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Does Puget Sound have a long-term memory?

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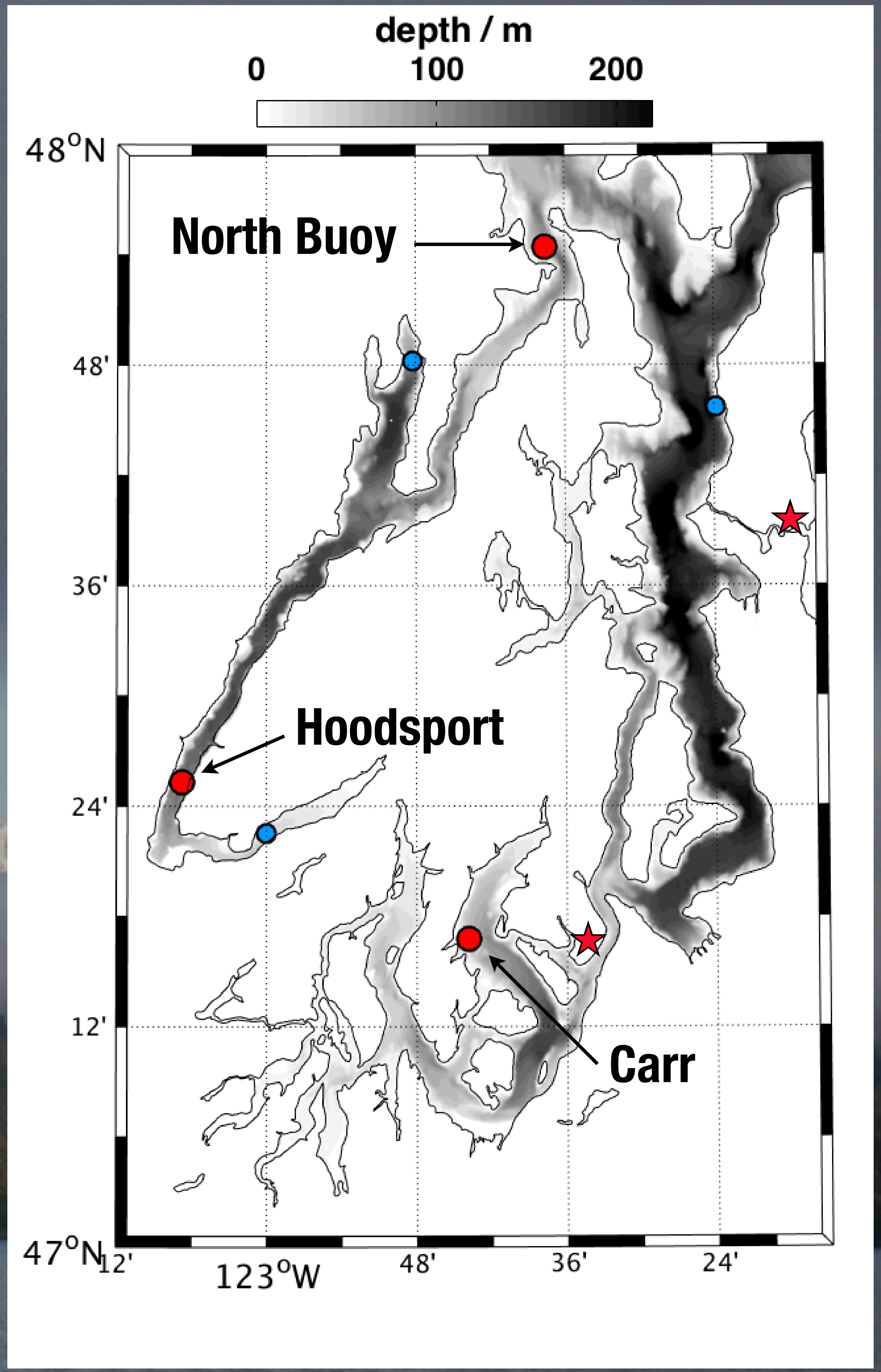
GOAL

Investigate factors controlling *inter-annual* trends/variability in water properties: specifically T, S, density in Puget Sound using:

1) decade-long+ NANOOS ORCA mooring high-frequency profile time series at multiple locations

2) USGS river flow

3) UW/NWS atmospheric obs and WRF model output



MOTIVATION

To understand decade+ trends, we need to:

1) understand the local and remote (BC) factors controlling the large inter-annual variability of water properties — *AND*

2) how long-term variability in these factors is related to global scale patterns and changes.

3) water property changes are linked with environmental stressors and ecosystem shifts.

CAVEAT—system of past is not necessarily the system of the future.

BACKGROUND

- Droughts can strongly influence salinity, density, and stratification — and exchange flow in SJdeF. (Siegel, Albertson, Newton 2003)

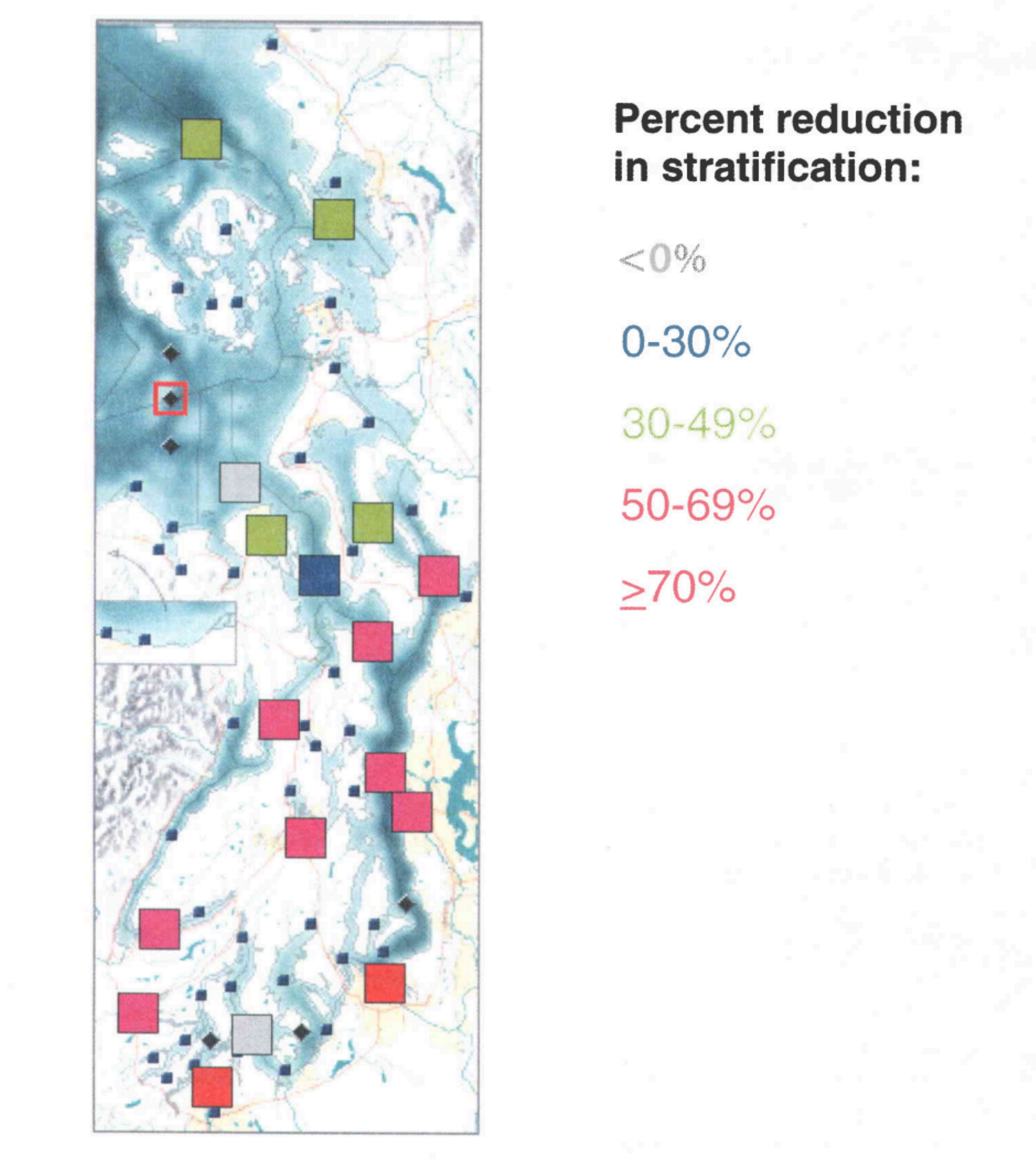


Figure 4. Percent Change in Stratification Intensity [(Oct 00–Sep 01 Mean Delta Sigma–t – 10–y Mean Delta Sigma–t)/10–y Mean Delta Sigma–t)] for Selected MWM Stations in the Puget Sound–Georgia Basin Area. The Mean Change for these Stations was a Reduction in Stratification of 56%.

