Moustafa T. Chahine: A Remembrance

Claire L. Parkinson/Aqua Project Scientist
NASA Goddard Space Flight Center

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Youth

- Birth: January 1, 1935, Beirut, Lebanon.
- Childhood in Lebanon.
- Moved to the U.S. in December 1954, at age 19.

Mous as a child in Lebanon.

Mous as a high school student in Lebanon.

(Photos courtesy of the Chahine family: sons Tony and Steve and wife Marina)

Studies

- Mous's life-long dedication to intellectual interests began in Lebanon.
- University of Washington, Seattle
  - B.S., Aeronautical Engineering, 1956
  - M.S., Aeronautical Engineering, 1957
- University of California at Berkeley
  - Emphasis in fluid physics
  - Ph.D., Mechanical Engineering, 1960

A teen-age Mous studying in Lebanon.

Far left: Mous as a UW freshman, 1955.

Near left: Mous at Berkeley on the day of his dissertation defense, 1960.

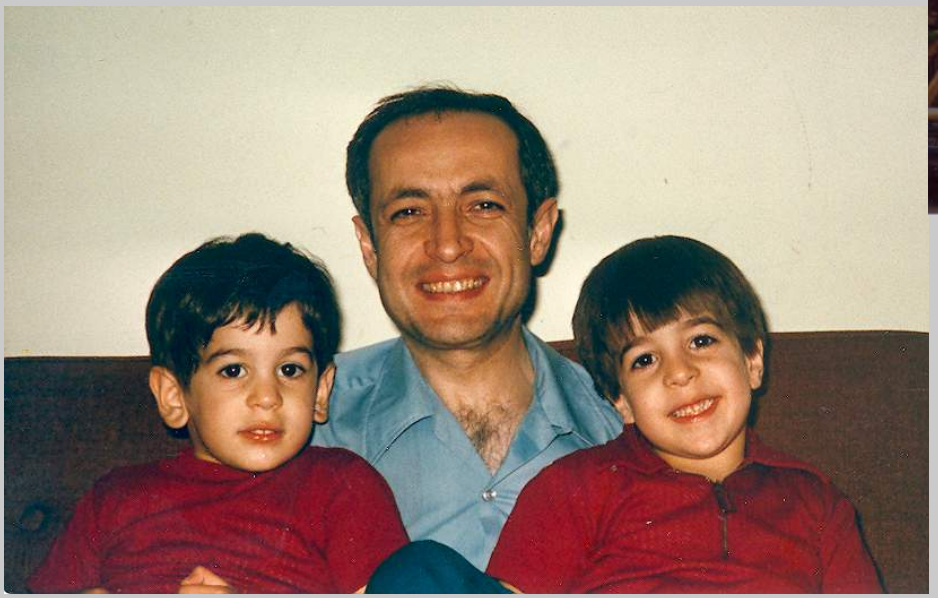
(Photos courtesy of the Chahine family: sons Tony and Steve and wife Marina)

An Early Source of Inspiration

Explorer 1, held aloft by William Pickering (Director of JPL), James van Allen, and Wernher von Braun, 1958 (from www.jpl.nasa.gov).

Family Man

Mous courting his future wife, Marina, 1959.



Mous with son's Steve (left) and Tony (right), 1974.

