I. Effects of local geometry on Accumulation and Desorption of ice

Michael Hecht, Jet Propulsion Laboratory

- Importance of local geometry on a local scale
- Importance of local geometry on a global scale
- CO_2 roughness and albedo
- H_2O temperature variations & humidity

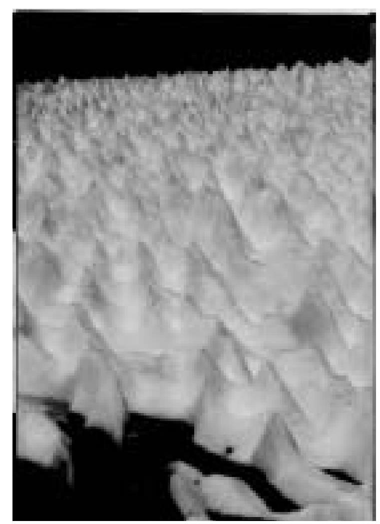
Topography, Topography, Topography

Several papers have addressed thermal balance of small 3-D structures on Mars (many have addressed slopes). Examples:

- Svitek & Murray, 1990 (rock shadows)
- Ingersoll, Svitek Murray, 1992 (spherical crater bowls)
- Kossacki, Markiewicz & Keller, 2000 (trenches), 2001 (roughness).
- Hecht, 2002 (gullies)
- Schorgofer, Aharonson, Khatiwala, 2002 (slope streaks)

Model surface ←

Real surfaces →

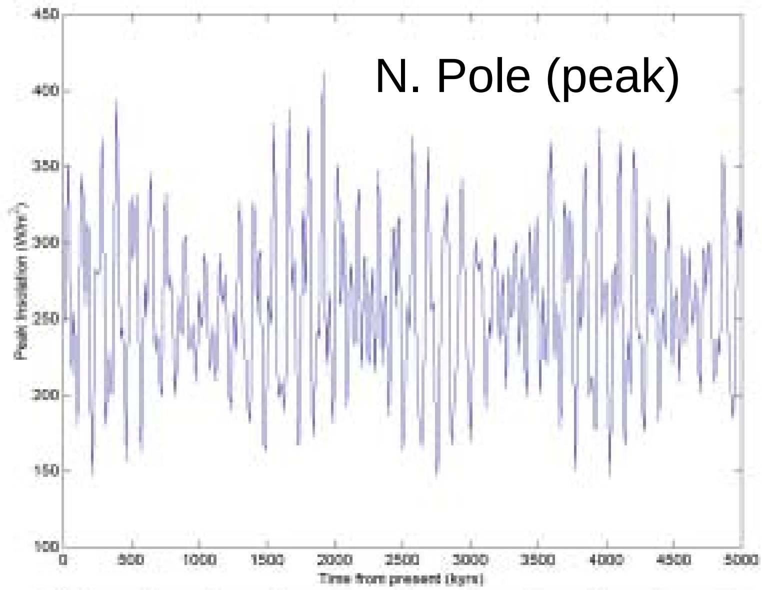


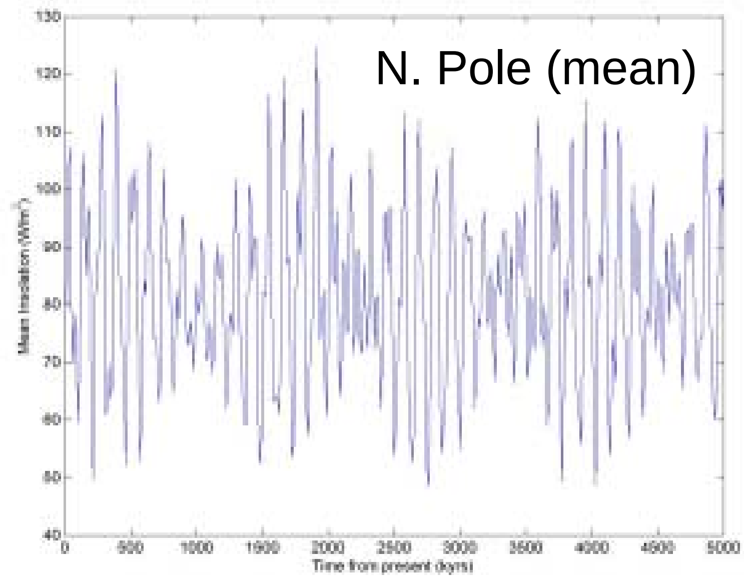
White mountain (CA) penitentes

Greenland moulin

Importance of local variation on a global scale

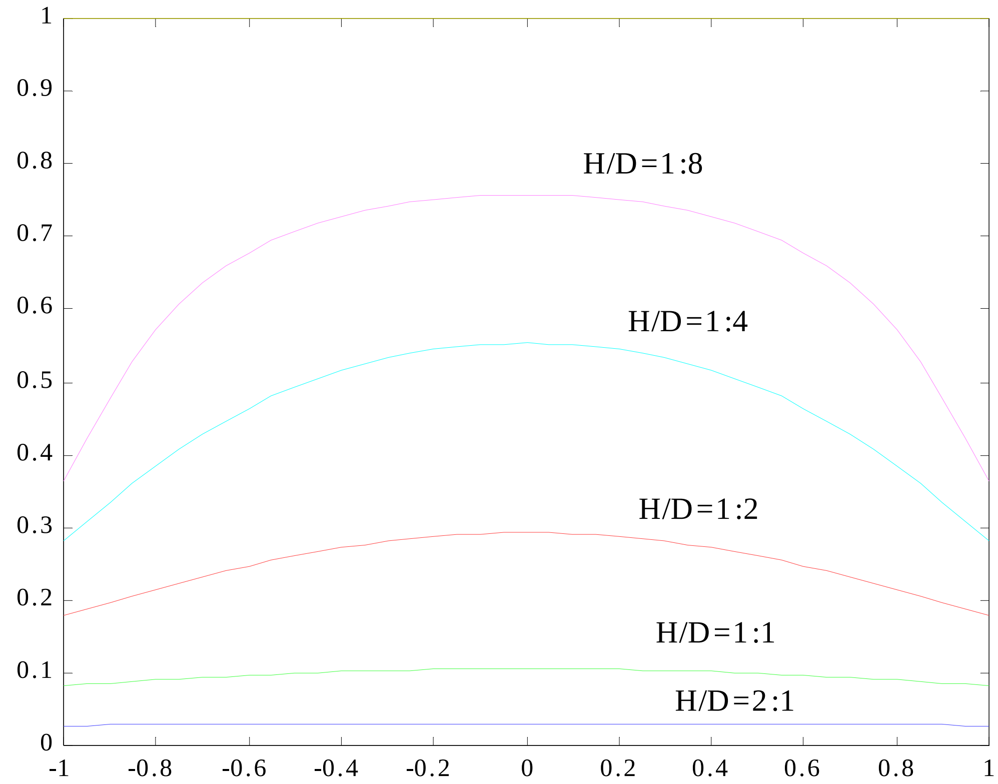
- Peak or mean insolation (at poles) varies with orbital elements by factor of ~2.
- Albedo can vary by factor of 4 or more (see Kieffer et al. ‘00)
- Apparent emissivity can vary with geometry by factor of 2 or more (see Ingersoll et al. ‘92, Hecht ‘02).
- Sublimation varies as power law of temperature, so a small fraction of the surface can impact atmosphere
- ...and accumulated frost could melt in favorable geometries (See Hecht, Icarus 2002). Local present conditions may mimic average past conditions.





