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Factors Controlling Diurnal Temperature Stratification in Riverine Pools

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Outline

- Overview
- Study objectives
- Field work & observations
- Statistical analyses
- Numerical modeling
- Conclusions

Thermal stratification in pools

- ❑Thermal heterogeneity is necessary for species to thrive
  - warm water near surface/margins suitable for benthic invertebrates, juvenile salmonids, frogs, turtles etc
  - cold water at depth suitable holding habitat for adult salmon, trout etc

- ❑Why we are interested?
  - Managed flow releases can alter thermal diversity and affect mixing of flow layers
  - We want to understand conditions that promote or prevent thermal stratification
  - Is it possible to provide guidance for flow management?

Thermal stratification in pools

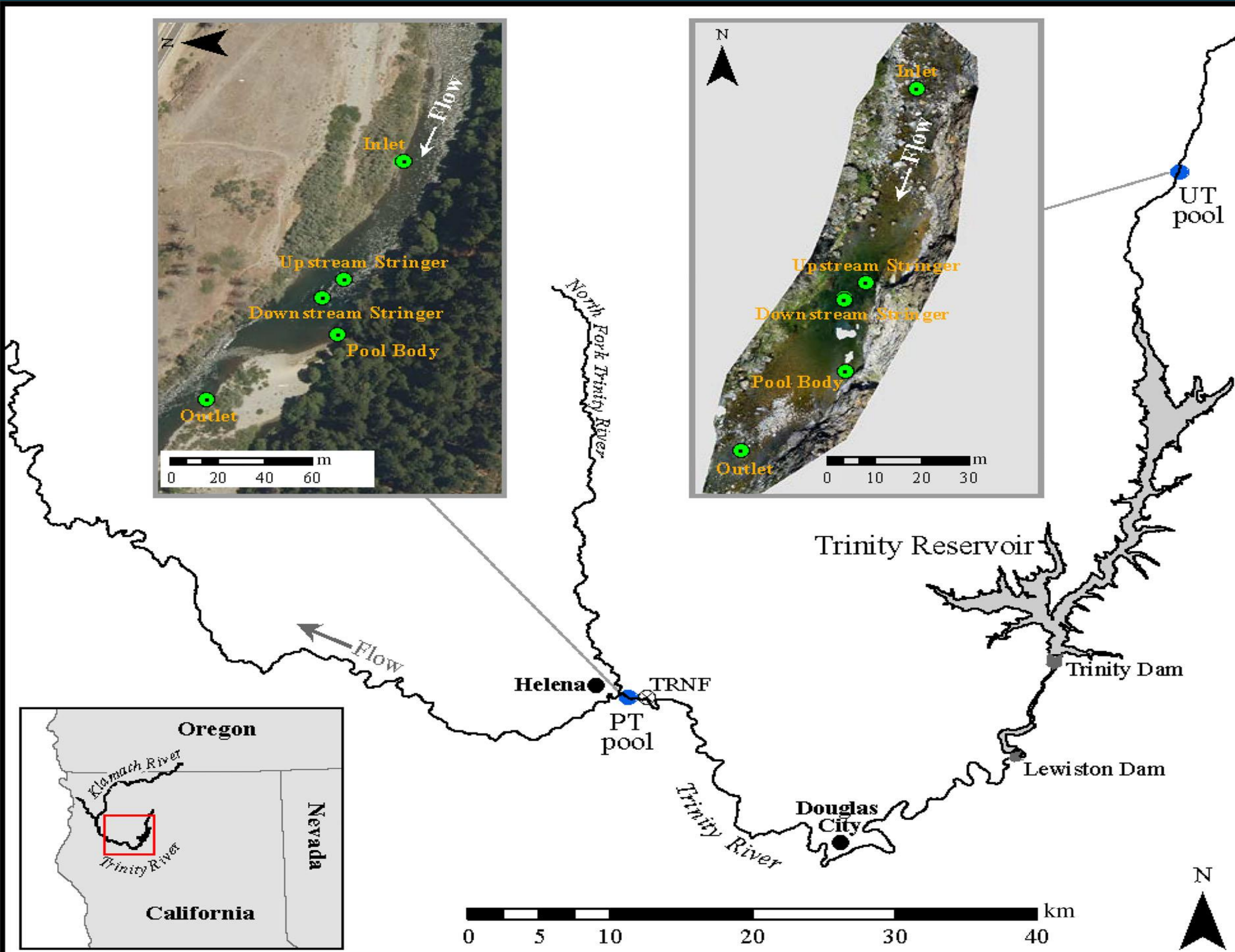
- ❑Mechanics of pool stratification not fully described yet
  - Complex and controlled by many factors

