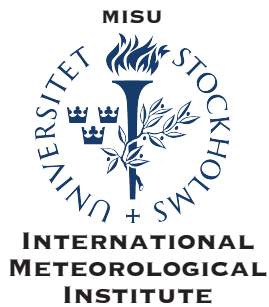# CO_2 **Oceans**
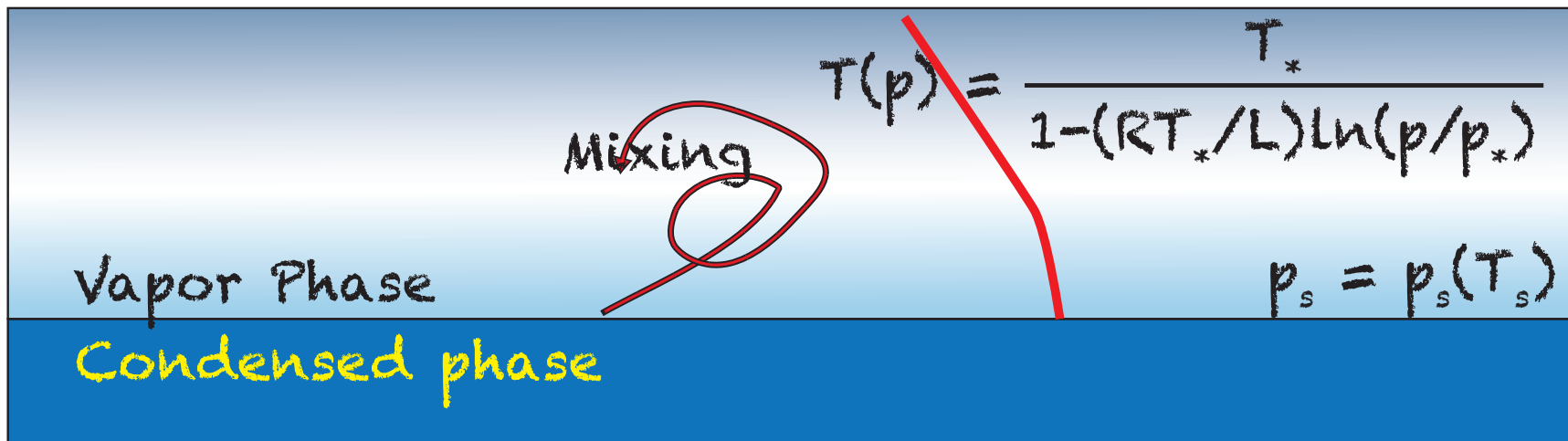
Raymond T. Pierrehumbert