Physical Processes

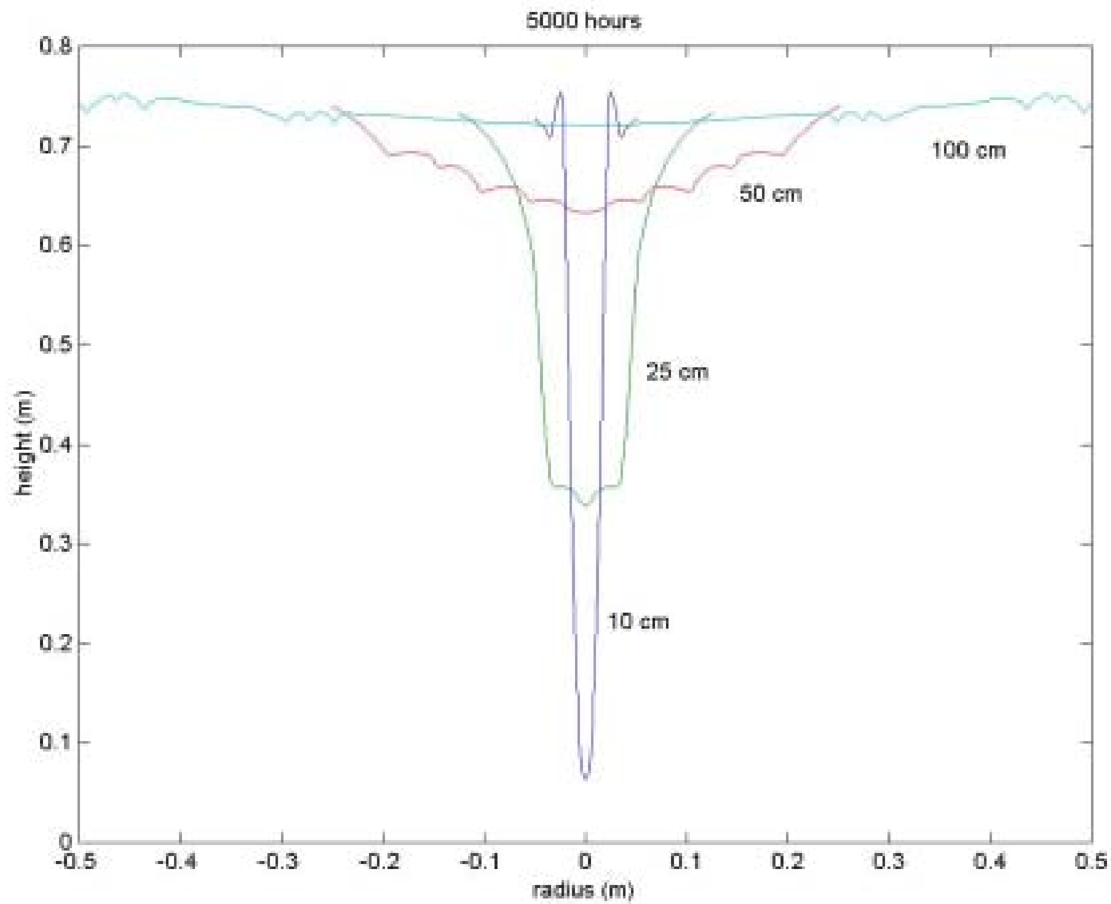
1. Sun-facing surfaces get warm (>273K) anywhere, anytime
2. Thermal gradients are large (15 cm scale length)
3. Convection is inefficient, sublimation & condensation efficient at moving heat
4. H_2O sublimation is rapid in sunlight: ~1 mm/hr at 273K, 100 W/m^2, without boiling
5. Apparent emissivity is low in sheltered areas
6. Peak insolation increases on slopes
7. Total albedo decreases with roughness, dust. For CO_2 ice, water could be a factor.



Radiation across bottom of 273K cavity to cold sky for various height/diameter ratios. Even for shallow depressions, it gets warm near the walls when the sun shines in