- ❑Past studies attribute stratification to:
  - Retention of cold water at night
  - Low air temperature and solar input
  - Cold hyporheic flows
  - Low turbulence/conditions preventing mixing

Study Objectives

- ❑Use a systemic approach to understand the mechanics of how stratification is formed, destroyed or prevented
- ❑Tease out the dominant factors
- ❑Provide guidance on promoting or preventing stratification
- ❑Focus on pools trinity river

Field Work – Two Sites



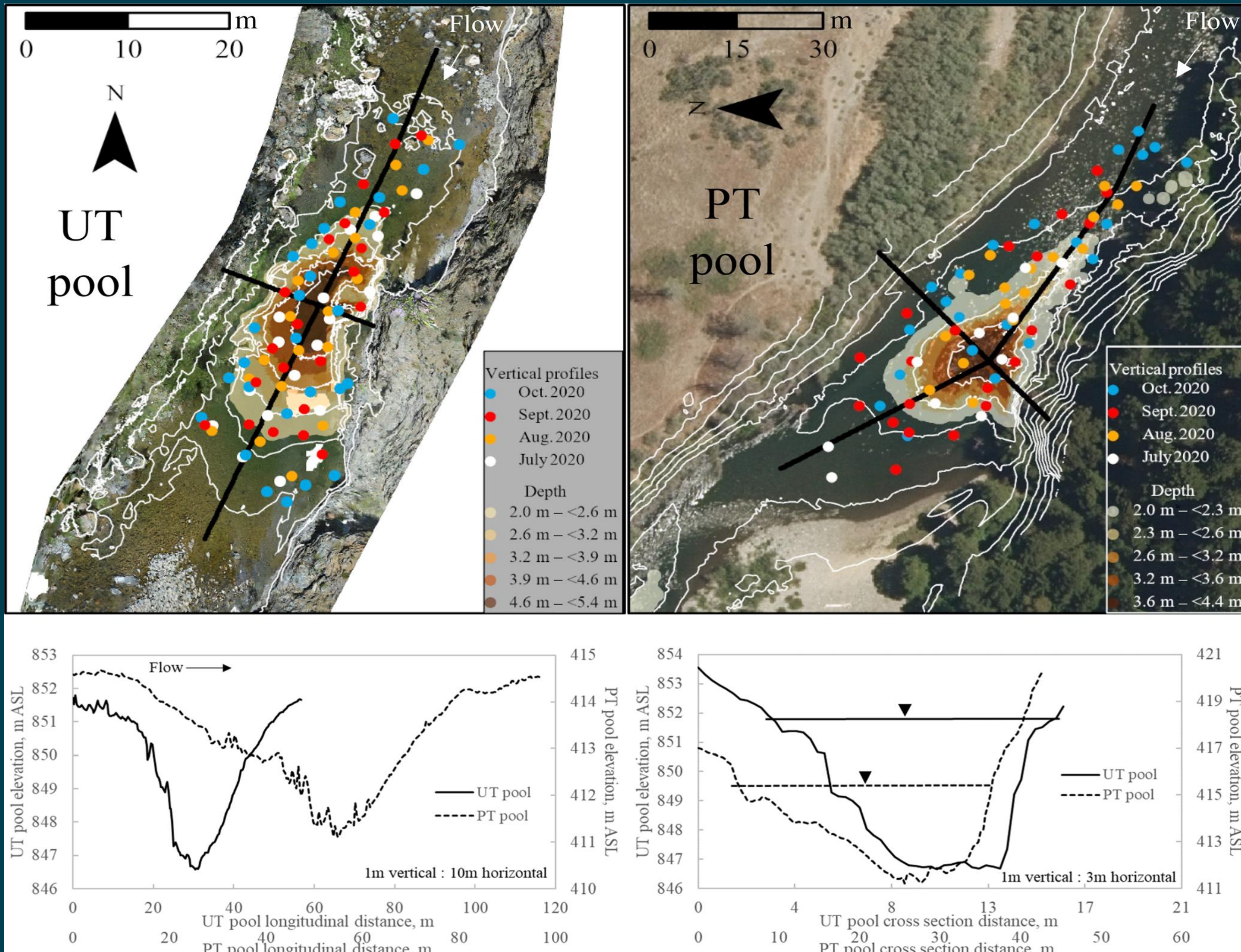
Field Work (Jun-Nov 2020)

