Determination of a Hydropneumograph in a Karst Spring

Robert J. Agnew &
Todd Halihan

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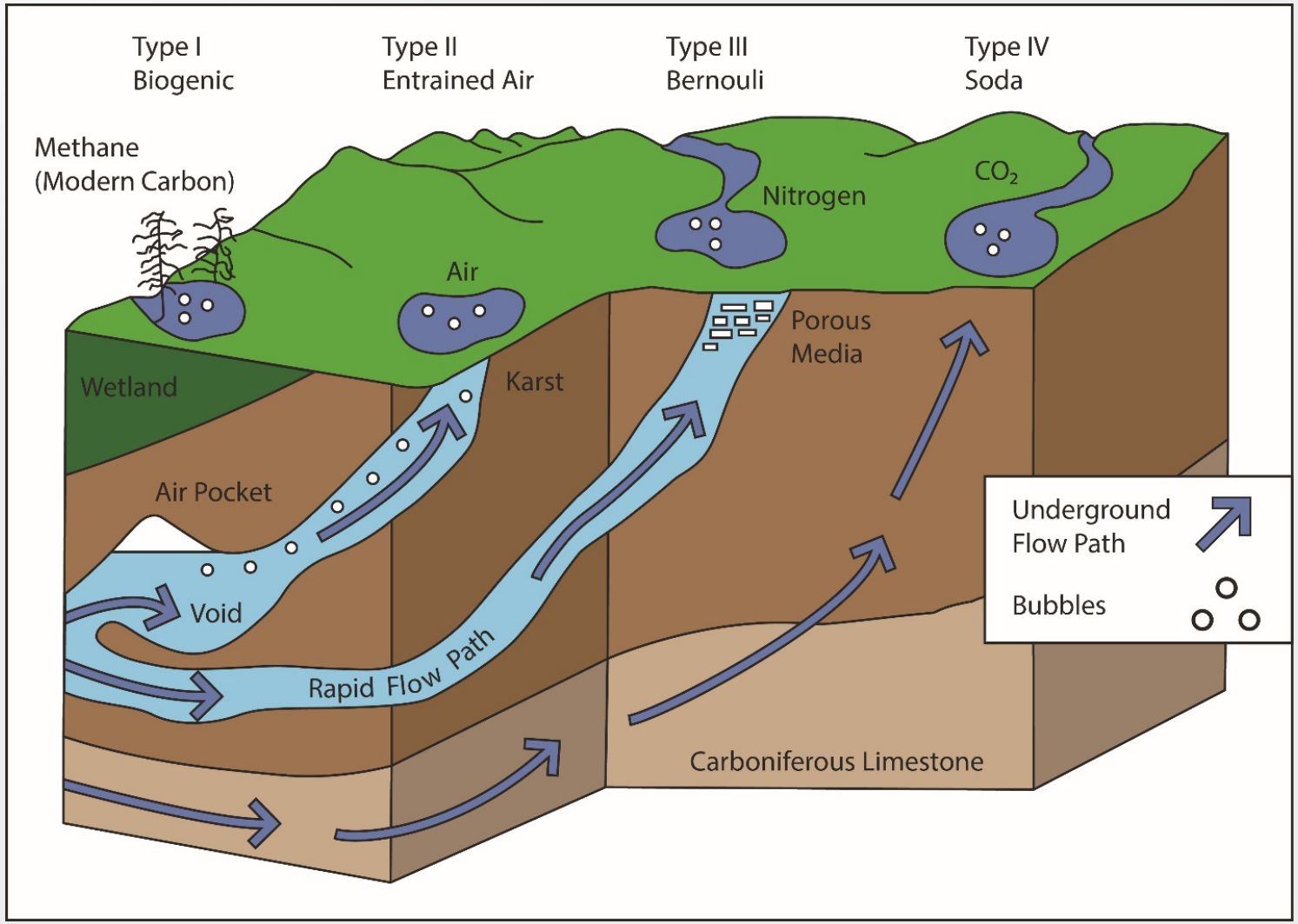
Why is the Gas Phase Significant?