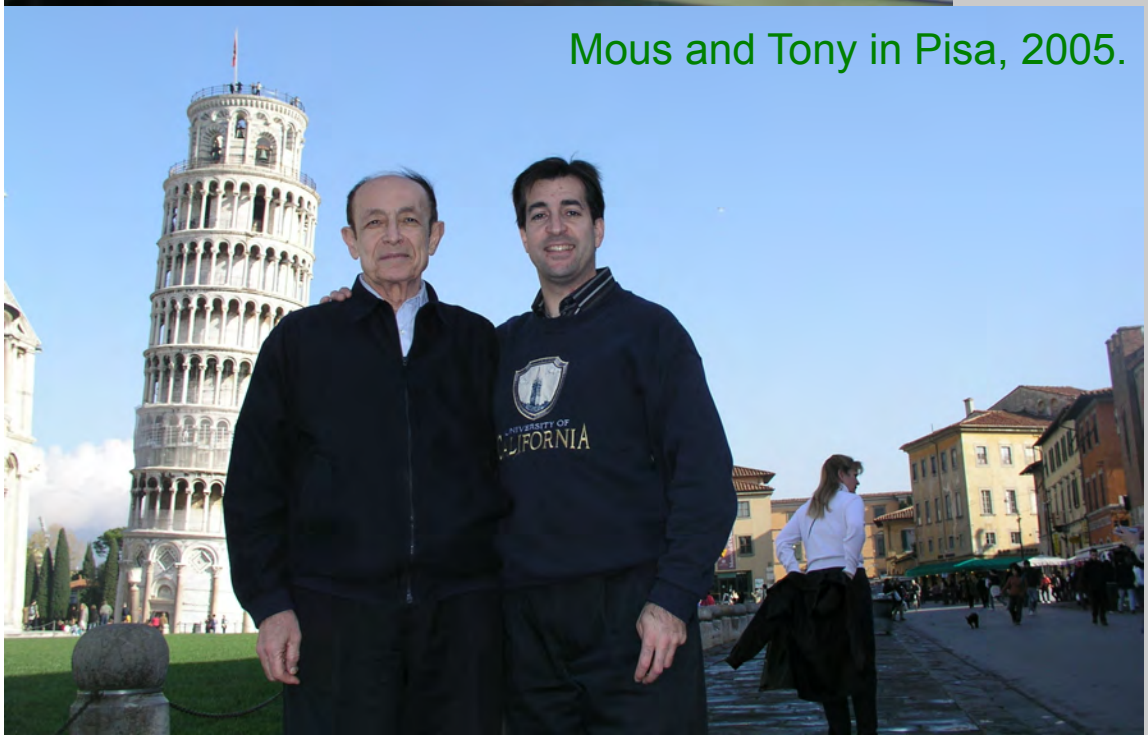
(Photos courtesy of the Chahine family:
sons Tony and Steve and wife Marina)

Mous and Marina in Paris, 1992.

Mous with (left to right) his daughter-in-law, son Tony, and son Steve, 2010.

Traveling with Family

Mous and Steve on the Euro Train, 2005.