❑Bathymetric Surveys
- Total Stations
- Real Time Kinematic GPS
- Sonar
- Photogrammetry SfM (above surface and underwater)
- Lidar

❑Flow Stage, Discharge and Temperature Measurement
- Pool inlet, body, outlet
- Hobo sensors (15-min measurements)
- Stage-discharge relationship

❑Repeated 3D Velocity Measurements
- Nortek Acoustic Doppler Velocimeter
- At various depths
- Instantaneous processed to get time-averaged
- Total 610 time-averaged at 151 vertical profiles

Field Work

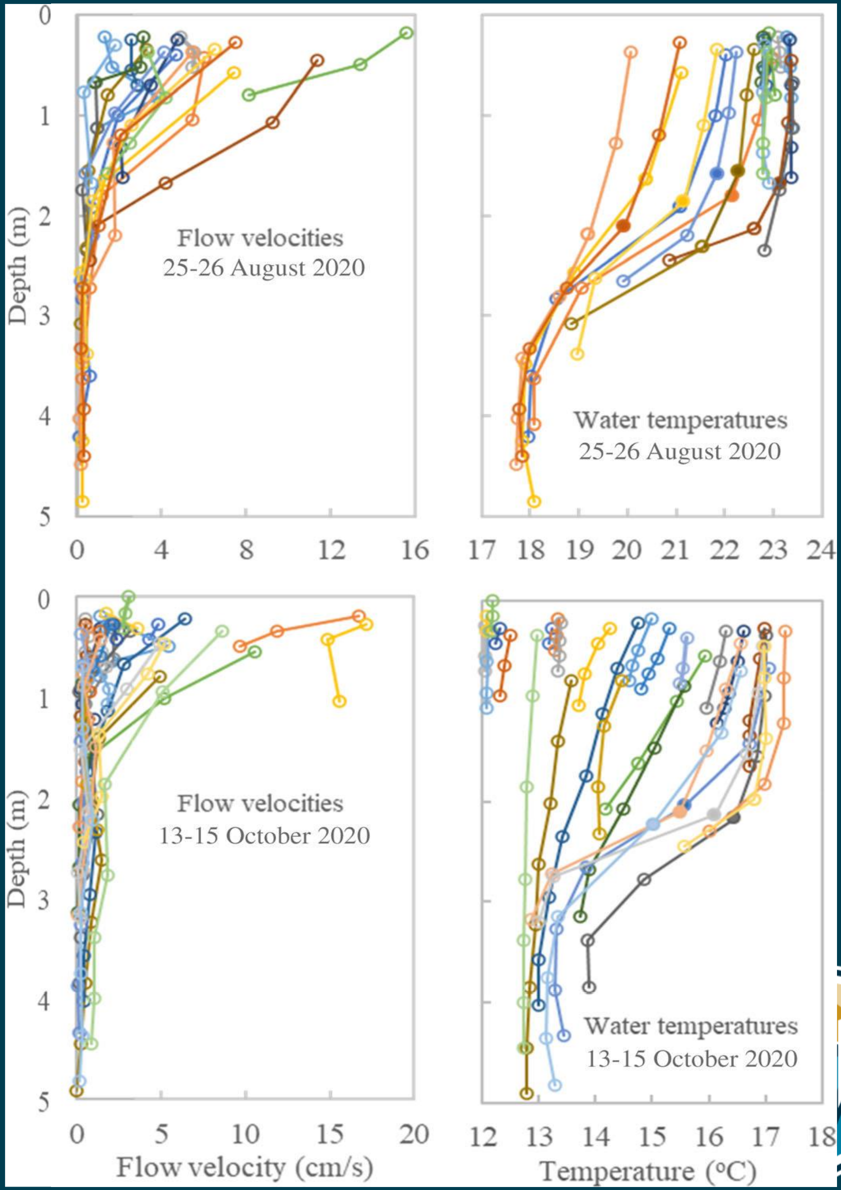


UT pool
N
Flow
0 10 20 m
Vertical profiles
Oct. 2020
Sept. 2020
Aug. 2020
July 2020
Depth
2.0 m – <2.6 m
2.6 m – <3.2 m
3.2 m – <3.9 m