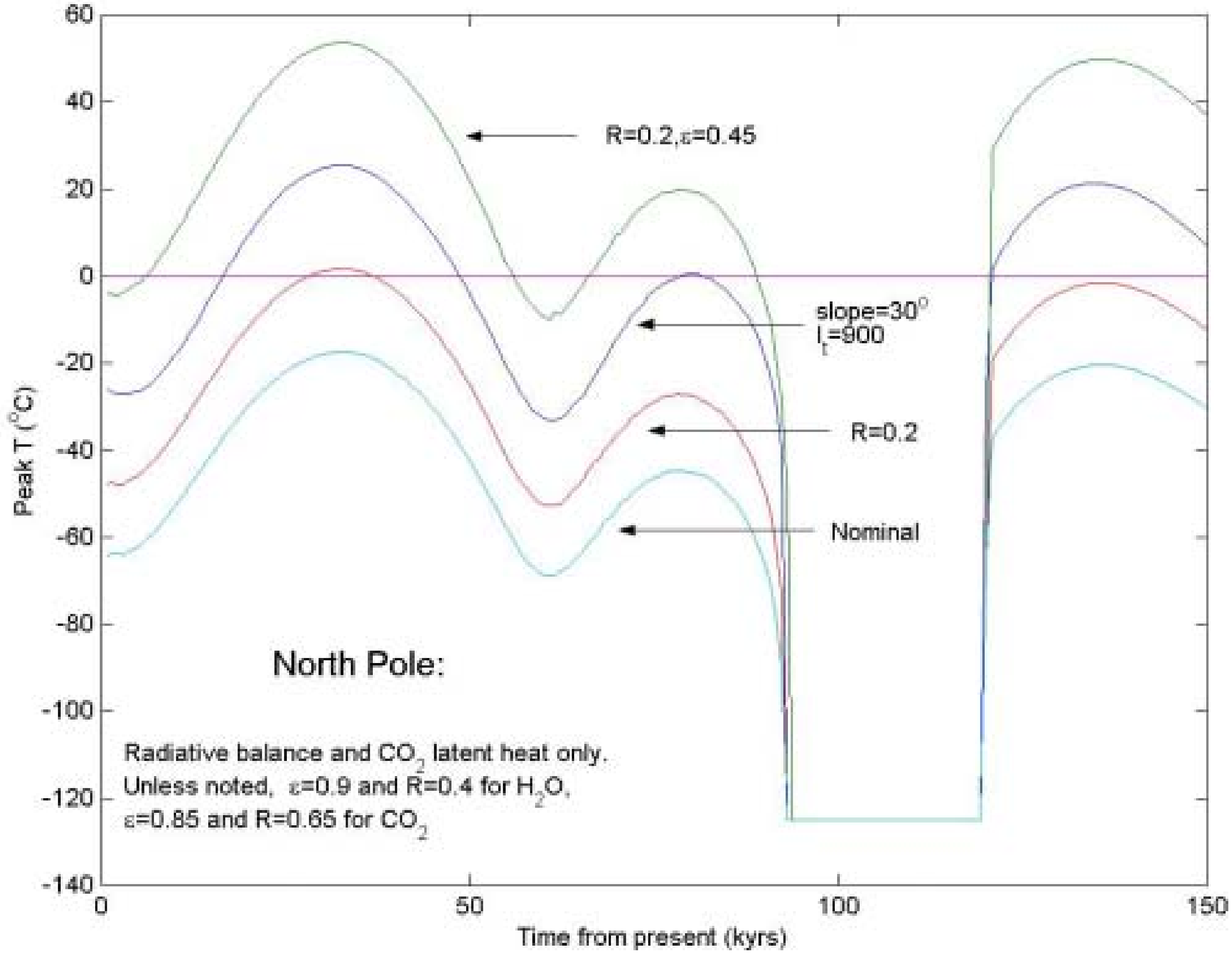
CO_2 roughness

- Low sun, (and high albedo) induces roughening of surface, resulting in decrease of albedo. At present, for example, this favors a darker N.polar seasonal cap, (Ingersoll, Svitek, Murray '90) and is consistent with insolation dependence of CO_2 albedo (Paige '85, Kieffer et al. '00). H_2O behaves similarly.
- In polar night, local depressions radiate less and CO_2 "grows" around them, causing roughening. This effect is mitigated by precipitation or settling.



Local & temporal variation in surface temperature

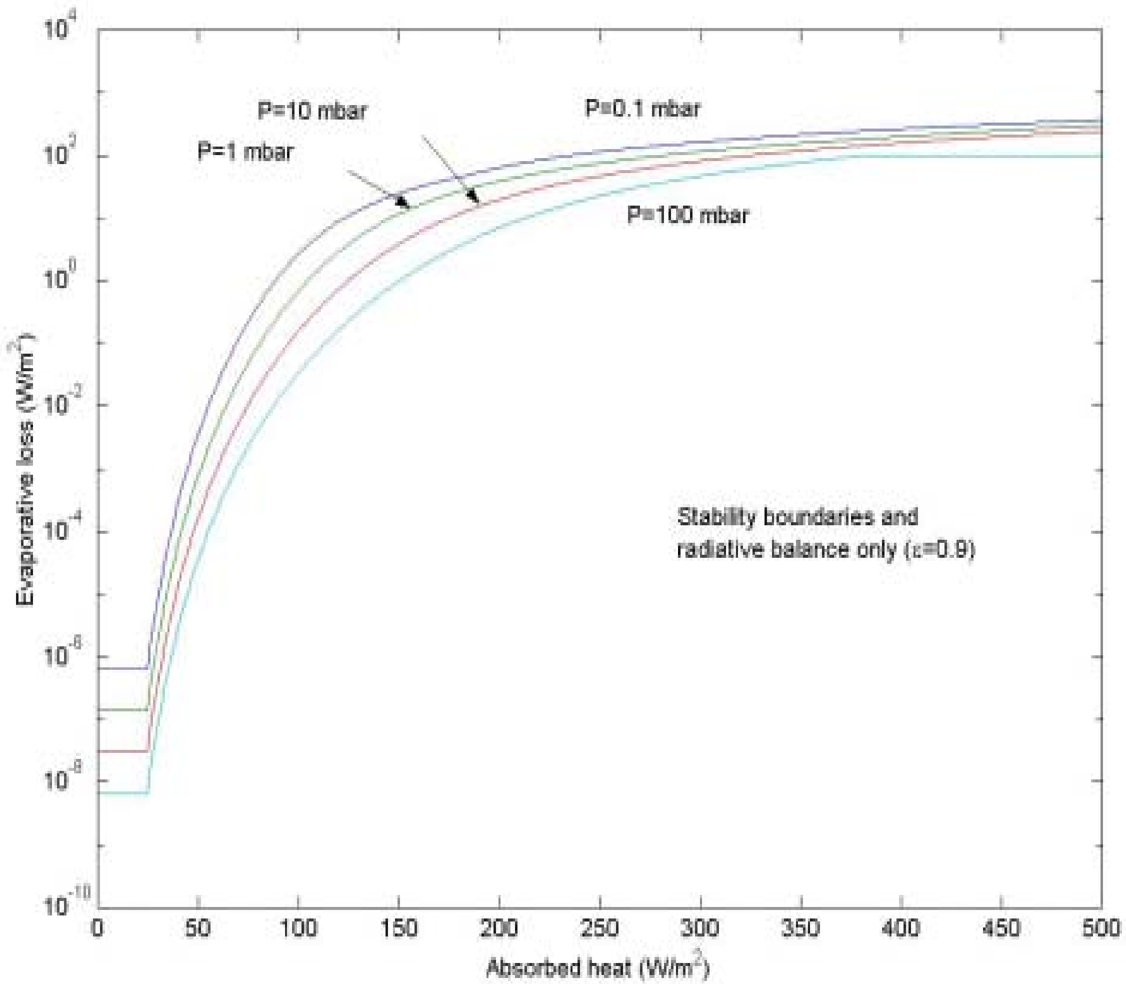
"Moon-like" approximation of equilibrium polar temperature for icy surface over 150,000 yrs (infinite CO_2 reservoir, neglecting H_2O latent heat and conduction into surface)



Heat retained by surface varies >50°C with albedo, slope, apparent emissivity, over and above orbital variations

Variations in atmospheric water content

- Evaporative loss (hence atmospheric H_2O) is exquisitely sensitive to heat balance. Small areas may dominate.
- Humidity also highly pressure sensitive (but no strong break at triple point)
- If high humidity results in darkening of permanent CO_2 cap, pressure variations may be dampened



Conclusions

- Roughness-induced or other variations in albedo, emissivity, or slope distribution are more important than orbital elements for determining local temperature.
- Roughening of CO_2 and H_2O by sublimation is insolation-dependent, possibly damping temperature variability. Roughening of CO_2 may be intrinsic to condensation.
- Atmospheric water vapor varies over orders of magnitude with temperature and pressure. This implies that:
  - Humidity may be sensitive to tail of temperature distribution.
  - If albedo of CO_2 cap is sensitive to humidity, feedback may moderate total pressure variations.