- **Safety Hazards** –
  - CO_2, Lake Nyos, Cameroon killed 1,250 people
  - Methane and Phosphine are ignitable.
- **Groundwater Transport** –
  - Ebullition
  - Alteration of dissolved phase gas measurements
- **Economics**
  - U.S. Sparkling Water Sales, 2016 - $1.3 Billion
  - Tourism, Yellowstone, US; Delphi, Greece
  - Global Natural Gas, 2017, 193 trillion m^3

What do they tell us about Groundwater?

- Discharge Mechanisms
- Fluid Pathways
- Fluid Origins



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Little Bubbler Spring

Little Bubbler Spring, near Connerville, OK

Spring Characteristics

- Isothermal aquifer, 16.4 +/- 0.2 ˚C at discharge
- Arbuckle Group - Fractured karstic carbonates
- Base flow of ~1.5 gpm
- Surge flow of ~65 gpm

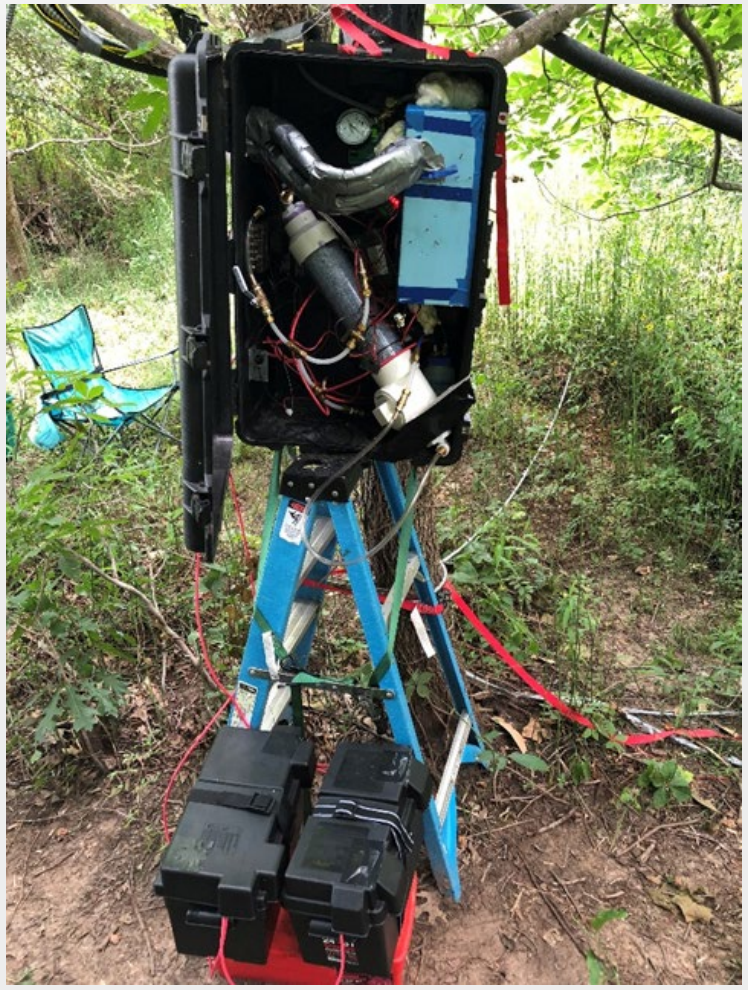
Gas Composition

- N_2 84.2%
- O_2 11.8%
- CO_2 2.6%
- Ar 1.0%
- Trace Gasses 0.4%, consistent with atmogenic origin
- Supersaturation ratio (SR) of 1.1, effervescence expected when SR >2