BACKGROUND

Moore et al. 2008: Investigated inter-annual variability of T, S, dens., *N* using PCA of 16 ~monthly WA ECY CTD profile stations 1993-2002.

- air temp and river flow variations explained up to 50% and 65% of the variance respectively of the leading PC patterns.
- connected this local forcing with large-scale patterns (ENSO, PDO, NPI, upwelling).

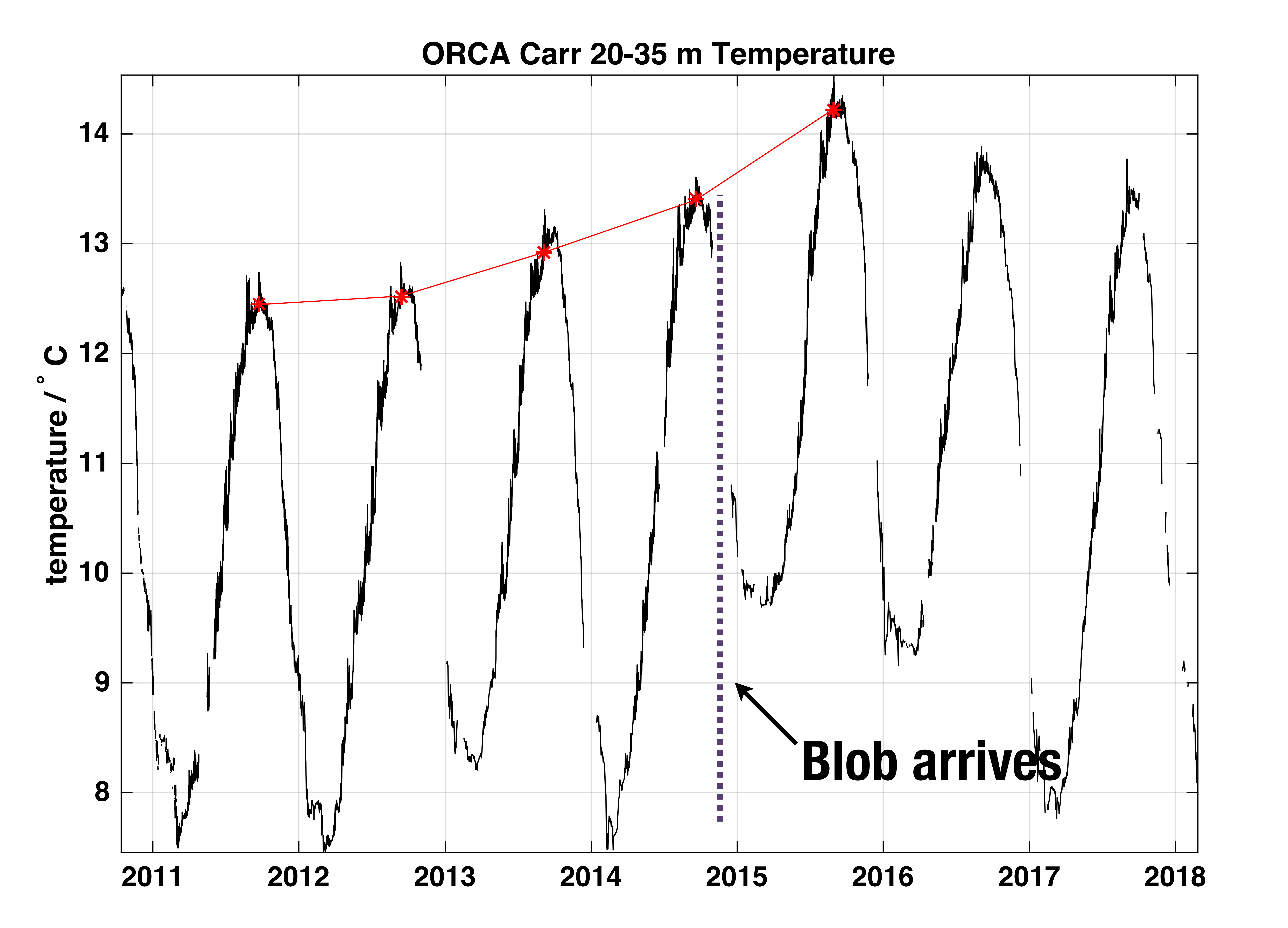
*limitations: coarse data (monthly), representing streamflow, air temp only proxy for surface heating

Babson et al. 2006, Sutherland et al. 2011: investigated rivers, tides, winds, BCs

	Winter 1993–2002		
	PC1T	PC1S	PC1N
PC1T	1		
PC1S	$-.40_3$	1	
PC1N	$.60_5$	$-.78_3$*	1
STRM	$.12_6$	$-.81_3$*	$.78_5$**
AIR	$.70_8$**	$-.30_3$	$.54_5$
UPWL	$-.46_8$	$.18_3$	$-.40_5$
NPI	$-.51_8$	$.02_3$	$-.05_5$
ENSO	$.45_8$	$-.01_3$	$.47_5$
PDO	$.27_4$	$-.11_3$	$.30_5$
SST	$.86_8$***	$-.45_3$	$.65_5$
SSS	$-.29_3$	$.73_3$	$-.66_3$

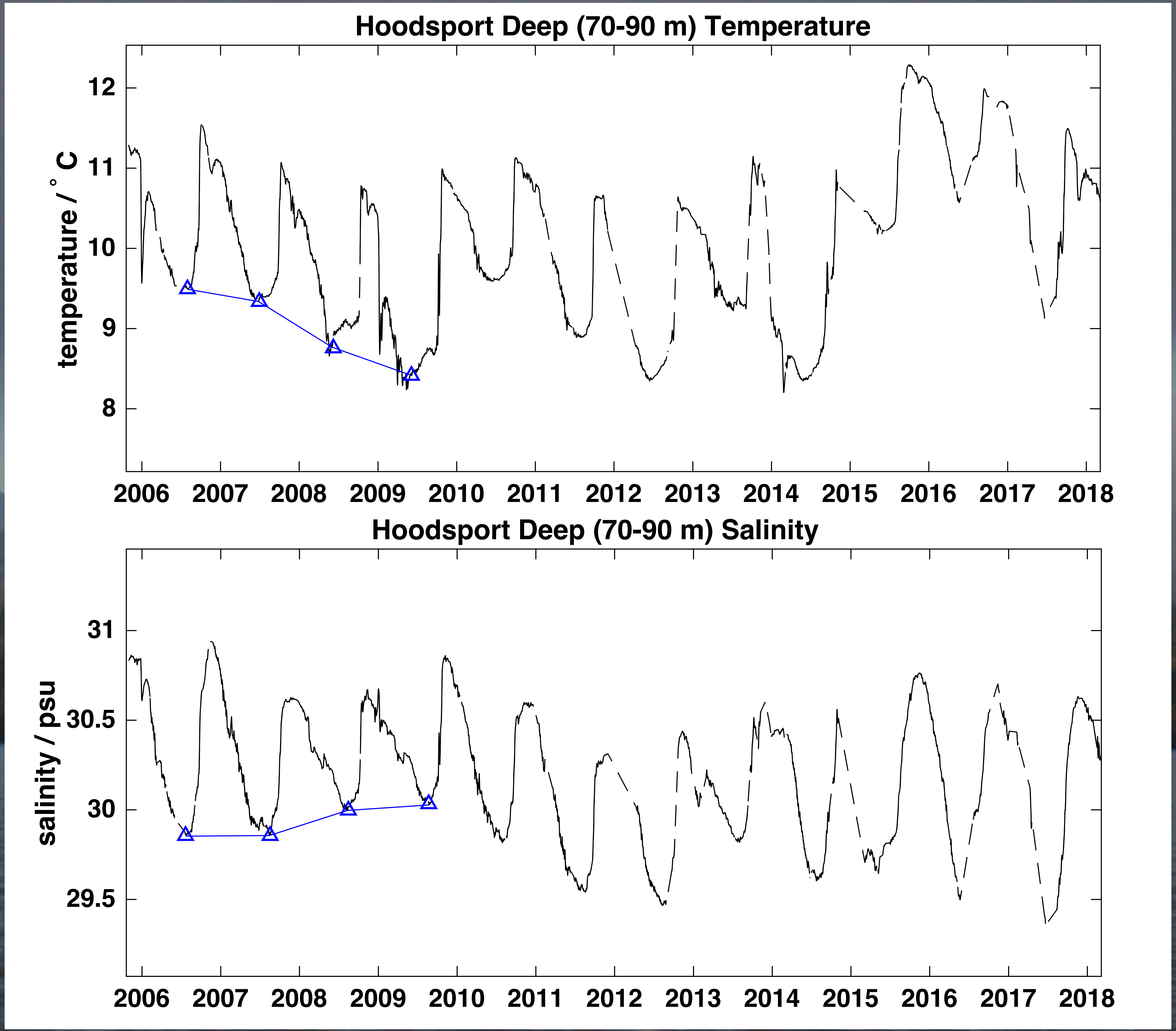
TRENDS: South Sound

- increase in annual max. temperature 5 years in a row!