3.9 m – <4.6 m
4.6 m – <5.4 m
PT pool
N
Flow
0 15 30 m
Vertical profiles
Oct. 2020
Sept. 2020
Aug. 2020
July 2020
Depth
2.0 m – <2.3 m
2.3 m – <2.6 m
2.6 m – <3.2 m
3.2 m – <3.6 m
3.6 m – <4.4 m
Flow
UT pool elevation, m ASL
PT pool elevation, m ASL
UT pool
PT pool
1m vertical : 10m horizontal
UT pool longitudinal distance, m
PT pool longitudinal distance, m
UT pool
PT pool
1m vertical : 3m horizontal
UT pool cross section distance, m
PT pool cross section distance, m

Field Work - Observations

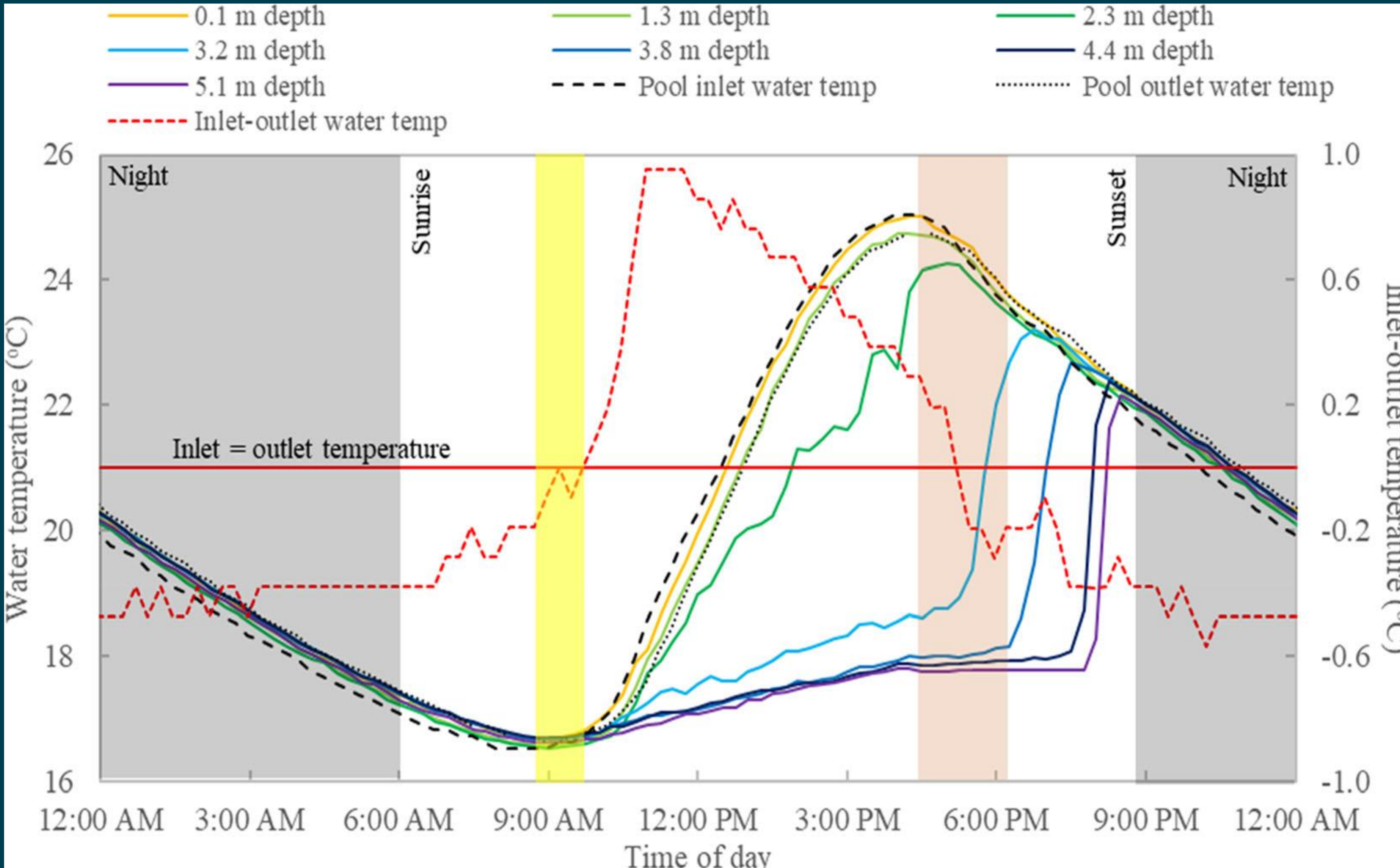
- Stratification was observed only at Upper Trinity pool site
- No stratification was observed at Pear Tree site entire study period