BubbleTron 9000 v3.2d

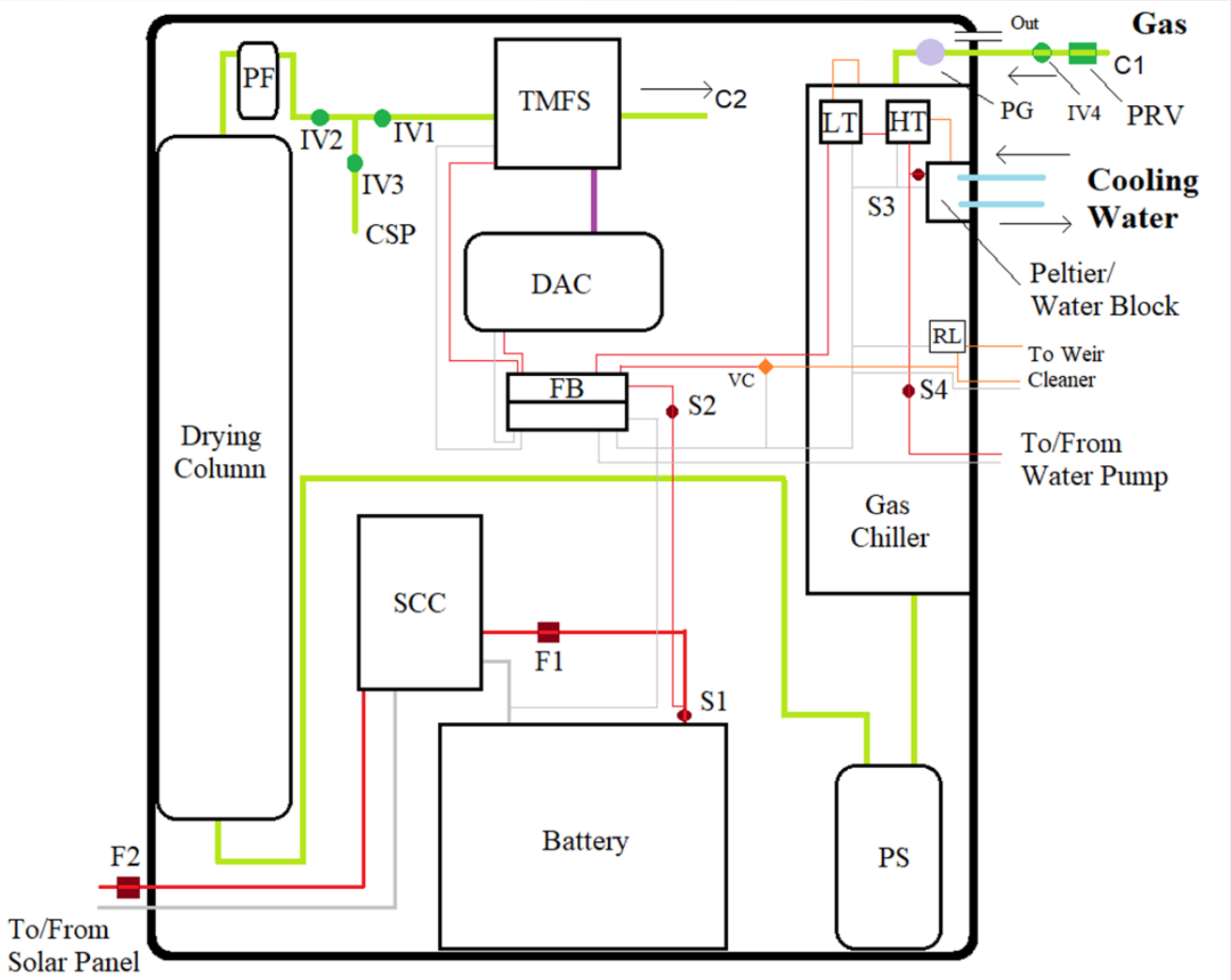
0.5 tons Sisyphean Ballast

6′ dia stock tank



Gas Conditioning and Measurement System

C1 – Connection 1
C2 – Connection 2
CSP – Calibration/Sampling Port
DAC – Data Acquisition System
F1 – Charge Fuse (30A)
F2 – Panel Fuse (15A)
FB – Fuse Block
HT – High Temperature Controller
IV1 – Isolation Valve 1
IV2 – Isolation Valve 2
IV3 – Isolation Valve 3
IV4 – Isolation Valve 4
LT – Low Temperature Controller
Out – Gas outlet
PF – Particulate Filter (40 µm)
PG – Pressure Gage (0-15 in H2O)
PRV – Pressure Relief Valve (0.25 psid)
PS –Phase Separator
S1 – Main Disconnect Switch
RL – Adjustable Relay
S2 – Isolation Switch
S3 – Chiller Switch
S4 – Pump Switch
SCC – Solar Charge Controller
TMFS – Thermal Mass Flow Sensor
VC – Voltage Converter



Mass of water – hydro
Mass of gas – pneumo

Over time
Hydropneumograph

What are we measuring?