TRENDS: Deep Hood Canal

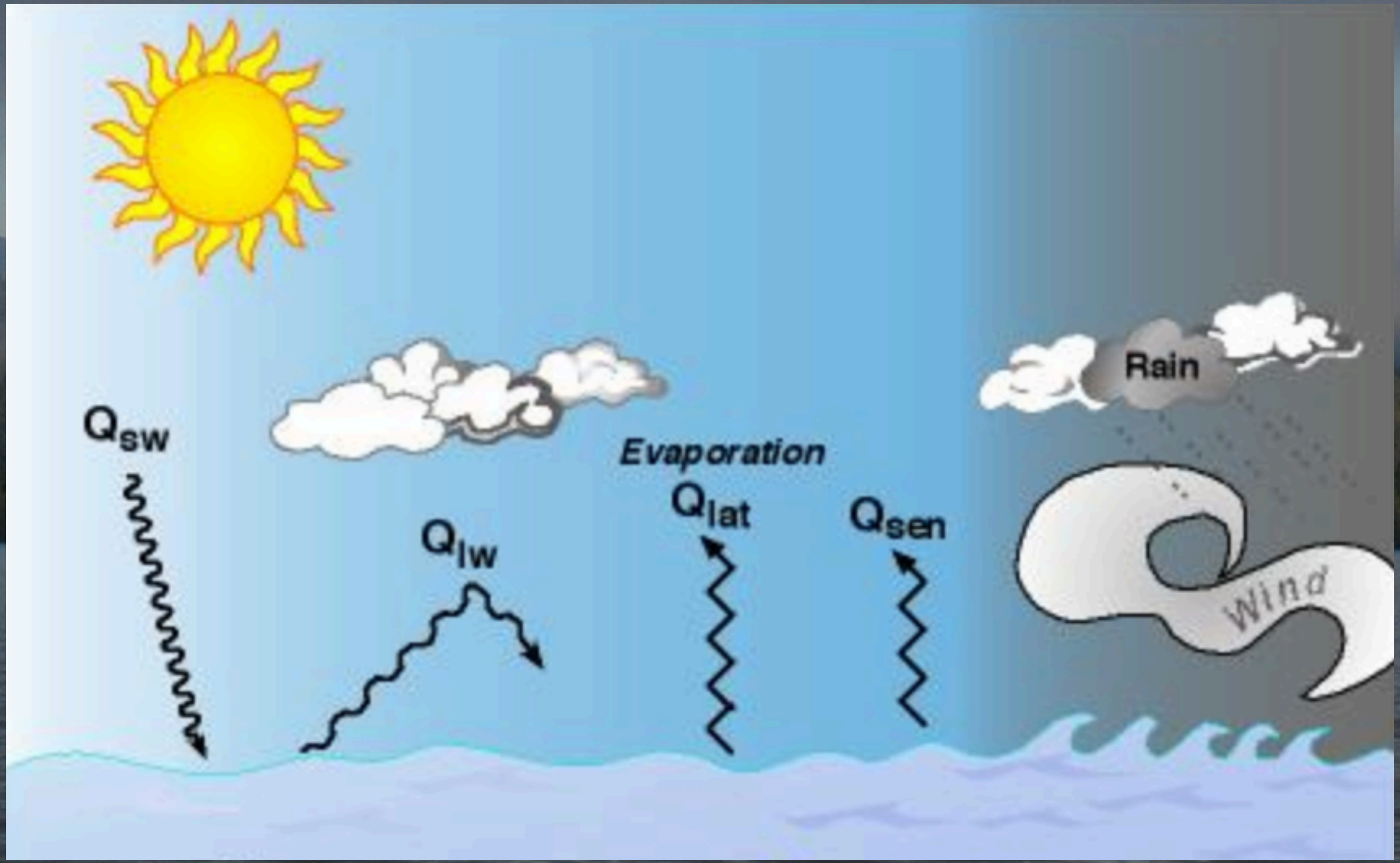
- decrease in min. deep T four years in a row (2006-2009)
- increase in min. deep S, density same four years



APPROACH: South Sound

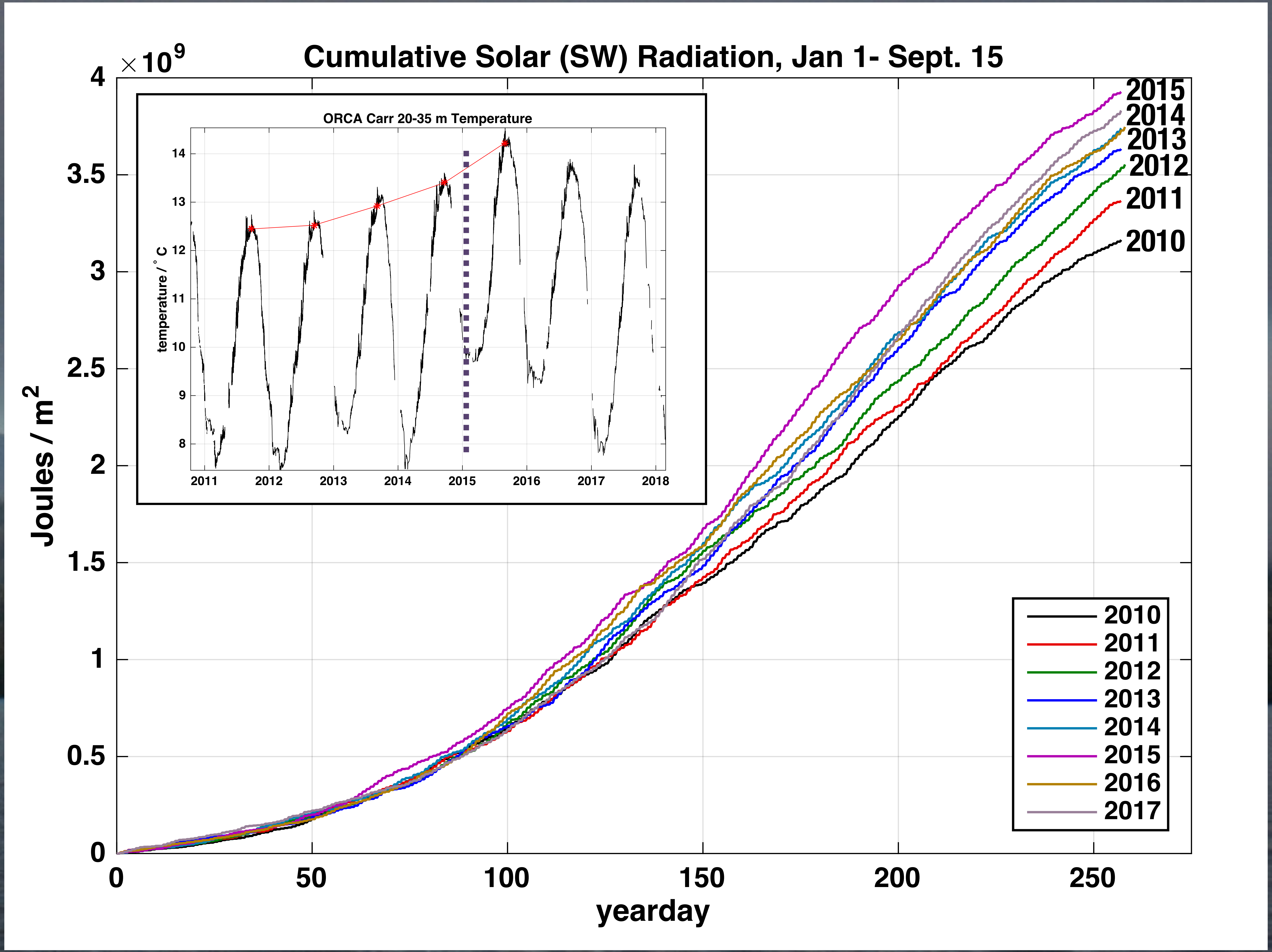
- calc. a rough surface heat-budget, looking at ΔT over a 25-m water column. Using COARE 3.0.

$$Q_{net\_surf} = Q_{sw} + Q_{lw\_up} + Q_{lw\_dn} + S_{sen.} + Q_{latent} + Q_{rain}$$