Addendum

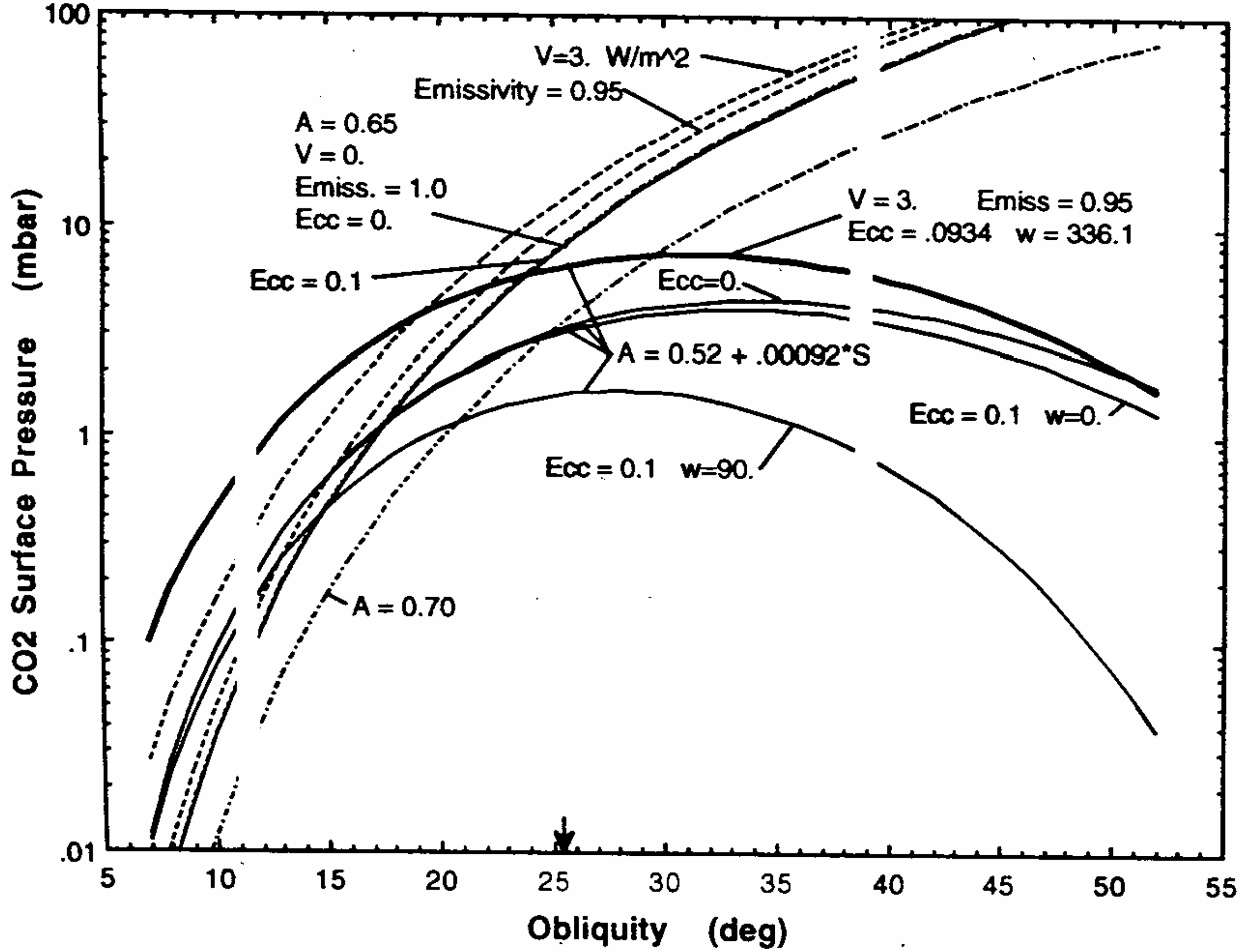


Fig. 4. Variation of CO_2 surface pressure with obliquity for a simple polar energy balance model. The nominal model is for eccentricity of 0, atmospheric advection V of 0 W m^{-2}, frost albedo A of 0.65, and frost emissivity of 1.0. The effects of small independent changes in emissivity, heating, albedo and eccentricity are shown. Three curves show the dramatic effect of an albedo that depends upon instantaneous insolation, in which case eccentricity and argument of perihelion become important. With estimates for the present parameters, $\varepsilon = 0.95$, $H = 3.$, $e = 0.0934$, $\omega = 336.1$, this simple model predicts a CO_2 surface pressure of 5.0 mbar at the current obliquity of 25°.2.

Kieffer & Zent, "Mars Book"

II. How to make liquid water on Mars

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How to make meltwater (from ~~1st~~ 2nd principles) :

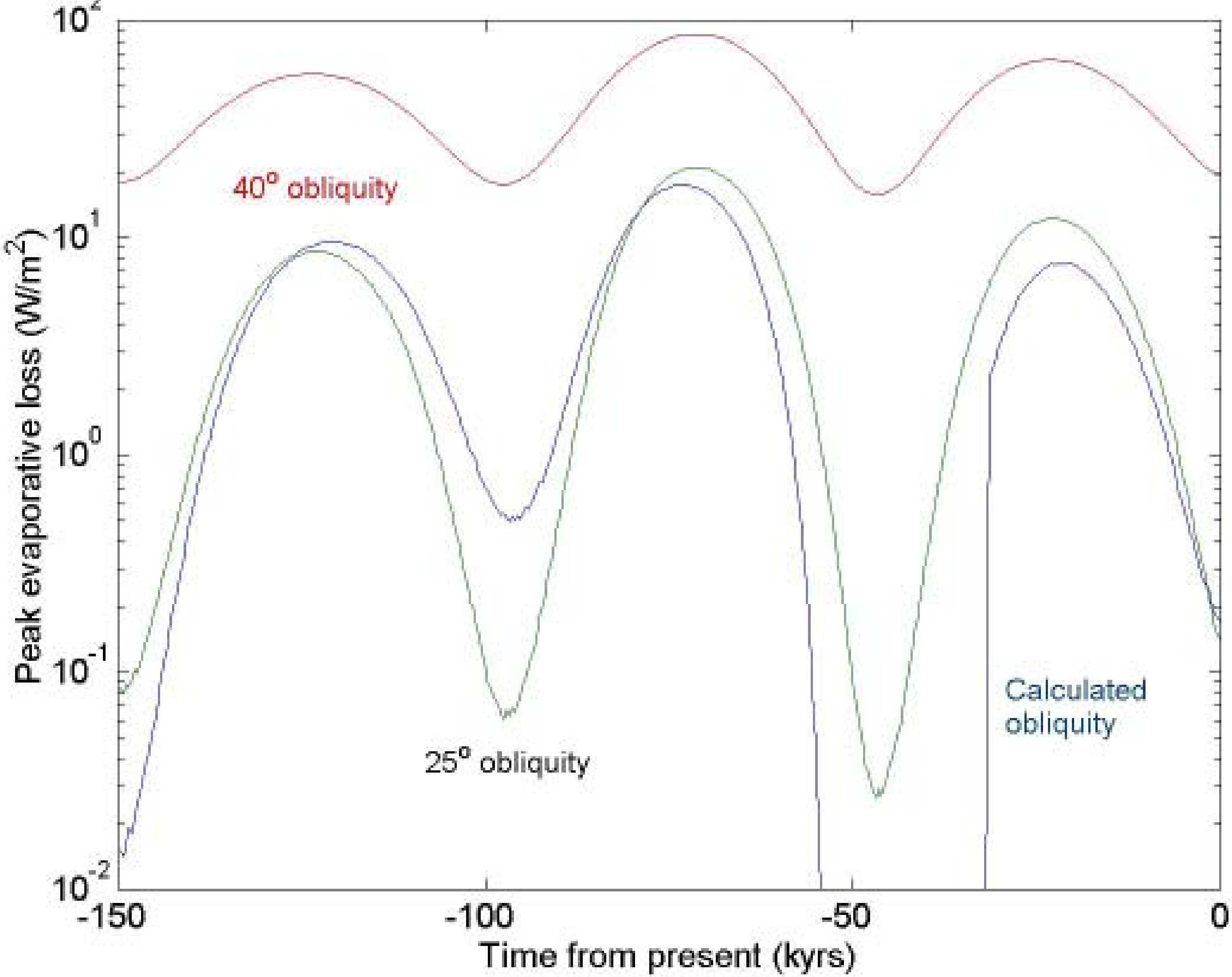
1. $T_{melt} > T_{frost}$, so must have circulation of water
   - Key timescale may be as short as 25,500 years
   - Cold trapping is important
2. Sublimation is fast, so warming must be fast
   - Annual phenomenon?
   - CO_2 buffering important
3. Melting: Geomorphology trumps obliquity
   - Variations in albedo, slope, apparent emissivity, thermal inertia, geochemistry, opacity, etc. >> than orbital element effects…
   - But only for melting, not deposition

