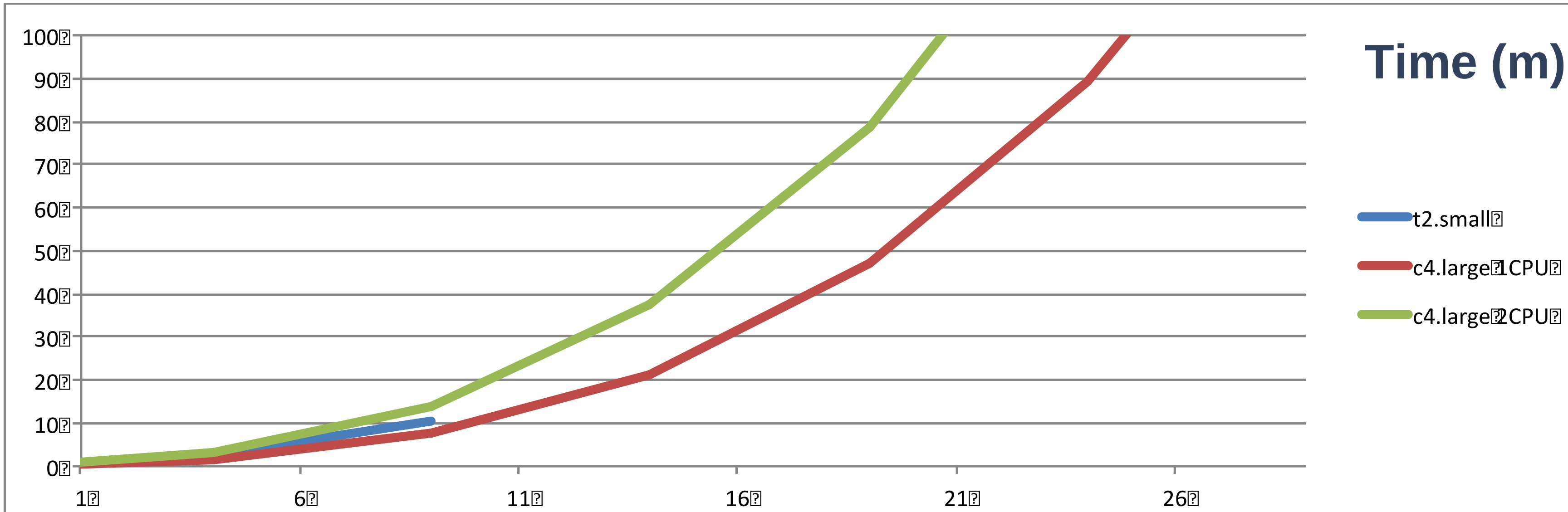
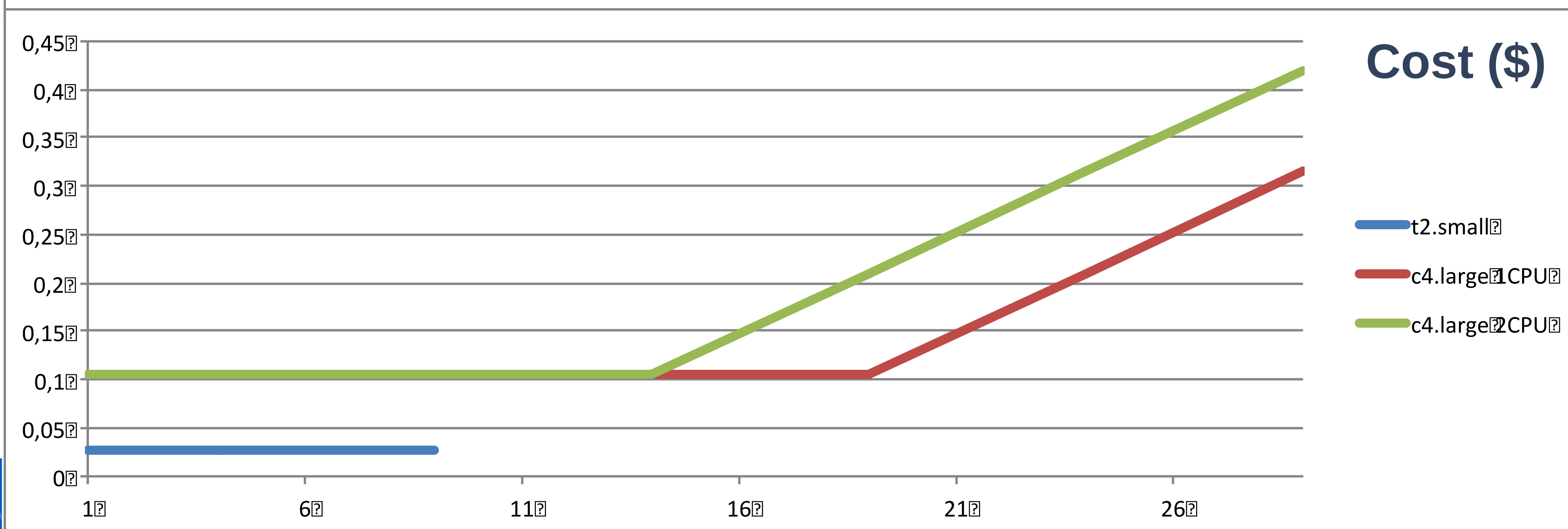
B: x=0:0.1:1, λ=1:1:*n* (model):





Ground Solar Radiation and Atmospheric Dust

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Motivation for developing a RTM

Martian atmosphere is very different to the Earth atmosphere.