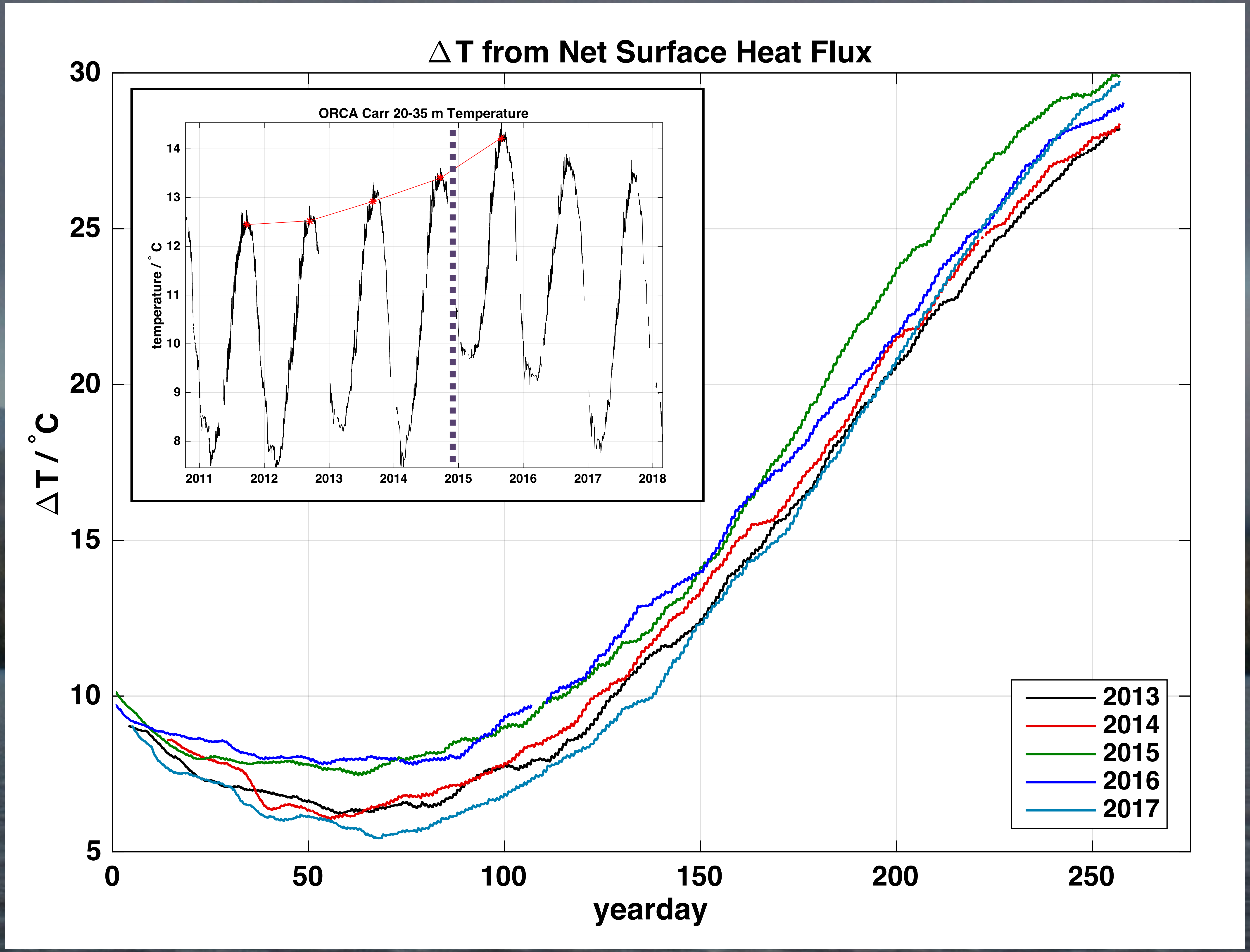
TRENDS: South Sound

- Q_{SW} increases 6 years in a row summing from Jan 1 to Sept 15!



TRENDS: South Sound

- $Q_{net\_surf.}$ follows Q_{sw} trend, ΔT is same order as observed changes
- warm winter (Blob) temps in 2015 matter to max summer temp.
- only have $Q_{net\_surf.}$ for 2013 and later due to limited model archive



APPROACH: Hood Canal

- Evaluate influence of inter-annual variability of river flow on salinity using a simple "bucket" model.

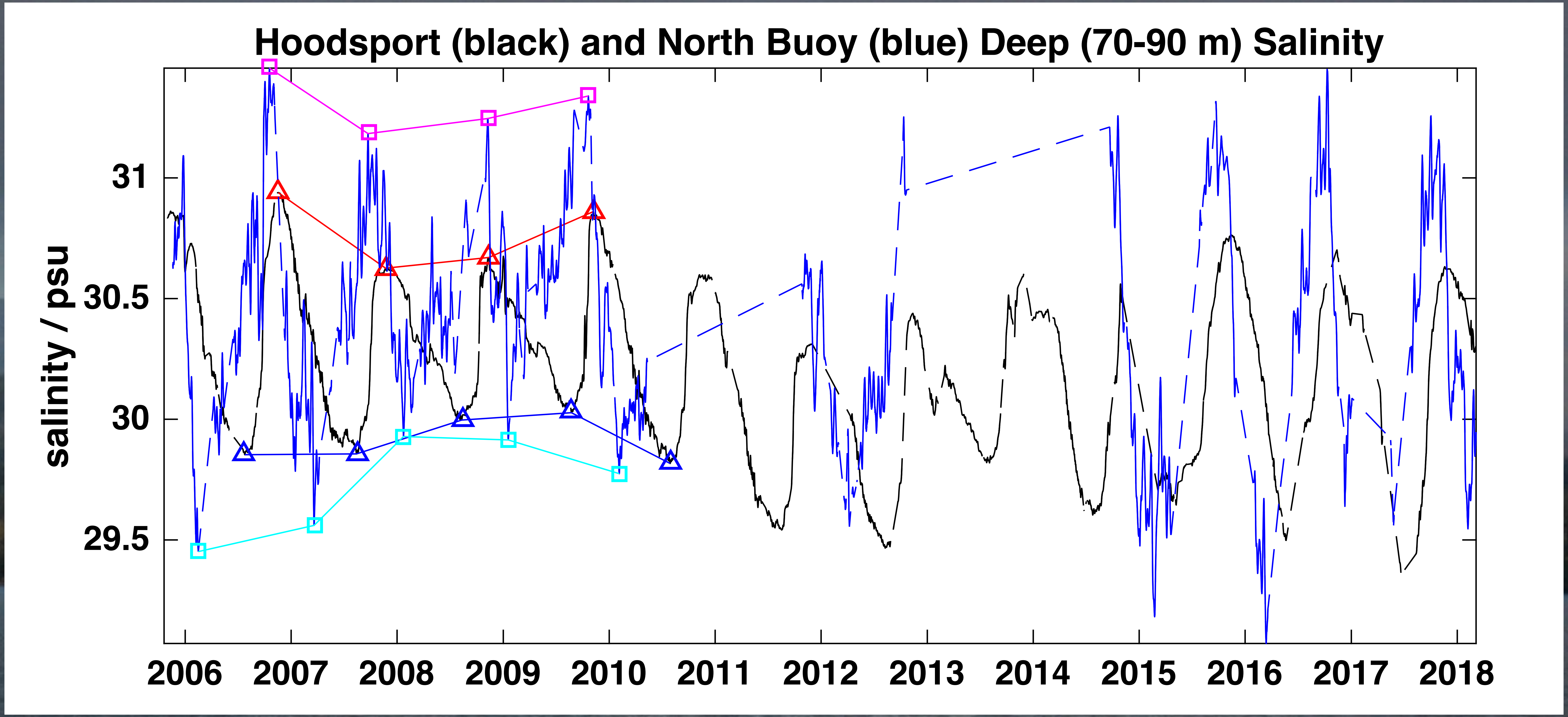
The bucket model

- only time-dependent input is river flow
- conservation of volume and salt—but time-dependent
- integrates salt fluxes in time to get S(t).
- relatively skillful: R=0.58 for HC, R=0.89 for South Sound over 4 and 5 years respectively.