Circulation model

- Potential meltwater sites are by definition geologically unstable (T>frostpoint). Cyclical recharging required.
  - Frost condensation or snow precipitation viable
  - Currently only 10's of precipitable microns available
  - Coldtrapping may add x10-100 (Svitek & Murray)
- Orbital cycle model (see plot)
  - Calculated annual peak sublimation from poles (like Fanale)
  - Included latent heats, optical properties of CO_2 and H_2O
  - Ignored atmosphere, thermal inertia, etc.

Calculated humidity variation

N. Pole sublimation (radiative balance & latent heats)

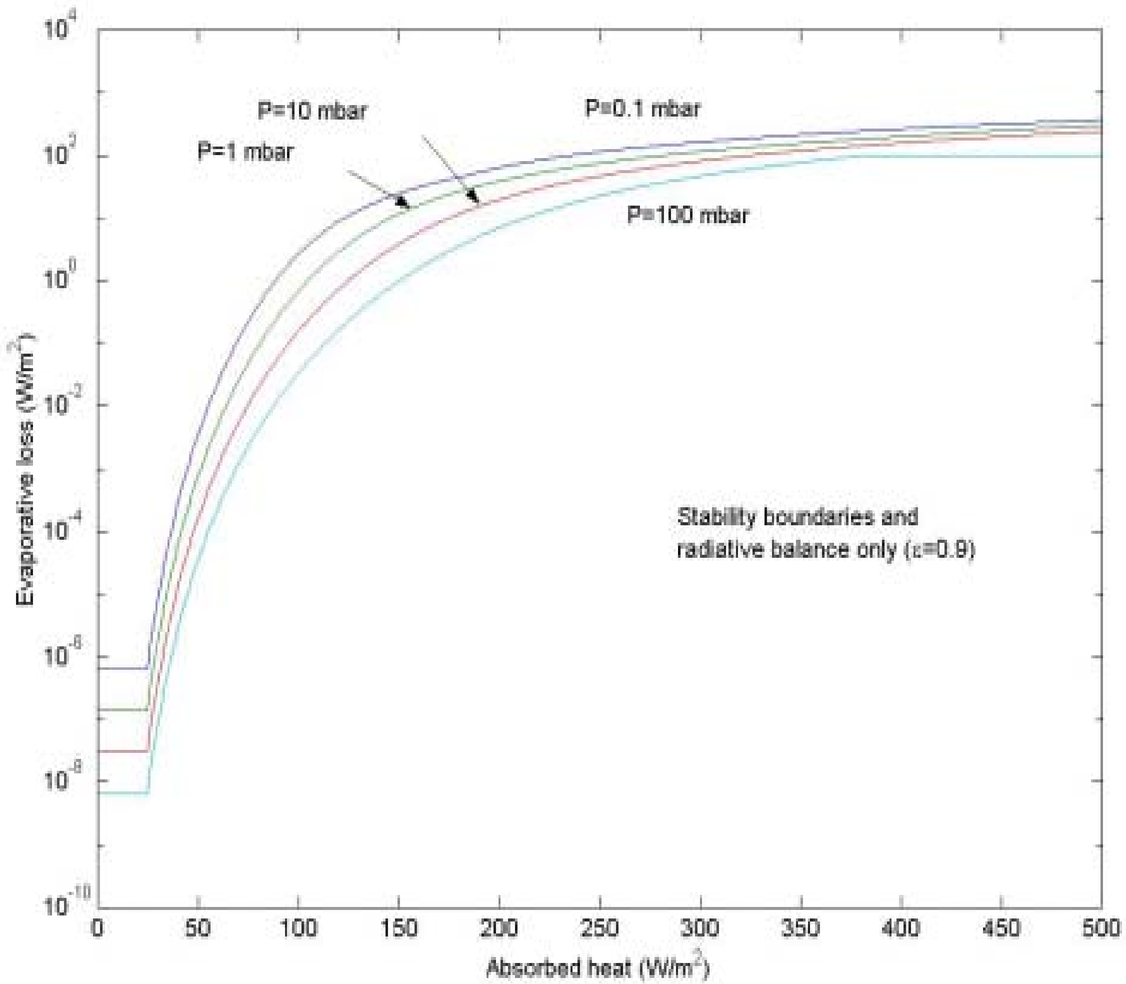


Model results

- 100x increase on 51 kyr cycle for each pole (25.5 kyrs?) → mms of precipitation/condensation, coldtrapped to 10’s of cm equivalent column.
- 40° obliquity adds only ~5x more
- Process may quench due to lag deposits of dust

Why is this so?

- Power law dependence on temperature “rectifies” periodic oscillation
- In warm periods, sublimation transitions from temperature-limited (power law) to heat-limited (linear)