University of Oxford
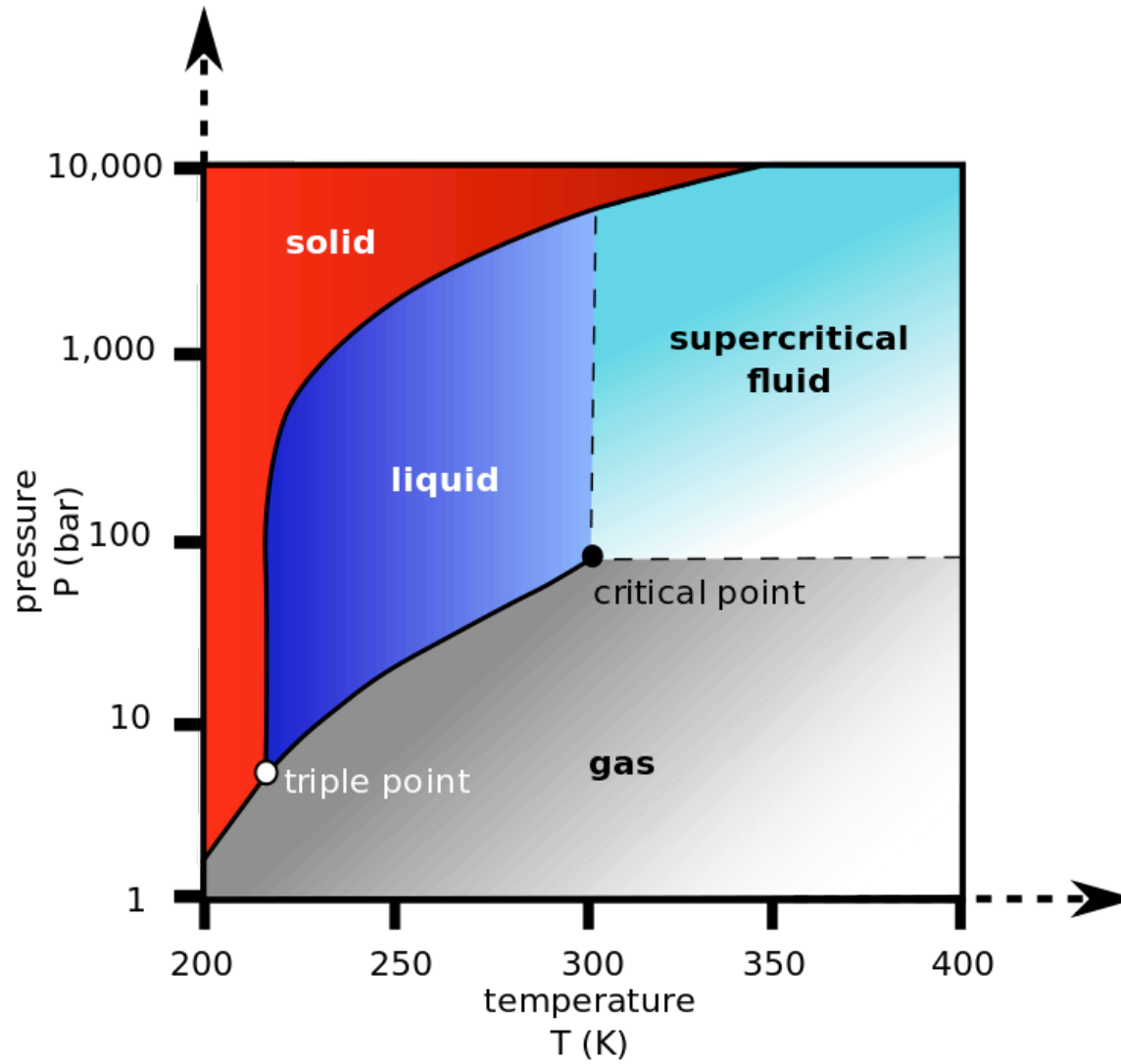
Single-component saturated atmosphere in equilibrium with condensed reservoir