It helps to characterize the radiative environment at the Martian surface.

It is necessary to maximize the scientific return of solar radiation measurements on Mars.

Radiation has to be studied in the same bands of the present and future instruments that will be sent to Mars.

	Mars	Earth
S_0 (W/m^2)	589	1367
Pressure (hPa)	6 to 9	1013
CO_2 (%)	95.32	0.04
N_2 (%)	2.7	78
Ar (%)	1.6	0.9
O_2 (%)	0.13	21
H_2O (%)	0.02	Variable
Amount of dust	High	Low
Amount of clouds	Low	High

Comparison between some parameters for Mars and Earth

Model inputs

In order to calculate the radiative fluxes that reach the surface, it is necessary to know:

- The radiation at the top of the atmosphere (TOA)
- The radiative properties of the atmosphere

Model inputs are:

- Dust optical depth
- Water ice clouds optical depth
- Dust size distribution
- Water ice particle size distribution
- Abundance of each gas
- Surface pressure
- Local time (hour angle)
- Surface albedo
- Orbital position of Mars (areocentric longitude, Ls)
- Latitude
- Wavelength range

By modifying those parameters, a great number of scenarios can be defined

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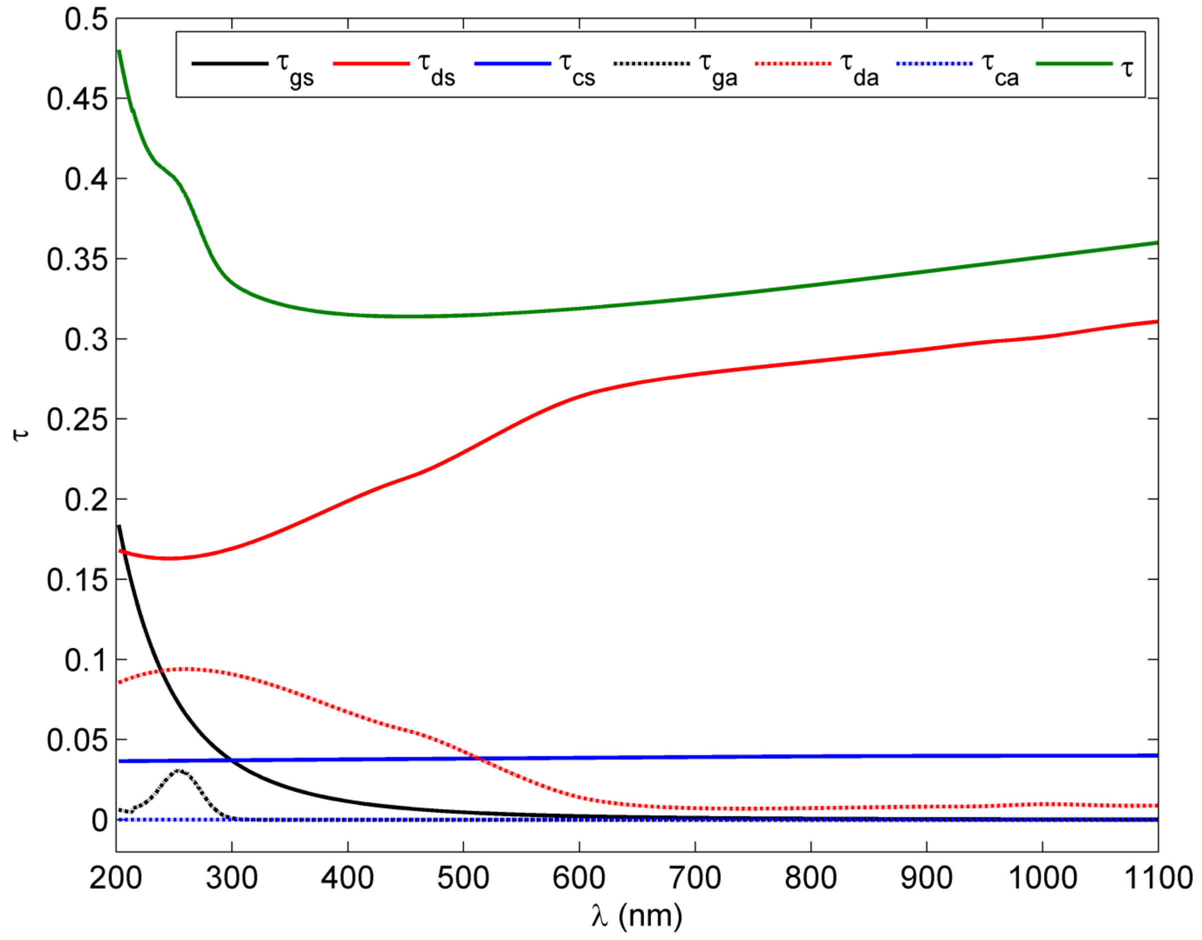
The role of the atmospheric components



