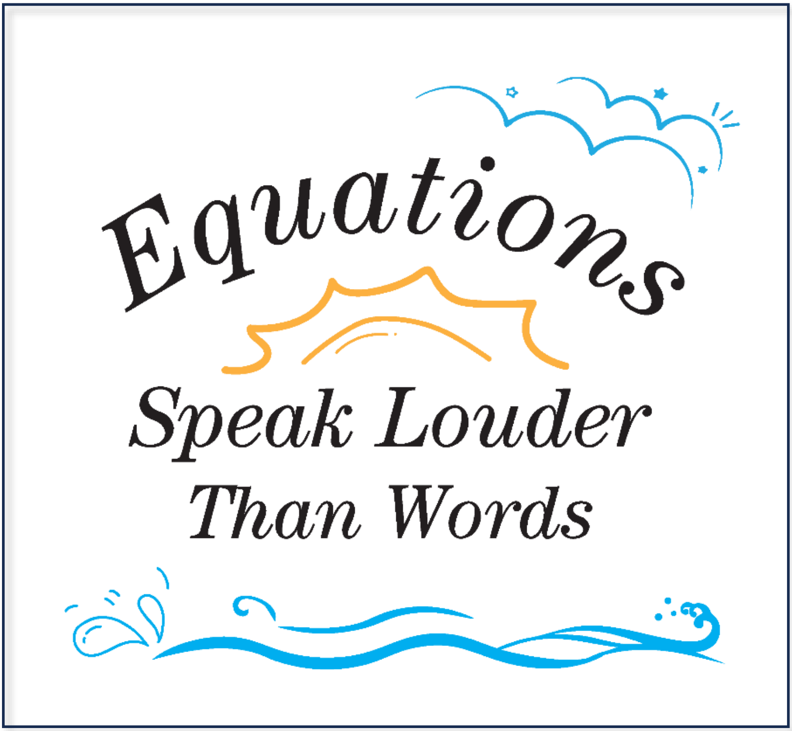


庄逸 Yi Zhuang

Ph. D. Student

Martian Atmosphere | Weather Predictability

Contents

Bio

Born in Hangzhou, China, I am 26-year-old PhD student at Institute of Atmospheric Physics, Chinese Academy of Sciences (IAP-CAS). At the intersection of planetary science and nonlinear dynamic, my research focus on **the predictability of the Martian atmosphere**. Aside from main research works, I often dive into personally interested mathematical, physical or technical problems and summarize with blogs. For future research, I am willing to explore planetary atmosphere dynamics, numerical modelling, predictability and nonlinear dynamic topics.

Education

Institute of Atmospheric Physics, Chinese Academy of Sciences

Ph.D. in Meteorology 2021 - 2026 (Expected)

University of California, Berkeley

Exchange student in Mechanical Engineering 2020 Spring

University of Chinese Academy of Sciences

B. Eng. in Theoretical and Applied Mechanics 2017 - 2021

Publications

1. Yi Zhuang, Wansuo Duan, Li Dong. **A novel Season-dependent weather predictability barrier phenomenon in the Martian Atmosphere**. *Geophysical Research Letters*. Under review.

I also published a book on study guides for high school mathematics in 2017.

Research Experiences

The predictability of Martian Atmosphere

Ph.D. Thesis Supervisor: Prof. Wansuo Duan

2022/09 - 2026/06 (Expected) IAP-CAS

Effects of Topography on Nonlinear Internal Wave in Three-layer Flows

Bachelor's Thesis Supervisor: Prof. Zhan Wang

2020/09 - 2021/06 IMECH-CAS

Material Transport of Flows induced by Nonlinear Internal Wave

Undergraduate Research Practice Supervisor: Prof. Zhan Wang

2019/07 - 2020/12 IMECH-CAS

Conferences

1. **Mars Through Time**. 2025/10. Paris, France. *Poster*.
2. **8th Symposium on Nonlinear Atmospheric and Oceanic Science**. 2025/08. Inner Mongolia, China. *Out-standing Poster (Top 6/32)*.
3. **Distinguished Lectures on Planetary Atmospheres 2023-2025**. 2023-2025. Peking University, China.
4. **AOGS-2025**. 2025/07. Singapore. *Oral*.
5. **2024 National Planetary Science Conference**. 2024/10. Nanjing, China.
6. **2nd, 3rd Summer School on Nonlinear Optimization Methods**. 2020-2021. Online.
7. **2020 BASC Symposium**. 2020/02. UC Berkeley, USA.