$$T(p) = \frac{T_*}{1-(RT_*/L)\ln(p/p_*)}$$

Mixing

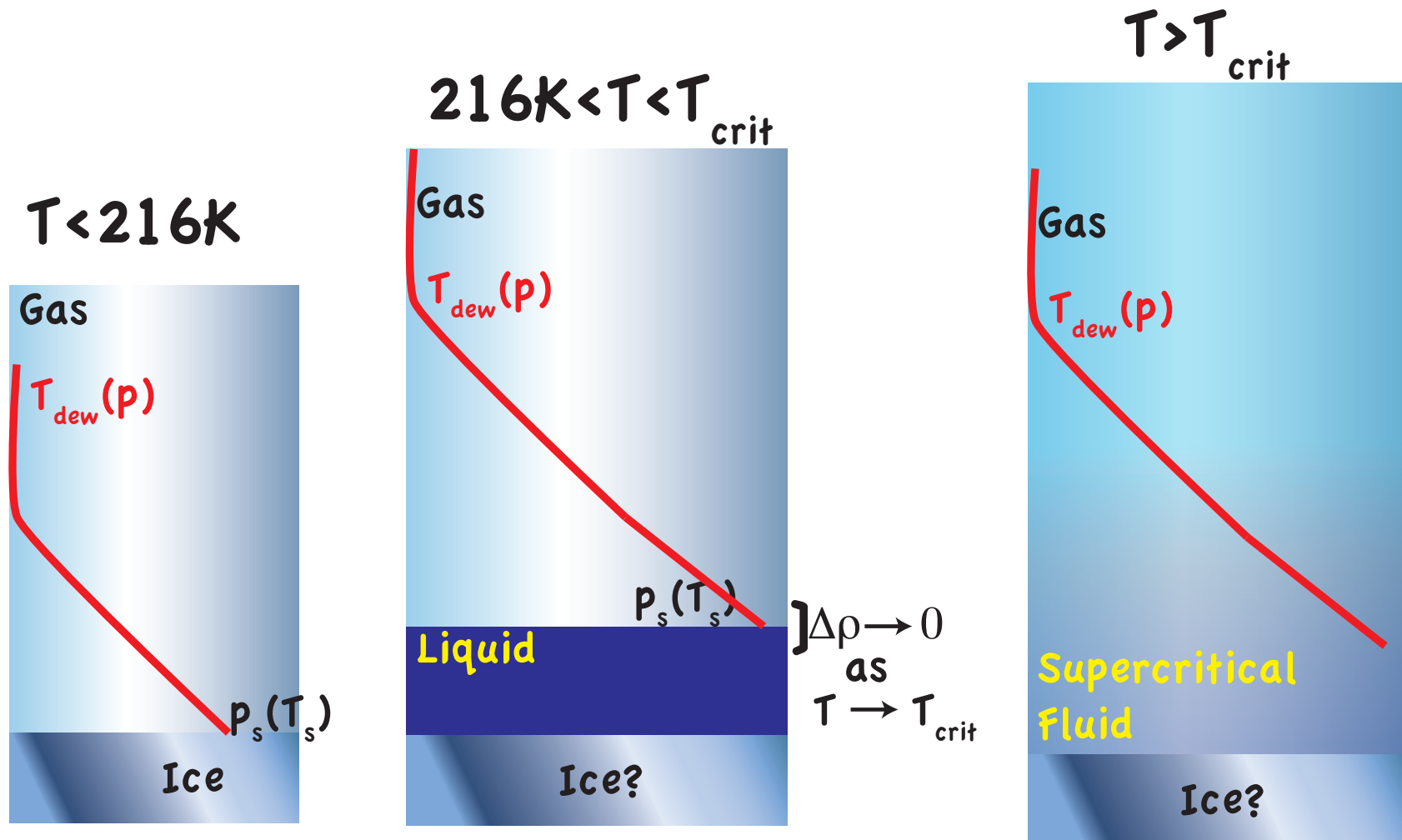Vapor Phase

$$p_s = p_s(T_s)$$

Condensed phase

We'll refer to this as the *steam atmosphere limit*, even if the condensible is something other than water vapor.