Spectral behavior of the scattering and absorption optical depths (subscripts s and a) of dust, water ice clouds, and gas molecules (subscripts d, c, and g) for a "clear" scenario.Vicente-Retortillo, A. et al. (2015). A model to calculate solar radiation fluxes on the Martian surface. Journal of Space Weather and Space Climate, 5, A33, DOI: 10.1051/swsc/2015035.

Calculating the fluxes

Two methods can be used: The delta-Eddington approximation and the Monte-Carlo method.

Delta-Eddington: Very low computing time. Suitable also for sensitivity studies.

Monte-Carlo: Provides additional information, which becomes necessary for some purposes.

Main advantage of using two methods: We can select the one that best meets the requirements of the desired information.

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The delta-Eddington approximation

$$\mu \frac{dI(\tau,\boldsymbol{\Omega})}{d\tau} = I(\tau,\boldsymbol{\Omega}) - \frac{\tilde{\omega}}{4\pi}\int_{4\pi} I(\tau,\boldsymbol{\Omega}')P(\boldsymbol{\Omega},\boldsymbol{\Omega}')\,d\Omega' - \frac{\tilde{\omega}}{4\pi}F_{\odot}P(\boldsymbol{\Omega},-\boldsymbol{\Omega}_0)e^{-\tau/\mu_0}$$

$$T = E\left[C_1\exp(-k\tau)(1+P')+C_2\exp(k\tau)(1-P')-(\alpha+\beta-1)\exp(-\tau/\mu_0)\right]$$

$$k = \left[3(1-\omega_0)(1-g\omega_0)\right]^{1/2}$$

$$P' = \frac{2}{3}\left[\frac{3(1-\omega_0)}{1-g\omega_0}\right]^{1/2}$$

$$\alpha = \frac{3}{4}\mu_0\omega_0\frac{1+g(1-\omega_0)}{1-\mu_0^2k^2}$$

$$\beta = \frac{1}{2}\mu_0\omega_0\frac{1/\mu_0+3\mu_0 g(1-\omega_0)}{1-\mu_0^2k^2}$$

$$C_1 = -\frac{(1-P')C_3\exp(-\tau/\mu_0)-(\alpha+\beta)C_4\exp(k\tau)}{(1+P')C_4\exp(k\tau)-(1-P')C_5\exp(-k\tau)}$$

$$C_2 = \frac{(1+P')C_3\exp(-\tau/\mu_0)-(\alpha+\beta)C_5\exp(-k\tau)}{(1+P')C_4\exp(k\tau)-(1-P')C_5\exp(-k\tau)}$$