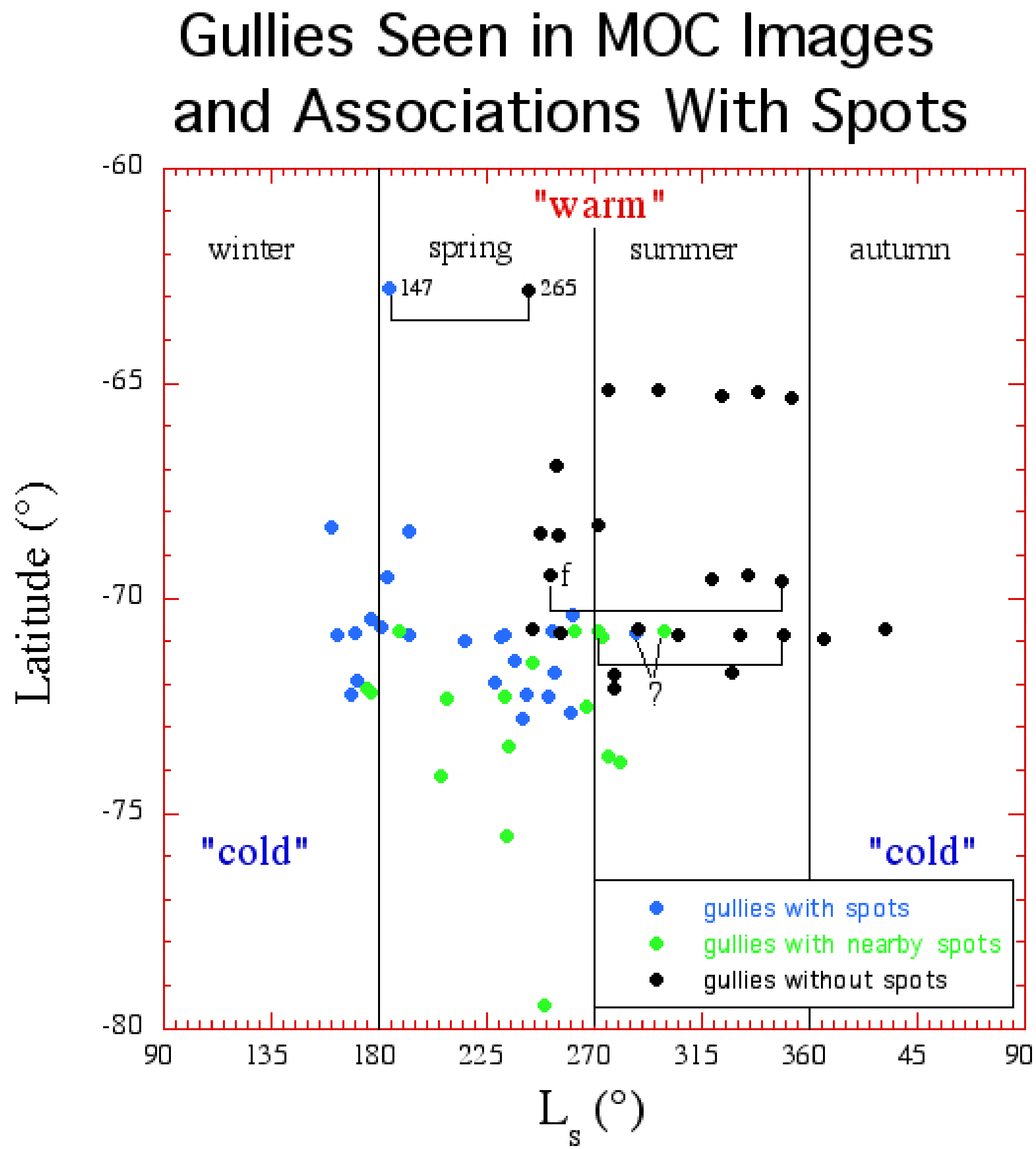


Sublimation

- Relatively rapid sublimation competes with melting
  - Rate is equivalent to ~60°C water on Earth (~1 mm/hr at 273K)
  - Robust seasonal water cycle is thus more compelling as source of liquid than long-term movement of water table
  - Temperature change must be rapid for melting – springtime buffering by CO_2 frost may be important to hold water until sufficient insolation is available.

CO_2 buffering

CO_2 burns off close to solstice, when peak heating occurs for pole-facing slopes

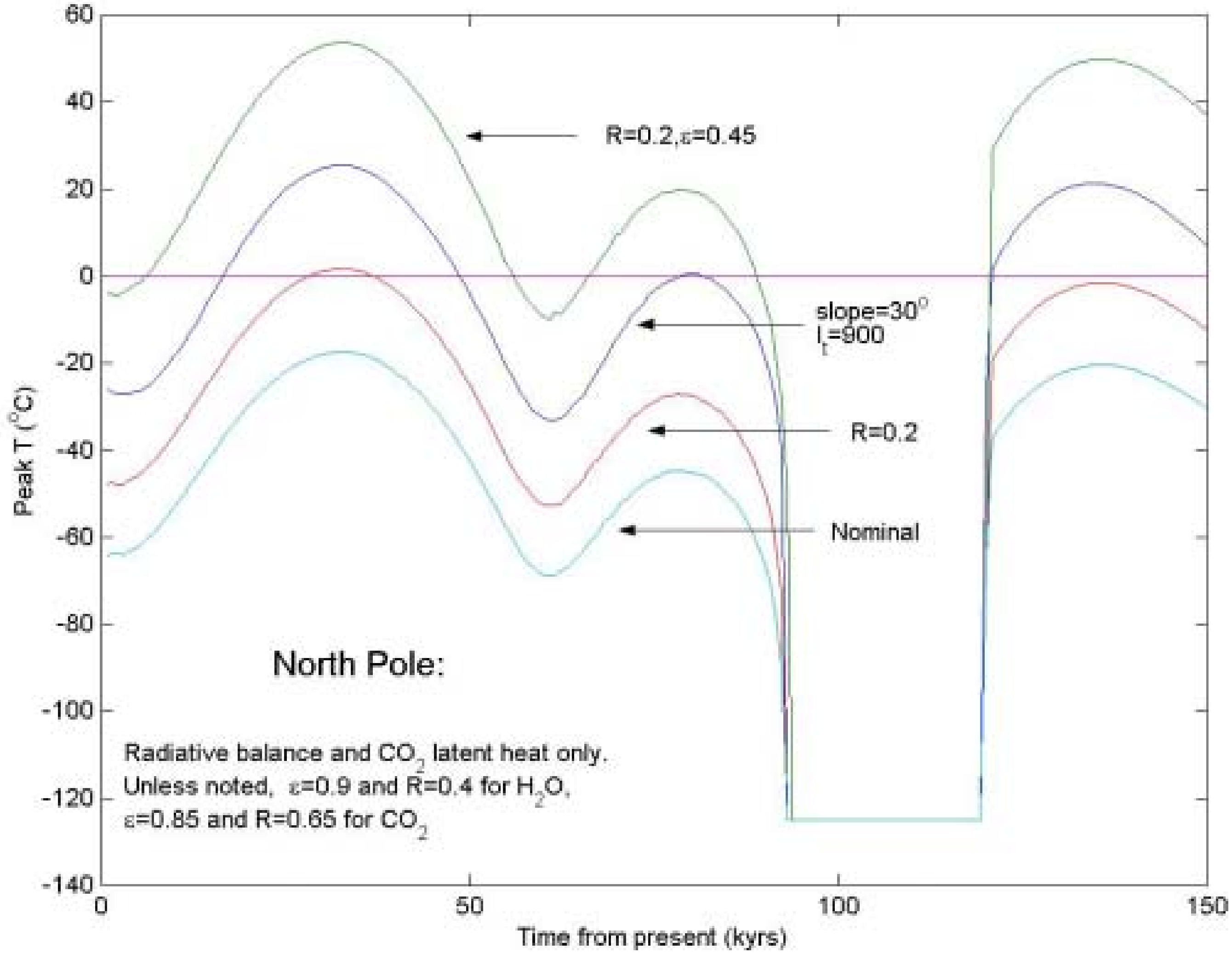


Melting

- Local contemporary conditions can emulate zonal conditions from other epochs
  - Peak or mean insolation (at poles) varies with orbital elements only by factor of ~2.
  - Albedo can vary by factor of 4 or more (see Kieffer et al. ‘00)
  - Apparent emissivity can vary with geometry by factor of 2 or more (see Ingersoll et al. ‘92, Hecht ‘02).
- Parameter space for modeling is huge. Significant portions of the parameter space allow for melting. Hence…
- Accumulated frost can seasonally melt in many geometries in nearly any epoch. See Hecht, Icarus (2002).