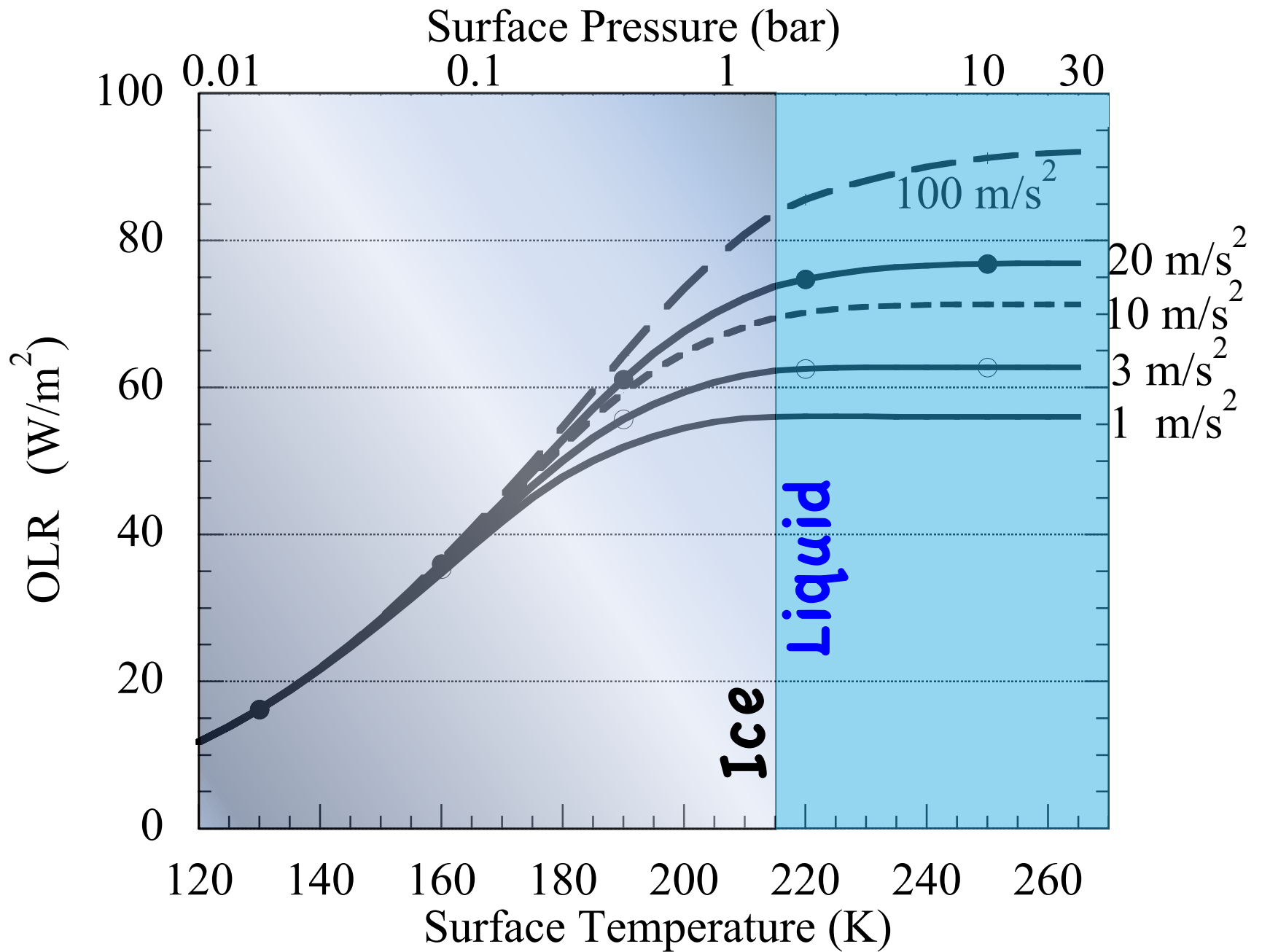It is the opposite extreme to the *dilute limit*.

CO_2 **Phase Diagram**

For what T_s do we have an ocean?