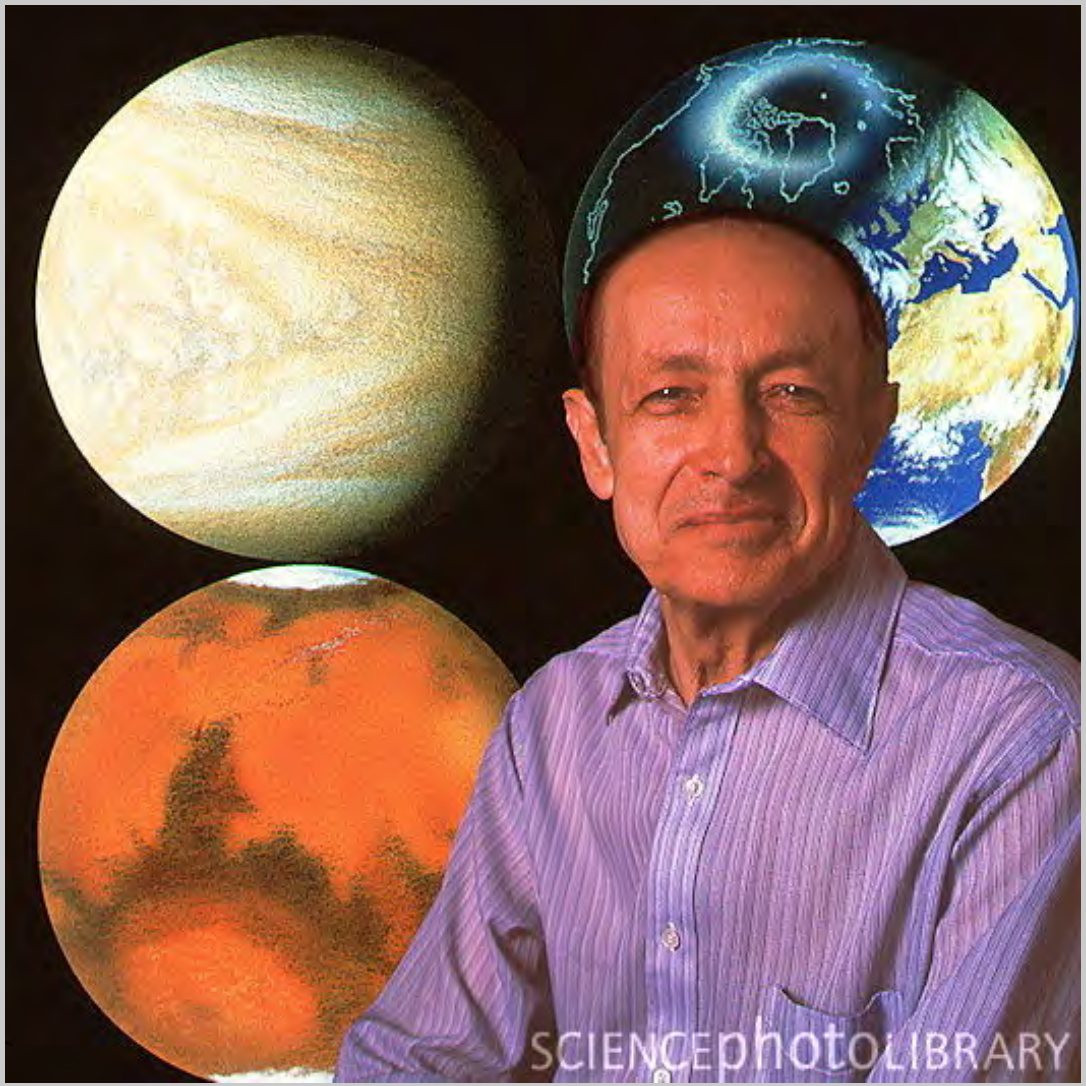
Mous and Tony in Pisa, 2005.

Mous and Marina in Cairo, 1993.

(Photos courtesy of the Chahine family: sons Tony and Steve and wife Marina)

Early Career

- Mous began his 51-year JPL career in 1960.
- Initial work: examining the shock waves anticipated as a space capsule reenters the atmosphere.
- Shift in the 1960s to deriving atmospheric information from satellites.
- Development, late 1960s, of the Relaxation Method for the inverse solution of the radiative transfer equation.
  - Derivation of atmospheric temperature and water vapor profiles.
  - Application to the atmospheres of Earth, Venus, Mars, and Jupiter.



Mid-Career

- Continued work on the Relaxation Method.
- Formulation of a multispectral approach to remote sensing in the presence of clouds.
- Use of Mous's equations to generate the first satellite-based global distribution of Earth's temperature, 1980.

A General Relaxation Method for Inverse Solution of the Full Radiative Transfer Equation

MOUSTAFA T. CHAHINE[1]

Jet Propulsion Laboratory, California Institute of Technology, Pasadena 91103

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ABSTRACT

The relaxation method for the inverse solution of the full radiative transfer equation is generalized to solve for all atmospheric parameters which appear in the integrand as functions or functionals, without any *a priori* information related to the expected solution. The method is illustrated by examples in the earth's atmosphere for the determination of water vapor mixing ratio profiles from observations in the 6.3 μ band.