Local v. temporal variation in surface temperature

"Moon-like" approximation of equilibrium polar temperature for icy surface over 150,000 yrs (infinite CO_2 reservoir, neglecting H_2O latent heat and conduction into surface)



Heat retained by surface varies >50°C with albedo, slope, apparent emissivity, over and above orbital variations

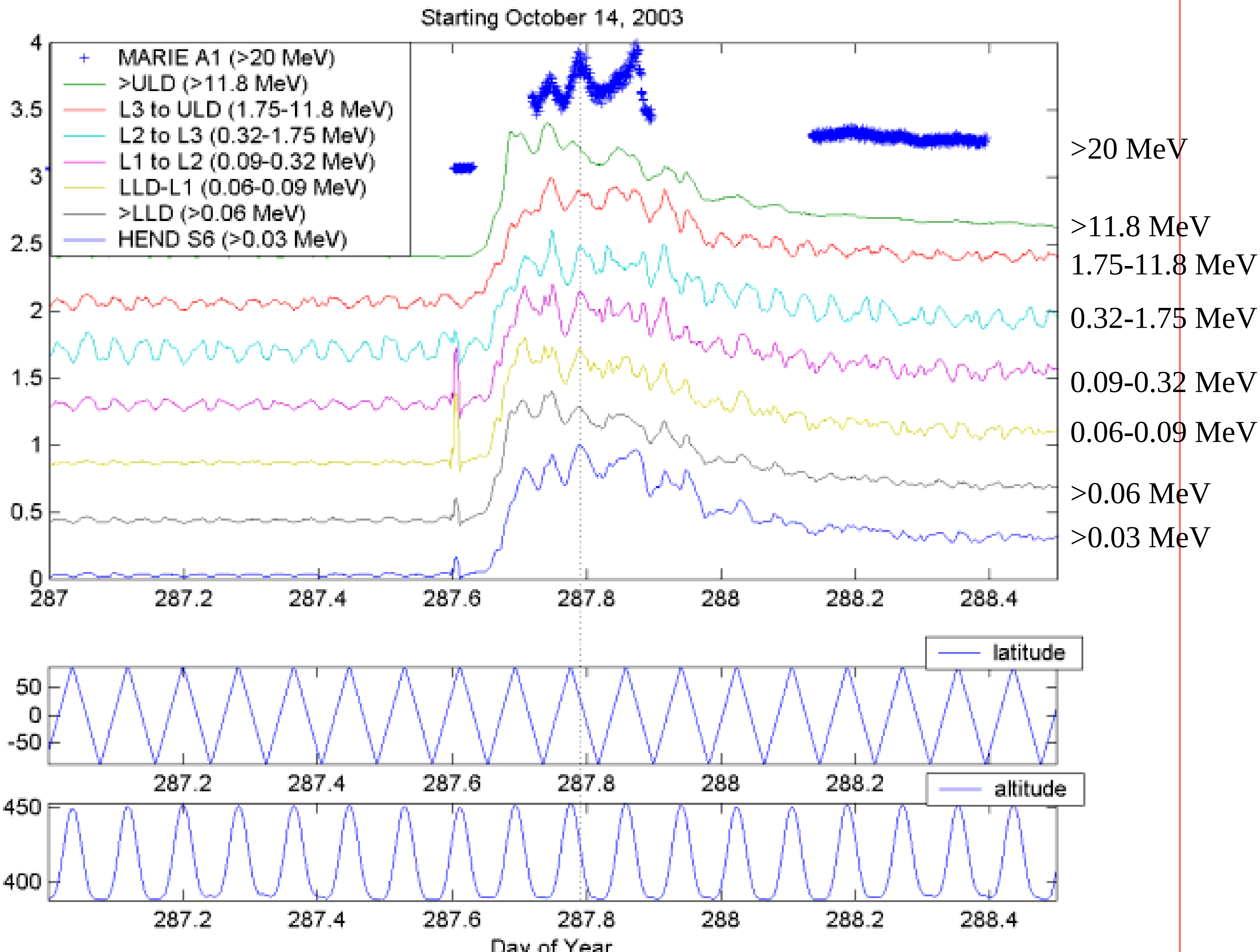
Conclusions

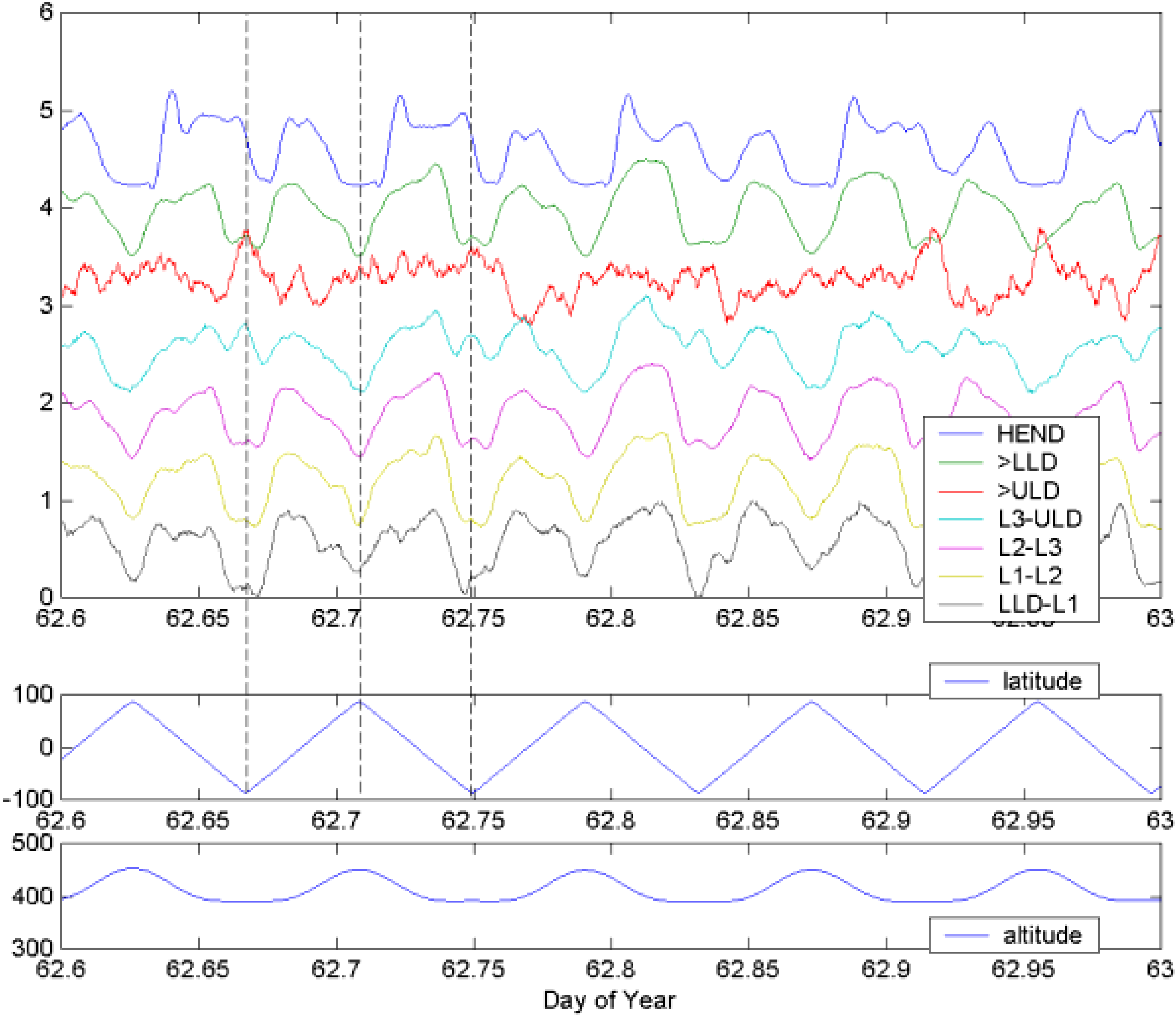
- Direct snow/frost melt is a robust mechanism for gully formation.
  - Process should be source limited. Significant that latitudes and orientation preference of gullies favor snow/frost accumulation.
  - Frost should be low density (like terrestrial hoarfrost). Subsurface melting, avalanches, other phenomena associated with terrestrial hoarfrost might occur
  - Ubiquitous presence of alcoves are a problem for such models, but not inexplicable. Examples exist on Earth (P. Lee)
- Pulses of water may be injected on ~25KY centers
  - Millimeters equivalent average deposition expected
  - 10-100x concentration possible from cold-trapping

