But first...

- Paper 4 is due at beginning of class Thursday
- No extensions over Spring Break!
- Thursday is movie day...
- "An Inconvenient Truth"
- Today we'll start by finishing up Mars climate...

Recall from last Tuesday...

Comparing Venus, Earth, & Mars

- Surface and Atmosphere of Venus
  - Radar mapping results
  - Greenhouse gone wild!
- Surface and Atmosphere of Mars
  - The view from orbiters, landers, and rovers
  - Once Earthlike, now not... How?
- Lessons for our home world...

Summary: Venus

- Radar has been used to penetrate the clouds of Venus and discover the underlying geology of the planet
  - Radard measures roughness (bright=rough; dark=smooth)
- Abundant evidence for volcanism, tectonism, impact, and erosion on Venus!
- Entire planet appears to have been resurfaced, possibly by volcanoes, ~500 million years ago
- Surface composition appears similar to Earth's volcanic rocks
Venus & Earth

- Venus and Earth similar in bulk properties, but with very different atmospheres
- The Greenhouse Effect is responsible for the high surface temperature of Venus
- Earth and Venus have had divergent histories
  - Similar starting compositions
  - But liquid water on Earth has removed most of the greenhouse gas CO$_2$ from our atmosphere
  - With no oceans, CO$_2$ has built up and caused the greenhouse to run wild on Venus

Large Martian dust storm in summer 2007...

Mars S. Hem. Dust Storm
June 20 to July 18, 2007
MRO/MARCI (MSSS)
Mars has Polar Caps

- Mars winters are so cold (-120°C or about -200°F) that CO₂ condenses out onto the surface!
  - 25% of the atmosphere "snows out" onto the ground!
  - Analogy for Earth: at -320°F, N₂ would snow out
- A seasonal CO₂ polar cap a few meters thick forms
- In spring, the CO₂ sublimes back to the atmosphere
- There are permanent polar caps underneath
  - Composed primarily of water ice! (only minor CO₂ ice)
  - May be 1-2 km thick! (depth uncertain...)

Geology of Mars

- Mars is a geologically exciting place!
  - Abundant evidence of past volcanism
  - Abundant evidence of past tectonism
  - Abundant evidence of past impact cratering
  - Abundant evidence of past and current erosion
- Our knowledge comes from orbital imaging, augmented by close-up studies at 5 specific landing sites

The View from the Surface

- Five missions have successfully returned images and other data from the surface of Mars
  - Viking Lander 1
    - 600 kg landed mass, powered by two 238Pu RTGs
    - Landing site: Chryse Planitia (22.7° N, 48.2° W)
    - Operated from July 20, 1976 to November 13, 1982
  - Viking Lander 2
    - Landing site: Utopia Planitia (48.3° N, 226.0° W)
    - Operated from September 3, 1976 to April 1, 1980
  - Mars Pathfinder
    - 360 kg landed mass (Rover = 16 kg), solar panels
    - Landing site: Ares Valles (19.3° N, 33.6° W)
    - Operated from July 4, 1997 to September 27, 1997
The View from the Surface

- **Mars Exploration Rover Spirit**
  - 180 kg landed mass, powered by solar panels
  - Landing site: Gusev crater (14.6° S, 175.5° E)

- **Mars Exploration Rover Opportunity**
  - Landing site: Meridiani Planum (2.0° S, 354.5° E)
  - Landed on January 24, 2004, *Still going!*

- **Next: Phoenix Mars polar lander**
  - 350 kg landed mass, powered by solar panels
  - Landing site: high northern latitudes (70° N, 250° E)
  - Landing planned for Memorial Day weekend 2008... Stay tuned!

Viking Landers (1976-1982)

- Trenches at VL2
- Frost at VL2
- Dunes, boulder at VL1

Mars Pathfinder (1997)

"...HOLD STILL, LARRY, IT'S TAKING ANOTHER PICTURE..."

By Will Hamblin, The Times-Picayune, New Orleans, La., Tribune Media Services
Today is Spirit sol 1489 and Opportunity sol 1469...

Volcanism on Mars

- Two large volcanic provinces on Mars
  - Tharsis: An enormous 10 km bulge in the crust
  - Elysium: Smaller, localized elevated region
- Relative age dating from crater counts indicates that these volcanoes are relatively young (< 100 million years?)
- Mars may be volcanically active today, though we have not seen direct evidence...