1. Introduction

The interpretation of radiance observations in terms of atmospheric parameters requires the inverse solution of the full radiative transfer equation. A relaxation method of solution (Chahine, 1968, 1970) was developed for the treatment of a class of meteorological parameters which appear mainly as *functions* in the integrand, and was subsequently applied by Conrath *et al.* (1970), Shaw *et al.* (1970) and Smith (1970), for obtaining temperature profiles from actual radiance data measured in the 4.3 or 15 μ CO_2 bands.

In this paper the relaxation method will be generalized for the determination of the other class of parameters which appear as *functionals* in the integrand, such as the variable compositional structure of planetary atmospheres. Our primary aim is to extend the method of solution specifically for reconstructing the composition profile of active absorbers from observations of atmospheric radiances, and to show that the relaxation method leads to unique results without any *a priori* information about the expected solution.

First we discuss the general nature of the relaxation

atmosphere in local thermodynamic equilibrium is

$$I(\nu)=B[\nu,T(p_s)]\tau(\nu,p_s)+\int_{\ln p_s}^{\ln \bar{p}} B[\nu,T(p)]\frac{\partial \tau}{\partial \ln p}d\ln p, \quad (1)$$

assuming a Planck blackbody boundary condition at the surface p_s with

$$B[\nu,T(p)]=a\nu^3/[e^{(b\nu/T)}-1].$$

The surface emissivity is assumed to be unity, and τ is the transmittance of a column of absorbers between levels p and $\bar{p}$.

From an appropriate set of J observed outgoing radiance values $\tilde{I}(\nu_i,\bar{p})$, we aim to determine the unknowns, such as temperature $T(p)$ or composition $q(p)$, by inverse solution of Eq. (1). The extraction of these unknowns from under the integration sign is difficult because it requires the solution of a nonlinear integral equation with fixed limits. Part of the difficulty can be related to the fact that the mathematical properties of the integrand of Eq. (1) precludes the

Mous at JPL, 2010.

Some of Mous's Many Roles During His 51 Years at JPL

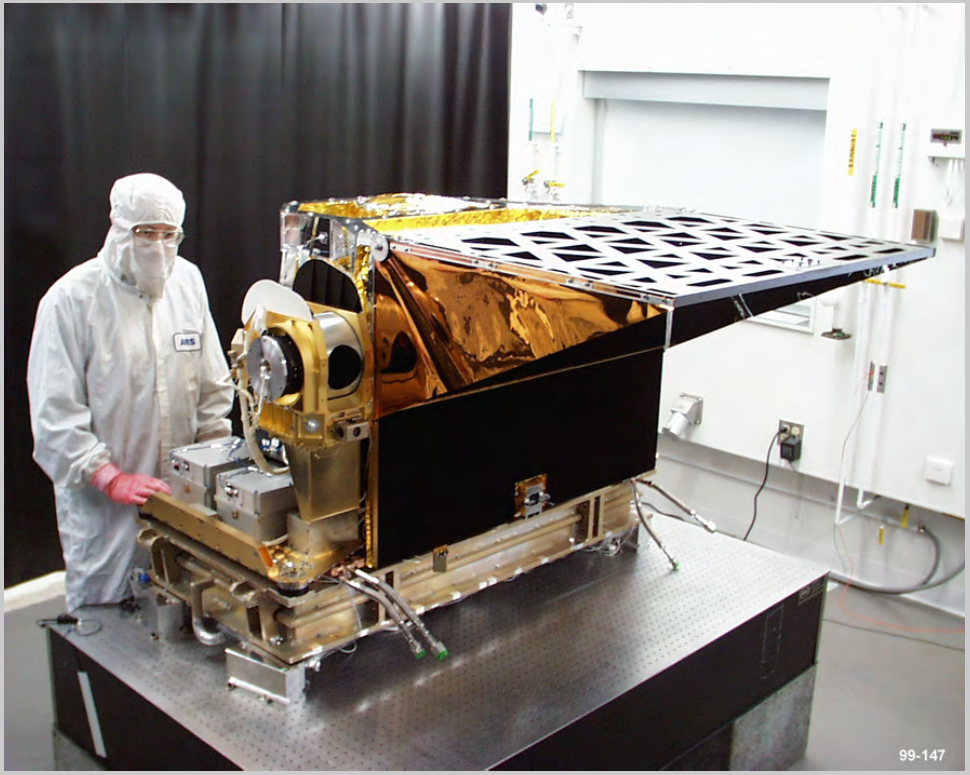
- Scientific researcher, 1960-2011.
- Head of the JPL Planetary Atmospheres Section, 1975-1978.
- Founder of the Division of Earth and Space Sciences, 1978.
- Head of the Division of Earth and Space Sciences, 1978-1984.
- JPL Chief Scientist, 1984-2001.
- First chair of the Science Steering Group of the WMO's GEWEX, 1989-1999.
- Guiding force behind the AIRS instrument, and AIRS Science Team Leader.
- Scientific leader, mentor, colleague, and friend.