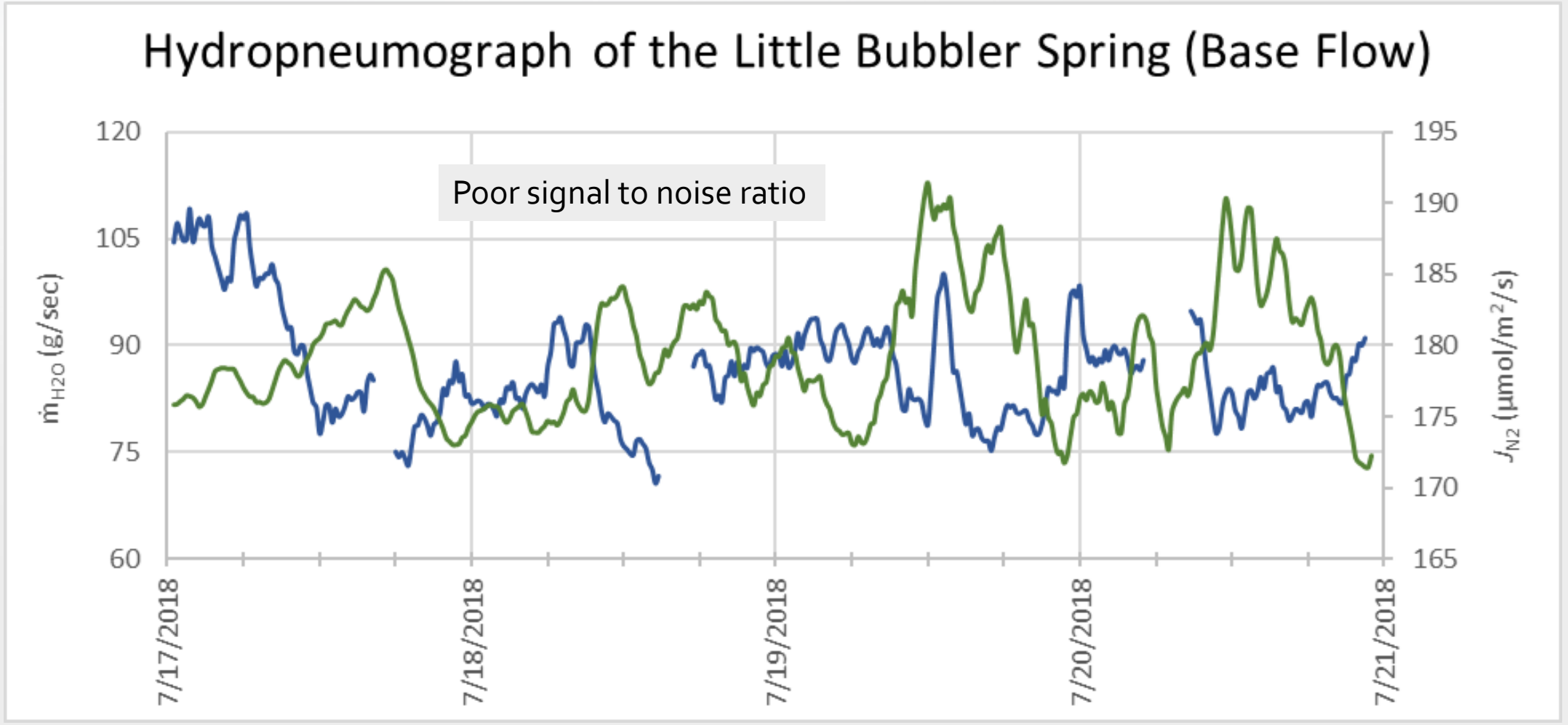
Total Gas Flux

- Free phase gas liberated from the bulk liquid across the interfacial area under the containment shroud
- Total Gas Flux = Diffusive Flux + Ebullitive Flux (bubbles)