$$C_3 = A+(1-A)\alpha-(1+A)\beta$$

$$C_4 = 1-A+P'(1+A)$$

$$C_5 = 1-A-P'(1+A)$$

$$g' = \frac{g}{1+g}$$

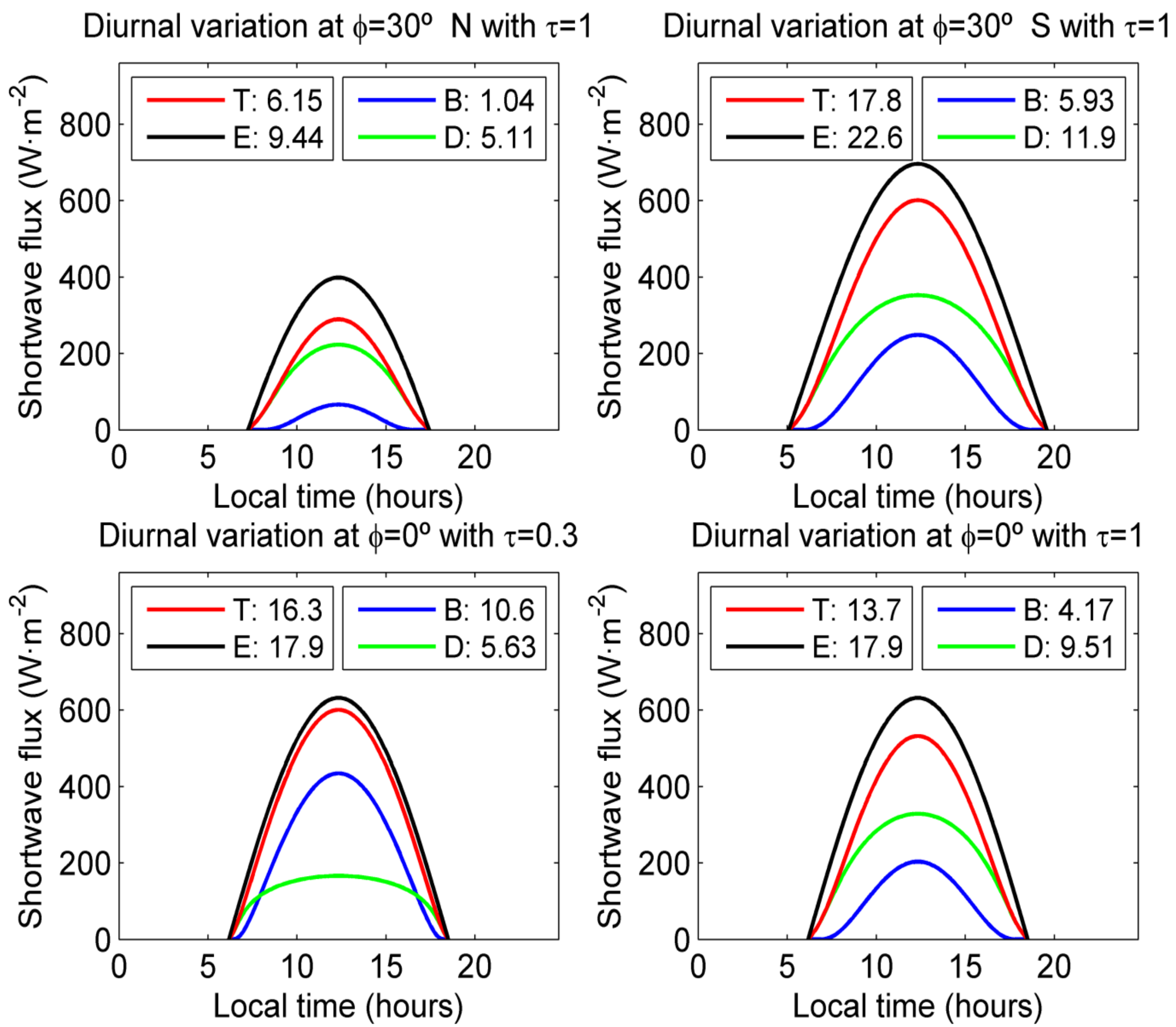
$$\omega' = \omega_0\frac{1-g^2}{1-\omega_0 g^2}$$

$$\tau' = \tau\left(1-\omega_0 g^2\right)$$

$$B = E\cdot\exp\left(-\tau/\mu_0\right)$$

$$D = T - B$$

Results: Diurnal evolution of solar fluxes



Diurnal evolution of the direct (B, blue line), diffuse (D, green line), and total (T, red line) surface solar flux for four combinations of latitudes and dust opacities during the Northern Hemisphere winter solstice.
Vicente-Retortillo, A. et al. (2015). A model to calculate solar radiation fluxes on the Martian surface. Journal of Space Weather and Space Climate, 5, A33, DOI: 10.1051/swsc/2015035.

Sensor multivariate analysis

Introduction

In Martian atmospheric science: humidity and temperature analyzed separately

Multivariate analysis: Statistical techniques that simultaneously analyze multiple measurements on individuals or objects under investigation

Objective: statistical model that maximizes in-sample predictive power

Without "over using" potential predictors (leading to poor out-of-sample performance)

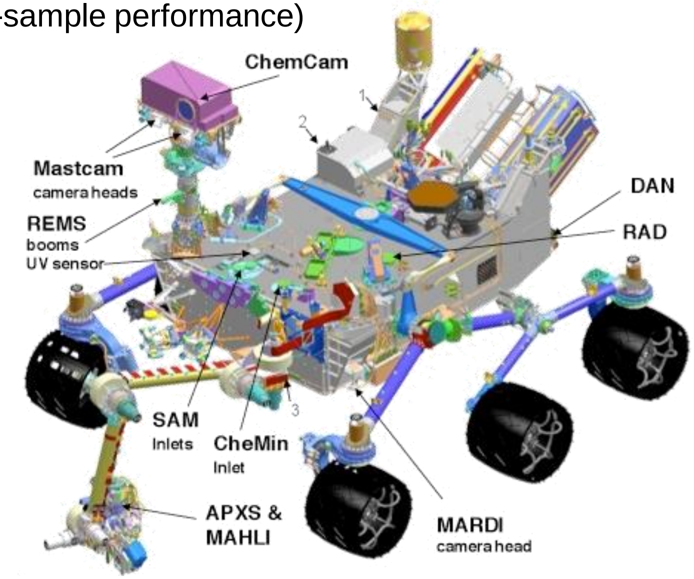
Use case

Study of humidity and temperature

REMS (MSL) data: 669 first sols

About 24 observations/sol

Observations during first 5 minutes/hour



Ari-Matti Harri, M. Genzer, O. Kemppinen, J. Gomez-Elvira, R. Haberle, J. Polkko, H. Savijärvi, N. Renno, J. A. Rodriguez-Manfredi, W. Schmidt, M. Richardson, T. Siili, M. Paton, M. De La Torre-Juarez,T. Mäkinen, C. Newman, S. Rafkin, M. Mischna, S. Merikallio, H. Haukka, J. Martin-Torres, M. Komu, M.-P. Zorzano, V. Peinado, L. Vázquez and R. Urqui. *Mars Science Laboratory Relative Humidity Observations – Initial Results*, **Journal of Geophysical Research** 119, n.9, 2132-2147 (2014).