T<216K

Gas

$T_{dew}(p)$

$P_s(T_s)$

Ice

216K<T<T$_{crit}$

Gas

$T_{dew}(p)$

$P_s(T_s)$

Liquid

$]\Delta\rho \rightarrow 0$
as
$T \rightarrow T_{crit}$

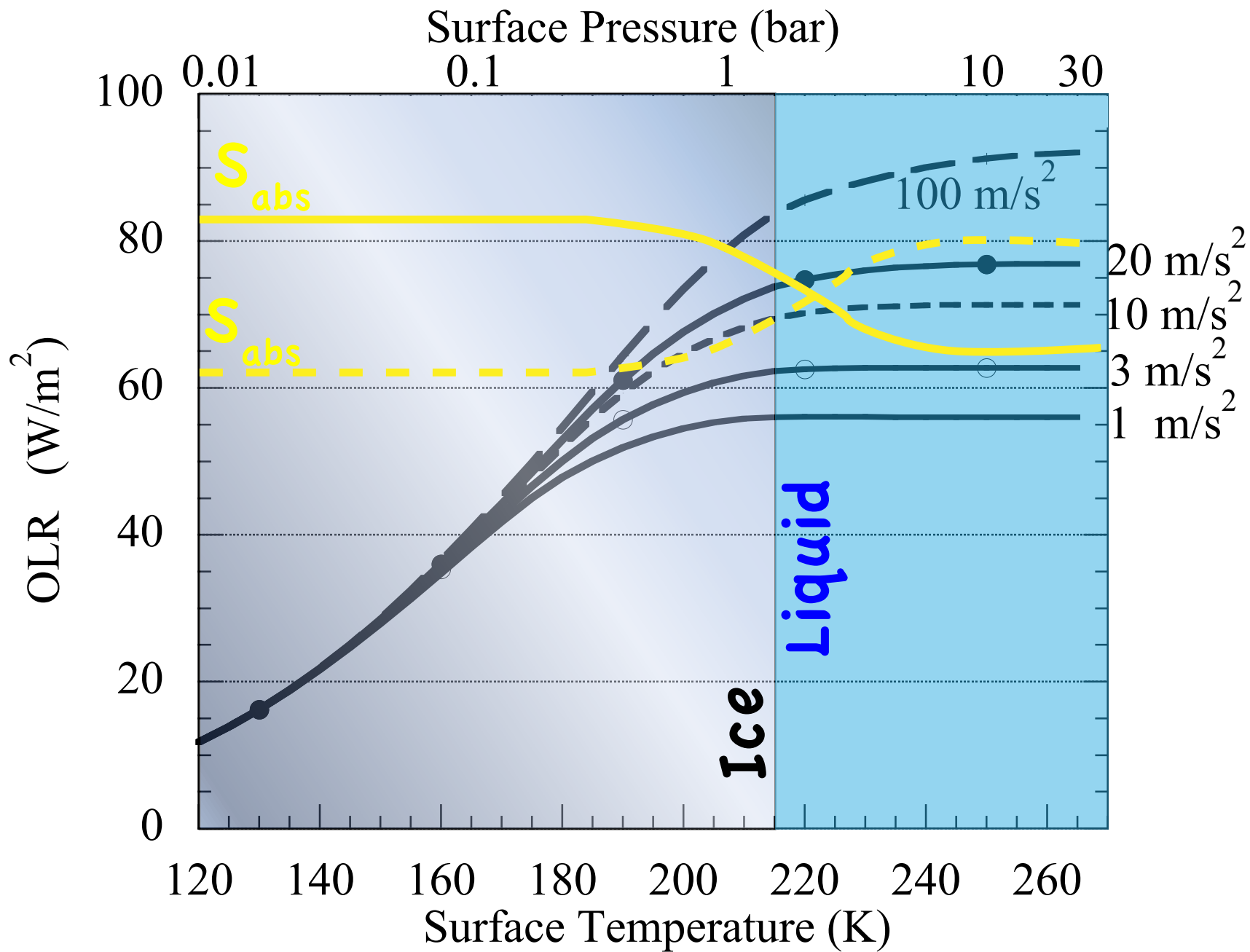Ice?

T>T$_{crit}$

Gas

$T_{dew}(p)$

Supercritical Fluid

Ice?

For what range of stellar absorption can we have an ocean?

Houston, we have a problem

But albedo also depends on temperature (via atmos. mass)

*Depends on stellar spectrum, surface albedo*

Adding a noncondensible background can help

- Tends to introduce OLR "overshoot" and introduce metastable non-runaway state at higher stellar absorption

- More importantly, allows atmosphere to be more subsaturated, which strongly inhibits runaway

- Noncondensible H_2 background would be a particularly interesting case to study because:

  - H_2 has a warming effect through collisional $H_2 - H_2$ and $H_2 - CO_2$ opacity