III. Odyssey notes

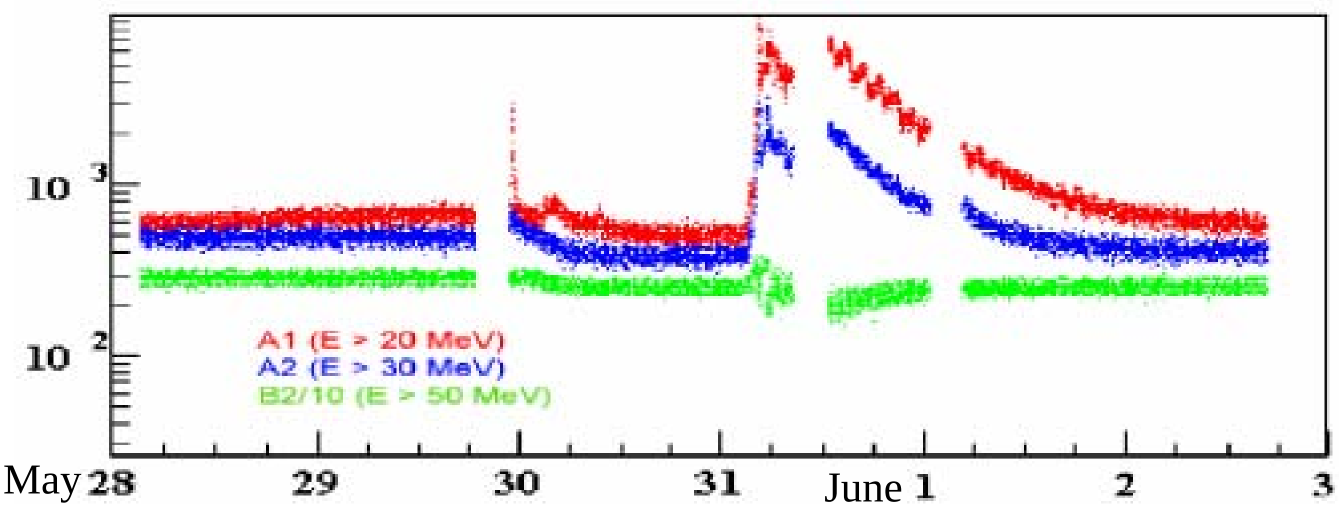
Michael Hecht, Jet Propulsion Laboratory

- Periodic signals in HEND, GRS, MARIE are sensitive to: subsurface position, energy, solar activity.
- Signals in MARIE are modulated during SPEs
- HEND S6 signals seem similar to GRS signals except for occasional sudden changes in amplitude

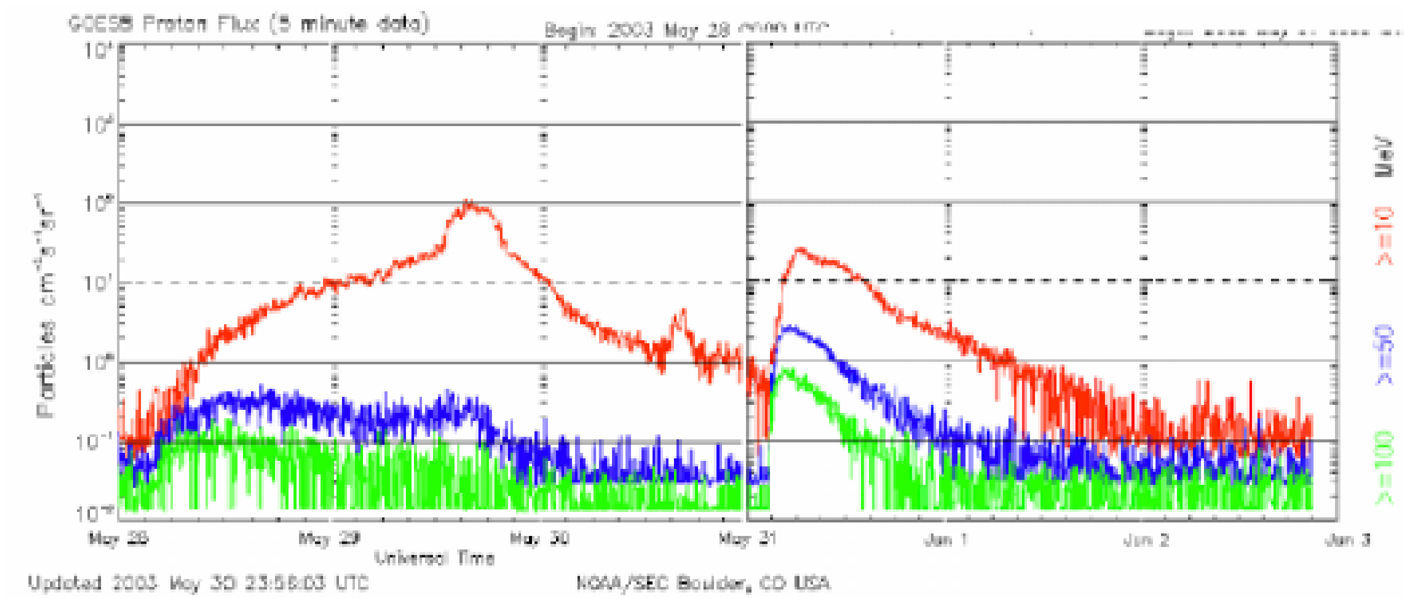

Starting October 14, 2003
MARIE A1 (>20 MeV)
>ULD (>11.8 MeV)
L3 to ULD (1.75-11.8 MeV)
L2 to L3 (0.32-1.75 MeV)
L1 to L2 (0.09-0.32 MeV)
LLD-L1 (0.06-0.09 MeV)
>LLD (>0.06 MeV)
HEND S6 (>0.03 MeV)
>20 MeV
>11.8 MeV
1.75-11.8 MeV
0.32-1.75 MeV
0.09-0.32 MeV
0.06-0.09 MeV
>0.06 MeV
>0.03 MeV
latitude
altitude
Day of Year


HEND
>LLD
>ULD
L3-ULD
L2-L3
L1-L2
LLD-L1
latitude
altitude
Day of Year

Latest SPE (MARIE data)



MARIE



GOES 8

Oscillations during SPEs

(MARIE movie courtesy of Ron Turner)