A.M. Harri, M. Genzer, O. Kemppinen, H. Kahanpaa, J. Gomez-Elvira, J. A. Rodriguez-Manfredi, R. Haberle, J. Polkko, W. Schmidt, H. Savijarvi, J. Kauhanen, E. Atlaskin, M. Richardson, T. Siili, M.Paton, M. De La Torre-Juarez, C. Newman, S. Rafkin, M. T. Lemmon, M. Mischna, S. Merikallio, H. Haukka, J. Martin-Torres, M.-P. Zorzano, V. Peinado, R. Urqui, A. Lapinette, A. Scodary, T. Makinen, L. Vázquez, N. Renno., *Pressure Observations by the Curiosity Rover – Initial Results*. **Journal of Geophysical Research** 119, n. 1, 82-92 (2014).

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Sensor multivariate analysis on Cloud

Application

PSPP code

Replicated database for generating different filesizes

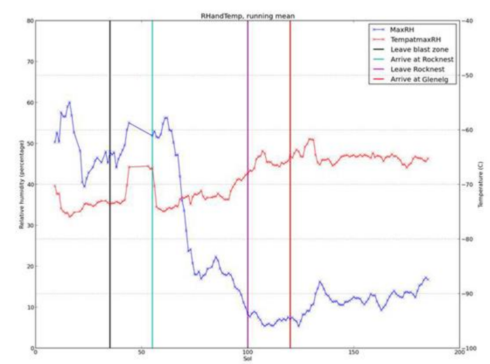
Considered machine setup (Amazon EC2)

- t2.small: 1 CPU, 2GB, $0.026/h
  - 1 task/machine
- c4.large: 2 CPU, 3.75GB, $0.105/h
  - 1 task/machine
  - 2 tasks/machine
- r3.large: 2 CPU, 15,25GB, $0.166/h
  - 1 task/machine
  - 2 tasks/machine

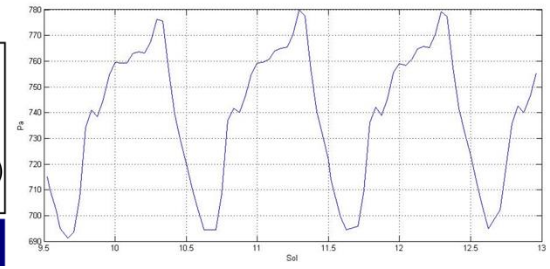
Experiment unit: Database size (GB)