Mars Tectonism

- Spectacular rifting of the Martian crust has occurred
  - Triggered by bulging of Tharsis?
  - Largest rift: Valles Marineris canyon system
    - 5000 km long, 100 km wide, 7 km deep (~ 5 miles deep!!)
- No signs of compression (e.g., no folded or uplifted mountains)
- Speculations, but no conclusive evidence for Earth-like plate tectonics on Mars
Impact Cratering on Mars

- Thousands of impact craters on Mars
- Sizes range from a few meters to 1500 km

- Many more craters in the south (older)
- But even "young" areas have many craters

Age of the surface based on craters

- Craters used to develop the stratigraphy of the Martian surface
- Absolute ages have large uncertainties
- Most recent volcanism: from 0.1 to 2.0 billion years ago?
Mars Erosional Features

- Evidence for substantial movement of materials on Mars
  - Gravity
    - Landslides, Slumps, Ejecta Blankets
  - Wind
    - Dunes, Streaks, Dust Storms, Dust Devils
  - Water
    - Outflow channels, Runoff channels (valley networks)
  - Ice
    - Polar ice caps today, glaciers elsewhere long ago?

Topography of Mars

- General trend:
  - North is low (blues); South is high (reds)
  - Implication: north "young", south "old"
  - Reference elevation: 6.1 mbar pressure

- Enormous range of elevations on Mars!
- Highest high: +25 km (Olympus Mons)
- Lowest low: -5 km (Hellas Basin)
- Factor of 20 in atmospheric pressure!
Mars Climate

Today

- Cold
  - Average temperature: -60°C
- Bone Dry
  - Equivalent to only a few microns of liquid H_2O
- Lifeless, as far as we can tell
  - Viking was sensitive to ppb levels of organics
  - No ozone layer: Sun's UV gets to surface

Mars ~3 billion years ago?

- Warm
  - Thicker atmosphere, more greenhouse effect
- Wet
  - More water, in liquid form?
- Hospitable?
  - Same ingredients for life as early Earth?

The Climate of Mars has Changed Drastically

This is a THEORY: What's the evidence?

Evidence for Mars Climate Change

- Valley Networks
  (a.k.a. "Runoff Channels")
- Heavy erosion of old craters
  (degraded rims, no ejecta blankets)
- Presence of surface and subsurface ice
  (abundant "stored" water?)

Mars had a Magnetic Field...

- Mars has no global magnetic field today
- If Mars has (or had) a molten iron core like the Earth, then why doesn't it have a magnetic field?

- Data from the Mars Global Surveyor mission reveal regions of the surface that appear to retain a remanent magnetism
- Was the core molten long ago?
- Consistent with early volcanism
- But the data still sparse and somewhat controversial...

Acuña et al., 2008
Martian Channels

- Outflow channels
  - Hundreds of km long, tens of km wide
  - Contain clear signs of fluid (water) erosion
  - Contain evidence of catastrophic flooding
  - Source areas: collapsed terrain
  - Formed by rapid melting of subsurface ice?
    - How? Volcanism? Impacts?
- OLD
  - 2.5-3.5 b.y.?
  - Drainage: S to N

Valley Networks

- a.k.a "runoff channels"
- Only tens of km long, a few km wide
- Little/no evidence of fluid erosion
- Caused by sapping (undermining)?
- VERY OLD
  - 3.5 b.y. + ?
  - Only found in the ancient S. highlands

Polar Layered Deposits

- Evidence for cyclical climate change on Mars
- Many years of warmer, dustier conditions
  - Accumulation of dark, dusty airfall layers in the ice
- Then, many years of colder conditions
  - Less dust accumulation, brighter, icier layers

From the thickness of the layers (tens of meters) and an assumption about the rate of dust accumulation, we can estimate how long it took to form each layer: 10^5 to 10^6 years

Darker layer (more dust, less ice)
Brighter layer (less dust, more ice)

etc...

N. Polar layers in Viking image
Trough is about 500 m deep
Each layer is about 50 m thick

Layers about 10 m thick could be detected from early orbiter images...

Layers only a few meters thick can be detected from newer high-resolution orbital images...
Liquid Water on Mars?

• Can liquid water exist on Mars today?
• Probably not, according to the phase diagram of water

- Phase of water (solid, liquid, or vapor) depends on Pressure & Temperature
- Important concept, but not well described/discussed in the textbook...

If the temperature on Mars is not > 273 K and the pressure is not > 6.1 mbar, no liquid water is possible.