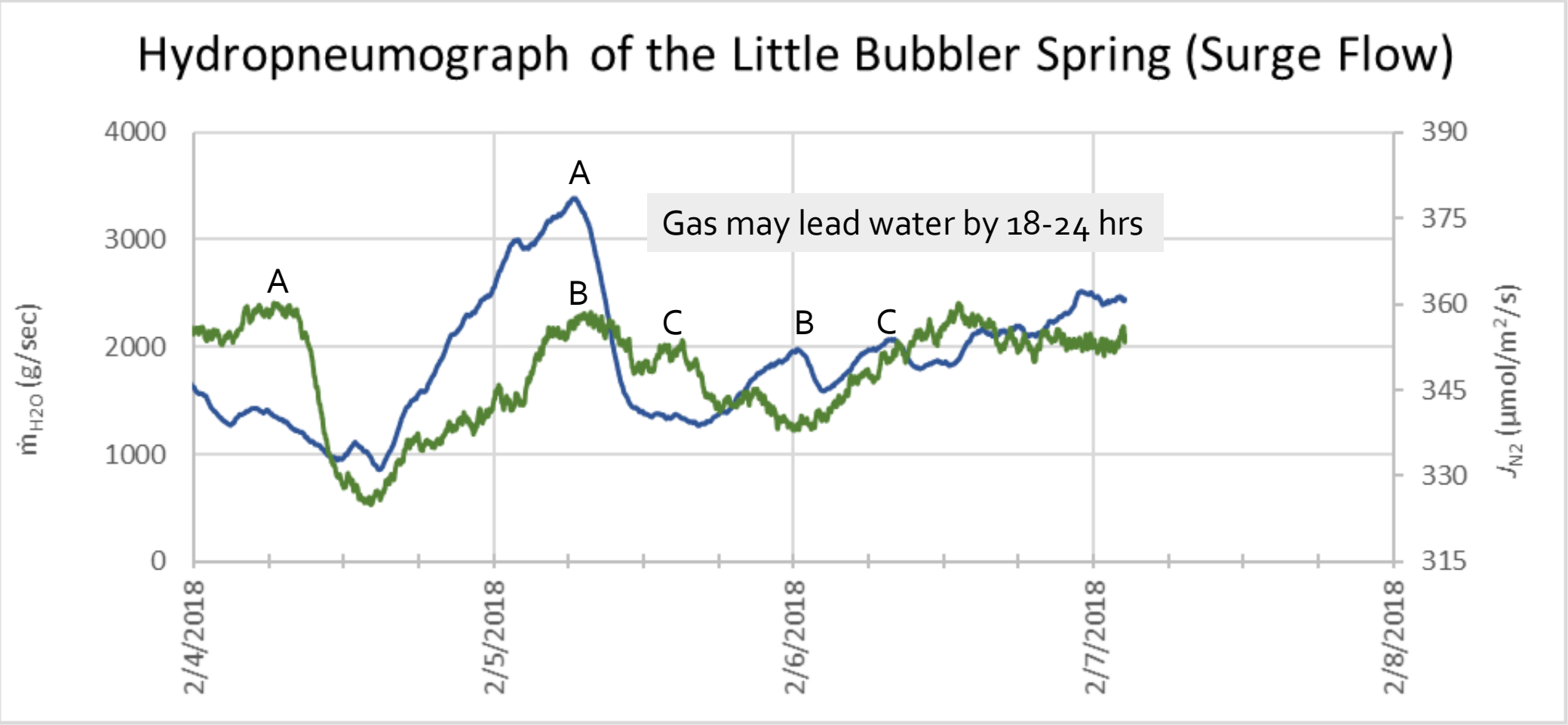
- **Diffusive Flux**
  - Governed by Fick's Laws of Diffusion
  - Supersaturation of atmogenic gas in the groundwater (Excess Air)