Using 2 CPUs = throughput study

ATMOSPHERE RELATIVE HUMIDITY



PRESSURE SENSOR



- VARIANCE KURTOSIS SKEWNESS
- MEANS

CHISQUARE

EXTREME PERCENTILES

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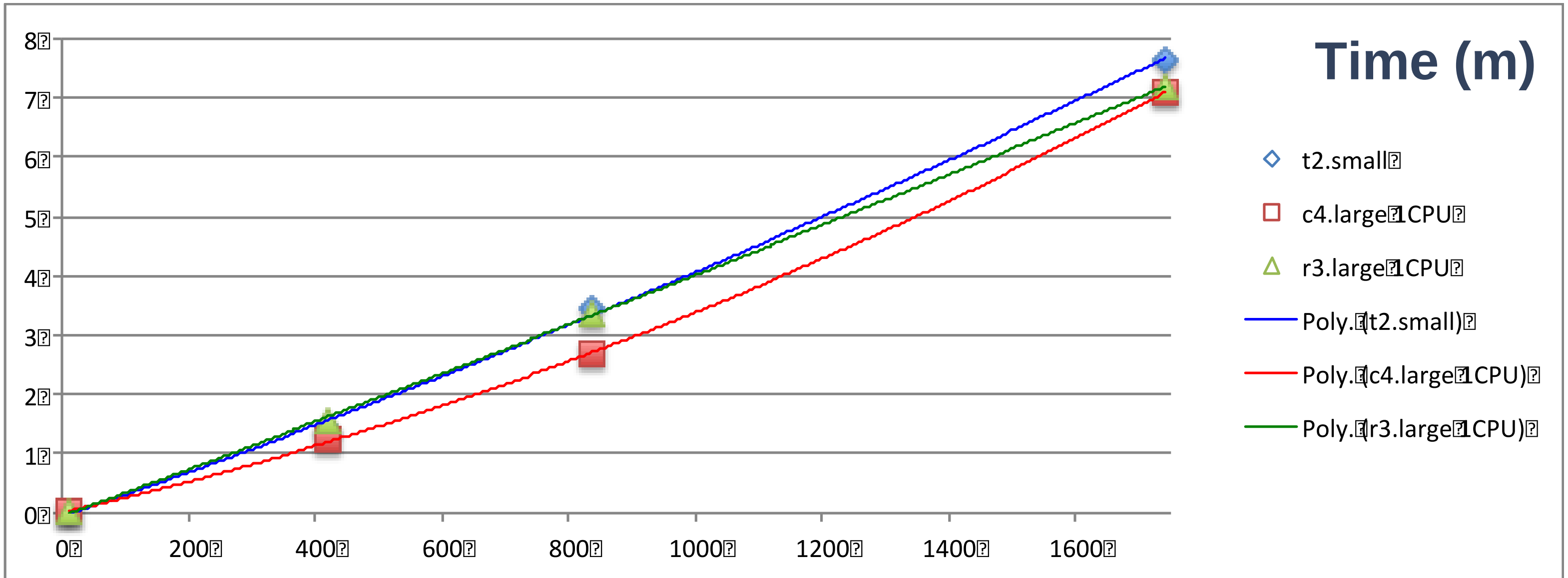
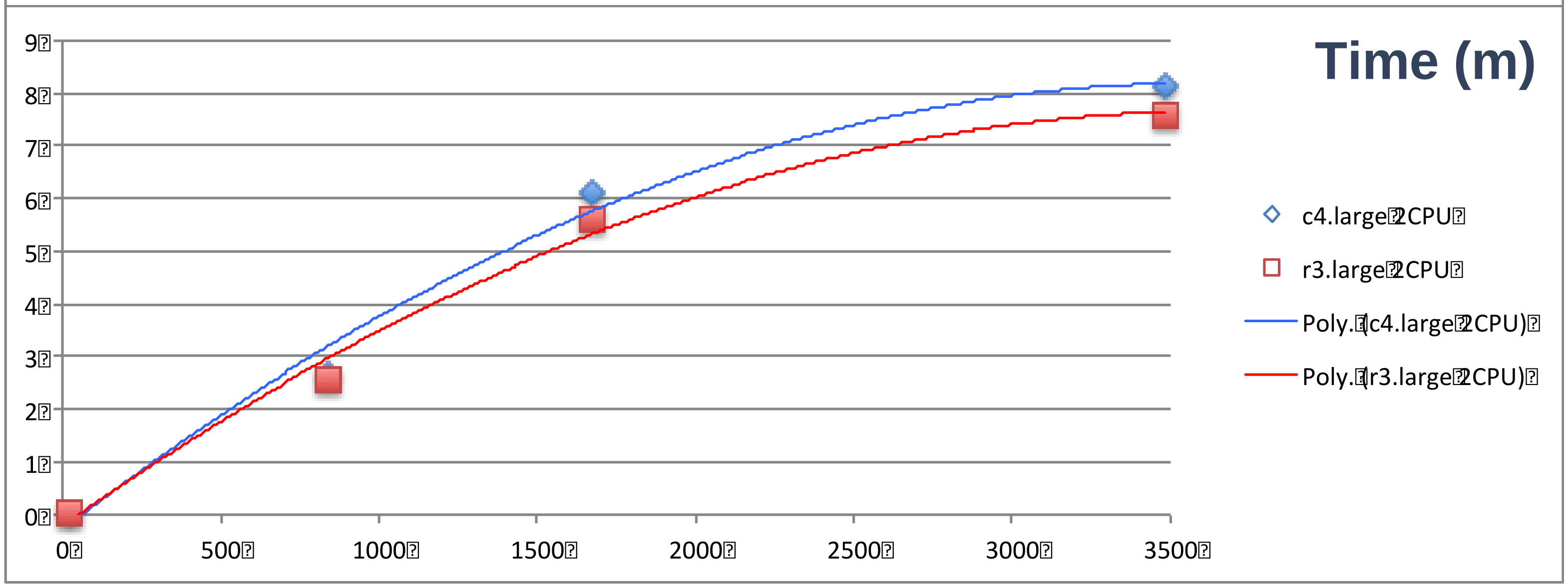
Sensor multivariate analysis on Cloud

Experimental results:





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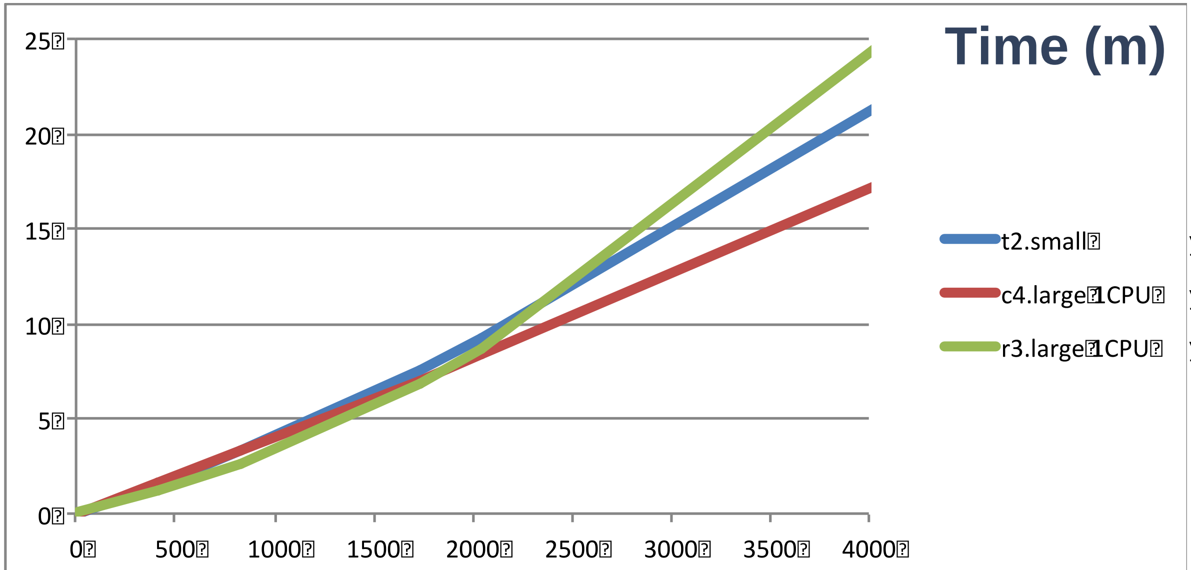
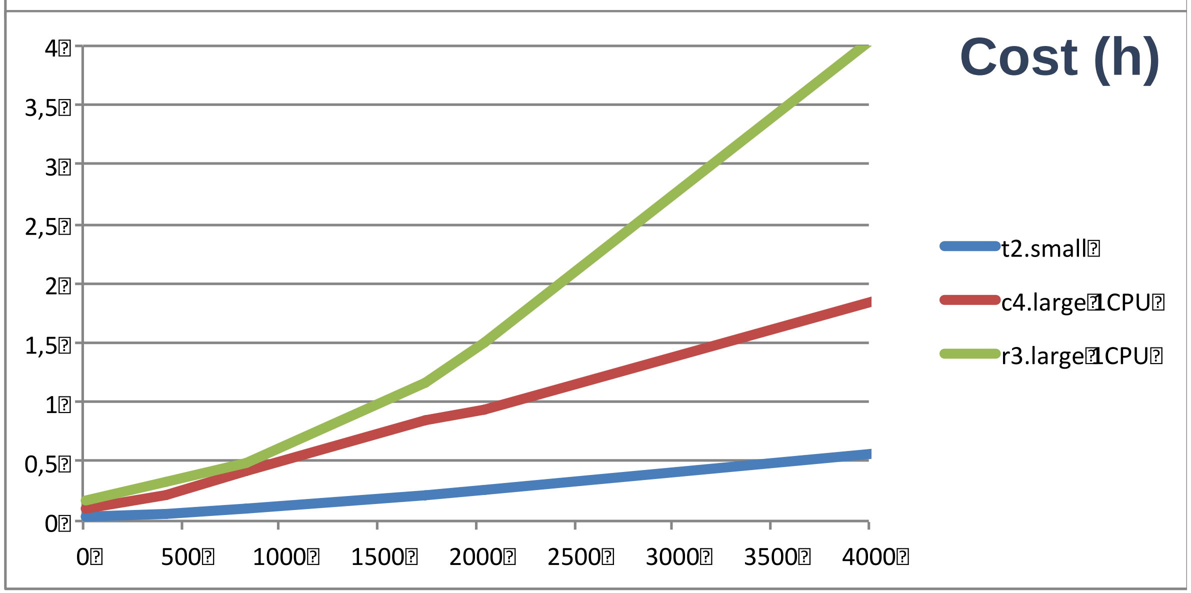
Model (1 CPU):