Professional Skills

- **Conduct Experiments with LMD Mars Planetary Climate Model**

– Develop Python and Shell scripts for flow control of model experiments, and modify model codes to achieve diverse objectives.

– Develop simple assimilation scheme for incorporating reanalysis data into models, and EGB-SPG optimization program for CNOP calculation.

- **Process data and Conduct Experiments with Python and MATLAB**

– Obtain data from Martian Climate Database through Python interface.

– Post-process and visualization of atmospheric reanalysis datasets and model experiment results.

– Explore mathematical and physical topics numerically, e.g. ENSO recharge oscillator, DJL internal wave simulation.

- **Profound Understanding of Research Fundamentals**

– Predictability study, origin of forecast errors, methods for improving forecast, concept and application of CNOP.

– Characteristics and key processes of Martian atmosphere.

– Behavior and characteristics of simple or stochastic dynamical system.

– Mathematical and Physical skills for solving differential equations and deriving governing equations for atmosphere and oceans.

- **Language**: English (TOEFL 100), Novice French and Japanese.

- **Other technical skills**: Latex, Git, Vue.js, Mathematica, WordPress, etc.

Transferrable Skills

- Managed research group’s **multimedia equipment** to ensure seamless hybrid (online/offline) meetings.
- Assisted in **hosting visiting international scholars** 3 times, coordinating their tours and gift exchanges.
- As a member of the **LASG Student Union Presidium**, lead information collection and equipment management for commencement ceremonies and graduate academic forums.
- Participate in **conference logistics** including registration, materials distribution, and poster mounting.

Awards and Honors

Merit Student of University of Chinese Academy of Sciences (UCAS) 2024/2019 2025/05, 2019/12

Outstanding President of the LASG Student Union Presidium 2024/03

Freshman Scholarship of IAP-CAS 2020/07

Guo Yonghuai Mechanics Honors Scholarship and Competition-Based Scholarship of UCAS 2019/09

My Math Book

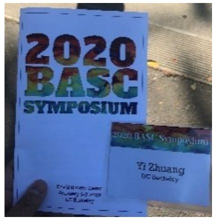
In the summer of 2017, I authored and published a study guide titled "Ace Your High School Math with the Masters." The project originated from my personal need to systematically consolidate mathematical formulas into a streamlined reference, which I initially called "Reference for High School Mathematical Study." Also, for sharing techniques with my friends, I enriched the content by adding my practical insights.

The drafting process was accelerated by a policy change in the Zhejiang provincial college entrance exam starting in 2014. This policy, which required me to focus only on Chinese, Mathematics, and English from October 2016 onward, afforded me the time to refine and complete the manuscript. Out of my expectation, the book was well-received by peers and even gained media attention. Later, my parents assisted me with its formal publication.

At university, I have continued this passion for synthesizing knowledge. I compile and reframe lecture notes into structured collections for courses such as Linear Algebra, Mathematical and Physical Methods, Applied Mathematics, Basic Physical Experiments, Heat Transfer, and Mesoscale Meteorology. I am also constantly exploring better ways to share these resources, having utilized the WeChat public platform, a personal website built with WordPress, and currently maintaining a static site with Jekyll on GitHub.