- **Ebullitive Flux**
  - Large non-effervescent bubbles
  - May alter dissolved phase gas measurements
  - Mechanism unclear, but suggestive of a Bernoulli (Type III Spring)

Baseflow Hydropneumograph



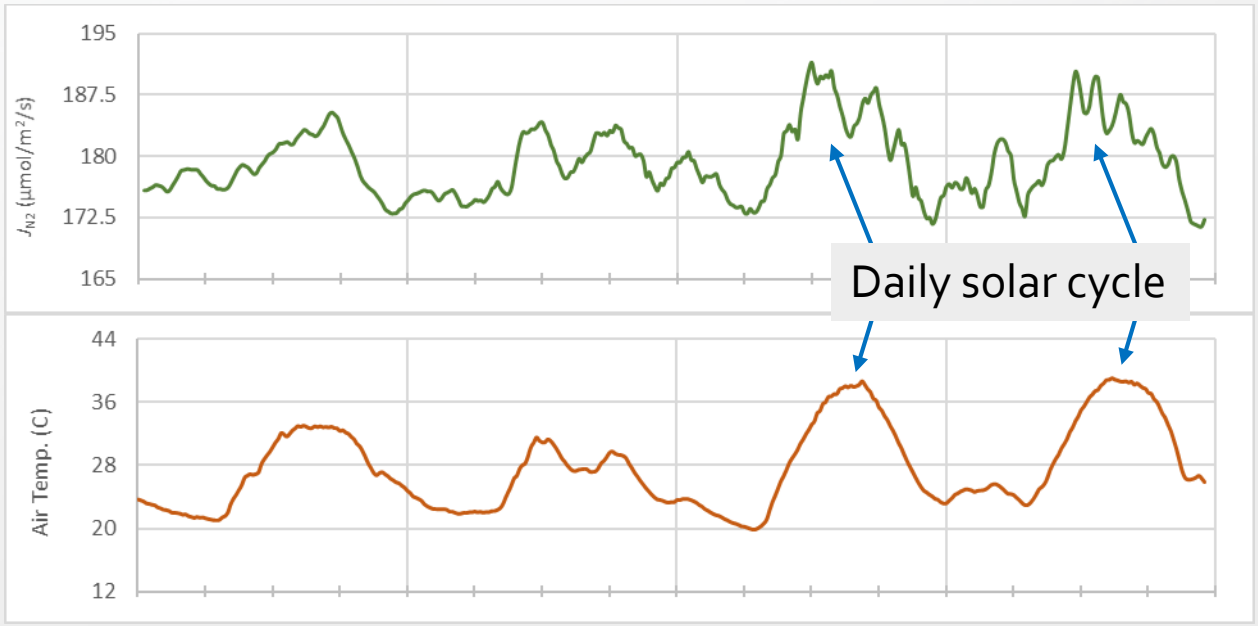
Surge Hydropneumograph



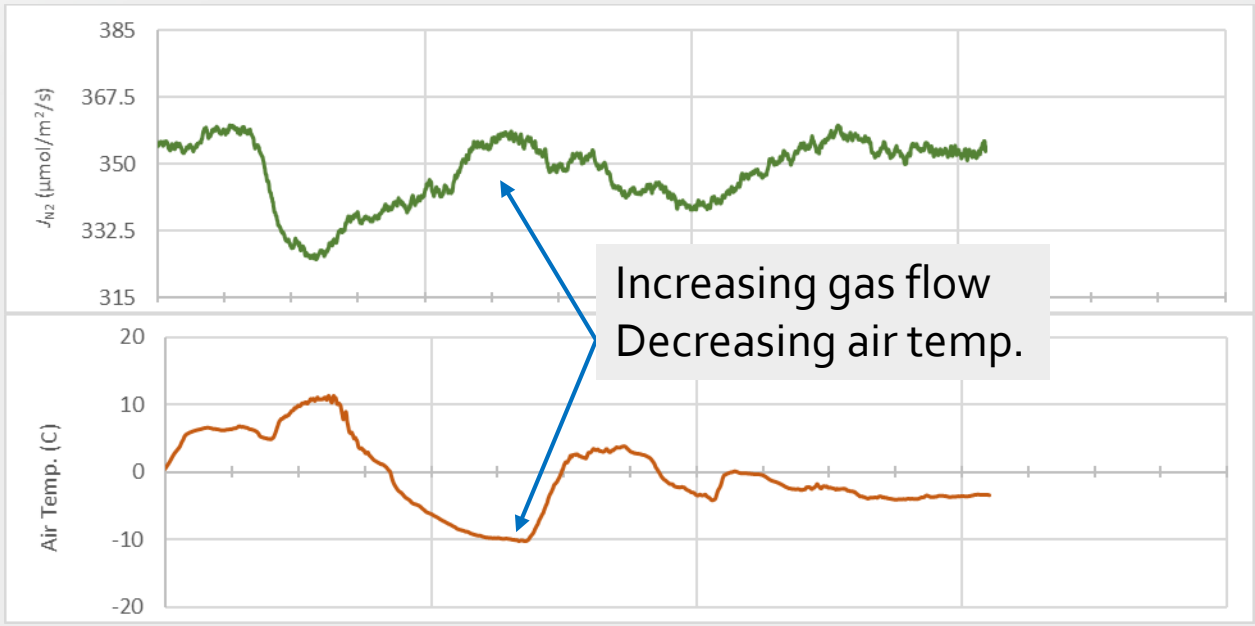