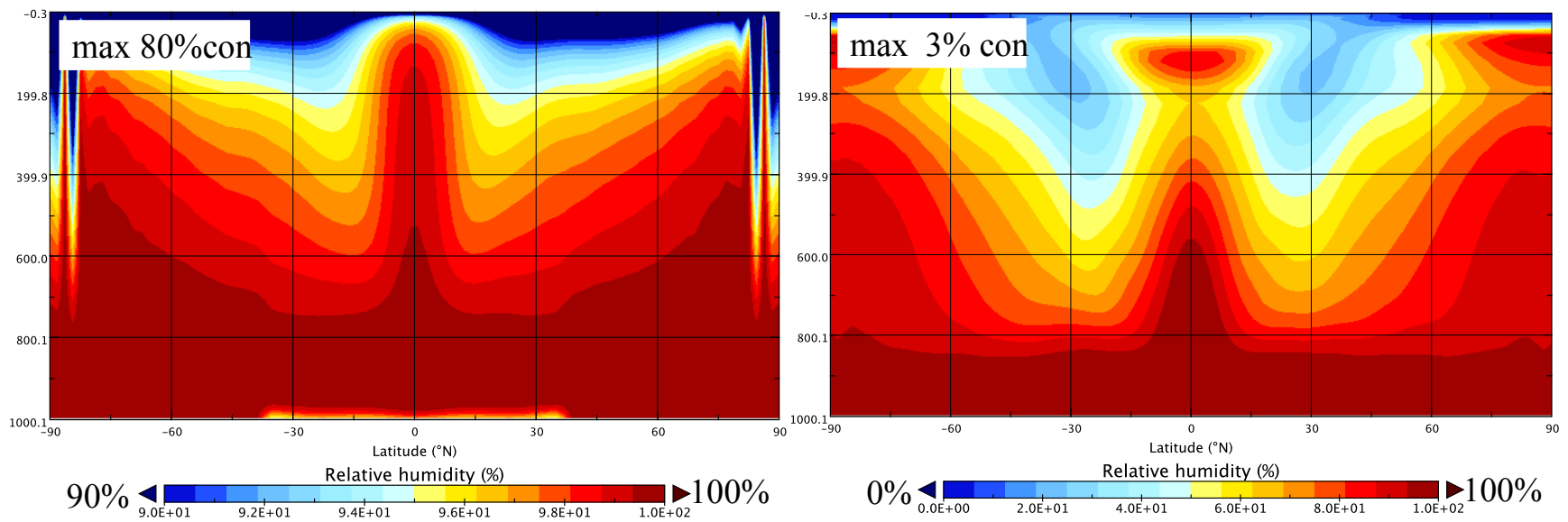 - Biology could release a lot of energy through methanogenesis

Nondilute FMS simulations

- Carried out by Feng Ding

- Simulations for condensible water vapor in N_2 background, but apart from temperature range behavior will be similar for other gases.