Upper Trinity pool body measurements during day time



Field Work - Observations

Diurnal change in stratification



Statistical Analyses

Standard Procedure for Statistical Model Selection using R

❑Continuous Response Variable

- Daily maximum degree of stratification
  (temperature range in a vertical profile)

❑Potential Explanatory Variables

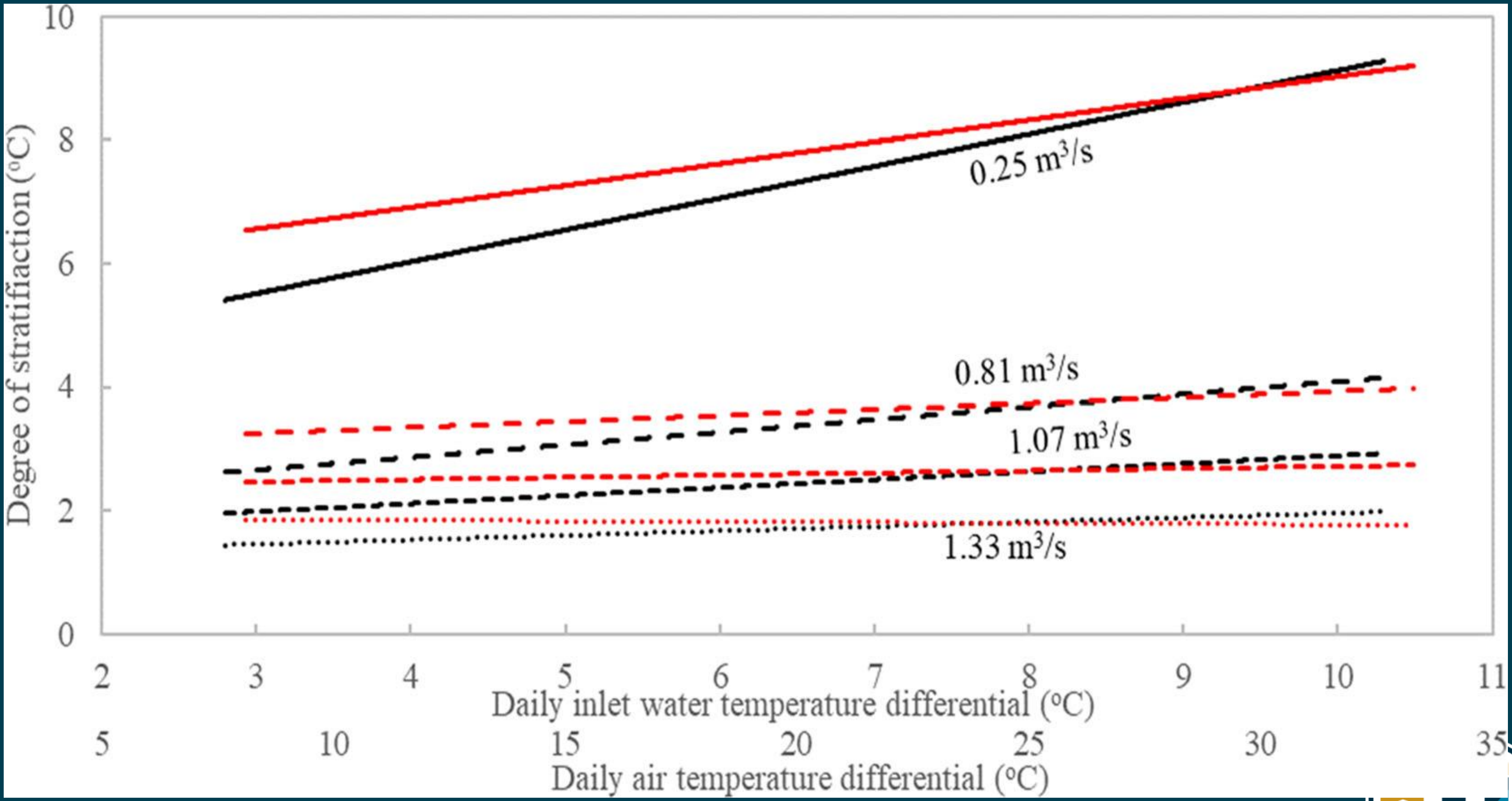
- Daily air temperature differential (DATD)
- Daily inlet water temperature differential (DIWTD)
- Mean daily inlet water temperature (MDIWT)
- Daily average flow (Qavg)
- Day length (DL)
- Sun exposure (SE)