$y = 4E\text{-}07x^2 + 0.0037x - 0.0719$

$y = 9E\text{-}07x^2 + 0.0024x + 0.0046$

$y = 1E\text{-}07x^2 + 0.0039x - 0.0549$



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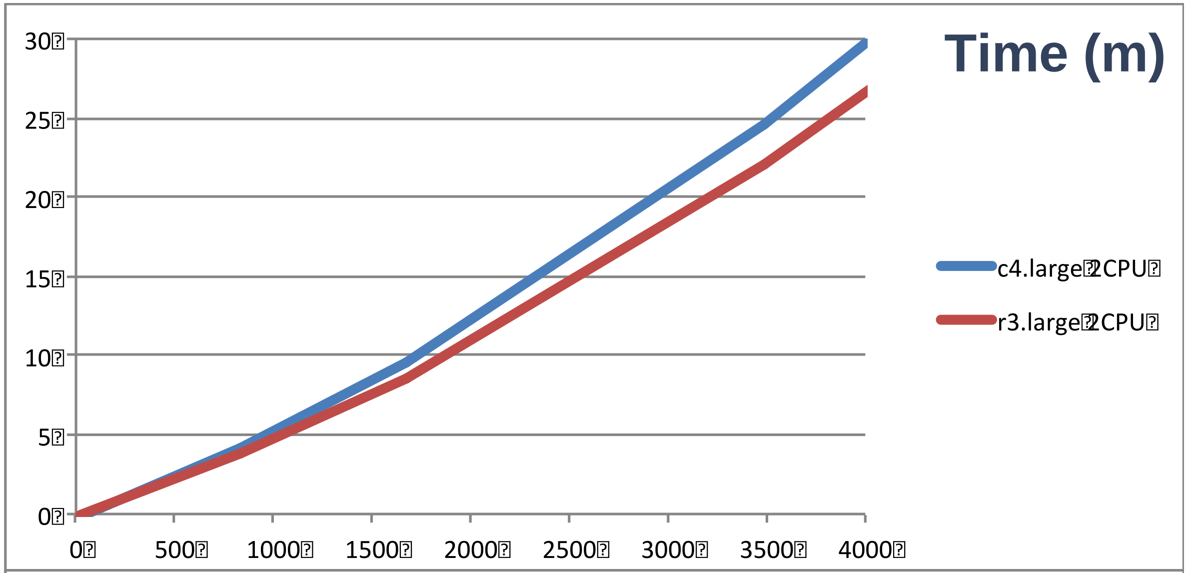
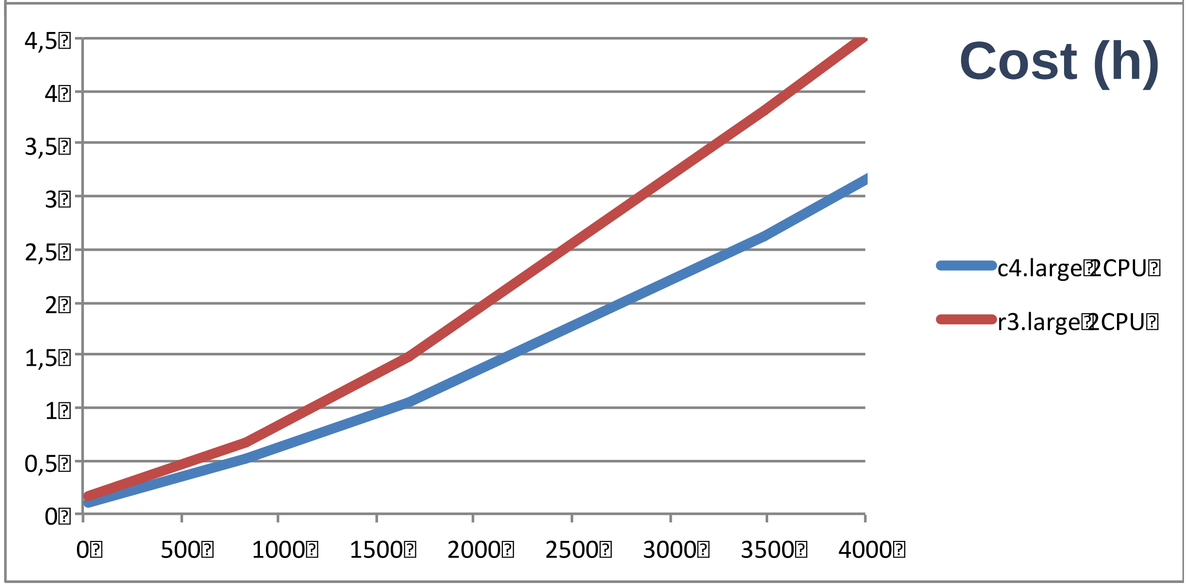
Sensor multivariate analysis on Cloud

Model (2 CPUs):



$y = -7E\text{-}07x^2 + 0.0047x - 0.3035$

$y = -6E\text{-}07x^2 + 0.0043x - 0.233$



Present and Future Work

To extend the Dust Devil tomography

- Apply to different Martian Mission data: atmospheric and electromagnetic phenomena

Dust and Solar Radiation diffusion

- Different levels of radiative transfer codes (*)
- Application of the fractional calculus models
- Apply **sensor multivariate analysis:** ***To cross the data from REMS-Humidity and DAN of MSL.***

(*) Stamnes, K., S.C. Tsay, W. Wiscombe, and K. Jayaweera*. Numerically stable algorithm for discrete-ordinate-method radiative transfer in multiple scattering and emitting layered media*. **Appl. Opt.**, 27, 2502–2509, 1988

(*) Stamnes, K., S.C. Tsay, W. Wiscombe, and I. Laszlo. *DISORT, a general-purpose FORTRAN program for Discrete-OrdinateMethod radiative transfer in scattering and emitting layered media*. **Documentation of methodology**, version 1.1, 2000.

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Kiitos Oikein Paljon
Thank You
Muchas Ggracias