TRENDS: Hood Canal

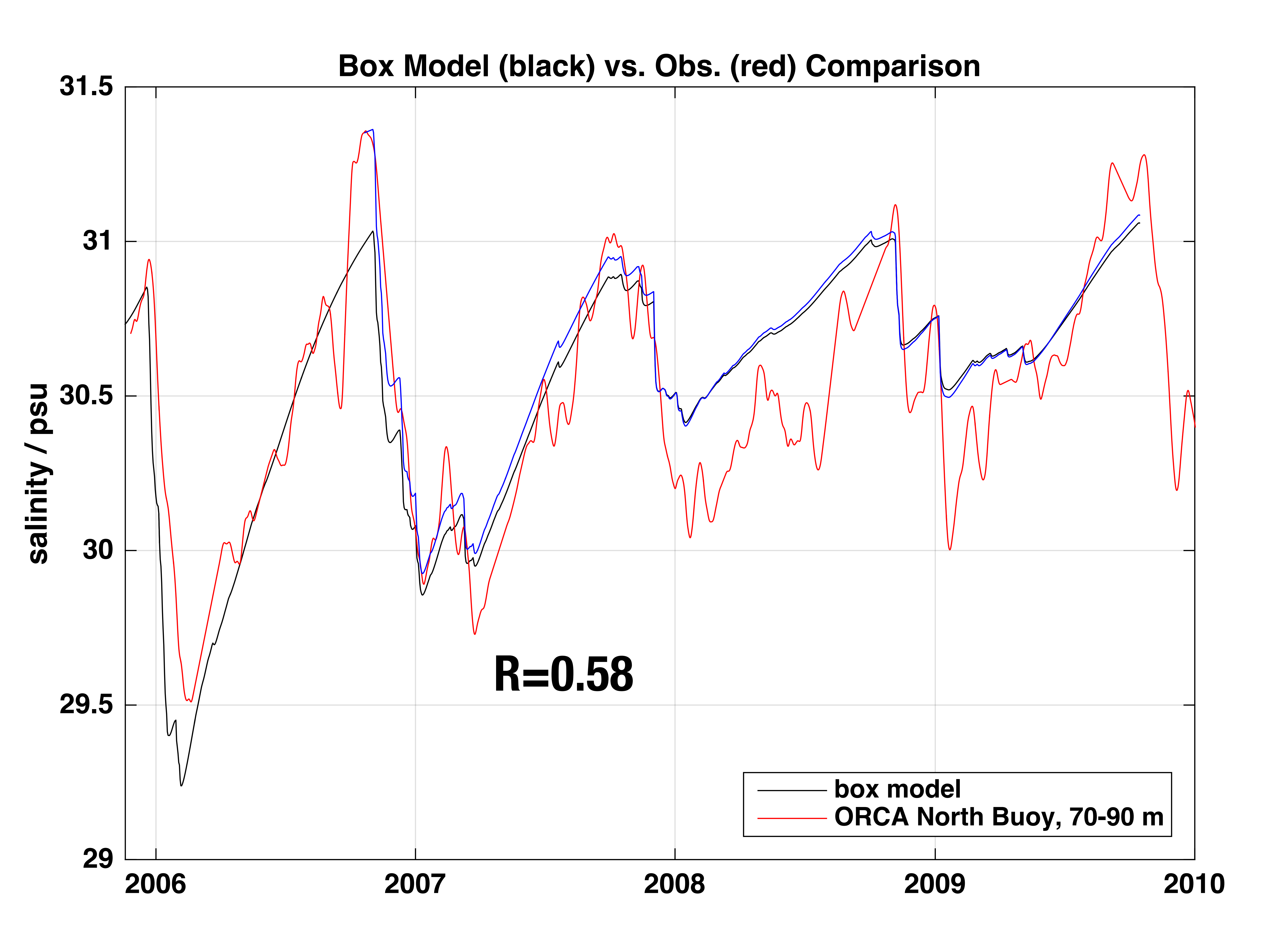
- Deep Hoodsport max/mins closely follow those at North Buoy for T, S, dens.

Deep Salinity



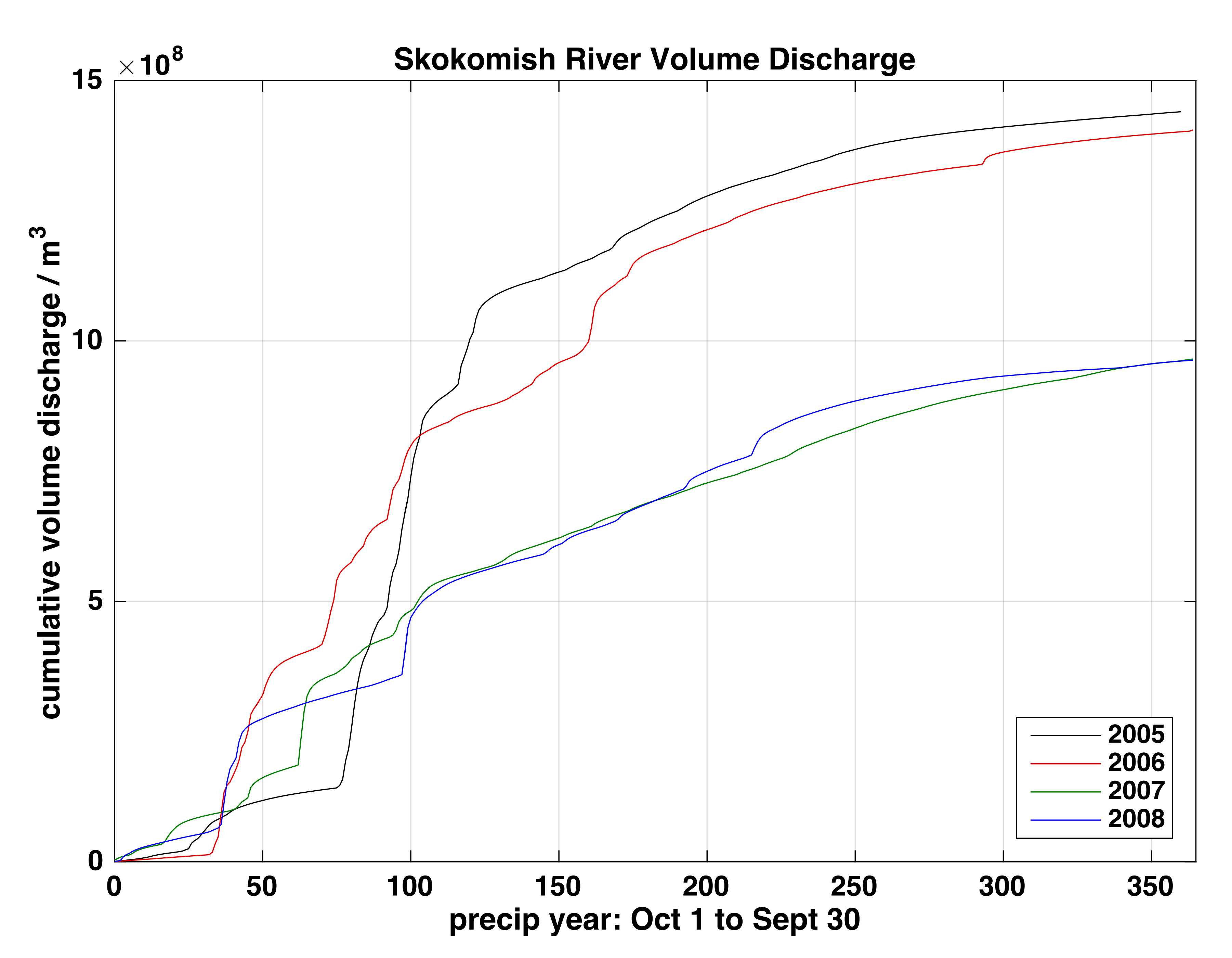
TRENDS: Hood Canal

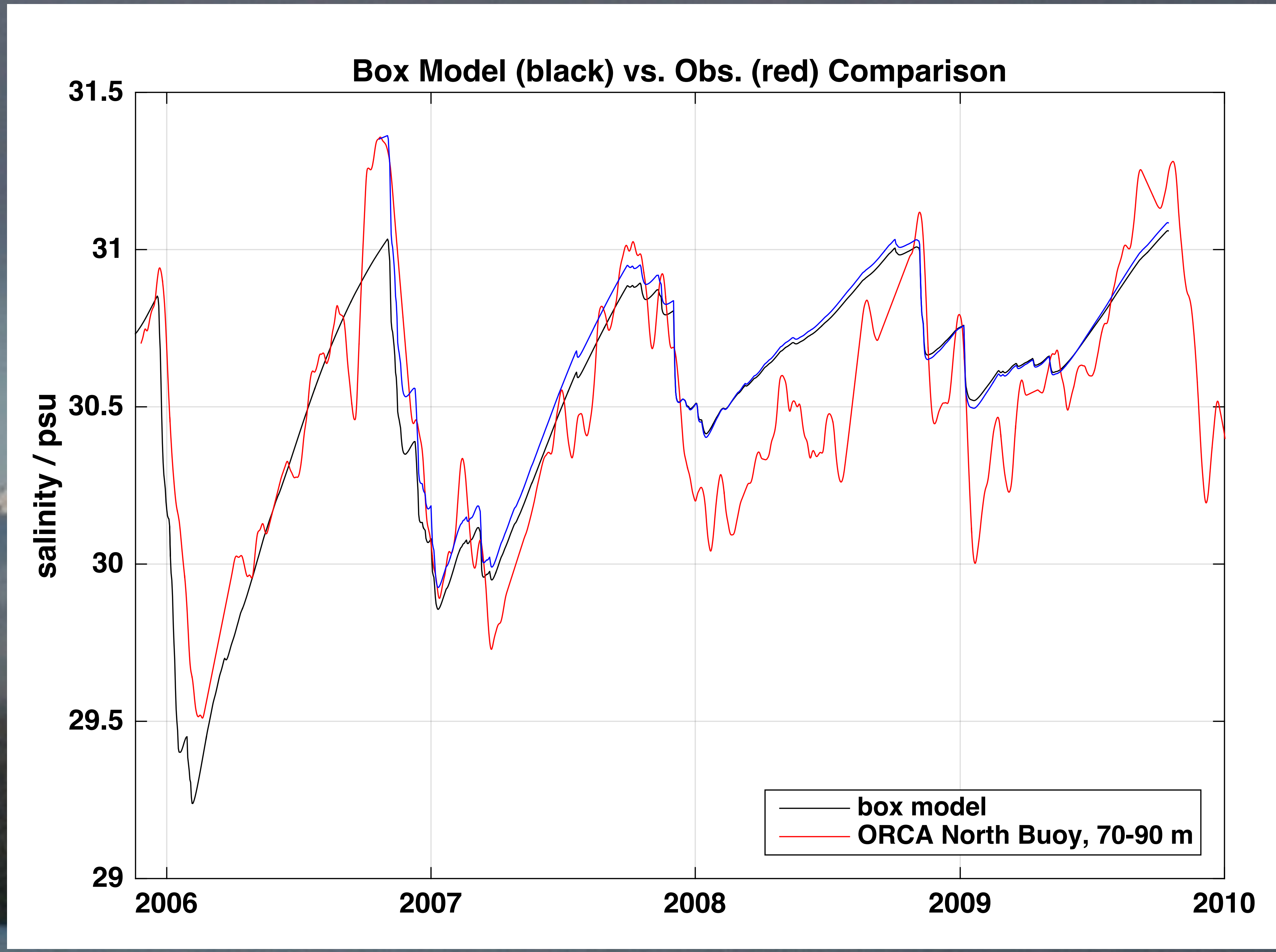
- Bucket model reproduces timing and trends in inter-annual variability of max/min salinities at North Buoy.