WMO = World Meteorological Organization
GEWEX = Global Energy and Water Cycle Experiment

(Photo by and courtesy of Tony Chahine)

AIRS: Pre-Launch

- Mous received his initial funding for AIRS in 1978.
- Mous continued to develop and advocate the AIRS concept, e.g., as a member of the NASA Earth System Sciences Committee (ESSC).
- In 1988, AIRS was selected as one of the primary EOS instruments, eventually placed on the Aqua spacecraft.
- Mous was selected as the first AIRS Science Team Leader and remained in that position for over 20 years, until his death in 2011.
- Under Mous's leadership, AIRS was built in the 1990s to exacting standards, and algorithms were developed to derive from the AIRS data a suite of atmospheric and surface variables.



AIRS under construction (courtesy BAE Systems and JPL).

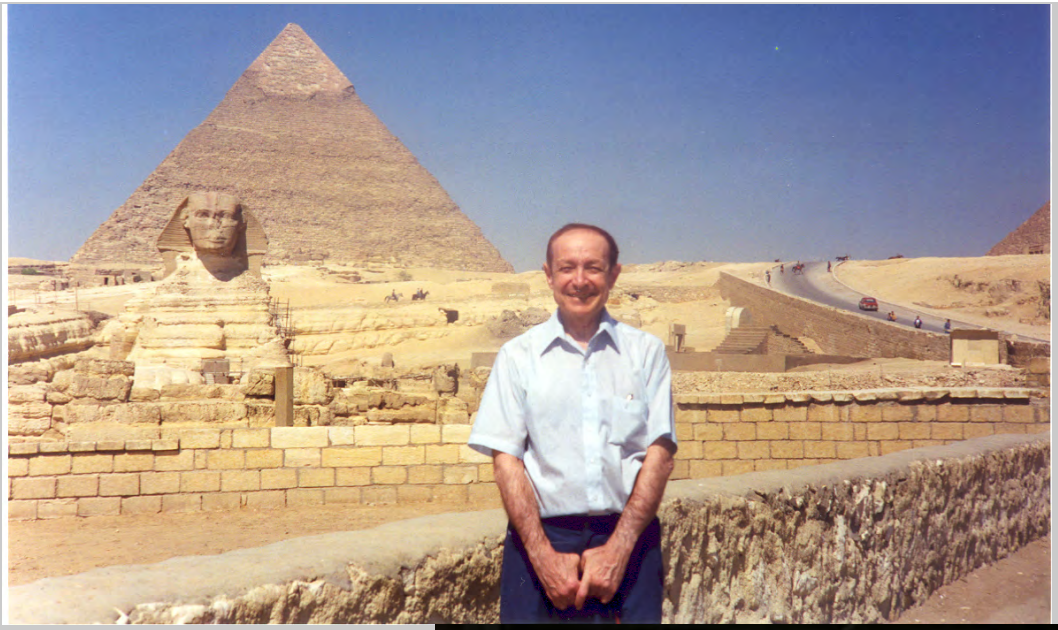
AIRS: Launch and Post-Launch

- AIRS was launched on Aqua on May 4, 2002.
- Since launch, the AIRS instrument has "exceeded all expectations," delivering an exceptional data set that has been used to derive numerous geophysical variables, including outgoing longwave radiation, cloud properties, dust, sea-surface, land-surface, and atmospheric temperatures, surface emissivity, and atmospheric carbon dioxide, carbon monoxide, methane, water vapor, ozone, and sulfur dioxide.
- Incorporation of AIRS data into forecast models has measurably increased forecast skill.

Mous's global mid-tropospheric CO_2 product, 2002-2009 (animation by the NASA SVS).

Varied Moods of the Mature Mous

Mous at JPL (courtesy JPL).