One Semester in UC Berkeley

In January 2020, I commenced a semester abroad at UC Berkeley as an exchange student through the University of Chinese Academy of Sciences. This is my first time living and studying abroad for several months. Despite being enrolled in Mechanical Engineering, I pursued an interdisciplinary curriculum. This includes “Convective Transport and Computational Methods”, which is a graduate-level course; “Atmospheres”, which is based on my decision to study atmospheric science; and “Nonlinear Dynamics and Chaos”, which is an interested mathematical class organized by students who were only one year my senior. I also attended the 2020 BASC symposium, marking my first participation in an atmospheric science conference. The interactions with professors there provided crucial guidance and encouragement for my future research.



The program was abruptly interrupted by the COVID-19 pandemic after just half a semester on campus. While many peers returned home, I persisted, completing all courses remotely by May despite significant logistical challenges, including securing a return flight with embassy assistance.

A pivotal moment during that time was the passing of Prof. Adam P. Showman, news I initially encountered in my Atmospheres class maybe. While it seemed a distant event then, I finally recognized its profound influence on the direction of my graduate studies many years later.

Applied Mathematics for Undergraduate

My undergraduate research supervisor, Prof. Zhan Wang from the Institute of Mechanics, Chinese Academy of Sciences, is an expert in applied mathematics. His course, "Applied Mathematics in Engineering Science," was a profound inspiration. He masterfully covered fluid dynamics equations and theoretical solving techniques, such as variational methods and asymptotic analysis, entirely on the chalkboard. Though I set down his notes and tried to organize them, I found truly mastering these techniques challenging.

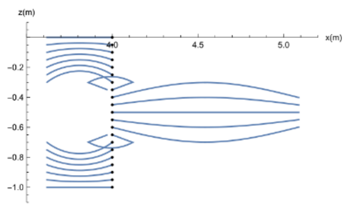
定理 2.6.1 (Rund-Trautman 等式). 若泛函 $J = \int_a^b L(t, q_i, \dot{q}_i)\,\mathrm{d}t$，在如下无穷小变换下不变

$$t' = t + \epsilon\tau + \cdots \qquad q_i' = q_i + \epsilon\xi_i + \cdots \tag{2.272}$$

则成立下面等式

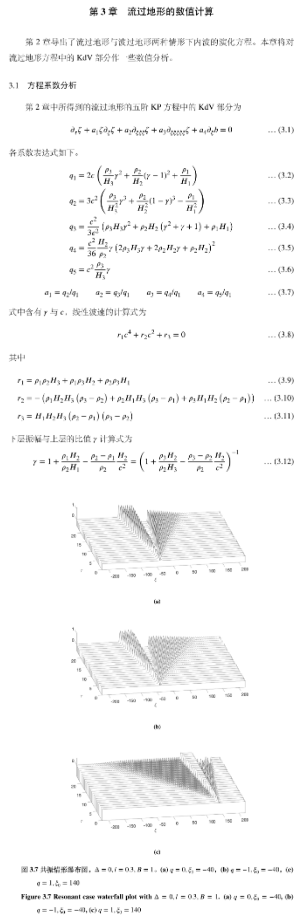
$$\frac{\partial L}{\partial q_i}\xi_i + p_i\dot{\xi}_i + \frac{\partial L}{\partial t}\tau - H\dot{\tau} = 0 \tag{2.273}$$

Under his guidance, I undertook two theoretical projects. The first is “Material Transport of Flows induced by Nonlinear Internal Waves”, including KdV, MCC and DJL type. Later, I worked on “Effects of Topography on Nonlinear Internal Wave in Three-layer Flows” as my bachelor’s thesis, where asymptotic methods were applied to derive the fifth-order KdV equation. In both theoretical works, I was stuck at certain points, making no progress for some time. It is tough as you have to find the direction of derivation independently. For the first, it is the mathematical expression for material



transport by wave-induced flows. For the second, it is the assumption that the third-order term should be small for fifth-order equation. Once the key obstacle was resolved, subsequent progress proceeded smoothly.