TRENDS: Hood Canal

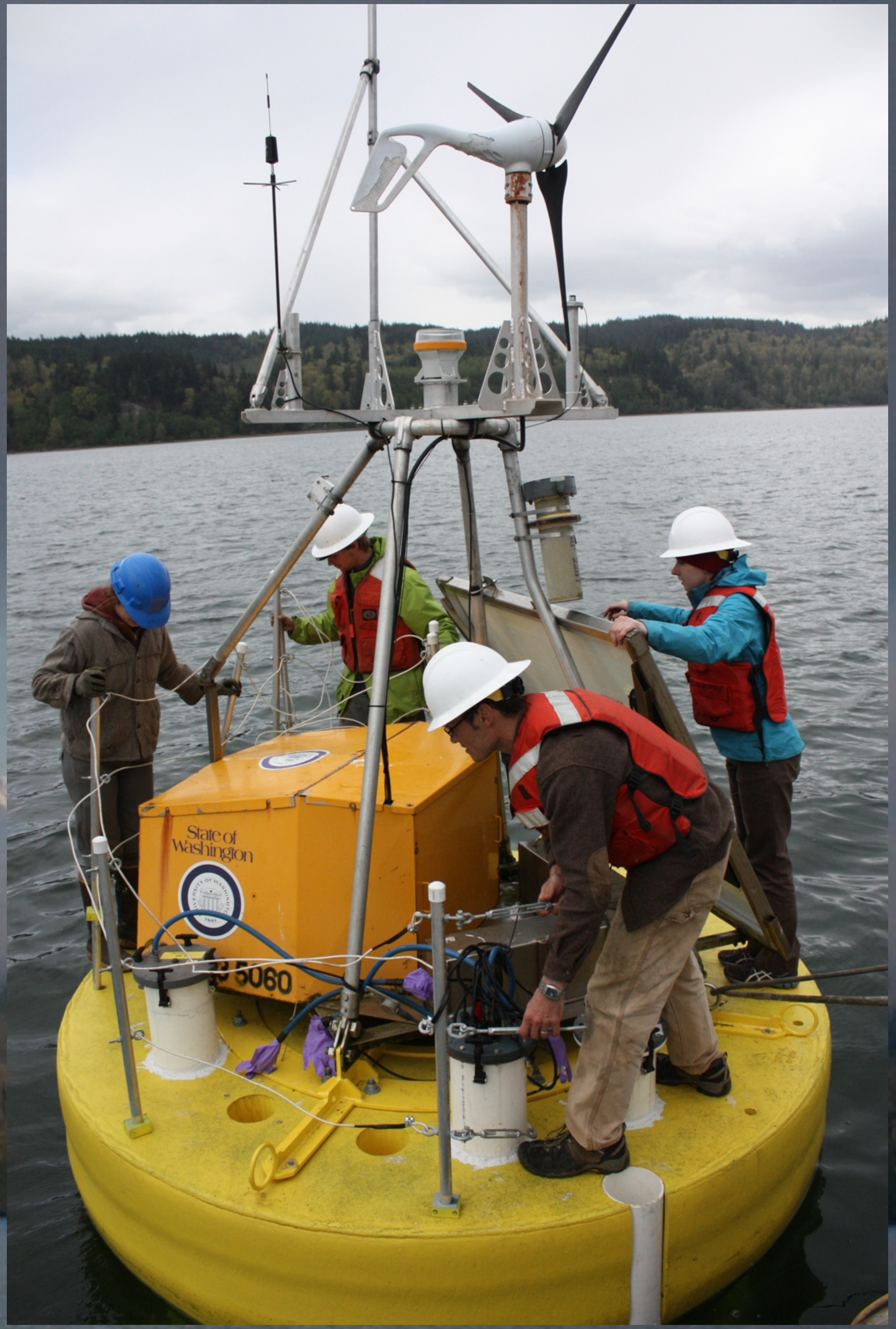
- Skokomish river strongly influences both winter minimum and summer maximum salinities at North Buoy—and in turn deep lower HC.





Implications

- Hood Canal (HC) and South Sound (SS) basins strongly respond to local atmos. forcing (heat, freshwater).
- sills communicate this local forcing to the deep water. For HC, slowly in winter, more quickly in late summer/fall.
- river flow dominates seasonal AND inter-annual salinity variability in HC and SS—possibly other basins.
- inter-annual variation in surface heat fluxes can cause inter-annual variability in min/max water temps in SS, but 2015 Blob indicates inflowing water can also play a role.



Thanks

Past and present ORCA team members: (Zoë Parsons, Chris Archer, Hannah Glover, Keith Magness, Sam Fletcher, Andrew Cookson, Colin Smith, Gretchen Thuesen), and many student volunteers.

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Washington State ECY Marine Waters (J. Bos., C. Krembs).

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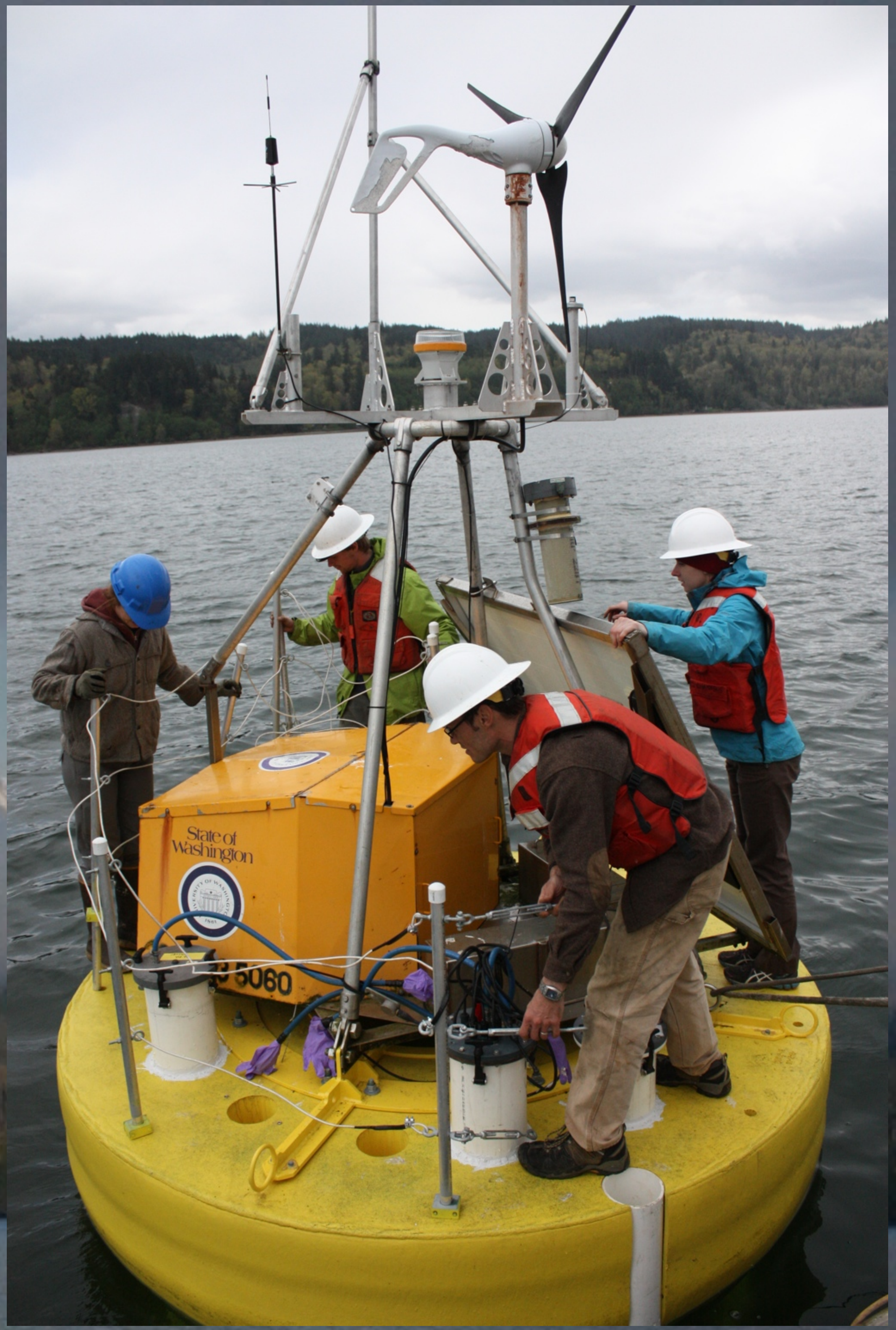
Implications

Sutherland et al. 2011

Delay in seasonal increase in salinity with landward distance from ADM sill "*suggests that the driver for the gain of salt is propagating in from outside Puget Sound and is not solely driven by decreasing river discharge, consistent with findings in Babson et al. (2006).*"

An alternative view: full-depth ADM mixing is the mechanism by which the effects of the reduced river flow will be eventually communicated to the various basins—but like changes in BCs, this starts at the outer sill so will show landward propagation of these changes.