Latitude-Height Temperature Patterns
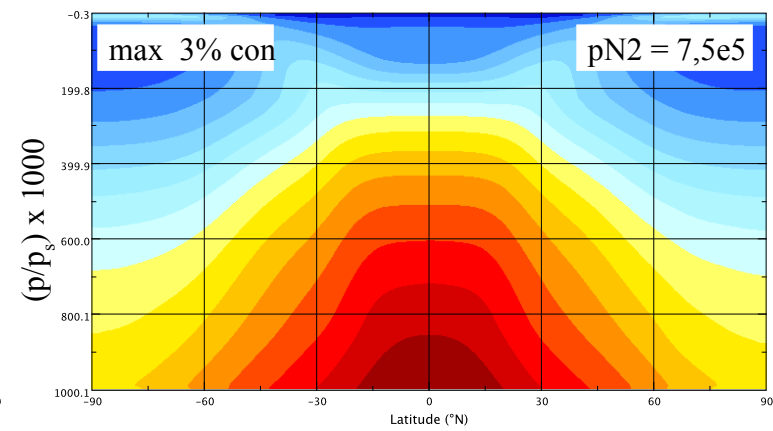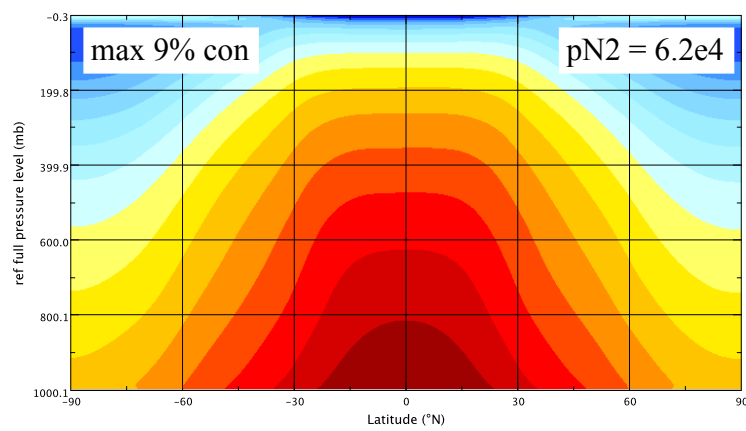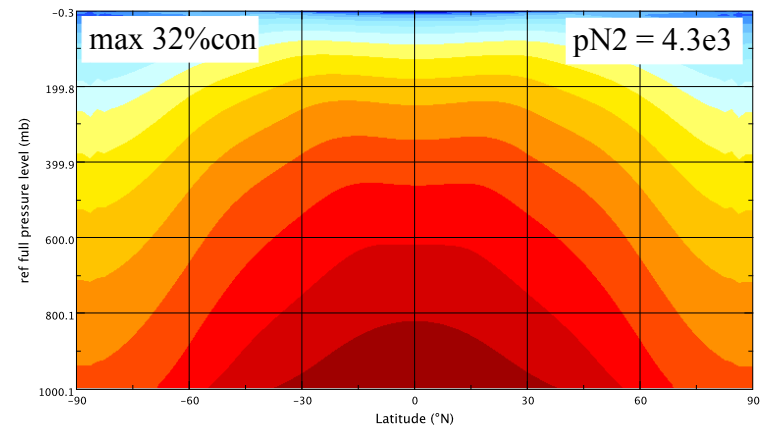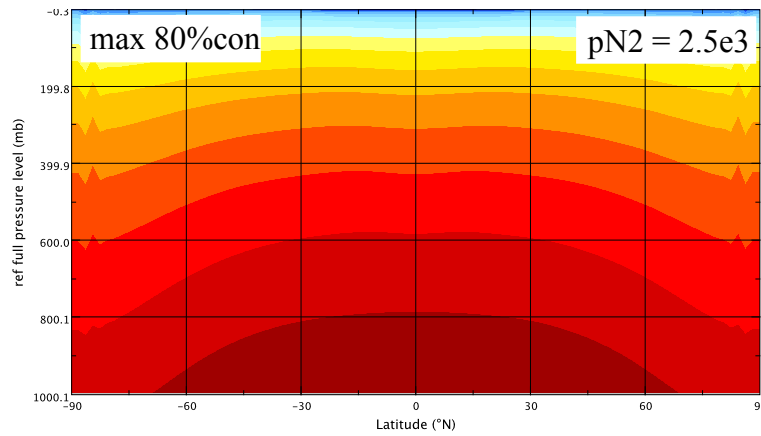
Latitude-Height Relative Humidity Patterns

Conclusions and Research Directions

- For pure CO_2 ocean/atmosphere, the range of conditions allowing a CO_2 ocean is extremely narrow

- Supercritical fluid CO_2 "oceans" can exist in a broader range of conditions

- Dependence of albedo on temperature via atmospheric mass needs further study but probably doesn't help

- Noncondensible background gases could help stabilize CO_2 oceans against runaway, especially through subsaturation

- Study of subsaturation requires nondilute 3D GCM's.
  (We can do that !)

- Effects of CO_2 clouds need to be considered.
  (Also requires 3D GCM)