❑Akaike Information Criterion (AIC) used for candidate models

- DATD, Qavg, DATD:Qavg
- DIWTD, Qavg, DIWTD:Qavg

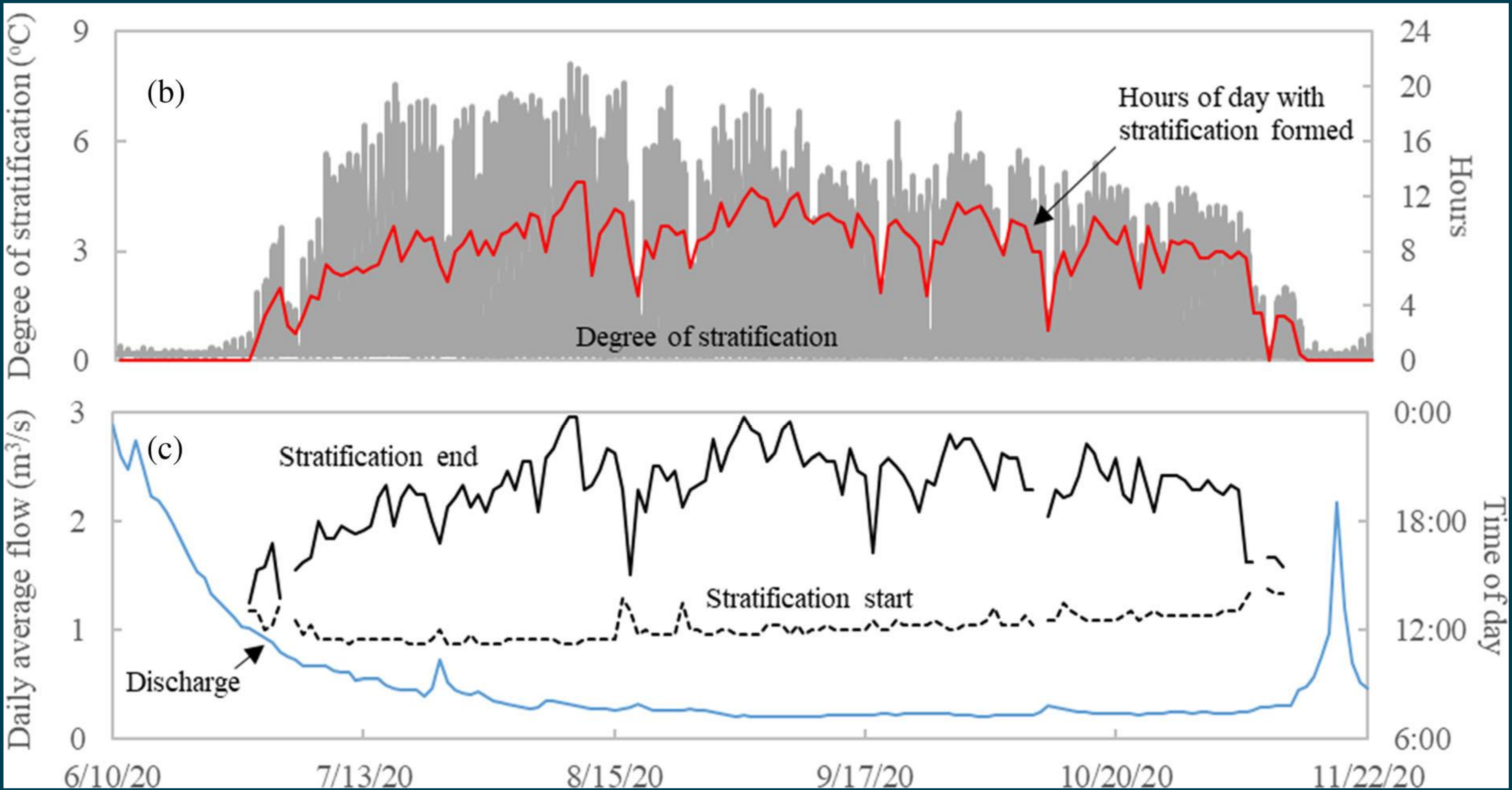
Statistical Analyses

Increasing discharge reduces degree of stratification and relationship



Red – DATD; **Black** – DIWTD;

Field Work - Observations



Numerical Modeling

- 3D Numerical Model, U^2RANS (Lai et al., 2003)
  - Reynolds-Averaged Navier Stokes Equations
  - Energy conservation for water temperature:

$$\frac{\partial T}{\partial t}+\frac{\partial\left(U_j T\right)}{\partial x_j}=\frac{\partial}{\partial x_j}\left(\alpha\frac{\partial T}{\partial x_j}-\overline{T' u_j}\right)+\frac{q_s}{\rho C_P}$$