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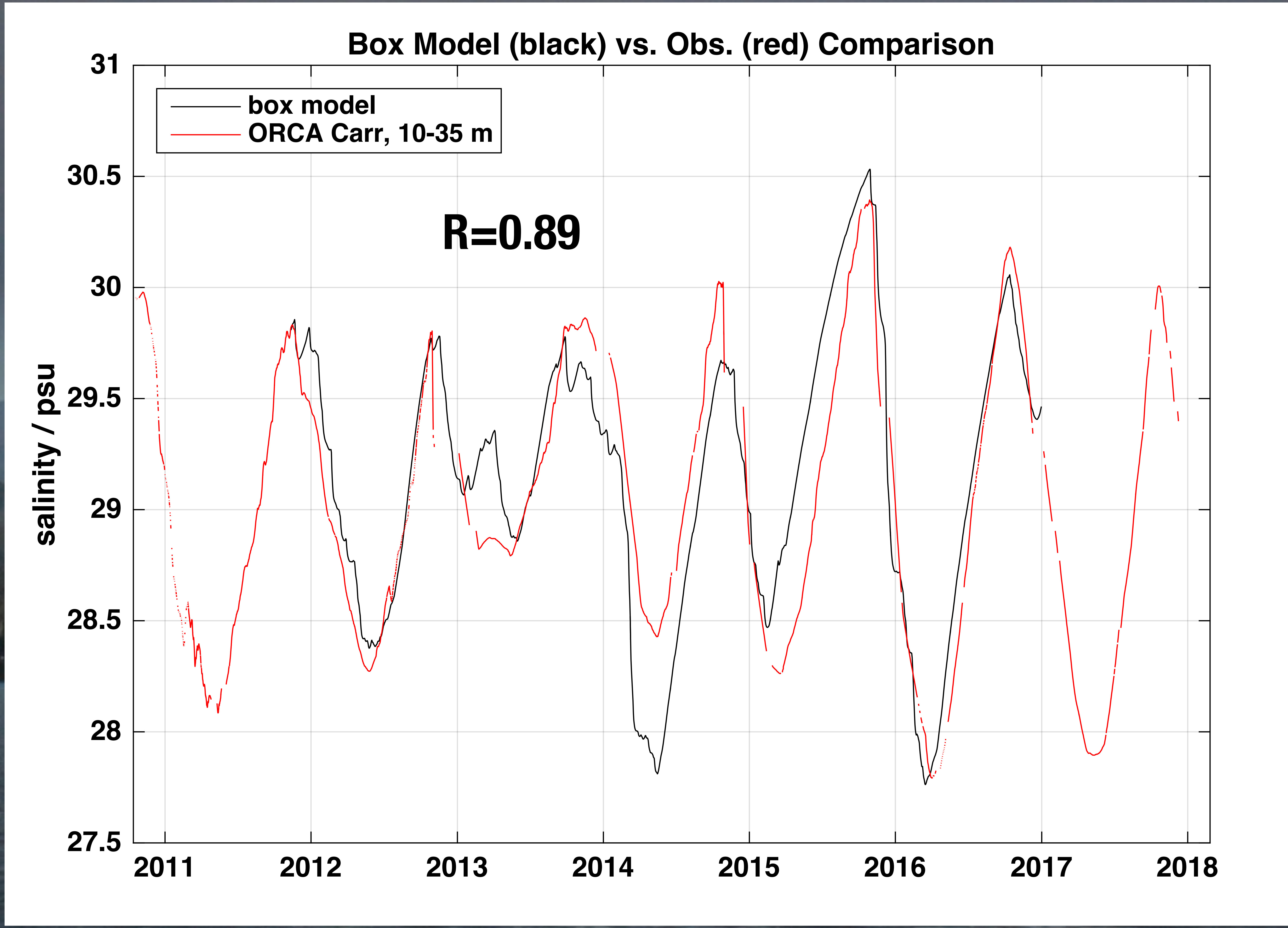
TRENDS: South Sound

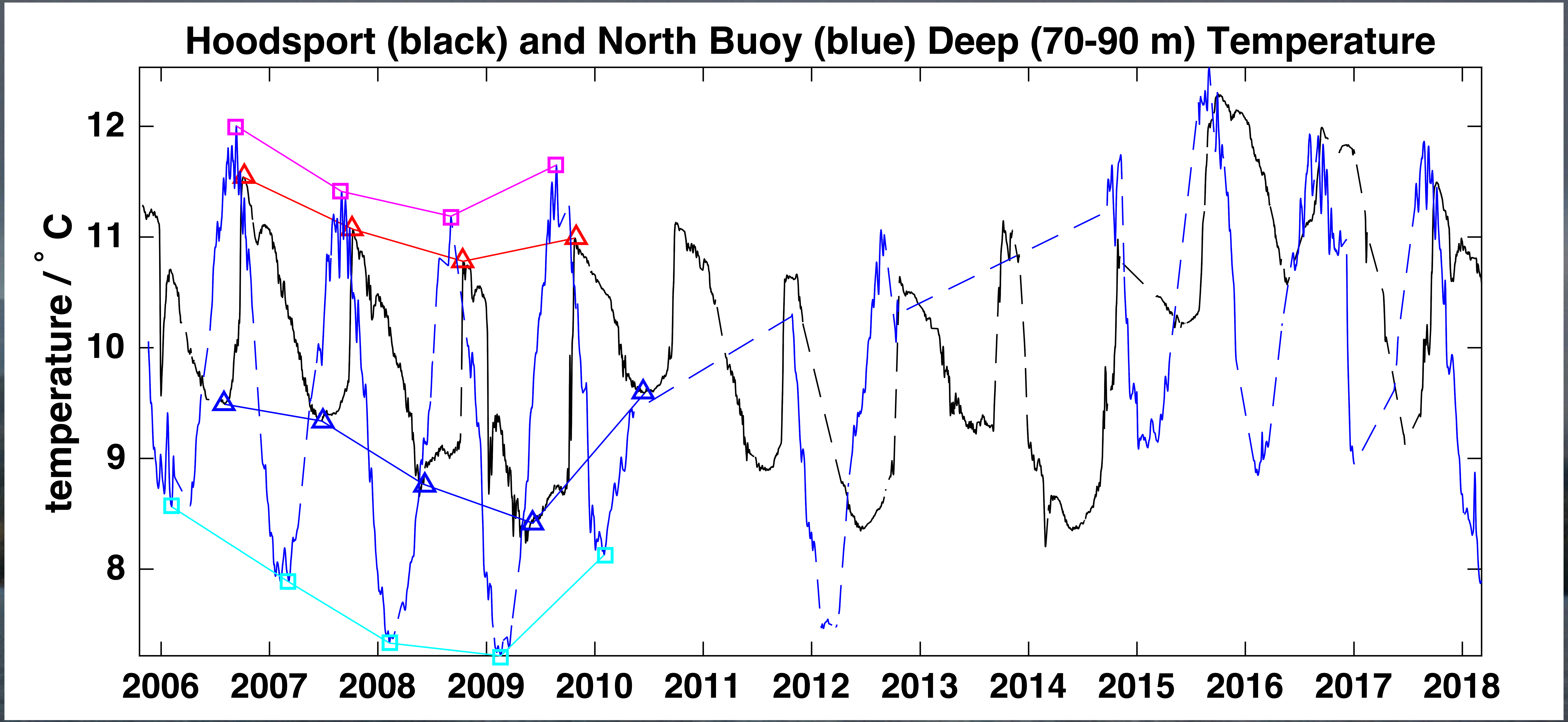
- Bucket model is highly skilled at reproducing South Sound salinity