It was regrettable that these theoretical works were not published—partly due to their abstract nature and my subsequent shift to atmospheric science for my Ph.D.—the experience was invaluable. In my current field, where numerical experiments dominate, such "old-school" theoretical approaches are rare, and I've been out of touch with this kind of formula derivation for quite a while. While I personally prefer this foundational style, I wonder if I would have opportunities to apply it in the future.



第 3 章　流过地形的数值计算

第 2 章导出了流过地形与波过地形两种情形下内波的演化方程。本章将对流过地形方程中的 KdV 部分作一些数值分析。

3.1　方程系数分析

第 2 章中所得到的流过地形的五阶 KP 方程中的 KdV 部分为

$$\partial_\tau \zeta + a_1 \zeta \partial_\xi \zeta + a_2 \partial_{\xi\xi\xi} \zeta + a_3 \partial_{\xi\xi\xi\xi\xi} \zeta + a_4 \partial_\xi b = 0 \qquad \ldots (3.1)$$

各系数表达式如下。

$$q_1 = 2c\left(\frac{\rho_3}{H_3}\gamma^2 + \frac{\rho_2}{H_2}(\gamma-1)^2 + \frac{\rho_1}{H_1}\right) \qquad \ldots (3.2)$$

$$q_2 = 3c^2\left(\frac{\rho_3}{H_3^2}\gamma^3 + \frac{\rho_2}{H_2^2}(1-\gamma)^3 - \frac{\rho_1}{H_1^2}\right) \qquad \ldots (3.3)$$

$$q_3 = \frac{c^2}{3e^2}\left(\rho_3 H_3 \gamma^2 + \rho_2 H_2 \left(\gamma^2+\gamma+1\right) + \rho_1 H_1\right) \qquad \ldots (3.4)$$

$$q_4 = \frac{c^2}{36}\frac{H_2}{\rho_2}\gamma\left(2\rho_3 H_3 \gamma + 2\rho_2 H_2 \gamma + \rho_2 H_2\right)^2 \qquad \ldots (3.5)$$

$$q_5 = c^2 \frac{\rho_3}{H_3}\gamma \qquad \ldots (3.6)$$

$$a_1 = q_2/q_1 \qquad a_2 = q_3/q_1 \qquad a_3 = q_4/q_1 \qquad a_4 = q_5/q_1 \qquad \ldots (3.7)$$

式中含有 γ 与 c，线性波速的计算式为

$$r_1 c^4 + r_2 c^2 + r_3 = 0 \qquad \ldots (3.8)$$

其中

$$r_1 = \rho_1\rho_2 H_3 + \rho_1\rho_3 H_2 + \rho_2\rho_3 H_1 \qquad \ldots (3.9)$$

$$r_2 = -\left(\rho_1 H_2 H_3 (\rho_3-\rho_2) + \rho_2 H_1 H_3 (\rho_3-\rho_1) + \rho_3 H_1 H_2 (\rho_2-\rho_1)\right) \qquad \ldots (3.10)$$

$$r_3 = H_1 H_2 H_3 (\rho_2-\rho_1)(\rho_3-\rho_2) \qquad \ldots (3.11)$$

下层振幅与上层的比值 γ 计算式为

$$\gamma = 1 + \frac{\rho_1 H_2}{\rho_2 H_1} - \frac{\rho_2-\rho_1}{\rho_2}\frac{H_2}{c^2} = \left(1 + \frac{\rho_3 H_2}{\rho_2 H_3} - \frac{\rho_3-\rho_2}{\rho_2}\frac{H_2}{c^2}\right)^{-1} \qquad \ldots (3.12)$$

(a)

(b)

(c)

图 3.7 共振情形瀑布图，$\Delta = 0, l = 0.3, B = 1$。(a) $q = 0, \xi_0 = -40$，(b) $q = -1, \xi_0 = -40$，(c) $q = 1, \xi_0 = 140$

Figure 3.7 Resonant case waterfall plot with $\Delta = 0, l = 0.3, B = 1$. (a) $q = 0, \xi_0 = -40$, (b) $q = -1, \xi_0 = -40$, (c) $q = 1, \xi_0 = 140$