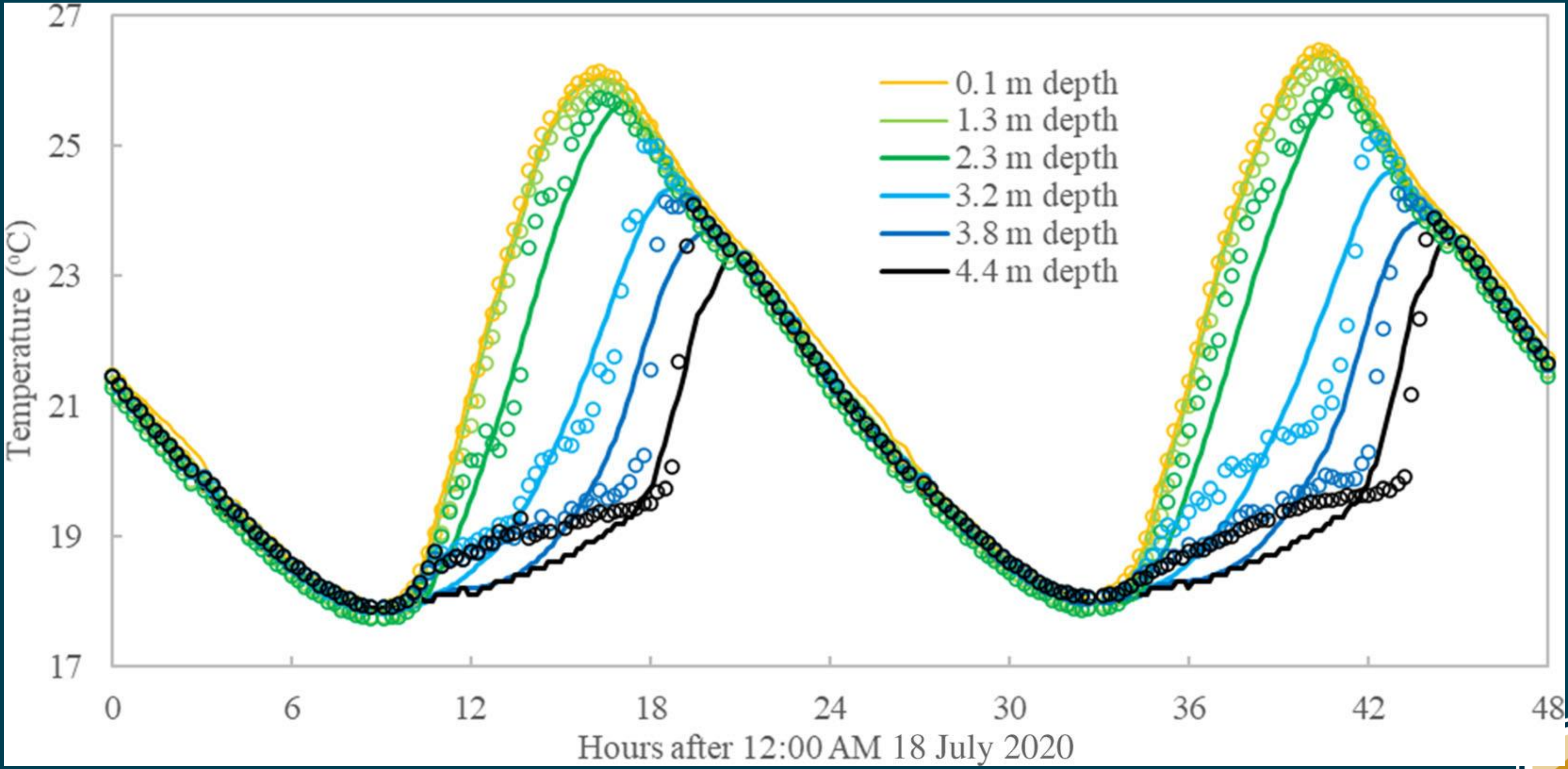
  - Turbulent thermal diffusion:

$$-\overline{T' u_j}=\frac{\upsilon_t}{P_{rt}}\frac{\partial T}{\partial x_j}$$

  - We ultimately neglected heat exchange at surface

Numerical Modeling

- **Model Prediction**



Lines – Model; **Dots** – Observed;

Numerical Modeling

❑Findings

- 3D model can be used to evaluate if there will be stratification
  - Replicates formation and destruction of stratification
  - Model also predicts no stratification when none is observed in field
  - Can be used to provide guidance on critical flows for stratification

- Primary cause of stratification
  - Temperature differential
    - Incoming flow
    - Indirect influence of air temperature on inflow
  - Low flow discharge/velocities
    - Prevent turbulent mixing
  - Cold flows at night
    - Cause mixing with denser flows sinking - buoyancy effects

- Heat fluxes at pool surface domain only had a minor impact on stratification

- Pool geometric properties affect critical flow for stratification


Thank you!
More Info:
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Buxton et al., 2022