Mous at the Egyptian Pyramids (courtesy Tony Chahine).

Mous in a spacesuit (courtesy Tony Chahine).

Mous in Italy, 2005

At the Vatican, as an invited guest.

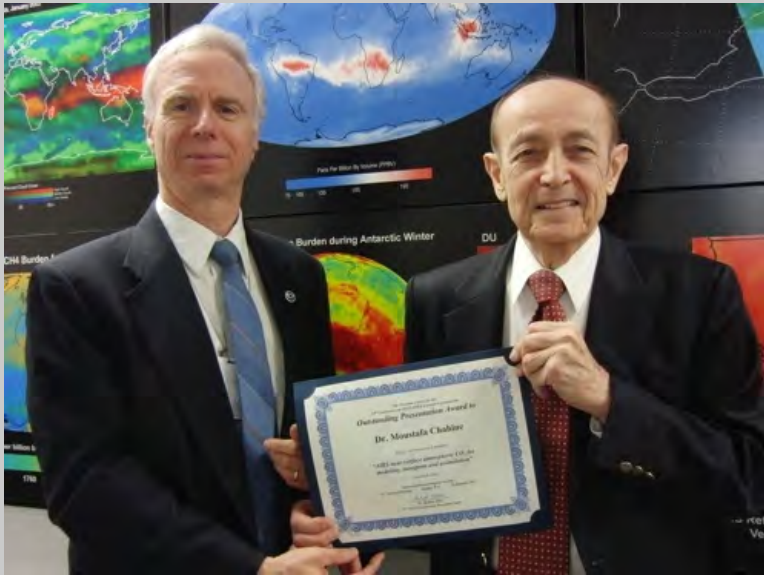
(Photos courtesy Tony Chahine)

At the tomb of Galileo, in Florence.

Some of Mous's Notable Honors

- NASA Medal for Exceptional Scientific Achievement, 1969.
- NASA Outstanding Leadership Medal, 1984.
- William T. Pecora Award from NASA and DOI, 1989.
- Jule G. Charney Award from the AMS, 1991.
- Losey Atmospheric Sciences Award from AIAA, 1993.
- William Nordberg Medal from COSPAR, 2005.
- NASA Medal for Exceptional Scientific Achievement, 2007.
- Election to the U.S. National Academy of Engineering, 2009
- George W. Goddard Award from the International Society for Optics and Photonics, 2010.
- Fellow of the American Physical Society, AMS, the British Meteorological Society, AGU, and AAAS.

AAAS = American Association for the Advancement of Science
AGU = American Geophysical Union
AIAA = American Institute of Aeronautics and Astronautics
AMS = American Meteorological Society
COSPAR = Committee on Space Research
DOI = Department of the Interior



Mous Chahine receiving an Outstanding Presentation Award from Bob Atlas, 3/18/11.

Mous being interviewed at NASA GSFC for an Aqua video, December 3, 2008.

Moustafa T. Chahine died on March 23, 2011, and is survived by his wife Marina, his sons Tony and Steve, his brother Najib, and his sisters Salma and Haifa.

Huge thanks go to Tony Chahine for contributing many wonderful photographs to this presentation.