No significant rainfall within 29 days of water flow surge.

Air Temperature Influence on Gas Flux

Base Flow (July)



Surge Flow (February)

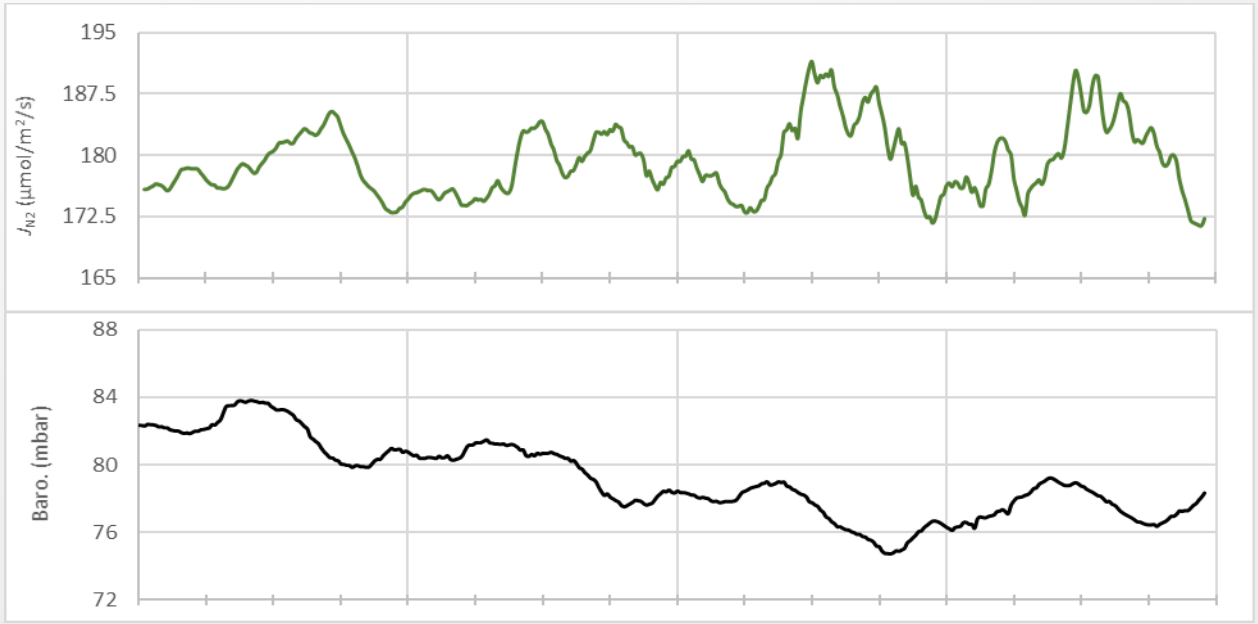


Small (~10%) change in gas flux with daily (20 ˚C) solar cycle. Water flow insufficient to cool insulated capture shroud.