Digression: Snowballs on Mars?

• Q: Could you have a snowball fight on Mars?
• A: Sadly, probably not...

- Compressing snow on Earth turns some of the snow into liquid water (line ABC), which "cements" the snowball...
- On Mars, the phase remains solid, whether H₂O or CO₂ (line DEF)
- This also means:
  - no skiing/snowboarding on Mars
  - no ice skating on Mars :

But then how can we explain the evidence for very recent liquid water on the surface from these and other new images??

- T > 273 K and P > 6.1 mbar?
- Other processes??

The state of our ignorance about Mars is profound.

Climate Change on the Earth...

✓ We know that significant and cyclic climate changes have occurred on Earth (e.g., ice ages)
✓ These climate changes are thought to be caused by variations in Earth's orbital parameters
  - Earth's polar axis precession: ~26,000 year timescale
  - Changes in Earth's tilt: ~ 41,000 year timescale
  - Changes in Earth's eccentricity: ~100,000 year timescale
✓ Sometimes called “Milankovitch Cycles”
Climate Change on Mars...
✓ The same kinds of orbital variations occur for Mars:
✓ Cyclic climate changes there too?

Summary: Mars
✓ Mars is a small rocky planet with a thin atmosphere
✓ Telescopic observations reveal changing surface features (polar caps, dust storms, dark features)
✓ The Martian atmosphere is almost entirely CO$_2$, and the surface pressure is only ~1% of Earth's
✓ Mars has seasons, and the planet's eccentric orbit results in big differences in seasonal weather
✓ Mars has been extensively studied by spacecraft

Summary: Mars & Earth
✓ There is very good evidence that the Martian climate was very different 3-4 billion years ago than today
  - Valley networks, suggesting subsurface ice or water
  - Outflow channels, indicating huge floods
  - Polar layered deposits, suggesting cyclic changes
✓ Mars climate changes may be caused by the same astronomical orbit variations that are thought to cause major changes in Earth's climate
✓ Amazingly, liquid water may be stable near the Martian surface today, despite contrary predictions
✓ Major implications for life on Mars... (Part 5 of class...)

"Milankovich Cycles"
• Astronomical forcing of changes in a planet's spin & orbital motions
  • Earth's precession (wobble) varies in ~20,000 yr cycles
  • Earth's obliquity (tilt) varies in ~40,000 yr cycles
  • Earth's eccentricity varies over ~100,000 and ~400,000 yr cycles

Climate Change on Mars...

Summary: Mars & Earth
Terrestrial Climate Change...

(external reading...)


• Feedbacks
• Land, Air CO\(_2\) exchange?
• Do Clouds cool or warm?
• Role of dust/soot?
• Ocean CO\(_2\) take-up?
• Sea level rise?
• Local weather changes?

Sagan (1990)

"Cromesus and Cassandra: Policy response to global warming." Carl Sagan’s acceptance speech for the 1990 Oersted Medal presented by the American Association of Physics Teachers, 23 January 1990


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"Last winter was so cold! I don’t notice any global warming!"

Global warming is ubiquitous, but its magnitude is far too early about one degree Fahrenheit. Day-to-day weather fluctuations are roughly 1.5 degrees F. Even averaged over a season, this natural year-to-year variability is about two degrees F. Global warming does not make away every season warmer than a few decades ago. But the global warming already makes the probability of a winter as “normal” as winter of about 10 percent, rather than the 30 percent that prevailed from 1958 to 1980.

"The warming of the past century is just a natural rebound from the little ice age."

Any rebound from the European little ice age, which peaked in 1550–1700, would have been largely complete by the 20th century. Indeed, the natural long-term climate trend today would be a cooler climate. But it is not the result of any human activity.

"Isn’t human-made global warming saving us from the next ice age?"

Yes, but the gases that we have added to the atmosphere are already far more than needed for that purpose.

The surface warming is mainly due to feedback from the atmosphere, regions such as central Asia and Alaska. The largest areas of surface warming are over the ocean, far from urban locations. [se map at www.giss.nasa.gov/gistemp/overview].

Temperature profiles in the solid earth, and drained of sunlight around the world, imply warming of the continental surface between 0.5 and 1 degree C in the past century.

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An example of the intersection of planetary science, Earth science, geopolitics, and national security policy...

Next Time...

- Movie Day!
- “An Inconvenient Truth”
- Climate Change goes Hollywood!
- Turn in Paper 4 on Thursday!