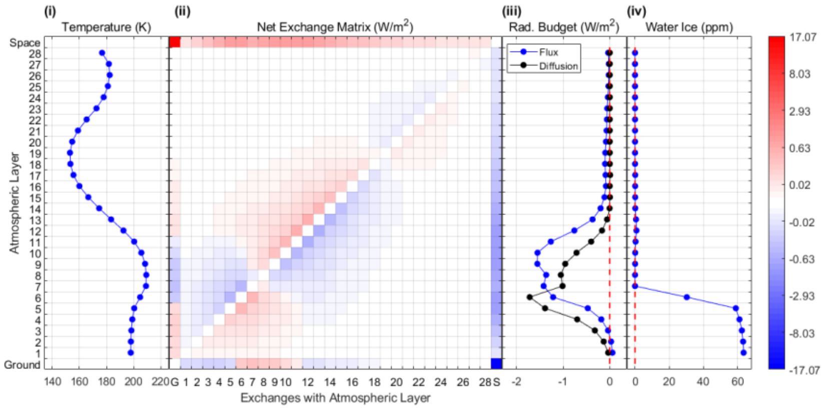
Apart from this, Prof. Zhan Wang has been a pivotal figure throughout my early academic journey, offering invaluable guidance during my undergraduate studies, my time at Berkeley, and even as I planned my future post-PhD. What I admire most is his proficiency in mathematics, profound insight and willingness to support students across different fields. It is these qualities that make him exactly the kind of scholar and mentor I aspire to become.

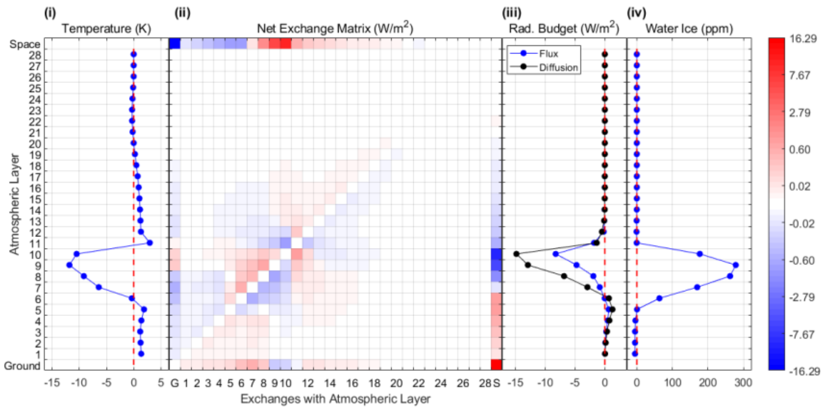
Net Exchange Matrix of Longwave Radiation

My PhD research unexpectedly pivoted to the Martian atmosphere, a field entirely new to me before 2022. In September 2023, I encountered a persistent problem: why cold initial temperature errors in the lower atmosphere strengthen in my experiments. It was not until spring 2024 that I discovered water ice takes effect in this case, which marked overcoming one of my toughest obstacles — think of something that wasn't even in your mind.

A temperature tendency decomposition pinpointed longwave radiation as the cooling source. However, with my foundational knowledge limited to basic concepts like $\varepsilon\sigma T^4$, I could not explain why water ice clouds were losing more longwave radiation than they absorbed. I began by consulting senior researchers and literature, which revealed the complexity of cloud radiative effects and their uncertain applicability to Mars. This led me to examine the model's mechanics directly, where I discovered that radiative transfer was far more complex than I had anticipated. Venturing into this field and studying relevant concepts cost me several weeks.