Apparent inverse relationship between cold temperatures and gas flux. However, the increase in gas flux is related to an increase in water flow, due to phreatophyte pumping ceasing during freezing temperature.

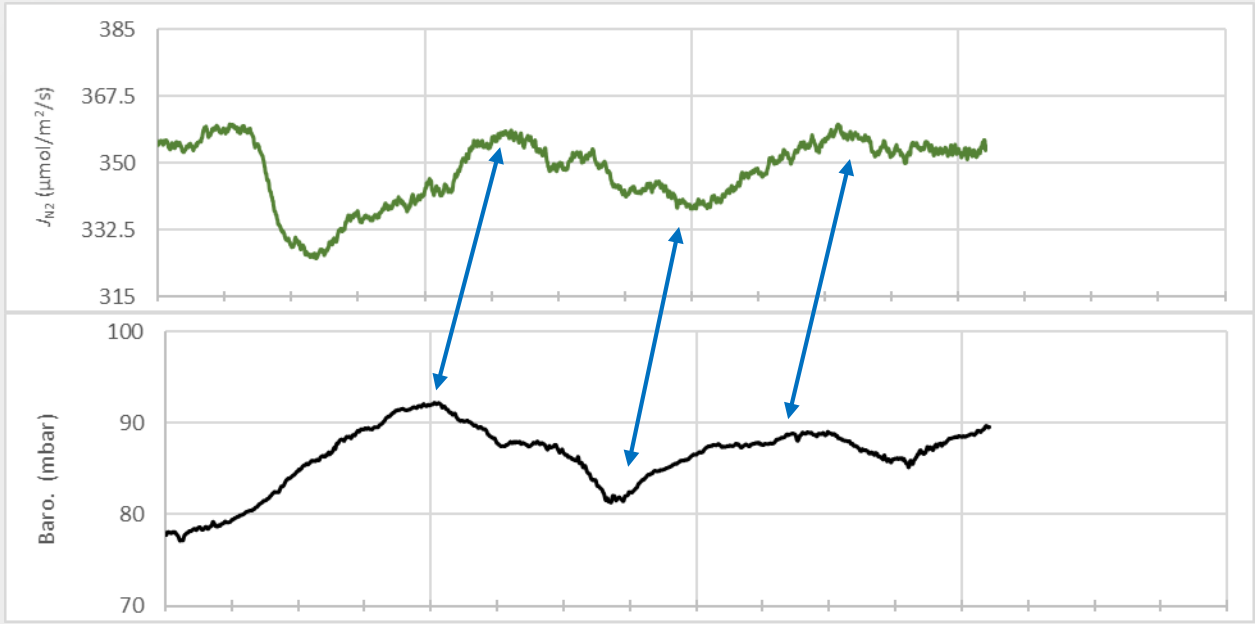
Barometric Influence on Gas Flux

Base Flow (July)



Difficult to separate temperature effect on air density and signal from shroud heating.

Surge Flow (February)



Barometric pressure appears to lead gas flux by ~6 hours. However, this effect is also seen in the water flow rate.

N_2 from Denitrification Unlikely

- Recharge area lacks agriculture associated with nitrates
- Four reductase steps necessary to convert NO_3^- to N_2
  - Typically occurs in anoxic environments
  - Discharge water contains 12% Oxygen
- Discharge waters contain only:
  - 0.76 mg/L Nitrate as N
  - <0.008 mg/L Nitrite as N
  - Production of NO→N_2O→N_2 unlikely
  - Mass balance of Nitrate to N_2 would account for <0.5% of discharging gas (using peak water flow and minimum gas flow)
- Excess N_2 % accounted for by depletion of O_2 and excess CO_2

Summary

1. Hydropneumograph data collection conceptually easy, actually pretty difficult
2. Hydropneumograph datasets shows promise as an additional insight into aquifer dynamics
3. Better understanding of the development of excess air could improve the estimation of recharge temperature
4. Simultaneous measurement of gas composition in both phases could reduce error in age dating due to ebullitive stripping

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