TRENDS: Hood Canal

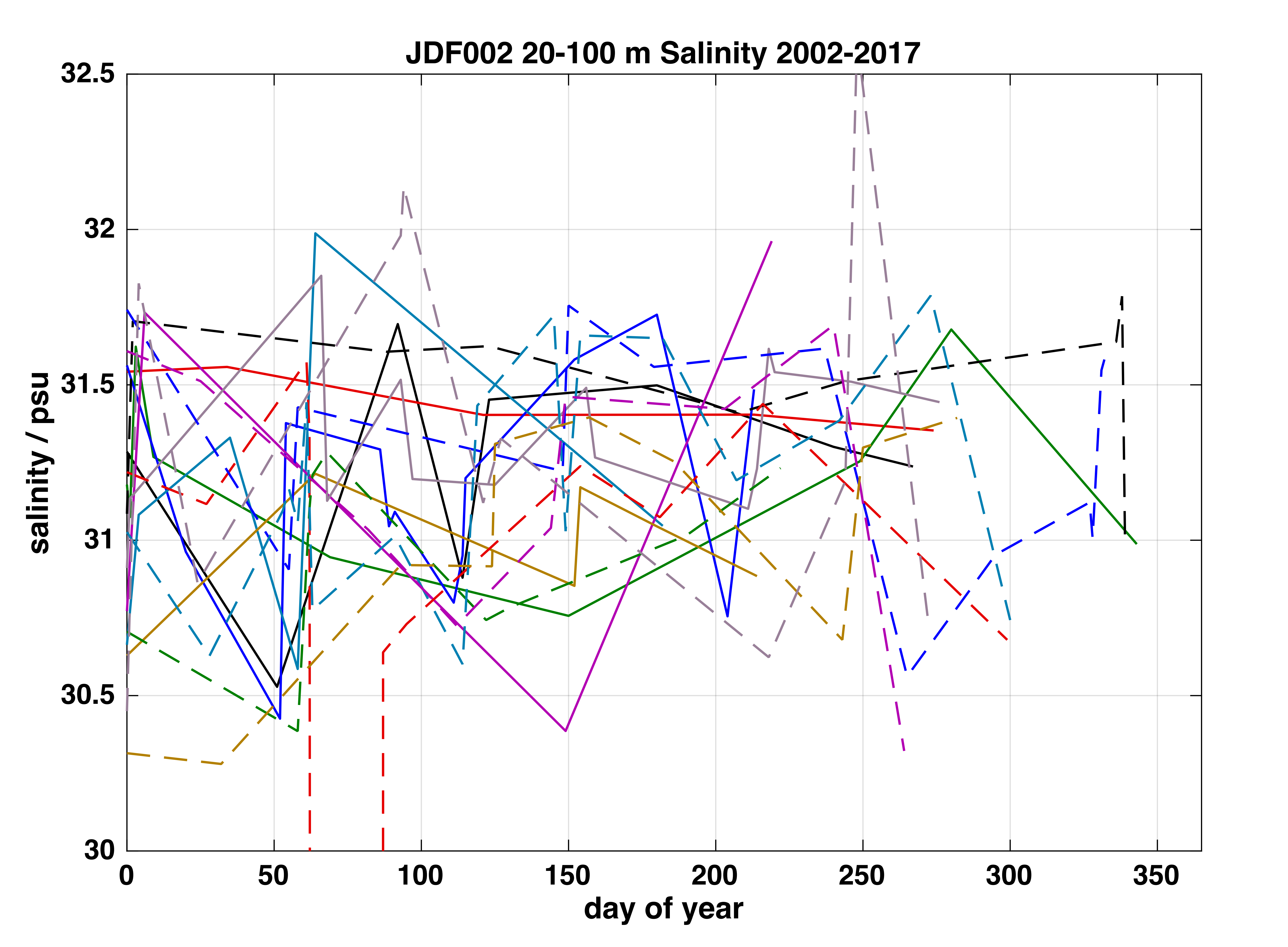
- Deep Hoodsport max/mins closely follow those at North Buoy for T, S, dens.

Deep Temperature



TRENDS: Hood Canal

- Strait seasonal cycle difficult to discern.

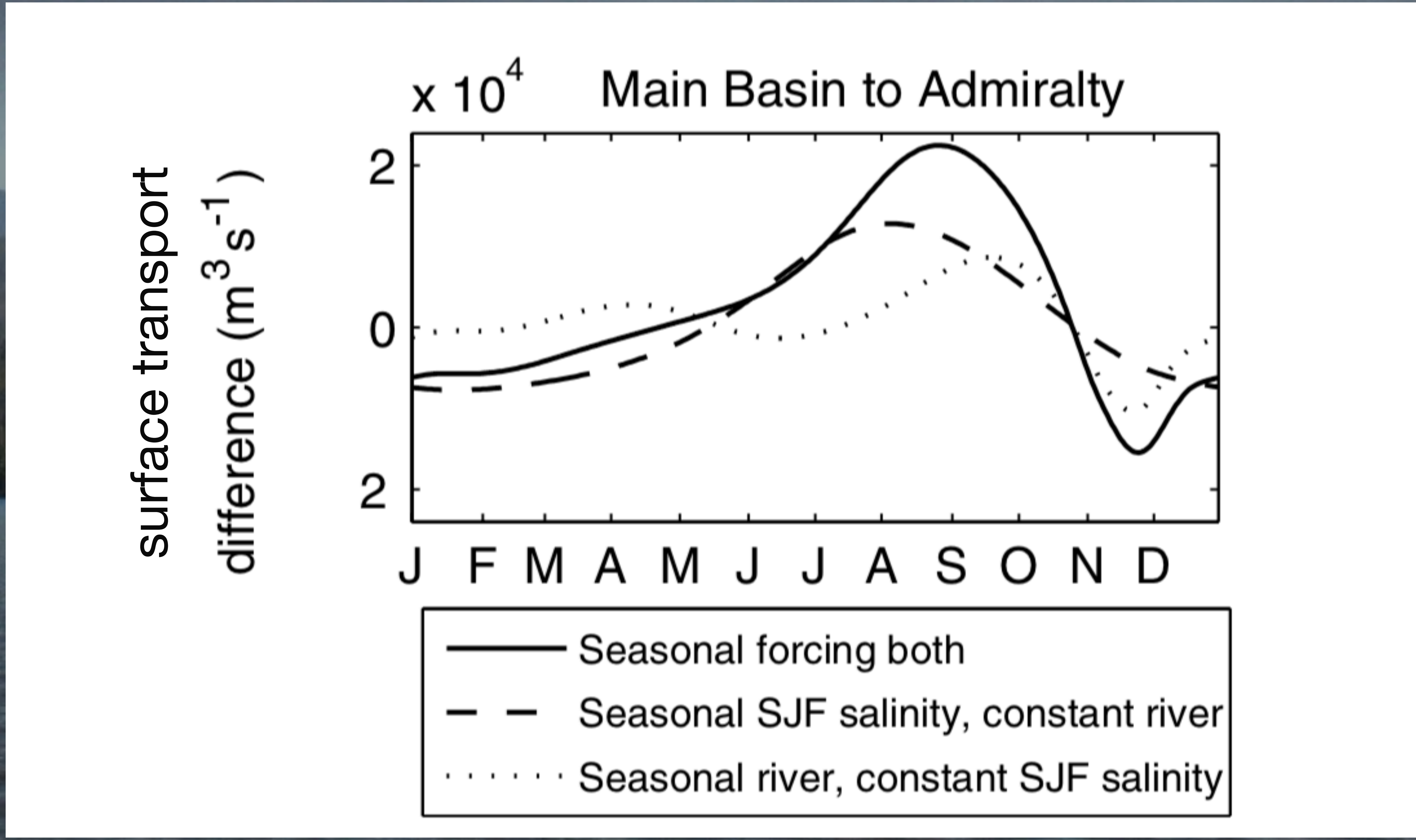


BACKGROUND

Babson, Kawase, MacReady 2006 (box model)

- <u>Seasonal</u> variability of transport more dependent on SJdeF salinity than river flow (except South Sound), BUT for
- <u>Inter-annual</u> variability of transport, river flow as important as SJdeF.

but, SJdF salinity a function of river flow and Babson cautioned limited seasonal data for Strait.



BACKGROUND

Sutherland et al. 2011: ROMS 2006 hindcast of Salish Sea to look at exchange flow and residence time.

1) Knudsen balance good approximation for salt balance in PS—storage (time-dependent) term is small.

2) Q_r strongly correlated (r=0.7) with net salt flux (F_in+F_out).

Delay in seasonal increase in salinity with landward distance from ADM sill "suggests that the driver for the gain of salt is propagating in from outside Puget Sound and is not solely driven by decreasing river discharge, consistent with findings in Babson et al. (2006)."

TABLE 5. Correlation coefficients at AIN between F_{out} and F_{net} against three forcing mechanisms: Skagit River discharge Q_r, tidal velocity U_T, and north–south wind stress τ. A negative correlation indicates that increases in Q_r, U_T, and τ weaken the respective salt flux term. Values significant at the 95% level are in boldface.

	Q_r	U_T	τ
F_{out}	−0.25	**−0.41**	**0.41**
F_{net}	**0.70**	−0.21	−0.15