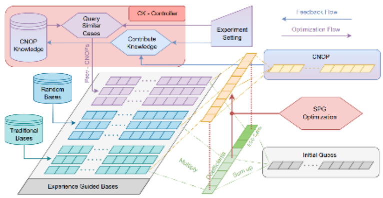
A key insight came when I noticed the LMD model uses the net exchange formulation by Dufresne (2005) for longwave calculations, unlike the common flux formulation. This method clearly illustrates longwave exchange between atmospheric layers, making it ideal for diagnosing my results. After familiarizing myself with this approach, I modified the model code to output the necessary matrix data, as it is not included in normal outputs. The results were conclusive: by decomposing the longwave budget into layer-by-layer net exchanges, I clearly demonstrated that the cloud layer simultaneously absorbs longwave radiation from the ground and lower atmosphere while emitting stronger outgoing longwave radiation, thereby completing the causal chain.





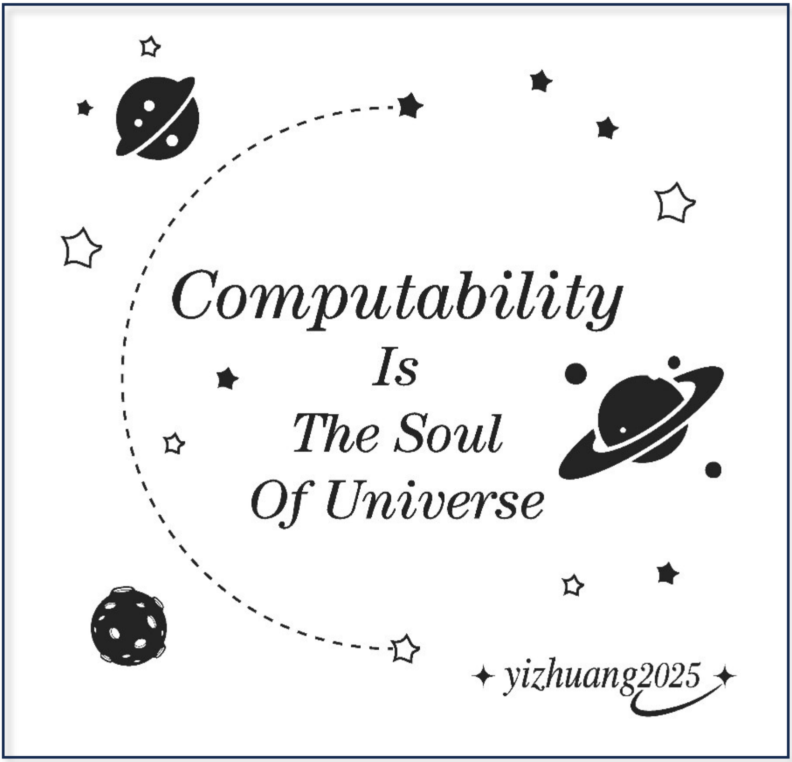
EGB-SPG Framework for CNOP Calculation

Since 2025, I have been developing a numerical program to calculate the Conditional Nonlinear Optimal Perturbation (CNOP) in the Martian atmosphere. CNOP identifies the initial errors that cause the largest forecast errors, and is derived by solving a nonlinear optimization problem. Initially, I adapted an existing code from senior group members, which combined dimension reduction with the Spectral Projected Gradient (SPG) algorithm, and transferred it to the LMD Martian model. However, the preliminary optimization results were unsatisfactory.



My supervisor suggested incorporating Bred Vector (BV) results I had obtained from earlier work. From February to April, I iterated through four versions, finding that its effectiveness varied across different time periods. This led me to take a further step: not only using BV results but leveraging all CNOP results in previous cases. This idea became the core logic of a new framework, where each CNOP is computed using knowledge from previous calculations and subsequently contributes to future ones. I named this framework Experience-Guided Bases-SPG (EGB-SPG), kind of inspired by Hofstadter's book.

Implementing this framework proved challenging. Through multiple iterations, I gradually realized that I was, in effect, designing a database from the ground up. This concept strongly appeals to me — it mirrors how we organize knowledge, with every new advance building upon this evolving "database."



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